The Milky Way Project:

Tracing Feedback across the Galaxy using Infrared Bubbles

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+ The Zooniverse, Milky Way Project Science Team and 35,000+ Users

Regulation of star formation in molecular gas, Ringberg, June 2013

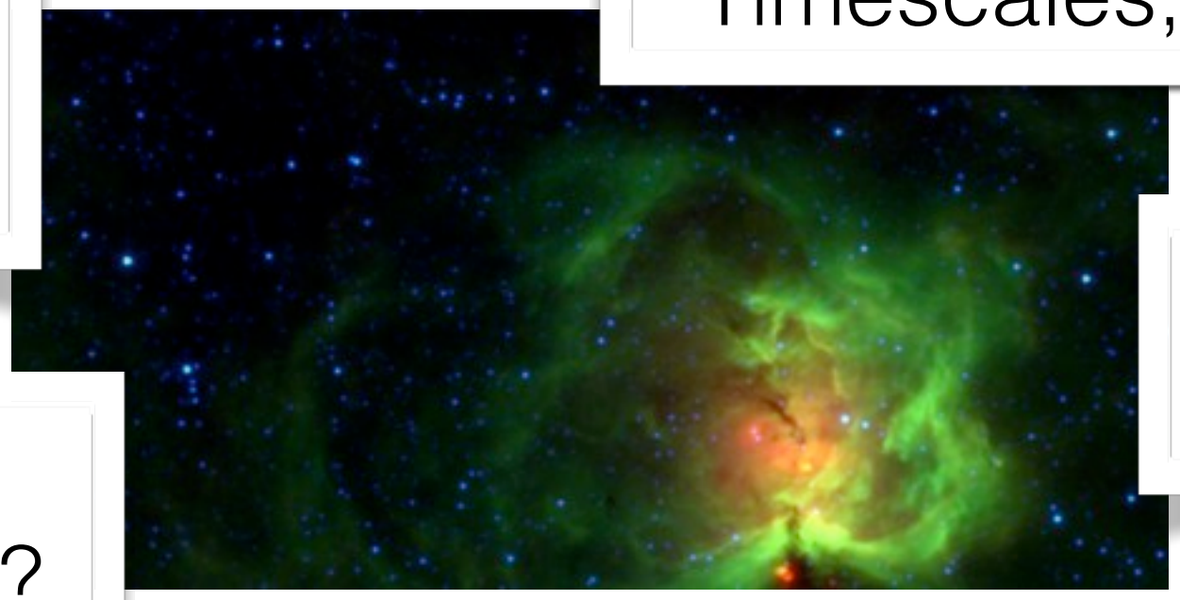
Image: Chris Beaumont

Importance of feedback

Sources of feedback

Different types of feedback

Timescales, spatial scales



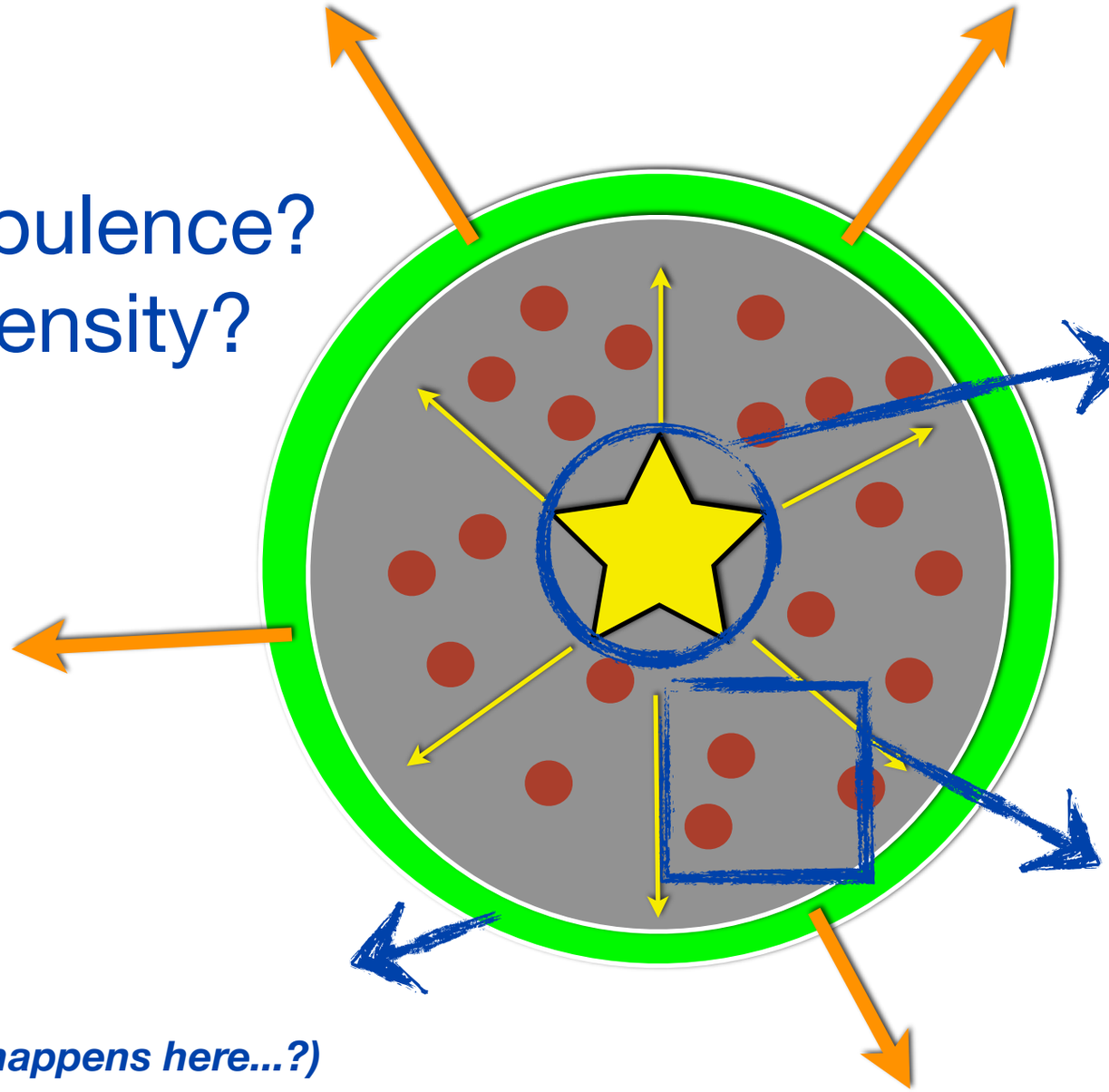
How to observe?

Effect of environment?

Feedback matters
Effects of feedback are hard to quantify

ISM Bubbles: Highly Visible Sites of Feedback

ISM Turbulence?
ISM Density?



Driving source: single, cluster, spectral type, age, winds?

Dust?

(and what happens here...?)

