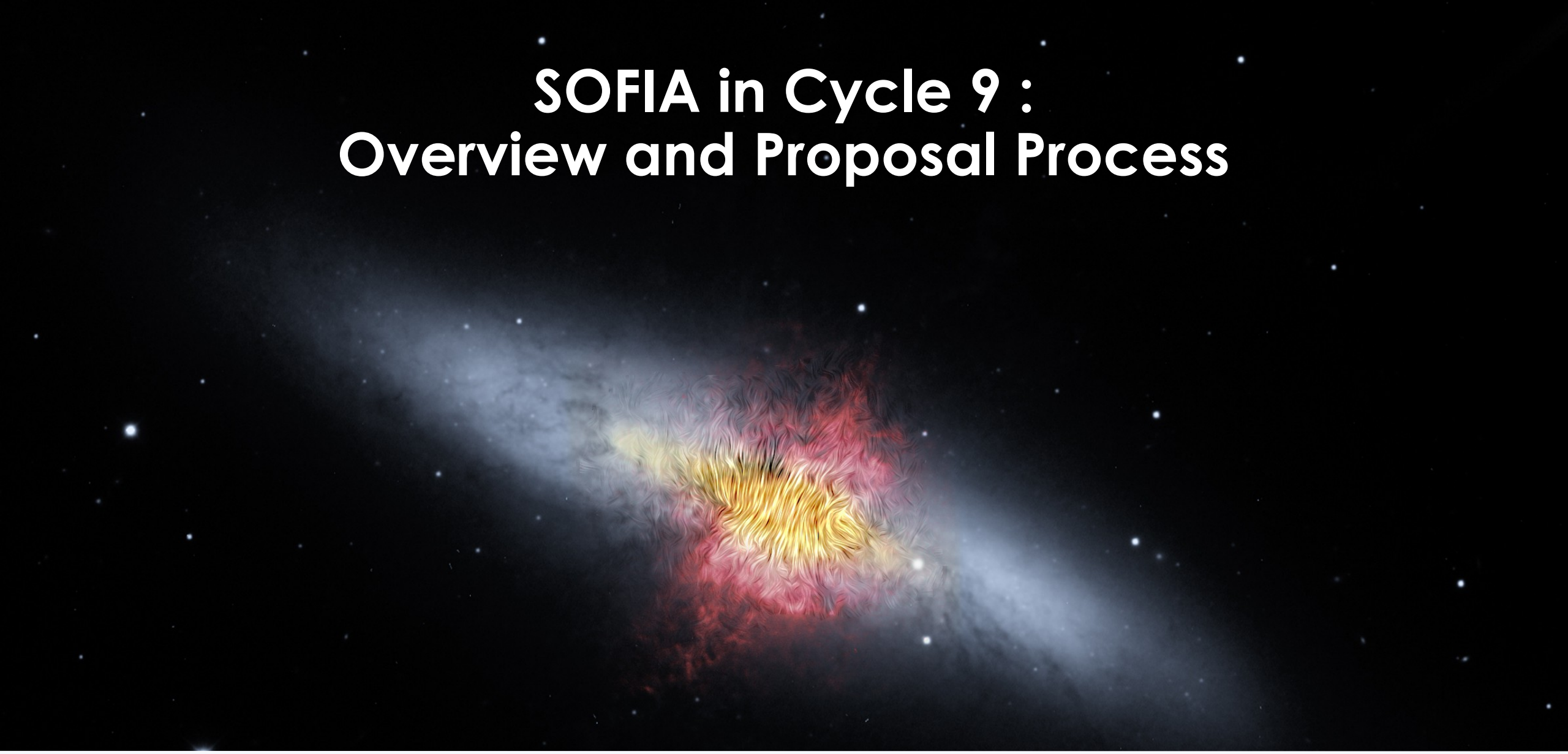
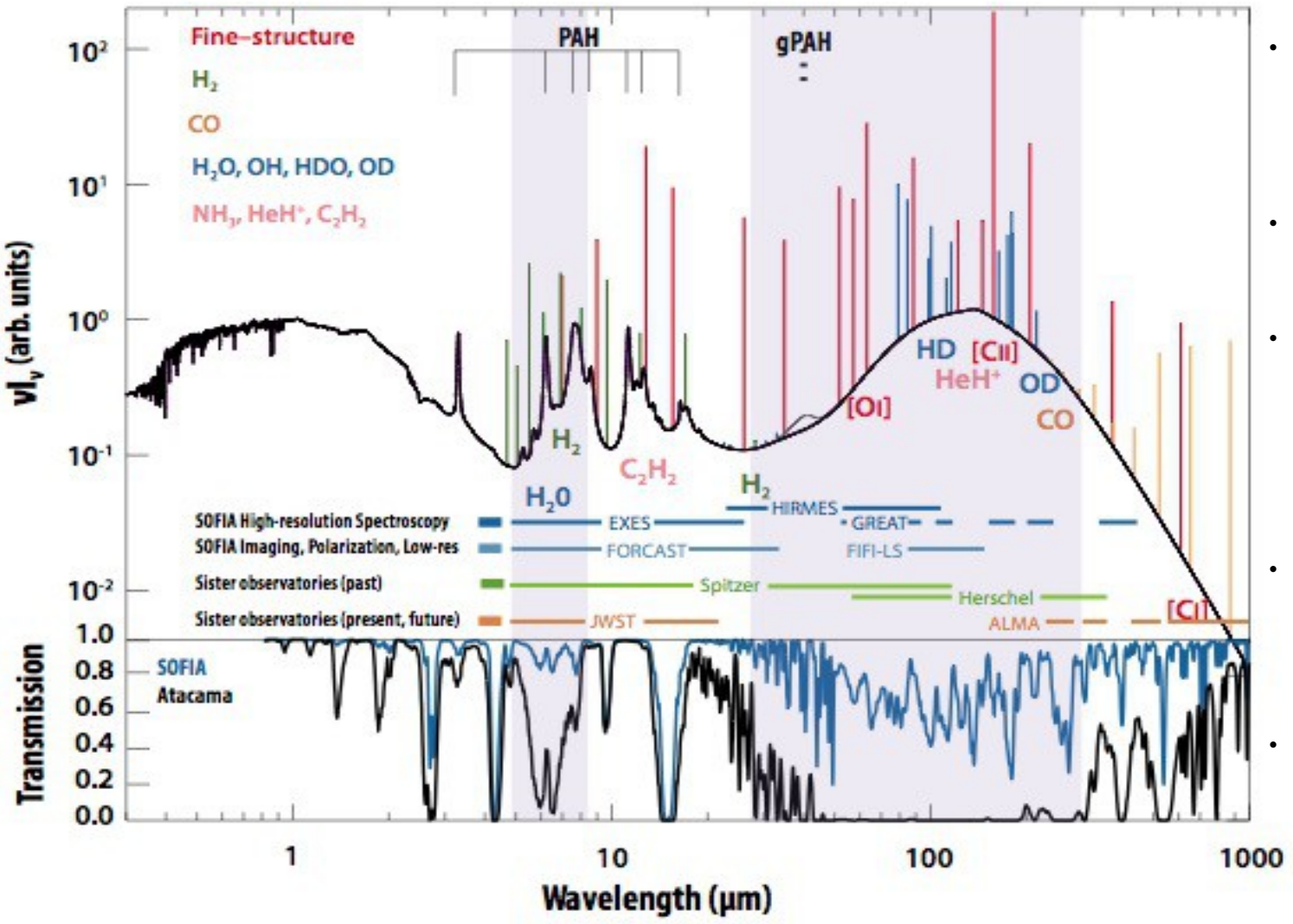
SOFIA in Cycle 9 :
Overview and Proposal Process



SOFIA
Stratospheric Observatory for Infrared Astronomy

NASA DLR USRA DSI

Why Infrared Astronomy?

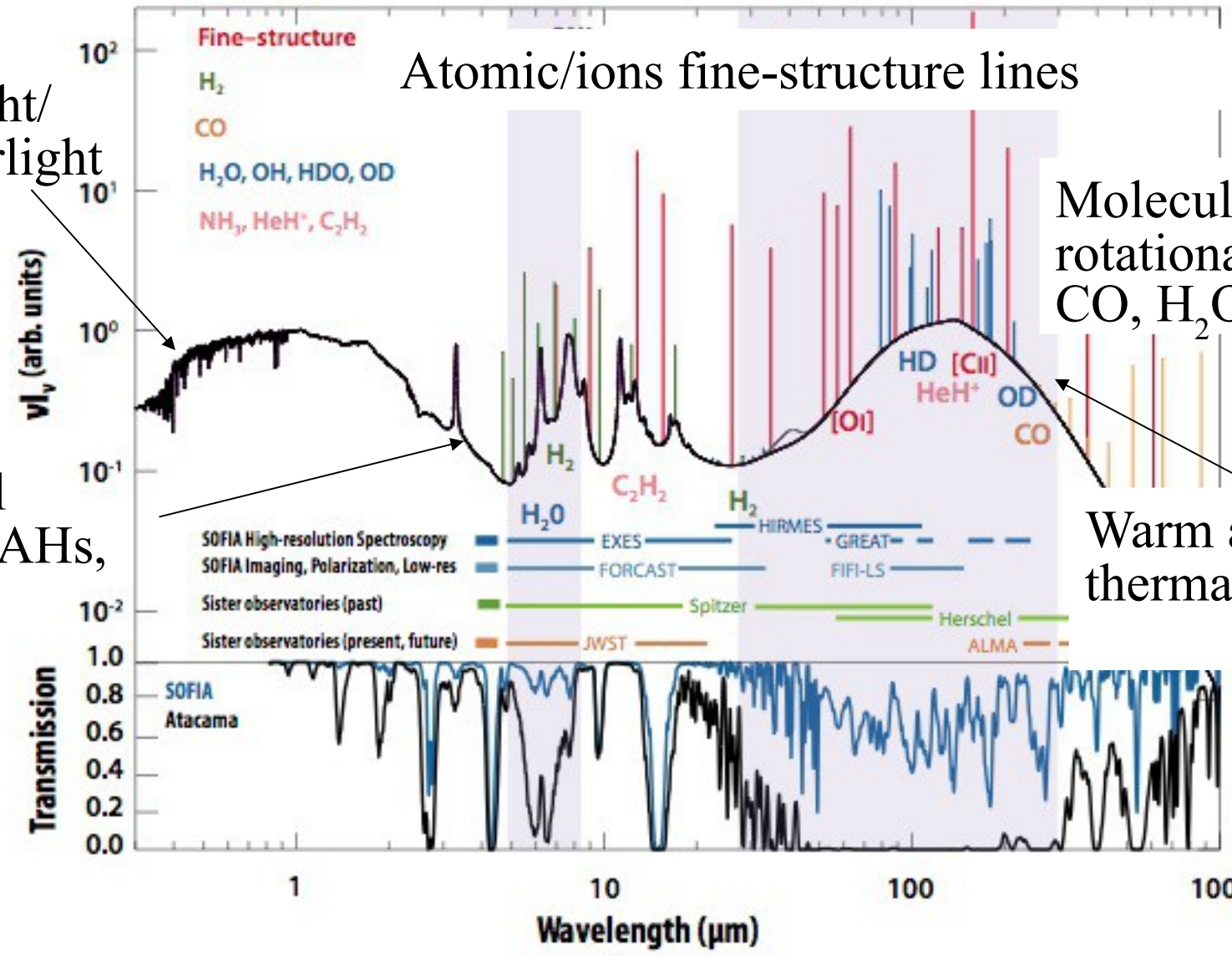


- Half of radiated energy in the Universe is **infrared**.
- Mostly re-radiated starlight
- Probes the cold-ish universe
- Most IR not observable from ground.
- SOFIA is a platform at up to 45000 feet km for IR observations.

Why Infrared Astronomy?

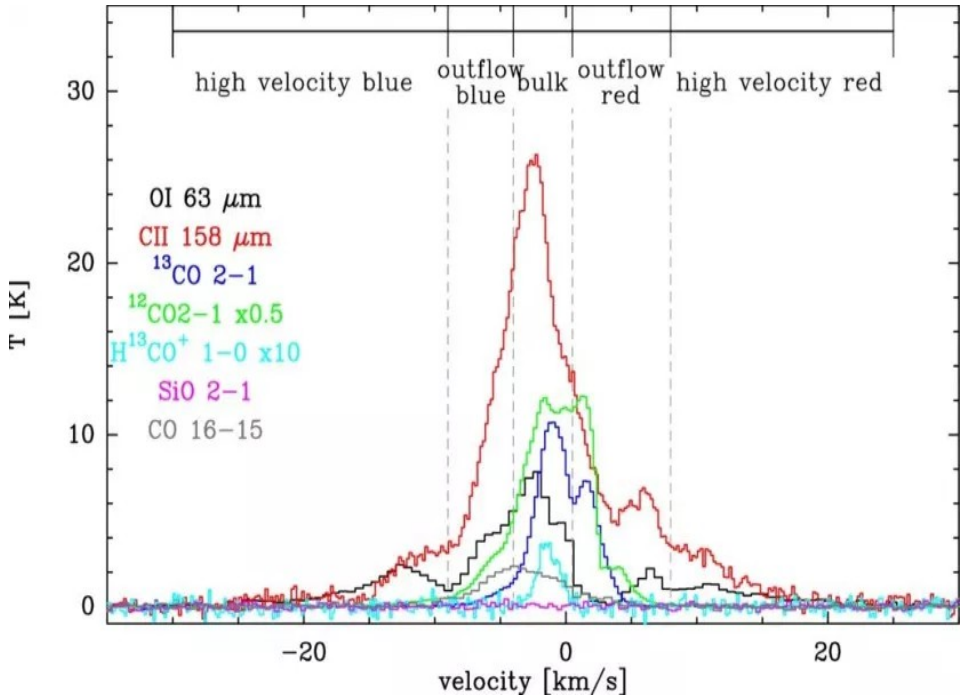
Some starlight/ reflected starlight

Dust spectral signatures: PAHs, silicates



Why Infrared Astronomy?

