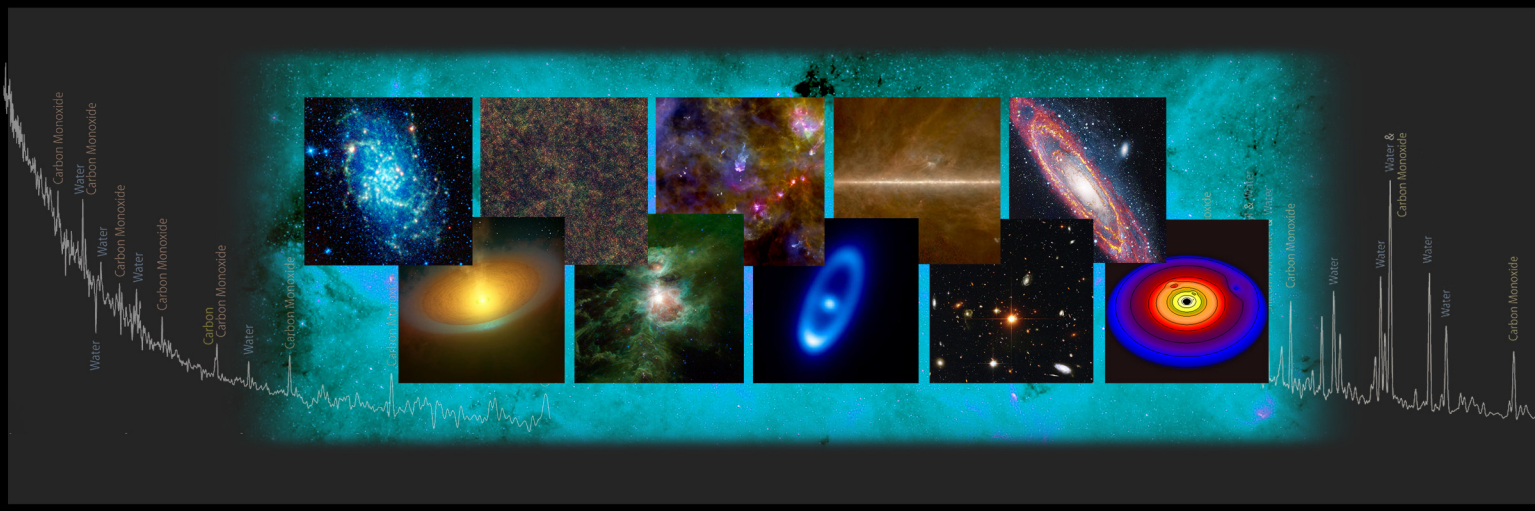
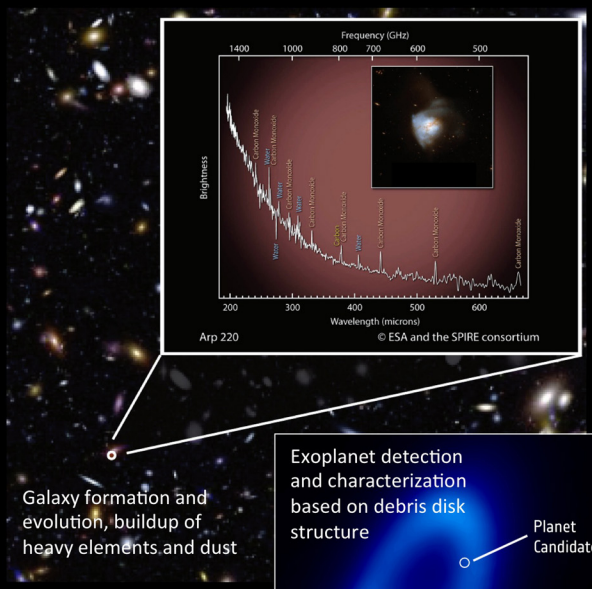
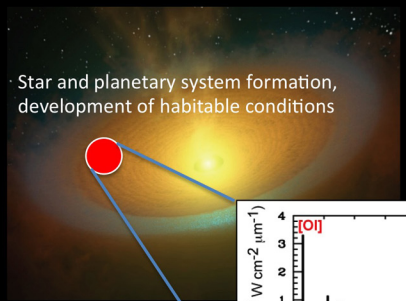
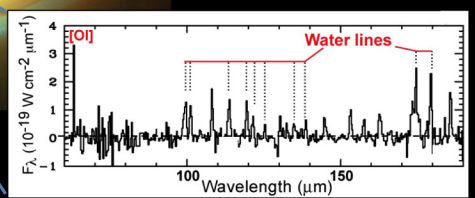
National Aeronautics and Space Administration

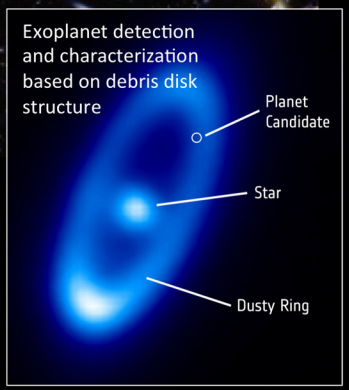
An Overview of Studied Far-Infrared Mission Concepts and Their Measurement Capabilities







