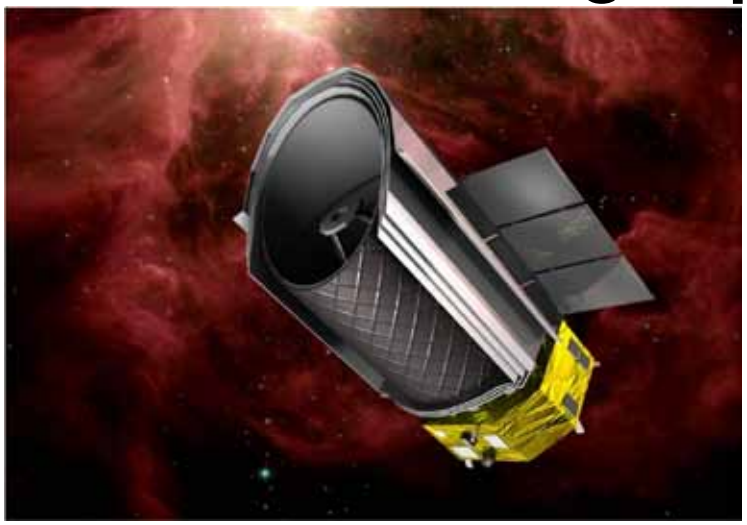
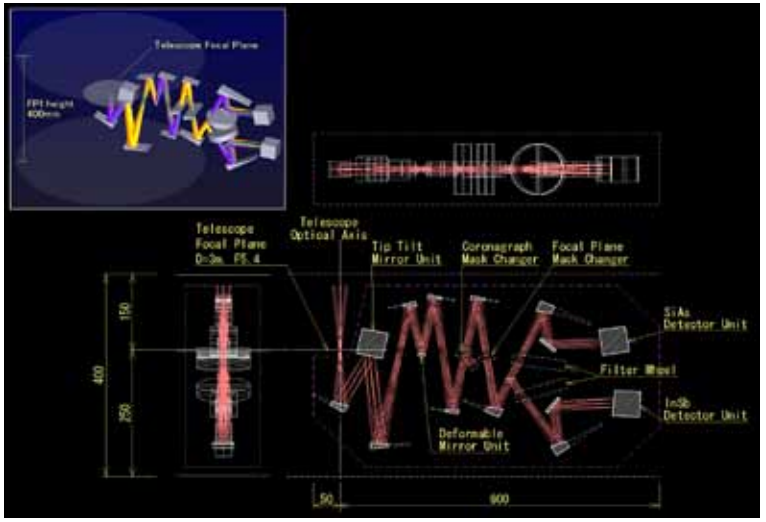
Exploring Strange New Worlds:
From Giant Planets to Super Earth
May 1-6, 2011 Flagstaff, Arizona

Introduction to Coronagraphs:
Coronagraph for SPICA





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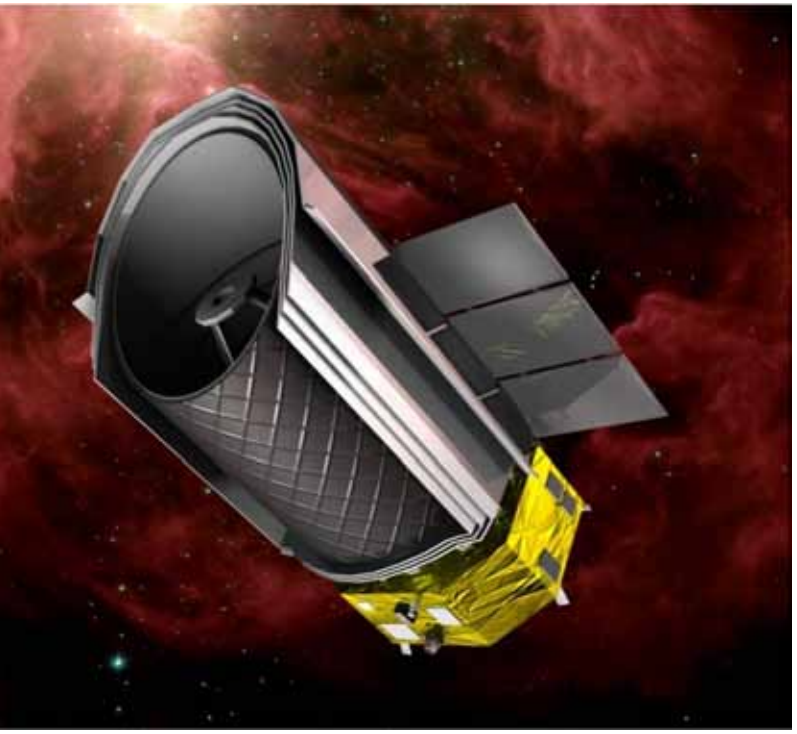
Outline

