

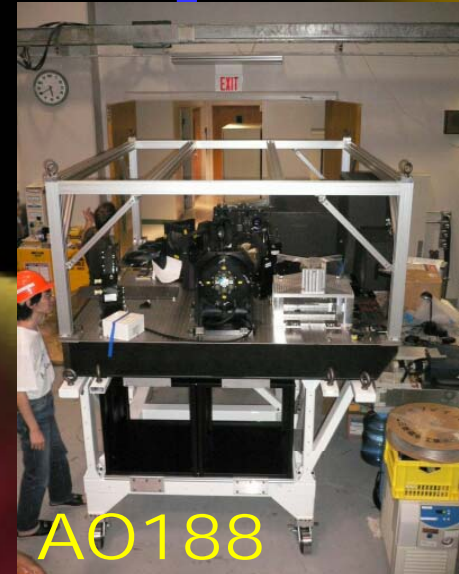


# Early Result from SEEDS and The Subaru's Next Step



HiCIAO

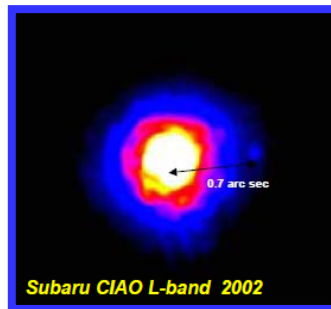
2011.5.3 Tue 16:40-16:55  
M. Tamura



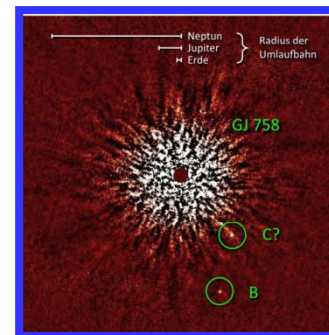
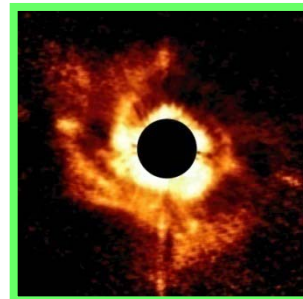
AO188

# SEEDS – Strategic Exploration of Exoplanets and Disks with Subaru

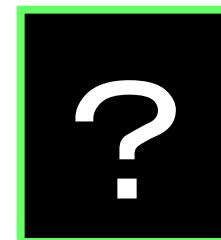
- First “Subaru Strategic Program (SSP)” – a new open-use category
- 120 Subaru nights in 5 years
- Direct imaging and census of giant planets in the outer regions (a few - 40 AU) around ~500 solar-type and massive stars
- Exploring protoplanetary disks and debris disks for the origin of their diversity and evolution at the same radial regions
- Direct linking between planets and protoplanetary disks



>100AU scale  
w/ CIAO



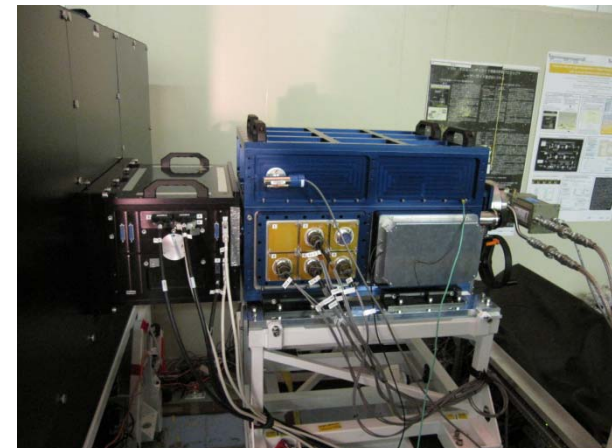
Solar-System  
Scale (<50AU)  
w/ HiCIAO



