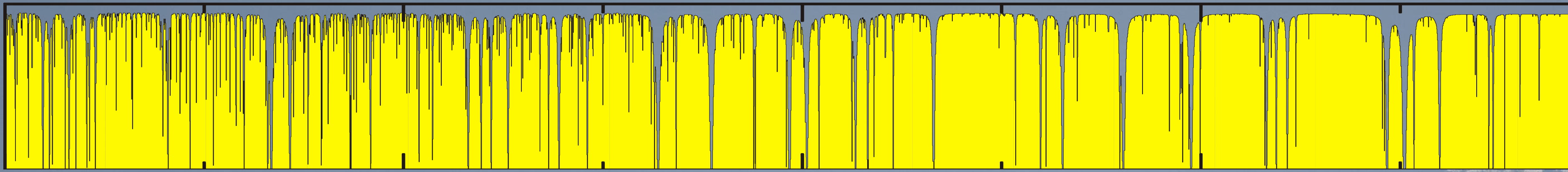
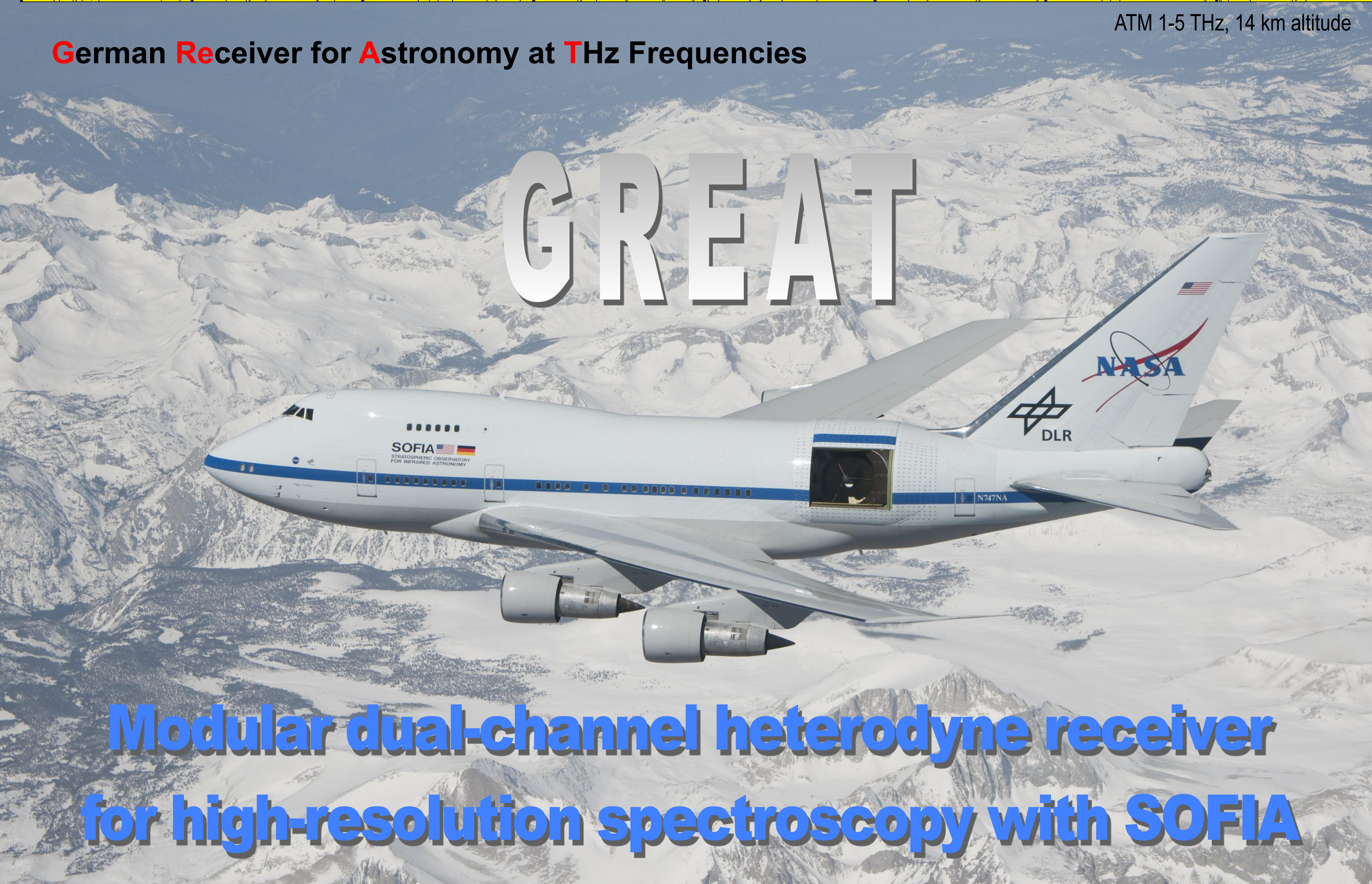


German Receiver for Astronomy at THz Frequencies

GREAT



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

Overview

GREAT - instrument status and science

- Introducing the instrument
  - system overview
  - performance as of today
- Instrument upgrades (within next year)
- Operation Modes /Access to communities
- Science highlights

GREAT - the Consortium

MPIfR
KOSMA
MPS
DLR-Pf

Principle Investigator instrument - funded, developed & operated by

- MPI Radioastronomie
  - R. Güsten (PI)
  - S. Heyminck (system engineer, PA/QA)
  - B. Klein (FFT spectrometer)
  - C. Risacher (upGREAT)
- Universität zu Köln, KOSMA
  - J. Stutzki (Co-P: software)
  - U. Graf (system engineer)
  - K. Jacobs (HEB mixers up to 2.7 THz)
- DLR Planetenforschung
  - H-W. Hübers (Co-PI: 4.7 THz HEB & QCL)
- MPI Sonnensystemforschung
  - P. Hartogh et al. (CO-PI: CTS)

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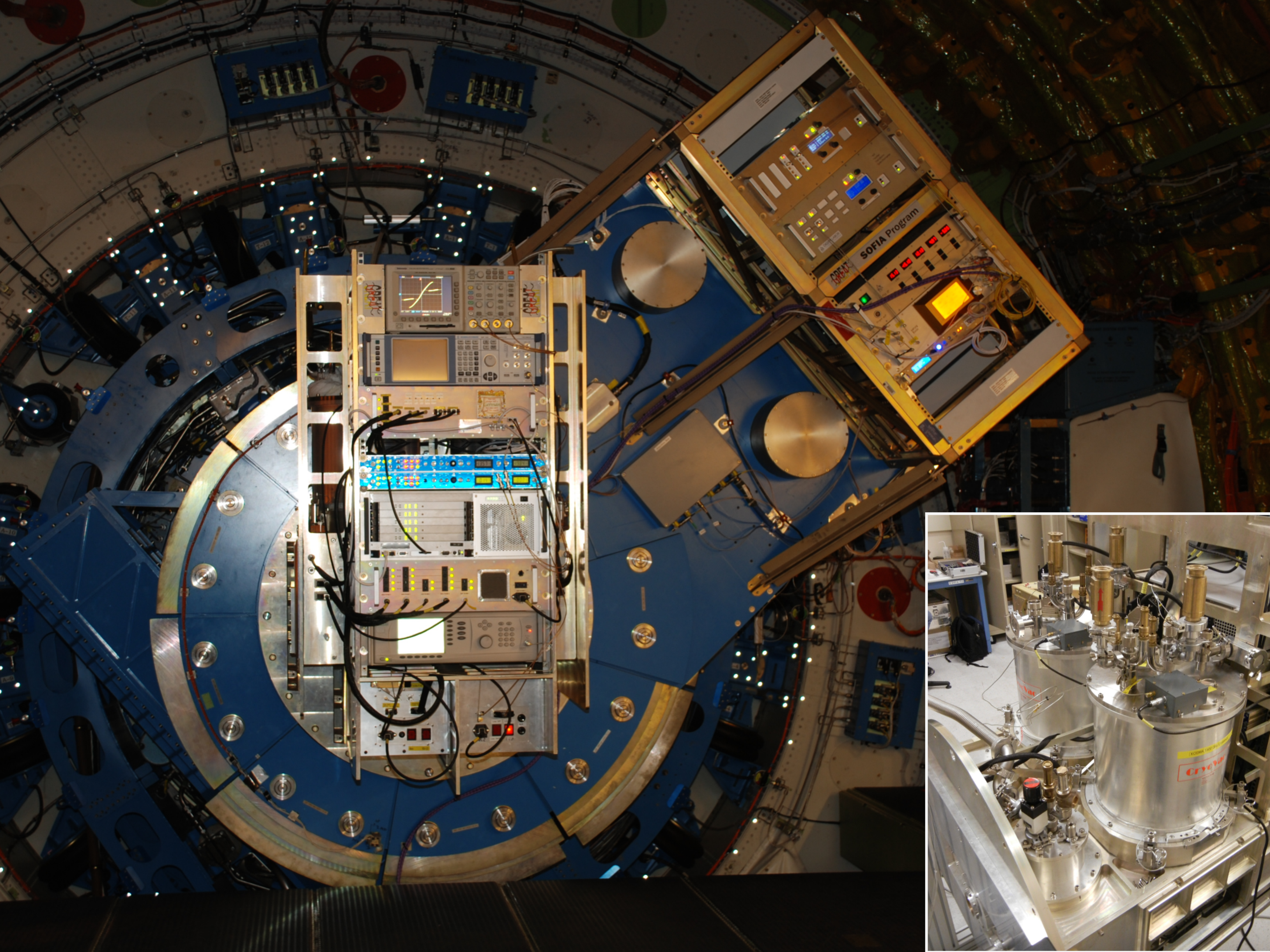
GREAT - System Overview

