How SPICE Images the Sky

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and

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Community Presentation September 14, 2022

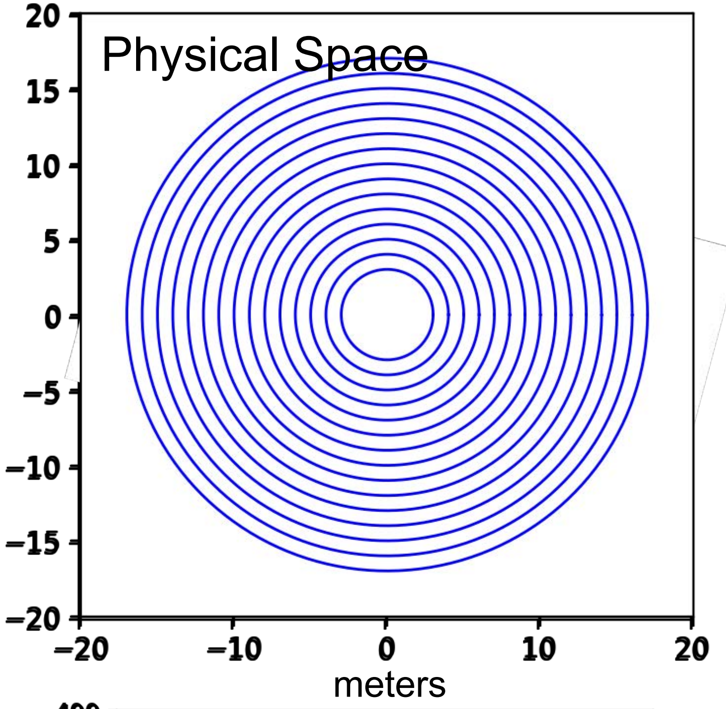
SPICE is a spatial-spectral interferometer

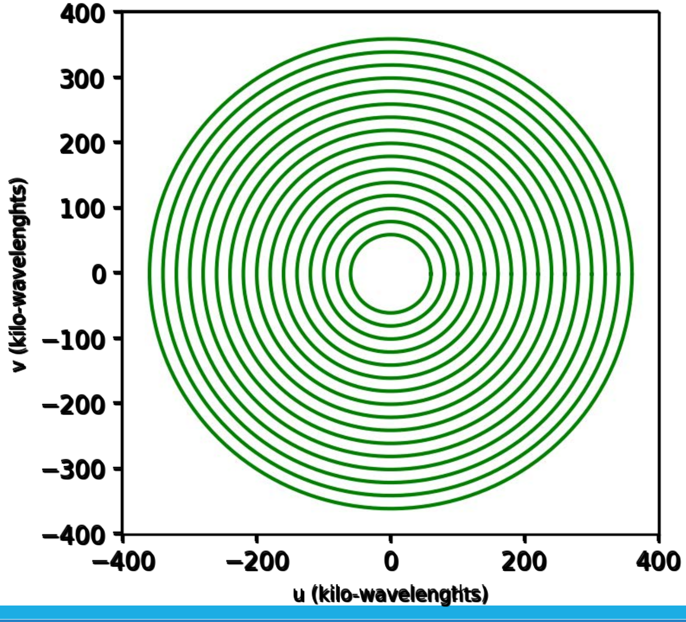
- Two telescopes point directly at the source
- Rotate around the central hub to change the angle of the baseline
- Telescopes move in and out to give different baseline lengths.
- Vary relative path length of the light from the two telescopes to measure the spectrum

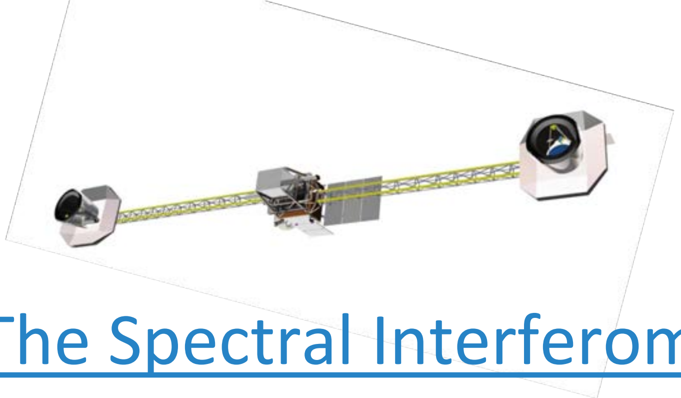
SPICE is a combination of a Fourier Transform Spectrometer which has heritage with COBE/FIRAS and Cassini/CIRS, and standard spatial interferometry.

