The next-generation infrared astronomy mission

SPICA
Space Infrared Telescope for Cosmology and Astrophysics

For the study of protoplanetary discs

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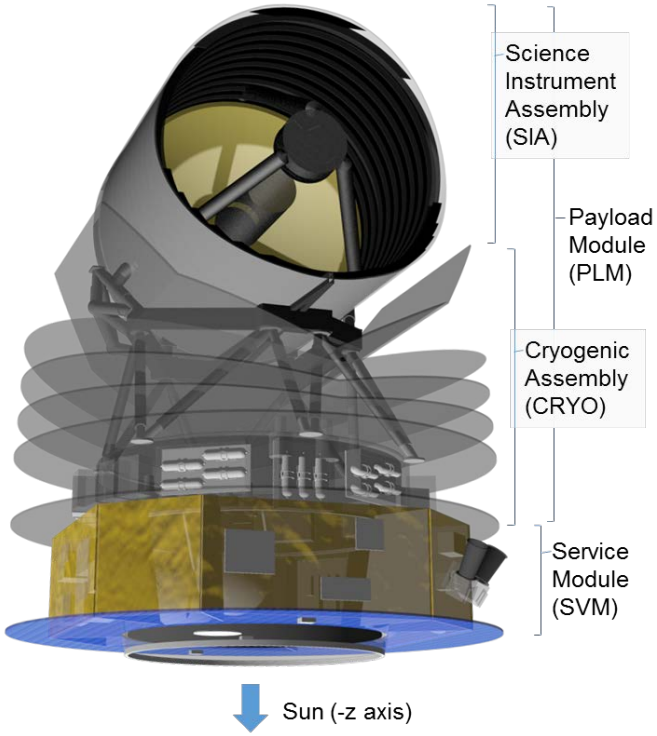
Outline

- What is SPICA ?
- SPICA for the study of protoplanetary discs
- Synergy with Subaru

What is SPICA ?

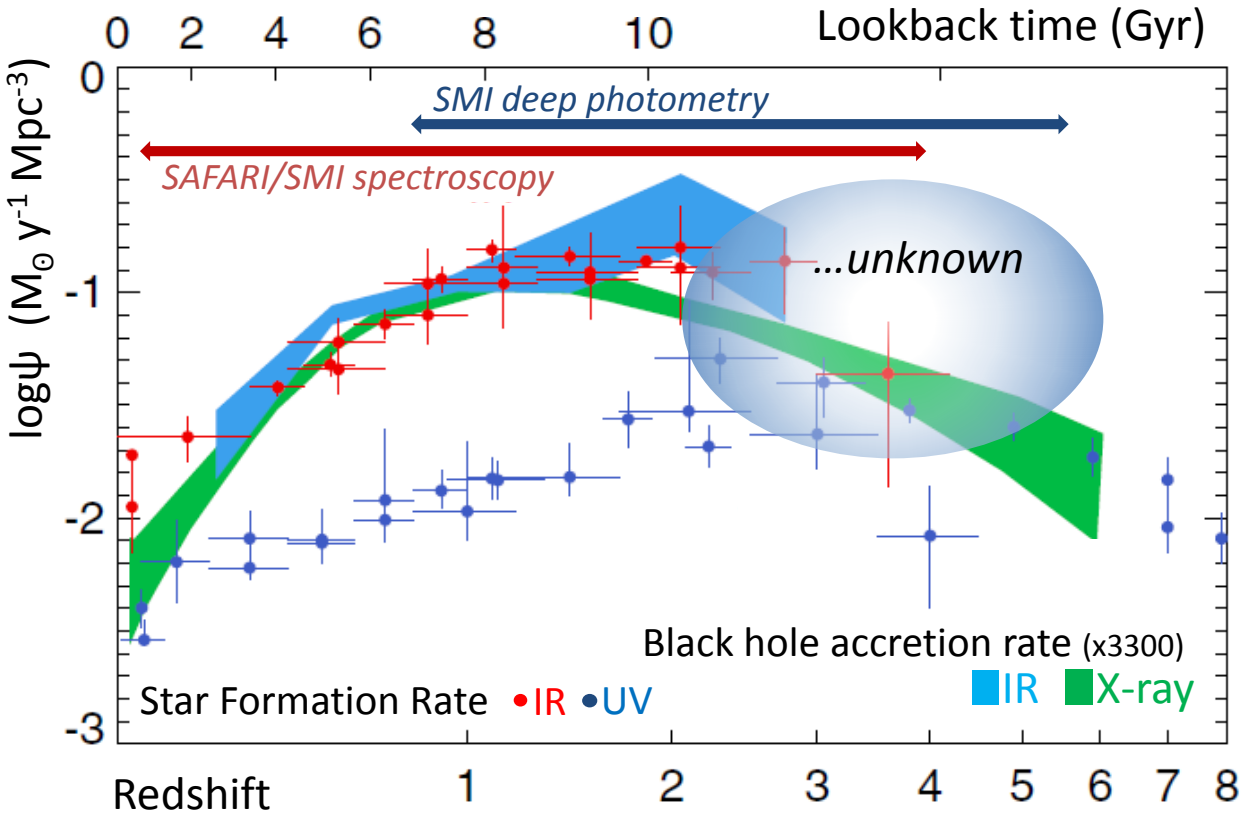
SPICA Overview



- Science Goal
  - To reveal the processes of enrichment of the Universe with metal and dust, leading to the formation of habitable worlds
- International mission led by ESA
- Focal-Plane Instruments
  - Mid-Infrared Instrument (SMI), 12-36 μm
  - Far-Infrared Instrument (SAFARI) 34-350 μm

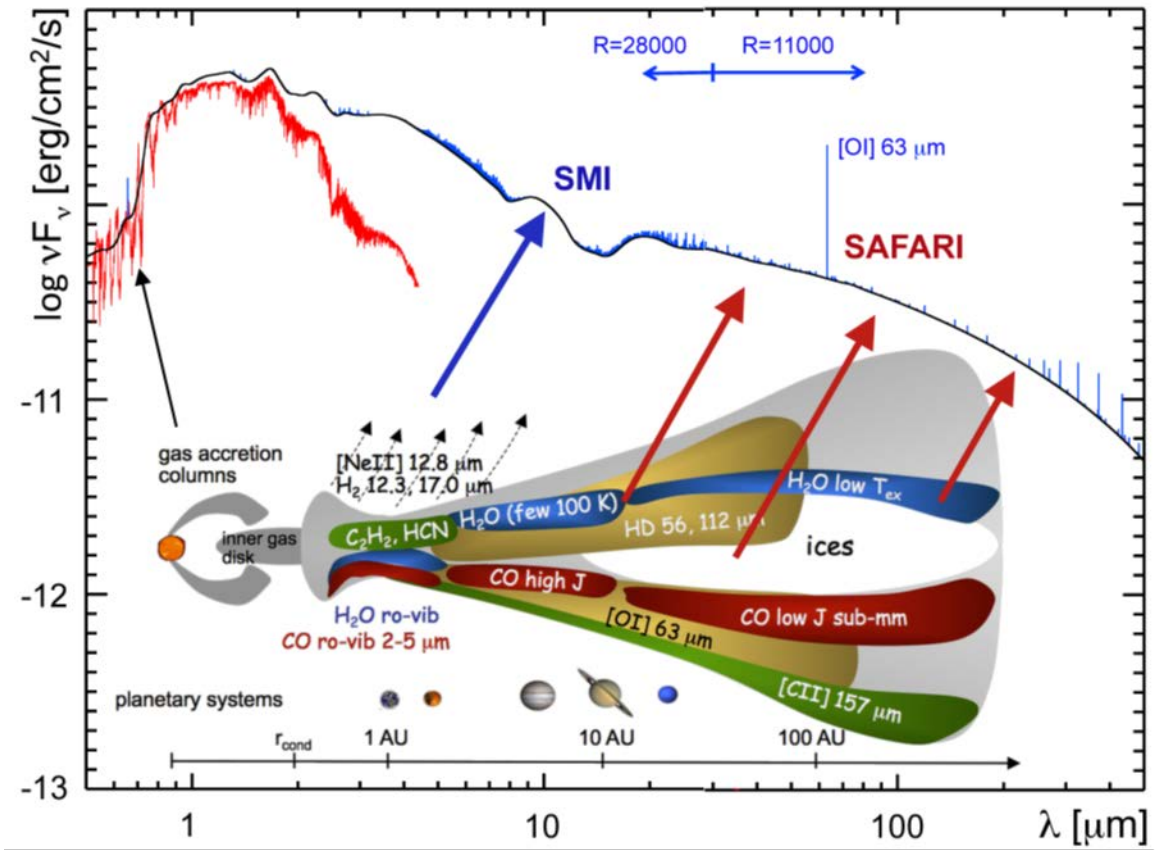
Parameter	Description
Telescope	2.5 m aperture, cooled below 8 K
Core Wavelength	12 – 350 μm
Orbit	Orbit around Sun-Earth L2
Launcher	JAXA H3
Launch Year	2027-2028

