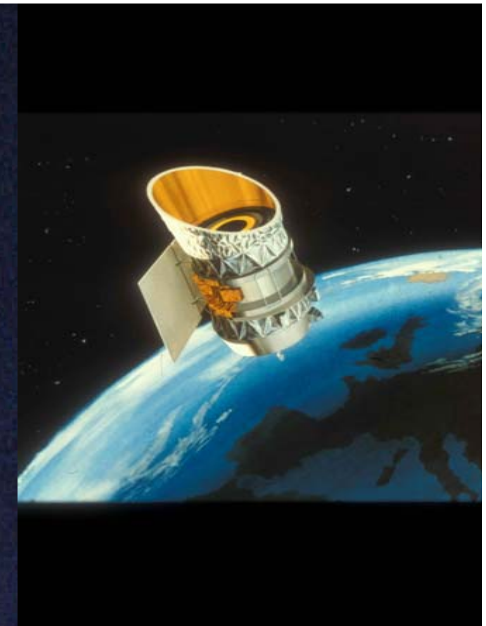


IRAS Technology

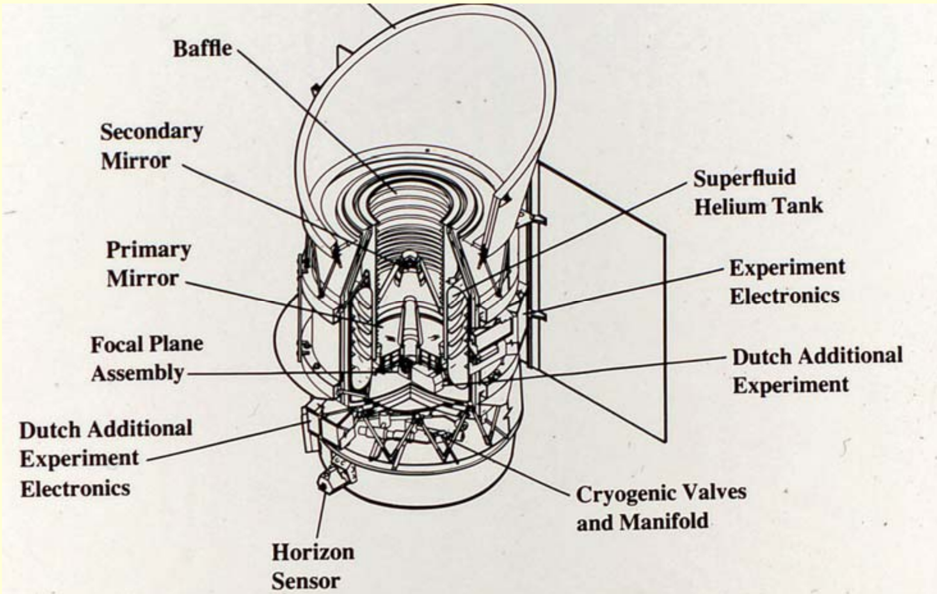
Challenges and Lessons Learned

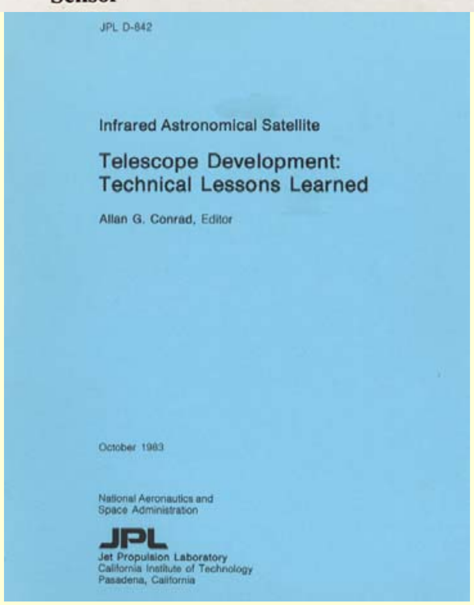
Mike Hauser

(with special thanks to Jim Houck, Gerry Neugebauer, George Helou, Erick Young, and Michael Rowan-Robinson)

May 28, 2009

IRAS Taught us Many Lessons




JPL D-842

Infrared Astronomical Satellite

Telescope Development: Technical Lessons Learned

Allan G. Conrad, Editor

October 1983

National Aeronautics and Space Administration

JPL

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

- Surveys from space
- The dewar
- Cryogenic focal plane assembly/electronics
- Cryogenic optics
- Data
- Science operations
- Legacy
- Final thoughts

The Sky Survey Experiment

THE AFCRL SKY SURVEY:

Supplementary Report
to the
Joint Scientific Mission Definition Team
for an Infrared Astronomical Satellite (IRAS)

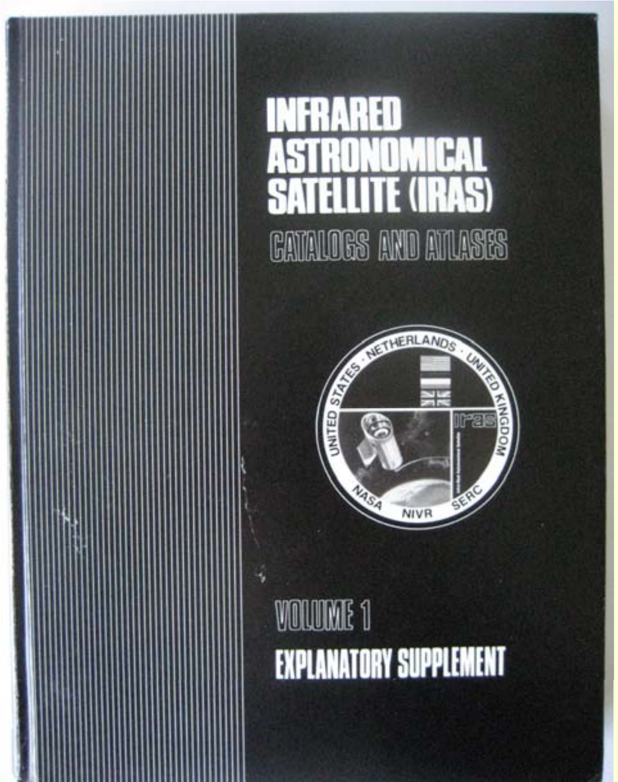
June 1976

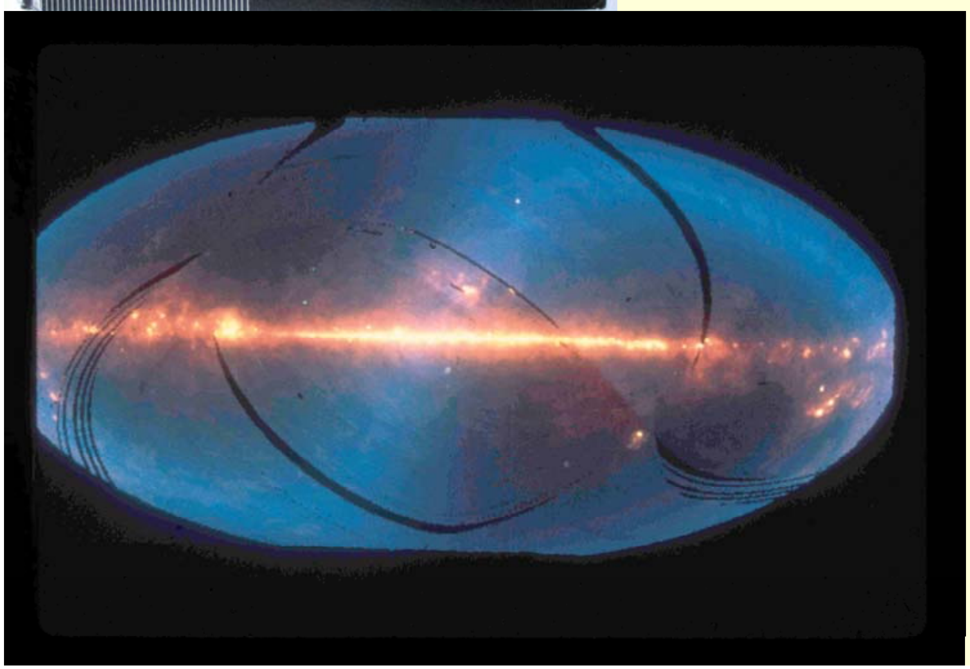
M.G. Hauser, F.J. Low, G.H. Rieke, and S.D. Price

- Ground-based Two Micron Sky Survey provided complete and reliable catalog
- Early IRAS study: is complete, reliable infrared astronomical sky survey from space feasible?
- Study motivated by confirmation problems with AFCRL Catalog
- Reviewed experience with AFCRL rockets (4, 11, and 20 μm)

The Sky Survey Experiment

- AFCRL Survey Study Report recommendations:
  - Results should be presented with clear definition of detection criteria, confidence, cautions for use
  - Survey design and data processing must provide intrinsic self-confirmation on scales of seconds, hours, weeks, months
  - Preserve noise in data to develop reliable detection criteria
  - Quality assurance requires human examination of data as well as machine processing
  - Instruments must be shielded from stray light
  - Shield detectors and design electronics to minimize effects of energetic particle radiation
  - Maintain payload cleanliness to minimize ‘detections’ of particulates
- Study conclusion: no fundamental obstacles to a high sensitivity, high reliability, unbiased survey of IR sky from a space telescope

