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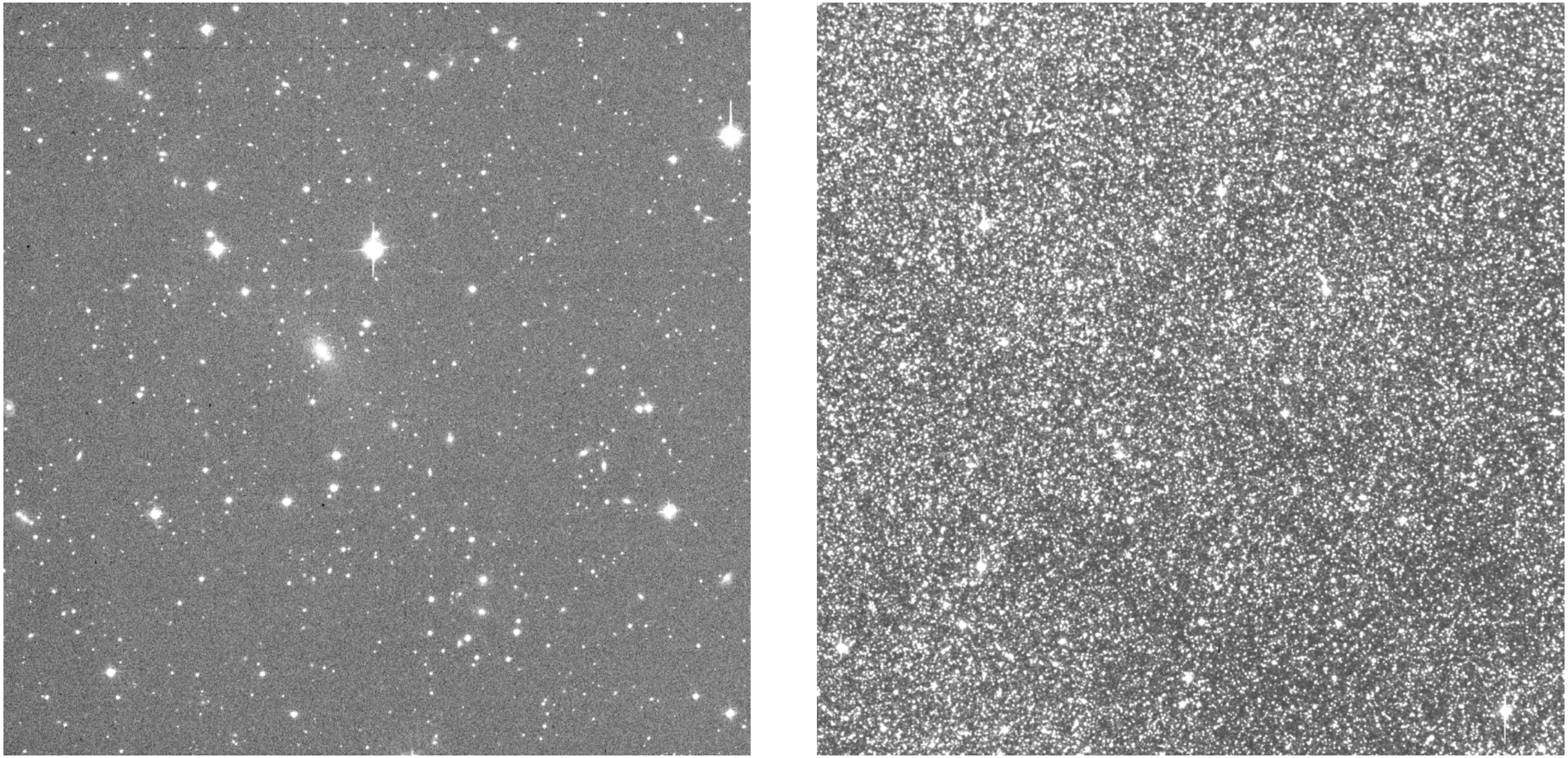

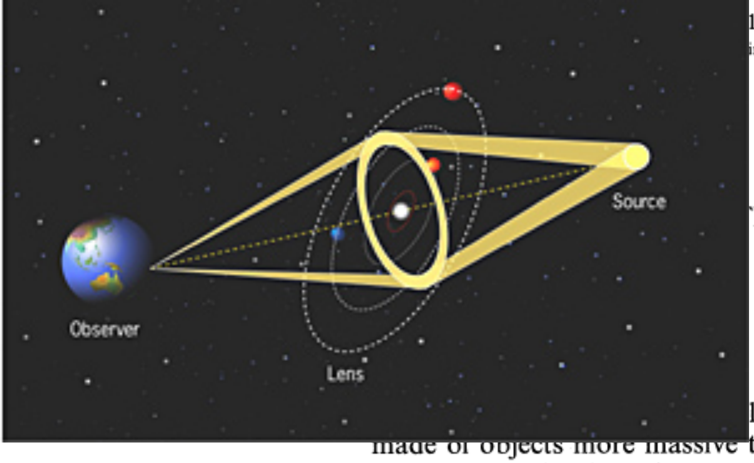

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inted in U.S.A.

IONAL MICROLENSING BY THE GALACTIC HALO

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Princeton University Observatory

Received 1985 August 1; accepted 1985 October 23

ABSTRACT

laxy has an optical depth to gravitational microlensing $\tau \approx 10^{-6}$. If the halo is made of objects more massive than $\sim 10^{-8}\ M_{\odot}$, then any star in a nearby galaxy has a probability of 10^{-6} to be strongly microlensed at any time. The lensing events last ~2 hr if a typical "dark halo" object has a mass of $10^{-6}\ M_{\odot}$, and they last ~2 yr for objects of 100 $M_{\odot}$. Monitoring the brightness of a few million stars in

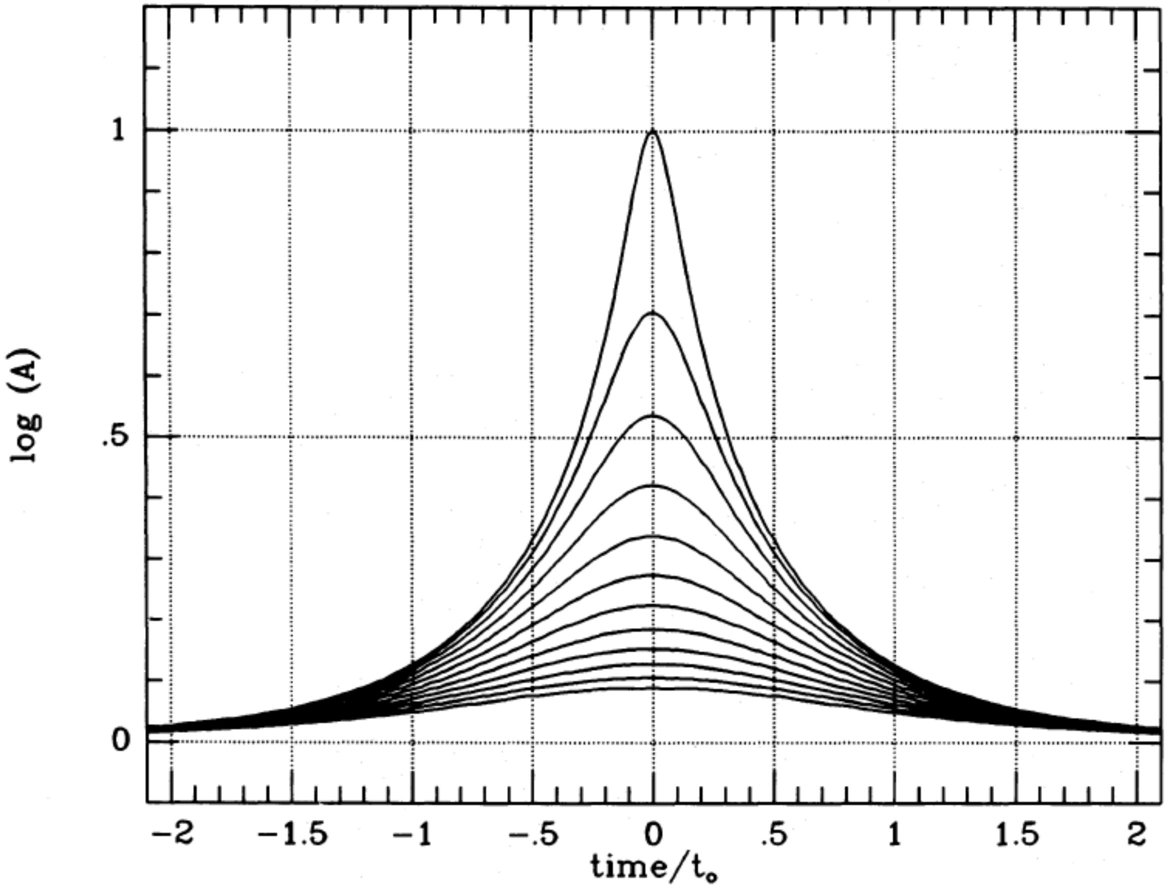
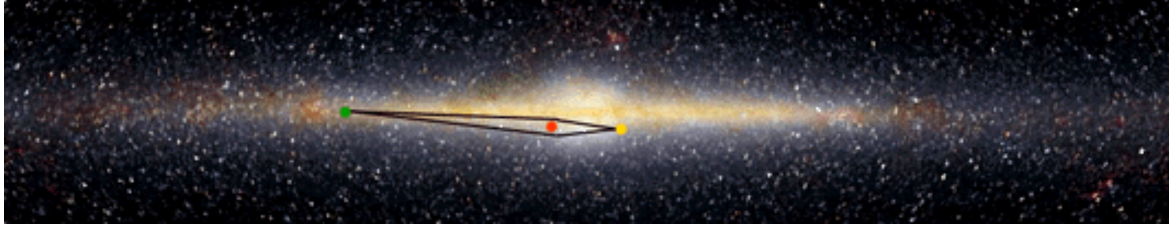


FIG. 2.—Time variation of the amplification due to gravitational microlensing for events with the impact parameter d/R_0 equal 0.1, 0.2, …, 1.1, 1.2. The largest amplitude corresponds to the smallest impact parameter. The unit of time is given as $t_0 \equiv R_0/v$, where R_0 is the radius of ringlike image formed when the source, the lensing mass, and the observer are perfectly aligned (see eq. [2] and [16]) and v is the relative tangential velocity of the lensing object.

THE ASTROPHYSICAL JOURNAL, 372:L79–L82, 1991 May 10



GRAVITATIONAL MICROLENSING AS A METHOD OF DETECTING DISK DARK MATTER AND FAINT DISK STARS

KIM GRIEST,[1] CHARLES ALCOCK,[2] TIMOTHY S. AXELROD,[2] DAVID P. BENNETT,[2] KEM H. COOK,[2] KENNETH C. FREEMAN,[3]
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AND CHRISTOPHER W. STUBBS[1] (The MACHO Collaboration)
Received 1990 December 6; accepted 1991 February 18

ABSTRACT

Gravitational microlensing of stars in the Galactic bulge is proposed as a method of probing the mass density of disk objects in the 10^{-3} to 10^{-1} $M_\odot$ range. A substantial rate is found if disk dark matter of this form exists, and even without any dark matter, a significant microlensing rate is found, owing to the faint low-mass disk stars which are known to exist. Such a search would provide new information on the disk dark matter question, probe the low-end stellar mass function, and also search for halo dark matter, all with rates comparable to those expected for the ongoing LMC microlensing halo dark matter searches.

Subject headings: dark matter — gravitational lenses — stars: low-mass

The amount of mass in the disk of our Galaxy is quite uncertain. The mass in stars is estimated from star counts and is uncertain because much of the mass is contained in low-mass stars which are intrinsically faint (Scalo 1986). The total local disk mass is estimated by measuring the disk gravitational potential using tracer stars, but again no consensus on the total amount of disk matter has been reached (Oort 1960; Bahcall 1984; Kuijken & Gilmore 1989). A related unresolved question is whether the mass in stars, dust, and gas is sufficient to explain the total disk mass or whether a substantial amount of disk dark matter must exist.

Gravitational microlensing has been suggested as a method of detecting dark extragalactic objects using quasars as sources (Gott 1981; Canizares 1982), and of detecting halo dark matter using Large Magellanic Cloud (LMC) stars as sources (Paczyński 1986). As a dark object moves close to the source-observer line of sight, it acts as a gravitational lens, causing two unresolved images to form and resulting in an overall magnification of the image. While the probability per source is much larger for the extragalactic microlensing, “local” microlensing has the advantage of being applicable to lenses in our Galaxy and avoiding the uncertain and variable nature of quasar luminosities. Paczyński showed that repeated observation of $\sim 10^6$ stars in the LMC should allow detection of the halo dark

that the rate of microlensing due to a canonical density and distribution of halo dark matter is as large for bulge star sources as for LMC sources (owing to the velocities of bulge stars). We find that the rate of microlensing due to disk dark matter (if it exists at the claimed densities) can be substantially higher than this. We also find that even in the complete absence of any dark matter, a substantial microlensing rate exists because of the faint disk stars. Observation of lensing by ordinary stars would be interesting, since it would test the microlensing technique, and the rate and duration of microlensing events would provide direct information on the density of low-mass stars in the disk. The present-day mass function (PDMF) would be probed especially at the low-mass end, where the uncertainties are great, and even in the 0.001–0.07 $M_\odot$ range, where almost no information now exists. This determination of the low-end PDMF and/or measurement of the amount of DDM would take place over an average of the entire Galactic disk, not just in the local solar neighborhood, as is now the case. If the observed microlensing rate is consistent with that predicted by local PDMF determinations, strong constraints could be placed on the density of disk (and halo) dark matter in these mass ranges.

In this *Letter*, we first briefly review the local gravitational microlensing basics and derive results for a simplified model of

THE ASTROPHYSICAL JOURNAL, 500:37–50, 1998 June 10

THE USE OF HIGH-MAGNIFICATION MICROLENSING EVENTS IN DISCOVERING EXTRASOLAR PLANETS

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Received 1997 October 30; accepted 1998 January 16

ABSTRACT

Hundreds of gravitational microlensing events have now been detected toward the Galactic bulge, with many more to come. The detection of fine structure in these events has been theorized as an excellent way to discover extrasolar planetary systems along the line of sight to the Galactic center. We show that by focusing on high-magnification events, the probability of detecting planets of Jupiter mass or greater in the lensing zone [$(0.6–1.6)R_E$] is nearly 100%, with the probability remaining high down to Saturn masses and substantial even at 10 Earth masses. This high probability allows a nearly definitive statement to be made about the existence of lensing-zone planets in each such system that undergoes high magnification. One might expect light-curve deviations caused by the source passing near the small primary-lens caustic to be small because of the large distance of the perturbing planet, but this effect is overcome by the high magnification. High-magnification events are relatively rare (e.g., $\sim 1/20$ of events have peak magnifications greater than 20), but they occur regularly, and the peak can be predicted in advance, allowing extrasolar planet detection with a relatively small use of resources over a relatively small amount of time.

Subject headings: gravitational lensing — planetary systems

1. INTRODUCTION

Microlensing has become a useful tool in astronomy for discovering and characterizing populations of objects too faint to be seen by conventional methods. By repeatedly monitoring millions of stars, several groups have now detected the rare brightenings that occur when a dark object passes between the Earth and a distant source star (Alcock et al. 1993; Aubourg et al. 1993; Udalski et al. 1993; Alard et al. 1995). These detections have now become routine, with hundreds of events reported toward the Galactic bulge, mostly by the MACHO collaboration (Alcock et al. 1996, 1997a). The reliable detection of large numbers of such lensing events allows one to use them for several auxiliary purposes. For example, relatively rare microlensing "fine-structure" events, where deviations from the simple brightening formula (Paczyński 1986; Griest 1991) are apparent, can be searched for. These have allowed several new effects to be observed, such as parallax motion (Gould 1992, 1994b; Alcock et al. 1995), the finite size and proper motion of the source star (Alcock et al.

planet last only a few hours or days (depending on the mass of the planet) and can occur at any time during the much longer (~ 40 days) primary lensing event. In order not to miss these short excursions, round-the-clock monitoring would be required, implying dedicated telescopes at several locations. In return, dozens to hundreds of planetary detections could be made, more than by any other proposed detection method. Thus, microlensing may be the best way to gather statistics on the frequency, mass distribution, and semimajor axis distribution of planets. Microlensing is also sensitive to planetary systems throughout the Galaxy and not just in the solar neighborhood, as are most other planet search techniques. The main disadvantage to microlensing is that further study of individual systems is probably impossible.

Following the early work, contributions have been made by several other groups. Bolatto & Falco (1994) calculated detection probabilities; Bennett & Rhie (1996) and Wambsganss (1997) extended to Earth-mass planets by including the finite source effect; Gaudi & Gould (1997)

Search for Gravitational Microlenses

First Generation of Large Scale Surveys

MACHO Project – Mt. Stromlo, Australia (1992 – 1999)

EROS Project – ESO, Chile (1992 – 2002)

OGLE Project – Las Campanas, Chile (1992 – …)

MOA Project – Mt. Johns, New Zealand (1997– …)

Discovery of the First Microlensing Events – September 1993

nature

INTERNATIONAL WEEKLY JOURNAL OF SCIENCE

Volume 365 No. 6447 14 October 1993 £3.00

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A strong upper crust

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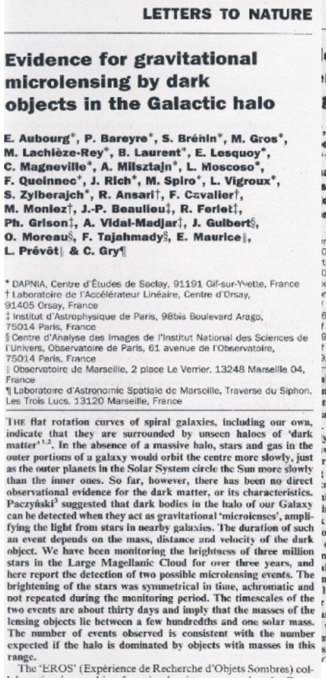

LETTERS TO NATURE

Evidence for gravitational microlensing by dark objects in the Galactic halo

E. Aubourg*, P. Bareyre*, S. Bréhin*, M. Gros*, M. Lachièze-Rey*, B. Laurent*, E. Lesquoy*, C. Magneville*, A. Milsztajn*, L. Moscoso*, F. Queinnec*, J. Rich*, M. Spiro*, L. Vigroux*, S. Zylberajch*, R. Ansari†, F. Cavalier†, M. Moniez†, J.-P. Beaulieu‡, R. Ferlet‡, Ph. Grison‡, A. Vidal-Madjar‡, J. Guibert§, O. Moreau§, F. Tajahmady§, E. Maurice‖, L. Prévôt‖ & C. Gry¶

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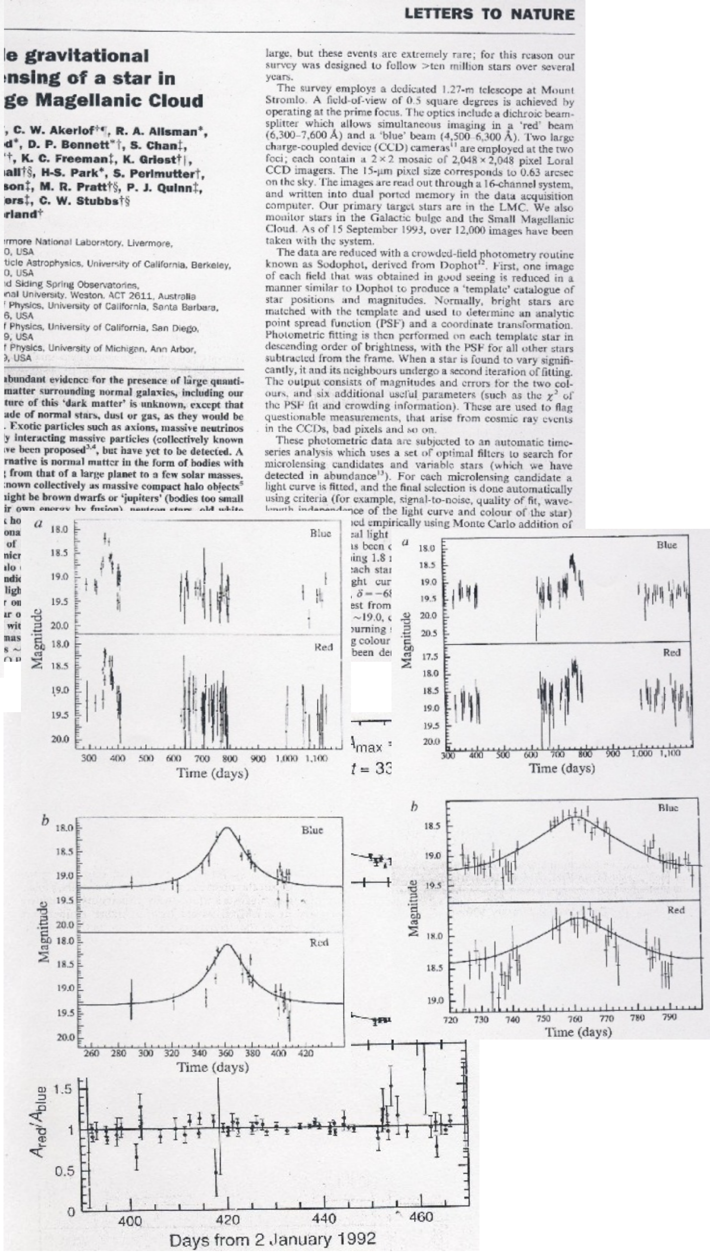
THE flat rotation curves of spiral galaxies, including our own, indicate that they are surrounded by unseen haloes of 'dark matter'[1,2]. In the absence of a massive halo, stars and gas in the outer portions of a galaxy would orbit the centre more slowly, just as the outer planets in the Solar System circle the Sun more slowly than the inner ones. So far, however, there has been no direct observational evidence for the dark matter, or its characteristics. Paczyński[3] suggested that dark bodies in the halo of our Galaxy can be detected when they act as gravitational 'microlenses', amplifying the light from stars in nearby galaxies. The duration of such an event depends on the mass, distance and velocity of the dark object. We have been monitoring the brightness of three million stars in the Large Magellanic Cloud for over three years, and here report the detection of two possible microlensing events. The brightening of the stars was symmetrical in time, achromatic and not repeated during the monitoring period. The timescales of the two events are about thirty days and imply that the masses of the lensing objects lie between a few hundredths and one solar mass. The number of events observed is consistent with the number expected if the halo is dominated by objects with masses in this range.

The 'EROS' (Expérience de Recherche d'Objets Sombres) col-



LETTERS TO NATURE

le gravitational ensing of a star in ge Magellanic Cloud

, C. W. Akerlof†¶, R. A. Allsman*,
d*, D. P. Bennett*†, S. Chan‡,
†, K. C. Freeman‡, K. Griest†‖,
all†§, H-S. Park*, S. Perlmutter†,
son‡, M. R. Pratt†§, P. J. Quinn‡,
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Physics, University of Michigan, Ann Arbor,
9, USA

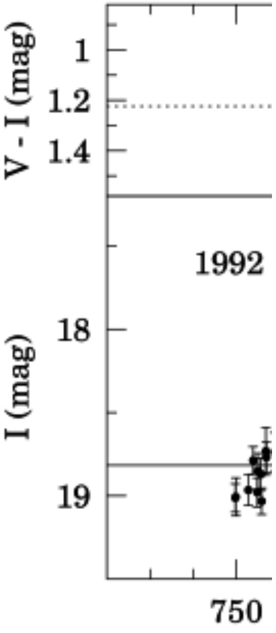
abundant evidence for the presence of large quanti-
matter surrounding normal galaxies, including our
ture of this 'dark matter' is unknown, except that
ade of normal stars, dust or gas, as they would be
. Exotic particles such as axions, massive neutrinos
y interacting massive particles (collectively known
ve been proposed[3,4], but have yet to be detected. A
rnative is normal matter in the form of bodies with
from that of a large planet to a few solar masses.
nown collectively as massive compact halo objects[5]
ight be brown dwarfs or 'jupiters' (bodies too small

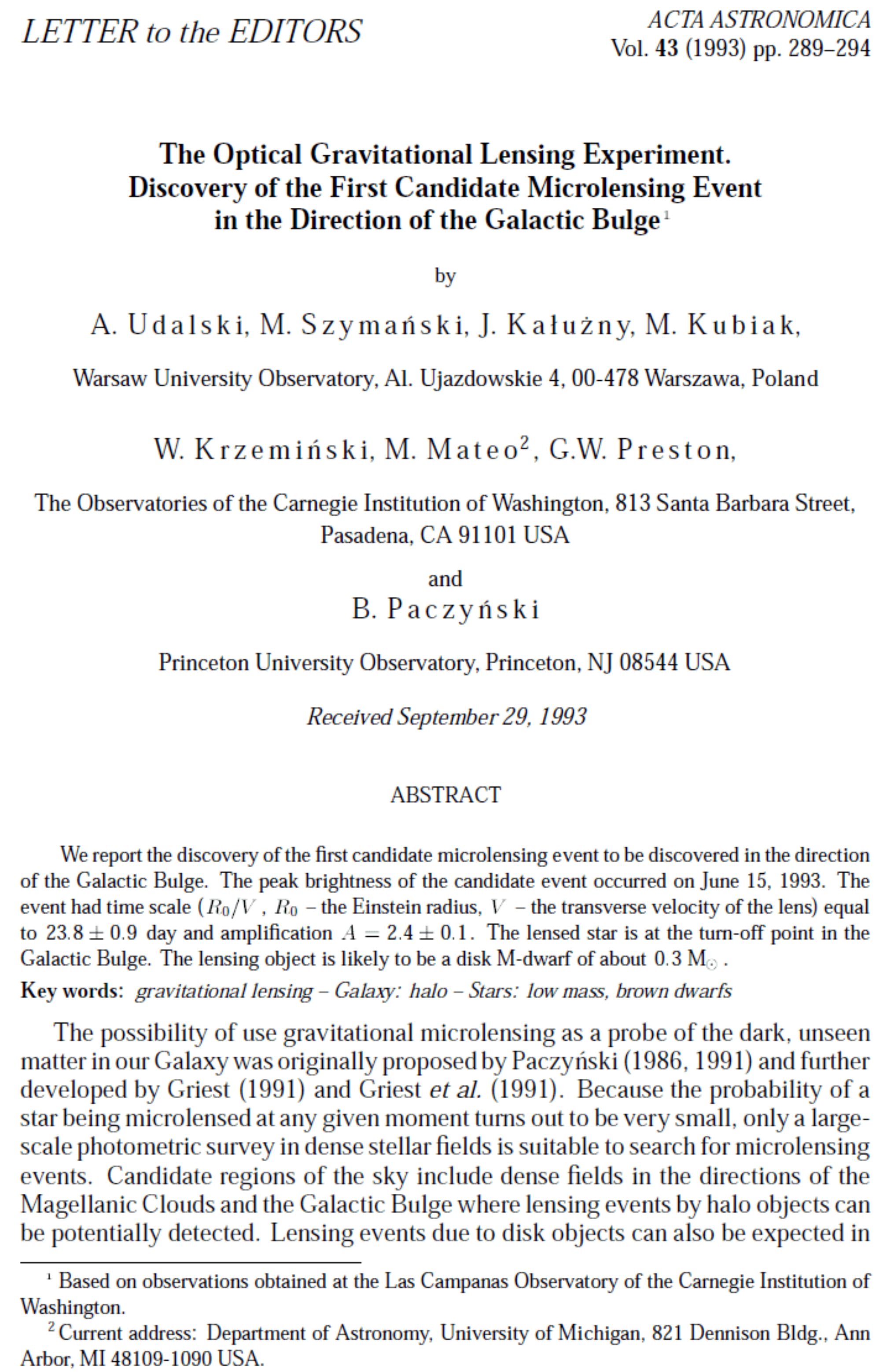
large, but these events are extremely rare; for this reason our survey was designed to follow >ten million stars over several years.

The survey employs a dedicated 1.27-m telescope at Mount Stromlo. A field-of-view of 0.5 square degrees is achieved by operating at the prime focus. The optics include a dichroic beam-splitter which allows simultaneous imaging in a 'red' beam (6,300–7,600 Å) and a 'blue' beam (4,500–6,300 Å). Two large charge-coupled device (CCD) cameras[11] are employed at the two foci; each contain a 2×2 mosaic of 2,048×2,048 pixel Loral CCD imagers. The 15-μm pixel size corresponds to 0.63 arcsec on the sky. The images are read out through a 16-channel system, and written into dual ported memory in the data acquisition computer. Our primary target stars are in the LMC. We also monitor stars in the Galactic bulge and the Small Magellanic Cloud. As of 15 September 1993, over 12,000 images have been taken with the system.

