Quo Vadis Mopra?
Some Thoughts on Surveys

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Some background...

1. Timing

We are a bit late to this game! Excluding FIR or shorter-λ surveys like GLIMPSE/MSX, we have:
— Bolocam Galactic Plane Survey at CSO, 150 deg^2, λ1.1mm, already done! Public data release by end of year.
— ATLASGAL at APEX, 220 deg^2, λ0.87mm, underway.

...and locally...
— CHaMP at Mopra: 120 deg^2, first pass (85–93 GHz) done! First public data release next year.
— HOPS at Mopra: 50 deg^2, ~1/3 done?

We still have a window of opportunity, but it is shrinking rapidly. If we are to go ahead with MMWS, we need to get on with it!

...background...

2. Direct competition

The ALMA-ISM community is starting to realise that it has a looming problem with field-of-view. They are also agitating for an increased emphasis on ***long-mm*** wavelengths, ie 3 and 7mm.

They ***may*** come to Mopra for these needs, or they may build their own solution. Compared to the total ALMA budget, buying a 15m-class dish with its own multibeam array, ***and putting it on an existing good mm-wave site***, is not such a big deal. If the Europeans or the (non-Nanten) Japanese decide they need to do this quickly, they will blow Mopra out of the water.

Bottom line: *don't kid yourselves that we have this field to ourselves for an arbitrary amount of time.*

Getting it done

Radiometer equation:

$$\Delta T_{rms} = \frac{Kf\,T_{sys}}{\sqrt{\Delta\nu.\tau}} \quad \text{per pixel/beam/etc.} \qquad (1)$$

Can turn this around to get time required for a particular observation:

$$\tau = \frac{1}{\Delta\nu}\left(\frac{Kf\,T_{sys}}{\Delta T_{rms}}\right)^2 = \frac{\lambda}{\Delta V}\left(\frac{Kf\,T_{sys}}{\Delta T_{rms}}\right)^2 \qquad (2)$$

At 3mm with Mopra looking at some “typical” molecular cloud,

$$\tau_{pix} \sim \frac{3\times10^{-3}\,\text{m}}{0.1\ \text{km s}^{-1}}\left(\frac{300\ \text{K}}{0.2\ \text{K}}\right)^2 \sim 15\ \text{sec} \qquad \text{in zoom mode.} \qquad (3)$$

Mapping Speed

So for a "typical" 5′×5′ OTF map with Nyquist-sampled pixels, we need

$$\tau_{map} \sim 400\ \tau_{pix} = 100 \text{ min.} \qquad (4)$$

Really, ~2 hr / map including overheads for pointing, etc. But really ***really***, ~3–4 hr / map including weather outages. This matches the CHaMP experience when mapping dense cores in "bright" lines ($T_A{}^* \sim$ 1–2 K @ 0.1 km/s resolution).

So if we want to map the fourth quadrant this way, for starters we need to cover (eg) 350° > l > 300°, $|b| < 1°$, or about 100 deg^2, whence

$$\tau_{survey} \sim 2{\times}12^2{\times}100\ \tau_{map} = 3 \times 10^6 \text{ min.} = 2{,}000 \text{ days} \qquad (5)$$

This is not feasible.

Workarounds

All is not lost!

1. The lesson of CHaMP

If you can get finder charts from (eg) a lower-resolution or higher-efficiency survey, you can get to your dense gas maps in a tiny fraction of the time. So, CHaMP uses Nanten $^{12}CO \rightarrow ^{13}CO \rightarrow C^{18}O$ to eliminate empty sky and do in 2 short seasons (~10 weeks total) what would have otherwise taken 20 years full-time all winter long!

Of course, you need the finder charts...... Nanten has done this for 300° > *l* > 280° only! ATLASGAL is not yet ready. Catch-22.

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Try again!

Workarounds

2a. Lower frequencies

$$\tau = \frac{\lambda}{\Delta V}\left(\frac{Kf\,T_{sys}}{\Delta T_{rms}}\right)^2 \qquad (6)$$

Time required very sensitive to $T_{\rm sys}$. At shorter wavelengths, $T_{\rm sys}$ is smaller, maybe by factor 2–4! (~ λ^{-1} to first order)

So what about CS J=1→0 (49 GHz), or NH_3 (24 GHz)? In these cases, $\Delta T_{\rm rms}$ and ΔV have the same requirements due to the nature of the sources, but λ is bigger by the same factor! Effectively cancels out one power of $T_{\rm sys} \sim \lambda^{-1}$.

