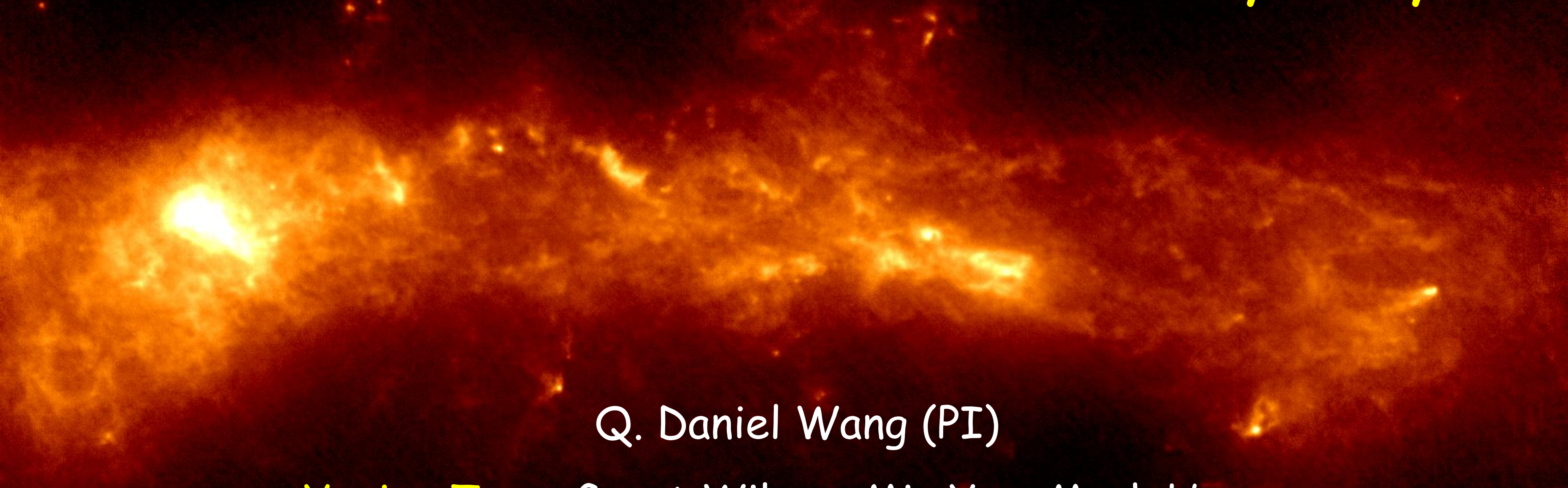
The Large Millimeter Telescope Survey of the Central Molecular Zone of the Milky Way



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Dependence of dust properties on the environment

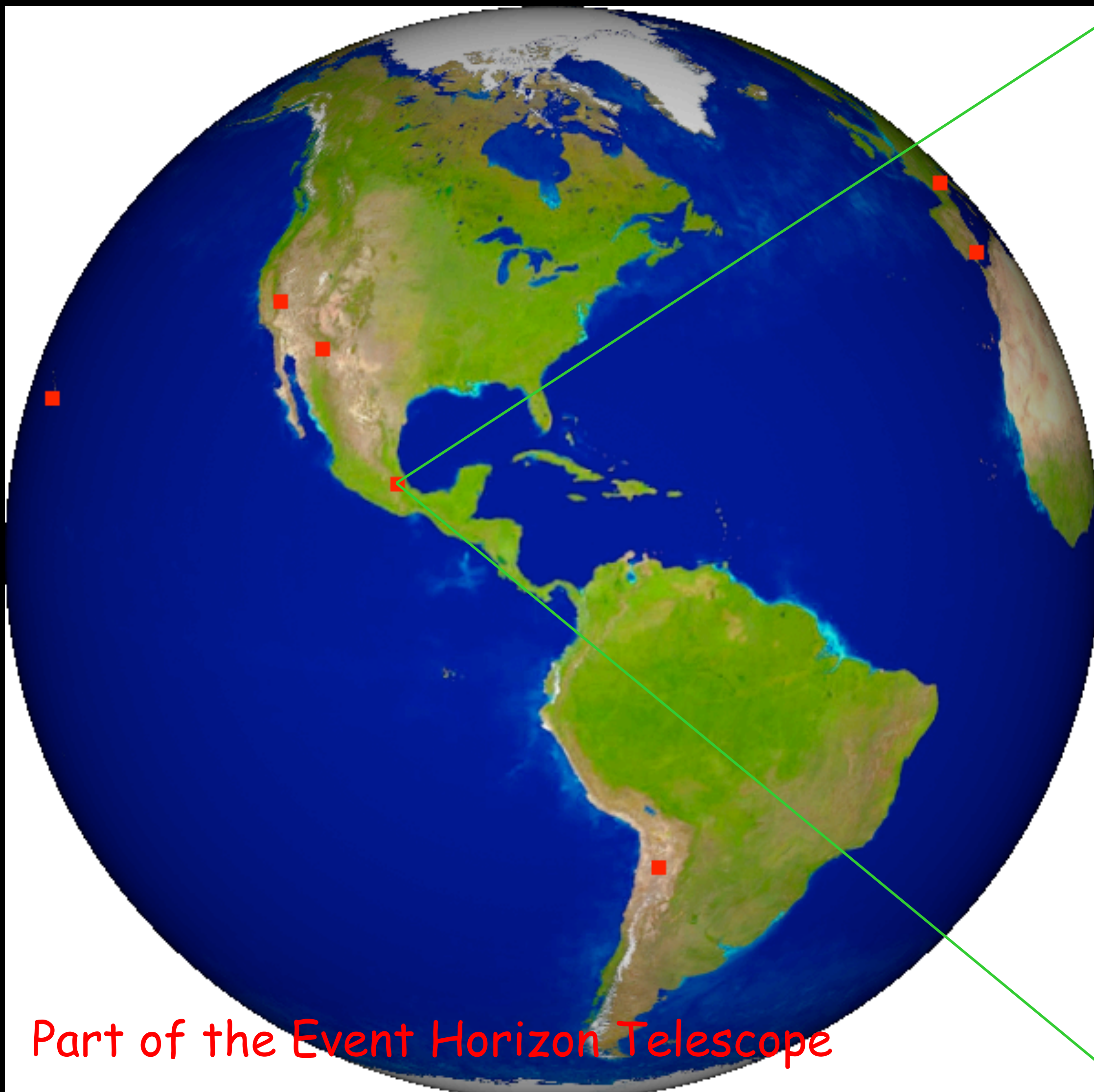
- Metal abundances → raw material for dust
- Turbulence, as well as density and temperature of the ISM → dust formation, growth, and/or destruction
- Radiation field, cosmic ray, B-field → dust thermal, emission, and spin states

Little is known on dust properties in extreme environments: e.g., galactic nuclei & extreme star forming regions seen at high-z!

