SAFIR
The Single Aperture Far Infrared Mission

Progress Report from the SAFIR study group
to the Origins and Structure & Evolution of the Universe Subcommittees of the NASA Space Science Advisory Committee

Dan Lester, University of Texas
27 February 2003
SAFIR in the OSS Roadmaps and Decade Survey

“… the Single Aperture Far Infrared mission consisting of a single 8-10-meter telescope operating in the far IR could serve as a building block for the Life Finder, while carrying out a broad range of scientific programs beyond JWST and SIRTF.”

2003 Origins Theme Roadmap

“A cryogenic, large aperture infrared telescope would be able to see these molecular lines, and offer a unique window into early star formation. Such a single aperture far-infrared (SAFIR) mission could build upon James Webb (next generation) Space Telescope technology.”

2003 SEU Theme Roadmap

“To take the next step in exploring this important part of the spectrum, the committee recommends the Single Aperture Far Infrared (SAFIR) Observatory…”

2000 NRC Decade Report
Goal of Presentation to A&P Subcommittees

- In view of value of SAFIR to SEUS and OS communities, we offer a briefing on its developing scientific vision and program status.

- SAFIR has $100K from A&P in FY03, and some substantial investments from both JPL and GSFC. $$ well spent.

- SAFIR is poised to benefit dramatically from technology investment. Look forward to continued subcommittee support for such investment.

- While no funding line for SAFIR at this time, NASA needs a mix of well studied science missions. It’s time to pick up the pace on SAFIR.

*It’s always important to identify opportunities. SAFIR presents us with a rich set.*
Genesis of SAFIR

pronounced “sapphire”!

Huge science need and opportunity coupled with feasibility!

- SAFIR was recommended in the Decade Report for technology and concept development that would form the path for future IR missions.

- Recognized that large aperture, low temperature FIR 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.

- SAFIR embraces what was known as FAIR, and the concept known as DART.
Facility-Specific Study Team Activities

- **3/7-8/02** 2nd Workshop New Concepts FIR/Submm Astronomy
  - “Charting the Winds that Change the Universe: SAFIR” (G. Reike)

- **5/7/02** SEUS meeting
  - SAFIR technology briefing to SEUS (D. Benford)

- **7/31-8/1/02** SAFIR Science Team meeting

- **8/22-28/02** SPIE
  - “A Single Aperture Far Infrared Observatory” (P. Harvey et al.)
  - “Engineering Concept and Enabling Technologies for SAFIR” (M. Amato et al.)
  - “DART Technology Development” (M. Dragovan & J. Dooley)

- **10/10-11/02** COSPAR
  - “NASA’s Far-IR Roadmap Missions SAFIR and SPECS” (D. Leisawitz)

- **1/5-9/03** AAS Seattle
  - “The Single Aperture Far-InfraRed Observatory (SAFIR)” (H. Yorke et al.)

- **2/5-6/03** New Millenium ST9 Workshop
  - contributions to “System Technology for Large, Space Telescopes” splinter groups

- **2/25/03** SAFIR Science Team meeting
SAFIR is defined as a set of science objectives that answer key astrophysics questions in the far-infrared. Several concepts are being developed. Commonality in technology needs. Implementation will flow from science requirements and technology capabilities.

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<thead>
<tr>
<th>Parameter</th>
<th>Requirement</th>
<th>Science Targets</th>
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<tbody>
<tr>
<td>Aperture</td>
<td>~10m</td>
<td>high z galaxies, debris disks</td>
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<tr>
<td>Temperature</td>
<td>4K (@L2?)</td>
<td>L* galaxy @ z=5 (zodi lim)</td>
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<tr>
<td>Wavelength</td>
<td>&lt;20-500+µm</td>
<td>coolant lines (JWST, ALMA overlap)</td>
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<tr>
<td>Diffraction limit</td>
<td>λ≥40µm (1”)</td>
<td>debris disks, distant galaxies</td>
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<tr>
<td>Lifetime</td>
<td>&gt;5 years</td>
<td>productivity!</td>
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The stage on which SAFIR plays …

- 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 -- near and far, now and long ago is an IR problem.
- The youngest primordial gas clouds will be visible only in the far-IR.
- Dust is everywhere (eventually) -- be not fooled …

  **JWST will detect the first galaxies -- SAFIR will understand why they hide!**

  **Era of JWST and ALMA.**
  **SIRTF, SPICA, Herschel are done.**
SAFIR Key Science Drivers (pre-SIRTF!)

• 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?

• 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 to ??

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

H₂, C, N, O, MgH, H₂O, CHₙ, SiH, CO, OH, SH, HD, LiH, AlH etc. etc. large pre-biotic molecules.