Schneider et al., 2017: lines in star forming region nebula S106



- C, Na, Mg, Al, Si, S, Ca, Fe, Ni can all be easily ionized by background starlight

- H_2(2-0)-para: 28 um, H_2(3-1)-ortho: 17 um

- water rotational lines > 35 um

Gas spectroscopy:

- composition
- kinematics
- temperature structure
- morphology (imaging): [OIII] traces very energetic UV fields

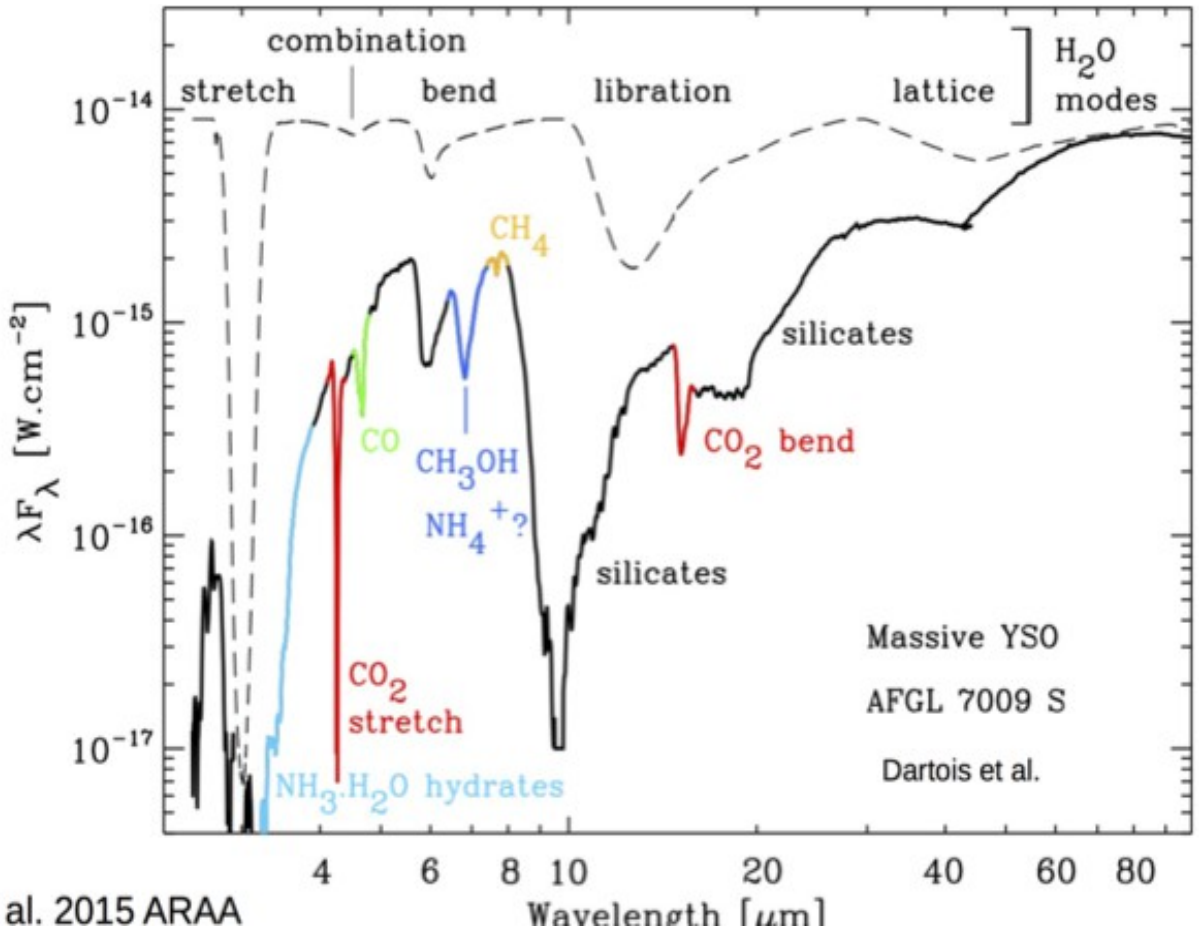
- role in heating/ cooling ([CII])

Why Infrared Astronomy?

Dust/ice spectroscopy/photometry:

- composition
- size distribution
- morphology (imaging)
- polarization fraction/orientation

- role in heating / cooling
- role in solid/gas chemistry
- role in hydrodynamics
- magnetic field coupling

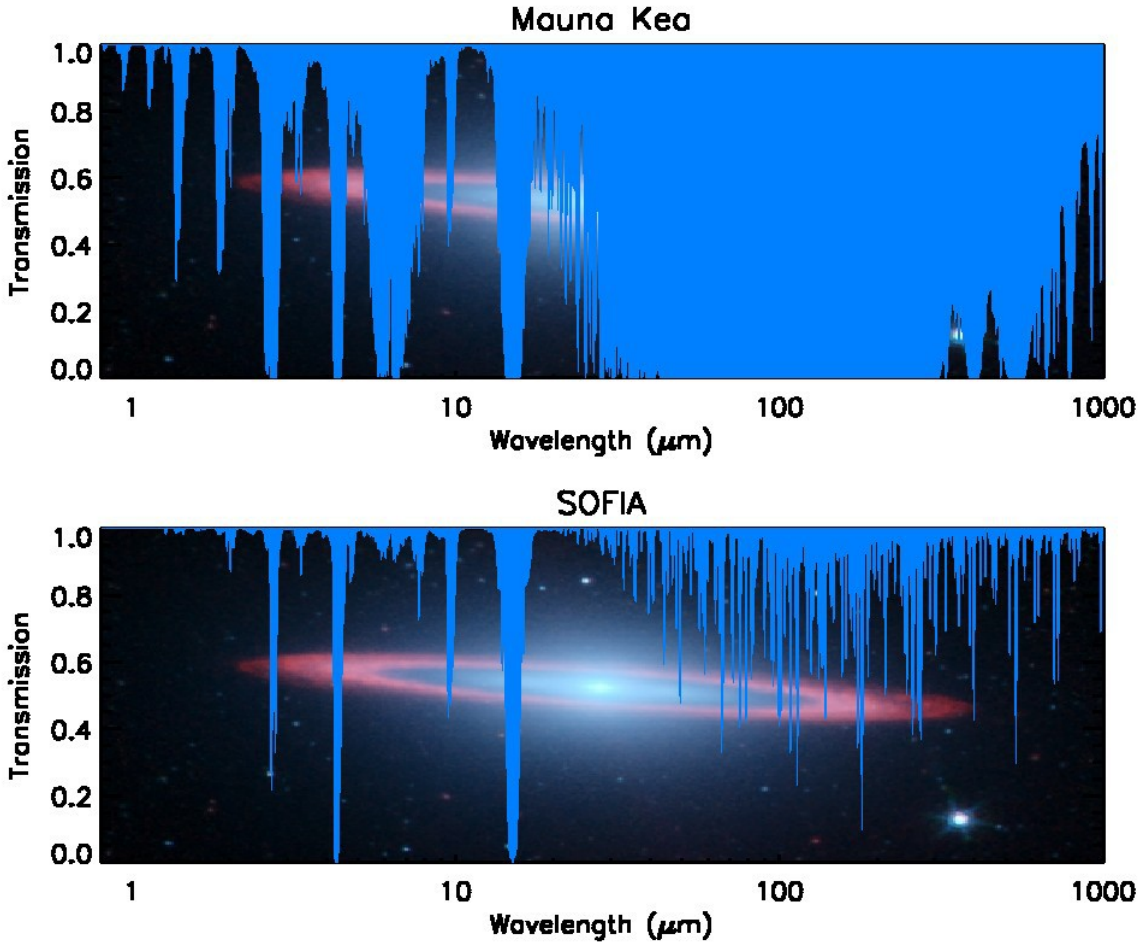


Boogert et al. 2015 ARAA

A flying telescope: some considerations

- SOFIA flies above ~99% of water vapor in the atmosphere, **but remaining 1% is still significant…**
  - SOFIA pwv: 4 – 27 um (45k – 35k feet)
  - Mauna Kea pwv: 0.8 – 4.5 *mm*

Choice of wavelength must be done considering transmission, instrument noise (sometimes source velocity)

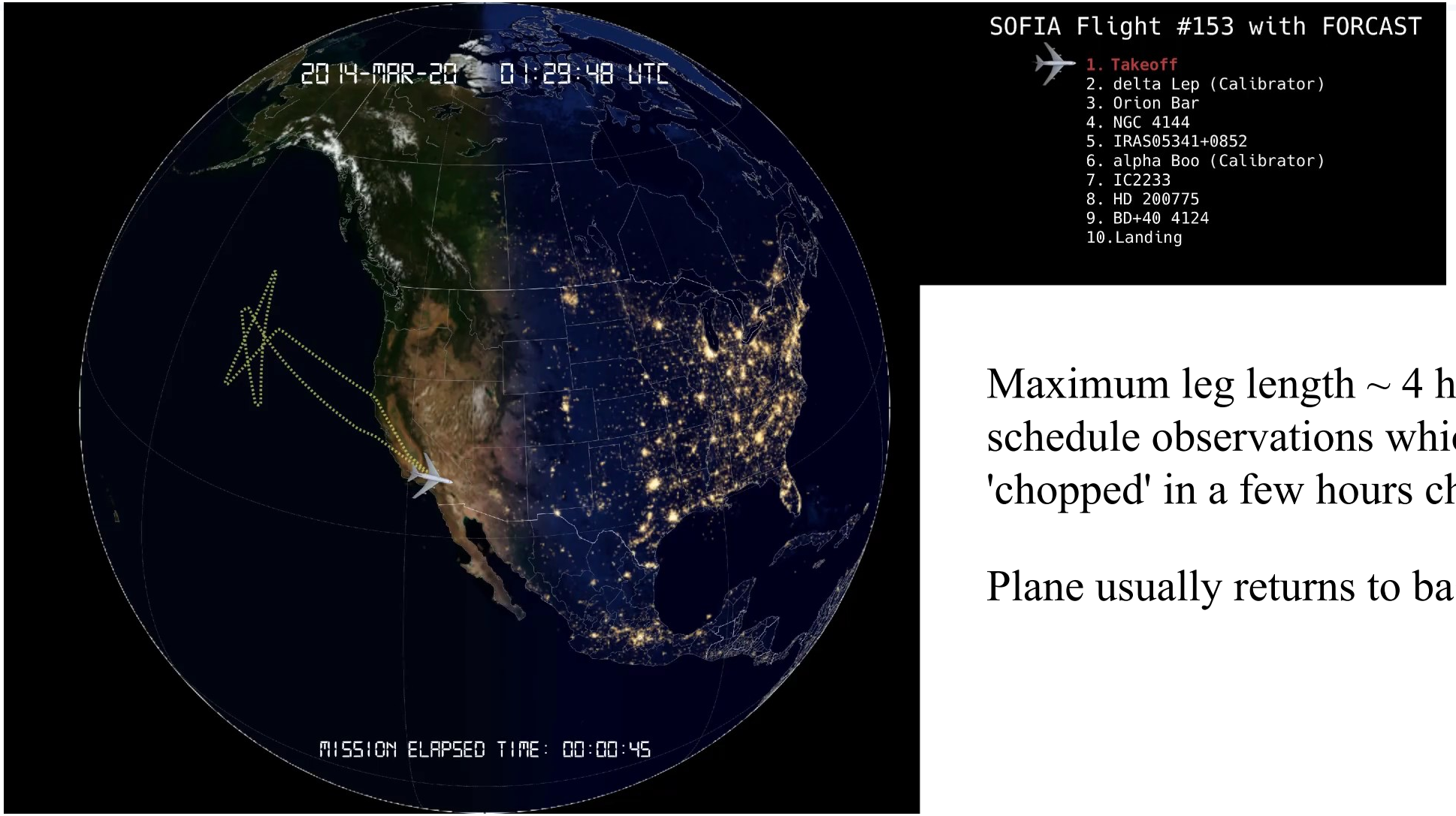


A flying telescope: some considerations

The telescope tilts up and down inside the plane: 22 – 58 deg elevation range

The telescope can rotate in all directions by +/-3 deg

A flying telescope: some considerations



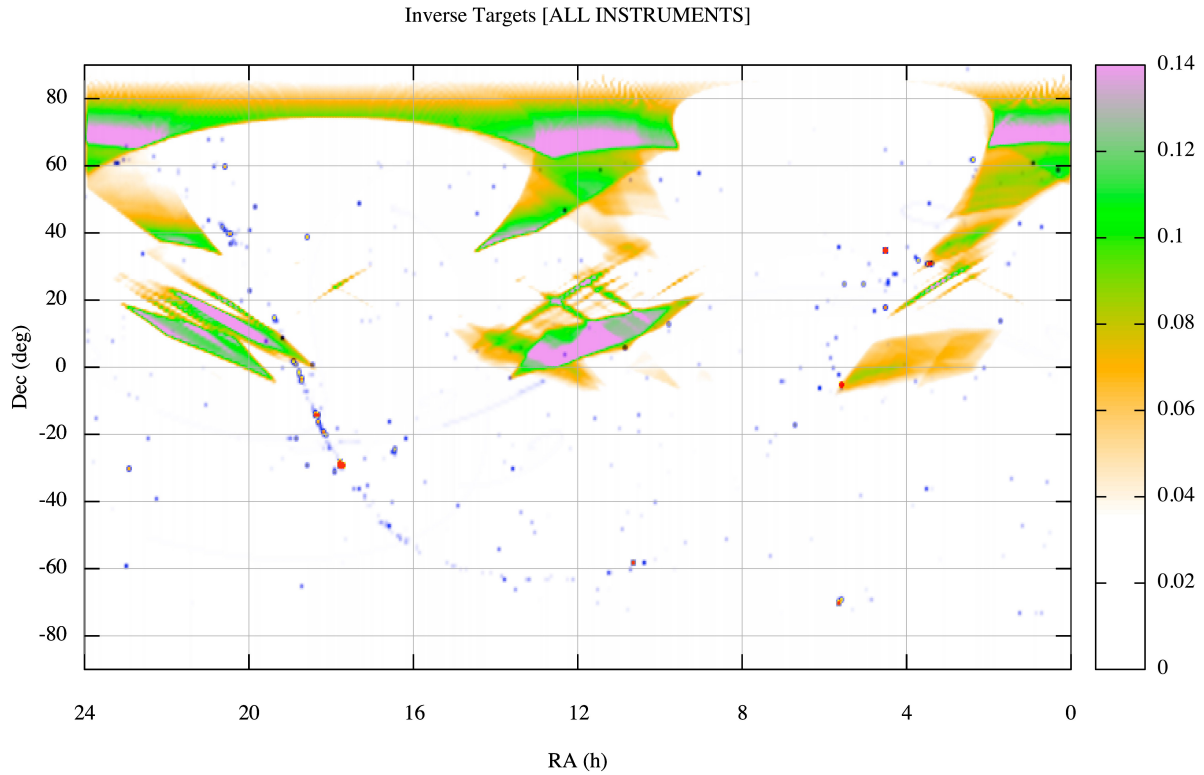
Maximum leg length ~ 4 hours : easier to schedule observations which can be easily 'chopped' in a few hours chunks

