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CCAT-p

Galactic **Eco**logy (Geco):

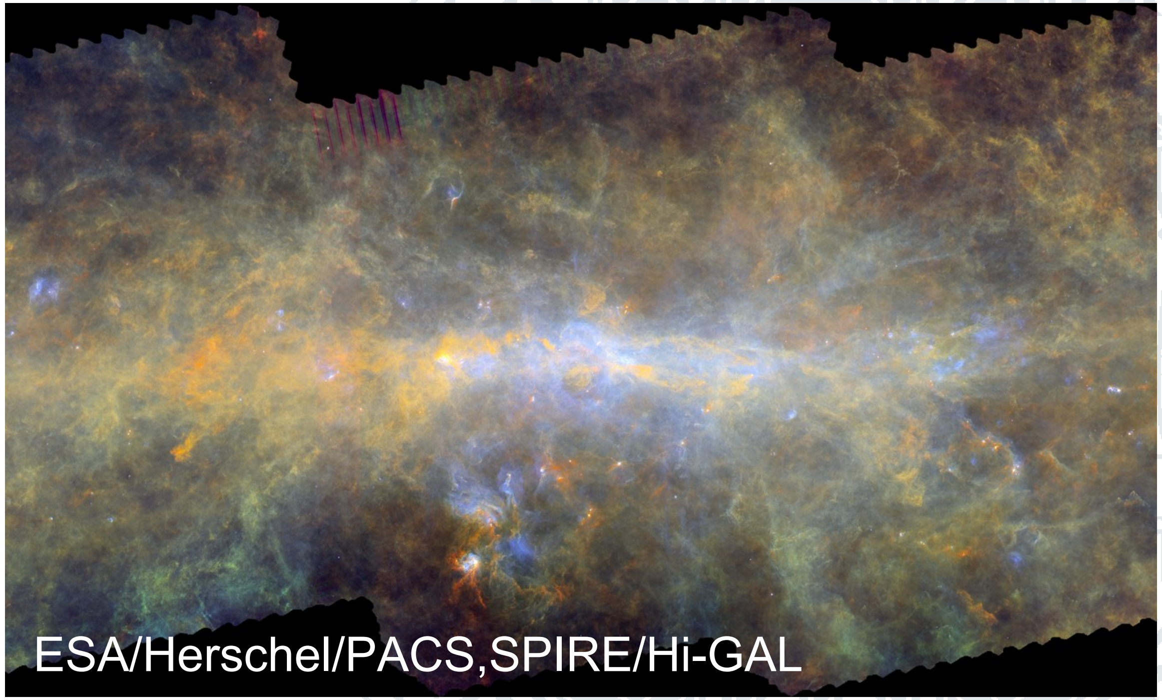
Study of the formation, growth, evolution, and dispersal of molecular clouds in the Milky Way, the Magellanic clouds and other nearby galaxies through submm spectroscopy and photometry

What governs the star formation rate?

- Gas flow over large scales: Mpc → AU
  - Accretion onto galactic disks
  - From galactic disks to molecular clouds
- Formation of clouds and clumps
  - Turbulence
- Heating and cooling
- Feedback
  - Winds, radiation, SNe

What do we have to observe?

