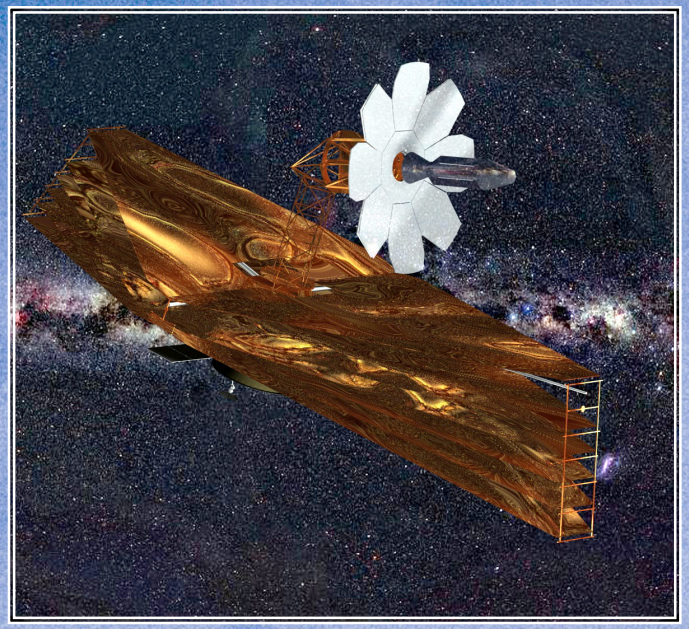

Cryogenic Detectors for Infrared Astronomy: the Single Aperture Far-InfraRed (SAFIR) Observatory

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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?

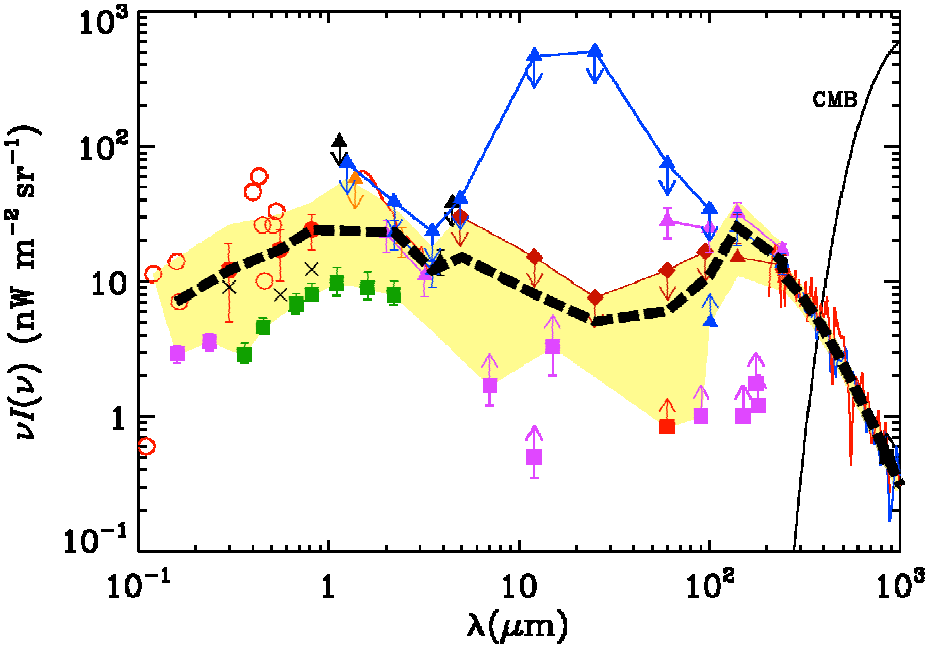
- SAFIR is a large (~10m), cryogenically-cooled observatory for the far-infrared (20-800μm)
- SAFIR can address several fundamental astrophysical problems:
  - Formation of stars and planets in our own neighborhood
  - Coalescence of galaxies in the early universe
- SAFIR is envisioned as a follow-on 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

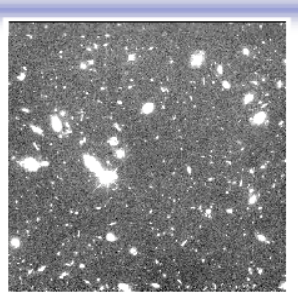
- Half the luminosity in the Universe is in far-IR! The young universe is redshifted there.
- Of the far-IR background, <1/3 is accounted for by discrete galaxies.
- Star formation – present and distant past – is an IR problem.
- The youngest primordial gas clouds will be visible only in the far-IR.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



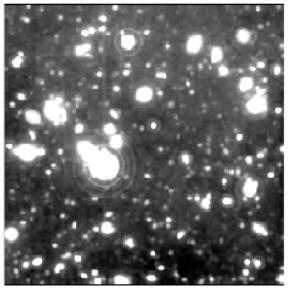
- *Era of JWST and ALMA.*
- *SIRTF, SPICA, Herschel are done.*

