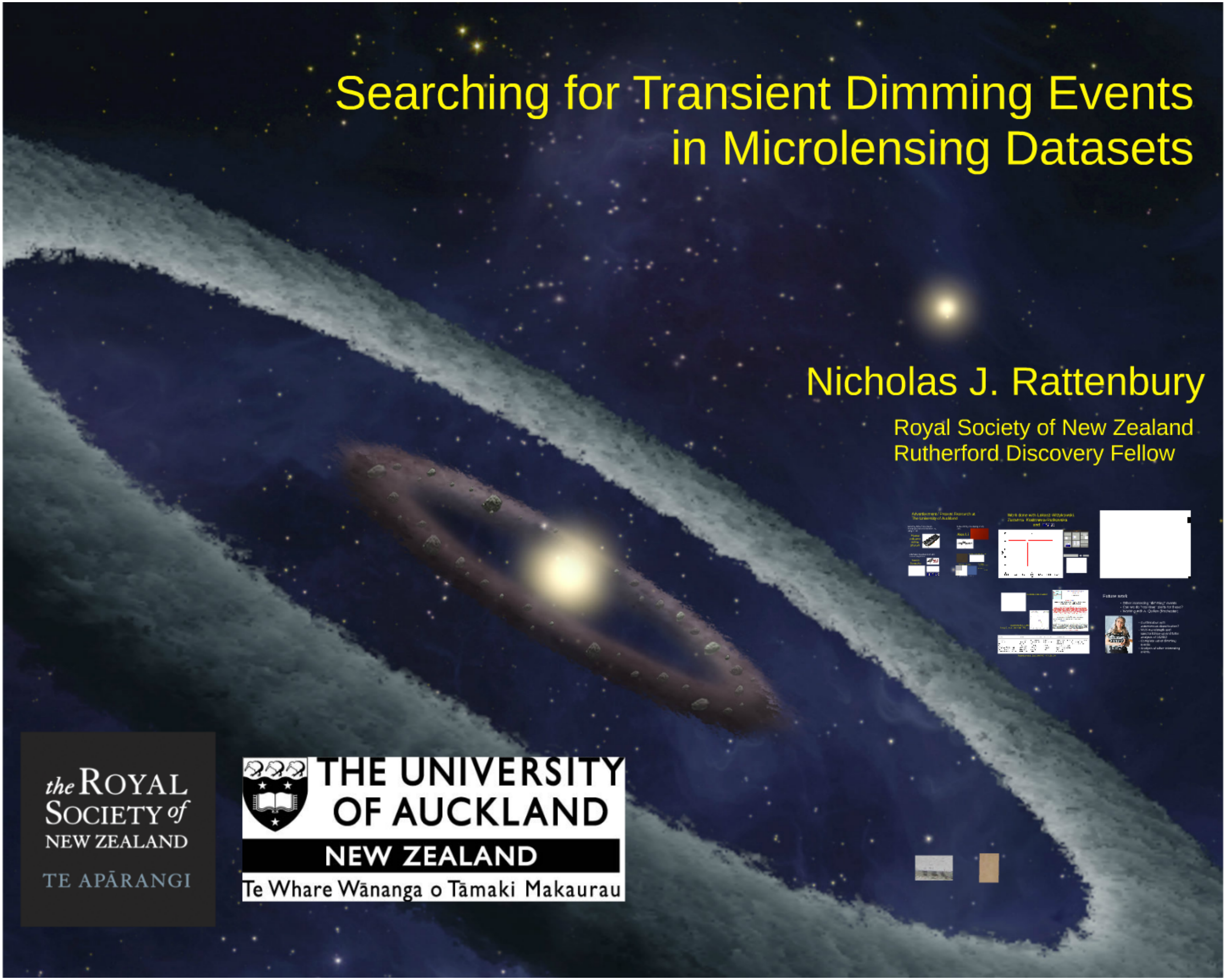
Searching for Transient Dimming Events in Microlensing Datasets

Nicholas J. Rattenbury

Royal Society of New Zealand
Rutherford Discovery Fellow



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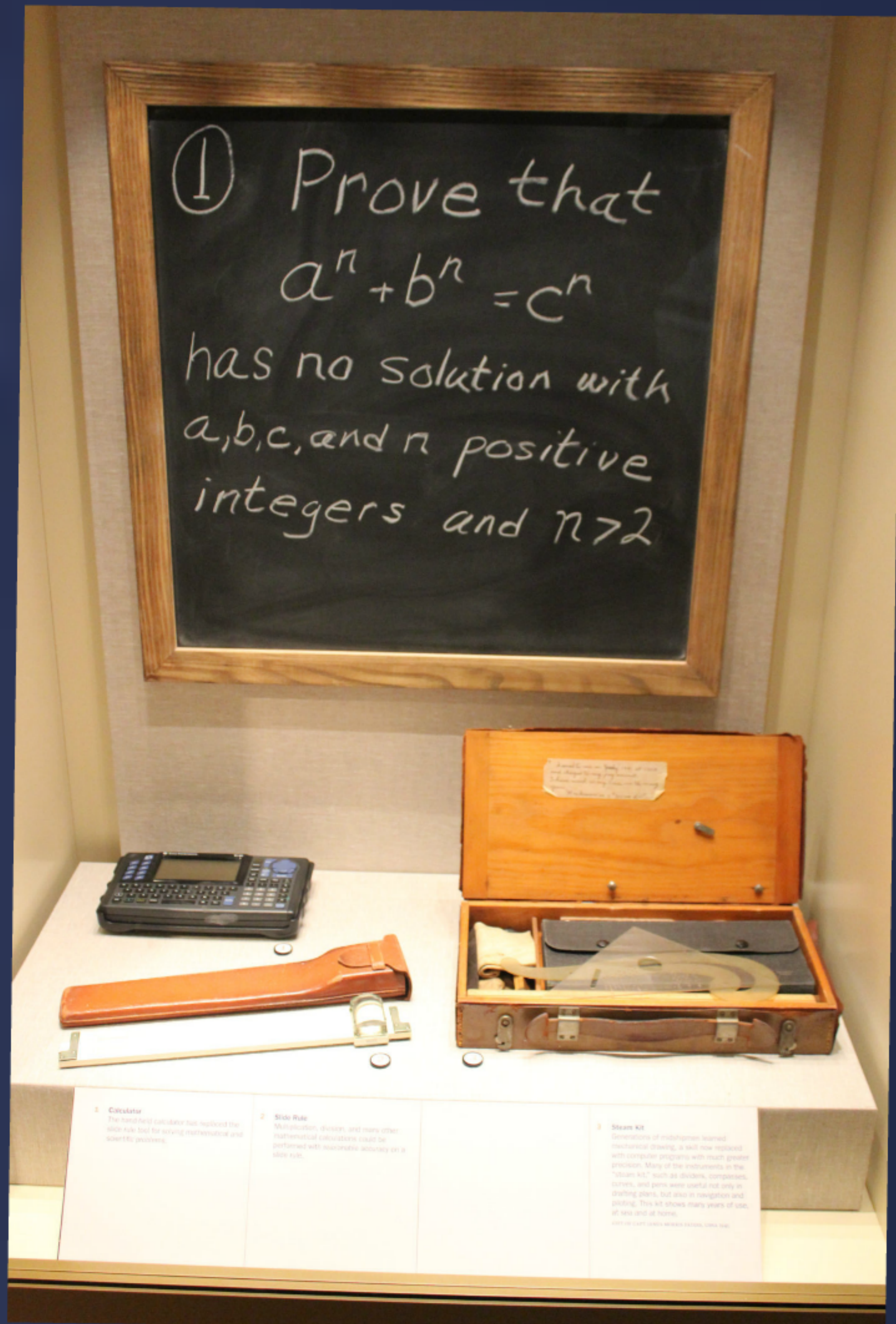

① Prove that
$a^n + b^n = c^n$
has no solution with
a, b, c, and n positive
integers and n>2
Calculator
Slide Rule
Steam Kit

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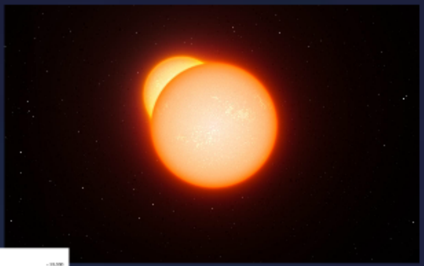
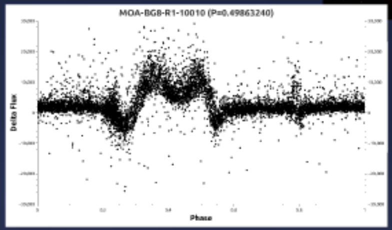
Detecting Extra-Solar planets through gravitational microlensing, using GPUs.

Please welcome Ashna Sharan!

Eclipse timing of eclipsing binary stars.

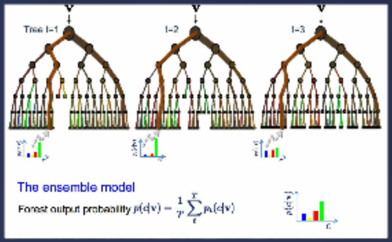
Alex Li



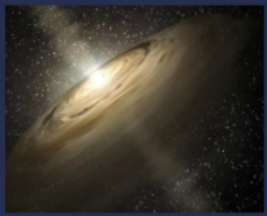


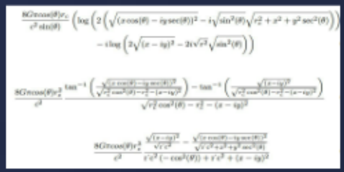
Automated classification of light curves using WEKA.