First catalogues from the GLIMPSE survey

THE ASTROPHYSICAL JOURNAL, 649:759–778, 2006 October 1

THE BUBBLING GALACTIC DISK

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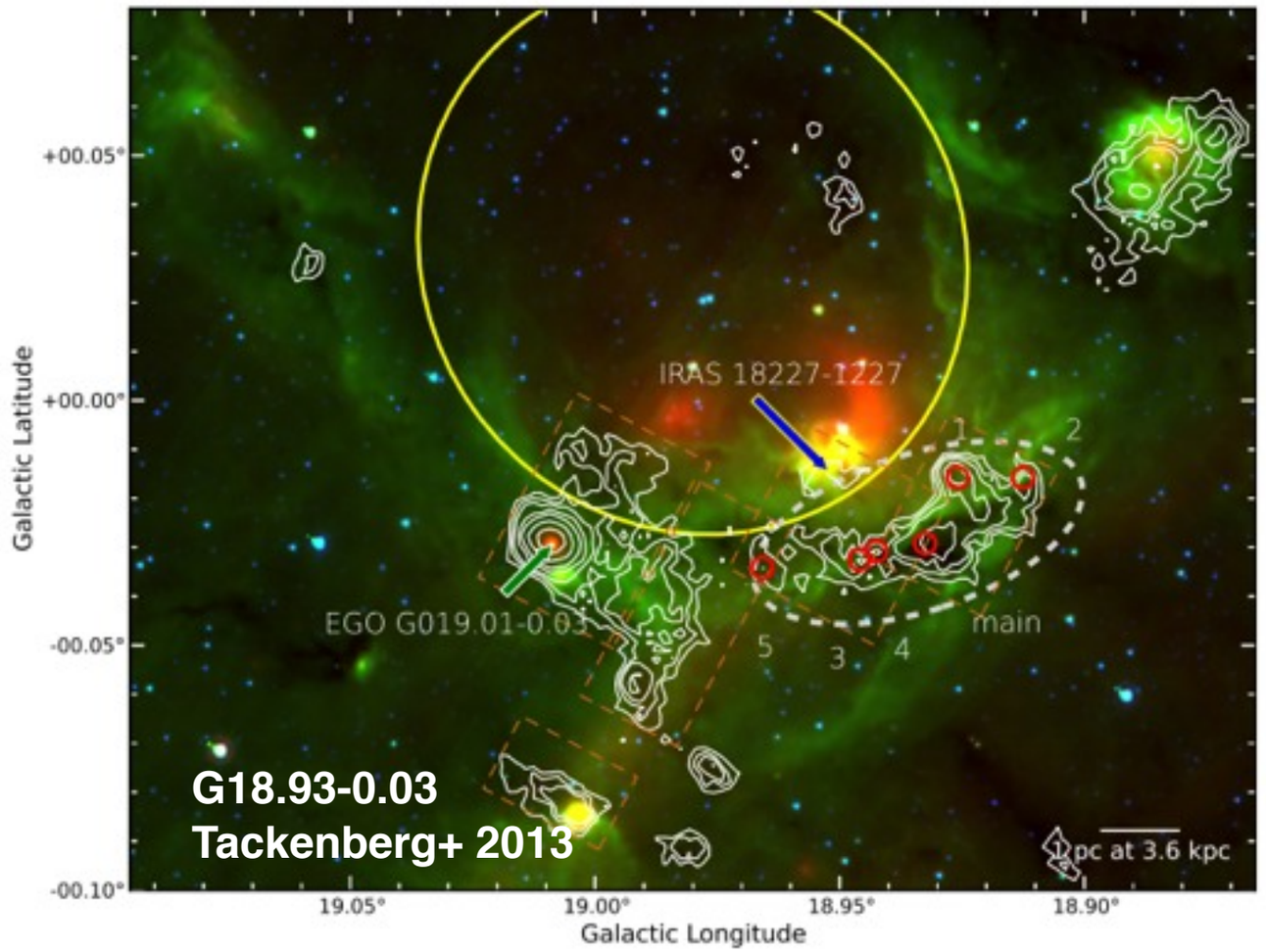
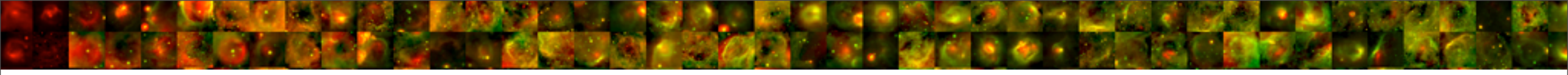


Cataloguing Bubbles with Citizen Scientists



First Milky Way Project Public Data Release

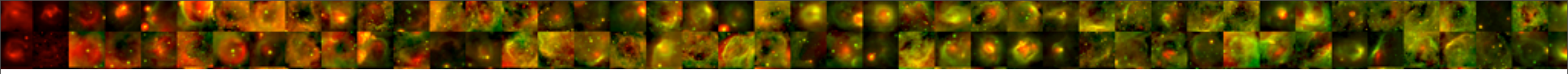
The Milky Way Project First Data Release: A Bubblier Galactic Disk*

R. J. Simpson[1]†, M. S. Povich[2,3], S. Kendrew[4], C. J. Lintott[1,5], E. Bressert[6,7,8], K. Arvidsson[5], C. Cyganowski[8,3], S. Maddison[12] K. Schawinski[10,11,13], R. Sherman[9], A. M. Smith[1,5], G. Wolf-Chase[5,9]

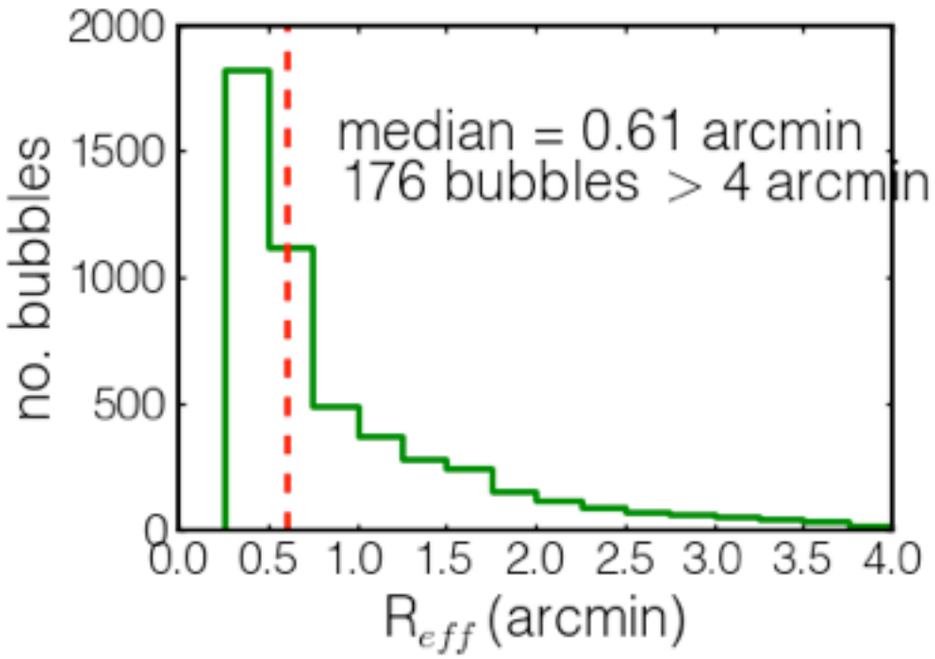
★ Simpson et al, 2012, MNRAS (Arxiv: 1201.6357) **> 5000 bubbles**

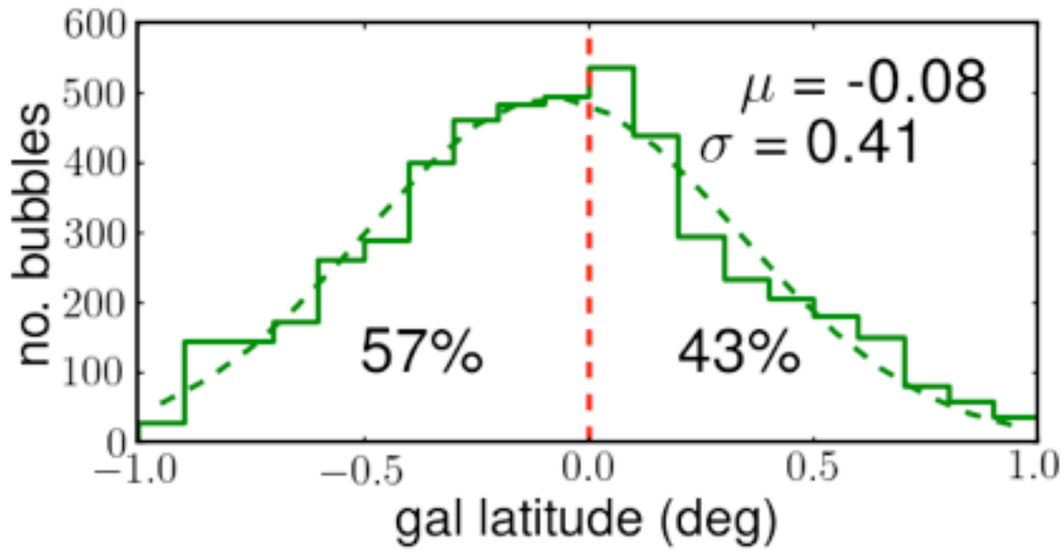
★ Data at http://www.milkywayproject.org/data

