

SPECS

The Kilometer-baseline Far-IR Interferometer in NASA's Space Science Roadmap

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- g - UT Austin
- h - NRL
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- j - Princeton Univ.
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- l - Univ. Maryland
- m - ISAS/JAXA
- n - Johns Hopkins Univ.
- o - NASA JPL/Caltech
- p - NRC Research Associate
- q - George Mason Univ.
- r - NASA MSFC
- s - UCLA

Industrial Partners:

Ball Aerospace, Boeing, Lockheed Martin, Northrop Grumman



Outline

- Context: community planning and study status
- Science goals
- Mission requirements
- Mission concepts for SPIRIT and SPECS
- Tethered formation flying, a key enabling technology

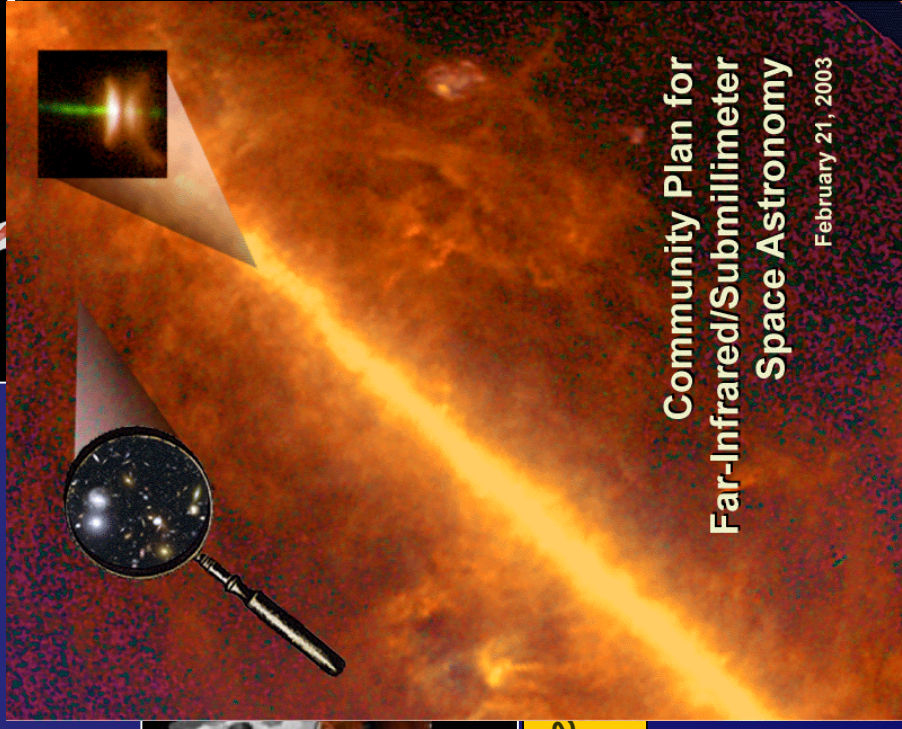


The Path Leading to SPECS



Single Aperture Telescope

ISO
COBE
IRAS
"now"
Spitzer
SOFIA
Herschel
SPICA



2010

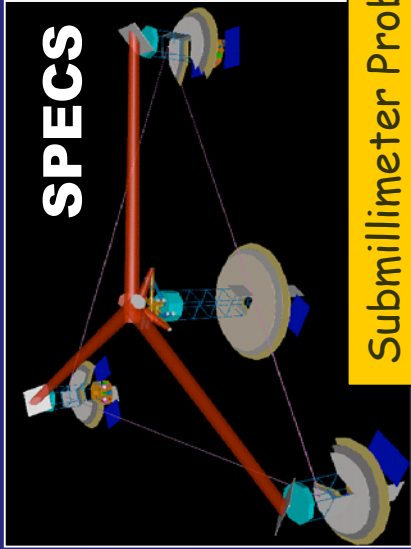
SPIRIT

Space Infrared Interferometric Telescope

2020

Next Generation
Space Probe of
Evolution of
Cosmic

In Europe, two white papers submitted for Cosmic Vision planning also call for far-infrared/submillimeter space interferometry

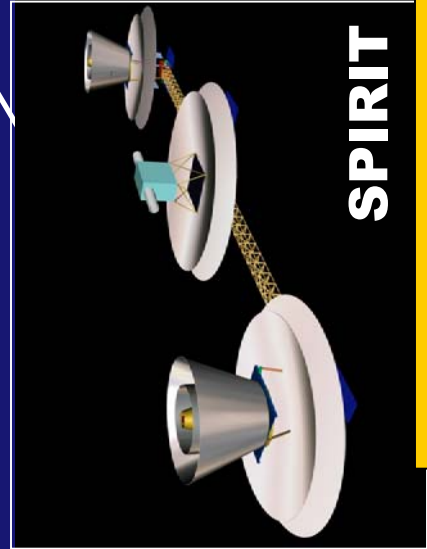


SPECS

Submillimeter Probe of the Evolution of Cosmic Structure

Missions to be discussed

2020



SPIRIT

Space Infrared Interferometric Telescope

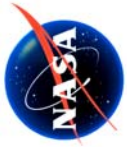
SPICA
Herschel 2010
SOFIA
Spitzer

"now"

ISO

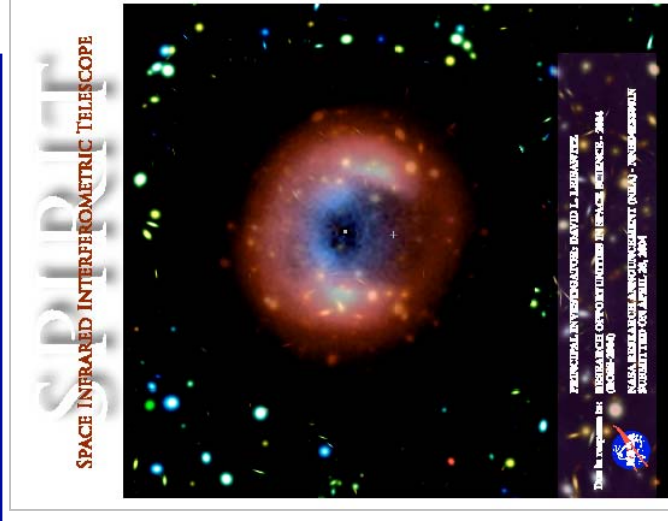
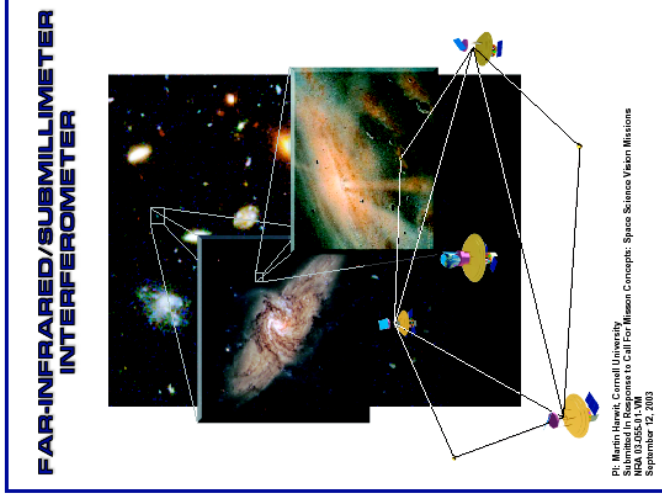
COBE

