Center for Backyard Astrophysics

22 years CBA Belgium
Celebrating two decades of CCD photometry

Pro-am Photometry Projects with Robotic Observatories

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Pro-am Photometry Projects with Robotic Observatories

Contents

- **Part 1: Two private robotic observatories:**
  CBA Belgium Observatory & CBA Extremadura Observatory

  - From a semi-automatic to a robotic observatory: CBA Belgium Observatory
  - CBA Extremadura Observatory: a new and fully robotic Spanish observatory
  - Practical experiences
  - Decision criteria for selecting a robotic observatory site

- **Part 2: Pro-am photometry projects driven by professional astronomers**
  within reach of amateurs with robotic observatories

  - Example projects: YSO, planetary debris around white dwarfs, microlensing events, HADS, …
  - Contributions amateurs can deliver
  - Why professionals are requesting amateurs to step in?

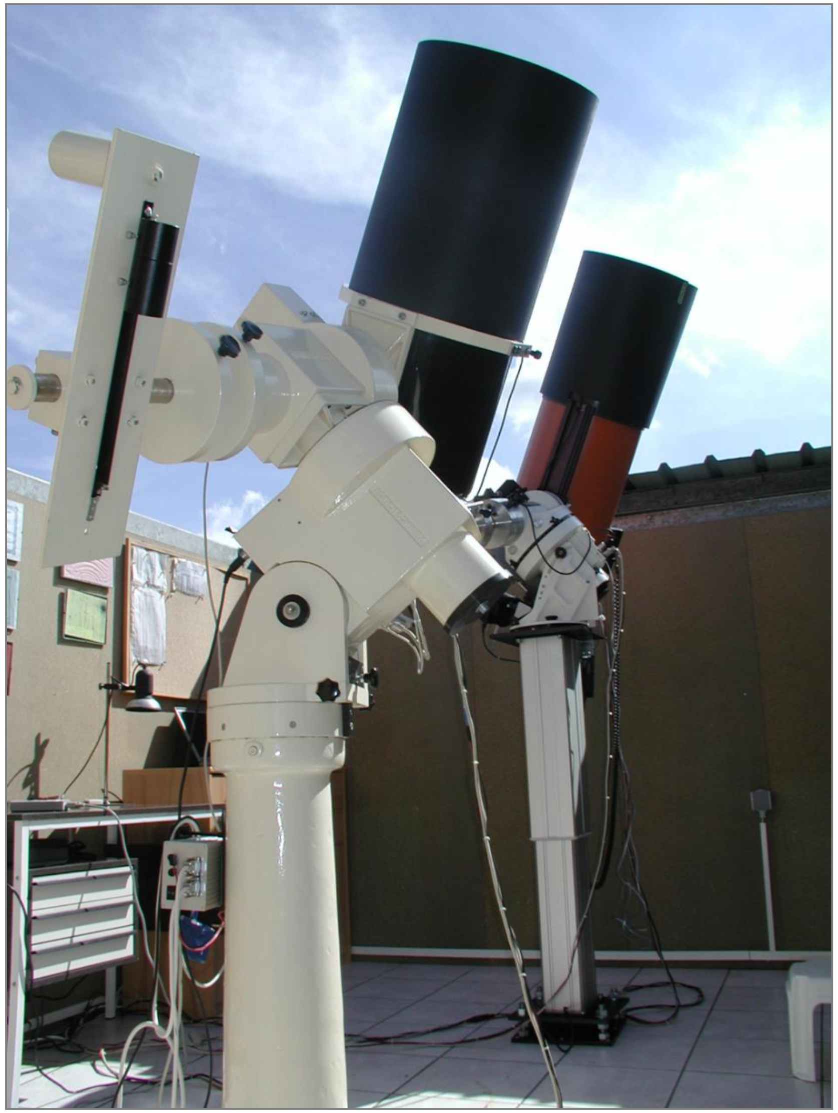
Semi-robotic observatory in Belgium

CBA Belgium Observatory (1996-2008)

- After more than 25 years of visual observations (mainly variable stars and meteors), I switched to CCD photometry in 1996.
- I built a first backyard observatory, which was operational from 1996 till end of 2008.
- ~400,000 CCD photometry observations predominantly of cataclysmic variables and exoplanet transits.
- Observations were submitted to CBA, AAVSO, XO, Transitsearch and other organisations.

CBA Belgium Observatory was remotely controlled and autonomously operated all night long without human intervention, except for roof opening/closure.

Robotic observatory in Belgium
CBA Belgium Observatory (1996-2008)



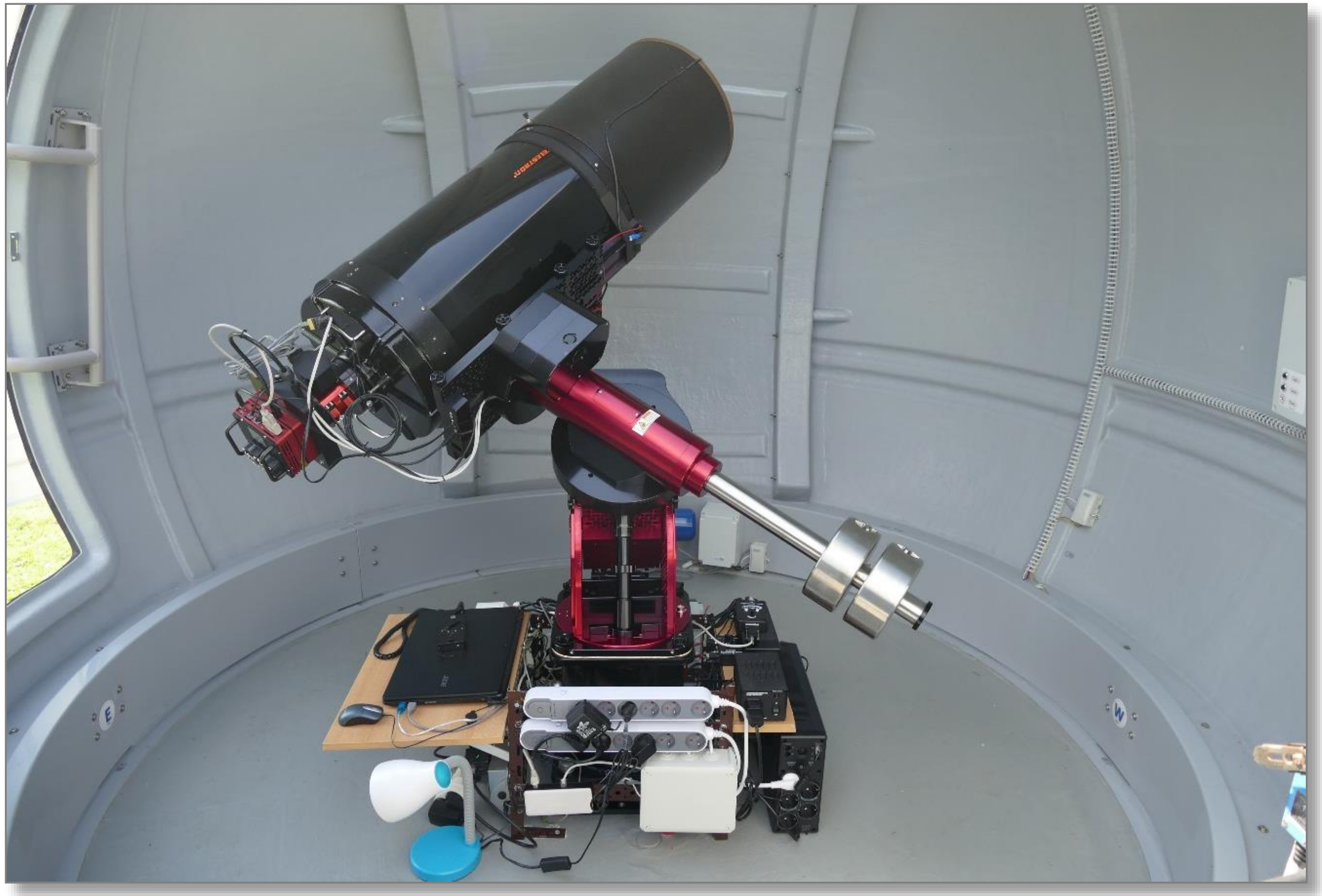
The observatory featured two 0.35-m (14”) f/6.3 Celestron telescopes on computerized mounts, each equipped with an SBIG ST-7XME CCD camera and Optec TCF-S focuser.

Robotic observatory in Belgium

CBA Belgium Observatory (2014-present)

- May 2014: started plans to build a **fully robotic backyard observatory**.
- **Requirements**: work **fully autonomously** on clear nights: open shutter, cool CCD camera, heat dew removers, slew telescope to target, autofocus, acquire series of images, move to next target and so on, till morning twilight appears. Then turn off all equipment, move telescope back to home position, close dome shutter, etc.
- Has to have **intelligence** to detect clouds, in which case it has to close dome shutter, with the ability to **autonomously resume** observations if skies become clear again.
- **First light** in October 2014. Opted for 3-m ScopeDome dome with motors to operate shutter and rotate dome.

Robotic observatory in Belgium
CBA Belgium Observatory (2014-present)



Dome initially housed a **Celestron 0.35-m f/6.3** telescope on a **Paramount ME II** with SBIG STT-3200ME multi-filtered CCD camera. Sky conditions are controlled through AAG CloudWatcher.

Early 2017, telescope upgraded to a **Meade 0.40-m f/10.0**

Setup of second robotic observatory
Motivation and selection of target location

- Used to cloudy winter skies in Benelux, but winter of 2017/2018 was very exceptional with only 10.5 hours of sunshine during December 2017. January 2018 was not any better: 11 minutes (!) between January 3 – 12.

- My CBA Belgium Observatory remained unused for several weeks in a row, driving me nuts.

- Just before Xmas holiday period, I started to explore options to setup an additional robotic observatory at a location with (much) more favourable weather conditions.

