CCAT-prime: Cerro Chajnantor Atacama Telescope

A novel high throughput, high sensitivity telescope
to study star & galaxy formation and cosmology starting 2021

CCAT-p

CCAT-prime: Cerro Chajnantor Atacama Telescope

- University consortium with strong emphasis on training & development
  - Cornell University
  - German consortium Univ. Cologne & Univ. Bonn
    - joining: LMU (Mohr), MPA (Komatsu, White)
  - Canadian university consortium
    - Waterloo, Toronto, British Columbia, Calgary, Dalhousie, McGill, McMaster, Western Ontario
- Funded by:
  - private donor and Cornell university
  - DFG Grossgeräte, Univ. Köln & Bonn, SFB956 (CHAI)

CCAT-prime Science cases

- What regulates star formation in galaxies?
  - Study the flow of gas into dense molecular clouds and YSOs in the MW and nearby galaxies, through large-scale spectral imaging of [CI] & CO line emission.
- How do galaxies evolve from the star-forming main sequence to the red & dead elliptical cloud?
  - Trace the high end of the IR-LF through deep & wide-field 350 mm surveys.
- How do star-forming galaxies re-ionize the IGM at redshifts 9 to 5?
  - Map the evolution of the [CII]158mm emission and its 2P-CF.
- What is the nature and evolution of “Dark Energy”?
  - Trace the cosmic evolution of the mass function of galaxy clusters. Measure the mass-observable scaling relation through tkrSZ observations of 100s to 1000s of clusters.
- What is the nature of early cosmic inflation?
  - Measure the CMB B-mode polarization to place limits on cosm. parameters at much lower level. Characterize the foreground dust properties.

What is CCAT-prime?

- High throughput, high sensitivity off-axis telescope
  - Designed and built by Vertex Antennentechnik GmbH, Duisburg
  - Novel crossed-dragone design → **sorry I'm not allowed to show it!**

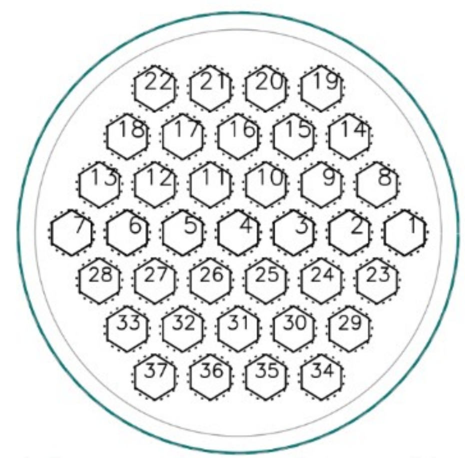
What is CCAT-prime?

- High throughput, high sensitivity off-axis telescope
  - Designed and built by Vertex Antennentechnik GmbH, Duisburg
  - Novel crossed-dragone design (concept by C. Dragone, AT&T 1978)