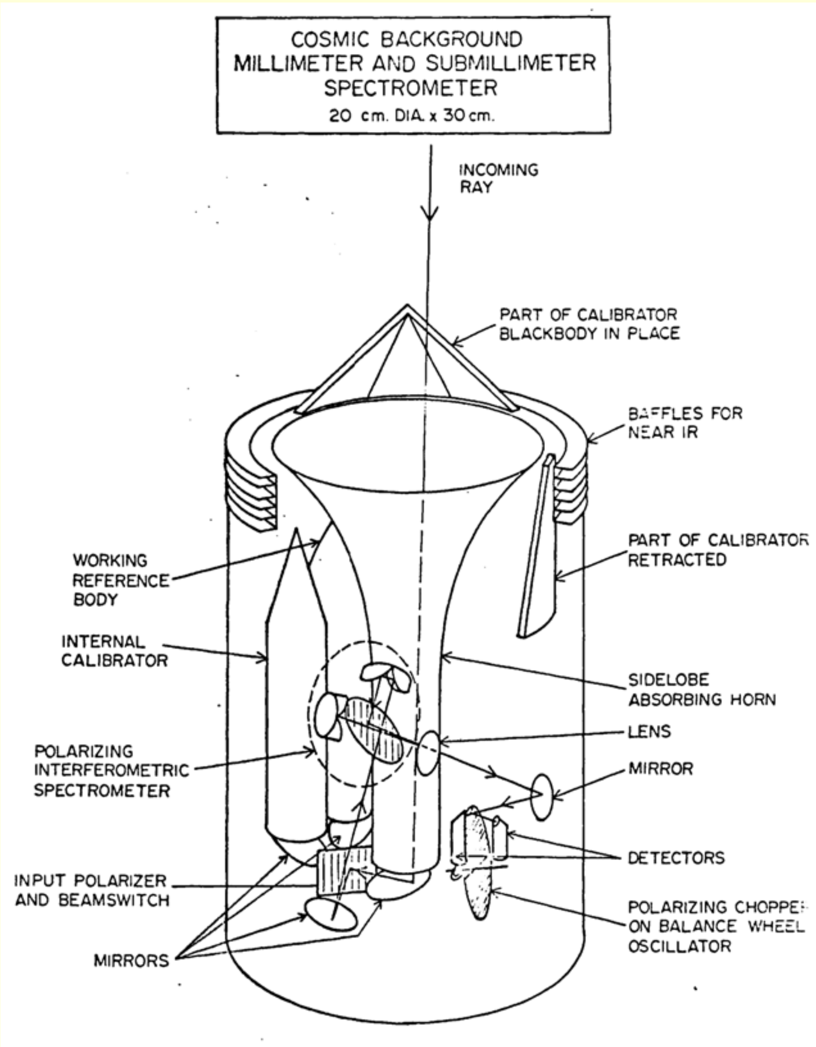




The Sky Survey Experiment

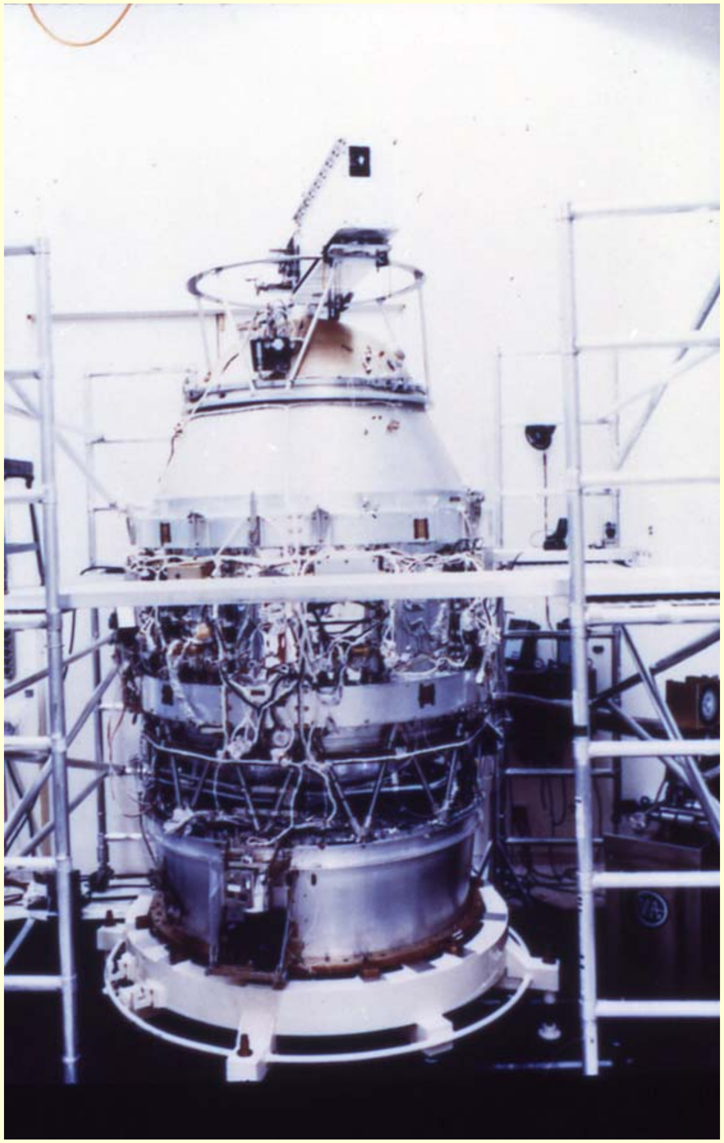
- Lesson Learned: rigorous implementation of all AFCRL Sky Survey Report recommendations yielded IRAS science of outstanding quality

Diversion: The CMB Spectrum Experiment



- Rai Weiss and John Mather included on initial IRAS study team to measure CMB spectrum
- Designed an instrument
- Concluded would compromise both IR survey and CMB spectrum measurement
- NASA initiated COBE study instead
- **LESSON: When attempting something impossible, resist the urge to add complications!**

The Dewar Experiment



- No prior technology for few Kelvin space instrument
- Porous plug for superfluid He containment developed by Selzer, Fairbank, Everitt (1971): it worked, but must be carefully designed
- R&D test dewar built by BBRC (it leaked; NASA proceeded)
- Cryogenic valves, wiring harness, SFHe top-off were challenges
- Flew the protoflight dewar

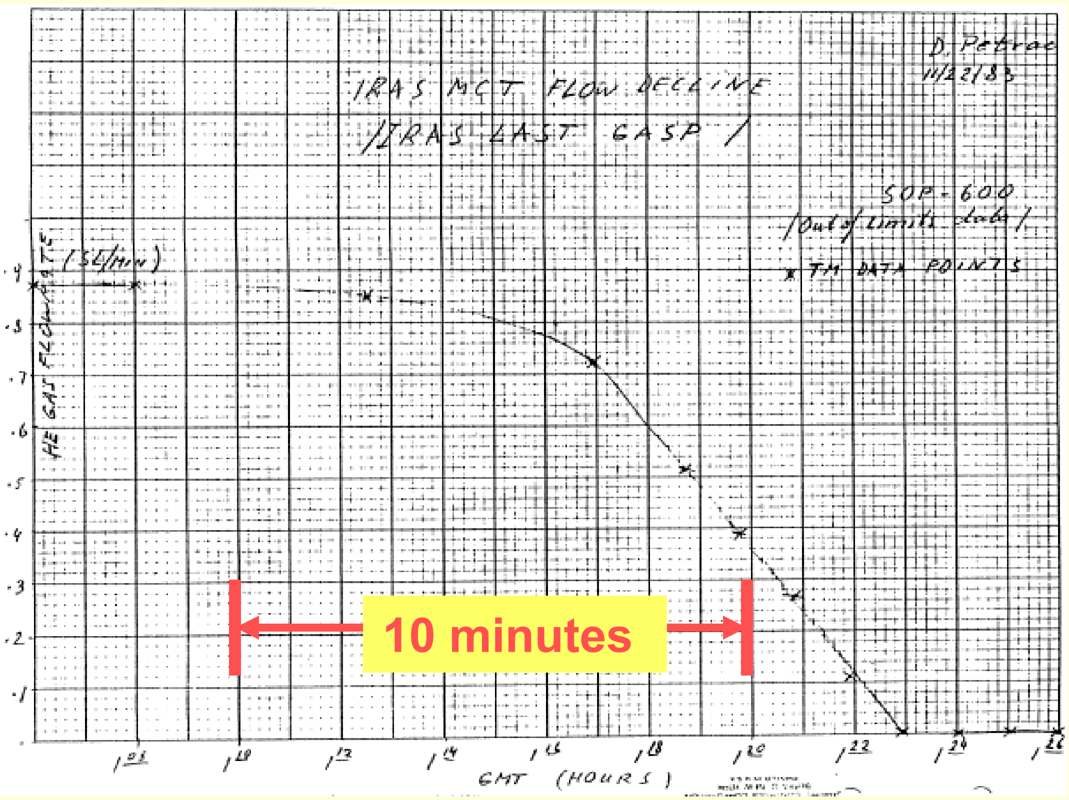
"Containing the LHe in zero g was a source of anguish throughout the mission. I think there were no previous successful porous plugs in space. " (Jim Houck)

The Dewar Experiment

- Leak in cover O-ring found just before launch
  - Concern: ice might prevent dewar cover ejection
  - Gillett argued strenuously for warm up, Project Manager refused (he got lucky!)
    - **"…only time I saw Fred get really upset." (Jim Houck)**
- Thermal vac test results indicated short dewar life
  - NASA Deputy Administrator opposed launch
  - Others argued it was a test condition anomaly, and launch was approved (we got lucky!)
- Flowmeter not a reliable He mass monitor
  - Predicted lifetime 345 days post-launch
  - Actual lifetime 300 days: need a better mass monitor

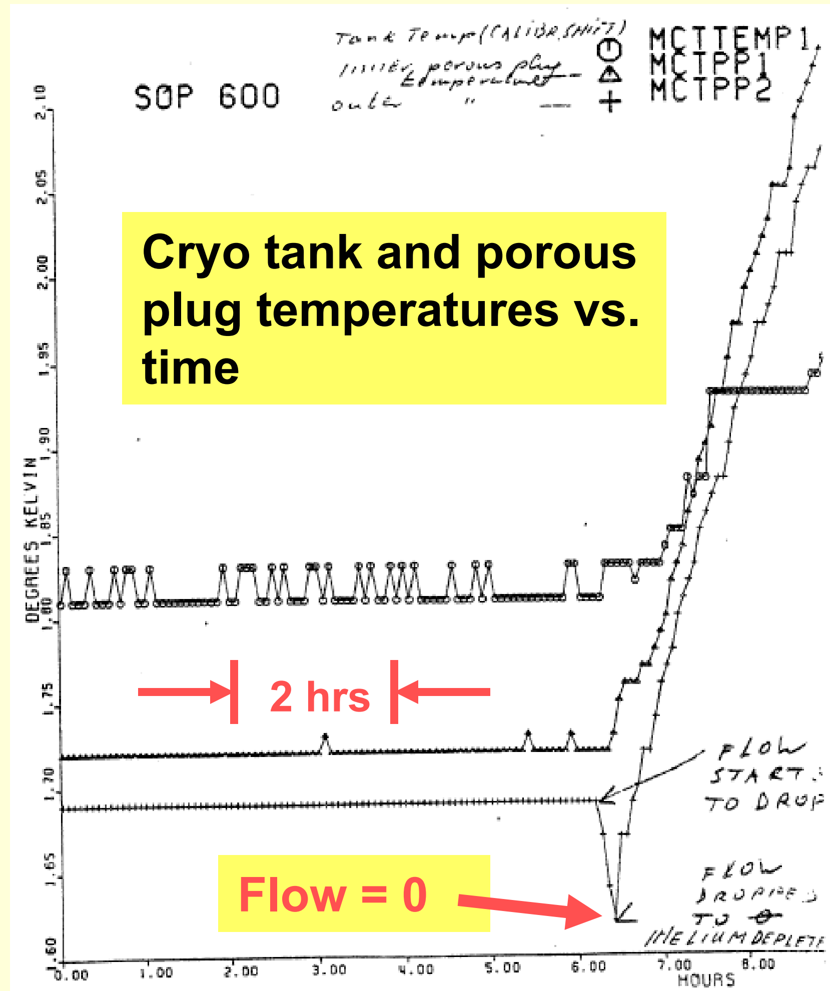
The Dewar Experiment (Finis)

November 22, 1983 (SOP 600)



Helium flow rate vs. time:

"IRAS LAST GASP"



Cryo tank and porous plug temperatures vs. time

The Dewar Experiment: Lessons Learned

"The IRAS Main Cryogen Tank maintained the FPA (Focal Plane Assembly) at a nearly constant temperature until the liquid helium was depleted. The temperature control worked reliably

"IRAS 'demonstrated' that superfluid helium was the ideal choice of cryogen for the mission"

(D. Petrac to P. Mason, JPL Interoffice Memorandum, Nov. 29, 1983)

IRAS "Telescope Development: Lessons Learned" document (JPL D-842) includes 29 dewar recommendations for future missions.

