CHaMPs of Star Formation:
A Galactic Census of High- and Medium-mass Protostars

Peter J. Barnes[1,2], Y. Yonekura[3], A. Miller[1], L. Agars[1], M. Mühlegger[1],
T. Wong[2,4], E.F. Ladd[5], N. Mizuno[6] and Y. Fukui[6]

[1] School of Physics, University of Sydney, NSW 2006, Australia; email: peterb@physics.usyd.edu.au
[2] School of Physics, University of New South Wales, NSW 2052, Australia
[3] Osaka Prefecture University, Japan ; email: yonekura@rishiri.cias.osakafu-u.ac.jp
[4] CSIRO Australia Telescope National Facility, PO Box 76, Epping, NSW 1710, Australia
[5] Bucknell University, USA
[6] Nagoya University, Japan

Abstract. We report preliminary results of an unbiased survey for higher-mass protostellar or protocluster dense molecular cores. In a 20°x3° swath of the Galactic Plane, the NANTEN surveys have revealed ~140 cores detectable in $C^{18}O$, covering only ~1% of the projected area of the Plane. We have now examined 52 of these cores in a variety of traditional dense gas tracers at much higher resolution than the NANTEN maps, using the Mopra antenna and the Compact Array, both part of the Australia Telescope National Facility. We have mapped the J=1-0 lines of HCO^+, $H^{13}CO^+$, and N_2H^+, and the (J,K)=(1,1) inversion line of NH_3. Apart from HCO^+, which is fairly widespread, we have found only ~25% of the $C^{18}O$ cores contain truly dense gas as traced by the other species; only ~15% of the cores have strong (>2.0 K) HCO^+ emission. This alone suggests that the dense phase of a molecular core is relatively short-lived.

Keywords. prestellar cores, protostellar cores, stars: formation, ISM: clouds, ISM: molecules, surveys

1. Motivation

Compared to isolated, low-mass star formation, where a rough paradigm has been developed (eg, André et al. 1999), our understanding of massive star formation is in its infancy (Churchwell 2002). Because of the IMF, massive star formation is relatively rare in a given volume of the interstellar medium; also, massive protostars evolve on much shorter timescales than their low-mass cousins, reducing the numbers available for detailed study even further. To counter this and obtain a representative sample of massive protostars, one has to survey out to much larger distances (several kpc) than has been necessary for low-mass stars (typically a few hundred pc). Covering a large amount of sky in a ***uniform, unbiased*** survey is difficult, but necessary in order to find and characterise all the important evolutionary stages in the formation of a massive star. In addition, only with a large sample can we identify the exceptions to the general pattern.