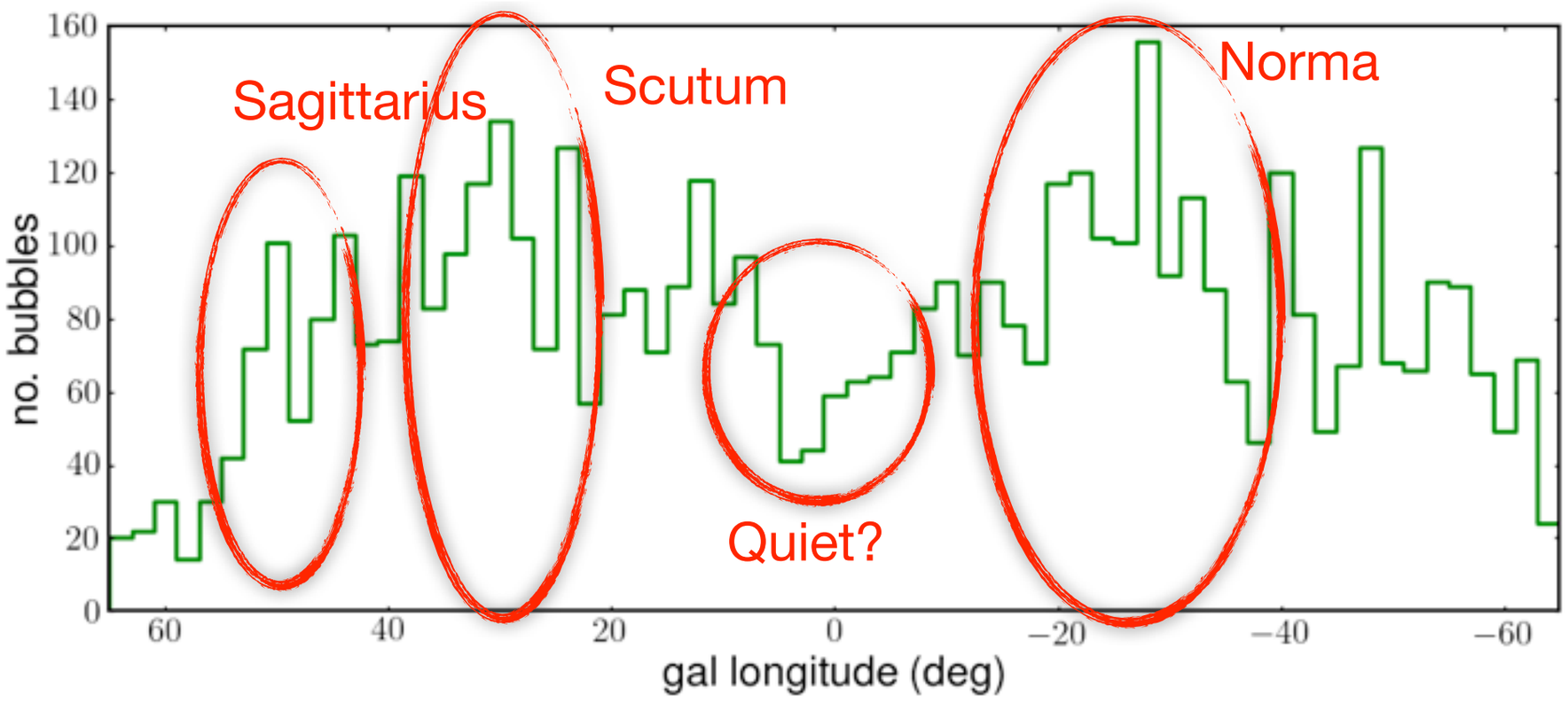
★ Interactive bubble explorer



Some bubble properties

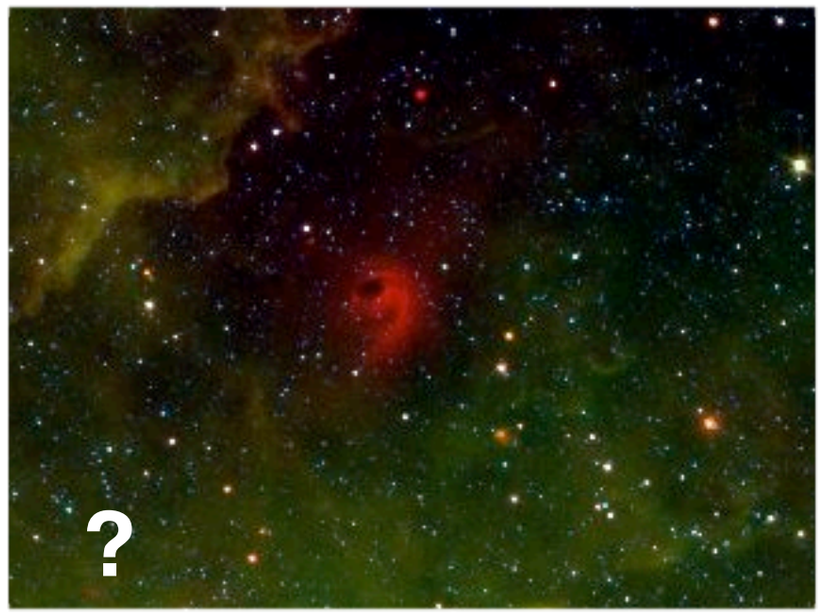






Bubbles form around many types of objects

- HII regions (recover > 95% of Anderson+ 2011 sample)
- Supernova remnants
- Evolved massive stars (LBV, WR)
- Planetary nebulae
- Spurious detections



Quantifying star formation near bubbles: A statistical approach

SK (MPIA), Rob Simpson (Oxford), Eli Bressert (Exeter/ESO), Matt Povich (Penn State), Chris Lintott (Oxford), Reid Sherman (Chicago), Tom Robitaille (MPIA), Kevin Schawinski (Yale), Grace Wolf-Chase (Adler/Chicago)

Feedback-driven “Triggered” star formation

- Fast-growing body of “evidence” of triggering near IR bubbles: W51a (Kang+ 09), RCW120 (Zavagno+ 10), Sh2-217 (Brand+ 11), W49A (Peng+ 10) .....

RCW 79 (Zavagno+ 05)

- Simulations show that triggering happens (Dale+) *

[* but is impossible to observe...?]

- How prevalent is triggered star formation on Galactic scales?

Trace massive star formation near bubbles statistically

MYSOs: Red MSX Source (RMS) Survey

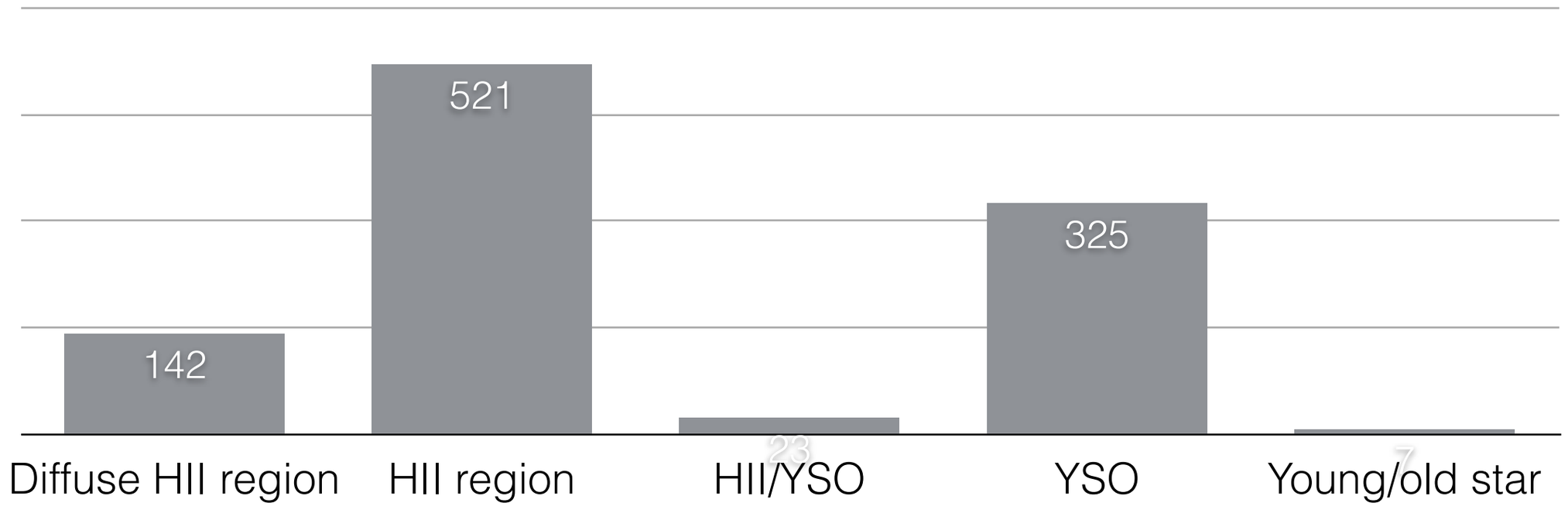
~2000 massive YSOs selected from colours of known objects (Lumsden+ 2002, Urquhart+ 2008); ~1000 ‘young’ sources in GLIMPSE I region.

~complete for > 10^4 L(solar) to ~15 kpc.

