# THE OBSERVATORY

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## MEETING OF THE ROYAL ASTRONOMICAL SOCIETY

Friday 2019 November 8 at $16^h\ 00^m$
in the Geological Society Lecture Theatre, Burlington House

A. M. CRUISE, *President*
in the Chair

*The President.* Good evening and welcome to the Open Meeting of the Royal Astronomical Society. I'd like to make a presentation now to one of our award winners who was not able to be present at the National Astronomy Meeting in Lancaster; this is for the George Darwin Lecture in Astronomy, and it's awarded to Professor Christine Done for her highly distinguished record of research in observing and furthering our understanding of accretion onto black holes and their associated jets and winds. I am going to ask Christine to come up in a moment, then we will hear a talk from someone else, and then we will hear Christine again; so Christine, please come up [applause]. Finally, I'd like to remind Fellows that in 2020 our National Astronomy Meeting, which will be our bicentennial meeting, will be held in Bath from the 12th to the 16th of July.

Now we move to our programme of talks. We've got two of our very favourite named lectures this evening, which is tremendous. The first one is from Dr. Mark Clilverd of the British Antarctic Survey who is going to give the James Dungey Lecture, and the title is 'Energetic particle precipitation and its effects on the upper atmosphere.'

*Dr. M. Clilverd.* [It is expected that a summary of this talk will appear in a future issue of *Astronomy & Geophysics*.]

*The President.* Thank you very much indeed. It's open for questions.

*Mr. H. Regnart.* May I take you up, having thanked you for a fascinating talk, on the fourth of your bullet points. Are we likely to be lucky enough to have a repeat of the Maunder Minimum, if so, when, and would this give us some extra time to save ourselves from what we're doing to the Earth's climate, provided we use the opportunity, instead of doing denial.

*Dr. Clilverd.* I would point you to the work of Mike Lockwood, who I think is often at these meetings. His work would predict a Maunder Minimum style of activity around about 2050 or so, between 2050 and 2100. If you don't have the auroral forcing of the system then the climatology will stay, and there will be a bit less variability year to year. So I don't think we can say it will do a great deal to stop or mitigate climate change. Mike Lockwood's most recent papers indicate a very non-active period around about 2050. Although I must admit I did this work as well myself, probably not quite as well as Mike, and found that it's going to get more active. The Sun, I don't know if you realize, is quite tricky!

*Dr. R. M. Catchpole.* My question is also round about the assumed Maunder Minimum. Until recently, people were suggesting that cosmic rays, which anti-correlate with solar activity, were the clue to understanding how it might affect the Earth's climate. Are you saying that this work, essentially, supersedes that idea? People had a problem explaining how cosmic rays could do it.

*Dr. Clilverd.* Well, cosmic rays are still being investigated. They tend to link in through cloud micro-physics and there are people working now on cloud micro-physics effects in that way. One of the issues is to try and get the models such that they can represent the physics that's going on in the clouds, so we can make informed decisions or draw informed conclusions about whether the Galactic cosmic rays have significant impact.

*Dr. Catchpole.* It didn't seem that that was very successful.

*Dr. Clilverd.* No, the success in this particular area was to get the models to reproduce the data even though the models are relatively complicated and it's quite hard actually to follow that path all the way through; but having all the chemistry that's required in these large climate models means that we have a really good feel for reproducing the data that we see and doing the studies that we need to do in order to test the mechanisms. And I think for the Galactic cosmic rays, we also need the cloud micro-physics before you can really start investigating that area and drawing strong conclusions.

*Mr. C. Barclay.* Two questions, one a very quick one; is the geomagnetic Kp index the same as the Ap index?

*Dr. Clilverd.* Yes, Kp is quasi-logarithmic and Ap is the linear expansion of that to make it easier to work with.

*Mr. Barclay.* You've hinted at redistribution of the heat. You haven't specifically mentioned kinks in the jet stream which I know have featured before. Is that something that you're looking at when you mentioned high-altitude effects?

*Dr. Clilverd.* Yes, certainly what's called the polar night jet is significant, so the winds in the stratosphere and the upper troposphere are very significant, and this idea of where the energy goes, guided by the jet, across the Atlantic for example, is part and parcel of the modelling studies that are going on, with the input being at higher altitudes and seeing how that energy then propagates down to influence that type of condition.

*Mr. Barclay.* But do you see a correlation?

*Dr. Clilverd.* Yes, there are correlations.

*Professor P. A. Charles.* Another long-term effect, of course, is the forthcoming flipping of the Earth's magnetic poles, and we know that the position of both the north and south poles is moving really pretty rapidly now. We don't even know what time it's going to happen — we just know it will happen. What would be the effect of that on your calculation?

*Dr. Clilverd.* Yes, that's a good point, and people are working on that with the same models that we're using for the energy input looking at varying magnetic field where there's a potential towards flipping. Certainly there are areas in the world that are much more sensitive to that effect — in the south Atlantic and in the southern polar regions, where the change in magnetic field is really seen as a significant factor at the moment. Clearly, the energy input is guided by the Earth's magnetic field; if the Earth's magnetic field changes substantially, then it becomes an even more complicated picture than it is at the moment. But certainly, the magnetic field is really important for this type of study — it defines where the energy is likely to be deposited, and therefore any significant reconfiguration of the Earth's magnetic field will make a difference. I think in that our 200-year runs, we are making extrapolations of the magnetic field but not to the level of flipping the magnetic field.

*Professor Kathy Whaler*. If I'm allowed, I'm also going to ask two questions. The first one is what fixes the longitude of that heating and cooling pattern? Why is it warmer over Europe and cold over Greenland rather than *vice versa*?

*Dr. Clilverd*. That's a very good question and I'm not sure I'm in the right place to answer that. My understanding is that if you just slightly skew the northern annular mode, effectively you're subtracting a similar pattern but it's been slightly rotated and you end up with some areas where it's plus and some areas it's minus, so you're actually just slightly readjusting where the energy is being deposited. The reason it is that shape is down to subtleties of orographic features in the northern hemisphere, so the surface features generate orographic and other wave activity which changes the orientation of the polar vortex or the strength of the polar vortex and things like that. I'm waving my hands a lot at this point.

*Professor Whaler*. I assumed it would be something like that. The other question is that, in terms of things like geomagnetically induced current and so on and so forth, we often see the situation where we have a magnetic storm as measured by one of your indices, and then the system starts to recover and then there's another event, which, although it's not as big as the initial one, is actually more damaging. I was wondering if there are similar effects seen in the chemistry of the atmosphere when you look at the kind of processes you've discussed today?

*Dr. Clilverd*. Yes, at the moment, the shortest time-scale we're working on in the atmosphere is about a month. By averaging activity levels over a month, we are saying "x is an active month", "x is not an active month", and things like that. There are some mechanisms that are being suggested, for example, cloud micro-physics which is much more to do with day-by-day response, but in this particular case, we're averaging. We would like to go to higher time sampling but the ability of the model and things like that are slowing us at the moment.

*The President*. Thank you very much indeed [applause]. It's now my pleasure to introduce again Professor Christine Done to give the George Darwin Lecture on 'Black holes, Einstein's gravity, and rocket science'. This should be exciting.

*Professor Christine Done*. [It is expected that a summary of this talk will appear in a future issue of *Astronomy & Geophysics*.]

*The President*. Thanks very much, Christine, so open for a few questions.

*A Fellow*. With the black-hole binaries, given that the black holes probably formed from supernovae, how does the companion star survive that?

*Professor Done*. Very good question.

*The Fellow*. I'm not a professional astrophysicist but I know that supernovae are very violent.

*Professor Done*. It's worse, actually, for the neutron stars. Because, for the black hole, what happens is you get the supernova exploding but the rest of the atmosphere is falling back down onto the black hole, so you lose some mass in the supernova but you swallow some of it down the black hole when you're making the black hole. For a neutron star, that's not the case. For the neutron star you must not go over 1·4 solar masses, so most of your mass you lose, and it's only the very small fraction of binary systems where the kick that it gives to the neutron-star orbit happens to kick towards the star, which means it doesn't unbind.

*Mr. Regnart.* I've always wondered why people don't have the escape-system equivalent for highly delicate and expensive technology that they do for thick, cheap, and rather wobbly bits of biology which human beings are. You would think, considering how many there are of us, and how cheap and expendable politicians think we are, that if we have escape systems when we're shoved into space, then really expensive kit would have the same. Is there a reason for this?

*Professor Done.* Weight is the reason. To build escape systems for your instrument would so increase the weight of the satellite, and you're always fighting against weight on your launcher. But it's actually not as bad as it sounds because when you're developing one of these new state-of-the-art instruments, you've got a 'flight spare'. It's the one used in all the vibration testing. I am going to shake it and see if it falls apart. I don't really want to do that on my real one, I'll do it on my spare. There is a 'flight spare', which we will be flying in two years' time on another rocket. I'm now a European member of the science team.

*Mr. Regnart.* Can I suggest having a system whereby you can have a go at igniting the top stage and then all you would need, all being well, would be a parachute system.

*Professor Done.* We'll suggest it to them.

*Ms. Yaling Xie.* Einstein thought that Newton's gravity is not right. Einstein wanted to unify the field, but he went in the wrong direction. Einstein's gravity has more problems than Newton's gravity, because Newton's gravity definitely does not exist whilst Einstein's gravity is more wrong. Think about the Solar System.

*Professor Done.* Ah, I think I see what you are asking. I talked at the very beginning about how we use two-dimensional pictures but really it's a three- or four-dimensional warping that we're talking about. But actually, you're right that Einstein has worse problems than Newton. When we go to quantizing gravity, when we try and unify gravity with all the other fields, then we're in real trouble, because all the other forces we describe through quantum mechanics and gravity don't quantize. So we have three forces that work together and then we have gravity, and we can't make them talk to each other. Yet we know we need them both when we start to talk about things like the singularity where we have really, really strong gravity on really, really small scales. Or the Big Bang origin of the Universe, where we have really, really strong gravity on really, really small scales. And until we have a better theory than Einstein's gravity, we're not going to be able to explore 'what's the structure of that singularity?' Until we have that new theory, we could maybe look in the data, but I am just showing you that these are the strongest gravitational fields we could ever hope to observe and they look like Einstein says they should. So it's going to be really tricky to find observational ways to find this new theory of gravity that we all know we need; we all know we need a theory of gravity that works with the other forces, and we don't yet have a good way of getting there.

*The President.* Let's thank our speaker again. [Applause.] I think our two talks this evening have shown we don't understand climate change and we don't understand gravity. On that note, can I thank the two speakers again for two excellent talks. Can I remind you that our usual drinks reception is in the RAS library now, immediately following this meeting, but I have some bad news. You will be asked to sign in and out — there will be a sheet provided. I am afraid we have to do this as a result of the health and safety regulations and insurance situation. We've had people coming in and going out and if there were a fire, we wouldn't know who to save [laughter]. Finally, I give notice that the next monthly A&G Open Meeting of the Society will be on Friday, the 13th of December, 2019.

# THE UNUSUAL ERUPTION OF THE EXTRAGALACTIC CLASSICAL NOVA M31N 2017–09A

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M31N 2017–09a is a classical nova and was observed for some 160 days following its initial eruption, during which time it underwent a number of bright secondary outbursts. The light-curve is characterized by continual variation with excursions of at least 0·5 magnitudes on a daily time-scale. The lower envelope of the eruption suggests that a single power law can describe the decline rate. The eruption is relatively long with $t_2 = 111$ days, and $t_3 = 153$ days.

