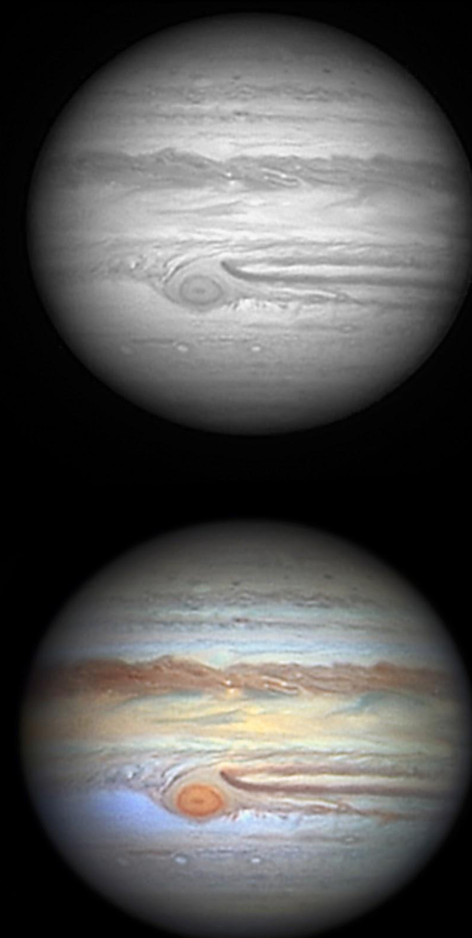
# Bosscha Photometry Pipeline

Muhammad Yusuf - Bosscha Observatory
**Faculty of Mathematics and Natural Sciences, ITB**

