SEEDS

Direct Explorations of Exoplanets and Disks with Subaru

Joint Subaru/Gemini Science Conference
2009.5.20 10:00-10:30

M. Tamura
National Astronomical Observatory of Japan

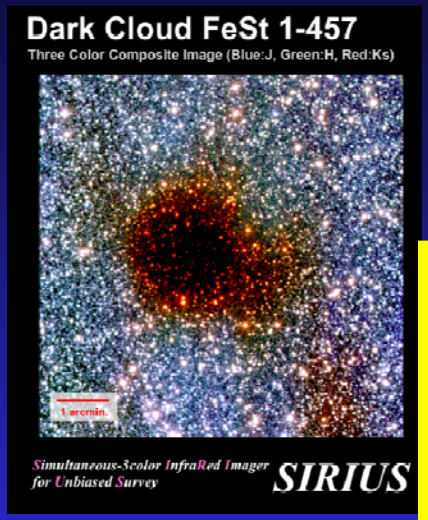
Talk Outline

1. Highlights of Subaru high-contrast sciences so far
   - Diversity of protoplanetary disk morphology
   - Low-mass companions
2. Next step
   - HiCIAO & SEEDS
   - SEEDS status
3. Summary

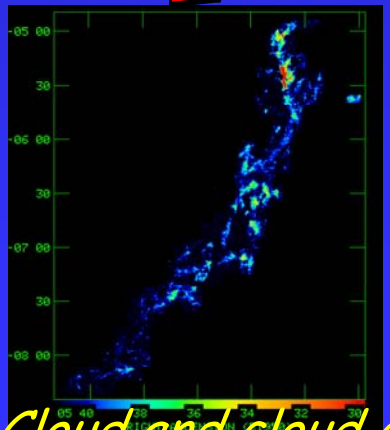
Current Paradigm of Star and Planet Formation

DIRECT OBS. Need < 1" resolution
Currently best studied at NIR

1. *Clouds collapse under gravity*

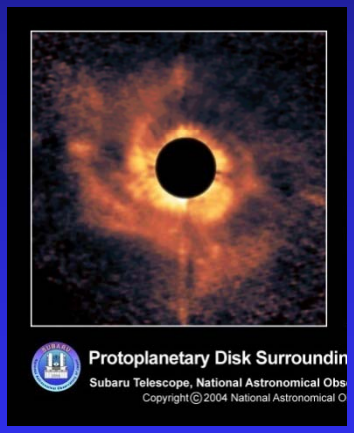


10,000 yr
IRSF/SIRIUS



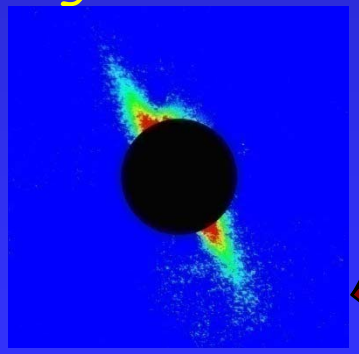
0. *Cloud and cloud cores (NRO)*

2. *Protoplanetary disks*



1 Myr
Subaru/CIAO

3. *Comets & asteroids form or Vega-like stars*

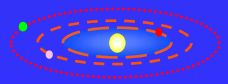


10 Myr
Subaru/CIAO/POL

100 Myr

Kaguya

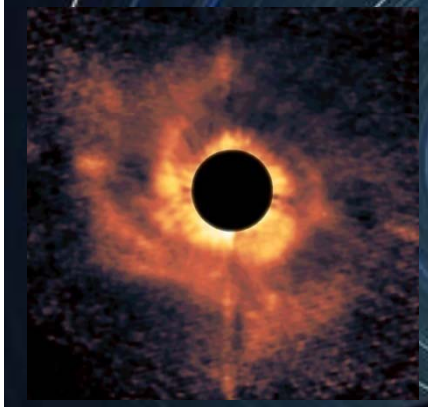
4. *Planetary system*

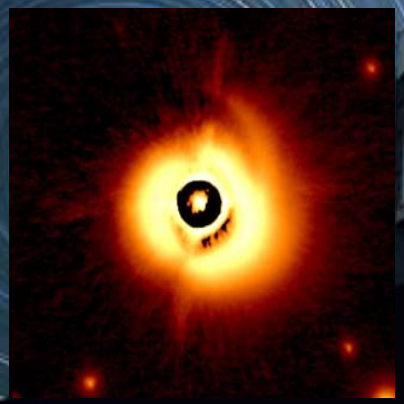


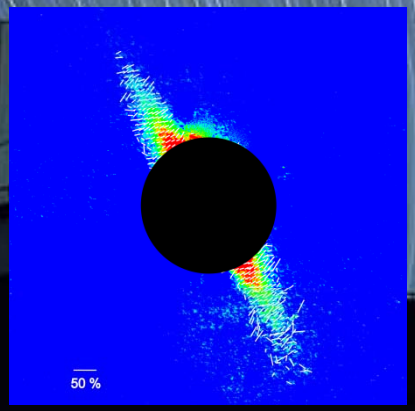
~270 systems known

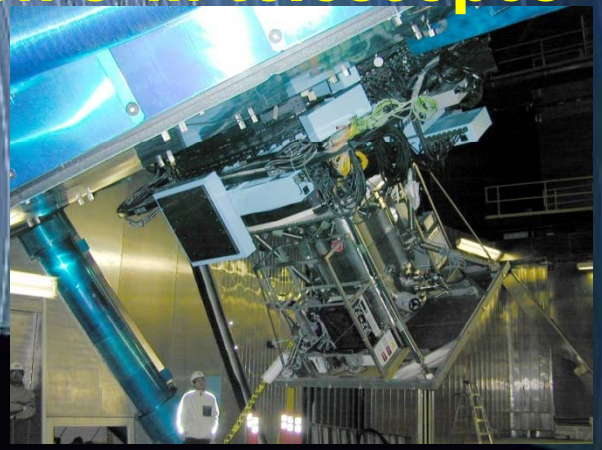
Subaru has an AO Coronagraph since 2001

- **CIAO + 36-actuator AO at Cass.**
  - ★ **First dedicated cold coronagraph on 8-m telescopes**