- GREAT is a highly modular heterodyne spectrometer (R ~10^8)
- operating in science-defined frequency bands 1.25 < ν < 4.7 THz
- 2 out of currently 4+1 cryostats can be operated simultaneously

- channel availability (as of Jan 2014)
  - 2 low-frequency channels are operational since Early Science (2011)
  - 2 mid frequency channels:
    - M_a operational; M_b on hold for mixer upgrade, waiting for commissioning slot
  - high-frequency channel (lab verified, ready to go, commissioning 05/14)

Channel		Frequencies [THz]	Lines of interest	
low-frequency	L1	1.26 – 1.52	[NII], CO series, OD, H_2D^+	operational
low-frequency	L2	1.82 – 1.91	NH_3, OH, CO(16-15), [CII]	operational
mid-frequency	Ma	2.49 – 2.56	$^{(18)}OH(^2\Pi_{3/2})$,	operational
	Mb	2.67	HD	on hold
high-frequency	H	4.74	[OI]	ready to go (May ′14)
upGREAT	LFA	14x (1.9– 2.5)	CO(16-15), [CII] and above	commissioning Q1 15
upGREAT	HFA	7x [4.74]	[OI]	1 yr after LFA


SOFIA Program

System Performance

The modular design allows for short technogical turn-arounds, keeping GREAT at technological forefronts.

Since commissioning in 2011 we have exchanged /upgraded

- all our HEB mixers
- all local oscillator sources (and related, the common optics)
- all our spectrometer back-ends

You, as our customer, should have noticed

- increasingly wider RF coverages (still limited to selected bands)
- much improved system noise temperatures
- wider IF bandwidths (defined by HEB roll-off), processed by
- monolythic spectrometers providing highest spectral resolution

The GREAT instrument (Early Science configuration) is described in Heyminck et al. A&A 542, L1

Receiver noise temperatures

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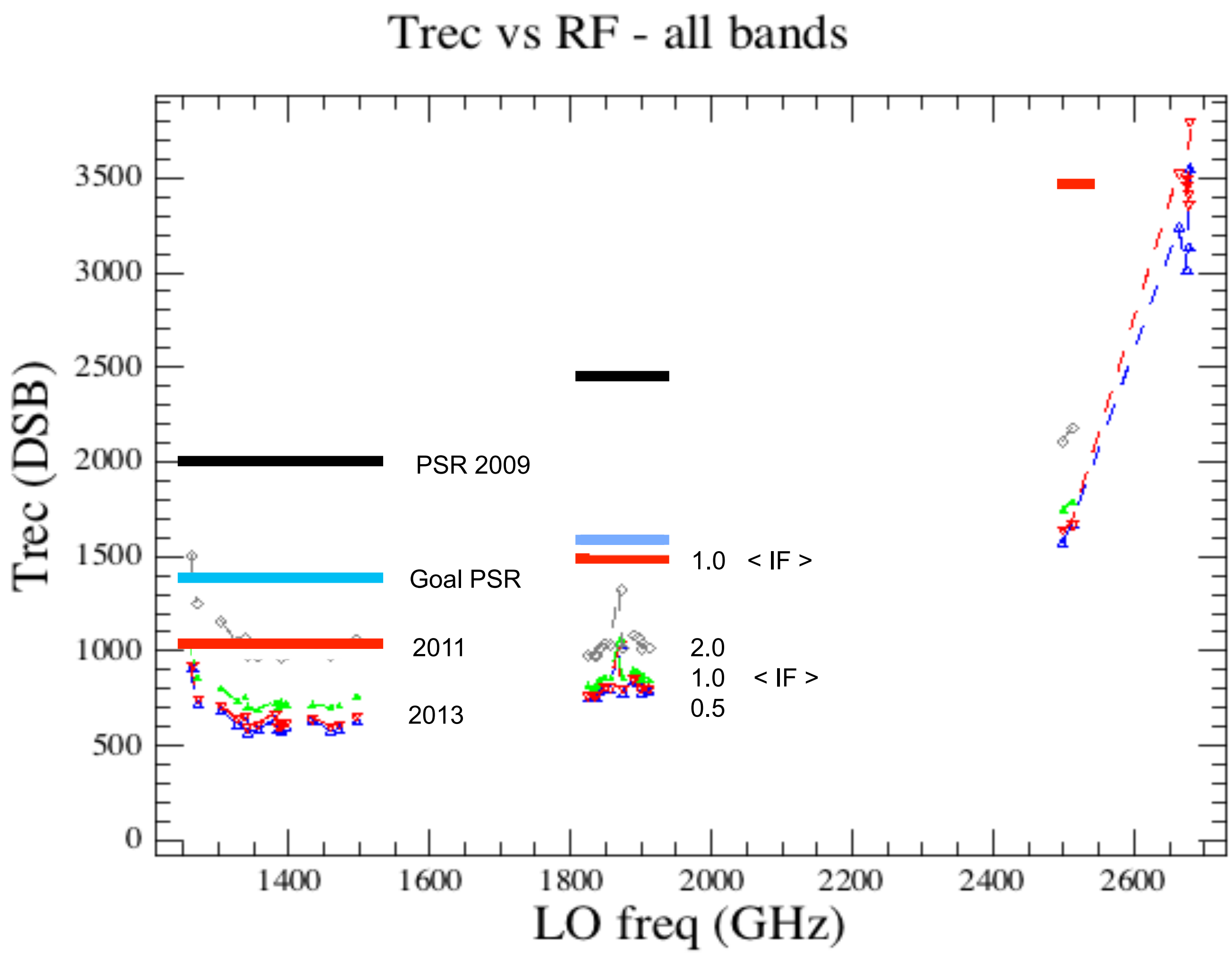
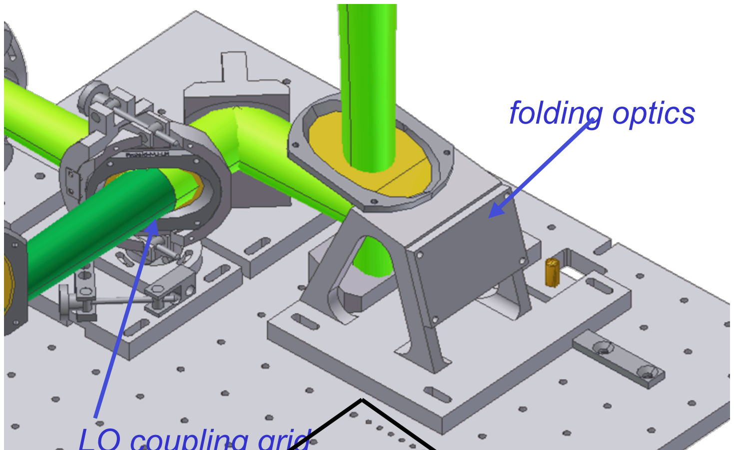
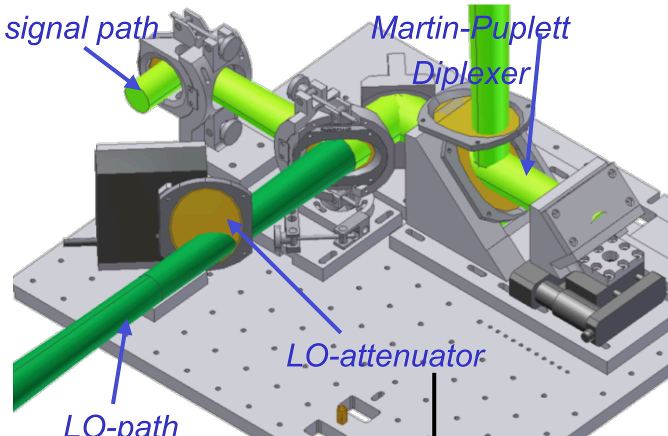
The performance of the Cycle-1 GREAT has improved significantly

