MPIfR sub-millimeter heterodyne arrays

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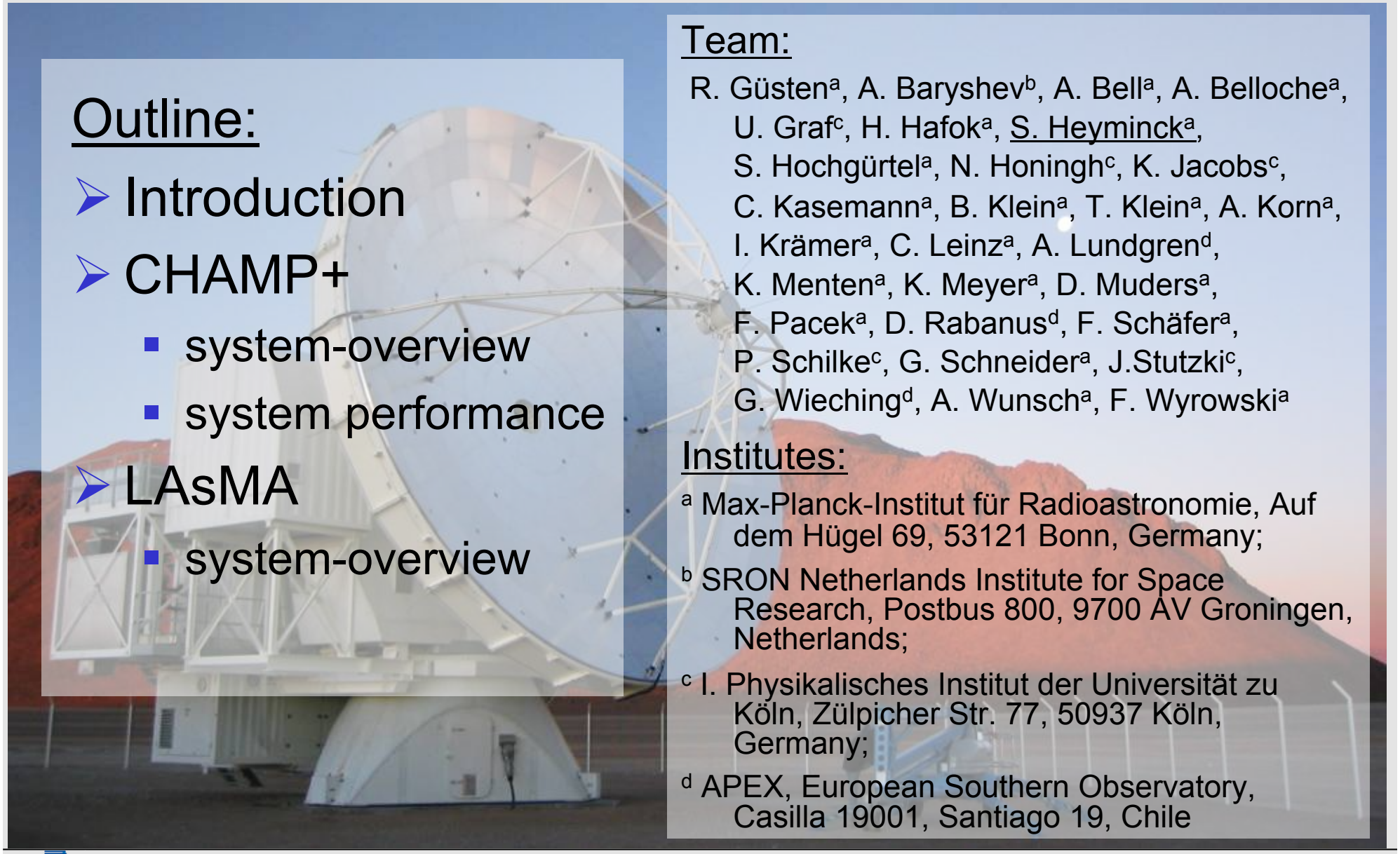

Outline:

- Introduction
- CHAMP+
  - system-overview
  - system performance
- LAsMA
  - system-overview

Team:

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Why heterodyne Arrays ?

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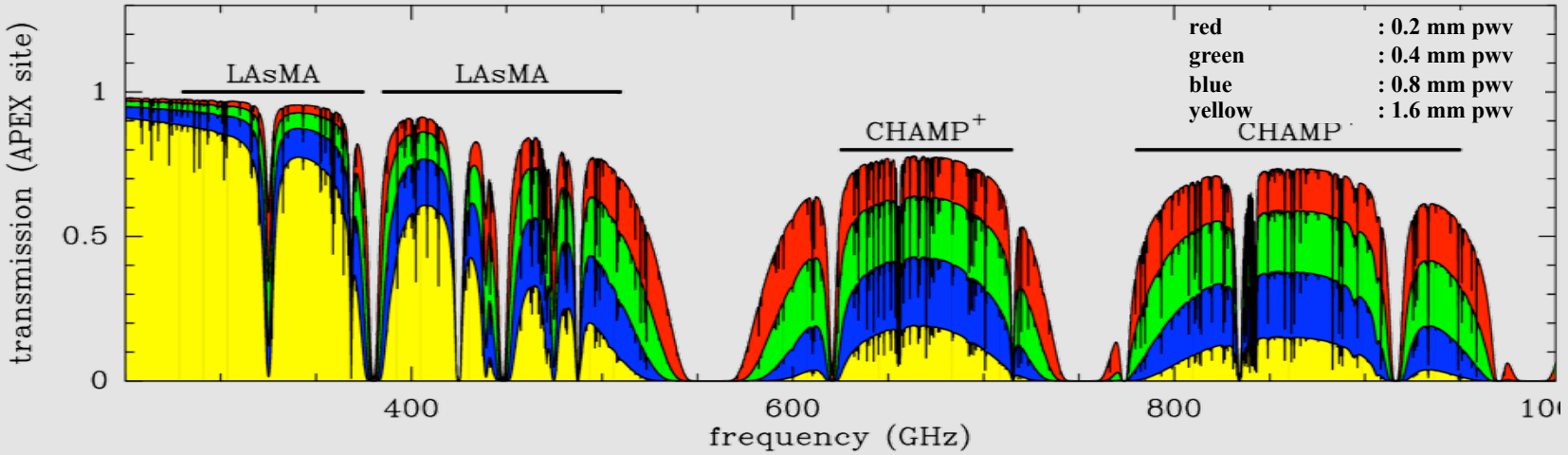
- enhance the productivity of the telescope facility



Atmospheric sub-millimeter windows are wide open from exceptional good sites like Chajnantor / Chile:

excluding the Bolivian winter (mid of January to end of March)

- 50% of the time < 1.0 mm pwv
- 25% of the time < 0.6 mm pwv

prime weather conditions < 0.3 mm pwv

➔ ***but still time of excellent weather is very limited***

- but performance of each pixel must be close to the one of an optimized singe pixel receiver

History

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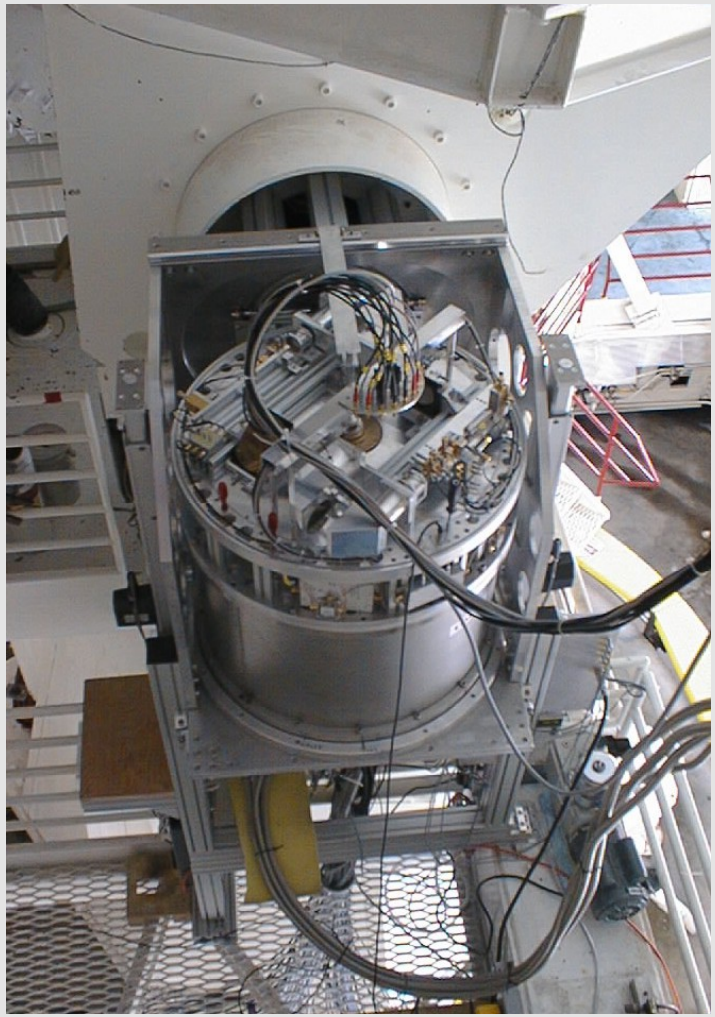
- CHAMP(1999 – 2003)
  - 16 pixel array @ 460 GHz
  - operated at the CSO
  - MACS backend

CHAMP during operation at the CSO (1999-2003).