SAFIR Science Drivers

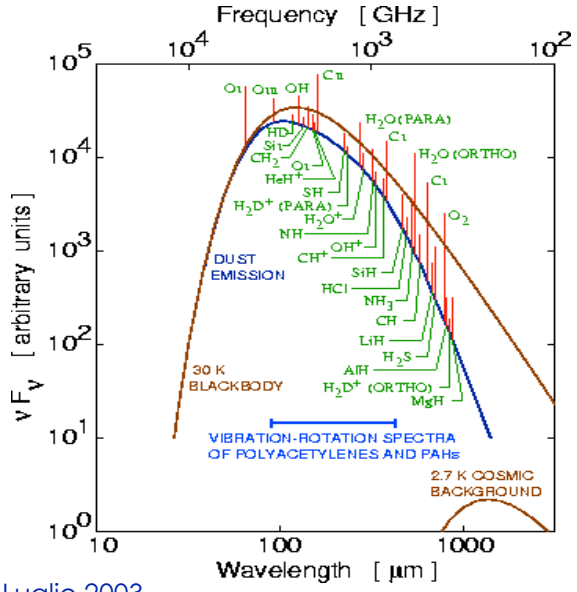
- Resolve the FIR background -- trace star formation to z>5 in an unbiased way, measuring redshifts directly.
- Understand how primordial material forms stars. Proto - bulges and -disk formation in pristine gas. H_2 @ z=20?
- Understand role of AGN in galaxy formation, and relevance to ULIRGS. Unification?



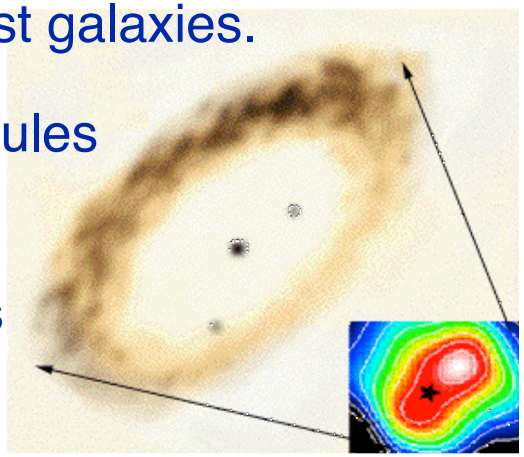
HDF



HDF at 1" res



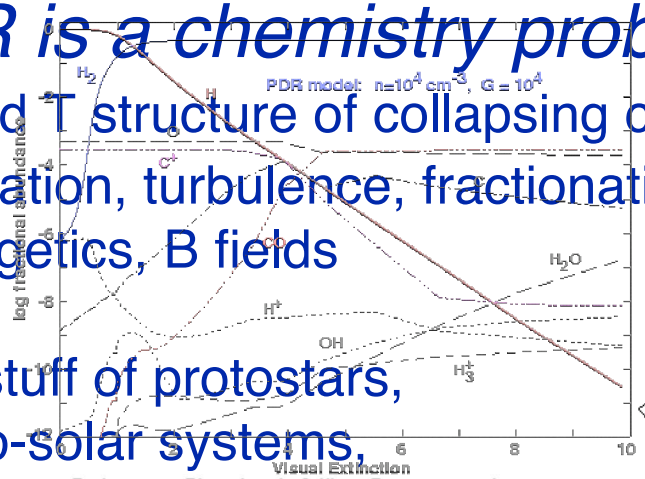
- Bridge gap between local high mass star formation and starburst galaxies.
- Track pre-biotic molecules from cores to planets.
- Identify voids in debris disks around stars.

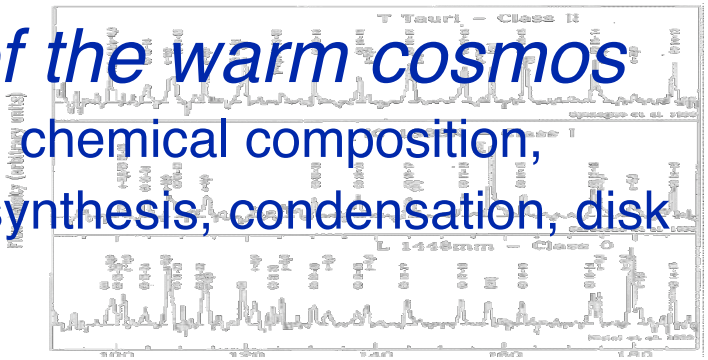


SAFIR: Molecules to Stars to Planets

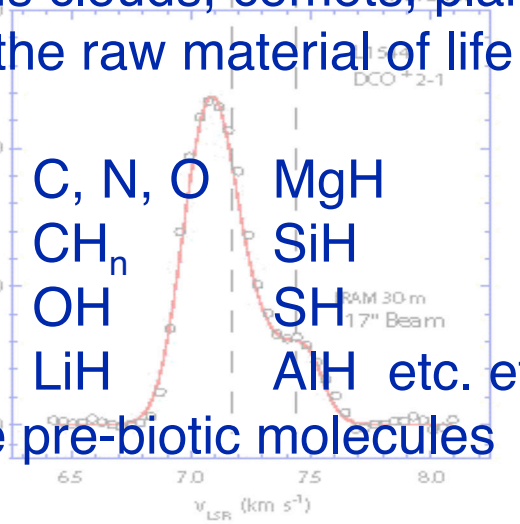
SAFIR is a chemistry probe of the warm cosmos