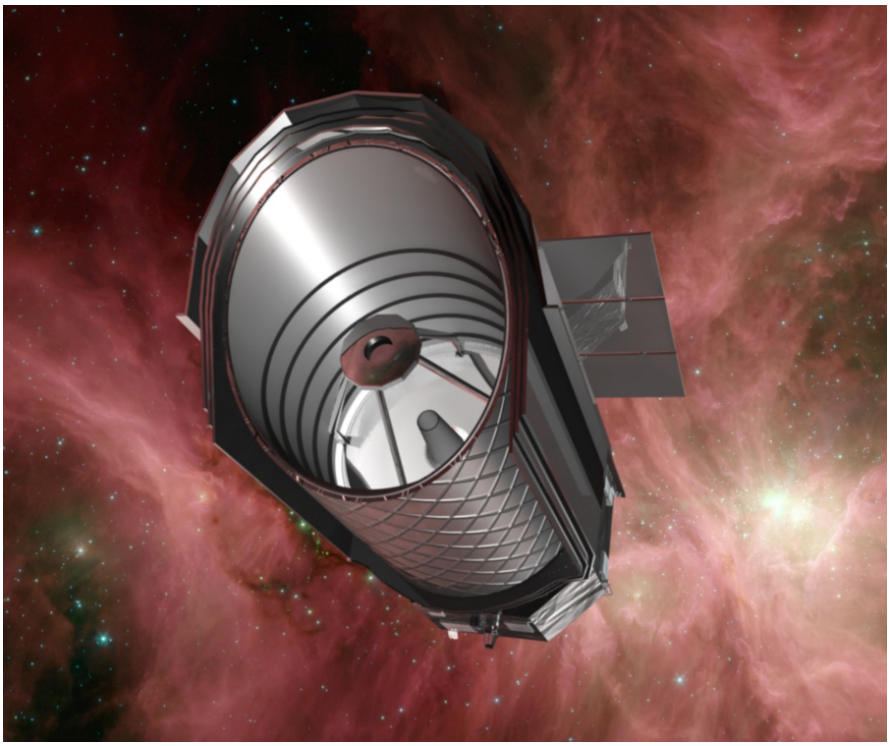




May 6, 2014

SPICA

SPace Infrared Telescope for Cosmology and Astrophysics



Name of concept:

Space Infrared Telescope for Cosmology and Astrophysics (SPICA)
References are papers by Nakagawa et al.,
and SPICA web site http://www.ir.isas.jaxa.jp/SPICA/SPICA_HP/index_English.html

Architecture:

- A 3.2-meter telescope cryogenically cooled to <6 K, with four focal plane instruments:
- SAFARI - 34 - 210 μm;
- Mid-IR Camera and Spectrometer - 5 - 38 μm (MCS);
- SCI Coronographic Instrument (SCI); and
- Focal Plane Camera (FPC)

Science drivers:

- Constrain the emission of ground state H_2 emission from the first (population III) generation of stars
- Detect biomarkers in the mid-infrared spectra of exo-planets and/or the primordial material in protoplanetary disks
- Detect H_2 haloes around galaxies in the local Universe
- Detect planets in the habitable zones of the nearest few stars
- Detect the far infrared transitions of PAHs in the ISM
- Detect dust formation in supernovae in external galaxies, and determine the origin of dust in high redshift galaxies

Measurement capabilities

Parameter	Unit	Value
Wavelength range:	μm	SAFARI 34 - 210 (considering extension to 350) ; MCS 5 - 38; FPC 0.7 - 5; SCI 4 - 28
Angular resolution:	arcsec	7.2 (λ/100 μm); diffraction limited at 5 μm
uv plane filling fraction:		complete (single-aperture telescope)
Spectral resolution:	(=λ/Δλ)	SAFARI: 50, 500, 2000; MCS 50 - 30,000; FPC 5 - 20; SCI 2 - 200
Instantaneous FoV	arcmin	SAFARI: 2 x 2; MCS 5 x 5 camera, or slit spectroscopy; FPC 5 x 5; SCI has IWA (1.7 to 4.4)(λ/D), OWA (6.5 to 32)(λ/D)
Sensitivity to		
Spectral lines	W m^{-2}	SAFARI: 3.7, 3.4, and 2.9 x 10^{-19} at band-center wavelengths 47, 85, 160 μm, respectively; MCS: ~10^{-19} (5σ, 1 hour)
Continuum	μJy	SAFARI: 15, 500, 5000 at band center wavelengths 47, 85, 160 μm, respectively (confusion-limited); MCS: 300- 800 in 12 - 35 μm range; FPC 27.3 mag (AB) at R = 5; SCI ~0.5 - 5 (5σ, 1 hour) at R = 5
Field of Regard (FoR):		all-sky in a year; large area instantaneous FoR

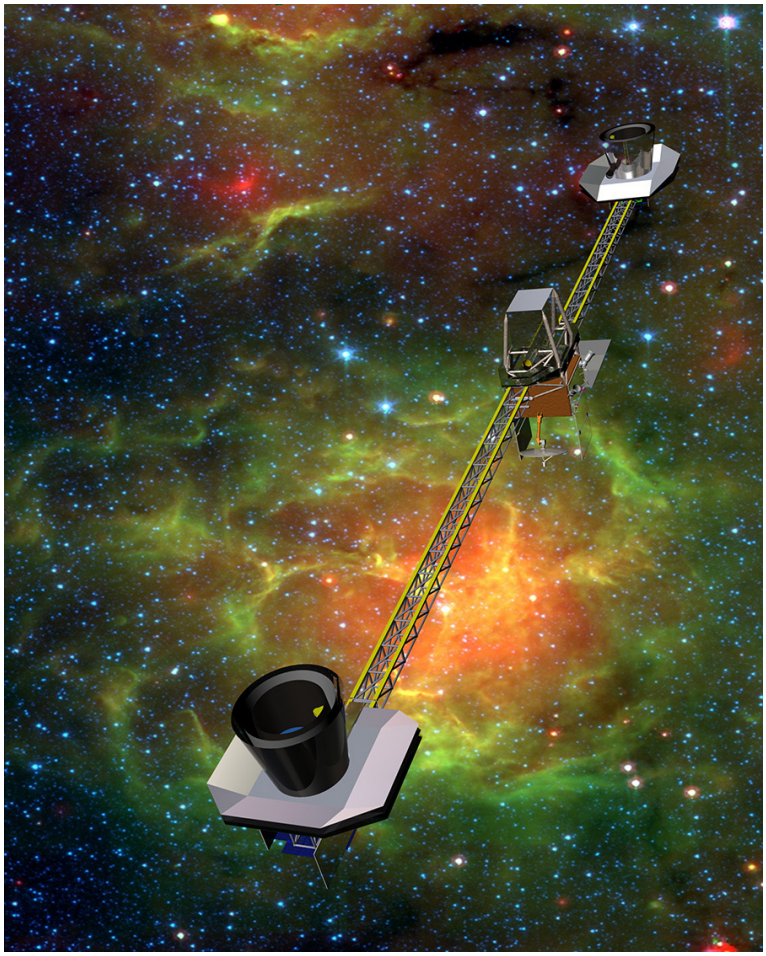
Potential launch vehicle(s): H-IIA

Orbit: Sun-Earth L2

Technology

Description	TRL (N.B. These are lower limits. Date of document unknown.)
Detectors	4
Cryocoolers	5
Sub-K cooler	4
FTS scan mechanism	6
DM for coronagraph	4
All component technologies	5 or greater by 2015

