Stratospheric Observing Primer

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SOFIA/USRA

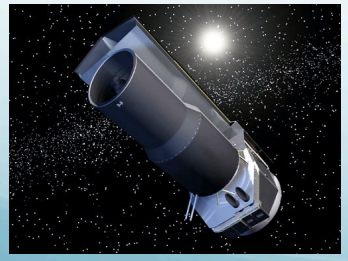
Space vs. Ground

Image credit: NASA astronaut Gregory Reid Wiseman

Space vs. Ground

Space

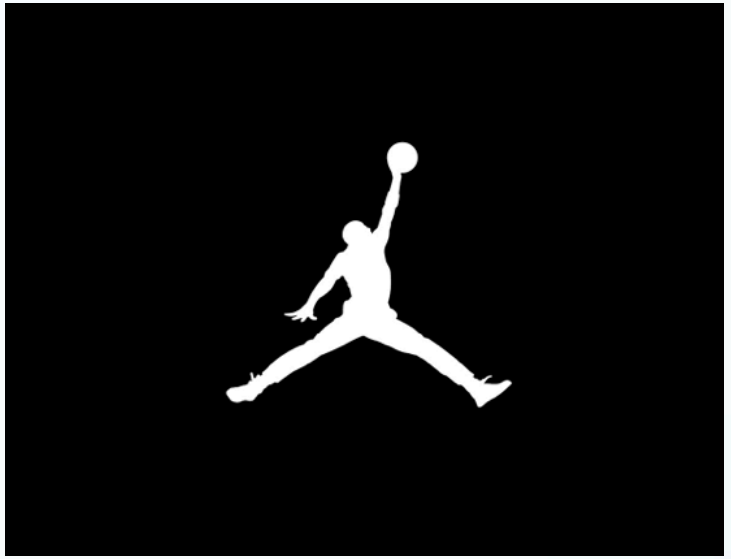
- **PRO**
  - Fantastic sensitivity/transmission
  - No atmospheric distortion (seeing)
- **CON**
  - Expensive (smaller telescopes)
  - Limited lifetime (cryo)* Small Time Domain
  - No easy repairs



Ground

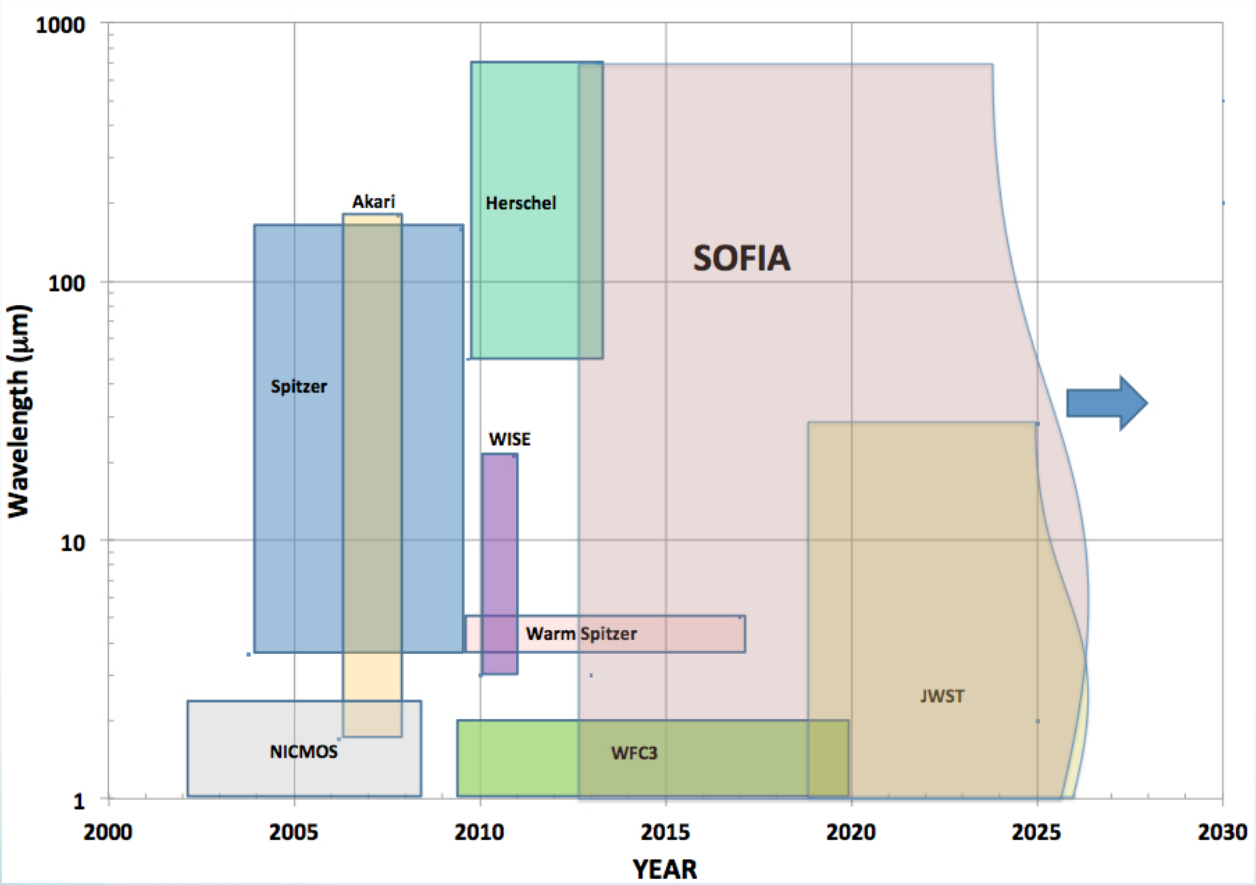
- **PRO**
  - Cheaper (larger telescopes)
  - No cryo issue* Large Time Domain
  - Repairable (duct tape?)
- **CON**
  - Worse transmission/ sensitivity
  - Atmospheric distortion (seeing)

AIR



- Advantage of both space and ground
- Unique issues with observing in plane
- Overview, highlighting a few instruments and modes

