A SURVEY FOR GALACTIC SNR/MOLECULAR CLOUD INTERACTIONS USING CARBON MONOXIDE

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OUTLINE

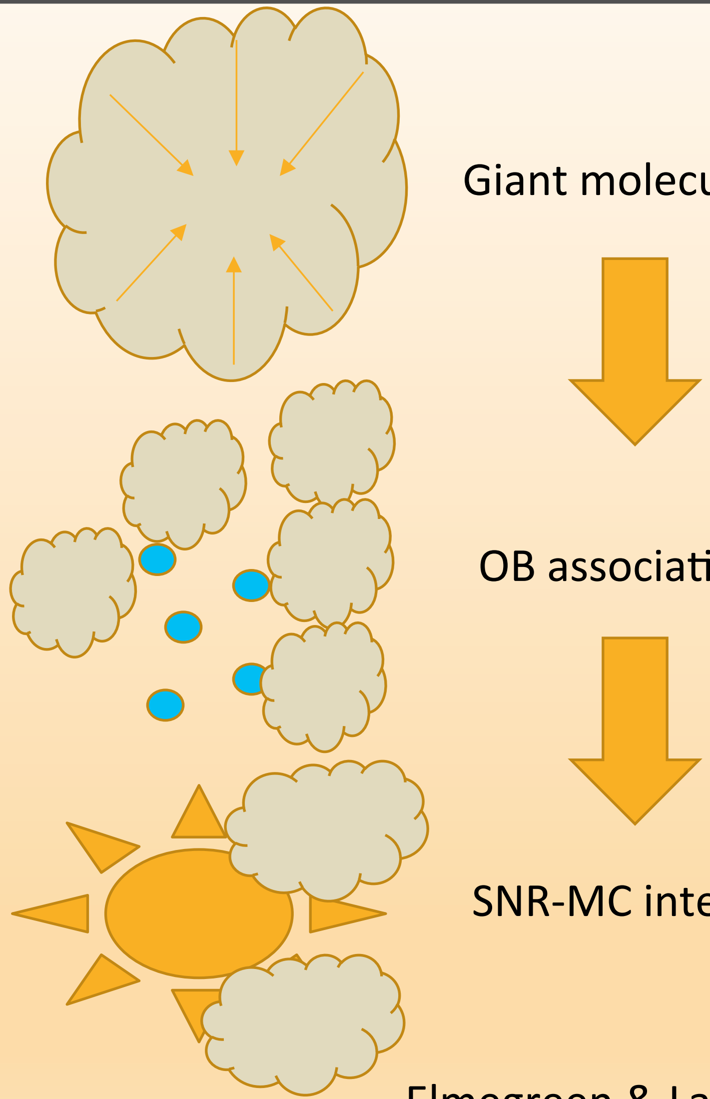
A. Supernova Remnant – Molecular Cloud (SNR-MC) interactions

B. Motivation of survey for SNR-MC interactions

C. Overview of survey and methods

D. Results and application to SNR properties and gamma-ray sources

SNR-MC INTERACTIONS

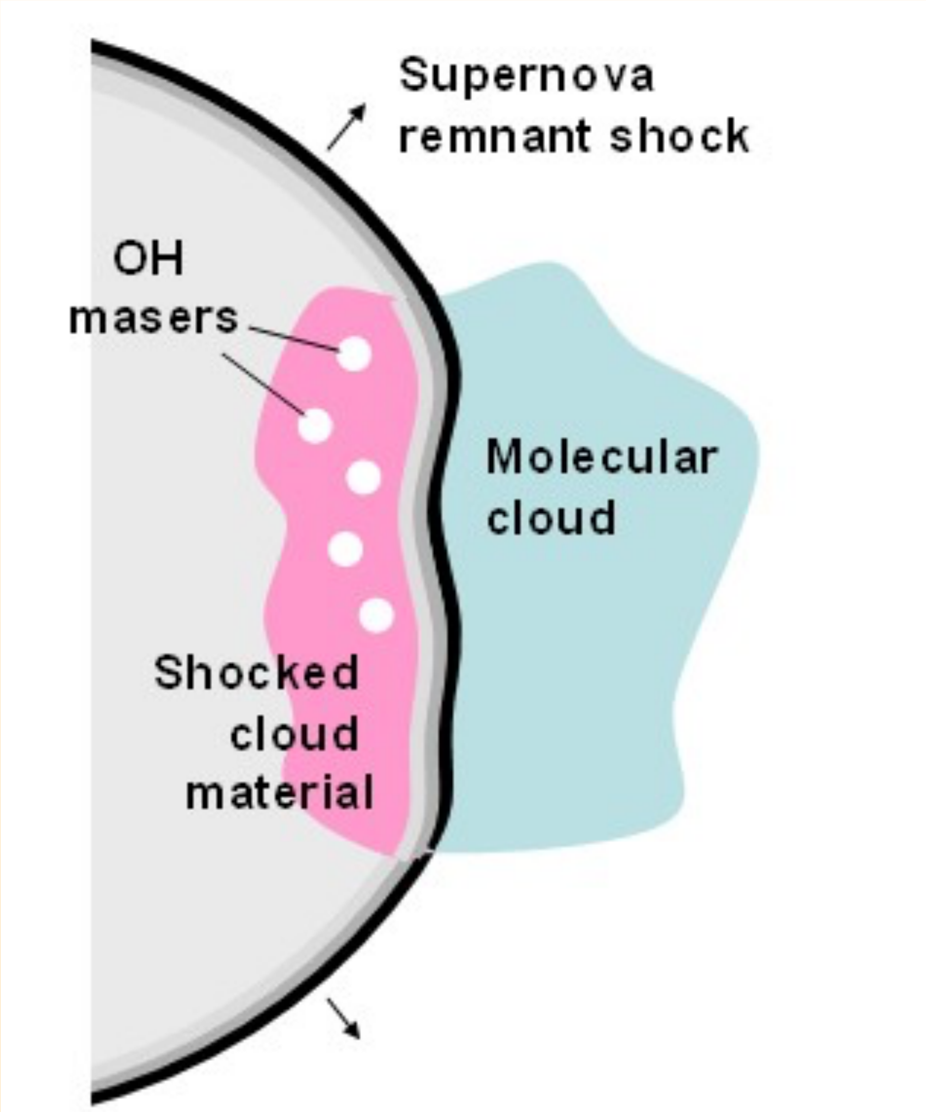


Giant molecular cloud

OB association

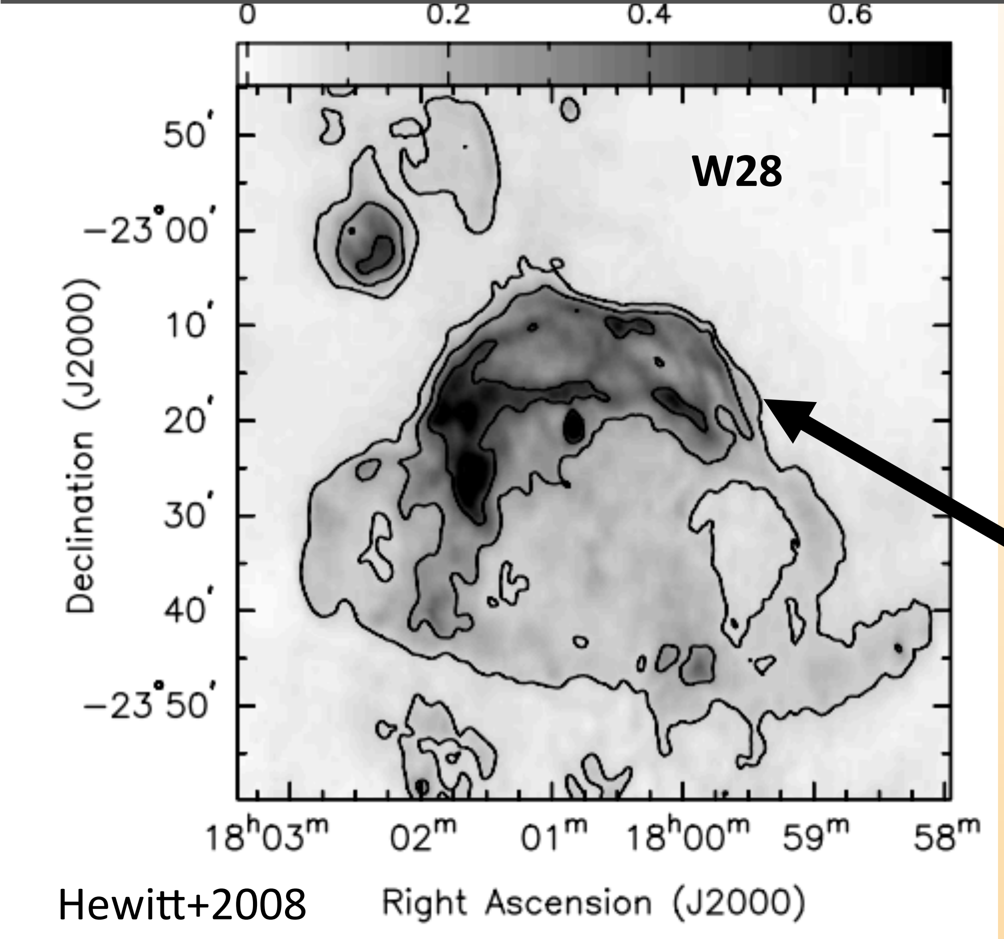
SNR-MC interaction

Elmegreen & Lada (1977)
Herbst & Assousa (1977)
Elmegreen (1995)



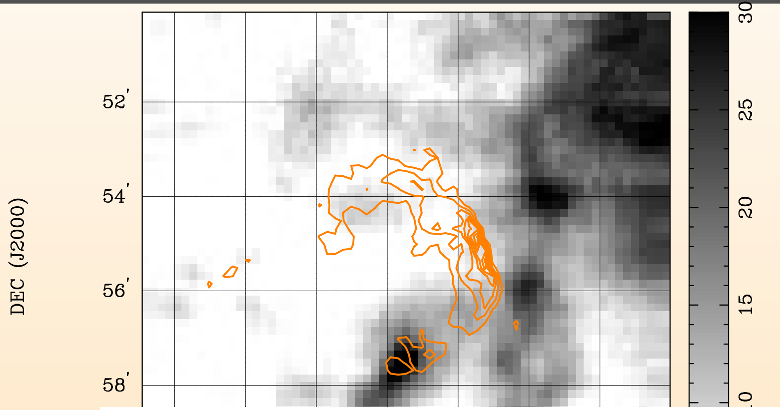
Wardle & Yusef-Zadeh (2002)

