Far-IR and Sub-mm Space Telescopes - an ESA technology perspective *(DD's personal experience)*

Dominic Doyle

Retired senior optical engineer, ESA

2025/04/03

Outline - Far-IR and Sub-mm Space Telescopes - an ESA technology perspective

From FIRST (dream –ESA proposal- 1982) to reality Herschel (launched May 2009)

Planck – an even colder telescope (40K) with FIRST material heritage

SPICA – the JAXA/ESA (5K background limited) next generation that was not to be ☹

PRIMA – 2030's NASA's new attempt to "fill the gap" (with European participation)

Themes:

Ambitious science drives technology and pushes design (please keep dreaming!)

New technologies are always a combination of push (can we use this?) and pull (what do we need?)

Risk taking – SiC had no heritage at Herschel scale (3.5m) and temperature (70-80K)

Very hard work – but extremely rewarding, seeing the science enabled and achieved

This is a very brief personal review of the Herschel telescope development with reference to its enabling technologies, context some of the many details we had to pay attention to and what perhaps comes next. It's always about **Dreams** and **Details!**

From FIRST to Herschel => The dream: 8m deployable!

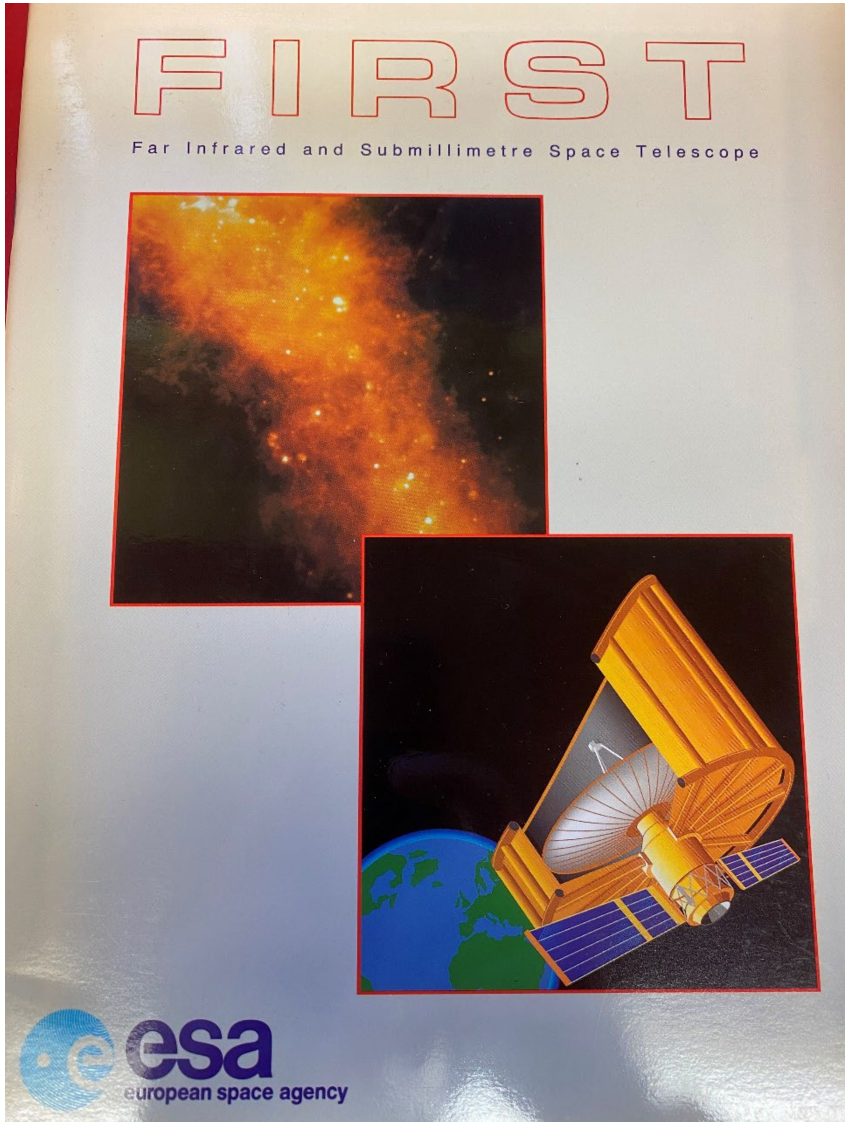


Table 1 – Design Goal

FIRST mission proposal 1982-'84

Submillimetre Telescope

Wavelength – Frequency Interval	ca. 1 mm – 0.1 mm 500 GHz – 3000 GHz
	Provides: Access to galactic/extragalactic objects in temperature region 10 K – 3000 K. Diagnostic tool for molecular clouds – atoms, molecules, ions Continuum radiation from dust
Telescope Size	8 m – deployable
	Provides: Hitherto unparalleled angular resolution High Sensitivity: 10 mJy at 0.1 m
	Difficulty: panel adjustment, long-term panel adjustment and accuracy
Angular Resolution	3.2 arcsec at 0.1 mm diffraction limited
Pointing Accuracy	1 arcsec
Pointing Stability	0.5 arcsec
	Provides: Resolution of small and clumped interstellar material.
Focal-Plane Instrumentation	Heterodyne package (500 – 2000 GHz) Short-wavelength spectrometer (0.1 – 0.2 mm) Imaging multiband photometer (λ = 0.05, 0.1, 0.15, 0.25, 0.9, 1.6 mm)

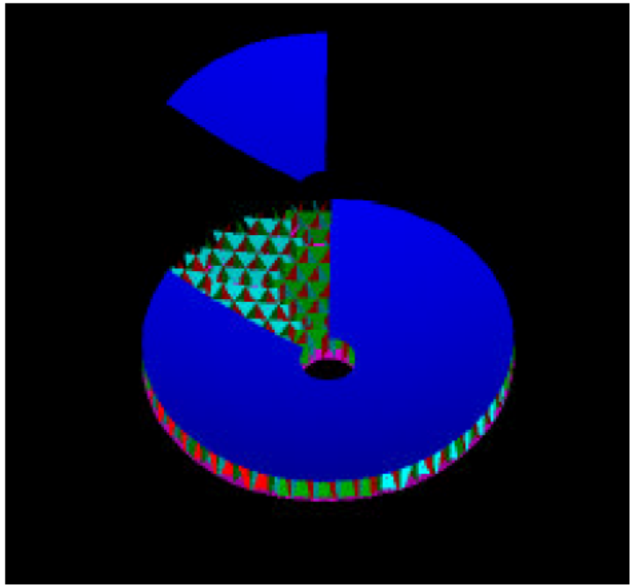
An "undecidable" concept!

See Chapter 6 of "Inventing a Space Mission!
(The story of the Herschel Space Observatory)
Thijs de Graauw et al, Springer 2017

NASA-JPL => 2m CFRP Telescope breadboard (1999)

Primary Mirror Design Approach

- Segmented Front and Back Faceskins
  - 60° Segments
  - Seams Coincident Front-to-Back
- Modular Core
- Embedded Metallic Fittings Serve As Interface Attach Points
- Assembly Process Results in Monolithic Mirror

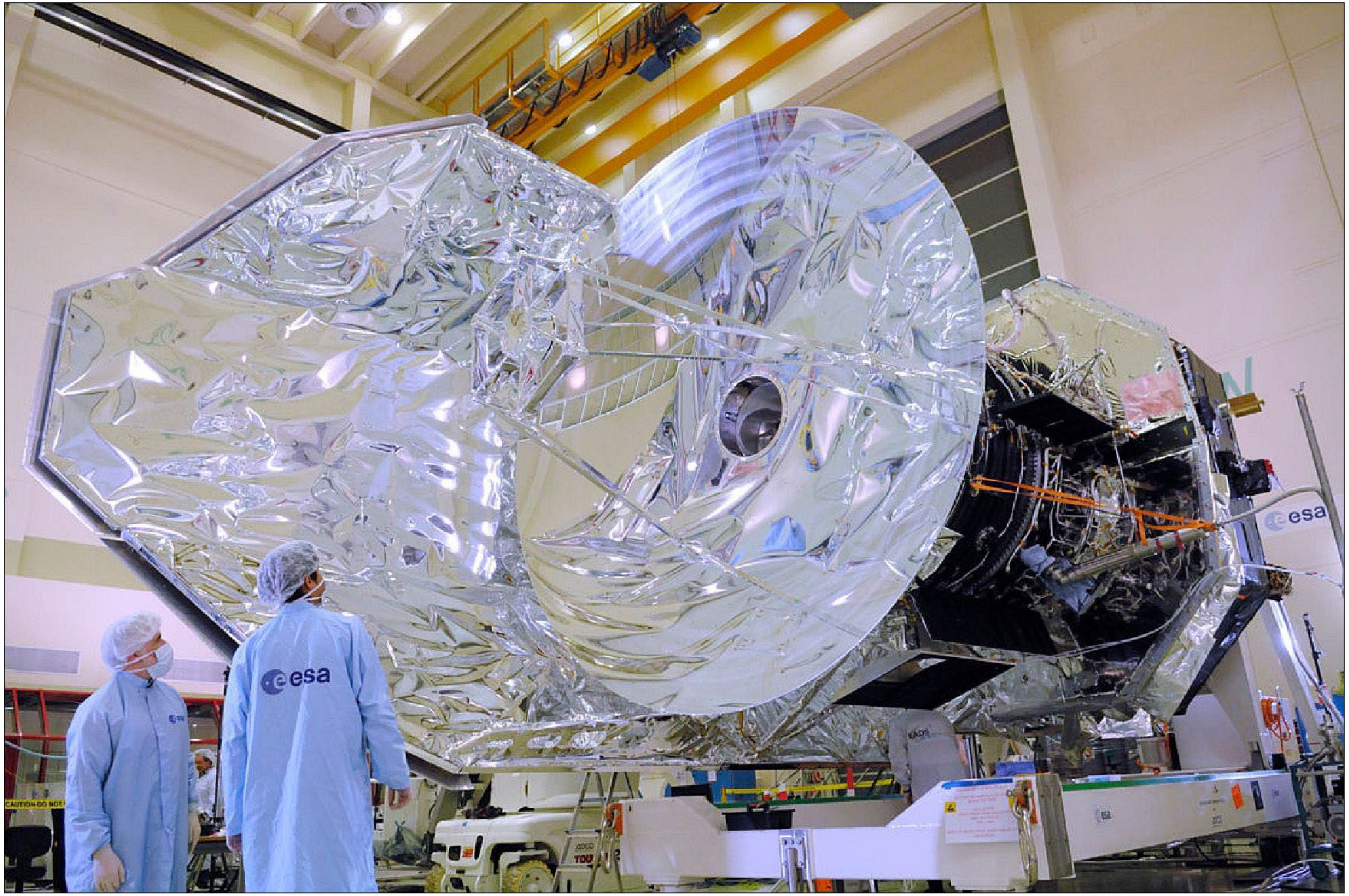


FIRST *Far Infrared and Submillimeter Telescope* 16 Peer Review - Optics • November 18, 1999

