

The role of spiral arms in Milky Way star formation

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VIA LACTEA
The Milky Way as a Star Formation Engine

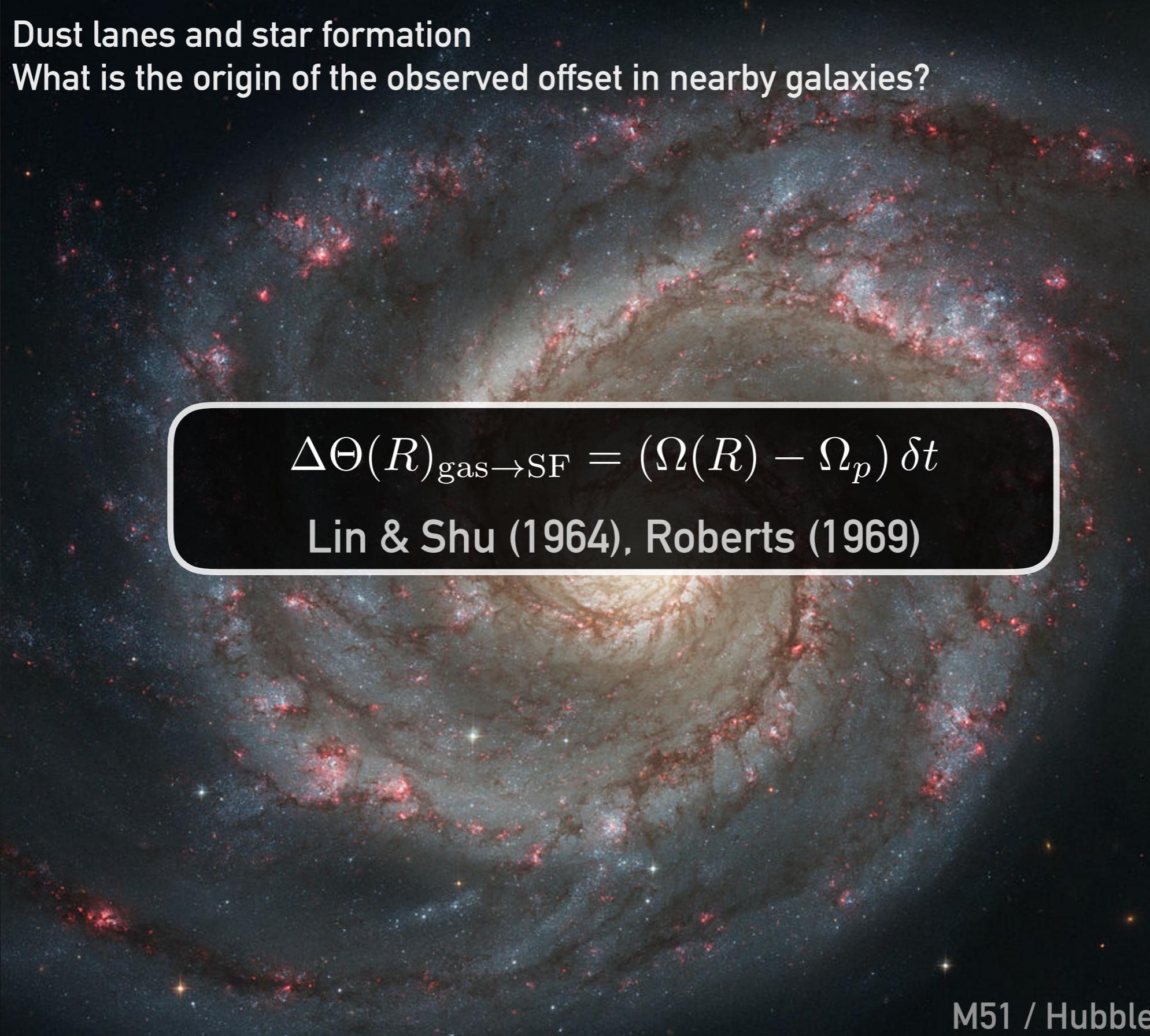
STAR FORMATION IN SPIRAL GALAXIES

Dust lanes and star formation

What is the origin of the observed offset in nearby galaxies?

$$\Delta\Theta(R)_{\text{gas}\rightarrow\text{SF}} = (\Omega(R) - \Omega_p) \delta t$$

Lin & Shu (1964), Roberts (1969)