- By the end of the Xmas holiday period my plans were firm and 90% of the decisions were made (location, equipment, …)

- **Selection criteria**: eliminated remote facilities with 1 central roof for all telescopes; sites with no on-site supervision/support; too expensive sites, etc.

- **Accessibility**: location had to be within “easy travel” range (max few hours flight distance) but still offering a fair amount of clear nights.

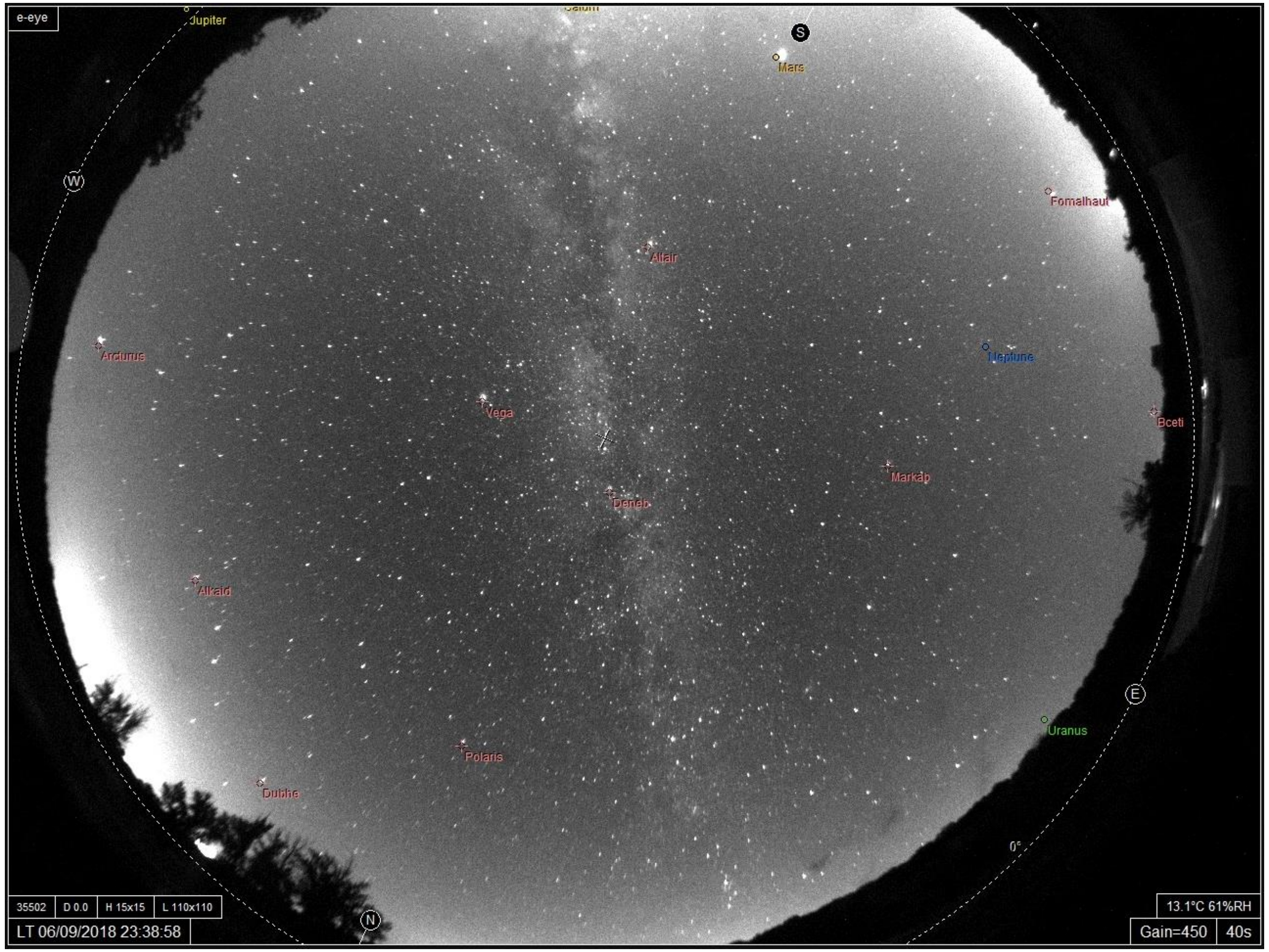
- Finally opted for **e-EyE “Entre Encinas y Estrellas” astronomical complex** in *Fregenal de la Sierra* (Extremadura, Spain)

E-EyE

https://www.entreencinasyestrellas.es

Robotic observatory in Spain

CBA Extremadura Observatory (2018-present) @ e-EyE astronomical complex



- **e-EyE astronomical complex** is run by Jose Luis Quiñones, who is a passionate amateur astronomer.

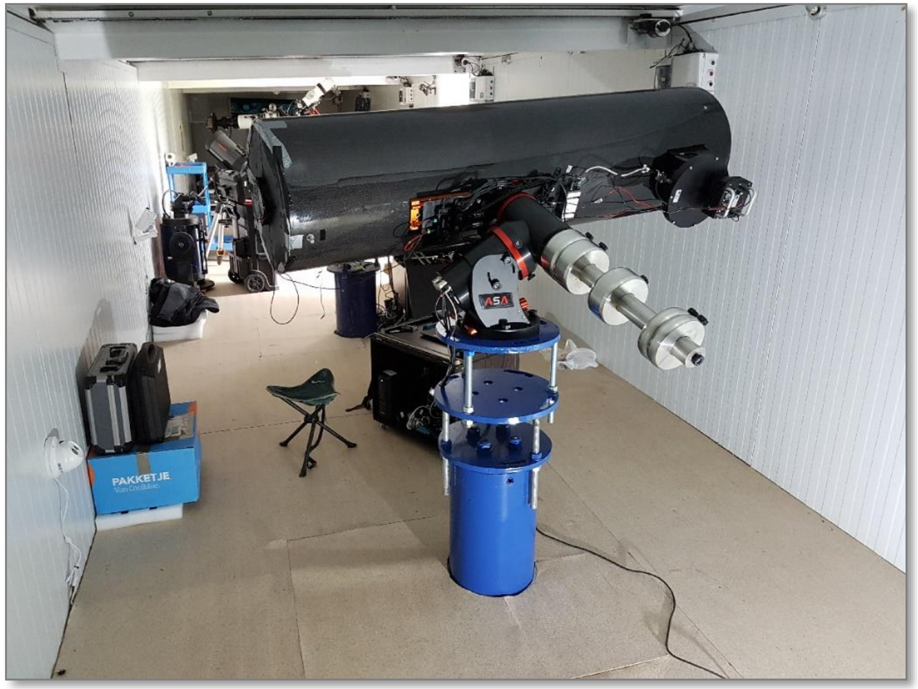
- e-EyE meanwhile has become the largest facility in Europe renting astronomical observatories and benefits from excellent sky conditions: around 250-270 clear nights per year and an average SQM of 21.7.

- Each modular complex at e-EyE consists of 8 independent observatories, equiped with a pier on which you install your own equipment. e-EyE provides all logistics (electricity, very high speed Internet, …). Complex #7 under construction.

- Support by e-EyE staff is excellent: very responsive and qualified people, charging affordable service fees.

Robotic observatory in Spain
CBA Extremadura Observatory (2018-present)

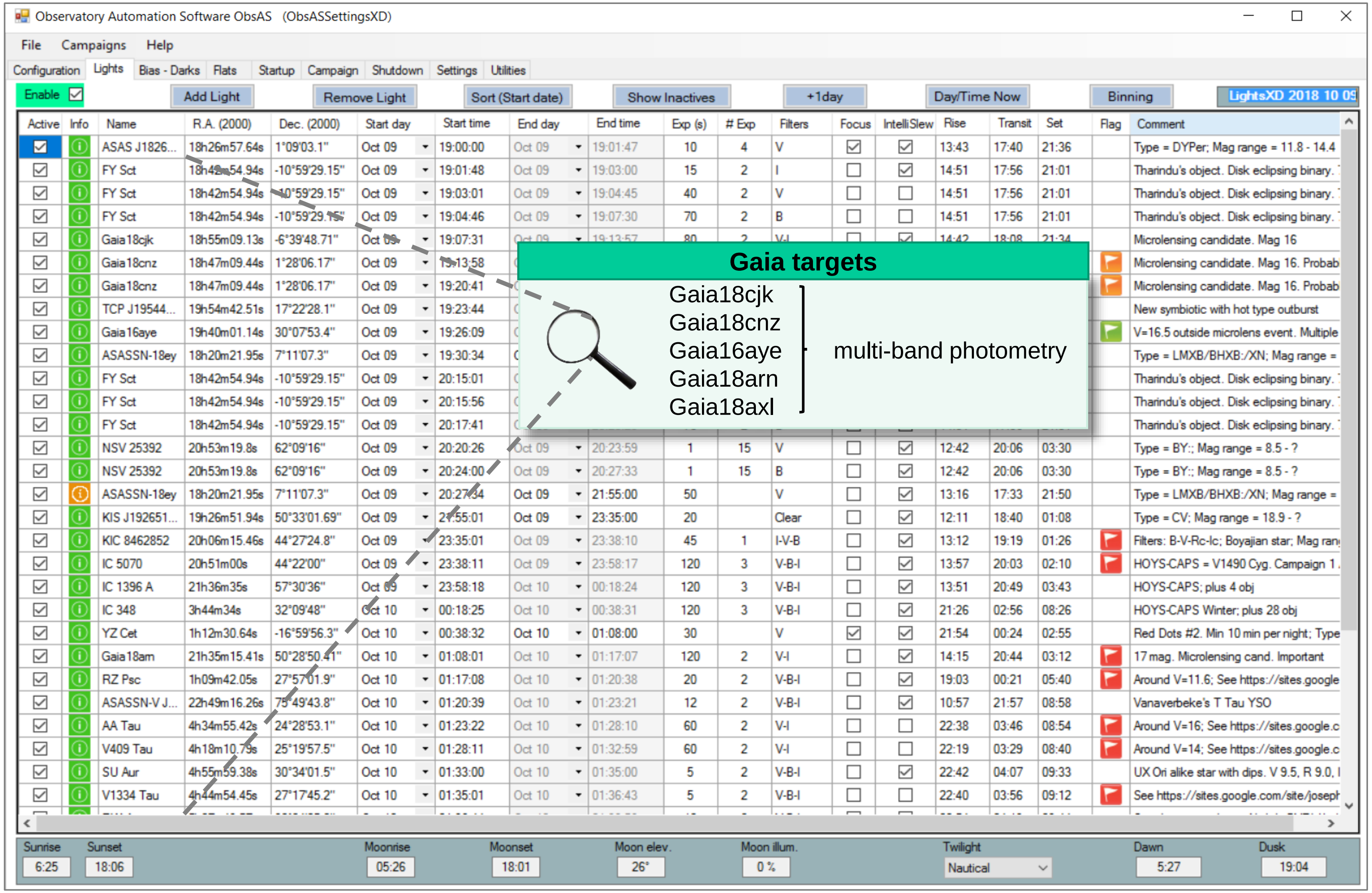
CBA Extremadura Observatory
May 2018 – first light



