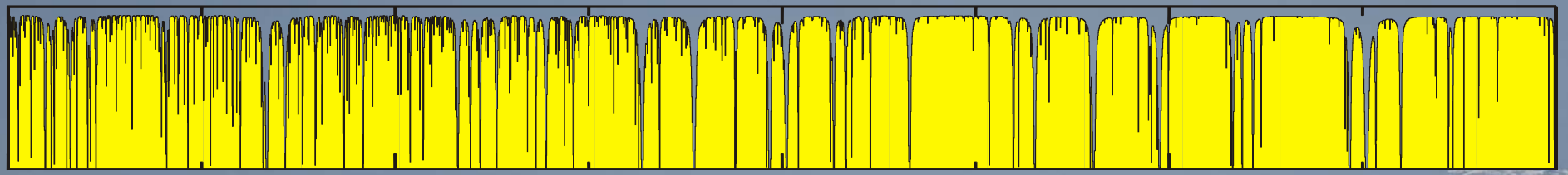

ATM 1-5 THz, 14 km altitude

German Receiver for Astronomy at THz Frequencies

GREAT

Modular dual-channel heterodyne receiver for high-resolution spectroscopy with SOFIA

GREAT - the Consortium

MPIfR
KOSMA
MPS
DLR-Pf

GREAT, L#1 & L#2 channels

PI-Instrument funded and developed by

- MPI Radioastronomie (2.7 THz channel)
  - R. Güsten (PI)
  - S. Heyminck (system engineer)
  - B. Klein (FFT spectrometer)
  - I. Camara, T. Klein (2.7 THz LO)
- Univ. zu Köln, KOSMA (1.4/1.9THz channels)
  - J. Stutzki (Co-PI)
  - U. Graf (1.4 &1.9THz LO, Optics)
  - K. Jacobs (HEB mixers up to 2.7 THz)
  - R. Schieder (array-AOS)
- DLR Planetenforschung (4.7 THz channel)
  - H-W. Hübers (Co-PI: 4.7 THz HEB, IF, cal unit)
- MPI Sonnensystemforschung
  - P. Hartogh et al. (CO-PI: CTS)

Configuration - overview

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Channel		Frequencies [THz]	Lines of interest
low-frequency	L1 a,b	1.25 – 1.50	[NII], CO series, OD, HCN, H_2D^+
low-frequency	L2 a,b	1.81 – 1.91	NH_3, OH, CO(16-15), [CII]
mid-frequency	M a,b	2.5, 2.7	OH($^2\Pi_{3/2}$), HD
high-frequency	H	4.7	[OI]

- two out of the 4 cryostats can be operated simultaneously
  - all channel combinations are possible
    - the actual flight configuration is science driven (within our operational limitations)
- channel availability
  - all of low-frequency channels operational (baseline for Basic Science)
    - have been flown routinely now since April
  - mid frequency channels (under development)
    - engineering flight with 2.5 THz LO today
  - high-frequency channel (commissioning foreseen 2012/13)

