LESSONS LEARNED FROM WISE

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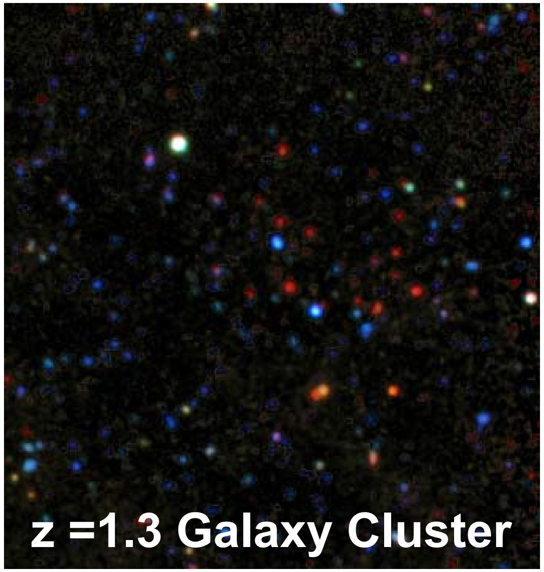
What Is WISE?

- The Widefield Infrared Survey Explorer (WISE)
  - An all-sky survey at 3.5, 4.7, 12 & 23 μm with 3 to 6 orders of magnitude more sensitivity than previous surveys
  - A cold 50 cm telescope in a sun-synchronous orbit
  - Enabled by new infrared detector arrays
- WISE will deliver to the scientific community
  - Over 1 million calibrated rectified images covering the whole sky in 4 infrared bands
  - Catalogs of $\approx 5 \times 10^8$ objects seen in these 4 IR bands

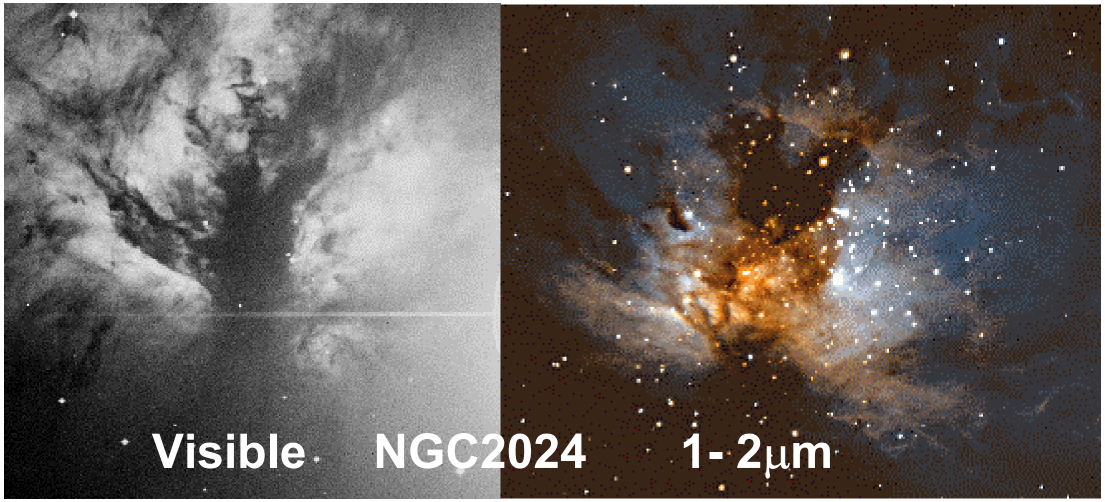
Why All Sky?

- For superlative and/or unique objects, such as the nearest stars or the most luminous galaxies, only an all-sky survey will do.
- For uniformly distributed objects, a fast shallow survey finds more sources per unit time than a deep narrow survey.
- An all-sky survey finds the brightest objects in a class, which are the easiest to follow up in detail with large telescopes like the JWST.

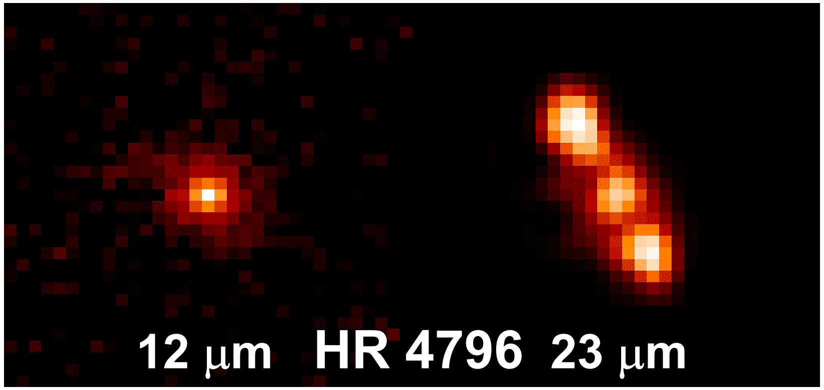
Why Infrared? IR Observations Probe:



The Distant Universe



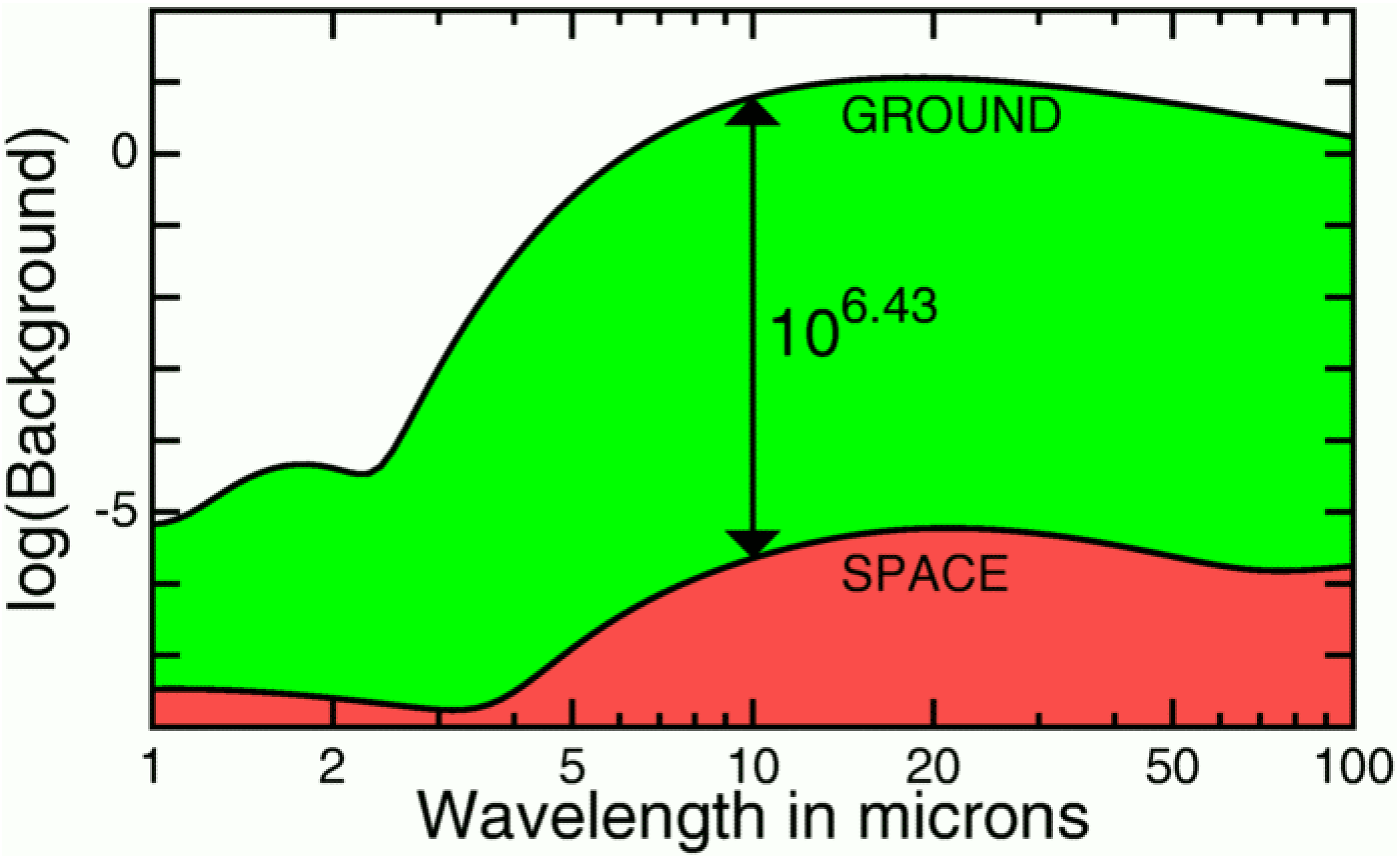
The Dusty Universe



The Cold Universe

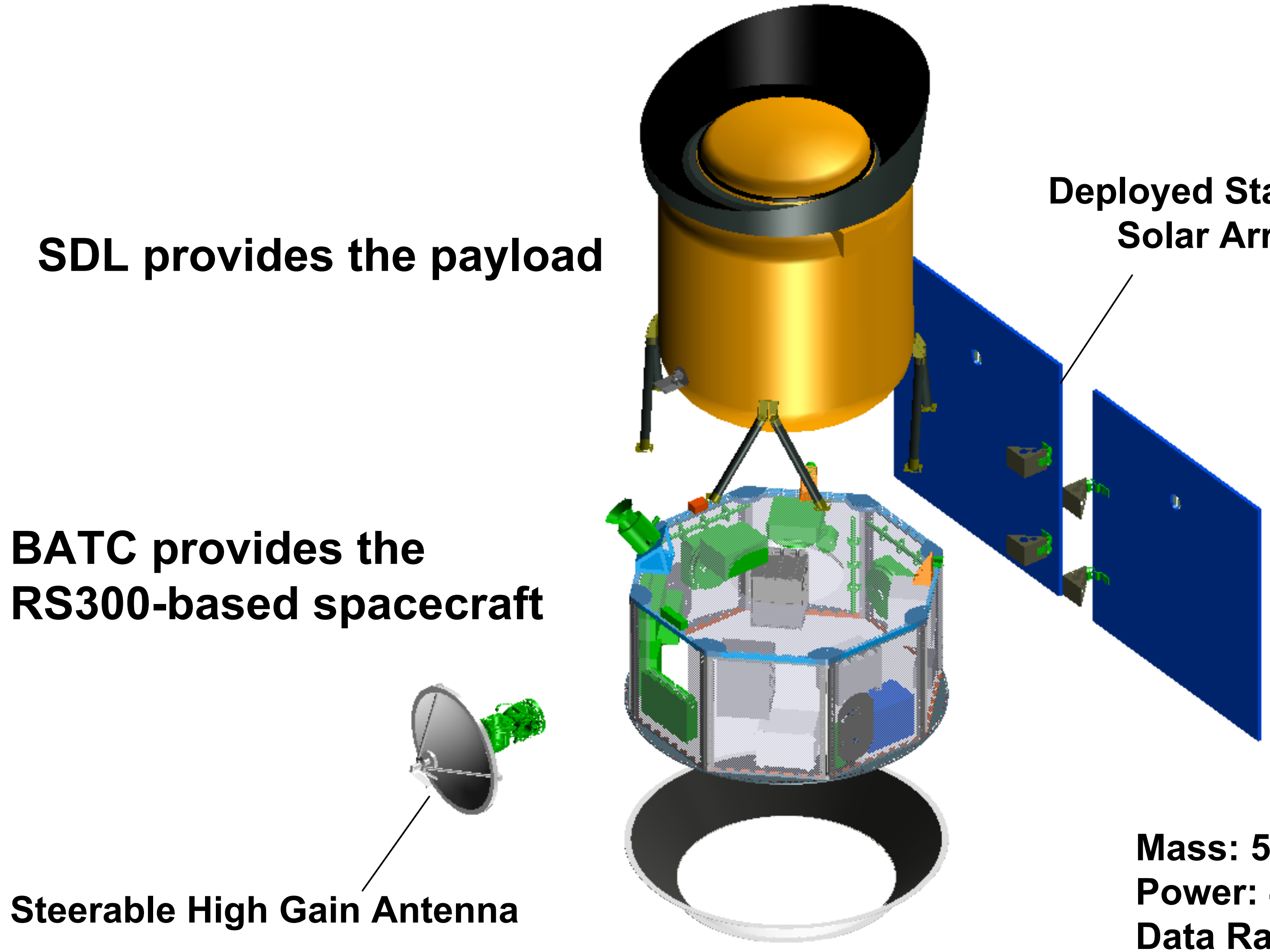
Why Is a Space Mission Needed?

"Ground-based infrared astronomy is like observing stars in broad daylight with a telescope made out of fluorescent lights'' — George Rieke.



50 cm WISE telescope in space equals ten thousand 8-meter telescopes on the ground!

