Subaru High-Contrast Imaging Characterizations for Exoplanetary Systems

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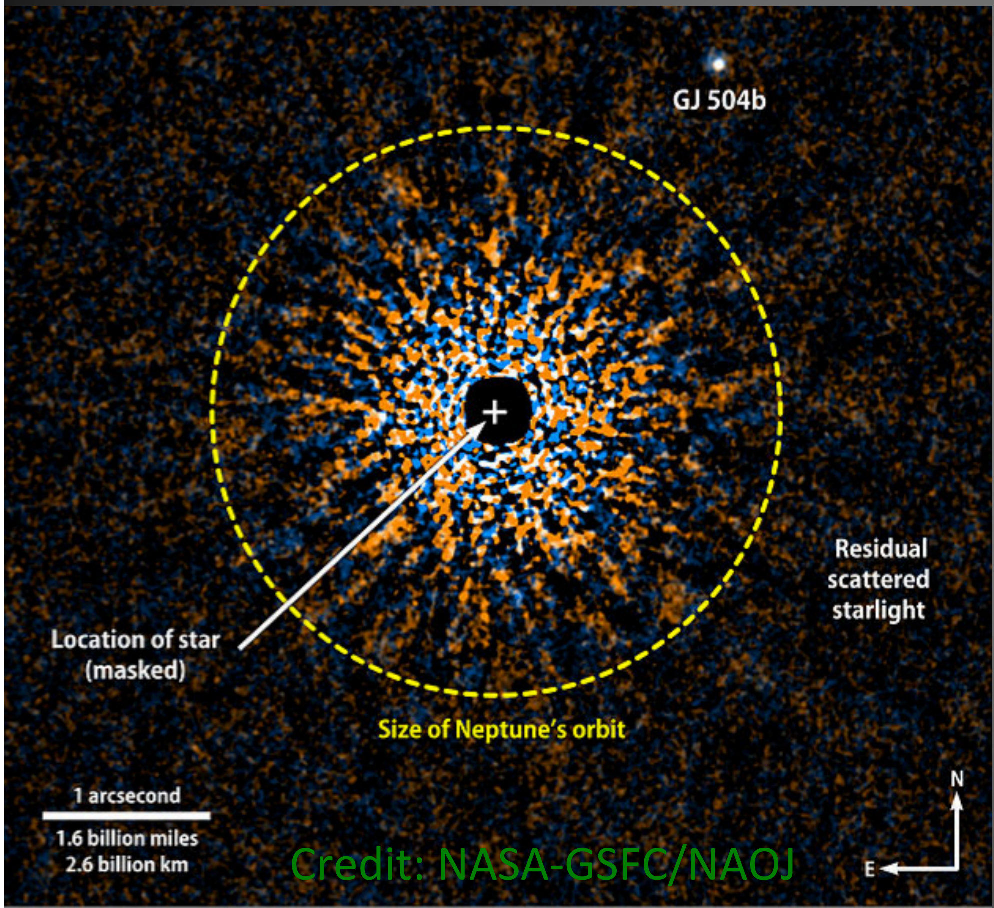
Topics:

Report our Subaru observations for exoplanetary systems

- High-contrast imaging for a star with a long-term period stellar companion and characterization of the system
- High-contrast imaging for giants with long-term RV trend
- High-contrast validation and characterization for the exoplanetary systems with transit planetary candidates observed by K2

Direct Imaging of Exoplanet and SEEDS

Direct Imaging enables the observation of wide-orbit planets



Jovian planet discovery around GJ 504 (Kuzuhara+13)

SEEDS:

- Subaru strategic campaign to search for wide-orbit exoplanets via high-contrast direct imaging (see talk by Motohide Tamura)
- Directly imaged some exoplanets and brown dwarfs
  (e.g., Kuzuhara+13; Carson+13; Thalmann+09)
- Statistical analysis for exoplanet and brown dwarf population
  (e.g, Yamamoto+13; Brandt+14)

Other Important Roles of Direct Imaging

Direct imaging is important for *not only* exoplanet survey *but also* characterizing exoplanetary system itself.

