BA
for Backyard Astrophysics

22 years CBA Belgium
Celebrating two decades of CCD photometry

Pro-am collaboration leads to the discovery of a Mildly Cold Neptune exoplanet during the brightest planetary microlensing event

Tonny Vanmunster
Vereniging voor Sterrenkunde VVS
CBA Belgium Observatory
CBA Extremadura Observatory
tonny.vanmunster@gmail.com
www.cbabelgium.com

4th European Variable Star meeting (EVS)

Public Observatory MIRA, Grimbergen, Belgium

September 14 -15 2019

Statement

Advancement in Amateur Astronomy has been larger

over the last few decades

than in >20 centuries together

Consequence

Skilled and motivated amateurs,

supported by technological innovation, can now

effectively participate in scientific research projects

resulting in outstanding pro-am collaborations

ontents

1. Pro-am photometry collaboration opportunities
2. Exoplanet detection methods
   a) Transit method
   b) Gravitational Microlensing method
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Pro-am photometry
Collaboration opportunities

Cataclysmic variables

C. Knigge - 14 Sep @13:30-14:15

- Natural "laboratories" for studying accretion-disk physics (has relevance in other contexts around the universe)
- Suitable par excellence for setup of global citizen-science networks dedicated to photometric study of CVs
- **Pro-am networks:** CBA (Prof. Dr. J. Patterson, Columbia Univ, NY) and VSNET (Dr. T. Kato, Kyoto Univ, Japan)

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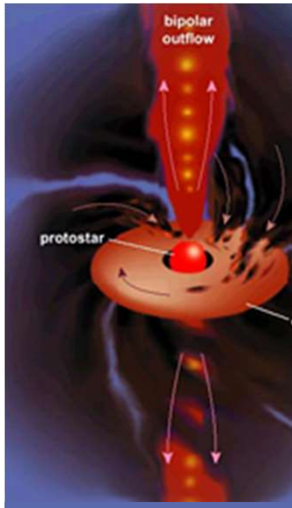
oung Stellar Objects YSO

D. Froebrich - 15 Sep @10:15-10:45

- Study star formation and formation of (terrestial) planets in circumstellar material, such as protoplanetary disks
- Understand YSOs variability through intense multi-filter photometric monitoring
- **Pro-am networks:** HOYS-CAPS (Dr. Dirk Froebrich, Univ of Kent, UK) → 17 young clusters/regions and several additional targets selected from Gaia Photometric Alerts



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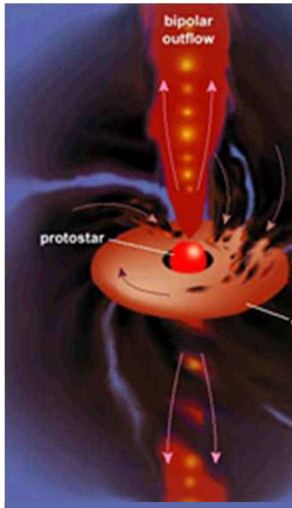

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hite dwarfs with planetary debris B. Gänsicke - 14 Sep @09:15-10:00

- Study accretion of planetary debris onto white dwarf systems
- Professionals rely on spectroscopy to determine geometry of metal distribution on white dwarf
- But: many white dwarfs are pulsating. Important to know pulsation mode at time of spectroscopy. Pulsation mode: photometry by ama
- **Pro-am networks:** ad-hoc and point-to-point pro-am collaborations (e.g., Prof. B. Gansicke, Univ of Warwick, UK)

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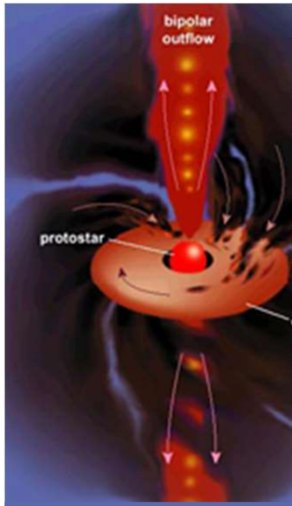

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Young Stellar Objects YSO

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White dwarfs with planetary debris

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High Amplitude Delta Scuti stars

P. Wils - 14 Sep @17:30-18:00

- Study O-C variations in light curves to detect and analyse period changes
- **Network:** HADS collaboration within Belgian Variable Star Section (P. Wils, VVS)

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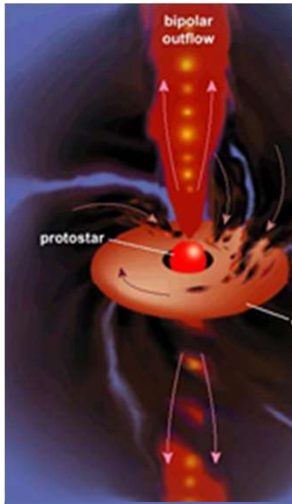

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any more: Exoplanets, Gravitational Microlensing, Red dwarfs with terrestial planets, …