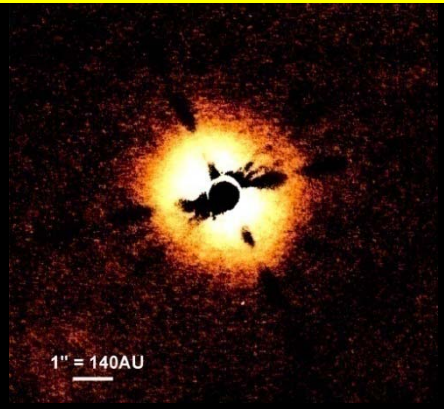


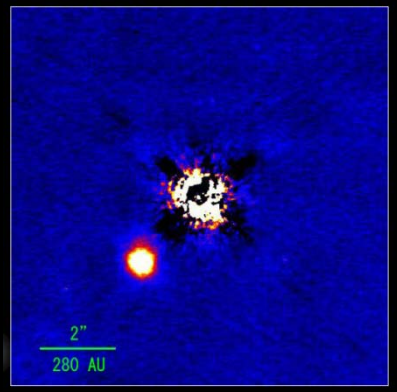


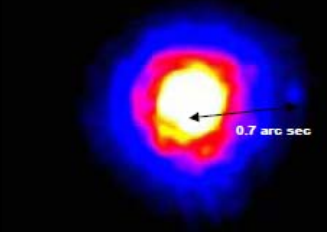
Diversity of proto-Planetary disks

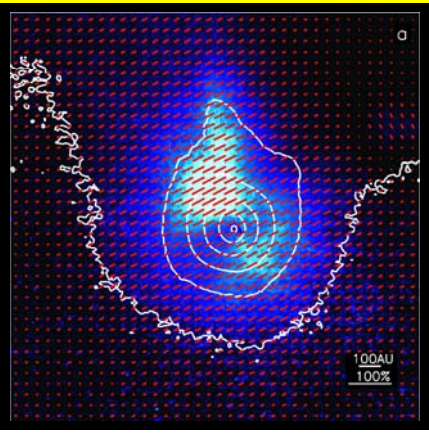
Young very low-mass Companion

Compact disk around massive YSOs







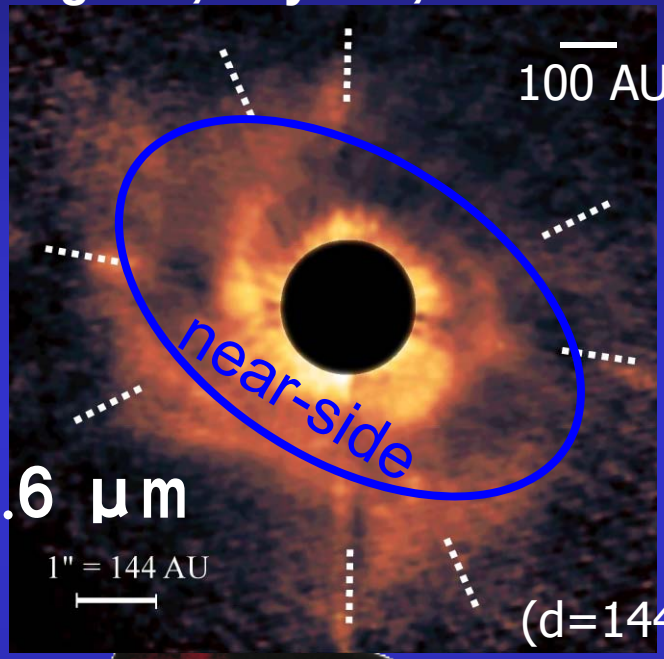


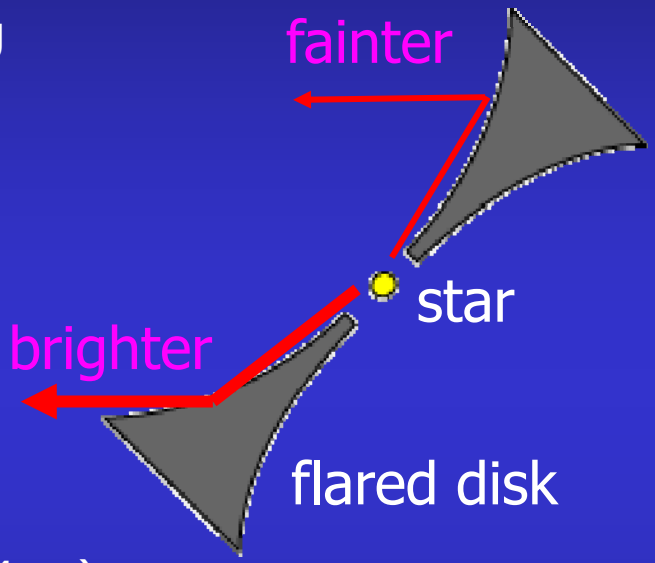
Subaru+CIAO+AO36 Science Summary

- **Disk - morphological diversity of young and debris disks**
  - **AB Aur: spiral structure in protoplanetary (PP) disk revealed (Fukagawa et al. 2004).**
  - **HD142527: new-type of PP disk morphology discovered (Fukagawa et al. 2006) & imaging of ice (Honda et al. 2009).**
  - **FN Tau: first PP disk around lowest-mass (0.1 Mo) star directly imaged (Kudo et al. 2007).**
  - **Beta Pic: First NIR polarimetry with coronagraph revealed nature of debris disk dust (Tamura et al. 2006).**
  - **Binary disks: GG Tau, UY Aur, etc. (Itoh, Hioki, Mayama)**
- **Exoplanets/brown dwarfs - new types of companions?**
  - **DH Tau, GQ Lup, EK60: "boundary objects" between planets and brown dwarfs around T Tauri stars discovered (Itoh et al. 2005; Neuhauser et al. 2005; Kuzuhara et al. 2009 - see his poster).**
  - **HR8799 image in 2002 (Fukagawa et al. 2009).**
- **Massive star disk - evidence for formation by accretion**
  - **BN, S140IR, IRAS23033, S255IRS1&3, N7538IRS1 : Ubiquity of compact disks around massive (at least up to ~10 Mo) YSOs (Jiang et al. 2005, 2007).**

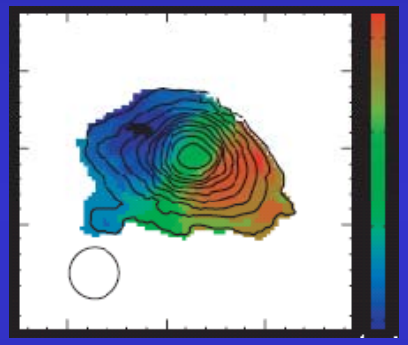
Spiral-shape disk around 2Mo-4Myr Herbig Ae star: AB Aur

