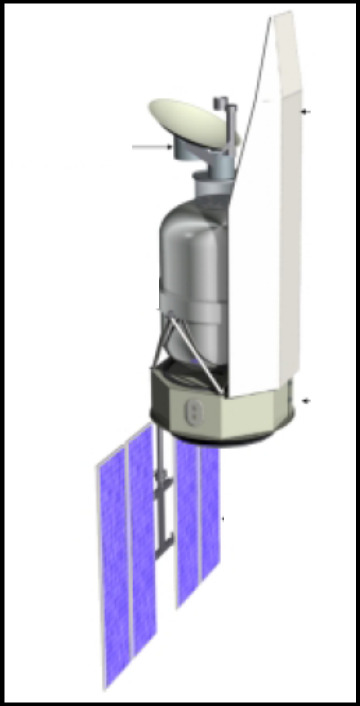
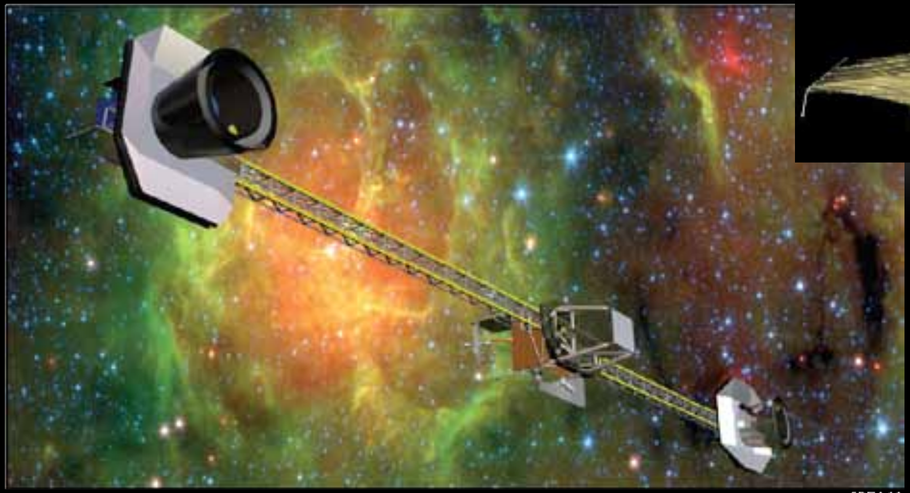
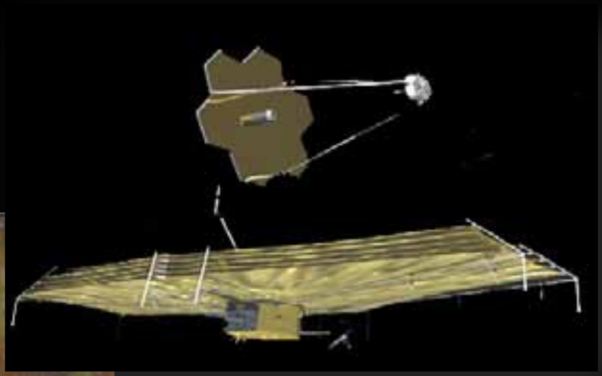
Science prospects for Probe and smaller far-IR missions

Dave Leisawitz, NASA GSFC





SPT019



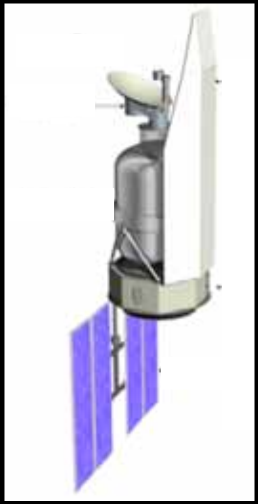
Outline

- Context: COPAG SAG #5
- Far-IR mission concepts and their science objectives and technology requirements:
  - FILM
  - SPIRIT
  - SAFIR/CALISTO
- Discussion

COPAG Science Analysis Groups

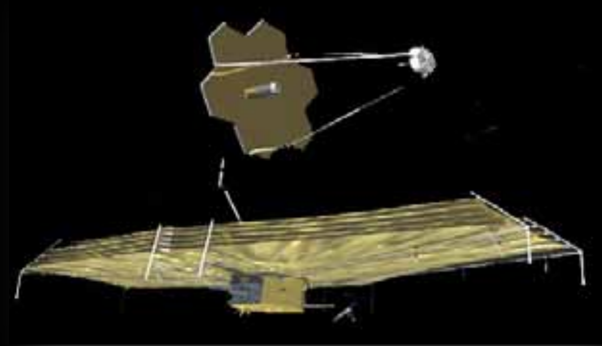
- SAG #1: Science objectives for a 4m–8m UV/Optical mission
- SAG #2: Technologies for a 4m-class monolithic telescope UV/Optical mission w/internal coronograph
- SAG #3: Technologies for an 8m-class segmented telescope UV/Optical mission w/external occulter
- SAG #4: Technologies for a future far-IR mission
- SAG #5: Science objectives & technology requirements for a series of Cosmic Origins Probes

FILM



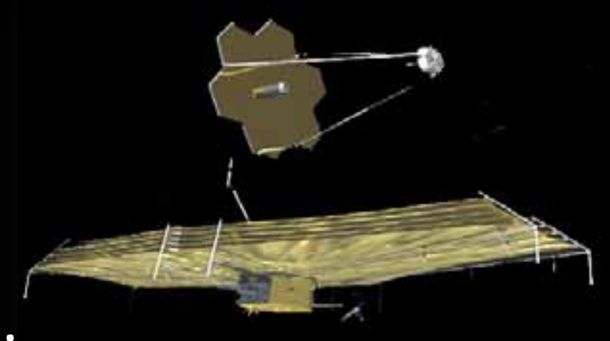
- Heterodyne instrument provides high sensitivity and high spectral resolution measurements of [CII] and [NII] lines throughout the Milky Way
- 50 cm diameter primary mirror
- 2 K mixers, 30 K amplifiers
- Instrument components are either flight proven, fully qualified, or in full-scale flight qualification development
- Proposed by JPL as a MIDEX mission

SAFIR/CALISTO



- Extraordinarily high sensitivity far-infrared continuum and moderate (R ~ 1000) resolution spectroscopic observations at wavelengths from ~30μm to ~300 μm
- 4 x 6 m primary telescope behind multi-layer Sun shade, cryocooled to <5 K
- Active optical system corrects for cooling-induced deformation, reduces test cost
- Full sky mapping to the confusion limit, plus targeted object spectroscopy
- JPL Team X estimated cost $1.7B (FY08)
- Mission white paper by P. Goldsmith *et al.*

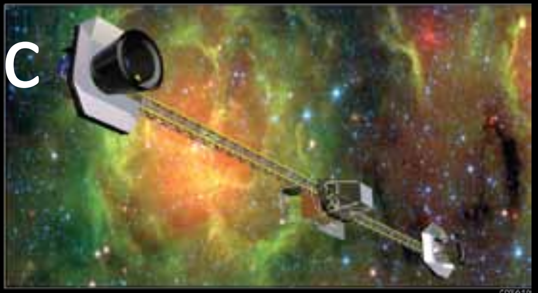
CALISTO Science



CALISTO's observations will provide vital information about:

- The first stars and initial heavy element production in the universe;
- Structures in the universe traced by H_2 emission;
- The evolution of galaxies and the star formation within them;
- The formation of planetary systems through observations of protostellar and debris disks; and
- The outermost portions of our solar system through observations of Trans-Neptunian Objects (TNOs) and the Oort cloud.

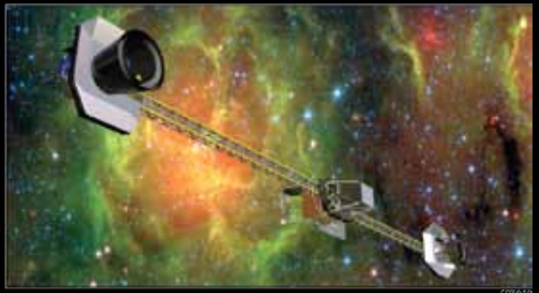
Space Infrared Interferometric Telescope (SPIRIT)



- Subject of a year-long pre-Phase A study as an “Origins Probe” mission
- Two 1-m diameter cryocooled telescopes on a 36 m structure
- Dense *u-v* plane coverage and scanning optical delay line for high-resolution spatio-spectral interferometry (technique developed in lab at GSFC)
  - high quality images
  - spectral resolution ~3000
- Grass roots cost estimate $1.3B (FY09) for full mission, including technology development; PRICE H independent cost estimate validates grass roots estimate
- BETTII balloon interferometer is under development at GSFC (S. Rinehart, PI)
- European partnership a strong possibility
- Mission white paper by D. Leisawitz *et al.*

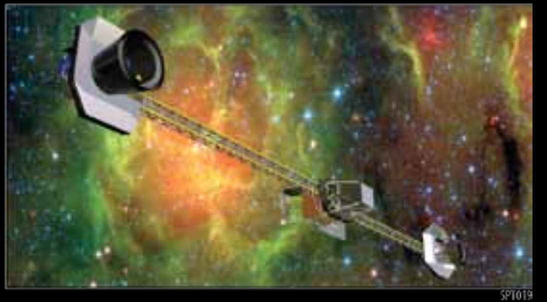
http://astrophysics.gsfc.nasa.gov/cosmology/spirit/

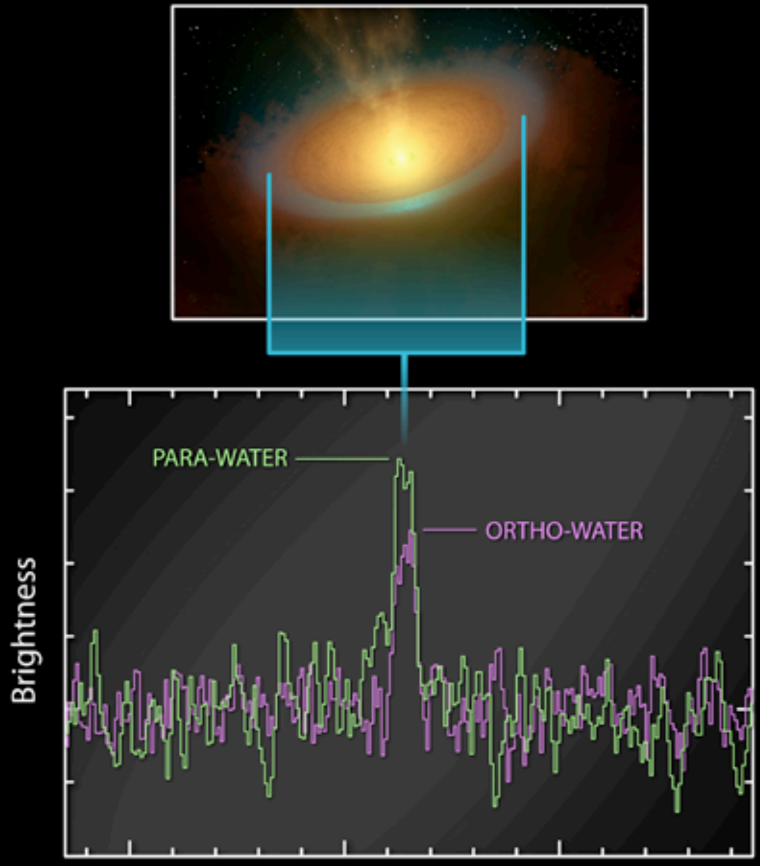
SPIRIT: Achievable Science in a Probe-class Far-IR Mission



- How do the conditions for habitability arise during planet formation?
- Find and characterize exoplanets by imaging and measuring the structures in protoplanetary and debris disks
- How did high-redshift galaxies form and merge to form the present-day population of galaxies?