disk data shown later

# Subaru/HiCIAO+AO188+SCExAO

- **HiCIAO**: High Contrast Instrument for the next generation Adaptive Optics
  - For Subaru 8.2m telescope
  - PI & CoPIs: Motohide Tamura (NAOJ), Klaus Hodapp (UH), Ryuji Suzuki (NAOJ; now TMT)
  - Based on a previous Japan/MEXT grant (~100%)
- Combined with the curvature-sensing **AO** with 188 elements (Hayano, Takami et al.) and SCExAO1024 upgrade (Guyon, Martinache)
- Commissioned mainly in **2009** with AO188 (including Princeton/MPIA teams for angular differential imaging and commissioning)
- **Specification and Performance**
  - 2048x2048 HgCdTe detector and ASIC readout
  - Wavelengths: 1 – 2.5 microns (NIR)
  - Observing modes: DI, PDI (dual beam), SDI (quad beam), & ADI; w/wo occulting masks ( $\geq 0.1''\phi$ ); 10mas/pixel
  - Contrasts on-sky:  $10^{-6}$  at  $1''$ ,  $10^{-4}$  at  $0.15''$ 
    - Roughly 10 times better than CIAO, as specified



# SEEDS Target/Observation Summary

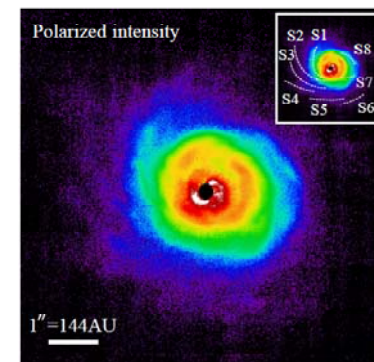
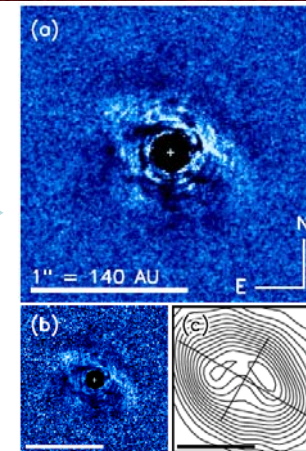
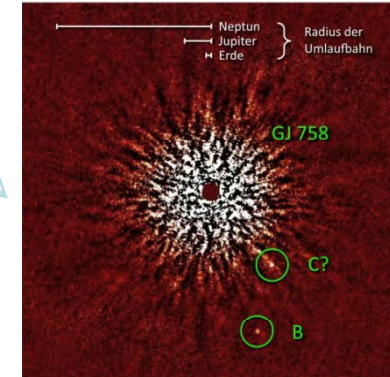
Category	Planet searches			Disk searches		Total number
	(a)	(b)	(c)	(d)	(e)	
	SFR YSOs	Open cluster & Moving group	Nearby stars & WDs	Protoplanetary disks	Debris disks	
Target #	210	60+40	140+37	Same targets as (a)	70	557
Distance	~140 pc	< ~125 pc	< ~30 pc	~140 pc	< ~130 pc	Target balance can change
Age	1-10 Myr	10~100 Myr	100 Myr - 1 Gyr	1-10 Myr	5 Myr - 6 Gyr	
Refereed Publications So Far			HAT-P-7, GJ758 x2	LkCa15, AB Aur		5

- AO-Deformable mirror broken in 2009 Jan, but fully recovered.
- SEEDS nights so far: 28 nights (but 2010 winter weather was poor).
- We already have some notable results as described below.