# JUPITER

17 JUNE 2019 16:02 UT

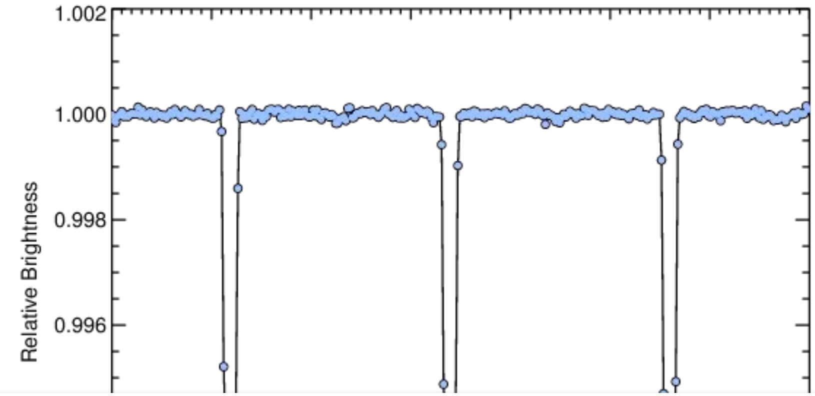


**BOSSCHA OBSERVATORY**

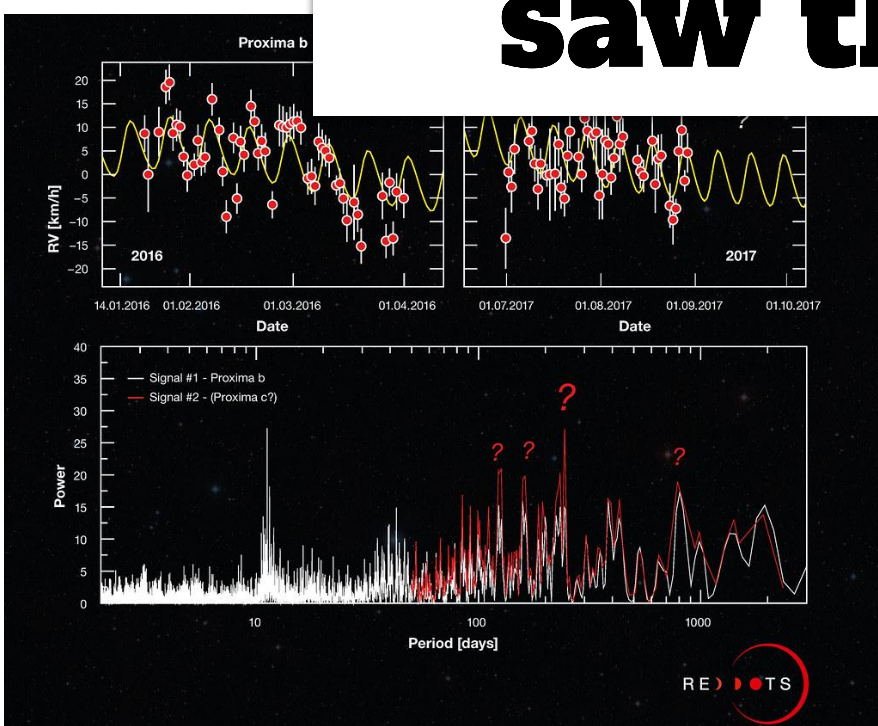
ZEISS DOUBLE REFRACTOR

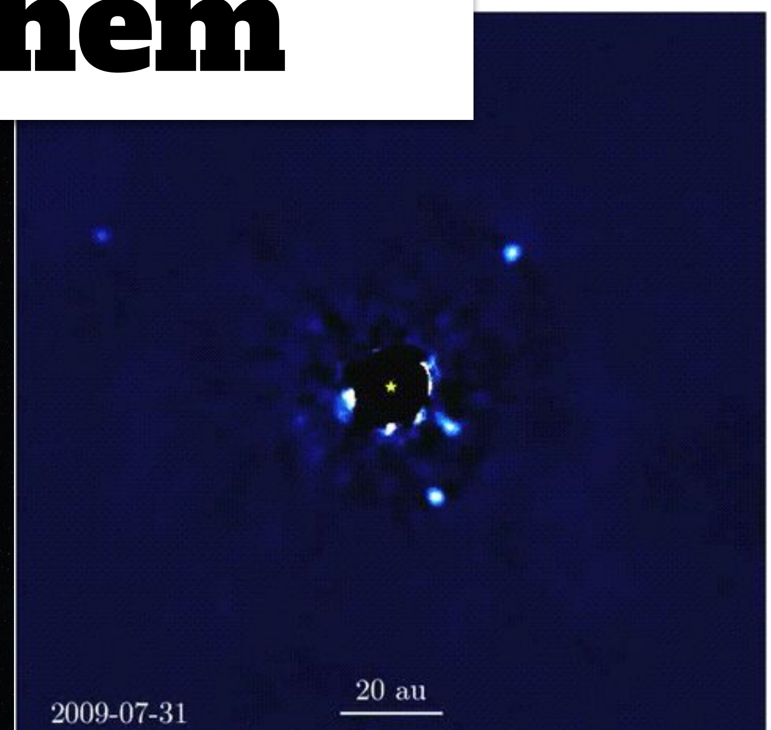
M. YUSUF - M. IRFAN - I. IMADUDDIN


How people
think we saw
exoplanet



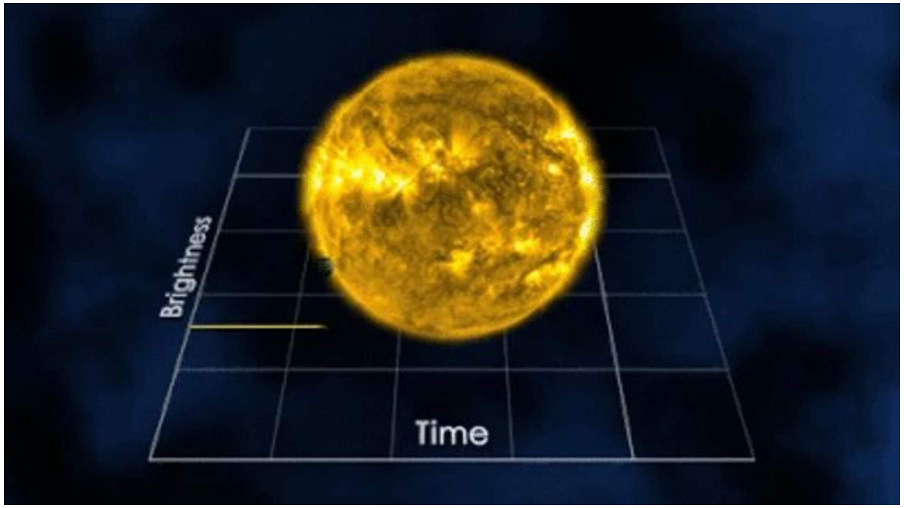

# How we really saw them



# Photometry Transit Method

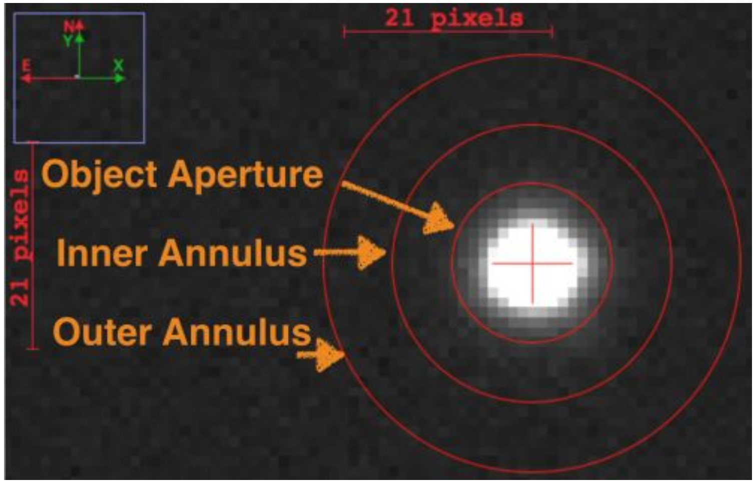
- Measure the dimming of light as an exoplanet passes in front of its host star and casts its shadow on our telescopes.
- The light curve is a graph the brightness of the star over time.
- The dip in light that happens when the planet passes in front of the star is called the "transit."
- The dimming of a star during transit directly reflects the size ratio between the star and the planet.




Source: NASA

# Aperture Photometry

- To extract the brightness of a star from the image, we must first sum the star's contribution over all pixels illuminated by it, and somehow estimate and subtract the contribution from the sky background.