Martin Donachie

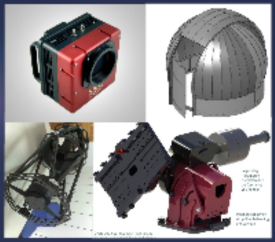


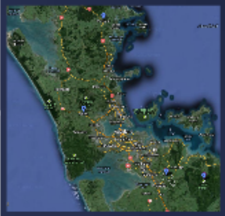
Microlensing of Protoplanetary Disks, J. Cherrie





Ana Snegota - site testing





collab: J. Eldridge, G. Austin, G. Christie (Stardome), M. Bessell (MSO/ ANU), P. Conway (ret. MSO/ANU), J. Greenhill (UTas).

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Real-time parameter estimation

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Minor planets

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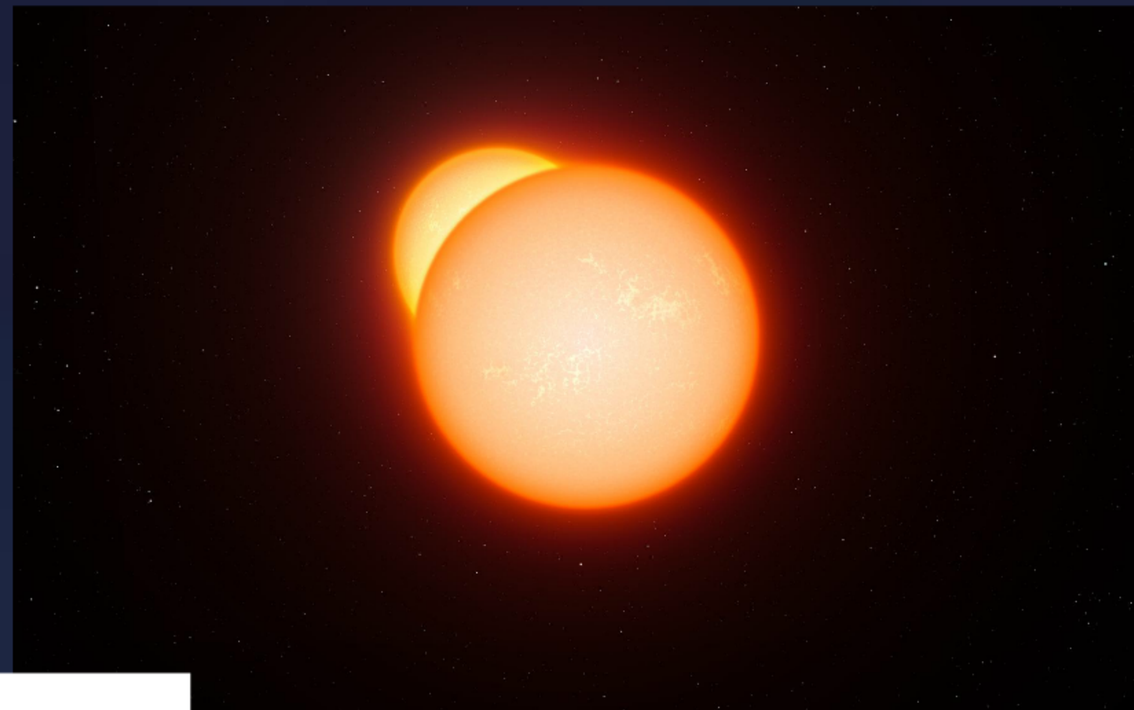

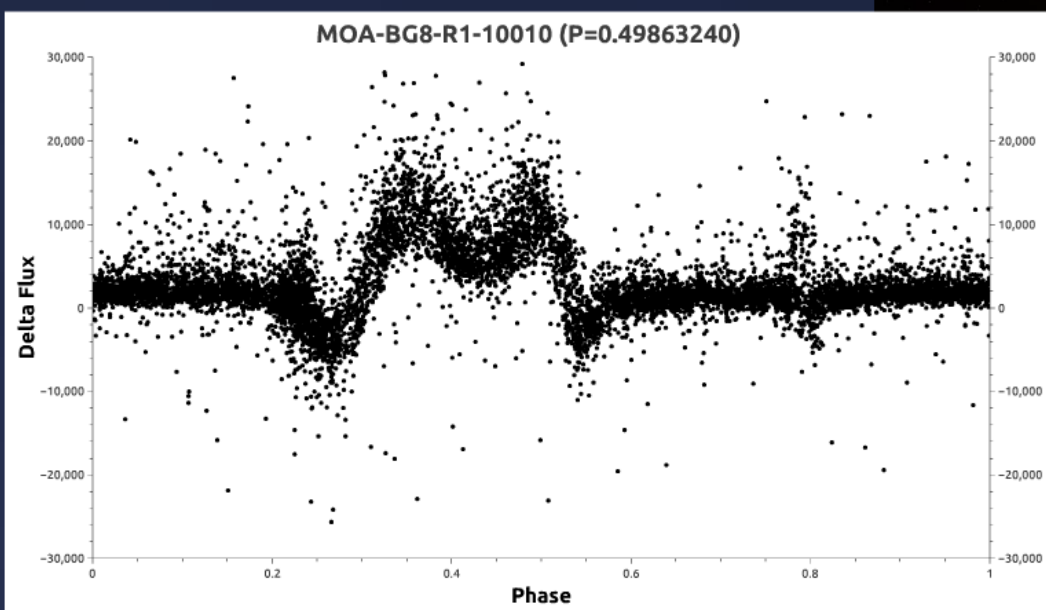

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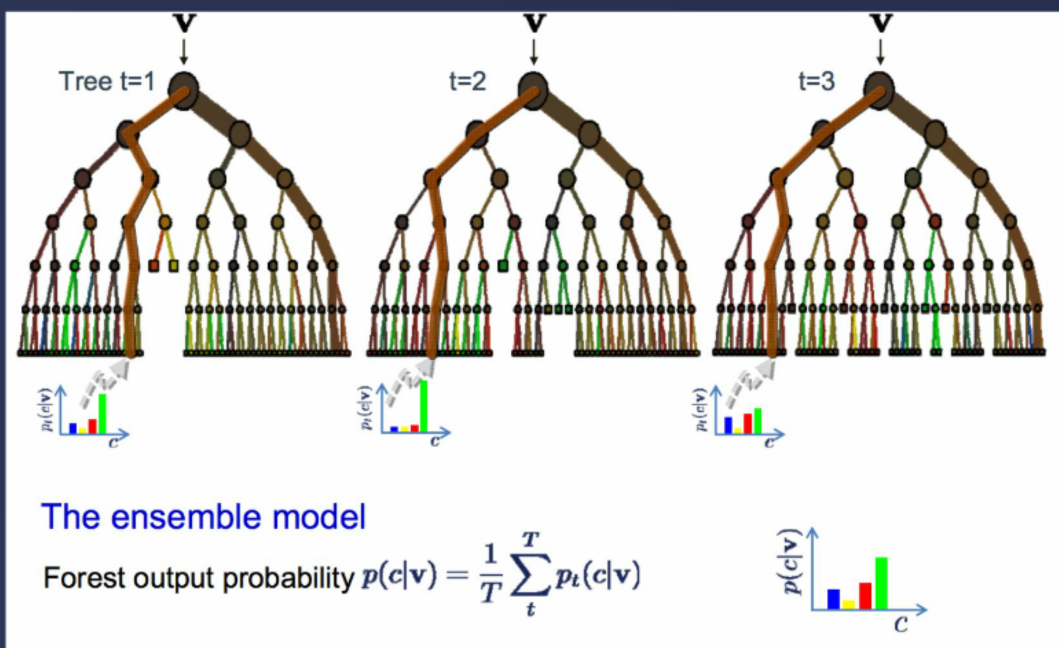
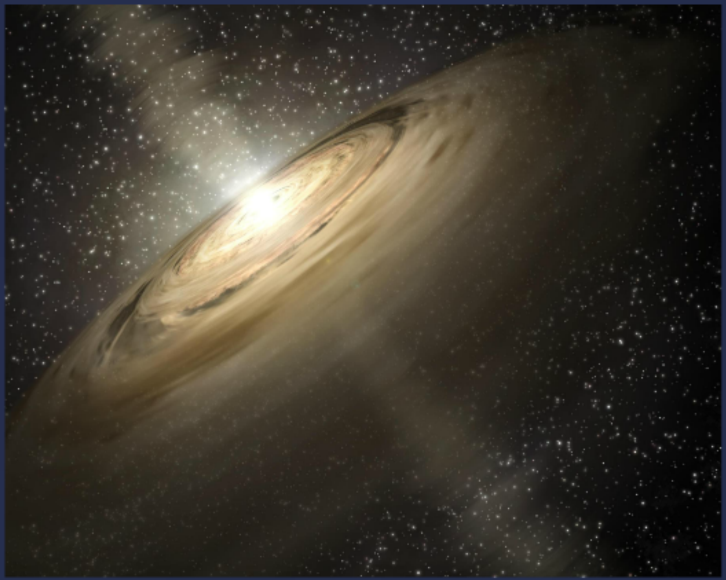