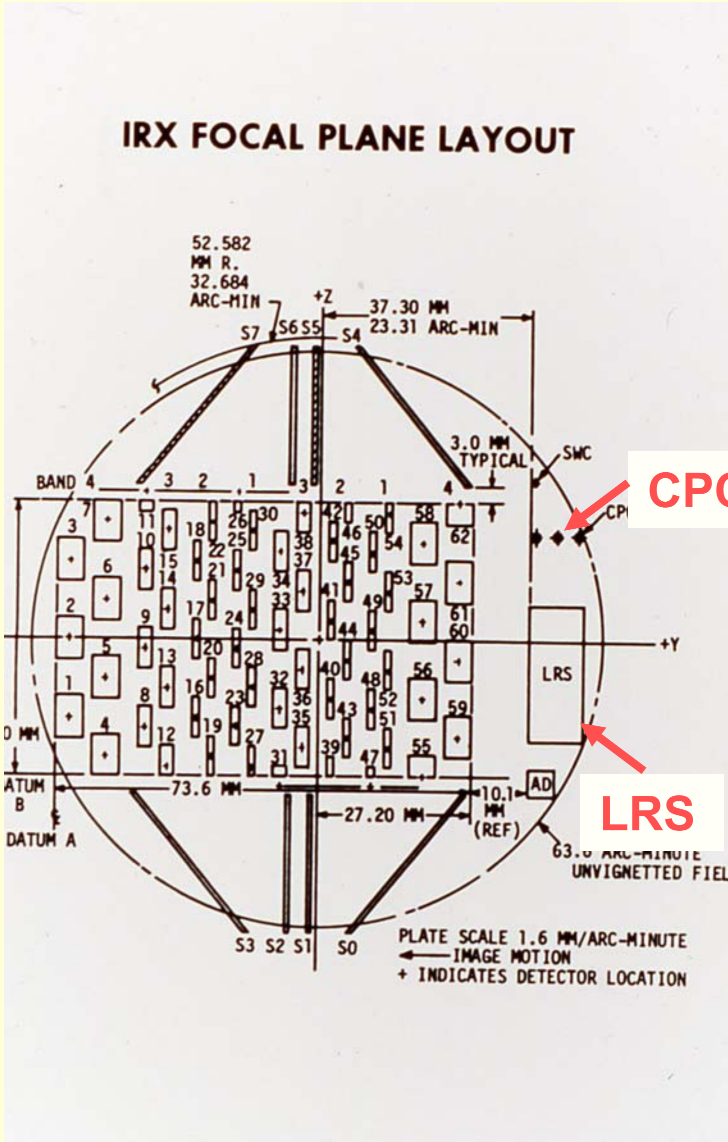
Legacy: COBE flew the IRAS flight model!

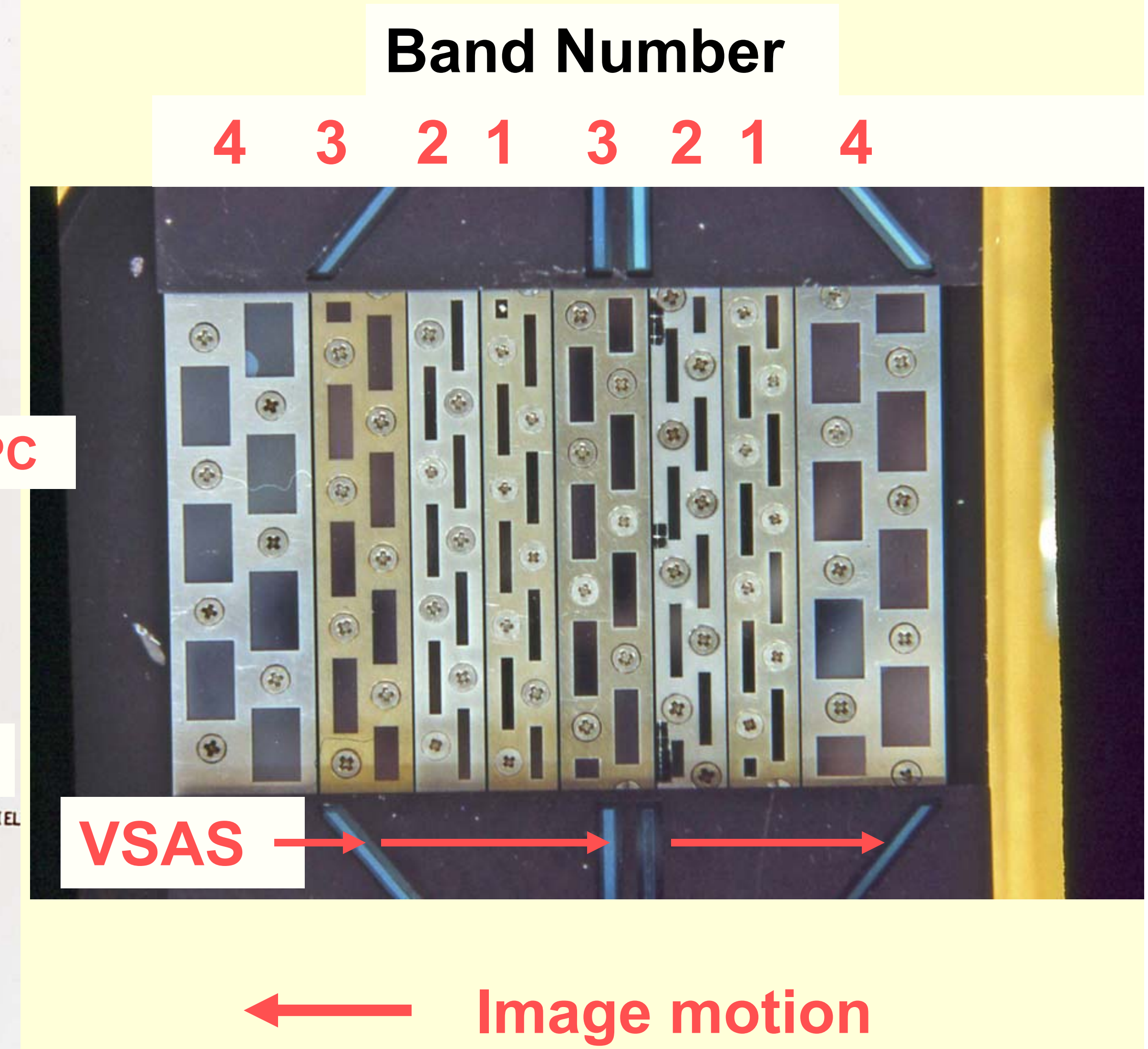
The Focal Plane Experiment

IRAS Detectors and Filters

Band	Number of Detectors	Detector Type	Bandpass (microns)	Filters
1	16	Si:As	8-15	BaF_2, Ge
2	15	Si:Sb	15-30	Si
3	16	Ge:Ga	48-81	Sapphire, KRS-5
4	15	Ge:Ga	87-118	Sapphire, CaF_2, KC1

The Focal Plane Experiment



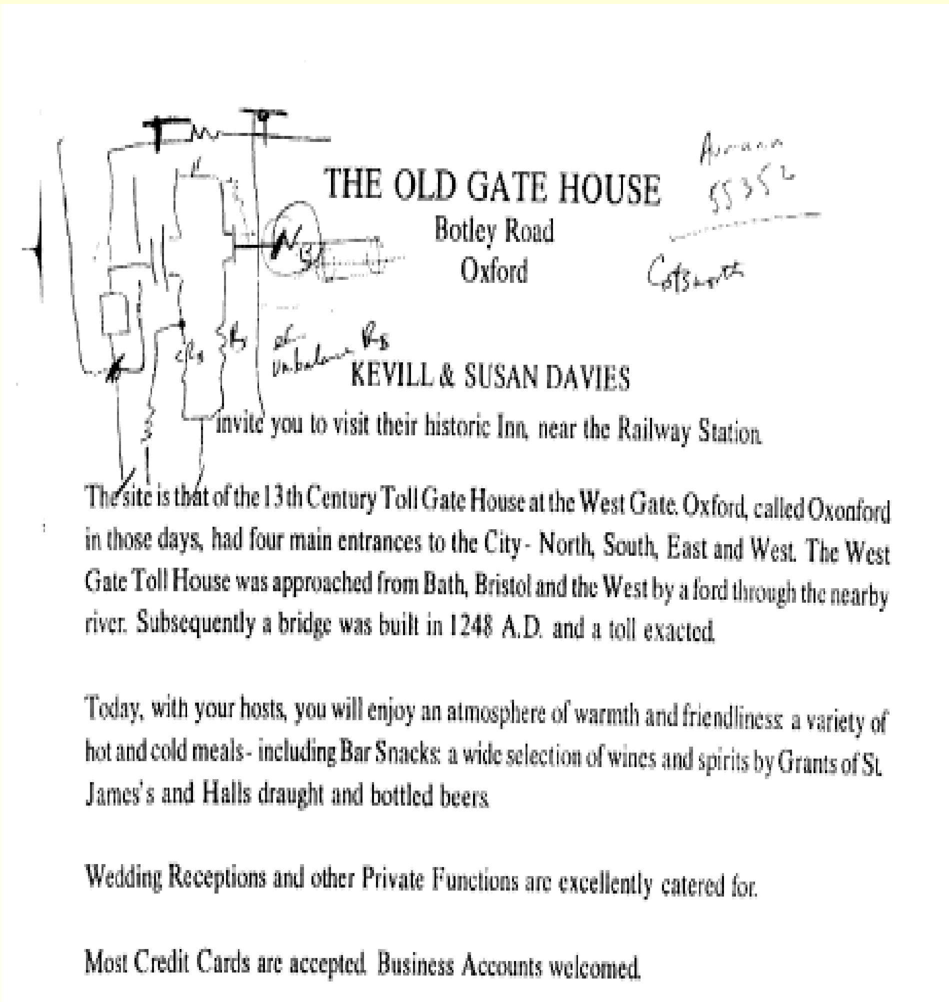


The Focal Plane Experiment: Detectors

"Major headache all the way" (Jim Houck)

- **Ge:Ga "the worst"**
  - **NRL did pioneering studies of Ge photoconductors**
  - **Ge:Be initial band 3 choice: "a bust"**
  - **Ge:Ga in flight focal plane from Rockwell had "woefully poor response" (Frank Low, ARAA 45)**
  - **Houck bought superior material (with no pedigree) from Eagle Pitcher for $20 and showed JPL how to build replacement detectors**
- **Si:As and Si:Sb had military heritage**
  - **Technology familiar to industry**
  - **Much test and performance information classified**
  - **NASA had to obtain DoD permission to use this technology**
- **Gillett, Houck, Low and Neugebauer intensively involved with Project, vendors, test labs throughout design/development of IRAS**