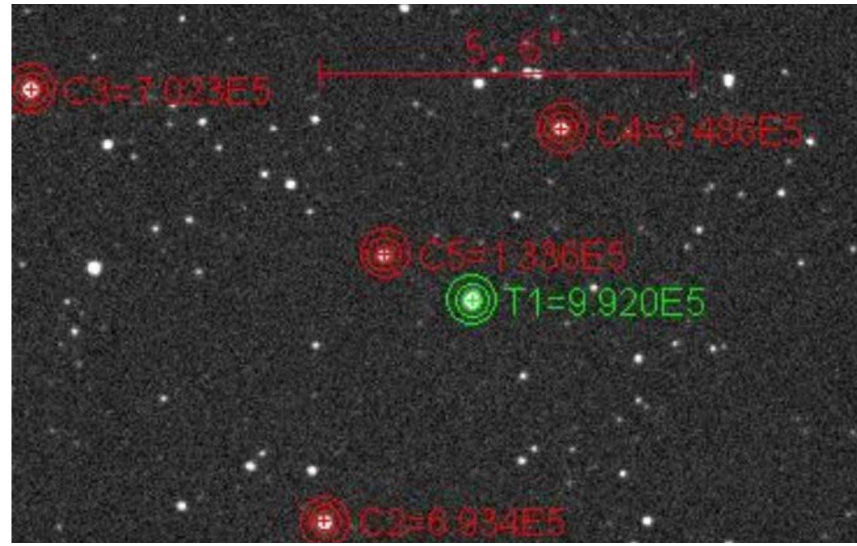


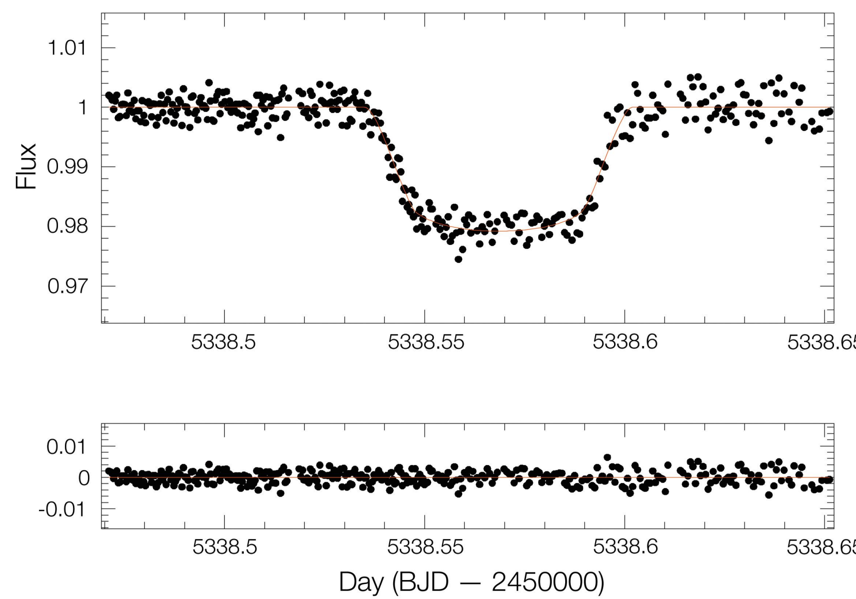

Source: astrobites.org

- To collect 99% of a star’s flux, it is usually necessary to choose an aperture four to five times the size of the star image (Full Width Half Maximum).
- The first calculation is to determine the sky background level (from the annulus). This average sky value is subtracted from all pixels inside the star aperture. The total flux in the star is then simply the sum of the pixel values in the star aperture.

# Differential Photometry

The differential photometry technique consists in obtaining measurements on the main target (the expected host star) and one or more reference stars (the comparison stars)



# Photometry Pipeline

- The development  of the pipeline emerged from the need to reduce and analyze the data from photometric monitoring of thousands of stars during a long time period.
- Modified code based on LEMON (Terron, V. 2018 → http://adsabs.harvard.edu/abs/2011hsa6.conf..755T).
- Written in Python utilizing standard astronomy software (SExtractor, IRAF, astropy, and photutils).
- It is possible to completely reduce thousands of FITS images of time series in a matter of only a few hours, requiring minimal user interaction.
- Use all the processors, parallel process.

# Astrometry Step

- Upon calibration, all the scientific images of the field taken with the same filter are combined (reference image) to increase S/N detection.
- Astrometry is done by matching the detected stars against the 2MASS catalog using astrometry.net.
- X, Y (pixel) coordinates ➔ $\boldsymbol{\alpha}$, $\boldsymbol{\delta}$

# Photometry Step

- Aperture photometry is done on every images by IRAF's qphot (migrating to photutils is almost done).
- Instead of using absolute values (example: 12 pixel), the value are defined in term of the **median** FWHM of the images in each band.
- The output is SQL database contains star_id, $\boldsymbol{\alpha}$, $\boldsymbol{\delta}$, instrumental magnitude, and image number (time).

