

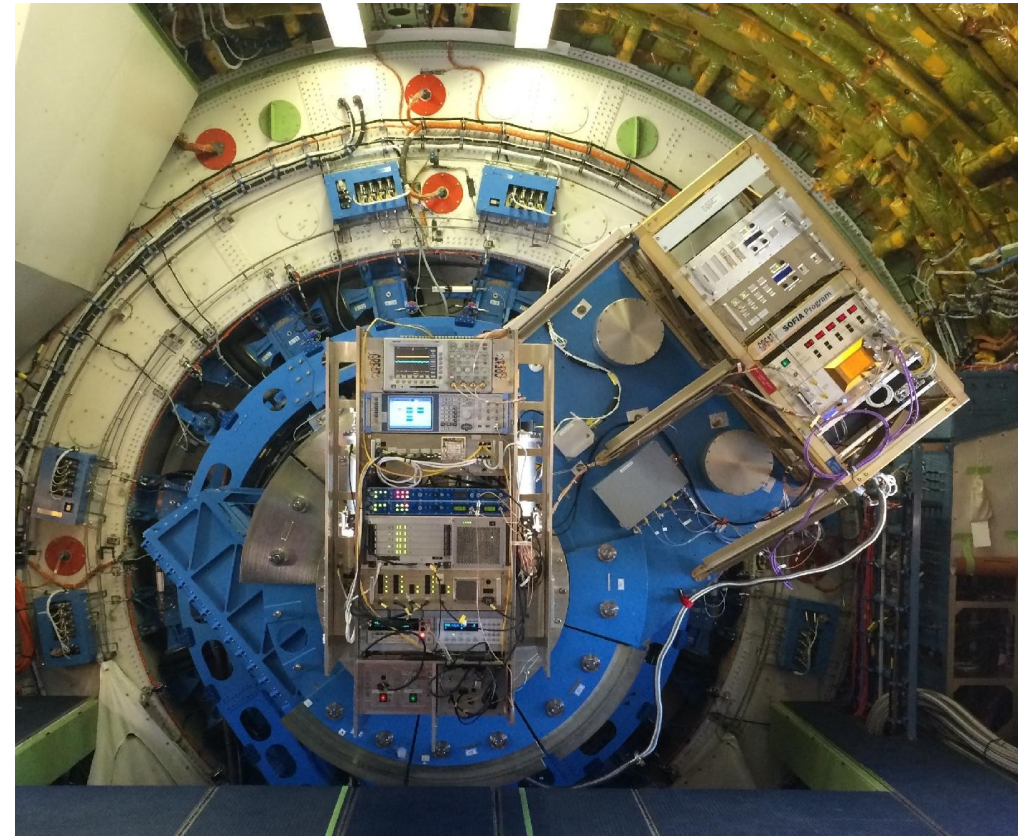


How to observe with upGREAT on SOFIA



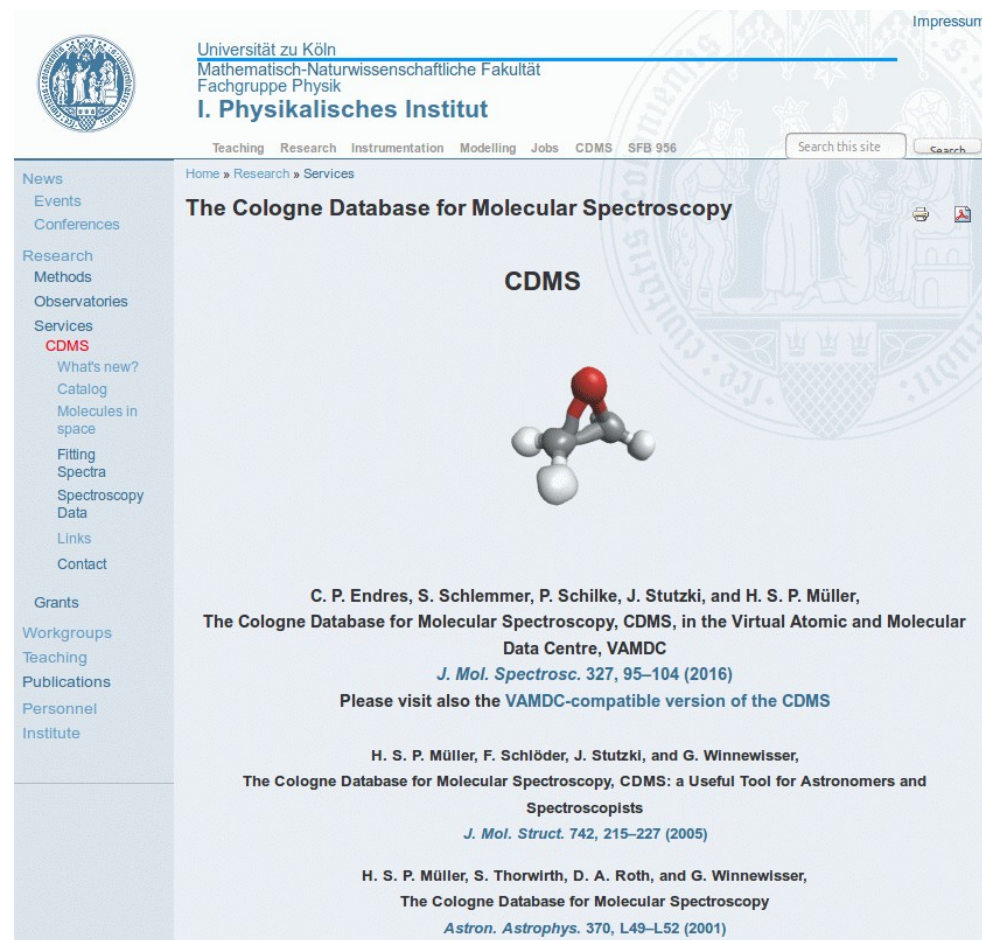
Volker Ossenkopf-Okada, I. Physikalisches Institut, Universität zu Köln

- What to observe?
 - Constraints
 - Instrument
 - Atmosphere
 - Flight tracks
- How to observe?
 - Noise
 - Observing modes
- How to use the data?
 - Data release
 - Data reduction



See tutorial of W.T. Reach

- What line(s) do I want to observe?
 - What is the line frequency?
- What source(s)?
 - coordinates, area
- What line intensity do I expect?
- Where is a good reference position?

The screenshot shows the homepage of the CDMS (Cologne Database for Molecular Spectroscopy) website. The header includes the University of Cologne logo and the text "Universität zu Köln, Mathematisch-Naturwissenschaftliche Fakultät, Fachgruppe Physik, I. Physikalisches Institut". A navigation bar contains links for Teaching, Research, Instrumentation, Modelling, Jobs, CDMS, and SFB 956. A search bar is located on the right. The main content area features the title "The Cologne Database for Molecular Spectroscopy" and a 3D molecular model of a water molecule (H2O). Below the model, there is a list of publications and a link to the VAMDC-compatible version of the CDMS. The left sidebar contains a list of links for News, Events, Conferences, Research, Methods, Observatories, Services, and Grants.

Main sources of info



MPIfR
KOSMA
MPS
DLR-Pf

Browser address bar: <https://dcs.sofia.usra.edu>

SOFIA Data Cycle System

RETRIEVE ARCHIVE
PROPOSE PLAN OBSERVE

Email: Password (Forgot password): Sign In

DCS Site Map

DCS 3.5.2

Message Of The Day

- SOFIA Cycle 6 Call for Proposals released on May 1st. New Unified Proposal and Observation Tool (USPOT) released.
- [Release Notes](#)

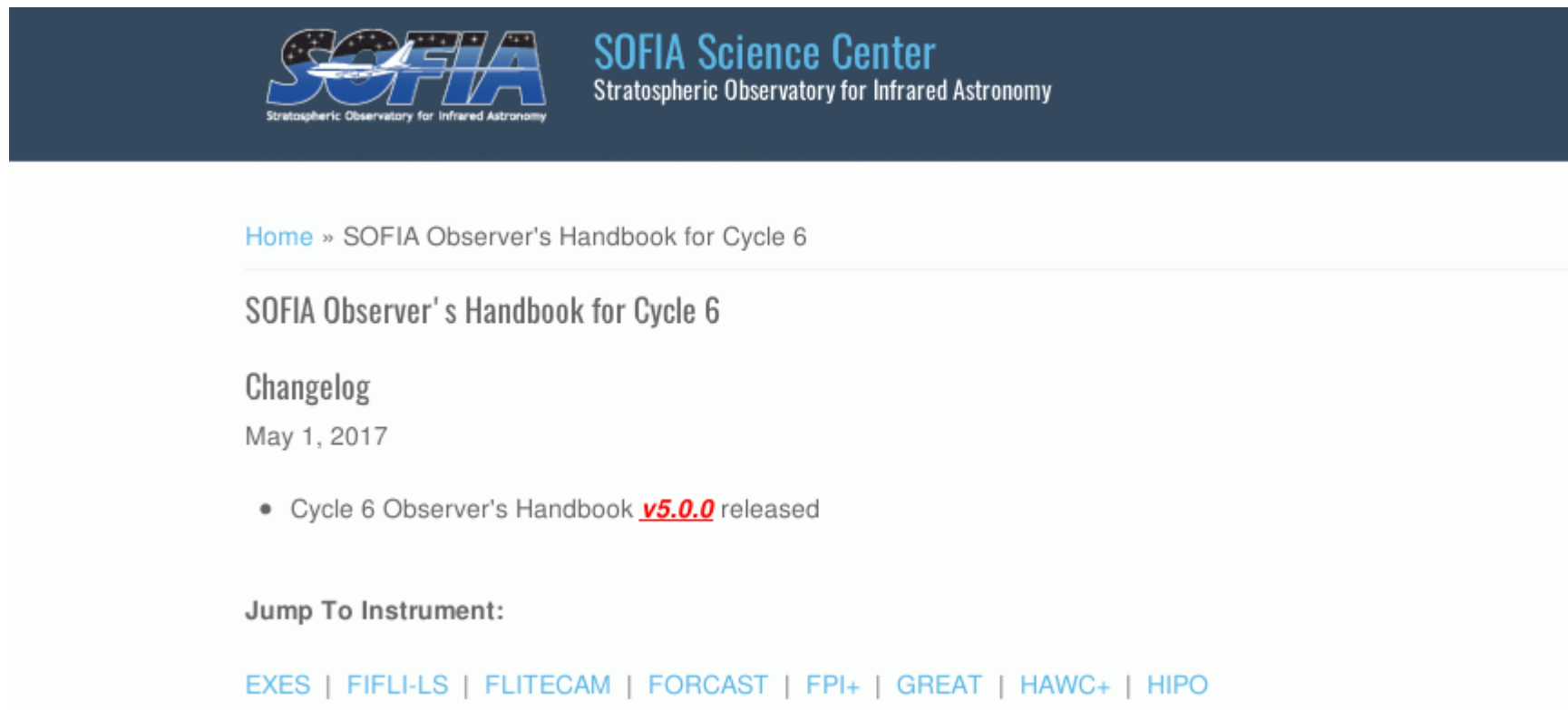
Welcome to the SOFIA Data Cycle System!

