Observing with SOFIA

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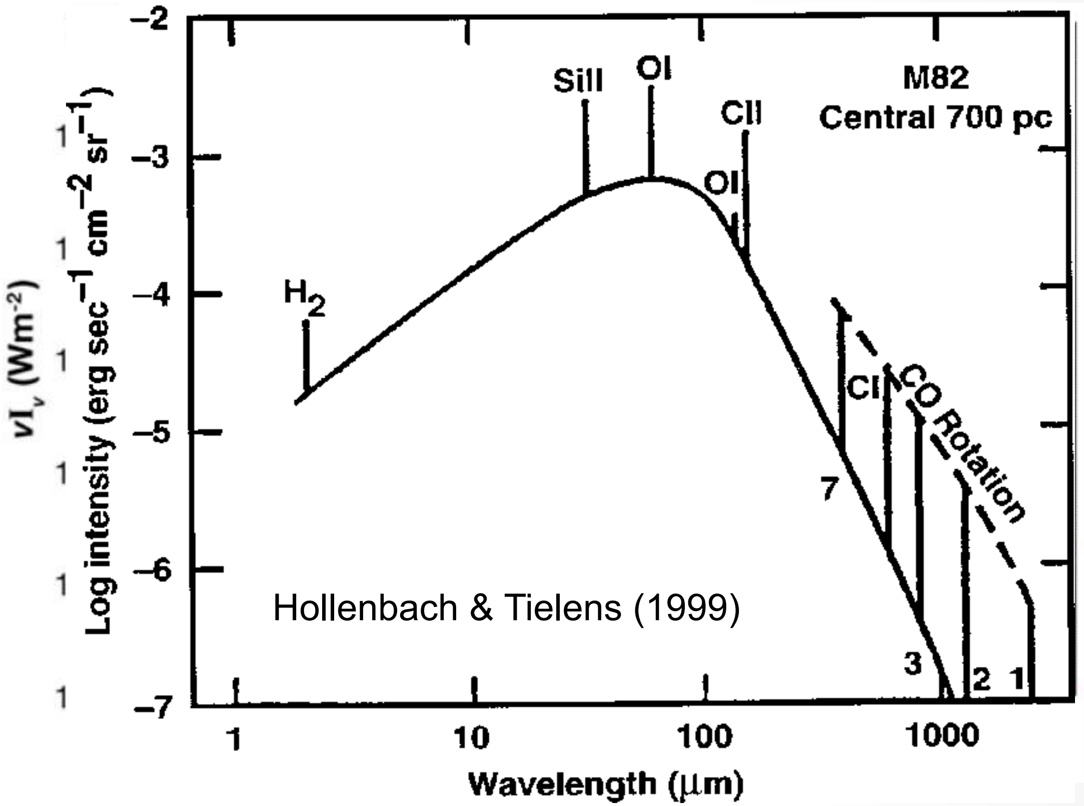
Motivation for Infrared Astronomy

- The **infrared** is a key part of the spectrum.
- The emission arises from **gas and dust** not in stars and allows to study the **colder universe**.
- It is crucial for studying the interstellar medium, young stars, galaxies, and planets.



All galaxies have an emission peak in the
inf
pea
the

On top of the dust continuum, the interstellar gas radiates significant amounts of energy in fine-structure lines.

DUSTY INFRARED GALAXIES: SOURCES OF THE COSMIC INFRARED BACKGROUND
Lagache et al., Annu. Rev. Astron. Astrophys. 2005. 43: 727-768

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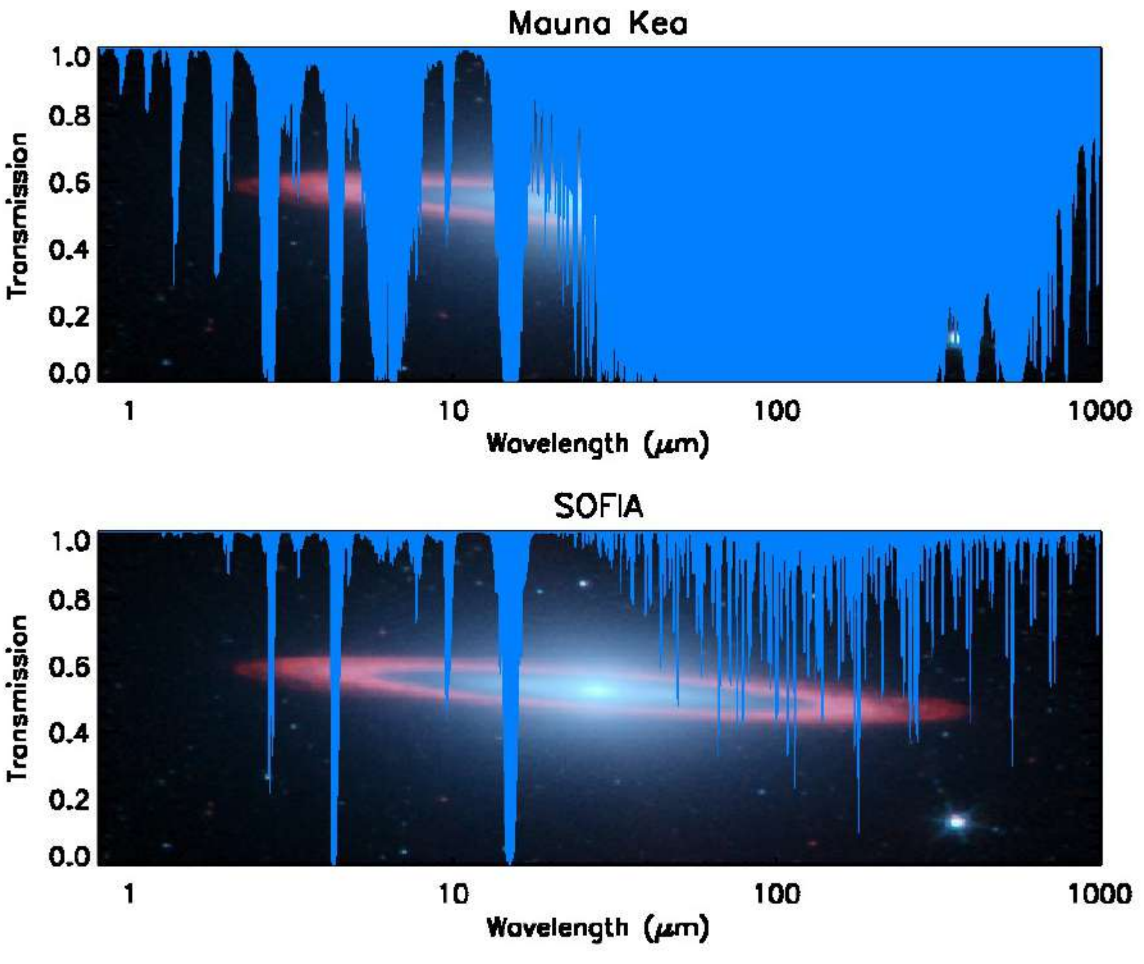
Motivation for SOFIA

- However, the Earth's atmosphere is **opaque** to large parts of the infrared wavelength range.
- **Water vapor** absorbs much of this radiation.
- Need to rise above 99% of the water vapor.



SOFIA Starting to Observe

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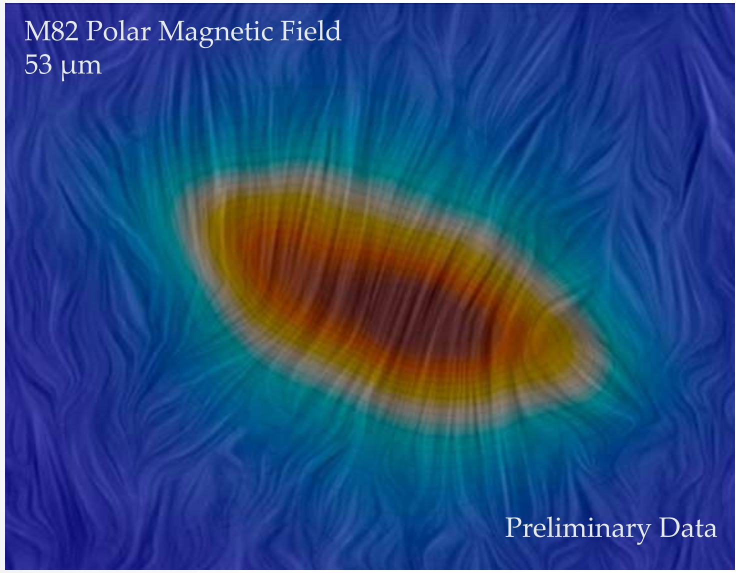
Starburst Galaxies vs Active Galactic Nuclei