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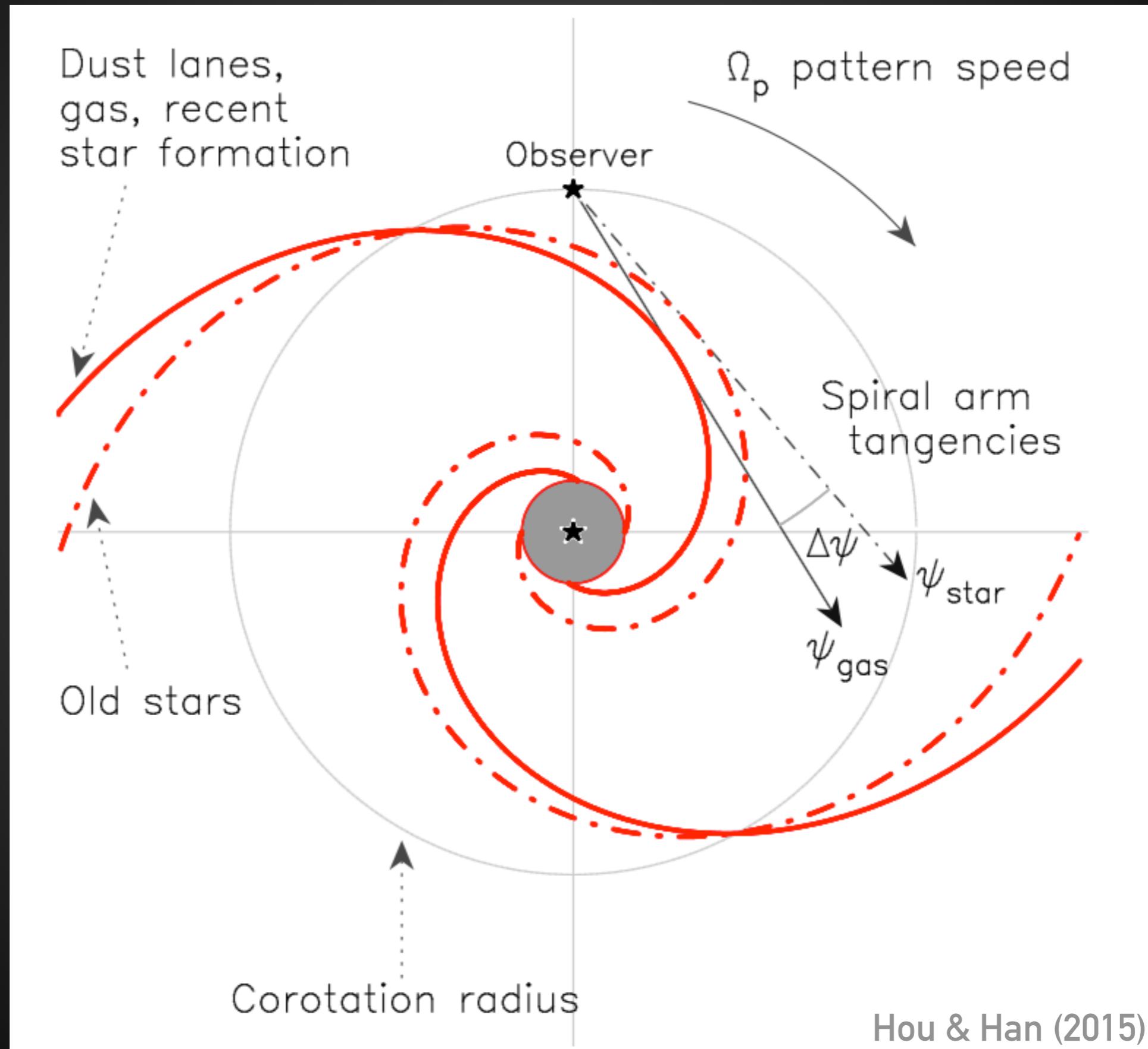
Lin & Shu (1964), Roberts (1969)

M51	Tracers		Analysis	Method	t_{SF} (Myr)	Ω_p ($\text{km s}^{-1} \text{kpc}^{-1}$)
	Gas	SF				
Tamburro et al. (2008)	H I	24 μm	Arm 1 and 2	CC	3.4 ± 0.8	21 ± 4
Egusa et al. (2009)	CO	H α	Arm 1 and 2	PT	13.8 ± 0.7	40 ± 4
Egusa et al. (2009)	CO	H α	Arm 1	PT	7.1 ± 0.5	31 ± 5
Foyle et al. (2011)	H I	24 μm	Arm 1 and 2	CC	No ordered offsets	

Different combinations of tracers of gas and star formation result in very different offset measurements. H I 21cm is tracing gas dissociated by stars, not parental gas that will form stars. (Louie et al. 2013)

- * **Can we test these ideas in the Milky Way?**
- * To date, most MW studies have compared arm to interarm regions rather than offsets across arms.
 - * Heyer & Terebey (1998) find higher H₂/HI ratio in Perseus spiral arm compared to interarm gas, interpret as increased cloud formation efficiency.
 - * Sawada et al. (2012a,b) find brighter and more compact CO in arms versus interarm regions, interpret as the arm “triggering” small scale collapse
 - * Eden et al. (2012, 2013) find no difference between clump formation efficiency in arm versus interarm regions
 - * Moore et al. (2012) show that there are greater differences from cloud-to-cloud than any large-scale trend
- * Are we still finding discrepancies due to mismatched tracers? Mismatched scales? ... Or, as some simulations are showing, are “arms” short-lived, transient features in which “clouds” intermingle and star formation is stochastic?

