



The new GREAT SOFIA scenario with 4GREAT

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On Behalf of the GREAT Consortium

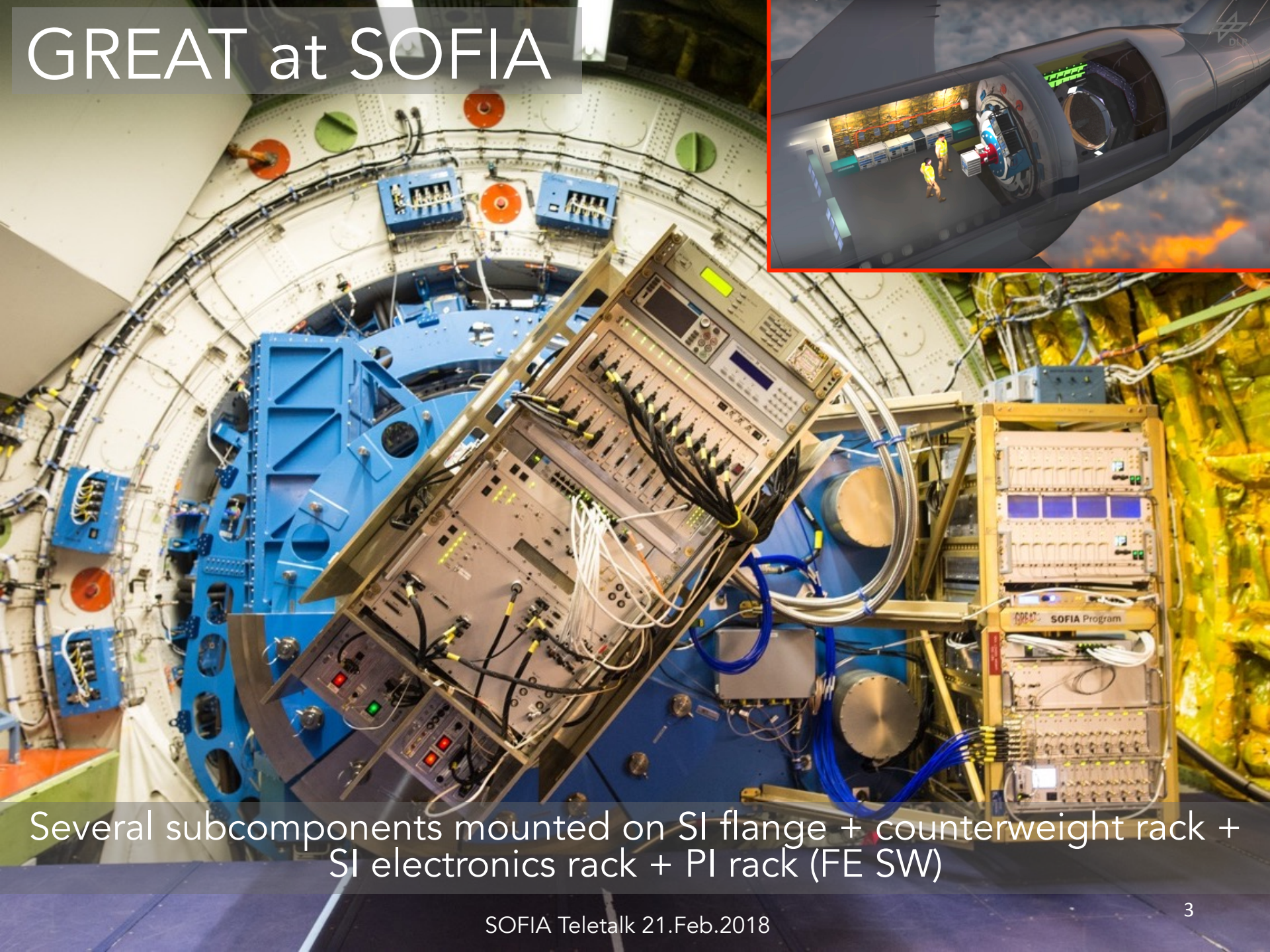
GREAT at SOFIA



German REceiver for Astronomy at Terahertz frequencies

- GREAT is a highly modular heterodyne spectrometer ($R \sim 10^8$)
- Operating in science-defined frequency bands 1.25 - 4.7 THz
- 2 out of currently 4+2 cryostats can be operated simultaneously

GREAT at SOFIA



Several subcomponents mounted on SI flange + counterweight rack + SI electronics rack + PI rack (FE SW)

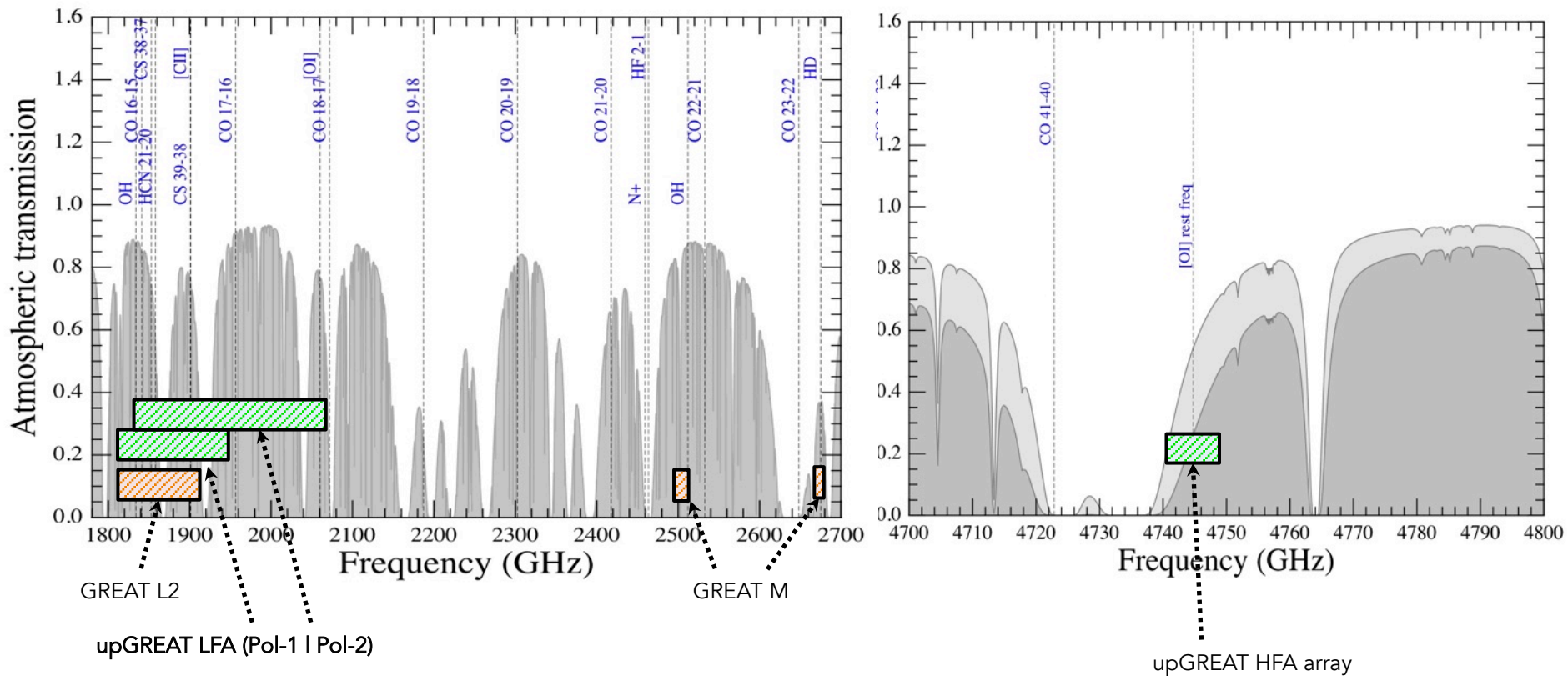
GREAT: Situation pre 4GREAT (2016)

Instrument	Channel	Frequencies	Lines of Interest	Remark	Cooling
GREAT	Low Frequency : L1	1252 - 1520	[NII], CO series, OD,HCN,H ₂ D ⁺	Single Pixel	Wet (LHe)
	Low Frequency : L2	1810 - 1910	NH ₃ ,OH,CO(16-15),[CII]	Single Pixel	Wet (LHe)
	Mid-Frequency : M	(a) 2490 - 2520	OH(2π3/2),HD	Single Pixel	Wet (LHe)
		(b) 2670 - 2680			
High-Frequency : H	4744	[OI]	Single Pixel	Wet (LHe)	
upGREAT	Low Frequency Array : LFA	1810 - 1950	OH lines, [CII],CO series, [OI]	7 x 2 Pixels (2 Pol)	Cryo-Cooler
		1830 - 2070			
	High Frequency Array : HFA	4744	[OI]	7 Pixels	Cryo-Cooler

Right side					
GREAT		upGREAT			
L2	H	LFA			
yes	yes	yes	L1	GREAT	Left Side
	yes		L2		
yes			M a/b		
yes		yes	HFA		

Very flexible:
7 cryostat combinations

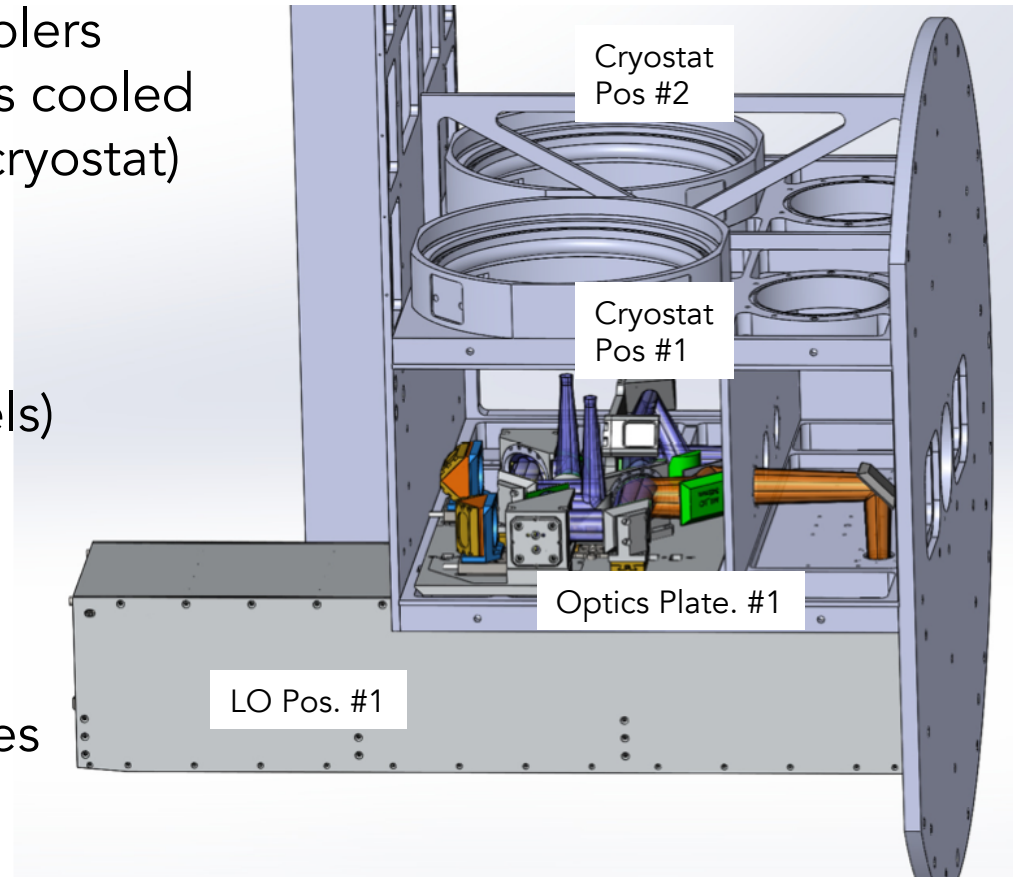
GREAT: Situation pre 4GREAT (2016)



