Signposts of Planets Observed by SEEDS

Signposts of Planets Conference

Michael W. McElwain
NASA GSFC

October 19, 2011

SEEDS – Strategic Exploration of Exoplanets and Disks At Subaru

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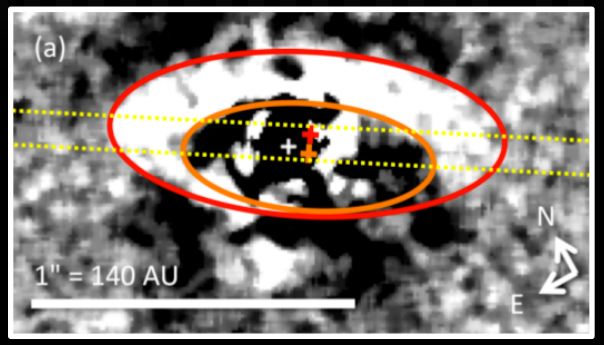
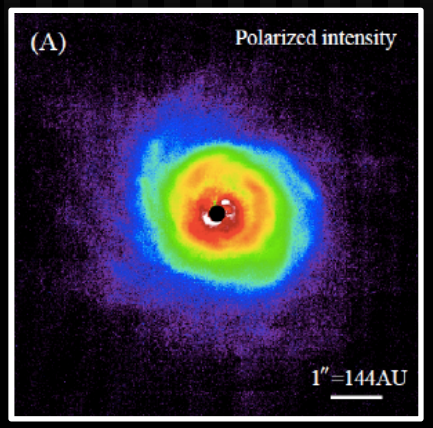
- ✓ First Subaru Strategic Observations
- ✓ 120 nights in 5 years at Subaru (> 10M USD)
- ✓ Direct imaging and census of giant planets around solar-type stars in outer disk regions (4-40 AU)
- ✓ Exploring the diversity and evolution of protoplanetary disks and debris disks
- ✓ Direct linking between planets and protoplanetary disks
- ✓ Full data release after ~18 months (http://smoka.nao.ac.jp)

