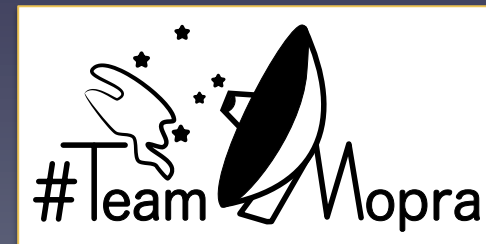


The Mopra Southern Galactic Plane CO Survey

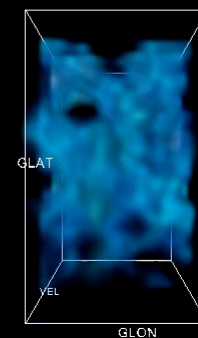
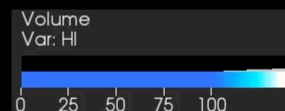
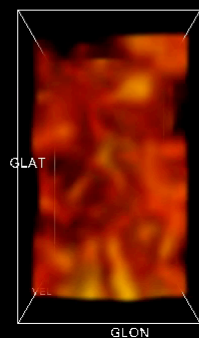
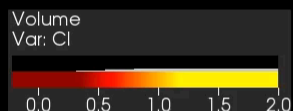
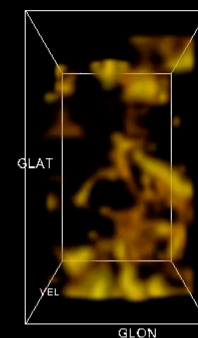
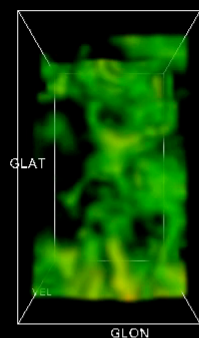
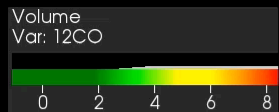
Catherine Braiding, Michael Burton, Gavin Rowell, N. Maxted, G. F. Wong, R. Blackwell

R. Alsaberi, K. Cubuk, R. Enokiya, K. Feijen, M. Filipovic, M. Freeman, S. Fujita, M. Ghavam, C. Glueck, P. Goldsmith, B. Gunay, J. Hawkes, D. J. Hollenbach, B. Indermuehle, E. Istiqomah, H. Katsuhiro, M. Kohno, C. Kulesa, J. Lau, C. L. Martin, T. Nagaya, Y. Nishimura, K. Okawa, J. L. Pineda, S. Pointon, D. Rebolledo, D. Romano, G. Rowell, H. Sano, R. Simon, C. Snoswell, A. A. Stark, J. Stutzki, N. J. H. Tohill, K. Tsuge, J. S. Urquhart, F. Voisin, C. Walker, A. J. Walsh, P. de Wilt, M. Wolfire, Y. Yamane, S. Yoshiike.

Also #TeamMopra backers.



UNSW, University of Adelaide, Western Sydney University, and others.

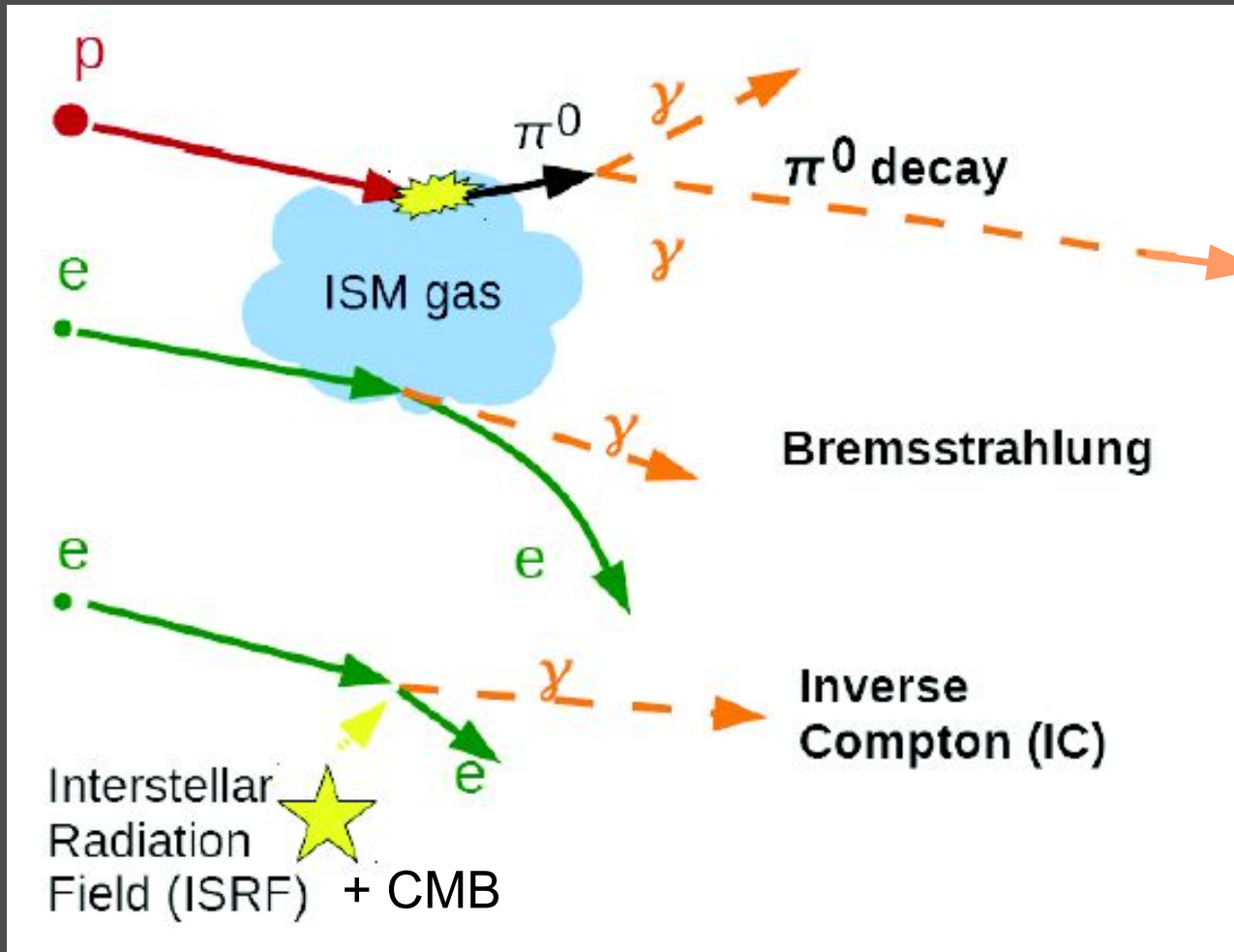


Formation of Molecular Clouds

- Matching Carbon Observations to PDR models to study structure & age.

PDR Model	
Input Parameters	
Parameter	Value
A_V	7.2 mag
P_{th}/k	$2.0 \times 10^4 \text{ K cm}^{-3}$
G_0	3 Habings
ΔV	2.4 km s^{-1}
ζ_{crp}	$2.0 \times 10^{-16} \text{ s}^{-1}$
[C/H] abundance	1.6×10^{-4}

Gamma Rays from multi-TeV particles



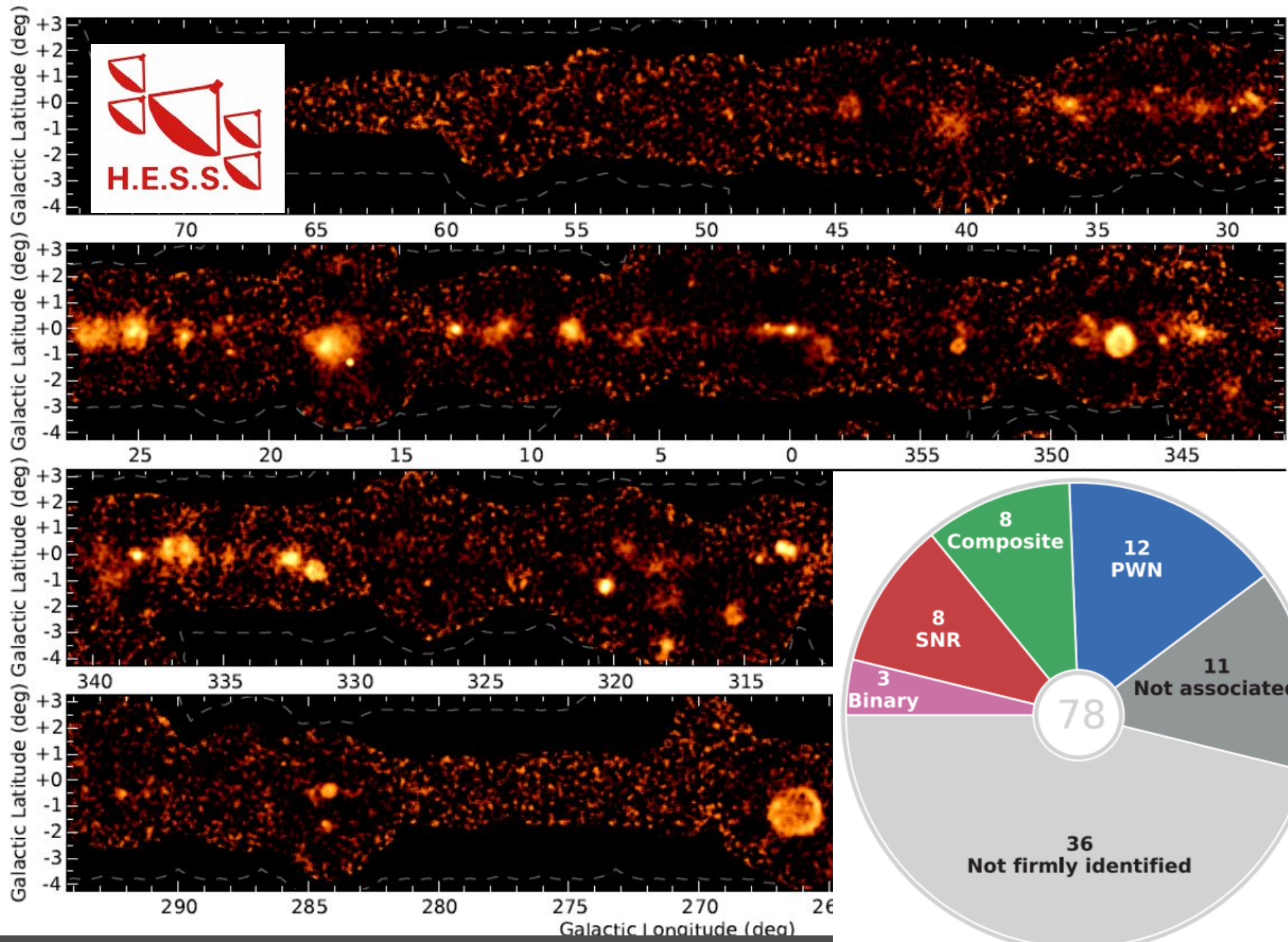
Protons: Gamma-rays and gas targets are generally spatially correlated
(need to map **atomic and molecular ISM** \rightarrow **mm radio astronomy**)

