Development of multi-lens modelling codes

Nicholas James Rattenbury
The University of Auckland, New Zealand

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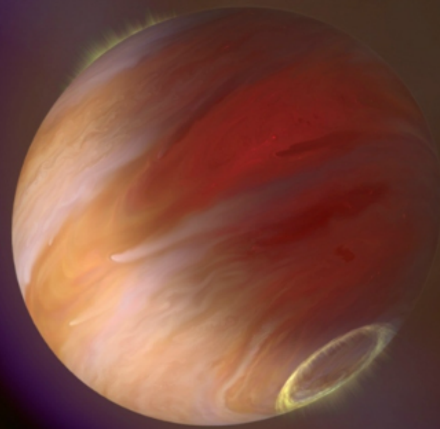
Te Whare Wananga o Tamaki Makaurau
NEW ZEALAND

Development of multi-lens modelling codes



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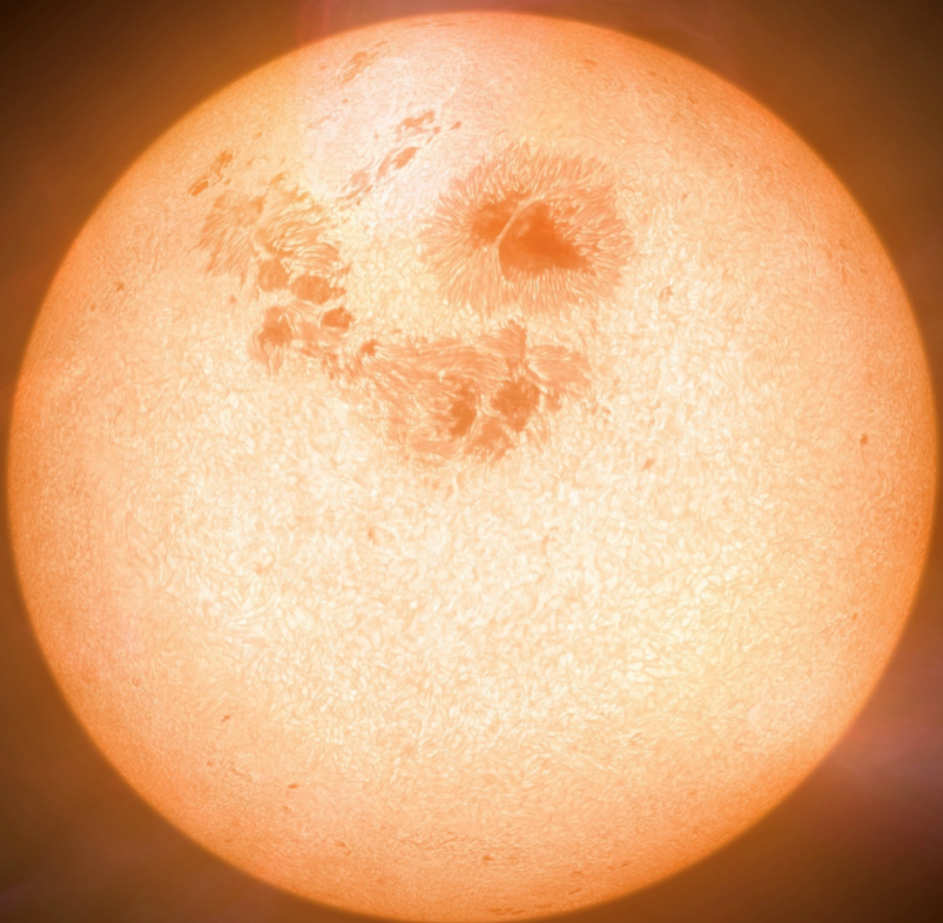

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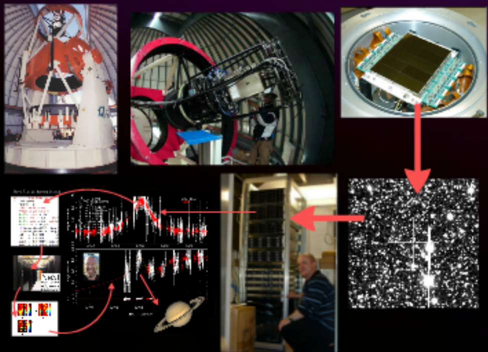
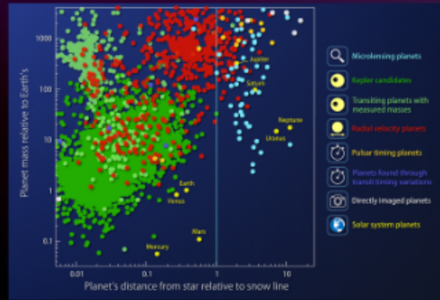
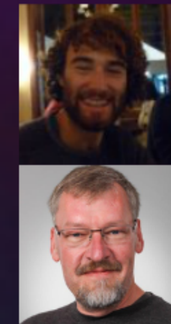




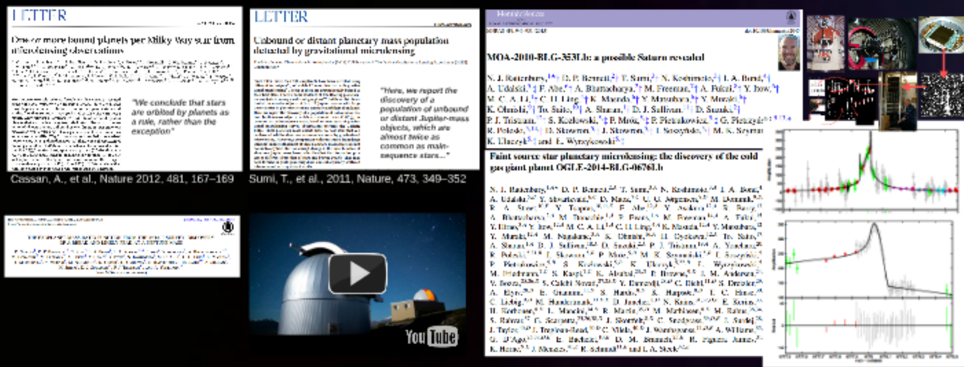
Efficient model exoplanet model discovery using GPU accelerated code and Nested Sampling.

Ashna Sharan



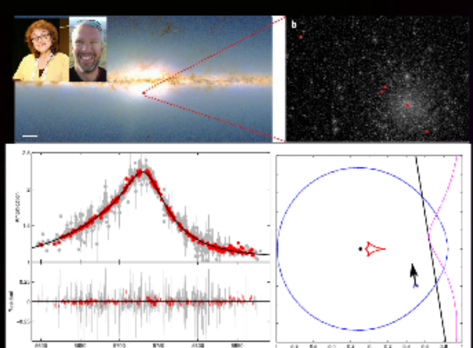
Reversible Jump
Markov Chain Metropolis Hastings Monte Carlo

N = 1 | 2 | 3 | ...