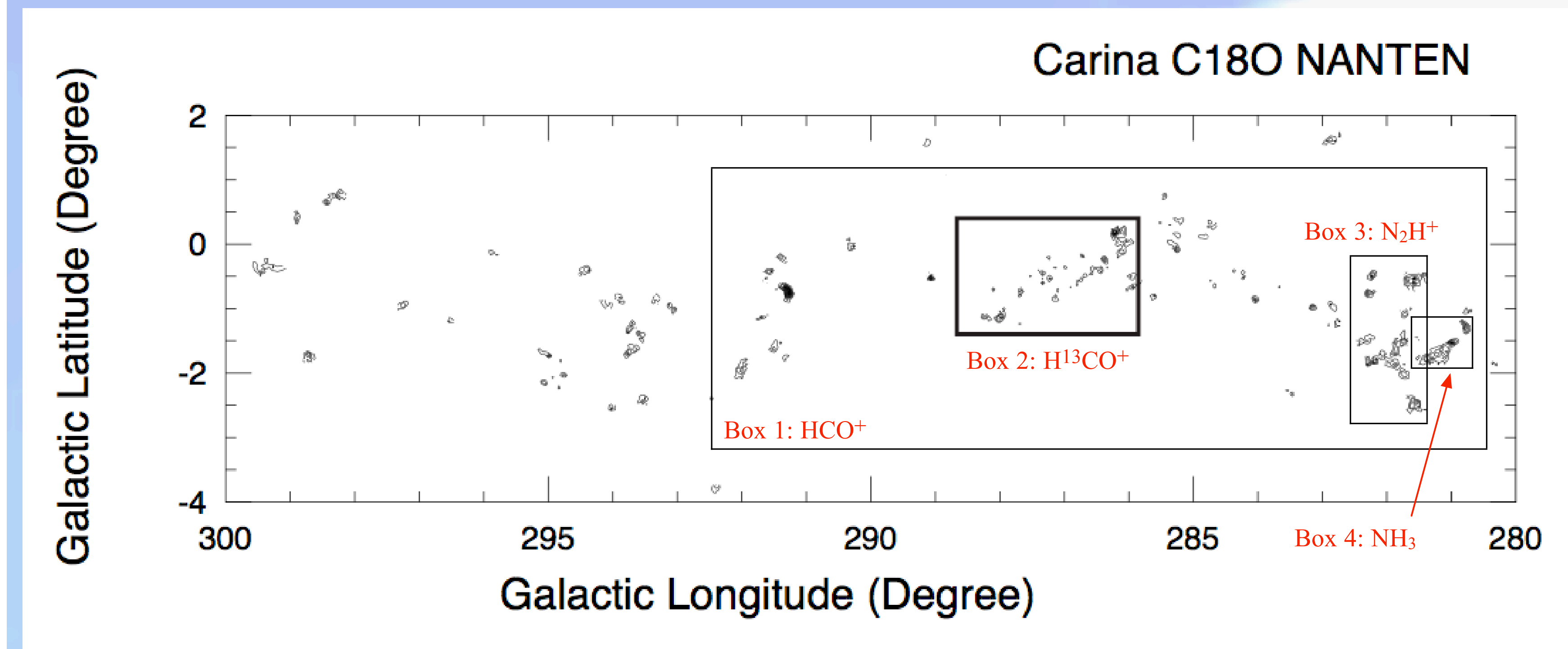

Figure 1. Integrated intensity of $C^{18}O$ emission from the Carina arm. Also shown are the regions surveyed at Mopra and the Compact Array in the indicated tracers: Box 1, HCO^+ at Mopra; Box 2, $H^{13}CO^+$ at Mopra; Box 3, N_2H^+ at Mopra; Box 4, NH_3 at ATCA.

The NANTEN surveys of Giant Molecular Clouds in the Milky Way at ~3´ resolution have taken the first step along these lines (eg Yamaguchi et al. 1999; see also Figs. 1,2). By successively mapping rarer isotopomers and species, not only are the NANTEN maps "peeling away" the density structure of the GMCs, but the sky coverage needed at each successive step drops (due to the knowledge of the mappable areas gained from the previous step) just as the signal strength drops, keeping the time requirements reasonable.

Using the 22m Mopra dish and the Compact Array, both part of the Australia Telescope National Facility, CHaMP continues this bootstrapping by making higher angular resolution (~10–35″) maps of *all* the molecular cores mapped by NANTEN in $C^{18}O$, and in a wider variety of dense-gas tracers. Because of this uniform and unbiased coverage, CHaMP will yield not only a good sample of physical and chemical conditions in massive dense cores, but for the first time also give robust statistics of the various evolutionary stages of massive star formation.

2. The Surveys

Between Galactic longitudes 280° and 300°, NANTEN found and mapped ~140 molecular cores in the J=1-0 line of $C^{18}O$ at 110 GHz (see Figs. 1 & 2, and Yonekura et al. 2005). Since these cores were identified through unbiased ^{12}CO and ^{13}CO surveys, they formed our primary source list for CHaMP. So far CHaMP has performed the following line surveys (box numbers refer to the labels in Fig. 1):

With Mopra: (Box 1) 52 cores in HCO^+ J=1-0 at 89 GHz for 292° > l > 280° (July 2005), detecting 8 strongly ($T_A^* > 2.0$ K) and 25 at moderate strength ($0.5 K < T_A^* < 2.0$ K) (see Fig. 7).
(Box 2) 19 cores in $H^{13}CO^+$ J=1-0 at 86 GHz around η Carinae (June 2003), detecting 4 (Yonekura et al. 2005; see Fig. 3).
(Box 3) 13 cores in N_2H^+ J=1-0 at 93 GHz for 283.5° > l > 281.5° (July 2004), detecting 5 (see Figs. 4,5).
With ATCA: (Box 4) 5 cores in NH_3 (J,K)=(1,1) at 24 GHz for 281.5° > l > 280.5° (October 2003), detecting 0 (see Fig. 6).

