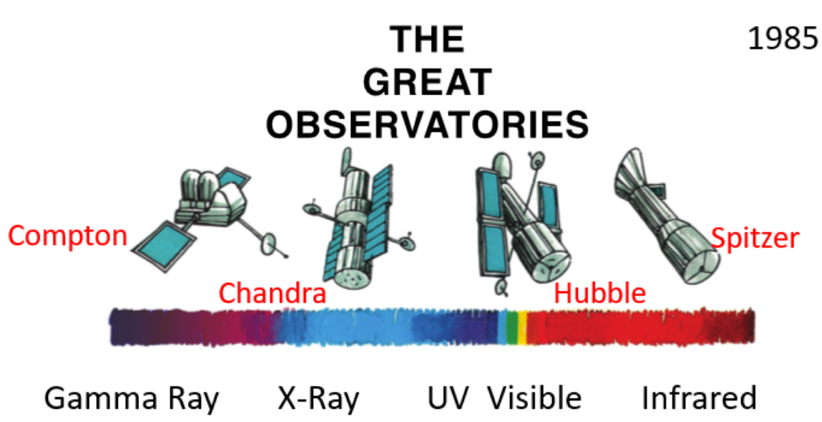
Technical Performance of the Spitzer Space Telescope – What Every Young Project Scientist Should Know

Michael Werner
Spitzer Project Scientist
JPL/Caltech
Presented to IRSIG of NASA's CoPAG
May 4, 2021



Motivation

Spitzer (2003-2020) was a great scientific success but also pioneered technical innovations, including radiative cooling in a orbit distant from Earth, the extensive use of infrared arrays, both cryogenic and warm mission phases, etc.

Rather than rely on faulty and aging memories or a collection of results spread over numerous obscure and inaccessible journals, we have gathered the key technical results most likely to be of use to future mission planners into a single paper, to be submitted to JATIS.

We hope that this will be as much a part of Spitzer's legacy as will be the many great scientific advances the observatory produced

Co-authors: Patrick Lowrance, Tom Roellig, Varoujan Gorjian, Joseph Hunt, Matt Bradford, Jessica Krick…thanks also to Paul Finley from Ball Aerospace

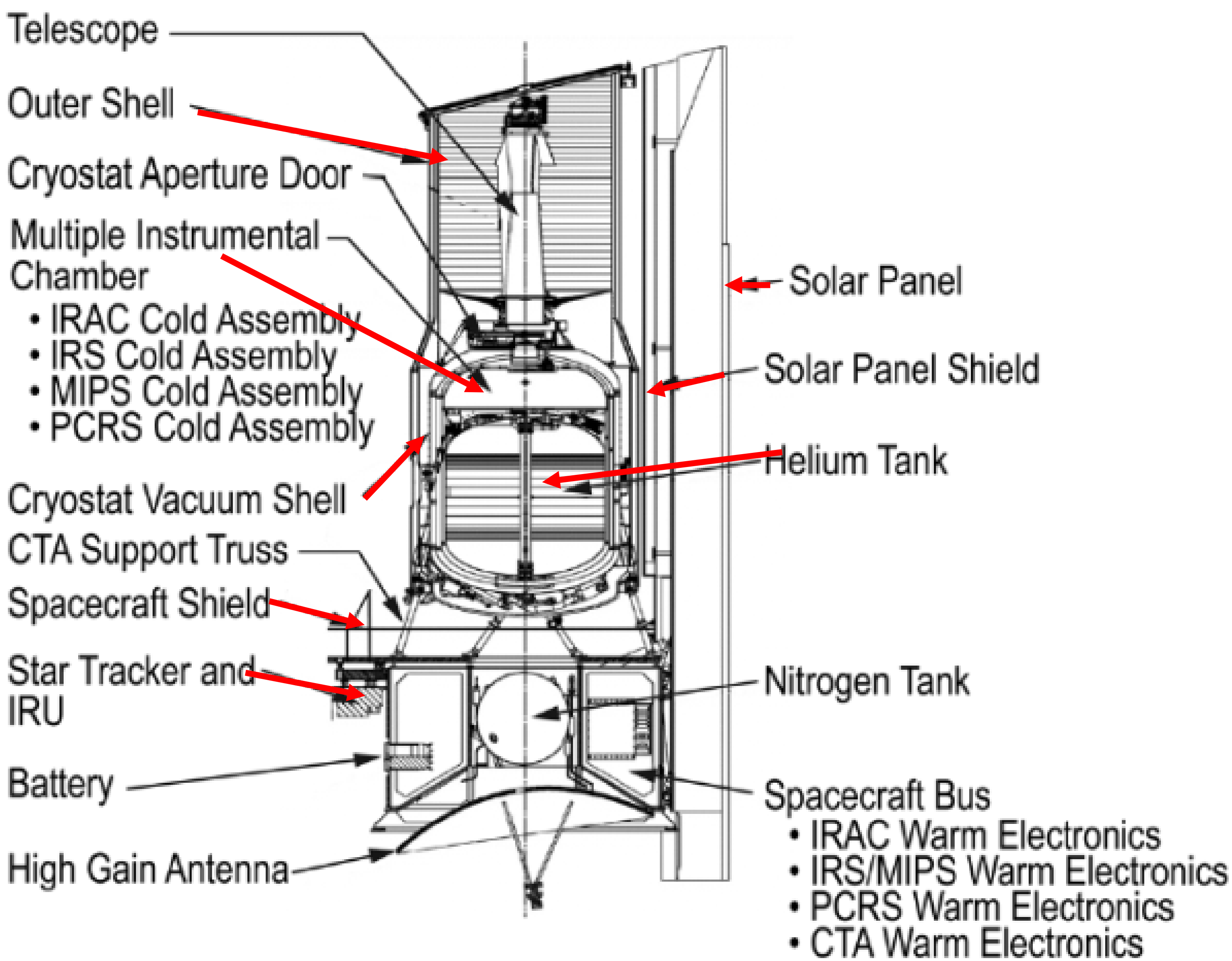
Jet Propulsion Laboratory
California Institute of Technology

TABLE OF CONTENTS

Note that we have been selective rather than comprehensive. Operational innovations in particular have been given short shrift. Much technical performance data is given in paper by Gehrz et al (Rev Sci Instruments, 2007) see also https://spitzer. caltech.edu
.

Jet Propulsion Laboratory
California Institute of Technology

Spitzer cutaway view



Spitzer undergoing system level thermal vac testing at LMMS, Sunnyvale. This figure features key elements of the radiative cooling approach

Solar panel

Solar Panel Shield

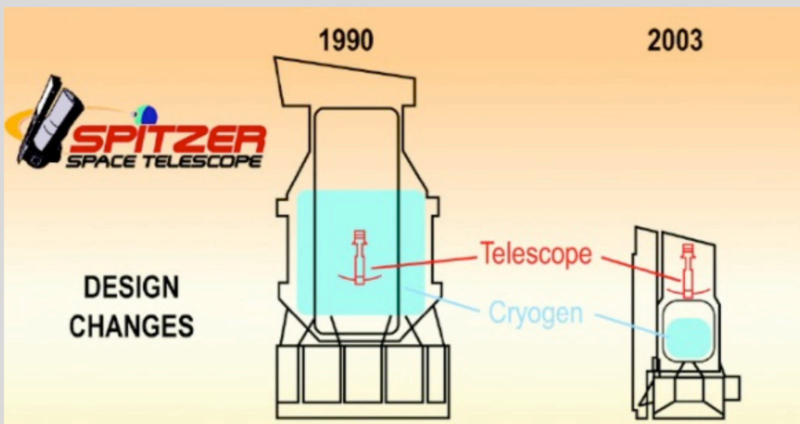
Outer shell with black anti-solar hemisphere