## *Introduction*

A nova eruption is generally understood to be caused by a thermonuclear runaway on the surface of a white dwarf after accreting sufficient material from a cool, low-mass companion; see the reviews by Warner[1] and Bode & Evans[2], and the more recent paper by Starrfield *et al.*[3]. The recurrence time-scale of classical novae is long, generally > 1000 years (see Shara *et al.*[4] and Mróz *et al.*[5], for example) and is related to the mass of the white dwarf. As material accumulates on the white dwarf the recurrence interval of the eruptions shortens to < 100 years and the system morphs seamlessly into a recurrent nova, of which there are currently only ten Galactic examples[6,7]. The system is then on an inexorable path to a type-1a supernova.

Novae in M31 are apparently easy to discover, relative to Galactic novae at least. Over the past five years 37 novae have been discovered on average per year in M31, which is typically four times the Galactic discovery rate[8,9]. Of course, these tend to be faint with the average discovery magnitude $V \sim 18$, so consequently few have more than the peak brightness and initial decline rate observed. However, some important objects have been discovered and followed up, the most significant in recent years being the recurrent nova M31N 2008–12a discussed by Darnley *et al.*[10,11], which has a remarkably short recurrence interval of approximately one year.

The nova discussed here is M31N 2017–09a (AT 2017glc, PNV J00440872+4143367) which was discovered by the XOSS Group[12] while making follow-up observations of M31N 2008–12a, and lies some 18 arc minutes distant from it. The nova was discovered at an unfiltered (calibrated as $V$) $CV$ magnitude of 19·5 on 2017 August 30·7 UT (JD = 2457997·2) and remained at $CV \sim 18$ for the following three days before peaking at $CV = 17{\cdot}6$, then fading very rapidly to $CV \sim 20$. Some ten days after maximum it was confirmed spectroscopically as an FeII-class nova by Williams & Darnley[13]. Although the nova continued to be observed it did not attract any particular attention until it underwent a significant rebrightening about 100 days after discovery when it peaked at $CV = 18{\cdot}3$, $R = 18{\cdot}2$[14,15], $0^{m}{\cdot}7$ below the peak brightness.

TABLE I

*List of equipment used*

| *Observer* | *Telescope* | *CCD* |
|---|---|---|
| Boyd | LX 200 0·35-m SCT | SXVF-H9 |
| Cook | 0·73-m reflector | STF8300M |
| Cook | CDK24 0·61-m [a] | PL09000 |
| Cook | CDK20 0·51-m [b] | PL11002MT11 |
| Kiyota | CDK24 0·61-m [a] | PL09000 |
| XOSS | NEXT 0·60-m | PL230 |
| XOSS | HMT 0·50-m SCT | QHY-16 |
| XOSS | C14 0·35-m SCT | QHY-9 |

[a] iTelescope T24 MPC U69 Sierra Remote Observatory, Auberry, CA
[b] iTelescope T11 MPC H06 New Mexico Skies, Mayhill, NM

*Observations*

The observations were made using several telescopes ranging in size from 0·35-m to 0·73-m based in the USA, China, and the UK, and with several different detectors (Table I). All the images were de-biassed and flat-fielded by the respective observers prior to image processing. In order to improve the signal to noise it was necessary to stack a number of images depending on a variety of constraints, and this varied from typically five images up to 30 in one case. The magnitude of the transient was determined relative to a comparison sequence* through professional or commercial aperture-photometry software. All the images bar one set were taken unfiltered, either as 'Clear' or 'Luminance', which is similar to 'Clear' but with an infra-red cut off. These were calibrated against a $V$ magnitude sequence to give $CV$ magnitudes.

The early images were centred on the recurrent nova M31N 2008–12a so the sequence for that field was used, particularly the two brighter comparison stars (148 and 154) which lie between the two novae. All the observers used these comparisons except for Cook who developed what has become the AAVSO sequence for M31N 2017–09a, which is fainter and centred on that target. It is based on an extrapolation of nearby APASS standards[16] but most of these stars are faint for APASS and have relatively large uncertainties. However, they simply provide the zero point, and the sequence magnitudes are based on many measurements of the field. It also incorporates some faint stars measured by Massey *et al.*[17] which reach $V = 22$. A comparison of the fainter sequence

* Sequence available through the AAVSO Variable Star Plotter (www.aavso.org/apps/vsp/)

stars with measurements based on the brighter M31N 2008–12a (148 and 154) comparison stars shows no significant difference within the measurement errors of the nova, and is small compared with its variations.

One of the stars on Massey *et al.*'s list lies 6 arc seconds from the nova at $V = 21{\cdot}15$ and was clearly identified on all the faint images. For some images this star marked the limiting magnitude but on others fainter stars could also be identified. So, despite the large uncertainties the nova was clearly identified on all the deep images.

A single set of additional *BVRI* magnitudes was taken on one night by the XOSS team with the *NEXT* 0·60-m telescope. These were taken during the major rebrightening ~ 100 days into the eruption and give colours of $B - V = 0{\cdot}39$ and $V - R = -0{\cdot}05$ at that time, with uncertainties of $0^{m}{\cdot}1$ (uncorrected for reddening). A set of five *R*-band observations reported by Valcheva *et al.*[15], has also been used. All the observations are collected in Table II.

*The evolution of the eruption*

The whole eruption is shown in Fig. 1 with the *CV*, the single *V*, and the small number of *R* magnitudes plotted without adjustment. Given the uncertainties in the measurements and that $V \sim R$, that is not unreasonable. However, as most nova eruptions evolve the continuum cools and emission lines develop, particularly Hα, which means that $(V - R)$ tends to decrease and so the *CV* magnitudes might also be expected to brighten relative to *V*. The change in $(V - R)$ could be small or up to one magnitude depending on the type of nova[18–21], but it is not clear how this translates into a difference between *V* and *CV* nor if it is even applicable to this system. In the rebrightening event $(V - R) \sim$ zero, and in fact all the *R* magnitudes are consistent with contemporary *V* or *CV* values, so any reddening of the nova must scale with magnitude rather than time, and be limited to the fainter magnitudes. Even if there is a one magnitude

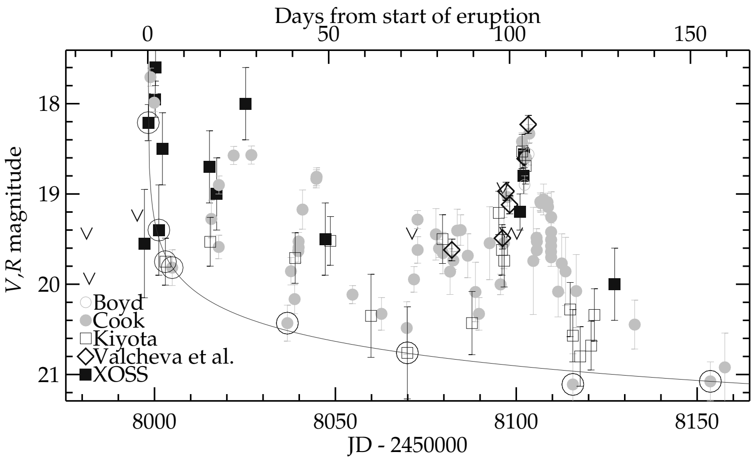


FIG. 1

Entire light-curve of the eruption. The line is the single-slope fit to the circled points which are taken to define the lower envelope of the eruption using Scenario 2 as described in the text. The single-slope fit to the first scenario is very similar, but marginally worse.

TABLE II

*Photometric observations of M 31 N 2017–09A*

| *JD* – 2450000 | *Mag.* | *Err.* | *Band* | *Observer* | *JD* – 2450000 | *Mag.* | *Err.* | *Band* | *Observer* |
|---|---|---|---|---|---|---|---|---|---|
| 7981·23 | >19·5 | | *CV* | XOSS | 8095·17 | 19·21 | 0·24 | *CV* | Kiyota |
| 7981·96 | >20·0 | | *CV* | Kiyota | 8095·65 | 20·00 | 0·11 | *CV* | Cook |
| 7995·22 | >19·3 | | *CV* | XOSS | 8096·05 | 19·62 | 0·28 | *CV* | Kiyota |
| 7997·22 | 19·55 | 0·60 | *CV* | XOSS | 8096·21 | 19·49 | 0·12 | *R* | Valcheva |
| 7998·28 | 18·21 | 0·20 | *CV* | XOSS | 8096·27 | >19·0 | | *CV* | XOSS |
| 7998·87 | 17·71 | 0·04 | *CV* | Cook | 8096·60 | 19·54 | 0·28 | *CV* | Cook |
| 7999·92 | 17·99 | 0·04 | *CV* | Cook | 8096·67 | 19·74 | 0·29 | *CV* | Kiyota |
| 8000·21 | 17·95 | 0·20 | *CV* | XOSS | 8097·10 | >19·5 | | *CV* | XOSS |
| 8000·30 | 17·60 | 0·20 | *CV* | XOSS | 8097·19 | 18·97 | 0·09 | *R* | Valcheva |
| 8001·21 | 19·40 | 0·50 | *CV* | XOSS | 8097·59 | 19·04 | 0·08 | *CV* | Cook |
| 8002·20 | 18·50 | 0·40 | *CV* | XOSS | 8098·20 | 19·12 | 0·08 | *R* | Valcheva |
| 8003·02 | 19·75 | 0·26 | *CV* | Kiyota | 8100·16 | >19·5 | | *CV* | XOSS |
| 8004·89 | 19·82 | 0·20 | *CV* | Cook | 8101·04 | 19·20 | 0·20 | *CV* | XOSS |
| 8015·20 | 18·70 | 0·40 | *CV* | XOSS | 8101·59 | 18·42 | 0·04 | *CV* | Cook |
| 8015·40 | 19·53 | 0·27 | *CV* | Kiyota | 8101·63 | 18·53 | 0·19 | *CV* | Kiyota |
| 8015·72 | 19·28 | 0·21 | *CV* | Cook | 8102·02 | 18·80 | 0·20 | *CV* | XOSS |
| 8017·20 | 19·00 | 0·40 | *CV* | XOSS | 8102·20 | 18·61 | 0·08 | *R* | XOSS |
| 8017·75 | 19·59 | 0·13 | *CV* | Cook | 8102·20 | 18·95 | 0·06 | *B* | XOSS |
| 8017·80 | 18·90 | 0·04 | *CV* | Cook | 8102·20 | 18·56 | 0·07 | *V* | XOSS |
| 8021·89 | 18·57 | 0·03 | *CV* | Cook | 8102·20 | 19·13 | 0·14 | *I* | XOSS |
| 8025·20 | 18·00 | 0·40 | *CV* | XOSS | 8102·31 | 18·90 | 0·09 | *CV* | Boyd |
| 8026·78 | 18·57 | 0·03 | *CV* | Cook | 8102·59 | 18·69 | 0·20 | *CV* | Kiyota |
| 8036·73 | 20·43 | 0·20 | *CV* | Cook | 8102·65 | 18·60 | 0·06 | *CV* | Cook |
| 8037·72 | 19·86 | 0·15 | *CV* | Cook | 8103·33 | 18·23 | 0·05 | *R* | Valcheva |
| 8038·74 | 20·17 | 0·16 | *CV* | Cook | 8103·42 | 18·56 | 0·12 | *CV* | Boyd |
| 8038·88 | 19·71 | 0·28 | *CV* | Kiyota | 8103·60 | 18·33 | 0·08 | *CV* | Cook |
| 8039·75 | 19·63 | 0·12 | *CV* | Cook | 8104·71 | 19·74 | 0·59 | *CV* | Cook |
| 8039·83 | 19·53 | 0·07 | *CV* | Cook | 8105·61 | 19·49 | 0·07 | *CV* | Cook |
| 8039·83 | 19·59 | 0·07 | *CV* | Cook | 8105·68 | 19·62 | 0·10 | *CV* | Cook |
| 8040·92 | 19·17 | 0·22 | *CV* | Cook | 8105·70 | 19·53 | 0·06 | *CV* | Cook |
| 8044·74 | 18·83 | 0·04 | *CV* | Cook | 8106·65 | 19·09 | 0·05 | *CV* | Cook |
| 8044·80 | 18·81 | 0·07 | *CV* | Cook | 8106·78 | 19·10 | 0·05 | *CV* | Cook |
| 8047·20 | 19·50 | 0·40 | *CV* | XOSS | 8107·54 | 19·06 | 0·17 | *CV* | Cook |
| 8048·61 | 19·52 | 0·27 | *CV* | Kiyota | 8108·63 | 19·09 | 0·04 | *CV* | Cook |
| 8054·73 | 20·12 | 0·07 | *CV* | Cook | 8108·78 | 19·14 | 0·07 | *CV* | Cook |
| 8059·85 | 20·35 | 0·46 | *CV* | Kiyota | 8109·61 | 19·64 | 0·10 | *CV* | Cook |
| 8062·74 | 20·33 | 0·18 | *CV* | Cook | 8109·63 | 19·58 | 0·10 | *CV* | Cook |
| 8069·73 | 20·49 | 0·29 | *CV* | Cook | 8109·63 | 19·42 | 0·07 | *CV* | Cook |
| 8069·89 | 20·76 | 0·51 | *CV* | Kiyota | 8109·64 | 19·51 | 0·08 | *CV* | Cook |
| 8071·20 | >19·5 | | *CV* | XOSS | 8109·64 | 19·70 | 0·10 | *CV* | Cook |
| 8071·73 | 19·95 | 0·14 | *CV* | Cook | 8109·66 | 19·26 | 0·28 | *CV* | Cook |
| 8072·71 | 19·28 | 0·07 | *CV* | Cook | 8111·57 | 20·08 | 0·28 | *CV* | Cook |
| 8072·74 | 19·62 | 0·15 | *CV* | Cook | 8112·58 | 19·77 | 0·33 | *CV* | Cook |
| 8077·79 | 19·45 | 0·29 | *CV* | Cook | 8113·61 | 19·86 | 0·38 | *CV* | Cook |
| 8078·64 | 19·60 | 0·07 | *CV* | Cook | 8114·90 | 20·28 | 0·30 | *CV* | Kiyota |
| 8079·61 | 19·50 | 0·27 | *CV* | Kiyota | 8115·63 | 20·57 | 0·29 | *CV* | Kiyota |
| 8079·72 | 19·66 | 0·23 | *CV* | Cook | 8115·64 | 21·11 | 0·34 | *CV* | Cook |
| 8081·70 | 19·86 | 0·25 | *CV* | Cook | 8116·56 | 20·08 | 0·41 | *CV* | Cook |
| 8082·20 | 19·62 | 0·12 | *R* | Valcheva | 8117·66 | 20·80 | 0·33 | *CV* | Kiyota |
| 8082·60 | 19·74 | 0·09 | *CV* | Cook | 8120·69 | 20·68 | 0·27 | *CV* | Kiyota |
| 8083·67 | 19·41 | 0·24 | *CV* | Cook | 8121·59 | 20·34 | 0·29 | *CV* | Kiyota |
| 8084·63 | 19·40 | 0·17 | *CV* | Cook | 8127·20 | 20·00 | 0·40 | *CV* | XOSS |
| 8086·59 | 19·68 | 0·24 | *CV* | Cook | 8132·73 | 20·45 | 0·27 | *CV* | Cook |
| 8087·76 | 20·43 | 0·35 | *CV* | Kiyota | 8153·65 | 21·08 | 0·22 | *CV* | Cook |
| 8088·71 | 20·09 | 0·33 | *CV* | Cook | 8157·65 | 20·92 | 0·38 | *CV* | Cook |
| 8089·69 | 20·33 | 0·18 | *CV* | Cook | 8153·65 | 21·08 | 0·22 | *CV* | Cook |
| 8092·65 | 19·55 | 0·40 | *CV* | Cook | 8157·65 | 20·92 | 0·38 | *CV* | Cook |

