Carbon-monoxide survey on a sample of Galactic Cold Cores

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Outline

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- Goals
- Observations
- Results
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Context

- understanding star formation (process, stages, efficiency, IMF, clustered/isolated): large sample of cloud cores needed
  —> Planck cold "cores"
- Herschel Key Programme Galactic Cold Cores:
  115 fields selected from the Planck cold sources
  —> T_{dust}, $N(H_2)$, dust properties
- representative cross-section of the Planck "core" population (l, b, T_{dust}, M, d=100 pc — kpc)
  —> the general properties of galactic SF
- ground-based molecular line observations (CO, NH_3…) needed:
  —> association, T_{gas}, turbulence, stability

Goals

- 26 northern GCC fields with no existing high spatial resolution, high-density tracer measurements
- 35 column density peaks with $N(H_2)_{dust} > 10^{21}$ cm^{-2}
- derive: v_{LSR} - velocity of cloud components
  D_{kin} - kinematic distance —> size
  T_{ex}, $N(^{13}CO)$ - temperature, density, abundance
  dv - linewidths —> turbulence, M_{vir}
  $N(H_2)_{dust}$, T_{dust} —> dust-based density and temperature
  —> M_{core}, stability
- compare continuum- and line-based parameters
- complete the survey of GCC fields observable from Onsala

Goals

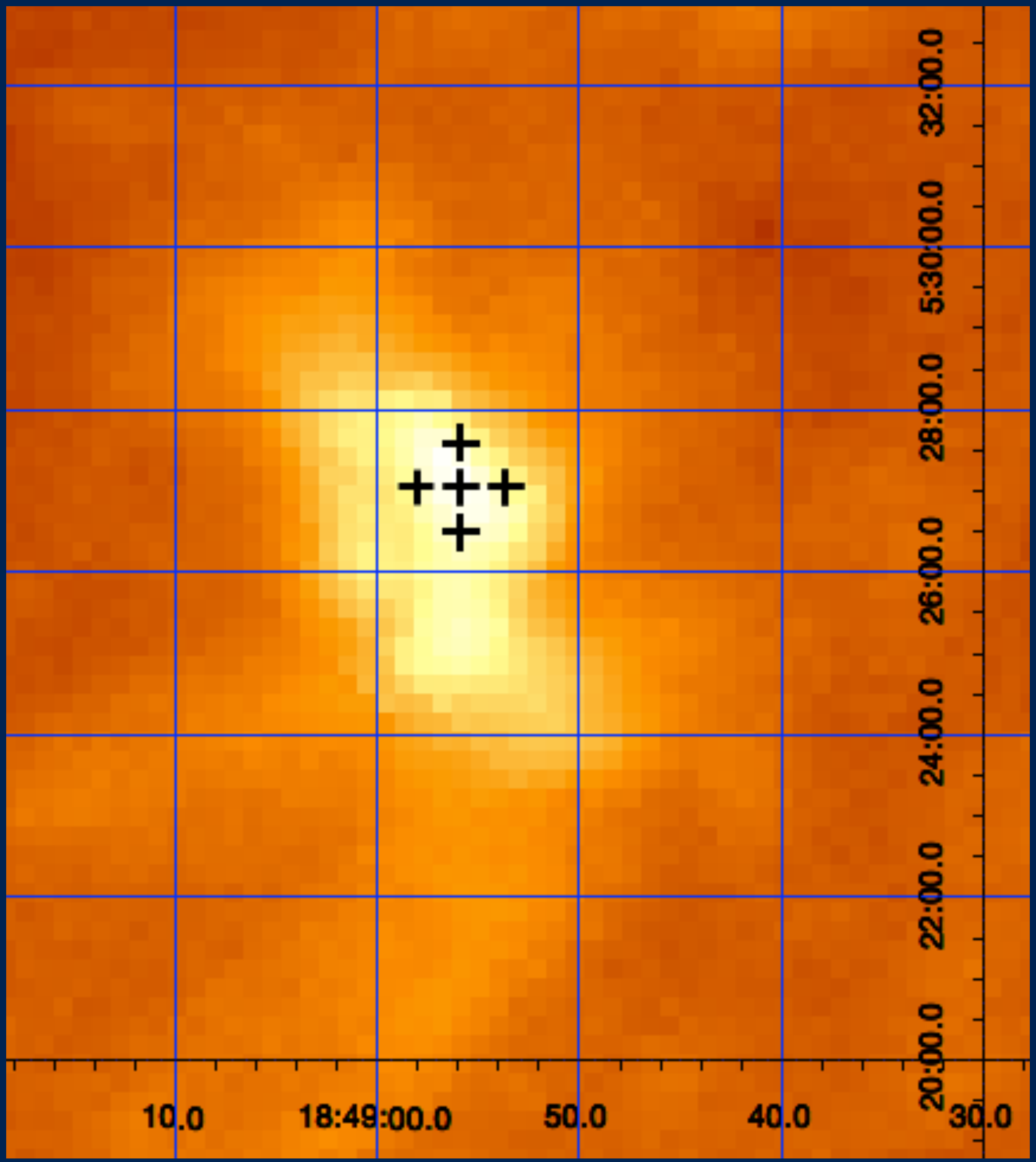
- what kind of objects are in our sample of dense, cold “cores”?
- what is the relation between T_{gas} and T_{dust}?
- what is the relation between H_2 density calculated from the continuum and line measurements?
- what is the distribution of these physical parameters in the sample?
- can we constrain their distances with their velocity?
- are they gravitationally bound (pre-stellar)?
- same question in the whole GCC sample - this study completes it
  statistical study of initial parameters & environments of SF