Spacecraft and spacecraft shield

Fixed antenna

Jet Propulsion Laboratory
California Institute of Technology

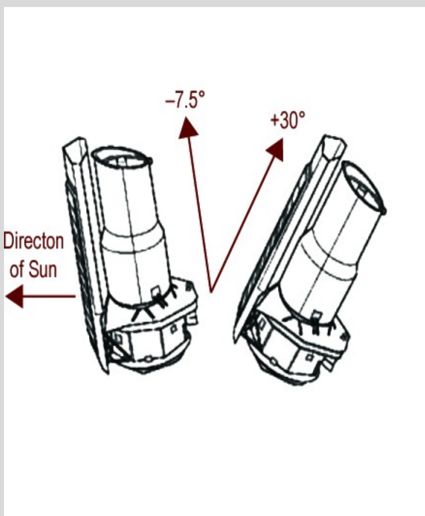
Spitzer’s warm launch, radiatively cooled thermal architecture was a sharp departure from previous cold launch systems and allowed us to fit into the cost and LV constraints imposed by NASA. It was very compatible with the solar orbit, which allowed us always to use the solar panel both as a sunshade and a power source. <u>Importantly, it also enabled the Warm mission, starting mid-2009, with the IRAC 3.6 and4.5um channels</u>

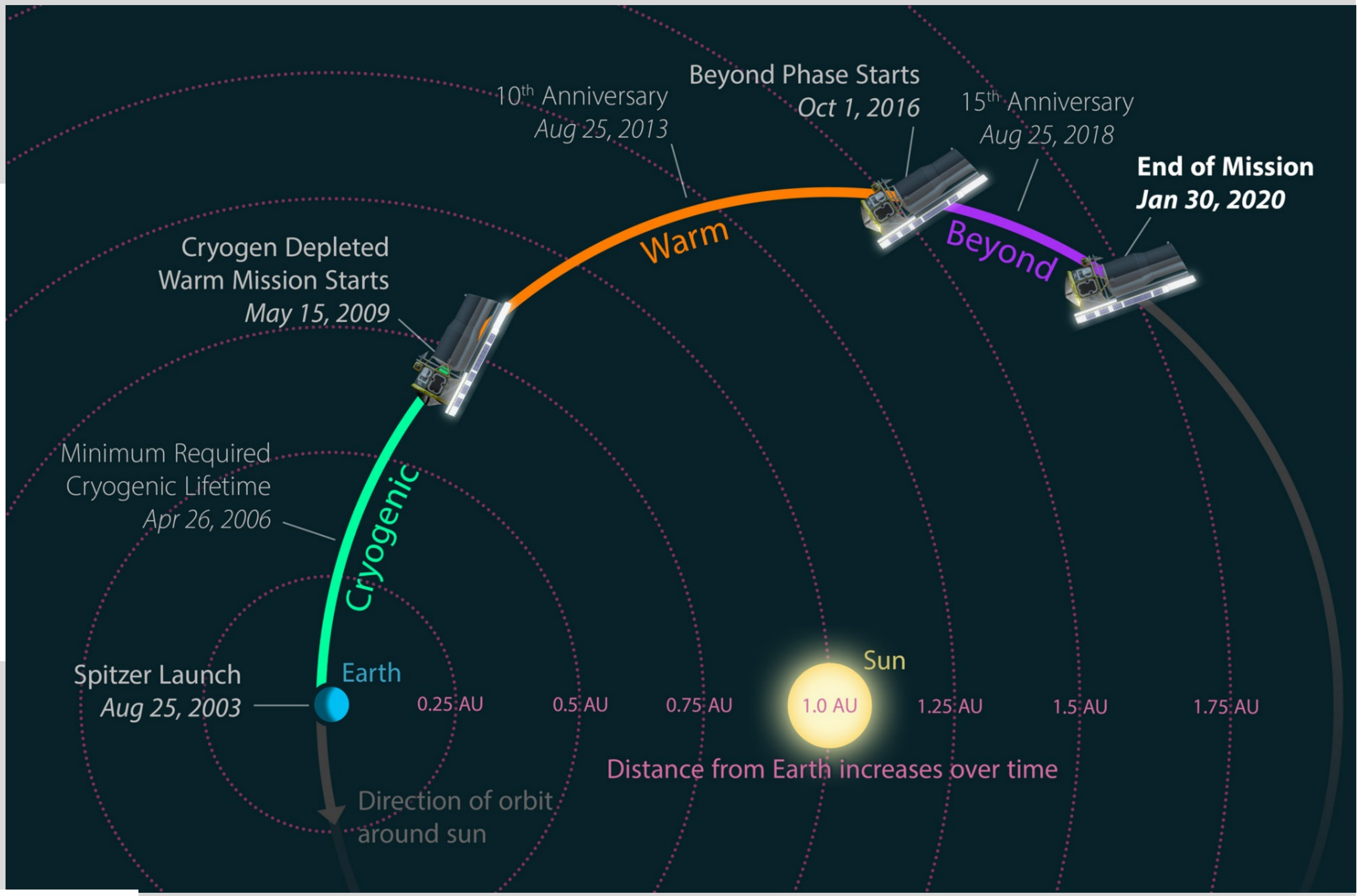


	COLD LAUNCH	WARM LAUNCH
Launch Mass	5700 kg	870 kg
Lifetime	5 years	5 years
Development Cost	$2.2B	$0.67B
Launch Vehicle	Titan IV	Delta

Bottom line: Spitzer’s Cryo mission lasted 2030 days and consumed 42.5 Kg of liquid helium, boiling off 0.24 mg/s, corresponding to a heat load of 5.1 mW. This was almost entirely due to power dissipated at the focal plane By contrast, IRAS, operating in low Earth orbit with a warm outershell, used 71 Kg of liquid helium in its ten-month mission. Its helium utilization was dominated by parasitics