Important Roles:

- Detection of long-period stellar companion, leading to
  - well know the property of system (e.g., Benjamin+15)
  - clarify the long-term RV trend (e.g., Crepp+12, ApJ, 761, 39)
  - reveal the origin of RV- or transit-detected planet (e.g., Ngo+15)
- Validation of transit signal (e.g., Adams, E. R+12)

→ Here,

I present the examples based on our recent three achievements

1. Characterization of Binary System and Test of Stellar Evolution Models

(Helminiak, MK, Mede, Brandt et al. 2016, in prep)

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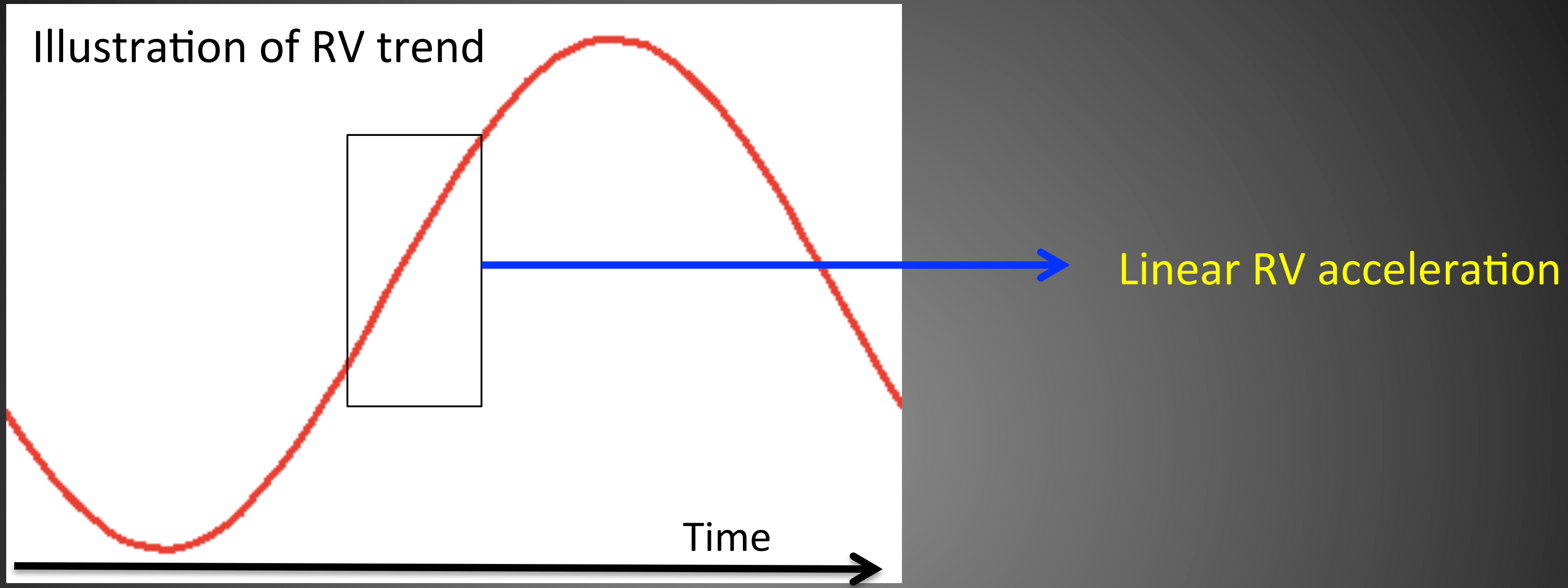
2. Direct Imaging for Long-Term RV Acceleration (RV trend)

(Ryu, Sato, MK, Narita et al. 2016 submitted to ApJ)