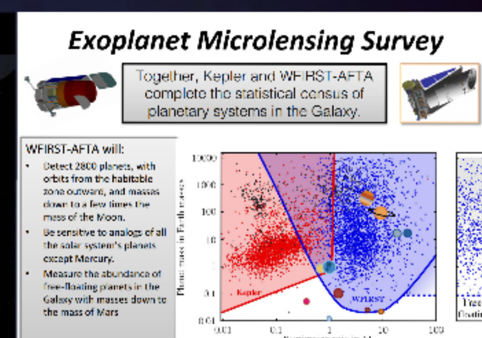


Cassan, A., et al., Nature 2012, 481, 167–169

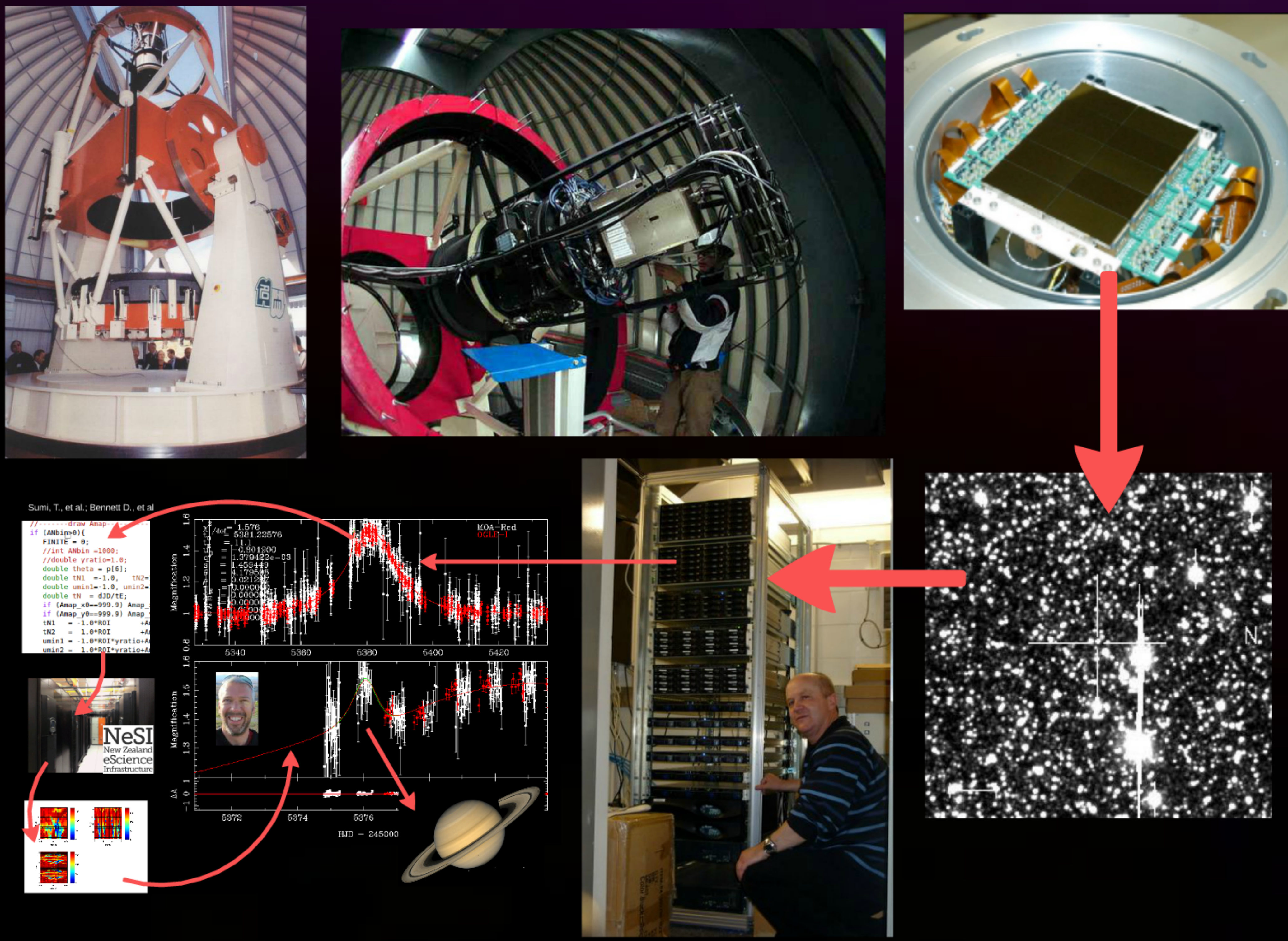
Sumi, T., et al., 2011, Nature, 473, 349–352