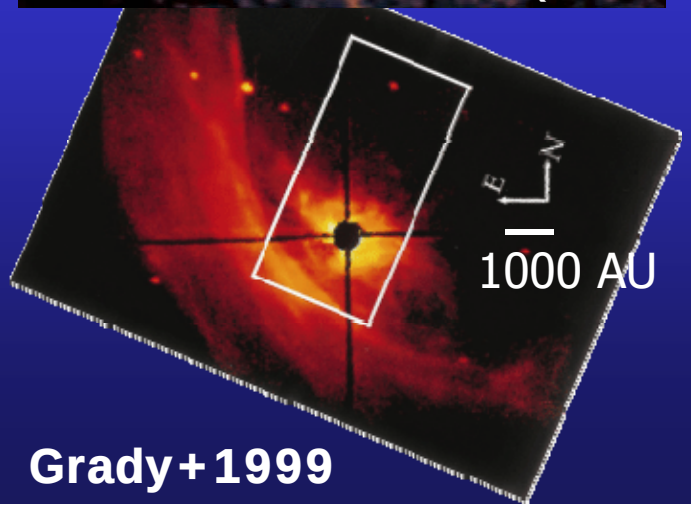
Fukagawa, Hayashi, Tamura+2004, ApJ





12CO
Velocity field
Corder+2006
OVRO

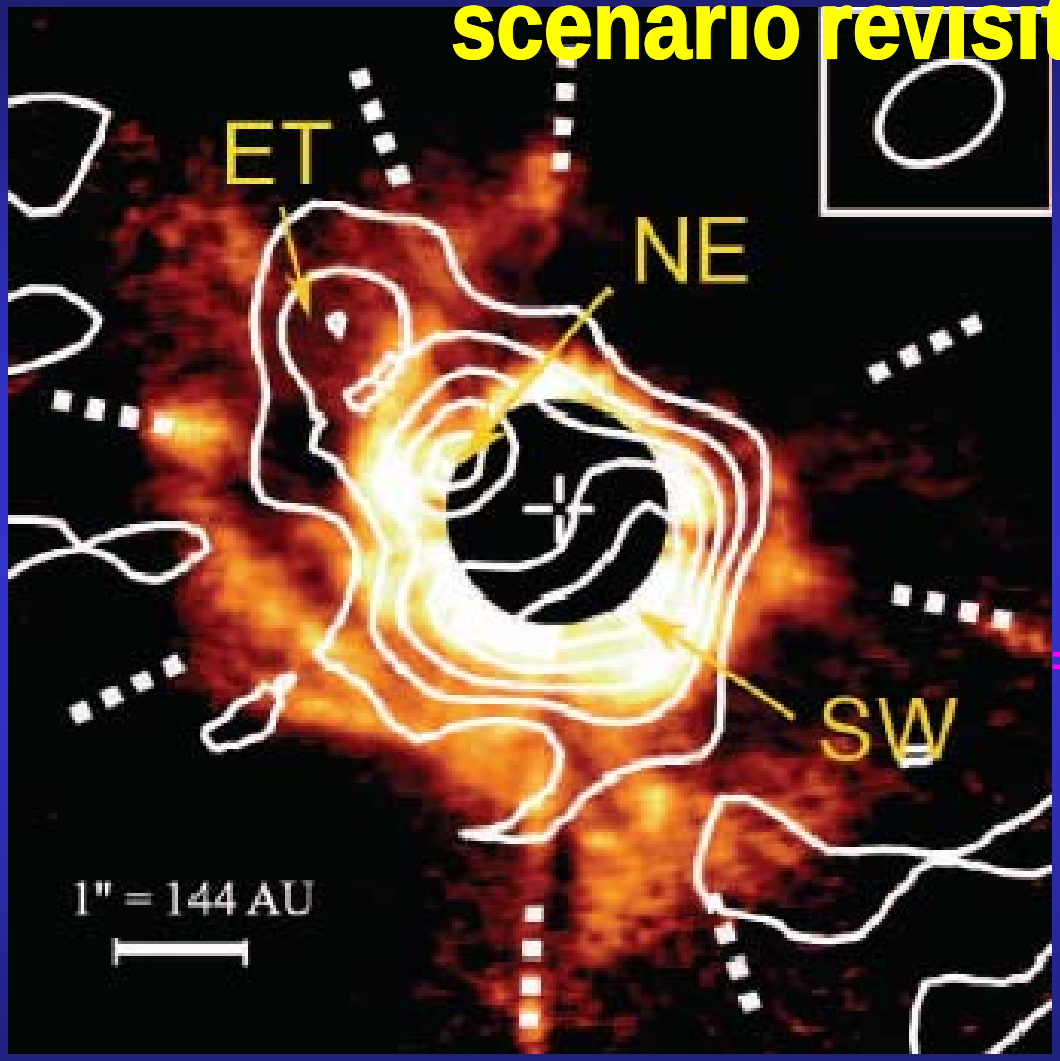




Grady+1999

- disk with spiral arms (r=450 AU)
- trailing arm ← com. w/radio data
  + brighter forward scattering
- no nearby companions in our images; but see Oppenheimer+08

Submm follow-up and planet formation scenario revisited

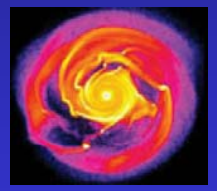


White contours:
345 GHz dust continuum (SMA)
Lin+2006, ApJ

M_{disk} ~0.15$M_\odot$

Gravitational instability?
(instability condition):

$$Q = \frac{c_s \Omega}{\pi G \Sigma} \leq 1$$



Probably supplies of matter from the envelope maintain the weak instability.