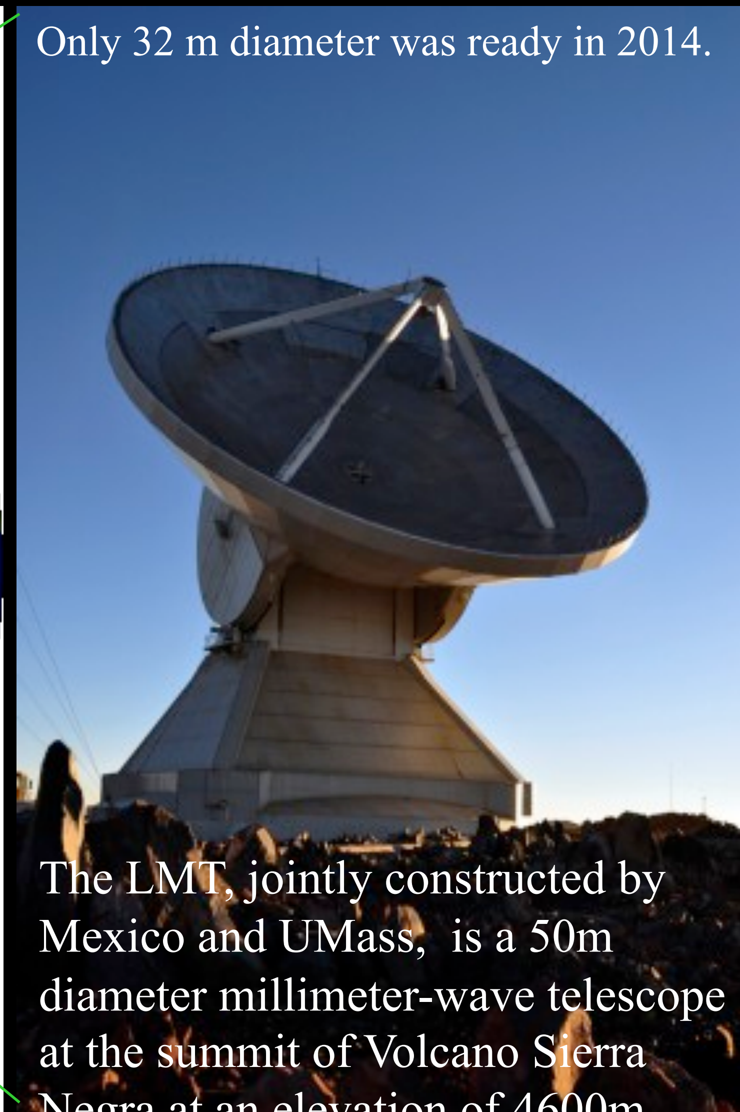
Study dust properties in the central molecular zone

- Motivation:
  - An excellent local lab for a close-up study of dust under extreme condition
  - Necessary step to understand the overall stellar structure, star formation history, etc.
- Approach:
  - Map out the emission of dust to infer its temperature, emissivity, and column density (or N_H) distributions.