Transits

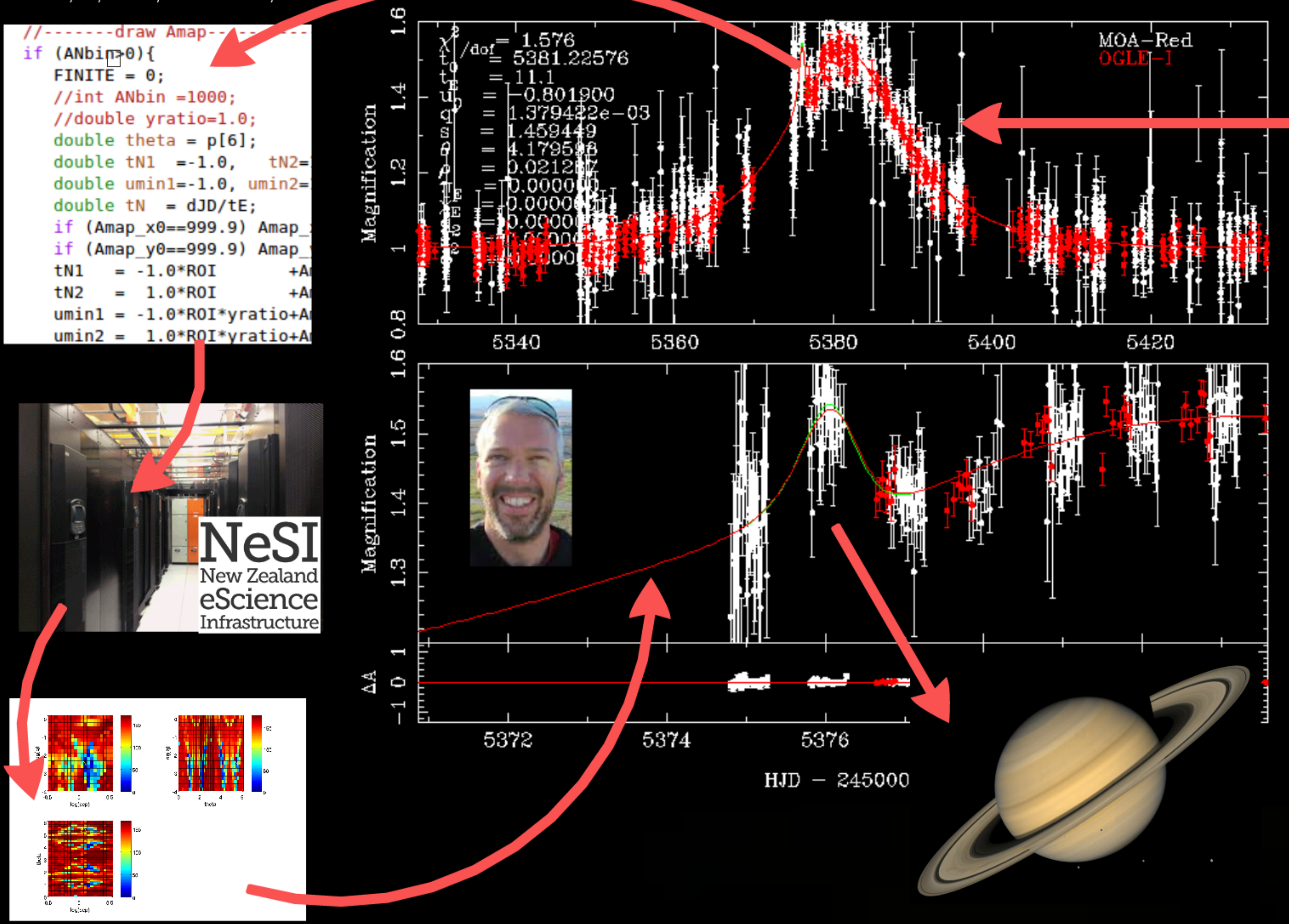


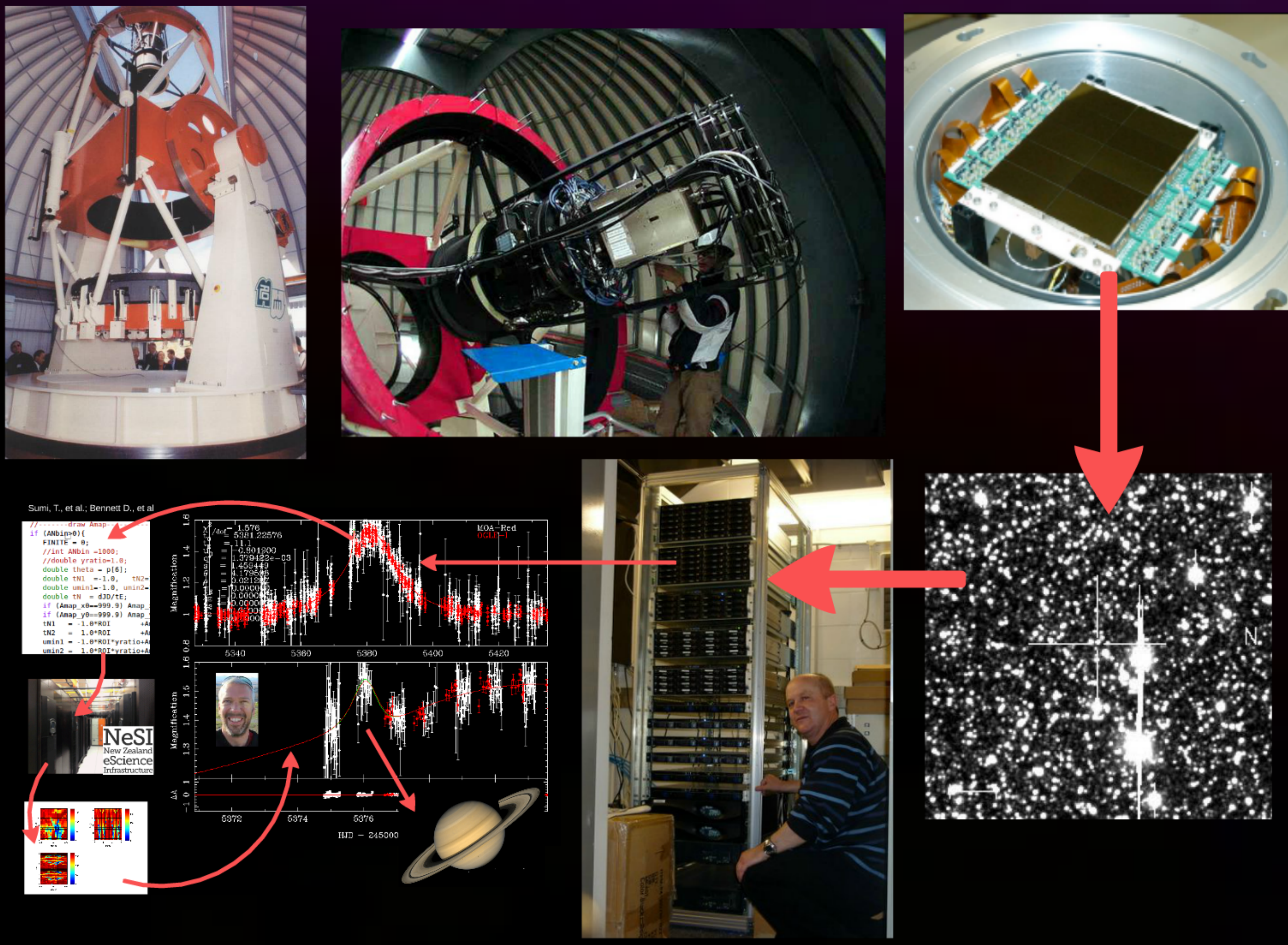
Microlensing Observations in Astrophysics



Sumi, T., et al.; Bennett D., et al
MOA-Red
Magnification
5340
5360
5380
5400
5420
5372
5374
5376
HJD − 245000
NeSI
New Zealand
eScience
Infrastructure
N