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



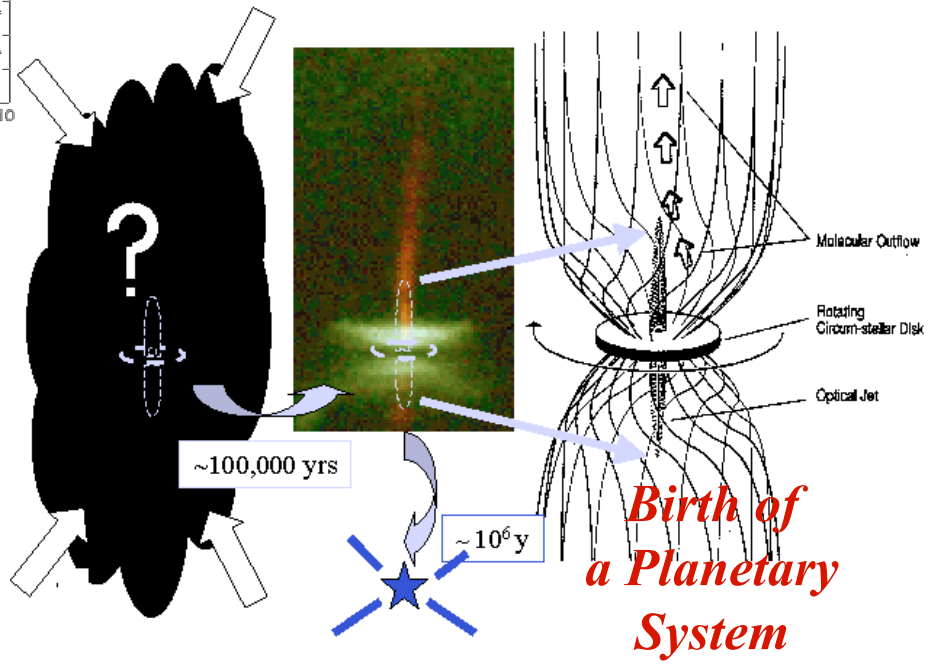


the stuff of protostars, proto-solar systems, debris clouds, comets, planets and the raw material of life



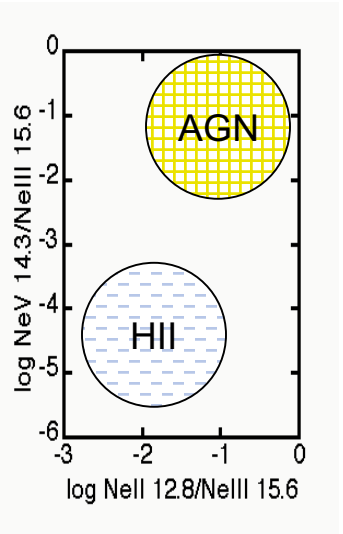
H_2	C, N, O	MgH
H_2O	CH_n	SiH
CO	OH	SH
HD	LiH	AlH etc. etc.

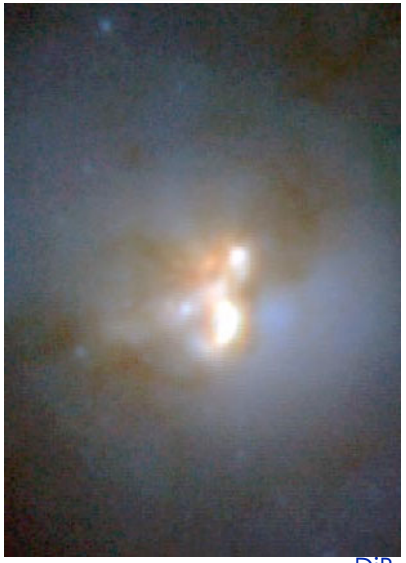
large pre-biotic molecules



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)