- Brief introduction
  - SPICA mission
  - SPICA Coronagraph Instrument (SCI)
- SPICA coronagrpah
  - Binary shaped pupil mask coronagraph
- A recent topic of development
  - Vibration and acoustic tests of a MEMS deformable mirror

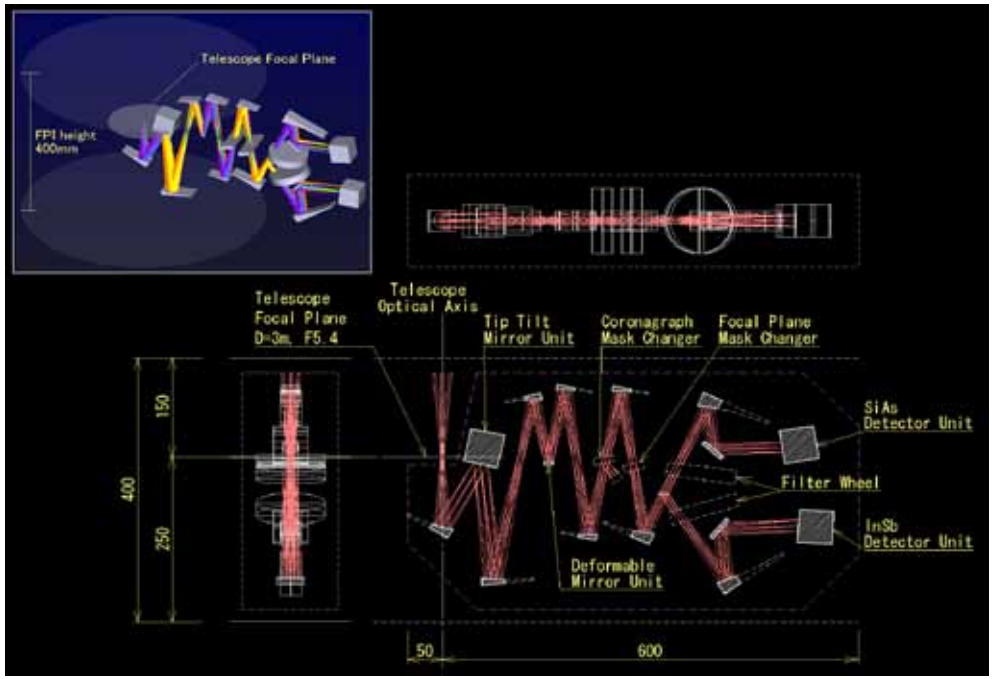
SPICA (Space Infrared telescope for Cosmology and Astrophysics)



Observatory type	Multi purpose observatory (not surveyer , not single purpose mission)
Telescope aperture	3.2m (3m EPD)
Main wavelength	5-210 micron
Telescope temperature	6K
Cooling	Mechanical cyro-cooler + radiation cooling
Orbit	Sun-Earth L2 Halo

- **International mission including JAXA-ESA collaboration**
- **Pre-project phase is ongoing in JAXA**

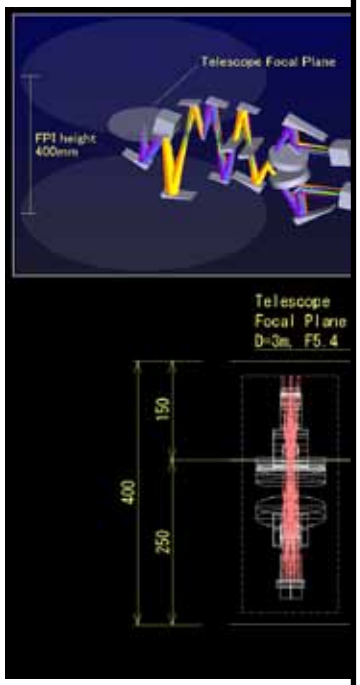
SPICA Coronagraph Instrument(SCI)