The data are reduced with a crowded-field photometry routine known as Sodophot, derived from Dophot[12]. First, one image of each field that was obtained in good seeing is reduced in a manner similar to Dophot to produce a 'template' catalogue of star positions and magnitudes. Normally, bright stars are matched with the template and used to determine an analytic point spread function (PSF) and a coordinate transformation. Photometric fitting is then performed on each template star in descending order of brightness, with the PSF for all other stars subtracted from the frame. When a star is found to vary significantly, it and its neighbours undergo a second iteration of fitting. The output consists of magnitudes and errors for the two colours, and six additional useful parameters (such as the χ^2 of the PSF fit and crowding information). These are used to flag questionable measurements, that arise from cosmic ray events in the CCDs, bad pixels and so on.

These photometric data are subjected to an automatic time-series analysis which uses a set of optimal filters to search for microlensing candidates and variable stars (which we have detected in abundance[13]). For each microlensing candidate a light curve is fitted, and the final selection is done automatically using criteria (for example, signal-to-noise, quality of fit, wavelength independence of the light curve and colour of the star)
ied empirically using Monte Carlo addition of





LETTER to the EDITORS

ACTA ASTRONOMICA
Vol. **43** (1993) pp. 289–294

The Optical Gravitational Lensing Experiment. Discovery of the First Candidate Microlensing Event in the Direction of the Galactic Bulge[1]

by

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Received September 29, 1993

ABSTRACT

We report the discovery of the first candidate microlensing event to be discovered in the direction of the Galactic Bulge. The peak brightness of the candidate event occurred on June 15, 1993. The event had time scale (R_0/V, R_0 – the Einstein radius, V – the transverse velocity of the lens) equal to 23.8 ± 0.9 day and amplification $A = 2.4 \pm 0.1$. The lensed star is at the turn-off point in the Galactic Bulge. The lensing object is likely to be a disk M-dwarf of about $0.3\ \mathrm{M}_\odot$.

Key words: *gravitational lensing – Galaxy: halo – Stars: low mass, brown dwarfs*

The possibility of use gravitational microlensing as a probe of the dark, unseen matter in our Galaxy was originally proposed by Paczyński (1986, 1991) and further developed by Griest (1991) and Griest *et al.* (1991). Because the probability of a star being microlensed at any given moment turns out to be very small, only a large-scale photometric survey in dense stellar fields is suitable to search for microlensing events. Candidate regions of the sky include dense fields in the directions of the Magellanic Clouds and the Galactic Bulge where lensing events by halo objects can be potentially detected. Lensing events due to disk objects can also be expected in

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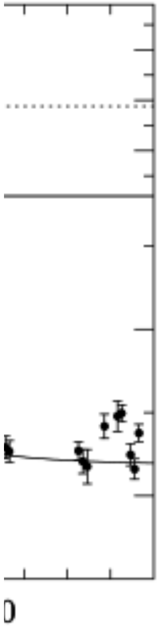

Microlense (1993).

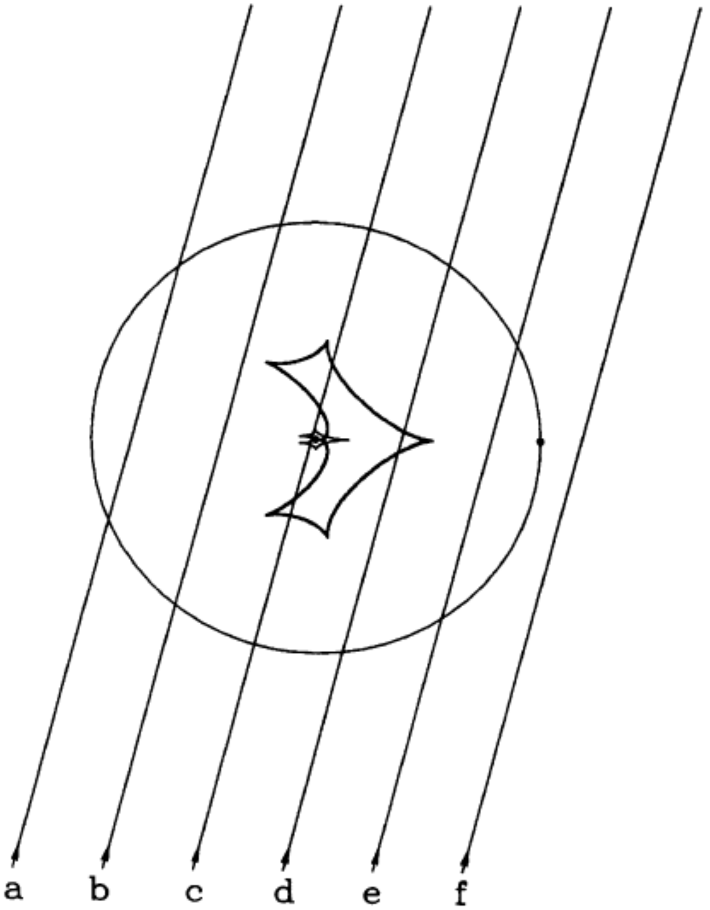

FIG. 1.—Geometry of microlensing by a binary, as seen in the sky. The primary star of 1 $M_\odot$ is located at the center of the figure, and the secondary of 0.1 $M_\odot$ or 0.001 $M_\odot$ is located on the right, on the Einstein ring of the primary. The radius of the ring is 1.0 mas for a source located at a distance of 8 kpc and the lens at 4 kpc. The two complicated shapes around the primary are the caustics: the larger and the smaller corresponding to the 0.1 $M_\odot$ and 0.001 $M_\odot$ companions, respectively. If a source is located outside these regions, then only three microimages are formed, while a source inside them forms five microimages. The parallel straight lines indicate the trajectories of sources for which the light variations are shown in Fig. 2.

that the secondary has a mass of only 0.001 of the primary, i.e., like that of Jupiter. They differ from the light curves corresponding to $q = 0.1$ in having a much shorter time interval during which the double nature of the lens is striking.

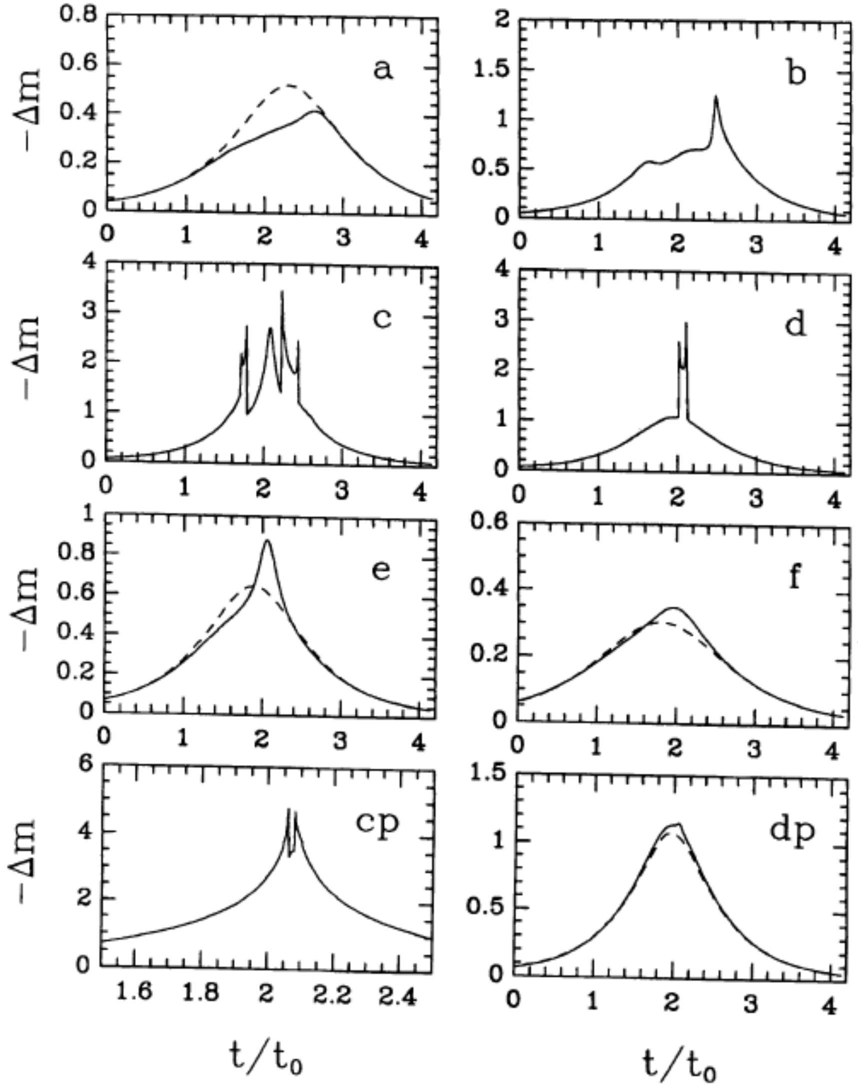

FIG. 2.—The light curves shown correspond to the six source trajectories in Fig. 1. The source is modeled as a uniform disk of radius $R_{\text{star}} = 10^{11}$ cm. The first six light curves, a–f, correspond to the case with a 0.1 $M_\odot$ companion; the last two, cp and dp, correspond to the case with a 0.001 $M_\odot$ companion. Notice very high spikes when a source crosses a caustic, or approaches a cusp, as in the light curves c, d, and cp. The low-amplitude light curves a, e, f, and dp, are shown together with the dashed light curves expected for single-mass microlenses matching the wings.

of the caustic region defined as

25 Years Perspective:
Three Main Scientific Contributions

Search for Dark Matter

Galactic Structure Studies

Extrasolar Planets – Planetary Microlensing

The Astrophysical Journal, 542:281–307, 2000 October 10

THE MACHO PROJECT: MICROLENSING RESULTS FROM 5.7 YEARS OF LARGE MAGELLANIC CLOUD OBSERVATIONS

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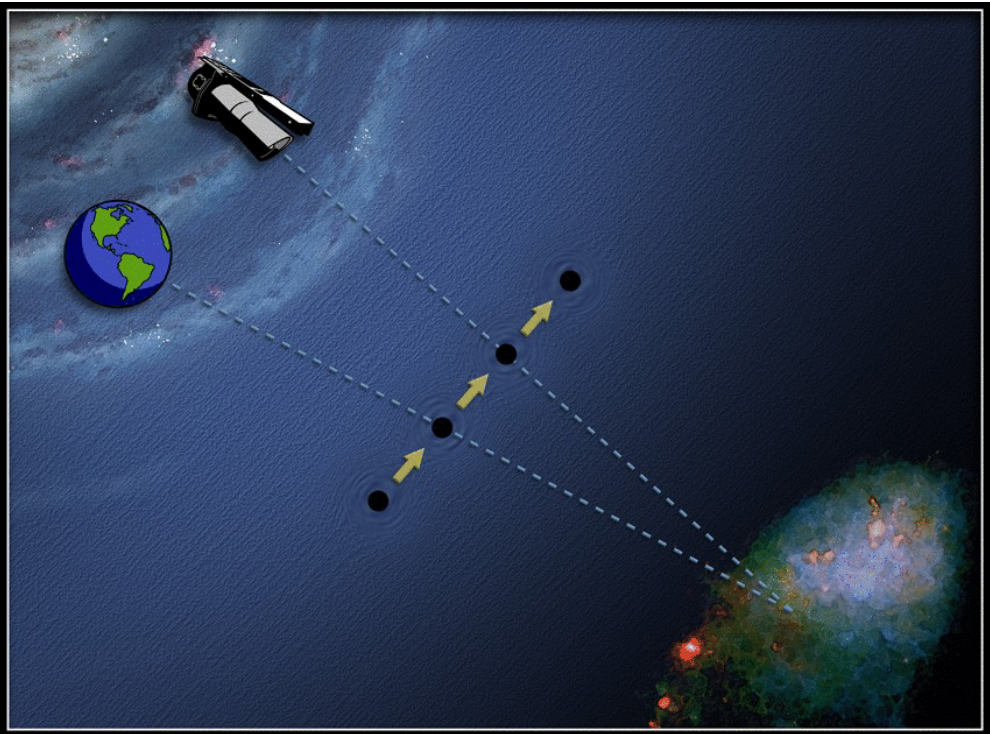

Microlens Parallax Observations of OGLE-2005-SMC-001 Spitzer Space Telescope • IRAC

NASA / JPL-Caltech / S. Dong (Ohio State University) ssc2007-XX

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supernova

Subject he ng —
stars: low-mass, brown dwarfs — white dwarfs

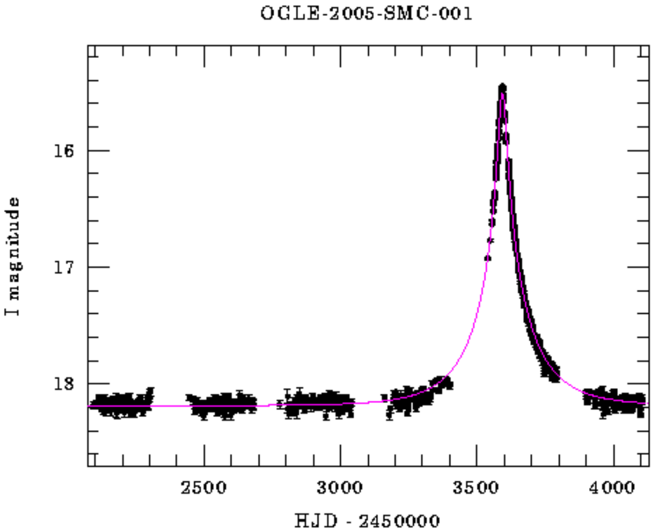
On-line material: Color figures

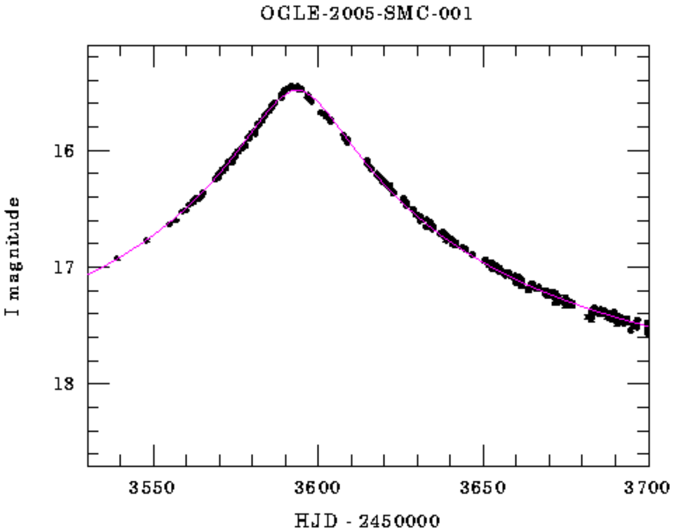
1. INTRODUCTION

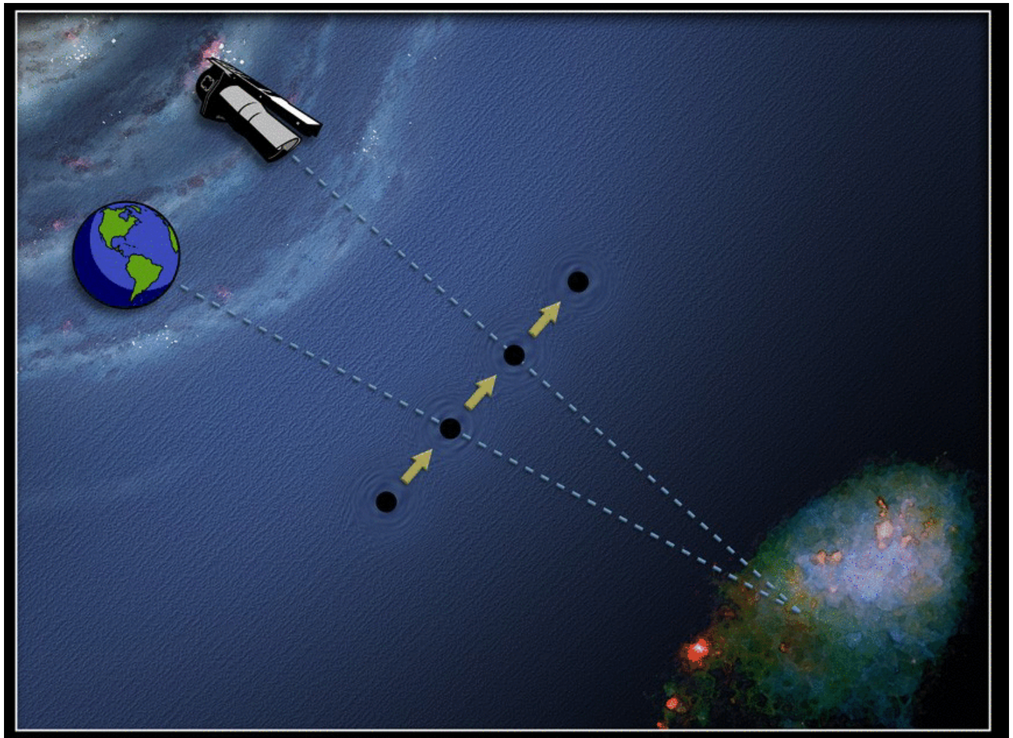
Following the suggestion of Paczyński (1986), several groups are now engaged in searches for dark matter in the form of massive compact halo objects (MACHOs) using gravitational microlensing, and many candidate microlensing events have been reported. Reviews of microlensing in this context are given by Paczyński (1996) and Roulet & Mollerach (1996).

Previously (Alcock et al. 1997a), we conducted an analysis of 2.1 yr of photometry of 8.5 million stars, and found 6–8 microlensing events, implying an optical depth toward the LMC of $2.9^{+1.4}_{-0.9} \times 10^{-7}$ for the 8 event sample and $2.1^{+1.1}_{-0.7} \times 10^{-7}$ for the 6 event sample (Alcock et al. 1996a, 1997a; hereafter A96 and A97, respectively). Interpreted as evidence for a MACHO contribution to the Milky Way dark halo, this implied a MACHO mass out to 50 kpc

OGLE-2005-SMC-001







Microlens Parallax Observations of OGLE-2005-SMC-001 Spitzer Space Telescope • IRAC

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Mon. Not. R. Astron. Soc. **416,** 2949–2961 (2011) doi:10.1111/j.1365-2966.2011.19243.x

The OGLE view of microlensing towards the Magellanic Clouds – IV. OGLE-III SMC data and final conclusions on MACHOs*

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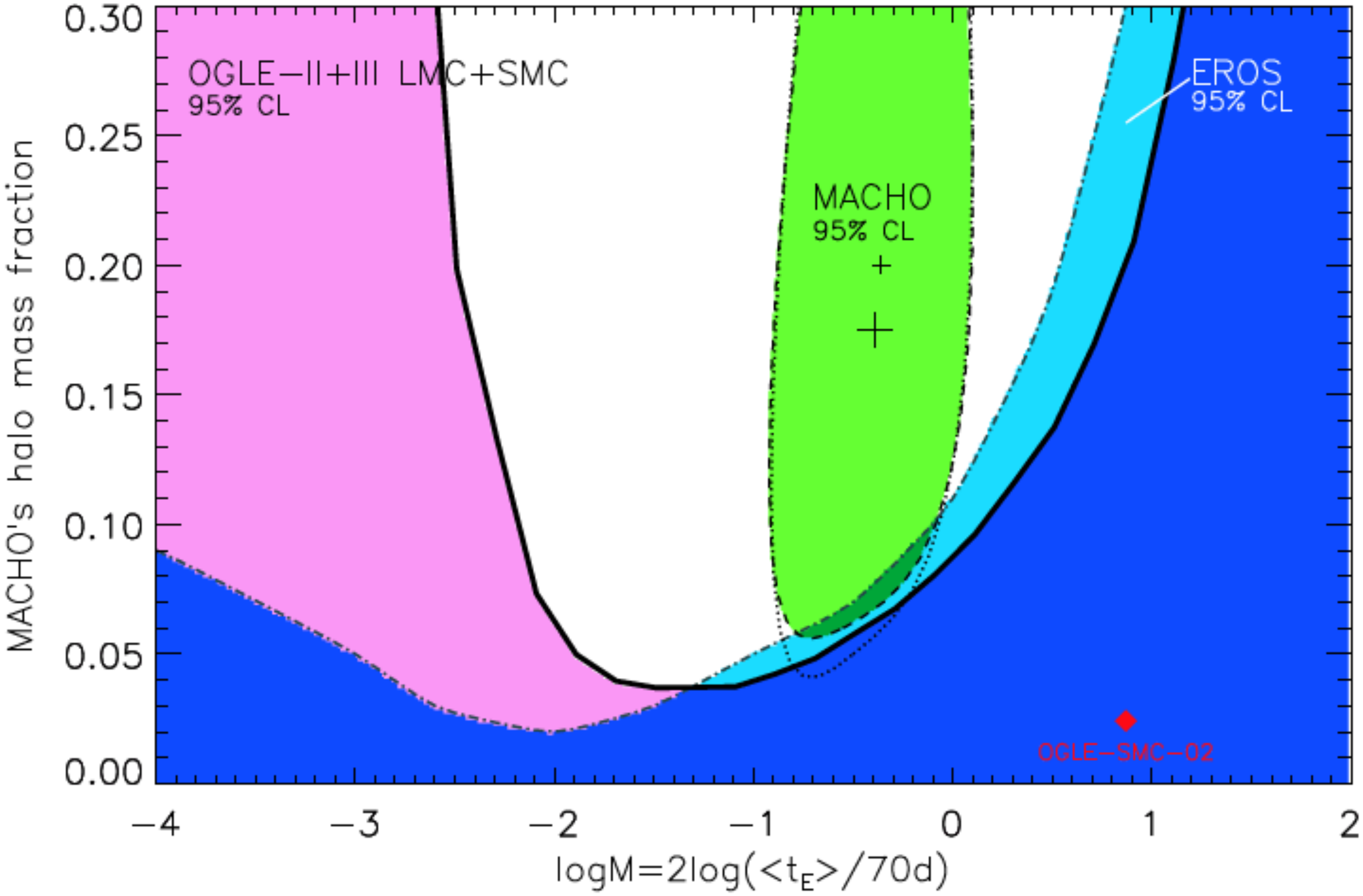


tometric surveys towards the Magellanic Clouds. The Large and Small Magellanic Clouds (LMC and SMC, respectively) were con-

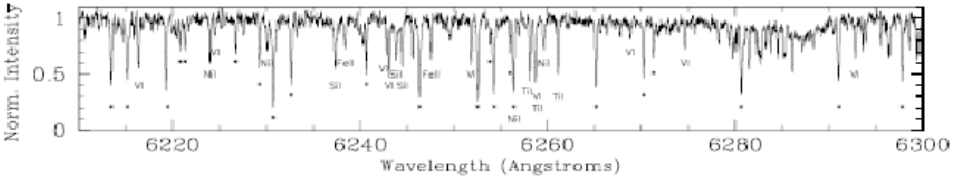
radius crossing time (event time-scale) and u_0 is the event impact

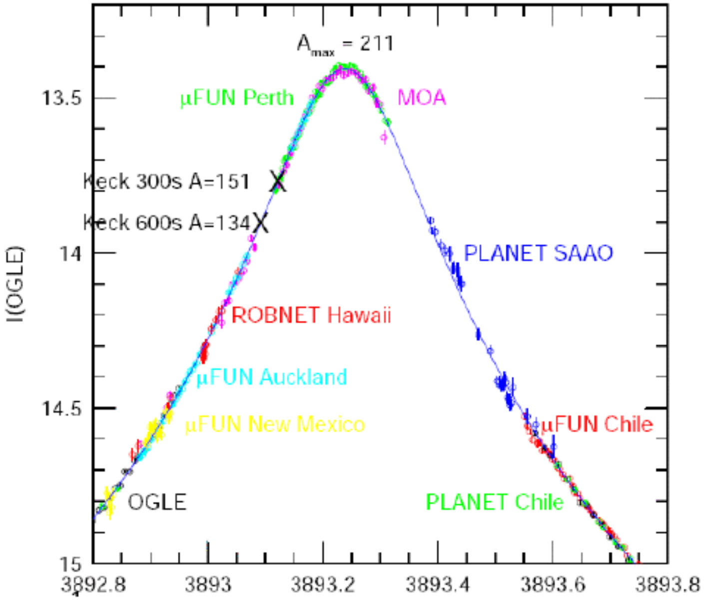
Galactic Structure

Optical depth for microlensing toward CG

High resolution spectroscopy of highly microlensed bulge dwarfs

Keck HIRES Spectroscopy of Bulge Dwarf OGLE-2006-BLG-265





OGLE-III Revolution: Detection of Microlenses by OGLE

OGLE-I (1992–1995) ~20 events

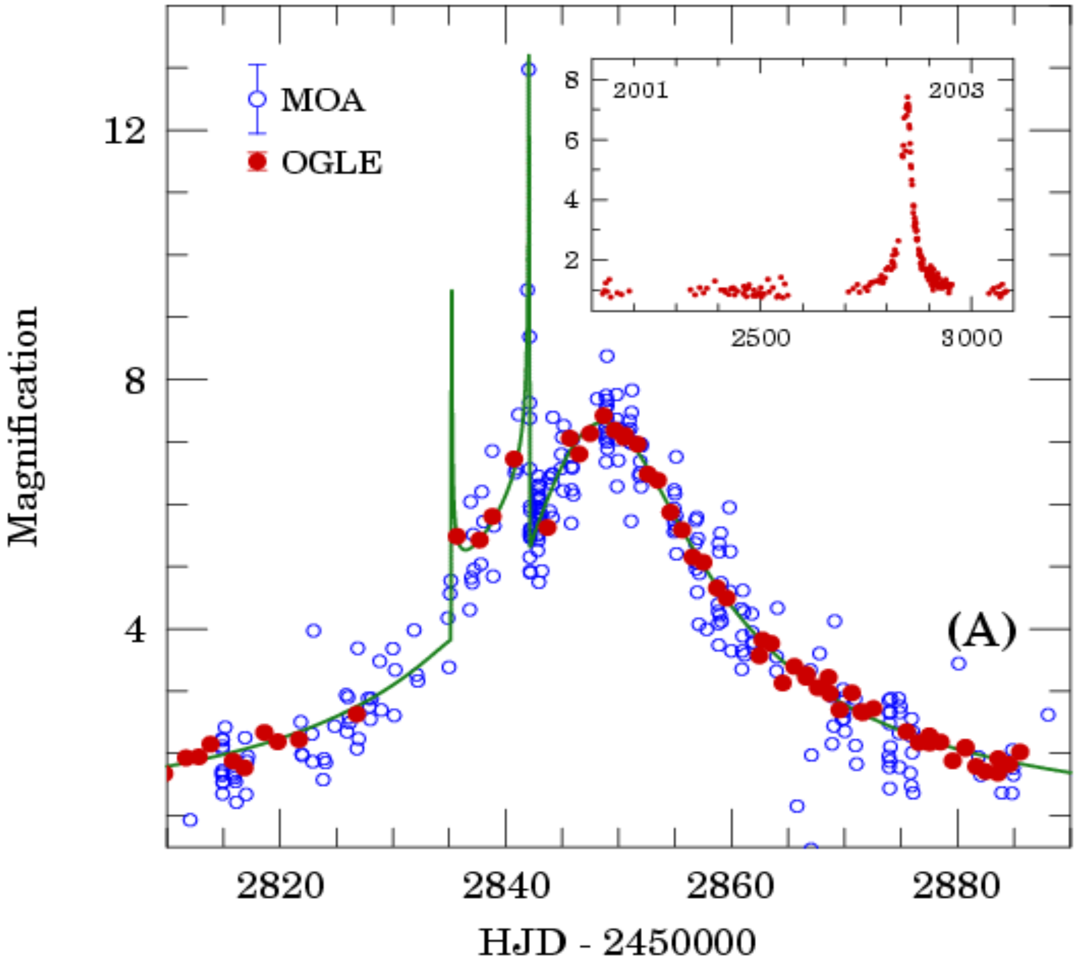
OGLE-II (1997–2000) ~500 events

OGLE-III (2001–2009) ~4000 events

OGLE-IV (2010– …) ~2000 events per season (~10 per night)

