

PROPOSAL FOR 30m RADIOTELESCOPE

Deadline: Sep 10th, 1999 – Period: Nov 15, 1999 - May 15, 2000

Registration N°:

Date:

TITLE

Continuum Mapping of a Coherent Dense Core: TMC-1C

Type: *Extragalactic*: continuum CO lines other *Galactic*: continuum lines circumstel. env. young stel. obj. cloud struct. chem. other

ABSTRACT

We will create a 1.3-mm continuum map of the dense “pre-stellar” core TMC-1C. From this map of dust emission, we will infer the H₂ column density distribution of the core. We need this column density information to fully interpret and understand the wonderful spectral-line maps of TMC-1C we have constructed using the 30-m over the past two years. In particular, the column density map will help in three ways: (1) we will see which molecular tracers are faithful representatives of the density distribution (i.e. not depleted onto grains); (2) we will use the information about depletion to carefully select which molecules to include in our kinematic “coherence” study; and (3) we will compare the measured column density profile with theoretical predictions on the nature of pre-stellar cores.

The map proposed will be constructed using OTF mapping with the 37-channel bolometer.

Is this a resubmission of a previous proposal? no yes – proposal number(s):Is this a continuation of (a) previous proposal(s)? no yes – proposal number(s):

Hours requested for this period:

16	LST range(s):	from: 0h	to: 8h	number of intervals: 2
		from:	to:	number of intervals:

Number of hours foreseen for full completion of this proposal: of which were already allocated

Special requirements: Service observing Remote observing Bolometer session I Bolometer session II
Other requirements (dates, OTF, etc.) OTF mapping is planned using 37-channel bolometer

Receivers: A B C D Bolometer

Frequencies*: (to 0.1 GHz and corrected for redshift) 230

List of Objects (give most common names)
with equatorial coordinates

Source	RA	DEC	VEL
TMC-1C	4:38:34.4	25:55:00.0	5.2

(continue on next page, if needed)

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Expected observer(s) Goodman and 1 other

Continuum Mapping of a Coherent Dense Core: TMC-1C

Scientific Background: For reviewers unfamiliar with the world of dense cores, allow us to give you a quick update. Current wisdom holds that stars form either alone, in small groups, or in clusters, out of gas that somehow becomes much denser than its surroundings. This “dense” gas (with $n \sim 10^4 \text{ cm}^{-3}$) is almost always called a “core,” although the nature of these cores seems to depend greatly on whether they are forming just a few stars or a whole cluster (Jijina & Myers 1999). In this proposal, we plan to observe TMC-1C, which is a relatively simple, so-called “low-mass” core, meaning its total mass is of order 10 solar masses or less. Some (e.g. Ward-Thompson, Motte, & André 1999) would call it a “pre-stellar” core, since it looks like it could form stars, but has not yet done so. When and if it does, its low mass will limit it to forming only one star, or a small handful of stars.

Background of This Project: This proposal’s heritage has two branches, one involving the so-called “coherence” of cores, and the other a study of molecular depletion in dense, cold gas.

Coherence: TMC-1C has been extensively observed at the 30-m and the FCRAO 14-m (by the current proposers and their collaborators) in a project entitled “How Coherent are Dense Cores”? In that project, we have now created, processed, and assembled 16 independent maps of TMC-1C and its environs, in molecular lines tracing densities from $\sim 10^3$ to $\sim 10^5 \text{ cm}^{-3}$. The combination of spectral and spatial resolution of offered by this set of high-quality maps of a dense core is unprecedented.¹ The spectral-line data from this project are being used to construct line width-size relations for all of the tracers observed (see Figure).

Any spectral-line transition is only excited above a certain “critical density,” and actually stops emitting efficiently (see discussion of depletion, below and the Figure) above some other density. Thus, each spectral-line we observe is most effective at tracing some density *regime*. Thus, the relationship between spectral line width and “size” (distance of spectrum from a map peak) measured in a single line tracer tells us about gas motions in a particular density regime.