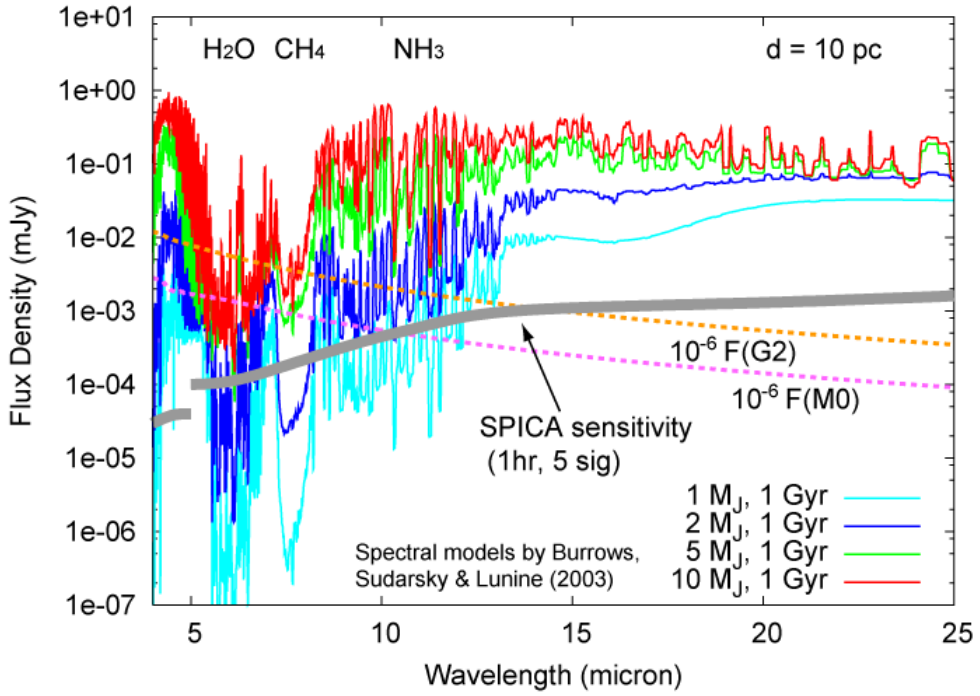
Core wavelength	3.5-27 micron
Obs. mode	Imaging , spectroscopy (w/wo a coronagraph mask)
Contrast	10^{-4} (w/o DM) 10^{-6} (with DM)
IWA	1.7-3.3 lambda/D
R	20-100
Detector	InSb (short channel) Si:As (long channel)

- SCI is proposed as one of focal plane instruments
  - Coronagraphic spectroscopy in IR (3.5-27micron)
  - High contrast design with an internal DM

SPI



What we want to get!

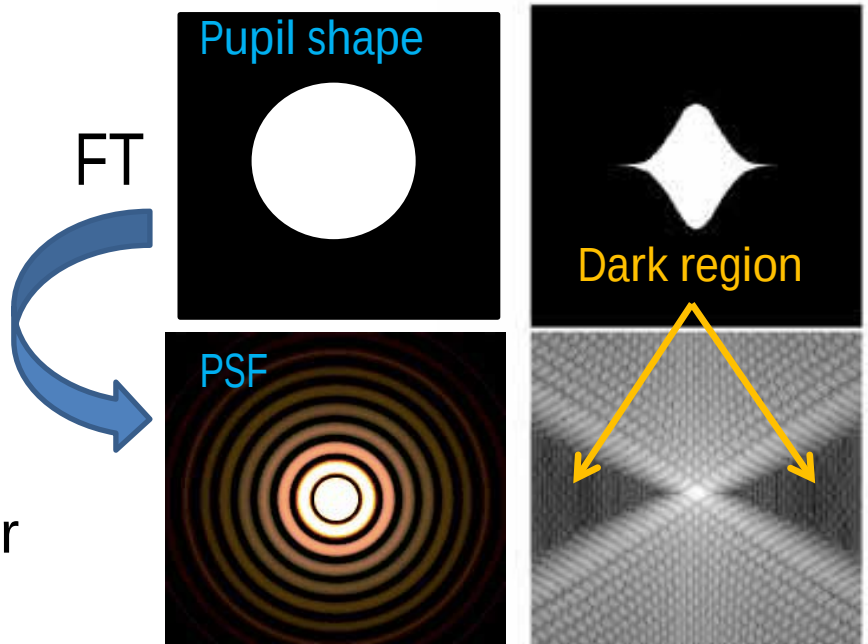


The primary target of SCI is coronagraphic observation of Jovian exoplanets

- SCI is proposed as one of focal plane instruments
  - Coronagraphic spectroscopy in IR (3.5-27micron)
  - High contrast design with an internal DM