# Summary of Early Results

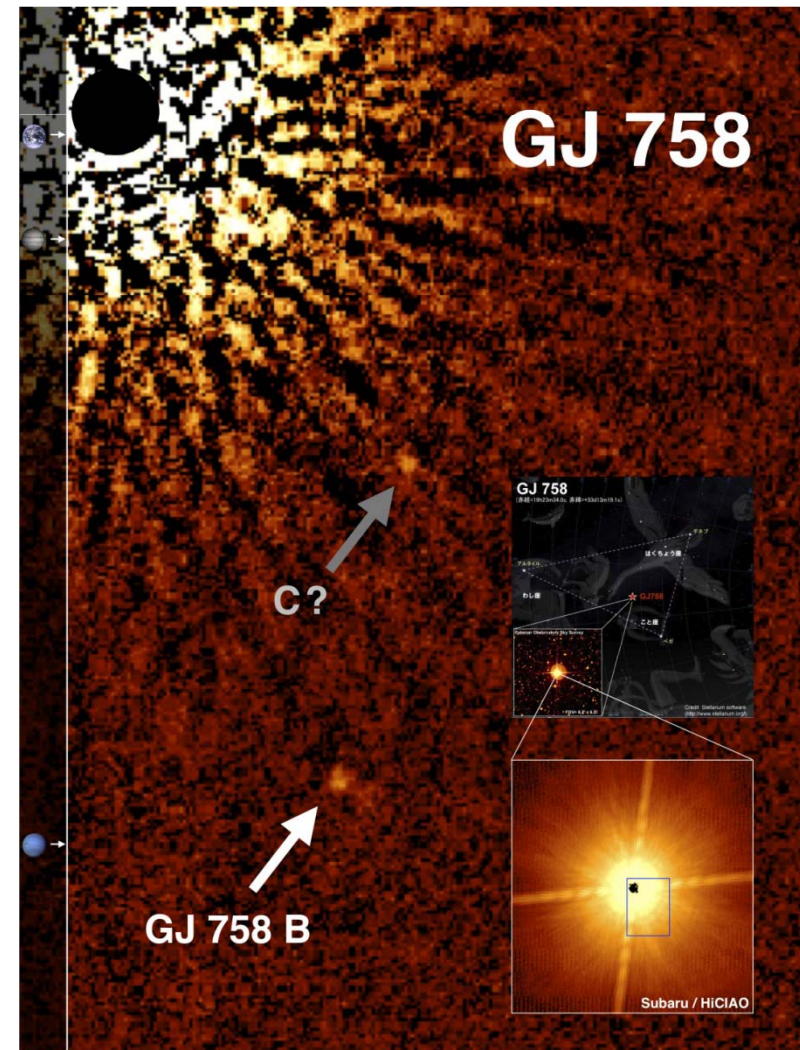
- Discovery of the Coldest Imaged Companion of an old G-type star GJ758,  
*Thalmann et al. 2009, ApJL, 707, L123.*
- Search for outer massive bodies around transiting planetary systems: Candidates of faint stellar companions around HAT-P-7,  
*Narita et al. 2010, PASJ, 62, 779*
- Imaging of a transitional disk gap in reflected light: Indications of planet formation around the young solar analog LkCa 15,  
*Thalmann et al. 2010, ApJL, 718, L87.*
- Near-infrared multi-band photometry of the substellar companion GJ 758b,  
*Janson et al. 2011, ApJ, 728, 85.*
- Direct imaging of fine structures in giant planet forming regions of a protoplanetary disk around AB Aur,  
*Hashimoto et al. 2011, ApJL, 729, L17,*



# Direct Imaging of Planet Candidates around a G Star GJ 758

- G9 Type
  - V=6; Mass=0.97Mo
- Distance: 16pc
- Age
  - Isochrone estimate: 700Myr (Takeda et al. 2007; isochrone)
- GJ 758B
  - Confirmed common proper motion
  - Possible orbital motion
  - 10-30MJupiter (age uncertainty)
- Follow-up with Keck, Gemini
  - Narrow-band spectroscopic confirmation
  - Methane feature in B
  - C is a BG star
  - Janson et al. 2011

