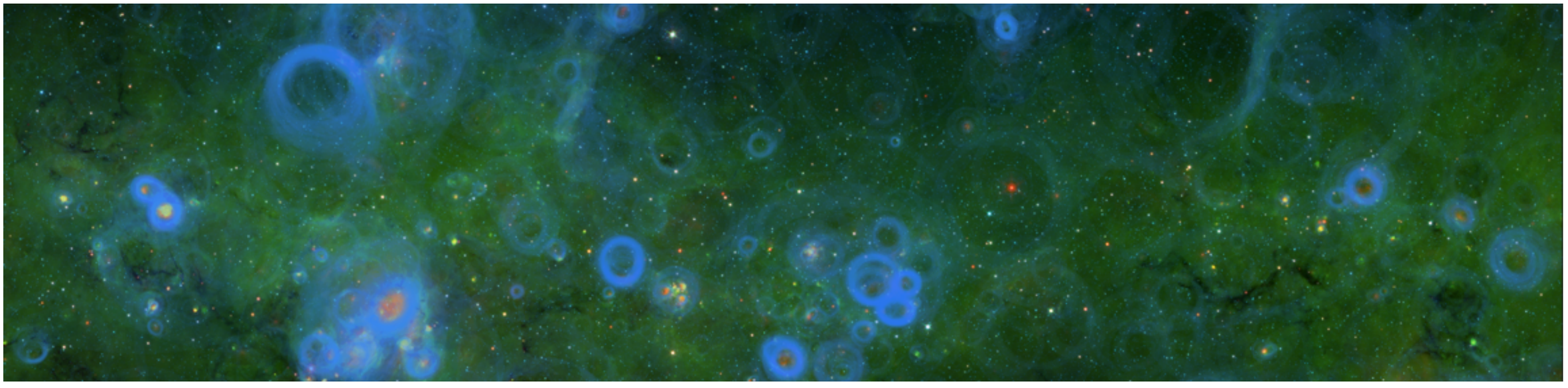
The Milky Way Project:

Tracing Star Formation in the Milky Way Galaxy with Infrared Bubbles

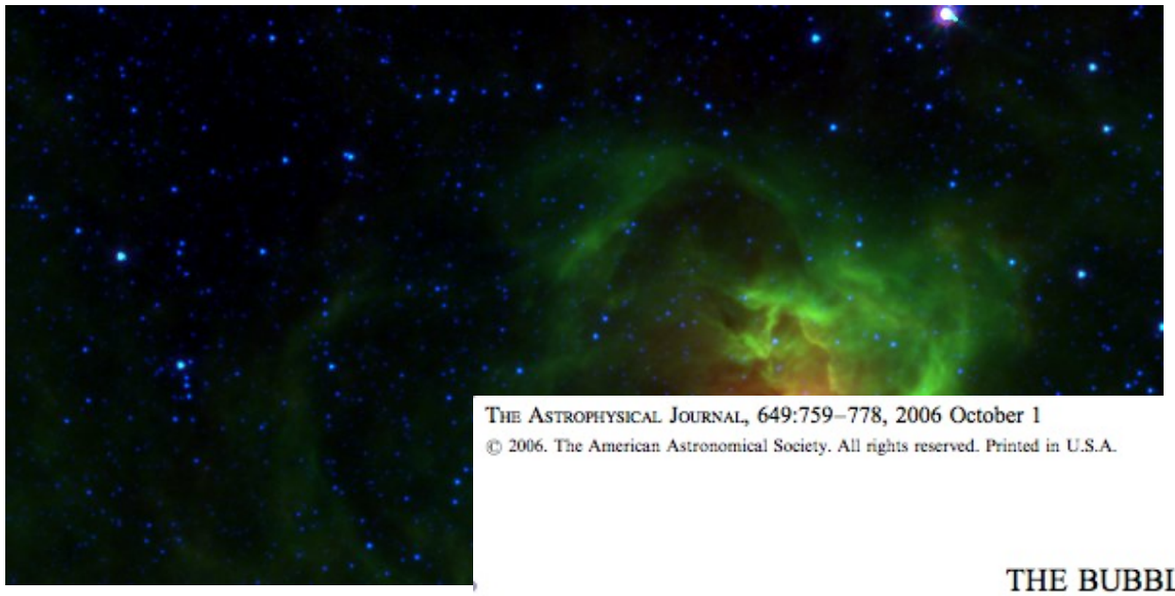
Sarah Kendrew (MPIA, Heidelberg)
+ The Zooniverse, Milky Way Project Science Team and 35,000+ Users