Coronagraph selection for SPICA

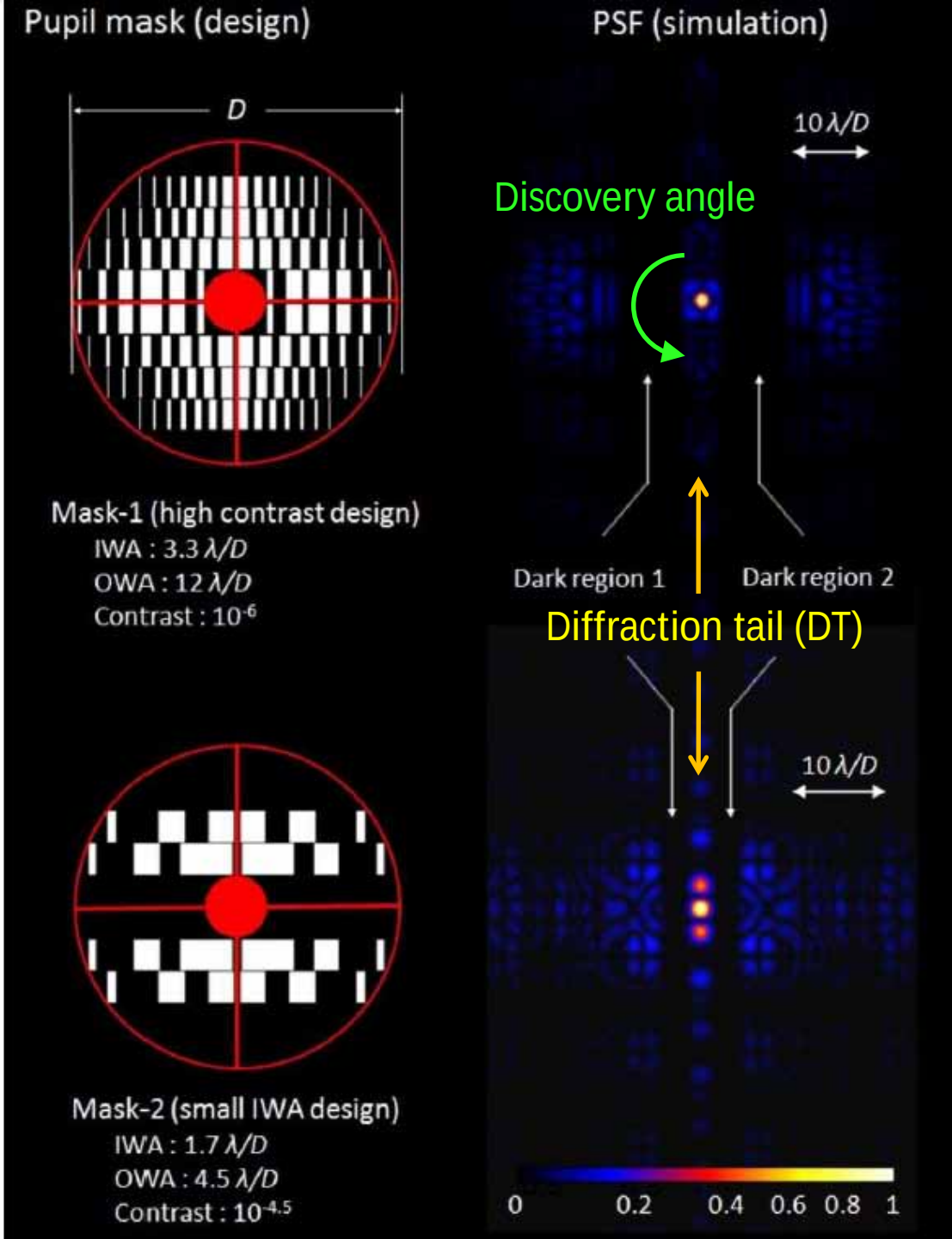
- Background issue
  - Scientific requirement for spectroscopy
    - Broad wavelength coverage is needed
  - SPICA is not optimized for coronagraph only
    - Pointing error by cryo-cooler's vibration (0."05)
    - Pupil obscuration
- Our selection
  - binary shaped pupil mask coronagraph
    - A mask works w/o wavelength dependence
    - Very robust against pointing error