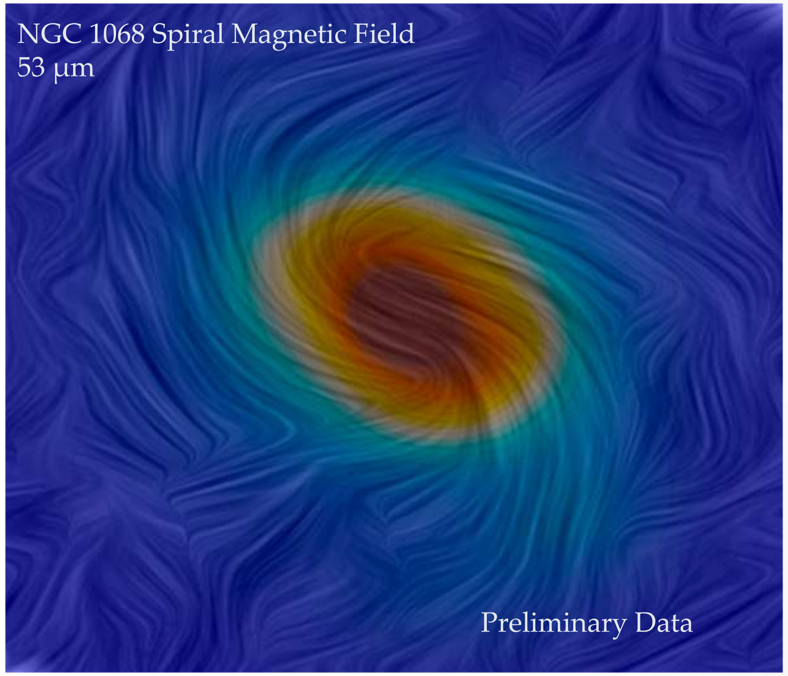
Starburst Galaxy

Dusty galactic outflows driven by star formation



Active Galactic Nuclei

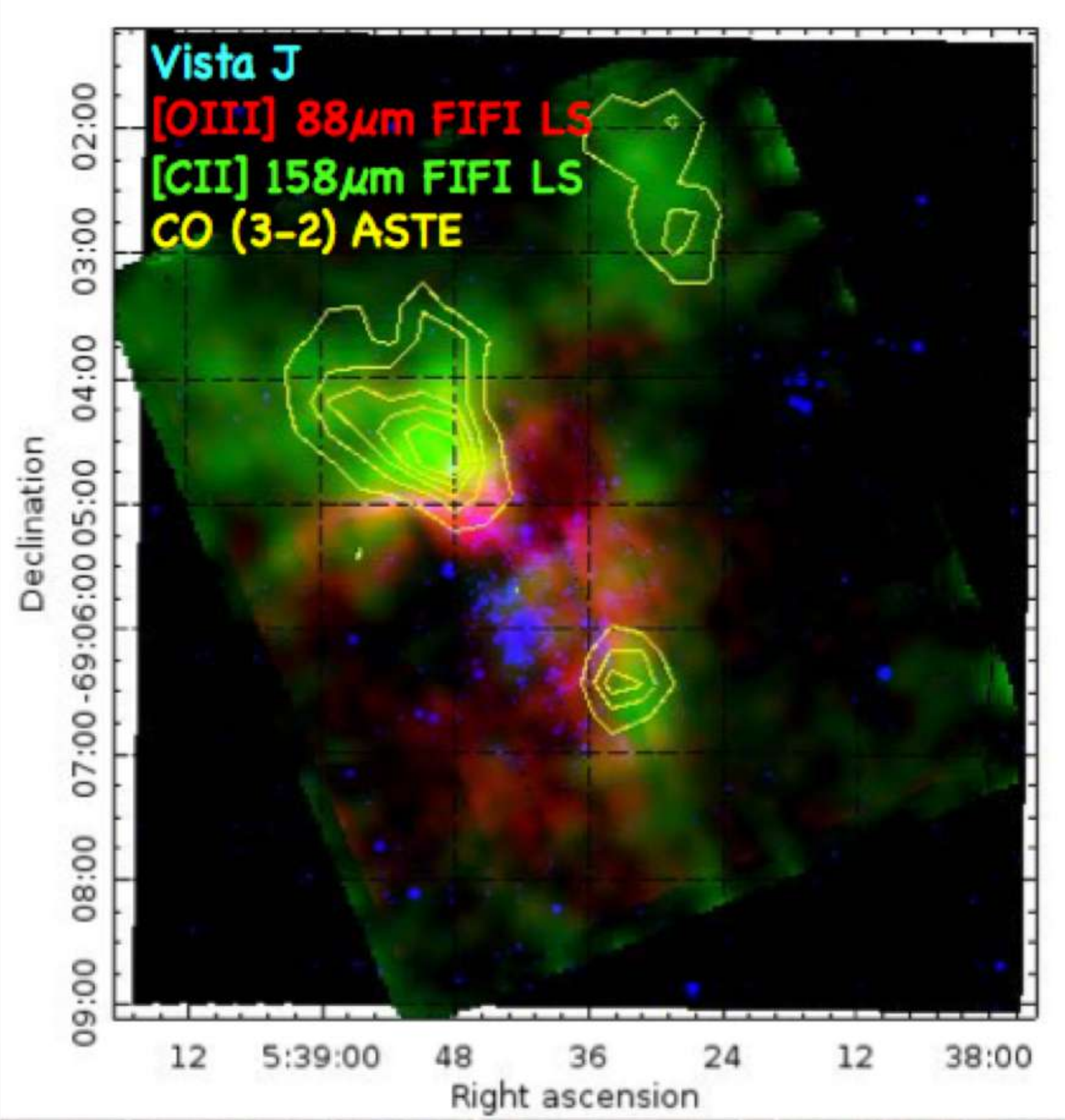
Magnetic arms due to polarized emission from aligned dust grains

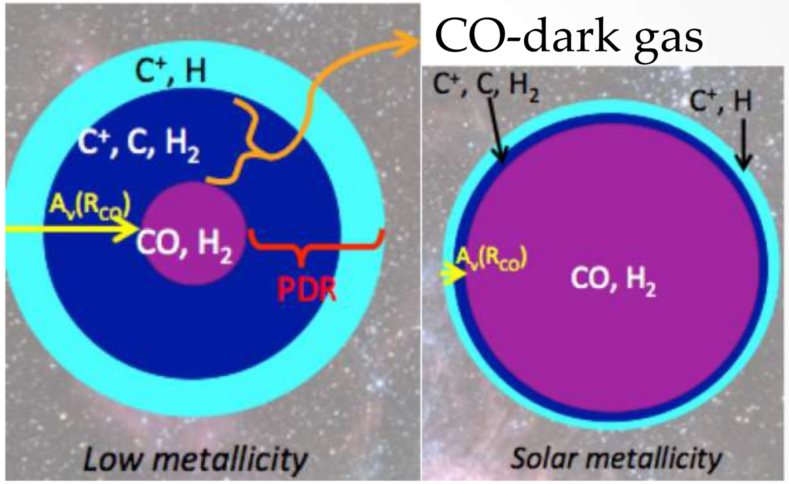


Polarized emission traces ordered magnetic fields.

Polarization Observations of Active Galaxies
Lopez-Rodriguez, E., et al., in prep
Instrument: HAWC+, 53–89 μm

30 Dor in the LMC with FIFI-LS



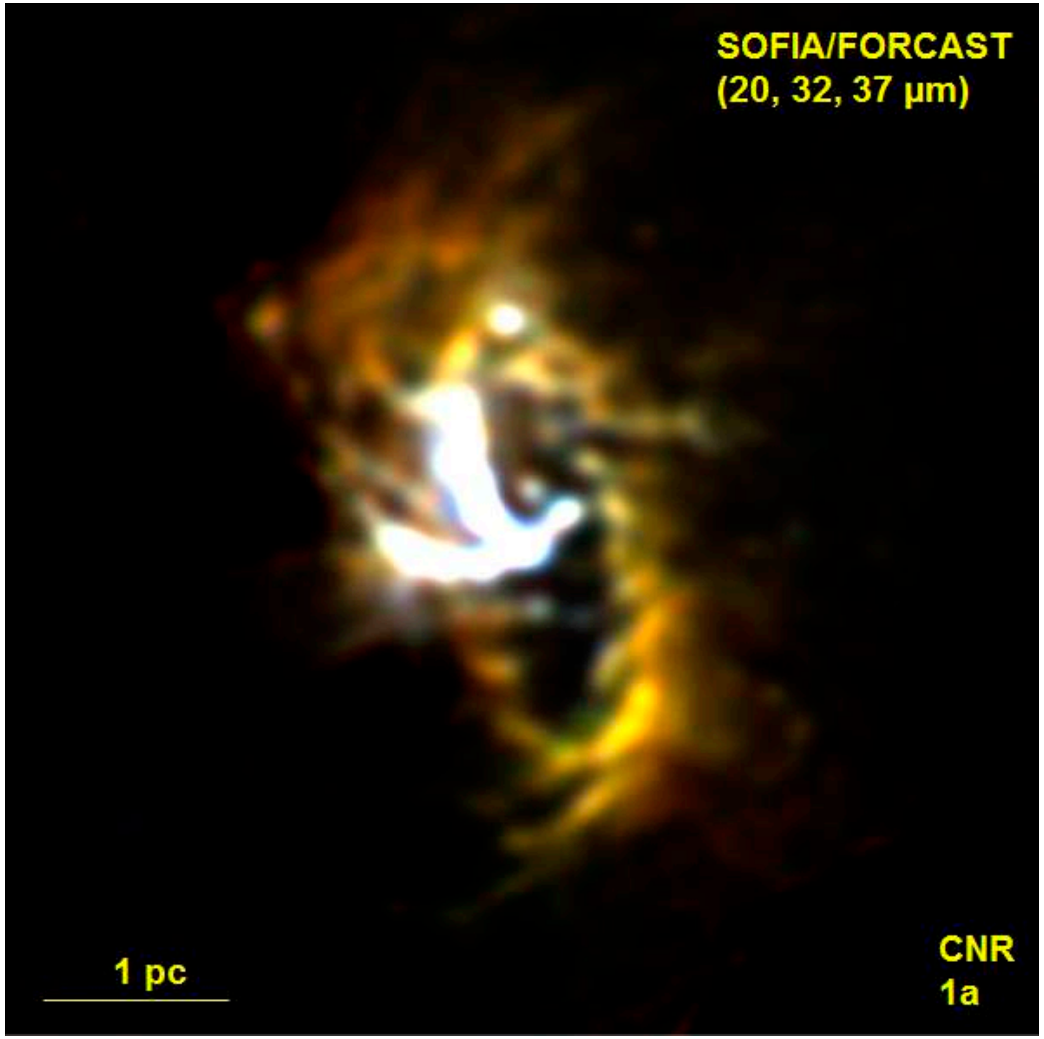


Tracing the different phases of the ISM and **CO-dark molecular gas** with several fine-structure lines in the 30 Dor observing a starburst in a low-metallicity environment.

30 Dor contains the cluster R136, which contains the most massive known star (315$M_{\odot}$).

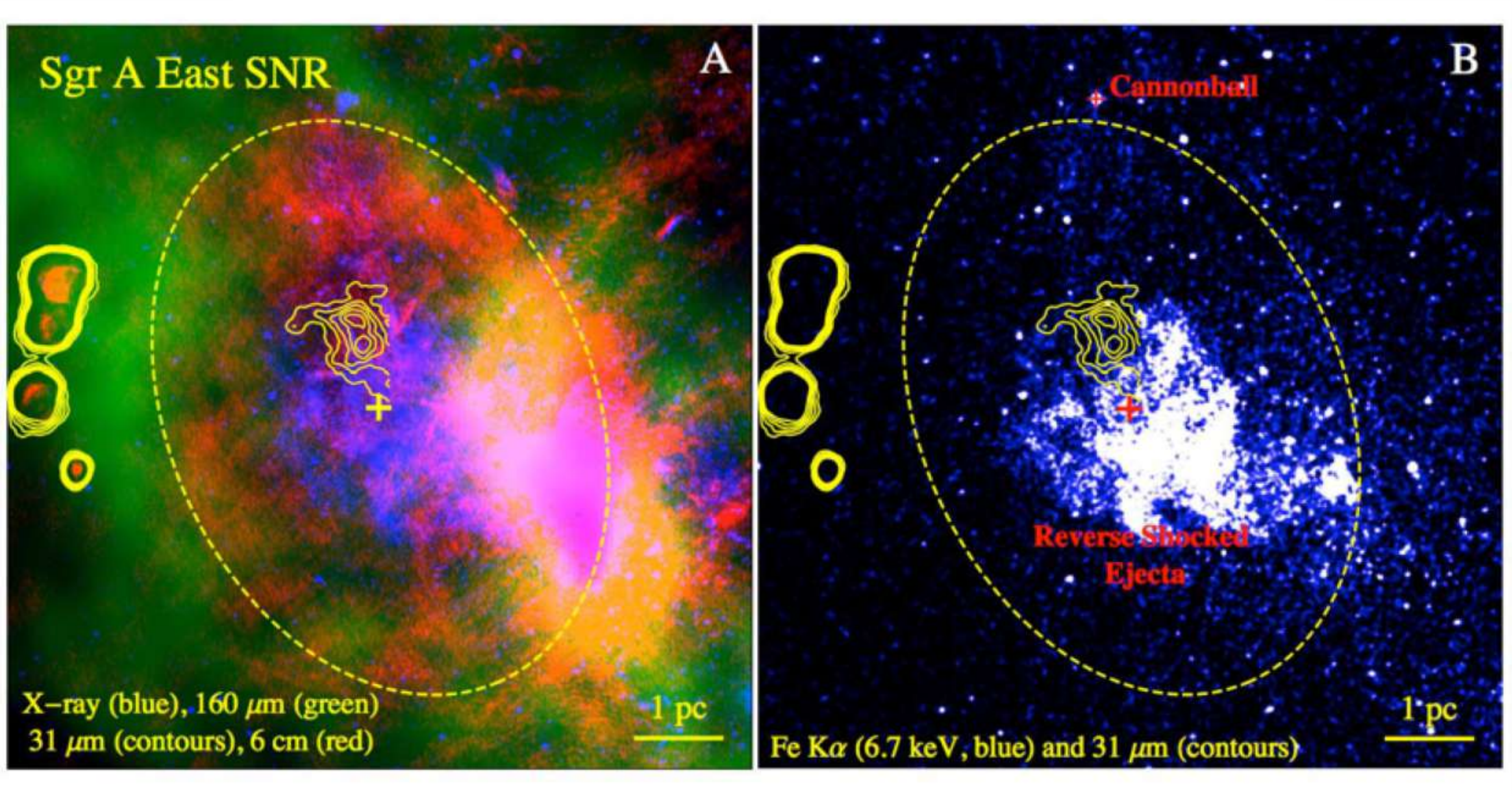
Chevance et al. (SOFIA tele-talk 2016)

Galactic Center with FORCAST



SOFIA/FORCAST Imaging of the Circumnuclear Ring at the Galactic Center.
Lau, R.M. et al. 2013 ApJ, 775, 37.