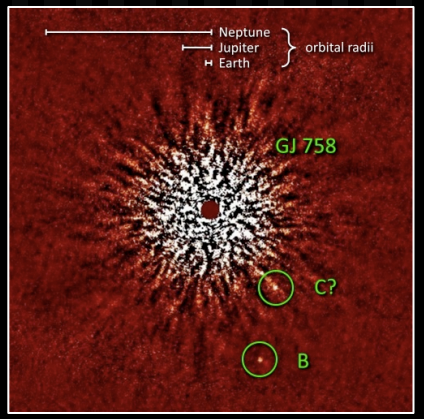
LkCa 15



AB Aur



GJ 758 B

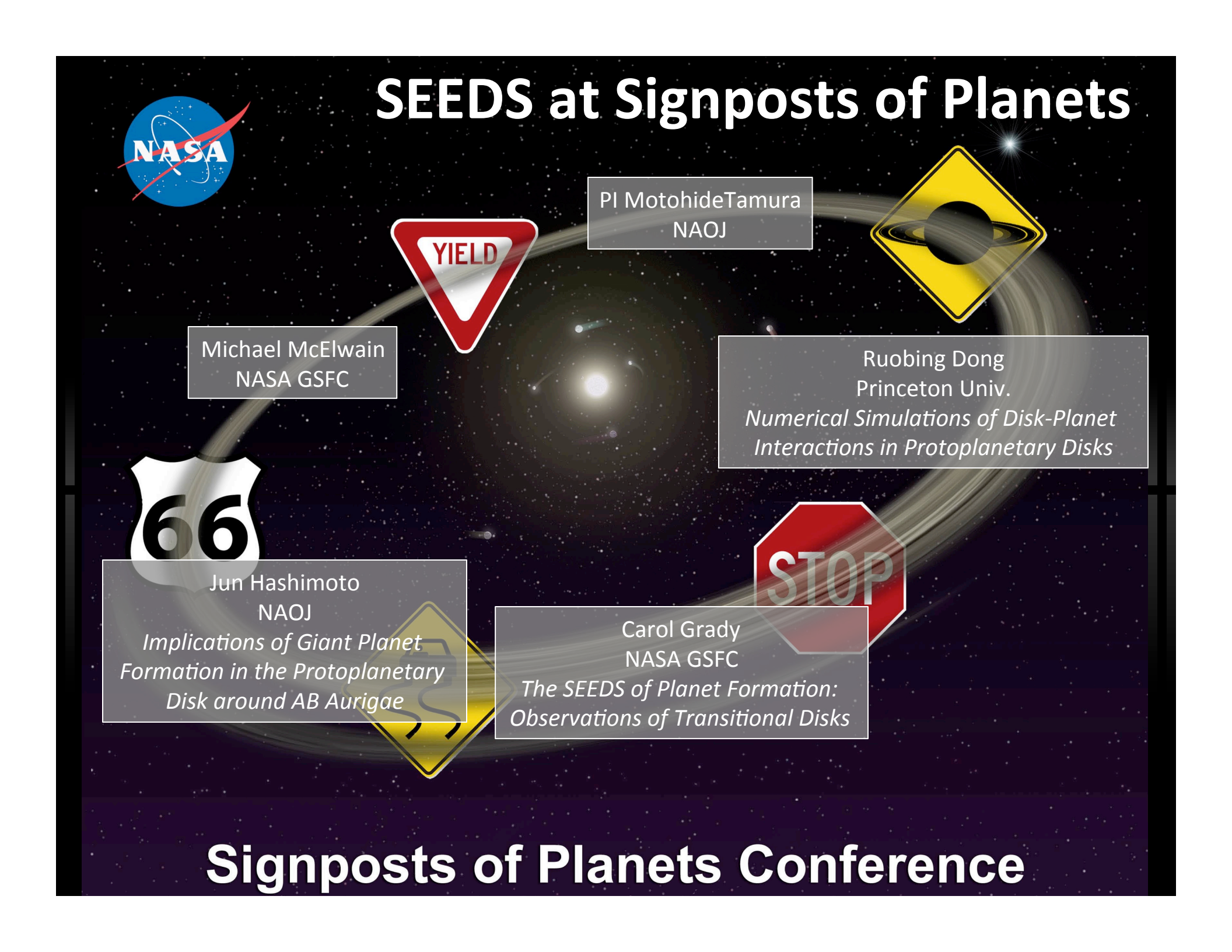


Current SEEDS Members

28 Institutes, 105 members, (35 non-Japanese)

- PI **Motohide Tamura**, co-PIs Tomonori Usuda & Hideki Takami
- **Co-Is**: (Univ. of Air) N. Kaifu; (ASIAA) J. Karr, N. Ohashi, M. Takami; (Hokkaido Univ.) N. Baba; (Ibaraki Univ.) M. Momose, Y. Okamoto; (Riken) N. Ebizuka; (JAXA/ISAS) K. Enya, H. Kataza, H. Makitsubo, T. Nakagawa; (Kanagawa Univ.) M. Honda; (Kobe Univ.) Y. Itoh, Y. Oasa, R. Tanii; (Kyoto Univ.) T. Muto; (Nagoya Univ.) S. Inutsuka, T. Ootsubo, T. Sumi; (Nagoya C.C.) K. Sugitani; (NAOJ) T. Fukue, J. Hashimoto, M. Iye, R. Kandori, E. Kokubo, T. Kudo, N. Kusakabe, S. Miyama, J. Morino, N. Narita, J. Nishikawa, M. Sato, H. Suto, Y. Takeda, J. Watanabe, T. Yamashita; (NAOJ/ALMA) M. Saito, T. Tsukagoshi, N. Ukita; (NAOJ/NRO) R. Kawabe; (NAOJ/Subaru) S. Egner, F. Martinache, T. Fujiyoshi, O. Guyon, Y. Hayano, M. Hayashi, M. Ishii, T. Matsuo, T. Pyo, N. Takato, H. Terada, K. Usuda, M. Yutani; (NAOJ/TMT) R. Suzuki; (Osaka Univ.) M. Fukagawa, H. Shibai, K. Yamamoto; (Sokendai) S. Mayama, T. Suenaga, Y. Takahashi, J. Kwon; (TI Tech) S. Ida, B. Sato; (Tohoku Univ.) A. Tsukamoto, T. Yamada; (Univ. of Tokyo) M. Kuzuhara, A. Nakashima, I. Sakon, M. Ueno
- **International Co-Is**: (College of Charleston) **J. Carson**; (CSIC-INTA) **A. Moro-Martín**; (Univ. of Hawai'i) K. Hodapp; (Univ. of Hertfordshire) T. Gledhill; J. Hough, P. Lucas; (MPIA Heidelberg) B. Biller, M. Bonnefoy, W. Brandner, M. Feldt, B. Goldman, M. Goto, T. Henning, R. Launhardt, V. Roccatagliata, J. Setiawan, C. Thalmann; (Univ. of Munster) I. Mann; (Univ. of Toronto) **M. Janson**; (NASA GSFC) **C. Grady; M. McElwain;** (NASA JPL) E. Serabyn; (Univ. of Nice) L. Abe; (Princeton Univ.) C. Blake, T. Brandt, A. Burrows, **R. Dong**, C. Dressing, E. Jensen, N. J. Kasdin, G. Knapp, R. Rafikov, D. Spergel, E. Turner, R. Vanderbei; (Russian Academy of Sciences) A. Tavrov; (Univ. of Washington) J. Wisniewski

SEEDS at Signposts of Planets



PI MotohideTamura
NAOJ

Michael McElwain
NASA GSFC

Ruobing Dong
Princeton Univ.
Numerical Simulations of Disk-Planet Interactions in Protoplanetary Disks

Jun Hashimoto
NAOJ
Implications of Giant Planet Formation in the Protoplanetary Disk around AB Aurigae

Carol Grady
NASA GSFC
The SEEDS of Planet Formation: Observations of Transitional Disks

Signposts of Planets Conference

SEEDS Milestones

2004	Sept	HiCIAO project officially started (MEXT Tokutei fund)
2007	Jul 31	Application submitted to Subaru (Two proposals)
	Dec 3	HiCIAO Telescope First Light without AO188
2008	Feb 1	First SEEDS workshop
	Dec 21	HiCIAO Telescope First Light coupled with AO188
2009	Oct 1	Performance Verification passed
	Oct 30-Nov1	SEEDS Survey Begins
2011	Feb 5	ScEXAO 1st light
2012	Spring	2 yr Middle Review
2014		End of SEEDS Survey
2015	Spring	Delivery of High Contrast IFS

Subaru High Contrast Instrumentation

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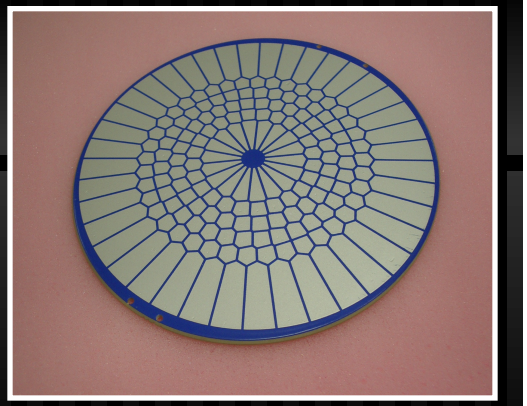
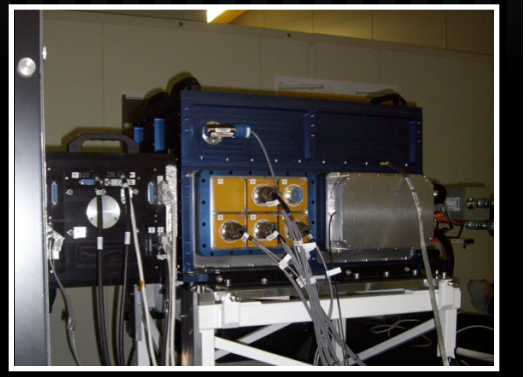
- ✓ Subaru – 8 m telescope
- ✓ AO 188 (+ SCExAO – 1st light 2/5/2011)
- ✓ Classical Lyot Coronagraph
- ✓ HiCIAO – NIR Science camera
  - ✓ Direct Imaging
  - ✓ Simultaneous Differential Imaging
  - ✓ Polarization Differential Imaging

→ DI, SDI, PDI can be used with Angular Differential Imaging





HiCIAO Observing Modes

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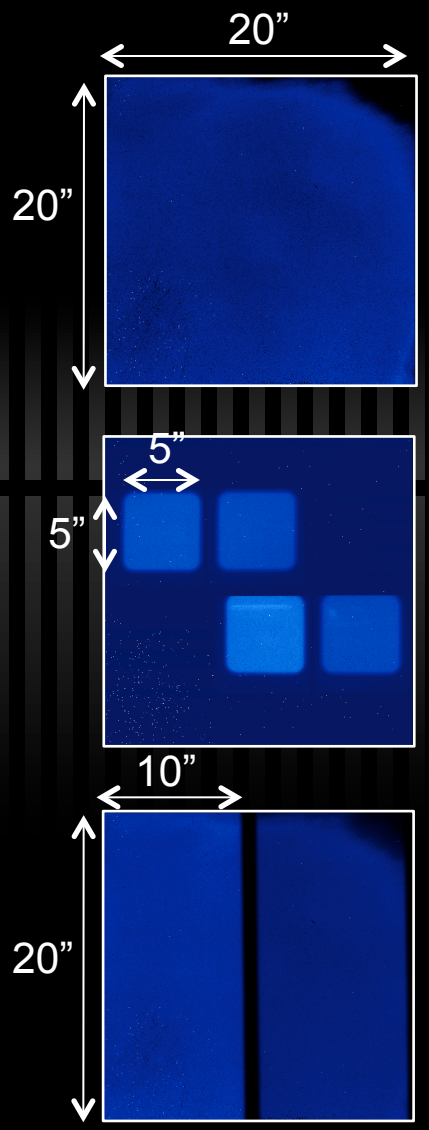
0.010”/pixel

- **Direct Imaging**
  - 20” x 20” FOV; J,H,K filters
- Simultaneous Differential Imaging
  - 5” x 5” FOV, narrowband H
- Polarization Differential Imaging
  - 10” x 20” FOV; J,H,K filters