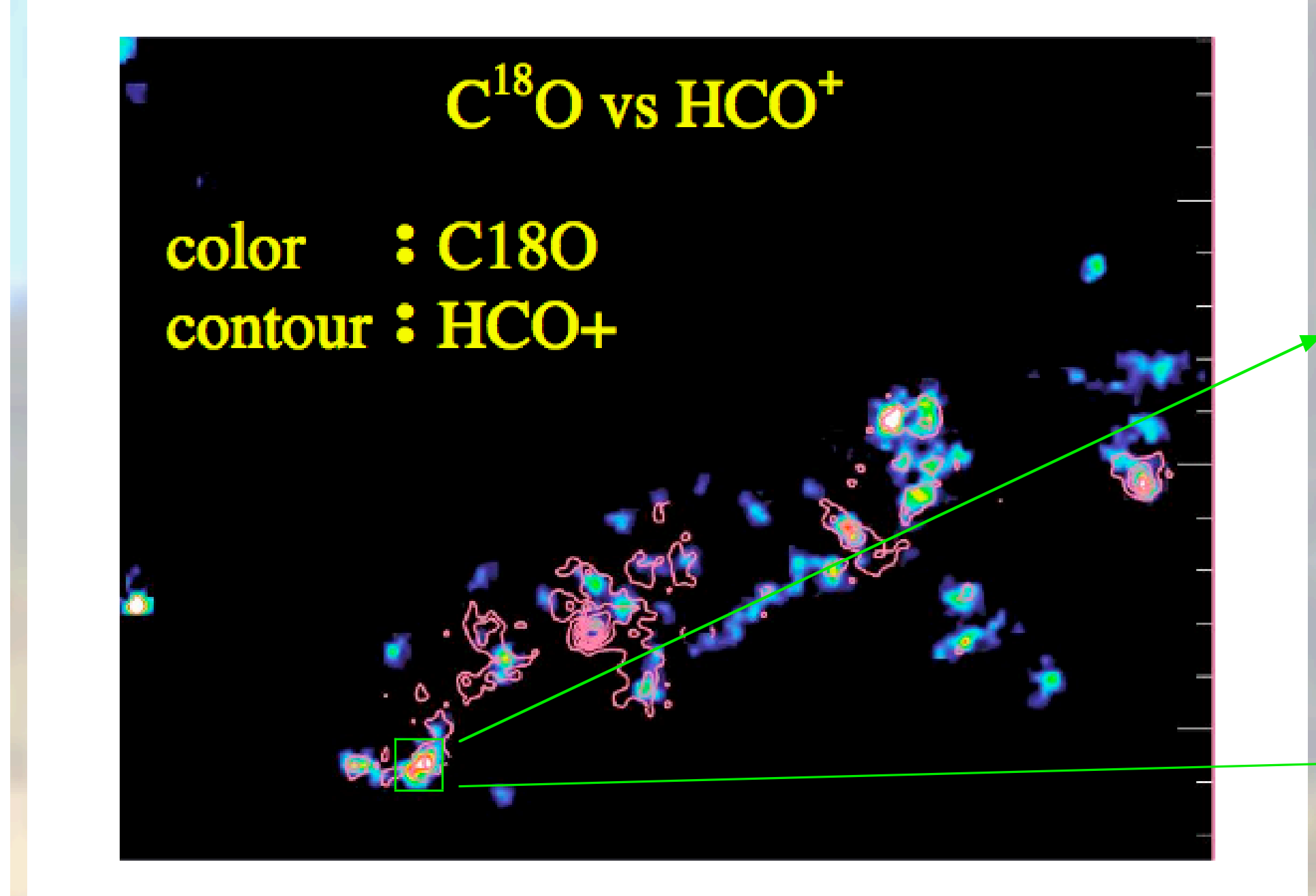

Figure 2. Overlay of NANTEN $C^{18}O$ maps and HCO^+ maps from Box 2 of Fig. 1. Note that while there is general coincidence of the emission, they do not match in detail.