Concept maturity Revised System Requirements Review (SRR) in 2014



SPIRIT

Space
Infrared
Interferometric
Telescope

Mission Concept Summary

Name of concept:

Space Infrared Interferometric Telescope (SPIRIT)
References available at http://astrophysics.gsfc.nasa.gov/cosmology/spirit/

Architecture:

Structurally-connected spatio-spectral interferometer with dense uv plane coverage out to maximum baseline length 36 m. Two 1 m diameter afocal off-axis telescopes serve as light collectors. The telescopes and instrument are cryocooled to ~4 K, and the focal plane cooled to ~30 mK. MKID or TES bolometer detectors in arrays with maximum pixel count 14 x 14 pixels cover an instantaneous FoV 1 arcmin in diameter.

Science drivers:

- Image protoplanetary disks and measure the distributions of water vapor and ice to learn how the conditions for habitability arise during the planet formation process;
- Image structures in a large number of debris disks to find and characterize unseen exoplanets; and
- Make profound contributions to our understanding of the formation, merger history, and star formation history of galaxies, including the role of AGN in galaxy evolution.

Measurement capabilities

Parameter	Unit	Value
Wavelength range:	μm	25 - 400
Angular resolution:	arcsec	0.3 (λ/100 μm)
uv plane filling fraction:		Dense coverage in both dimensions. Baseline coverage: "zero spacing" plus 6 to 36 m. May be tailored to source.
Spectral resolution:	(=λ/Δλ)	>3000 over entire wavelength range
Instantaneous FoV	arcmin	1
Sensitivity to		
Spectral lines	W m^{-2}	2.9, 1.7, 1.4 and 1.3x10^{-19} at band-center wavelengths 35, 70, 140, and 280 μm, respectively (5σ, 24 hours)
Continuum	μJy	14, 20, 31, and 48 at band-center wavelengths 35, 70, 140, and 280 μm, respectively (5σ, 24 hours)
Field of Regard:		40° band centered on ecliptic plane

Potential launch vehicle(s):

Atlas V 531 with medium-length fairing, or equivalent
(flight system is volume-limited by the fairing dimensions)

Orbit: Sun-Earth L2

Technology

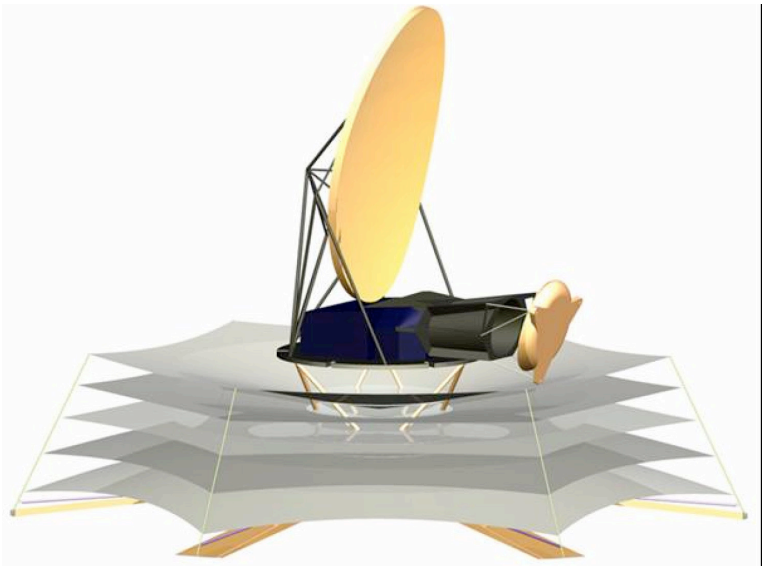
Description	TRL	
Detectors (MKID or TES bolometers)	3	challenge is to produce detectors with NEP ~ 10^{-19} W $Hz^{-1/2}$ with time constant ~200 μsec; modest array dimensions (14 x 14 pixels or smaller) (Benford et al. 2007)
Cryo-thermal system w/ cryocoolers	4	challenge is to demonstrate sufficient, reliable cooling power and thermal system performance. Detailed cooling requirements are known (DiPirro et al. 2007)
Wide-field spatio-spectral interferometry	5	challenge is to demonstrate thorough undertanding of practical limitations, and to develop and verify performance of the hyperspectral image synthesis software (Leisawitz et al. 2012)

Concept maturity

Conducted a robust pre-Phase A study. Grass roots and independent parametric cost estimates agree to within 20%.