Big Question (1)



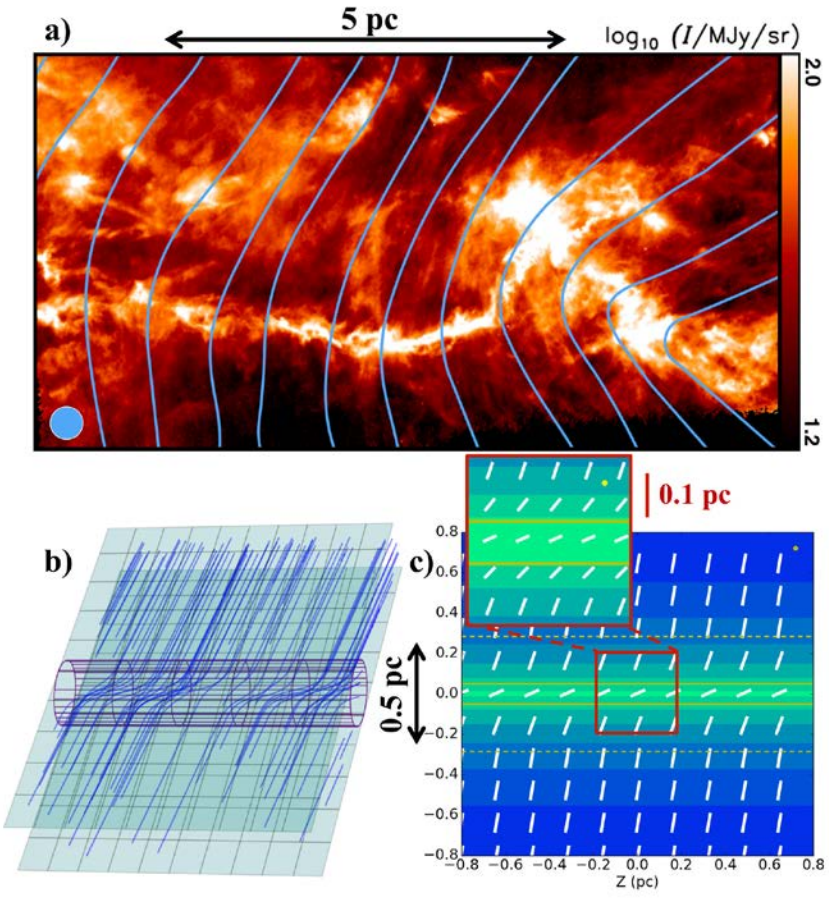
- What physical processes regulate star formation and black hole growth in galaxy evolution?
- How did primordial gas clouds collapse into the first galaxies and black holes?

Big Questions (2)



- When and how does gas evolve from primordial discs into emerging planetary systems?
- How do ices and minerals evolve in the planet formation era, as seed for Solar Systems?

Big Question (3)

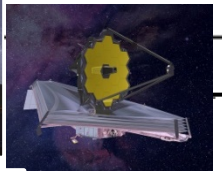


- What is the role of magnetic fields at the onset of star formation processes?

Toward the peak of ISM/SED

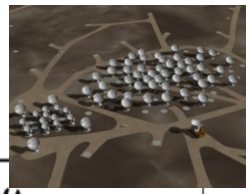
ATHENA:
AGN central engine, hot plasma

Subaru, JWST ,TMT:
stellar components



JWST

SPICA



ALMA:
cold gas/dust components

cool dust
cool gas

warm/hot dust/gas components

Important for understanding multi-phase ISM

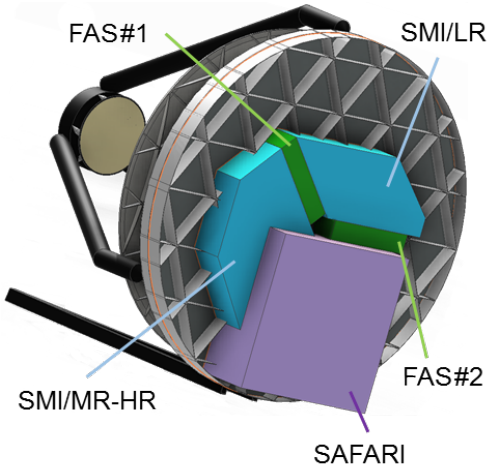
SPICA Yellow Book (2009)

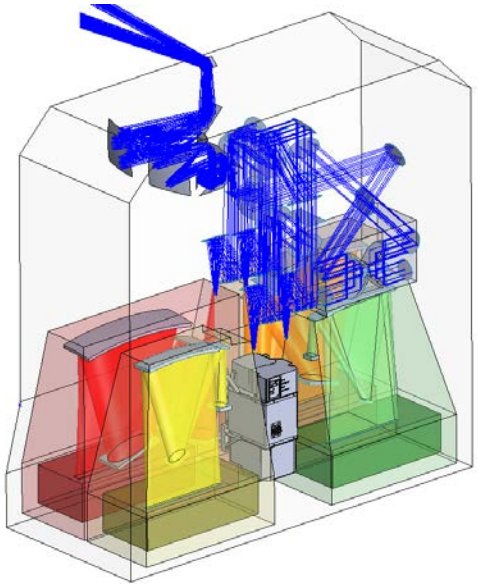
SPICA Focal Plane Instruments

SMI

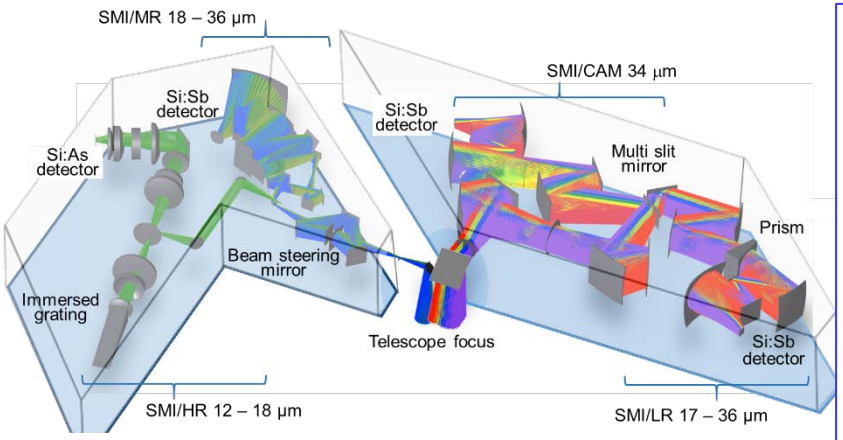
SPICA MIR Instrument

- LR **R=50**, **Si:Sb**
  17-36μm
- Camera **10'x12'**, **Si:Sb**
  @ 34μm
- MR **R=1300-2300**, **Si:Sb**
  18-36μm
- HR **R=28000** **Si:As**
  12-18μm
  Immersion Grating





The SAFARI/SPEC focal plane unit.