GREAT installed aboard SOFIA

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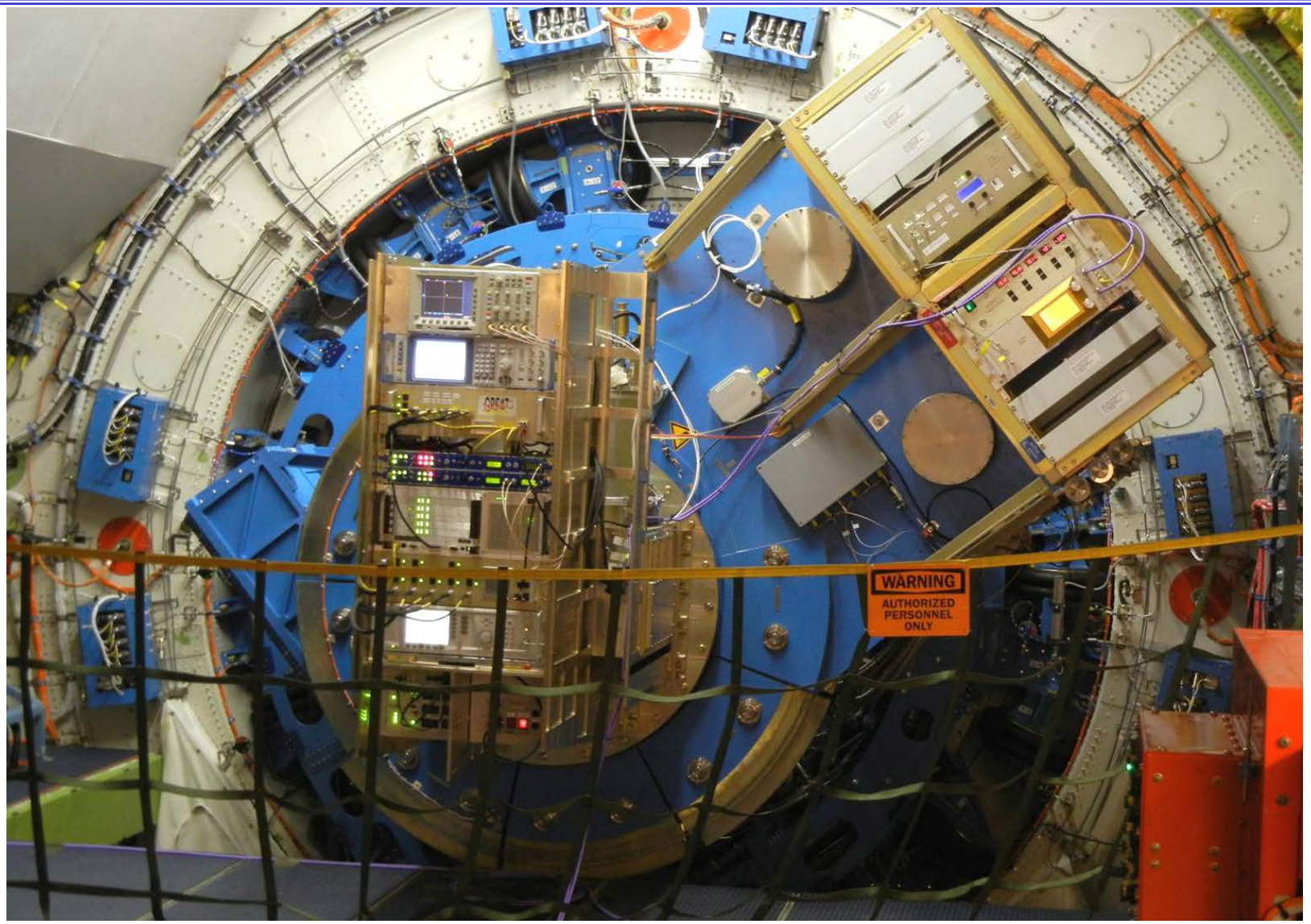

system performance: L#1 a,b

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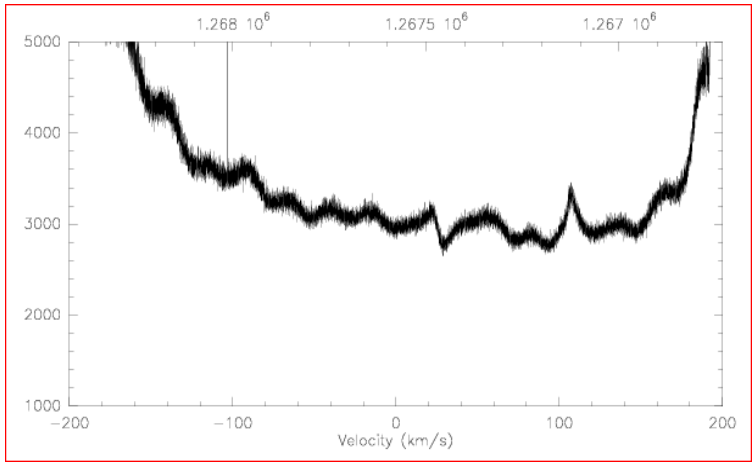
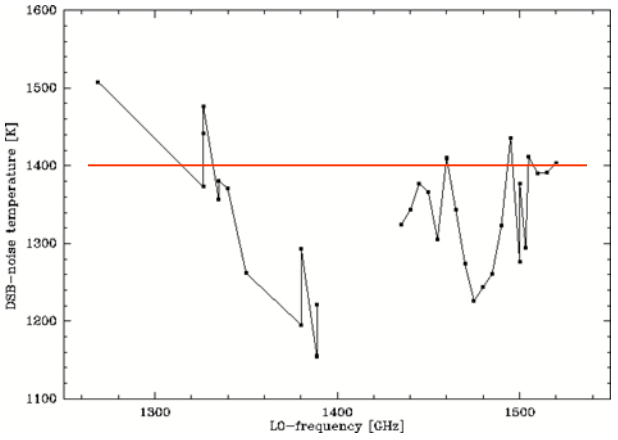