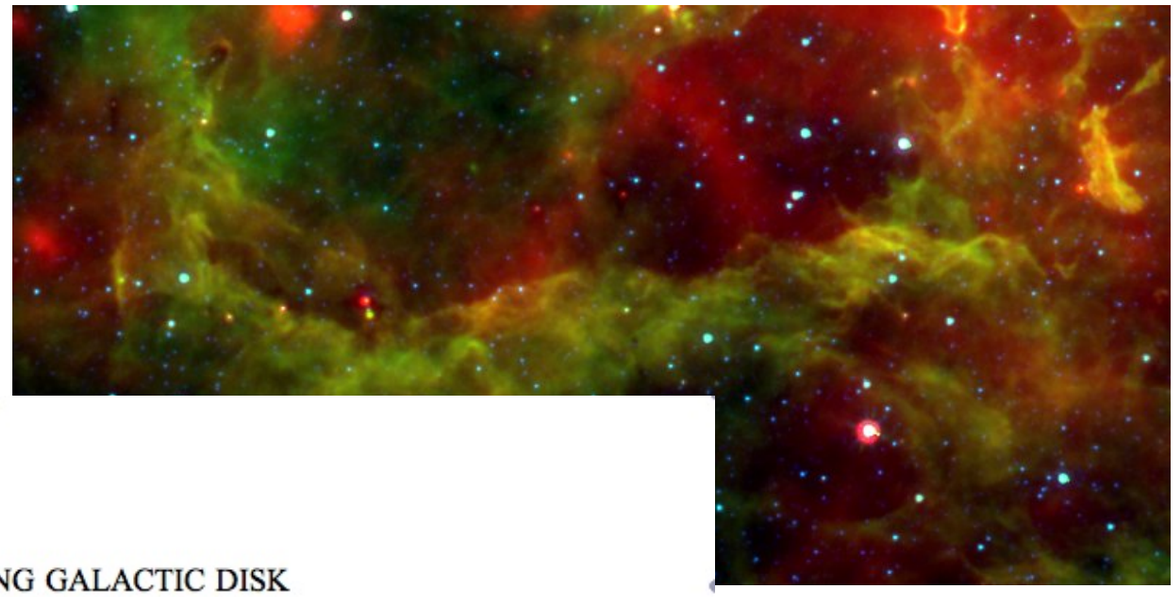


Galactic Scale Star Formation conference, Heidelberg, July 2012

Infrared surveys reveal beautiful & complex Interstellar Medium

MIPS 24 μm IRAC 8 μm IRAC 4.5 μm





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THE BUBBLING GALACTIC DISK

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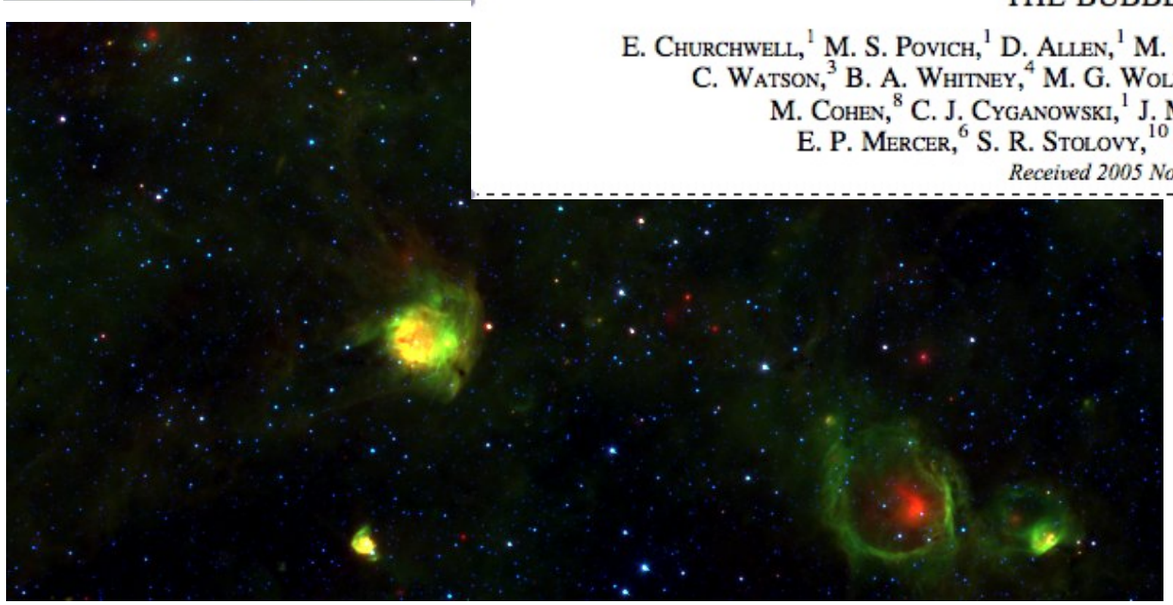
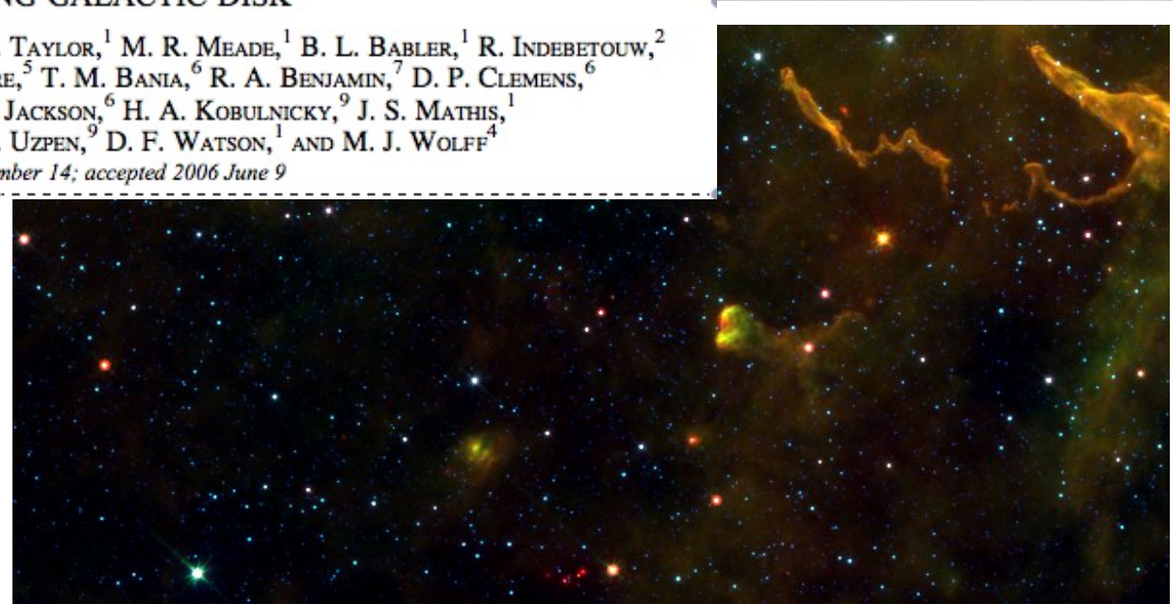


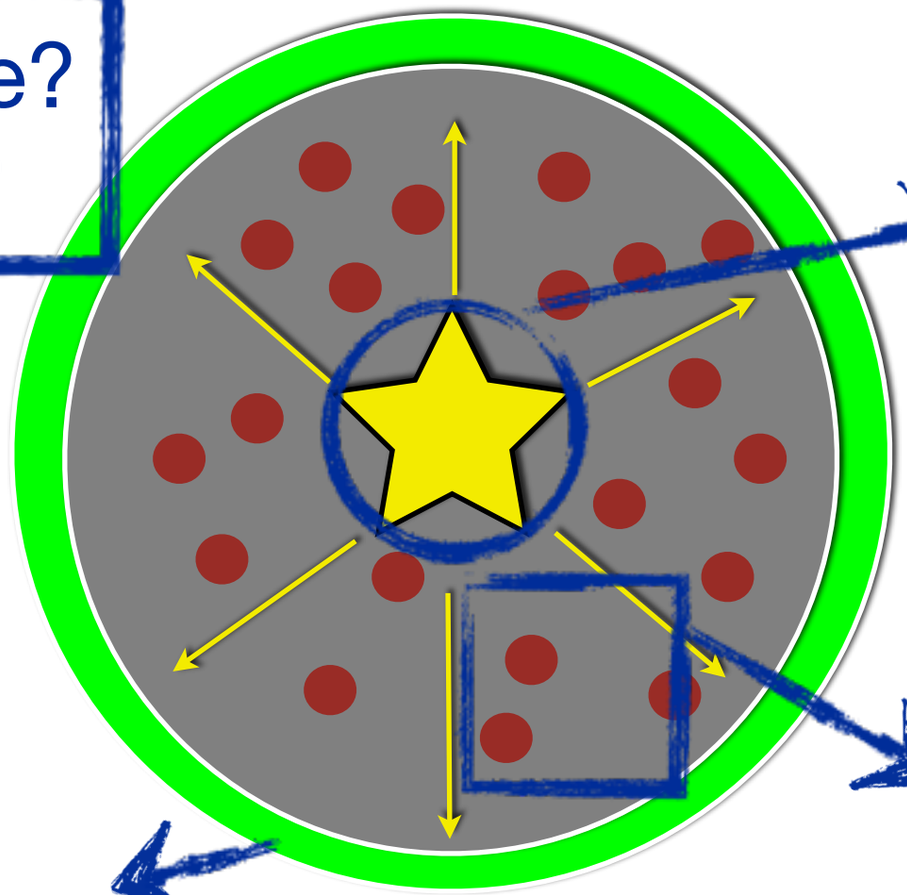


Glimpse I: Benjamin et at (2003); MIPSGAL: Carey et al (2009)

What can we learn from bubbles?

Sites of feedback from (massive) star(s) -> ISM
Bubble expansion: a complex process
Bubbles: Not a single type of object!

ISM Turbulence?
ISM Density?



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

Dust?

(and what happens here...?)

Drawing Bubbles (www.milkywayproject.org)