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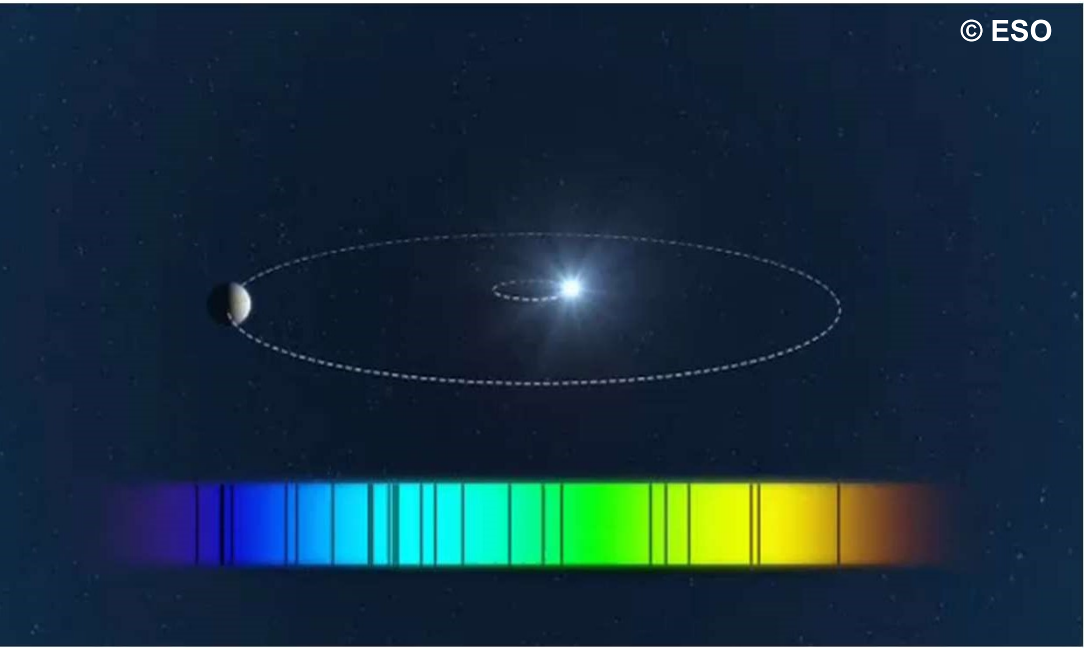
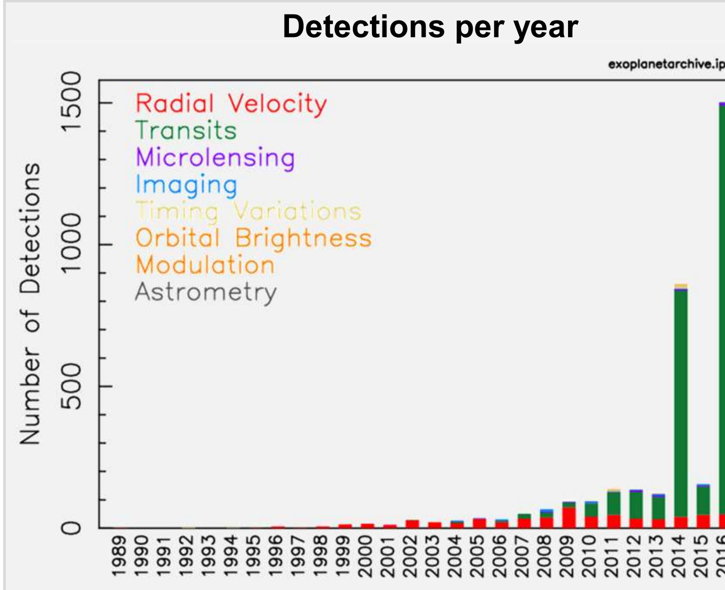
Exoplanet detection methods

043 exoplanets confirmed per mid August 2019

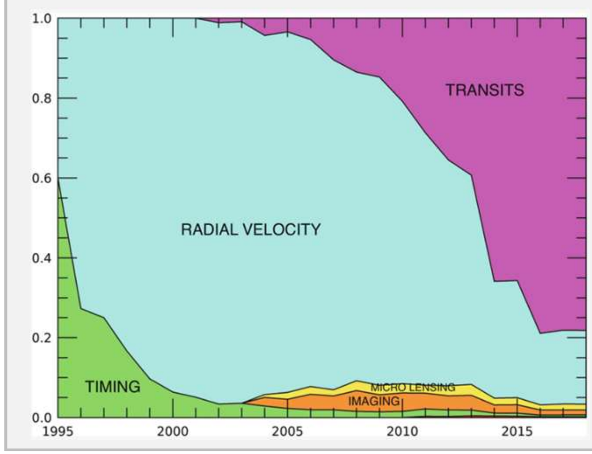
lost common detection methods:

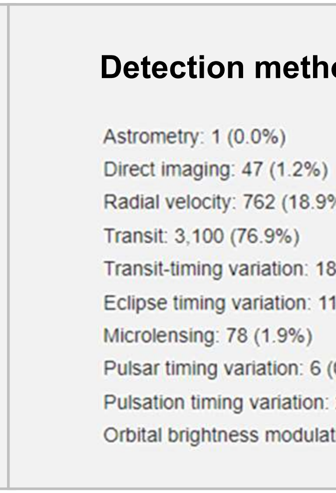
Radial velocity





(c) Handbook of Exoplanets, Hans J. Deeg et al., 2018





Exoplanet detection methods

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lost common detection methods:

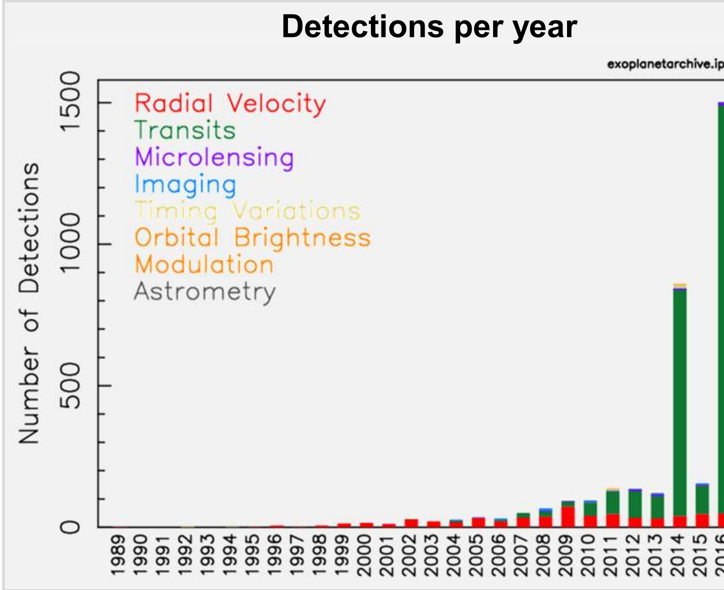
Radial velocity

Transit photometry

Gravitational microlensing

Direct imaging

Astrometry (see Gaia)



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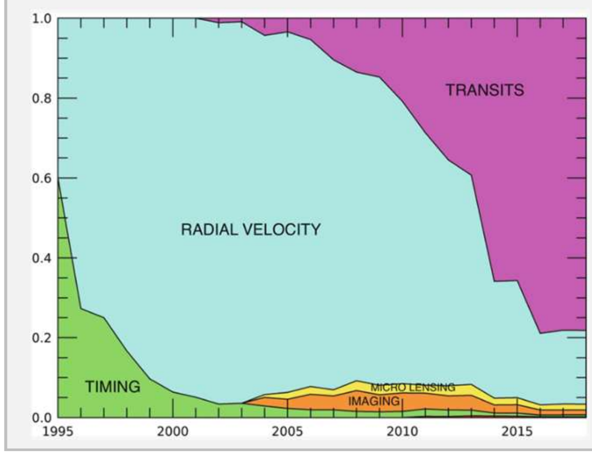


Detection meth

- Astrometry: 1 (0.0%)
- Direct imaging: 47 (1.2%)
- Radial velocity: 762 (18.9%
- Transit: 3,100 (76.9%)
- Transit-timing variation: 18
- Eclipse timing variation: 11
- Microlensing: 78 (1.9%)
- Pulsar timing variation: 6 (
- Pulsation timing variation:
- Orbital brightness modulat

ontents

ansit photometry
inciple

asure dimming of star as exoplanet transits between it and Earth.

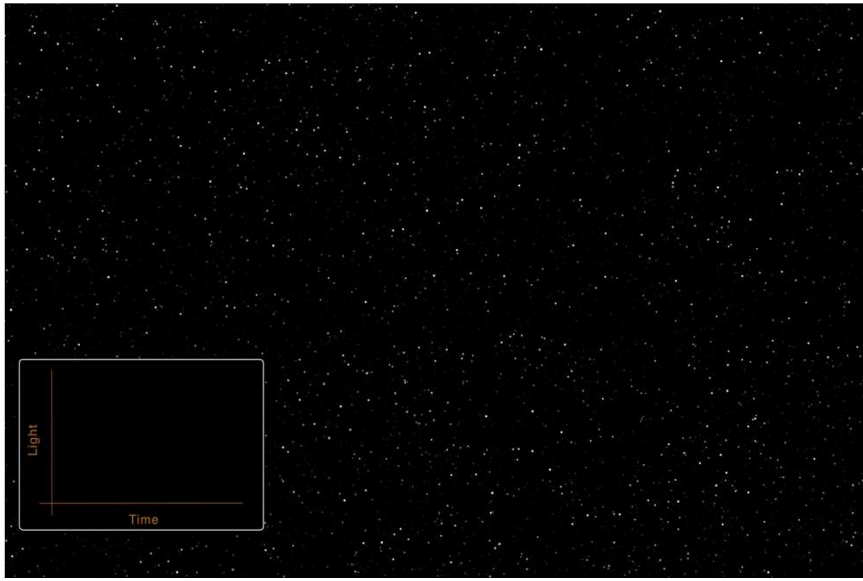
nsit photometry gives good estimate of the orbiting planet's size, not its mass. Excellent complement to spectroscopic method, which vides estimate of a planet's mass, but not its size.