MACS **(MPI Array Correlator System)**

- 32 Input-bands with1024 spectral channels each
- 3-Level sampler
- Input level 0 dBm
- Data-rate 2Mb/s @ 100ms dump-time

CHAMP+: Instrument description

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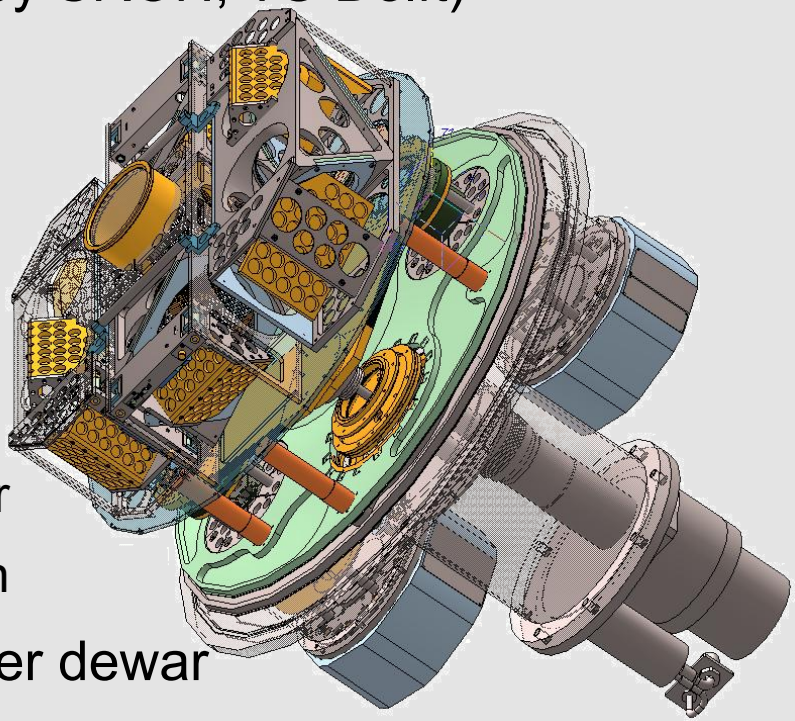
- two 7-pixel sub-arrays (624 – 716 GHz and 785 – 935 GHz)
  - operating on orthogonal polarizations allows for parallel observations
- fixed tuned DSB SIS-mixers (provided by SRON, TU Delft)
  - mixer instant. bandwidth: 4 – 8 GHz
- main optics cooled to 15 K
- SSB-filter for both sub-arrays
  - image side-band terminated at 15 K
- quasi-optical LO-injection
  - Martin-Puplett interferometer as diplexer
  - phase-gratings for LO-power distribution
- image de-rotation by rotating the receiver dewar
- backend/IF processes 2.8 GHz instantaneous bandwidth for each pixel
- fully remote controlled operation



CHAMP+: Footprint

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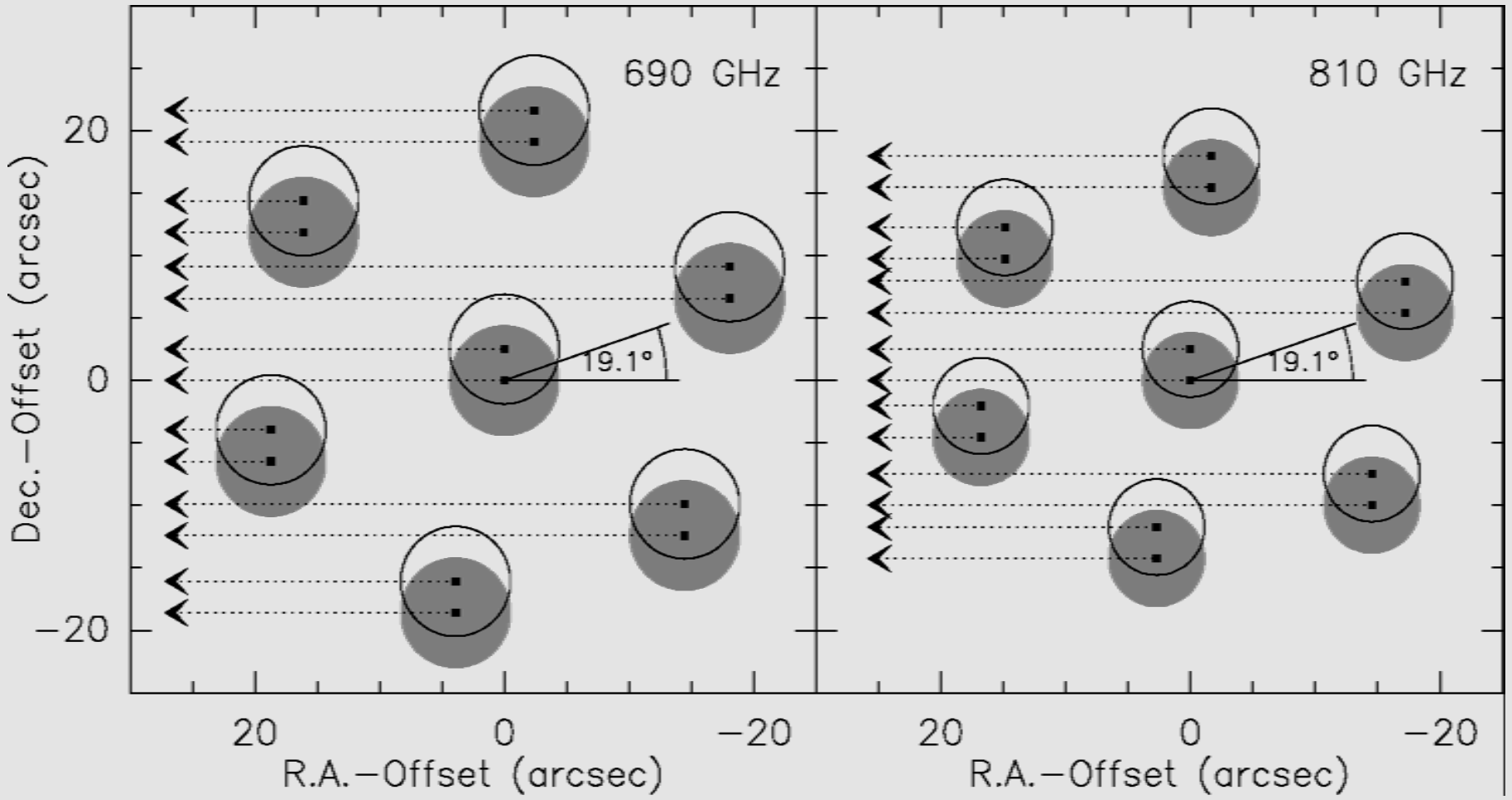

OTF-Scanning under 19.1°

fully sampled maps with two scans only

CHAMP+: System overview

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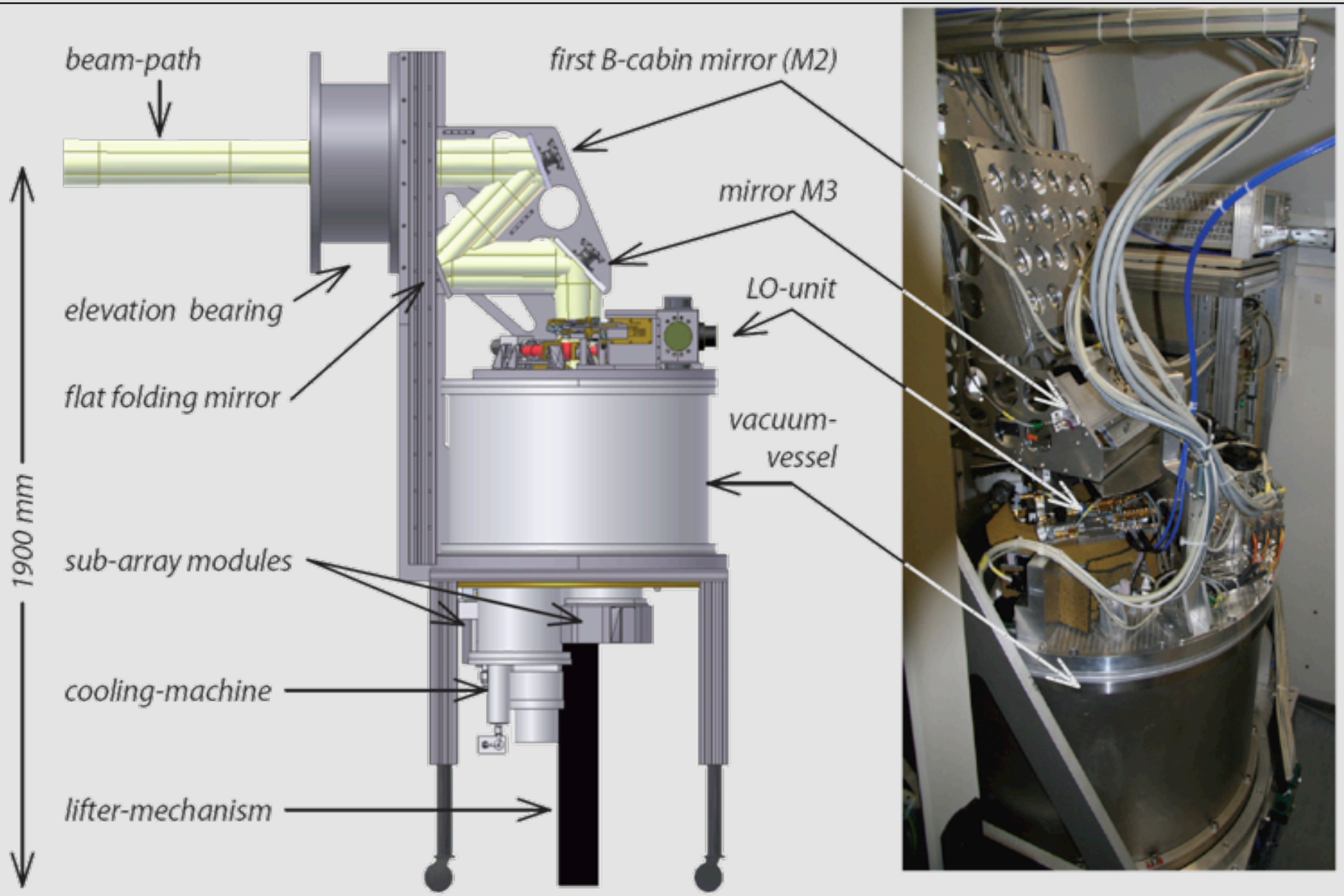

CHAMP+: Cold optics (15K)