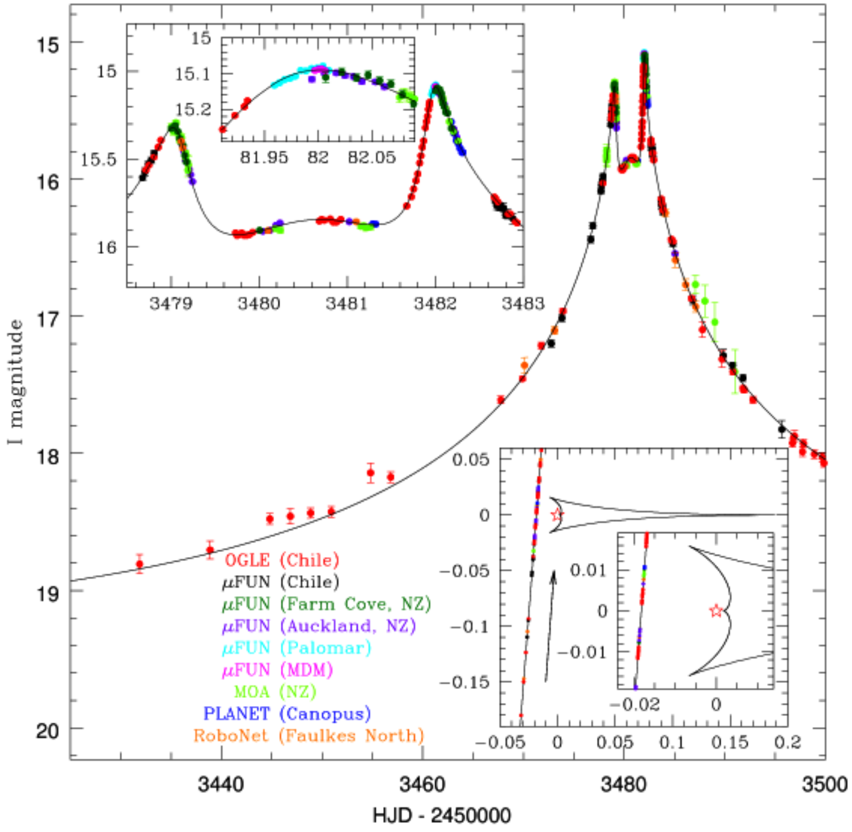
Since 1994 – real time detection – OGLE EWS system

OGLE-2003-BLG-235/MOA-2003-BLG-53
First Planetary Microlensing



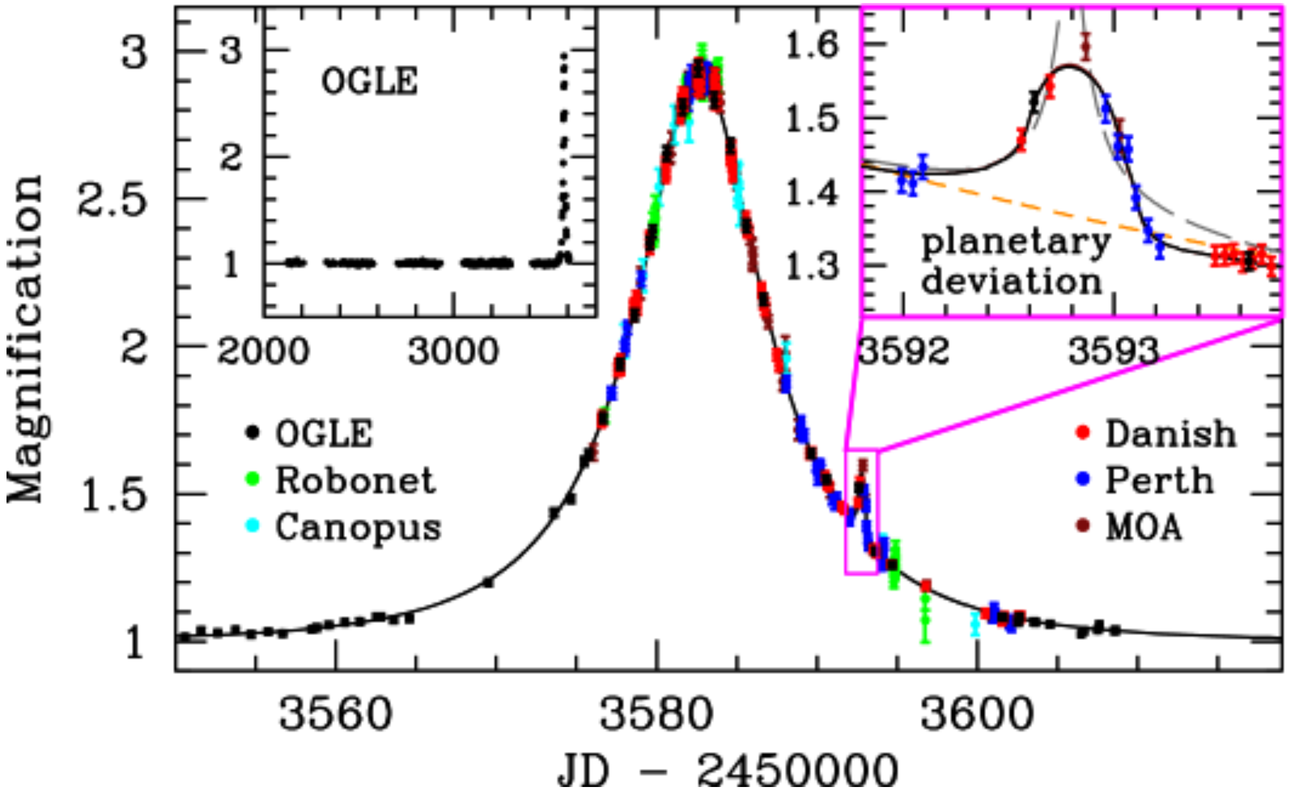
Planet/star mass ratio: q~0.004

OGLE-2005-BLG-71



Planet/star mass ratio: q~0.007

OGLE-2005-BLG-390



Planet/star mass ratio: q~0.00008. Mass of the planet: ~6 Earth masses. The least massive planet at the discovery

OGLE-IV: 2010 – ….

32 chip 256 Mpixel mosaic CCD camera (+ 2 chips for guiding)

2048 x 4102 pixel E2V 44-82 DD CCD detectors

(15 μm).

1.4 square degrees field (~7 Moon disks), scale – 0.26”/pixel

20 sec. reading time

First light September 7, 2009

Regular observations since March 4/5, 2010

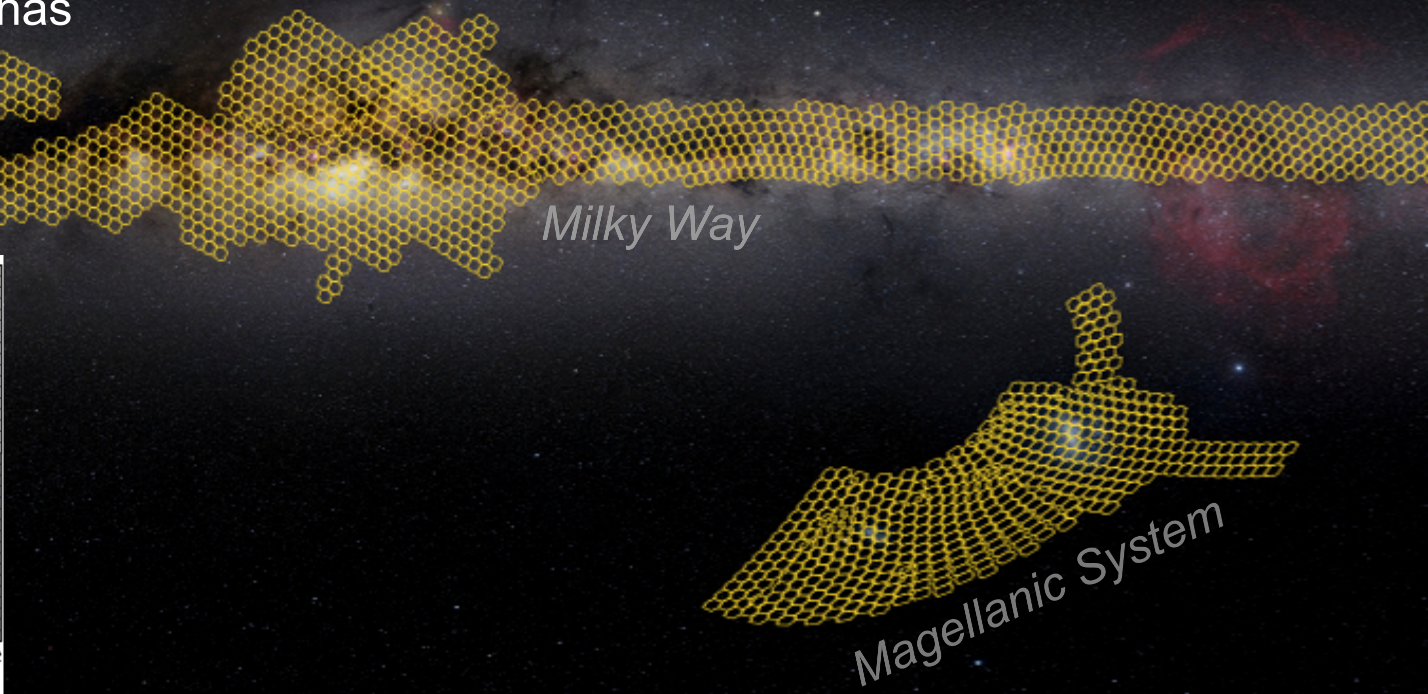
30-50 TB of raw data per year

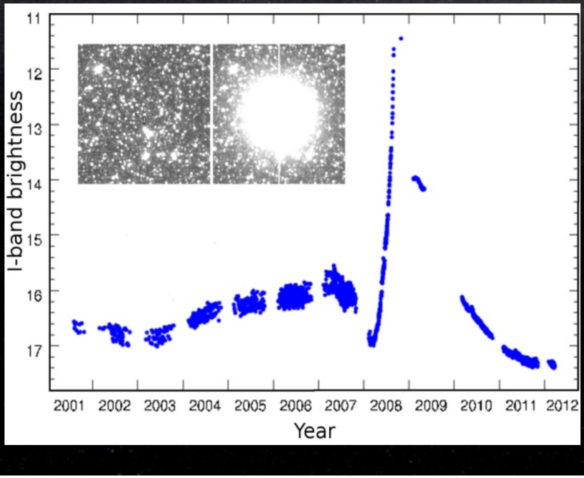
~3 mmag accuracy (DIA photometry since 2001)

OGLE – an Extremely Large Sky Variability Survey

- in operation since 1992
- since 2010 as OGLE-IV (Udalski *et al.* 2015)
- 3500 deg² sky coverage
- 1.3 billion sources monitored every night
- 10^{12} photometric measurements by 2016
- over 17,000 microlensing detections
- more than 70 extrasolar planets discovered
- ~1,000,000 new variable stars

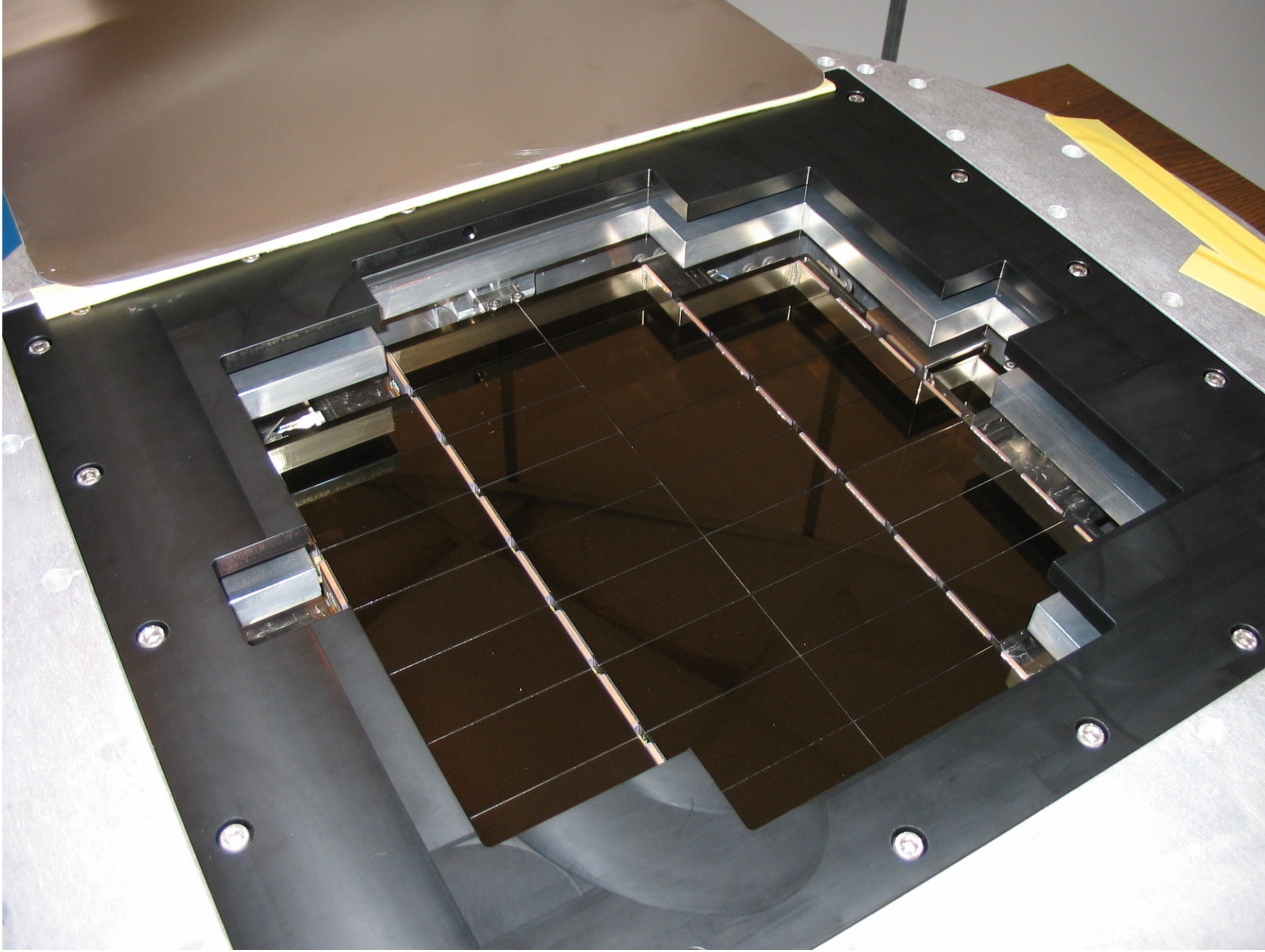
Warsaw 1.3-m @ Las Campanas



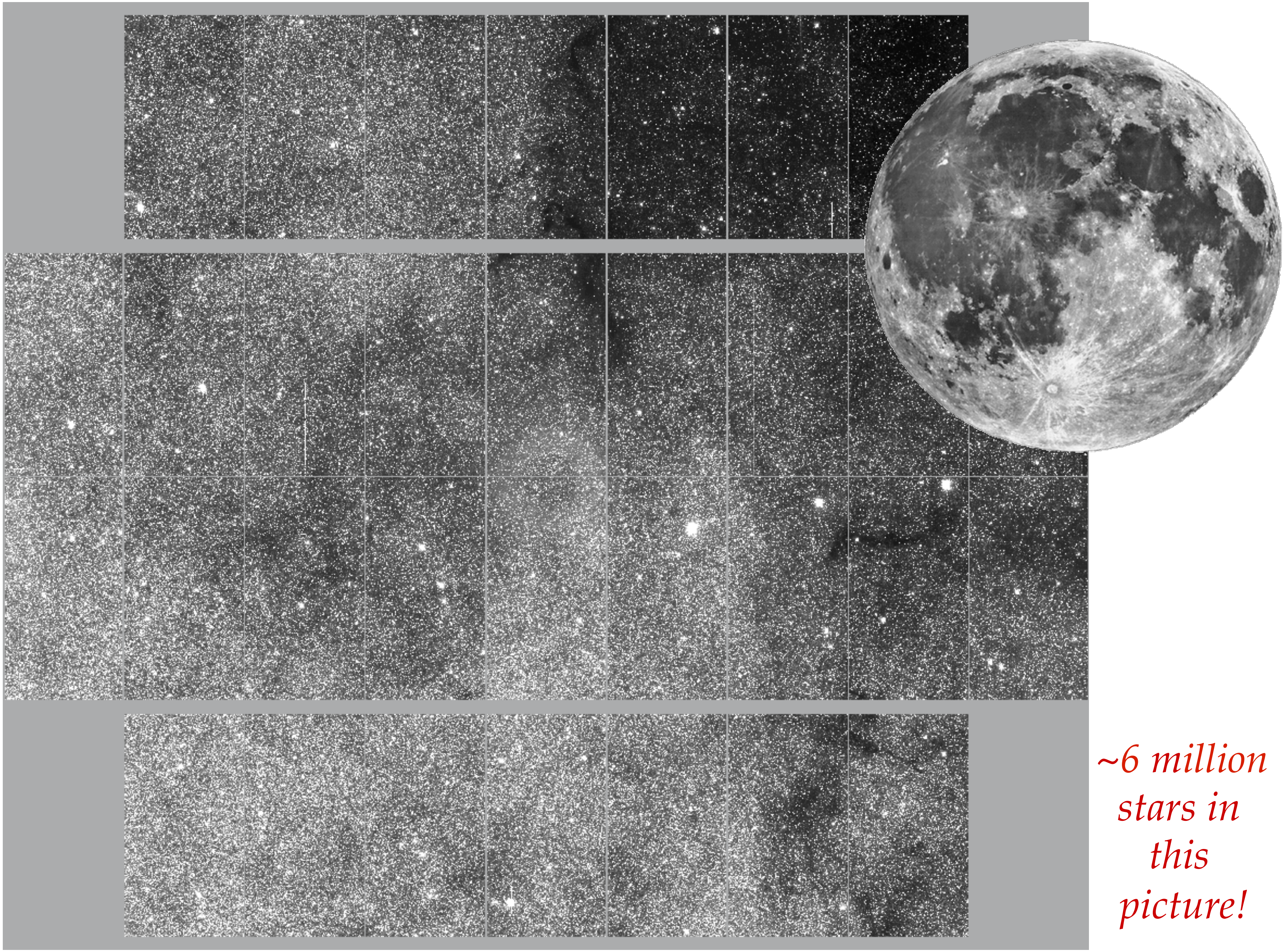


Las Campanas Observatory, Chile


1A
1B
REMOVE BEFORE OPERATION
REMOVE BEFORE OPERATION

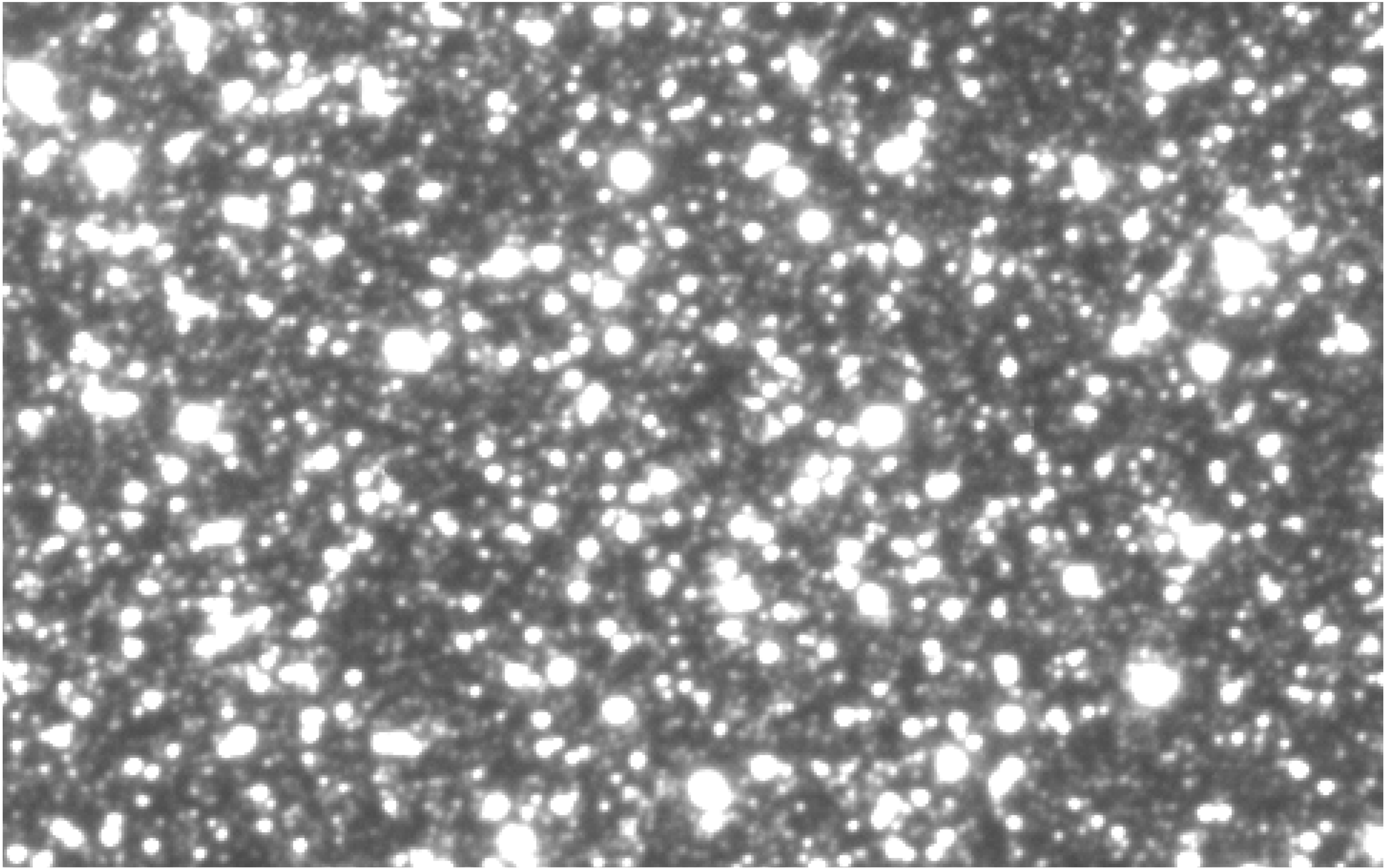


OGLE-IV SKY: 1.4 deg^2 FOV, I~21mag



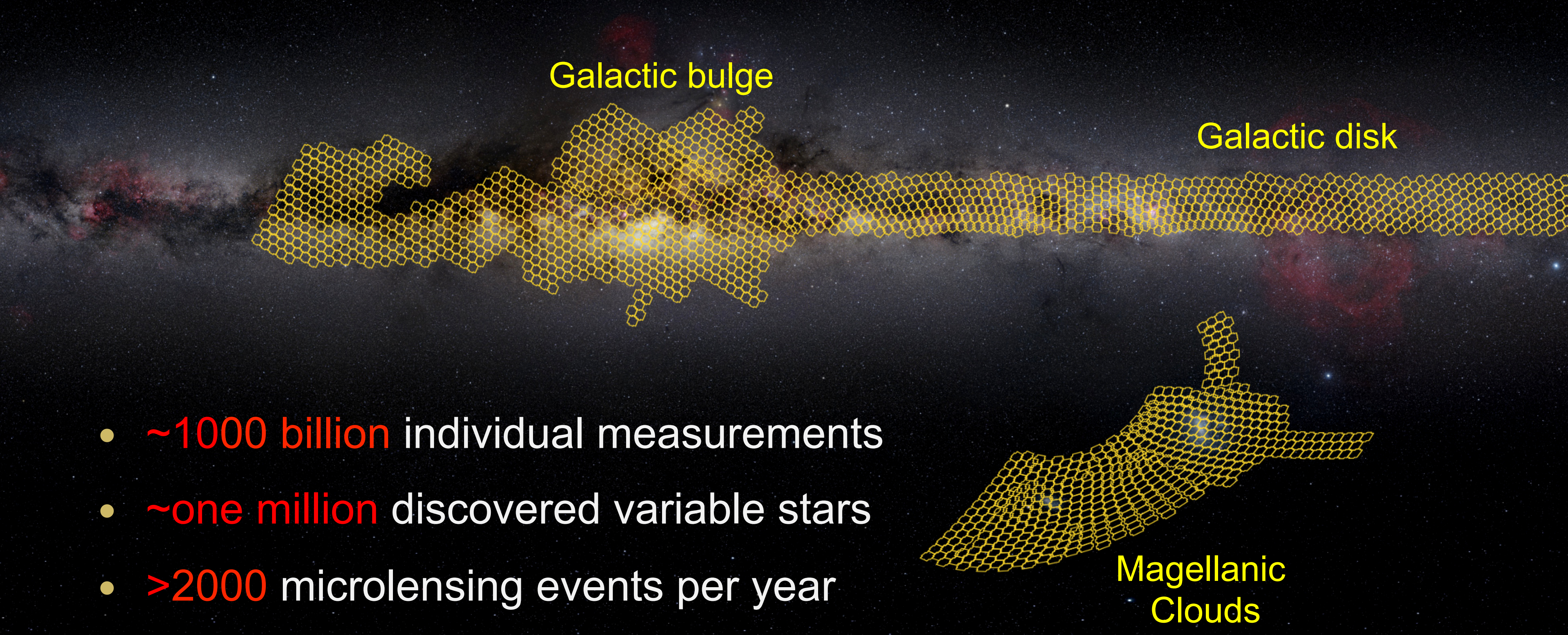
~6 million stars in this picture!