First Milky Way Project Public Data Release

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

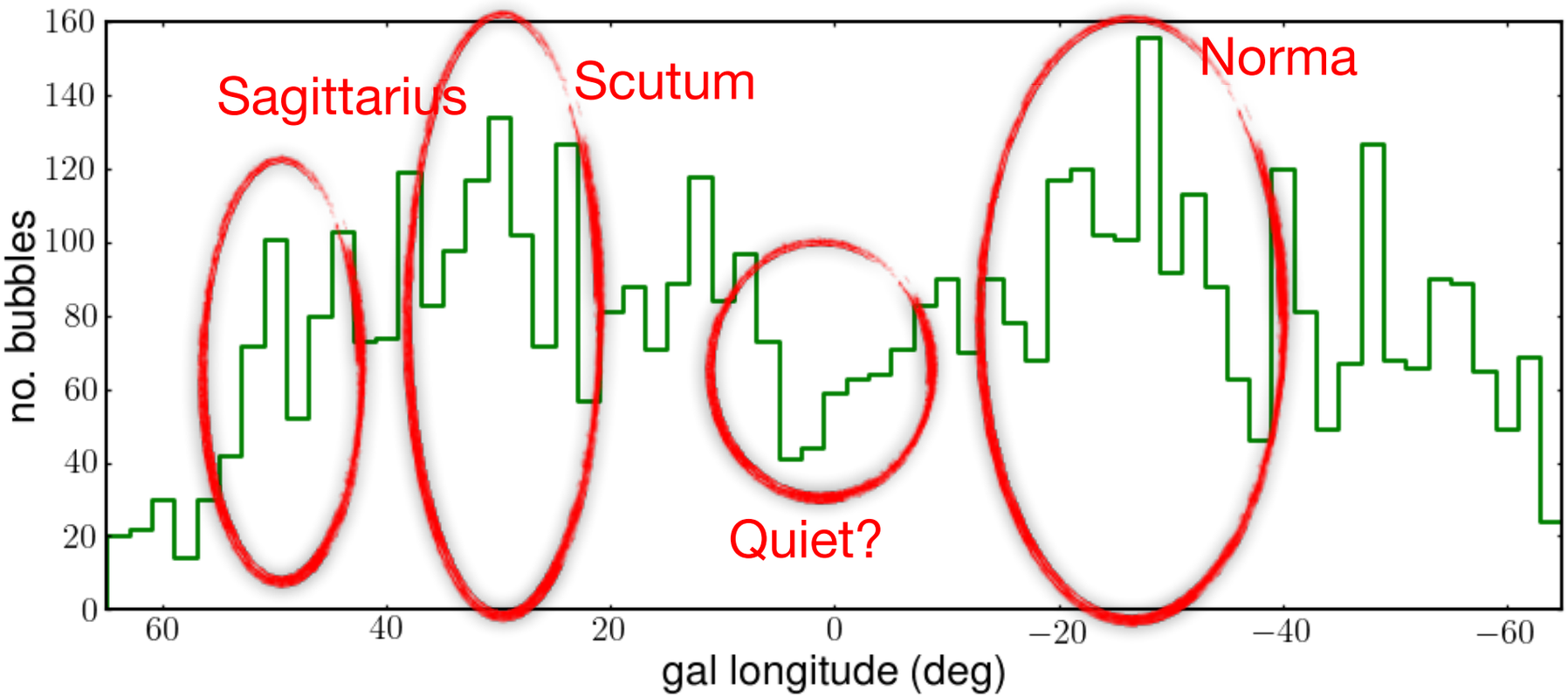
R. J. Simpson[1]†, M. S. Povich[2,3], S. Kendrew[4], C. J. Lintott[1,5], E. Bressert[6,7,8], K. Arvidsson[5], C. Cyganowski[8,3], S. Maddison[12] K. Schawinski[10,11,13], R. Sherman[9], A. M. Smith[1,5], G. Wolf-Chase[5,9]

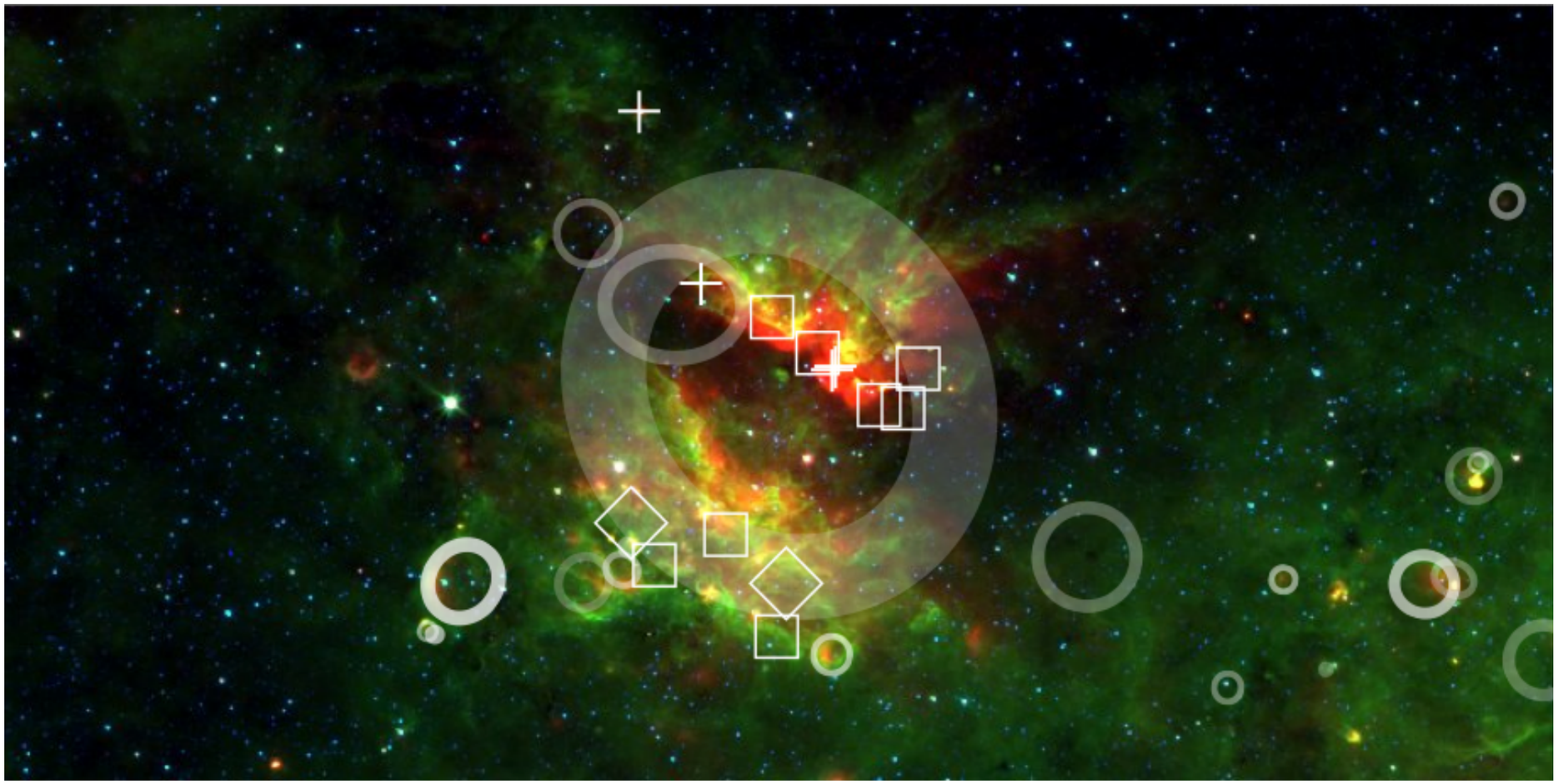
★ Simpson et al, 2012, MNRAS (Arxiv: 1201.6357): 5000 bubbles

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

★ Interactive bubble explorer

★ Bubble “heat maps”


Sagittarius
Scutum
Quiet?
Norma
no. bubbles
gal longitude (deg)
160
140
120
100
80
60
40
20
0
60
40
20
0
−20
−40
−60