The Large Millimeter Telescope



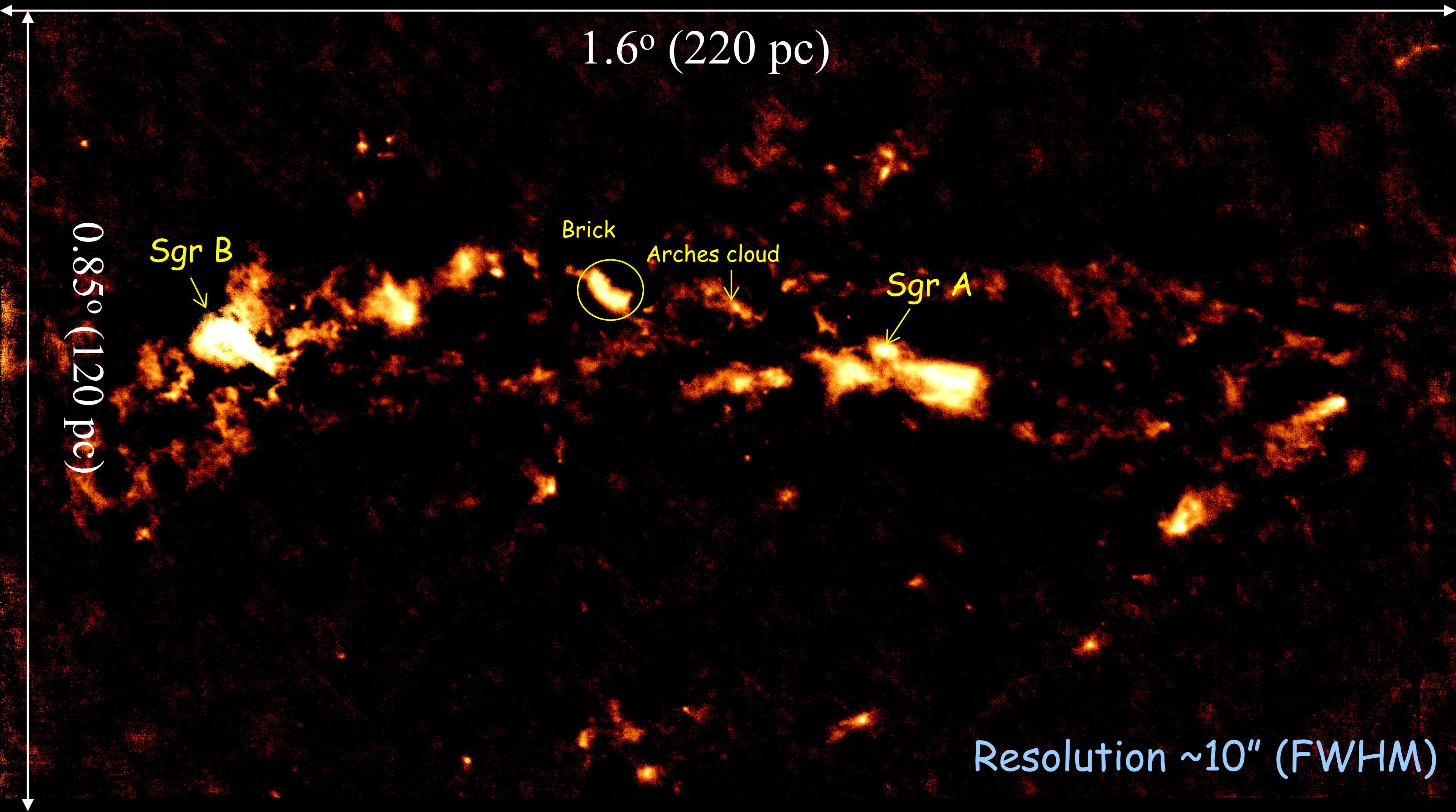
Part of the Event Horizon Telescope



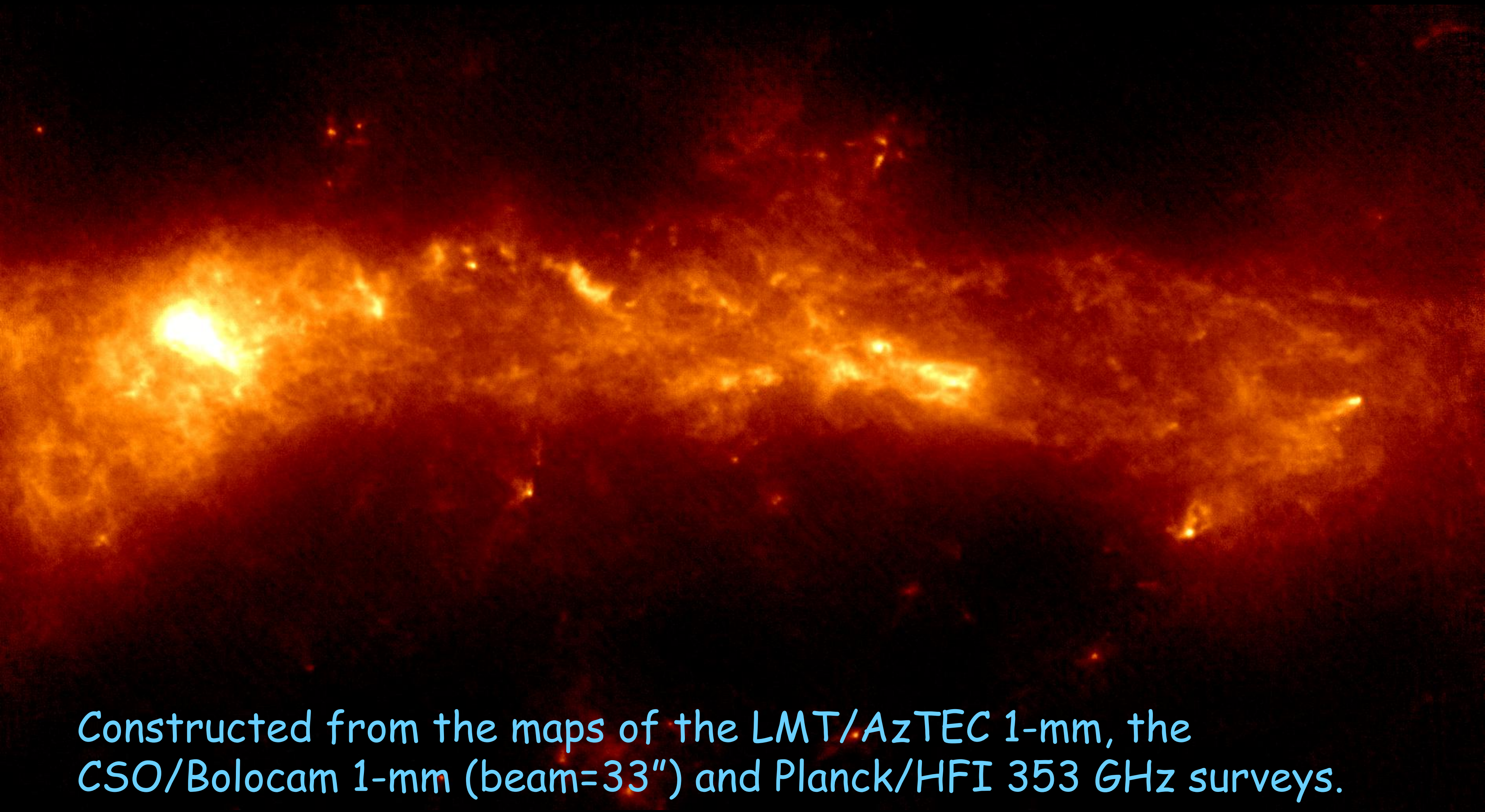
Only 32 m diameter was ready in 2014.

The LMT, jointly constructed by Mexico and UMass, is a 50m diameter millimeter-wave telescope at the summit of Volcano Sierra Negra at an elevation of 4600m.

LMT/AzTEC 1-mm map of the CMZ



1-mm composite map of the CMZ



Constructed from the maps of the LMT/AzTEC 1-mm, the CSO/Bolocam 1-mm (beam=33") and Planck/HFI 353 GHz surveys.