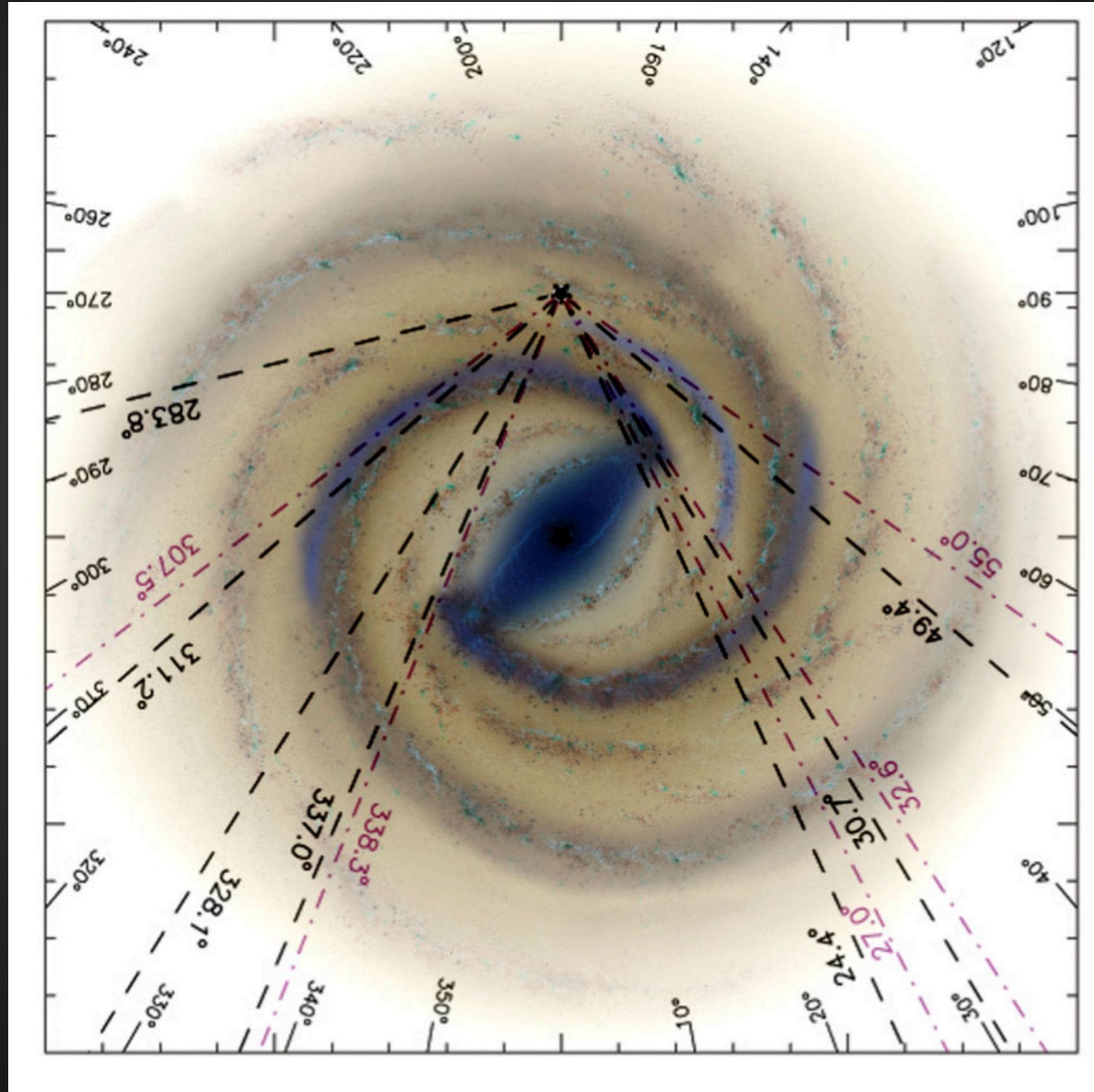
STAR FORMATION IN SPIRAL GALAXIES



SPIRAL ARM TANGENT POINTS: MILKY WAY PERSPECTIVE



SPIRAL ARM TANGENT POINTS IN THE MILKY WAY



SPIRAL ARM TANGENT POINTS IN THE MILKY WAY

(NOT TO SCALE)