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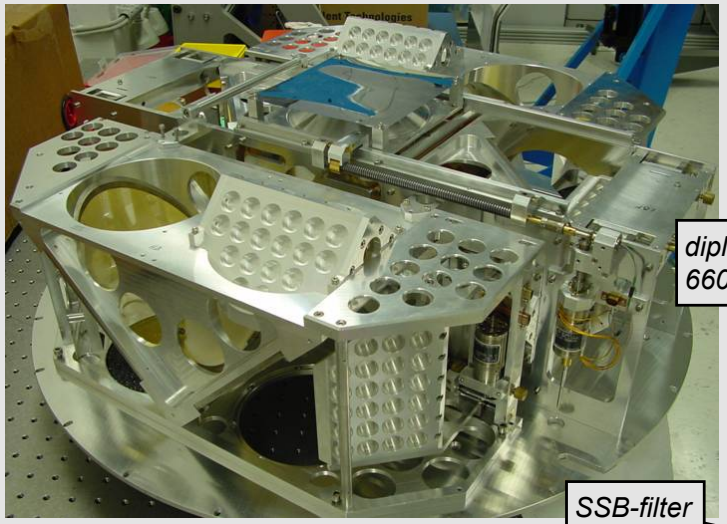
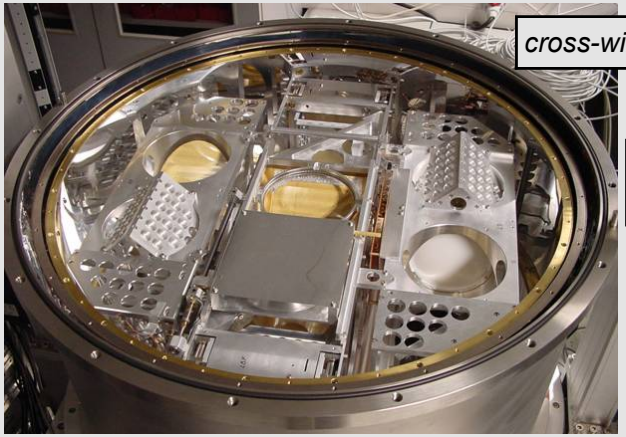
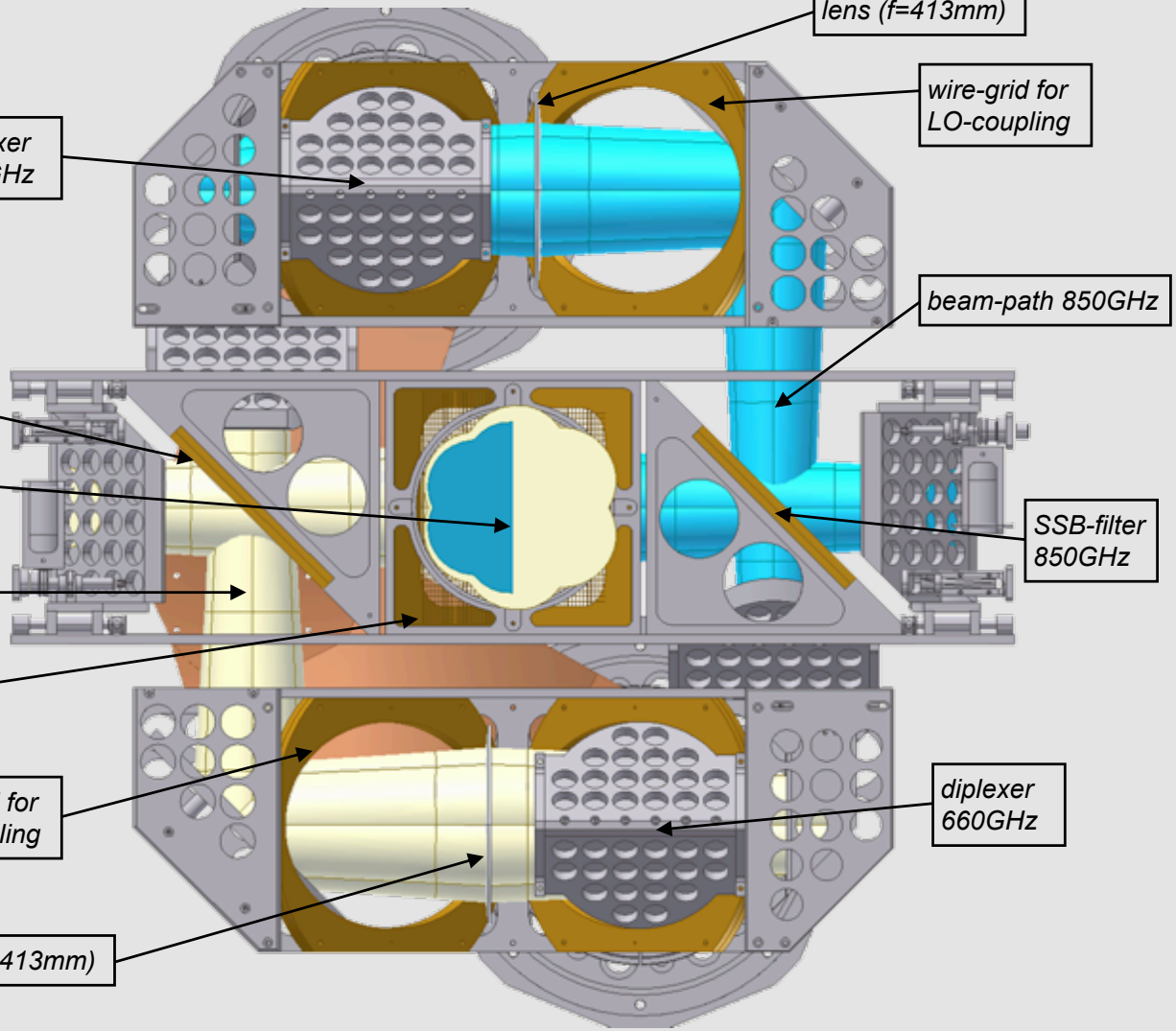


Photographs of the cold optics assembly





CHAMP+: SSB-filter

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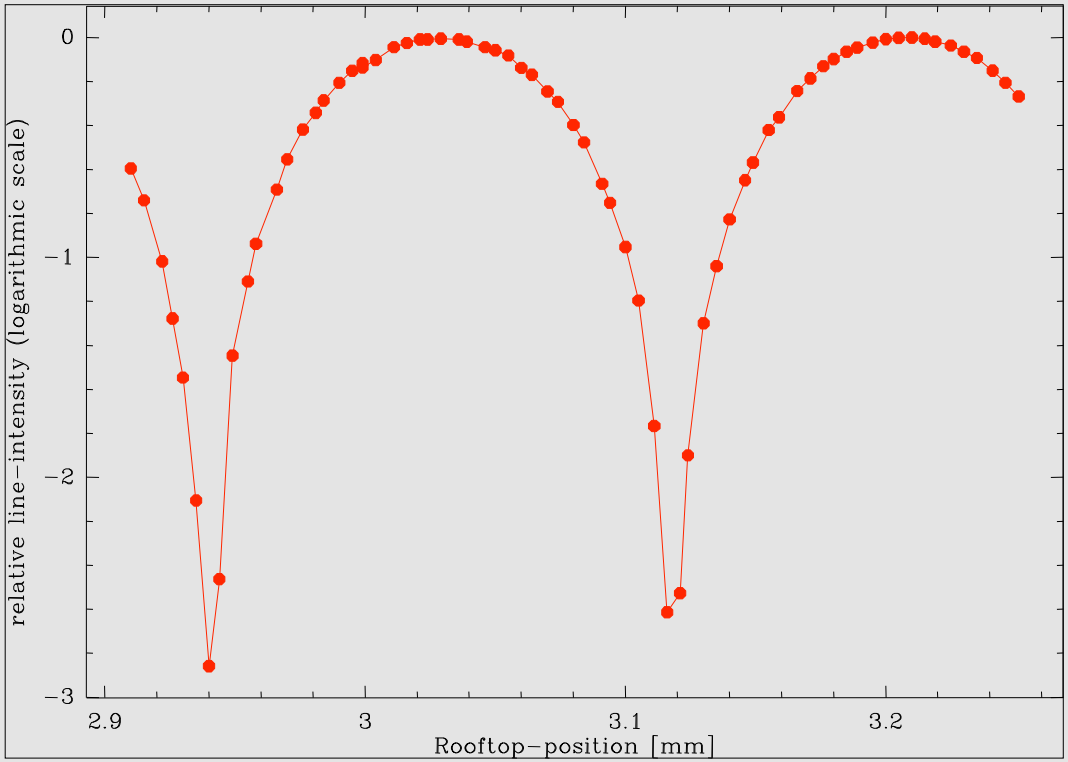

determination of SSB filter curve:

- using a harmonic mixer to create the Rx-input signal
- scan the SSB-filter position and determine signal strength vs. position

➔ ***suppression > 15dB for all pixels***
(in the IF band center)

confirmed by measurements on sky (CO / Orion)

- full auto-tuning established

Frequency [GHz]	Side-band	Filter-position [mm]	Pixel 1 [dB]	Pixel 2 [dB]	Pixel 3 [dB]	Pixel 4 [dB]	Pixel 5 [dB]	Pixel 6 [dB]	Pixel 7 [dB]
630	LSB	3.240	-17,7	-24,4	-16,6	-21,0	-27,1	-34,7	-23,3
650	USB	3.274	-16,1	-25,4	-14,6	-23,5	-24,4	-28,3	-25,4
691.47	LSB	3.118	-16,6	-24,6	-15,3	-27,6	-21,6	-25,5	-28,3
806.65	USB	3.118	-16,9	-22,1	-16,3	-21,7	-29,6	-23,6	-26,6
850	LSB	3.150	-15,1	-20,9	-16,3	-26,7	-22,8	-25,4	-27,3
921.8	LSB	3.153	-15,4	-21,5	-19,8	-25,8	-23,3	-19,0	-19,4

