The future of space far-infrared astrophysics: interferometry

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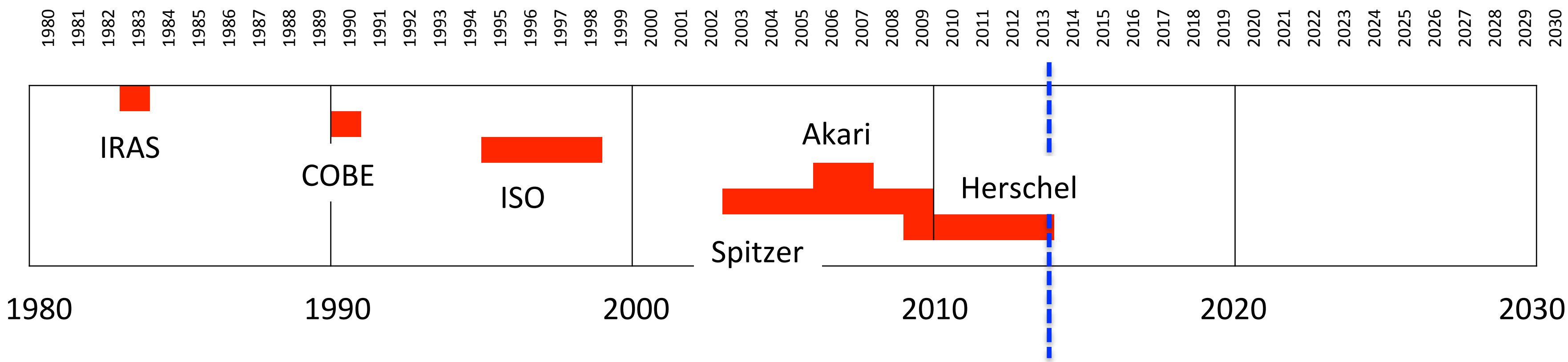
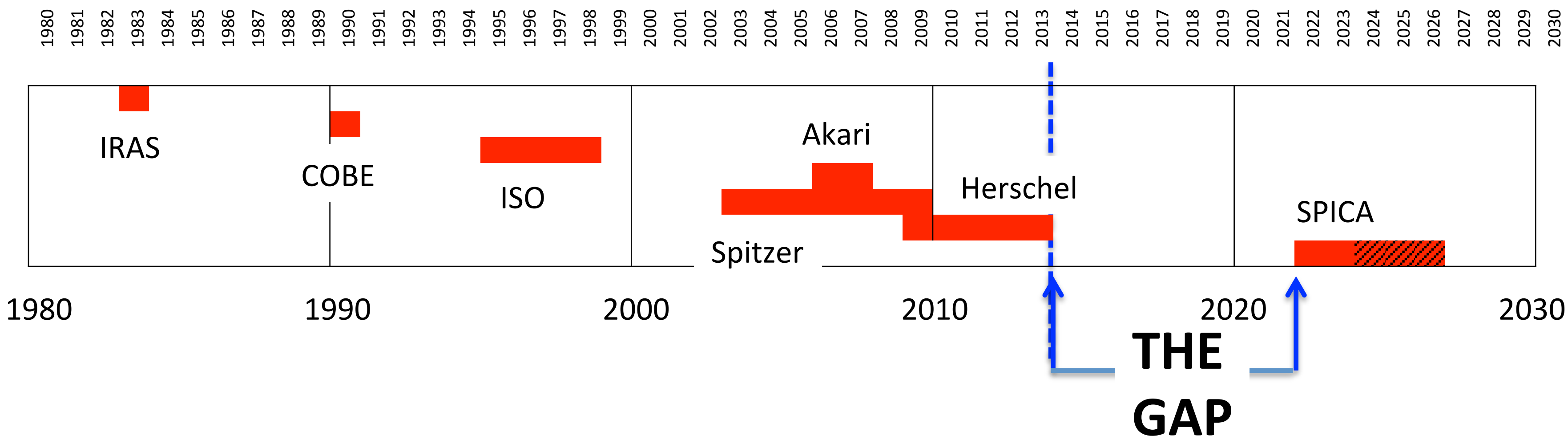
Far-IR space mission timeline

An awesome track record, and a tremendous legacy …



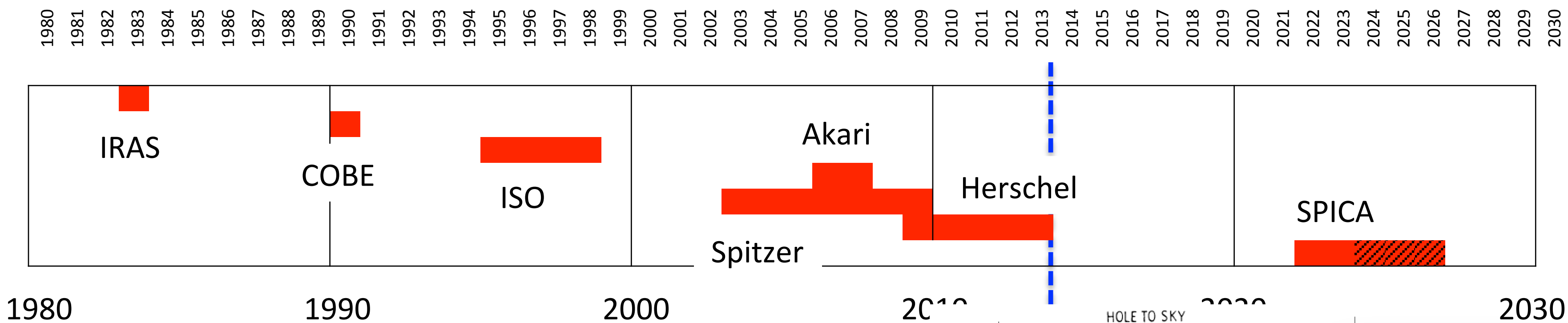
… until now

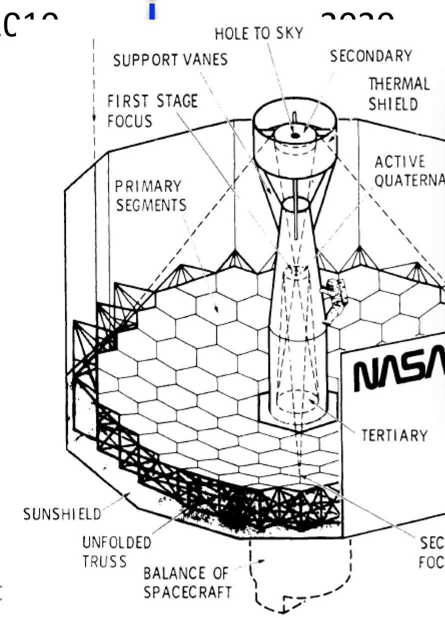
Far-IR space mission timeline

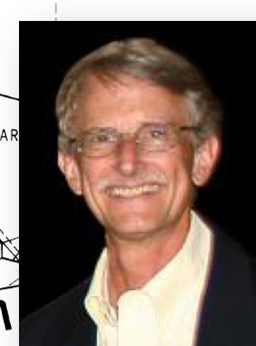


... but mind the gap!

Far-IR space mission timeline

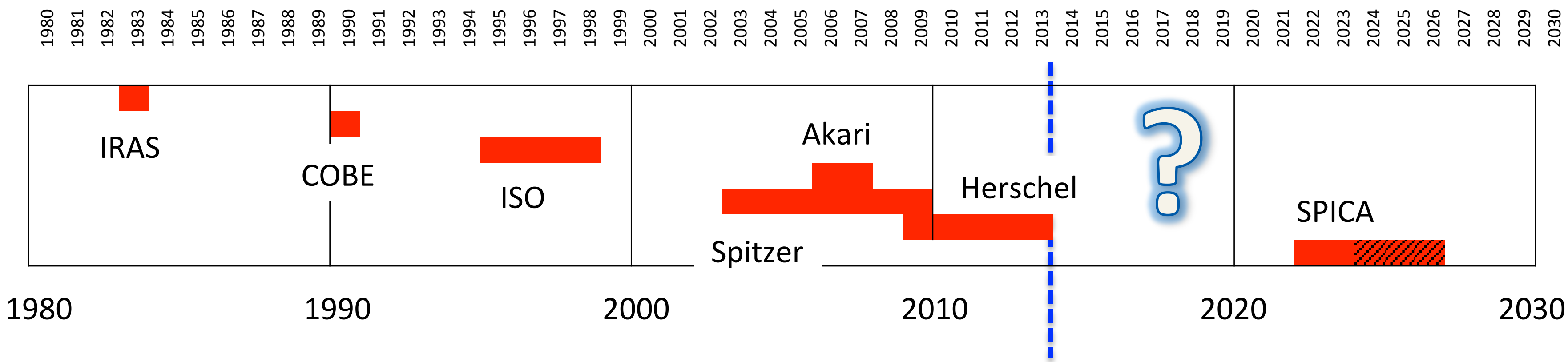






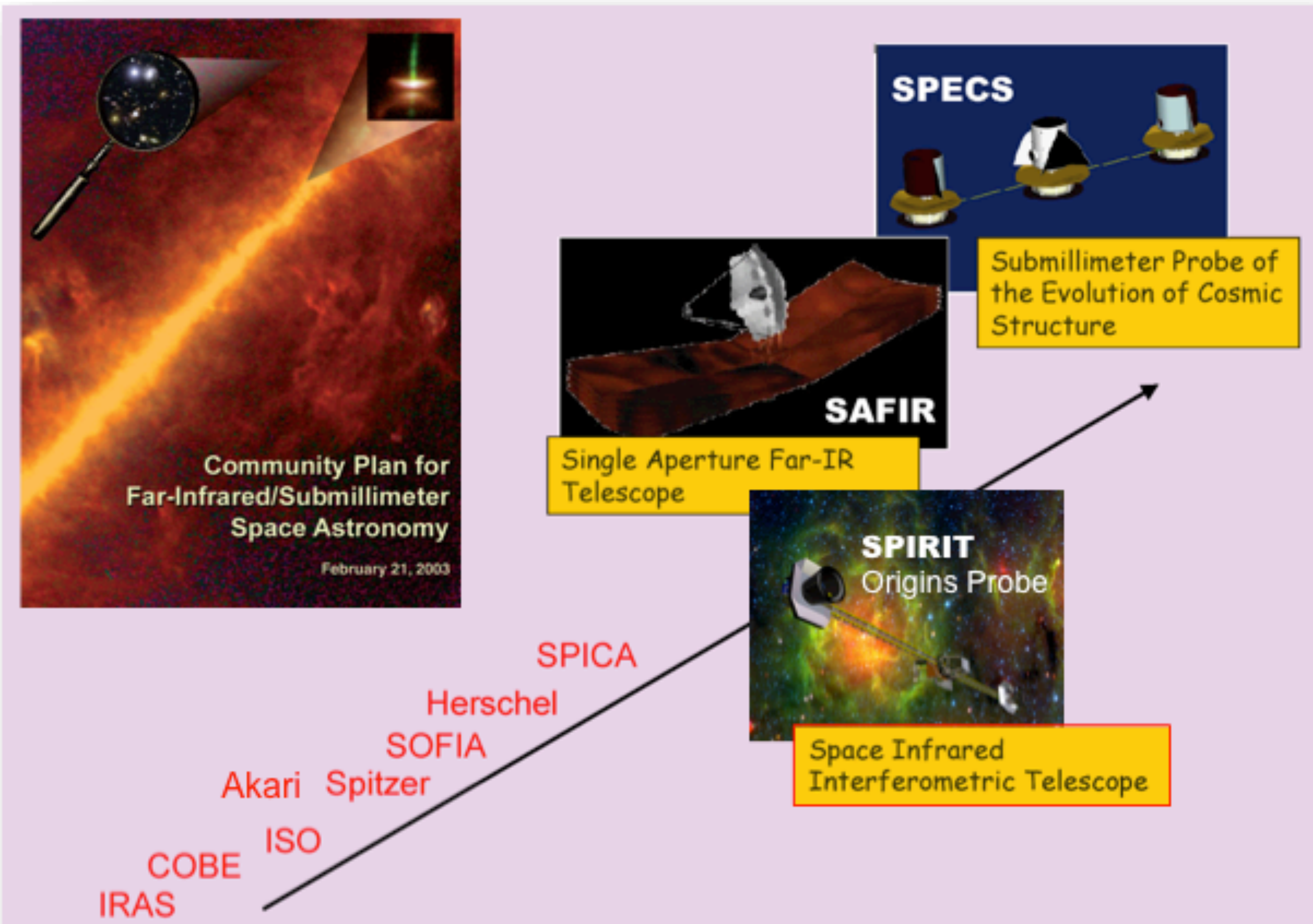
Large Deployable Reflector (LDR) concept

Far-IR space mission timeline



It's up to us to visualize the future and turn our dreams into reality.