y powerful method:

- Measure transit depth at different wavelengths ➔ recreate absorption spectrum and deduce composition of exoplanet **atmosphere**.
- 'Subtract' star's light spectrum when exoplanet is hidden, from spectrum when it is visible ➔ derive exoplanet's actual spectrum ➔ deduce **temperature** & composition of atmosphere.

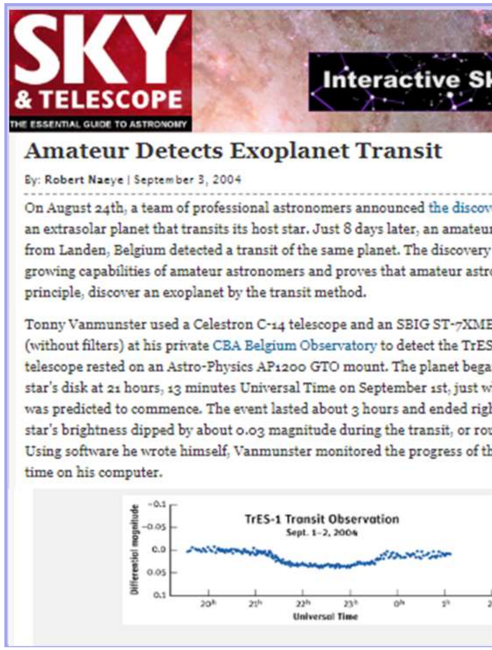
nsit searches:

- Automated ground-based surveys (e.g., WASP, HAT/HATS, KELT, NGTS, …)
- Space-based observatories. E.g., Kepler monitors 145K stars and detected 2345 confirmed exoplanets. TESS is successor, now started hunting.



ansit photometry
o-am collaborations

st pro-am collaboration to search for exoplanets by transit photometry was launched in 02 and called **Transitsearch.org** (Dr. Greg Laughlin). Inspired by **first exoplanet transit servation** made by Finnish amateurs at the Nyrölä Observatory on Sep 16, 2000, using a cm telescope (HD 209458).


SKY & TELESCOPE
THE ESSENTIAL GUIDE TO ASTRONOMY
Interactive Sk

Amateur Detects Exoplanet Transit

By: Robert Naeye | September 3, 2004

On August 24th, a team of professional astronomers announced the discov
an extrasolar planet that transits its host star. Just 8 days later, an amateur
from Landen, Belgium detected a transit of the same planet. The discovery
growing capabilities of amateur astronomers and proves that amateur astro
principle, discover an exoplanet by the transit method.

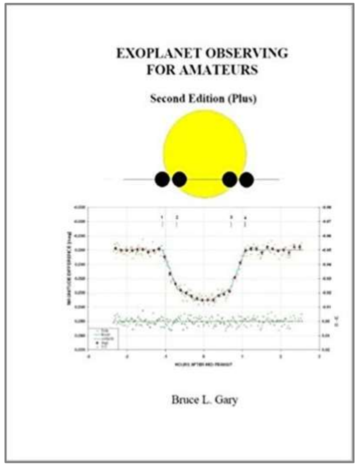
Tonny Vanmunster used a Celestron C-14 telescope and an SBIG ST-7XME
(without filters) at his private CBA Belgium Observatory to detect the TrES
telescope rested on an Astro-Physics AP1200 GTO mount. The planet bega
star's disk at 21 hours, 13 minutes Universal Time on September 1st, just w
was predicted to commence. The event lasted about 3 hours and ended righ
star's brightness dipped by about 0.03 magnitude during the transit, or rou
Using software he wrote himself, Vanmunster monitored the progress of th
time on his computer.

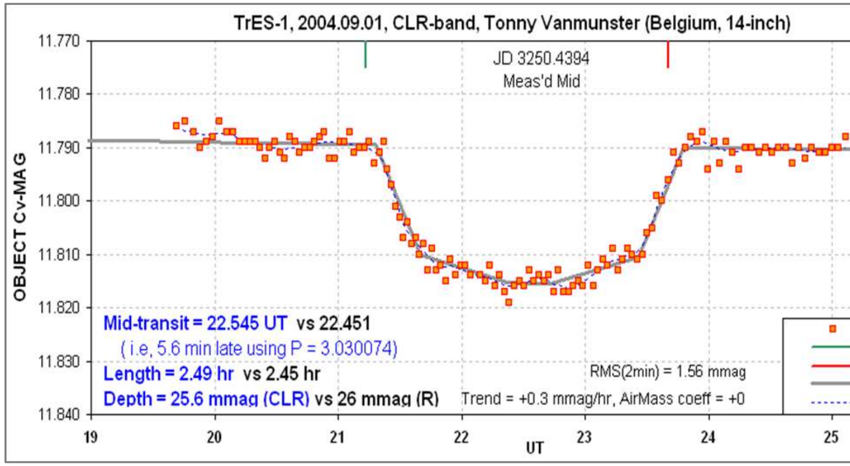
ES-1b discovery was announced by professional astronomers on Aug 24, 2004, and only ays later I was first amateur astronomer to confirm the 2% dip transit. Attracted lots of ention with a/o publications in Sky & Telescope and a dozen other magazines.