Net time gain is about one factor of λ^{-1}, except.....

Workarounds

2b. Lower frequencies

It's actually worse than this: in an OTF map, you can scan at the Nyquist rate, so if you want the fastest map you can go λ^2 times faster due to the larger beam. But then your point-source sensitivity gets worse by λ! This takes care of the other λ^{-1}.

So (eg) for HOPS with a T_{sys} ~ 75 K, you can go ~64 times faster for Nyquist-sampled maps, but then your ΔT_{rms} ~ 0.8 K. Or you can go 4 times faster to recover ΔT_{rms} ~ 0.2 K (although really you'd want ΔT_{rms} < 0.1 K for ammonia). So HOPS can only detect bright "hot cores", and a similar problem holds at 7mm. This is not the kind of MMWS we are talking about.

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So (eg) for HOPS with a $T_{sys} \sim 75$ K, you can go ~64 times faster for Nyquist-sampled maps, but then your $\Delta T_{rms} \sim 0.8$ K. Or you can go 4 times faster to recover $\Delta T_{rms} \sim 0.2$ K (although really you'd want ΔT_{rms} < 0.1 K for ammonia). So HOPS can only detect bright "hot cores", and a similar problem holds at 7mm. This is not the kind of MMWS we are talking about.

Thank you for playing!

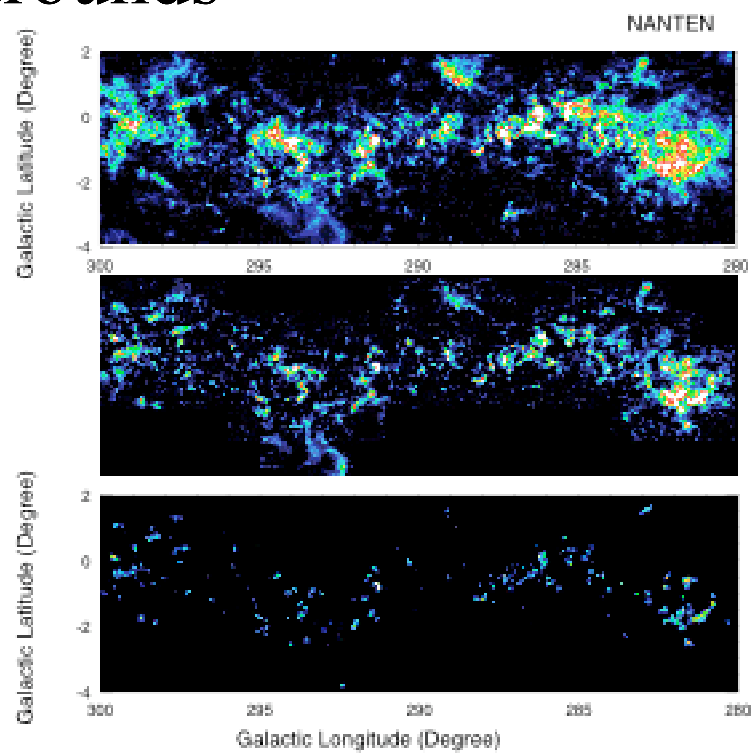
Workarounds

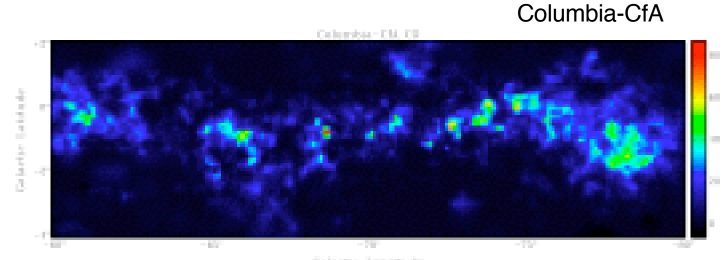
1,2: A further note about these two (non-)options —

Going straight to the high-density tracers is extremely inefficient, unless you have prior knowledge of their distribution.

Prior knowledge ≠ Colum. ^{12}CO nor even Nanten ^{12}CO.

You can't cheat Mother Nature! Compare CHaMP with 1, 10 deg^2 survey.