Electrons: **Gamma-ray** (IC) + **non-thermal X-ray, radio emission** (synchrotron)
highly coupled

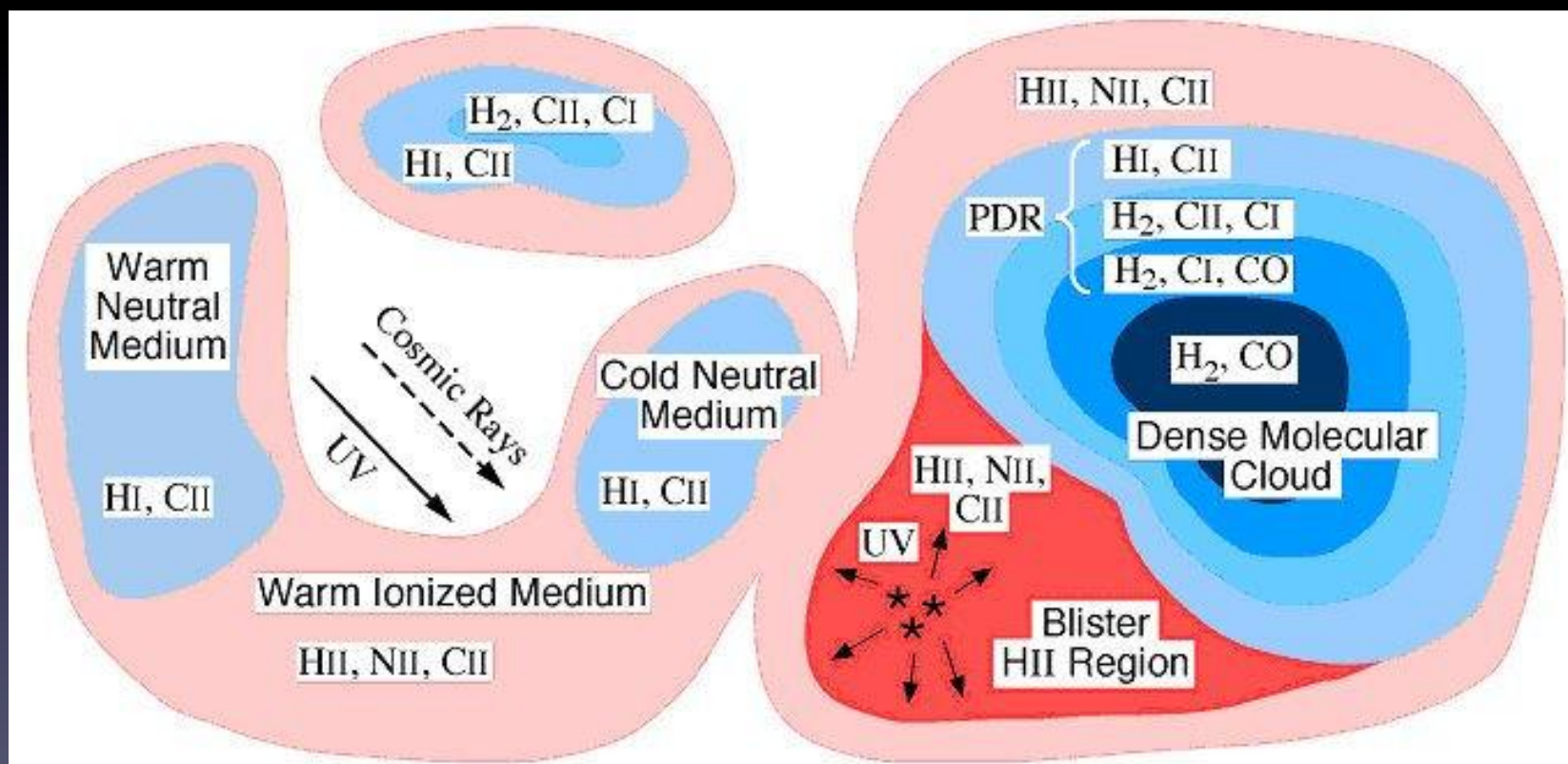
HESS Galactic Plane Survey (HGPS)

Deil et al 2015, HESS 2017

→ 78 sources (13 new sources)

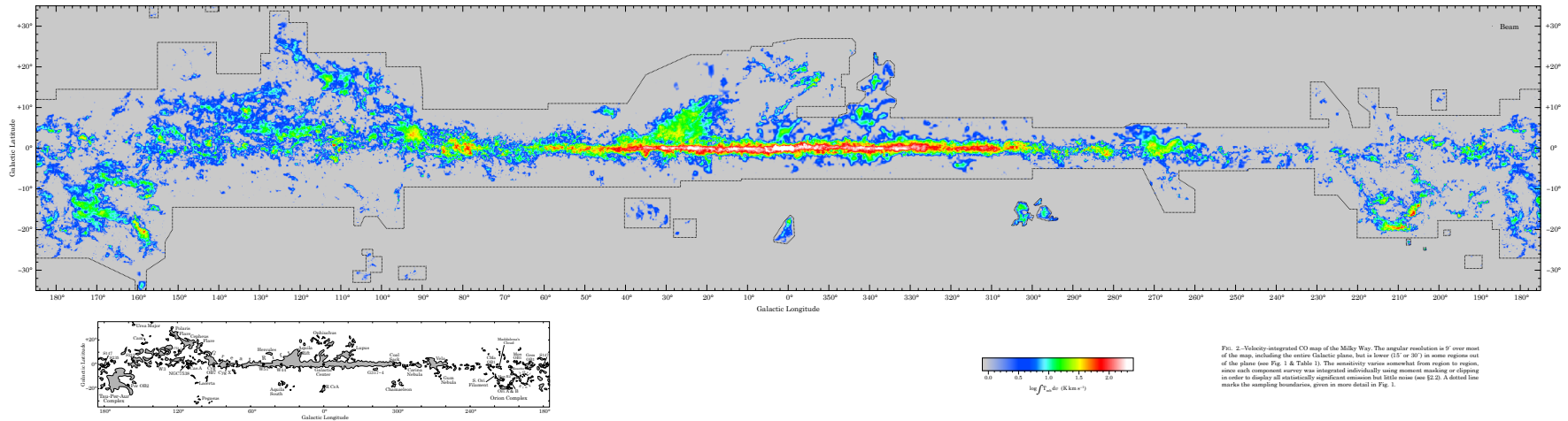


Schematic of the multi-phase ISM and its diagnostic tracers



Follow the Carbon Trail: $C^+ \rightarrow C \rightarrow CO$

CO Surveys



- Dame et al. (2001) – Columbia CO Survey
 - Resolution $\sim 8'$, similar to HESS
- CTA will be an order of magnitude better.