Forming habitable planets





HIFI Spectroscopic Signatures of Water Vapor in TW Hydrae Disk
ESA/NASA/JPL-Caltech/M. Hogerheijde (Leiden Observatory)

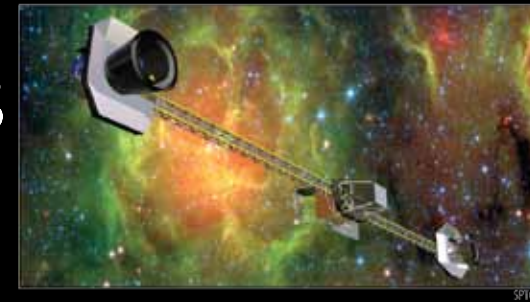
How did the Earth acquire its water? How do habitable plants form?

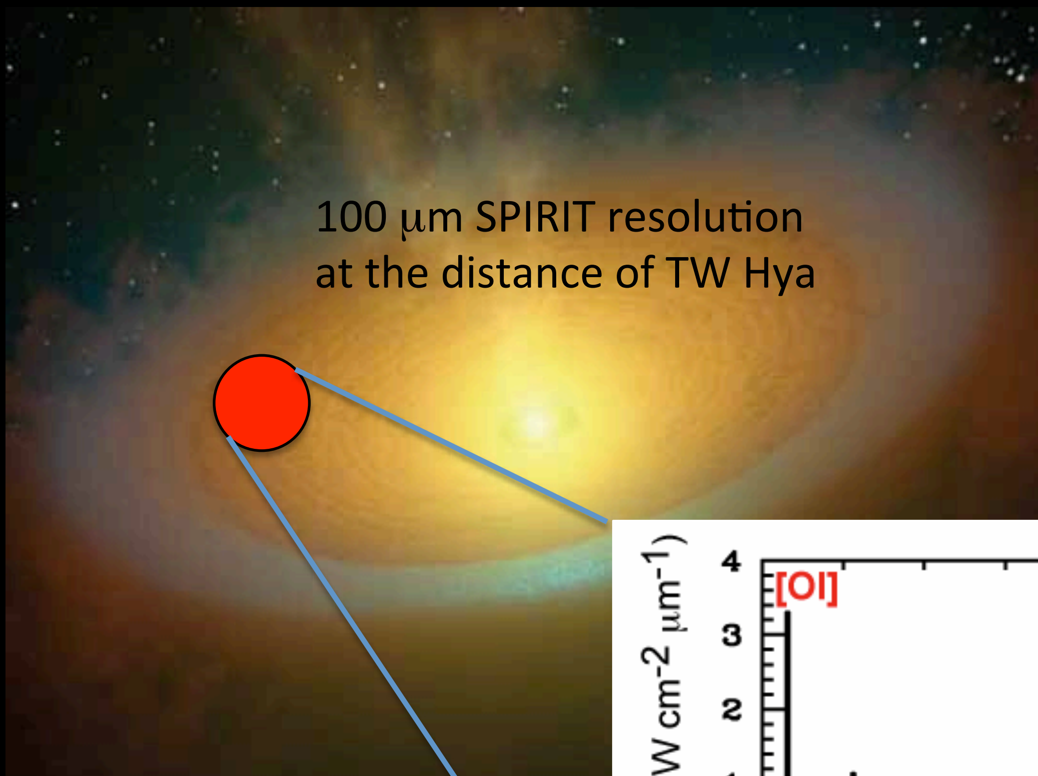
Herschel observes developing planetary systems and measures water, but it can't resolve these objects spatially.

Theorists have models, but lack unique solutions.

Spatially resolved spectroscopy will break model degeneracy.

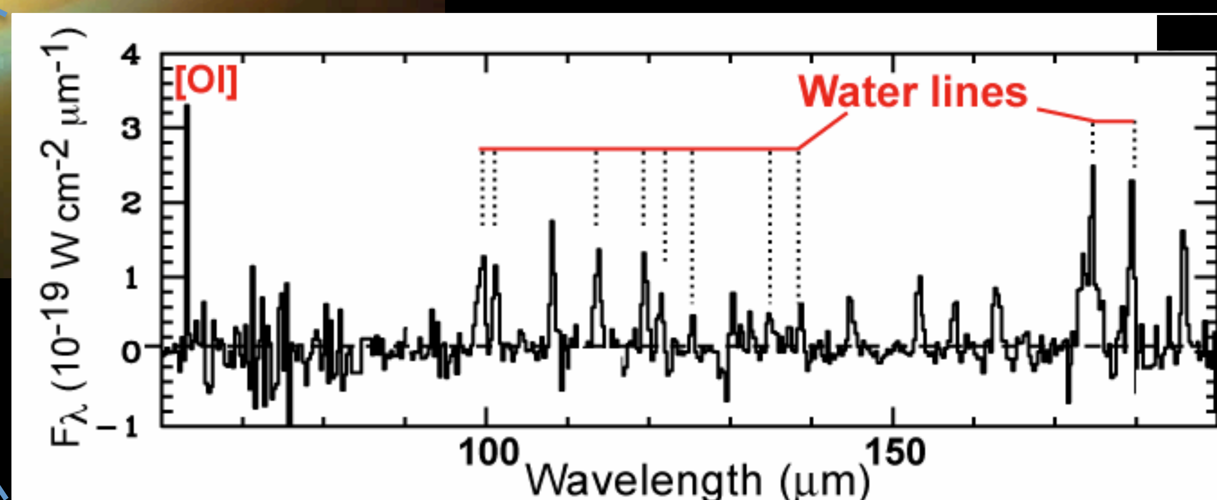
Forming habitable planets



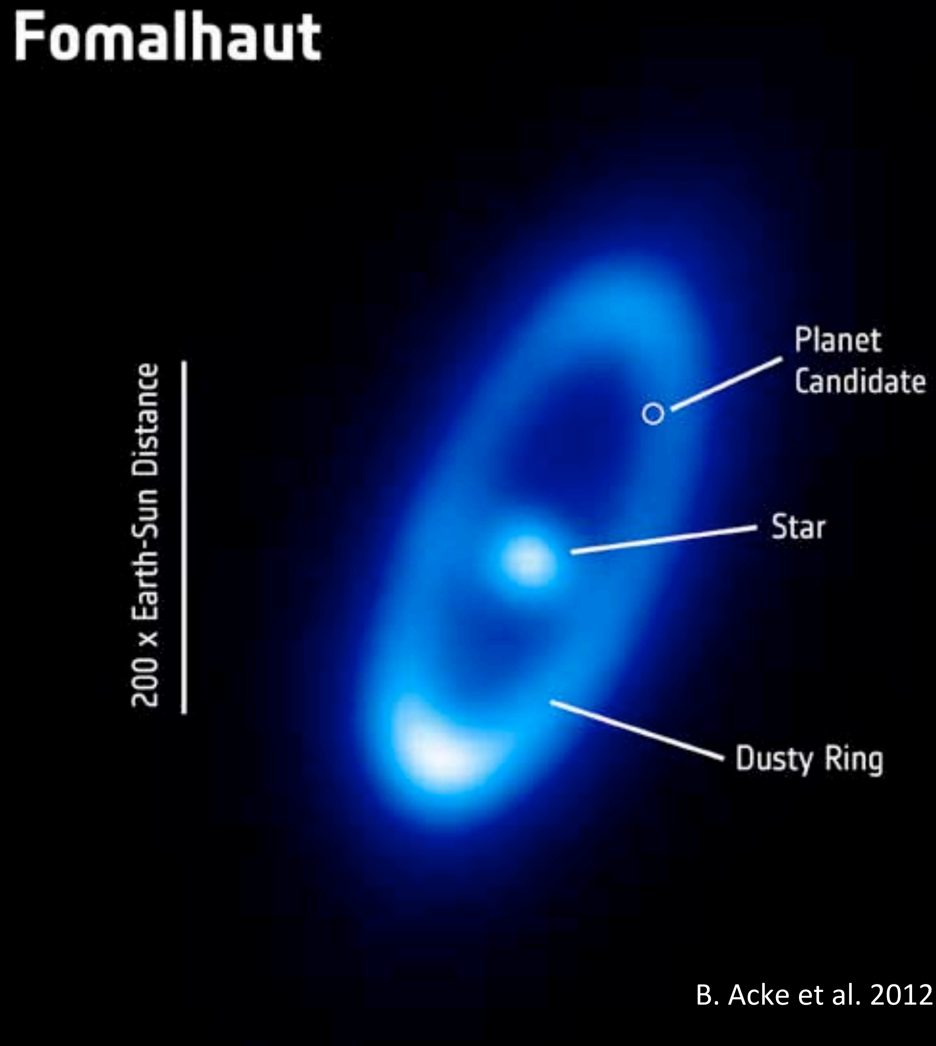


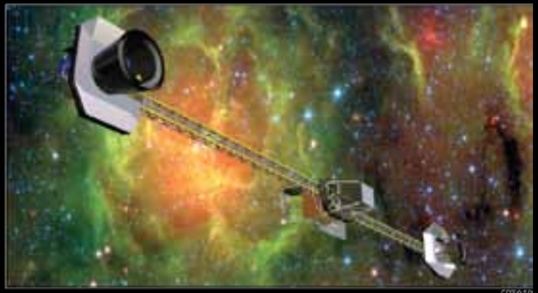
How did the Earth acquire its water? How do habitable plants form?