change in $(V - R)$, if less than half of this translates to $CV$ then the fainter $CV$ magnitudes may be too bright by perhaps $0^{m}\cdot3$, which is about equal to the uncertainties. So, as a working hypothesis it is assumed that for all practical purposes $CV = V = R$.

The eruption is clearly dominated by several large secondary outbursts, which although not as well observed as the documented rebrightening, are nearly as bright. These recur on an approximate time scale of 25 days, but there is also significant short-term activity. Despite the sometimes large uncertainties there are excursions of half a magnitude or more on a daily basis.

Despite the fragmentary nature of the data this nova is probably one of the best observed in M31 in recent years so every attempt has been made to derive useful parameters from it. In a major study of a large sample of novae Strope *et al.*[22] identified seven broad classes based on the light-curve shape and measured properties, while recognizing the enormous variation in the light-curves, and indeed the measured properties. For novae in Strope *et al.*'s 'smooth' class, with well-behaved light-curves, there is often a well-defined power-law relationship between the magnitude and the time from the eruption, of the form, $V \propto \alpha \log(t - T_0)$ where $T_0$ is time zero point of the relationship, and $\alpha$ is the slope of the power law. Although less well defined, power-law relationships are also seen in the other classes of novae, where the power law defines the lower envelope of the eruption. In practice well-observed light-curves can show several different power-law sections with break points between them. As well as being observed there are theoretical reasons for expecting a relationship of this kind. Hachisu & Kato[23] have proposed a 'universal decline law' which predicts the slope of the power law over time as the expanding shell evolves, with the first break point being closely related to the mass of the white dwarf.

The light-curve in Fig. 1 seems to divide naturally into two parts, the early rapid decline and the later slow fade which is marked by large secondary outbursts. However, the light-curve shows so much short-term activity it is difficult to define any base level that marks the decline of the nova. If there are two power-law sections, then one would cover the short section at the start of the eruption with a break point after ~ 5–10 days, and the second lasting for the rest of the observed eruption.

An attempt has been made to measure the underlying power laws but there is so much activity even in the initial eruption that it is not completely clear how it developed. The most obvious interpretation (Scenario 1) is that the eruption was caught on the rise and that the maximum occurred over the two days while the object was brighter than $V = 18\cdot0$. During this time there is significant variation of ~ $0^{m}\cdot3$ and there is also the suggestion of further instability during the rapid decline to $V \sim 20$ over the following 4 days. During this interval five points have been identified that might represent the baseline of the eruption and various power laws have been fitted assuming different values for $T_0$ over one day prior to the first point.

The less obvious, alternative interpretation (Scenario 2) is that the eruption occurred earlier, in the one day between the first two positive observations, which treats all the following bright points as secondary maxima. Given the behaviour over the rest of the eruption this is not unreasonable. In this interval four points define the baseline, three of which are shared with the previous scheme, and the power law was fitted in the same way. For the later part of the light-curve the lower envelope is very sparsely covered and only four points were used as shown in Fig. 1. The same $T_0$ values were used and the slope was fitted in the same way. The intersection of these two sets of curves defines the break point between the two power laws, and the difference between this and $T_0$ gives $t_{b1}$.

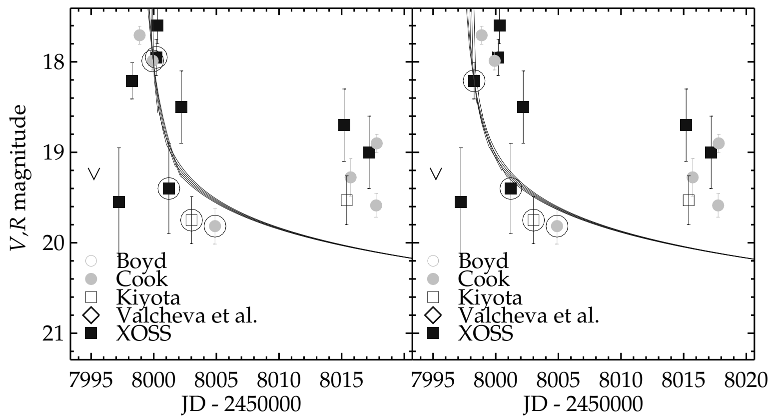


FIG. 2

The early part of the eruption showing (left) Scenario 1 the fits to the circled data for a variety of $T_0$ values as described in the text, assuming the eruption was caught on the rise. Scenario 2 (right) similarly shows the fits to the early circled data assuming the eruption occurred between the first two positive points.

The fits to the early data are shown in Fig. 2 and apart from a small offset in time show very little perceptible difference. The slope of the power law lies in the range 2·5 – 1·3 for Scenario 1, and 1·9 – 1·1 for Scenario 2, and in both cases the break point falls between ~ 0 – 17 days after $T_0$. The implication of $t_{b1} \sim 0$ is that a single power law could fit all the data. The reason for the wide range of slopes and particularly $t_{b1}$ is that the power law is a measure of the decline rate as the eruption unfolds. Near $T_0$ it becomes unstable and tends to infinity, and this can be seen in the plots. Using all the points that define the lower envelope it is possible to fit all the parameters of the power law using a non-linear least squares, which is not possible for the individual sections. Doing this yields $\alpha = 1{\cdot}1 \pm 0{\cdot}2$ and $0{\cdot}9 \pm 0{\cdot}2$ for Scenarios 1 and 2 respectively, and in both cases $T_0$ occurs very close, and obviously prior, to the first point of their respective sets. To test the effect of overestimating the brightness of the later points of the envelope they have also been set $0^{m}{\cdot}3$ fainter, in which case the slopes are increased by 0·2.

Strope *et al.* provide useful and descriptive names for their classes of novae and at 38% of their sample the smooth class is the most abundant. The next three most populous classes are light-curves showing plateaus (21%), dust dips (18%), and jitters (16%), and it is this last class that M31N 2017–09a most closely resembles. These tend to be active for a long period before finally declining and so although the light-curve may pass 2 or even 3 magnitudes below the peak early in the eruption it is the *final time* it passes this point, that determines $t_2$, $t_3$ *etc.*, so it tends to be late. From Fig. 1 it can be seen that both these points are passed very close to the end of the observed eruption giving $t_2$ = 111 days, and $t_3$ = 153 days. These values, particularly $t_2$, are among the largest in Strope *et al*'s sample.

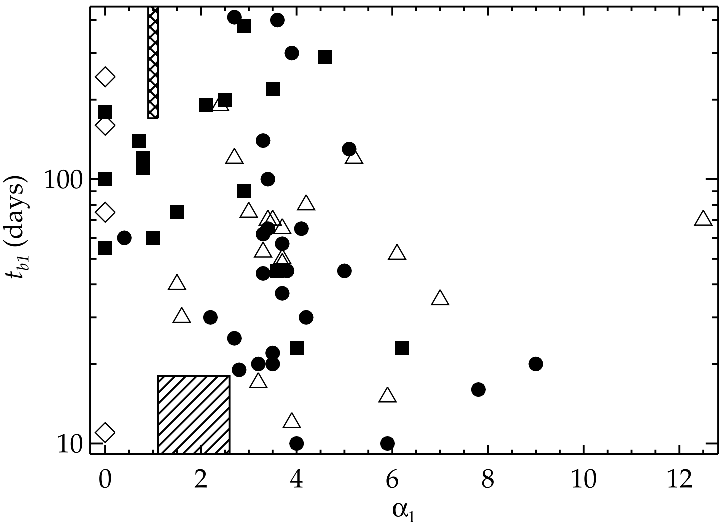


FIG. 3

Plot of the time to the first break in the power-law gradients *vs.* the first gradient ($\alpha_1$) for all the novae in Strope *et al.*'s sample for which both values exist. The main points of interest are from the 'smooth' (filled circles) and the 'jitter' (filled squares) light-curves. The vast majority of the 'jitter' light-curves have $t_{b1} > 50$. The hatched region at the bottom of the plot covers the values of the two-slope solutions while the cross-hatched region at the top is formed by the two single-slope solutions and a lower limit of the break point from the length of the data.