CBA Extremadura Observatory hosts a **0.40m f/5.1 Newton telescope** on an **ASA DDM85** direct drive mount, with a **Starlight Xpress SX46** CCD camera, using an Integra85 focuser and rotator.
The roll-off roof structure is controlled by Talon6 hard- and software.

Robotic observatory observations

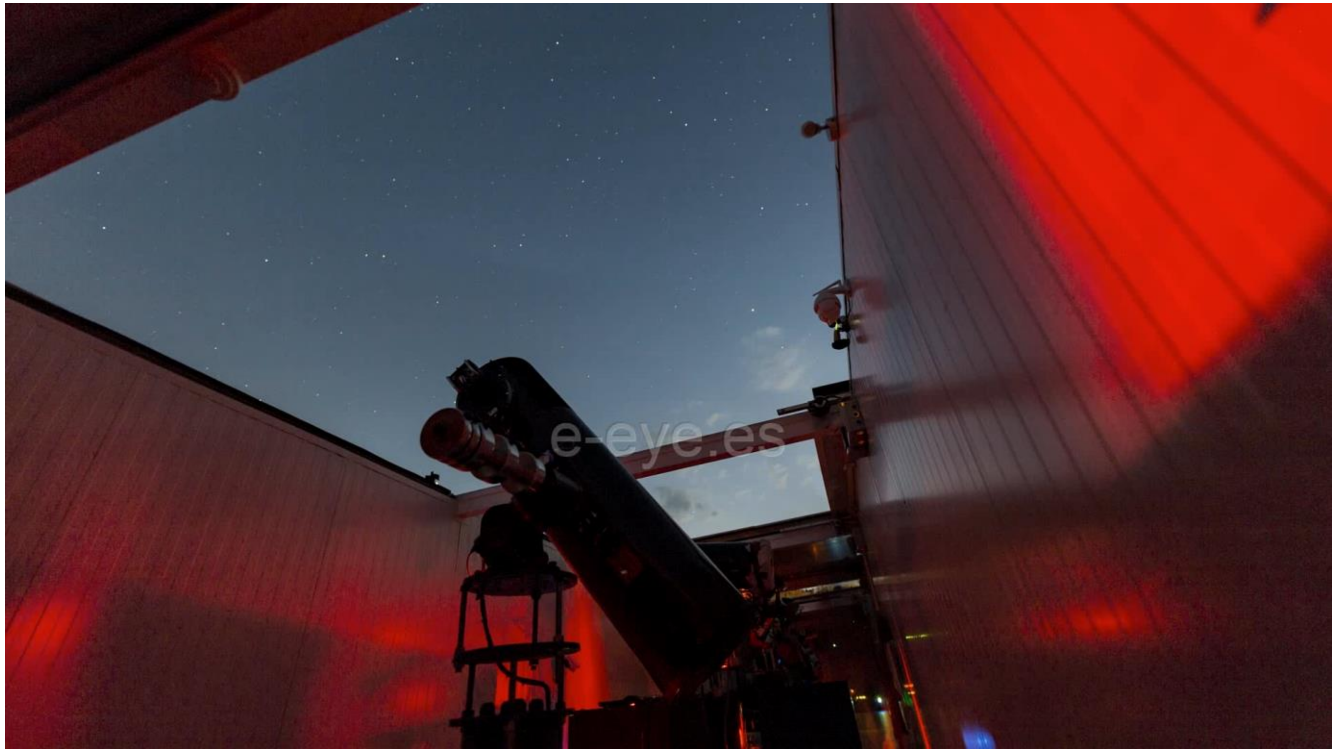
Example of a nightly observing schedule

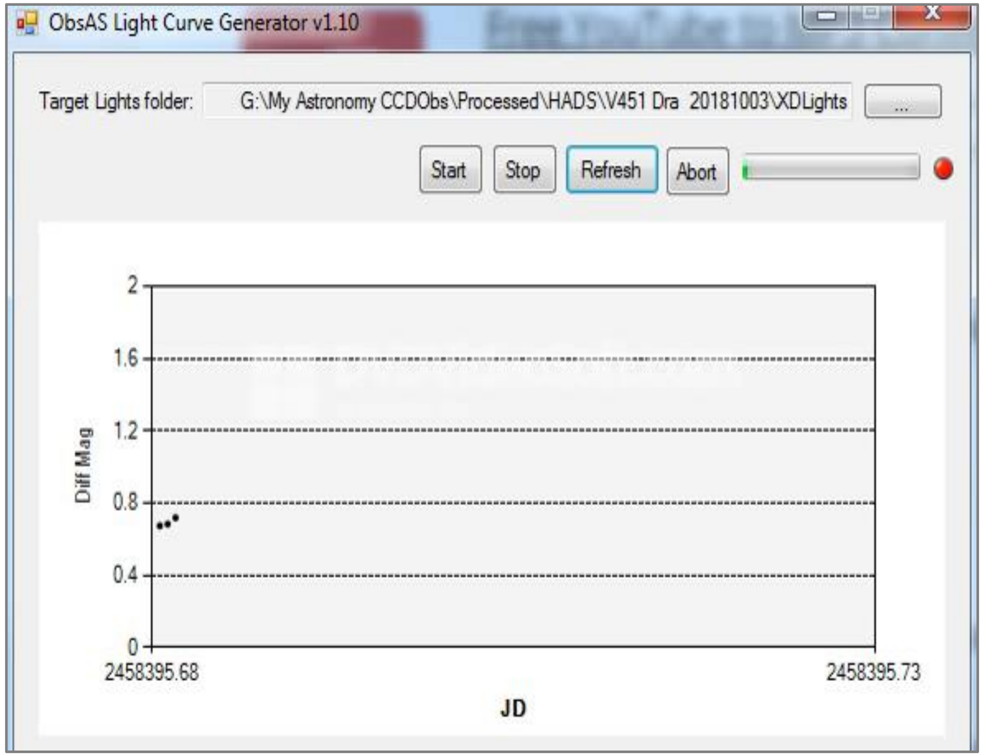


- Mixture of time-series (multi-hour) and snapshot (few images) photometry
- Mixture of cataclysmic variables, R CrB stars, symbiotic stars, Young Stellar Objects with suspected planet forming disks, Red dwarfs with possible terrestrial planets, microlensing events, etc.
- Some targets are observed in parallel (telescope moves to target 1, takes exposure, moves to target 2, takes exposure, moves back to target 1, and so on). Others sequentially.
- Single filter and multi-filter (UBVRI) photometry
- Scheduler is part of self-written **ObsAS** (Observatory Automation Software) programme.

Robotic observatory observations

CBA Extremadura in action





If weather conditions are excellent at both observatories, we accumulate:

- **> 10 hours** of continuous CCD photometry during a single summer night
- **> 25 hours** of continuous CCD photometry during a single winter night

Over 20 years of CCD photometry

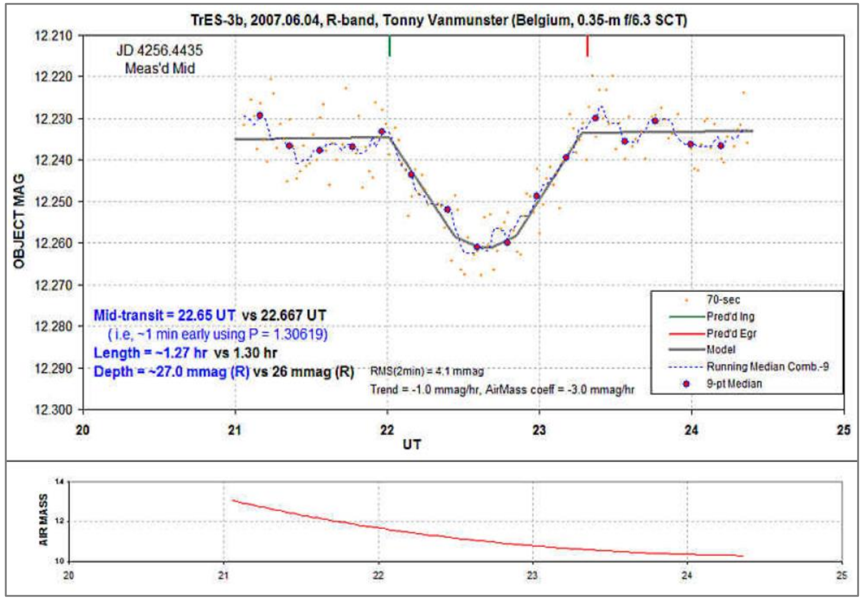
Some achievements …

- Doing CCD photometry since 1996, working primarily on cataclysmic variable stars for the Center for Backyard Astrophysics (CBA) headed by Prof. Dr. Joe Patterson (Columbia Univ, NY)
- Detection of superhumps in ~100 dwarf novae, allowing to establish their subtype classification
- Discovery of supernova 2002jy
- First amateur to detect a transit of exoplanet TrES-1 in 2004
- Co-discovery of exoplanet XO-1b in 2005 together with Dr. Peter McCullough (Space Science Institute). Co-discovery of 4 more XO exoplanets in 2007 and 2008
- Nov 2017 observations of a Gravitational Microlensing event allowed professionals to detect a Neptunian exoplanet in TCP J05074264+2447555 (Kojima event)
- Following setup of CBA Extremadura Observatory, I have extended my observing schedule to include observations of Young Stellar Objects, and to search for planetary debris around white dwarfs, terrestrial planets around nearest red dwarfs, etc.
- I have co-authored 124 publications in specialized journals (PASP, PASJ, JAAVSO, SASS, MNRAS, AN, JBAA, ApJ, ..). *Source: ADS Astrophysics Data System*
- Observations are submitted to AAVSO, CBA, VVS Wgr Veranderlijke Sterren (HADS), HOYS CAPS (YSO), Red Dots #2 (red dwarfs), VSNET, …. Close to 550.000 CCD observations.