User Support	Proposal Development	Observation Planning	Data Archive & Retrieval
			
About DCS	Download USPOT	Search Observing Plans	Search Science Archive
Register With DCS	Search Proposals	Search AORs	Search Mission Data Archive
DCS Help Resources	SOFIA Instrument Time Estimator	Download Visibility Tool	Search Missions
	ATRAN		SOFIA Publications

- GREAT time estimator: <https://great.sofia.usra.edu/cgi-bin/great/great.cgi>
- VT (Visibility tool)
- USPOT (Proposal handling system)

- SOFIA Observers Handbook

- <https://www.sofia.usra.edu/science/proposing-and-observing/sofia-observers-handbook-cycle-6>

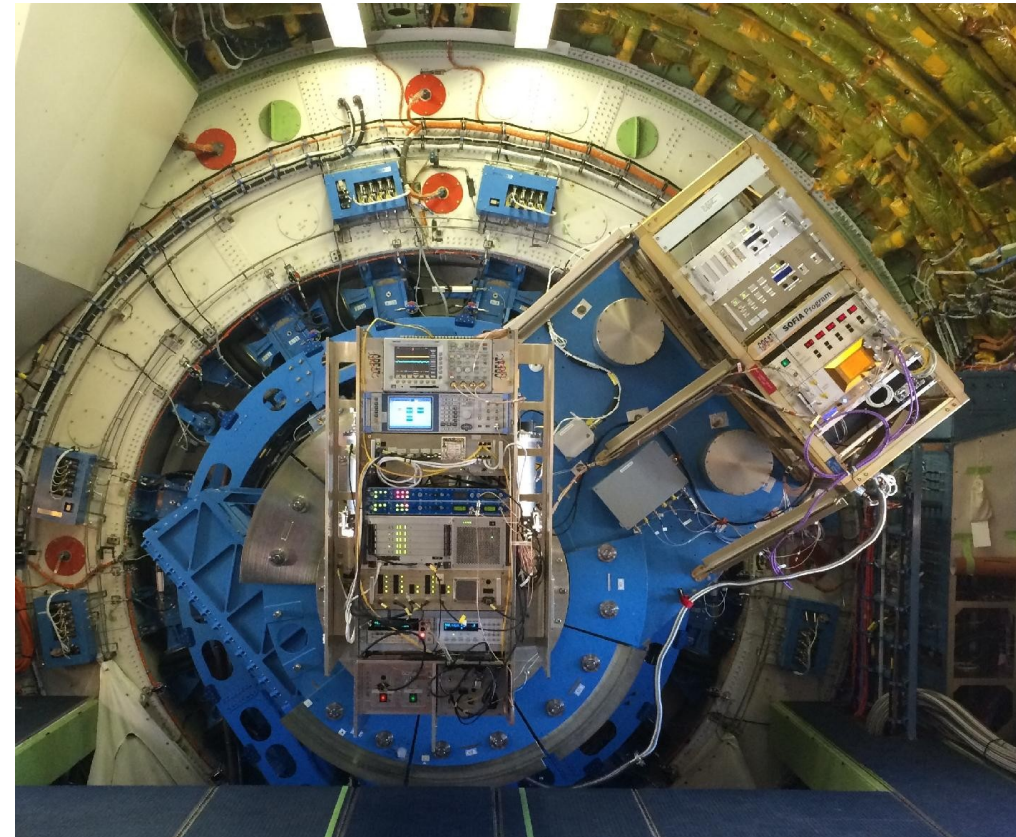
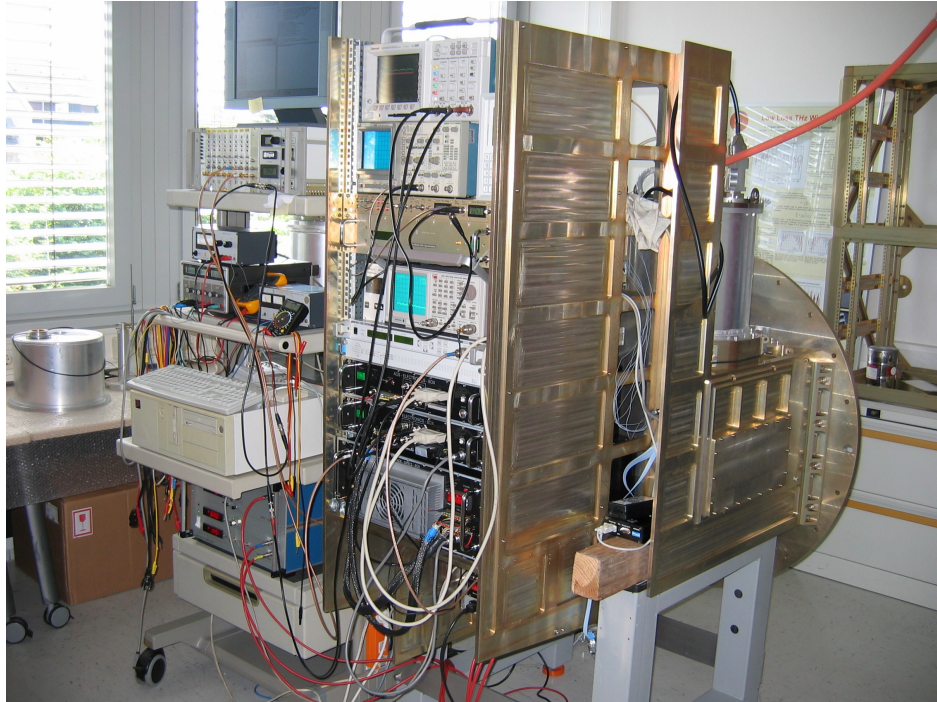


- Data reduction: CLASS (GILDAS):

- <https://www.iram.fr/IRAMFR/GILDAS/gildasli2.html>

German REceiver for Astronomy at Terahertz-Frequencies

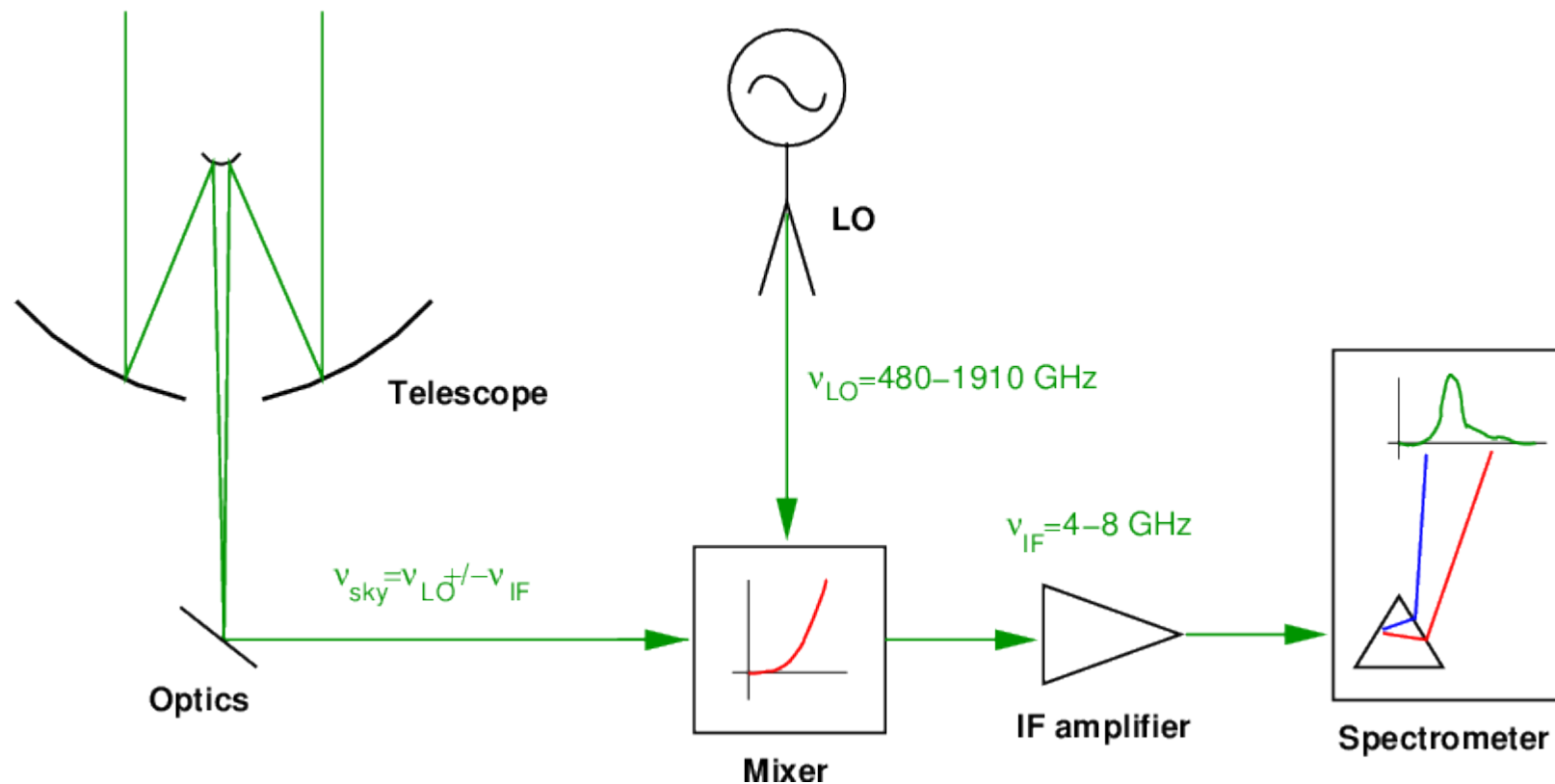
- Heterodyne receiver
 - Dual channel
 - 2-5 frequencies simultaneously
 - 0.5 – 4.7 THz
 - in 6 frequency-bands



