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PROPOSAL FOR 30m RADIOTELESCOPE
Deadline: March 5th, 1998 – Period: May. 15 1998 - Nov. 15 1998

For IRAM use
Registration N°:
Date:

TITLE *(self-explanatory)*

How "Coherent" are Dense Cores?

Type: extragalactic: continuum ○ CO lines ○ other ○

galactic: continuum ○ lines ● circumstel. env. ○ young stel. obj. ● cloud struct. ● chem. ● other ○

ABSTRACT

We plan to complete a suite of new spectral-line maps of the TMC-1C dense core, which are allowing us to **test our model of "coherent dense cores."** The model was proposed to explain the *observed* differences between cores and their environs. The cores appear to have nearly constant line widths, and sharply peaked column density distributions, while their environs, like most of the molecular ISM, exhibit a power-law relation where line width increases with size scale (Larson 1981), and nearly constant column density. Our model predicts that the level of density and velocity sub-structure inside the cores should be diminished in comparision with its surroundings.

(max. 8 lines)

Is this a resubmission of a previous proposal ? no ● yes ○ ; proposal number: ...

Is this a continuation of (a) previous proposal(s) ? no ○ yes ● ; proposal number(s): ... 82-97

hours requested for this period: **49**

LST range(s): from: 0h to: 10h number of intervals: 7
from: to: number of intervals:

Number of hours foreseen for full completion of this proposal: 75 of which 26 were already allocated

Special requirements *(dates, etc...)*: really none ?

Receivers: 3mm1 ● 2mm ● 230G1 ● 0.8mm ○ bolometer ○
3mm2 ○ 230G2 ● (*see Table of Compatibilities*)

Frequencies*: (to 0.1 GHz and corrected for redshift) 93.2 112.4 144.1 144.6 216.1 224.7

List of Objects (give most common names) with equatorial coordinates
EPOCH: 1950.0

Source	RA	DEC	
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 + 2 others

join to this form: scientific aims(≤ 2 typed pages + 1 page Figs., Tables) and list of related publications **imperatively*

How "Coherent" are Dense Cores?

Introduction

This proposal requests the time to complete a project begun at the 30-m telescope in November of 1997. The goal of the proposal remains unchanged, and we are very happy to report that the data we obtained in the 26 (out of 75 requested) hours granted thus far are great! Not only were our sensitivity estimates correct, our physical model for the velocity structure of dense cores and their environs also seems to be standing up to this stringent testing. In addition, the maps we are creating will allow an unprecedentedly sensitive view of the density structure of cores on scales of 0.01 pc.

In the text below, we remind the reviewer of our "coherent" core model. Then, we explain what the results from our first 26 hours of observing have shown us, and what new questions they have raised. We finish by proposing a set of new observations which would be completed in the balance (49 hours) of the time we had initially requested. These additional observations are very similar to those originally proposed, but they have been optimized based on the results already in-hand.

What are "Coherent Dense Cores?"

We have recently proposed a physical picture of star-forming dense cores and their environs where the **cores can be identified in velocity space** as regions of nearly constant line width (Barranco & Goodman 1998). As part of the picture, we also offer a self-consistent **explaination of the differences in** the power-law slopes among various Types of **"line width-size" relations** in the literature (Goodman et al. 1998a).

We call the regions of nearly constant line width "coherent dense cores." These cores, previously identified as regions of high extinction ($A_V > 5$) and as density peaks ($n \gtrsim 10^4$ cm^{-3}) in spectral-line maps, are associated with the formation of stars like our Sun (Beichman *et al.* 1986; Benson and Myers 1989; Myers and Benson 1983). Although many theories of low-mass star formation begin with an isothermal sphere (e.g. Shu 1977), the line width inside the coherent cores is *not* purely thermal. A clearly measureable turbulent component remains even in these "coherent" regions.

Coherent cores are distinguished from their environs by two features. First, the slope of a single-tracer single-cloud line width size relation, which is positive in the core environs, approaches zero (see the Figure and Goodman et al 1998a for more discussion). Second, the column density inside the core rises rapidly toward its center, wheras the column density in the environs is nearly constant, rising only very slowly toward the core. These factors imply that the gas filling factor inside the cores is much higher than in their surroundings, and that the cores are condensation centers.

The physical picture we propose for cores and their environs is analogous to each core representing an "island of calm in a turbulent sea." We, and others, have speculated that a decrease in the magnetic field's ability to control gas motions in regions of very low ionization is responsible for the buildup of gas which leads to the formation of a coherent dense core. Our goal here is to see just how "coherent" this built-up gas is.