Plane usually returns to base at the end of flight

A flying telescope: some considerations

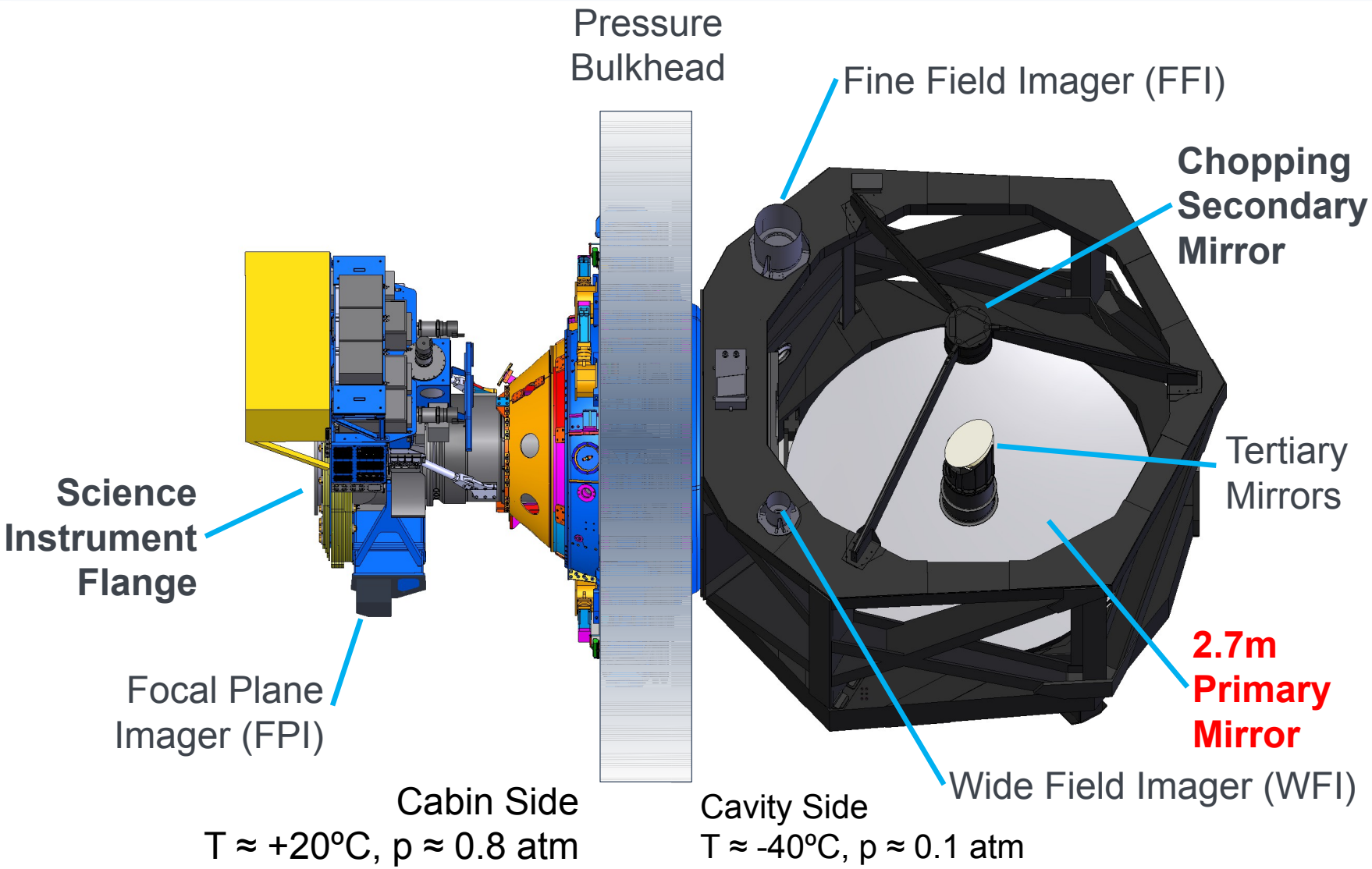
Even though bulk of targets are concentrated in the GP and ecliptic, you can only spend 1/2 of the time flying to view those directions and the other 1/2 on the return

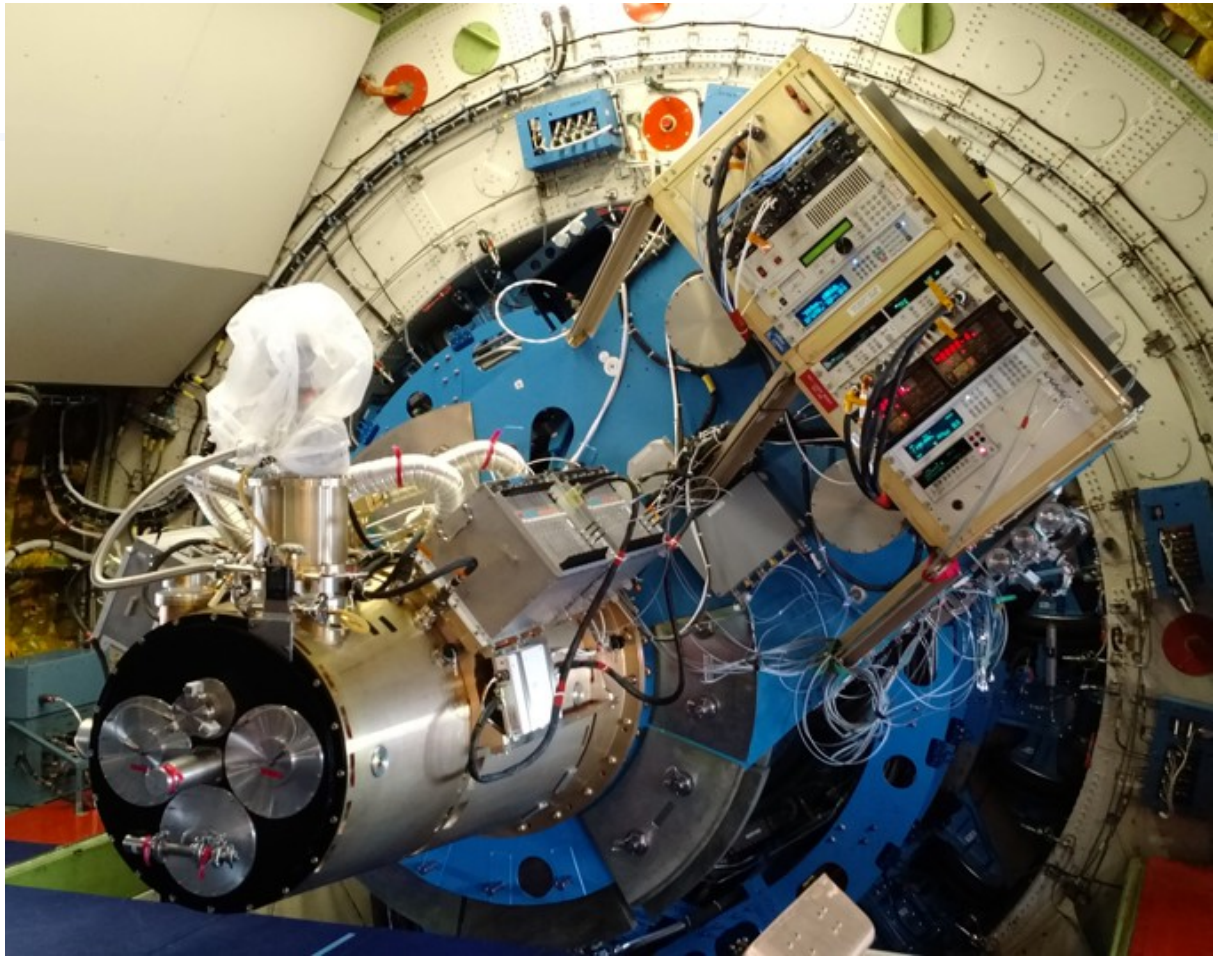
Whenever possible (surveys), choose targets with distribution at all parts of the sky. High latitudes are desirable.

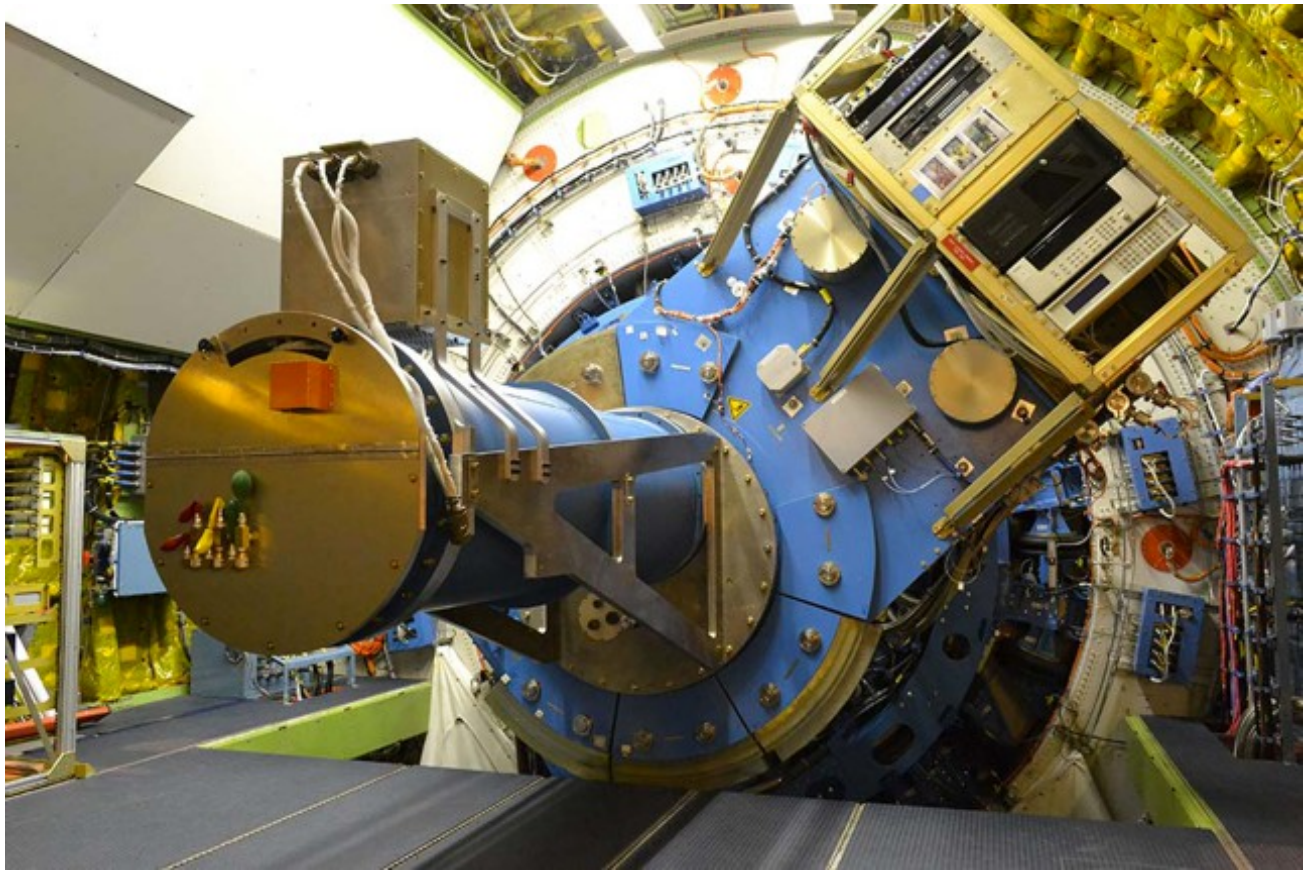


Optics and Imaging

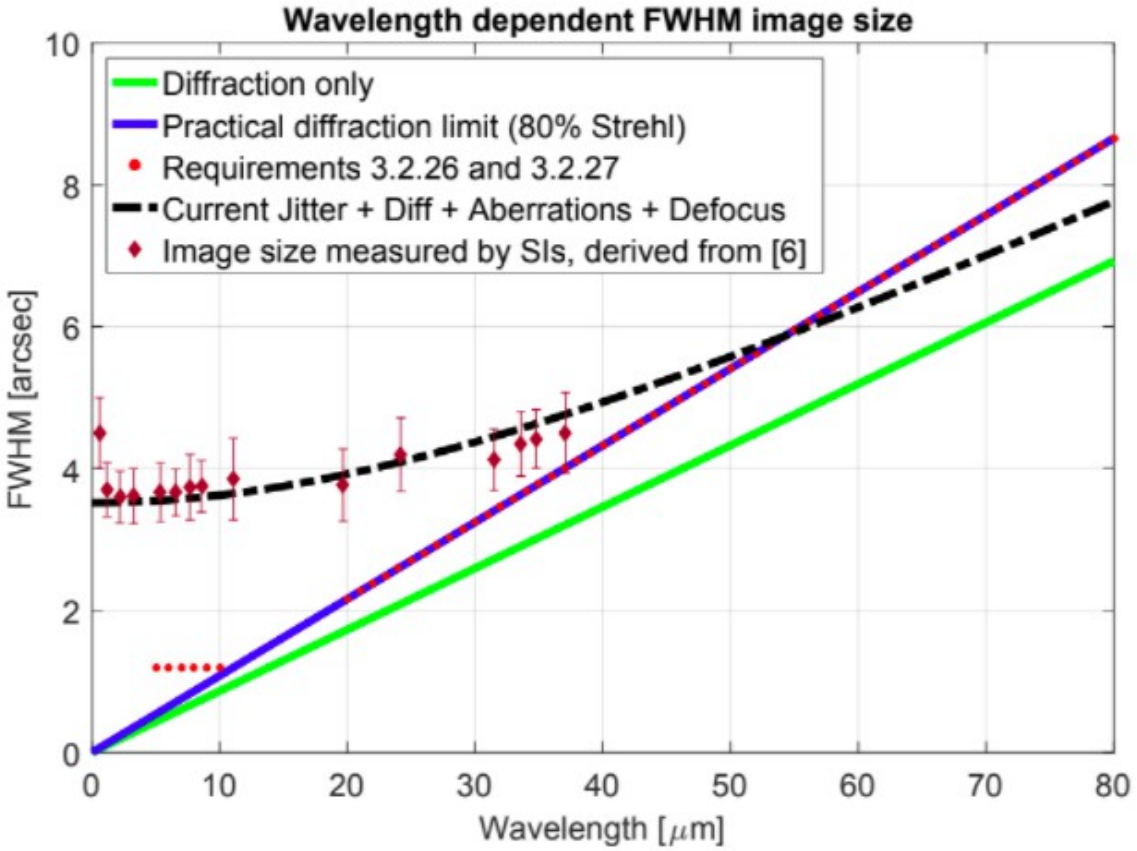
- Rotates on spherical bearing (3-axes)
- Actively stabilized by gyros and star trackers in closed-loop control







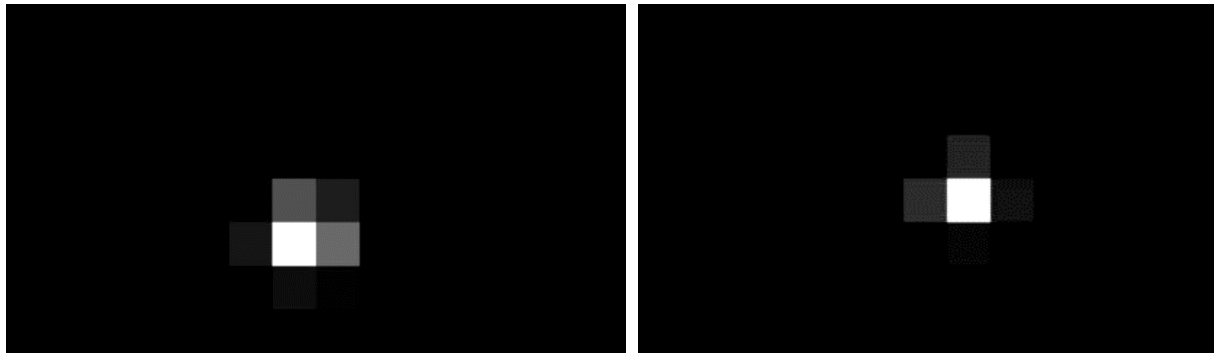
Optics and Imaging



PSF FWHM ~ 3.5” at short wavelengths, **diffraction limited >35 um**. Beam size (") lambda (um)/10