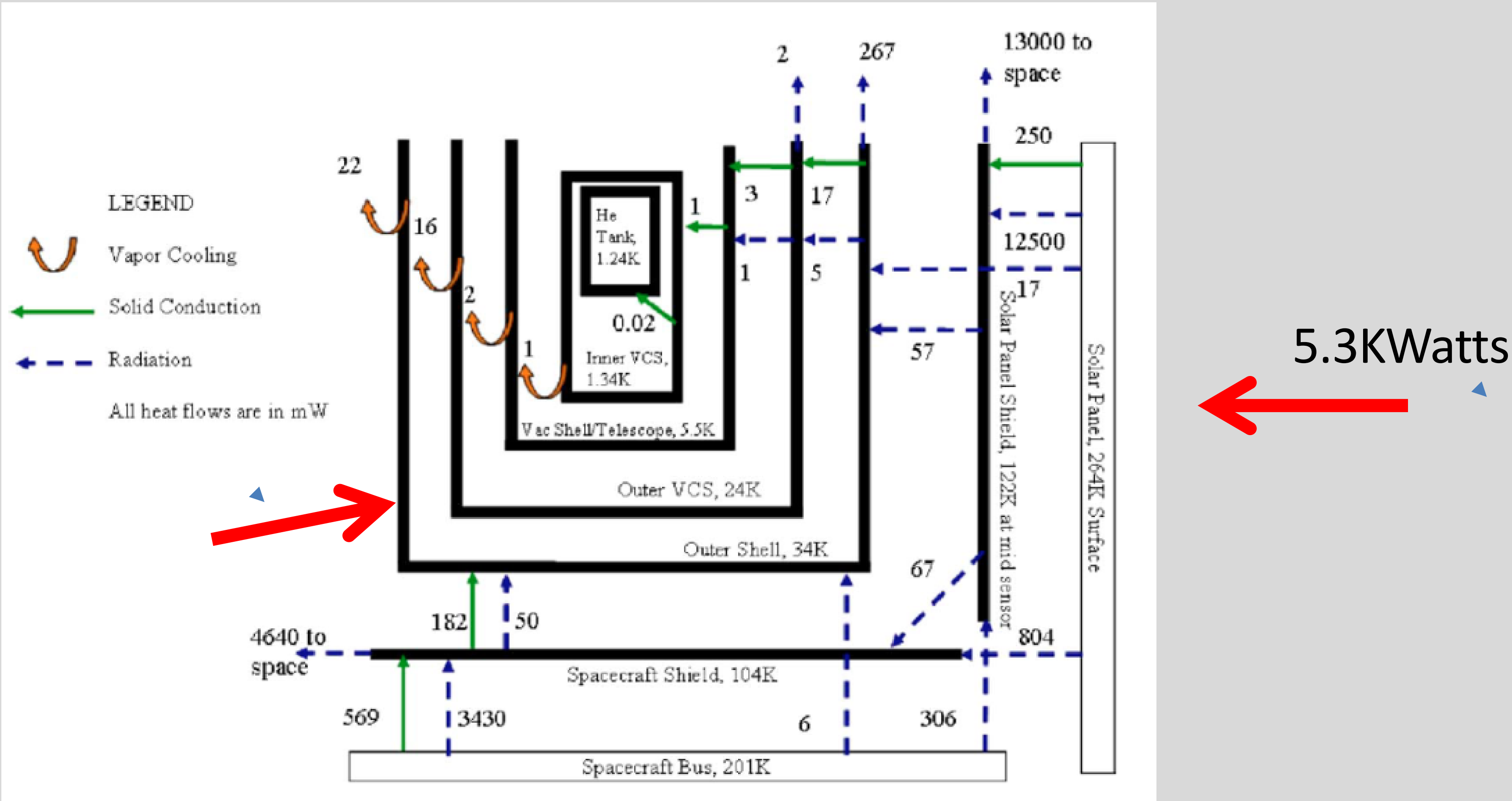
Spitzer viewing constraints – the solar panel as a sunshade. All power energizing and heating Spitzer comes through solar panel until late in the mission





Jet Propulsion Laboratory
California Institute of Technology

A Heat Flow Diagram is very helpful in explaining the performance of a complex thermal system. This one applies to Cryogenic Spitzer

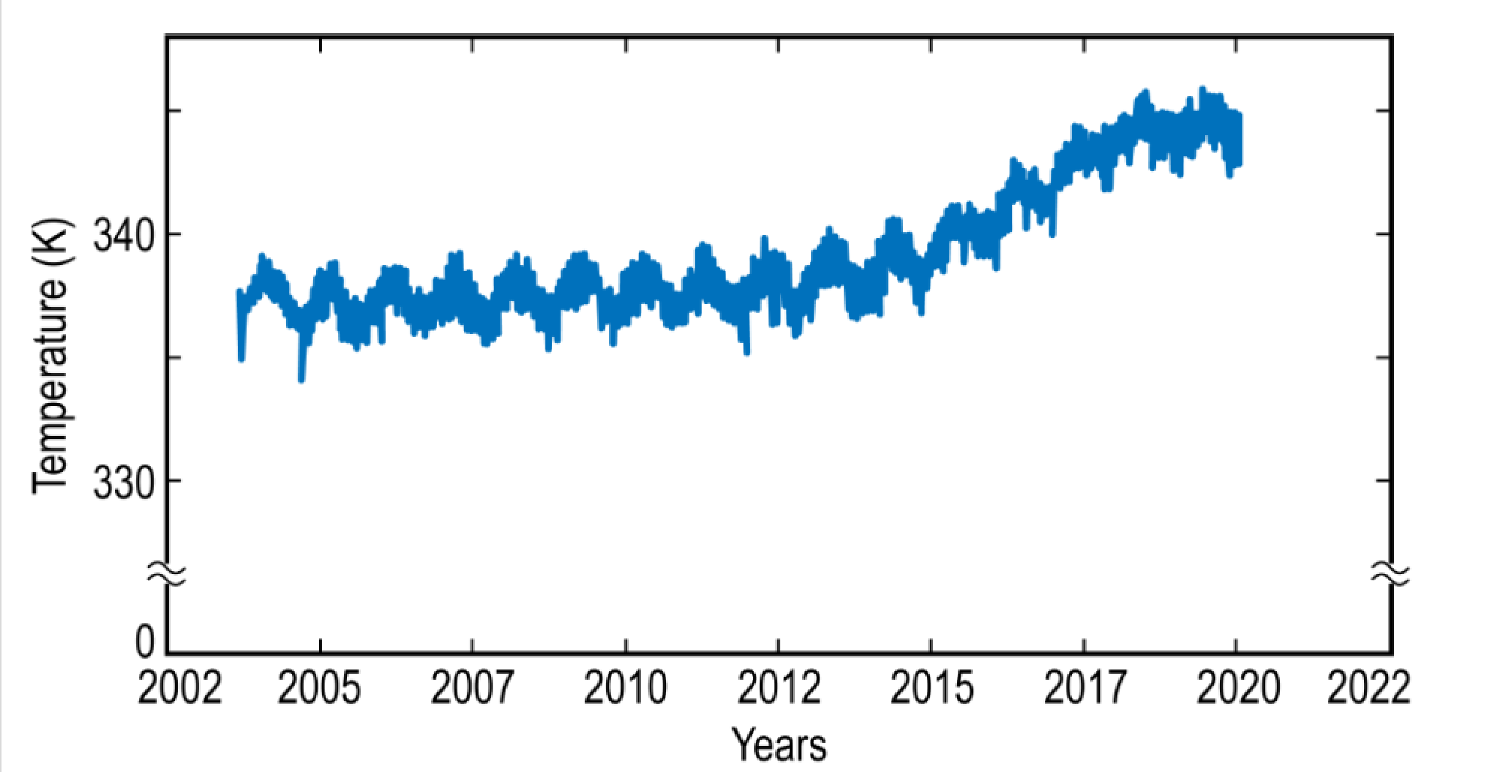


5.3 Kwatts of solar power incident from the right. Fewer than 500 mW get to the outershell, which is a 2x10 ft cylinder.   Only **22mWatts** are conducted or radiated to the interior of the outer shell. A 273K blackbody radiates 30mW/cm2. This gives idea of efficiency of cryothermal design, difficulty of test, and precision of assembly. From Gehrz et al, 2007

