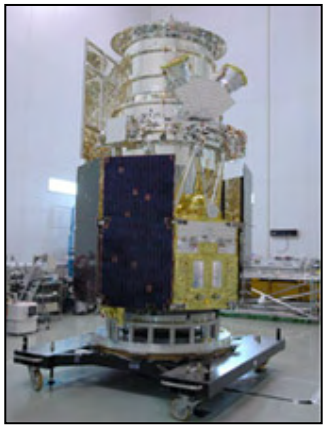
The SPICA Coronagraph

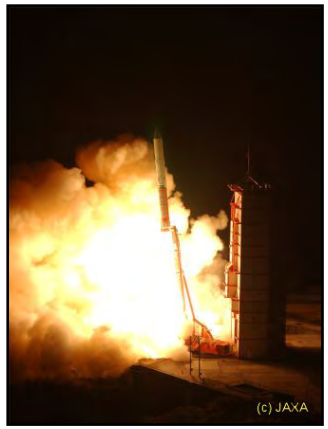
2007, Jun 7th,

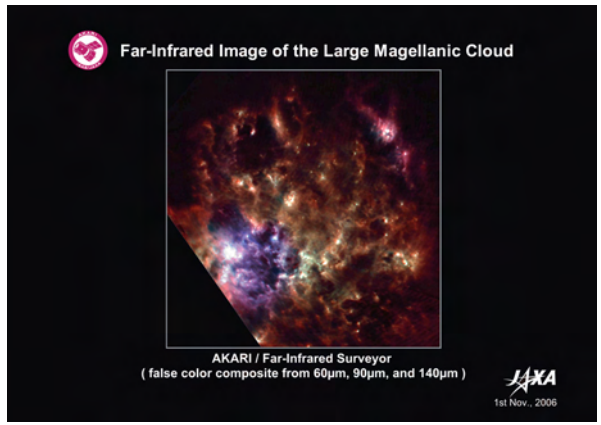
UC BERKELEY

K. Enya[1], L. Abe[2], S. Tanaka[1], T. Nakagawa[1], M. Tamura[2],
H. Kataza[1], O. Guyon[3], SPICA Working Group
(**1: ISAS/JAXA**, 2: NAOJ, 3: NAOJ/SUBARU observatory)

Introduction on JAXA, ISAS, and AKARI



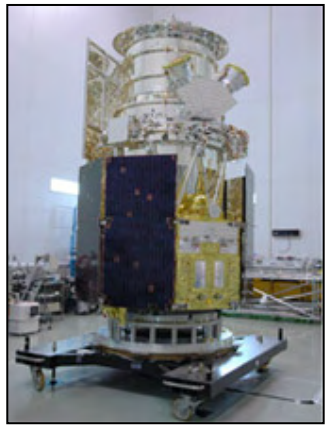


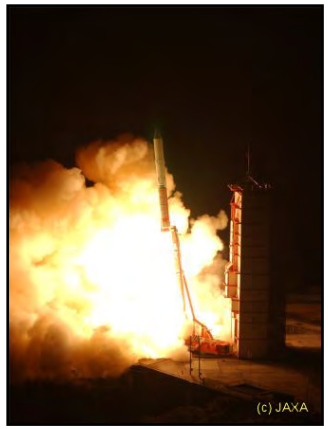


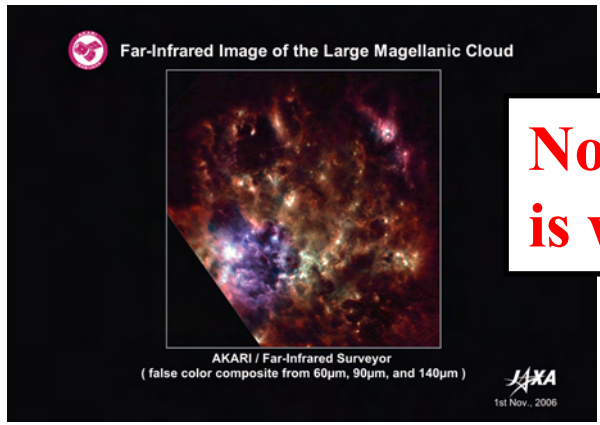
(C) JAXA

- JAXA (Japan Aerospace Exploration Agency)
  - The space agency of Japan.
- ISAS (Institute of Space and Astronautical Science)
  - A division of JAXA for space and astronautical science.
- AKARI
  - IR surveyor mission by ISAS/JAXA.
  - Cooed 68.5 cm telescope for 1.7-180 micron observation(~ SPITZER).
  - Launched in Feb. 2006 by a M-5 rocket of ISAS.
  - All sky survey is successfully undergoing.

Introduction on JAXA, ISAS, and AKARI





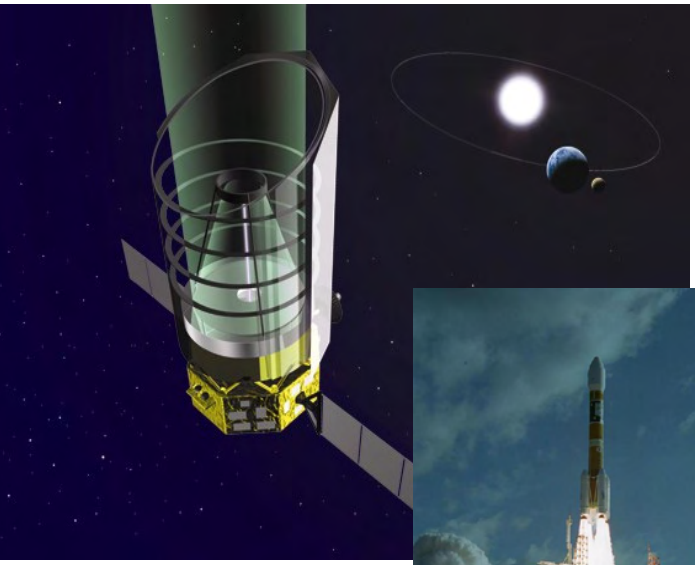


Now AKARI is working in orbit!

