SPICA mission

Hiroshi Shibai (Osaka University & ISAS/JAXA)
On Behalf of the SPICA Team

Bern
2015 July 16

AKARI Far-IR all-sky map
SPICA is a space mission optimized for mid- and far-IR astronomy.
SPICA unveils the “dusty era” in the Universe (evolution of galaxies), and finds a route to habitable planets (formation of planetary systems).
SPICA is launched at ambient temperature, and cooled down in space. (The cryo-cooler system is a key heritage of JAXA from IRTS and AKARI.)
Japanese SMI is a mid-IR spectrometer covering 17–37 μm.
European SAFARI is a far-IR spectrometer covering 34–230 μm.
SPICA is a joint mission of JAXA and ESA with other international partners.
SPICA is now in its re-definition phase in JAXA, and will go to the open competition as an M-class mission of the ESA Cosmic Vision program.

Baseline specifications
- Telescope : 2.5 m aperture, cooled below 8 K
- Core wavelength : 17–230 μm
  (+ High-resolution spectrometer at 12–18 μm, Exoplanet instrument at 5–20 μm)
- Orbit : S-E L2 Halo Orbit
- Launcher : JAXA H3 Vehicle
- Launch Year : 2027–2028
Importance of a cryogenically-cooled IR telescope

A cryogenically-cooled telescope significantly reduces the thermal emission from the telescope.
Baseline Design

Planck-type PLM with a 2.5 m, 8 K telescope (JAXA follow-up study)

- **payload module**
  - secondary mirror
  - cryo-cooler system

- **service module**

- **telescope baffle**
- **telescope thermal shield**
- **V-groove thermal shields**

**Front view**

**Side view**

- instrument optical bench
Telescope

- **Optical design**
  - The 2.5 mφ optical design is scaled from the 2.0 mφ CDF study.

- **Optical specifications**
  - Telescope type: Ritchey–Chrétien
  - Entrance Pupil Diameter: 2.5 m
  - Field of View: 30 arcmin
  - Wave Front Error: <1.4 μm rms
  - Diffraction limited at 20 μm

- **Temperature**
  - Launch: Room temperature
  - Operation: <8 K

- **Fabrication**
  - ESA is in charge of the procurement of the telescope.

- **Technical Heritage**
  - The mirrors are based on the AKARI and Herschel heritage (SiC mirrors).
Work-sharing plan

Telescope

Payload Module

Cryocooler

Bus Module

SPICA Data Center (NAOJ)

Focal Plane Instrument Assembly

FIR Spectrometer (SAFARI)
- NL + European countries
- + Canada & US

MIR Instrument (SMI)

Exoplanet Spectroscopy (SPEChO)
- European countries

Science Community
### Project Schedule

#### Reviews & Phases

<table>
<thead>
<tr>
<th>CY</th>
<th>q2</th>
<th>q3</th>
<th>q4</th>
<th>q1</th>
<th>q2</th>
<th>q3</th>
<th>q4</th>
<th>q1</th>
<th>q2</th>
<th>q3</th>
<th>q4</th>
<th>q1</th>
<th>q2</th>
<th>q3</th>
<th>q4</th>
<th>q1</th>
<th>q2</th>
<th>q3</th>
<th>q4</th>
<th>q1</th>
</tr>
</thead>
<tbody>
<tr>
<td>JAXA</td>
<td>MDR</td>
<td>SRR</td>
<td>SDR</td>
<td>Project Appr. Rep</td>
<td>Pre-PDR</td>
<td>Sys-PDR</td>
<td>Pre-CDR</td>
<td>Sys-CDR</td>
<td>PSR</td>
<td>Launch</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ESA</td>
<td>Phase-A PRR</td>
<td>Phase-B1</td>
<td>SRR</td>
<td>Phase-B2</td>
<td>PDR</td>
<td>Phase-C</td>
<td>CDR</td>
<td>Phase-D</td>
<td>QR?</td>
<td>AR</td>
<td>margin</td>
<td>Phase-E1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Model & Tests

- **JAXA**
  - PLM Comp Dev.
  - MCS Comp. Dev.

- **ESA**
  - JAXA
  - ESA
  - SMI
  - SAFARI

#### Operation:

*3 Years (Nominal), 5 Years (Goal)*
Dramatic improvement in the sensitivity

A cryogenically-cooled telescope makes dramatic improvements in the sensitivity in IR observations.

Limiting Line Flux (5σ-1hr) / Wm⁻²

Wavelength / μm

SOFIA
AKARI IRC
Spitzer

AKARI FIS-FTS
ISO/LWS

2010's

×100 Improvement

SPICA (2.5m, 8K)

ALMA

JWST/MIRI

2020's
Enrichment of the Universe with metal and dust leading to the formation of habitable worlds

IR spectroscopy

SPICA's unique probes

AKARI Mid-IR all-sky map
Science goals and objectives

**Top-level goal**
Enrichment of the Universe with metal and dust, leading to the formation of habitable worlds

### SCIENCE GOALS

#### [SG1] Evolution of galaxies

- **Science objectives**
  - [SO1] Star formation of distant galaxies
  - [SO2] AGN outflow
  - [SO3] Star formation in nearby galaxies

#### [SG2] Formation of planetary systems

- **Science objectives**
  - [SO4] Gas dissipation in PPDs
  - [SO5] Debris disks to solar system
  - [SO6] Exoplanet atmosphere
SPICA’s uniqueness in extra-galactic astronomy

Sensitivity ($5\sigma$, 1 hour) of ALMA, SPICA, JWST and TMT, plotted on spectra of typical star-forming galaxies at $z = 3$ with different dust extinction values ($A_V = 0.3, 3, 30$ mag).