Optical layout for SMI/MR-HR (left) and SMI/LR with SMI/CAM (righ

SAFARI/SPEC, /POL

SPICA FIR Instrument

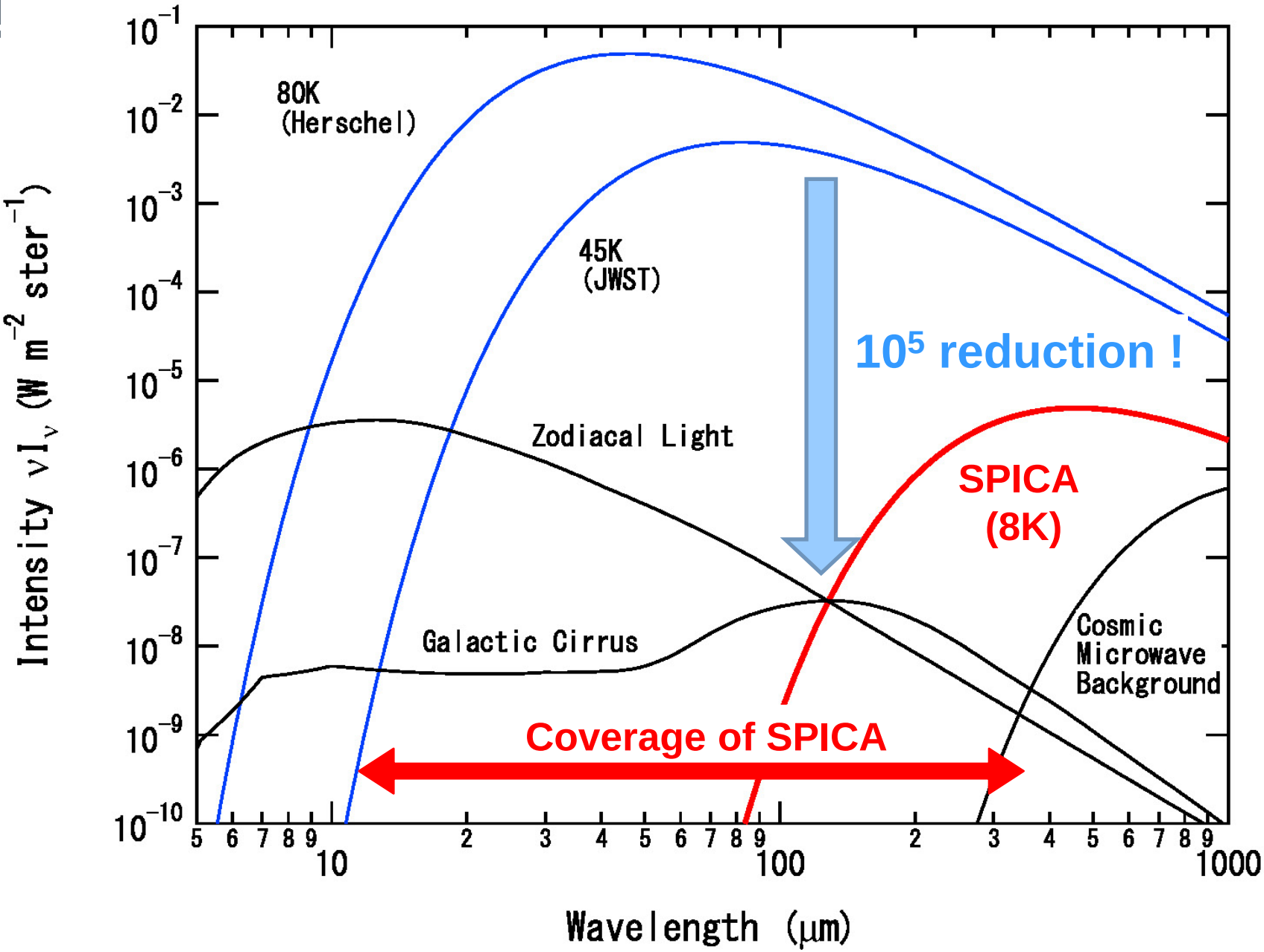
TES Bolometer Arrays operated at 50mK

NEP of 2 x 10^{-19} W/√Hz

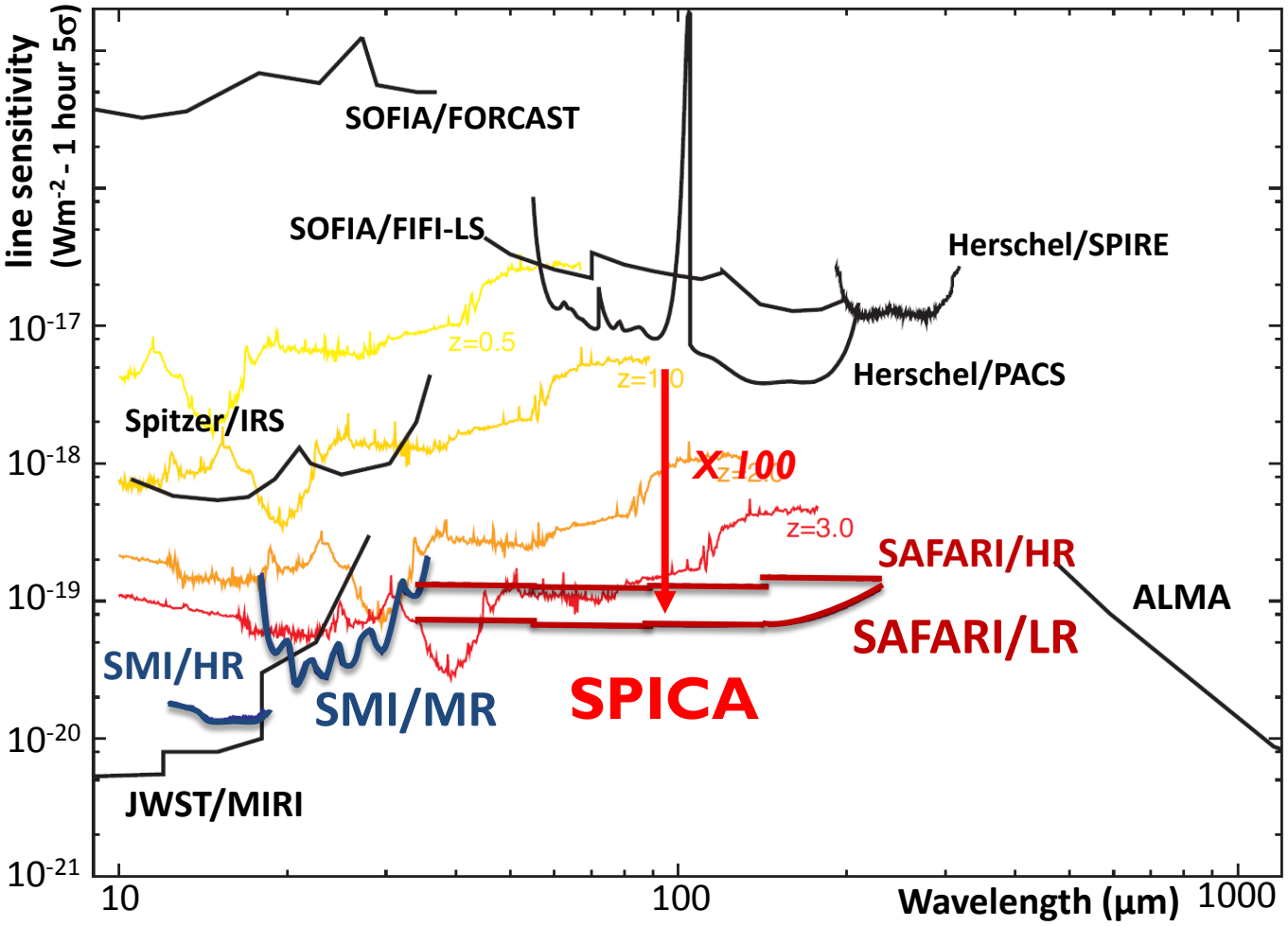
- LR **R=300**, 34-230μm, grating
- HR **R=1500-11000** 34-230μm FTS+grating