It is also possible to compare parameters of the power-law fits with Strope *et al*'s sample. Fig. 3 shows the time to the first break point $t_{b1}$ *vs.* $\alpha_1$, the slope of the first power law. It should be noted that Strope *et al.* define $\alpha$ in the opposite sense ($-\alpha$) so their values have been reversed. Using $\alpha_1$ from the two-slope fit and the limits on $t_{b1}$ gives the box at the bottom of the plot. Although the values of $\alpha_1$ are consistent with other 'jitter'-class novae, $t_{b1}$ is not, and also the box appears to lie in a zone of avoidance. By contrast, $\alpha$ from the single power law and a lower limit to $t_{b1}$ from the length of the data, are both consistent with similar 'jitter'-class novae.

*Conclusions*

The eruption of M31N 2017–09a is very complex and probably dominated by four secondary outbursts which are nearly as bright as the initial one. These recur on a time-scale of approximately 25 days but there is also considerable short-term activity with variations of half a magnitude on a daily basis. The exact shape of the initial outburst is not completely clear as this also shows short-term activity. The general behaviour of the eruption is consistent with the 'jitter' class of Strope *et al.*[22] and it seems most likely that the lower envelope of the eruption is consistent with a single power law with $\alpha_1 = 0{\cdot}9$. A lower limit to the first break point is given by the length of the data, so $t_{b1} > 160$ days. The values of $t_2 = 111$ and $t_3 = 153$ days are measured from the light-curve and these are also consistent with that class of nova.

There are two possibly contentious issues. The first is that the *CV* magnitudes are not a good proxy for *V*, but it has been shown that for much of the eruption $CV = V = R$, although the faintest magnitudes may be too bright relative to *V* by some probably insignificant, but unknowable, amount. The second issue is that the lower envelope of the eruption has not been sampled and it is certainly true that the statistics are poor, but again this is in the domain of the unknown. Having said that, all the points that appear to define the lower envelope are consistent and provide a result that is not unreasonable.

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# CORRESPONDENCE

## *To the Editors of 'The Observatory'*

### *Otto Heckmann: Friend or Foe?*

Some readers might get a false impression of Otto Heckmann from the brief mention of him in Trimble's recent book review in these pages[1], so I would like to add some more information. I studied physics and astronomy at the University of Hamburg and worked as a student at the Hamburg Observatory*, of which Heckmann had been director (long before my time), so while I have no

*The Hamburg Observatory was founded in 1802, and has been at its current location for about 110 years. The University of Hamburg was founded in 1919, taking in the observatory. The Hamburg Observatory became an institute of the department of physics of the University in 1968.

first-hand information, some is second- or third-hand. It is true that Heckmann was a member of the Nazi party (not just before — having joined in 1937 to avoid an end to his career — but also during World War II). It is also true that he continued to employ at least one endangered person — Eleonora Grünwald, who had Jewish ancestry on her father's side; he knew this and was required to report it (which, of course, would have led to her deportation to a concentration camp), but didn't — and probably three more in a similar situation[2]. This is not a contradiction. When they learned that he had joined the Nazi party and that that would allow him to become director in Hamburg, many at the observatory were relieved, because that meant that they wouldn't get a *real* Nazi, especially since there were efforts to install such a person (there were several potential candidates) as director instead of Heckmann. He was the first choice of the preceding director Richard Schorr and the observatory at large after Walter Baade (who, along with Rudolph Minkowski*, had also worked in Hamburg before emigration) had declined. Heckmann was suspicious to the authorities because he didn't oppose Einstein's theory of relativity, and also because he had many Jewish acquaintances and was a sympathizer of the left wing of the *Zentrum* party; at the time, there was a '*Deutsche Physik*' movement (led by Nobel laureate Philipp Lenard) which intended to rid physics of Jewish influence. (Einstein was not only the most famous scientist in the world, but also, though not religious (not that that mattered to the Nazis), didn't hide his Jewish background.) Heckmann managed to get the post by emphasizing Newtonian cosmology[2] as developed by McCrea and Milne[3] (I wonder why this work is almost always referred to as "Milne and McCrea"), intentionally giving the impression that General Relativity might not be needed in cosmology. This was just a smokescreen, however, obvious to those in the know, and Heckmann's book[4] actually did much to popularize relativistic cosmology. Together with Carl Friedrich von Weizsäcker and others, he was a member of a group opposing the '*Deutsche Physik*', which actually led to the isolation of the latter after 1940, long before the war would end. He had joined the *NS Fliegerkorps* (not actually affiliated with the Nazi party); it was common knowledge that many who joined this organization often did so not out of conviction but in order to do the minimum possible to avoid losing their careers. This is not necessarily a mark of opportunism; someone formally on the wrong side of history can often do more good than someone who lays low, emigrates, *etc.*; had Heckmann emigrated, he couldn't have saved anyone's life essentially by hiding her at the observatory. Also, not everyone was able to emigrate; keep in mind that the United States of America had refused asylum to Anne Frank and her family[5]. (Frank later died in a concentration camp, probably of typhus.)

There were, of course, scientists, such as Lenard, who opposed Einstein and 'Jewish science'. (Einstein got his Nobel Prize for explaining Lenard's observations of the photoelectric effect.) Although some, such as Pascual Jordan† (one of the few to have made substantial contributions both to quantum mechanics and General Relativity), were unrepentant with regard to their

*Minkowski, nephew of Hermann Minkowski, had Jewish ancestry. Sensing what was to come, Baade, who had been at Mt. Wilson since 1931, helped Minkowski and his family to emigrate to California in 1935[2].

†I have often heard people speak of the 'Dshordan' frame, as opposed to the 'Yordan' frame, in gravitation theory, concluding that they don't know that he was German (though of Spanish ancestry) or don't know how German is pronounced.

political views (though Jordan remained a defender of Einstein and other Jewish scientists), most tried to continue their work despite the political situation, some realizing later rather than sooner the true evil of fascism. (Planck's son Erwin was executed for his part in the failed attempt to assassinate Hitler organized by Claus Schenk Graf von Stauffenberg.) Of course, many had no chance and were forced to emigrate, the effect perhaps best documented by a conversation between a politician and a mathematician. When asked by the minister of education Bernhard Rust whether it was true that his institute had suffered due to the exit of Jewish mathematicians, David Hilbert replied that the institute no longer existed[6].

After two decades as director of the Hamburg Observatory, during which he was also vice-president (1955–1961) of the IAU, Heckmann became the first Director General (1962–1969) of ESO (headquartered in Hamburg for a while as a result) and, later, president of the IAU (1967–1970). He held an extraordinary IAU General Assembly in Poland to commemorate the 500th anniversary of the birth of Copernicus. Heckmann was a foreign member of many academies of science and astronomical organizations, received honorary doctorates from universities in many countries as well as prestigious astronomical medals, and was a major figure in international cooperation in astronomy[7,8].

Yours faithfully,
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*To the Editors of 'The Observatory'*

*Chess-playing armchair cosmologists*

I've often used Rees's description, mentioned in the Gerald Whitrow Lecture on 2019 February 8[1], of the observable Universe shrunk to the size of the Solar System. The interesting thing, though, is that the density would be within an order of magnitude or so of that of a neutron star, thus not extremely far removed from our experience. Of course, that demonstrates how empty the Universe is, mainly between stars and within atoms: the Hubble Deep Field, where one sees the sky almost covered in galaxies, is about the same angular size as a grain of rice held at arm's length; a sky of such fields, compressed to what is still a familiar density, would form a ball of radius not much larger than that of the asteroid belt.

All in all, an enjoyable lecture, even including a reference to Lewis Carroll[2] (at least I hope so; if not, then it's not a literary allusion but rather an illusion). However, although Zwicky[3] might have first suggested dark matter about 80 years ago (actually, closer to 90 now), he wasn't the first to suggest it. The concept and sometimes even the name (perhaps in another language) had been mentioned before by the likes of Kelvin[4], Poincaré[5–7], Jeans[8], and Oort[9] (Zwicky used the German term *dunkle Materie*) and the concept of dark matter goes back at least to the discovery of Neptune due to its gravitational influence on Uranus, though to be sure the last item was not an indication that most of the mass of the Universe was in dark matter, nor did it imply matter of unknown composition.

Given the restricted length, Rees deals well with the ideas of the multiverse, fine-tuning, and the anthropic principle, but the questions indicate that there is still some confusion. Readers interested in exploring those topics in depth should consult the books by Barrow and Tipler[10] (an extensive treatise on the anthropic principle), Tegmark[11,12] (which discusses many topics related to multiverses, including fine-tuning), and Lewis and Barnes[13,14] (which discusses many topics related to fine-tuning, including Tegmark's Level II multiverse), as well as the volume on many aspects of the multiverse edited by Carr[15]. Trimble[16] has written a very enjoyable history of the multiverse idea; like Tegmark, she also has four types of multiverse, but there is not a one-to-one mapping. A very extensive recent review[17] explores "[t]he degree of fine-tuning in our universe — and others". Such topics, though explored primarily by chess players sitting in armchairs, are a very active area of research.

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## REVIEWS

**Cherenkov Reflections: Gamma-Ray Imaging and the Evolution of TeV Astronomy**, by David Fegan (World Scientific), 2019. Pp. 321, 23·5 × 15·5 cm. Price £105 (hardbound; ISBN 978 981 3276 85 7).

The field of TeV-energy astronomy is today part of the observational landscape in a way that would have been hard to imagine when the author of this interesting book started his career. He charts the difficult, not to say at times highly frustrating, history of TeV astronomy in detail, revealing both the characters involved and the technological developments in an entertaining way.

Using Cherenkov light to image astronomical sources grew from the study of cosmic rays. The field really expanded after the discovery of atmospheric Cherenkov radiation in the 1950s by scientists looking for the sources of cosmic rays. The earliest experiments did not detect any astronomical sources, and as the author notes, it "might appear easy to dismiss these early cosmic-ray point source directionality experiments as premature or naïve, but such a judgement would be unfair". Indeed, as so often in astronomy, looking for one thing leads to another, as several Nobel prize winners can testify. Once atmospheric Cherenkov light had been discovered, turning those precious brief flashes of light into known sources took several decades of hard, determined graft by many scientists. Leading eventually to the famous *Imaging Atmospheric Cherenkov Telescope* (*IACT*) *Whipple* observatory in the USA, *via* numerous experiments around the world, including Russia, France, the UK, and Ireland, the story is truly heroic. The pioneers showed a determination that should inspire those who think astronomy is something you do simply *via* a computer screen.

There are many insights littered throughout this book, coupled with anecdotes and tales of multiple experiments, some located in what could be called 'sub-optimal' observing locations — the Harwell–UCD collaborative twin mirrors on a Bofors gun mount in a remote Irish valley being a good example. Progress came not just from technological developments but also from statistical analysis, a topic rightly highlighted in several chapters. Eventually techniques were developed to simulate air showers, remove the background, and use true imaging. These advances led to the first detections of the brightest sources, including the Crab Nebula, independently by several groups. The source list now totals several hundred, spanning many classes both Galactic and extragalactic.

Very recently the first gamma-ray bursts have been detected by the *MAGIC* and *HESS* consortia, members of the so-called third-generation systems. This bodes well for the next generation Cherenkov system, the *Cherenkov Telescope Array* (*CTA*), under construction right now on La Palma and in Chile. The author ends the book with some thoughts on the prospects for *CTA*, a project which has managed to combine virtually all astronomers working in the field, and some newcomers like me. *CTA* will be a true general-purpose observatory, but will be capable of detecting well over a thousand sources and will operate in the era of other powerful new facilities.

This book is recommended to those interested in knowing how TeV astronomy began, evolved, and remains a growth area. The author has captured the difficulties of being a pioneer, amply demonstrating the need to keep the faith and work the problem until you succeed. Cherenkov telescopes are now in operation around the world, and at the dawn of the *CTA* era TeV astronomy has a lot of evolving still to do. — PAUL O'BRIEN.