Long-Term RV Trend

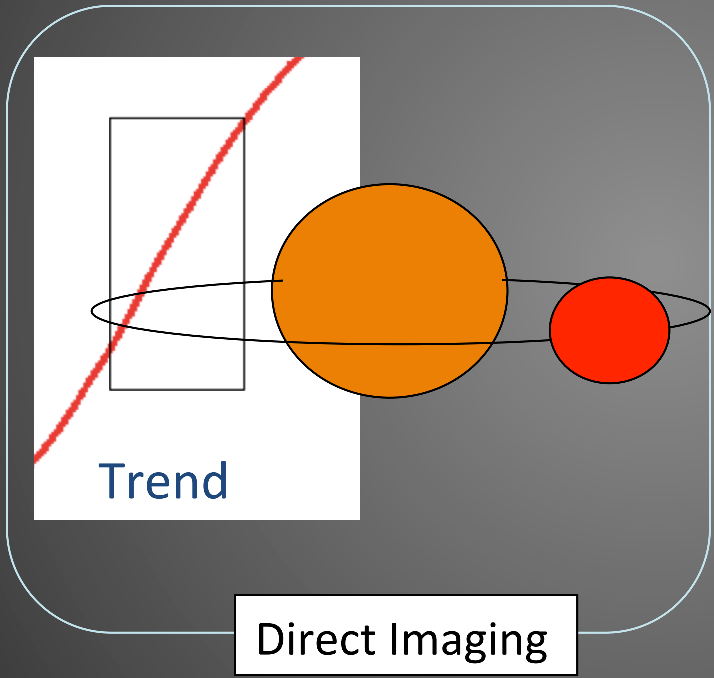


- RV observations sometimes detect a part of sin curve caused by a very long-period companion => so-called, RV Trend (V')

- V' ~ M/a^2 => *M* and *a* are degenerate:
  only trend detection does not enable us to clarify the source of RV trend
  (planet or longer-period stellar companion?)

Direct Imaging to Clarify RV-Trend

Direct imaging helps to reveal what object generates a long-term RV trend



Detect a companion

⟹ Check weather the RV trend is due to the companion

Not detect a companion

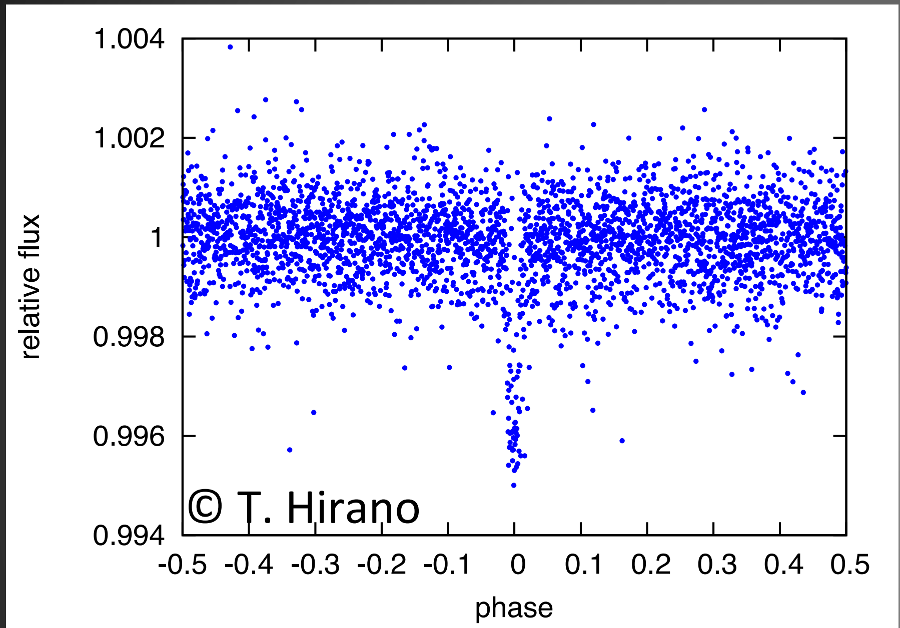
⟹ Constrain the mass and period range that can generate the trend

