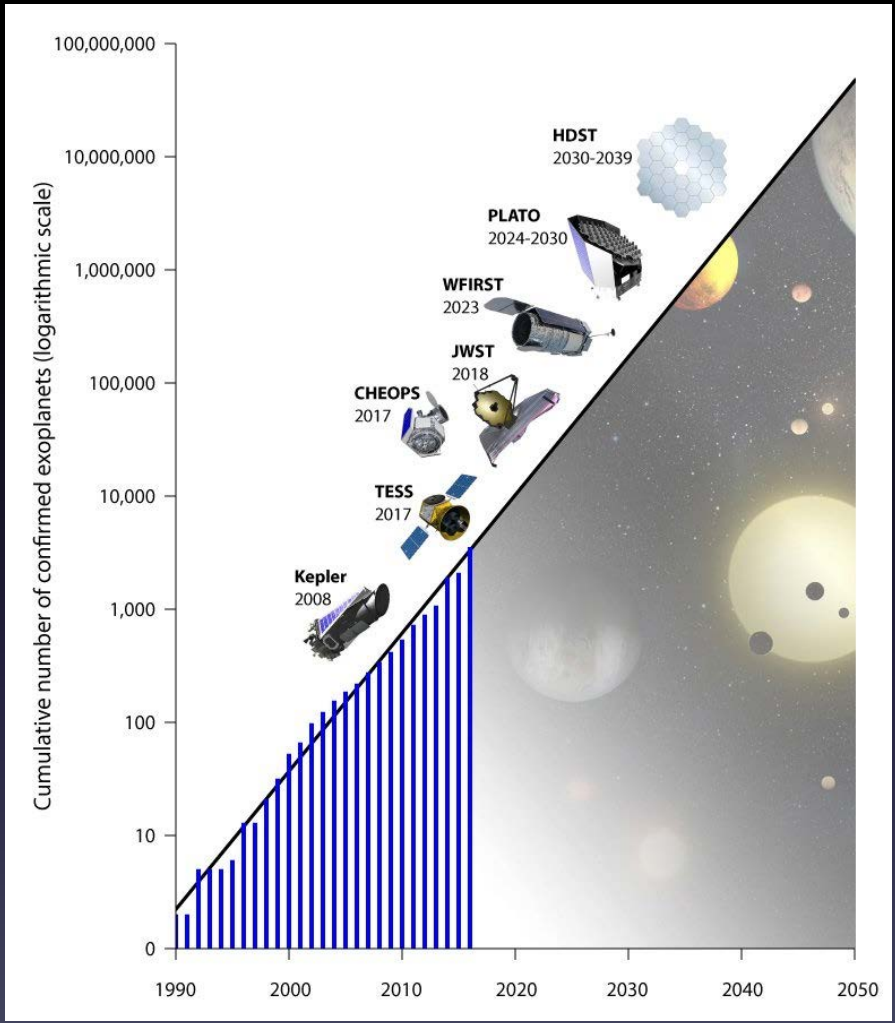
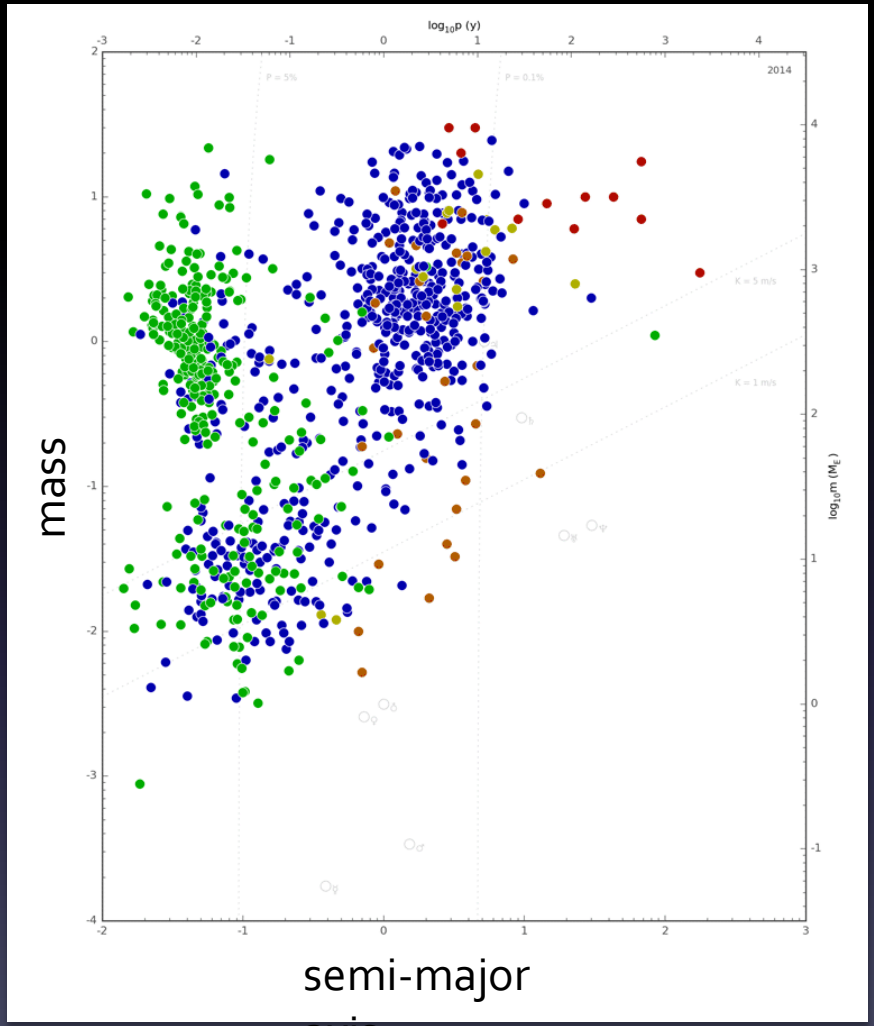
# Photometric observations of exoplanet candidates from Montsec

Kike Herrero
OAdM astronomer (IEEC-CSIC)

# Exoplanet search and characterization programs



# Exoplanet follow-up observations

Big telescopes (ground & space) ⟶ High precission / little time

Small ground-based telescopes ⟶ Low precission / long time

**The role of robotic 1-m telescopes**

Before mission

- Target selection and characterization

During mission

- Monitoring of the planet hosts
- Transit searches / confirmation

IEEC

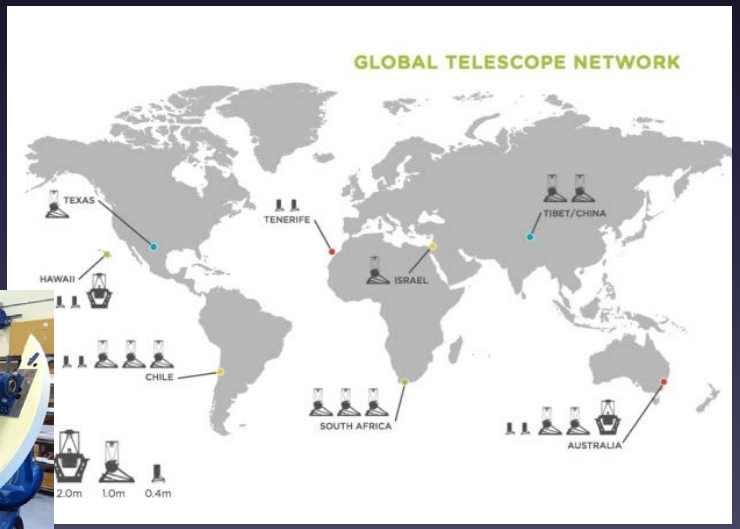
OAdM
Observatori Astronòmic del Montsec
Parc Astronòmic Montsec

# The future of robotic 1-m telescopes

- Advanced and flexible scheduling of observations
- Broad longitude coverage
- Photometric precission better than 1 ppt for transits and long term monitoring

**example:**

LCO
Las Cumbres Observatory




https://lco.global/

IEEC

OAdM
Observatori Astronòmic del Montsec
Parc Astronòmic Montsec

# Montsec Astronomical Observatory (OAdM)

- Location: St. Esteve de la Sarga, Montsec, at 1570 m
- Good weather conditions > 65-70% night time
- Good sky quality (seeing ~1”)
- Dark sky conditions (Starlight certification by UNESCO)
- Unattended operations

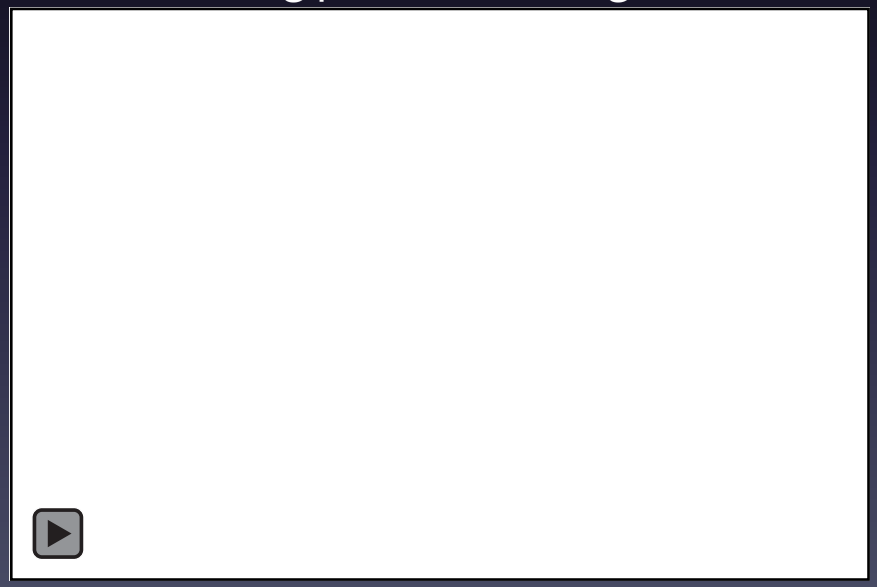


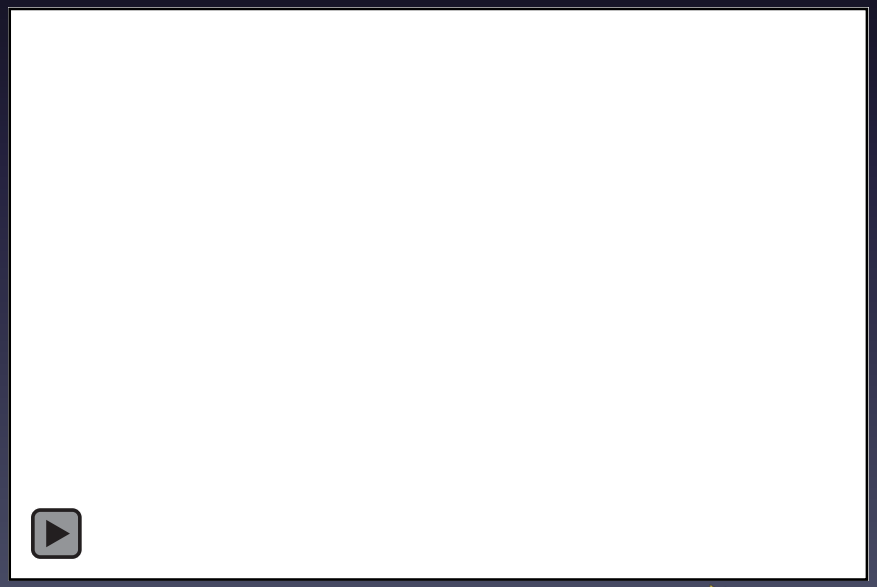
IEEC

OAdM
Observatori Astronòmic del Montsec
Parc Astronòmic Montsec

# The Joan Oró telescope (TJO)

- Operated by IEEC
- 0.8 m Ritchey-Chrétien
- 2 instruments (imager & spectrograph)
- Robotic operation with artificial intelligence control suite
- Multi-purpose telescope: science & space debris
- Two AO per year: unrestricted access policies ➈ **mur.ieec.cat**
- Increasing pressure during the last semesters





# Instrumentation at the TJO

## **LAIA** imager

4k x 4k back-illuminated
0.5º FOV
UBVRI filters

~1 ppt/min photometry
~1 arcsec astrometry

## **ARES** spectrograph

R=12000
red (Ha line) and green (MgI) windows

Stellar characterization
Stellar activity monitoring
~1 km/s RVs

IEEC

OAdM
Observatori Astronòmic del Montsec
Parc Astronòmic Montsec

# Observing exoplanets with the TJO

- How to apply?
  - ✓ OAdM area in IEEC web page (oadm.ieec.cat) ➞ MUR
  - ✓ Phase 1 with science case + total required time + targets ➞ TAC
  - ✓ Phase 2 with observation details ➞ OAdM database

