

Cryogenic Detectors for Infrared Astronomy: the Single Aperture Far-InfraRed (SAFIR) Observatory

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Context



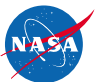
- SAFIR was recommended as a major NASA mission (with JWST, Con-X, TPF) by the NAS Decadal Review
- Recommended for technology and concept development during this decade, for launch late next decade.
- Recognized that large aperture, low temperature Far-IR telescope is now achievable, especially with technology advances from JWST.
- Recognized SAFIR as a scientific successor to SIRTf and Herschel, and as a powerful scientific partner to JWST and ALMA



What is SAFIR?



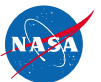
- SAFIR is a large ($\sim 10\text{m}$), cryogenically-cooled observatory for the far-infrared ($20\text{-}800\mu\text{m}$)
- SAFIR can address several fundamental astrophysical problems:
 - Formation of stars and planets in our own neighborhood
 - Coalescence of galaxies in the early universe
- SAFIR is envisioned as a follow-on to JWST, but extended to longer wavelengths.



Current Status

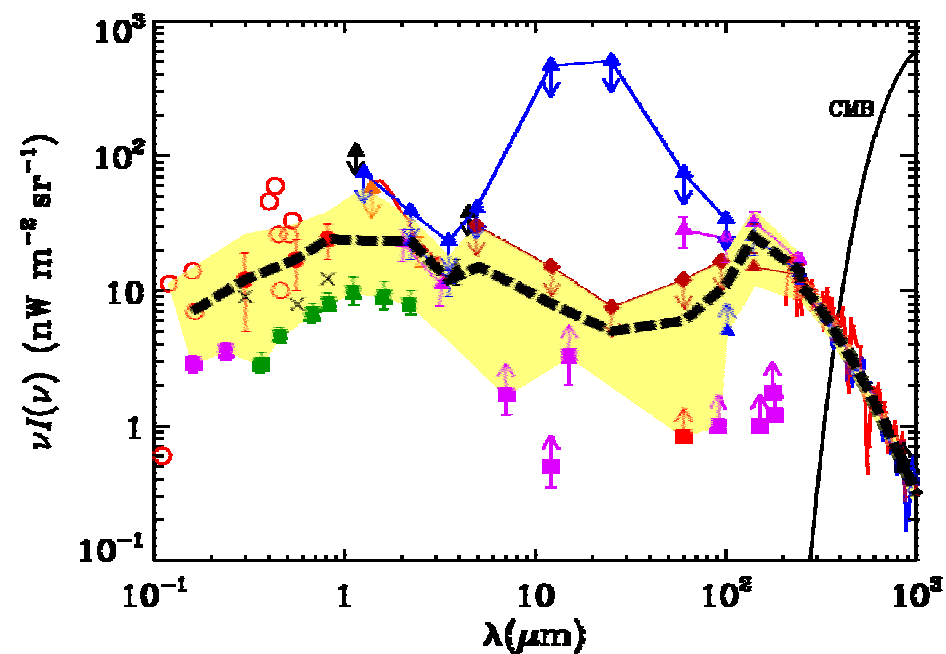


- SAFIR Science Working Group started in 2002; mission appears on NASA theme roadmaps in 2003.
- GSFC developed SAFIR mission concept, based on JWST, in 2002.
- Funding opportunities for mission concept studies, detector development currently available.



Motivation

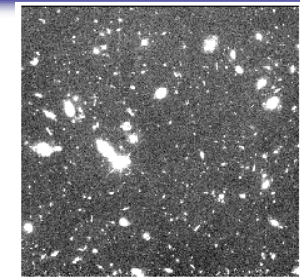
- Half the luminosity in the Universe is in far-IR! The young universe is redshifted there.
- Of the far-IR background, <1/3 is accounted for by discrete galaxies.
- Star formation – present and distant past – is an IR problem.
- The youngest primordial gas clouds will be visible only in the far-IR.
- Dust is everywhere (eventually) – and obscures understanding
- *Era of JWST and ALMA.*
- *SIRTF, SPICA, Herschel are done.*



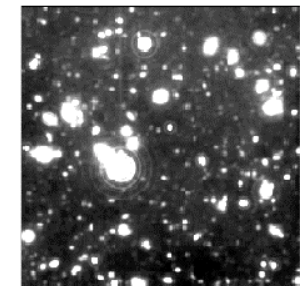
SAFIR Science Drivers



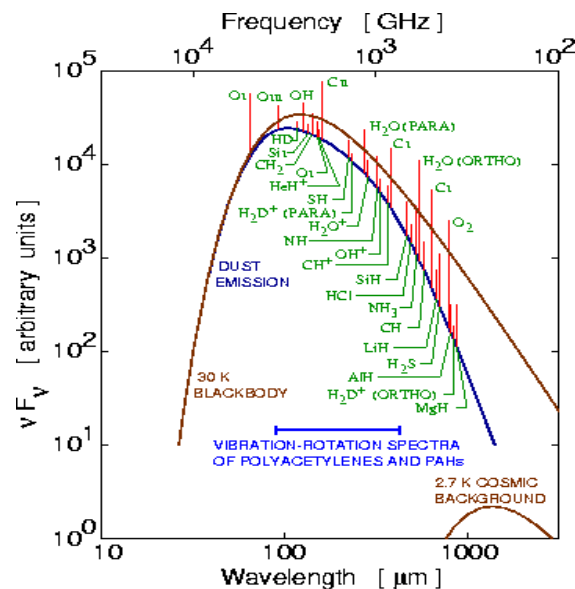
- Resolve the FIR background -- trace star formation to $z > 5$ in an unbiased way, measuring redshifts directly.
- Understand how primordial material forms stars. Proto-bulges and -disk formation in pristine gas. H_2 @ $z=20$?
- Understand role of AGN in galaxy formation, and relevance to ULIRGS. Unification?