(C) JAXA

- JAXA (Japan Aerospace Exploration Agency)
  - The space agency of Japan.
- ISAS (Institute of Space and Astronautical Science)
  - A division of JAXA for space and astronautical science.
- AKARI
  - IR surveyor mission by ISAS/JAXA.
  - Cooed 68.5 cm telescope for 1.7-180 micron observation(~ SPITZER).
  - Launched in Feb. 2006 by a M-5 rocket of ISAS.
  - All sky survey is successfully undergoing.

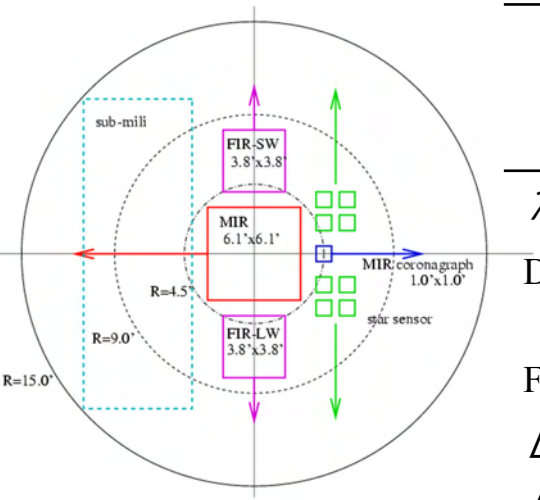
SPICA（Space Infrared telescope for Cosmology and Astrophysics）



- Observatory type IR telescope mission
  (⇔ AKARI is a surveyor)
- Orbit: halo orbit around Sun-Earth L2 point
- Launch: in the Middle of 2010s
- Rocket: H-IIA rocket of JAXA
- Telescope
  - Aperture: 3.5m
  - Core wavelength: 5-200 micron
  - Optics type: on-axis Ritchey-Chretien
  - Temperature: 4.5 K
  - Mirror: monolithic mirror of SiC or C/SiC

SPICA is the next generation IR telescope mission led by JAXA following to AKARI.

SPICA instruments



Focal plane is shared.

	NIR instrument (optional)	MIR instrument	Coronagraph instrument	FIR instrument	Sub-millimeter instrument (optional)
λ (μm)	2 – 5	5 - 40	5 - 28	28 - 200	200 - 600
Detector	InSb	Si:As, Si:Sb	Si:As	Ge:Ga, bolometer	Bolometer
FoV	6.1' × 6.1'	6'.6 × 6'.6	1'.0 × 1'.0	7'.7 × 7'.7	TBD
$\Delta\theta$	0".35	0".35 – 2".8	0".35 – 2".0	2".0 – 14"	14" – 42"
$\Delta\lambda/\lambda$	-	～3000	～200	～2000	～1000
note	Imaging mode only.		Contrast:10^{-6}		

We are going to develop a MIR coronagraph as one of FPI of SPICA

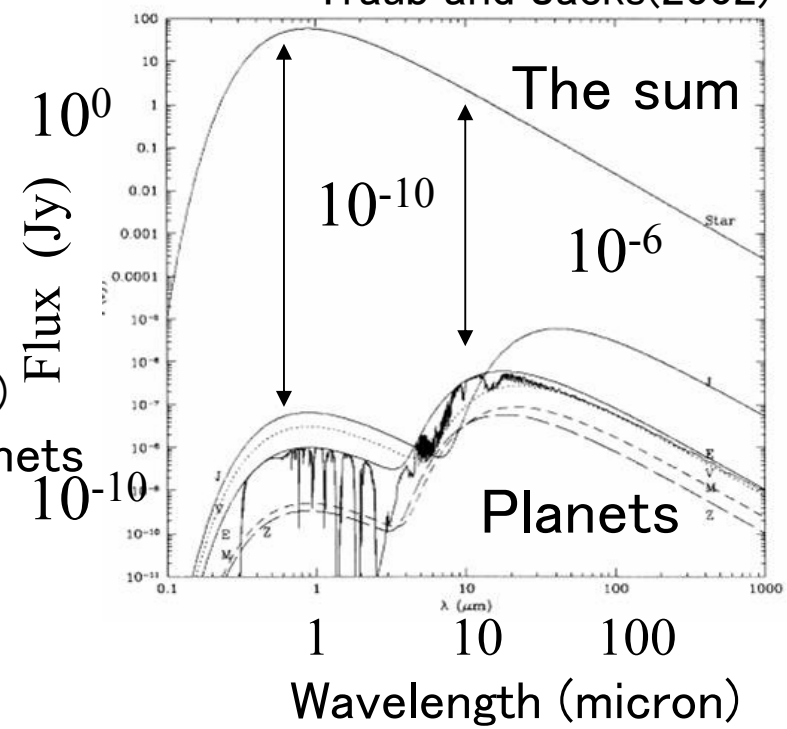
Target of the SPICA coronagraph

- Primary target
  - Contrast in MIR
    - ＊ 10^{-6} : realistic target for near future coronagraph
    - ＊ Self-luminous warm (1-5 Gyr old) plantes (Tamura et al.2000)
  - Diffraction limit:
    - ＊ 10AU@10pc -> 3 λ/D (λ=5μm, D=3.5m)