Minor planet (340071) Tonnyvanmunster

In 2014, the International Astronomical Union (IAU) decided to name minor planet (340071) *Tonnyvanmunster*. The announcement text was:

(340071) Tonnyvanmunster = 2005 VF82
Discovered 2005 Nov. 9 by P. De Cat at Uccle Observatory, Belgium. Tonny Vanmunster (b. 1961) is a Belgian amateur astronomer, active in the Pro-Am collaborative research on photometric studies of cataclysmic variables, (co-)author of many papers on variable stars and author of Peranso, a widely used period-search software. Name suggested by P. Van Cauteren and P. Lampens.



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Pro-am Photometry Projects with Robotic Observatories

1. Gravitational microlensing events
2. Young Stellar Objects (YSOs)
3. Planetary debris around White Dwarfs
4. High amplitude Delta Scuti stars (HADS)
5. Cataclysmic Variables

1. Gravitational microlensing

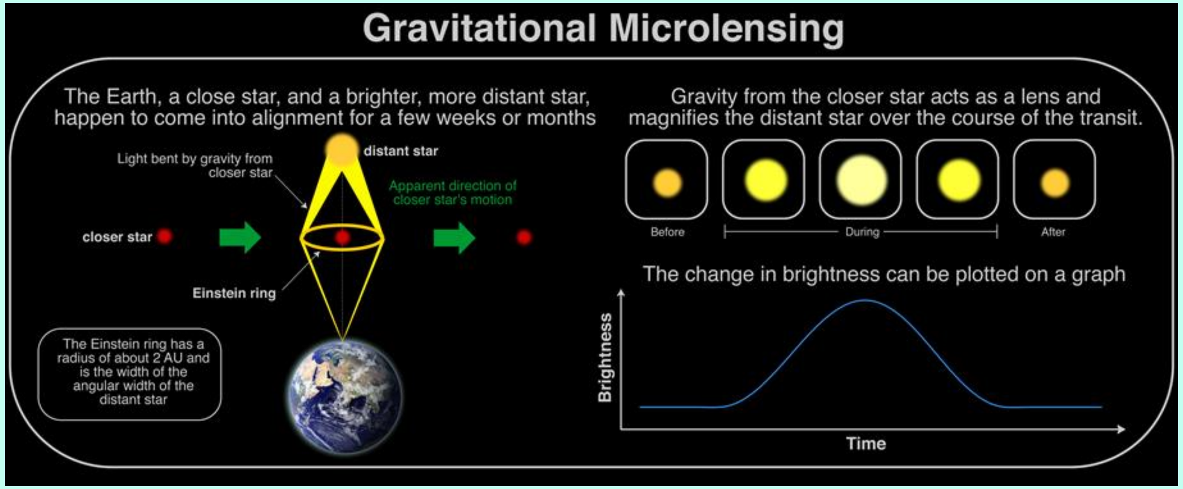
Gravitational Microlensing

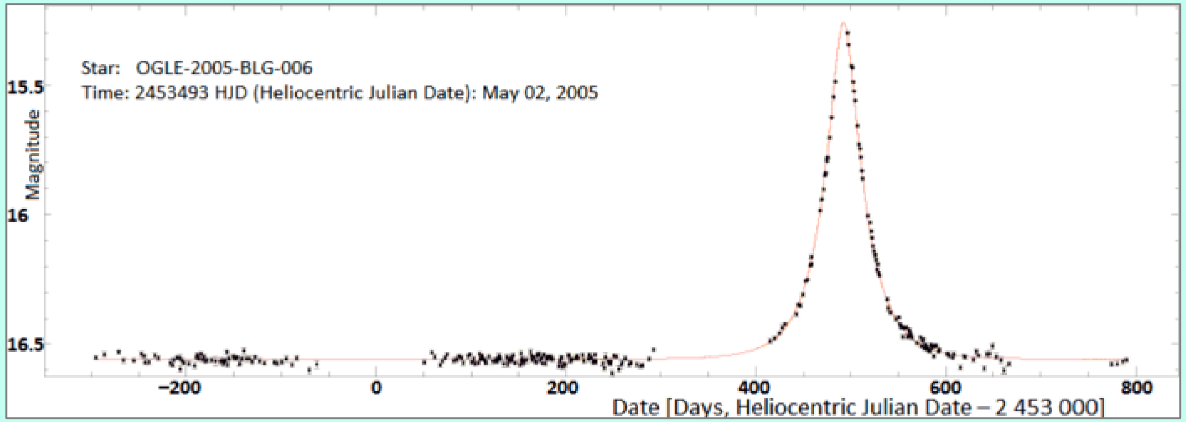
What? | Contribution by amateurs | Pro-Am collaboration | Results

Gravitational microlensing is caused by a gravitational lens effect. When a distant star gets aligned with a massive compact foreground star, the light of the distant star will bend due to the gravitational field of the foreground star and results in an observable magnification of the distant star. The foreground star acts as a 'lens'.

The time-scale of the transient brightening depends on the mass of the foreground star and on the relative proper motion between the background 'source' and the foreground 'lens' object.

Microlensing allows astronomers to detect and study objects orbiting the foreground star, no matter how faint they are, with masses ranging from a planet to a star. It is thus an ideal technique to study f.i. brown dwarfs, detect exoplanets, etc. First event detected in 1989.





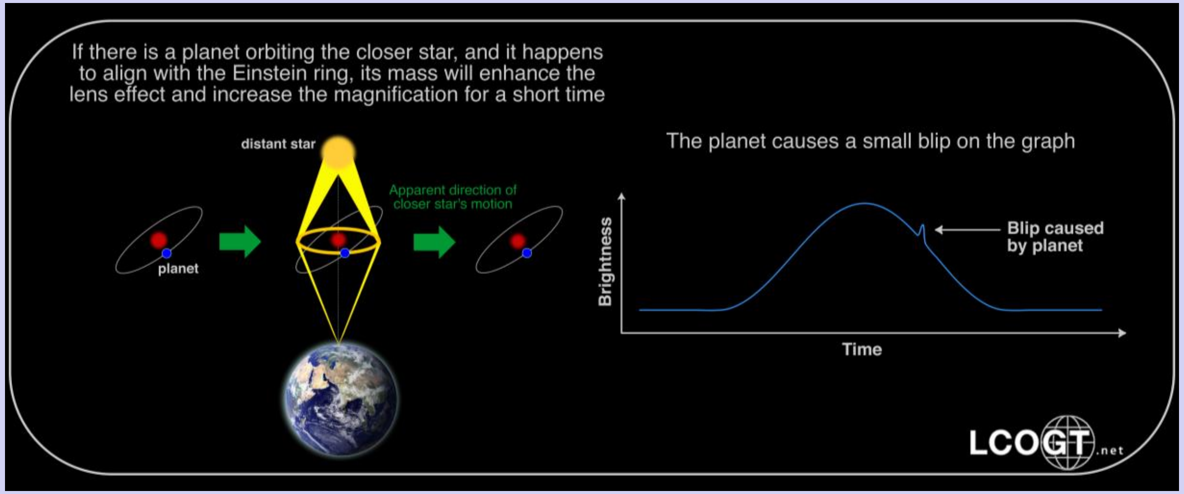
Gravitational Microlensing

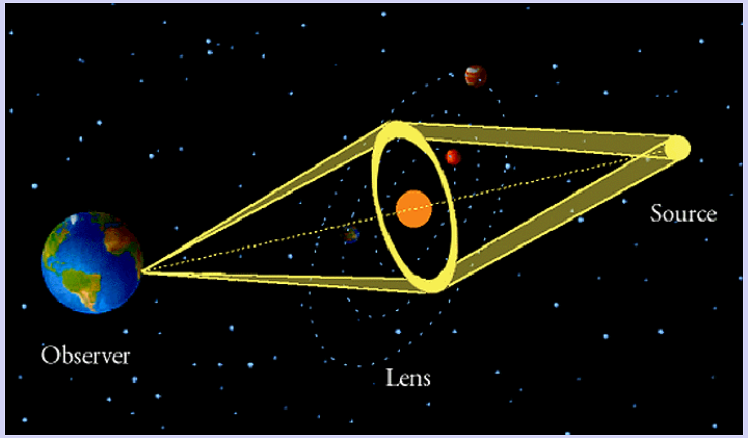
What?	Contribution by amateurs	Pro-Am collaboration	Results

Amateur astronomers can contribute photometric CCD observations as soon as a gravitational microlensing event is reported.

Intensive multi-hour (every successive night) and multi-color photometry by amateurs spread across the globe, is highly recommended to closely monitor the photometric evolution of the event.