ortly afterwards, I was invited by Dr. Peter McCullough (Space Science Institute) to join **consortium**, together with 3 other amateurs. In 2005 we announced the discovery of **-1b**, the **first exoplanet co-discovered** by professionals and amateurs. We announced nore XO planet discoveries in 2007 and 2008.

lay, many pro-am collaborations to study oplanet transits, ephemeris refinements, transit e variations (TTV). See also **Exoplanet Transit tabase** ETD.

cellent book by Bruce L. Gary "*Exoplanet serving for amateurs*"





CBA Belgium Observatory
A robotic private observatory

- erational since 1996 and fully robotic since 2014
- serving cataclysmic variable stars, exoplanets, gravitational microlensing ndidates, YSO (Young Stellar Objects), High Amplitude Delta Scuti (HADS), ..
- ntributing observations to “Center for Backyard Astrophysics” CBA, AAVSO, NET, VVS Belgium and many professional astronomers …
- cm f/10.0 Meade telescope on Paramount ME-II
- IG STT-3200ME CCD, Moonlite CSL focuser, Johnson-Cousins filters
- Scopedome dome

Fully robotic observatory

- Opening/closing dome shutter
- Control of CCD camera and heating elements
- Successive “Slew to” selected targets
- Autofocus
- Plate solving for accurate mount positioning
- Selection of photometric filters
- Monitoring of sky conditions
- Optimisation for Belgian weather: dome shutter closes upon arrival of clouds, but auto resumes observing session when sky clears out

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Gravitational microlensing
Principle

avitational microlensing occurs when the light of a tant background (source) star is bent by a massive eground star resulting in an observable magnification.

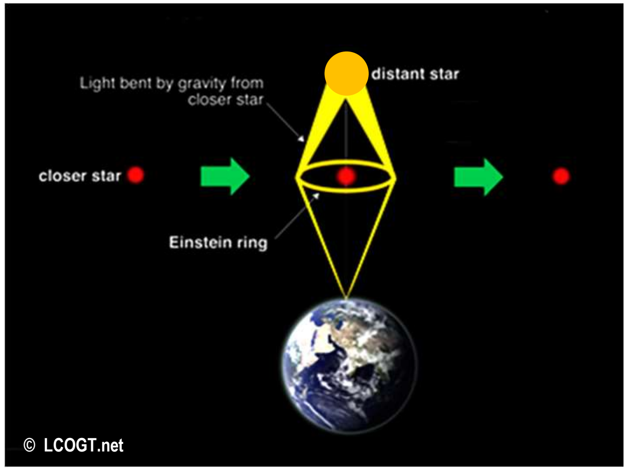
quires a perfect alignment between foreground and ckground star and earth, and is caused by the vitational field of the foreground star, acting as a lens.

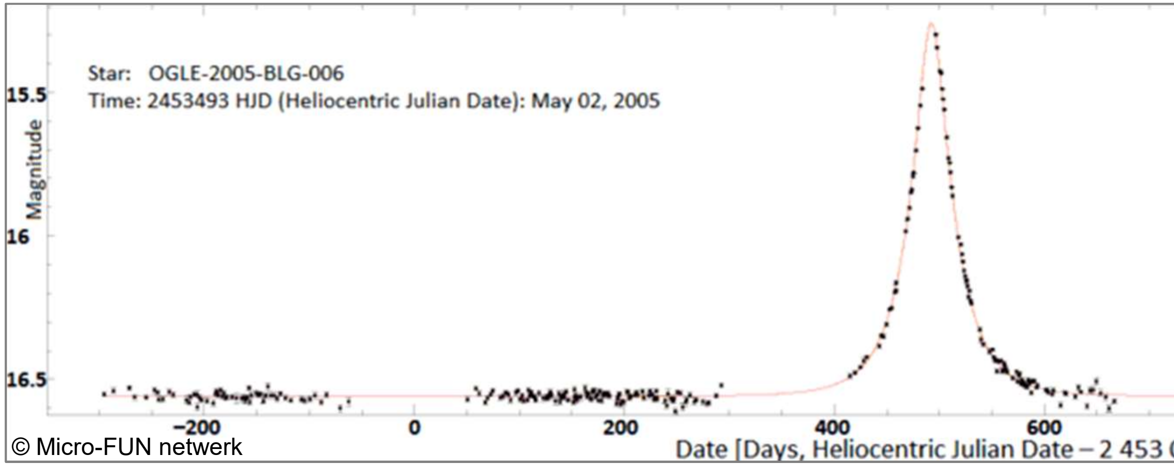
result is a an increase in brightness of the distant star a few weeks or months, depending on the mass of the eground star and the proper motion between the fore- d background stars.

edicted by Einstein in 1915 ("Einstein ring"). First ccessful microlensing observation in 1989.

y few microlensing events are observed annually side of Galactic bulge. Gaia space telescope nificantly increases chances of finding events.