Direct Detection of Extrasolar Planets Requires High Contrast

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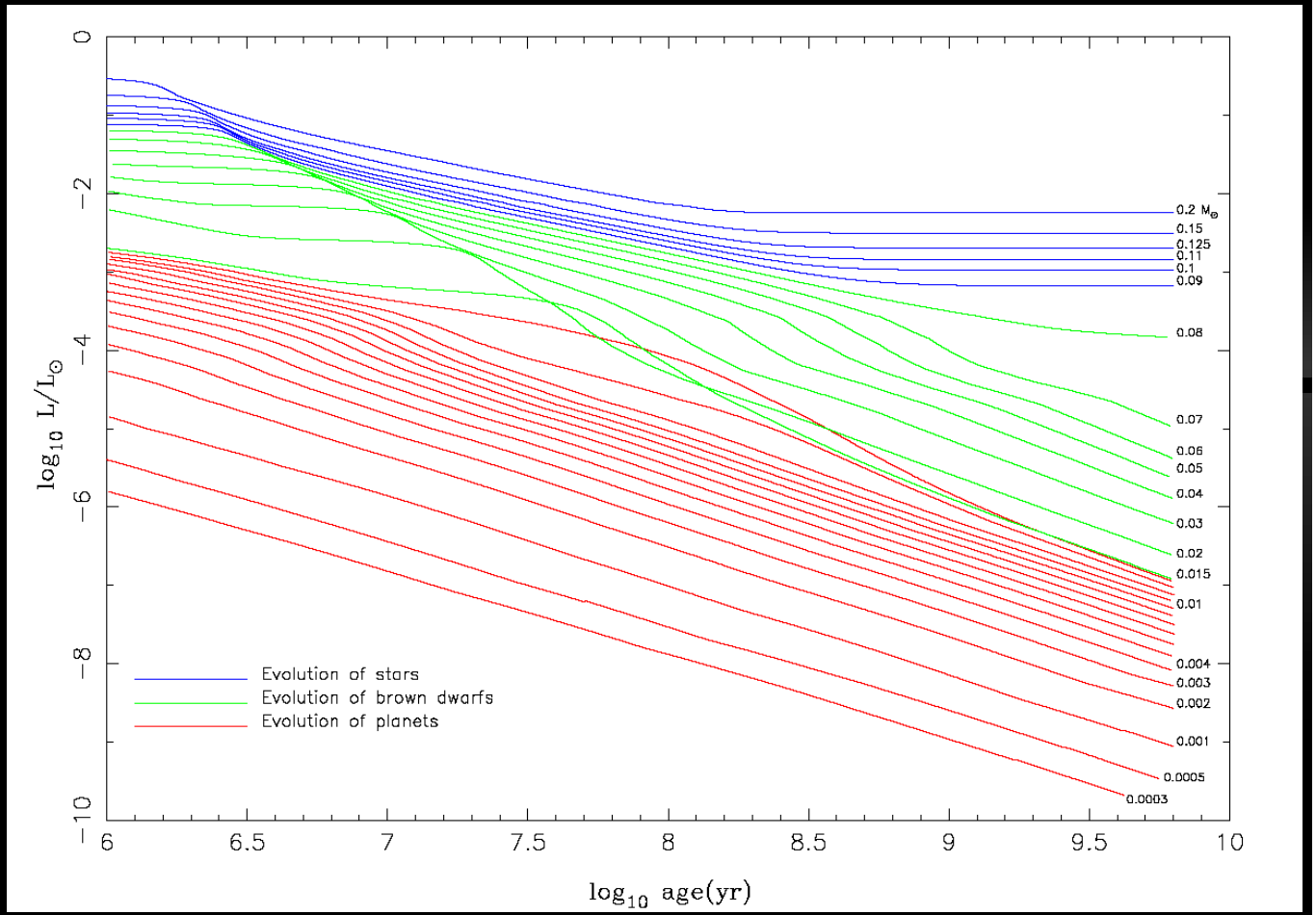
1. Angular Separation
   - Distance to star
   - Orbital Separation
2. Flux ratio (Δmag)
   - Mass and age of target
   - Mass and age of companion



Burrows et al. 1997

SEEDS Observations

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 Target balance subject to change
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	
Observed Incl. Follow-up	31	18+36	86+1	Same targets as (a)	31	203 Including multiple observations
Refereed Publications	LkCa15 ← **Grady talk** AB Aur ← **Hashimoto talk**		HAT-P-7 GJ758	Same as (a)	HR4796A	6
Drafts in prep.	7 papers	One-Yr paper each	One-Yr paper & Indiv.	Same as (a)		~12