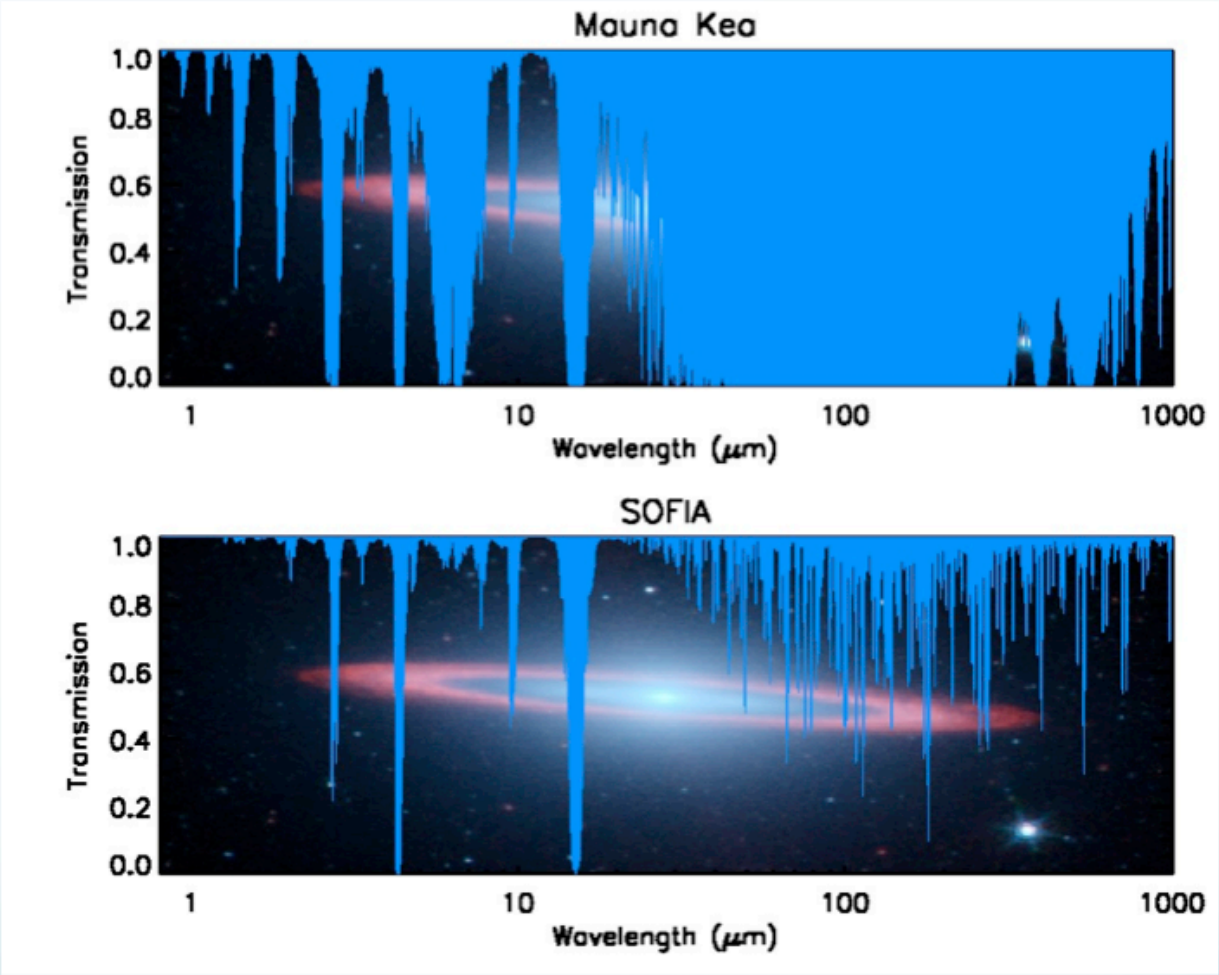
Air



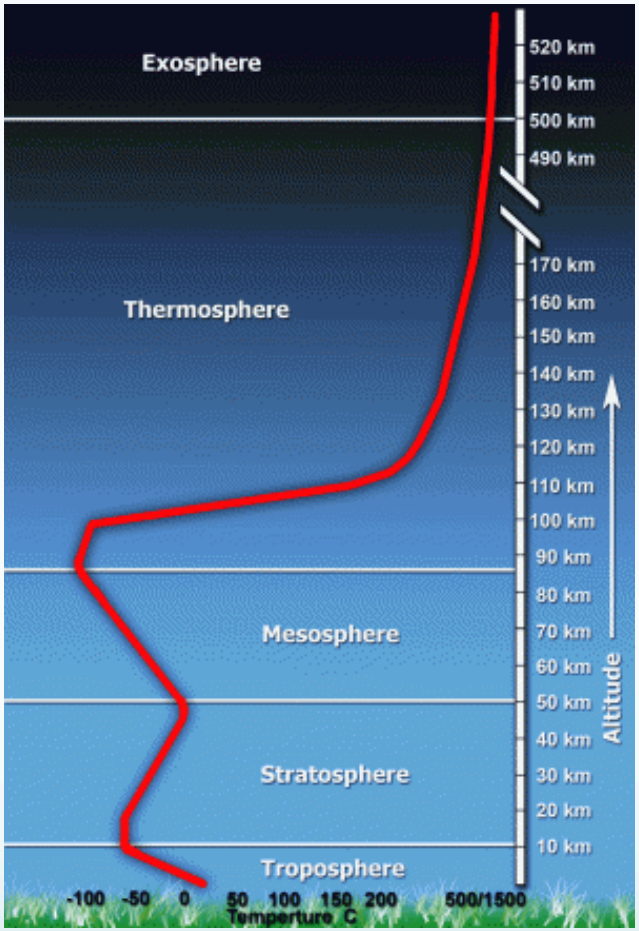
- Large Time Domain*
- Repairable
- Cost savings over comparable space mission
- Instrument technologyupgrades (upGreat, HAWC+)
- Better transmission than ground

Air

- Even at the very best ground-based sites, the transmission in the mid to far-infrared is poor or nonexistent
- Cool dust, light molecule rotation lines, atomic fine-structure lines etc., in this range provide unique tracers
- Operational elevation: 38,000 – 45,000 ft. (12 – 14 km) Above > 99.8% of atmospheric water vapor