Dust in a supernova remnant with FORCAST

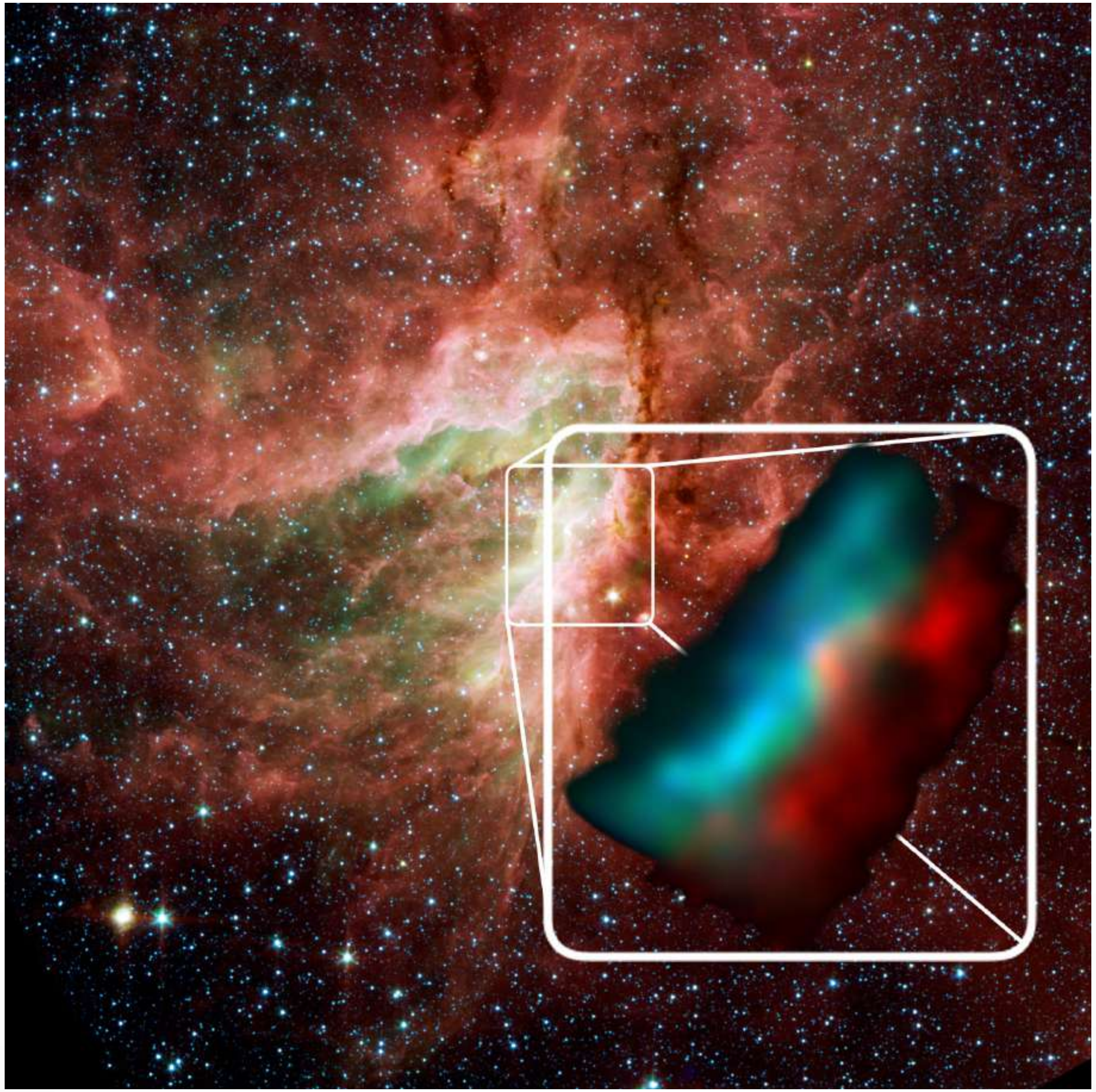


(A)Composite false-color image of the Sgr A East SNR overlaid with contours of the 31.5 μm emission east of the Circumnuclear Disk. Blue: 2 - 8 keV (Chandra), green: 160 μm (Herschel), red: 6 cm (VLA).
(B)Fe Kα (6.7 keV) emission from the SNR overlaid with the 31.5 μm emission

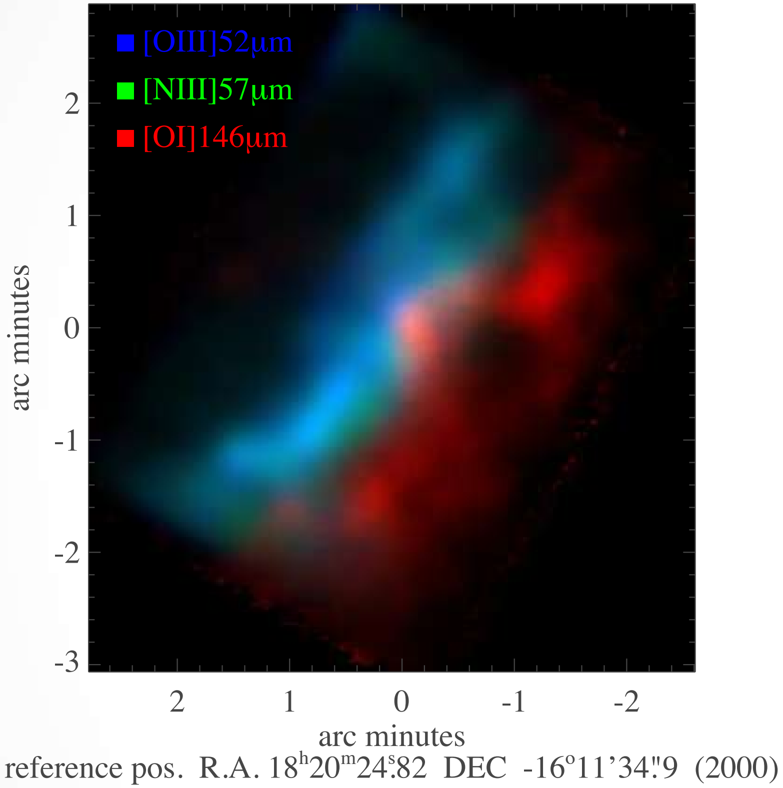
Old supernova dust factory revealed at the Galactic center.
6700$M_\oplus$ of warm (100K) dust observed that survived the reverse shock.

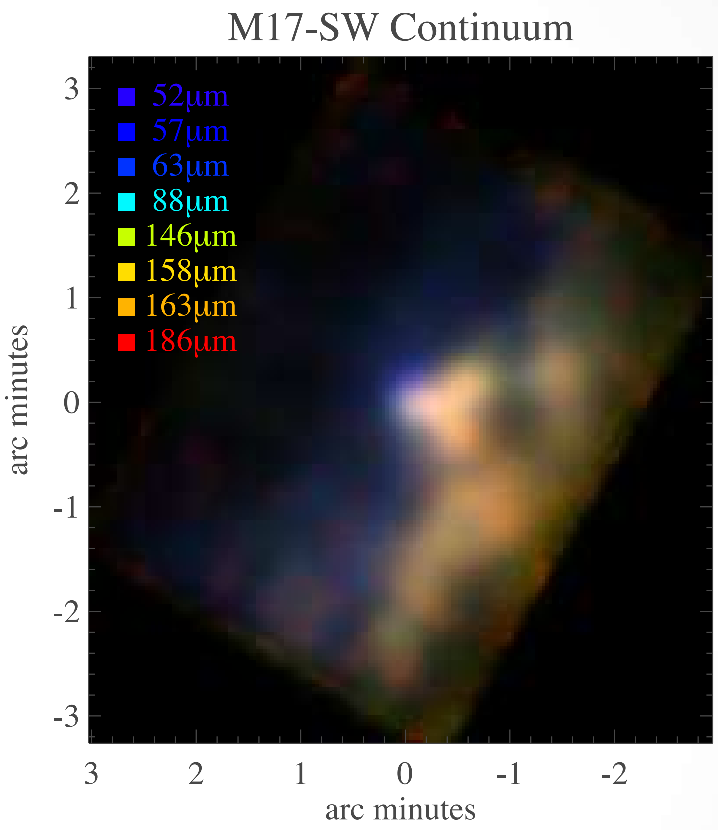
Lau, R. et al. 2014 Science 348, 413.

M17-SW with FIFI-LS



M17-SW with FIFI-LS

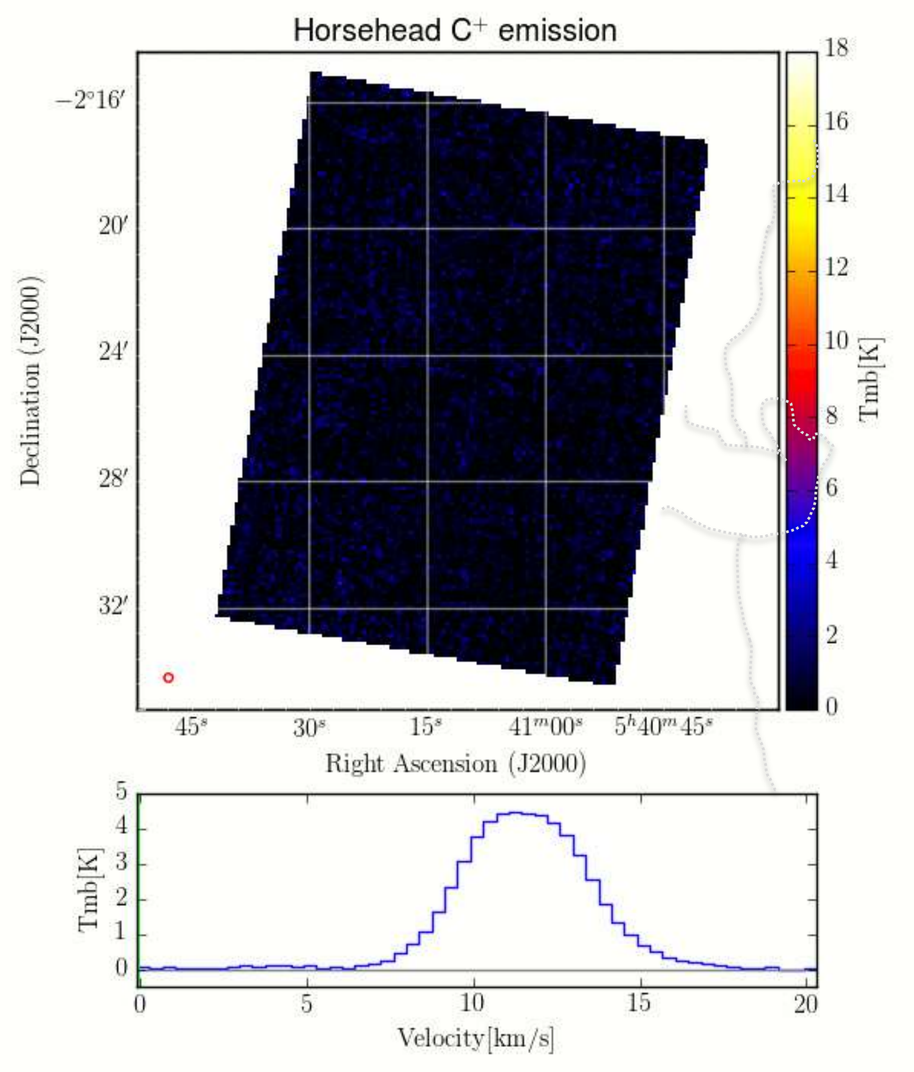




M17-SW is a well studied Photon-Dominated Region (PDR), the transition region from ionized to molecular gas.