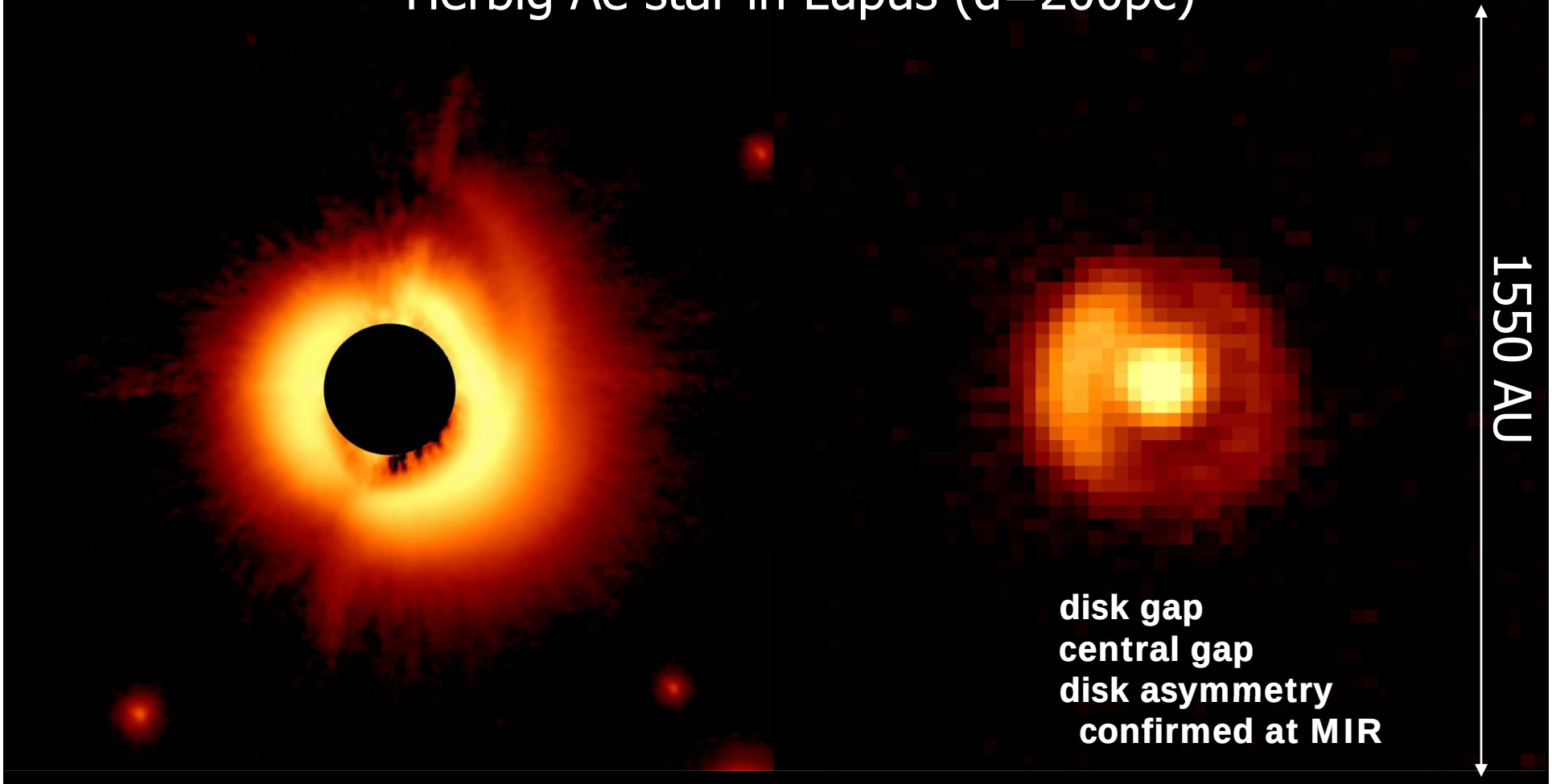
⇒ Q ~ 2; "weak" instability

A suggestion of planet formation by gravitational instability? (for some systems)
Matsuo+2007, ApJ

Also note recent imaging discovery of outer (>10AU) planets around A stars (Marois; Kalas).

NEW type of disk: HD142527 – banana split

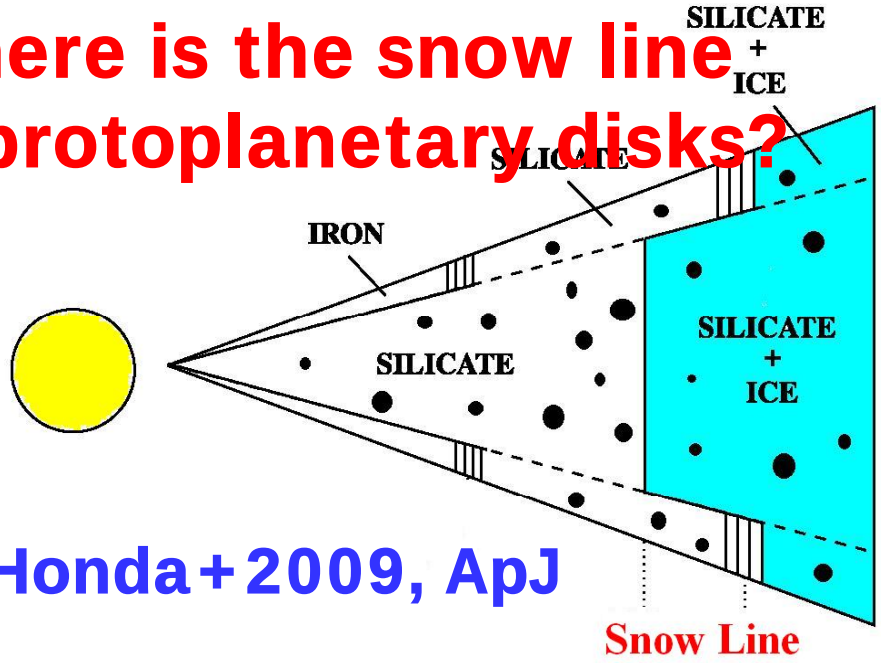
Herbig Ae star in Lupus (d=200pc)



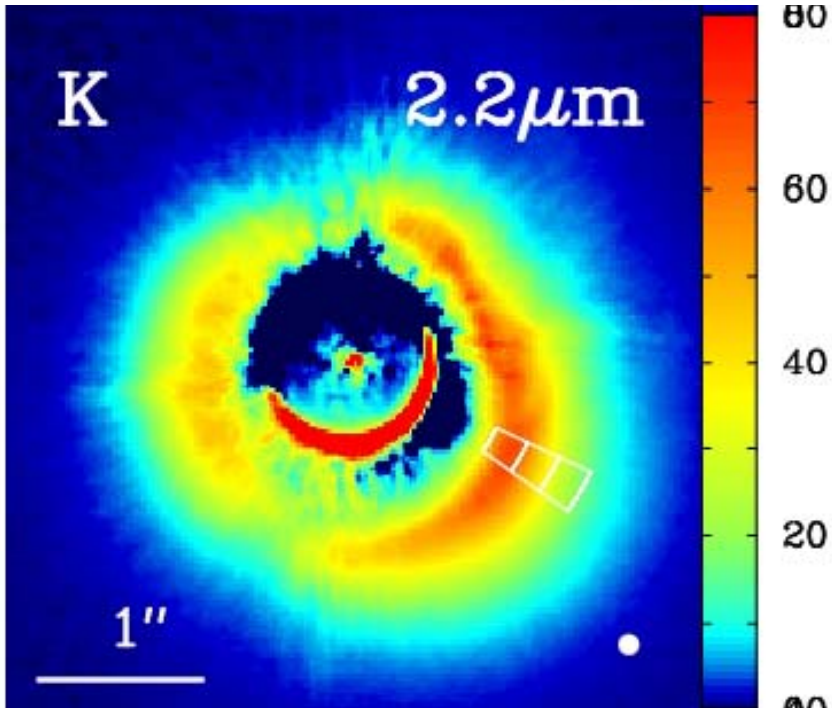
λ=1.65 micron
Subaru/CIAO
(Fukagawa+2006, ApJ)