Sumi, T., et al.; Bennett D., et al




Sumi, T., et al.; Bennett D., et al
MOA-Red
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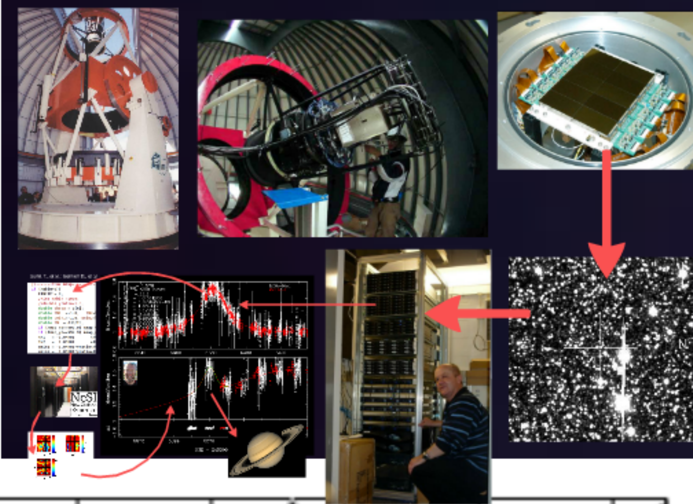
New Zealand
eScience
Infrastructure
N

Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY
MNRAS **454**, 946–951 (2015) doi:10.1093/mnras/stv2045

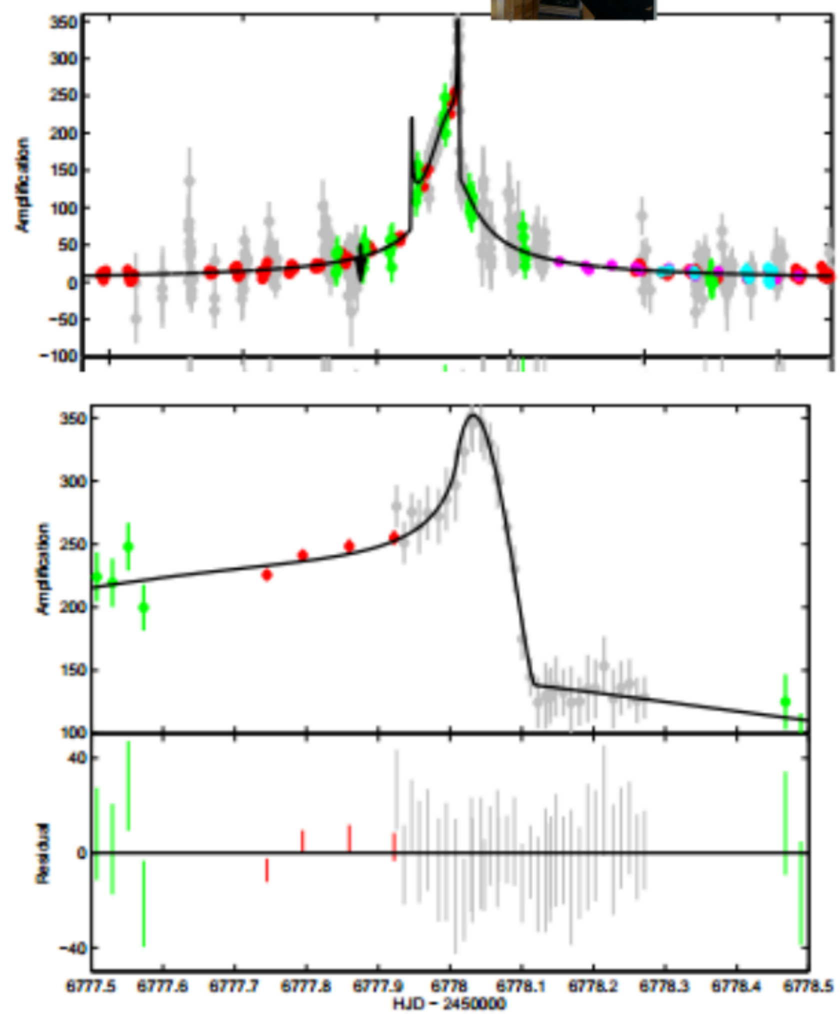
MOA-2010-BLG-353Lb: a possible Saturn revealed

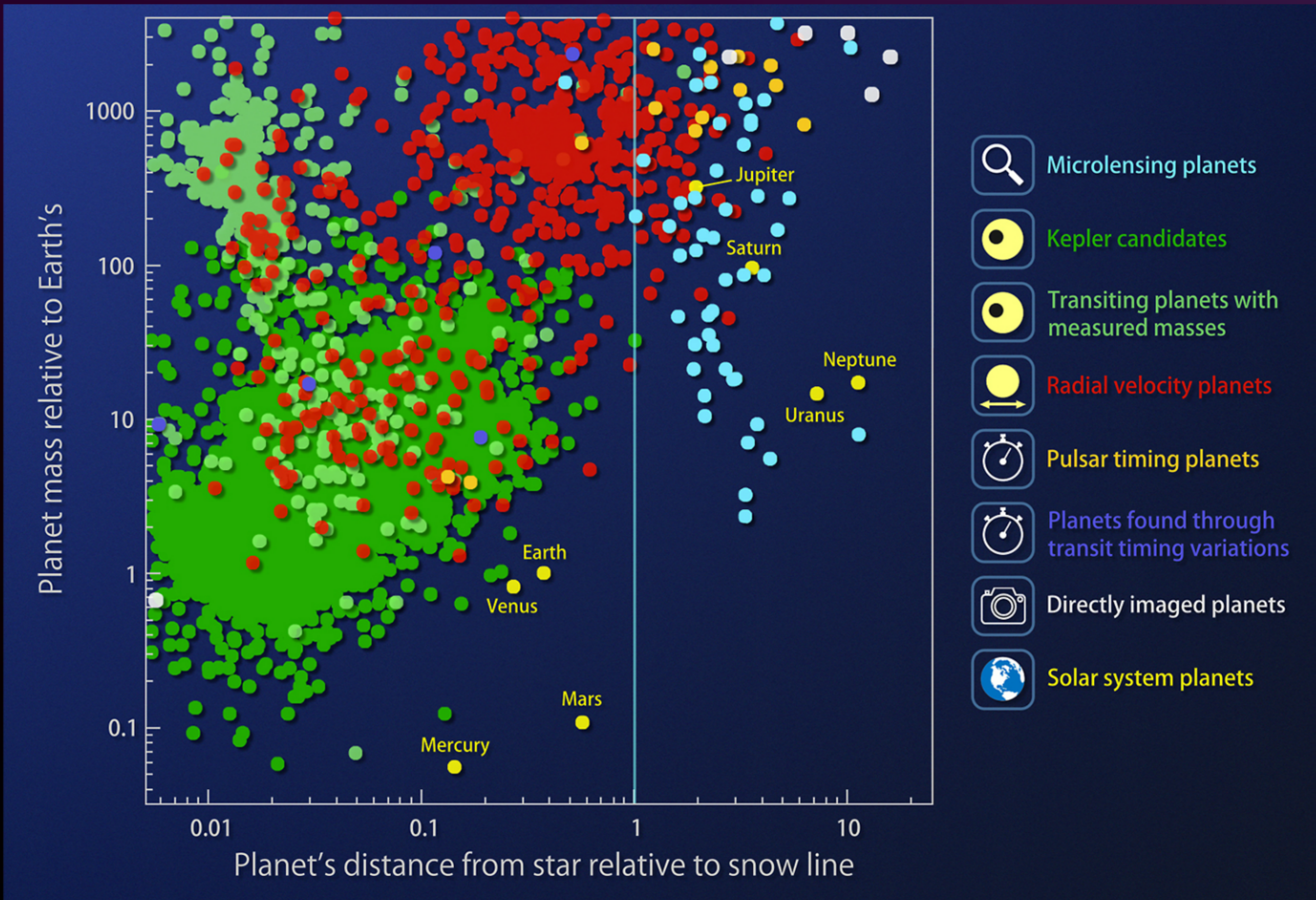
N. J. Rattenbury,[1★†] D. P. Bennett,[2†] T. Sumi,[3†] N. Koshimoto,[3†] I. A. Bond,[4†] A. Udalski,[5,‡] F. Abe,[6†] A. Bhattacharya,[2†] M. Freeman,[7†] A. Fukui,[8†] Y. Itow,[6†] M. C. A. Li,[1†] C. H. Ling,[4†] K. Masuda,[6†] Y. Matsubara,[6†] Y. Muraki,[6†] K. Ohnishi,[9†] To. Saito,[10†] A. Sharan,[1†] D. J. Sullivan,[11†] D. Suzuki,[2†] P. J. Tristram,[12†] S. Kozłowski,[5,‡] P. Mróz,[5,‡] P. Pietrukowicz,[5,‡] G. Pietrzyńs [5,13,‡] R. Poleski,[5,14,‡] D. Skowron,[5,‡] J. Skowron,[5,‡] I. Soszyński,[5,‡] M. K. Szymai K. Ulaczyk[5,‡] and Ł. Wyrzykowski[5,‡]