The lines from ionized and neutral species trace the different regimes. Also the color temperature of the continuum indicates the transition from a warmer to a colder phase.

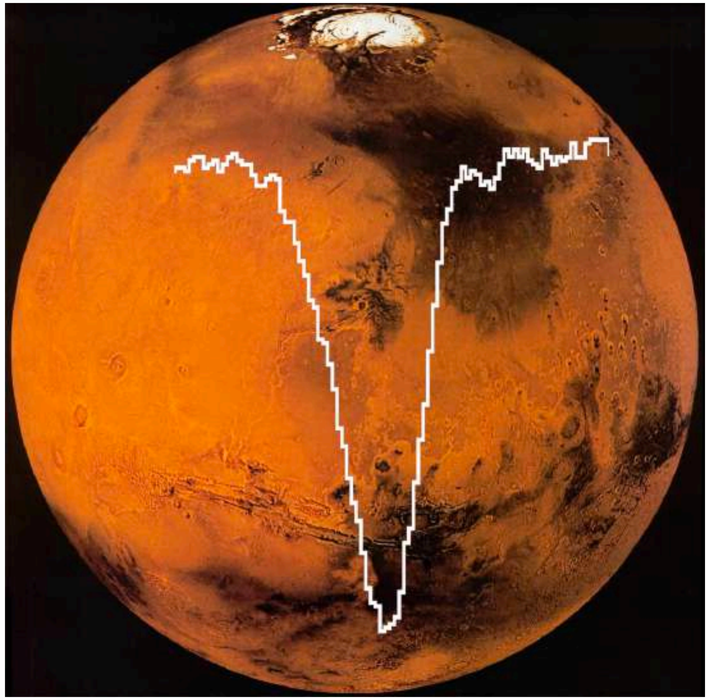
Horsehead with upGREAT



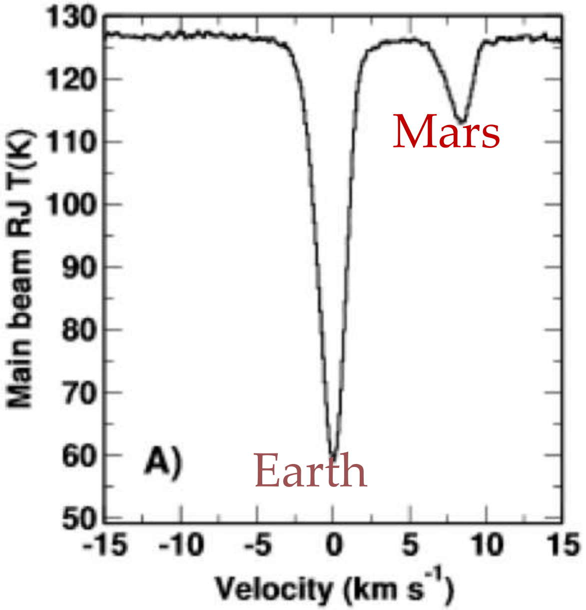
Averaged line profile over mapped region. Smoothed to 0.76 km/s velocity resolution

Map required 4.5^h of SOFIA time, would have taken $>200^h$ on Herschel/HIFI.

First detection of atomic oxygen in Mars' Mesosphere with GREAT

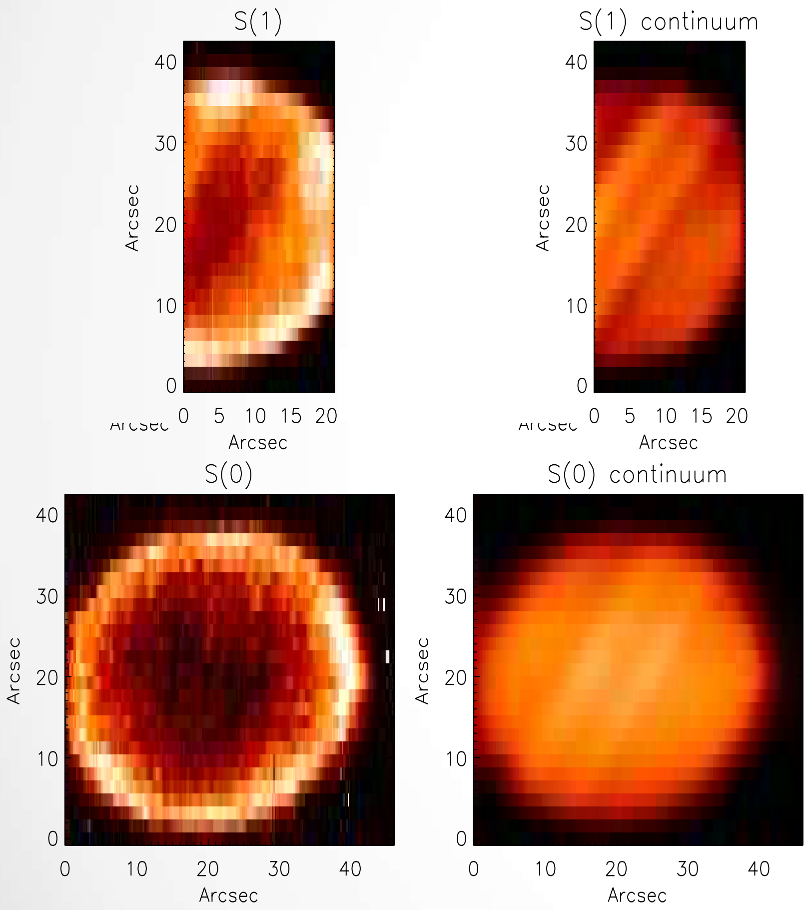


GREAT: 63μm line



First detection of the 63 um atomic oxygen line in the thermosphere of Mars with GREAT/SOFIA. Rezac, L. et al. 2015 A&A, 580, L10.

Ortho/para H_2 maps of Jupiter with EXES



- Spectral maps produced by stepping slit position across extended sources
- Stratospheric emission from H_2 shows limb brightening
- S(0) at 28.3um is cannot be observed from ground.
- S(1)/S(0) gives temperature, with long latency
- The ortho-para ratio measures vertical transport of H_2 in the Jovian atmosphere. High ratios are from warm clouds deeper inward that rise.

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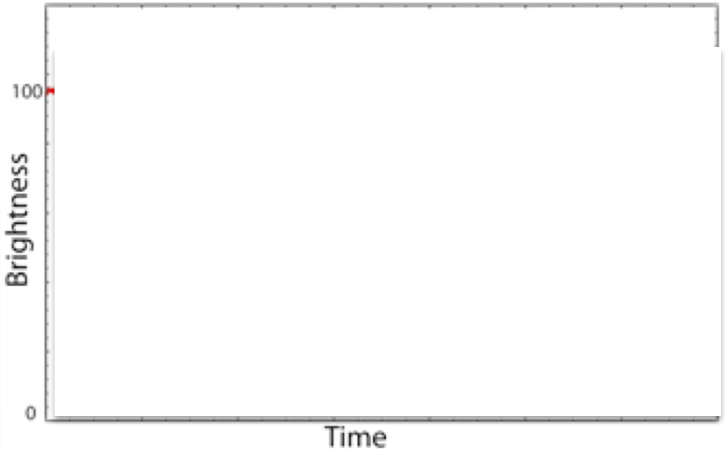
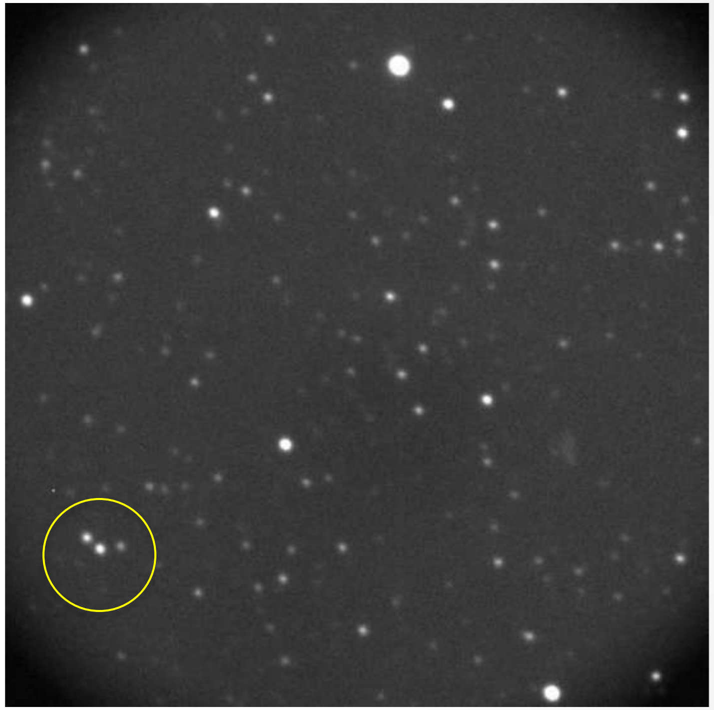
Pluto Occultation with HIPO, FLITECAM, FPI

- Occultation of 12-mag star by Pluto on 2015 June 29
- Simultaneous SOFIA observations with HIPO, FLITECAM, & FPI
- Final ground-based shadow updates required course adjustments of 230 km
- Detection of strong "central flash" confirms accuracy of course corrections
- Comparison of multi-wavelength observations will allow detailed analysis of atmospheric profiles and aerosol content.



As observed by SOFIA, the central bright flash represents starlight refracted by the atmosphere of Pluto when the star was completely behind the planet.



Focal Plane Imager+ observation of Pluto occultation event on UT 2015-06-29 16:55. Video is approximately 4X real time.