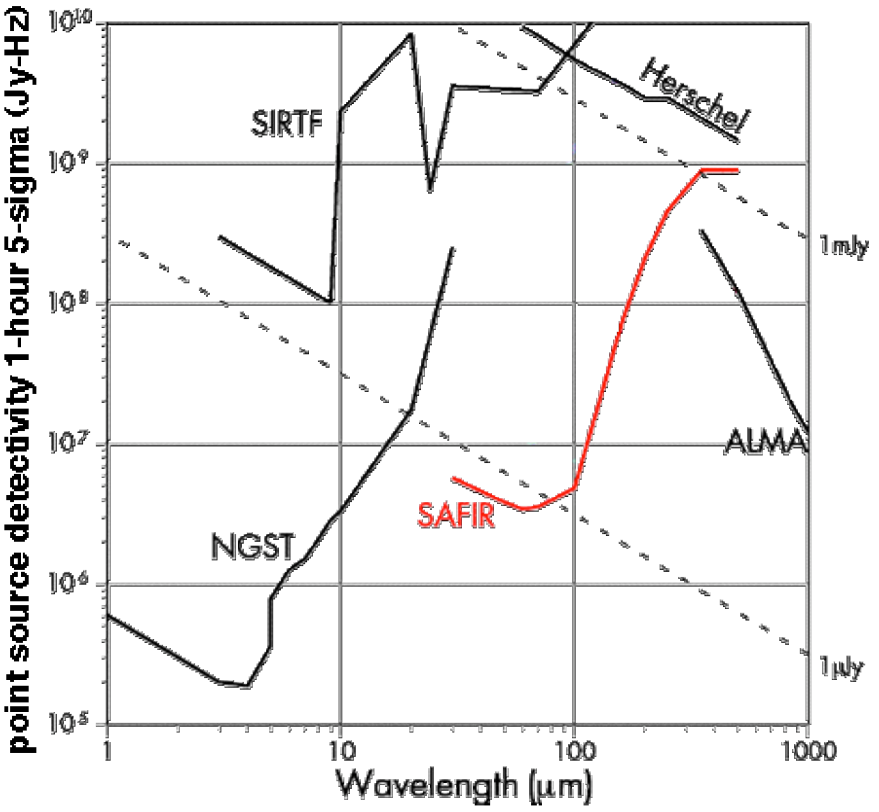


see Arp220-class galaxies with SAFIR out to z=7 !

SAFIR: Comparison of Capability

SAFIR will offer orders of magnitude improvement in:

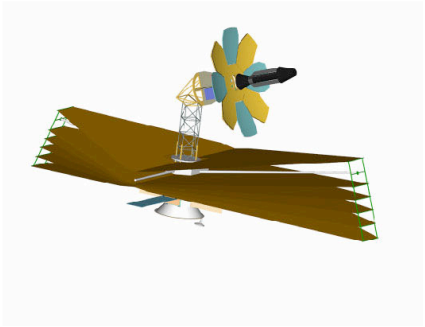
- point source detectivity
  (1s of SAFIR worth 1 week of SIRTF!)
- spectroscopic sensitivity
  (1s of SAFIR worth 1 year of Herschel with noise-free detectors, 1 day with quantum-limited detectors)



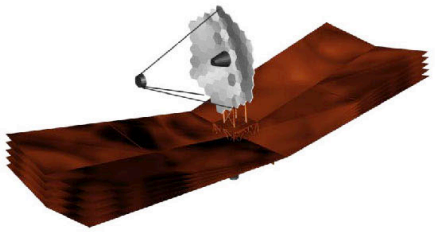
no confusion limits for spectroscopy!

SAFIR Mission Implementations

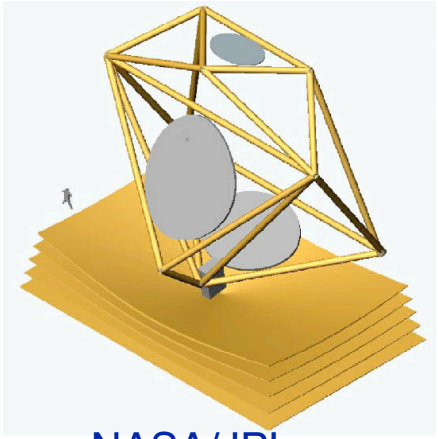
- SAFIR is defined as a set of science objectives that answer key astrophysics questions in the far-infrared.



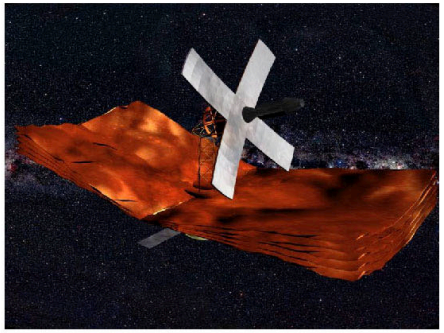
NASA/GSFC



NASA/GSFC



NASA/JPL



NASA/GSFC

- 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.

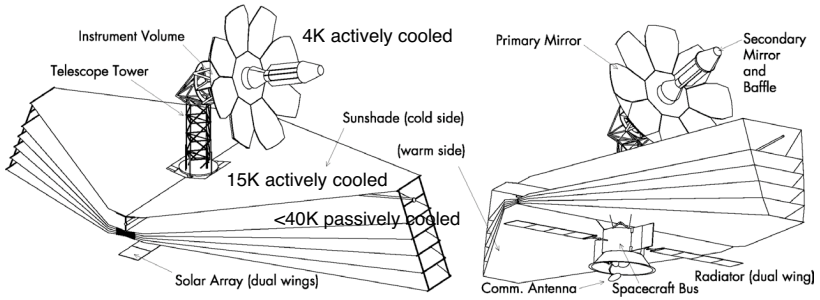
- Mitigating factors:
  - Cryocoolers for ~4K are under development for, e.g., JWST, TPF, etc.
  - Detectors - superconducting TES bolometer development for Con-X
  - Deployable telescope to be demonstrated by JWST