OBSERVATIONAL SIGNATURES

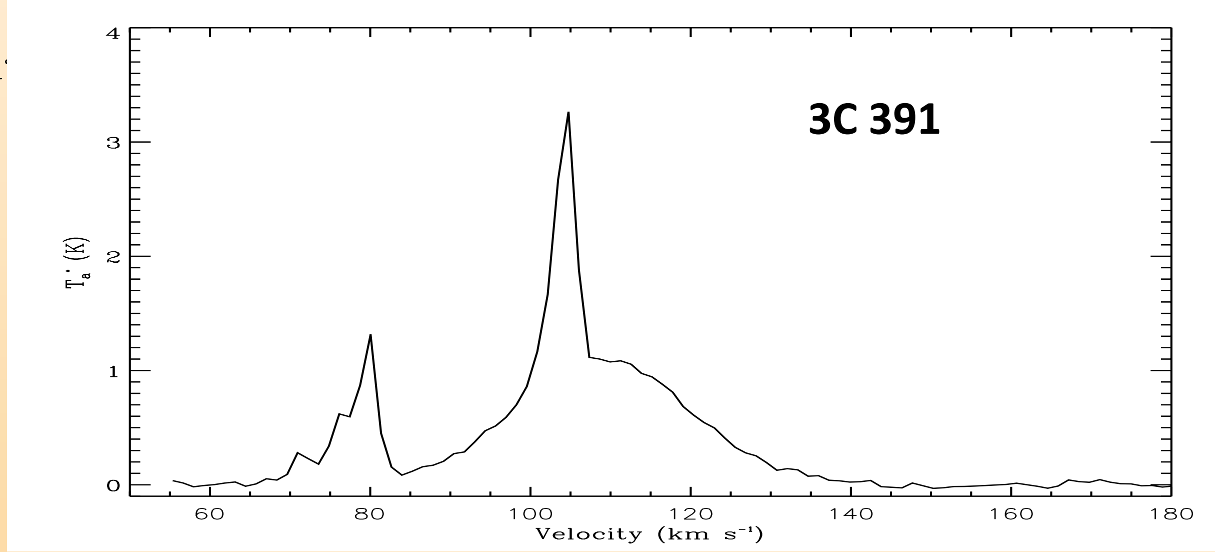


Hewitt+2008

Contours are GBT 1720 MHz



Kilpatrick et al. 2016, ApJ



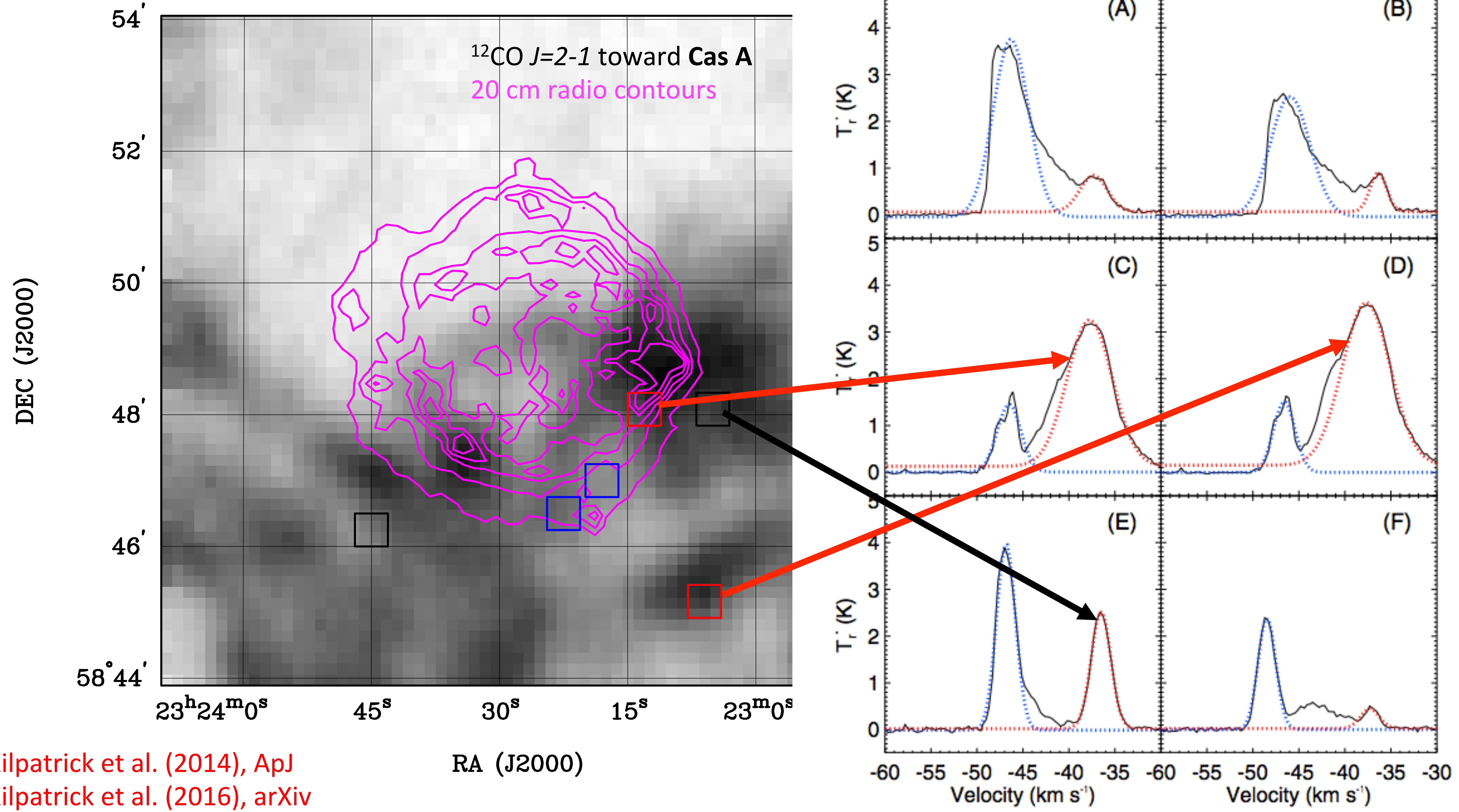
OH maser emission (1720 MHz)

Pros: Easy correlation with interaction

Cons: Long integration for velocity info, interferometry for exact positions, not excited over entire interaction ($n_{H_2} = 10^5$, T = 50–125 K; Lockett et al. 1999)

Pros: Decent resolution with single-dish at high frequency, CO is bright, velocities are easy

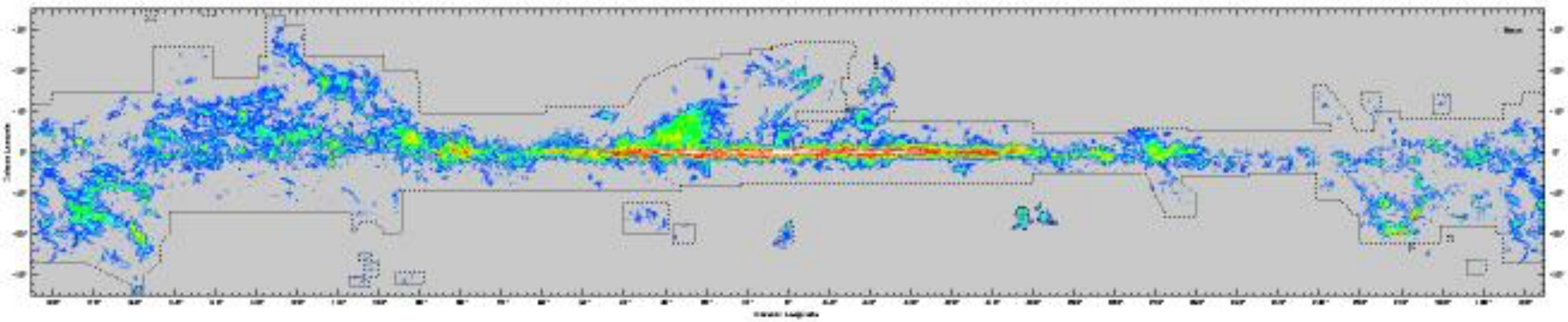
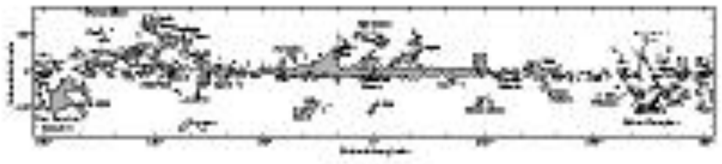
Cons: Difficult to discriminate SNR-shocked broad features



Kilpatrick et al. (2014), ApJ
Kilpatrick et al. (2016), arXiv

Moving beyond detailed studies of individual remnants…

how do we build up our statistics of SNR-MC interactions?
how do we apply our understanding of SNR-MC interactions to Galaxy-wide processes?


Milky Way CO,
Dame et al. (2001)

SCIENCE QUESTIONS FOR THIS SURVEY

How many Galactic SNRs are interacting with molecular clouds?

How do interactions correlate with physical properties of the SNR?

