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Follow-up observations of YETI planet candidates

Prof. Dr. Ralph Neuhäuser - Jena

Prof. Dr. Ronald Redmer – Rostock

Dr. Nadine Nettelmann – Rostock

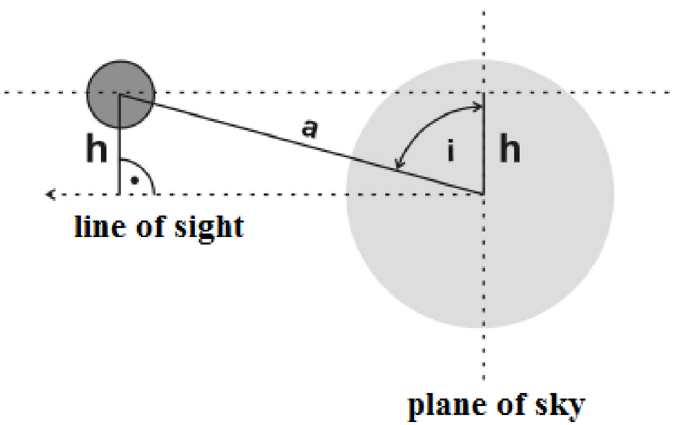
Dr. Markus Mugrauer – Jena

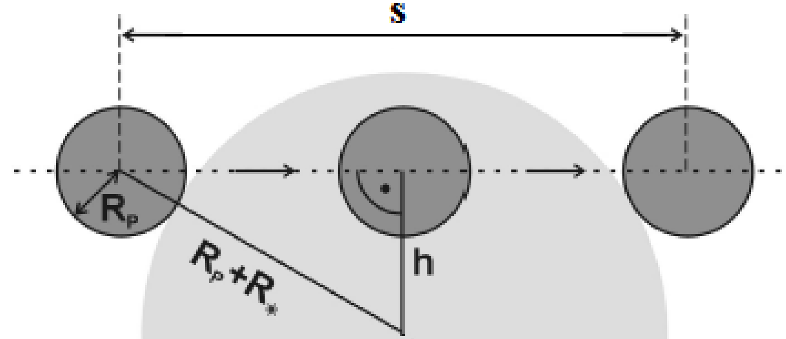
Anna Julia Poser - Rostock

Richard Bischoff - Jena

Transit technique

- information about planet radius R_P





$$S = 2 \cdot \sqrt{\left(R_P + R_*\right)^2 - h^2}$$

$$h = a \cdot \cos(i)$$

$$t = \sqrt{\left(R_P + R_*\right)^2 - a^2 \cdot \cos^2(i)} \cdot \frac{P}{\pi \cdot a}$$

→ inclination angle i

Why young transiting planets ?

Problem:

Almost all known transiting planets are old

- almost all detected planets are $\sim 10^9$ yr old

- studying planet formation:
  mass and radius of young planets needed

- so far only two young transit planets known:

- **K2-33b** a Neptune-sized transiting planet
  (not observed by YETI)

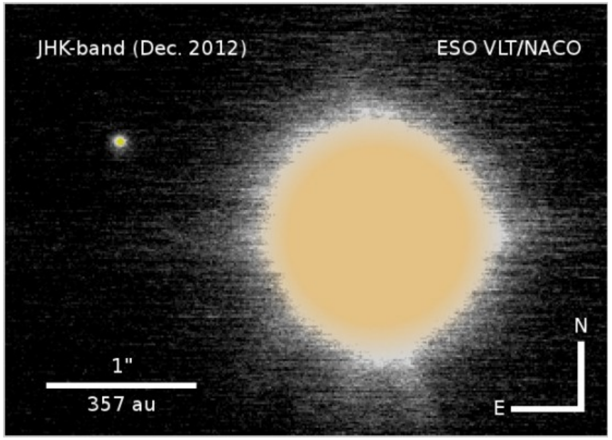
  – discovered and analyzed by David et al. 2016