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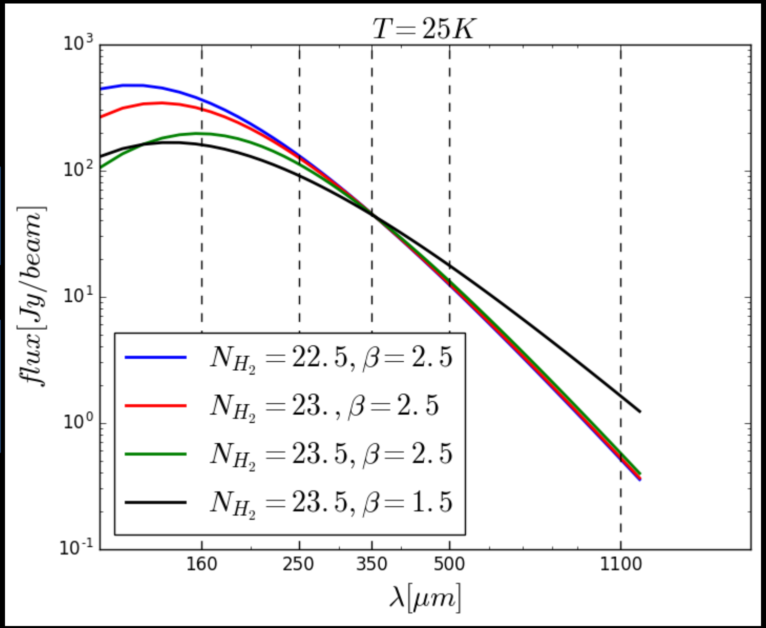
Hierarchical Bayesian SED Fitting

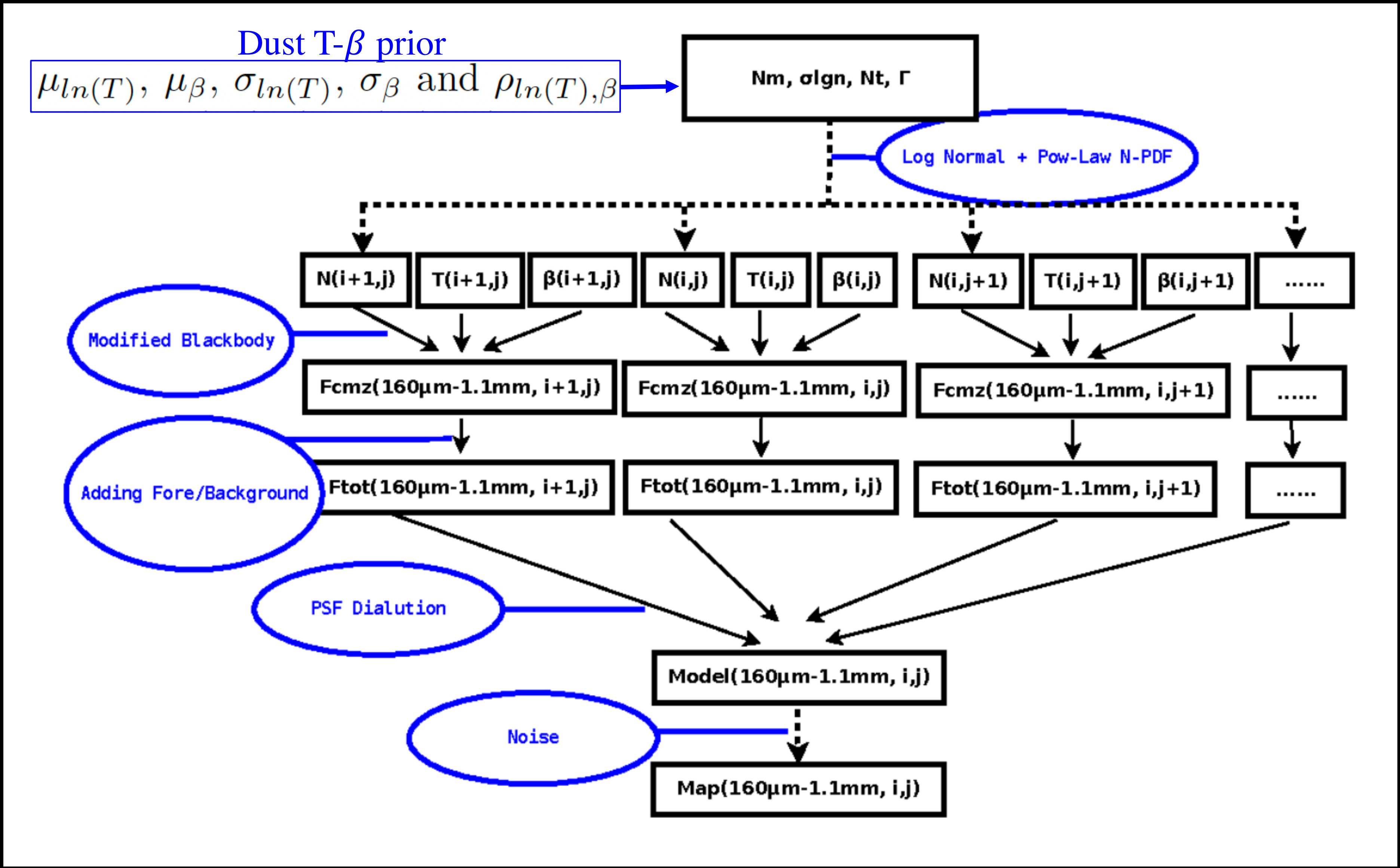
- Dust emission at 1 mm is optically-thin and is only linearly dependent of temperature.
- MCMC Bayesian SED is fitted in 5 bands: 4 from Herschel and 1 from the LMT, covering the 160 µm - 1.1 mm range.
- N_H distribution is modeled as a hyper prior: a log-normal + (broken) power law.

$$F_{ix,iy}(\nu_j) = [1 - exp(-\tau_{ix,iy,\nu_j})]B_{\nu_j}(T_{ix,iy})\Omega_j$$