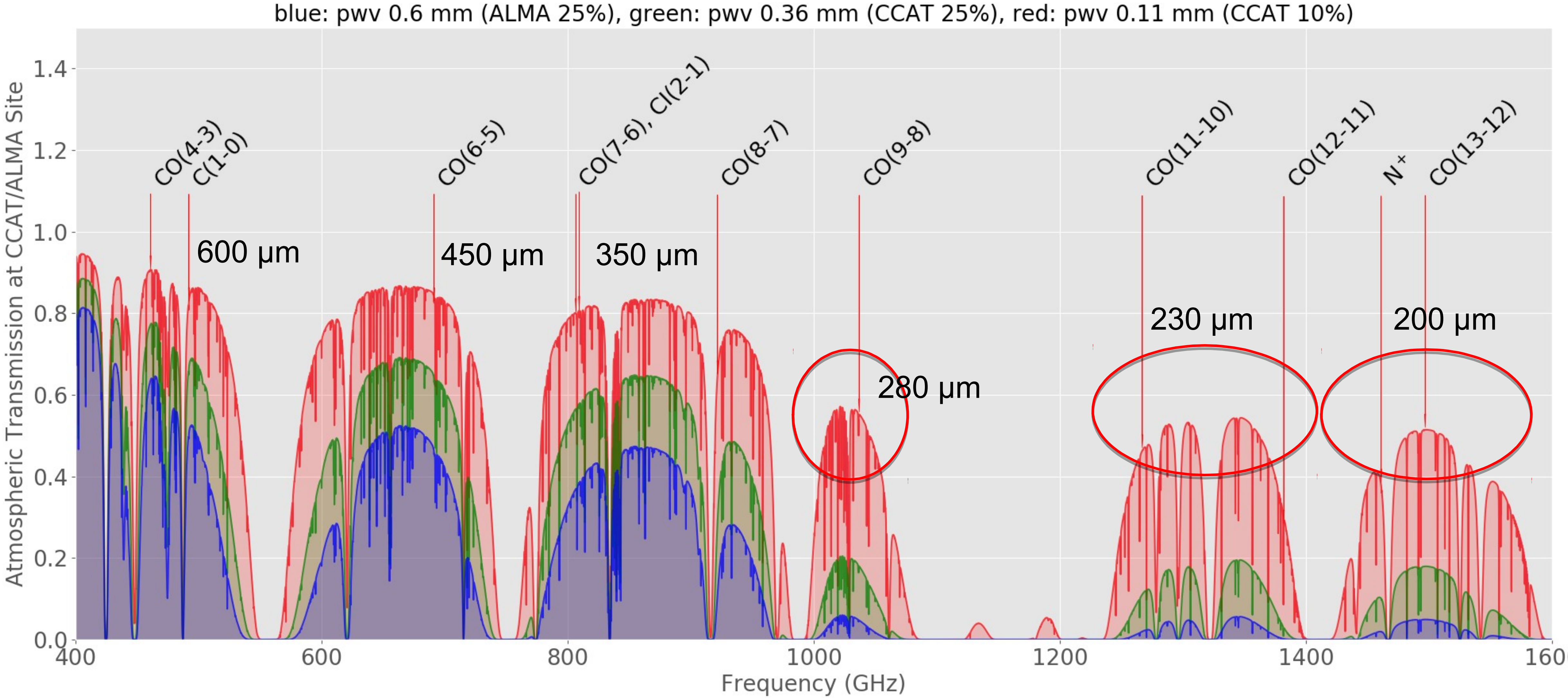
5.8m offset
hyperboloid

6m offset
paraboloid

- Wide field of view:
  2.5 m focal plane, 8 deg.
- Can host camera tubes with 10,000s of pixels



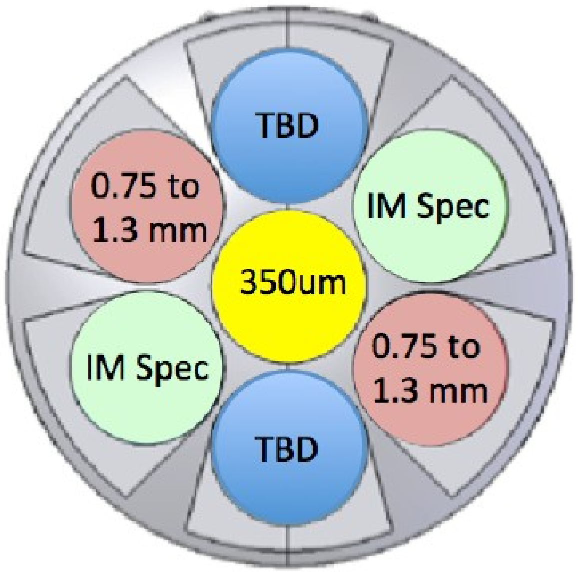
Atmospheric conditions: Cerro Chajnantor opens up the THz windows