Pillars of the SOFIA Project

- **Science:**
  - Unique access to Mid- and Far-Infrared for the scientific community
  - Flexible and comprehensive instrument suite
  - Northern and Southern hemisphere
- **Technology**:
  - Testbed for new detectors / instrument development
  - Always state-of-the-art technology (allowable to have “problems”)
  - Instrument access in flight
- **Education**:
  - Unique opportunities for education and public outreach
  - Educators get an extraordinary first-hand experience of science
  - Combines the fascination for aircrafts and astronomy

The Observatory

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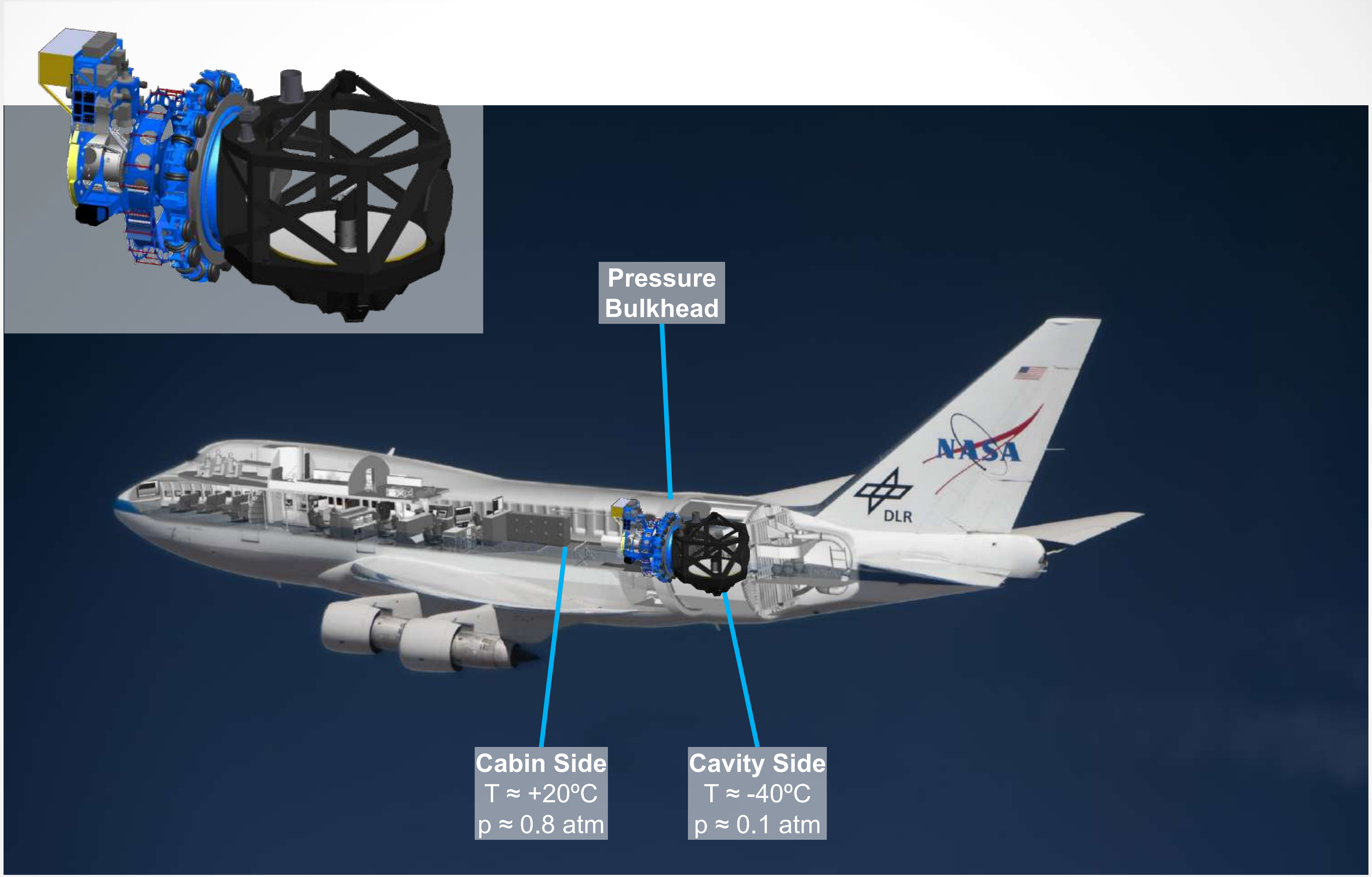
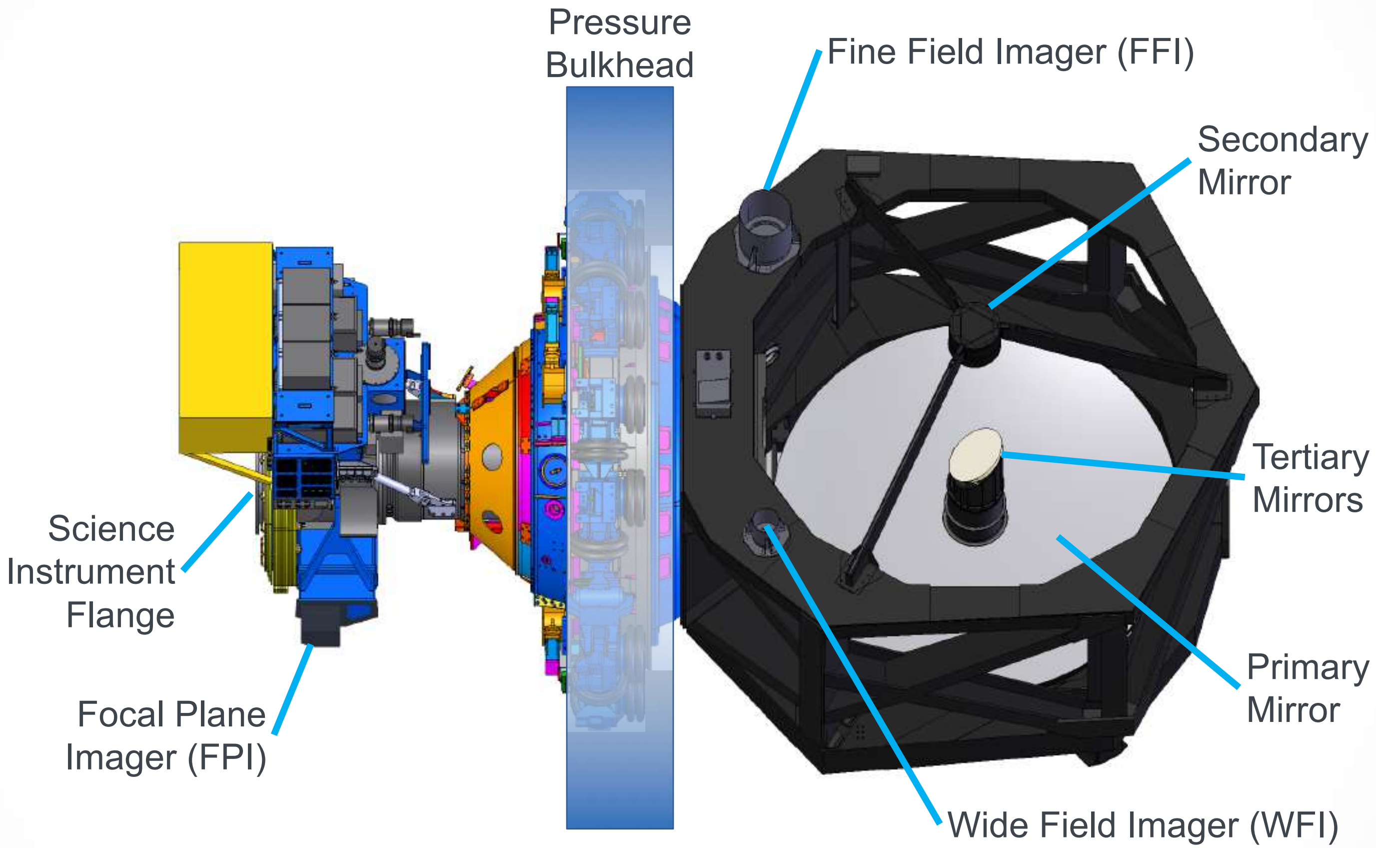

Pressure Bulkhead
Cabin Side
T ≈ +20ºC
p ≈ 0.8 atm
Cavity Side
T ≈ -40ºC
p ≈ 0.1 atm
NASA
DLR

SOFIA Telescope Assembly

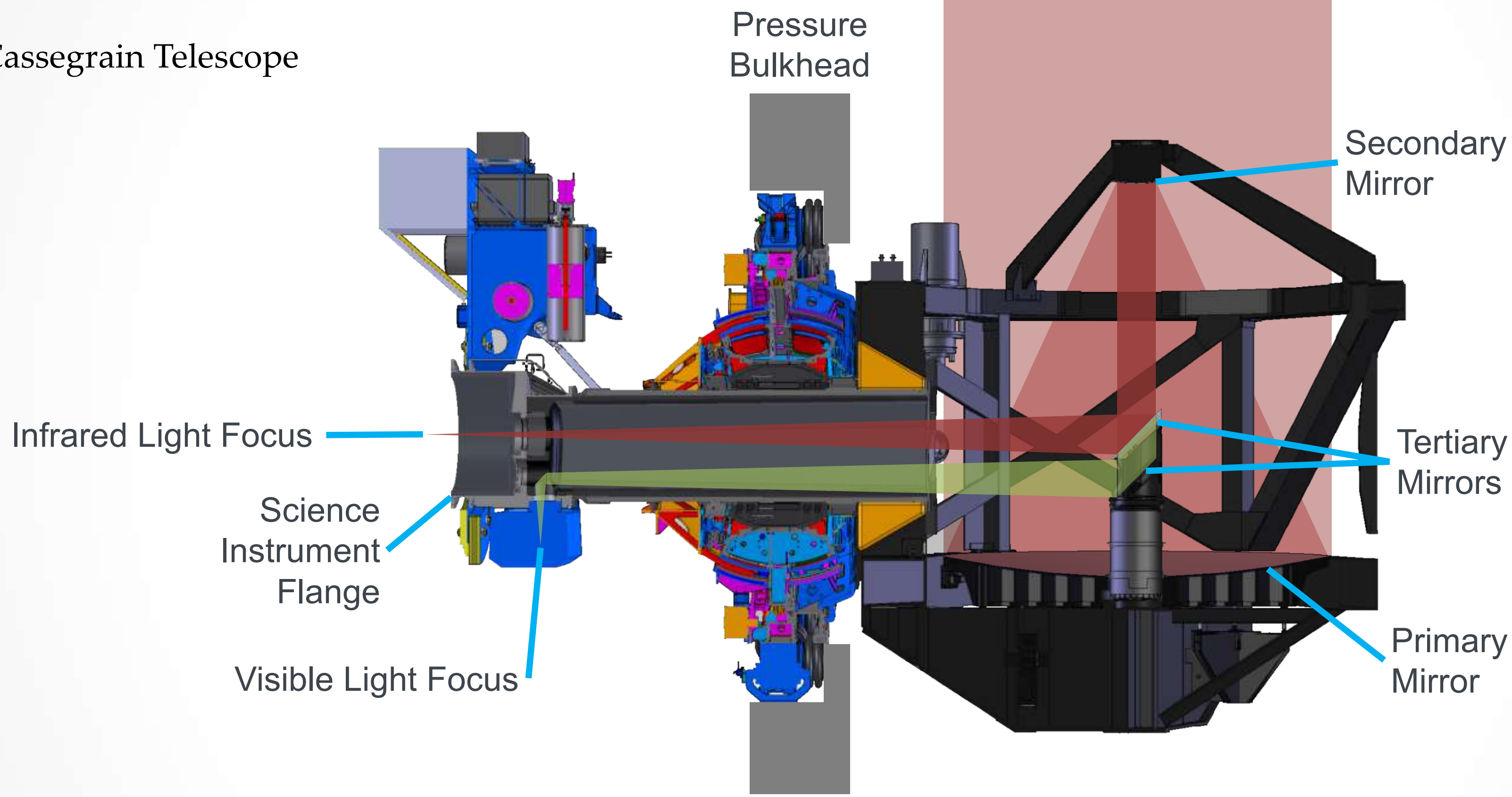


Cabin Side
T ≈ +20ºC, p ≈ 0.8 atm

Cavity Side
T ≈ -40ºC, p ≈ 0.1 atm

SOFIA Telescope Assembly

Cassegrain Telescope



Cabin Side
T ≈ +20ºC, p ≈ 0.8 atm

Cavity Side
T ≈ -40ºC, p ≈ 0.1 atm

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Telescope

The telescope was built by our partner, the German Aerospace Center, DLR. It is made of a glass-ceramic material called Zerodur that does not change shape when exposed to extremely cold temperatures. The telescope has a honeycomb design, which reduces the weight by 80%, from 8,700 lb to 1,764 lb.

The mirror has a diameter of 2.7 m. Due to the usage of the secondary for chopping, the effective diameter is 2.5 m.