CALISTO

Cryogenic Aperture Large Infrared Space Telescope Observatory



Mission Concept Summary

Name of concept:	Cryogenic Aperture Large Infrared Space Telescope Observatory (CALISTO)
Architecture:	4 m x 8 m aperture off axis Gregorian telescope cooled to ~4K. Unblocked design for extremely low sidelobes and stray pickup Wavelength coverage: 30μm - 300μm
Science drivers:	• Exploring SubMM galaxies at high redshift with FIR line spectroscopy • The first supernovae • Intergalactic molecular hydrogen • Star formation as function of galactic environment • Tans-Neptunian Obects (TNOs) • Water in the Solar System

Measurement capabilities

Parameter		Unit	Value
	Wavelength range:	μm	30 - 300
	Angular resolution:	arcsec	1.2 - 12 (minimum beam size)
	uv plane filling fraction:		Single antenna high-quality PSF
	Spectral resolution:	(=λ/Δλ)	1000 (10^6 with heterodyne)
	Instantaneous FoV	arcmin	
Sensitivity to			
	Spectral lines	W m^{-2}	5σ 1 hr =$2.2x10^{-20}$ for dν/ν = 1 and $6.2x10^{-22}$ for dν/ν = 0.001
	Continuum	μJy	21 (5σ, 1 hr)
	Confusion Limit		5 μJy @ 70μm 8 beams/source
	Field of Regard:		Survey entire "dark" sky in 2 year mission plus pointed observations and small scale mapping

Potential launch vehicle(s):

Atlas V 551

Orbit:

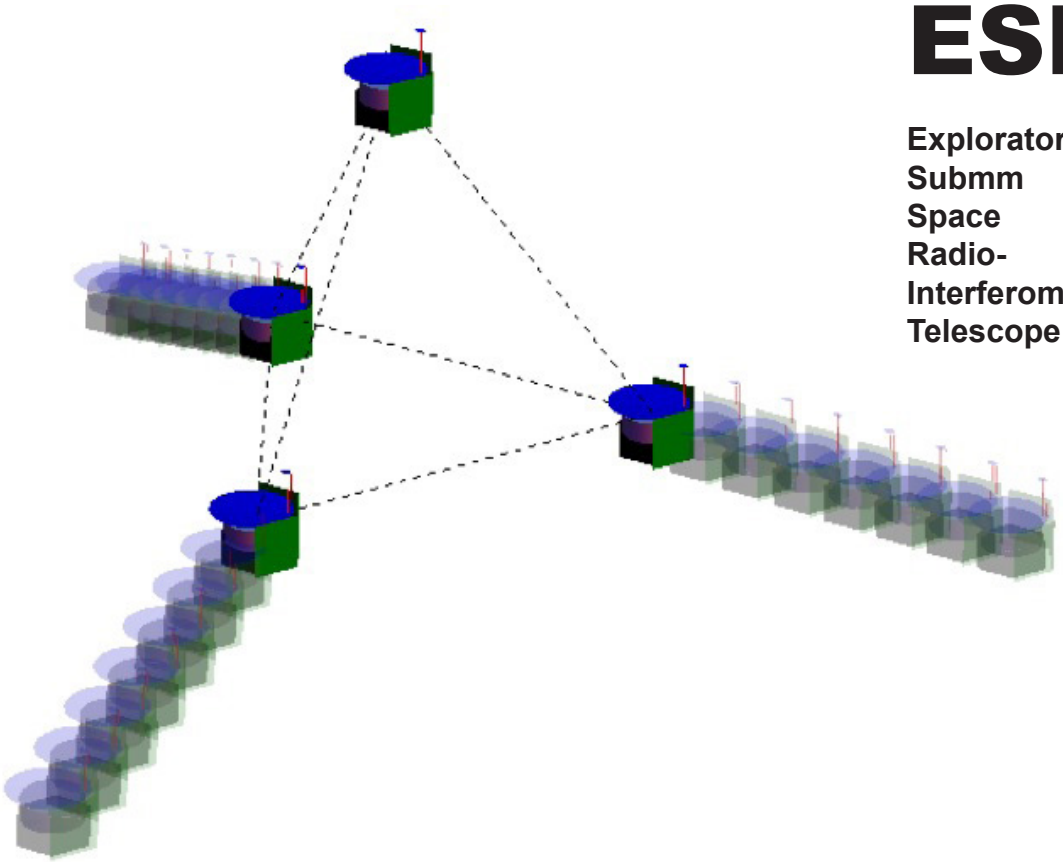
L2 Halo

Technology

Description	TRL

Concept maturity

- JPL Team X study
  White paper submitted to 2010 Decadal Survey.



ESPIRIT

Exploratory Submm Space Radio-Interferometric Telescope

Mission Concept Summary

Name of concept:

Exploratory Submm Space Radio-Interferometric Telescope (ESPRIT)
Information source: Frank Helmich, private communication
(Ref. Wild et al. 2006, Proc. SPIE 6265, 62651Z; updated by Baryshev for ESA L2/L3 white paper)

Architecture :

Free-flying THz heterodyne interferometer comprised of four 3.5 m off-axis telescopes with deployable secondary mirrors. Satellites drift in 3D to sample a variety of interferometric baselines up to 50 m (extendable to longer). Correlation in space, with calculated visibility data downlinked.

Science drivers:

- Understand the formation of stars and planets by following the evolution of disks around forming stars
- Understand the role of starbursts in the evolution of galaxies

Measurement capabilities

Parameter	Unit	Value
Wavelength range:	μm	50 - 600 in several discrete channels (frequency bands TBD)
Angular resolution:	arcsec	0.2 (λ/100 μm)
uv plane filling fraction:		dense, since 50 m with 2 cm/s drift would take close to one hour for travel, giving a fair amount of integration at the longer baselines
Spectral resolution:	(=λ/Δλ)	3×10^5
Instantaneous FoV	arcmin	0.1, with possibility to extend by mosaicing
Sensitivity to		
Spectral lines	μJy	3×10^5 in 1hour on resolved lines, assuming 6 telescopes (Wild et al.)
Continuum	μJy	17000 in 1 hour
Field of Regard:		all-sky two times per year; large area instantaneous FoR