*Targets*

| Id | Source name * | Coordinate format * | Coordinate value * | |
|---|---|---|---|---|
| 1 | GJ555 | Equatorial | 14:34:30.81 0.0 -12:31:10.39 0.0 2000.0 | X |
| 2 | TZAri | Equatorial | 02:00:12.95 0.0 +13:03:07.02 0.0 2000.0 | X |
| 3 | Wolf1069 | Equatorial | | |
| 4 | GJ458A | Equatorial | | |
| 5 | GJ251 | Equatorial | | |

*Observing constraints*

**Observing constraint 10**

| | |
|---|---|
| Sky brightness * | Bright |
| Seeing * | Medium |
| Cloud cover * | Photometric |
| Solar elevation * | Nautical twilight (-12°) |
| Moon distance | 0 (degrees) |
| Airmass (min) | 1 |
| Airmass (max) | 3 |
| Hour angle (min) | 0 (hours) |
| Hour angle (max) | 24 (hours) |
| Delay (before) | 0 (hours) |
| Delay (after) | 0 (hours) |

Windows

| Start (JD) * | End (JD) * | Period * |
|---|---|---|
| 2458559.84 | 2458560.12 | 2.59872 |

Add window

*Instrument configurations*

**Instrument configuration 1**

| | |
|---|---|
| Instrument * | MEIA3 |
| Target type * | Science |
| Follow type * | Sidereal |
| Dither pattern * | 1x1 |
| Dither (RA) | 0 (degrees) |
| Dither (Dec) | 0 (degrees) |
| DeFocus | Enabled |
| Exposures | 5 |
| Exposure time | 25 (seconds) Adapt time |
| Binning * | 1x1 |
| Subframe | 4096 (pixels) |
| Filter | R |

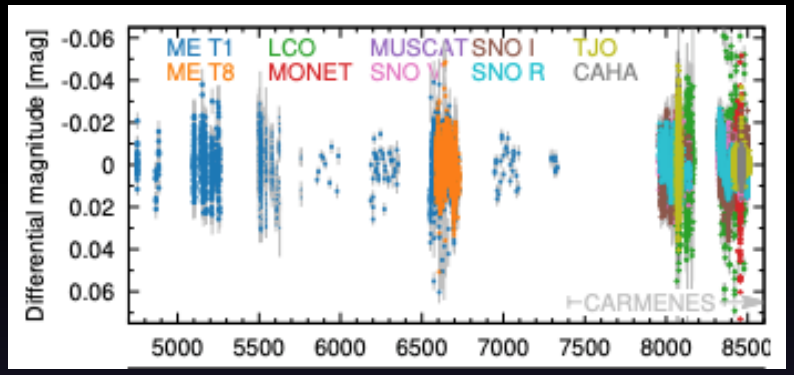
IEEC

OAdM Observatori Astronòmic del Montsec Parc Astronòmic Montsec

# Observing exoplanets with the TJO

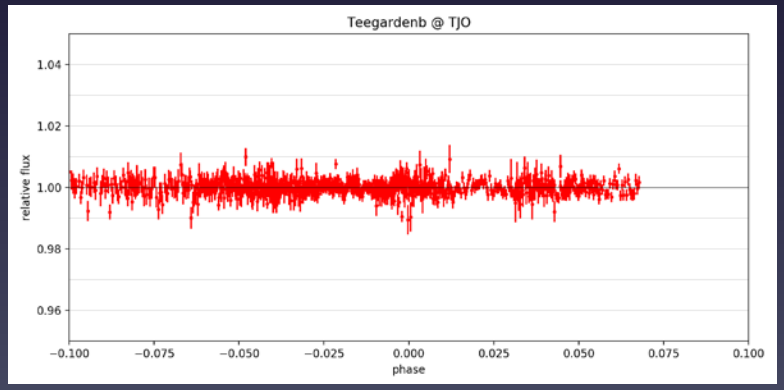
Monitoring the host star

- Several measurements per night, many nights
- Determine rotation period, activity, age…
- Disentangle stellar and planetary signals




Looking for transits

- Intensive observations covering the transit window
- Confirm transit or NEBs
- Refine ephemeris




IEEC

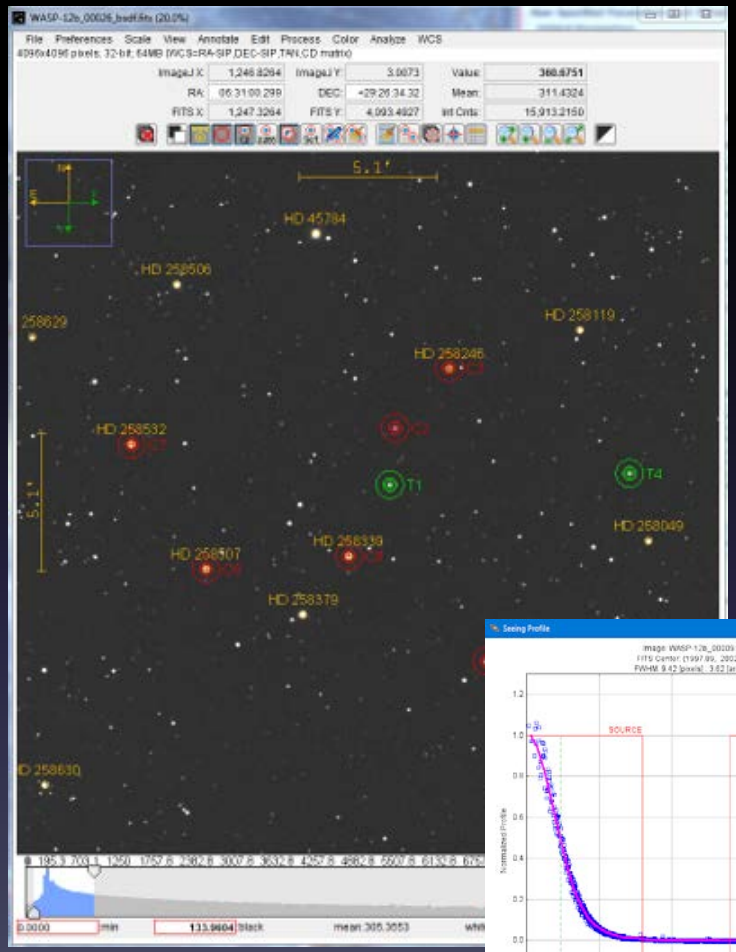
OAdM
Observatori Astronòmic del Montsec
Parc Astronòmic Montsec

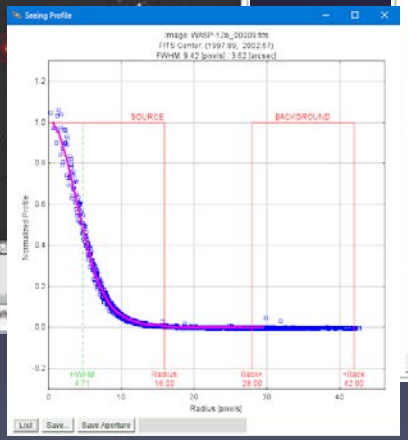
# Data reduction

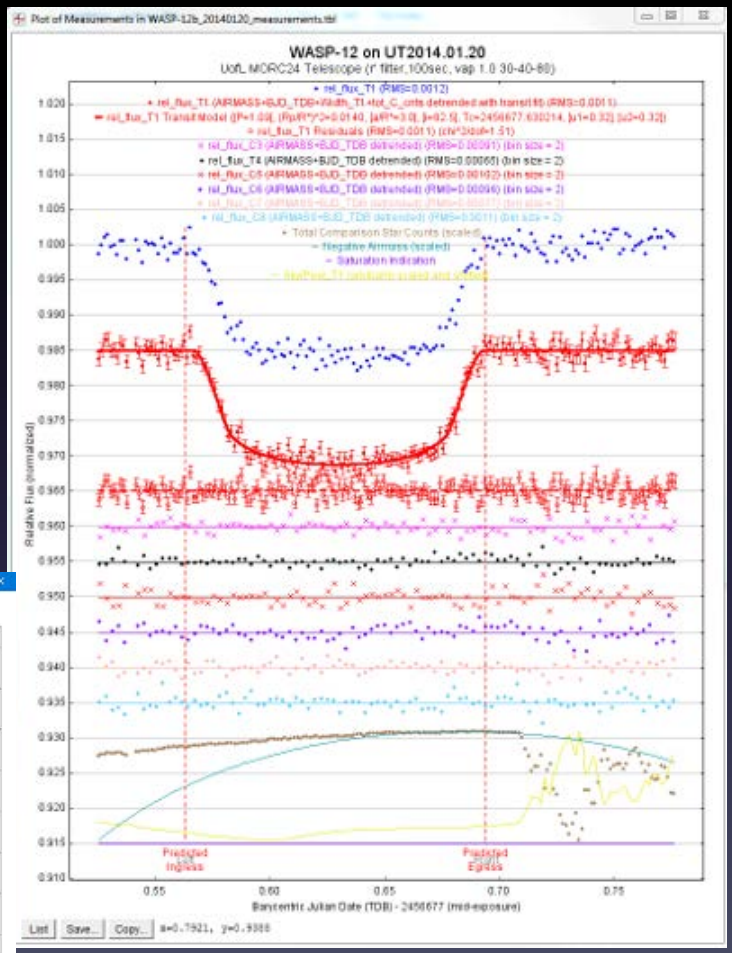
**AstroImageJ (AIJ)**

Image processing and photometric extraction

Collins et al. 2017

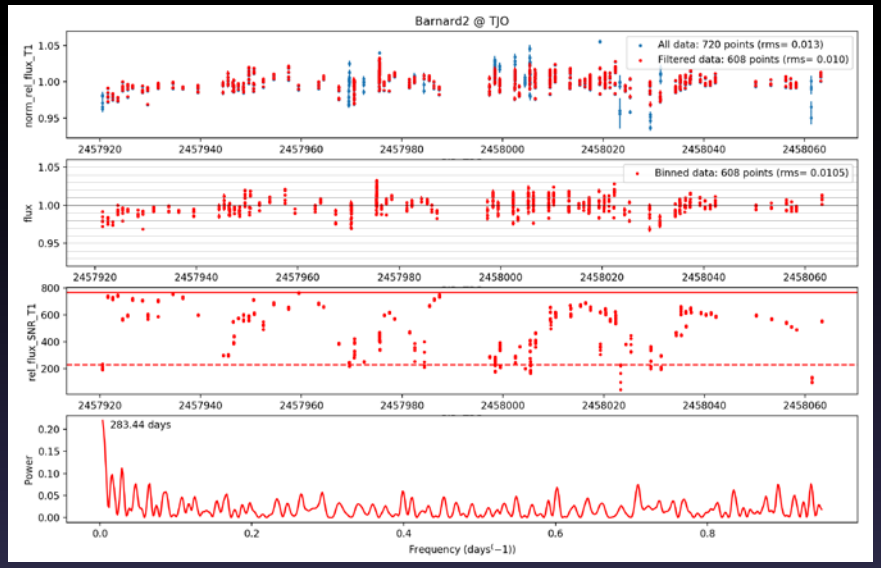


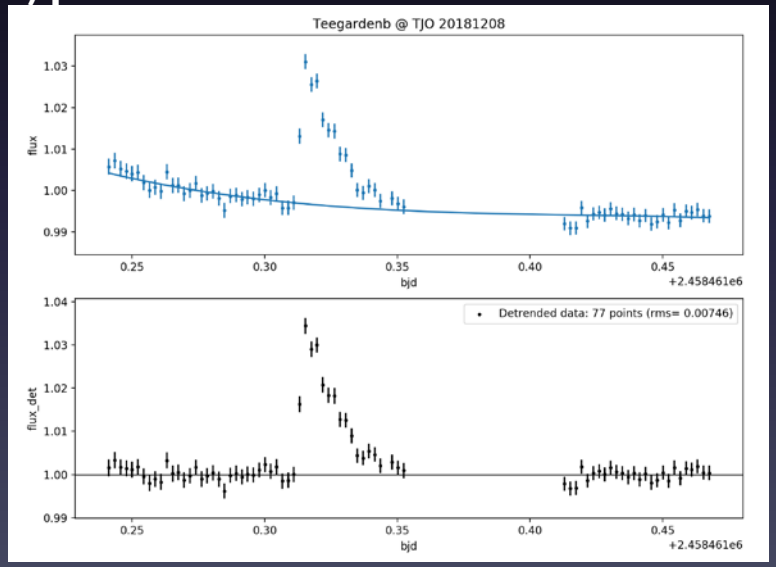



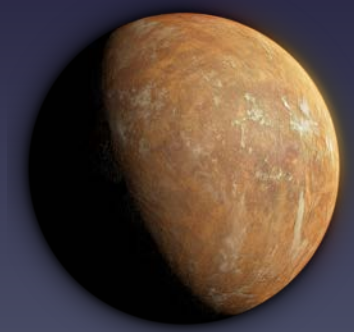
# CARMENES follow-up results

- **TJO participates in photometric observations of M dwarfs from the CARMENES survey**
- **Observed as part of the CAT time (regular proposals)**