**Extragalactic Novae: A Historical Perspective**, by Allen W. Shafter (IoP Publishing), 2019. Pp. 130, 26 × 18·5 cm. Price £99/$150 (hardbound; ISBN 978 0 7503 1297 4).

This book is part of my history, because author Allen Shafter (now a professor at San Diego State University) received a physics bachelor's degree from the University of California, Irvine, when I was already on the faculty. And, in the immortal words of Jan Oort, you know you are getting old when they start asking you to retirement parties for your students! Actually, they didn't, but all is forgiven.

When was the first nova seen — in 1006, 1054, 1572, or 1604? Well, no, as the volume makes clear, those were supernovae. And S And discovered near the centre of the Andromeda Nebula (M31, NGC 224) in 1885 September was indeed extragalactic, but also a supernova. What about CK Vul, 1670? Galactic and quite possibly a stellar merger or collision, rather than a common, garden variety, or classical nova. Onward to WY Sge 1783 and V841 Oph 1848, still only in the Milky Way. In 1866 William Huggins recorded the spectrum of T CrB, so we truly know it was a nova, indeed a recurrent one. The 1895 event in NGC 5253 (Z Cen) was also a supernova, so we have reached the end of Chapter 1 without getting to the actual subject, though T Sco (1860) was at least in a globular cluster, M 80.

To the rescue come the new, large, reflecting telescopes, used by George Ritchey (Mt. Wilson 60-inch, which indeed he designed) and Heber Doust Curtis (36-inch *Crossley* at Lick), recognizing transients in M31 and other galaxies (well, spiral nebulae as they were then, and probably some of the transients, just long-period variable stars). But our subject finally exists. Contemporaneous were the first nova theories. Shafter describes the first one as stars passing through gaseous nebulae and credits J. G. Hagen (1921). Shapley was of this view at the time of the 1920 April debate with Curtis, but since spiral nebulae were already known (at least by Slipher) to display large radial velocities, they would be overtaking the stars. Soon Hubble and others were accumulating dozens of Galactic novae and, up to 1930 (Shafter's Figure 2.7), 19 extragalactic supernovae. And, by 1927, W. H. Pickering and Hugo von Seeliger (quoted in Russell, Dugan and Stewart) had suggested that a swarm of meteorites or a planetary body might collide with a star, triggering a rapid release of sub-atomic energy from near enough the surface for the surviving star to look more or less unchanged after some decades.

The current best-buy model (Chapter 4) is thermonuclear run-aways on the surfaces of white dwarfs that have been accumulating mostly unburned hydrogen by mass transfer from a non-degenerate companion star. There are also dwarf novae, whose less-spectacular but more frequent outbursts reflect variable accretion, with no nuclear reactions or mass ejection: "The instability of Bath" resides in the donor star. The winning instability in the accretion disc was put forward by Osaki in about 1971 and supported by Paczyński a few years later, but is credited here to Pringle in 1981.

Much of the rest of the book is devoted to surveys and attempts to determine the rates of nova outbursts in the Milky Way and other galaxies, as a function of underlying stellar-population type and maximum luminosity, and to the existence and ubiquity, or not, of a correlation of maximum luminosity with the rate of fading, the MMRD (maximum-magnitude – rate-of-decline relation, where faint equates to slow, the opposite of supernovae). Nearly a century of controversy over this has spanned the alphabet of scurrilous adjectives, as you might expect for something first studied by Adams (Walter S.) and Zwicky (Fritz), not together. Knut Lundmark, Walter Baade, and others of our favourite debaters come in here too, some with great insight, others not. Perhaps it is only a selection effect, favouring the discovery of brighter and more slowly evolving novae (pp. 8–14).

The theoretical discussion merges into cataclysmic variables as potential progenitors of type-Ia supernovae, for which the bitter battle is between 'single-degenerate' and 'double-degenerate' models with, unquestionably, evidence both for and against both possibilities. Shafter suggests that the best single-degenerate progenitor candidate may be a recurrent nova in M 31 called M 31N 2008–12a. It has a recurrence time of only about a year, implying both a very massive white dwarf and a rapid mass-transfer rate, plausibly taking the white dwarf to the Chandrasekhar mass in only about 500 000 years, by which time, of course, M31 should have had something like 5000 other type-Ia-supernova events and 25 million nova explosions.

Whether novae are over-represented in globular clusters (the way X-ray binaries are) is another topic still to be settled. And our fun fact for today is that, while globular clusters in the Milky Way have names beginning with M (for Messier) or N (for Dreyer, well, New General Catalogue), globular clusters in M31 have names beginning with Bol, not the same guy who coined $M_{bol}$ for absolute brightness at all wavelengths, but short for Bologna, where Luigi Jacchia and later Leonid Rosino compiled a catalogue (I looked that bit up; the author assumes we know how things get their names, but does credit the phrase "cataclysmic variable" correctly to the Gaposchkins).

Author Shafter is most reliable when discussing these surveys and statistics, issues to which he has made major contributions. On the other hand, the statement that Williamina Fleming classified the majority of the spectra in the *Henry Draper Catalogue* (*vs*. Annie J. Cannon) counts as distressing, and I am not sure where to put the statement that Arthur Eddington was a candidate for director of the Harvard College Observatory at the same time (1920) as Shapley.

The topic of novae is, at any rate, a timely one. The November issue of *Physics Today* (received by most members of the 11 societies that are part of the American Institute of Physics) features *The New Science of Novae*, by Koji Mukai (many of whose papers are cited by Shafter) and Jennifer L. Sokoloski, the science director of the *Large Synoptic Survey Telescope*, whose large surveys Shafter hopes will resolve many of the issues he discusses about nova rates, types, and parent populations. — VIRGINIA TRIMBLE.

**Southern Horizons in Time-Domain Astronomy (IAU S339)**, edited by R. Elizabeth Griffin (Cambridge University Press), 2019. Pp. 361, 25·5 × 18 cm. Price £95/$125 (hardbound; ISBN 978 1 107 19263 8).

Aristotle, the famous Greek philosopher, wrote in 350 BC that the stars are unchanging and invariable. David Fabricus was the first to identify a periodic variable when he noticed Mira brightening twice over a period of 15 years around 1600. Since then we've discovered that variability of all sorts pervades the Universe.

This timely conference addressed the variety of new tools (*e.g.*, *SkyMapper, Gaia*) that are available to explore the variable Universe and the ones that will be coming on-line in the next few years (*e.g.*, the *Vera Rubin Observatory* (*VRO*)). Time variability is being explored across the electromagnetic spectrum and indeed beyond with experiments such as *LIGO*. Some of these tools, *e.g.*, the *VRO*, will provide immense amounts of data that will require machine-learning techniques to extract the science properly.

A novel aspect of this conference was the afternoon workshops that offered opportunities to discuss topics in depth or to provide training in some cases. I found the paper from the workshop on radio transients particularly interesting to read as it covered the subject extremely well.

Other themes explored were explosive transients, long-term and stellar variability, and high-energy variability. Two of the newest, and perhaps most exciting, types of variability include gravitational waves (GWs) and their electromagnetic counterparts, and the fast radio bursts (FRBs) were discussed. FRBs are a mystery to be solved while GWs provide insight in a hitherto unobservable part of the Universe.

The final day of the conference was a critical examination of the techniques available to study transients. Can these techniques meet the challenge of types and volume of new data that will become available over the next several years? The answer seems to be 'yes' in some cases and 'maybe' in others, and there is clearly the need for additional work in further instances.

This volume clearly lays out the exciting future for time-domain astronomy, as well as the challenges that face the community if the science is to be extracted from the vast types and volume of data that will be available in years to come.

The phrase "the more things change, the more they stay the same" will always apply to daily life. In astronomy the more appropriate phrase might be "the more things change, the more the Universe reveals itself". — DENNIS CRABTREE.

**Time-Domain Studies of the Andromeda Galaxy**, by Chien-Hsiu Lee (IoP Publishing), 2019. Pp. 67, 26 × 18·5 cm. Price £99/$150 (hardbound; ISBN 978 0 7503 1354 4).

This slim 67-page volume, better described as a monograph than a book, takes the reader through all studies of our nearest galactic neighbour in space that bear upon the variability of its many and diverse stellar constituents. The author groups aspects of variability under three headings: periodic and aperiodic variables, transients, and multi-wavelength studies. In so doing, he also brings the reader up to speed in the techniques that are severally applied in the many studies that are mentioned — Cepheids, eclipsing binaries, LBVs and R Cor Bor stars, microlensing, period-search algorithms, and the plethora of wavelength-specific instruments on the ground and in space. Even with the condensed style that Lee adopts, one cannot but marvel at the enormous potential wealth of science which this one island universe holds, rivalling that of the Milky Way but inevitably limited as regards detail from high-resolution data owing to restrictions imposed by distance.

Lee has produced a scholarly work that embraces a great many subtopics, drawing from a rich archive of references and providing detailed descriptions of methods where needed. It will form a helpfully concentrated adjunct to libraries of more voluminous studies of the same subject, and will be especially useful for someone wanting a quick guide to studies — past or current — on M31.

In a couple of aspects the book falls a little short of what most scientific books seek to offer, particularly a lack of an index. The pages are numbered as sequences within each of the six chapters, rather than consecutively throughout, a scheme that is unusual though apparently adequate. There is an overabundance of acronyms, and as there is no glossary it can be difficult to identify a given one. The Preface asserts that studies of M31 are utilized "as an example to walk the reader through the ideas and techniques of time-domain analysis", thereby introducing some ambivalence into the purpose of the book — whether a monograph on M31 or a survey of time-domain astronomy.

Lee's approaches tend to be somewhat stylized; for instance, his confident assertion that time-domain studies are a recent feature of astronomy and owe their present burgeoning to CCDs and upcoming sky surveys, rather ignores the unavoidable fact that it was the *variability* of objects in the Universe that really triggered the study of astronomy and astrophysics in the first place. His English occasionally leaves something to be desired (*e.g.*, "digitized detector"), and a few other slightly misty descriptions are a bit puzzling; he could have benefited from the assistance of someone more fluent in the language to straighten out those places and perhaps avoid the repetition of so many clichés. Figures to illustrate the text are fairly numerous and generally helpful, but Lee has relied on the use of colour to transmit information and those colours have not always been well reproduced (and in one bad case, almost not at all). But these petty grumbles aside, this is a neatly condensed study that deserves a welcome. — ELIZABETH GRIFFIN.

**Radiative Signatures from the Cosmos: A Conference in Honor of Ivan Hubeny** (ASP Conference Series, Vol. 519), edited by Klaus Werner *et al.* (Astronomical Society of the Pacific), 2019. Pp. 320, 23·5 × 15·5 cm. Price $88 (about £69) (hardbound; ISBN 978 1 58381 925 8).

Ivan Hubeny is a charming gentleman with (at least) 68 good friends from (at least) 15 countries, who joined together in Paris (where Hubeny had done some of his early computations) in 2018 October, to celebrate his 70th birthday. That 68 is a small enough number that many actual human beings are recognizable in the conference photograph, and some also in the many images from meeting sessions, meals, poster sessions, and so forth scattered through the pages (at least if you are good at recognizing your colleagues from the back). The conference sessions and sections in these proceedings track closely the topics for which the honoree is noted: radiative transfer and modelling techniques, for stars both hot and cool, extending through the years to the atmospheres and discs of exoplanets, brown dwarfs, binaries, and supernovae, and adding these up to make stellar populations. The concluding remarks, from Katia Cunha of Brazil, focussed on Galactic Archaeology, deriving accurate stellar abundances, and the problems of dealing with very large, high-precision data sets, condensed to a single, reference-less, page in the proceedings.