Jet Propulsion Laboratory
California Institute of Technology

Spitzer Solar Panel Temperature vs Time

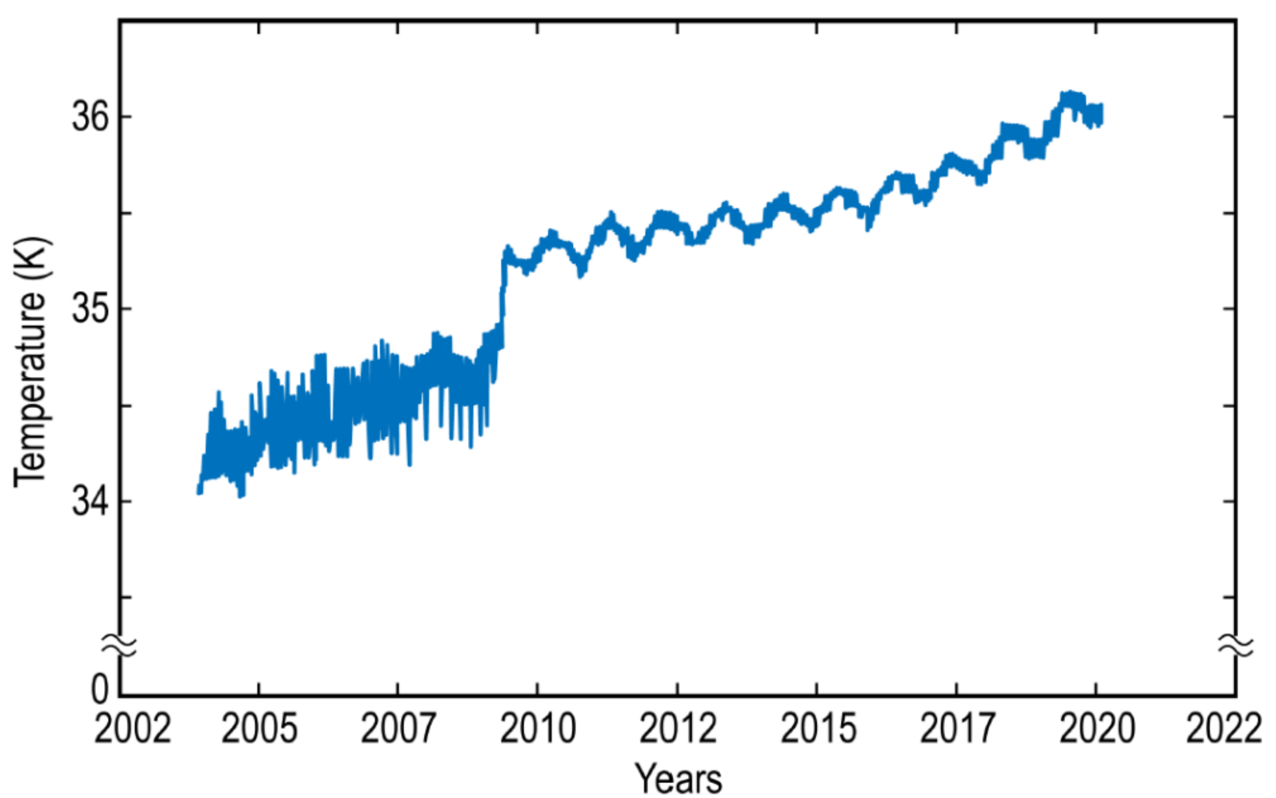
Increase in temperature means more power absorbed and transported inward to outer shell. Absorbed power increased by about 7% over 16 year mission. Modulation due to orbital eccentricity clearly seen



This is the temperature measured for the lower, active portion of the solar panel where the solar cells are mounted. Temperature rise attributed to degradation of optical materials in ultraviolet and cosmic ray environment

Spitzer Outer Shell Temperature vs. Time

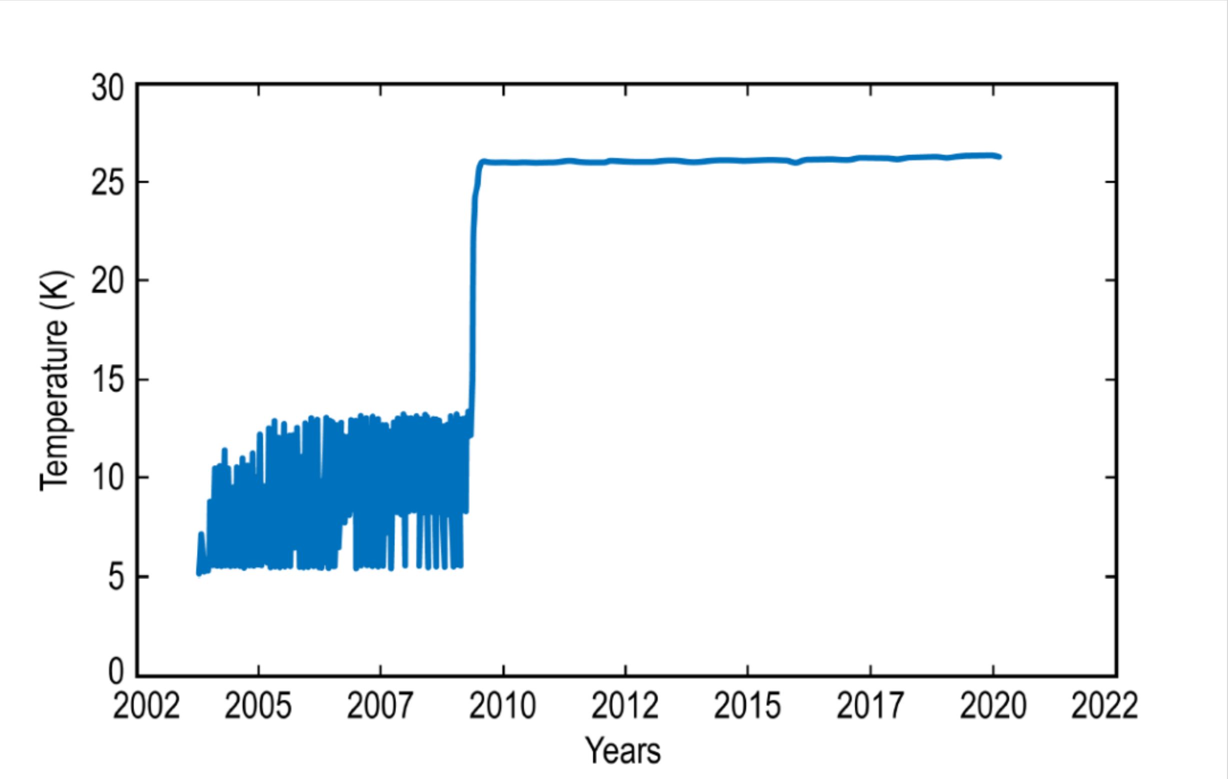
Increase in temperature means more power transported inward to telescope, esp. as vapor cooling no longer in effect after mid-2009. increase in heat input to outershell was about 13% over 16 years



Discontinuity in 2009 due to transition to warm mission and loss of vapor cooling. Fluctuations prior to 2009 due to adaptive helium utilization.

Spitzer Telescope Temperature vs. Time.