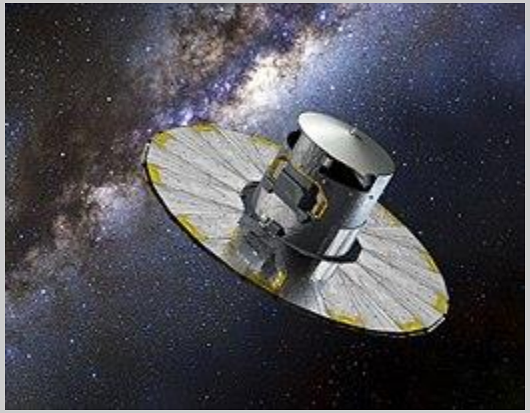
In exceptional cases, "glitches" or "anomalies" may be seen in the lightcurve of a microlensing event, revealing the signature of an **exoplanet** orbiting the foreground star.





Gravitational Microlensing

What? | Contribution by amateurs | **Pro-Am collaboration** | Results


Gaia spacecraft (artists impression)

- **MicroFUN** was founded in 2004 by Prof. A. Gould (Ohio State University) as an informal network to bring amateur astronomers and professionals together to study gravitational microlensing events. It consists of 23 observatories including 16 amateur-run. Currently focusing on Kepler objects. MicroFUN had several success stories.
See http://www.astronomy.ohio-state.edu/~microfun/

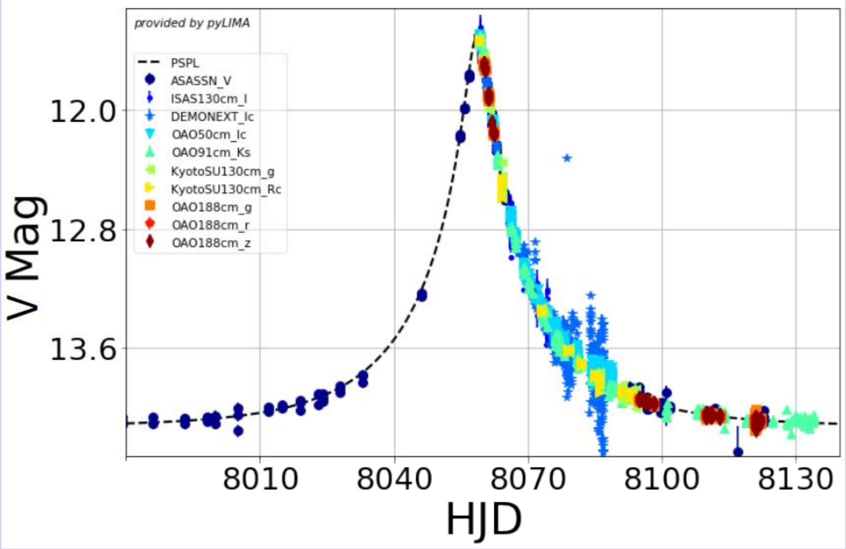
- Several professional astronomers cooperate with amateurs world-wide. Examples:
    - Dr Lukasz Wyrzykowski (Univ. Warsaw, Poland).
    - Dr. Akihiko Fukui (Okayama Astro-physical Observatory, Japan) who mostly collaborates with professional astronomers but occasionally also calls in amateurs.

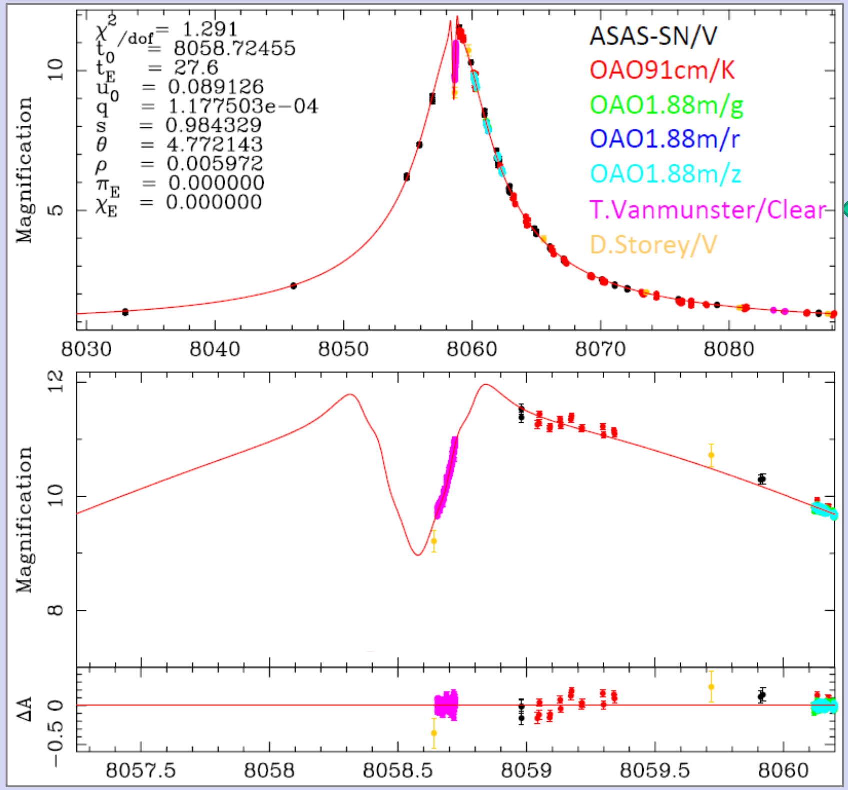
- We may expect a strong increase in the number of gravitational microlensing detections, thanks to the observations of the ESA Gaia spacecraft, especially with forthcoming DR3/DR4 releases.

Gravitational Microlensing (Kojima microlens)

What? | **Contribution by amateurs** | **Pro-Am collaboration** | **Results**

TCP J05074264+2447555 was discovered on Oct 31, 2017 as a mag 13.9 star, by amateur astronomer Kojima. Microlensing nature was quickly recognized by professional astronomers. It looked like a regular (bright) microlensing event.





I started contributing observations from my CBA Belgium Observatory, including on the night of Nov 7, 2017.

Soon after, Japanese astronomer Akihiko Fukui (Okayama Astrophysical Observatory) contacted me asking for my CCD images, as he saw an important "anomaly" in my observations.

That anomaly apparently fitted a "model" implying an **exoplanet** orbiting the foreground star. Spectroscopic observations soon confirmed this hypothesis. They pointed to a K-dwarf foreground star, orbited by a Neptunian planet at 0.9 AU with about 25x earth mass at a distance of 550pc.

In a few years, it will be possible to resolve foreground and background star and the exoplanet will be detectable (RV study) with a 30m telescope.

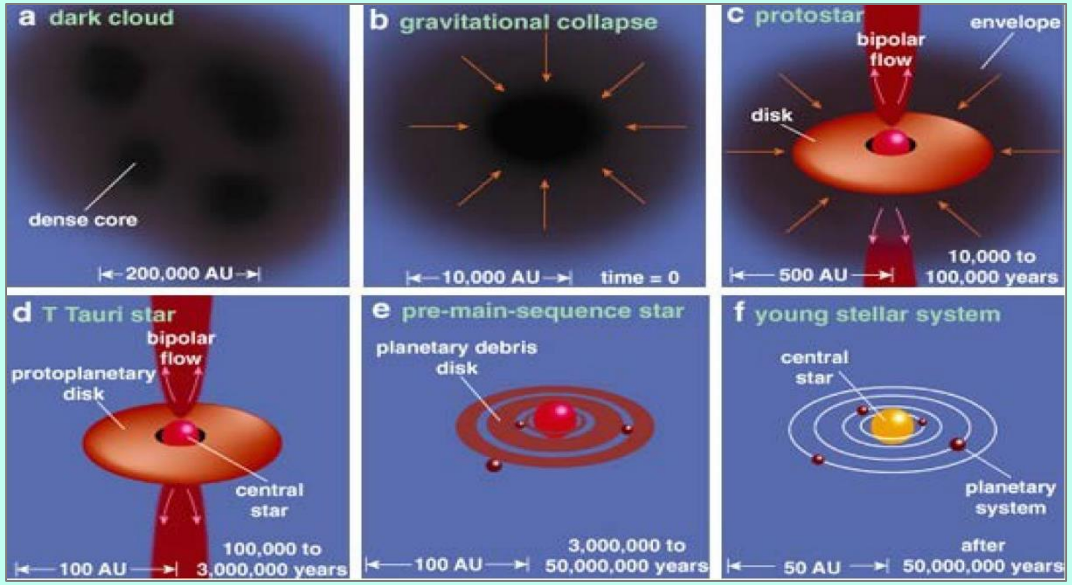
2. Young Stellar Objects (YSOs)