CHAMP+: LO-system

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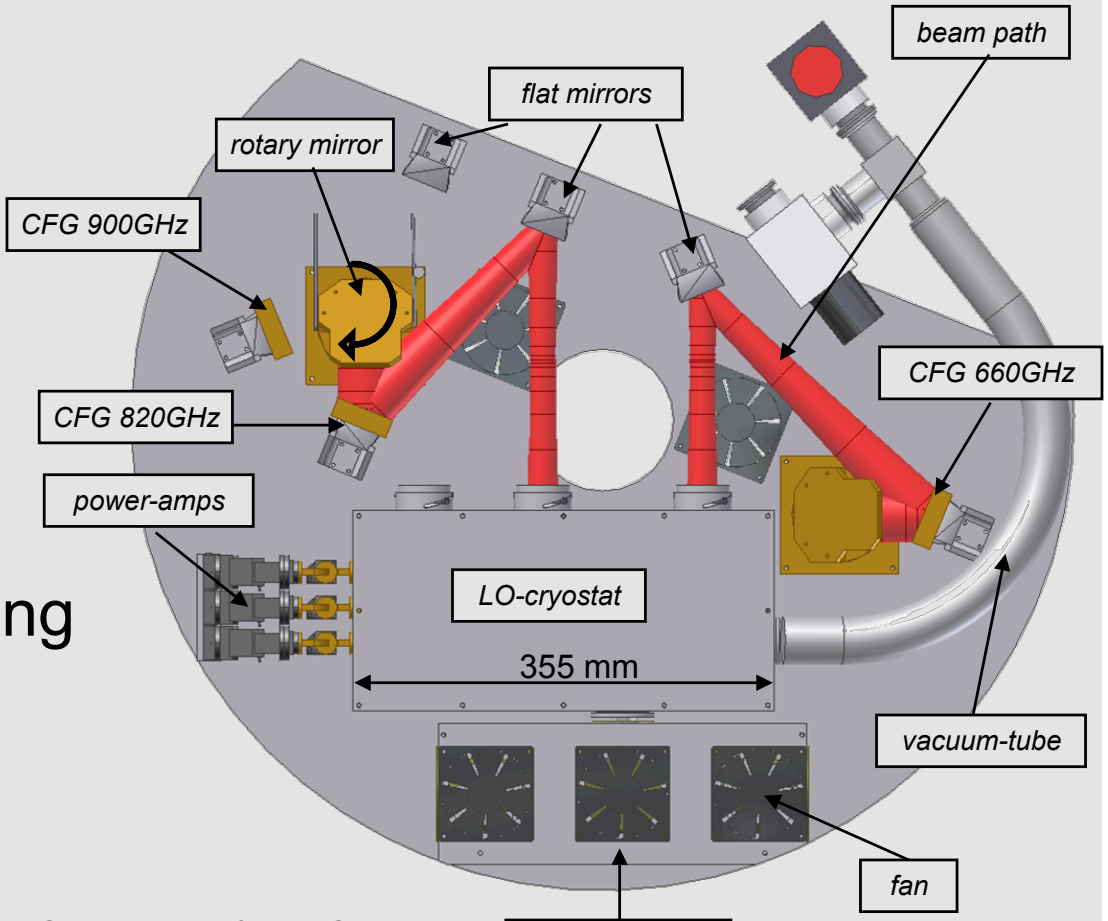
- LO-chains are a spin-off from HIFI/Herschel development
  - three LO-chains to cover the RF-bandwidth:
    - 630-710GHz
    - 790-836GHz (lower)
    - 840-936GHz (upper)
  - multipliers are cold (<130K)
    - increased lifetime
    - better performance
  - using compact design with commercial Stirling-cooler
- LO-splitting using collimating Fourier gratings (CFGs):
  - single quasi-optical device
  - high efficiency (>77%)
  - easy to fabricate



CAD model of the LO-system. Signal-path is shown in red.

CHAMP+: SIS-Mixers (SRON)

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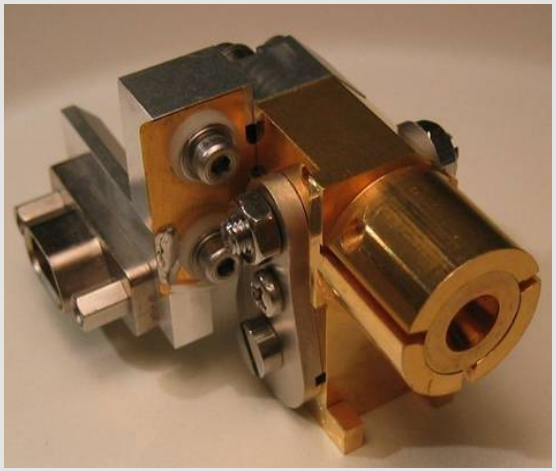
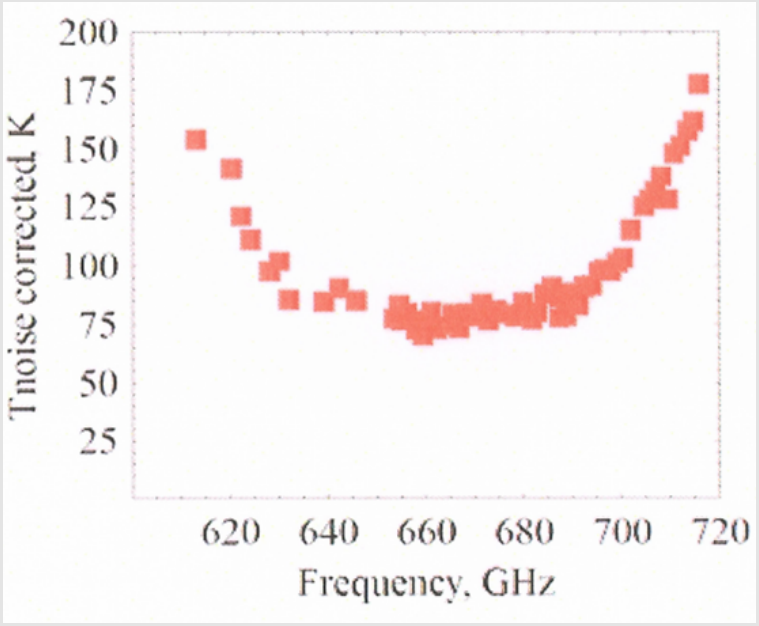
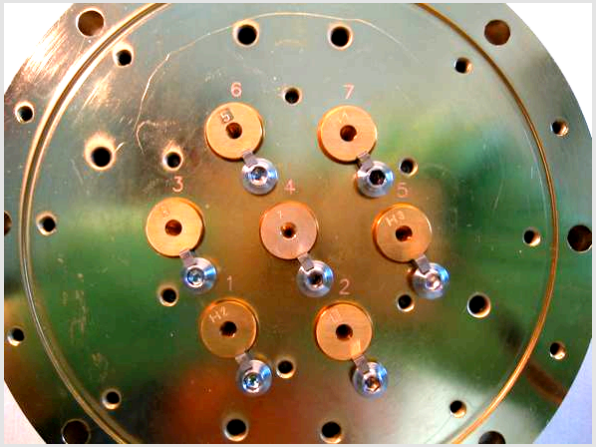
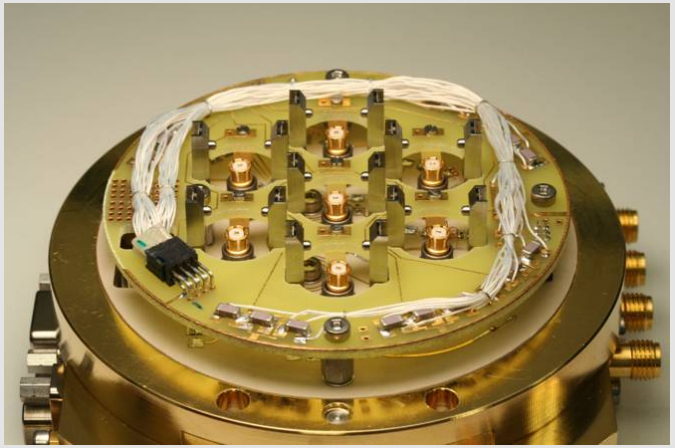
- THz SIS mixers
  - quantum-limited sensitivities
  - 600-720 & 780-950 GHz RF-bandwidth
  - 4-8 GHz IF bandwidth
- SIS junctions (TU Delft)
  - Nb SIS technology (660GHz)
  - Nb-NbTiN SIS technology (850GHz)
  - optimized fabrication
    - larger quantities
    - improved pattern accuracy
    - high reproducibility
- waveguide device mounts
  - optimized for series production
- corrugated horn antennas (RPG)



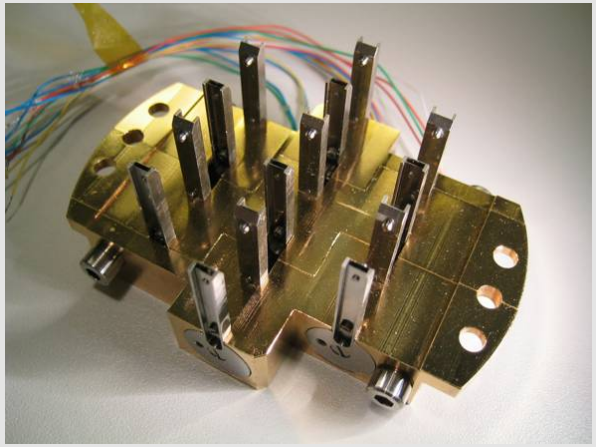




Mixers assembled to the mixer-mount



Mixer electronics with connector-block



Magnet block

CHAMP+: Array-FFTS

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Bandwidth: 32 x 1.5 GHz = 48 GHz (option 58 GHz)
Spec. channels: 32 x 8k = 256k channels @ 212 kHz