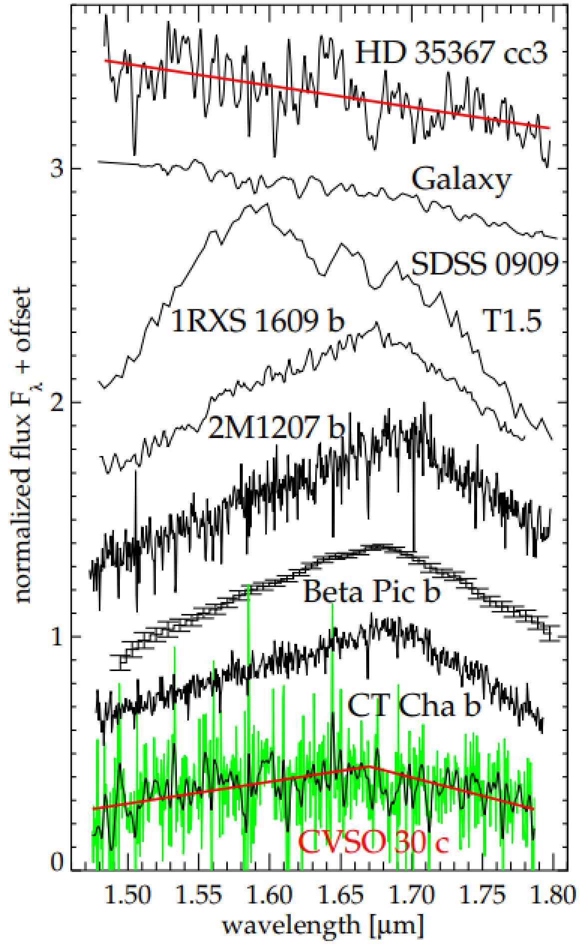
  – M-type star with:

$$M_{\text{star}} = (0.31 \pm 0.05)\ \mathrm{M}_{\odot}$$
$$d \approx (139 \pm 11)\ \text{pc}$$
$$\text{age} \approx 5\ \text{Myr} - 10\ \text{Myr}$$
$$P = (5.42513 \pm 0.00029)\ \text{d}$$

$$R_{\text{Planet}} = (1.49 \pm 0.16)\ \mathrm{R}_{\text{Neptune}}$$
$$a = (0.0409 \pm 0.0023)\ \text{AU}$$
$$M_{\text{Planet}} \approx 1\ \mathrm{M}_{\text{Neptune}}$$

- young star CVSO 30 with both, a transit planet and a direct imaging planet





left: Direct image of CVSO 30 c and its host star, common proper motion confirmed

right: H-band spectrum of CVSO 30 c in comparison to other planetary candi-dates and background objects (from Schmidt, Neuhäuser et. al 2016)

- close & wide planet may allow conclusions about dynamics

YETI-Candidates

- in Trumpler 37 (PhD thesis Errmann 2015)

$d \approx 870\,\mathrm{pc}$ age of cluster $\approx 4\mathrm{Myr}$

$P = \left(0.736867 \pm 0.000004\right)\mathrm{d}$ $\Delta R = \left(11.7 \pm 0.5\right)\mathrm{mmag}$

- in NGC 7243 (Garai et al. 2016)

