Large scale spectral line mapping of Galactic regions with CCAT-prime

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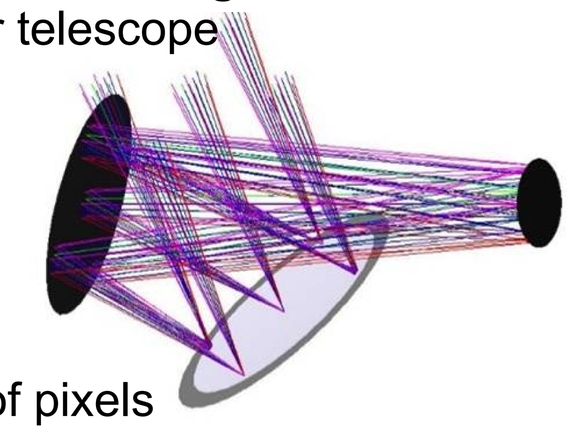
The CCAT-prime project

CCAT-prime, presently under construction (first light 2021), will be a 6-m submillimeter telescope on Cerro Chajnantor (5600 m altitude) overlooking the ALMA plateau in the Atacama Desert of northern Chile. Its Crossed-Dragone design enables a large field of view without blockage and is thus particularly well suited for large scale surveys in the continuum and spectral lines targeting science cases from star formation in the Milky Way to cosmology. CCAT-prime will be a pathfinder towards a future, large (~25 m aperture) submm telescope and a demonstrator that one can operate telescopes at such a high site, which would be very attractive for AtLAST. On this poster, we focus on the large scale mapping opportunities in important spectral cooling lines of the interstellar medium opened up by CCAT-prime and the Cologne heterodyne instrument CHAI.

Telescope specifics

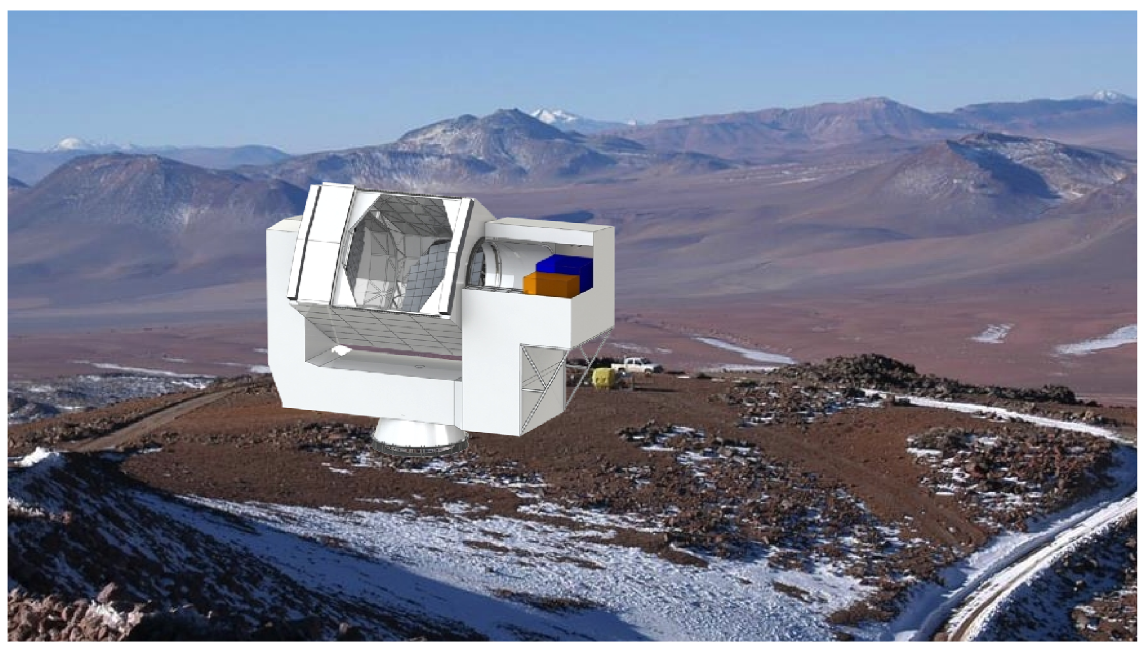
CCAT-prime will use a **Crossed-Dragone** off-axis design for its 6 m diameter telescope