CHAMP+: Beam-pattern & shape

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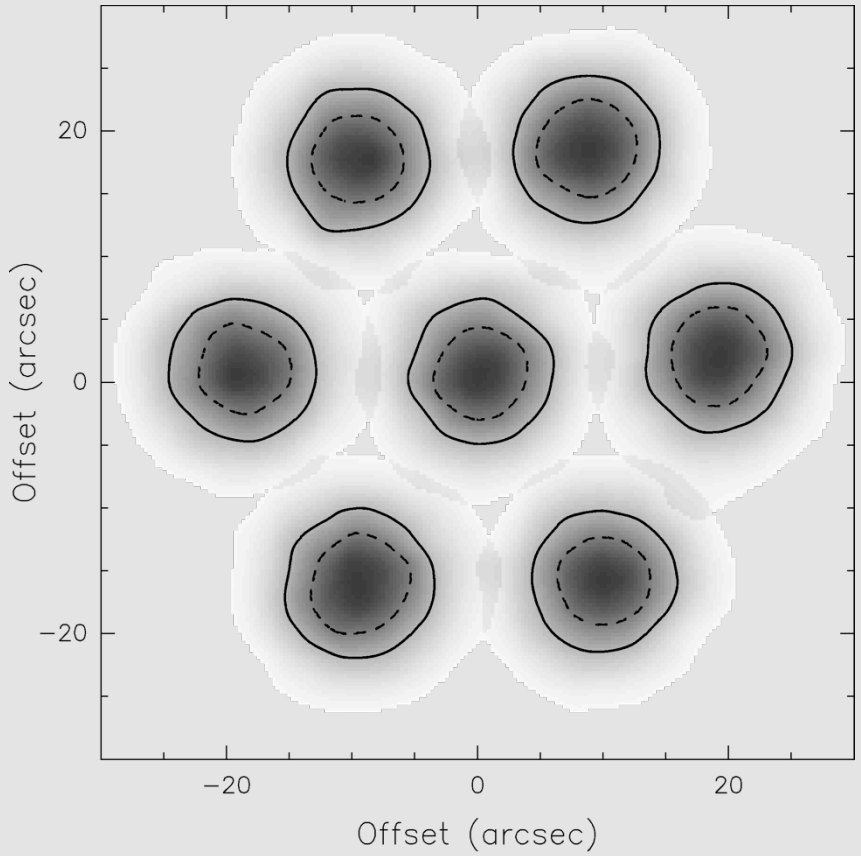

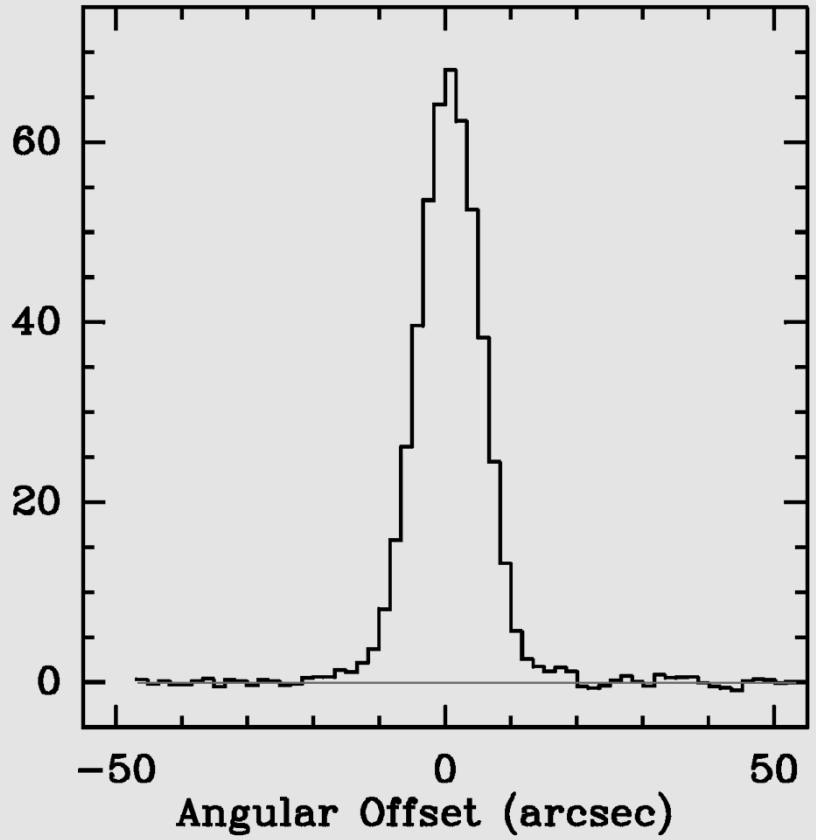

Beam pattern of the low-frequency array:

- obtained on Mars using total power scanning mode
- diffraction limited
- beam-shape as expected (clean down to -16dB)

CHAMP+: Noise-Performance

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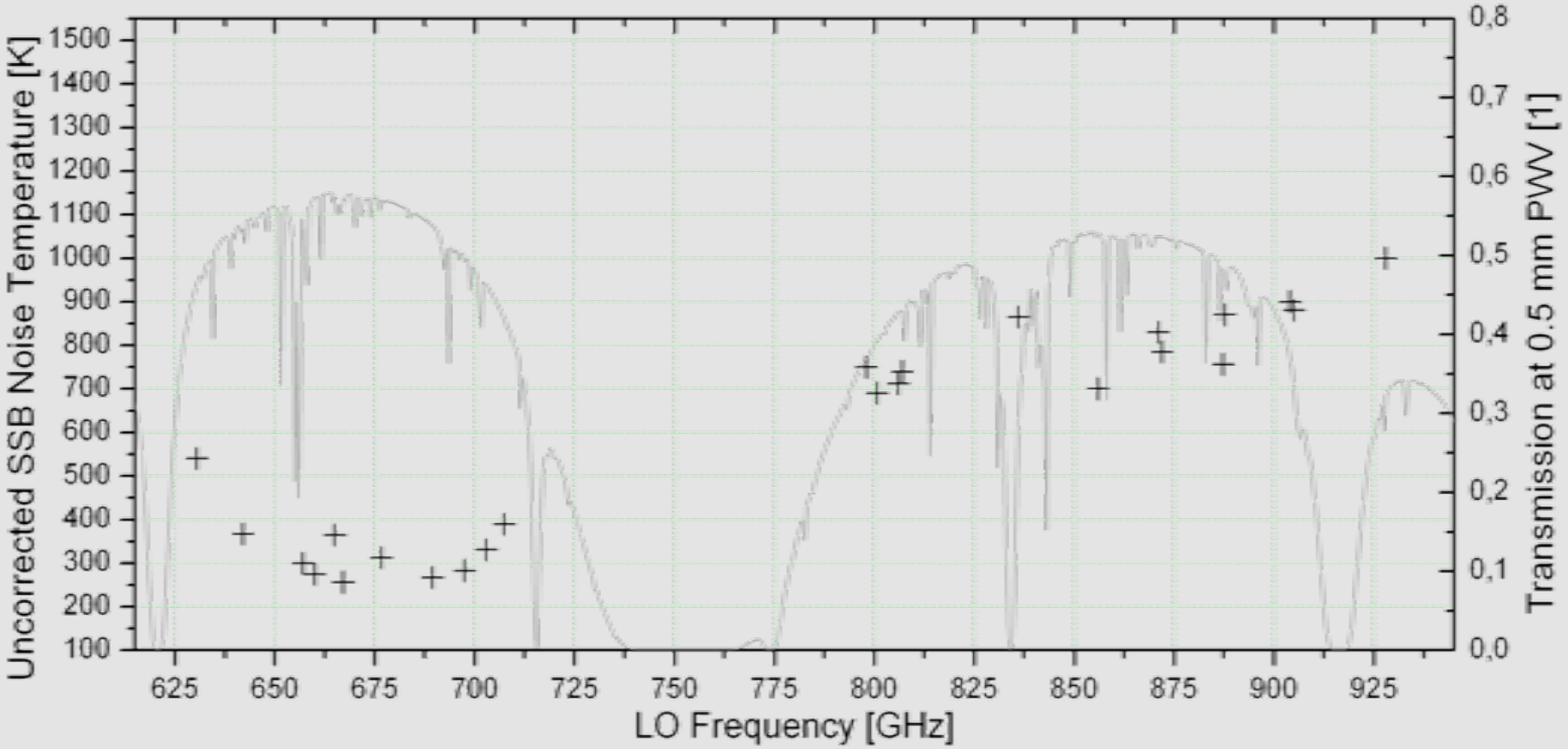

SSB receiver noise temperatures of the central pixel:

- Y-factors measured using the internal cold load
- do not include losses due to the cryostat window.

(for reference the atmospheric transmission is superimposed)

CHAMP+: System stability

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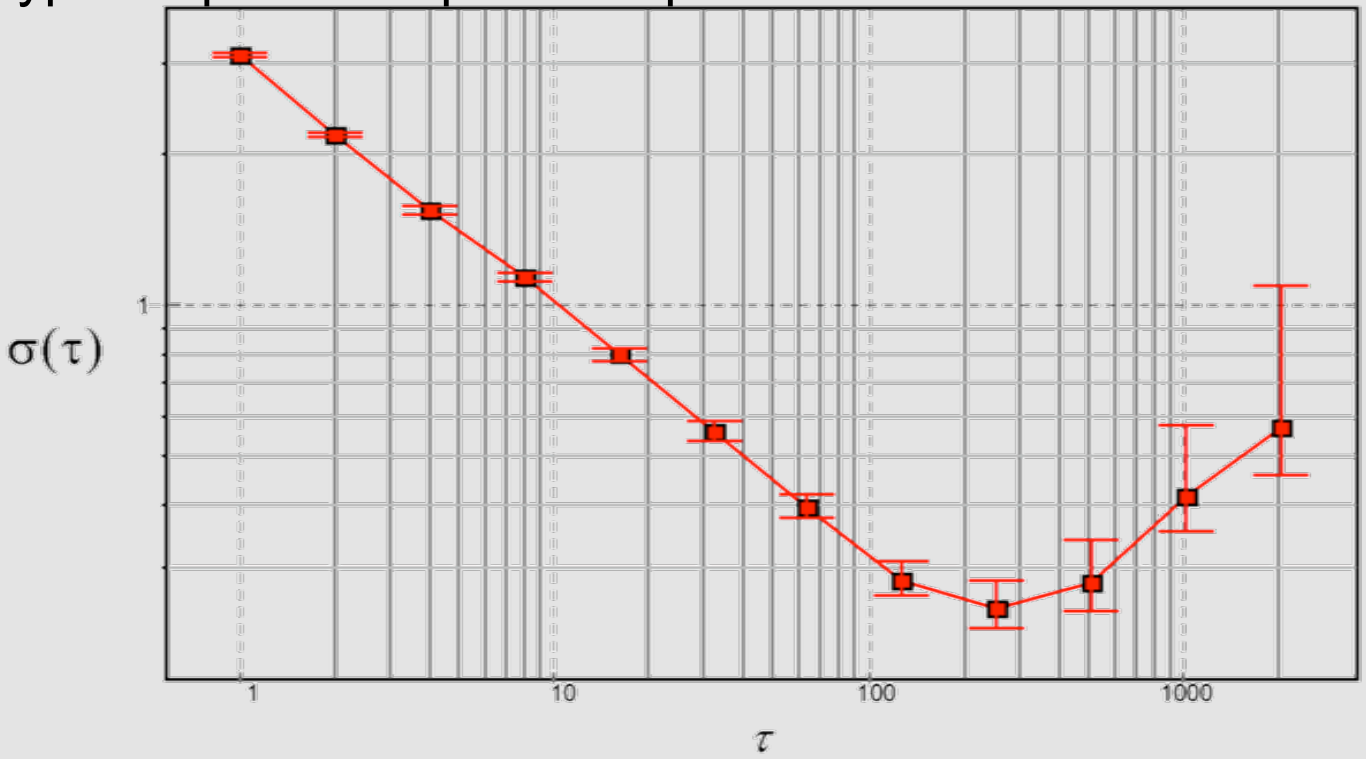
typical spectroscopic Allan-plot of one of the 850GHz channels