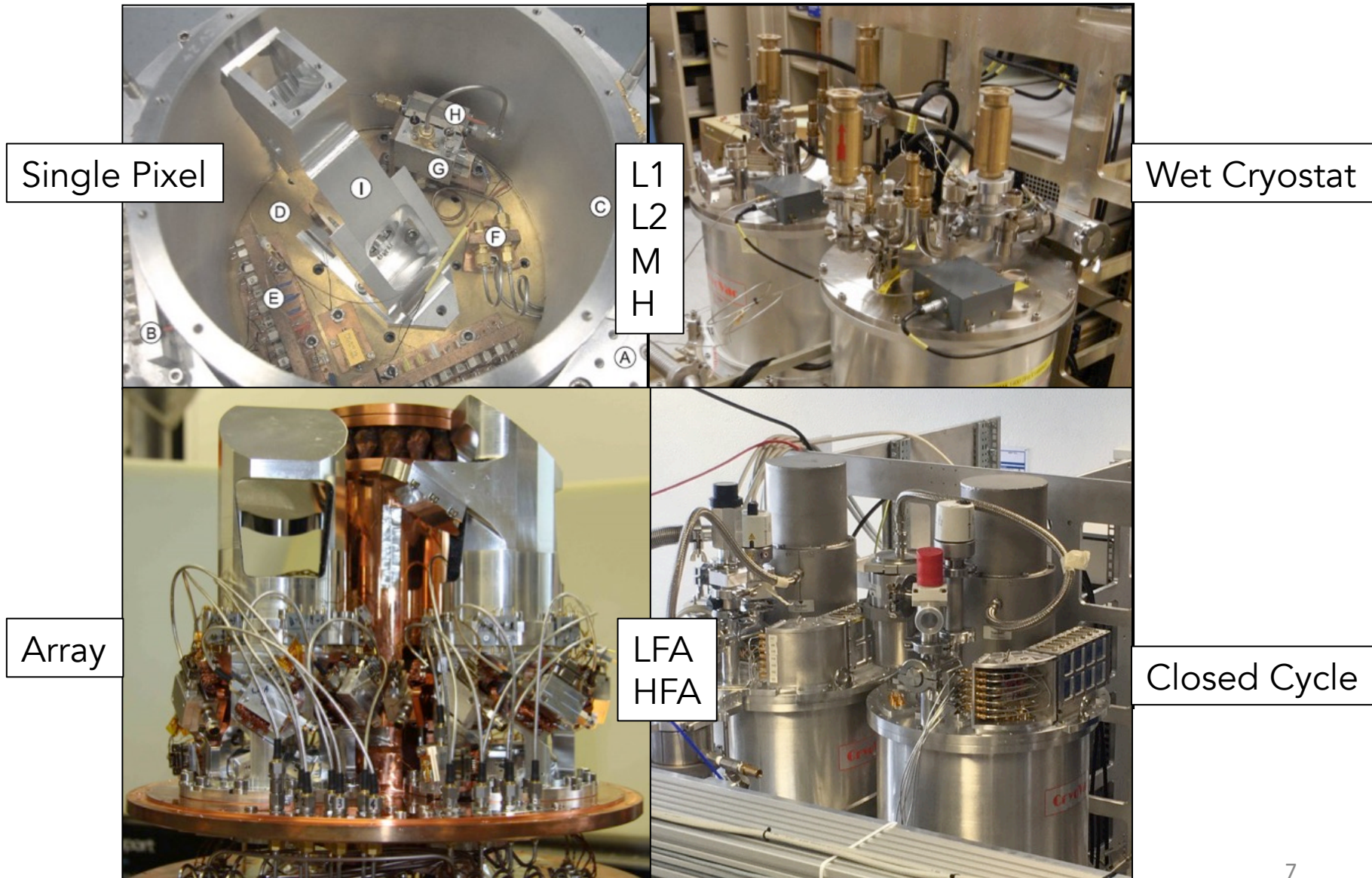
Atmospheric transmission for SOFIA, PWV of 15 and 20 μm .

GREAT: Modules and Sub-modules (HW)

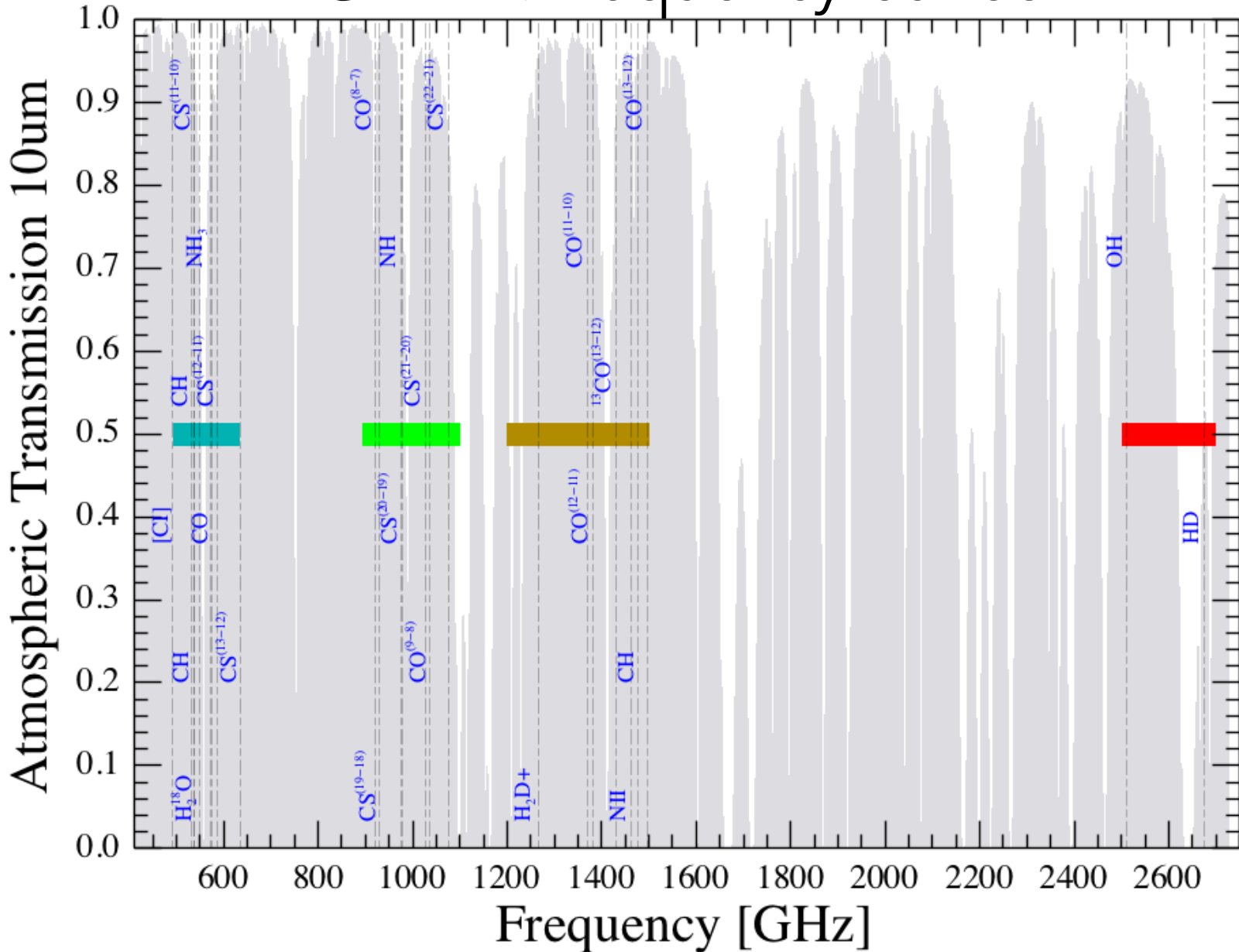
- Cryostats with detectors
 - Arrays (2) – Closed Cycle Coolers
 - Single Pixel (4) – Cryo-Liquids cooled
- Local Oscillator sources (+1 per cryostat)
 - Solid State (6)
 - QCL (1)
- Optics Plates (+1 per cryostat)
- Bias Electronics (Com. 21 channels)
- IF Processor (Com. 21ch)
- FFT Spectrometer (Com. 21ch)
- Calibration Unit
- De-rotator / Control
- References / Controllers / Supplies
- Computers



GREAT: Situation pre 4GREAT (2016)

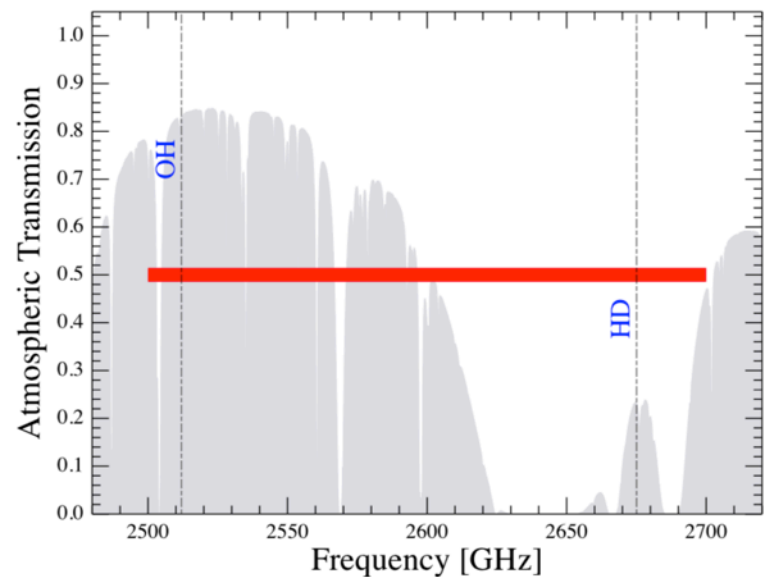
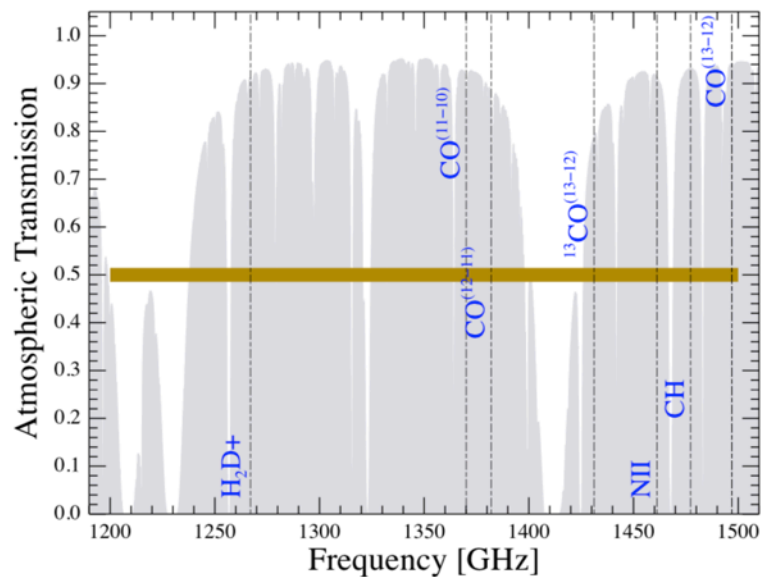
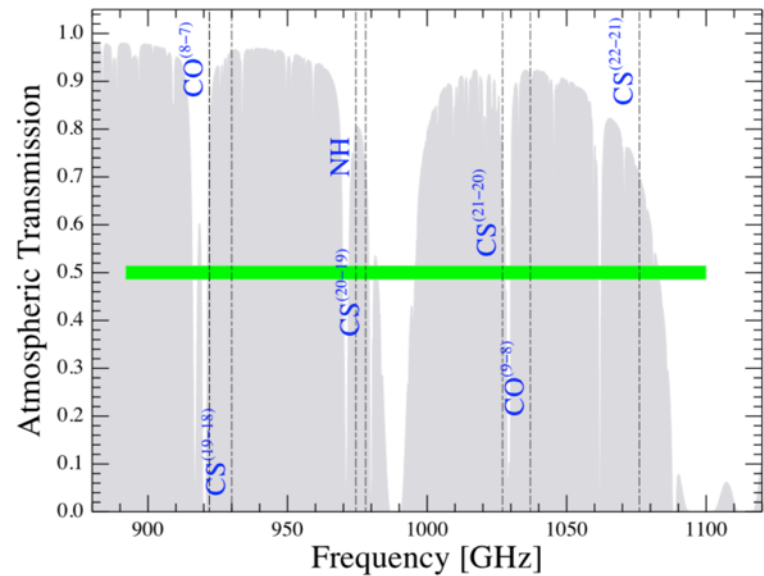
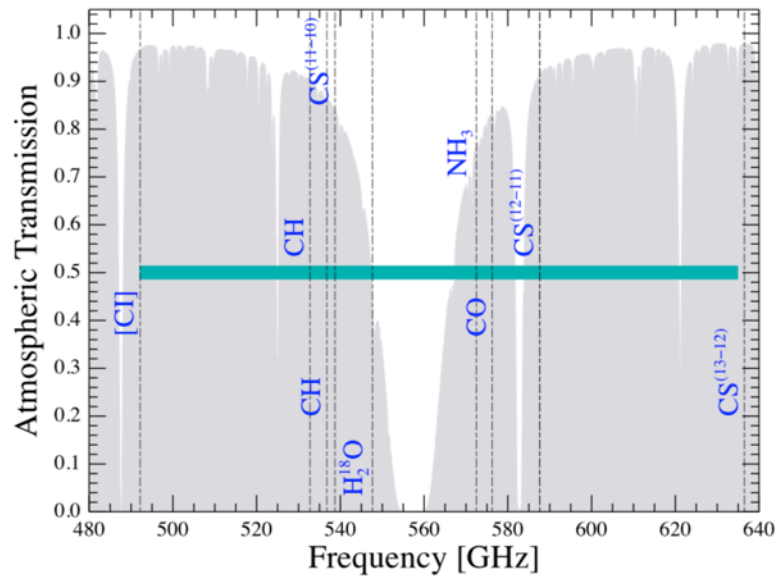