Faint source star planetary microlensing: the discovery of the cold gas giant planet OGLE-2014-BLG-0676Lb

N. J. Rattenbury,[1,A★] D. P. Bennett,[2,A] T. Sumi,[3,A] N. Koshimoto,[3,A] I. A. Bond,[4, A. Udalski,[5,B] Y. Shvartzvald,[6,C] D. Maoz,[7,C] U. G. Jørgensen,[8,D] M. Dominik,[9,D, R. A. Street,[10,E] Y. Tsapras,[10,11,E] F. Abe,[12,A] Y. Asakura,[12,A] R. Barry,[13, A. Bhattacharya,[2,A] M. Donachie,[1,A] P. Evans,[1,A] M. Freeman,[14,A] A. Fukui,[15, Y. Hirao,[3,A] Y. Itow,[12,A] M. C. A. Li,[1,A] C. H. Ling,[4,A] K. Masuda,[12,A] Y. Matsubara,[12, Y. Muraki,[12,A] M. Nagakane,[3,A] K. Ohnishi,[16,A] H. Oyokawa,[12,A] To. Saito,[17, A. Sharan,[1,A] D. J. Sullivan,[18,A] D. Suzuki,[2,A] P. J. Tristram,[19,A] A. Yonehara,[20, R. Poleski,[5,21,B] J. Skowron,[5,B] P. Mróz,[5,B] M. K. Szymański,[5,B] I. Soszyński,[5, P. Pietrukowicz,[5,B] S. Kozłowski,[5,B] K. Ulaczyk,[5,22,B] Ł. Wyrzykowski,[5, M. Friedmann,[7,C] S. Kaspi,[7,C] K. Alsubai,[23,D] P. Browne,[9,D] J. M. Andersen,[24, V. Bozza,[25,26,D] S. Calchi Novati,[27,25,D] Y. Damerdji,[28,D] C. Diehl,[11,D] S. Dreizler,[29, A. Elyiv,[28,D] E. Giannini,[11,D] S. Hardis,[8,D] K. Harpsøe,[8,D] T. C. Hinse,[30, C. Liebig,[9,D] M. Hundertmark,[11,D,E] D. Juncher,[8,D] N. Kains,[31,32,D,E] E. Kerins,[33, H. Korhonen,[8,D] L. Mancini,[34,D] R. Martin,[35,D] M. Mathiasen,[8,D] M. Rabus,[36,34, S. Rahvar,[37] G. Scarpetta,[25,26,38,D] J. Skottfelt,[8,D] C. Snodgrass,[39,D,E] J. Surdej,[28, J. Taylor,[40,D] J. Tregloan-Reed,[40,D] C. Vilela,[40,D] J. Wambsganss,[11,D,E] A. Williams,[35, G. D'Ago,[25,38,D,E] E. Bachelet,[10,E] D. M. Bramich,[23,E] R. Figuera Jaimes,[31, K. Horne,[9,E] J. Menzies,[41,E] R. Schmidt[11,E] and I. A. Steele[42,E]





Planet mass relative to Earth's
1000
100
10
1
0.1
0.01
0.1
1
10
Planet's distance from star relative to snow line
Jupiter
Saturn
Neptune
Uranus
Earth
Venus
Mars
Mercury
Microlensing planets
Kepler candidates
Transiting planets with measured masses
Radial velocity planets
Pulsar timing planets
Planets found through transit timing variations
Directly imaged planets
Solar system planets

LETTER

doi:10.1038/nature10684

One or more bound planets per Milky Way star from microlensing observations

A. Cassan[1,2,3], D. Kubas[1,2,4], J.-P. Beaulieu[1,2,25], M. Dominik[1,5], K. Horne[1,5], J. Greenhill[1,6], J. Wambsganss[1,3], J. Menzies[1,7], A. Williams[1,8], U. G. Jørgensen[1,9], A. Udalski[10,11], D. P. Bennett[1,12], M. D. Albrow[1,13], V. Batista[1,2], S. Brillant[1,4], J. A. R. Caldwell[1,14], A. Cole[1,6], Ch. Coutures[1,2], K. H. Cook[1,15], S. Dieters[1,6], D. Dominis Prester[1,16], J. Donatowicz[1,17], P. Fouqué[1,18], K. Hill[1,6], N. Kains[1,19], S. Kane[1,20], J.-B. Marquette[1,2], R. Martin[1,8], K. R. Pollard[1,13], K. C. Sahu[1,14], C. Vinter[1,9], D. Warren[1,6], B. Watson[1,6], M. Zub[1,3], T. Sumi[21,22], M. K. Szymański[10,11], M. Kubiak[10,11], R. Poleski[10,11], I. Soszynski[10,11], K. Ulaczyk[10,11], G. Pietrzyński[10,11,23] & Ł. Wyrzykowski[10,11,24]