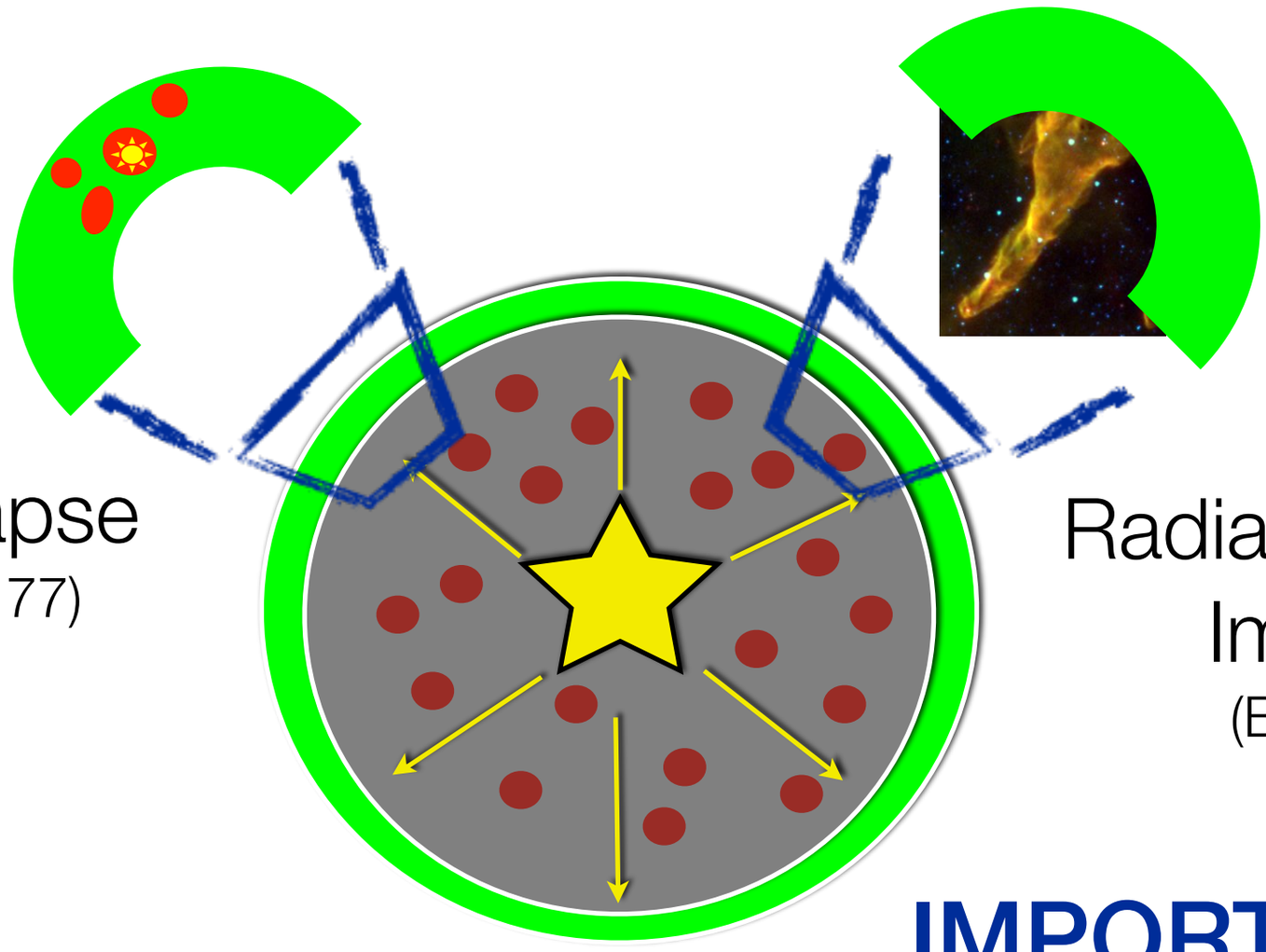


Massive star formation near bubbles (Arxiv: 1203.5486)

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) .....



Collect & Collapse
(Elmegreen & Lada 77)

Radiatively Driven Implosion
(Bisbas+ 11)

CAUSALITY?

IMPORTANCE ON GALACTIC SCALE?

MYSOs: Red MSX Source (RMS) Survey

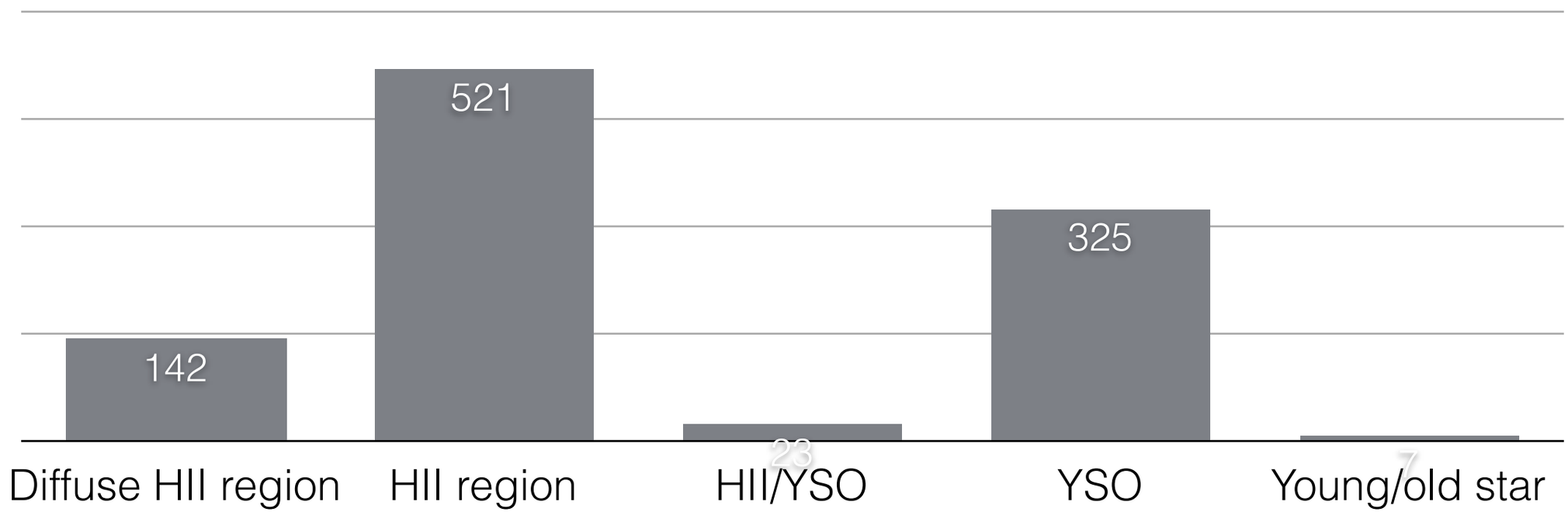
~2000 massive YSOs selected from colours of known objects (Lumsden+ 2002, Urquhart+ 2008); ~1000 ‘young’ sources in GLIMPSE I region.

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

Excluding |l| < 10°

Spatial resolution 18” (0.3’)