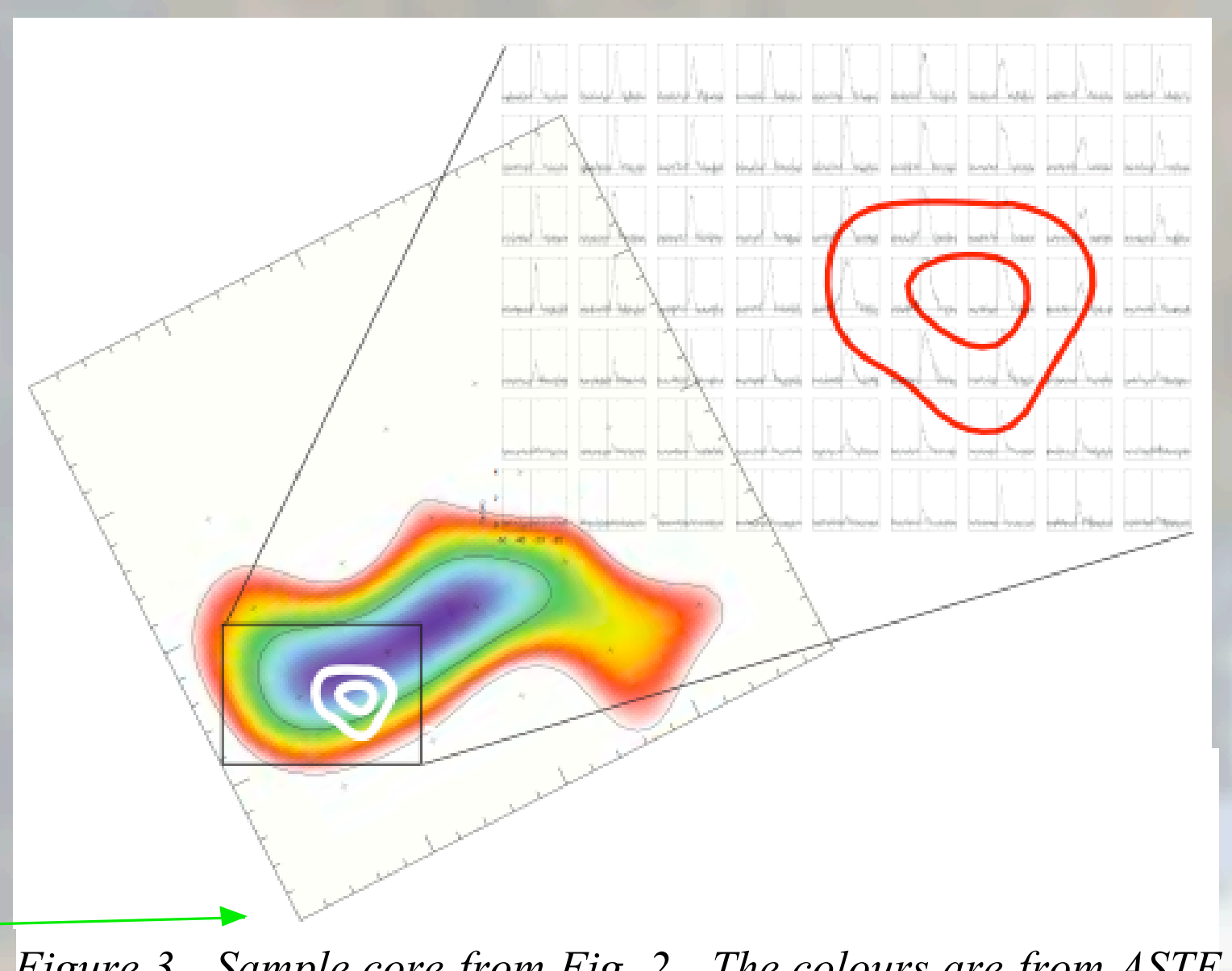

Figure 3. Sample core from Fig. 2. The colours are from ASTE CO J=2-1 observations, while the contours and postage stamp spectra are Mopra $H^{13}CO^+$ data (Yonekura et al. 2005).