SPICA provides unique spectral tools to study physics in dust-obscured galaxies.
How well do models simulate our Universe?

Cosmological hydro-dynamical simulations are performed based on the first principle. Illustris: Vogelsberger+ Nature 509, 177 (2014)

Latest simulations successfully reproduce a snapshot of the present universe with $\sim 10^{10}$ resolution elements.

Semi-analytical models can explore a large parameter space.

$v^2GC$ (Mitaka model) calculates $5.5 \times 10^{11}$ dark matter particles.

(Ishiyama+2015 PASJ in press)

Simulations reproduce the evolution of star-formation rate density (SFRD) within a factor of $\sim 2$.

SFRD vs redshift

Makiya+ in prep.
Discrepancy in IR luminosity density

- Discrepancy by a factor of 2–5 exists in $L_{\text{IR}}$ density at $z = 0.5–3$.
- Simulations cannot account for rapid decrease in $L_{\text{IR}}$ density at $z < 1$.

Difficulty in reproducing $L_{\text{IR}}$ density is a general consequence of simulations.

SPICA investigates the following possibilities to solve this problem:

1. A large contribution to $L_{\text{IR}}$ from hidden, obscured AGNs
2. Rapid growth of metallicity and dust grains in obscured regions at $z = 0.5–3$
3. Top-heavy initial mass function (IMF) in IR-bright galaxies

---

**Graphical Representation**

- **Total IR luminosity density ($L_{\odot} \text{Mpc}^{-3}$)**
- **Redshift**
- **Observations (Herschel)**
- **Model**
- **UV Dust extinction**
- **Model**

**Legend**

- Red: Model
- Red dotted: Model, intrinsic
- Black: Hopkins 2004
- Triangle: Bouwens et al. 2014

**Mitaka model (SAM) (Makiya et al. priv com)**

---

- **Total IR luminosity density ($L_{\odot} \text{Mpc}^{-3}$)**
- **Redshift**
- **Model**
- **UV Dust extinction**
- **Model**

**Legend**

- Red: Model
- Red dotted: Model, intrinsic
- Black: Hopkins 2004
- Triangle: Bouwens et al. 2014

**Mitaka model (SAM) (Makiya et al. priv com)**
Feedback processes in galaxy evolution

- Difference between the dark matter mass function and the galaxy stellar mass function (GSMF) calls for AGN outflow and stellar feedbacks that quench star formation at both ends of the GSMF.

- AGN outflow is the key to reproducing the SFRD with cosmic time.
Revealing gas dissipation by H$_2$

High spectral-resolution ($R>20000$) spectroscopy with SPICA detects the line emission arising from the innermost region (1–2AU) of the disk by their line width using the Keplerian motion.

H$_2$ S(1) & S(2) spectroscopy is sensitive to H$_2$ gas at planet-forming regions ($T\sim300$K). $M_{\text{gas}} > 10^{-5} M_{\odot}$ can affect dust growth.

H$_2$ S(2) emission from a PPD model of a 1 $M_{\odot}$ star with $i = 45$ deg with $R = 25000$.

Model estimate of H$_2$ flux from a 1 $M_{\odot}$ star at 140 pc (Gorti & Hollenbach 2004 ApJ 613, 424).
Evolution of debris disks to our solar system

Spectroscopy of various mineral features in 17–100 μm in different environments (e.g., metallicity, radiation field, and stellar age) enables the characterization of debris disks along their evolution and the study of the history of our solar system.

SPICA offers the first opportunity to search for true zodiacal disk analogues and study our solar system in the framework of evolution of debris disks.

Spectroscopy of various mineral features in 17–100 μm in different environments (e.g., metallicity, radiation field, and stellar age) enables the characterization of debris disks along their evolution and the study of the history of our solar system.

SPICA offers the first opportunity to search for true zodiacal disk analogues and study our solar system in the framework of evolution of debris disks.
Characterization of Atmosphere of sub-Neptune and super-Earth by Transit Spectroscopy

Targets will be provided by TESS & PLATO.

- SPICA can have a dedicated small instrument for exoplanet science. SPICA has a potential capability for cooler exoplanets (300K or cooler).

JWST-SPICA can cover wide temperature range of exoplanet’s atmosphere.

JWST/NIRCam, NIRISS covers hot (> 600 K) planets.

Flux ratio of Super-Earth around M-type stars.

SPICA 5-20 micron (tentative)

JWST/NIRCam, NIRISS covers hot (> 600 K) planets.

Flux ratio (x 10^{-4})
After the re-definition,
- SPICA has 2.5 m, 8 K telescope with cryo-cooler.
- SPICA is a collaborative mission between JAXA and ESA with other international consortiums.
- The expected launch year is 2027-8.
- SPICA will soon go into its next project phase in Japan.
- SPICA will be proposed as a next M-class mission to ESA jointly by the European and Japanese team.
- SPICA has a capability for a small exoplanet instrument, but not decided yet.