/POL infrared **polarimetry** imager 100-350μm

Ultra Low Background (a cryogenically-cooled telescope)



Sensitivity Jump

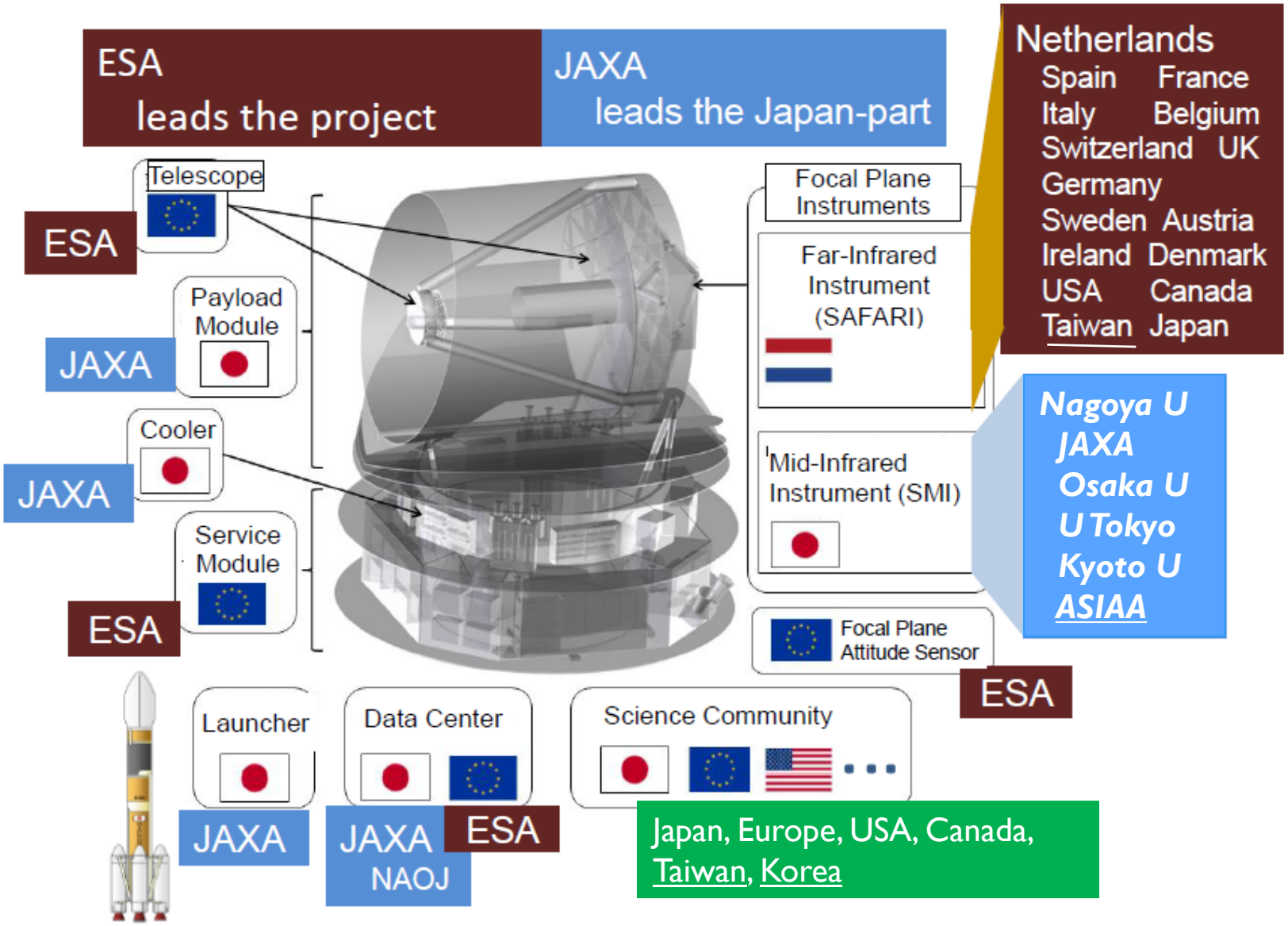


- SPICA is expected to achieve the unprecedented sensitivity in MIR and FIR.

History and Perspective of the SPICA Project

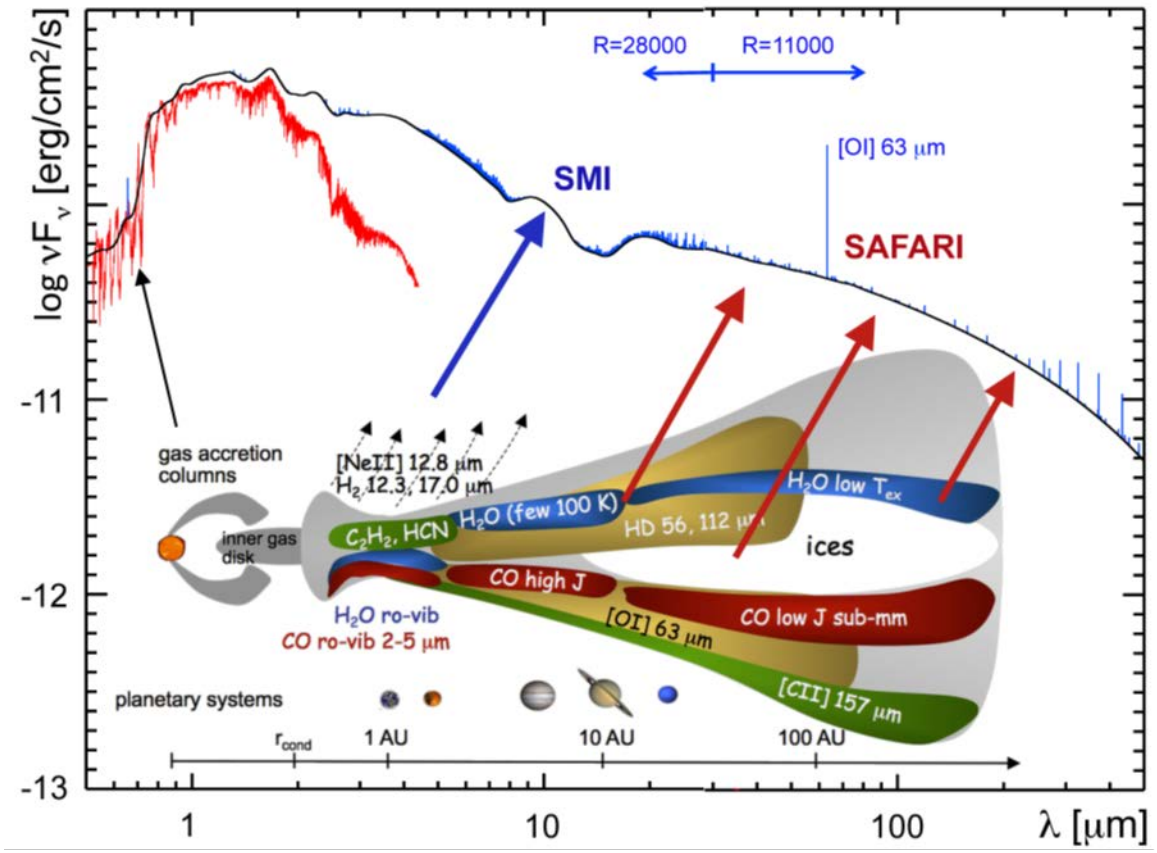
- Old SPICA (2007-)
  - Proposed as a JAXA-led mission under the collaboration with ESA (& European consortium), USA, Korea, and Taiwan.
    - ESA: Candidate for ESA Cosmic Vision M1/M2 (2007)
    - JAXA: Mission Definition Review (2008)
    - JAXA: System Requirement Review (2010)
- New SPICA (2013-)
  - Proposed as an ESA-led mission
    - JAXA: Mission Definition Review as a strategic L-class mission (2015)
      - Currently at Phase-A
    - ESA: Proposal for the ESA Cosmic Vision M5 submitted (2016)
      - The announcement of the 1st selection expected soon.
  - Launch Target 2027/28

