# Introduction to the Subaru telescope

## Studies on Exo-planets and protoplanetary disk using the Subaru telescope

Nagayoshi Ohashi

(Subaru Telescope, NAOJ)

Credit: H. Fujiwara

Subaru (昴) ＝ Pleiades

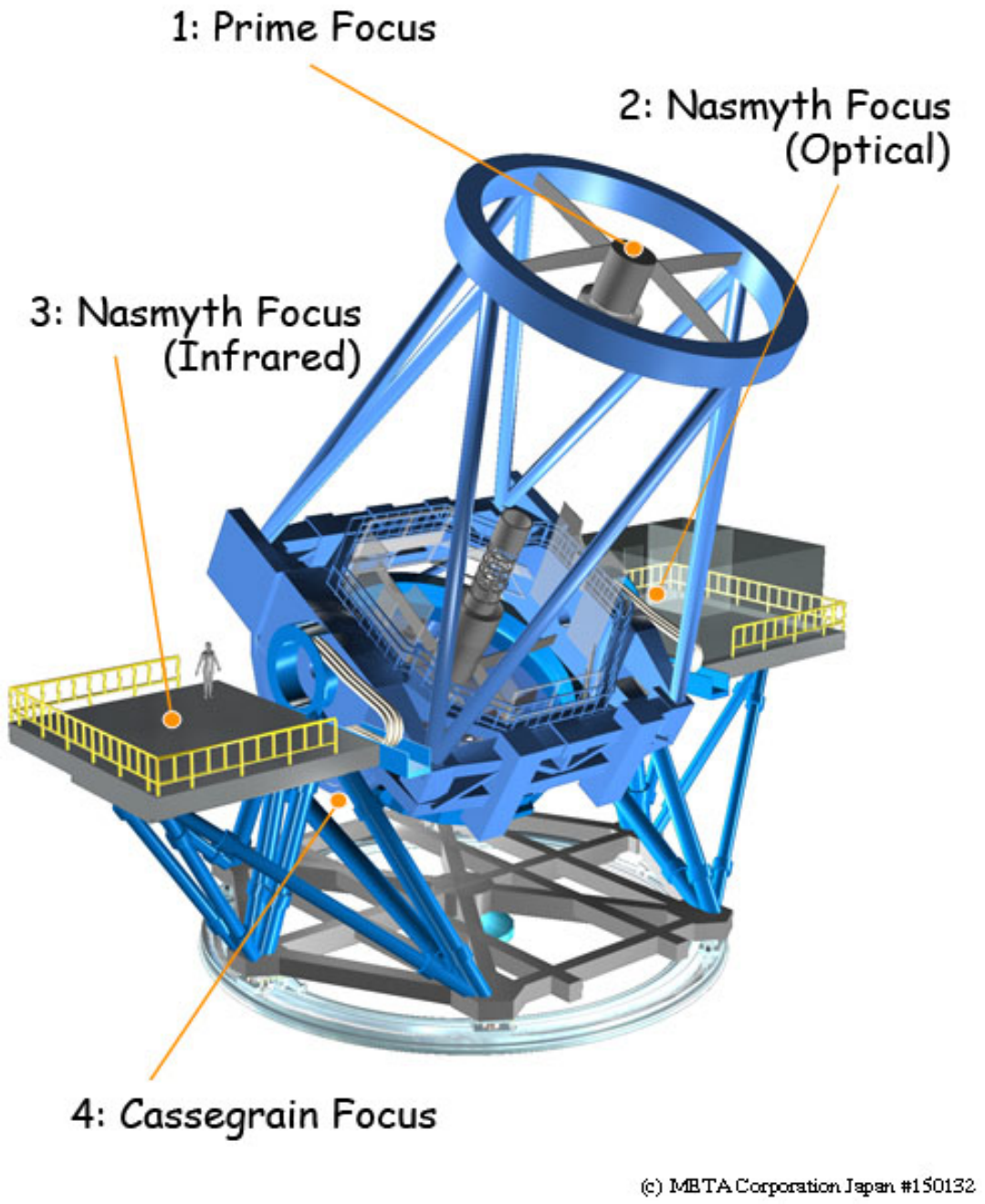
# Subaru Telescope

**Operated by NAOJ**

**Open-use observations since Dec 2000**

Base Facility at Hilo
Number of staff ~100

**Visit http://www.subarutelescope.org**




- Primary mirror:

  D= 8.2 m (2.7 ft.)

  W= 20 cm (7.9 in.)
- Height:

  22.2 m (72 ft.)
- Weight:

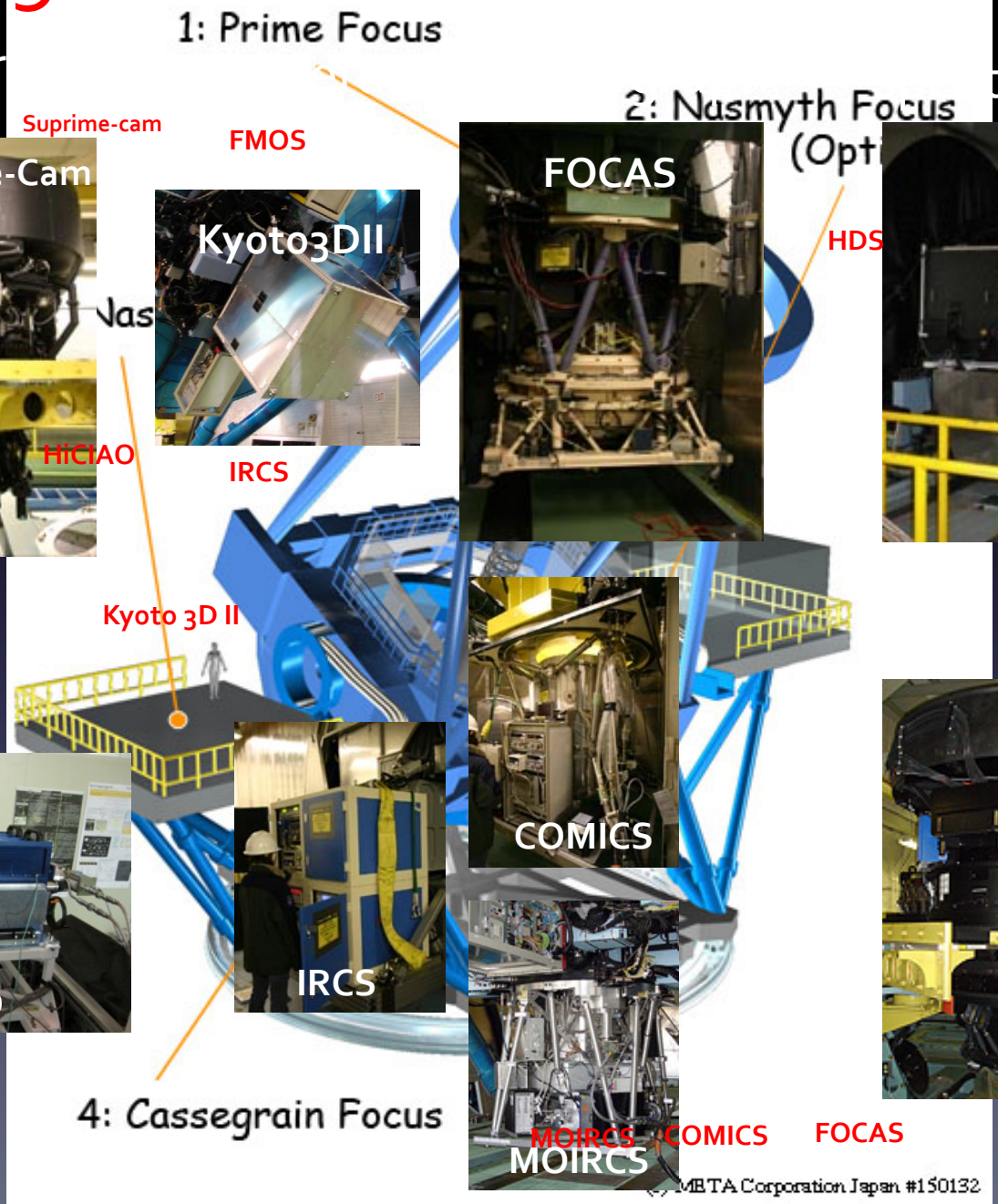
  612 tons
- 4 Foci:
  - Primary
  - Cassegrain
  - 2 Nasmyth
- Angular resolution:

  ~0.05" at NIR with AO

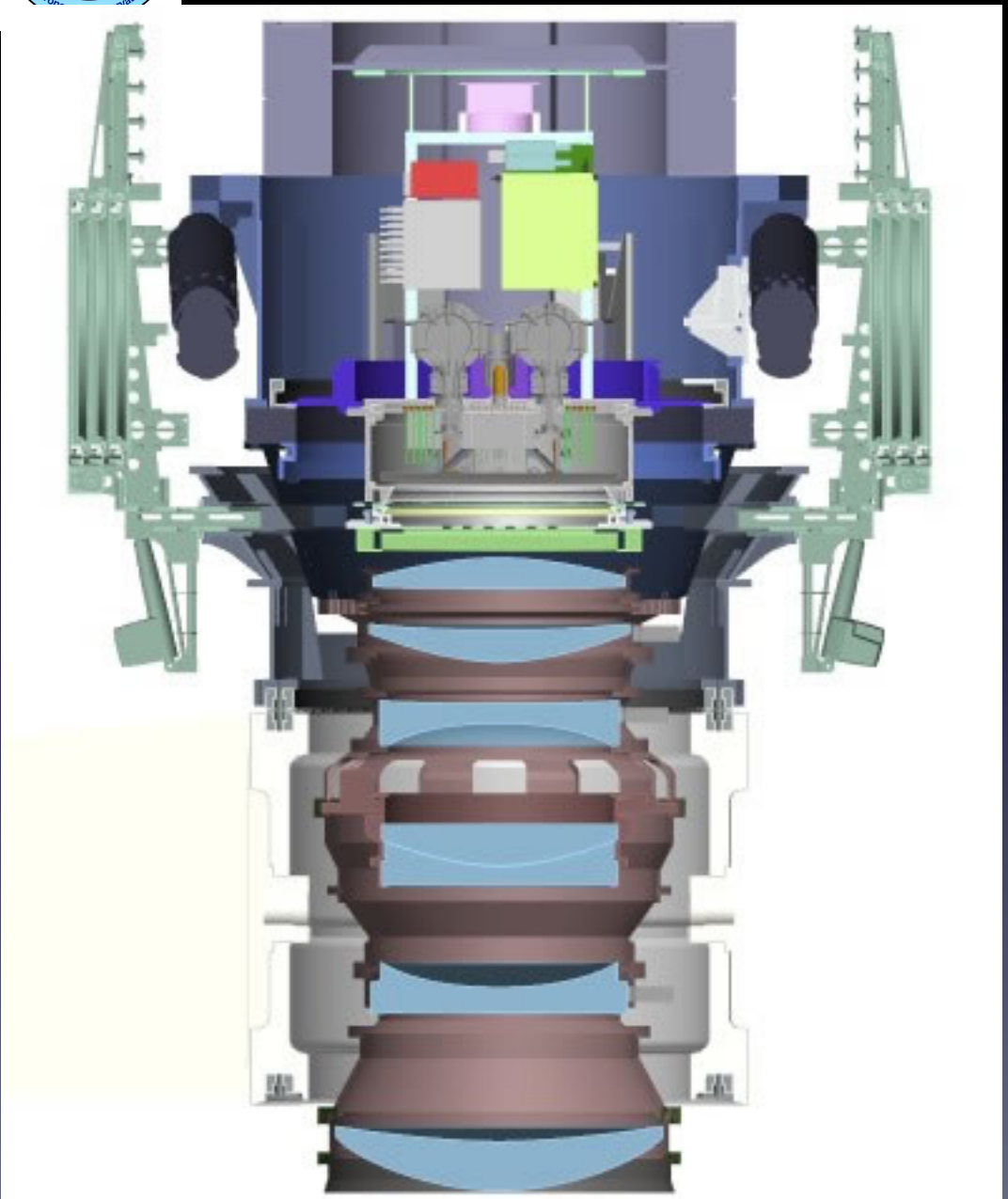
# 9 Instruments on Subaru

optical

infrared



# Hyper Suprime-Cam (HSC)



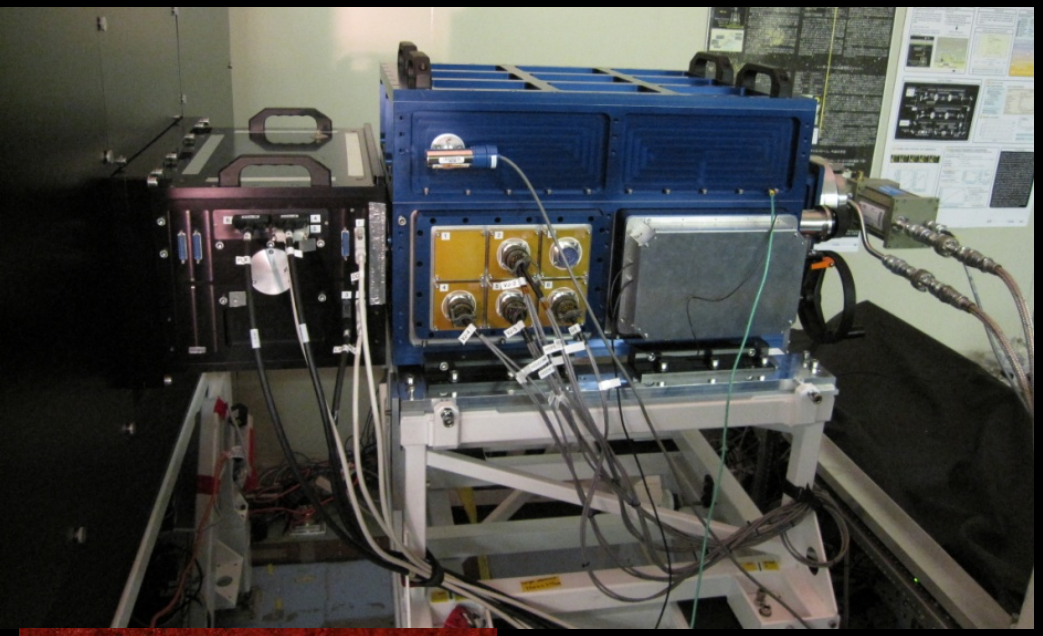
- 116 FD CCD (4K x 2K)
  - 104 science
  - 4 auto-guide
  - 8 focusing
- ϕ1.5°FOV
- D80 < 0.3 arcsec