- **4 proposals, ~500 hours of TJO time, 19 light curves with new periods**
- **8 (+3) publications since 2018**



- **Barnard's b**
- **Ribas et al. Nature, 563 (2018)**

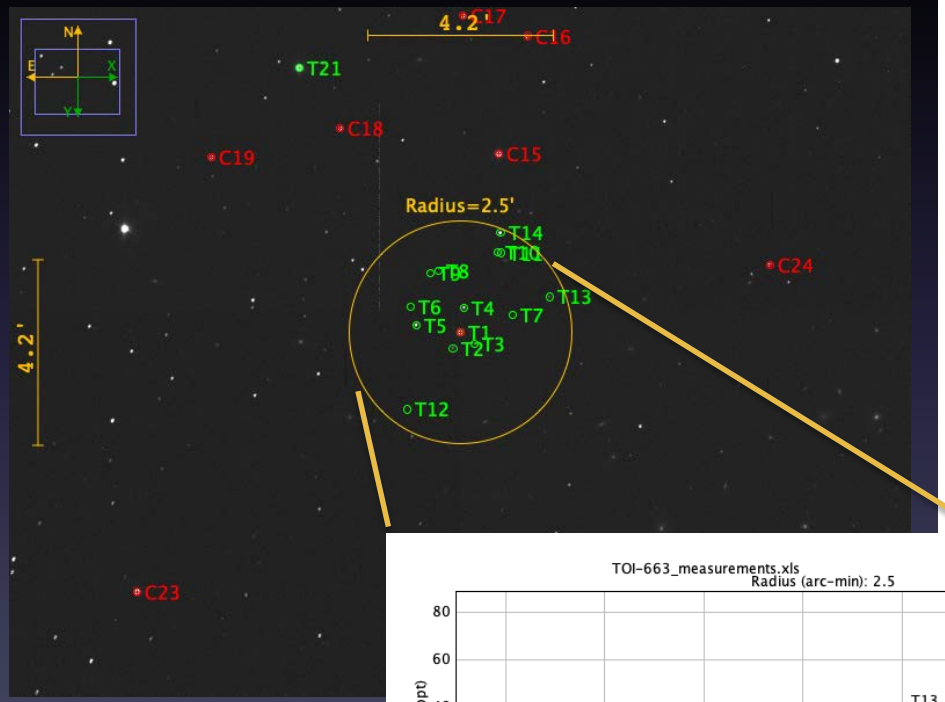
IEEC

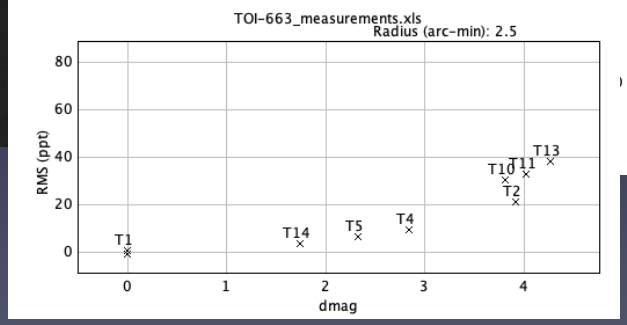
OAdM
Observatori Astronòmic del Montsec
Parc Astronòmic Montsec

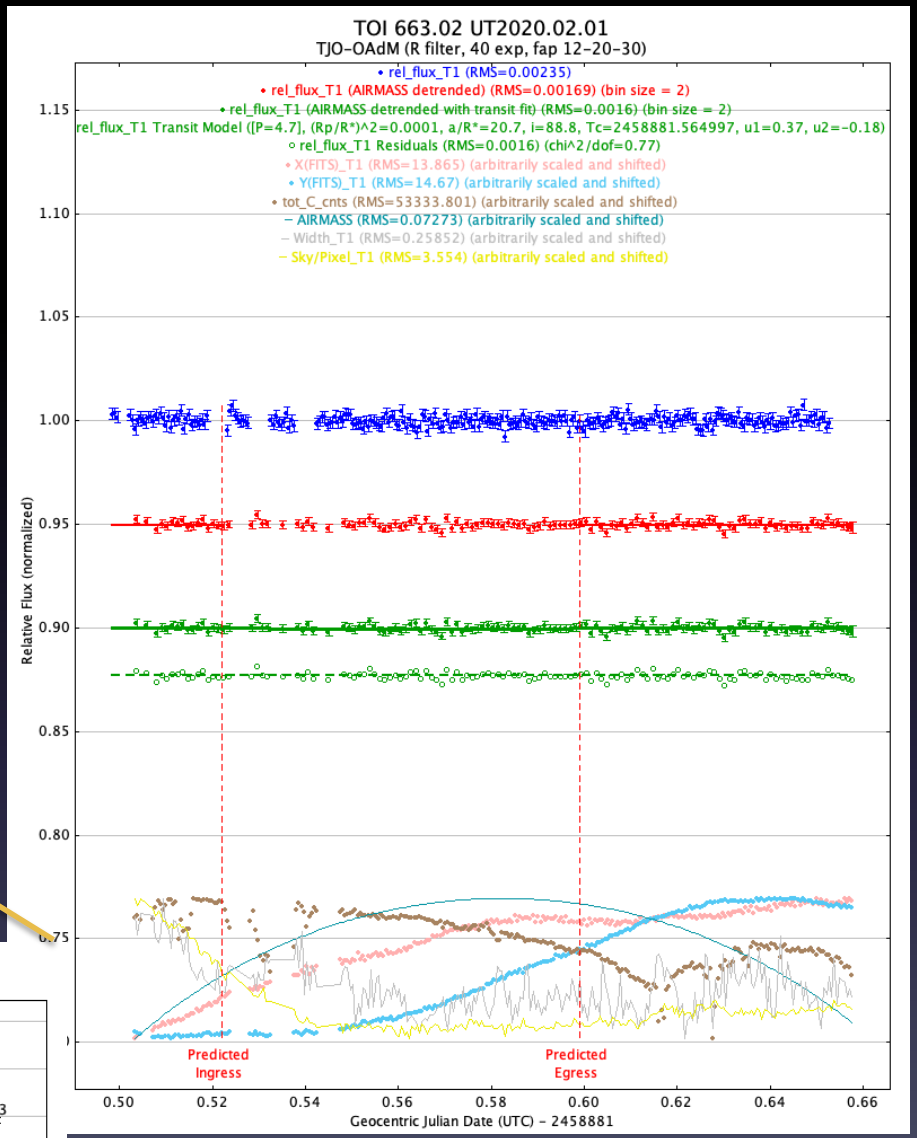
# Transit searches

- Confirm transit
- Identify false positives (NEBs)

*TESS candidate TOI-663.02*



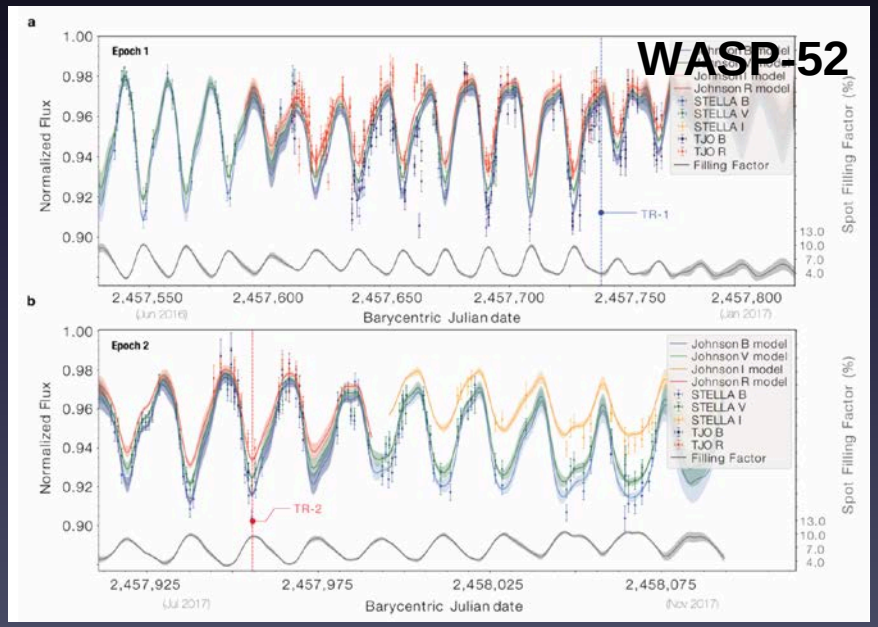
# The VaMoS project

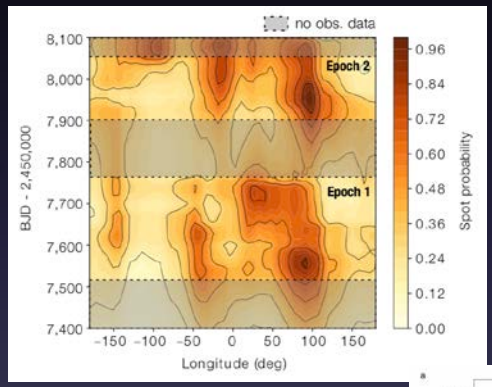
Mallonn et al. 2018
Rosich et al. (submitted)

**Variability Monitoring of Exoplanet Hosts**
2 TJO proposals (> 200 hours)

- Long term monitoring of stars with transiting planets (STELLA + TJO)
- **StarSim** modelling tool

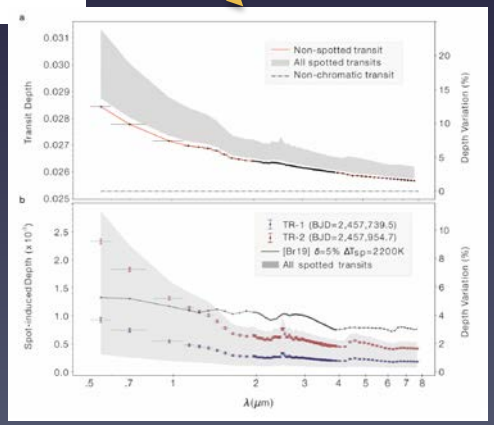
- Properties of activity features
- Activity correction of transit spectroscopy observations