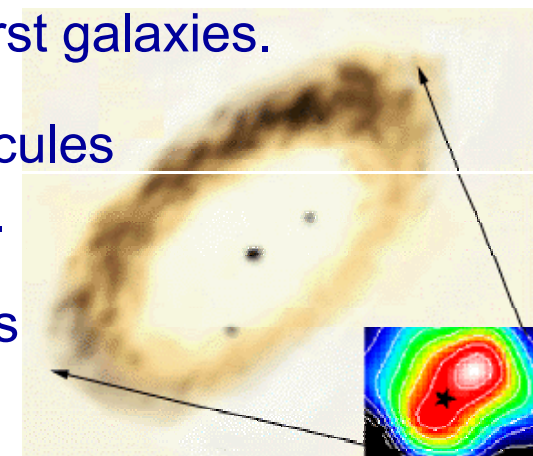
HDF



HDF at 1" res



- Bridge gap between local high mass star formation and starburst galaxies.
- Track pre-biotic molecules from cores to planets.
- Identify voids in debris disks around stars.



SAFIR: Molecules to Stars to Planets

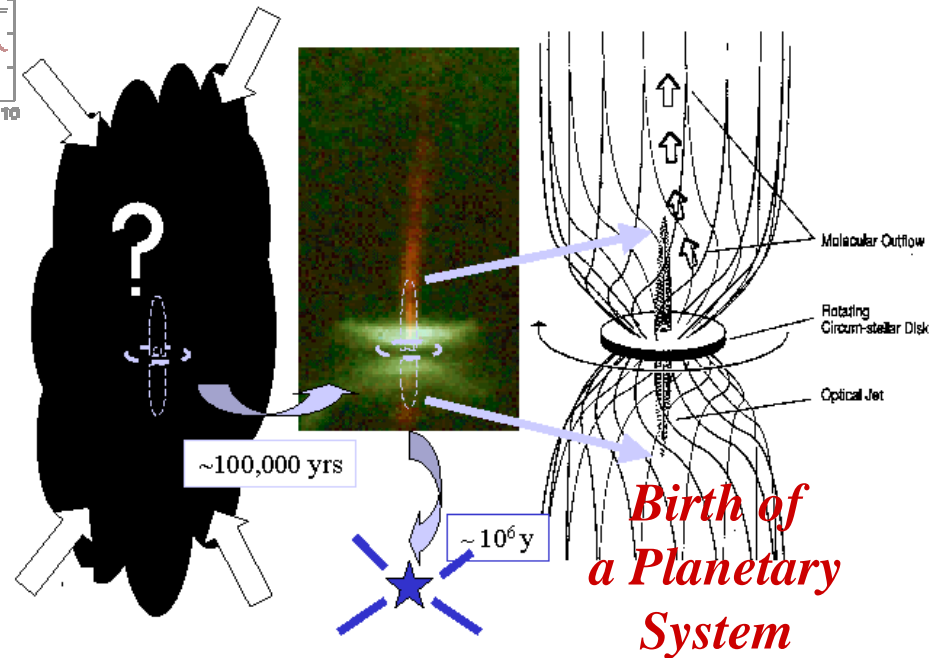
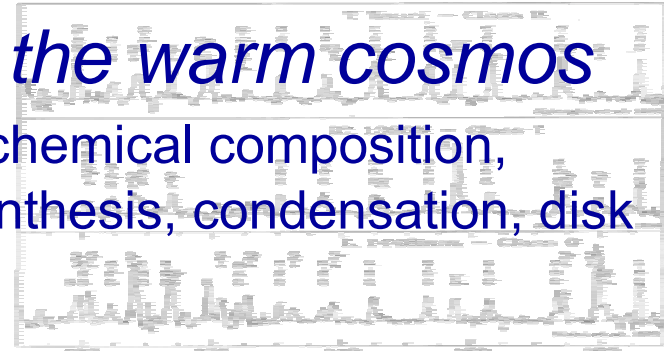
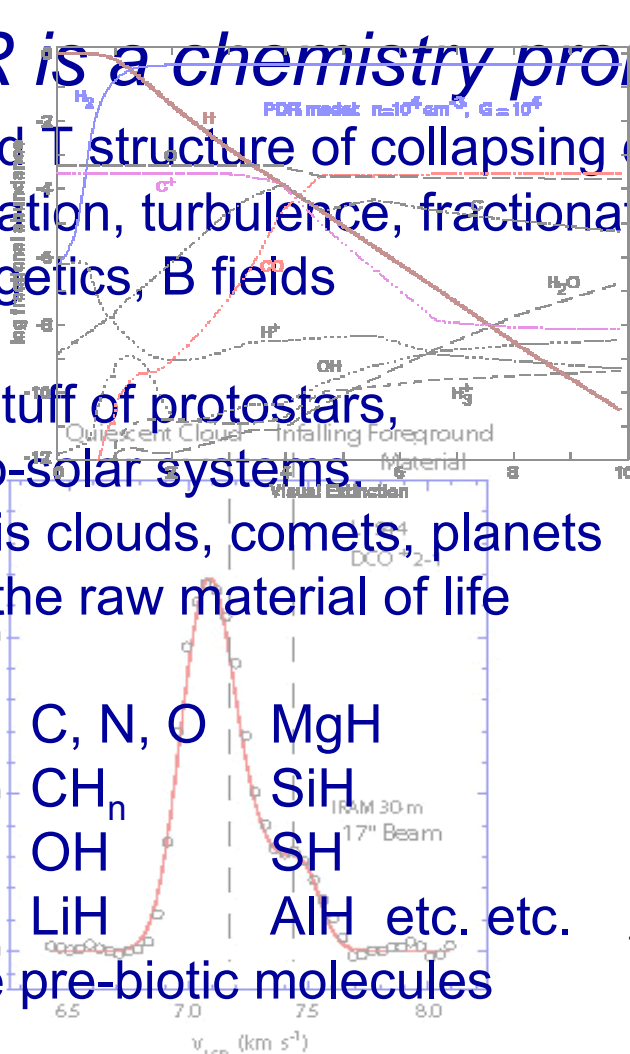