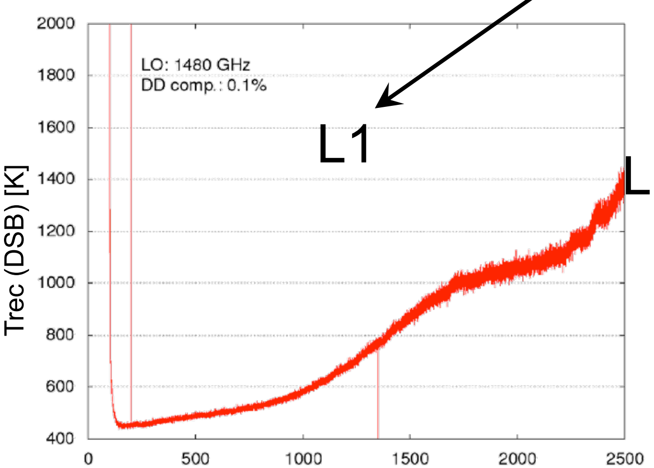


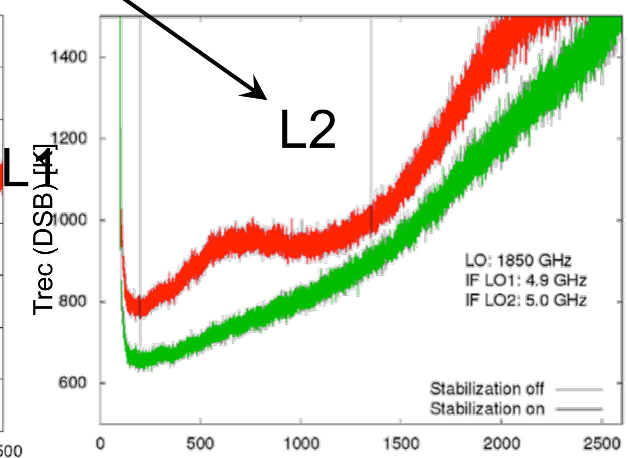
GREAT sensitivities: L& M-bands

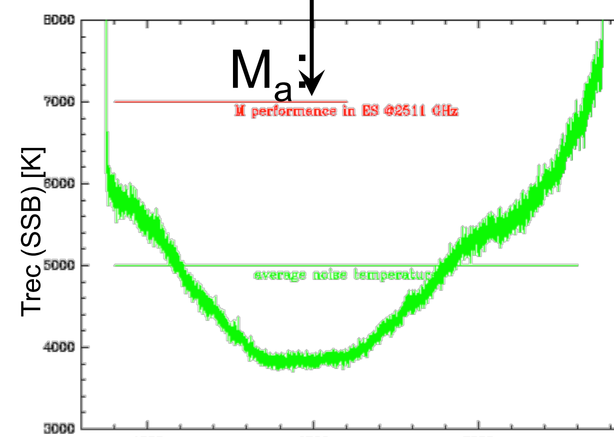
More powerful solid-state local oscillators (Virginia Diodes Inc.) allowed substituting Martin-Puplett diplexers with coupling grids in channels L1 & L2, thereby providing access to the most sensitive IF frequencies of the HEB.





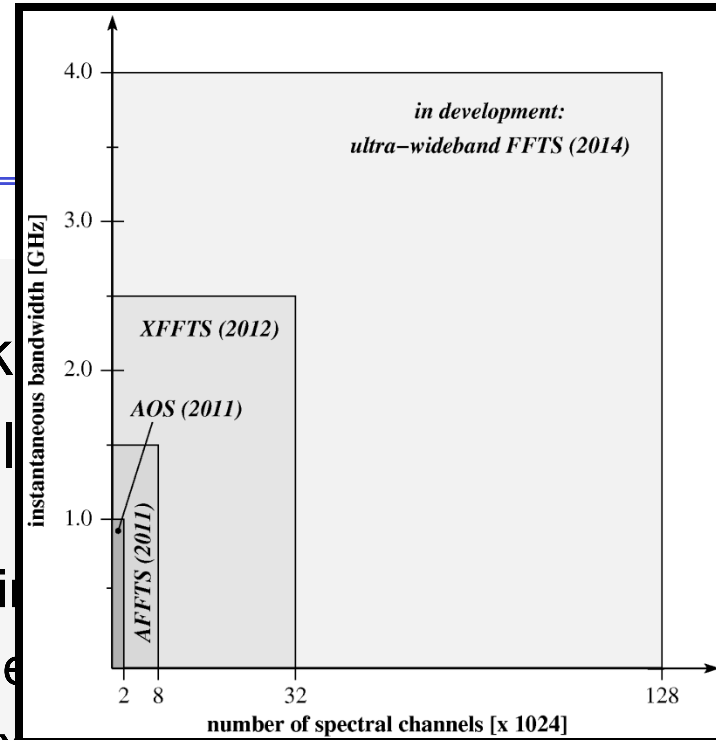






Mixer IF [MHz]

GREAT Spectrometers



GREAT operates a wide suite of back

integrating new technologies as avail

- until now the usable IF bandwidth was defi
- with new NbN HEB devices this will change
- the latest for upGREAT 4 GHz IF bands/pixel have to be processed

back-end spectrometer	Bandwidth [GHz]	Resolution [MHz]	Status
AOS: acousto-optical array	4 x 1.0	1.6	de-commissioned
CHIRP Transform spectrometer			de-commissioned
AFFTS: Fast Fourier Transform	2 x 1.5	0.212	operational
XFFTS: Fast Fourier Transform	2 x 2.5	0.088/0.044	operational
?FFTS (no name yet)	2 x 4.0	0.035	in development

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

GREAT Observing Modes

- classical observing mode: telescope position switching
  - in practice limited to throws 0.5 deg or less (atmosphere)
- preferred for compact objects: chopping with secondary
  - dual beam switching with 1-2 Hz, throw up to several arcmin
- advised for extended structures: „on-the-fly“ scanning
  - due to excellent Allan Variance stability times of overall system
- for very extended/confused regions: load chopping (tbc)
  - modifications implemented, on-sky verification pending

GREAT observations can be executed as (though not all verified)

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

Community Access to GREAT

- GREAT is available to SOFIA communities in **collaboration**
  - „rules“ stated in Cycle 1-2 call-for-proposals
- GREAT as PI instrument operates in **service mode** only
  - observations are performed by the GREAT team
- observations are executed via **observing scripts**
  - preparation supported by SMO (based on your uploaded AORs)
- GREAT delivers calibrated data in standard **CLASS** format
  - raw data (FITS format) into archive within 2 days after flight
  - quick look analysis (prelim. reduced) within 2 weeks
  - calibrated data within 45 days after end of flight series

The next steps

So far I have described

- the status of GREAT as flown during Cycle 1 and
- the min performance you may expect for Cycle 2.