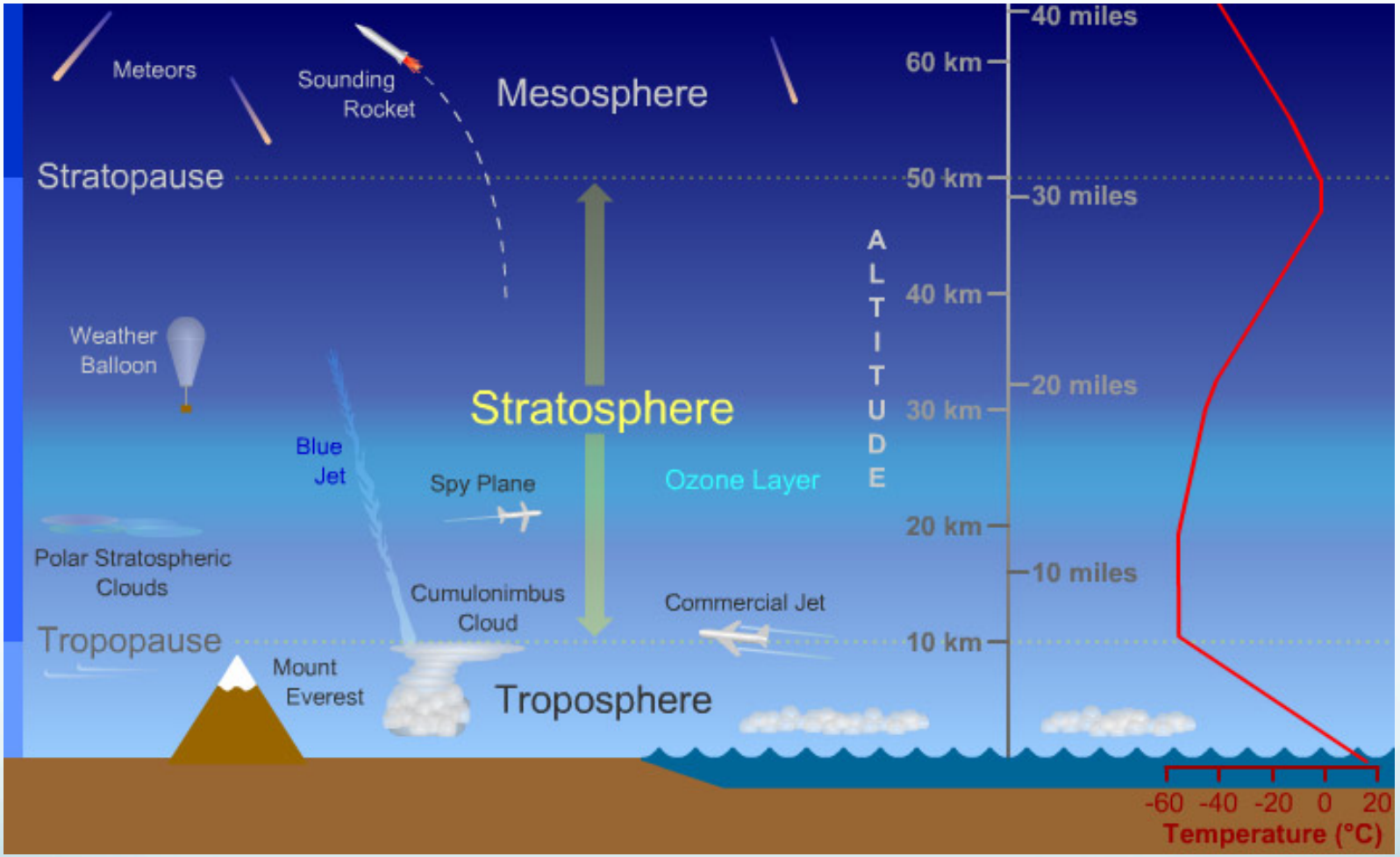


Earth's Atmosphere



http://www.ces.fau.edu/nasa/module-2/atmosphere/earth.php

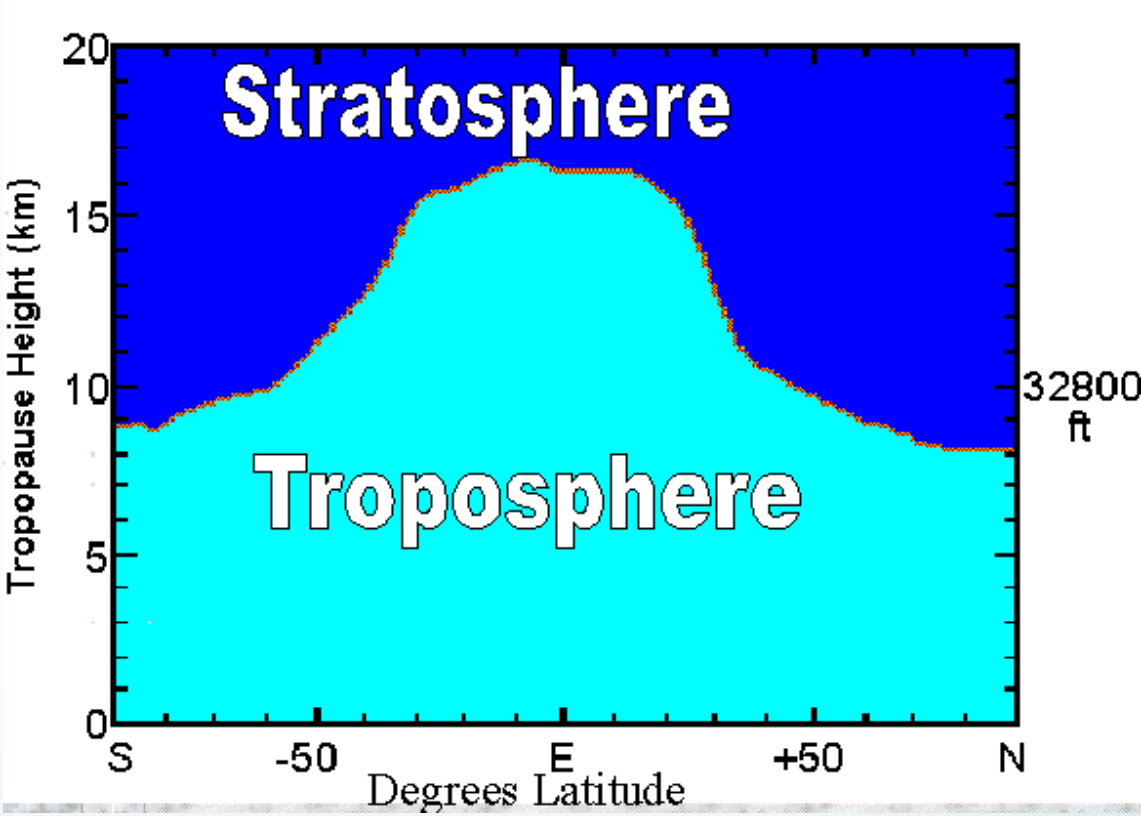
Earth's Atmosphere



http://scied.ucar.edu/shortcontent/stratosphere-overview

Stratosphere

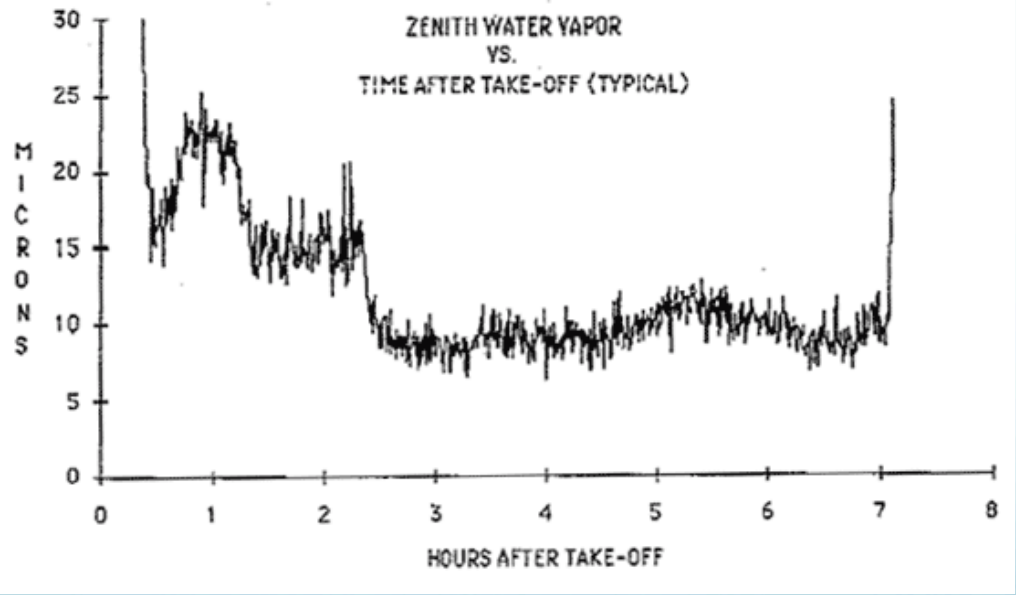
- Height of the Tropopause depends on the location
- Seasonal
- Colder regions have a lower Tropopause



http://www-das.uwyo.edu/~geerts/cwx/notes/chap01/tropo.html

Water Vapor Monitor

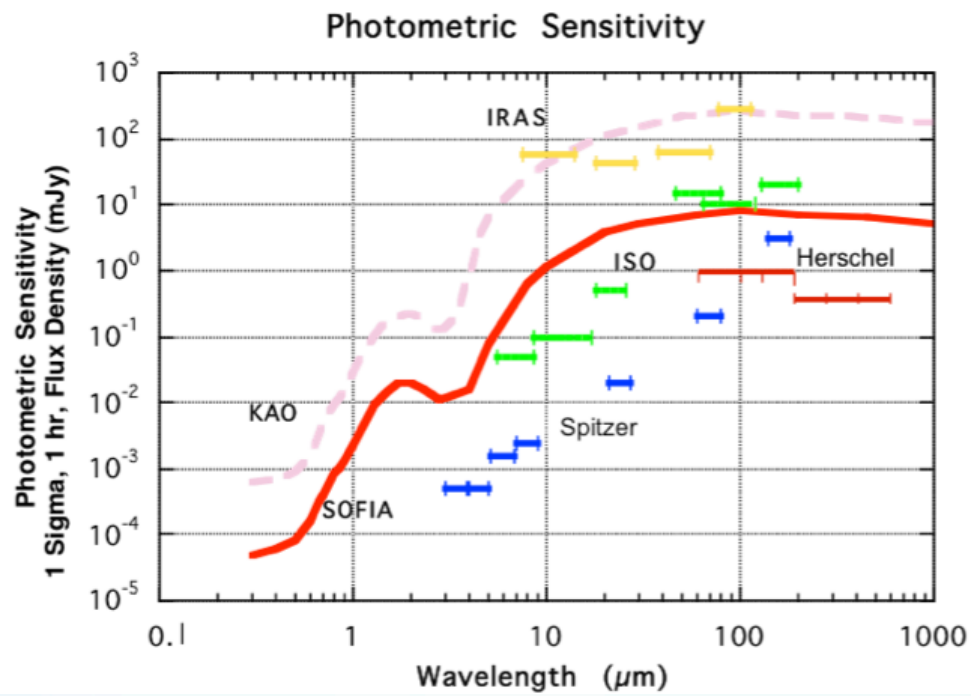
- Heterodyne mixer configured for the measurement of the 183 GHz rotational line of water.
- Mounted at a fixed elevation of 40° in the upper deck of the aircraft
- Stratospheric water vapor can be quite variable: as much as a factor of three on time scales as short as 15 minutes



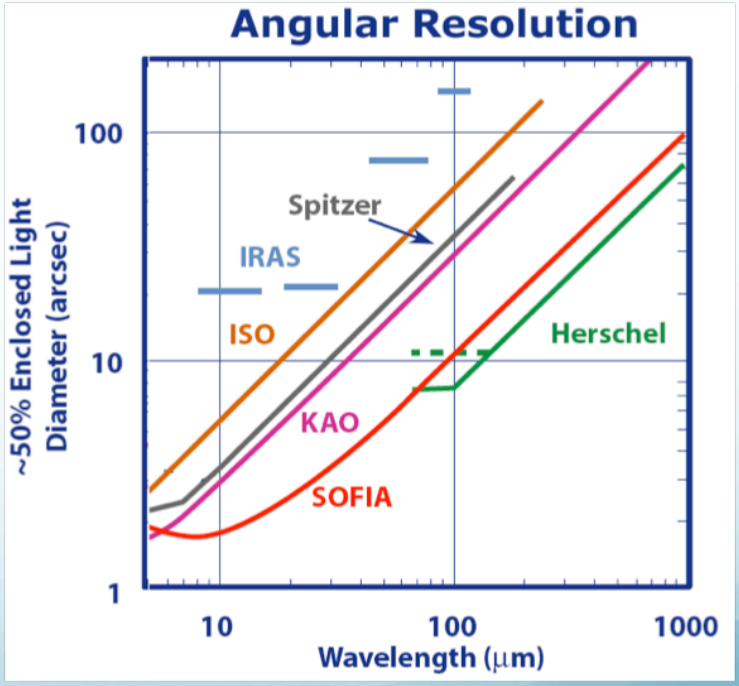
KAO Example

https://www.sofia.usra.edu/Science/instruments/waterVaporMonitor.html

Sensitivity/Resolution



SOFIA is diffraction limited beyond ~25 μm and can produce sharper images than Spitzer



Updated Sensitivities (SITE):
https://dcs.sofia.usra.edu/proposalDevelopment/SITE/