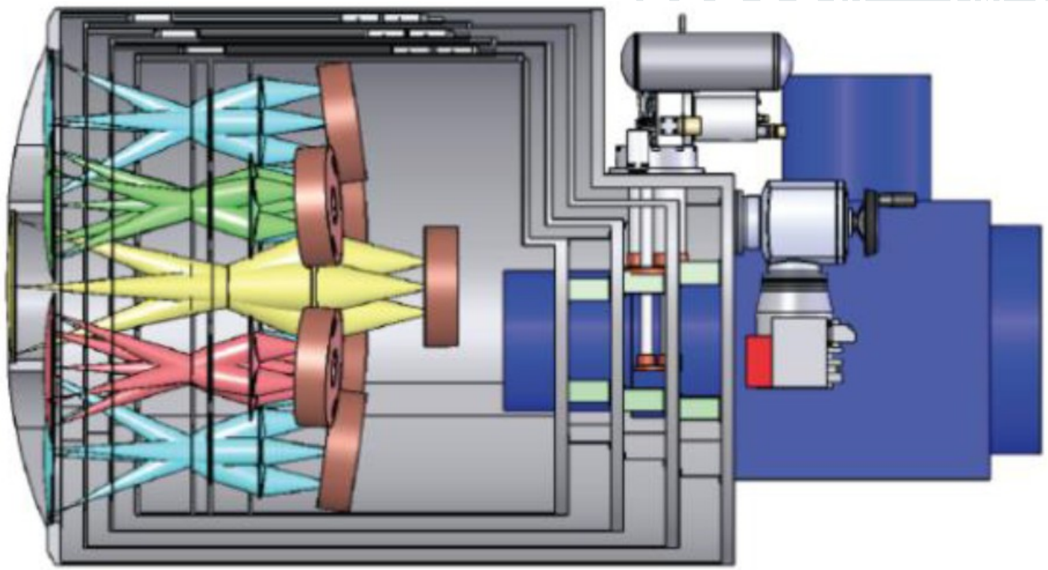


Science Instruments: First light

- Bolometer cameras
  - P-Cam, Cornell
  - Fabry-Perot interferometer for intensity mapping
- Heterodyne instrument for high res. Spectroscopy
  - CHAI, Univ. zu Köln