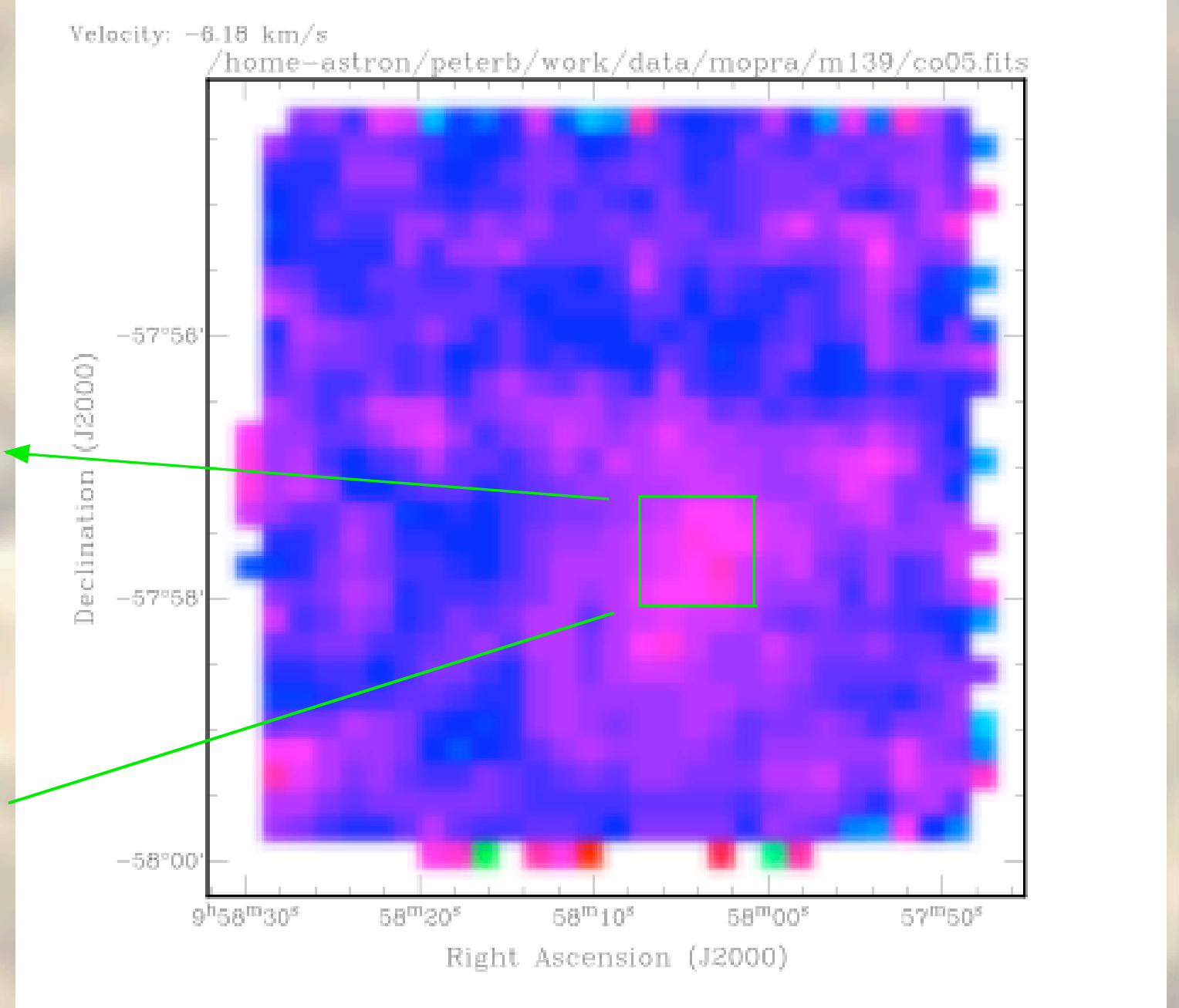

Figure 4. Sample Mopra N_2H^+ channel map of a massive dense core from Box 3 of Fig. 1. See also the sample spectrum from this core in Fig. 5b.