Focal Plane Experiment: Detectors



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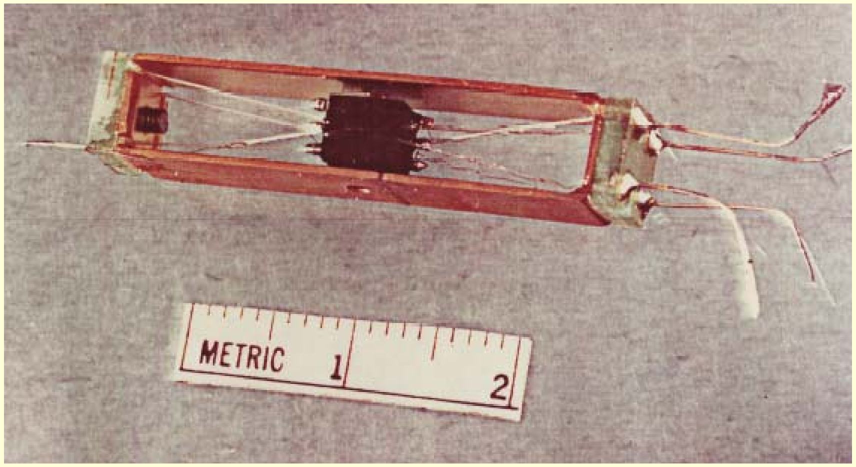
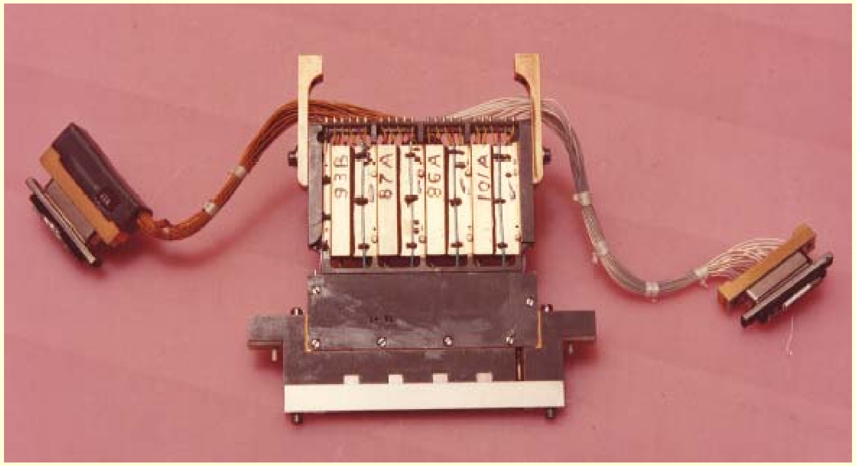
Houck sketch of solution

- Focal plane testing showed that one sub-array of Band 2 was dead: bias-line short to ground
- Houck invented rewiring approach
- Project skeptical, but tried it and it worked!
- Rewired sub-array better than the other one

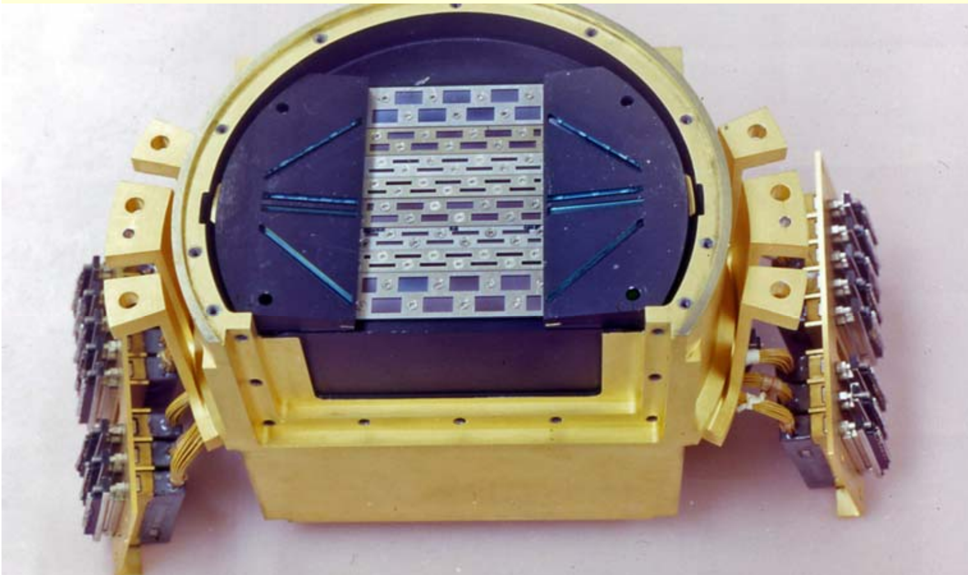
The Focal Plane Experiment: cold electronics

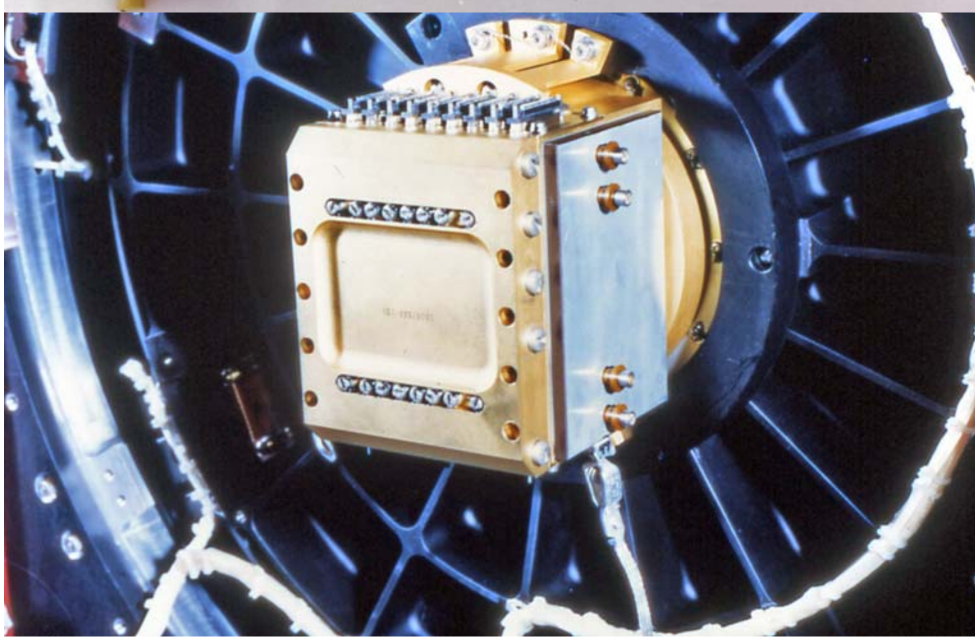




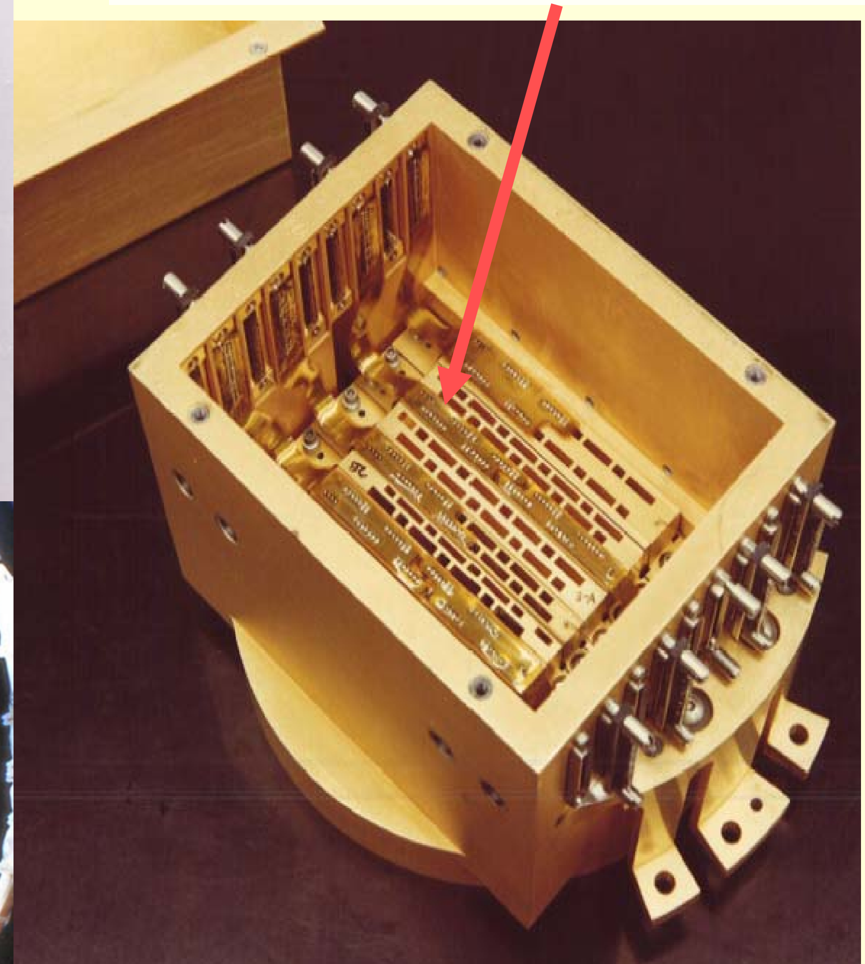
- IRAS designed and built with MOSFET cold preamps (TIAs)
  - MOSFETs had poor noise & stability; fragile (electrostatics)
- Low, Rieke & Rieke (assistance from Young, Gautier) developed cold JFET: Project refused to change
- Focal plane MOSFETs destroyed in test by electrostatics
- NASA HQ directed use of JFET preamps
- Preamps built by Low's company ("violated most traditional NASA flight HW guidelines but worked beautifully"—Erick Young)
- Improved survey sensitivity ~10X
- **Legacy: COBE and ISO adopted JFETs**