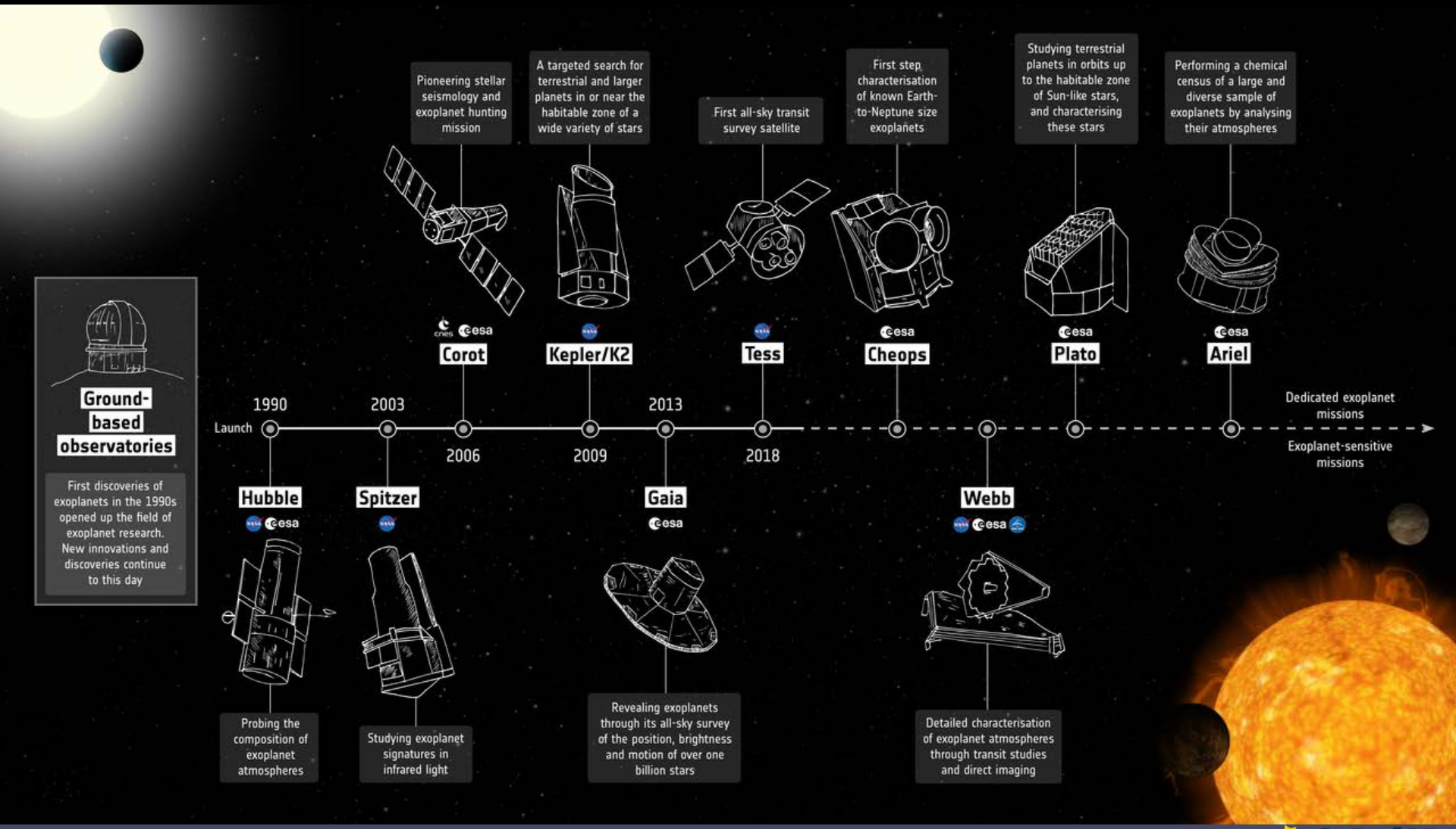

*properties of spots*

*effects on transit spectroscopy*




*multiband photometry*

# Near future…

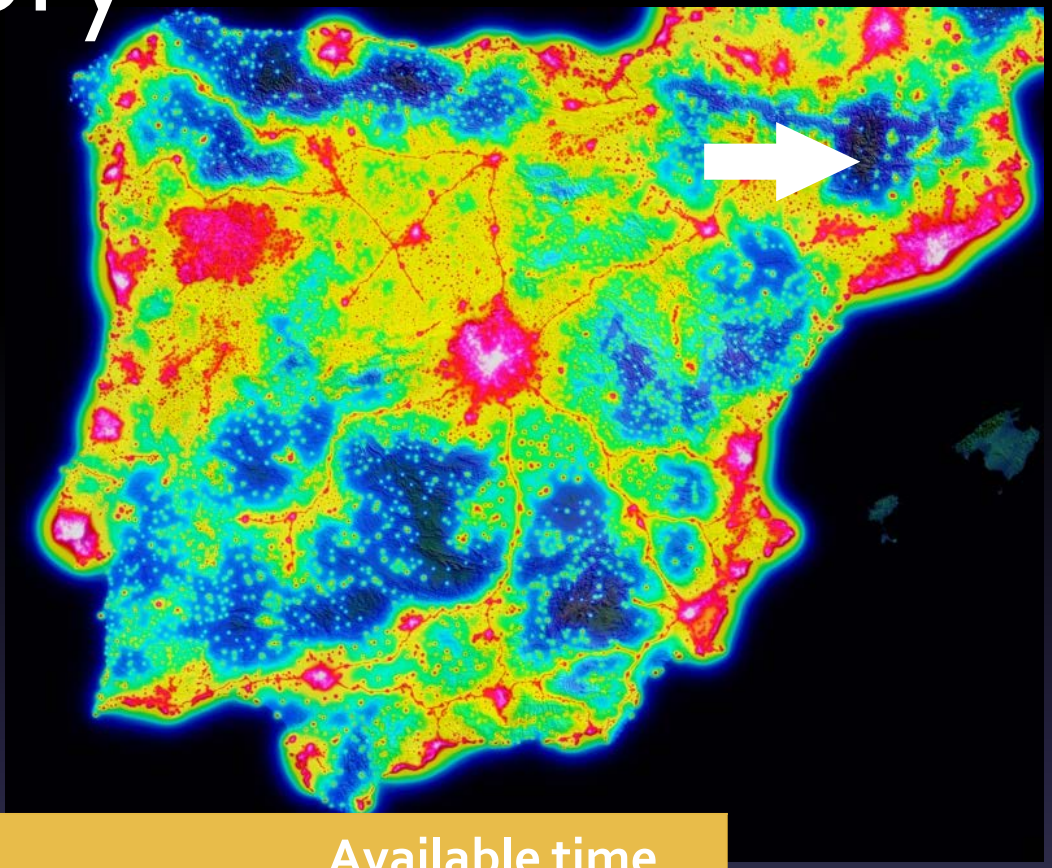

Ground-based observatories
First discoveries of exoplanets in the 1990s opened up the field of exoplanet research. New innovations and discoveries continue to this day
Pioneering stellar seismology and exoplanet hunting mission
A targeted search for terrestrial and larger planets in or near the habitable zone of a wide variety of stars
First all-sky transit survey satellite
First step characterisation of known Earth-to-Neptune size exoplanets
Studying terrestrial planets in orbits up to the habitable zone of Sun-like stars, and characterising these stars
Performing a chemical census of a large and diverse sample of exoplanets by analysing their atmospheres
Corot
Kepler/K2
Tess
Cheops
Plato
Ariel
1990
2003
2013
Launch
2006
2009
2018
Dedicated exoplanet missions
Exoplanet-sensitive missions
Hubble
Spitzer
Gaia
Webb
Probing the composition of exoplanet atmospheres
Studying exoplanet signatures in infrared light
Revealing exoplanets through its all-sky survey of the position, brightness and motion of over one billion stars
Detailed characterisation of exoplanet atmospheres through transit studies and direct imaging

# Near future…


@kike_herrero eherrero@ieec.cat

# The observatory

- Main astronomical observatory in Catalonia
- Located at the Serra del Montsec, at 1570 m asl:
  - ✓ Dark sky
  - ✓ Good climatology (similar to Calar Alto)
  - ✓ Good sky quality (seeing ~1″)



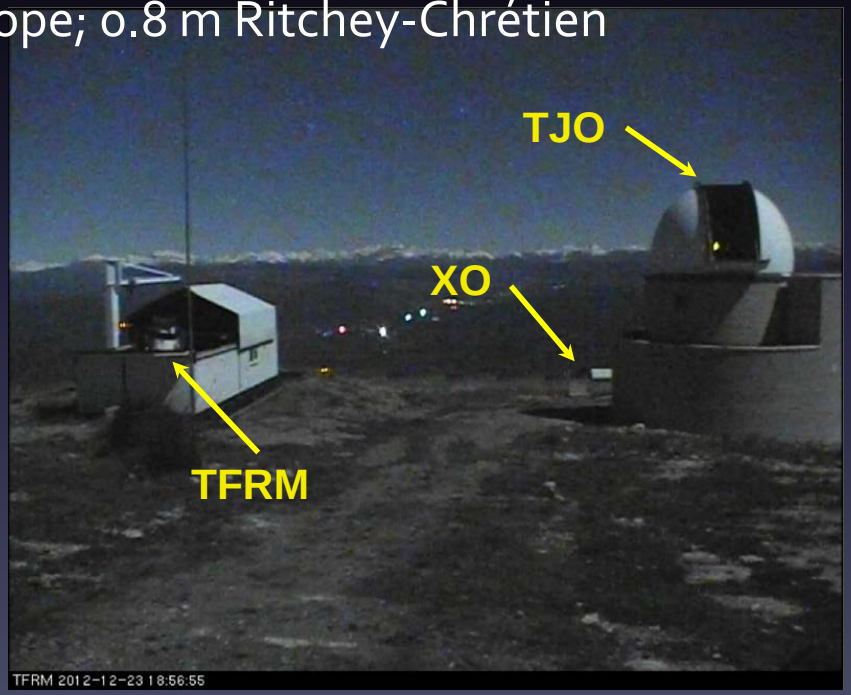
| Criterion | Available time |
|---|---|
| Humidity (<90%, 4h) | 85% |
| Wind speed (<15 m/s) | 100% |
| Clarity (>0.7) | 62% |
| Clarity (>0.9) | 40% |

IEEC

OAdM
Observatori Astronòmic del Montsec
Parc Astronòmic Montsec

# The facilities

- The operation of the OAdM is in charge of the IEEC, with funding from GenCat's Direcció General de Recerca (+ UB + CSIC)
- There are 6 research facilities operating at the l'OAdM
  - ✓ Generalitat de Catalunya: TJO telescope; 0.8 m Ritchey-Chrétien
  - ✓ RACAB&ROA: TFRM telescope; 0.5 m Baker-Nunn
  - ✓ SMC: Meteorological station XEMA
  - ✓ ICTJA-CSIC: Air pollution monitoring station XVPCA
  - ✓ IEEC-CSIC: All-sky camera for meteor detection
  - ✓ STScI: Telescope of the XO exoplanet detection network

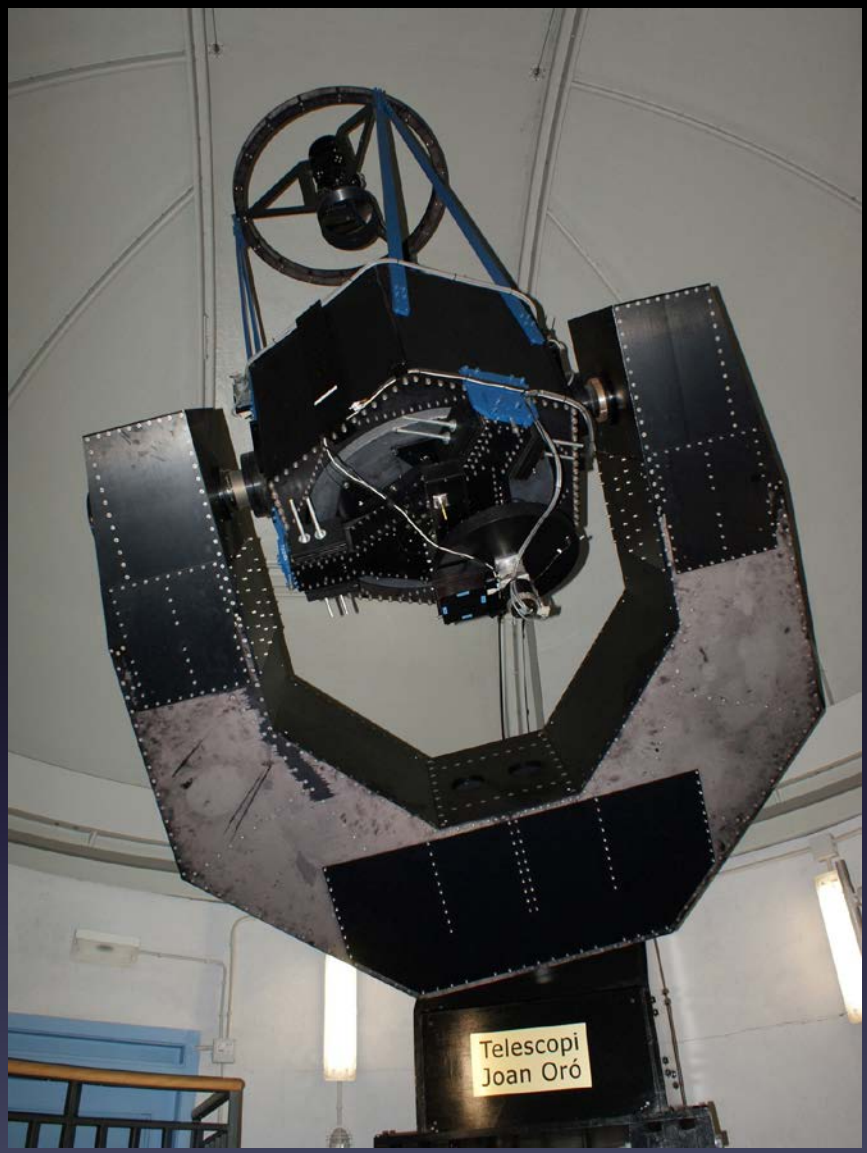



IEEC

OAdM
Observatori Astronòmic del Montsec
Parc Astronòmic Montsec

# The Joan Oró telescope

- 80 cm, Ritchey-Chrétien f/9.6
- Equipped with two instruments:
  - ➢ MEIA2 camera(subst. MEIA 04/2015): CCD with UBVRI filters
  - ➢ ARES spectrograph: Intermediate-resolution (R=12000) spectrograph
- Operates robotically (no human intervention)
- Offered to the international community since 2013