(0.47 – 1.2 μm, full field)

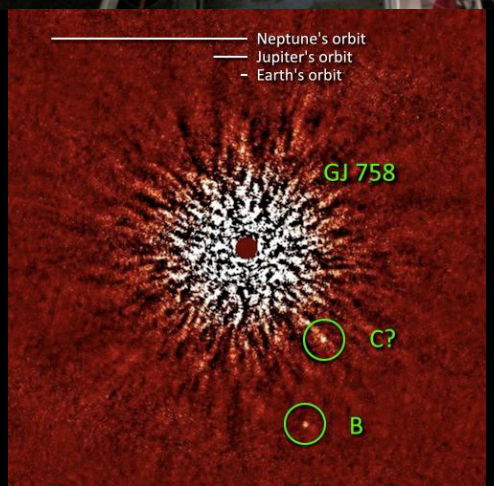
- Hold 6 filters
- 2012 Sep: first engineering light

# HiCIAO

## (High Contrast Coronagraphic Imager with AO)

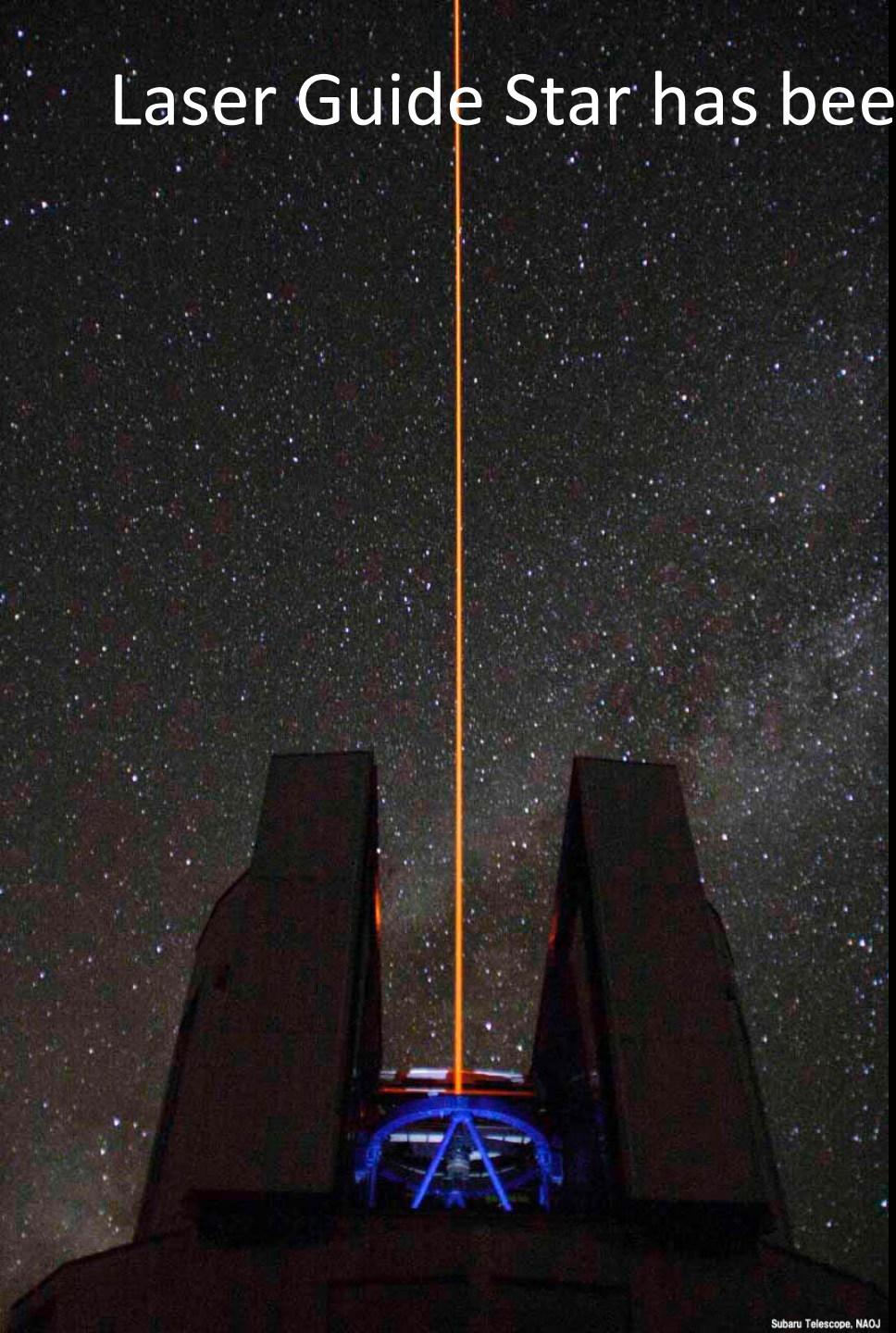


- **λ=0.85~2.5μm, HAWAII-2RG (0.01”/pixel)**
- **FOV=20”x10” (PDI ), 6”x6” (SDI), ADI**
- **4 occulting masks: 0.2”, 0.3”, 0.4”, 0.6” → ~10E-5.5**




Thalmann+ 2009

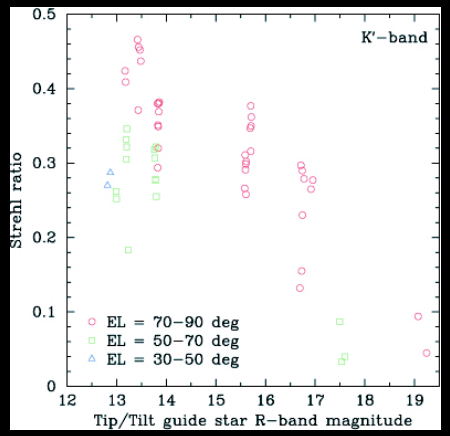
# Laser Guide Star has been opened for community

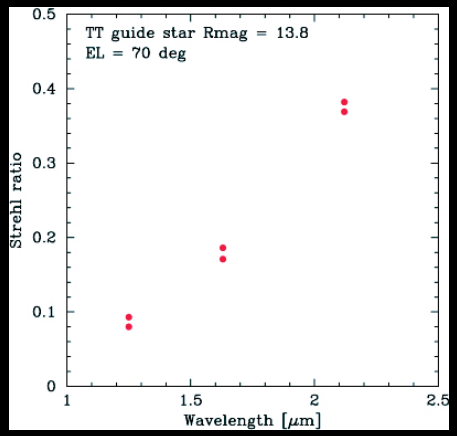



- All-Solid-State Sum-Frequency laser
- Photonic crystal fiber feed
- 6.5 W (4.0W on-sky)
- R ~ 11 mag

- SR ~ 0.4 @K
- AO works up to R~ 18 mag

Tip/Tilt guide star




Minowa + 2012

# SEEDS –Strategic Explorations of Exoplanets and Disks with Subaru

SEEDS

- First “Subaru Strategic Program (SSP)” – a new open-use category
- 120 Subaru nights in 5 years from 2009; ~3/4 finished by now
- Direct imaging and census of giant planets in the outer regions (a few AU - ~40 AU) around ~500 solar-type and massive stars