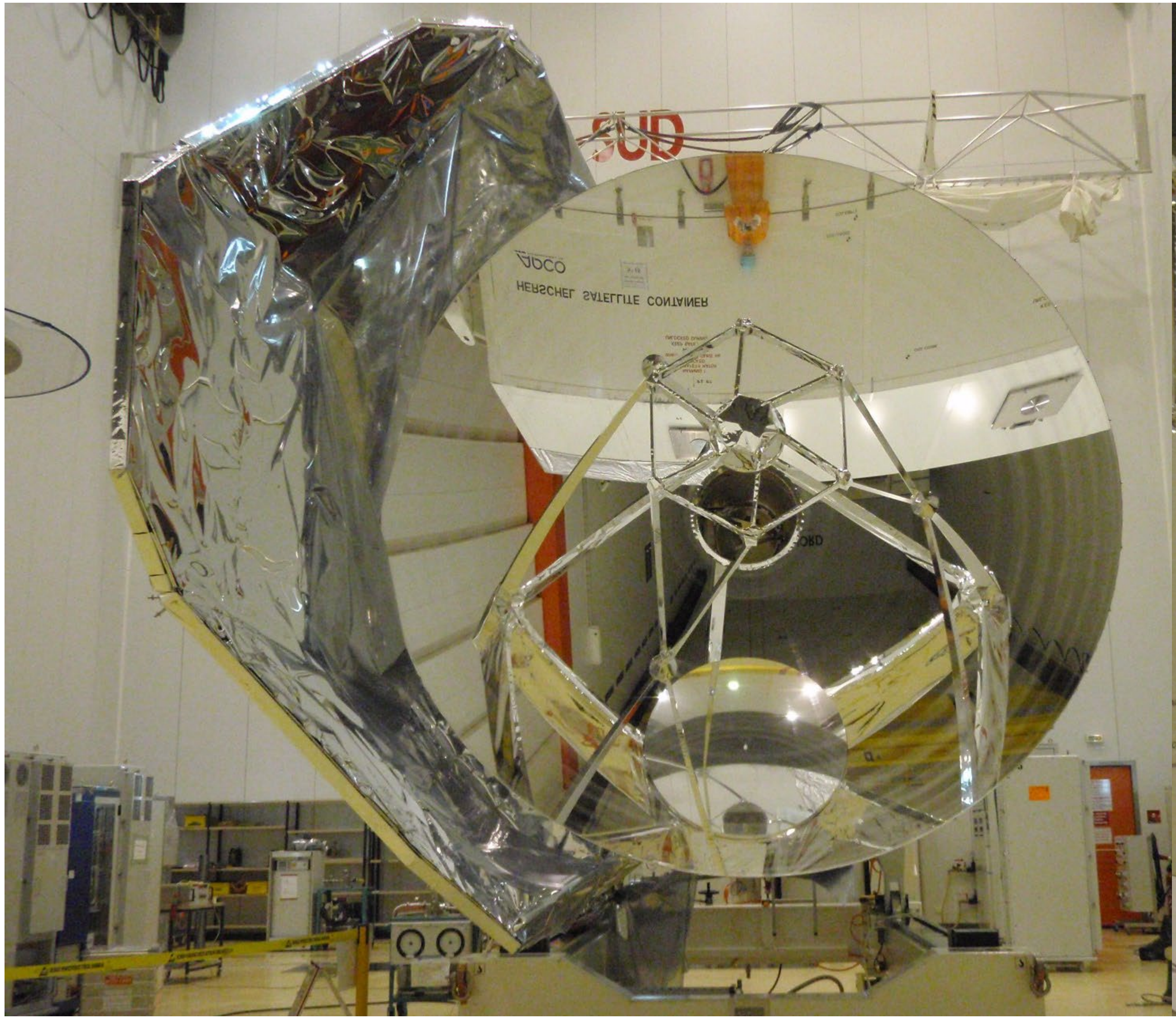
Cryo measurements were challenging

Herschel the reality: 2009 => 3.5m fixed focus

Herschel Telescope at ESTEC during final AIT activities in 2008.



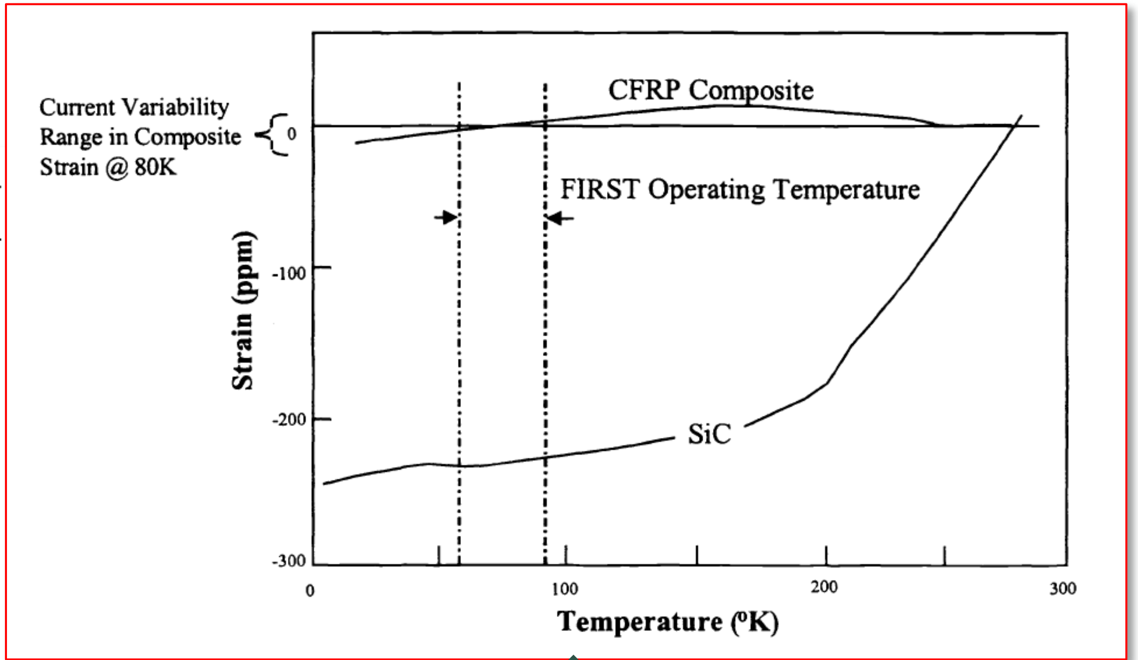
In May 2009 dreams come true with a perfect launch



Some technological details along the way

Material drivers => From Aluminium to CFRP to Al and **SiC** … and now back to Al (Ariel and PRIMA)

	Sintered SiC	Beryllium	Zerodur	Aluminum
Density (g/cm^3)	**3.14**	1.85	2.53	2.73
Young Modulus E/ρ (Gpa)	**420**	303	91	71
CTE α (ppm/K)	**2**	11.4	0.05	24
Thermal conductivity λ (W/m/K)	**180**	180	1.6	237
Specific heat cp (J/K/kg)	**680**	1880	821	900
Ratio λ/α (thermal toughness)	**90**	16	33	10
Ratio E/ρ (specific stiffness)	**133**	164	36	26
Figure of merit ($\lambda/\alpha \times E/\rho$)	**11970**	2624	1188	260



CFRP looked attractive … but there were too many challenges scaling up to 3.5 m

Material design trade-space

In the meantime, the entire trade-space has now been exploited for space telescopes.