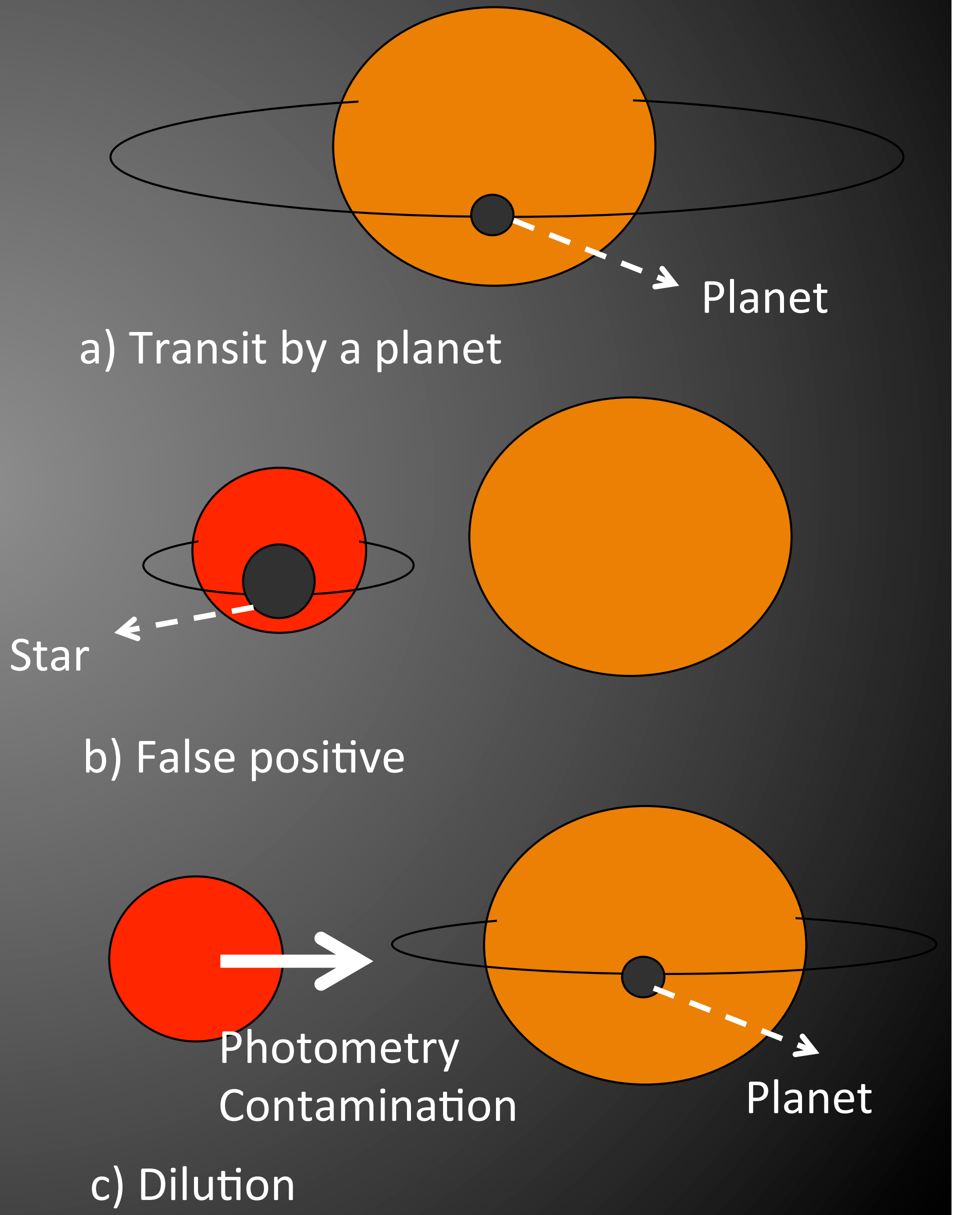
SEEDS (Ryu+16) has observed intermediate-mass giants with long-term RV trends

3. Validation of Transit Signal Detected by K2

(Hirano, MK, Fukui, and Narita et al.)