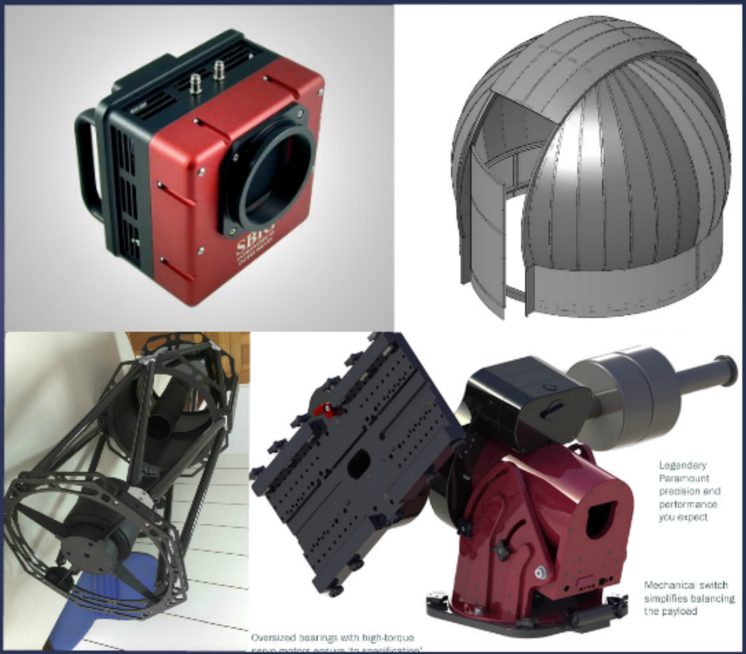
Microlensing of Protoplanetary Disks, J. Cherrie

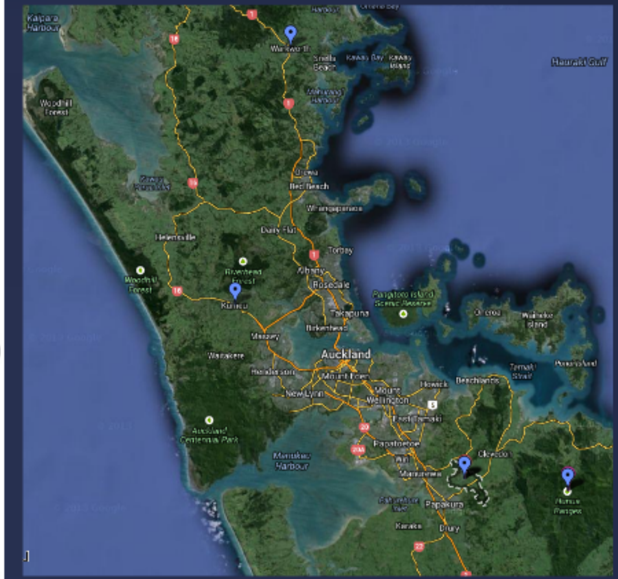
$$\frac{8G\pi cos(\theta) r_c}{c^2 \sin(\theta)} \left(\log \left(2 \left(\sqrt{(x\cos(\theta) - iy\sec(\theta))^2} - i\sqrt{\sin^2(\theta)}\sqrt{r_c^2 + x^2 + y^2\sec^2(\theta)} \right) \right) - i\log \left(2\sqrt{(x-iy)^2} - 2i\sqrt{r^2}\sqrt{\sin^2(\theta)} \right) \right)$$

$$\frac{8G\pi cos(\theta) r_c^2}{c^2} \frac{\tan^{-1}\left(\frac{\sqrt{(x\cos(\theta)-iy\sec(\theta))^2}}{\sqrt{r_c^2\cos^2(\theta)-r_c^2-(x-iy)^2}} \right) - \tan^{-1}\left(\frac{\sqrt{(x-iy)^2}}{\sqrt{r_c^2\cos^2(\theta)-r_c^2-(x-iy)^2}} \right)}{\sqrt{r_c^2\cos^2(\theta) - r_c^2 - (x-iy)^2}}$$

$$\frac{8G\pi cos(\theta) r_c^3}{c^2} \frac{\frac{\sqrt{(x-iy)^2}}{\sqrt{\mathrm{r\dot{}c}^2}} - \frac{\sqrt{(x\cos(\theta)-iy\sec(\theta))^2}}{\sqrt{\mathrm{r\dot{}c}^2+x^2+y^2\sec^2(\theta)}}}{\mathrm{r\dot{}c}^2\left(-\cos^2(\theta)\right) + \mathrm{r\dot{}c}^2 + (x-iy)^2}$$

Ana Snegota - site testing





Philip Evans

Real-time parameter estimation

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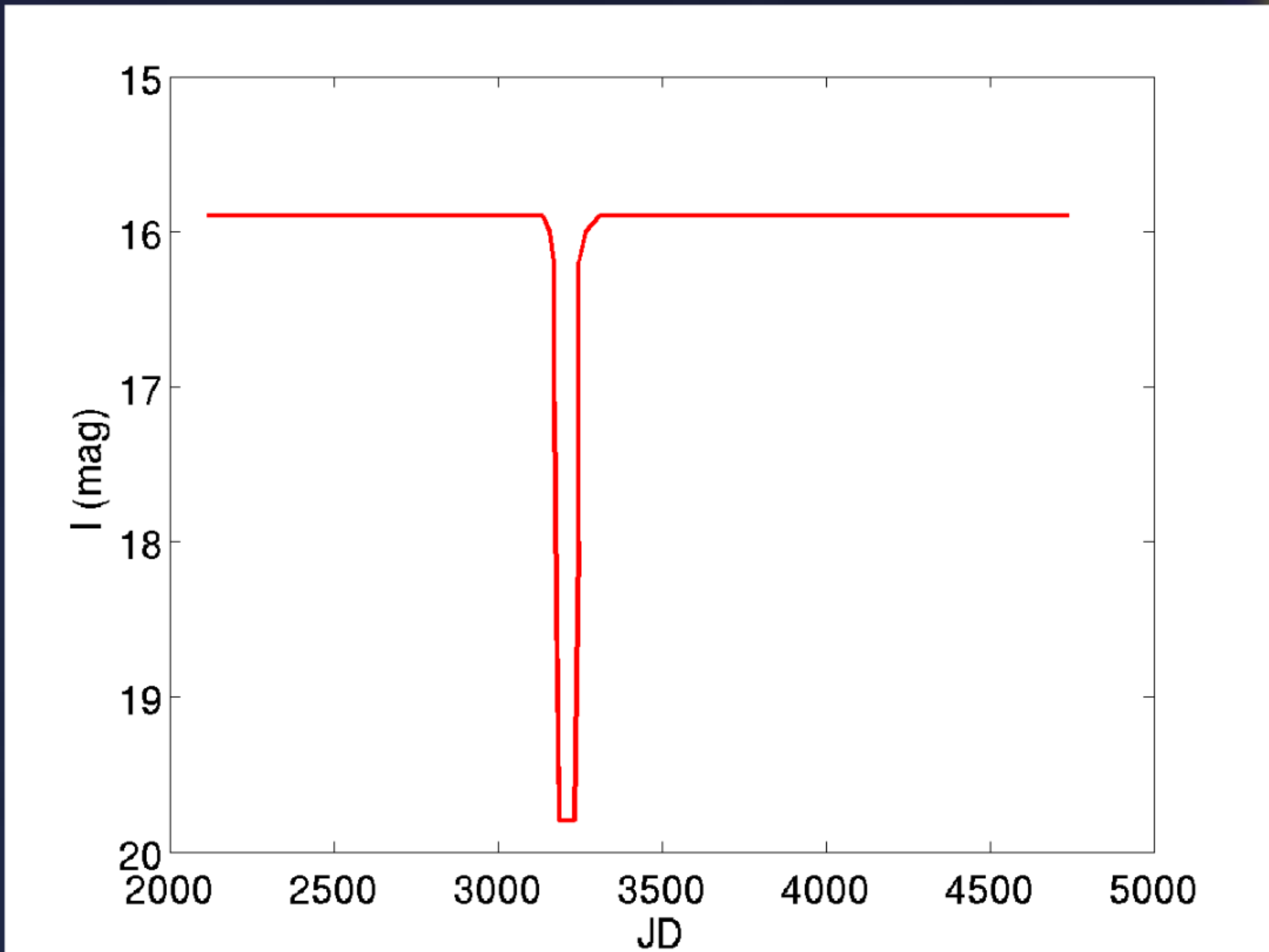
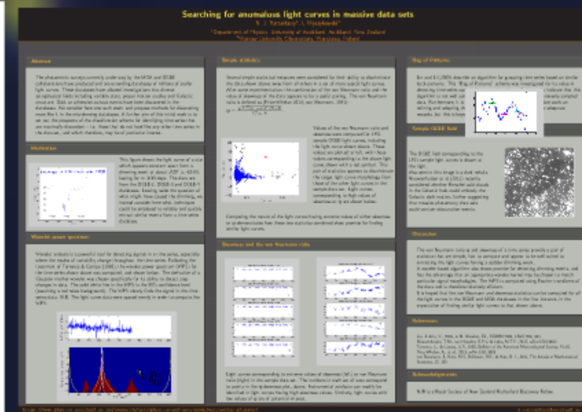
Minor planets

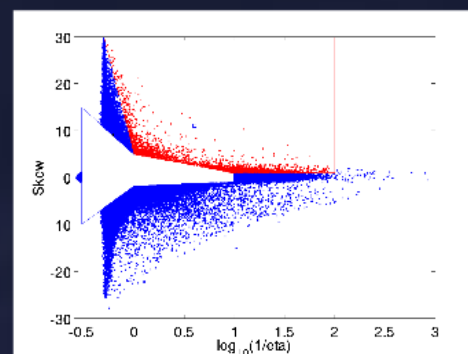
collab: J. Eldridge, G. Austin, G. Christie (Stardome), M. Bessell (MSO/ ANU), P. Conway (ret. MSO/ANU), J. Greenhill (UTas).