4GREAT: frequency bands

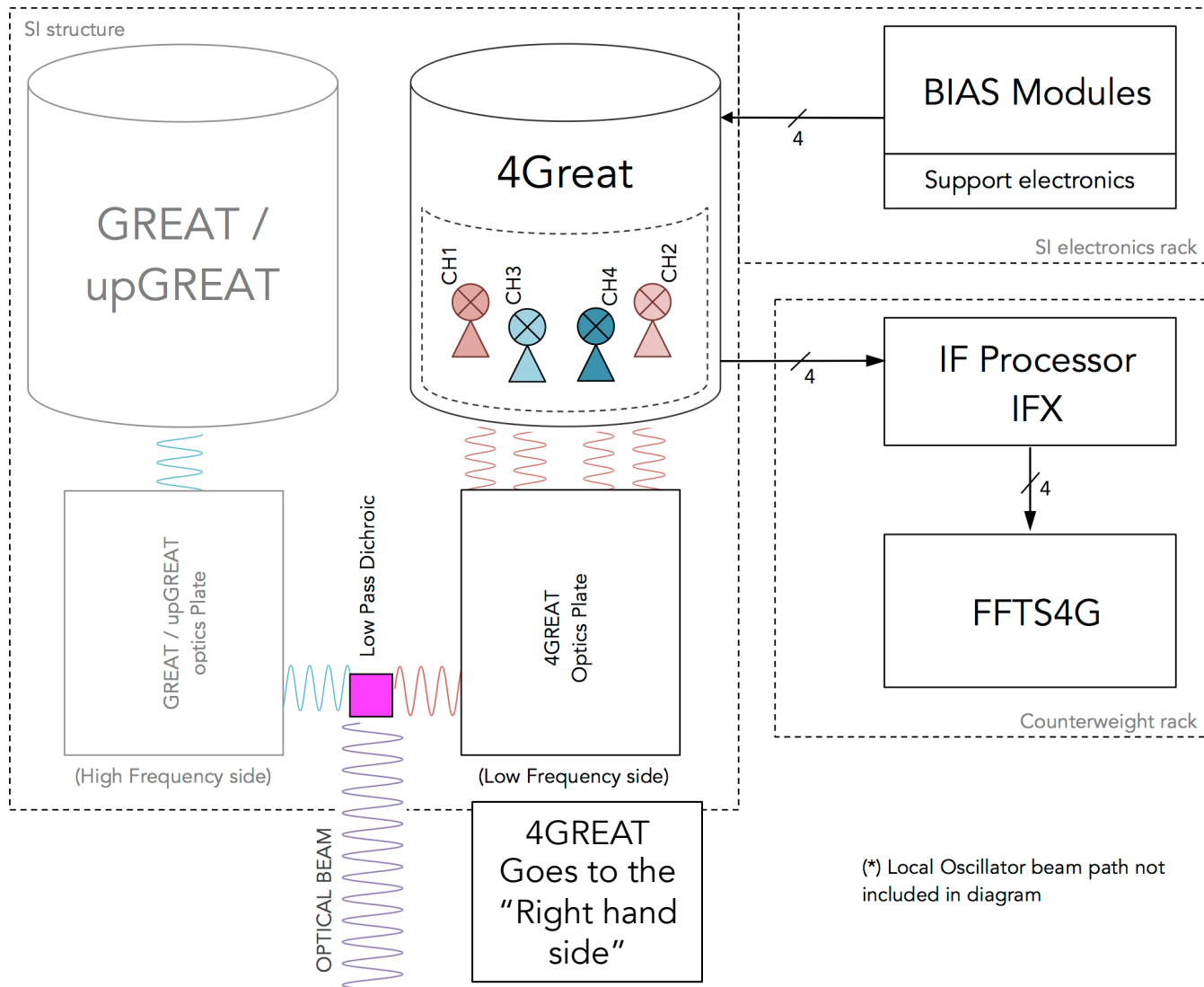


8 Atmospheric transmission for SOFIA, at 43,000 feet and a PWV of 10 um. Some of the observable lines by 4GREAT are included. The different channels are highlighted by different colors

4GREAT: frequency bands



4GREAT in a glimpse



New GREAT scenario with 4GREAT

Instrument	Cryostat	Frequencies (GHz)	Lines of Interest	IF (BW) GHz	Remark
GREAT	L2	1815 - 1910	NH ₃ ,OH,CO(16-15),[CII]	0.5 - 3.5	Backup
upGREAT	LFA	1810 - 1950	OH lines, [CII],CO series, [OI]	0.5 - 3.5	
		1830 - 2070		0.5 - 3.5	
	HFA	4745	[OI]	0.5 - 3.5	
4GREAT	4G	490-635	[CI], CH, NH ₃ , CO	4 - 8	HIFI -1 (FS) - LERMA
		890-1100	CO Series, CS	4 - 8	HIFI -4 (FS) - SRON
		1200-1500	[NII], CO series, OD,HCN,H ₂ D ⁺	0.5 - 3.5	L1 - KOSMA
		2480-2700	OH(2π3/2),HD	0.5 - 3.5	M-HD - KOSMA

Only 2 combinations (from 7)
but with more capabilities

- HFA + LFA
- HFA + 4G

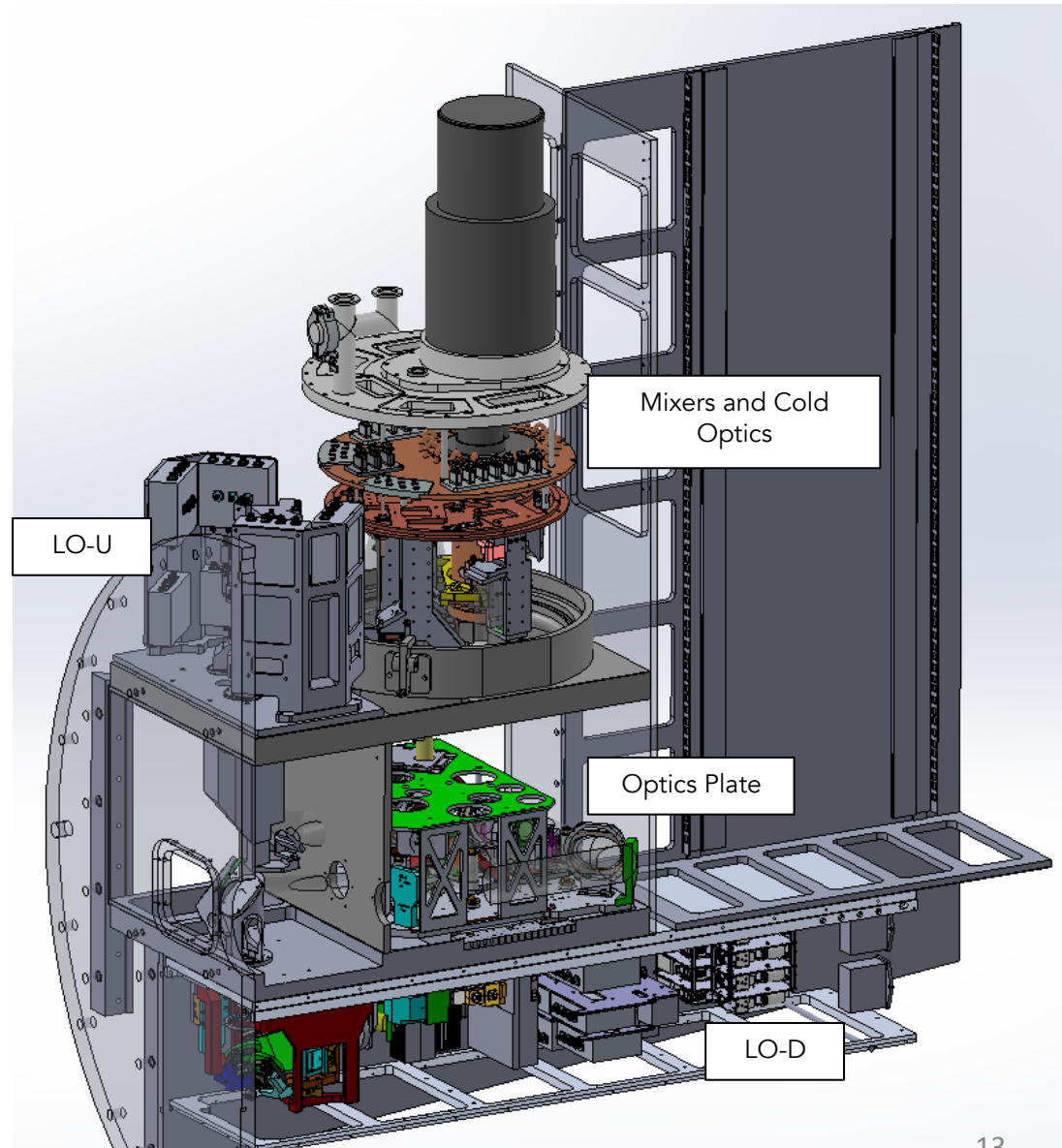
4GREAT: Design Challenges and constraints

- Optics
 - 4 Different “frequency bands” simultaneously
 - Frequency separation → **Dichroic / Grids**
 - Telescope Taper / Coupling → 14dB / 5 ω
 - Optics for Signal + Optics for Los → New LO “cavity”
 - 4G4 LO very low power → Diplexer
- Cooling
 - Mixer CH1, very temperature sensitive → Clamping the mixer horn
 - Closed cycle coolers → Two compressors (same as LFA+HFA)
- Size
 - Limited space.
 - Allocating 4 Solid state Local Oscillators → LO-U + LO-D
 - Beams and effective apertures. → 4G1, 4G2
- Weight Constraints
 - Maximum Weight – 600 Kg. (including mounting frame) → OK.
- Simultaneous Operation
 - 4 LO tunable independently at same time (parallel operation) → 4 Synthesizers / Attenuators + Bias Cards (2xSIS)

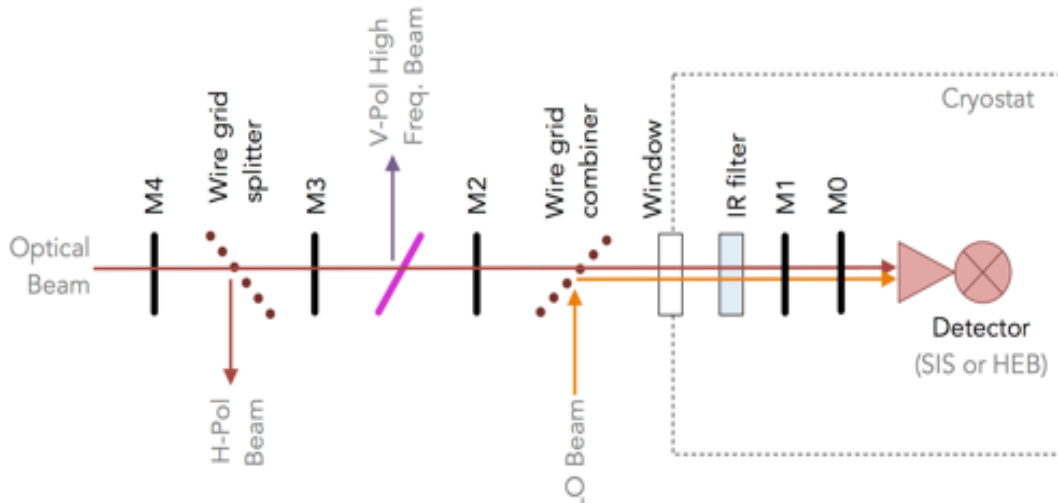
4GREAT: How does it look like?