OGLE Targets



OGLE fields

- Sky coverage: ~3500 square degrees
- ~1,3 billion stars monitored



- ~1000 billion individual measurements
- ~one million discovered variable stars
- >2000 microlensing events per year
- ~70 extrasolar planets

OGLE-IV Microlensing Pointings

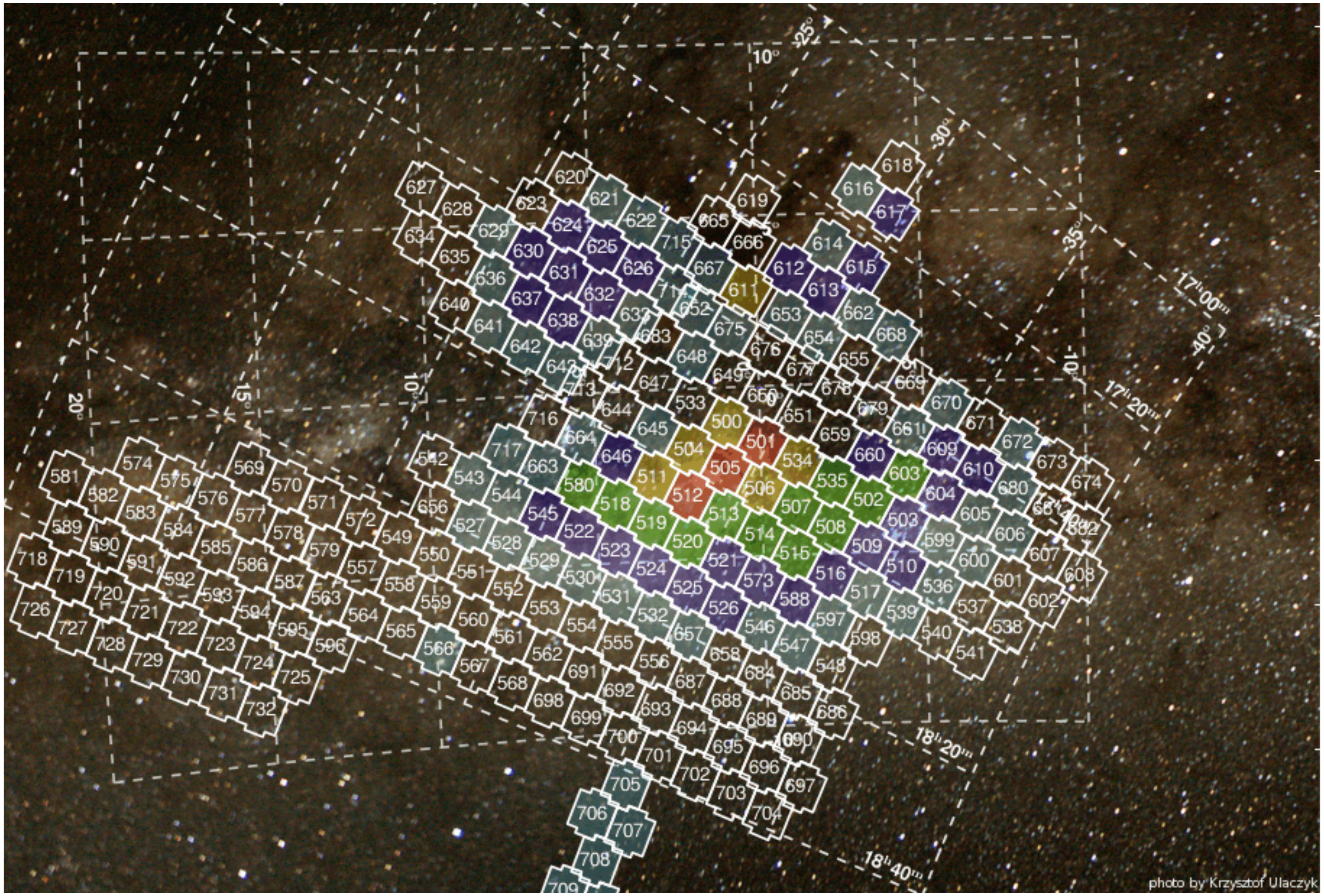


photo by Krzysztof Ulaczyk

Detection of Microlenses by OGLE

OGLE-I (1992–1995) ~20 events

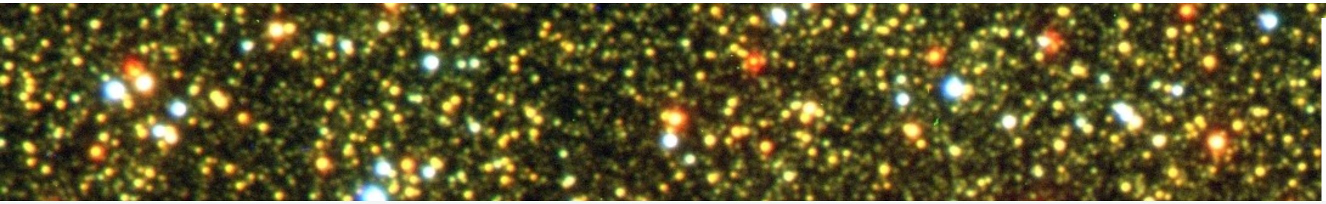
OGLE-II (1997–2000) ~500 events

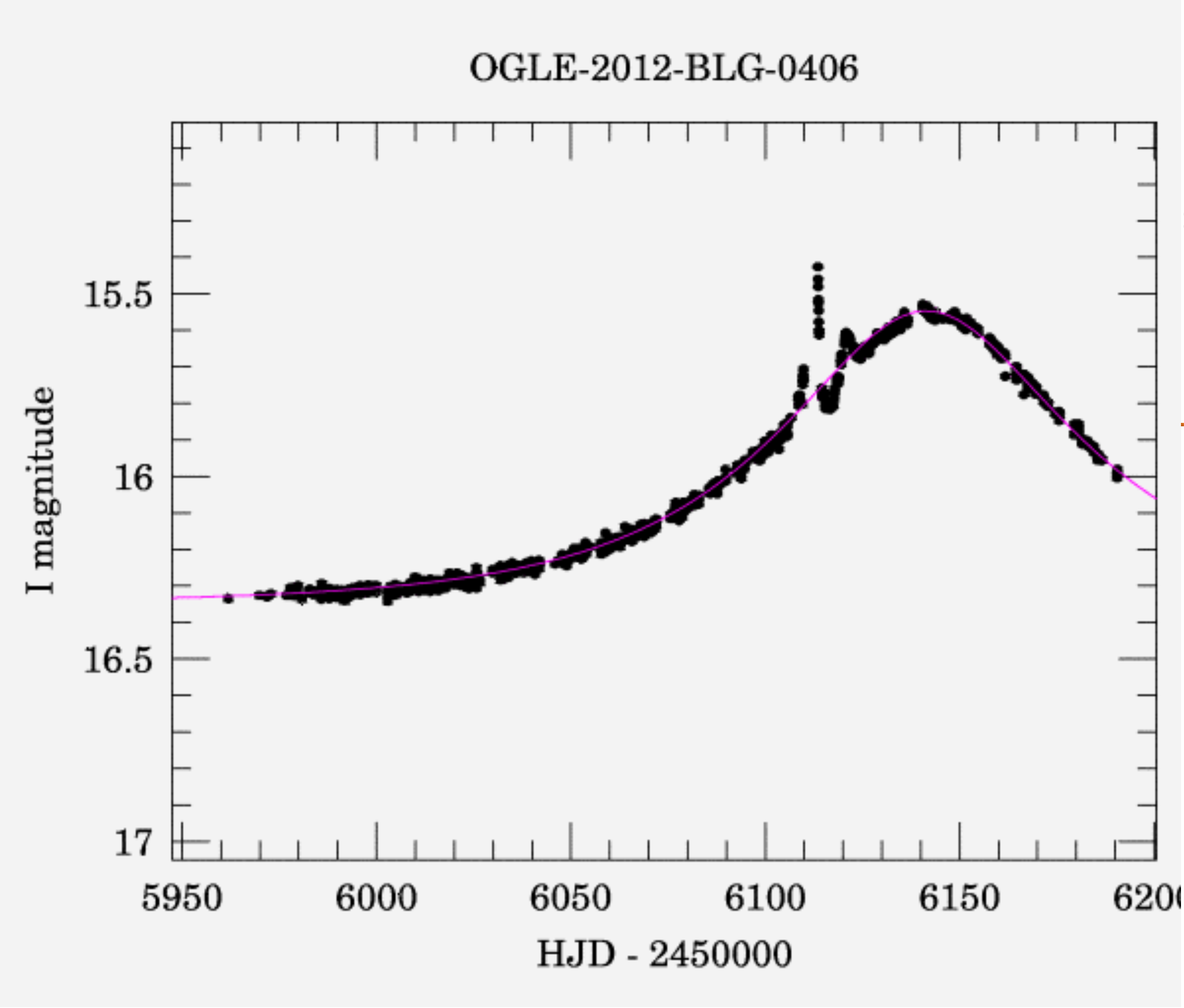
OGLE-III (2001–2009) ~4000 events

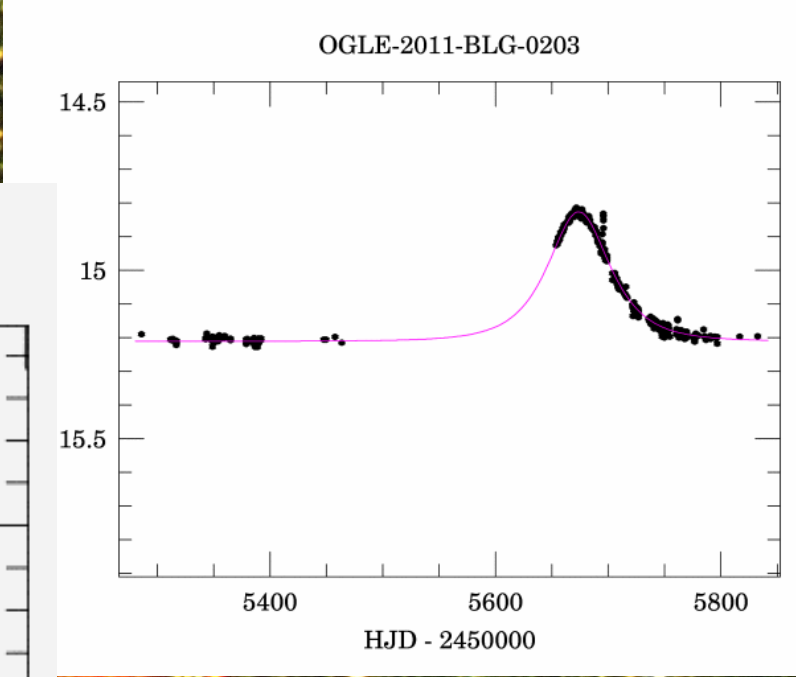
OGLE-IV (2010– …) ~2000 events per season (~10 per night)

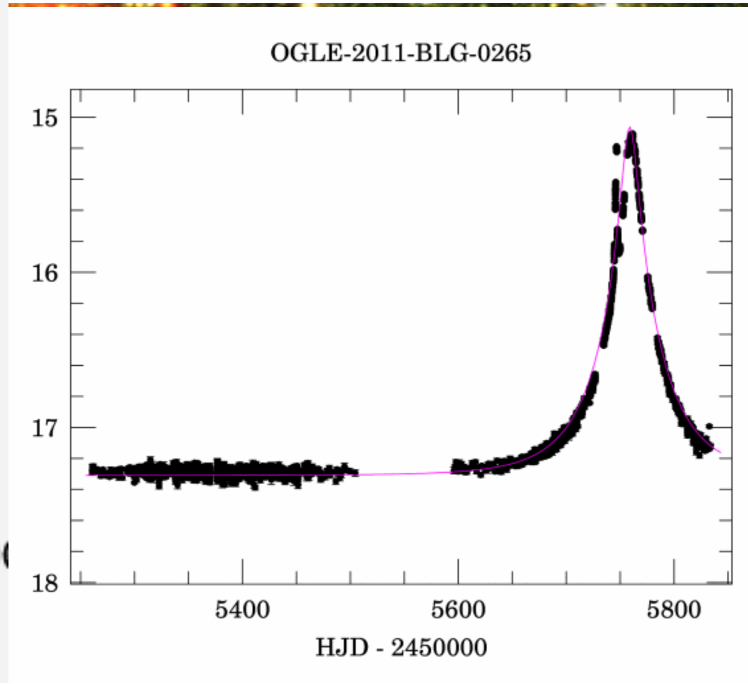
Since 1994 – real time detection – OGLE EWS system

Planetary Microlensing in Practice

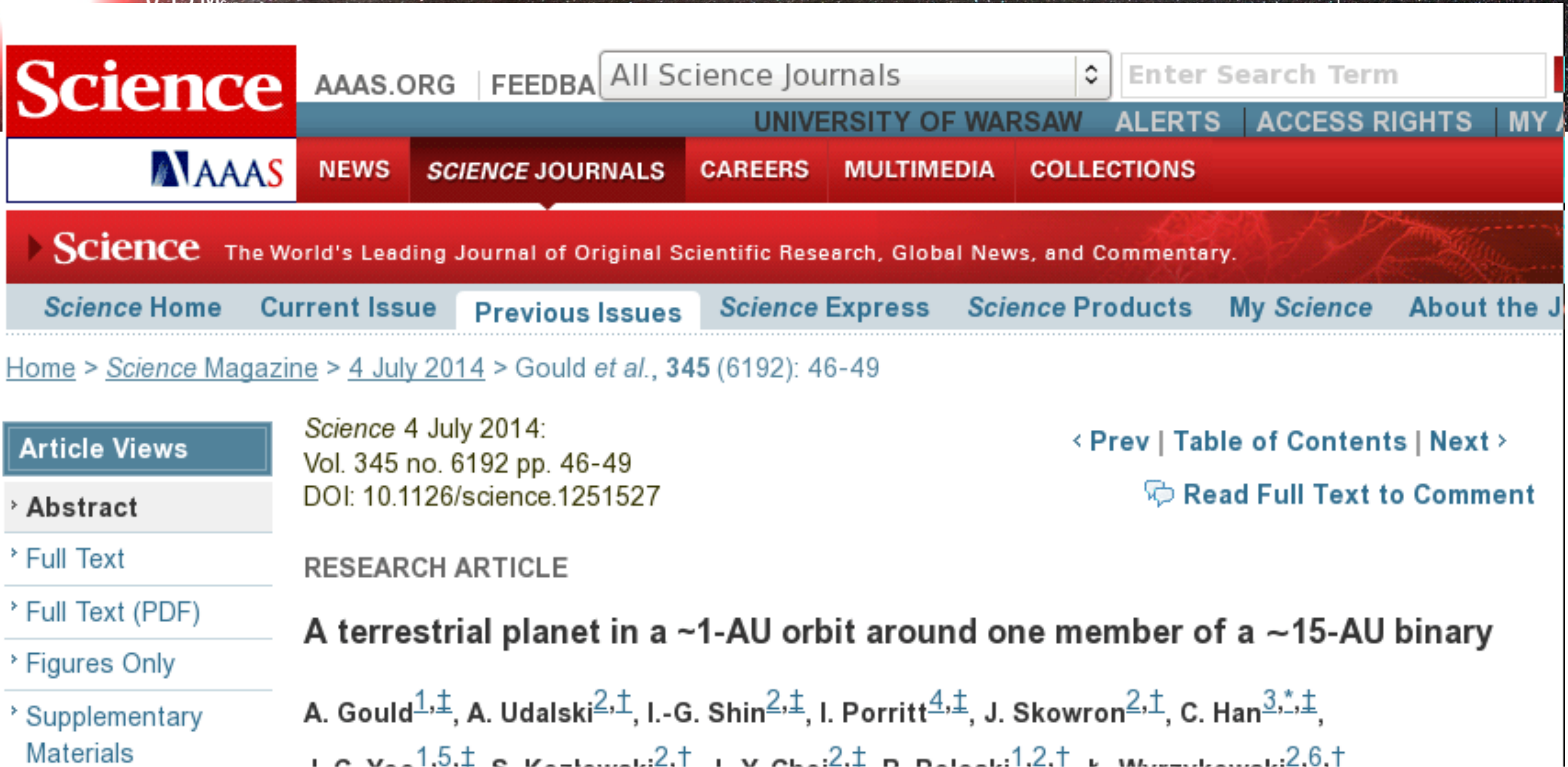








OGLE-2013-BLG-0341



Home > *Science* Magazine > 4 July 2014 > Gould *et al.*, **345** (6192): 46-49

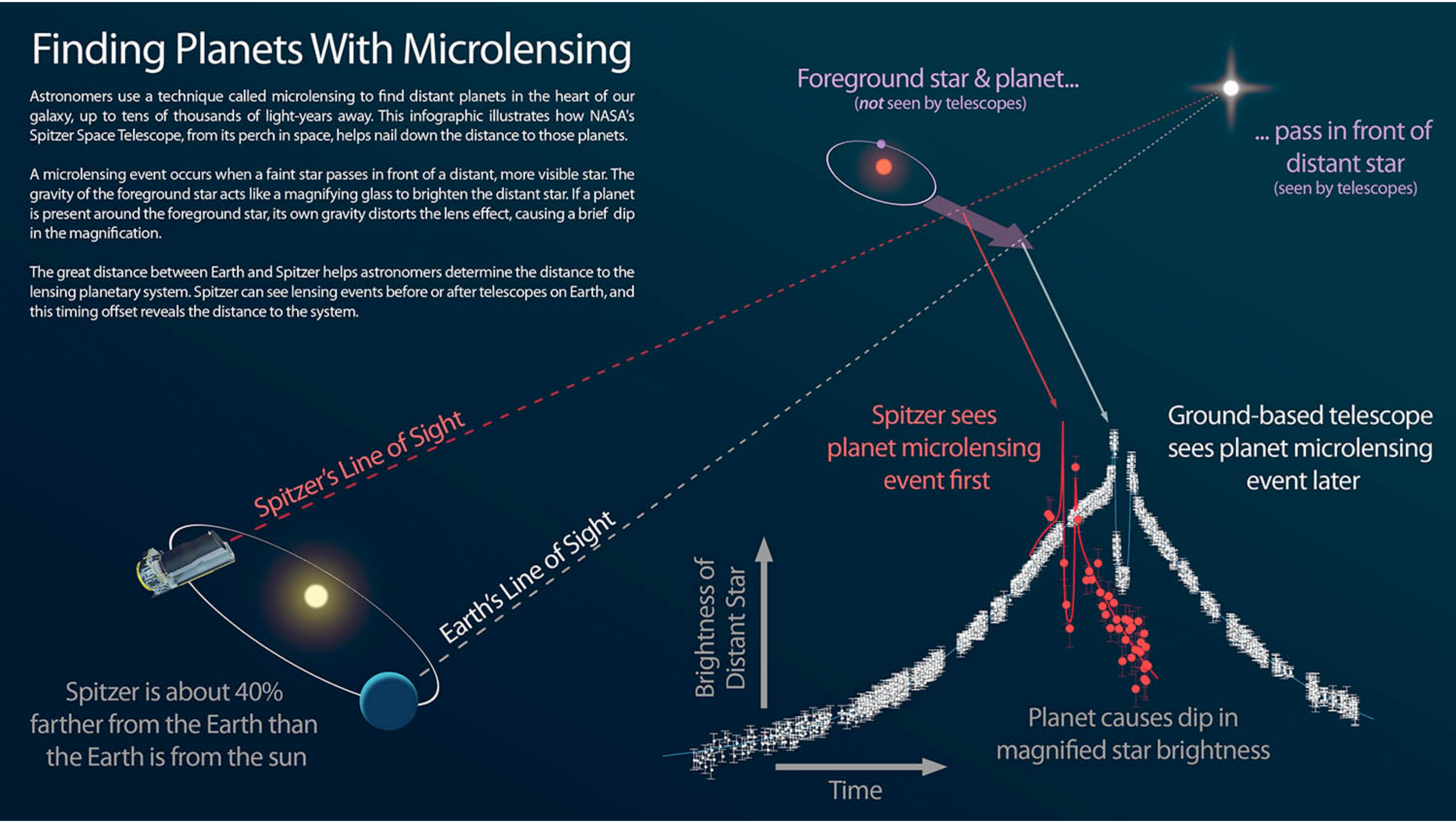
Science 4 July 2014:
Vol. 345 no. 6192 pp. 46-49
DOI: 10.1126/science.1251527

RESEARCH ARTICLE

A terrestrial planet in a ~1-AU orbit around one member of a ~15-AU binary

A. Gould[1,‡], A. Udalski[2,‡], I.-G. Shin[2,‡], I. Porritt[4,‡], J. Skowron[2,‡], C. Han[3,*,‡],

Space Microlensing



Finding Planets With Microlensing

Astronomers use a technique called microlensing to find distant planets in the heart of our galaxy, up to tens of thousands of light-years away. This infographic illustrates how NASA's Spitzer Space Telescope, from its perch in space, helps nail down the distance to those planets.

A microlensing event occurs when a faint star passes in front of a distant, more visible star. The gravity of the foreground star acts like a magnifying glass to brighten the distant star. If a planet is present around the foreground star, its own gravity distorts the lens effect, causing a brief dip in the magnification.

The great distance between Earth and Spitzer helps astronomers determine the distance to the lensing planetary system. Spitzer can see lensing events before or after telescopes on Earth, and this timing offset reveals the distance to the system.

Main Goals

The determination of the distribution of lens distances

Part of them planetary – distribution of planetary systems across the Galaxy

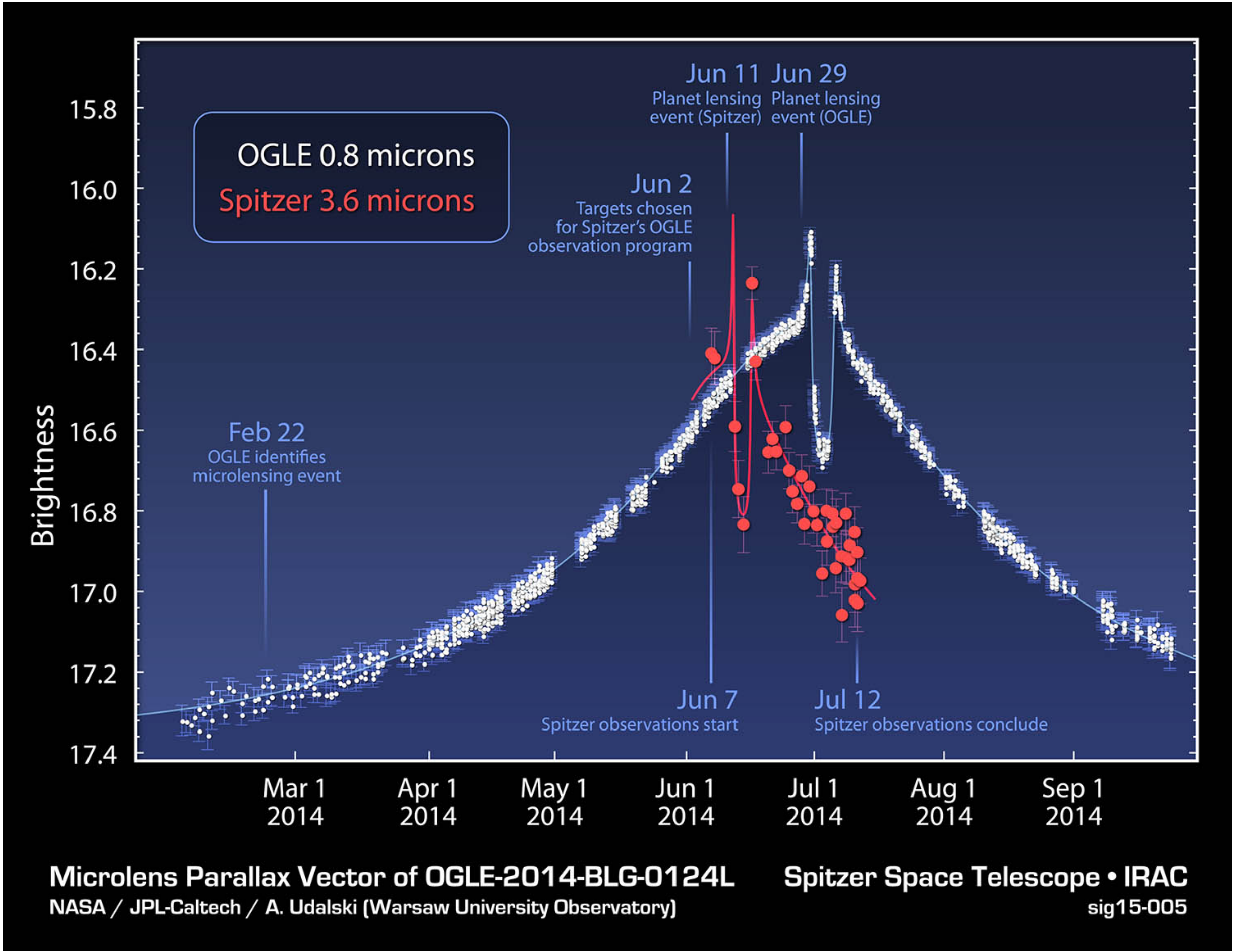
2014 Spitzer campaign – ~100 hours: pilot campaign

2015 Spitzer campaign – ~900 hours/40 days for microlensing!

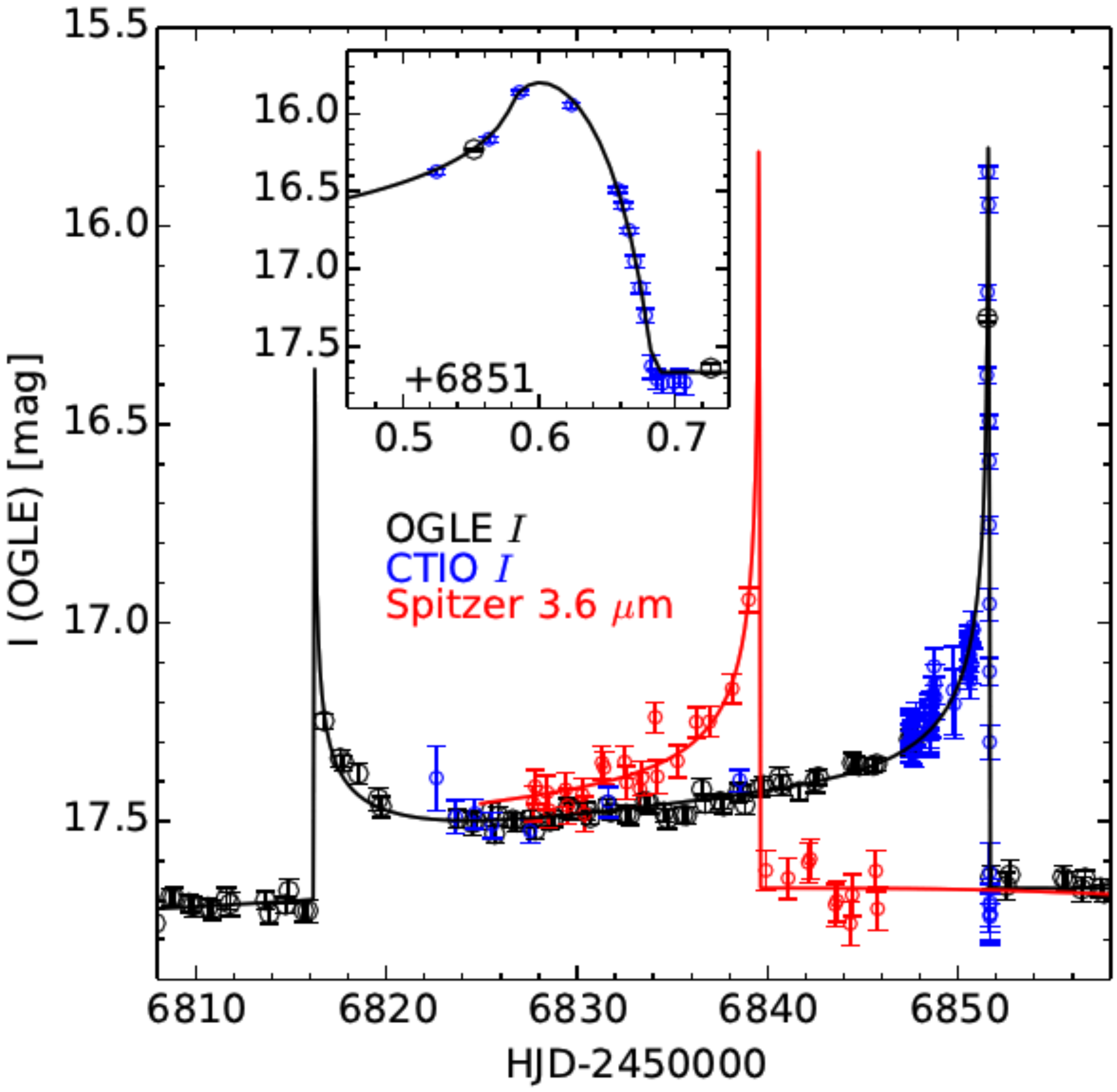
2016 Spitzer campaign – ~150 hours

2016 Kepler K2C9 pointing toward the Galactic bulge. ~3.7 square degrees monitored simultaneously with OGLE et al. Additional targets during K2C11