Follow-up: distances, source types

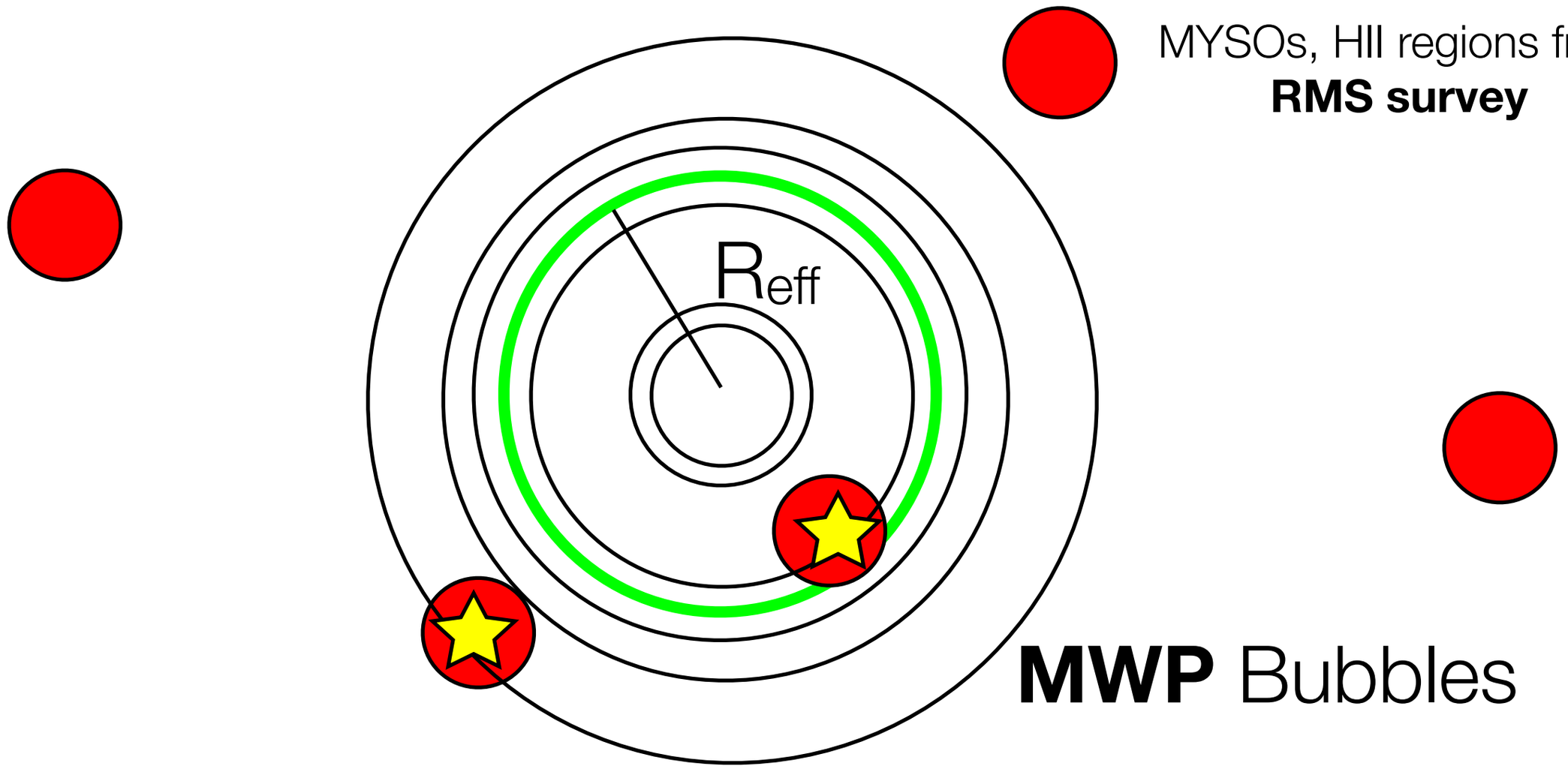


Two-point correlation function

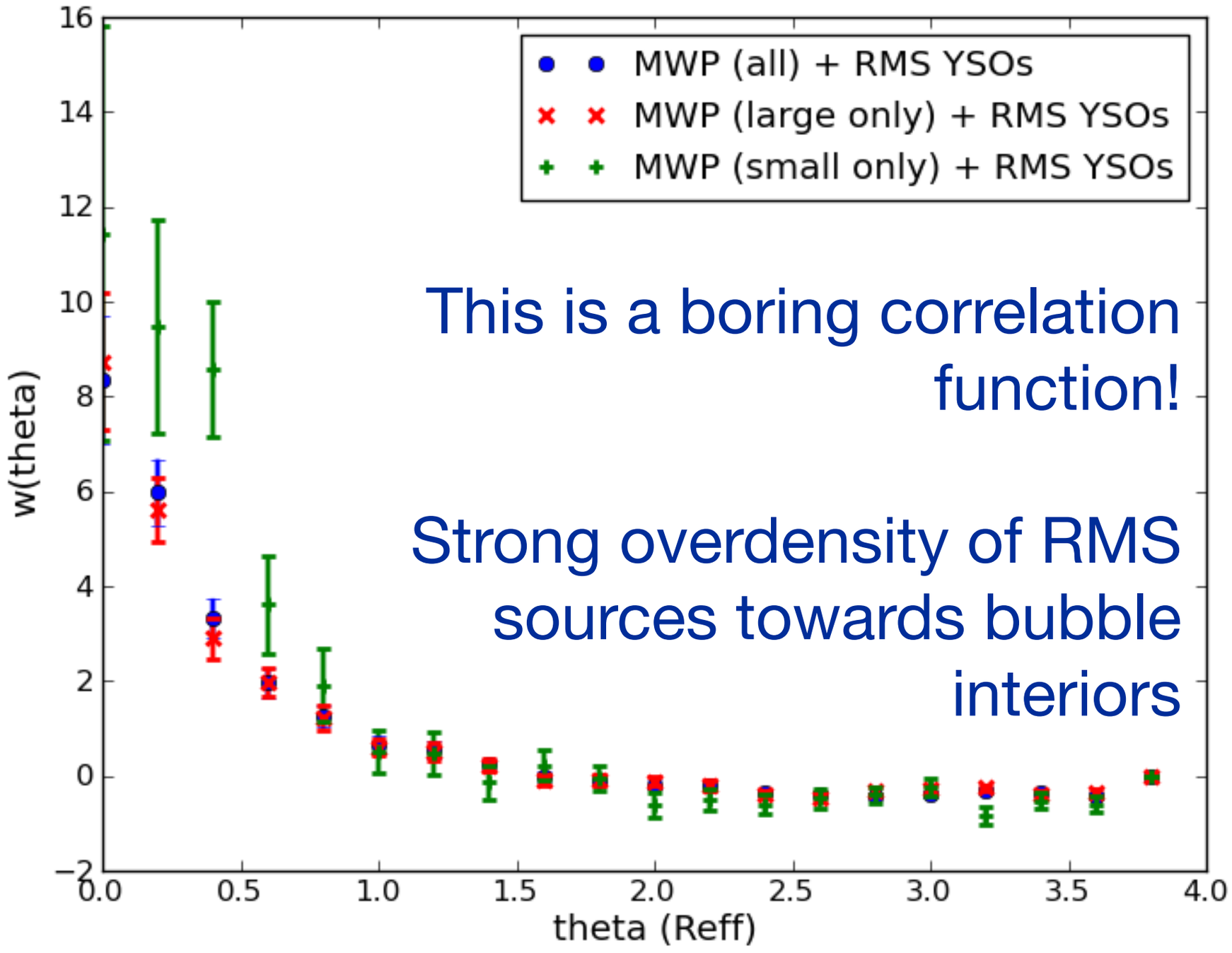
= excess probability of finding sources at separation theta over what is expected from random distribution