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

Image stabilization - Pointing done by Focal Plane Imager, 50 Hz updates to tip-tilt secondary mirror



off on

Optics and Imaging

- IR observations are completely background (sky + telescope) dominated. **Background can be >10^6 times brighter than most sources**

- Sky background varies rapidly (order of less than a few sec) -Telescope background varies on timescales of minutes

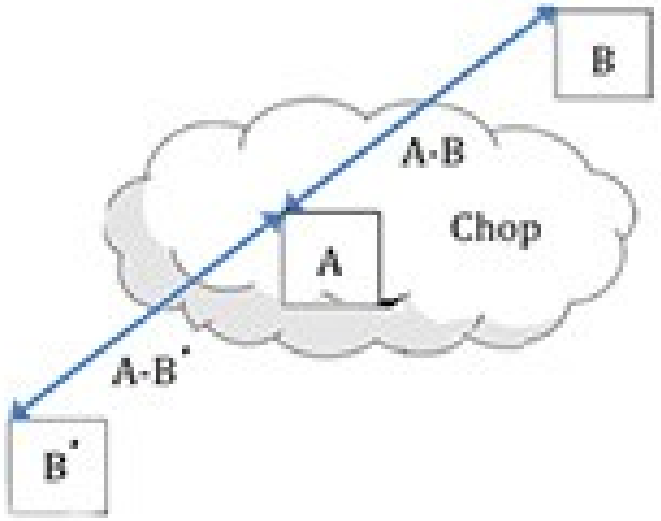
- Different methods are used to achieve background subtraction:

  - Chopping and Nodding (fixed telescope during observations)

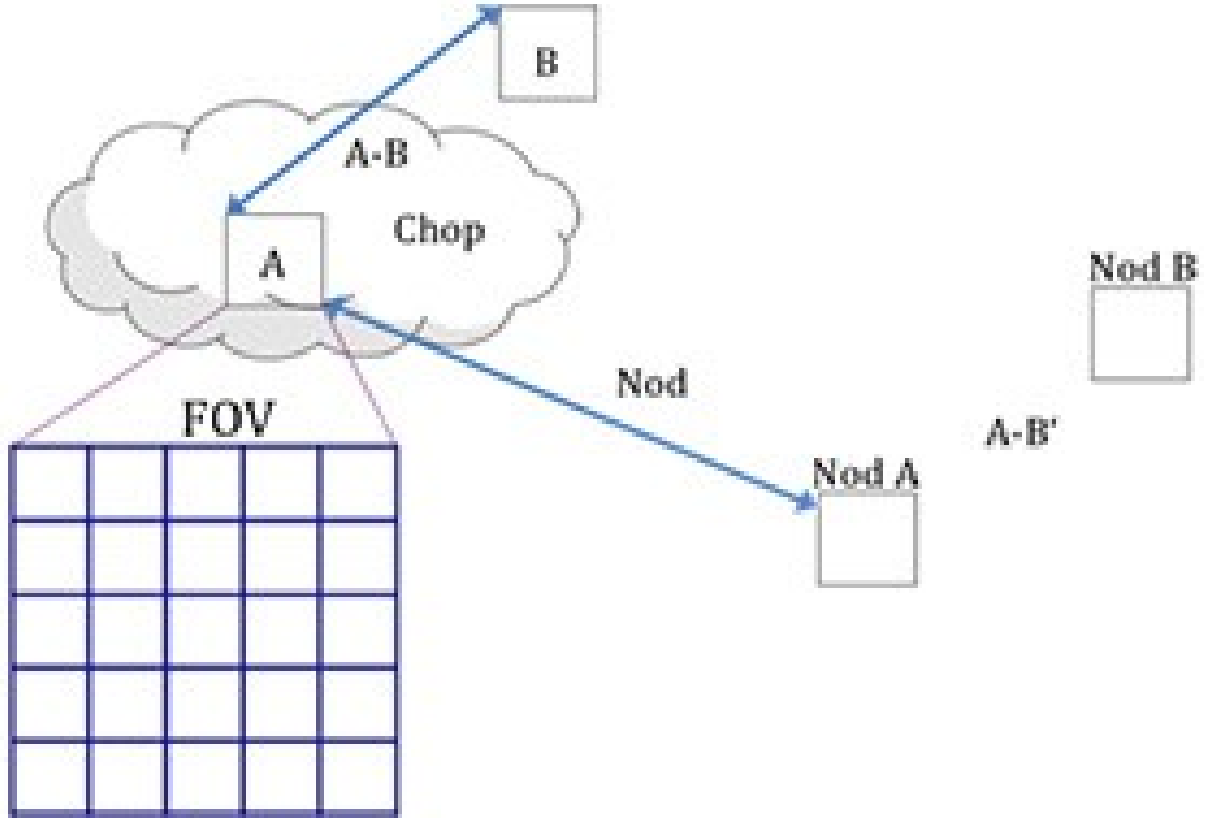
  - On-the-fly observations (telescope is moving during observations)

Optics and Imaging

Symmetric vs Asymmetric Chop Modes



Symmetric



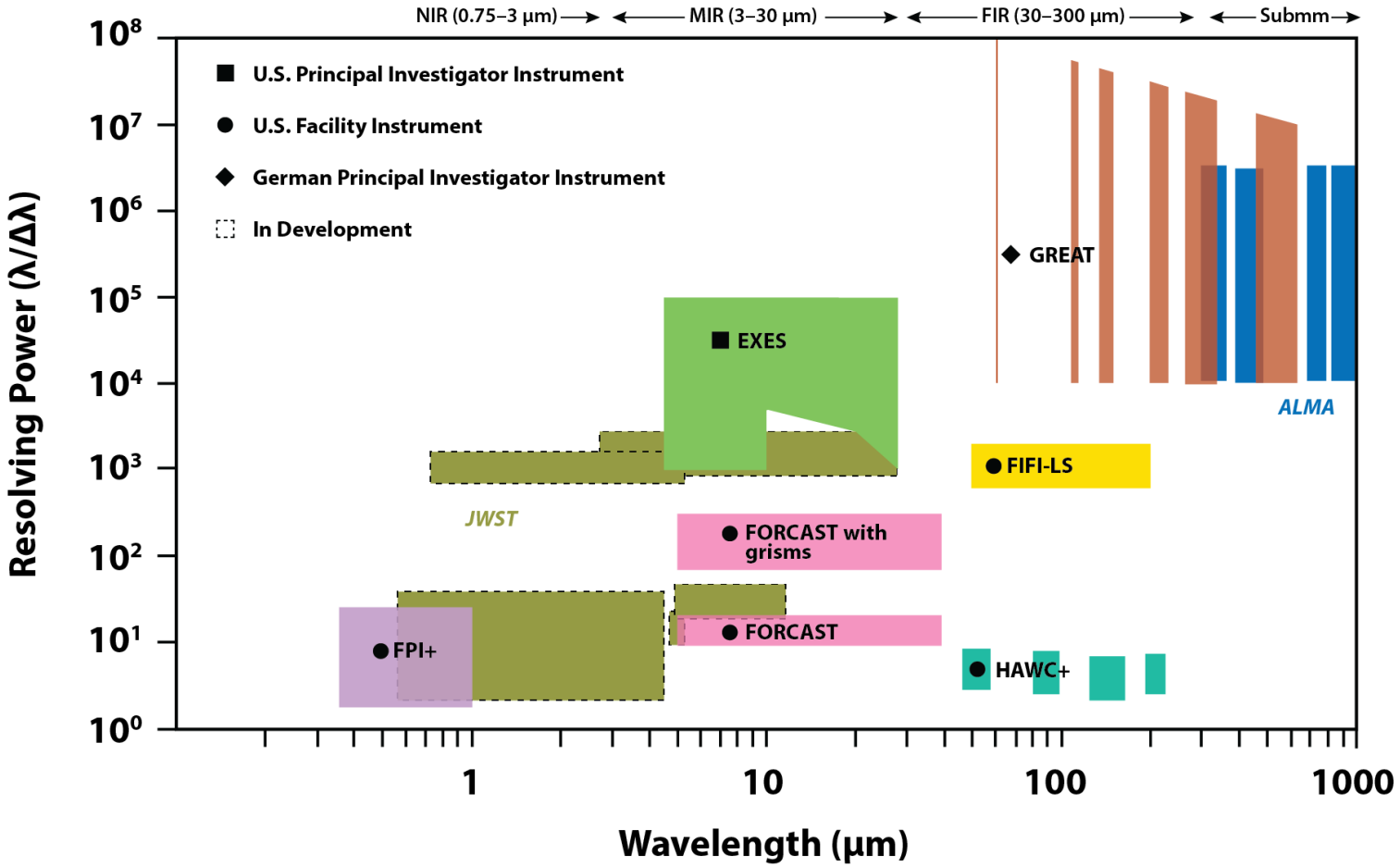
Asymmetric

SOFIA Instrument Suite

SOFIA covers most of the Mid and Far-IR spectrum (5-600 μm), at a variety of spectral resolutions

Instruments are installed for series of consecutive flights (1-4 weeks each) during a Cycle

Series scheduling made based on proposal pressure



FORCAST: MIR Imager + grisms

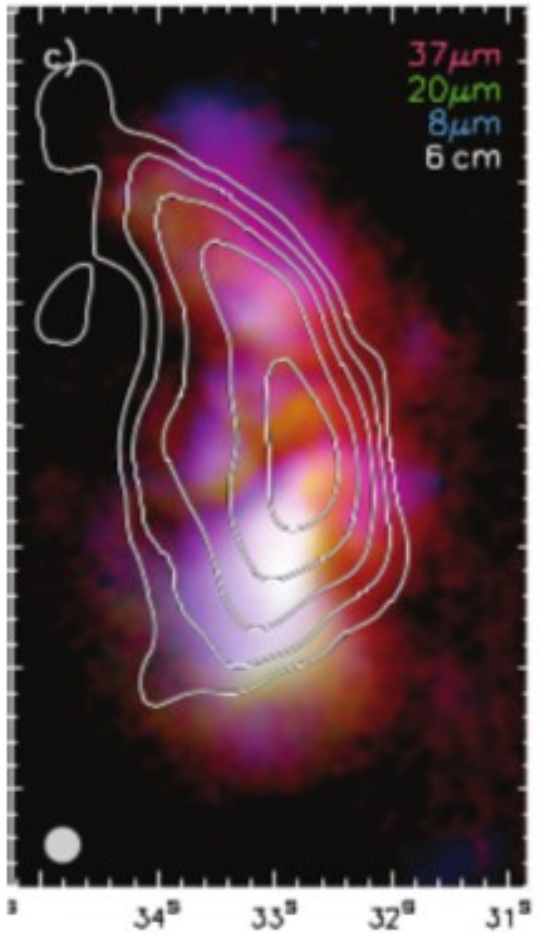
- **5-40 microns**
- 256x256 pixels array
- **R~70-300** with grisms
- PAHs, amorphous silicates, atomic/ionized features, does not saturate on bright sources

Grism Details

Grism	Coverage (μm)	R (λ/Δλ)[a]
G063	4.9–8.0	120[c]/180
G111	8.4–13.7	130[c]/260
G227	17.6–27.7	110/120
G329	28.7–37.1	160/170[b]

Filter Parameters

SWC Filters		LWC Filters	
λ_{eff} (μm)	Δλ (μm)	λ_{eff} (μm)	Δλ (μm)
5.4	0.16	24.2	2.9
5.6	0.08	31.5	5.7
6.4	0.14	33.6	1.9
6.6	0.24	34.8	3.8
7.7	0.47	37.1	3.3
8.8	0.41	A subset of these will be chosen each cycle as the nominal set.	
11.1	0.95		
11.2	2.7		
11.3	0.24		
11.8	0.74		
19.7	5.5		
25.4	1.86		



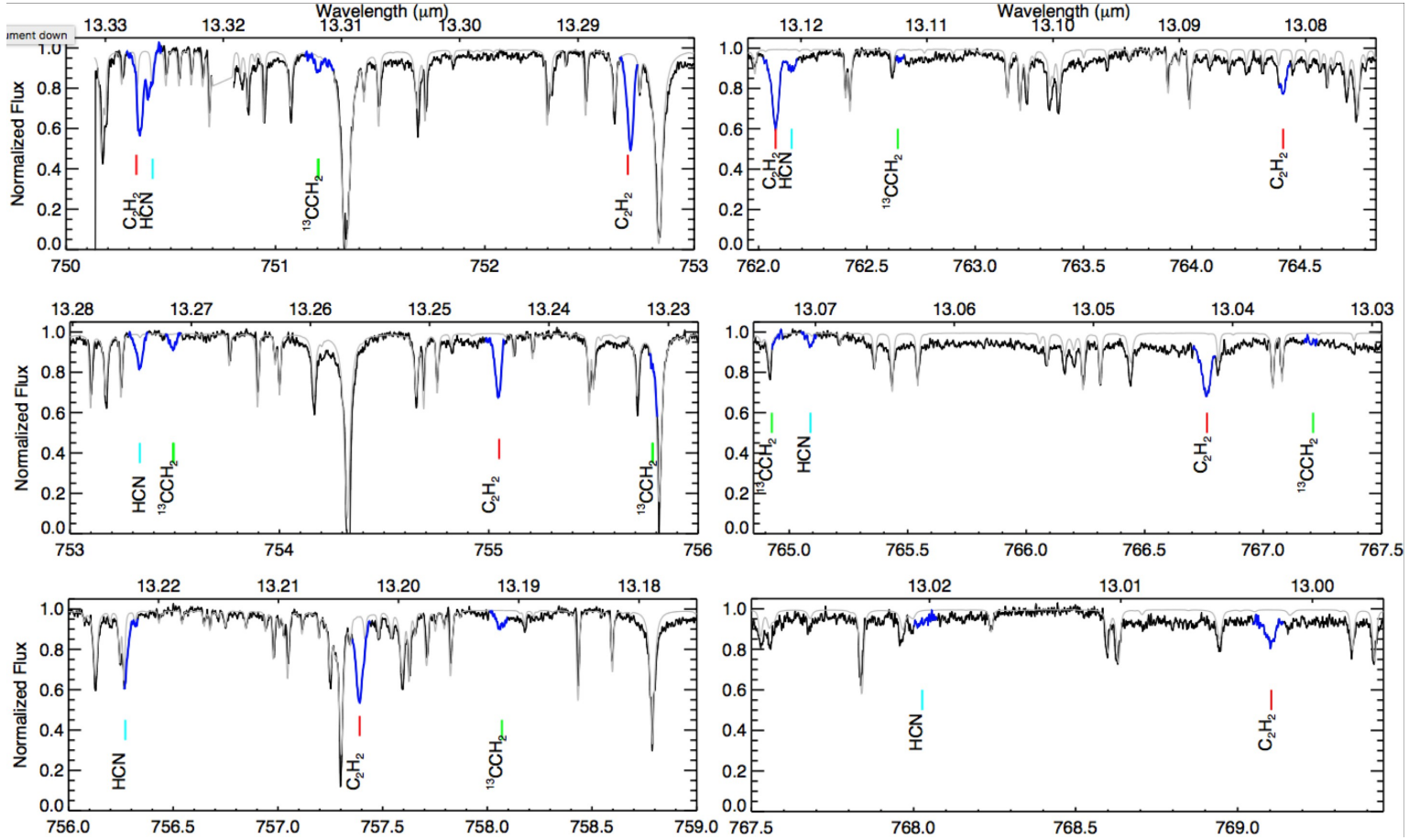
W51A - G49.5 (Lim et al., 2019)