SAFIR is a chemistry probe of the warm cosmos

ρ and T structure of collapsing cores, chemical composition, ionization, turbulence, fractionation, synthesis, condensation, disk energetics, B fields

the stuff of protostars,
proto-solar systems,
debris clouds, comets, planets
and the raw material of life

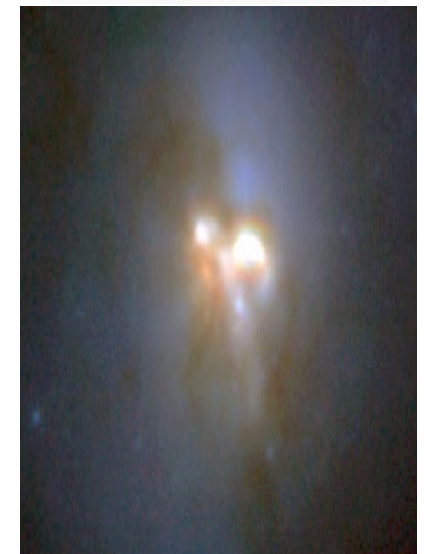
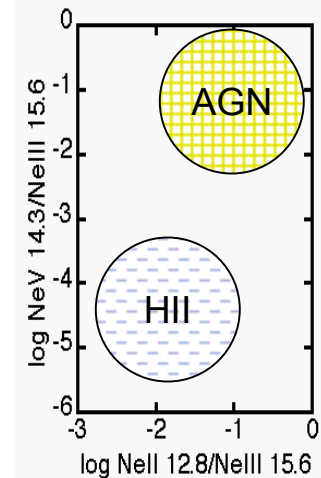
H_2	C, N, O	MgH
H_2O	CH_n	SiH
CO	OH	SH
HD	LiH	AlH etc. etc.
large pre-biotic molecules		



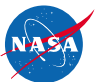
SAFIR: Relationship of AGNs & ULIRGs



- $10^{12} L_{\odot}$ galaxies are numerous in early universe; huge A_V : *Are they super starbursts? Buried AGNs? Some intermediate stage?*
- Powerful, extinction-free mid-IR radiation diagnostic lines
- SAFIR can search for broad lines; analyze dynamics of nuclear toroids; accretion history of universe (with X-ray missions)



see Arp220-class galaxies with
SAFIR out to $z=7$!

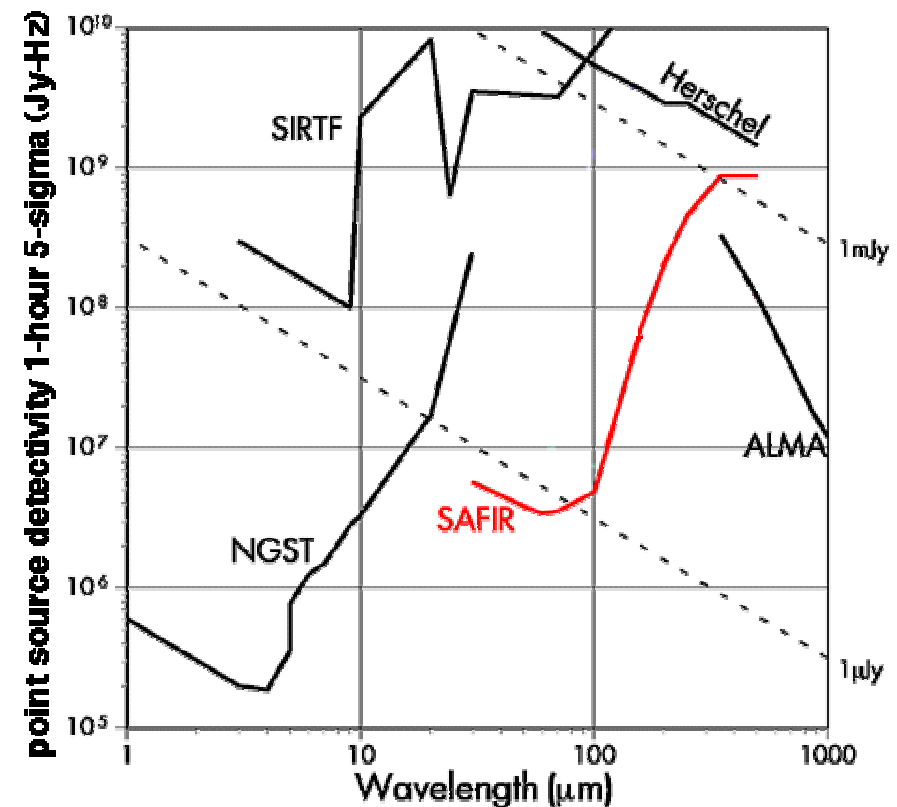


SAFIR: Comparison of Capability

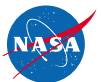


SAFIR will offer orders of magnitude improvement in:

- point source detectivity (1s of SAFIR worth 1 week of SIRTf!)
- spectroscopic sensitivity (1s of SAFIR worth 1 year of Herschel with noise-free detectors, 1 day with quantum-limited detectors)



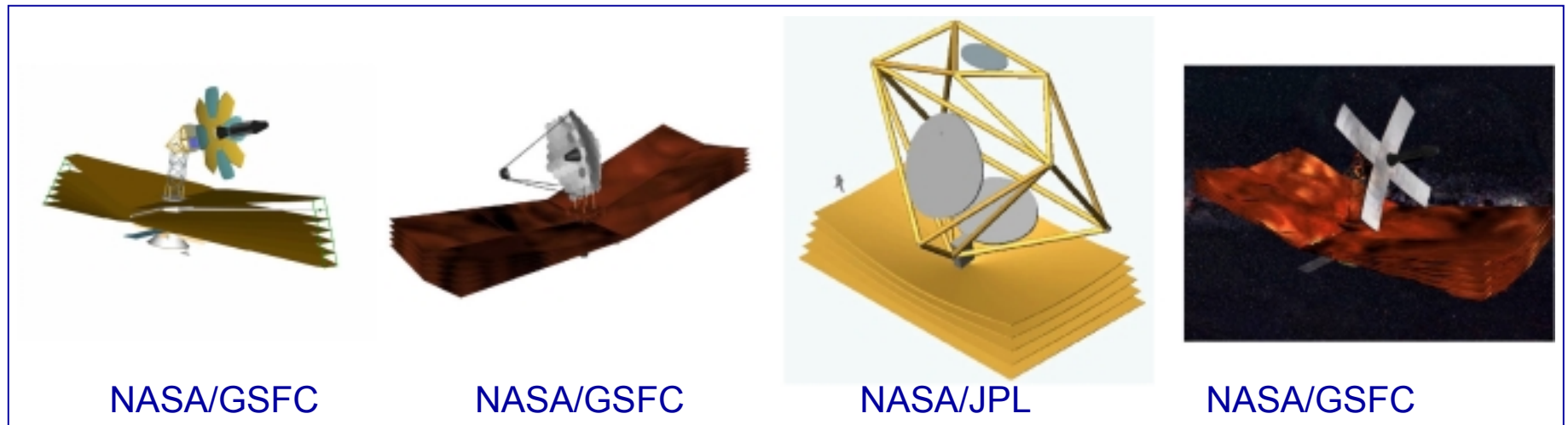
no confusion limits for spectroscopy!



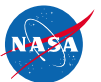
SAFIR Mission Implementations



- SAFIR is defined as a set of science objectives that answer key astrophysics questions in the far-infrared.



- Mission architecture is being refined; can be optimized for several different science requirements & technological capabilities.
- All implementations have numerous common technology needs, including detectors.



Technology Challenges



- **Detectors with sufficient sensitivity, in large format arrays.**
- Cooling a large telescope to 4K (& detectors to ~0.05K).
- Deployable cryogenic telescope of 10m class.
- Adequate testing facilities for components & integrated systems.
- Mitigating factors:
 - Cryocoolers for ~4K are under development for, e.g., JWST, TPF, etc.
 - Detectors - superconducting TES bolometer development for Con-X
 - Deployable telescope to be demonstrated by JWST