The Focal Plane Experiment: cold electronics





JFETs mounted in here

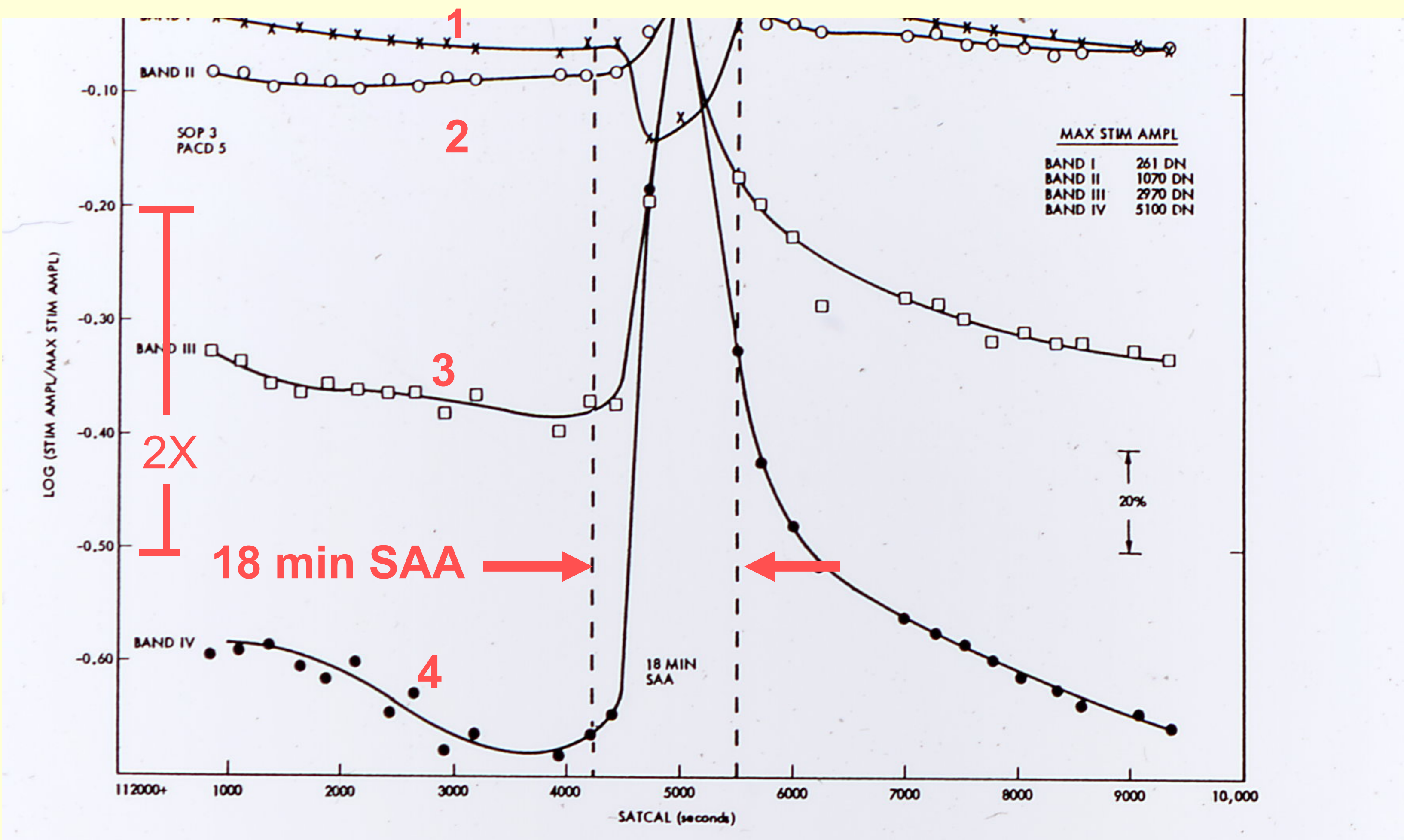


The Focal Plane Experiment: Radiation Effects

- IR detectors are good charged particle detectors
  - Electronic clamping circuit used to eliminate large pulses
- Late in development program, Nancy Boggess prodded science team to be sure that we understood nuclear radiation effects
  - **I found published article showing that the detector noise and responsivity were disturbed by a dose of ionizing radiation, with long recovery time at cryogenic temperatures**
- Thermal anneal not possible since focal plane already built with strong thermal contact to the cryogen tank
- Erick Young idea: bias boost might have same effect. Tests with γ-rays and protons confirmed this
- Technique essential to calibration of 60 and 100 μm data
- **Lesson Learned: test all effects of ionizing radiation under flight-like conditions**

The Focal Plane Experiment:
Radiation Effects with no bias boost

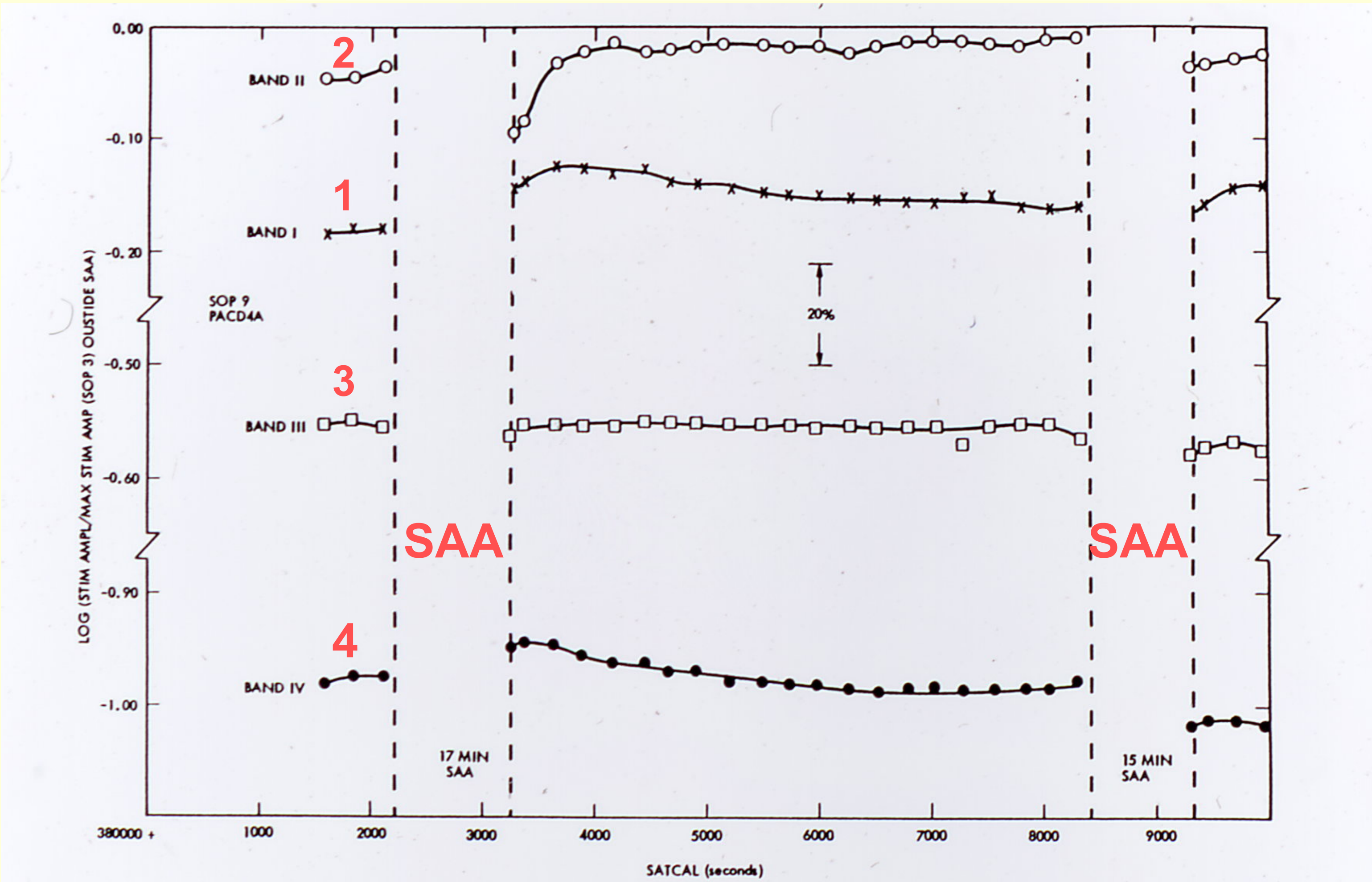
Log(relative response to stimulator) vs. time



SAA Effect on Detector Response Without Bias Boost

The Focal Plane Experiment: Radiation Effects with bias boost

Log(relative response to stimulator) vs. time



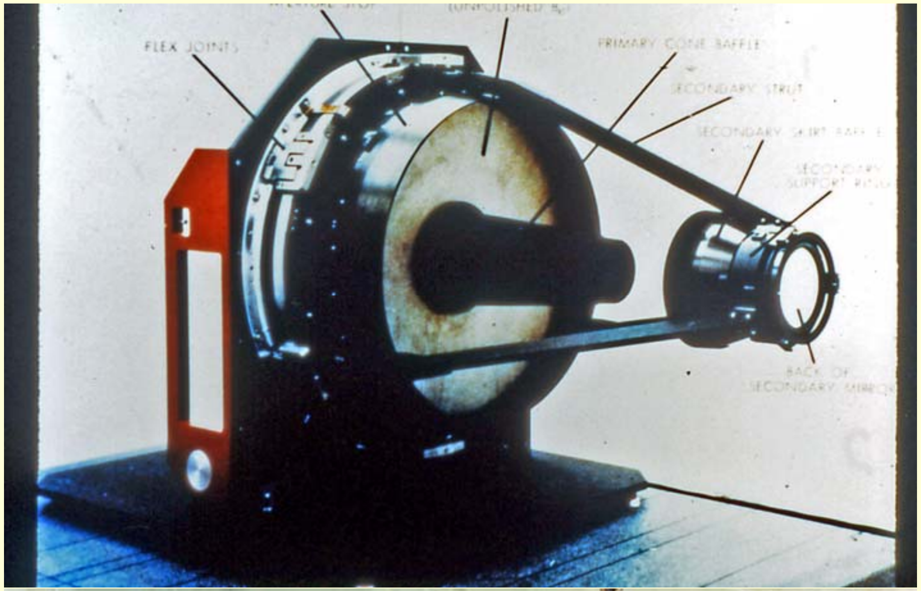
The Focal Plane Experiment: Filters

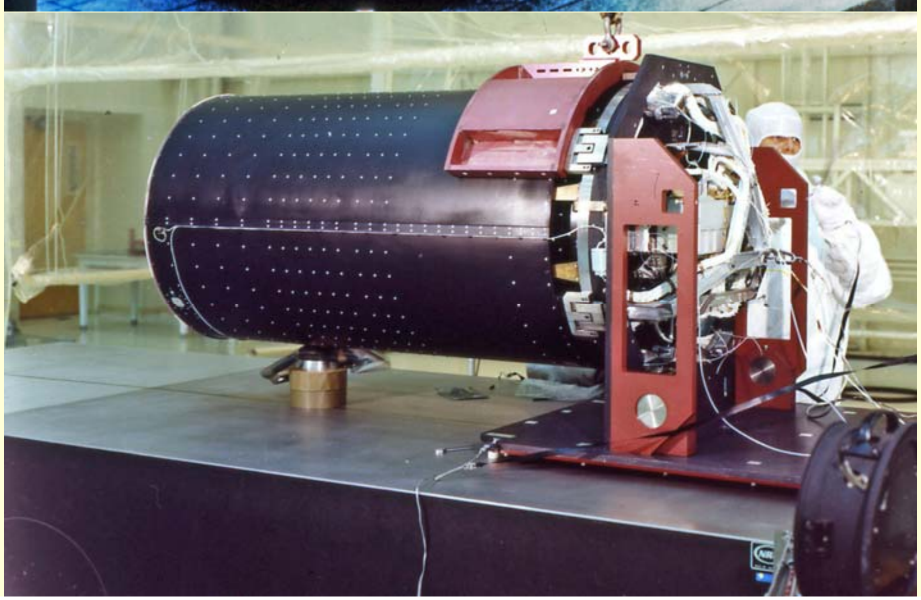
- Filters were difficult to get, especially for 60, 100 μm bands
- Gillett and Neugebauer did much of the filter design and testing
  - (comments from Jim Houck)