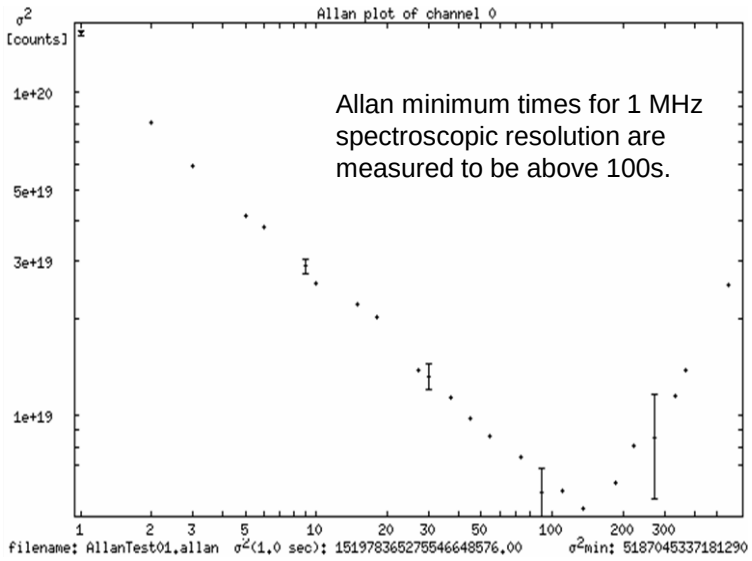
SSB receiver noise performance measured @ 1267GHz



Baseline: 2000 K ⇑

Goal: 1400 K

Above: DSB receiver temperature of the L1a,b bands



Allan minimum times for 1 MHz spectroscopic resolution are measured to be above 100s.

Parameter	baseline	goal	achieved
RF tuning [GHz]	1250 -1530		
Rx noise (DSB) [K]	2000	1400	1200 -1400
IF bandwidth [GHz]	0.6	4	1.2+
stability, spectr. [s]	>10	>100	100+

Note: trade-off IF bandwidth vs. stability (as with HIFI)