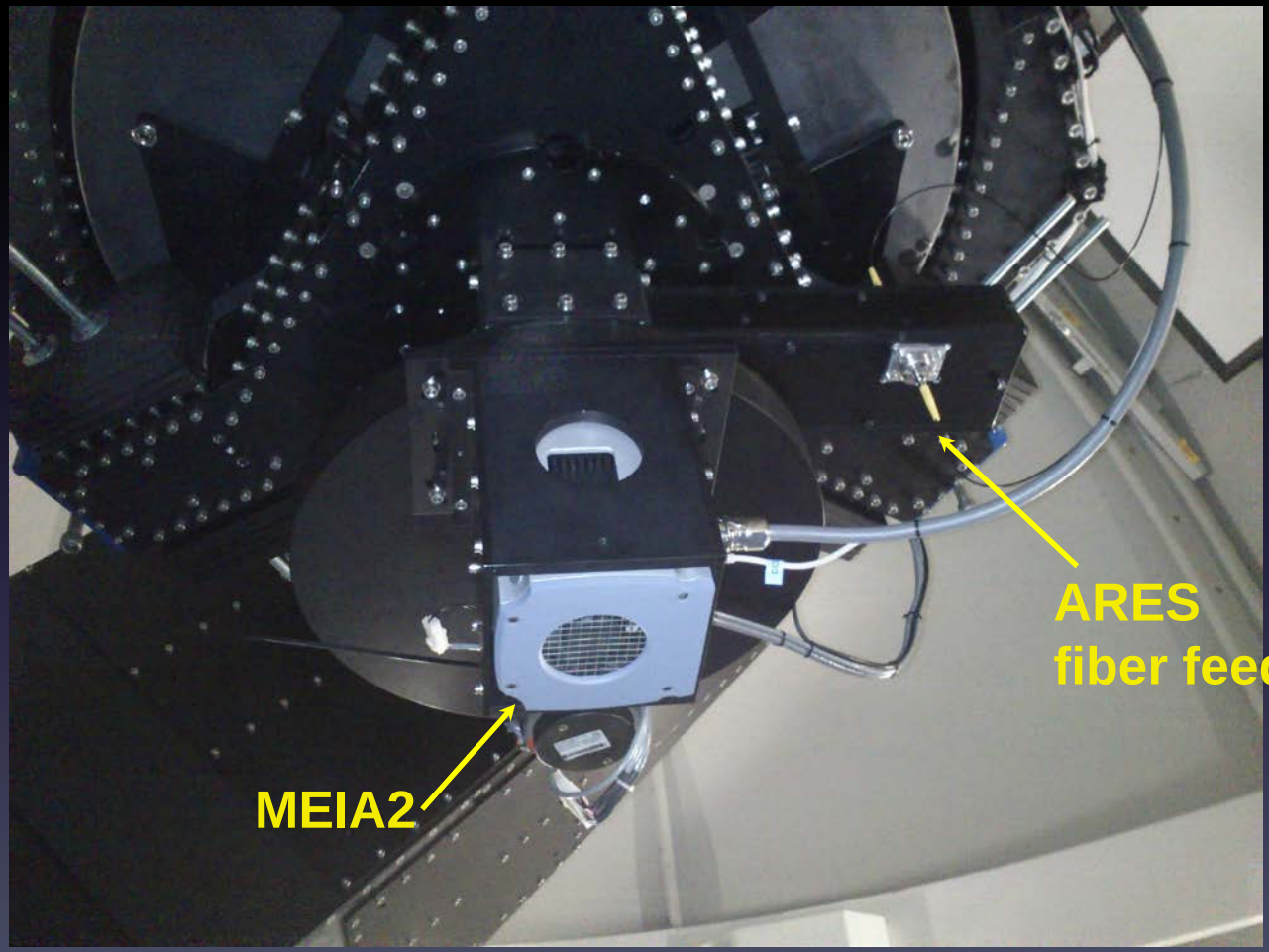



IEEC

OAdM
Observatori Astronòmic del Montsec
Parc Astronòmic Montsec

# The instrumentation: MEIA2

Front End: Own design and construction



# The instrumentation: MEIA2

MEIA2

- Imaging camera
- Manufacturer: Andor Technology™
- 2048×2048 back-illuminated chip (27.6x27.6 mm)
- Pixel size: 13.5 µm
- Pixel scale: 0.36×0.36 arcsec
- Field of view: 12.3×12.3 arcmin
- Readout time 6 seconds
- Johnson-Cousins filters: U, B, V, $R_C$, $I_C$

| Band | S/N~100 in 300 seconds |
|---|---|
| U | 13.2 |
| B | 17 |
| V | 17 |
| $R_C$ | 17.2 |
| $I_C$ | 17 |

- Status: OPERATIONAL (MEIA - FLI ProLine backup since 04/2015)

IEEC

OAdM
Observatori Astronòmic del Montsec
Parc Astronòmic Montsec

# CARMENES monitoring campaigns at the TJO

2016/17: Photometry and radial velocity correlations of stellar activity jitter (80 hours)
2016/17: Determination of rotation periods of M dwarfs (100 hours)
2017/18: Characterization of rotation and stellar activity on M dwarfs thorigh photometric variability (100 hours)
2017/18: Pale Red Dot 2: photometric monitoring of the nearest potential planet hosts (80 hours)
2018/19: Characterization of M dwarfs stelar activity (100 hours)

| Target | Other | Data | Filter | Number of nights | Time span (days) | Time span (dates) | Period (days) | Comment |
|---|---|---|---|---|---|---|---|---|
| GJ388 | AD Leo | 742 | R | 47 | 313 | march 2018 - may 2018 | - | |
| GJ873 | EV Lac | 1056 | R | 114 | 698 | july 2016 - january 2018 | 4.36 | |
| G234-057 | | 937 | R | 16 | 242 | august 2016 - april 2017 | - | |
| GJ109 | VX Ari | 461 | R | 80 | 229 | july 2016 - march 2017 | - | |
| GJ207.1 | V371 Ori | 509 | R | 66 | 172 | september 2016 - march 2017 | 2.85 | |
| GJ285 | YZ CMi | 1023 | R | 98 | 526 | october 2016 - march 2018 | 2.78 | |
| GJ362 | | 290 | R | 56 | 212 | september 2016 - april 2017 | - | |
| GJ410 | DS Leo | 479 | R | 63 | 167 | november 2016 - april 2017 | 14.26 | |
| GJ525 | | 425 | R | | | july 2016 - april 2017 | | |
| GJ9520 | OT Ser | 835 | R | 95 | 810 | july 2016 - november 2018 | - | |
| GJ83.1 | TZ Ari | 793 | R | 33 | 62 | september 2018 - november 2018 | 8.98 | |
| GJ251 | | 159 | R | 10 | 12 | september 2018 - november 2018 | - | |
| GJ3512 | | 634 | R | 66 | 330 | december 2017 - november 2018 | 89.23 | |
| GJ686 | | 584 | R | 36 | 70 | july 2018 - november 2018 | 30.40 | moon cicle? |
| GJ880 | | 1602 | R | 40 | 68 | july 2018 - november 2018 | 45.33 | |
| GJ908 | | 243 | R | 10 | 10 | september 2018 - november 2018 | - | |
| Teegarden | | 3013 | R, I | 68 | 335 | november 2017 - november 2018 | - | long term + transit search |
| GJ4276 | | 219 | R | 1 | 1 | august 2018 | - | transit search |
| Barnard | | 608 | R, I | 72 | 142 | june 2017 - november 2017 | - | |

IEEC

OAdM Observatori Astronòmic del Montsec Parc Astronòmic Montsec

# Data reduction

## Calibration

ICAT (TJO)