4G "Sub Modules"

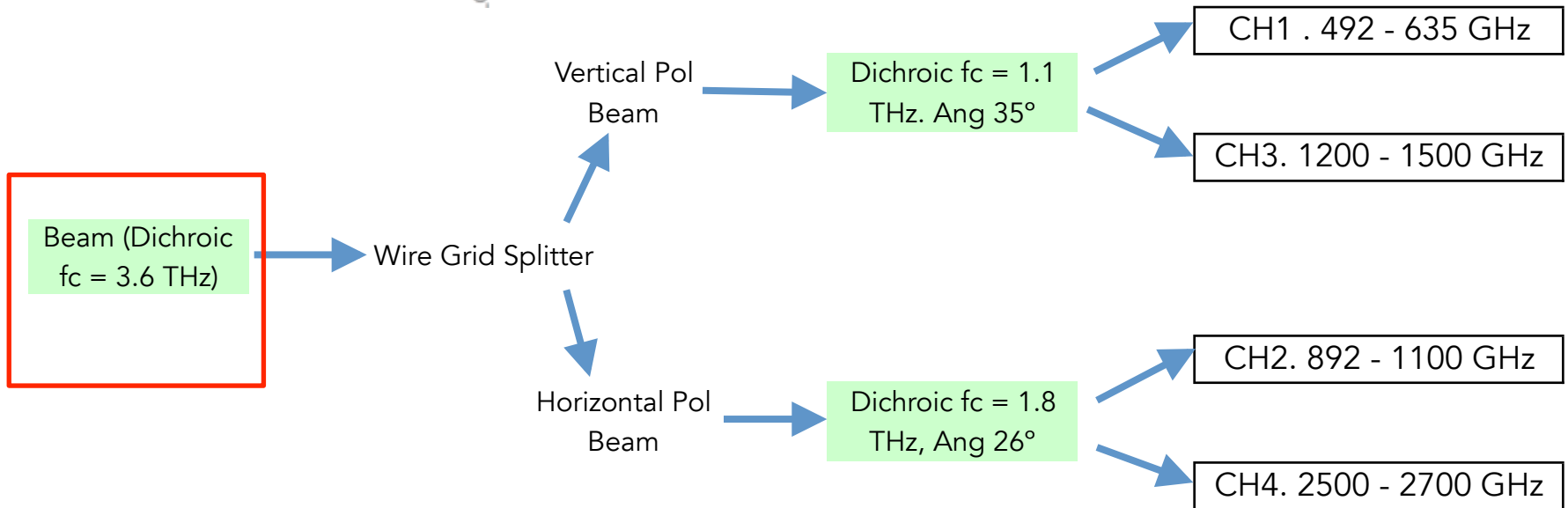
- LO-U (LO 4G-1 + 4G-2)
- LO-D (LO 4G-3 + 4G-4)
- 4G Optics Plate
- 4G Cryostat (c.c. cooler)



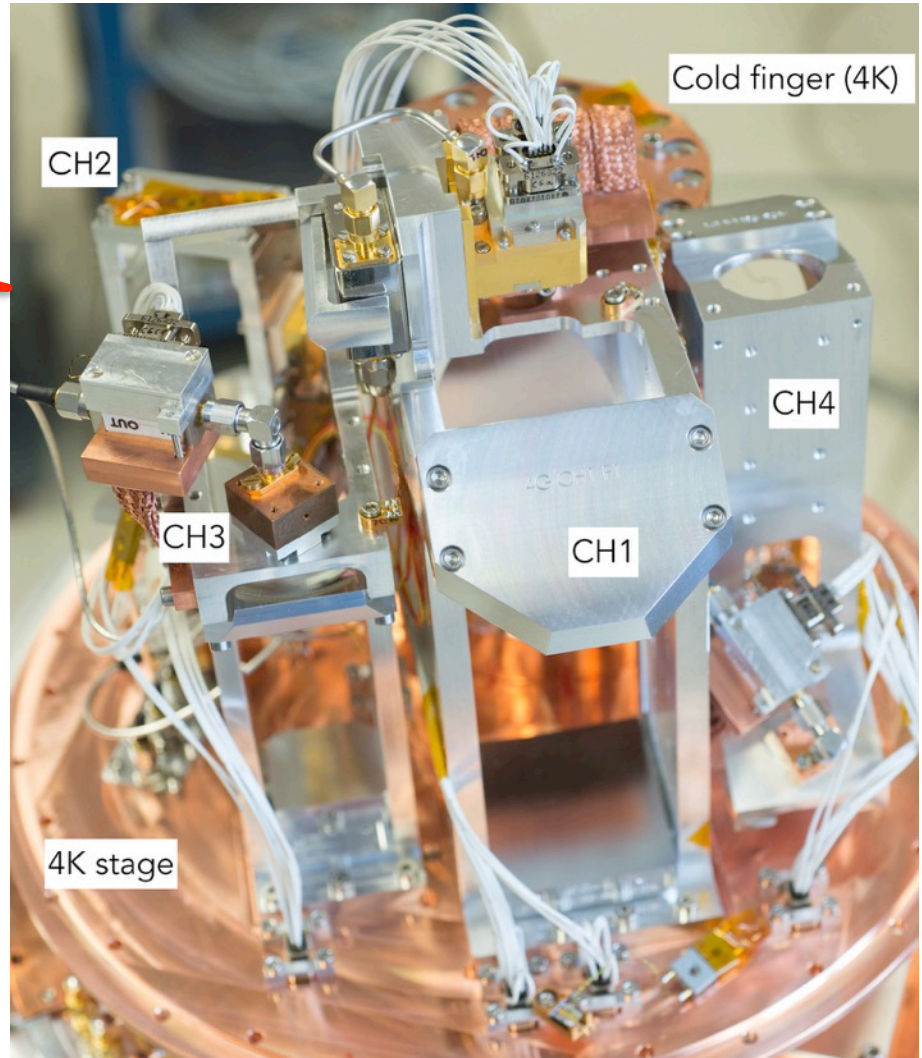
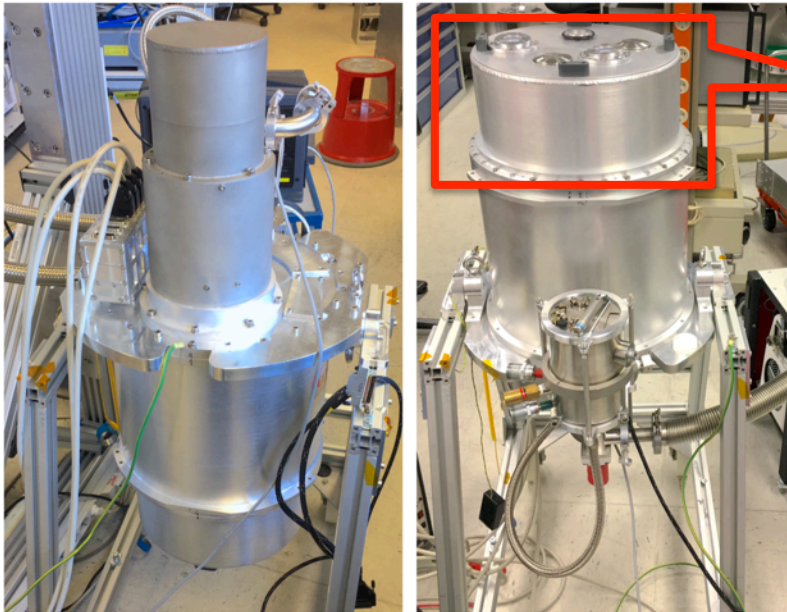
4GREAT: Optics



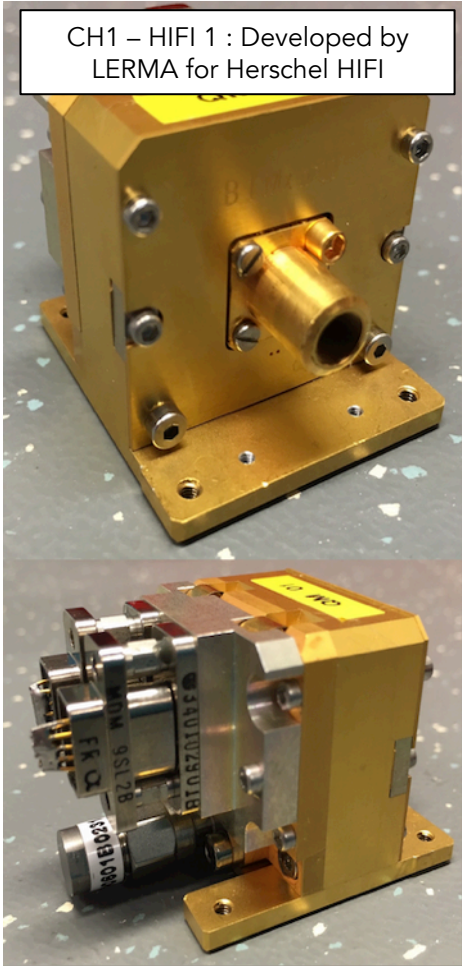
- 2 Gaussian telescopes: M4-M3 + M2-M1
- Cold Optics: M1+ F1+ M0, as a block + Mixer.
- Wiregrid (Beam splitting) – Dichroic – Wiregrid (LO Combiner)
- M4 and Wiregrid 1 common to all channels



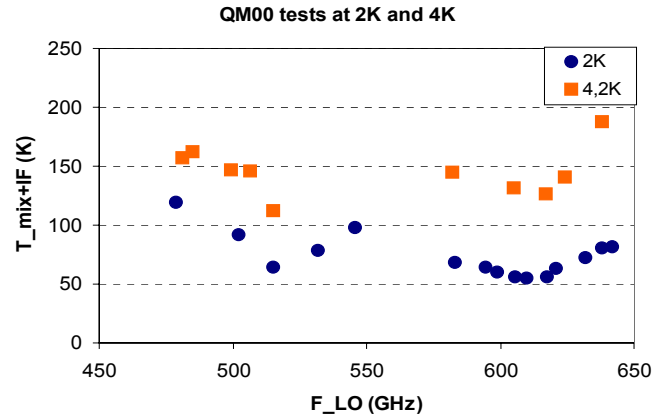
4GREAT: Cold Optics and Cryostat



4GREAT: Mixers – SIS: CH1 and CH2

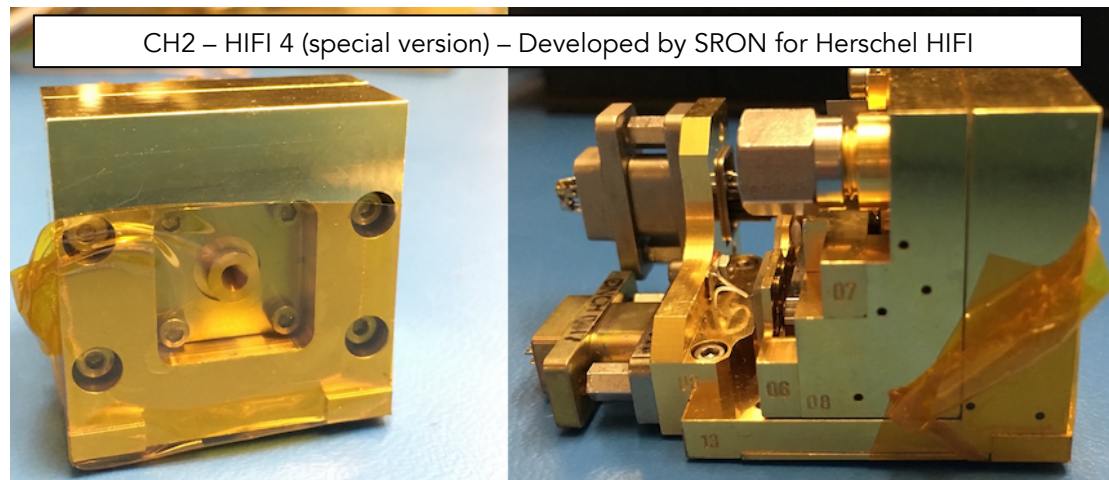


CH1 – HIFI 1 : Developed by LERMA for Herschel HIFI



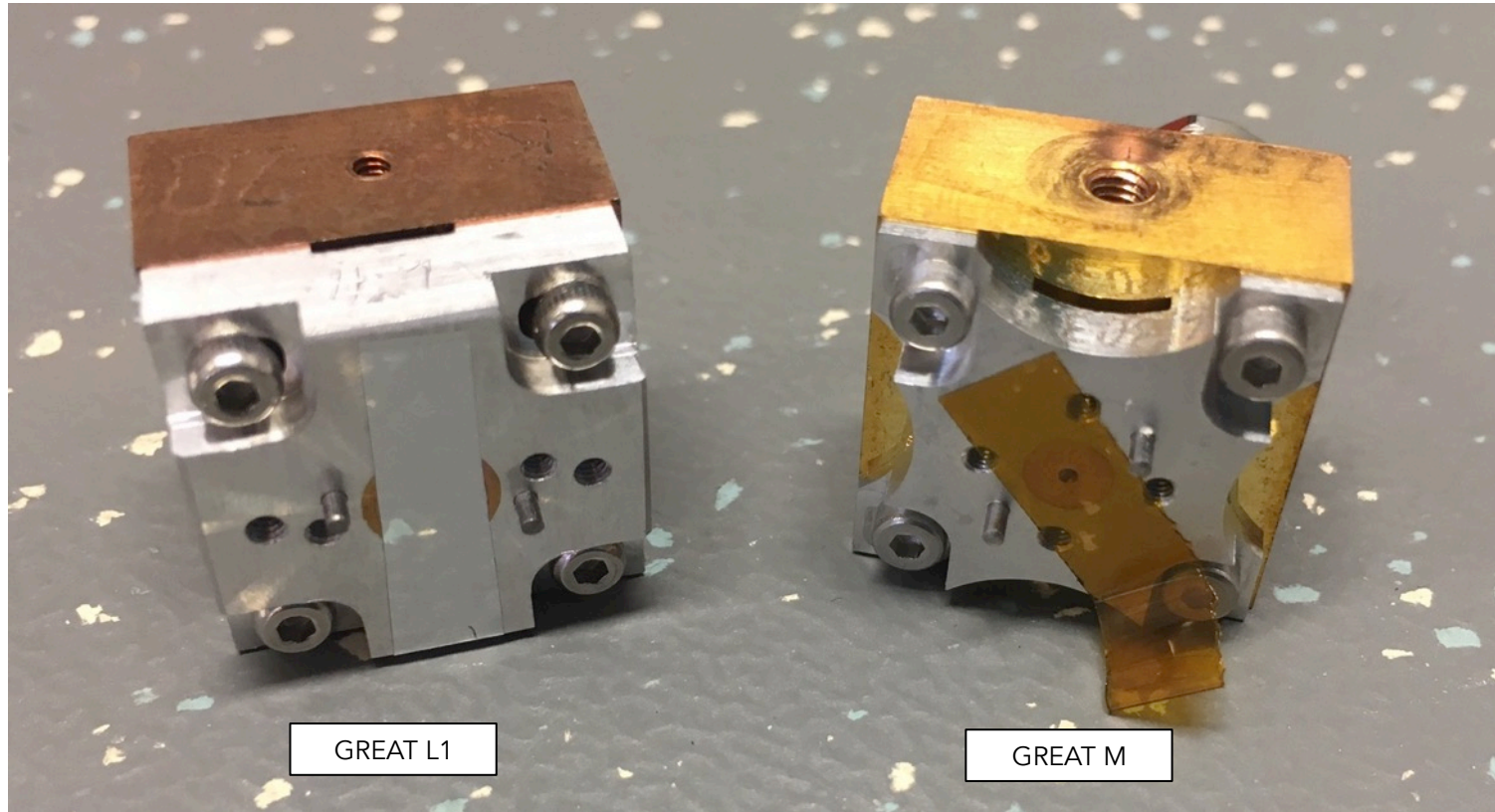
Channel 1 - Noise temperature for QM00 at 2K and 4.2K. Data provided by LERMA