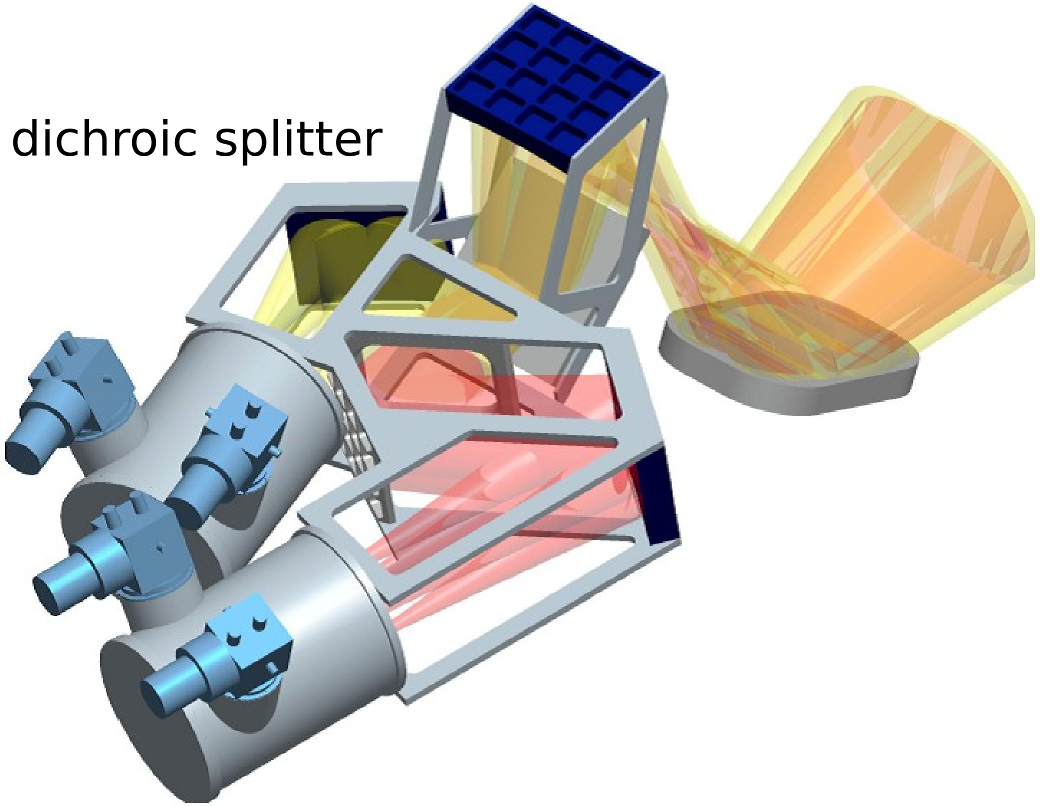
P-Cam



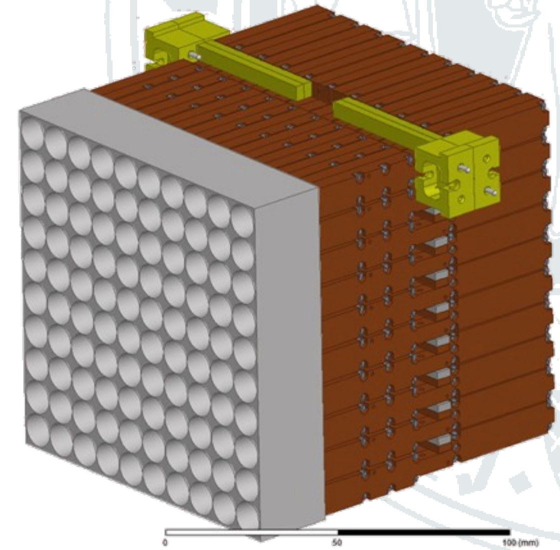


- 7-13 subcamera “tubes” populated with TES/KID bolometers
- each have FoV ~ 0.9 degree
- Fabry-Perot Interferometers on two tubes for intensity mapping.
- Cameras are modular (size, optics, filtration), easily exchanged
- Start with modest numbers of pixels and grow to fill out camera, then entire FoV if desired/affordable

CCAT Heterodyne Array Instrument (CHAI)



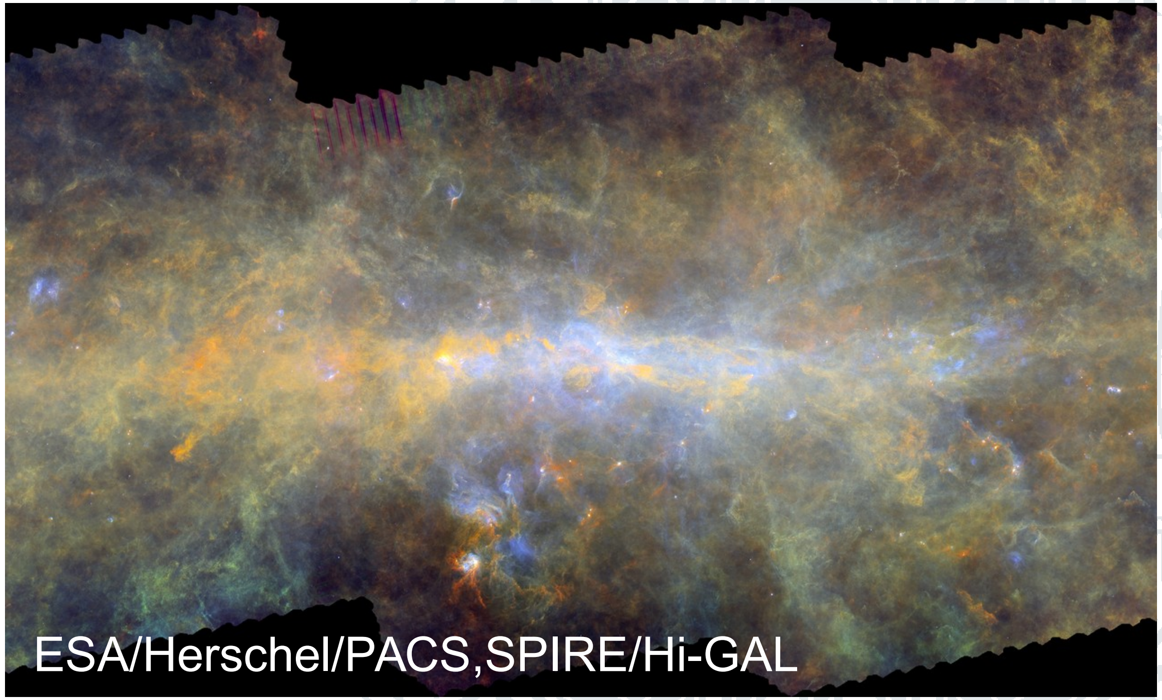
Graf, Stutzki et al.