The Spatial Interferometer

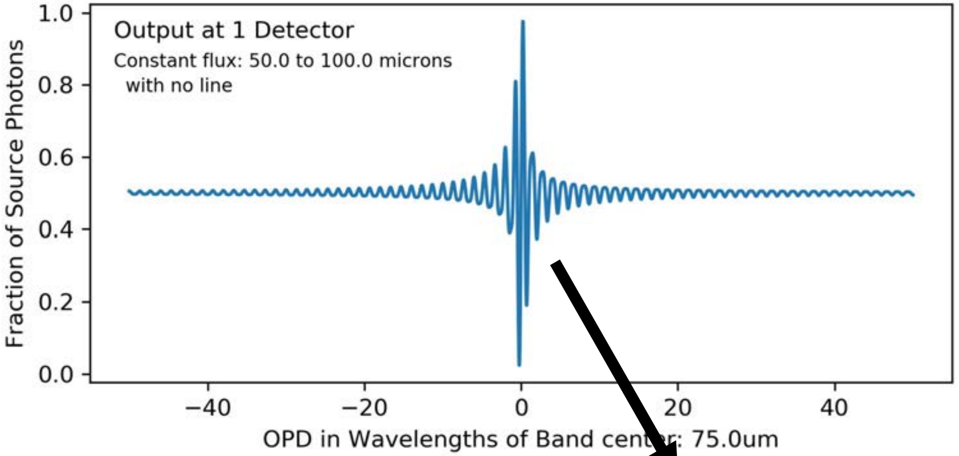
- The combined telescope beams measure the spatial power spectrum of the sky.
- rotating and moving the telescopes to different separation and angles -- the Fourier Transform of the sky emission, which is commonly referred to as the u,v plane.
- SPICE collects the spatial data to form an image of the sky.
- The spatial resolution is determined by the range of baselines.
- Current 36-meter maximum baseline give a resolution of 0.3” at 100 microns wavelength.







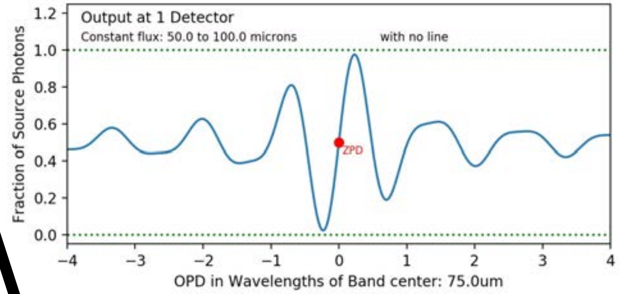
The Spectral Interferometer



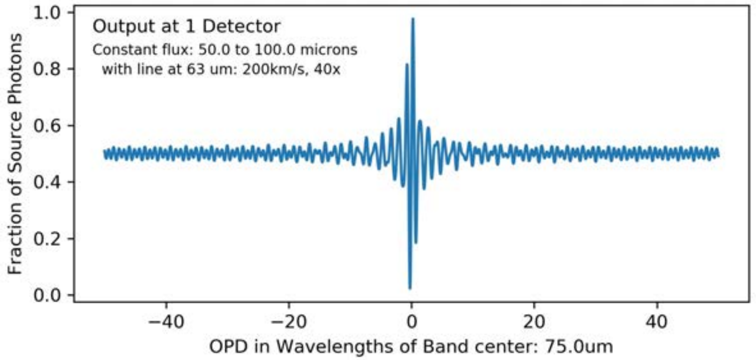
- The light from the two telescopes is combined with different delays to create the interferogram.

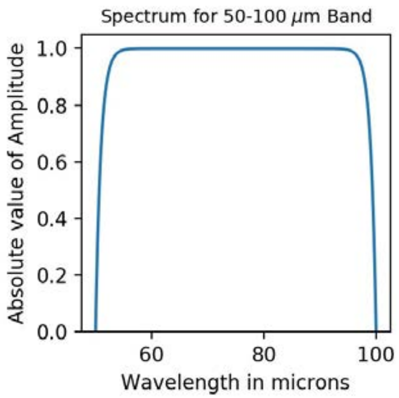
- Fourier transform of the interferogram is the frequency spectrum.