SPIRIT will provide the missing information



Debris disks: from the Fab 4 …





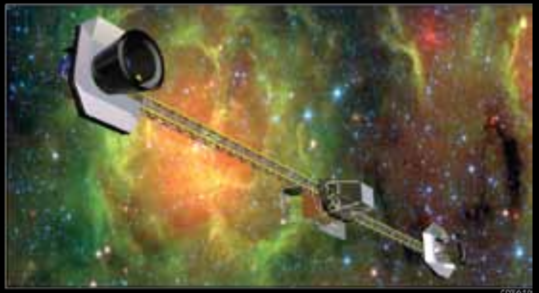
IRAS discovered the "fabulous 4" debris disks

Spitzer imaged them

Herschel vastly improved the picture and captured this stunning image of the Fomalhaut disk

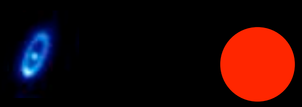
B. Acke et al. 2012

… to hundreds!



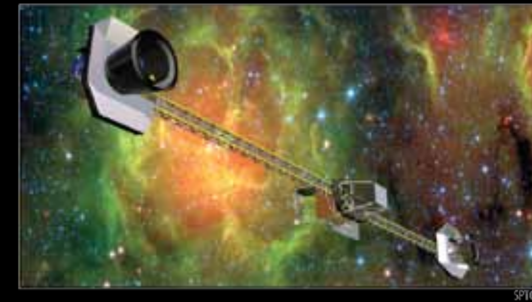
At 100 pc,

To image <u>hundreds</u> of debris disks and tap them for information about planetary systems, we'll have to image disks out to 100 pc.

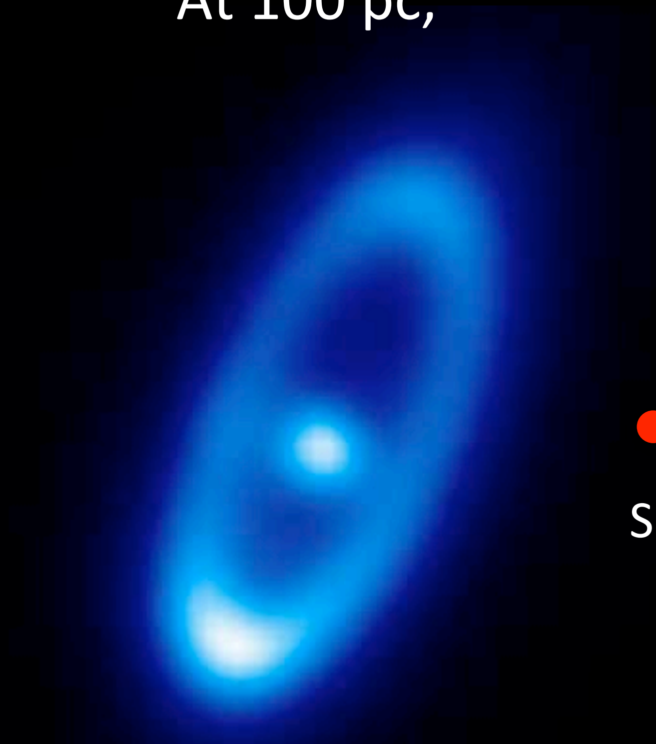


Herschel at 70 μm

a 3.5 m telescope isn't big enough.



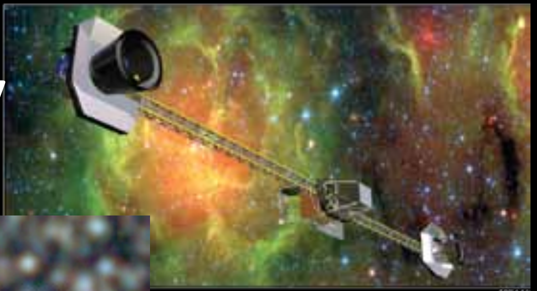
At 100 pc,

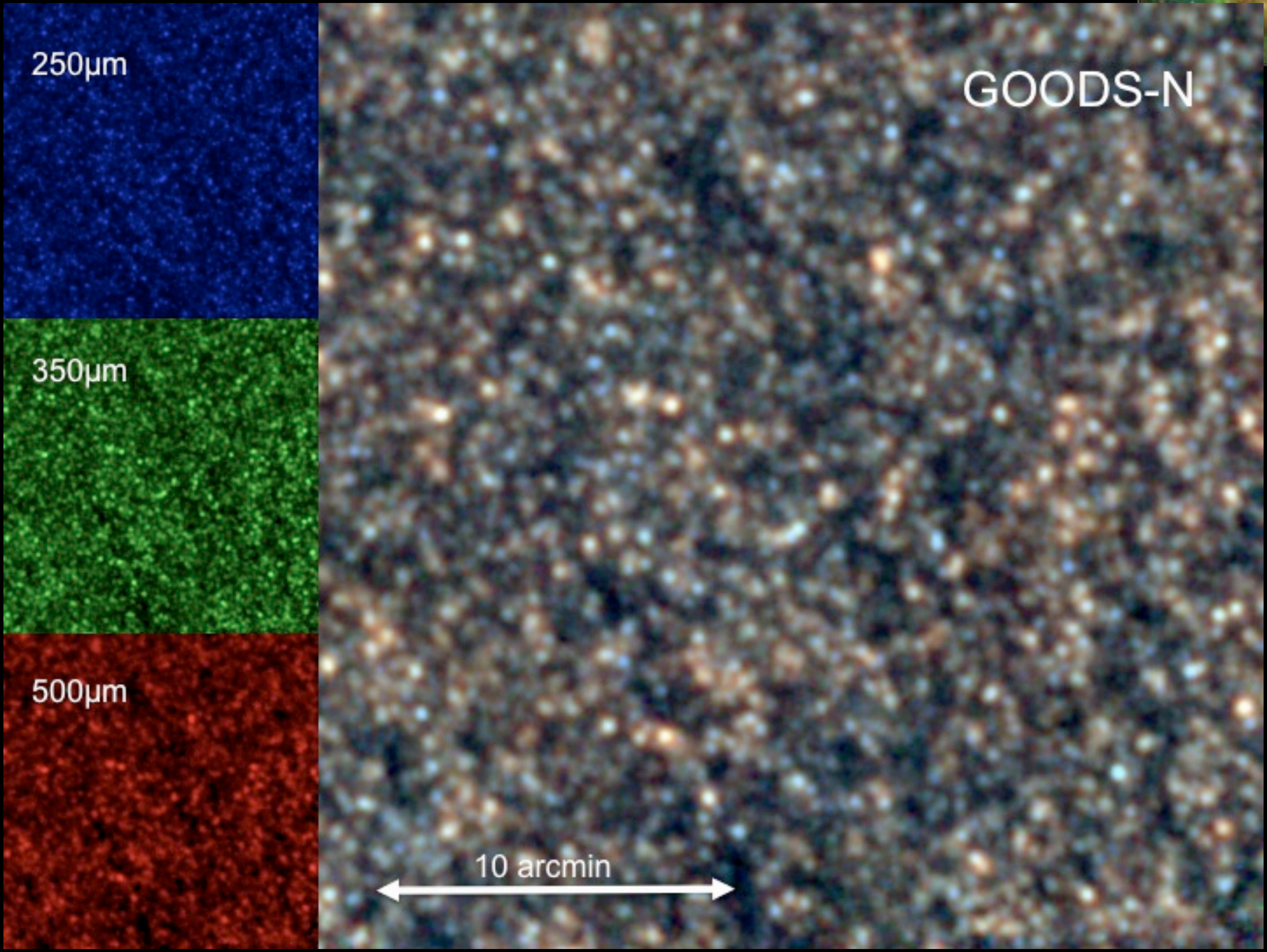


SPIRIT at 70 μm

SPIRIT will image <u>hundreds</u> of debris disks!

