THRUMMS : The Three-millimetre Ultimate Mopra Milkyway Survey

Completed survey within the 4th Quadrant - 300-360 deg lat +/- 1 deg.
$^{12}CO(1\text{-}0)$, $^{13}CO(1\text{-}0)$, $C^{18}O(1\text{-}0)$, CN(1-0)

PIs: Barnes + Muller (Ufl and EA- observatory, Chile)
Co-Is: Indermuehle, Balthasar; O'Dougherty, Stefan N.; Lowe, Vicki; Cunningham, Maria; Hernandez, Audra K.; Fuller, Gary A.
Nguyễn, Hans; Nguyễn Lu'o'ng, Quang; Martin, Peter G.;Lo, Nadia; Motte, Frédérique

See also:

The Three-mm Ultimate Mopra Milky Way Survey. I. Survey Overview, Initial Data Releases, and First Results' - 2015,ApJ,812,6
(Barnes, Peter J.; Muller, Erik; Indermuehle, Balthasar; O'Dougherty, Stefan N.; Lowe, Vicki; Cunningham, Maria; Hernandez, Audra K.; Fuller, Gary A.)
and
The Three-mm Ultimate Mopra Milky Way Survey. II. Cloud and Star Formation Near the Filamentary Ministarburst RCW 106 - 2015,ApJ,812,7
(Nguyễn, Hans; Nguyễn Lu'o'ng, Quang; Martin, Peter G.; Barnes, Peter J.; Muller, Erik; Lowe, Vicki; Lo, Nadia; Cunningham, Maria; Motte, Frédérique; Indermühle, B.; and 3 coauthors)

With media releases (in the USA and Australia)
http://news.ufl.edu/articles/2015/10/peeking-into-our-galaxys-stellar-nursery-.php
http://www.abc.net.au/news/2015-10-21/milky-way-galaxy-star-forming-clouds/6861712

Data repository (DR III):
http://www.astro.ufl.edu/~peterb/research/thrumms/
http://alma-intweb.mtk.nao.ac.jp/~emuller/THRUMMS
Also (~end 2015) hosting at ATOA and EA-ALMA science portal for ALMA use (e.g. Single-dish calibration)

THRUMMS:

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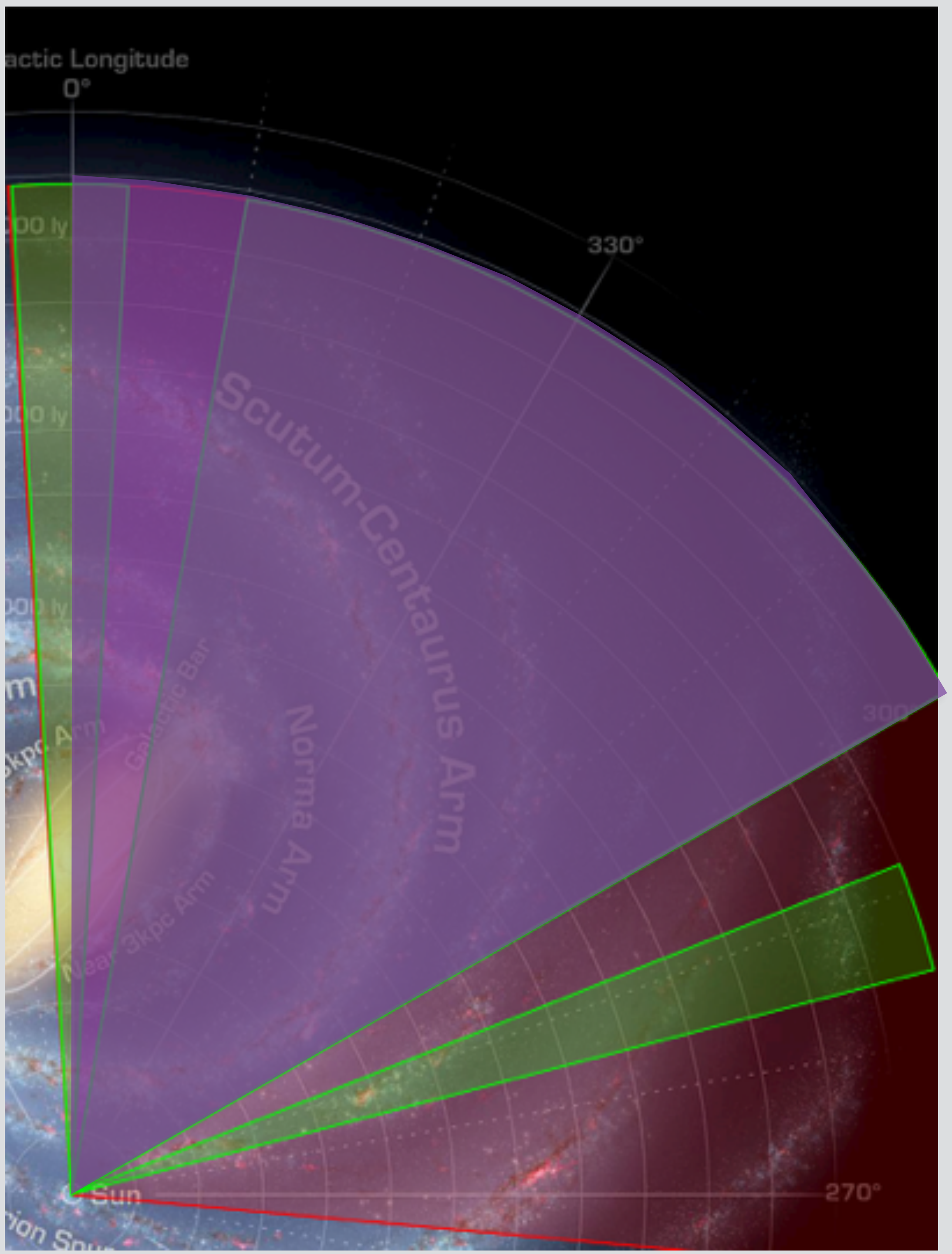


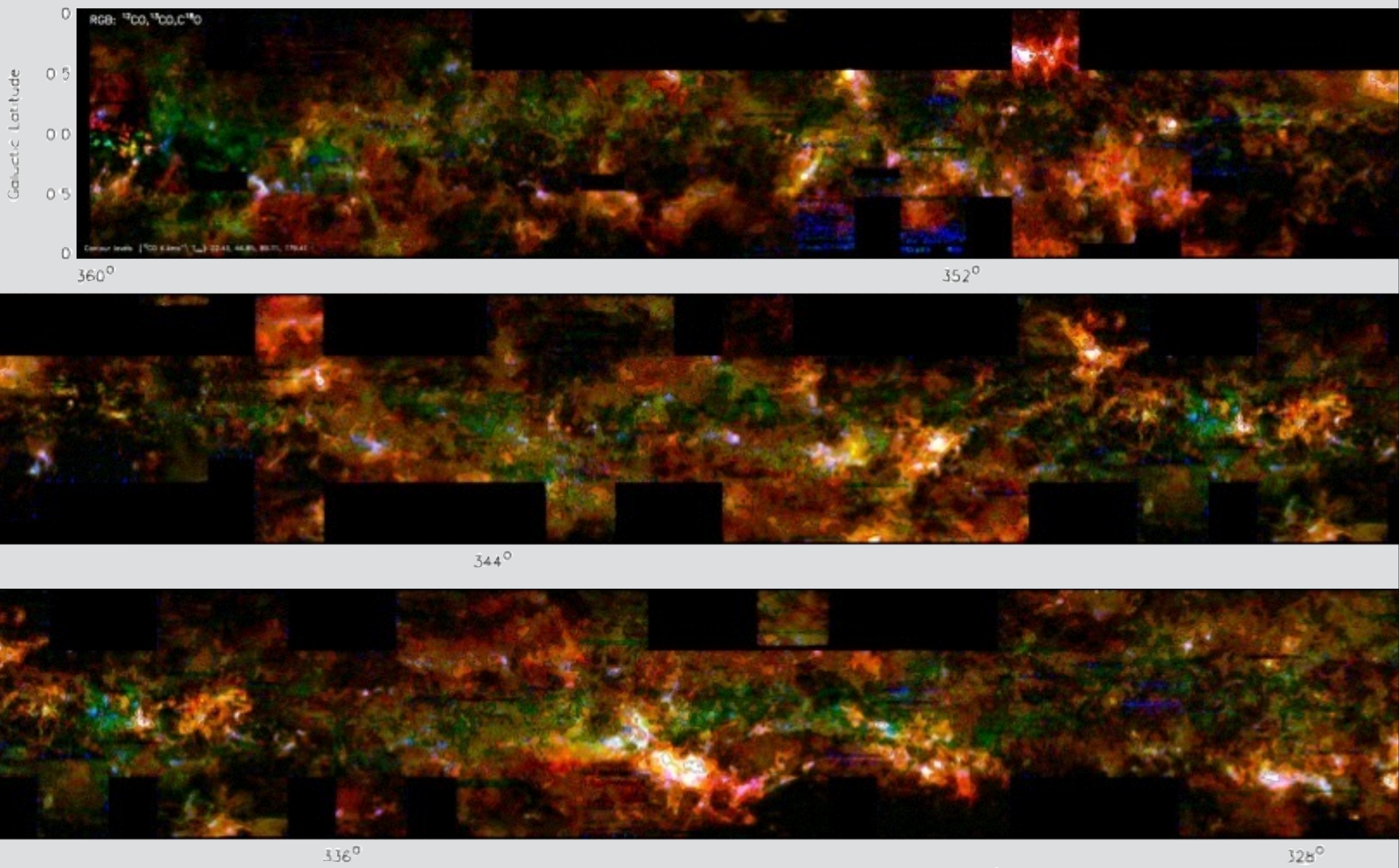
Status:
This survey is complete

DR III in public domain (since 2010)
DR IV to be released in a few weeks.

DR III.