# Light Curve Generation

- Computing an optimum artificial comparison star ➔ http://adsabs.harvard.edu/abs/2005AN....326..134B (Broeg et al. 2005)
- Broeg algorithm:
  - **Identify the most constant stars in the field**
  - Combine them into an artificial comparison star, with weights inversely proportional to their statistical dispersion
  - Compare the instrumental magnitude to the artificial one
- Output SQL database contains differential magnitude of each stars and its comparison stars.

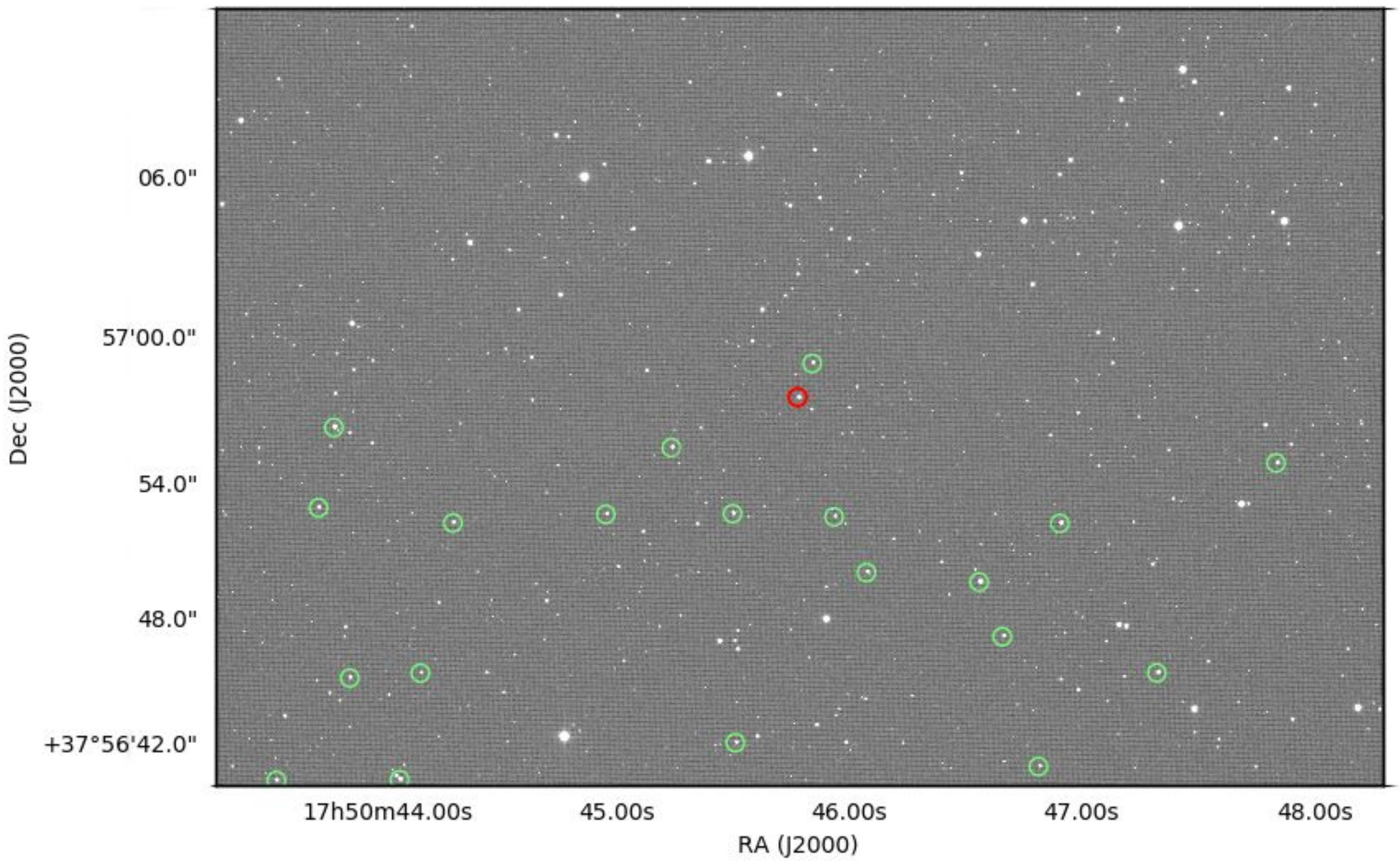
# Identify the most constant stars in the field