See also,

“A New View of Transiitonal Disks from the Subaru-based SEEDS Direct Imaging Survey”
Ruobing Dong (Talk on Thursday)

“SEEDS: Direct Imaging of Exoplanets and Their Forming Disks with the Subaru telescope”
Tomoyuki Kudo (Poster ##)

# SEEDS members (as of 2013 January)

**PI: Tamura,M. (Univ. Tokyo/NAOJ) , Co-PI: Usuda,T., Takami,H. (NAOJ/Subaru)**

**Co-Is:**

**NAOJ:** Akiyama, E. Fukue,T. Hashimoto,J. Hayashi,M. Iye,M. Kandori,R. Kawabe,R. Kokubo,E. Kusakabe,N. Morino,J. Narita,N. Nishikawa,J. Ohashi,N. Suto,H. Suzuki, R. Takeda,Y. Ukita,N. Watanabe,J. Yamashita,T.

**Subaru:** Frantz,M. Fujiyoshi,T. Guyon,O. Hayano,Y. Ishii,M. Kudo,T. Pyo,T.S. Takato,N. Terada,H. Usuda,S.K. Yutani,M.

**Hokkaido Univ**.: Baba,N. **Saitama Univ.:** Oasa,Y. **Nagoya City Univ**.: Sugitani,K. **Univ. of Air:** Kaifu,N. ,

**Osaka Univ.:** Fukagawa,M. Shibai,H. Yamamoto, K. Konishi, M. Maruta, Y. Sudo, J.

**Tohoku Univ.** Yamada,T. Fujii, J. Mizuki, T. **Ibaraki Univ.** Momose,M. Okamoto,Y. Tsukagoshi,T.

**GUAS**: Kwon,J. Mayama,S. Suenaga,T. Oh, D. **Kogakuin Univ**. Muto,T. **TiTECH:** Ida,S. Sato,B..

**Univ. of Tokyo** Kuzuhara,M. Mede, K. Takahashi,Y., Sakon,I. Ueno,M. **Kanagawa Univ.** Honda,M.

**JAXA/ISAS:** Enya,K. Kataza,H. Makitsubo,H. Nakagawa,T. **Kyoto Univ.** Matsuo,T. Nomura, H.

**Nagoya Univ.** Inutsuka,S. Nagashima, A. Otsubo,T. Sumi,T. **Kyogo-kenritu Univ.** Itoh,Y.

**Hiroshima Univ.:** Miyama,S. **ASIAA:** Takami,M. Karr,J. **Anton Pannekoek:** Thalmann , C.

**College of Charleston:** Carson,J. **Univ. of Nice** Abe,L. **Univ. of Hawaii (IfA)** Hodapp,K.

**Univ. of Arizona:** Follette , K. **Univ. of Washington:** Wisniewski,J. **Univ. of Toronto:** Janson,M. Currie T.

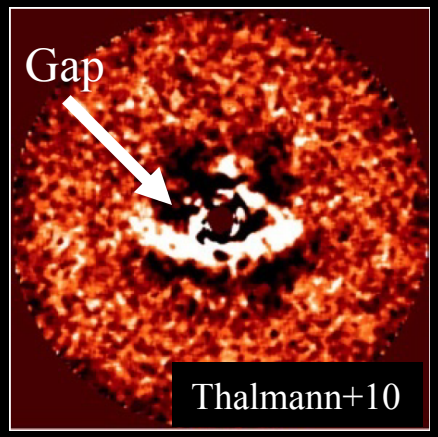
**NASA/Goddard:** Grady,C. McElwain,M. **NASA/JPL:** Serabyn,E. **CSIC-INTA (Spain):** Moro-Martin,A.

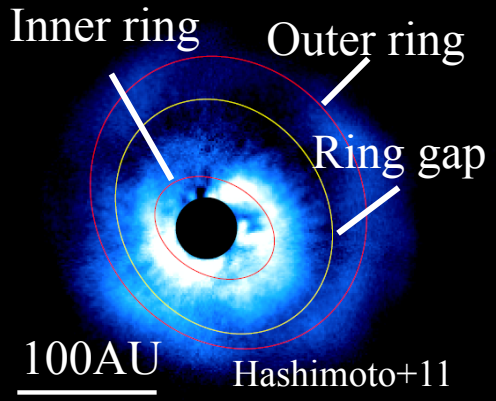
**Princeton Univ:** Brandt,T. Dong,R. Dressing,C. Kasdin,J. Knapp,G.R. Shen,Y. Spergel,D. Turner,E.L. Vanderbei,R. Blake,C. **MPIA:** Bonnefoy, M. Brandner,W. Feldt,M. Goldman,B. Henning,T. Launhardt,R. Roccatagliata,V. Setiawan,J. Westfalische Wilhelms-Universitat Mann,I. **Munhen Univ.:** Goto,M.

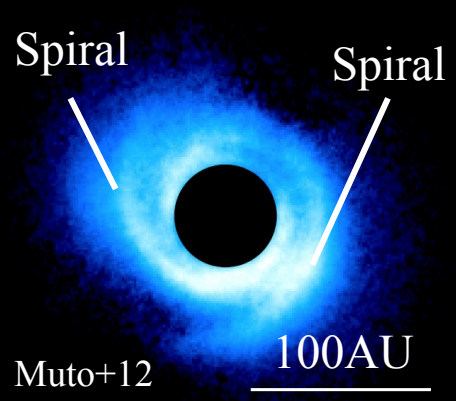
**Univ. of Hertfordshire** Gledhill,T. Hough,J.H. Lucas,P.W. **Russian Academy of Sciences** Tavrov,A.V.

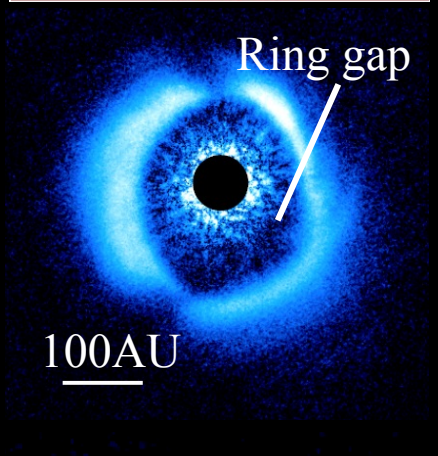
**114 members (35 institutes, of which 40 foreign members from 16 institutes)**

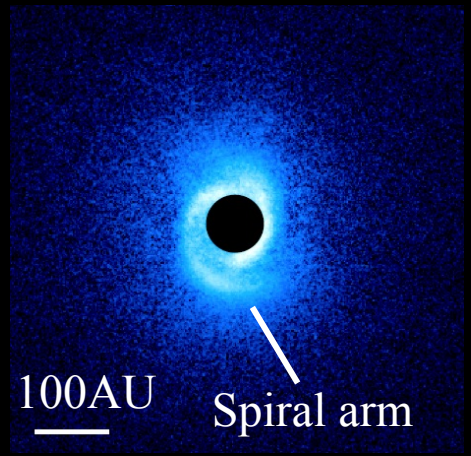
# SEEDS disk galleries in <0.1 arcsec resolution