IRAS

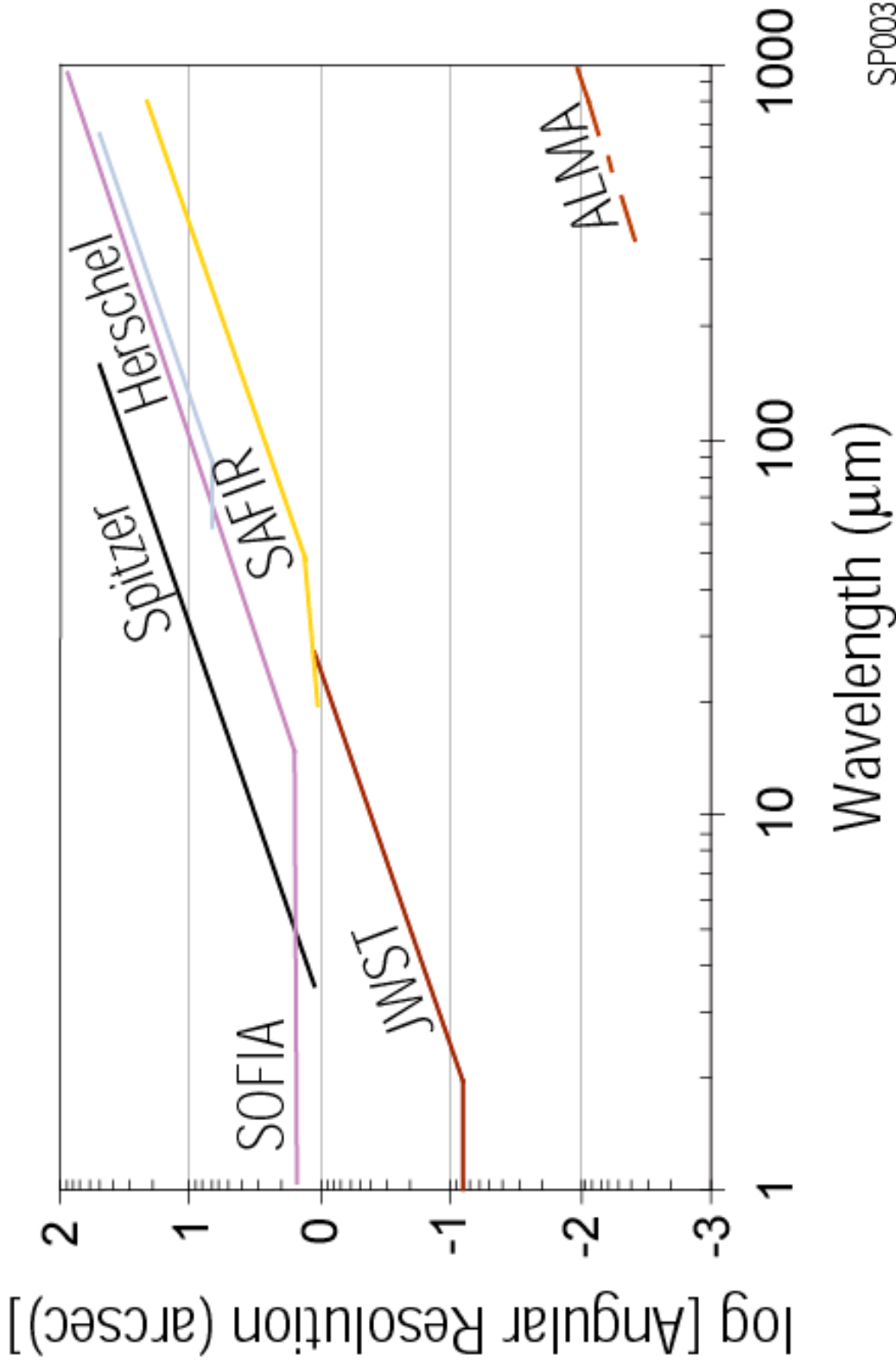


Mission Study Status

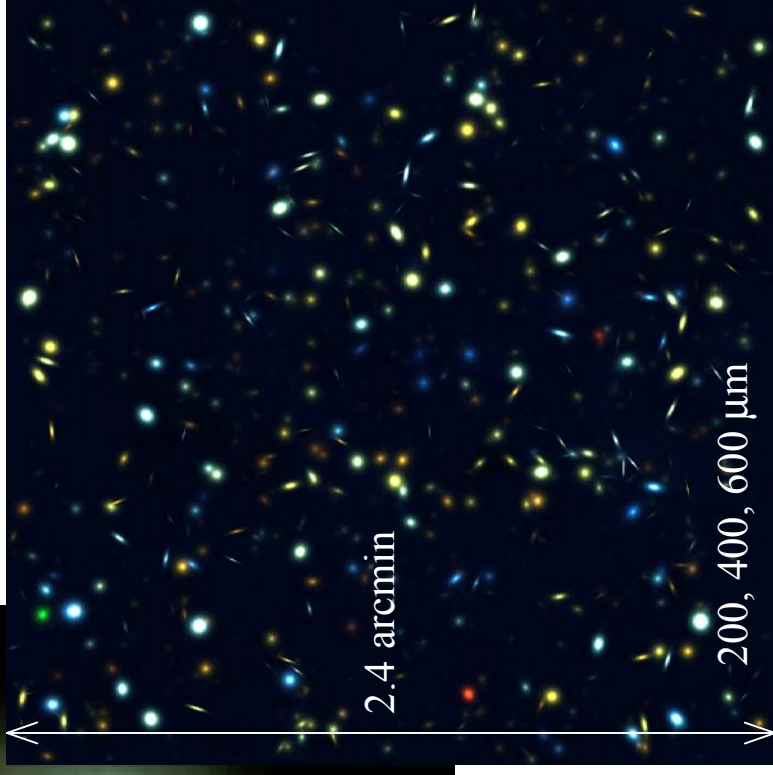
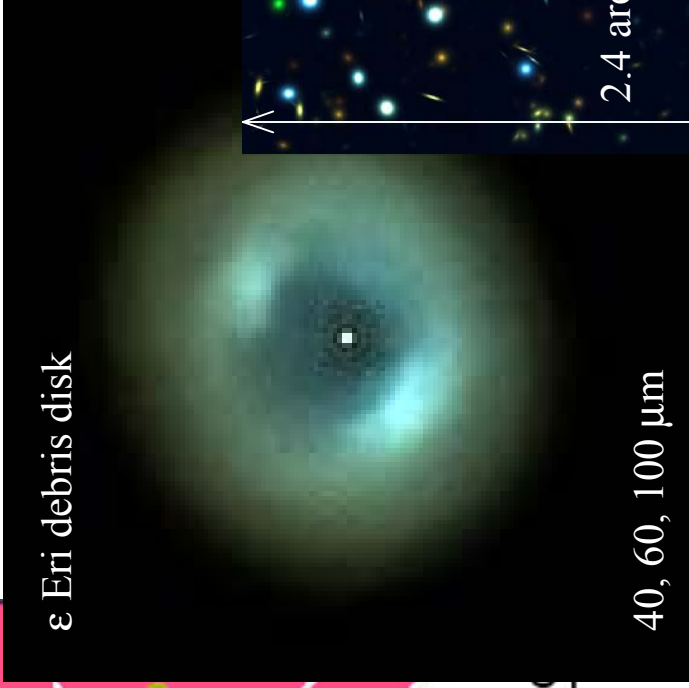
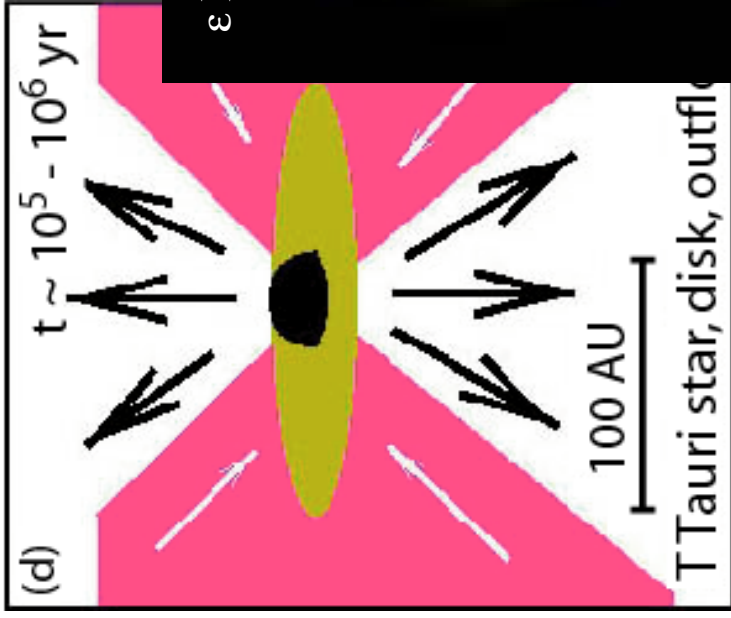
- The Infrared Era has begun
 - Spitzer now
 - Herschel soon
 - international community and public interest
 - new information from Spitzer available for mission planning
- Key elements of the *Community Plan* are being implemented
 - SAFIR and **SPECS** Vision Mission studies underway
 - **SPIRIT** “Origins Probe” study underway
 - Opportunities to report to NASA’s Astronomy and Physics Roadmap Committees coming in December and January
 - Reasonable progress on all technology frontiers



