

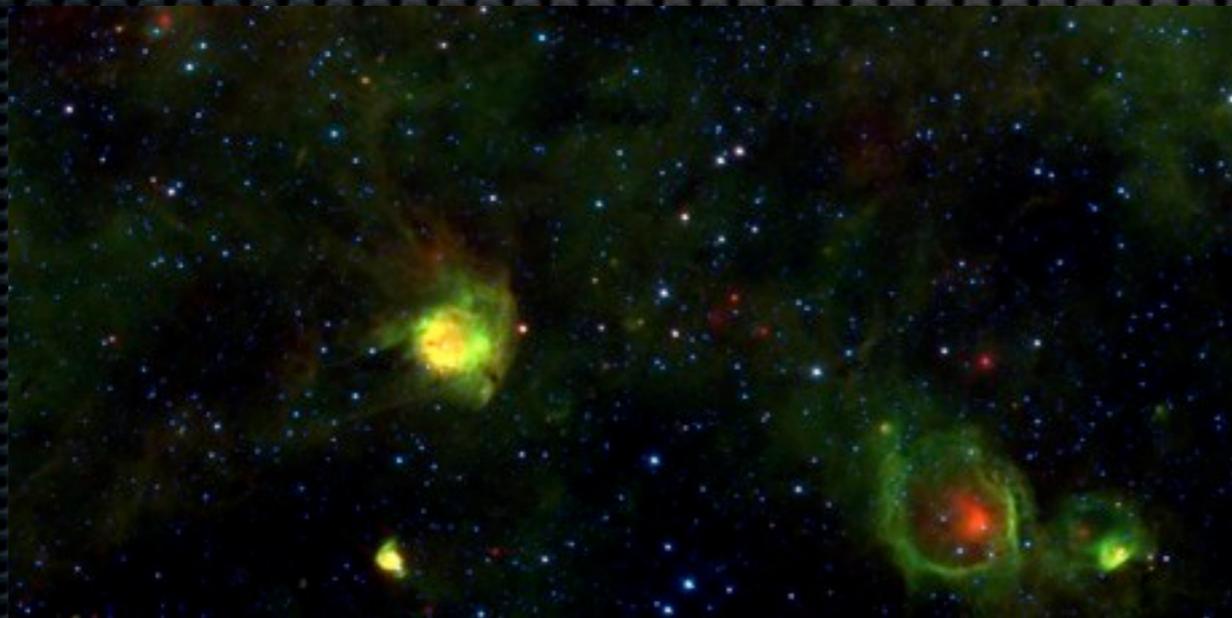
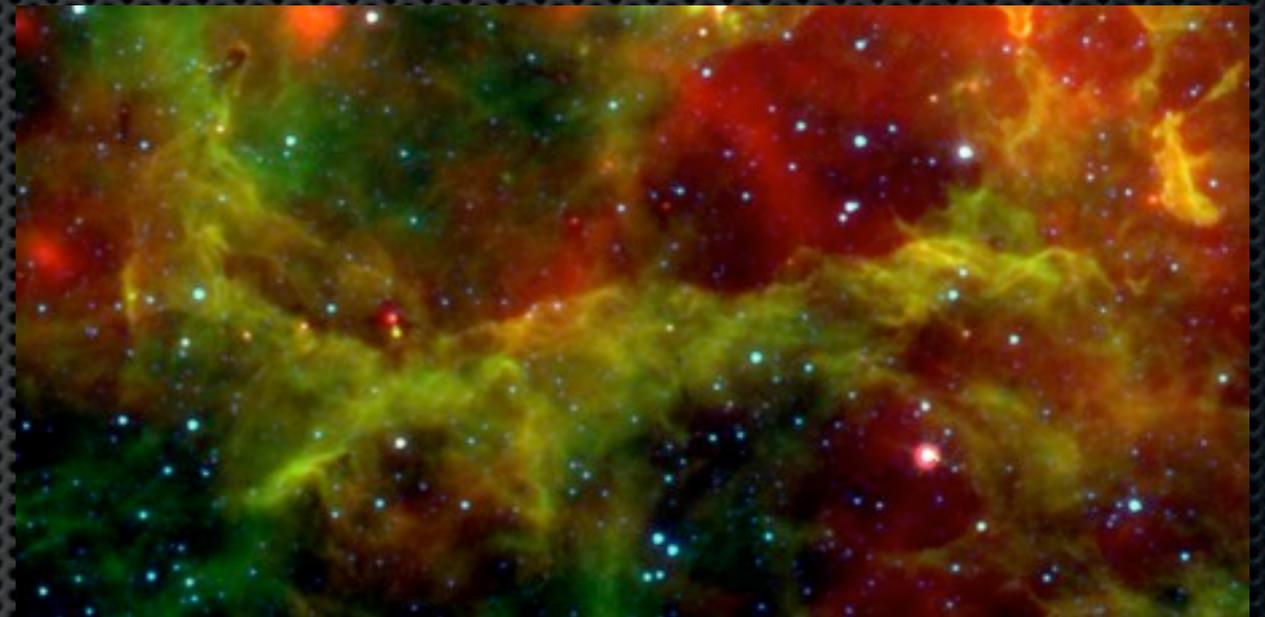
The Milky Way Project: Tracing massive star formation near infrared bubbles

Sarah Kendrew (MPIA, Heidelberg)

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

Infrared surveys reveal beautiful & complex Interstellar Medium

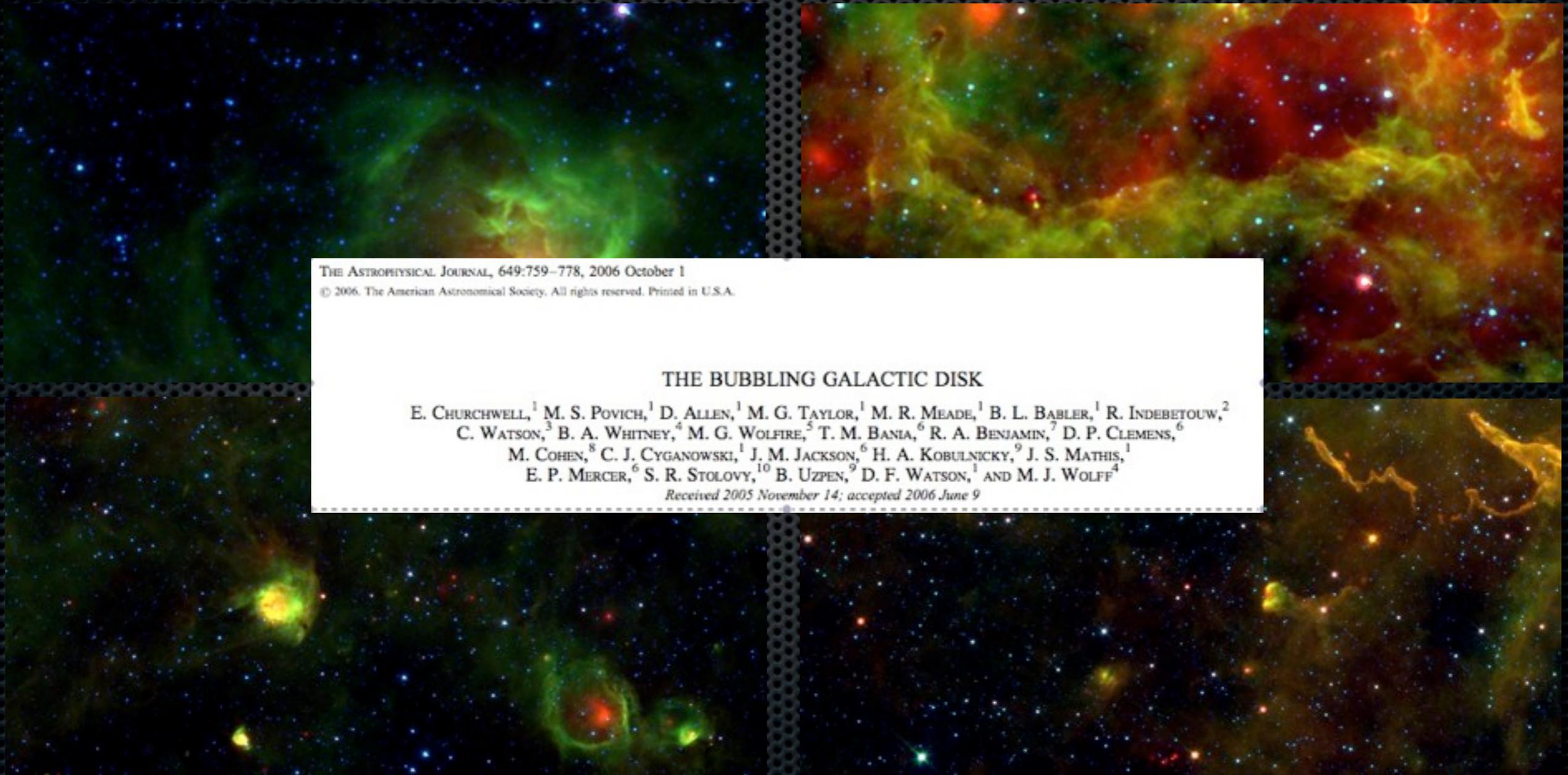
■ MIPS 24 μm ■ IRAC 8 μm ■ IRAC 4.5 μm



Glimpse I: Benjamin et al (2003); MIPS GAL: Carey et al (2009)

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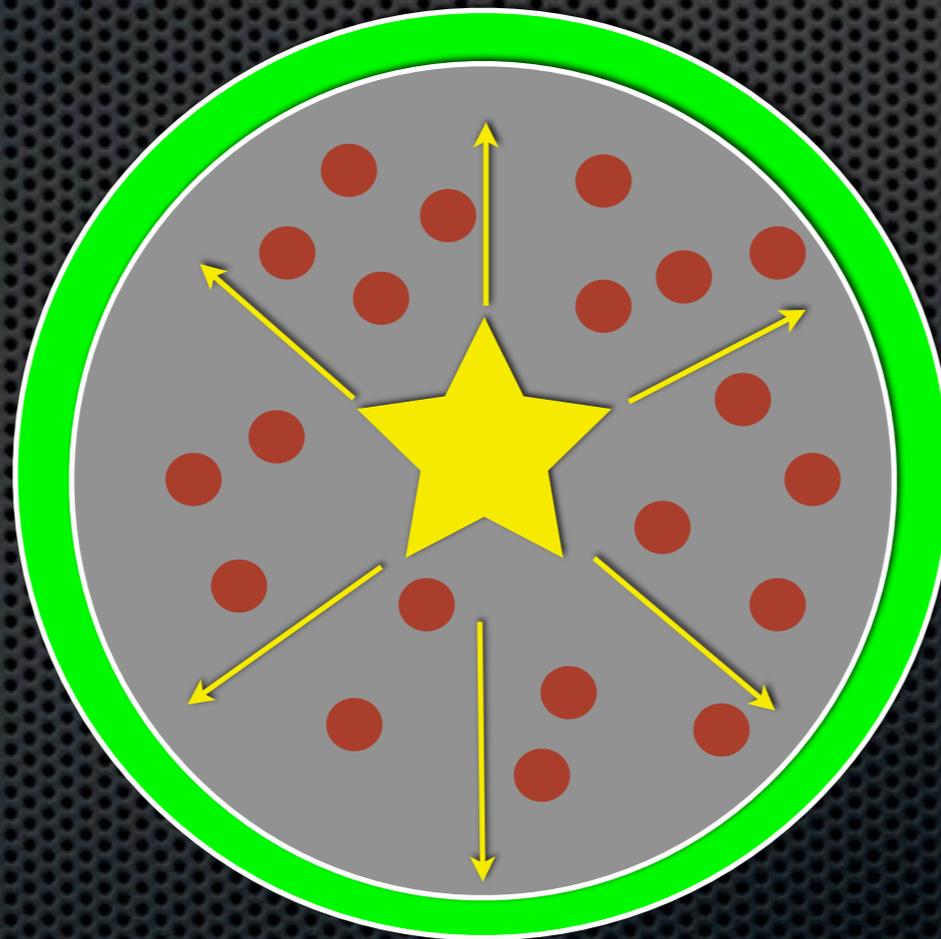
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What can we learn from bubbles?

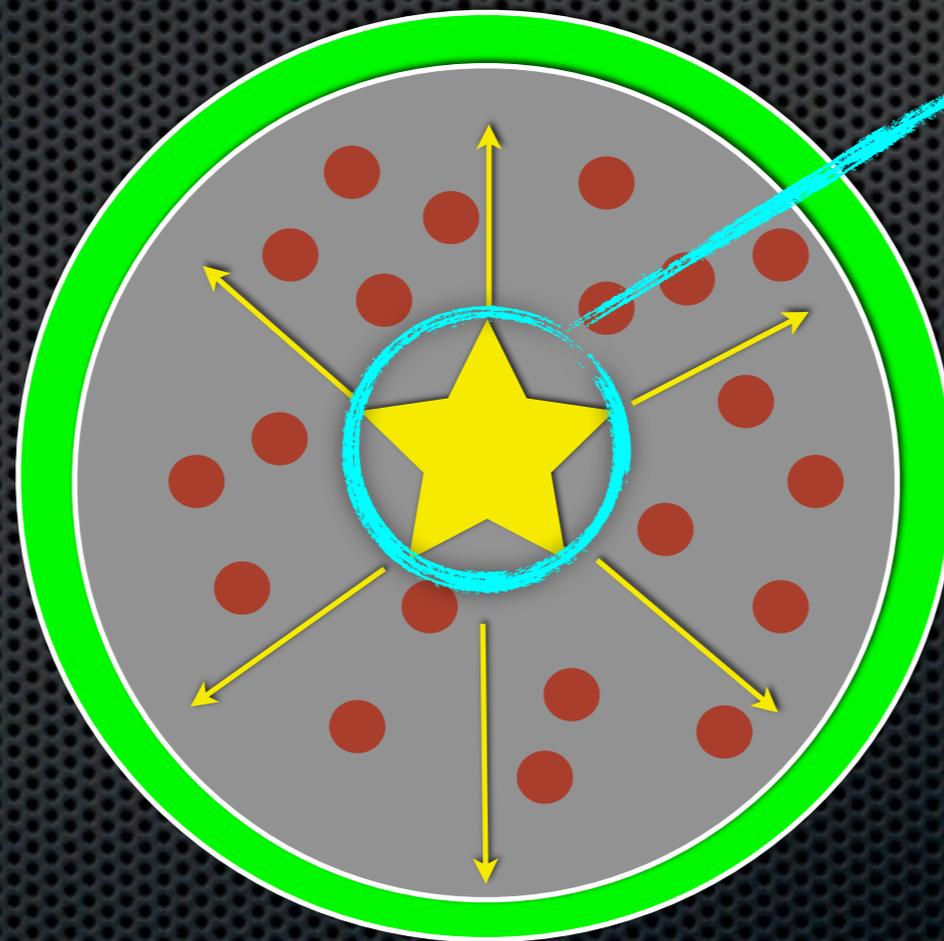
Sites of feedback from (massive) star(s) -> ISM
Bubble expansion: a complex process



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Bubble expansion: a complex process

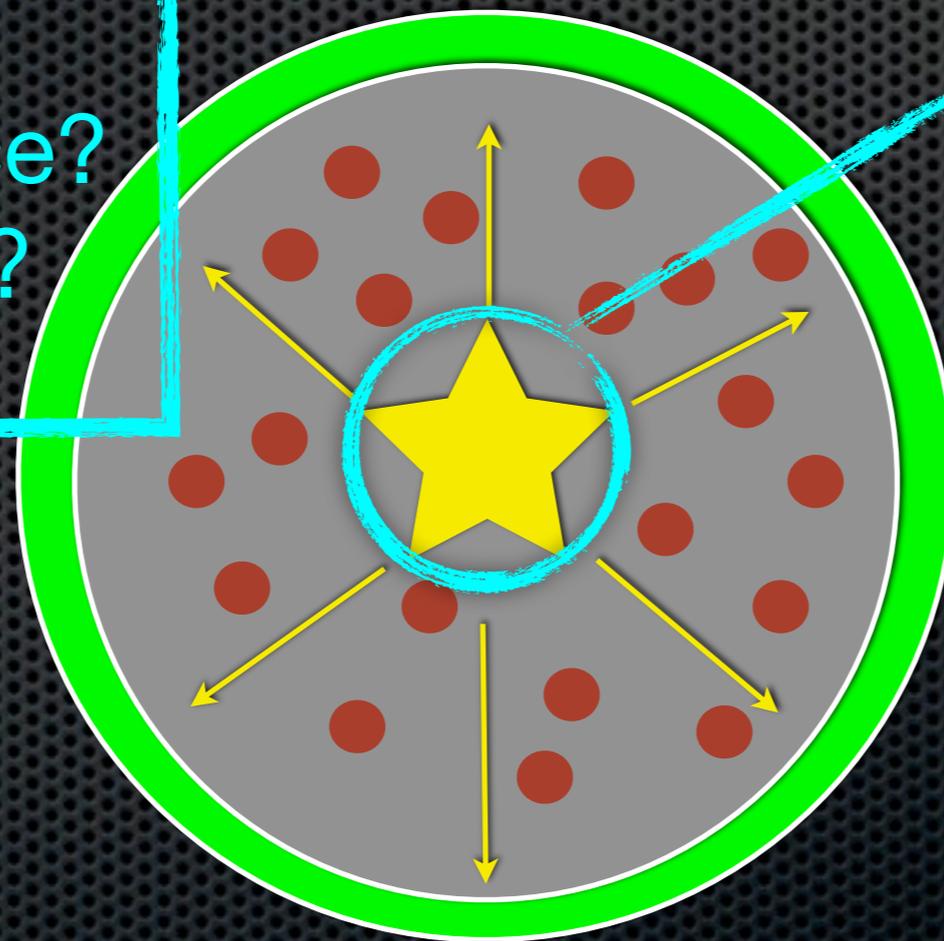


Driving source:
single, cluster,
spectral type, age,
winds?