Excluding |l| < 10°

Spatial resolution 18” (0.3’)

Follow-up: distances, source types

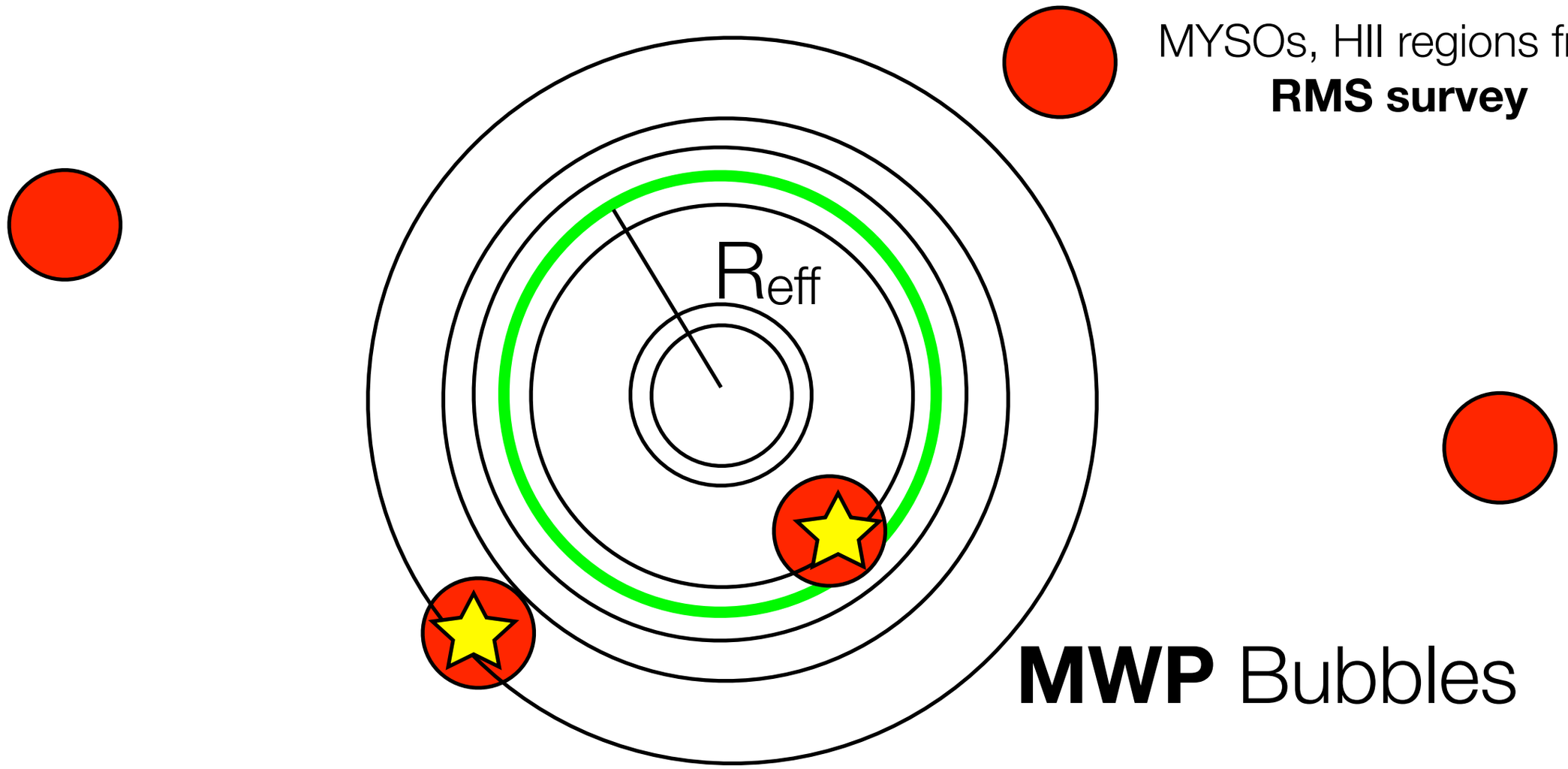


Two-point correlation function

= excess probability of finding sources at separation theta over what is expected from random distribution

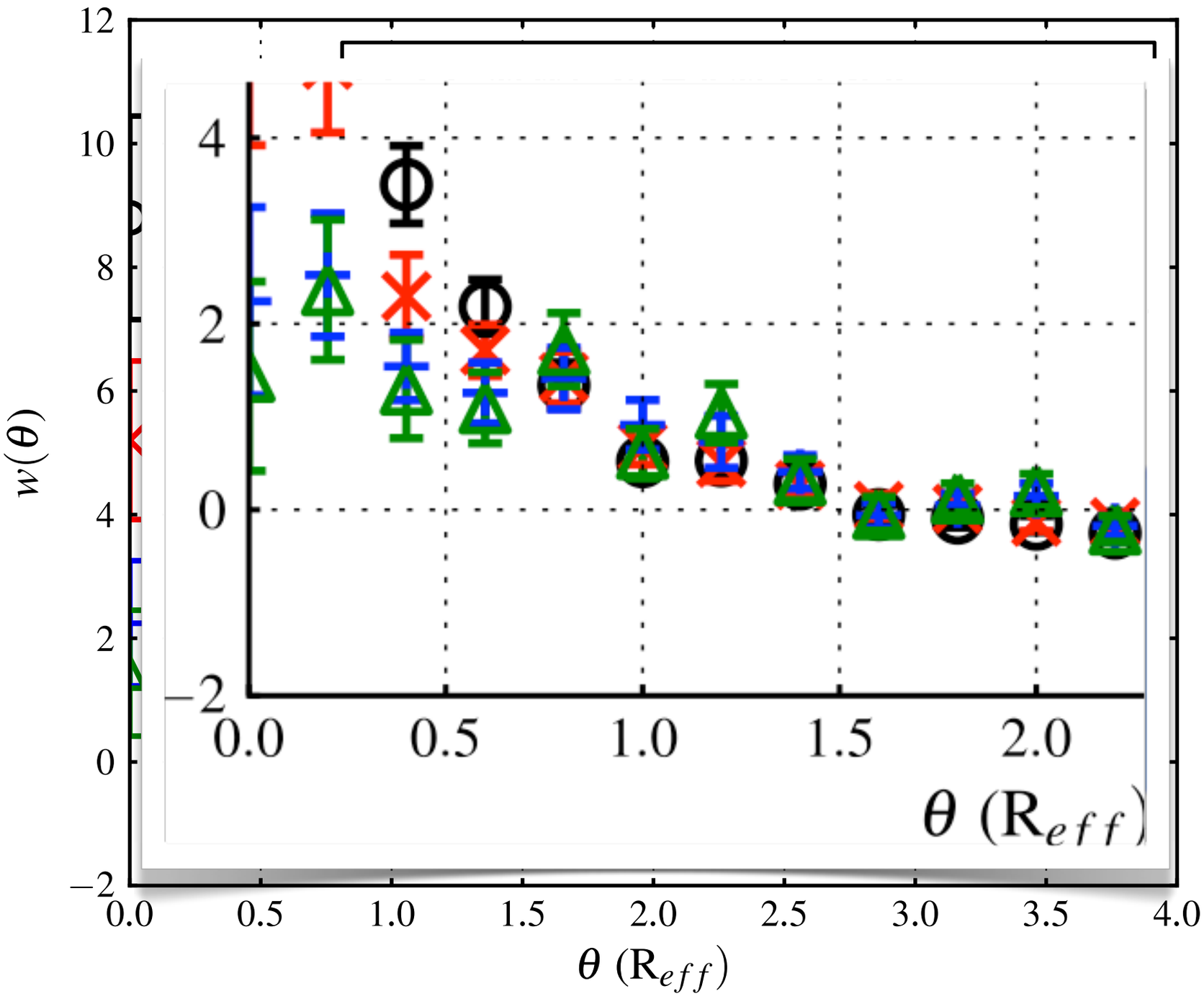
$w(theta) = (N_{dd}-N_{dr}-N_{rd}+N_{rr})/N_{rr}$ (Landy & Szalay 93)

N = Pair counts, d = data, r = random



MWP + RMS correlation function

Size matters!



Conclusions & Caveats (Kendrew+ 12)

67 ± 3% of massive young sources in RMS lie within 2 Radii from a bubble

22 ± 2% lie near a bubble rim (triggered?)