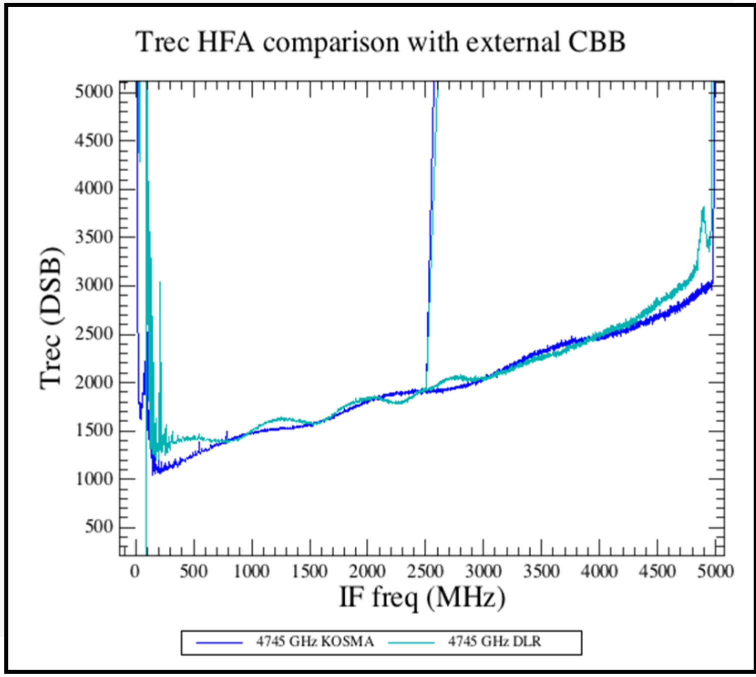
Next, an outlook on our next development milestones

- H-channel – our single-pixel high-frequency channel
- upGREAT – the extension of GREAT into mid-sized het array

4.7 THz H channel - ante portas

Our latest addition, the high-frequency channel passed pre-shipment verification in the labs of MPIfR with truly outstanding peformance:

- aiming at observations of [OI] at 4.74 THz (mostly galactic, due to ATM)
- based on new technologies: the NbN HEBs will be pumped by a novel QCL local oscillator (DLR-Pf)
- amazingly, we have a choice of 2 mixers with comparable noise figure T_{rx} ~1500 K
  - an open-structure HEB [DLR-Pf, Hübers]
  - a waveguide HEB [KOSMA, Jacobs]
- the integrated system complies with specs
  - optics, stability, tuneability – all fine
- we prepare for commissioning in May 14

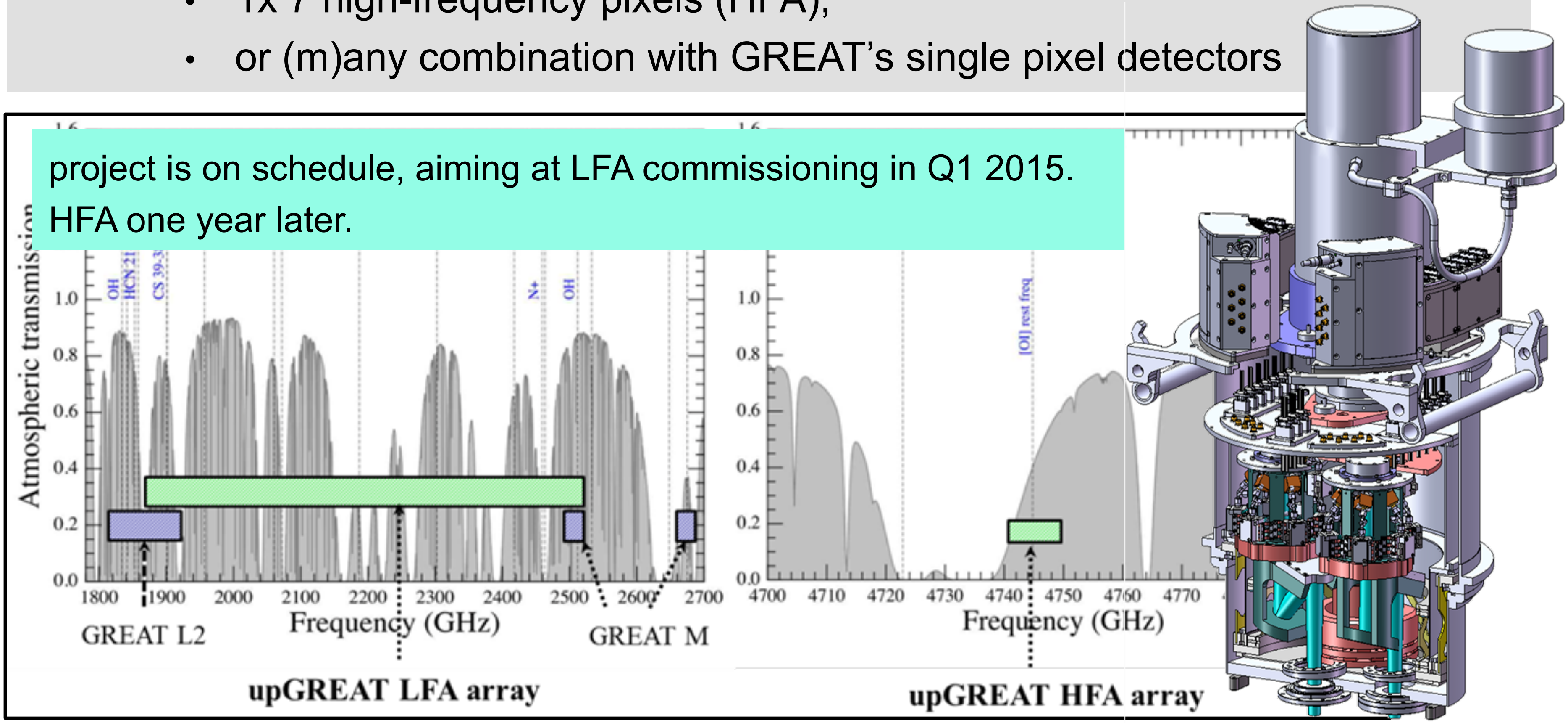


upGREAT – GREAT multiplexed…

the extension of GREAT into 2 hex arrays, operating in parallel

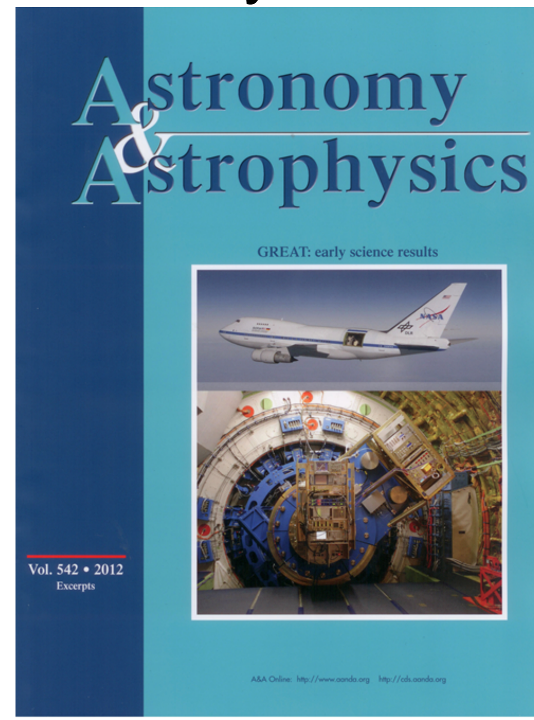
- 2x 7 low-frequency pixels (LFA) and
- 1x 7 high-frequency pixels (HFA),
- or (m)any combination with GREAT's single pixel detectors

project is on schedule, aiming at LFA commissioning in Q1 2015.
HFA one year later.



GREAT Flight Records

- GREAT performed 15+2 flights during SOFIA‘s Early Science
  - observed a total of 26 science projects (G+US)
  - final release of data completed in Nov 2011
  - 22 papers published in A&A Special (Vol.542)



- during Cycle 1 GREAT concluded
  - 15.2 successful flights so far, incl.
  - 9 flights during New Zealand deployment.
  - 5 scheduled for end of Jan 14 will close Cycle 1
  - calibrated data for all community projects were released in Nov. 2013
  - I expect that with conclusion of Cycle1 more than 2 dozen projects will have received quality-validated data.
  - We aim again at „pooled“ publication