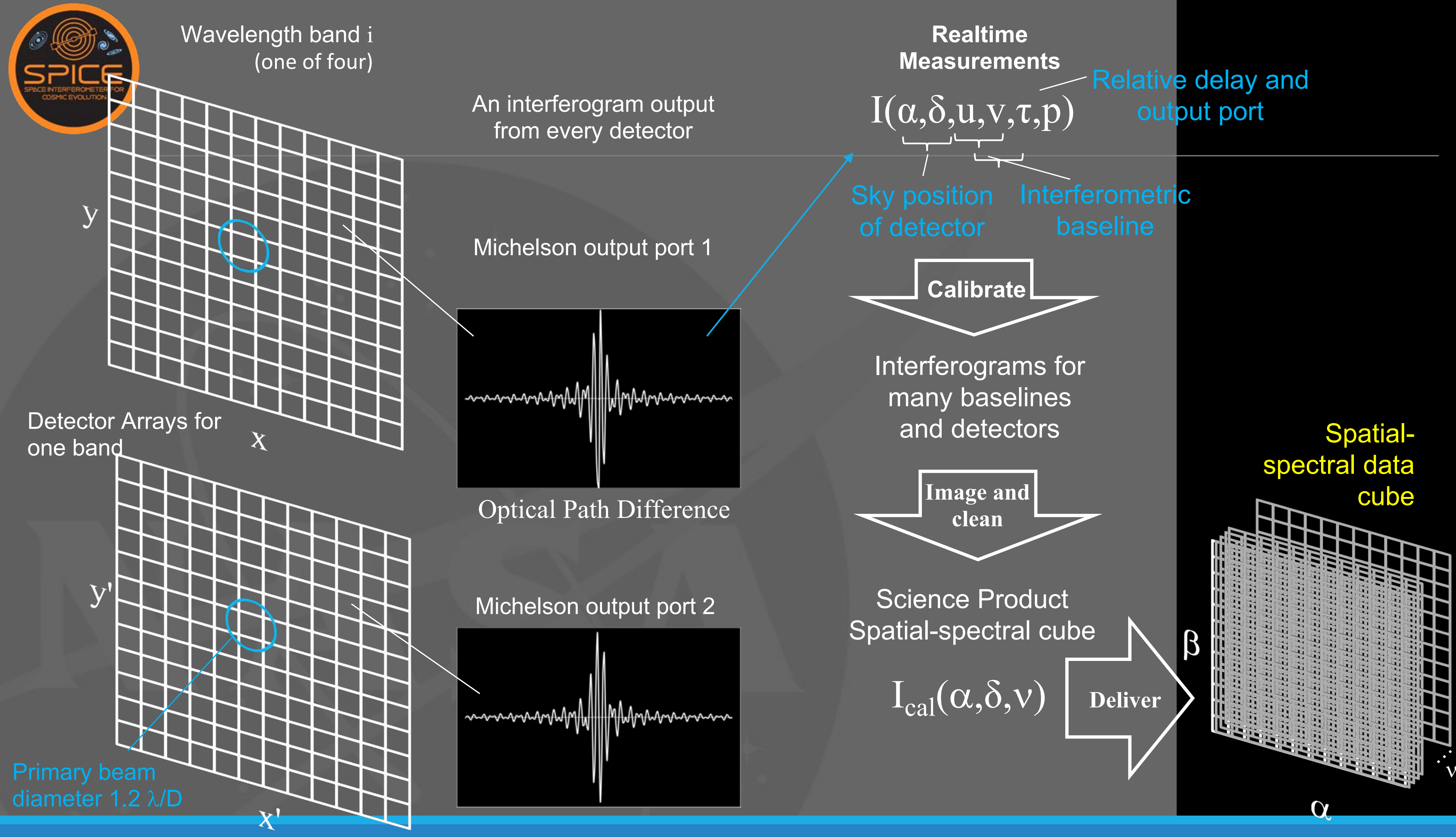
- The resolution is determined by the range covered by the delay.



The anticipated spectral resolutions will be up to $\mathrm{R} = \frac{\lambda}{\Delta\lambda} \sim 3{,}000$