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

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



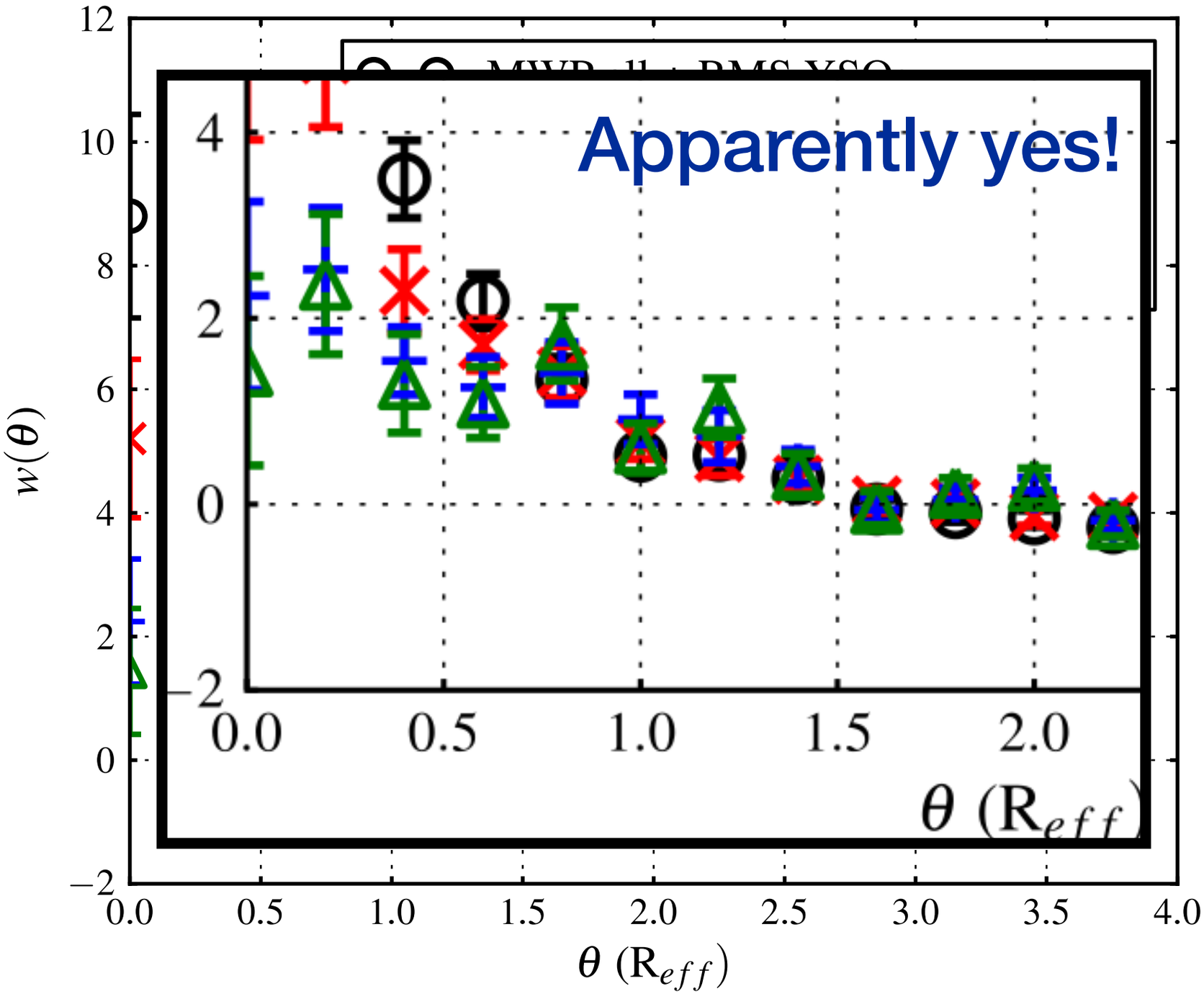
MWP + RMS correlation function



This is a boring correlation function!

Strong overdensity of RMS sources towards bubble interiors

Does size matter?



Conclusions

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

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

Correlation between RMS sources and bubble rims increases with bubble angular size (collect & collapse?)

For believers only!

What do we need?

Distances

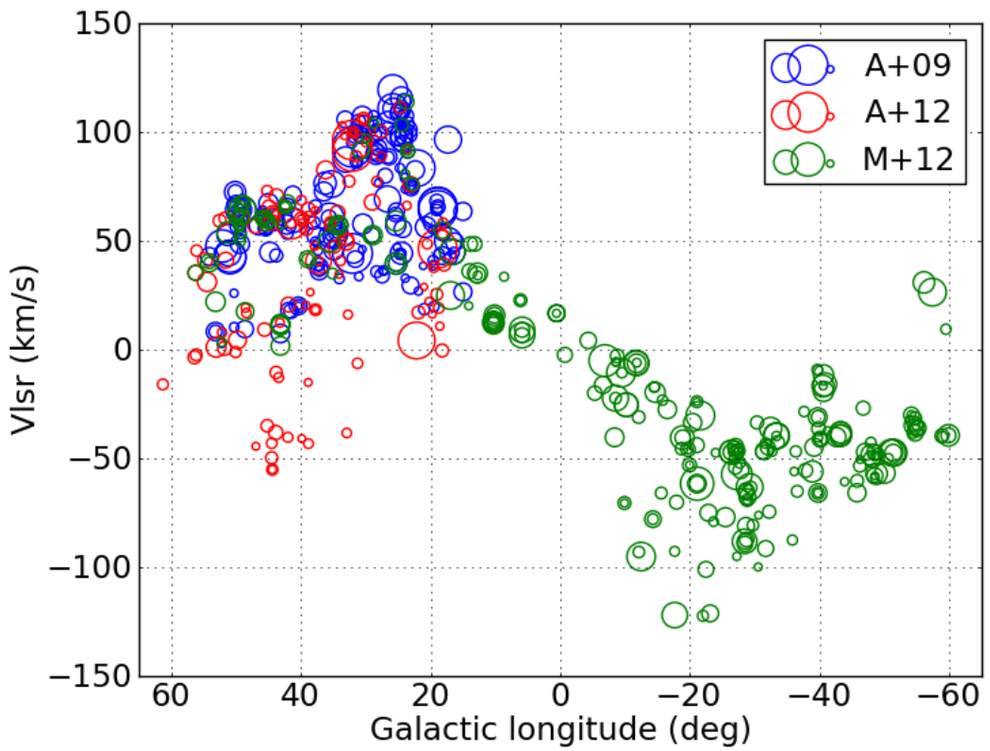
Evolutionary stages

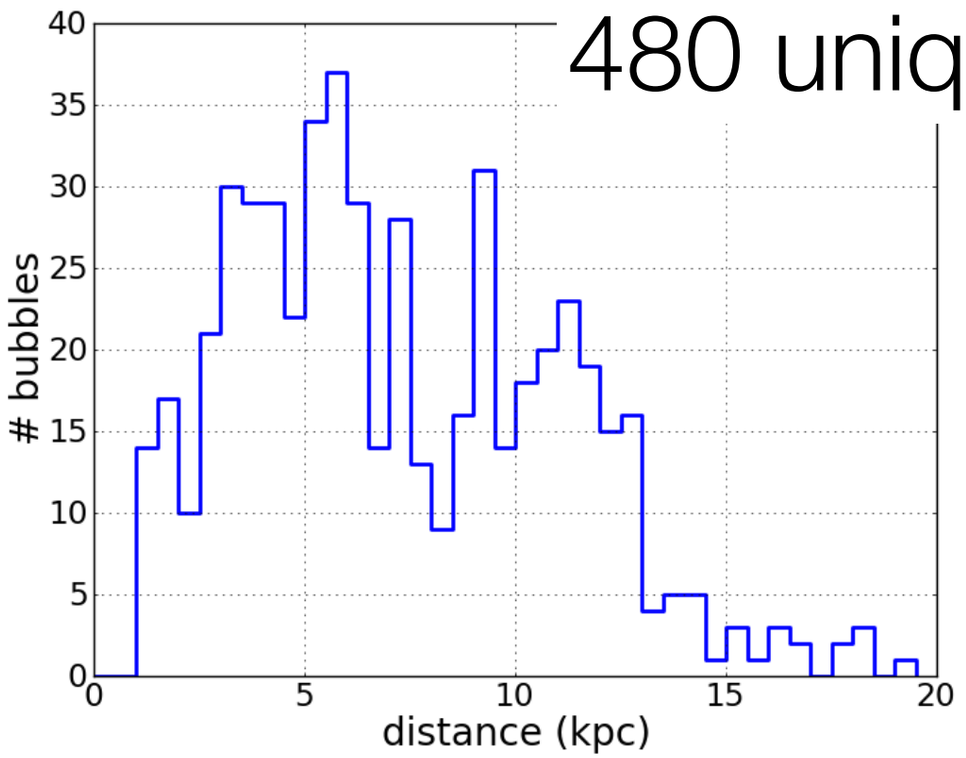
Line of sight effects (in 3D!)