Flats + darks + bias calibration

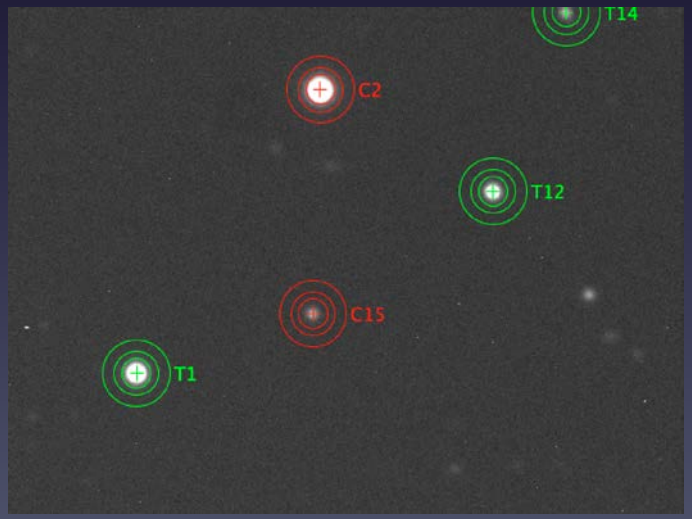
## Photometry

ICAT (TJO)
AstroImageJ

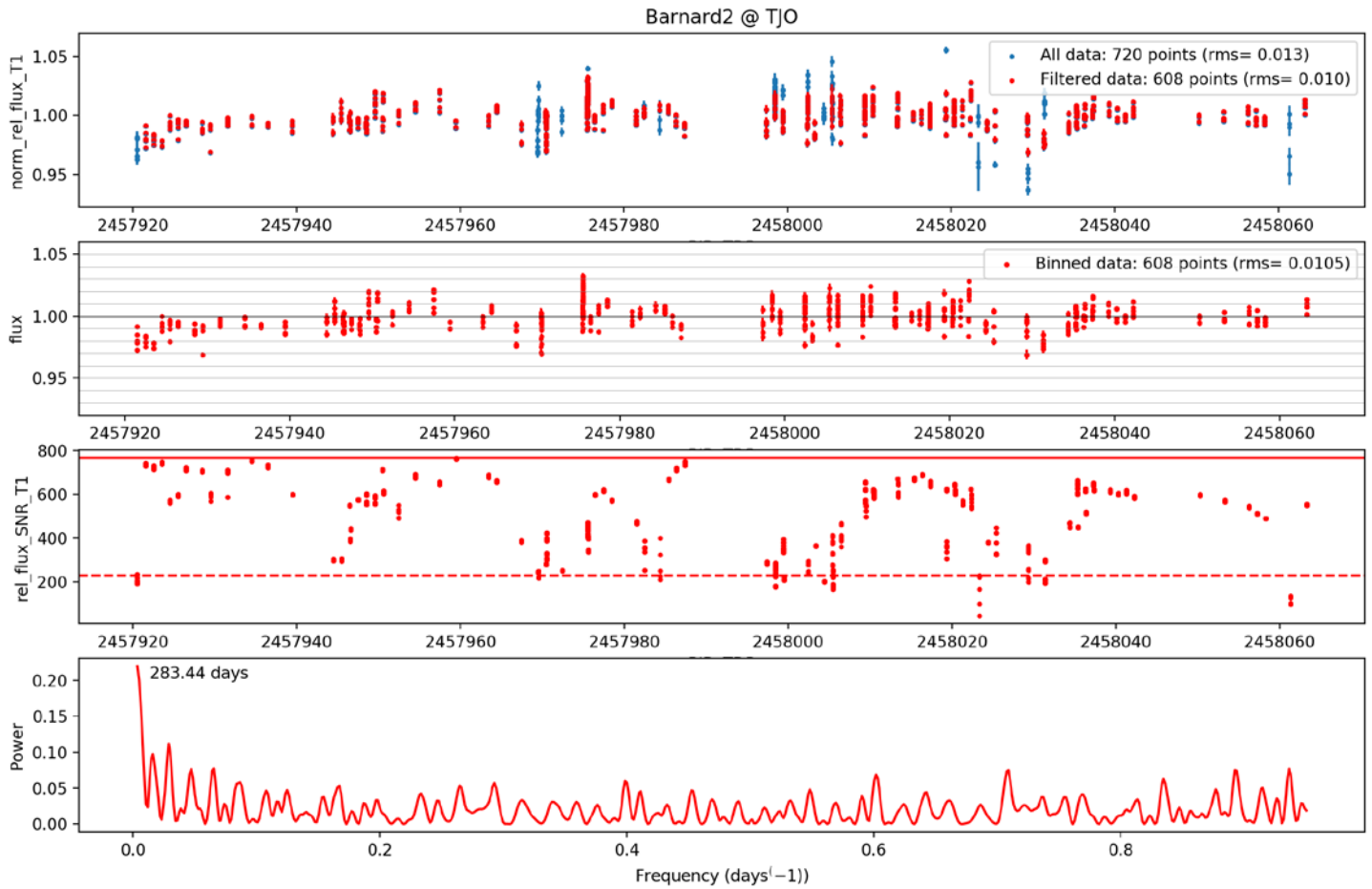
Differential photometry

## Analysis

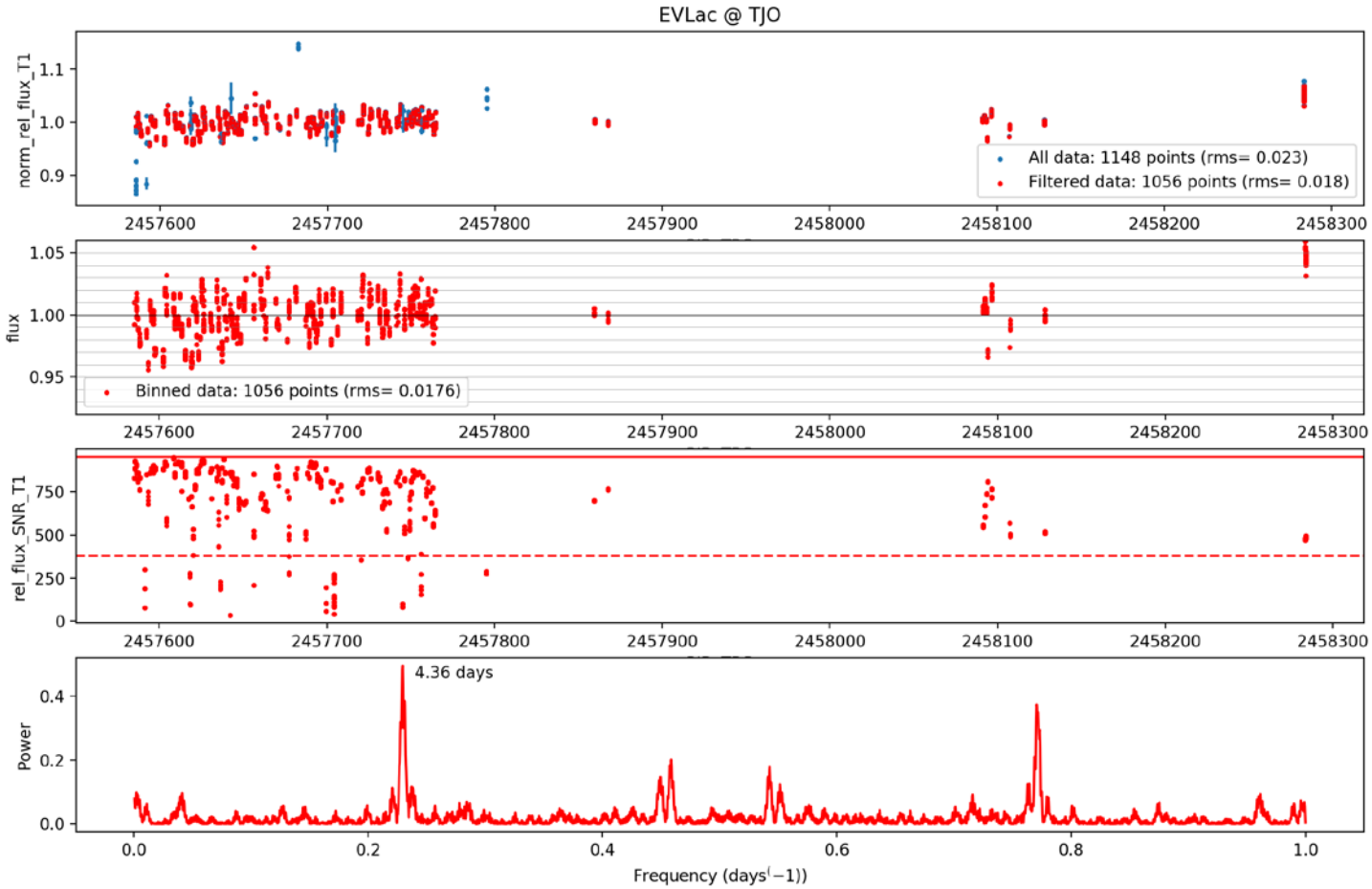
Remove outliers
Remove low SNR data
Premiminary LS periodogram
etc...



# Barnard’s star

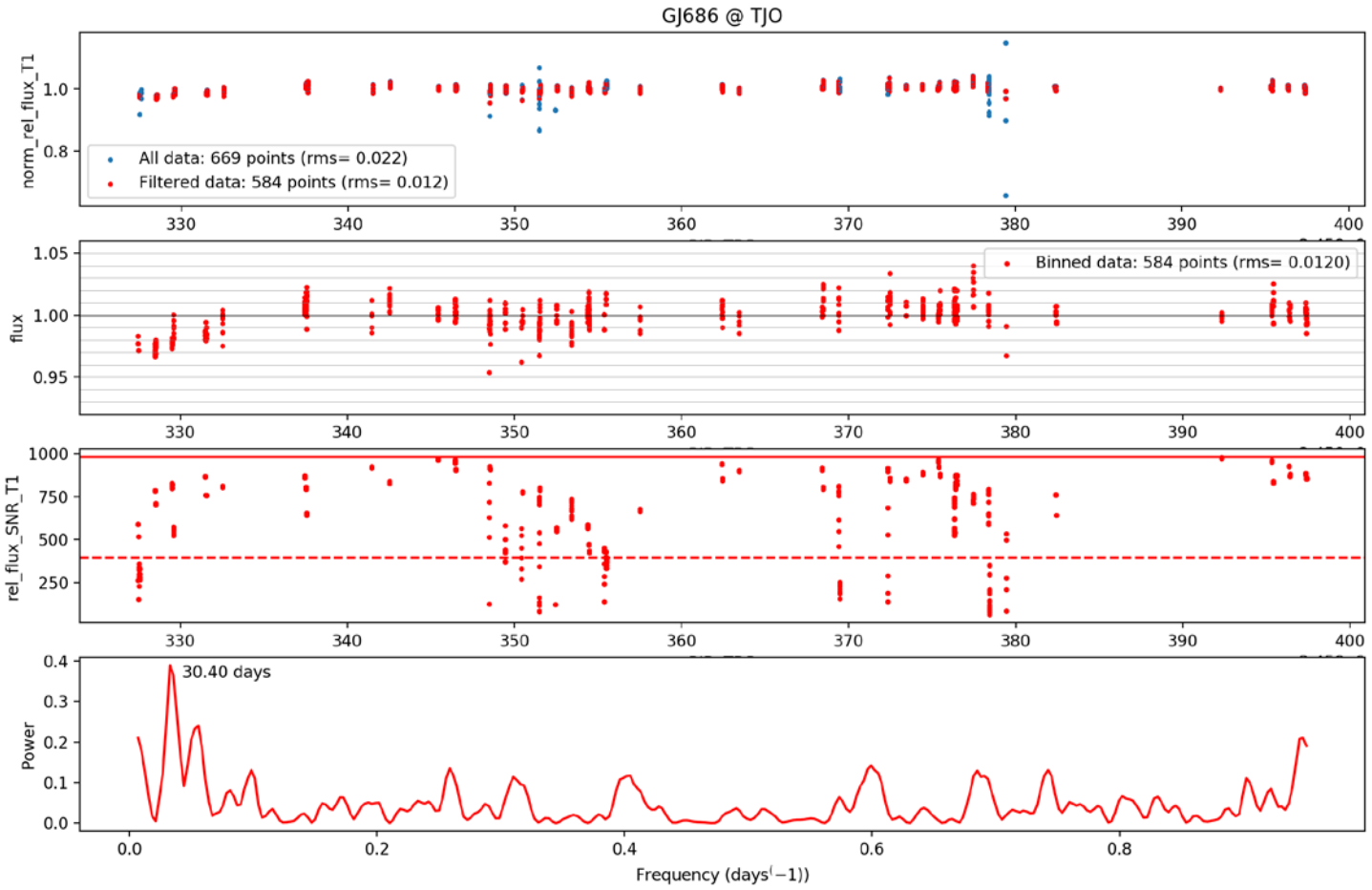


# EV Lac

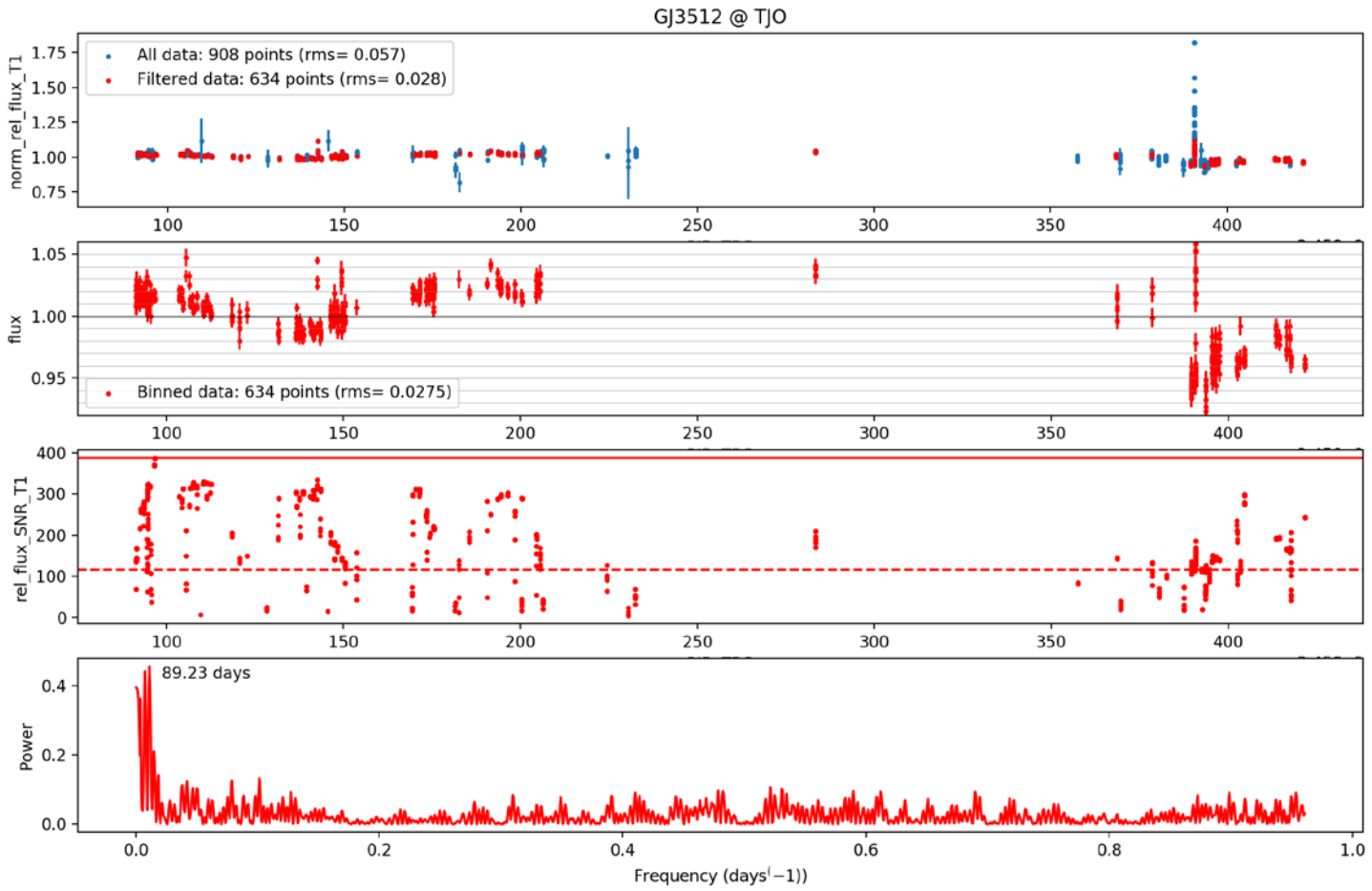

EVLac @ TJO
norm_rel_flux_T1
All data: 1148 points (rms= 0.023)
Filtered data: 1056 points (rms= 0.018)
flux
Binned data: 1056 points (rms= 0.0176)
rel_flux_SNR_T1
4.36 days
Power
Frequency (days^(−1))