Observations

- January 14-16, 2014
- 20m telescope in Onsala, Sweden
- beam FWHM is 33" at 115 GHz (3 mm)
- 100 MHz bandwidth, 12 kHz (0.032 km/s) resolution
- two polarization directions simultaneously
- position and frequency switching modes (PSW, FSW)
- requested time = 26 hours

Observations

- $^{12}CO(1\text{-}0)$ on a five-point map around the $N(H_2)_{dust}$ maxima
with a spacing of 33”, PSW mode

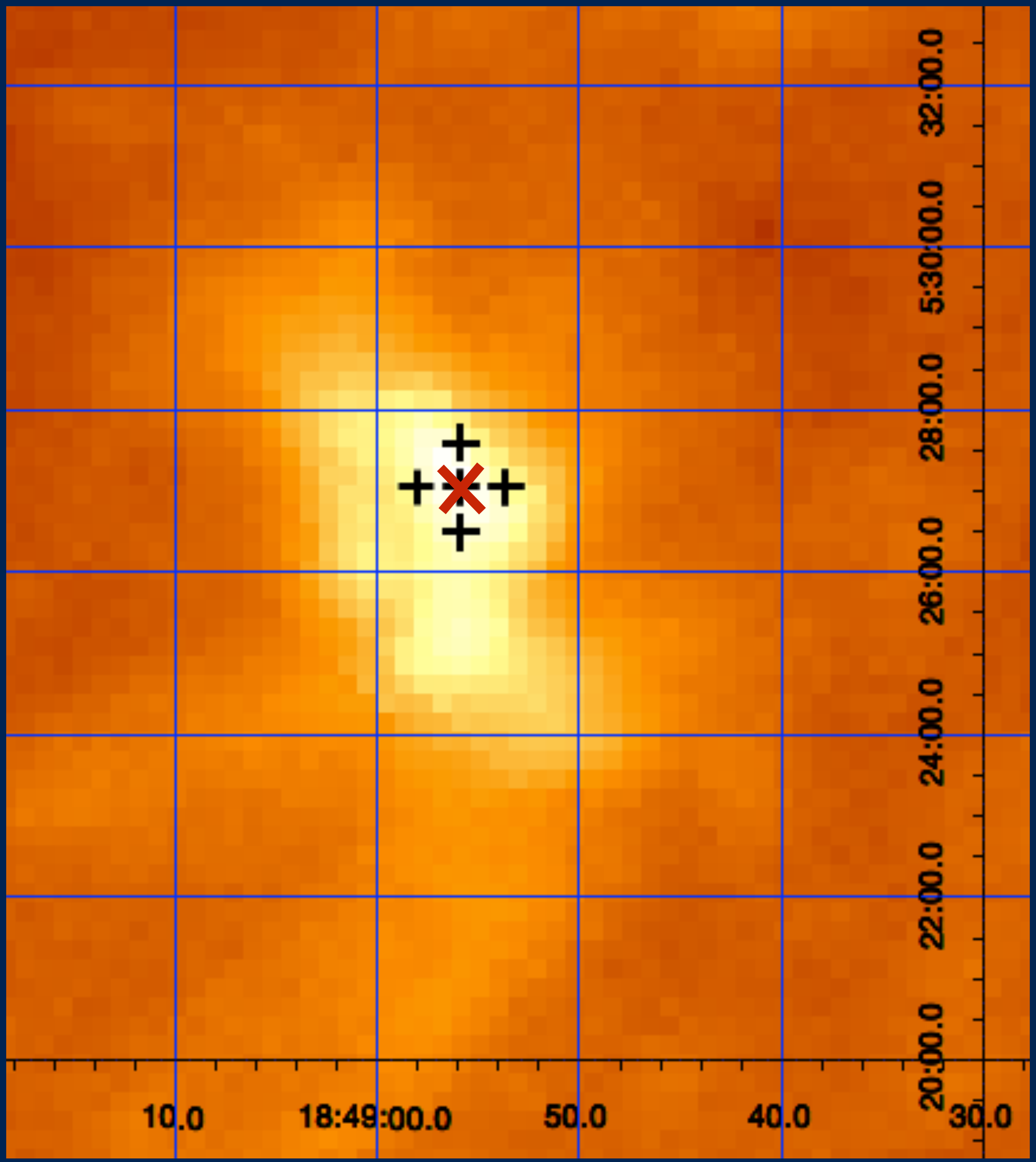


τ_{250} map of G37.49-A with the observing points

Observations

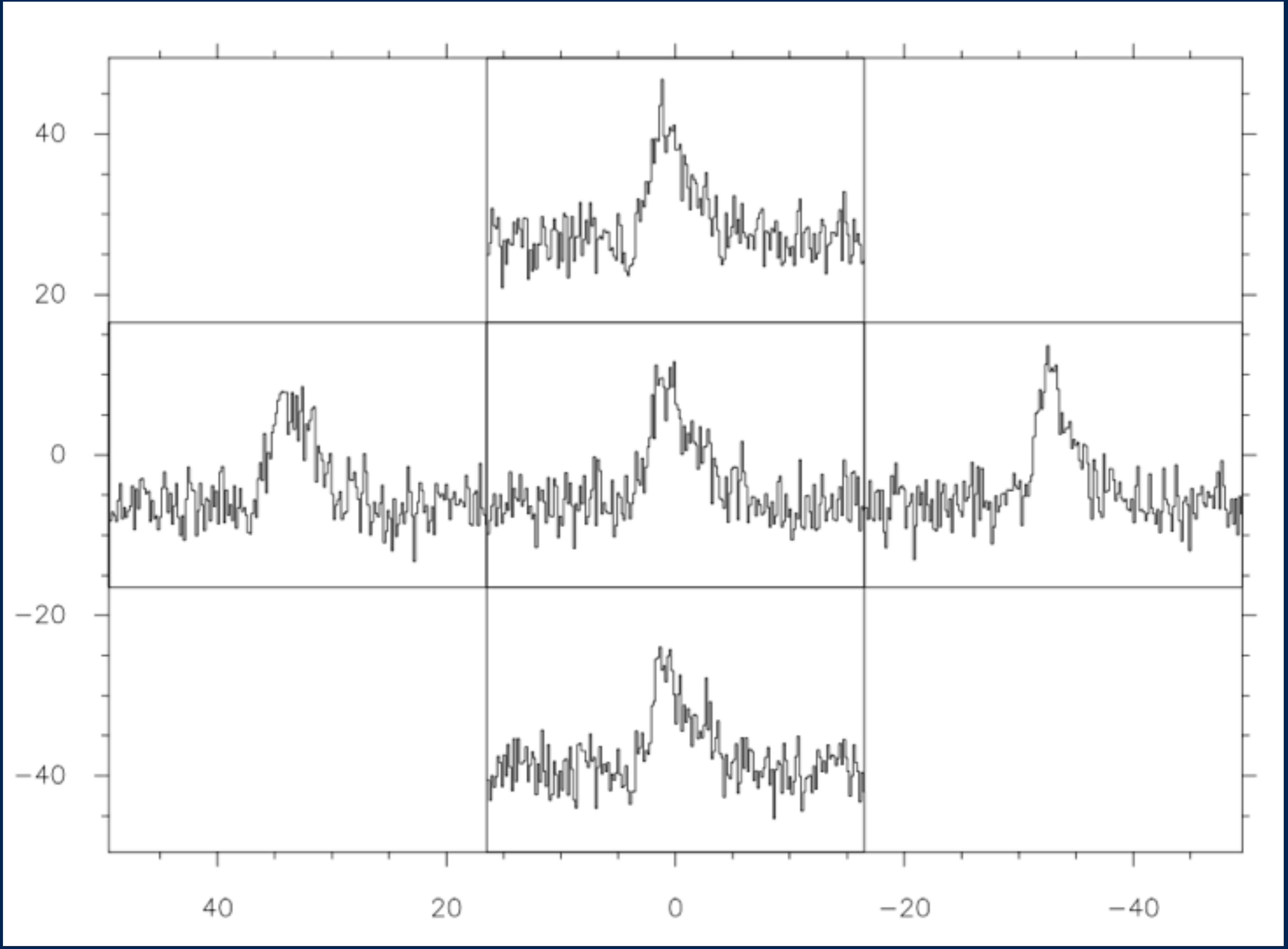
- $^{12}CO(1\text{-}0)$ on a five-point map around the $N(H_2)_{dust}$ maxima
  with a spacing of 33”,
  PSW mode