Astrochemistry: detections of light hydrides

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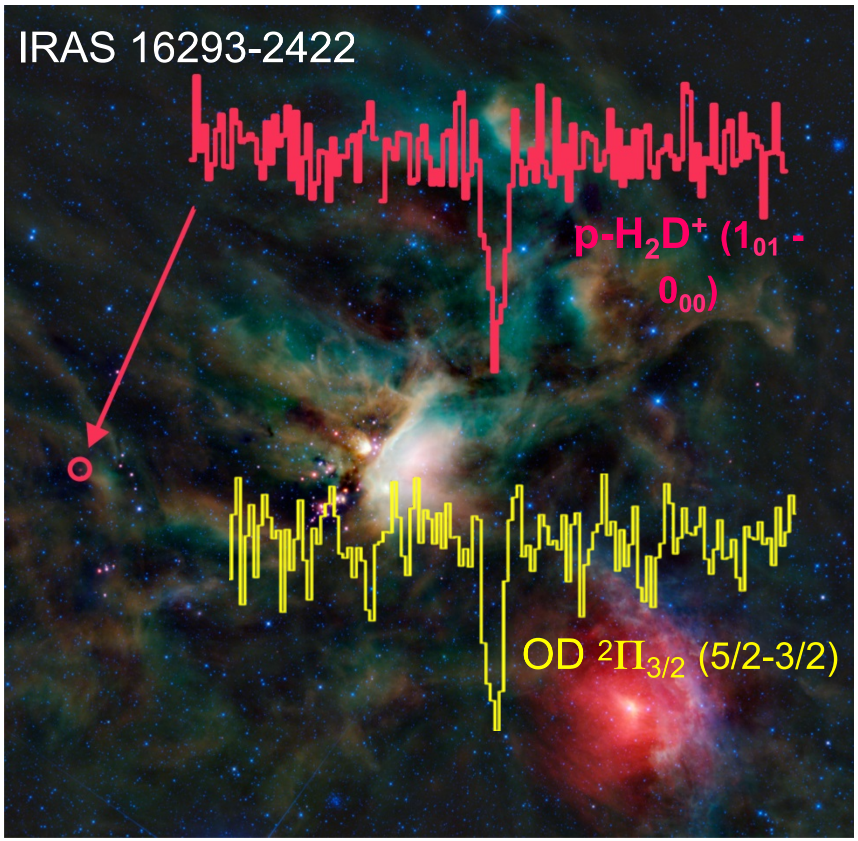
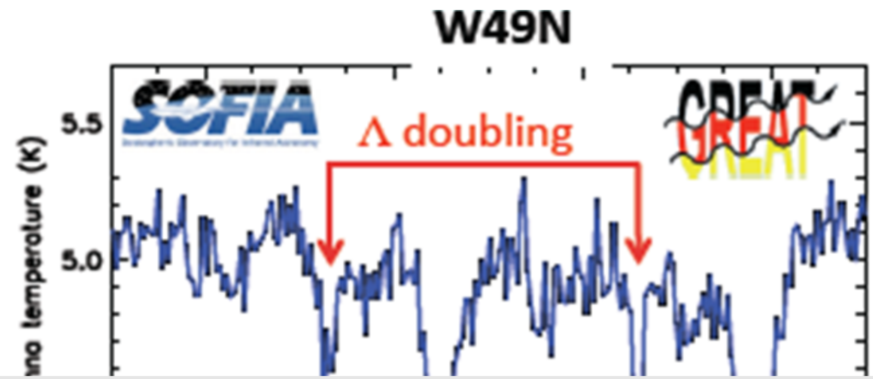
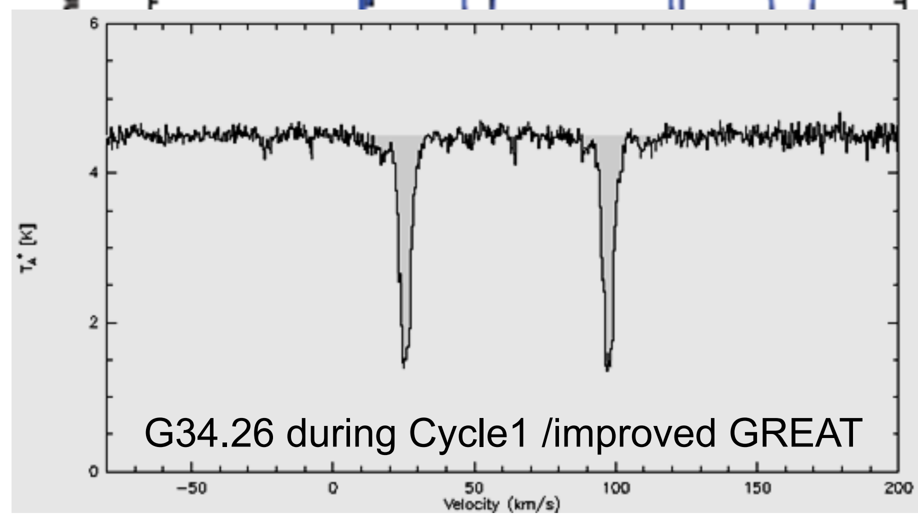
Search for light hydrides has been very succesful: SH, OD, p-H_2D^+



background false-color infrared image from WISE .





Detection of OD ground-state (1.39 THz) during Basic Science (Parise et al. A&A 542 L5). p-H_2D^+ ground-state during Cycle 1 (New Zealand - Schlecker et al. in prep.). SH Λ-doublet detected in BS, follow-up during Cycle 1 on half dozen targets (Neufeld et al.)

HD detection towards SgrB2(M)

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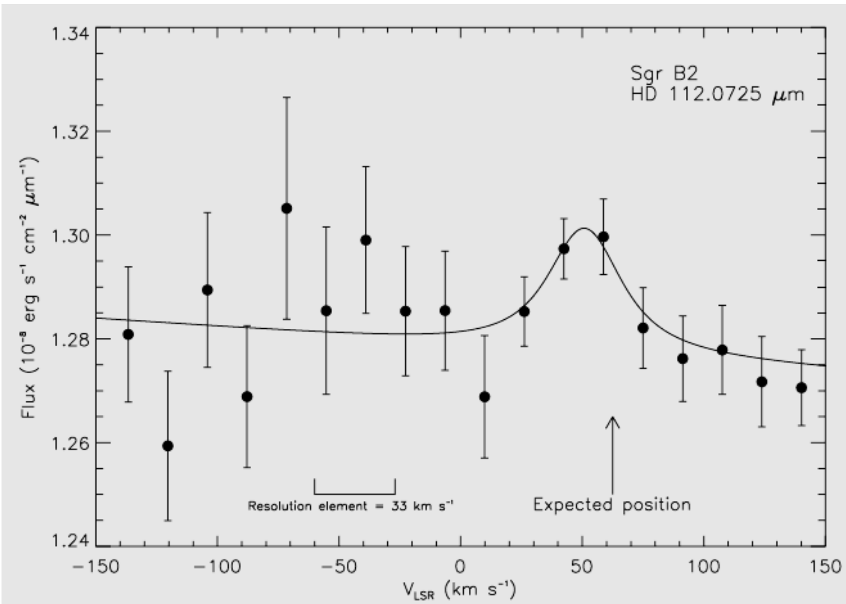
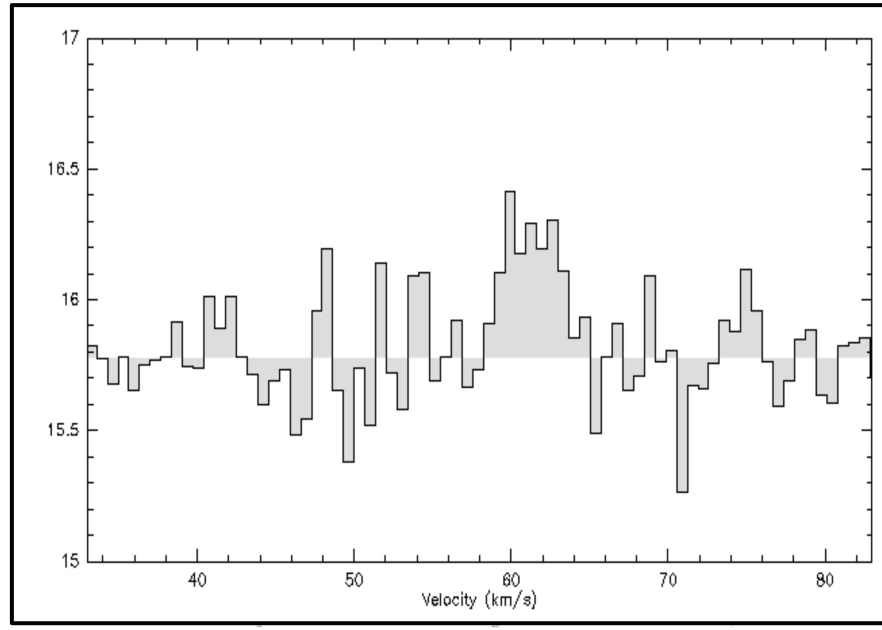
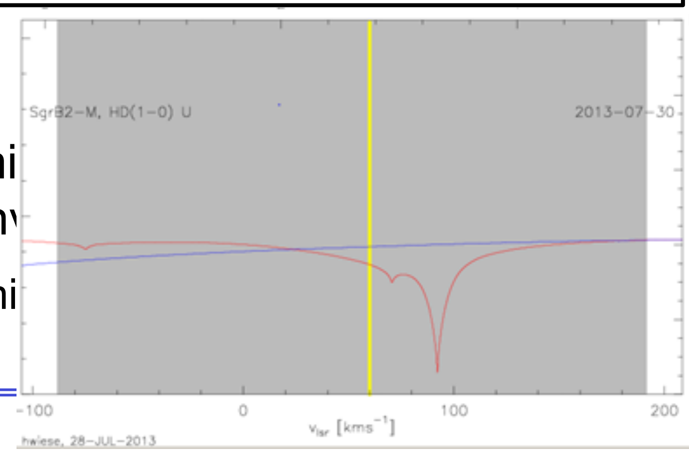
Tentative detection of HD emission was reported from ISO/LWS (Polehampton et al.)