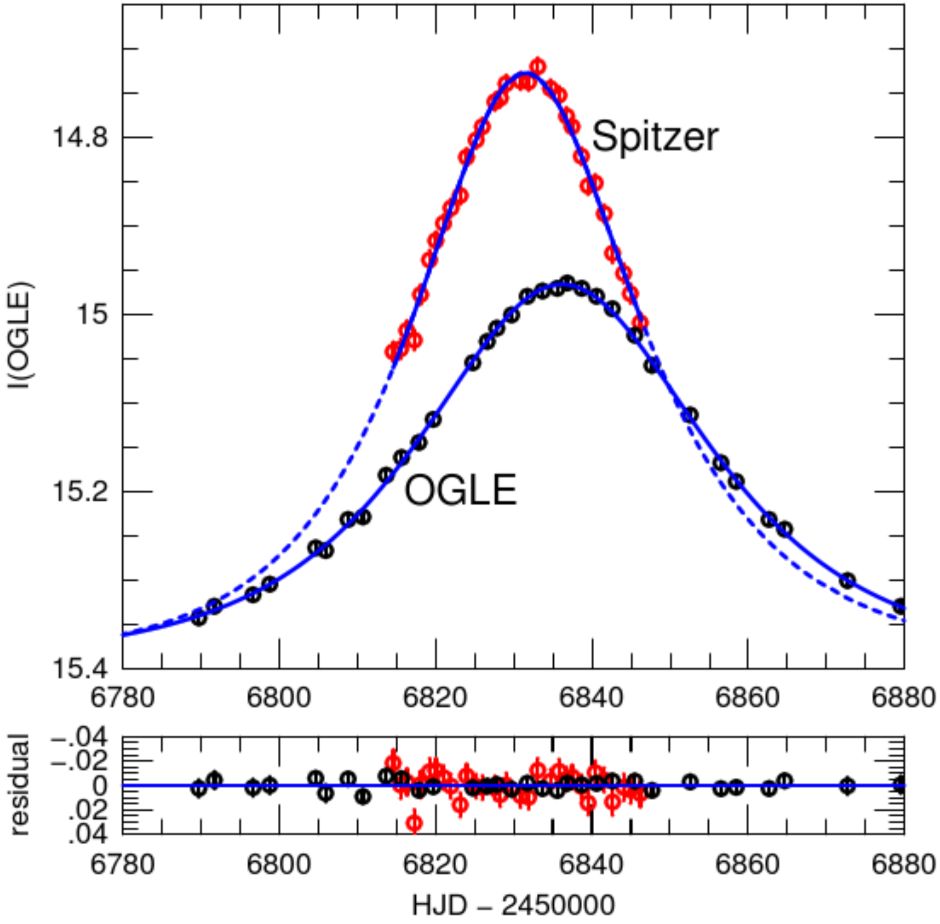
Space Microlensing



OGLE-2014-BLG-1050

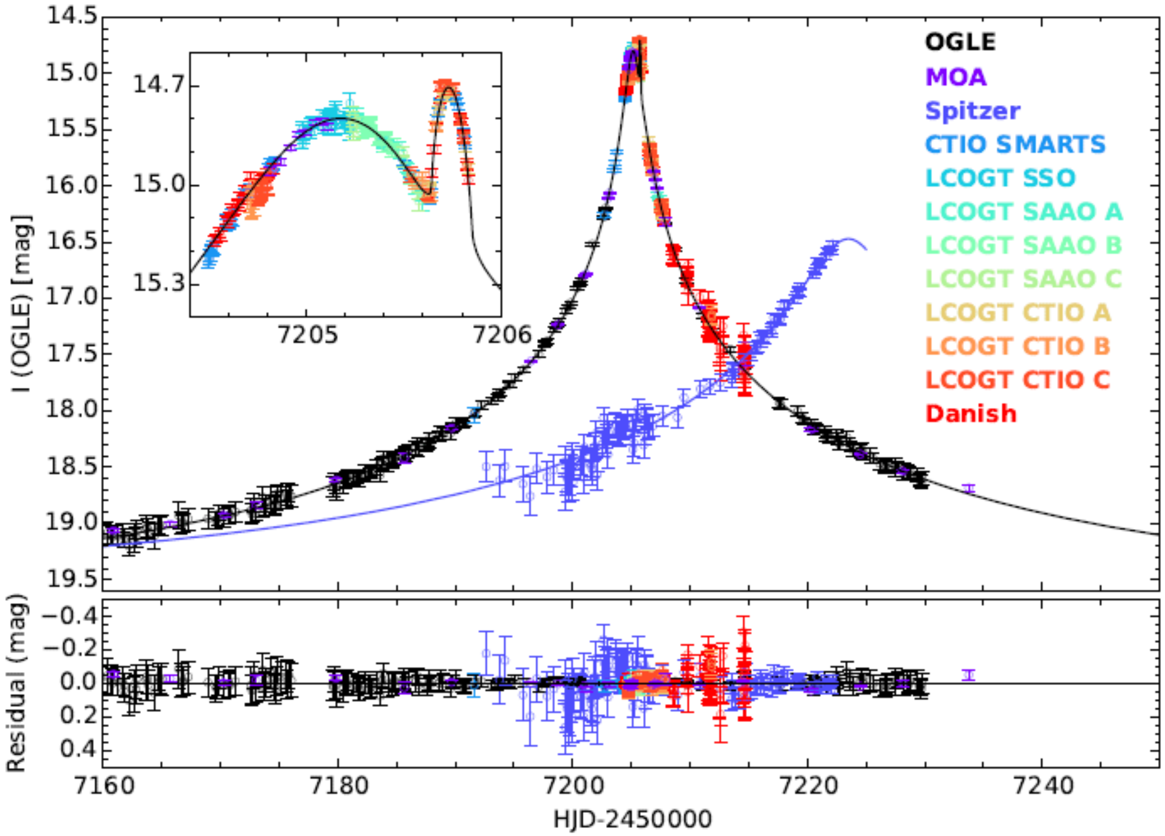


OGLE-2014-BLG-0939

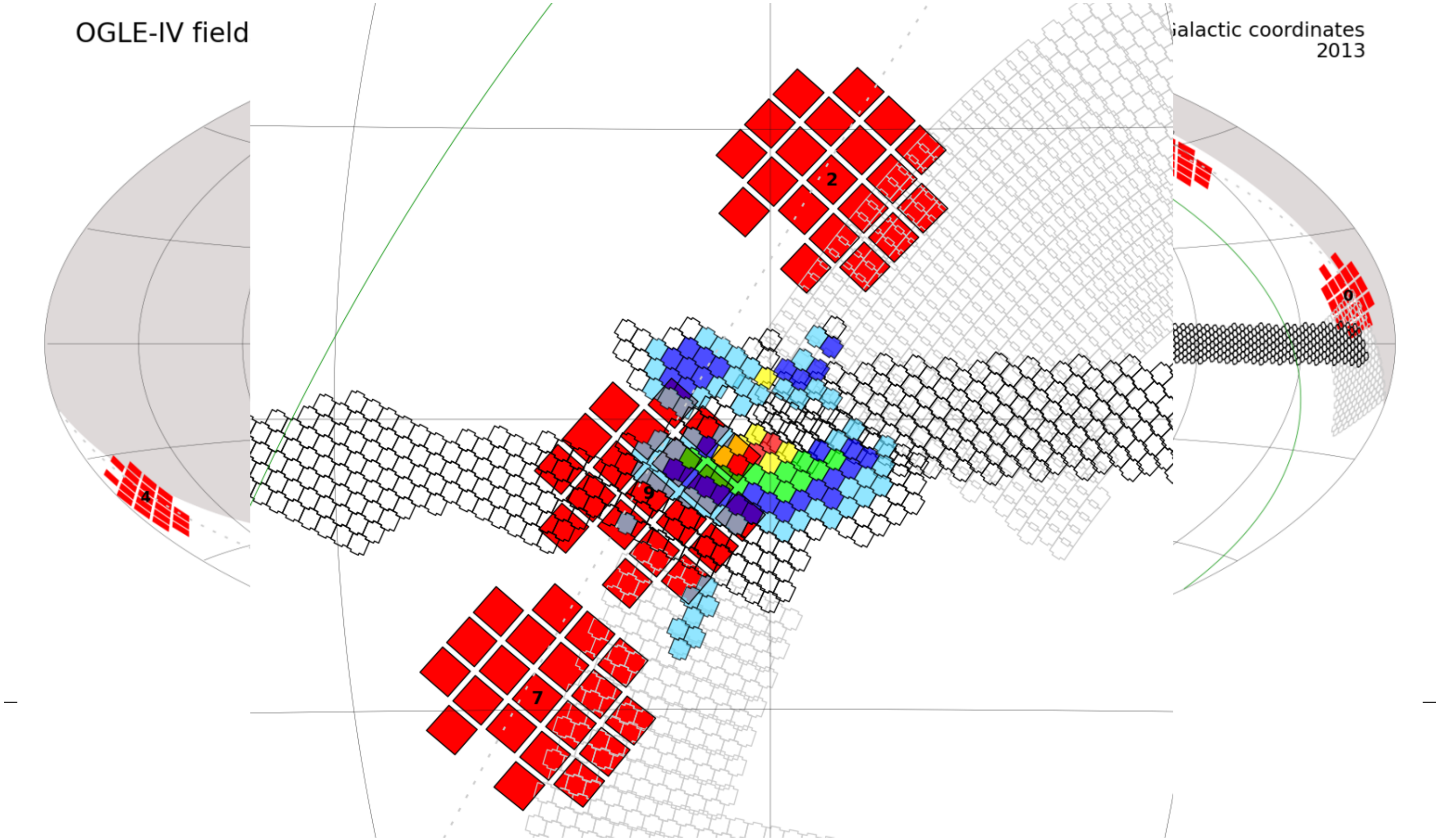


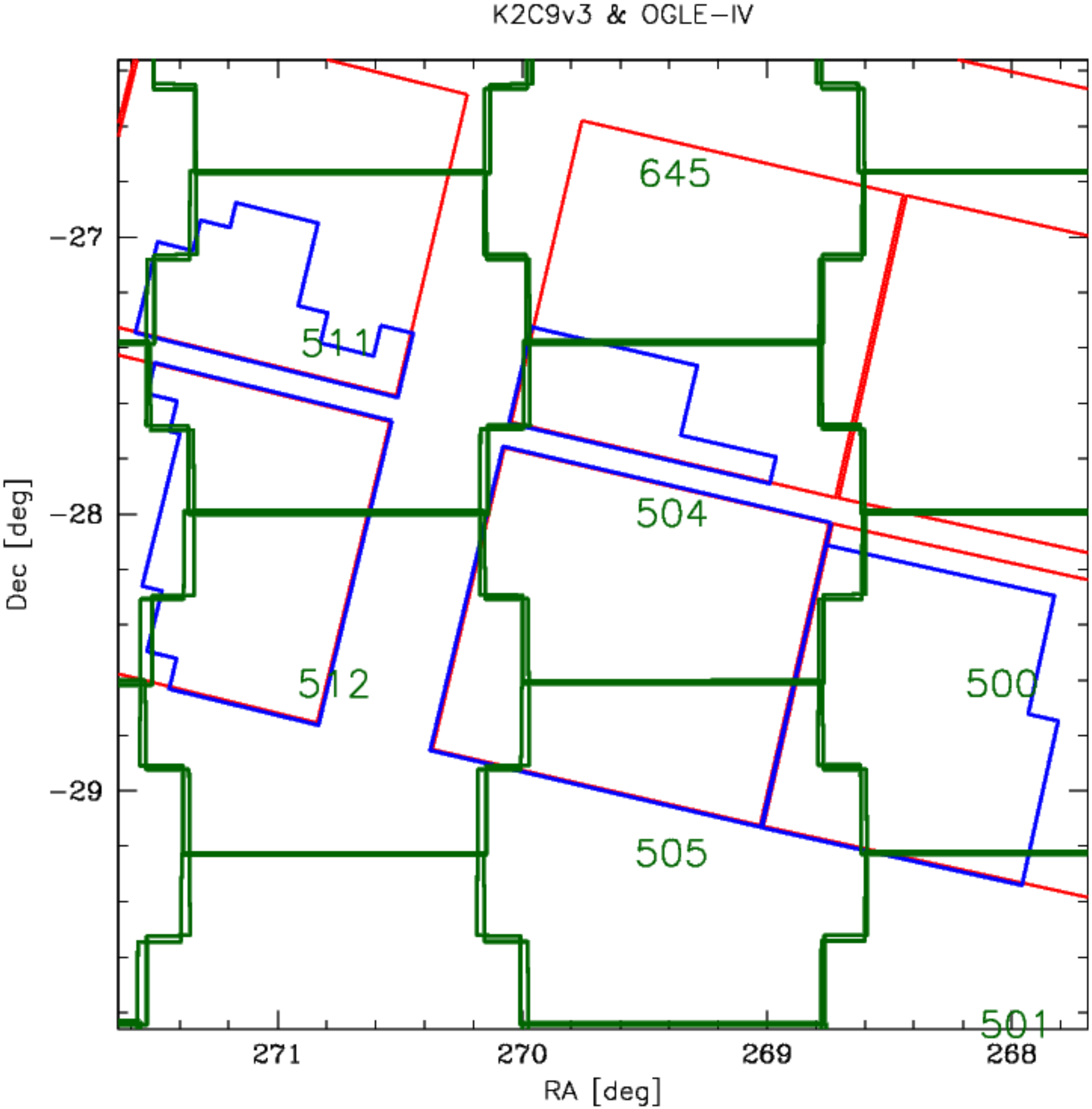
2015 Spitzer campaign – ~900 hours/40 days for microlensing!

170 microlenses observed by Spitzer simultaneously with OGLE *et al.*



Kepler – K2



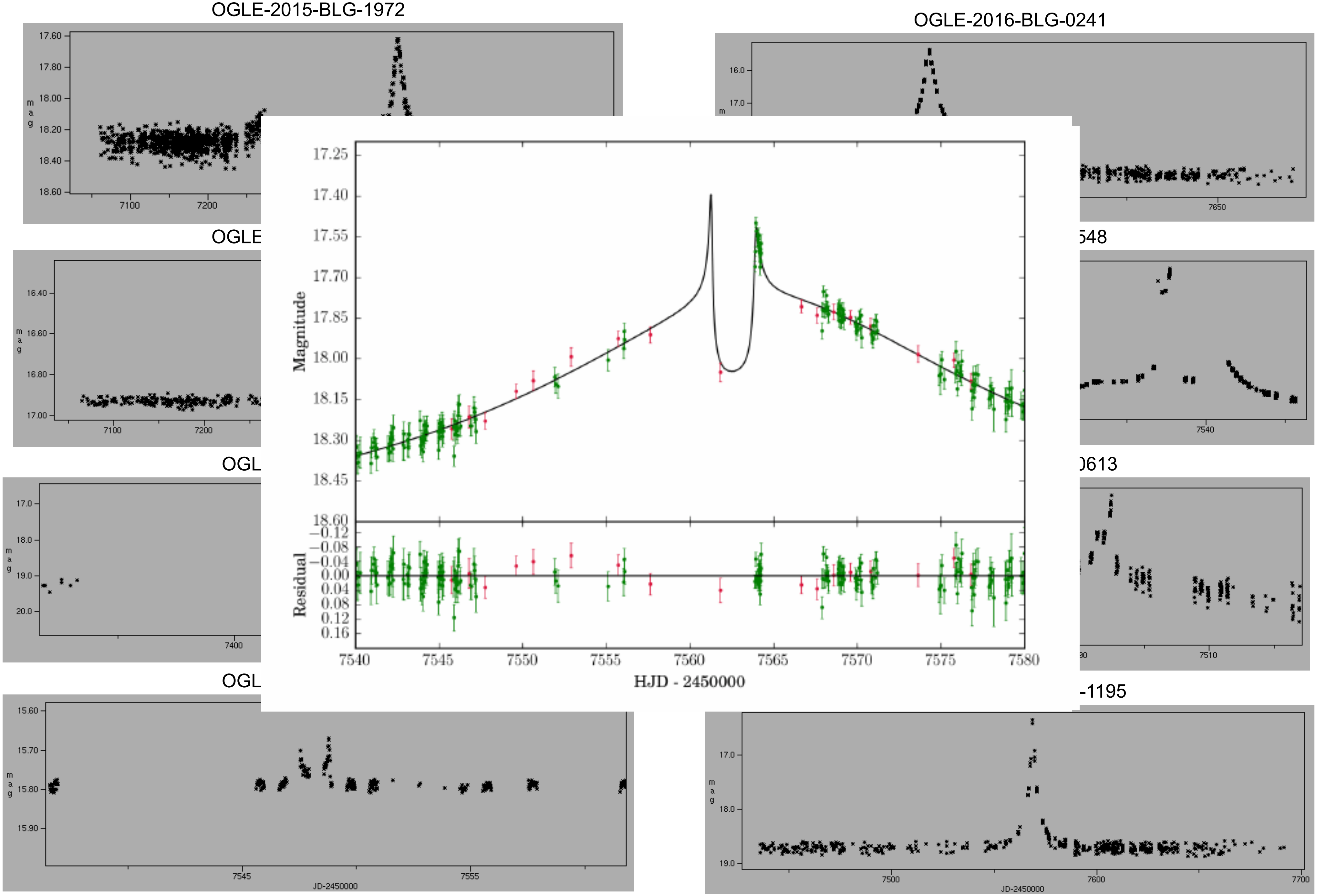

K2C9v3 & OGLE-IV
645
511
504
512
500
505
501
−27
−28
−29
Dec [deg]
271
270
269
268
RA [deg]

•

•

n

OGLE 2016 μlensing Gallery

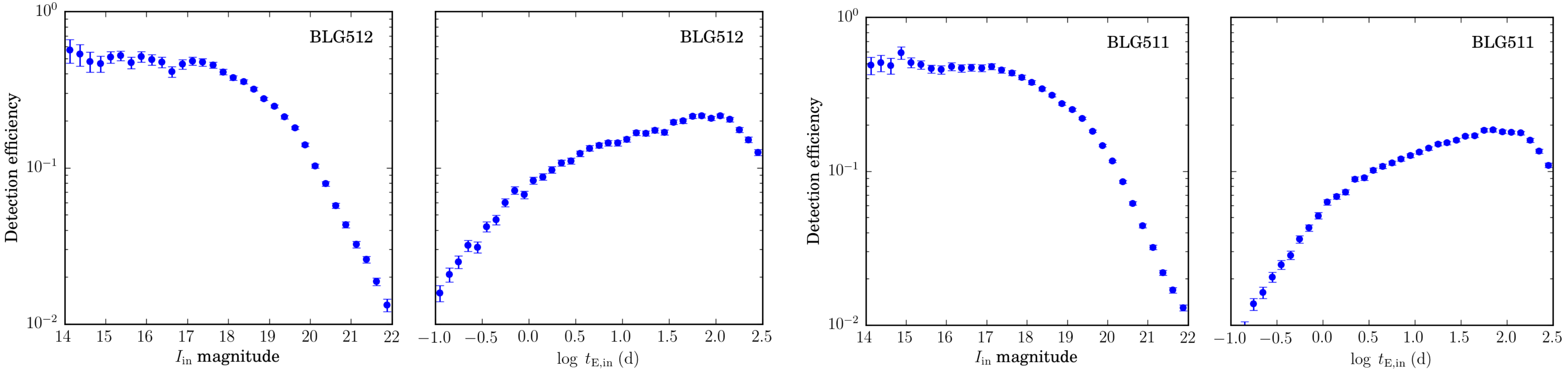


2017 Microlensing Season

- Lower cadence of the central fields
- Finishing OGLE non-microlensing projects competing for BLG time

OGLE Microlensing Statistics

- ~17 000 Microlensing Events discovered by OGLE (~90% of all detected ulenses)
- OGLE-IV: ~2000 ulenses/observing season (in real time – OGLE EWS system)
- Unique homogeneous data set for statistical studies



CELEBRATING 25 YEARS OF THE OGLE PROJECT

JULY 24 – 28, 2017
WARSAW UNIVERSITY, POLAND


Photo by Yuri Beletsky

TOPICS INCLUDE

- Variable Stars
- Magellanic Clouds
- Transients
- Planets
- Microlensing
- Galactic Structure
- Distance Scale
- Supernovae
- Star Clusters
- Large-scale Surveys

INVITED SPEAKERS

GIUSEPPE BONO
Universita di Roma Tor Vergata

LAURENT EYER
University of Geneva

SCOTT GAUDI
Ohio State University

ANDREW GOULD
MPIA / KASI / OSU

SHUDE MAO
Tsinghua University / National Astronomical Observatories of China

MARK PHILLIPS
Carnegie Observatories

PAUL SCHECHTER
MIT Kavli Institute for Astrophysics and Space Research

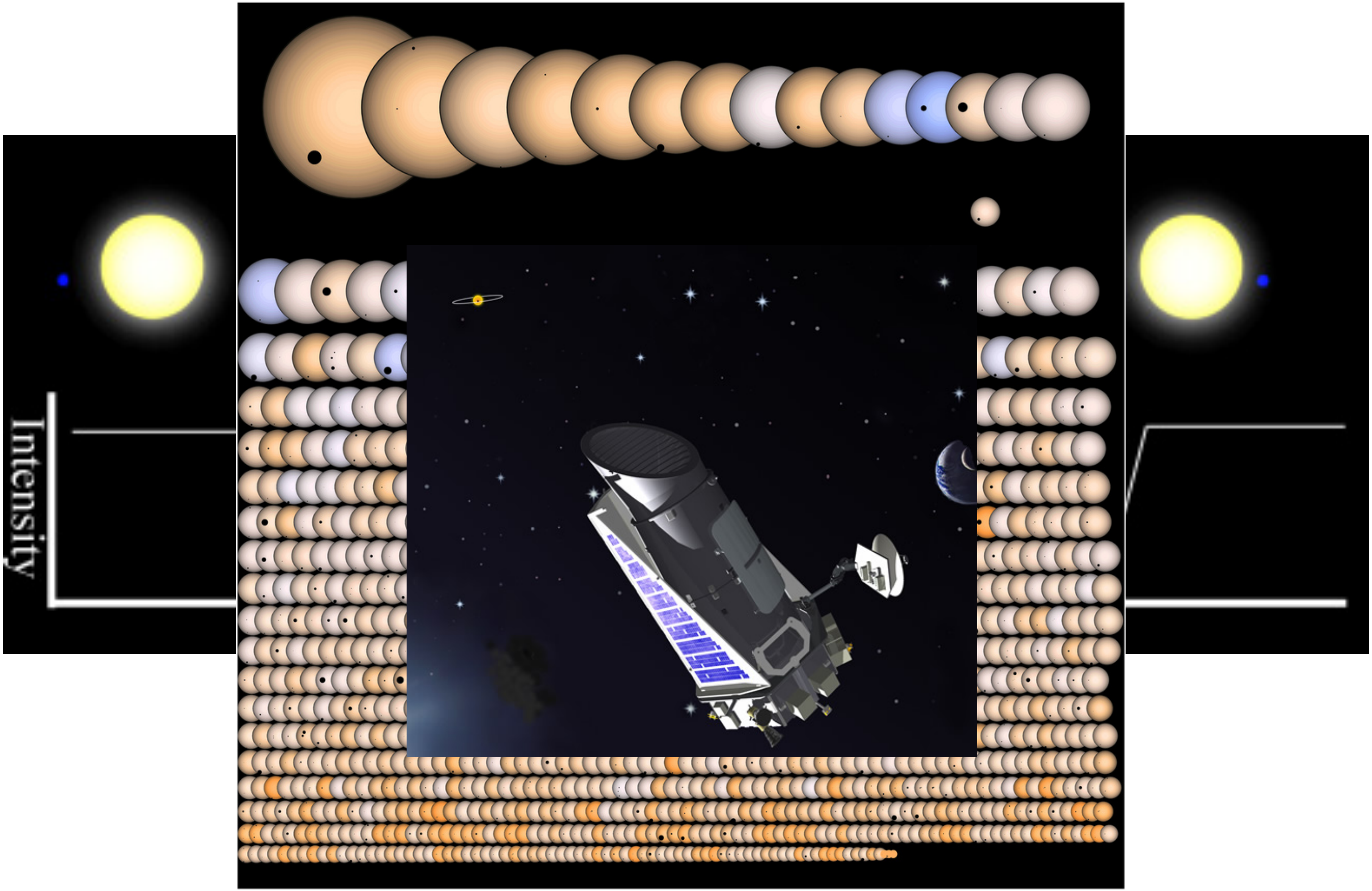
ANDRZEJ UDALSKI
Warsaw University Observatory

http://ogle25.astrouw.edu.pl/ ogle25@astrouw.edu.pl

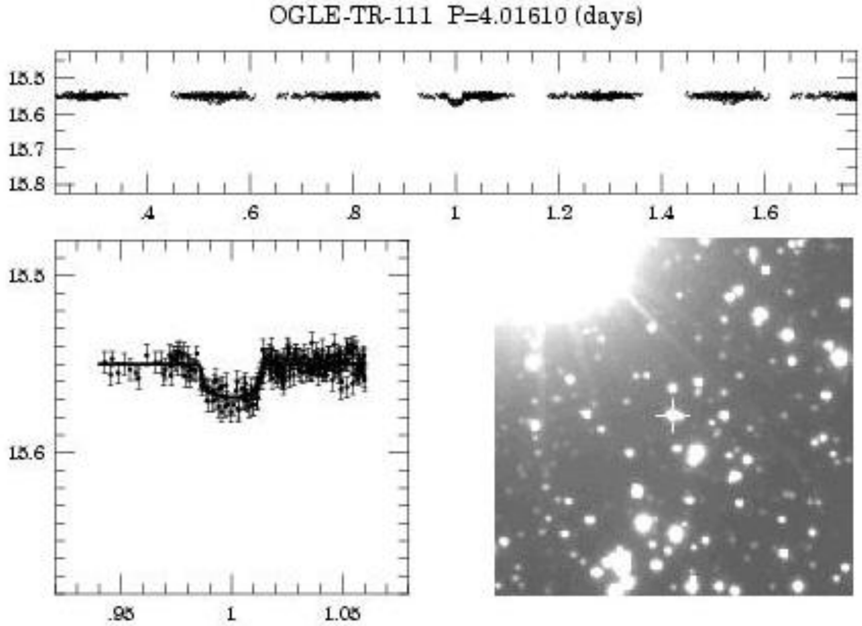
OGLE

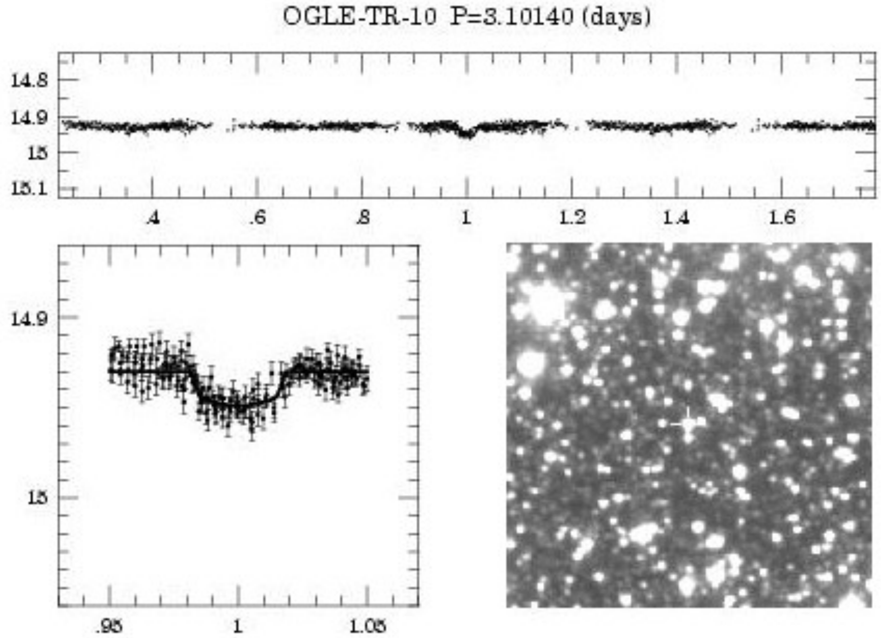
Science Factory

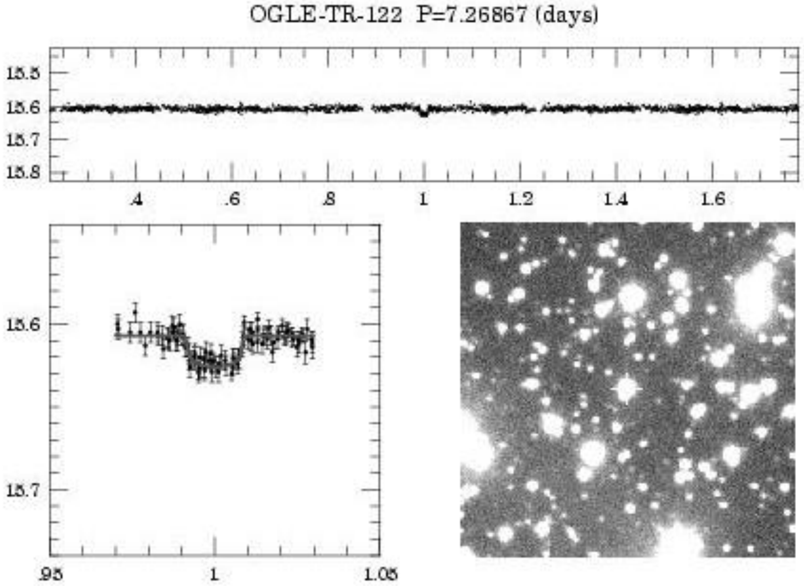
Exoplanets: Transit Method

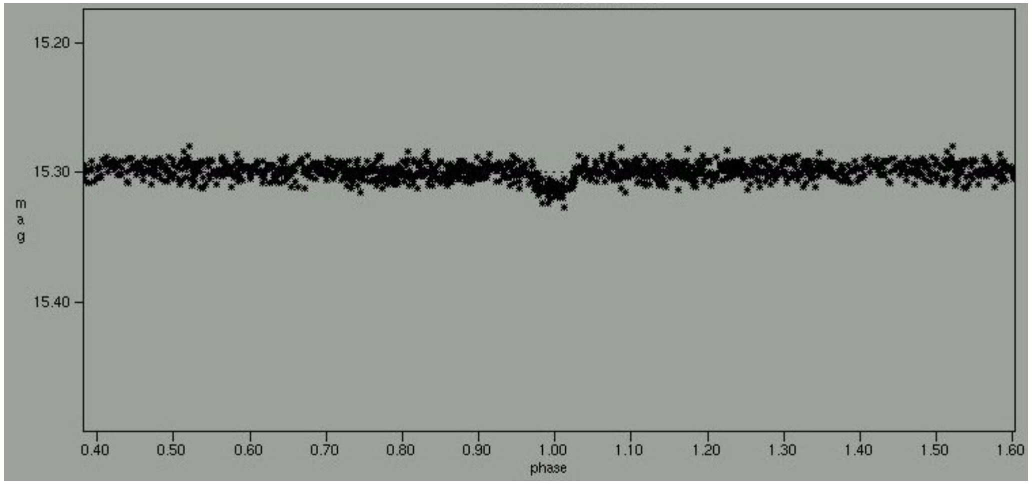


Transiting OGLE Exoplanets (2001—2006)