CO Surveys

Mopra CO SGPS
 Coverage:
 GLAT $|b| < 1.0^\circ$
 GLON $l = 250-11^\circ$

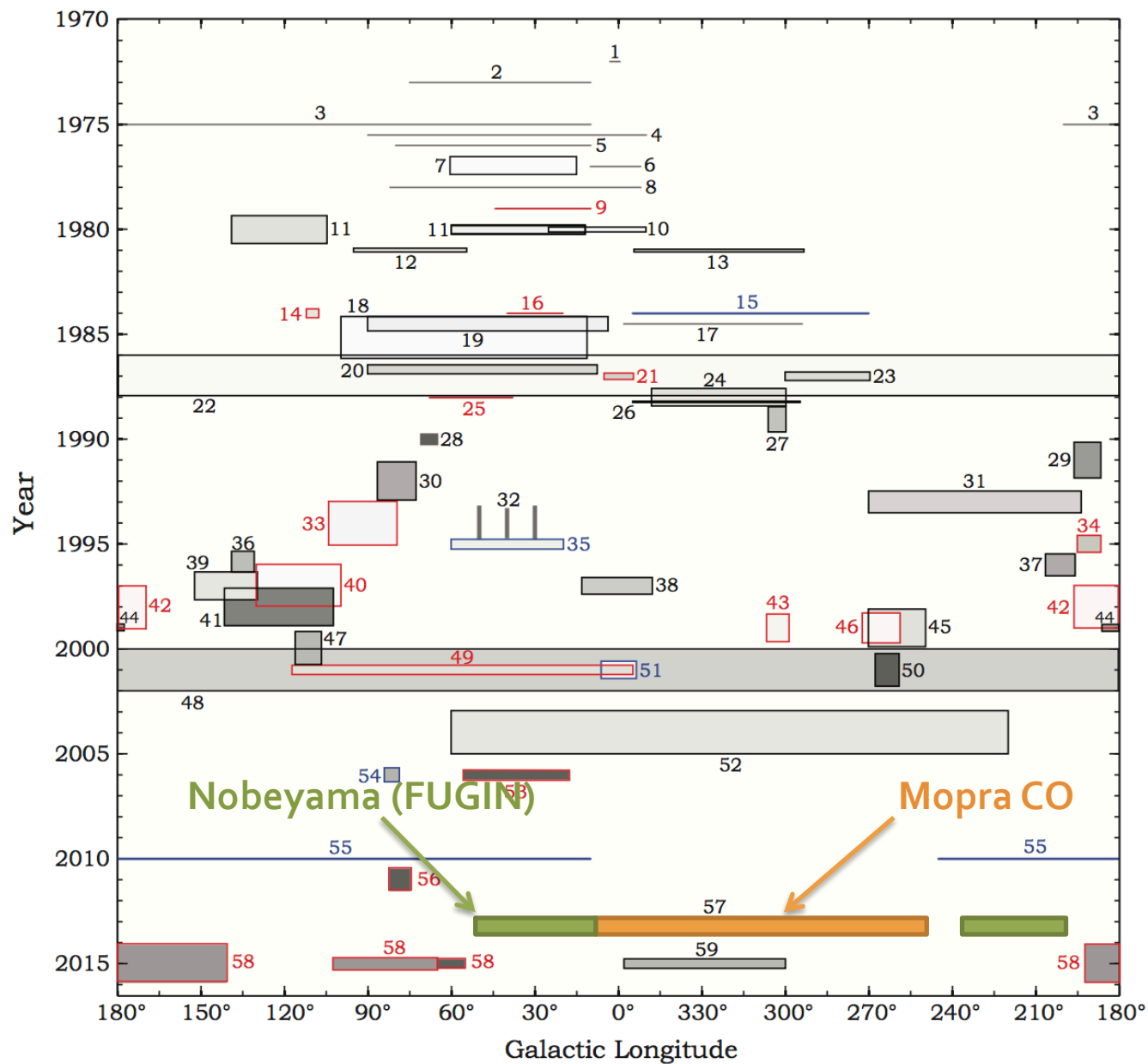
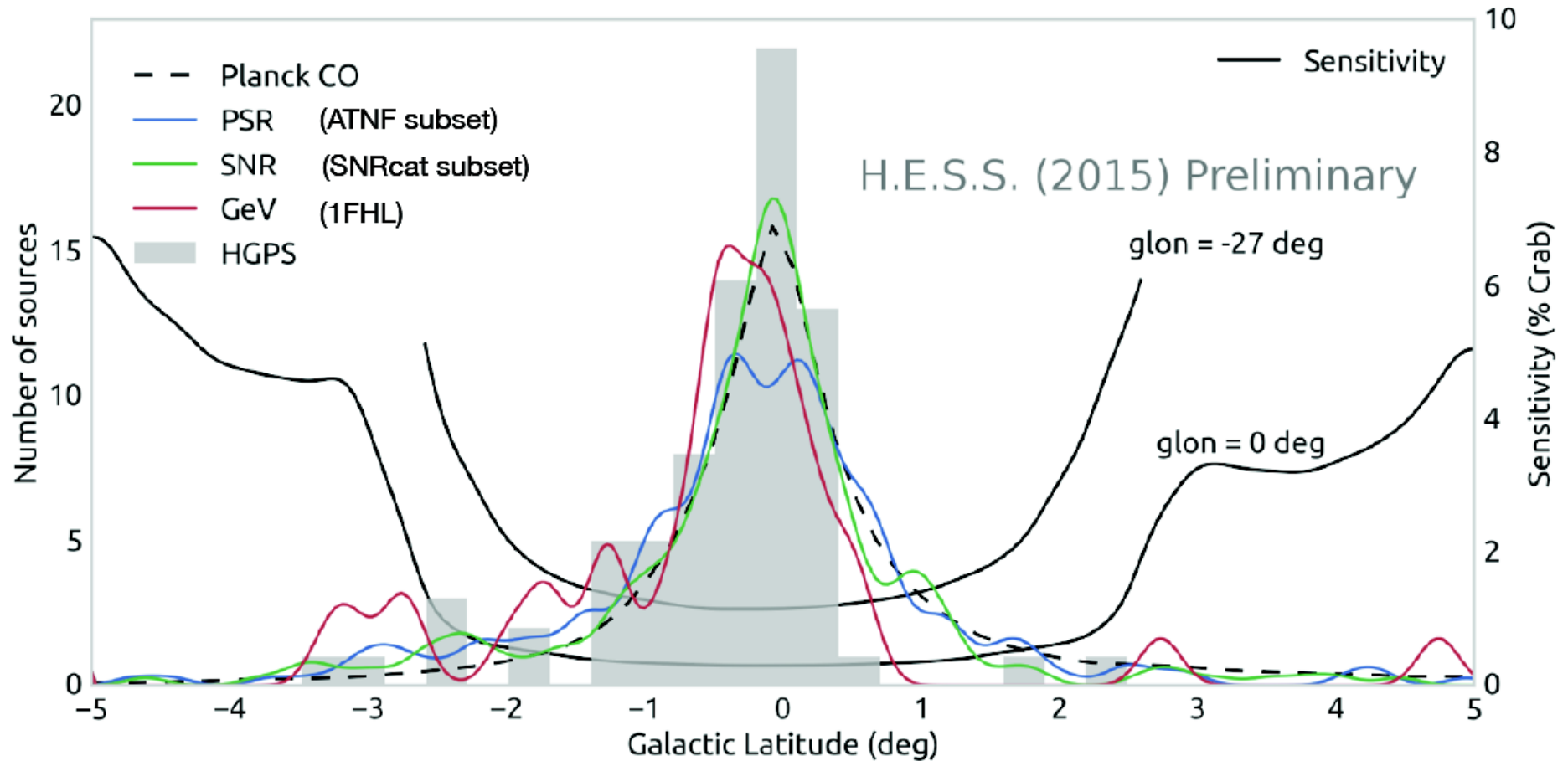


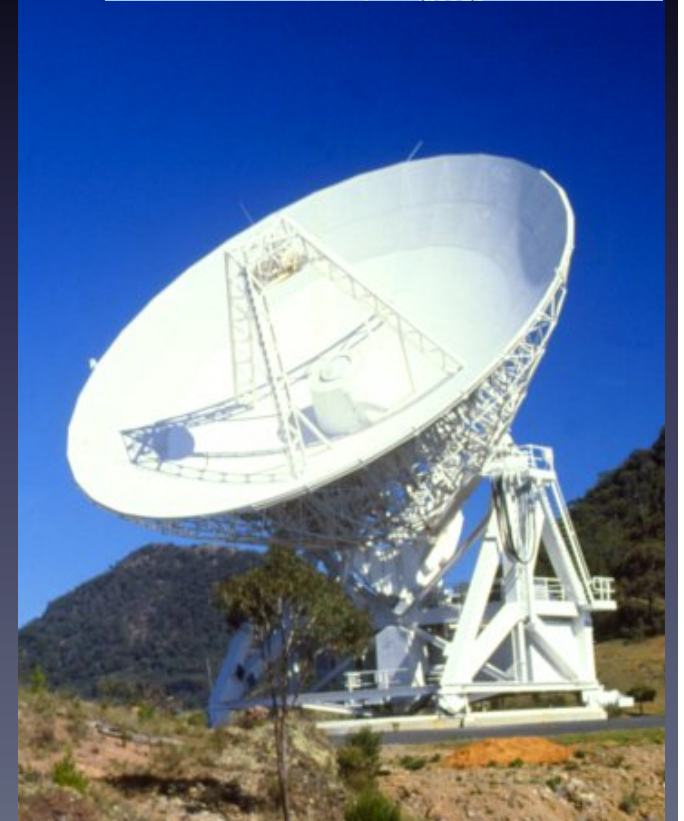
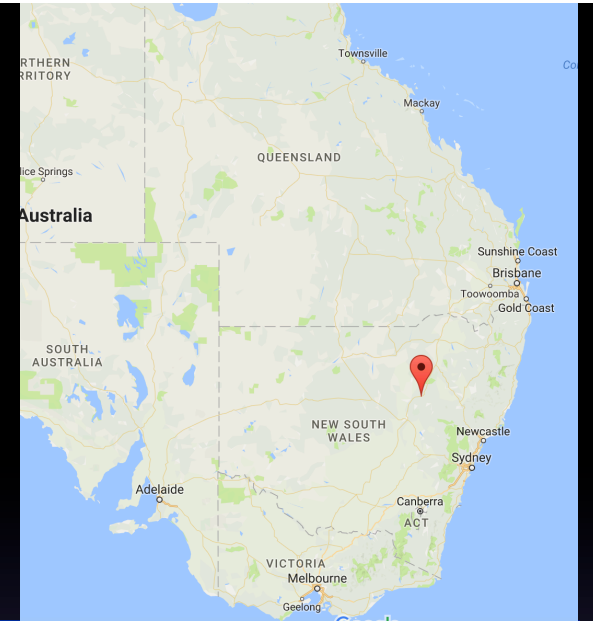
Figure 2 from Heyer & Dame (2015)

HESS Sources by Latitude

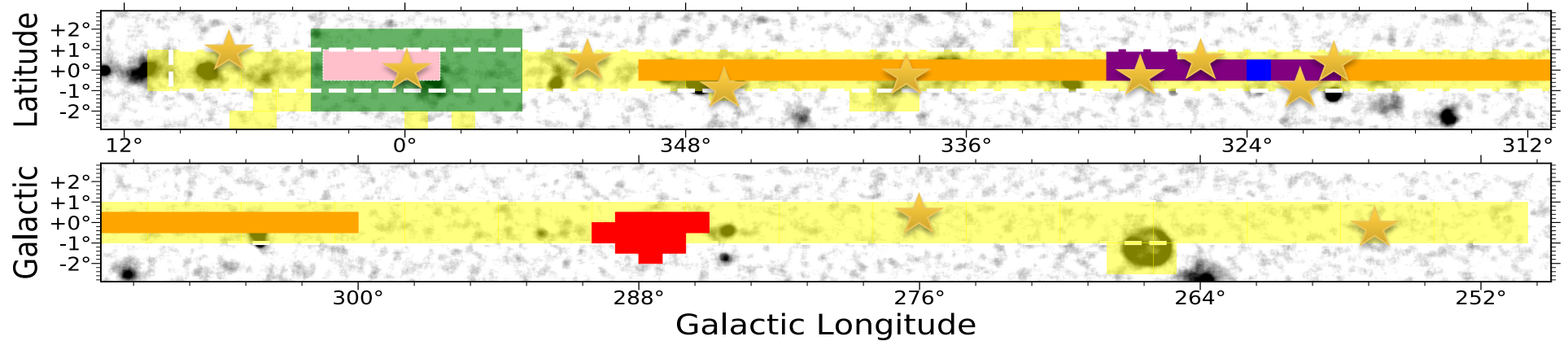


Mopra!

- 22m telescope for long-wave mm astronomy
 - 3mm + 7mm + 12mm
- 77–116 GHz MMIC receiver (2.5-4 mm)
 - $T_{\text{sys}} \sim 150\text{K}$ (@85GHz) – 600K (@115GHz)
 - 35" beam
 - η_{mb} (86 GHz) = 0.49, η_{mb} (115 GHz) = 0.42
 - η_{xb} (86 GHz) = 0.65, η_{xb} (115 GHz) = 0.55
- 8 GHz UNSW-MOPS correlator.
 - Broadband 32,000 channels, 0.8 km/s resⁿ.
 - 16 zoom modes over 137 MHz
 - 4 per band, 4096 channels/zoom, 0.1 km/s@3mm
- Surprisingly bushfire resistant (see youtube)