Large Wavelength Range

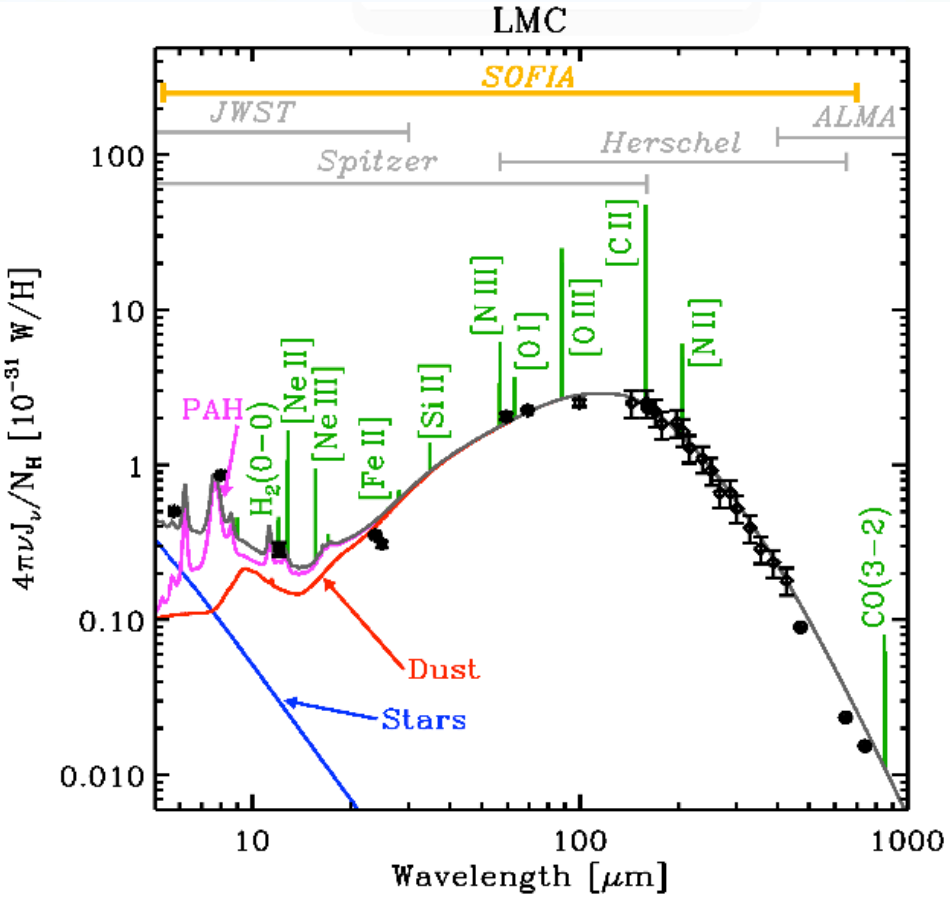


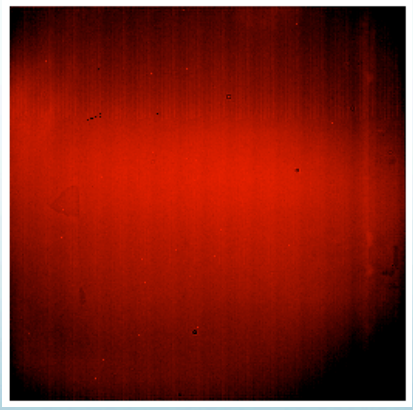
Figure 3-2. *The spectral energy distribution of the entire LMC, based on data from Spitzer, IRAS and FIRAS (Bernard et al. 2008). SEDS are fitted with the dusty PDR model of Galliano et al. (2008). Spitzer has and Herschel will provide good photometric coverage of a galaxy's spectral energy distribution (SED) over a portion of the wavelengths. SOFIA will provide excellent wavelength coverage and spectroscopic capability across the entire SED. In the future, JWST and ALMA will provide complementary wavelength coverage and work on nearby galaxies and the most distant Universe. Figure courtesy of Galliano.*

Ground Similarities

- Observing techniques (still atmosphere)
  - Chop Nod
  - Scan Mapping
- Variability (weather)
- Calibration

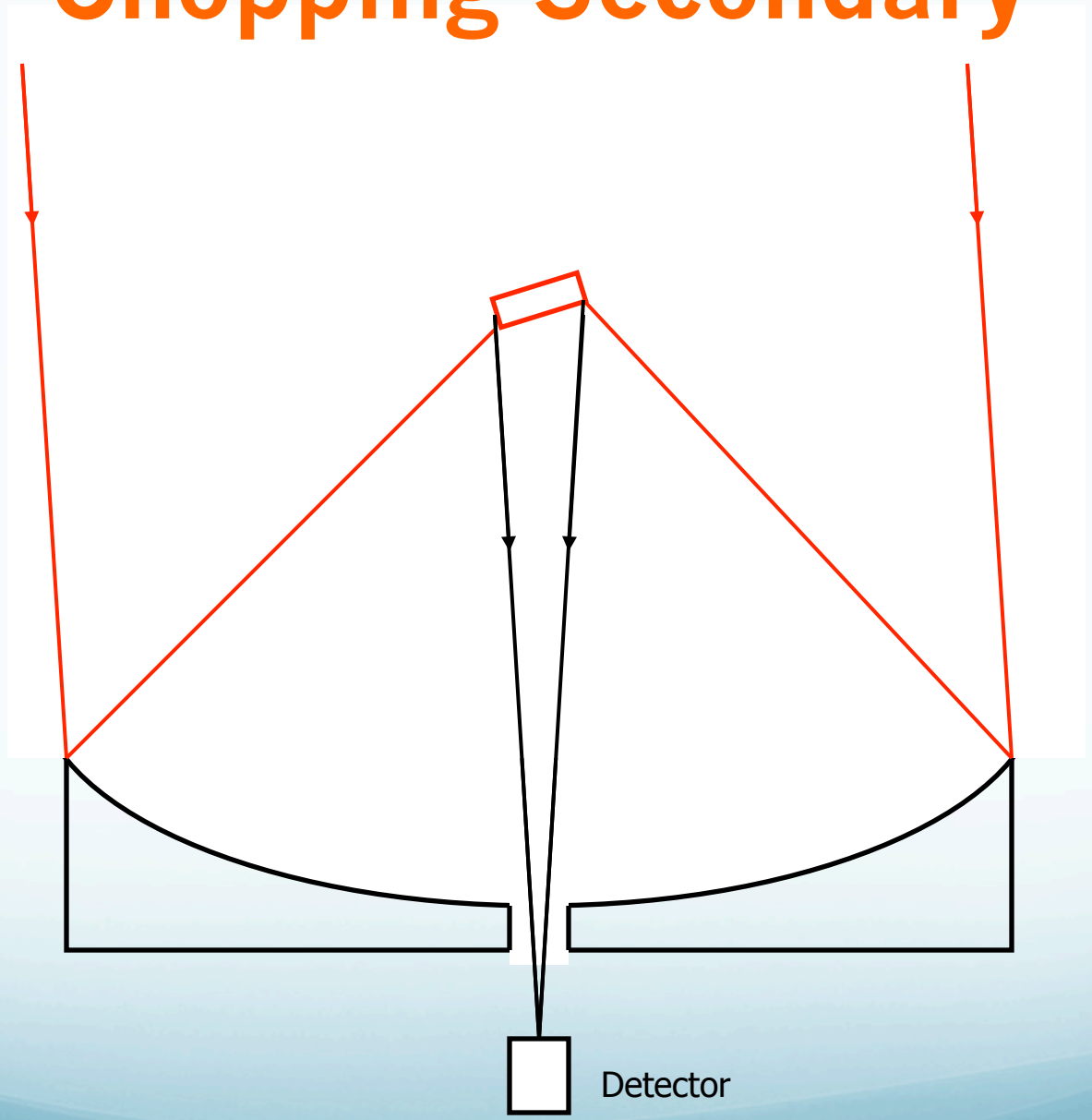
Chopping and Nodding

- Done due to overwhelming photons from sky and telescope (~100,000 to 1)
- Chopping ~a few HZ
- Nodding ~ 10's of seconds
- Affects overhead to exposure time
- Distorts optical path (so limited chop amplitude)