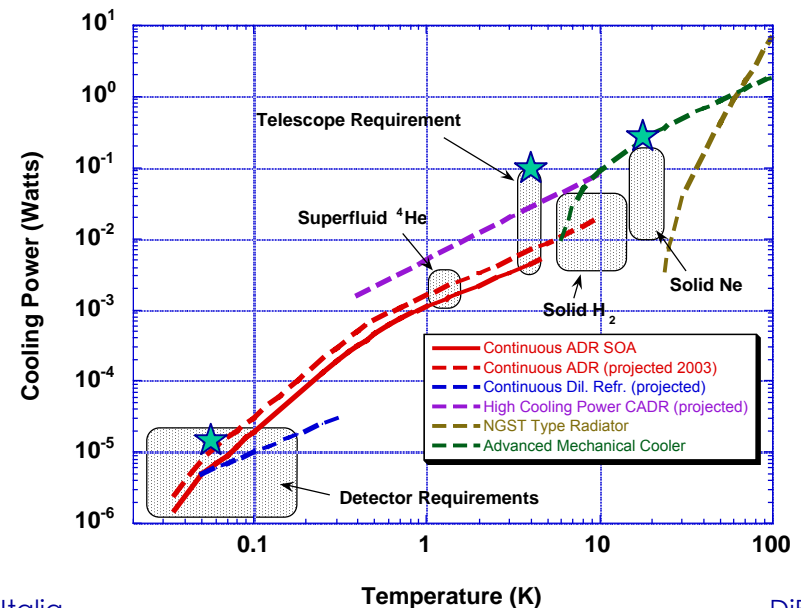
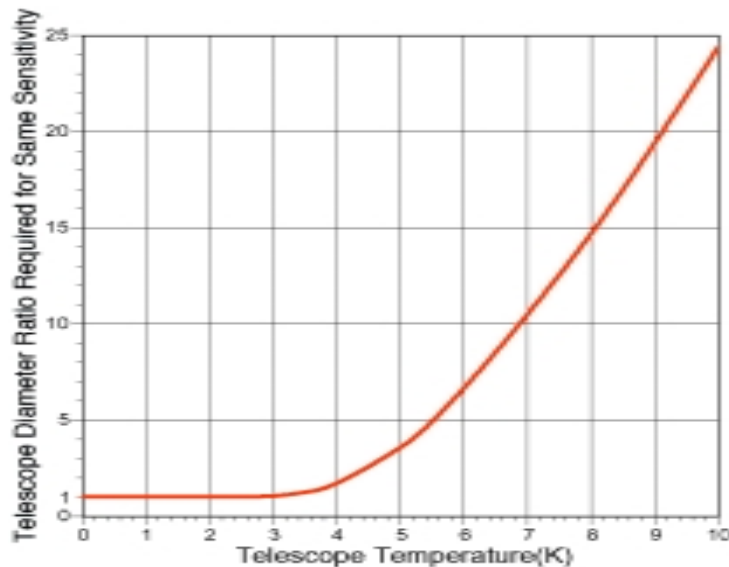
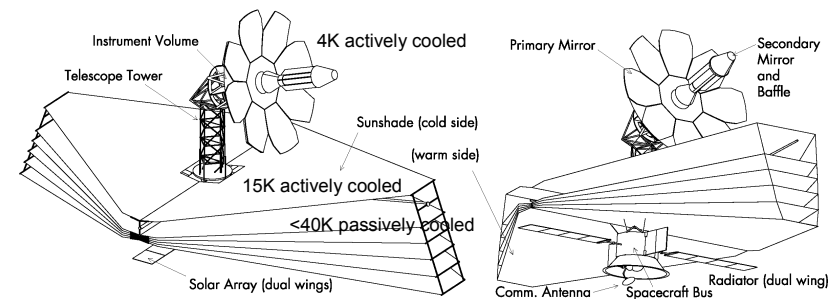
But Why 4K for SAFIR?



Because it makes a big difference!

A 4K telescope is background-limited
(zodi @ $<200\mu\text{m}$, CMB @ $>200\mu\text{m}$)

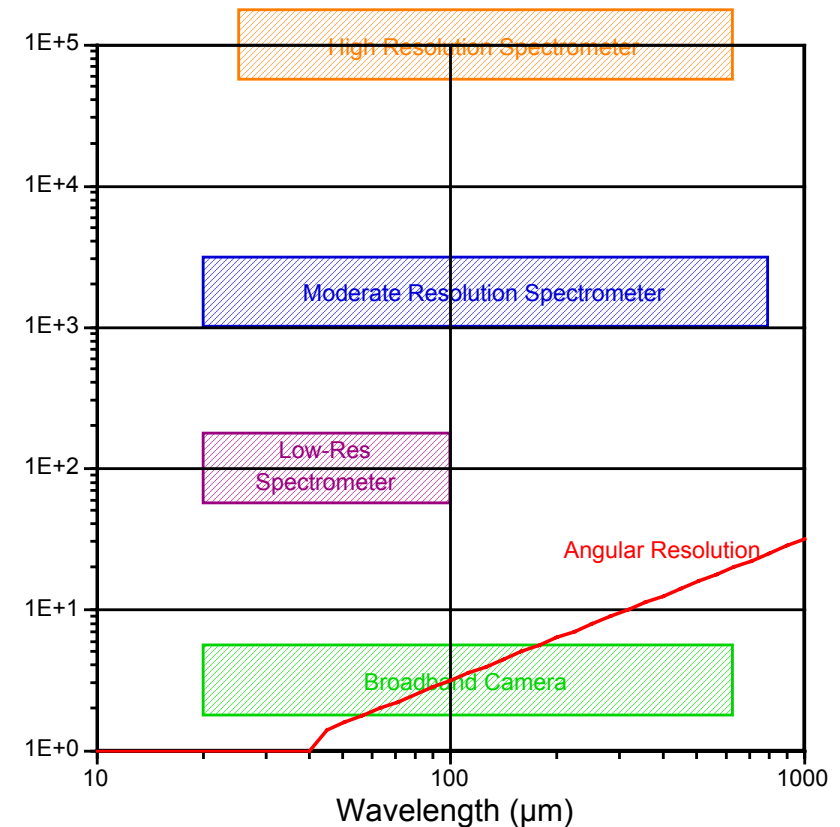
At these wavelengths, point source
sensitivity is more dependent on
temperature than on aperture!