Mopra CO SGP Survey: Availability

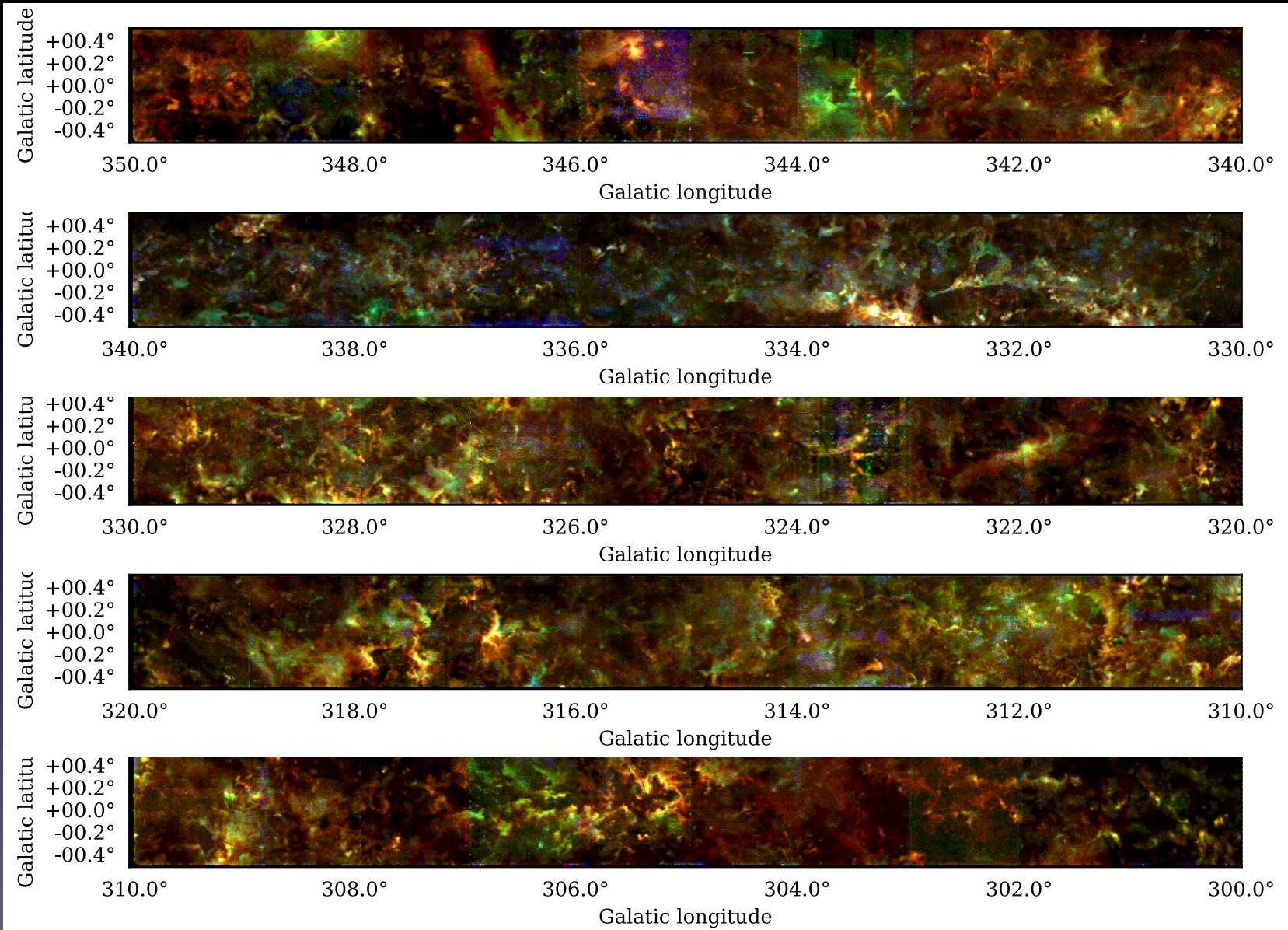


- Pilot region G328 (Burton, *et al.*, 2013)
- Data release I (Braiding, *et al.*, 2015)
- Data release II: Carina nebula (Rebolledo, *et al.*, 2016)
- Data release III: G300 to G350, $|b| < 0.5$ (Braiding, *et al.*, 2018)
- Central Molecular Zone (Blackwell, *et al.*, submitted.)
- ★ Other Mopra studies: <http://www.physics.adelaide.edu.au/astrophysics/MopraGam/>

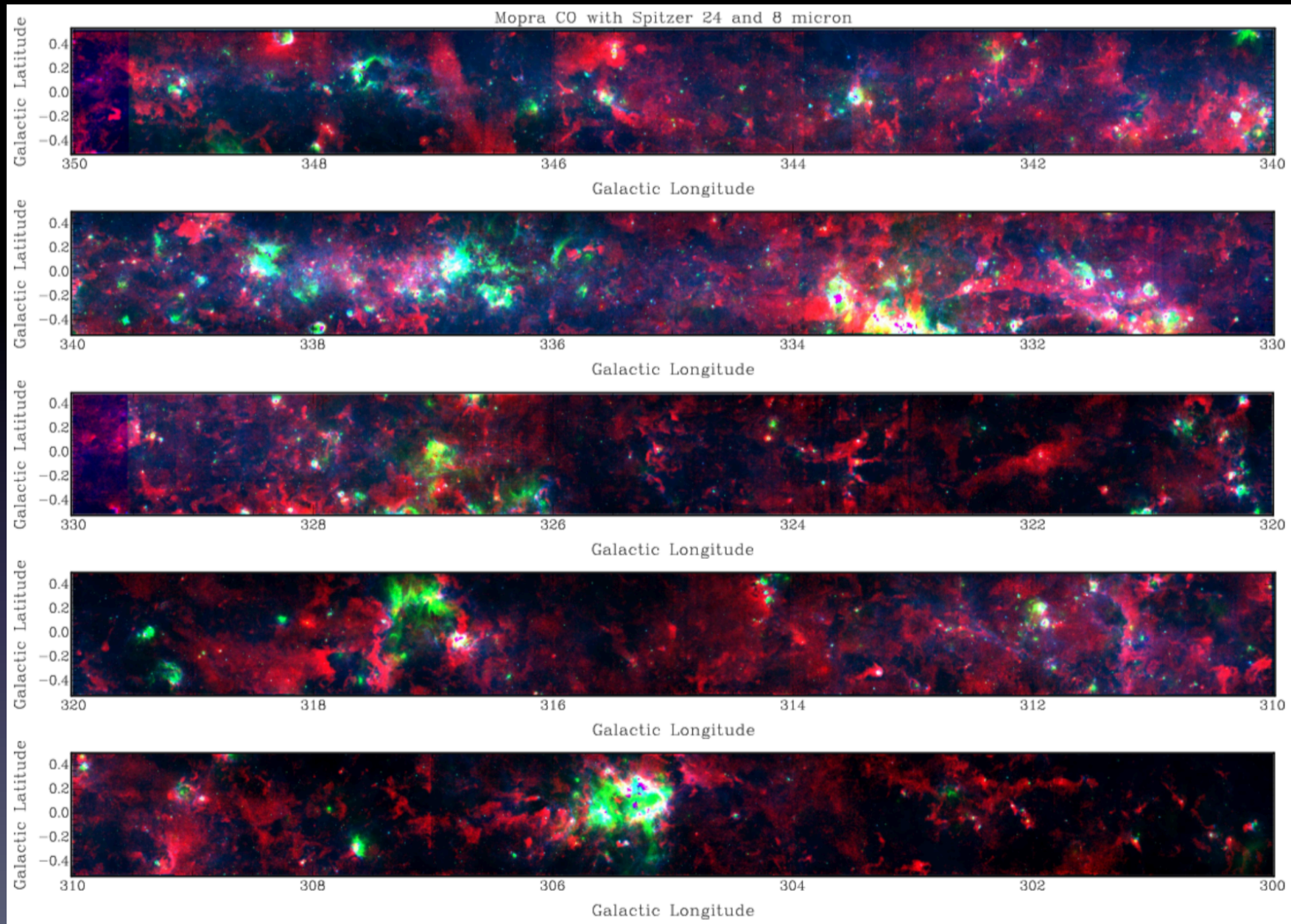
Data Release 3 (DR3)

$$l=300 - 350^\circ, |b| < +/- 0.5$$

- Braiding *et al.* (2018), PASA, 35, p. e029.
- Paper: doi:10.1017/pasa.2018.18
- Data: doi:10.7910/DVN/LH3BDN
- Covers many HESS sources, at CTA's resolution.

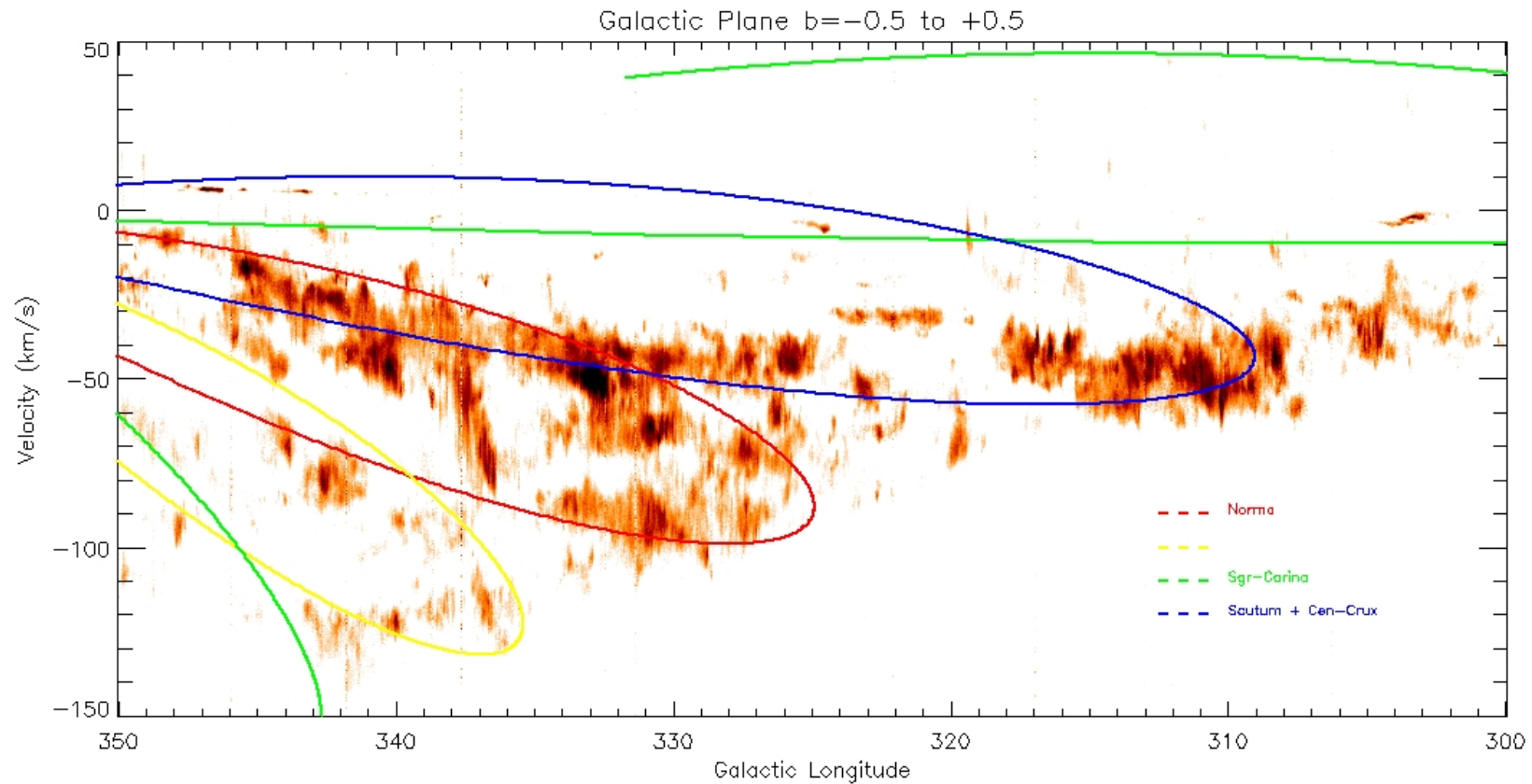


Mopra CO Peak Intensity (Red: ^{12}CO , Green: ^{13}CO , Blue: C^{18}O . Image by G.Wong)