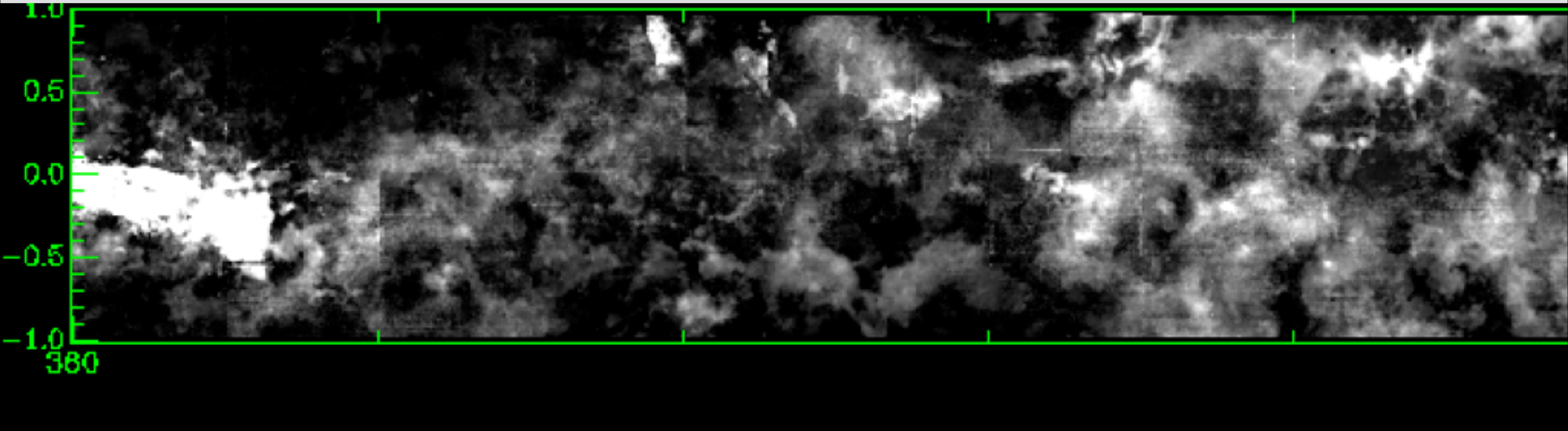
Barnes & Muller et al,. ApJ, 2015

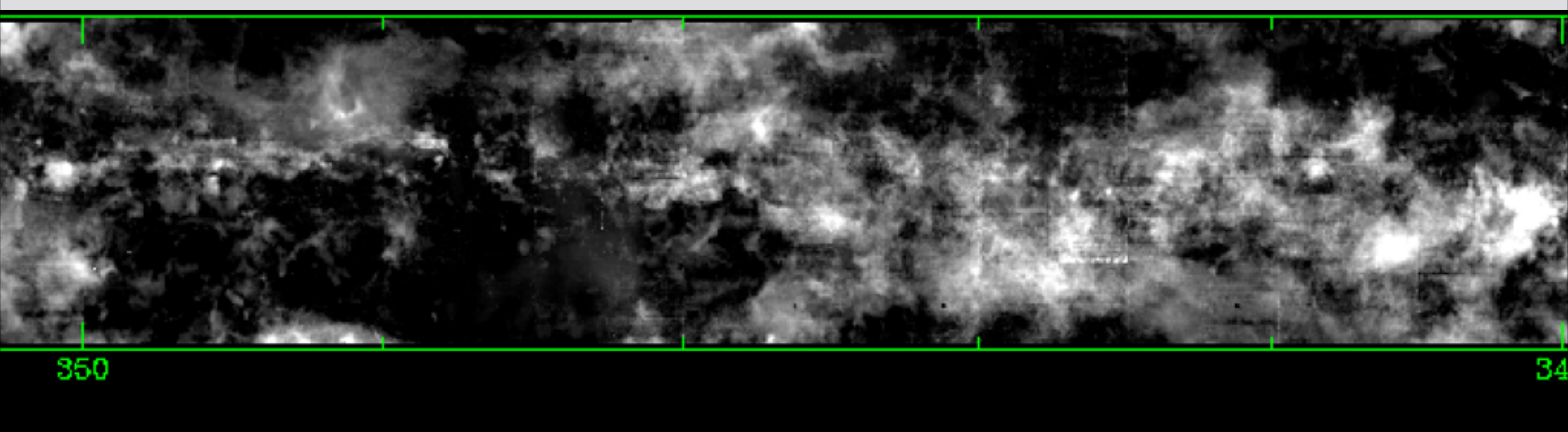
R:G:B - ^{12}CO, ^{13}CO, $C^{18}O$



DR IV prelim…

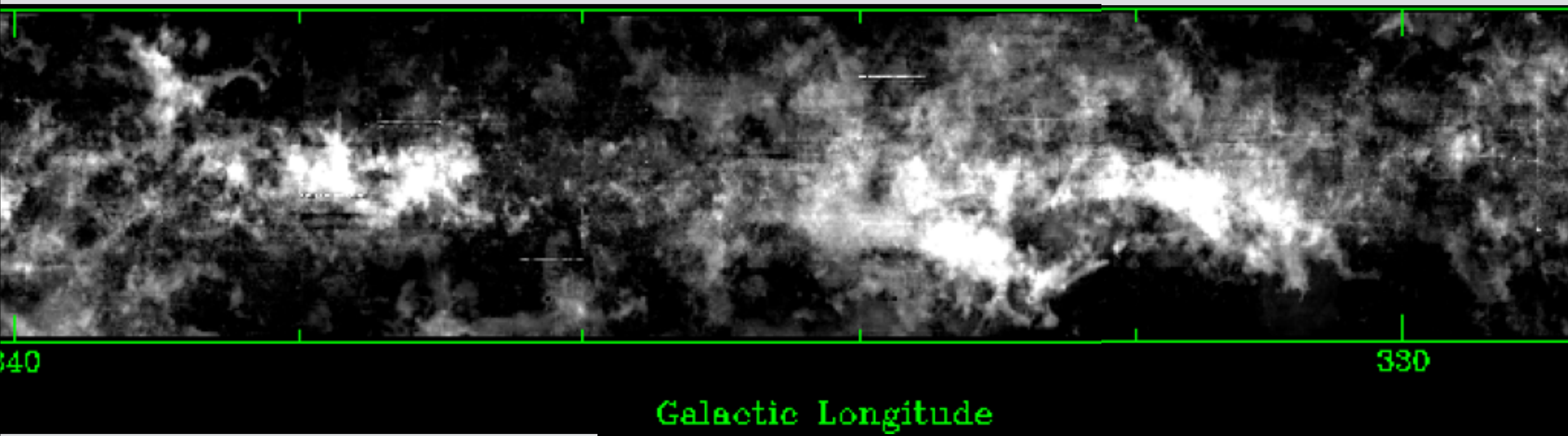
^{12}CO Filtered ('SAM') and moment 0
(Greyscale; linear 0:100 $Kkms^{-1}$)

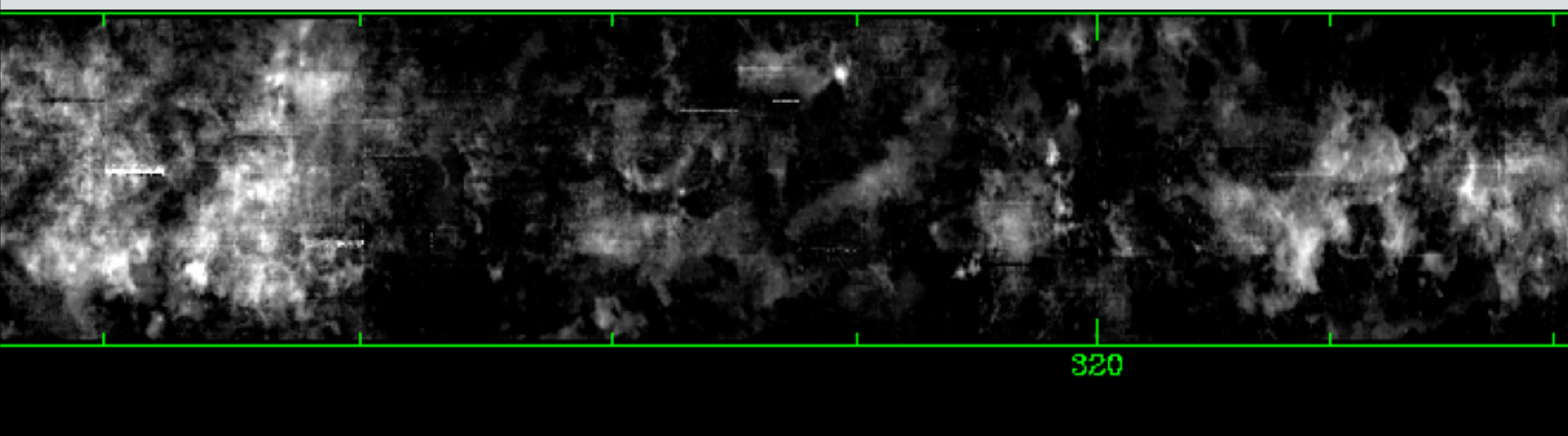




DR IV prelim…

^{12}CO Filtered ('SAM') and moment 0 (Greyscale; linear 0:100 K km s^{-1})