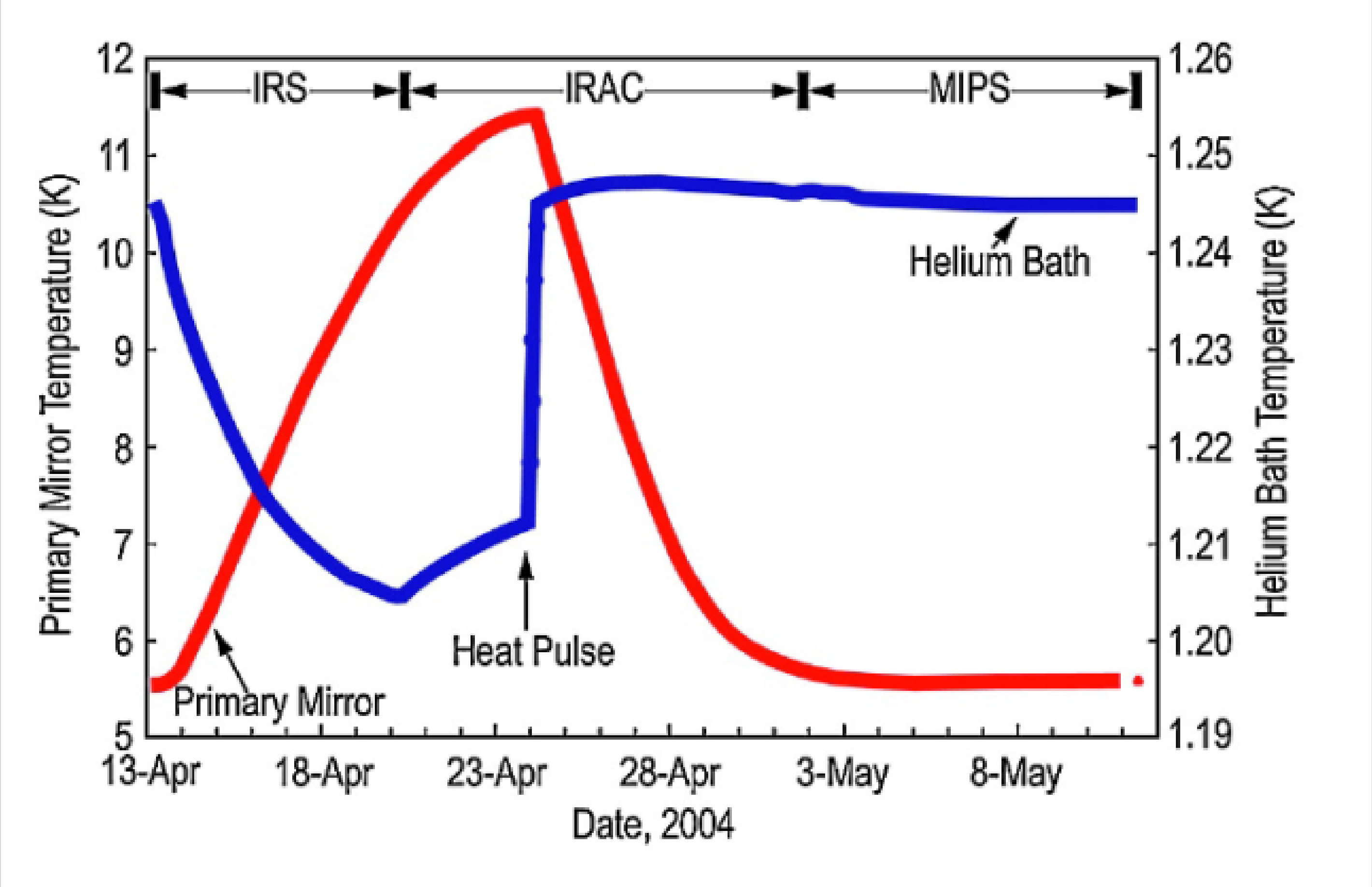
Sharp rise in mid-2009 due to loss of vapor cooling. Temperature immediately rose to 26K* and continued to creep upward as Solar Panel temp rose.



* Radiation through open end of outer shell allowed telescope temperature to fall below outer shell temperature. Telescope radiates about 20mW through the aperture, qualitatively consistent with inst power plus inward heat flow.

Jet Propulsion Laboratory
California Institute of Technology

Maximizing Spitzer's Cryogenic Lifetime



A team led by Charles Lawrence figured out how to maximize Spitzer's cryogenic lifetime by using a heater in the cryostat to control the bath [and hence the telescope] temperature to the level needed by particular instrument in use. This added about six months to Cryo mission lifetime

Verifying the Cryogenic Lifetime of Spitzer through ground test (I)

- Real challenge because couldn't replicate space environment on Earth
- Broke verification into two parts:
  - Interior to outershell, verified in cryo test at Ball
  - Exterior to outershell, verified in thermal vac at LMMS
- Cryo test had intended to drive outershell temperature to levels expected on orbit
  - Test hellishly complex – involved four or five liq helium cooling loops
  - Proposed scheme failed because of test induced artefacts
  - Resorted to careful modelling of entire test configuration
  - Ran test cases with imposed heat loads; monitored transient behavior to assess couplings
  - Even so, about 15 mW remained unaccounted for

Verifying the Cryogenic Lifetime of Spitzer through ground test (II)

- Thermal vacuum test at LMMS faced similar challenges
  - Emphasis was on coupling of solar panel shield and spacecraft shield to outershell
  - Measurements were made at three carefully spaced time periods during initial cool down
  - Modelling again encompassed test configuration as well as spacecraft, and transient behavior

- In the end, at launch, the predictions for cryo lifetime were
  - Worst case: 3.1 years [reqt was 2.5]
  - Nominal: 5.1 years [goal was 5]
  - Adding additional 0.5 years from optimization predicted 5.6 years, very close to what was achieved

Conclusions from Cryo-Thermal Discussion

From the point of view of evaluating the durability of the radiative cooling alone, we can say that after 16+ years at 1au from the sun, a well-designed and well-constructed radiatively cooled system maintained the telescope primary mirror temperature at 26K. Stepping outward, the temperature of the outer shell increased by no more than 1.5K over the 16+ years, and much or all of that can be attributed to the increased power absorbed by the solar array, which trickled down to the outer shell. So there is no evidence over this time period of degradation in the low temperature thermal and optical properties of the components of the system responsible for the radiative cooling.

Setting the Focus on Orbit

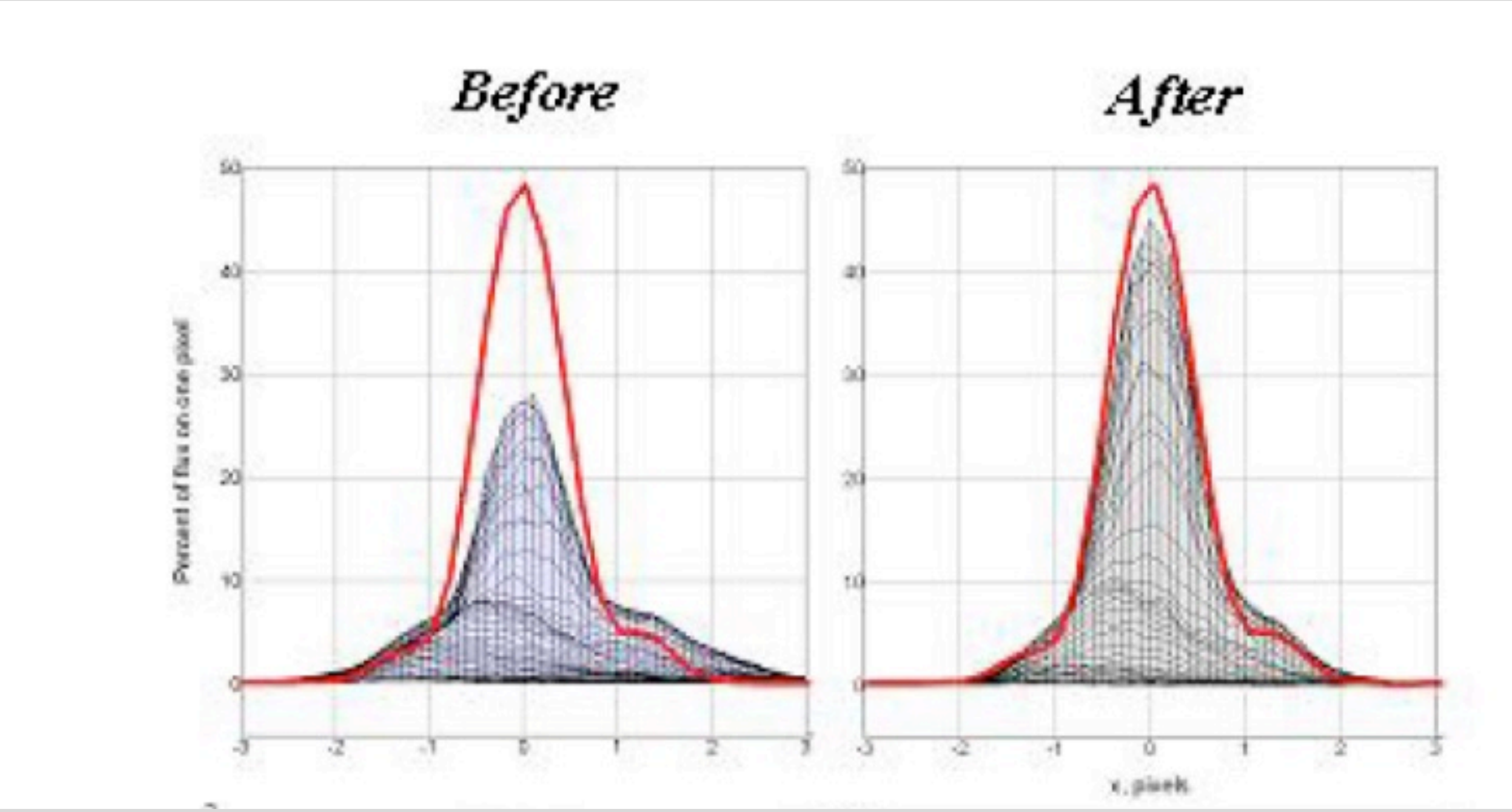
- Spitzer was equipped with a well designed, robust, electrically redundant focus mechanism which moved the secondary mirror along the optical axis.