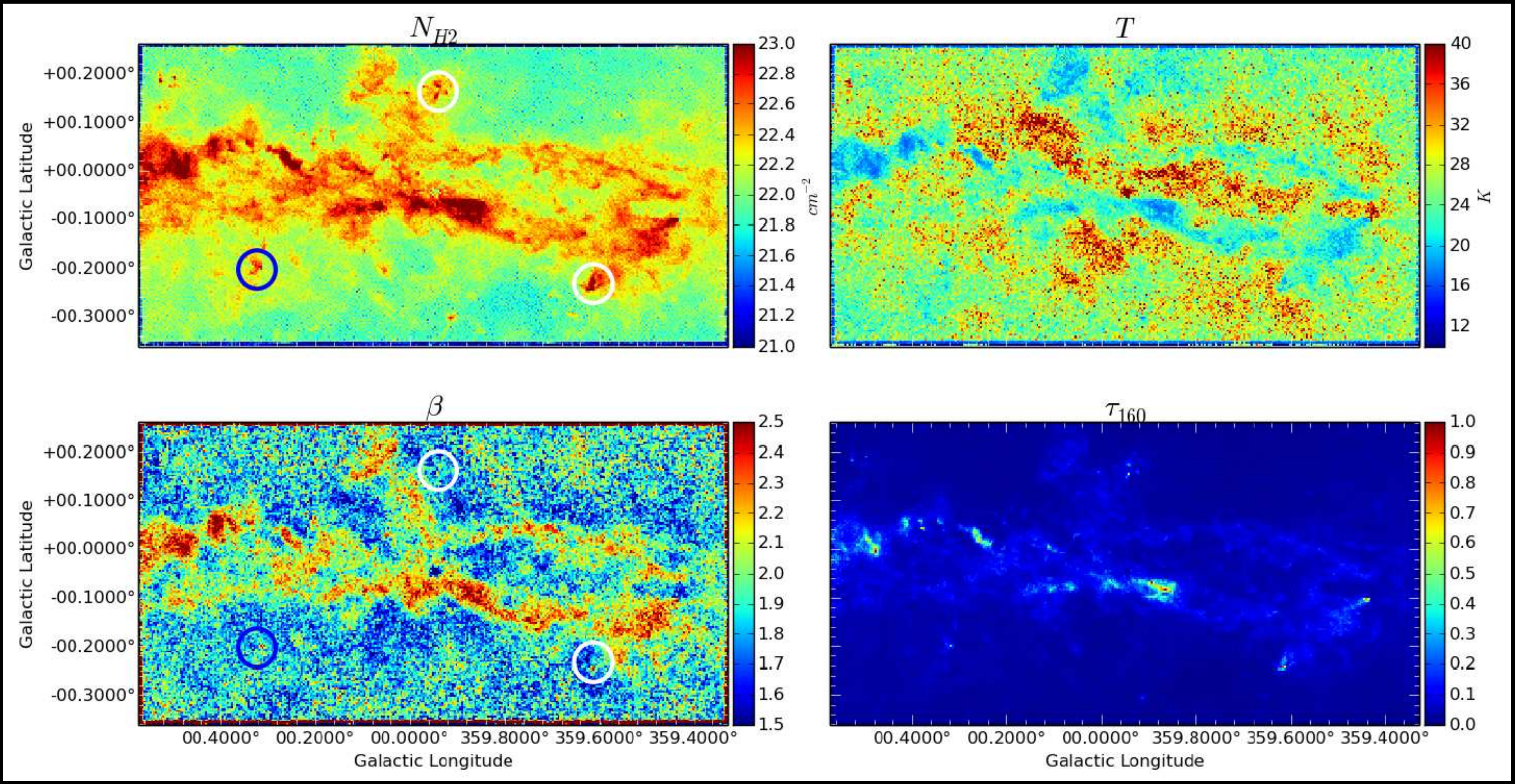
$$\tau_(ix, iy, \nu_j) = \kappa_0(\frac{\nu_j}{\nu_0})^{\beta_{ix,iy}}\mu m_H \times N_{H_2\,ix,iy} \times 1\%$$



Hierarchical Bayesian SED Fitting



1-T dust SED modeling: paramter maps



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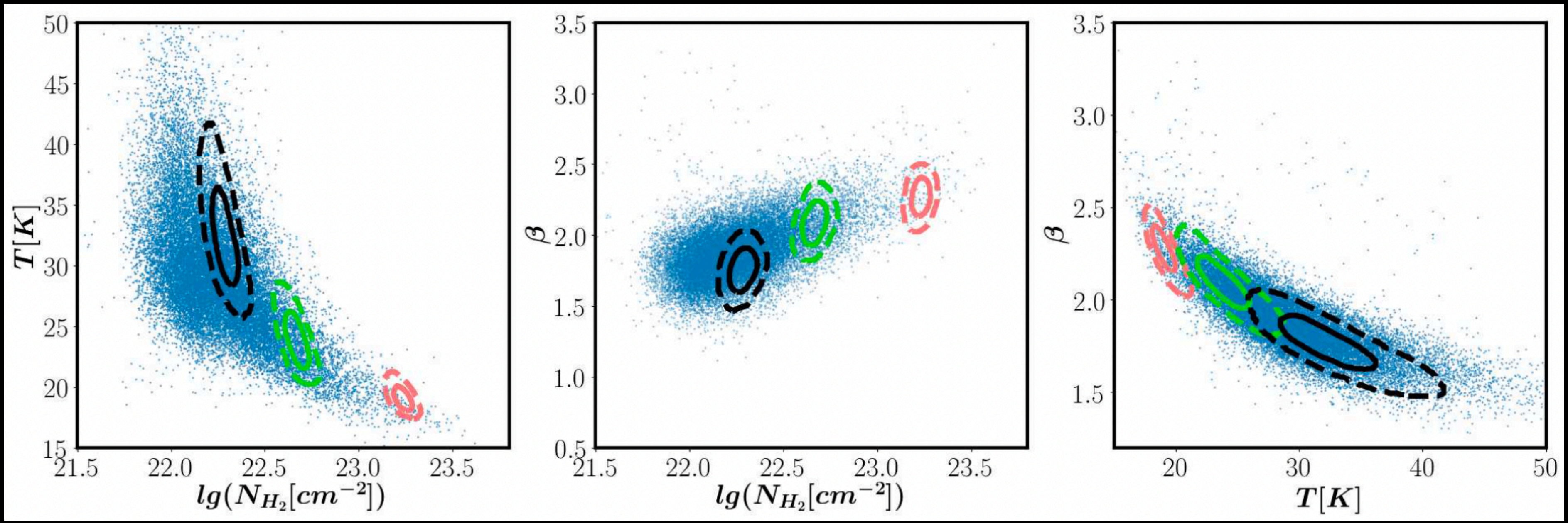
1-T dust SED modeling: dust parameters