GJ758=HD182488=HIP95319



**1.6 micron image with ADI**  
Thalmann et al. 2009

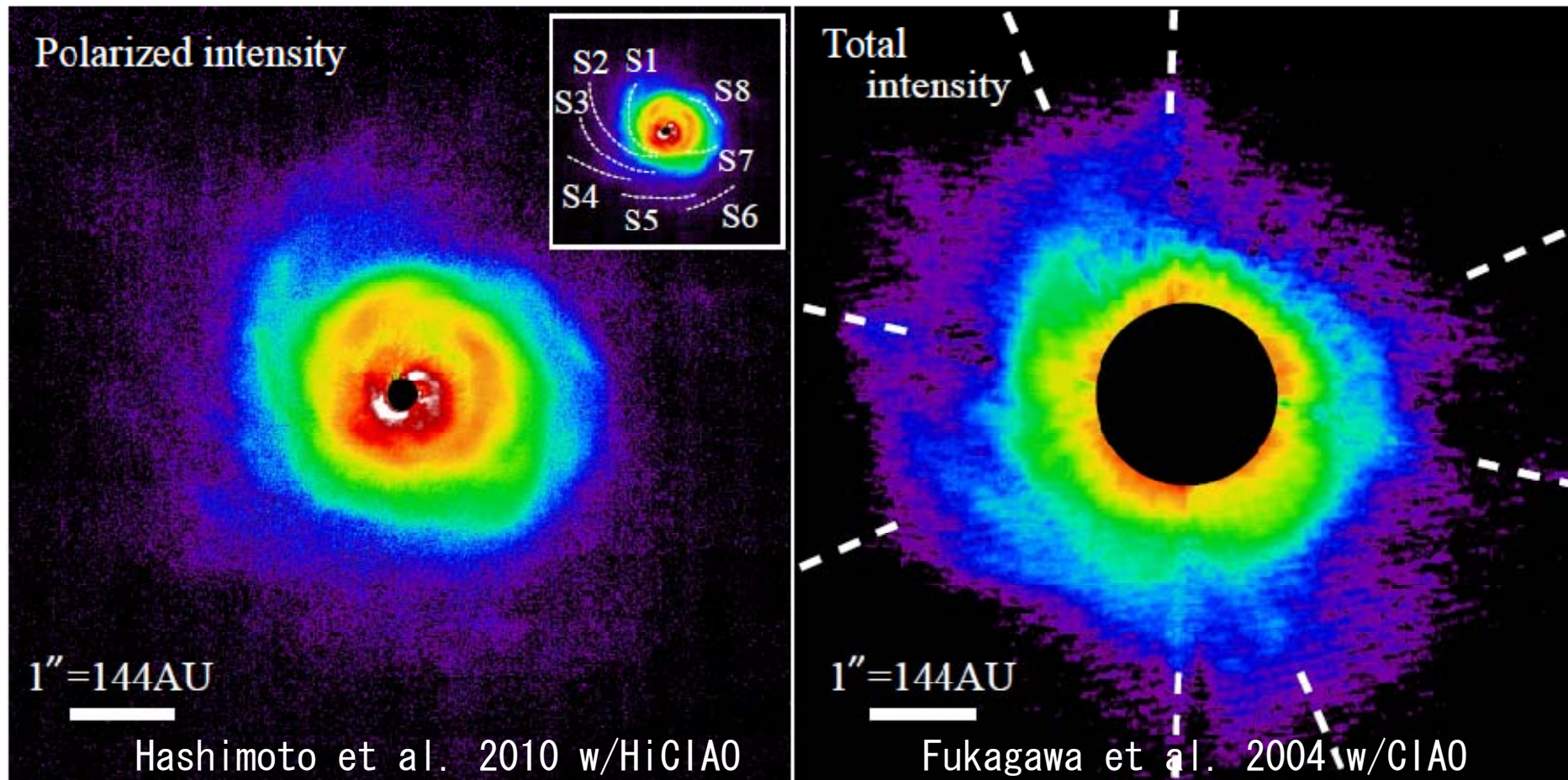
# Various Other Candidate Companions

- Several companion candidates from:
- Moving Group Category
  - 23pc, 120Myr mean sample
- Open Cluster Category
  - Pleiades
- YSO Category
  - Some data obtained with PDI+ADI can be used both disk imaging and companion detections (PDI only mode miss planet candidates)
- Follow-up observations at Subaru are included in SEEDS time