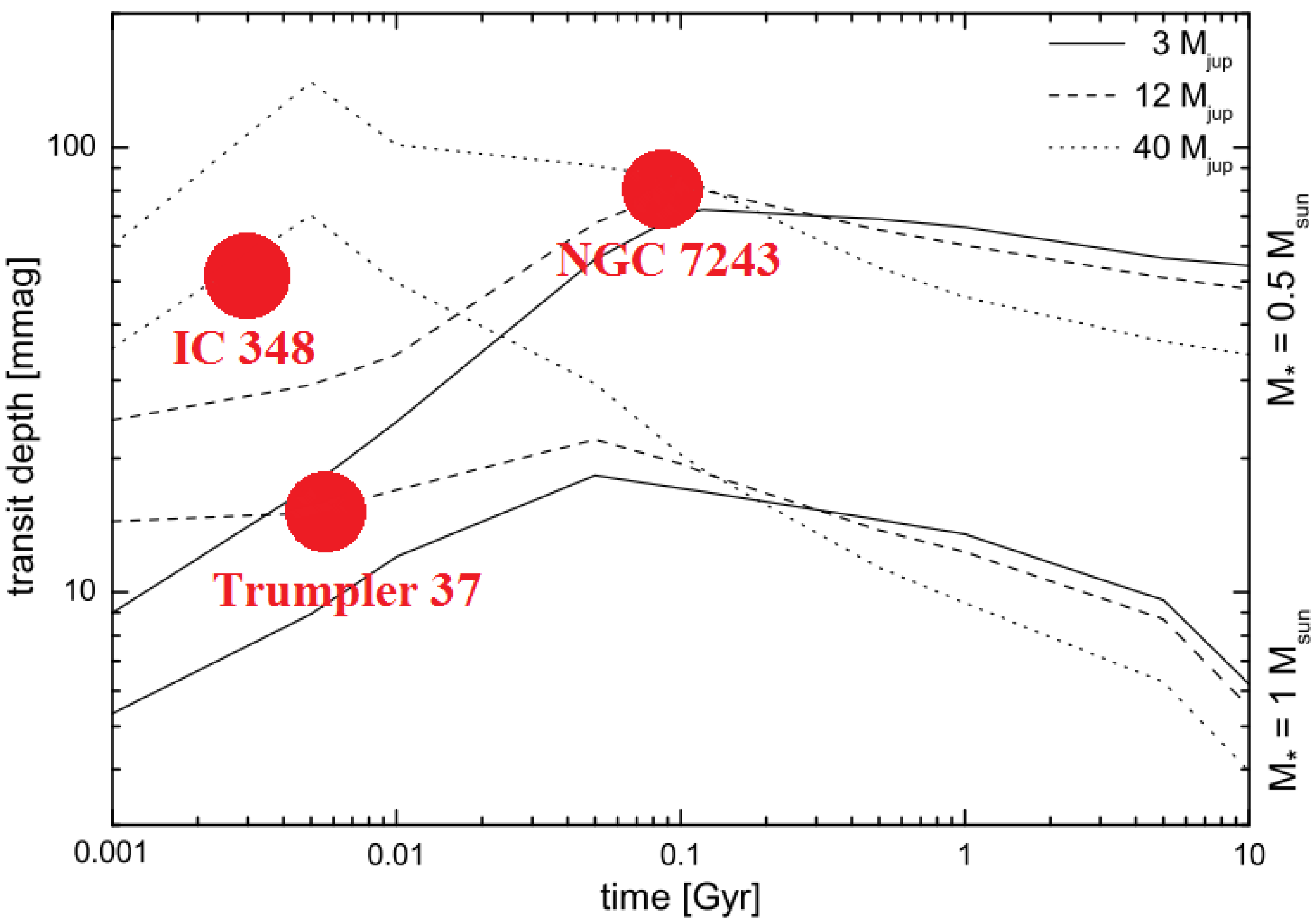
$d \approx 750\,\mathrm{pc}$ age of cluster $\approx 76\,\mathrm{Myr}$

$P \approx 4.380383(12)\,\mathrm{d}$ $\Delta R \approx 80\,\mathrm{mmag}$

- in IC 348 (Fritzewski et al. 2016)

$d \approx 315\,\mathrm{pc}$ age of cluster $\approx 2\,\mathrm{Myr}$

$P \approx (5.123874 \pm 0.000063)\mathrm{d}$ $\Delta R \approx 50\,\mathrm{mmag}$