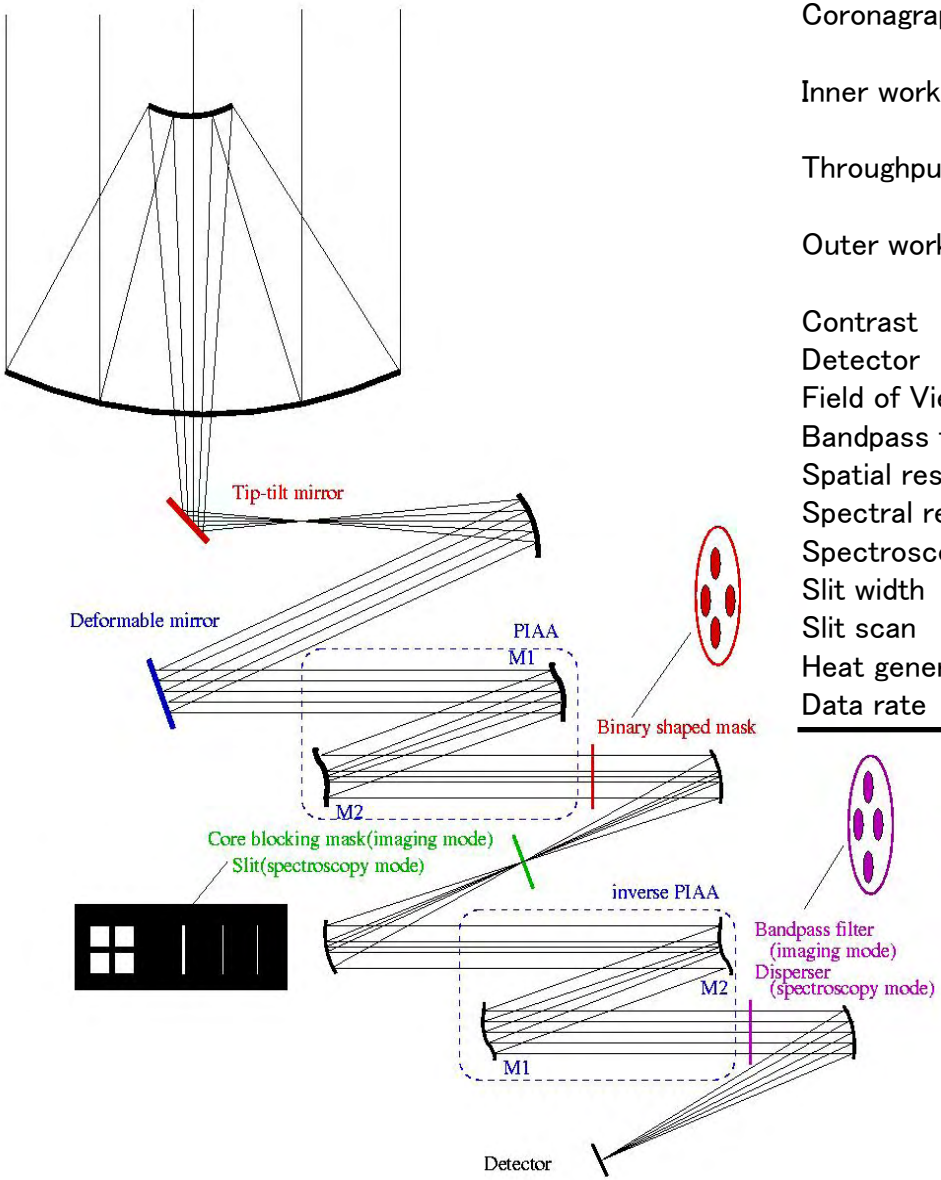
⇒ Jovian planets rather than Terrestrial planets

- Other target
  - Circumstellar environment of red giant (contrast:10^{-4} – 10^{-5}@ λ=20micron)
  - Proto-planetary disk around YSO, Debri disks (contrast:10^{-3}@ λ=5-20micron)

Traub and Jacks(2002)



Primary target:
Systematic detection and spectroscopy survey of self-luminous warm Jovian exo-planets (around 1-5 Gyr old)



Parameter	Specification
Core wavelength (λ)	5—27 micron (3.5-5 micron is optional)
Observation mode	Imaging, Spectroscopy
Coronagraphic mode	binary shaped pupil mask, Hybrid (binary shaped pupil + PIAA)
Inner working angle (IWA)	~ 3.5 × λ / D * (binary shaped pupil mask mode) < 2 × λ / D * (hybrid mode)
Throughput~30%	(binary shaped pupil mask mode) ~80% (hybrid mode)
Outer working angle (OWA)	~ 30 × λ / D (binary shaped pupil mask mode) ~ 10 × λ / D (hybrid mode)
Contrast	Higher (better) than 10-6
Detector	1k × 1k format Si:As array, 0."1/pixel
Field of View	2OWA × 2OWA
Bandpass filter	3.5-4.5, 4.5-5.5, 5.5-8, 8-12, 12-18, 18-27(micron)
Spatial resolution	< IWA
Spectral resolution	~ 200
Spectroscopy method	Slit + bandpass filter + disperser
Slit width	0.2", 0.4", 0.8", 1.6", 3.2"
Slit scan	2D slit scanning on a focal plane is available
Heat generation	< a few mW
Data rate	0.62 Mbps