The far-IR community's vision

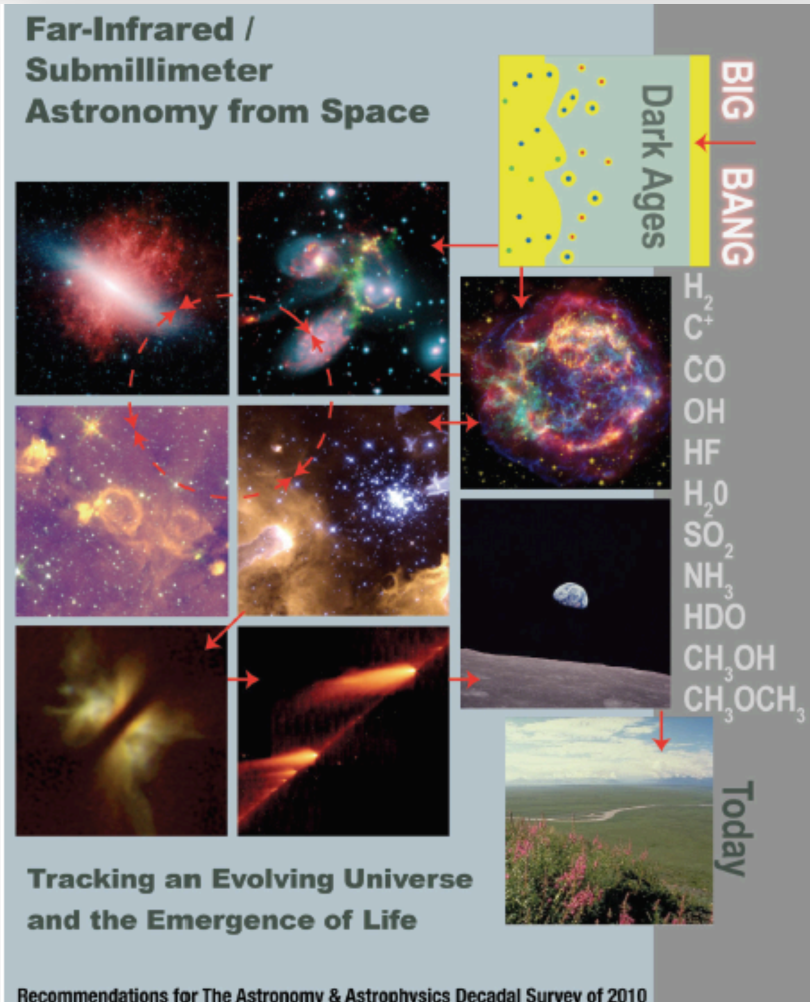


Started in 1997

A practical plan was developed in 2003

Consensus!

The vision updated



Recommended again to the Decadal Survey in 2009

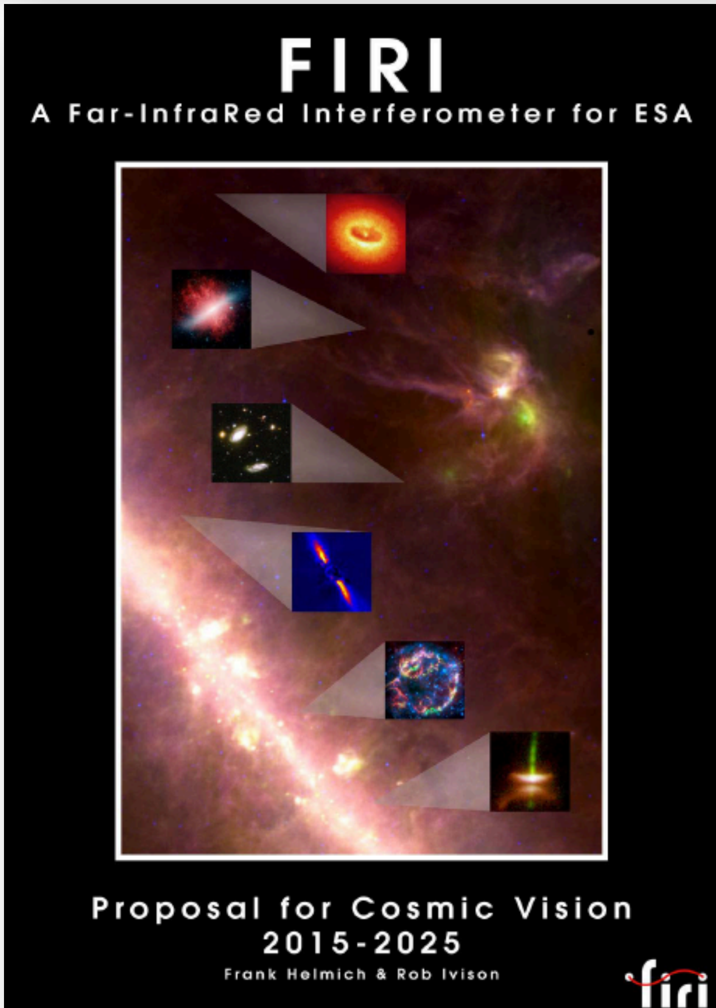
A robust plan!

Why interferometry?

The human quest to understand our place in the cosmos – How did we get here? – depends on our probing sensitively and in fine detail developing planetary systems and distant galaxies in the far-infrared.

No alternative method is as capable, technically feasible and affordable.

A vision without borders



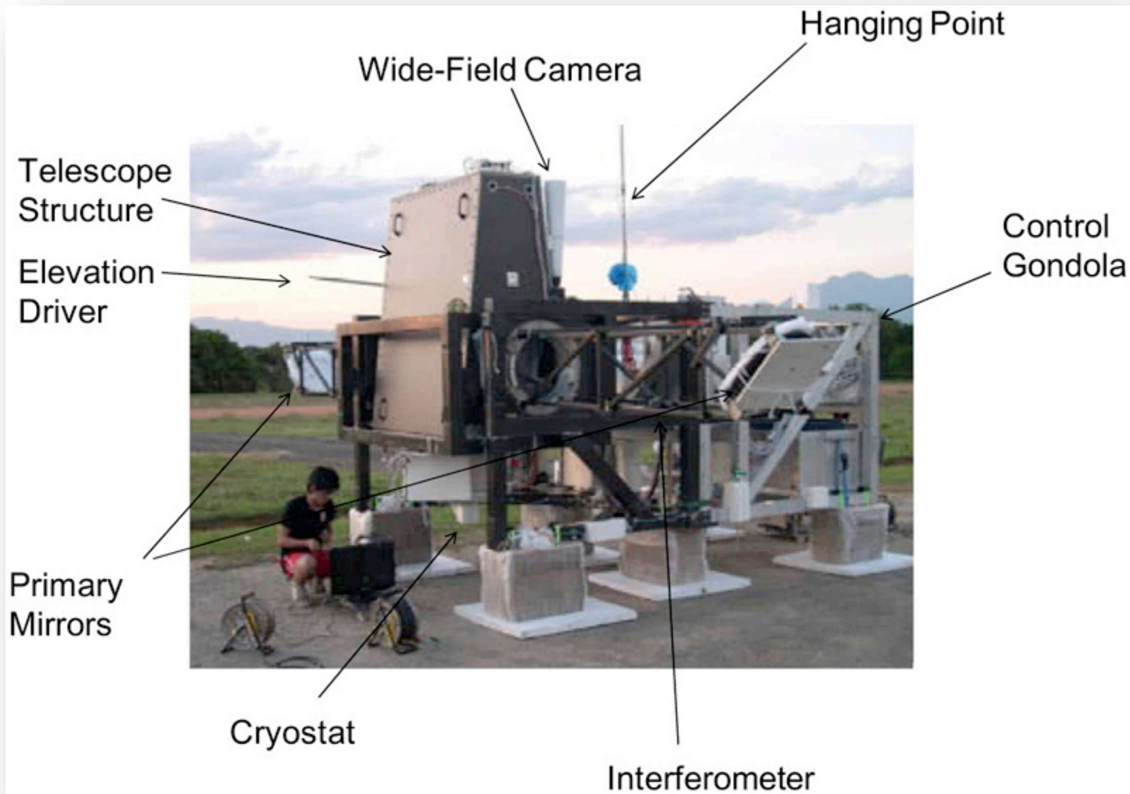
Cosmic Visions FIRI proposal in Europe, 2007

The European community is presently preparing science white papers that will guide ESA's selection of future L-class missions