EXES: High-res MIR Spectrometer (echelon-cross-echelle)

- Mid-IR High-Resolution Spectrograph: **4.5-28.3 µm**
- *Slit mapping mode available*

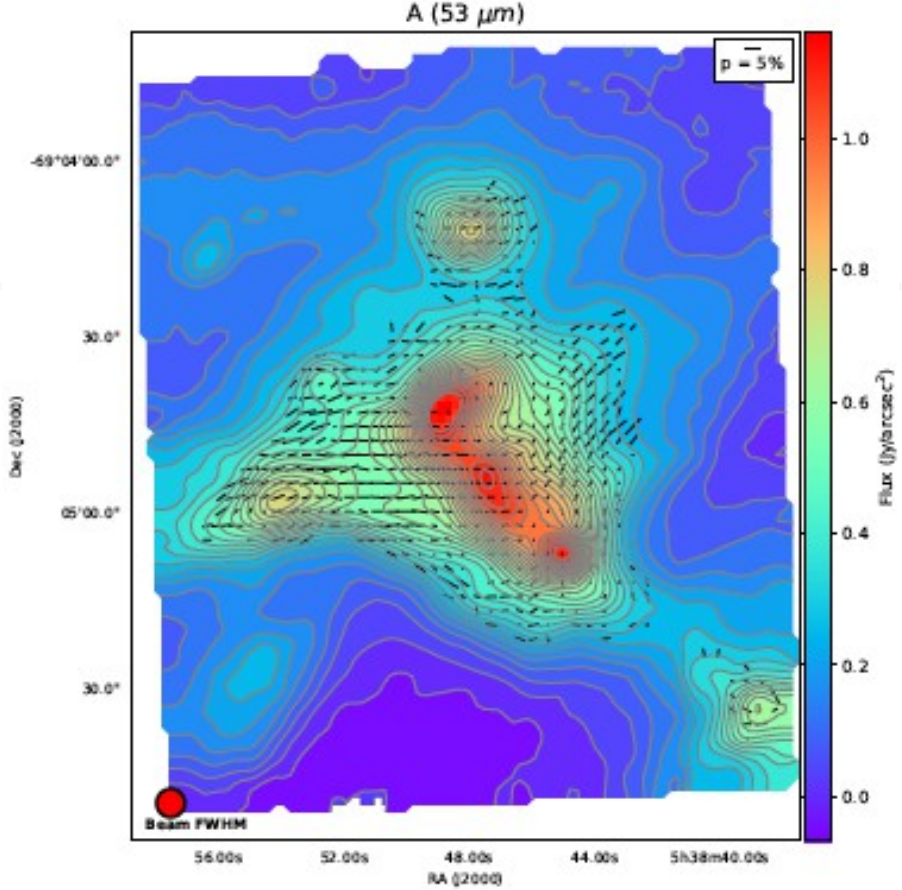
Configuration	Slit Length	Spectral Resolution
Low	25”– 180”	1,000 – 3,000
Medium		5,000 – 20,000
HIGH_MED	1.5” – 45”	50,000 – 100,000
HIGH_LOW	1” – 12”	

In the Medium and Low configurations the slit lengths vary from 25” to 180” depending on the number of rows to be read.



Orion Hot Core line survey (Rangwala et al. 2018)

HAWC+: FIR Polarimetric Imager



30Dor polarization map
(Gordon et al., 2018)

- **53-220 microns , 64x40 array**
- Superconducting TES

- Polarimeter (half wave plates)

- Diffraction limited at all bands
- dust polarization and distribution

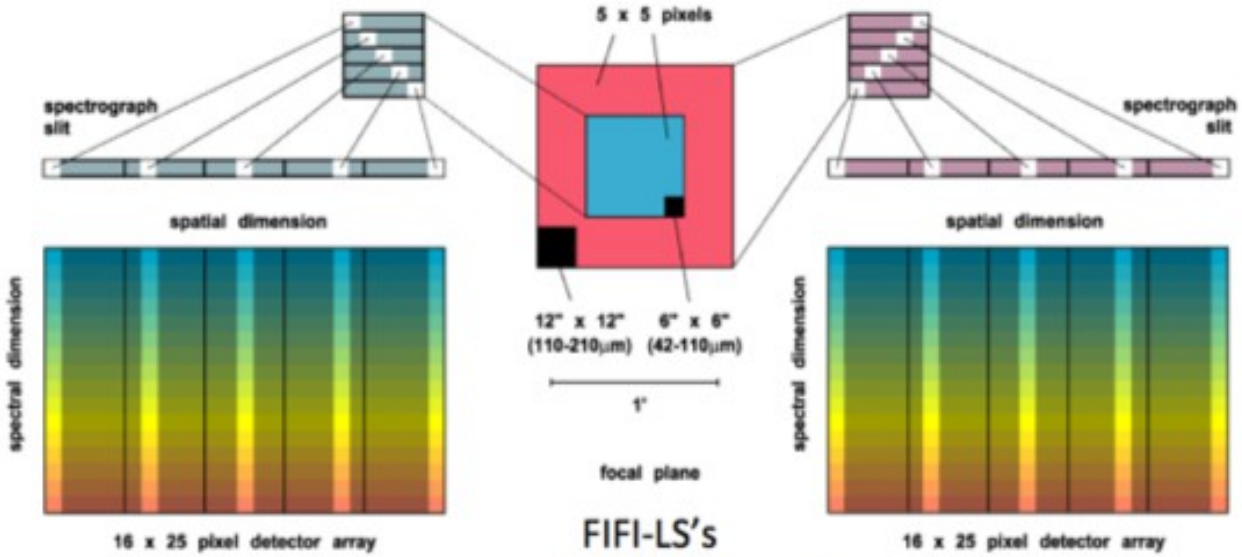
Band / Wavelength	Δλ/λ	Angular Resolution	Total Intensity FOV (arcmin)	Polarization FOV (arcmin)
A / 53 μm	0.17	4.7” FWHM	2.7 x 1.7	1.3 x 1.7
C / 89 μm	0.19	7.8” FWHM	4.2 x 2.6	2.1 x 2.6
D / 154 μm	0.22	14” FWHM	7.3 x 4.5	3.6 x 4.5
E / 214μm	0.20	19” FWHM	8.0 x 6.1	4.0 x 6.1

FIFI-LS: FIR Integral field Spectrometer

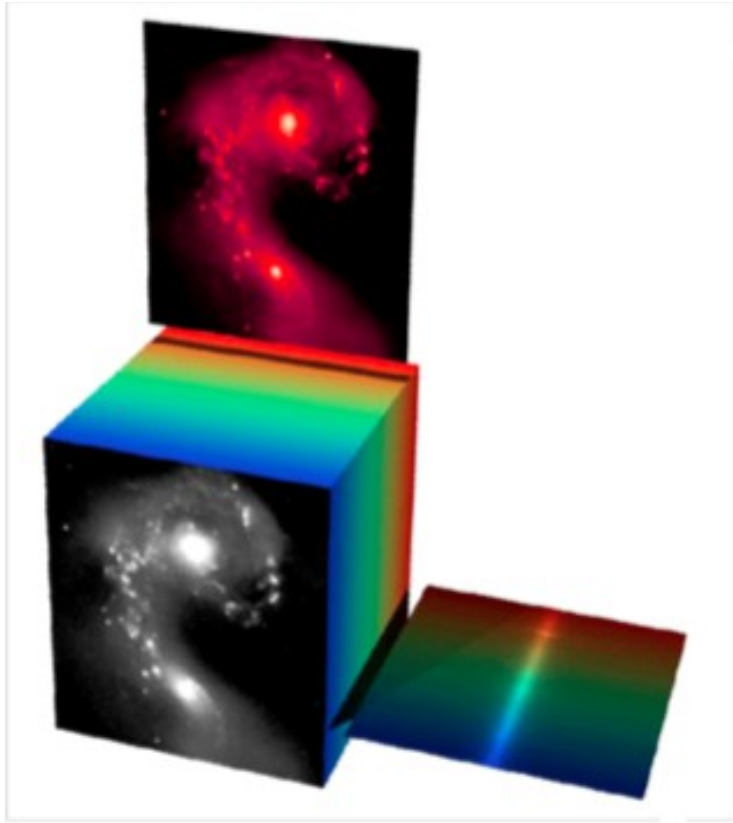
FIFI-LS: Far-infrared spectrometer with two parallel channels and an integral field unit:

Blue 50-110 μm & Red 110-200 μm

Spectral resolution: R=500-2000



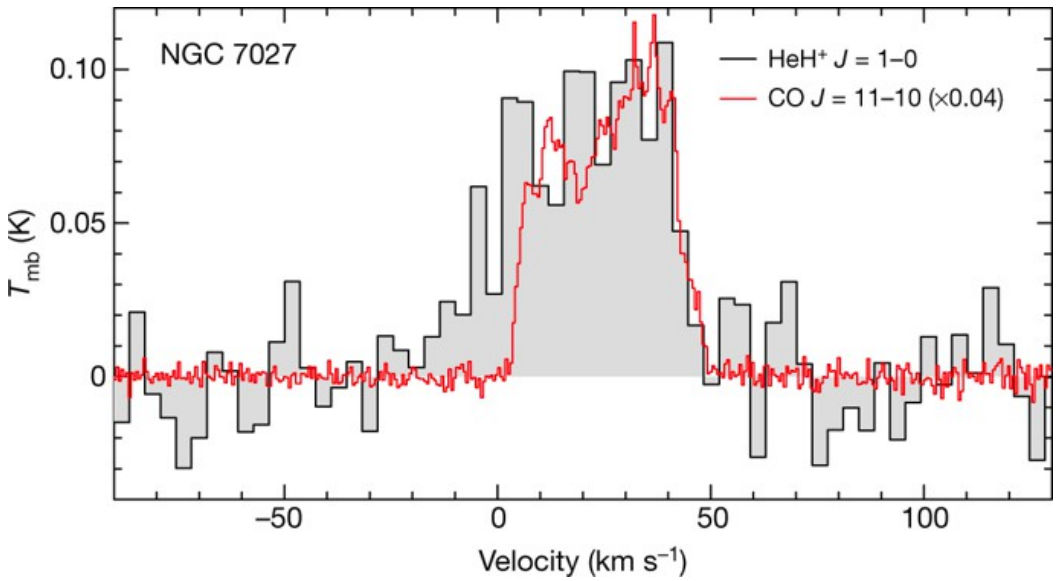
FIFI-LS's image slicer concept



Standard pipeline product is a *datacube*.

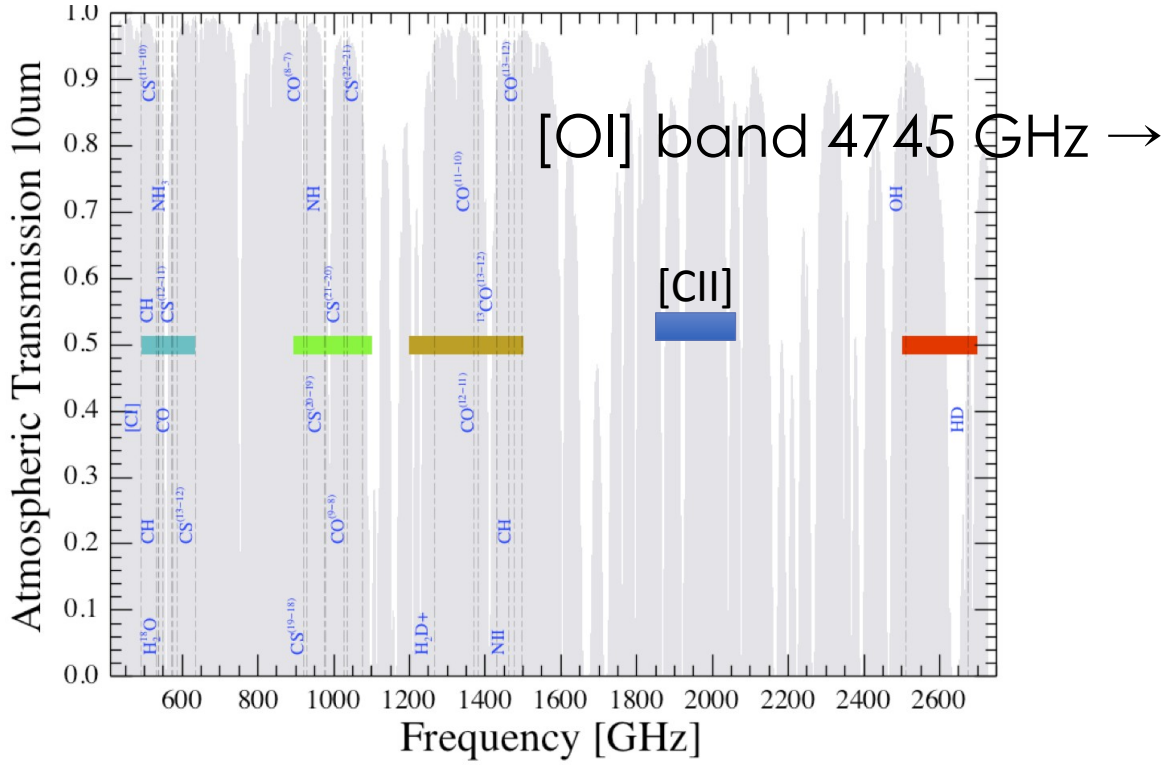
GREAT: THz heterodyne spectroscopy

- Six bands in the 0.5 – 4.7 THz range
- R = 10^8 (<0.1 km/s!)



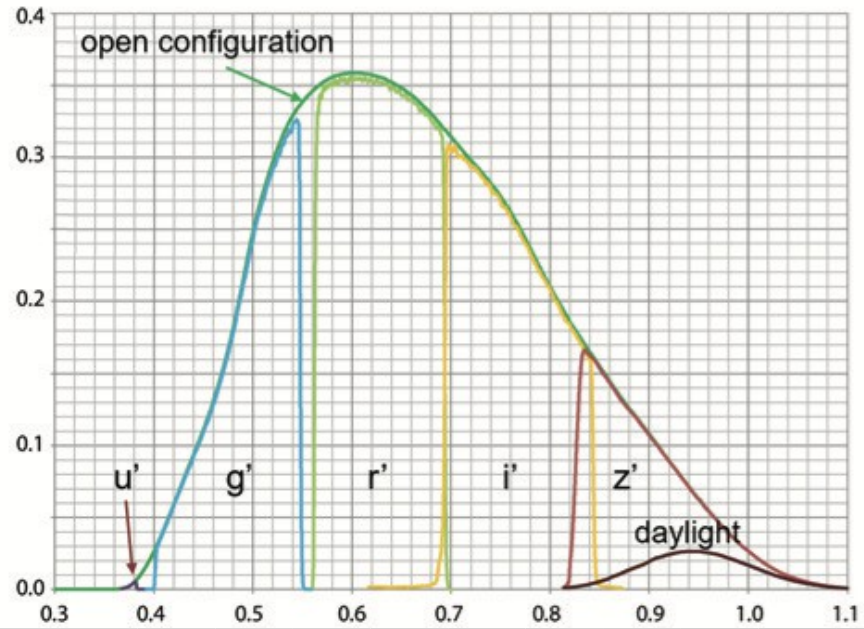
HeH+ first detection (149µm, NGC 7027),
Güsten et al. (2019) Nature 568, 357.