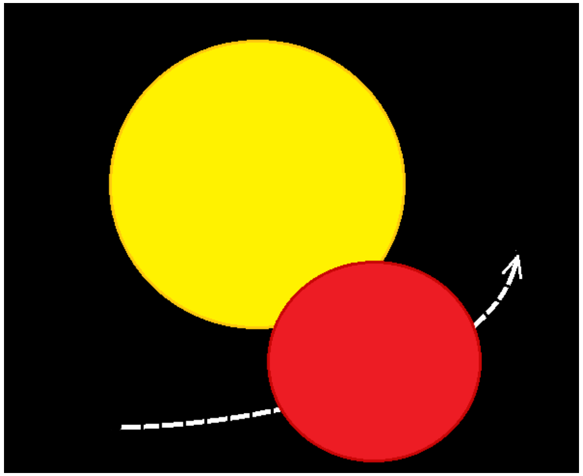


Theoretical position of the candidates for given cluster ages and transit depths

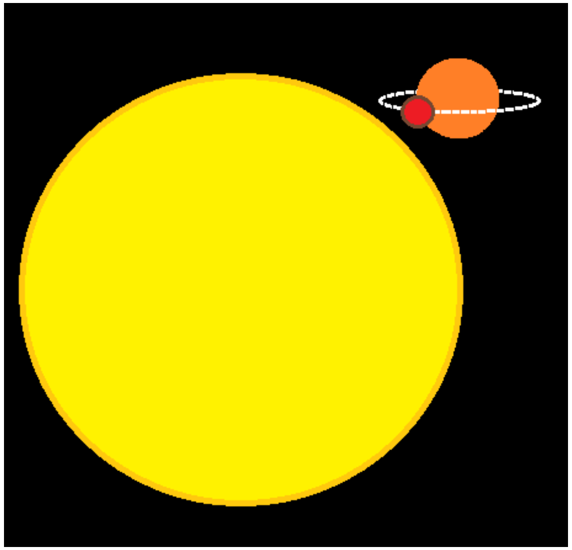
Possible false positives

- different non planetry objects can mimic a transit signal:
  - eclipsing binary with **early main sequence** star orbiting **around giant star**
  - degenerated **low mass star** or **brown dwarf** (same size as jupiter like planet)

– **grazing eclipse** of a binary star



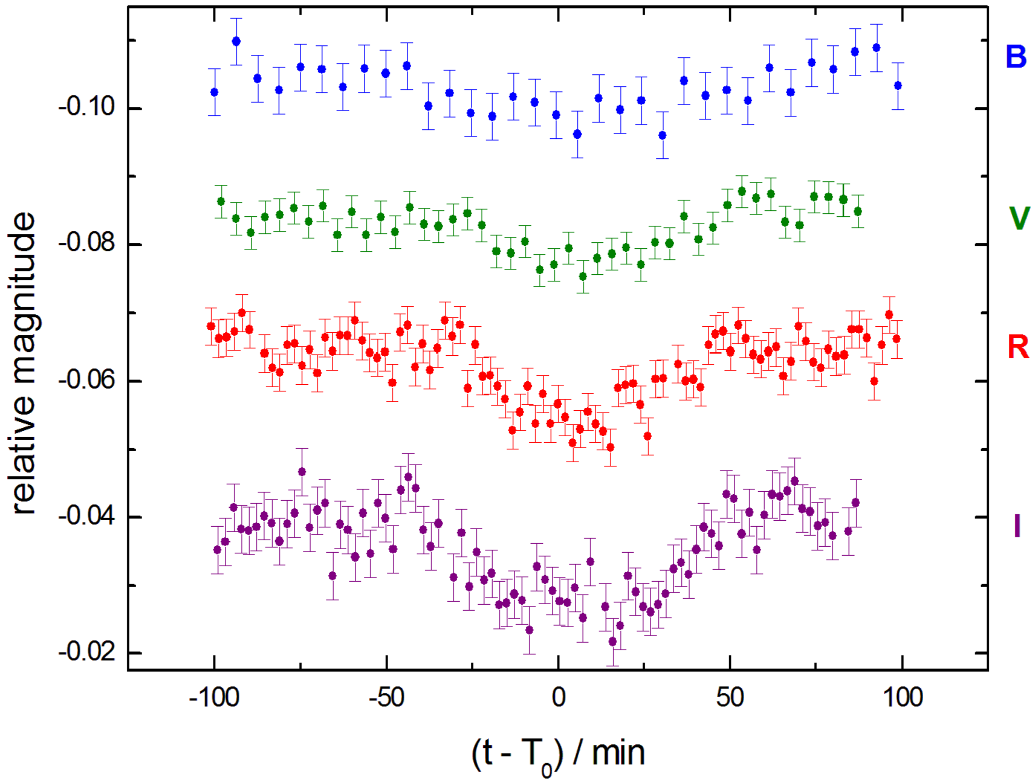
– **eclipsing binary** with bright **foreground star** in the optical PSF