Exploded Diagram of WISE



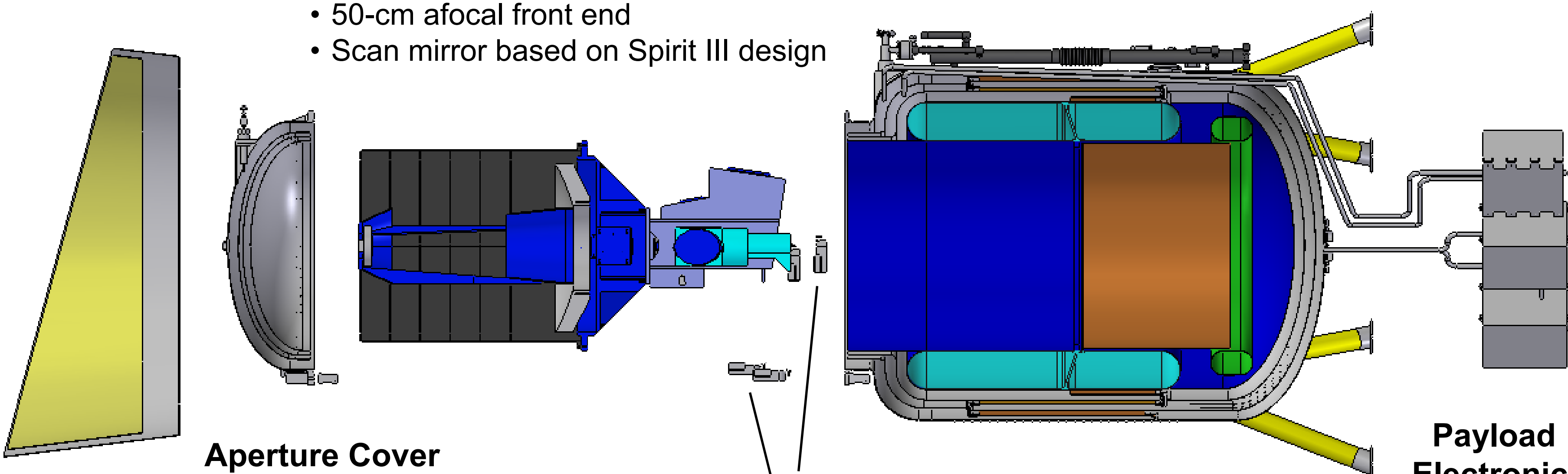
Mass: 532 kg
Power: 467 W
Data Rate: 78 GB/day

Exploded Diagram of Science Payload

Cryostat
- 2-stage solid hydrogen
- Team has experience flying hydrogen cryostats

Aperture Shade

Telescope Assembly
- 50-cm afocal front end
- Scan mirror based on Spirit III design



Payload Electronics

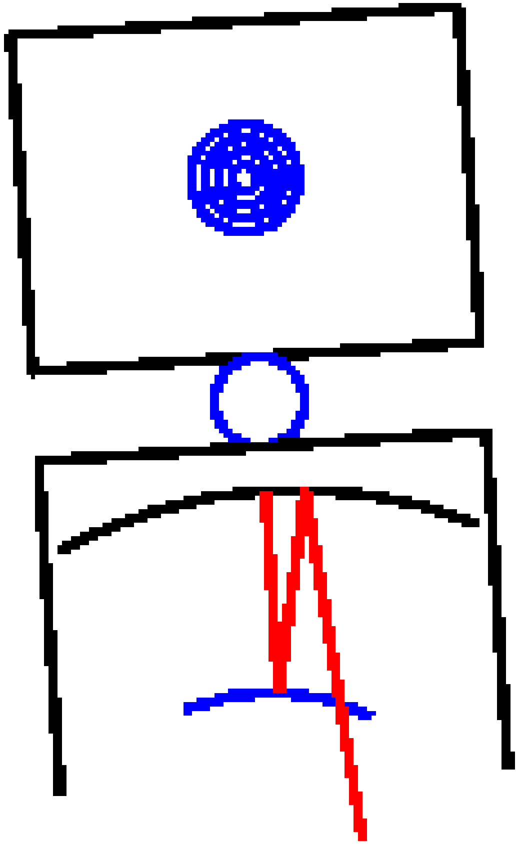
Aperture Cover
- Deployed on-orbit

1024² Focal Planes
- HgCdTe arrays at 3.5 and 4.7 microns
- Si:As BIB arrays at 12 and 23 microns
- Team includes co-inventor of Si:As BIBs

WISE Basic Mission Design

- Scan circle perpendicular to the Earth-Sun line at a constant inertial rate.
- Use a Sun-synchronous nearly polar orbit at the terminator, and set the scan rate equal to the orbital rate.
  - Scan rate = orbital rate with 1-2% tolerance.
  - Scan rate = scan mirror rate with 0.1% tolerance
- Line-of-sight is always 90^{o} from the Sun and within 31^{o} of the zenith which is good for a cryogenic mission.
- Heritage: IRAS, COBE, ASTRO-F