OGLE-TR-111 P=4.01610 (days)


OGLE-TR-10 P=3.10140 (days)

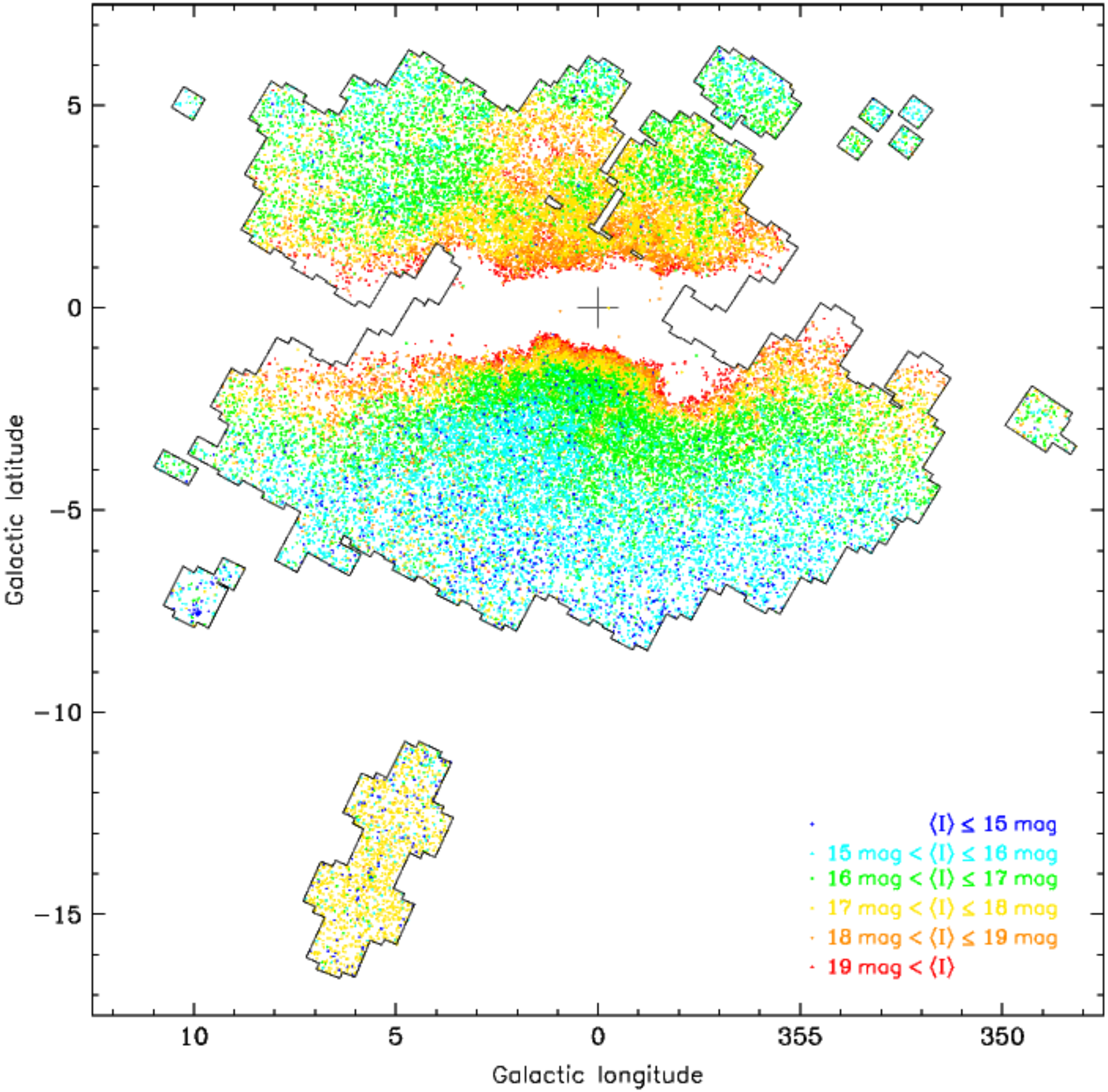

OGLE-TR-122 P=7.26867 (days)



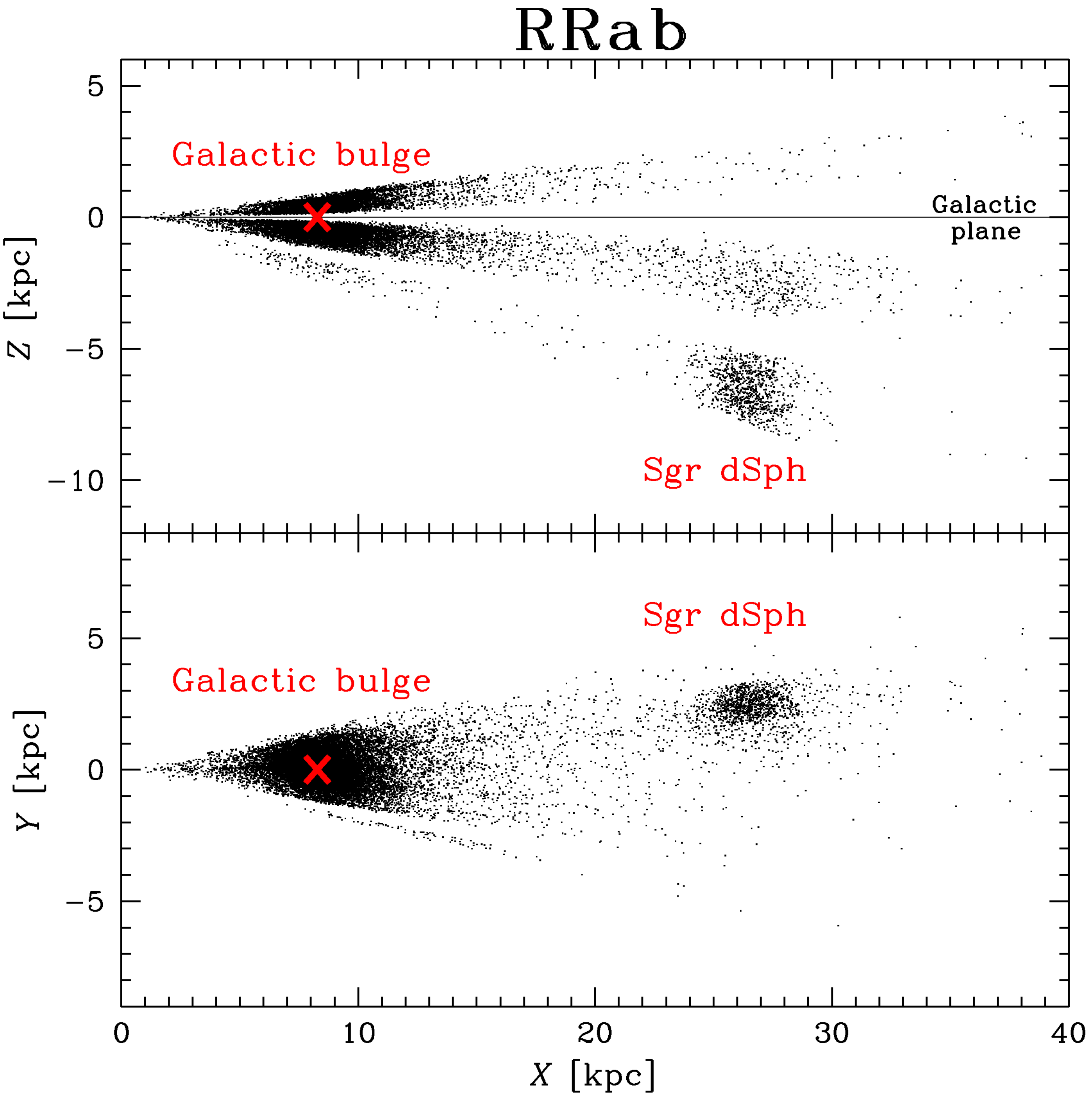
OGLE Collection of Variable Stars

- OGLE-IV data discoveries supplemented with previous OGLE-III, OGLE-II and OGLE-I detections
- ~25 years time span, very precise photometry
- High completeness (>90%) and classification purity
- Open project – recent extensions:
- RR Lyrae in the Galactic Center (>38 000 objects)
- Classical and Anomalous Cepheids in the Magellanic System (~9 800 objects)
- RR Lyrae in the Magellanic System (~45 000 objects)
- Eclipsing stars in the Galactic Center and Magellanic System (~500 000 systems)
- ~one million OGLE variable stars

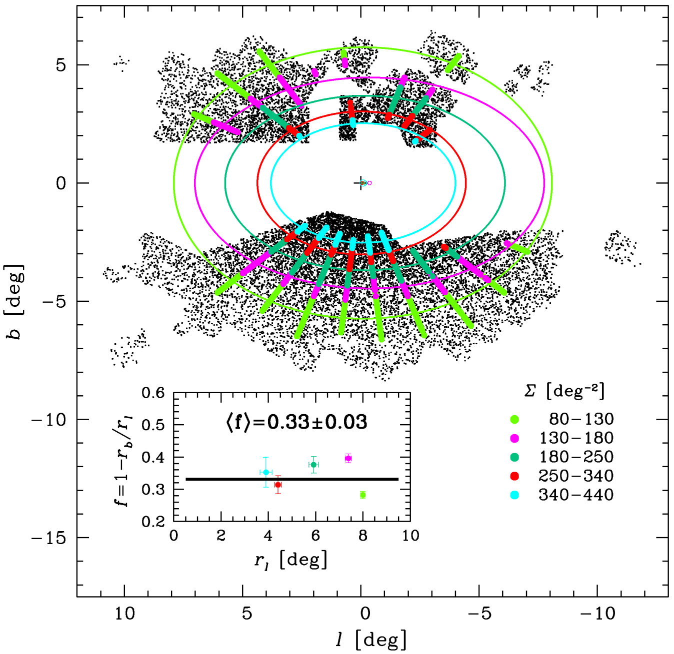
GB RR Lyrae

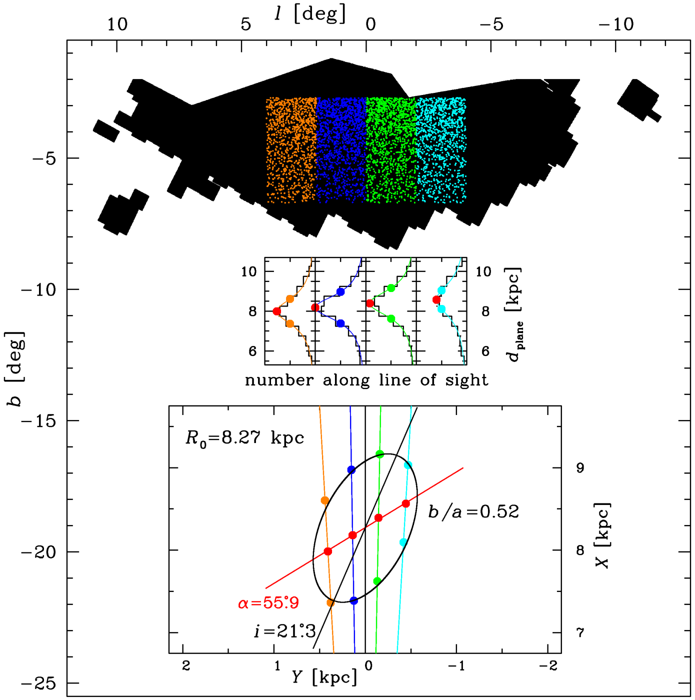

5
0
−5
−10
−15
Galactic latitude
10
5
0
355
350
Galactic longitude
⟨I⟩ ≤ 15 mag
15 mag < ⟨I⟩ ≤ 16 mag
16 mag < ⟨I⟩ ≤ 17 mag
17 mag < ⟨I⟩ ≤ 18 mag
18 mag < ⟨I⟩ ≤ 19 mag
19 mag < ⟨I⟩