- total-power stability (1GHz band-width)
  - Allan minimum times > 25s for all channels
- spectroscopic (1MHz resolution)
  - Allan minimum times > 150s for all channels
  - most channels around 200s with A-FFTS as backend

CHAMP+: Conclusion

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- CHAMP+ is successfully operated at APEX for nearly three years now
  - meets all design requirements
  - offers very good performance throughout the whole tuning range
  - further optimizations still possible and ongoing
- CHAMP+ in combination with APEX now offers unique observing opportunities in the high sub-millimeter atmospheric windows

LAsMA: Instrument description

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Large APEX sub-Millimeter Array:

- 7-pixel at 280–375 GHz and 7-pixel at 380–510 GHz (prepared for a 19 pixel extension in the higher frequency band)
  - operating on orthogonal polarizations allows for parallel observations
  - hexagonal beam-pattern
- fixed tuned DSB SIS mixers (provided by the University of Cologne)
  - mixer instant. bandwidth 4-12GHz (goal)
- frequency-independent optics (Gaussian telescope setup)
- SSB-filters for both sub-arrays
  - image side-band terminated at 20K
- quasi-optical LO-injection
  - phase-gratings for LO-power distribution
  - coupling foil for LO-injection in both bands
- K-mirror as image de-rotator
- full remote controlled
  - optical filters, mixer control, LO-systems, and IF
- using of the CHAMP+ IF-system and A-FFTS at the beginning
  - Individual IF and FFTS-System with wider bandwidth as upgrade

LAsMA: Optical path

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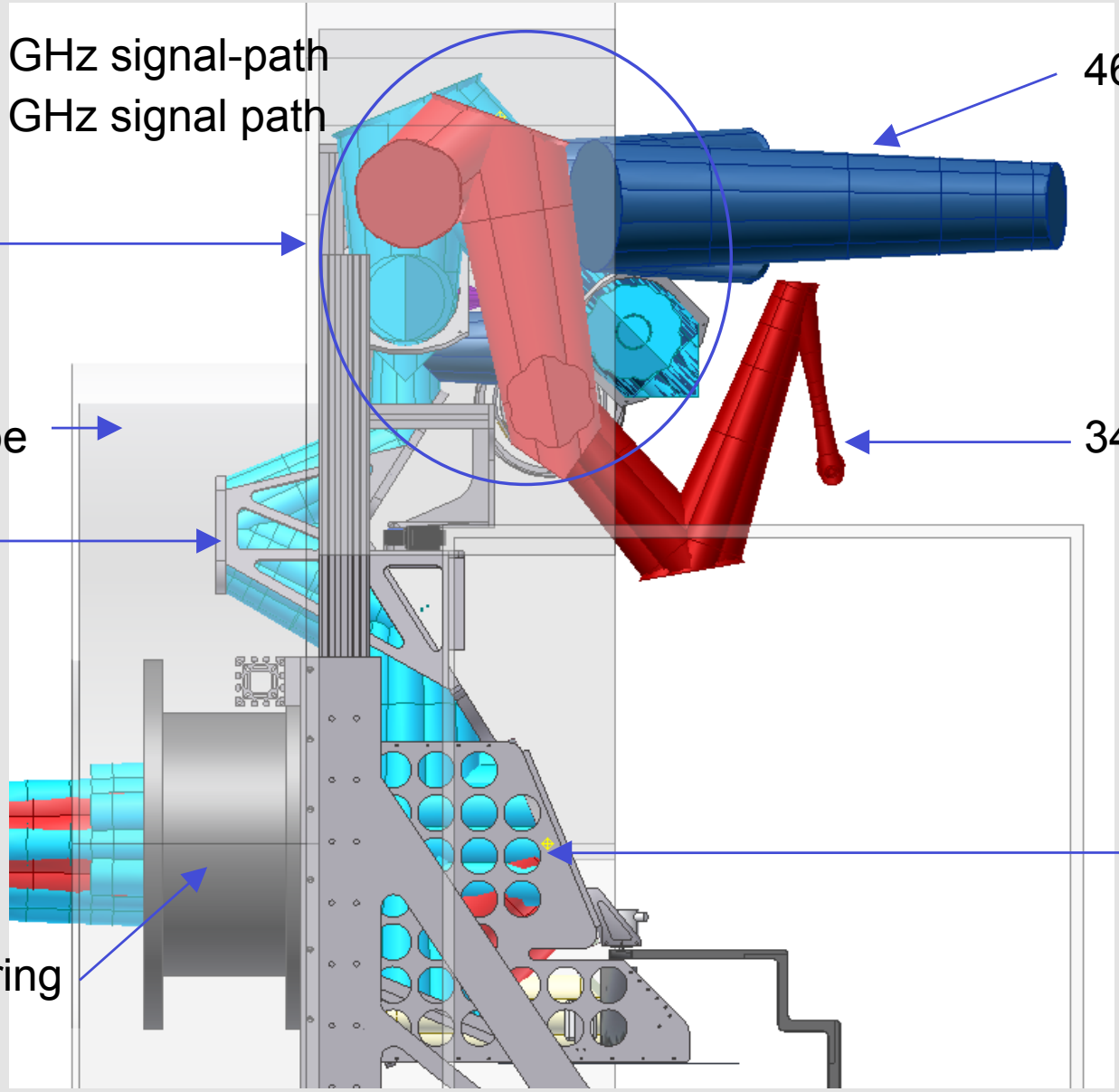
light blue: 460 GHz signal-path
red : 345 GHz signal path



LAsMA: K-Mirror

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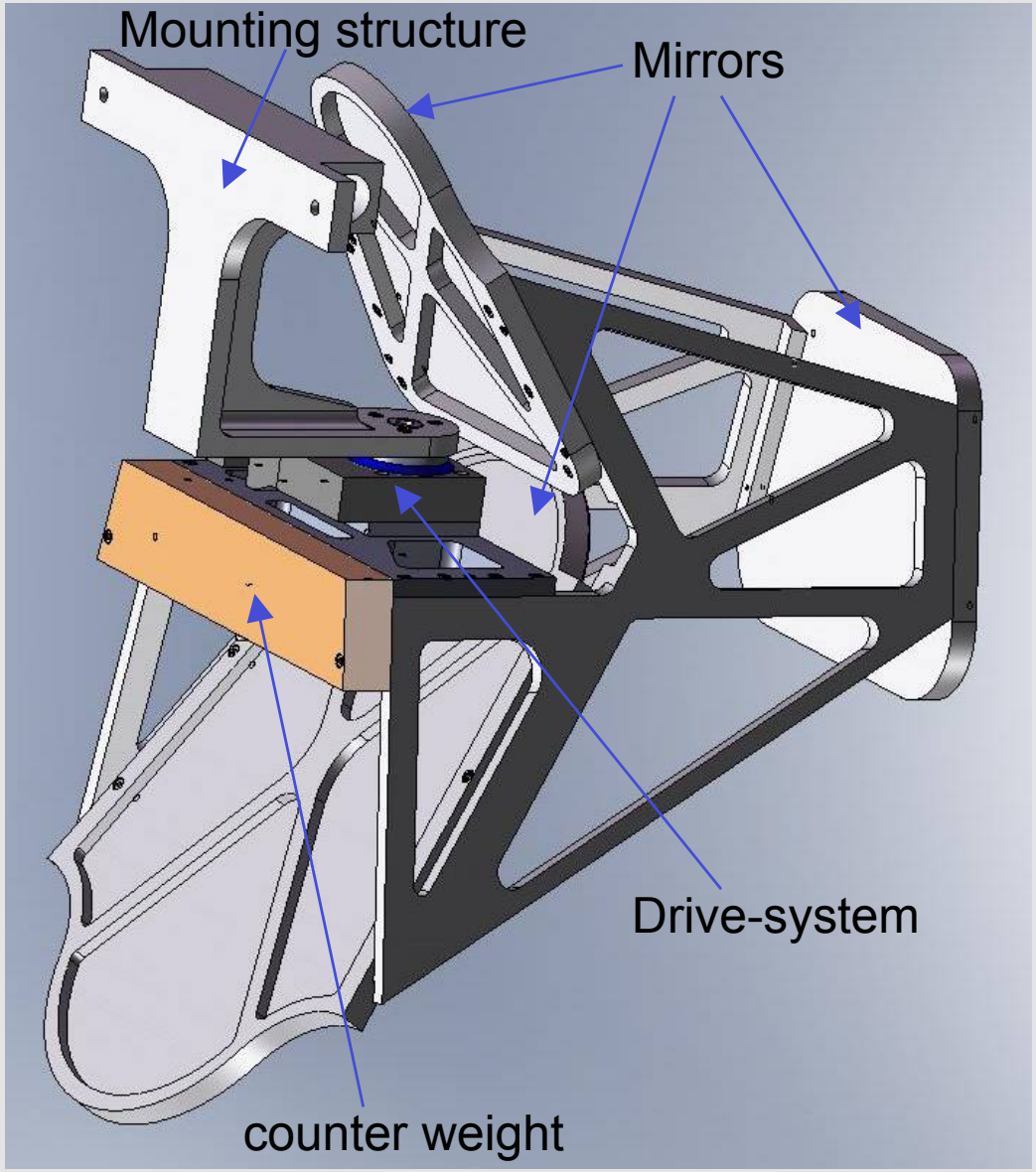
- 3 flat mirrors only
- allows for >360° image rotation
- no cable-twisting
- quasi monolithic fabrication
  - no internal adjustment required
- aperture covers the full field of view of the Nysmith cabin