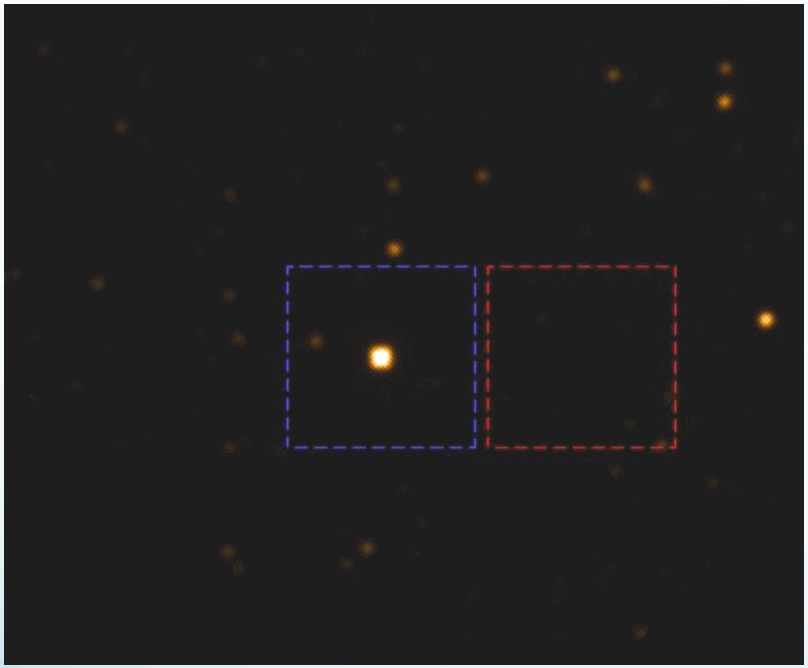


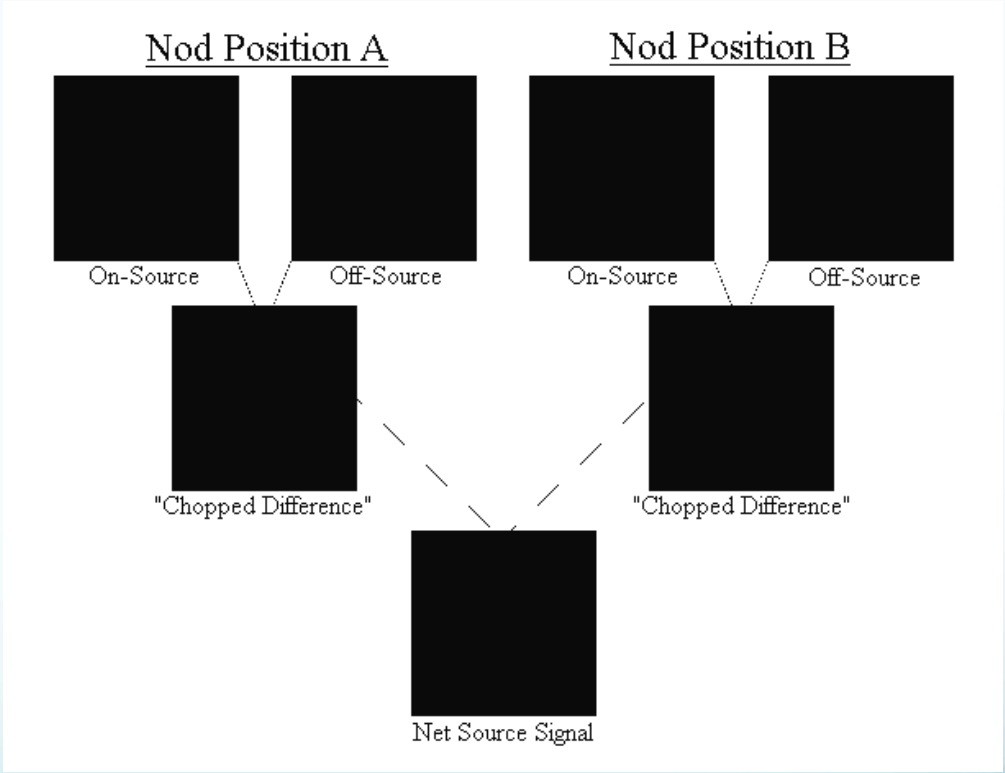
FORCAST image (guess?)