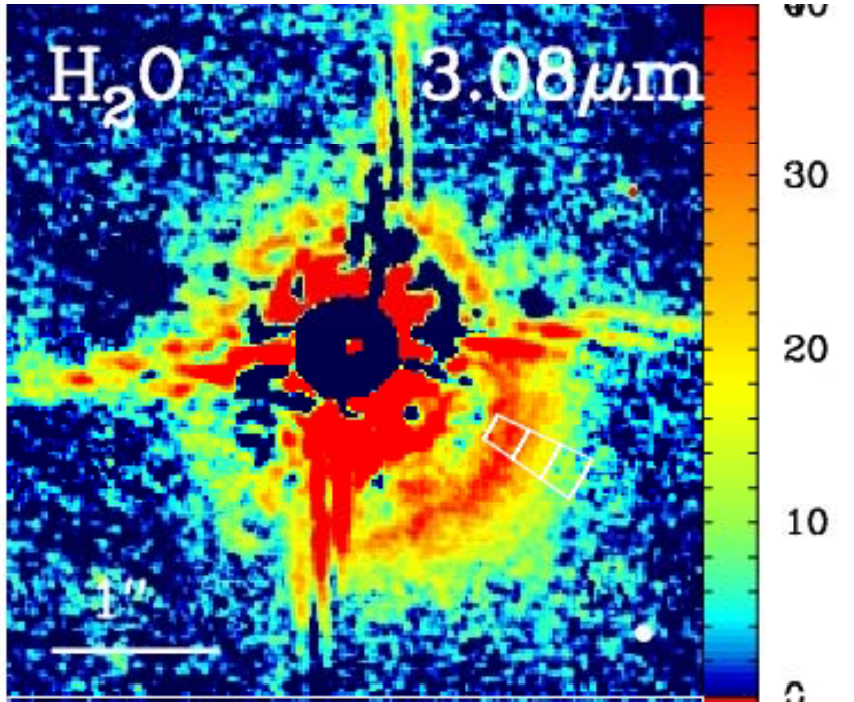
λ=24.5 micron
Subaru/COMICS
(Fujiwara+2006, ApJ)

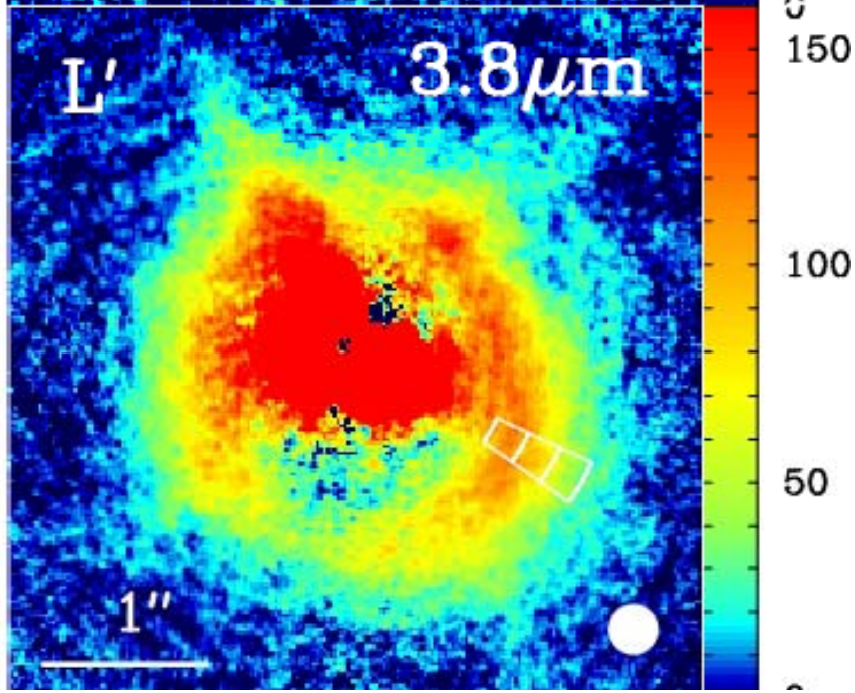
Where is the snow line in protoplanetary disks?