- $^{13}CO(1\text{-}0)$ on the $N(H_2)_{dust}$ maxima on the fields
  FWS mode with a switching frequency of ±15 MHz



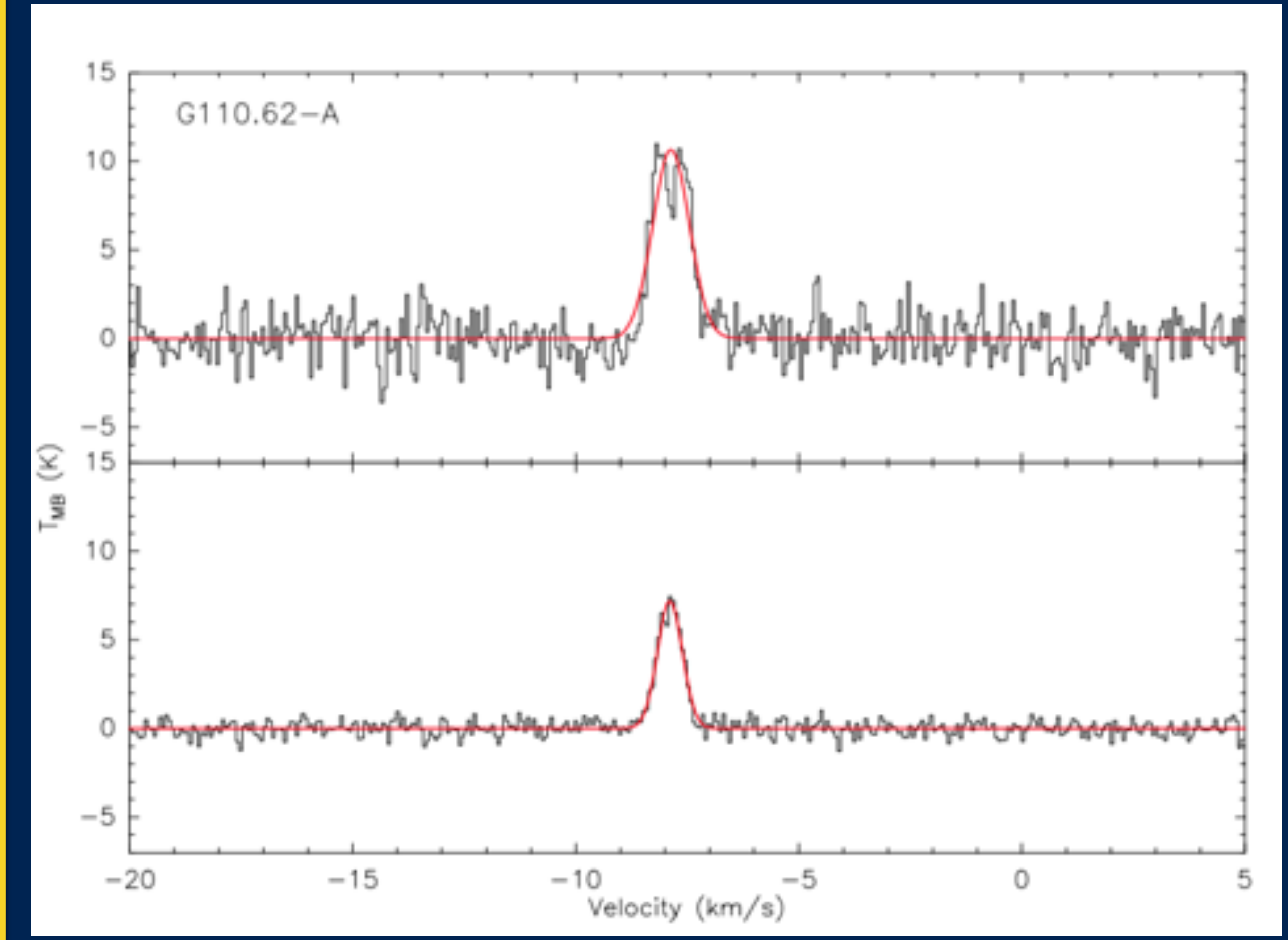
τ_{250} map of G37.49-A with the observing points