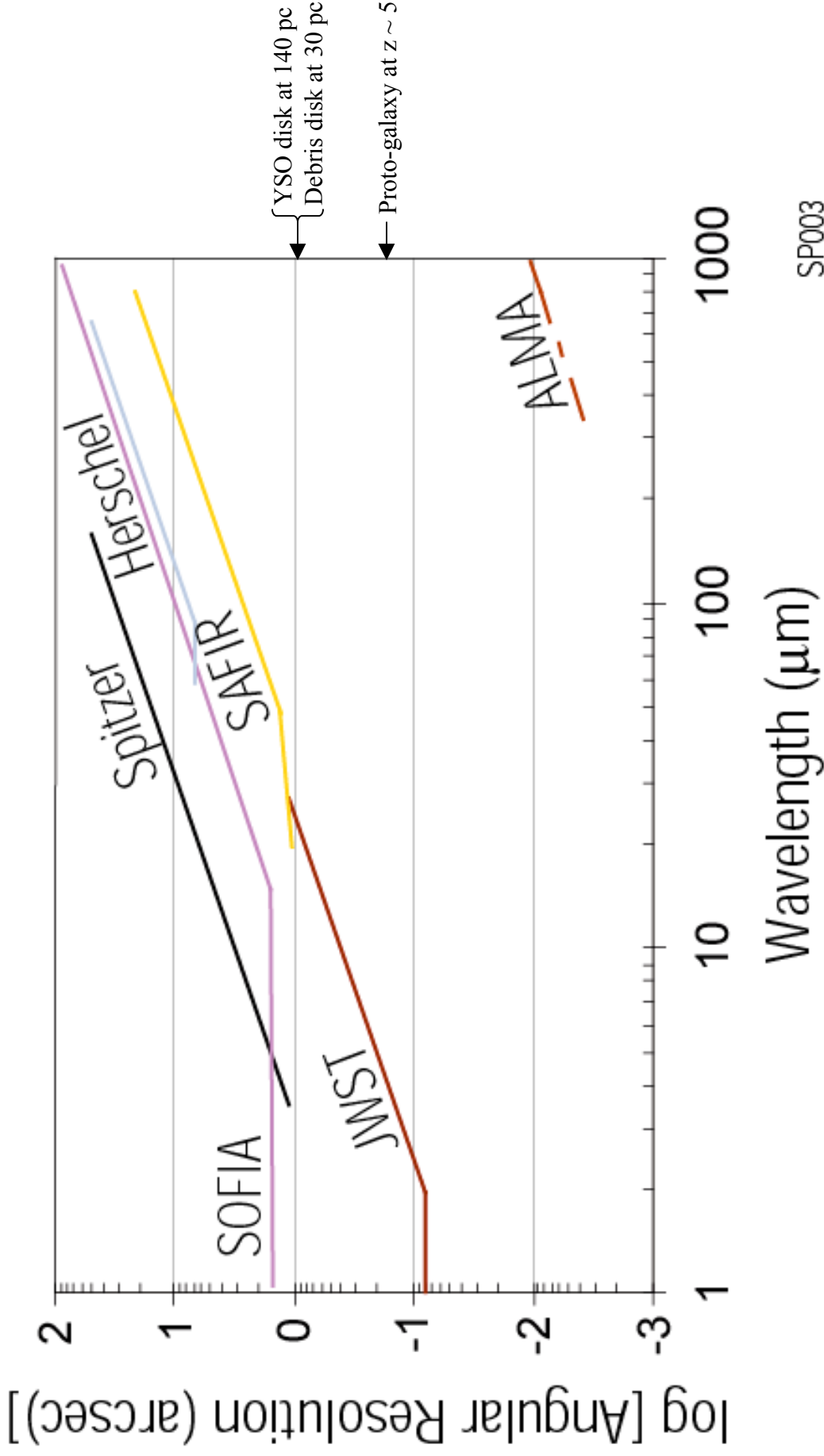
The Importance of High Angular Resolution