International Workshare Plan



SPICA for the study of protoplanetary discs

Big Questions (2)

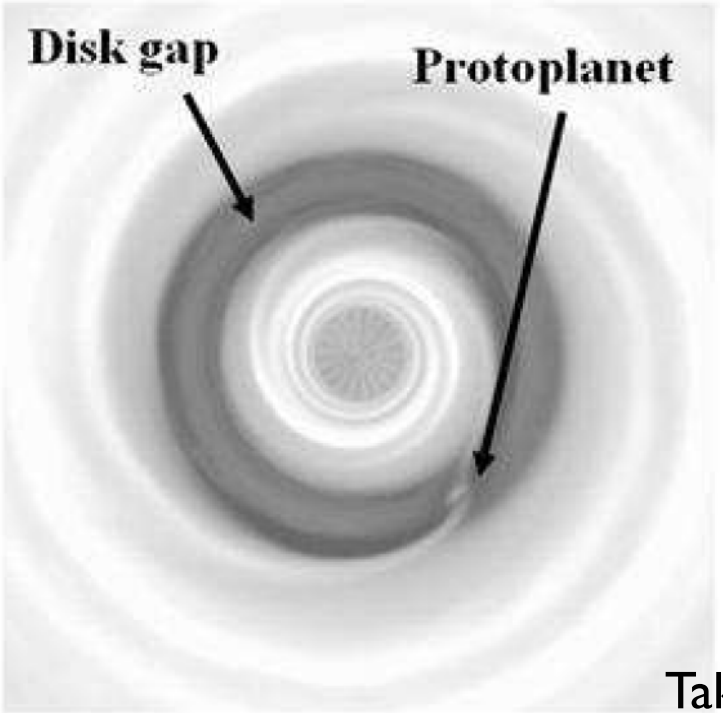


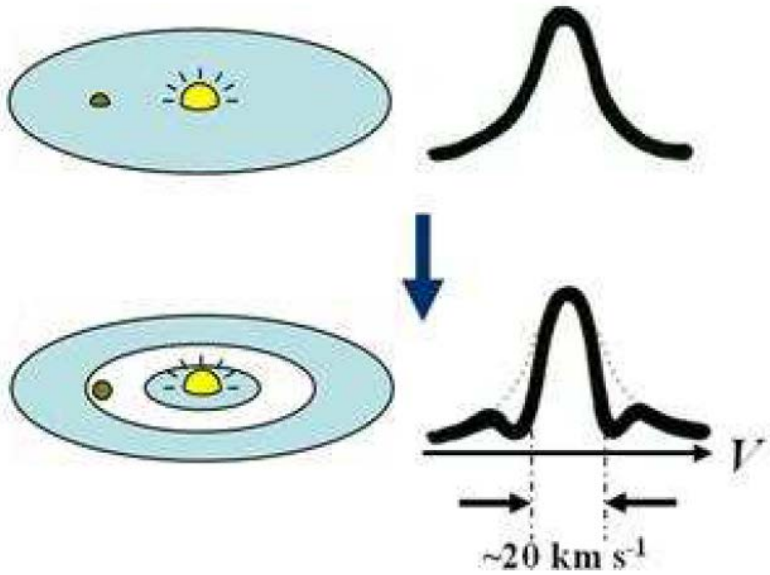
SPICA M5 proposal

- When and how does gas evolve from primordial discs into emerging planetary systems?
- How do ices and minerals evolve in the planet formation era, as seed for Solar Systems?

High-Resolution Spectroscopy

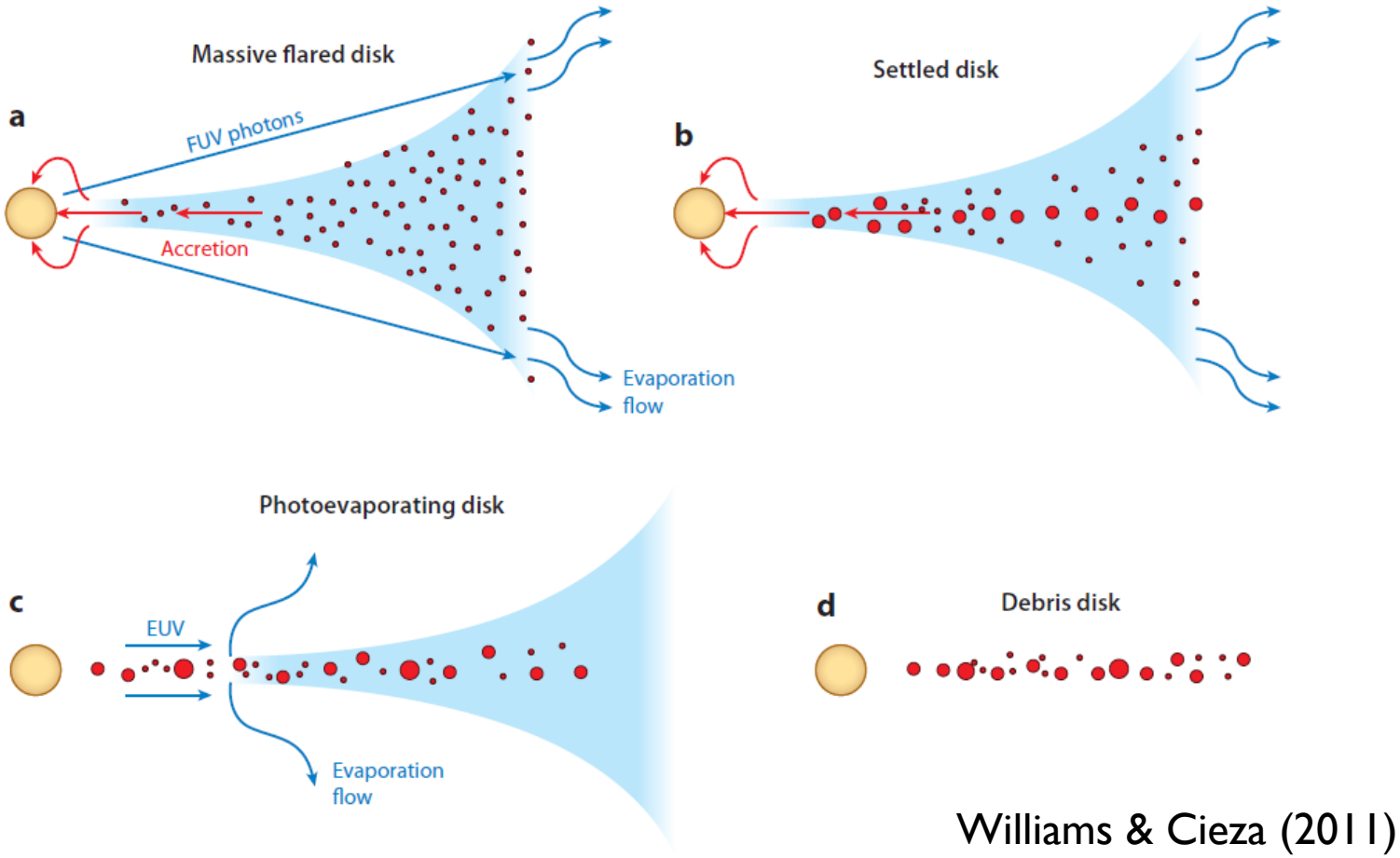
- High-resolution spectroscopy can show the spatial structure of the inner disc, where planets are being formed.
  - e.g. 1AU @140 pc
    - Easy for SPICA ($\Delta v \sim 30$km/s)
    - Challenging even for ALMA ($\Delta\theta \sim 7$ mas)