Potential launch vehicle(s): Ariane 5 ECA

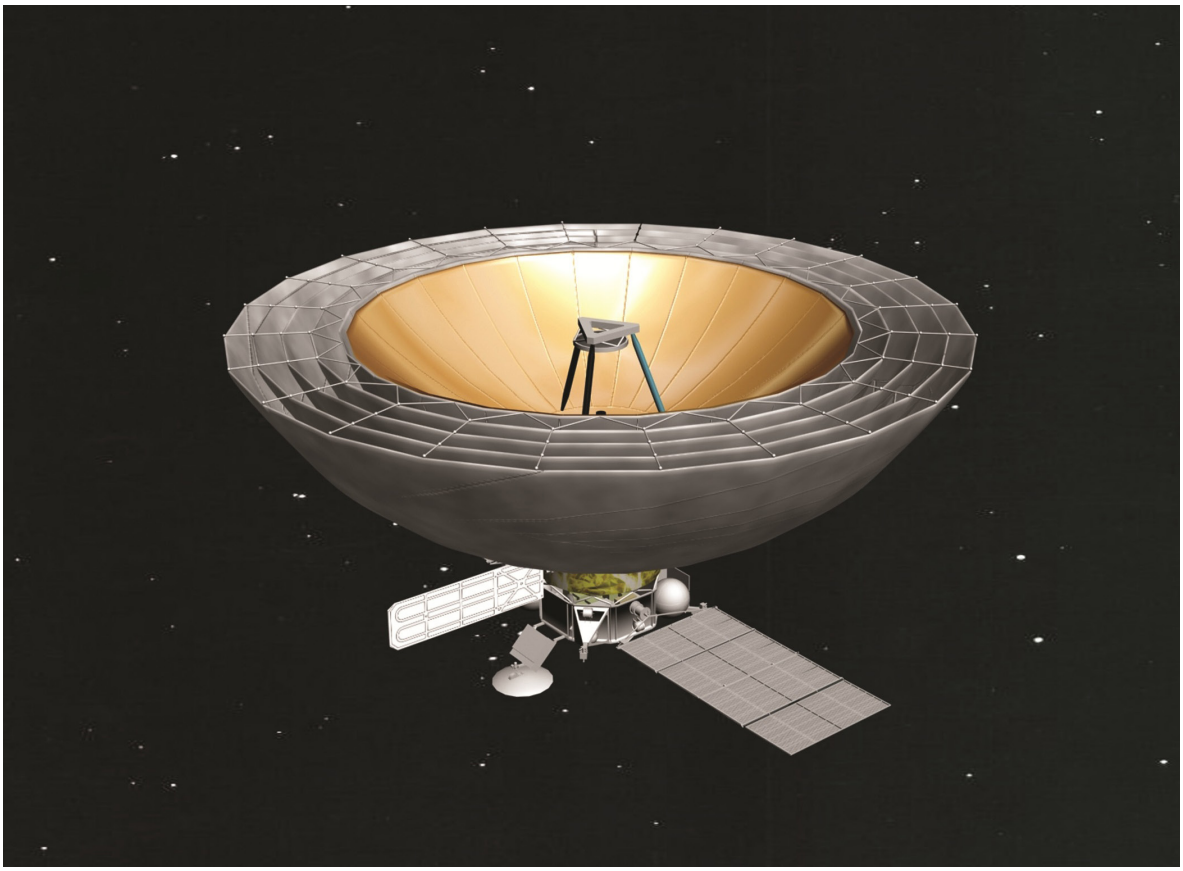
Orbit: Sun-Earth L2

Technology

Description	TRL	
cold gas thrusters	9	GAIA heritage
collision avoidance control system	0	swarms are coming within ESA
SIS THz mixers close to quantum limit	6	ALMA, HIFI
HEB THz mixers close to the quantum limit	7	GREAT on SOFIA
space-qualified correlator	?	
Quantum Cascade Laser	3	will reach TRL 6 with STO-2 balloon flight
LO distribution system	0	builds on ALMA and GPS (TRL 6 and 9), this is not considered an item of long development
4 K crycooler (Planck heritage)	9	

Concept maturity pre-Phase A (SRON study by Helmich et al. 2005)

Millimetron



Mission Concept Summary

Name of concept: Millimetron

Architecture:

10m diameter deployable telescope cooled to < 6 K
Central 3m portion usable to 60 microns; full 10 m to 150 microns
Short-wave Camera & Spectrometer(SACS): 70, 125, 230, 375 μm & grating spectrometer
Long-wave Camera & Spectrometer: FTS covering 300 μm to 3 mm wavelength
Heterodyne instrument covering 500 GHz to 5 THz with 3 & 7 pixel arrays
Space VLBI (S-VLBI) 18 GHz to 720 GHz with ALMA & other ground-based facilities

Science drivers:

- Black hole/event horizon/accretion disk physics (S-VLBI)
- Sunyaev-Zeldovich effect
- Distant galaxies and star formation through cosmic time
- Diffuse ISM and evolution
- Astrochemistry beyond Herschel

Measurement capabilities:

Parameter		Unit	Value
Wavelength range:		μm	
Angular resolution:		arcsec	S-VLBI: $4x10^{-8}$ SACS: 1@ 50 μm - 10 @ 450 μm; LACS: 7.5 @ 300μm - 42 @ 3mm
uv plane filling fraction:			Single aperture telelscope
Spectral resolution:		(=λ/Δλ)	SACS 500 - 100; LACS: 1.2 GHz (500-80) Heterodyne: 10^6
Instantaneous FoV		arcmin	modest: ≤ 10 diffraction-limited beams
Sensitivity to			
	Spectral lines	W m^{-2}	TBD
	Continuum	μJy	TBD
Field of Regard:			Primarily pointed observations and small-scale mapping capability

Potential launch vehicle(s):