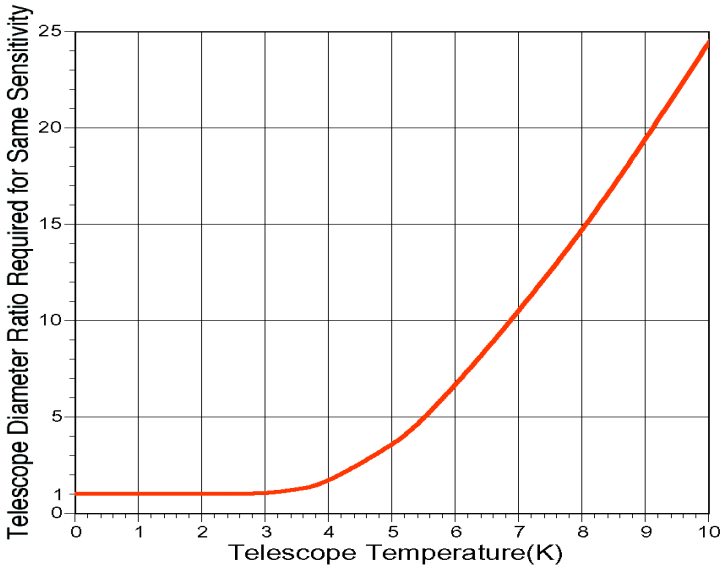
But Why 4K for SAFIR?

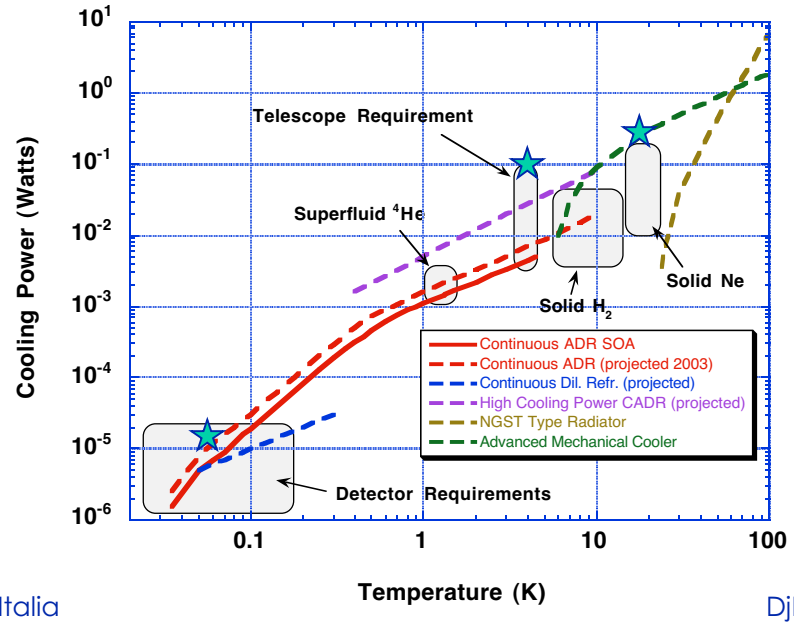
Because it makes a big difference!

A 4K telescope is background-limited (zodi @ <200μm, CMB @ >200μm)