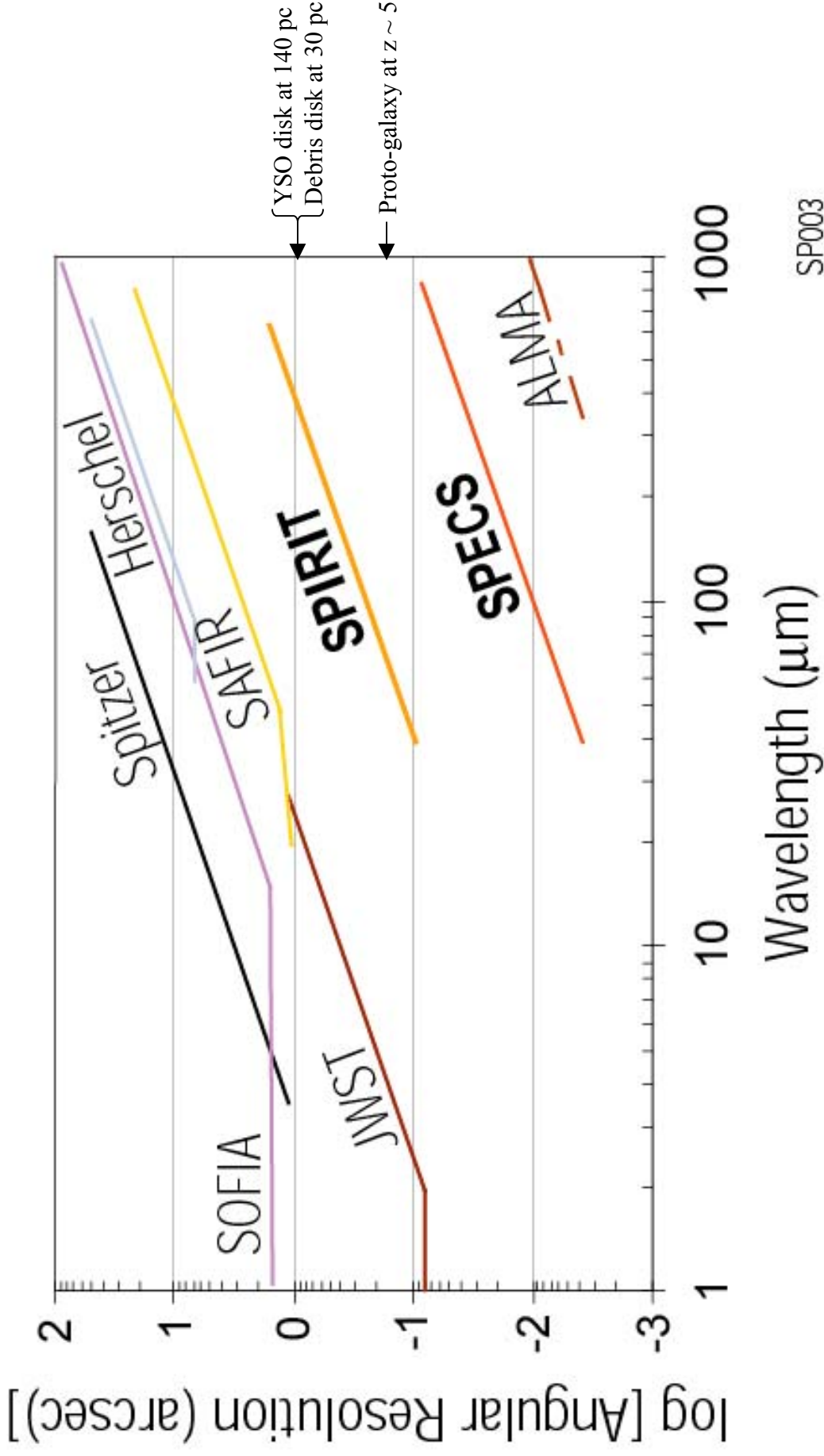
The Importance of High Angular Resolution

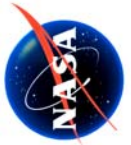


The Importance of High Angular Resolution

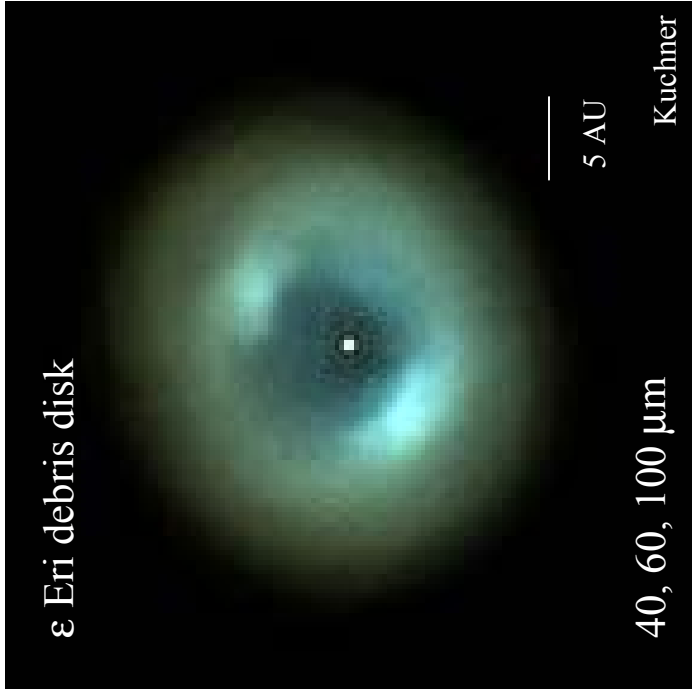
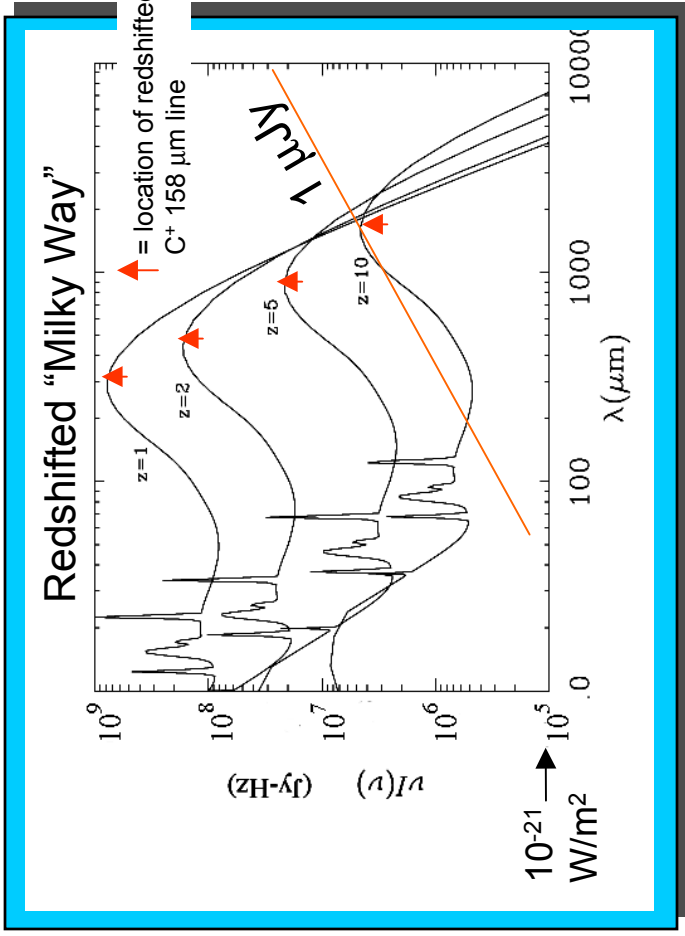


The Importance of High Angular Resolution



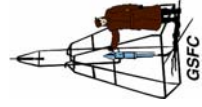


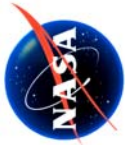
Sensitivity Requirements: Distant and Local



To see an L* galaxy at high z, need better than 1 μJy sensitivity. Protogalaxies might have been $\sim 100\times$ fainter.

To image debris disk dust emission on a 1 AU scale, need $\sim 1 \mu\text{Jy}$ sensitivity.





Why Interferometry?

An interferometer is a good design choice when angular resolution rather than sensitivity drives the aperture size requirement

Spatial resolution:

$$\Delta\theta = 10 \text{ mas } (\lambda / 100 \text{ }\mu\text{m})(b_{\text{max}} / 1 \text{ km})^{-1}$$

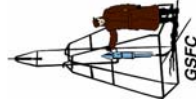
for maximum baseline b_{max} at wavelength λ . (For comparison, a diffraction limited 10 m telescope provides 2.5 arcsec resolution at 100 μm .)

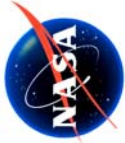
Spectral line sensitivity for an unresolved (point) source:

$$\text{MDLF} \sim 7 \times 10^{-22} \text{ W/m}^2 \{ \text{FBW } I_{\nu, \text{bg}} (\text{MJy/sr}) / [n(n-1)(\tau_{\text{sys}}/0.1)] \}^{1/2} (D/4\text{m})^{-2} (t/10^5\text{s})^{-1/2}$$

for $n = 3$ mirrors of diameter D in integration time t , where τ_{sys} is the system efficiency and FBW, the fractional bandwidth, could be ~ 0.7 .