Critical Detector Technologies



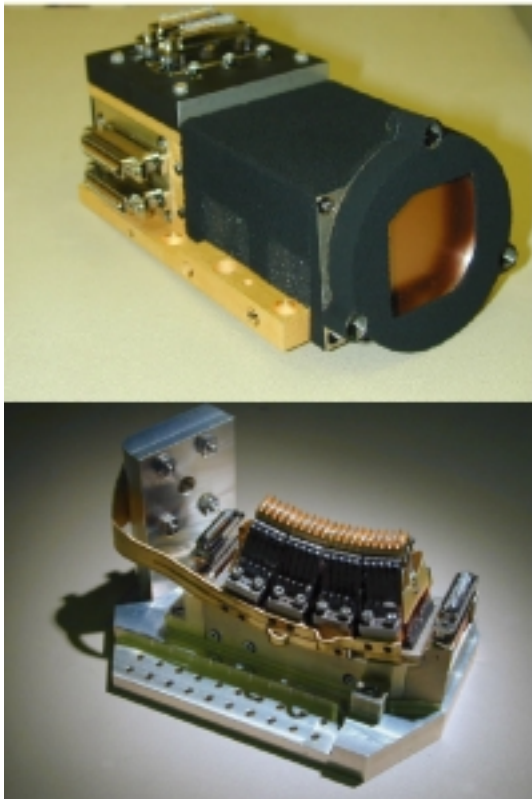
- Large-format (10^3 - 10^4 pixel) broadband arrays:
 - semiconducting and superconducting (TES) bolometers
 - Ge, Si BiB photoconductors
- Arrays for spectroscopy:
 - RF-SET / STJ
 - Kinetic Inductance
- High resolution spectroscopy:
 - quantum noise-limited heterodyne spectrometers
 - new spectrometer architectures
- focal plane cooling technologies for $<100\text{mK}$
 - multistage ADR
 - dilution refrigerators