DR IV prelim…

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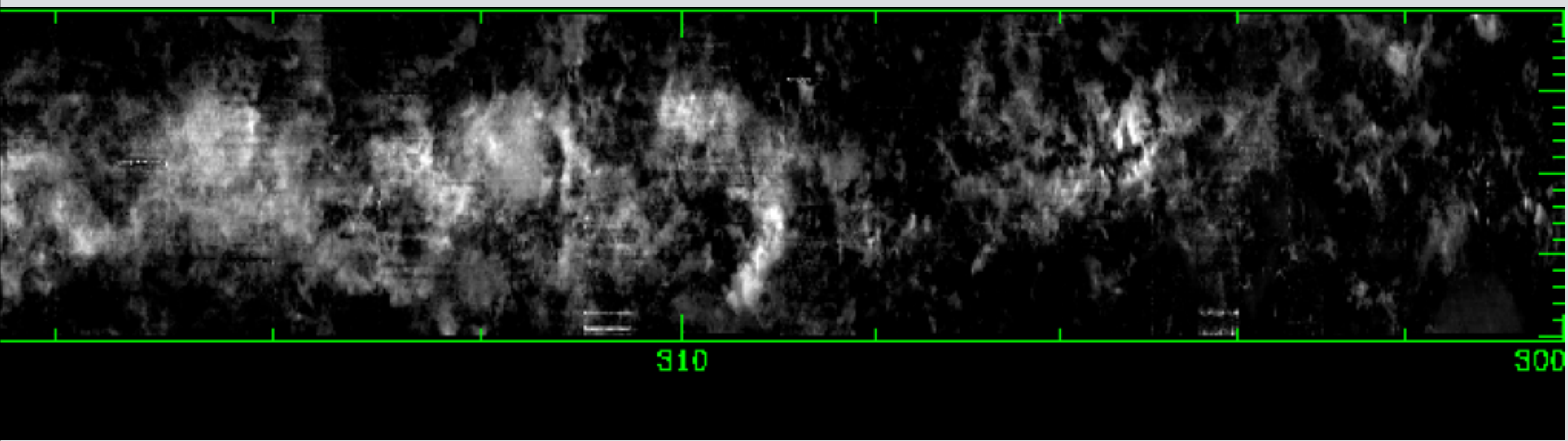
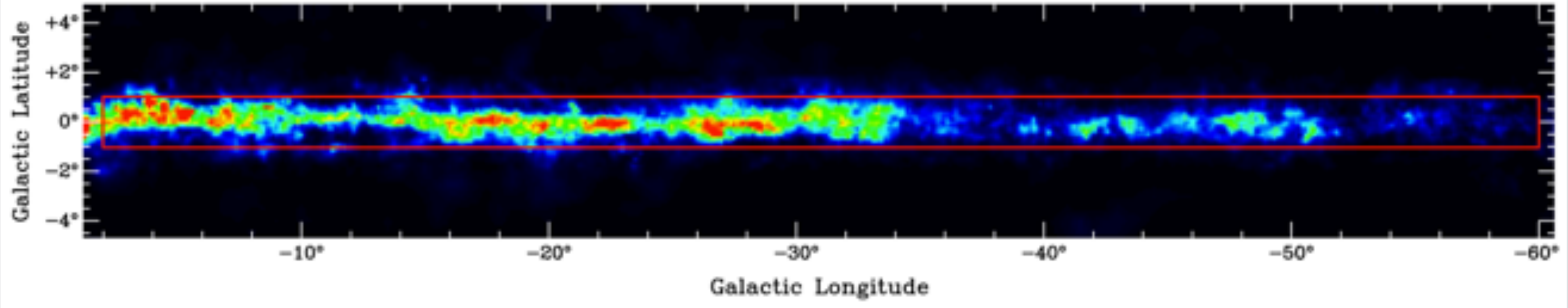


ThruMMs survey outline



ThrUMMS:

- Mopra Telescope: 22m, ~75-116 GHz
- $^{12}CO(1\text{-}0)$, $^{13}CO(1\text{-}0)$, $C^{18}O(1\text{-}0)$, CN(1-0)
- Latitude range: 1.0 ~ -1.0 deg
- Longitude range: 360°-300°
- Velocity range: -200 km/s - 50-100 km/s
- Spatial resolution: ~72''

Thrumms samples > 75% of ALL CO Mass in the 3-4 Quadrants

Species	Frequency	Resolution	RMS	RMS 1km/s	RMS 5km/s
12	115.271	0.083 km/s	2.6 K	750 mK	330 mK
13	110.201	0.085 km/s	1.4 K	400 mK	180 mK
C	109.782	0.085 km/s	1.4 K	400 mK	180 mK
CN(1-0)	113.5	0.083 km/s	1.8 K	510 mK	230 mK

*CN has 9 hyperfine transtions, 5 of which are measured in the band ('stacking' will improve S/N by sqrt(5))
**Naturally, improved RMS can be obtained at the expense of velocity resolution, or even spatial resolution.

Generalized Science Drivers:

1. High-resolution exploration of the Wide-field properties of Galactic-plane molecular clouds. GMC envelopes, velocity distributions, outflows, molecular column density.

   $^{12}CO(1\text{-}0)$, $^{13}CO(1\text{-}0)$, $C^{18}O(1\text{-}0)$, CN

2. Tracing molecular component with optically thin(ner) molecular tracers: PDRs, Optical Depth, velocity dispersion, molecular excitation, molecular column density.

   $^{13}CO(1\text{-}0)$, $C^{18}O(1\text{-}0)$, CN(1-0)

3. Tracing dense molecular component, gas depletion.

   $C^{18}O(1\text{-}0)$, CN(1-0)

4. Higher density Molecular component, Zeeman candidates.

   CN(1-0)

Specific Science Drivers:

1. The Three-Dimensional Structure of the Southern Milky Way
2. Regional variations of ISM conditions & impact on cloud profile
3. Star Formation Efficiency on Larger Scales
4. SEDs, Masses, and Luminosities of Dust Clouds
5. Understanding and Characterising the Cloud Mass Function
6. The shape of Magnetic Fields (via zeeman-splitting of CN - ALMA)

ThrUMMs and MopraCO.

The scientific elements of ThruMMS might be looking familiar at this point.

and that's because they are....

More on this later

Observing strategy I:

Benchmark “normal” observing at 115 GHz:

1.5 hours for 5’x5’ field yeilds ~300 mK RMS at 33’’ resolution

Fast mapping:

- Increased scanning & survey rate x 8
- (therefore reduced sampling rate by x8)
- per-channel sensitivity reduced only by sqrt(8) ~ 3.

5’x5’ field is ~11 min, ~1.0 K RMS, 33’’ resolution

Beam-sampled Mapping:

- Increased linear scanning rate x 4
- (survey rate increased by x16)
- per-channel sensitivity unchanged.
- (spatial resolution reduced by only ~2)

5\`x5\` field is ~11 min, ~300 mK RMS, 1.1’ resolution

“Very Fast Mapping”

- survey rate increased by x32
- per-channel sensitivity reduced by ~ 3.
- spatial resolution reduced by ~2

Benchmarks (for 5’x5’ field):

~1.4 min, ~1.0 K RMS, 1.1’ resolution

Observing strategy II:

$$\nu_N(el) = \nu_N(90)\left(\frac{T_{sys}(el)}{T_{sys}(90)}\right)$$

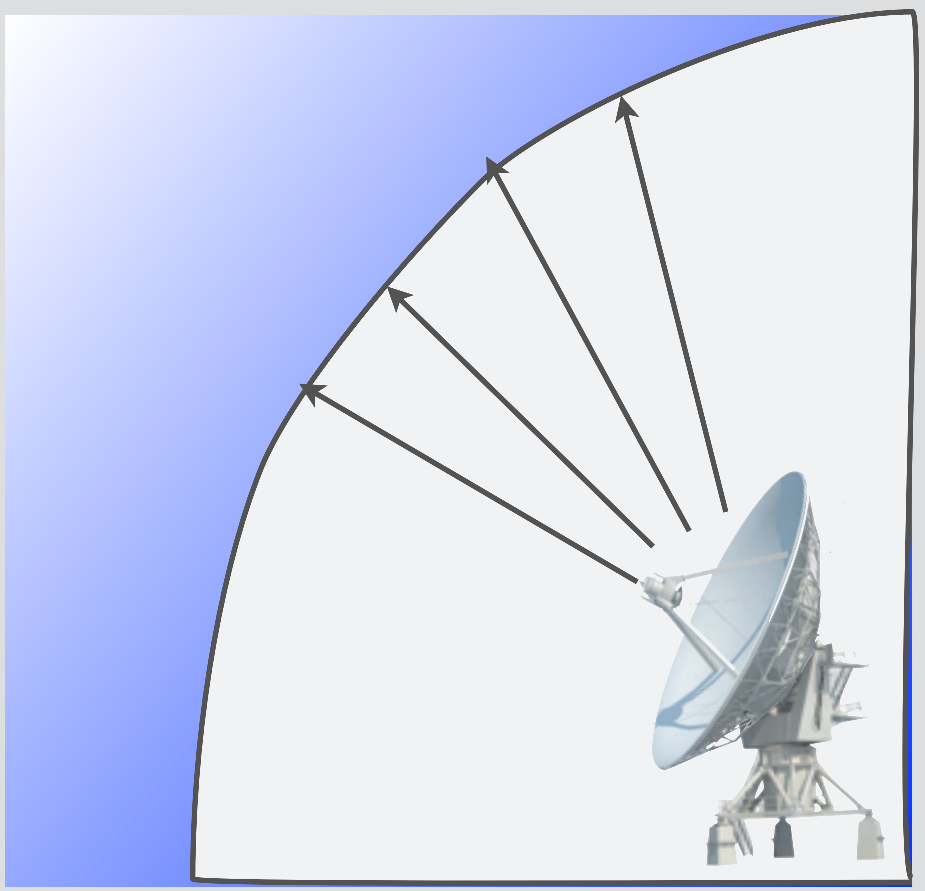
$$\nu_N(90) = 55GHz(\sim 70'')$$

$$T_{sys}(90) = 400K$$

Active mapping:

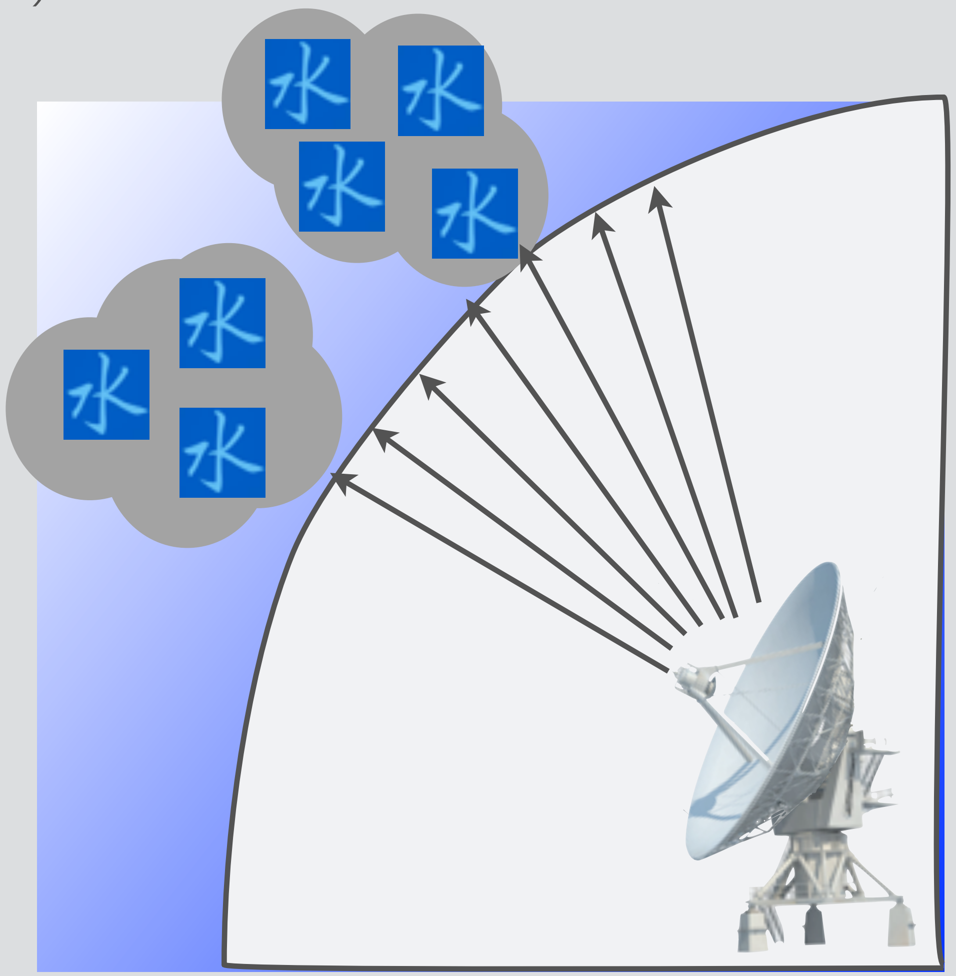
Active mapping takes Tsys measurement prior to data-taking, and recomputes the sampling interval to ensure ~homogenous sensitivity.

(usually works, even in summer, number of repeat fields < 10%)



Tsys = X, sampling interval =1 (arbitrary values)

E.g. Tsys = 400 K



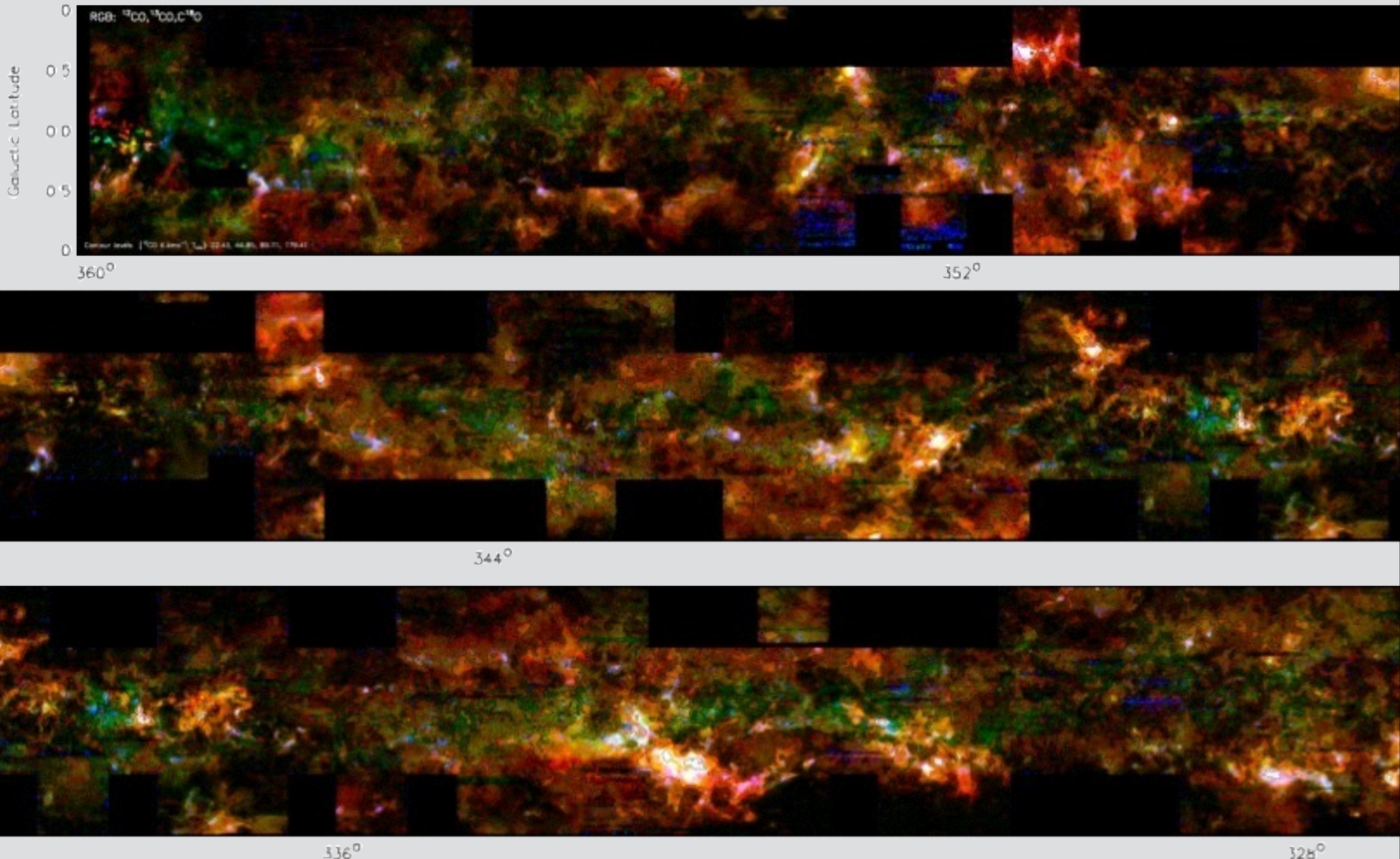
Tsys =√2X, sampling interval =1/2

E.g. Tsys = 565 K

Line ratios on steroids.

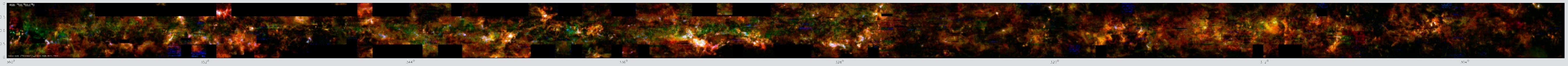
R:G:B - ^{12}CO, ^{13}CO, $C^{18}O$

Barnes & Muller et al,. ApJ, 2015



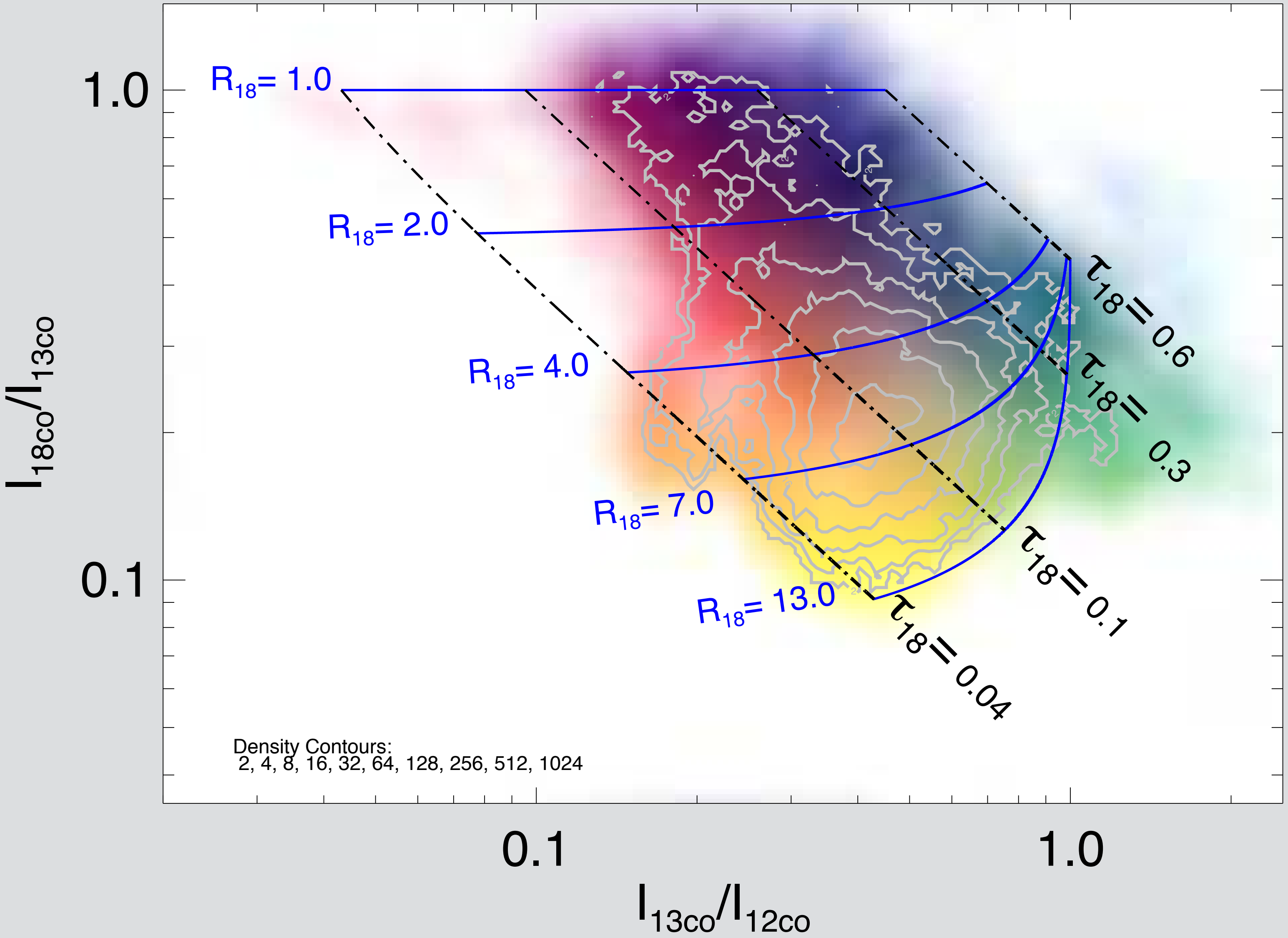
Line ratios on steroids. Tau and abundance