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Wavelength band i
(one of four)
An interferogram output
from every detector
y
x
Detector Arrays for
one band
y'
x'
Primary beam
diameter 1.2 λ/D
Michelson output port 1
Optical Path Difference
Michelson output port 2
Realtime
Measurements
I(α,δ,u,v,τ,p)
Relative delay and
output port
Sky position
of detector
Interferometric
baseline
Calibrate
Interferograms for
many baselines
and detectors
Image and
clean
Science Product
Spatial-spectral cube
I_cal(α,δ,ν)
Deliver
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cube
β
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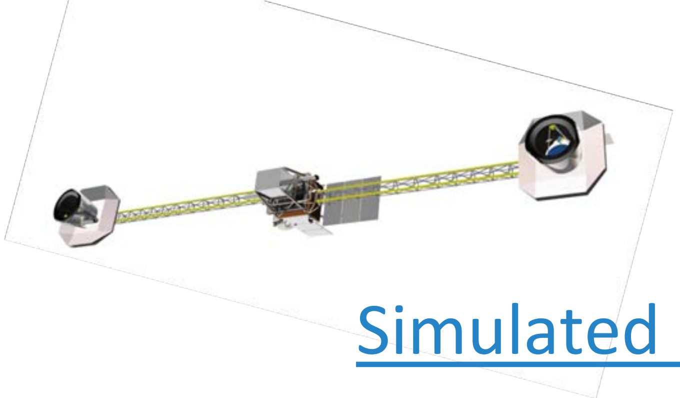
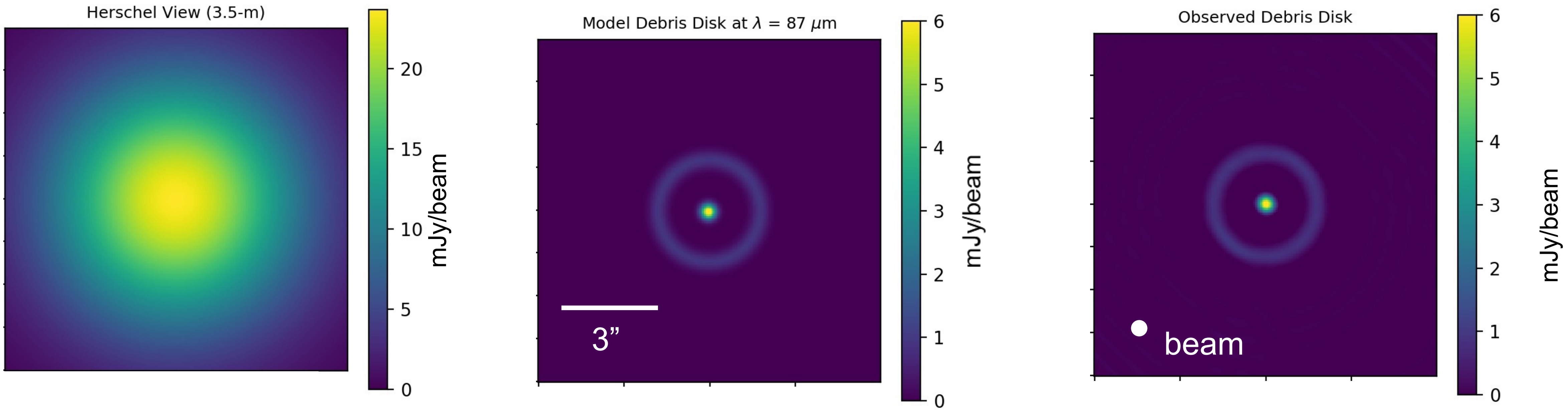
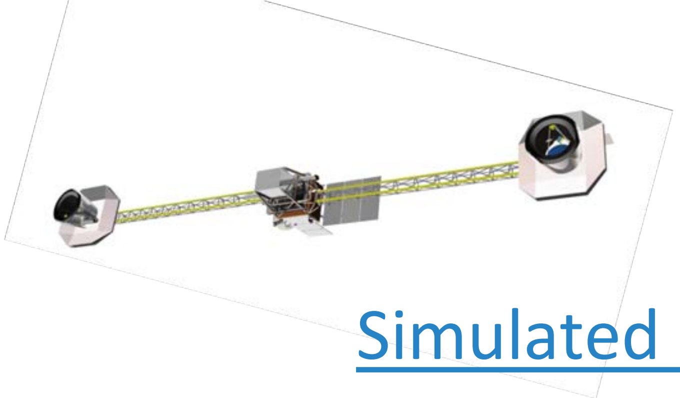


Simulated Observation of Debris Disk

Software under development for full simulation (digital twin) covering from data-taking to final science image.