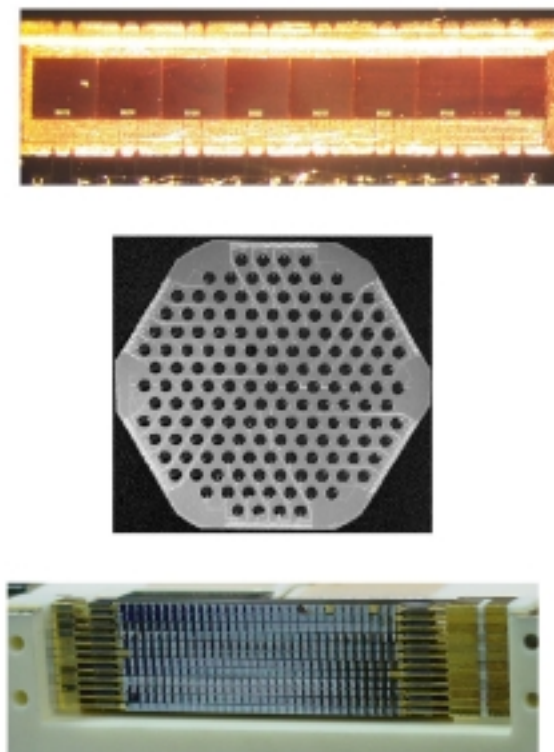
Representative Detectors



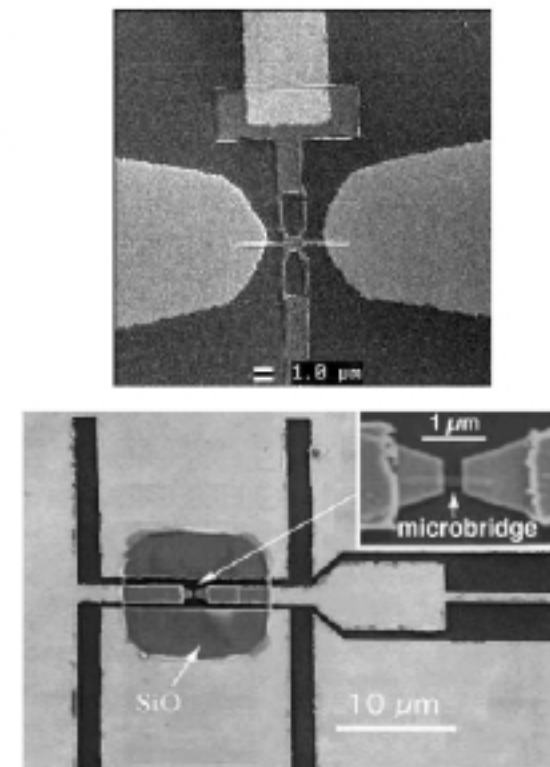
Photoconductors



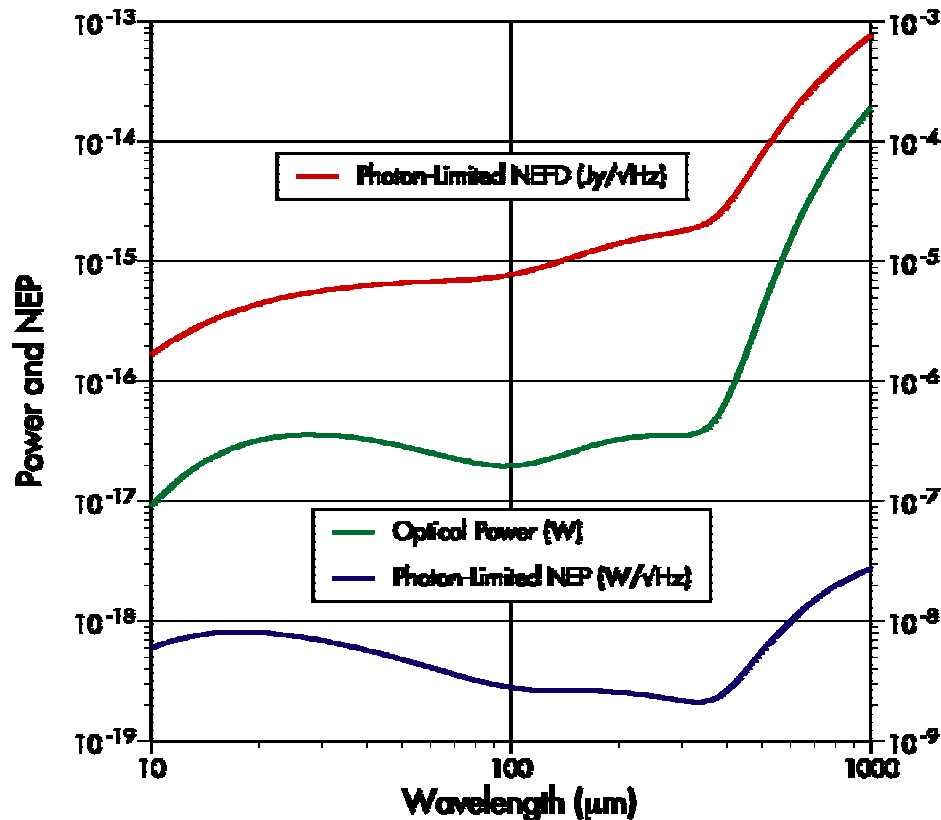
Bolometers



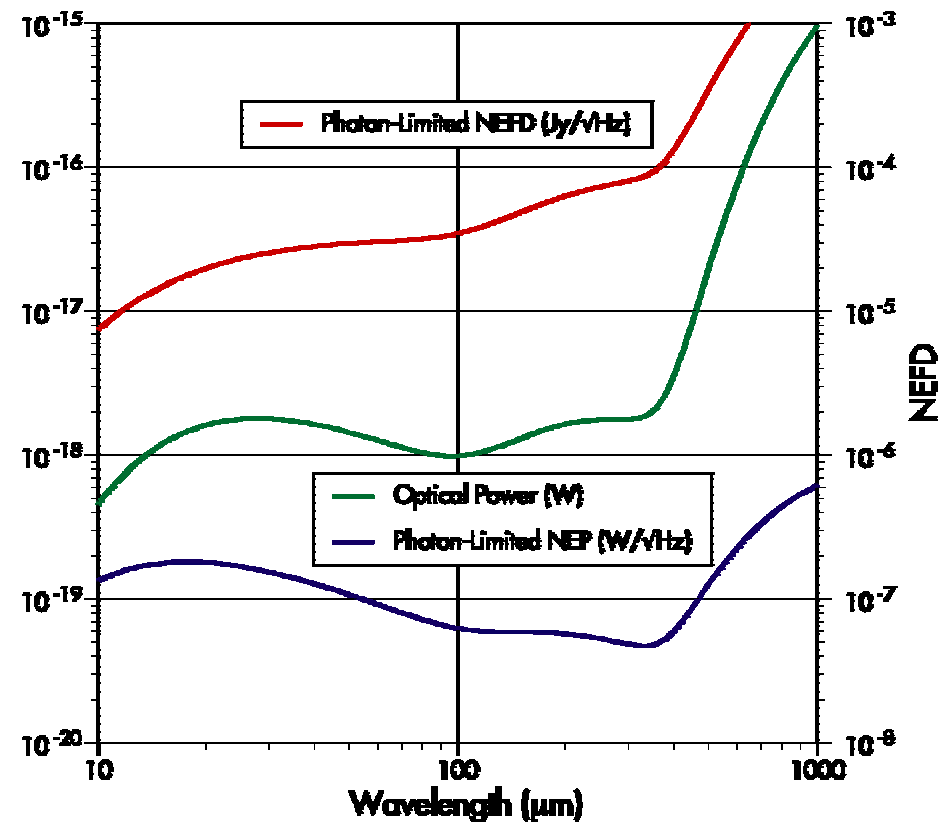
Other



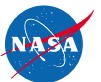
SAFIR Detectors (low resolution)