Most known extrasolar planets (exoplanets) have been discovered using the radial velocity[1,2] or transit[3] methods. Both are biased towards planets that are relatively close to their parent stars, and studies find that around 17–30% (refs 4, 5) of solar-like stars host a planet. Gravitational microlensing[6–9], on the other hand, probes planets that are further away from their stars. Recently, a population of planets that are unbound or very far from their stars was discovered by microlensing[10]. These planets are at least as numerous as the stars in the Milky Way[10]. Here we report a statistical analysis of microlensing data (gathered in 2002–07) that reveals the fraction of bound planets 0.5–10 AU (Sun–Earth distance) from their stars. We find that $17^{+6}_{-9}\%$ of stars host Jupiter-mass planets (0.3–10 M_J, where $M_J = 318\ M_{\oplus}$ and $M_{\oplus}$ is Earth's mass). Cool Neptunes (10–30 $M_{\oplus}$) and super-Earths (5–10 $M_{\oplus}$) are even more common: their respective abundances per star are $52^{+22}_{-29}\%$ and $62^{+35}_{-37}\%$. We conclude that stars are orbited by planets as a rule, rather than the exception.

"We conclude that stars are orbited by planets as a rule, rather than the exception"

Cassan, A., et al., Nature 2012, 481, 167–169

LETTER

doi:10.1038/nature10092

Unbound or distant planetary mass population detected by gravitational microlensing

The Microlensing Observations in Astrophysics (MOA) Collaboration & The Optical Gravitational Lensing Experiment (OGLE) Collaboration*

Since 1995, more than 500 exoplanets have been detected using different techniques[1,2], of which 12 were detected with gravitational microlensing[3,4]. Most of these are gravitationally bound to their host stars. There is some evidence of free-floating planetary-mass objects in young star-forming regions[5–8], but these objects are limited to massive objects of 3 to 15 Jupiter masses with large uncertainties in photometric mass estimates and their abundance. Here, we report the discovery of a population of unbound or distant Jupiter-mass objects, which are almost twice ($1.8^{+1.7}_{-0.8}$) as common as main-sequence stars, based on two years of gravitational microlensing survey observations towards the Galactic Bulge. These planetary-mass objects have no host stars that can be detected within about ten astronomical units by gravitational microlensing. However, a comparison with constraints from direct imaging[9] suggests that most of these planetary-mass objects are not bound to any host star. An abrupt change in the mass function at about one Jupiter mass favours the idea that their formation process is different from that of stars and brown dwarfs. They may have formed in proto-planetary disks and subsequently scattered into unbound or very distant orbits.

"Here, we report the discovery of a population of unbound or distant Jupiter-mass objects, which are almost twice as common as main-sequence stars..."

Sumi, T., et al., 2011, Nature, 473, 349–352

The Astrophysical Journal, 833:145 (26pp), 2016 December 20
doi:10.3847/1538-4357/833/2/145

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THE EXOPLANET MASS-RATIO FUNCTION FROM THE MOA-II SURVEY: DISCOVERY OF A BREAK AND LIKELY PEAK AT A NEPTUNE MASS

D. Suzuki[1], D. P. Bennett[1,2], T. Sumi[3], I. A. Bond[4], L. A. Rogers[5,14], F. Abe[6], Y. Asakura[6], A. Bhattacharya[1,2], M. Donachie[7], M. Freeman[7], A. Fukui[8], Y. Hirao[3], Y. Itow[6], N. Koshimoto[3], M. C. A. Li[7], C. H. Ling[4], K. Masuda[6], Y. Matsubara[6], Y. Muraki[6], M. Nagakane[3], K. Onishi[9], H. Oyokawa[6], N. Rattenbury[7], To. Saito[10], A. Sharan[7], H. Shibai[3], D. J. Sullivan[11], P. J. Tristram[12], and A. Yonehara[13]
(the MOA collaboration)

Efficient model exoplanet model discovery using GPU accelerated code and Nested Sampling.

Ling, C., 2013, Simulation and modelling of gravitational microlensing events using graphical processing units, Ph.D. thesis, URL http://muir.massey.ac.nz/handle/10179/5148

$$
\begin{aligned}
P(M1|D) &= \frac{P(D|M1)P(M1)}{P(D)} \\
&= \frac{P(D|M1)P(M1)}{P(D|M1)P(M1) + P(D|M2)P(M2)} \\
&= \frac{1}{1 + \frac{P(D|M2)}{P(D|M1)}\frac{P(M2)}{P(M1)}}
\end{aligned}
$$

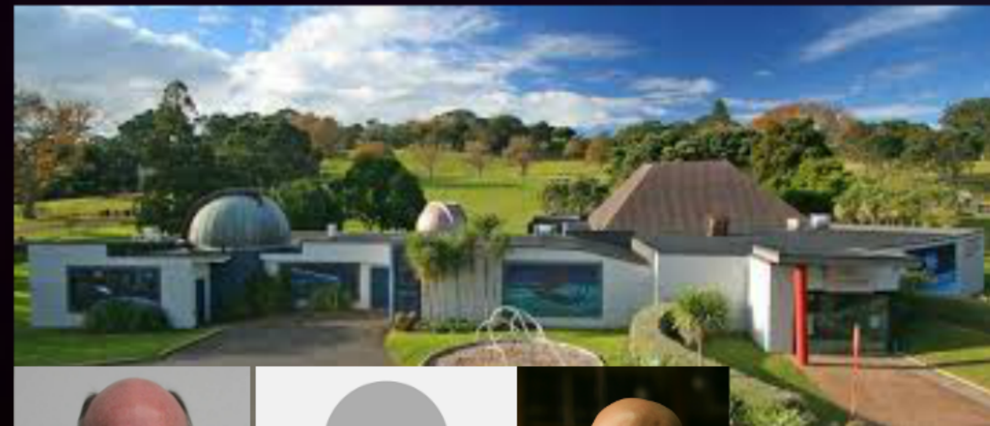
Skilling, John (2004). "Nested Sampling". AIP Conference Proceedings 735: 395–405. doi:10.1063/1.1835238

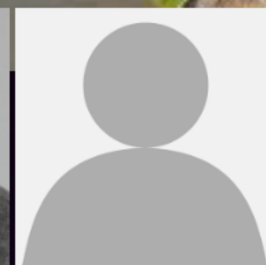
Ashna Sharan

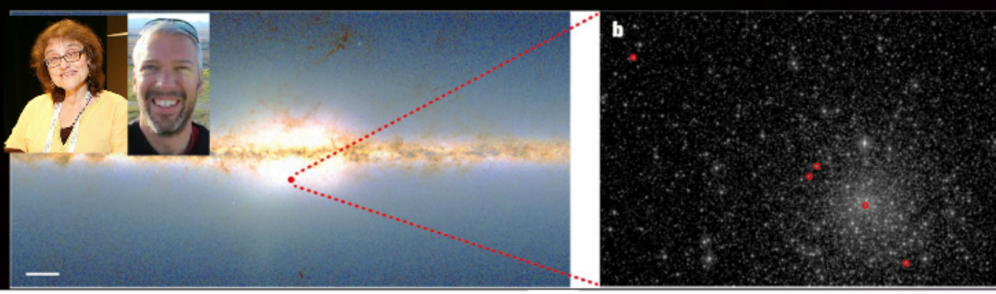
Reversible Jump
Markov Chain Metropolis
Hastings Monte Carlo