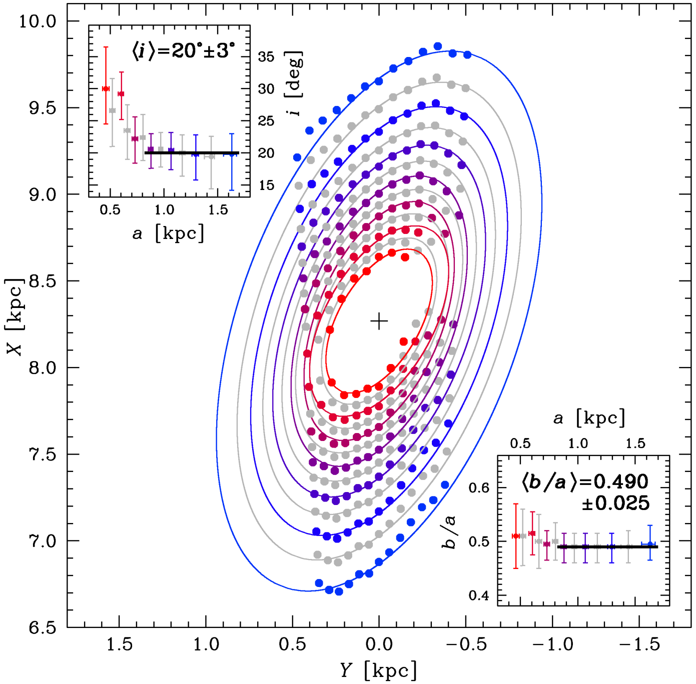
Galactic Structure from RR Lyrae Stars

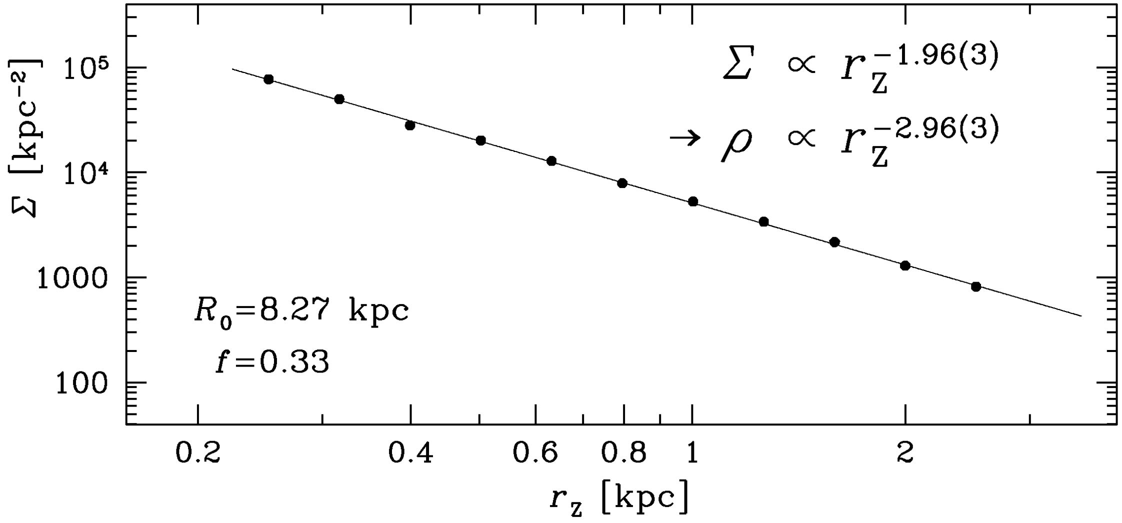


Galactic Structure from RR Lyrae Stars

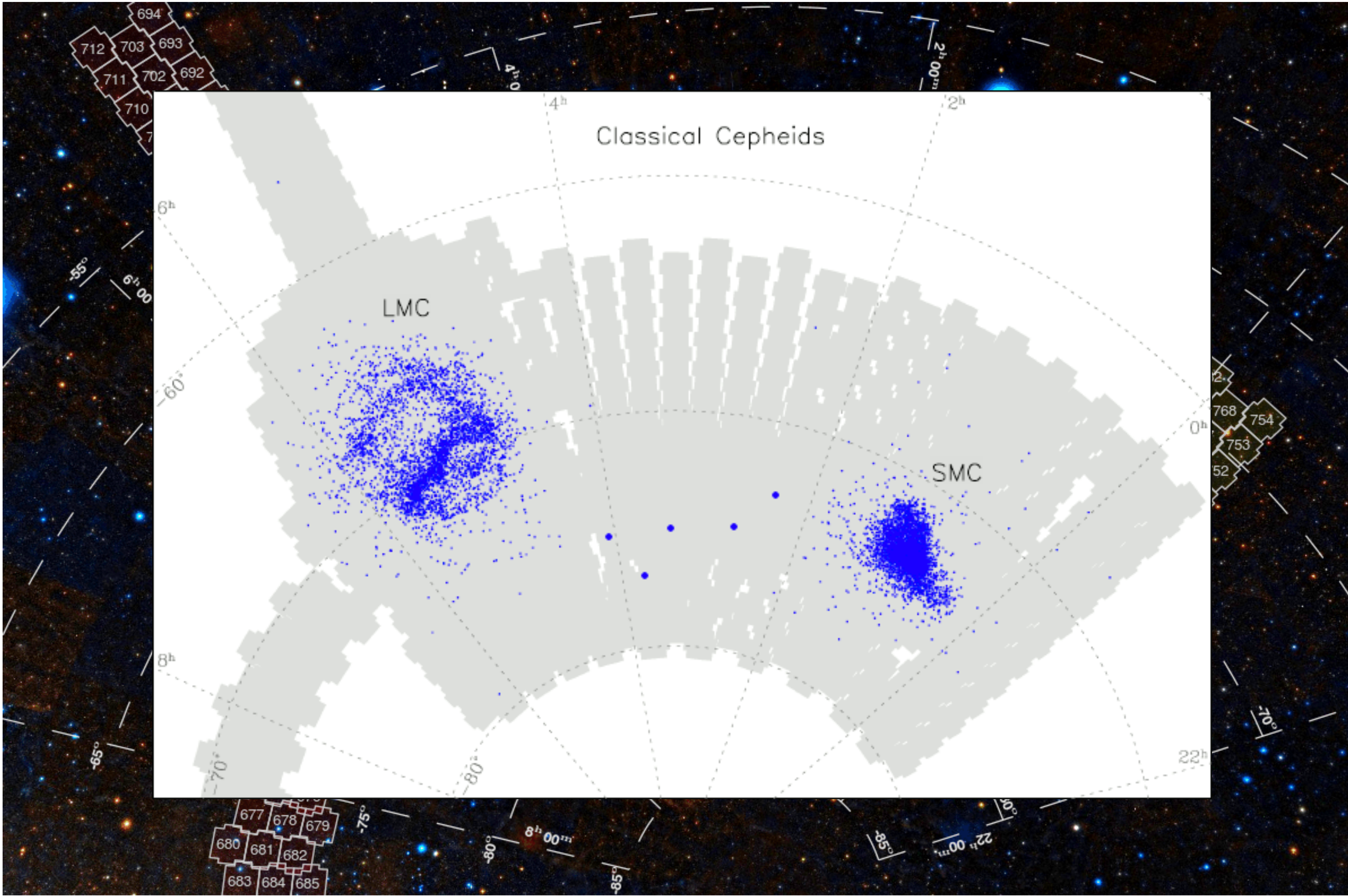




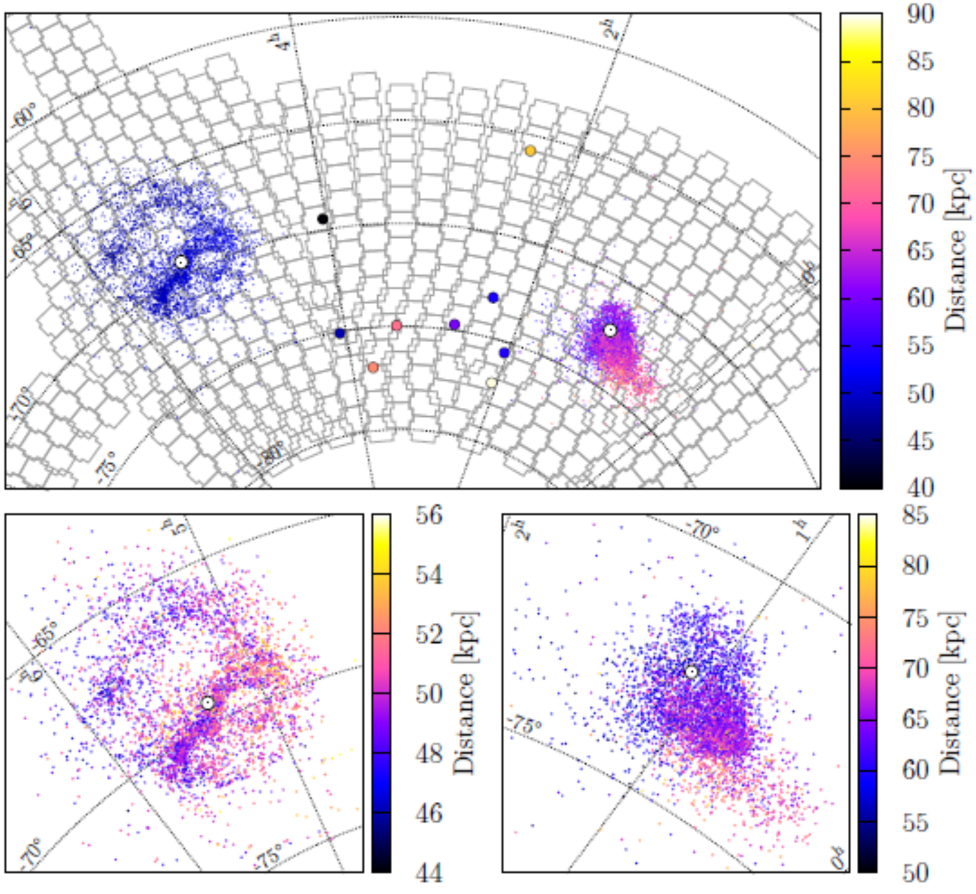


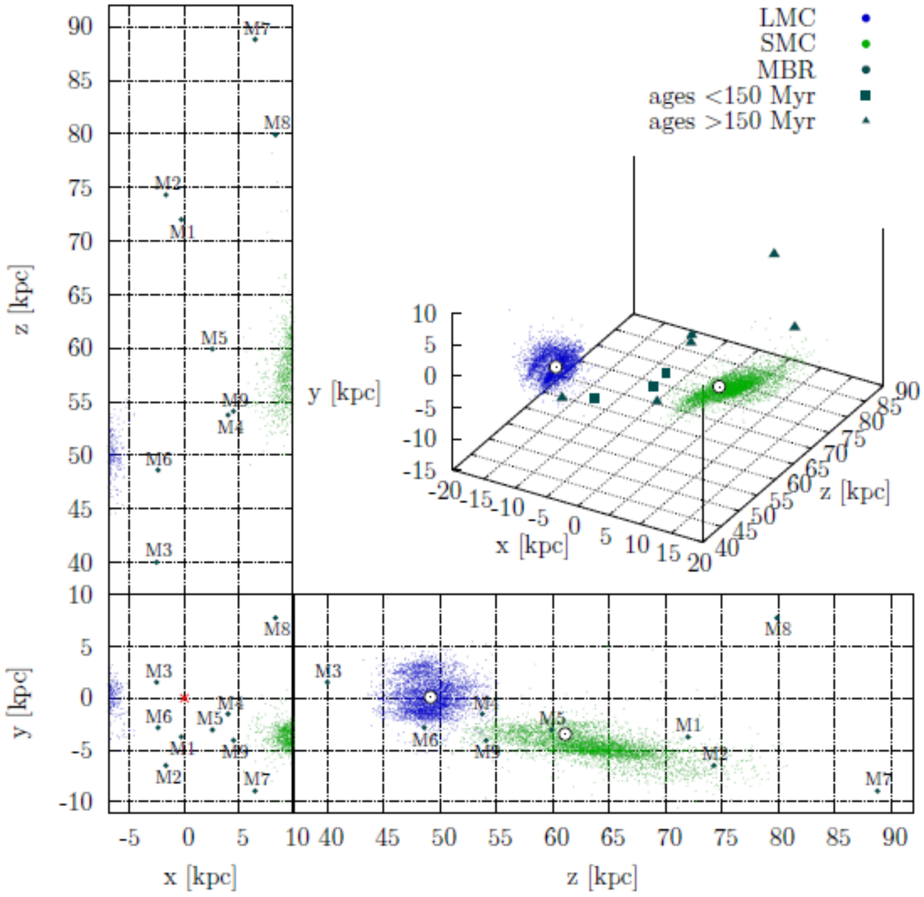


Classical Cepheids in the Magellanic Clouds

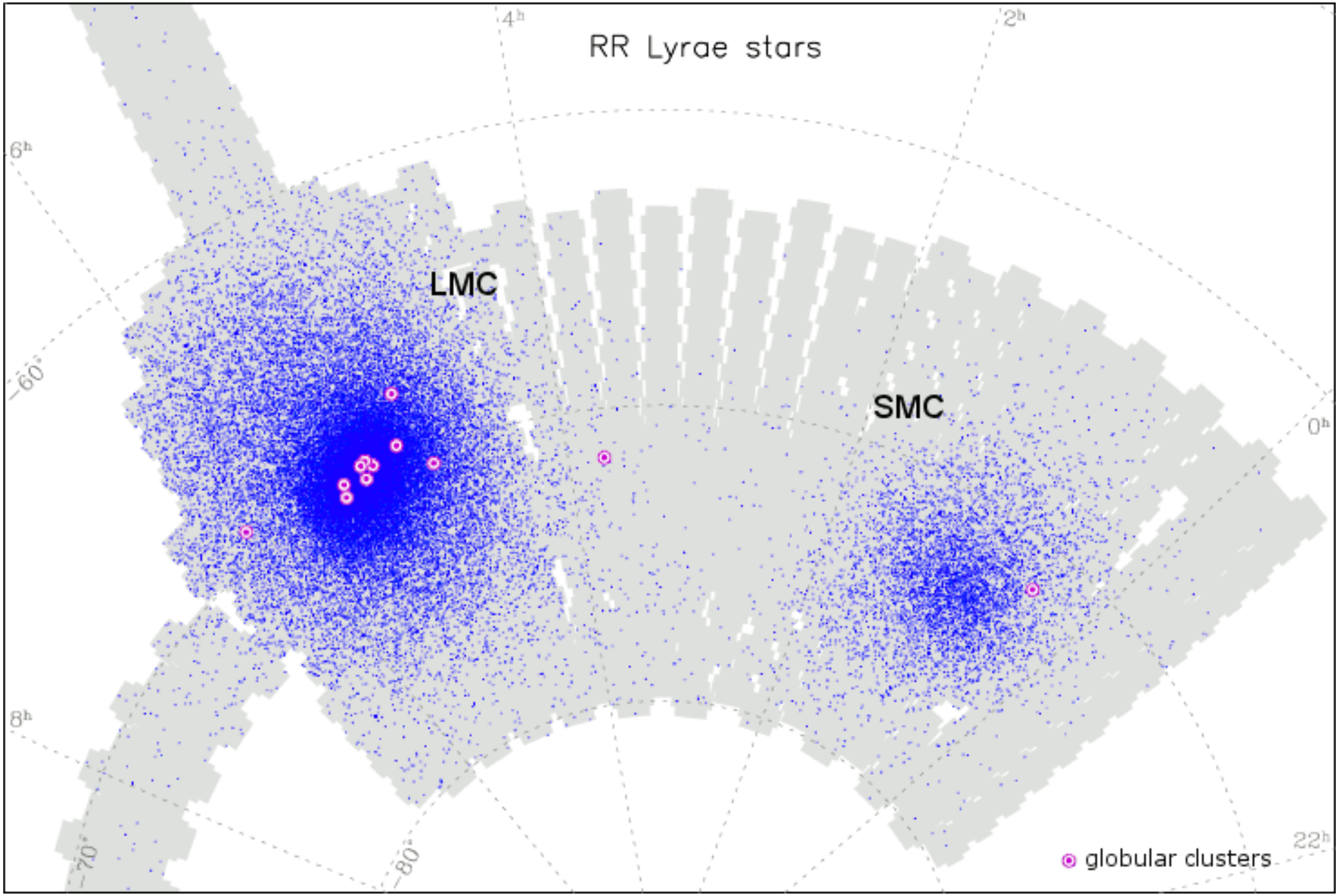


Structure of the Magellanic System *via* Cepheids

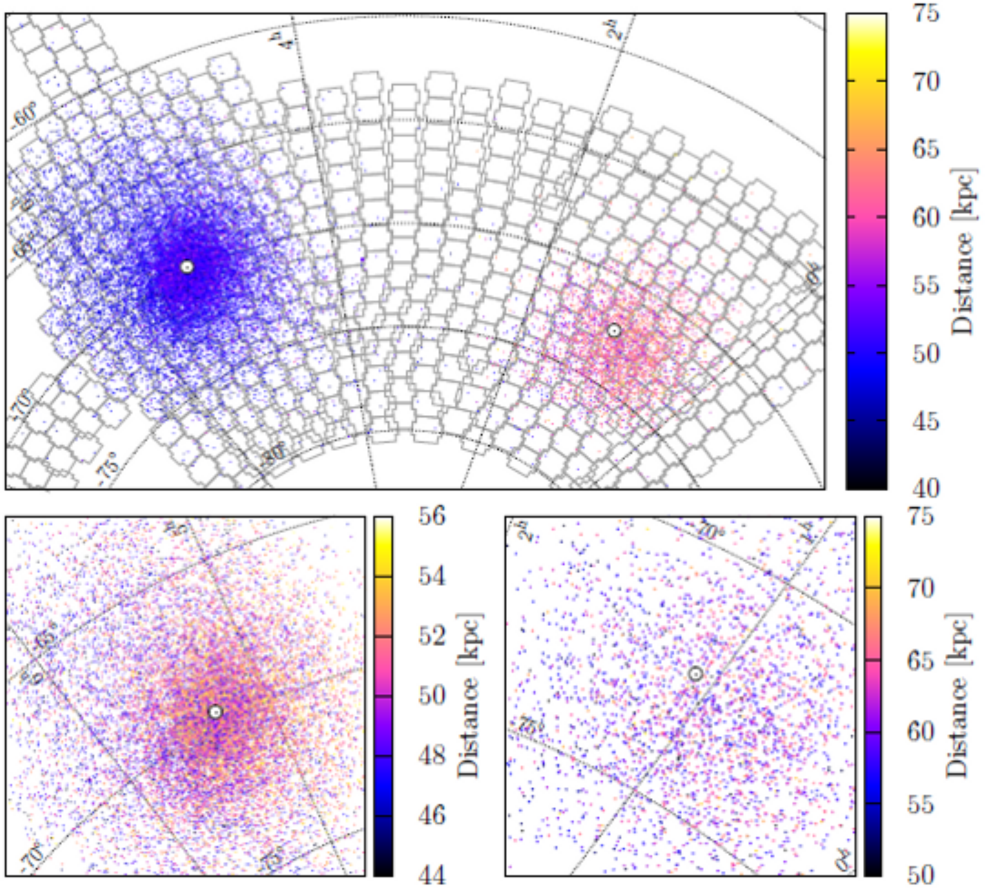


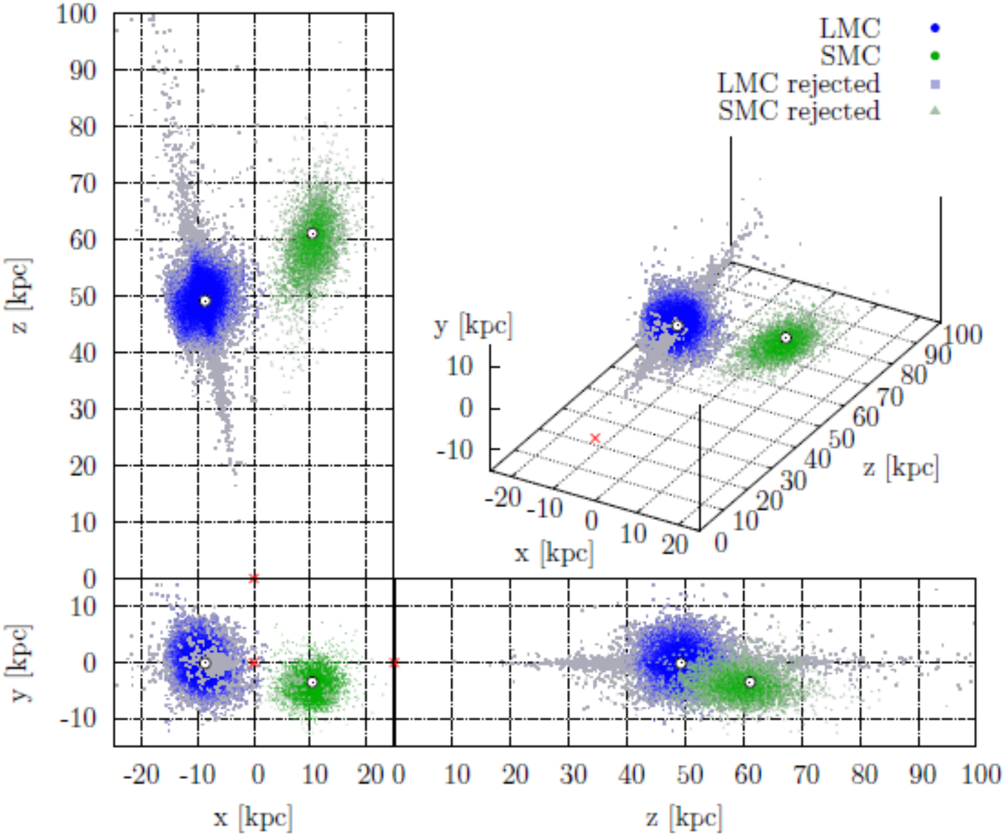


RR Lyrae Stars in the Magellanic Clouds



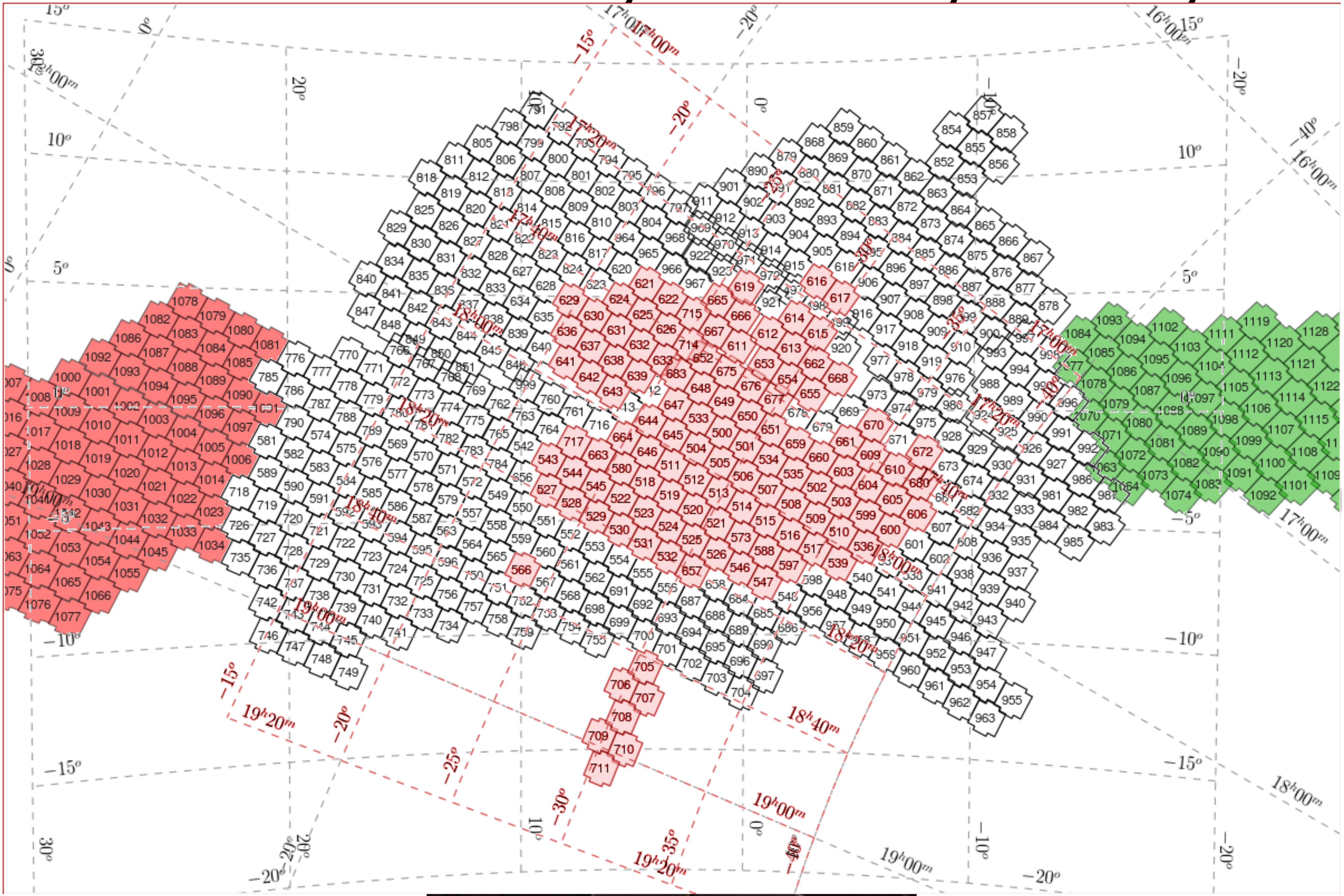
Structure of the Magellanic System *via* RR Lyrae





Las Campanas – Warsaw Telescope – LCO Sky

OGLE-IV Galaxy Variability Survey



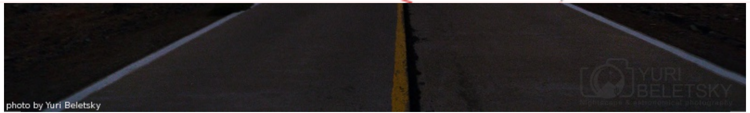
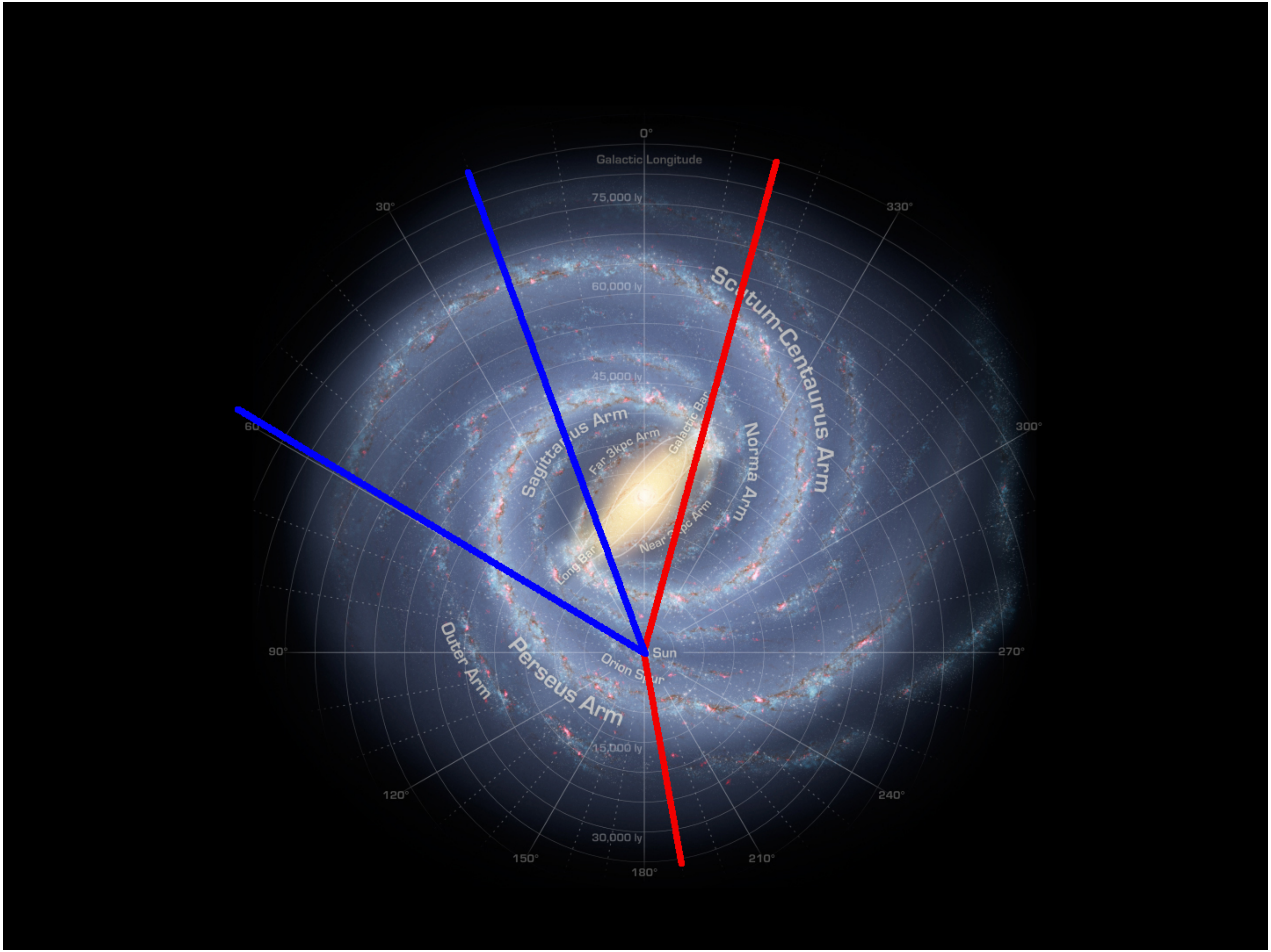


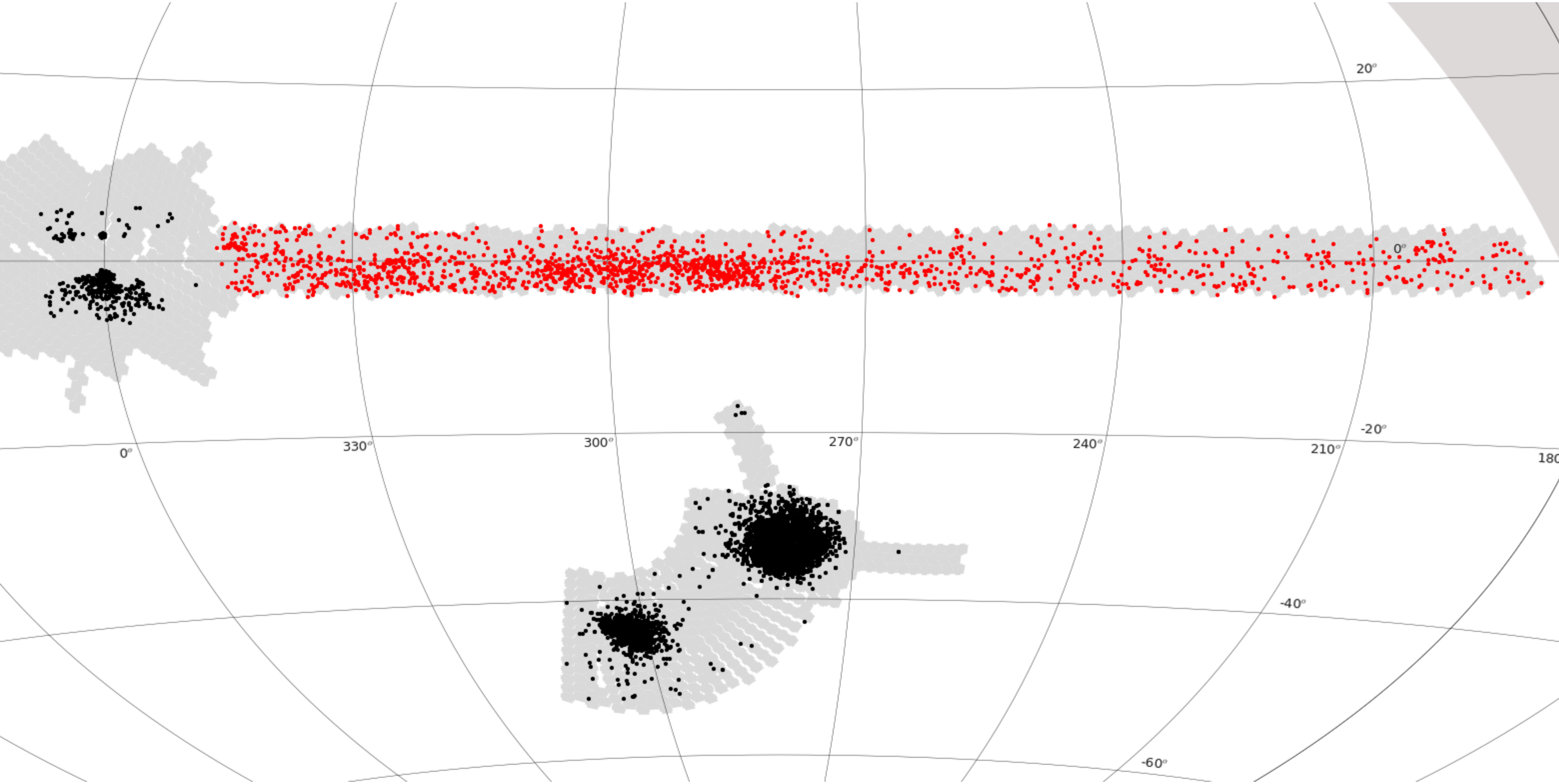
photo by Yuri Beletsky

Galaxy and OGLE-GVS

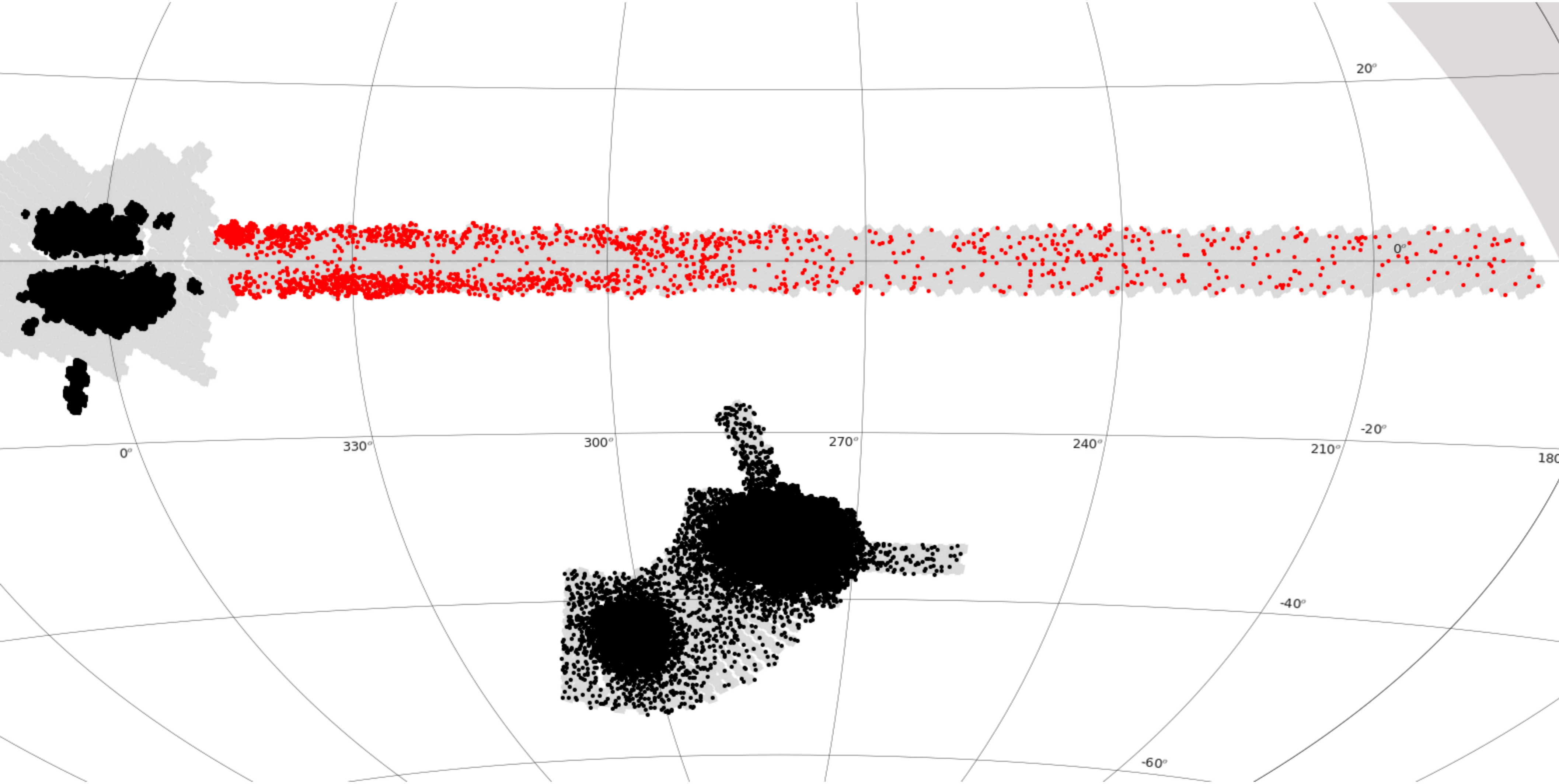


Credit: NASA/Adler/U. Chicago/Wesleyan/JPL-Caltech

Distribution in our Galaxy



Distribution in our Galaxy



Transients 2016

~ 2000 Microlensing Events per Season

Novae

CVs

SNe

LETTER

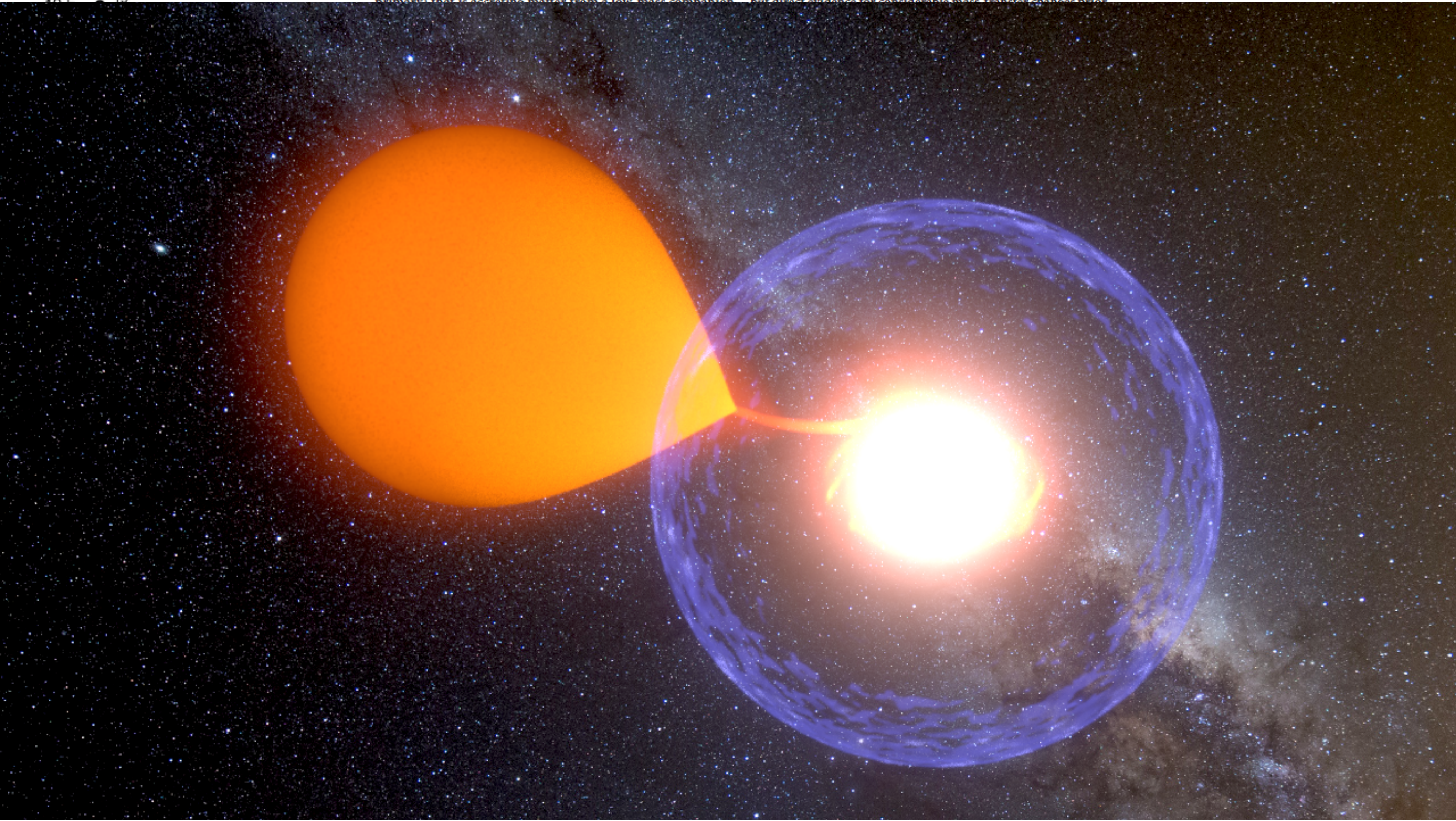
doi:10.1038/nature19066

The awakening of a classical nova from hibernation

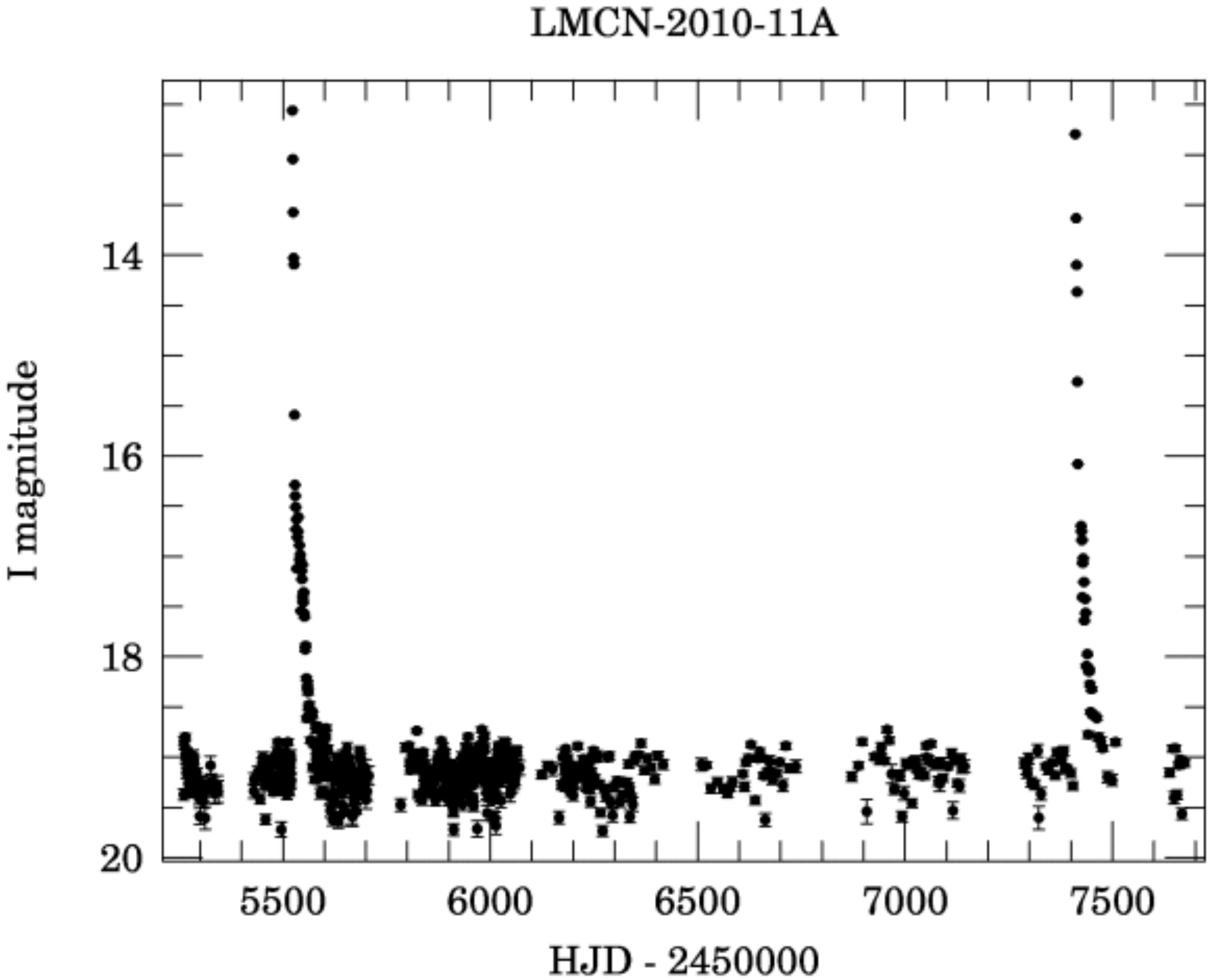
Przemek Mróz[1], Andrzej Udalski[1], Paweł Pietrukowicz[1], Michał K. Szymański[1], Igor Soszyński[1], Łukasz Wyrzykowski[1], Radosław Poleski[1,2], Szymon Kozłowski[1], Jan Skowron[1], Krzysztof Ulaczyk[1,3], Dorota Skowron[1] & Michał Pawlak[1]