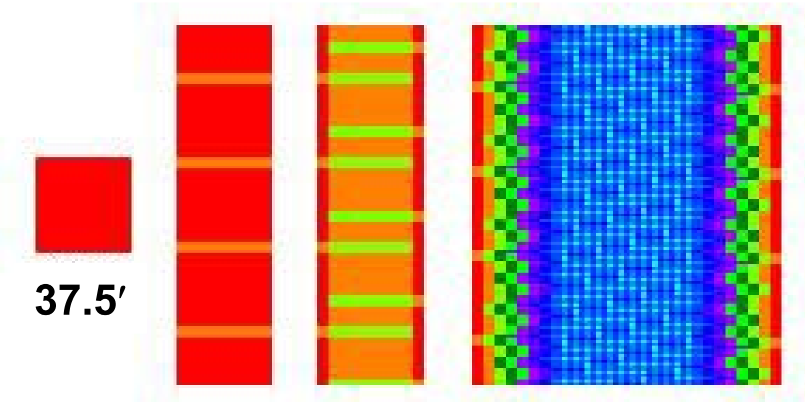
Animated Scan Mirror Icon



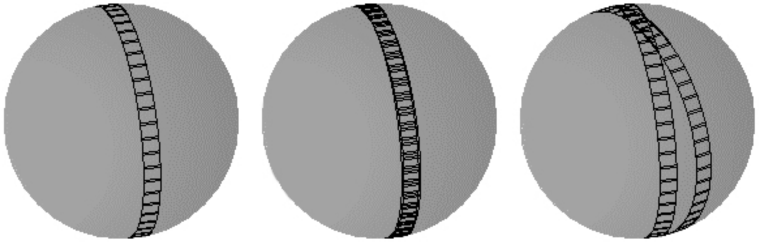
WISE Survey Strategy Provides Minimum of 5 Exposures Per Position

- Scan mirror enables efficient surveying
  - 6.6-s exposure/8.8-s duty cycle
- 10% frame to frame overlap
- 90% orbit to orbit overlap
- Sky covered in 6 months observing

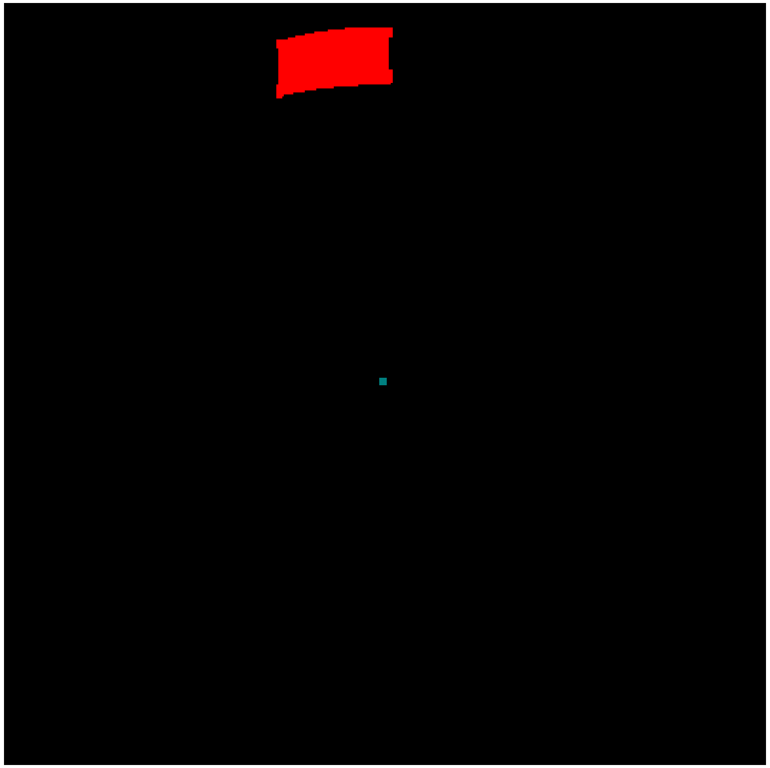
- Single observing mode
- Minimum 5, median 11 exposures/position after losses to Moon and SAA



One frame | One orbit | Two orbits | Many orbits



1 Orbit | **2 Consecutive Orbits** | **2 Orbits 20 Days Apart**



Pre-history of the WISE Proposal: I

- 1977 – a 5 μm "HIPPARCOS" to find the nearest brown dwarf stars.
  - Just a concept in my notebooks.
  - Used a "Tycho" style experiment with skewed chevron masks on single detectors to get accurate positions of bright 5 μm sources.
  - Used "ANS" orbit since IRAS/COBE were in the future.
  - If brown dwarfs followed Salpeter IMF then they would dominate the local mass density and the nearest ones would be very near and bright.
- 1988 – the NIRAS SMEX proposal.
  - PI: Giovanni Fazio, co-I's ELW and Carol Lonsdale
  - Multi-band all-sky imaging survey.
  - 40 cm telescope
  - Continuously scanning spacecraft with a scan mirror to freeze the sky on "large" HgCdTe arrays (58x62).
  - Not funded. Review panel said "do what you can from the ground first".