Larger overdensity around the rims of the largest bubbles

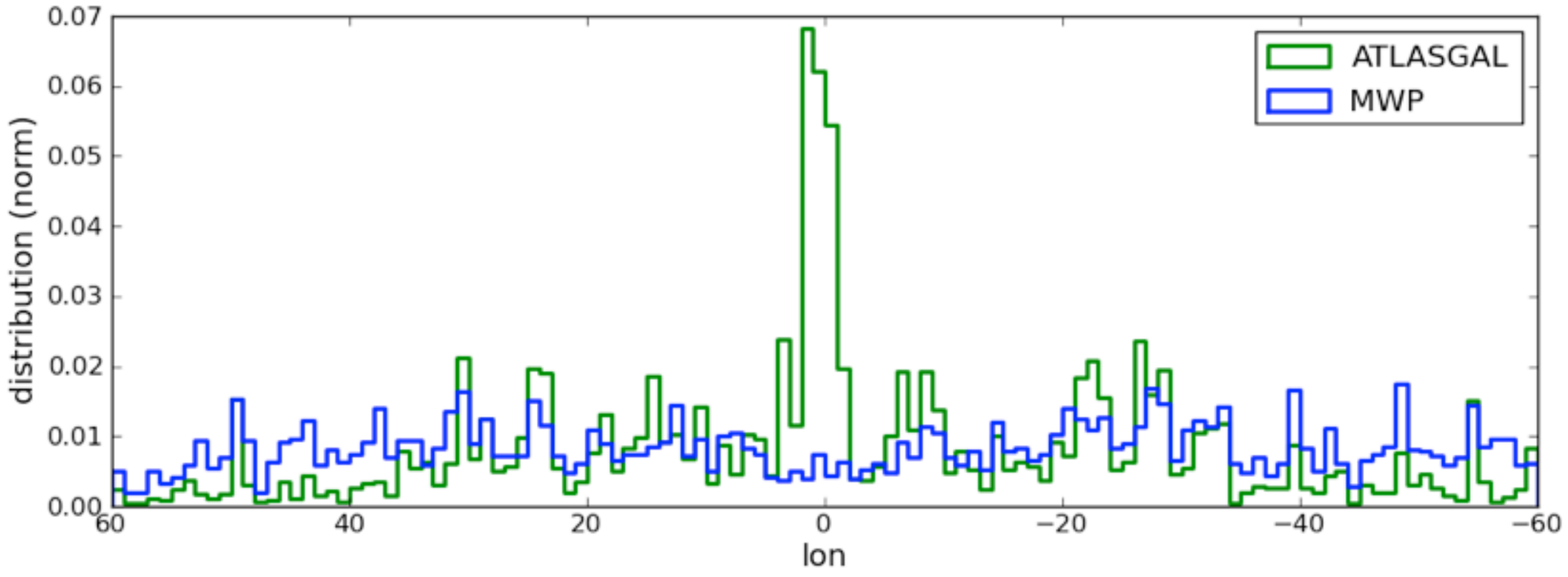
For believers only!

Angular size impossible to interpret without distances

Is “associated” = “coincident”? RMS sources and bubbles trace similar evolutionary stages

The ATLASGAL survey (Schuller+ 09)

- Galactic Plane survey with APEX at 870 μm - Beam size ~19”
- Traces cold dense dusty material over 360 deg^2
- Preliminary catalogue contains > 11,000 clumps over -60<l<60, -1<b<1 with effective radius, maximum flux, integrated flux source; size < 2.5’
- Beuther+ 12, Contreras+ 13 for further details

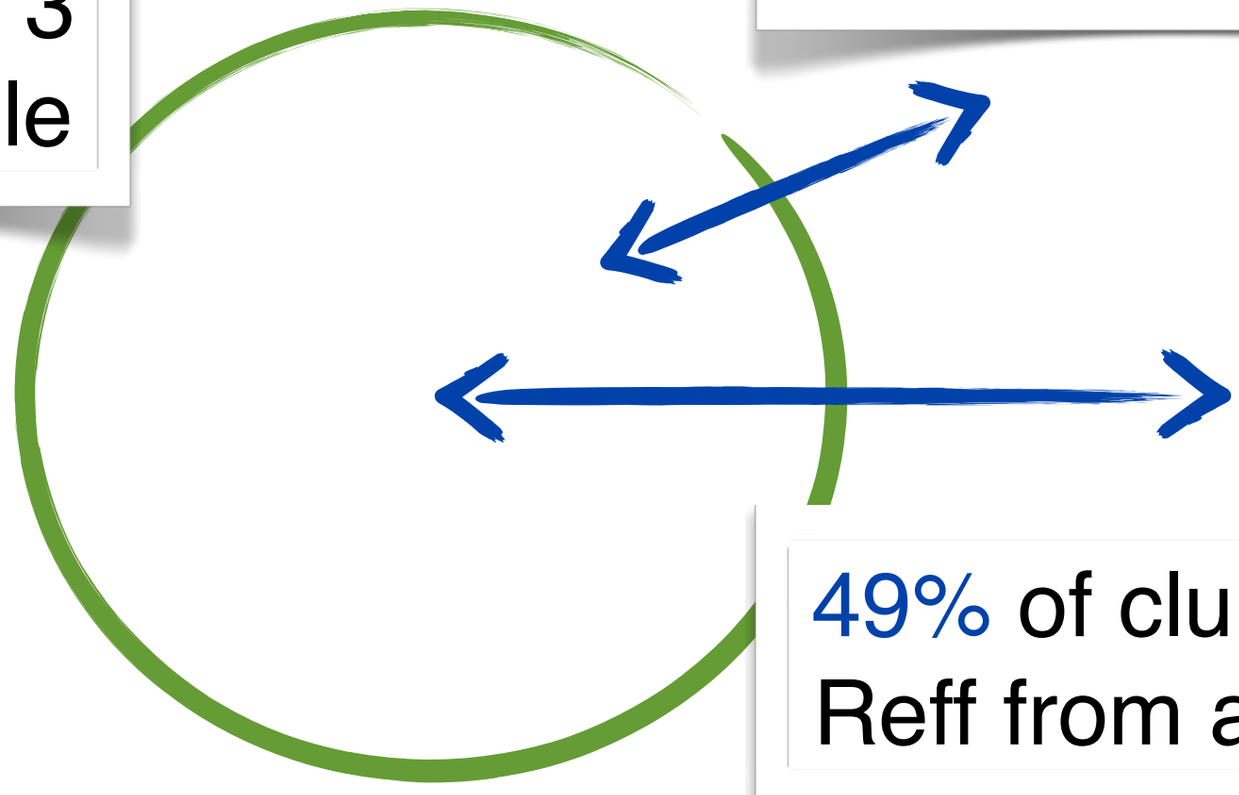


Are cold clumps preferentially found near bubbles?

11073 clumps

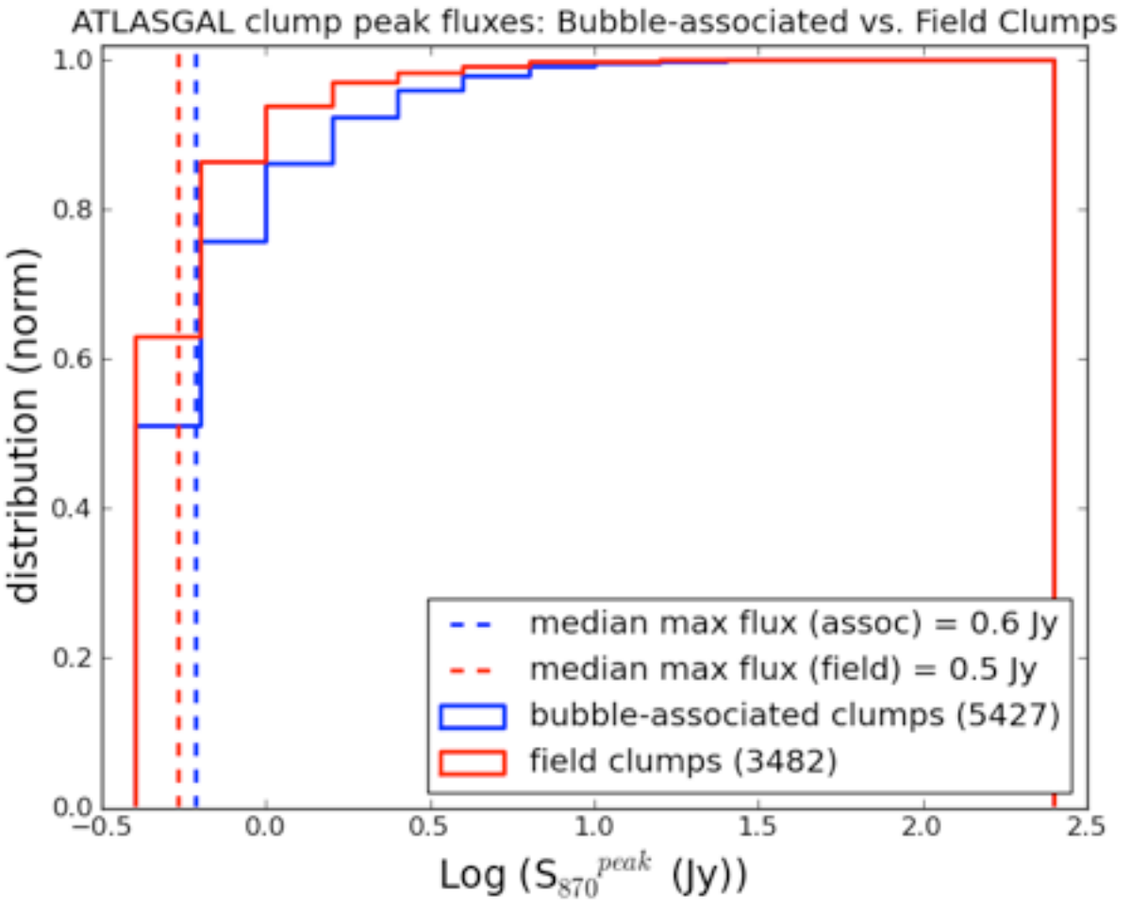
27% of clumps near bubble rims (0.8 - 1.6 Reff)