LAsMA: LO power splitting

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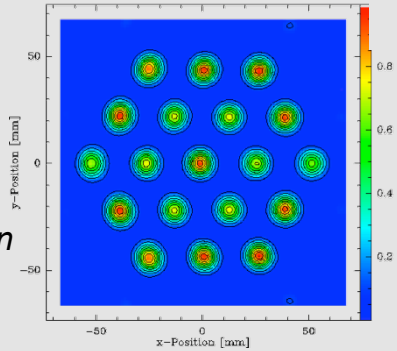
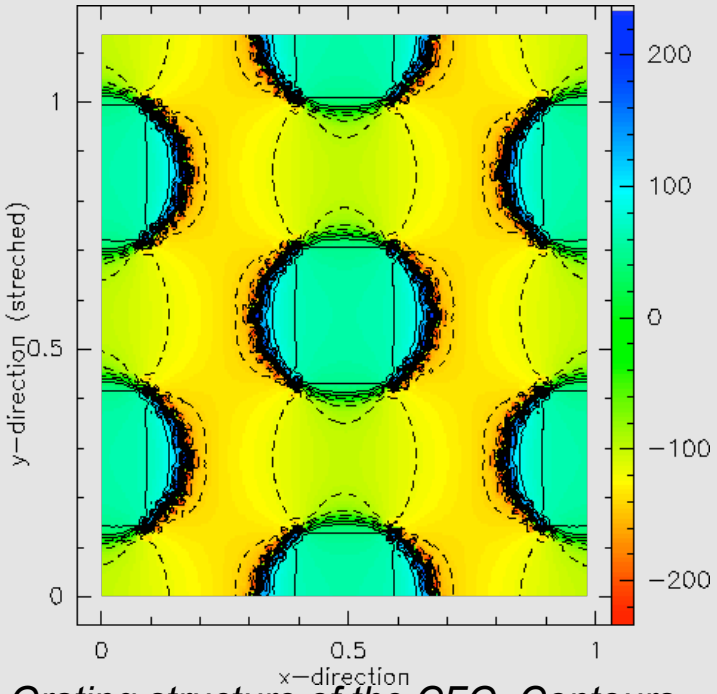
using CFGs (collimating Fourier gratings)

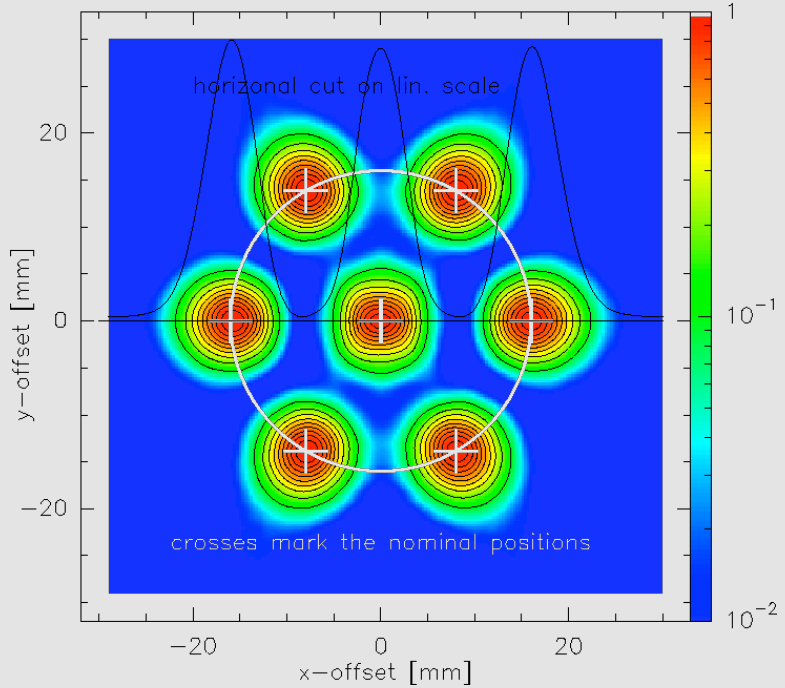
- *phase-gratings which are superimposed onto a parabolic mirror*
- *usable bandwidth: approx. ±8%*



Right: Simulation for 19 pixels



Grating structure of the CFG. Contours are in steps of .314 and denote the structure height in phase-units



Simulated intensity distribution of the LO-beam after passing the CFG. Contours in steps of 10% of the maximum intensity.

LAsMA: Mixers (KOSMA)

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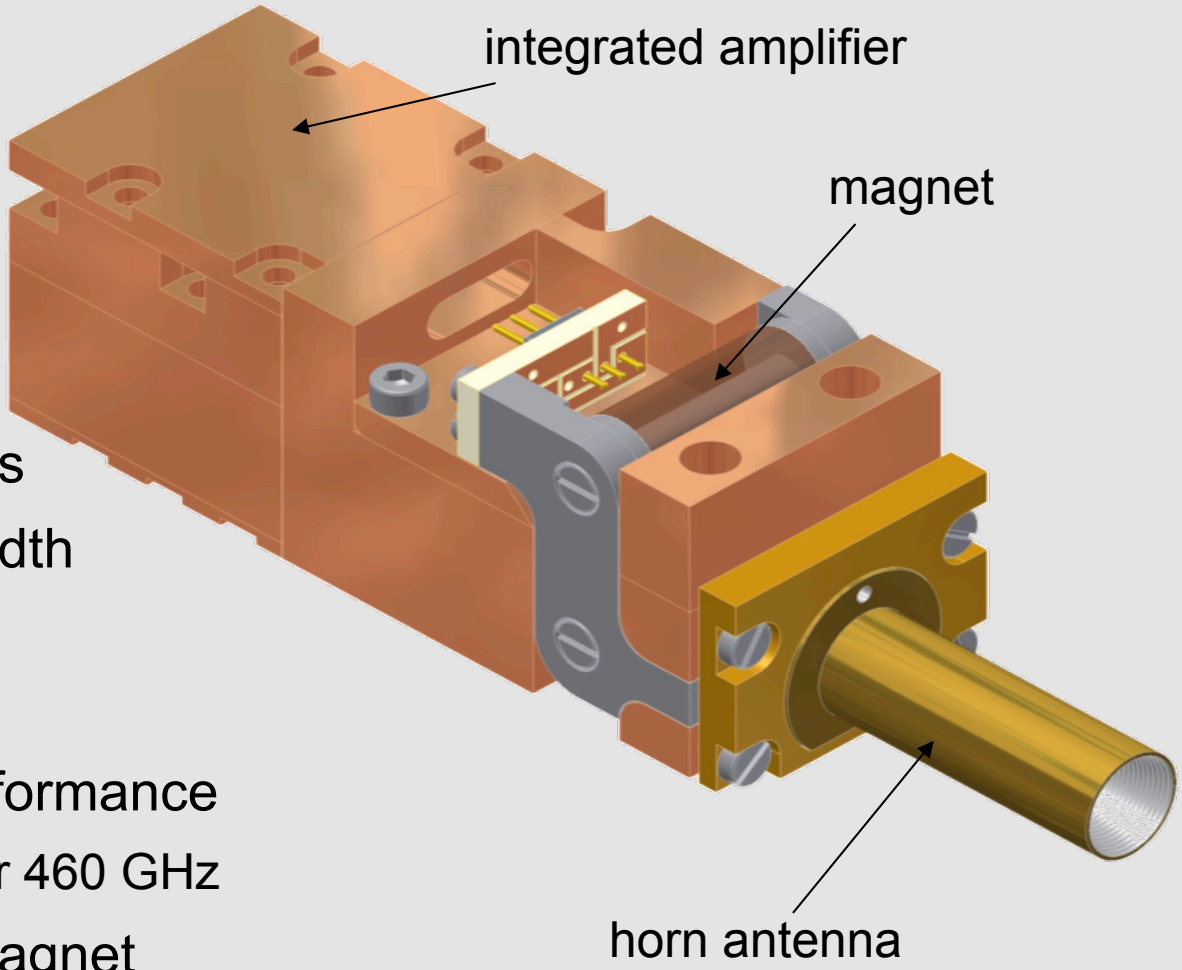
Right hand side: 3D CAD model of the LAsMA mixer assembly. The front part with the SIS-device and the horn antenna is provided by the KOSMA group. The amplifier Part is a contribution from MPIfR



- fixed-tuned DSB-SIS mixers
- baseline for the RF-bandwidth
  - 280 – 375 GHz
  - 380 – 510 GHz
- goal for the DSB noise-performance
  - 40 K for 345 GHz, 60 K for 460 GHz
- internal superconductive magnet
- IF-bandwidth: 4–12GHz
- integrated low-noise amplifier (provided by MPIfR)