- Spectrometers: FFTS4G
 - 16k channels
 - Bandwidth: 4GHz
 - Resolution: 283kHz ($R = 10^7$)

Heterodyne principle

- Mixing of sky signal with reference frequency
- Amplification of difference (IF) frequency



→ double-sideband sensitivity: $\nu_{sky} = \nu_{LO} \pm \nu_{IF}$

Radiometry

- Noise determined by
 - Forward efficiency, main beam efficiency $\eta_{\text{fwd}} \approx 0.96$, $\eta_{\text{mb}} \approx 0.7$
 - Receiver temperature (double sideband) $T_{\text{rec,dsb}}$
 - Atmospheric transmission in signal + image sideband $\eta_{\text{sky,ssb}}$, $\eta_{\text{sky,isb}}$
 - Frequency resolution
 - Integration time

$$T_{\text{rms,ssb}} = \frac{T_{\text{sys,ssb}}}{\sqrt{t_{\text{int}} \times \Delta\nu}}$$

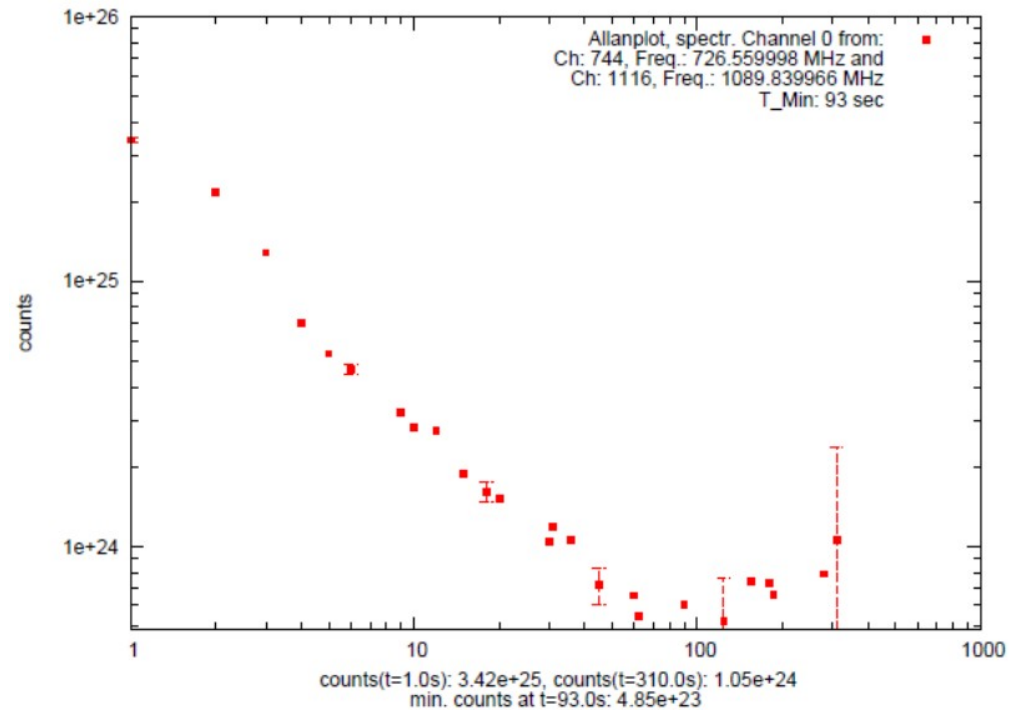
$$T_{\text{sys,ssb}} \approx \frac{2}{\eta_{\text{mb}} \eta_{\text{sky,ssb}}} \left[T_{\text{rec,dsb}} + (1 - \eta_{\text{fwd}}) T_{\text{tel}} + \frac{1 - \eta_{\text{sky,ssb}}}{2} T_{\text{sky}} + \frac{1 - \eta_{\text{sky,isb}}}{2} T_{\text{sky}} \right]$$

Radiometry

- Stability of heterodyne instruments ~ 100s

- Requires repeated OFF measurements
 - Eat time and add noise
 - Factor 2 for symmetric schemes with $t_{\text{on}} = t_{\text{off}}$

$$T_{\text{rms,ssb}} = \frac{2 \times T_{\text{sys,ssb}}}{\sqrt{(t_{\text{on}} + t_{\text{off}}) \times \Delta\nu}}$$



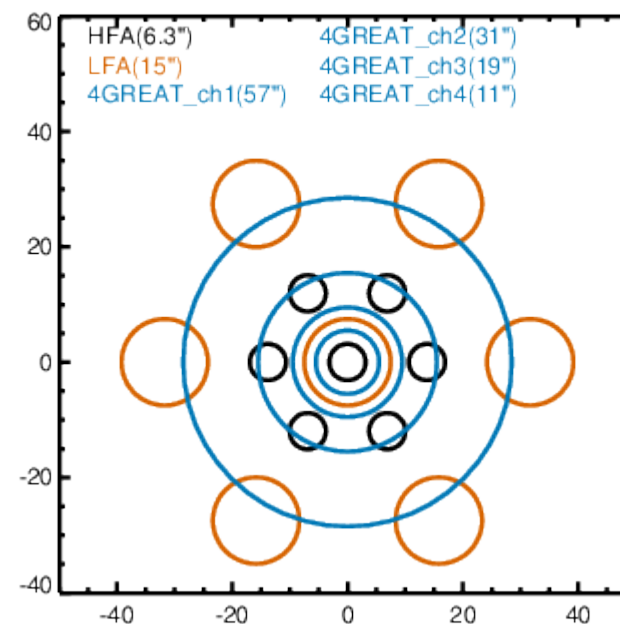
4G3 stability Feb. 2018

Frequencies:

Channel		Frequencies [THz]	Pixels	Lines of interest	$T_{\text{rec,dsb}}$ [K]
4GREAT	4G1	0.490-0.635	1	[Cl], CH, CO, NH ₃ , H ₂ ¹⁸ O	120
4GREAT	4G2	0.890-1.100	1	NH, OH ⁺ , CO, HDO	350
4GREAT	4G3	1.20-1.53	1	[NII], CO, OD, SH, H ₂ D ⁺	1100
4GREAT	4G4	2.48-2.69	1	OH	1700
upGREAT	LFA	1.83 – 2.01	2x7	CO, [CII], [OI], OH	1050
upGREAT	HFA	4.74	7	[OI]	1100

- Beams:

- 57" (0.5 THz) ... 6.6" (4.74 THz):



Tested lines (incomplete):

4G-1

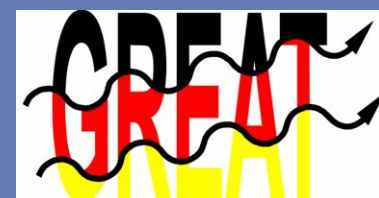
IF Offset 6		
Specie	Rest (GHz)	SB
HDO(110-101)	509.29242	
CH ₅₅₉	536.7610	USB
H ₂ 18O(110-101)	547.67644	USB
NH ₃ (100-001)	572.49816	
CO J = 5-4	576.26793	
HCl(1-0)	625.91876	

4G-2

IF Offset 6		
Specie	Rest	SB
HDO(111-000)	893.63867	
OH ₊ (10-01)	909.1588	
CO(8-7)	921.7997	
OH ₊ (12-01)	971.8038	
NH	974.47861	USB
H ₃ O ₊ (000-101)	984.71191	USB
¹³ CO(9-8)	991.32935	LSB
H ₂ 18O(202-111)	994.67513	LSB
OH ₊ (11-00)	1033.1186	USB
CO(9-8)	1036.9124	LSB
H ₂ S(221-110)	1072.8365	LSB

- Check for your own lines of interest in covered frequency range

Frequencies



MPIfR
KOSMA
MPS
DLR-Pf

4G-3

IF Offset 2		
Specie	Rest	SB
HF(1-0)	1232.476	
HCN(14-13)	1239.890	
HCO+(14-13)	1247.735	
HCL(2-1)	1251.4519	
CO(11-10)	1267.0145	
H2O2(1274)	1274.577	USB
H2O(743-652)	1278.265	USB
H2O(827-734)_L	1296.4111	
H2F+(111-000)	1305.315	
HCN(15-14)_U	1328.3022	USB
7LiH(3-2)_U	1329.414	USB
PH3(5-4)_L	1333.2	LSB
HCO+(15-14)_L	1336.7149	LSB
6LiH(3-2)	1356.928	
H2D+(101-000)	1370.0849	
CO(12-11)	1381.9951	
SH	1383.08	
OD_LOW	1390.614	USB
OD_HIGH	1391.4947	USB

4G-4

IF Offset 2		
Specie	Rest	SB
18OH2PI32_L	2494.6951	
18OH2PI32_H	2498.9945	
OH2PI32_L	2509.949	
OH2PI32_H	2514.3167	
CO(22-21)	2528.1721	
HD(1-0)_L	2674.9861	