# GJ 686

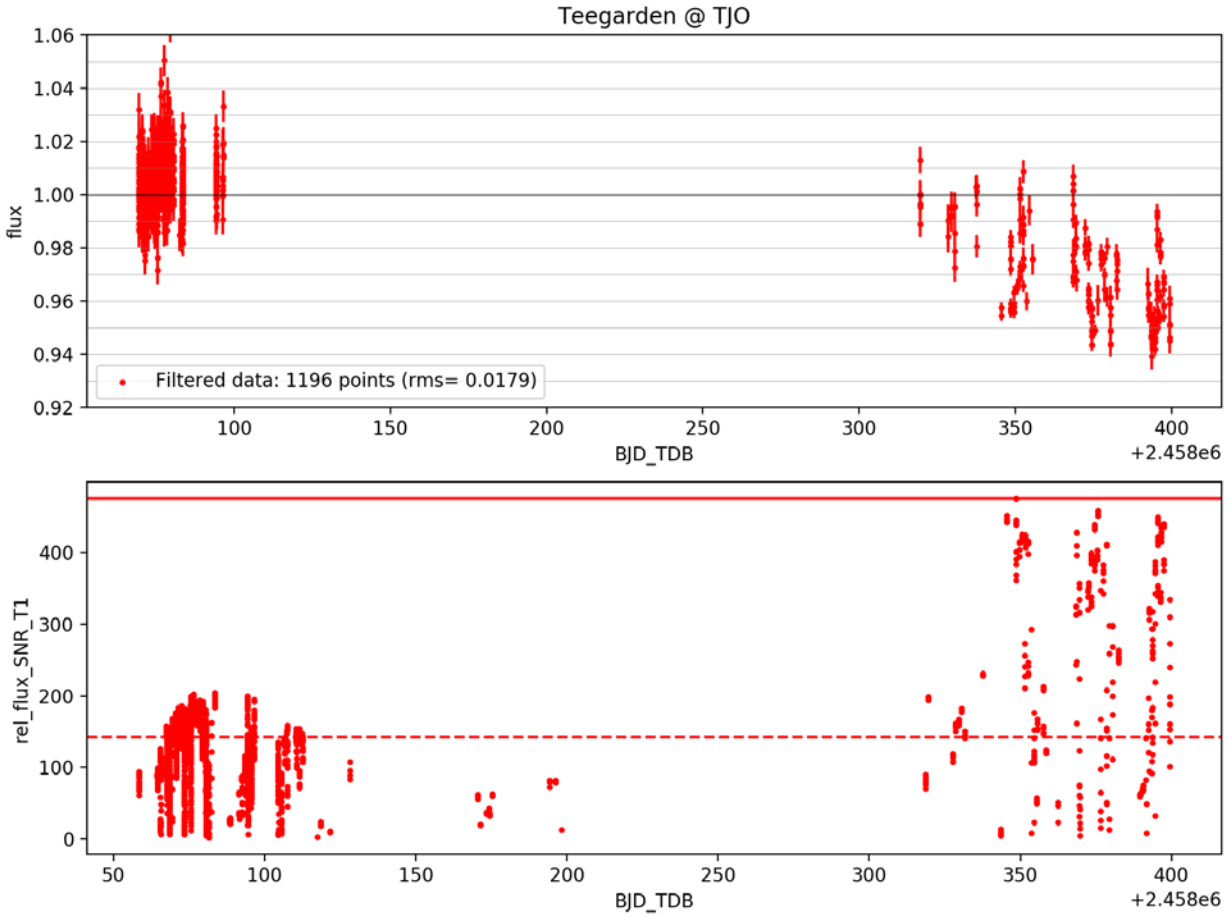
~37 d from activity indicators



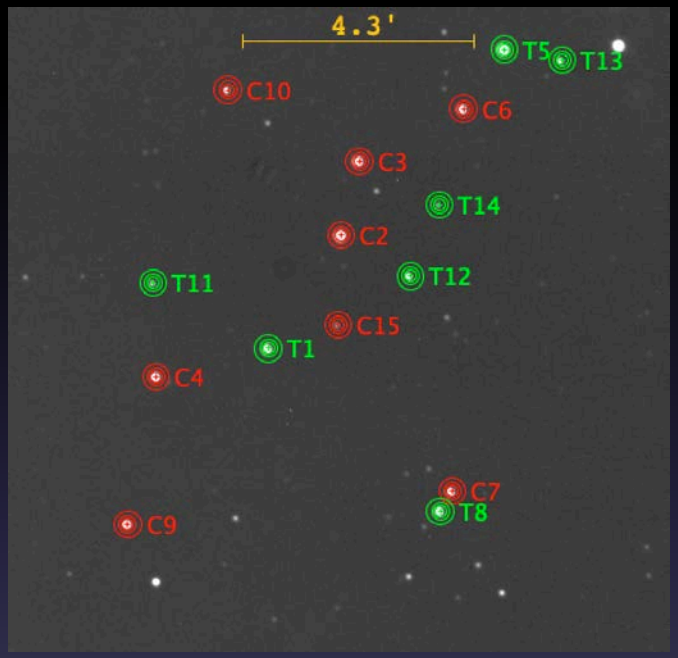
# GJ 3512

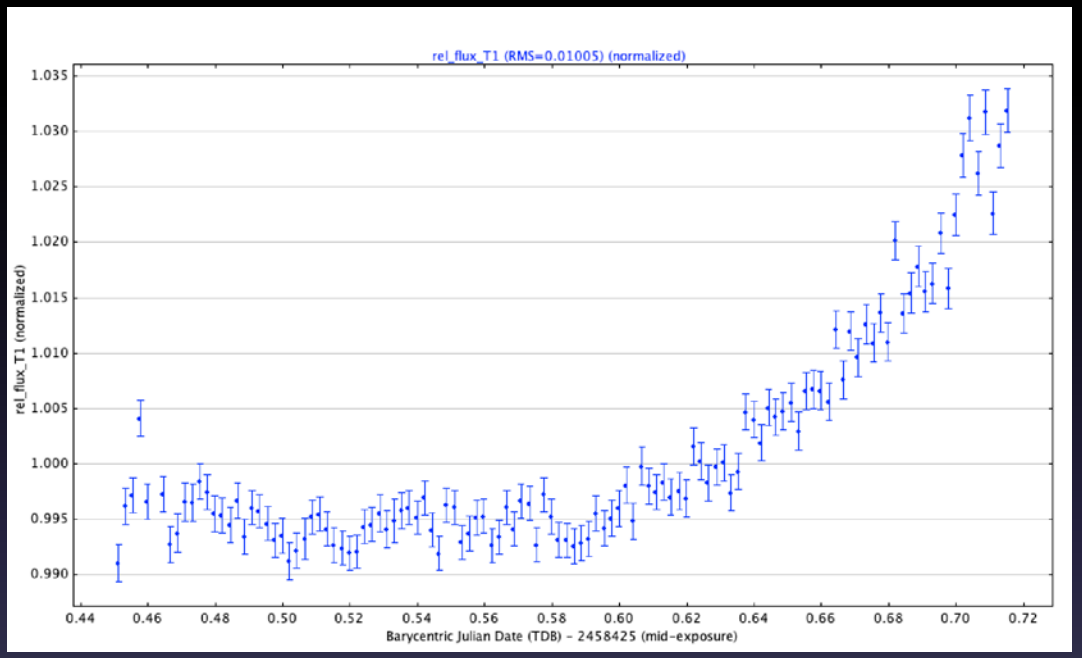

GJ3512 @ TJO
All data: 908 points (rms= 0.057)
Filtered data: 634 points (rms= 0.028)
norm_rel_flux_T1
Binned data: 634 points (rms= 0.0275)
flux
rel_flux_SNR_T1
89.23 days
Power
Frequency (days$^{-1}$)

# Teegarden's star long term monitoring



# Teegarden's star long term monitoring



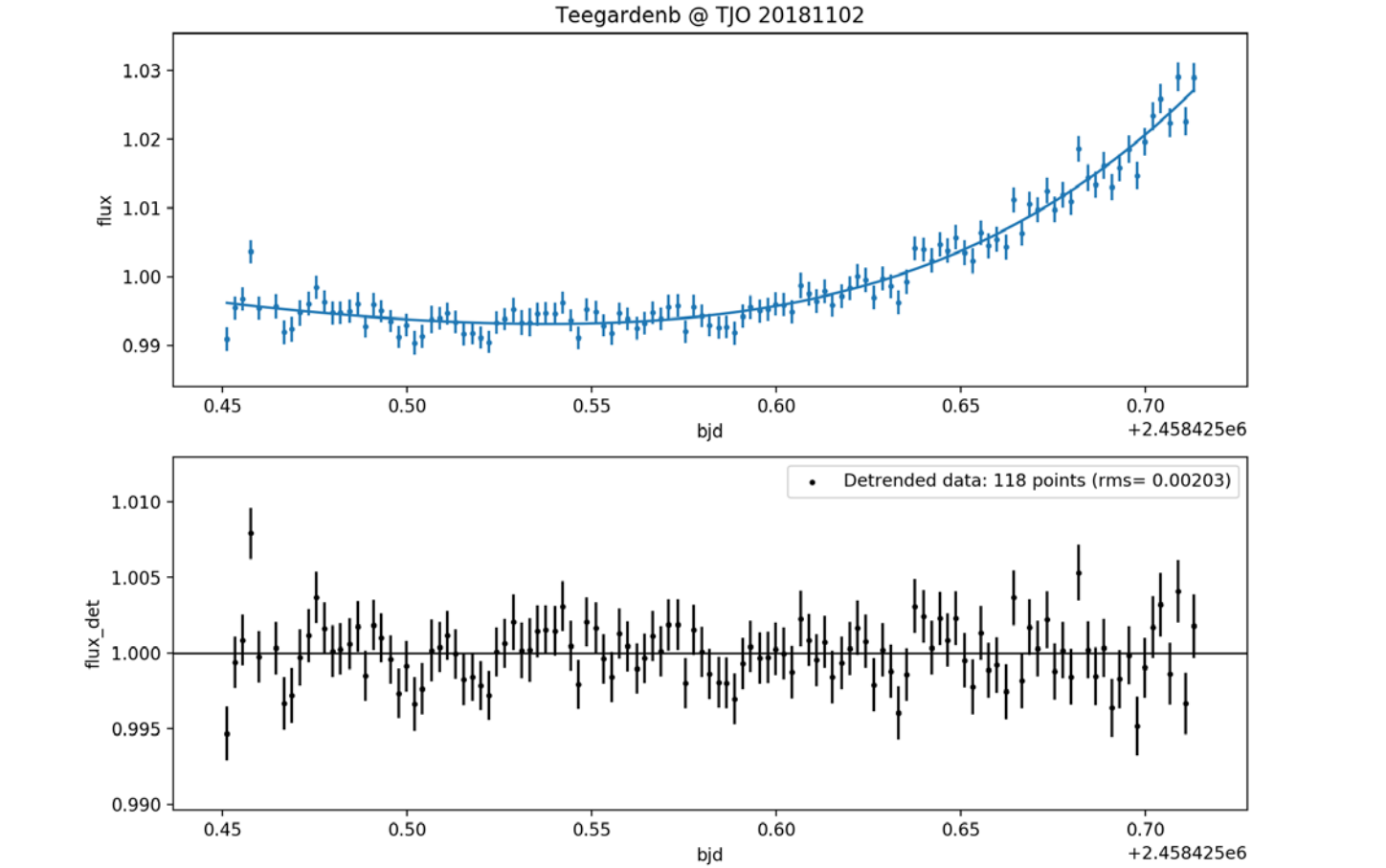




Large nightly trends due to the moon!