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

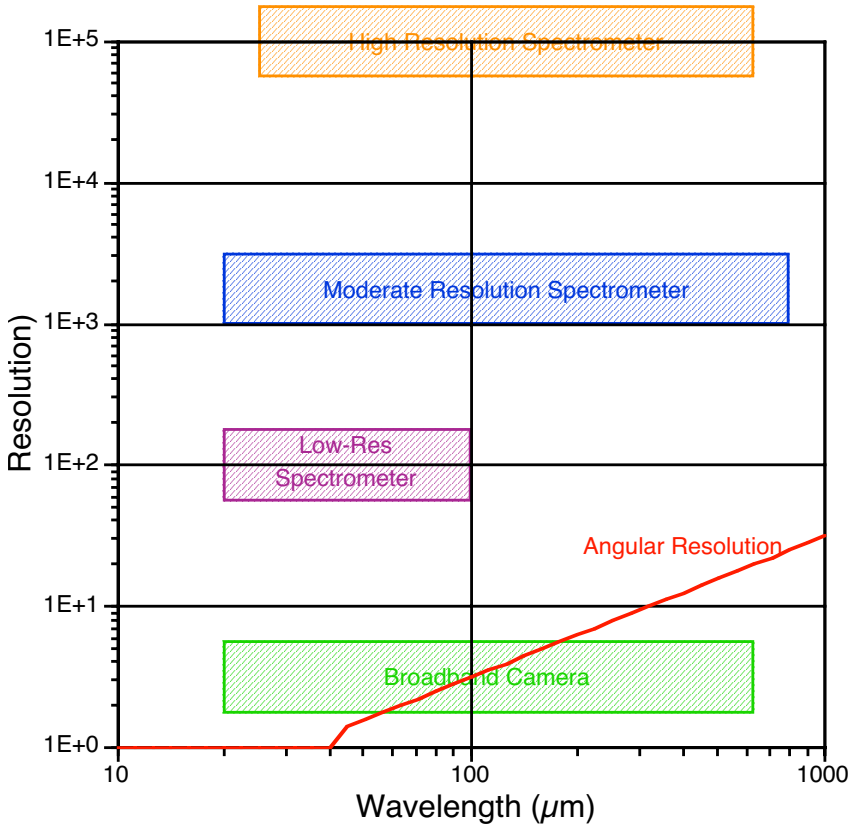






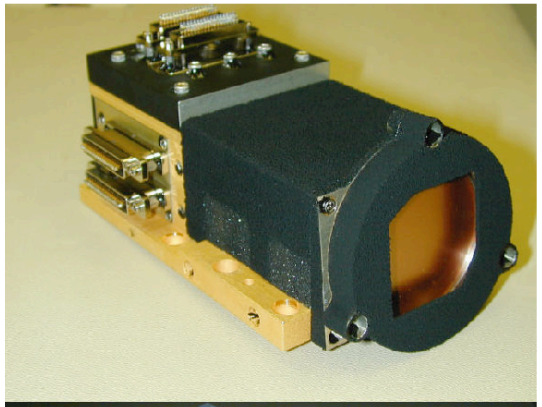
Critical Detector Technologies

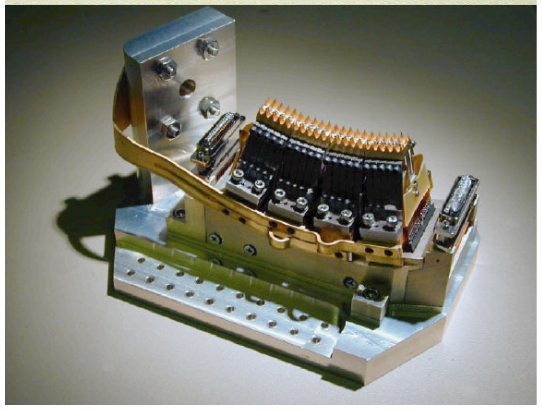
- Large-format (10^3-10^4 pixel) broadband arrays:
  - semiconducting and superconducting (TES) bolometers
  - Ge, Si BiB photoconductors
- Arrays for spectroscopy:
  - RF-SET / STJ
  - Kinetic Inductance
- High resolution spectroscopy:
  - quantum noise-limited heterodyne spectrometers
  - new spectrometer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