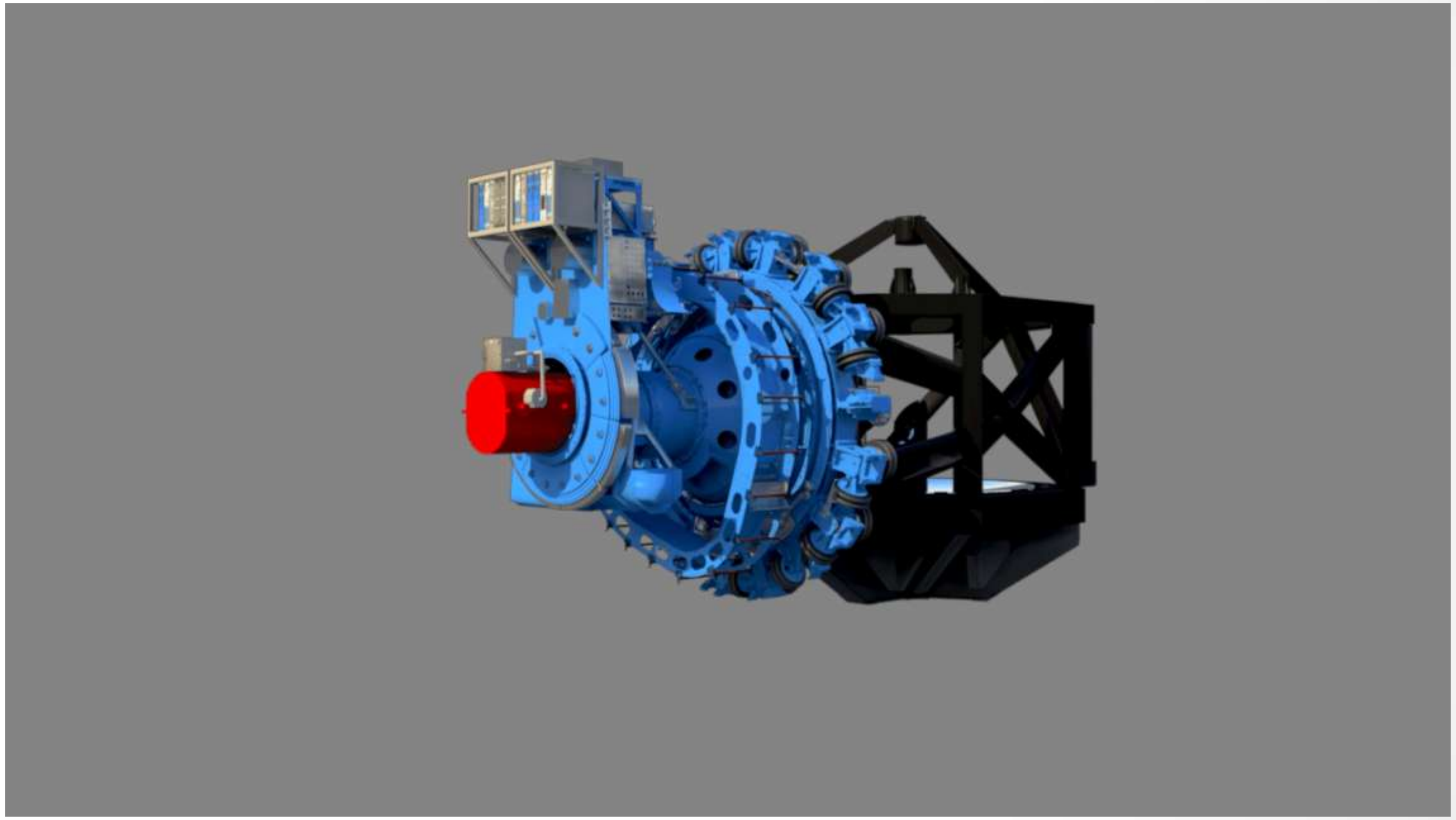
Instruments

Instruments are mounted on the instrument flange one at the time.

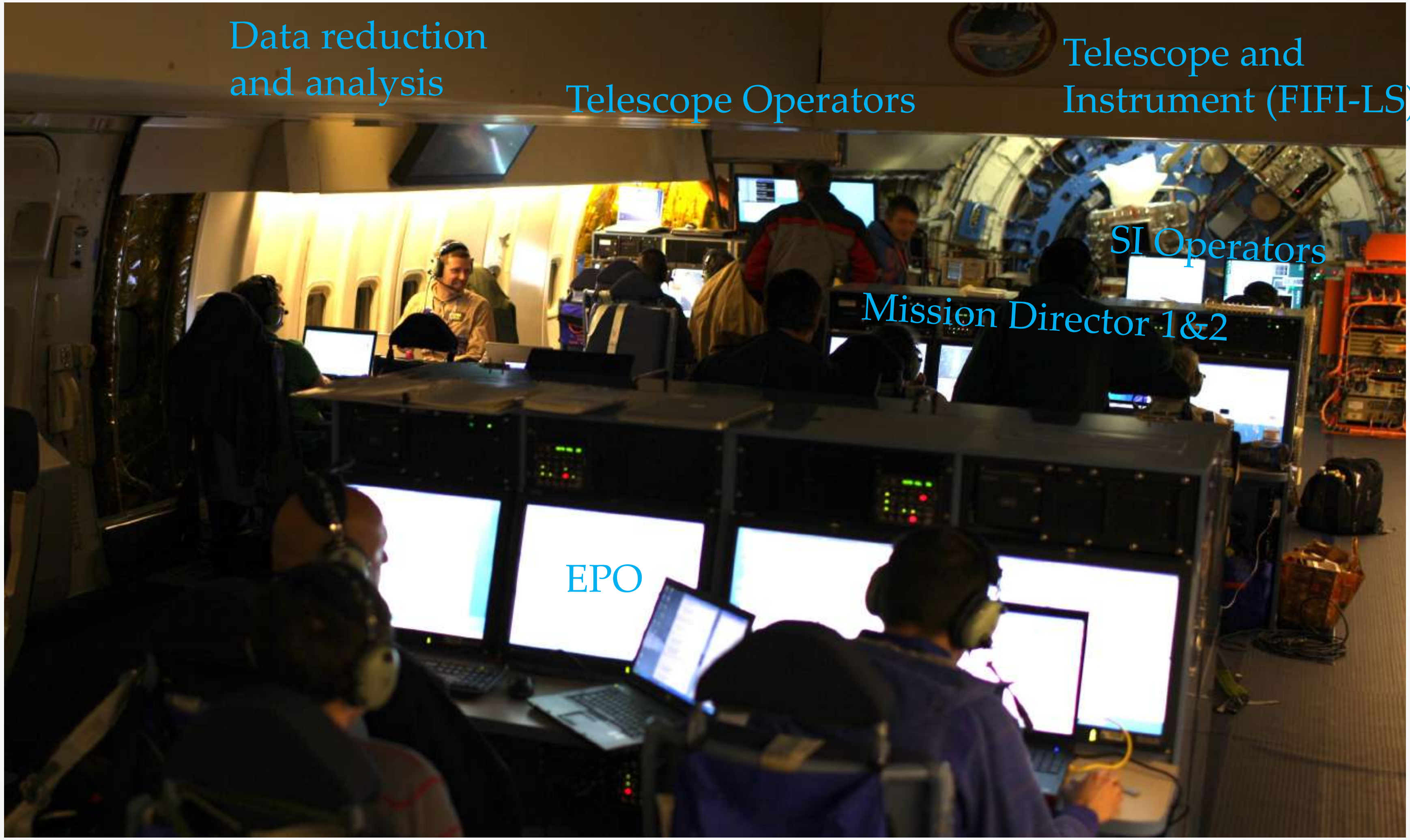
A typical observation series lasts 1 to 3 weeks. Changing instruments takes 2 days of work.

Currently there are 5 instruments available plus the optical camera.

A 3rd generation instrument is in development and there is a call for a 4th generation instrument.



Inside SOFIA



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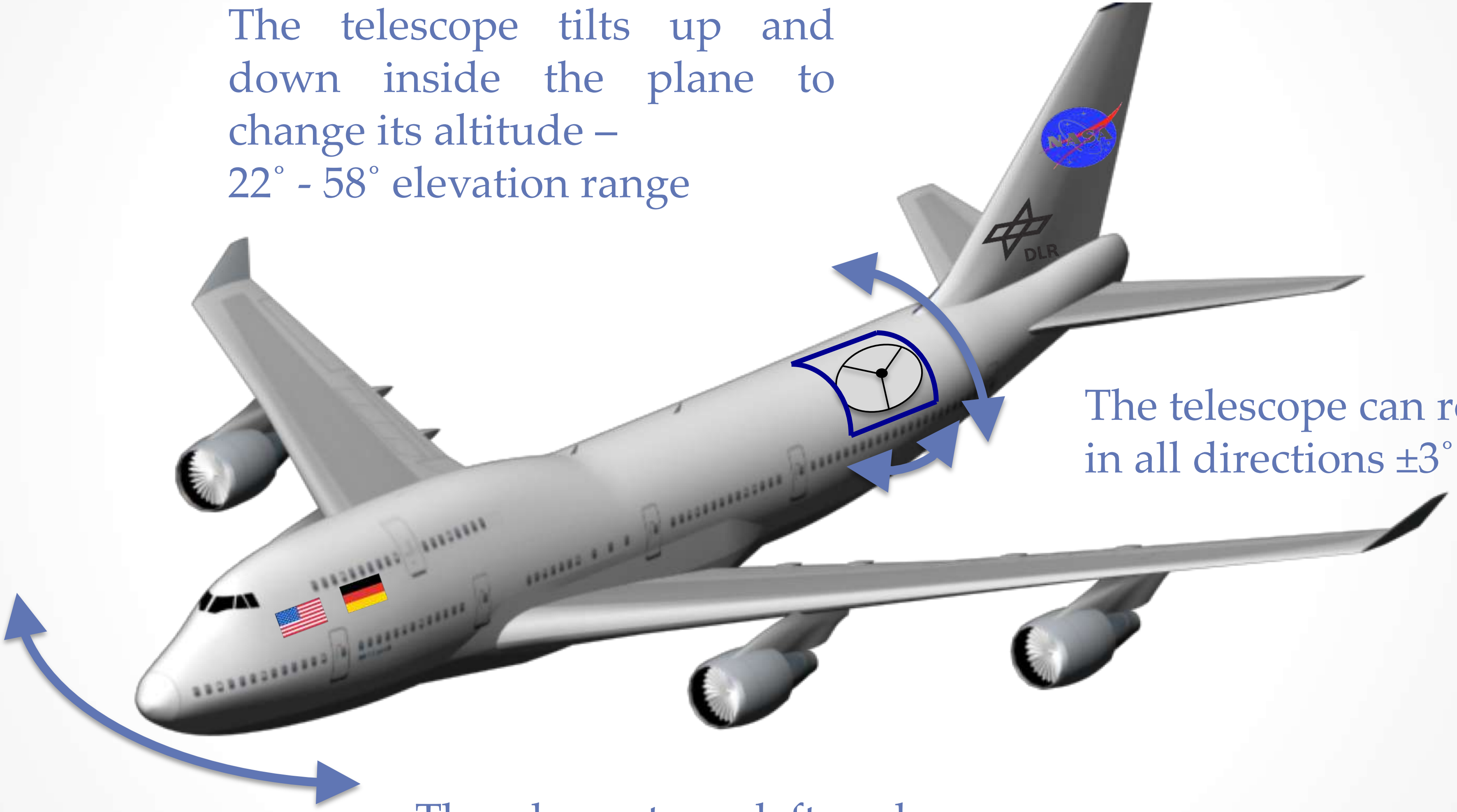
Airborne Observatory Alt-Az

The telescope tilts up and down inside the plane to change its altitude –
22° - 58° elevation range



The telescope can rotate in all directions ±3°

The plane steers left and right to change azimuth

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Apparent Telescope Jitter

In flight, the telescope appears to jitter because of the motion of the plane relative to the motion of the telescope. The telescope is actually held stationary (within the inertial reference frame of the plane's motion) to remain fixed on its target of observation, shown in the video on the right as a star. The plane is moving with respect to the telescope, thus creating the apparent jitter of the telescope.