Work done with Lukasz Wrzykowski, Zuzanna Kostrzewa-Rutkowska and OGLE





$$\eta = \frac{\sqrt{\sum_i^N (x_{i+1}-x_i)^2/(N-1)}}{\sum_i^N x_i/N}$$ + skewness



Searching for anomalous light curves in massive data sets

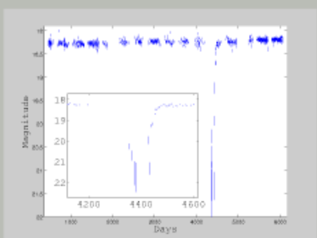
N. J. Rattenbury[1], Ł. Wyrzykowski[1]

[1]Department of Physics, University of Auckland, Auckland, New Zealand
[2]Warsaw University Observatory, Warszawa, Poland

Abstract

The photometric surveys currently under way by the MOA and OGLE collaborations have produced and are extending databases of millions of stellar light curves. These databases have allowed investigations into diverse astrophysical fields including variable stars, proper motion studies and Galactic structure. Odd, or otherwise curious events have been discovered in the databases. We consider here one such event and propose methods for discovering more like it in the microlensing databases. A further aim of this initial work is to set out the prospects of the classification scheme for identifying time series that are maximally discordant - i.e. those that do not look like any other time series in the data set, and which therefore, may be of particular interest.

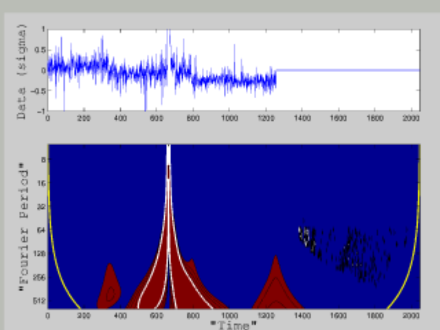
Motivation



This figure shows the light curve of a star which appears constant apart from a dimming event at about $JD' \simeq 4350$, lasting for $\simeq 100$ days. The data are from the OGLE-2, OGLE-3 and OGLE-4 databases. Leaving aside the question of what might have caused the dimming, we instead consider here what techniques could be employed to reliably and quickly extract similar events from a time series database.

Wavelet power spectrum

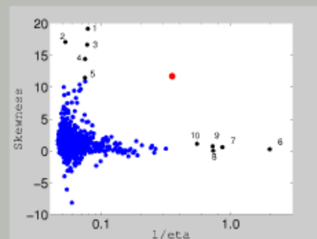
Wavelet analysis is a powerful tool for detecting signals in a time series, especially where the modes of variability change throughout the time series. Following the treatment of Torrence & Compo (1998), the wavelet power spectrum (WPS) for the time series shown above was computed, and shown below. The derivative of a Gaussian mother wavelet was chosen specifically for its ability to detect step changes in data. The solid white line in the WPS is the 95% confidence level (assuming a red noise background). The WPS clearly finds the signal in the time series data. N.B. The light curve data were spaced evenly in order to compute the WPS.



Simple statistics

Several simple statistical measures were considered for their ability to discriminate the data shown above away from all others in a set of more typical light curves. After some experimentation, the combination of the von Neumann ratio and the value of skewness of the data appears to be a useful pairing. The von Neumann ratio is defined as (Price-Whelan 2013; von Neumann, 1941):

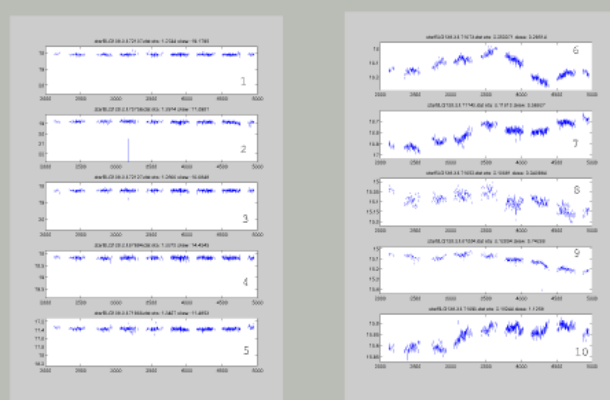
$$\eta = \frac{\sqrt{\sum_i^N (x_{i+1}-x_i)^2/(N-1)}}{\sum_i^N x_i/N}.$$



Values of the von Neumann ratio and skewness were computed for 1451 sample OGLE light curves, including the light curve shown above. These values are plotted at left, with those values corresponding to the above light curve shown with a red symbol. This pair of statistics appears to discriminate the target light curve morphology from those of the other light curves in the sample data set. Light curves corresponding to high values of skewness or η are shown below.

Comparing the nature of the light curves having extreme values of either skewness or η demonstrates how these two statistics combined show promise for finding similar light curves.

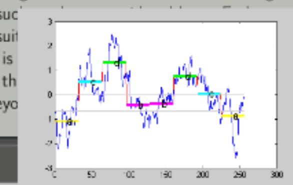
Skewness and the von Neumann ratio



Light curves corresponding to extreme values of skewness (left) or von Neumann ratio (right) in the sample data set. The numbers in each set of axes correspond to points in the η-skewness plot, above. Instrumental artefacts can readily be identified in light curves having high skewness values. Similarly, light curves with low values of η are of potential interest.

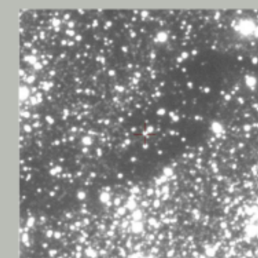
Bag of Patterns

Lin and Li (2009) describe an algorithm for grouping time series based on similar local patterns. This "Bag of Patterns" scheme was investigated for its value in detecting time series suc[...]s indicate that this algorithm is not well sui[...]unevenly sampled data. Furthermore, it is [...]ore work on refining and adapting th[...]e adequate rewards, but this is beyo[...]



Sample OGLE field

The OGLE field corresponding to the 1451 sample light curves is shown at the right.
Also seen in this image is a dark nebula. Nieuwenhuizen et al.(2012) recently considered whether Herschel cold clouds in the Galactic halo could embody the Galactic dark matter, further suggesting that massive photometry data sets could contain obscuration events.



Discussion

The von Neumann ratio η and skewness of a time series provide a pair of statistics that are simple, fast to compute and appear to be well suited to extracting the light curves having a sudden dimming event.
A wavelet-based algorithm also shows promise for detecting dimming events, and has the advantage that an appropriate wavelet kernel may be chosen to match particular signal morphologies. The WPS is computed using Fourier transforms of the data and is therefore relatively efficient.
It is hoped that the von Neumann and skewness statistics can be computed for all the light curves in the OGLE and MOA databases in the first instance, in the expectation of finding similar light curves to that shown above.

References

Lin, J. & Li, Y., 2009, in M. Winslett, Ed., SSDBM 2009, LNCS 556, 461
Nieuwenhuizen, T.M., van Heusden, E.F.G. & Liska, M.T.P., 2012, arXiv:1210.0489
Torrence, C., & Compo, G.P., 1998, Bulletin of the American Meteorological Society, 79, 61
Price-Whelan, A., et al., 2013, arXiv:1311.3683
von Neumann, J., Kent, R.H., Bellinson, H.R., & Hart, B. I., 1941, The Annals of Mathematical Statistics, 12, 153

Acknowledgements

NJR is a Royal Society of New Zealand Rutherford Discovery Fellow.