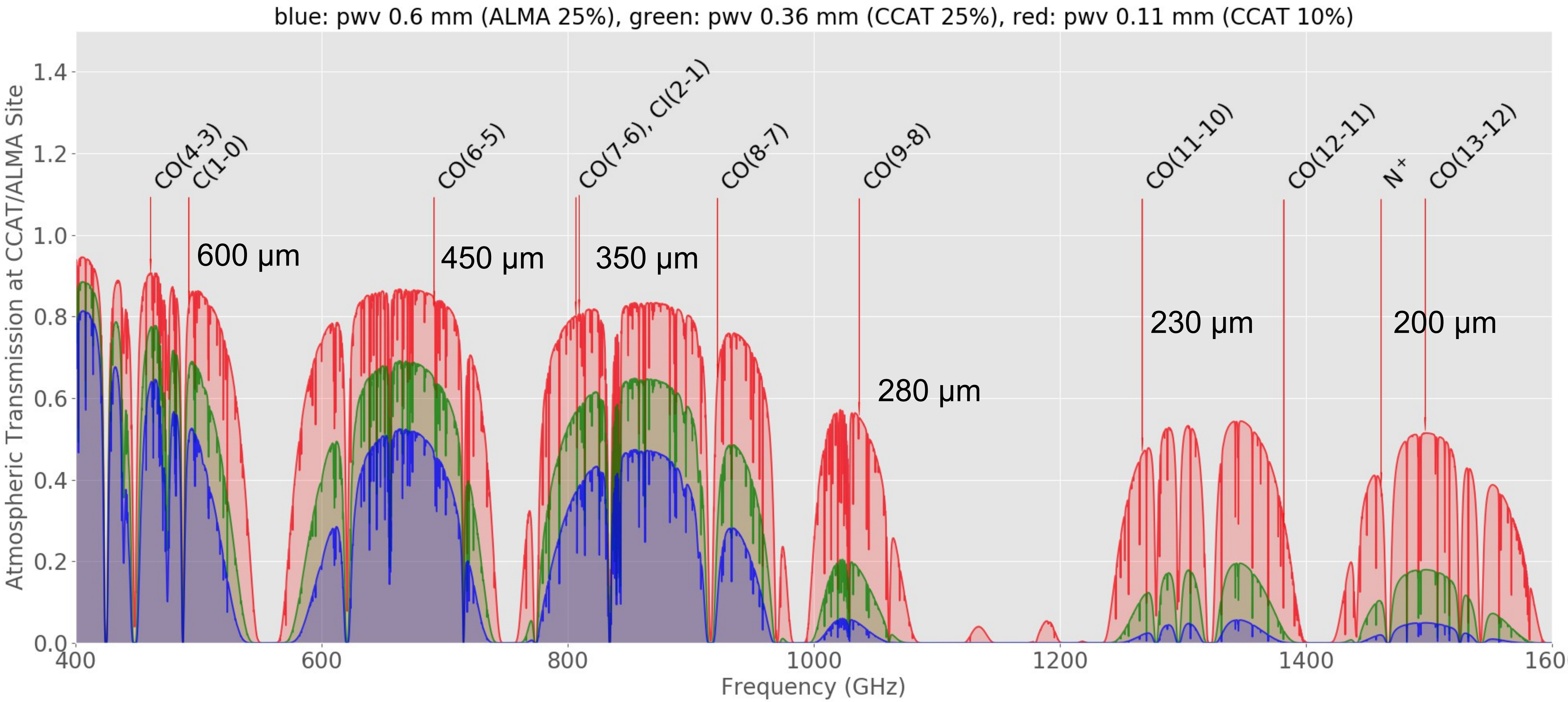
- (Sub)millimeter continuum
  - Cooling through dust emission
  - Spitzer, Herschel, ...
- Cooling lines
  - Mid- to high-J CO lines
  - Fine structure lines: [CI], [CII], [OI], [NII]
  - Herschel/HIFI, APEX, SOFIA, ALMA, …
- Environmental factors
  - Metallicity, temperature, pressure, dust composition,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



What do we have to observe?

- To understand the physics, we need high spatial and spectral resolution
  - Nearby targets
  - CCAT-p / CHAI
- Targets
  - Galactic star forming regions (Galactic Plane, Gould Belt)
  - Galactic Center
  - Magellanic clouds
  - Nearby galaxies
- Continuum (CCAT-p can observe close to the peak of the protostellar SEDs, 350/450 micron)
- Spectral lines accessible from 5600 m altitude