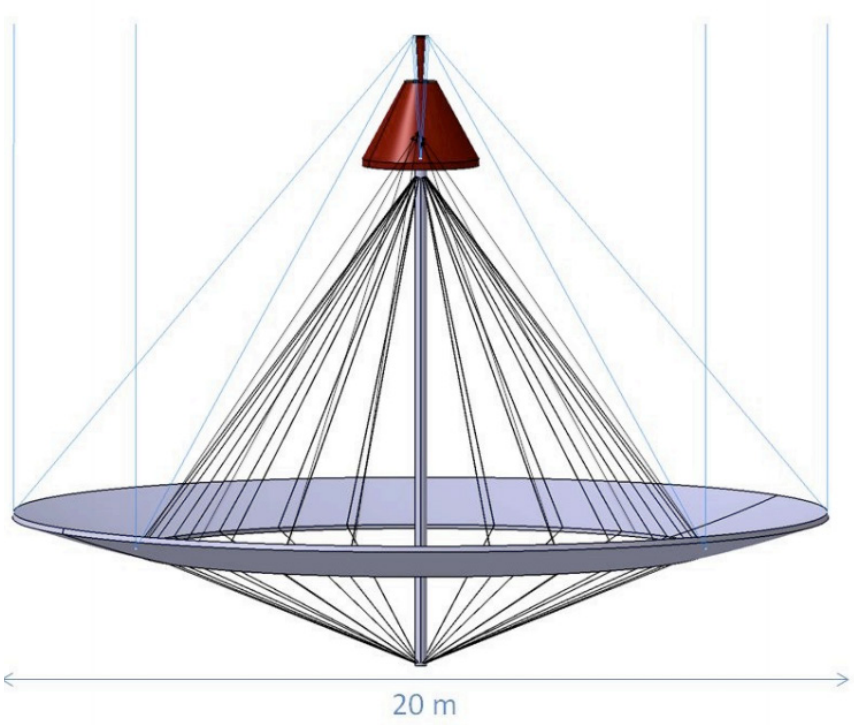
Orbit: L2 halo

Technology

Description	TRL
NA	

TALC

Thinned Aperture Light Collector



Mission Concept Summary

Name of concept:

Thinned Aperture Light Collector (TALC)
Information source: Marc Sauvage, private communication.

Architecture:

A "single-dish" concept consisting of an annular, deployable mirror, with 20m outer diameter and 14m inner diameter. The annular concept allows a fan-like deployment scheme, compatible with an extremely compact volume for the launch configuration.

Science drivers:

- wide-field imaging, surveys of star forming regions in the Galaxy and beyond
- AGN-Star formation co-evolution on the z=1-3 epoch
- High spectral resolution studies of the ISM (water, HD…)

Measurement capabilities

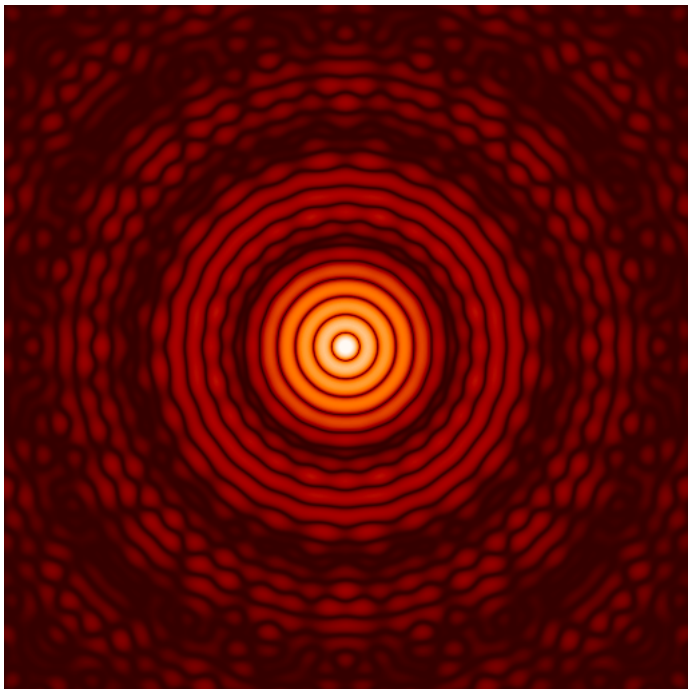
Parameter		Unit	Value
Wavelength range:		μm	50-500
Angular resolution:		arcsec	<1 at 100 μm
uv plane filling fraction:			As a "single-dish" concept TALC offers continuous coverage of a fraction of the UV plane, but data processing
Spectral resolution:		(=λ/Δλ)	From a few for the imaging instrument to very high for heterodyne spectrometers.
Instantaneous FoV		arcmin	~2
Sensitivity to			
	Spectral lines	W m^{-2}	TBD
	Continuum	μJy	0.1 mJy 5σ 1hr (with R~5)
Field of Regard:			Foreseen implemetation resembles the JWST, thus the FoR is the whole sky

Potential launch vehicle(s): Ariane 6 with electric propulsion module to reach L2

Orbit: Sun-Earth L2

Technology not relevant at this point

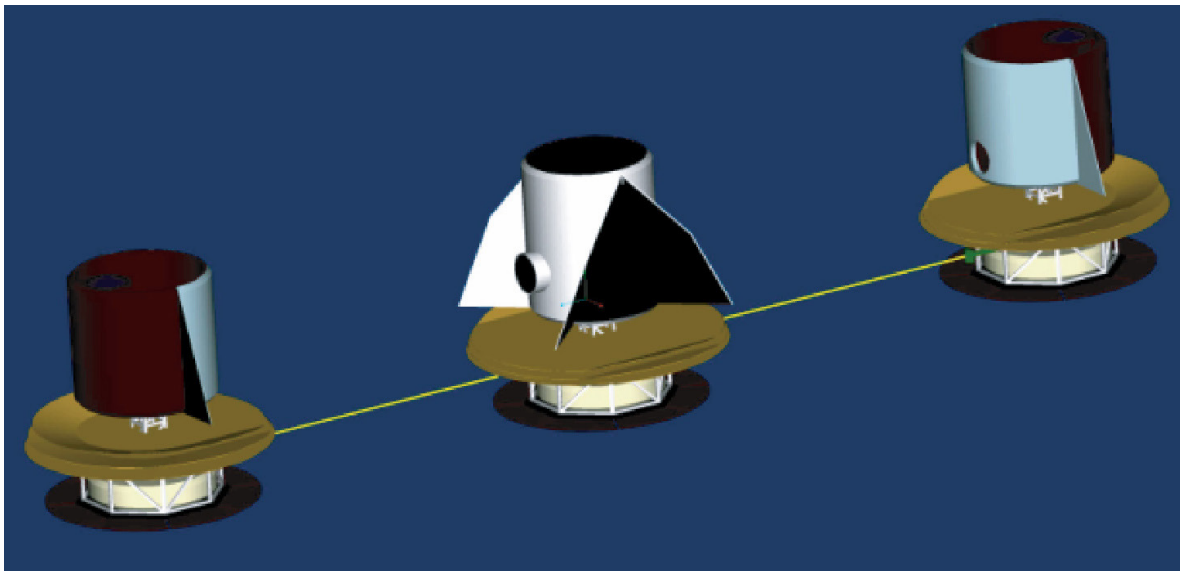
Concept maturity TALC is essentially an "immature" concept, that we develop to explore the feasibility and constraints related to placing large apertures in space.