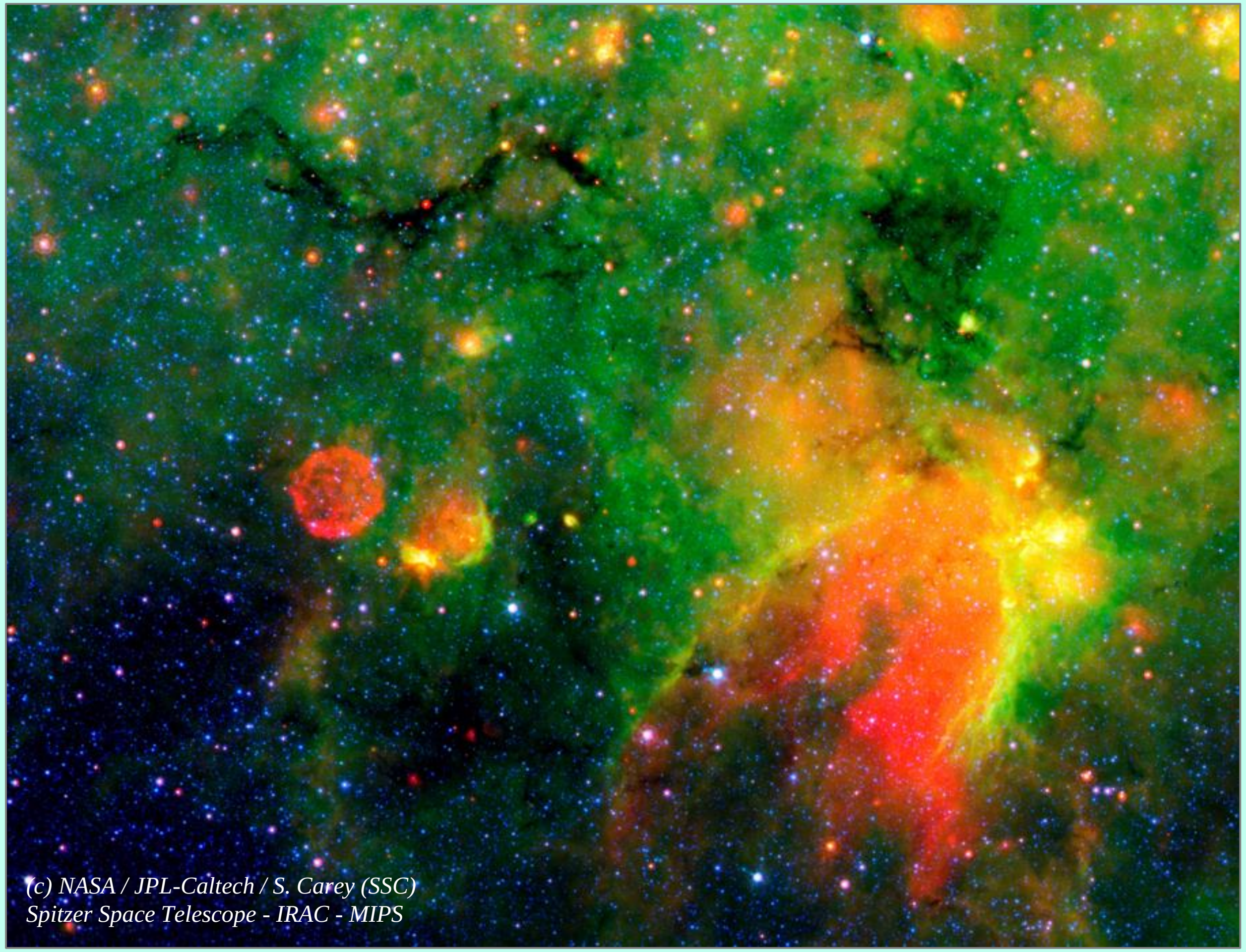
Young Stellar Objects YSOs

What? | Contribution by amateurs | Pro-Am collaboration | Results

YSOs are stars under construction, i.e. in their first phase of live. They are formed by contraction of molecular clouds. The dense center of the cloud is the new protostar.

YSOs have circumstellar material such as protoplanetary disks, outflows (jets and winds), in-falling material, etc.
Much of our knowledge of star formation comes from a few nearby regions (Taurus, Cygnus, Orion, Cepheus, …).





Young Stellar Objects YSOs

What?	Contribution by amateurs	Pro-Am collaboration	Results

- Help understand the YSOs variability by intense photometric monitoring, studying both:
  - short time, mostly small magnitude changes. Nature unknown, might be caused by:
    - rotation of star
    - occultations from disk
    - ‘flickering’
  - long time, larger amplitude outbursts, as seen in f.i. FU Ori type variables
- Professionals study variability in YSOs through a/o the GAIA space observatory
- Professionals develop simulation models trying to explain the physics causing the observed variabilities. They intensively use amateur photometric observations for this. Example questions they try to answer:
  - What fraction of time do YSOs spend in “outburst”, of what strength and does it depend on mass, environment, etc?
  - What mass fraction is accreted in the outbursts?

Young Stellar Objects YSOs

What? | Contribution by amateurs | **Pro-Am collaboration** | Results

- The University of Kent (UK) runs the **HOYS-CAPS** (Hunting Outbursting Young Stars with the Centre of Astrophysics and Planetary Science) project since Oct 2014. The aim of the project is long term, multi-filter optical photometric monitoring of young (age less than 10Myr), nearby star clusters or star forming regions, visible from the northern hemisphere.

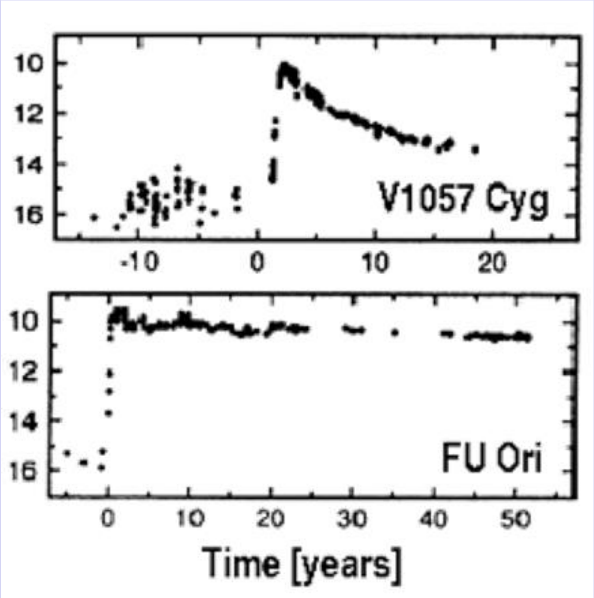
  The data is being used to study star formation and the formation of (terrestrial) planets in the disks surrounding young stars.

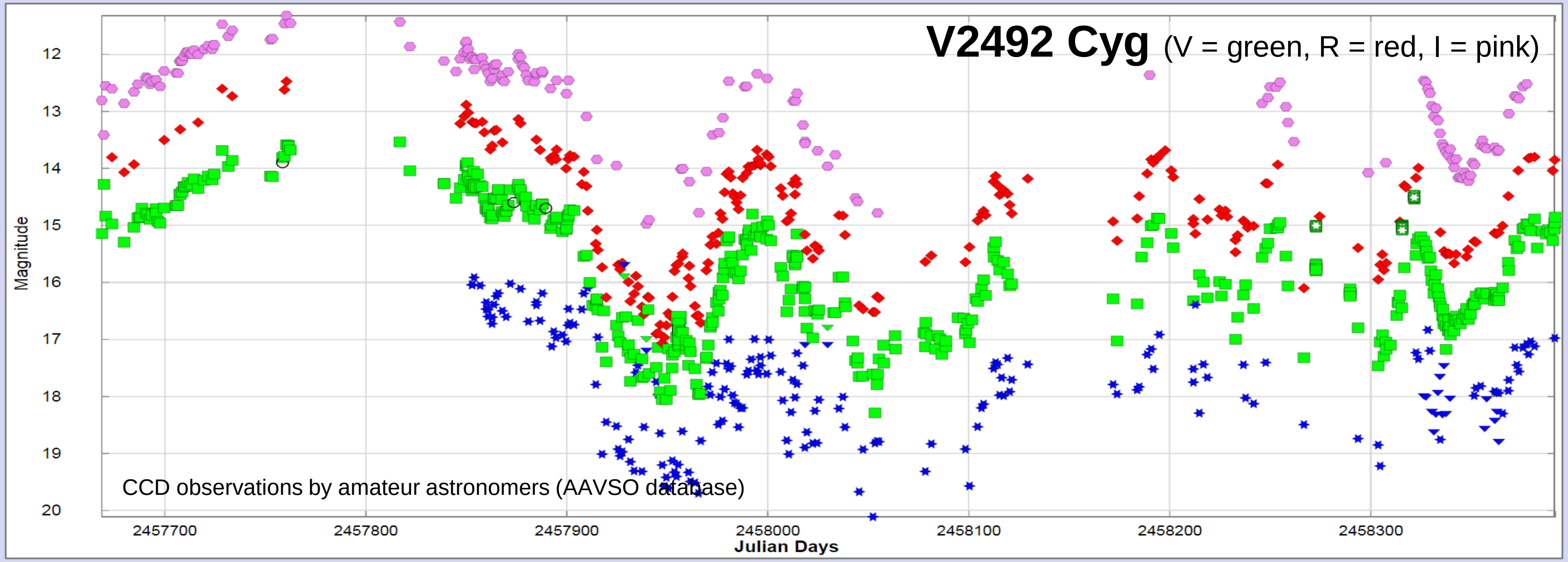
  HOYS-CAPS contains 17 young clusters/regions and several additional targets selected from the Gaia Photometric Alerts.

  Coordinator: Dr. Dirk Froebrich, HOYS-CAPS PI
  http://astro.kent.ac.uk/~df/hoyscaps/index.html

Young Stellar Objects YSOs

What?	Contribution by amateurs	Pro-Am collaboration	Results





V2492 Cyg is a young eruptive star. To learn about the origin of the light variations and to explore the circumstellar environment of this object, V2492 Cyg was observed in 10 different wavelengths, including ground-based amateur multi-color CCD observations.