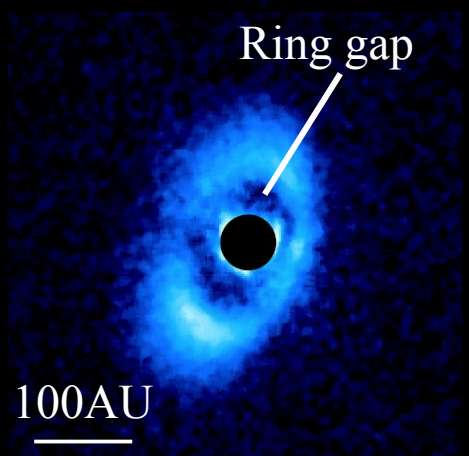


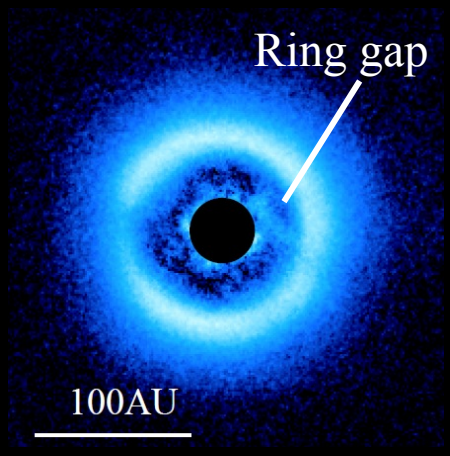



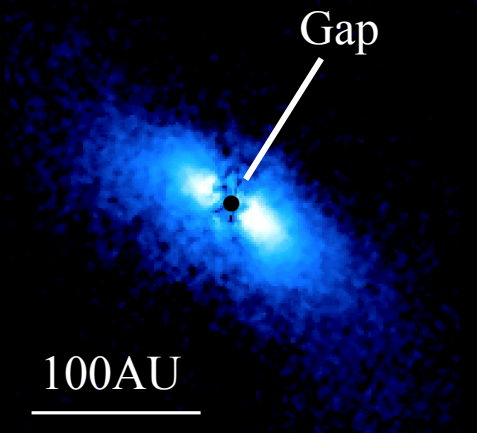



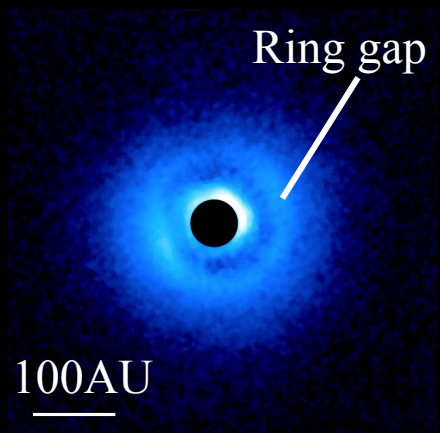



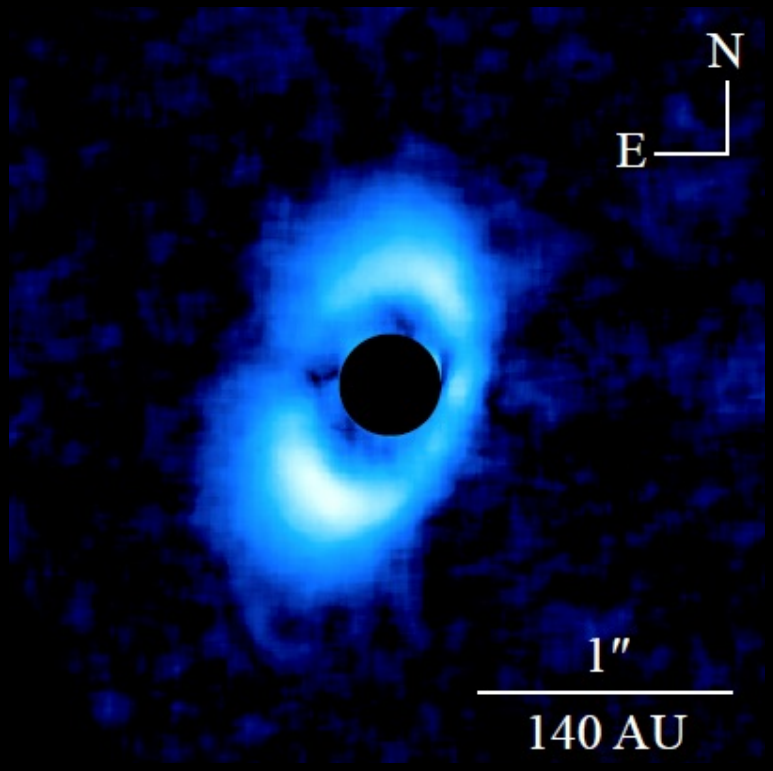



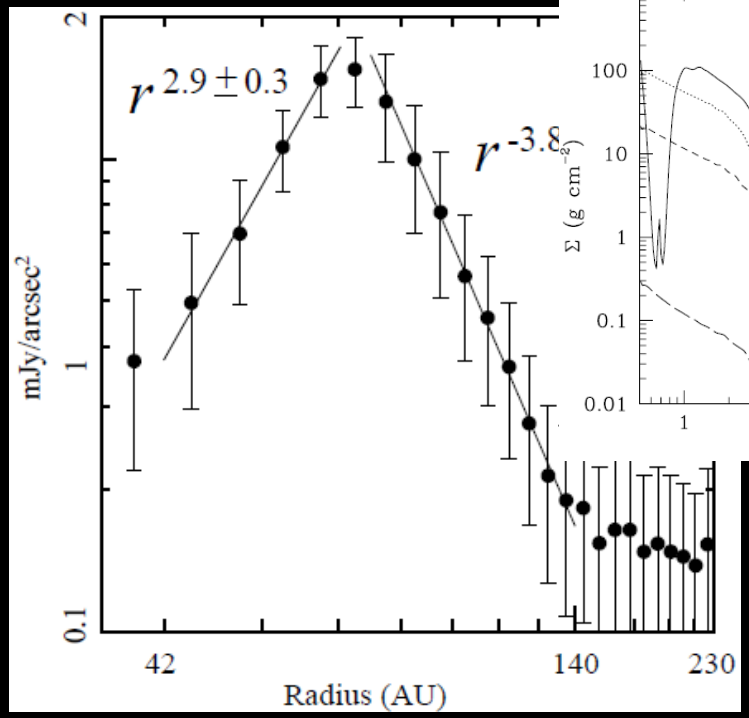

**Detection of morphological diversity of protoplanetary disks at wide-orbit planet radii.**

10 disk papers published/accepted.