A More Thourough Investigation of the Coherence Scenario: Existing, Current, and Proposed Observations

Our papers on Coherhence in Dense Cores have raised a number of questions, including "how much density and velocity sub-structure is there within a coherent core?" If these cores represent regions of higher filling-factor and lower velocity dispersion than their surroundings, then **there should be markedly less contrast in the density and velocity structure within the cores.**

To date, we know of only two dense cores having been mapped in single-dish multi-transition observations with spatial resolution high enough to see significant structures within the 0.2 pc scale typical of a half-power NH_3 contour (often used to define core size): TMC1 "Core D" (Langer *et al.* 1995; Kuiper *et al.* 1996) and L1498 (Lemme *et al.* 1995). Both studies do find identifiable structures in the high-resolution maps, but they also point out that those structures may be highly transient–and thus different than structures seen on larger scales. In an extensive set of new interferometric observations of the 1.3 cm transitions of NH_3 with a $10''$ synthesized beam at the VLA, we only find detectable flux in cases where a core harbors an embedded young star (Goodman et al. 1998b). The interferometer is only sensitive to the highest spatial frequencies, and the flux we find around the young stars is typically $\sim 10\%$ of the single-dish flux and is probably produced by warm, dense circumstellar material.

Thus, existing observations have shown: 1) potentially transient structures, and 2) structures associated with circumstellar gas. (Note that small, transient, but significant structures have also been observed far from cores at cloud edges in multi-transition CO 30-m observations (Falgarone et al. 1992).) We seek data which will allow us to do a **quantitative** analysis (e.g. Figure) of the density and velocity structure inside the FWHM NH_3 contour of a dense core, for the explicit purpose of comparing the core to its environs. The 30-m telescope is optimally suited to mapping out the core interior. As for the environs, we have already been awarded time at the FCRAO 14-m telescope to map out multiple transitions in TMC-1C with $40''$ resolution.

We would like to emphasize that the observations we are carrying out under this proposal are not simply "exploratory." Our coherence picture makes very specific predictions (e.g. about how line width will depend on scale) about the differences between cores and their environs, and the 30-m observations we request below, along with our upcoming and existing FCRAO observations are carefully aimed at providing a stringent test of the picture. If the picture is correct, the "fractal" nature of the ISM changes within cores, which may fragment, but are not as self-similar as their surroundings. If the coherence picture turns out to be incorrect, these new observations will give us a better idea of what the correct picture looks like!

Update on November 1997 Observations

In the 26 hours of time allotted last November, we observed using the "$C^{17}O$ setup" described below. We created small maps of TMC-1C in $C^{17}O$ (1-0), $C^{34}S$ (2-1), $C^{17}O$ (2-1), and $C^{18}O$ (2-1). (See the Figure for a sample.) Meanwhile, we have been mapping the same lines, and others, with the FCRAO telescope. The detailed Caption accompanying the Figure explains how analysis of the line width-size data already in-hand appears to support the coherence picture, and how a small number of additional observations of the very highest density tracers we have proposed to observe (e.g. N_2H^+(1-0), DCO^+(2-1), DCO^+(3-2)) will allow us to identify where (at what size scale) the transition to coherence occurs in a dense core.

While they are of extraordinary quality, the November observations alone do not cover enough of the TMC-1C core for us to either: 1) meaningfully compare the amount of "structure" in the 30-m maps of the core with that in the FCRAO maps of the core's environs; or 2) establish the relationship between antenna temperature and size scale necessary for us to reliably complete the plot labelled "GOAL" in the Figure. However, we are confident that the additional observations requested below will allow us to complete both of these tasks, and to complete this project as first proposed, in the amount of time originally requested.

Observing Plan

As we stated in our original proposal, in order to investigate the internal structure of dense cores we plan to map N_2H^+(1-0), DCO^+(2-1), DCO^+(3-2), $C^{17}O$(1-0), $C^{17}O$(2-1), and $C^{34}S$(3-2) and/or $C^{34}S$(2-1) inside the half-power NH_3 contour of the TMC-1C core.