- Two bands with 7-beam array (2 polarization)s 4 bands with 1 pixel
- Compares to Herschel-HIFI, with faster mapping and similar point source sensitivity

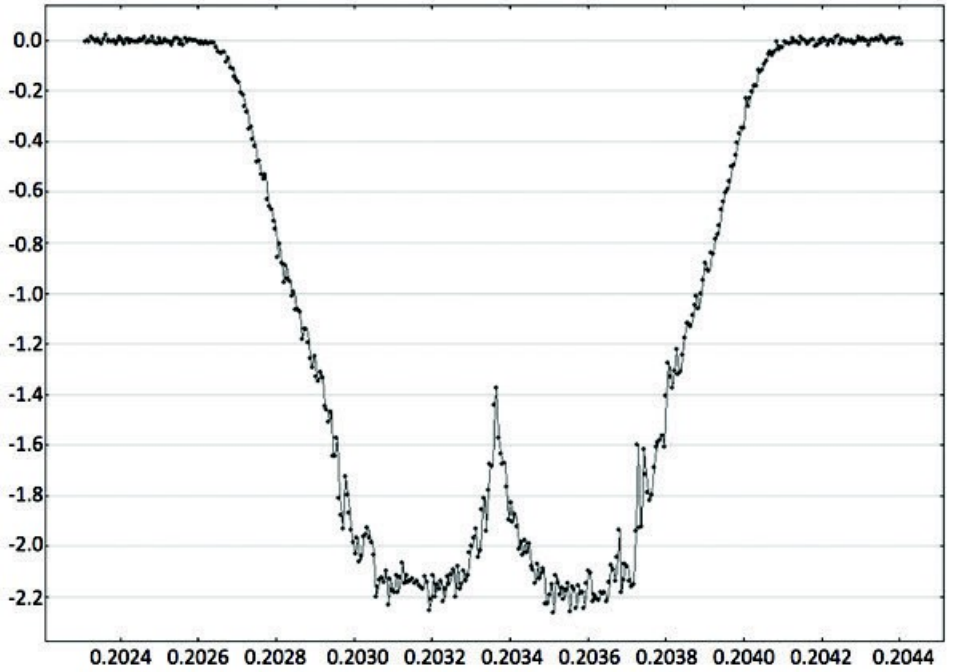


FPI+: The Guider that is a Science Instrument

- Guider camera with science grade EMCCD.
- Fast optical photometry for e.g. occultations.
- Different filters available: 330-1100 nm



Stellar Occultation by Pluto 2015-06-29



Preparing your SOFIA proposal

Science case

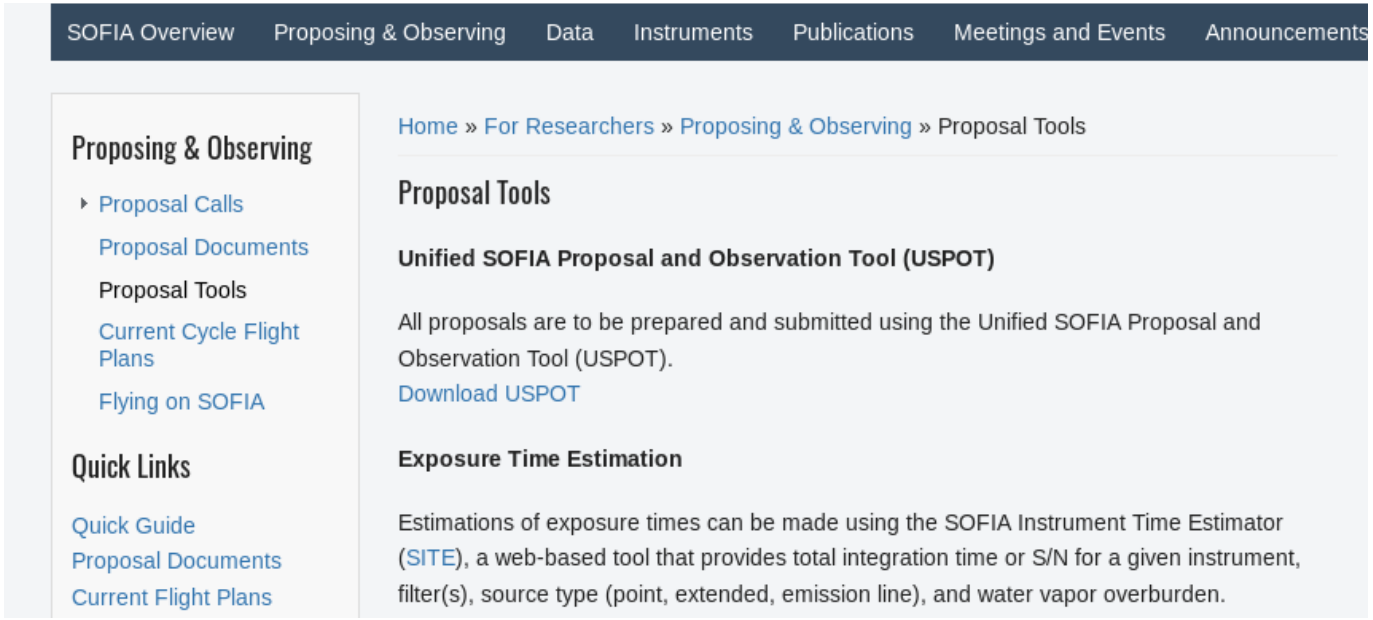
What is offered in Cycle 9

Evaluate feasibility

Define observations in USPOT

Upload justification and bio pdfs

Validate then Submit!
Deadline Sept 4th, 21h PDT



Call For Proposals

Observers' Handbook

Time estimates: SITE

USPOT manual

USPOT (to download)

Any missing information: Help Desk
sofia_help@sofia.usra.edu

Science case tips

- Preference given to substantial investigations that demonstrate significant scientific impact from SOFIA
- Programs using multi-wavelength data from major facilities (ALMA, HST, Spitzer, etc) are highly encourages
- Programs informing future JWST observations highly encouraged (up to 20 hours reserved)
- Joint proposal agreement with Green Bank Observatory
- Survey proposals are encouraged. Plan is to have up to 100 hours for survey proposals.
- Criterion: degree to which the investigation uses SOFIA's Unique capabilities.

What is offered in Cycle 9

In short:
- July 1,2021 to Sep 30, 2022
- All six instruments
- 3 instruments deployed to NZ
GREAT and HAWC + (July-Sep 2021, 2022)
FIFI-LS (March 2022)

New:
- more standard modes: GREAT honeycomb OTF maps, FIFI-LS total power
- in shared risk: FIFI-LS on-the-fly mapping mode, HAWC+ 63 microns (Band B)
- The two polarizations of the GREAT Low Frequency Array can now be set to two different frequencies

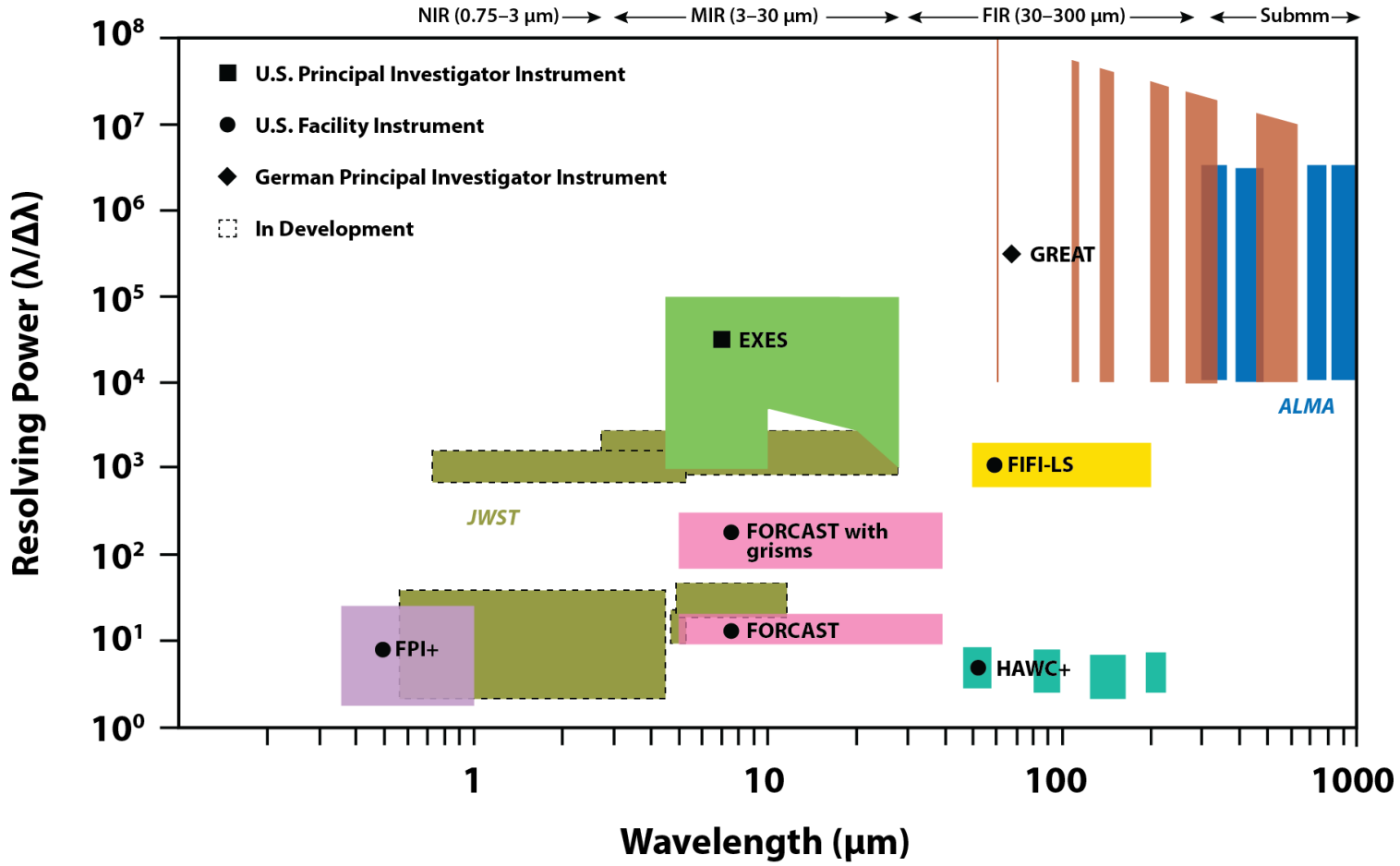
What is offered in Cycle 9

2 different types of proposals

- **Regular**: up to 500h total, includes surveys, ToO

- **Legacy:** 1-4 large proposals, up to 200h observations each over 2 cycles. Up to 400 h total in C9. No proprietary period, team contributes enhanced products

Feasability: wavelength, spectral resolution, spatial resolution

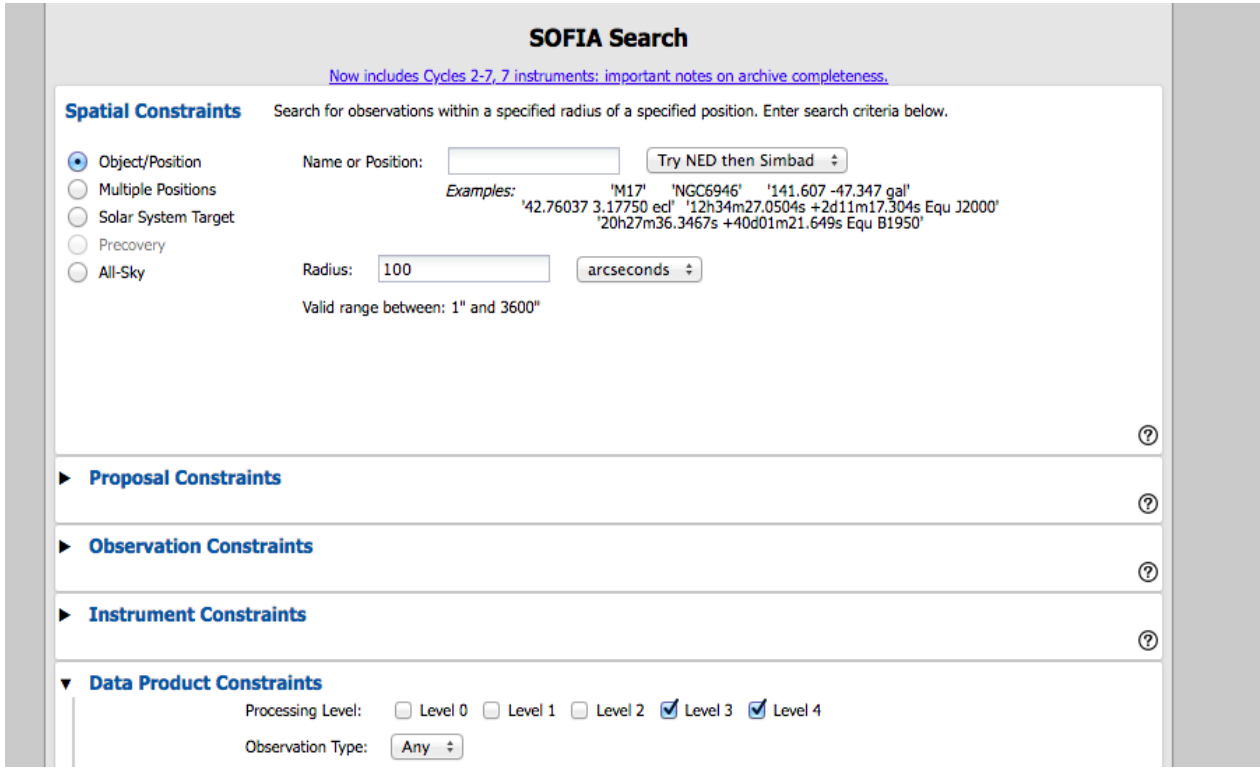


PSF FWHM ~ 3.5” at short wavelengths, **diffraction limited >35 um**. Beam size (") lambda (um)/10

Feasability: Archival search and reserved observations catalogues

Reserved observations (GREAT and FIFI-LS):
duplicates from Reserved Observations Catalog (ROC) lists not allowed, unless explicit permission from the instrument's PI (SMO should be notified prior to proposal submission)