- We need their light curves
- Recursive problems ➔ $O(N^2)$
- How to solve
  - Assume that all the stars in the field are constant
  - Use all the stars in the field (except itself) as comparison star
  - Generate light curve and compute its statistical dispersion
  - After doing this for all the stars, discard those with the highest dispersion
  - Rinse and repeat until only *N* stars remain ➔ COMPARISON STARS

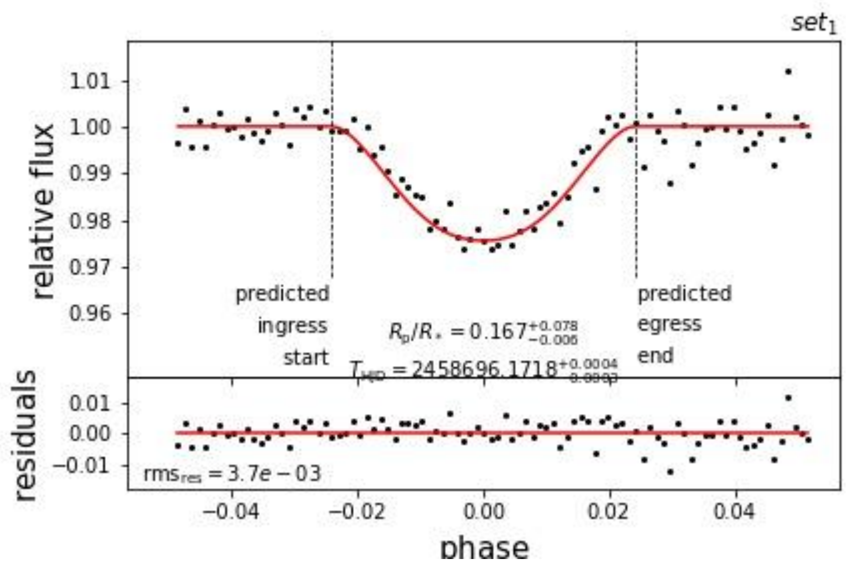
# Bosscha Observatory Projects

- Long-term observation of known exoplanets ➔ TTV and TDV
- TESS follow up program ➔ identify false positive and confirming exoplanet candidates
  - 600 events ➔ 2 events per night
- Long-term observation of exoplanet survey in the open star cluster near the celestial equator
- Study of variable stars (ASAS database)

# Example: TrES-3 b



# Example: TrES-3 b

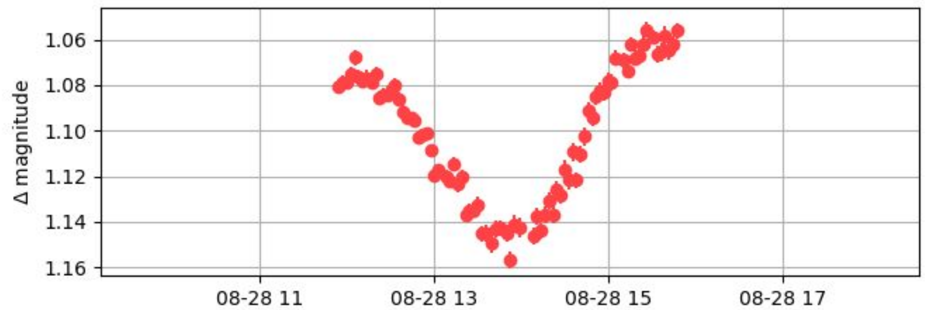



| Parameters | Observation | Reference |
|---|---|---|
| Planet radius (Rj) | 1.38 (± 0.08) | 1.305 (± 0.09) |
| Inclination (deg) | 81.3 (± 0.9) | 81.93 (± 0.13) |
| Midtransit (HJD) | 2458696.1718 | 2458696.1718 |