# Sharpest and closest image of AB Aur Disk

- AB Aur: Herbig Ae star, age=4Myr, mass=2.4Mo, distance=144pc
- The first  $r < 40$  AU & 8 AU resolution images (1.6 $\mu$ m); cf. our NEW/OLD images
- PI image, but tracing not POL change but mostly INTENSITY pattern.
- Hashimoto, Tamura, Muto et al. 2011

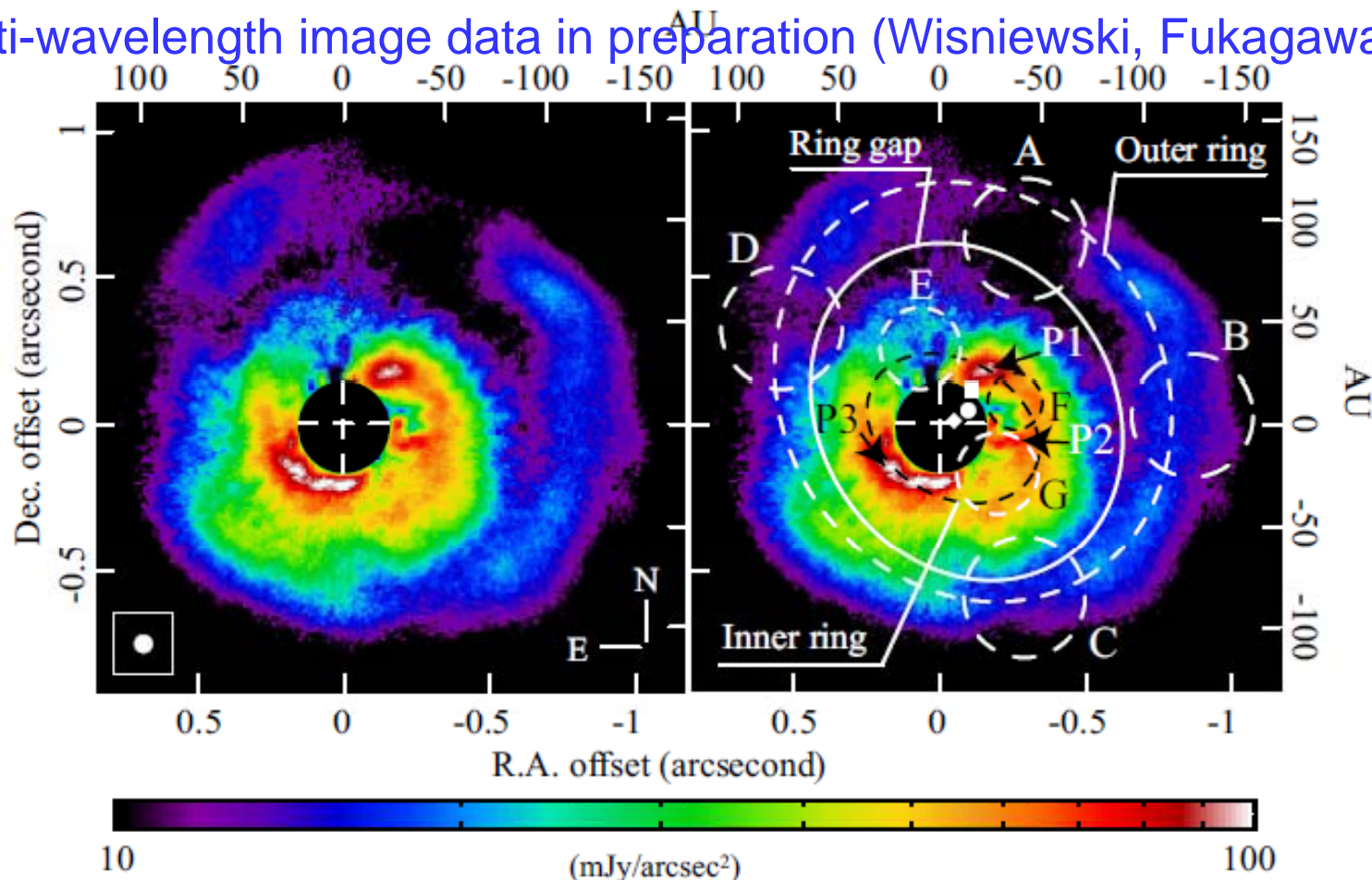




# Sharpest and closest image of AB Aur Disk

- CLOSE-UP view of the central “Solar-system-scale” region