# Large Cavity Structures in Protoplanetary Disk around PDS 70

**Central star: 0.8 Mo, 140 pc, <10 Myr old**



# J160421.7-213028 (1Mo, 5Myr, 140pc)

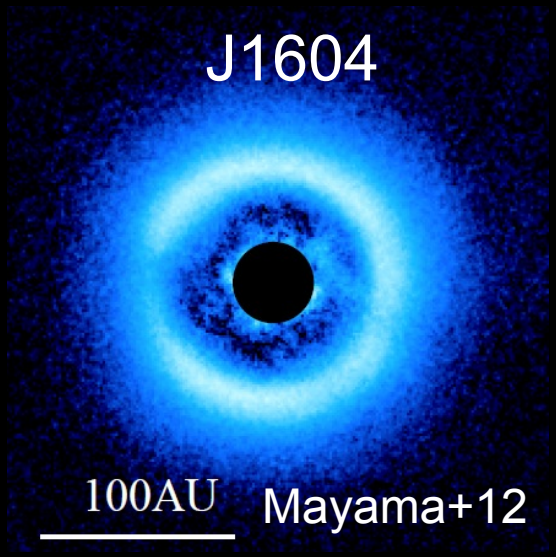
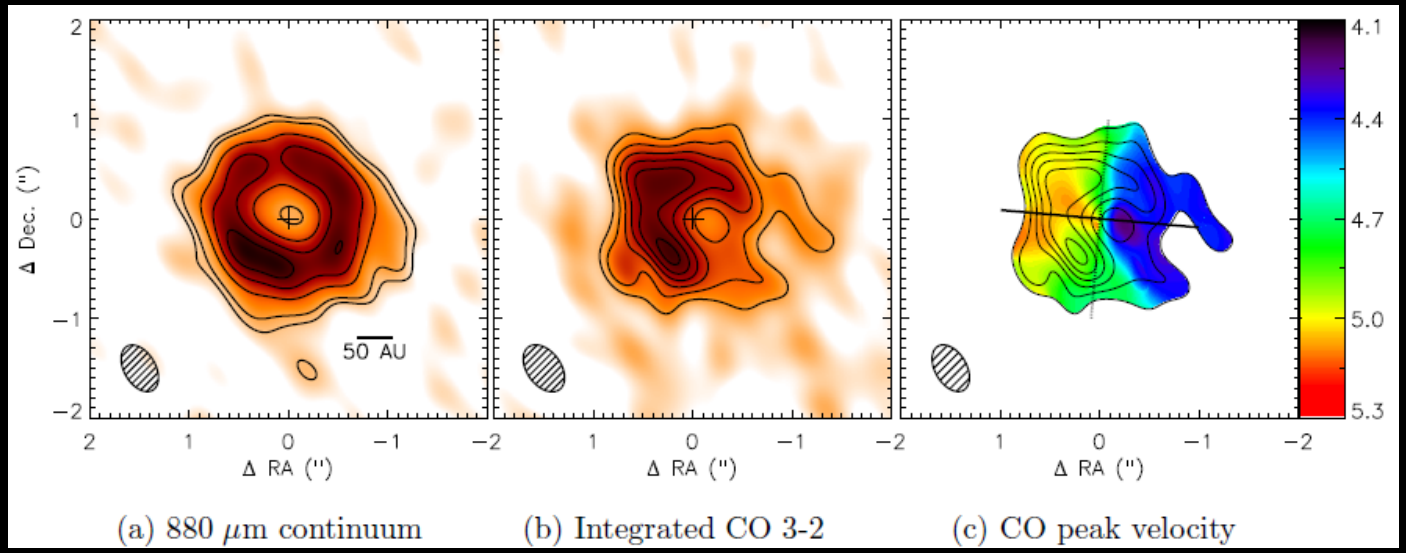



**Table 2**
Observational Properties

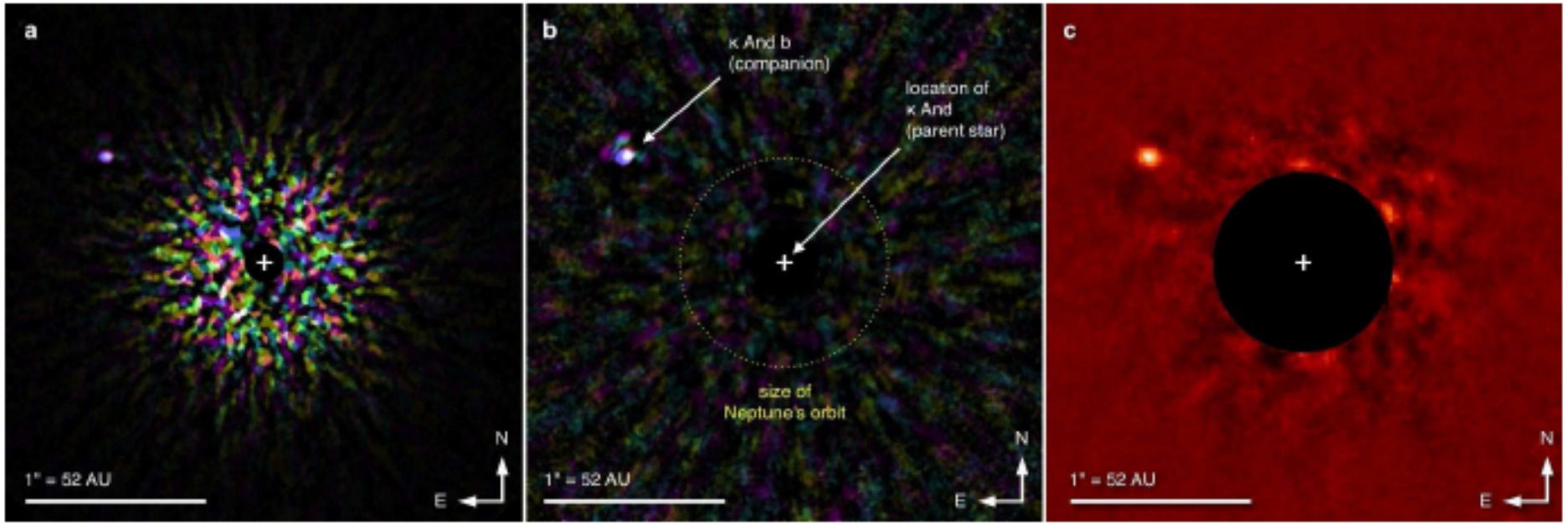
| Property | Value |
|---|---|
| $F_{880\mu m}$ | 164±6 mJy |
| $F_{CO\ J=3\rightarrow2}$ | 5.2 ± 0.1 Jy km/s |
| $F_{2600\mu m}$ | 5.1±0.5 mJy |
| $F_{CO\ J=1\rightarrow0}$ | 0.48 ± 0.04 Jy km/s |
| central position | 16:04:21.645 -21:30:28.83 |
| inclination | 6°±1.5° |
| position angle | -5°±10° |
| systemic velocity (LSRK) | 4.7 km/s ±0.1 km/s |