GREAT (Mb channel) confirms: HD is recorded in emi
no obvious trace of line-of-absorption (from SgrB2 env

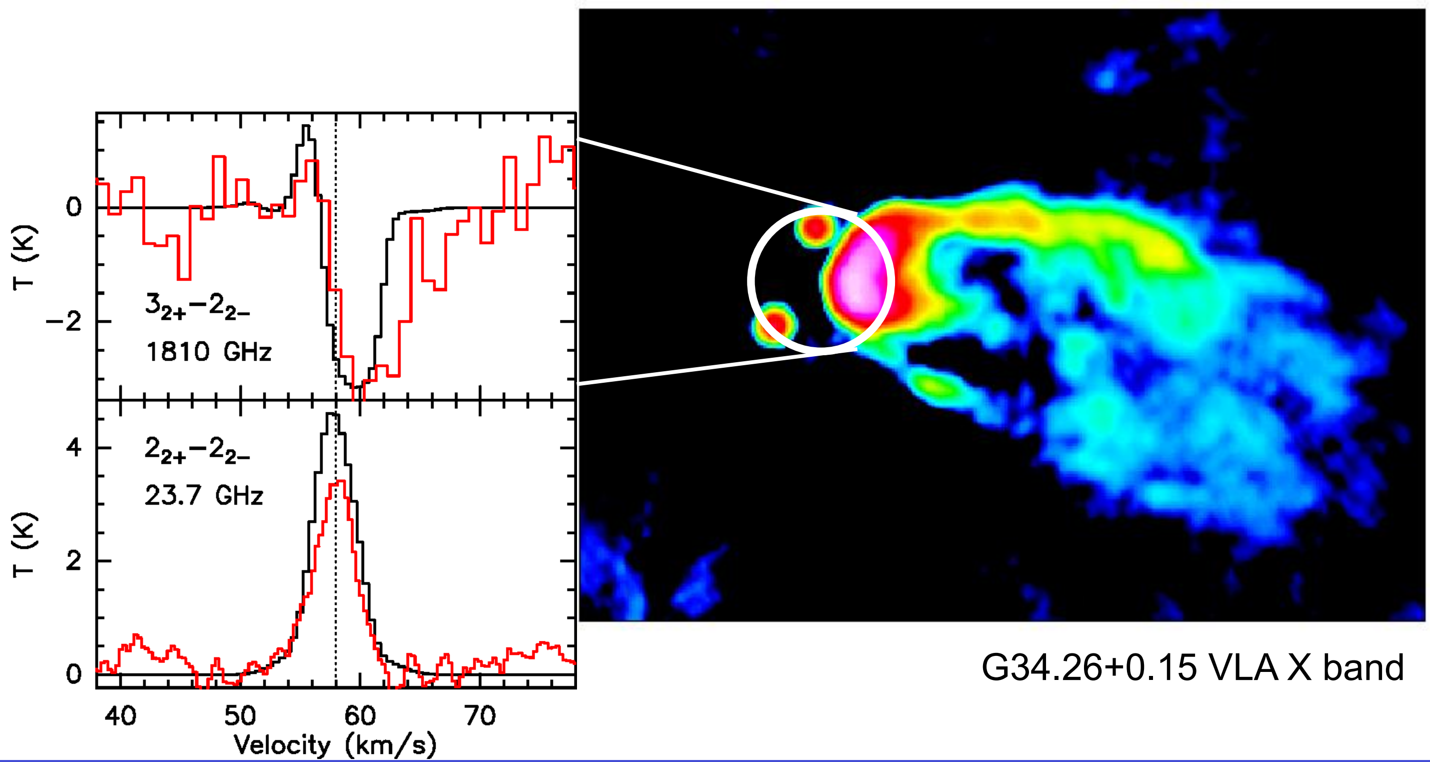
Note: this is a difficult experiment, with generally low transmi
velocity blending with strong atmospheric absorption.



NH_3 absorption: probing infall

Probing infall with ammonia absorption against dust continuum

- during ES 3 massive clumps with red-shifted absorption detected
- modeled with infalling envelope (Wyrowski et al. 2012, A&A 542, L15)
- half dozen additional targets observed during cycle 1 follow-up



G34.26+0.15 VLA X band

Probing clean MHD shocks

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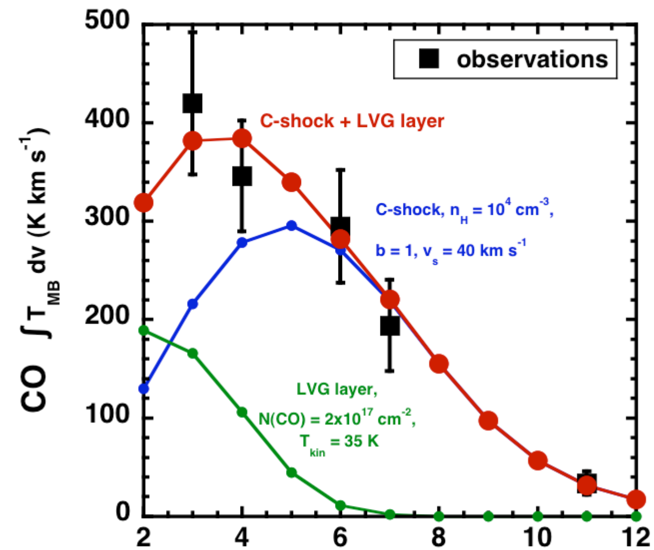
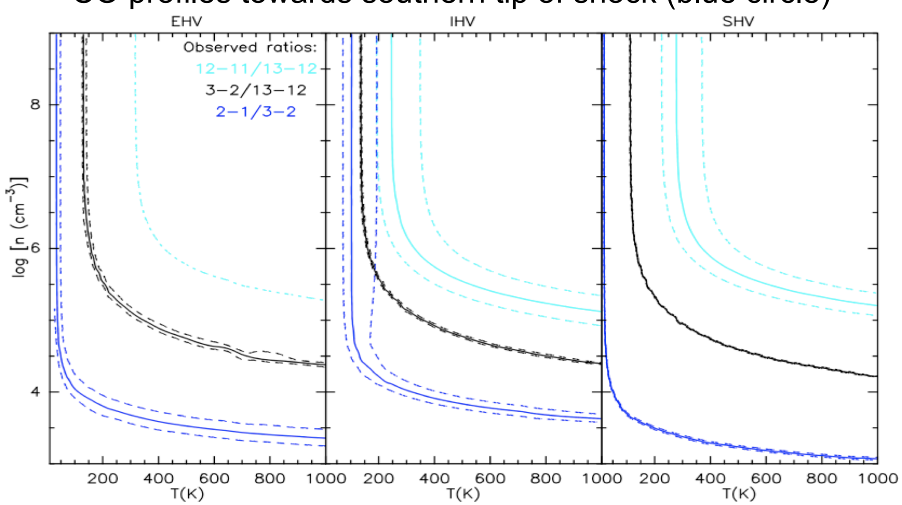
Gusdorf et al.: SN driven MHD shocks

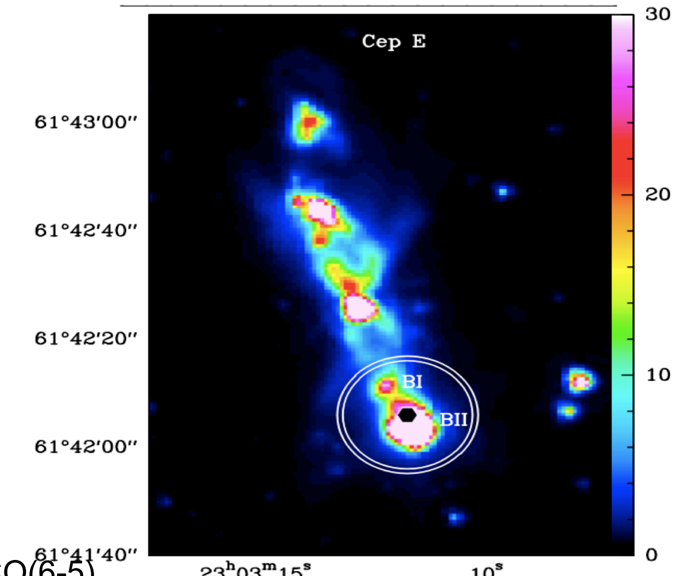
W28F (A&A 542), IC443 ongoing in Cycle 1