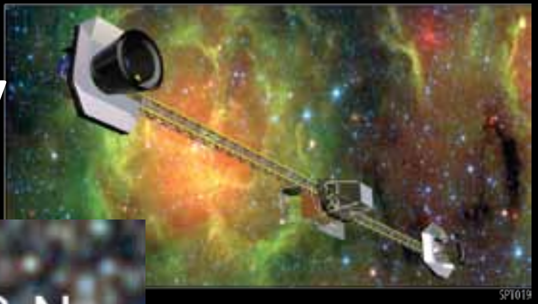
Probe the Universe deeply

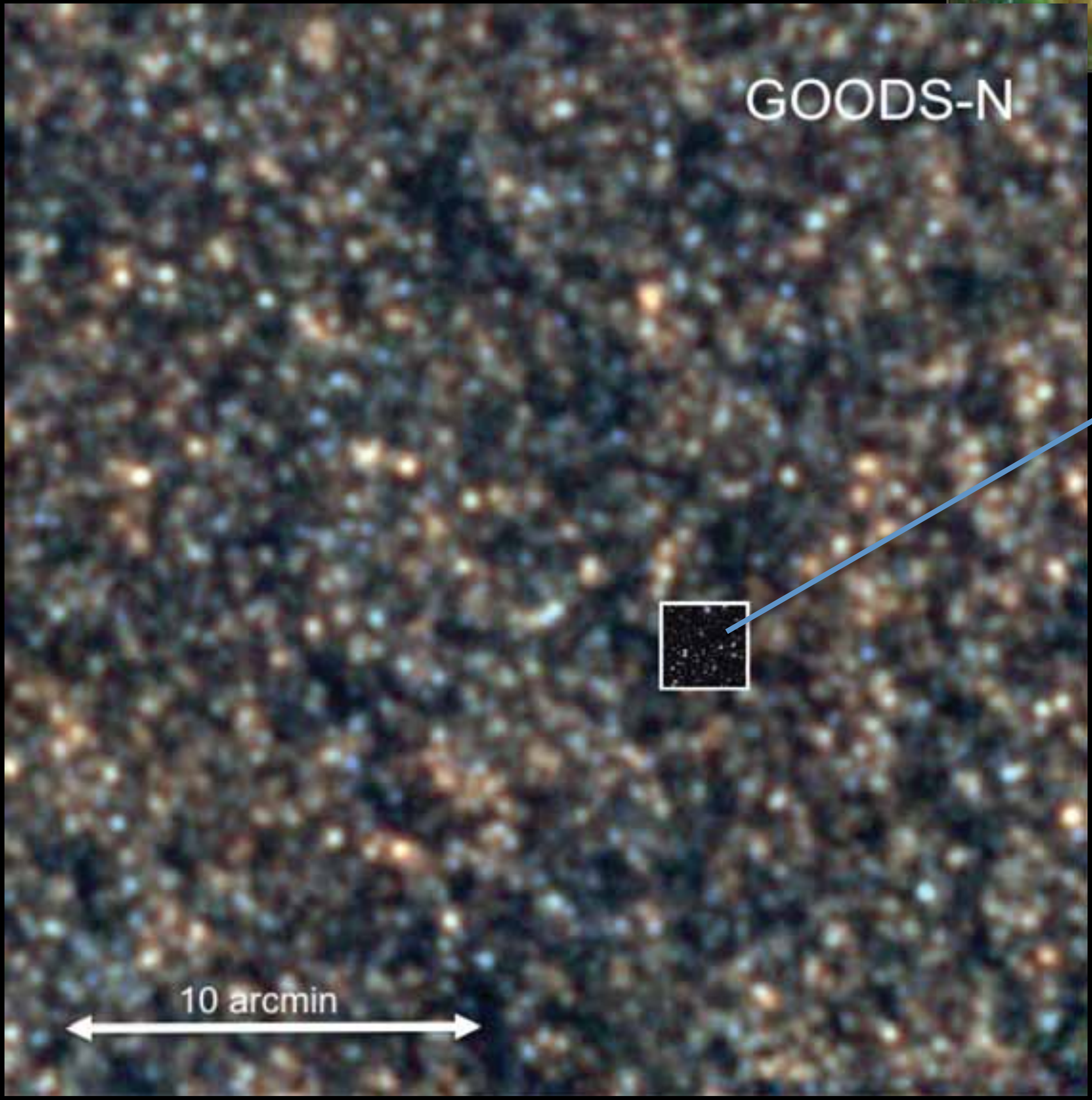




Herschel deep field

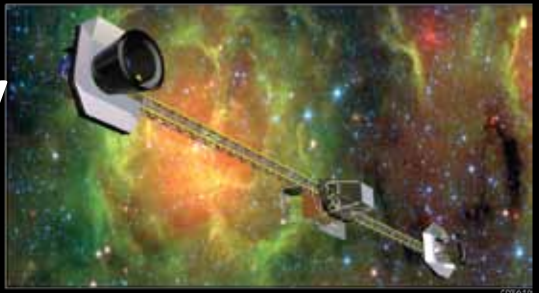
Probe the Universe deeply



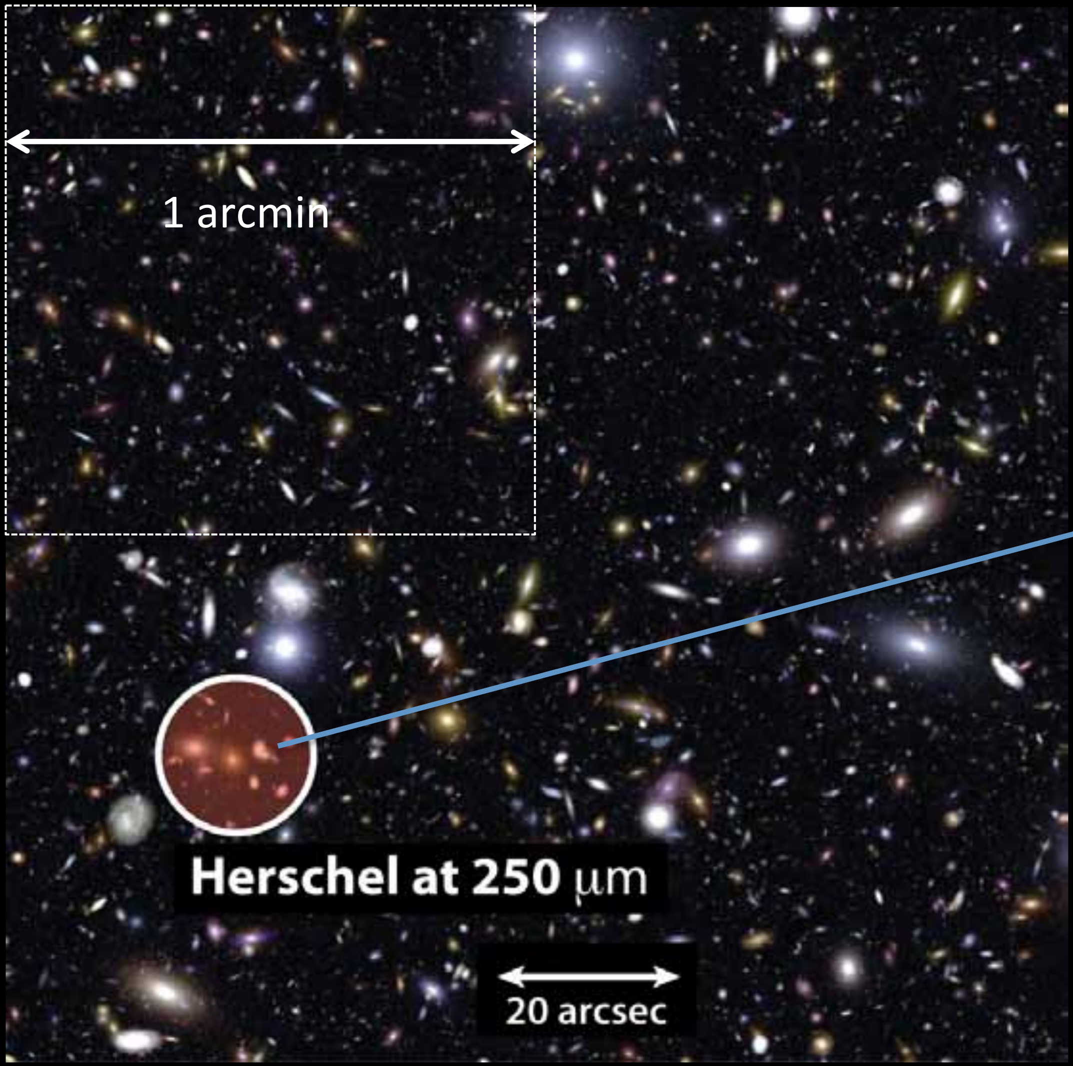


JWST deep field

Probe the Universe deeply