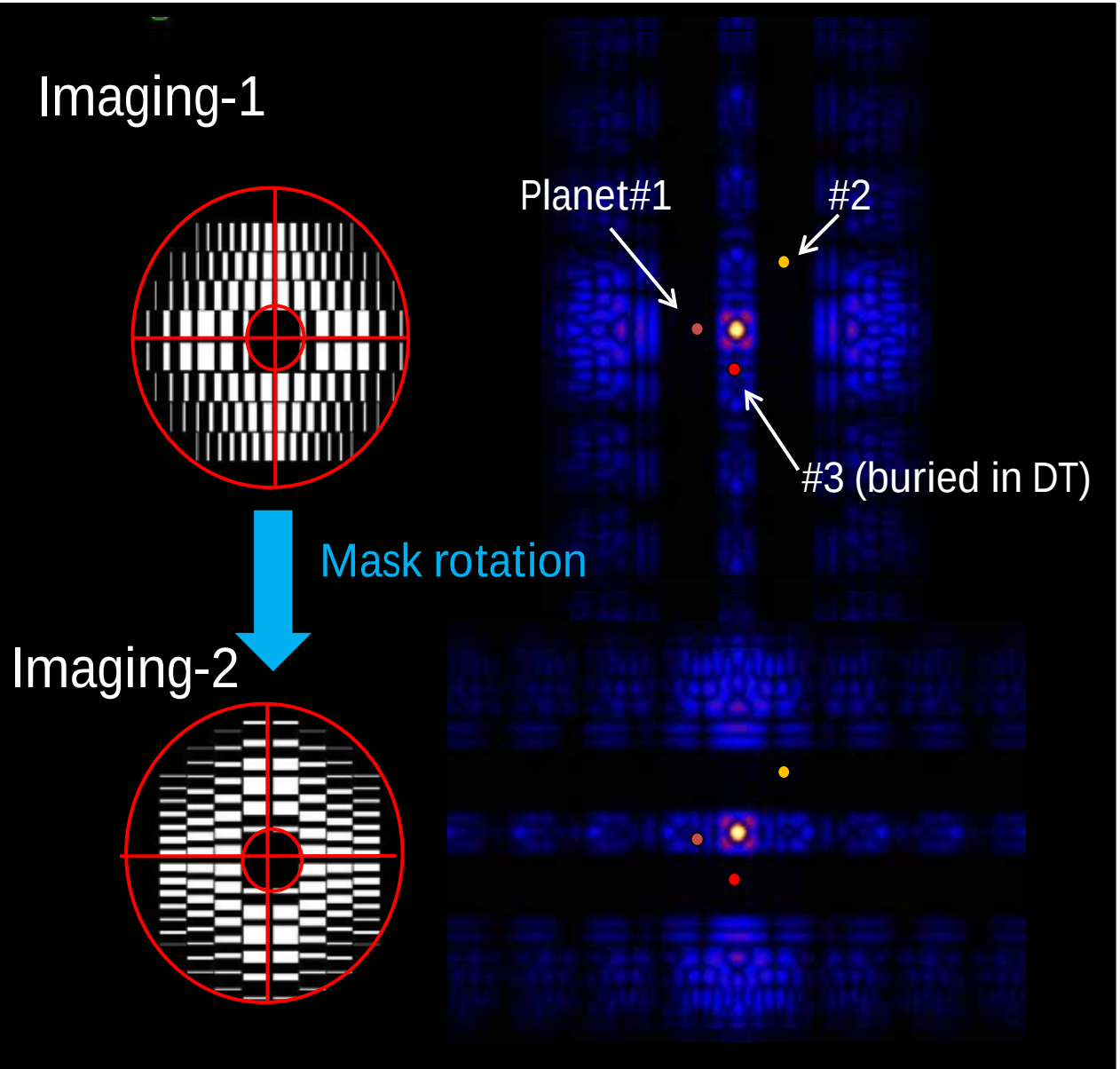
Mask design for obscured pupil

- Pupil obscuration is “skipped over”
- 1D multi-barcode mask provides large discovery angle (only 2 DT)
- Contrast and IWA is in trade-off
- Mechanical mask changer is used for complementaly masks

Enya & Abe 2010, PASJ
(Barcode mask: Kasdin et al 2005
LOQO software: Vanderbei 1999)