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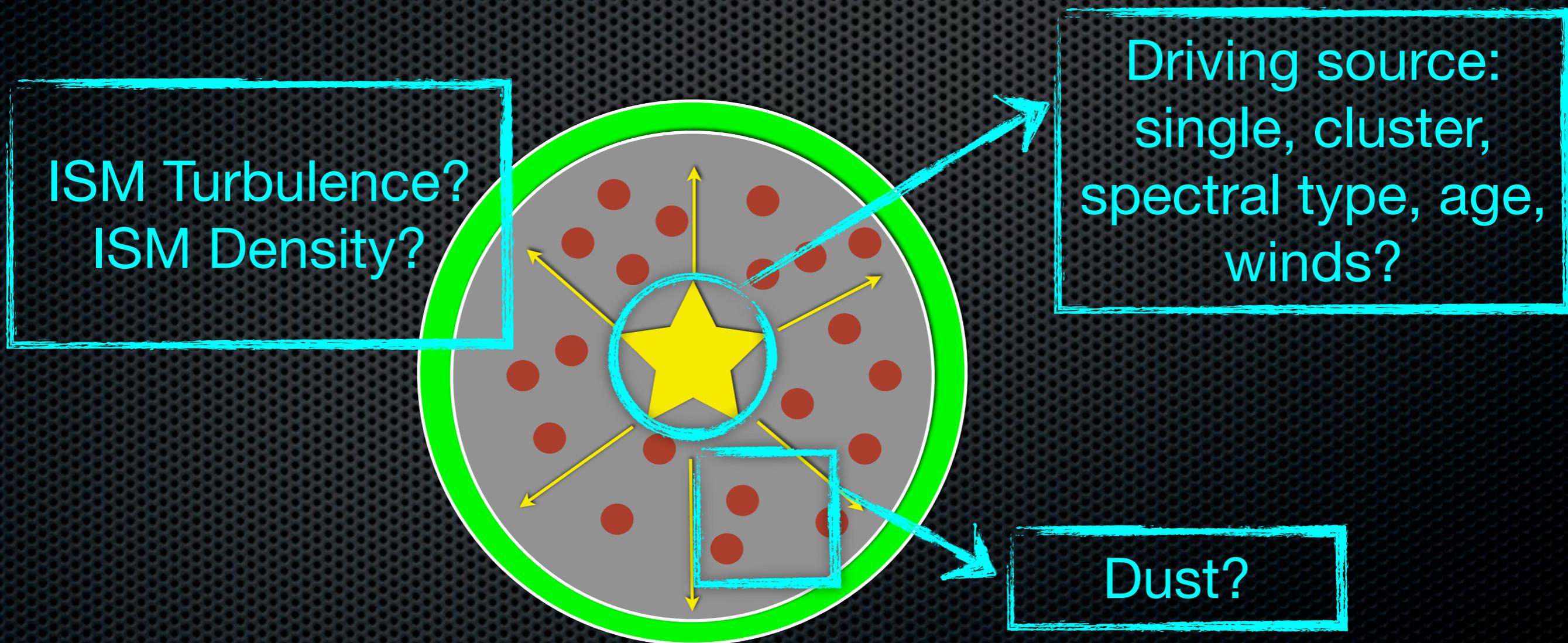
ISM Turbulence?
ISM Density?



Driving source:
single, cluster,
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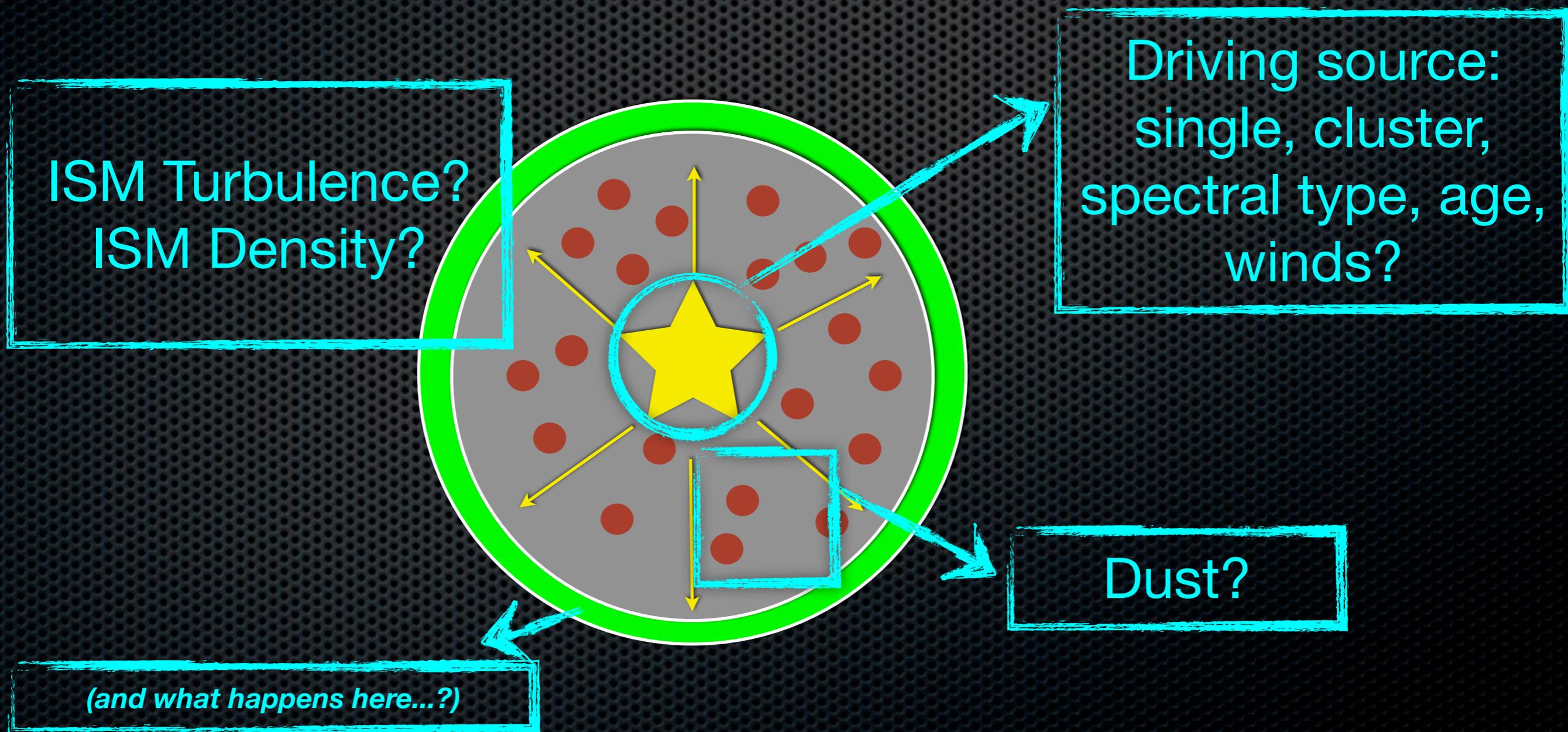
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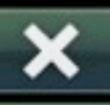
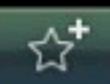


Drawing Bubbles

THE MILKY WAY PROJECT

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- 
- 
- 
- 
- 
- HIDE CURRENT
- HIDE ALL
- 
- SUBMIT



DR1: > 5000 bubbles; PI: Rob Simpson

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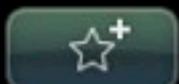
LOG OUT

GALACTOMETER™

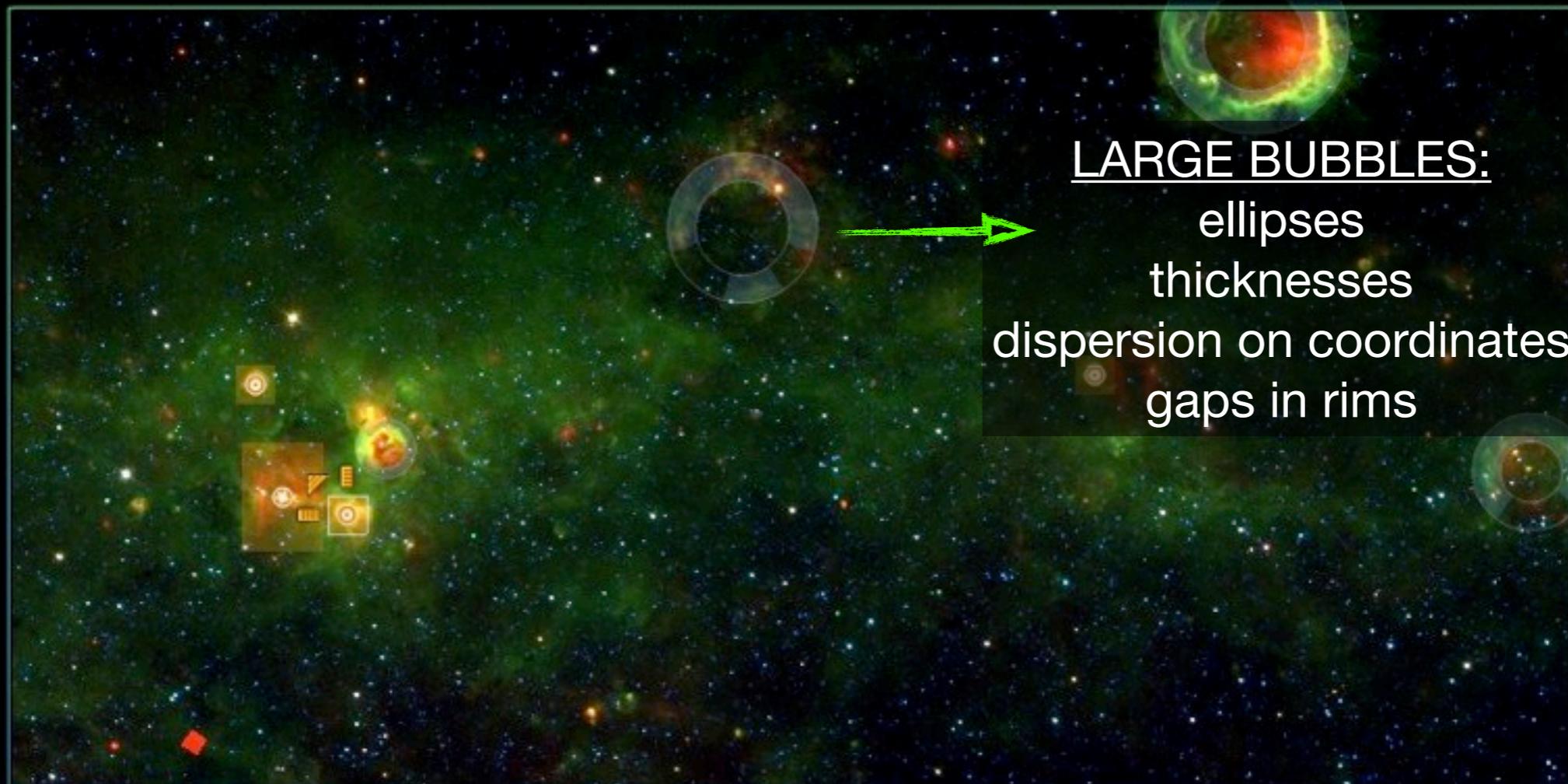


HIDE CURRENT

HIDE ALL



SUBMIT



LARGE BUBBLES:

ellipses

thicknesses

dispersion on coordinates

gaps in rims

DR1: > 5000 bubbles; PI: Rob Simpson

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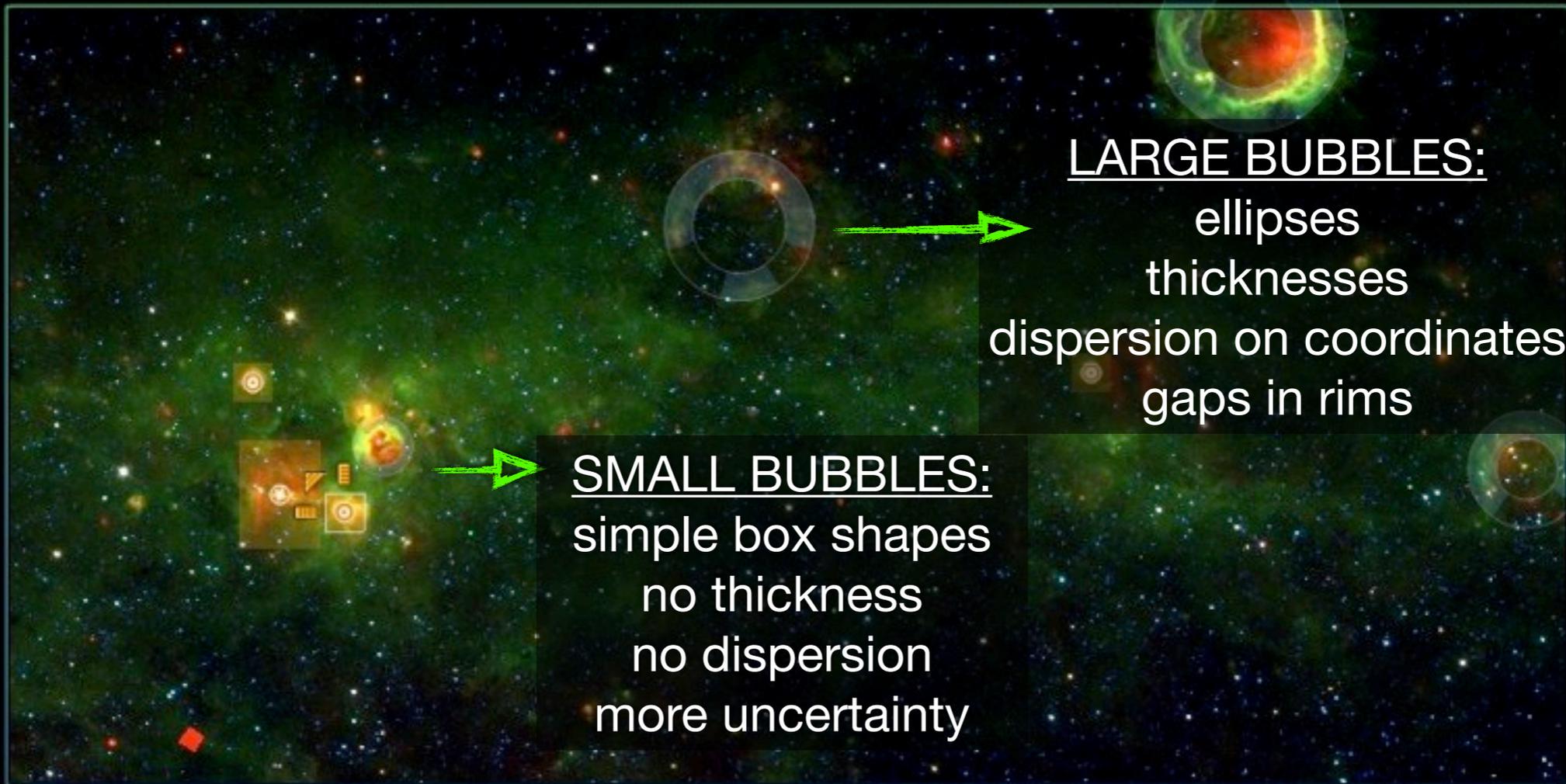
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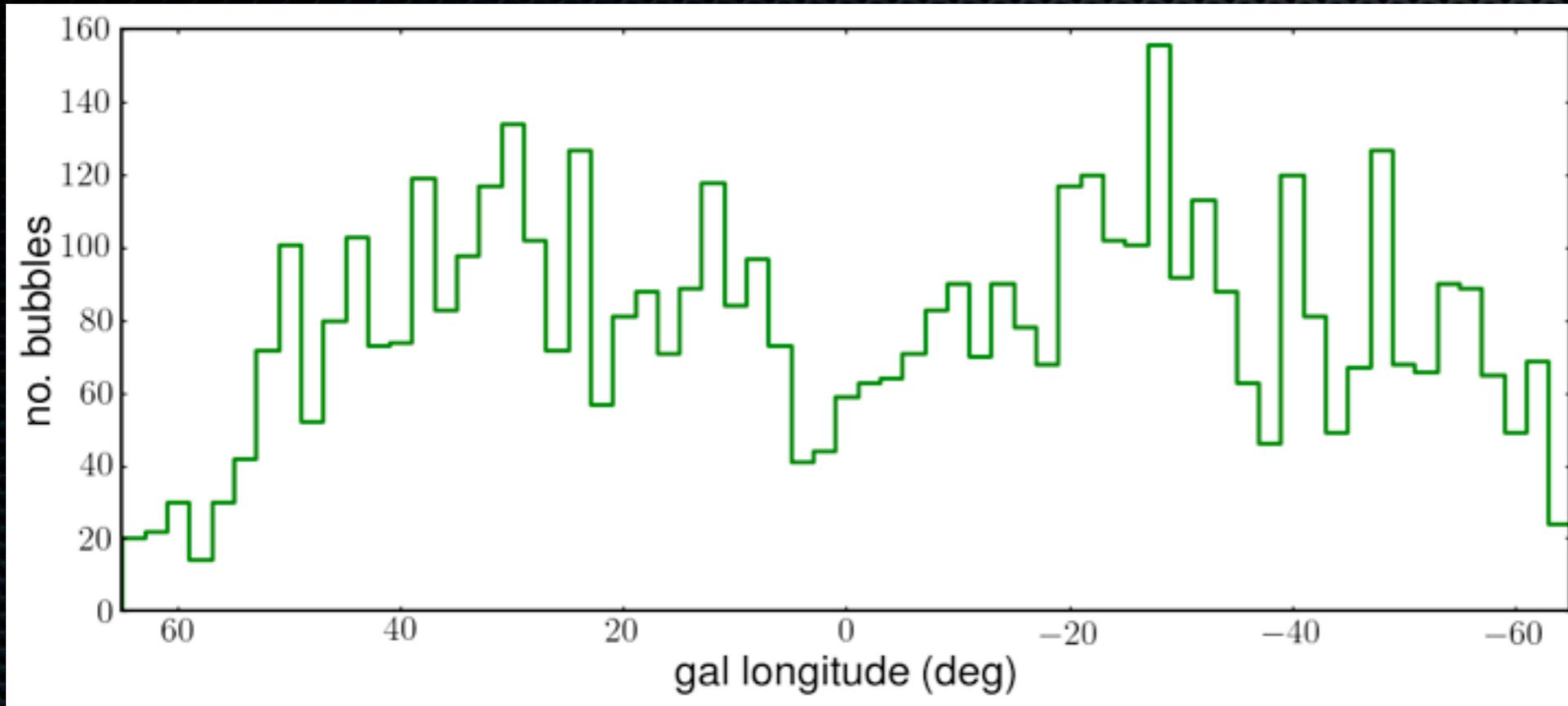
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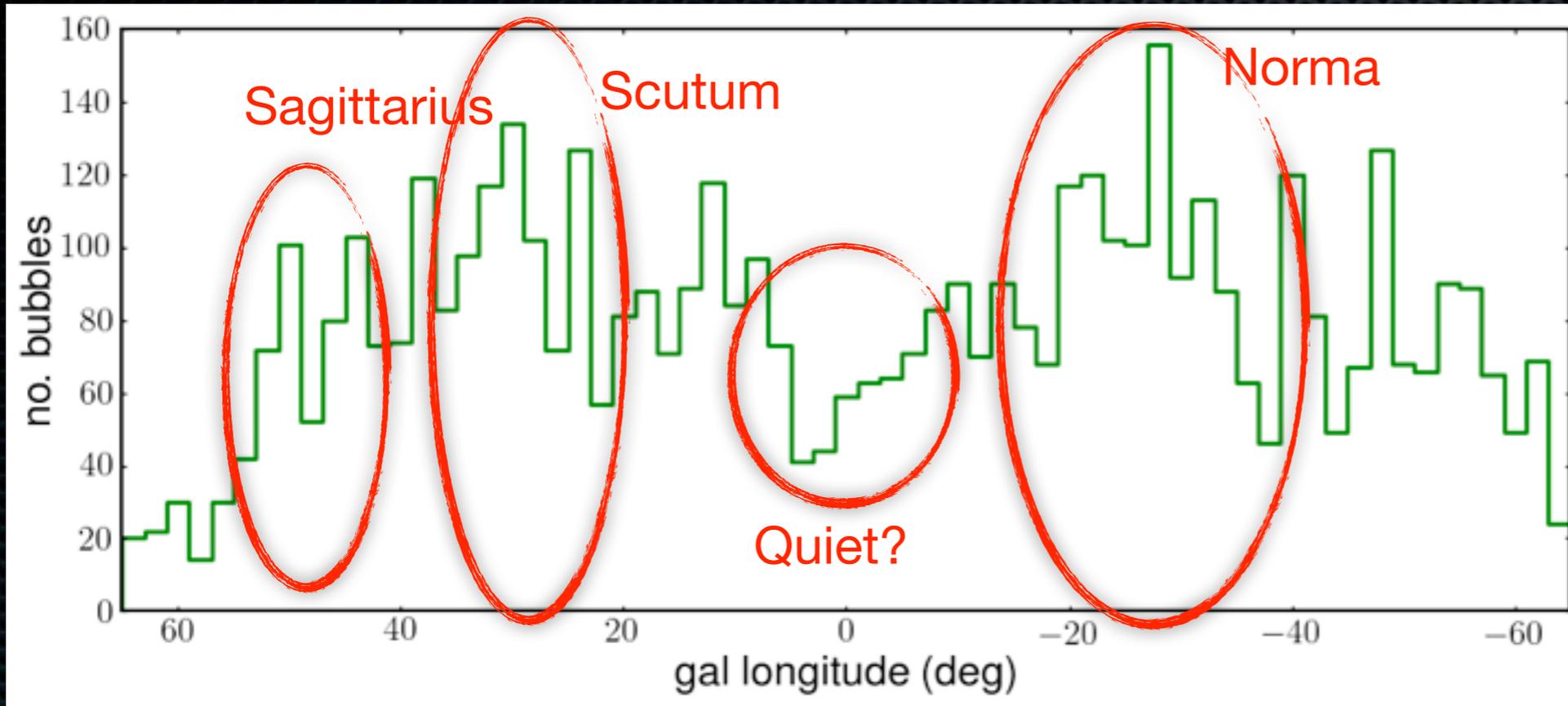
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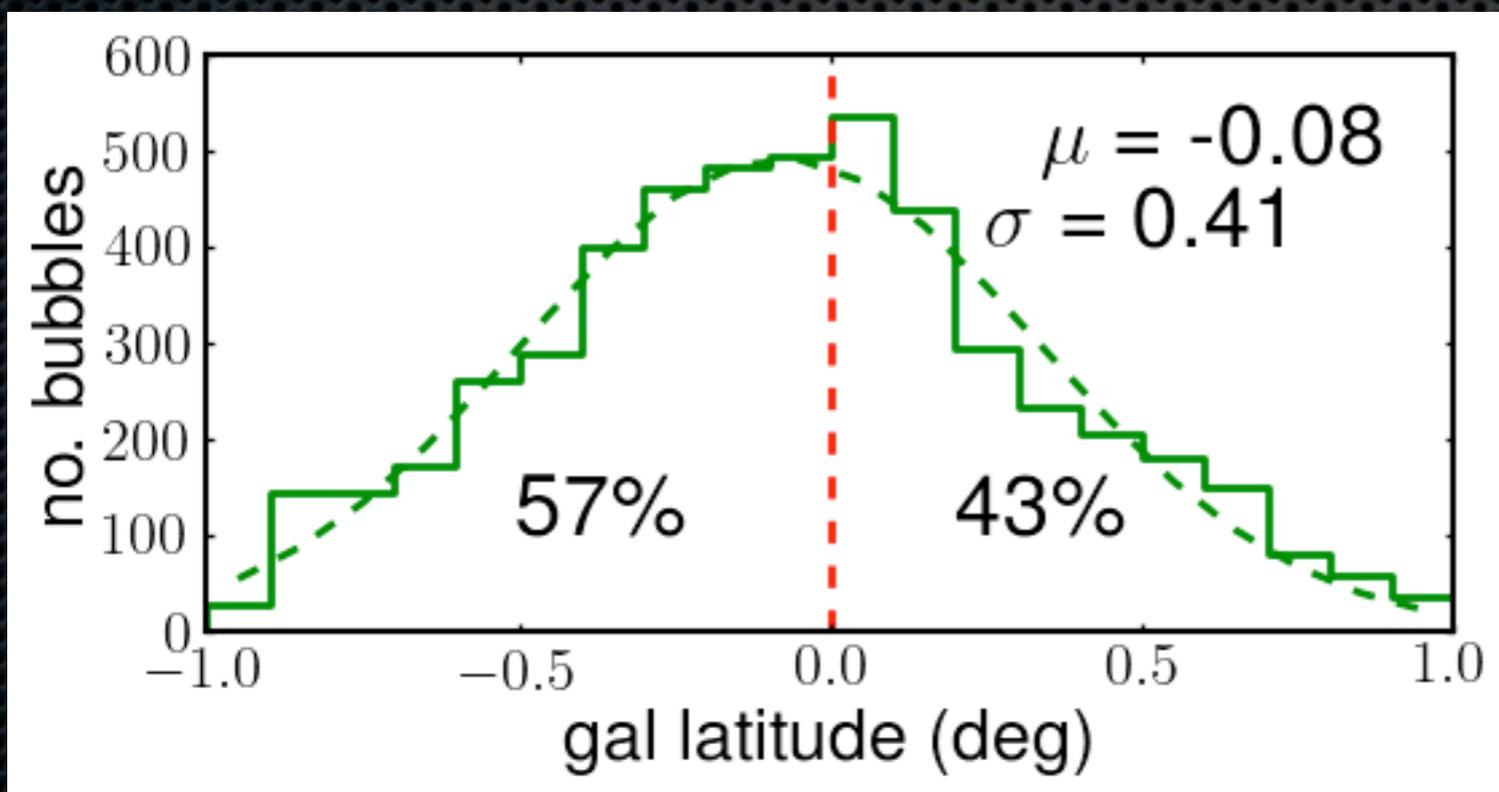
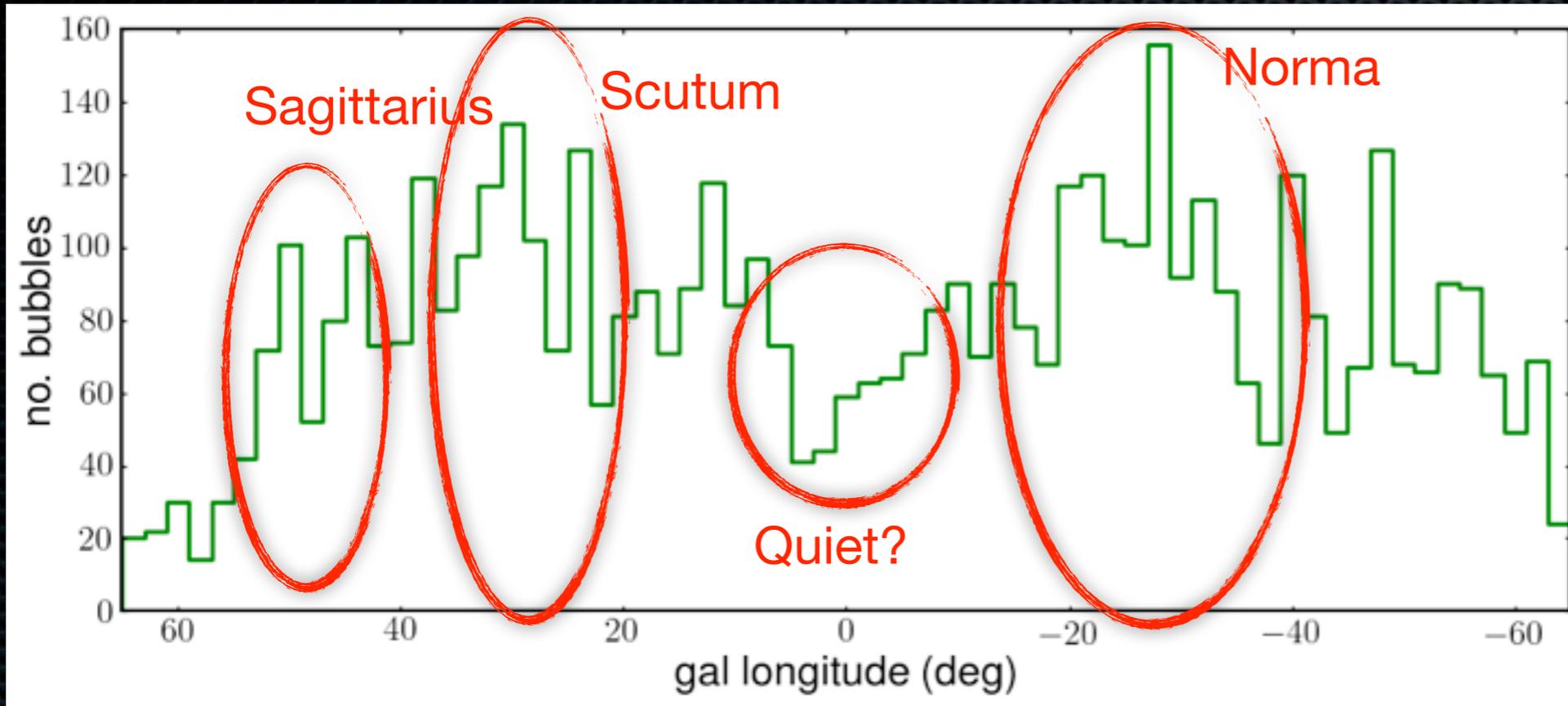
Some Milky Way Project statistics...