- \- CO and rot H_2 complemetary data base
- \- GREAT: subthermally excited high-J CO
- \- model: only stationary C-type shock fit
  - physics: [10^4 cm^{-3}, 45-100 μG, 25 km/s]



CO profiles towards southern tip of shock (blue circle)

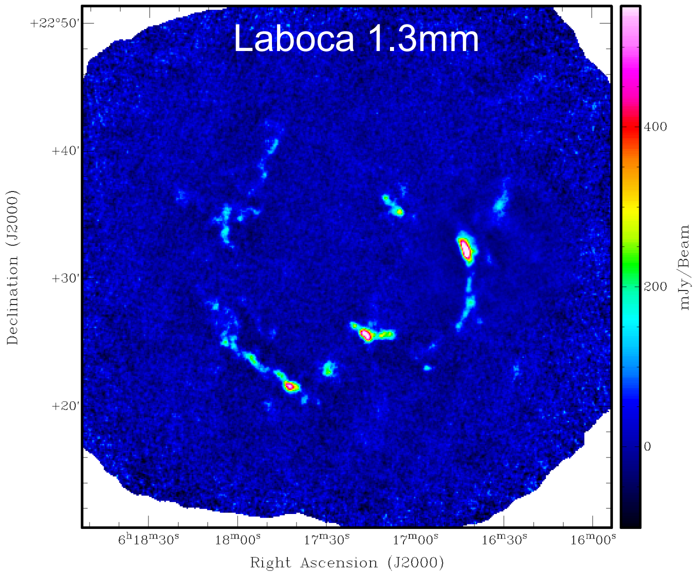


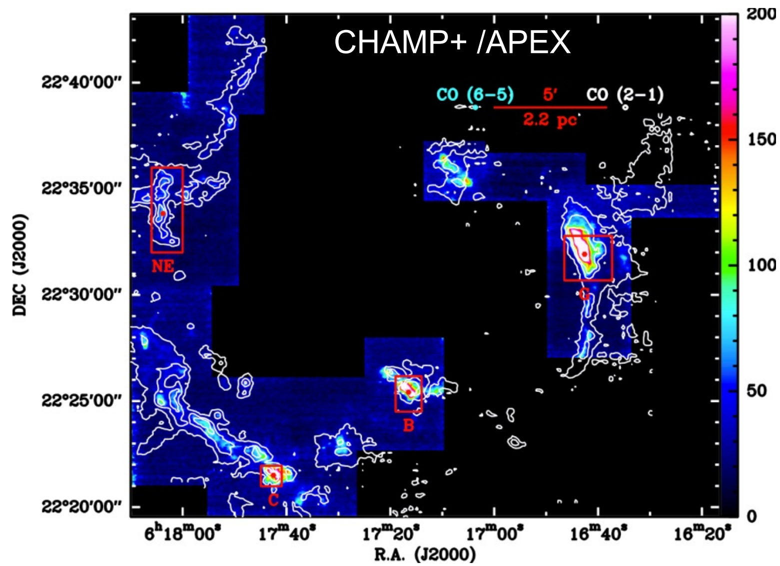


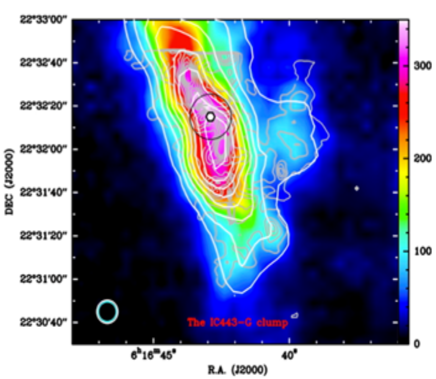
Color image: CO(6-5)

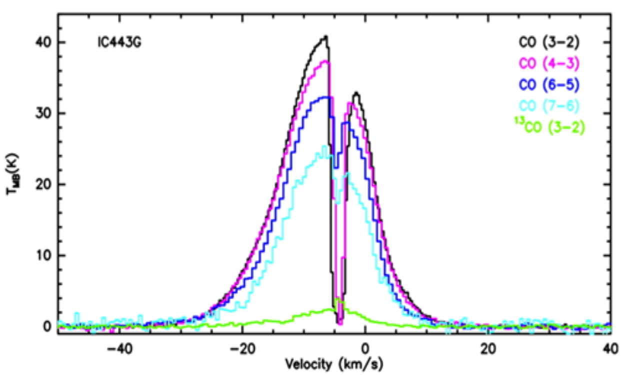
Probing clean MHD Shocks - II

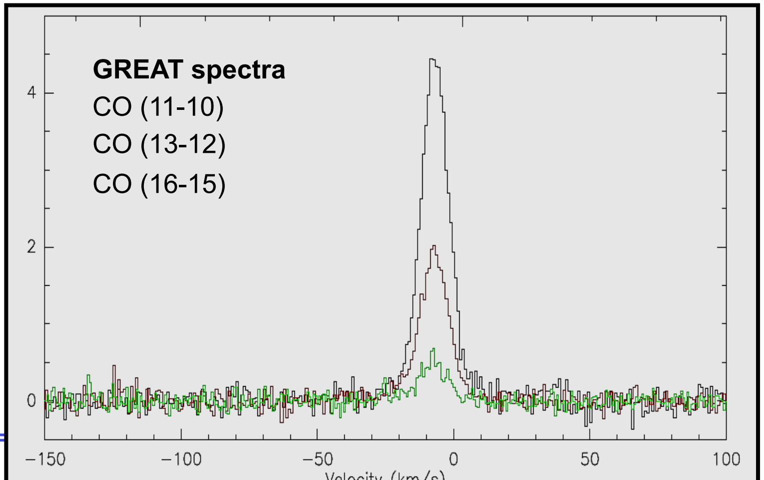
CO excitation study towards 3 IC443 cores – archetypal SN driven MHD shock











R.Güsten

Milky Way’s most active stellar nursery

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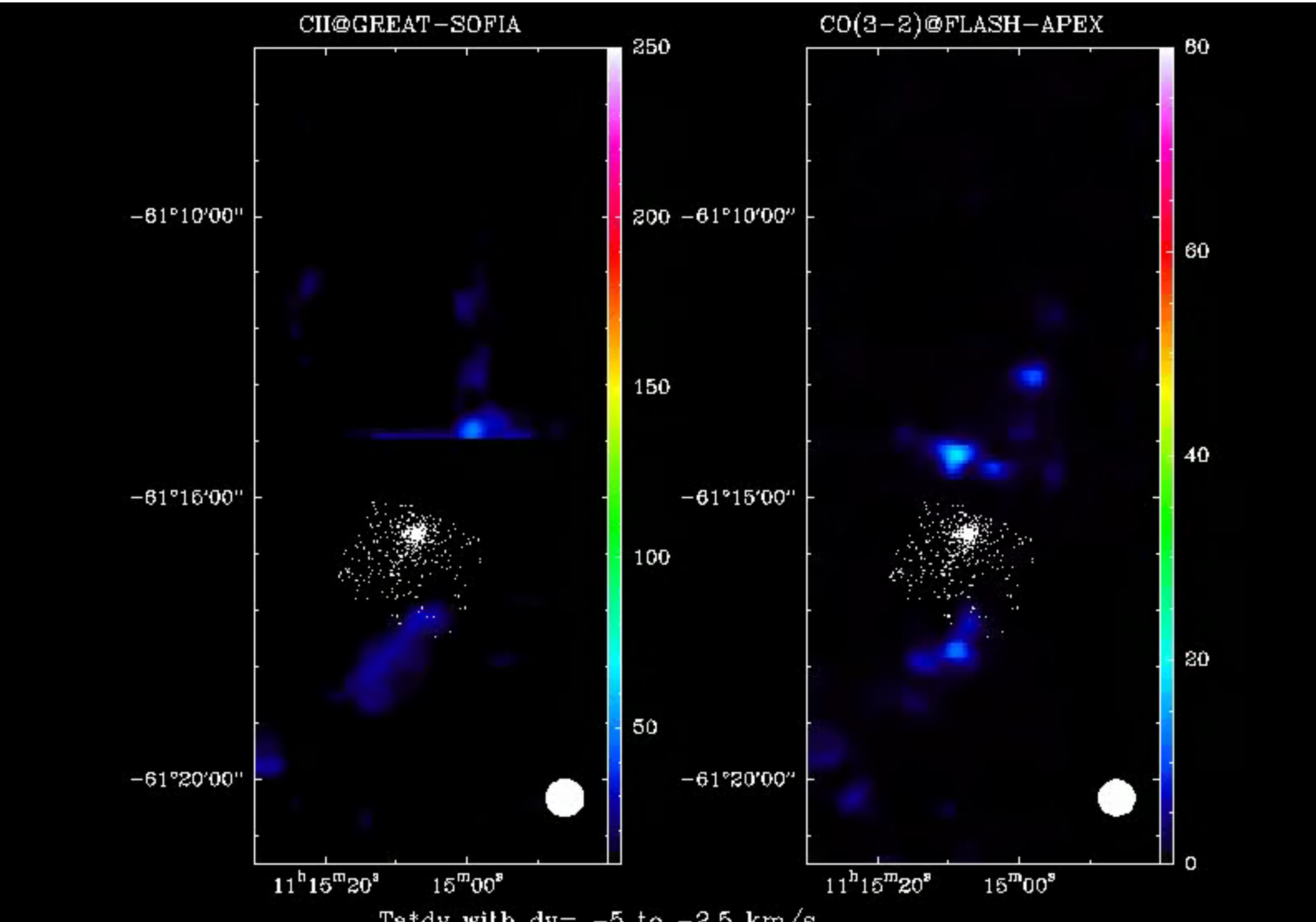