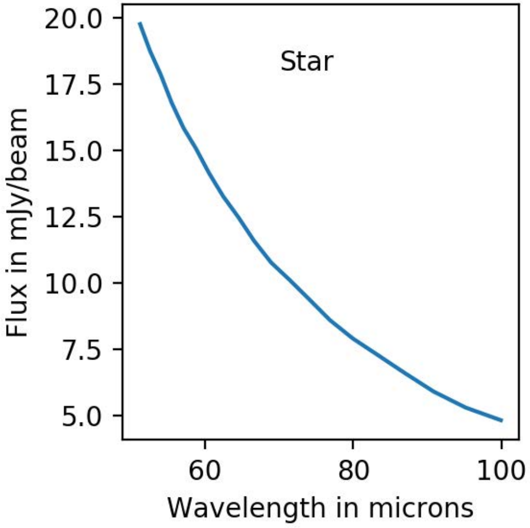


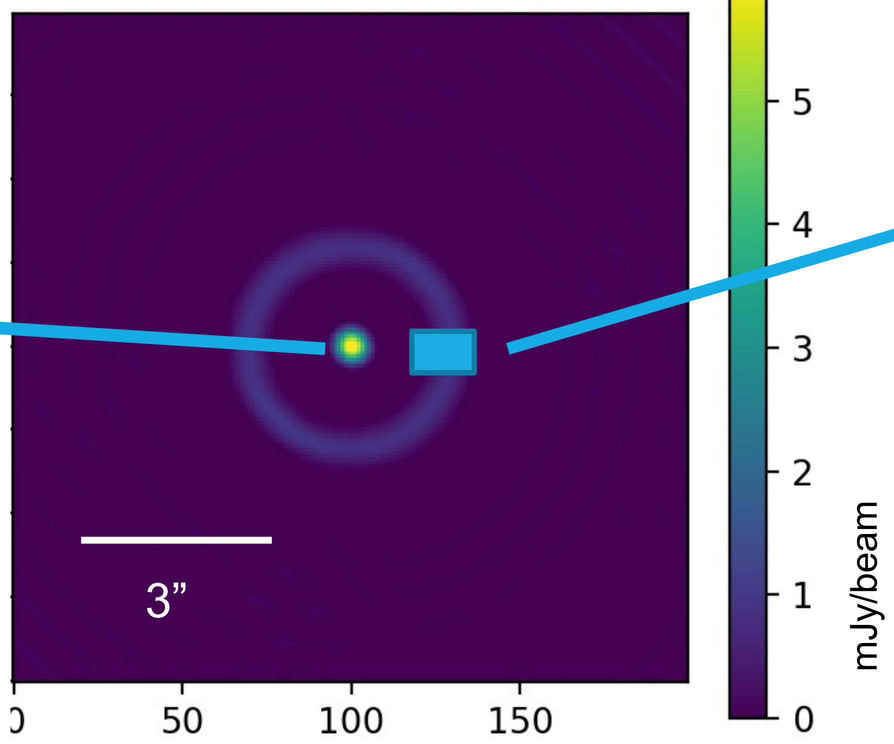


Simulated Observation of Debris Disk

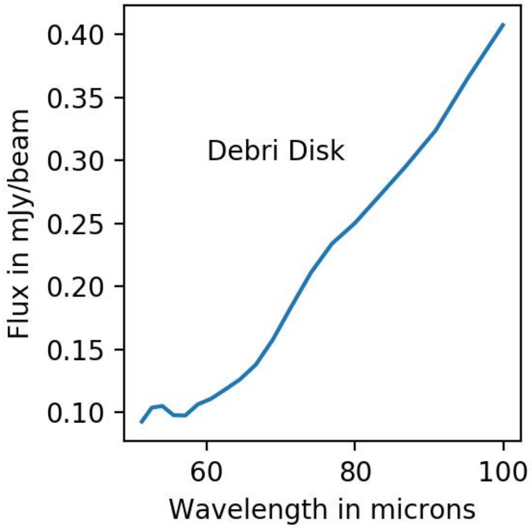
With spectra for every image pixel. R=20 in this example.