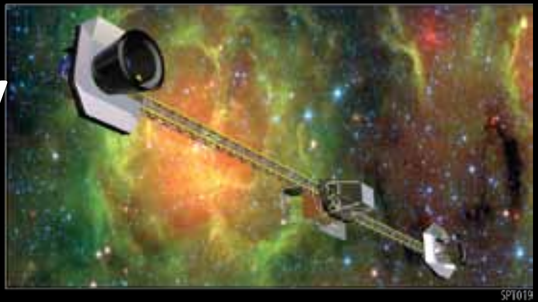


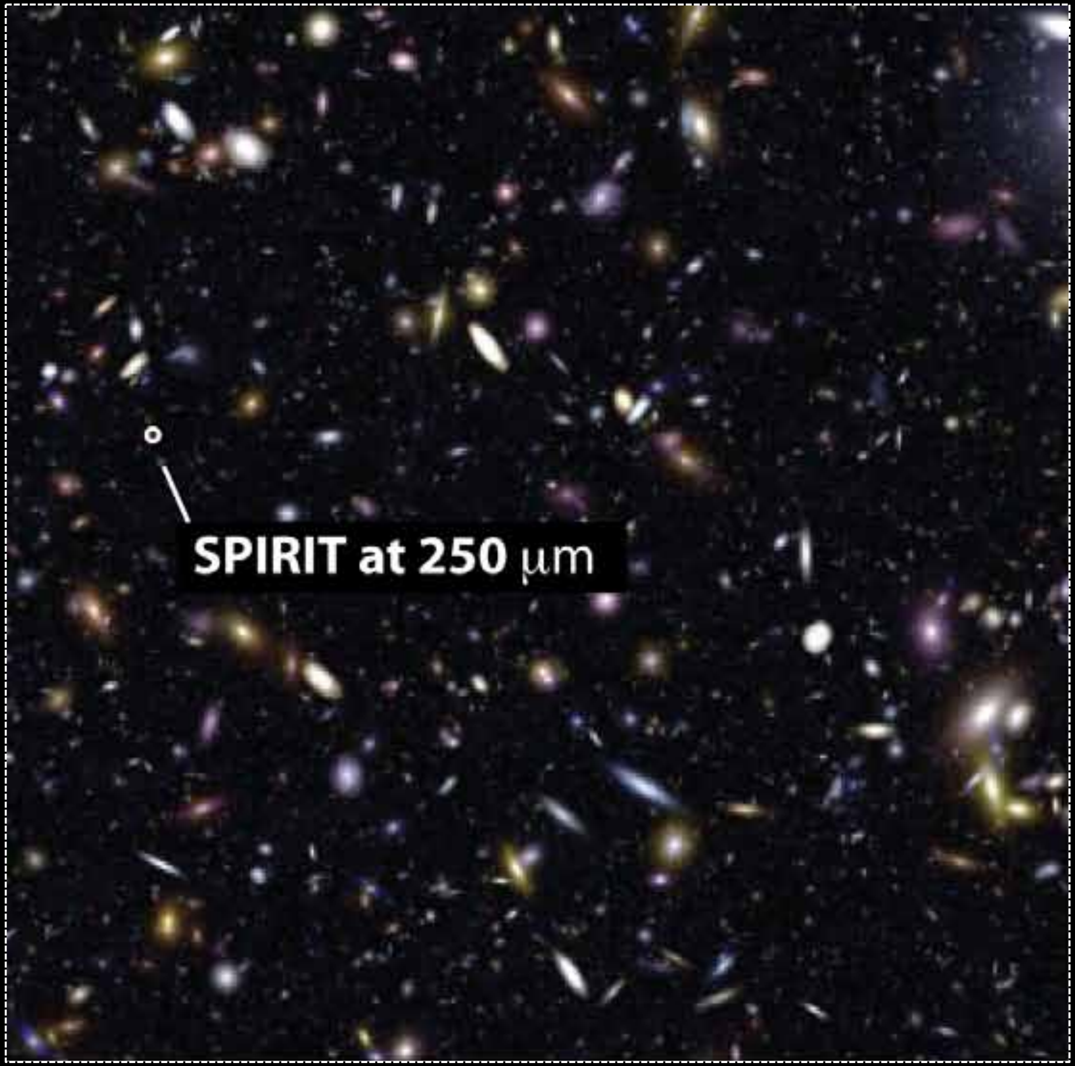
JWST deep field



many galaxies per Herschel beam

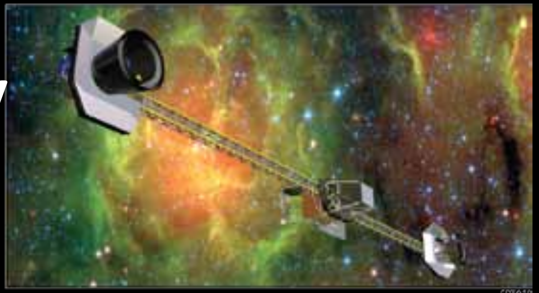
Probe the Universe deeply

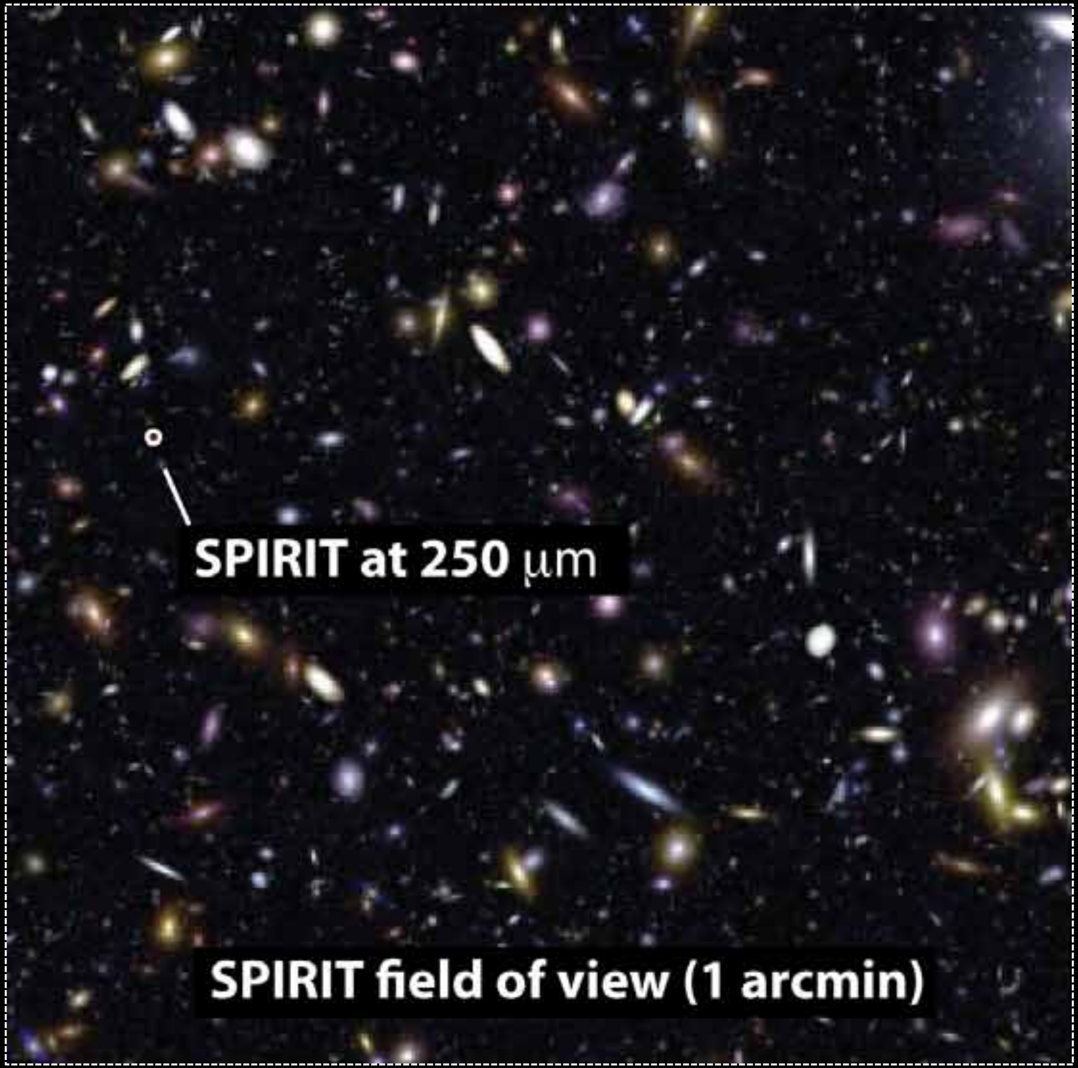




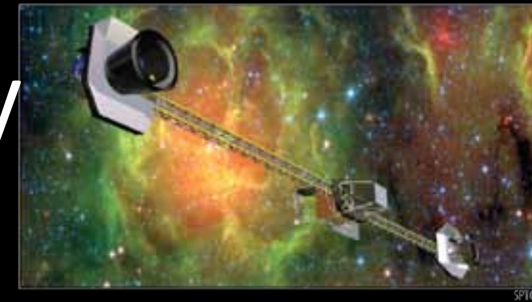
JWST deep field
(1 arcmin cutout)