AO-assisted Subaru PSF

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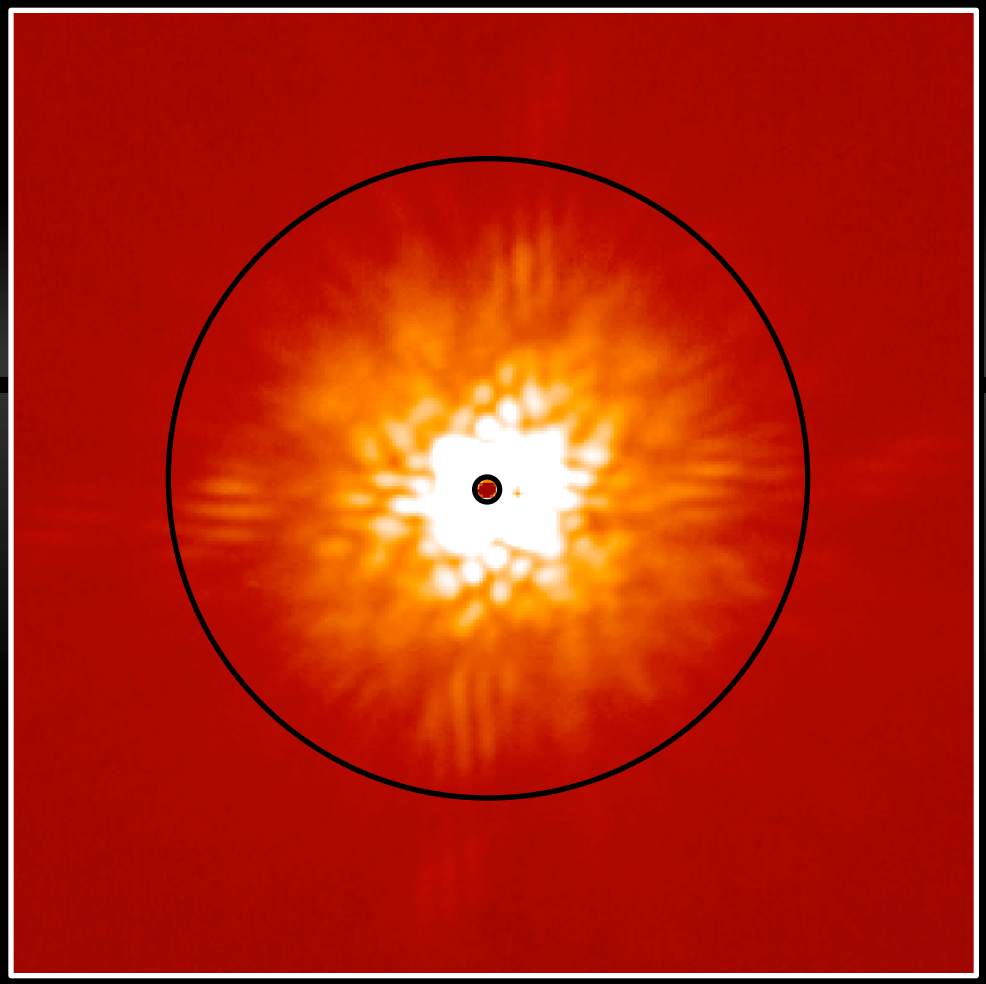
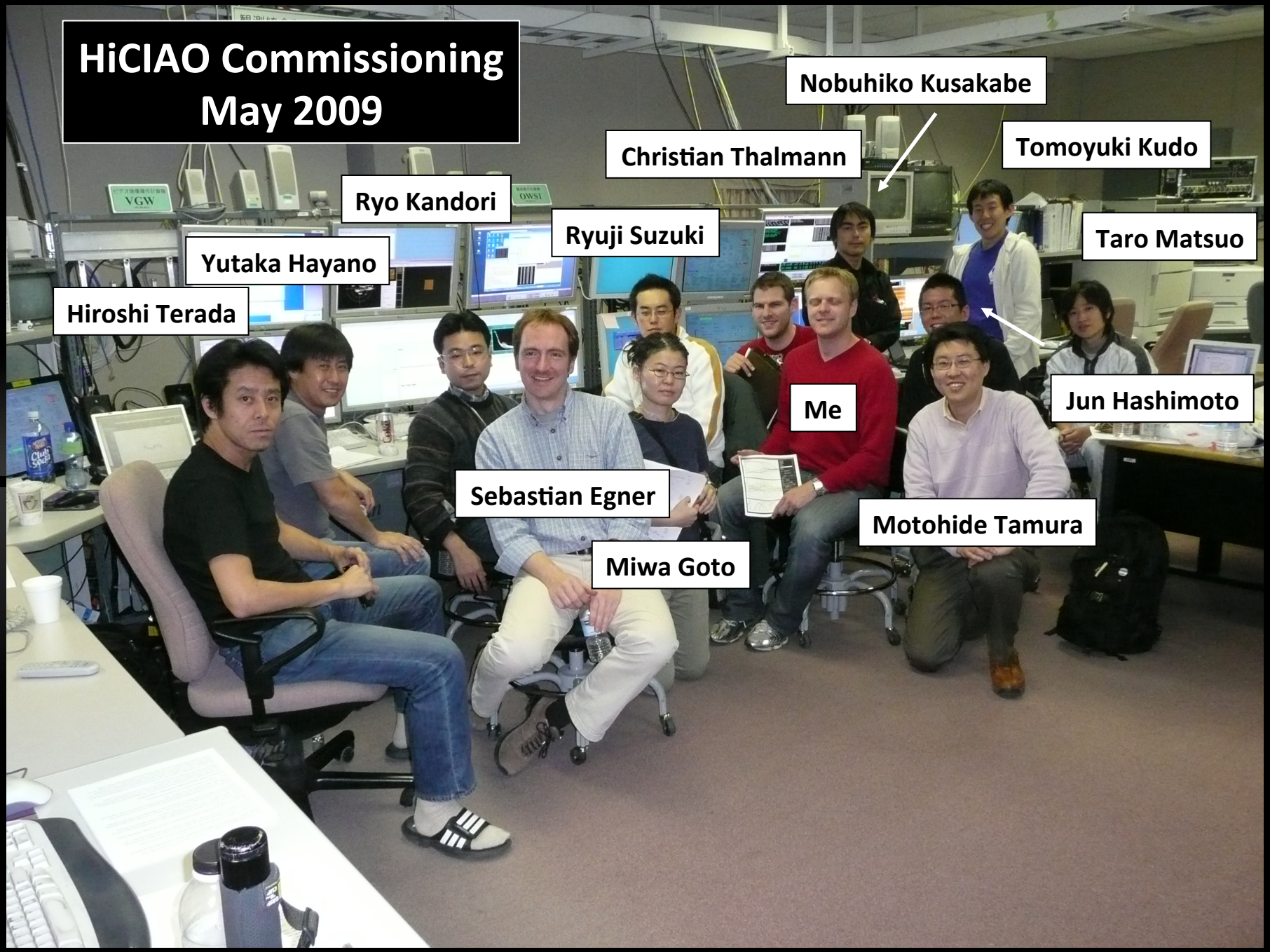
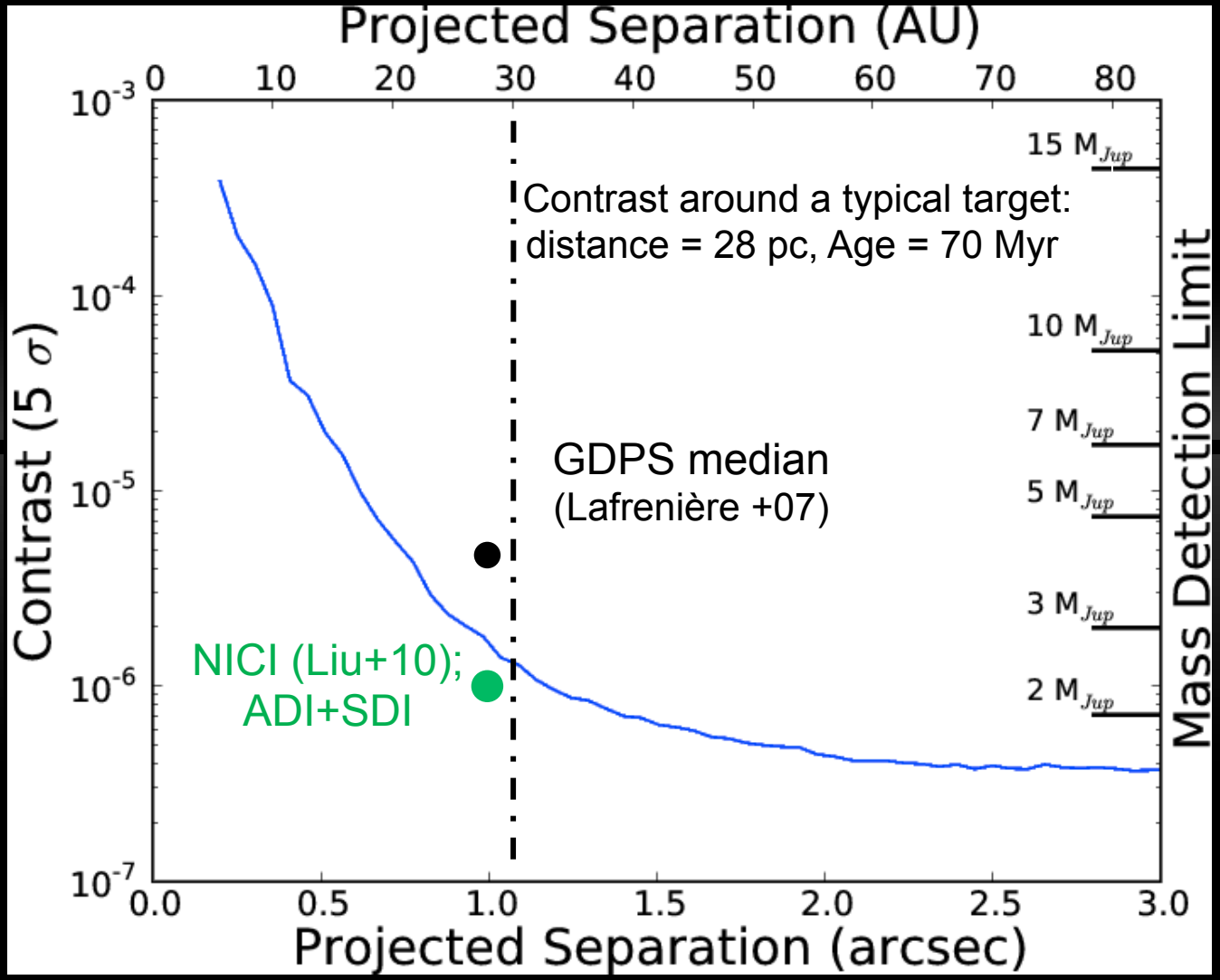



HiCIAO Commissioning
May 2009
Nobuhiko Kusakabe
Christian Thalmann
Tomoyuki Kudo
Ryo Kandori
Ryuji Suzuki
Taro Matsuo
Yutaka Hayano
Hiroshi Terada
Jun Hashimoto
Me
Sebastian Egner
Motohide Tamura
Miwa Goto

SEEDS ADI Point Source Contrast



This curve was created for the Moving Groups sub-category data.

Contrast determination:

1. Calculate standard deviation in the annuli at each radius
2. Calculate the 5σ noise in the aperture with one FWHM diameter
3. Divide by the central stellar flux in the same aperture and self-subtraction correction factor

< 3 Mjup @ 30AU detectable

HiCIAO Commissioning Discovery: GJ 758 B and C?