Focal Plane Experiment: Lesson Learned

- Flight focal plane delivered by Rockwell was essentially “a box of non-functional parts”
- JPL tiger team led by Bob White had to rebuild the focal plane
- Project succeeded largely because of close collaboration between engineering team and “amazing collection of infrared instrumentalists including Fred Gillett, Gerry Neugebauer, Frank Low, and Jim Houck”
- Concern: “…as missions are getting larger and more complicated, opportunities for instrumentalists to develop hands-on experience are getting rarer…”
  - (above quotes from Erick Young)

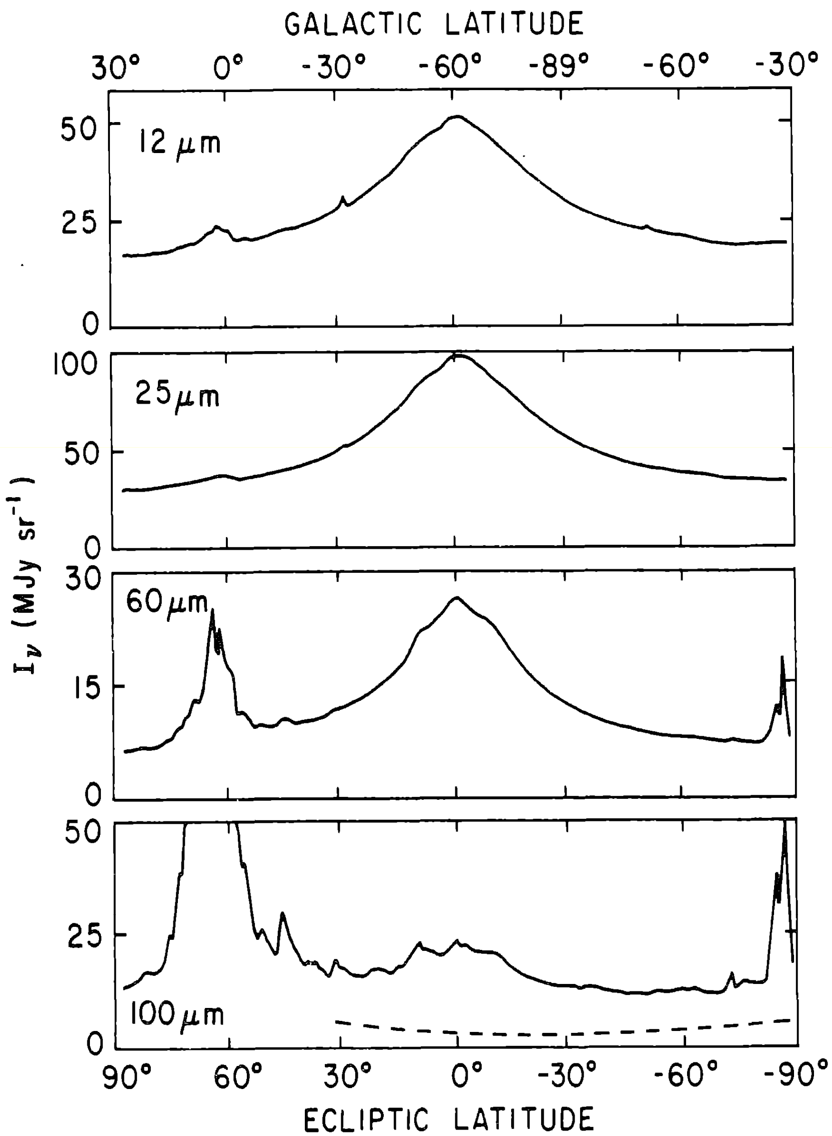
The Cryogenic Optics Experiment





- Mirrors were Be
- Cryo null figuring required
- Telescope alignment done at room temperature
- Focus laboriously checked at LN2 through thick quartz vacuum window by Houck
  - **“Fred told me on the day of the first down load that all the stars were donuts… I don’t think they had seen any data for a couple of hours after that.” (Jim Houck)**
  - **After allowing Jim time to worry, Fred told Jim the images were actually fine**

The Data Experiment



- Sample the data to the noise level
  - Permitted understanding of instrument data and extraction of full scientific value
- DC couple the electronics
  - Permitted extended source and image products
  - Allowed determination of absolute IR sky brightness, essential for future mission planning

The Data Experiment: Calibration

- **Primary point source standards: α Tau (12-60 μm) & asteroids (100 μm)**
- **Secondary (stability) standard**
  - **PRPR: NGC 6543 (Cat's Eye Nebula)**
- **DC brightness standard (TFPR): field near N. Ecliptic pole**
- **Legacy: IRAS discrete source calibration is widely used standard.**

The Data Experiment: Calibration

- **Broad band photometry**
  - **Report spectral intensities f_v at nominal wavelengths, assuming source spectrum vf_v = constant over IRAS band**
  - **Provided color correction tables for various source spectral shapes**
- **Legacy: IRAS approach has become standard**

The Data Experiment: Calibration

- **Lesson Learned: IRAS detectors were far from ideal photometric devices**
  - Non-linear
  - AC/DC responsivity differences
  - Excellent nuclear radiation detectors
  - Slow to recover from nuclear radiation exposure
  - Slow to recover from strong IR exposure (photon induced responsivity enhancement)
- **Lesson Learned: Complex calibration data processing system and extensive Explanatory Supplement required**

The Science Operations Experiment

- **Science data processing complex, formally engineered, planned from beginning of study phase**
- **Emphasis on completeness and reliability of catalog**
- **Goal: rapid dissemination of high quality data products to whole community**

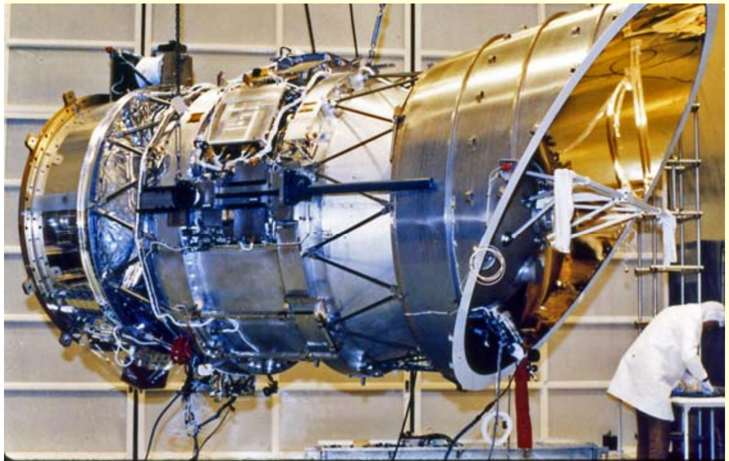
- **Lessons**
  - **Availability of instrumental scientists to guide the operations and data reduction personnel was critical to scientific success**
  - **Continuing dedicated data center made products accessible to broad community of non-experts**
  - **Difficult to plan observations and process data from non-standard "additional observations"**
    - **Gael Squibb introduced Astronomical Observation Templates in ISO, continued in Spitzer**

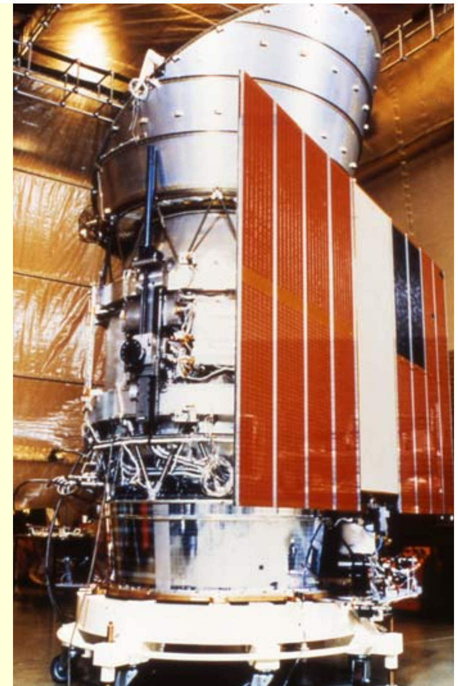
The Science Operations Experiment

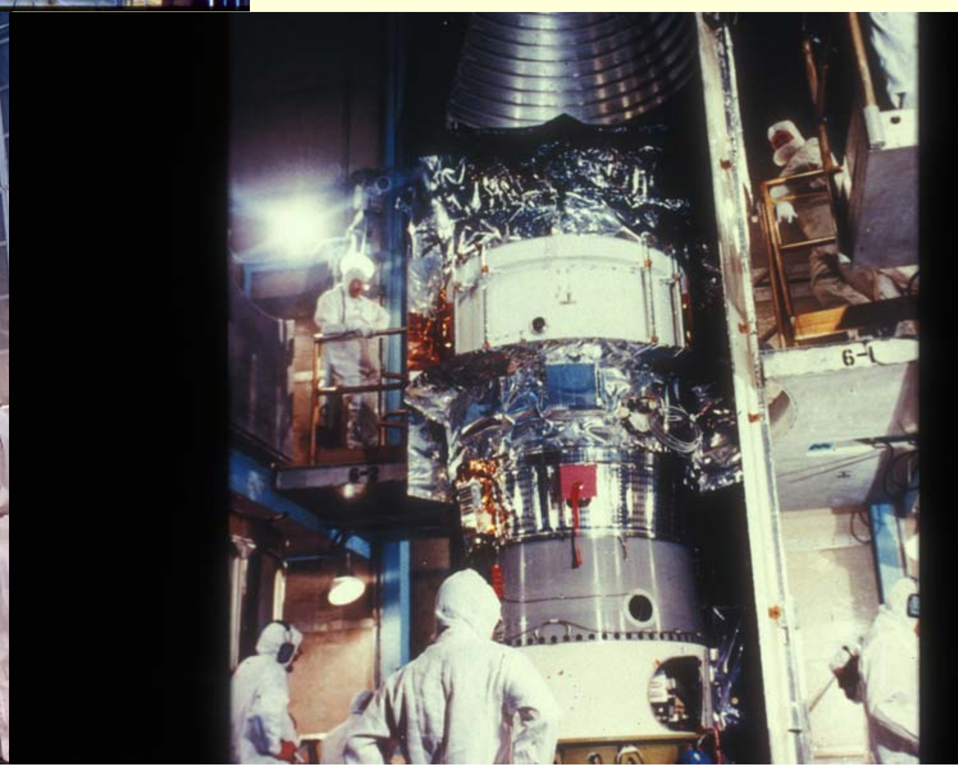
- "IRAS was interesting data processing model
  - professional software engineers, with little direct interest in the science of the mission, developed a full data processing system prior to launch
  - after launch a small group of scientists worked with these engineers to try to tune the parameters of the system
  - some parts of the system better than others
- **The confirmation strategy of the IRAS PSC was certainly a strong influence on my subsequent work with ISO, Spitzer, and Akari… I always wanted to see the direct link from the time-lines to the final source catalogues which we used so effectively in IRAS"**