Birth of a Planetary System

~100,000 yrs

~10⁶ y
SAFIR: relationship of AGNs and ULIRGs

$10^{12} \, L_{\text{sun}}$ galaxies are numerous in early universe; huge $A_V$ super starbursts? buried AGNs? intermediate stage?

powerful extinction-free mid-IR radiation diagnostics:

- **Soft HII**: $[\text{FeII}]$ 26, 35 …, $[\text{NeII}]$ 12.8, $[\text{FeIII}]$ 23, 33 …, $[\text{SIII}]$ 18 & 33µm
- **Hard HII**: $[\text{SIV}]$ 10.5, $[\text{Nell}]$ 16 & 36 , $[\text{OIII}]$ 52 and 88µm
- **AGN**: $[\text{MgV}]$ 13.5 , $[\text{OIV}]$ 26 , $[\text{ArV}]$ 13, and $[\text{NeV}]$ 14 and 24µm

search for broad lines; dynamics of nuclear toroids
accretion history of universe (with X-ray missions)

see Arp220-class galaxies with SAFIR out to $z=7$ !
A Huge Discovery Space

SAFIR will offer orders of magnitude improvement in:

- spectroscopic sensitivity
- point source detectivity

**Background-Limited Spectroscopy with SAFIR**

- Spectral Line in M82 at $z=4$
- or Arp 220 at $z=6$
- CMB
- Zodiacal Light
- Galactic Cirrus
- 4 K Tel. Telescope @ 5%

**Spectral Capability in the FAR-IR**

- SIRTF IRS High Res
- Herschel PACS
- SOFIA at $R=1000$
- JWST at $R=1000$

**no confusion limits for spectroscopy!**
Flavors of SAFIR

- JWST-like
  - max system validation
- sparse aperture
  - maximize baselines
  - deployment simplicity
- “DART” w/ membrane mirrors
  - large aperture/weight ratio

- deployment, active surface control
- large format, low noise detectors
- cryocoolers, thermal management
- large, lightweight optical structures
SAFIR Observatory Critical Technologies

incremental steps …

• cryogenic, deployable large apertures
  - actuators, latches, mirror substrates
  (zero-G proof-of-concept highly desirable)

• optimized sun shield technology
  - material properties, refine designs
  (LEO or L2 proof-of-concept highly desirable)

• thermal transport technology
  - gas flow, capillary technology
  (zero-G proof-of-concept highly desirable)

• cryocooler technology
  - extension of ACTDP at 4-20K
  - augment existing ADR capabilities at 50mK-4K
SAFIR Focal Plane Critical Technologies

- new spectrometer architectures

- focal plane cooling technologies for <100mK
  multistage ADR
dilution refrigerators

- large-format ($10^3$-$10^4$ pixel) broadband arrays
  semiconducting and superconducting (TES) bolo arrays
  Ge, Si BiB photoconductor arrays
  SQPCs

- quantum noise-limited heterodyne spectrometers
Thermal Model Targets for SAFIR
(cooling is the biggest challenge …)

- <40K “JWST plus” sunshade
- 15K actively cooled shield blocks sunshade; 1W lift
- 4K actively cooled telescope under shield; 85mW lift
- 50 mK actively cooled focal plane; 10µW lift

SOA suggests that thermal requirements are achievable!
But Why 4K for SAFIR?

Because it makes a big difference!

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

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

we’re not far from where we need to be!

SAFIR targets

Temperature (K)

Cooling Power (Watts)

10^{-6} 10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1} 10^{0} 10^{1}

0.1 1 10 100

Superfluid $^4$He

Solid H$_2$

Solid Ne

Detector Requirements

Telescope Requirement

Continuous ADR SOA
Continuous ADR (projected 2003)
Continuous Dil. Refr. (projected)
High Cooling Power CADR (projected)
NGST Type Radiator
Advanced Mechanical Cooler

SAFIR Cryogenic Technology

2/27/03 • OS-SEUS presentation • DFL 17

cooled JWST-like shield sunshade

Solid H$_2$

Solid Ne
Summary

• SAFIR has seen a lot of thought and effort over the year.
  Convergence of science opportunity and tech feasibility.

• we ask OS and SEUS to support technology development for SAFIR
  – support work with Code R for science-driven technology funding
  – insist that SAFIR needs be mapped into A&P technology initiative
  – ensure awareness of SAFIR needs in JWST and Con-X efforts
  – support SOFIA and ground based proof-of-concepts for new
    detector and spectrometer architectures

• we ask OS and SEUS to recommend continued funding to ensure
  further progress on pre-Phase A feasibility studies.

• we ask OS and SEUS to recognize FIR/submm community white
  paper which presents a programmatic case for a new mission line!
# SAFIR Study Team

## Science Team

<table>
<thead>
<tr>
<th>Name</th>
<th>Institution</th>
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<tbody>
<tr>
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## Study Leads

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## Technology Contributors

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