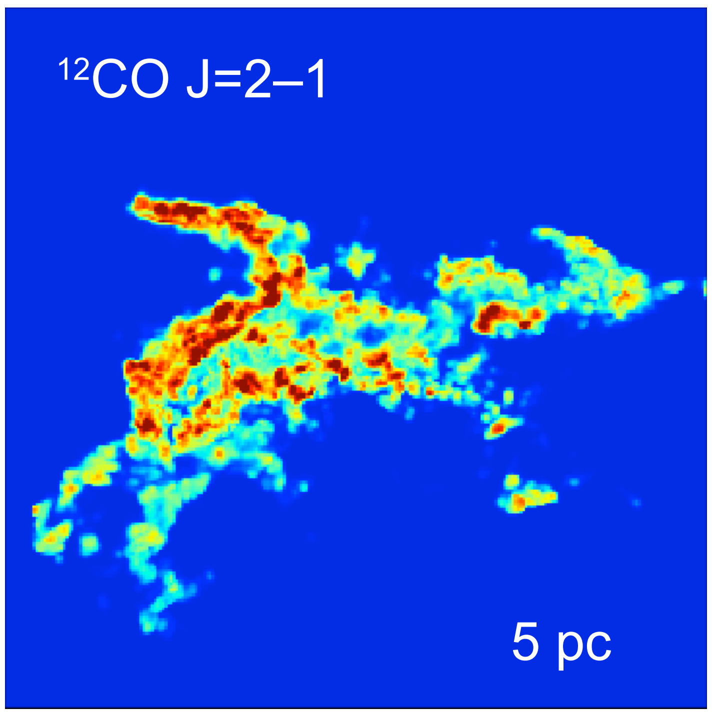
- Heterodyne, dual frequency array
- 500 GHz (600 μm) and 850 GHz (350 μm): CO 4-3,7-6 [CI] 1-0, 2-1
- Pixels: 64 (baseline), 128 (goal) in each band

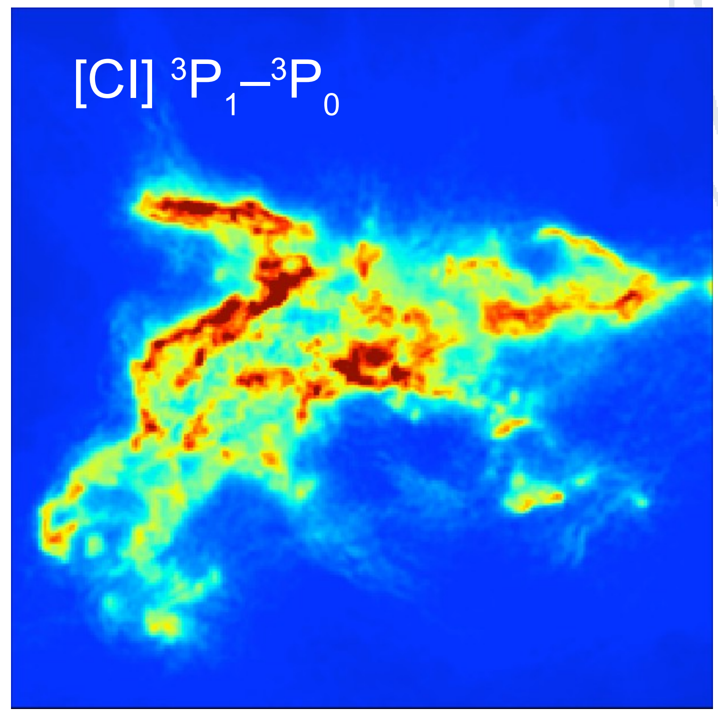
Star and galaxy formation and evolution

- (Sub)millimeter continuum
  - Cooling through dust emission
  - Spitzer, Herschel, …
- Cooling lines
  - Mid- to high-J CO lines
  - Fine structure lines: [CI], [CII], [OI], [NII]
  - Herschel/HIFI, APEX, SOFIA, ALMA, …
- Environmental factors
  - Metallicity, temperature, pressure, dust composition, (column) density, interstellar radiation field, ...