system performance: L#2a

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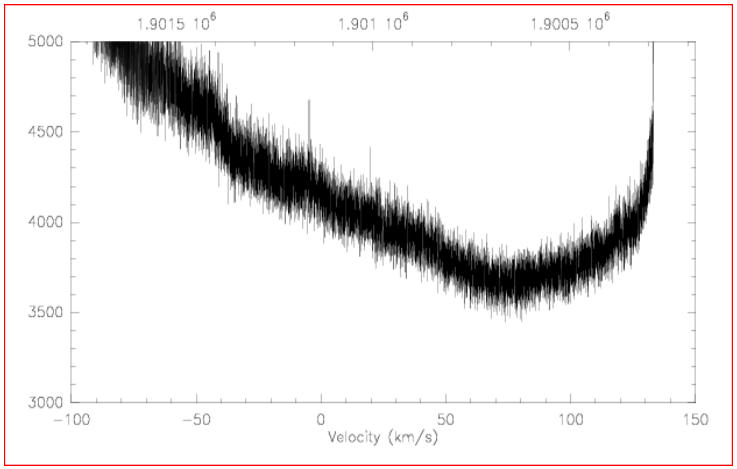
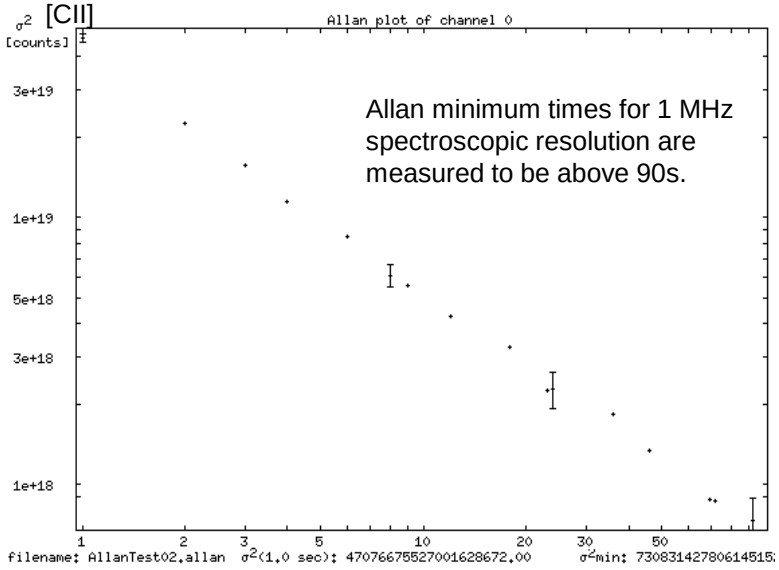
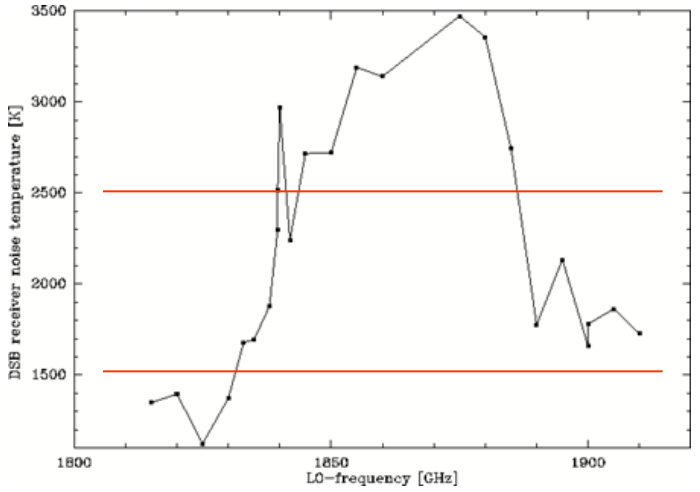


Above: SSB receiver noise performance measured @ 1.9 THz





Above: DSB receiver temperatures across the L #2 band

Parameter	baseline	goal	achieved
RF tuning [GHz]	1810 -1920		
Rx noise (DSB) [K]	2500	1500	1300 -1800
IF bandwidth [GHz]	0.6	4	1.2+
stability, spectr. [s]	>10	>100	100+

GREAT Spectrometers

GREAT offers a suite of back-ends, operated in parallel

Back-ends	Width [GHz]	Resolution(#) [MHz]	Provided by
AOS: acousto-optical spectrometer array	4 x 1.00	1.6	KOSMA
AFFTS: Fast Fourier Transform spectrometer	2 x 1.80	0.255	MPIfR
XFFTS: ibid, latest technologies	2 x 2.50	0.076	MPIfR

Note: (#) spectral resolution is measured as equivalent noise bandwidth, the 3 dB bandwidth is generally smaller.