Spec. of contrast:
hither than 10^{-6}

Coronagraph selection for SPICA

- SPICA coronagraph
  - use in MIR, Obscruration in pupil, Satellite vibration..
  - Contrast is 10-6 but it's still challenging.
  - We have to develop the flight model in our schedule.

The 1st priority: to get a feasible and robust solution

→ Shaped pupil mask coronagraph

(Princeton team pionered. *see presentation of Belikov et al*)

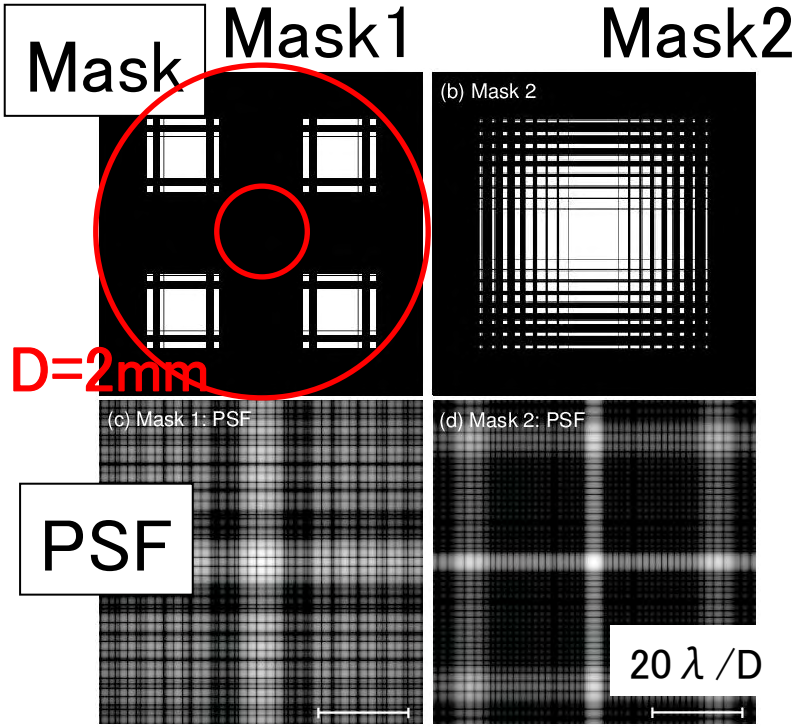
The 2nd priority: to improve performance

→ PIAA/binary mask hybrid

(e.g., Guyon2003. *see presentation of Abe et al., Guyon et al., poster of Tanaka et al, Totem et al.)*

Experiment: Mask design

Experimental demonstration:
Enya, Tanaka, Abe, Nakagawa
2006, A&A, in press



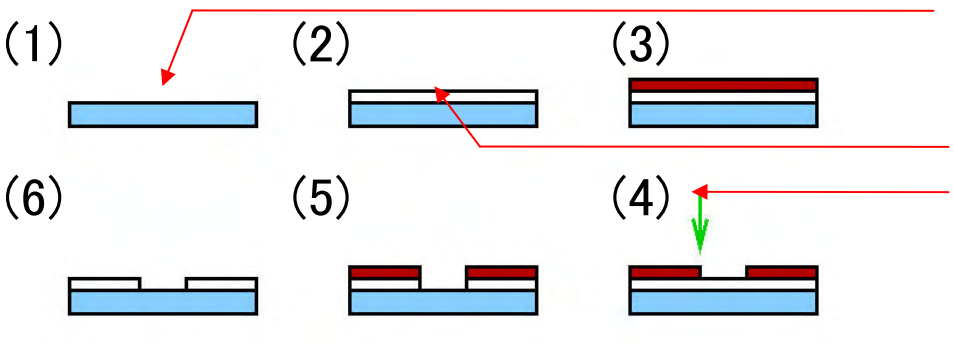
	Mask 1	Mask 2
Type	Symmetric	Symmetric
Central obstruction	30%	No obstruction
IWA*(λ/D)	7	3
OWA*(λ/D)	16	30
Contrast	10^{-7}	10^{-7}
Throughput**(%)	16	24

- Checkerboard mask
  (Vanderbei, Kasdin, Spergel 2004)
- LOQO optimizer (Vanderbei 1999) used
- Study for optimization for obscured pupil
  (Tanaka, Enya, Abe, Nakagawa, Kataza 2006; Enya, Tanaka, Abe, Nakagawa 2006)