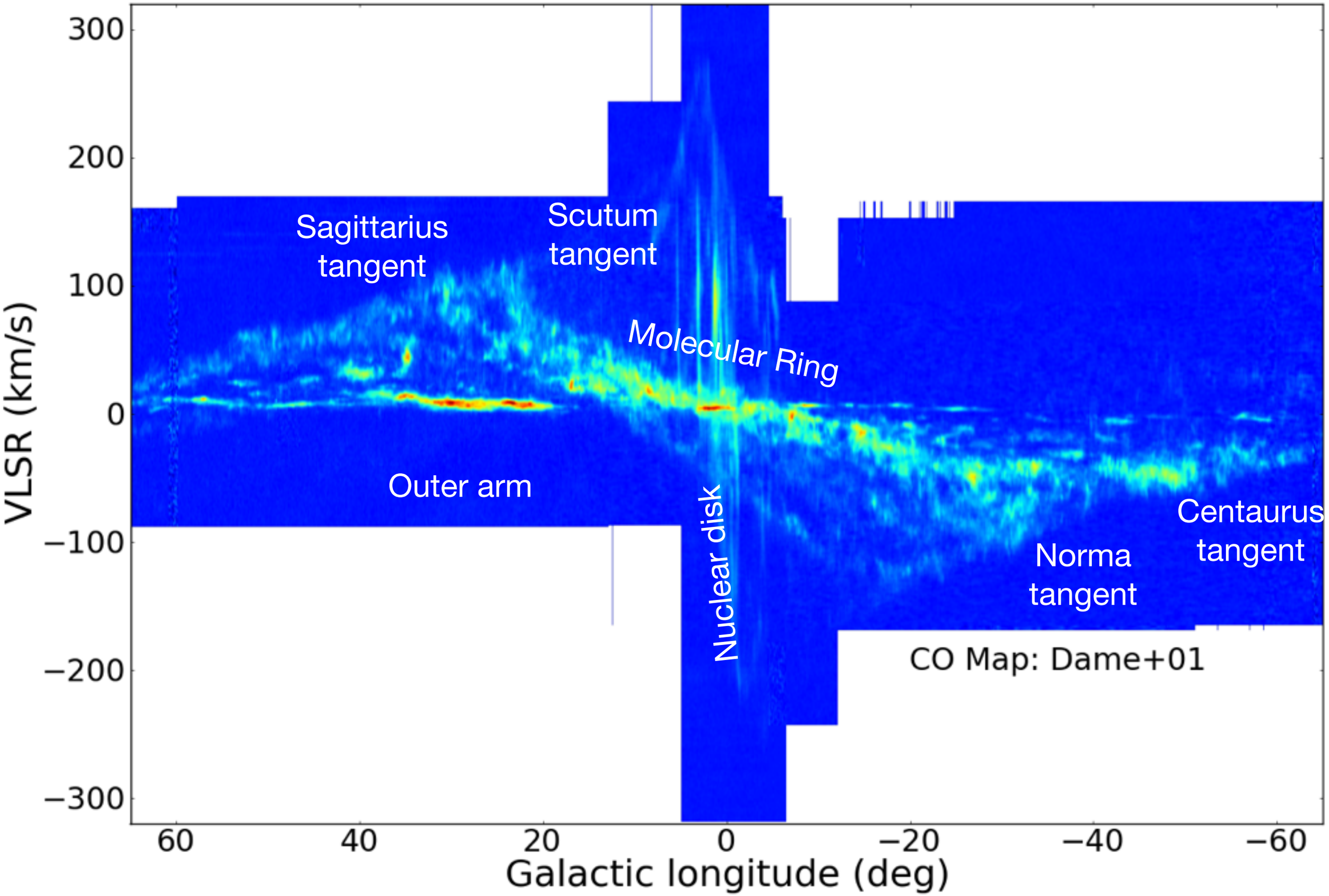
Distances & Velocities

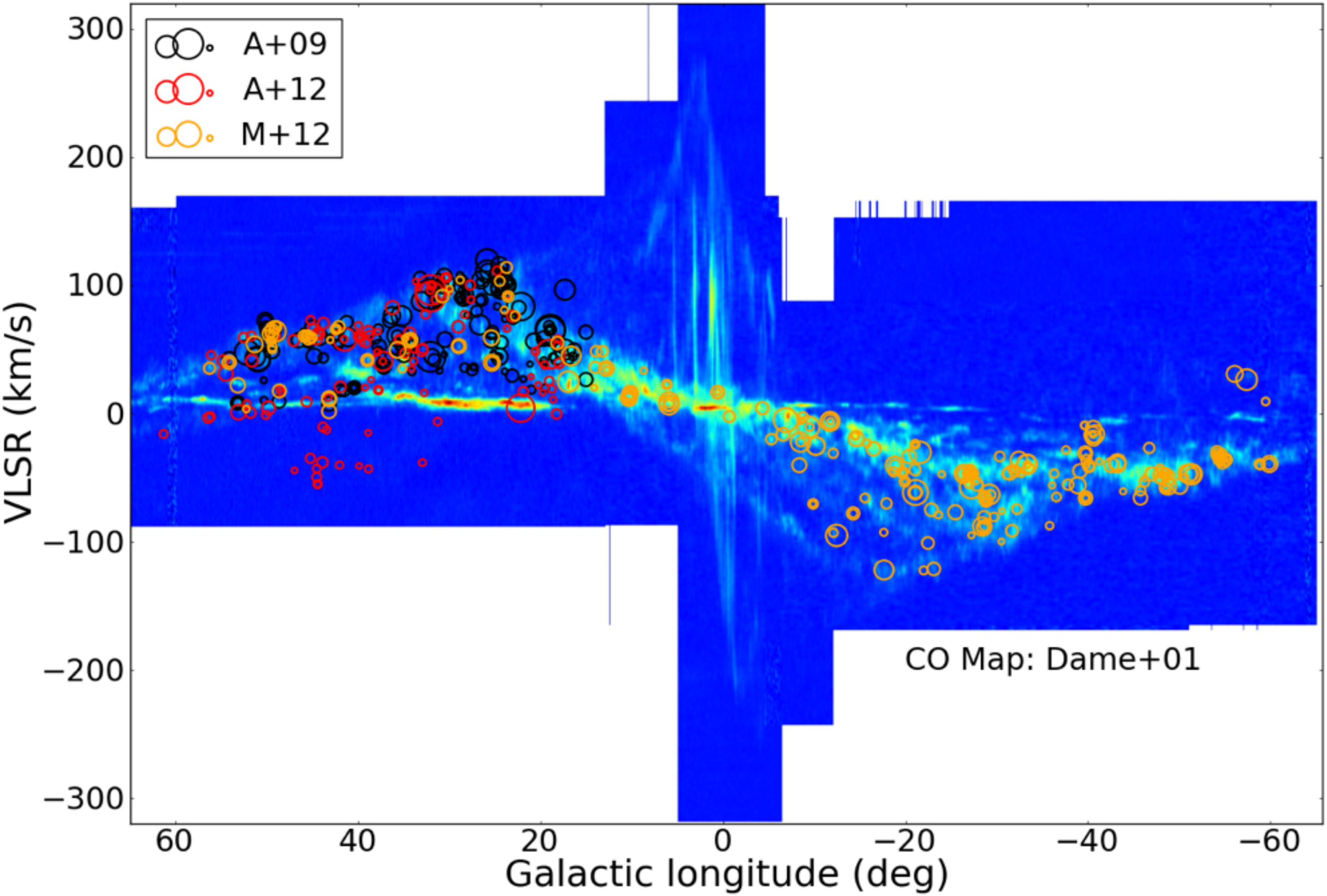
- Cross-match MWP bubbles with:
  - HII regions → Anderson & Bania (2009), Anderson+ (2012), RMS
  - Clusters → Morales+ (in prep.)
  - (Sub-) mm clumps → ATLASGAL, BGPS
  - .....

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

With distances & velocities we can....

Place the bubbles in 3D space in the Galaxy - study 3D distribution

Compare bubble distribution with molecular gas

Correlate star formation activity with bubble physical sizes

Disentangle line of sight effects in correlation analyses

... Statistically!

What do we need?

Distances

Evolutionary stages

Line of sight effects (in 3D!)