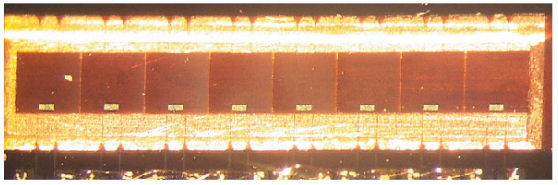
Representative Detectors

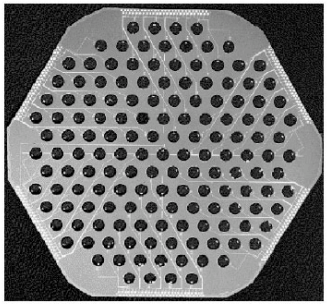
Photoconductors

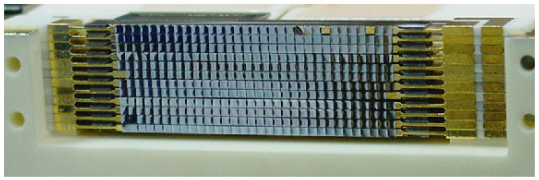




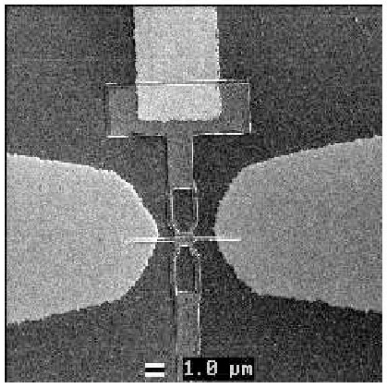
Bolometers

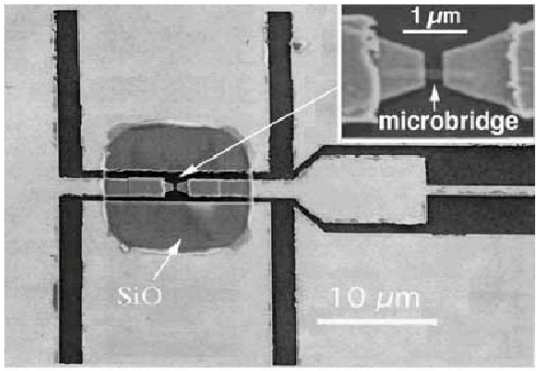




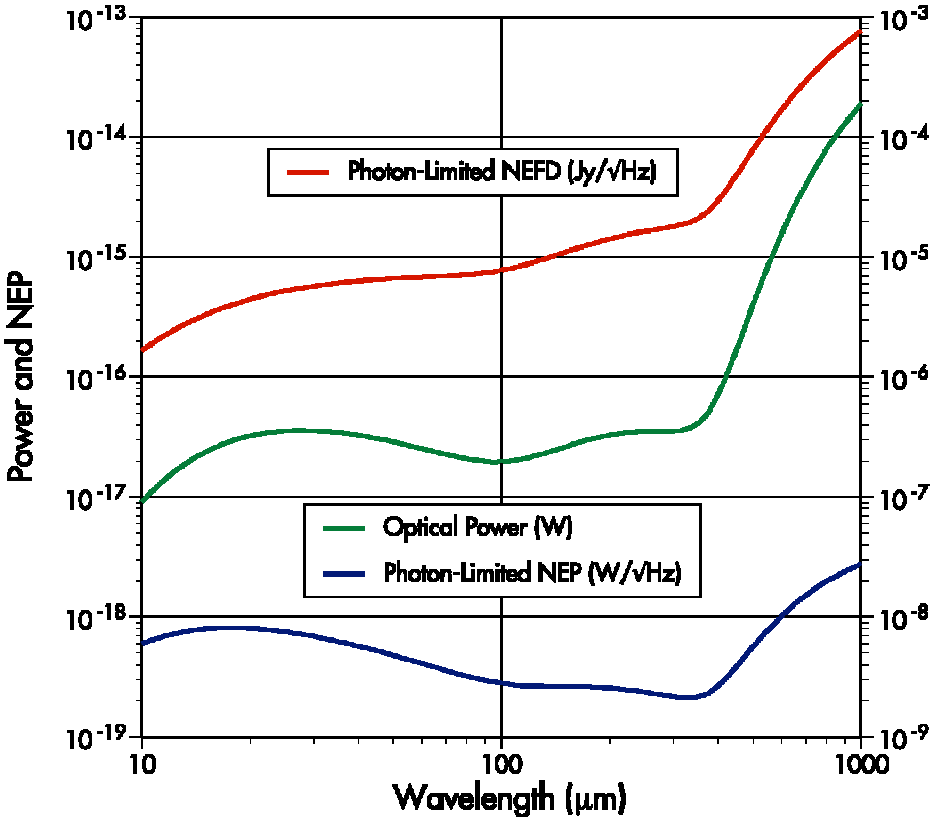


Other



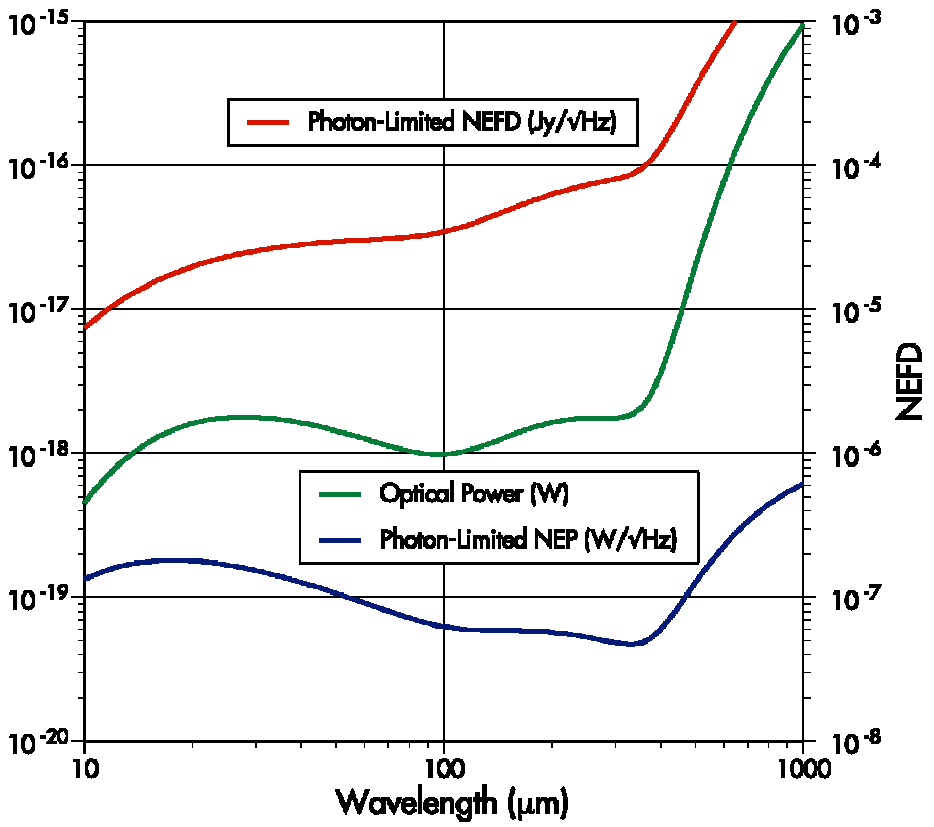


SAFIR Detectors (low resolution)