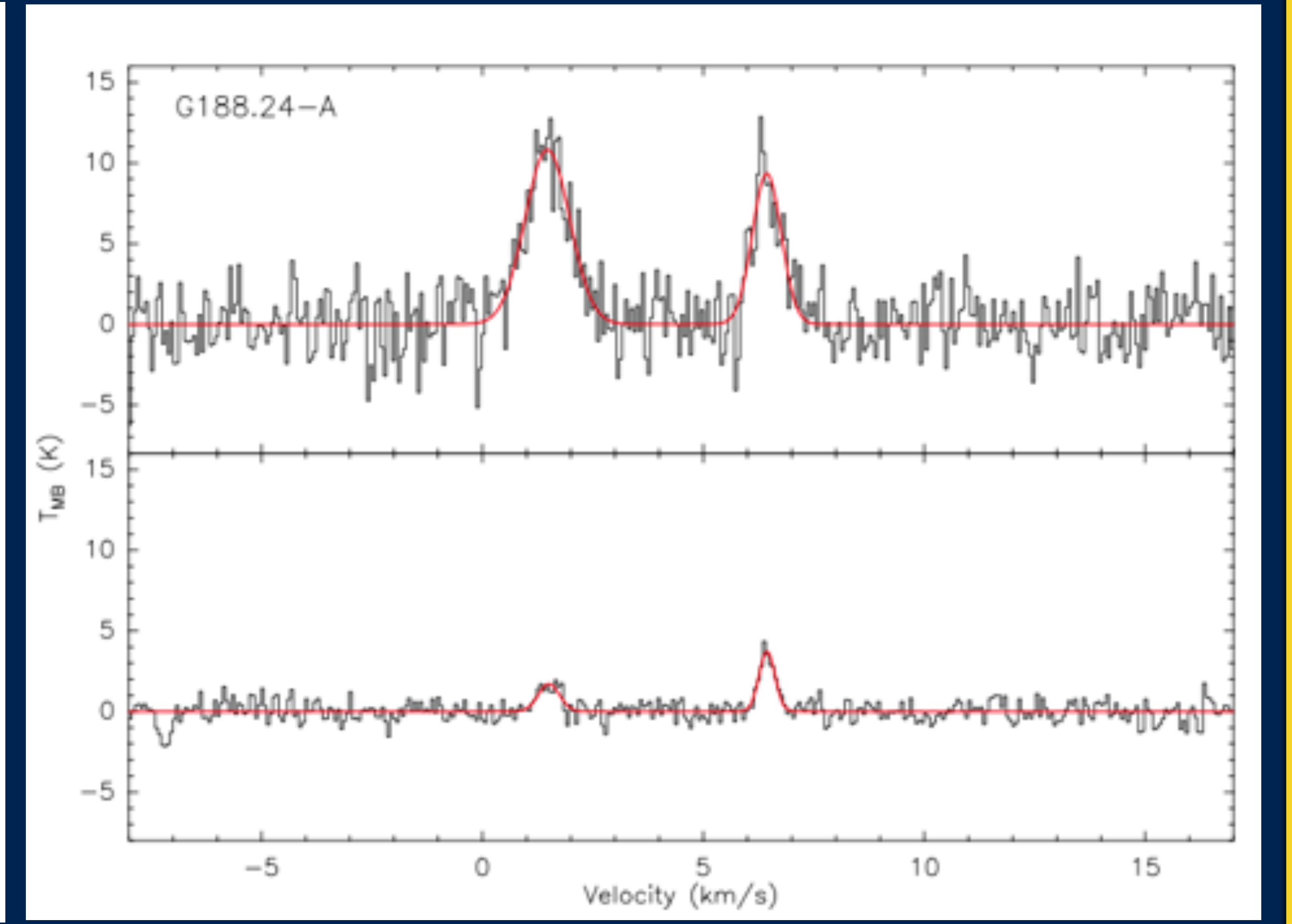
Observations



the five point grid of $^{12}CO(1\text{-}0)$ observations towards G141.25-A

Observations





^{12}CO(1-0) and ^{13}CO(1-0) spectra in the center of G110.62-A and G188.24-A

Observations

- Herschel Key Programme Galactic Cold Cores
- Herschel SPIRE intensity maps at 250, 350 and 500 micron
- November-December, 2009 and May, 2011
- reduced with HIPE v12.0. official pipeline
- calibration accuracy ~ 7%

Results

- observed at least one of the CO isotopomers in 35 clumps
- all lines were measured with S/N > 3 except in 3 clumps (G26.34-A, G126.24-A, G171.35-A)
- multiple velocity components in 3 clumps (G69.57-B, G188.24-A, G39.65-B)
- significant velocity gradient in 4 clumps (> 1 km/s/pc) (G141.25-A, G159.23-A, -C, G126.24-A)