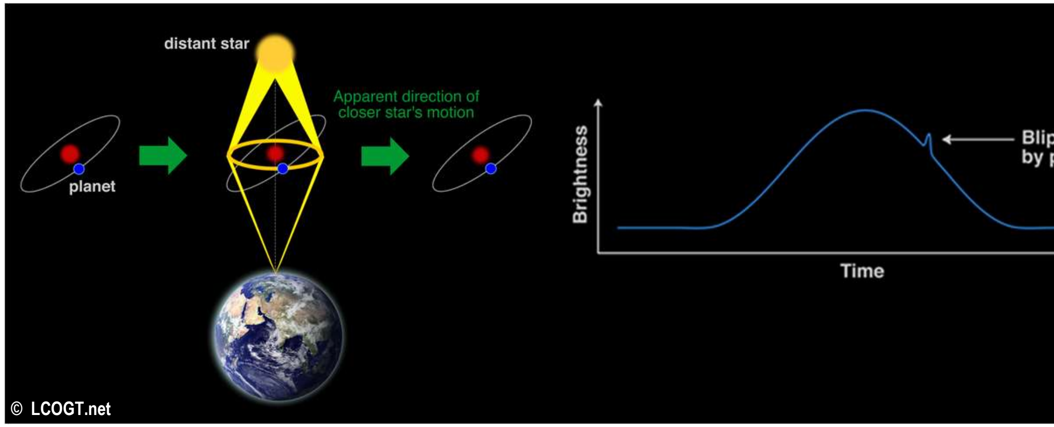
ateur astronomers can scientifically contribute by otometrically monitoring microlensing candidates





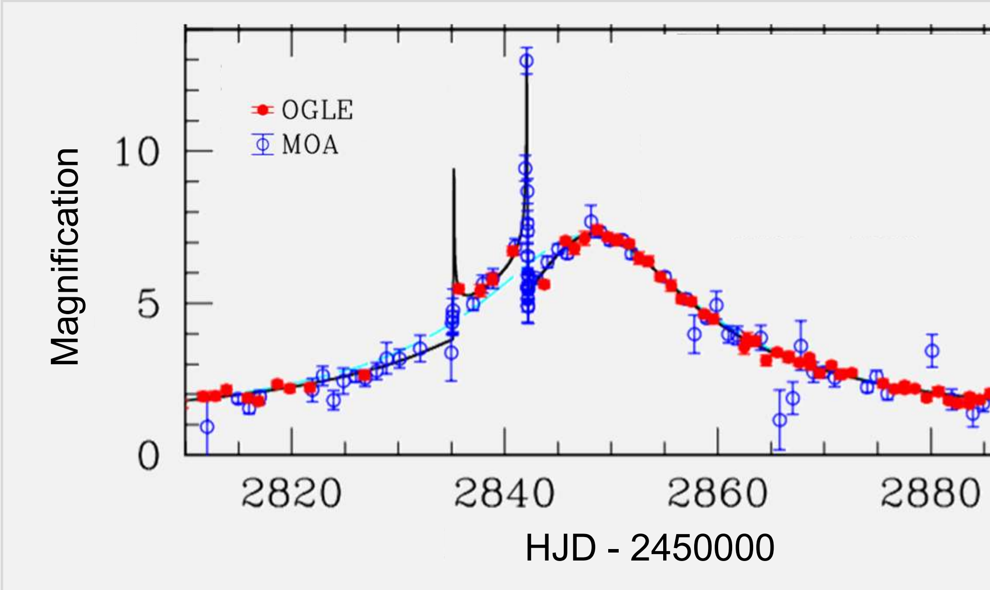
Gravitational microlensing
lost star with exoplanet

reground (host) star with exoplanet ➔ exoplanet also nds light of distant star, resulting in temporary spike of ghtness superimposed on regular microlensing lightcurve. sting several hours or days.



ows astronomers to deduce total mass, orbit and period of oplanet with high accuracy. Complementary to radial velocity d transit methods, as it is very effective at detecting low mass oplanets orbiting relatively far away from host star.

st exoplanet discovery through microlensing in 2003 by GLE/MOA (OGLE 2003-BLG-235).