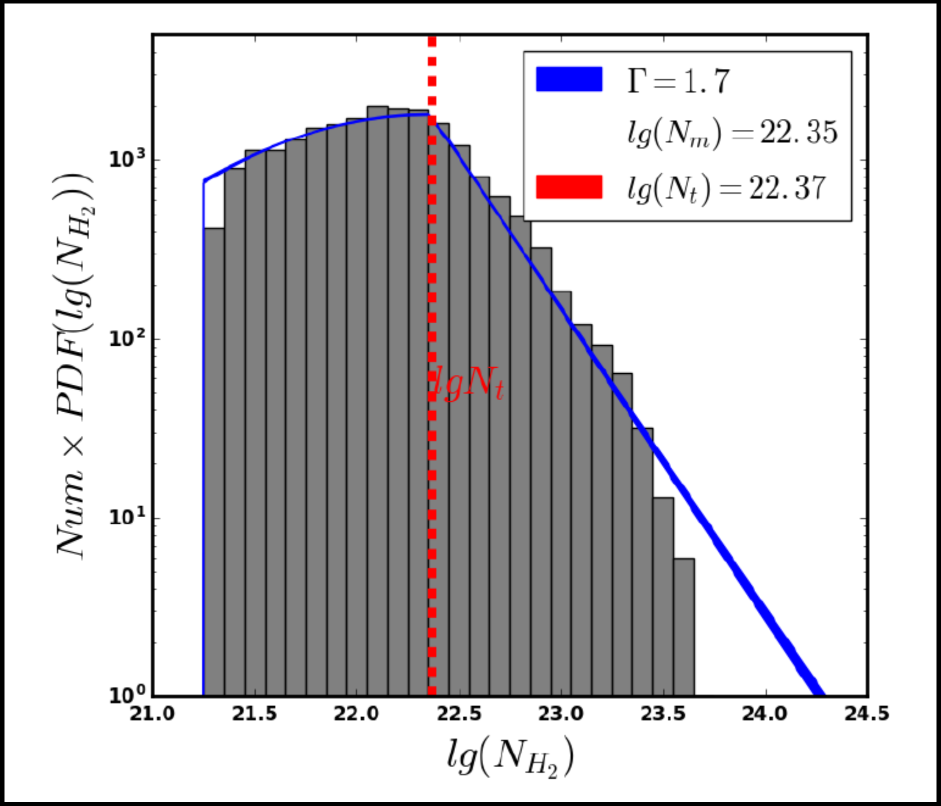


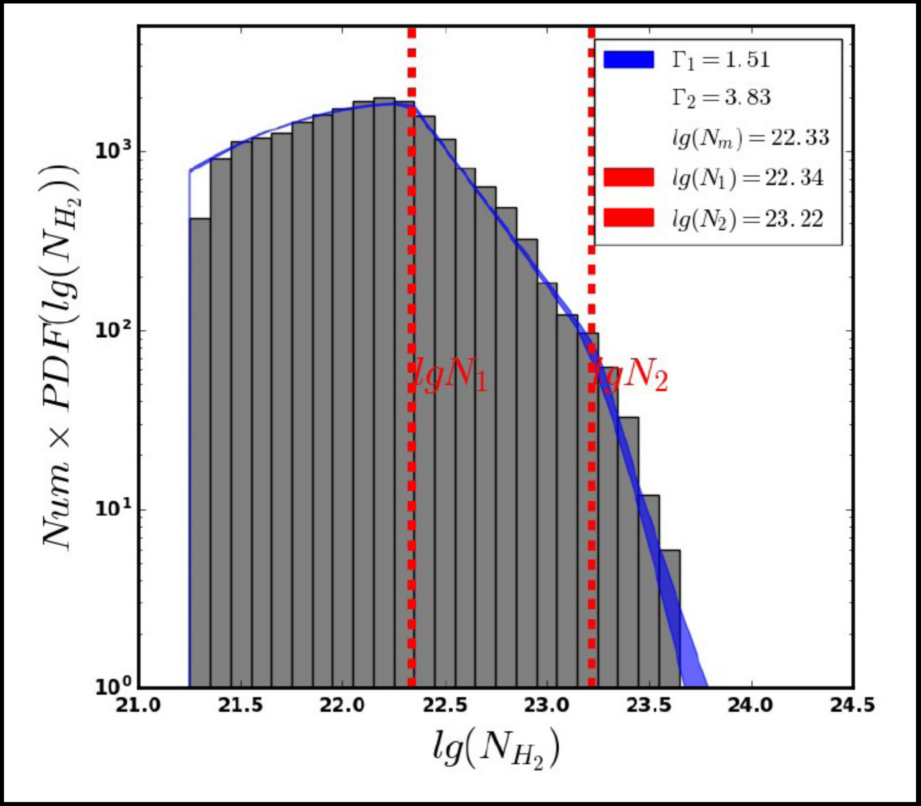
Dust emissivity index increases with N_H

→ a deficiency of large grains (e.g., due to turbulent shattering) and/or a fundamental change in dust optical properties (crystallization).

→ partly explaining the low dust temperature inferred previously for the CMZ.

1-T dust SED modeling: N_H PDF





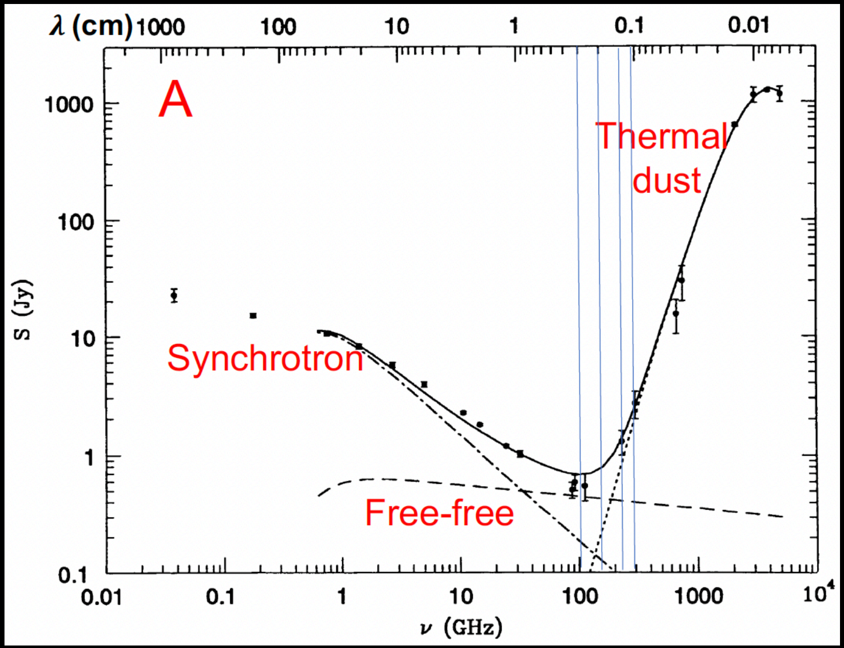
N_H-PDF is better fitted by a broken power-law signature at high N_H; no significant dependence on the cloud location

→ consistent with the low star formation rate of the clouds.