TALC's PSF for an annular segmented mirror. The central peak has 0.9" FWHM.

SPECS

Submillimeter Probe of the Evolution of Cosmic Structure



Mission Concept Summary

Name of concept: Submillimeter Probe of the Evolution of Cosmic Structure (SPECS)
Primary reference: Harwit et al. NASA Vision Mission concept study, 2005, and subsequent papers

Architecture:

Tether-connected spatio-spectral interferometer with dense uv plane coverage out to maximum baseline length 1 km. Two 4 m diameter afocal off-axis telescopes serve as light collectors. The telescopes and instrument are cryocooled to ~4 K, and the focal plane cooled to ~30 mK. MKID or TES bolometer detectors in arrays with maximum pixel count 14 x 14 pixels cover an instantaneous FoV 1 arcmin in diameter.

Science drivers:

- Characterize the epoch of first generation star formation
- Probe the luminosity evolution and physical conditions in galaxies since the epoch at which they formed
- Observe the chemical and dynamical processes that lead to the formation of stars
- Image the dusty disks around newly formed stars to study temperature, density, grain size distribution and chemical fractionation to learn how planetary systems form

Measurement capabilities

Parameter		Unit	Value
Wavelength range:		μm	40 - 640
Angular resolution:		arcsec	0.05 (λ/250 μm)
uv plane filling fraction:			Dense coverage in both dimensions. Baseline coverage: "zero spacing" plus ~10 m to 1 km. May be tailored to source.
Spectral resolution:		(=λ/Δλ)	~1000 - 3000, with possible heterodyne mode for $>10^5$
Instantaneous FoV		arcmin	1
Sensitivity to			
	Spectral lines	W m^{-2}	$\sim 10^{-22}$
	Continuum	μJy	~1
Field of Regard:			at least 40° band centered on ecliptic plane

Potential launch vehicle(s): Delta IV Heavy or equivalent

Orbit: Sun-Earth L2

Technology

Description	TRL
Spin-stabilized tethered formation flight	2.5
FIR photon-counting detectors	2.5 challenge is to produce detectors with NEP < 10^{-20} W $Hz^{-1/2}$ with time constant ~35 μsec or faster; 50 x 50 pixel array
Cryo-thermal system w/ cryocoolers	4
Wide-field spatio-spectral interferometry	5

Concept maturity pre-Phase A ("Vision Mission" concept study by Harwit et al. 2005)