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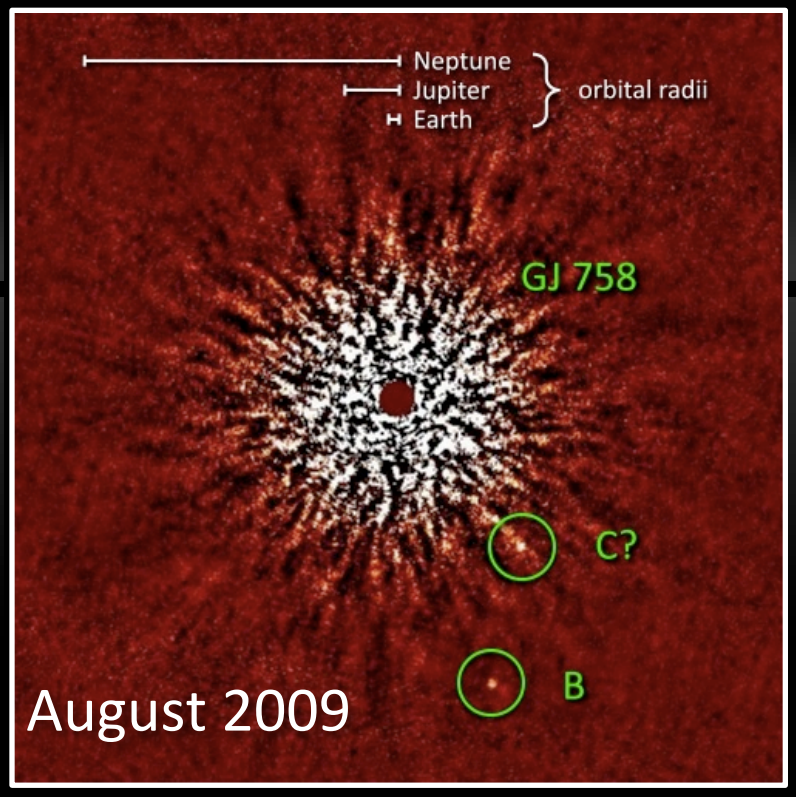
TIME
IN PARTNERSHIP WITH CNN

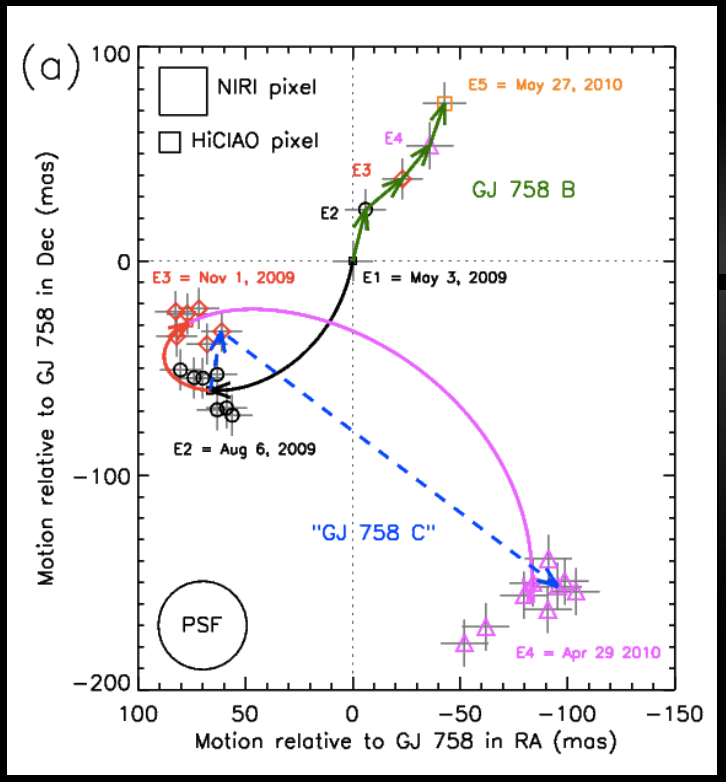
The Top 10 Everything of 2009

TIME charts the highs and lows of the past year in 50 wide-ranging lists

Top 10 Scientific Discoveries

10. A New Planet (or Brown Dwarf?) Discovered



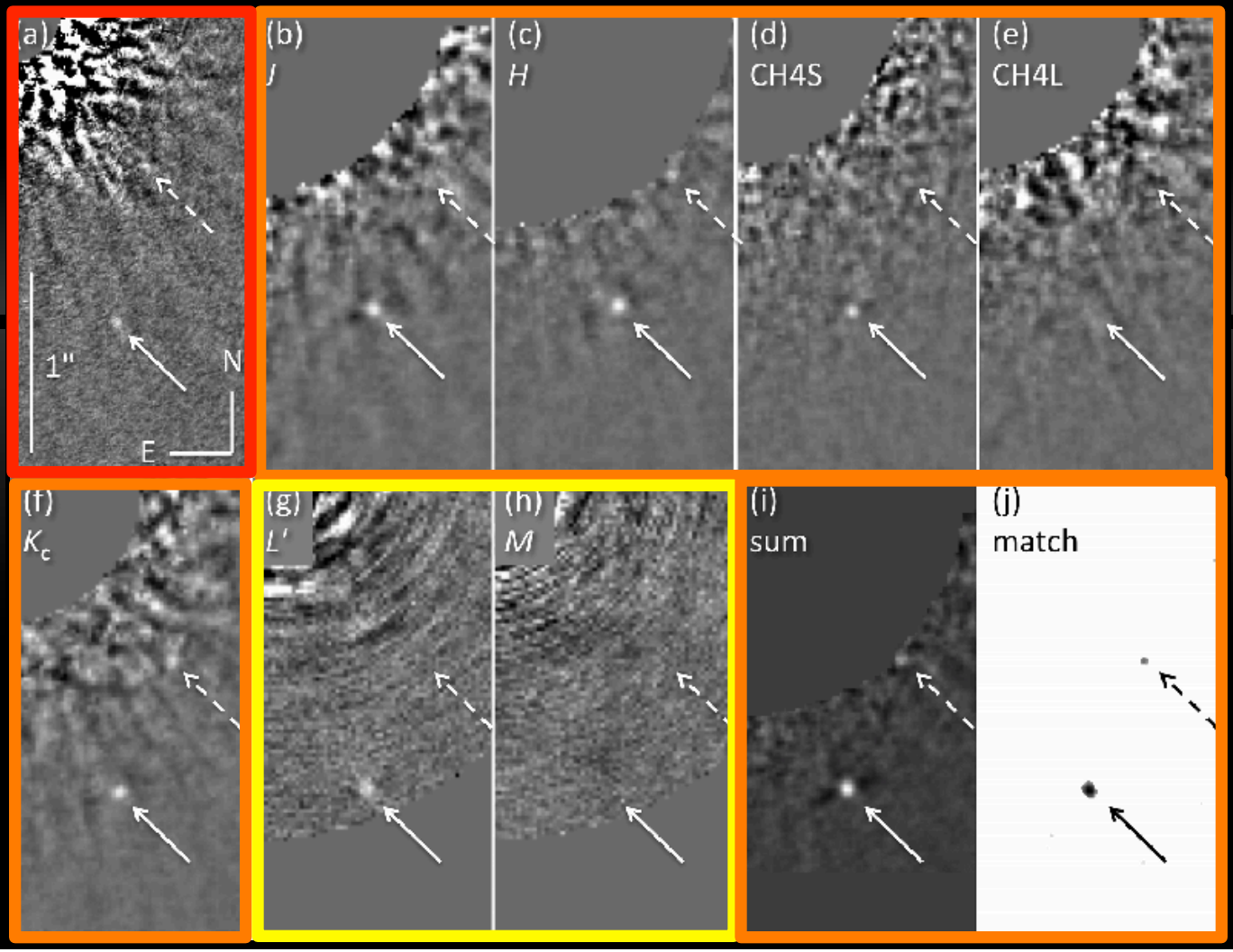


Note: Masked area is not saturation or coronagraph – it is insufficient field rotation for ADI.