LFA

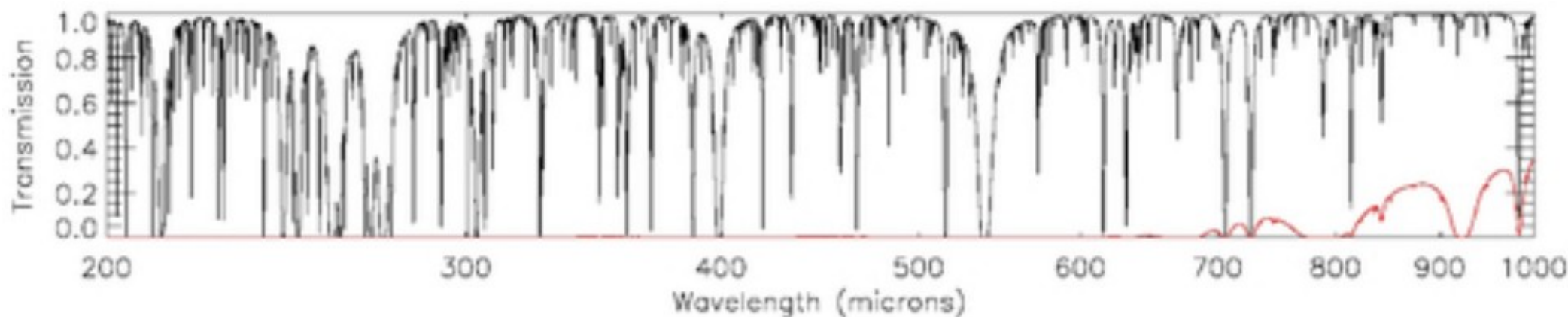
IF Offset 1.5		
HCN(14-13)	1239.8903	LSB
HCO+(14-13)	1247.7350	LSB
CO(11-10)	1267.0145	USB
OD	1391.4947	USB
CO(16-15)	1841.3455	USB
CII	1900.5369	LSB
CH_149	2006.7625	USB
OI_145	2060.0688	USB

Frequencies

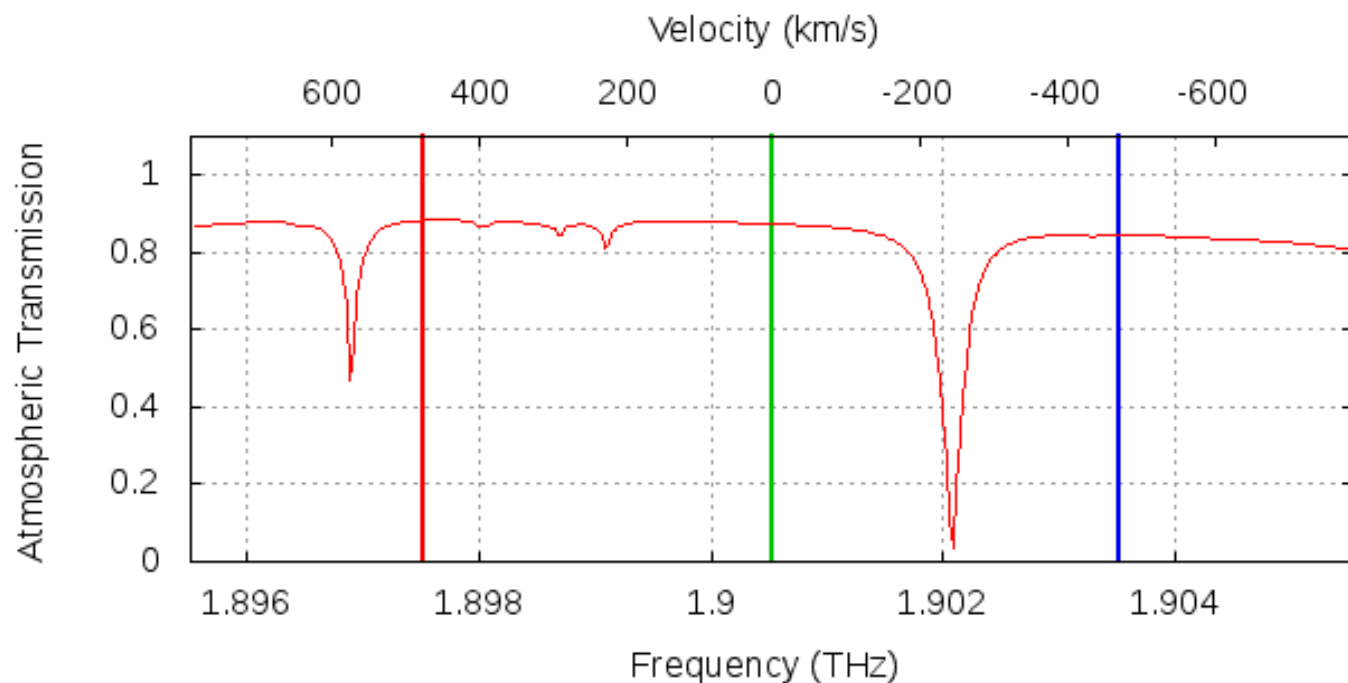


MPIfR
KOSMA
MPS
DLR-Pf

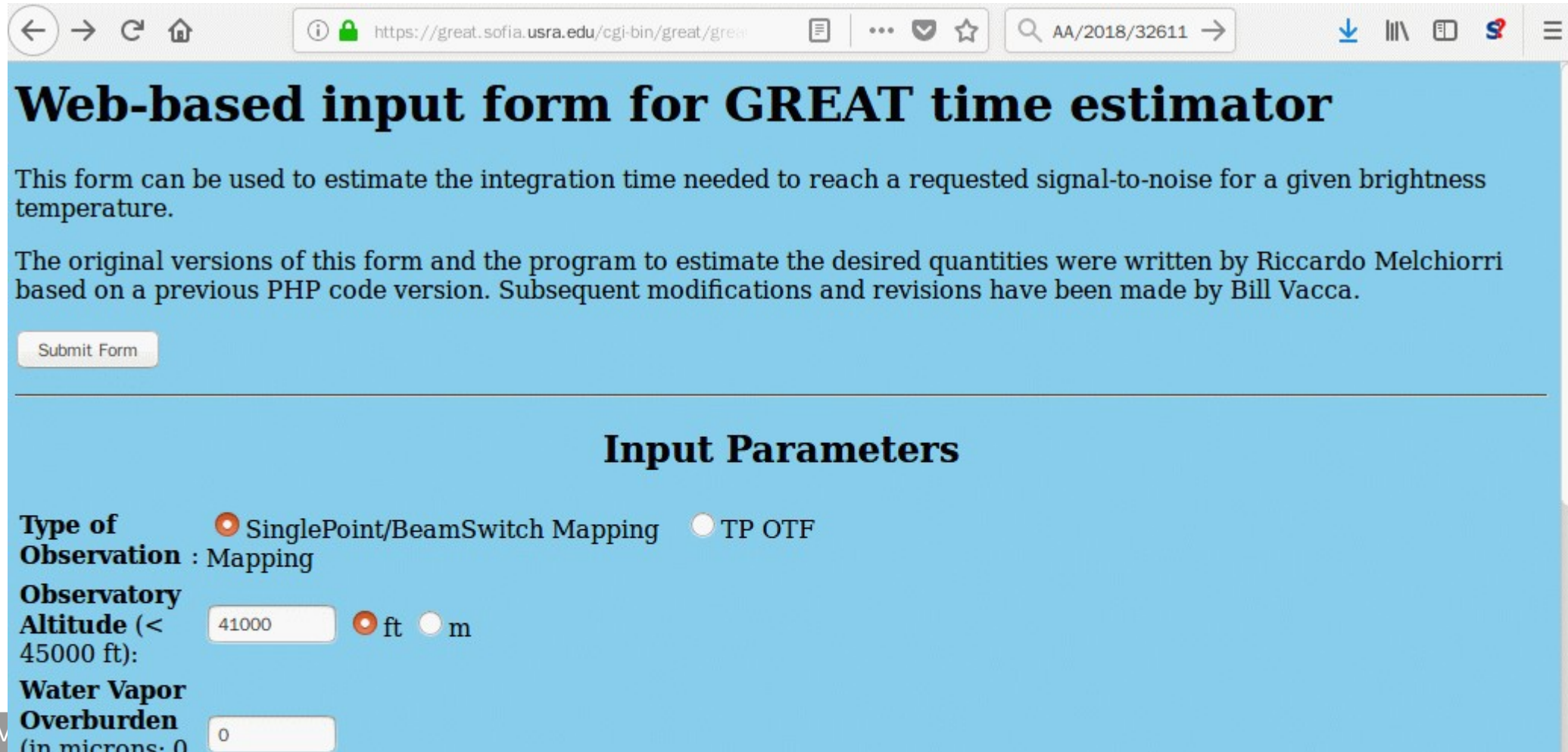
But: Be aware the atmosphere!



- Atmospheric lines cover parts of the bands
- Coverage depends on observing date
- Selection of the sideband



- Check the atmospheric transmission:
 - GREAT time estimator:
 - <https://great.sofia.usra.edu/cgi-bin/great/great.cgi>

A screenshot of a web browser displaying the "Web-based input form for GREAT time estimator". The browser's address bar shows the URL "https://great.sofia.usra.edu/cgi-bin/great/great.cgi". The page has a light blue background. At the top, there is a title "Web-based input form for GREAT time estimator" in bold black text. Below the title, a paragraph explains the form's purpose: "This form can be used to estimate the integration time needed to reach a requested signal-to-noise for a given brightness temperature." Another paragraph mentions the original authors: "The original versions of this form and the program to estimate the desired quantities were written by Riccardo Melchiorri based on a previous PHP code version. Subsequent modifications and revisions have been made by Bill Vacca." A "Submit Form" button is located below the text. The form itself is titled "Input Parameters" in bold black text. It contains several input fields and radio buttons. The "Type of Observation" section has two radio buttons: "SinglePoint/BeamSwitch Mapping" (selected) and "TP OTF". The "Observatory Altitude (< 45000 ft):" section has a text input field containing "41000" and two radio buttons: "ft" (selected) and "m". The "Water Vapor Overburden (in microns: 0" section has a text input field containing "0".