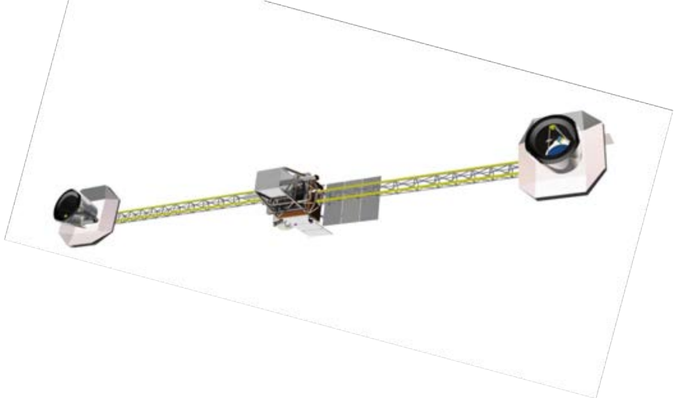
Star is a point source





Average flux in blue box

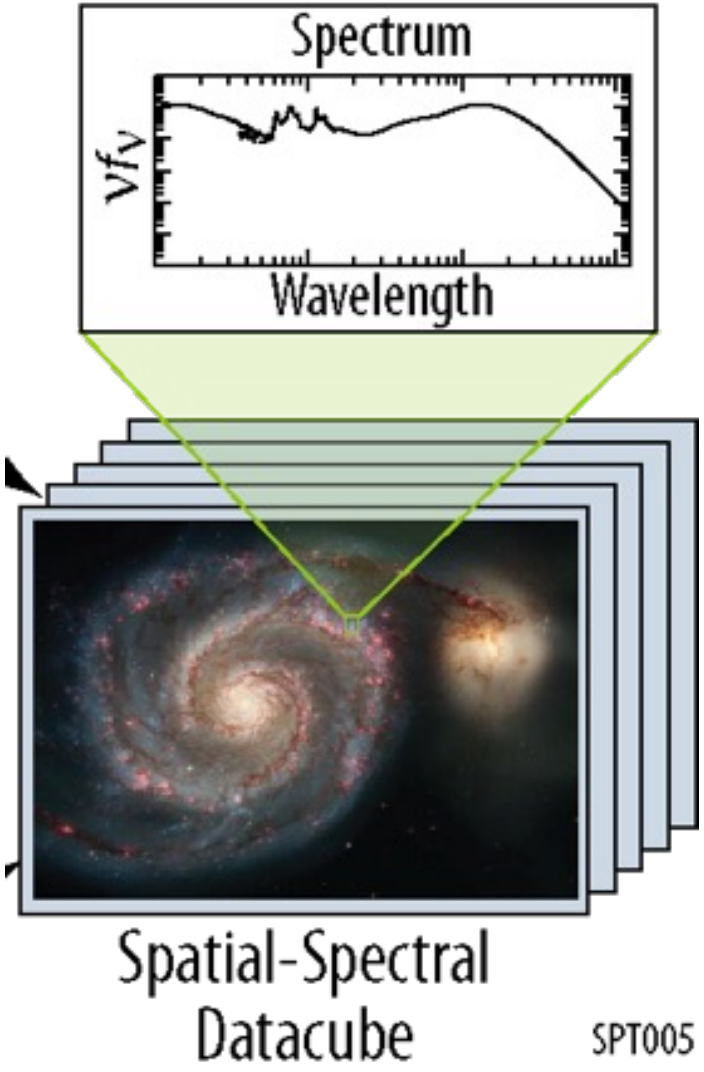




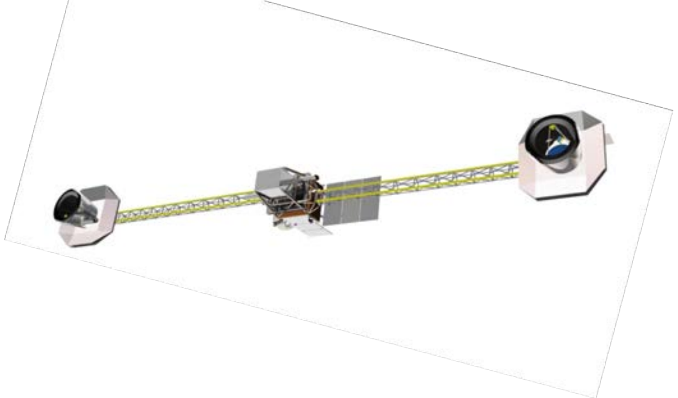
Science Data: Spectral Data Cubes

The primary science products will be hyperspectral cubes:

- one each of the four bands
- combined detector pixels within each band into a single cube.
- the data cube will be 1’ x 1’ (or larger at longer wavelengths and number of spectral channels deep



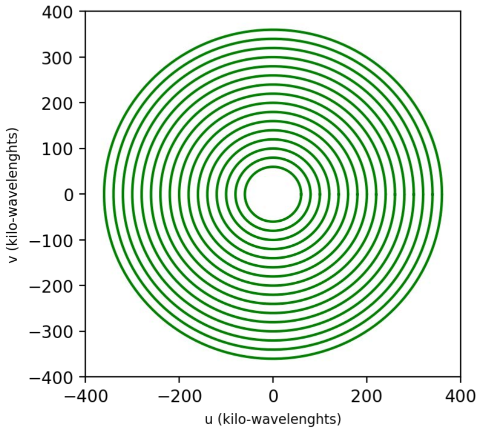
Experts will be able to access the interferograms and instrument data to design specialized observations or develop new reduction techniques.