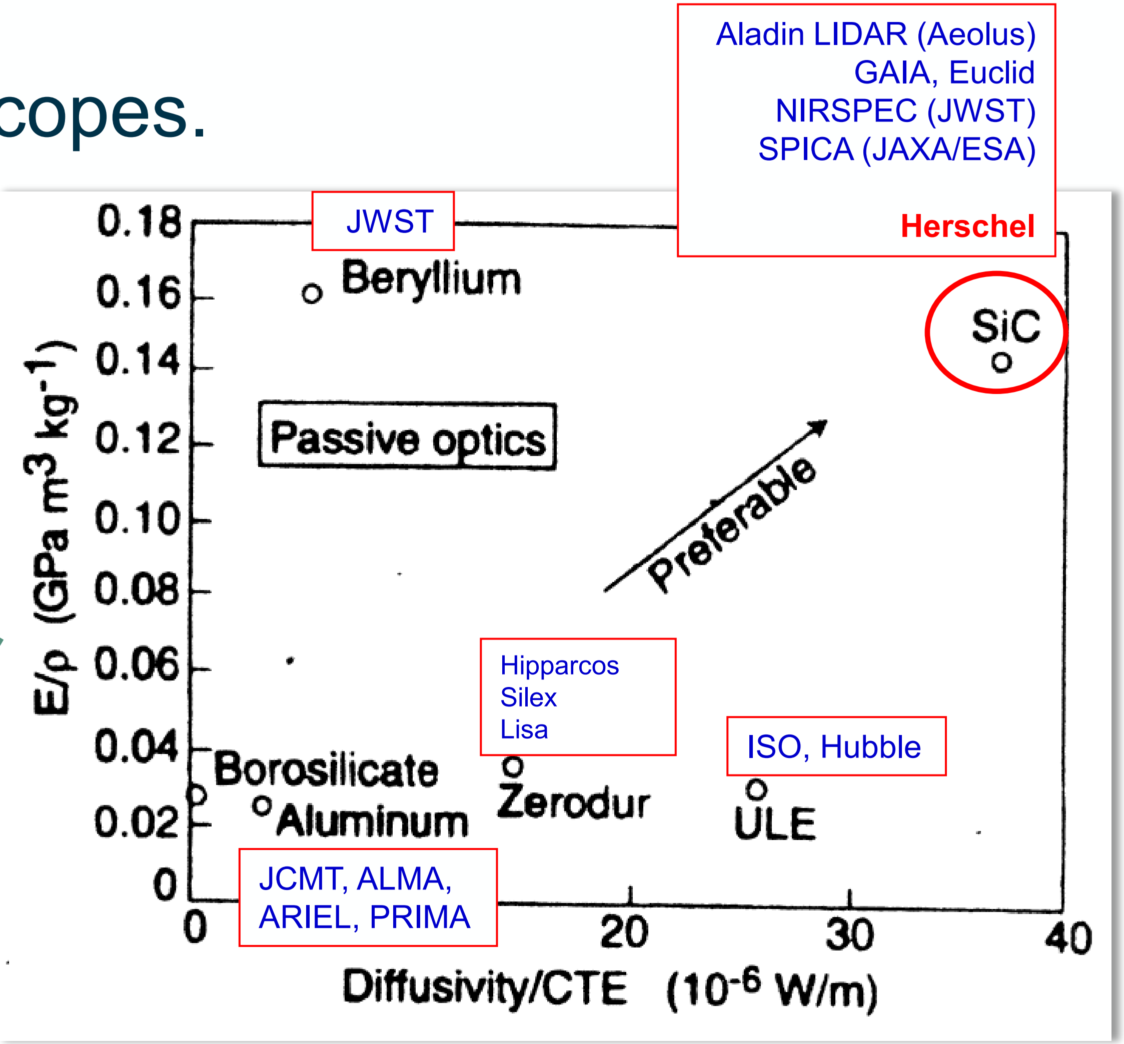
In 2000, SiC was an attractive but still a challenging "outlier"

From
Fig 4.29 Bely ed
"Design and construction of large telescopes"

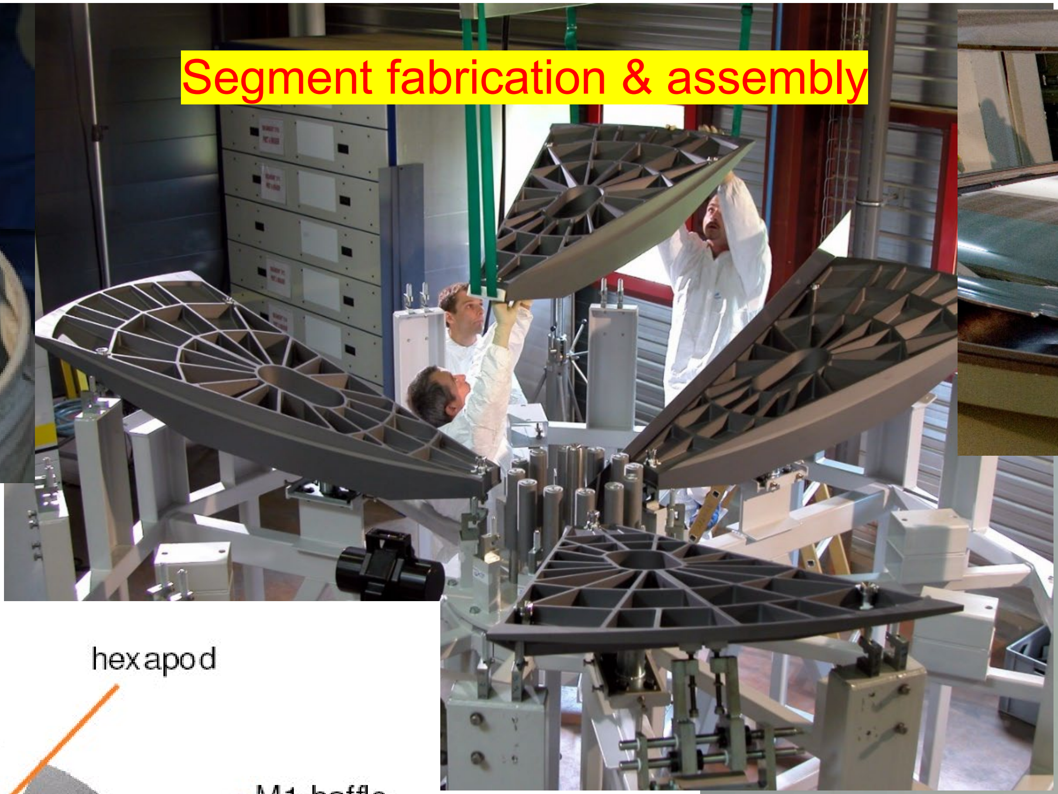
Useful figure of merit.

Specific Stiffness vs Thermal Diffusivity/CTE

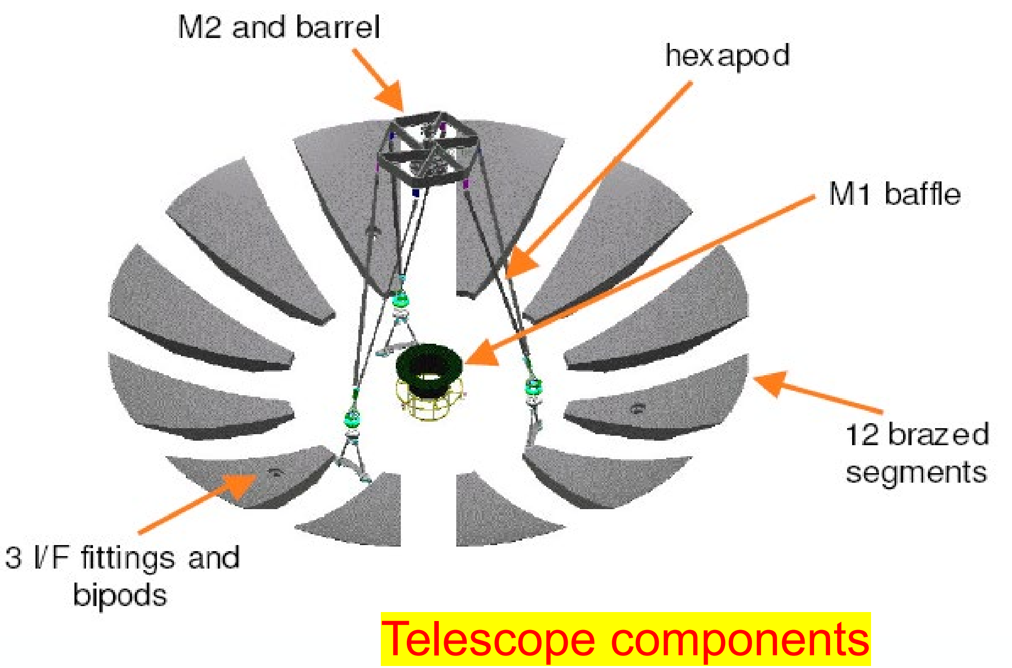
Many materials possible: Need very careful optical, optomechanical and interface design and quality control