- Coma-corrected f/2.6
- High surface accuracy (7–10 μm r.m.s.)
- High throughput
- Wide field-of-view
- Flat focal plane
  Accomodates 100,000s of pixels

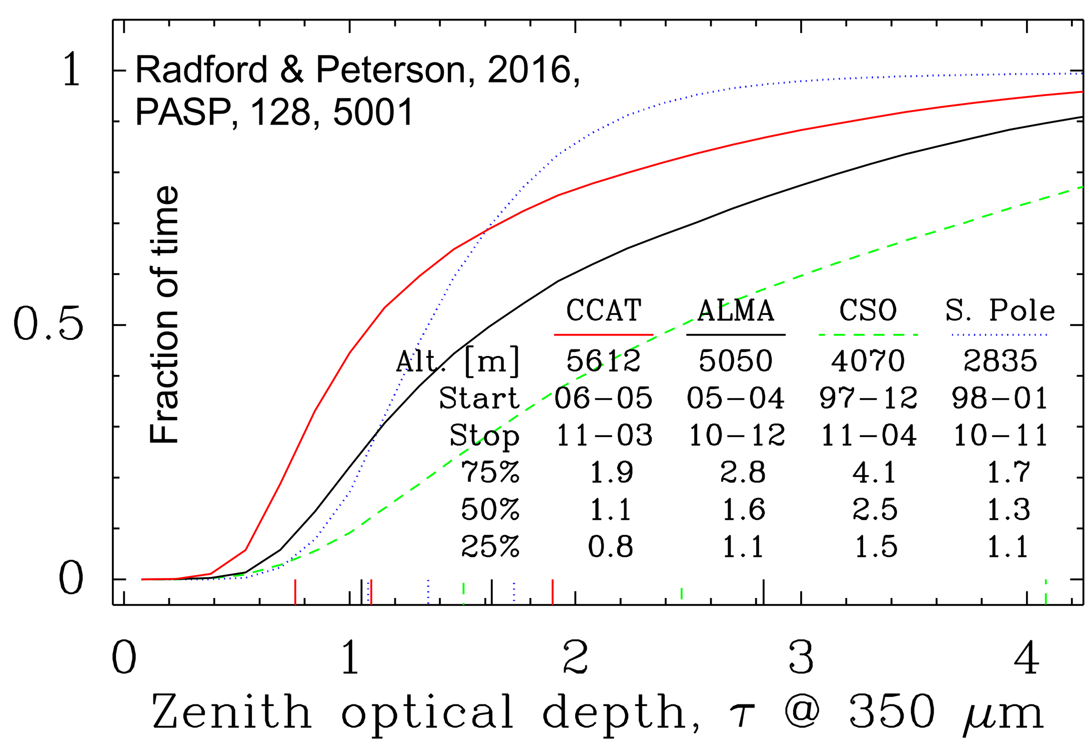


The telescope is being built by VERTEX ANTENNENTECHNIK with financial support from the Deutsche Forschungsgemeinschaft (DFG).