PyLightcurve (https://github.com/ucl-exoplanets/pylightcurve) ➜ MCMC Fitting

# Example: NGC 6494

- Apply machine learning to detect and classify periodic variable stars
- UPSILoN (AUtomated Classification of Periodic Variable Stars using MachIne LearNing) (Kim, 2016)
- Train model from OGLE (the Optical Gravitational Lensing Experiment) and EROS-2 (Expérience pour la Recherche d'Objets Sombres)
- New delta scuti variable stars?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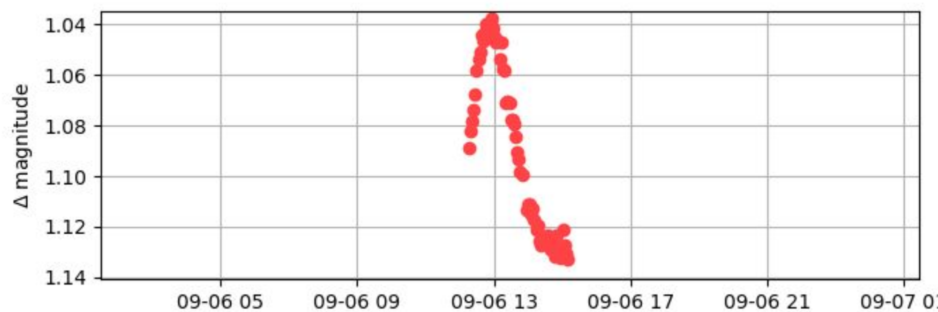
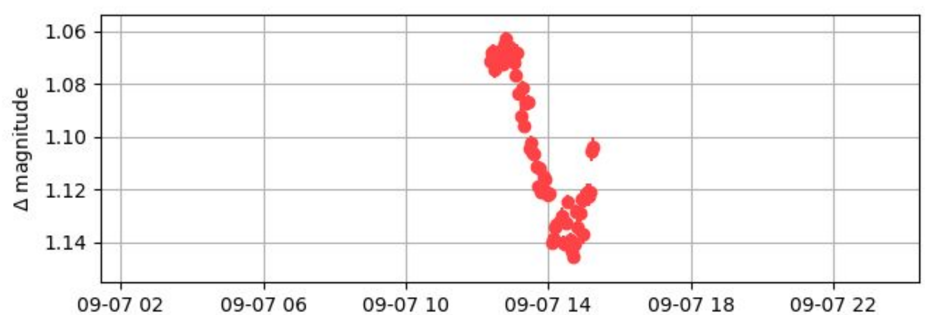
1.06
1.08
1.10
1.12
1.14
1.16
08-28 11
08-28 13
08-28 15
08-28 17


Δ magnitude
1.04
1.06
1.08
1.10
1.12
1.14
09-06 05
09-06 09
09-06 13
09-06 17
09-06 21
09-07 01


Δ magnitude
1.06
1.08
1.10
1.12
1.14
09-07 02
09-07 06
09-07 10
09-07 14
09-07 18
09-07 22

# Future work

- Install several new telescopes in Timor island (more ideal condition)
  - 20cm f/10
  - 50cm f/3.8
  - 50cm f/8
  - 1m f/8
  - 3.8m f/2 with tri-band camera

  ~ 300TB/year of raw data

- Machine learning to detect exoplanets
- Release the pipeline to Github under GPL
- Collaborate with other facilities in Indonesia