- Mass accretion as source of turbulence
  - Primarily diffuse atomic gas
    - Atomic hydrogen: highly confused emission
    - Atomic carbon:

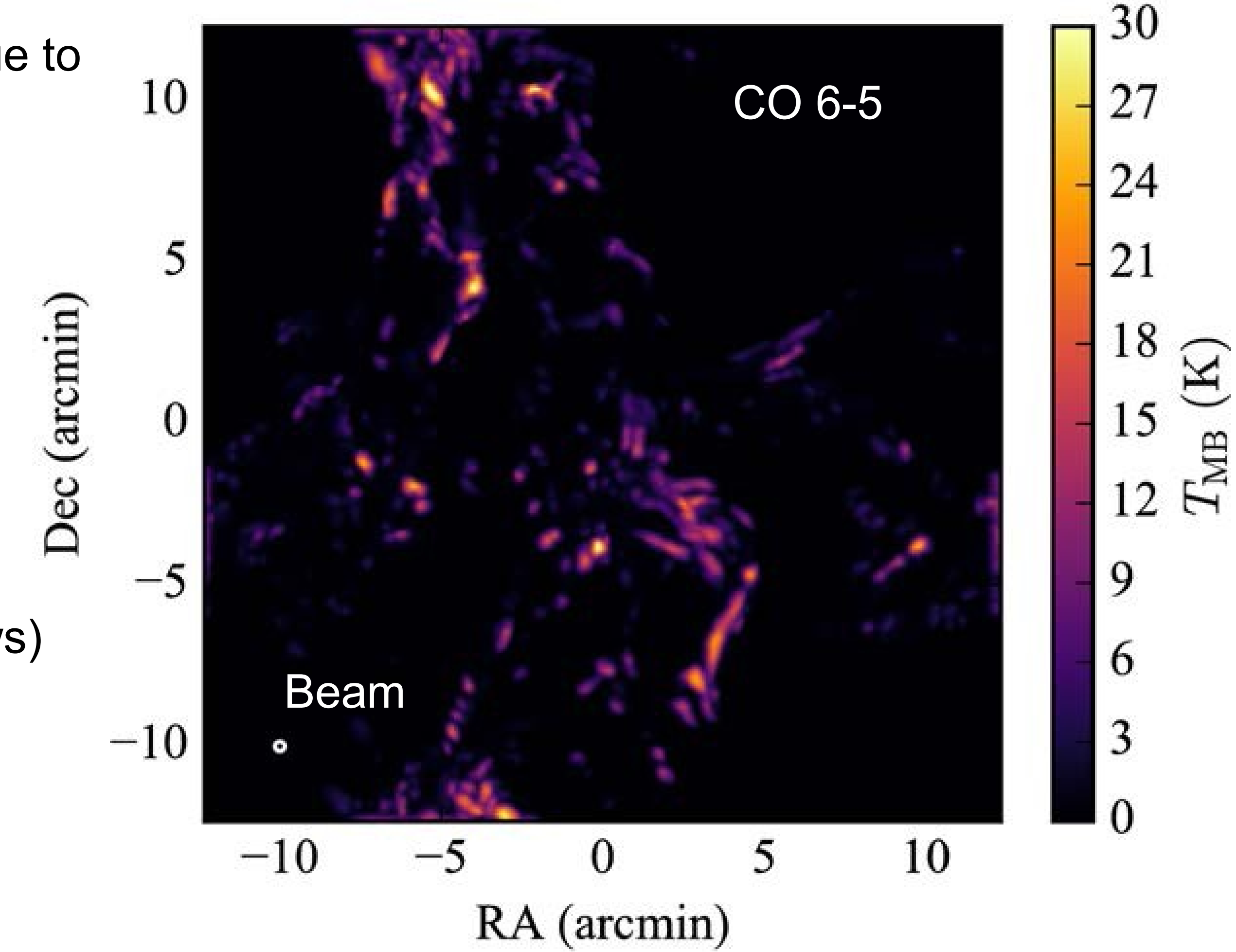




Simulations, Glover et al. 2015 + priv. comm.