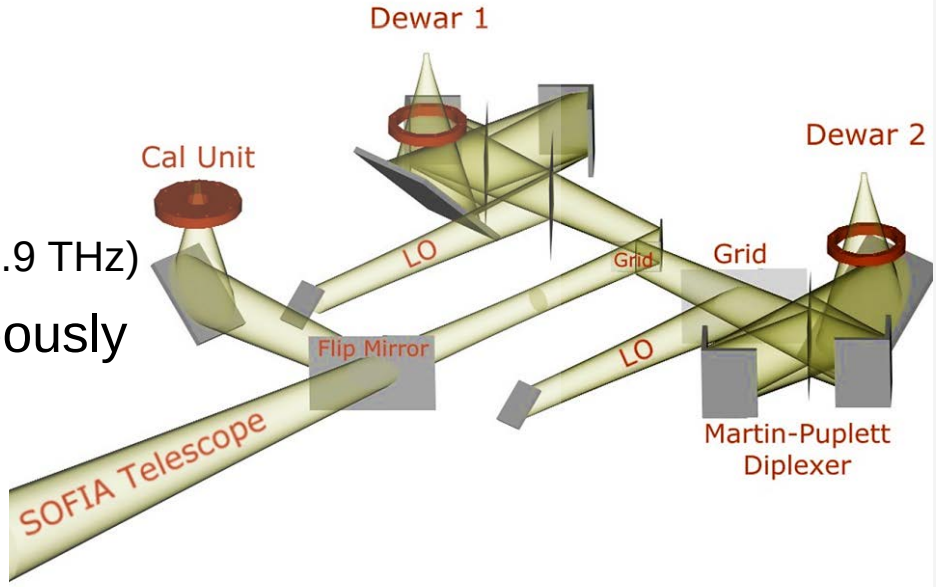
GREAT operation

GREAT operates

- with diffraction limited optics

  HP beam widths: 22″ (1.4) and 16 ″ (1.9 THz)

- co-aligned channels, simultaneously



The modular design allows changing

- between in-band frequencies within minutes, in flight
- configurations (channels) between flights

GREAT Observing Modes

- classical observing mode: telescope position switching
- preferred for compact objects: chopping with secondary
  - dual beam switching with 1-2 Hz, throw up to several arcmins
- advised for extended structures: „on-the-fly“ scanning
  - due to excellent Allan Variance stability times of overall system

GREAT observations can be executed as

- single pointed
- raster map
- on-the-fly

observing prep & data pipeline

- GREAT is available to SOFIA communities in **collaboration**
- GREAT as PI instrument operates in **service mode** only, handling of the observations is by the GREAT team
  - during BS2 successful PIs have been invited to join „their“ flight
- observations are executed in the environment of „KOSMA control“ via **observing scripts** only
  - preparation of set-up is supported by USRA/DSI (and GREAT)
- GREAT delivers calibrated data in standard **CLASS** format and raw data in FITS format

GREAT detects first photons

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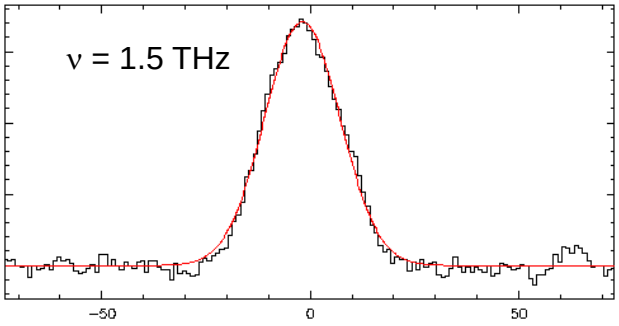
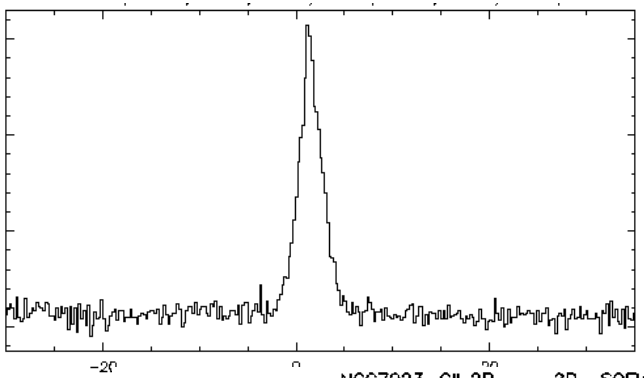
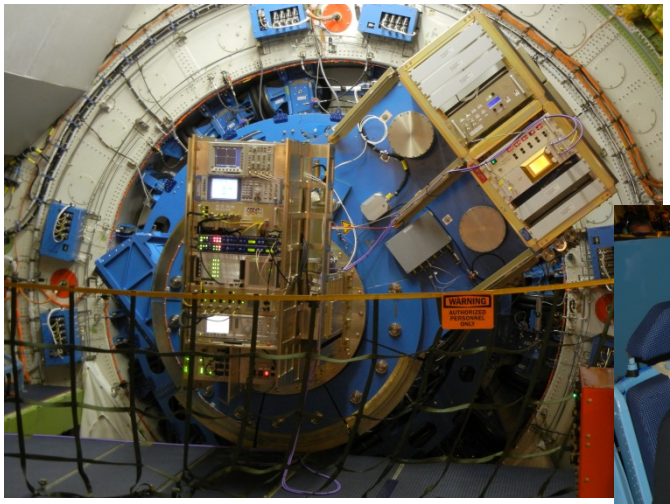
On 1st April 2011, GREAT successfully concluded its commissioning flight