Hubeny's own contribution to the conference, 'Radiation Transport in Astronomical Objects: Yesterday, Today, and Tomorrow', comes about a third of the way in and reveals, among other secrets, the origin of the name TLUSTY for his radiation-transport code, which I had vaguely supposed to be an acronym for Theoretical Linear whatever. It is, in fact, the Czech word for 'fat' chosen to amuse the handlers of the giant boxes of IBM punch cards initially needed to accommodate the thing. It contrasts with the word Hubeny itself, which means thin or skinny, which he has managed to remain into "late middle life".

The preceding paper comes from his daughter, Veronika Hubeny (who was an undergraduate at the University of Maryland when I was on that faculty). She is concerned with black holes, not so much for astrophysics, but as pointers to quantum gravity, holography, entanglement, gauge/gravity duality, and such. She and her father have, however, collaborated on a couple of AGN papers, thus joining Estonians Jaan Einasto and his daughter Maret as one of very few father–daughter pairs in the field. The mother–daughter territory includes Cecilia Payne-Gaposchkin and Katherine Gaposchkin Haramundanis, and Vera Cooper Rubin plus Judith Rubin Young. Veronika's is the one chapter in the proceedings whose colour photos I wish had been reproduced at larger scale. They are seven family photos ranging from her parents' wedding day (yes, mother and wife Jana was also at the symposium) to recent climbing adventures.

Ivan (Ivanek to his family) Hubeny was born in 1948 (we knew that from the fact of the conference) in Prague (Praha) Czechoslovakia on the 5th of Června* (from which you deduce that his Wiki is in Czech). He received his PhD from the Charles (Karlova) University of Prague in 1977, early work having been done with Jan Hekela.

The latter was a member of IAU Commission 26, Double Stars, and was still in Ondrejov in 2000, but disappears from the 2003 IAU Directory. Hubeny was a member of Commissions 29 (Stellar Spectra) and 36 (Theory of Stellar Atmospheres — curiously, the title of his magisterial 2014 textbook with Dimitri Mihalas) under the old system, having been elected to the IAU in 1982. Under the current system, Hubeny belongs to Divisions B, F, and G, and to Commissions B5 (Laboratory astrophysics), F2 (Exoplanets and Solar System), and G5 (Stellar and planetary atmospheres).

Despite the boxes of IBM cards, computing facilities at Ondrejev in 1977 were too slow for what Hubeny wanted to do, and he spent part of 1977–78 in Paris under the auspices of Françoise Praderie and Jean-Claude Pecker. By way of time line, while 1948 saw the establishment of the Czechoslovakian Socialist Republic, Charter77 was the beginning of real, permanent change there. (Miroslav (Mirek) Plavec had left at the time of the 1968 Prague Spring and had settled at UCLA, leaving younger colleagues in charge of the Prague binary-star-evolution project.)

The Hubenys' move to the United States was a slightly complex one, with time at UCLA and a visiting fellowship at JILA (Colorado) for 1987–88, during

*You may not believe that there is a single book I own that I have not reviewed in *The Observatory*, but in fact there are several volumes of Polish Calendars of past years, from the month names of which one can deduce that this is June.

which time the TLUSTY code was completed and submitted for publication in *Computer Physics Communications* (**55**, 103). Their time at JILA and NCAR extended through the 1989 Velvet Revolution, and they settled into Goddard Space Flight Center and its environs from 1992 onward (according to submission addresses on various papers). Veronika is now a fellow Californian, at UC Davis, and her folks have found a comparably warm spot in Tucson, Arizona.

The key TLUSTY paper had been cited more than 600 times as of Friday 2019 December 13. It was described as having been developed on the JILA VAX8600, in 8100 lines of Fortran77 code, to describe plane-parallel, horizontally-homogeneous, radiative and hydrostatically equilibrated, non-LTE gas with as many elements, ionization states, and transitions as the user was prepared to find computing space and time for, with no macroscopic velocity fields. It was related to codes from Auer and Mihalas, but completely independent; SYNSPEC, to predict the spectrum of light emitted by such an atmosphere, came later, in work mostly with T. G. Lanz. An update of the codes, extending cool enough for brown dwarfs and exoplanets, was in progress as the proceedings went to press, still in Fortran77.

Curiously, only about four of the papers included cite the code paper; indeed many of the presentations do not cite any of the honoree's work. However, SYNSPEC was used and cited in my private favourite of the papers appearing in the volume under consideration: Heap, Hubeny & Lanz, 'Stars and stellar black holes in the low-metallicity galaxy I Zw 18'. This provided supporting evidence for the HMXRB in the NW part of the galaxy having an accreting black hole of something like 85 $M_{\odot}$. This accounts for the XMM flare to $3{\cdot}2 \times 10^{40}$ ergs $s^{-1}$ and also for the optical (from SDSS) and UV (from *HST*/*COS*) spectra of the surrounding gas. We need black holes like this in low-mass, low-metallicity galaxies like I Zw 18 to produce merger events like those recorded in recent years by *LIGO*, *VIRGO*, and all. — VIRGINIA TRIMBLE.

**Astronomical Heritage of the Middle East** (ASP Conference Series, Vol. 520), edited by Sona V. Farmanyan *et al.* (Astronomical Society of the Pacific), 2019. Pp. 305, 23·5 × 15·5 cm. Price $88 (about £69) (hardbound; ISBN 978 1 58381 927 2).

What we have here is a rich, diverse, and attractive collection of short essays on a multitude of features presented at an international conference on Middle East Astronomical Heritage. Those features range from archaeological sites (protected, and in various stages of preservation) and petroglyphs (rock art) dating back a bewildering number of centuries, through libraries (papers, records, books, and specimens of art), museum collections, and religious buildings, to relatively modern centres of astronomical research and scientific activities, including vigorous education and outreach. Some of the papers describe what has been discovered and preserved as tangible astronomical treasures, some investigate ancient manuscripts and draw out from them the very oldest relationships between humans and the skies, some present research that is pushing back millennia to uncover, through those early interests, the creation of calendars for pursuing things both astronomical and agricultural, while others (with Byurakan Observatory in Armenia particularly strongly represented) illustrate numerous examples of more modern astronomical science that has been, and is being, pioneered in Middle Eastern countries. Between them the contributions represent most of the nations in that region.

Education in astronomy and related scientific disciplines appears to be well supported, particularly in Armenia where this conference was hosted. Moreover, visits to astronomical sites feature prominently in tourist schedules and include actual observing and astronomy lectures as well as discussions about heritage artifacts and culture.

The Middle East is a kindlier host of archaeoastronomy than damp and chilly lands like the UK, where frost slowly pulverizes stone and weathering is a harsh year-round hazard. Nevertheless, it came as a pleasant surprise to learn that evidence for astronomical investigations extends back *reliably* into deepest history, as exhibited and interpreted in reconstructed calendars and in stone orientations and their alignments on critical dates. It was also fascinating to think that tourist companies are dabbling in public outreach on behalf of — or in tandem with — professional astronomers. That must be a novelty which is not (yet) widespread in the west. Here we tend to use 'only' volunteers, which indicates how important we really believe outreach to be.

Although very few of the authors had a native fluency in English, most of the papers are well written, and in fact several (notably by those tending to the arts rather than to the sciences) are quite flowery in their choices of words and phrases. My strongest criticism is with the ASP, in whose Conference Series this book is listed as Volume 520. With over 500 previous volumes to practise on, one might have hoped that criticisms aired by reviewers like me would have reached some sensitive spot, and that the photos which are dispersed throughout could have been large enough and in high enough resolution to show their subjects clearly, rather than continuing to be printed in tones of grey so dark that writing is in places indecipherable, and for the most part to lack captions. The Frontispiece, said to show 'Conference Participants', only includes 25 delegates, though 72 were reported as attending. Another group photo in front of an unnamed telescope (probably the 2·6-m at Byurakan Observatory in Yerevan) again shows only 25–30 people, though the scale is too small to see if it's the same group. A few technical errors have slipped in; one chapter omits its list of references, spelling or grammatical slips are not altogether absent, and in a couple of places figure captions are mixed or missing. But apart from those minor grumbles, this account highly deserves the attention of anyone who has — or maybe has not yet discovered — that nascent spark of interest in the history and heritage of astronomy in parts of the world very different to that of the majority of readers of this *Magazine*. — ELIZABETH GRIFFIN.

**Saturn**, by William Sheehan (Reaktion Books), 2019. Pp. 224, 23 × 18 cm. Price £25 (hardbound; ISBN 978 1 78914 153 5).

In a Solar System beauty parade the Saturn system is a very probable winner. And in a competition to choose the scientifically most interesting planetary system I would put it very close to the top of the list too. Saturn has an intricate observational history, the most massive ring system, and a diverse family of moons (as I write it has just overtaken Jupiter and the number stands at 82).

William Sheehan is an amateur astronomer living in Flagstaff, Arizona. He has spent a life-time observing the planets, and has 20 astronomy books to his name. This latest book is aimed at his amateur friends and also the entry-level astronomer. It is a very readable page-turner, non-mathematical, beautifully and profusely illustrated, and well referenced.

Saturn's fascination lies in its variability and mysterious nature. Sheehan has clearly loved observing the planet and enthusiastically encourages others to continue. He starts historically, the book's first chapters abounding with names like Galileo, Huygens, Cassini, Herschel, Encke, Dawes, Lassell, Maxwell, Keeler, and Hall. The book then divides into three parts, reviewing our knowledge of the planetary body, its rings, and the moons. As often happens in the outer Solar System, the moons are more interesting than the planet itself. But what I liked best was Sheehan's emphasis of both the present-day unknowns and the results of recent satellite observations. Are the rings only about 100 million years old? How long will they last? Do they only have a mass that is 40% that of Mimas? Why do the moons have such widely different compositions? Why does Enceladus have a reflectance greater than the Herschelian telescopic mirror that was used to detect it? Why are the hemispheres of Iapetus different brightness? Do life forms exist in the subsurface liquid oceans of Titan and Enceladus?

Sheehan is clearly a huge Saturn fan, and this lovely book will do much to encourage others to follow in his footsteps. — DAVID W. HUGHES.

**Jan Hendrik Oort: Master of the Galactic System**, by Pieter C. van der Kruit (Springer), 2019. Pp. 726, 24 × 16 cm. Price £129·99/$179·99 (hardbound; ISBN 978 3 030 17800 0).

The Netherlands has been punching well above its weight in astronomy for at least a century. One colleague, himself a student of Jan Oort, told me that it all went back to Prince Henry the Navigator. More recent opinion credits Oort himself, the subject of this wonderful biography, and his "inspireerenden leermeester" (Oort's words, not mine), Jacobus Cornelius Kapteyn (1851–1922)*, of whom author van der Kruit has also written an impressive biography (*Jacobus Cornelius Kapteyn: Born lnvestigator of the Heavens*, Springer, 2015) reviewed in these pages (**135**, 299, 2015).

There are other sources of information about Oort — an oral history with David DeVorkin in the American Institute of Physics archives, and an autobiographical chapter in *Annual Review of Astronomy and Astrophysics* (**19**, 1, 1981), at five pages the shortest of any of these — but this is the gold standard. Portions of the volume are good fun, like the discovery that he and his wife read Agatha Christie and a Nicholas Meyer Sherlock Holmes pastiche, and the challenges of identifying the astronomers in a large number of conference (*etc.*) photographs before you read the caption. Some of our colleagues aged better than others! Examples of Oort's generosity abound — his passing out copies of a paper by Vera Rubin at a 1960 summer school on galactic structure and his description of the instrumental expertise of Theodore (Fjeda) Walraven which enabled their first polarization map of the Crab Nebula. His diligence appears in an image of pages of notes he kept on the astronomical literature (systematically from 1945 to 1983); though the journals were in English, his notes were in Dutch (as were the ones he made on a preliminary copy of my PhD dissertation back in 1968 February).