G. S. Mathews, et al. 2012

# Planet around the most massive (B9, 2.5Mo) star ever imaged – κ And

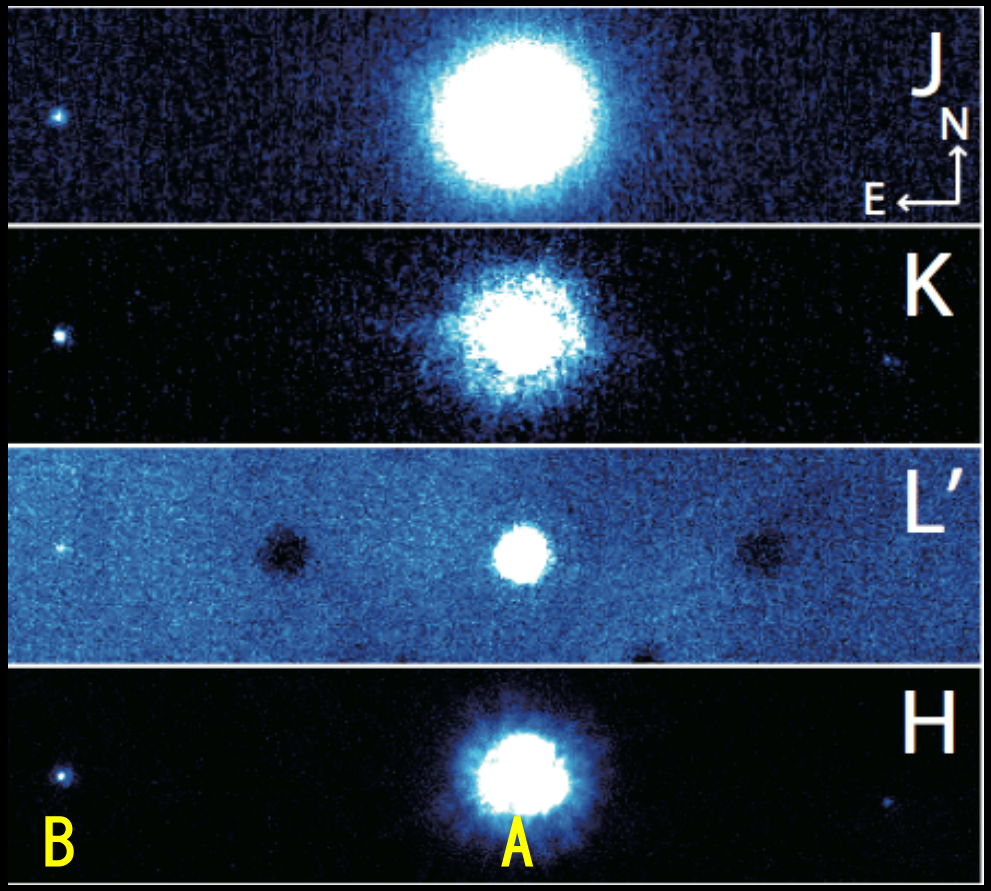
**Detected super-Jupiter ($M = 13\ M_J$)**