In practice, a “coherent” dense core is defined the region where the line width of a high-density tracing molecule is independent of position (Barranco & Goodman 1998). In meaning, a coherent dense core is a place where molecular clouds change in nature from being “turbulent” in the sense that line width (velocity dispersion) is a function of scale, to being “coherent” in that a single velocity dispersion is representative of the region. We often like to call coherent cores “islands of calm in a turbulent sea.” We think these islands form due to the dissipation of turbulence, possibly related to a loss of magnetic coupling, in molecular clouds (Goodman et al. 1998).

In Goodman et al. 1998, we explain in detail how careful observations of a coherent core should produce a set of line width size relations like those pictured in the upper right panel of the Figure. (Each line segment in the figure represents a line width size relation for a single molecular line tracer. The density of the tracers decreases *to the left* in the Figure, as size increases.) The past two years of our FCRAO and IRAM observations have been aimed at creating a non-cartoon version of this figure, and we are now very close to testing our prediction with a “real” figure. Once that figure is completed, we will have made the first detailed kinematic view of the “transition to coherence” in the star-formation process.

It turns out, though, that to fully understand the line width-size figure we create, we should incorporate bolometer observations. ... Don’t worry—you didn’t miss anything—it is not obvious why this is so from what we’ve told you so far. First, we have to explain our concerns about depletion—the second “branch” of this project’s heritage.

Depletion: Some very recent studies using the IRAM 30-m telescope have found the clearest evidence yet for depletion of CO onto dust grains in cold dense gas (e.g. Kramer et al. 1999; Caselli et al. 1999). The lower-right panel of the Figure summarizes the Caselli et al. results, showing that non-depleted species, such as N_2H^+ follow dust continuum emission, while the intensity of emission from depleted species, such as CO isotopes, actually *dips* towards core peaks. Obviously, the depleted species are not doing a good job of tracing the innards of dense cores.

The lower-left panel of the Figure is excerpted from Goodman et al. 1998, and shows the connection between the coherence and depletion questions. The figure is drawn to illustrate the region over which NH_3 (or N_2H^+ , or any other non-depleted high-density tracer) emits in a dense core. Notice that the maximum scale traced, determined by the lowest density which can collisionally excite NH_3 , labeled “ R_{out} ,” is just a bit larger than the radius, R_{coh} , of the coherent region, and that $R_i n$, the smallest scale (corresponding to highest density) traced is much smaller than either R_{out} or R_{coh} . This cartoon is justified by real observations, which show NH_3 to be

¹Reduced data are presented and discussed at: <http://cfa-www.harvard.edu/~agoodman/coherent/collab.html>.

centrally-peaked (see figure at lower-right) in dense cores, and never to show any limb-brightening. Imagine, though, that we were to adjust the labeled radii in the lower-left figure to match the “Depleted Molecular Species” curve in the right figure. We would need to move R_{in} to a much larger scale, so that the emitting region formed more of a shell than a filled volume.

Depleted tracers must not be used in constructing the line width-size plot at the upper-right of the Figure. They will produce misleading, virtually horizontal, line width-size relations like the one shown as a dashed line in the Figure, because the size scale being traced will essentially be constant, equal to the thickness of the emitting shell.

In plotting the data from our 16 spectral-line maps of TMC-1C, we have noticed that the line width-size relations for a few of the tracers *do* seem to be aberrant in the way represented by the dashed line in the cartoon Figure. However, we cannot eliminate these tracers from our study just because they do not match our prediction!