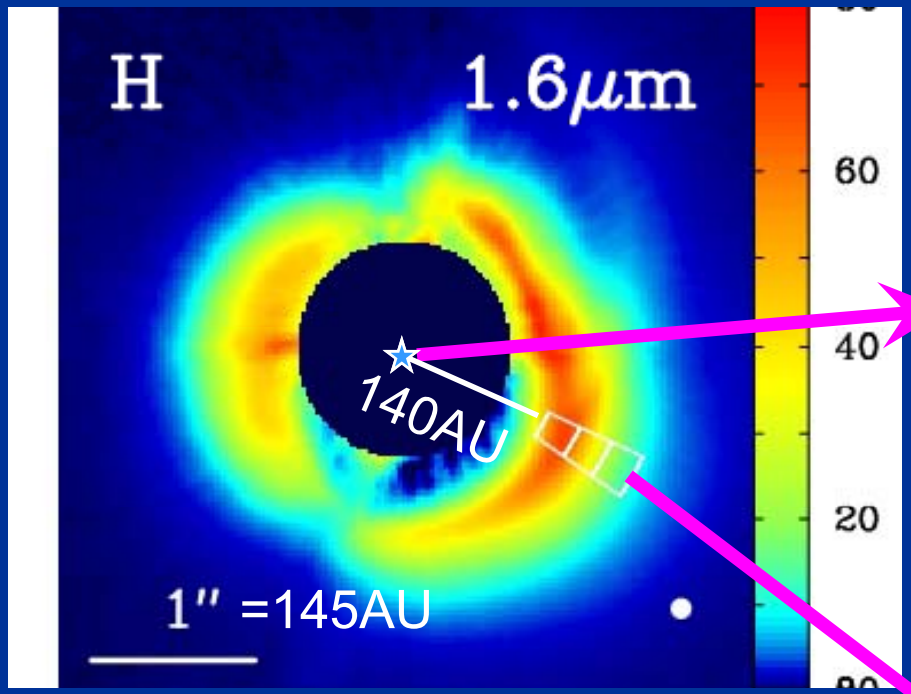


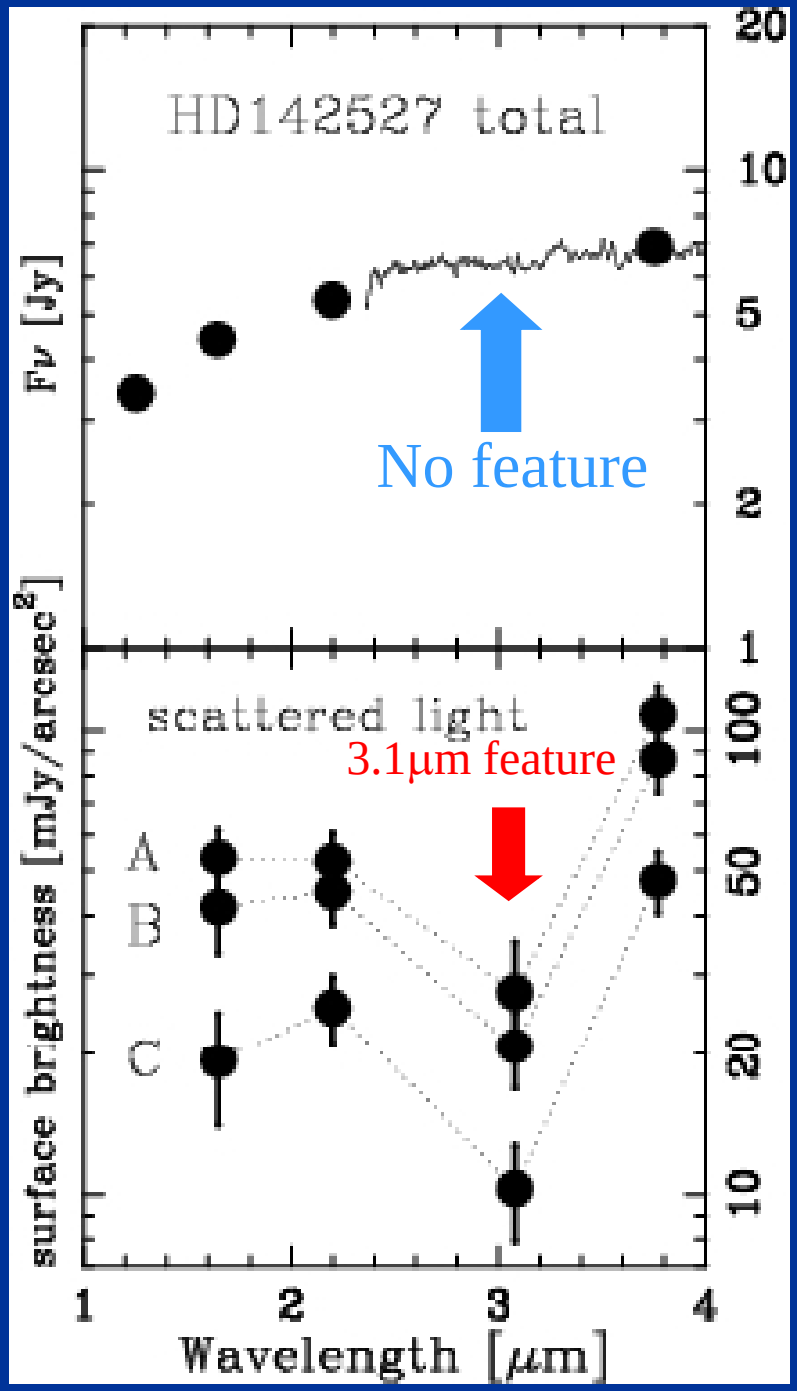
Honda+2009, ApJ











- ice absorption everywhere
  - T(dust)=82-85K (by MIR; Fujiwara+2006)
  - cold enough
- Snow line is much inner
  - R_{snow} << ～140AU

Honda+2009

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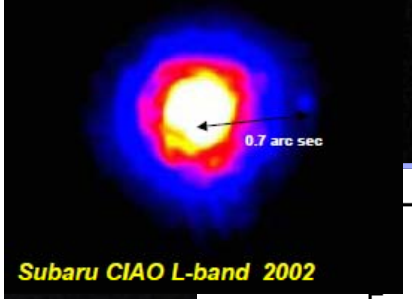
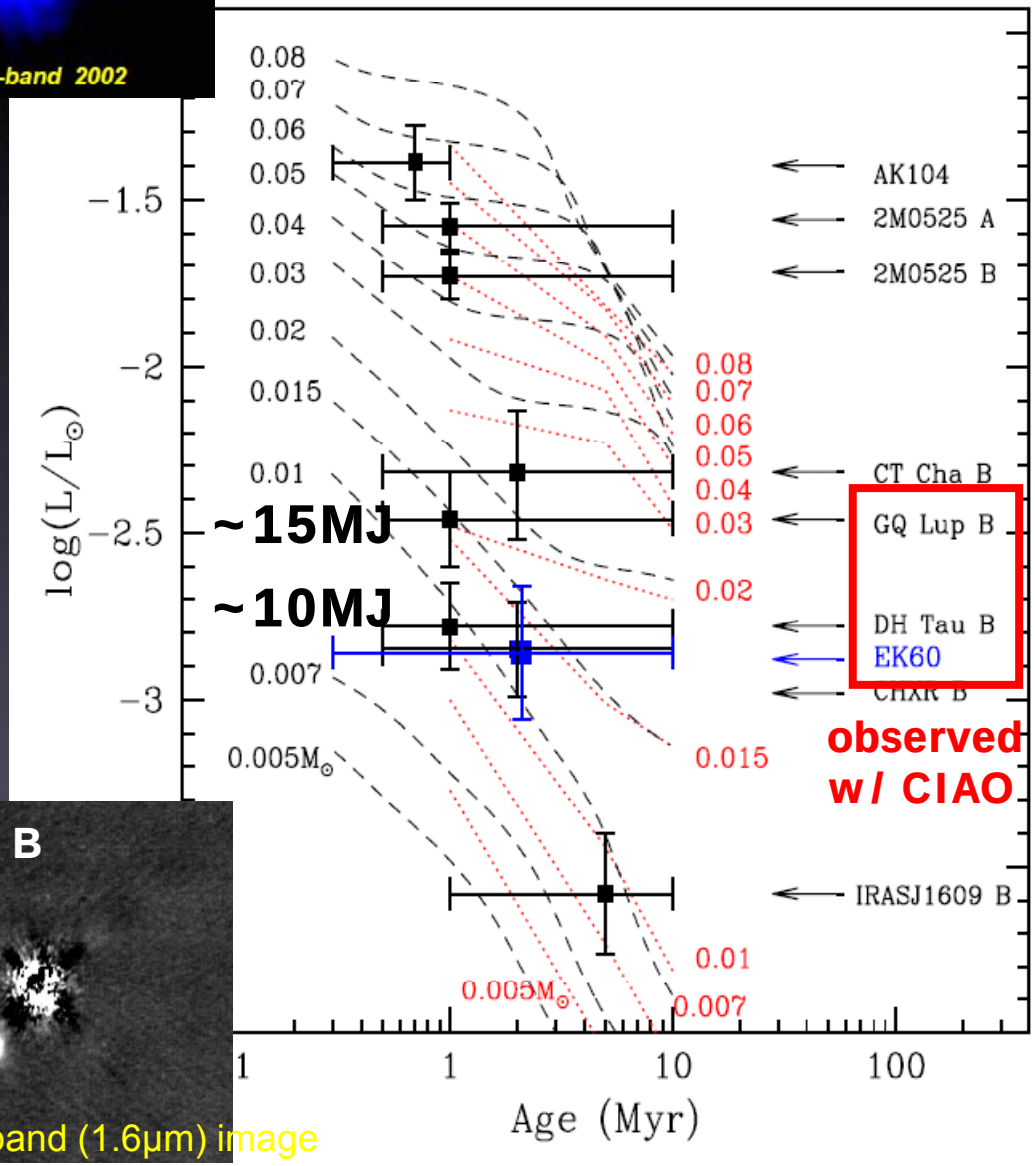
DH Tau B & GQ Lup B & EK60: Planets or Brown Dwarfs ?