*Carson et al. 2013, ApJL, in press*

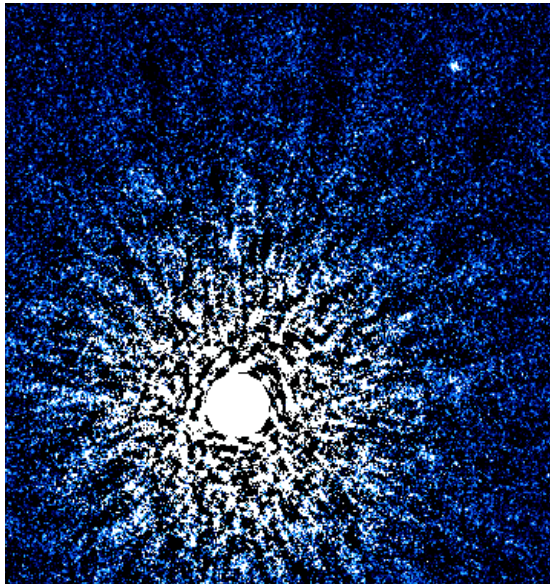
# Detection of HAT-P-7 companion

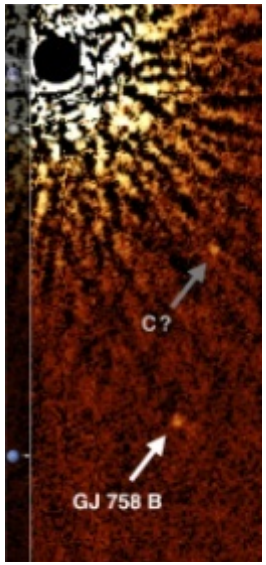
**First retrograde planet**

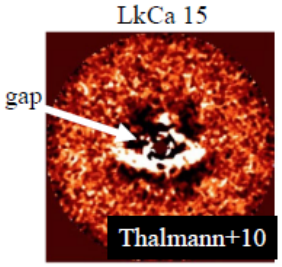


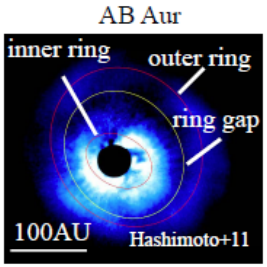

# Summary: SEEDS will explore detection and formation of outer planets

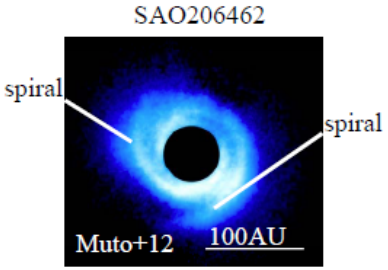
SEEDS

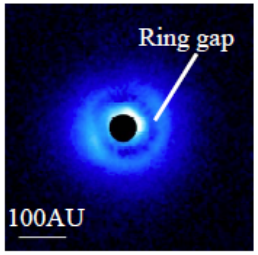


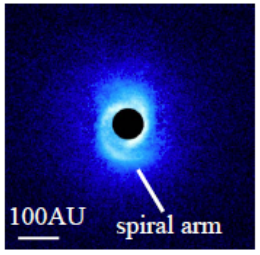


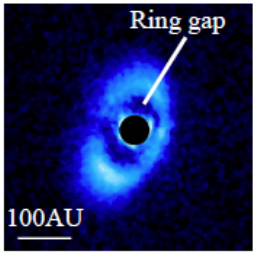



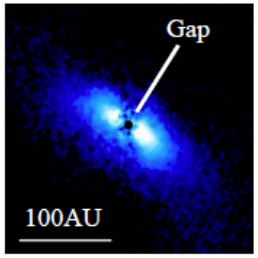



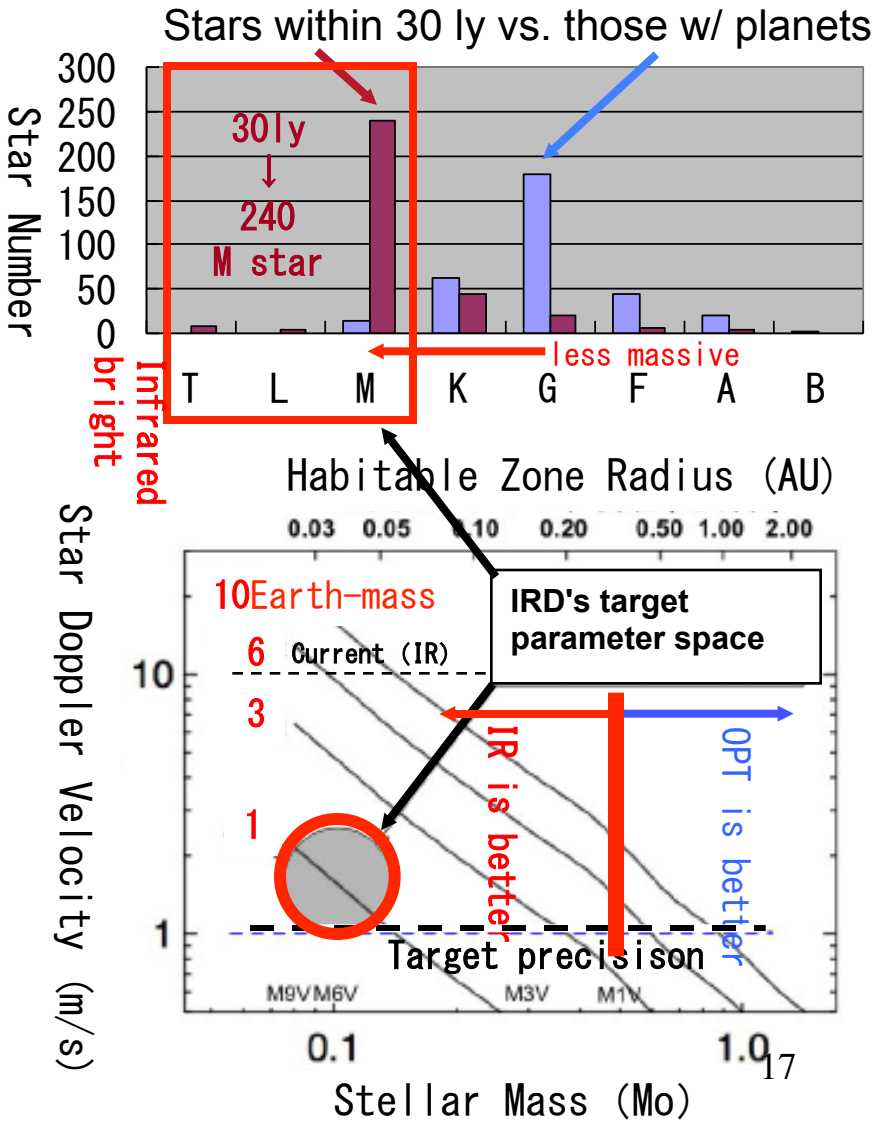



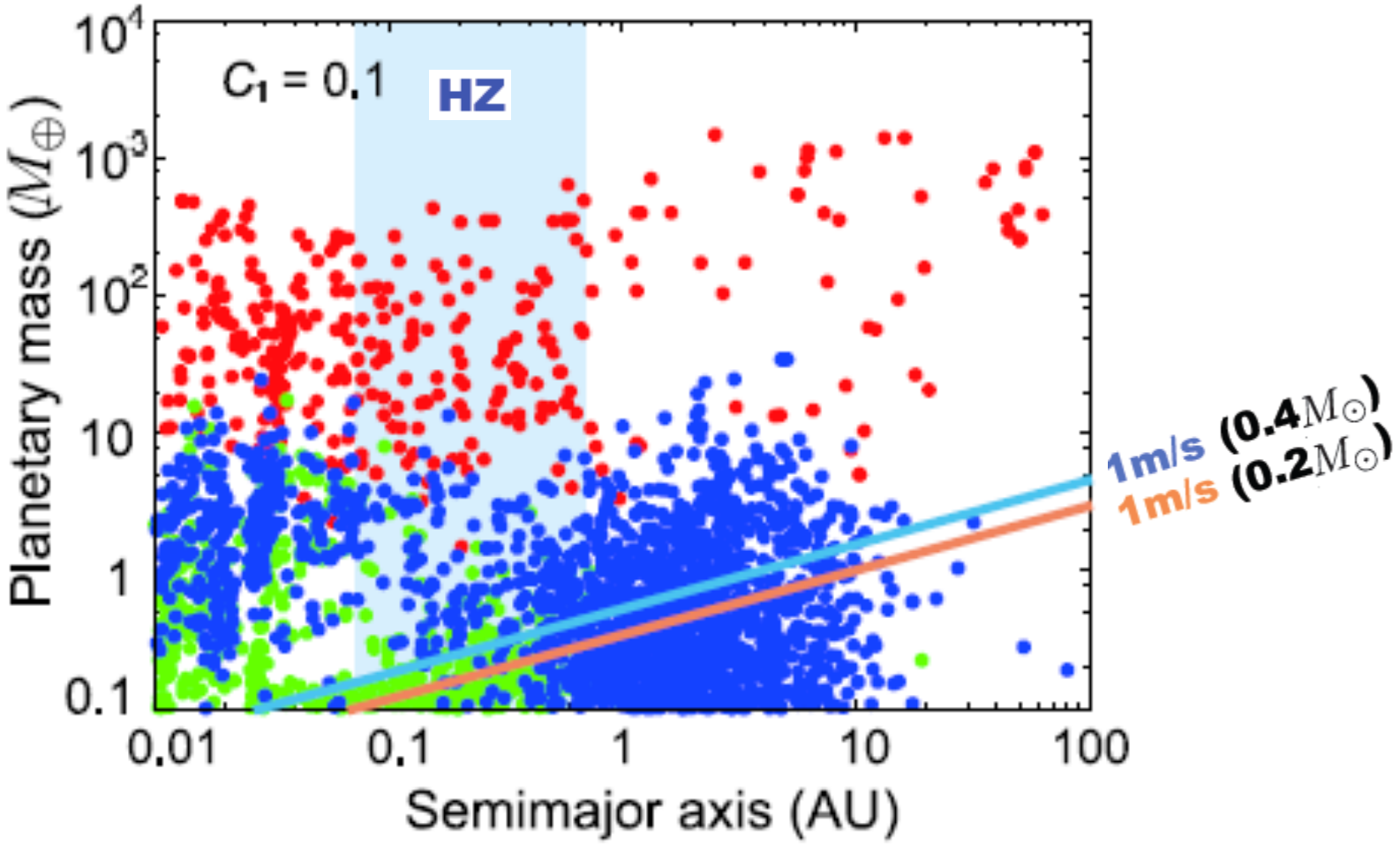

- SEEDS is directly detecting “outer planets” and their candidates (3 planets, a few BDs so far).
- SEEDS is also detecting “signpost of planet” via directly imaging the unprecedented details of the protoplanetary disks and debris disks.
- NEXT : From individual to statistics and New IR instruments (IRD)

# Subaru's next step: Earth-like planet hunting with IR Doppler Instrument

- ★ **Kepler planets are relatively distant** and follow-up is difficult.
- ★ There are **many nearby M stars** that are not studied with high precision RV because **they are faint at optical.**
- ★ **Late-M stars and brown dwarfs are best studied at IR**
- ★ Infrared Doppler instrument (**IRD**) can be a unique 1m/s precision IR **Earths finder** around low-mass stars on 8-m class telescopes.
- ★ **~1000 targets** can be observed for nearby M stars.
- ★ Providing good targets for future direct imaging w/ **TMT-30m (SEIT; Matsuo et al. SPIE).**
- ★ First Light target: 2014



# Planets around M stars expected from recent core accretion model simulations




Rocky planets(green), ice-rich super-Earths (blue), gas giants (red)

1m/s precision for M dwarfs with 0.2-0.4$M_{Sun}$

# Summary

- HiCIAO on the Subaru telescope has been observing protoplanetary disks and exoplanets.

-> Following up with ALMA is necessary

- The Subaru telescope will try to observe earth-like planets with the IRD instrument.