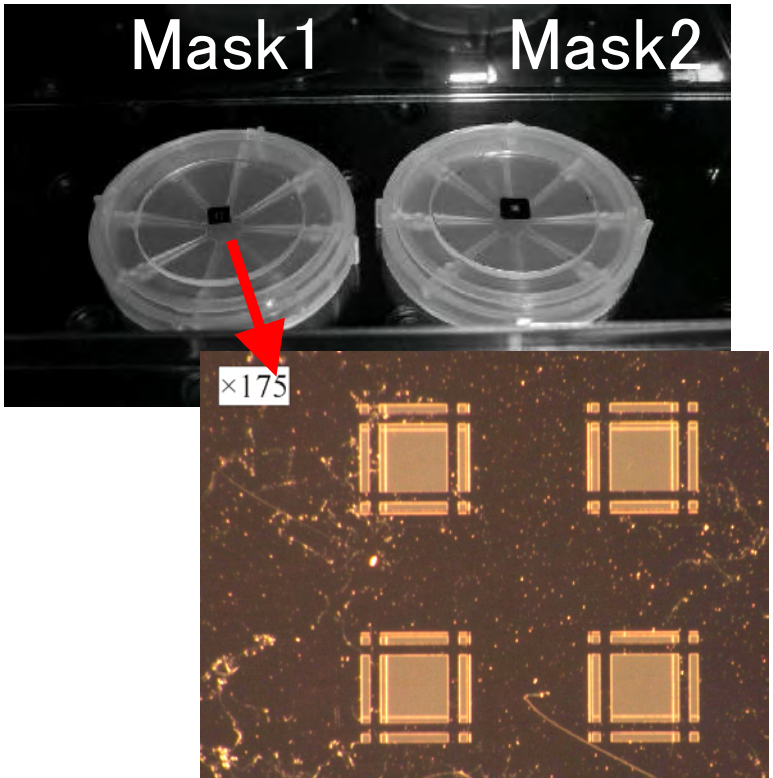
Checkerboard Mask1, Mask 2 were optimized

- Required contrast: 10^{-7}
- Beam diameter: 2mm

Checkerboard mask : fabrication

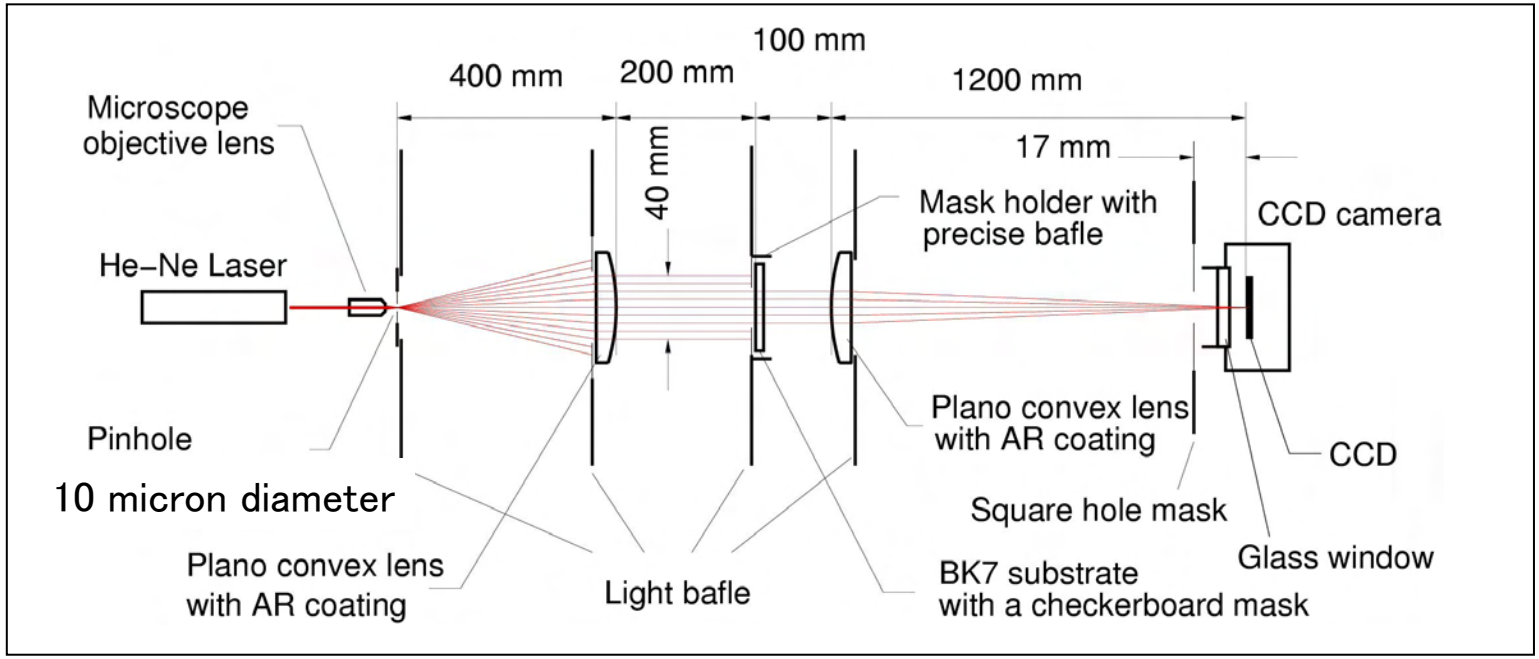


- KB7 substrate: 30mm diameter, 2mm thickness
- Al film: 100nm thickness
- Electron beam patterning in collaboration with AIST (National institute of Advanced Industrial Science and Technology)
- Lift off process
- AR coating for both side



Precise fabrication method was developed with AIST using electron beam patterning