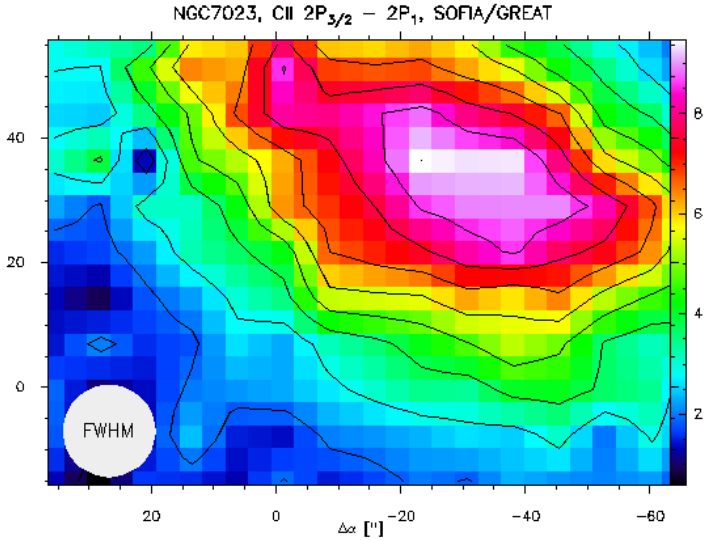
Total power scan across Saturn



[CII] 1.9 THz towards NGC 7023





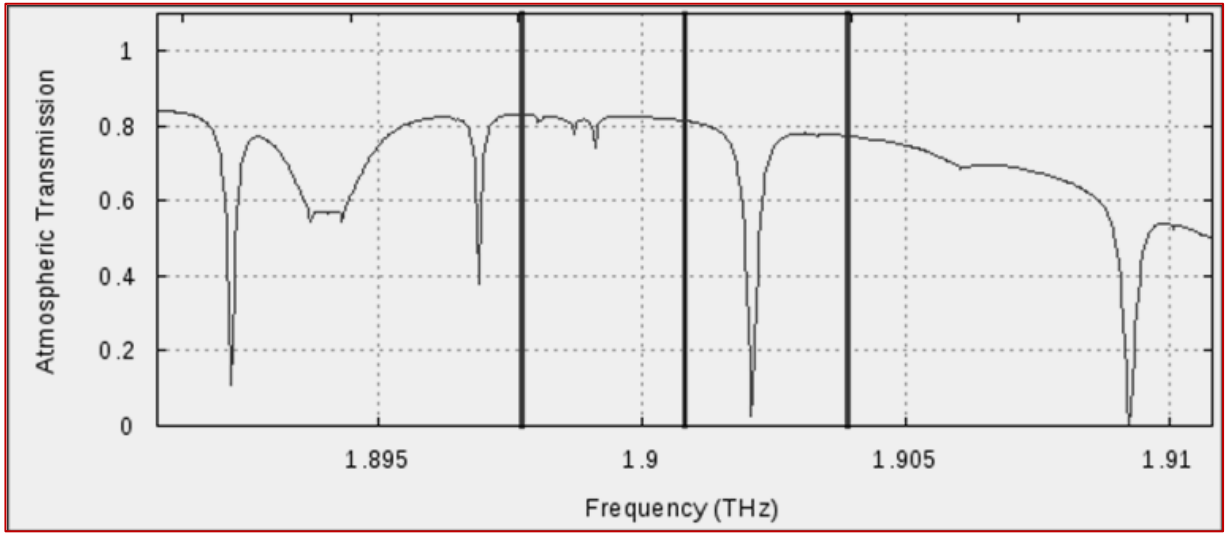


Basic Science Projects

- Short & Basic Science projects covered a wide range of astrophysical topics, from extragalactic to planetary atmospheres
  - 23 science projects (G+US) have been executed so far
  - additional 7 planned for this week‘s flights
  - most of data has been pre-released to PI (one pending)
  - final release of data within next 2-3 weeks (ex new flights)
- overall BS2 was amazingly successful (shared risk operation)
- but every flight had new challenges, new surprises
- publication in A&A special volume has been arranged

Instrument calibration - I

- the calibration of GREAT spectra involves several steps
  - the temperature scale is defined against internal calibration loads, providing ambient & cold (LN) references
  - the atmospheric absorption is then fit – frequency dependent – with appropriate models of the high atmosphere (challenging)