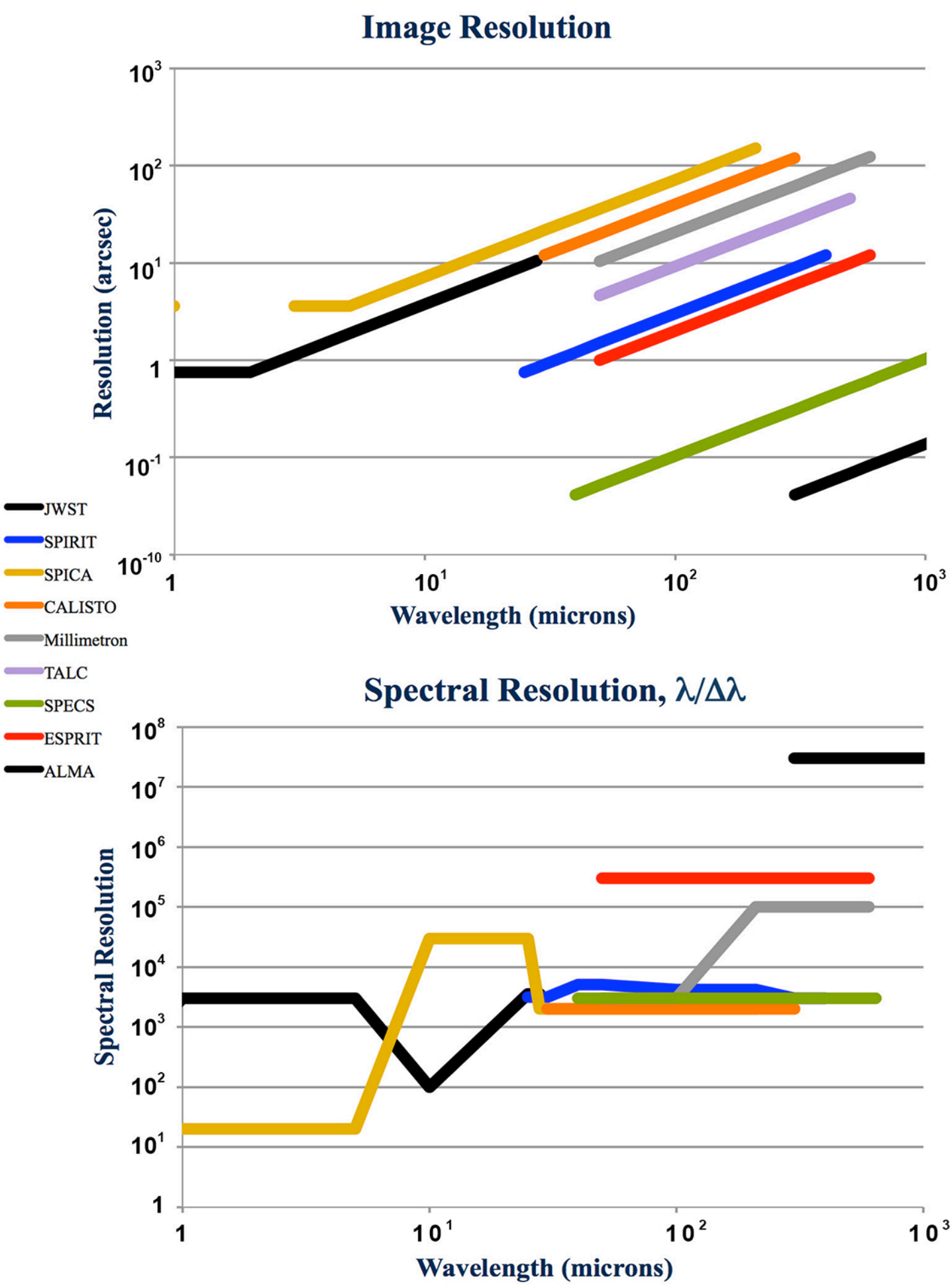
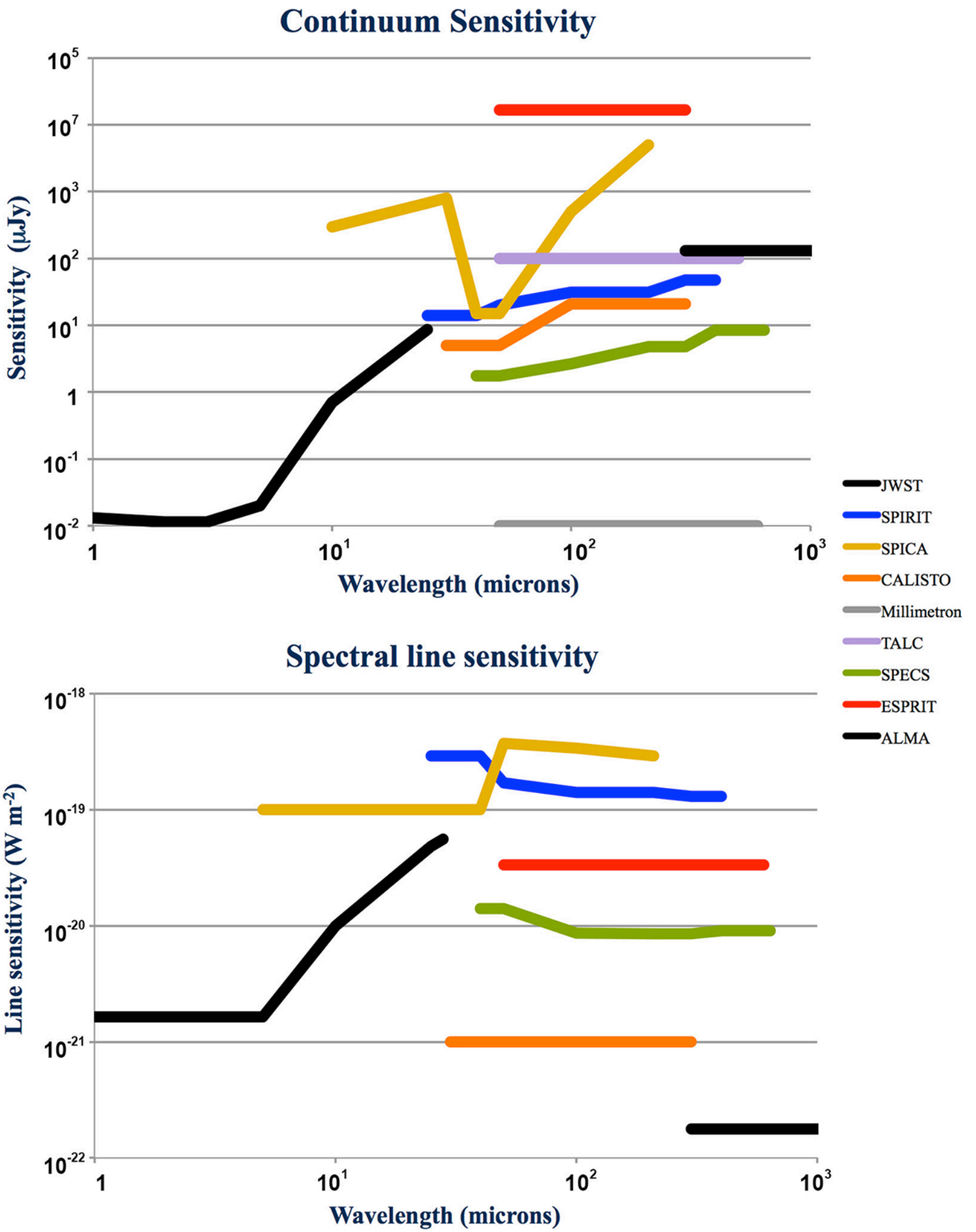


Image Resolution
Resolution (arcsec)
10^3
10^2
10^1
1
10^-1
10^-10
1
10^1
10^2
10^3
Wavelength (microns)
JWST
SPIRIT
SPICA
CALISTO
Millimetron
TALC
SPECS
ESPRIT
ALMA
Spectral Resolution, λ/Δλ
Spectral Resolution
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10^1
1
1
10^1
10^2
10^3
Wavelength (microns)


Continuum Sensitivity
Sensitivity (μJy)
10^5
10^7
10^3
10^2
10^1
1
10^-1
10^-2
1
10^1
10^2
10^3
Wavelength (microns)
JWST
SPIRIT
SPICA
CALISTO
Millimetron
TALC
SPECS
ESPRIT
ALMA
Spectral line sensitivity
Line sensitivity (W m^-2)
10^-18
10^-19
10^-20
10^-21
10^-22
1
10^1
10^2
10^3
Wavelength (microns)