Barnes & Muller et al,. ApJ, 2015



$$\frac{T_{13}}{T_{12}} = \frac{1 - e^{-\tau_{13}}}{1 - e^{-R_{13}\tau_{13}}}$$

Assume LTE (Tex).
Empirically solve for Tau,

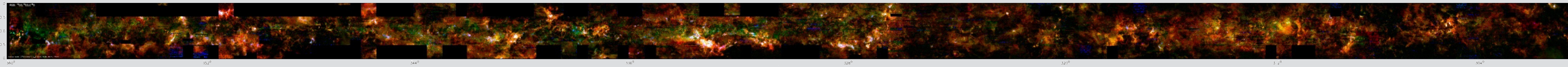


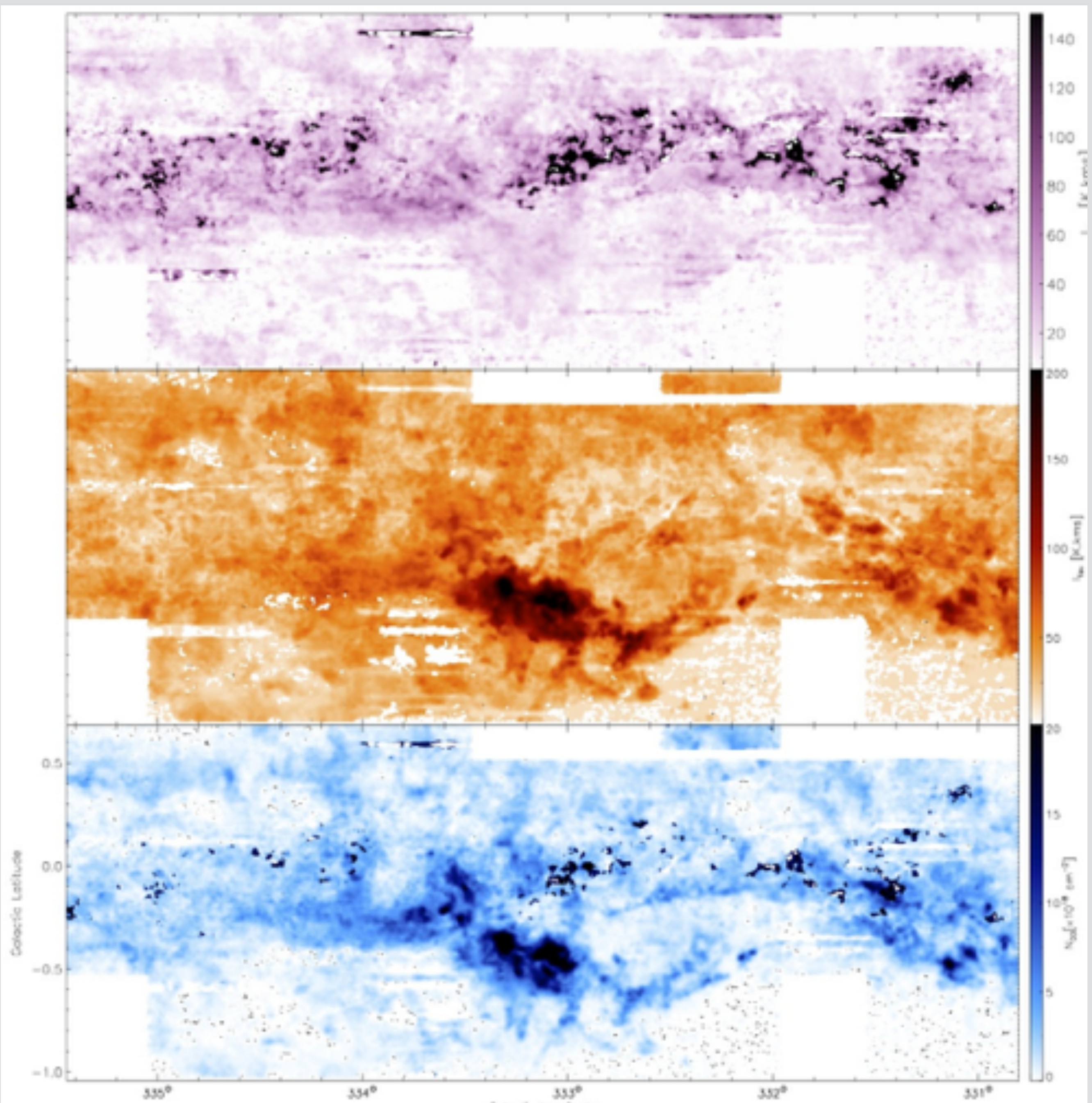
Red: ~low τ and high Tex,
"warm and translucent".
Green~cyan/blue: ^{13}CO or C^{18}O (or both) > *average LOS* ^{12}CO
(^{13}CO, C^{18}O are saturated, but not bright) - High tau, low Tex.
"cold and opaque".

Holistic views.

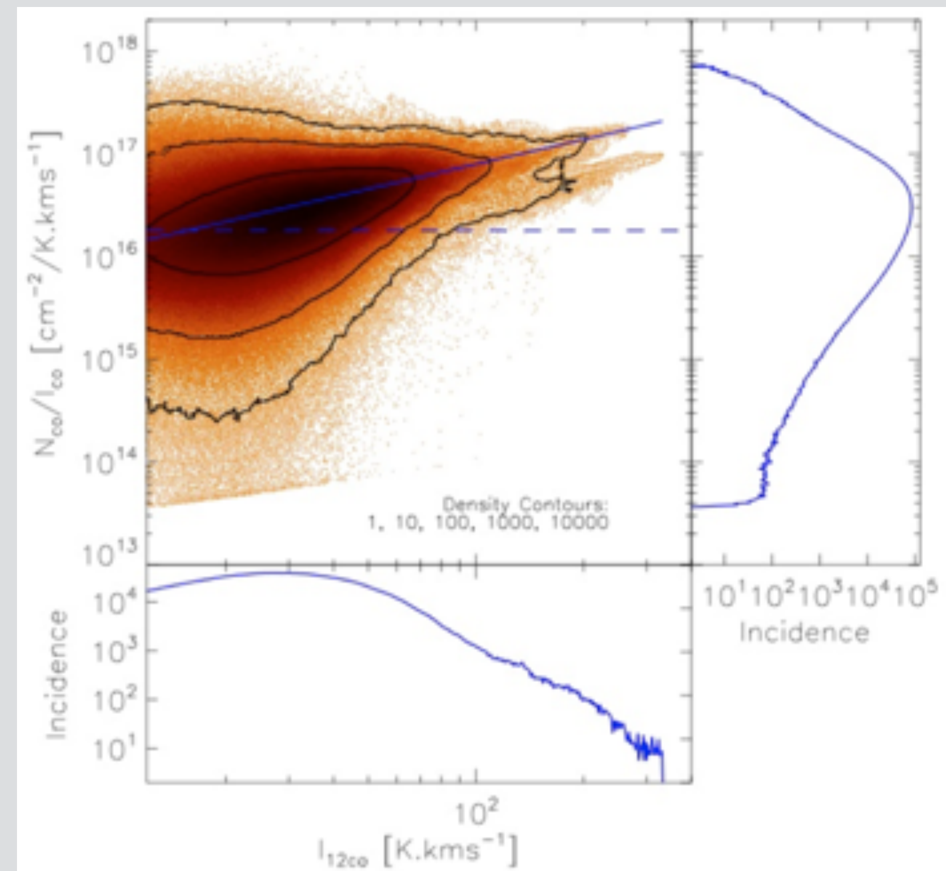
Tex, Column density and Xco

Barnes & Muller et al,. ApJ, 2015





$$N_{CO} = 2.28 \times 10^{14}\mathrm{cm}^{-2}\mathrm{T}_{\mathrm{ex}}^{1.56} \int \tau dV$$



$N_{H2} = X_{CO}I_{CO} = R_{12}N_{CO}$

The dashed blue line ~ standard X_{CO}/R12 ratio

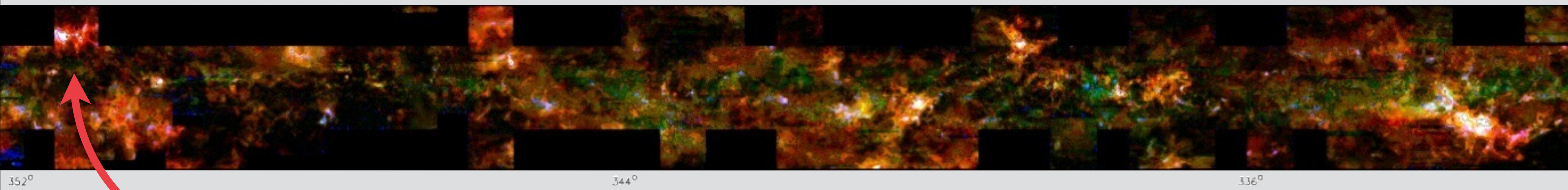
Solid line is a rough power-law fit to the modal trend, suggesting a more universal X-factor ratio of ~8-40 X 10^{20}

TOP: ^{12}CO Tau MIDDLE: Ico BOTTOM: Nco

(See Dame et al, 2001, ~2 X 10^{20} cm^{-2} Kkms^{-1})