Chopping Secondary

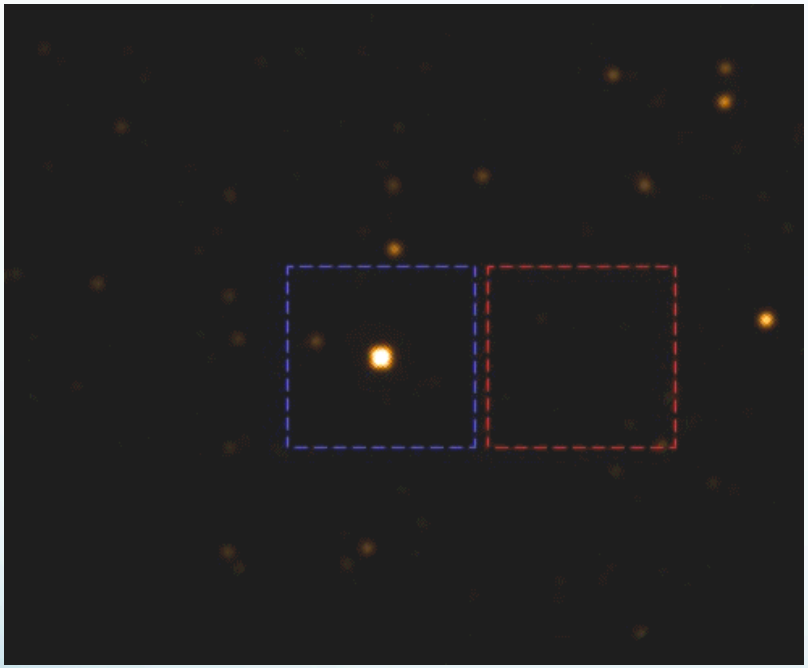


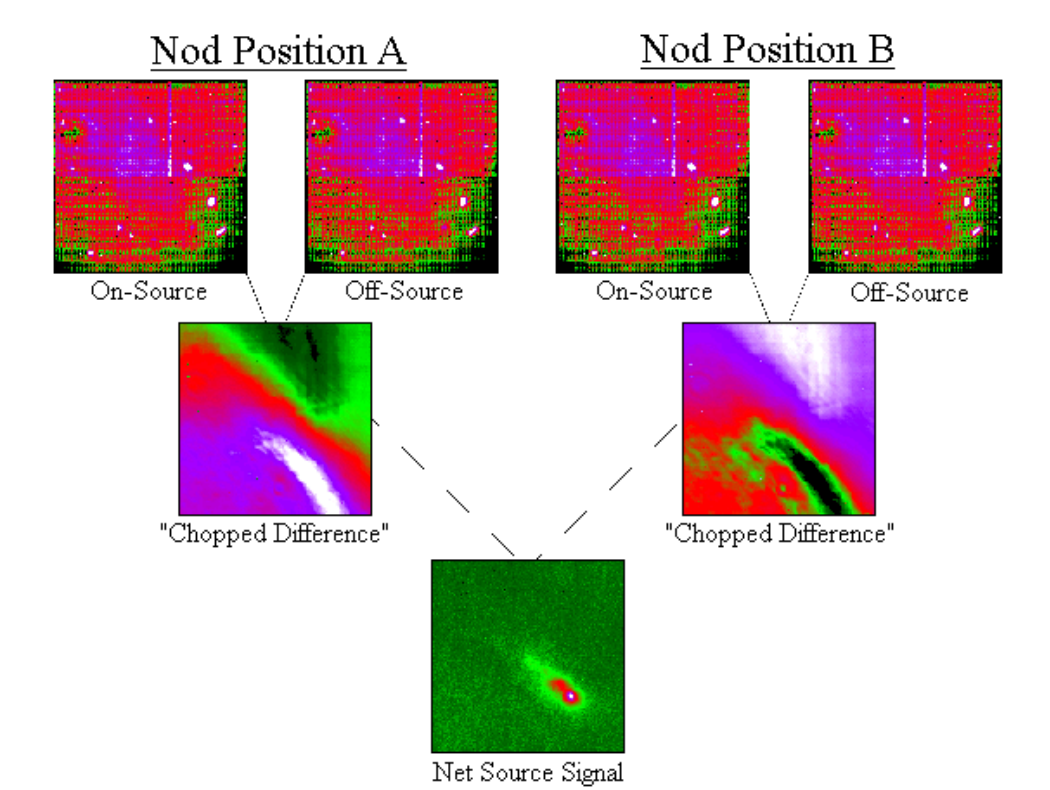
Chop Nod/ Scan Mapping





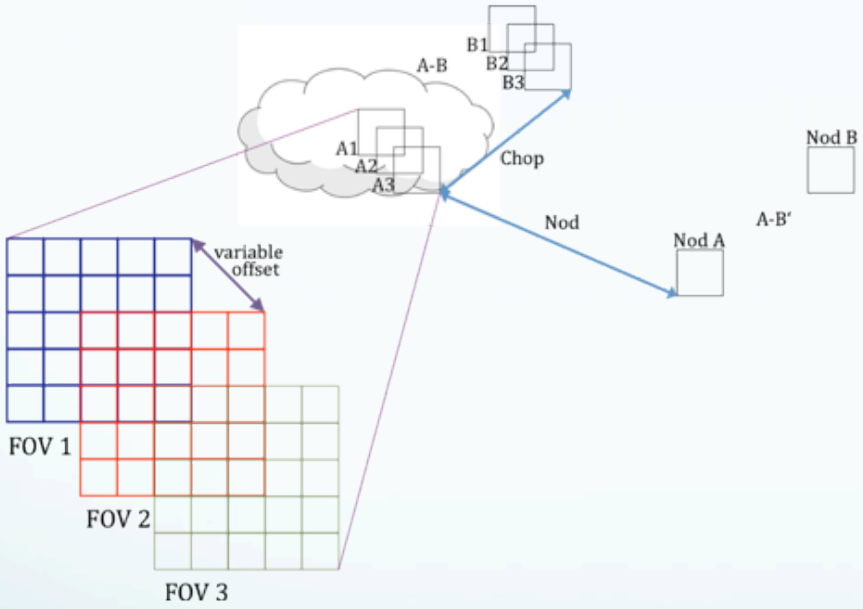
Chop Nod/ Scan Mapping





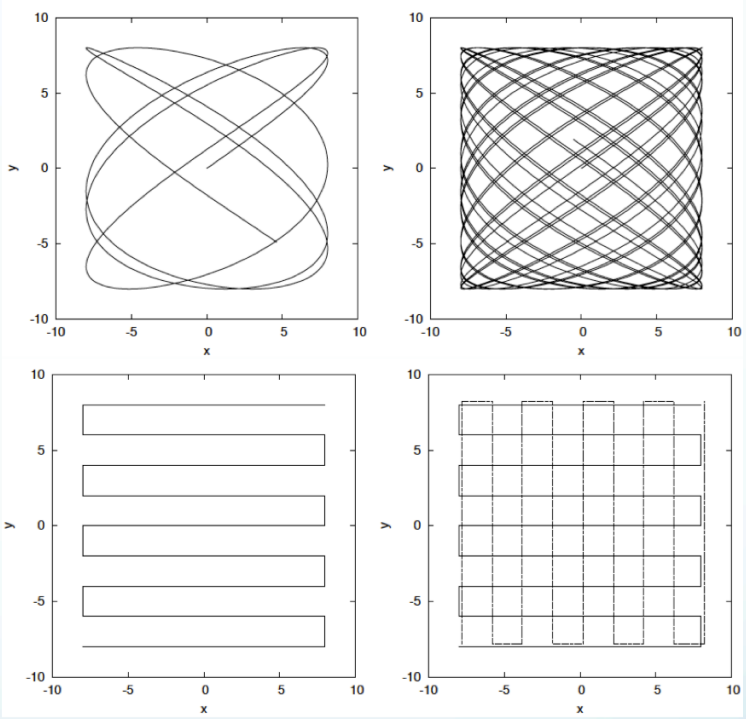
Chop Nod/ Scan Mapping

Asymmetric Chop Nod



FIFI-LS

Scan Mapping

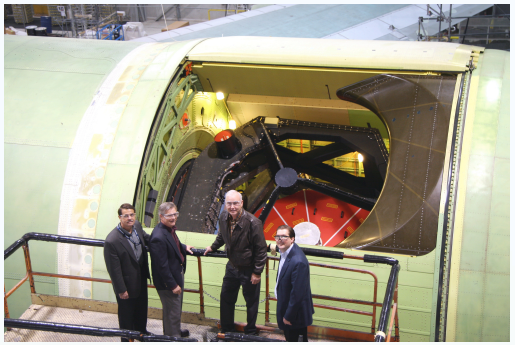


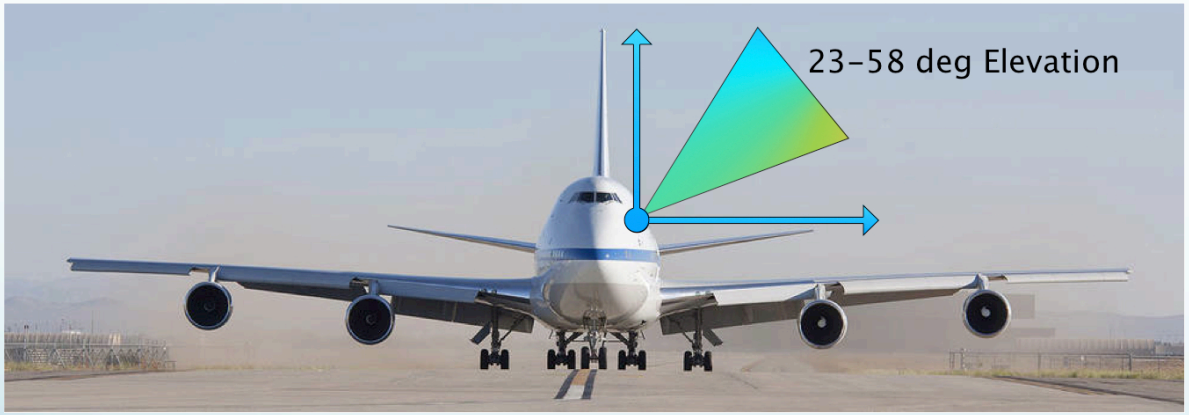
HAWC+

Unique Attributes

- Alt Az Telescope restrictions
  - LOS (Line of Sight) Rewinds
- Overhead uncertainty
- Flight Plans
- Calibration Differences

Telescope Altitude

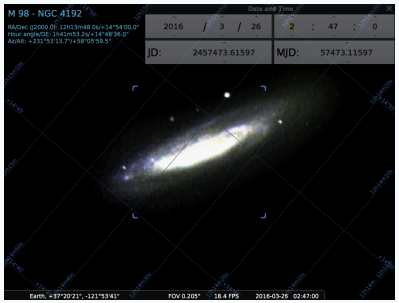


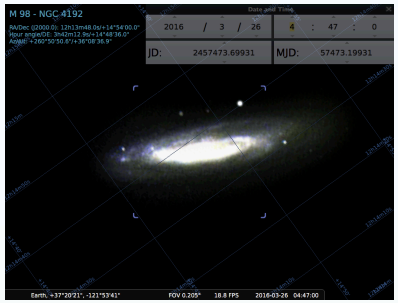


- About ~2.5m (~Hubble sized)
- Telescope points out one side of craft
- Limited altitude range (~35 degrees)

Azimuth (LOS Rewinds)

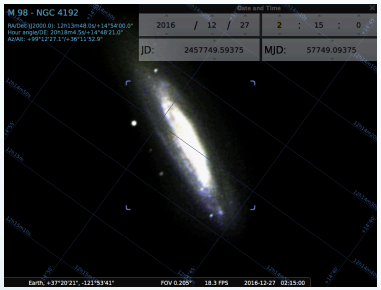
2hr observation March 2016

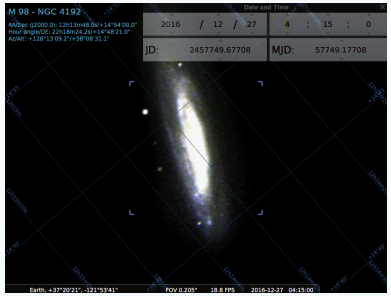


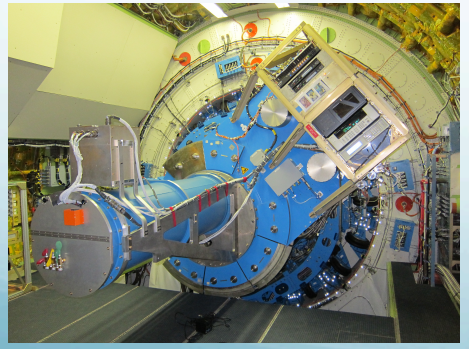


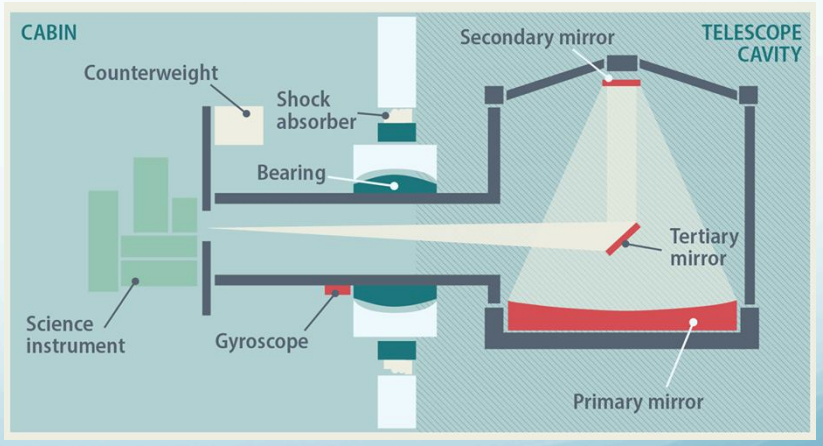
- No Rotator
- Limited to ~6 degrees
- Rotation rate based on location of object in sky
- Correction needed to prevent image smearing