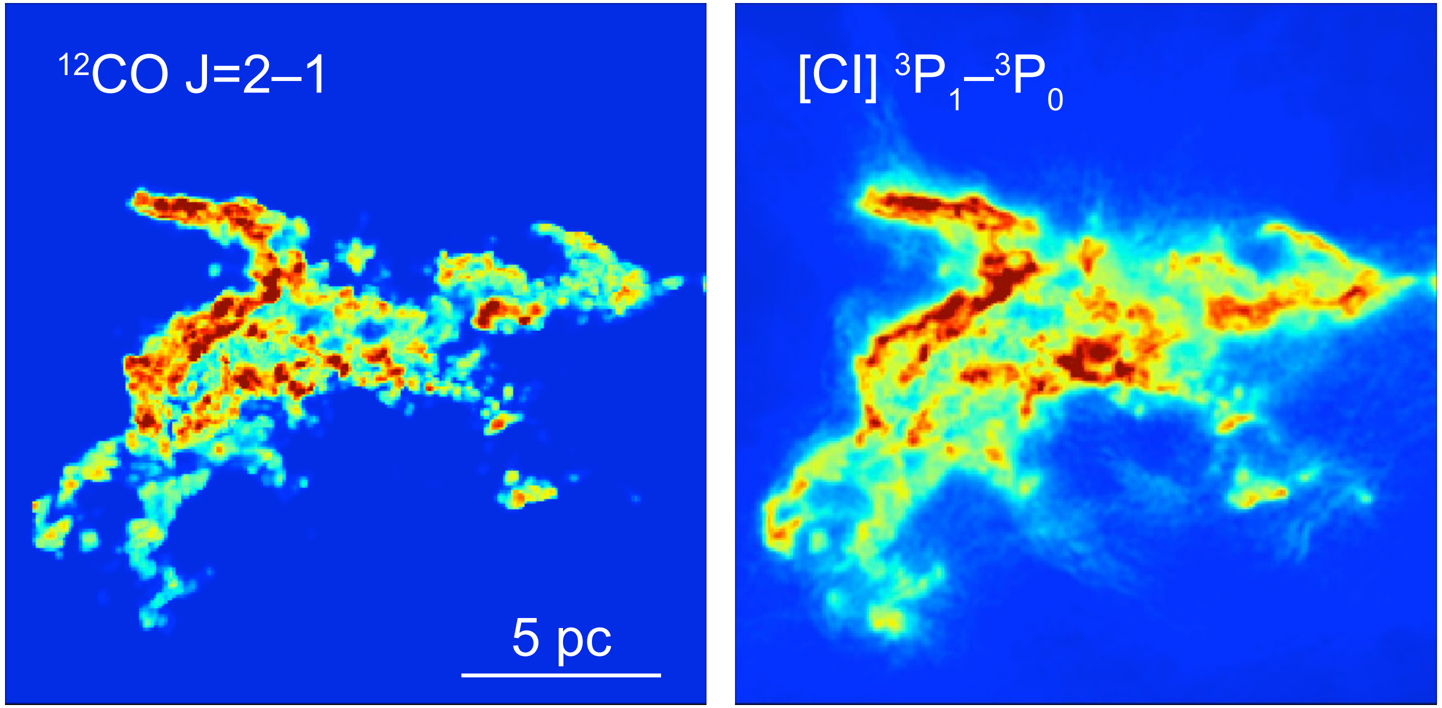
Atmospheric conditions: Cerro Chajnantor opens up the THz windows