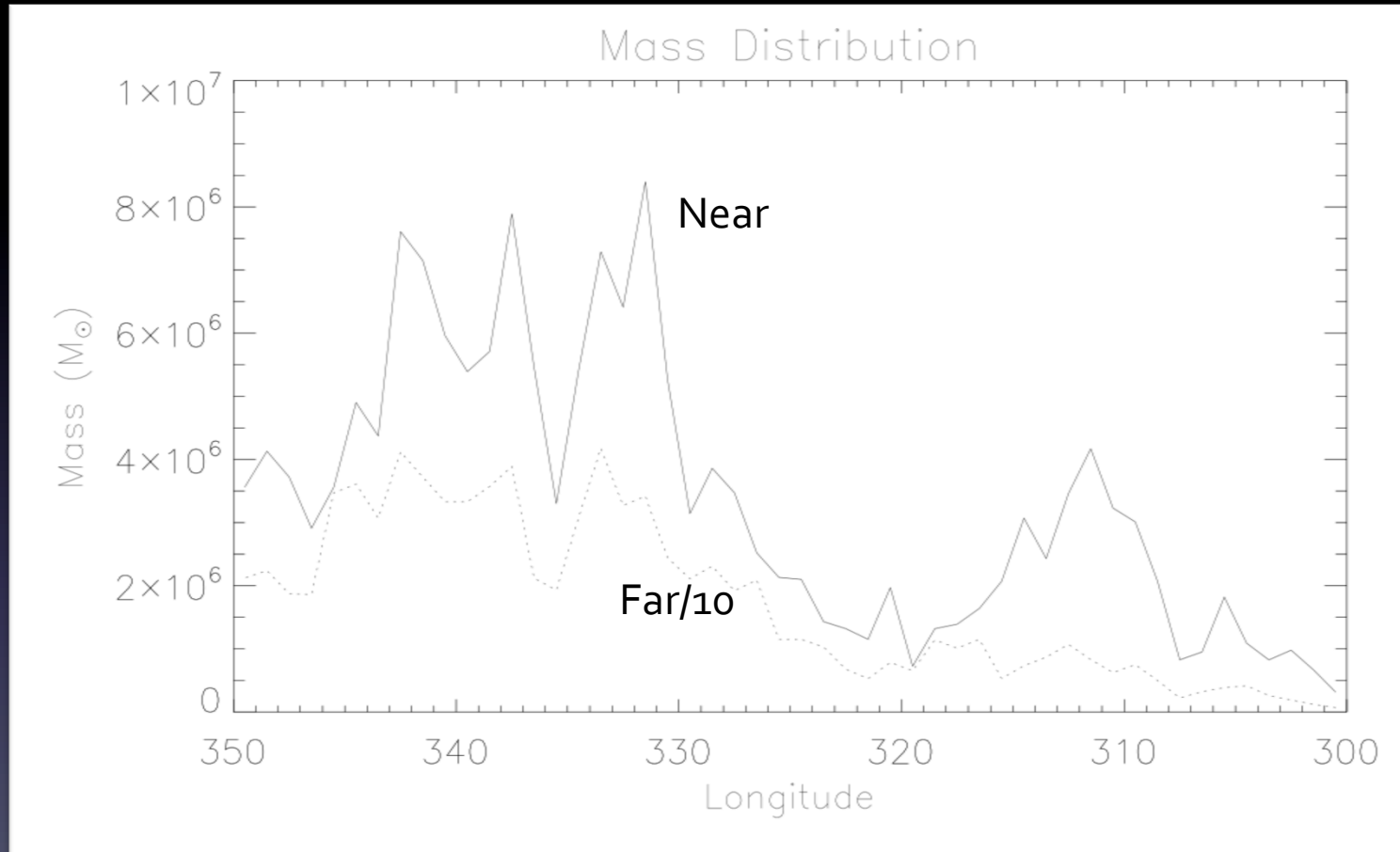


Mopra CO Peak Intensity (Red: ^{12}CO , Green: MIPS GAL $24\mu\text{m}$, Blue: GLIMPSE $8\mu\text{m}$)

DR3 – PV Diagram



Mass Distribution



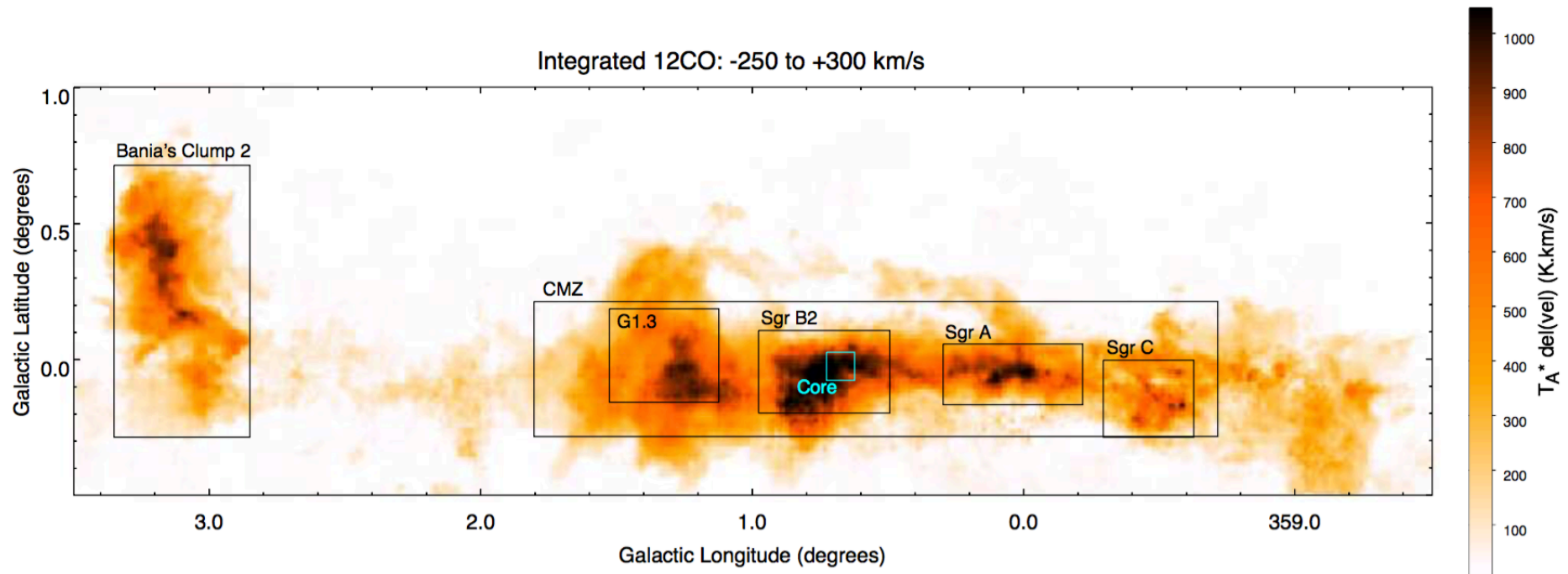
- $2 \times 10^8 M_{\odot}$ total, assuming near distances ($9 \times 10^8 M_{\odot}$ far).
- Assumes CO factor is constant.

DR₃ – C¹⁸O clump catalogue

Clump ID	Coordinates		V _{LSR} km/s	Δ <i>l</i> arcsec	Δ <i>b</i> arcsec	Δ <i>V</i> km/s	R arcsec	A 10 ³ arcsec ²	A _{fwHM}	D ^N kpc	D ^F	$\overline{T_{MB}^{18}}$	$\widehat{T_{MB}^{18}}$	$\overline{N_{H_2}}$	$\widehat{N_{H_2}}$	M ₁₈ ^N 10 ² M _⊙	M ₁₈ ^F
	<i>l</i> deg.	<i>b</i> deg.										K	10 ²¹ cm ⁻²				
MCO_330.227-0.019	330.227	-0.019	-42.7	120	86	1.0	76	18	32	3.3	11.5	0.9	1.1	5.9	7.0	5	62
MCO_330.394-0.052	330.394	-0.052	-41.8	218	129	1.0	107	36	88	3.2	11.6	0.9	1.1	5.8	7.0	9	123
MCO_330.410+0.323	330.410	0.323	-97.0	187	76	1.5	91	26	44	6.8	8.0	1.0	1.5	9.2	18.9	49	67
MCO_330.685-0.377	330.685	-0.377	-67.6	374	280	3.3	169	90	329	4.7	10.1	1.1	1.7	12.1	33.5	104	491
MCO_330.685+0.181	330.685	0.181	-63.0	115	78	1.0	74	17	28	4.4	10.4	1.0	1.2	9.3	13.3	14	76

- D. Romano (2018, submitted)
- $l = 330\text{-}340^\circ$: ~400 clumps, (4.5σ lower limit)
- $\sim 2.5 \times 10^6 M_\odot$, 10% of ¹²CO mass

Data Release 4 - CMZ



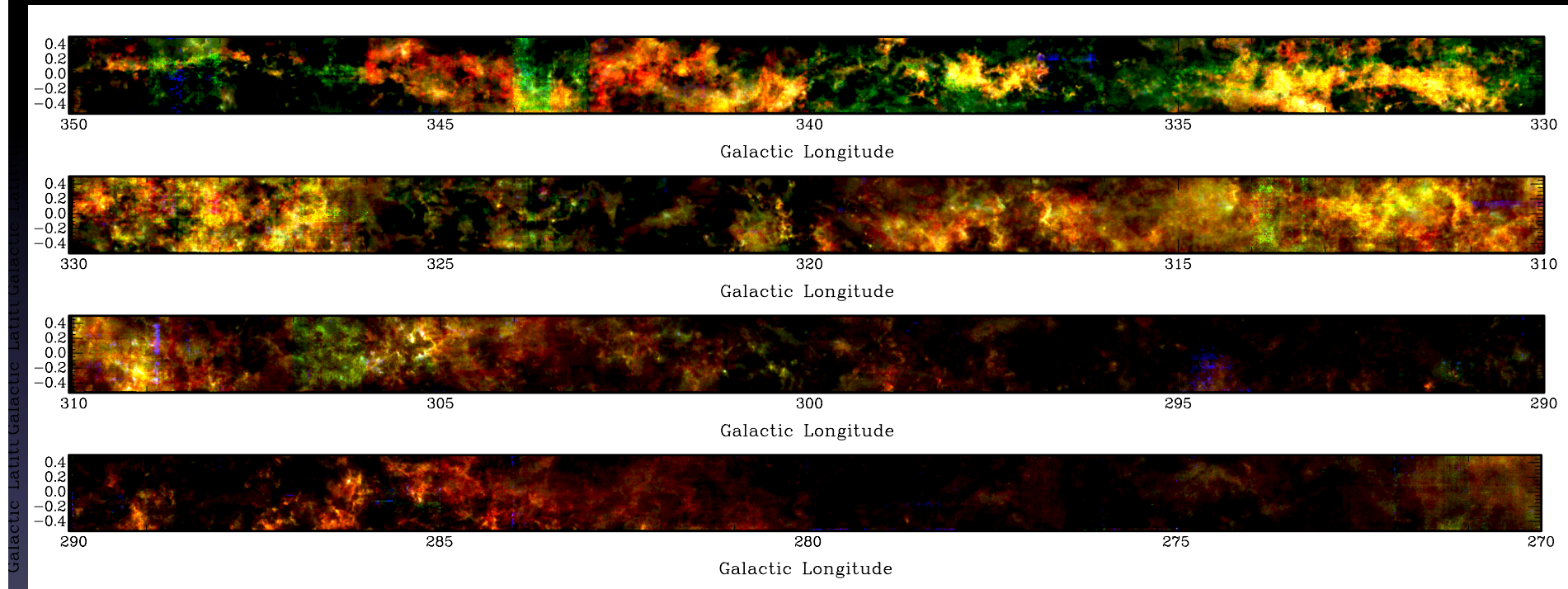
- Blackwell *et al.*, 2020 (submitted)
- Rest of CMZ data not yet fully reduced.