Band	Technology	T-Rec (DSB)	Manufacturer	Remark
CH1	SIS	120	LERMA	HIFI-1
CH2	SIS	350	SRON	HIFI-4



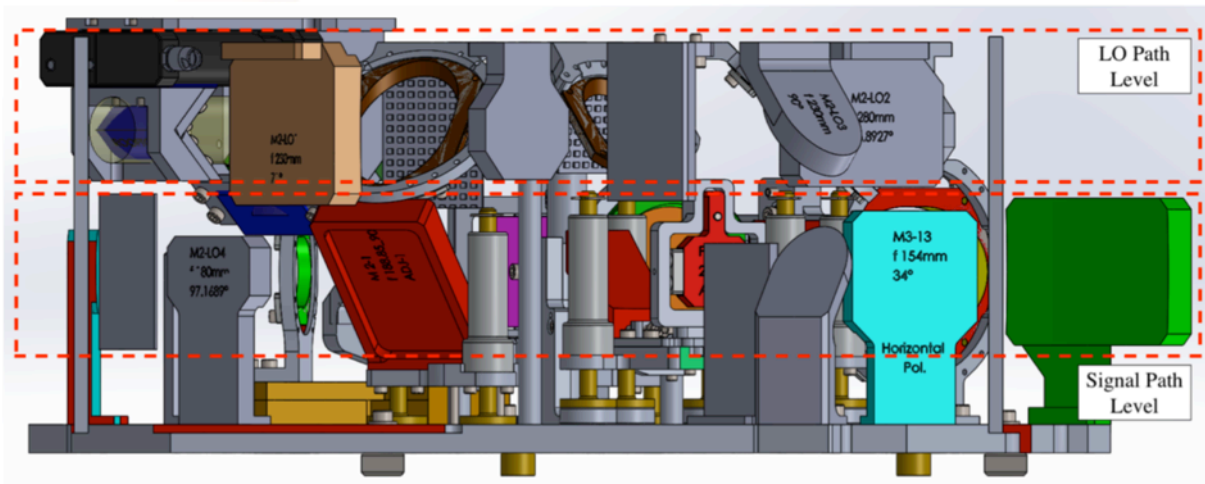
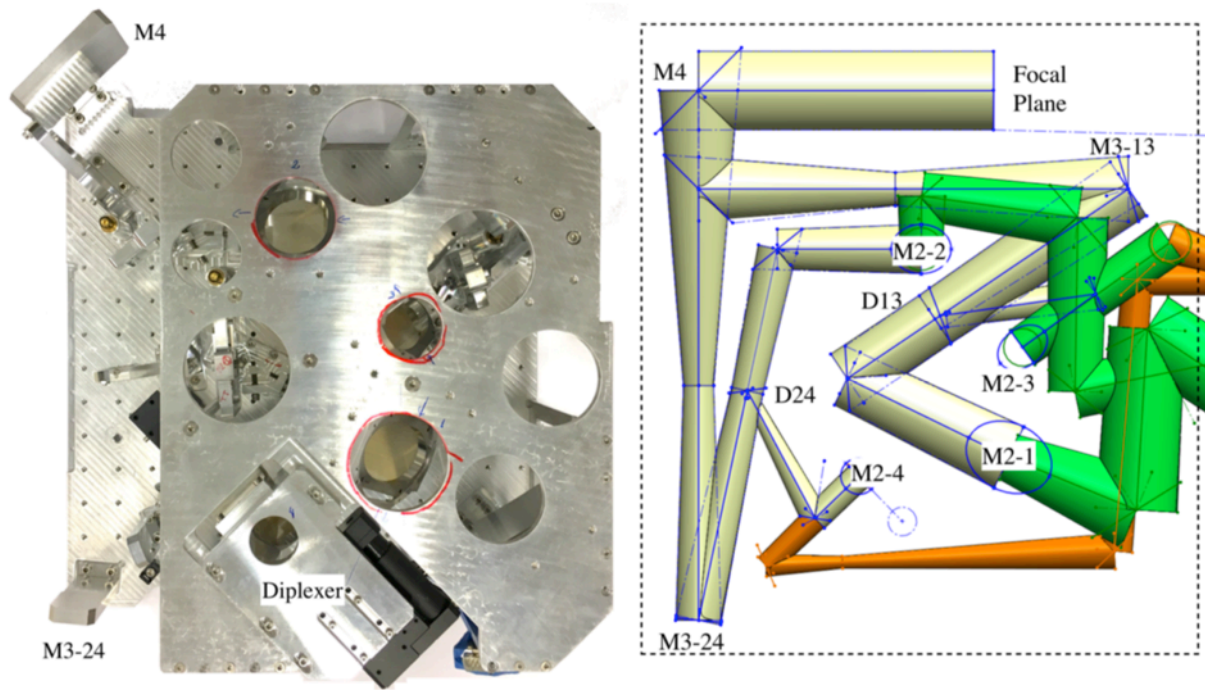
CH2 – HIFI 4 (special version) – Developed by SRON for Herschel HIFI

4GREAT: Mixers – HEB: CH3 and CH4

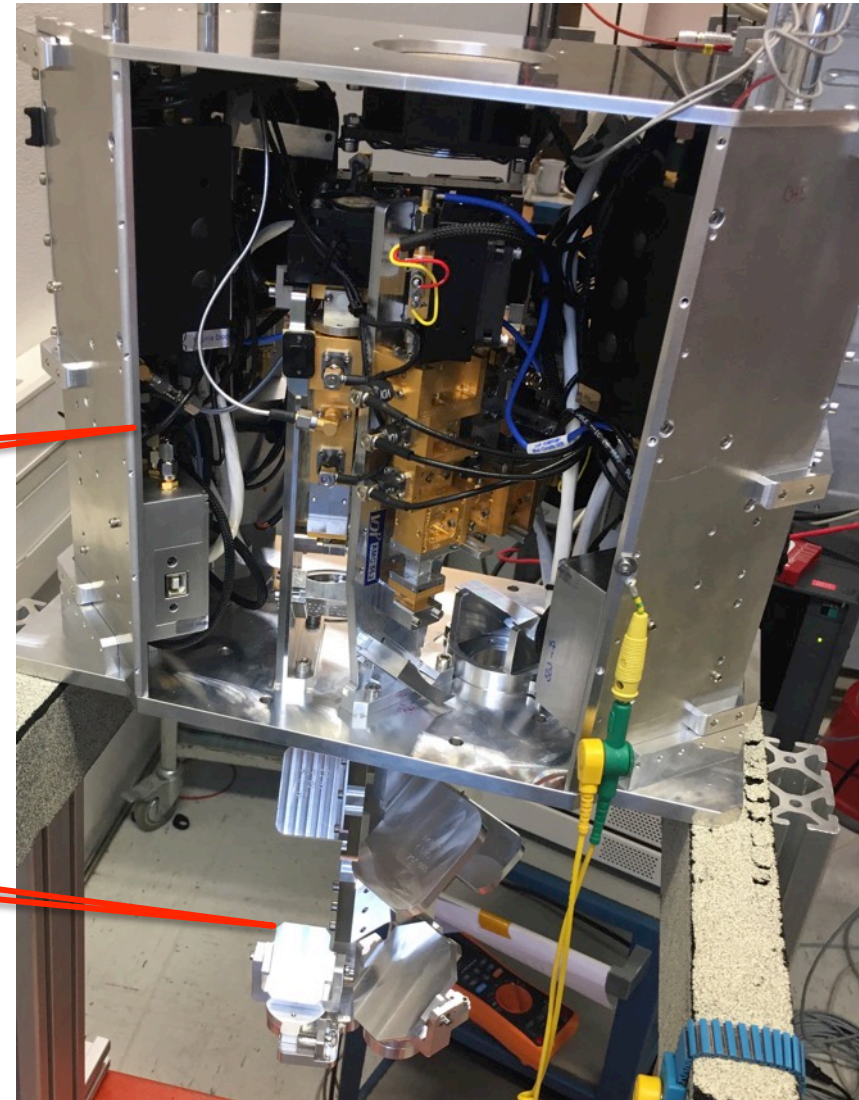
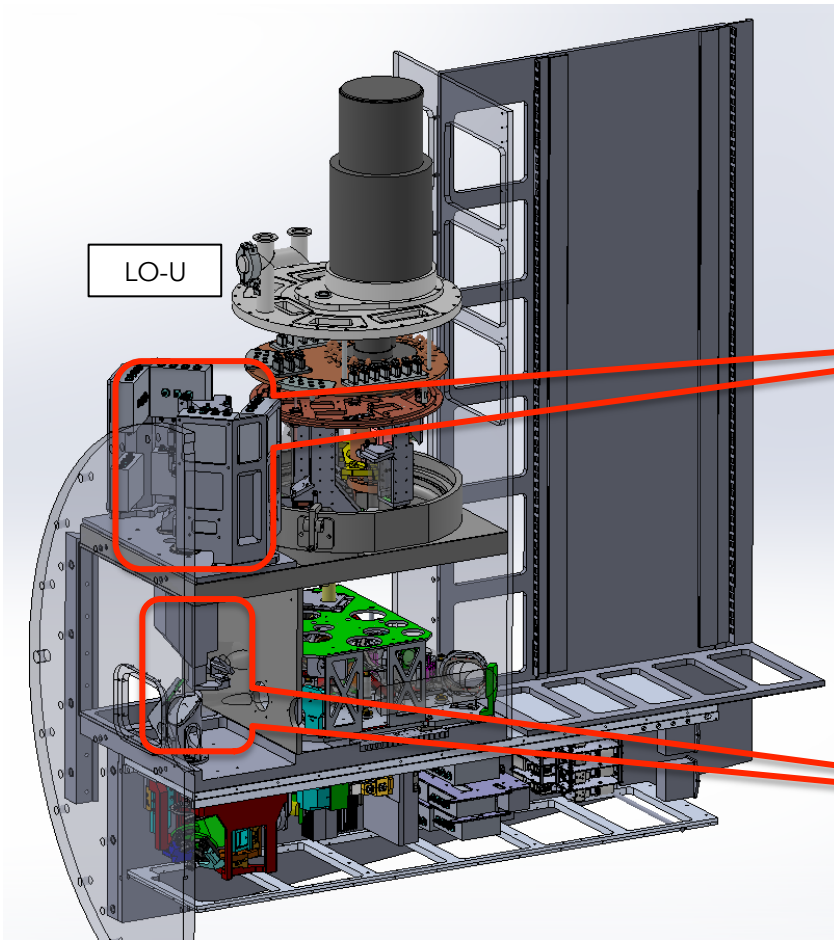


Band	Technology	T-Rec (DSB)	Manufacturer	Remark
CH3	HEB (NbTiN)	1100	KOSMA	GREAT L1
CH4	HEB (NbN)	1700	KOSMA	GREAT M-HD