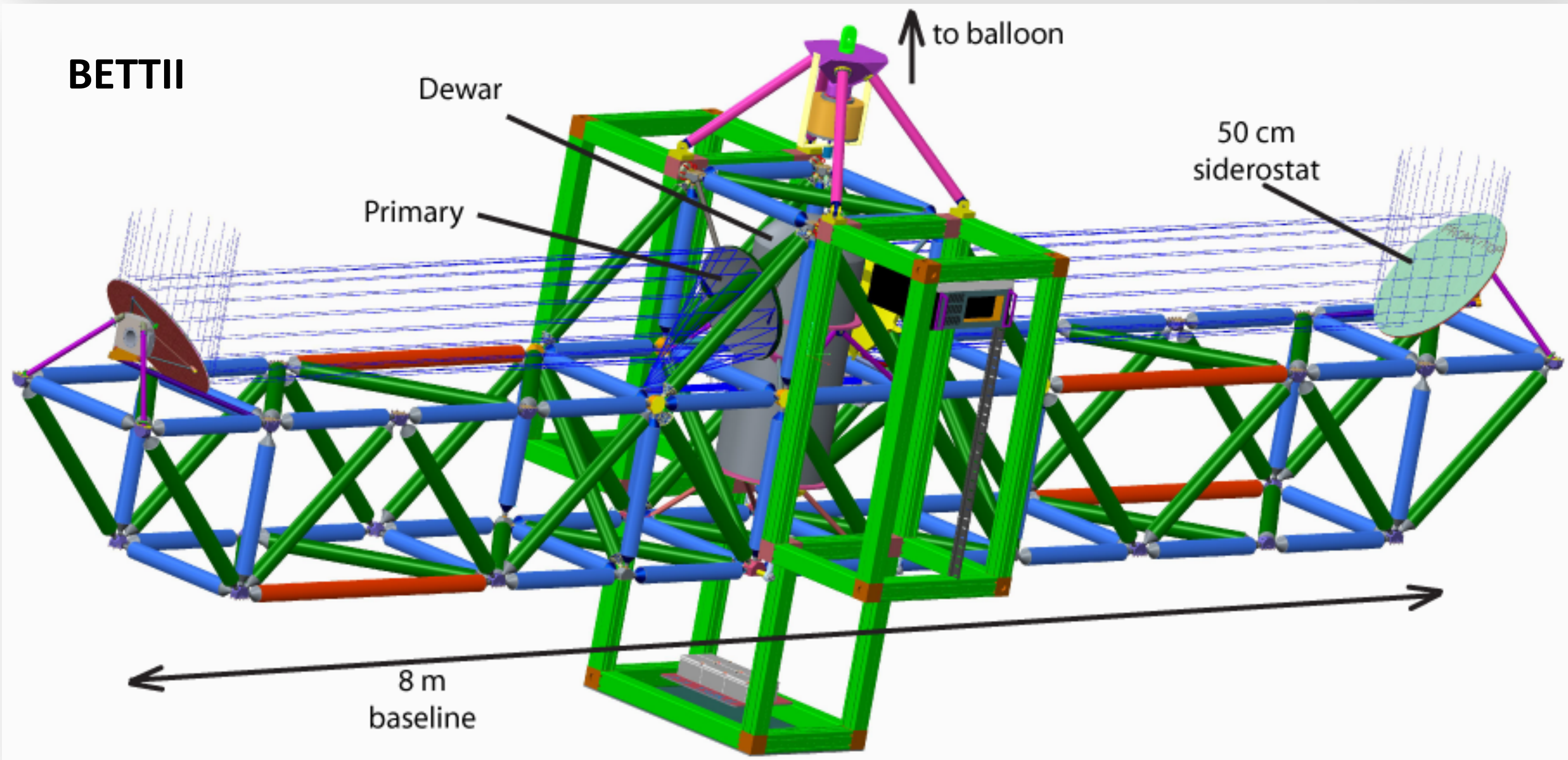
A vision without borders

Japan's Far-IR Interferometric Telescope Experiment (FITE), a balloon project

Maiden flight in May or June 2013 from Alice Springs, Australia.
- H. Shibai, PI

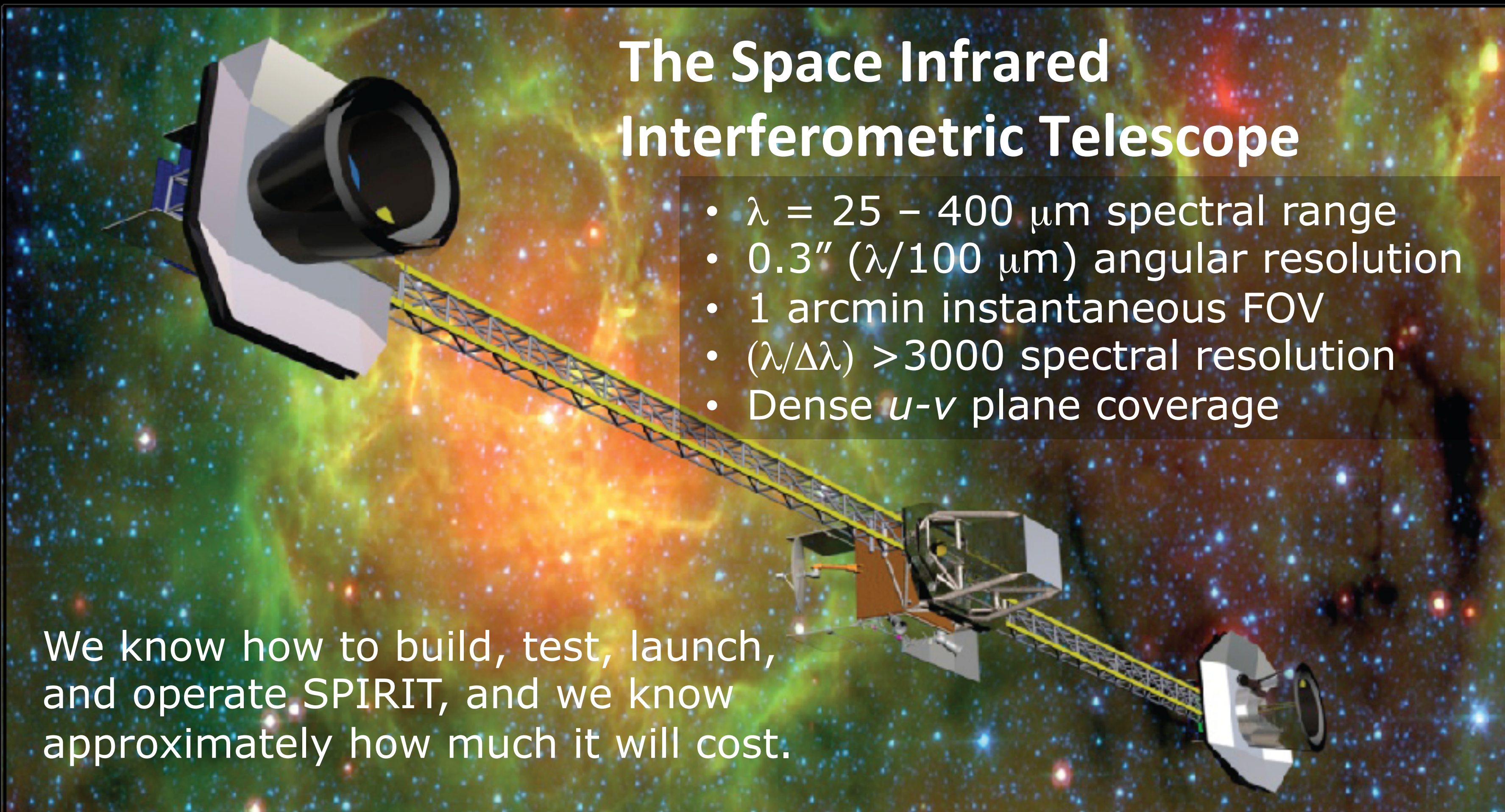


NASA's first far-IR interferometer



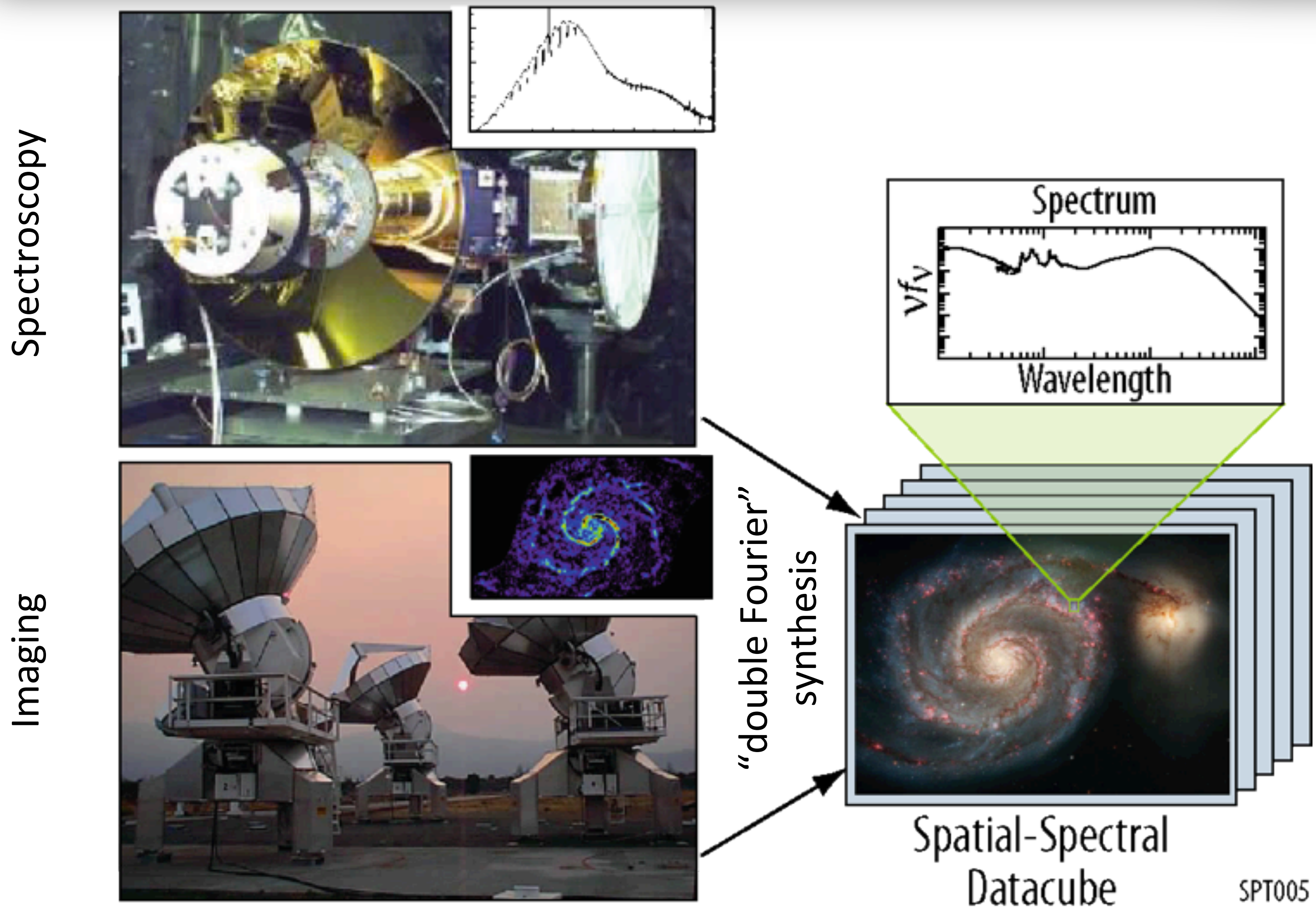
The Balloon Experimental Twin Telescope for Infrared Interferometry (BETTII; S. Rinehart, PI) is nearing design completion and will fly in 2015.

SPIRIT is within reach

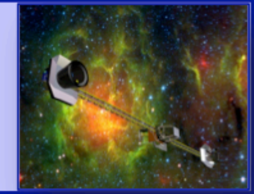


SPT019

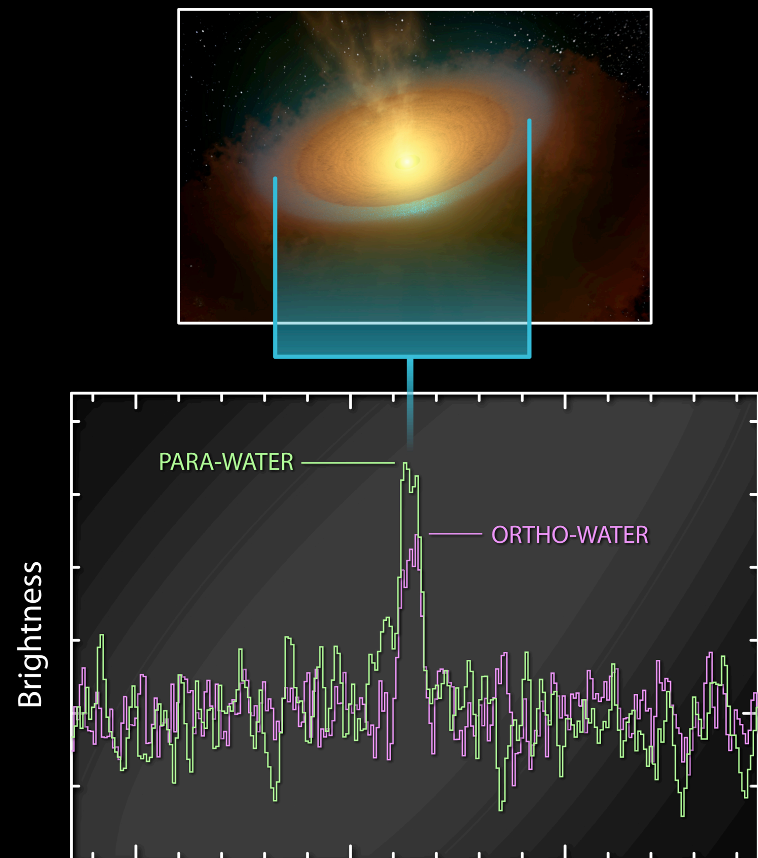
Spatio-spectral interferometry



Science with SPIRIT



Forming habitable planets



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

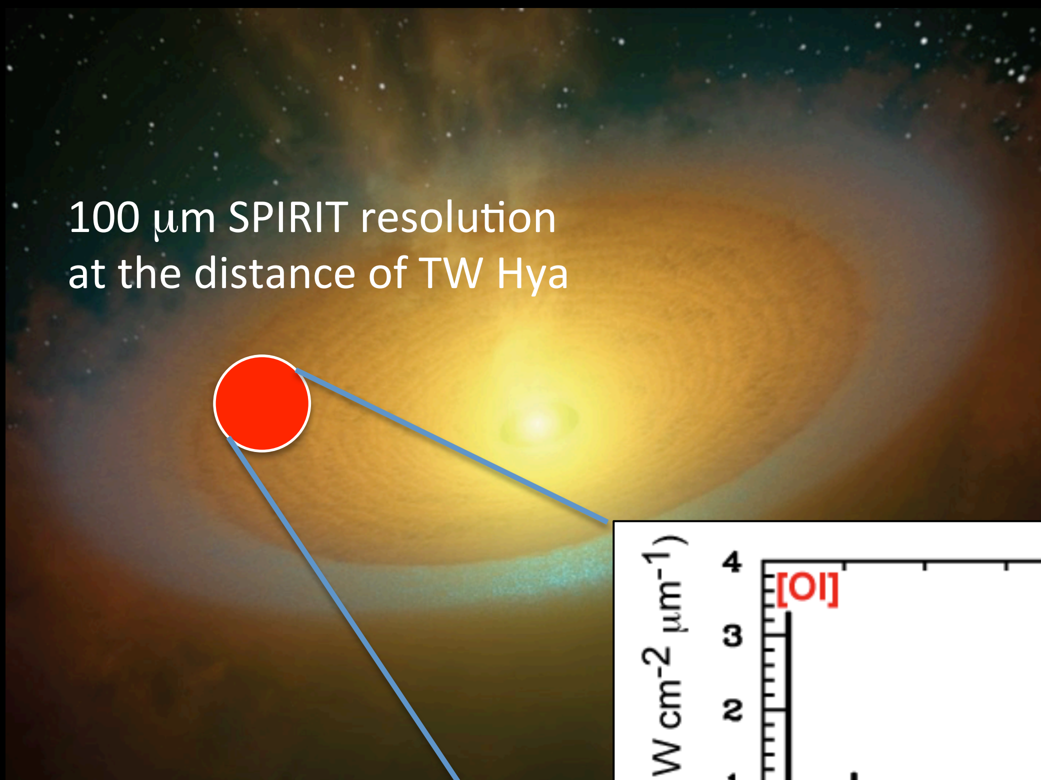
How did the Earth acquire its water? How do habitable plants form?

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

Theorists have models, but lack unique solutions.

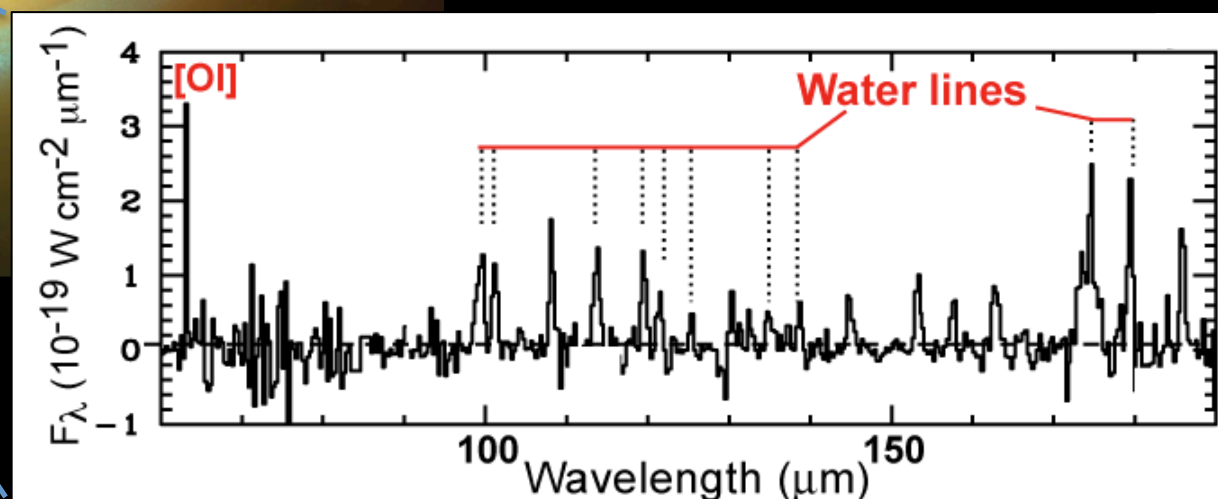
Spatially resolved spectroscopy will break model degeneracy.