2hr observation Dec 2016



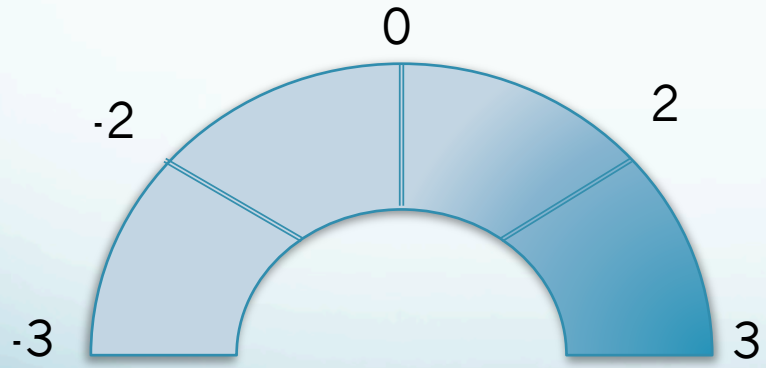




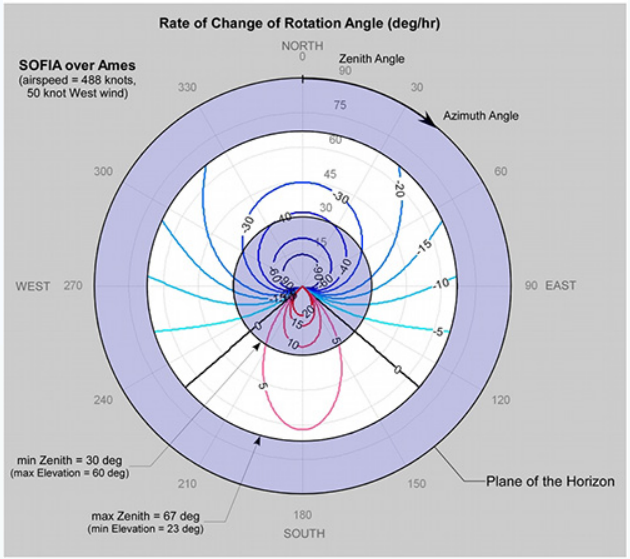


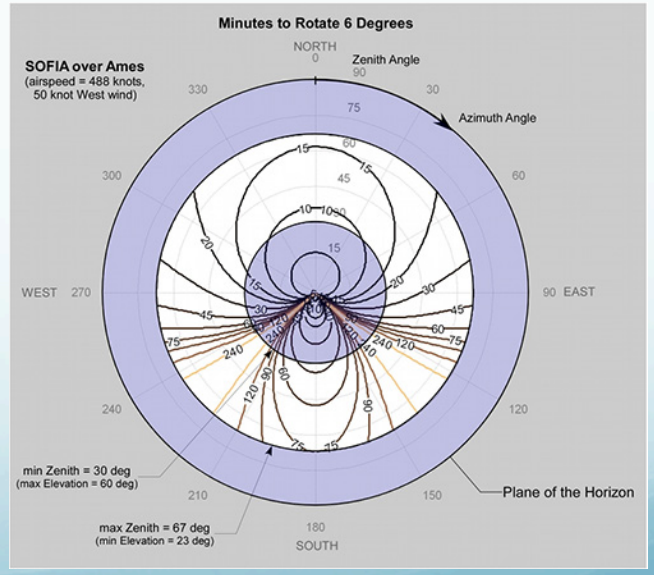
LOS Rewinds

- Require overhead based on speed of rotation
- Not known till flight plan
- Full range 6 degrees, but keep with 3-4 degrees
- SI responsibility (see also Visibilty tool (https://dcs.sofia.usra.edu/observationPlanning/installVT/)



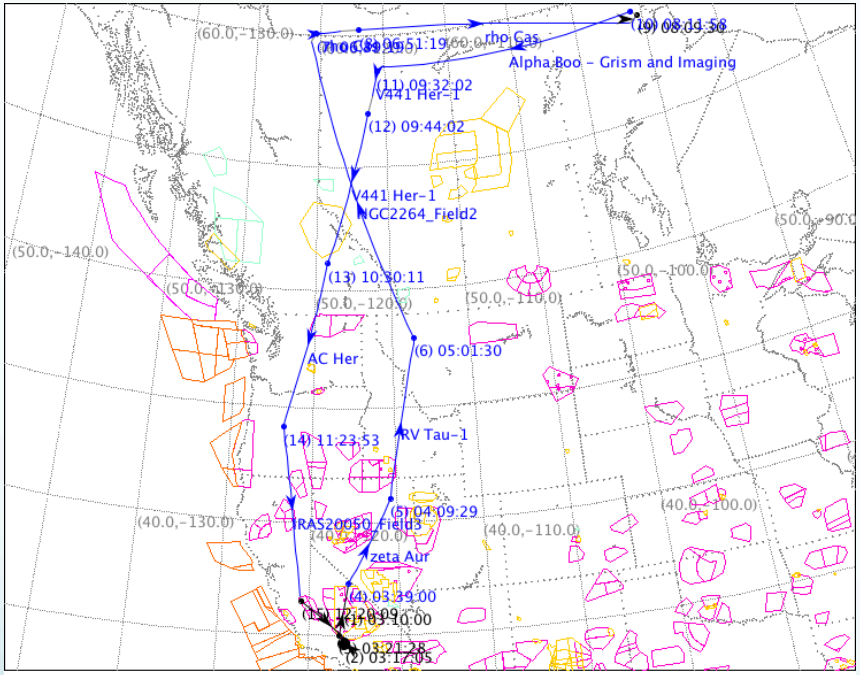
http://www.sofia.usra.edu/Science/ObserversHandbook/Cy2.html#LOS



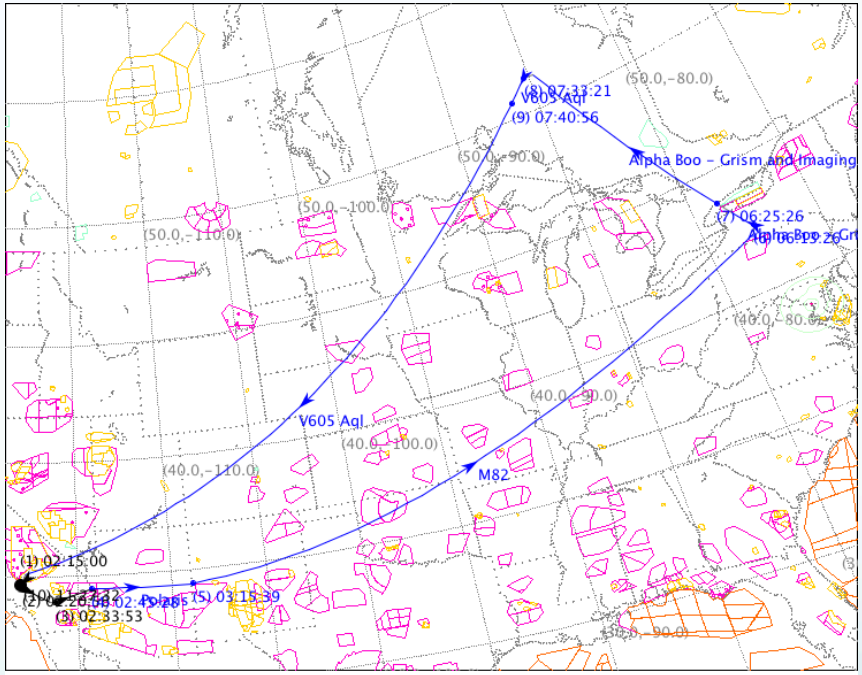


Flight Plans

- Quantized Observing (limits to how short and how long)
- No real flexibilty
- Complicated to plan



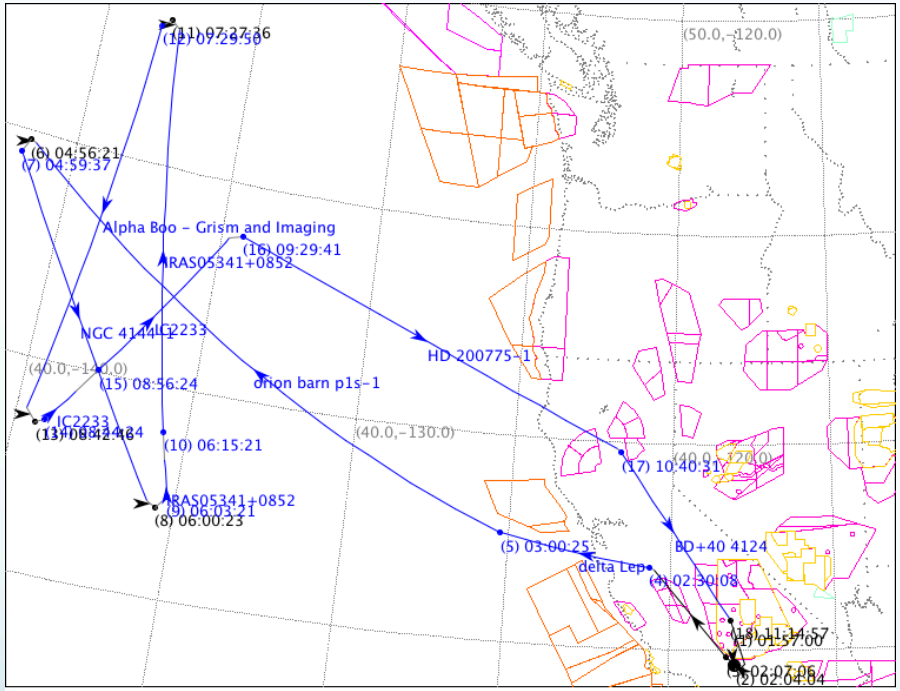
Flight Plan Name: File: 201403_FO_04_post-MOpsV2.fp
Flight ID: 2014/03/27
Est. Takeoff Time: 2014-Mar-27 03:10 UTC
Est. Landing Time: 2014-Mar-27 12:48 UTC
Flight Duration: 09:38
Weather Forecast : 1200 Thu Feb 20 2014 - 0000 Sun Feb 23 2014 UTC
Saved: 2014-Feb-20 19:03 UTC User: kbower