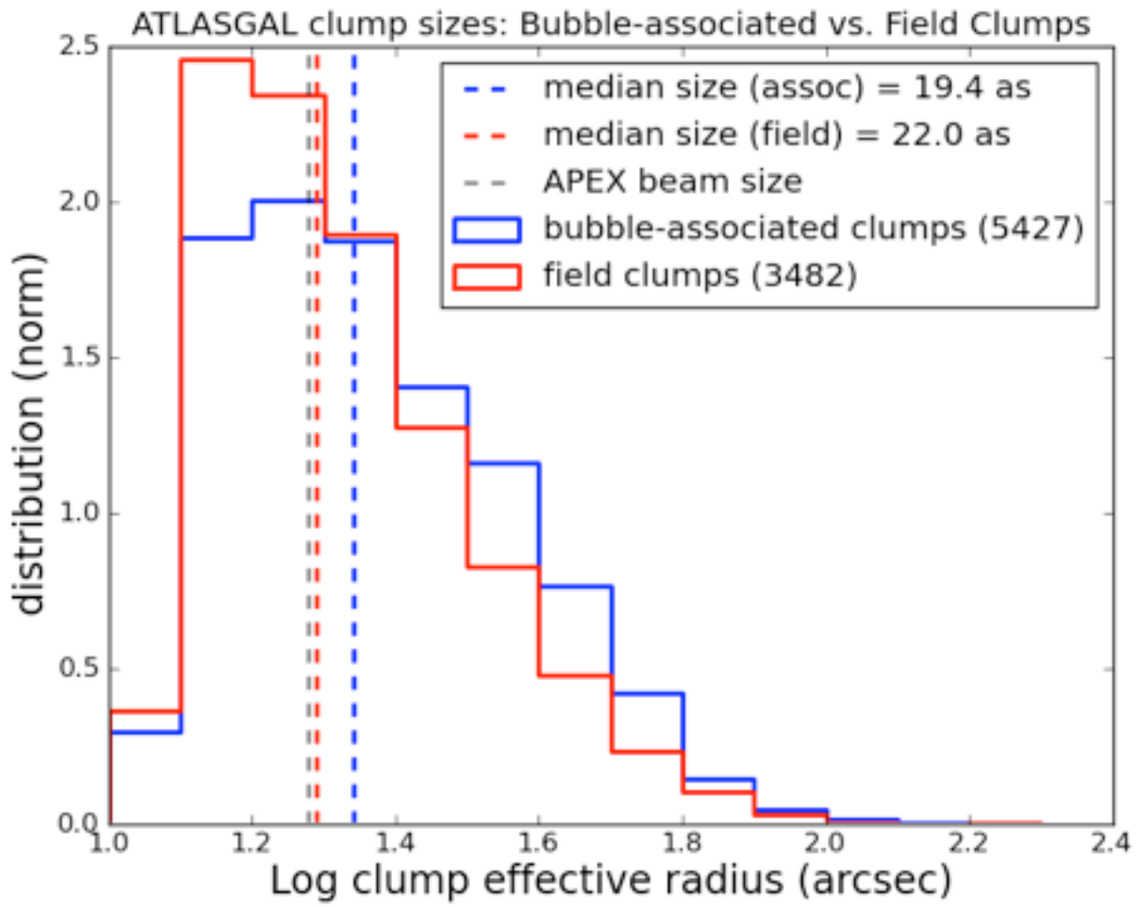
35% of clumps > 3 Reff from a bubble



49% of clumps < 2 Reff from a bubble

Do these populations vary in physical properties?



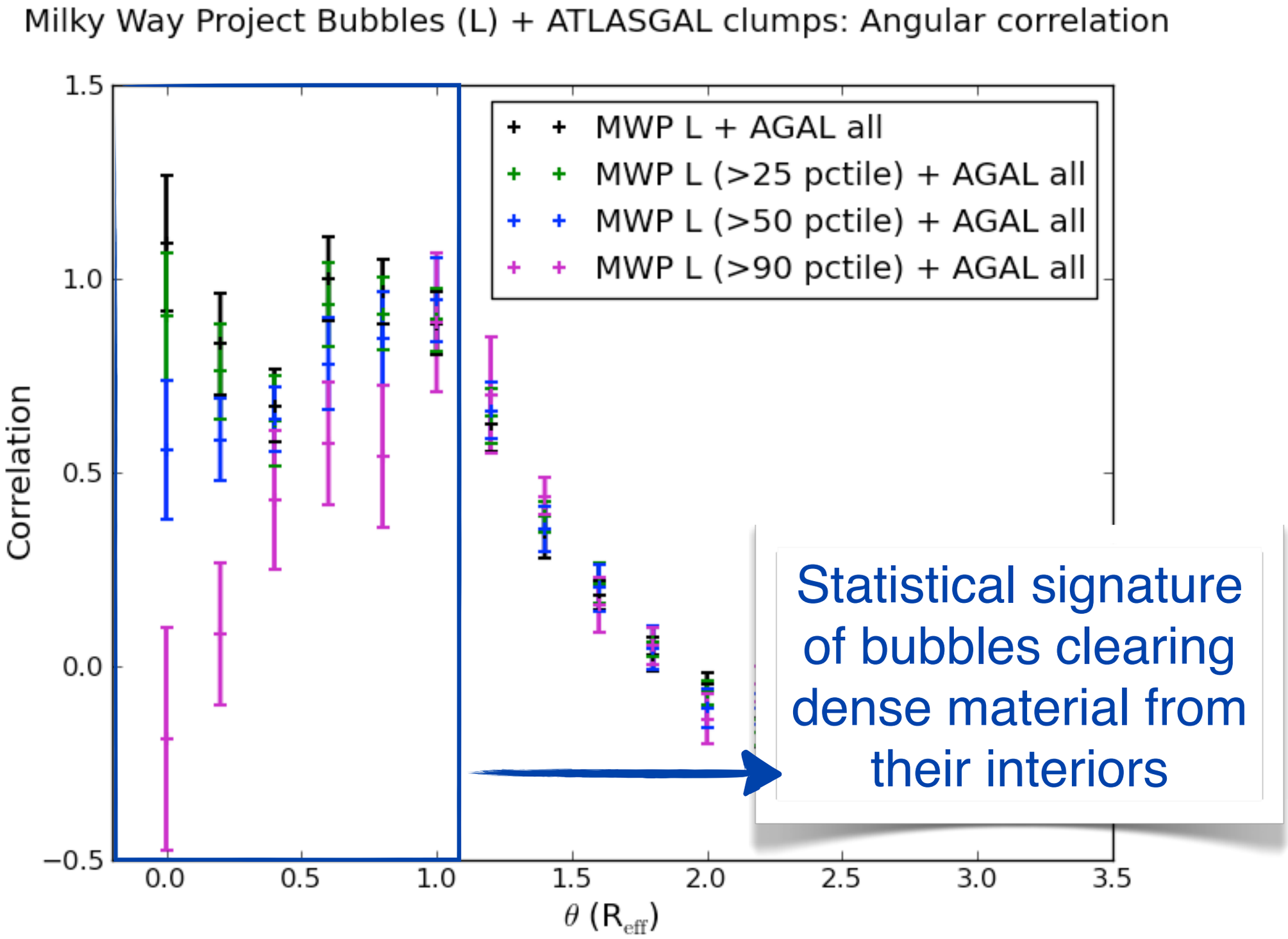


Cold clumps near bubbles tend to be bigger (on sky), with higher peak column densities

Expected as HII regions likely to form in (and expand into) dense massive clouds

But column density is not enough!

Which bubbles are associated with cold clumps?



Statistical signature of bubbles clearing dense material from their interiors

Which clumps are forming stars? How efficiently?