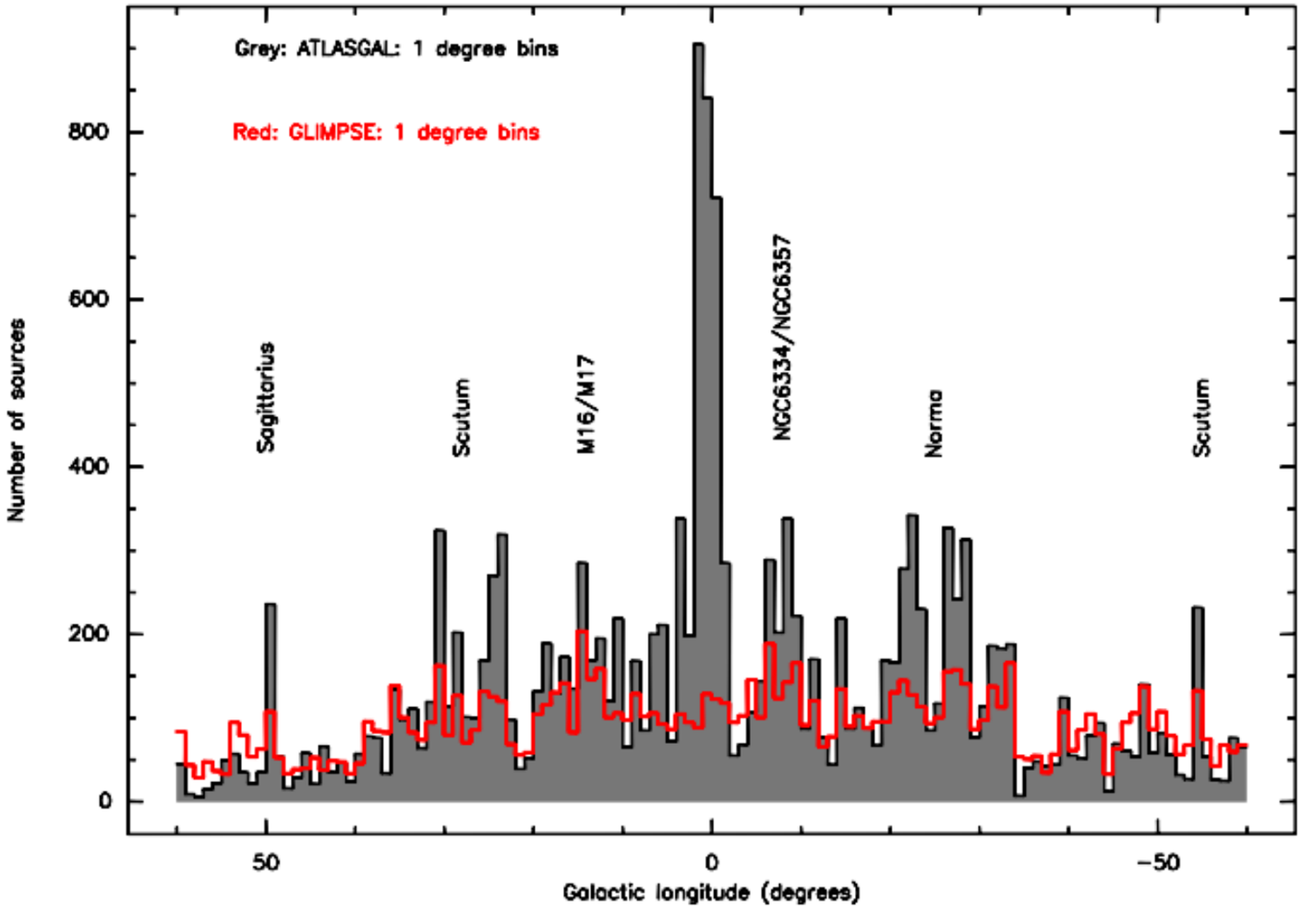
The evolutionary sequence in triggering

Bubbles - RMS sources: ~ Same evolutionary stage

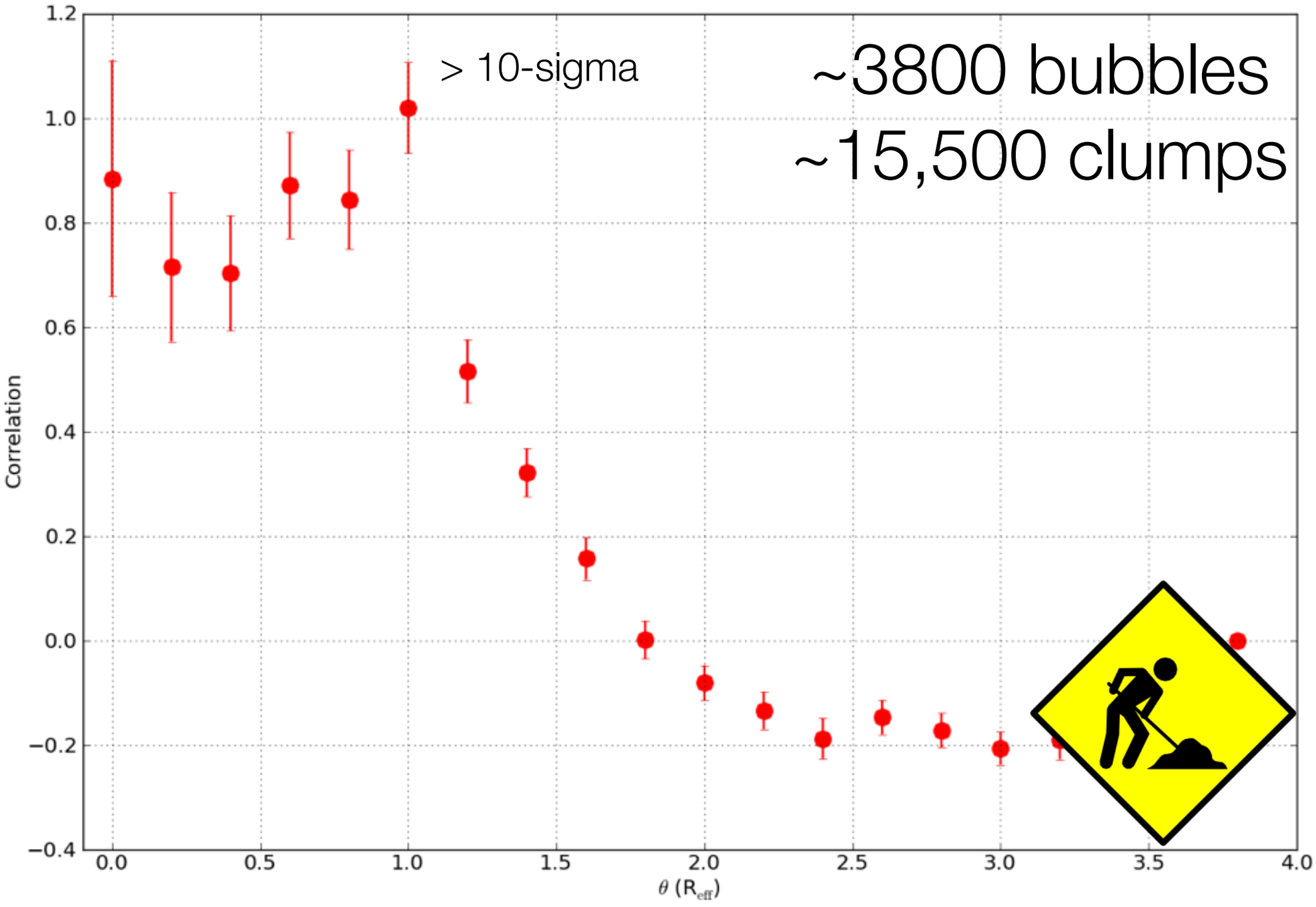
Can we correlate bubbles with star formation markers at an earlier stage?

ATLASGAL - the inner Galactic Plane at 870 μm

Galactic distribution & catalogue described in Beuther+ 2012



Correlating bubbles + ATLASGAL clumps



To be addressed....

ATLASGAL sources >> # bubbles or RMS sources

Chance alignments much higher than in previous analysis

Examine trends in correlation with bubble size & compare with RMS result

ATLASGAL clump auto-correlation

With ATLASGAL & bubble distances: Correlation in 3D space?

Conclusions

- Bubbles are good tracers of massive young stars to large distances in the Galactic plane

- Bubble correlations with other star formation tracers (HII regions, sub-mm clumps) allow statistical study of triggered star formation on Galactic scales***

    - Bubble + RMS survey catalogue yields ~20% of massive young stars possibly triggered*** (Kendrew+ 2012)

- Using ATLASGAL can break the evolutionary degeneracy of the RMS correlation study

- Bubble distances, velocities & physical sizes will greatly increase their power in such studies

- 3D Line of sight effects are complicated & still need addressing

*** *if you believe in triggering!*

thanks