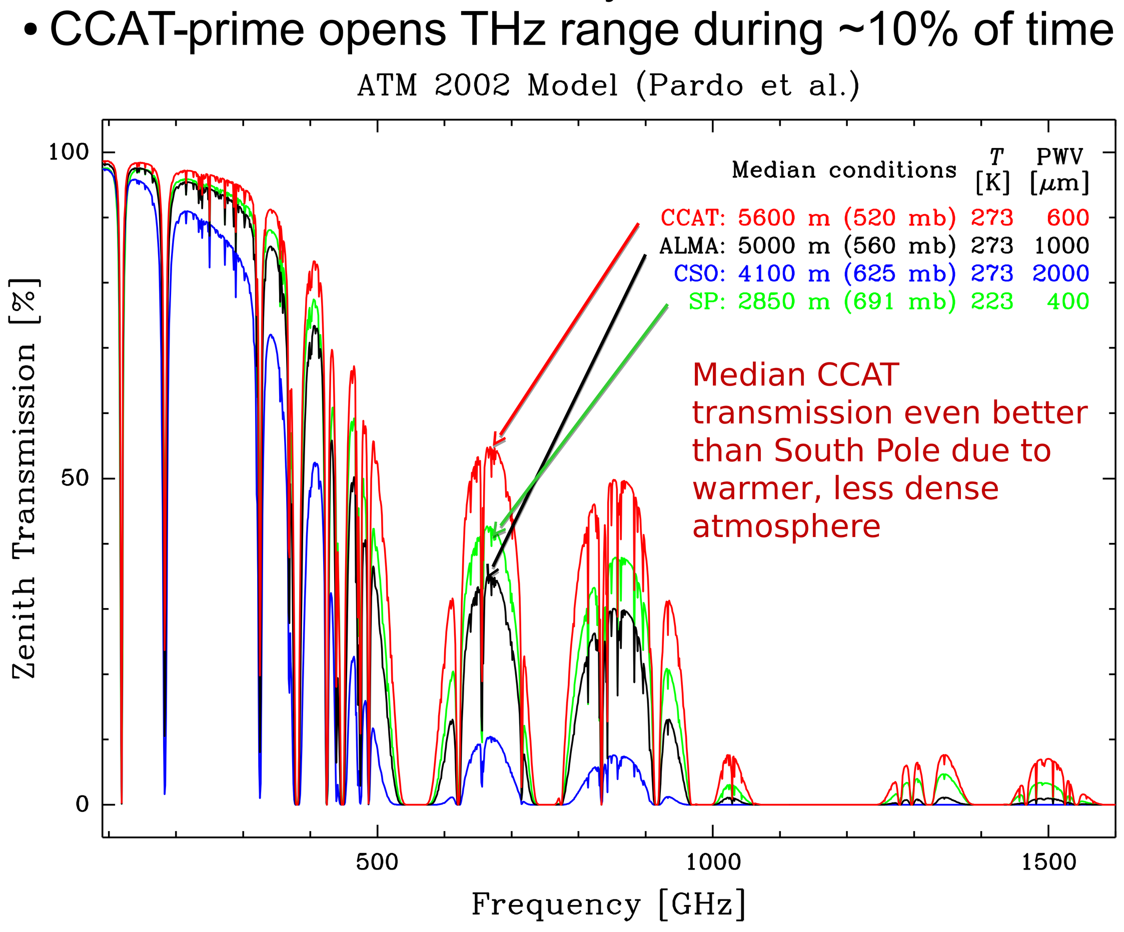
Cerro Chajnantor: A superb submm site



CCAT-prime site below the summit of Cerro Chajnantor at 5600 m altitude including a montage of the telescope (VERTEX ANTENNENTECHNIK, not to scale).



- Tipping radiometers at primary sites for more than a decade. Simultaneous period for CCAT-prime vs. ALMA site show median pwv is 0.6 vs. 1 mm → factor of 1.7 in sensitivity
- CCAT-prime opens THz range during ~10% of time