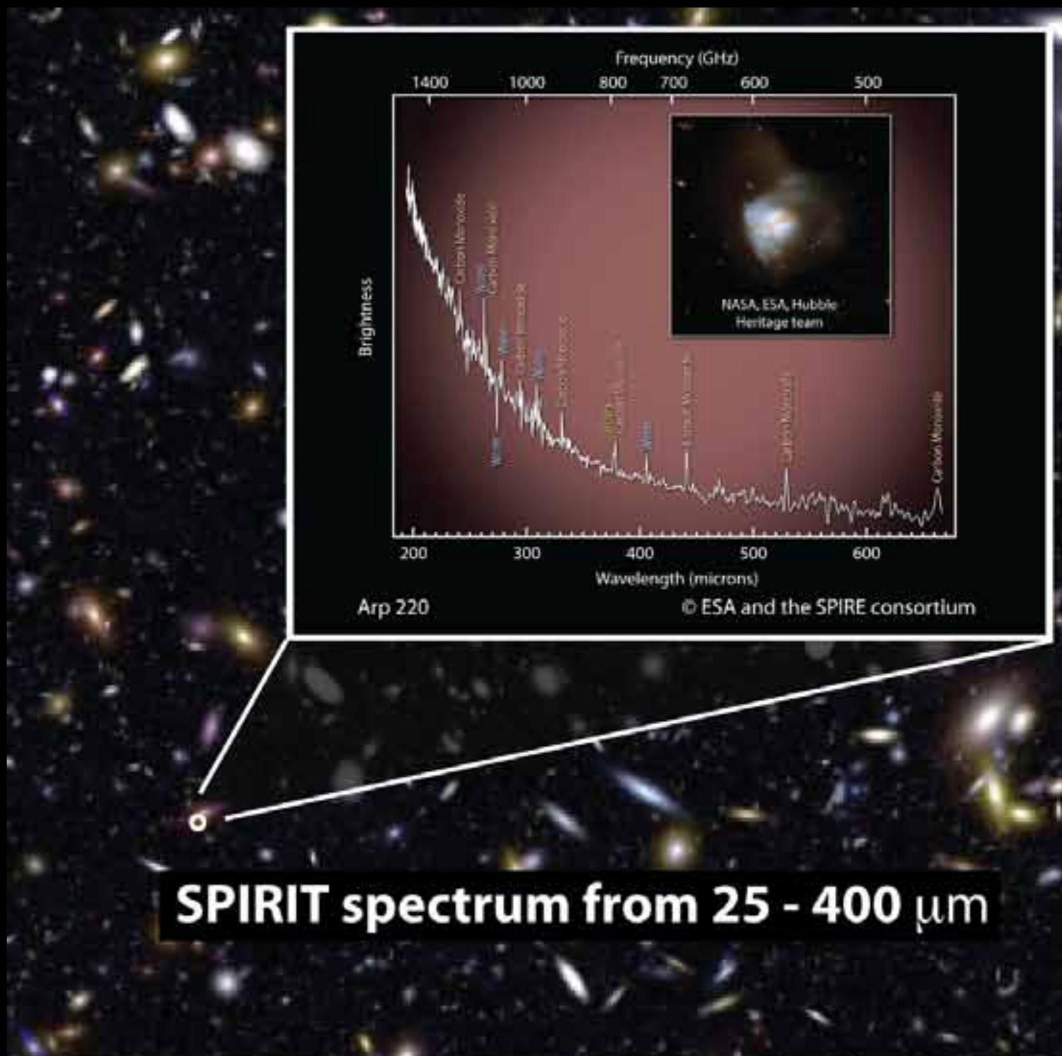
Probe the Universe deeply





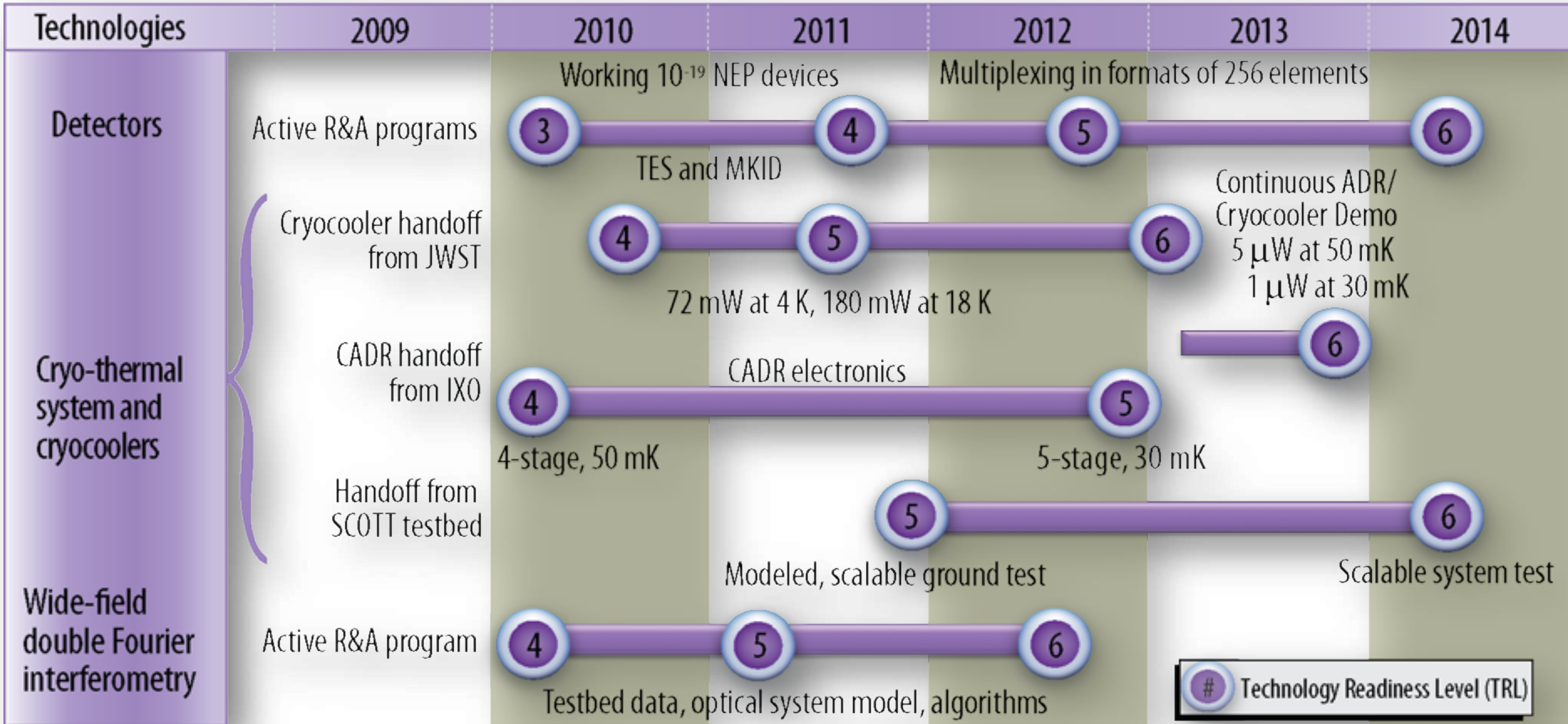
Probe the Universe deeply





SPIRIT will measure the dominant interstellar gas cooling lines and diagnostic lines in the spectra of individual high-redshift galaxies.

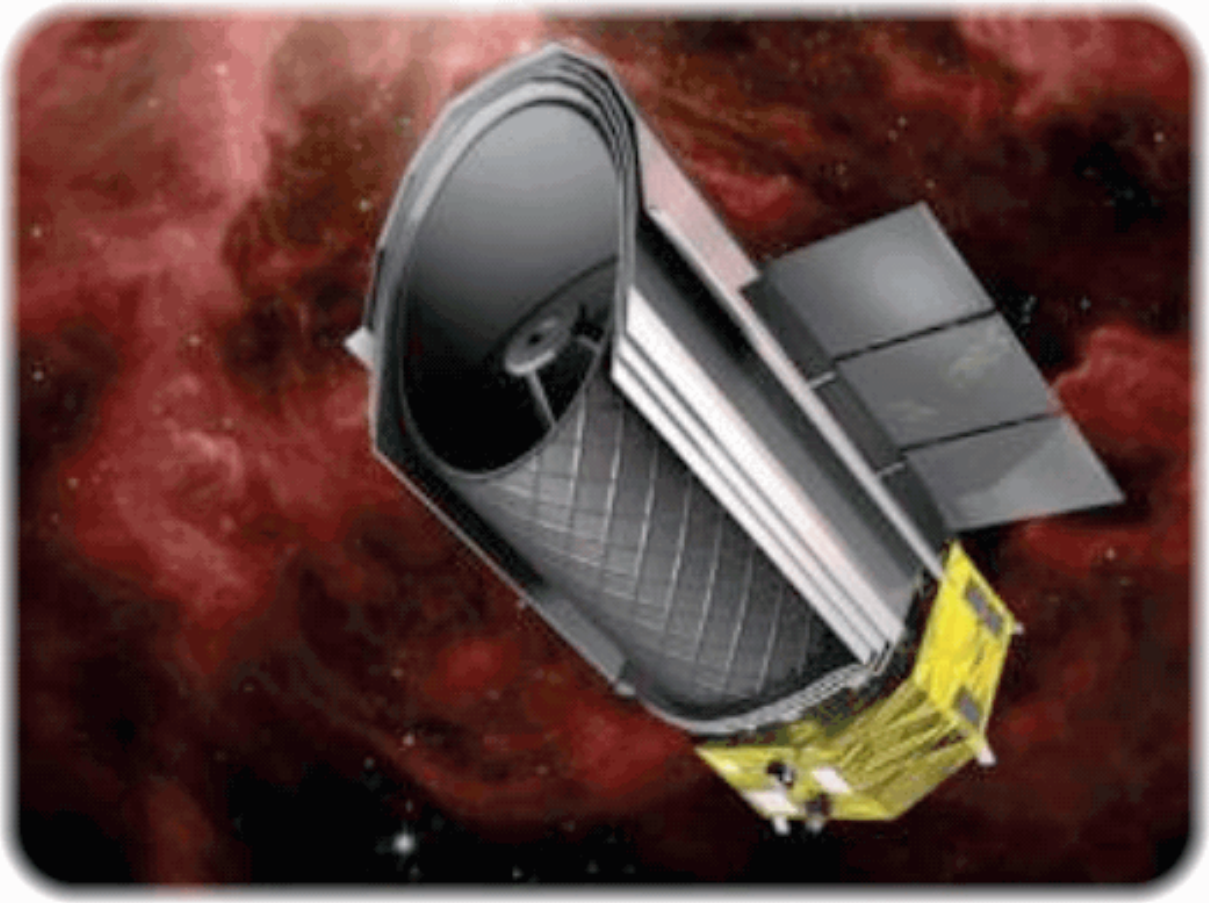
Technology Roadmap



and an active optical system for SAFIR/CALISTO

See Program Annual Technology Report for Cosmic Origins at http://cor.gsfc.nasa.gov

SPICA is driving detector technology



T. Nakagawa's talk, SPIE [8442-21], July 2012

Conclusions and Recommendation

- A Probe-class far-IR mission can achieve high priority Decadal science goals
- The enabling technology is within reach
- The European community is very interested in far-IR interferometry (Cosmic Visions FIRI concept and organized technology investment), suggesting possible ESA partnership to make SPIRIT affordable as a Probe
- With sustained, coordinated investment in the enabling technologies and post-Herschel mission studies, the US community can provide NASA with a viable far-IR Probe concept in time for the mid-Decadal review

We recommend a program of sustained, coordinated investment in the enabling technologies for a far-IR Probe, and post-Herschel far-IR Probe mission studies in the coming year.

BACKUP

SPIRIT Mission Study Team

SPIRIT Origins Probe Mission Concept Study Team

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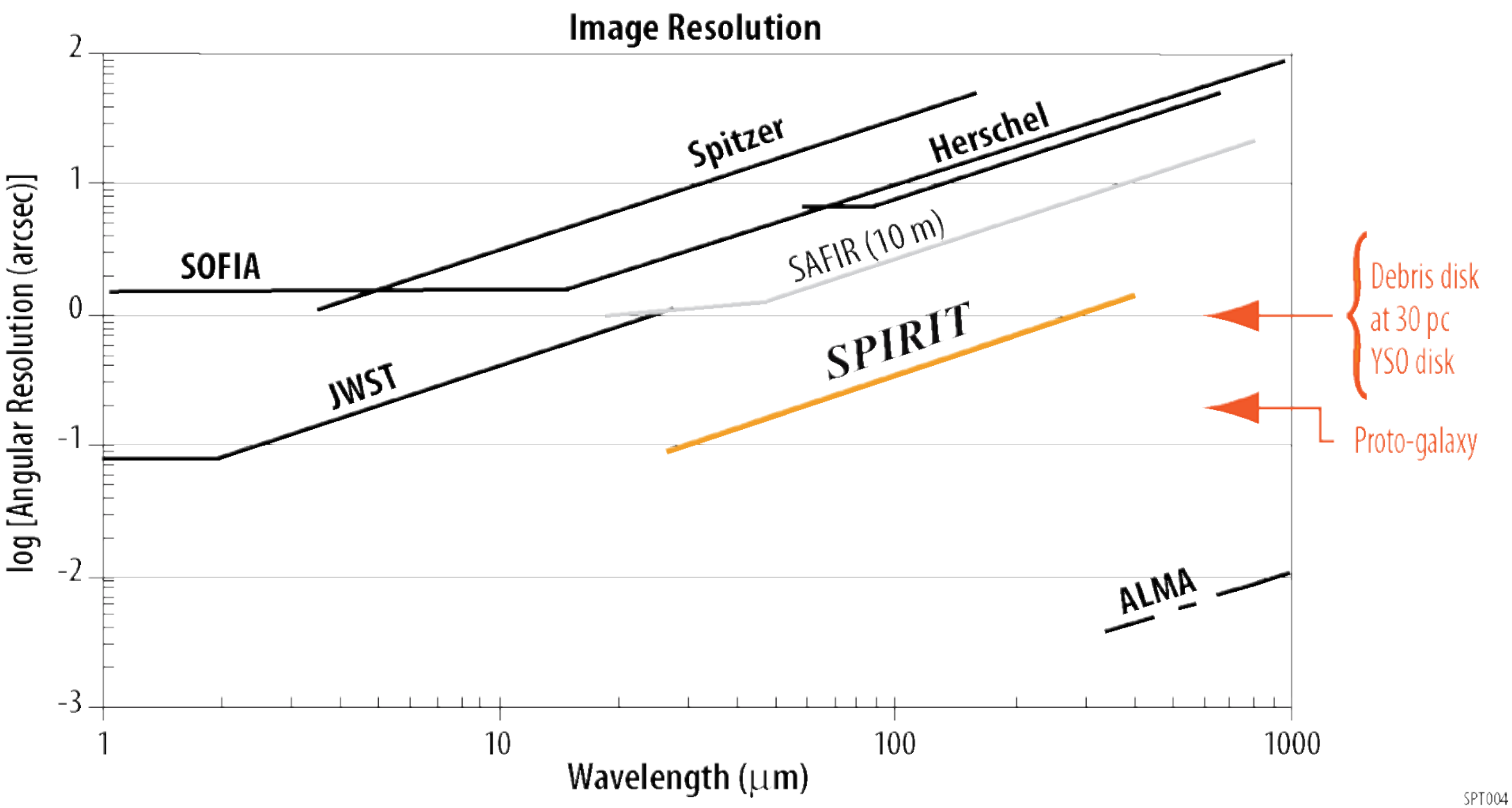
Interferometry is the natural choice when the need for better angular resolution surpasses the need for improved sensitivity as the driver for aperture size.