Takami et al. (2010)

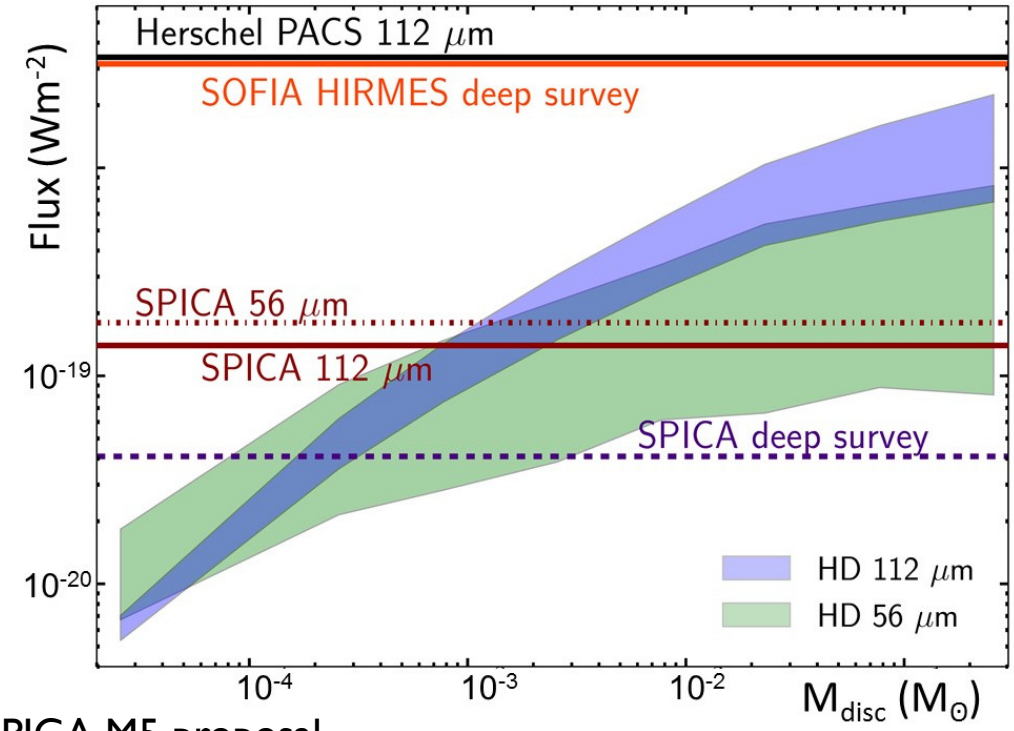
Q1: When and how does gas evolve from primordial discs into emerging planetary systems?



Williams & Cieza (2011)

- It is essential to make a robust estimate of gas mass.

Robust Mass Estimator: HD



SPICA M5 proposal

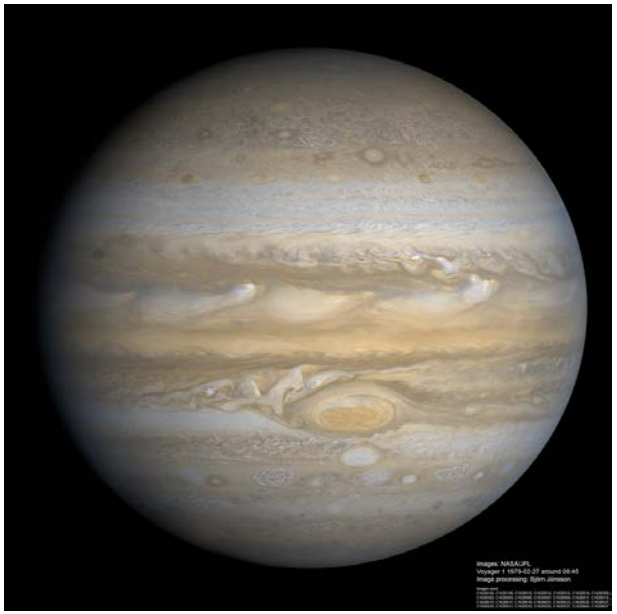
- CO: large uncertainty
  - ✓ Large optical depth
  - ✓ Depends on complex chemistry
- HD: robust mass indicator
  - ✓ moderate optical depth
  - ✓ Simple chemistry

- SPICA will characterize warm (~100 K) gas down to masses of 10^{-4} M_solr (well into gas dispersal stage) for hundreds of protoplanetary discs.
  - C.f. Herschel: several objects
- SPICA will shed light on how the transition from primordial to secondary generated gas occurs through planetary formation.

Q2: How do ices and minerals evolve in the planet formation era, as seed for Solar Systems?

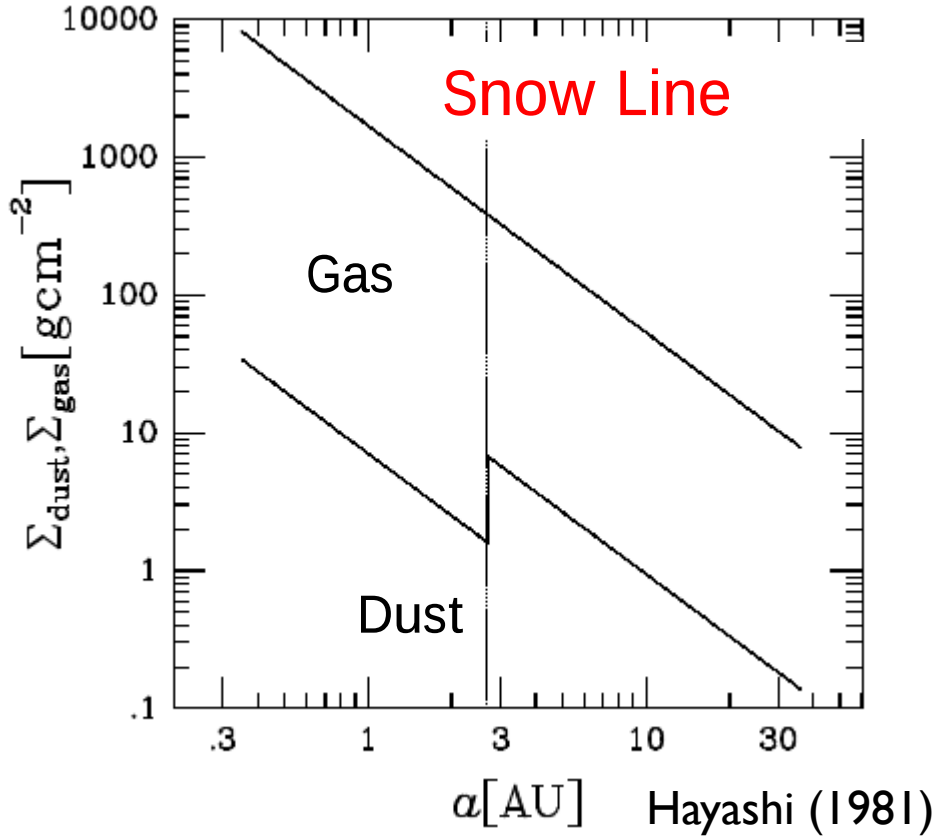
What makes them different ?