Mask rotation



Diffraction tail in image plane is rotated, but position of planets is not moved

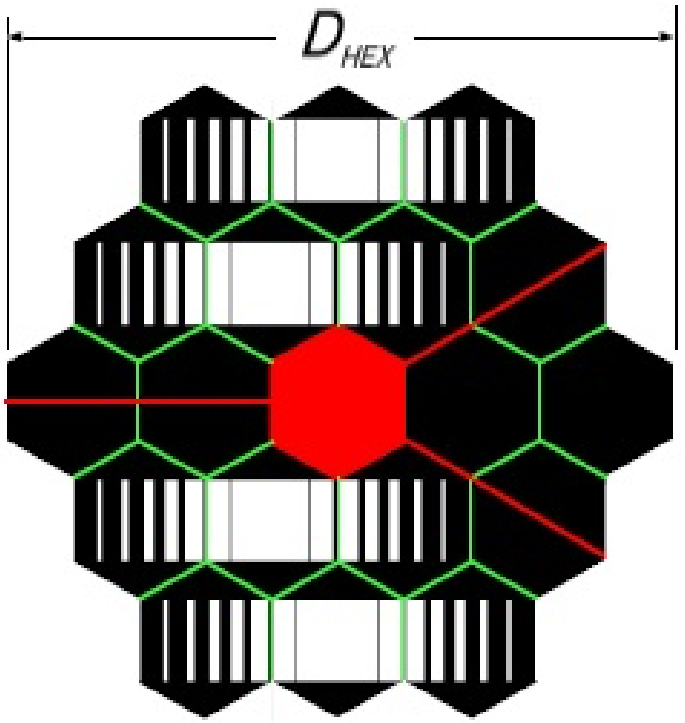
Effective DA inproved up to 360deg.

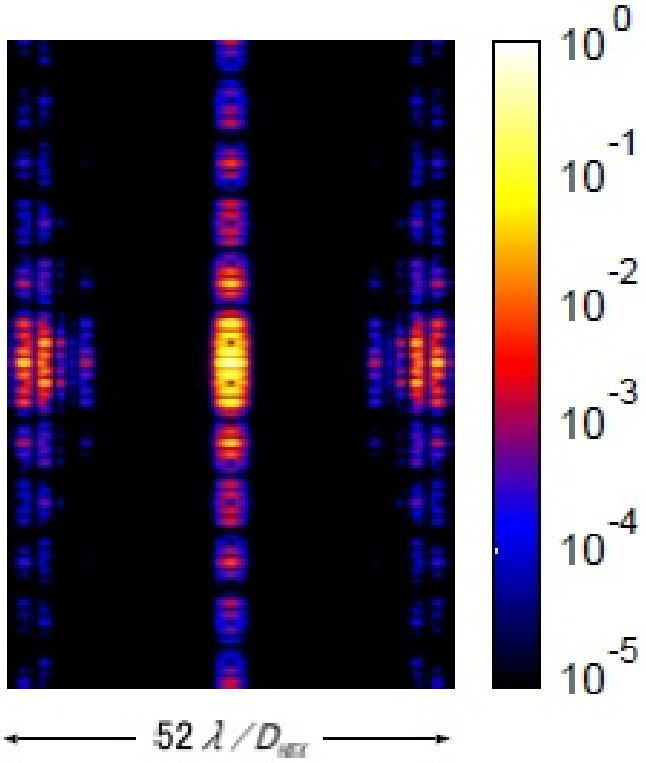
Use or not use in SCI Is TBD because of limitation of a mask slot in the mask changer.