Spectral line imaging with CHAI

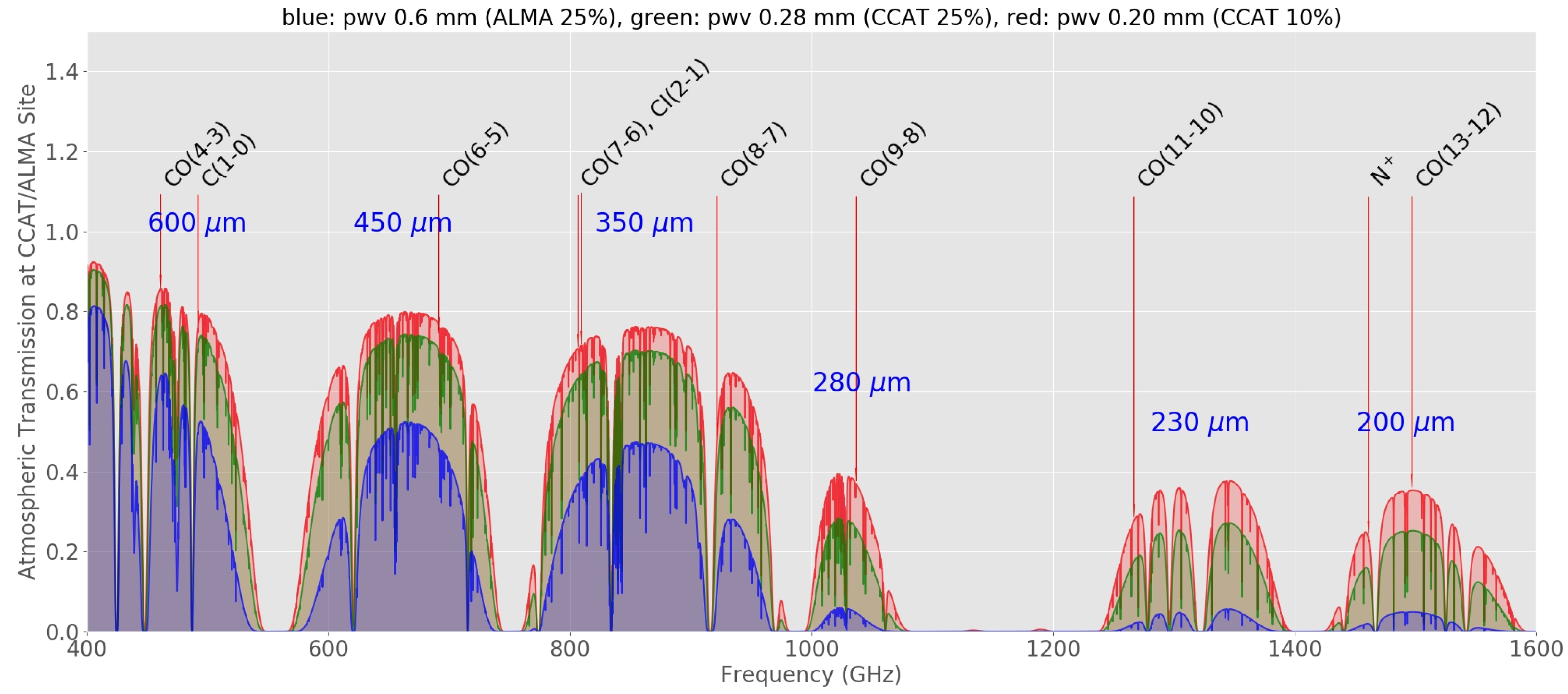
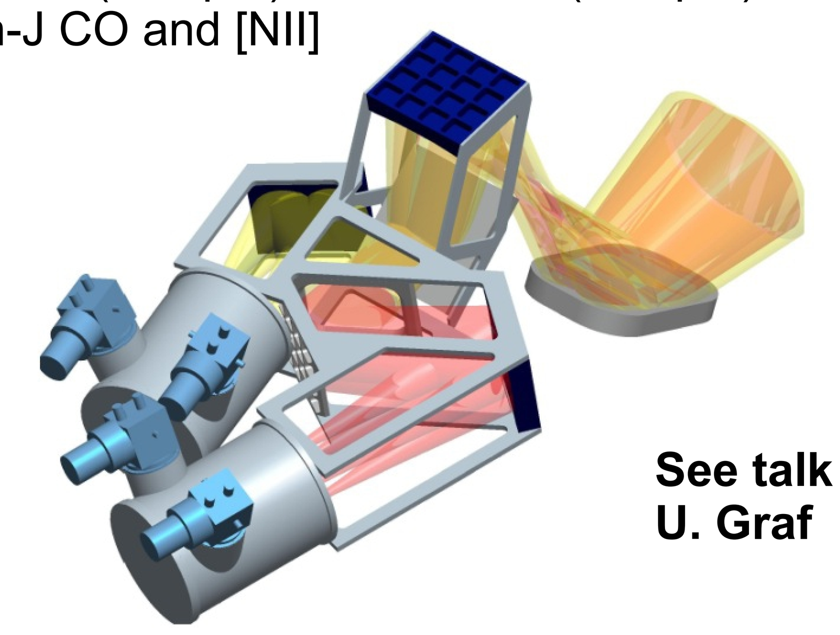


FIG. 2: Atmospheric transmission in different submm windows calculated with the AM model (Paine, S. 2011, SMA memo, 152) for the CCAT-prime and ALMA sites. Spectral lines of interest for large scale mapping and smaller scale zoom-ins are marked. This figure demonstrates the excellent atmospheric conditions at the high altitude site how even the THz windows open up at the higher site during 10% of the time.