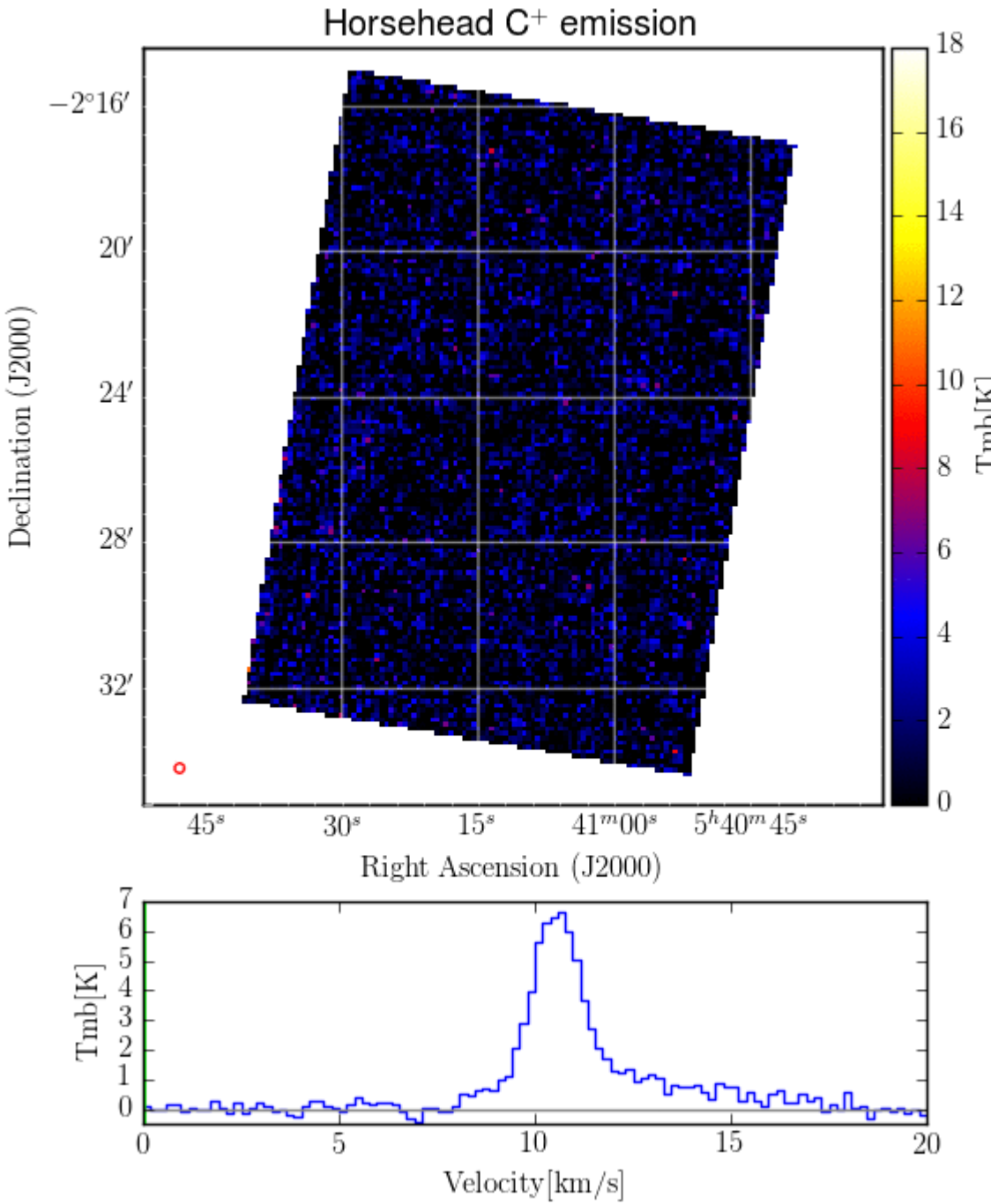
Duplication of observations:
generally not allowed, and if proposed for must be identified and explicitly justified.
Check the IRSA SOFIA archive



Feasibility: Signal

Expected source signal: needs to be soundly justified!
- archival data (possibly w. SED extrapolation)
- your own radiative transfer model (describe)
- classic models/ correlations: Hyperion (dust), Planetary Spectrum Calculator, Meudon PDR ...

Signal must be defined by **flux density by beam/pixel o**
surface brightness (depends on instruments)
- Jy or W.m-2µm-1 (flux density)
- Jy /arcsec-2 (surface brightness)
- W.m-2 (flux density integrated on resolution unit)
- T (brightness temperature)



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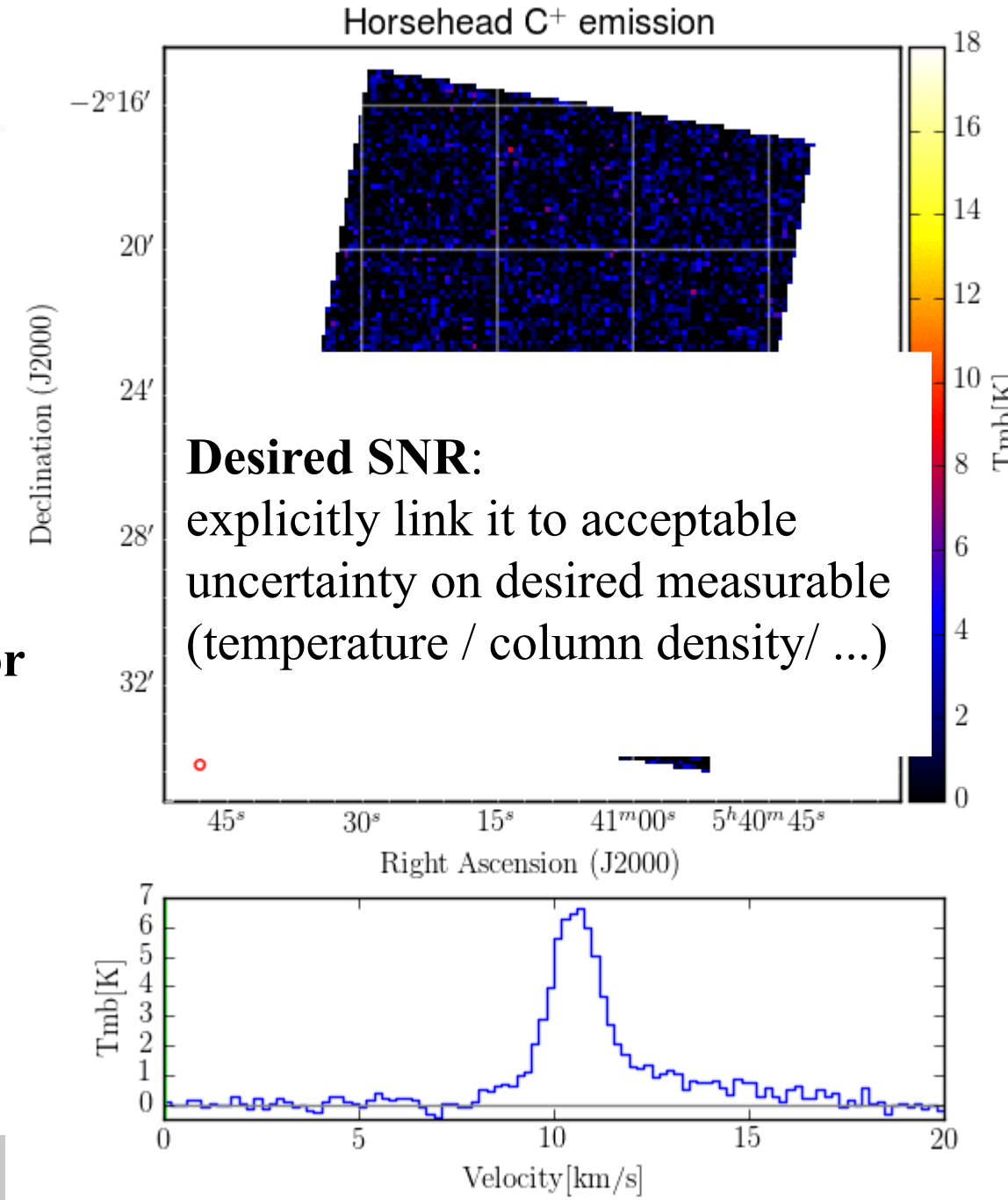
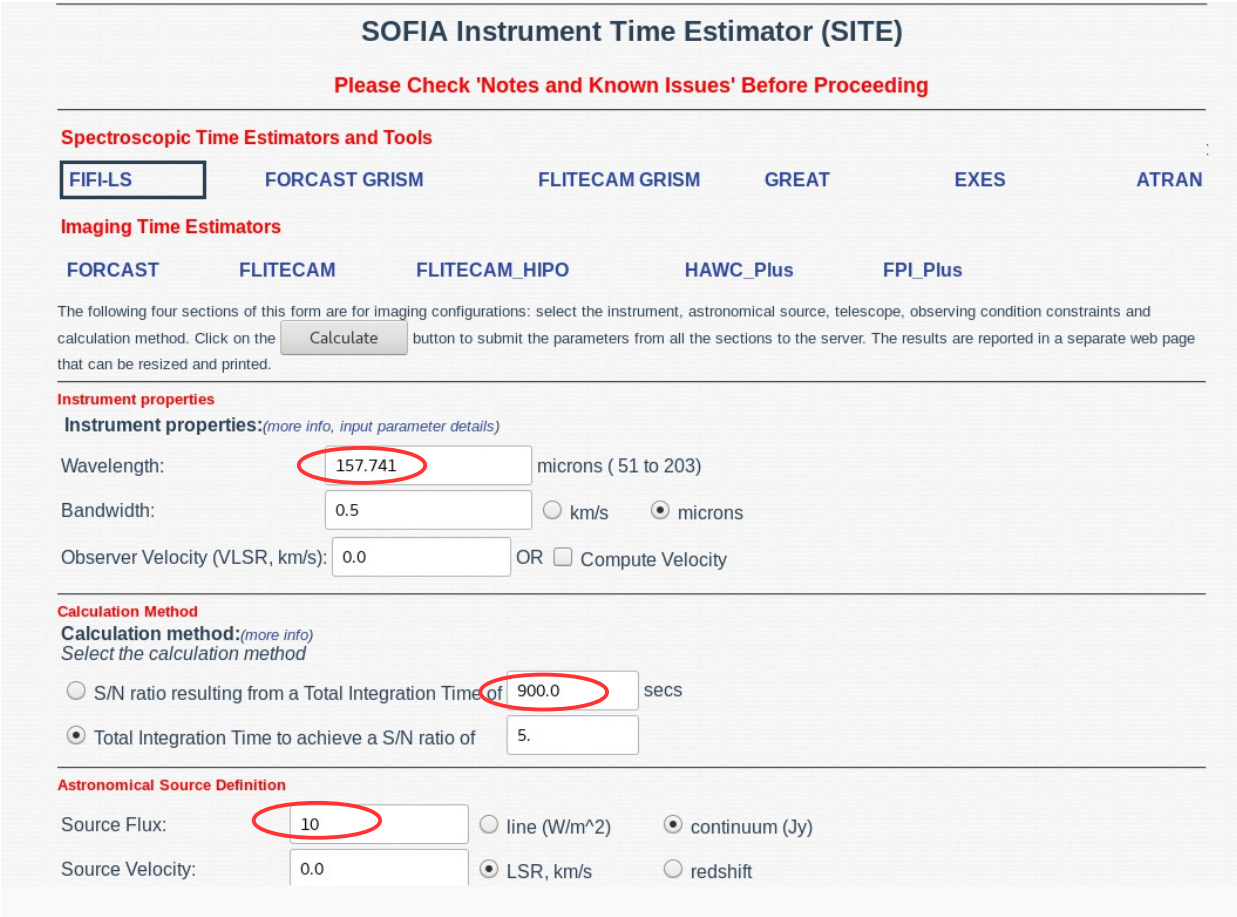


SITE: estimating corresponding observing time



SOFIA Instrument Time Estimator (SITE)

Please Check 'Notes and Known Issues' Before Proceeding

Spectroscopic Time Estimators and Tools

FIFI-LS | FORCAST GRISM | FLITECAM GRISM | GREAT | EXES | ATRAN

Imaging Time Estimators

FORCAST | FLITECAM | FLITECAM_HIPO | HAWC_Plus | FPI_Plus

The following four sections of this form are for imaging configurations: select the instrument, astronomical source, telescope, observing condition constraints and calculation method. Click on the Calculate button to submit the parameters from all the sections to the server. The results are reported in a separate web page that can be resized and printed.

Instrument properties

Instrument properties: *(more info, input parameter details)*

Wavelength: 157.741 microns (51 to 203)

Bandwidth: 0.5 km/s microns

Observer Velocity (VLSR, km/s): 0.0 OR Compute Velocity

Calculation Method

Calculation method: *(more info)*
Select the calculation method

S/N ratio resulting from a Total Integration Time of 900.0 secs

Total Integration Time to achieve a S/N ratio of 5.

Astronomical Source Definition

Source Flux: 10 line (W/m^2) continuum (Jy)

Source Velocity: 0.0 LSR, km/s redshift

https://dcs.arc.nasa.gov/proposalDevelopment/SITE/index.jsp

Output Parameters

V_LSR:	0.000	km/s
Velocity corrected Wavelength:	157.741	microns
Plotted wavelength range:	156.938 - 158.544	microns
Interpolated values from data table:		
Bandwidth =	0.803	microns
MDLF =	2.087e-17	W/m^2
MDCF =	0.570	Jy
Atmospheric Transmission:	0.843 (smoothed)	0.862 (unsmoothed)
Integration time (t_on):	0.107 (smoothed)	0.102 minutes (unsmoothed)

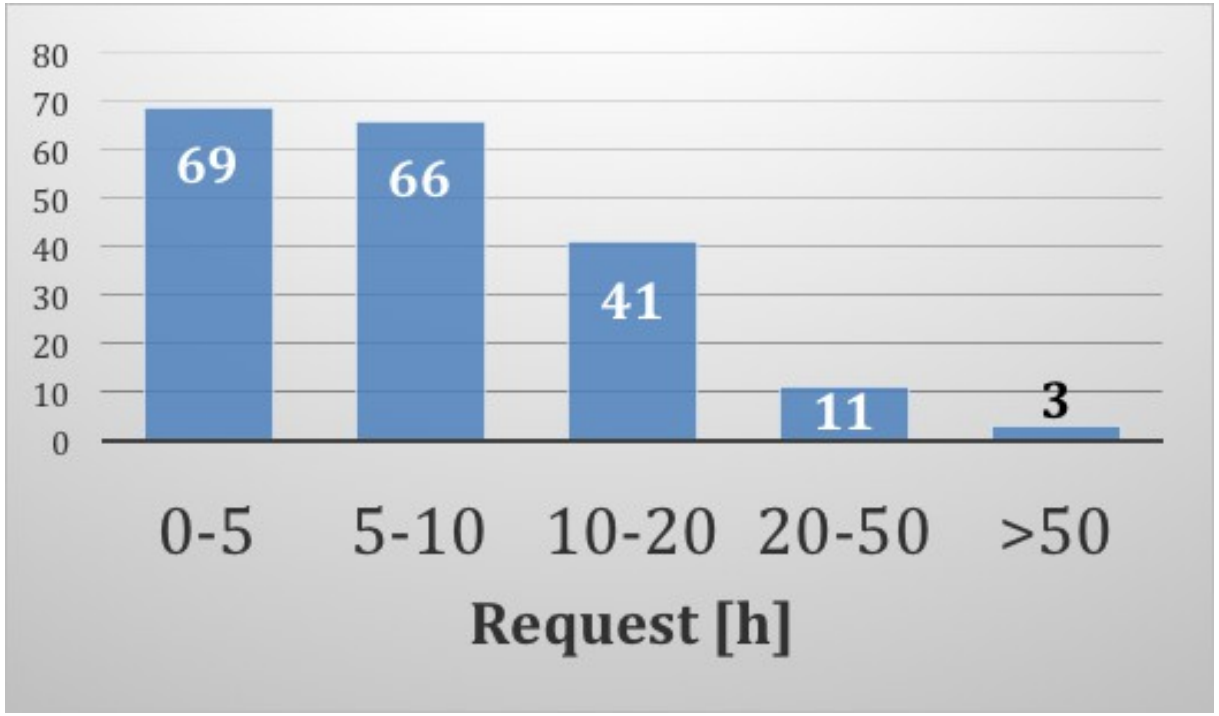
SITE: estimating corresponding observing time