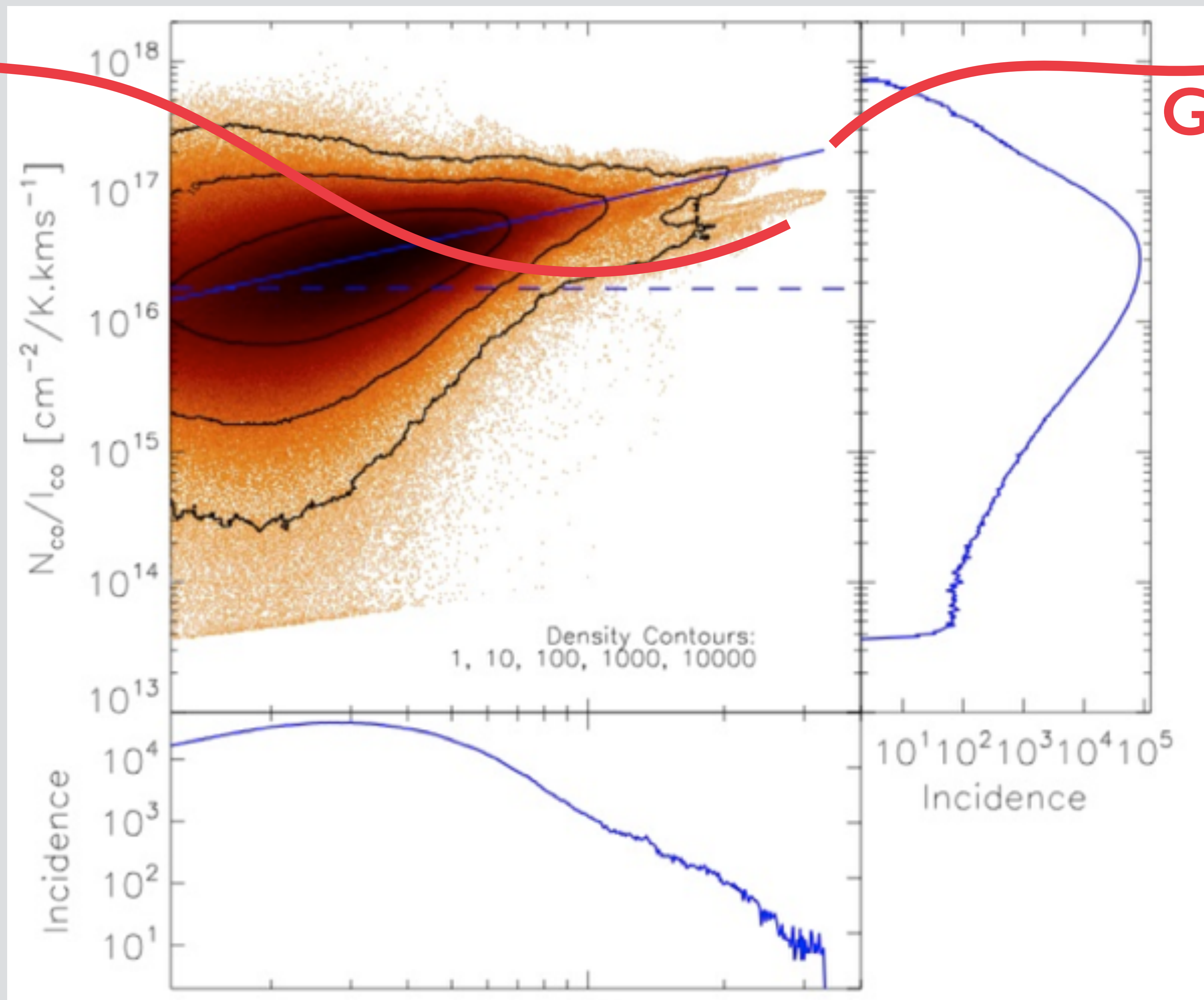
Holistic views. Column density and Xco

Barnes & Muller et al,. ApJ, 2015



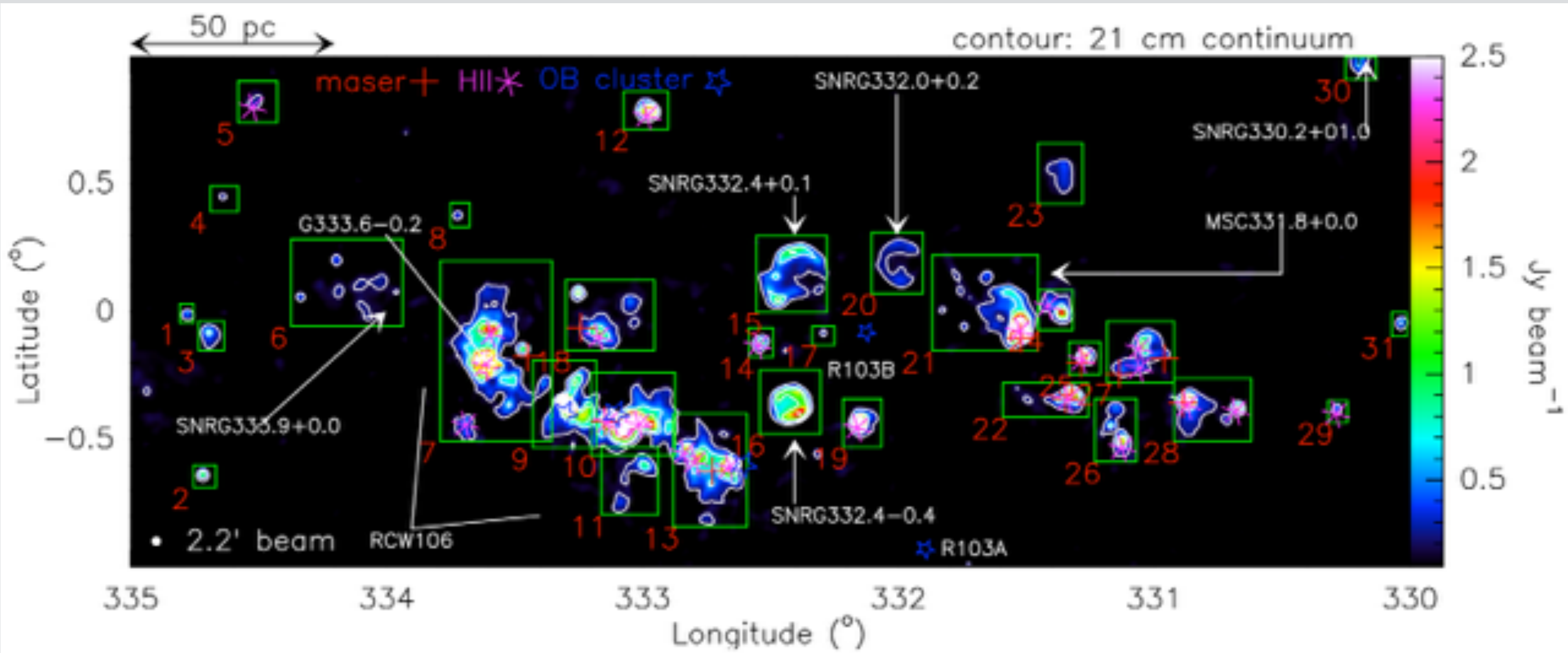
NGC6334

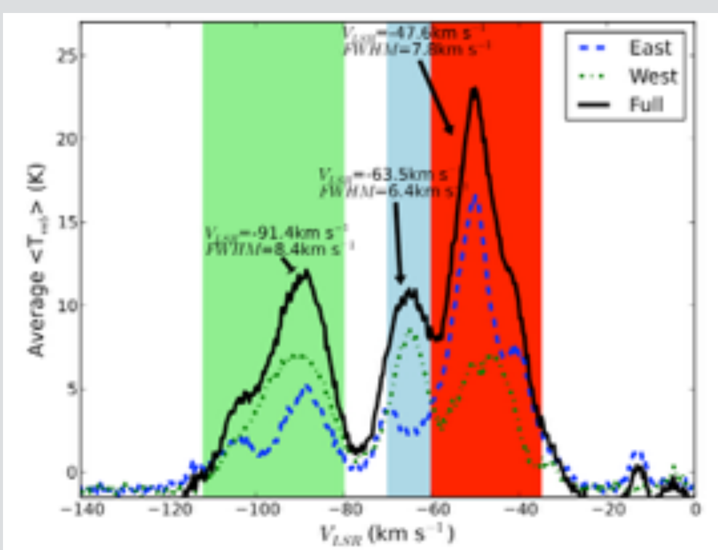
G333 complex

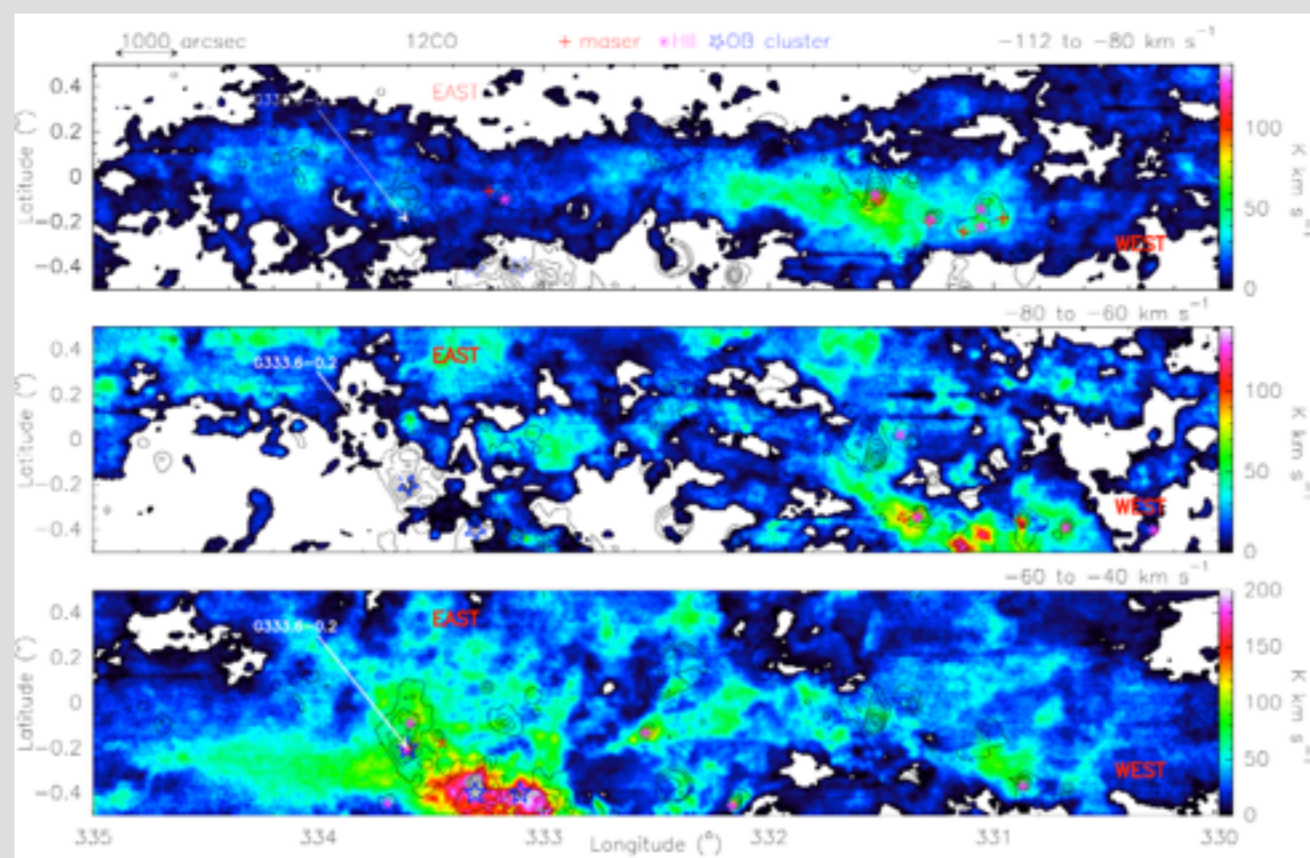


Disentangling the third dimension:

RCW 106 complex, and GMC 331.0+0.0
Nguyen et al,. ApJ, 2015