IEEC

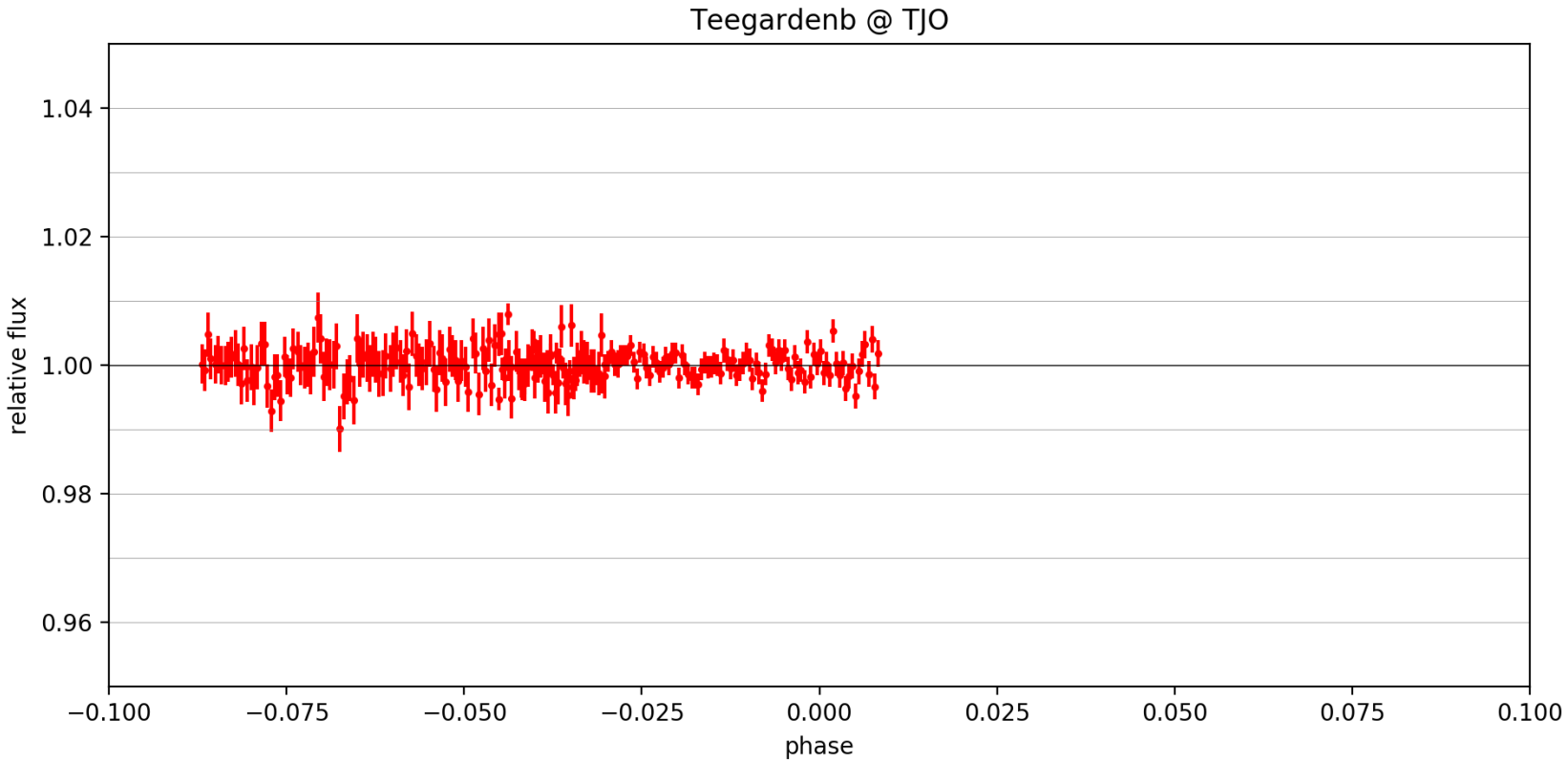
OAdM
Observatori Astronòmic del Montsec
Parc Astronòmic Montsec

# Teegarden's star transit search



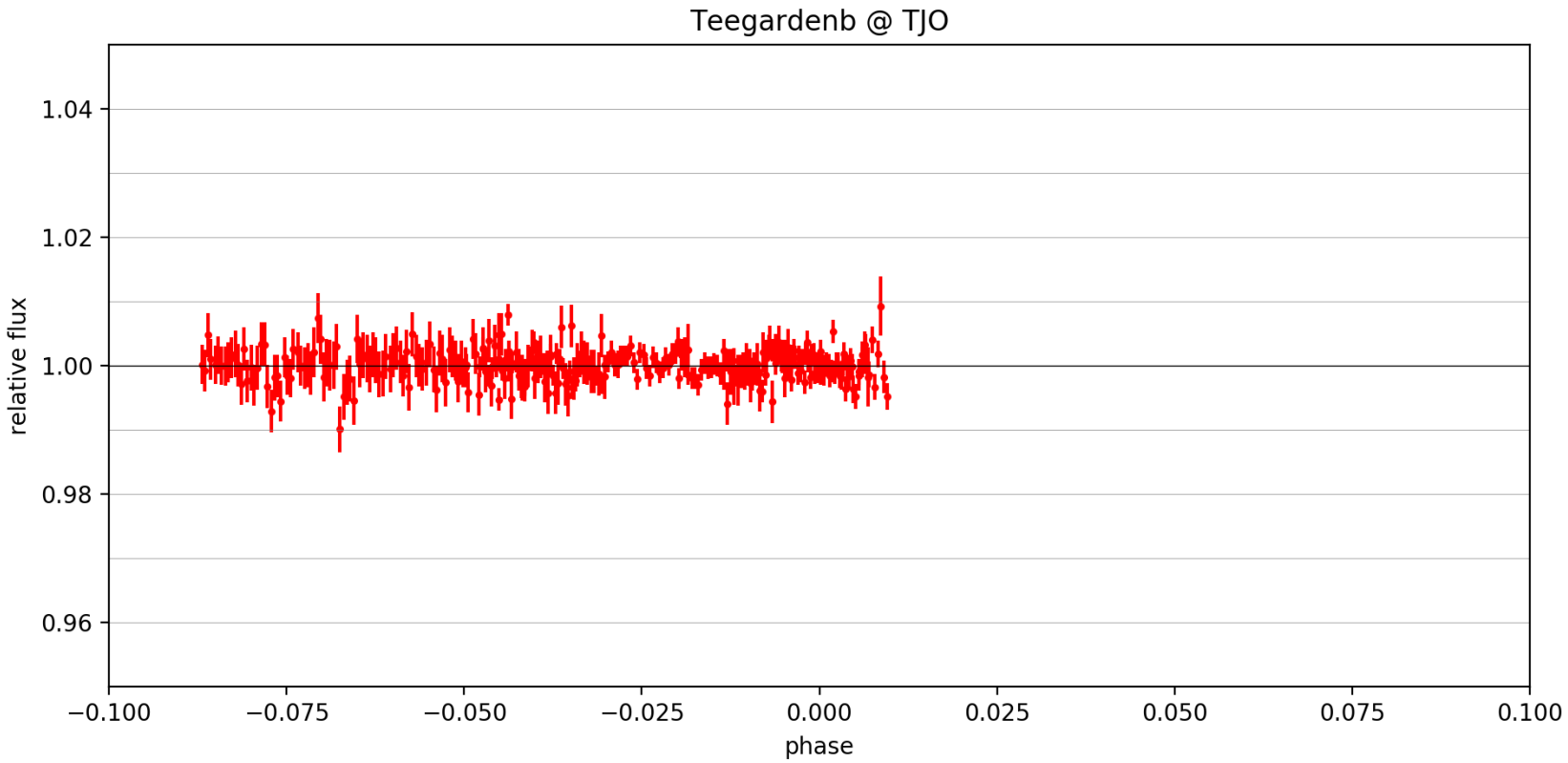
# Teegarden's star transit search

$JD_0$ = 2458401.085856
P = 4.91009 days



# Teegarden's star transit search

$JD_0$ = 2458401.085856
P = 4.91009 days



# CARMENES photometric monitoring from the TJO

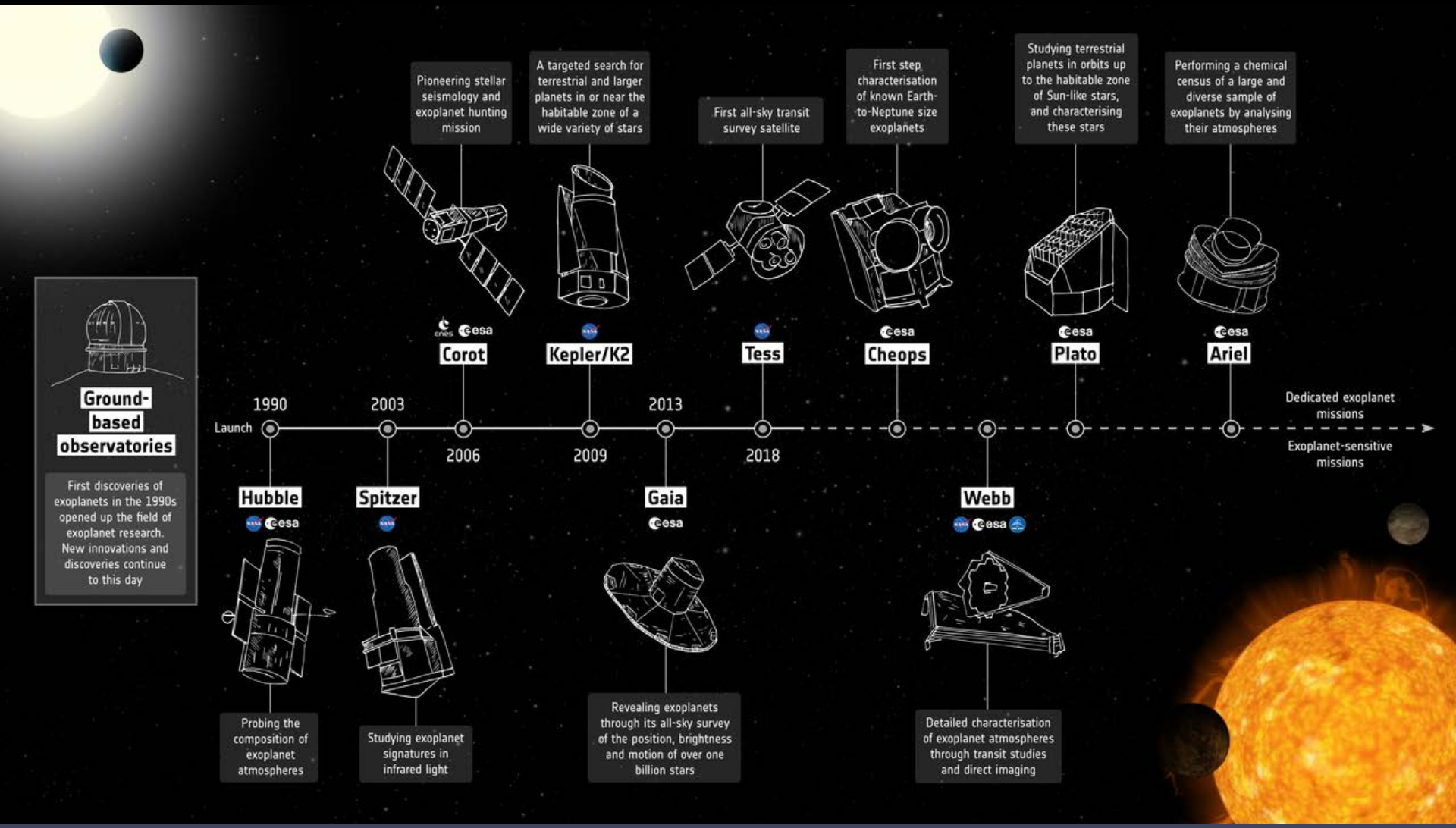
| Target | Other | Data | Filter | Number of nights | Time span (days) | Time span (dates) | Period (days) | Comment |
|---|---|---|---|---|---|---|---|---|
| GJ388 | AD Leo | 742 | R | 47 | 313 | march 2018 - may 2018 | - | |
| GJ873 | EV Lac | 1056 | R | 114 | 698 | july 2016 - january 2018 | 4.36 | |
| G234-057 | | 937 | R | 16 | 242 | august 2016 - april 2017 | - | |
| GJ109 | VX Ari | 461 | R | 80 | 229 | july 2016 - march 2017 | - | |
| GJ207.1 | V371 Ori | 509 | R | 66 | 172 | september 2016 - march 2017 | 2.85 | |
| GJ285 | YZ CMi | 1023 | R | 98 | 526 | october 2016 - march 2018 | 2.78 | |
| GJ362 | | 290 | R | 56 | 212 | september 2016 - april 2017 | - | |
| GJ410 | DS Leo | 479 | R | 63 | 167 | november 2016 - april 2017 | 14.26 | |
| GJ525 | | 425 | R | | | july 2016 - april 2017 | | |
| GJ9520 | OT Ser | 835 | R | 95 | 810 | july 2016 - november 2018 | - | |
| GJ83.1 | TZ Ari | 793 | R | 33 | 62 | september 2018 - november 2018 | 8.98 | |
| GJ251 | | 159 | R | 10 | 12 | september 2018 - november 2018 | - | |
| GJ3512 | | 634 | R | 66 | 330 | december 2017 - november 2018 | 89.23 | |
| GJ686 | | 584 | R | 36 | 70 | july 2018 - november 2018 | 30.40 | moon cicle? |
| GJ880 | | 1602 | R | 40 | 68 | july 2018 - november 2018 | 45.33 | |
| GJ908 | | 243 | R | 10 | 10 | september 2018 - november 2018 | - | |
| Teegarden | | 3013 | R, I | 68 | 335 | november 2017 - november 2018 | - | long term + transit search |
| GJ4276 | | 219 | R | 1 | 1 | august 2018 | - | transit search |
| Barnard | | 608 | R, I | 72 | 142 | june 2017 - november 2017 | - | |

GJ 338 B, GJ 514, GJ 458 A, GJ 15 B, …

IEEC

OAdM Observatori Astronòmic del Montsec Parc Astronòmic Montsec


www.oadm.cat
IEEC
Image: K. Herrero




IEEC

OAdM
Observatori Astronòmic del Montsec
Parc Astronòmic Montsec