... Are fascinating unanswered questions

- Tackenberg+ 2012: identified star-forming / starless ATLASGAL clumps in $10 < l < 20$ based on Spitzer imaging

- Find ~23% of clumps in this area to be “starless”

- Studying the star-forming properties of dense clumps associated with bubbles compared with field clumps could help understand the effect of feedback energy

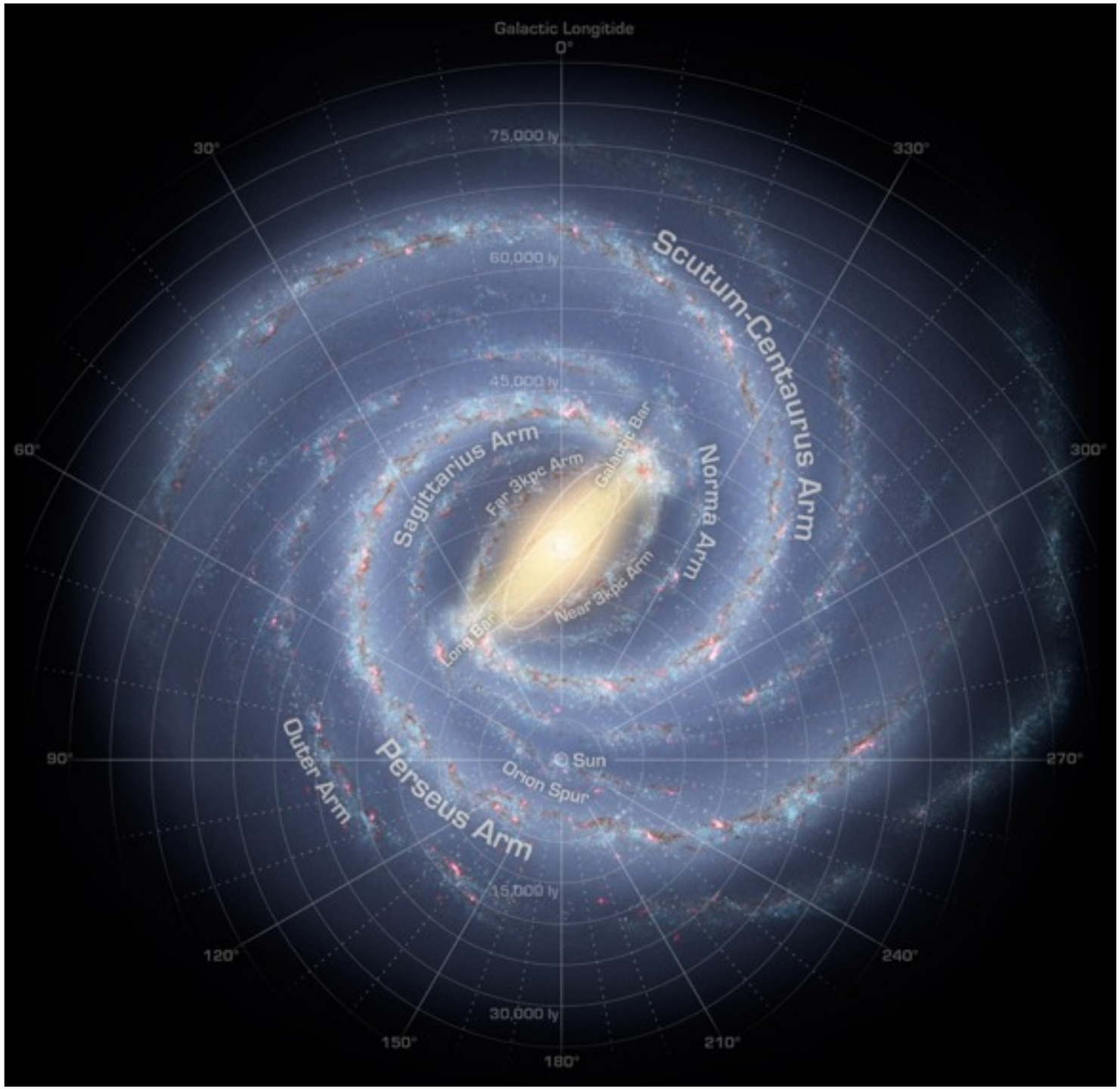
- Hi-GAL source catalogue would be excellent!

Tracing Galactic structure with bubbles

Having catalogues of bubbles with distances would allow:

statistical studies in 3D

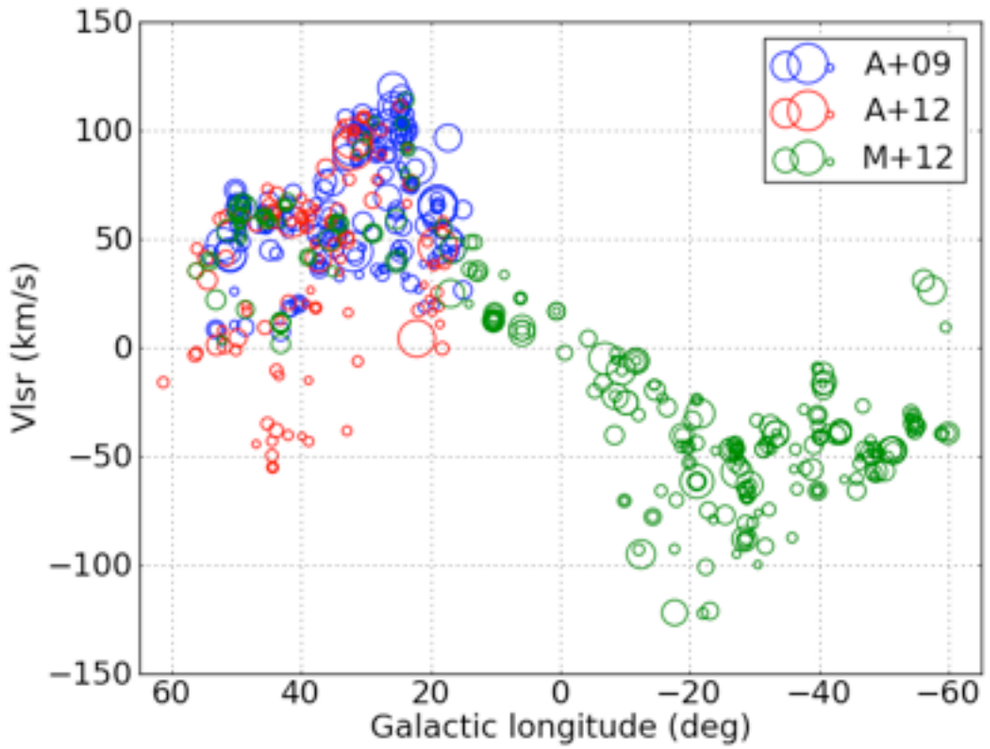
better test of environment

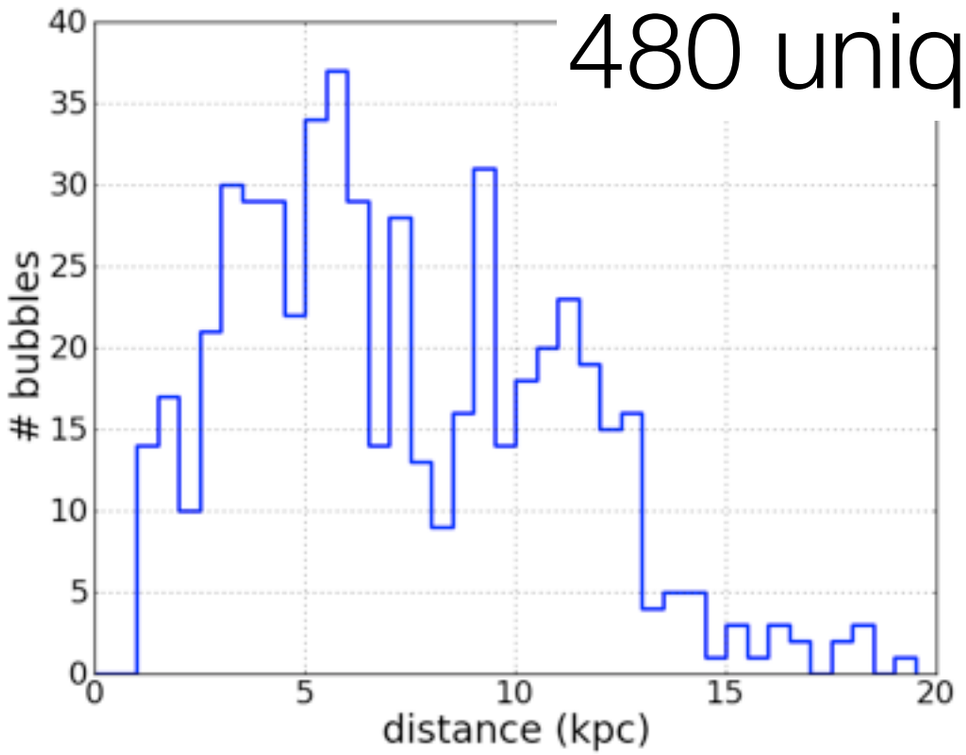


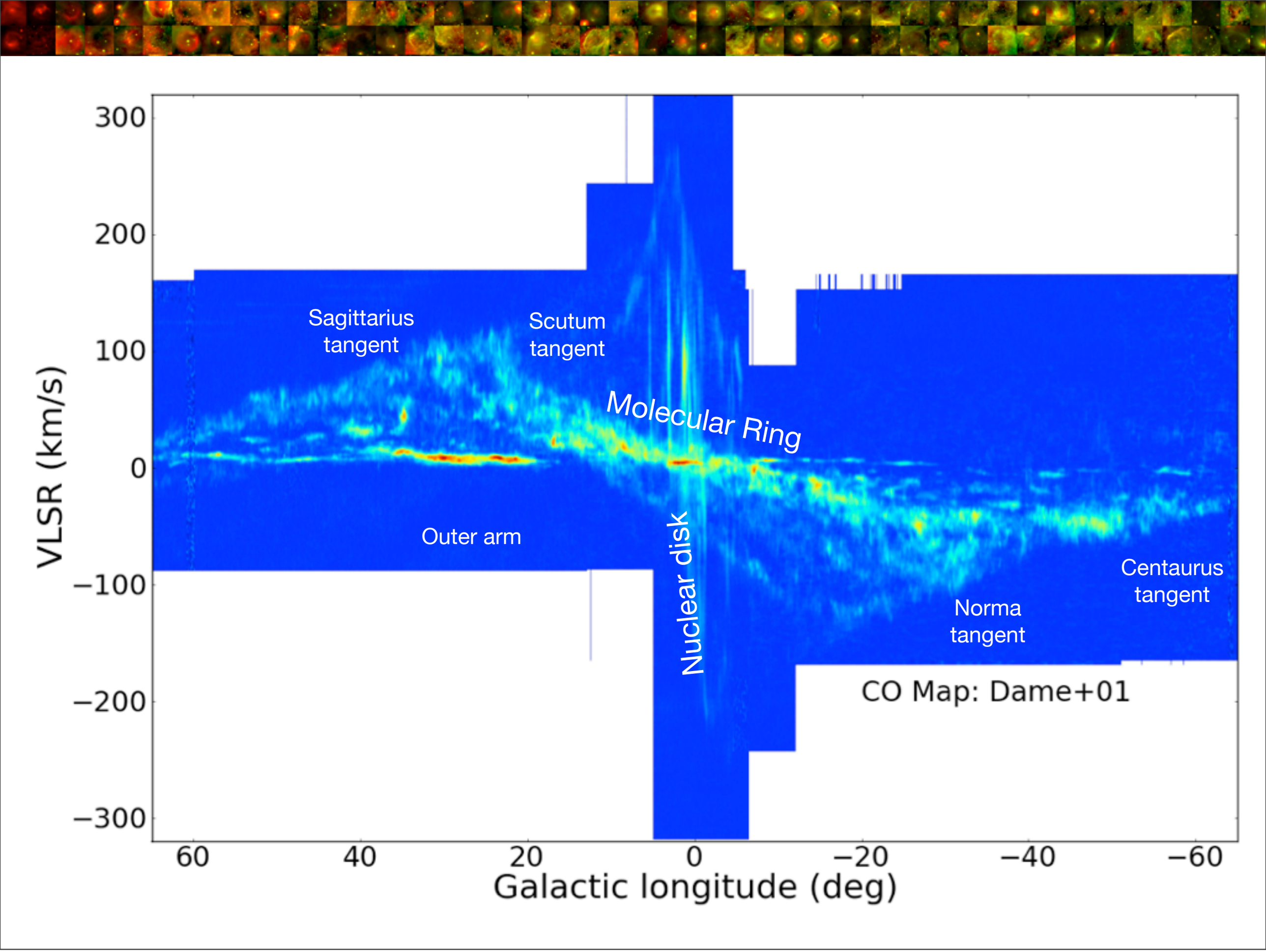
Distances & Velocities

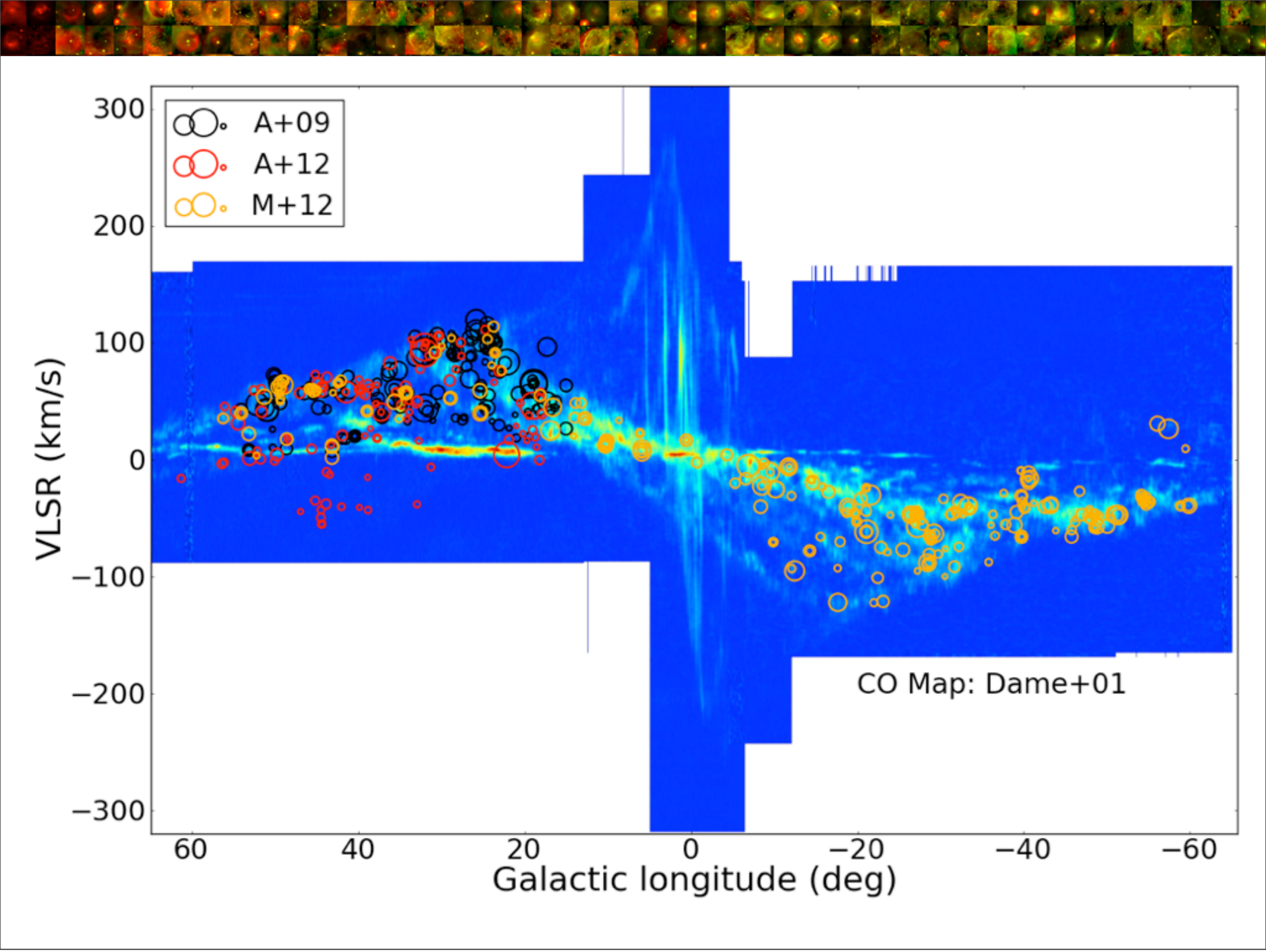
- Cross-match MWP bubbles with:
  - HII regions → Anderson & Bania (2009), Anderson+ (2012), RMS
  - Clusters → Morales+ (in prep.)
  - (Sub-) mm clumps → ATLASGAL, BGPS

566 matches
480 unique






300
200
100
0
−100
−200
−300
VLSR (km/s)
Sagittarius
tangent
Scutum
tangent
Molecular Ring
Outer arm
Nuclear disk
Norma
tangent
Centaurus
tangent
CO Map: Dame+01
60
40
20
0
−20
−40
−60
Galactic longitude (deg)


A+09
A+12
M+12
300
200
100
0
−100
−200
−300
VLSR (km/s)
60
40
20
0
−20
−40
−60
Galactic longitude (deg)
CO Map: Dame+01

Conclusions

- Bubbles are good tracers of massive young stars and clusters, all over the Galaxy

- Correlation study with RMS catalogue shows enhancement of massive star formation near the rims of the largest bubbles; possible signature of triggering

- Correlation study with ATLASGAL catalogue shows the effect of expanding bubble feedback on cold dense material

- Clumps near bubbles are larger and have higher peak column densities than those in the field

thanks