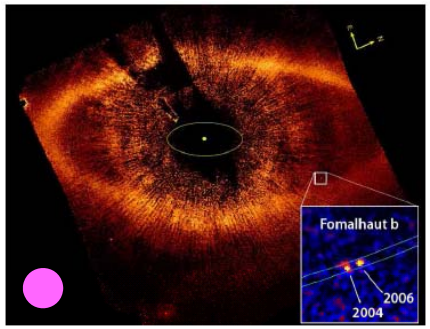


H-band (1.6μm) image

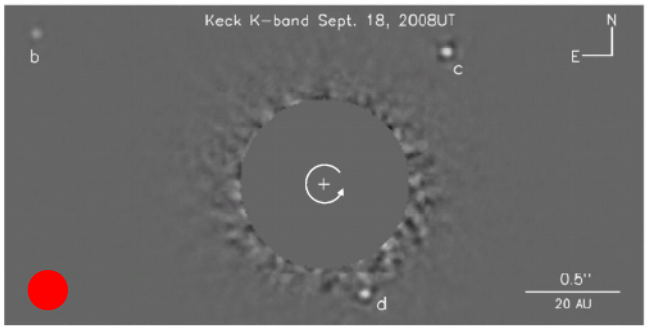
- Very low-mass companions around T Tauri Stars; what are they?
- spectroscopic temperature estimate is still not reliable
- thus, we use age/luminosity
- then DH Tau, GQ Lup, EK60 are three of the lowest and nearly planetary-mass companions.
- But they are very far from star (>100AU)

Itoh, Tamura, Hayashi+05
Neuhauser+05
Luhman+06
Kuzuhara+09

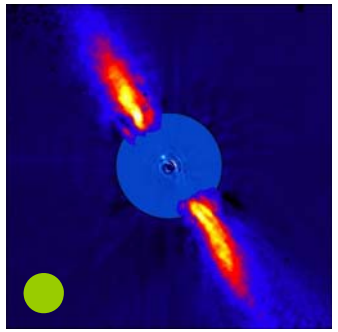
Then, finally "planets" imaged around A stars: HR8799, Fomalhaut, b Pic



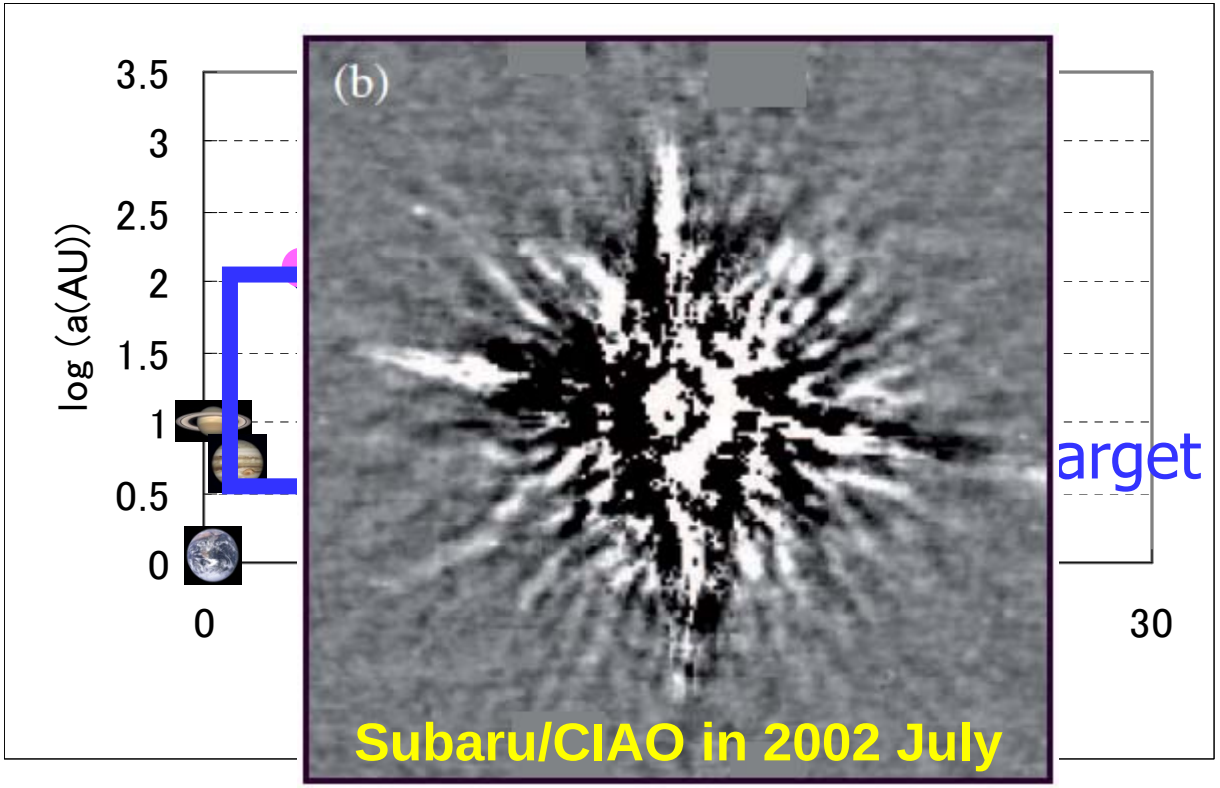
HST



GEMINI+KECK



VLT



arget space

Subaru new coronagraph - HiCIAO

Nasmyth platform

Telescope

Warm

Common Optics + **AO Module**

Coronagraph Module

High Contrast Optics Module

Cold

IR Camera Module

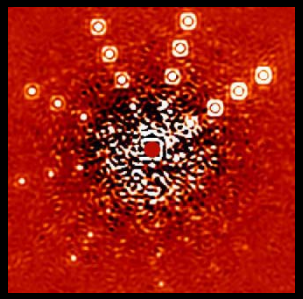
188 actuators AO
Future:
Complementary MEM DM (32×32)

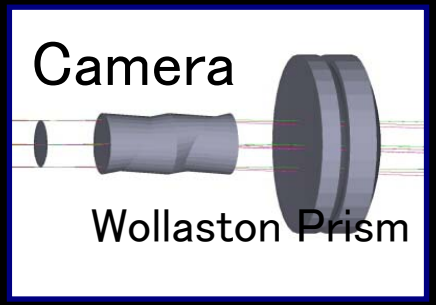
Coronagraph
Focal masks
Pupil stops

Differential optics
(Wollaston prisms - single/double)