Image quality

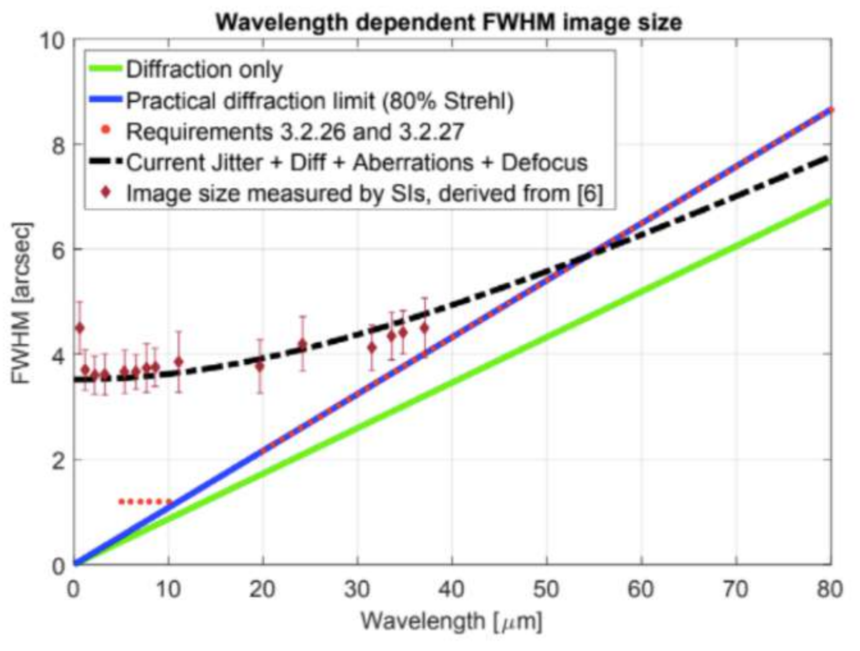
Image stabilization – Pointing is handled by Focal Plane Imager, 8’ FOV with 50 Hz updates to the tip-tilt secondary mirror.

PSF FWHM starts at around 3.5” at short wavelengths and asymptotes to diffraction limits at longer wavelengths

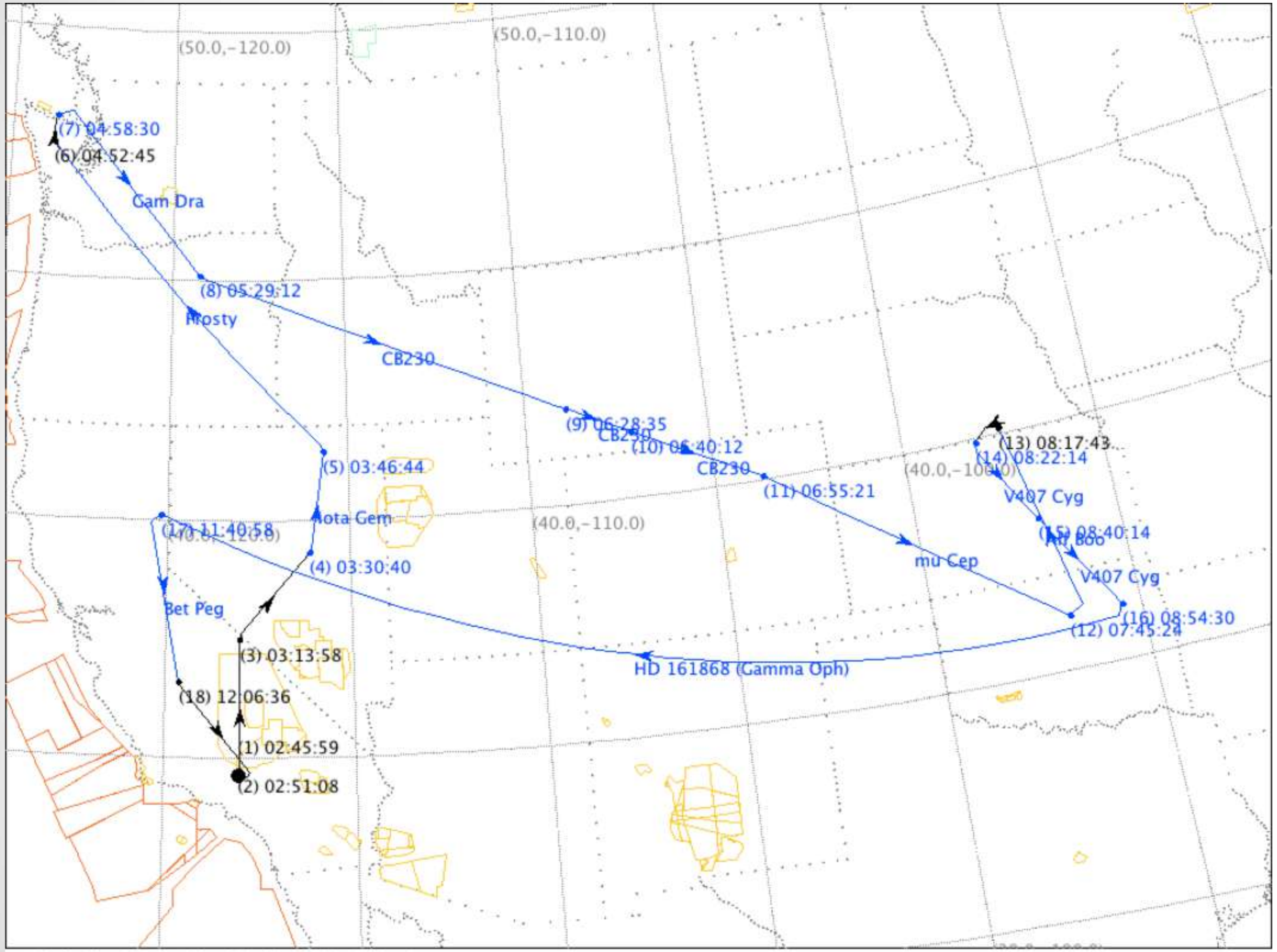
PSF contribution comes from Pointing jitter + Diffraction + Aberrations + Defocus

Tip / Tilt Movements of the Secondary Mirror

off **on**



Flight plans

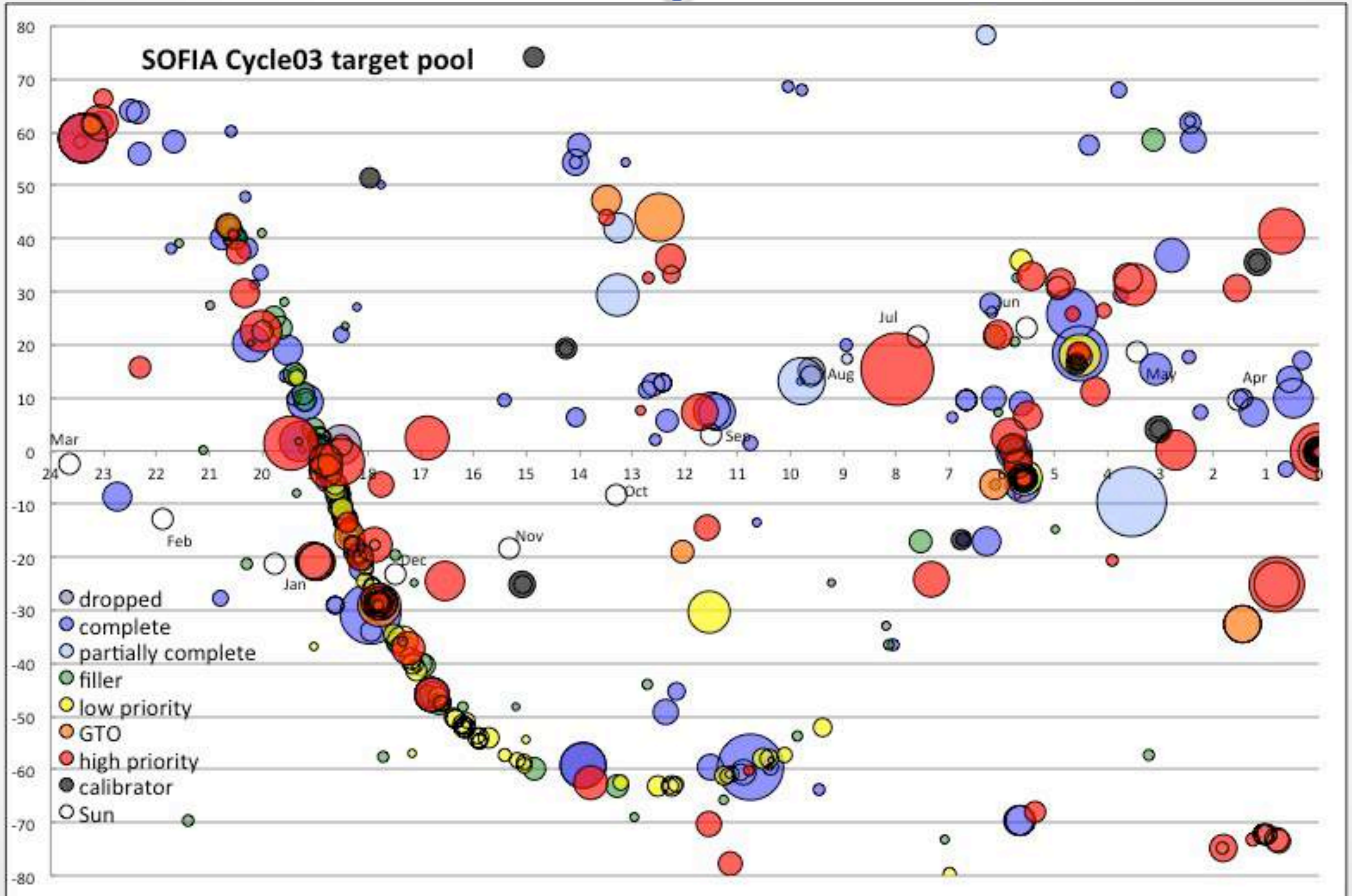


Flight Plan Name: File: BS1_01_Wx12_Fallon.fp
Flight ID: 2011/05/06
Est. Takeoff Time: 2011-May-06 02:45 UTC
Est. Landing Time: 2011-May-06 12:29 UTC
Flight Duration: 09:44
Weather Forecast : 0000 Mon May 16 2011 - 1200 Wed May 18 2011 UTC
Saved: 2011-May-16 22:37 UTC User: kbower

10 hrs take-off to Landing due to crew fatigue rules

Round trips from either Palmdale, CA or Christchurch, NZ

Where are the targets?