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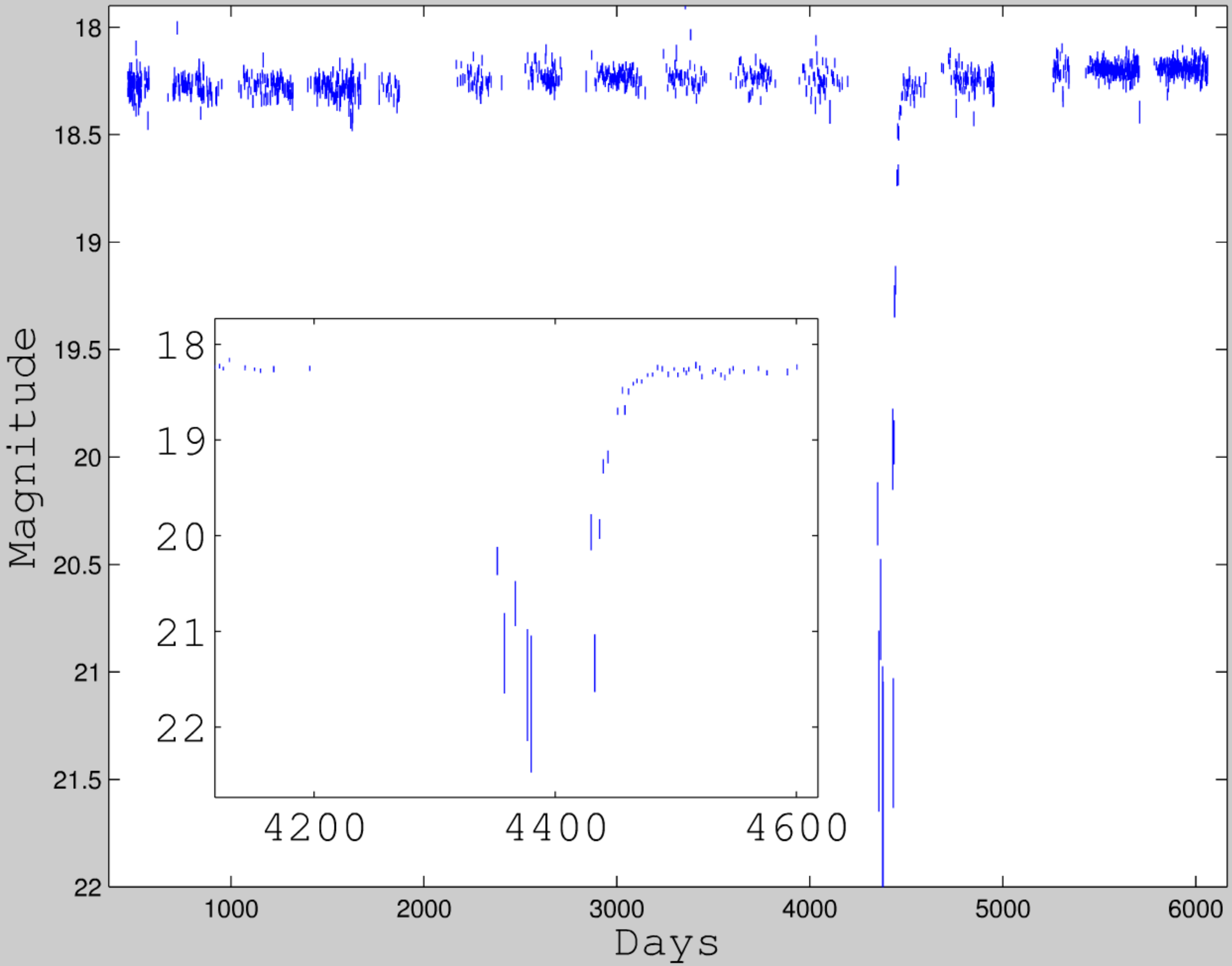
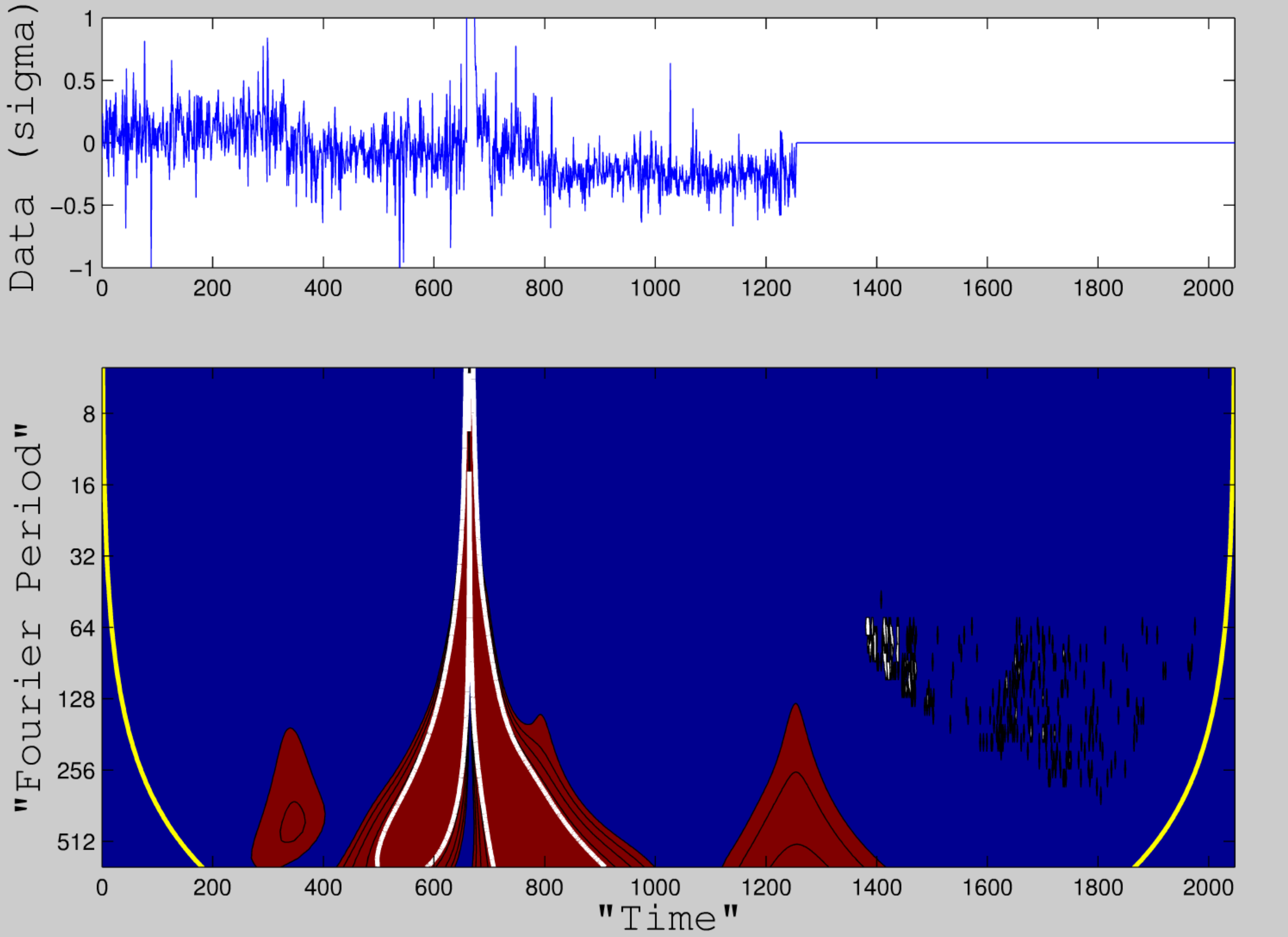


18
18.5
19
19.5
20
20.5
21
21.5
22
Magnitude
1000
2000
3000
4000
5000
6000
Days
18
19
20
21
22
4200
4400
4600



Data (sigma)
1
0.5
0
−0.5
−1
0
200
400
600
800
1000
1200
1400
1600
1800
2000
"Fourier Period"
8
16
32
64
128
256
512
"Time"