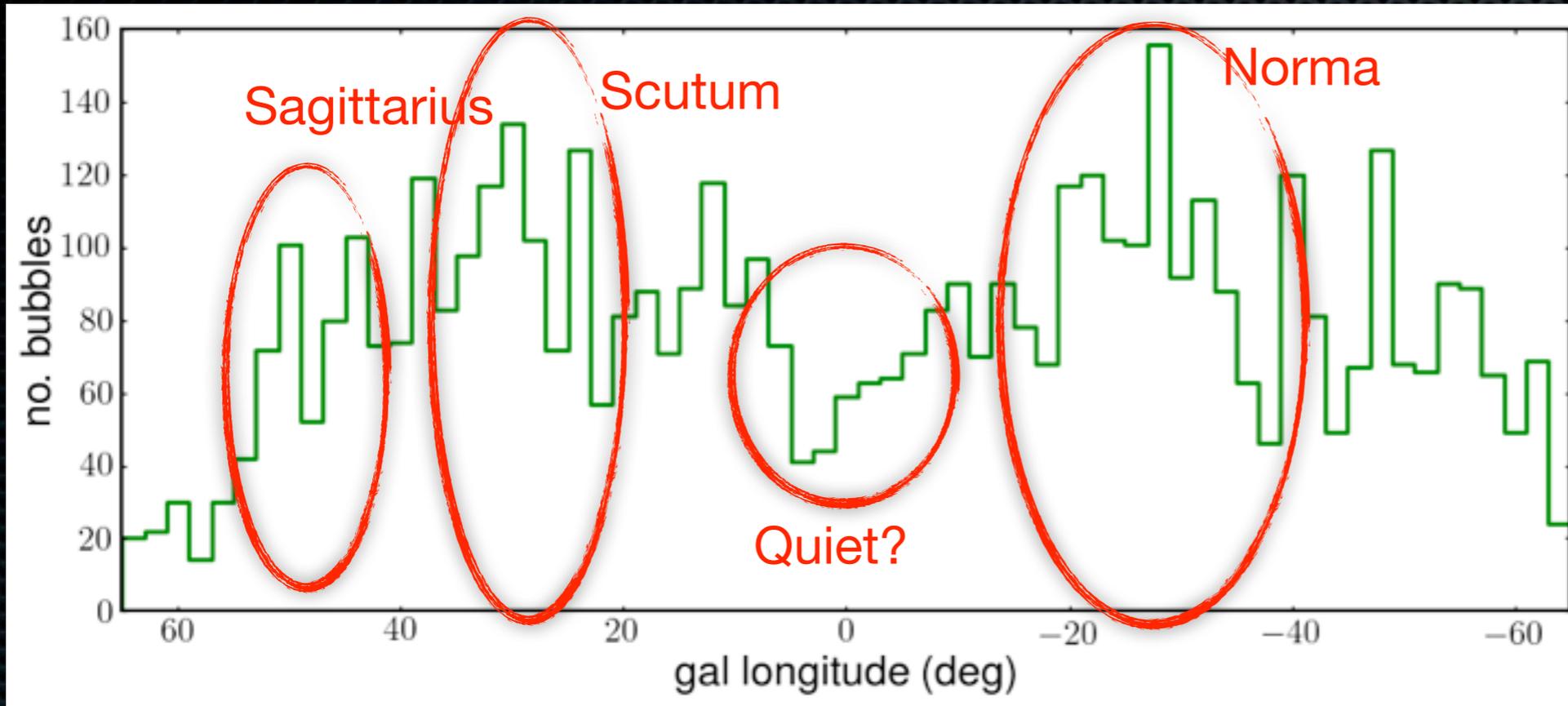
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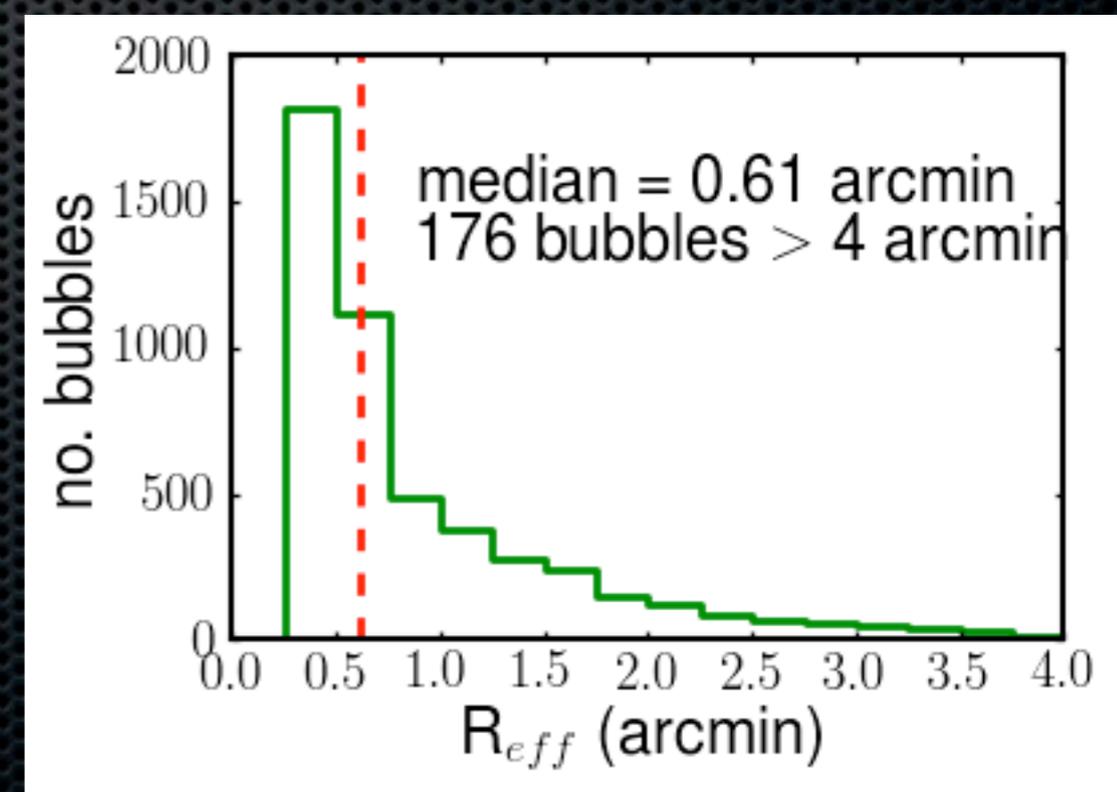
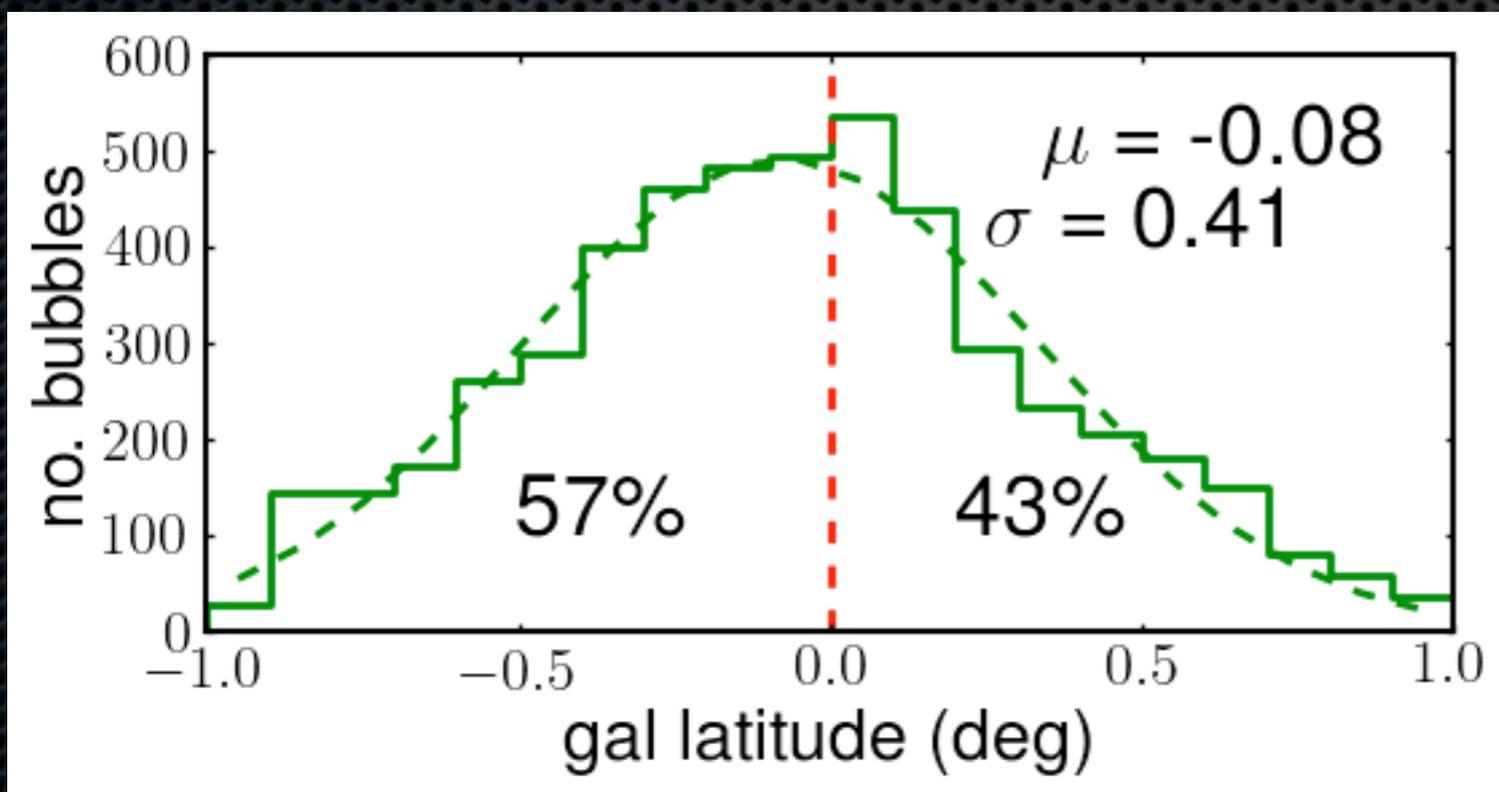
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$$R_{eff} = \frac{[(R_{in} * r_{in})^{0.5} + (R_{out} * r_{out})^{0.5}]}{2}$$



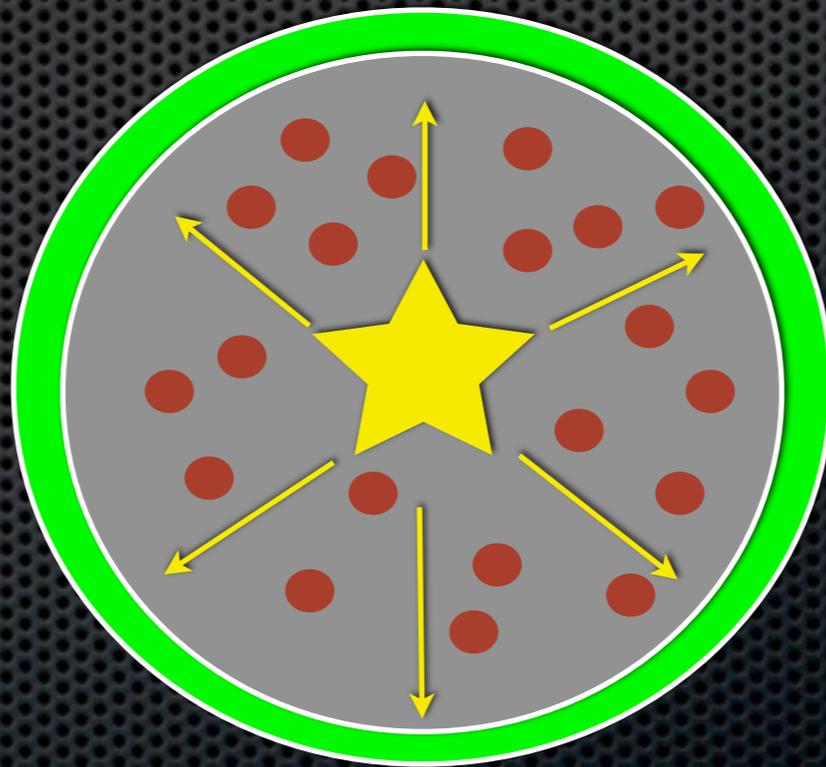
Massive star formation near bubbles (astro-ph/1203.5486)

With:

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

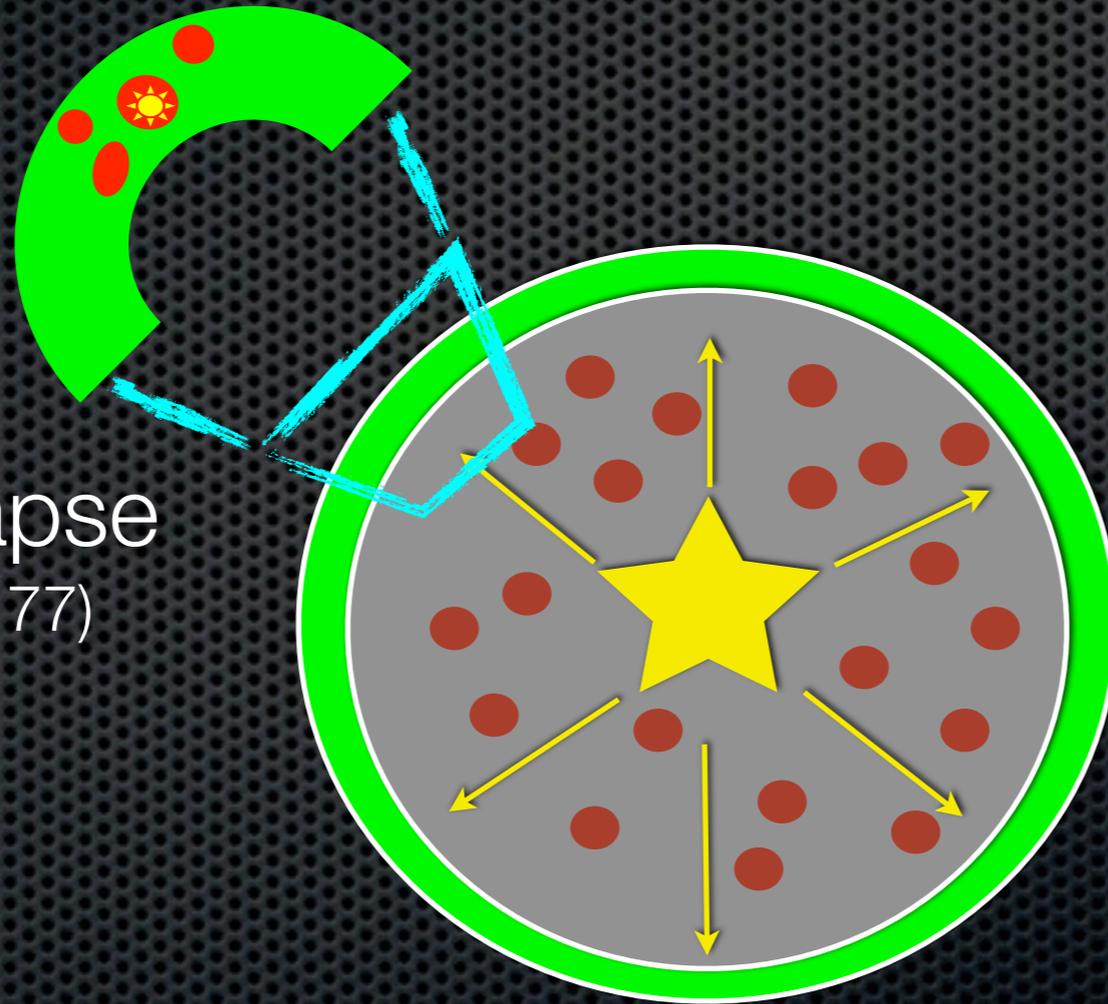
Fast-growing body of “evidence” of triggering near IR bubbles: W51a (Kang+ 09), RCW120 (Zavagno+ 10), Sh2-217 (Brand+ 11), W49A (Peng+ 10)



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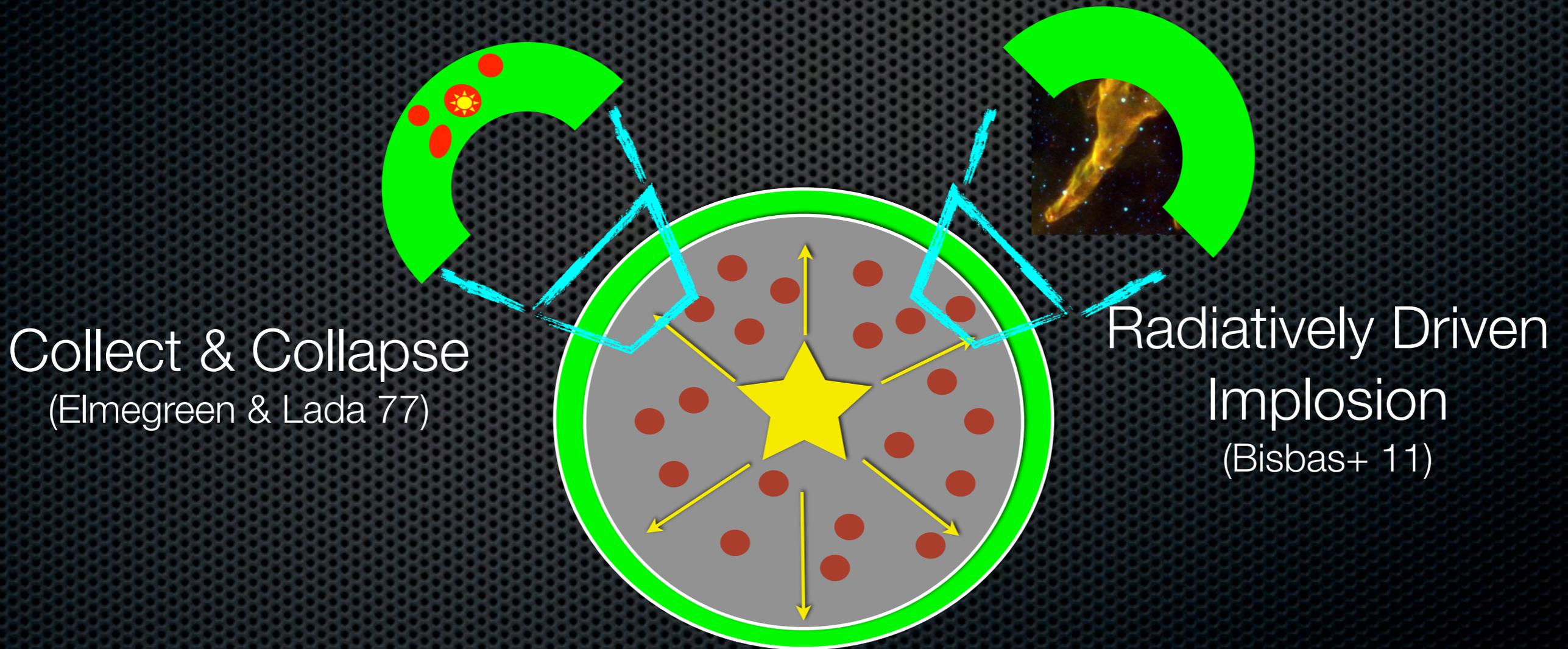
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Collect & Collapse
(Elmegreen & Lada 77)