* My Dutch leaves a great deal to be desired, and a multilingual colleague informs me that it is the only language in which even the vowels give him a problem. While we are at it, let us tackle the pronunciation of our hero's name. In the given names, 'J' is of course English 'Y', and the 'a' in most European languages is traditionally describe as the 'a' of 'father'. I never heard anybody call him Hendrik. And, as for Oort, American astronomers rhyme it with 'port', but the one of his students I interacted with most often, Lodewijk Woltjer, gave it the 'oar' of English 'poor'. Of course he spoke 'Oxford Dutch', which JHO did not. Primarily to confuse the issue, I note here that Jan, writing home from Yale to his parents in 1924, claimed that in America "people make many mistakes in the pronunciations of their own language, even preachers, public speakers and professors, *etc.*"

And there are moments of great sadness: a letter from Kapteyn's widow to the wife of Elis Stromgren (and mother of Bengt, who attended an AAS talk I gave in 1966 December) alluding to the unhappy marriage of Henriette Kapteyn, her daughter, to Ejnar Hertzsprung; the death of older brother Heinrich (to whom Jan wrote during his first college days) from diabetes in his 20s; the last-minute decision of Jan Oort himself not to attempt a long, recreational, and competitive ice-skating tour in December 1942, because he would need extra food — weight by then only 55 kg, with worse, tulip bulbs and sugar beets supplementing scarce potatoes during the winter 1944–45, still to come.

Biographical materials are interspersed with discussions and explanations of the astronomical issues that concerned Oort — the meaning of high-velocity stars; the spiral structure of the Milky Way; what is going on at the centre; and a number of other topics. I have a good many lines of notes (not in Dutch; indeed some of my colleagues would say not even in English) with minor objections to how credit is apportioned and to a few of the explanations, but nothing that should keep you from reading, enjoying, and learning from van der Kruit's enormous contribution to the history of 20th-Century astronomy.

Oort received the first post-war (1946) Gold Medal from the Royal Astronomical Society, and he and Arthur S. Eddington had begun terms in 1938 as, respectively, general secretary and president of the International Astronomical Union, horribly interrupted by Eddington's death in 1944 (Harold Spencer-Jones served out the term to 1948) and by the German occupation of The Netherlands, leaving Oort unable to communicate with nearly all other IAU members (Walter S. Adams was acting GS 1940–45).

So let us give the last word to another Englishman, Roger John Tayler (1929–1997), who wrote in 1984 a poem, appearing just before the preface of the biography. The first two lines are: "My name is Jan Hendrik Oort, I'm well known where astronomy's taught." This pronunciation is, I believe, wrong in every one of the five or so languages that Jan Hendrik spoke. — VIRGINIA TRIMBLE.

**Solving Fermi's Paradox**, by Duncan H. Forgan (Cambridge University Press), 2019. Pp. 413, 25 × 18 cm. Price £120/$155 (hardbound; ISBN 978 1 107 16365 2).

If intelligent life is common in the Universe, where is everybody? In this comprehensive review, *Solving Fermi's Paradox*, Duncan Forgan presents a range of possible solutions to this question, and in doing so covers a lot of ground on the topic of SETI (the Search for Extraterrestrial Intelligence). From the outset, Forgan recognizes that this topic demands a multi-disciplinary approach that encompasses "all of human knowledge", and in particular, expertise not only in the 'hard sciences' but also in social sciences and the humanities. From my admittedly limited perspective, it appears that Forgan makes a good attempt to be proficient in all of these areas, though his own formal training is in the area of physics and astronomy.

The book begins by describing the historical circumstances in which the 'paradox' arose, how it evolved, and our fairly limited attempts to resolve it *via* conventional SETI searches in the radio and optical wavelength domains. The heart of the book discusses 66 distinct solutions to the paradox, which are collected together under the general areas of 'Rare Earth', 'Catastrophic', and 'Uncommunicative' solutions.

What I personally appreciate about the book is that Forgan uses maths and physics wherever possible to justify his claims and to draw significant conclusions. The text is often quite complicated and often rather challenging, and while the advanced maths can probably be skipped over to some extent, the book is likely to be best received by those that are fairly proficient with such a rigorous academic approach. Personally, I found the discussion on global cosmic mechanisms that can temporarily regulate the emergence of ETI over large regions of the Milky Way, most (if not fully) compelling.

I have to say that progressing through the various excellent mathematical sections of the book, it struck me that the author's full creativity was somewhat constrained by a natural — and of course required — focus on the topic at hand. It often felt as though there was an outstanding and better organized general SETI text book for advanced undergraduate or graduate students screaming to get out! But perhaps that is something Forgan can pursue in the future — it would be well worth the additional effort.

Not surprisingly the final section of the book does not reveal the solution to the paradox but it does recognize that enormous progress is now being made in conventional SETI searches after a long time of stagnation. In particular, the privately funded Breakthrough Listen programme is now operational in both the northern and southern hemispheres, and a deluge of astronomical data will be generated by next-generation astronomical-survey instruments in the coming decade. The latter will explore new regions of observable parameter space with unprecedented time, frequency, and spatial resolution. In addition, radically new instruments such as gravitational-wave interferometers and neutrino telescopes will open up unique views on the Universe for the first time.

These advances, together with the recent discovery of exotic new phenomena such as fast radio bursts (FRBs), suggest that the prospects for an ETI detection have never been better! — MICHAEL A. GARRETT.

**Origin and Evolution of the Universe: From Big Bang to ExoBiology, 2nd Edition**, edited by Matthew A. Malkan & Ben Zuckerman (World Scientific), 2020. Pp. 224, 23 × 23·5 cm. Price £35/$38 (paperback; ISBN 978 981 120 772 3), £70/$78 (hardbound; ISBN 978 981 120 645 0).

A large topic for a relatively small book, but of course any one book on such a wide range of subjects is an introduction only. Introductory books could be, and have been, written about the material in each of the six chapters, so the question is whether the chapters in this book are long enough to give a meaningful basic introduction; on the whole, I think that they are. They cover the Universe itself; galaxies; the chemical elements; stellar explosions, neutron stars, and black holes; stars and planets; and life. The writers are all well-known scientists; all are good writers; the material is up to date. So what's not to like? Mainly production issues, but since I read a galley proof, and the editors are grateful to me for pointing out some mistakes, hopefully the finished product will be much improved. Above and on the cover of the book, only the editors are listed; the writers of the individual chapters are Ned Wright, Alan Dressler, Virginia Trimble, Alex Filippenko, and Fred Adams, with the final chapter having been written by the editors and Christopher McKay.

The only chapter I didn't like was the first one, although (or perhaps because) the topic is most familiar to me. First, it is too short. (Only the final chapter is just as short, at 24 pages, the others are 40–46 pages; since not that much is known about the origin of life, the length of the final chapter is not a problem.) Second, it is more about general cosmology than about the origin of the Universe. (Of course, little if anything is known about the actual origin of the Universe, but I expected more on details of structure formation before the formation of galaxies and less on general cosmology, for which the chapter is too short, even if it were about only that.) Third, there is too much emphasis on (real or imagined) problems in cosmology and less on the many aspects which are now secure knowledge, which creates an imbalanced impression, particularly with regard to the flatness problem: not only are newer developments (see refs. 1 and 2 for review and discussion) not mentioned at all, a common mistake which I've seen in other books[3,4] I've reviewed[5,6] in these pages, but Wright spends a couple of pages illustrating almost all the mistakes which one can make on that topic. Remarks on corrections to the Doppler formula being needed when one approaches the speed of light are too brief to determine whether they are wrong or merely confusing; since that topic has been cleared up in the literature years ago, it is surprising that it still often mentioned[7]. Having said that, it is well written and the rest of it is good as far as it goes; it just doesn't go far enough.

The five following chapters are all well written and provide good and up-to-date summaries of the corresponding fields. It is particularly difficult to give a brief overview of a broad topic without simplifying too much and at the same time writing in an enjoyable style, but the authors manage to pull it off. The overall level of presentation is very similar in all chapters. The style is somewhat non-uniform: four chapters contain references and two of those also a glossary. There are several figures scattered throughout the text. There is no index nor are there any notes or additional material other than that mentioned above. On the whole I can recommend the book, though with some slight reservations regarding the first chapter. — PHILLIP HELBIG.

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**The Number of the Heavens: A History of the Multiverse and the Quest to Understand the Cosmos**, by Tom Siegfried (Harvard University Press), 2019. Pp. 330, 21·5 × 14·5 cm. Price $29·95 (about £30) (hardbound; ISBN 978 0 674 97588 0).

The number of good books published on the multiverse almost constitutes a multiverse of its own. I count at least fifteen over the past 15 years alone: Paul Halpern's *The Great Beyond* (2004), Michio Kaku's *Parallel Worlds* (2005), Leonard Susskind's *The Cosmic Landscape* (2006), Alex Vilenkin's *Many Worlds in One* (2006), Bernard Carr's *Universe or Multiverse?* (2007), Paul Steinhardt & Neil Turok's *Endless Universe* (2007), Jeffrey Zweerink's *Who's Afraid of the Multiverse?* (2008), John Gribbin's *In Search of the Multiverse* (2010), John Barrow's *The Book of Universes* (2011), Brian Greene's *The Hidden Reality* (2011), Steven Manly's *Visions of the Multiverse* (2011), Mary-Jane Rubenstein's *Worlds Without End* (2014), Victor Stenger's *God and the Multiverse* (2014), Max

Tegmark's *Our Mathematical Universe* (2014), and David Wallace's *The Emergent Multiverse* (2014). Potential readers may wonder if another is needed; and if so, whether the need is filled by Tom Siegfried's new book, *The Number of the Heavens*. Thankfully, the answers to these questions are "Yes" and "Yes".

The books listed above all approach this inherently vast subject in different ways. Halpern's focus is on dimensionality, while the accounts of Kaku, Susskind, and Greene reflect their expertise in string theory. Vilenkin, Gribbin, and Barrow take us on tours with a more astronomical/cosmological feel. The collection of essays edited by Carr exposes readers directly to the full range of expert opinions in the field. Steinhardt & Turok and Tegmark introduce us to their own alternatives to multiverse theory based on cyclic cosmology and what might be termed mathematical Platonism. The books by Zweerink and Stenger explore the religious implications of the subject, from two quite opposite but equally interesting perspectives. Manly gives perhaps the most accessible account, while Rubenstein's emphasis is on the philosophical and theological aspects. Wallace's more technical treatment focusses on the physical basis of multiverse theory in the many-worlds interpretation of quantum mechanics.

Siegfried's new book earns its place in this field by elucidating the *history* of the multiverse idea and its many precursors, in unprecedented but highly readable detail. His account of the demolition of Aristotle's argument against many worlds by Nicholas of Cusa, for instance, is luminously clear. Giordano Bruno and Johannes Kepler come alive for us as ancestors of the 'pro' and 'con' positions toward multiverse theory today. The writing is conversational, perhaps overly casual in places ("Bruno should have been a character from Harry Potter. He believed in magic" … "Kepler's personal life was a mess") but mostly spot-on, as in this introduction to Descartes, born in La Haye, France: "Do not look for La Haye on a map. It has long since changed its name — to Descartes."

The command of secondary sources is impressively wide, and made easily accessible to the reader through deftly placed endnotes. For example, we do not just learn about Lucretius' contributions, but also about the precarious way in which these came down to us through history, as beautifully told in Stephen Greenblatt's *The Swerve* (2011). But Siegfried also makes some significant contributions of his own to historical scholarship. He notes that French philosopher Michel de Montaigne was the first to speculate explicitly that other worlds might be governed by different physical laws. Careful detective work enables him to establish that the German mathematician Johann Mädler was the first to use the term "world island", but that credit for the phrase "island universe" should go to the American astronomer and Civil War general Ormsby Mitchel, not Immanuel Kant (as widely believed).