Multiband photometry

- planet should cause the same depth in BVRI filters

- studying possible colour effects with YETI
  - W. P. Chen, P. C. Huang at Lulin Observatory
  - M. Fernández at Observatory Sierra Nevada
  - Z. Garai at Stará Lesná Observatory
  - G. Maciejewski at Torun Observatory
  - P. Zielinski at Adiyaman and Suhora Observatory



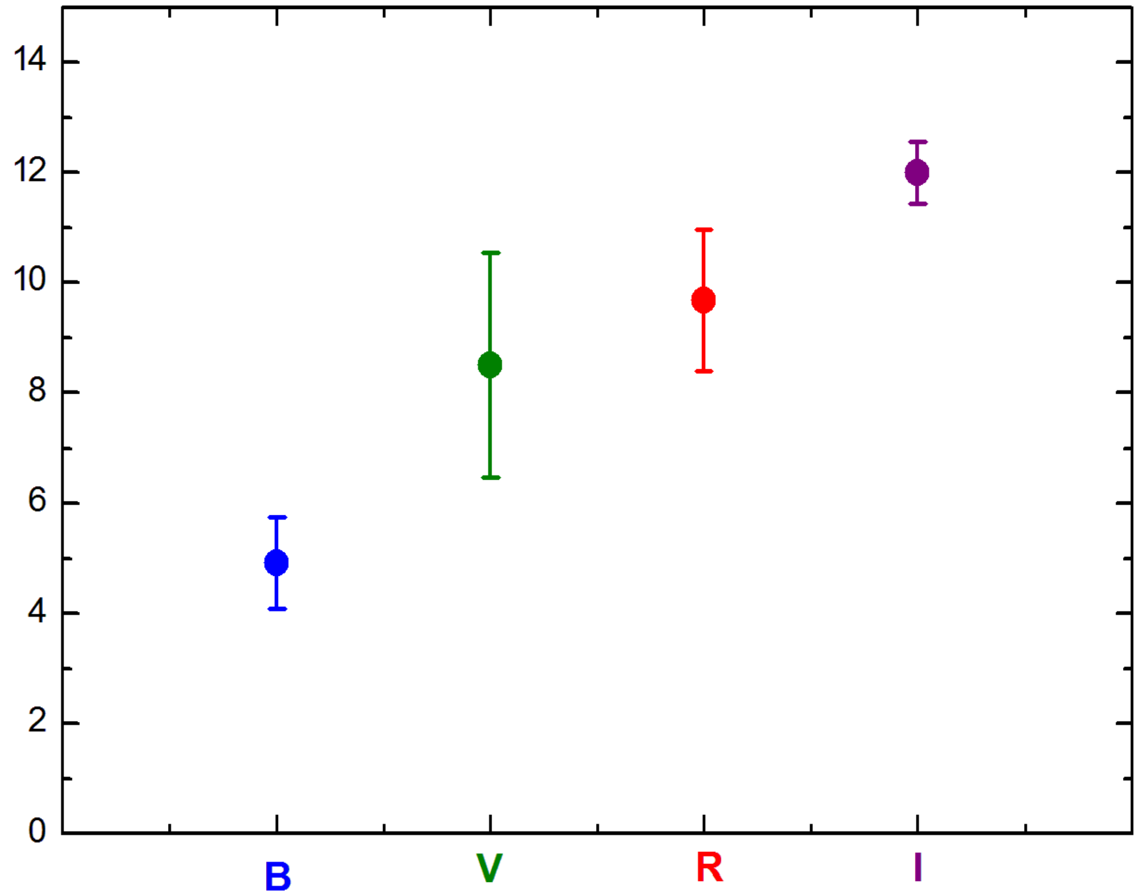
example lightcurves of the transit candidate in Trumpler 37