Camera: 10^4 pixels,

NEP=10^{-19} W/√Hz



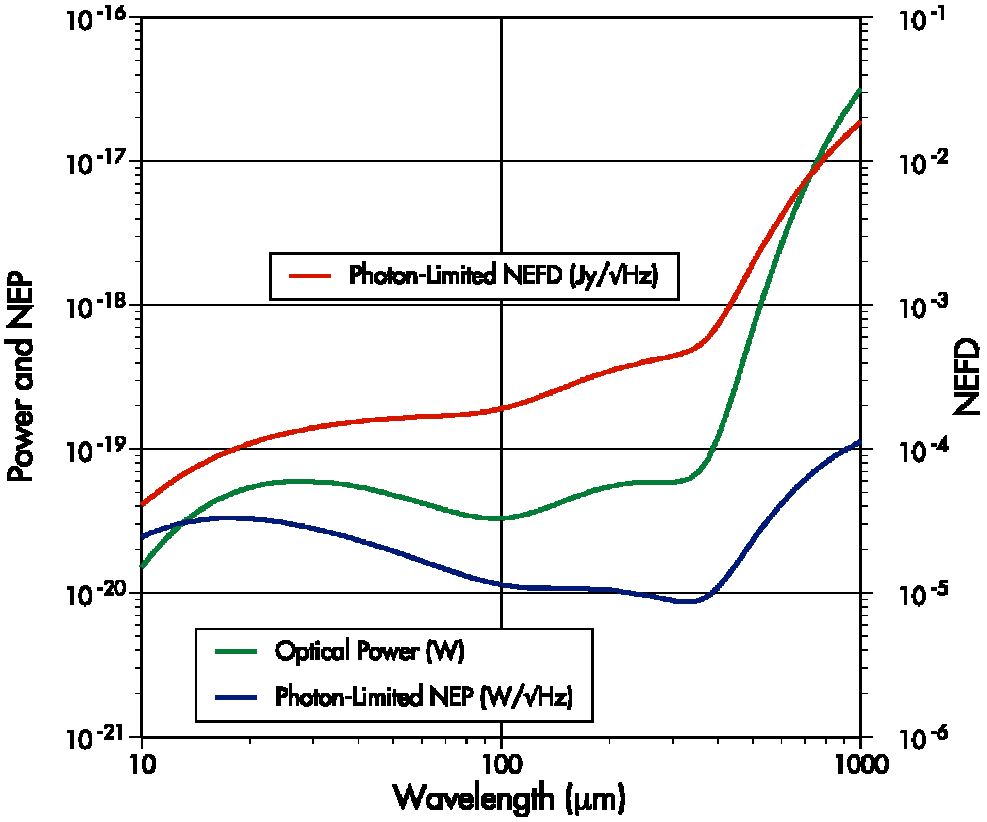
LRS: $4 \cdot 10^3$ pixels,

NEP=$2 \cdot 10^{-20}$ W/√Hz

SAFIR Detectors (med. resolution)

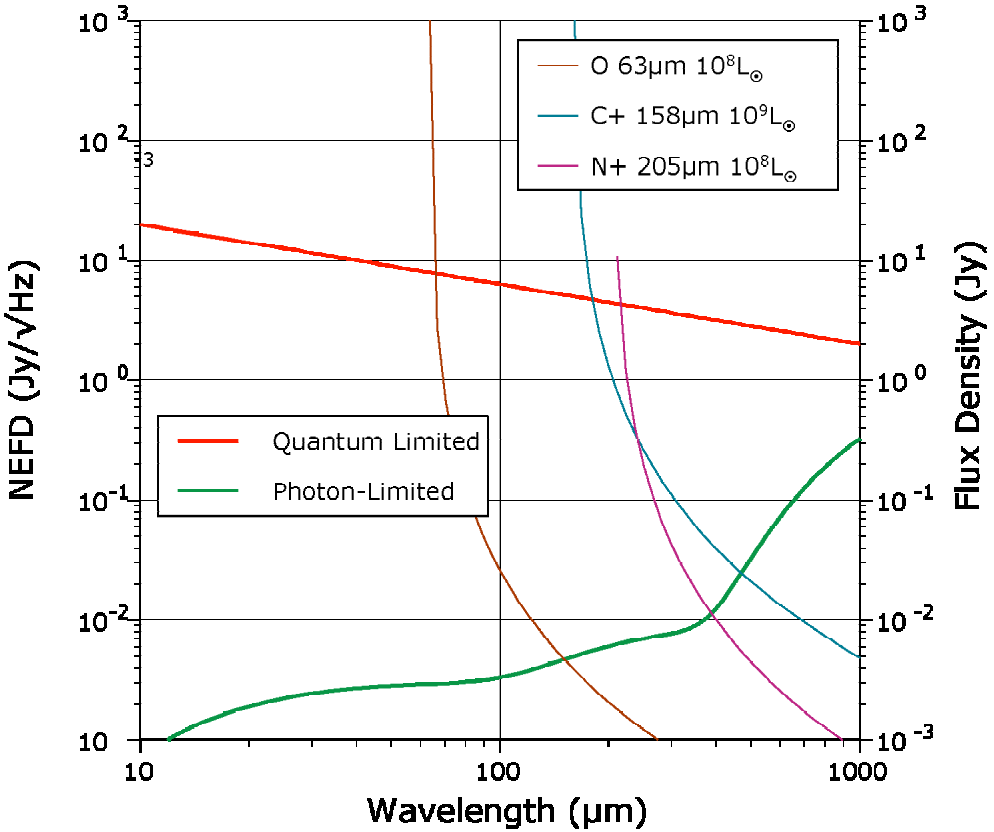
- With $\lambda/\delta\lambda$~1000 (300km/s) resolution, power is low
- Requires >10^3 pixels with NEP=$3 \cdot 10^{-21}$ W/$\sqrt{Hz}$

- At 100μm, rate is ~50 γ/s
- Need noise of 5 γ/s/$\sqrt{Hz}$



SAFIR Detectors (high resolution)

- Heterodyne spectrometers are quantum-limited, therefore not optimally sensitive.
- Direct detection approach probably not feasible. Photon rate ~0.01 γ/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