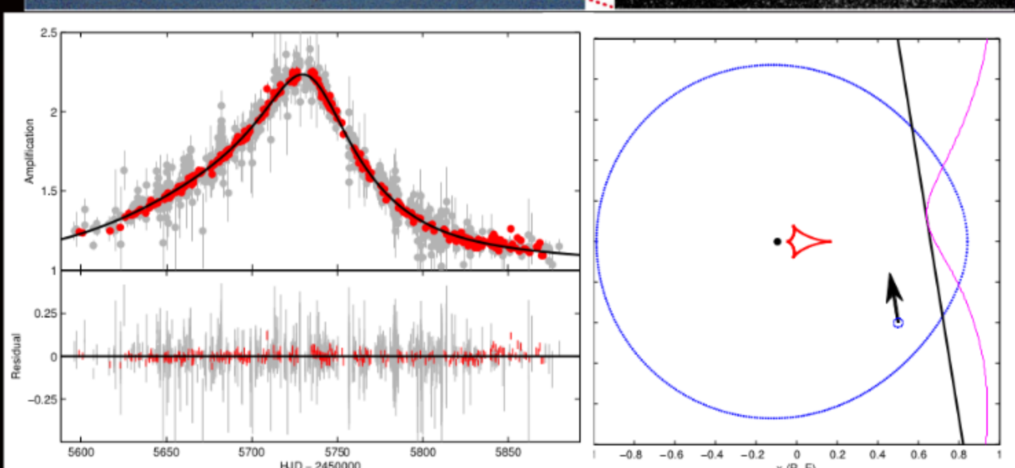
N = 1 | 2 | 3 | ...

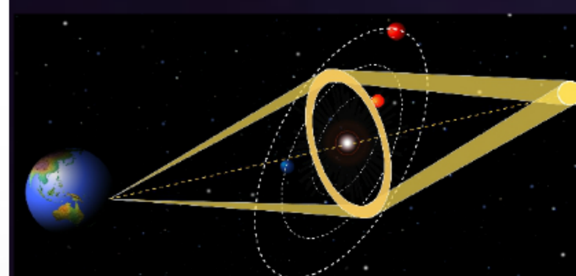
Transits

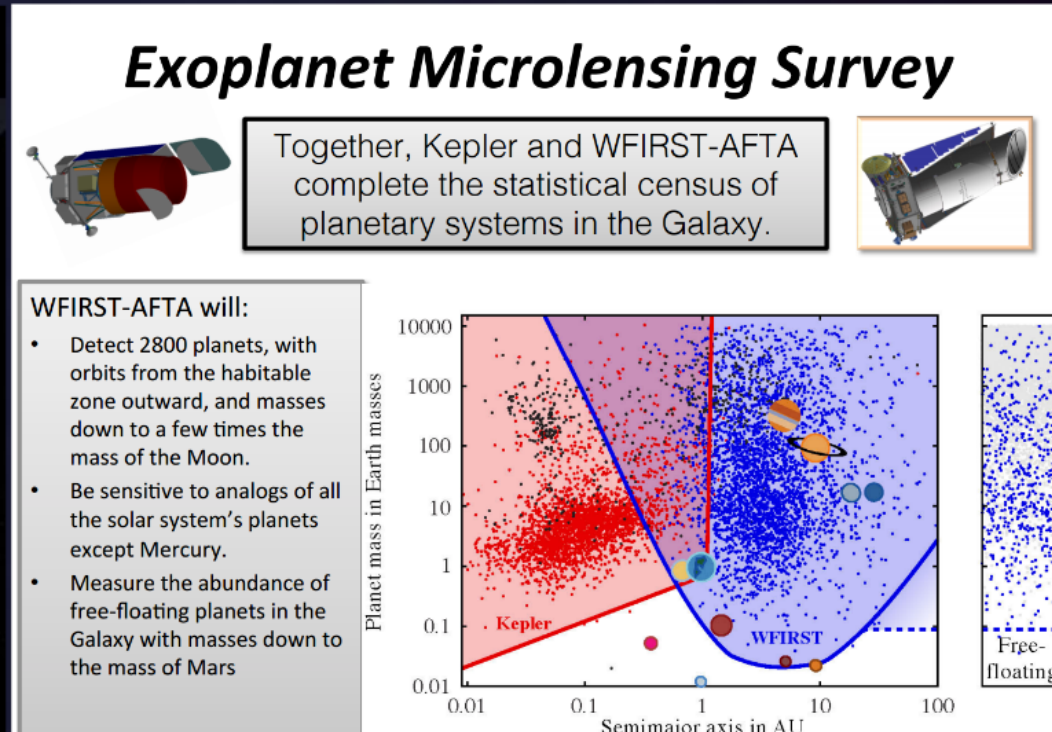












Microlensing Observations in Astrophysics

The Astronomical Journal, 152:125 (14pp), 2016 November
doi:10.3847/0004-6256/152/5/125

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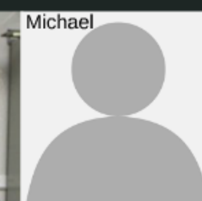
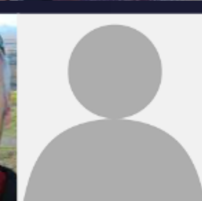
THE FIRST CIRCUMBINARY PLANET FOUND BY MICROLENSING: OGLE-2007-BLG-349L(AB)c