Results

- Herschel-based T_{dust} and $N(H_2)_{dust}$

$$I_\nu \propto B_\nu(T_{\rm dust})\nu^\beta$$

fitting a MBB-function to the SED, β = 2

$$I_{\nu_0} = B_{\nu_0}(T_{\rm dust})(1 - e^{-\tau_{\nu_0}}) \approx B(T_{\rm dust}) \times \tau_{\nu_0}$$

τ_{250}: optical depth at λ = 250 μm

$A_J = \tau_{250}/0.0016$ —> $A_V = 3.55\ A_J$ —>

$$2N(H_2) = (2.21 \pm 0.09) \times 10^{21} A_V$$

- T_{dust} = 12 - 16 K
- $N(H_2)_{dust}$ = 1.2 - 63 x 10^{21} cm^{-2}

Results

- T_{ex} excitation temperature, $N(^{13}CO)$ column density

$$T_{MB}(\nu) = T_0\left(\frac{1}{e^{T_0/T_{ex}}-1} - \frac{1}{e^{T_0/2.7}-1}\right)(1-e^{-\tau_\nu})$$

LTE, isothermal medium

$$T_{ex} = \frac{5.5\,\mathrm{K}}{\ln\left[1+\left(\frac{5.5\,\mathrm{K}}{T_{MB}{}^{12}\mathrm{CO}+0.82\,\mathrm{K}}\right)\right]}$$

if $^{12}CO(1\text{-}0)$ optically thick,
$^{13}CO(1\text{-}0)$ optically thin

$$\tau^{13} = -\ln\left[1 - \frac{T_{MB}{}^{13}\mathrm{CO}/5.3\,\mathrm{K}}{1/(e^{5.3\,\mathrm{K}/T_{ex}}-1)-0.16}\right]$$

$$N(^{13}\mathrm{CO}) = \left[\frac{\tau^{13}}{1-e^{-\tau^{13}}}\right] 3\times10^{14}\,\frac{W(^{13}\mathrm{CO})}{1-e^{-5.3/T_{ex}}}$$

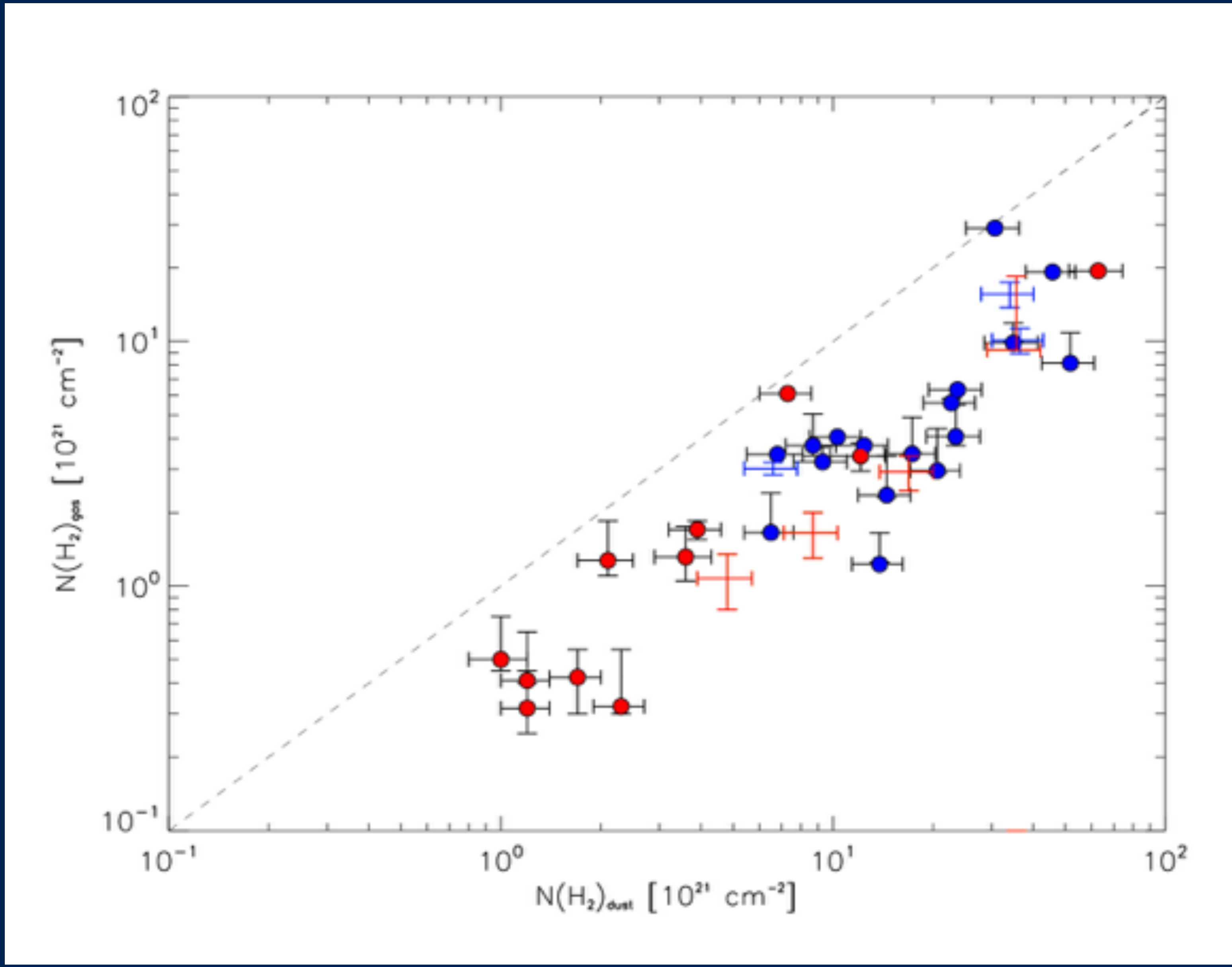
T_{ex} is uniform for all molecules
and isotopes in the (1-0) transition
^{12}CO and ^{13}CO are emitted
from the same volume