Gaseous Giants ($\rho \sim 1 g\ cm^{-3}$)



NASA

Rocky planets ($\rho \sim 5 g\ cm^{-3}$)

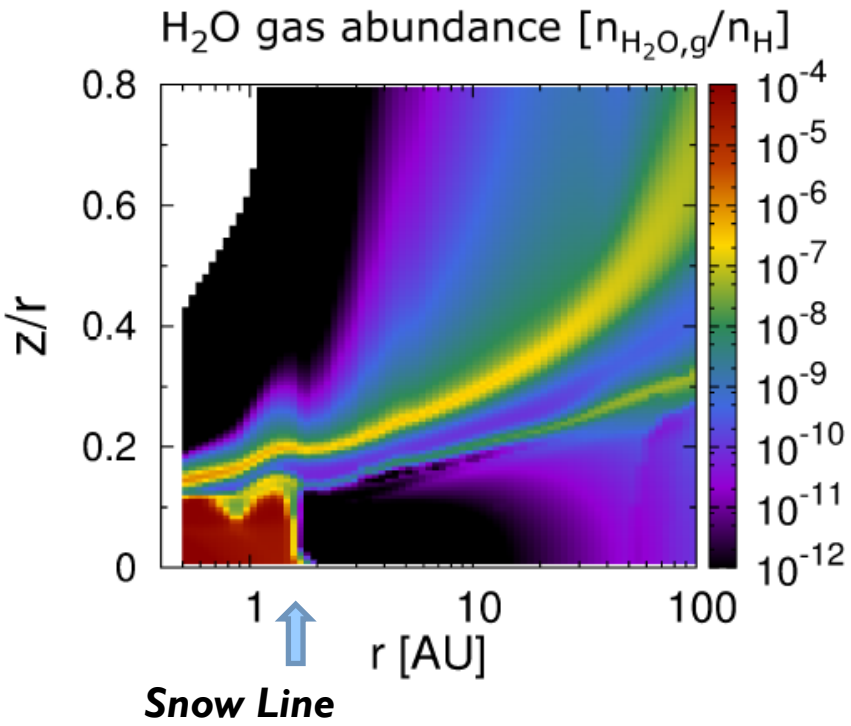


Hayashi (1981)

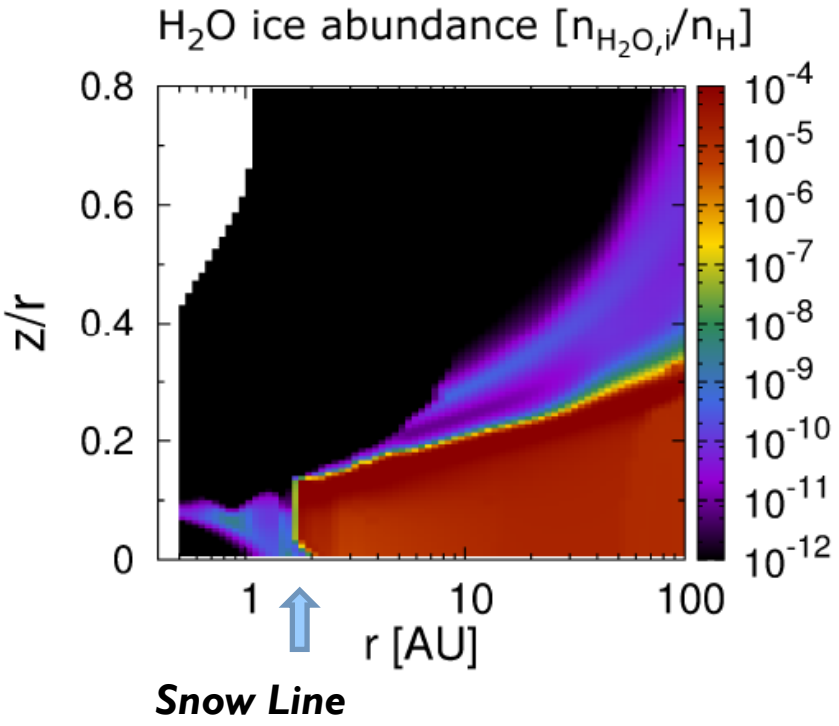
- "**Snow line**" is a key
- Is it too much simplified ?

Does the snow line really exist ?