4GREAT: Optics Plate

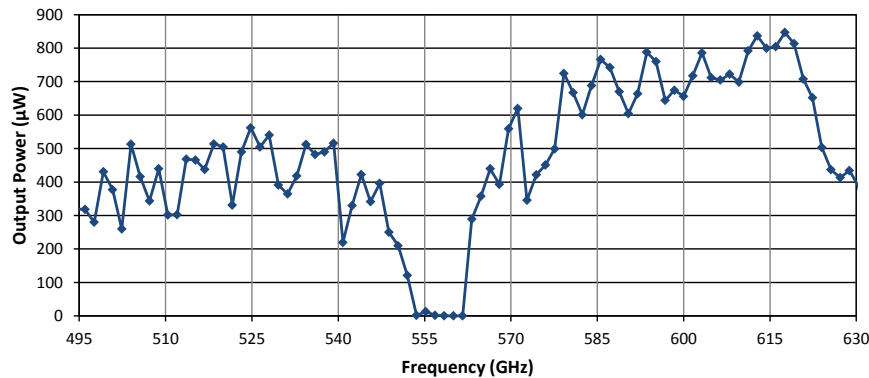


4GREAT Local Oscillator : LOU



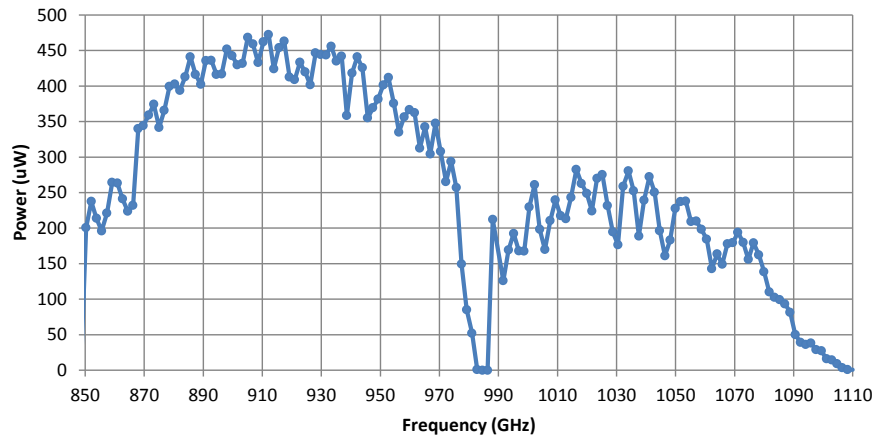
4GREAT Local Oscillator : LOU

AMC 563 Performance

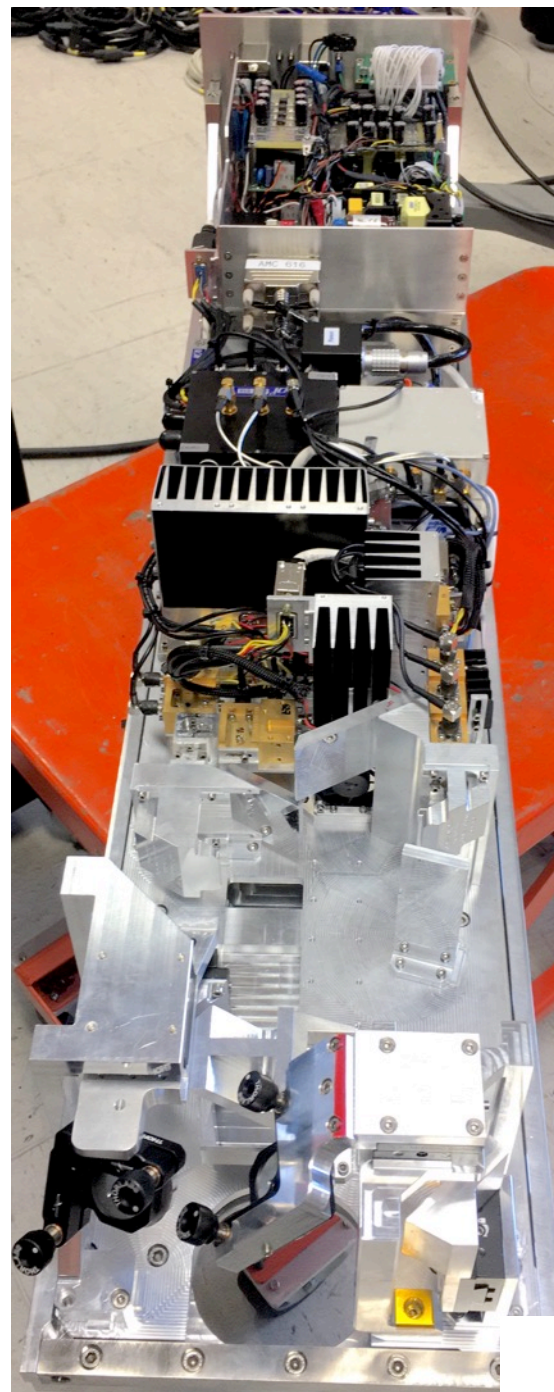
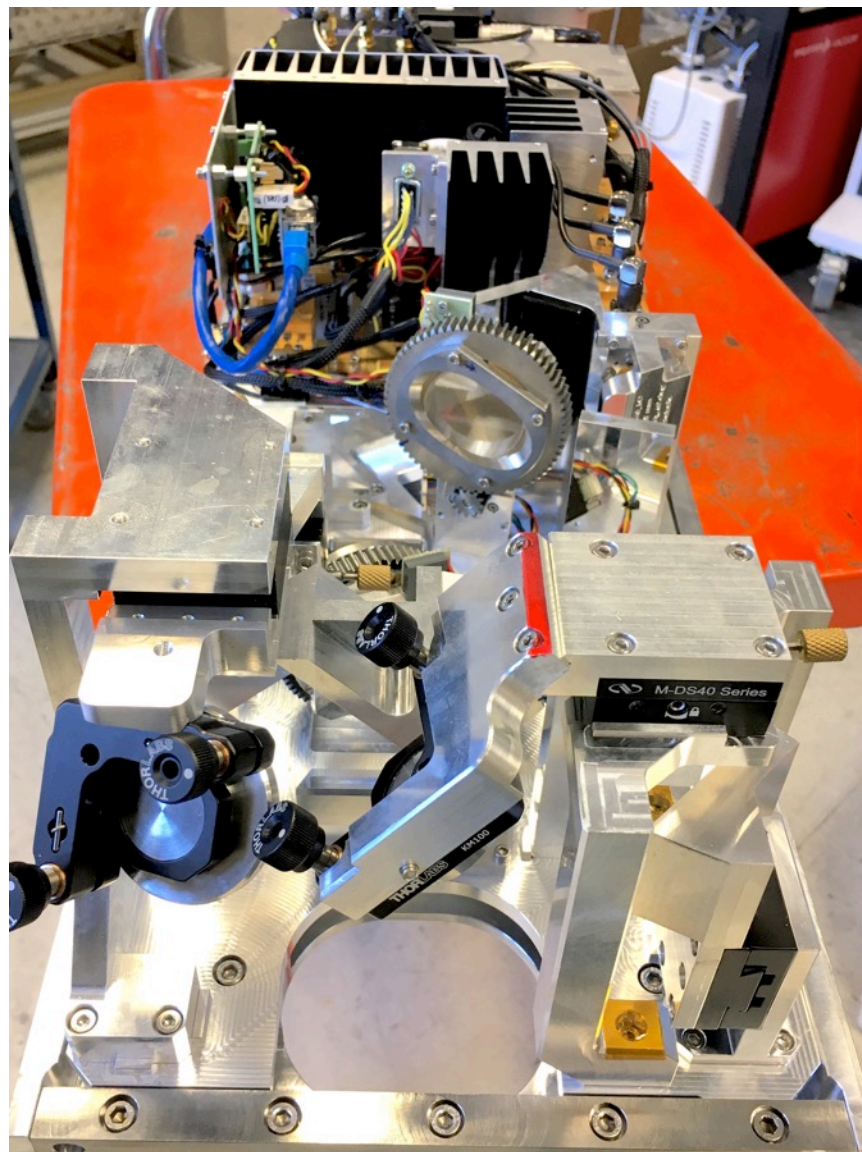


- Located on the 2nd CALUNIT position.
- Optics for LO signal coupling
 - CH1: Parabolic Mirror + 2 Gaussian Telescopes
 - CH2: Parabolic Mirror + 2 Gaussian Telescopes
- 2 independent Solid State LO chains (Virginia Diodes)
 - CH1. AMC563 – [495 to 628 GHz] @ 200 uW.
 - CH2. AMC581 – [890 to 1085 GHz] @ 150 uW.

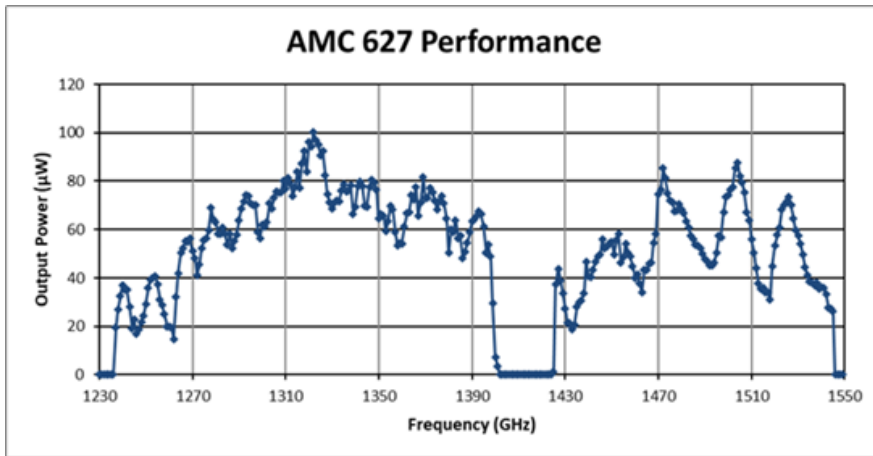
AMC 581 Output Power Versus Frequency



4GREAT Local Oscillator : LOD

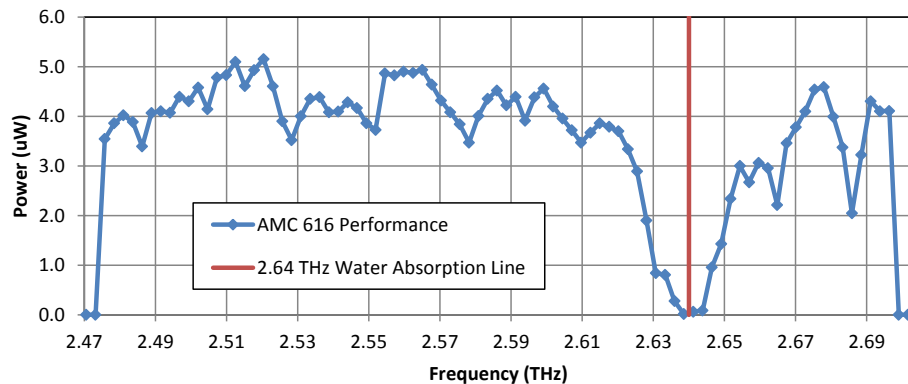


4GREAT: Local Oscillator II (LOD)



- Optics for LO signal coupling
 - CH3: 1 Parabolic. + 1 GT + 1 Active mirror
 - CH4: Parabolic Mirror + 2 Gaussian Telescopes
- 2 independent Solid State LO chains (Virginia Diodes)
 - CH3. AMC627 – [1240 to 1525 GHz] @ 30 µW *
 - CH4. AMC616 – [2490 to 2685 GHz] @ 2.5 µW.

VDI AMC 616



- Power supplies for 4 x LO chains
 - CH3, CH4 – same compartment
 - CH1, CH2 – LOU