Forming habitable planets



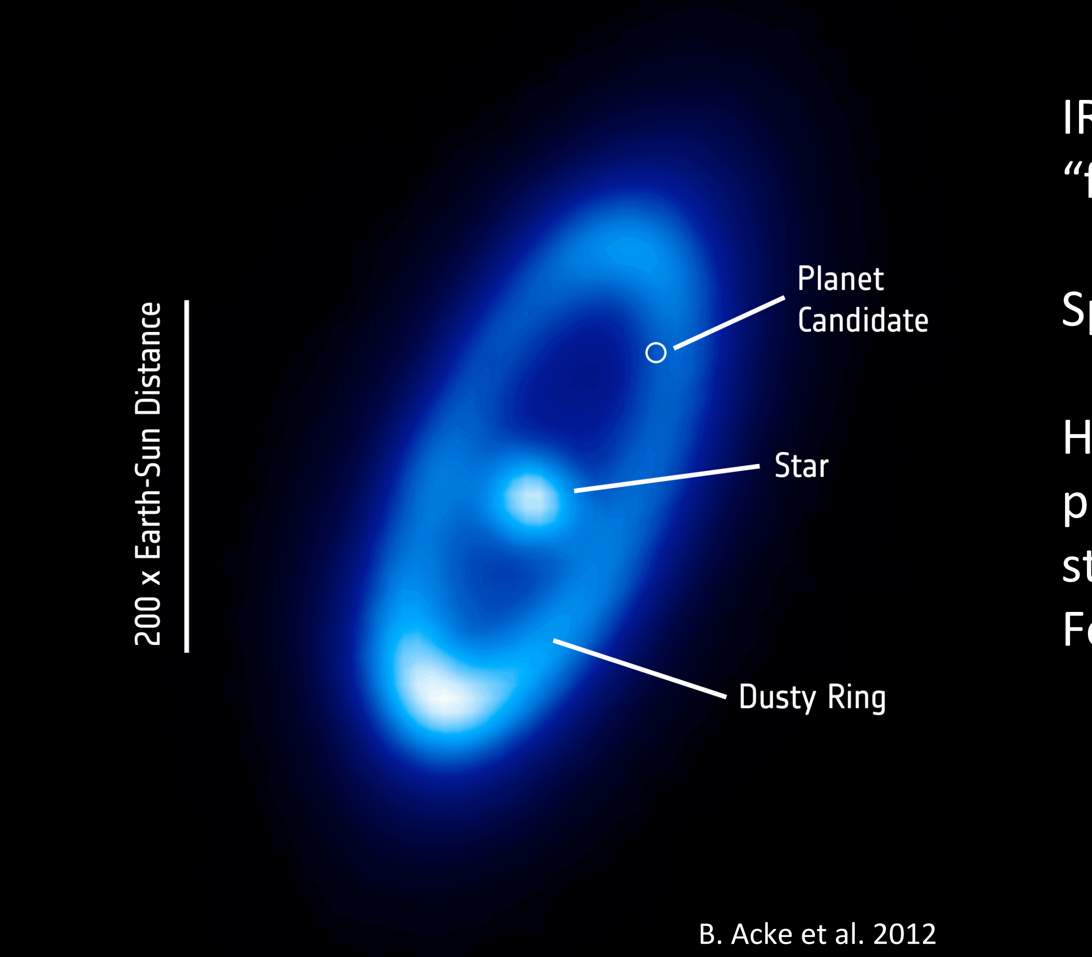
How did the Earth acquire its water? How do habitable plants form?

SPIRIT will provide the missing information!



Debris disks: from the Fab 4 …

Fomalhaut



IRAS discovered the "fabulous 4" debris disks

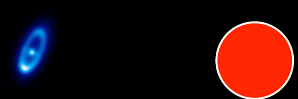
Spitzer imaged them

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

… to hundreds

At 100 pc

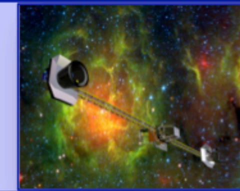
To image <u>hundreds</u> of debris disks and tap them for information about planetary systems, we'll have to image disks out to 100 pc.



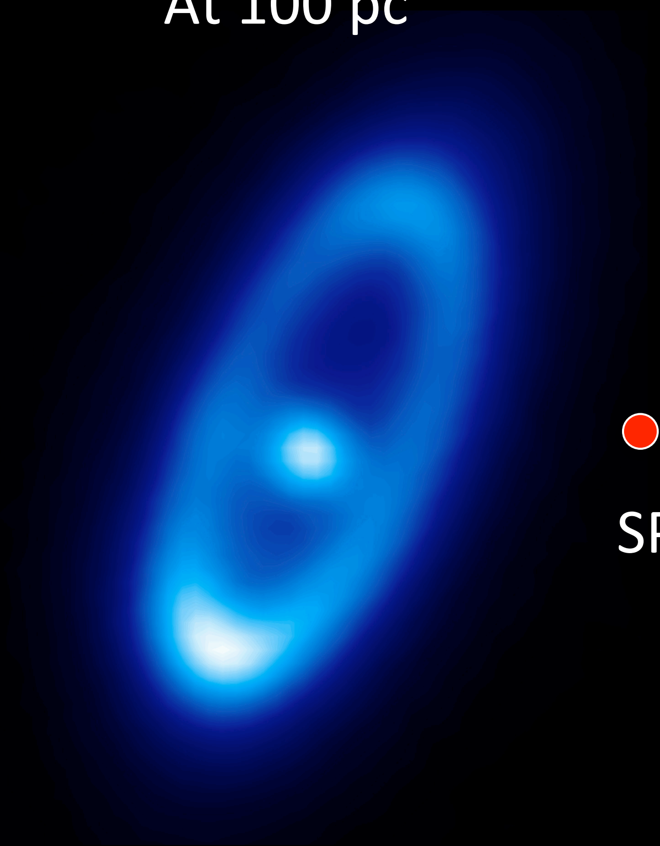
Herschel at 70 μm

A 3.5 m telescope isn't big enough.