This is a time estimate **per ON point or ON-OFF pair (depending on instrument mode)**: to estimate total integration time, multiply by number of pointings needed to cover desired area

This is a needed time estimate **per array element**: in some mapping modes, different pixels can 'sweep' the same area of the sky → more total integration time / area of the sky → less integration per pixel may be needed to reach same SNR

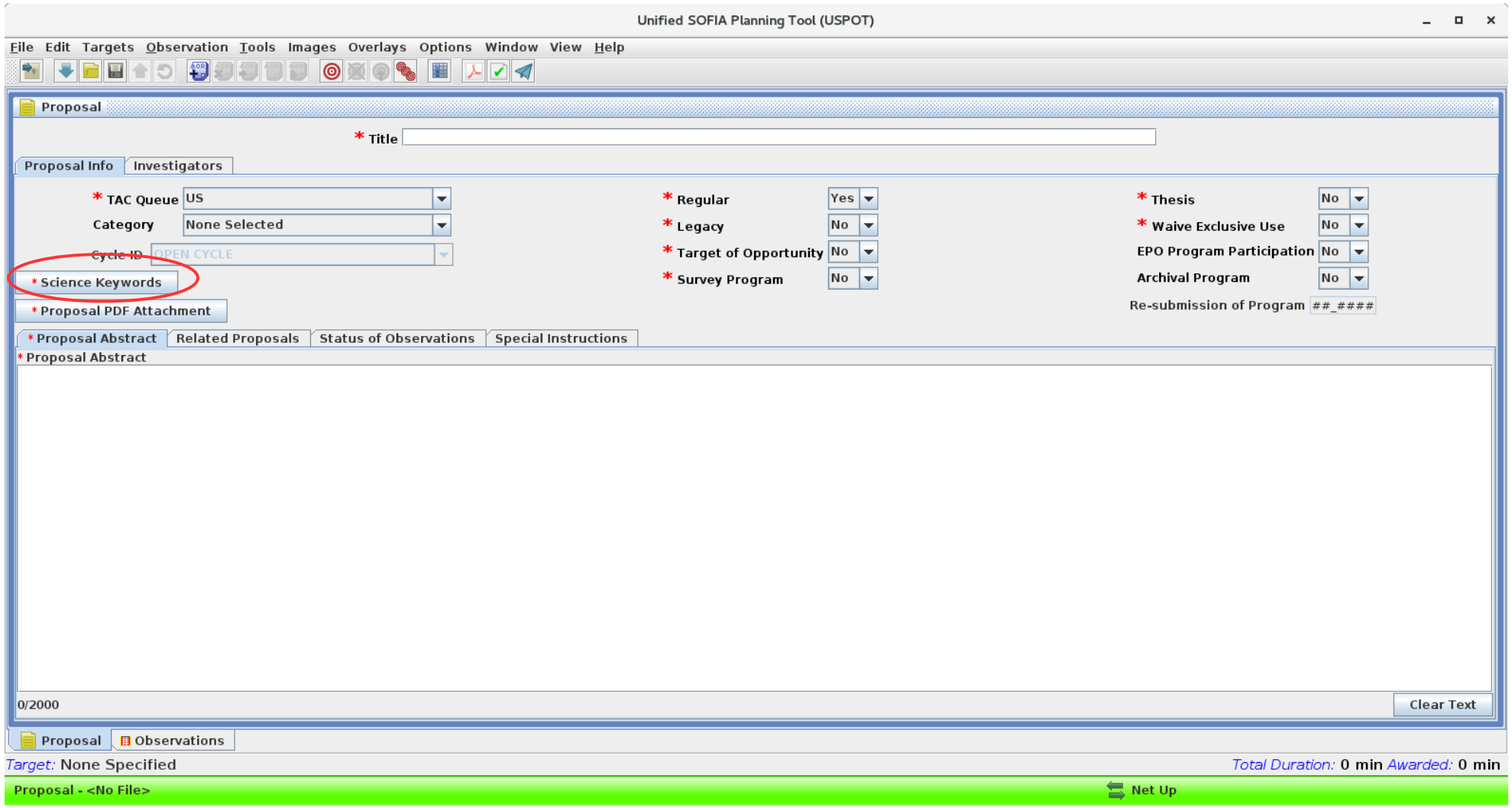
Does not include calibration overheads: those will be calculated by USPOT

SITE: estimating corresponding observing time

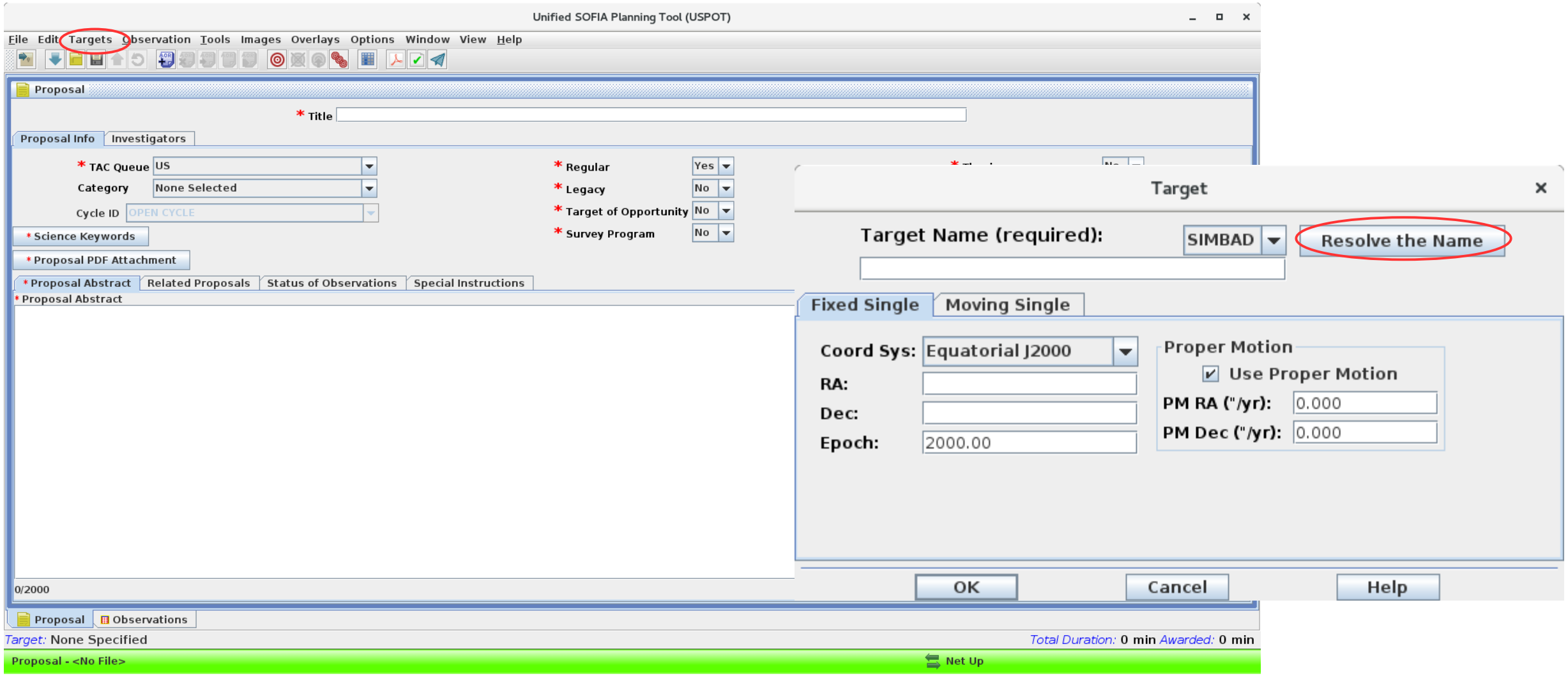


Distribution of time requests in Cycle 8 (regular proposals, US queue)

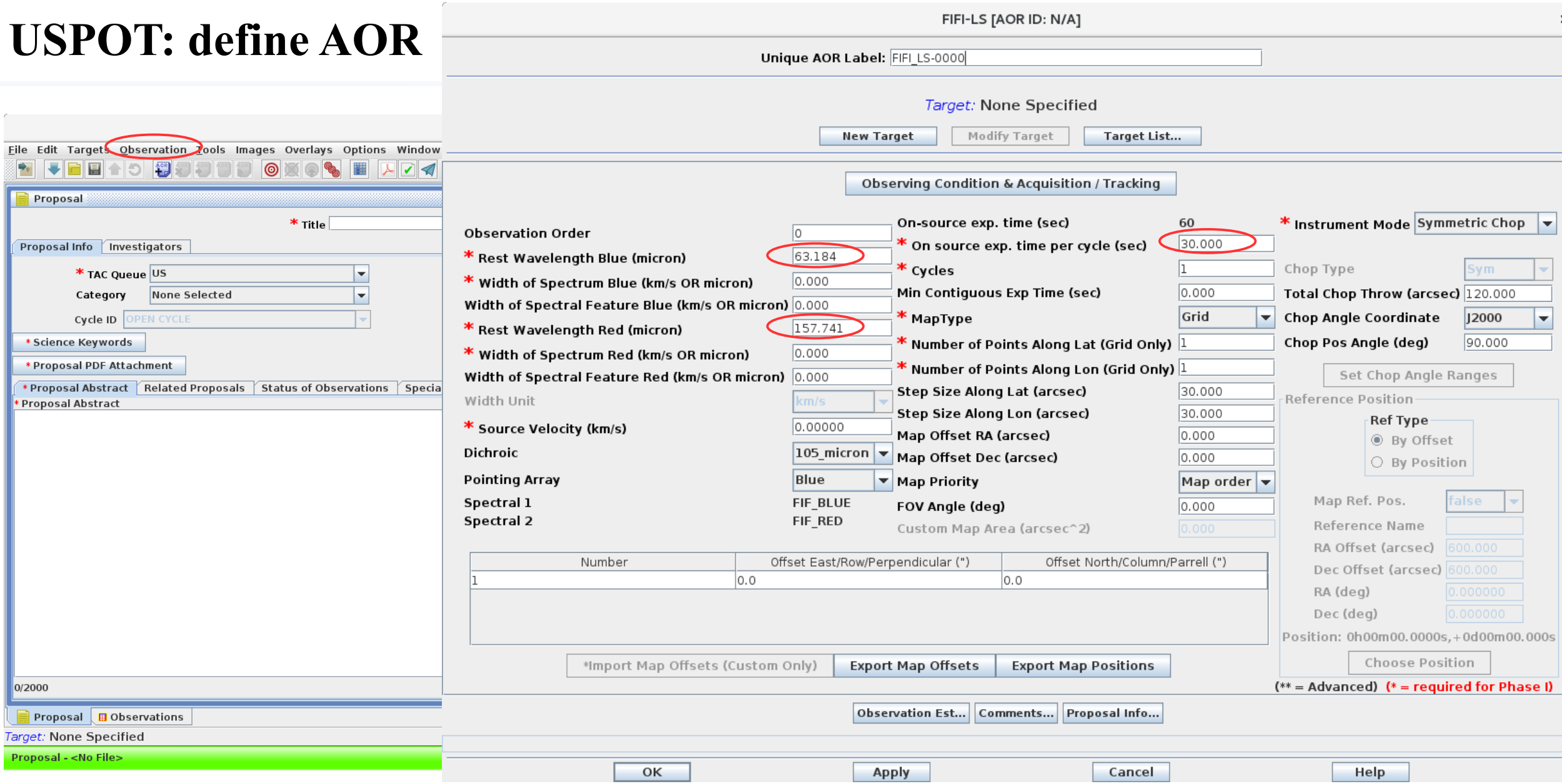
USPOT: cover page



USPOT: define targets



USPOT: define AOR



USPOT: building justification pdf (main body)

- Context, aim, methods, synergies, anticipated results (0.5p / 1p)
- Scientific justification (3p + references / 5 p)
  - Don't forget instrument and data justification (as opposed to i.e., TEXES, archival data, ...)
- Feasibility + path to publication (3p)
  (instrument and modes, exposure time, time constraints)
- Budget (for Legacy only, 2p)
- Implementation (for Legacy only, 2p)
- Thesis enabling program (1 p)

Starting this Cycle: justification PDF must follow Dual Anonymous Guidelines

USPOT: building justification pdf (main body)

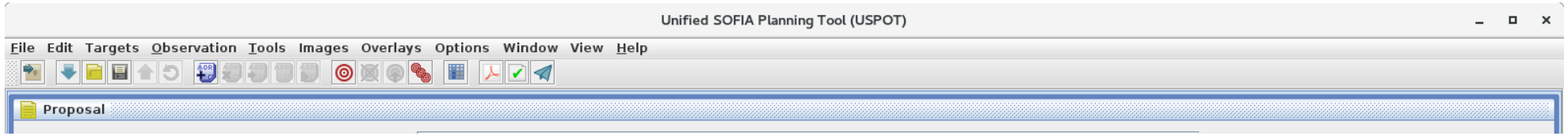
- The TAC will not know the identity of the proposers during the science review

- Goal is to make the review about science, and attenuate TAC biases

- Justification must be anonymized: no pronouns ('we have..'), obvious references to ongoing programs ('private comm'), overload references with own papers

- 'You are not trying to hide yourself, just not show who you are'

- Blatant disregard will lead to proposal rejection



Upload justification pdf, bio pdf, validate, submit (with DCS account)

Post deadline – what to expect

- December 2020: results announced
- Budget submission (US GOs)
- February 2021 : Phase 2 – further definition of AORs, supported by instrument scientists
- Observations (July 2021-Sep 2022): GOs receive flight summaries post-flight series

Post observations – what to expect

• Processed data delivered and staged in archive ~ 1 month after observations
- GOs notified by email. All data gathered in **IRSA**
https://irsa.ipac.caltech.edu/Missions/sofia.html

• Post-delivery: assistance available from science center / instrument scientists.
Proprietary length 6 months (regular), 0 months (DDT, legacy)

• Data analysis resources are available at the SOFIA website data section:
https://www.sofia.usra.edu/science/data : Cookbooks Recipes, Data Handbooks

Funding opportunities (for US-institutions only)-

- Up to $4M for Regular Proposals (~$10k/ h)
- Up to $2M / year for Legacy Proposals

- For proposals which are central to a PhD thesis, additional funding can be requested through the Thesis-enabling Program (up to two years of graduate student funding)
- Timing of funding depends on program priority ('rank'): must do (~25% of available time), should do (50%), do if time

Helpdesk: sofia_help@sofia.usra.edu

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