The 85 cm diameter Spitzer telescope demonstrates the extraordinary power of a space-based cryogenic telescope equipped with low-noise detectors. The sky is teeming with far-IR photons!

In the far-IR, interferometry (wavefront control) is not difficult; the technical challenges are those to which we are accustomed: detectors and cold temperatures.

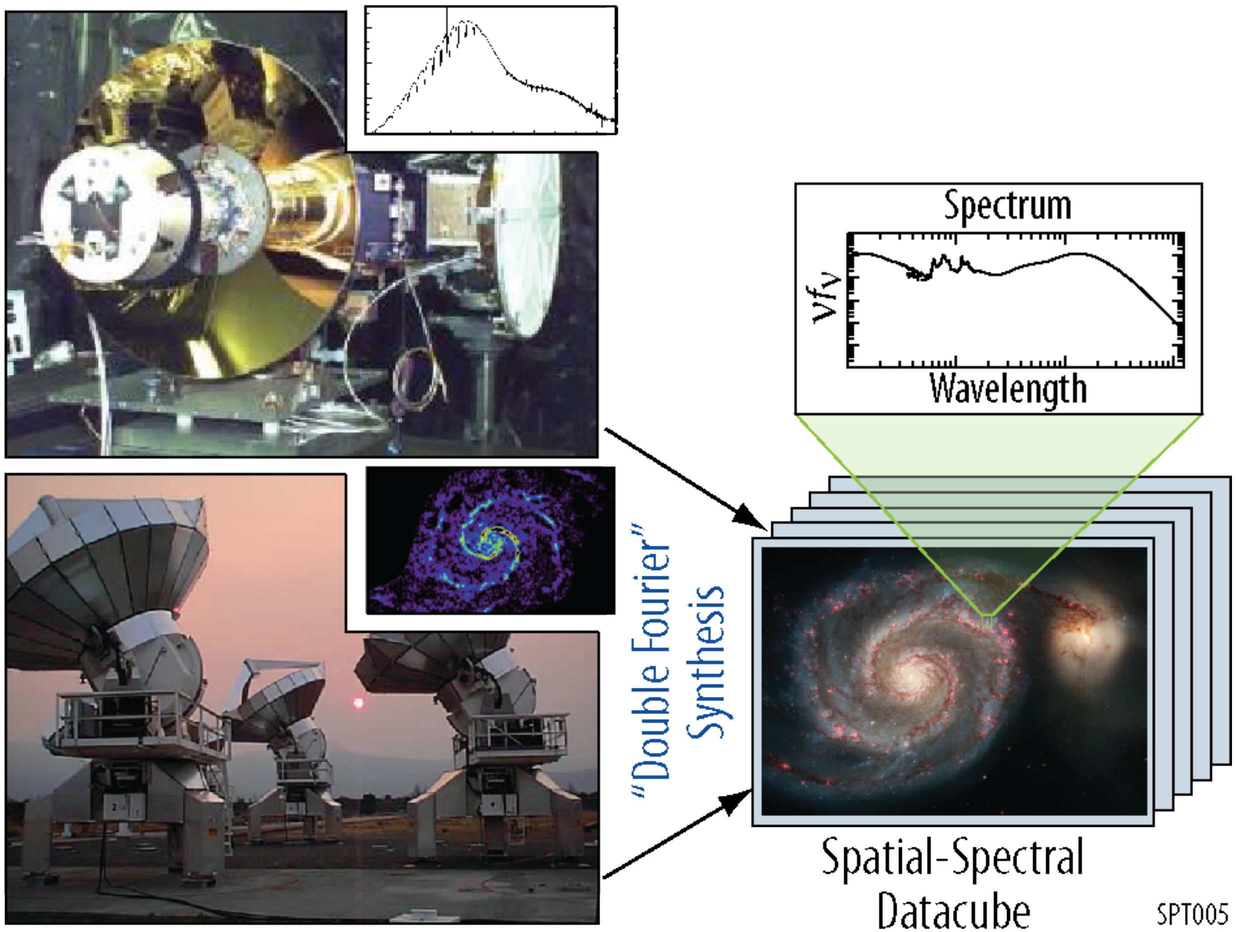


To image protoplanetary and debris disks and definitively distinguish the emissions of individual high-z galaxies requires sub-arcsecond angular resolution. This capability is sorely lacking in the far-IR, where these objects are bright and their information content is great.

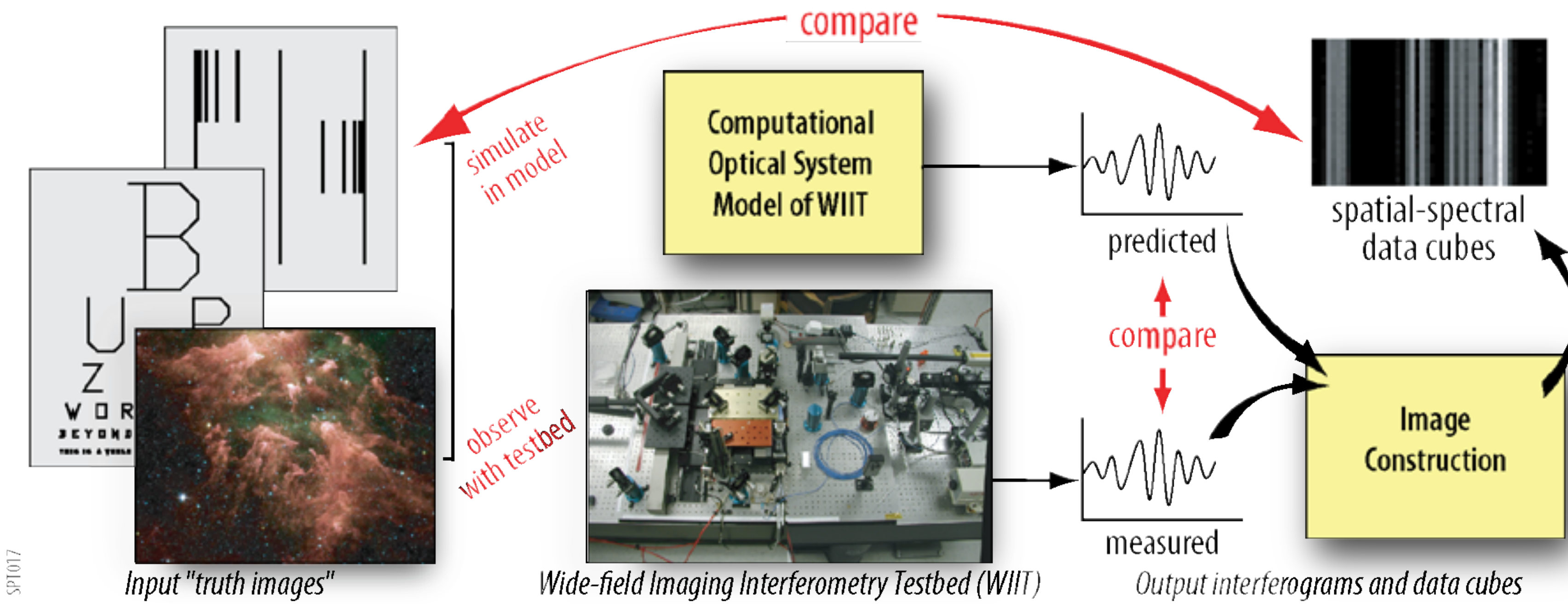
Derived Requirements

- Sub-arcsecond angular resolution over the wavelength range 25 – 400 μm (between JWST and ALMA)
  - Image protostellar and debris disks
  - Resolve the far-IR extragalactic background
- ~10 μJy continuum, 10^{-19} W/m^2 line sensitivity
  - Detect low surface brightness debris disks
  - Measure SEDs and spectral lines of high-z galaxies
- >1 arcmin instantaneous FOV
- Spectral resolution, R ~ 3000 (integral field spectroscopy)

The technique: something old and something new…



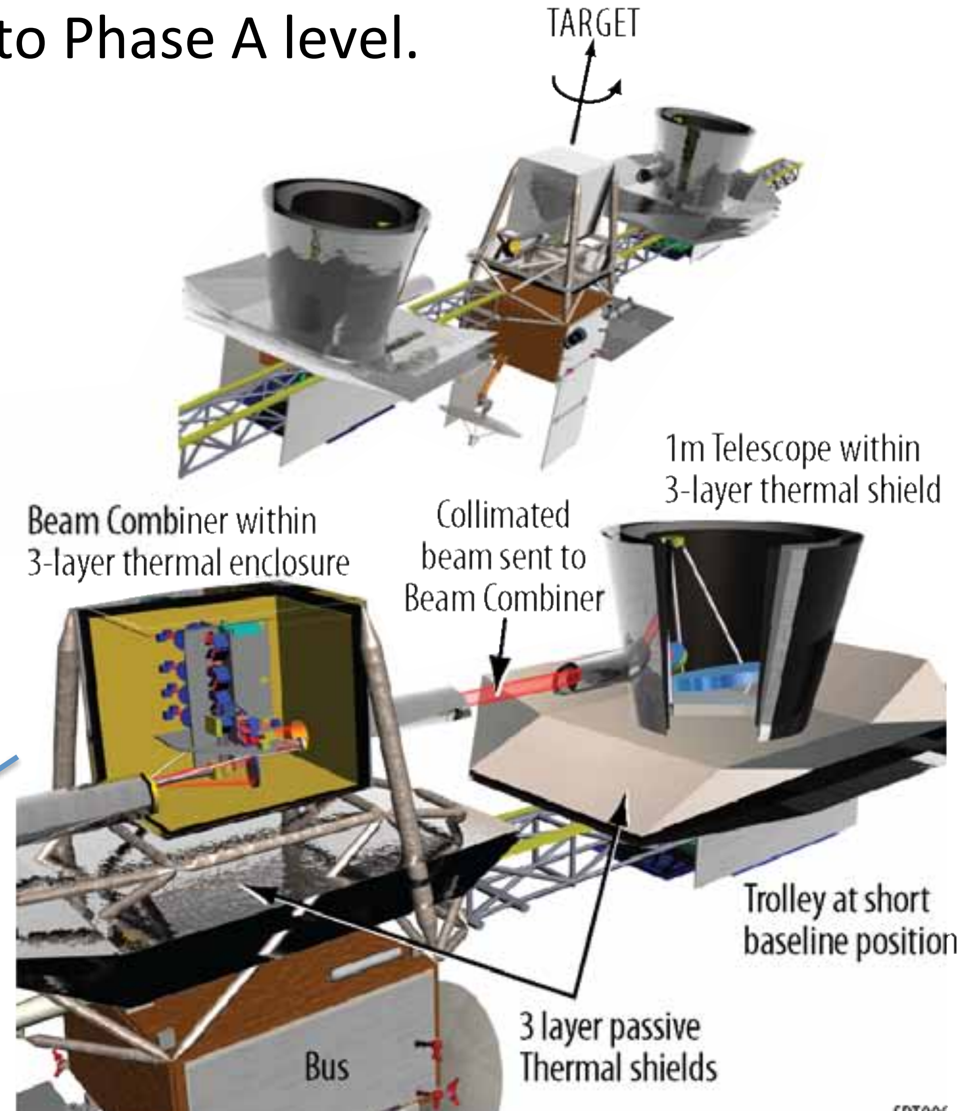
Wide-field double-Fourier (spatio-spectral) interferometry



We've been developing and gaining practical experience with this technique in the lab for the past decade

SPIRIT was studied as a candidate Origins Probe mission and recommended to the Decadal Survey Committee.