Data Release 5



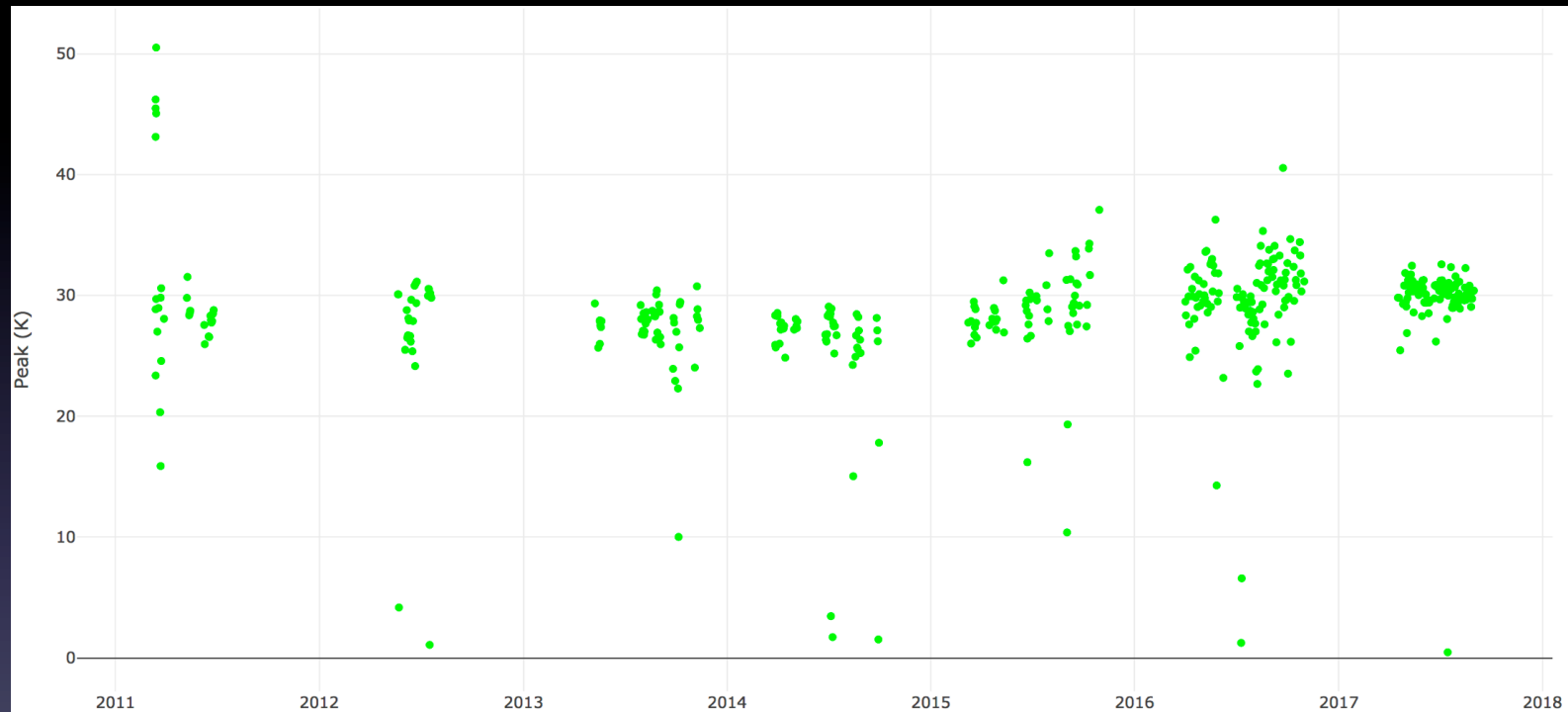
Preliminary Data, only 80 square degrees...

Data Release 5



- Integrated Intensity Map (^{12}CO blue; ^{13}CO green; C^{18}O blue), $-100 < V_{\text{LSR}} < +40$
- Preliminary Data, only 80 square degrees...
- Full Data Set: $250 < l < 11^\circ$, $|b| < 1.0^\circ$

DR5 – Mopra Stability

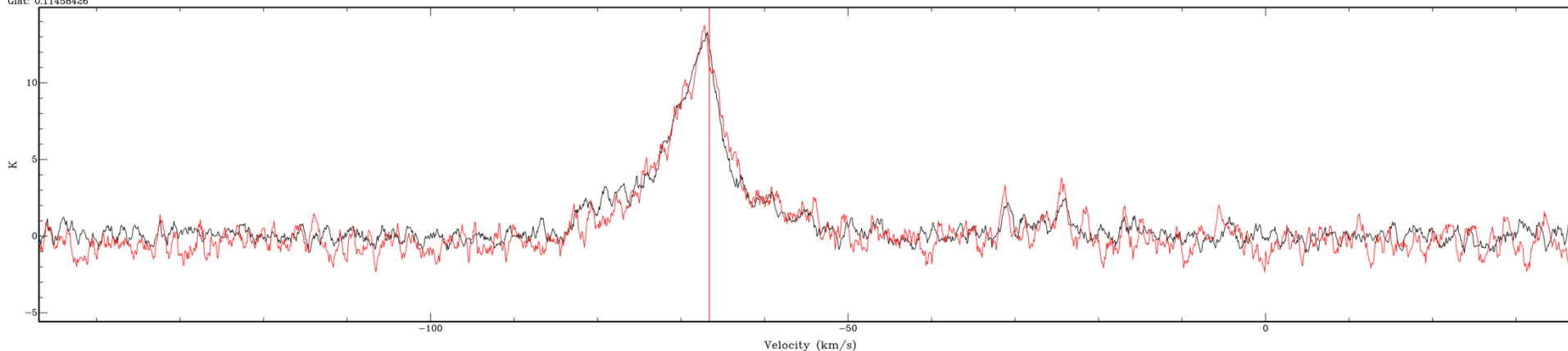


- M17 Calibration Observations – 2011-2018

DR5 – Mopra Stability

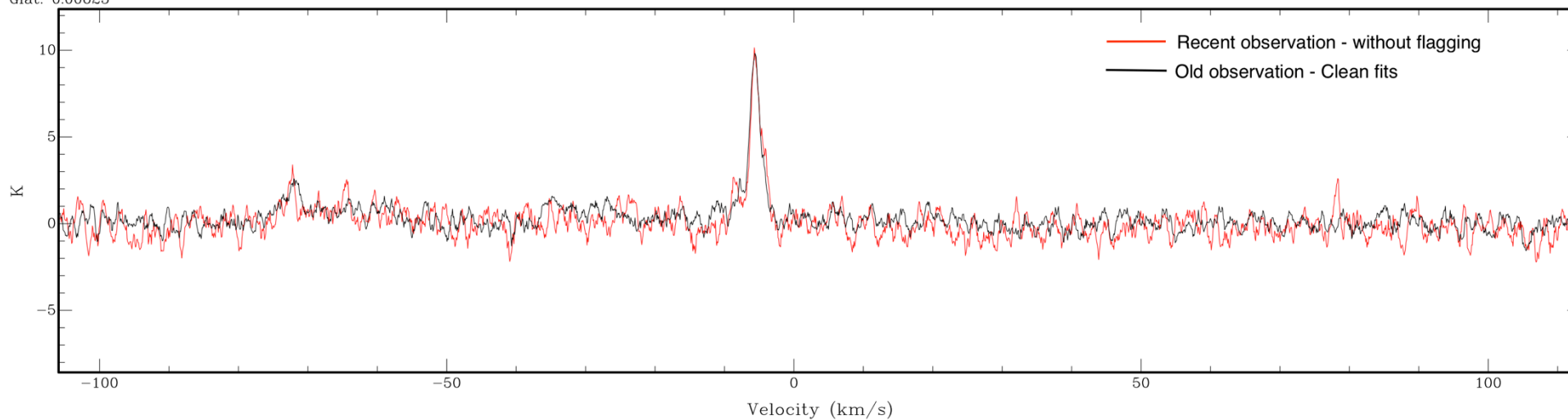
Glon: 323.21875
Glat: 0.11458426

G323



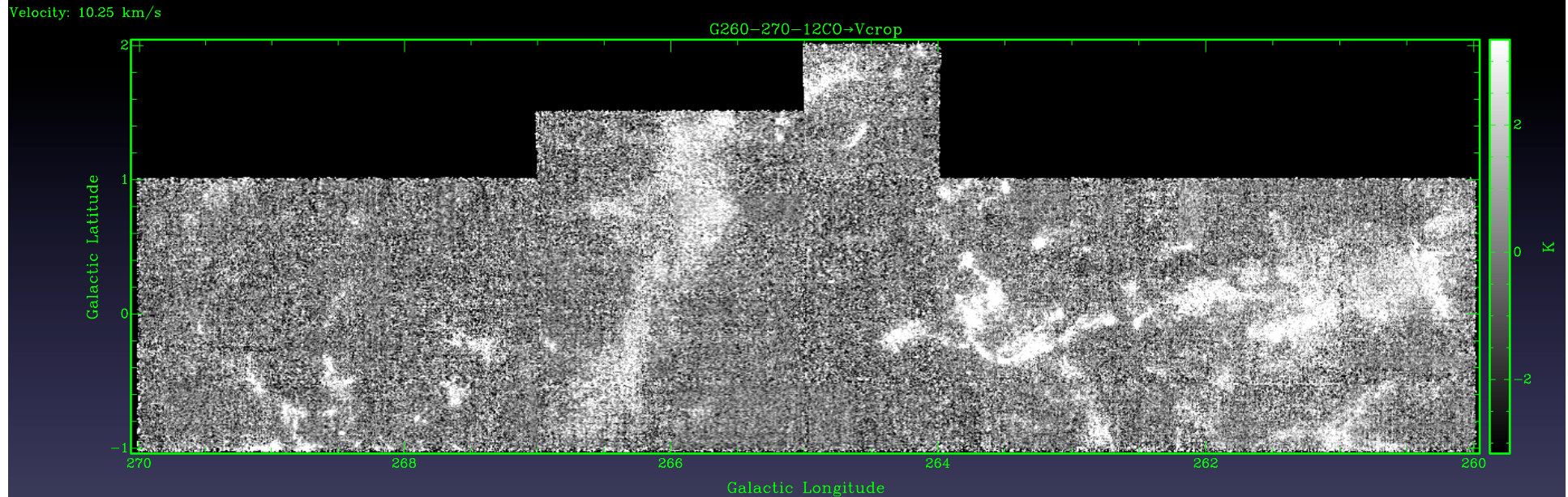
Glon: 350.81042
Glat: 0.00625

G350



2011 intensities match those from 2018
(Analysis by K. Cubuk, Armagh Observatory)

DR5 – G260-270



- Single velocity channel ($v = 10.25 \text{ km/s}$)
- Does not include Vela Jr extension.