- Size
- Radio flux

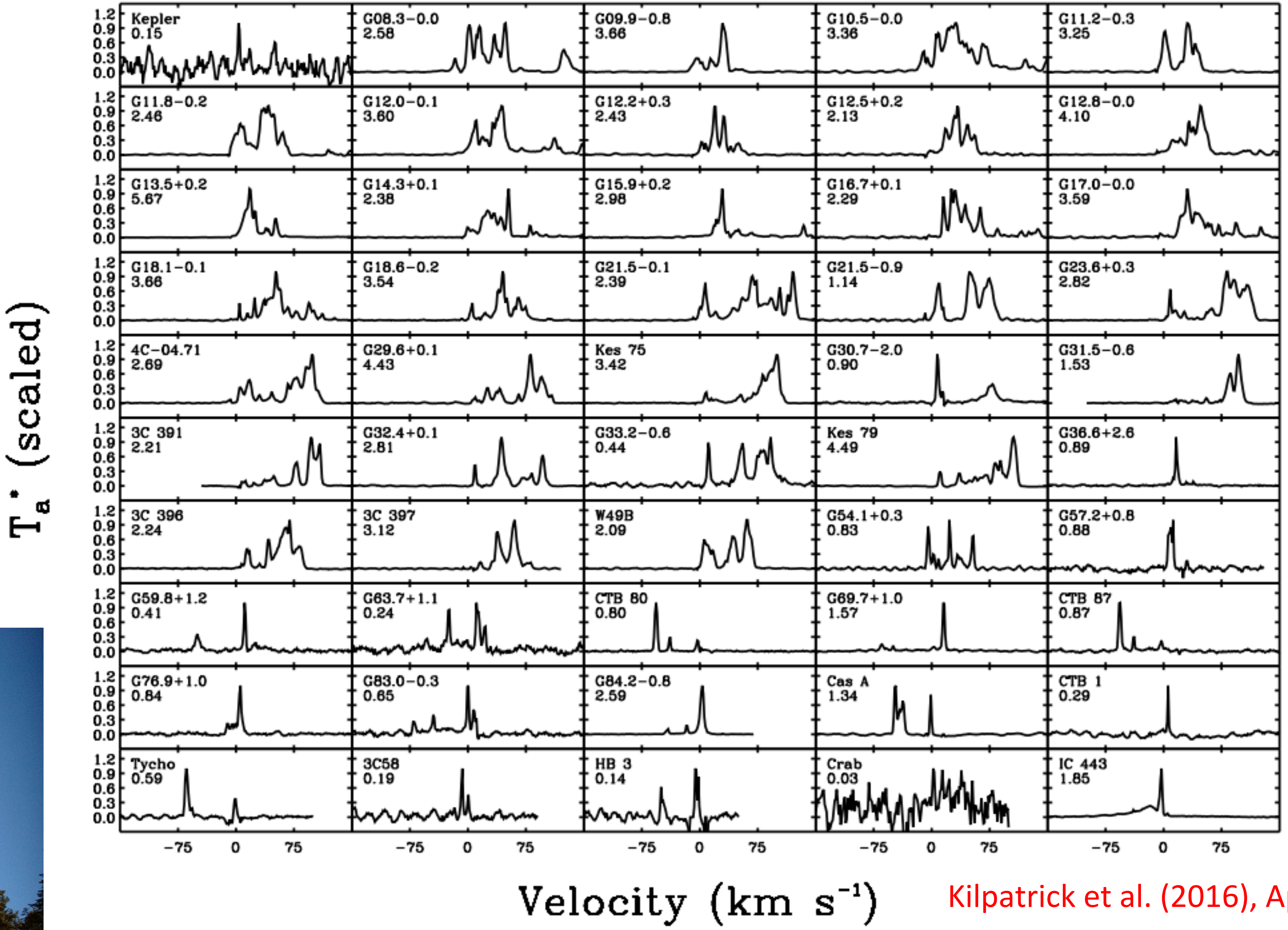
How do interactions correlate with GeV and TeV gamma-rays?

50 SNRs in ^{12}CO *J=2-1*

~1/3 of SNRs in *l* = +4 and +190

SNRs with sizes < 20’

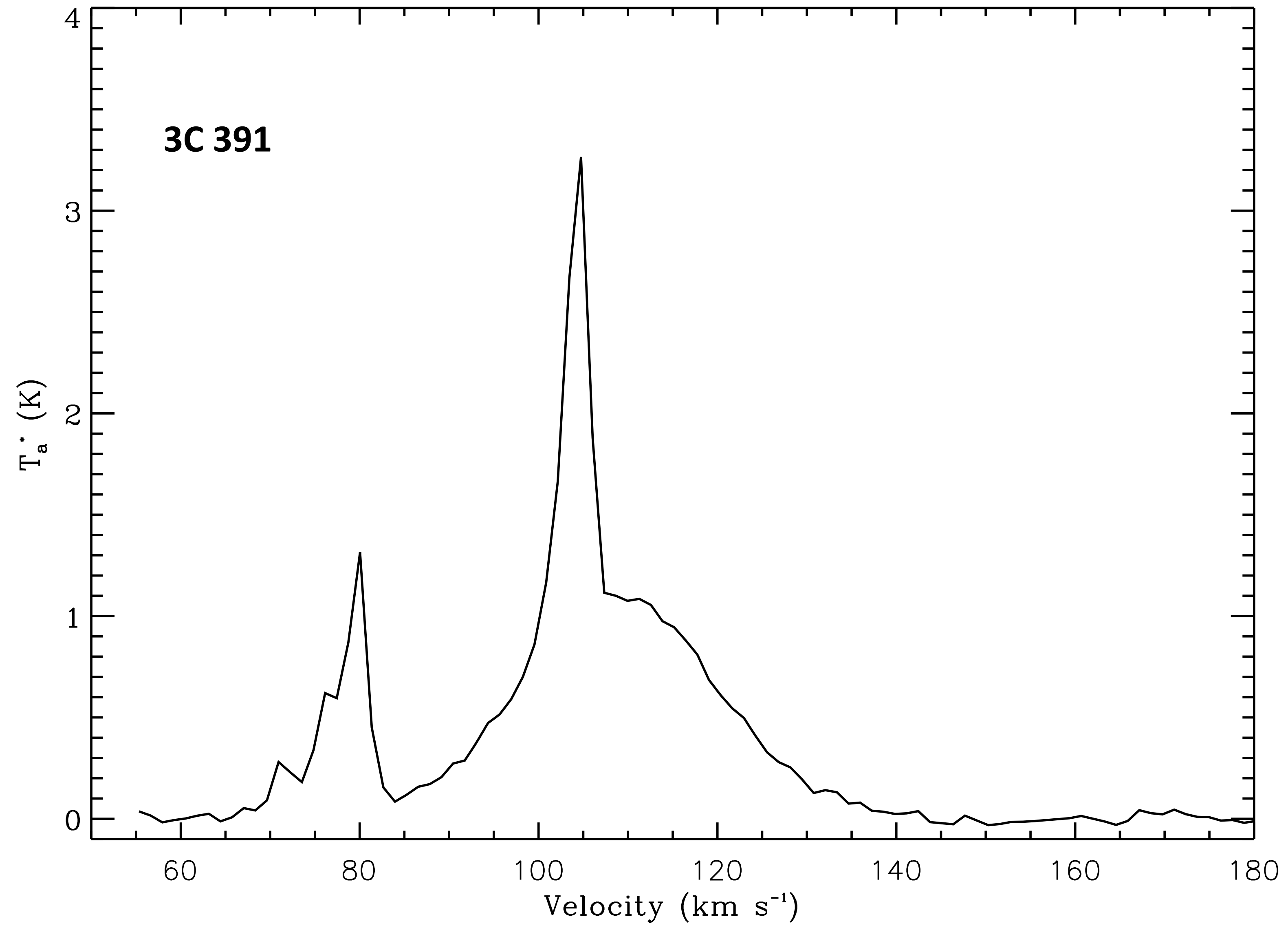
Four in our sample not included in overall statistics