Web-based input form for GREAT time estimator

This form can be used to estimate the integration time needed to reach a requested signal-to-noise for a given brightness temperature.

The original versions of this form and the program to estimate the desired quantities were written by Riccardo Melchiorri based on a previous PHP code version. Subsequent modifications and revisions have been made by Bill Vacca.

Submit Form

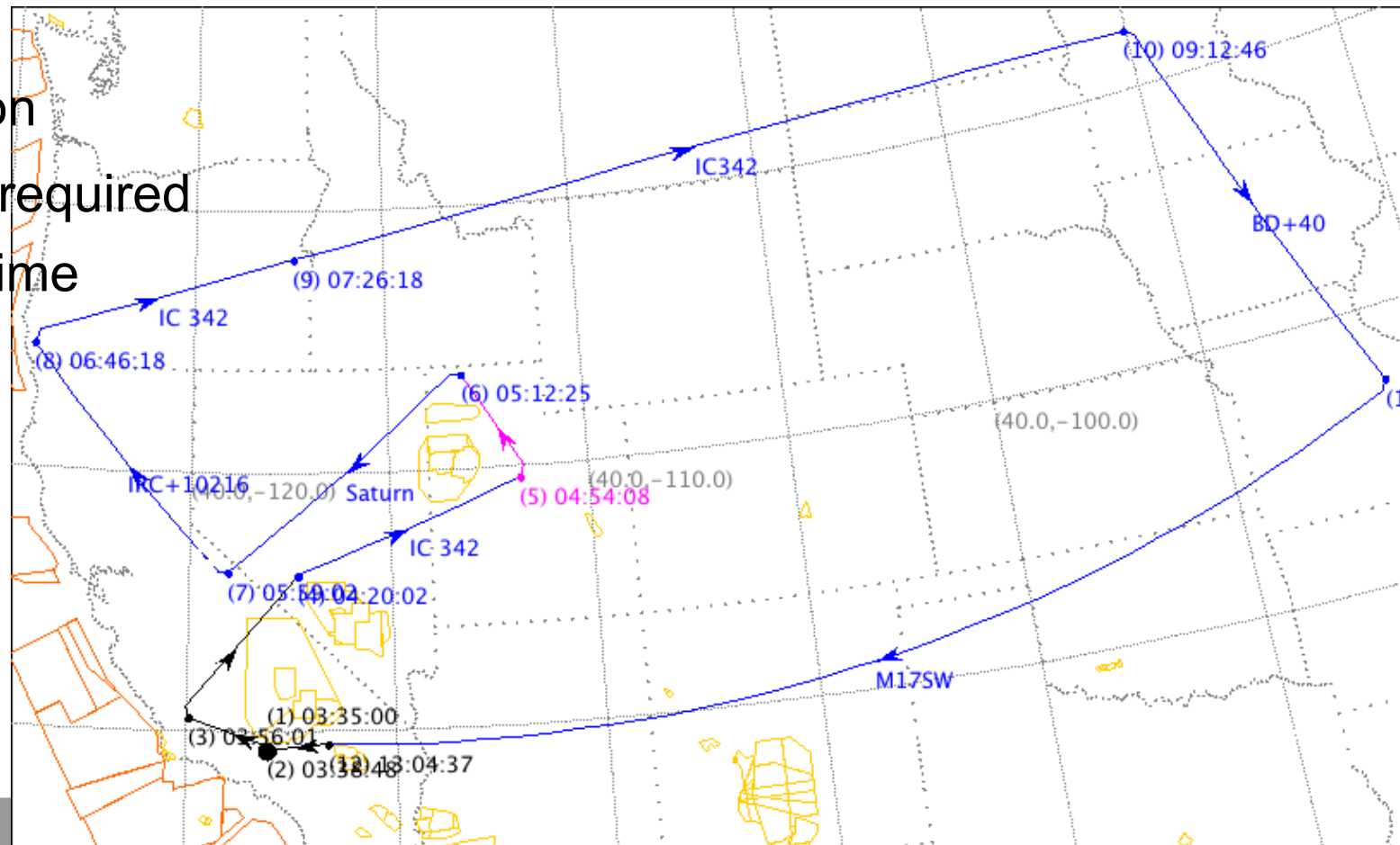
Input Parameters

Type of Observation : ☒ SinglePoint/BeamSwitch Mapping ☐ TP OTF

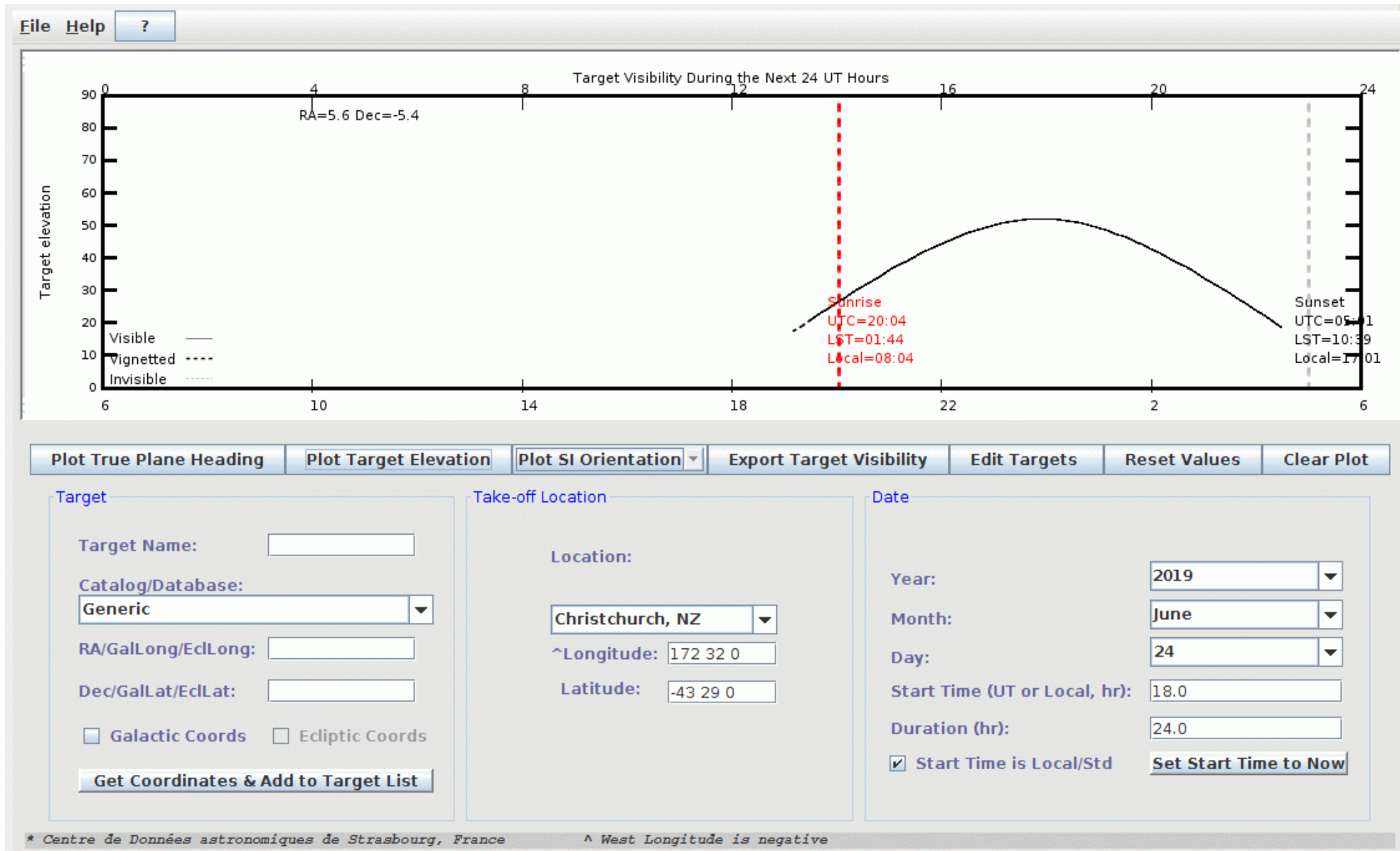
Observatory Altitude (< 45000 ft): ☒ ft ☐ m

Water Vapor Overburden (in microns: 0

- Time constraints:
 - LSR velocity of source relative to atmospheric features
 - GREAT time estimator
 - Visibility at observing altitude
 - 20° - 60°
 - Flight direction
 - Round-trip required
 - Maximum time per lag ~ 3 h



- Visibility Tool (3.5.1):