Summary

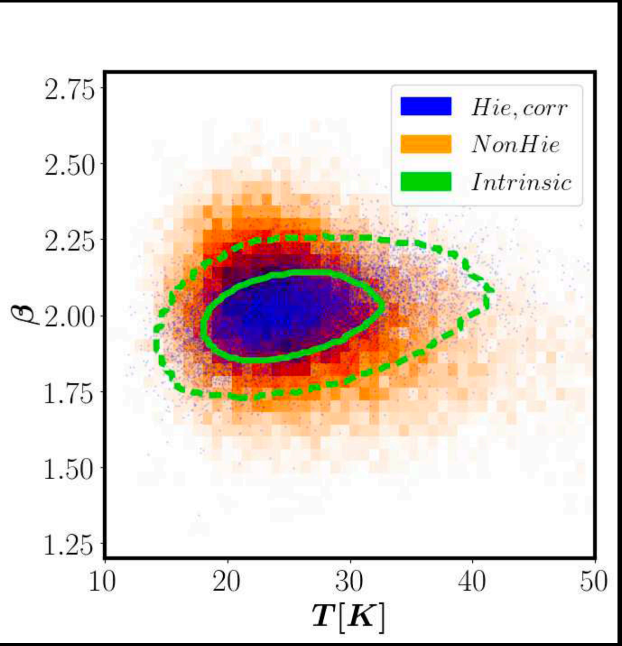
- We have made a wide-field, ~10″ resolution survey of 1.1-mm continuum emission from the CMZ.
- SED analysis of the combined complementary data sets →
  - Emissivity index increases from 1.8 to 2.4 with N_H=$10^{22.5}$ to $10^{23.5}$ cm^{-2}.
  - this correlation is not due to model degeneracy and may be caused by dust grain shattering in a highly turbulent environment
  - Dust temperature depends on the assumed index, changes; assuming the N_H dependence leads to a (up to 50%) higher dust temperature.
  - N_H-PDF is a good indicator of the cloud structure at a spatial scale of 0.5 pc and typically shows a broken power-law signature at high N_H

Future work



- Extend the wavelength coverage of the dust emission (3-bands with LMT/TolTEC), particularly powerful for accurately determining β and decomposing nonthermal and ionized gas contributions at longer wavelengths.
- Construct single disk + ALMA dust emission map.
- Map out various key molecular lines to study the kinematics and chemistry of CMZ.
- Constrain 3-D spatial distributions of stars, dust, and gas properties.

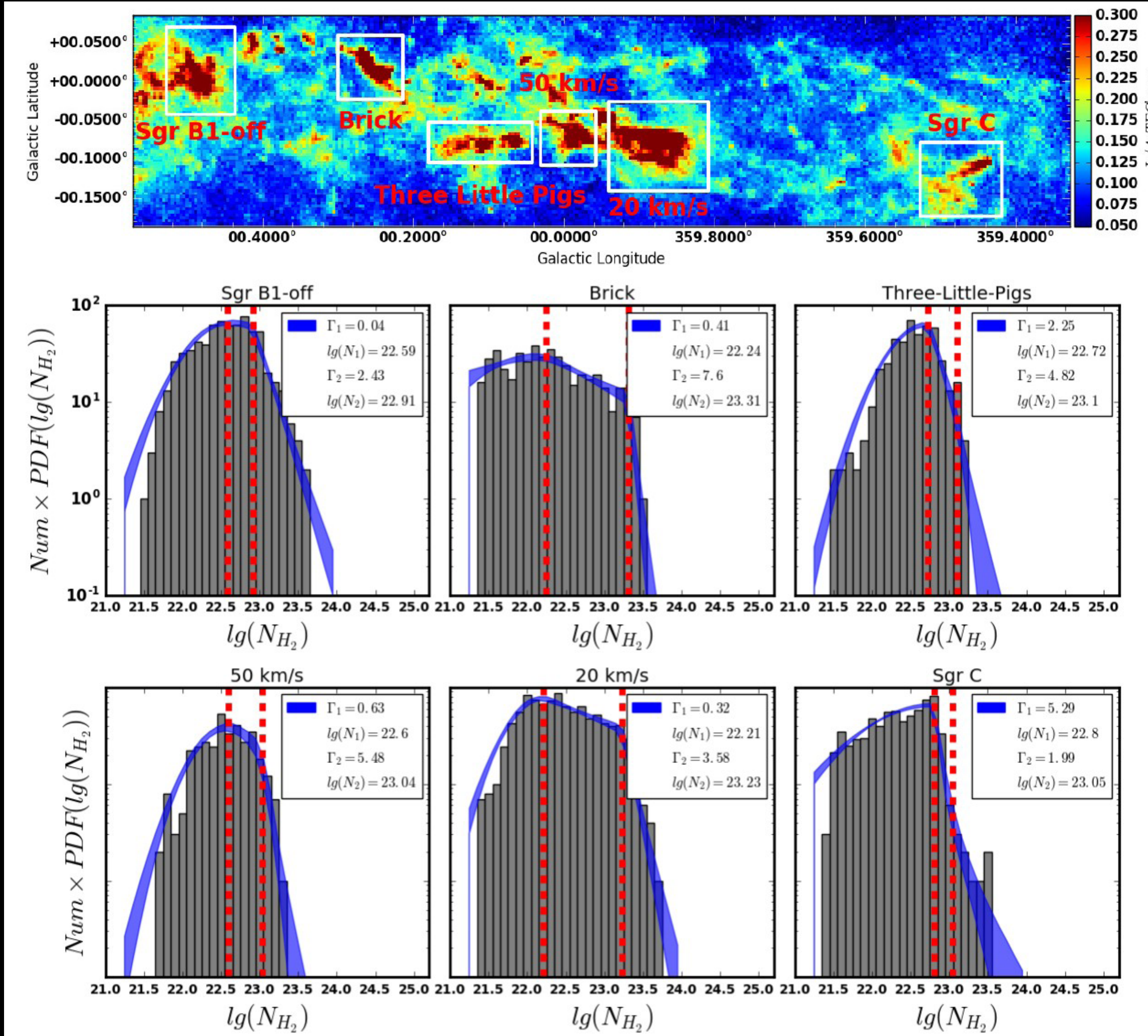
Hierarchical Bayesian analysis of dust parameters