Why Bolometer Observations? A bolometer map of TMC-1C will allow us to measure dust column density directly, and compare the column density map with the spectral line maps, thus testing how well the various spectral lines are representing the material. Two effects can cause the “aberrant” behavior shown by the dashed line in the line width-size cartoon: depletion or high-opacity. (Or, of course, it is also possible that our theory is wrong, although most of the tracers follow our prediction remarkably well. ²)

In principle, the opacity of the lines can be directly estimated from our maps of $N_2H^+(1-0)$, $C^{17}O(1-0)$ and $(2-1)$, because both tracers present hyperfine structure. And, we should be able to rely on optically thin lines of $C^{34}S$ to resolve the core’s density profile. However, low-mass cores have a very inhomogeneous chemical structure and some of the gas tracers are expected to be highly depleted in the innermost and densest parts of these cores (e.g. Bergin & Langer 1997). Therefore, we need to study depletion to better understand the chemistry and core structure. This understanding of chemistry is crucial in characterizing the “transition to coherence” in star-forming cores.

A measure of depletion implies a combination of bolometer-based column density measurements with multi-transition spectral line observations. In particular, following the work by Caselli et al. (1999), we will compare the 1.3-mm continuum emission with our $C^{17}O(1-0)$ and $(2-1)$ maps of TMC-1C, to determine CO depletion and then deduce meaningful inner and outer emission scale for each tracer. Then, we will be able to include only tracers which have the capacity to trace gas all the way through a coherent core and/or its environs in our final line width-size plot. *We expect that this detailed, quantitative, picture of the transition to coherence in TMC-1C will then be used as a new observational standard which theories of low-mass core and star formation will need to match.*

Observing Plan and Time Request: We plan to use the on-the-fly (OTF) technique to make a bolometer map of an area covering roughly 8 by 8 arcminutes around TMC-1C. The source is very elongated (in a NW-SE direction) on the sky. As such, we may need to construct multiple OTF maps, and then mosaic them, so as to keep the chopping pattern feasible. If we were to construct the whole map with just one OTF pattern, the on-line Time Estimator version 2 calculates that two passes to a final rms of 3 mJy/beam would take 9.4 hours, with 8.8 of those spent integrating. In addition, there would be 42 minutes of overhead. Since we cannot observe TMC-1C for these ~ 10 hours in a row from Pico Veleta, and we are likely to break the map into two pieces, the overhead will be increased by at least a couple of hours. Therefore, we request two days of observing, with 8 hours on each day, totalling a **16-hour** request.

References

- Barranco, J.A. and Goodman, A.A. 1998, ApJ, 504, 207
Bergin, E. A. & Langer, W. D. 1997, ApJ, 486, 316
Caselli, P., Walmsley, C.M., Tafalla, M., Dore, L. & Myers, P.C. 1999, ApJL, 523, TBA
Goodman, A.A., Barranco, J.A., Wilner, D.J. and Heyer, M.H. 1998, ApJ, 504, 223
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Kramer, C., Alves, J., Lada, C. J., Lada, E. A., Sievers, A., Ungerechts, H. & Walmsley, C. M. 1999, A&A, 342, 257
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²See <http://cfa-www.harvard.edu/~agoodman/Presentations/santacruz99/sld018.htm> for corroborative 30-m data.

The figure **below**, reproduced from Goodman et al. 1998, illustrates how emission from a particular molecular species is likely to come only from a limited range of densities, and not from *all* densities above a critical density. For a variety of reasons (see text), emission will cease at an *inner* radius, R_{in} , and thus not trace mass or motions within R_{in} .

The figure **immediately to the right**, is identical to one from our successful 1998 IRAM 30-m proposal--except for the addition of the virtually horizontal dashed line. That dashed line shows what happens if R_{in} is relatively large, and emission comes from a shell-like region, rather than a more filled volume. In this case, the scale being sampled will appear to vary on the sky, but will actually be almost constant, because each line of sight samples only a "shell thickness" worth of material (i.e. roughly the same size scale everywhere in the map).

The figure to the **bottom right** is a cartoon summary of the results of Caselli et al. 1999, which show evidence for significant depletion of CO in the dense core L1544. This kind of depletion can cause R_{in} to be so large as to make it impossible to even detect cores in allegedly high-density-tracing species like $C^{17}O$.

Note that the **dashed line** represents a depleted species in both of the plots at right.