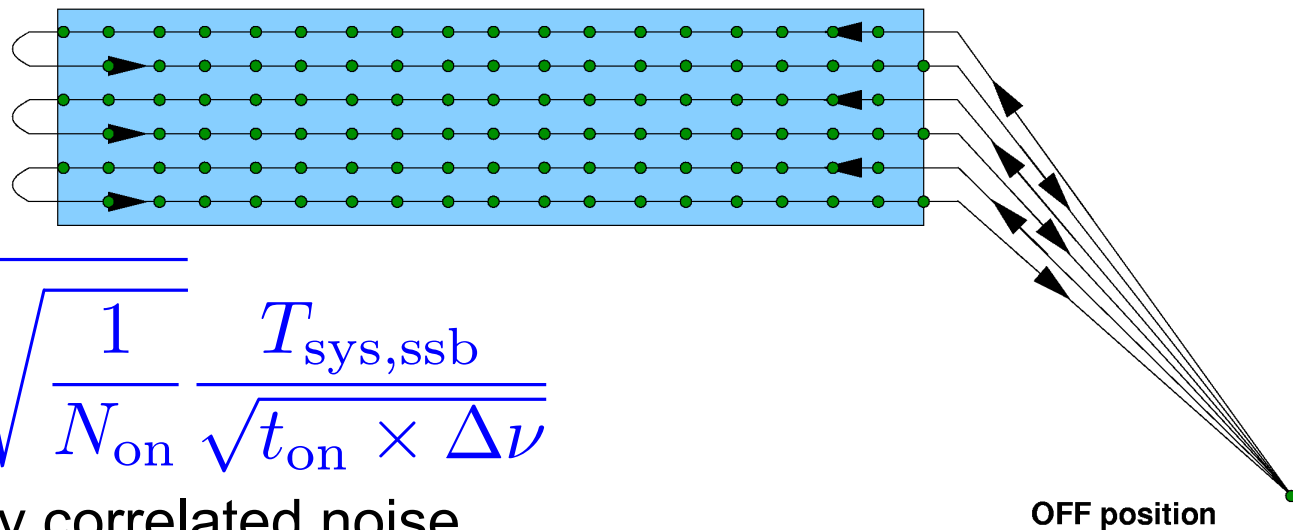


- Symmetric modes $t_{\text{on}} = t_{\text{off}}$
 - e.g. double-beam switch (=chop-nod)
 - for broad lines/instable frequencies

$$T_{\text{rms,ssb}} = \frac{2 \times T_{\text{sys,ssb}}}{\sqrt{(t_{\text{on}} + t_{\text{off}}) \times \Delta\nu}}$$

- OTF mapping

- Combines N_{on} map points with a single OFF measurement
- Saves time and noise



$$T_{\text{rms,ssb}} = \sqrt{1 + \sqrt{\frac{1}{N_{\text{on}}}} \frac{T_{\text{sys,ssb}}}{\sqrt{t_{\text{on}} \times \Delta\nu}}}$$

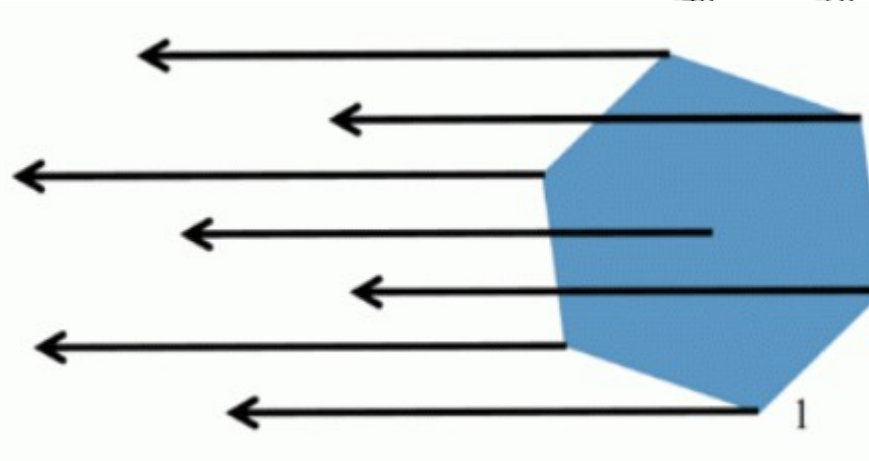
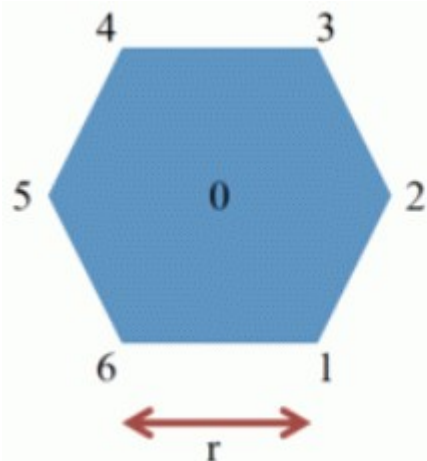
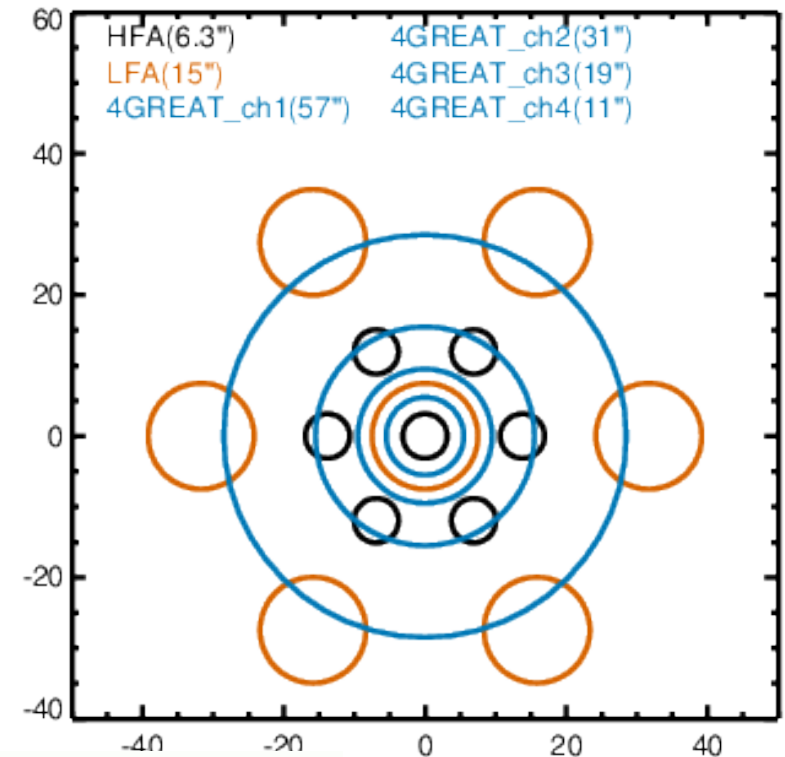
- But introduces spatially correlated noise

Mapping modes



MPIfR
KOSMA
MPS
DLR-Pf

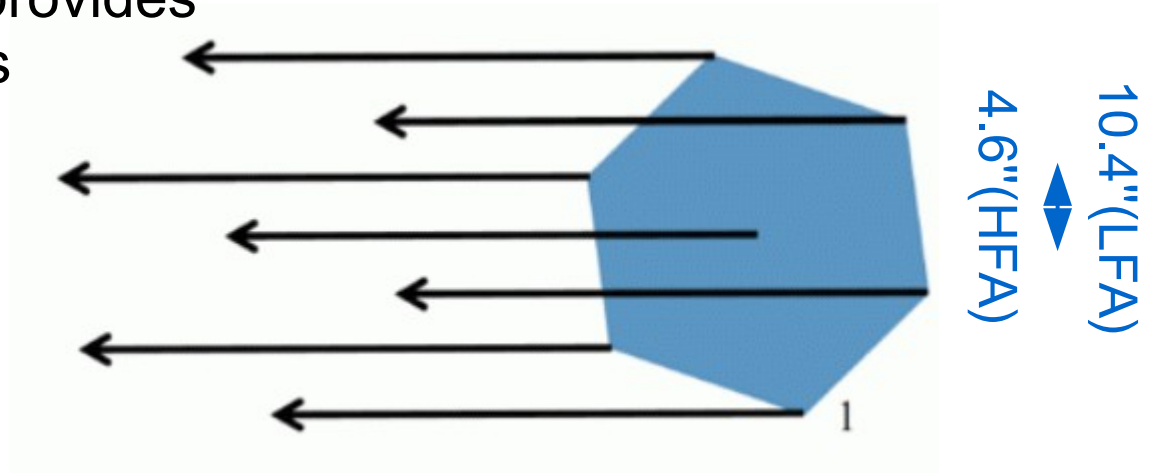
- Combine with receiver geometry
 - Single pixels (4GREAT)
 - Use Nyquist sampling or half-beam sampling depending on beam width
 - Array mapping (LFA, HFA)
 - Array tilt by 19.1 degrees provides equal spacing of scan lines



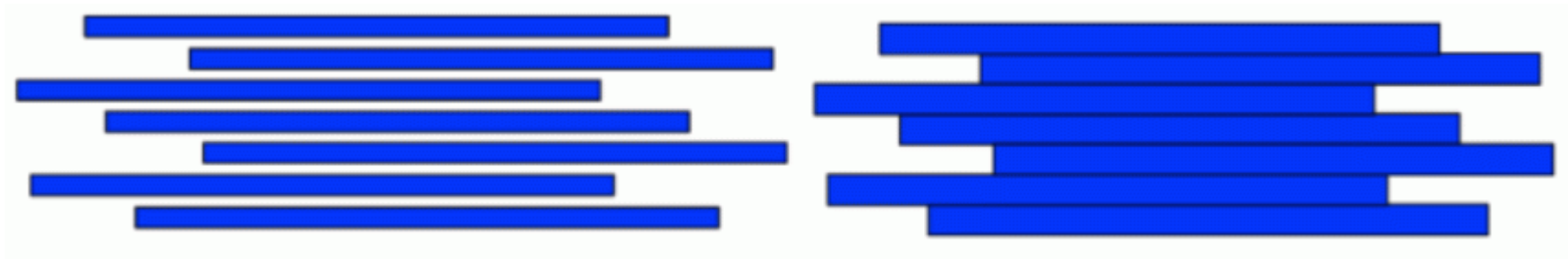
63.4" (LFA)
27.6" (HFA)

- Array mapping (LFA, HFA)