In the far-IR/sub-mm, a total light collecting area comparable to that of JWST provides ample sensitivity, but an effective aperture diameter (b_{max}) of $\sim 30 - 50$ m is needed to overcome extragalactic source confusion into the sub-mm, 1 km to provide HST (or JWST) class angular resolution.





Far-IR Diagnostic Potential

Spectroscopy is vital to our ability to answer the important science questions.

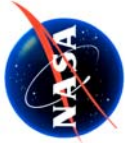
For extragalactic problems we might be satisfied to measure the integrated line intensity. $R \sim 1000$ would be okay.

However, for star formation research we are interested in resolving lines. For this we desire $R > 10^5$.

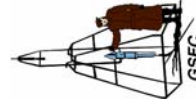
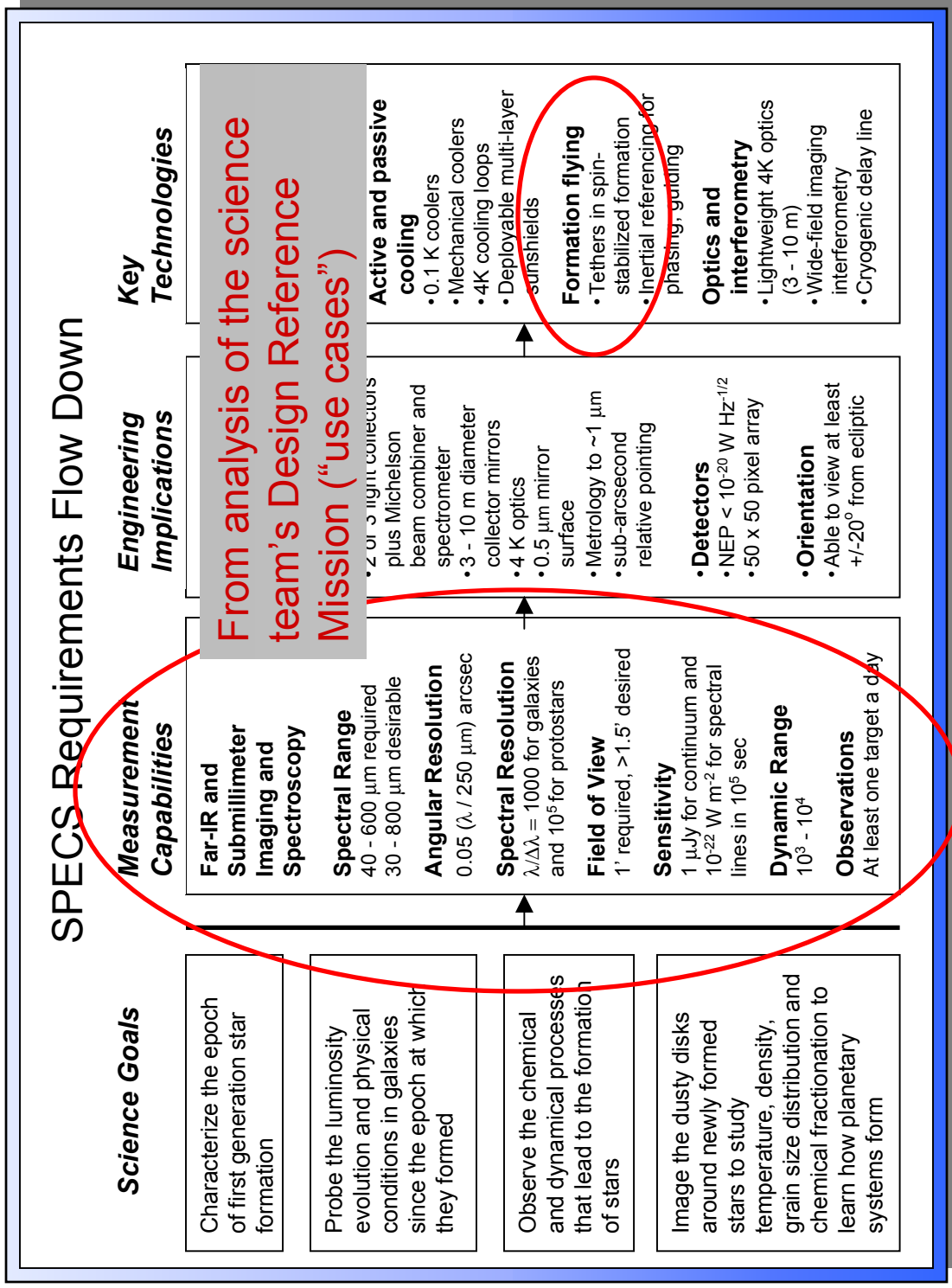
Typical Spectral Lines ¹	Derived Properties
Starburst Galaxies	
[ArIII]9, [ArII]7, [NeIII]15, [NeII]12, [NIII]57, [NII]122	Ionizing SED ζ , U^3 , IMF ⁴ , age
H recombination lines	Age, IMF, starburst luminosity
Dust features	Starburst luminosity
Active Galactic Nuclei (AGN)	
[NeV]14,24, [NeIII]15, [OIV]25, [SiIX]4	U, SED
Broad H recombination lines	Buried AGN
Dust features	AGN luminosity
Interstellar Medium (ISM)	
HII Regions	
[NeIII]36, [NeII]15, [SIII]34, [SIII]19, [OIII]52, [OIII]88	Visual extinction (A_V), electron density (n_e)
All Ne lines, H recombination	Abundance
AGN Narrow Line Region (NLR)	
[NeV]14/24, [NeIII]36/15	A_V (NLR), n_e
Photon Dominated Regions, Shocks	
H ₂ 2, [S II]25, [SIII]35, PAH ⁶ features, Far-UV field strength & [CII]158, [OI] 63, 145, [FeII]18,24, [FeII]24	SED, density, temperature, shock parameters
Molecular Clouds, Protostars, and Disks	
Rotational and rovibrational lines of H ₂ O, CO, and small hydrides	Temperature, density, turbulent & systemic velocities, isotopic abundances

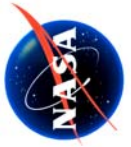
- ¹ Rest wavelengths in μm , but redshifted at high z
- ² Spectral Energy Distribution
- ³ Ionization parameter
- ⁴ Initial Mass Function