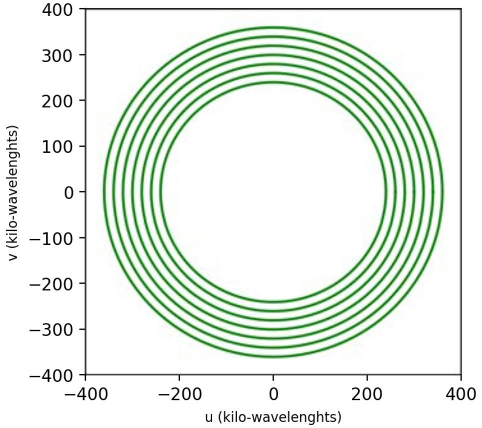


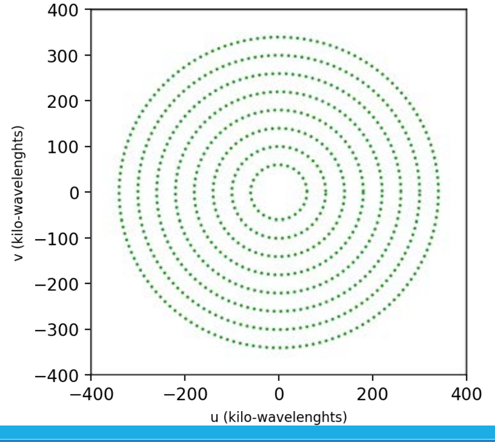
SPICE Observing Modes

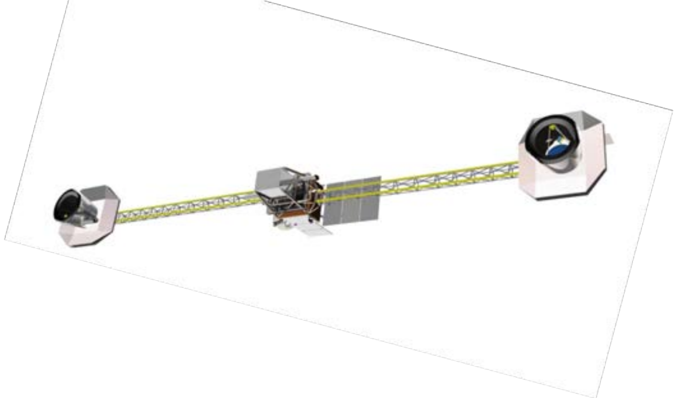
Spice can utilize a number of observing modes to achieve the request scientific objectives.

- Full imaging mode would cover baselines from 6-m to 36-m with a Gaussian weighted distribution in the u,v plane.
- High resolution mode would focus on the longest baselines to study compact sources.
- Survey mode would sparsely sampled along each ring to allow for more area coverage.





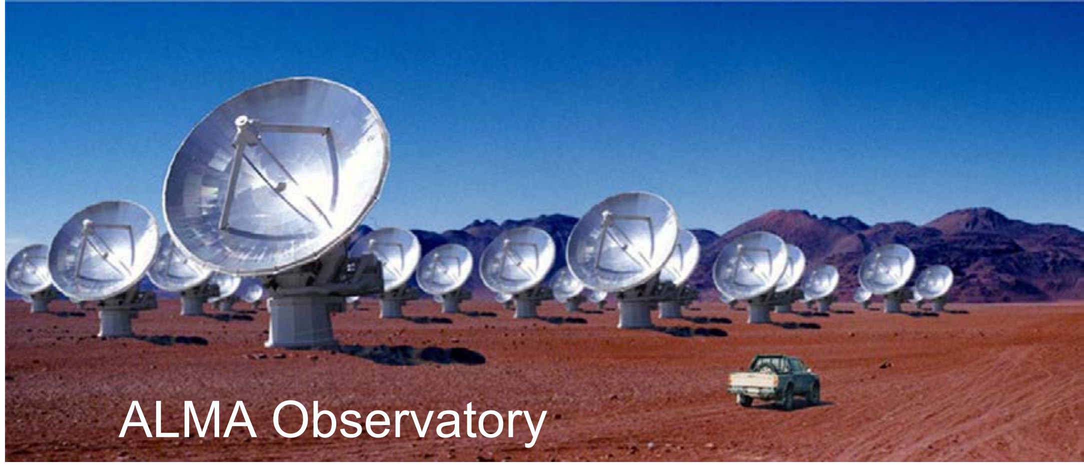




SPICE Spectral Observing Modes

SPICE naturally produces spectra simultaneously on all four wavelength bands. The science can dictate the target resolution.

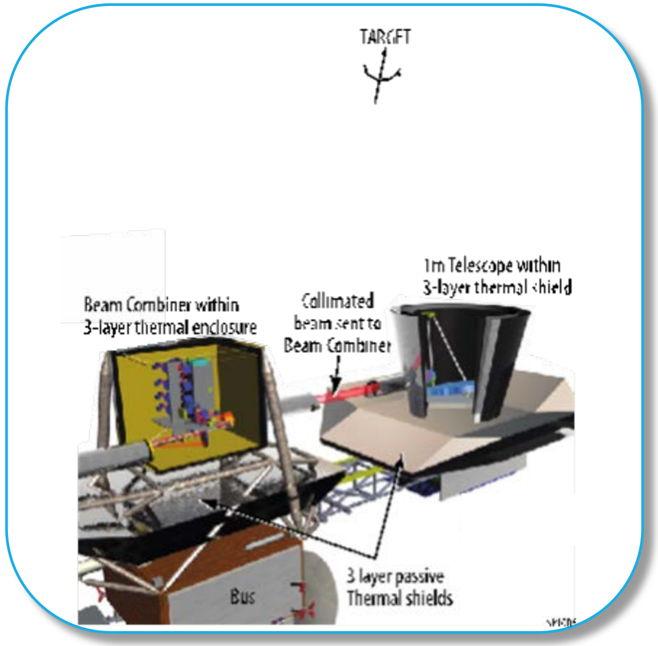
- Low Resolution Mode would be R of 20-30 across each band which would be good for spectral energy distributions.
- High Resolution Mode would be R of 3,000 or greater in each band which would optimize line detections.