Starting material


Segment fabrication & assembly

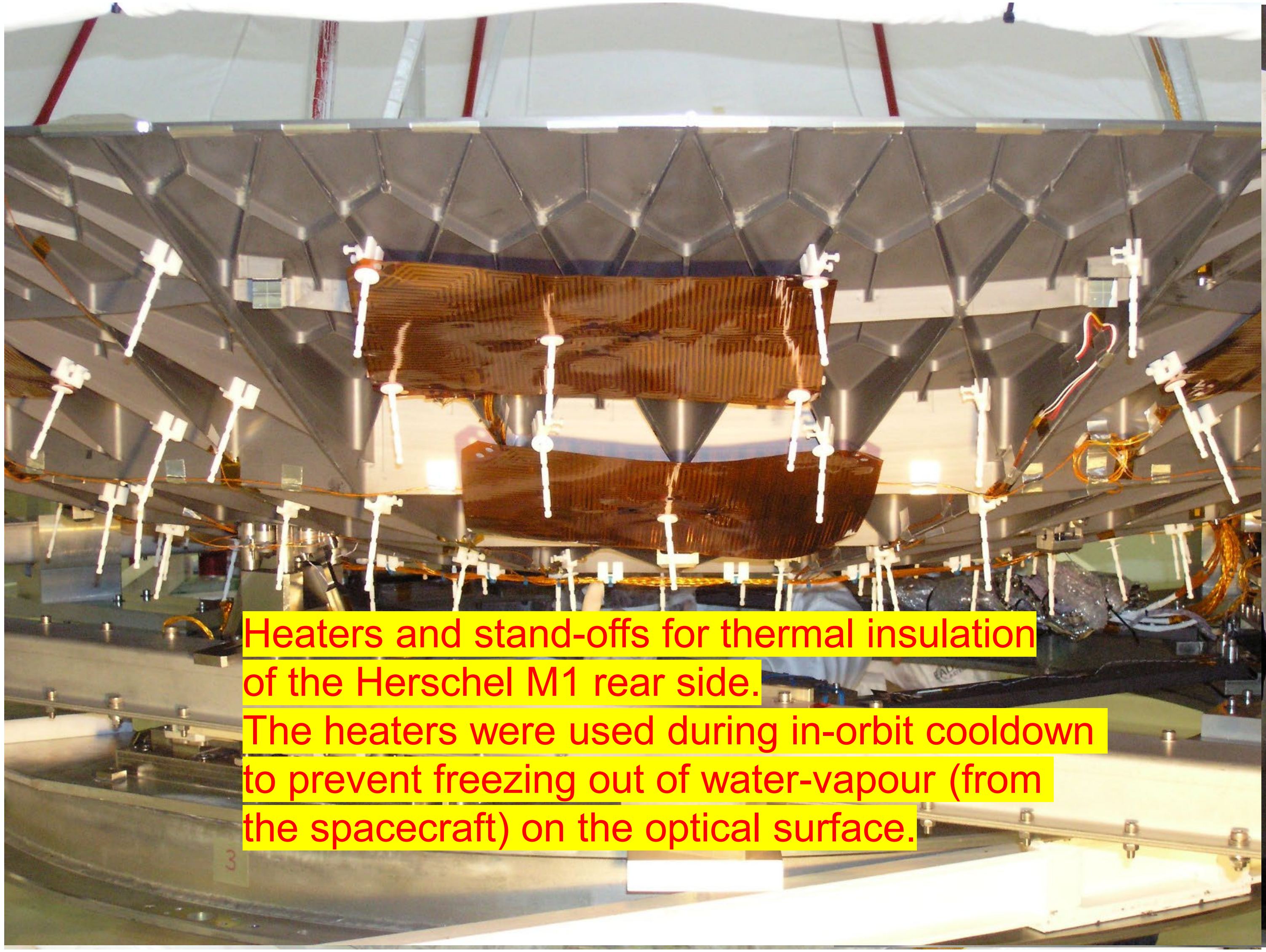

After coating (Al) in Calar Alto (Sp)


M2 and barrel
hexapod
M1 baffle
12 brazed segments
3 I/F fittings and bipods
Telescope components

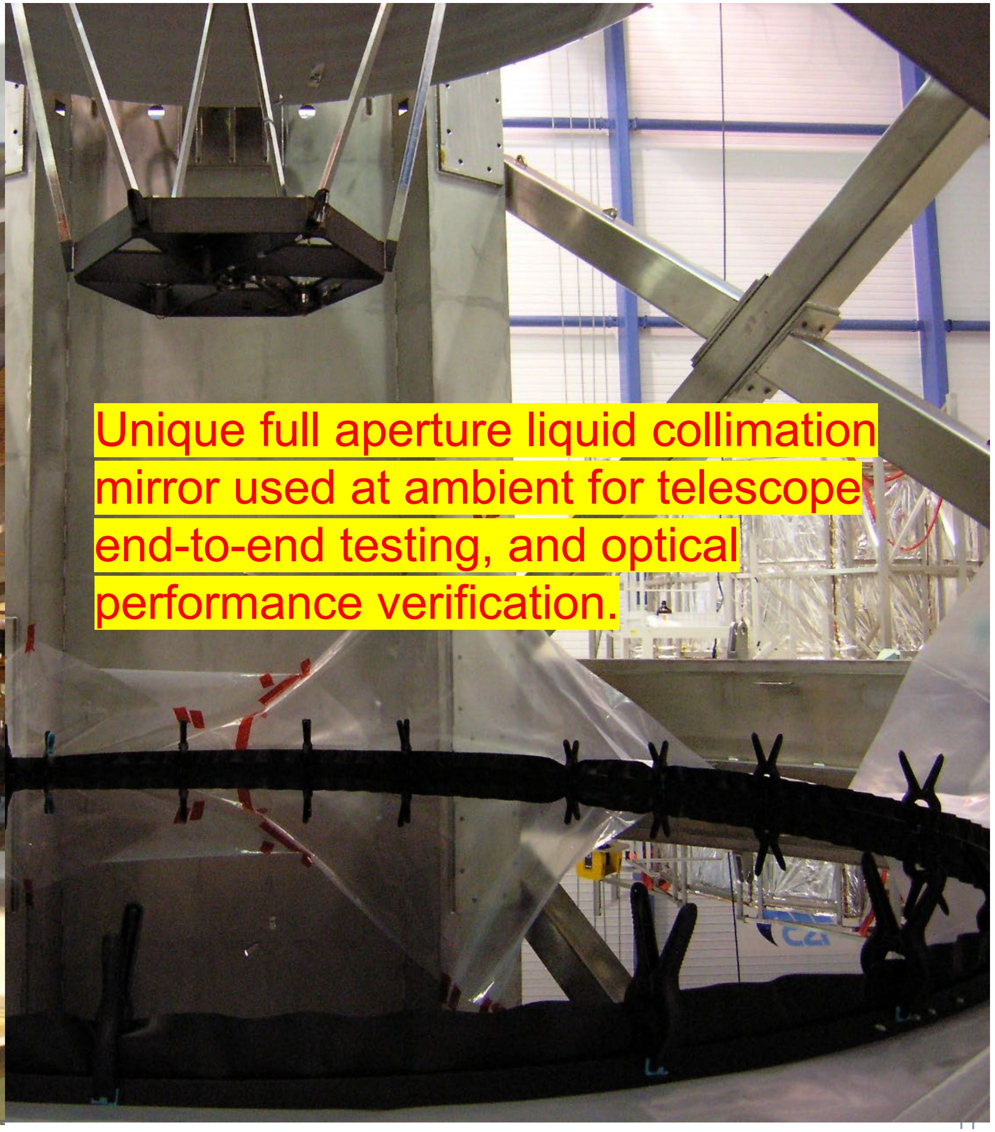

TV cryo testing in CSL


Finished telescope

HERSCHEL PFM Telescope development & AIT

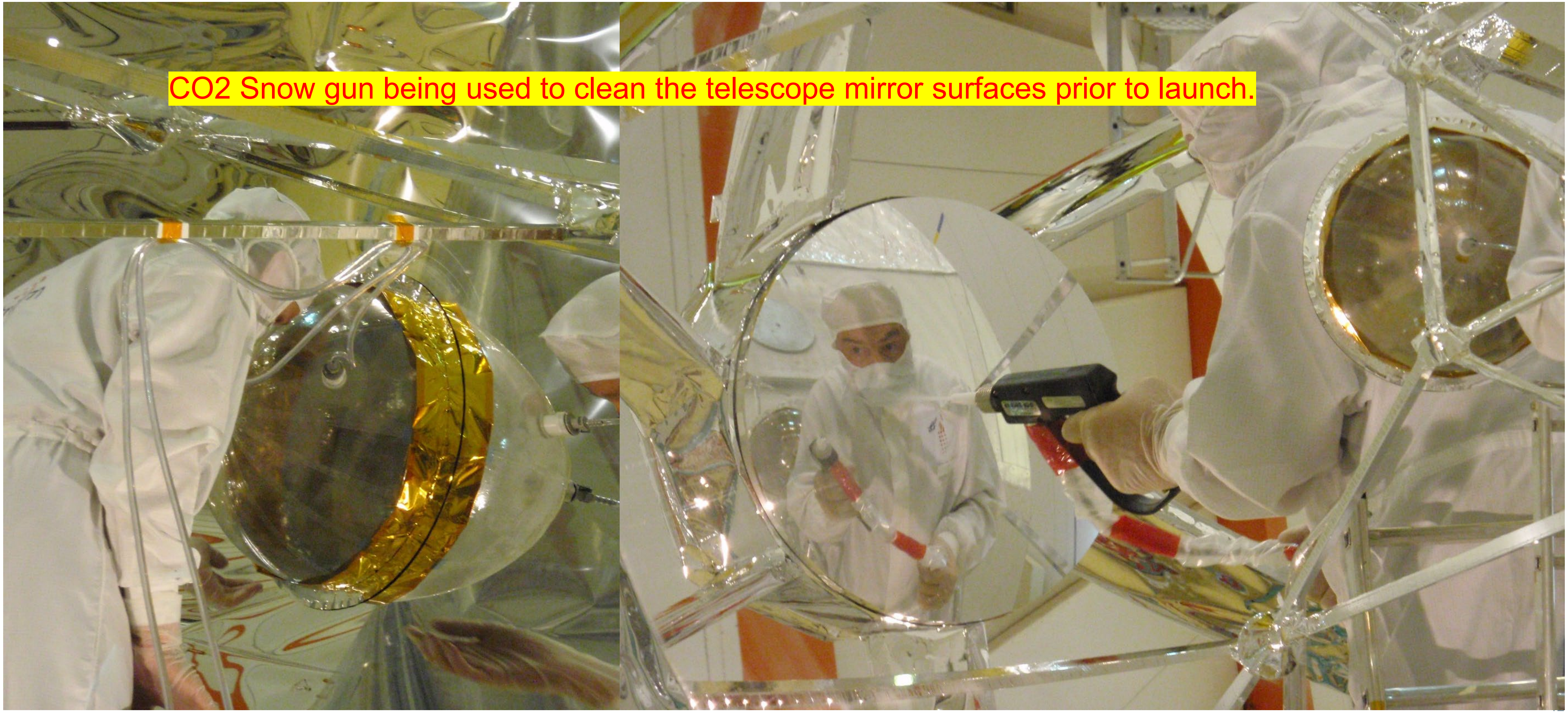


Heaters and stand-offs for thermal insulation of the Herschel M1 rear side.
The heaters were used during in-orbit cooldown to prevent freezing out of water-vapour (from the spacecraft) on the optical surface.



Unique full aperture liquid collimation mirror used at ambient for telescope end-to-end testing, and optical performance verification.

Herschel Telescope Launch Prep – some details



CO2 Snow gun being used to clean the telescope mirror surfaces prior to launch.