N_2H^+, DCO^+, and $C^{34}S$ are good tracers of high density gas ($n \sim 10^4$ to 10^5 cm^{-3}). In particular, N_2H^+ and DCO^+ are easily detected in low mass cores with typical brightness temperatures of ~ 2 K (e.g. Butner *et al.* 1995; Caselli et al., in preparation; Tafalla et al., in preparation). Observations of the J=1-0 rotational transition of N_2H^+, which presents hyperfine structure, will also provide a direct measure of the line optical depth. The two transitions of DCO^+ will allow us to estimate the volume density and excitation conditions in the densest part of the core. $C^{17}O$ lines are optically thin and are needed to make accurate column density estimates.

As can be seen in the $C^{17}O$ map presented in the Figure, we have already mapped a sizeable fraction of the region we seek to study, but much of the brightest emission (to the Northeast), appears to fall partially outside our mapped area. In order to trace out a the half-power contour in this map, we estimate that we need to approximately double the number of positions observed thus far. So, as described below, our plan for the new observations is to spend **half** the time requested (about 25 hours) **completing the mapping** in the setup (see below) which includes the $C^{17}O$ line, and the other **half** of the time (about 24 hours) observing the very **"high-density" tracing lines** (N_2H^+(1-0), DCO^+(2-1), and DCO^+(3-2)) we did not have time to tune to in our initial run. At least one, if not more, of these lines should serve as the "Tracer X" identified in the Figure.

Time requirements

We plan to use the 3mm, 2mm, 230G1 receivers simultaneosly to map N_2H^+(1-0), DCO^+(2-1), and DCO^+(3-2). Assuming the 230G2 receiver is available as well, we will use it to observe a relatively bright line such as $C^{18}O$ (2-1), as we did in our November 1997 run. From recent 30-m observations in L1544, a core with characteristics similar to TMC-1C (Tafalla et al., in preparation; Caselli et al., in preparation), we expect peak brightness temperatures of all the lines of about 2 K (and greater for the $C^{18}O$ (2-1)). This translates in the following values of antenna temperature: 1.5 K at 3 mm, 1.2 K at 2 mm, and 1.0 K at 1 mm. By frequency switching (if possible[1]) at the three frequencies, and assuming a spectral resolution of 20 kHz at 3 mm and 40 kHz at 2 and 1 mm, we will need to integrate the signal for 5 min in each position to reach a S/N ratio > 5 ($\Delta T_{A,\mathrm{rms}}$=0.11, 0.16, and 0.20 K at 3, 2, and 1 mm, respectively).

The second part of the project consists of extending the mapping we begun in November (e.g. 3mm1: $C^{17}O$ (1-0); 3mm2: $C^{34}S$ (2-1); 230G1: $C^{17}O$ (2-1); 230G2: $C^{18}O$ (2-1)). To obtain a peak S/N > 5 we need to integrate 10 min ON source assuming position-switched observations.

Using our recent (November 1997) experience as a guide, we expect that the time requested in the current proposal, 49 hours, will allow us to complete the mapping begun in November with the $C^{17}O$ setup, and to create maps large enough to use as "Tracer X" information in the Figure in the DCO^+ setup. Assuming good weather, this project will be **completed** in this 49 hours, to the point where we will have studied the internal velocity and density structure of TMC-1C well enough to say just how "coherent" a core it is. In other words, *we will publish results which: 1) establish at what radius the transition to a coherent dense core takes place, and how that transition manifests itself in line width-size relations; and 2) quantify the amount of structure in the core as compared with its environs.*

In November, frequency switching caused poor baselines, but we are hopeful that this may not be the case in the future. If necessary, we will position switch as we did in November.