NIRAS – Near Infrared Astronomy Satellite

PROPOSAL TO
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
FOR A
NEAR-INFRARED ASTRONOMY SATELLITE

P1976-9-88

For the period 1 July 1989 through 30 September 1993

Total Estimated Cost: $15,457,092
(not including costs from NASA Centers)

Volume I – Investigation and Technical Plan

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NIRAS 1988

- All sky survey.
- "Big" arrays (58x62).
- Continuous slew.
- Scan mirror to freeze image on array.
- Exposures every 4.5 seconds.
- 40 cm telescope.
- Proposed Cost: $15.5M

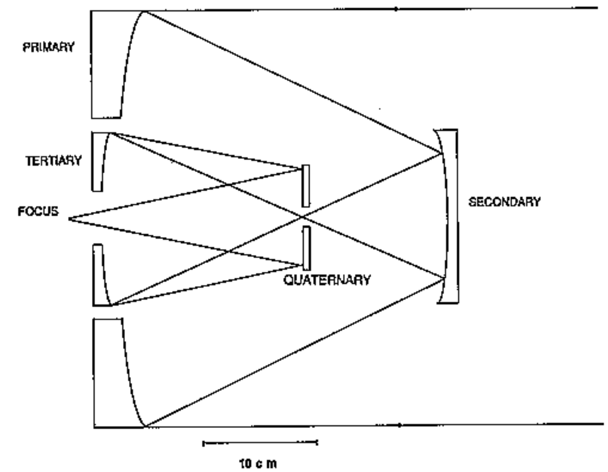


Figure 3-3. Optical Diagram of the Telescope

A scan mirror is used to freeze the sky field-of-view on the detectors for a period of 4.3 seconds as the spacecraft rotates at the orbital rate. The field-of-view is then advanced within 0.2 seconds.

Table 3-1. NIRAS Sensitivity

WAVELENGTH (microns)	BANDWIDTH (microns)	S/N	NUMBER OF PASSES	FLUX DENSITY POINT SOURCE (mag)	(mJy)	DIFFUSE (μJy/arcsec^2)
1.87	1.14	1	1	14.6	1.2	1.8
		5	1	12.8	6.0	
		1	4	15.3	0.6	0.9
		5	4	13.6	3.0	
3.52	2.16	1	1	13.4	1.2	1.7
		5	1	11.7	6.0	
		1	4	14.2	0.6	0.9
		5	4	12.4	3.0	

Pre-history of the WISE Proposal: II

- 2MASS is NIRAS from the ground.
  - Multi-band all-sky imaging survey.
  - 1.3 m telescopes in North and South.
  - Continuously scanning telescopes with a scan mirror to freeze the sky on “large” HgCdTe arrays (256x256).
- 1994 - Near Infrared Solar orbit Telescope (NIRST).
  - Mission concept study in 1994. ELW & PRME as co-PIs.
  - 85 cm telescope in SIRTF style Earth trailing heliocentric orbit.
  - Multi-band imaging with large arrays (1024x1024).
  - Long-slit spectroscopy.
  - Stop and stare operation.
  - Could cover several percent of sky per year.

WISE History: I

- First meeting in early 1998.
- SDL, Ball represented.
- Next Generation Sky Survey (NGSS) chosen as name.
- The SELVS II B with 1200 kg capacity to a polar orbit selected.
- On board data storage using a solid state recorder with several dumps per day to a polar ground station using a lot of bandwidth at X band.
- Mass including 22% reserve 818 kg, giving 382 kg margin.
- Step one proposal submitted in 1998.
- Selected for Phase A study. SELVS II B had not been developed so NGSS was given a ride on a Delta ($39 M cost) at the SELVS II B cost: $32 M.
- WIRE launched and failed due to premature cover injection.
- Swift and FAME chosen for flight.

WISE History: II

- Team reformed in 2001 to propose again.
- There was a 1200 kg capacity option on the Explorer library: the Athena for $43 M. Quite an increase over $32 M in 1998.
- But the Athena disappeared from the Explorer library. Now the only rocket able to carry NGSS was the Delta for $67 M. More than double our $32 M launch cost from 1998.
- NGSS had to downsize to the Taurus launch vehicle.
- Ball's BCP 2000 (formerly the RS 2000) was replaced with the new RS 300 to save mass. Now the mass including contingency is 532 kg.
- X band telemetry frequency allocation goes primarily to downlooking Earth science experiments. NGSS would need a waiver. Ground data system listed as a Phase A study item.

LEO Small Satellite Business Dried Up

- The idea that everybody would want to have a way cool Iridium phone and pay $3/min to call from anywhere in the world did not work out.
- Instead, cell towers were built covering most of the area where most of the people are most of the time. Cell phones are much smaller, cheaper and calls are only $0.10/min.

Iridium Goes Bust

It all seemed such a good idea...

Bankrupt US phone firm Iridium is to send 66 satellites worth $6bn out of orbit to burn up in the Earth's atmosphere.

The satellite phone company ran out of time on Friday in its hopes of finding a rescuer for its ailing business.