Atmospheric transmission at 41 kft flight altitude and excellent 10 μm PVW at the [CII] frequency
[see the GREAT time estimator on the DSI web pages]

Instrument calibration - II

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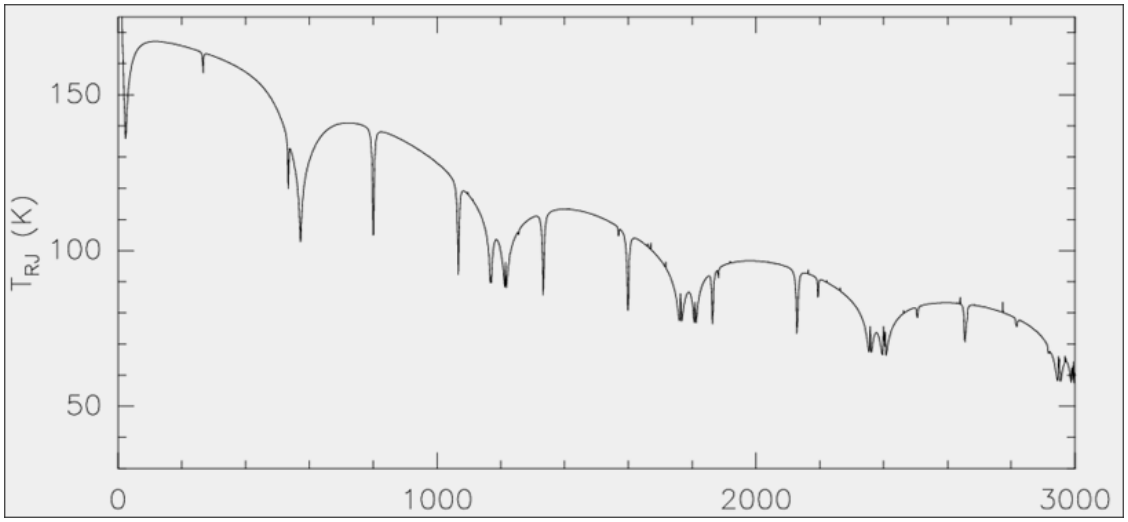
- finally, the coupling of the GREAT beam to the astronomical object was determined by observations of Mars & Jupiter



RJ Temperatures of Jupiter at FIR wavelengths [Model by (ESA2) Rafael Moreno)]

the so determined GREAT beam coupling efficiency 0.57 compares very well with calculated figure for SOFIA optics

Outlook & Ongoing Upgrades

- while operating GREAT baseline configurations routinely now
- GREAT as a PI instrument will constantly be upgraded with newest technologies
  - improving performance and bandwidth in the low frequency channels
  - adding more frequency bands (M-channel in 2012, H-channel 2012/13)

- **upGREAT**: the extension of the instrument into a compact heterodyne array
  will operate 14 pixels at 1.9-2.5 THz and 7 pixels at 4.7 THz (2014)