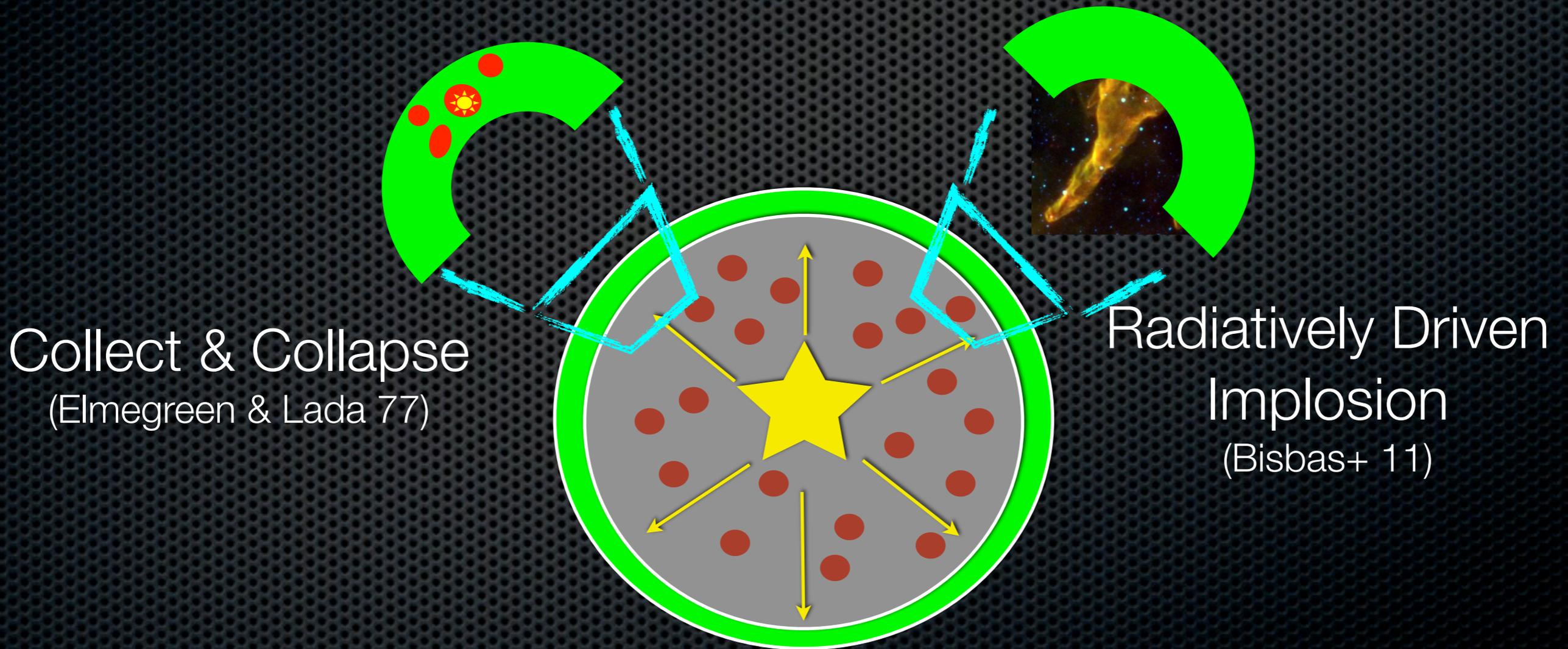
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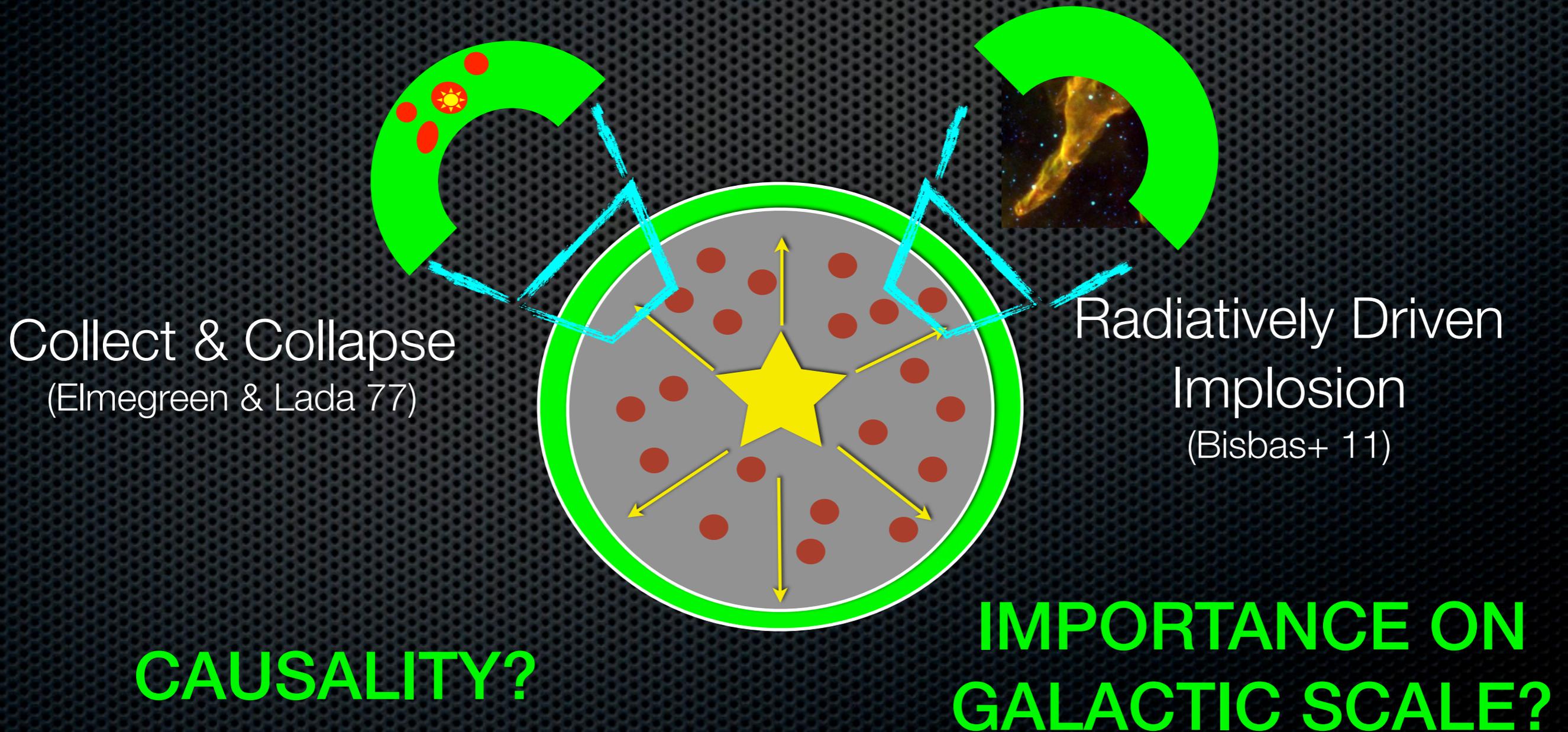
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CAUSALITY?

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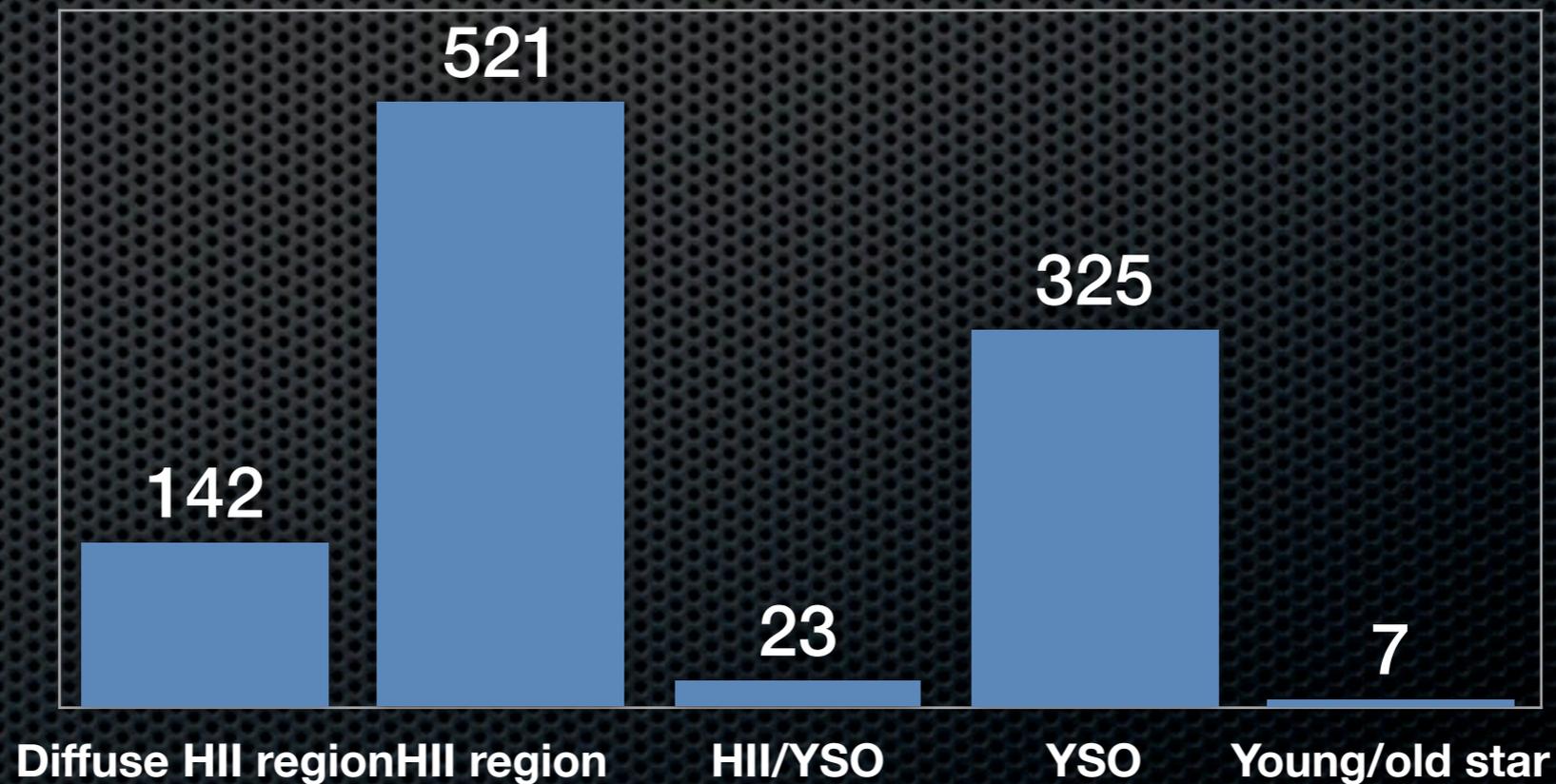


Statistics of triggering

- ✦ Thompson+ 12:
 - ✦ **Statistical** correlation between MYSOs and Churchwell bubbles
 - ✦ How many of the Galaxy's MYSOs **may** have been formed by triggering?
- ✦ > 14 % of MYSO associated with IR bubble
(**"potentially triggered"**)
- ✦ Kendrew+ 12: Extended this work to use MWP bubbles

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 $> 10^4 L(\text{solar})$ to ~15 kpc.
- Excluding $|| < 10^\circ$
- Spatial resolution **18" (0.3')**
- Follow-up: distances, source types