M2 – anti-narcissus cone (very important for HIFI)

(Flight spare Herschel M2 gifted to Jacques Louet)

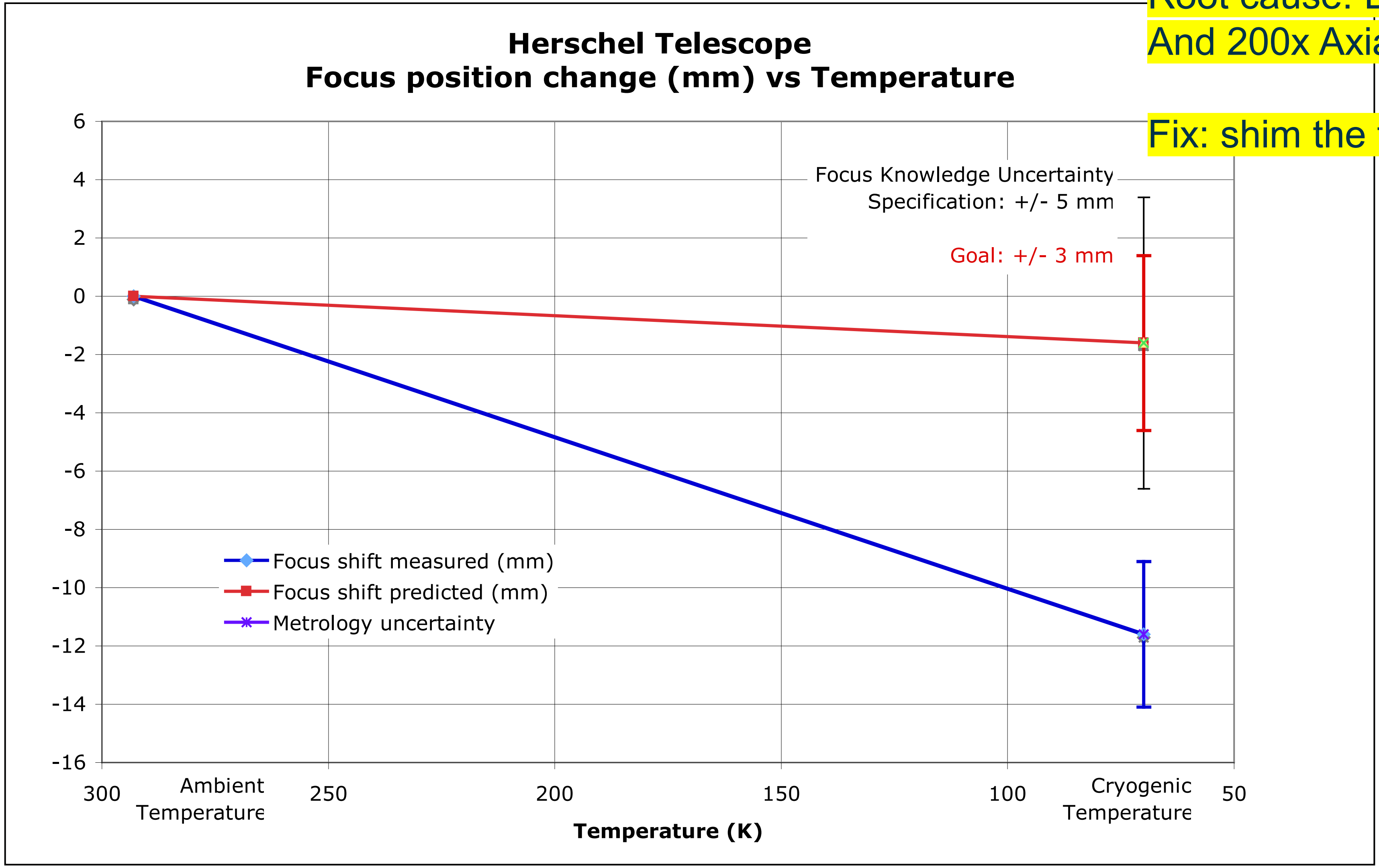
A fantastic technological polishing achievement for Zeiss

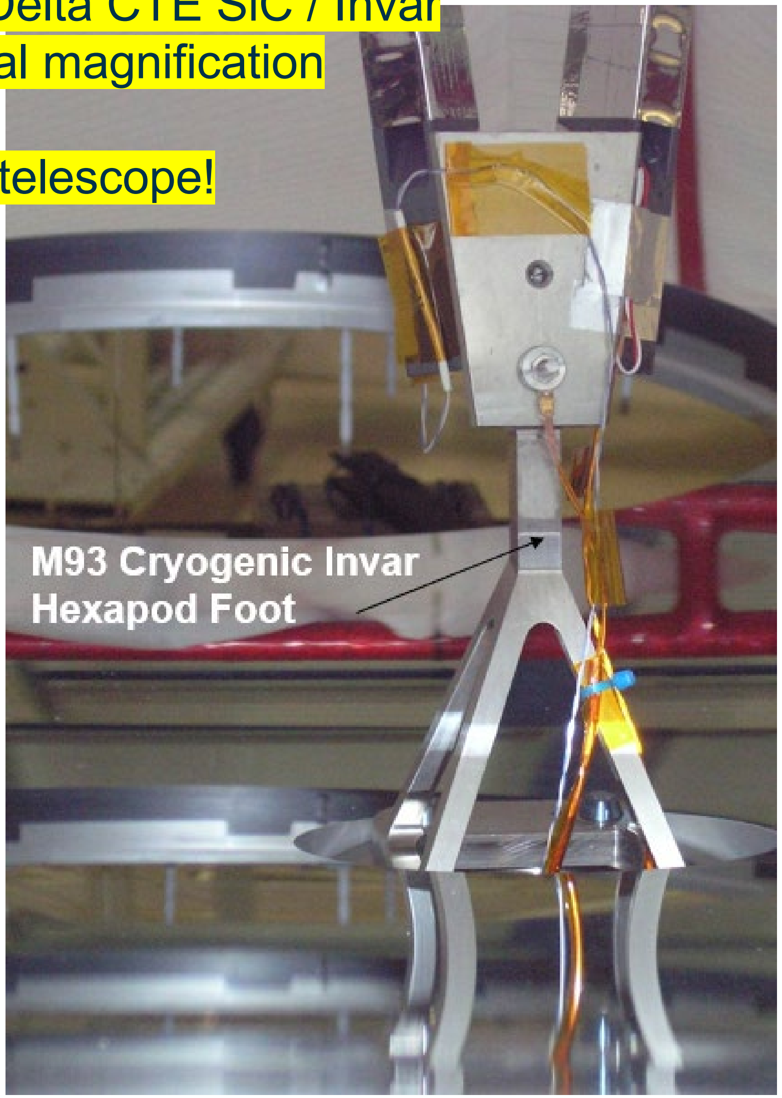
Didn't know if possible, at KO

Materials came back to haunt us – Cryo-focus problem

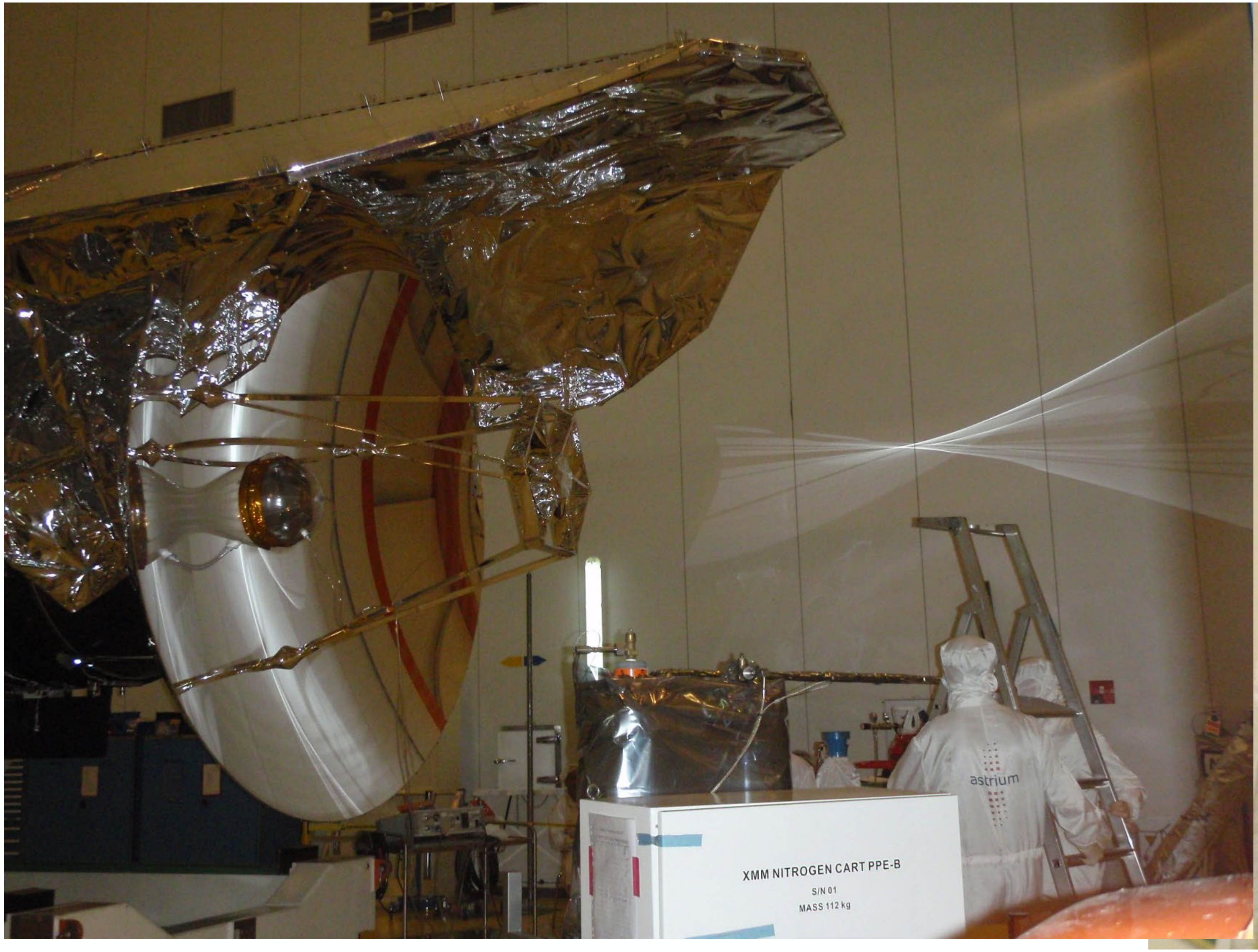
Root cause: Delta CTE SiC / Invar
And 200x Axial magnification