- Nevertheless, there was reluctance to commit to the usual focus sweep which moves the secondary through a range of positions

- Instead, Bill Hoffmann* of the IRAC team, and colleagues, found a way to assess the focus based on the variation of the images across the ~5x10 arcmin field of view of the two shortest wavelength IRAC arrays 3.6 and 4.5um

- This was verified by a double-blind test on the ground and used on orbit to focus the instruments with just two moves

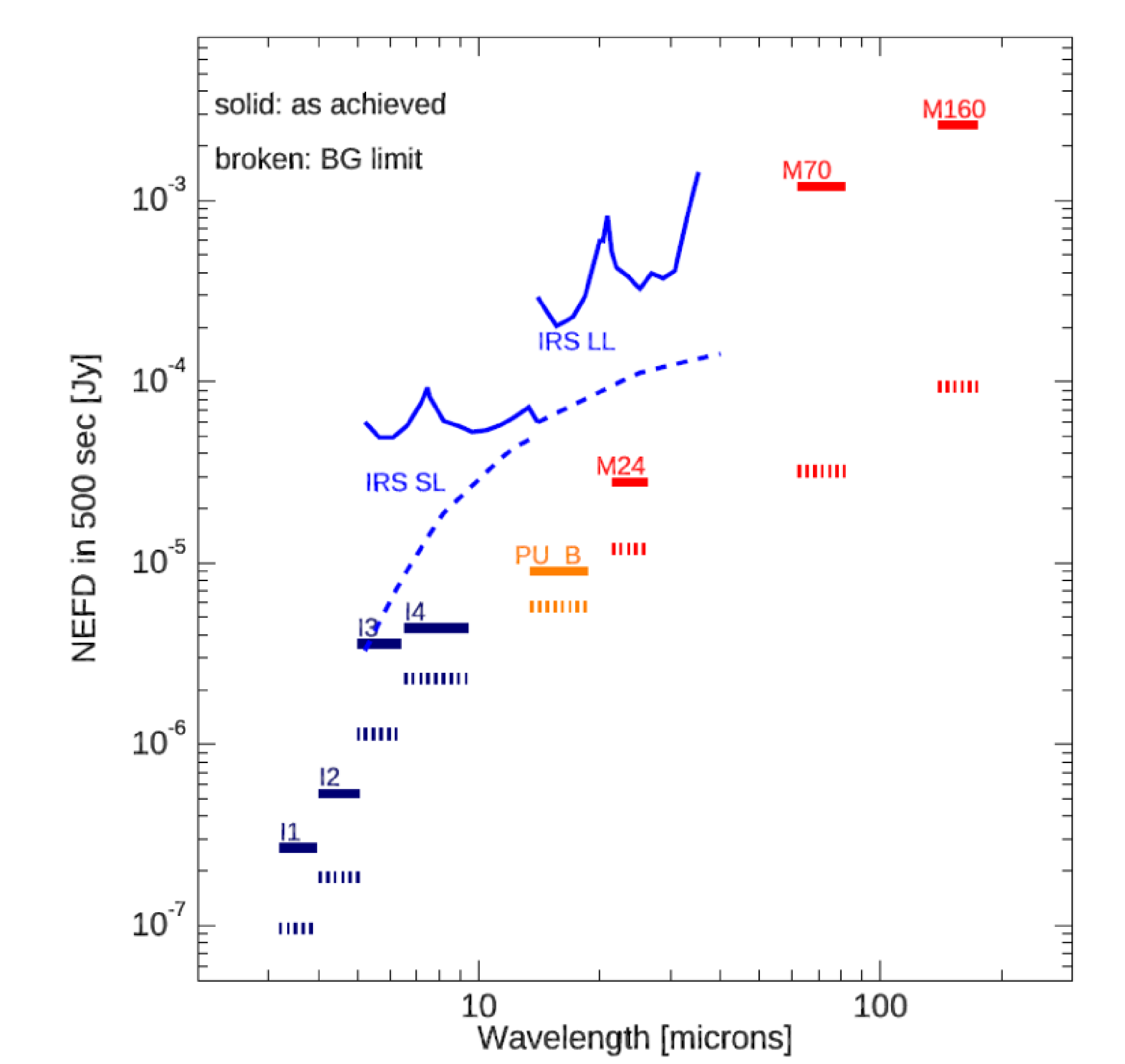
IRAC Band 1 [3.6um]images before and after on orbit focus adjustments



Red curve is predicted image profile from prelaunch models. Solid curves are observed image averaged over field of view before and after focus adjust