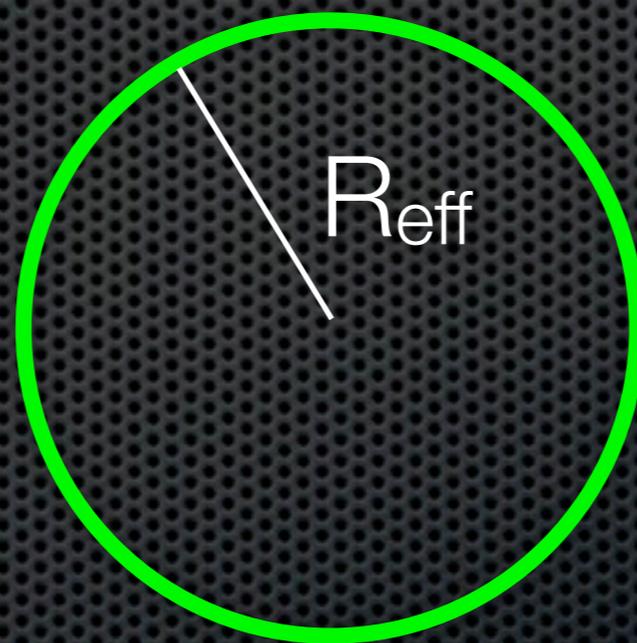


Two-point correlation function

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

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

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

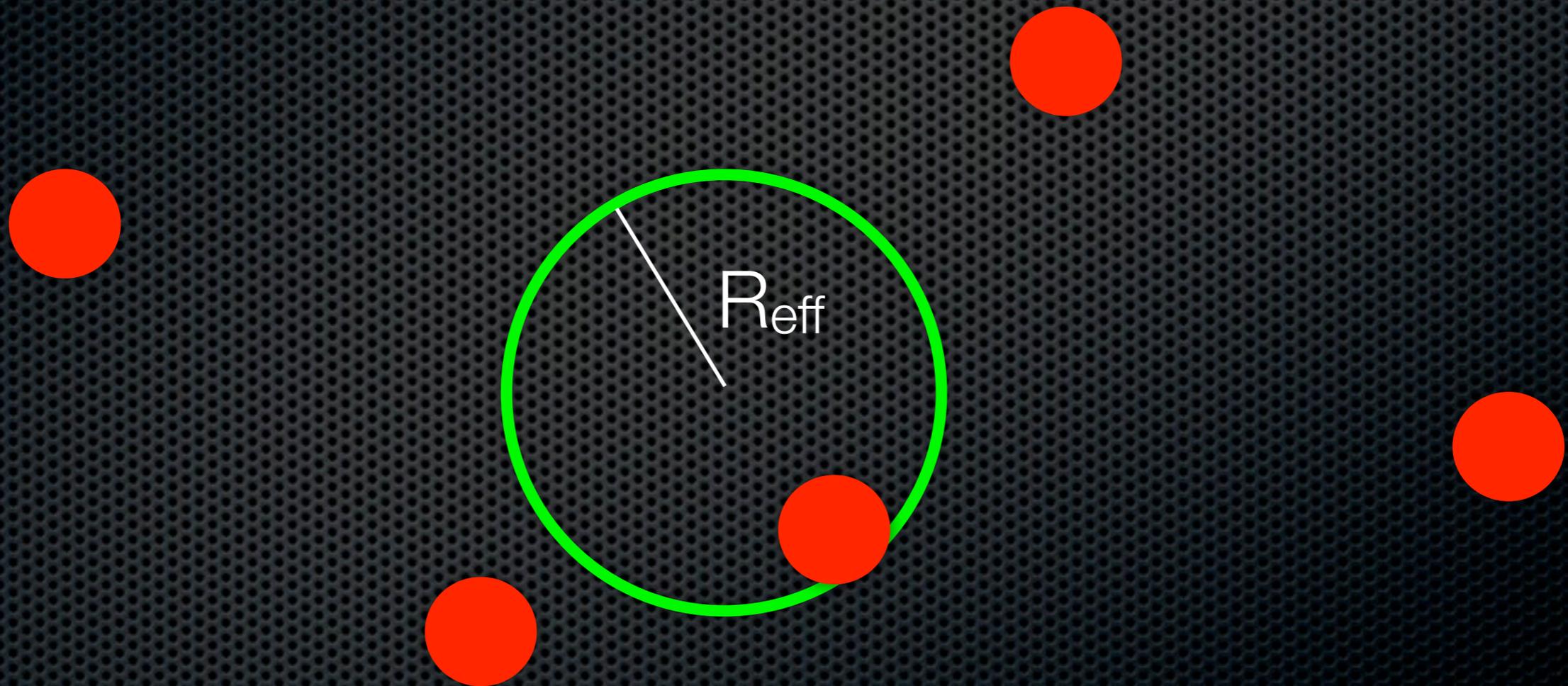


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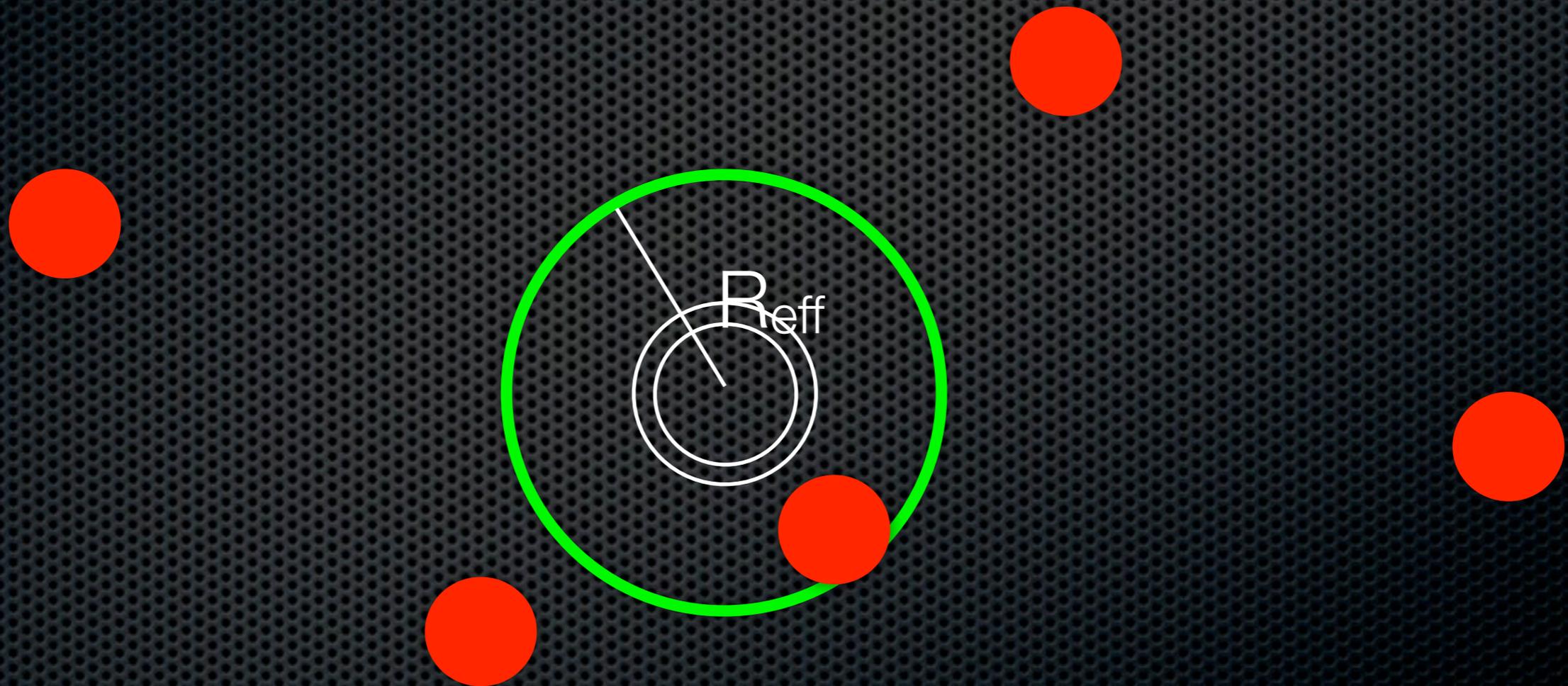


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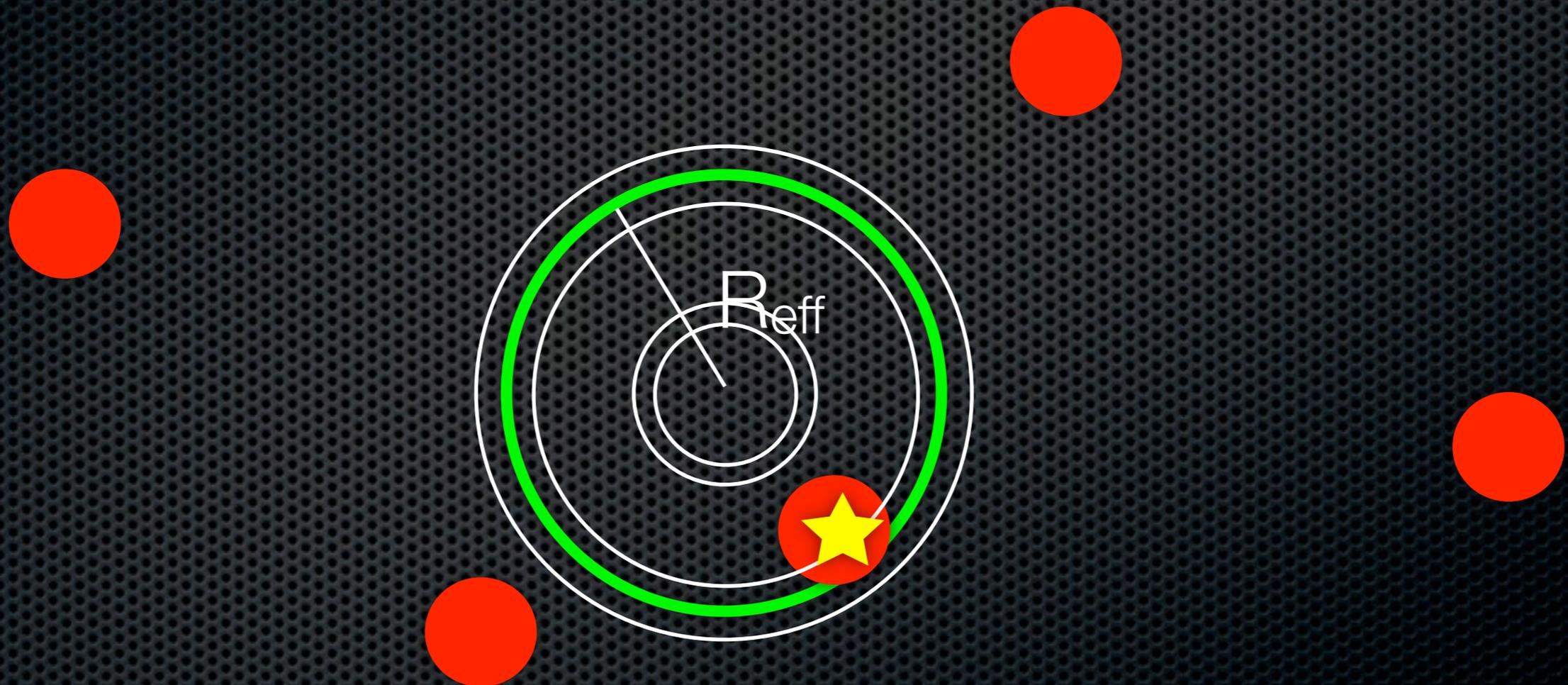


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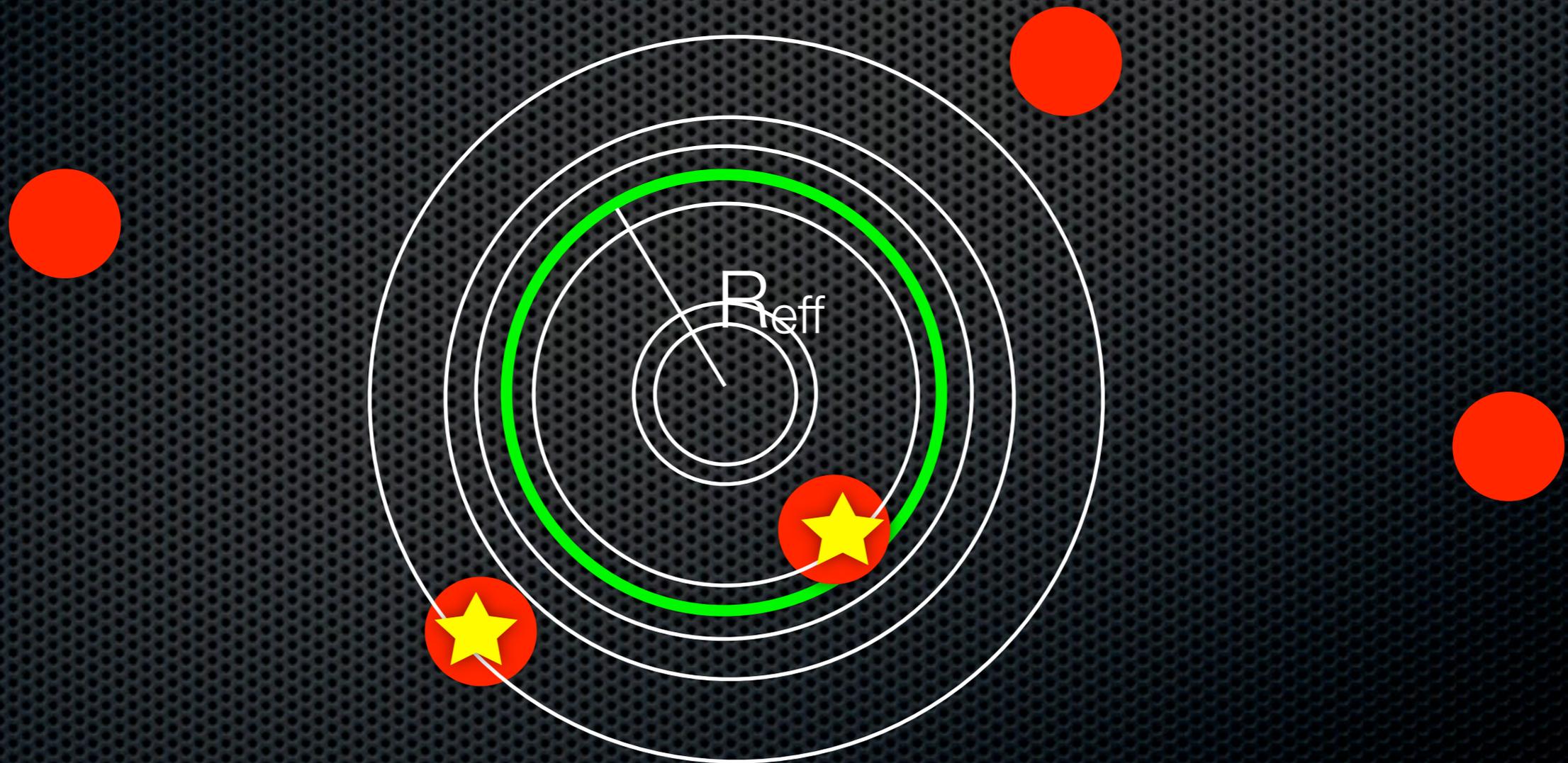