- Double & bumpy “rings” as well as ring-like “gap”
- Possible disk “warp” and “offset”
- Planet formation at outer (~80AU) region by gravitational instability?
- Multi-wavelength image data in preparation (Wisniewski, Fukagawa)

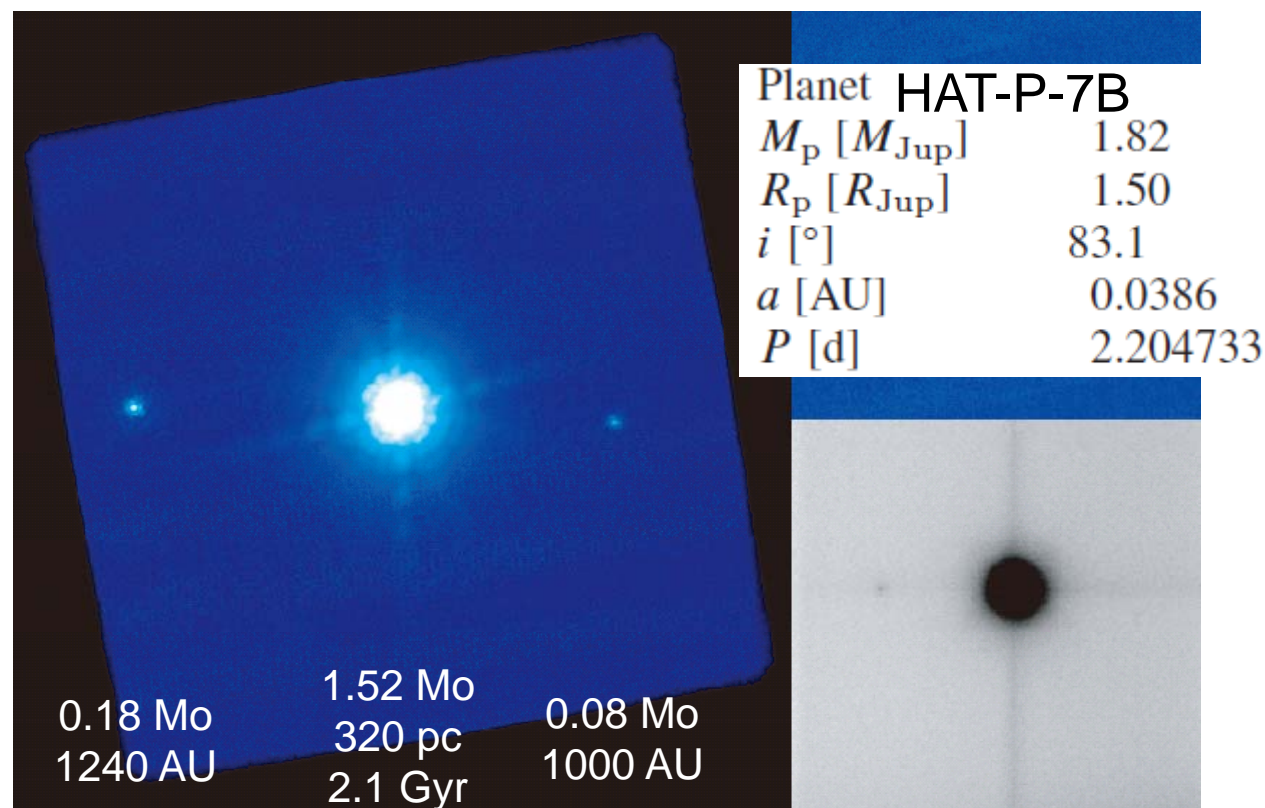
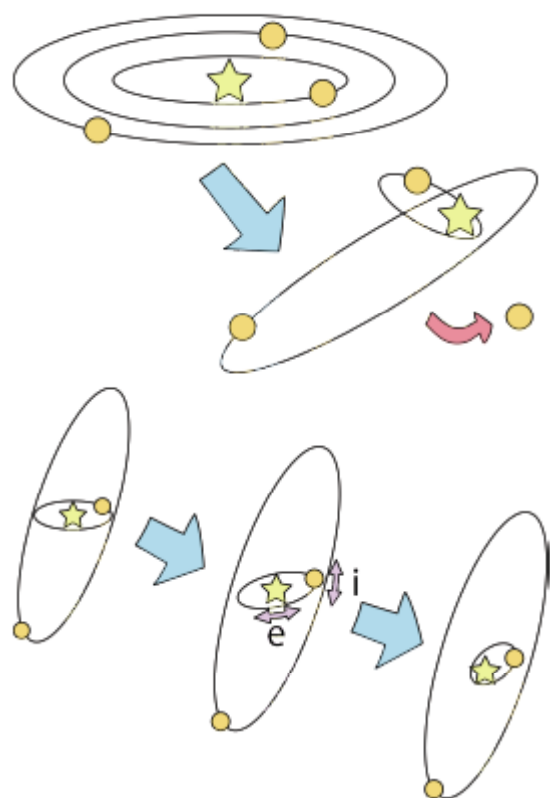
**Disk fine structures**  
⇒ **Planet existence**