Columbia CO Survey

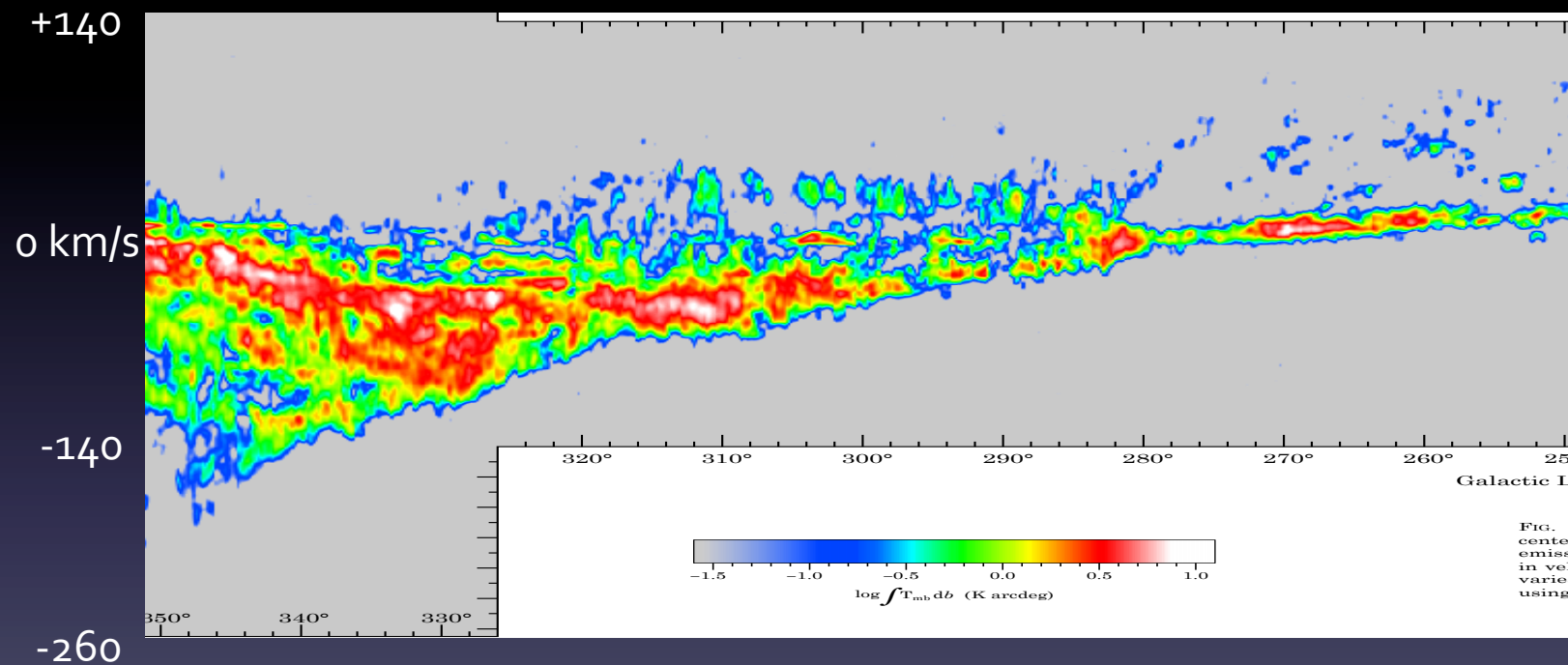
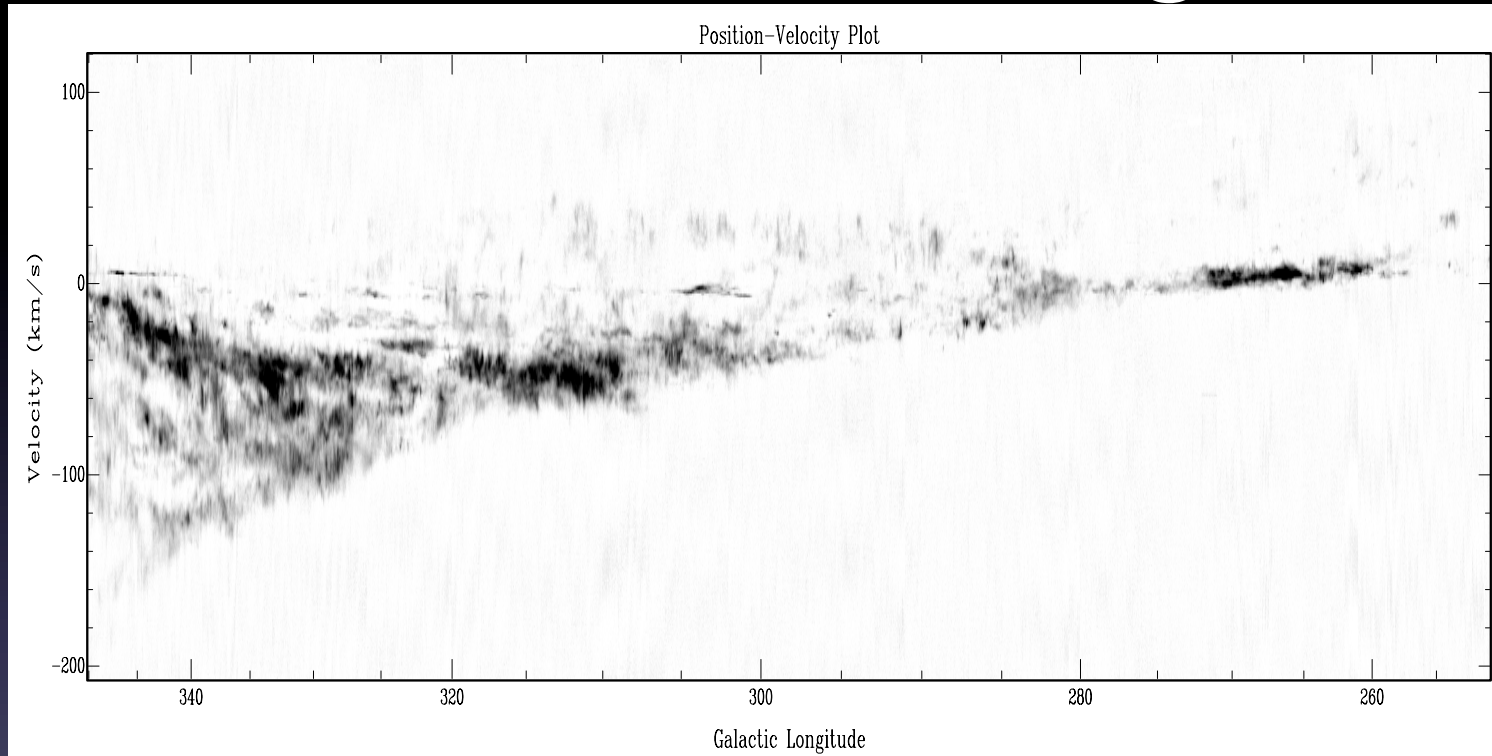