LAsMA: Electronics

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- compact multi-pixel electronics
  - will directly be attached to the LAsMA dewar
- fully computer-controlled
  - remote access via Ethernet incl. measurement of IV-curves
  - but oscilloscope online monitoring is also possible
- usable also for single pixel receivers
- design ready, mass-production started
  - successfully tested with a 460 GHz SIS-mixer in the Lab


power-supply


control-computer

LAsMA: mixer electronics

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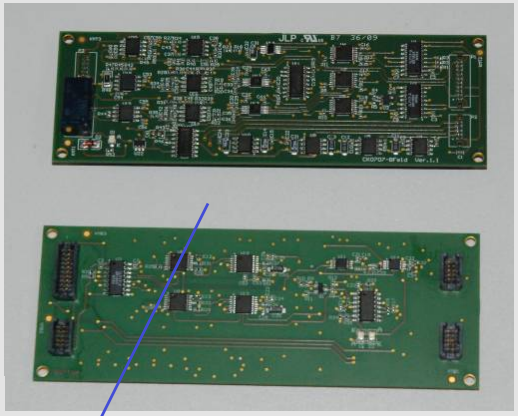
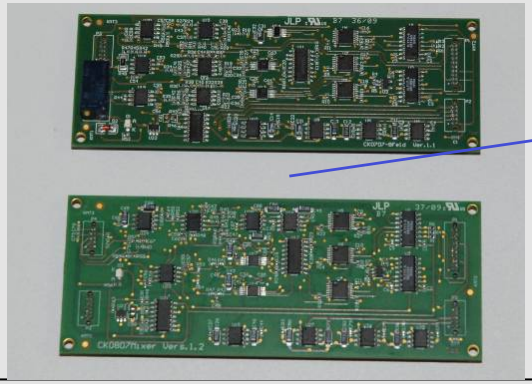
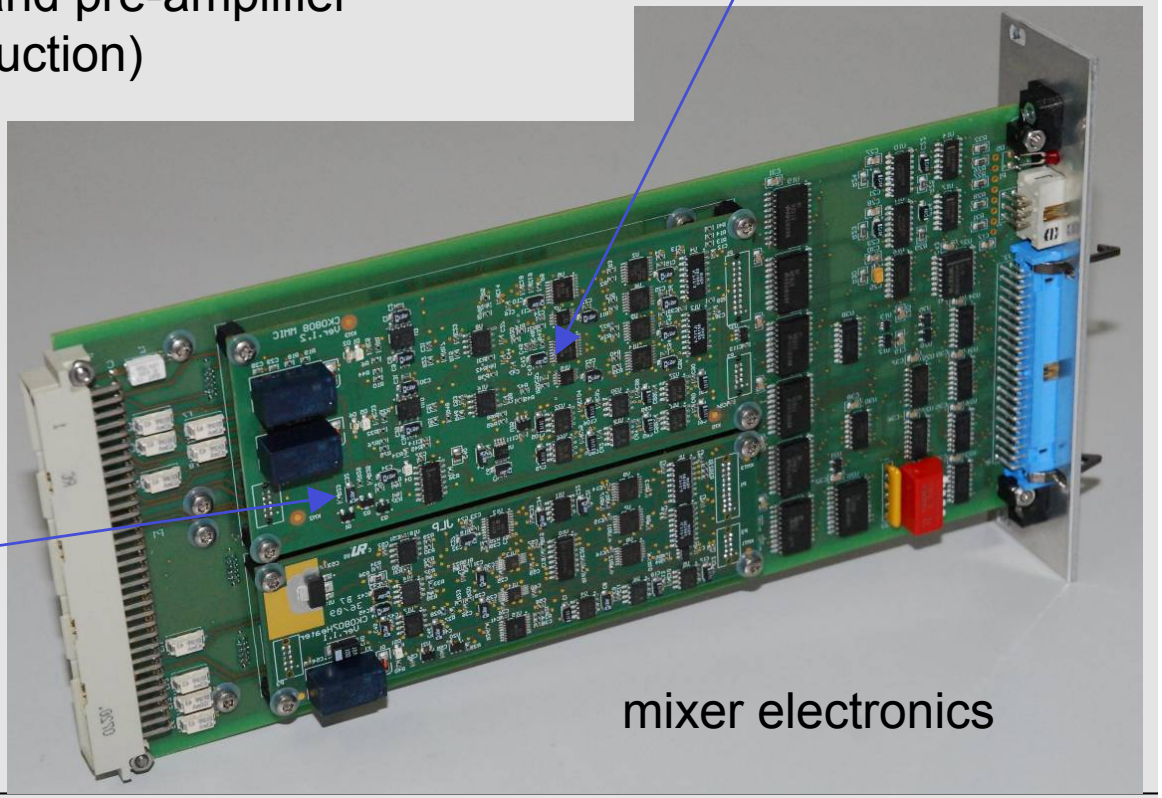
- each channel has its individual electronics
  - easy to debug
  - system upgrade easily possible
- highly stackable
  - bus system (PC-connection, power, analog for IV-curve)
  - individual mixer connection and pre-amplifier
  - easy to fabricate (mass production)
- one card only includes
  - mixer-BIAS
  - magnet current supply
  - MMIC BIAS
  - heater supply







mixer electronics

LAsMA: Outlook and timeline

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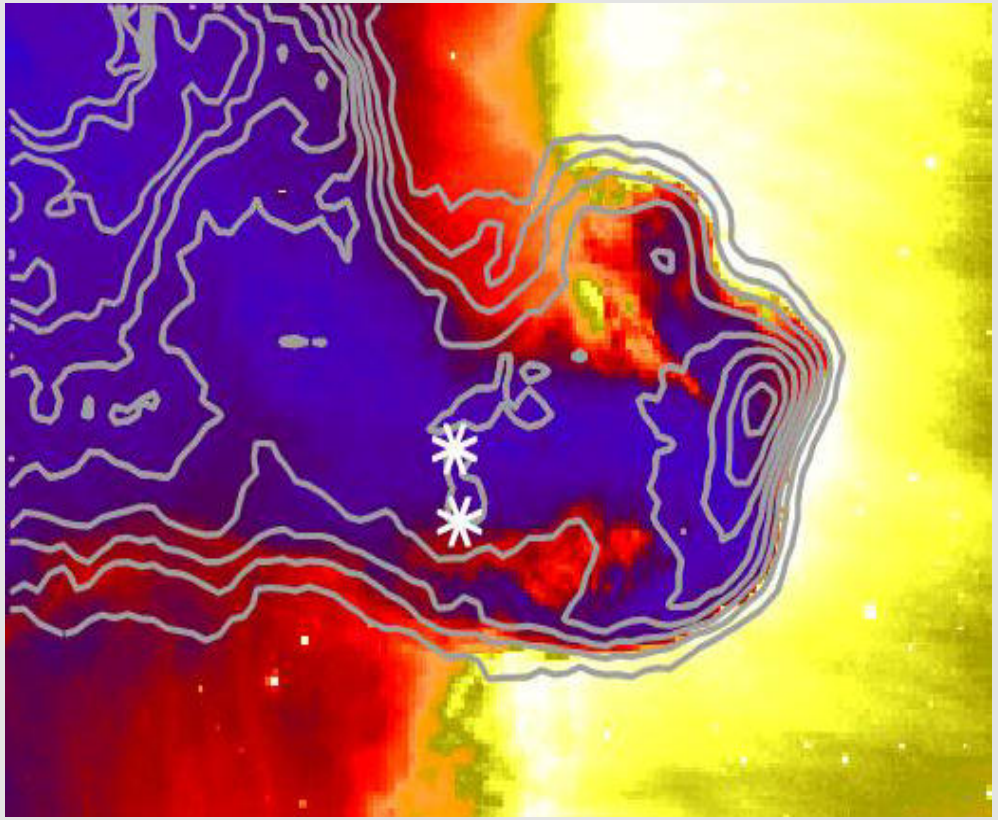
- 7-Pixels at 460GHz plus 7-pixels at 345GHz
  - will offer outstanding mapping capabilities
- LAsMA will be an important addition to CHAMP+
- installation at the APEX telescope is foreseen in late 2010



Distribution of warm carbon monoxide CO(4-3) as measured towards the Horsehead nebulae with the precursor instrument to CHAMP+.

Conclusions

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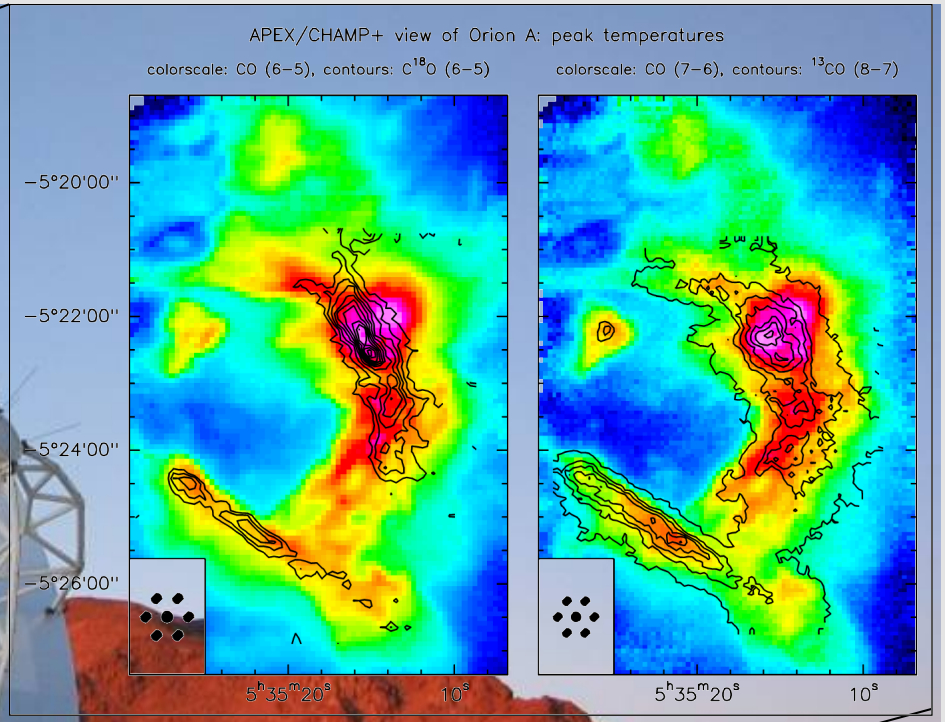
Orion OTF-Map

- approx. 1Million spectra
- 1s dump time per spectrum

➔ ~25 hrs on source
incl. overheads



APEX will soon be equipped with

- two state of the art array receiver systems
  - CHAMP+ which is in operation
  - LAsMA delivered in late 2010

covering all important sub-millimeter windows accessible routinely with APEX