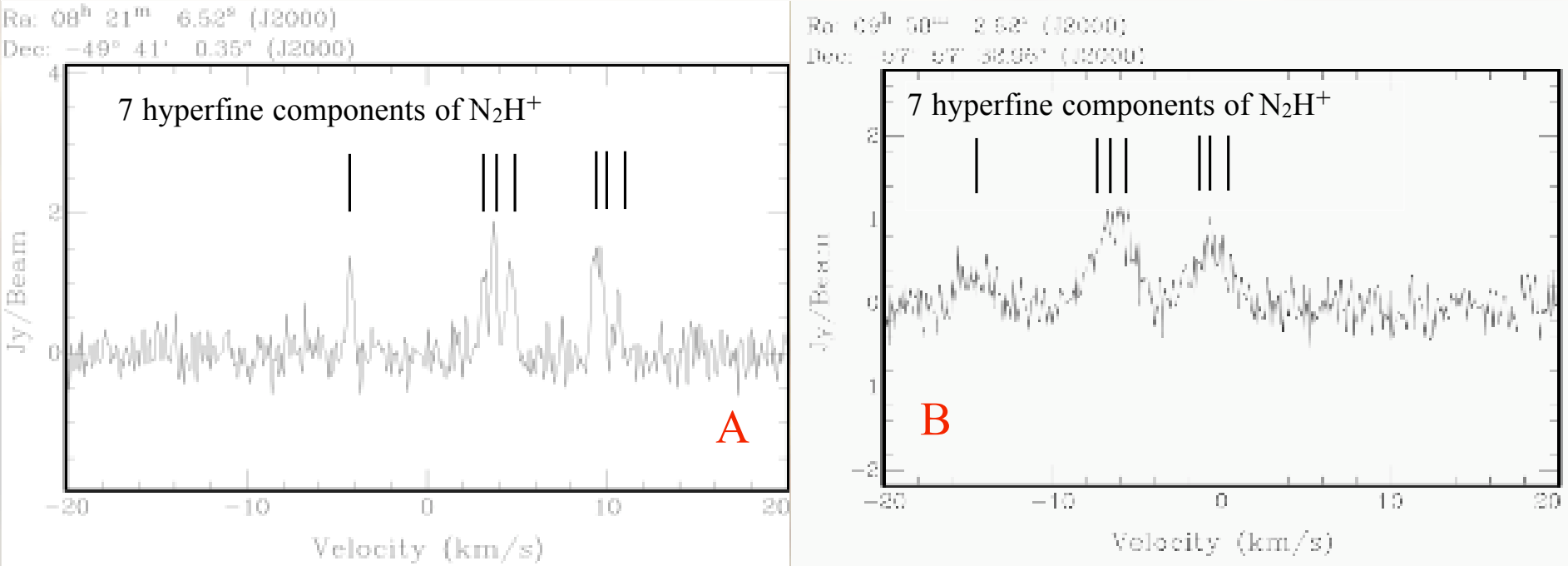

Figure 5. (a) N_2H^+ spectrum from a low-mass core from the Spitzer C2D Legacy Project (not part of CHaMP). Note how each of the hyperfine components is clearly separable. (b) Sample N_2H^+ spectrum from Box 3 of Fig. 1 (the same core as in Fig. 4). Note now the blending of the hyperfine components in this massive core. The difference between (a) and (b) is typical of low-mass and massive cores, and is likely due to a combination of higher kinetic temperatures plus larger non-thermal motions in the gas of a massive core.

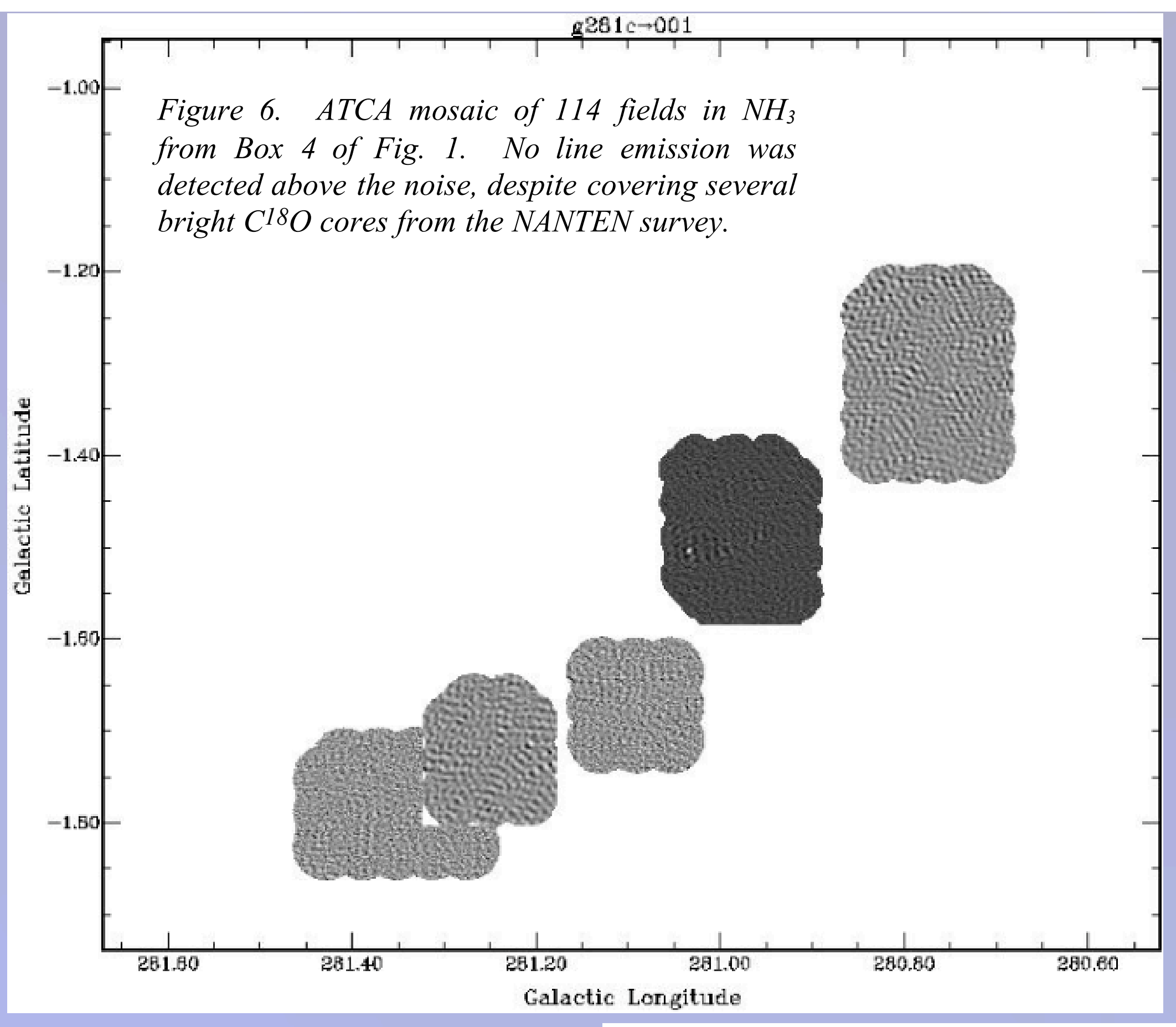

Figure 6. ATCA mosaic of 114 fields in NH_3 from Box 4 of Fig. 1. No line emission was detected above the noise, despite covering several bright $C^{18}O$ cores from the NANTEN survey.