“Flow Down” from Science Questions to Technology Requirements: SPECS

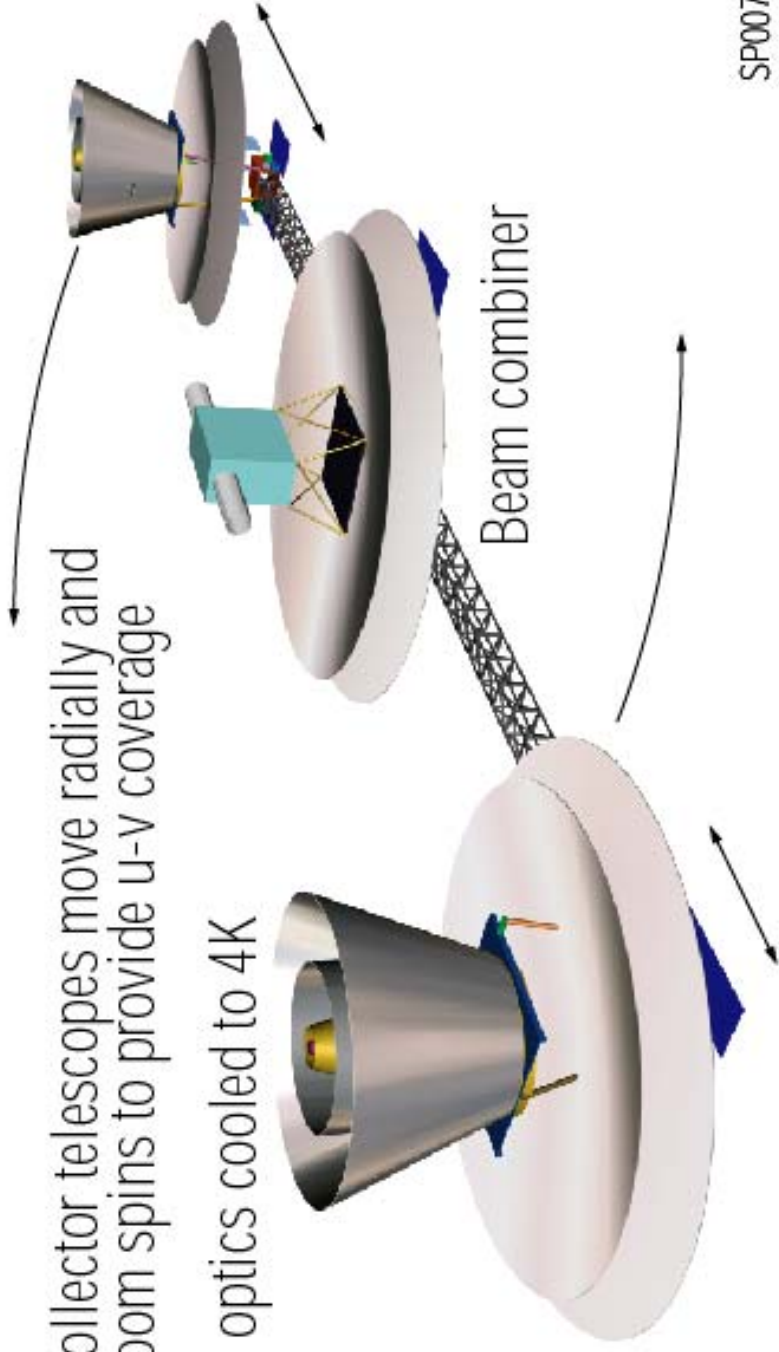




SPIRIT Mission Concept

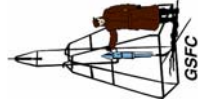
Collector telescopes move radially and boom spins to provide u-v coverage

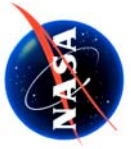
All optics cooled to 4K



SP007

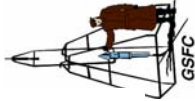
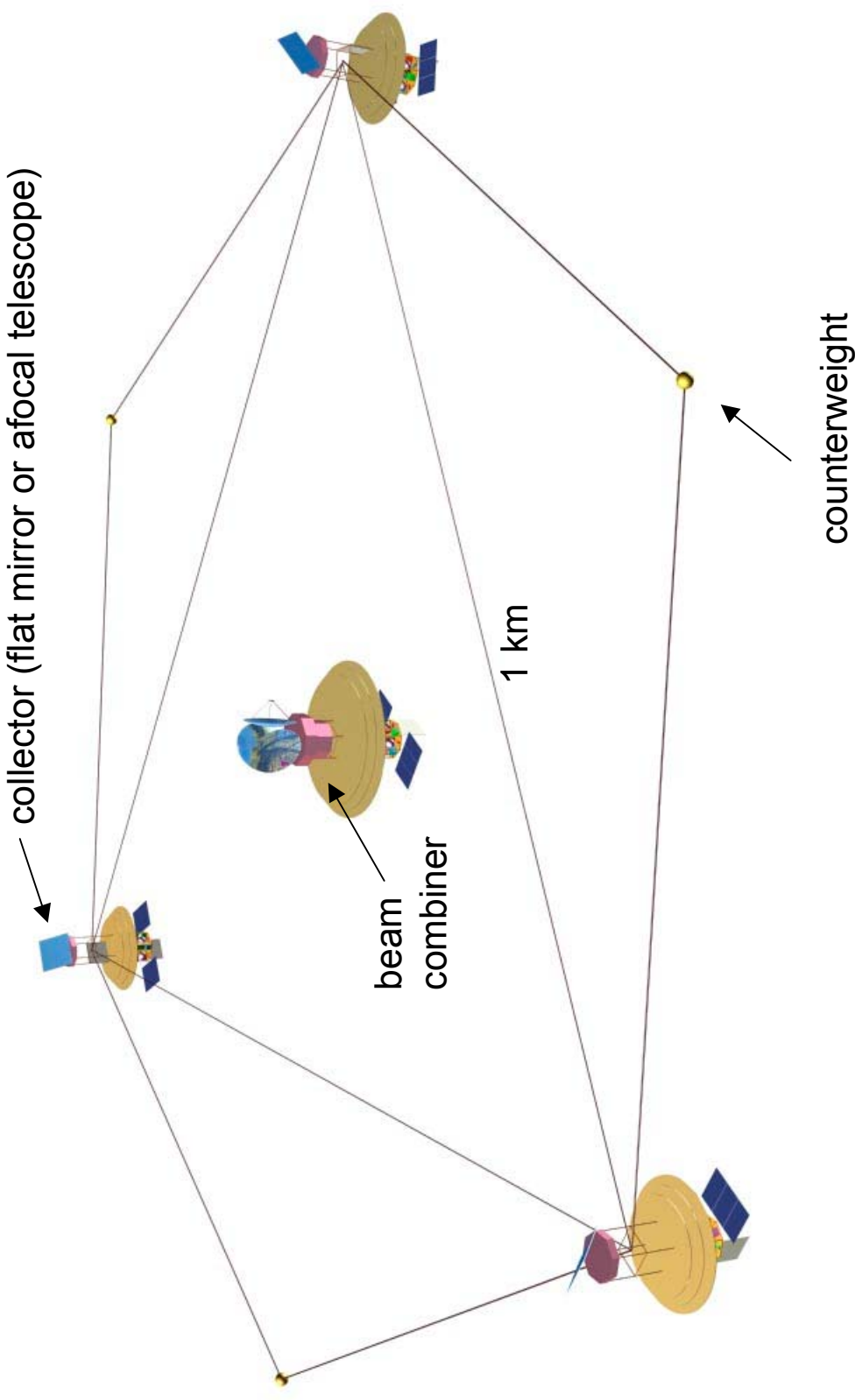
SPIRIT could fly in the next decade as an Origins Probe