OGLE 2003-BLG-235 lightcurve © OGLE/MOA

o-am microlensing networks on hunt for exoplanets

- **MicroFUN** (*Microlensing Follow-Up Network*): informal group of Southern hemisphere observers, founded in 2004 by Prof. A. Gould (Ohio State Univ). 23 observatories incl 16 amateur-run. Multiple success stories. Intensive cooperation with OGLE team lead by A. Udalski, Warsaw Univ, Poland and MOA at Univ of Canterbury, NZ.
- **Pro-am network of Dr Lukasz Wyrzykowski** (Warsaw Univ, Poland). Intense photometry of GAIA alerts with microlensing potential.

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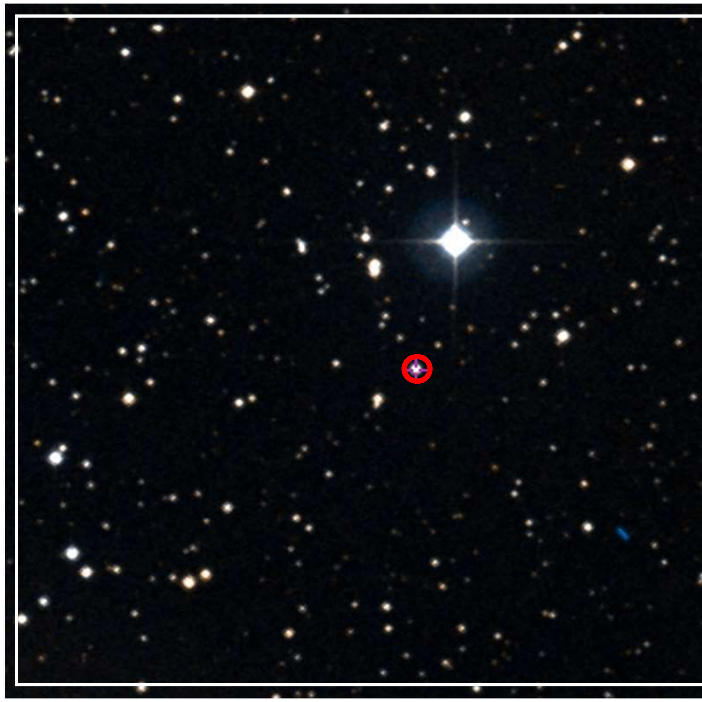
Exoplanet pro-am collaboration
Discovery of a Neptune exoplanet through Gravitational Microlensing

t 25, 2017: amateur astronomer **Kojima** detects an unknown transient event a R = 13.6 mag star in Taurus. His object receives the designation TCP 5074264+2447555 (we refer to it as Kojima-1).



thin a few days, astronomers using spectroscopy conclude that the transient is nicrolensing event.

Oct 31, 2017, I started a time-series photometry session on Kojima-1 from my ckyard CBA Belgium Observatory, and uploaded my observations to the VSO database.

ey were independently picked up by astronomers **A.A. Nucita** (Univ of lento, Italy) and **Dr. Akihiko Fukui** (Okayama Astrophysical Observatory, pan)

urned out that my observations were crucial and pointed to an anomaly near the peak of the Kojima lightcurve, allow th astronomers to establish the planetary nature of this microlensing event. A. A. Nucita was the first to make nouncement (*The Astronomer's Telegram #10934*) using also anomaly observations obtained at the R.P. Feynr servatory by D. Licchelli (CBA Lecce, Italy).

Akihiko Fukui started an in-depth pro-am campaign and analysis of Kojima-1, using photometric, spectroscopic and h solution imaging. He obtained far more accurate results, which soon will be published in a paper, which I'm co-authoring.