Comments from Michael Rowan-Robinson

Bringing it all together

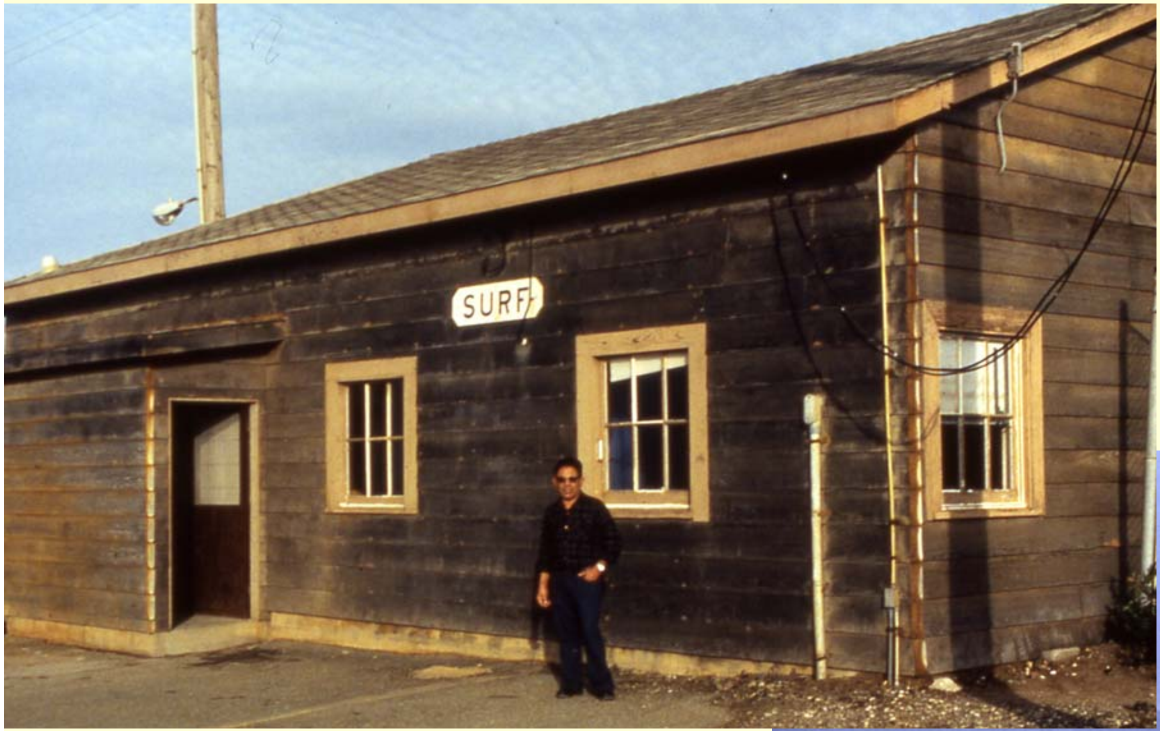




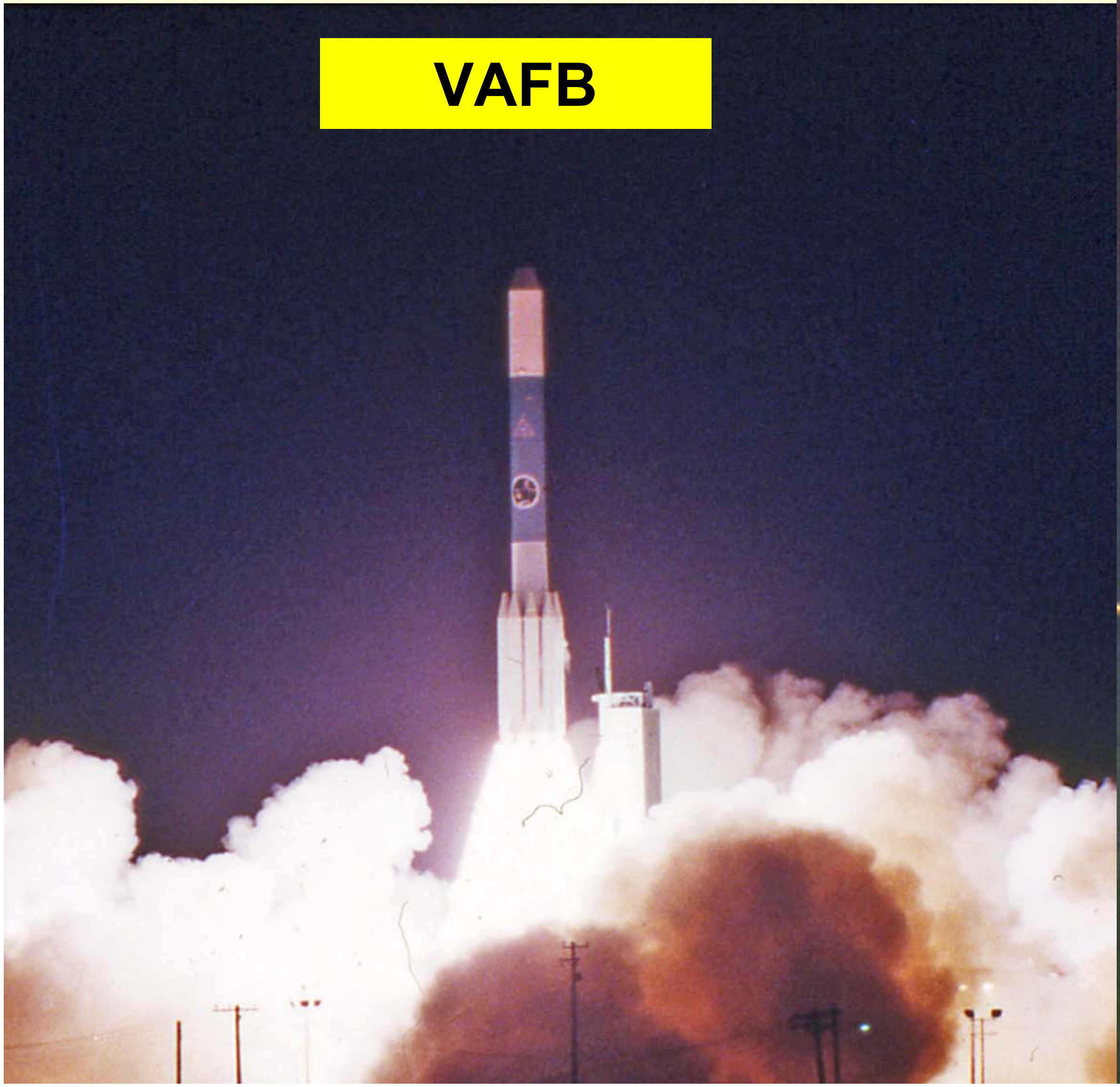


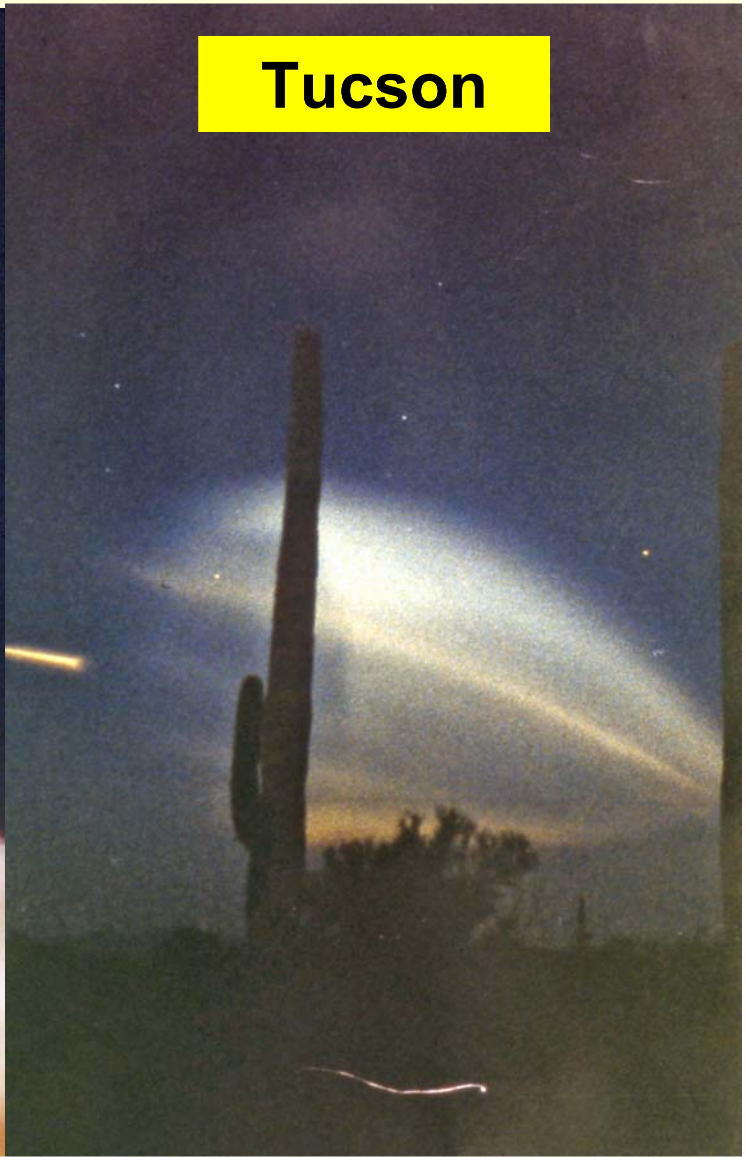
Launch Day--VAFB

Launch Day--Surf

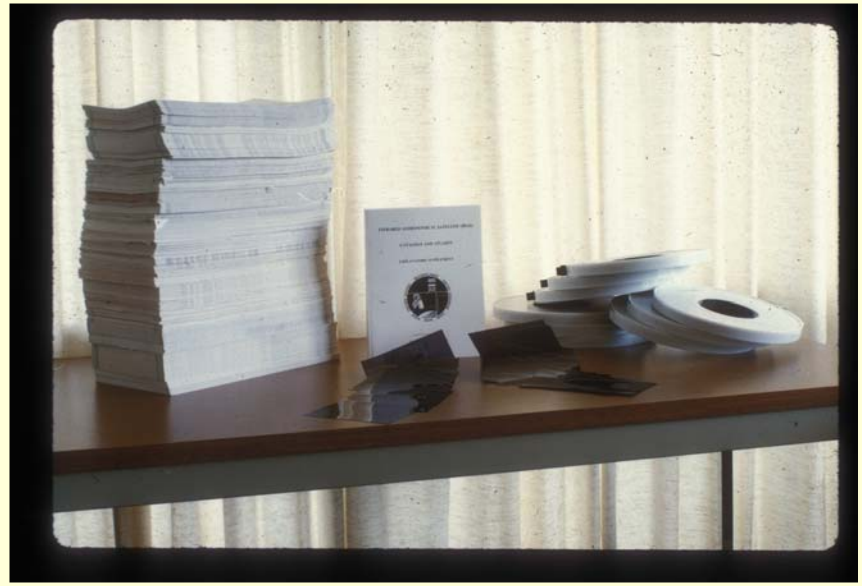


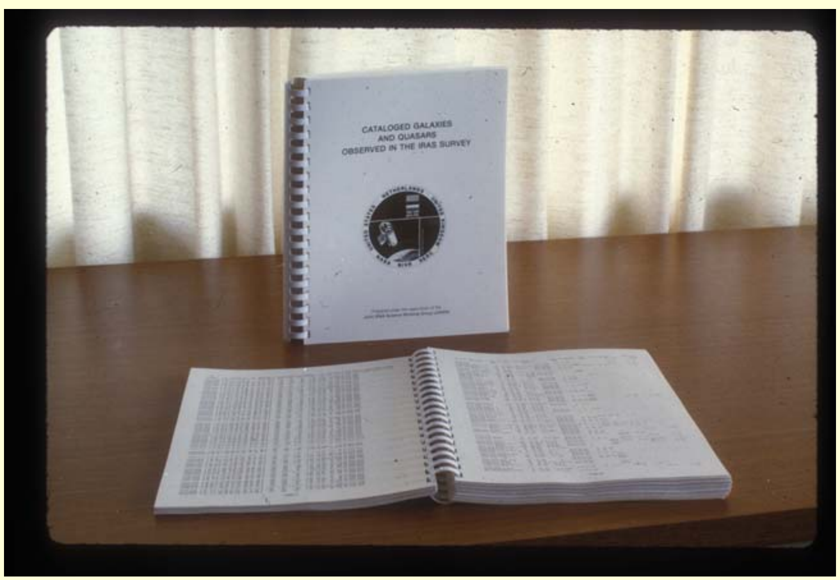
Launch!