Experiment configuration

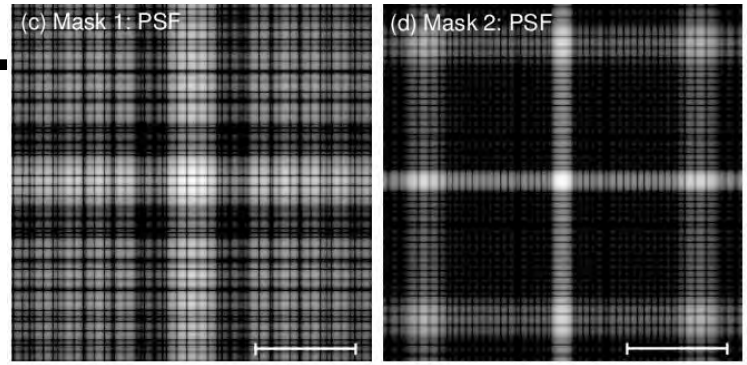


- Clean and dark room, air suspension optical bench
- For high dynamic range measurement:
  - ND filter (OD=2–4)
  - Various exposure time (0.03–10 sec)
- CCD temperature: 0 C°
- Dark frame was subtracted

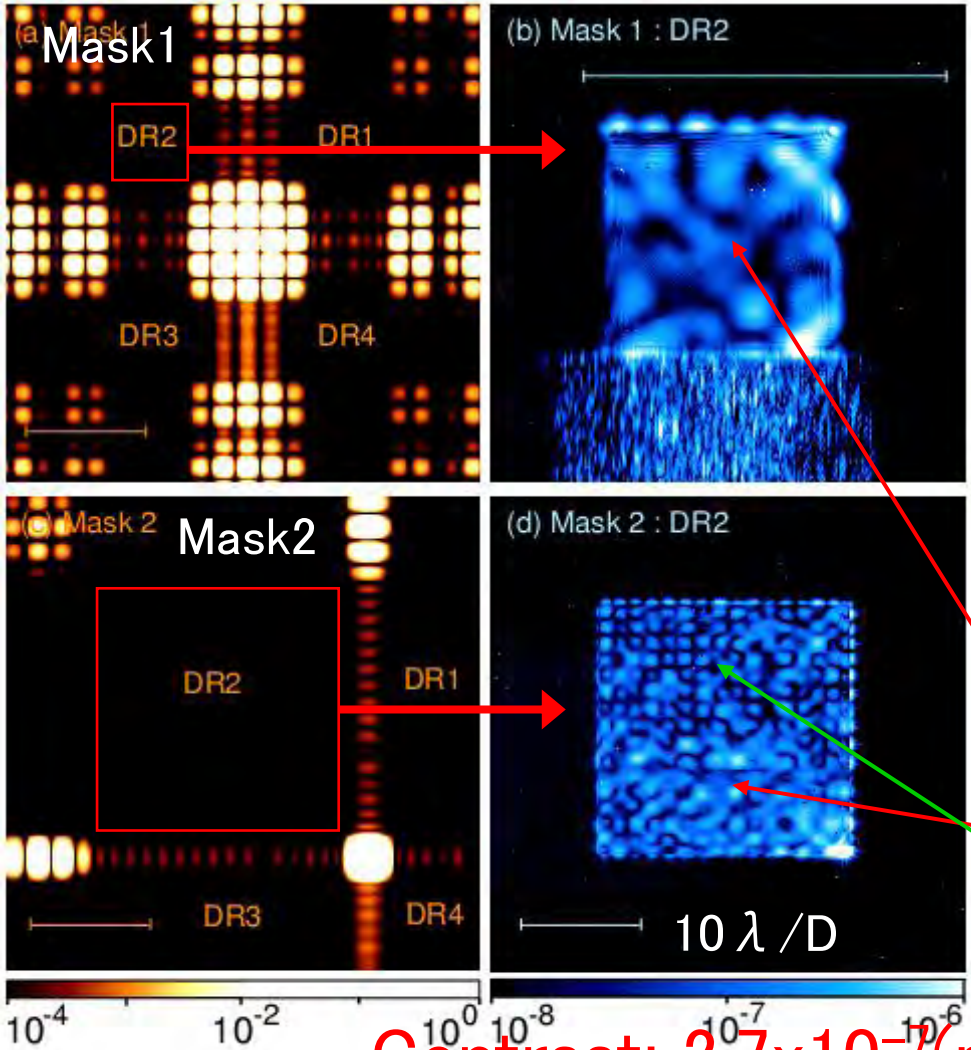
Result: image of PSF

Designed PSF

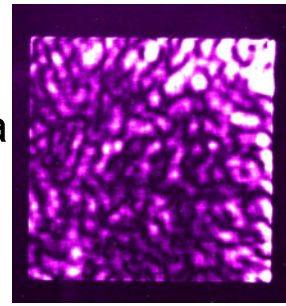
Maks1 Mask2



Core Dark region



- PSF core
  - Quite consistent with design
- Dark region
  - Scatter in the camera is serious problem
  - measured with core blocking mask
  - Speckle limited pattern
  - Limit of design