star-burst

R studies
REAT

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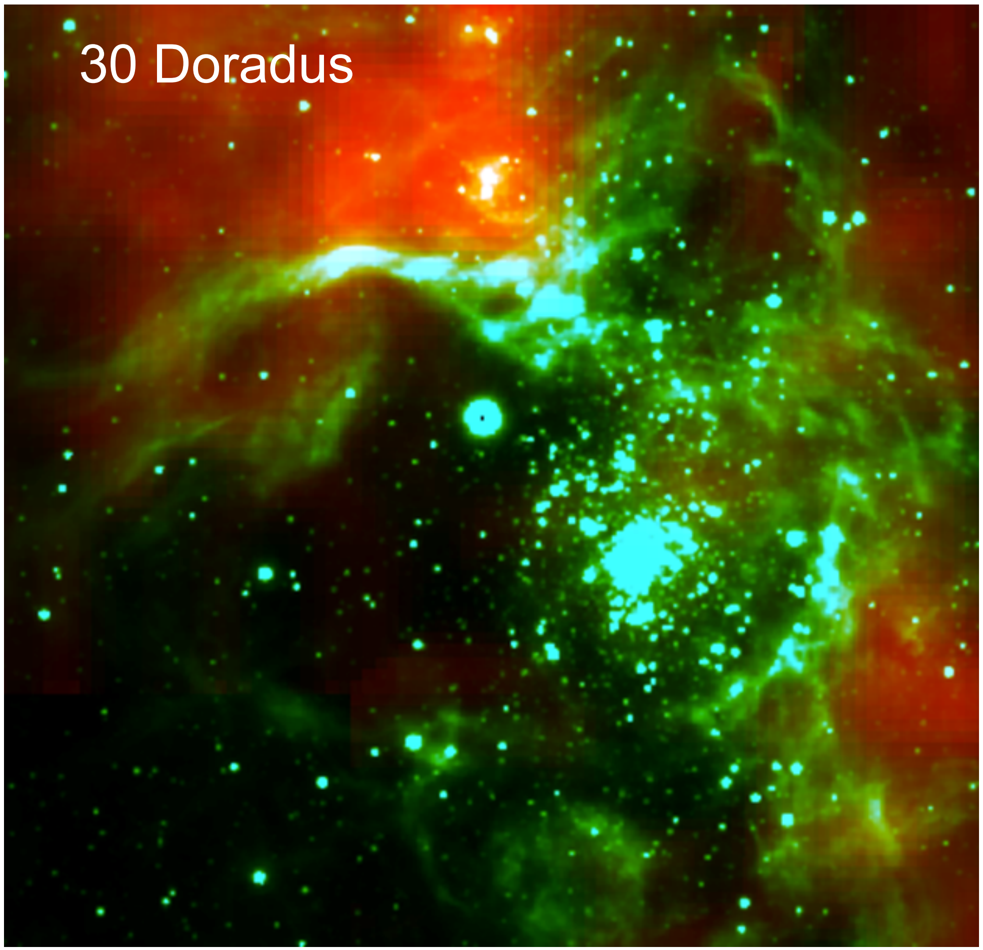
R.Güsten

A unique opportunity: Magellanic Clouds

GREAT performed 5 science projects towards the Large & Small Magellanic Clouds



30 Doradus in the LMC

- most productive star formation site in Local Group; R136 cluster contains most massive stars known
- Science goal: study ISM physics / star formation process in extreme environ-ment of low metallicity gas exposed to high UV field

Color composite near-infrared image (Ks filter) towards the central part of 30 Dor, extrac-ted from ESO's VISTA Magellanic Cloud survey. Superimposed in red is the velocity-integrated emission of ionized carbon [CII], observed with GREAT.

Data provided by Requena-Torres et al.

Impressions from NZ deployment

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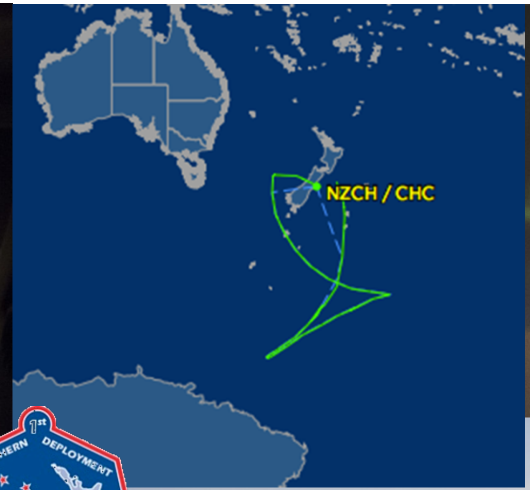

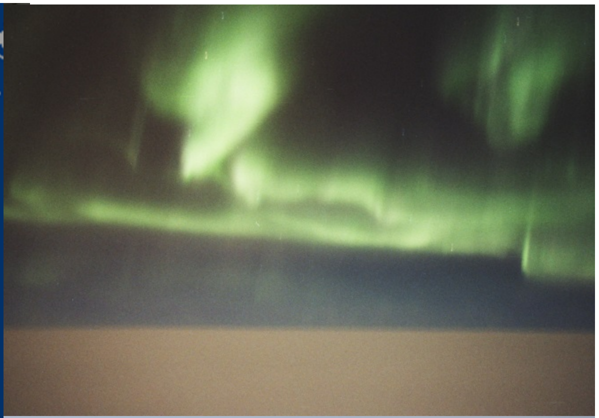

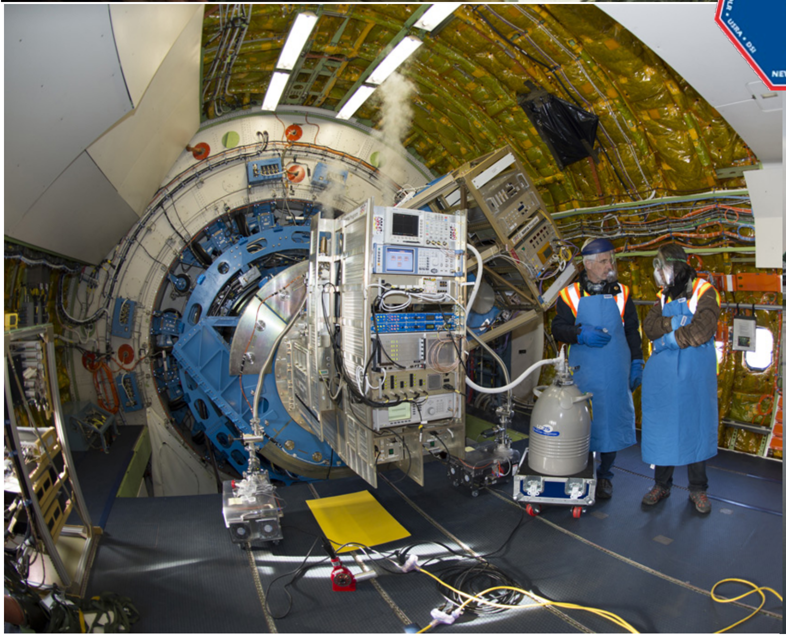

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