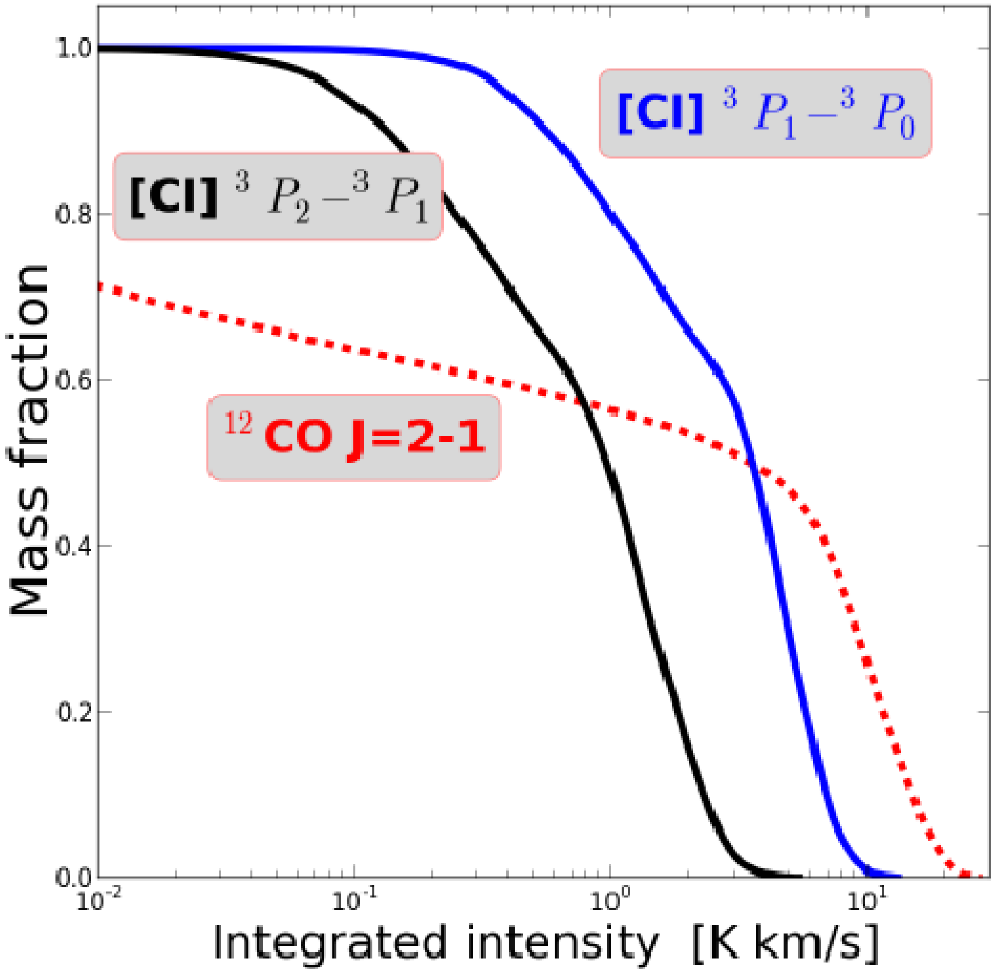


I. The Formation of molecular clouds and stars: The origin of turbulence

- Molecular cloud formation and evolution:
  Long-lived ↔ Short-lived Giant Molecular Clouds
- Long-lived, quasi-static GMCs
  - Must be supported against collapse
    - Magnetic fields, stellar feedback
    - Turbulence: quick dissipation → needs to be replenished (HII regions, SNe, …)
- Short-lived, dynamic GMCs
  - Observed complex structures, filaments
  - Supported by MHD turbulence simulations
  - Clouds form, collapse, form stars, and get dispersed, no equilibrium state
  - Accretion from surrounding material can drive observed turbulent motions (Goldbaum et al. 2011)
  - Large scale colliding flows of HI to create filamentary structures

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





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

I. The Formation of molecular clouds and stars: The origin of turbulence

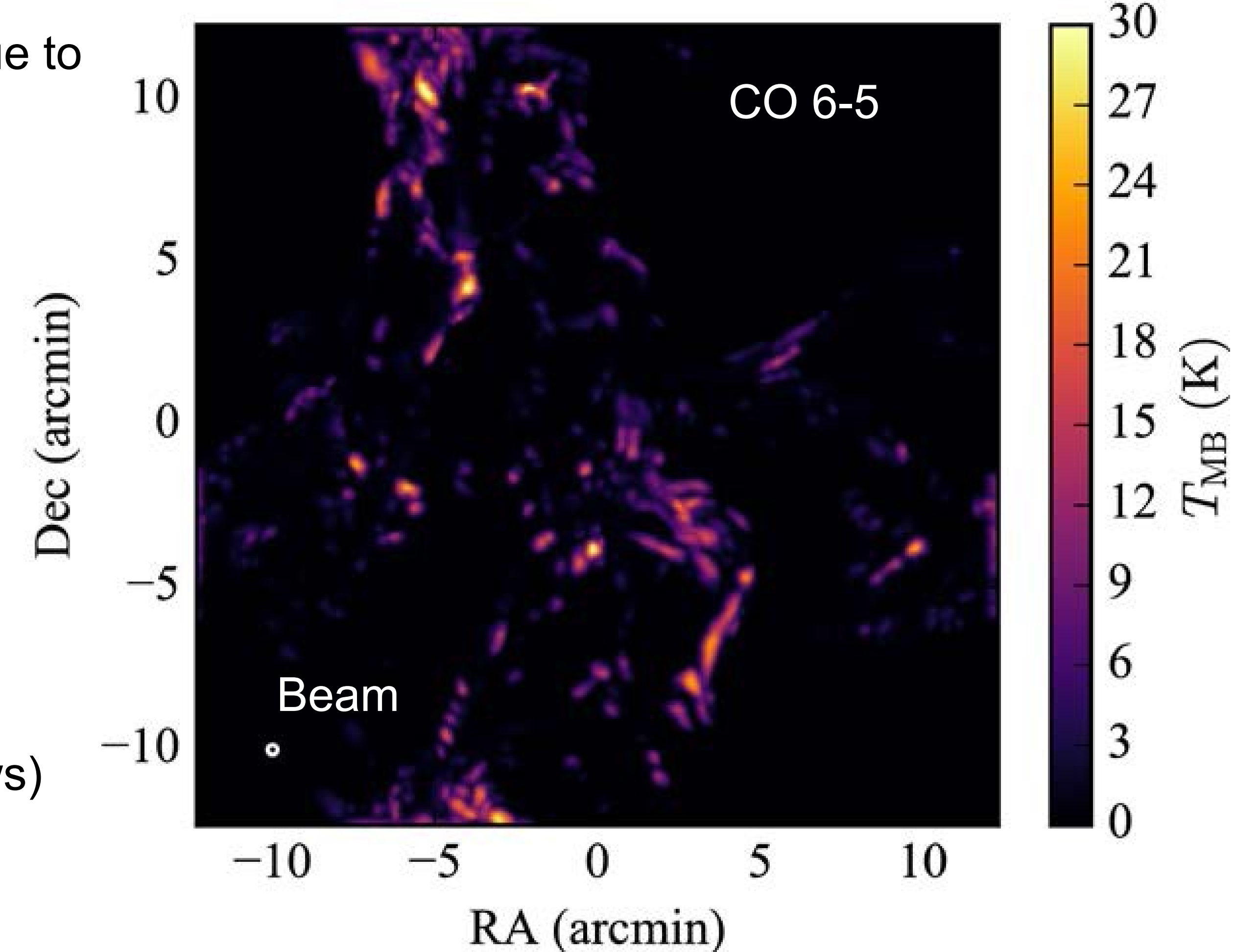
- Mass accretion as source of turbulence
  - Primarily diffuse atomic gas
    - Atomic hydrogen: highly confused emission
    - Atomic carbon
  - Low density molecular hydrogen:
    - Undetectable in the cold ISM
    - CO as proxy, but CO formation lags behind that of H_2