Hawaii 2-RG
2k × 2k array
ASIC Sidecar Controller

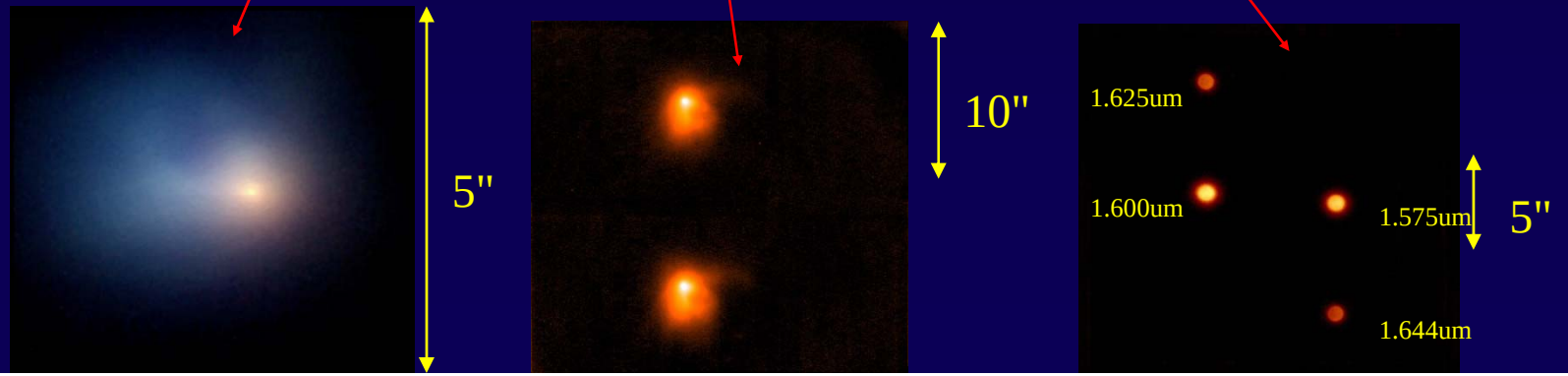
Filters
Common+Differential





HiCIAO Specifications

Focus	**IR Nasmyth（w/ AO188）**
Wavelength	**0.85 – 2.50 microns**
Observation modes	**DI, PDI, SDI, ADI (w/ & w/o coronagraph)**
Resolution	**0.03" (J), 0.04" (H), 0.055" (K)**
Strehl ratio	**0.2 (J), 0.3 (H), 0.5 (K) with AO**
Field of view	**20"x20" (DI), 20"x10" (PDI), 5"x5" (SDI)**
Contrast	**$10^{3.8}$ at 0.1", $10^{5.5}$ at 1.0" (SDI w/ coronagraph)**
Pixel scale	**0.010"/pix**
Occulting masks	**0.2", 0.3", 0.4", 0.6", 1.5" diameter**
Filters	**Y, J, H, Ks (DI, PDI), CH4, FeII, H2 (SDI)**



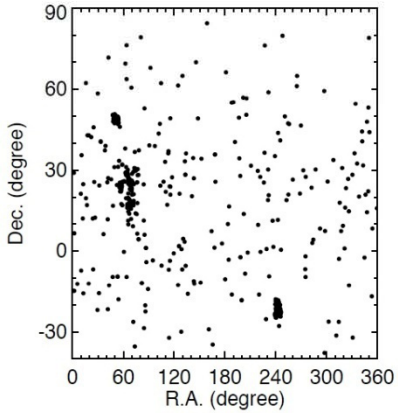
SEEDS – Subaru Strategic Exploration of Exoplanets and Disks with HiCIAO/AO188

- First "Subaru Strategic Observations"
- 120 nights in 5 years on Subaru
- Direct imaging and census of giant planets around solar-type stars in the outer regions (~4-40 AU)
- Exploring protoplanetary disks and debris disks for origin of their diversity and evolution at the same radial regions
- Direct linking between planets and protoplanetary disks

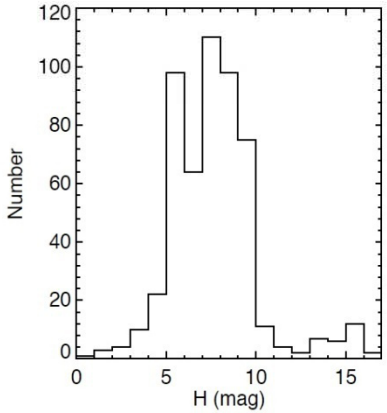
HiCIAO
0.6" mask
coronagraph
images in
ADI mode

SEEDS Target Summary as of Jan 09

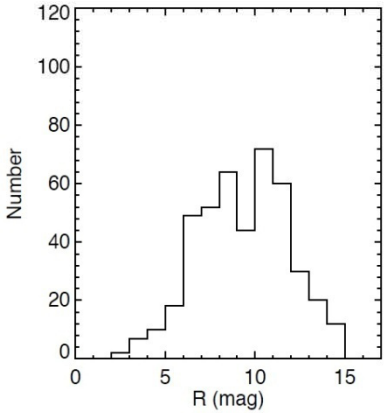
Category	Planet searches (in methane SDI/ADI mode)			Disk Searches (in PDI mode)		Total number
	(a)	(b)	(c)	(d)	(e)	
	SFR YSOs	Open cluster & Moving Group	Nearby stars & WDs	Protoplanetary disks	Debris disks	
Number	90	100	140+37	130	70	567
Distance	~140 pc	<125 pc	<30 pc	~140 pc	<130 pc	
Age	1-10 Myr	10~100 Myr	100 Myr - 1 Gyr	1-10 Myr	5 Myr - 6 Gyr	
Comment	Tau/Sco	UPleiades/ several MGs	subcategory	TTS/HAeBE/ polarized sources	SST/AKARI sample	



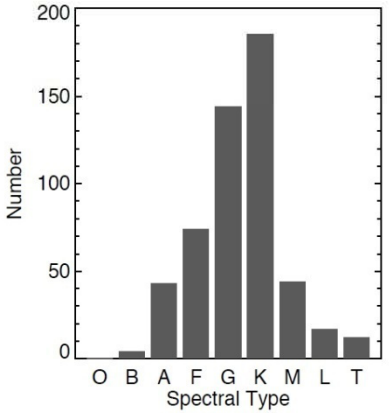
RA-DEC



H-mag



R-mag



Sp-Type

SEEDS Members & Stutus

- **24 institutes 91 members (20 foreigners).**
  - **Principal Investigator (PI): M. Tamura (NAOJ)**
  - **Co-PI: T. Usuda, H. Takami (NAOJ)**
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SAC and TAC already approved!
SEEDS will start in 09B as soon as PV finished.

SUMMARY

- Various results with Subaru CIAO+AO36 have been reviewed: disk diversity, disk ice, nearly planetary mass companions at distance, massive star disks, and polarimetry.
- SEEDS will conduct a 5-year legacy survey of ~500 solar-mass and massive young stars for direct imaging of exoplanets and disks in 120 nights with a "all-Japan" team collaborating with foreign researchers.
- Our targets consist of 5 categories, each of which includes about ~100 stars (enough for statistics).
- We believe that we can image at least a handful of giant (<13 MJ) exoplanets in a few to 10s AU regions and the similar radial regions of many disks in each category.
- Various follow-up programs should be organized, including spectroscopy with various instruments and telescopes.