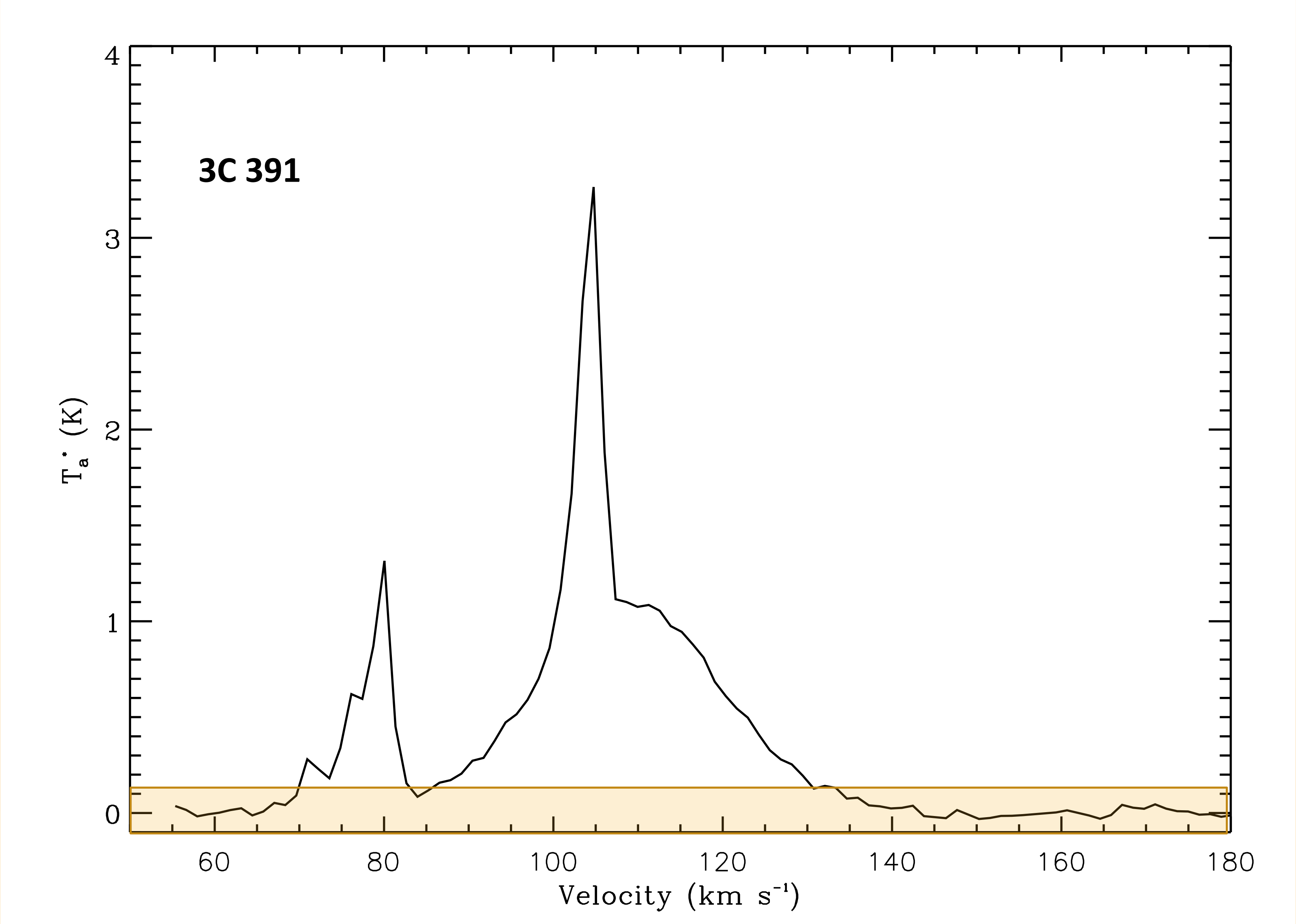
Kilpatrick et al. (2016), ApJ

10m SMT,
Mt. Graham, Arizona

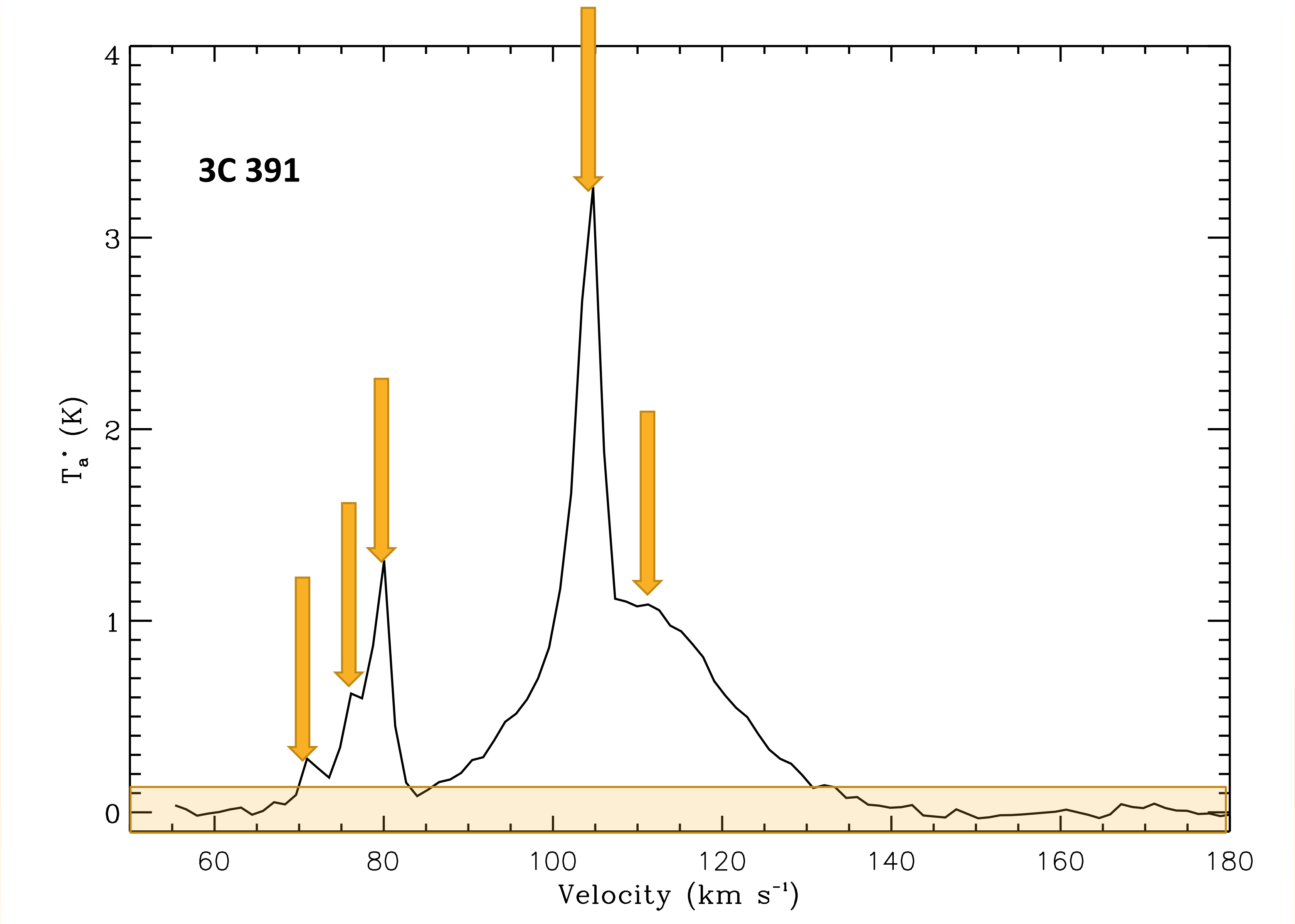
IDENTIFYING BROAD MOLECULAR LINES



IDENTIFYING BROAD MOLECULAR LINES



IDENTIFYING BROAD MOLECULAR LINES



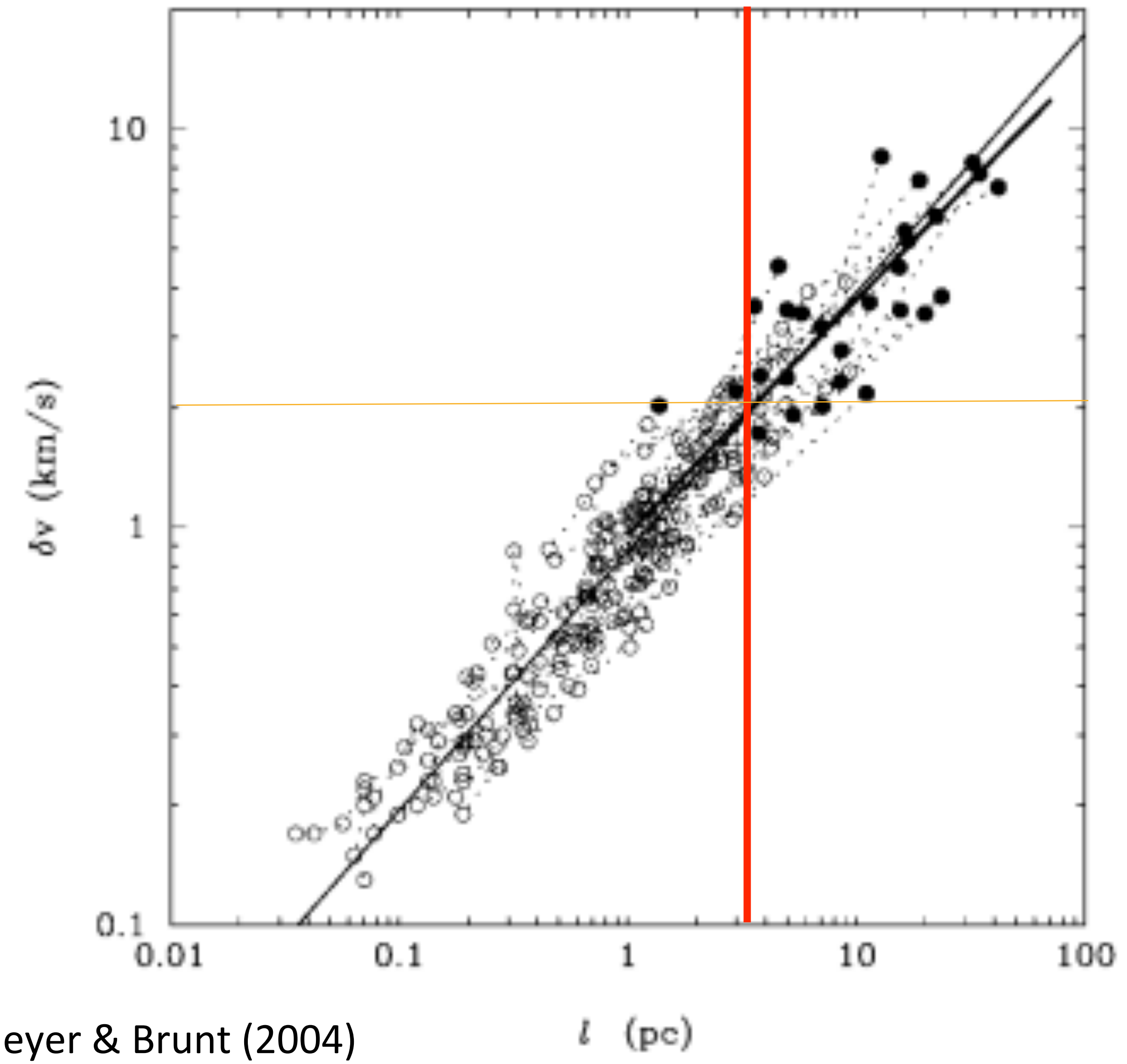
IDENTIFYING BROAD MOLECULAR LINES

Cut in line peak:

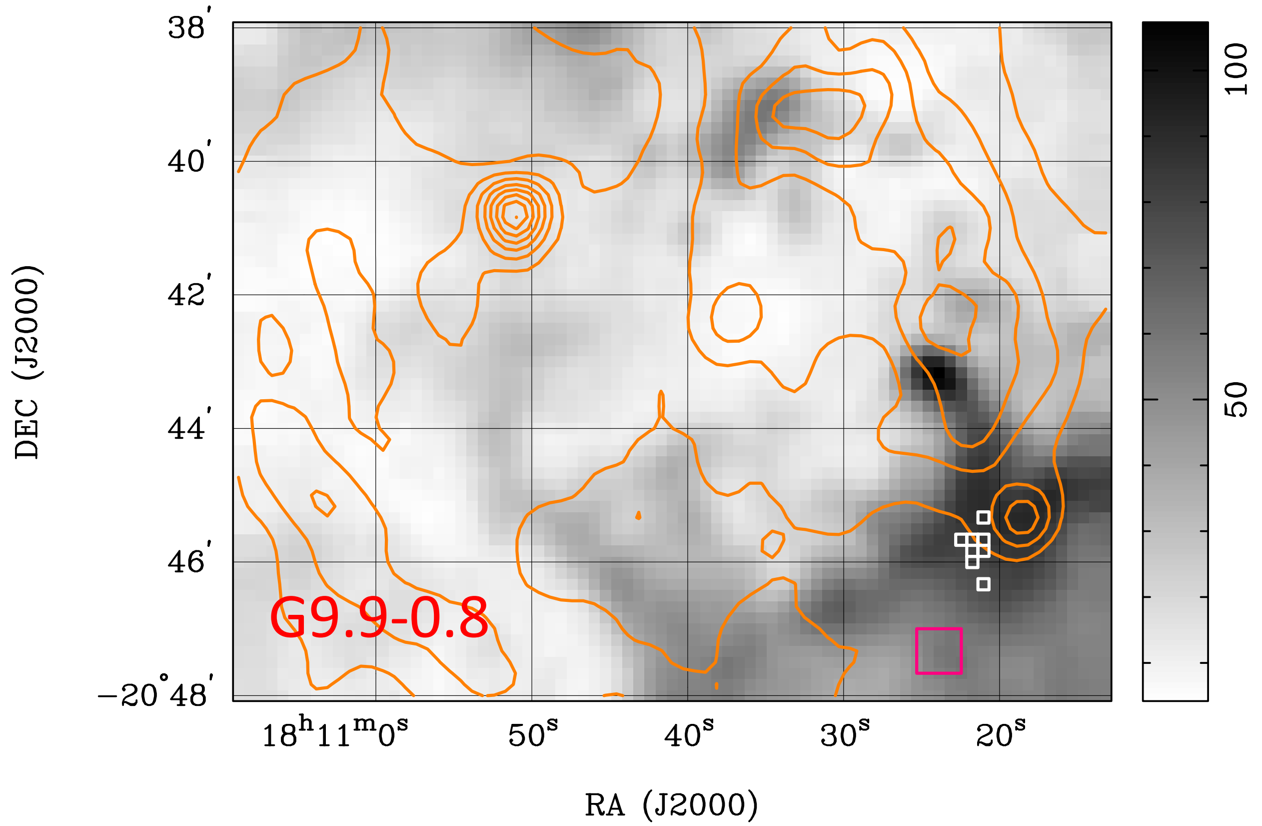
$3\sigma_{RMS}$

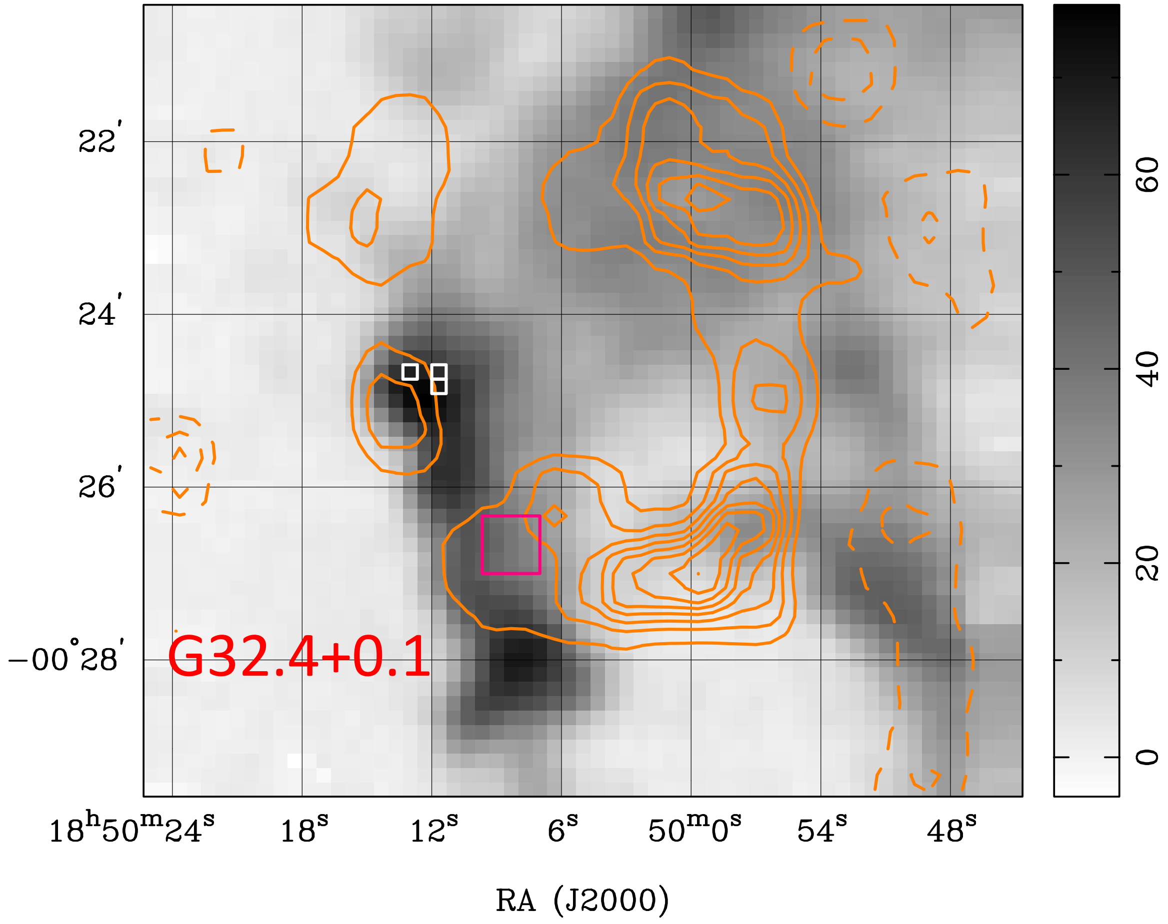
Cut in line width:

FWHM > 6 km s^{-1}

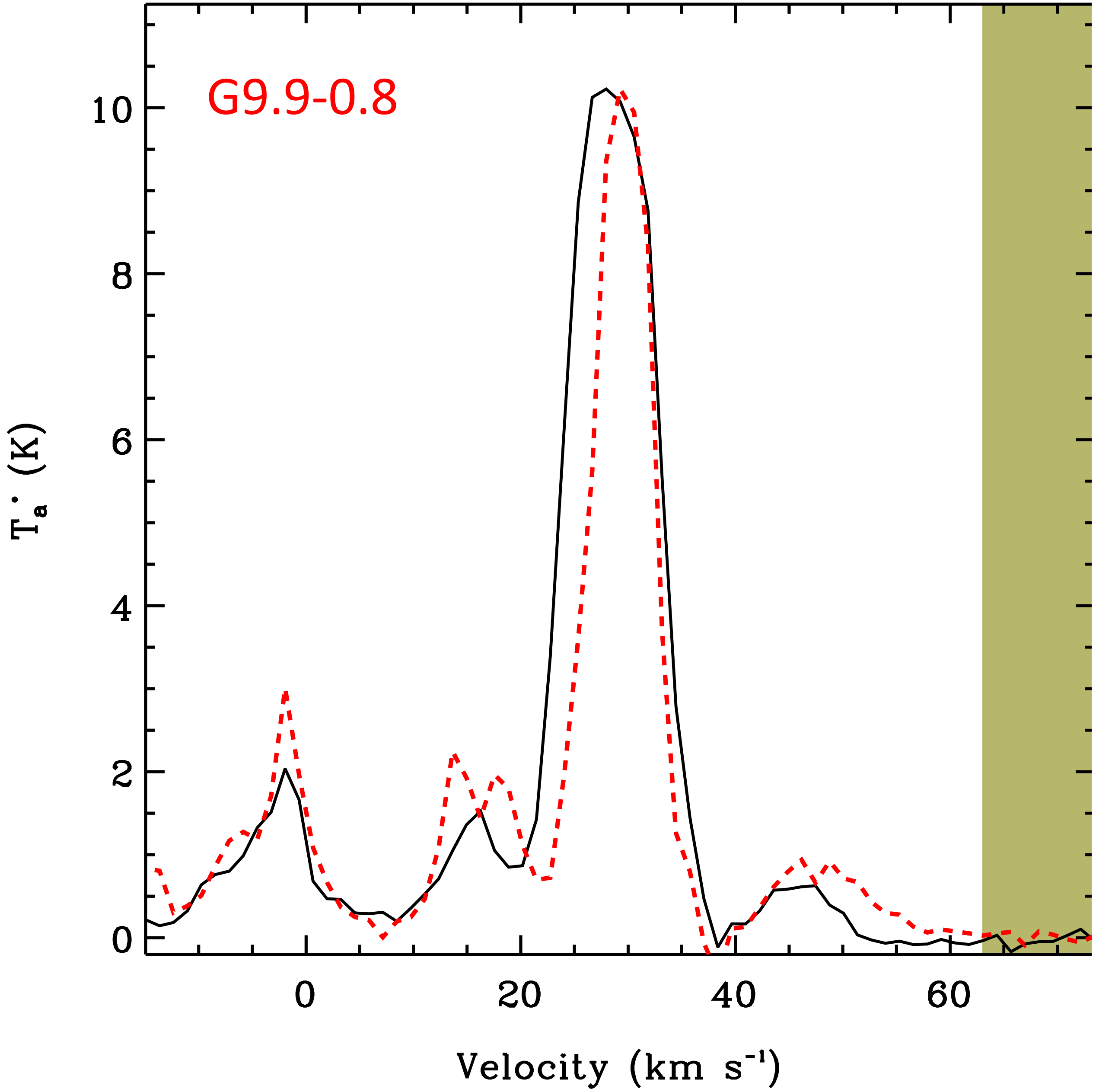


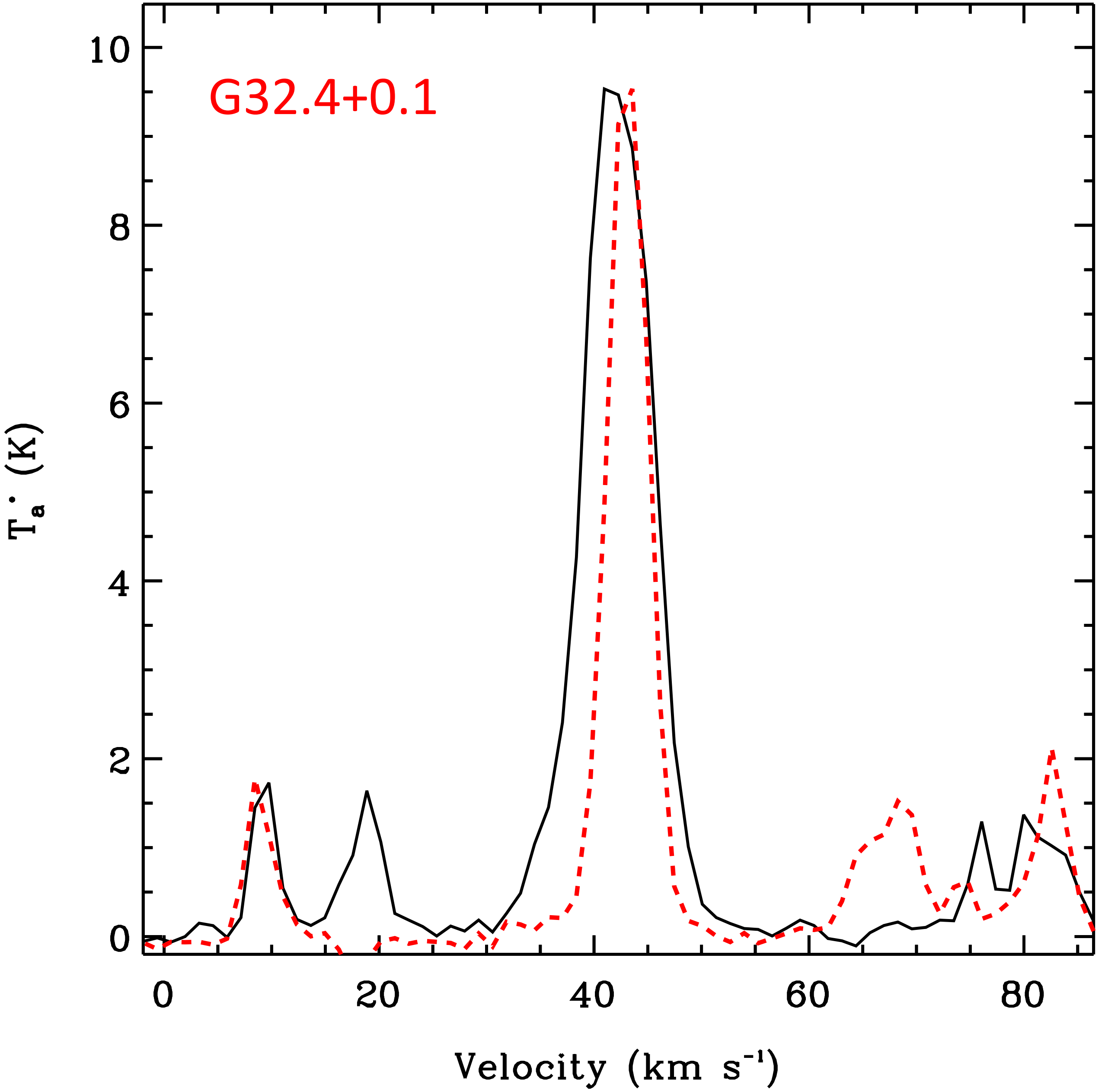
Heyer & Brunt (2004)



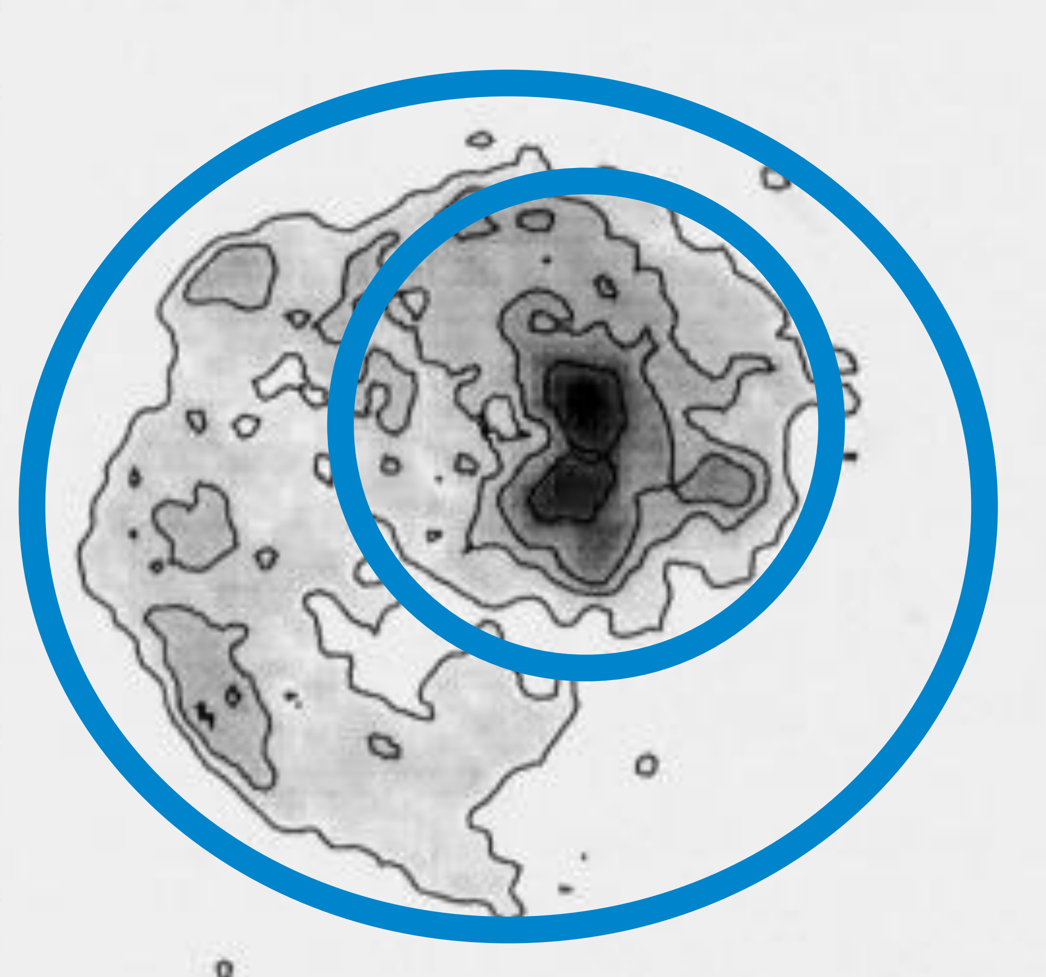


- 17 (of 46; 37%) SNRs with broad molecular lines (overall sample is 19/50; 38%)
- We found 9 SNRs with previously undetected broad molecular lines
- Full list of SNRs with interaction signatures is given in Kilpatrick et al. (2016), ApJ


G9.9-0.8
10
8
6
4
2
0
0
20
40
60
T_a^* (K)
Velocity (km s^{-1})


G32.4+0.1
10
8
6
4
2
0
0
20
40
60
80
T_a^* (K)
Velocity (km s^{-1})

EXPLANATION FOR % INTERACTIONS < % CC SUPERNOVAE



N63A at 8.6 GHz; Dickel et al. (1993)

NASA/JPL Caltech

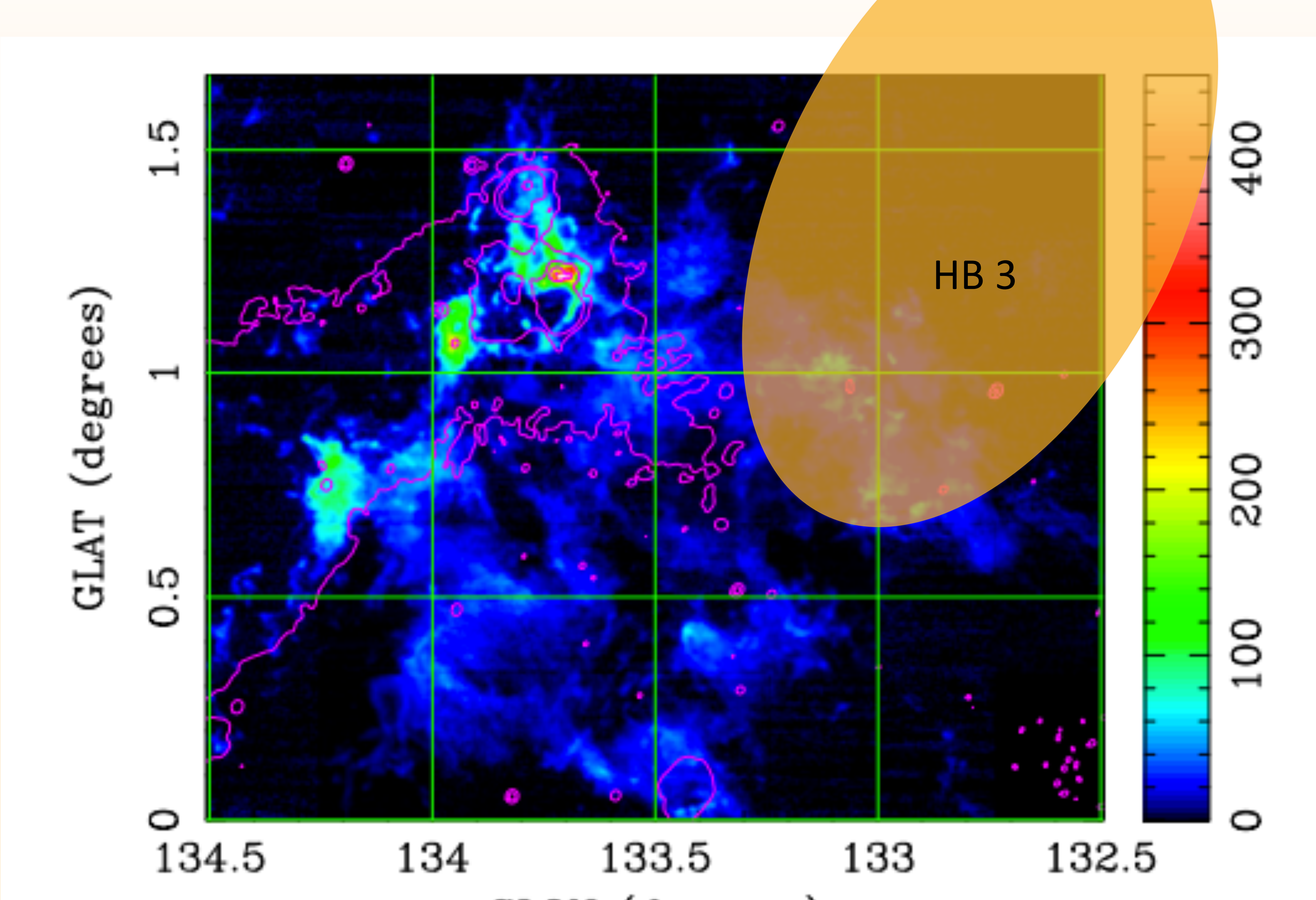
Exploding in a bubble?

Explosion of runaway stars?