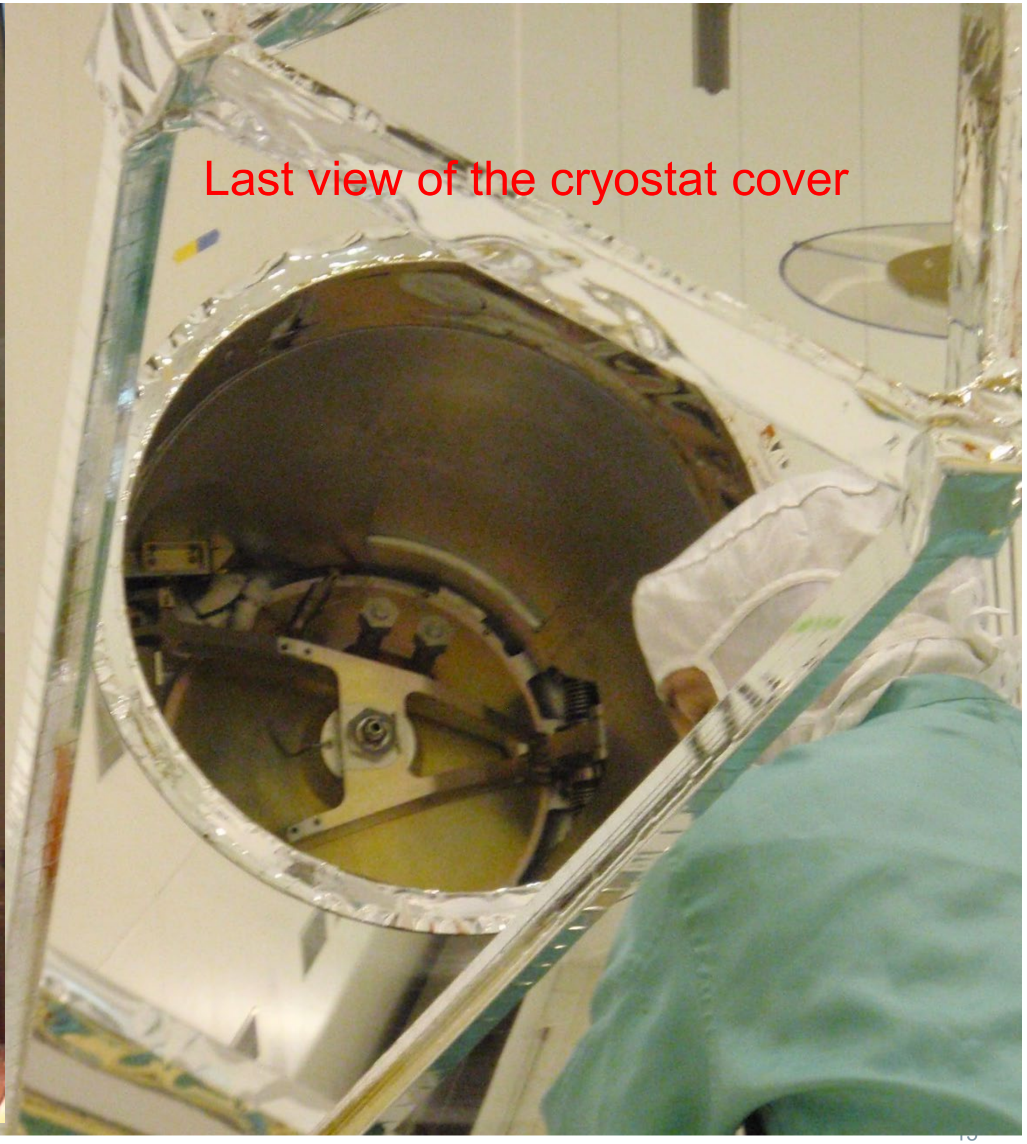
Fix: shim the telescope!