GREAT: Modules and Sub-modules with 4G

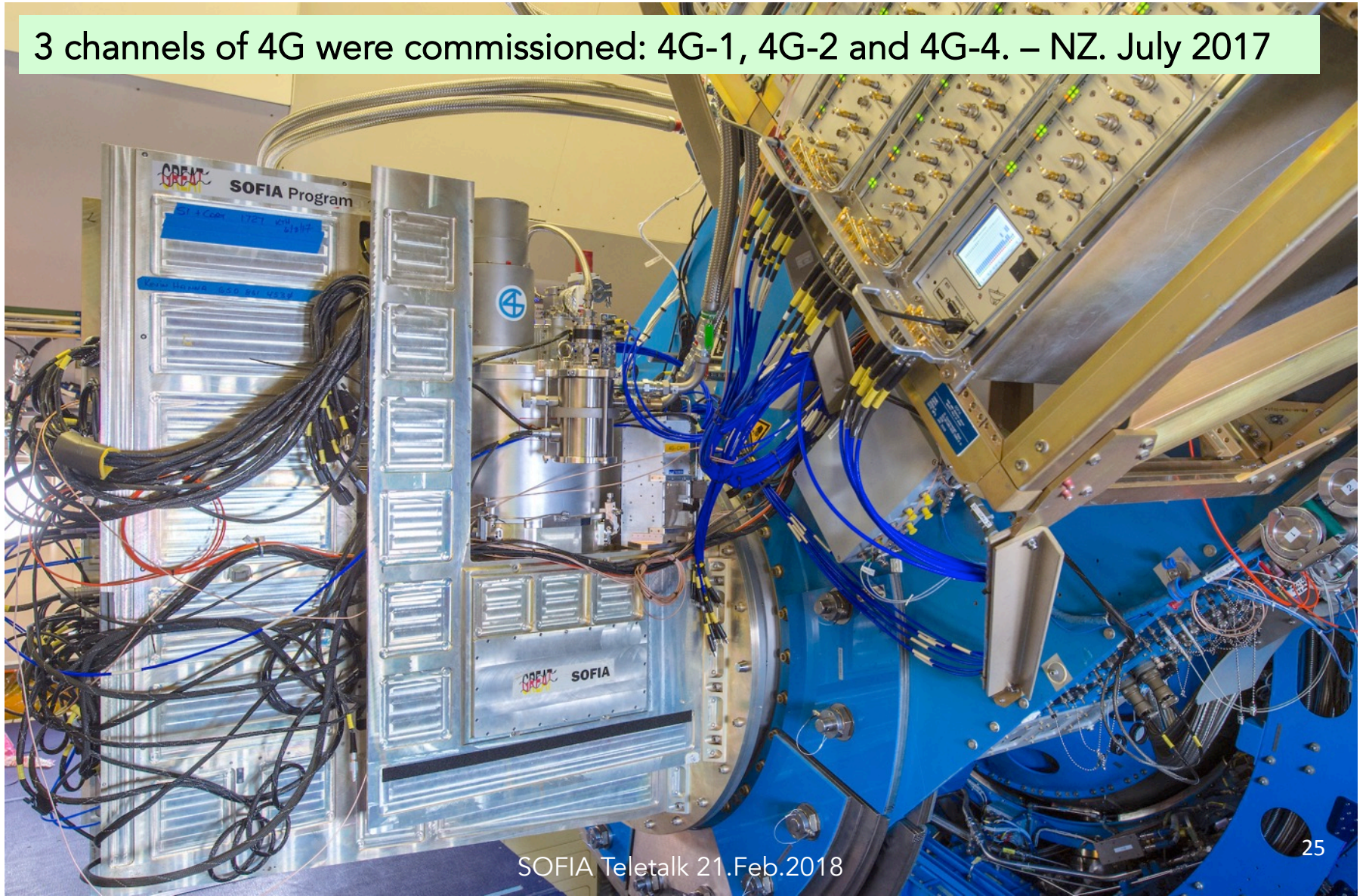
- Cryostats with detectors (All Closed cycle)
 - upGREAT LFA (7+7 pixels) and upGREAT HFA (7 pixels)
 - 4GREAT (1+1+1+1 pixels)
- Local Oscillator sources
 - Solid State: LFA (1+1), 4G-LOU(1+1), 4G-LOD(1+1)
 - QCL: HFA
- Optics Plates (1 per cryostat)
- Bias Electronics (Common : 21channels)
- IF Processor (Common: 21 + 3 channels)
- FFT Spectrometer (Common: 22 + 3 channels)
- Calibration Unit
- De-rotator / Control
- References / Controllers / Supplies
- Computers

4GREAT : General Specs - Summary

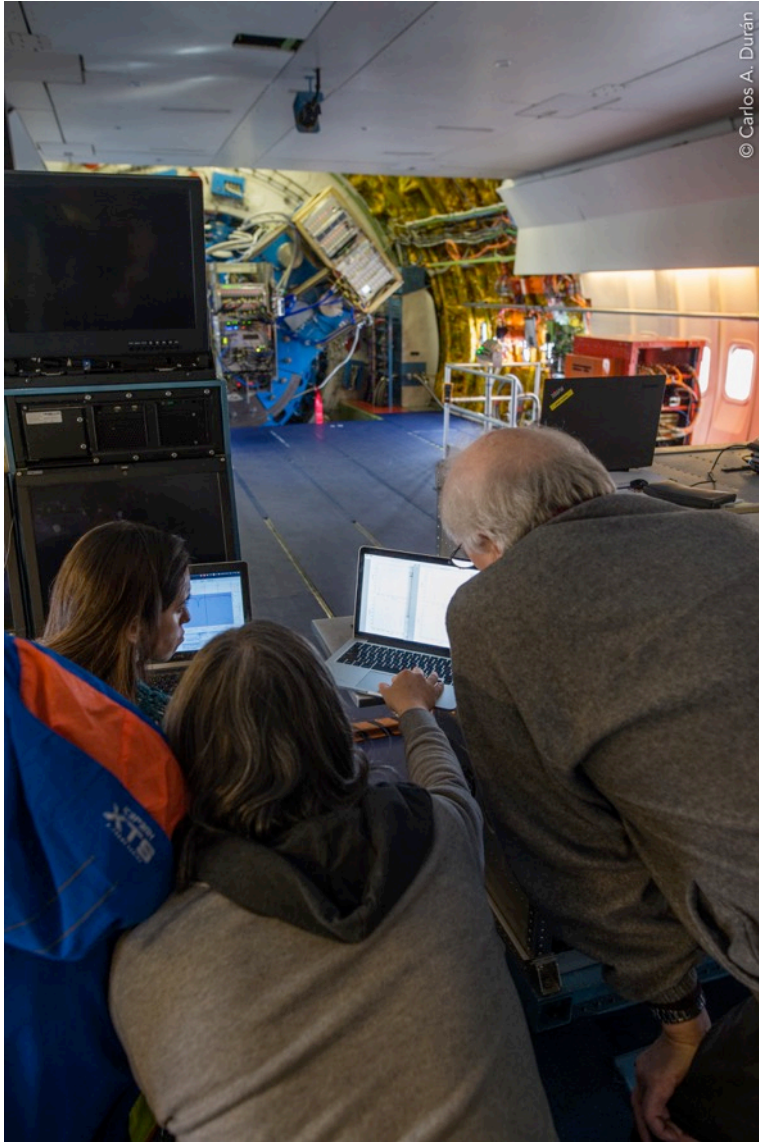
Channel	CH1	CH2	CH3	CH4
RF Bandwidth [GHz]	492 - 630	892 - 1100	1200-1500	2490 - 2700
IF Bandwidth [GHz]	4 - 8	4 - 8	0.5 - 3.5	0.5 - 3.5
Mixer	SIS	SIS	HEB	HEB
	Herschel HIFI - 1 (LERMA)	Herschel HIFI - 4 (SRON)	GREAT -L1 (KOSMA)	GREAT - M-HD (KOSMA)
Amplifiers (LNA / Warm Amp)	LNF-LNC4_8C (LNF)	LNF-LNC4_8C (LNF)	CITLF4 (CMT)	CITLF4 (CMT)
	AFS3-00100800 (Miteq)	AFS3-00100800 (Miteq)	AFS3-00100800 (Miteq)	AFS3-00100800 (Miteq)
Local Oscillator	S.S.Chain AMC563@LO-U (200uW)	S.S. Chain AMC581@LO-U (150uW)	S.S. Chain AMC627@LO-D (30uW)	S.S. Chain AMC616@LO-D (2.5 uW)
LO Coupling	Wiregrid Splitter	Wiregrid Splitter	Wiregrid Splitter	Diplexer
Optics	Common optic plate + Mixer block optics + LOU Optics	Common optic plate + Mixer block optics + LOU Optics	Common optic plate + Mixer block optics + LOD Optics	Common optic plate + Mixer block optics + LOD Optics
TRec (DSB)	120	350	1100	1700
IF Processor	IFX x 1. High Order BPF 4-8 GHz	IFX x 1. High Order BPF 4-8 GHz	IFX x 1. High Order BPF 0-4 GHz	IFX x 1. High Order BPF 0-4 GHz
Backend	FFTS4G. Nyquist Band 4-8	FFTS4G. Nyquist Band 4-8	dFFTS4G x 1ch	dFFTS4G x 1ch
Taper (dB)	11.86 - 16.54	12.25 - 16.09	13.29 - 14.78	14.35 - 13.68

4GREAT: status.

3 channels of 4G were commissioned: 4G-1, 4G-2 and 4G-4. – NZ. July 2017



Preparation for first light (and every flight)



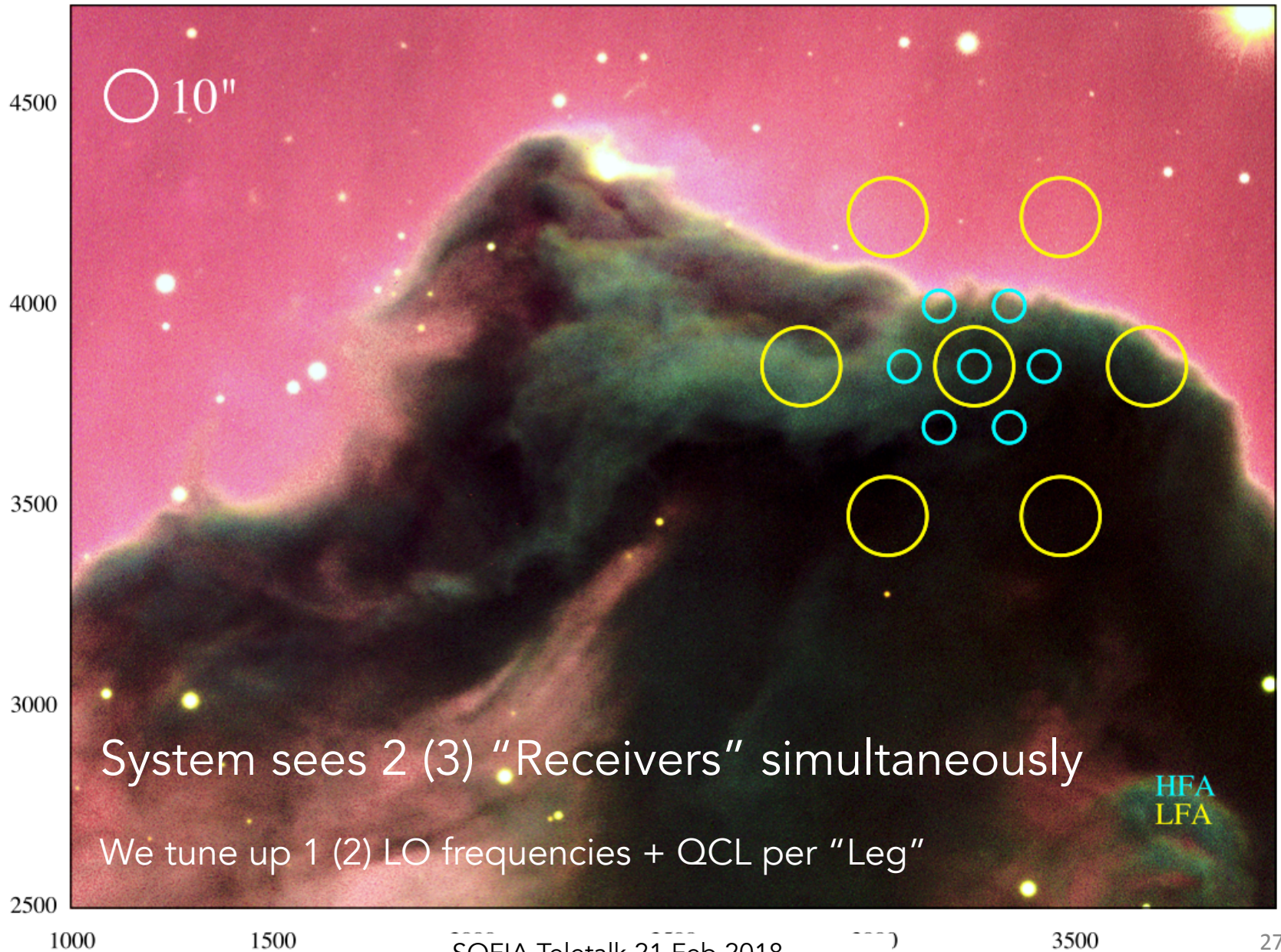
Determination of optimum operational point for each requested frequency / project.