Cataclysmic variable stars—novae, dwarf novae, and nova-likes—are close binary systems consisting of a white dwarf star (the

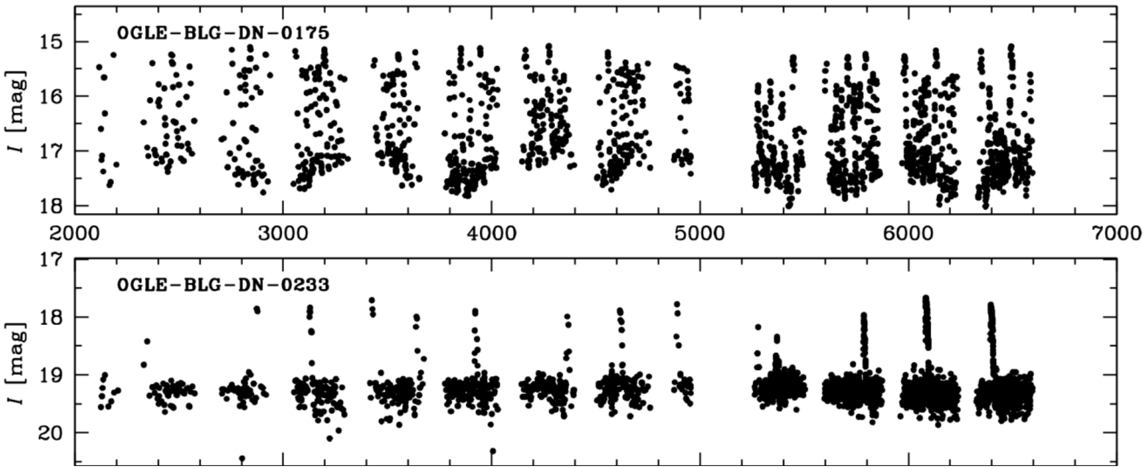
theory gained some support from the discovery of ancient nova shells around the dwarf novae Z Camelopardalis[7] and AT Cancri[8],

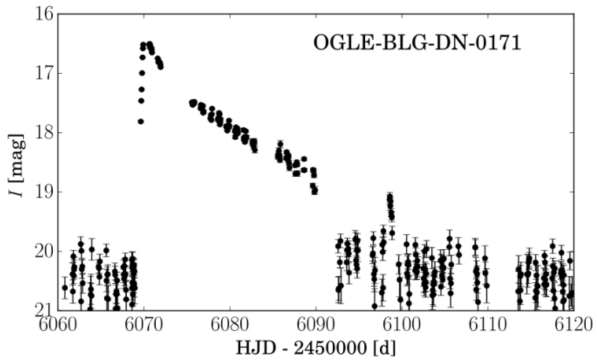


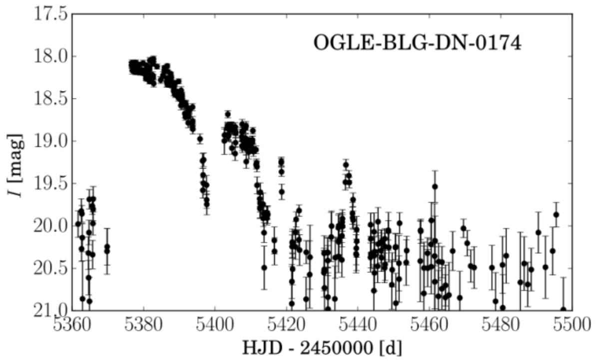
OGLE-2016-NOVA-01

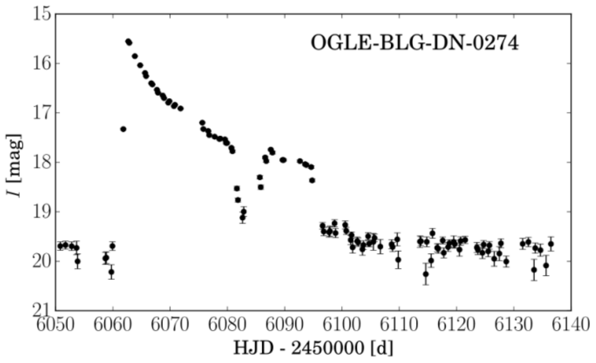


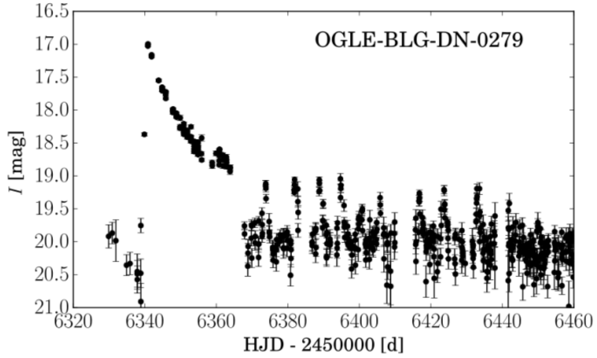
Dwarf Novae in OGLE

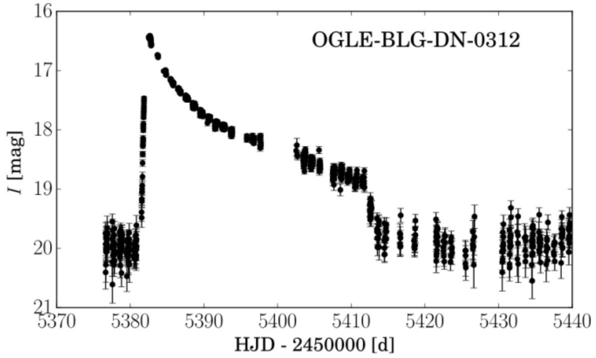


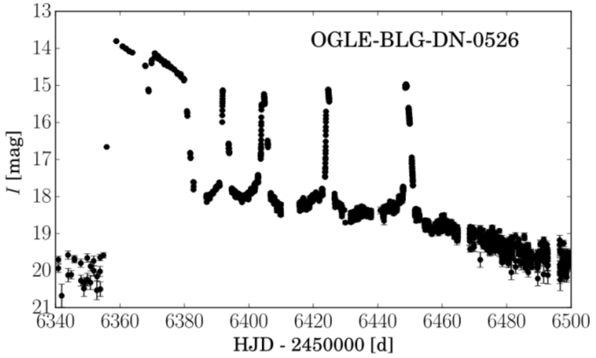










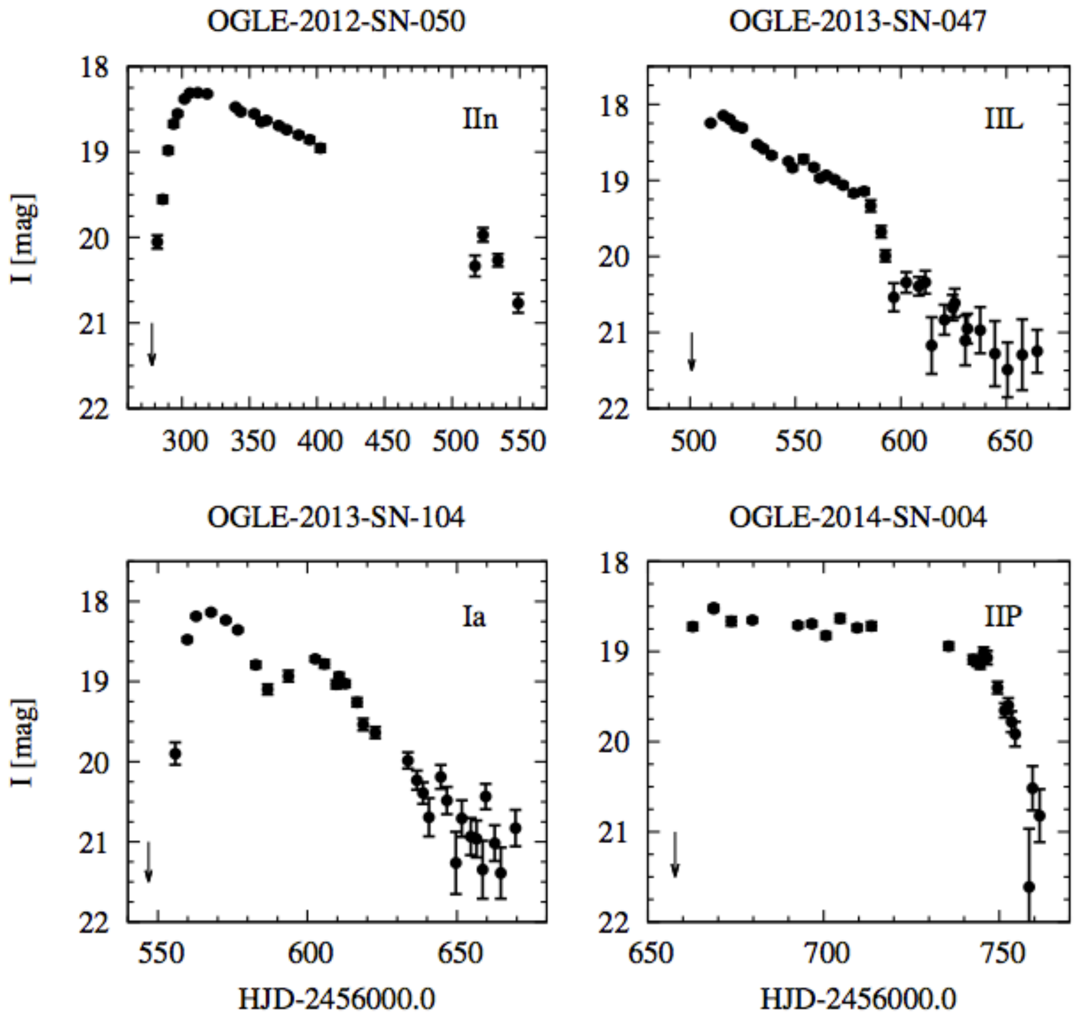


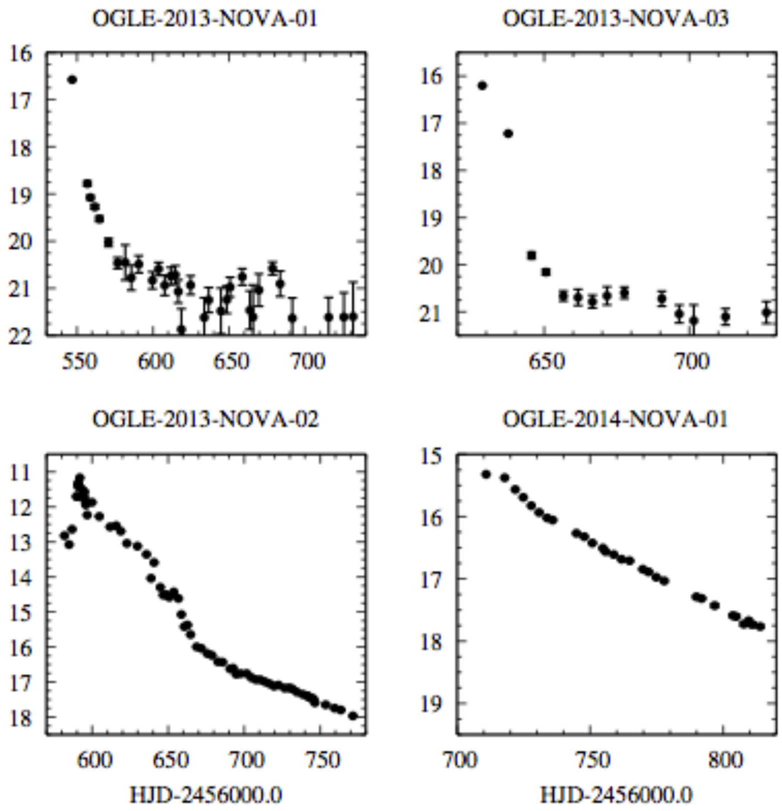
SUPERNOVAE IN OGLE

since 2012

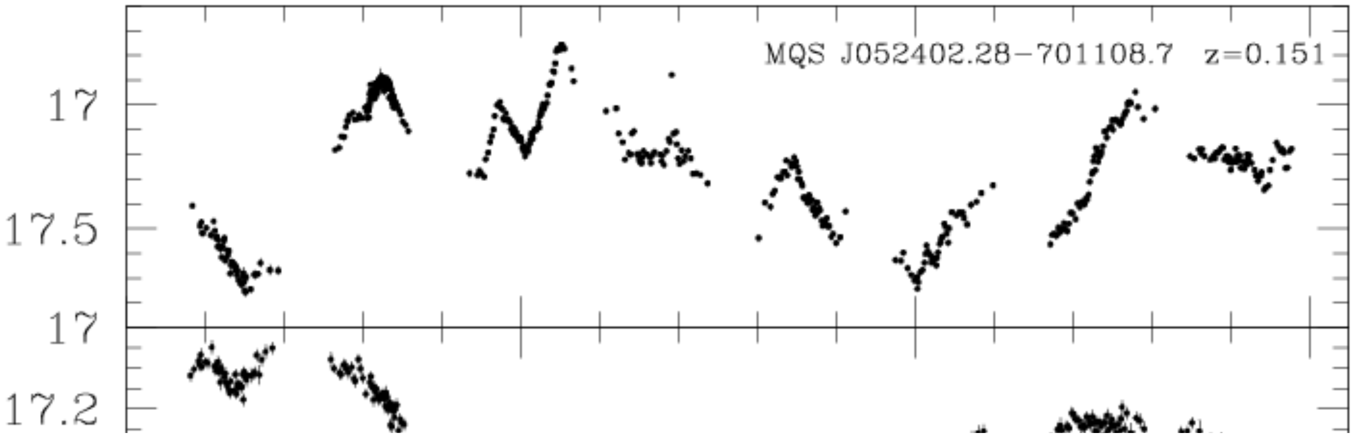
650 sq.deg.

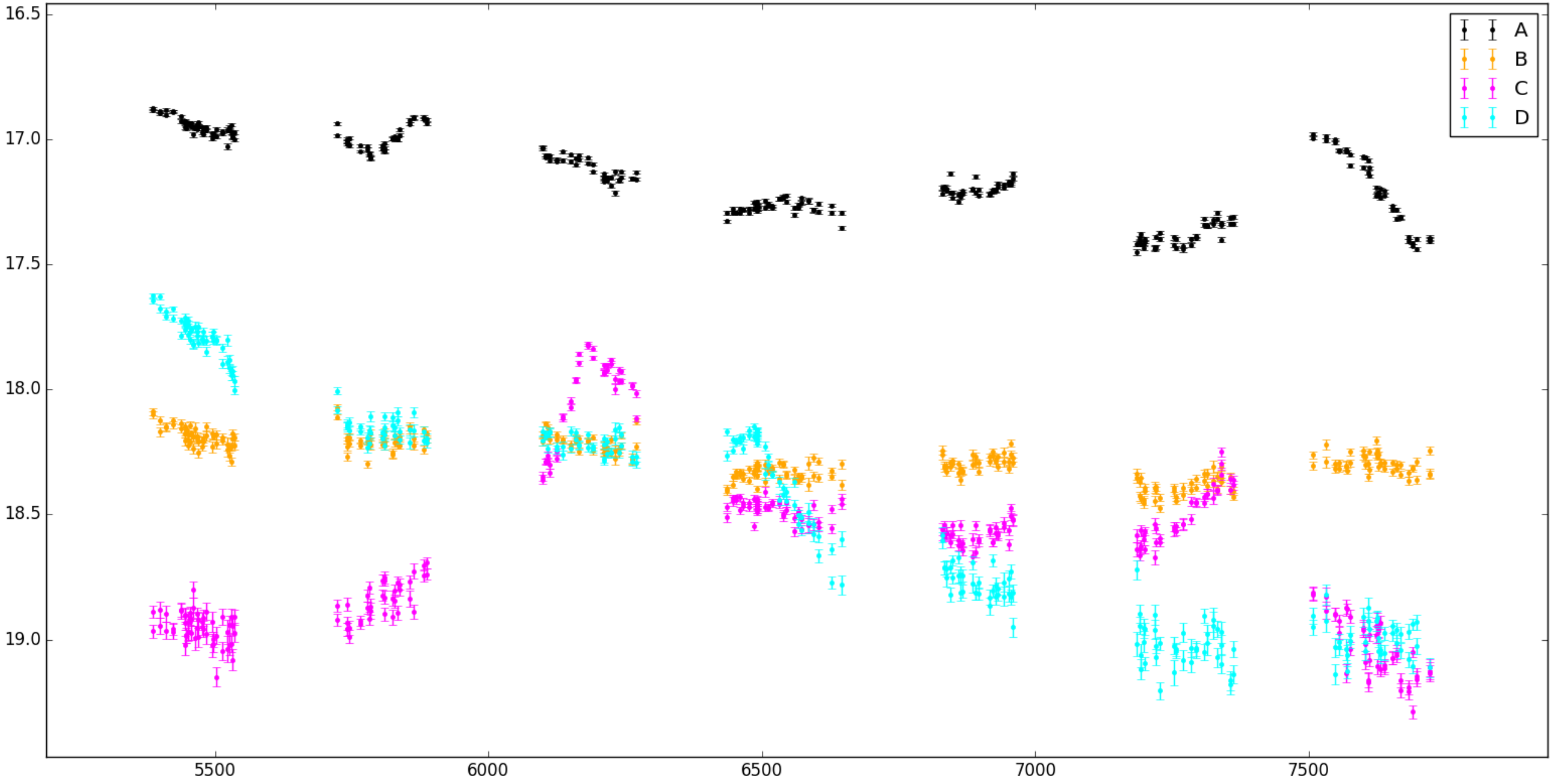
4 days mean sampling



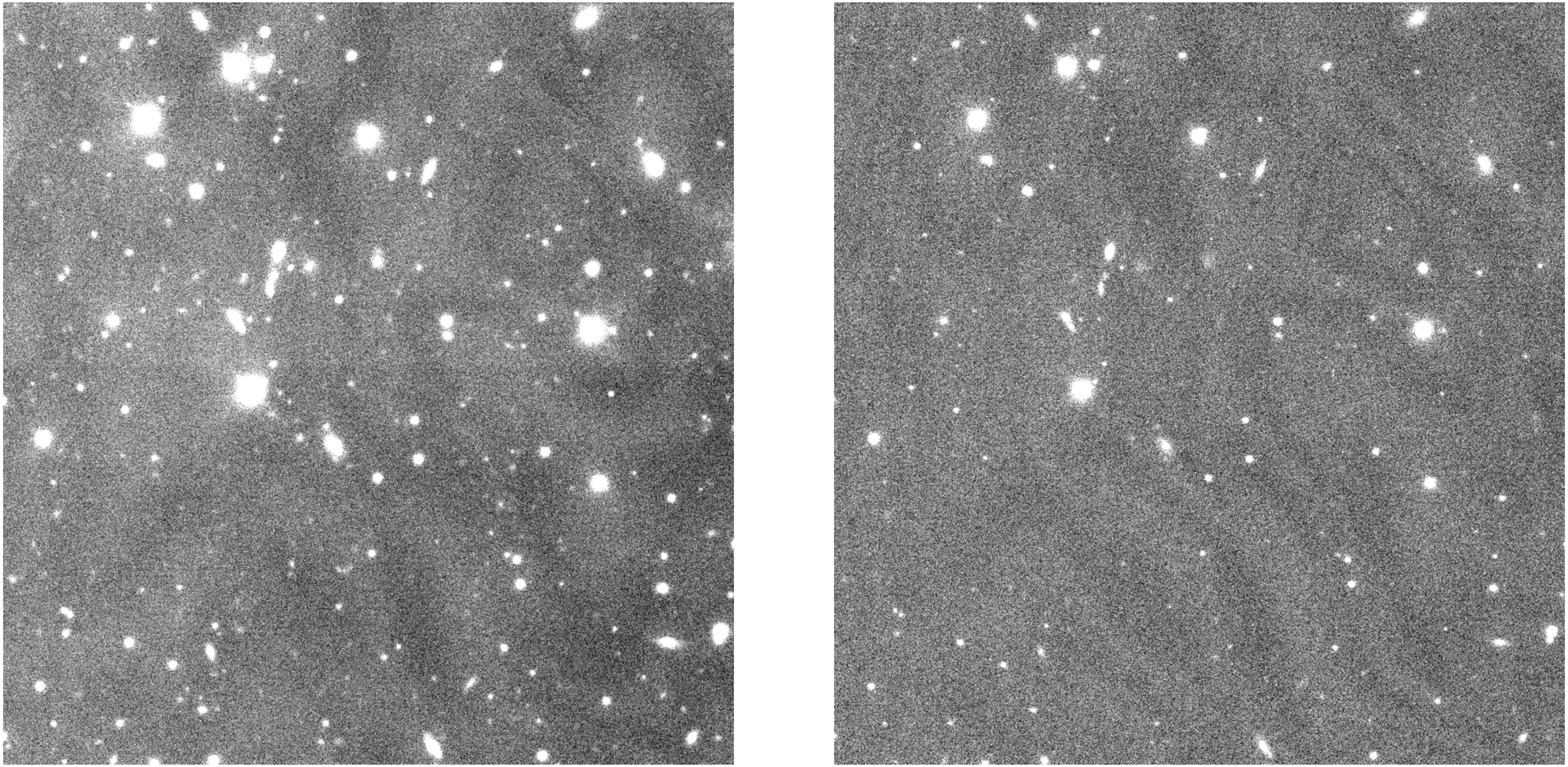


http://ogle.astrouw.edu.pl/ogle4/transients/

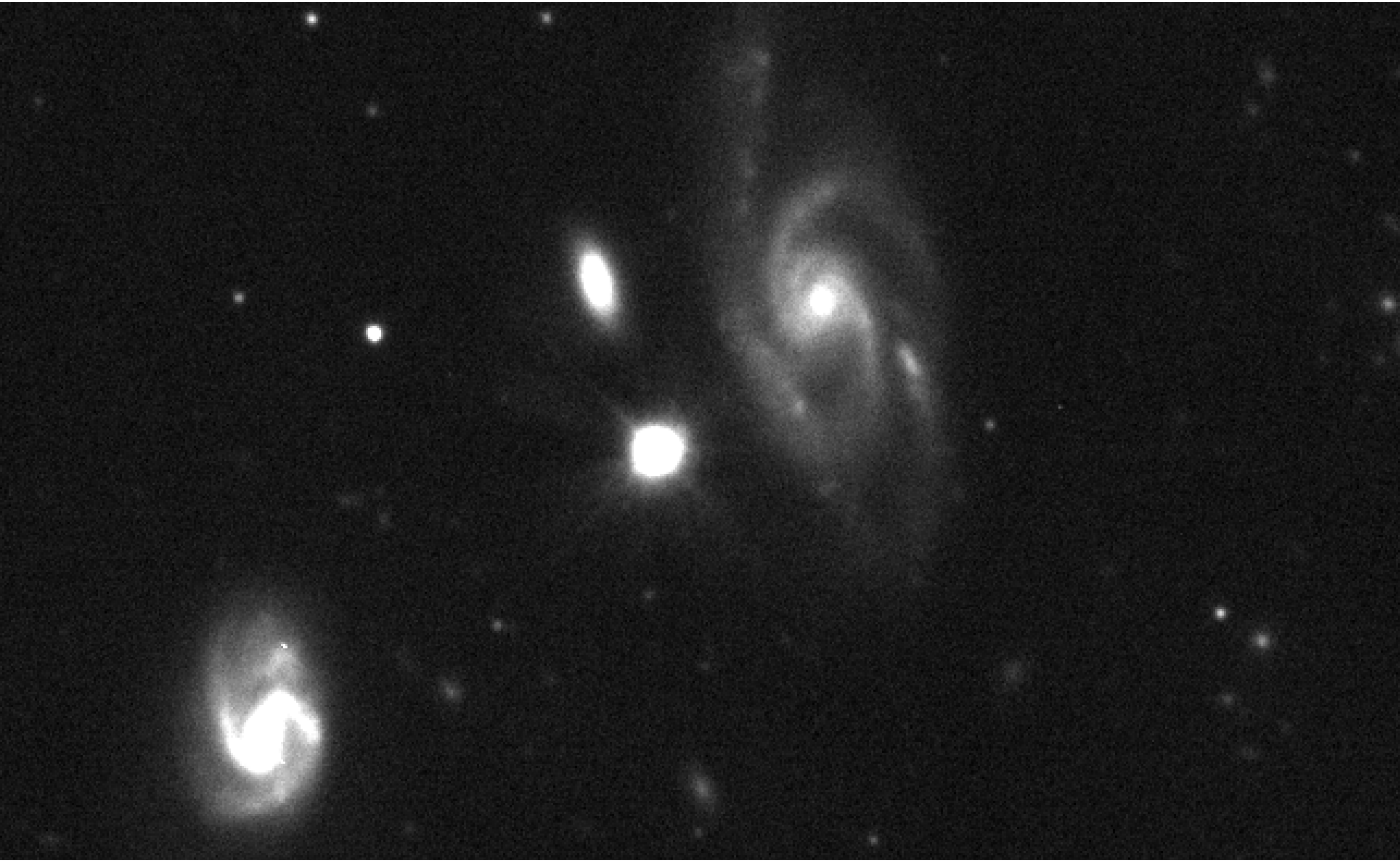

MQS J052402.28−701108.7 z=0.151
17
17.5
17
17.2


16.5
17.0
17.5
18.0
18.5
19.0
5500
6000
6500
7000
7500
A
B
C
D

DEEP OGLE SKY



OGLE http://ogle.astrouw.edu.pl



CELEBRATING 25 YEARS OF THE OGLE PROJECT

JULY 24 – 28, 2017
WARSAW UNIVERSITY, POLAND

TOPICS INCLUDE

- Variable Stars
- Magellanic Clouds
- Transients
- Planets
- Microlensing
- Galactic Structure
- Distance Scale
- Supernovae
- Star Clusters
- Large-scale Surveys

INVITED SPEAKERS

GIUSEPPE BONO
Universita di Roma Tor Vergata

LAURENT EYER
University of Geneva

SCOTT GAUDI
Ohio State University

ANDREW GOULD
MPIA / KASI / OSU

SHUDE MAO
Tsinghua University / National Astronomical Observatories of China

MARK PHILLIPS
Carnegie Observatories

PAUL SCHECHTER
MIT Kavli Institute for Astrophysics and Space Research

ANDRZEJ UDALSKI
Warsaw University Observatory

`http://ogle25.astrouw.edu.pl/` `ogle25@astrouw.edu.pl`

Photo by Yuri Beletsky