Exoplanet pro-am collaboration

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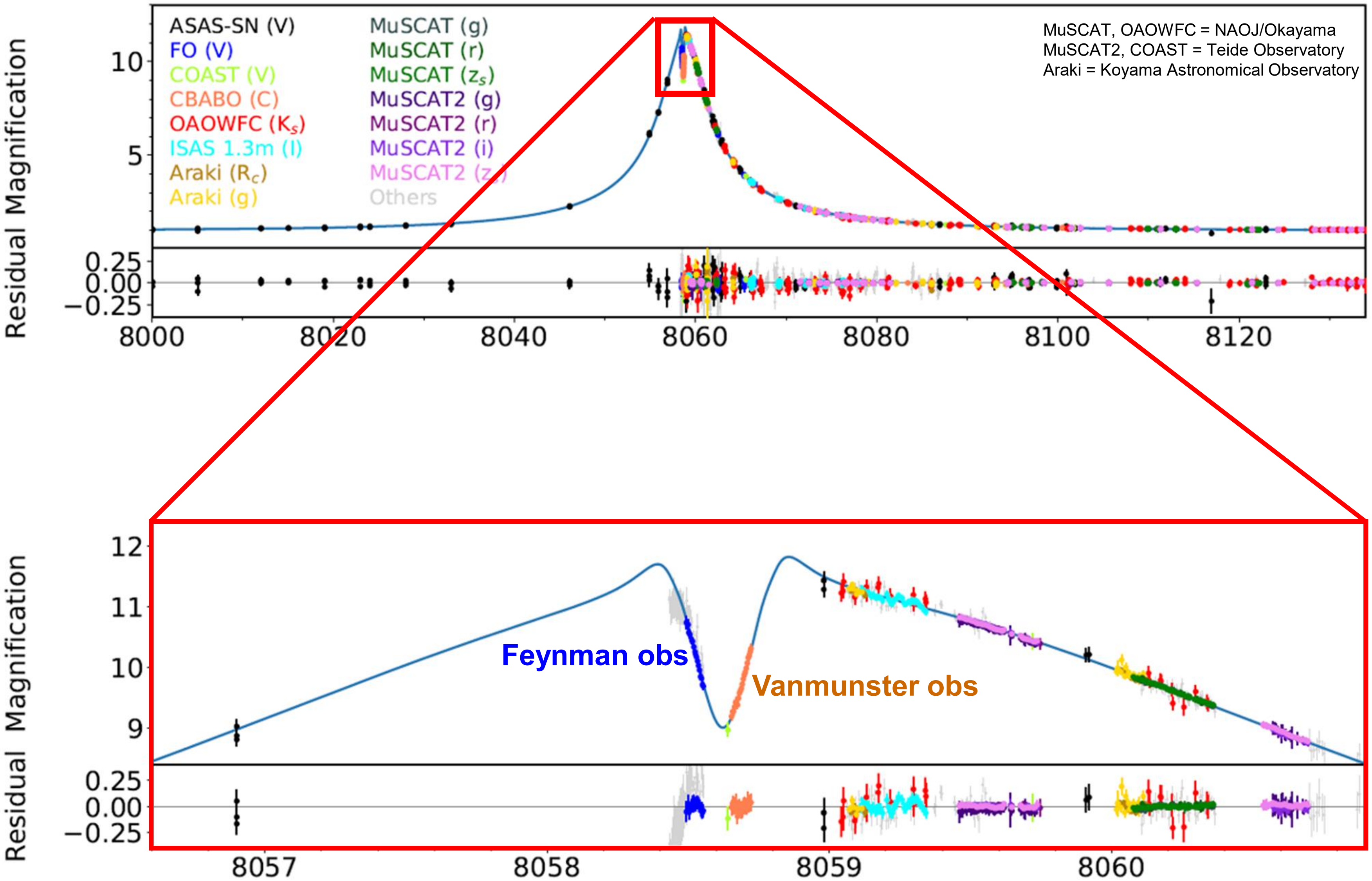

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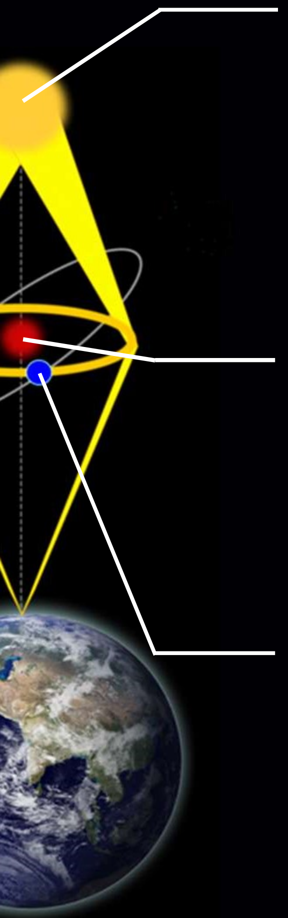
* Publication in press
** MNRAS, Volume 476, Issu



	Fukui et al. Results*	Nucita et al. Results**
Source	Late F-dwarf star V=14.151 ± 0.005 Effective temp = 6407 ± 81 K Radius = 1.49 ± 0.25 $R_{\odot}$ Distance = 800 ± 130 pc	F5V star V=14.151 ± 0.005 Effective temp = ~6700 K Radius = ~1.4 $R_{\odot}$ Distance = ~700-800 pc
Lens star	K/M-dwarf star Distance = 505 ± 47 pc Mass = 0.586 ± 0.033 $M_{\odot}$ Radius = 0.598 ± 0.062 $R_{\odot}$	Distance = ~380 pc Mass = 0.25 ± 0.18 $M_{\odot}$ Radius = unknown
Planet	Mildly cold Neptune Mass = 20.0 ± 2.0 $M_{\oplus}$ Separation = 0.88 ± 0.08 au Semi-major axis = 1.08 ± 0.62 au	Super Earth Mass = 9.2 ± 6.6 $M_{\oplus}$ Separation = ~0.5 au Semi-major axis = unknown

Model fit with binary-lens microlens model

ontents

CBA Extremadura Observatory in Spain
Second robotic private observatory

onclusion

Skilled and motivated amateurs,

supported by technological innovation, can now

effectively participate in scientific research projects

resulting in outstanding pro-am collaborations

Thank you!

Tonny Vanmunster
tonny.vanmunster@gmail.com
www.cbabelgium.com