… to study planetary systems



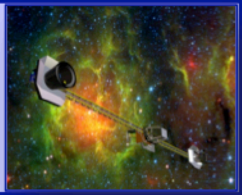
At 100 pc

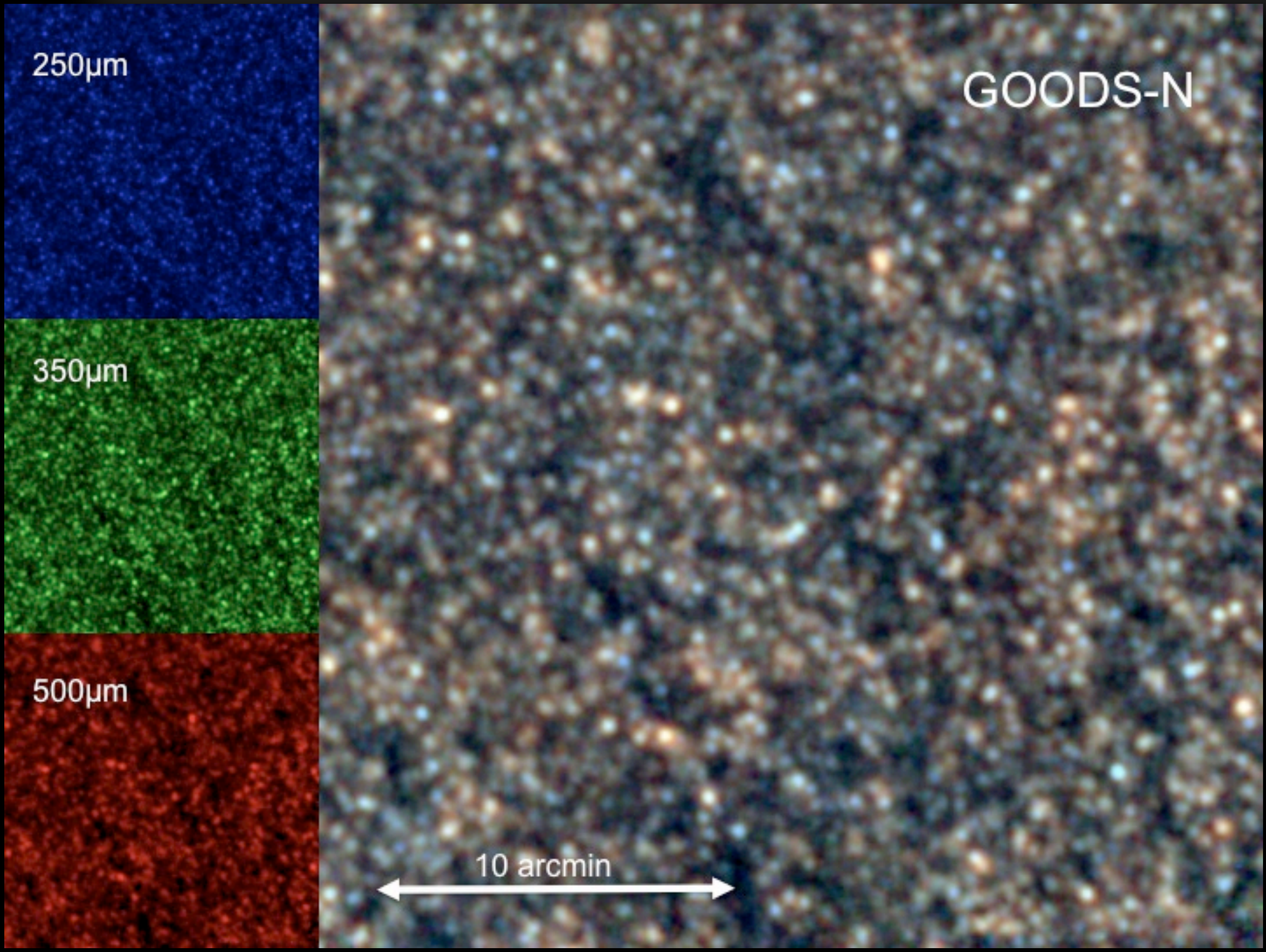


SPIRIT at 70 μm

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

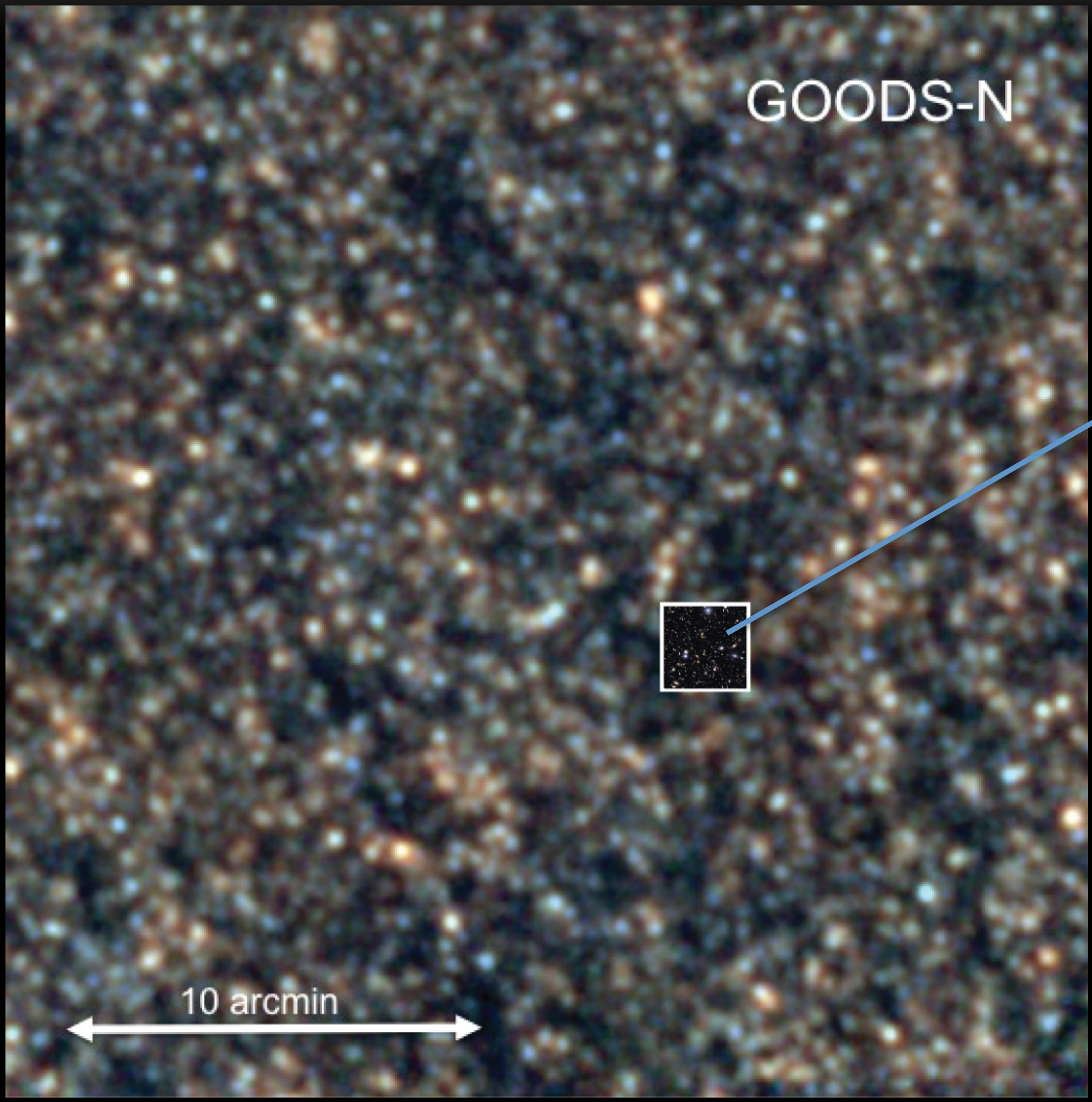
Probing the universe deeply



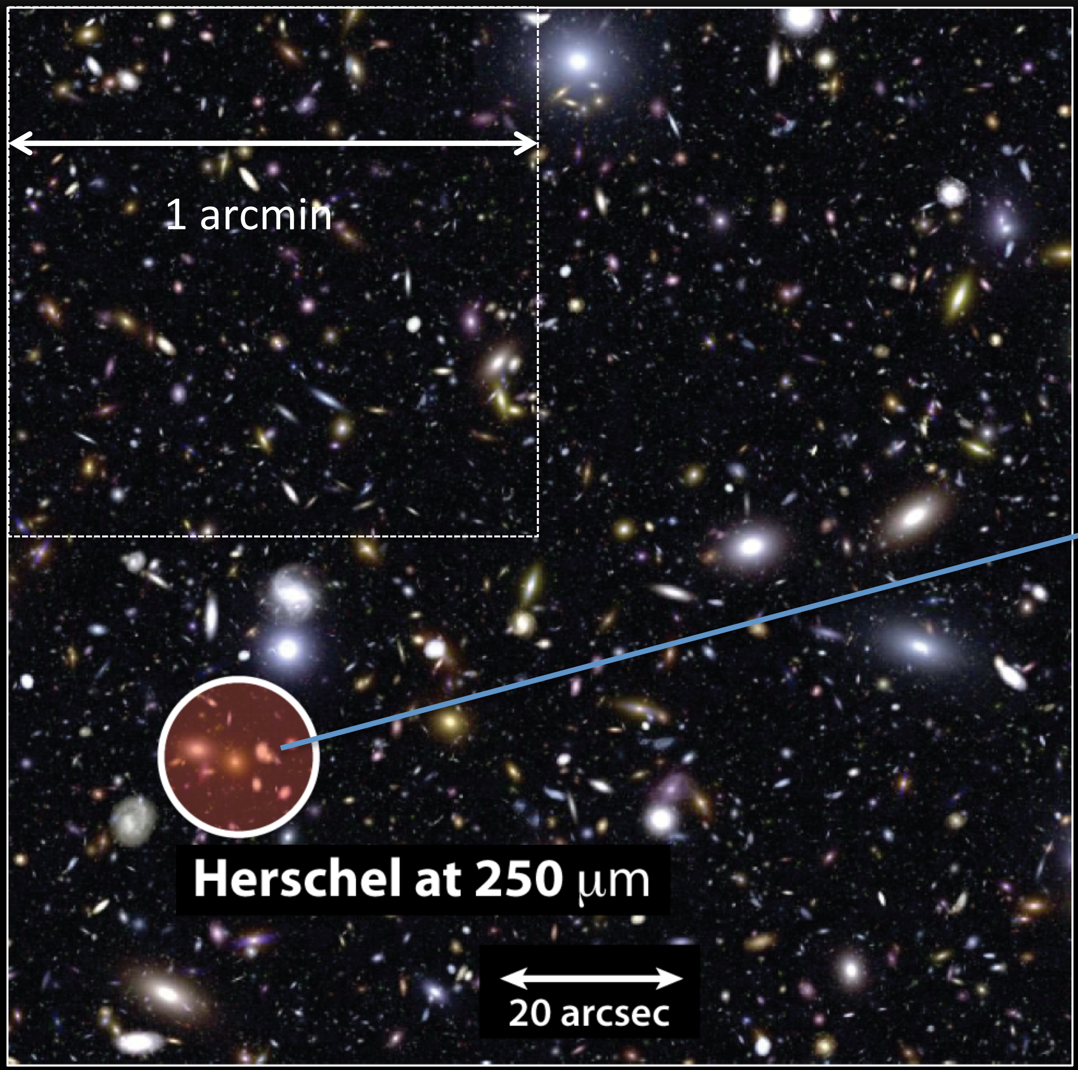


Herschel deep field

Probing the universe deeply



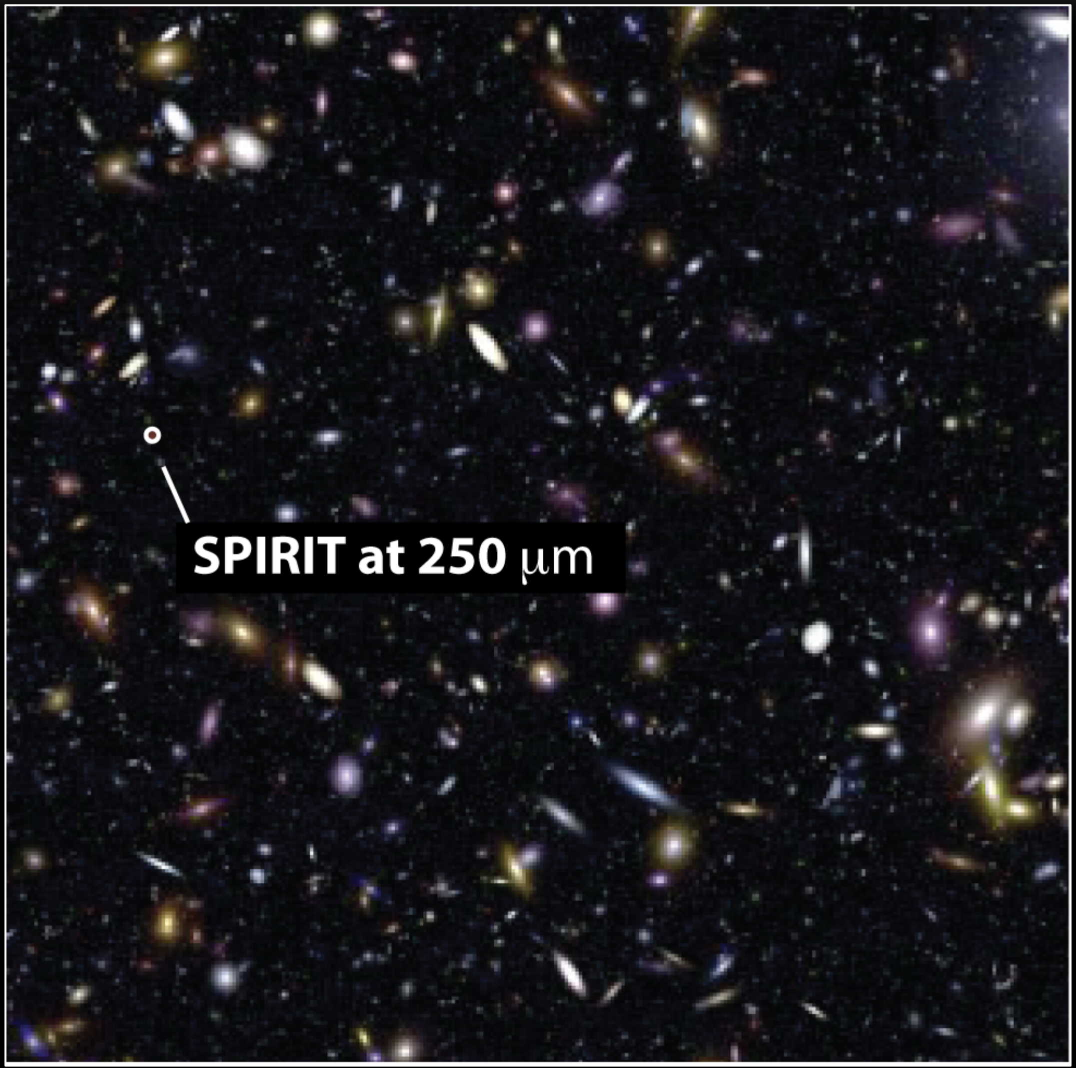
Probing the universe deeply



JWST deep field

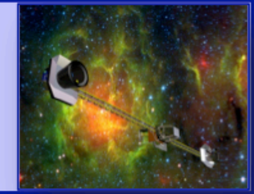
many galaxies per Herschel beam

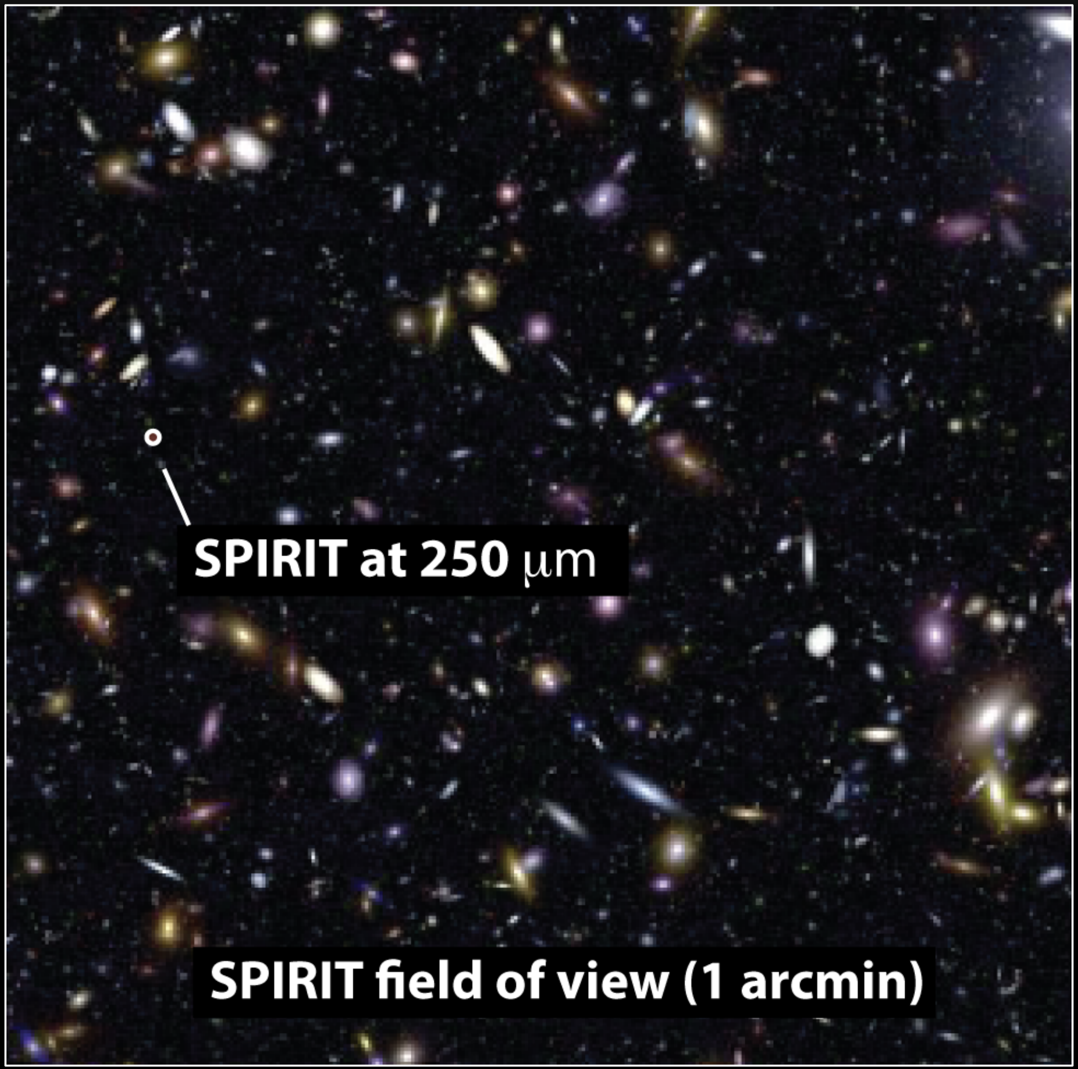
Probing the universe deeply



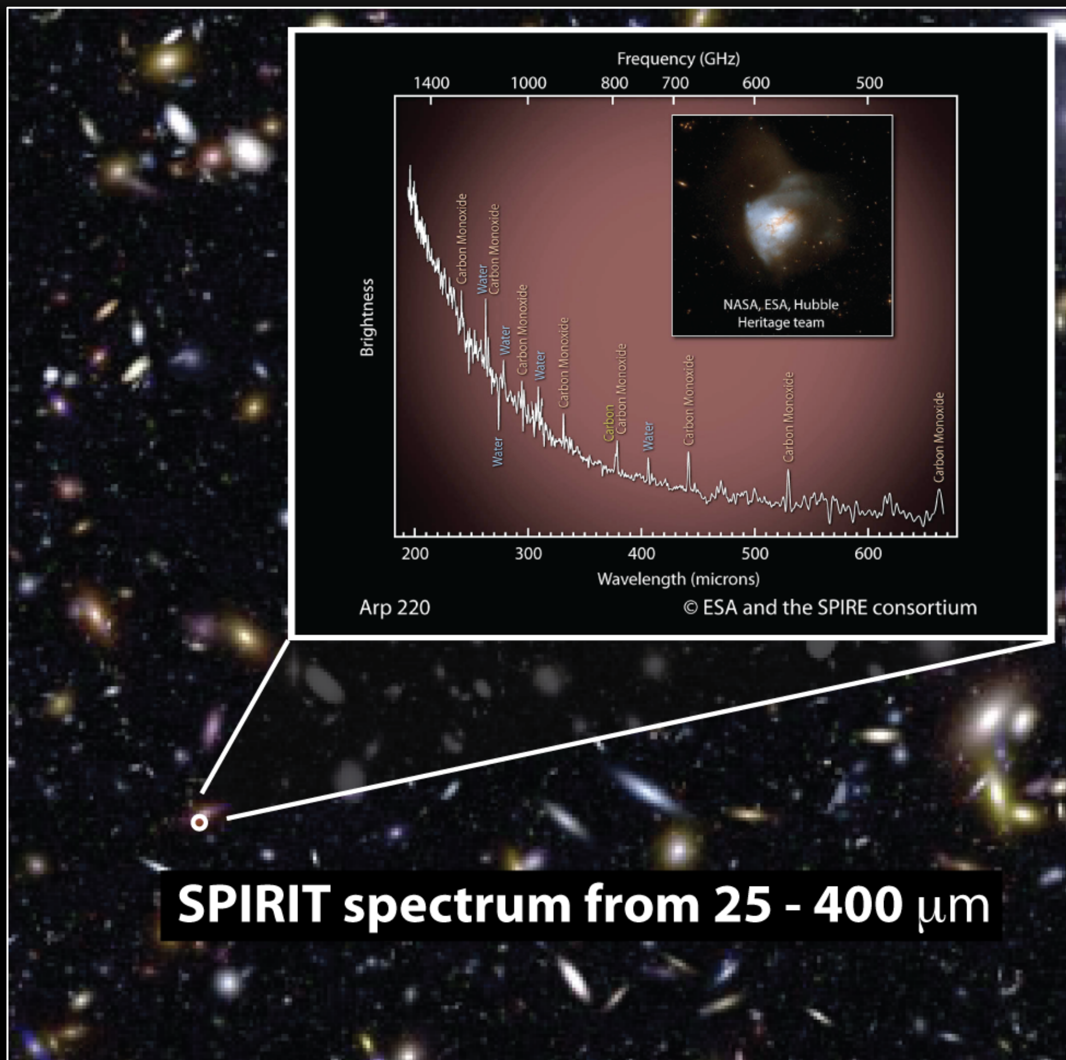
JWST deep field
(1 arcmin cutout)