- Dissipation of turbulence
  - Turbulence predicted to be highly dissipative: Line cooling in low velocity shocks
  - Mid-J CO lines will highlight dissipative shocks Supported through targeted Herschel observations (Pon et al. 2014)
  - Localized and direct measure of energy losses due to turbulent dissipation observed in post-shock gas

    Predicted CO 6-5 emission (simulation of Offer et al. 20014) for a cloud at 250 pc distance



  - Untangle other contributions to mid- and high-J emission (PDRs, winds, outflows, converging flows)

Observation plan for CHAI

Survey	Line	Size (sq.deg)	rms (K)	Δv (km/s)	Beam (")	Percentile	Time (h)	Days (8 h)
Gal. Plane	CI(1-0)	200	0.25	0.5	26	50	250	31
	CO(4-3)	200	0.25	0.5	26	50	100	13
LMC	CI(1-0)	64	0.10	1	26	50	250	31
	CO(4-3)	64	0.10	1	26	50	100	13
SMC	CI(1-0)	20	0.10	1	26	50	80	10
	CO(4-3)	20	0.10	1	26	50	30	4
Gould Belt	CO(6-5)	30	0.25	0.25	19	50	240	30
	^{13}CO(6-5)	30	0.25	0.25	19	50	135	17
	^{13}CO(8-7)	30	0.25	0.25	14	25	120	15
Total							**1305**	**163**
Zoom-ins	CI(2-1)	50	0.25	0.5	16	25	150	19
	CO(11-10)	1	0.25	0.5	10	10	96	12
	CO(13-12)	1	0.25	0.5	8	10	63	8

Other observations

- Protostellar variability
  - Monitoring of protostellar variability in the continuum near the peak of the protostellar SED on month to year timescales
- Spectroscopic observations of compact THz sources
  - In competition with SOFIA, but possible

Thank you!

II. Protostellar variability: Observation plan

- Monitor multiple fields on month timescales
  - Shortest CCAT-p wave lengths 350/450 micron: protostars are bright (~1 Jy)
  - Large field of view (1/3 sq.deg.):
    5 – 10 protostars in one shot, 10 – 100 Class I sources
  - Sensitivity 10 mJy / beam
    3 nights per month, 15 – 20 fields, ~6 sq. deg. total
    60 epochs in 5 years
  - Final depth comparable to that reached in cosmological surveys
  - Significant increase over ongoing JCMT SCUBA-2 survey in area and depth

III. Compact THz sources: A scientific niche for CCAT-p

- Atmospheric transmission good enough for THz observations during ~10% of time
- In competition with SOFIA
  - Angular resolution factor ~2.4 better for CCAT-p
  - Point source sensitivity better for CCAT-p below a certain system temperature
    This happens for pwv < 0.4 mm (25% of the time)
- Relevant for
  - Absorption towards continuum point sources (H_2D^+, ...)
  - Compact emission of highly excited lines

GEco Science case summary

- Study of formation, growth, evolution, and dispersal of molecular clouds
- Spectral large scale imaging with CHAI
  - High angular and spectral resolution
  - Large area coverage at low frequency, zoom-ins at higher frequencies
  - Nearby targets: Milky Way, Gal. Center, Gould Belt, LMC, SMC, nearby galaxies
  - [CI] to trace cloud mass accretion, gas temperature and (CO dark) mass.
  - Mid- and high-J CO / ^{13}CO to trace shocks and dissipation of turbulence, stellar feedback, gas excitation, density and mass
- Monitoring of protostellar variability in the continuum near the peak of the protostellar SED on year timescales
- Spectroscopic observations of compact THz sources