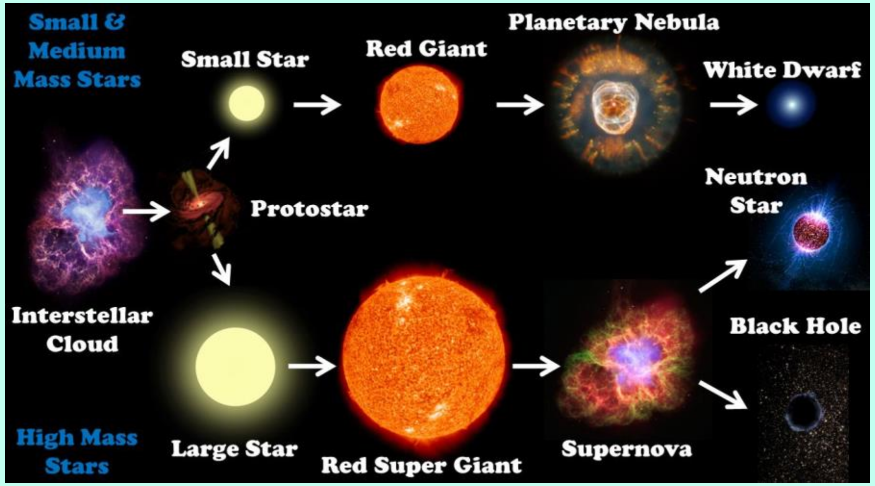
Professional astronomers found that the observed variability is probably resulting from the star being episodically occulted by a dense dust cloud in the inner disk with an asymmetric structure. See https://arxiv.org/abs/1301.0898

3. Planetary debris around White Dwarfs

Planetary debris around White Dwarfs

What?	Contribution by amateurs	Pro-Am collaboration	Results

We know over 3000 **extrasolar planets**, mostly orbiting **solar-like stars**. What is the future of these planetary systems (and ours) as the host stars evolve off the main sequence?



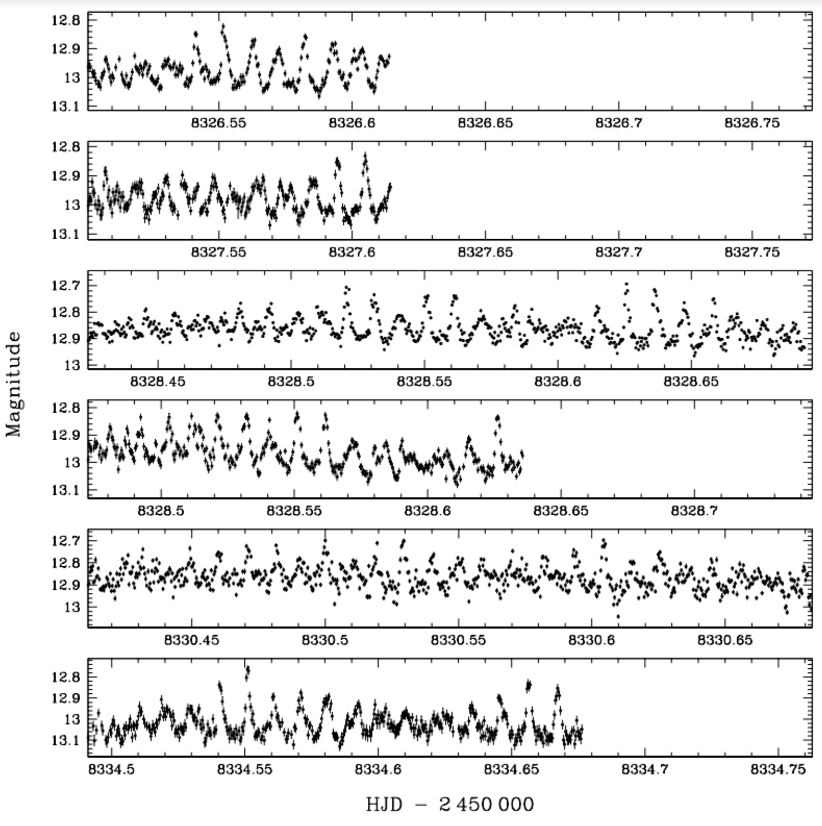
At first, these planet host stars evolve into **red giants** and lose substantial amounts of mass. Consequently, the orbits of the planets, and all other bodies around the red giant, will widen, with many of them moving far beyond the maximum radius that the star will reach during the red giant phase.

Eventually, the red giants become **white dwarfs**, bearing the remnants of planetary systems. Some planets and asteroids move too close to the white dwarf. They are shredded and form a debris disk of dust and/or gas. Those dust disks are detected as infrared excess emission.

Directly detecting planets around white dwarfs is (still) beyond the reach of current telescopes. But spectroscopy with very powerful telescopes (for instance Hubble HST) allows to measure the chemical composition of accreted bodies. This is critical to validate planetary formation theories.

Planetary debris around White Dwarfs

What? | **Contribution by amateurs** | Pro-Am collaboration | Results



G29-38 (aka ZZ Psc). July 2018 observations by Belgian amateurs Berto Monard and Tonny Vanmunster, made upon request of Prof. Dr. Boris Gaensicke (Univ of Warwick)

- Professional astronomers rely on intense time-series spectroscopy to determine the geometry of metal distribution on a white dwarf, accreting from a planetary disk.
- However, spectroscopy is not sufficient. Many white dwarfs are pulsating. Critically important is to identify the pulsation modes of the white dwarf during the spectroscopic observations. Knowing the pulsation modes allows to reconstruct the exact location of the temperature variation on the surface of the white dwarf.
- The pulsation modes can be obtained from optical photometry. For “bright” white dwarf, amateurs can very well contribute this optical photometry (see example at left), at the same moment that professional astronomers are obtaining their spectroscopic observations.

Planetary debris around White Dwarfs

What?	Contribution by amateurs	Pro-Am collaboration	Results

- One example of pro-am collaboration in the field of planetary debris around White Dwarfs is the informal cooperation between a handful of leading amateur photometrists and Prof. Boris Gaensicke & team from the University of Warwick.
- Very rewarding to see that amongst the 5 contributing amateurs are 3 Belgians (!): Berto Monard (now living in South Africa), Josch Hambsch (robotic observatory in Chile) and myself (robotic observatories in Spain and Belgium).
- A very active collaboration is scheduled for 2019, when these amateurs will contribute uninterrupted ground-based optical photometry observations while “another professional instrument” will obtain spectroscopic observations of a particular white dwarf.
- Further details can not be disclosed at this moment.

4. High Amplitude Delta Scuti (HADS) stars

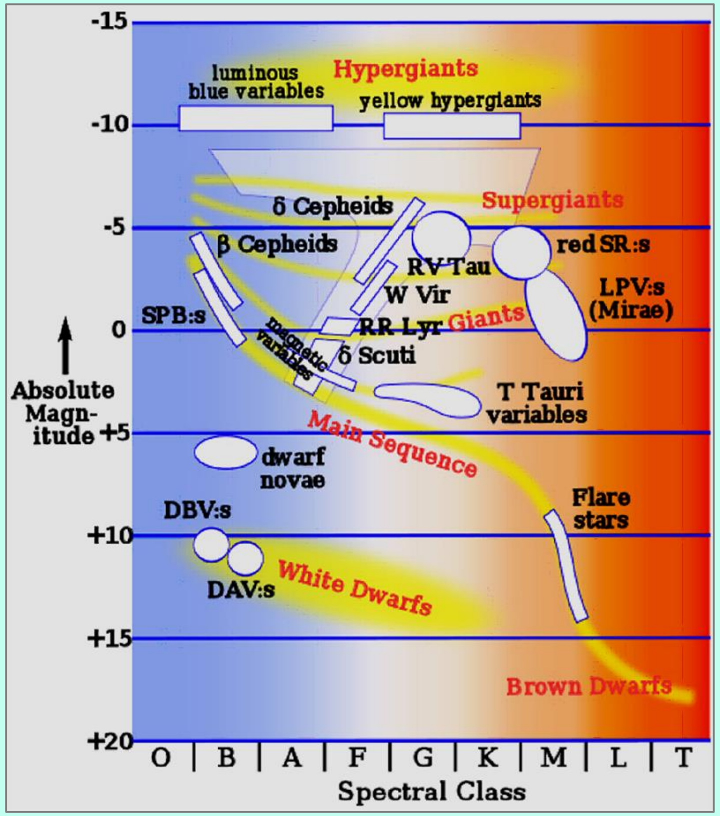
High Amplitude Delta Scuti Stars (HADS)

What? | Contribution by amateurs | Pro-Am collaboration | Results

Delta Scuti stars are variable stars that exhibit light variations in the range of 34 min up to 5 hours, but usually with amplitudes < 0.1 mag. The light variations are caused by radial and non-radial pulsations of the star's surface. Delta Scuti stars are important “standard candles” and have been used to measure distances in the universe.

HADS or High-amplitude delta Scuti stars have amplitudes >0.1 mag in V, to distinguish them from low-amplitude delta Scuti stars. Though the amplitude break is somewhat arbitrary, there is a reasonable physical basis for it. The large-amplitude stars tend to be those undergoing *radial* pulsations, and typically only pulsate in one dominant mode at a time. The low-amplitude stars may either be multiperiodic or monoperiodic.

Multiperiodic delta Scuti stars are useful in asteroseismological studies, and are often the targets of long-duration, multi-site photometric campaigns designed to detect larger and larger numbers of pulsation periods.