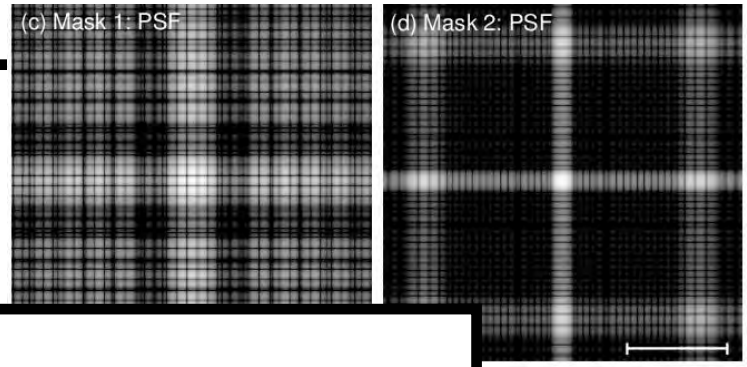


Contrast: 2.7×10^{-7}(mask1), 1.1×10^{-7}(mask2)

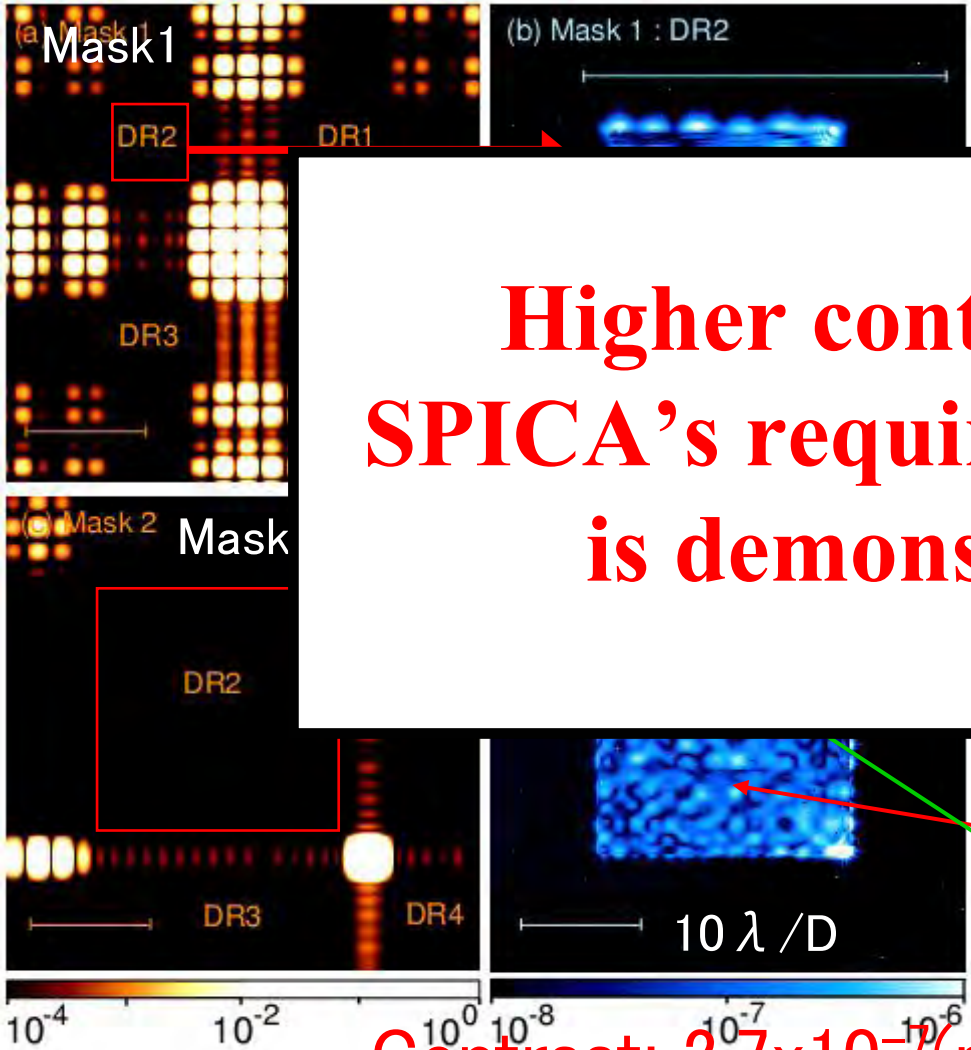
Result: image of PSF

Designed PSF

Maks1 Mask2



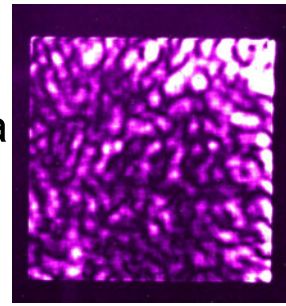
Core Dark region



Higher contrast than SPICA's requirement (10^{-6}) is demonstrated!