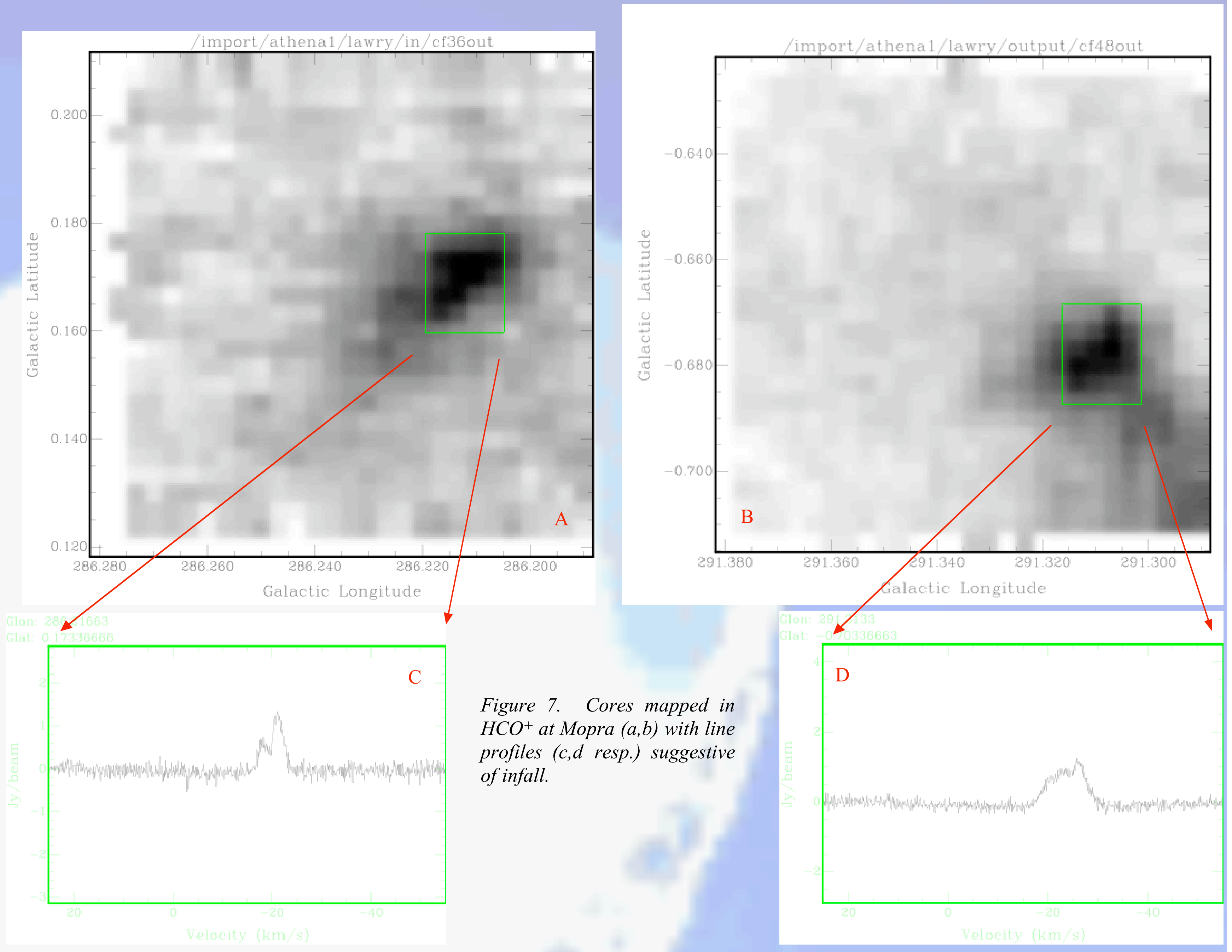

Figure 7. Cores mapped in HCO^+ at Mopra (a,b) with line profiles (c,d resp.) suggestive of infall.