S/N Map Scaling [-1σ, 5σ]

See Thalmann, et al. 2009, ApJL, arXiv:0911.1127

GJ 758 B Multiband Photometry



See Janson et al. 2010, ApJL

GJ 758 B Comparison to Theoretical Models

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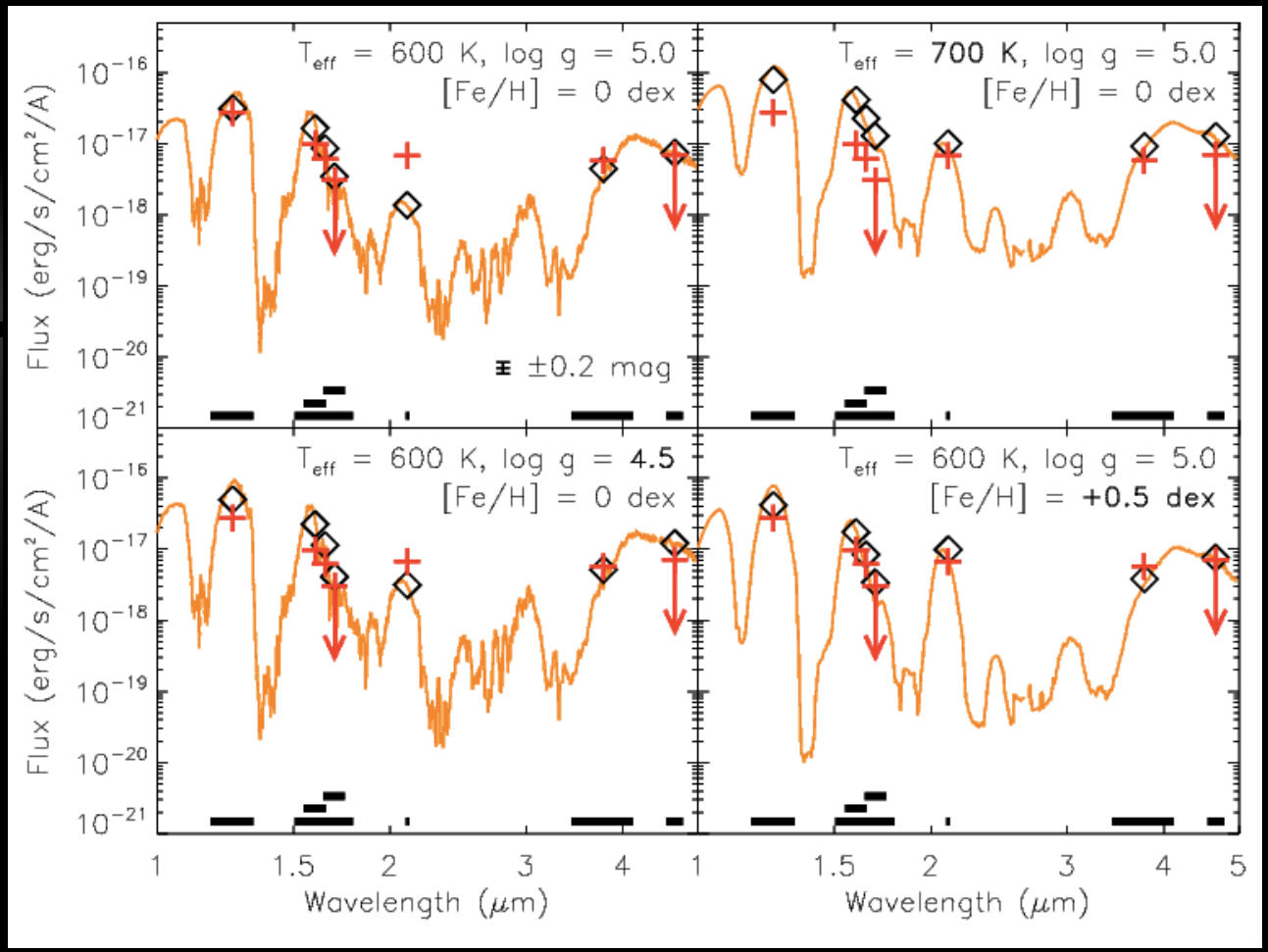
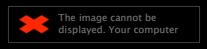


Janson
et al. 2010, ApJL

GJ 758 Target properties

Name:	**GJ 758 B**
Host type:	G9 MS star
Host distance:	15.5 pc
Age:	5 – 9 Gyr
Separation	1.9” (29 AU)
H-band contrast:	$1.52 \cdot 10^{-6}$
Mass:	30 – 40 M_{Jup}
Temperature	~600 K
Radial acceleration	~1 m/s/yr