References to Relevant Work

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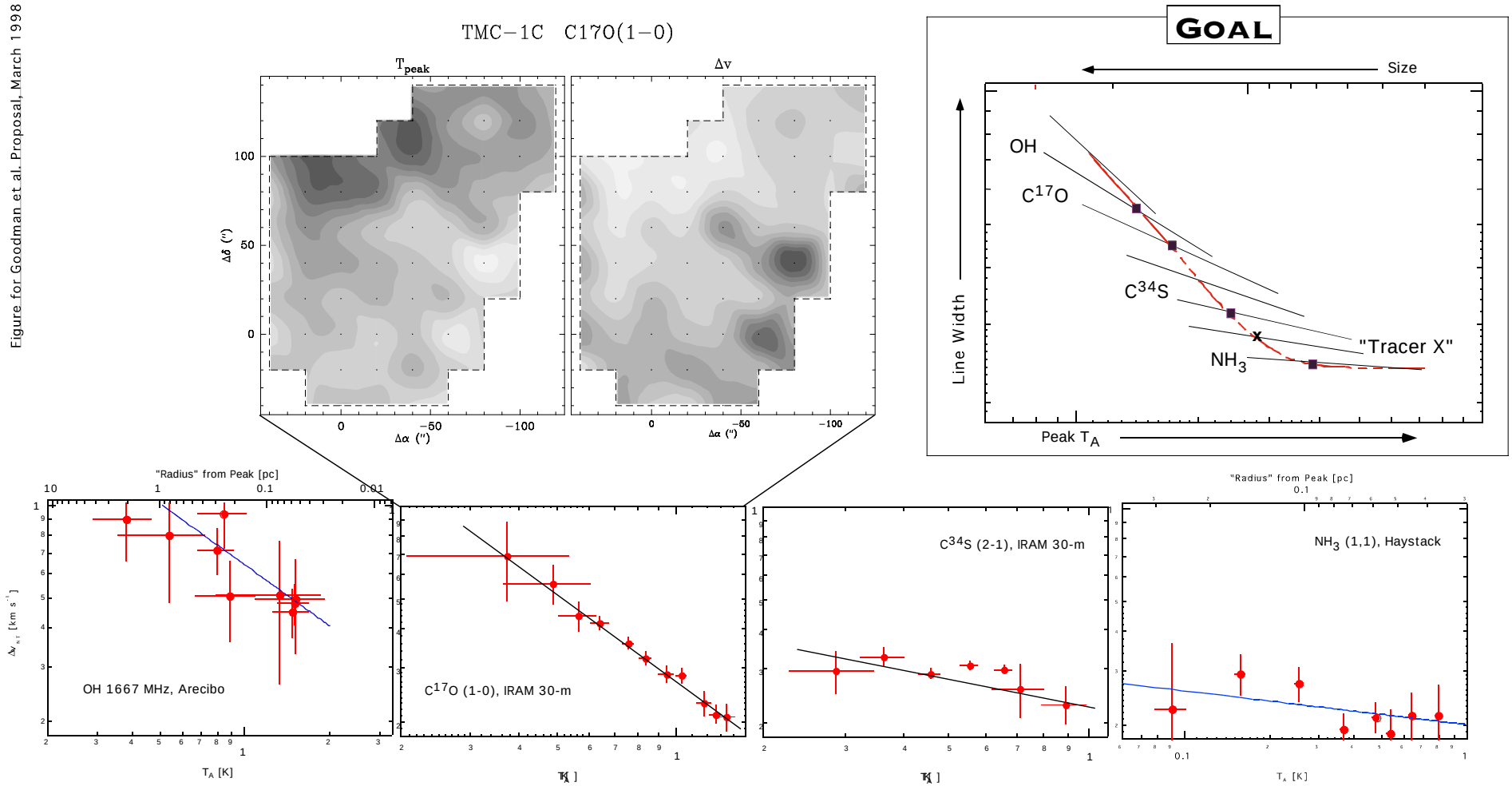
*See cfa-www.harvard.edu/∼agoodman/vel_coh.html for preprints.

Figure for Goodman et al. Proposal, March 1998



The greyscale figure above shows the results of November 1997 observations of $C^{17}O$ (1-0). Note the impressive anticorrelation between line width and peak antenna temperature. It is this kind of Δv-T_A relation which we can turn into a line width-size (Δv-R) relation once we have mapped enough of a region to establish a meaningful T_A-R relation. Our coherence model (see text) predicts, as shown in the panel optimistically labeled "GOAL," above, that the slope of these single-tracer single-cloud Δv-R (or Δv-T_A) relations should become progressively shallower at smaller radii (higher T_A). The dashed line in the GOAL panel shows what happens when the line width-size values representative of the FWHM contour of a cloud mapped in several species are connectected: a "multi-tracer single cloud" line width-size relation is obtained, one which specifically tells us about density structure. With enough observations of single-tracer single-cloud line width-size relations like those shown in the other panels above, we should be able to actually observe the "bend" in the multi-tracer single-cloud line width-size relation shown as the dashed line in the GOAL panel. That bend indicates where (at what size scale) the "transition to coherence" in cores occurs.

Notice that for the two panels of IRAM data above, we do not yet have large enough maps to establish the T_A-R relation needed to turn the Δv-T_A relation plotted into the Δv-R relation we will need to plot all the data together in GOAL-like figure. Also, we have not yet observed enough of the high-density-tracing species ("Tracer X") we need to clearly trace out the bend. The data obtained under this proposal will allow us to fill in enough of this missing information to create a real figure like the one labelled "GOAL."