The concept has matured to Phase A level.

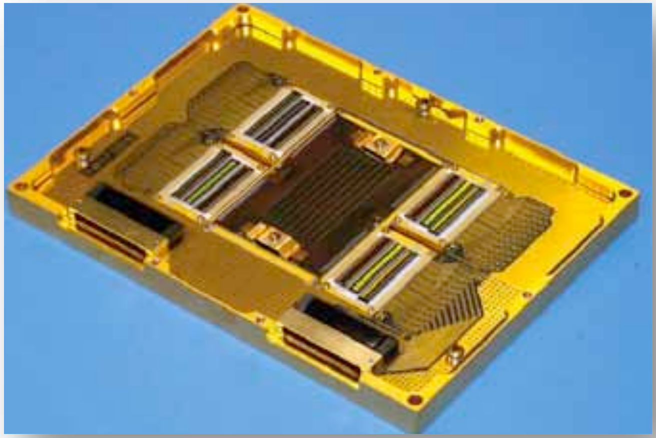


A single instrument

Detectors

Detectors are the pacing technology. The required sensitivity, readout speed (detector time constant), and pixel count are well within reach.

- Enables:
- Requirements: 14 x 14 pixels, NEP ~10^{-19} W/$Hz^{1/2}$, 200 μsec time constant
- Most promising: TES bolometers and MKIDs
- Requires: T ~ 30 mK focal plane
- Current TRL: 3
- Time to TRL 6: 4 years



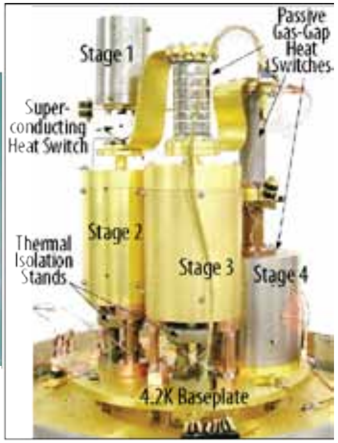
J. Staguhn et al. - GISMO

Cryocoolers

Cryocoolers will be used instead of expendable cryogen

- Enables: photon background-limited sensitivity; lower launch mass and volume; longer lifetime
- Requirements: 4 K optics; ~30 mK focal plane
- Requires: 72 mW at 4 K, 180 mW at 18 K; 5 mW at 50 mK, 1 mW at 30 mK
- Most promising: JWST MIRI cooler w/ ^{3}He; C-ADR
- Current TRL: 4
- Time to TRL 6: 3 years

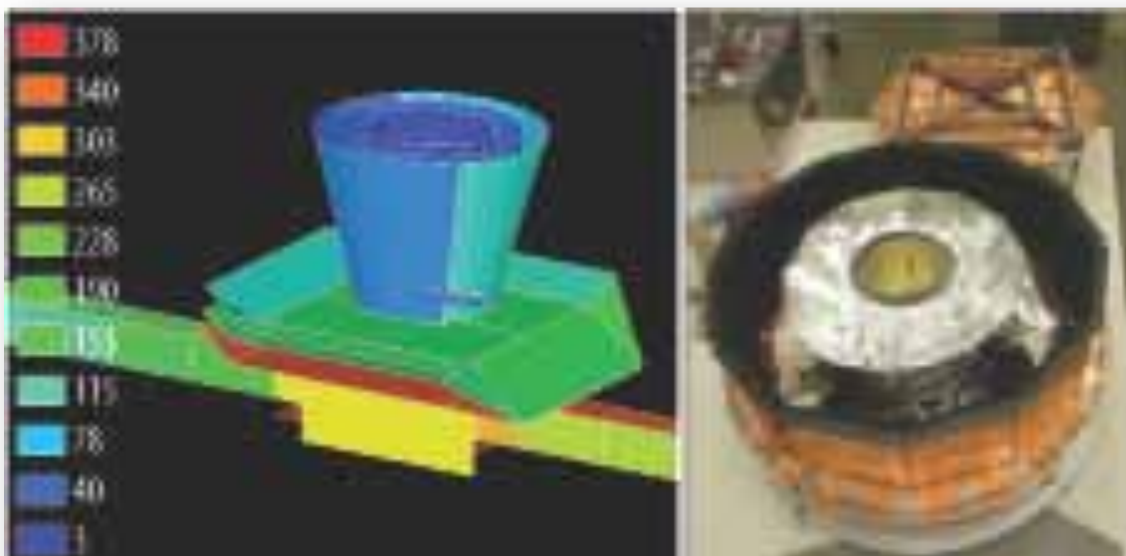
N-G's JWST MIRI cooler



P. Schirron - CADR

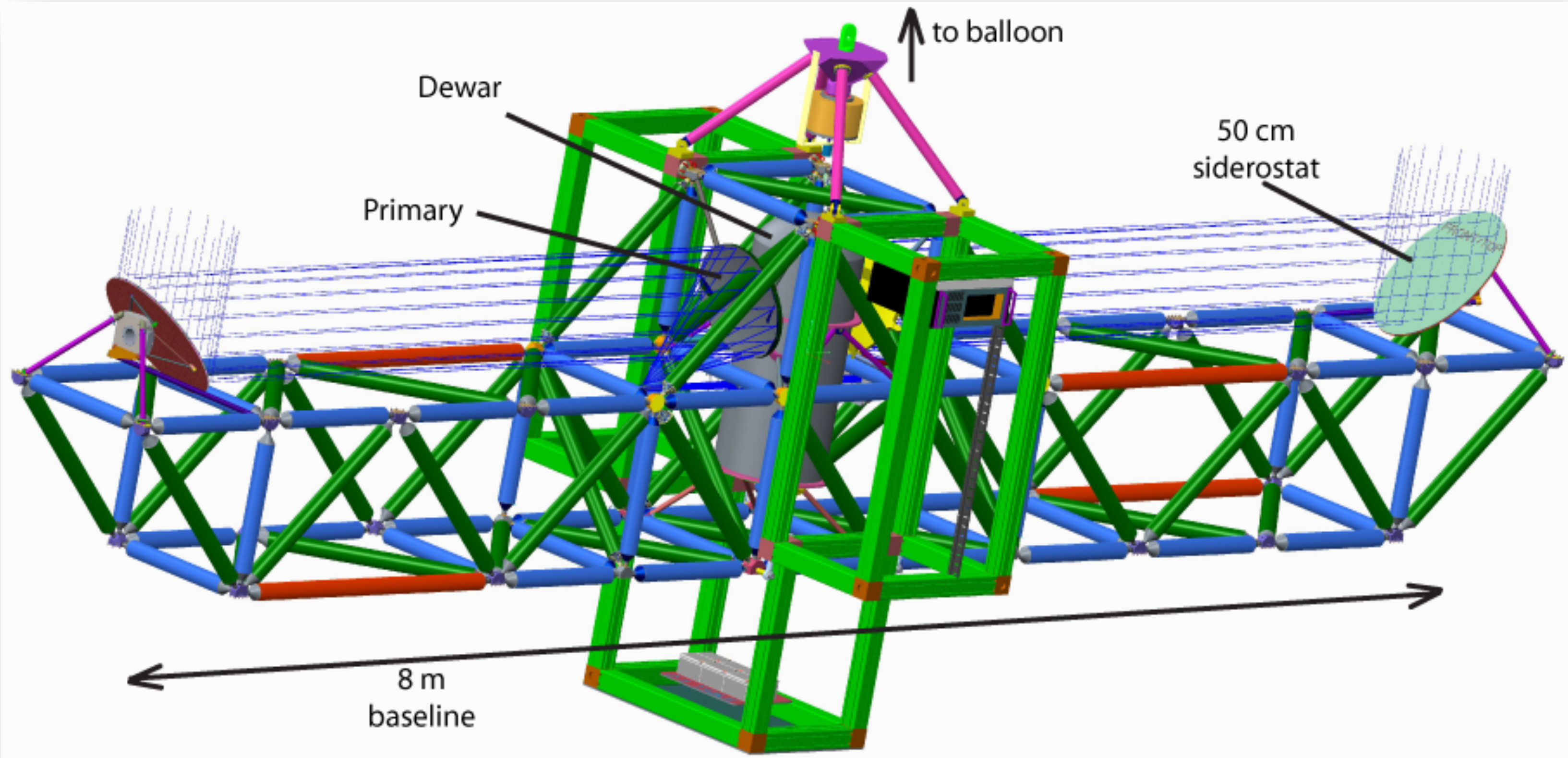
Cryo-thermal System

- Integrate cryocoolers into subscale Engineering Test Unit with solar simulator
- Verify understanding of system thermal performance with computational model



M. DiPirro – SPIRIT thermal model and SCOTT testbed

BETTII



The Balloon Experimental Twin Telescope for Infrared Interferometry (BETTII; S. Rinehart, PI) is nearing design completion and will fly in a few years. Japan's Far-IR Interferometric Telescope Experiment (FITE; H. Shibai, PI) is waiting for a maiden flight opportunity.