Probing the universe deeply



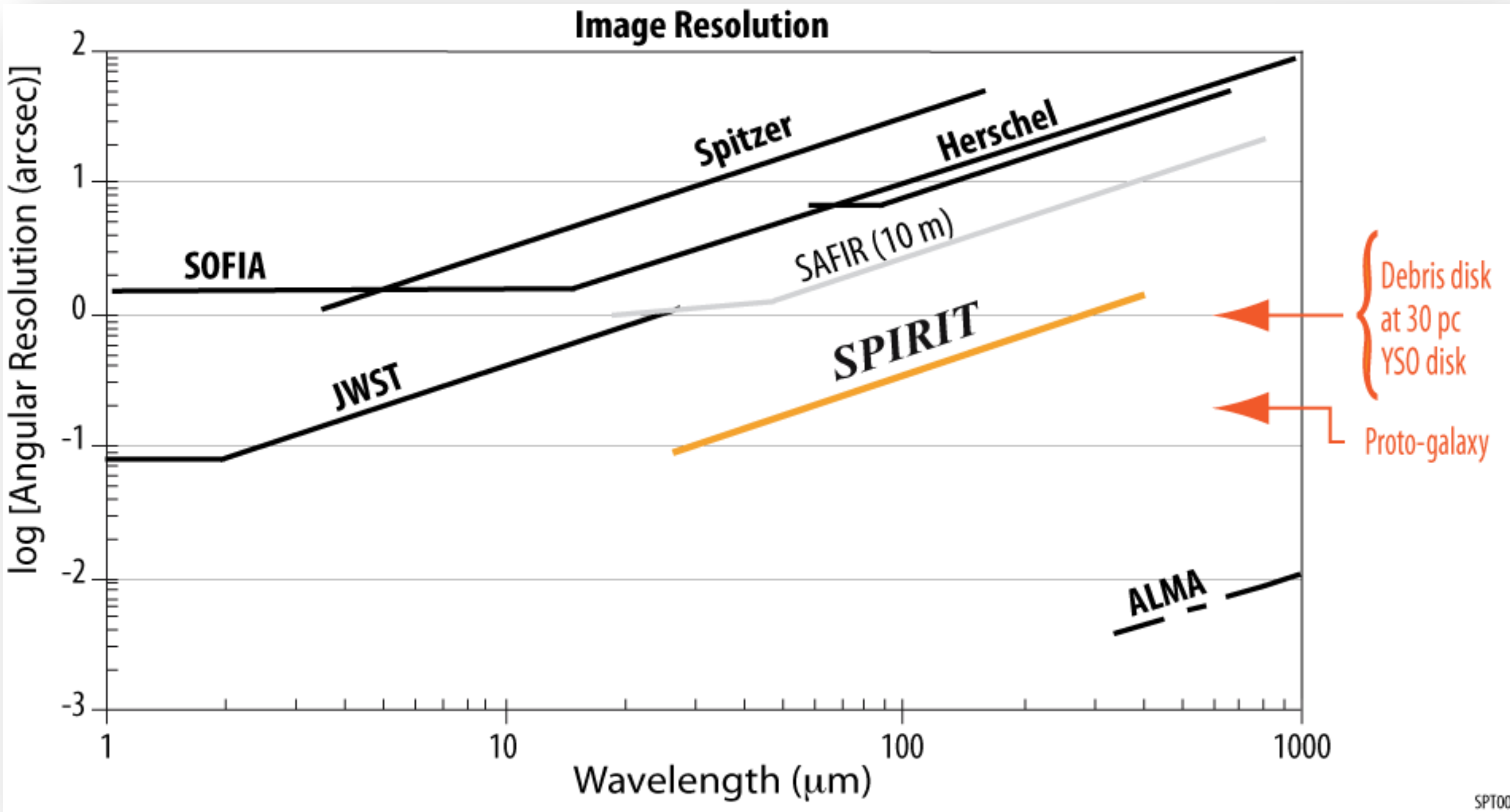


Probing the universe deeply



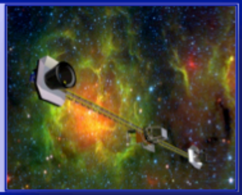
SPIRIT will measure the dominant interstellar gas cooling lines and diagnostic lines in the spectra of individual high-redshift galaxies.

Angular resolution requirement



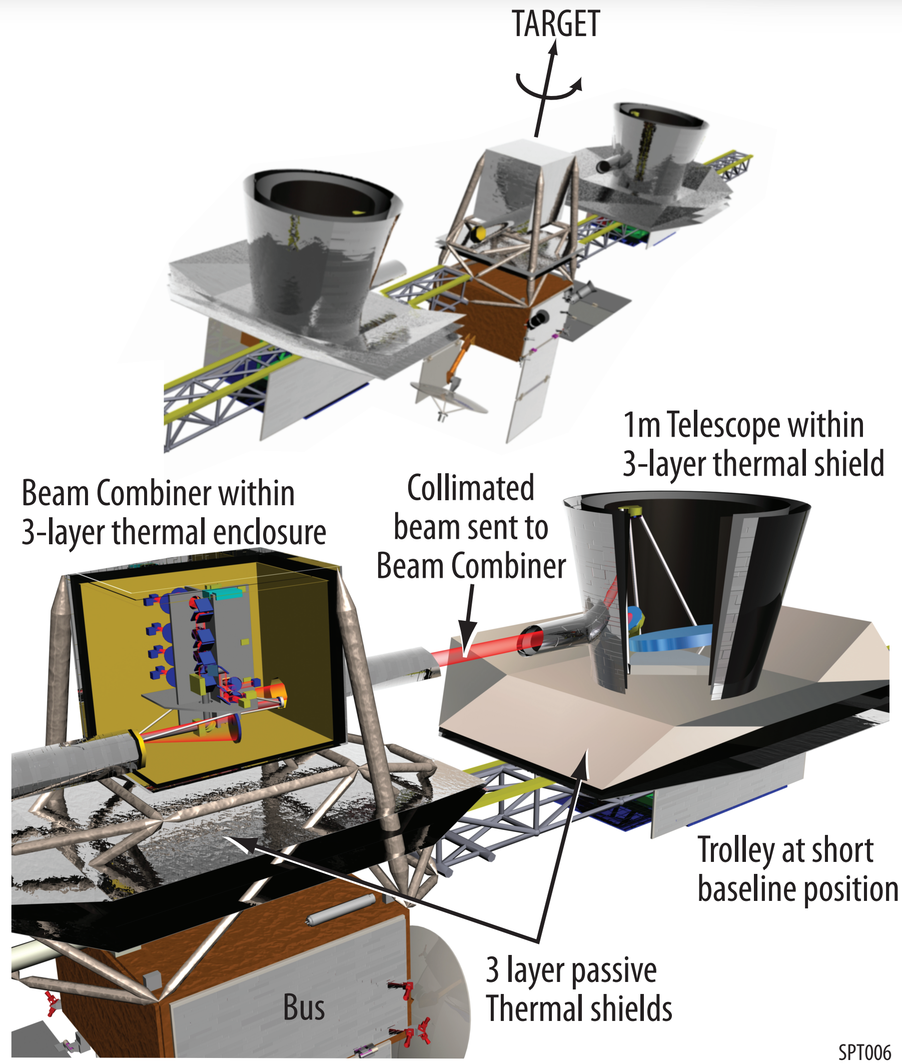
WANTED: Sub-arcsecond angular resolution

A few more words about SPIRIT…

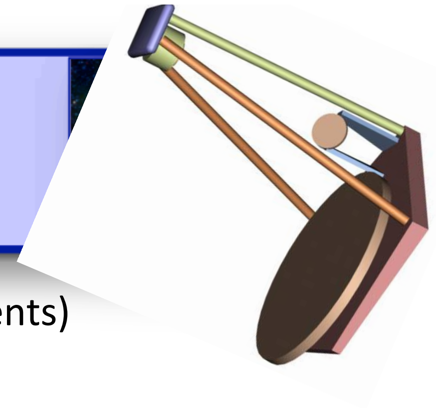


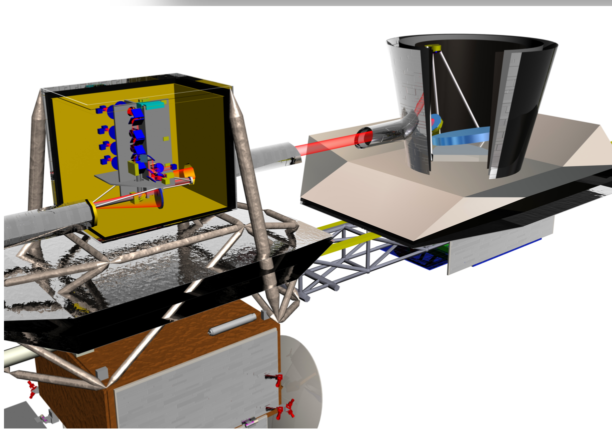
Major flight system components

SPIRIT has two movable, cryocooled afocal off-axis telescopes and a single beam-combining instrument. Major spacecraft functions are centrally located.