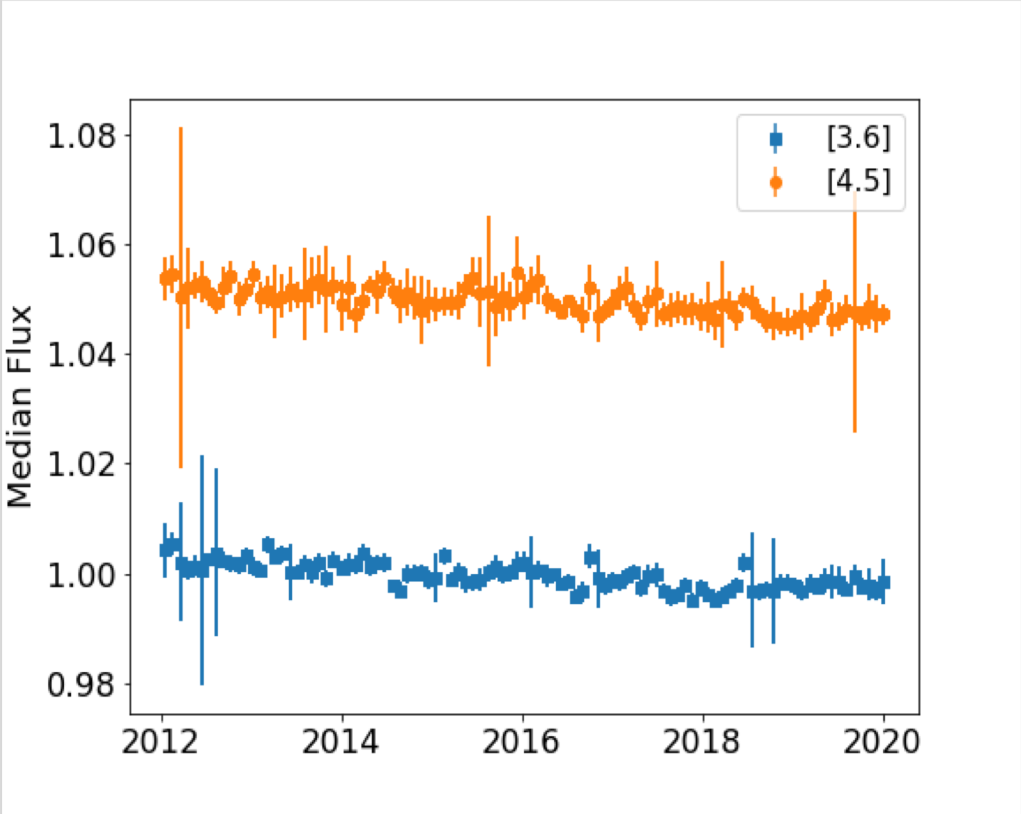
Jet Propulsion Laboratory
California Institute of Technology

Comparison of Spitzer Instrument performance with limits set by zodiacal background for estimated instrument throughput



- **Ideal instrument with no excess noise due to electronic, non-zodi background, sampling, rad hits, confusion nose [important for MIPS70&160] , etc. is assumed.**
- **Conclude that we are capable of building instruments which approach fundamental limits**

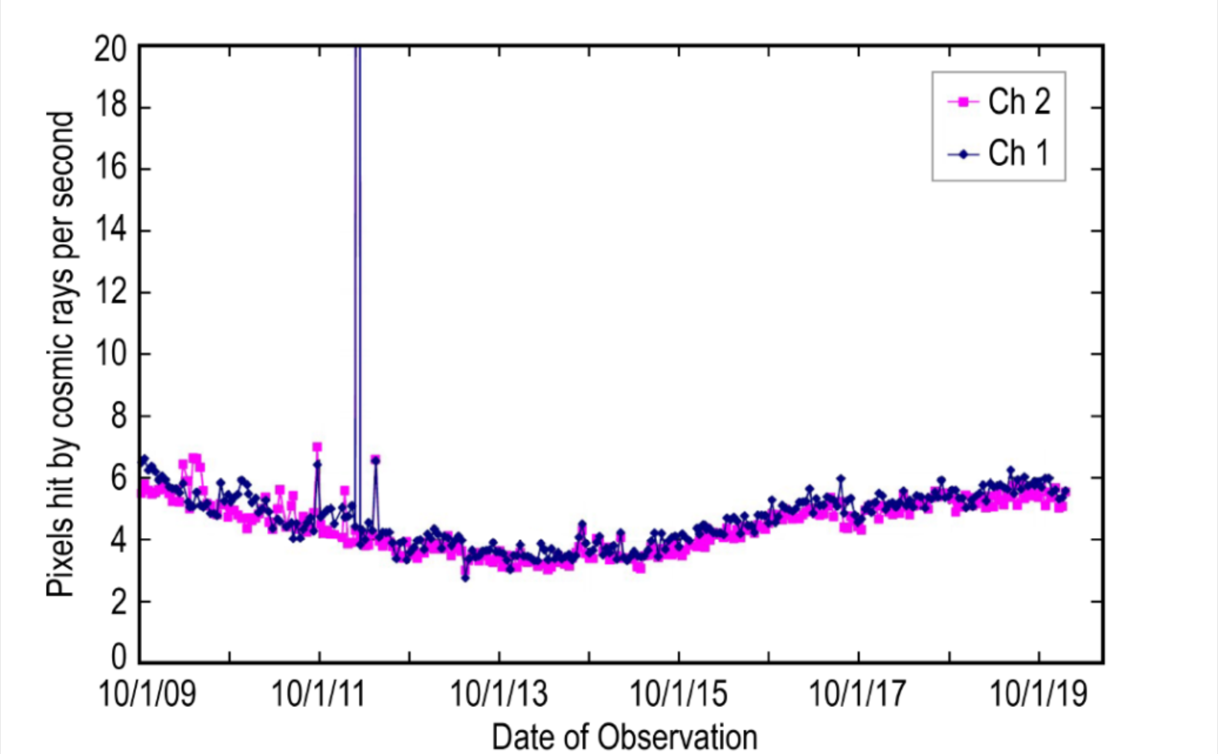
The responsivity of Spitzer's arrays has decreased by less than 1% over the last 8 years of the mission – no evidence for prior decrease



Based on repeated measurements of 7 standards in each band, referenced to median of each star's measurements. Would include any degradation of optics [lenses, filters, beam splitters] . Estimate 0.1 (0.05)%/yr decrease in Channel 1 (2) responsivity. InSb arrays and standard alkali halide lenses and multilayer filters.

Jet Propulsion Laboratory
California Institute of Technology

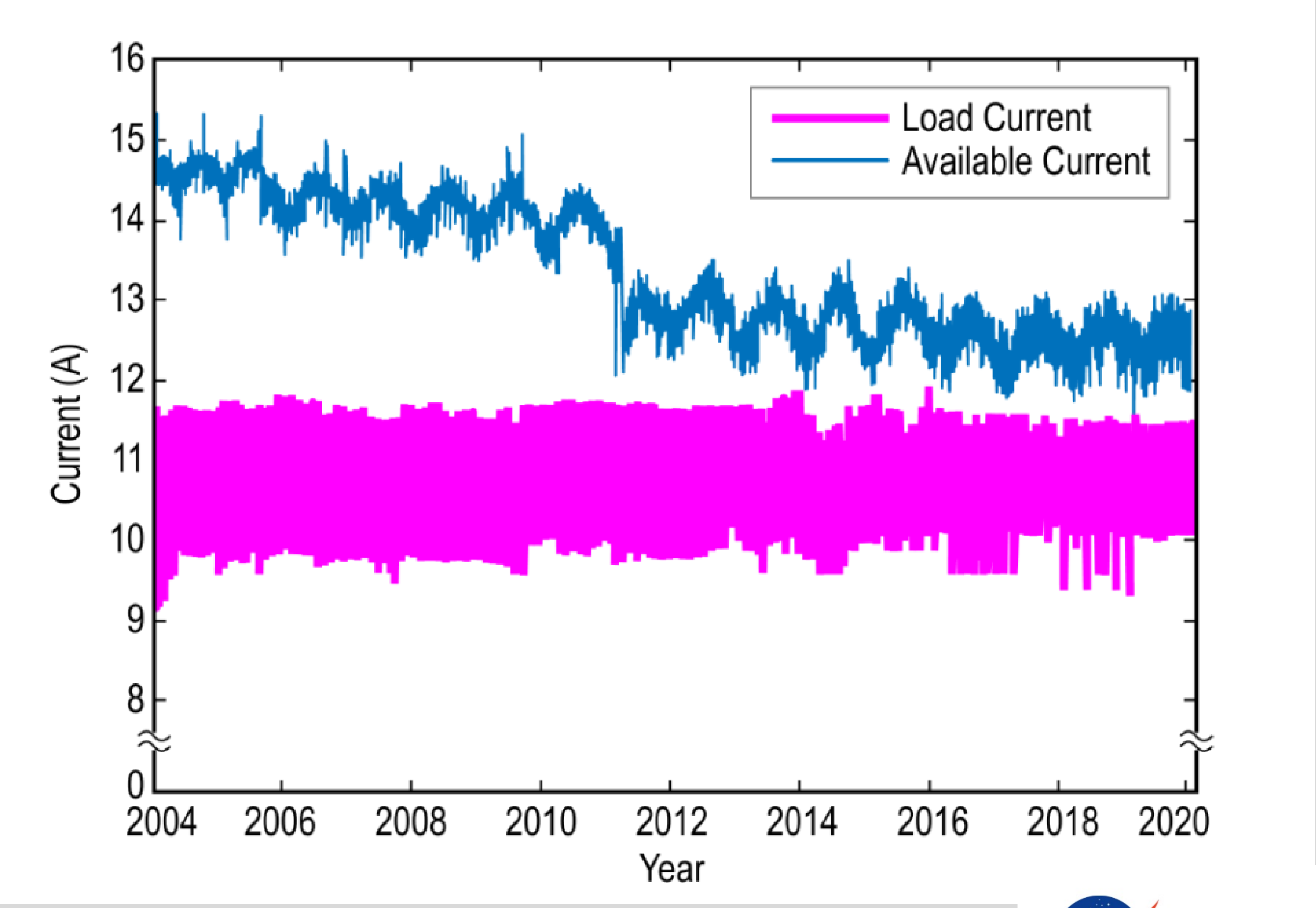
Cosmic ray hit rate –on average ~4 pixels/sec are hit. Note modulation due to solar cycle. Spitzer is outside magnetosphere