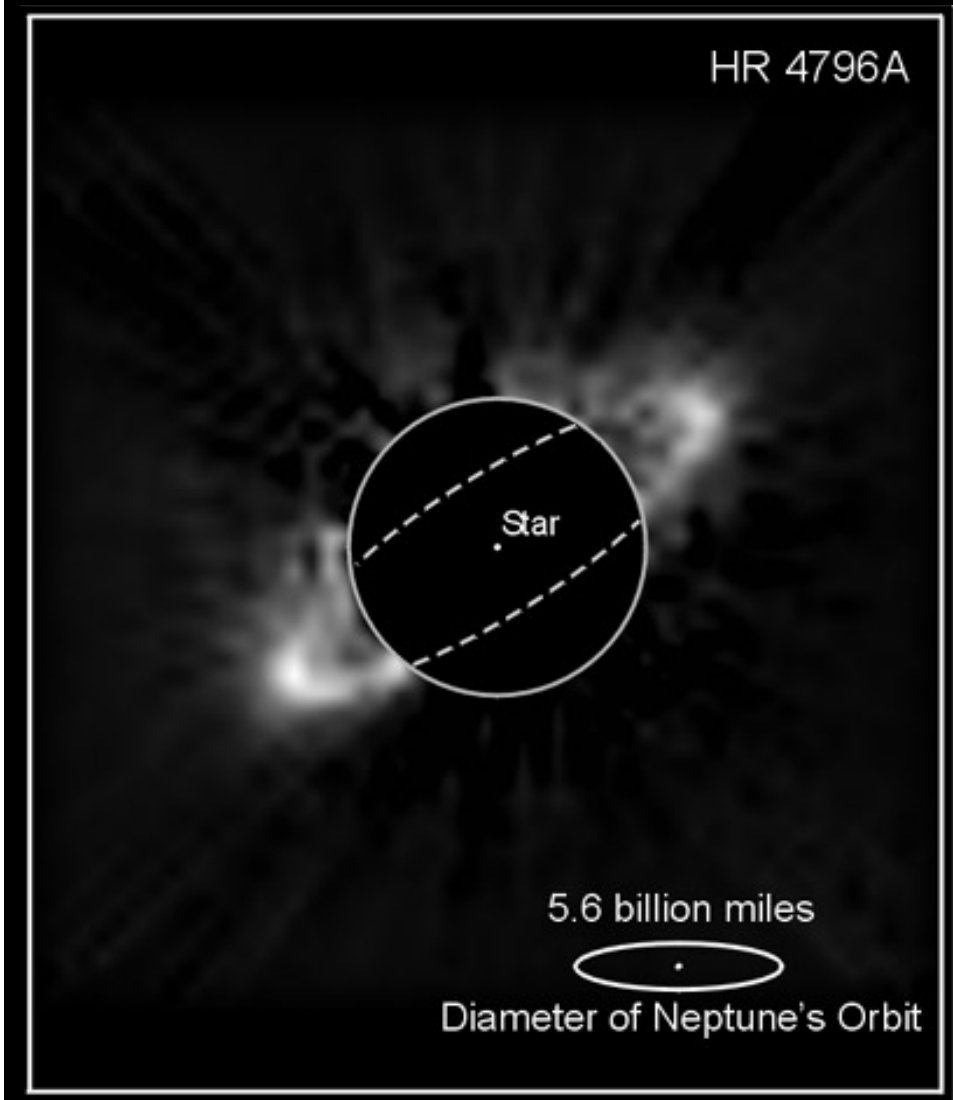
Path to Understanding GJ 758 B

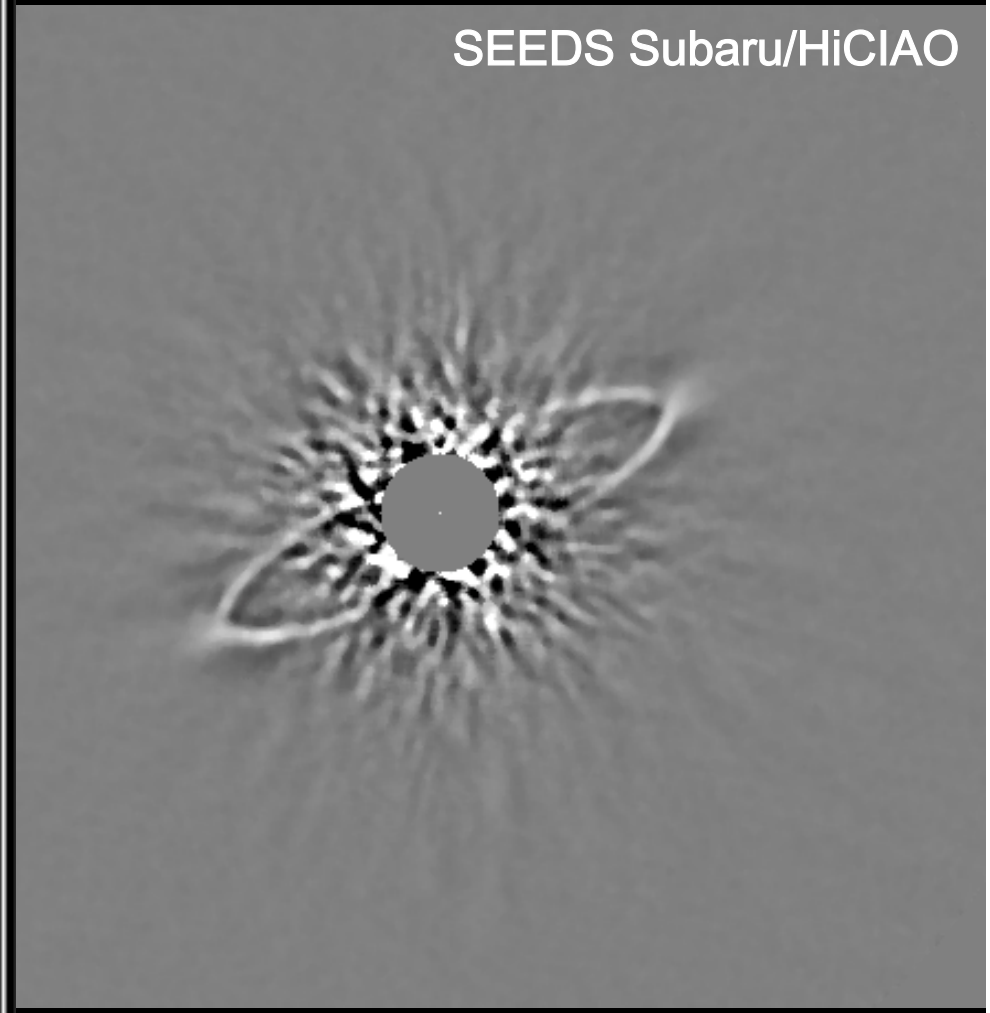


Date	Event
May 2009	Candidate Discovery
Aug. 2009	Common Proper Motion Confirmation
Sep. 2009	Multiband Imaging Proposals Submitted
Aug. 2010	Currie et al. L-band paper posted on astro-ph
Aug. 2010	Multiband Imaging Campaign Completed
Nov. 2010	Janson et al. (this work)

Data taken over 9 nights on 3 telescopes ≥ 8 m.!

HR 4796A Disk

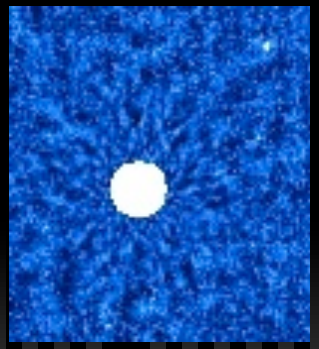


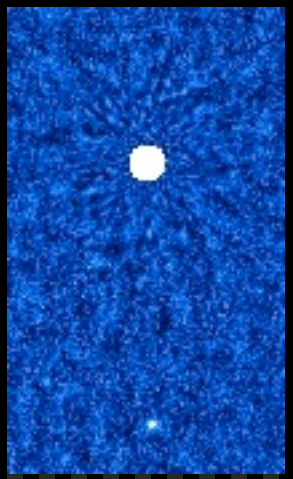


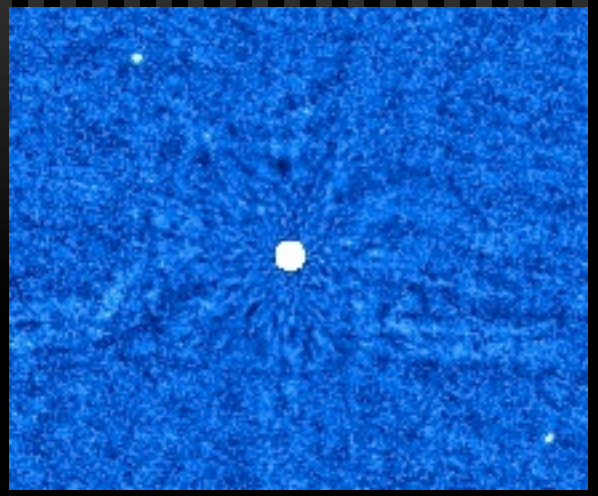
Thalmann et al. 2011 (arXiv:1110.2488)

New SEEDS Candidate Companions

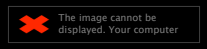
- New planet candidates
  - > 10 possible candidates in nearby stars, moving groups, oper clusters, and YSO categories
  - Archival data comparison and second epoch follow-up (astrometry and multi-band imaging) on-going
  - Possibly 3 additional common proper motion companions
    - Most promising candidate
      - 2.5-7.5 M_{Jup} at 40AU
  - Stay tuned!







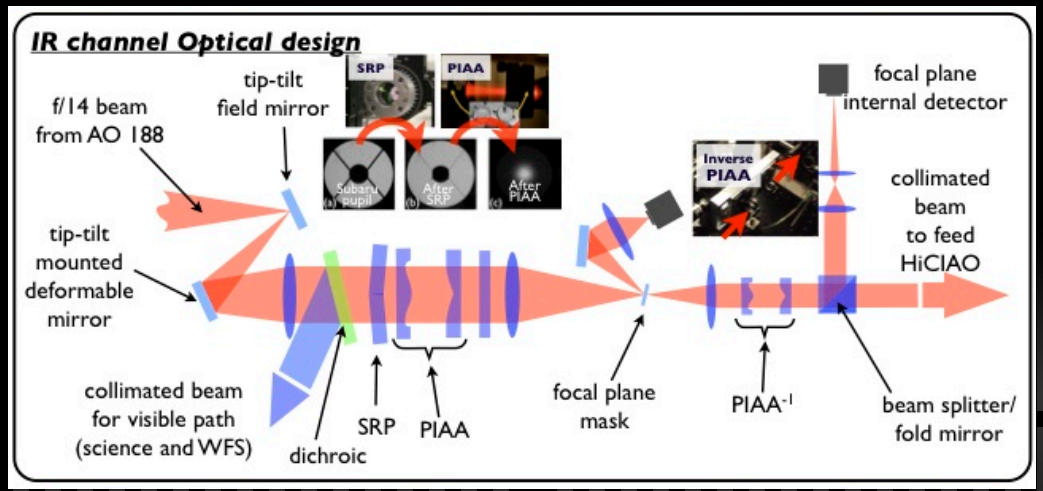
Subaru Telescope Future Upgrades: Commitment to High Contrast Imaging