Bag of Patterns

Lin and Li (2009) describe an algorithm for grouping time se
local patterns. This "Bag of Patterns" scheme was investiga
detecting time series suc
algorithm is not well suit
data. Furthermore, it is
refining and adapting th
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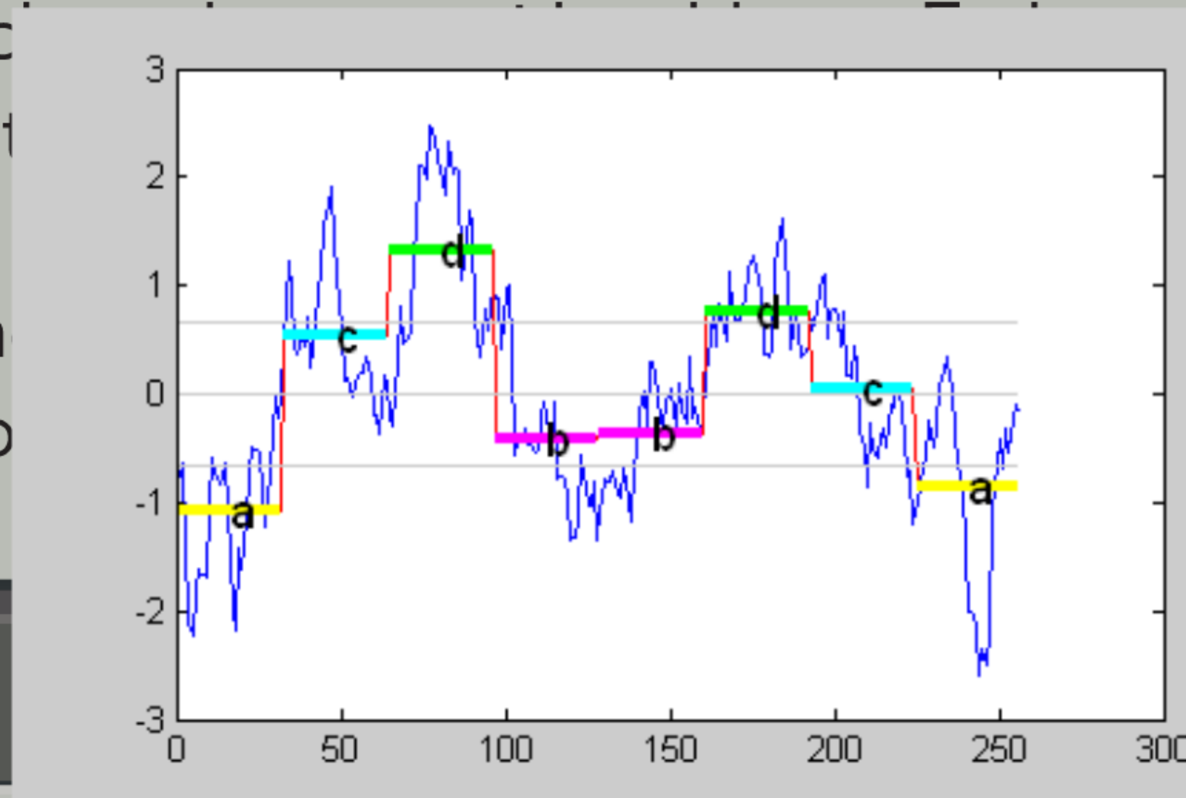
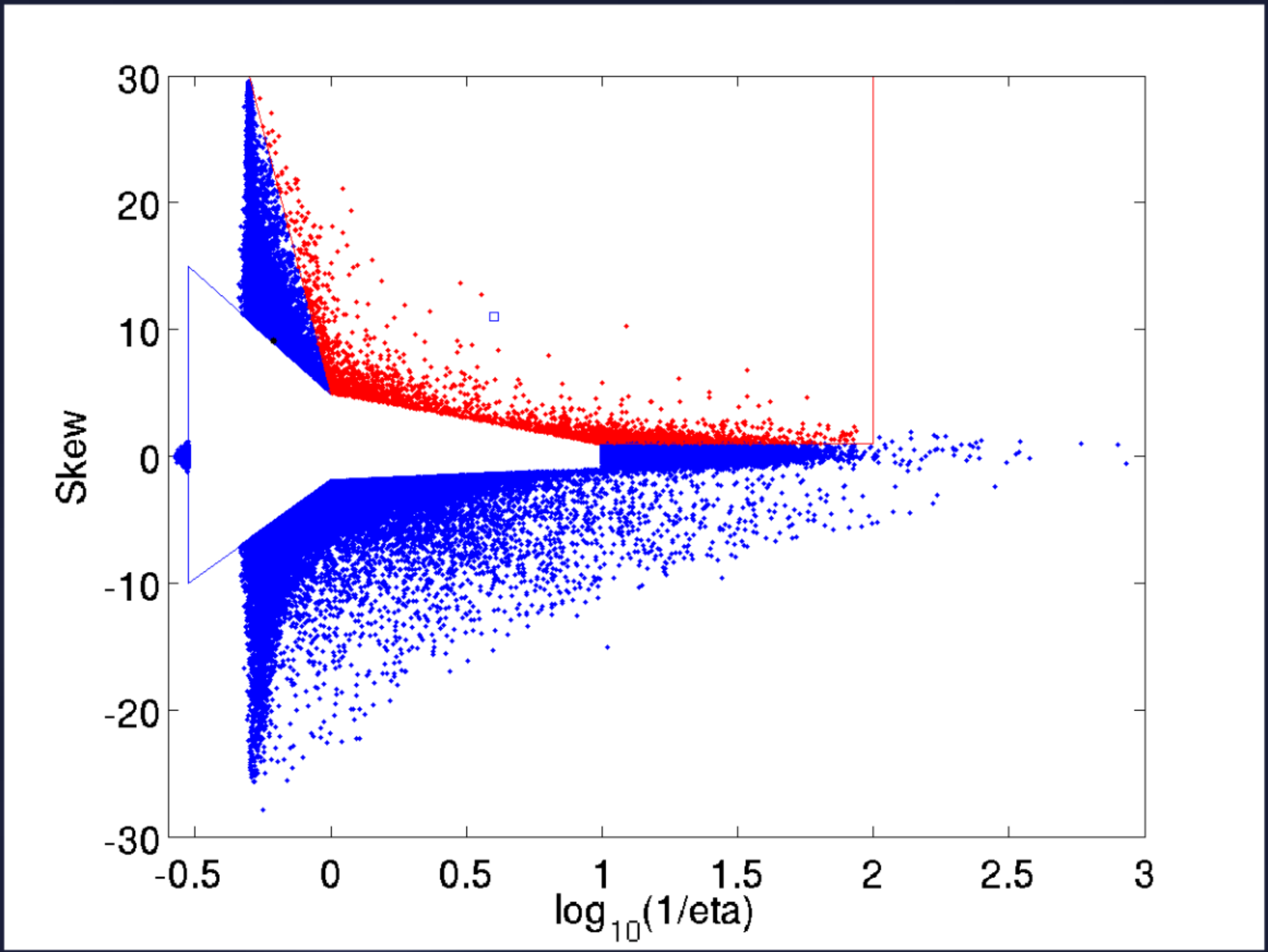
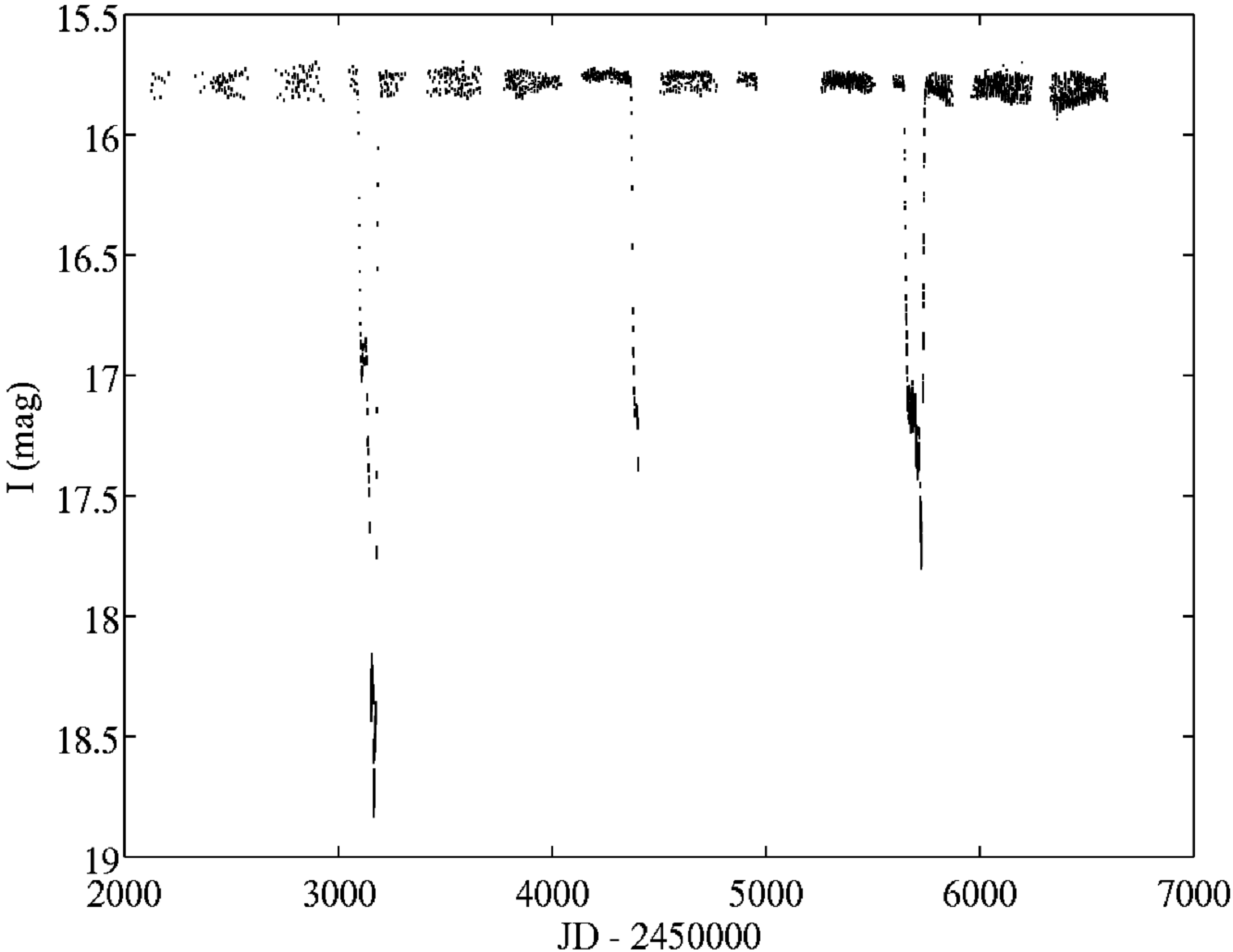