- Array tilt by 19.1 degrees provides equal spacing of scan lines

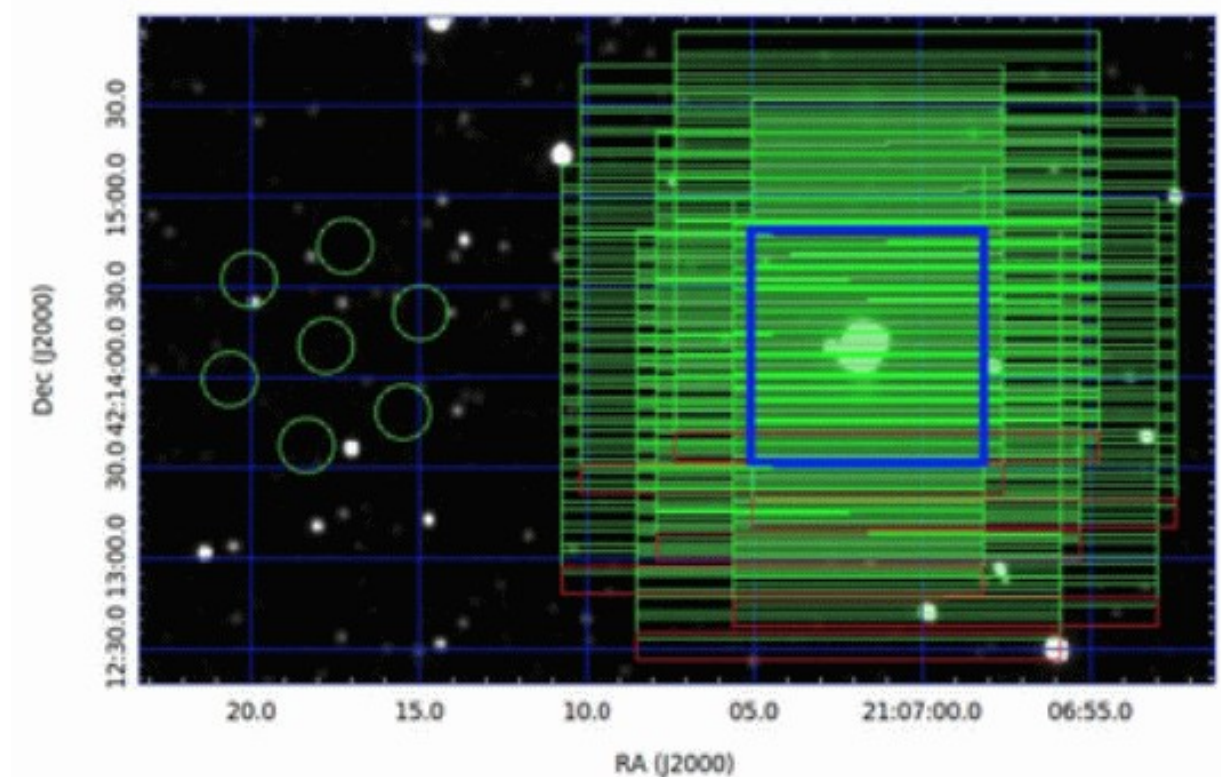


- Two adjacent scans provide fully sampled maps



- 5.2" spacing for LFA
 - 2.3" spacing for HFA

- Classical OTF
 - Every pixel covers every part of the map
 - Allows to compensate for different pixel sensitivities
 - Arbitrary map size
 - Ideal for weak, small sources



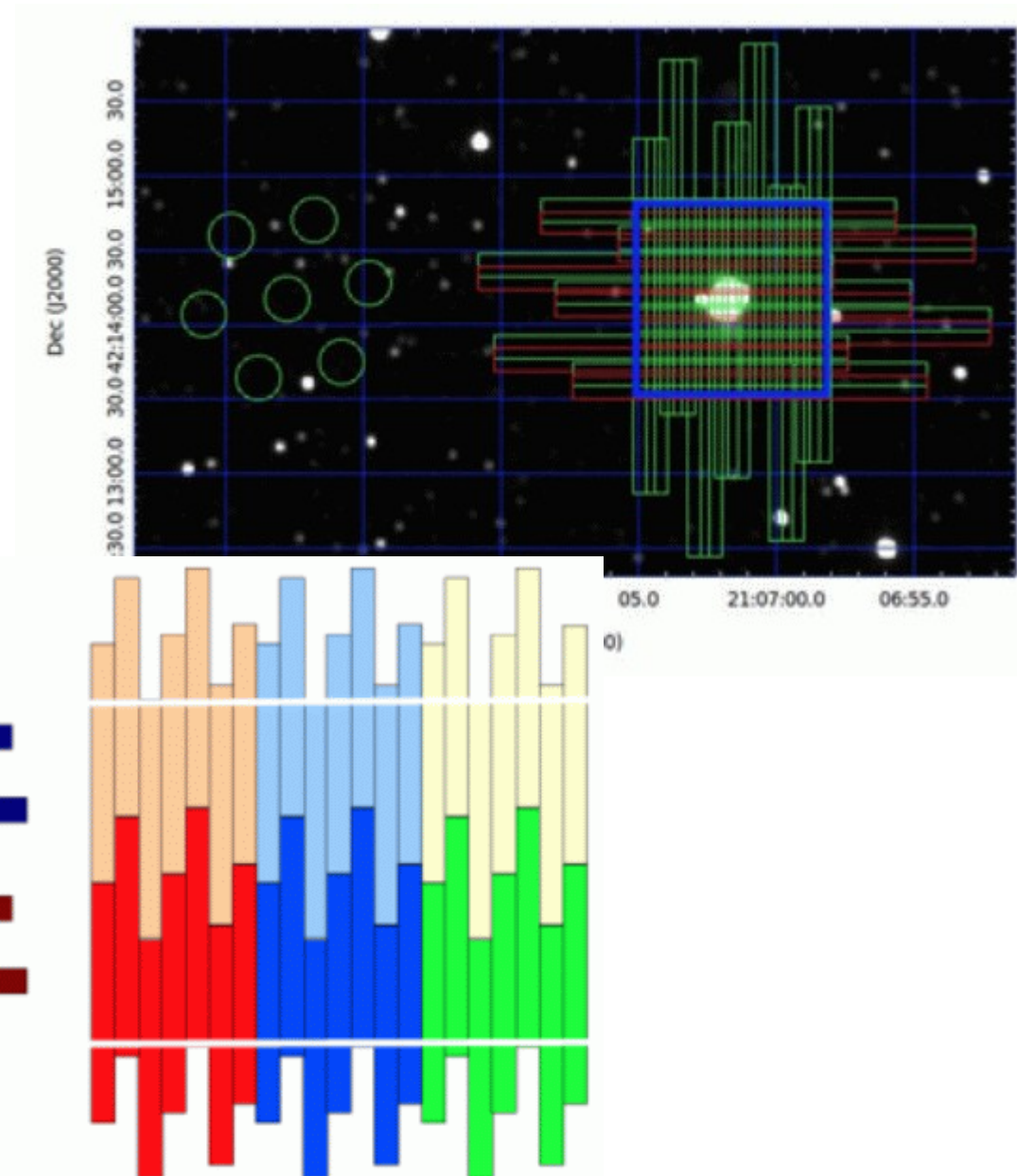
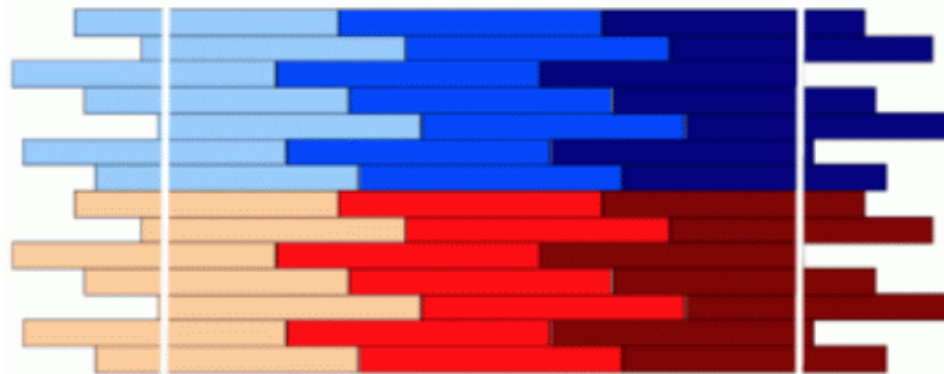
Mapping modes



MPIfR
KOSMA
MPS
DLR-Pf

- Array OTF

- Assembly of map from minimum array coverages
- Mosaicing for large areas
 - 73.8" (LFA), 32.2" (HFA)
- Ideal for strong extended sources
- Not in HFA-LFA combination



Visualization



MPIfR
KOSMA
MPS
DLR-Pf

• USPOT (3.5.2):

File Edit Targets Observation

Unique AOR Label: S235C_OI_mapping

Target: S235 Type: SOFIA Fixed Single
85.216417, 35.693192 Equ J2000 or 5h40m51.9401s, +35d41m35.491s Equ J2000

New Target Modify Targ... Target List...

Observations

La...	T...	P...	In...	D...	...	M...
S23...	S235	5h...	GR...	63...	n...	✓ Tot...
S23...	S235	5h...	GR...	52...	n...	✓ Tot...

Instrument Parameters

Velocity (km/s) -20.000

Mixer1: Frequency 1 (GHz) 4,744.777490

Mixer2: Frequency 2 (GHz) 1,900.536900

Mixer2: Frequency 3 (GHz) 921.799700

Mixer2: Frequency 4 (GHz) 1,267.014490

Mixer2: Frequency 5 (GHz) 2,514.316705

Primary Frequency Frequency 1

Array Rotation Angle (deg) -19.200

** Tracking required in off position FPI

** ID String

Mixer 1 GRE_HFA

* Mixer 2 GRE_LFA

Observing Condition & Acquisition / Tracking

* Instrument Mode Total Power

Chop Throw (arcsec) 0.000

Chop Angle (deg) 0.000

Chop Angle Coordinate Sky

Reference Position

Ref Type

By Offset

By Position

Reference Name

RA Offset (arcsec) 600.000

Dec Offset (arcsec) 600.000

RA (deg) 85.422

Dec (deg) 35.860

Position: 5h41m41.2800s, +35d51m36.000s

Choose Position

Parameters for Scans Mapping

Parameters for scans in x direction

* Scan length in units of array size (31.6" or 72.6") 6.000

* Number of blocks in scan direction 1

* Number of blocks perpendicular to scan direction 4

* Exp. Time per Point (sec) 2.050

Parameters for scans in y direction

* Scan length in units of array size (31.6" or 72.6") 5.000

* Number of blocks in scan direction 1

* Number of blocks perpendicular to scan direction 5

* Exp. Time per Point (sec) 2.050

(** = Advanced) (* = required for Phase I)

Observation Est... Comments... Proposal Info...