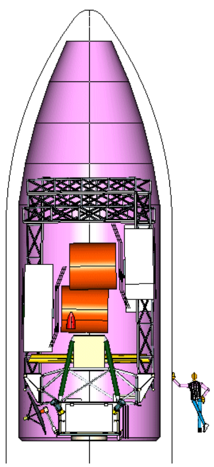


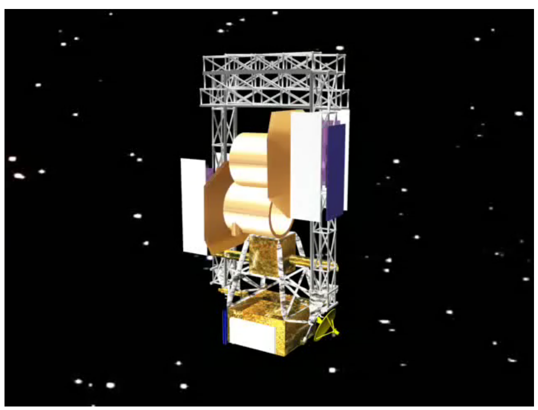
SPIRIT mission concept





- 1 m afocal, off-axis telescopes (no deployments)
- Interferometric baselines from ~7 to 36 m
- Dense *u-v* plane coverage (very good image quality)
- Michelson (pupil plane) beam combination
- Scanning optical delay line for $\lambda/\Delta\lambda$ = 3000 spectroscopy
- All optics at 4 K
- TES bolometers or MKIDs in small arrays (up to 14 x 14 pixels) cooled to 30 mK





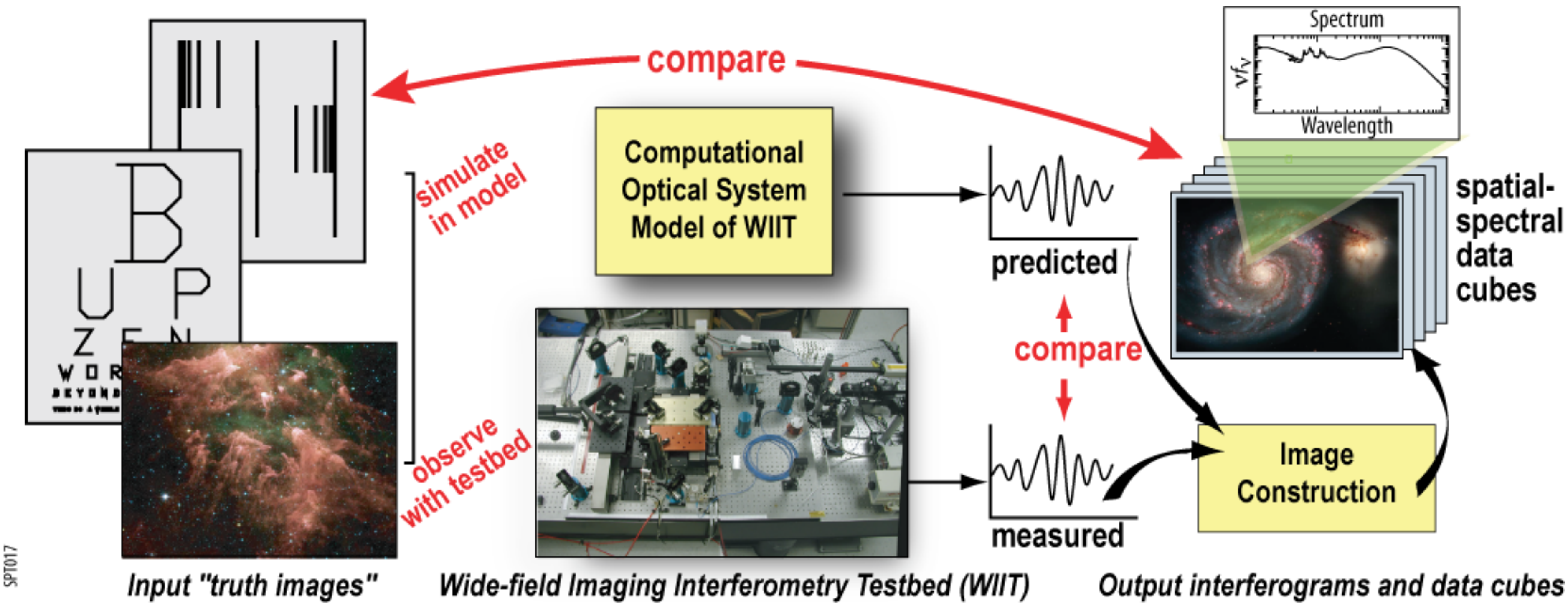
- Sun shades sized for 40 deg wide viewing zone around the ecliptic plane
- Operates in Lissajous orbit at Sun-Earth L2

Astrophysical background-limited sensitivity across a four-octave spectral range from **25 to 400 μm**

Avg time per observation ~29 hrs

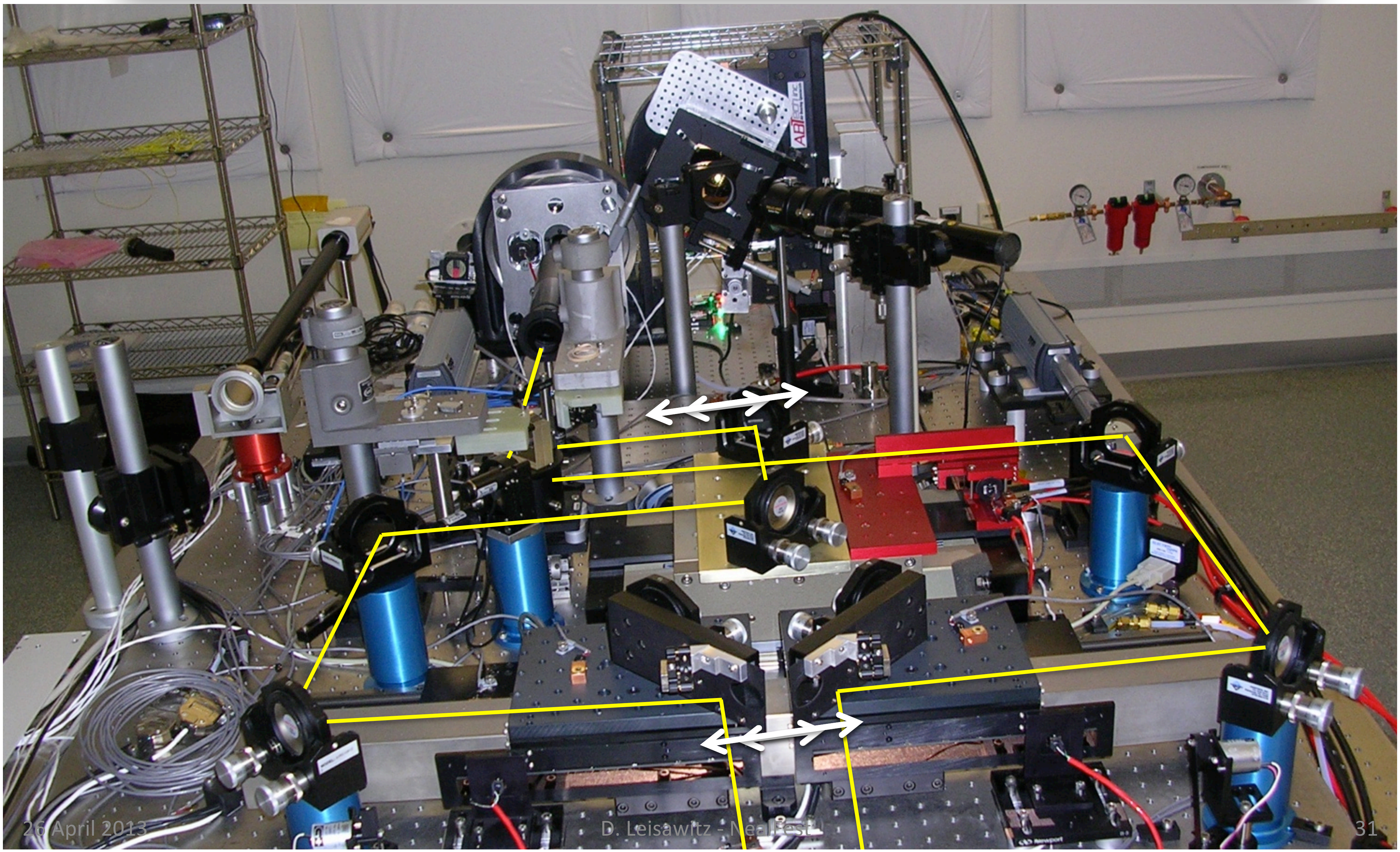
Each observation yields a spatial-spectral data cube with sub-arcsecond angular resolution over a 1 arcmin square field and a spectrum for every resolution element

Will it work?

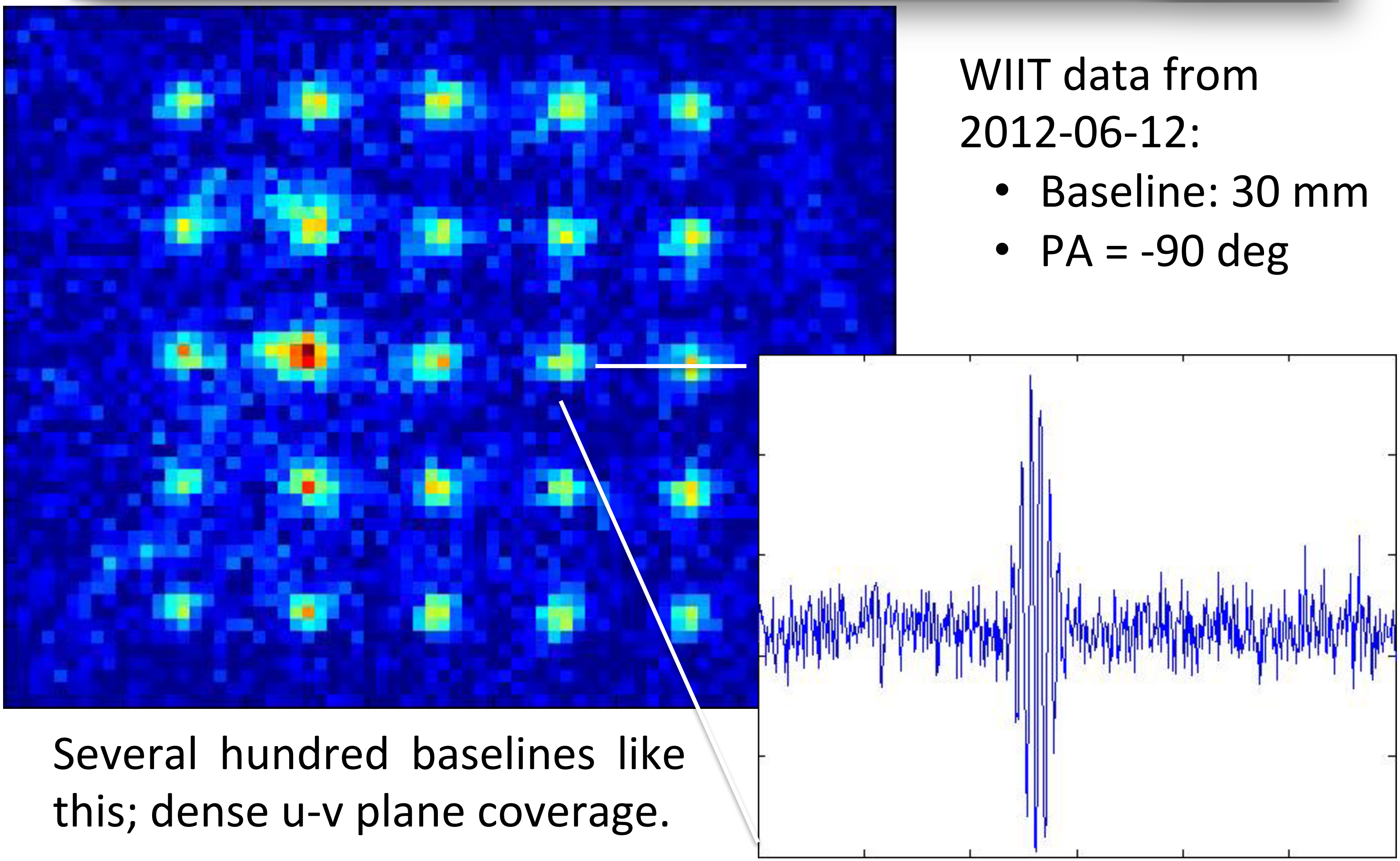


Wide-field spatio-spectral interferometry is approaching TRL 6 for far-IR space mission applications. (System model in an operational environment relevant to its intended space flight application.)