FIG. 3
center
emissi
in vel
varies
using

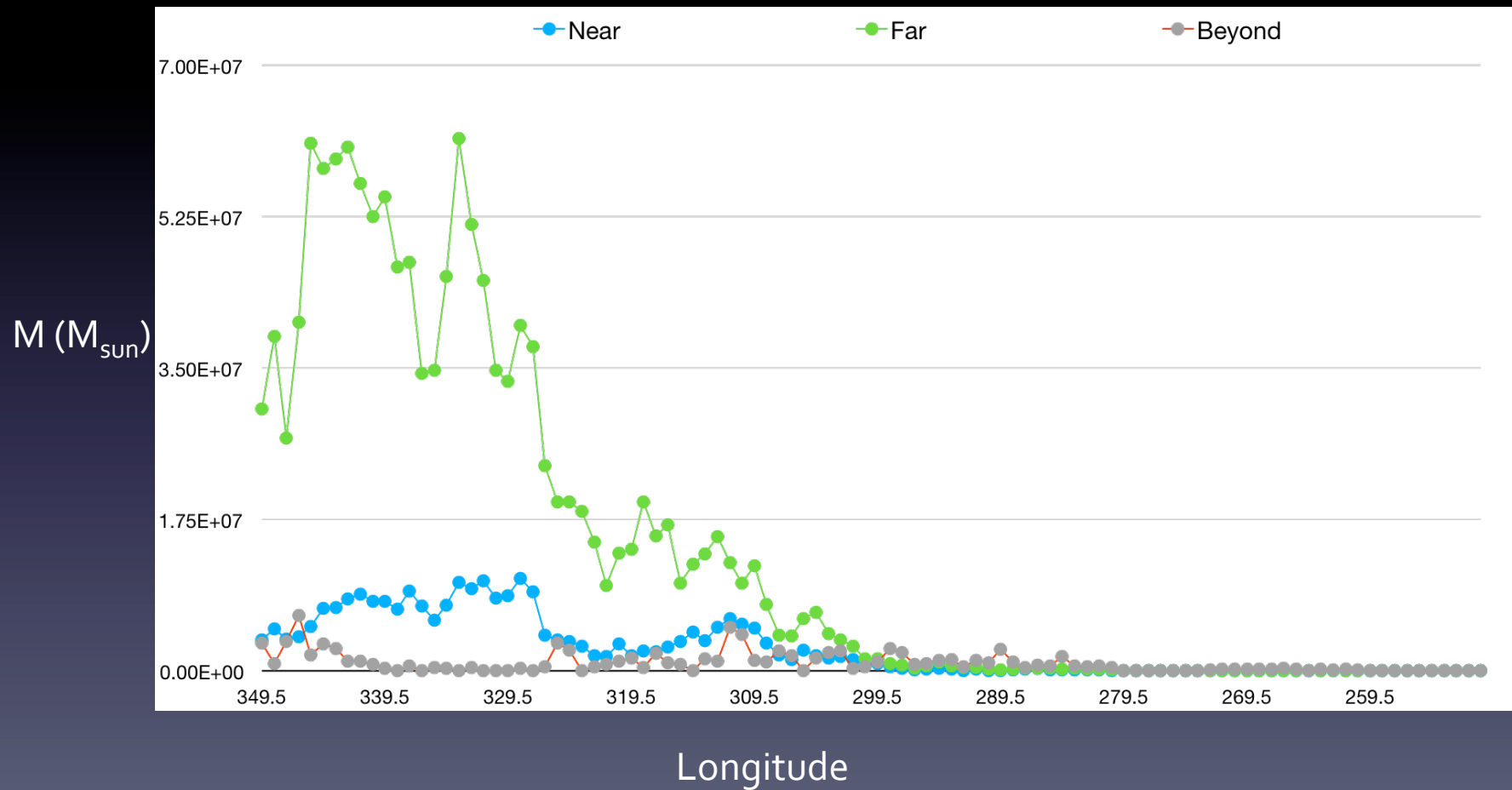
Longitude

Data Release 5

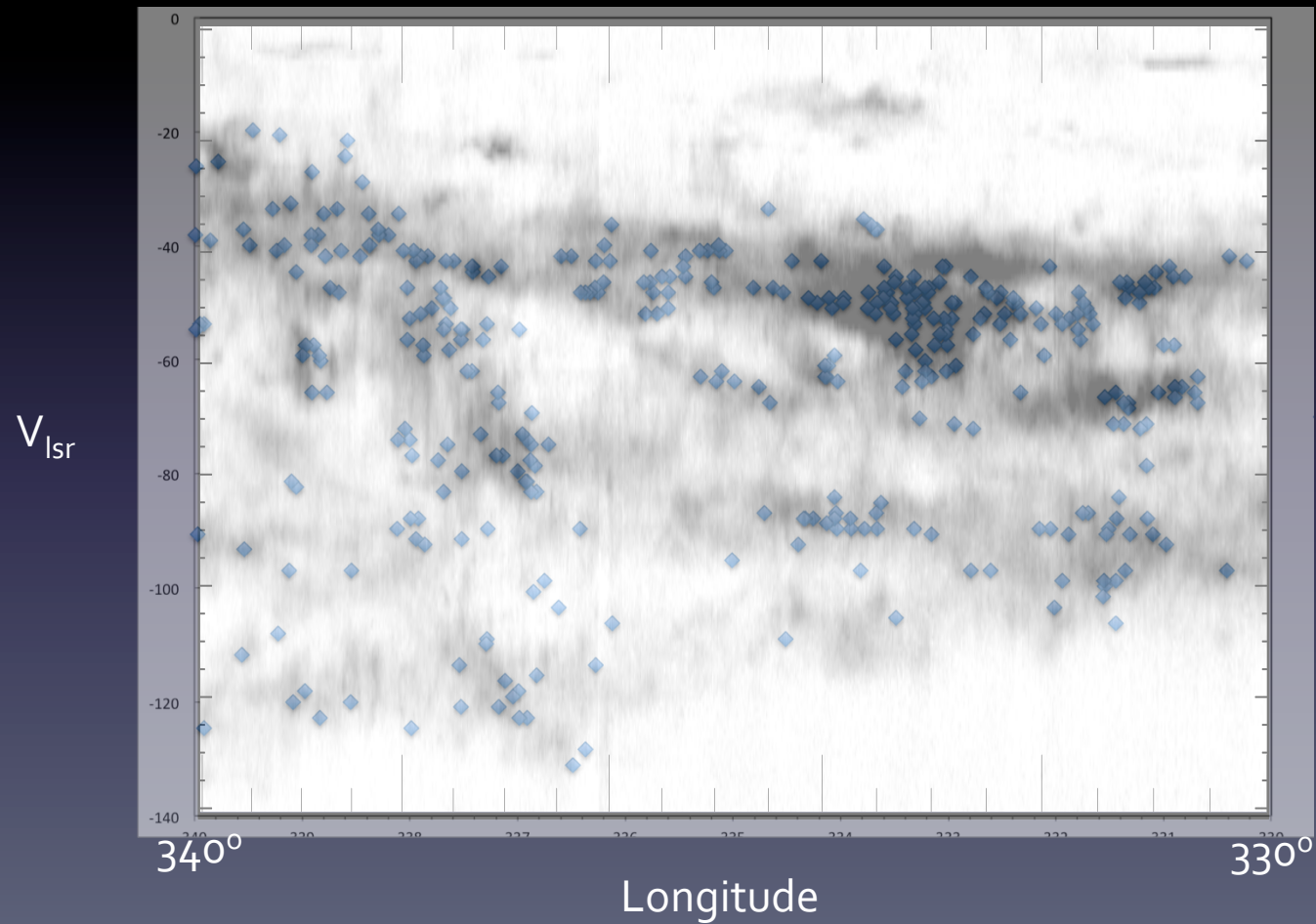


- Individual clouds resolved
- Spiral arm structure is very clear
- Outflows, far GMCs, all sorts of stuff.

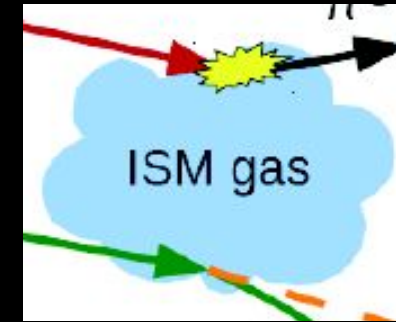
Mass Distribution



C¹⁸O Clumps



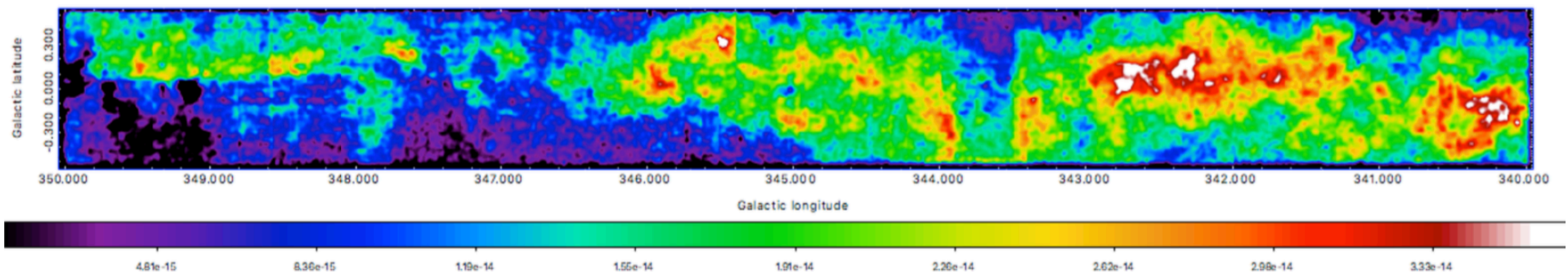
DR5 for CTA



- Plan to build model of column density across whole survey.
- Experimenting with detection algorithms
 - ^{12}CO (optically thick), ^{13}CO and C^{18}O (optically thin)
 - temperature, density estimates
 - assuming near distance to clouds
 - Relies on X_{CO} factor.

(Nigel Maxted)

Simulated gamma-ray map (some assumptions, errors):

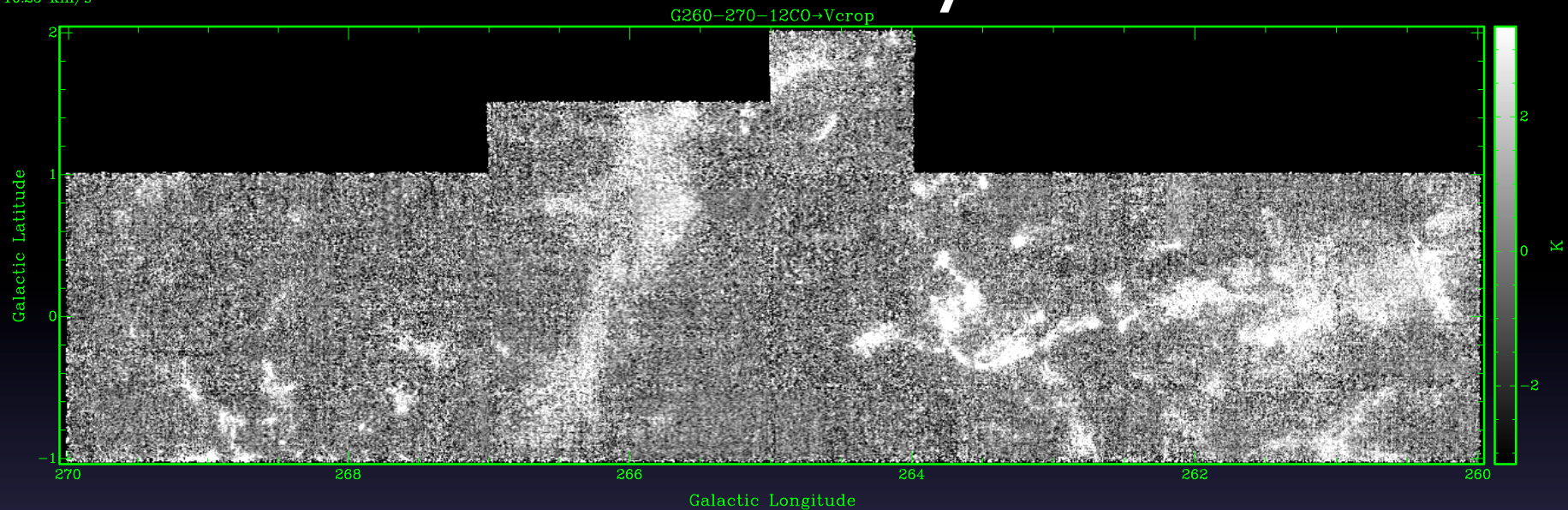


Mopra + Nagoya Surveys

- FUGIN ($l=10-50^\circ$, $200-235^\circ$; $|b| < 1.0^\circ$) and NASCO (Nanten2, all sky)
- Early work to merge our surveys underway.

Summary

Velocity: 10.25 km/s



- Mopra CO SGPS: $l = 250-11^\circ$, $|b| \leq 1^\circ$, $-200 \leq v \leq 100$ km/s, 0.5' resolution
- Resolution-matched to GASKAP (HI, OH, etc), MALT, CTA.
- ^{12}CO , ^{13}CO , C^{18}O and C^{17}O cubes available.
- newt.phys.unsw.edu.au/MopraCO/
- CMZ submitted, DR5 in prep!
- For pre-release data: email catherine.braiding@gmail.com,
or @AstroCate!