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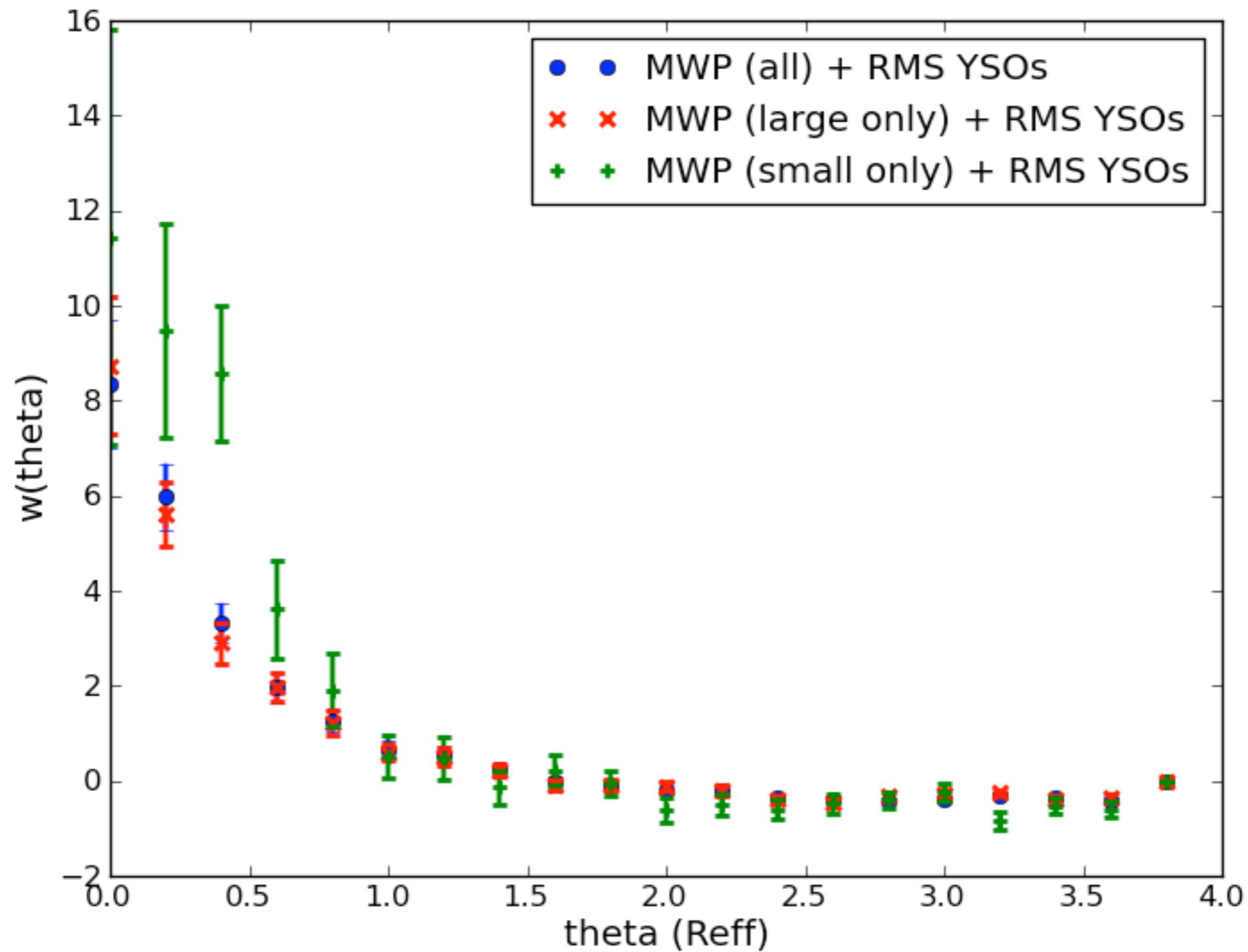
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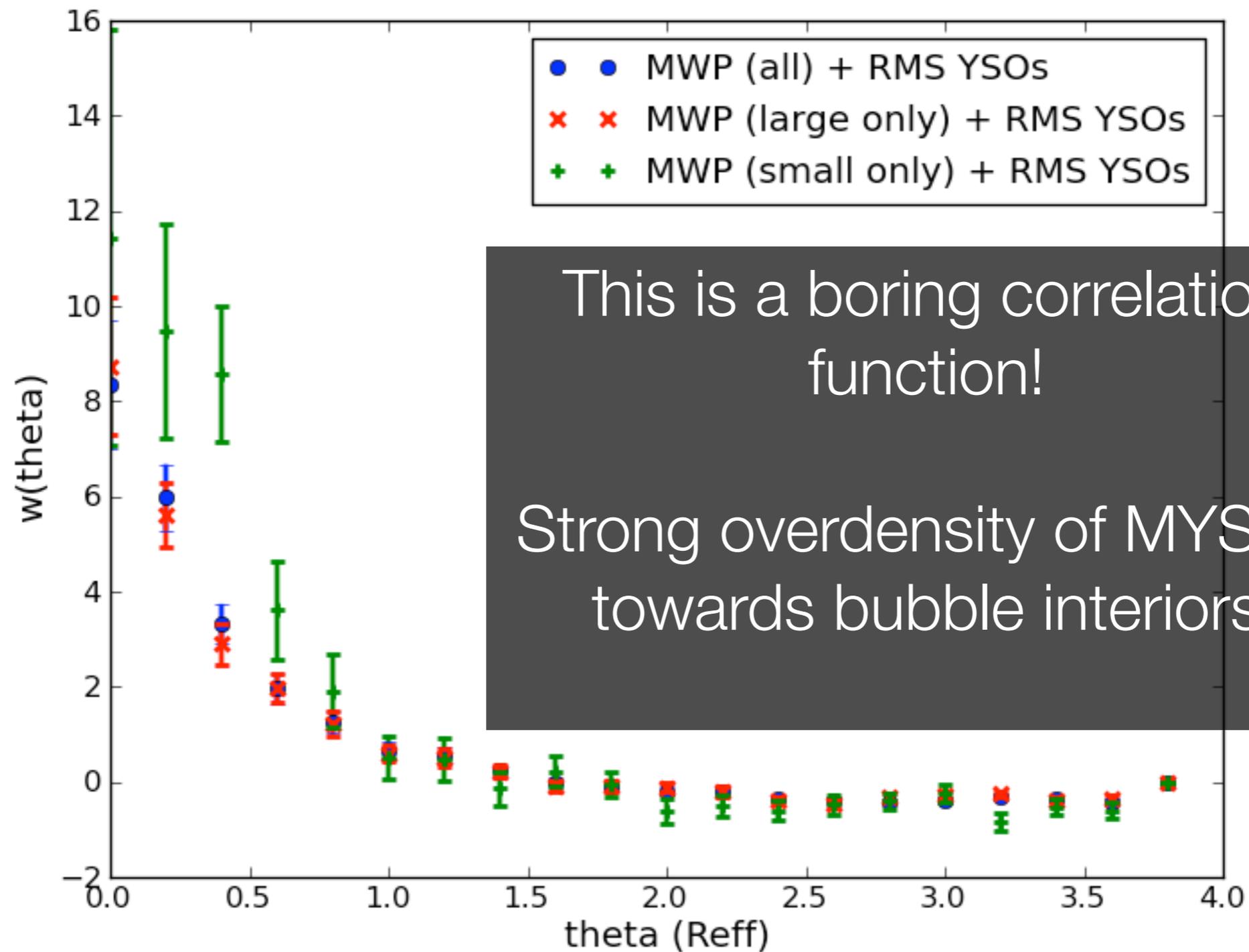
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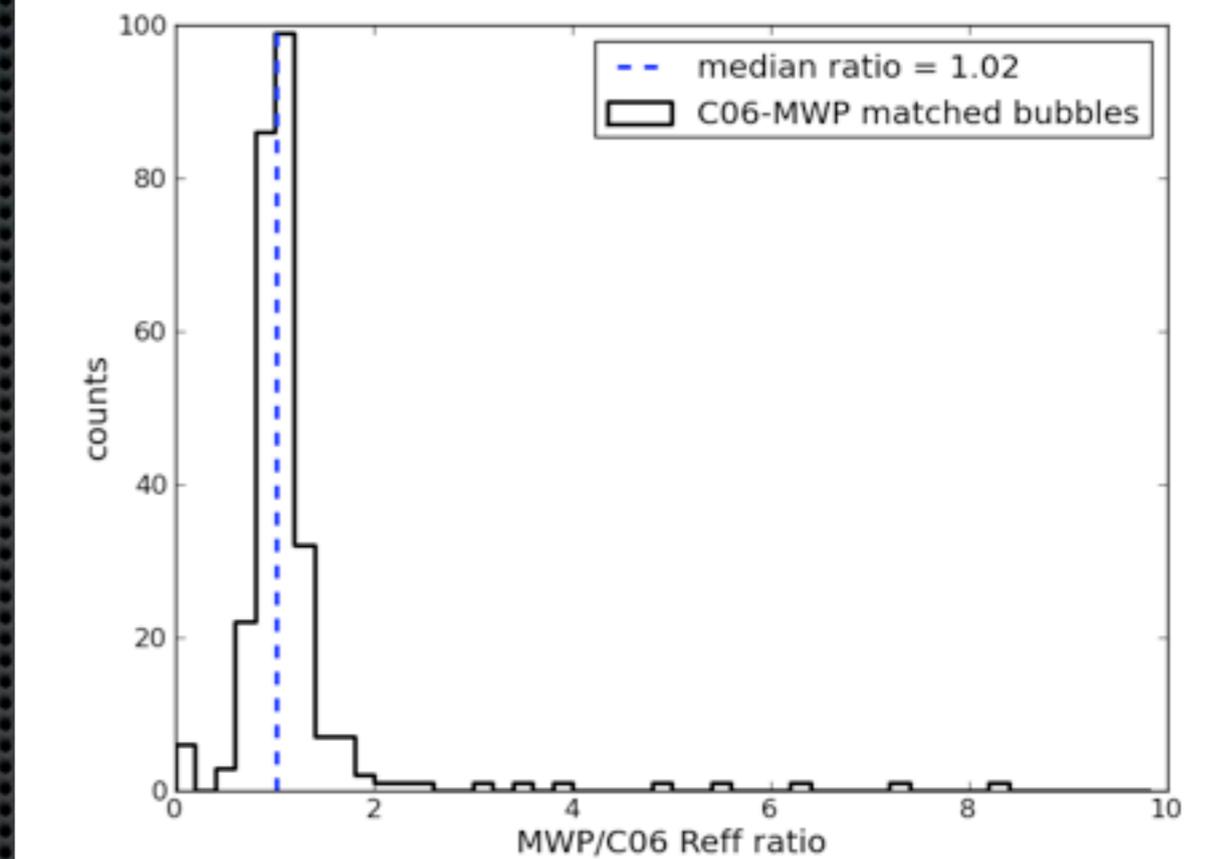
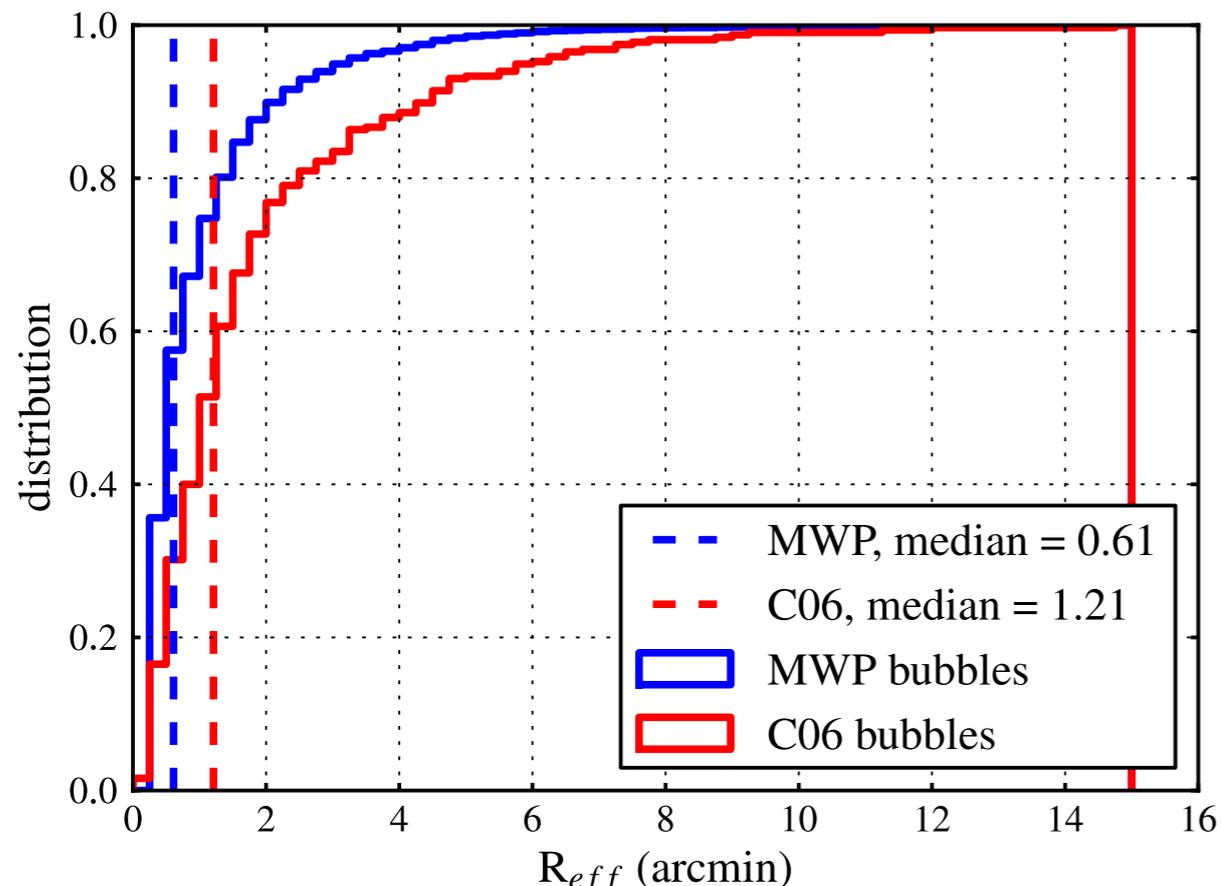
MWP + RMS correlation function



MWP + RMS correlation function

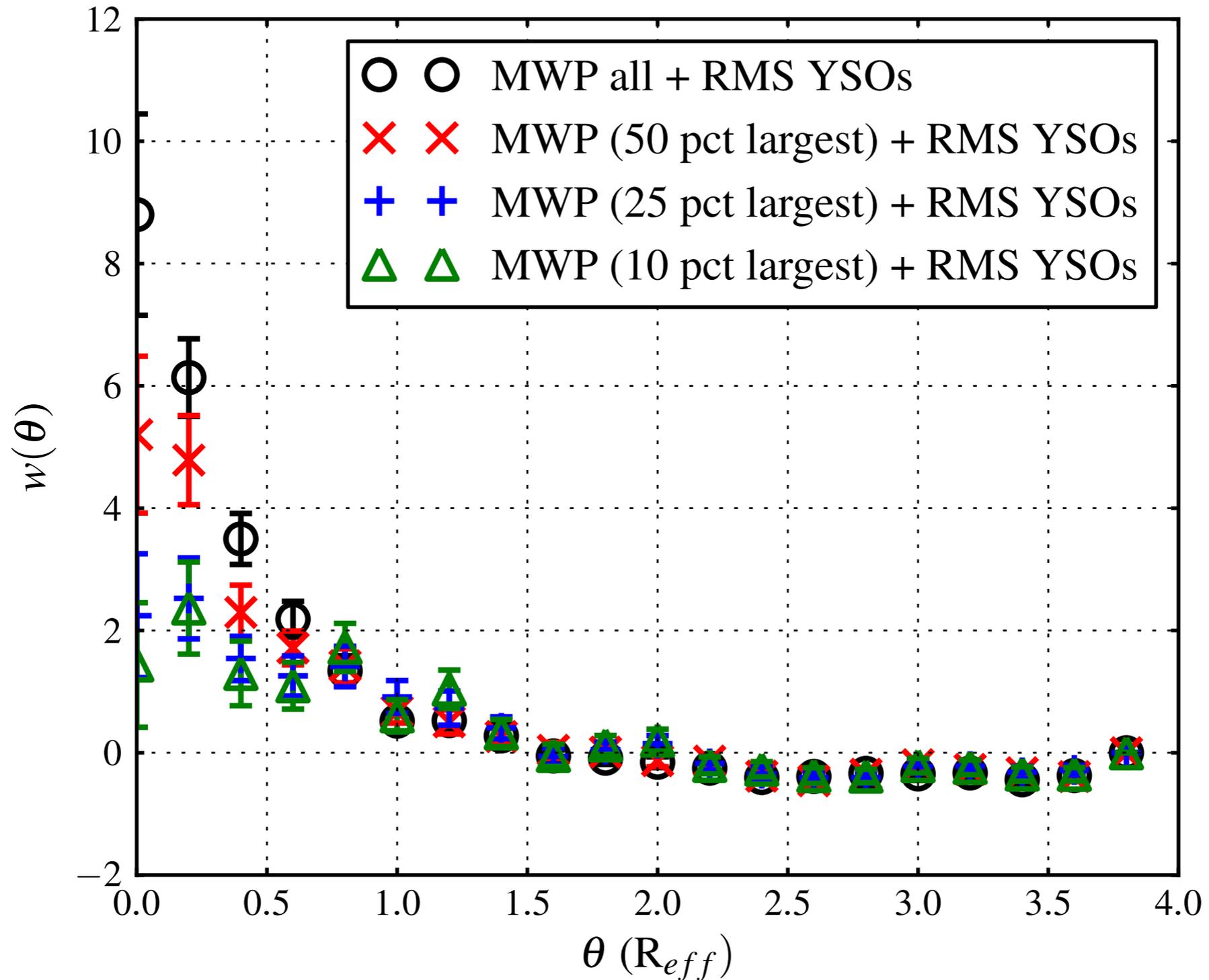


How do MWP and Churchwell bubbles differ?

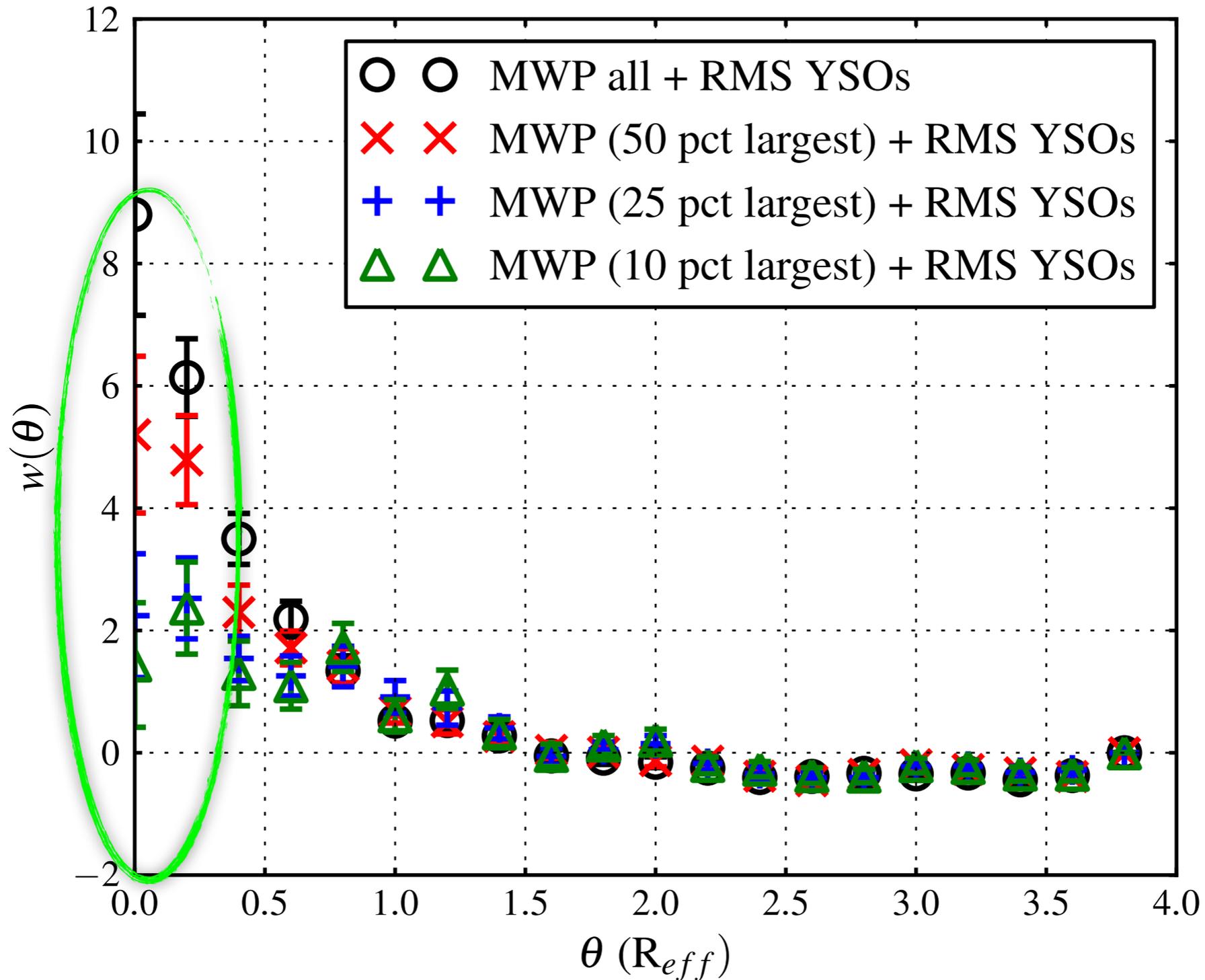


Churchwell bubbles clearly larger in size
Matched sample of 275 shows good agreement
between catalogues (median R_{eff} ratio = 1.02)