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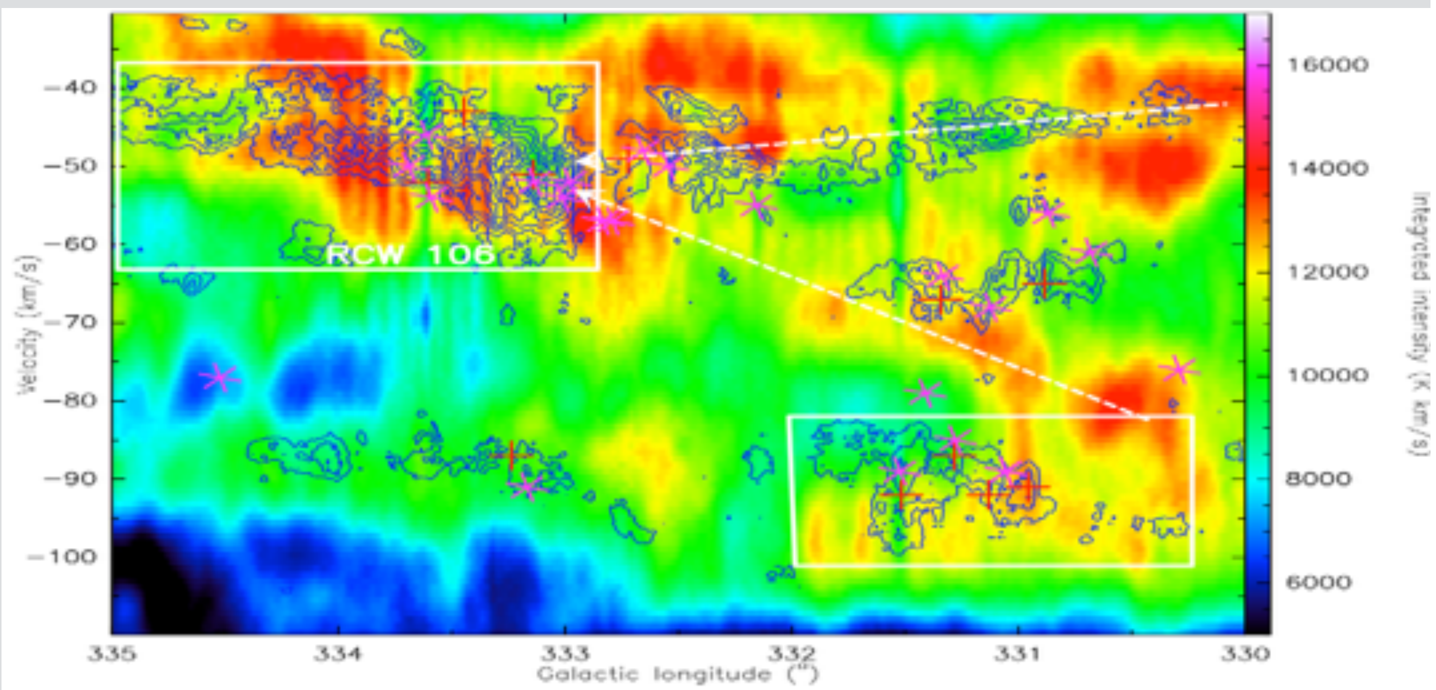
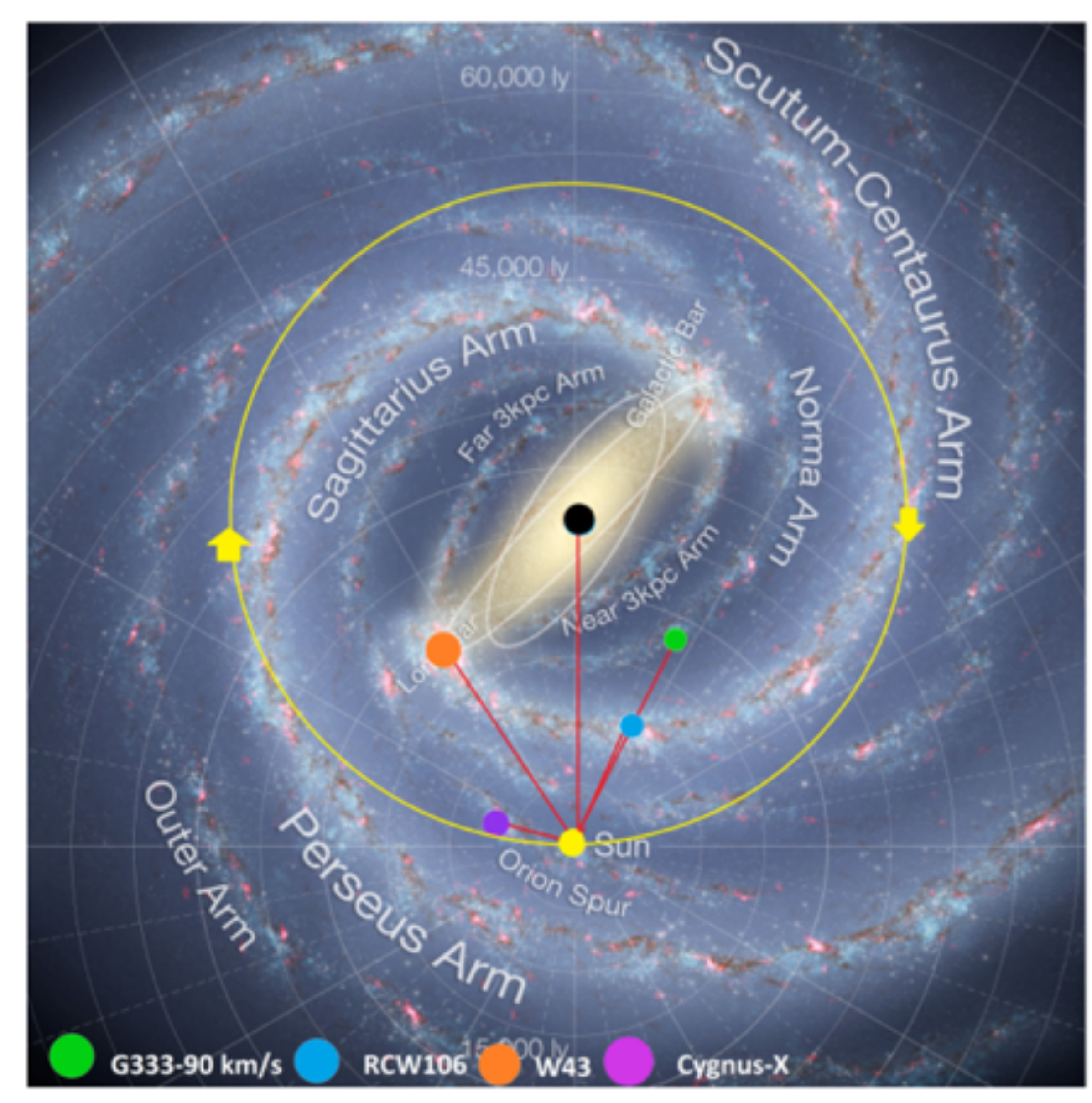




Cross collaborations:

SEDIGISM - PI F. Schuller

- CO(2-1) with field matched to ThrUMMS, resolution is superior: 20''
- Wide ranging collaboration, relevance to Thrumms is radiative transfer. tau, optical depth, temperature, density, etc. etc.)