ALMA Observatory

SPICE is ALMA in Space

- All of the physics of SPICE is essentially the same as ALMA. The big implementation difference:
  - ALMA uses heterodyne receivers to convert the astronomical signal to electrical signals
  - SPICE works with photons until the final detection.
- Spinning and in/out movement give SPICE the u,v coverage achieved by ALMA with multiple telescopes and Earth rotation synthesis
- Phase tracking is done with near-IR sources for SPICE
- SPICE scanning of delay space is the equivalent of the ALMA correlator



SPICE: One telescope and the central combiner

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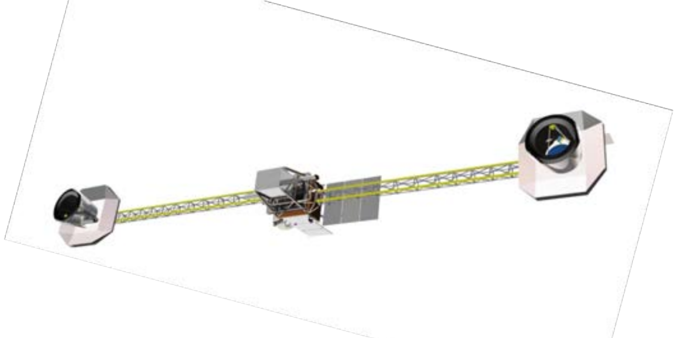
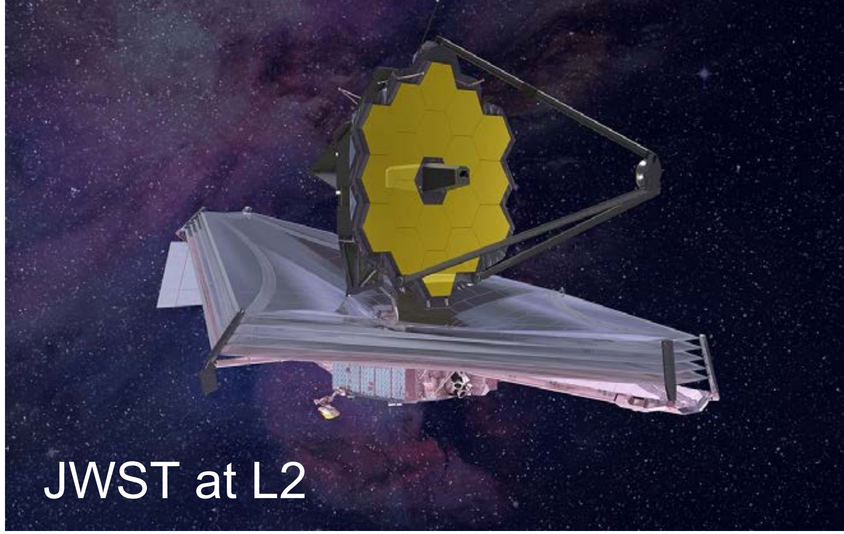
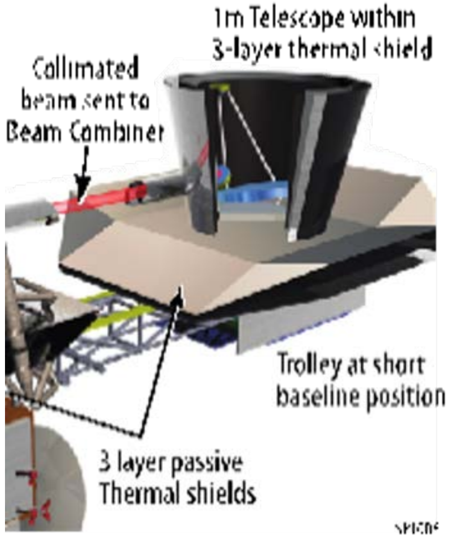




The Space Advantage

Being in space has a number of advantages for an interferometer:

- No atmosphere to create phase instability
- Cold telescopes allows the instrument to be noise limited by irreducible astronomical sources: zodiacal light, galactic cirrus, and diffuse cosmological emission
- SPICE is designed to have symmetric light paths to minimize relative path variations.



Building on the long history of cold telescopes in space