Enya & Abe 2010, PASJ

“Skipping over” mask is applicable for various pupil type

For examle,

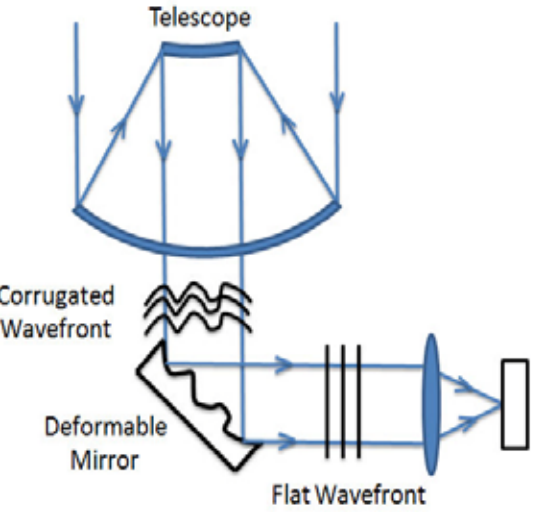


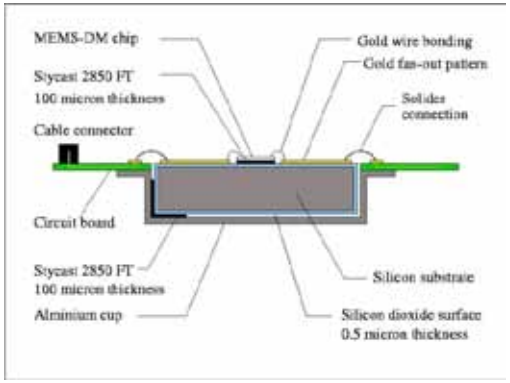


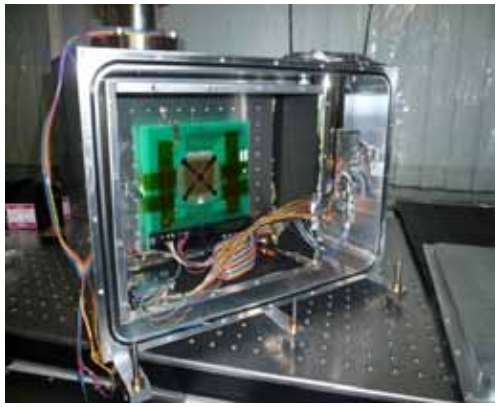
- Contrast: 10-5
- IWA: 3.5 lambda/D
- Num. of diffraction tail: 2