Now, after receiving permission from a bankruptcy judge to cut off service to its 55,000 customers, Iridium plans to use $8.3m of its remaining money to start closing its business, including paying severance to employees.

Fortunately the satellites are still in orbit producing spectacular "Iridium Flares" reaching magnitude -8.

Very little commercial LEO traffic

- With Iridium bankrupt, projects such as the Teledesic system with several hundred satellites in LEO did not proceed.
- None of the new small boosters designed to launch these satellites were brought on line.
- The market for commercial ground station telemetry and mission control got thinner.

Cost of a Step 1 Midex Proposal

- Survey says: 7 ± 2 man-years.
- Roughly 1 M$.
- Proposal teams are contributing a lot of nights, weekends, and IR&D to the Explorer program.

Cost of this estimate:

WISE History: III

- NGSS again selected for a phase A study.
- The TMCO debrief when we were selected to go on included a comment asking whether we had considered a space-qualified Redundant Array of Inexpensive Disks (RAID) for our on-board data storage. We decided to switch from the Solid State Recorder to a RAID, which has more storage and less mass.
- We did an extensive trade study on getting the data to the ground and decided that TDRSS worked well for us.

WISE History: IV

- The name change:
  - The NGSS team was strongly advised to change its name because it was to similar to NGST. Of course, we chose NGSS because it was just before NGST.
  - NGST became the James Webb Space Telescope, but NGSS was still advised to change its name.
  - Many names were considered:
    - ASTIREX: the All sky Thermal InfraRed EXplorer
      - Too French in the era of freedom fries
    - Paul Hertz contributed:
      - NASTI: Ned's All-sky Survey Telescope in the Infrared
      - EX-WIFE: Explorer for Wide-field Infrared Features and Emission
    - Chuck Bennett suggested the Infrared Wide-field Survey Telescope, or IWST, so as to be still just before JWST.
    - Permutation gave WIST, and then changing telescope to Explorer gave WISE.
- The new name was first used at the site visit in January, 2003

WISE History: V

- Selected in March 2003 for an extended Phase A study with 5 M$ in funds and a year.
- It has taken several months to get the funding flowing but we have a plan to work on the tall poles and long lead items.

Independent Cost Estimates

SMIRNOFF
ICE

ICE is like Appraising Real Estate

- Compare the target to several comparable items, and estimate its price using the comparable prices.
  - In real estate compare using rooms, total area, architectural style & beauty.
  - In space hardware compare using mass, power & complexity.
- But space missions are much too unique for this to work well.
- Subdivide the mission into components to get more comparable items.
- Style and beauty are hard to quantify, and complexity is hard to quantify.
- The alternative is to get a second opinion in medicine, or several bids when contracting a job.
- But bidders are hoping for future profits and thus are not independent. A truly independent grass roots cost estimate would cost a large fraction of the 1 M$ cost of the proposal.

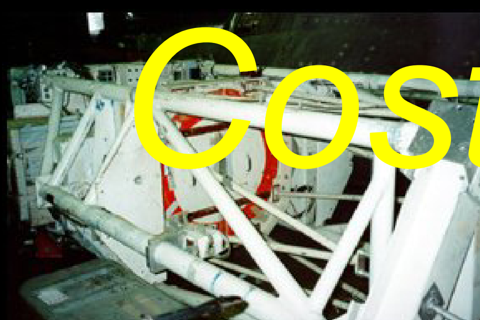
My PhD Project is in the Smithsonian!

Space Science
Astronomy

Smithsonian
National Air and Space Museum

Smithsonian Astrophysical Observatory 1-Meter Balloon-borne Telescope Payload

Cost: $135/kg



Source: Space History

Source: Space History

But Balloons Come Back

- My thesis was based on the 4th flight of this payload.
- The first three flights failed, but the telescope always came down on the parachute to a relatively benign landing.
- Otherwise this mission was close to space:
  - Radio link for telemetry and commanding.
  - Attitude control using reaction wheel.
  - Attitude sensing using gyroscopes, magnetometers and Earth sensors.
  - Limits on power and mass.
  - Severe thermal environment.
  - Cryogenic detectors.
  - O-rings heated to prevent failure due to cold.

What about WISE?

- Cost is roughly $170,000 per kg, more than 1000 times the cost of balloon hardware.
- This factor of 1000 ratio between balloons and space hardware has some heritage behind it.
- So WISE is in the right order of magnitude, but it is hard to be accurate to 10%.

Why WISE is Simple

- There is only one mode of scientific data-taking. The instrument always does the same thing, over and over again.
  - COBE only had one data taking mode.
  - WMAP only has one data taking mode,.
- The cryostat is based on the WIRE cryostat, which worked pretty well.
- There is only one moving part in the instrument.
- The spacecraft only has to do what a rigid body will do naturally: rotate at a constant inertial rate.
- Good mass margin, power margin, and sensitivity margin.