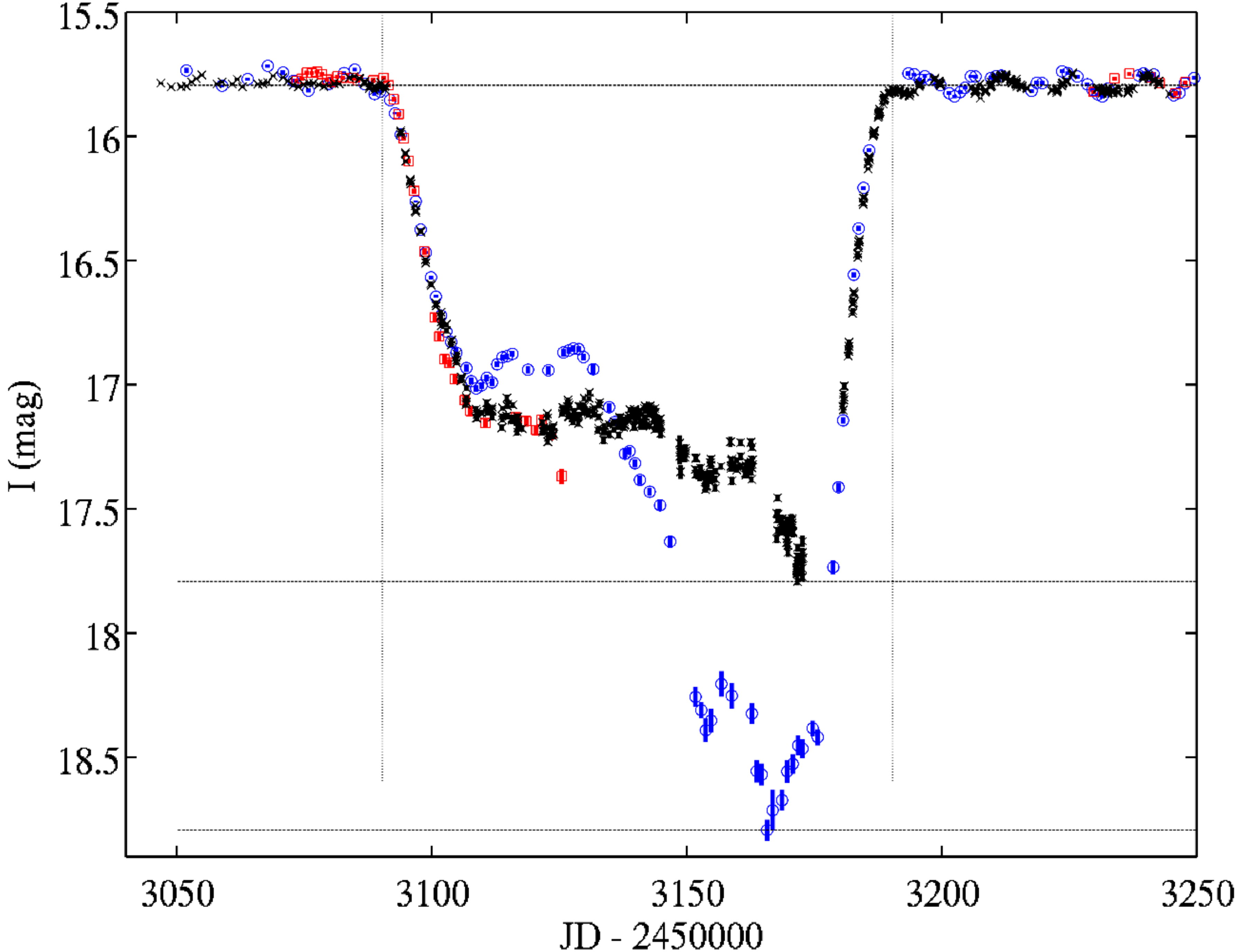
Sample OGLE field

$$\eta = \frac{\sqrt{\sum_i^N (x_{i+1}-x_i)^2/(N-1)}}{\sum_i^N x_i/N}$$

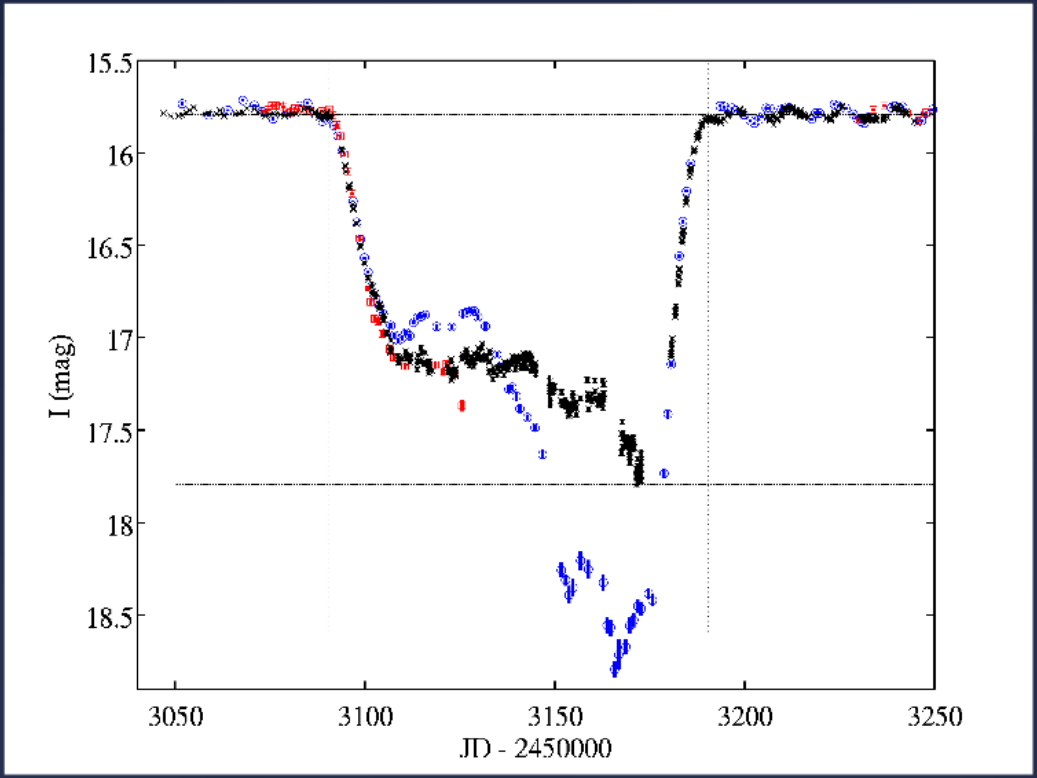
+ skewness



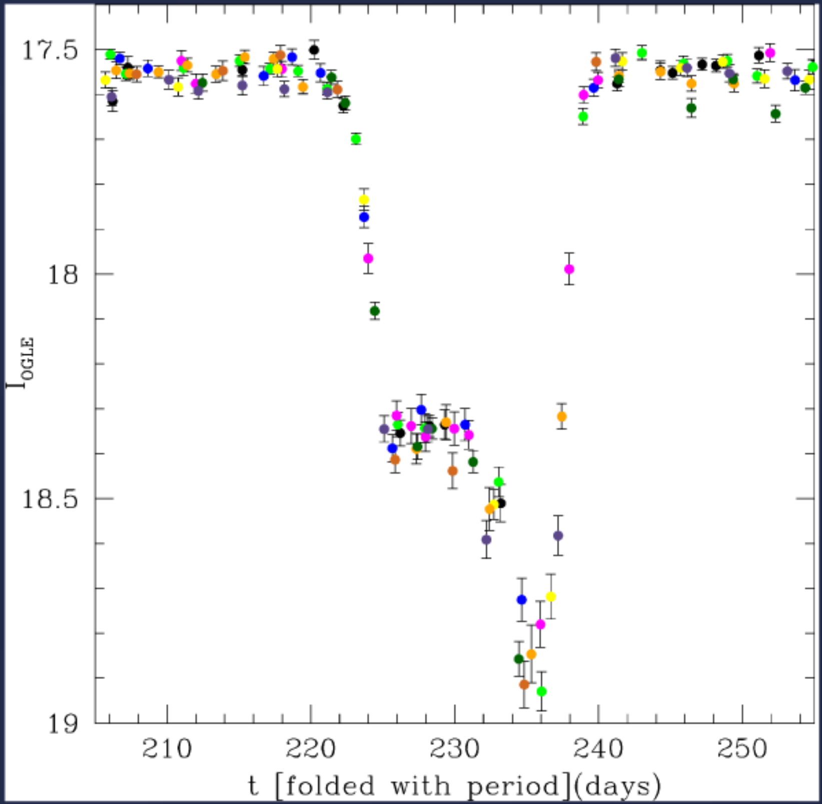

15.5
16
16.5
17
17.5
18
18.5
19
I (mag)
2000
3000
4000
5000
6000
7000
JD - 2450000