The arrays are 256x256 InSb. Each pixel ~30x30um. Isotropic ionizing flux calculated to be around 8 particles/cm2/sec. [perhaps less if secondaries contribute to hit rates]. Radiation effects were transient: at end of 16 year mission more than 98% of pixels remained usable.

Jet Propulsion Laboratory
California Institute of Technology

Solar array output decreased with time due to degradation of optical coatings on solar cells. Sharp drop in 2011 attributed to micrometeorite hit disabling part of one of the strings of solar cells



Jet Propulsion Laboratory
California Institute of Technology

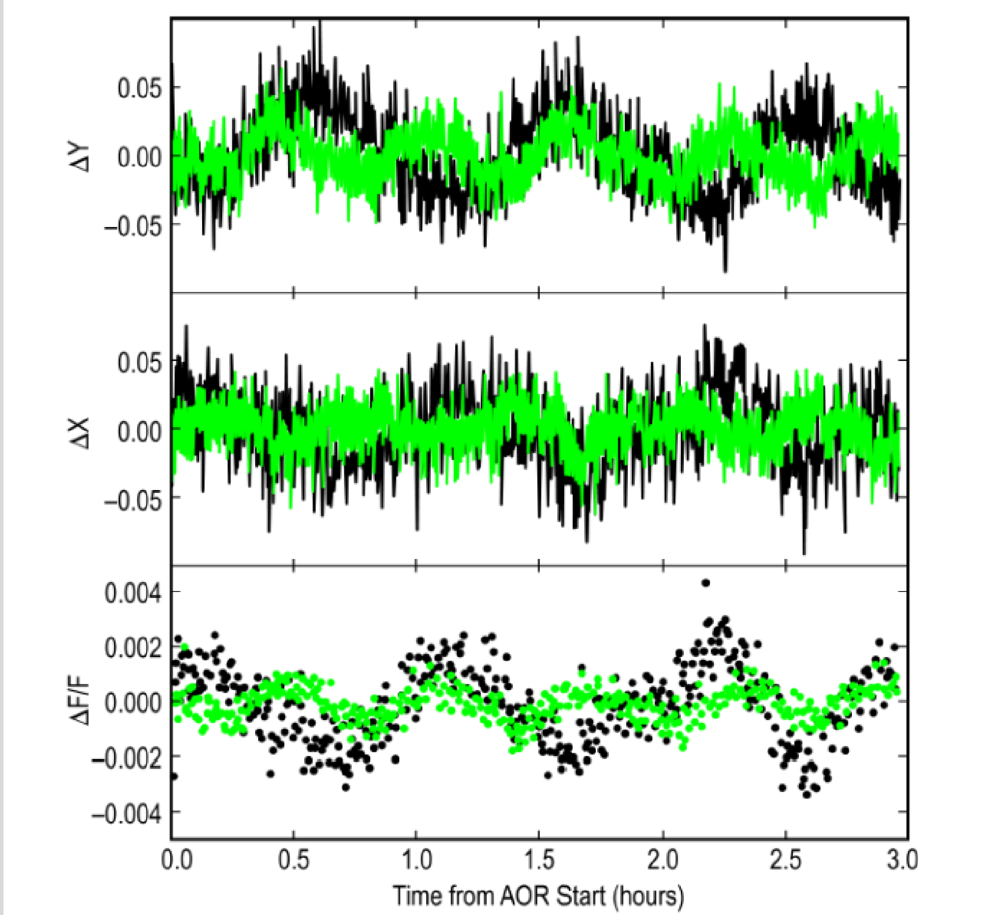
Undesirable ~1 hr modulation of signal from exoplanet-bearing stars complicated searches for transits/eclipses which had a similar time scale [black]

The modulation was traced to pointing wobble induced by battery heater in s/c [and intrapixel gain variations of up to 8%]

Amplitude was less than 0.1 arcsec pk-pk

Signal modulation was 0.2%, large compared to 0.01% goal

Problem mitigated **[green]** by reducing dead band on battery temperature control



Note that pointing offset too small for PCS sensors to register. Effects first seen in science data. Close coupling of users to Spitzer team facilitated identifying and solving problem

Jet Propulsion Laboratory
California Institute of Technology

Jet Propulsion Laboratory
California Institute of Technology

A few other facts about Spitzer:

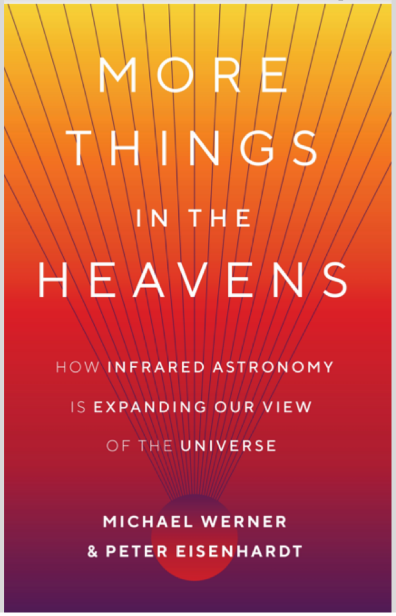
Observatory was very robust

Averaged Just over one safe/standby mode event/year

Observing time lost to recovery less than 4 days/year

Observatory was also very efficient

Even at the end, efficiency, defined as [time spent on science, calibration, and slews]/[wall clock time] was ~90%



The science was great: See “More Things in the Heavens”, by Peter Eisenhardt and myself, Princeton University Press, 2019

THAT’S ALL, FOLKS!

Communications Geometry and Distance from Earth stressed the system towards the end of the mission