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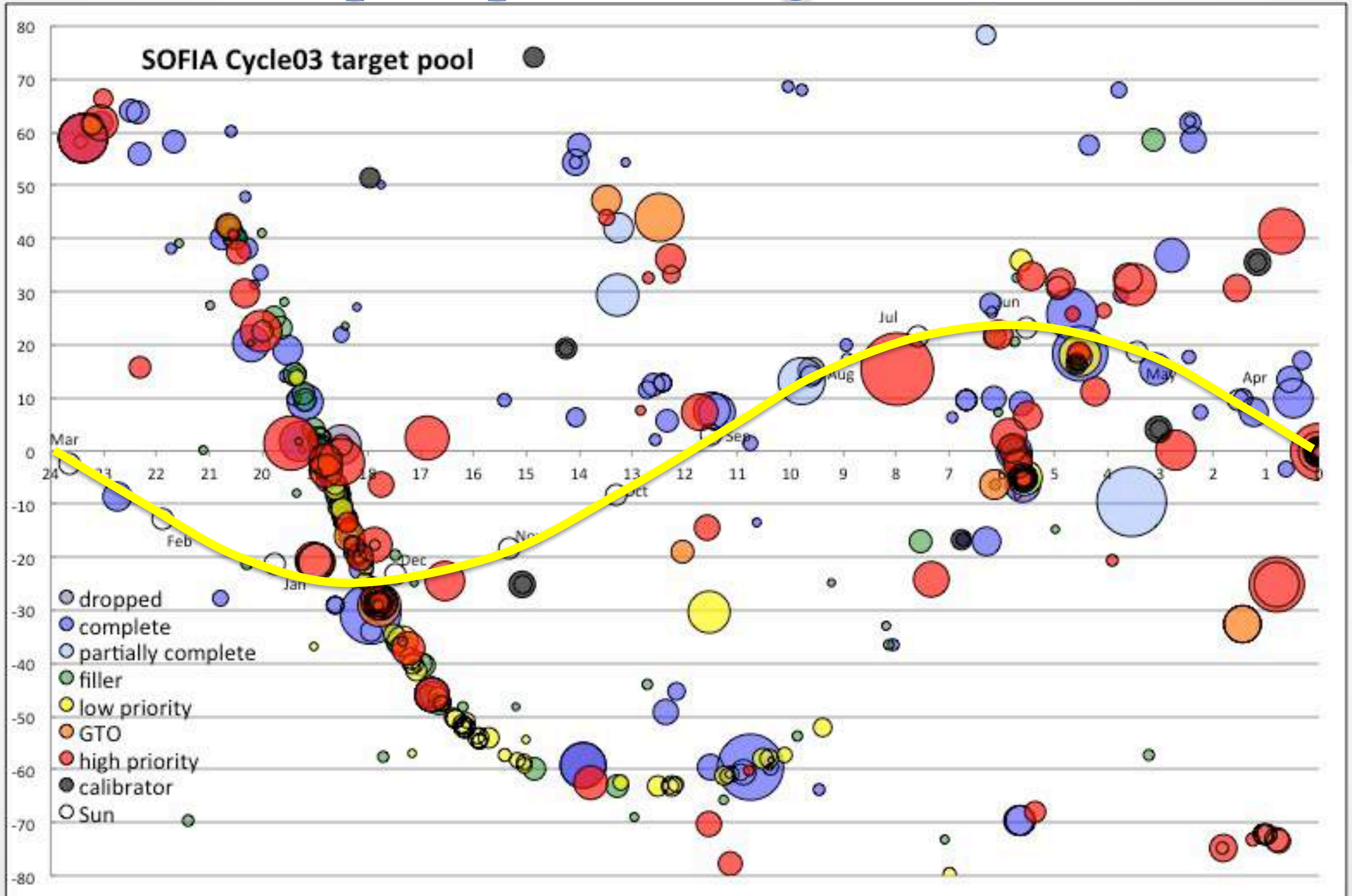
The ecliptic plane targets



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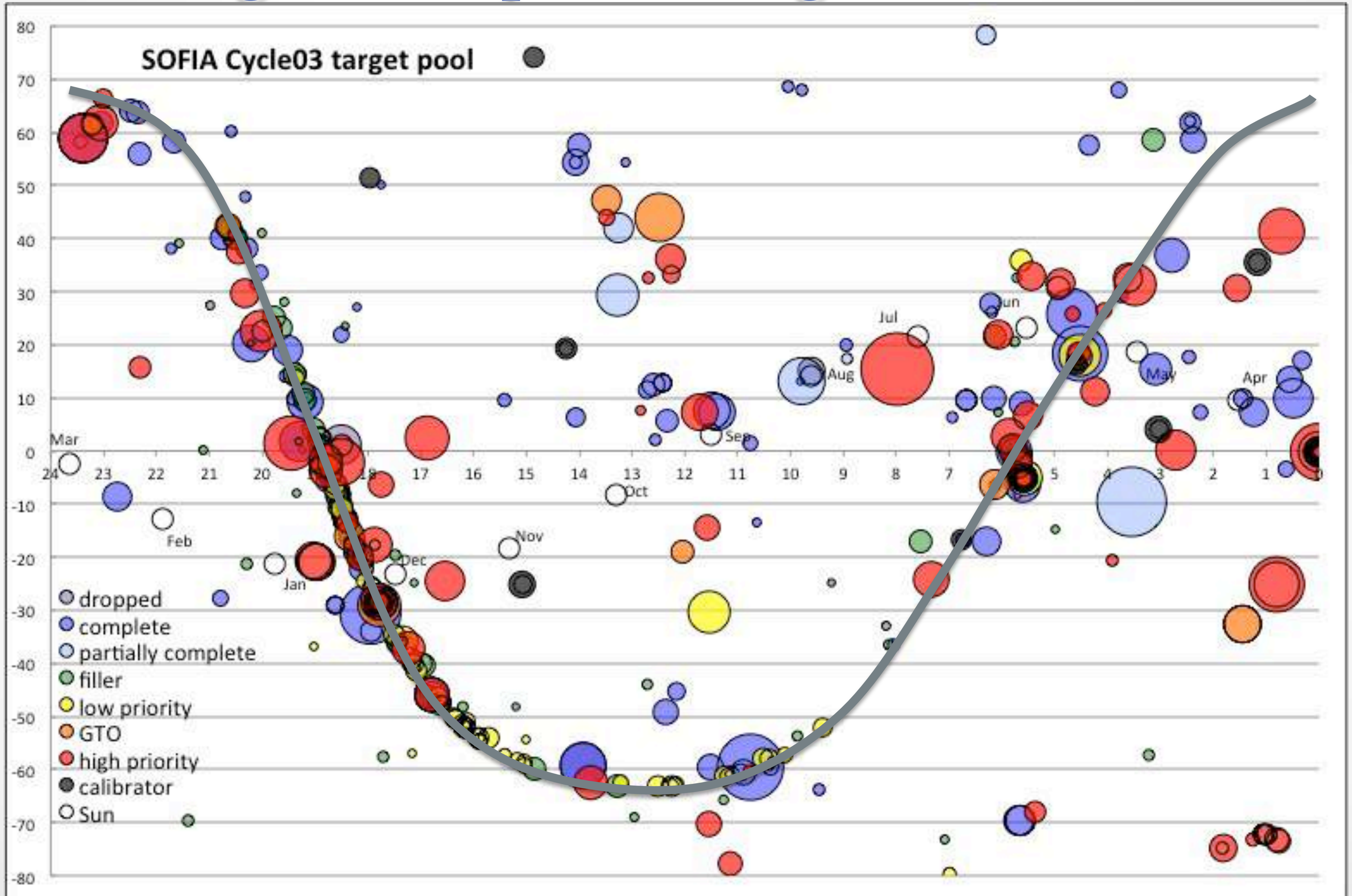
The galactic plane targets



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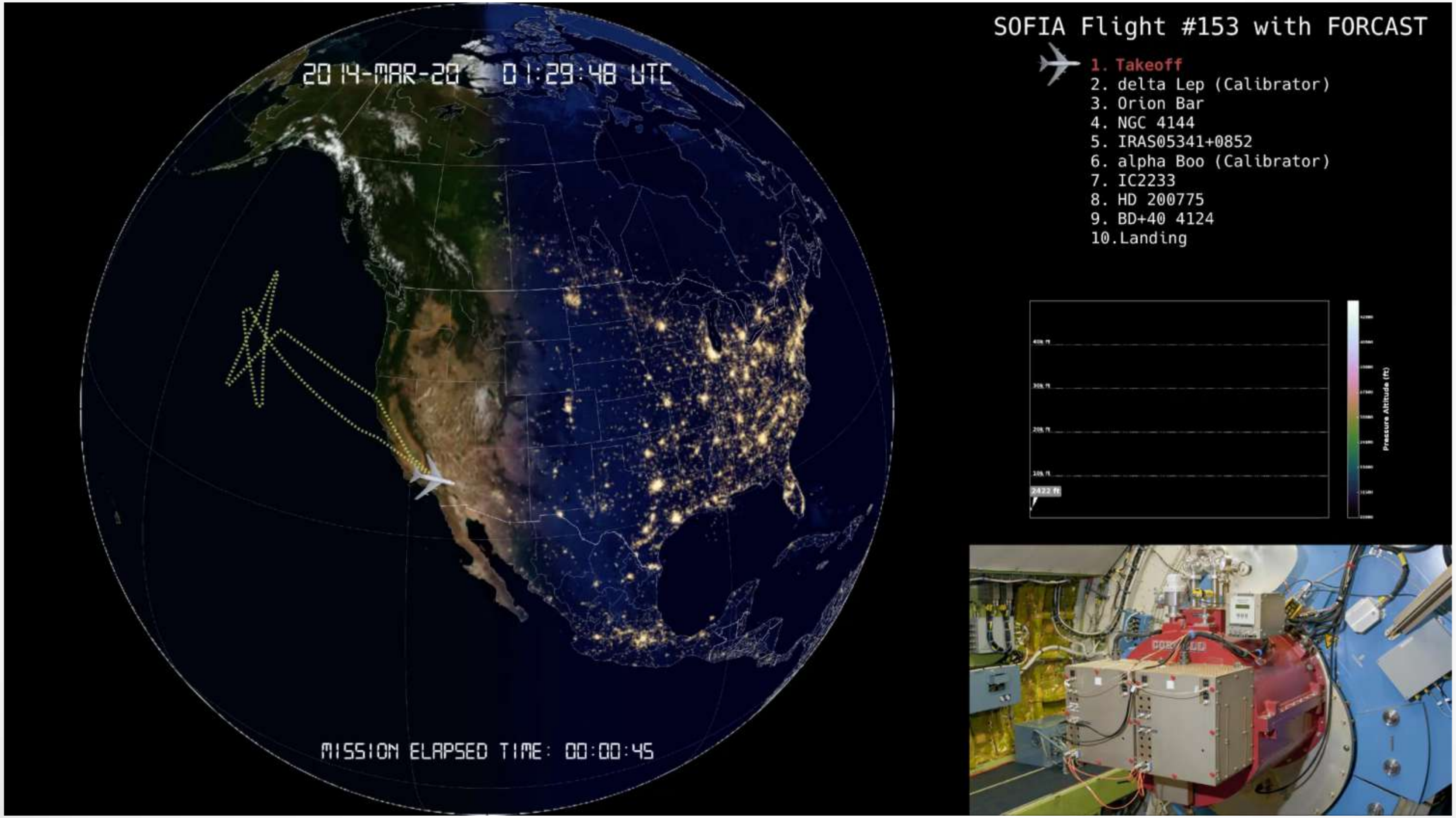
NASA USRA DLR DSI

Target Selection tips

- Even though bulk of targets are concentrated in the GP and ecliptic, you can only spend 1/2 of the time flying to view those directions and the other 1/2 on the return
- Whenever possible, choose targets with distribution at all parts of the sky. More chances to win! High latitudes are desirable.
- Only programs in upper quartile grades are designated "must-do", where they drive the scheduling, and will be automatically carried over to the next Cycle.
- Other proposals have some risk of being weathered out (or "aircraft maintenanced" out) or being unscheduled due to competition for over requested parts of the sky

A Flight Plan



More Information

SOFIA Information for Researchers Website

https://www.sofia.usra.edu/science

SOFIA Help Desk

sofia_help@sofia.usra.edu