Wide-field Imaging Interferometry Testbed



Representative testbed data

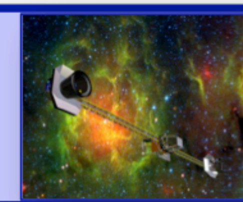


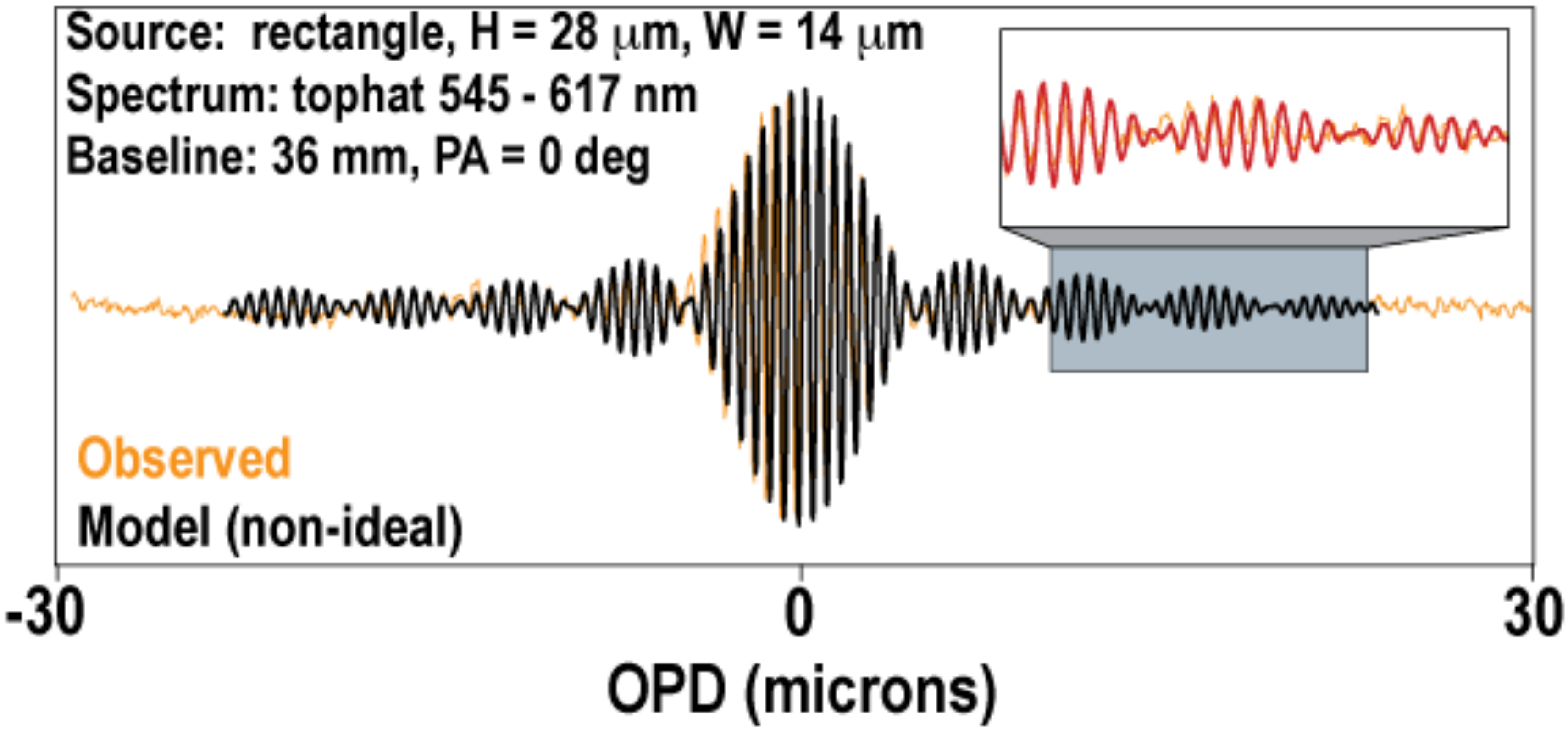
WIIT data from 2012-06-12:

- Baseline: 30 mm
- PA = -90 deg

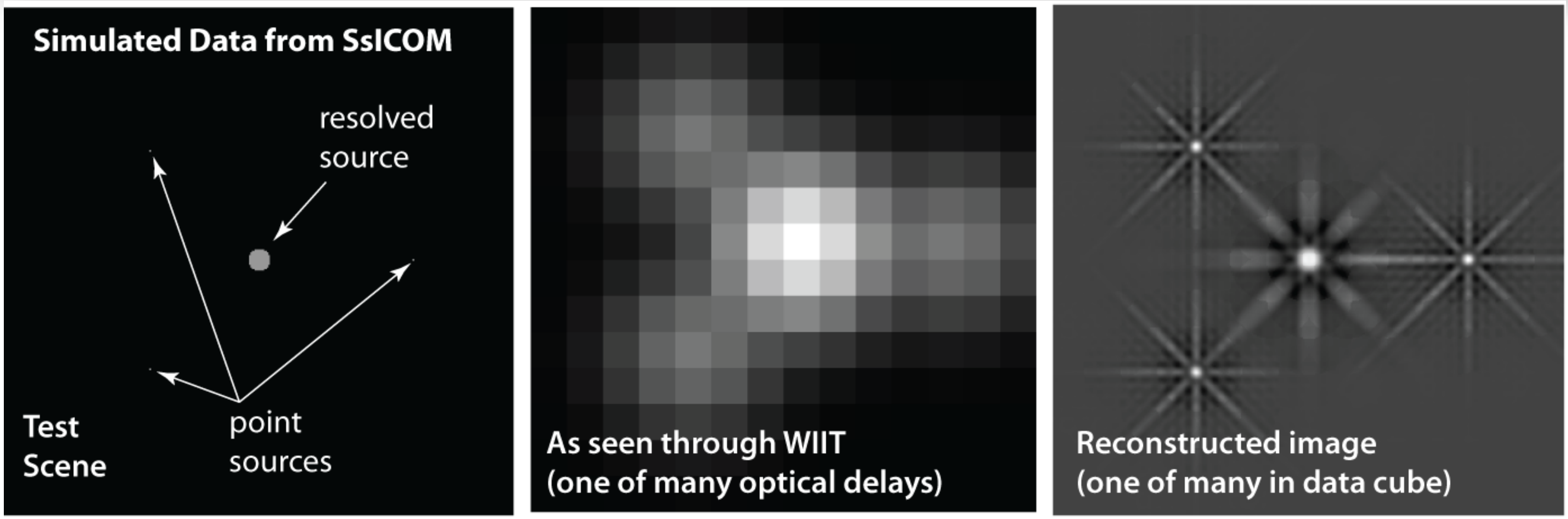
Several hundred baselines like this; dense u-v plane coverage.

Observed and model interferograms





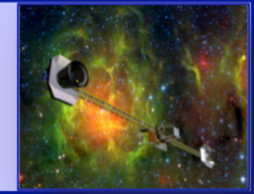
“Double Fourier” synthesis



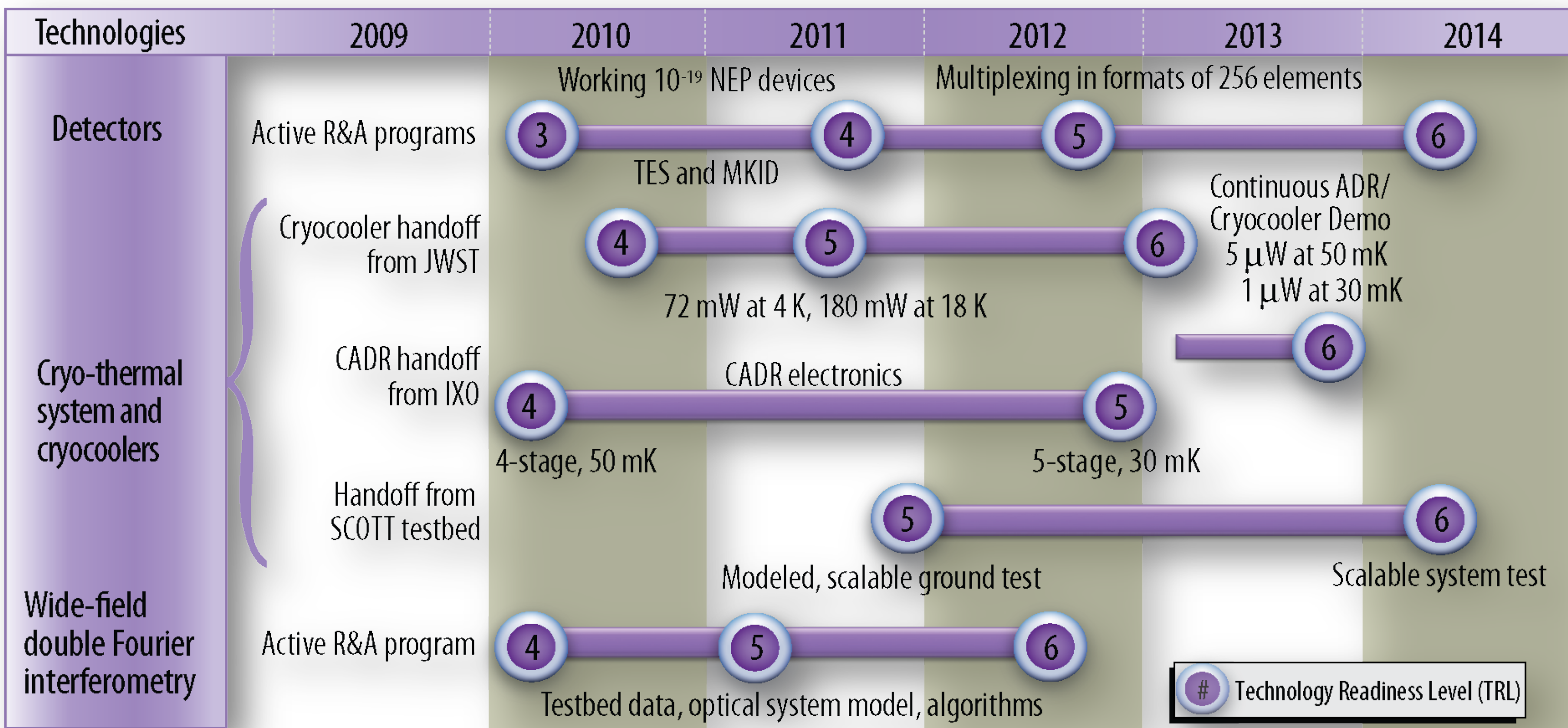
Concluding thoughts

- ALMA and JWST are testaments to the power of human ingenuity and perseverance.
- In due course, you will also reap the benefits of a space-based far-IR interferometer.
- The complementary measurement capabilities of ALMA, JWST, and SPIRIT will enable us to understand how habitable worlds form.
- **Thank you, Neal, for inspiring us in so many ways!**

Backup slides



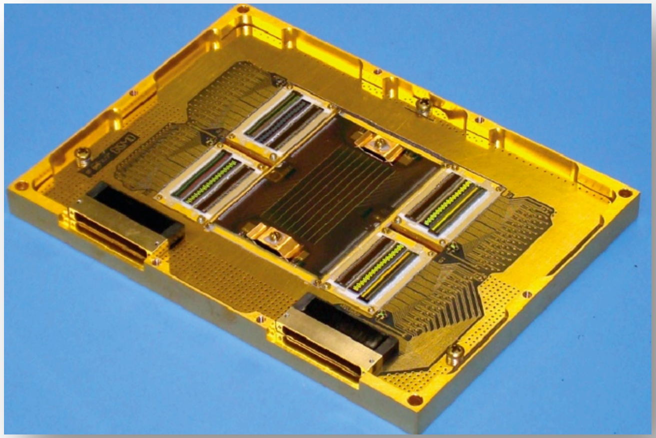
Technology roadmap



Detectors

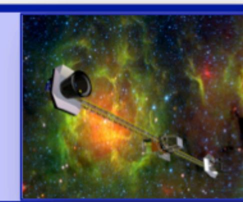
Detectors are the pacing technology. The required sensitivity, readout speed (detector time constant), and pixel count are well within reach.

- Enables: astrophysical background-limited sensitivity
- 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



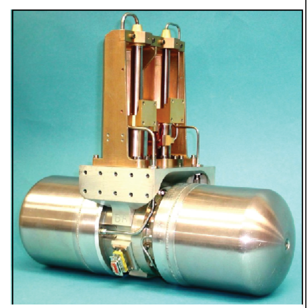
J. Staguhn et al. - GISMO

Cryocoolers

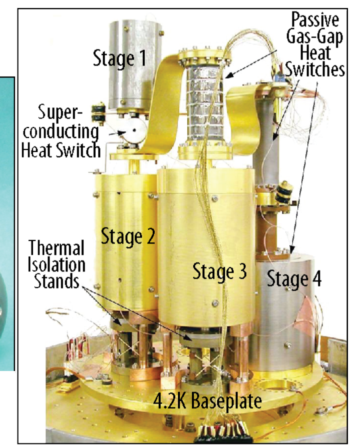


Cryocoolers will be used instead of expendable cryogen

- 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



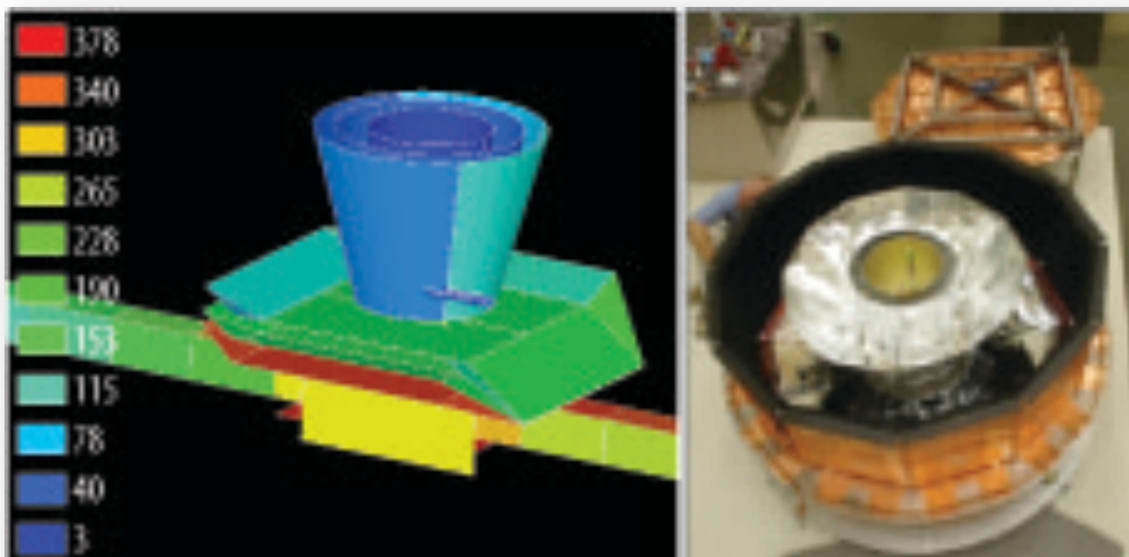
N-G's JWST MIRI cooler



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

SPICA drives detector technology