SPIRIT
The Space Infrared Interferometric Telescope:
a Starting Point for the Next FIRI Proposal

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SPIRIT as a Starting Point for FIRI

- Incorporates many of the features of any double Fourier interferometer concept
  - Beam combination
  - Aperture and detector cooling
  - Detector performance
  - Data processing
  - Etc.

- Has been studied in detail

- Is on the affordable end of the price range
SPIRIT Science Drivers

- Formation of planetary systems
SPIRIT Science Drivers

Debris disks and exoplanet signatures

SPIRIT resolution at 40 μm
SPIRIT Science Drivers

Galaxy evolution

Spitzer
Additional Goals

- Spectra of gas giant exoplanets
- Map nearby spiral galaxies in fine structure lines
- Thermal and density structure of pre-stellar and protostellar cores
- Spectrophotometry of KBOs
- Etc.
SPIRIT Summary

- Two 1-m telescopes cooled to 4 K and mounted on deployable boom
- Baseline adjustable: 6 – 36 m
- Combined with rotation, provides dense uv plane coverage
- Typ. ~ 1 day per observation
- $\lambda = 35 – 400 \ \mu m$
- Angular resolution: 0.3” at 100 $\mu m$
- One scientific instrument
- $\lambda/\Delta \lambda = 3000-5000$ spectroscopy
- Sky photon noise limited sensitivity with ~ 50 mK detectors
Performance Summary

- **Sensitivity (5 σ; 24 hrs)**
  - Lines: $3 - 1.5 \times 10^{-19}$ W m$^{-2}$ (35 – 280 μm)
  - Continuum: 15 – 50 μJy
- **Lifetime** 3 yrs minimum
- **Instantaneous fov:** 1 arcmin
- **Field of regard** 40° band centred on ecliptic
Launch and Deployment

- Launch vehicle: ATLAS V-531
  - 5.4 m fairing diameter

- Payload stowed for launch with hinged boom and jettisonable support structure

- Mass: 4.5 Tonnes

- Orbit: L2
Deployment

- Four hinges on each side of the boom
- Hinges latched after deployment
Operation and $uv$ Plane Coverage

- Combination of rotation and stepping baseline provides dense $uv$ plane coverage
- Typ. 30 positions from 6 – 36 m baseline
- Rotation period 0.5 – 3 rev/hr depending on baseline
- Typ. ~ 1 day per science observation
- Multiple days for deep observations
Telescope and Instrument Modules

Telescope with 3-layer thermal shield

Instrument Module

Beam

0.5 x 0.5 m truss

3-layer thermal shields
Silicon Carbide Telescopes

- Afocal Gregorian design
- Off-axis design to avoid diffraction effects that would complicate fringe visibility
- Telescope size limited to ~1 m by launch vehicle fairing size
Telescope Modules

- 700 kg total mass
- Independent power, cooling, trolley drive, and communications systems
- Internal pointing mechanism allows independent telescope pointing by up to 3°
- Typical movement along the trolley of 1.5 m in ~40 sec.
- 2.5 m position precision
Instrument Module

Combiner Secondary
- Calibration lamp array
- Leg 1 Shutter

CBSM1, CBSM2
- CBSM Combiner Mirror Steering Mechanism
- Tip/Tilt continuous 4K
- 0.3 arcsec over +/- 1 deg

from Combiner Secondary, Primary, & Y Collector

1K SHROUD

Path Length Compensation Mechanism
- Piston continuous 4K
- 0.25 micron over +/- 2.5 mm

Sacred Delay Line Scan Mechanism
- Continuous linear scan, 4K

Optical Delay Line Scan Mechanism

Combiner Primary

BS Band 1, BS Band 2, BS Band 3, BS Band 4

ZCM1 & 2
- ZPD Centering Mech
- 2 Axis
- 50 micron over +/- 3 mm

ZPD Sensor

Angle Sensor
Instrument Module

- Four quadrants
  - Metrology
  - Cameras (two per band)
  - Fixed optical delay line
  - Scanning optical delay line
Detectors

- Four $\lambda/\Delta\lambda = 2$ bands:
  - 25-50, 50-100, 100-200, 200-400 $\mu$m

- Nyquist sampling of Airy disk at GM wavelengths (35, 70, 140, 280 $\mu$m)
  - Pixel sizes: (4.2, 8.7, 17, 35) arcsec

- 60 arcsec fov then gives required array sizes

- Sensitivity requirement: $\text{NEP}_{\text{det}} < 0.5\text{NEP}_{\text{photon}}$ so <10% contribution to total noise