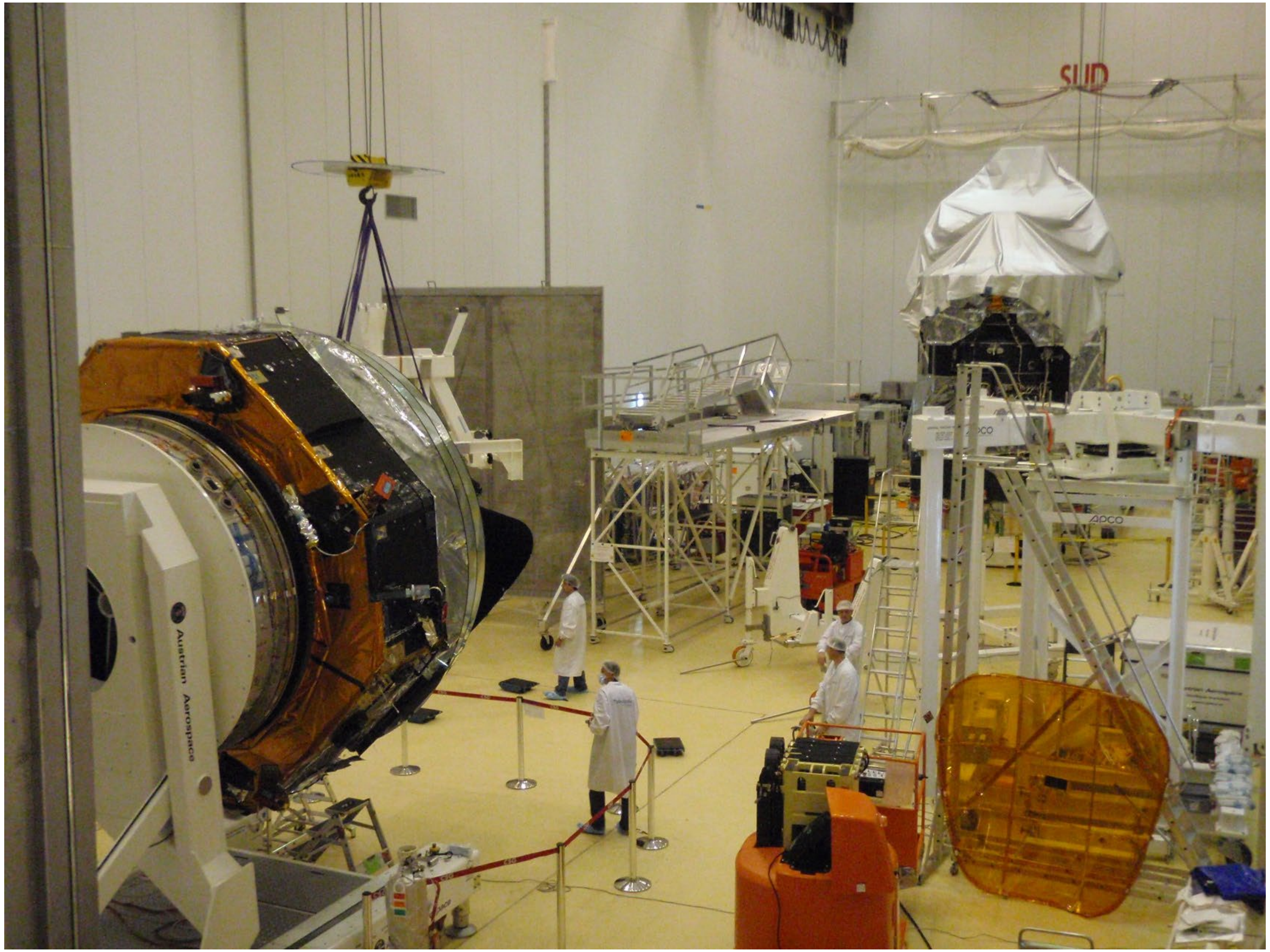


During final telescope cleaning in Kourou

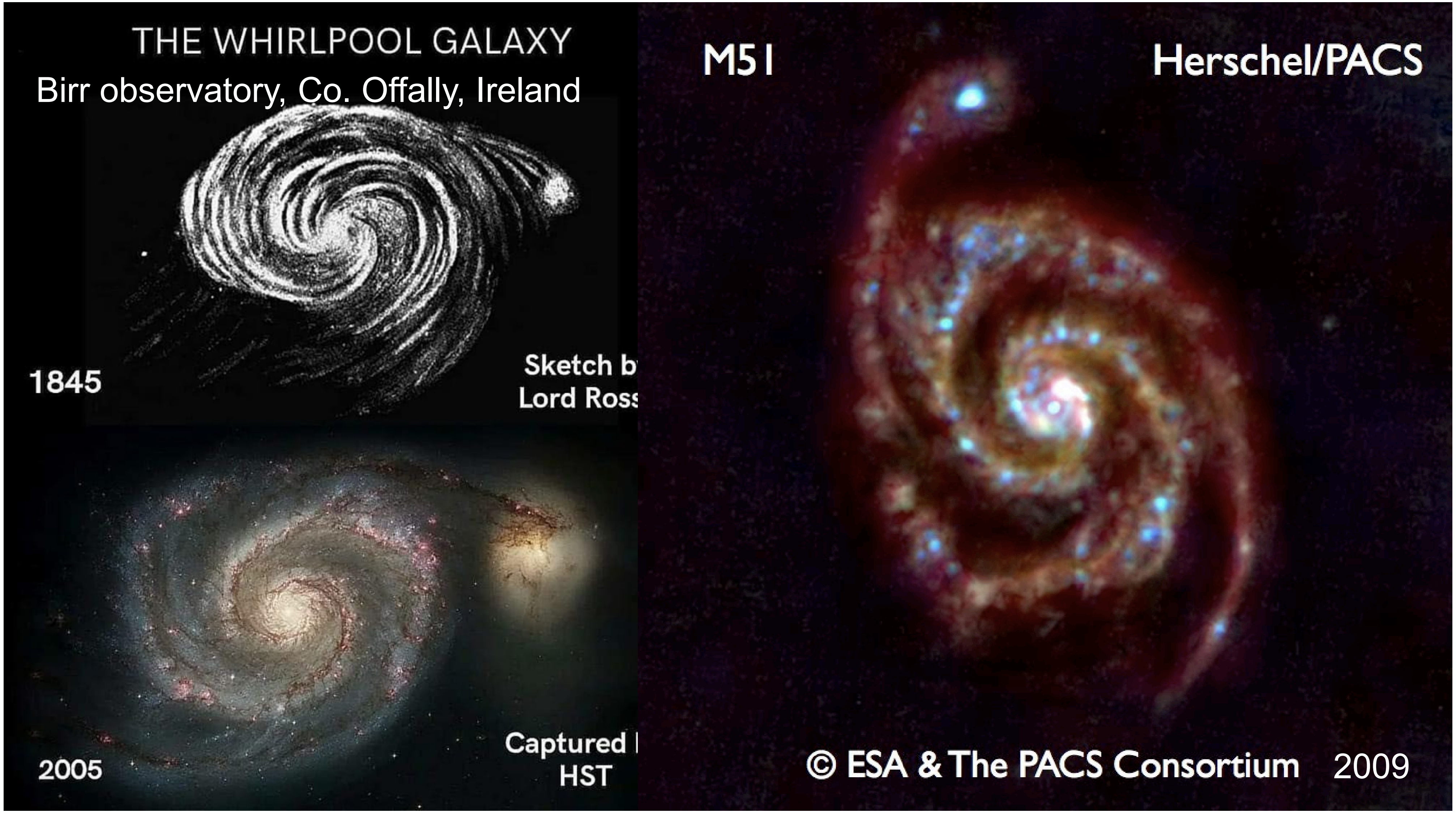




Herschel & Planck meet in Kourou just before launch



Was the telescope shim good? In focus or not? First light



The image is a composite of three observations taken at 70, 100 and 160 microns, taken by Herschel's Photoconductor Array Camera & Spectrometer (PACS) on 14 and 15 June, immediately after the satellite's cryocover was opened on 14 June 2009.

Relief was huge!

Planck – a very special CFRP telescope (40K)

Testing was a complex mix of –
* IR Interferometry
* Videogrammetry
And
* CATR RF far field (as seen here)

SPICA – the JAXA/ESA next generation (SiC)

“ astro-politics ”

SIA Assembly Summary

Telescope Opt

- Extensive trade in Chrétien and Cass internal freeform fo telescope orientatio
- Selection of RC ver Decision Point; mini load paths.
- Earlier Korsch and o accommodation complexity
- RC Evolution since te
  - Increase back foca accommodation
  - Increase FoV radiu accommodation. Ho SAFARI remain with
  - Decrease EPD from

ESA and JAXA/ISAS have therefore taken the difficult decision to no longer consider SPICA as a candidate to the ESA M5 selection. Both ESA and JAXA/ISAS consider this a very unfortunate development, that however is made unavoidable, among other things, by the strict financial constraints faced by both agencies. As lead institute for this mission, SRON understands the difficult position this creates and therefore accepts the necessity of this decision.

While the industrial activities for the mission studies will be brought to their natural, planned conclusion (thus providing the interested scientific community with a complete study that can allow them to usefully plan for future opportunities), these will be decoupled from the M5 selection.

Regards,

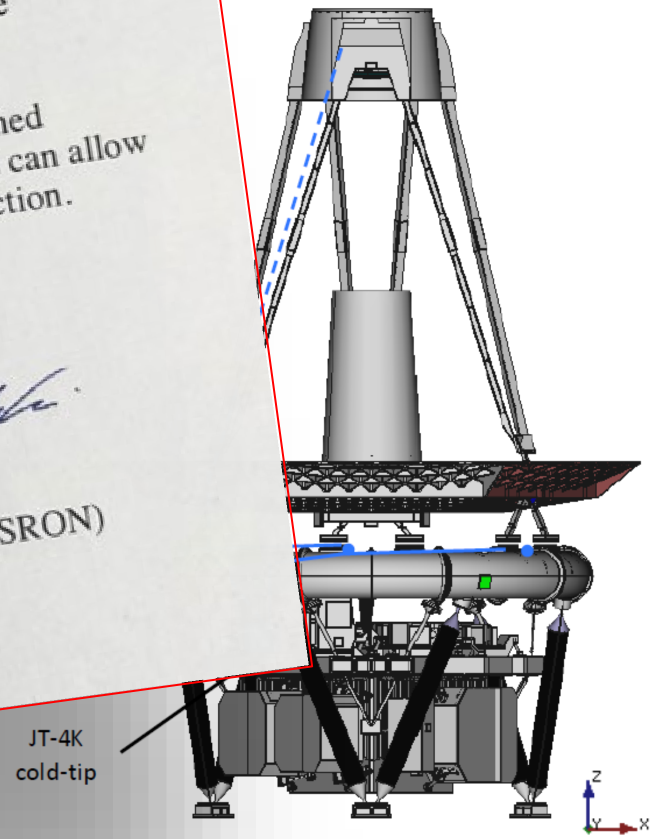
G. Hasinger (Director of Science, ESA),

H. Kuninaka (Director General, ISAS/JAXA),

M. Wise (Director General, SRON)

Oct. 7, 2020

	600 to 800 mm	705 mm
Distance Between Exit Pupil and Focus	≥ 2400 millimetres	3160 mm
Field Curvature	≥ 500 mm	512 mm



PRIMA – 2030’s NASA’s new gap filler (incl. Europe)

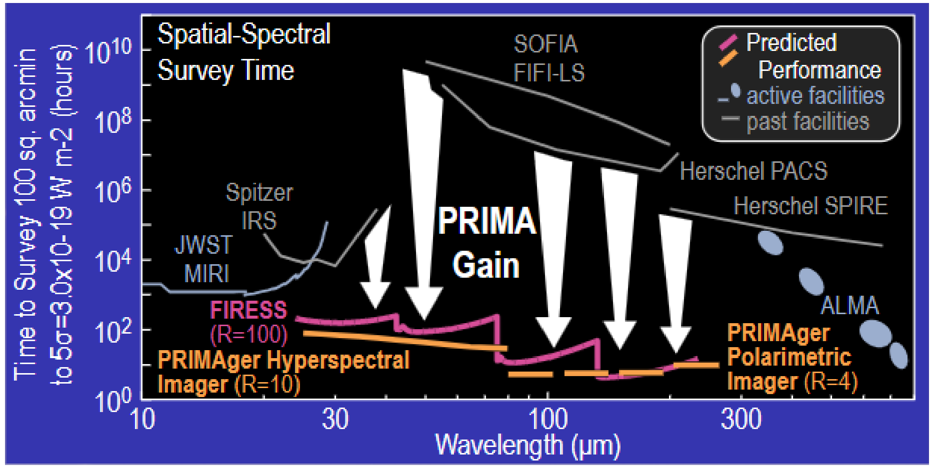
https://prima.ipac.caltech.edu/

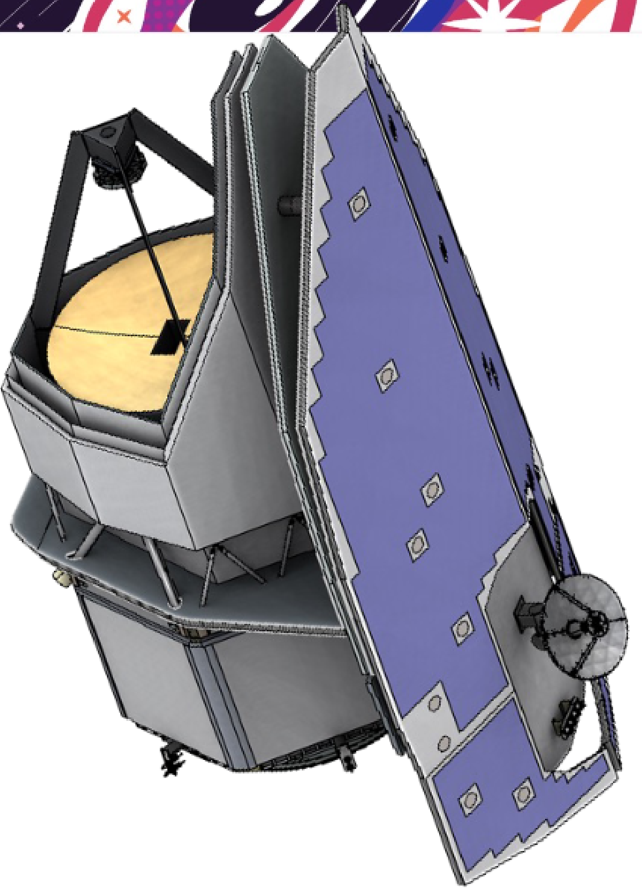
Back to Aluminium (not as easy as it seems, cf ARIEL)