CCAT Heterodyne Array Instrument (CHAI)

- Heterodyne, dual frequency array
- 64 pixels (baseline, 128 goal) in each band
- 500 GHz (600 μm) & 850 GHz (350 μm) windows: CO(4-3), CO(7-6), ^{13}CO 8-7, [CI] (1-0) and (2-1)
- 1.5 THz (200 μm) and 1.3 THz (240 μm) windows:
- high-J CO and [NII]



See talk by U. Graf

FIG. 1: Layout of CHAI instrument being built at University of Cologne.

Unique features of the planned observations are:

- Maps at (15'' x λ/350 μm) resolution over 200 deg^2 scales of the Milky Way (Galactic plane and Gould Belt), Galactic Center, Magellanic Clouds (low metallicity) and nearby external galaxies.
- Full area coverage in CO 4-3 and CI 1-0. Zoom-ins at higher frequencies (CO 7-6, ^{13}CO 8-7, CI 2-1).
- Shortest wavelengths at 200 μm for limited time and area coverage (high-J CO and [NII]).
- Angular resolution similar to SOFIA at THz frequencies and IRAM 30 m at mm wave lengths.

Atmospheric conditions and lines of interest

The 5600 meter site enables routine access to the 350 μm window as well as improved performance at longer wavelengths and, under best conditions, access to the 200 μm window.

Due to its high surface accuracy, low error beam, and large field of view, CCAT-prime is ideally suited for large scale mapping observations to probe spectral line tracers of the ISM and cloud/star formation over a wide range of environments in the Milky Way, the Magellanic Clouds and other nearby galaxies.

Science Goals

Most of the observations are planned within the **Galactic Ecology (GEco, see talks by P. Schilke and D. Johnstone)** science case, where spectral large-scale mapping with CHAI of fine structure and mid- to high-excitation CO lines will be used as diagnostics of physical processes associated with star formation in different environments to trace the flows and accumulation of gas into clouds, filaments, cores, and young stars.

- [CI] to trace cloud mass accretion, gas temperature and (dark) mass.
- Mid- and high-J CO/^{13}CO to trace shocks and dissipation of turbulence, stellar feedback, gas excitation, density and mass.
- [NII] to trace embedded star forming regions and the number of ionizing photons.

Observing time estimates

Based on estimates of the receiver performance, atmospheric conditions, and requirements on the observations, we have compiled a table of total approximate observing times to accomplish observations for the GEco science case (Galactic star forming regions and the Magellanic Clouds) and a template for the mapping of nearby galaxies (typically 50 to 100 square arcmin in size).

Requirements on to be achieved rms noise temperatures ΔT per velocity bin Δv come from existing observations.

For our observing time estimates, we assume an elevation (airmass) of 42° (1.5), fully sampled mapping with 64 CHAI pixels per band and the DSB receiver temperatures as given in the table below.

Line	Trec(DSB,K)
CI(1-0)/CO(4-3)	70
CO(7-6)/CI(2-1)	130
^{13}CO(8-7)	130
CO(11-10)/(13-12)	500

Survey	Line	Size (sq.deg)	rms (K)	Δv (km/s)	Beam ('')	pwv (mm)	Time (h)	Days (8 h)
Gal. Plane	CI(1-0)	200	0.25	0.5	26	0.60	1000	**125**
	CO(4-3)	200	0.25	0.5	26	0.60	400	**50**
LMC	CI(1-0)	64	0.10	1	26	0.60	1000	**125**
	CO(4-3)	64	0.10	1	26	0.60	395	**50**
SMC	CI(1-0)	20	0.10	1	26	0.60	310	**39**
	CO(4-3)	20	0.10	1	26	0.60	125	**16**
Gould Belt	CO(7-6)	30	0.25	0.25	16	0.28	480	**60**
	13CO(8-7)	30	0.25	0.25	14	0.28	335	**42**
Zoom-ins	CI(2-1)	50	0.25	0.5	16	0.28	362	**45**
	CO(11-10)	1	0.25	0.5	10	0.20	1200	**150**
	CO(13-12)	1	0.25	0.5	8	0.20	305	**38**
Nearby galaxies	Line	Size (sq.arcmin)	rms (K)	Δv (km/s)	Beam ('')	pwv (mm)	Time (h)	Days (8 h)
	CI(1-0)	10	0.01	1	26	0.60	4.5	--
	CO(4-3)	10	0.03	1	26	0.60	1.7	--
	CI(2-1)	10	0.006	1	16	0.28	17.5	--
	CO(7-6)	10	0.02	1	16	0.28	1.7	--