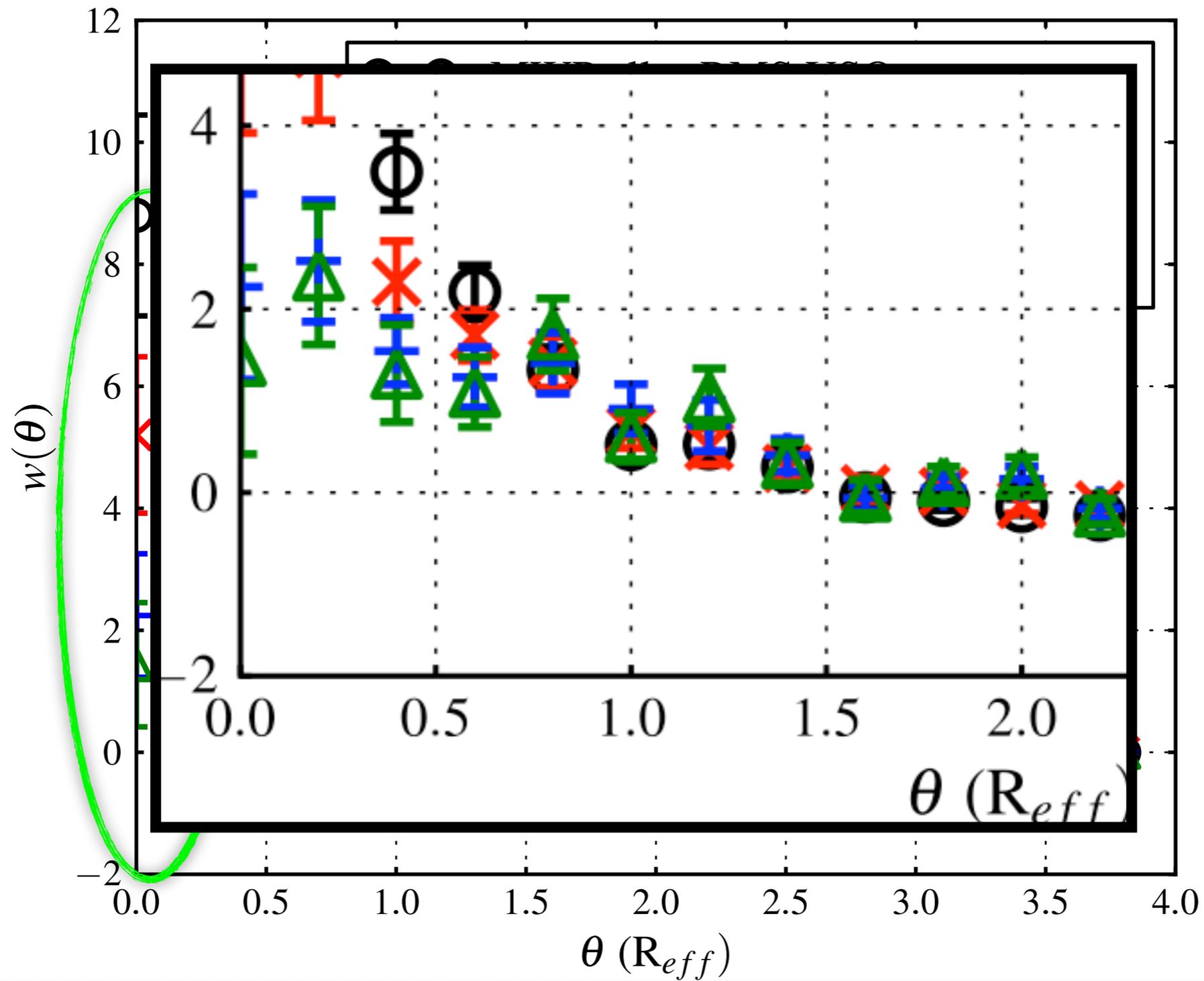
Does size matter?



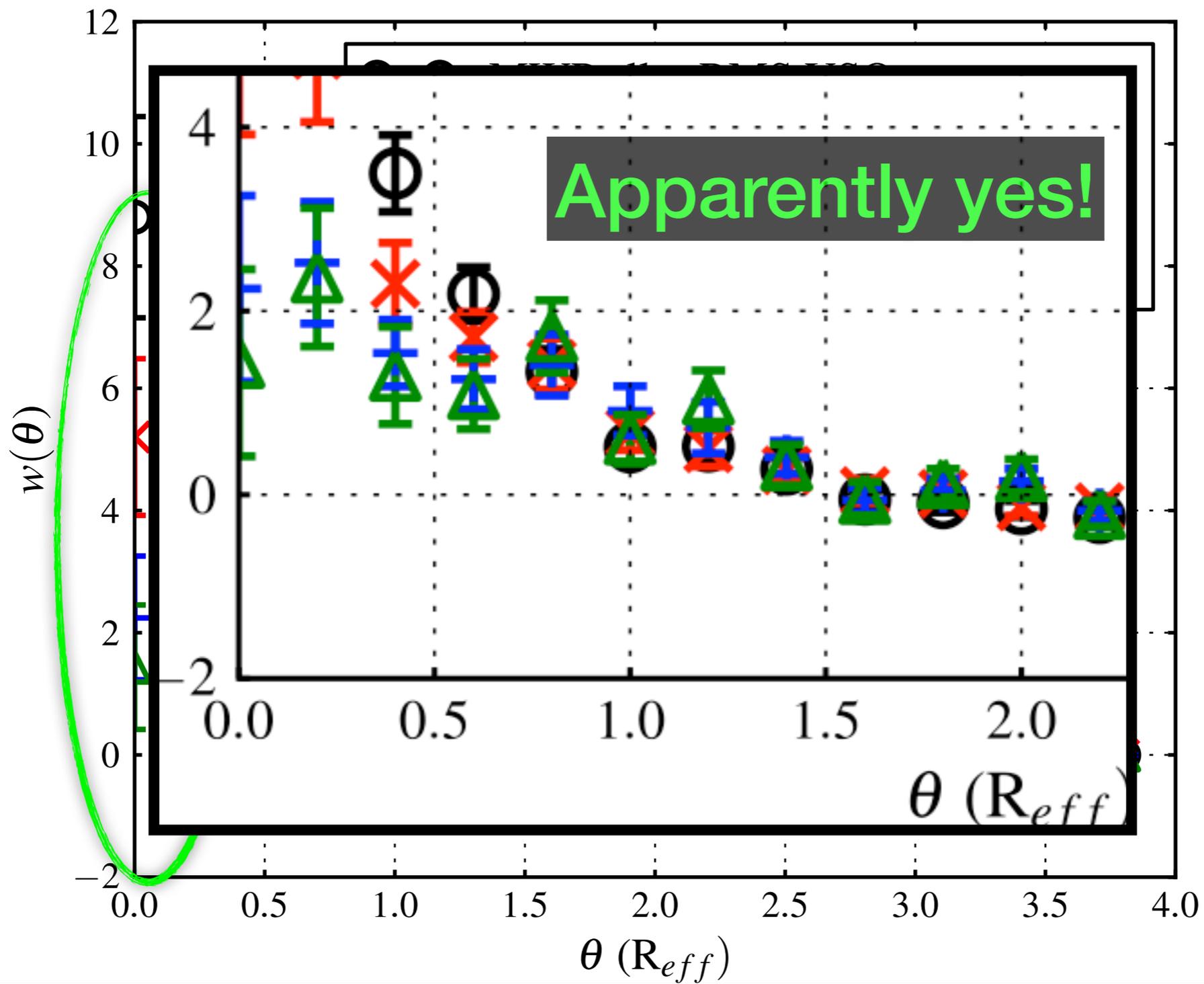
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Does size matter?



Caveats!

- ✦ Cannot distinguish between MYSOs 'associated with' vs. 'identical to'
 - ✦ Is the MYSO *triggering* or *triggered* source?
 - ✦ Astrometric precision + source sizes of both catalogues limits the accuracy of separation calculation
- ✦ Without bubble distances, sizes **cannot** be interpreted
 - ✦ More evolved?
 - ✦ Closer by?
 - ✦ Different in nature?
- ✦ 3D effects?
- ✦ **Analysis cannot prove or disprove that triggering occurs**

Implications for triggering

- ✦ [For believers only!]
- ✦ Theory of collect & collapse triggering consistent with MYSOs being formed along rims of evolved (i.e. larger?) bubbles
- ✦ Potentially triggered population of MYSOs estimated at $22 \pm 2\%$
- ✦ More detailed study requires:
 - ✦ Bubble distances
 - ✦ Evolutionary stages of young sources
 - ✦ Consideration of 3D effects (line-of-sight confusion)

Conclusions

- ✦ Large Galactic plane surveys (e.g. Milky Way project) allowing statistical study of star formation on a Galactic scale -> exciting
- ✦ High level of correlation between IR bubbles and massive young stars
- ✦ Overdensity of MYSOs towards shells of the largest bubbles not inconsistent with collect & collapse triggering (but not proof of occurrence!)

Thanks

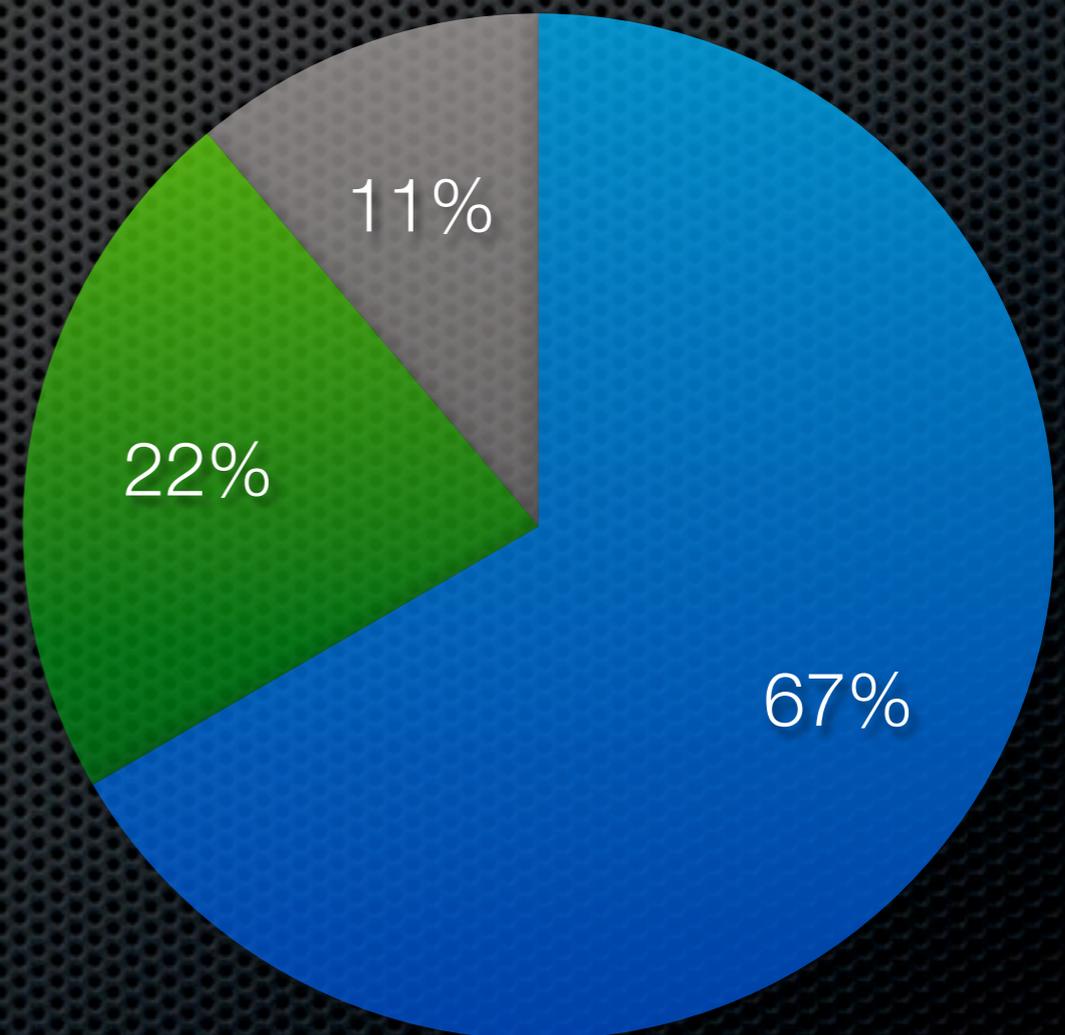
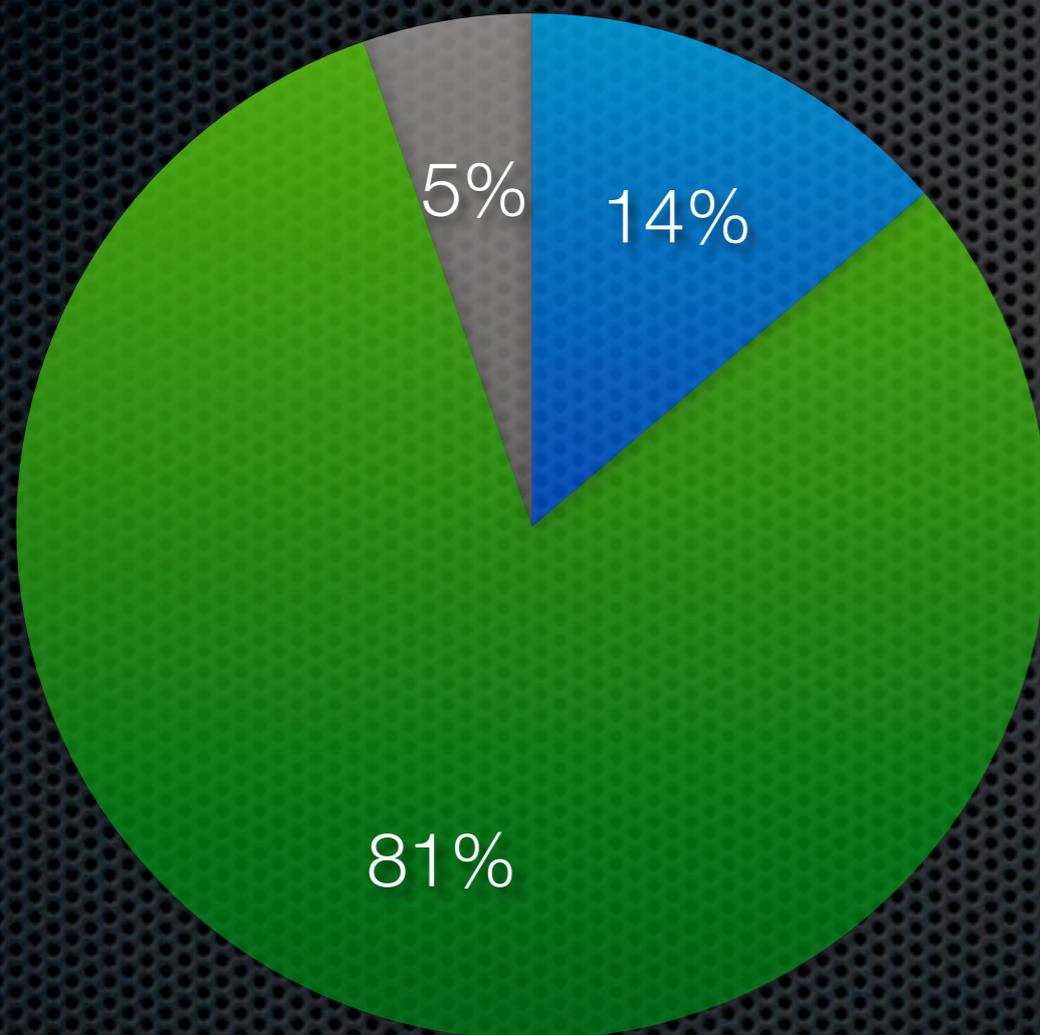
Simple MYSO-Bubble Association

'Associated' = MYSO within $2 R_{\text{eff}}$ from a bubble

'Control' = MYSO $> 3 R_{\text{eff}}$ from a bubble

MYSOs + Churchwell bubbles

MYSOs + Milky Way Project bubbles



● Associated

● Control

● Rest