Suggest an interaction timescale effect

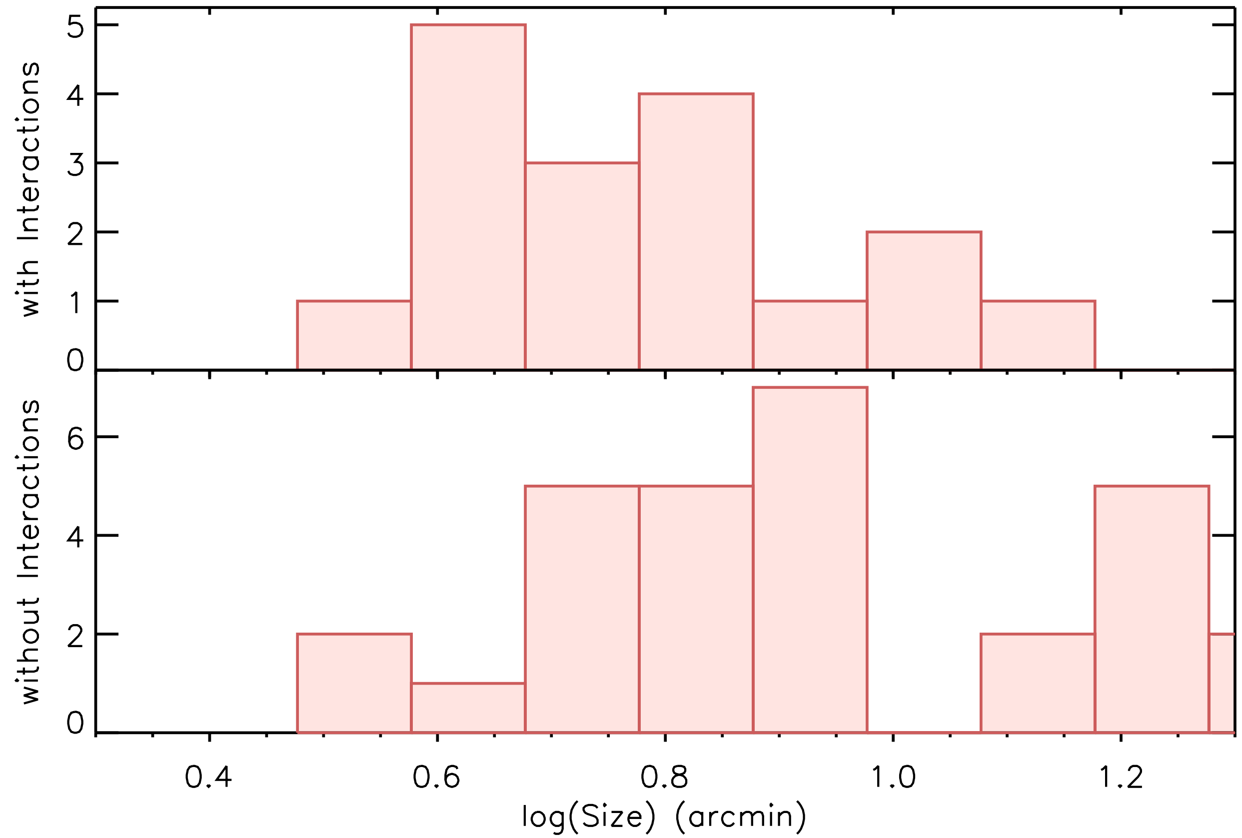
H II regions/OB stars carve out molecular gas before SNRs go off

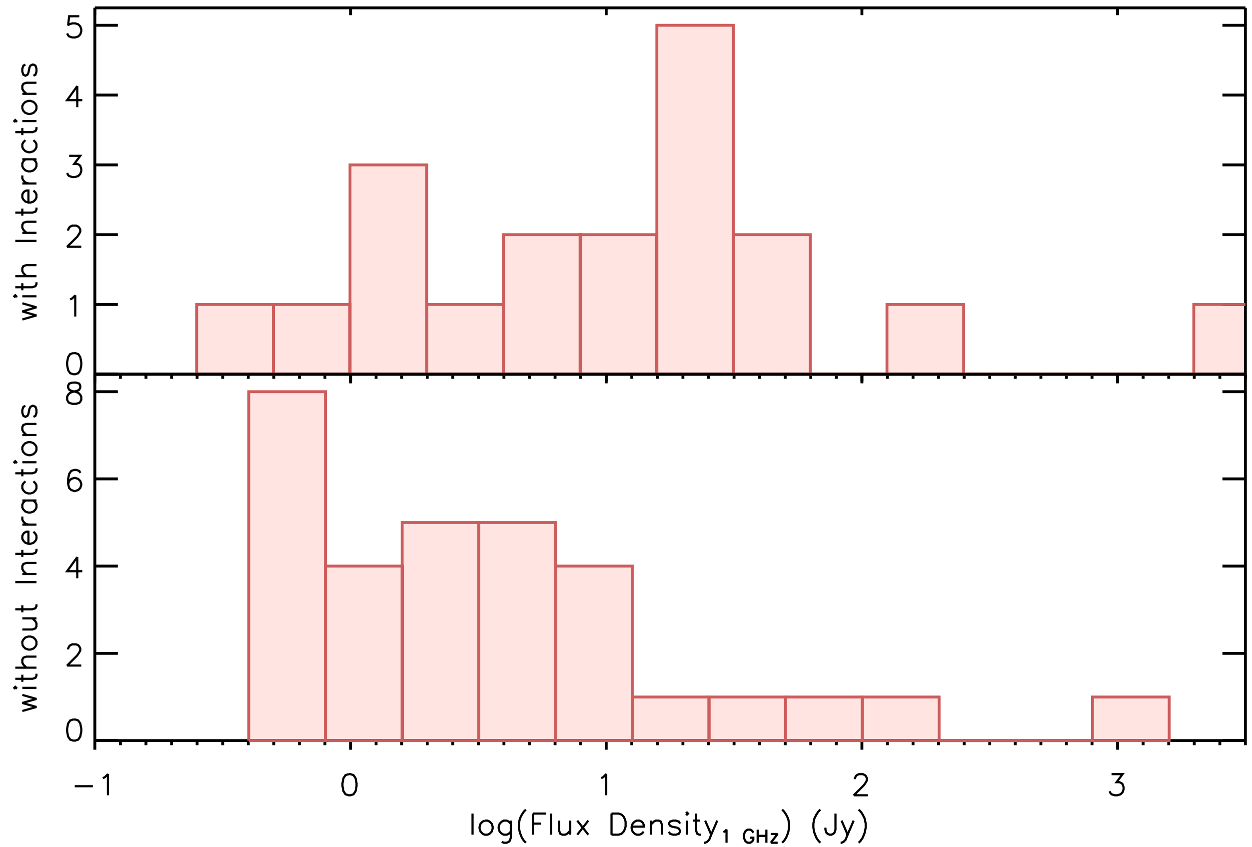
W3 destroyed most of its molecular cloud before HB3 got there



W3; Bieging & Peters (2011)

PHYSICAL CONDITIONS OF THE SNRS





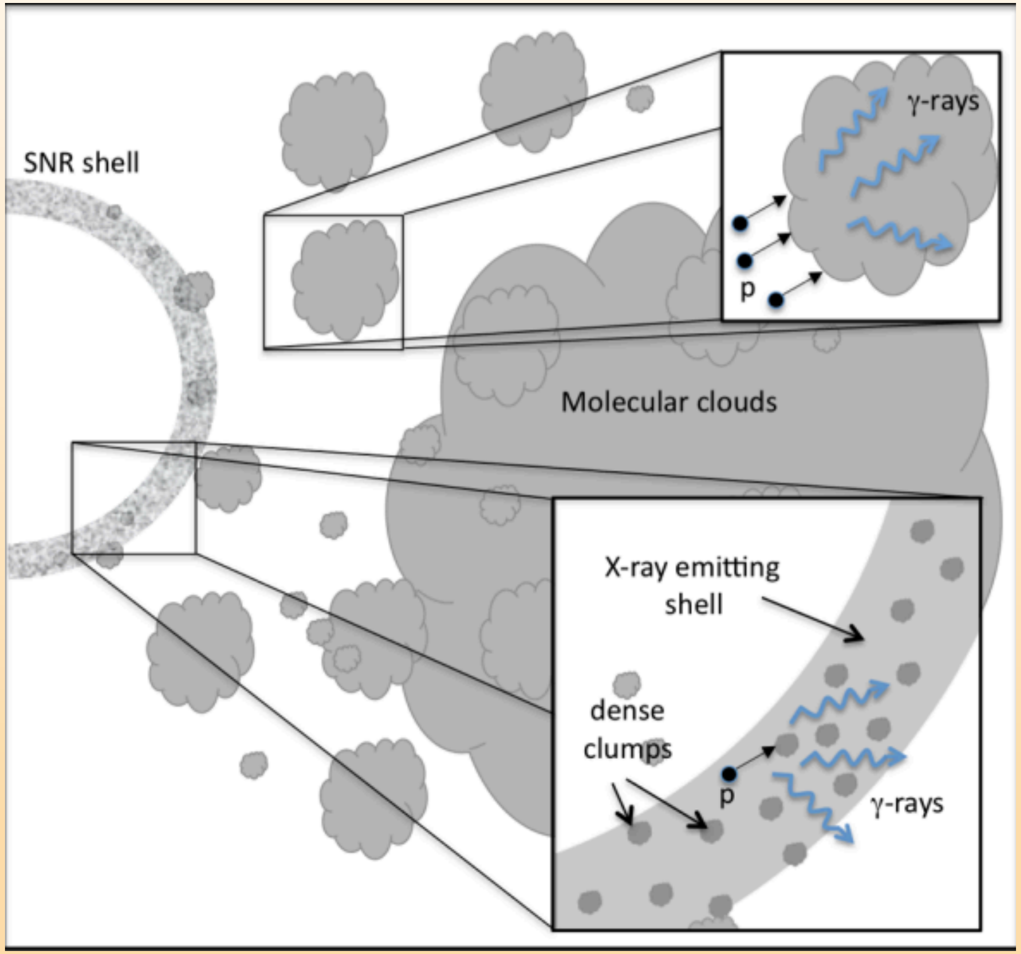
$$\theta \propto d^{-1}\rho^{-1/5}t^{2/5}$$