$$\Delta m_{\mathrm{B}} = (5.3 \pm 1.3)\,\mathrm{mmag}$$

$$\Delta m_{\mathrm{V}} = (6.9 \pm 0.9)\,\mathrm{mmag}$$

$$\Delta m_{\mathrm{R}} = (10.7 \pm 0.8)\,\mathrm{mmag}$$

$$\Delta m_{\mathrm{I}} = (12.7 \pm 0.9)\,\mathrm{mmag}$$



average transit depths (in mmag) for different filters with 2σ error bars for the candidate in Trumpler 37

- checking the characteristics of transit candidate host star in Trumpler 37 with GAIA DR2:

$$T = \left(4906^{+486}_{-88}\right) \mathrm{K} \qquad L = \left(0.827 \pm 0.097\right) L_{\odot}$$

$$R = \left(1.26^{+0.04}_{-0.22}\right) R_{\odot} \qquad \mathrm{plx} = \left(1.7849 \pm 0.1019\right) \mathrm{mas}$$

$$d = \left(560^{+34}_{-30}\right) \mathrm{pc}$$

- Contreras et al. (2002): d$\sim$ 870 pc

- mass estimation with GAIA DR2 values and models from Baraffe et al.

$$T = \left(4906^{+486}_{-88}\right)\mathrm{K} \quad R = \left(1.26^{+0.04}_{-0.22}\right)R_{\odot} \quad L = \left(0.827 \pm 0.097\right)L_{\odot}$$

for an age of 4 Mio yrs

T [K]	R [$R_{\odot}$]	L [$L_{\odot}$]	M [$M_{\odot}$]
4850	1.882	1.738	1.50
4722	1.803	1.445	1.40
4611	1.727	1.202	1.30
4497	1.661	1.000	1.20
4438	1.627	0.912	1.15
4379	1.602	0.832	1.10

- mass estimation with GAIA DR2 values and models from Baraffe et al.

$$T = \left(4906^{+486}_{-88}\right)\mathrm{K} \quad R = \left(1.26^{+0.04}_{-0.22}\right)R_{\odot} \quad L = \left(0.827 \pm 0.097\right)L_{\odot}$$

for an age of 13 Mio yrs

T [K]	R [$R_{\odot}$]	L [$L_{\odot}$]	M [$M_{\odot}$]
4543	1.176	0.525	1.05
4690	1.215	0.631	1.10
4848	**1.263**	**0.776**	**1.15**
5038	1.318	1.000	1.20
5482	1.468	1.738	1.30
6003	1.765	3.548	1.40

- for the other candidates not enough lightcurves are analyzed so far
- GAIA DR2: no light sources detected around candidates that can cause transit signals

  distances of host stars consistent with cluster distances
- nevertheless unresolved eclipsing binary in PSF possible
- IR photometry with AO necessary