The transition from history to modern science about two-thirds of the way through the book is seamless and authoritative, buttressed by personal interviews with some of the significant figures in the field. Siegfried's discussion of extra dimensions is excellent, establishing Kant, as well as the astronomer Simon Newcomb, as being the first to consider them as "repositories" of multiple universes. Newcomb is, however, wrongly identified as American; he was actually born in Canada. There are some other minor misstatements. For example, time as a fourth dimension is not "required by Einstein's theory of relativity". This interpretation was introduced by Hermann Minkowski in 1908, and was in fact initially dismissed by Einstein as "superfluous learnedness" (although he subsequently embraced it, and a good thing too, as it later led him to the discovery of General Relativity). Siegfried's style is refreshingly brisk, as when he intentionally omits any discussion of spiritualistic interpretations:

"They don't count". Occasionally his familiar tone may raise some eyebrows, as when Siegfried writes that Kaluza's extra dimension was "just what the doctor ordered (I presume it was Doctor Who)."

The treatment is non-mathematical; there are no equations, and few illustrations (a dozen or so, mostly small headshots of key characters). But the main ideas are well conveyed, and organized in new and thought-provoking ways. For instance, work by fellow historian Helge Kragh is cited to suggest that 'pro' and 'con' attitudes toward the multiverse today echo those of Big Bang *versus* steady-state cosmologists in the 1950s. Readers may wish for more details in places, as when Siegfried notes in passing that "some scientists have suggested" that anomalies in the cosmic microwave background can be interpreted as observational evidence for other universes, but gives no references. (Full disclosure: together with colleagues Ron Adler and James Bjorken, I am one of many people who have written papers on this idea — but it is surely an intriguing one that deserves more discussion.)

Siegfried's book is mainstream in its treatment, but not quite neutral in its tone. He is open about his position on the 'pro' side of the debate, referring to sceptics in places as "multiverse deniers". But his passion is undoubtedly also part of the book's charm, and if readers are prepared to take it in their stride, then they will find *The Number of the Heavens* an essential contribution to the subject. — JAMES OVERDUIN.

**The Importance of Binaries in the Formation and Evolution of Planetary Nebulae**, by Henri M. J. Boffin & David Jones (Springer), 2019. Pp. 113, 23·5 × 15·5 cm. Price £44·99/$59·99 (paperback; ISBN 978 3 030 25058 4).

Do you (considering yourself as the star that you are) have to be part of a binary system in order to produce a planetary nebula? The answer is as familiar as the punch-line of a large number of politically incorrect jokes. Q: Do you have to be crazy to be (insert your favorite ethnicity or occupation)? A: No, but it helps. Authors Boffin and Jones make clear in this slim volume that having a binary companion makes it easier, both theoretically and observationally, to eject a visible planetary near the end of a star's life, especially the sort with complicated symmetries and asymmetries in *HST* photos. Thus the answer to "will the sun form a planetary nebula ?" is "maybe, but at best it will be rather faint and probably not the most interesting in terms of morphology" (page 95).

Perhaps the most charming moment comes in the References, where the 1781 Messier *Catalogue des Nebuleuses et des Amas d'Etoiles* is described as a "technical report". This inevitably led me to read the full reference list, with a couple of less-happy discoveries. Quite a few are listed as "arXiv e-prints." but with no indication of the number, except the year. And some of the books (including the classic Perek & Kohoutek *Catalogue of Galactic Planetary Nebulae*, are missing publisher name and place, and sometimes page number, for instance, "Boffin, H. M. J. (2014) In *Ecology of blue straggler stars*". There are some eternal verities: that the nebulium line (5007 Å, due to [O III]), really is very strong, and tops out at the same flux for the PNe in all galaxies, perhaps permitting them to be used as standard candles in our cosmological distance ladder. No way of writing, capitalizing, or punctuating 'proto planetary nebula' leaves the reader absolutely sure whether the object is about to form a PN or to form planets. "For an eclipse to be observed, the configuration of the system must be such that one star passes in front of the other" (p. 30).

The figures include some glorious colour images of some of the more extreme morphologies (many from *HST*, some from ESO and elsewhere). That of NGC

6543 (the Cat's Eye) shares a page with a reproduction of the original 1864 Huggins and Miller spectrogram, in which 5007 Å is called N, for nitrogen, rather than nebulium. Of course, in 1864, wavelengths were not customarily given in Angstroms, and astronomical objects didn't have NGC names (= *New General Catalogue*, Dreyer 1888). Indeed, I'm not quite sure what Huggins actually called that source.

The volume provides a short discussion of pre-PN stellar evolution, careful consideration of the effects of mass transfer and common-envelope binary evolution of close pairs, and an honest (somewhat discouraging) discussion of the extreme difficulties of getting statistically complete or even meaningful samples of sources and good data on individual ones. Back in winter seasons 1965–66 and 1966–67, I spent a good deal of time at the 48-inch Schmidt telescope of Palomar Mountain Observatory attempting to expose spectrograms of a well-studied planetary nebula, in an abortive attempt to calibrate line fluxes in spectra of various filaments of the Crab Nebula. Now if only I could remember which PN it was, I could tell you whether it has made the cut for discussion by Boffin and Jones. Unfortunately ... but it is up in the winter, and I learned a great deal from it, such as that it is a mistake to put a photographic plate into the plate holder with the emulsion facing away from the telescope mirror; that there is a preferred sequence for the use of developer and hypo; and that you should not turn on the light to look for the cover to the developer tray while the plate is in there.

The many things to be learned from this book are somewhat more up to date and thus important for anyone who wants to go forward from 2020 (rather than 1965) studying planetary nebulae and their central stars.

Careful readers of *The Observatory* will perhaps have noted that author Boffin and reviewer Trimble published a joint paper in the 2020 February issue. On the other hand, we have never actually met, so is this a conflict of interest? — VIRGINIA TRIMBLE.

**Introduction to Modern Dynamics: Chaos, Networks, Space and Time, 2nd Edition**, by David D. Nolte (Oxford University Press), 2019. Pp. 479, 24·5 × 19 cm. Price: £37·50 (paperback; ISBN 978 0 19 884463 1).

This book is exactly what it says on the cover — it is an introduction to modern dynamics *via* a fairly advanced discourse on geometric dynamics. The text is written to a very high standard with an attractive and welcoming appearance.

The first section (100+ pages) is a fairly advanced development of mechanics, which is then followed by slightly longer sections on nonlinear dynamics, complex systems and, finally, relativity and space time. That is a fairly wide remit for a single text book, and, I would suggest, an impossible remit for a single undergraduate course! Several standard undergraduate courses (at least four in my view) within a programme are needed to address the breadth and depth of the material covered in this text. It is, of course, often the case that attempting to cover at most 100 pages of text might be a sensible taught-course objective for most standard books.

The book uses diagrams well, which is very necessary to bring the content to life. The author covers the wide academic remit of the text with confidence and style. There are several nicely constructed chapters on network-, evolutionary-, and neuro-dynamics.

I think the question that the book provokes is how could this be used sensibly by your typical undergraduate? It goes into considerable detail for many undergraduate mechanics courses these days, and then uses the style and content of that first section to branch off into more general systems and network theory.

Perhaps the increasingly popular options in mathematical sciences are for courses in nonlinear dynamics, complex systems, and networks — the more general 'dynamical systems' covered in the middle sections of Nolte's text. The student may be concerned if the text is used to cover a course in these topics, in that they would have to start in the 'middle' of the text, as the first section covers traditional dynamics perhaps too thoroughly. The section is probably too substantial for a useful and concise approach to the more general dynamical processes considered from Section 2 onwards. Often, more approachable and understandable topics such as population growth and competing species are used to provide an insight to the general questions asked in dynamical systems. Although, as the book-cover picture of Saturn's rings shows, there is plenty of exciting motion in dynamical and celestial mechanics!

It is an extremely pleasant and wide-reaching book to peruse and learn from, and it welds together all of the key modern ideas in dynamics and networks to make the whole book very attractive from a scholarly viewpoint. Nevertheless, it would have to be used with great care in the selection of material for any single module, other than, perhaps, a mechanics course based on the first section, with potentially just a few highlights from the other sections. — DAVID ARROWSMITH.

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## THESIS ABSTRACT

### EXPLORING GALAXY CLUSTERS AND GROUPS WITH COSMOLOGICAL SIMULATIONS

*By Nick Henden*

Galaxy clusters are the largest gravitationally bound objects in the Universe, their unparalleled size providing powerful leverage to probe large-scale structure growth and cosmology. At the same time, clusters and groups of galaxies represent unique astrophysical playgrounds in which galaxies interact with each other and with the intervening gas, the properties of which are influenced by a plethora of astrophysical processes, such as the formation of stars or feedback from supernovae and active galactic nuclei (AGN). In this thesis I present the Feedback Acting on Baryons in Large-scale Environments (FABLE) project, a new suite of cosmological hydrodynamical simulations of galaxies, groups, and clusters that follow the complex interplay between such processes in order to advance our understanding of galaxy-cluster formation and evolution.

I perform a detailed comparison of the FABLE simulations to observational constraints at redshift $z <\sim 1$, demonstrating simultaneous agreement with the galaxy stellar mass function, the total stellar and gas mass contents of groups and clusters, and their radial gas profiles. In common with several other recent simulation works, residual deviations in the thermodynamic properties of the cluster-core region suggest that more sophisticated AGN feedback modelling or

additional physical processes may be needed to explain the observed properties of cluster cores.

I generate synthetic X-ray spectra for each FABLE galaxy group and cluster, finding good agreement with a range of observed X-ray scaling relations at $z \leq 1$. I also investigate the scaling between the Sunyaev–Zel'dovich (SZ) signal and total mass, showing good agreement with cluster data from *Planck* and the *South Pole Telescope* over a wide redshift range. I find that all examined X-ray and SZ scaling relations deviate from the self-similar prediction in terms of their slope at fixed redshift and the redshift evolution of their normalization and intrinsic scatter. For example, the simulations predict increasing scatter about the relations with decreasing redshift, contrary to the assumptions of most observational studies. I further describe the processes that lead to these deviations from self-similarity, such as non-thermal pressure support provided by kinetic motions in the intracluster gas and the effects of non-gravitational physics such as AGN feedback. I demonstrate the importance of accounting for these effects in the context of cluster cosmology by demonstrating the sensitivity of the predicted number of detected clusters in an SZ-selected survey to the assumed SZ scaling relation based on a range of observational and simulation constraints.

Lastly, I investigate the halo mass and redshift dependence of the total baryon content of FABLE clusters and groups, and of the stellar mass, size, and shape of brightest cluster galaxies (BCGs). In particular I show that the simulations agree with recent constraints on the lack of redshift evolution in the total gas and stellar mass of massive clusters. In addition I use the stellar mass profiles of FABLE BCGs to highlight potential biasses in observational studies of BCG growth associated with the assumed light profile and the outer radius of the fit. — *University of Cambridge; accepted 2019 May*.

## *Here and There*

IS THE SUN NOT ALREADY BRIGHT ENOUGH?

The goal of the [*Parker Solar Probe*] mission is to shed light on some of the mysteries surrounding the Sun. — *Victoria Times-Colonist*, 2019 December 5, p. A9.

GEE, WHAT ARE ALL THOSE PROTONS HANGING AROUND FOR?

White dwarfs are mostly made of electrons, held apart by rules of quantum physics. — *New Scientist*, 2019 December 14, p. 15.

DOUBT LIGO IF YOU MUST, AND EVEN THE NEUTRINOS FROM SN1987A, BUT NEVER DOUBT THE COSMIC RAYS

Everything we know about the universe beyond our solar system has come from photons and a few grains of interstellar dust. — *Sky & Telescope*, 2020 January, p. 14.