3. Preliminary Results

We have more telescope time scheduled, and so will continue to accumulate statistics. Meanwhile some trends are becoming apparent. As has been found in many individual sources, while the $C^{18}O$ and HCO^+ emission roughly follow each other, they do not coincide in detail. One suspects that the freezing out of CO and related species onto cold dust grains that has been seen in low-mass dense cores (eg Caselli et al. 2002) may also be occurring in these massive cores. Thus several strong HCO^+ peaks coincide with fairly modest $C^{18}O$ peaks, while a number of strong $C^{18}O$ peaks show weak or no emission at all from the high-density tracers, especially in the western cores (l ~ 280°–285°), although the proximity of HII regions to the western cores may be resulting in core heating and destruction, rather than freeze-out, in this case.

Regardless, the fraction of $C^{18}O$ cores that show strong HCO^+ or any of $H^{13}CO^+$, N_2H^+ or NH_3 is quite small, ~15–25%. This is not a sensitivity effect, since when we do detect dense cores the S/N is quite high, and we can also see quite widely distributed weak emission around the peak positions (see especially Fig. 6a,b). This suggests that, if all $C^{18}O$ cores detected belong to a single class of object, and if differences between them can be solely attributed to the temporal evolution of these objects' density, temperature, and chemical composition, then the dense phase of a molecular core lasts only a fairly small fraction of the total lifetime of a molecular cloud. For a typical GMC lifetime ~10^7 yr, the dense phase might then only last ~$2x10^6$ yr.

An even smaller fraction of cores show any blue asymmetry indicative of possible gravitational infall (Zhou et al. 1993, Mardones et al. 1997). Thus for 52 cores mapped in HCO^+, only 2 show the classic infall profile (Fig. 6c,d). Under the above assumptions about the sources as a single class and their lifetimes, and if these 2 sources are confirmed as true massive protostars with infall, this suggests that the infall phase of a massive core lasts ~$4x10^5$ yr. Naturally such claims would have to be confirmed by more detailed observations and modelling, as well as collecting a larger dataset in order to firm up the statistics. If these 2 cores turn out not to be true infall sources, then the implied lifetime of this phase would be proportionately less. As upper limits therefore, such lifetimes are consistent with models such as those of McKee & Tan (2003), which predict that accretion of a massive star directly from its gaseous envelope can happen very quickly.

These purely demographic timescales are (to our knowledge) the first such available for a uniform set of massive molecular clouds. For example, our fraction of infall candidates is much smaller than the massive core sample of Fuller et al. (2005). Their sample, however, was not unbiased: they specifically selected for sources which were likely to be the immediate precursors to ultracompact HII regions, which themselves are fairly short-lived entities. By looking at *all* molecular gas within a large volume of the Galaxy, we have avoided any such bias in our sample, and this allows us to look at the overall timescales of star formation in massive molecular clouds.

For the 2 infall candidates, we can use the simple model of Myers et al. (1996) to obtain an estimate of the speed of the inflowing material from an analysis of each HCO^+ spectrum. Thus for the core in Fig 6a,c we obtain V_{in} ~ 1.7 km/s, while for Fig. 6b,d the core has V_{in} ~ 4.9 km/s. At a critical density of ~$5x10^4$ cm^{-3} for HCO^+, a distance to these cores of 2.5 kpc (Feinstein 1995), and the cores' angular size (40″ and 35″, resp.), this corresponds to a "kinematic" accretion rate of $1.3x10^{-2}$ and $2.8x10^{-2}$ M_o/yr (Myers et al. 1996). These rates should be compared to models such as Shu (1977) which for these cores give gravitational accretion rates of $0.6x10^{-2}$ and $2.9x10^{-2}$ M_o/yr. Given the large uncertainties in these estimates, the rough agreement shows that the profiles are not inconsistent with infall.

4. Summary

CHaMP is an ongoing large-scale survey of massive star formation in the Milky Way. Its main aim is to obtain a ***uniform, unbiased*** sample of pre- and protostellar (and protocluster) massive dense molecular cores, in order to identify all the important evolutionary stages of massive star formation, determine their timescales, and derive how the physical conditions (density, temperature, chemical state) vary during this evolution. CHaMP will do this by making extensive observations in many molecular species using the Mopra antenna of the ATNF, at a resolution (~35″) sufficient to distinguish major dense core features (~0.5pc @ 3kpc), and following these up with higher-resolution (~10″) maps of bright species and cores with the ATCA.

Our first results suggest that, if all cores sampled make up a single population whose differences are due mostly to evolutionary effects, then the dense core phase ($n > 10^5$ cm^{-3}) of a molecular cloud only lasts ~15–25% of the lifetime of the GMC itself. Furthermore, under the same assumptions, the incidence of infall is so low that it must last only ~4% or less of the lifetime of a GMC.

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