Why WISE is Complicated

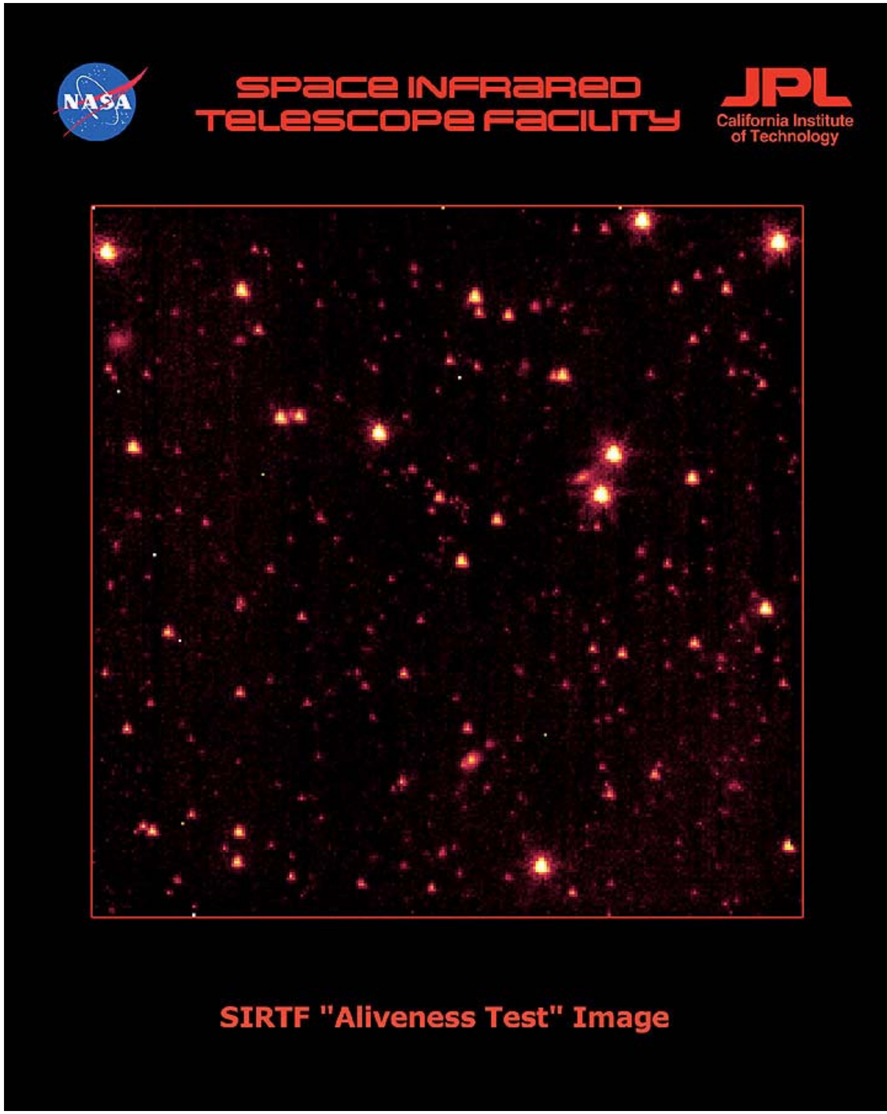
- It can't look at the Sun or the Earth.
- It has one cryogenic moving part.
- The spacecraft and scan mirror both have to execute smooth linear scans with equal rates but opposite directions.
- It needs 4 IR detector arrays.
- It generates a lot of data.

What WISE is doing now

- Working on the science payload:
  - Long wavelength multiplexor and hybrid development.
  - Updating the optical design.
  - Updating the cryostat design.
- Working on the spacecraft attitude control performance.
  - Current estimates on spacecraft pointing jitter around a smooth linear scan are close to the image quality budget allocation.

WISE Scientists are Watching SIRTF

- Science team will examine first results from SIRTF which has cameras in 3 of the 4 WISE bands and see whether the science requirements need to be updated.
- SIRTF will observe a very small fraction of the sky but with better sensitivity and resolution than WISE.
- SIRTF should show the tremendous power of thermal IR observations from space.



WISE isn't over

- So there are many more lessons to learn.
- But lessons learned in the proposal process:
  - You need a good idea. Mostly these will be old ideas that have been proposed before.
  - You need to be in a field where substantial progress is being made, such as IR astronomy where array sizes have been pretty much following Moore's law for two decades.
  - You should have 1000 fold advantages over previous work and over anything that can be done from the ground.
  - You need an experienced proposal team. Very few universities could do it alone.