      → *CO-dark* molecular gas

- Atomic carbon is a promising tracer of cloud mass and accretion in the low density regimes of dynamic molecular clouds and filaments
- Requirements on observations
  - High angular and spectral resolution
  - Large scales
  - Both [CI] lines (to determine total mass in carbon)
  - Complementary CO → from existing surveys (FCRAO, Mopra, ...)

I. The Formation of molecular clouds and stars: Dissipation of turbulence

- How is kinetic energy dissipated at different scales?
  - 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. 2014) for a cloud at 250 pc distance

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

I. The Formation of molecular clouds and stars: Observation plan

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

See also posters by Monika Ziebart (M51) and Christoph Bruckmann (Milky Way)

II. Protostellar variability

- Evolution of mass accretion in low mass star formation
  - Core collapse
  - Circumstellar disk as mass reservoir
- Census of nearby star forming regions from Spitzer c2d (Dunham et al. 2012)
  - Protostellar life times, mean accretion rates
  - Typical luminosity of protostars too low for steady accretion
- Accretion not constant, episodic (FU Ori variables)
  - Pile up of material in outer disk
  - Mass accretion in outbursts as disk becomes gravitationally unstable
- Monitoring of bolometric luminosity on month timescales
  - With CCAT-p: observe close to the SED peak (~100 micron)
  - Timescales and amplitudes of variability
  - Direct measure of physical processes within the disk (AU scales)