Workarounds

3. The one exception (ok, two exceptions)

Cleverly neglected in previous discussion is any mention of observing ^{12}CO or ^{13}CO at Mopra. Typically for Galactic clouds,

$$T_A^*(^{12}\mathrm{CO}) \sim 10\ T_A^*(\mathrm{C}^{18}\mathrm{O}) \qquad (7a)$$

and

$$T_A^*(^{13}\mathrm{CO}) \sim 5\ T_A^*(\mathrm{C}^{18}\mathrm{O}) \qquad (7b)$$

So to get the same S/N for ^{12}CO or ^{13}CO maps as we usually do for C^{18}O maps, we need only integrate for $\Delta T_{\mathrm{rms}}^{-2}$ as long:

$$\tau_{\mathrm{survey}}(^{13}\mathrm{CO}) = \tau_{\mathrm{survey}}(\mathrm{C}^{18}\mathrm{O}) \times (4/25) = 320 \text{ days} \qquad (8a)$$

$$\tau_{\mathrm{survey}}(^{12}\mathrm{CO}) = \tau_{\mathrm{survey}}(\mathrm{C}^{18}\mathrm{O}) \times (4/100) = 80 \text{ days} \qquad (8b)$$

where we have also allowed for T_{sys} (110 GHz) ~ $2T_{\mathrm{sys}}$ (90 GHz).

NOTE: these are S/N requirements only!

How to get there

The sample time

But how do we get Nyquist-sampled maps so quickly? The key is the data dump rate, currently 2 sec. This fixes the Nyq-sampled scan rate as well during an OTF, as in eqs. (3–5). If we have lines that are bright enough, we could scan much faster with an accelerated dump rate.

Suppose t_{dump} = 0.32 sec, then eq. (4) becomes

$$\tau_{map}(^{13}CO) = 17 \text{ min.} \tag{9}$$

for a Nyquist-sampled 5′×5′ OTF map with ΔT_{rms} = 1.0 K, which is roughly what we need for ^{13}CO in eq. (8a) (ok, so I peeked).

If we can get this dump rate with 4 or even 2 dual-polarisation zoom modes (instead of 16), then we get ^{12}CO at the same sensitivity, for free. This seems feasible (WW).

Justification *post facto*

A real survey

This is exactly what we want: a dual ^{12}CO and ^{13}CO survey at 1K rms per 0.1 km/s channel over 100 deg^2, which will take 320 days including overheads(!) of continuous telescope time.

If we allow for smoothing to 0.2 km/s channels, this can be achieved as a "Mopra Key Project" in just 3 winter seasons assuming it can be run for 16 hours/day over 13 weeks in each season (or some combination of similar numbers). However we can probably do ~2× better if we use the existing Nanten ^{12}CO maps as finder charts for MMWS.

A built-in finder chart

Subsequent deeper integrations can always be added in selected areas, eg to flesh out the ^{13}CO maps, and we have our complete set of finder charts for other submm–1–3–7–12 mm tracers.

Benefits 1

Beyond finder charts for dense gas: Maximum downstream applications

The general nature of such a survey will guarantee maximum flexibility and usefulness for subsequent investigations, whether at ATCA, ALMA, or anywhere else.

Legacy value

Prompt availability of data cubes from a pipeline reduction process to the community will be essential, for all imaginable follow-up projects. FITS- and Virtual-Observatory-compatible format will both be desirable.

Benefits 2

We won't be able to think of everything!

Besides finder chart generation, extensions to the MMWS in later seasons can be conducted in a number of ways:
—extending in *l* and/or *b*,
—deeper integrations for ^{12}CO outflows and/or ^{13}CO extents,
—comparison with ATLASGAL, GRS, GLIMPSE, HI-GAL, etc.
—follow-up at Nanten2, ALMA, ATCA, ASKAP, Herschel, SOFIA, APEX, ASTE, CCAT, etc etc etc.

These options are limited only by the community's imagination!

Final warning

Objects in mirror are closer than they appear, or,
Don't try this at home, kids!

This is a ***VAST*** project, ***way*** too big for anything less than a community-wide effort. (Eg, CHaMP has ~300 Gb raw data from 10 weeks on the telescope: reduction and analysis is a major logistical challenge.) A data management and publication plan ***must*** be devised and agreed beforehand.

Let us be perfectly frank: if we are to use MMWS to stave off repeated attempts to shut Mopra down, we are fighting an uphill battle against the entrenched cm-bias in Australian radio astronomy. Nothing less than a unified mm-community approach will succeed.

We all have to be part of this.