# ~10 More Results on Disk Details Coming

- Inner gap/dip ( $<$ the Uranus orbit) seems to be a common structure.
- Again, strong support of planet formation in the inner disk region.
- Supporting planet formation theories in an early stage of star formation ( $<1$  Myr).
- *To be reported soon.*

# Search for Outer Massive Bodies around Transiting Planetary Systems: Candidates of Faint Stellar Companions around HAT-P-7 (320pc) (Narita et al. 2010; **see also poster by Narita**)



Left: 1.6  $\mu\text{m}$  image of HAT-P-7 (12"x12"). Upper right: A ADI/LOCI reduced Subaru image (6"x6"). Lower right: AstraLux z' band image of HAT-P-7 and the eastern companion candidate.

Seeking for evidence for planet scattering or migration



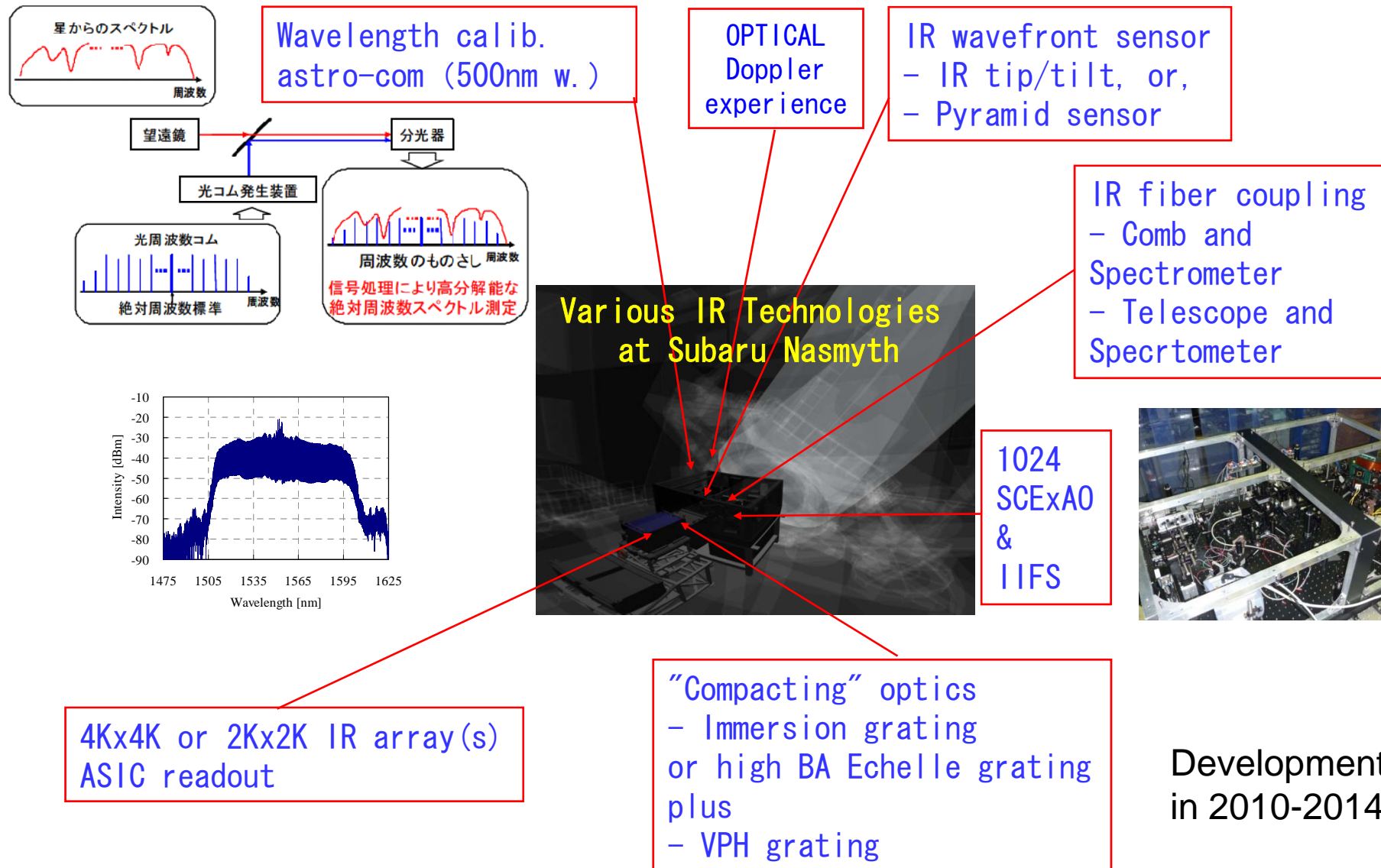
# SEEDS Members

- ◆ 26 institutes 110 members (36 international).
- Principal Investigator (PI): M. Tamura (NAOJ)
- Co-PI: T. Usuda, H. Takami (NAOJ)
- US, Germany, UK active members

## Runs in S11A and S11B

- ◆ ~12 nights per semester allocation continues.
- ◆ In S11A significant Subaru downtime (for Hyper-wide field optical prime-focus mosaic camera) in but does not affect the SEEDS program
- ◆ 3/24-3/27: SEEDS run #7; coming soon
- ◆ 5/20-5/25: SEEDS run#8
- ◆ 7/16-7/19: SEEDS run#9
- ◆ Three runs in S11B to be scheduled (Sep, Nov, Jan).

# Subaru IR Doppler Instrument under development: 1m/s for 1 Earth-mass planets around M stars



Development  
in 2010-2014

# Summary

- Direct imaging techniques for exoplanet studies are important for detecting wide orbit planets and studying their formation mechanisms.
- Various planet formation theories including core-accretion, gravitation instability, planetary scattering/migration, and first-core instability can now be compared with such observations.
- First Subaru Strategic Program “**SEEDS**” of a direct imaging survey for exoplanets/disks has started (120 nights for 5 years) in 2009.
- Early results on planet candidates and protoplanetary disk fine structures are introduced.
  - GJ758, HAT-P-7: **SUGGESTION OF OUTER PLANETS**
  - AB Aur, LkCa15: **DISK SIGNPOST OF PLANETS**
- Some 110 people including 25% international member are now involved in SEEDS.
- Lots of international science collaboration experiences management experiences in a large international science project.