D. P. Bennett[1,2,48,49], S. H. Rhie[2,50], A. Udalski[3,51], A. Gould[4,5,6,52], Y. Tsapras[7,8,53], D. Kubas[9,49], I. A. Bond[10,48], J. Greenhill[11,50,49], A. Cassan[9,49], N. J. Rattenbury[12,48], T. S. Boyajian[13], J. Luhn[14], M. T. Penny[4], J. Anderson[15], F. Abe[16], A. Bhattacharya[2], C. S. Botzler[12], M. Donachie[12], M. Freeman[12], A. Fukui[17], Y. Hirao[18], Y. Itow[16], N. Koshimoto[18], M. C. A. Li[12], C. H. Ling[9], K. Masuda[16], Y. Matsubara[16], Y. Muraki[16], M. Nagakane[18], K. Ohnishi[19], H. Oyokawa[16], Y. C. Perrott[12], To. Saito[20], A. Sharan[12], D. J. Sullivan[21], T. Sumi[18], D. Suzuki[1,2], P. J. Tristram[22], A. Yonehara[23], P. C. M. Yock[12]
(The MOA Collaboration) ,
M. K. Szymański[3], I. Soszyński[3], K. Ulaczyk[3], Ł. Wyrzykowski[3]
(The OGLE Collaboration) ,
W. Allen[24], D. DePoy[25], A. Gal-Yam[26], B. S. Gaudi[4], C. Han[27], I. A. G. Monard[28], E. Ofek[29], R. W. Pogge[4]
(The μFUN Collaboration),
R. A. Street[8], D. M. Bramich[30], M. Dominik[31], K. Horne[31], C. Snodgrass[32,33], I. A. Steele[34]
(The Robonet Collaboration),
and
M. D. Albrow[35], E. Bachelet[8], V. Batista[9], J.-P. Beaulieu[9], S. Brillant[36], J. A. R. Caldwell[37], A. Cole[11], C. Coutures[9], S. Dieters[11], D. Dominis Prester[38], J. Donatowicz[39], P. Fouqué[40,41], M. Hundertmark[31,42], U. G. Jørgensen[42], N. Kains[15], S. R. Kane[43], J.-B. Marquette[9], J. Menzies[44], K. R. Pollard[35], C. Ranc[8], K. C. Sahu[15], J. Wambsganss[45], A. Williams[46,47], M. Zub[45]
(The PLANET Collaboration)

Continuing the work of Denis Sullivan and students..

TE WHARE WĀNANGA O TE ŪPOKO O TE IKA A MĀUI
VICTORIA
UNIVERSITY OF WELLINGTON





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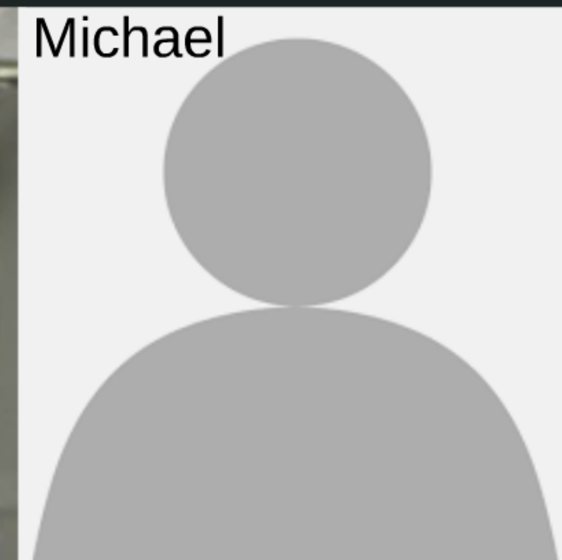
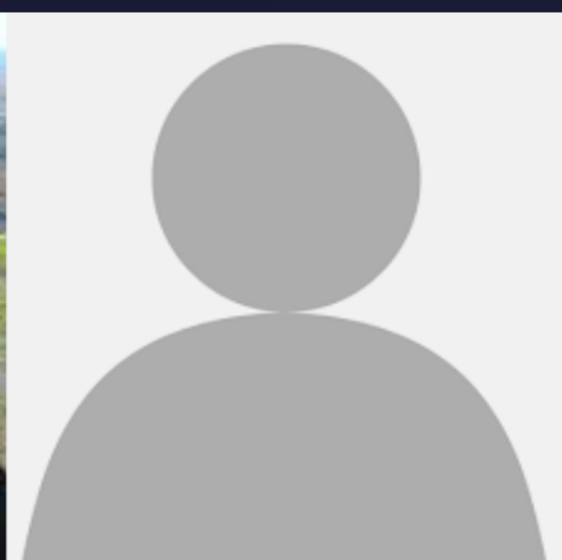
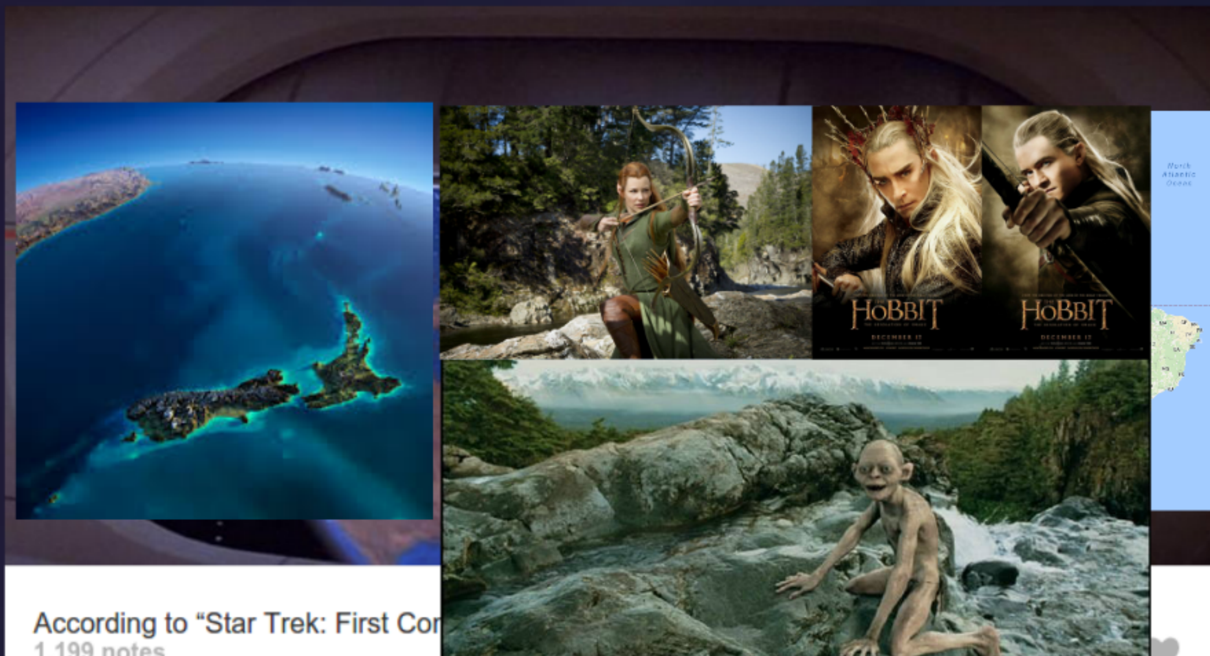
Continuing the work of Denis Sullivan and students..





Auckland Microlensing Conference 2018



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