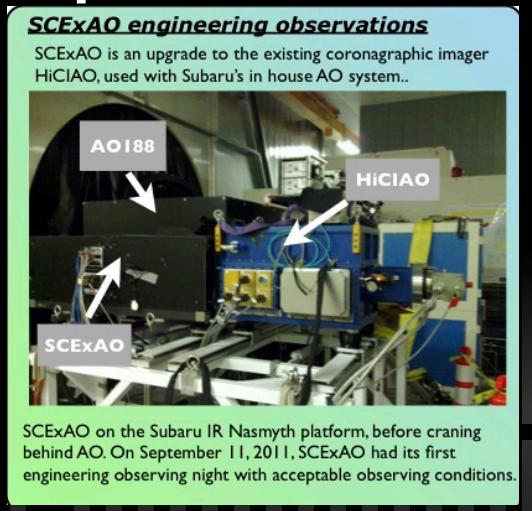


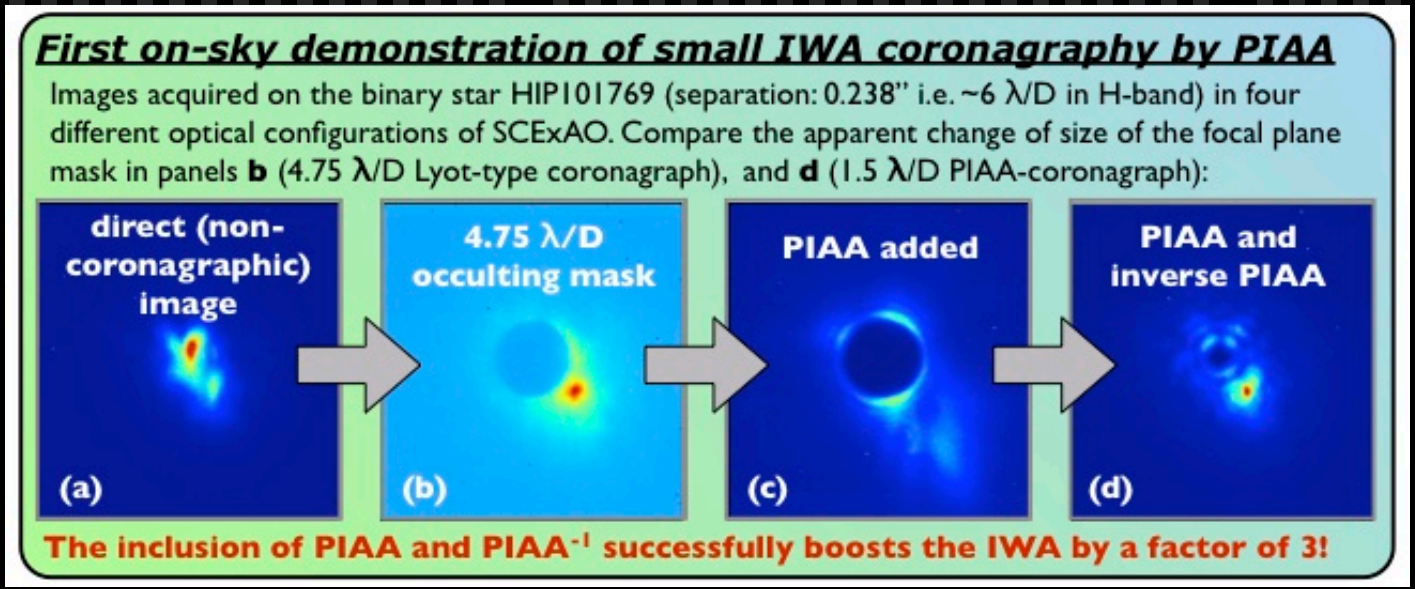
- ✓ Laser Guide Star-AO
- ✓ Pupil grid mask
- ✓ SCExAO Extreme AO system
- ✓ Advanced coronagraphy, including phase-induced amplitude-apodization coronagraph
- ✓ Integral field spectroscopy

Extreme AO at Subaru: SCExAO

- First light Feb. 2011
- Two telescope engineering runs completed







See Martinache & Guyon 2009 SPIE

Subaru ScEXAO/AO188 Assisted IFS

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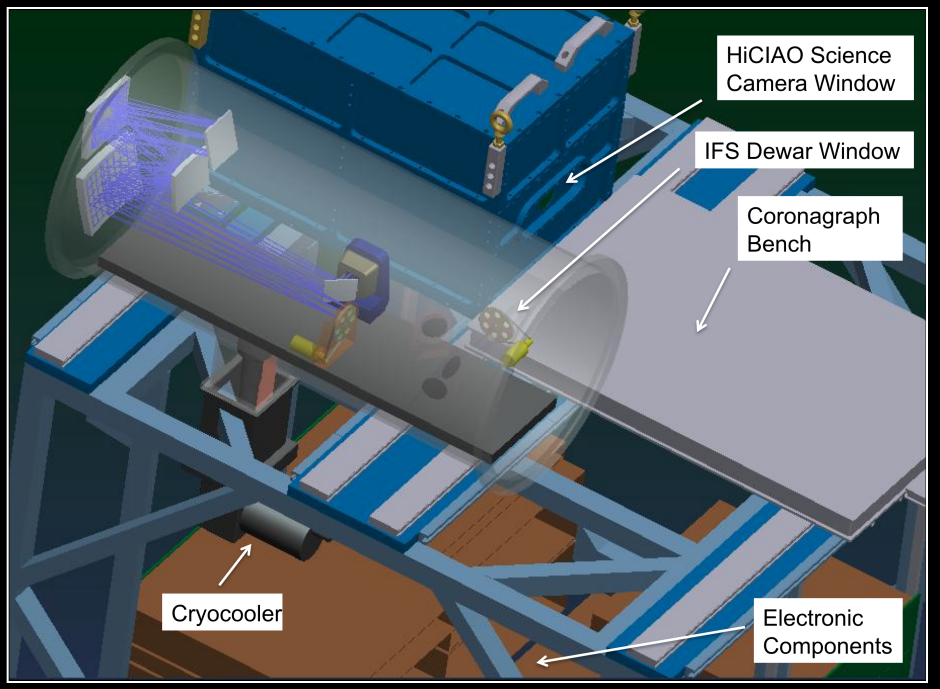
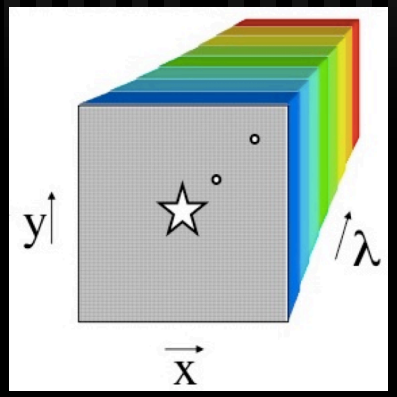
- Recently awarded funding – scheduled first light Spring 2015
- See also Keck/OSIRIS Palomar/ Project 1640, Gemini S/GPI, VLT/SPHERE





McElwain et al. 2008 SPIE

Conclusions

- ✓ High contrast imaging is critical for detecting and characterizing exoplanets on wide orbits
- ✓ SEEDS is the first Subaru Stragetic Observing Program, with 120 nights of observations allocated over 5 years
- ✓ Commissioning results demonstrate that survey sensitivities are as planned.
- ✓ Early results include GJ 758 B, HAT-P-7, AB Aur, LkCa 15, HR 4796A
- ✓ Large international collaborations can be fun and exciting.