- observing time granted for AO imaging at

  Subaru Telescope (Hawaii) in autumn 2018

  &

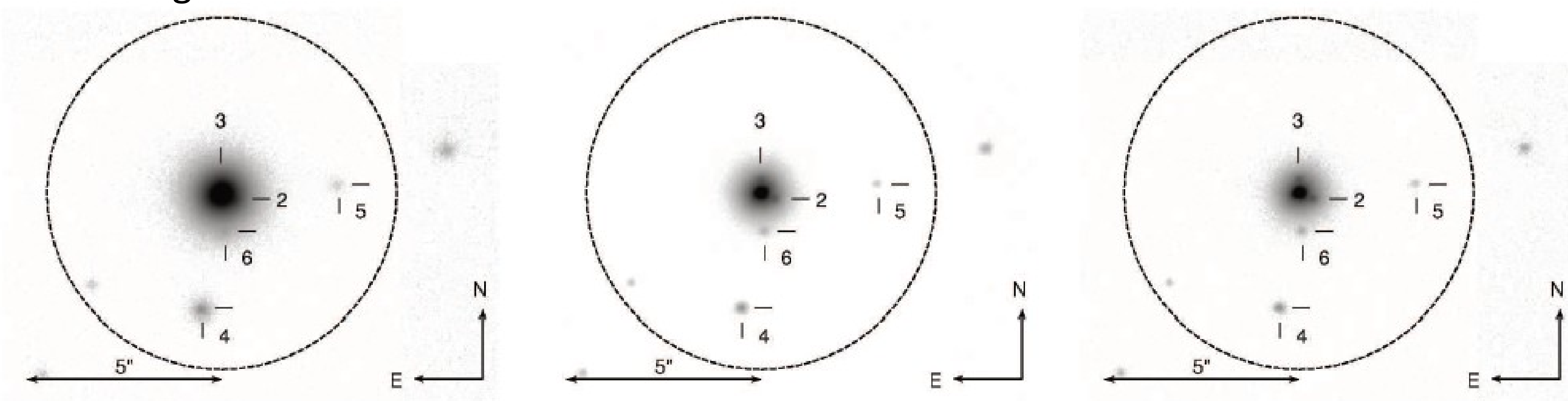
  Large Binoculare Telescope (Arizona) in January 2019

Subaru Teleskope from: https://www.nao.ac.jp/en/project/hawaii.html

LBT from : https://upload.wikimedia.org/wikipedia/commons/4/4a/LargeBinoTelescope_NASA.jpg

IR imaging with AO (example)

IR images with AO in different filters from Errmann et al. 2016:



J H K

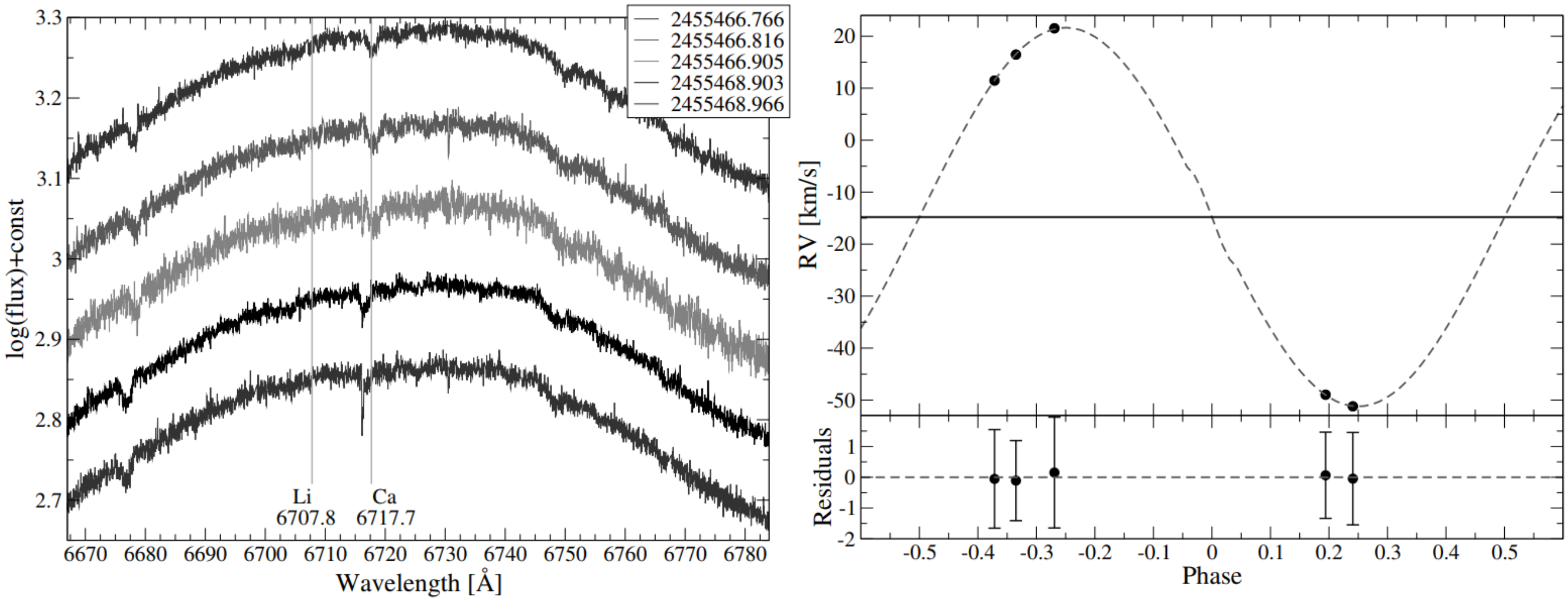
- according to measured flux in JHK-filters:
  calculation of R-band brightness for each source possible

Spectroscopy

- yields information about mass through $m \cdot \sin(i)$ from v_{rad} of the components

- detection of all gravitational bound objects during time critical observation

- Li as indication of a young age, chemical composition, temperature, surface gravity,…



- spectra and RV-curve of a false positive:
  M-star orbiting around a F4…G0 main sequence star
  (Errmann et al. 2014)

Follow-up observations summary

- updating ephemeris **done**
- multiband photometry **currently**
  B, V, R, I
- adaptive optics in the IR to exclude **time granted**
  eclipsing binaries in the optical PSF
- spectroscopy to measure mass of
  companion (RV technique) **next**

Thank you for your attention

References

Baraffe et al. *Evolutionary models for low-mass stars and brown dwarfs: uncertainties andlimits at very young ages* A&A 2002

Barnes et al. *Measurement of spin-orbit misalignment and nodal precession for the planet around pre-main-sequence star PTFO 8-8695 from gravity darkening*, ApJ 2013

David et al. *A Neptune-sized transiting planet closely orbiting a 5–10-million-year-old star*, Nat. Phys. 2016

Errmann et al. *Investigation of a transiting planet candidate in Trumpler 37: An astrophysical false positive eclipsing spectroscopic binary star*, AN 2014

Fritzewski et al. *Long-term photometry of IC 348 with the Young Exoplanet Transit Initiative network,* MNRAS 2016

Garai et al. *Search for transiting exoplanets and variable stars in the open cluster NGC 7243,* AN 2016

Neuhäuser et al. *The Young Exoplanet Transit Initiative (YETI),* AN 2011

Rätz et al. *YETI observations of the young transiting planet candidate CVSO 30 b,* MNRAS 2016

Schmidt et al. *Direct Imaging discovery of a second planet candidate around the possibly transiting planet host CVSO 30*, A&A 2016

Van Eyken et al. *The PTF Orion Project: A possible planet transiting a T-Tauri star*, ApJ 2012

Zari et al. *Mapping young stellar populations toward Orion with Gaia DR1*, A&A 2017