Camera: 10^4 pixels,
NEP= 10^{-19} W/ $\sqrt{\text{Hz}}$

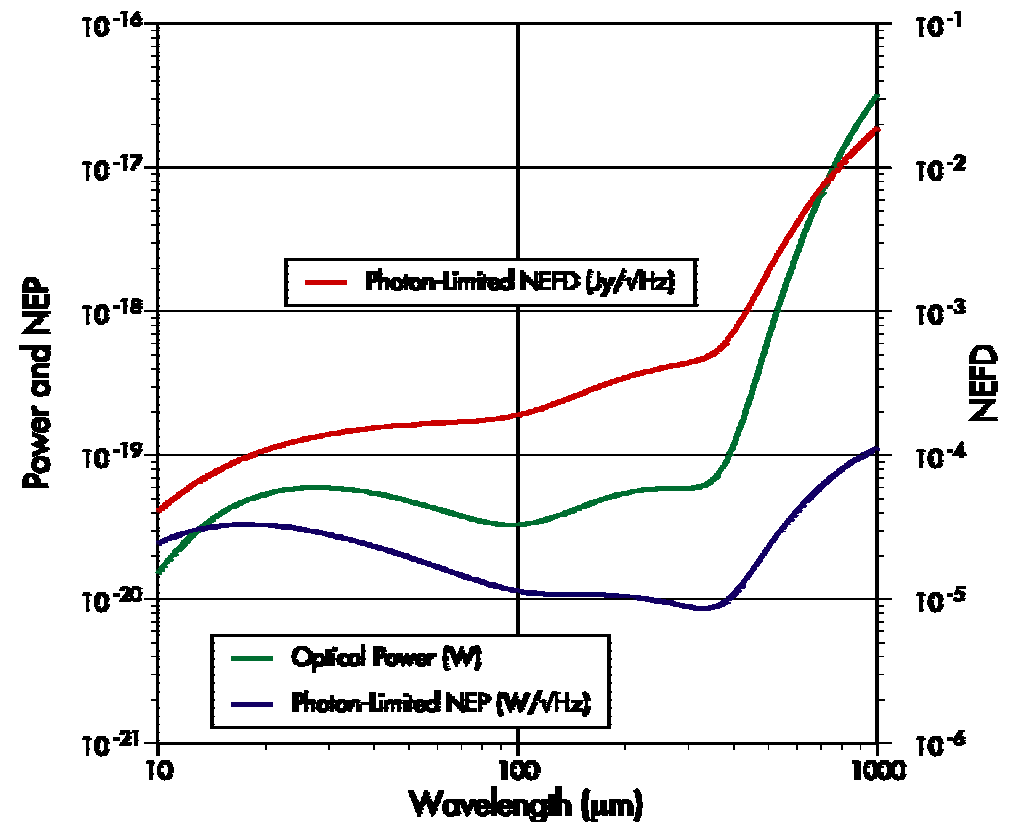


LRS: $4 \cdot 10^3$ pixels,
NEP= $2 \cdot 10^{-20}$ W/ $\sqrt{\text{Hz}}$



SAFIR Detectors (med. resolution)

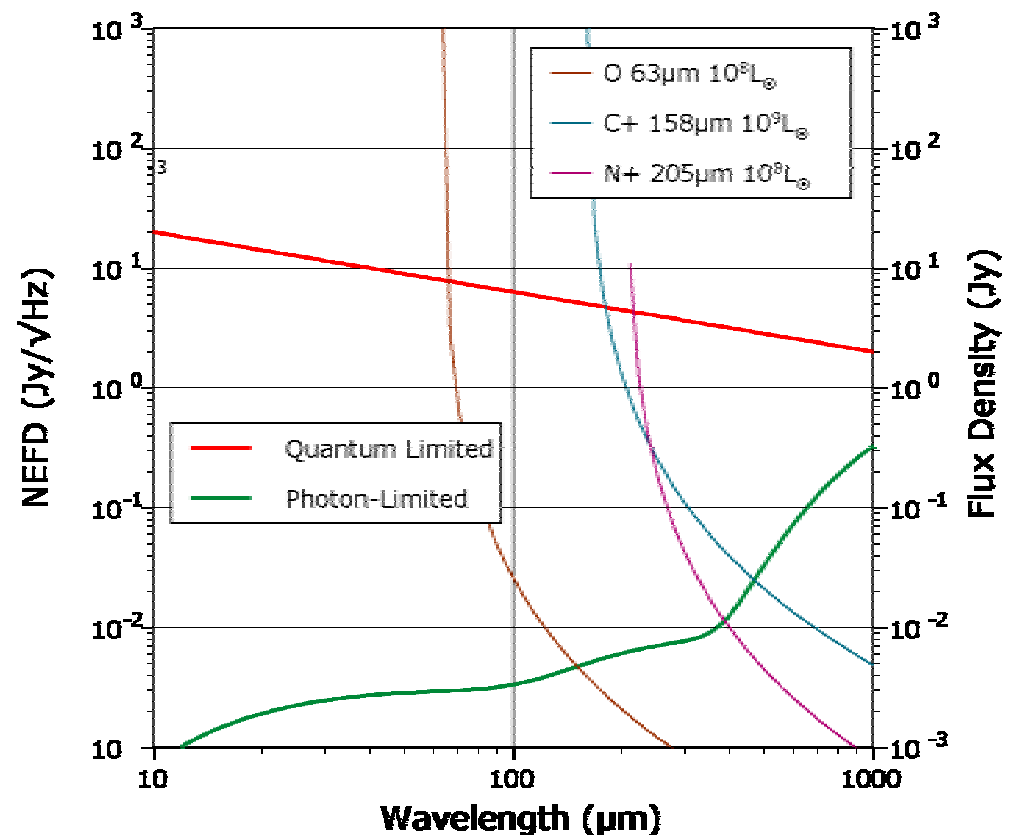
- With $\lambda/\delta\lambda \sim 1000$ (300km/s) resolution, power is low
- Requires $>10^3$ pixels with $\text{NEP} = 3 \cdot 10^{-21} \text{ W}/\sqrt{\text{Hz}}$
- At $100\mu\text{m}$, rate is $\sim 50 \gamma/\text{s}$
- Need noise of $5 \gamma/\text{s}/\sqrt{\text{Hz}}$



SAFIR Detectors (high resolution)



- Heterodyne spectrometers are quantum-limited, therefore not optimally sensitive.
- Direct detection approach probably not feasible. Photon rate $\sim 0.01 \text{ } \gamma/\text{s}$.



Summary



- SAFIR will enable very compelling science
- SAFIR is a high priority mission for the astronomical community, for launch in 2015-2020
- GSFC mission concept is ambitious, but technically feasible with modest advances – *except for detectors!*
- SAFIR is likely to be one of the larger missions driving detector development in the coming decade
- Substantial work needed, especially in the following areas:
 - Large format (10^4 pixel) broadband arrays
 - Very sensitive (few photons noise) detectors