SPECS Mission Concept

Fully extended array

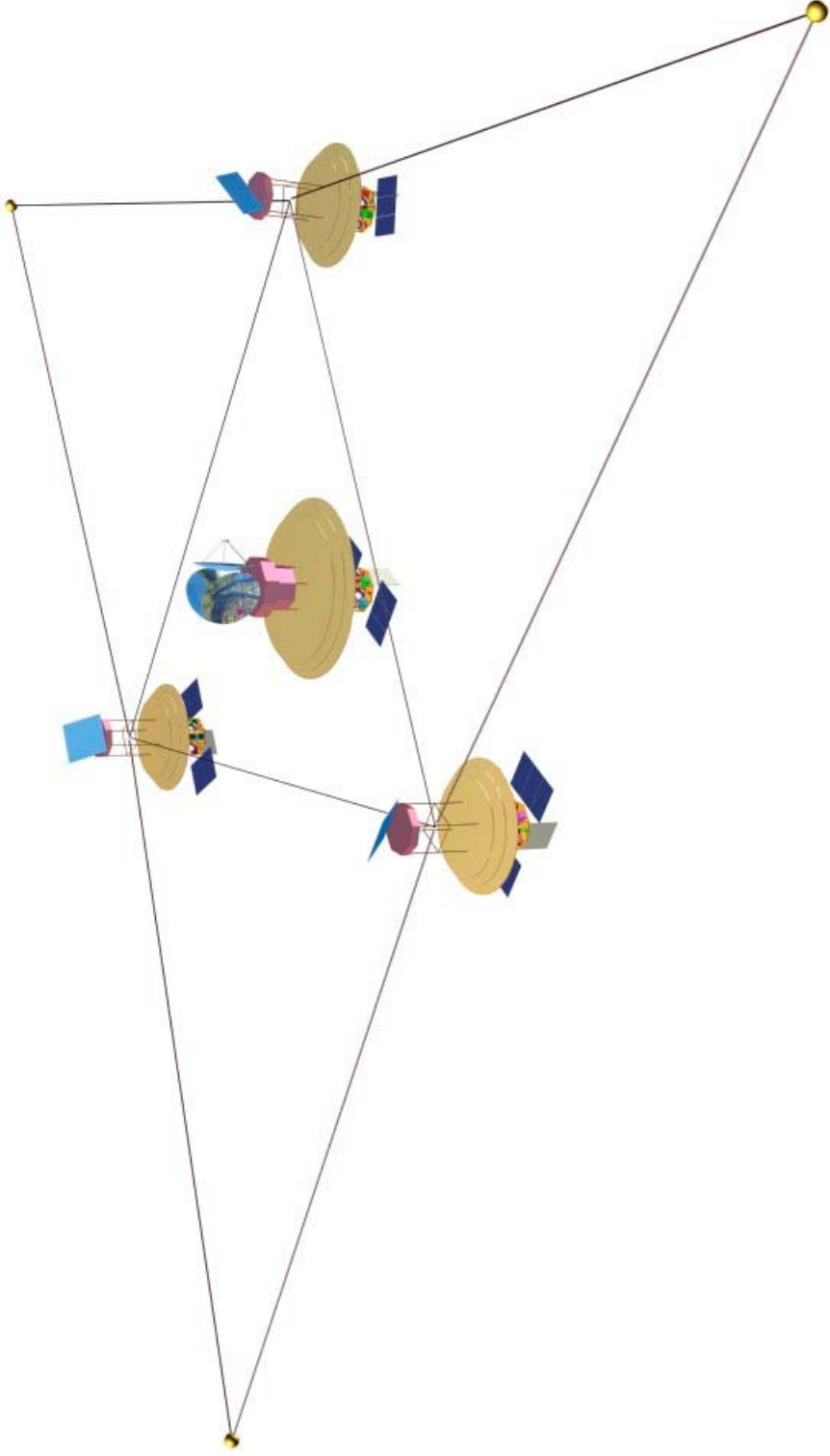


Tether configuration developed by Farley and Quinn (2001)

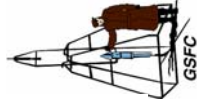


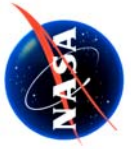
SPECS Mission Concept

Partially contracted array



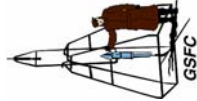
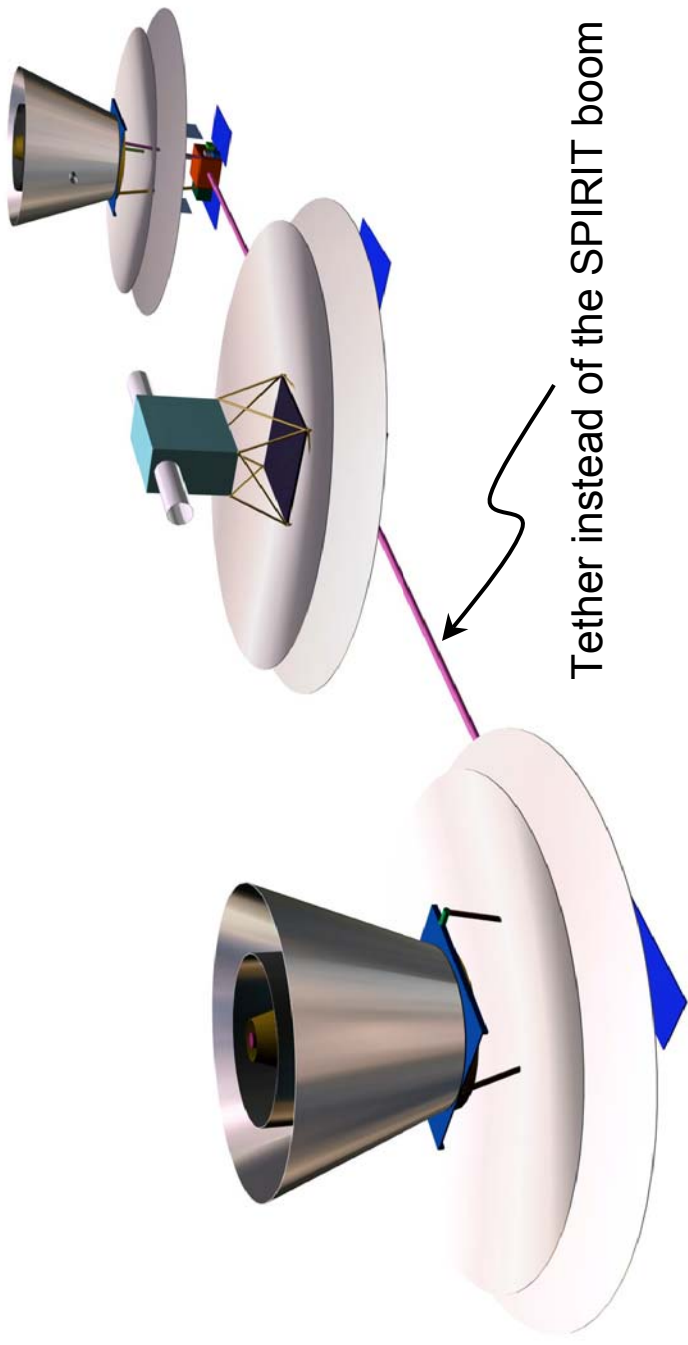
2-collector systems and off-axis afocal telescopes
are under study