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

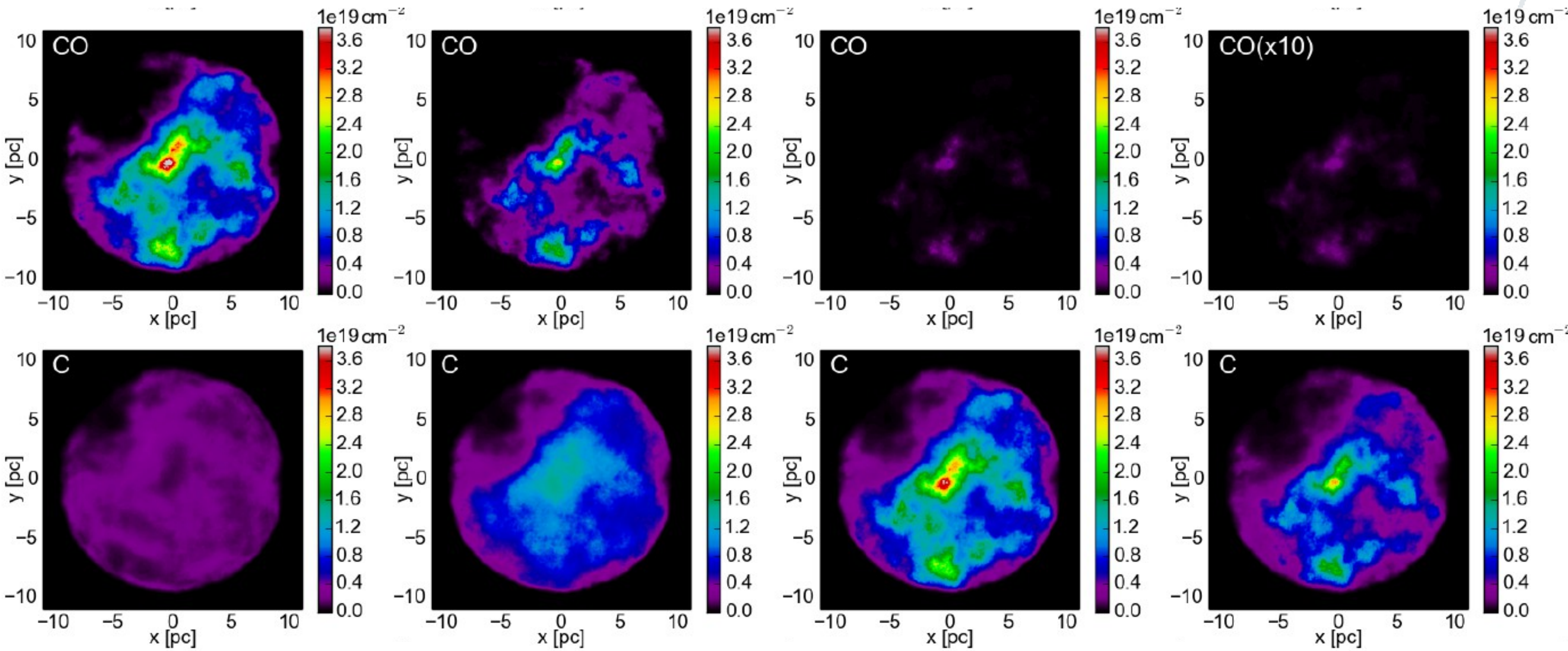
III. Compact THz sources: A scientific niche for CCAT-p

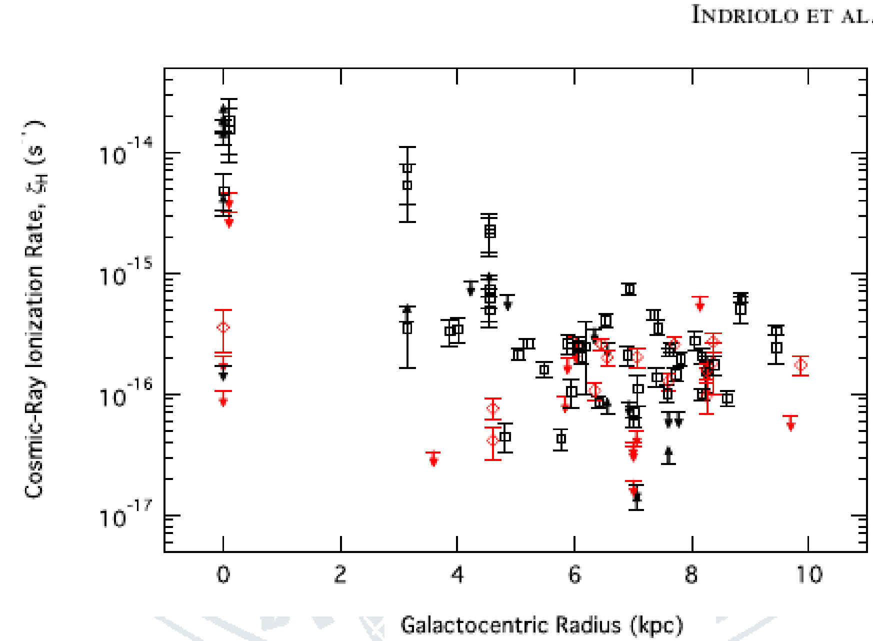
- Atmospheric transmission good enough for THz observations during ~10% of time
- In competition with SOFIA
  - Angular resolution factor ~2.4 better for CCAT-p
  - Point source sensitivity better for CCAT-p below a certain system temperature
    This happens for pwv < 0.4 mm (25% of the time)
- Relevant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

IV. Cosmis ray ionization

- CCAT-p will provide full surveys of Galactic Plane and LMC/SMC in CI

$\zeta = 10^{-17}$ $\zeta = 10^{-16}$ $\zeta = 10^{-15}$ $\zeta = 10^{-14}$





Simulations, Bisbas et al., 2017

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