Transit Signal and Its Identity

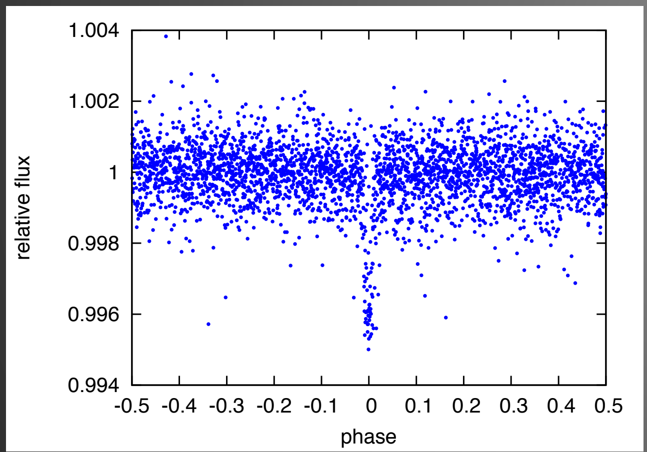




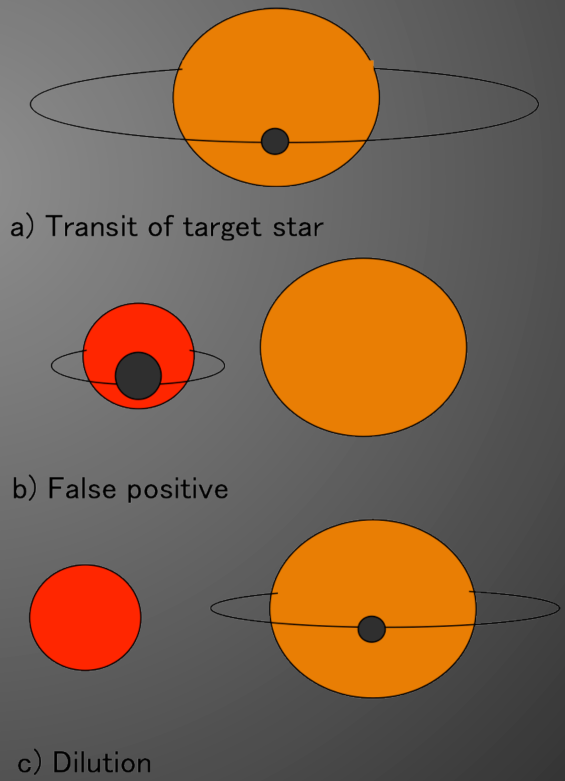
With only transit information,
it is difficult to ensure the robustness
of detected transit signal.
(a), (b), or (c) ?

High-Contrast Imaging for Transit Signal

High-contrast imaging can help to clarify whether or not the star(s) other than the target exists within a photometry aperture in the transit observations