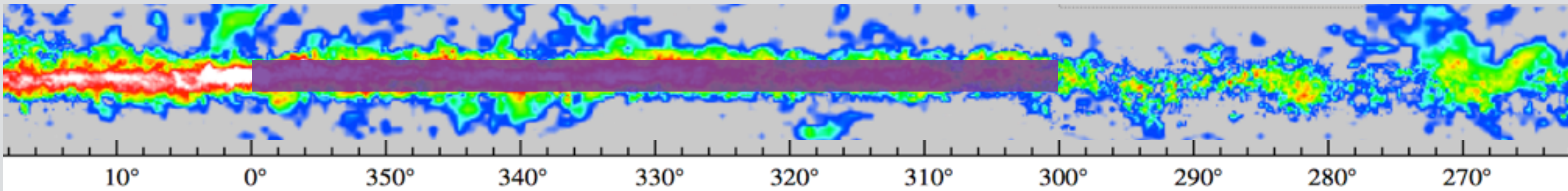
Nobyama GPS (PIs: Minamidani+Umemoto)

- Science goals are similar, ^{12}CO, ^{13}CO, $C^{18}O$., resolution is superior: 20''
- 1st+4th Quadrant complimentarity
- Better statistics of similar environments

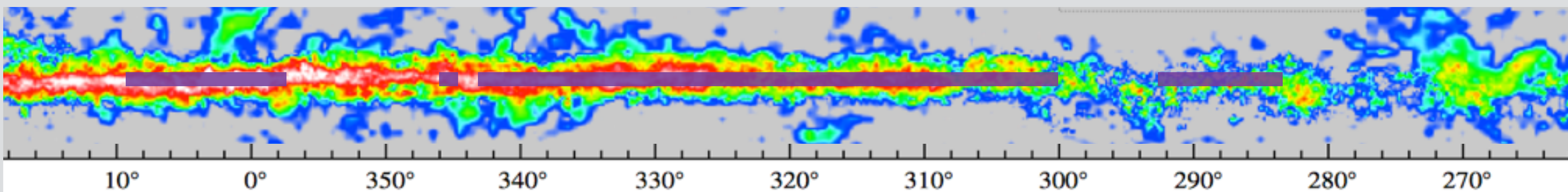
..also planned and formulated: CO3-2 in the 1st quadrant w/ JCMT
(PI: T. Moore, see also Dempsey et al, 2013)
.. in discussion (EA-ALMA) ASTE CO(3-2) in 4th quadrant
(we'll have fully Rad transf input for ^{12}CO J transitions , 1-0, 2-1, 3-2)

ThrUMMs and MopraCO.

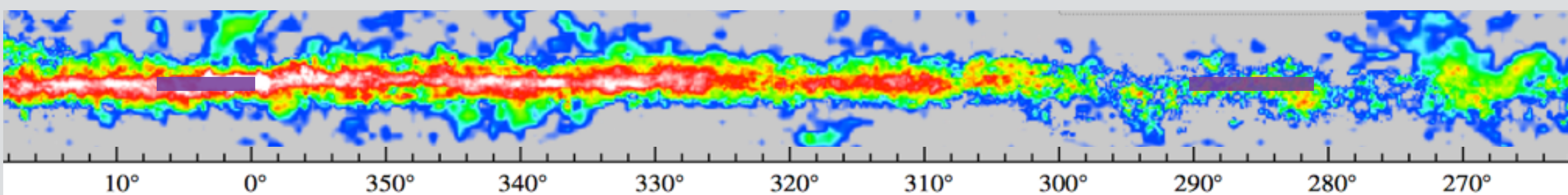
Data of this region (ThrUMMS field) already exist, and are available at a resolution useful to MopraCO



This is the area proposed described by MopraCO (unreviewed) - C. Braiding slides 6, 37.

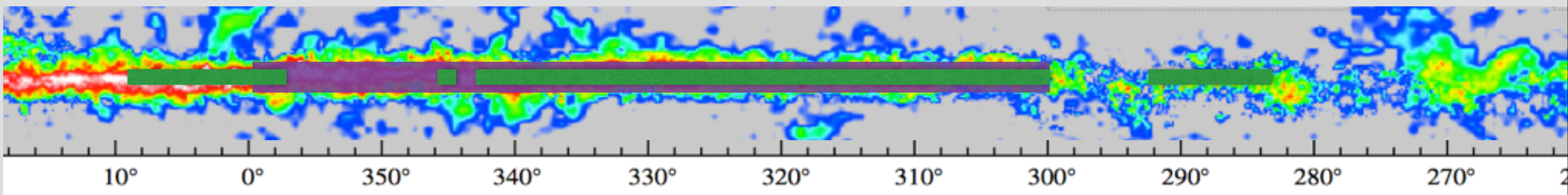


This is the net unique contribution to science from mopraCO (8 years and $93k public money).

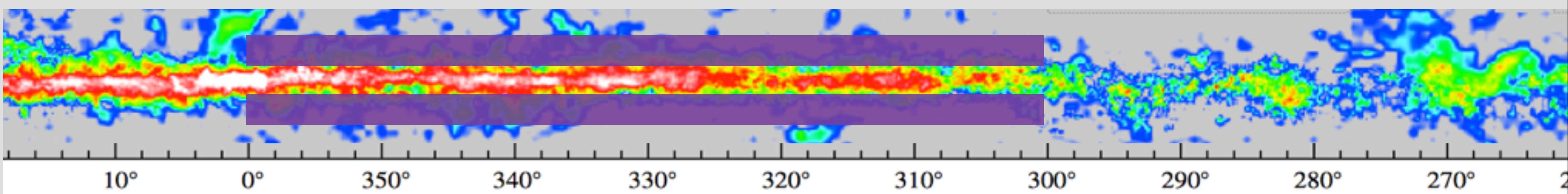


AN OPEN PROPOSAL TO MOPRACO:

MopraCO spends ~67% of its time re-walking already-explored territory. ***This benefits noone***.



Over 8 years, (past+future), mopraCO ***could*** survey 0.25 x 120 x 8 ~240 sq deg
(or propotionally, in whatever time is available…) I.e. - change the field. Save time, money and integrity.



High(ish)-latitude CO clouds (|l|>1) are in a ~different environment to |l|<1:
less cluttered velocity structure, CO/13CO ratio is less affected by optical depth etc.

'magnetic loop footprints' - e.g. Fukui et al, 2006: Chemistry, fluid dynamics, Vel, Temp, density distribution.
Spitzer bubbles - e.g. Beaumont & Williams (JCMT), 2008
Chiminey walls & vents - e.g. GSH 277+00+36 (Dawson et al, 2010)

FINALLY - A RANT.

By appealing to public funding via kickstarter, Mopra CO have bypassed external expert peer review. This is okay in some cases.. but generally:

This style of fund sourcing enters a new model where ethical use of public funding and efficient production of unique science that can only be self-policed.

I would not say that has happened in this case, from the very earliest stage.

Presently, only ~<33c of each kickstarter dollar goes to unique science. This could be, and should be100%. Even worse: at this point, well-meaning kickstarter supporters have not been informed that the goals of MopraCO can already be realised **NOW** without their contribution,

….RANT ASIDE - HERE IS A SOLUTION..

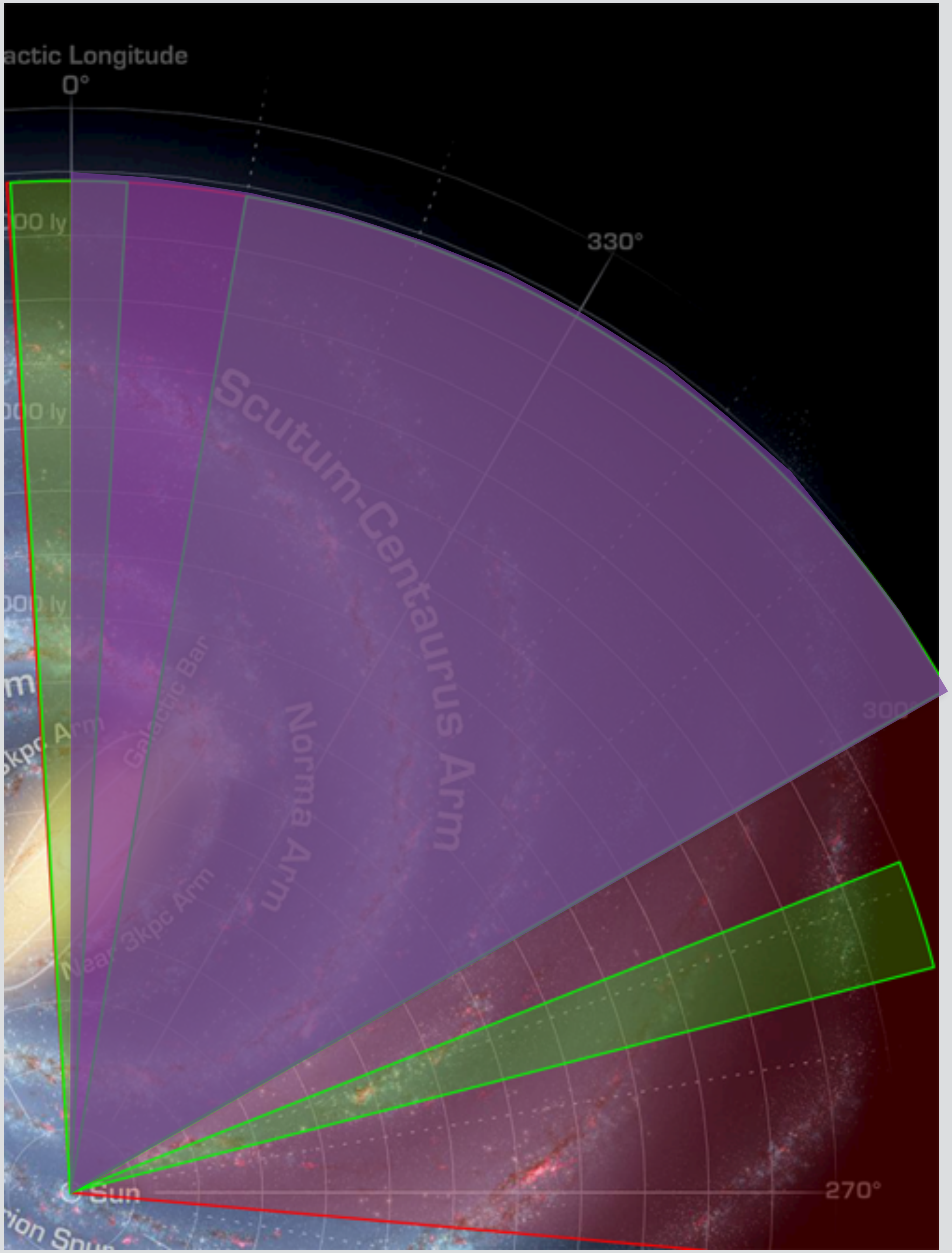
ThrUMMS has data, but few personel.

MopraCO has lots of people, but want data….

ThrUMMS wants more data too (just not of the same thing all over again…)

Solution: **change the field**, share the effort (and please communicate!)

In 2016… actually < =2015



Anything within 300-360 deg lon, +/- 1 deg lat

http://www.astro.ufl.edu/~peterb/research/thrumms/rbank/