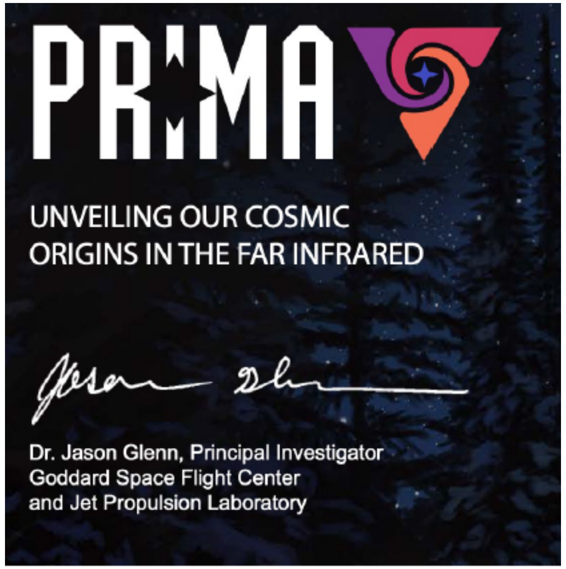
PR:MA The PRobe far-Infrared Mission for Astrophysics

PRIMA at a Glance

- 1.8-m, all-aluminum telescope cooled to 4.5 K.
- PRIMAger imager and polarimeter (France / Netherlands): 25-80 microns R=10 hyperspectral imaging, 91-232 μm imaging polarimetry.
- FIRESS Spectrometer (JPL w/ GSFC) : 24-235 μm in 4 grating modules with R>85. High-res mode gives R of thousands across full band.
- 100 mK focal planes with kinetic inductance detectors, provided by joint JPL/ GSFC and SRON team.
- JPL lead with GSFC, Ball spacecraft, IPAC data handling, many others.







Jan 11, 2024
Jason Glenn (NASA GSFC)
Presented by Margaret Meixner
(Jet Propulsion Laboratory, California Institute of Technology)
on behalf the PRIMA team.

Ted Bergin yesterday: “ PRIMA will be the glue linking JWST and ALMA ” !

AI mirror technology in Europe => ARIEL Telescope

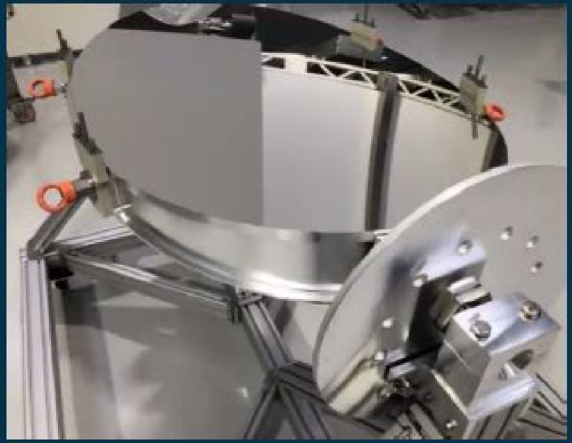
ARIEL (LS/PH)

AL polishing is more challenging than expected & M1 is now on the spacecraft critical path

Atmospheric Remote-sensing Infrared Exoplanet Large-survey

	VISphot	FGS1	FGS2	NIRspec	AIRS0	AIRS1
µm	0.5 - 0.6	0.6 - 0.8	0.8 - 1.1	1.1 - 1.95	1.95 - 3.9	3.9 - 7.8

1.8 m telescope @ 55K, 3 micron diff limit, f 13.4

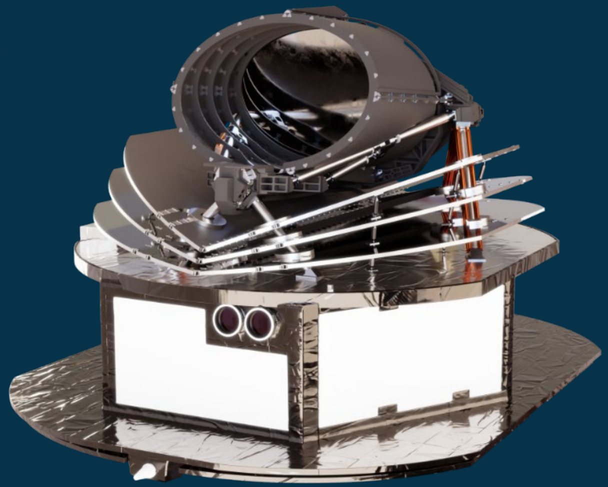


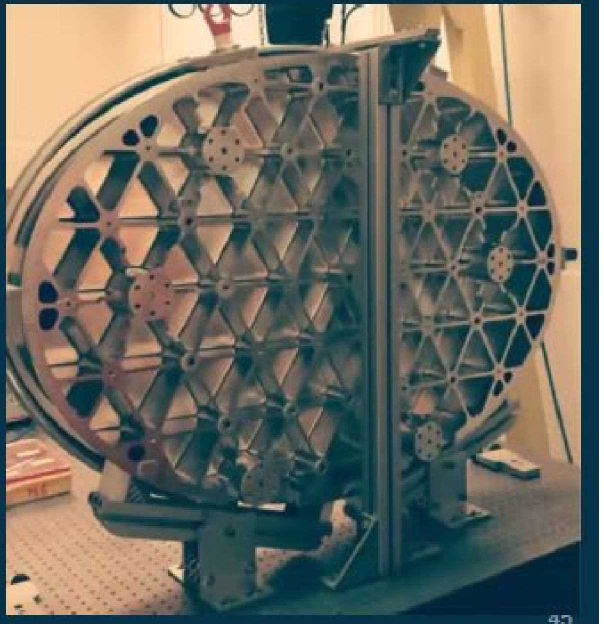
2024 Achievements

- Assessment of critical issues, trade-off, way forwards, …
    - M1 mid spatial frequencies, aperture stop
    - Straylight
    - OGSE, tests configuration

End-to-end straylight model implementation

- From individual instrument models
    - ASAP, Zemax, and FRED…





What’s next technologically for “cool” space telescopes

Al => Scale up beyond 1m class and exploit ultra lightweighting to push areal densities down

Be => Challenging in Europe, mastered in the US (JWST) => TALC?

SiC => European heritage is very well established, surface roughness can be improved with polishing layer

C/SiC => A long established challenger to SiC, but still has challenges scaling up and at cryo

Si^3N^4 => Promising, but limited size, lower surface roughness than SiC.

Technology push R&D activities ongoing.

CFRP etc => BHEX?

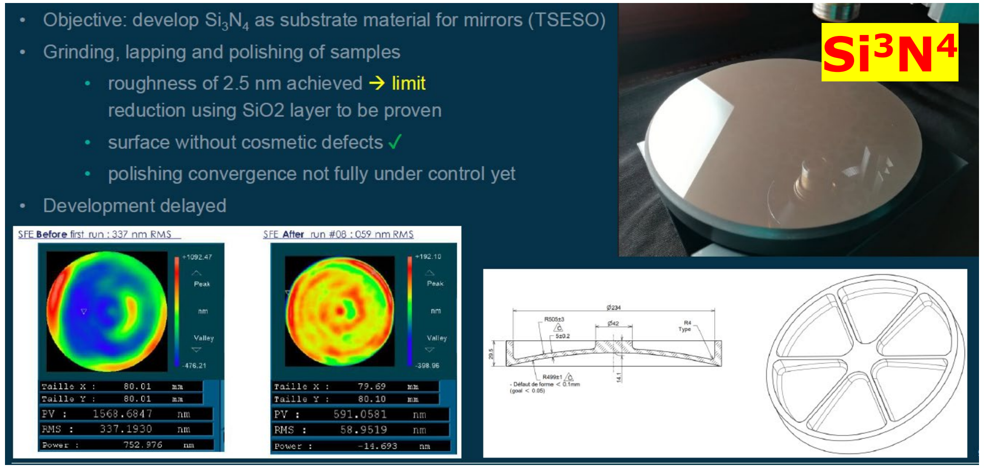
Future telescope morphologies:

Small or large monolithics; SPICA & ORIGINS?

Deployables – JWST as enabler; SUPERSHARP?

Sparse-distributed apertures – TALC?

Interferometers – LIFE as DARWIN revival etc?



Mirror shape => we’re exploring free-form as an enabler

Teamwork – Happy Herschel science community ☺

… one more thing, don't forget to submit a proposal !

https://www.cosmos.esa.int/web/call-for-missions-2025/home

Sign in → SCIENCE MISSIONS → THE EUROPEAN SPACE AGENCY → SCIENCE & TECHNOLOGY

science announcement of opportunities

To be informed about new Announcements of Calls please subscribe to the dsciannounce mailing list.

Announcement of Opportunity	Status
Call for a Medium-size and a Fast mission Opportunity in ESA's Science Programme	**Open** Deadline for receipt of Step-1 proposals: 21 May 2025 – 12:00 (noon) CEST Deadline for receipt of Step-2 Medium-class proposals: 19 March 2026 – 12:00 (noon) CET Deadline for receipt of Step-2 Fast-class proposals: 21 April 2026 – 12:00 (noon) CEST

References

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Next Generation Space Telescope Science and Technology, ASP Conference Series, Vol. 207. Proceedings of a conference held at Hyannis, MA, 13-16 September, 1999. Edited by Eric Smith and Knox Long. ISBN: 1-58381-036-6 (2000)., p.43. http://adsabs.harvard.edu/abs/2000ASPC..207..435C

Architecture of the FIRST Telescope., E. J. Cohen et al, In Radio Telescopes, Harvey R. Butcher, Editor, Proceedings of SPIE Vol. 4015 (2000)

J. Michael Rodgers, James P. McGuire, Robert J. Calvet, "*Optical and opto-mechanical design of the PRIMA telescope*," Proc. SPIE 12676, UV/Optical/IR Space Telescopes and Instruments: Innovative Technologies and Concepts XI, 126760B (24 October 2023) https://doi.org/10.1117/12.2676221

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