OK Apply Cancel Help

Proposal Observations

Target: S235 Type: SOFIA Fixed Single Total Duration: 193 min Awarded: 0 min

Existing Project - s235abc.aor Net Down Total AORs: 2 / Active: 2 5/4/18 22

Visualization

- Array OTF:

Parameters for Scans		Mapping
Parameters for scans in x direction		
* Scan length in units of array size (31.6" or 72.6")	3.000	
* Number of blocks in scan direction	2	
* Number of blocks perpendicular to scan direction	2	
* Exp. Time per Point (sec)	1.000	
Parameters for scans in y direction		
* Scan length in units of array size (31.6" or 72.6")	3.000	
* Number of blocks in scan direction	1	
* Number of blocks perpendicular to scan direction	5	
* Exp. Time per Point (sec)	1.000	

Unified SOFIA Planning Tool (USPOT)

File Edit Targets Observation Tools Images Overlays Options Window View Help

Flux: 271.71872 DN EqJ2000 RA: 5h40m57.86s X: 178.50000
1 Pixel: 1.00000" J2000 Dec: +35d42m46.3s Y: 321.50000

Mouse Con... Meta-Left Mouse Button: Drag to adjust bias (horizontally) and contrast (vertically); double-click to reset.
Mouse: Shift-Left Mouse Button: Shift the center of image

2MASS- k, S235

Grid
[X] [Y] [Z]
S235C...
[X] [Y] [Z]
Base Image
[X] [Y] [Z]

Proposal Observations 2MASS- k, S235

Target: S235 Type: SOFIA Fixed Single Total Duration: 193 min Awarded: 0 min
Existing Project - s235abc.aorChecking For Updates... Net UpTotal AORs: 2 / Active

Visualization

- Classical OTF:

Mapping Parameters	
Exposure Time Per Cycle (sec)	2821.22
* On-source Exp. Time Per Point (sec)	1.000
* Cycles	1
Min Contiguous Exp Time (sec)	0.000
Map Offset RA (arcsec)	0.000
Map Offset Dec (arcsec)	0.000
Step size in the x-direction (arcsec)	3.000
Step size in the y-direction (arcsec)	3.000
* Num Steps in the x-direction	61
* Num Steps in the y-direction	41
ScanDirection	x direction
** ScanDirectionVector	+1
** ScanOrder	+1
** Scan Lines Per Off	1
MapAngle (deg)	0.000
** Number of off measurements per load	5
** Number of OTF lines per load	5

(** = Advanced) (* = required for Phase I)

Unified SOFIA Planning Tool (USPOT)

File Edit Targets Observation Tools Images Overlays Options Window View Help

Flux: 270.44565 DN Eq-J2000 RA: 5h40m50.96s X: 262.50000
1 Pixel: 1.00000" J2000 Dec: +35d40m39.3s Y: 194.50000

Mouse Con... Meta-Left Mouse Button: Drag to adjust bias (horizontally) and contrast (vertically); double-click to reset.
Mouse: Shift-Left Mouse Button: Shift the center of image

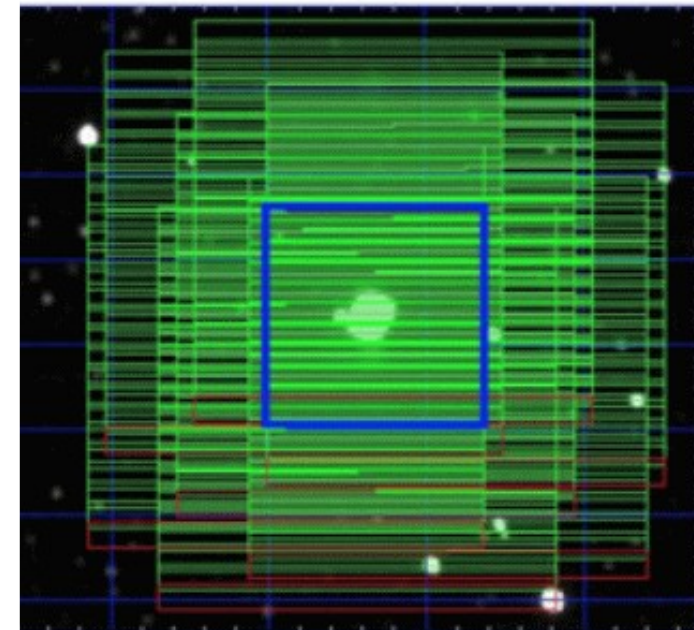
2MASS- k, S235

GREAT_...
Base Image

Proposal Observations 2MASS- k, S235

Target: S235 Type: SOFIA Fixed Single Total Duration: 289 min Awarded: 0 min
Existing Project - s235abc.aor Checking For Updates... Net UpTotal AORs: 3 / Ac

- Output from GREAT time estimator → USPOT (3.5.2)
 - Single point observations
 - Use $t_{\text{on}+\text{toff}}$ in USPOT as given by time estimator
 - Single beam switch / double beam switch mapping
 - Divide $t_{\text{on}}+t_{\text{off}}$ by 2 for input as t_{on} in USPOT
 - Array-OTF
 - Use t_{on} in USPOT as given by time estimator
 - Classical OTF
 - Divide t_{on} from time estimator by number of pixels for central area
 - 1/14 for LFA
 - 1/7 for HFA
 - Smaller reduction for noise goal at edges





- Release:

Proposal Identification	75_0015	
Project Title	Horsehead and the IC434 PDR interface	
Principle Investigator	E. Young	eyoung@sofia.usra.edu
SMO contact person	G. Sandell, E. Chambers	gsandell@sofia.usra.edu, echambers@sofia.usra.edu
GREAT processing liaison	D. Riquelme (MPIfR)	riquelme@mpifr-bonn.mpg.de

Observations			
Mission Identification	2015-12-11-GR_F266		
Flight date	2015 December 11		
GREAT configuration ^(1,2)	front-ends: LFA	back-ends: 4GFFT spectrometers	
Astronomical Sources	Horsehead, IC434	Scans: 12715-12790	lines: CII

Calibrated data products based on: kosma_calibrator ver. December 2015, GILDAS software ver. Nov15a

product level	file name	description
3a	Cycle3_GR_DDT_75_0015_EYoung_Ta.great Cycle3_GR_DDT_75_0015_EYoung_Ta_reduced.great Cycle3_GR_DDT_75_0015_EYoung_Tmb_CII.great	Calibrated to T_A^* scale ($\eta_f = 0.97$). Calibrated to T_A^* scale, baselines removed as explained in the Data Reduction letter. All scans quality validated. Calibrated ⁽³⁾ to T_{mb} scale, using η_{mb} (LFA-V) = (0.67, 0.71, 0.71, 0.70, 0.65, 0.66, 0.71) η_{mb} (LFA-H) = (0.66, --, 0.60, --, 0.66, 0.68, 0.70). Pixel H1 and H3 are not included. Independent fit of dry & wet atmosphere. Created with Cycle3_GR_DDT_75_0015_EYoung.class.
3b	Cycle3_GR_DDT_75_0015_EYoung_CII.lmv Cycle3__GR_DDT_75_0015_EYoung_CII.fits Cycle3__GR_DDT_75_0015_EYoung_CII_final.fits	Gridded map for CII (1/ σ_{rms}^2 weighting of individual spectra, σ_{rms} baseline noise). See the attached CLASS script for details of the data processing. Equivalent map in fits format, and with an outer rim (45") removed.

- Release:

The data were acquired on Dec 11 (SOFIA flight #266), the observing scripts are described in the GREAT flight dossier GP9700066. The large area to be studied was divided into 4 slightly overlapping sub-fields, each field was covered several times (scanning in orthogonal directions), then repeating the cycle with the array orientation rotated by +60 deg. The final map reveals a very uniform noise distribution (~ 2 K for a spectral resolution of 0.19 km/s). Data was taken fast “on-the-fly” (dump times 0.3-0.4 sec) on a 6" grid (the half-power beam width of upGREAT at the [CII] frequency is 15.1"). The on-sky reference position was at offset -733,+27.5" (RA,Dec) to the nominal center position of the map.

The data has been processed with the latest version of the GREAT calibrator. The data package (attached as .tar file) does contain

- an overview, providing basic information about your project
- data product level 3, containing
 - (a) the calibrated spectra in standard CLASS format, and
 - (b) the final data product (map) as “lmv”-data cube.
- the *.class script used in CLASS to process the data.
- a read-me file with details of the data reduction
- a brief log of the observations.

If you have questions about the data, the way they were processed or the observations proper, feel free to contact D. Riquelme (riquelme@mpifr-bonn.mpg.de), your data processing liaison.

- **GILDAS (CLASS):**

- Change spectral and/or spatial resolution
- Baseline subtraction
- Inspection / export

```
file in Cycle3_GT_DDT_75_0015_EYoung_Tmb.great  
find  
list /toc
```

```
file out Horsehead_smoothed.great s /o  
for i 1 to found  
  get next  
  smooth box 5  
  base 1  
  write  
next
```

```
file in Horsehead_smoothed.great  
find
```

```
set weight sigma  
table Horsehead_DDT_CII new /range -50 80 v /nocheck  
let map%beam '15.1'  
let map%cell 6.0 6.0  
xy_map Horsehead_CII
```

```
let name Horsehead_CII  
let type lmv  
go view
```

Example



MPIfR
KOSMA
MPS
DLR-Pf

let name Horsehead_CII
let type lmv
go view

S: HORSEHEAD PC L: CII L 1.9005369E+03 GHz @ 10.5 km/s LSR B: 15.9