$$S \propto \theta^2\Sigma \propto d^{-2}\rho^2 t^{-3/5}$$

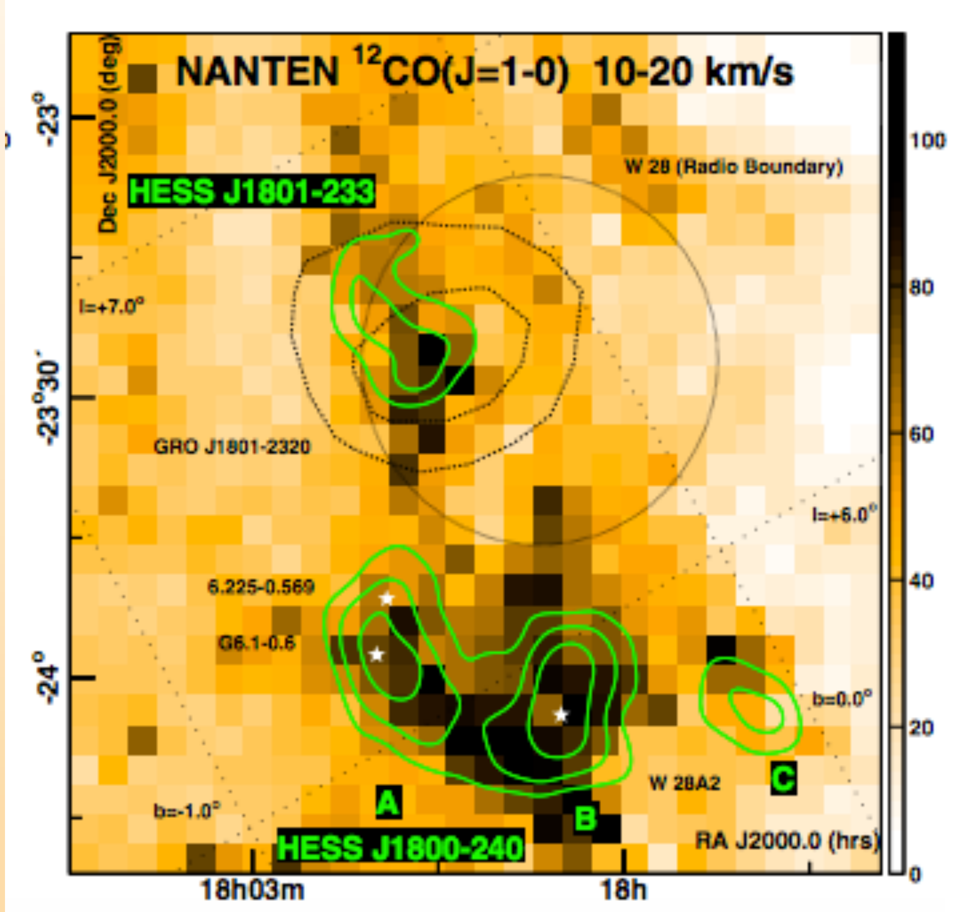
Assuming similar distributions in distance:

- distributions agree with higher densities
- no evidence for differences in age distribution

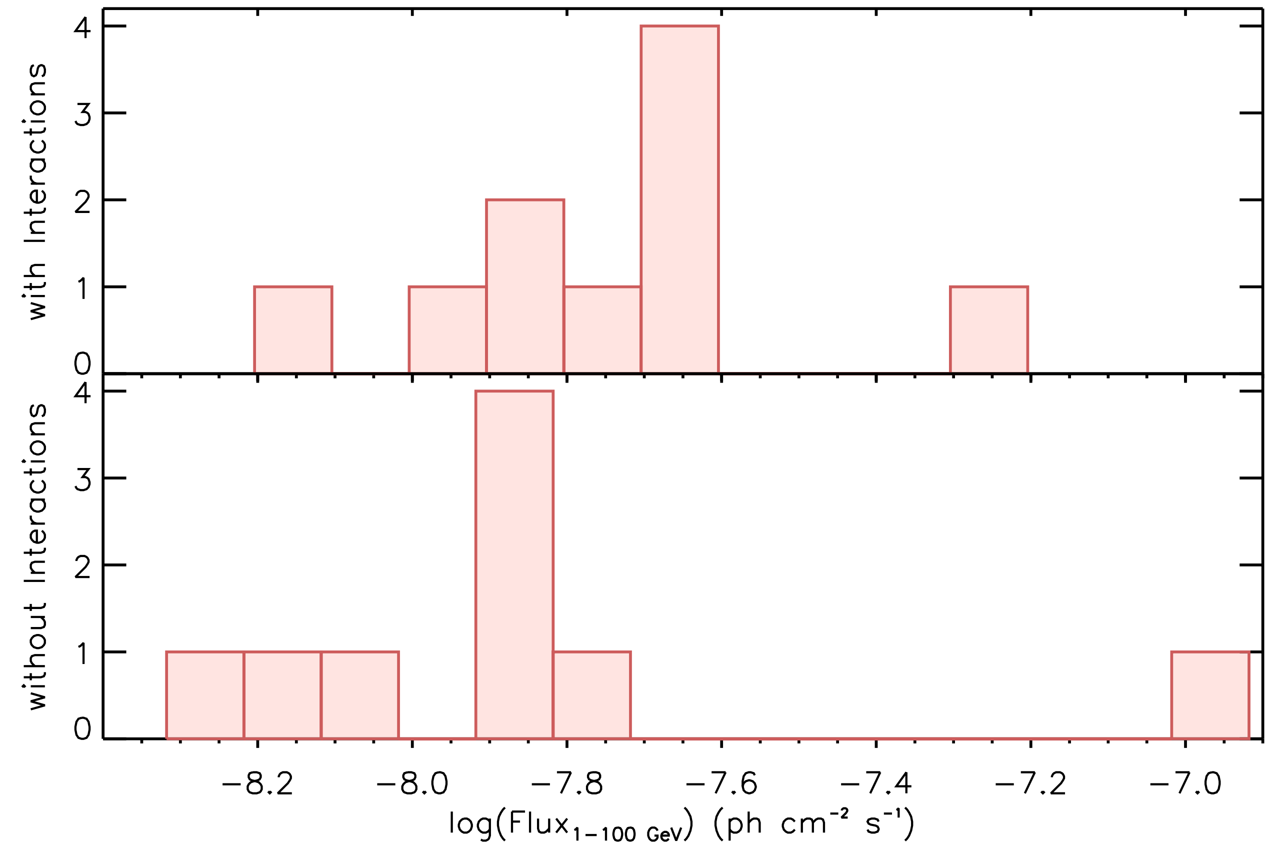
Some examples – but is this typical?

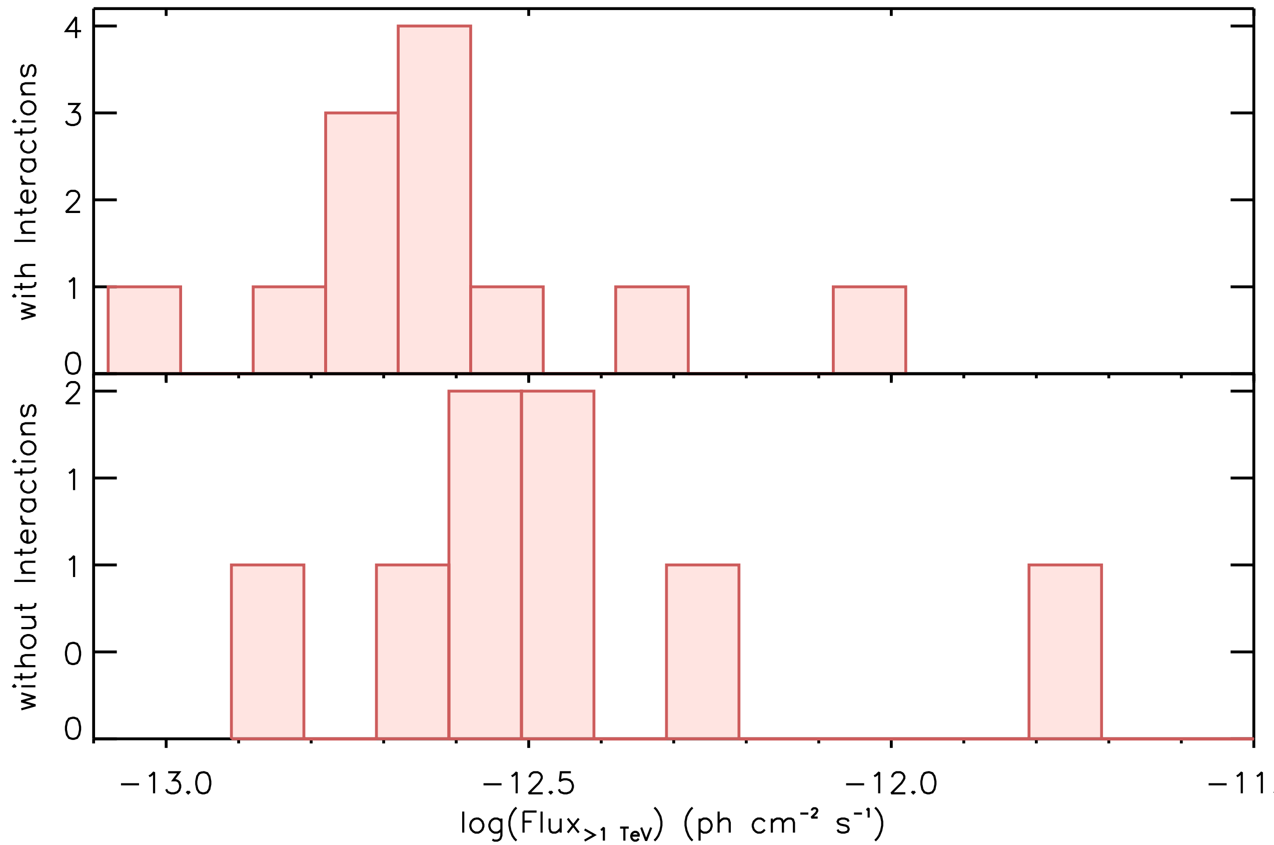


Slane et al. (2015)



W28 from HESS collaboration,
Aharonian et al. (2008)





GeV sources from *Fermi* First SNR catalog
Acero et al. (2015)

TeV sources detected by HESS near SNRs (> 2σ)
Bochow, PhD thesis (2011)
Hahn, PhD thesis (2014)

SNR-MC interactions in this sample appear correlated with bright GeV gamma-rays but not TeV

CONCLUSIONS

- Broad molecular line studies reveal 19 SNRs with MC interactions (9 new ones)
- # of SNRs with MC interactions is low compared to fraction of CCSNe
- Difficult to tell from sizes and flux densities whether a correlation exists with age
- Comparison with gamma-ray sources suggest SNR-MC interactions are correlated with GeV but anti-correlated with TeV sources