Flight Plan Name: File: 201404_FO_05a_post-Science.fp
Flight ID: 2014/05/07_1
Est. Takeoff Time: 2014-May-07 02:15 UTC
Est. Landing Time: 2014-May-07 11:54 UTC
Flight Duration: 09:39
Weather Forecast : 1800 Tue Apr 01 2014 - 0600 Fri Apr 04 2014 UTC
Saved: 2014-Apr-05 23:31 UTC User: kbower

More Flight Plans

- Flights for instruments occur in blocks typically of a week or two
- All flights planned like classical



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Flight ID: 2014/03/20
Est. Takeoff Time: 2014-Mar-20 01:57 UTC
Est. Landing Time: 2014-Mar-20 11:44 UTC
Flight Duration: 09:47
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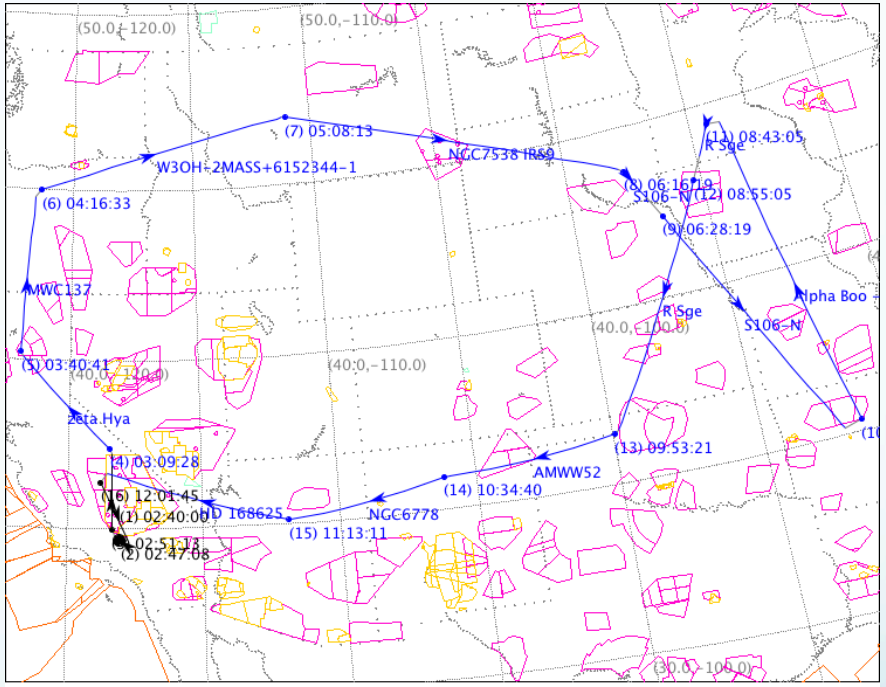
Saved: 2014-Feb-20 19:00 UTC User: kbower



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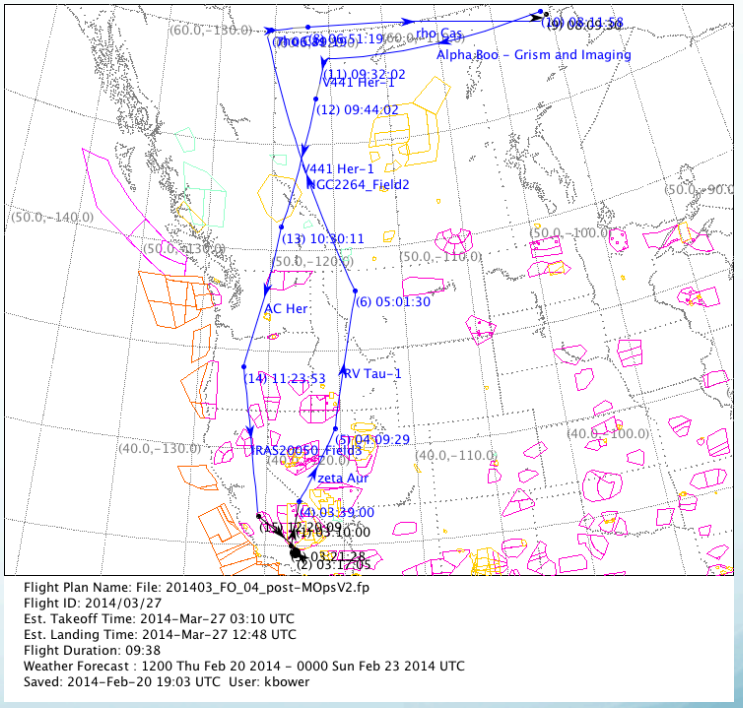
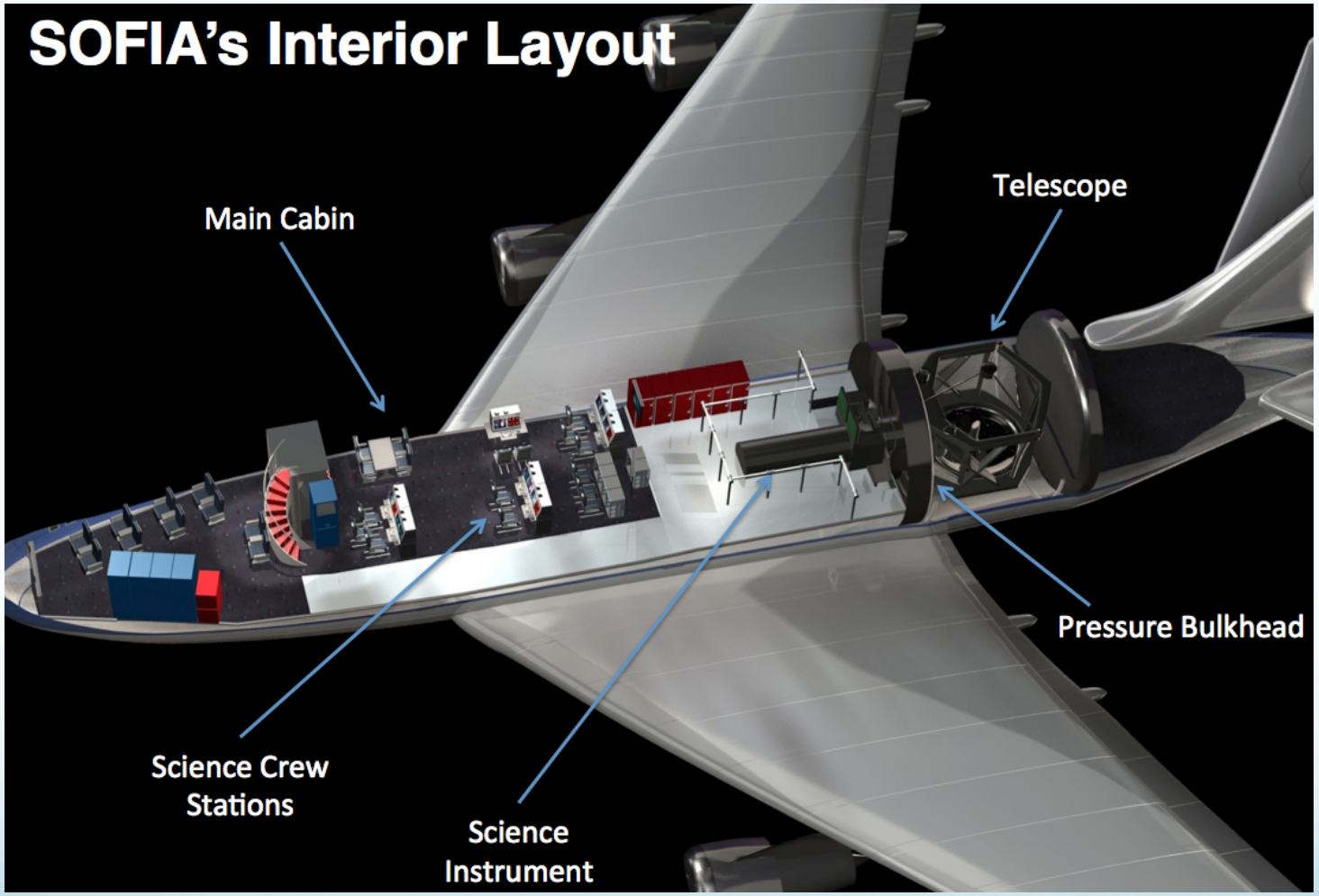
Flight ID: 2014/05/09
Est. Takeoff Time: 2014-May-09 02:40 UTC
Est. Landing Time: 2014-May-09 12:28 UTC
Flight Duration: 09:48
Weather Forecast : 1800 Tue Apr 01 2014 - 0600 Fri Apr 04 2014 UTC
Saved: 2014-Apr-05 23:41 UTC User: kbower

Calibration

- Different by instrument (e.g. EXES vs FORCAST)
- FORCAST
  - Calibration accuracy +-20%
  - PSF calibration difficult
  - Limited number of bright stars
  - Averages done for flight series



SOFIA interior



SOFIA interior

Image Credit: Sky and Telescope

15s SOFIA Flight

Video credit: Dr. Daniel Angerhausen, Rensselaer Polytechnic Institute
https://plus.google.com/+NASA/posts/dpVqr3DDBrq