15.5
16
16.5
17
17.5
18
18.5
I (mag)
3050
3100
3150
3200
3250
JD - 2450000

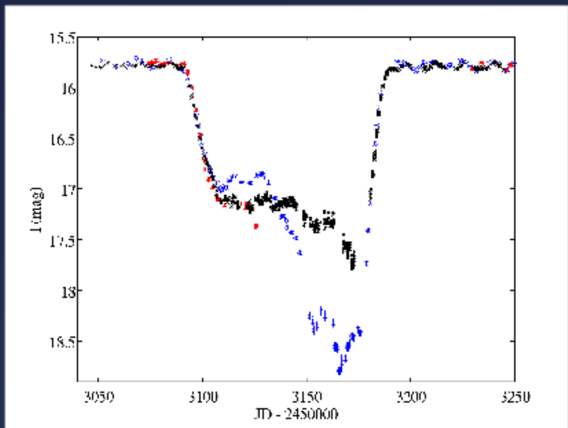


OGLE-BLG182.1.162852



OGLE-LMC-ECL-11893

Dong, S., et al., 2014, ApJ, 788, 41



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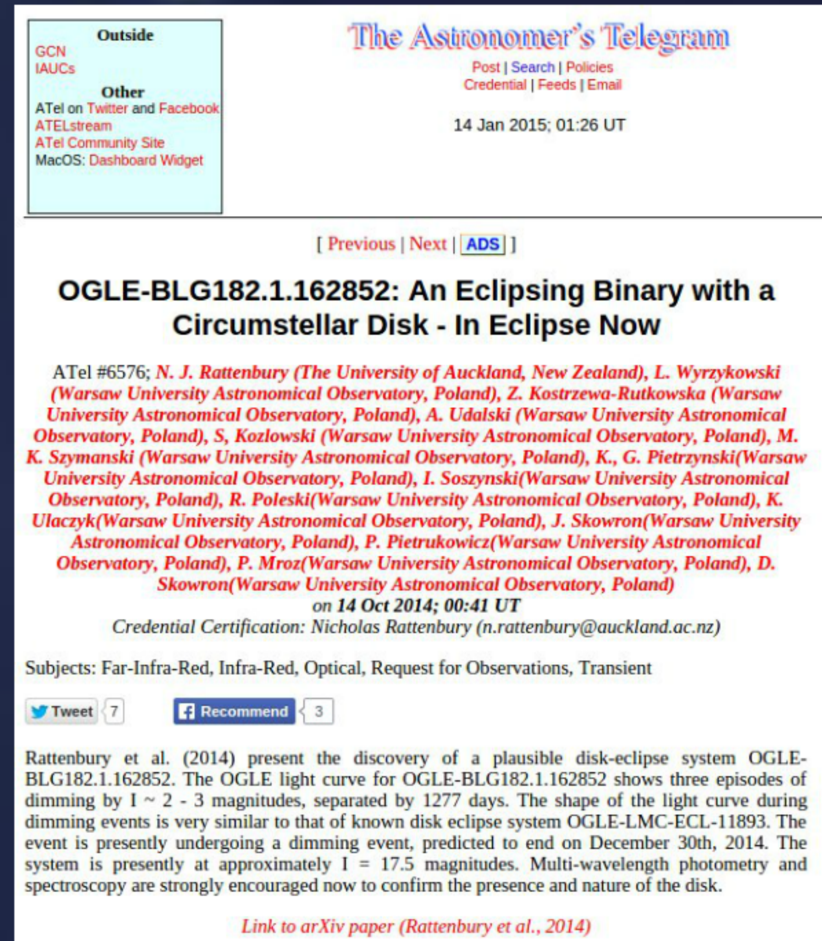
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14 Jan 2015; 01:26 UT

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OGLE-BLG182.1.162852: An Eclipsing Binary with a Circumstellar Disk - In Eclipse Now

ATel #6576; *N. J. Rattenbury (The University of Auckland, New Zealand), L. Wyrzykowski (Warsaw University Astronomical Observatory, Poland), Z. Kostrzewa-Rutkowska (Warsaw University Astronomical Observatory, Poland), A. Udalski (Warsaw University Astronomical Observatory, Poland), S, Kozlowski (Warsaw University Astronomical Observatory, Poland), M. K. Szymanski (Warsaw University Astronomical Observatory, Poland), K., G. Pietrzynski(Warsaw University Astronomical Observatory, Poland), I. Soszynski(Warsaw University Astronomical Observatory, Poland), R. Poleski(Warsaw University Astronomical Observatory, Poland), K. Ulaczyk(Warsaw University Astronomical Observatory, Poland), J. Skowron(Warsaw University Astronomical Observatory, Poland), P. Pietrukowicz(Warsaw University Astronomical Observatory, Poland), P. Mroz(Warsaw University Astronomical Observatory, Poland), D. Skowron(Warsaw University Astronomical Observatory, Poland)*
on ***14 Oct 2014; 00:41 UT***
Credential Certification: Nicholas Rattenbury (n.rattenbury@auckland.ac.nz)

Subjects: Far-Infra-Red, Infra-Red, Optical, Request for Observations, Transient

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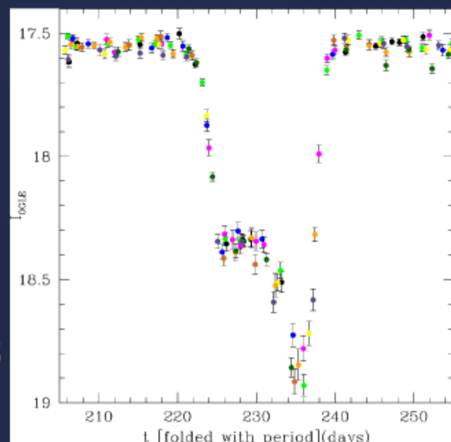
Rattenbury et al. (2014) present the discovery of a plausible disk-eclipse system OGLE-BLG182.1.162852. The OGLE light curve for OGLE-BLG182.1.162852 shows three episodes of dimming by I ~ 2 - 3 magnitudes, separated by 1277 days. The shape of the light curve during dimming events is very similar to that of known disk eclipse system OGLE-LMC-ECL-11893. The event is presently undergoing a dimming event, predicted to end on December 30th, 2014. The system is presently at approximately I = 17.5 magnitudes. Multi-wavelength photometry and spectroscopy are strongly encouraged now to confirm the presence and nature of the disk.

Link to arXiv paper (Rattenbury et al., 2014)

OGLE-LMC-ECL-11893
Dong, S., et al., 2014, ApJ, 788, 41



System	Period	Eclipse Duration	Eclipse Depth	Reference(s)
ε Aurigae	27.1 years	$\sim$ 22 months	0.9 (V)	Kloppenborg et al. (2010); Stefanik et al. (2010)
EE Cephei	5.6 years	$\sim 30 - 90$ days	0.5 – 2.0 (B,V)	Gałan et al. (2012); Graczyk et al. (2003)
KH 15D	48.4 days	variable^a	$\sim$ 4 (I)	Hamilton et al. (2005); Winn et al. (2006)
J1407	$>$ 850 days	$\sim 54^b$ days	$>$ 3.3 (V)	Mamajek et al. (2012)
OGLE-LMC-ECL-17782	13.35 days	2.67 days	$\sim$ 0.4 (I)	Graczyk et al. (2011)
OGLE-LMC-ECL-11893	468.124 days	$\sim$ 15 days	1.5 (I)	Dong et al. (2014)
OGLE-BLG182.1.162852	**1277 days**	**100 days**	**2 – 3 (I)**	**This work**

Rattenbury et al., 2015, MNRAS, 447, L31-L34

The Astronomer's Telegram

14 Jan 2015; 01:26 UT

OGLE-BLG182.1.162852: An Eclipsing Binary with a Circumstellar Disk - In Eclipse Now

ATel #6576; *N. J. Rattenbury (The University of Auckland, New Zealand), L. Wyrzykowski (Warsaw University Astronomical Observatory, Poland), Z. Kostrzewa-Rutkowska (Warsaw University Astronomical Observatory, Poland), A. Udalski (Warsaw University Astronomical bservatory, Poland), S, Kozlowski (Warsaw University Astronomical Observatory, Poland), M. Szymanski (Warsaw University Astronomical Observatory, Poland), K., G. Pietrzynski(Warsaw University Astronomical Observatory, Poland), I. Soszynski(Warsaw University Astronomical Observatory, Poland), R. Poleski(Warsaw University Astronomical Observatory, Poland), K.*

Period	Eclipse Duration	Eclipse Depth
27.1 years	$\sim$ 22 months	0.9 (V)
5.6 years	$\sim$ 30 – 90 days	0.5 – 2.0 (B,V)
48.4 days	variable[a]	$\sim$ 4 (I)
$>$ 850 days	$\sim$ 54[b] days	$>$ 3.3 (V)
13.35 days	2.67 days	$\sim$ 0.4 (I)
468.124 days	$\sim$ 15 days	1.5 (I)
1277 days	**100 days**	**2 – 3 (I)**

Rattenbury et al., 2015, MNRAS, 447, L31-L34

Future work

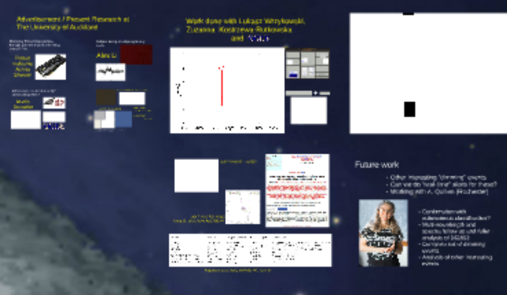
- Other interesting "dimming" events
- Can we do "real-time" alerts for these?
- Working with A. Quillen (Rochester)

- Confirmation with autonomous classification?
- Multi-wavelength and spectra follow-up and fuller analysis of 162852
- Complete set of dimming events
- Analysis of other interesting events

Searching for Transient Dimming Events in Microlensing Datasets

Nicholas J. Rattenbury

Royal Society of New Zealand
Rutherford Discovery Fellow



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