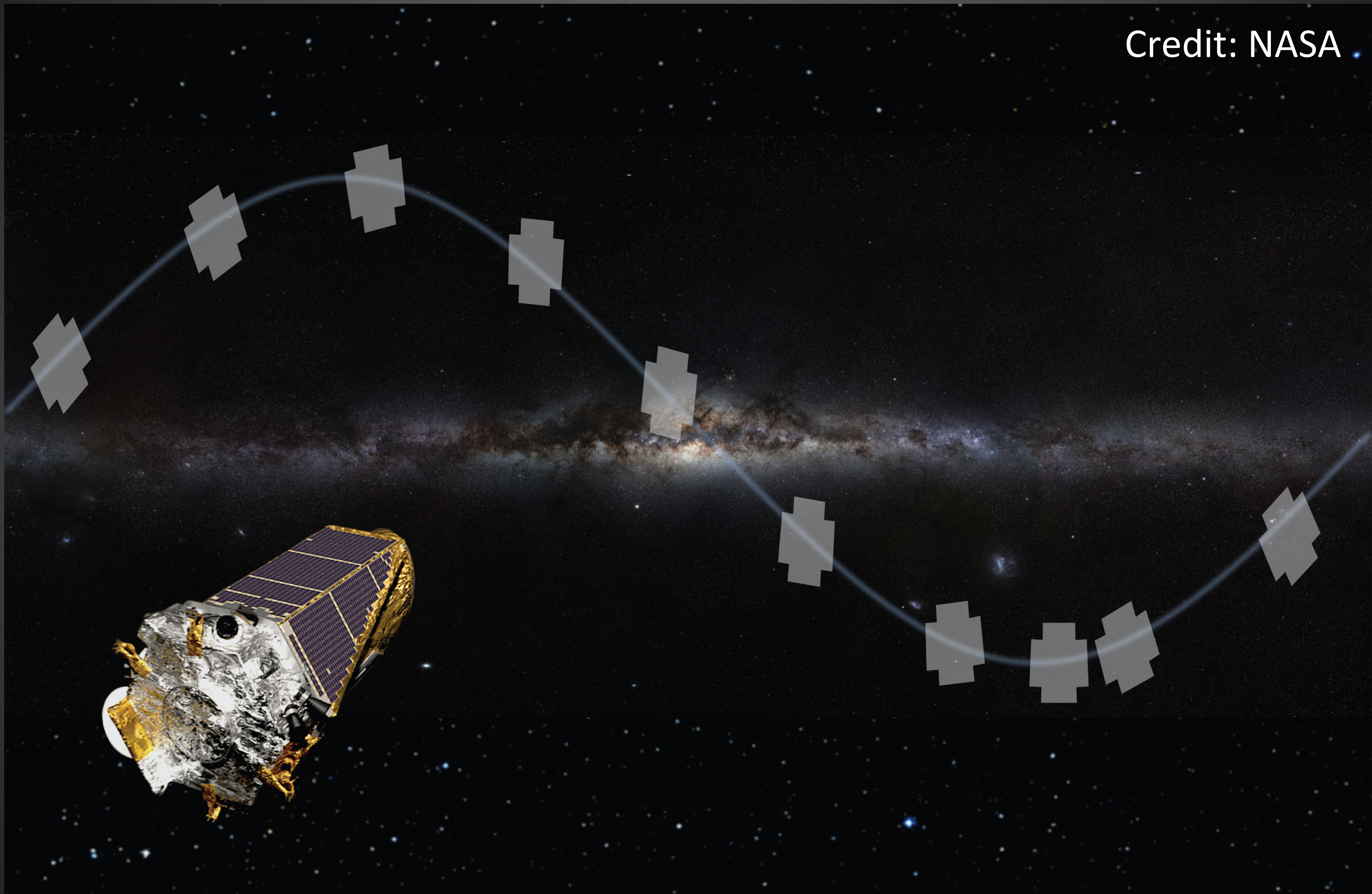


High-Contrast Imaging



Which?

K2 Transit Planet Survey



Kepler is now observing transits in new various areas,
enabling the characterization of transit planets orbiting nearby stars

ESPRINT Project and Subaru Follow-Up

ESPRINT:

- International team to search for and characterize the K2 transit planets
- Japanese PI is Teruyuki Hirano (Tokyo Tech)
- Using Subaru Telescope, and its instruments: HSC, HDS, HiCIAO, IRCS, to follow-up the transit signals detected by K2
- Some papers, including Subaru results, have been already published:
  - Sanchis-Ojeda et al. (2015) using HSC
  - Narita et al. (2015) using HDS and HiCIAO
  - Hirano et al. (2016 submitted) using IRCS
- Ongoing Follow-up Program with HiCIAO and HDS

Here, I demonstrate

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Take-Home Messages

High-contrast direct imaging is useful to characterize the exoplanetary system with or without planet

Here I have demonstrated some examples:

- Good determination of stellar property such as mass via orbit analysis, leading to test stellar evolution models
- Direct imaging is useful to clarify the source of long-term RV trend
- Direct imaging validates a transit signal, in order to check a false-positive, dilution, …

Keep in mind that direct imaging can provides many useful tools for studying exoplanetary systems, in addition to directly detecting exoplanets