th design

a



blocking mask

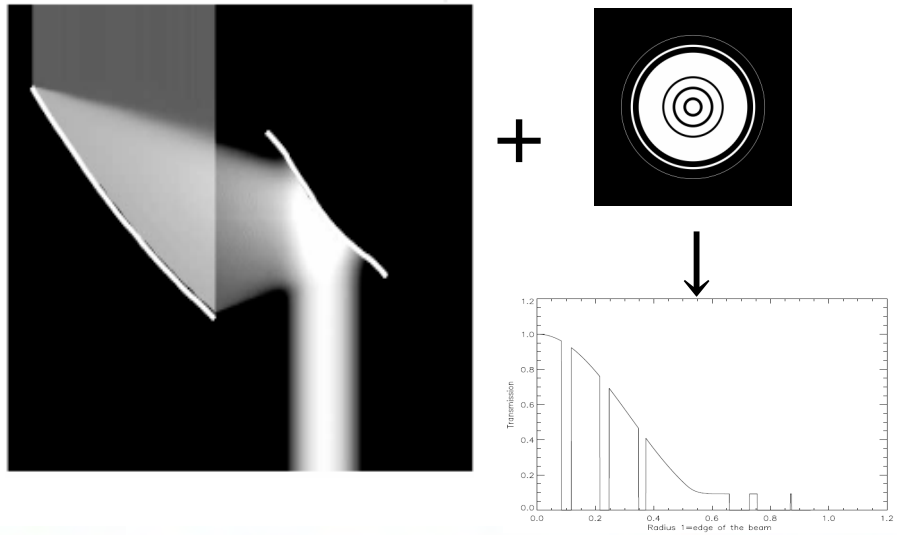
– Speckle limited pattern

– Limit of design

Contrast: 2.7×10^{-7}(mask1), 1.1×10^{-7}(mask2)

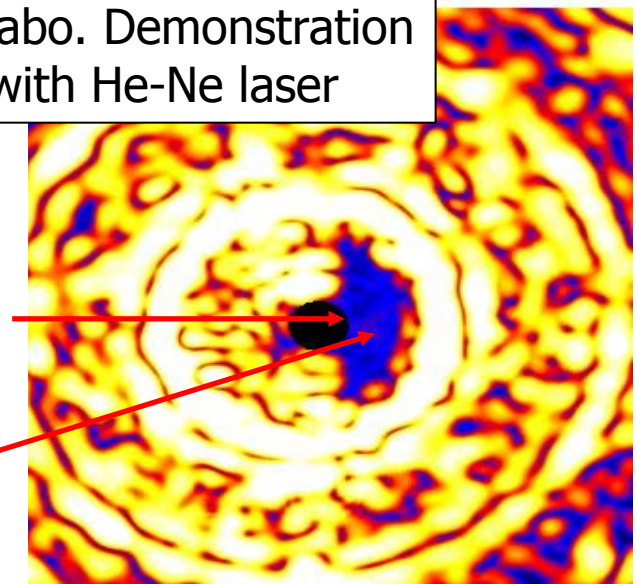
PIAA/Binary mask hybrid Coronagraph (*see poster of Tanaka et al., Totem te al.,*)

- PIAA (Guyion 2003)
  - small IWA
  - high throughput
  - reflective optics
  - manufacture of mirror is very challenging



- PIAA/Binary mask hybrid solution
  - relax difficulty of mirror manufactureing

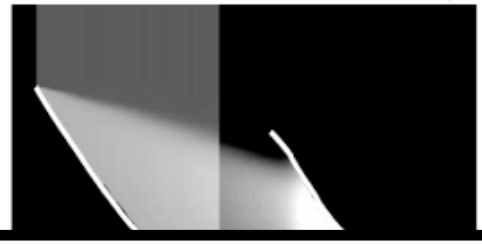
Labo. Demonstration with He-Ne laser



IWA～1.5 λ /D

Contrast 6.5x10^{-7}

PIAA/Binary mask hybrid Coronagraph (*see poster of Tanaka et al.*)

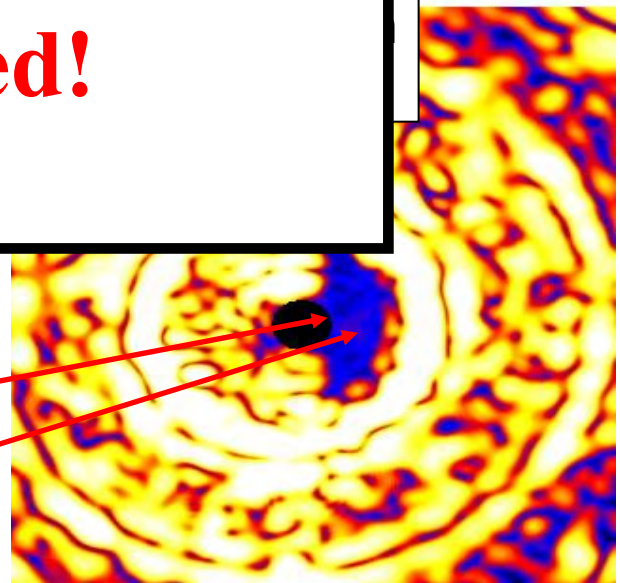


+

- PIAA (Guyion 2003)
  - small IWA
  - high thr
  - reflectiv
  - manufac
    very cha

- PIAA/Bin
  - relax di
    manufactureing

Higher contrast than SPICA's requirement (10^{-6}) is demonstrated!



IWA～1.5 λ /D

Contrast 6.5×10^{-7}

Summary

- SPICA is the next generation IR telescope mission led by JAXA following to AKARI.
- We are developing the MIR-coronagraph for SPICA.
- The primary target of the SPICA coronagraph is self-luminous Jovian exo-planets.
- We demonstrated SPICA's requirement contrast(10^{-6}) was satisfied with visible light.
  - Shaped pupil mask coronagraph (1.1×10^{-7}) … as the feasible, robust solution
  - PIAA/Binary hybrid (6.5×10^{-7}) … as the high performance mode
- Next step:
  - demonstration with visible light → MIR coronagraph demonstration
  - higher contrast???