INDONESIA
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VIETNAM
CAMBODIA
PHNOM PENH
HO CHI MINH CITY (Saigon)
THAILAND
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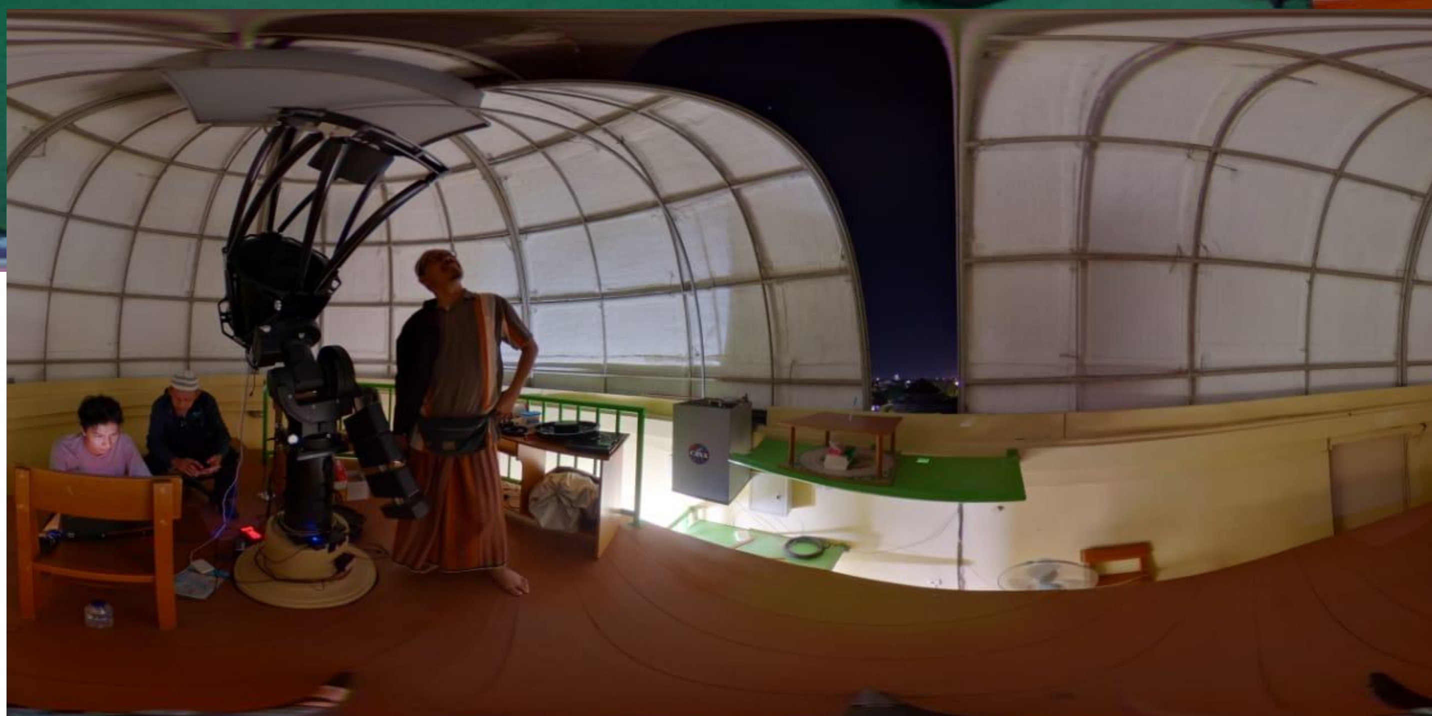
PHILIPPINES
PACIFIC OCEAN
PALAU
BANDAR SERI BEGAWAN
KUALA LUMPUR
BRUNEI
MALAYSIA
SINGAPORE
Kalimantan
Maluku
Sulawesi
Irian Jaya
PAPUA NEW GUINEA
NUSA TENGGARA
Java
Bali
Flores
Lombok
& Rinca
EAST TIMOR
INDIAN OCEAN
Darwin
0 500 km
0 300 miles
AUSTRALIA




SHOT ON OPPO
Kupang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# Thank You