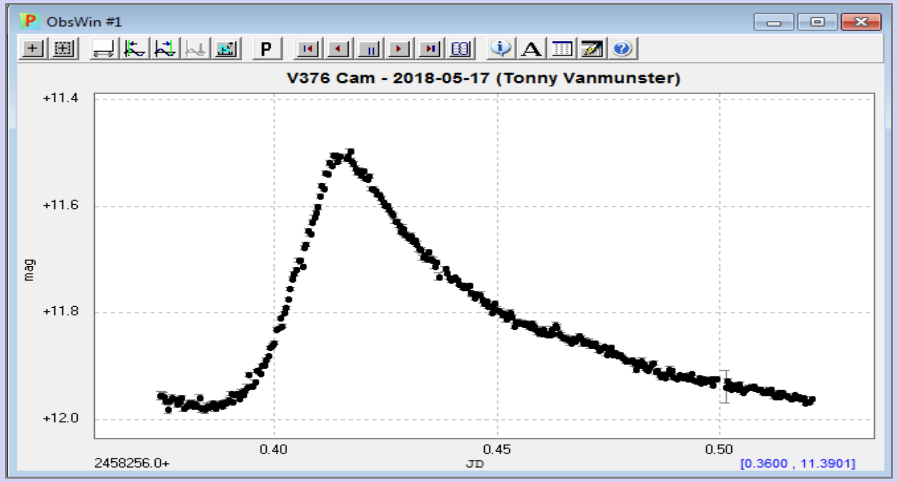
High Amplitude Delta Scuti Stars (HADS)

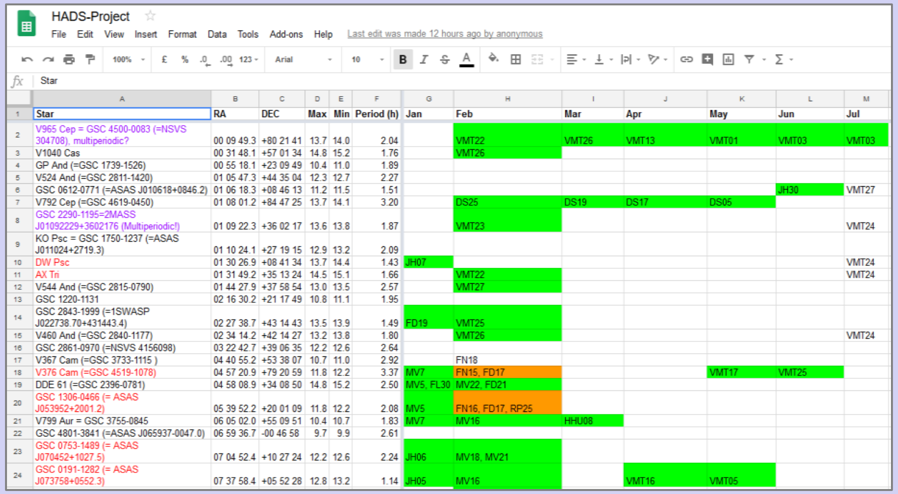
What? | **Contribution by amateurs** | **Pro-Am collaboration** | **Results**

- Amateur astronomers can easily contribute HADS CCD observations. Due to the short periodicity and high amplitude, they will already obtain first results after just 1 observing night.

- Purpose is to observe at least one maximum (or minimum) in the lightcurve and to determine the Time of Maximum/Minimum (ToM). One maximum per HADS per month is sufficient. No filters are needed.

- A systematic HADS observing campaign exists in the VVS Werkgroep Veranderlijke Sterren, and is headed by Patrick Wils.





HADS-Project
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	Star	RA	DEC	Max	Min	Period (h)	Jan	Feb	Mar	Apr	May	Jun	Jul
2	V965 Cep = GSC 4500-0083 (=NSVS 304708), multiperiodic?	00 09 49.3	+80 21 41	13.7	14.0	2.04		VMT22	VMT26	VMT13	VMT01	VMT03	VMT03
3	V1040 Cas	00 31 48.1	+57 01 34	14.8	15.2	1.76		VMT26					
4	GP And (=GSC 1739-1526)	00 55 18.1	+23 09 49	10.4	11.0	1.89							
5	V524 And (=GSC 2811-1420)	01 05 47.3	+44 35 04	12.3	12.7	2.27							
6	GSC 0612-0771 (=ASAS J010618+0846.2)	01 06 18.3	+08 46 13	11.2	11.5	1.51						JH30	VMT27
7	V792 Cep (=GSC 4619-0450)	01 08 01.2	+84 47 25	13.7	14.1	3.20		DS25	DS19	DS17	DS05		
8	GSC 2290-1195=2MASS J01092229+3602176 (Multiperiodic!)	01 09 22.3	+36 02 17	13.6	13.8	1.87		VMT23					VMT24
9	KO Psc = GSC 1750-1237 (=ASAS J011024+2719.3)	01 10 24.1	+27 19 15	12.9	13.2	2.09							
10	DW Psc	01 30 26.9	+08 41 34	13.7	14.4	1.43	JH07						VMT24
11	AX Tri	01 31 49.2	+35 13 24	14.5	15.1	1.66		VMT22					VMT24
12	V544 And (=GSC 2815-0790)	01 44 27.9	+37 58 54	13.0	13.5	2.57		VMT27					
13	GSC 1220-1131	02 16 30.2	+21 17 49	10.8	11.1	1.95							
14	GSC 2843-1999 (=1SWASP J022738.70+431443.4)	02 27 38.7	+43 14 43	13.5	13.9	1.49	FD19	VMT25					
15	V460 And (=GSC 2840-1177)	02 34 14.2	+42 14 27	13.2	13.8	1.80		VMT26					VMT24
16	GSC 2861-0970 (=NSVS 4156098)	03 22 42.7	+39 06 35	12.2	12.6	2.64							
17	V367 Cam (=GSC 3733-1115)	04 40 55.2	+53 38 07	10.7	11.0	2.92		FN18					
18	V376 Cam (=GSC 4519-1078)	04 57 20.9	+79 20 59	11.8	12.2	3.37	MV7	FN15, FD17			VMT17	VMT25	
19	DDE 61 (=GSC 2396-0781)	04 58 08.9	+34 08 50	14.8	15.2	2.50	MV5, FL30	MV22, FD21					
20	GSC 1306-0466 (= ASAS J053952+2001.2)	05 39 52.2	+20 01 09	11.8	12.2	2.08	MV5	FN16, FD17, RP25					
21	V799 Aur = GSC 3755-0845	06 05 02.0	+55 09 51	10.4	10.7	1.83	MV7	MV16	HHU08				
22	GSC 4801-3841 (=ASAS J065937-0047.0)	06 59 36.7	-00 46 58	9.7	9.9	2.61							
23	GSC 0753-1489 (= ASAS J070452+1027.5)	07 04 52.4	+10 27 24	12.2	12.6	2.24	JH06	MV18, MV21					
24	GSC 0191-1282 (= ASAS J073758+0552.3)	07 37 58.4	+05 52 28	12.8	13.2	1.14	JH05	MV16		VMT16	VMT05		

High Amplitude Delta Scuti Stars (HADS)

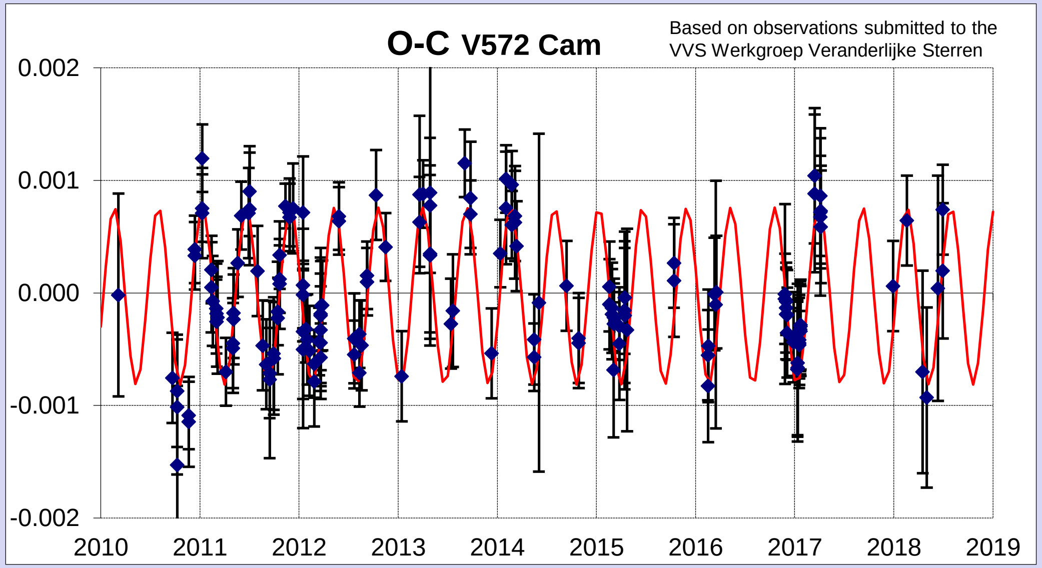
What? | **Contribution by amateurs** | **Pro-Am collaboration** | **Results**

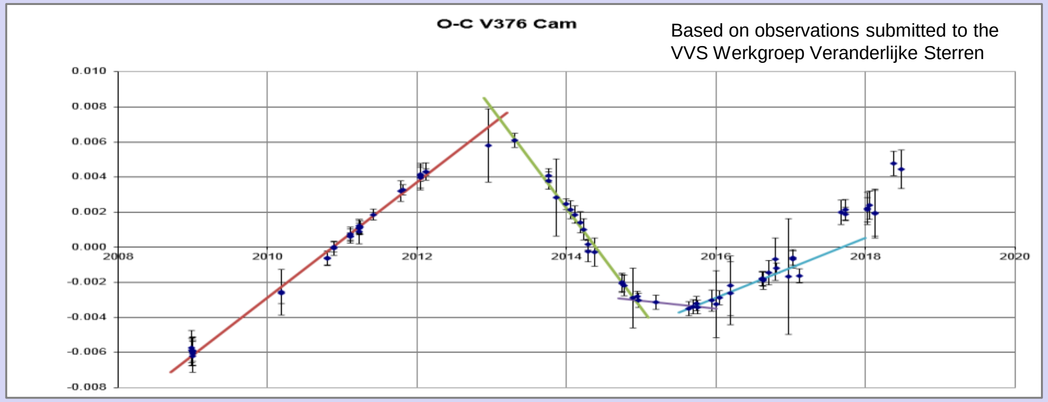
- **O-C diagrams** (Observed minus Calculated) are used in astronomy to compare the observed time of maximum/minimum versus the predicted time.

- The difference between observed and calculated time can be plotted in graph, called the O-C diagram. It is a powerful diagnostic tool and allows to measure changes over time in the period of a star.

- For a star with a constant period, points on the O-C diagram will scatter about a straight horizontal line across the graph. The size of the scatter is an indication of the accuracy of the observed times of maximum.

- For stars with a variable period, the O-C diagram will look very different, indicating that there's a **period change** in the system. It's a first indicator to trigger interest in the Delta Scuti star and to intensify observations.





Pro-am Photometry Projects with Robotic Observatories

Thank you