GAS



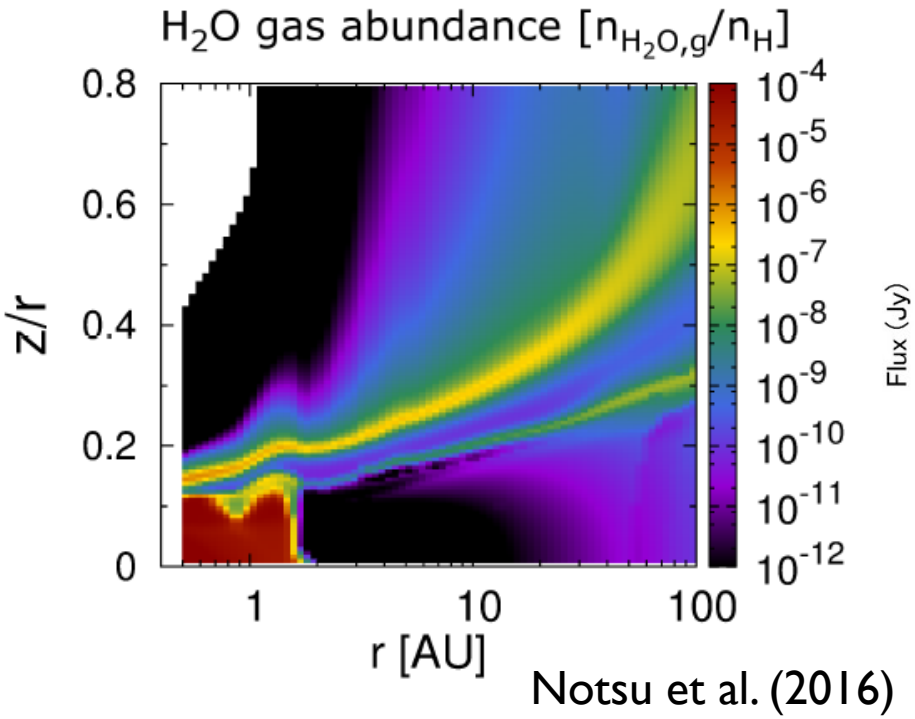
ICE



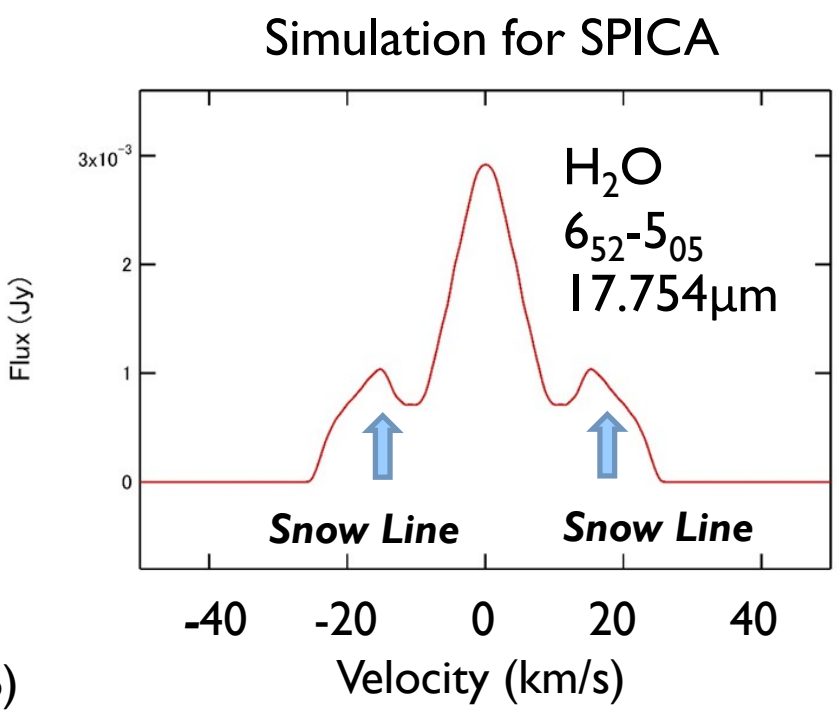
Notsu et al. (2016, 2017)

- Snow line exists inside the disc (not on the surface)

Can SPICA detect the snow line ?

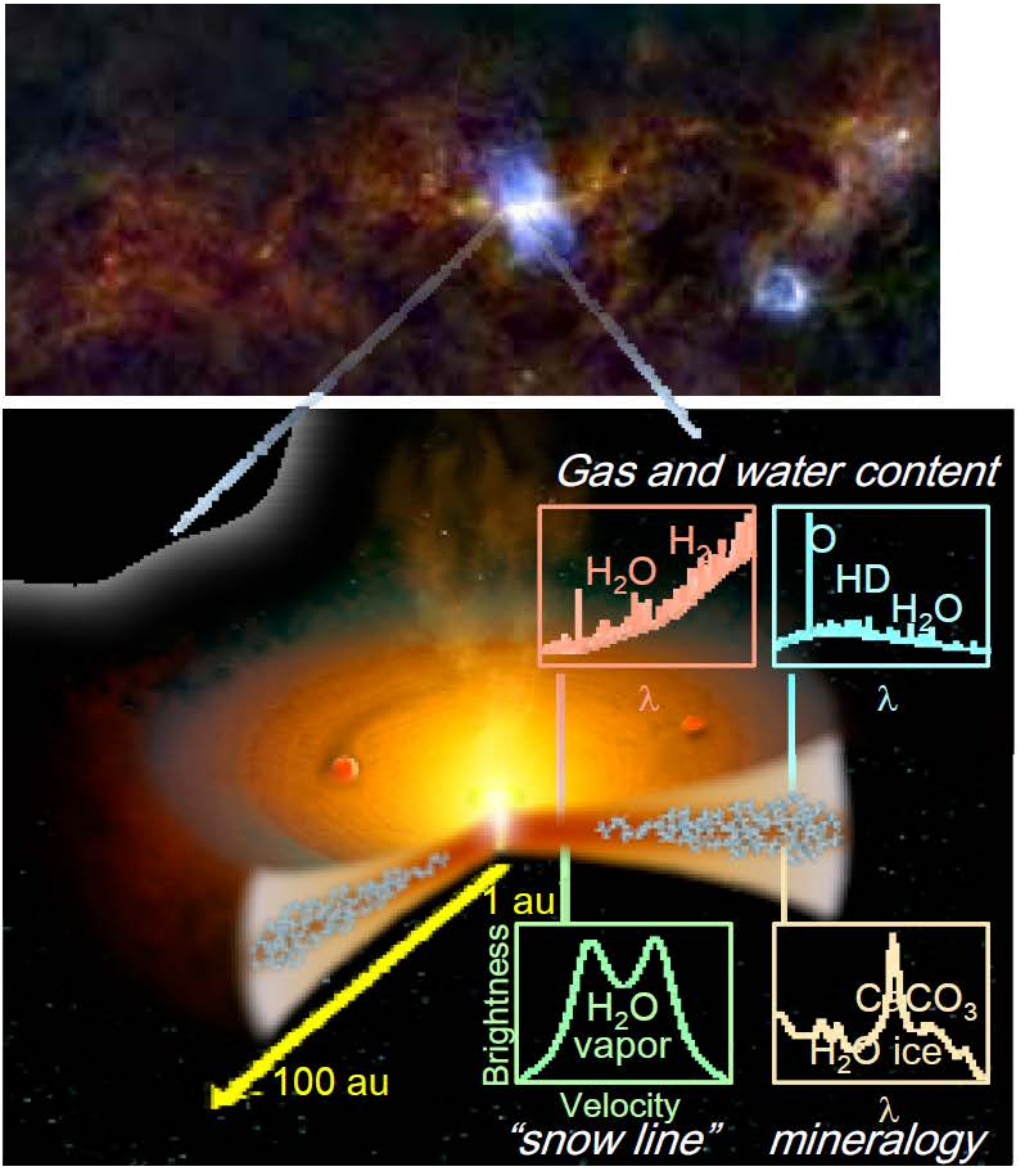


Notsu et al. (2016)



- We have to see deep inside the disc.
  - Water lines with small A coefficients required. (high sensitivity required)
- Velocity information tells us where the snow line is.
- SPICA will carry out survey observations of ~100 of T-Tauri and Herbig A/B stars.

SPICA's roles



SPICA probes the innermost region of the protoplantary disc, where terrestrial planets are formed, and tracks the water trail in the disc by revealing

- ✓ Snow line position (boundary of rocky and gaseous planets)
- ✓ Dust composition (mineralogy)
- ✓ Gas composition and mass (gas dissipation mechanism)

Synergy with Subaru

Synergy with Subaru

- Question 1: When and how does gas evolve from primordial discs into emerging planetary systems?
  - SPICA:
    - Robust estimate of gas mass along the evolutionary track
  - Subaru:
    - Revealing the gas dissipation processes with high spatial and spectral resolution
- Question 2: How do ices and minerals evolve in the planet formation era, as seed for Solar Systems?
  - SPICA
    - Direct observations of minerology
    - Tracing the evolution of the snow line
  - Subaru
    - Tracing the innermost part of the dust disc
    - Detecting and characterizing planets themselves.

Summary

- SPICA is expected to reveal the protoplanetary disc evolution by making the best use of
  - (1) high sensitivity observations of critical molecular lines in MIR and FIR
  - (2) velocity information to reveal the structure of the inner disc.
- Subaru has been and will be essential to reveal the "real structure" of the inner disc.

White Papers on SPICA

- "Galaxy Evolution Studies with the SPace IR Telescope for Cosmology and Astrophysics (SPICA): The Power of IR Spectroscopy", L. Spinoglio et al.
  - https://doi.org/10.1017/pasa.2017.48
- "SPICA and the Chemical Evolution of Galaxies: The Rise of Metals and Dust", J. A. Fernández-Ontiveros et al.
  - https://doi.org/10.1017/pasa.2017.43
- "Unbiased Large Spectroscopic Surveys of Galaxies Selected by SPICA Using Dust Bands", H. Kaneda et al.
  - https://doi.org/10.1017/pasa.2017.56
- "Tracing the Evolution of Dust Obscured Star Formation and Accretion Back to the Reionisation Epoch with SPICA", C. Gruppioni et al.
  - https://doi.org/10.1017/pasa.2017.49
- "Feedback and Feeding in the Context of Galaxy Evolution with SPICA: Direct Characterisation of Molecular Outflows and Inflows", E. González-Alfonso et al.
  - https://doi.org/10.1017/pasa.2017.46
- And more coming …