- Requirements

<table>
<thead>
<tr>
<th>Band</th>
<th>NEP (W Hz$^{-1/2} \times 10^{-19}$)</th>
<th>No. of Pixels</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 – 50</td>
<td>1.9</td>
<td>14 x 14</td>
</tr>
<tr>
<td>50 – 100</td>
<td>1.1</td>
<td>7 x 7</td>
</tr>
<tr>
<td>100 – 200</td>
<td>0.7</td>
<td>4 x 4</td>
</tr>
<tr>
<td>200 – 400</td>
<td>1.8</td>
<td>2 x 2</td>
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</tbody>
</table>

- Speed of response determined by delay line scan rate:
  - $\tau_{\text{det}} < 185 \mu$s ($\approx 1$ kHz 3-dB frequency)
Thermal Model

Telescope Module

- Optical bench
- ACTDP 1.84 W, 45 K
- ACTDP 194 mW, 18 K
- ACTDP 56 mW, 4 K
- Passive Thermal Shields

Instrument Module

- Optical bench & IR Metrology
- ACTDP 107 mW, 4 K
- Detectors 0.05 K
- CADR 0.05 K, 6 uW
- CADR 1 K, 0.2
- CADR 1-3 mW to 4 K

ACTDP 376 mW, 18 K
ACTDP 574 mW, 45 K

Warm Section

ACTDP Compressor(s) 304 W

CADR Electronics 75 W
ACTDP Compressors & Electronics 576 W
US Cryocooler Development
Advanced Cooler Technology Development Program
# Heatloads Summary

<table>
<thead>
<tr>
<th></th>
<th>Conductive (strut+wire)</th>
<th>Radiative</th>
<th>Mechanism Power</th>
<th>Cooling Needed From Cryocooler</th>
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</thead>
<tbody>
<tr>
<td><strong>Telescope</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4K</td>
<td>2mW + 15mW</td>
<td>11 mW</td>
<td>8 mW</td>
<td>72 mW</td>
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<tr>
<td>18K</td>
<td>17mW + 9mW</td>
<td>0 mW</td>
<td>N/A</td>
<td>52 mW</td>
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<tr>
<td>45K</td>
<td>0.223 W + 0.147 W</td>
<td>0W</td>
<td>N/A</td>
<td>0.74 W</td>
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<tr>
<td><strong>Instrument Module</strong></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>4K</td>
<td>2mW + 12mW</td>
<td>44 mW</td>
<td>8 mW + 3mW from CADR</td>
<td>138 mW</td>
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<tr>
<td>18K</td>
<td>17mW + 7mW</td>
<td>156 mW</td>
<td>N/A</td>
<td>360 mW</td>
</tr>
<tr>
<td>45K</td>
<td>0.223 W + 0.773 W</td>
<td>0.228 W</td>
<td>N/A</td>
<td>2.448 W</td>
</tr>
</tbody>
</table>
SPIRIT vs FIRI as Proposed in 2007
SPIRIT vs FIRI as Proposed in 2007

SPIRIT with 1-m apertures:
\[ \Delta F \] in 24 hrs similar to SPICA
In 1 hr
SPIRIT Papers and Documents


1. The Space Infrared Interferometric Telescope (SPIRIT): High-resolution imaging and spectroscopy in the far-infrared
2. System engineering the Space Infrared Interferometric Telescope (SPIRIT)
3. Mechanical Design of the Space Infrared Interferometric Telescope (SPIRIT)
4. The Space Infrared Interferometric Telescope (SPIRIT): Optical System Design Considerations
5. The SPIRIT Thermal System
6. Cryogenic Far-Infrared Detectors for the Space Infrared Interferometric Telescope (SPIRIT)
7. The Space Infrared Interferometric Telescope (SPIRIT): the mission design solution space and the art of the possible
Some Comments/Questions

- SPIRIT incorporates many of the features of any double Fourier interferometer concept
  - Beam combination
  - Aperture and detector cooling
  - Detector performance
  - Data processing
  - Etc.

- A credible L-class mission proposal will probably have to be affordable as a European-dominated project

- Will a SPIRIT-like system meet the science requirements?
  - How have the science requirements evolved since 2007?
  - Enhanced importance of exoplanetary systems/exoplanet characterisation?

- Without making the concept unaffordable:
  - Can the aperture size be increased?
  - Can a free-flying version be considered, to give greater baseline?
  - Can a dual launch + docking version be considered?