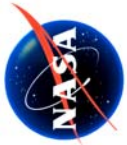




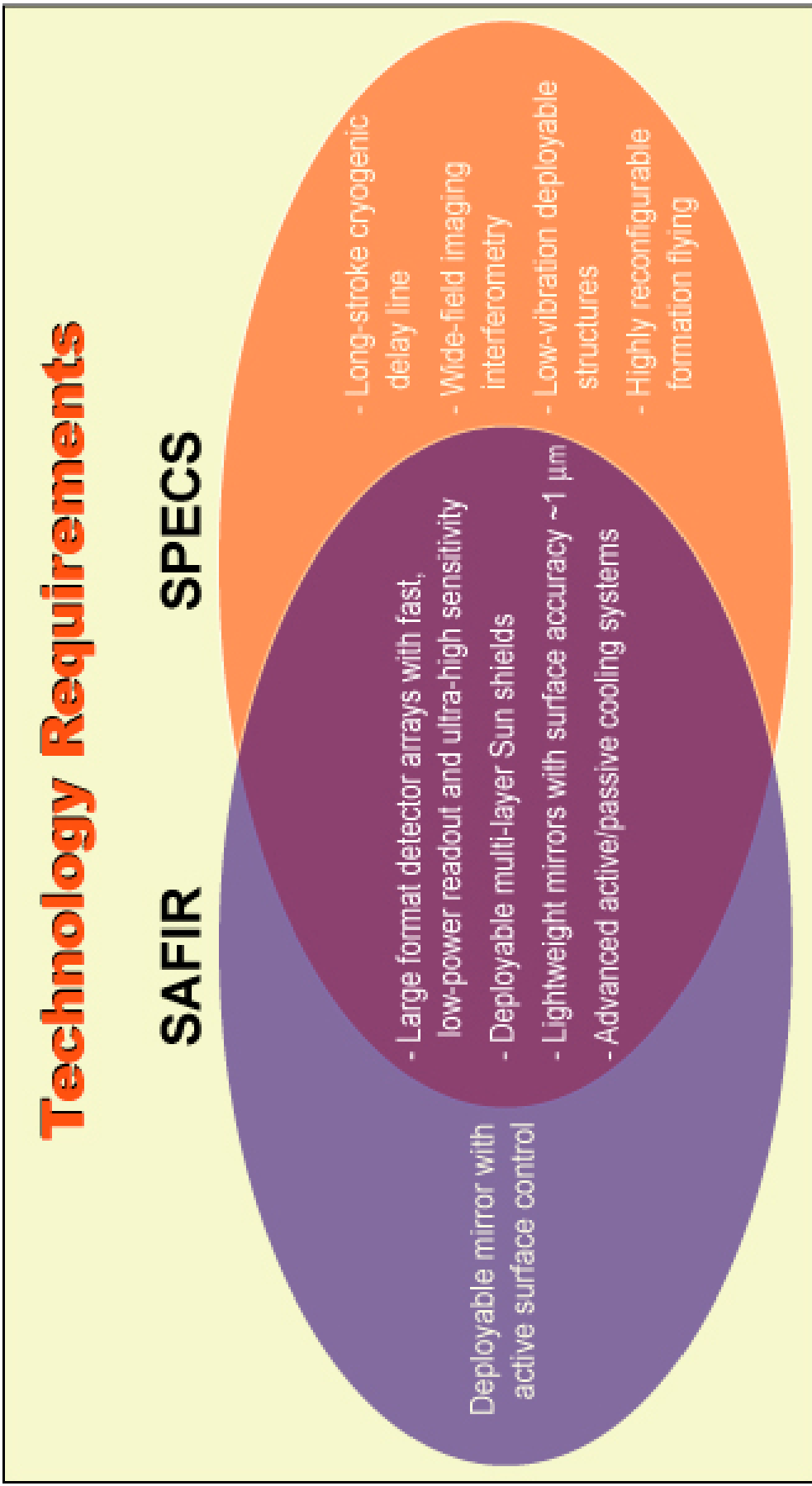
SPECS Simple Concept

Linear array

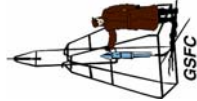


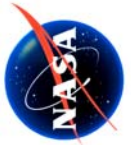


Technology: Heritage and Common Needs



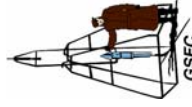
- Stable boom and metrology in common with SIM
- Wide-field double Fourier technique in common with TPF-I/Darwin

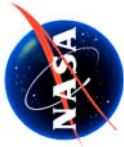




Highly Reconfigurable Arrays

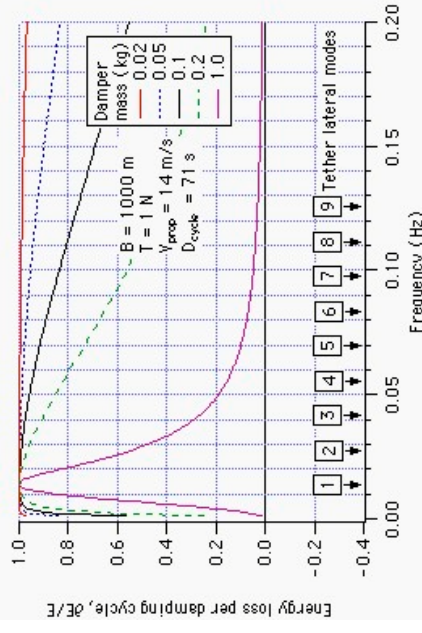
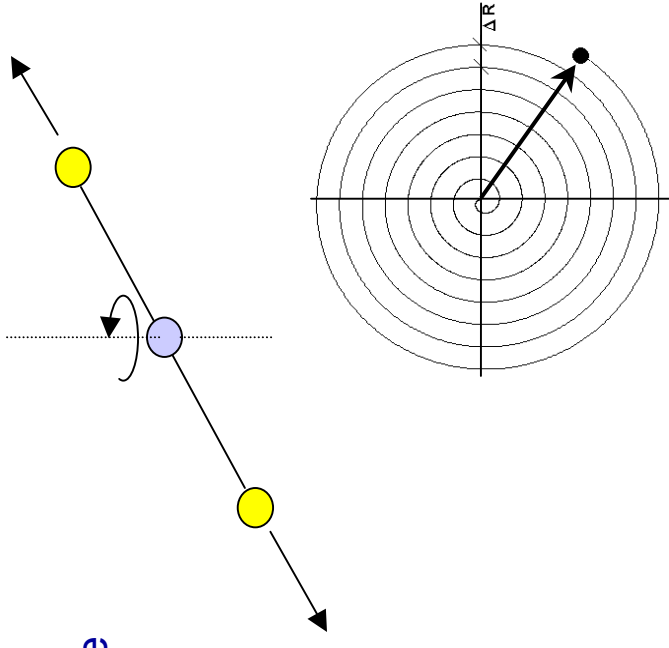
- “Highly reconfigurable” for dense u - v plane coverage
- Rotating deployable boom with light collectors on trolleys - works for b_{\max} up to ~50 m
- Formation flying works for b_{\max} up to ~200 m (too much thruster propellant or too few images per mission if b_{\max} bigger)
- Formation flying with tethers works for b_{\max} up to ~1 km
 - Quinn et al. study suggests viability, addresses requirements, alternative architectures, re-pointing; tools developed to facilitate further analysis
 - Lorenzini et al. have analyzed tether dynamics
 - Sell et al. adapting SPHERES to test tethers, could lead to air table demo and first space demo
 - Need inexpensive long-baseline space demo scalable to SPECS

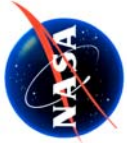




Formation Flying with Tethers

- Propellant mass prohibitively large for a highly-reconfigurable, km-baseline array (essential for good image quality)
- Tethers have many advantages:
 - light weight
 - passive stability
 - ease of reconfiguration
 - easier metrology and spacecraft relative bearing
 - planar spin-stabilized tethered configuration can have many shapes
- Centrifugal forces in the spin plane provide tether tension and shape stability
- High angular momentum due to spin provides stable pointing to target and low sensitivity to external torques
- For heliocentric and L2 halo orbits **cm-level stability of tethered units is provided by spin-stability with no need for thruster control** during station-keeping
- Tether oscillations, excited by maneuvers, can be damped out in minutes (long baselines) or seconds (short baselines)
- With damping, tethered formation naturally converges to rigid flat spin configuration
- Tether noise spectrum is at low frequency (periods from a fraction of a second to a minute)





Summary

- SPIRIT and SPECS satisfy critical needs of NASA's space science program (e.g., characterize exo-zodi debris disks) and address compelling scientific questions (How did we wind up on a watery rock orbiting the Sun in the disk of a spiral galaxy?)
- Broad support exists for far-IR/sub-mm space interferometry in the international scientific community
- SPIRIT could fly next decade as an "Origins Probe" (SPECS will come later)
- **Formation flying with tethers is an enabling technology for space-based long-baseline imaging interferometry**