$$P(\mu, \Sigma | D) = \prod_i P(D|\mathbf{x_i}) P(\mathbf{x_i}|\mu, \Sigma) \times P(\mu, \Sigma)$$

$$P(\mathbf{x_i}|\mu, \Sigma) \propto \frac{1}{|\Sigma|^{1/2}} \times [1 + \frac{1}{d}(\mathbf{x_i} - \mu)^T \Sigma^{-1} (\mathbf{x_i} - \mu)]^{-(d+2)/2}$$

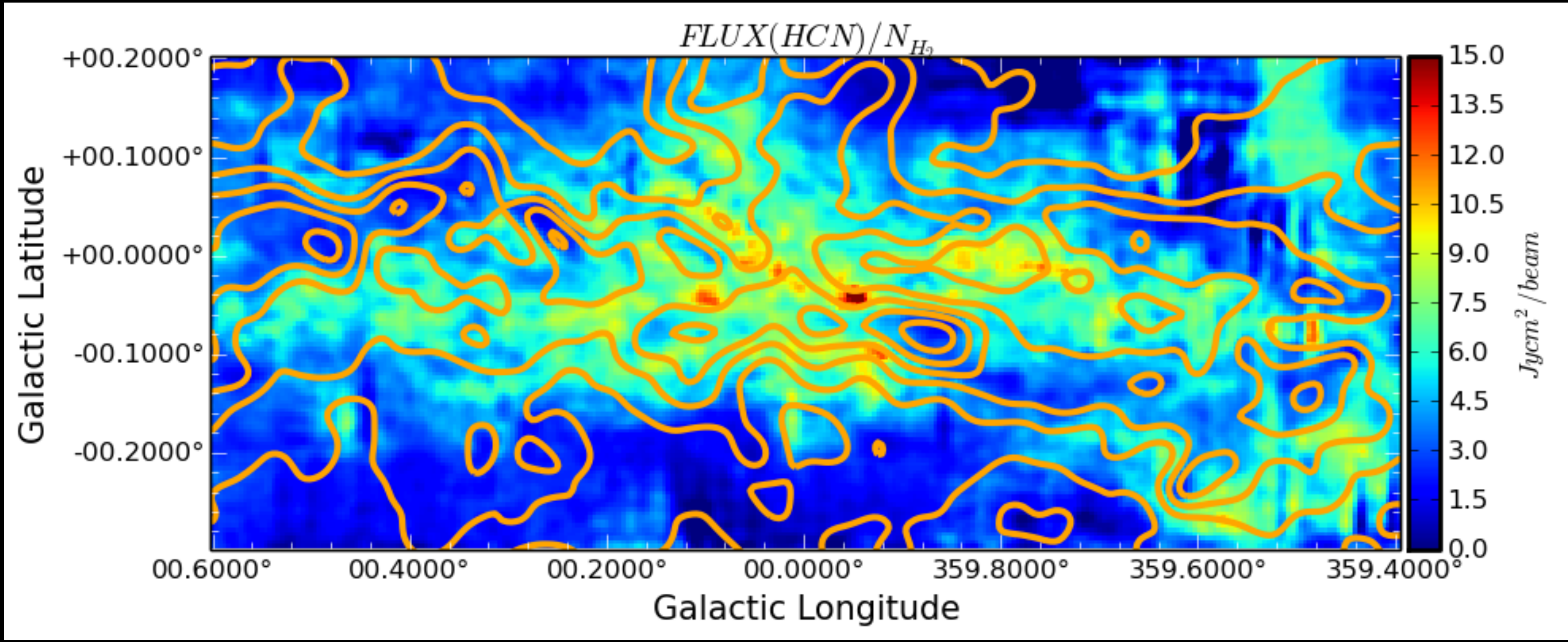
$$\mathbf{x_i} = (ln(T_i), \beta_i)$$



Sgr B1-off
Brick
50 km/s
Three Little Pigs
20 km/s
Sgr C
Galactic Latitude
Galactic Longitude
$Jy/AzTECbeam$
Sgr B1-off
$\Gamma_1 = 0.04$
$lg(N_1) = 22.59$
$\Gamma_2 = 2.43$
$lg(N_2) = 22.91$
Brick
$\Gamma_1 = 0.41$
$lg(N_1) = 22.24$
$\Gamma_2 = 7.6$
$lg(N_2) = 23.31$
Three-Little-Pigs
$\Gamma_1 = 2.25$
$lg(N_1) = 22.72$
$\Gamma_2 = 4.82$
$lg(N_2) = 23.1$
50 km/s
$\Gamma_1 = 0.63$
$lg(N_1) = 22.6$
$\Gamma_2 = 5.48$
$lg(N_2) = 23.04$
20 km/s
$\Gamma_1 = 0.32$
$lg(N_1) = 22.21$
$\Gamma_2 = 3.58$
$lg(N_2) = 23.23$
Sgr C
$\Gamma_1 = 5.29$
$lg(N_1) = 22.8$
$\Gamma_2 = 1.99$
$lg(N_2) = 23.05$
$Num \times PDF(lg(N_{H_2}))$
$lg(N_{H_2})$

Enhanced HCN line emission in the Sgr A cloud complex

The enhancement can be explained by high free electron density in low density regions, which could be due to shock X-ray/CR (Goldsmith & Kauffmann 2017).



All data smoothed to the angular resolution of the Mopra HCN(J=1-0) image (39″; Jones et al. 2012)

Hierarchical Bayesian SED Fitting