- Avoid telluric line and atmosphere features (IF, Sideband)
- LO Tuning / Mixers Biasing / Subsystems optimization.
- Best Trec.
- Performed for every "channel"

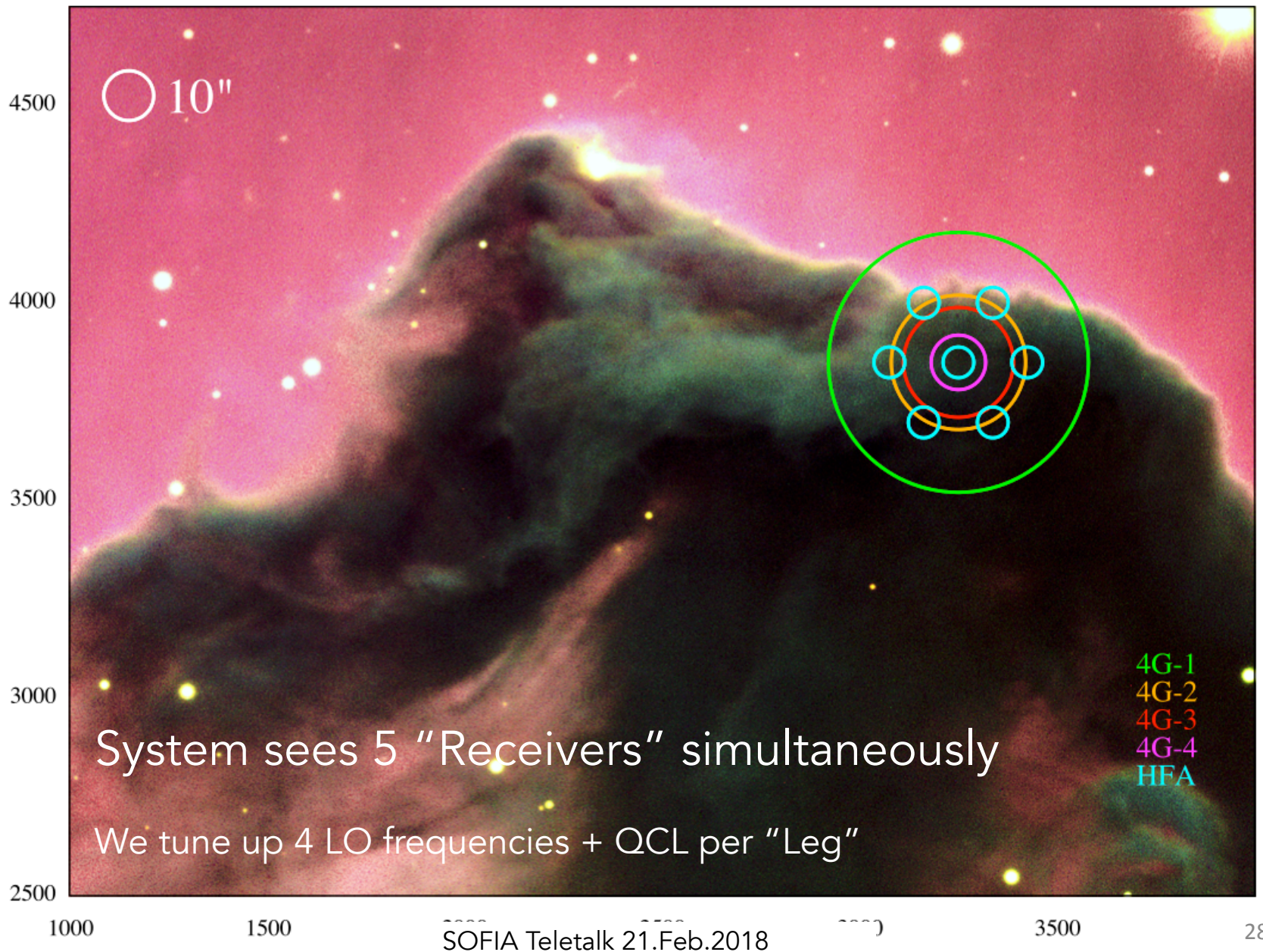
Hardware and Software Maintenance.

- Pumping / Cryo-service (If L2 installed)
- Check for health of every channel (before flight)

GREAT pixel mapping: HFA + LFA



GREAT pixel mapping: HFA+4G



Some of the science with GREAT (HFA, LFA, 4G)

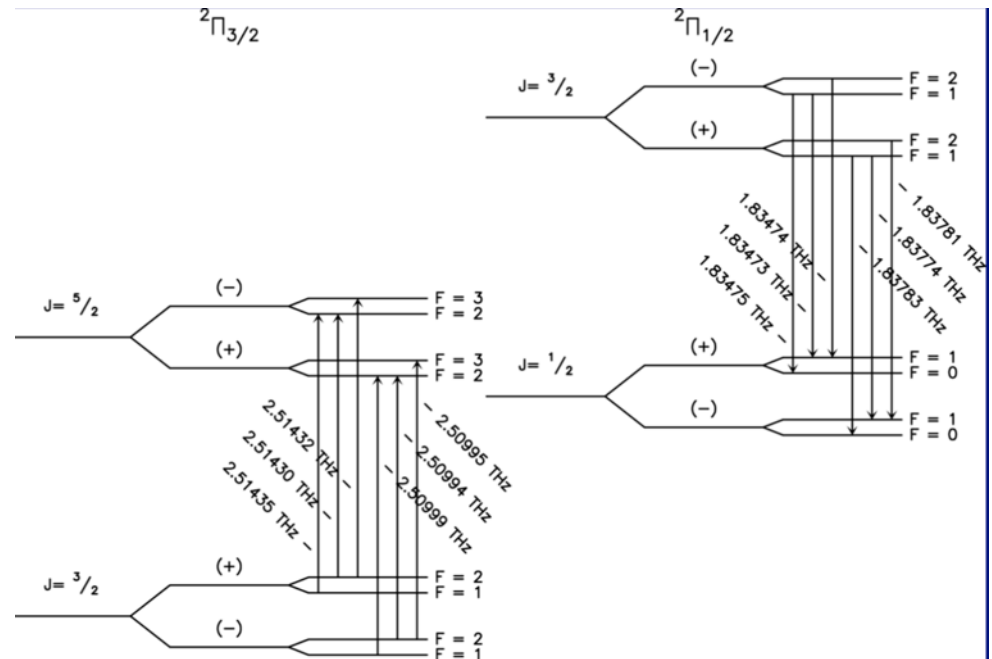
Channel	Detector	Frequency -Goal [GHz]	Lines of Interest
4G-1	HIFI Band 1	492 - 635	[CI], CH, NH ₃ , CO ⁵⁻⁴
4G-2	HIFI Band 4	892 - 1100	CO ⁸⁻⁷ , CO ⁹⁻⁸ , CS ¹⁹⁻¹⁸
4G-3	GREAT L1	1200 - 1500	NH, NII, CO ¹¹⁻¹⁰ , ¹³ CO ¹³⁻¹² , H ₂ D+
4G-4	GREAT M-HD	2500 - 2700	OH, HD

Chemistry of the ISM → Phases. [CII]
(LFA)

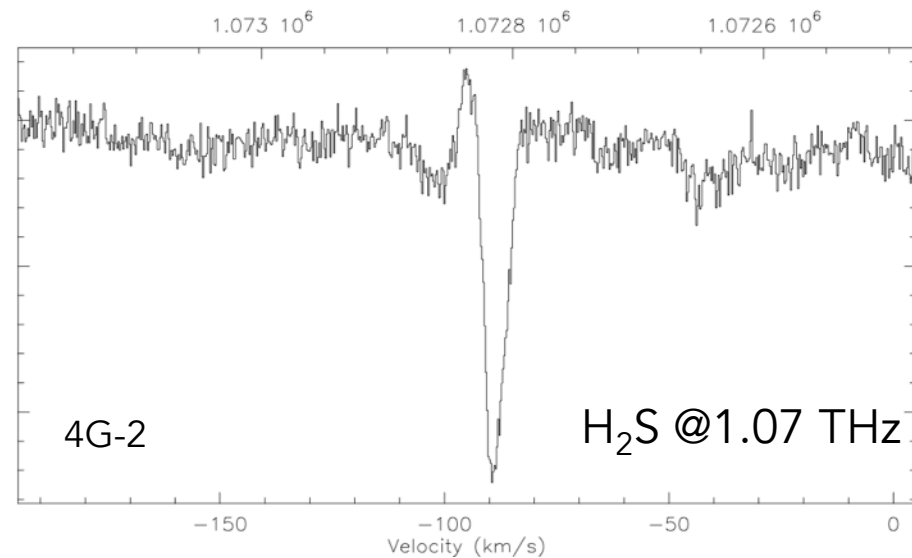
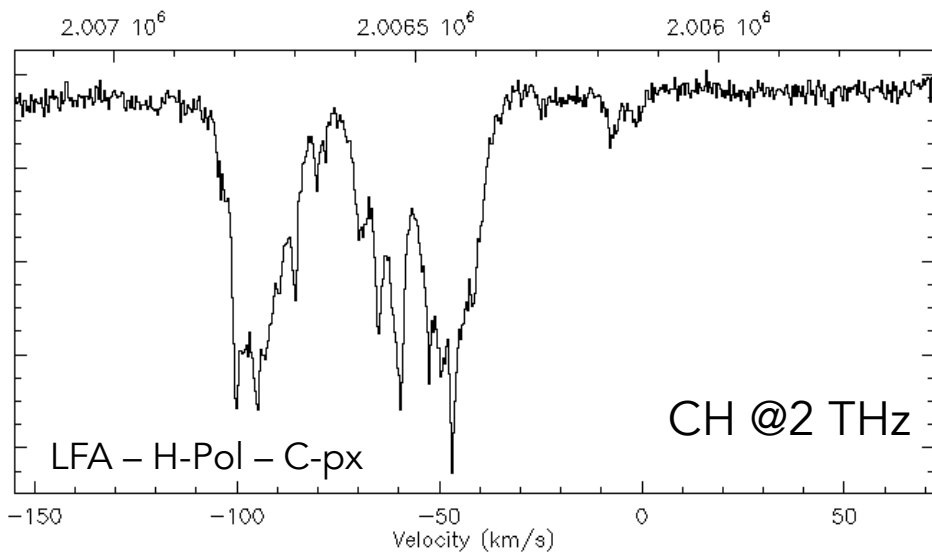
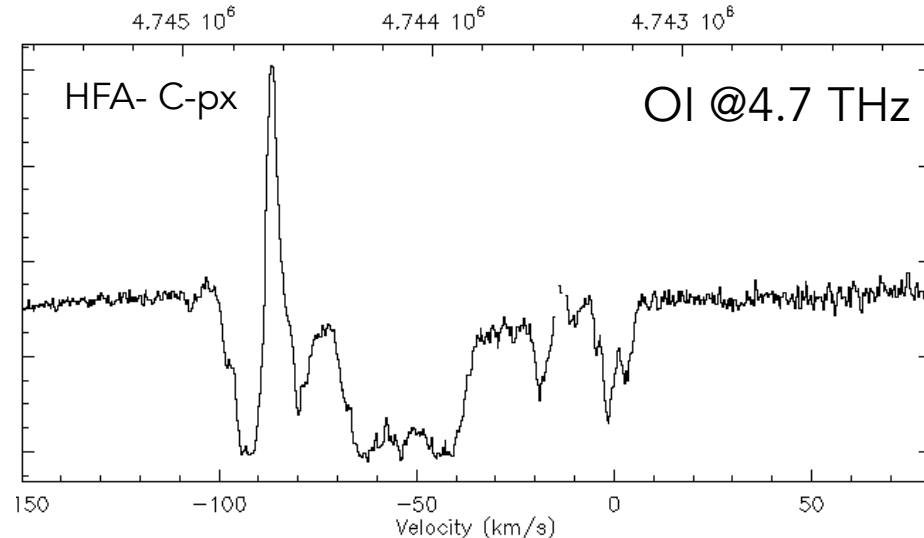
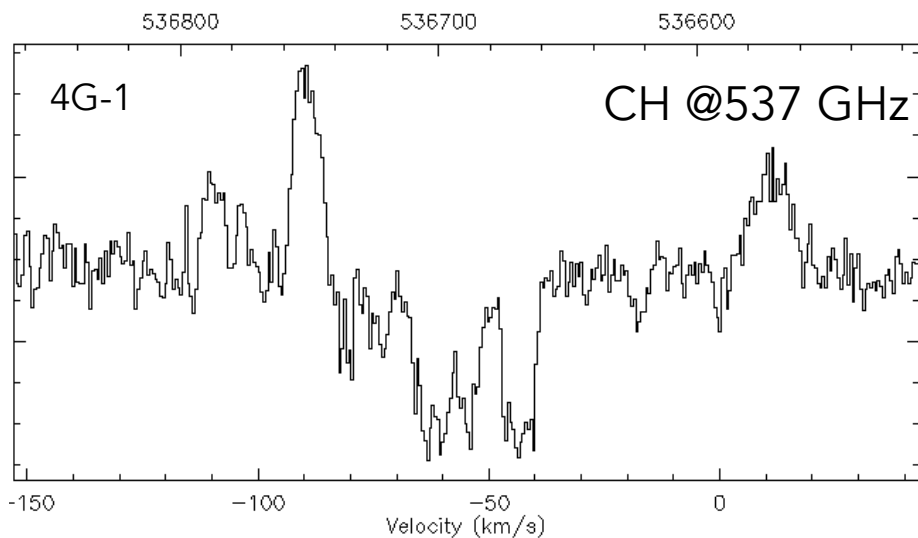
Ground state transitions of light hydrides : OH, HF, HD, CH → Profile abundances of H₂. (LFA, HFA)

Oxygen tracing OI (HFA)

High J lines of CO. → Turbulent Dissipation Regions, shock layers, etc. (LFA, 4G)



Same source with 4G-1, 4G-2, LFA, HFA \rightarrow H₂



GREAT 2018+ : Summary

- 4G to be fully operational by June 2018
- “Only 2” closed cycle cryostat combinations
 - HFA + LFA
 - HFA + 4G
- More capabilities per flight.
 - HFA: Array (7) at 4.7 THz
 - LFA: Dual Array (7+7) at 2 THz
 - 4G: Single Pixel 500 GHz, 1THz, 1.4THz, 2.7THz

upGREAT LFA	1.81 – 2.07 THz (14 pixels)	OH lines, [CII],CO series, [OI]
upGREAT HFA	4.7 THz (7 pixels)	[OI]
4GREAT	490-635 GHz	[CI], CH, NH ₃ , CO
	892-1100 GHz	CO Series, CS
	1200-1500 GHz	[NII], CO series, OD,HCN,H ₂ D ⁺
	2490-2700 GHz	OH(2 π 3/2),HD

GREAT with 4G back on
SOFIA for May / June 2018 flight series.

THANKS