Results

- T_{ex} = 8.5 - 19.5 K, most of them 10 - 15 K
- coldest: G26.34-A, G174.22-B with 9 K
  warmest G139.60-A (32 K) and G195.74-A (23 K)
- $N(^{13}CO) = 0.5 - 44 \times 10^{15}$ cm^{-2}
  (lower and upper limits with T_{ex} = 8.5 and 19.5 K)
- densest: G70.10-A, G139.60-A (> 38 x 10^{15} cm^{-2})
  less dense: G71.27-A, G126.24-A (< 1 x 10^{15} cm^{-2})
- $[^{13}CO]/[H_2] = 5.3 \times 10^{-7}$ (lower than the canonical 1-2 x 10^{-6})

Results

- $[^{13}CO]/[H_2] = 2 \times 10^{-6}$
- good correlation
- lower abundance
- < 14 K objects are denser
- > 14 K objects generally less dense
- e.g. G139.60-A and G195.74-A warm and dense



correlation of $N(H_2)_{dust}$, $N(H_2)_{gas}$ and T_{dust}
$N(H_2)_{gas} = N(^{13}CO)/2 \times 10^{-6}$

Results

- D_{kin} kinematic distances (Reid et al. 2009)
  revised method: kinematic distances from v_{LSR} measurements
  (distance of Sun from gal.center, orbital speed, rotation curve)

- kinematic distance derived for 28 cores
  - good correlation with Montillaud et al. 2015 values when > 1kpc
  - new distance estimate with good certainty for 3 clumps
  (G71.27-A d=1.6 kpc, G37.49-A d=1.22 kpc, G37.49-B d=1.25 kpc)
  - one clump still without a distance estimate
  (G171.35-A)

Results

- M_{core} clump/core masses:

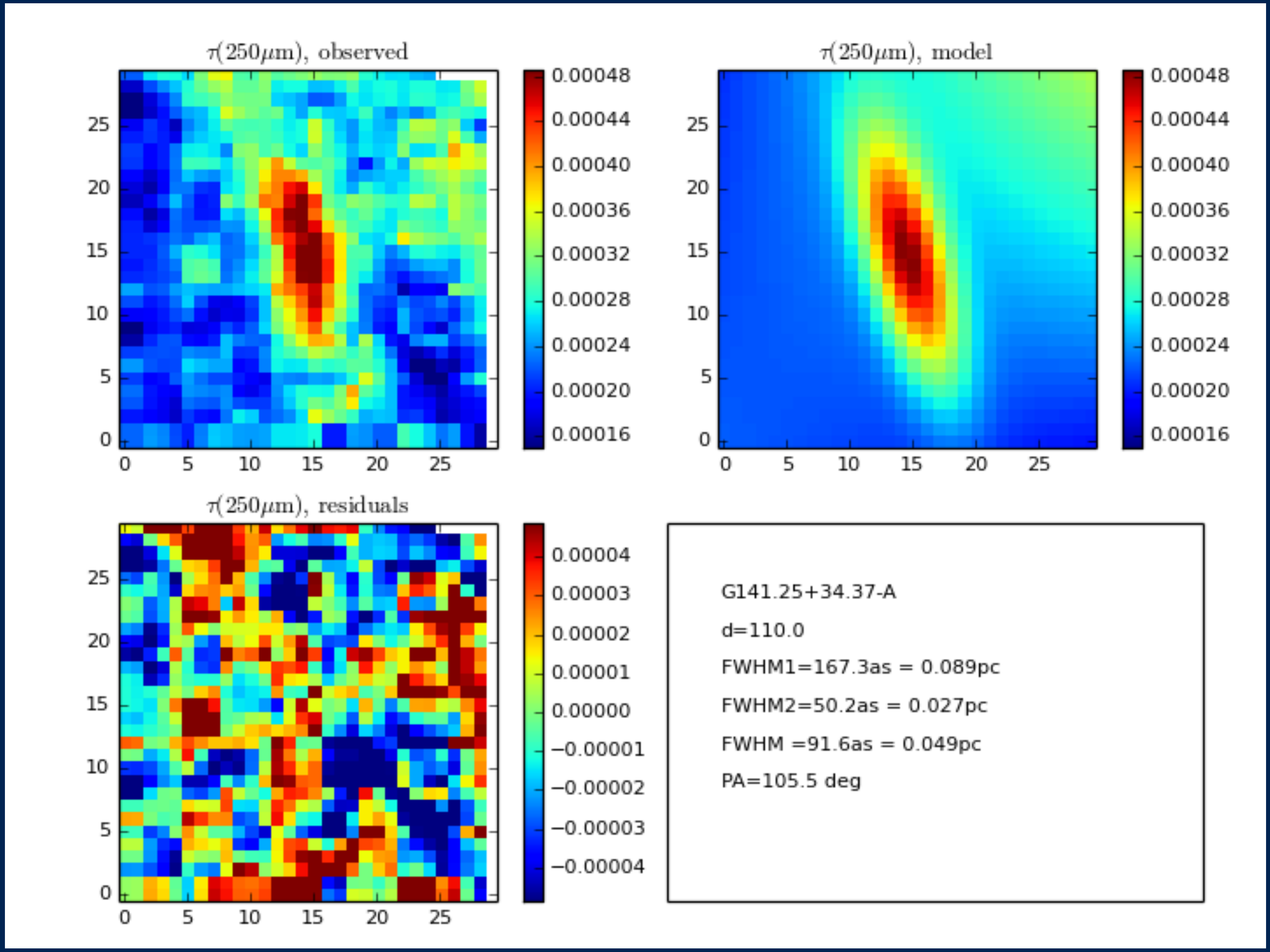
  1. 2D Gaussian fit of the clumps on the τ_{250} map
  2. sum of $N(H_2)_{dust}$ in the 2D Gaussian (using distances from Montillaud et al. 2015)

- M_{vir} virial masses:

$$M_{vir} = k\frac{\sigma^2 R}{G}$$

where k: 3/2 when $\rho \sim r^{-1}$
σ: total velocity dispersion

Results



2D Gaussian fit on the τ_{250} map of G141.25-A: observed, model, residual, parameters

Results

- 22 clumps with reliable distance estimates (Montillaud et al. 2015):
  sizes 0.01 - 2.7 pc
  distances 0.1 - 2.5 kpc
  masses 0.04 - 1300 M_{Sun}
- > pc size objects: large clouds/clumps possibly with many cores
  all gravitationally bound (G70.10-A, -B, G139.60-A, G174.22-A, -B...)
  > 1 kpc distance
- < 1 pc size objects: real clumps or cores
  6 gravitationally bound
  3 unbound
  3 close to equilibrium
- ! the error in mass estimation is high (distance…)
  4 gravitationally bound (G26.34-A, G39.64-A, G159.23-A, G195.74-A)
  2 unbound (G141.25-A, G189.51-A)
  no significant difference in T_{ex} or T_{dust} between them

Summary

- 35 clumps on 26 northern GCC fields > 10^{21} cm^{-2}
- where T_{dust} < 14 K: above $N(H_2)_{dust}$ = 5 x 10^{21} cm^{-2}
  warmer clumps have both low and higher densities
- ^{13}CO relative abundance is lower than expected
  T_{gas} and T_{dust} do not correlate well
- kinematic distance estimates for 28 objects
  in 10 cases: good correlation with previous estimates
  new distance estimate for 3 clumps
- 7 objects > 1 pc size: large gravitationally bound clouds at great distances
  15 cores/clumps < 1pc size: gravitationally bound and unbound
- no significant differences in T_{ex}, T_{dust} between bound and unbound cores
  unbound cores generally have $N(H_2)$ < 6 x 10^{21} cm^{-2} and M_{core} < 10 M_{Sun}