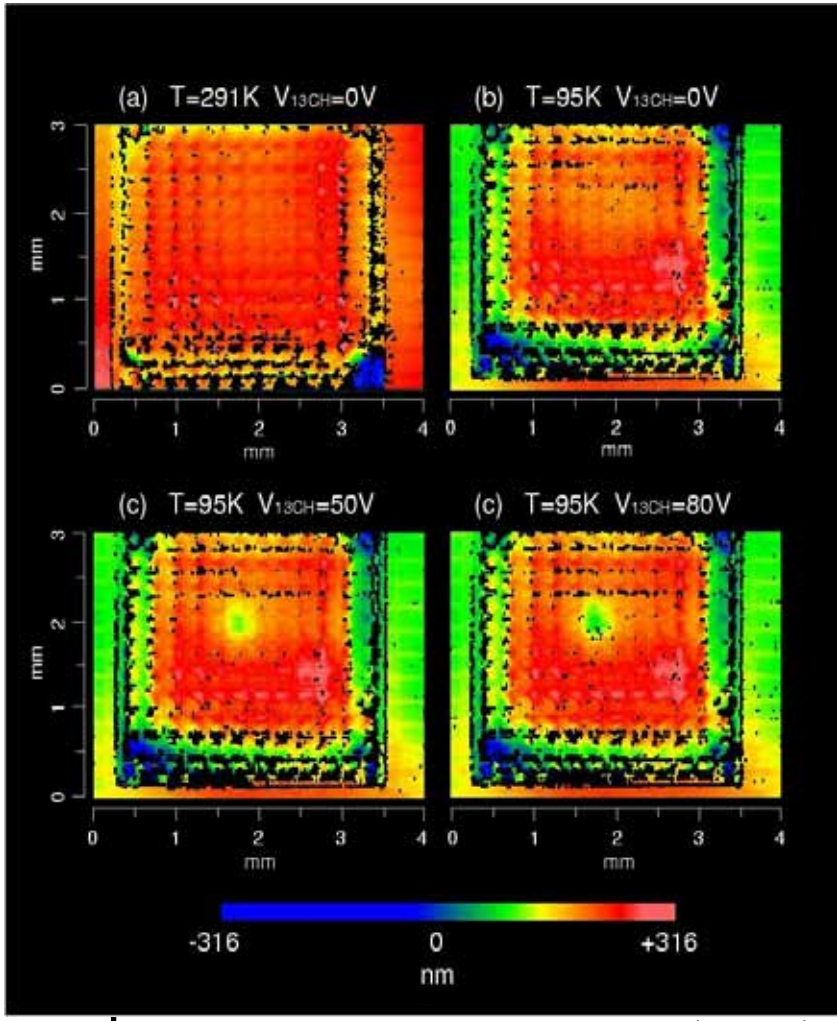
Enya & Abe 2010, PASJ

Cryogenic MEMS-DM





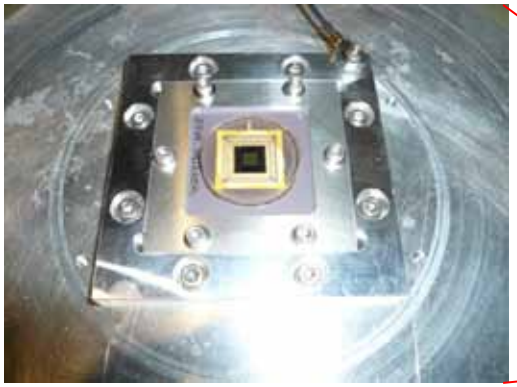




- Wave front error of SPICA telescope (350nm rms) is not enough for coronagraph
- So we are developing cryogenic DM

Enya, Kataza, Bierden. (2008)

Vibration test

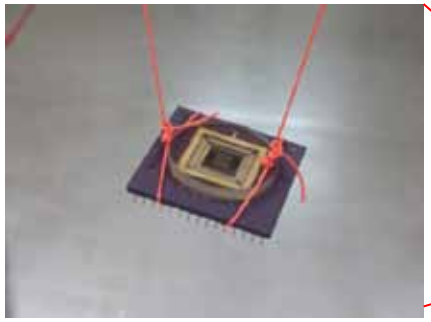


0dB

Frequency (Hz)	PSD (G^2/Hz)
20	4.3
80	67.3
270	67.3
413	28.9
800	28.9
2000	2.5
Over all	21.1 Grms

- DM: BMC Mini DM with window (same one used for the acoustic test)
- Temperature: ambient
- Pressure: 1atm
- Date: Feb. 14th, 2011
- Place: ISAS/JAXA
- Test sequence: Zygo check -> vibration -> Zygo check -> heavier vibration … -> Zygo check (all were done in ISAS/JAXA)
- Vibration level: -12dB, -6dB, -3Db, 0dB, +3dB (please see the table above to know 0dB)
- Direction of the vibration: only the vertical direction for the DM surface.
- Time of each vibration load: 60 second
- Conclusion: the DM survived! (no significant change is fund by the ZYGO check)

Acoustic test



1/1oct center frequency	Acoustic pressure (dB)	torelance
31.5	128.0	+5/-10 dB
63	135.0	+- 3dB
125	139.6	+- 3dB
250	138.0	+- 3dB
500	135.0	+- 3dB
1000	132.0	+- 3dB
2000	129.0	+- 3dB
4000	124.0	+3- 10dB
8000	118.0	+- 6dB
Over all	144.0	+- 2dB

* 0dB=$2x10^{-5}$[Pa]

- DM: BMC Mini DM with window (commercially available one. No special tuning)
- Temperature: ambient
- Pressure: 1atm
- Date: Feb. 3th, 2011
- Place: Tsukuba Space Center(TSC)/JAXA
- Host project of the test: SPRINT-A (JAXA's small science satellite. Acoustic test of its solar panel)
- Acoustic level: please see the table above
- Time of acoustic load: 60(+2-0) second
- Test sequence: Zygo check in ISAS/JAXA -> acoustic load in TSC -> Zygo check in ISAS/JAXA
- Conclusion: the DM survived! (no significant change is fund by the ZYGO check)

Zygo check: for each test the both the actuator yield and surface figure was measured and in both cases there was no change before and after the acoustic/vibration tests. Quantitative measurement of the influence function is not done.

What is done/what is not yet done?

- What is done?
  - Sequential load tests (first acoustic, then vibration in one direction, considering the load at the instrument stage of the rocket)
  - It is confirmed toughness of a MEMS DM for launch is not out of the question.
  - This is our first, very important step of toughness test for our development.
- What is not yet done?
  - Test for a DM without window.
  - Test considering sag of the structure of the instrument.
  - Vibration for xyz direction.
  - Rapid vacuum pumping test.
  - Combination load test (in the actual launch, acoustic, vibration, rapid decrease of pressure hit the DM simultaneously).

Summary

1. We are developing a SPICA Coronagraph Instrument (SCI) as one of FPI for SPICA.
2. The primary target of SCI is the direct detection of exo-Jovian planets and spectroscopy (3.5-27 micron)
3. Binary shaped pupil masks are adopted for SCI
4. A topic of development: A MEMS-DM survived the first preliminary vibration test.