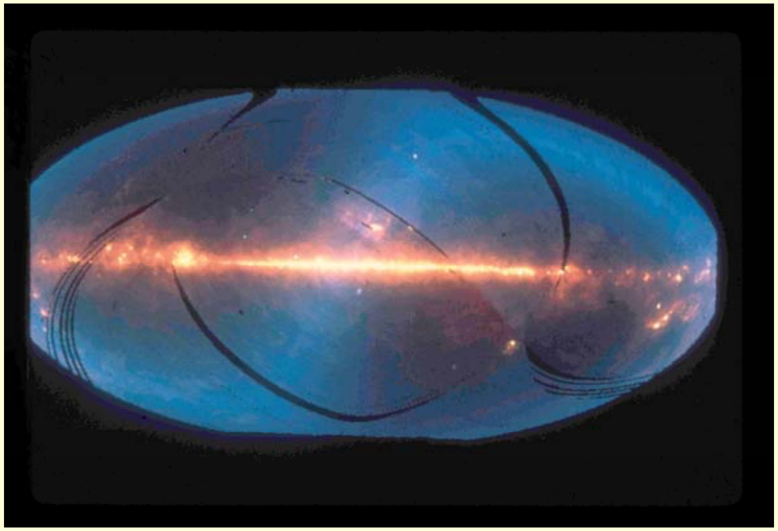


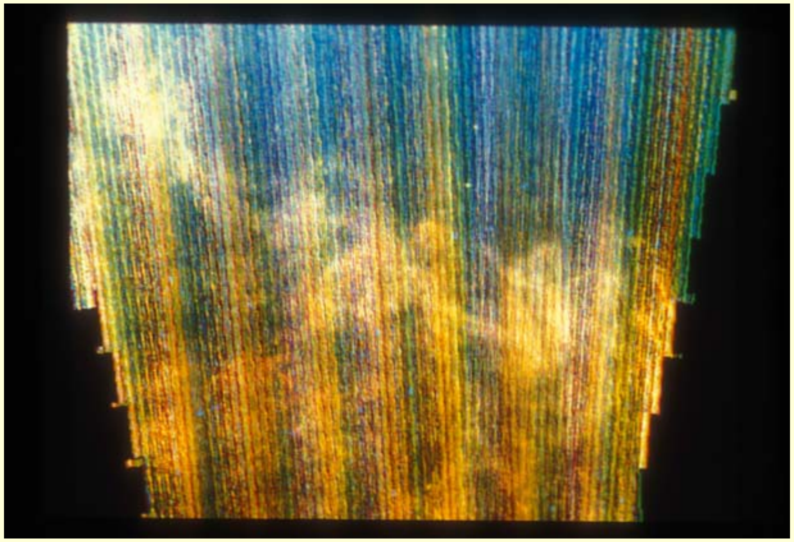
The IRAS Legacy





The Infrared Sky Legacy





- IRAS showed us the whole infrared sky for the first time
- Brightness of interplanetary dust, 3:1 plane-to-pole ratio, seasonally varying
- Brightness of galactic plane
- Brightness, patchiness of ISM, “infrared cirrus”

•IRAS Legacy: Essential information for subsequent IR mission planning

The Joint IRAS Science Working Group

G. Neugebauer	Co-chairman	1977-1984
R.J. van Duinen	Co-chairman	1977-1982
H.J. Habing	Co-chairman	1982-1984

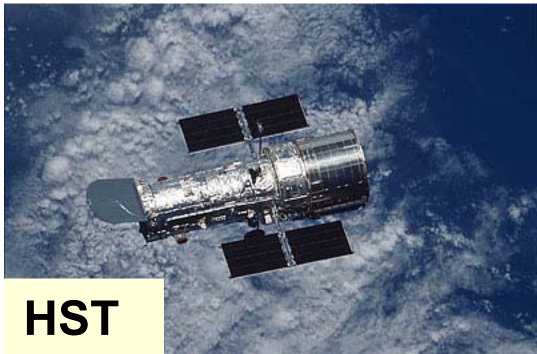
H.H. Aumann	T. de Jong	P.R. Wesselius
D.A. Beintema	F.J. Low	B. Baud
N. Boggess	P.L. Marsden	C.A. Beichman
J. Borgman	S.R. Pottasch	T.N. Gautier
P.E. Clegg	B.T. Soifer	S. Harris
F.C. Gillett	R.G. Walker	G.K. Miley
M.G. Hauser	J.P. Emerson	F.M. Olnon
J.R. Houck	E. Raimond	E. Young
R.E. Jennings	M. Rowan- Robinson	

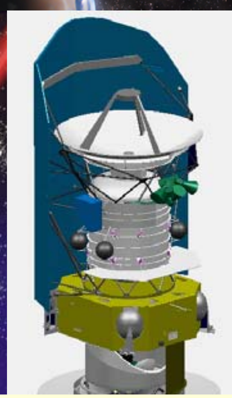
US IRAS Science Working Group

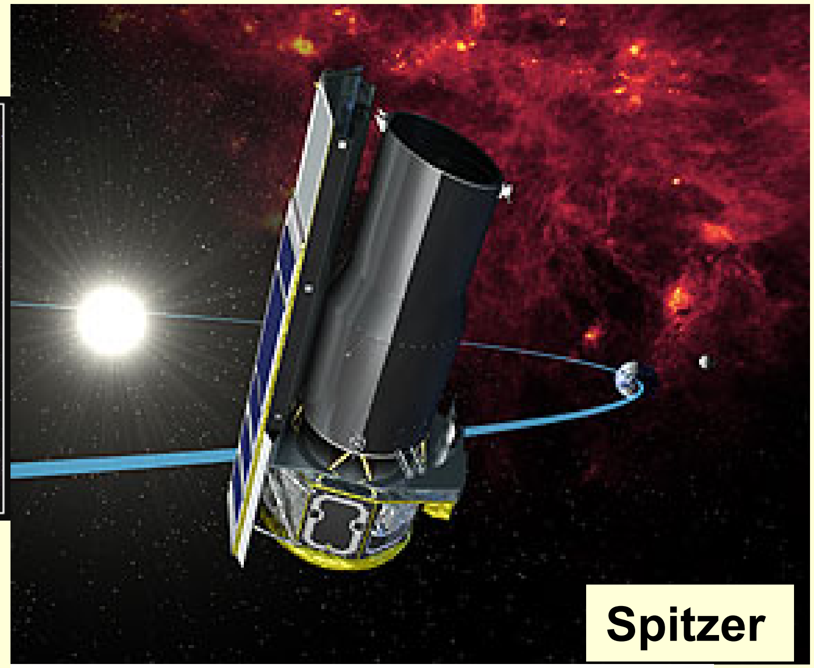
Missing: Nick Gautier

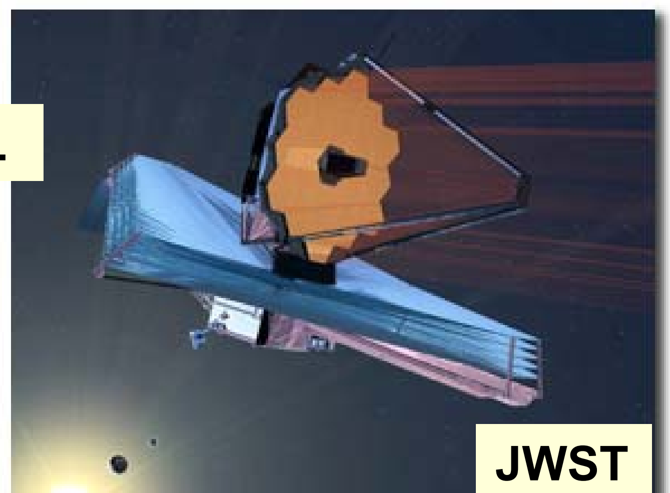
IRAS people – L+25 years

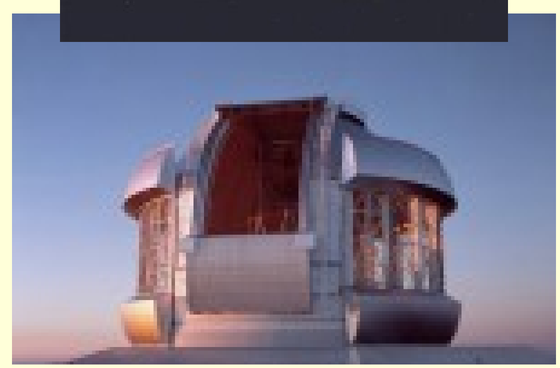
The IRAS Legacy











Fred Gillett Telescope

IRAS Lessons Learned: Final Thoughts (1)

- **IRAS technology advances in space and on the ground established the foundation for space infrared astronomy**
- **"Although it's not strictly technological, I hope you will emphasize how important it was that scientists with experimental expertise like Fred, Frank, Jim, and you worked with, in fact led, the engineers on all the different aspects of IRAS both technological and scientific."** (Gerry Neugebauer)
- **An intimate connection between engineers and expert instrumental scientists in the design, development, testing, operations and data processing is critical for scientific success**
  - **Scientists need suborbital opportunities to develop such expertise (ground, aircraft, rockets, balloons)**

IRAS Lessons Learned: Final Thoughts (2)

- **Learn from your predecessors (e.g., Two Micron Sky Survey and Lessons from AFCRL Survey Study Report)**
- **Develop critical technology before flight development begins**
- **Involve the science operations/data center from an early phase of the mission**
  - **Science operations will take more effort than you can imagine: consult experts at the planning/budgeting stage**
- **Capture and preserve 'Lessons Learned' during and immediately after the mission**
- **Take pictures of the people from the start of any great enterprise**


IRAS Technology
That's all, Folks!