STARS



GAS TRACERS

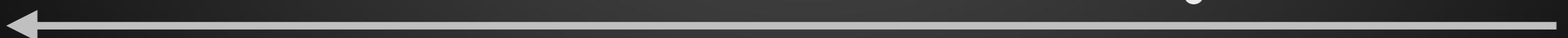
CO

COLD DUST

METHANOL
MASERS

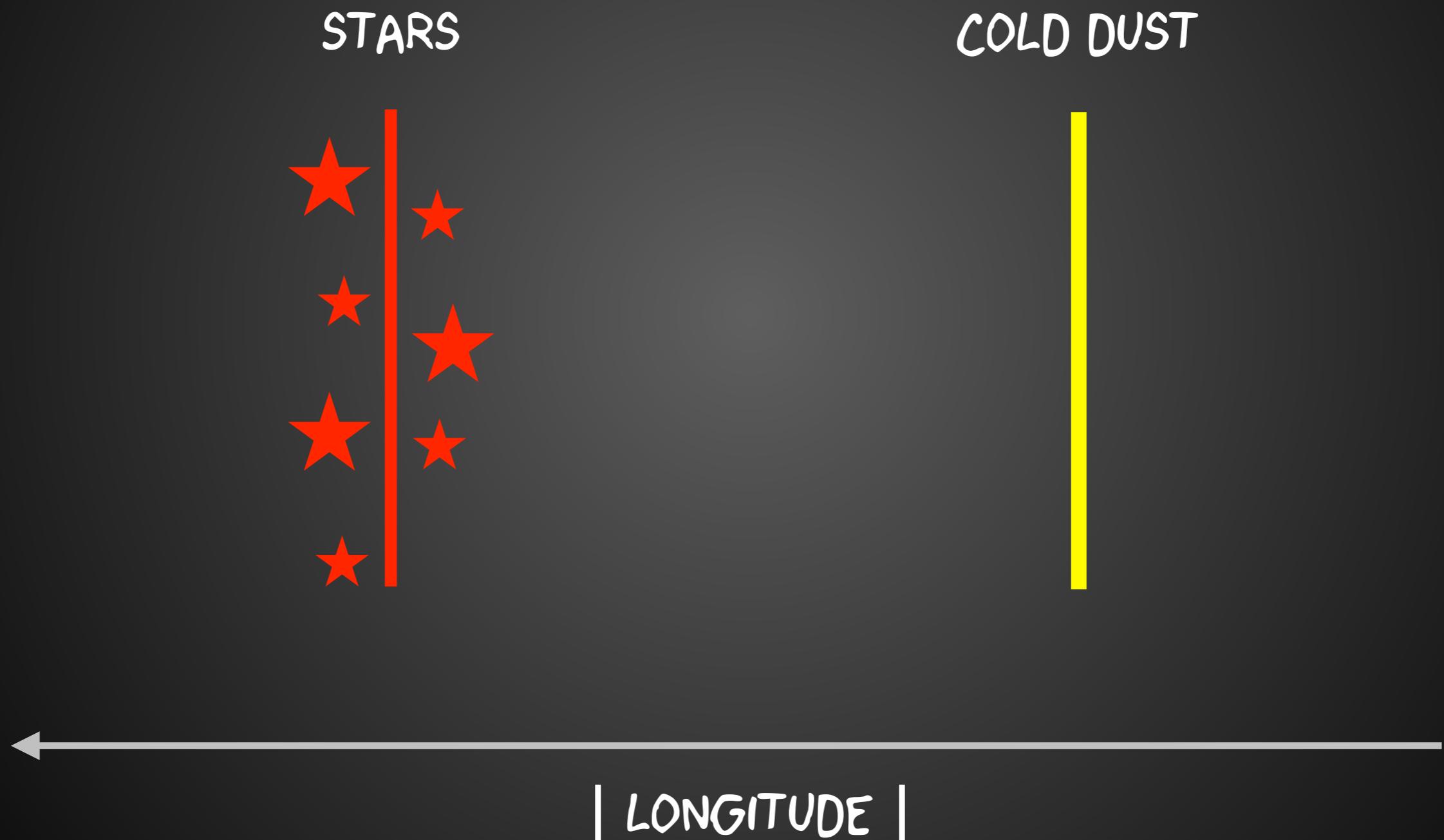


Possible small offsets between gas tracers
 $<<$ offset between gas and stars



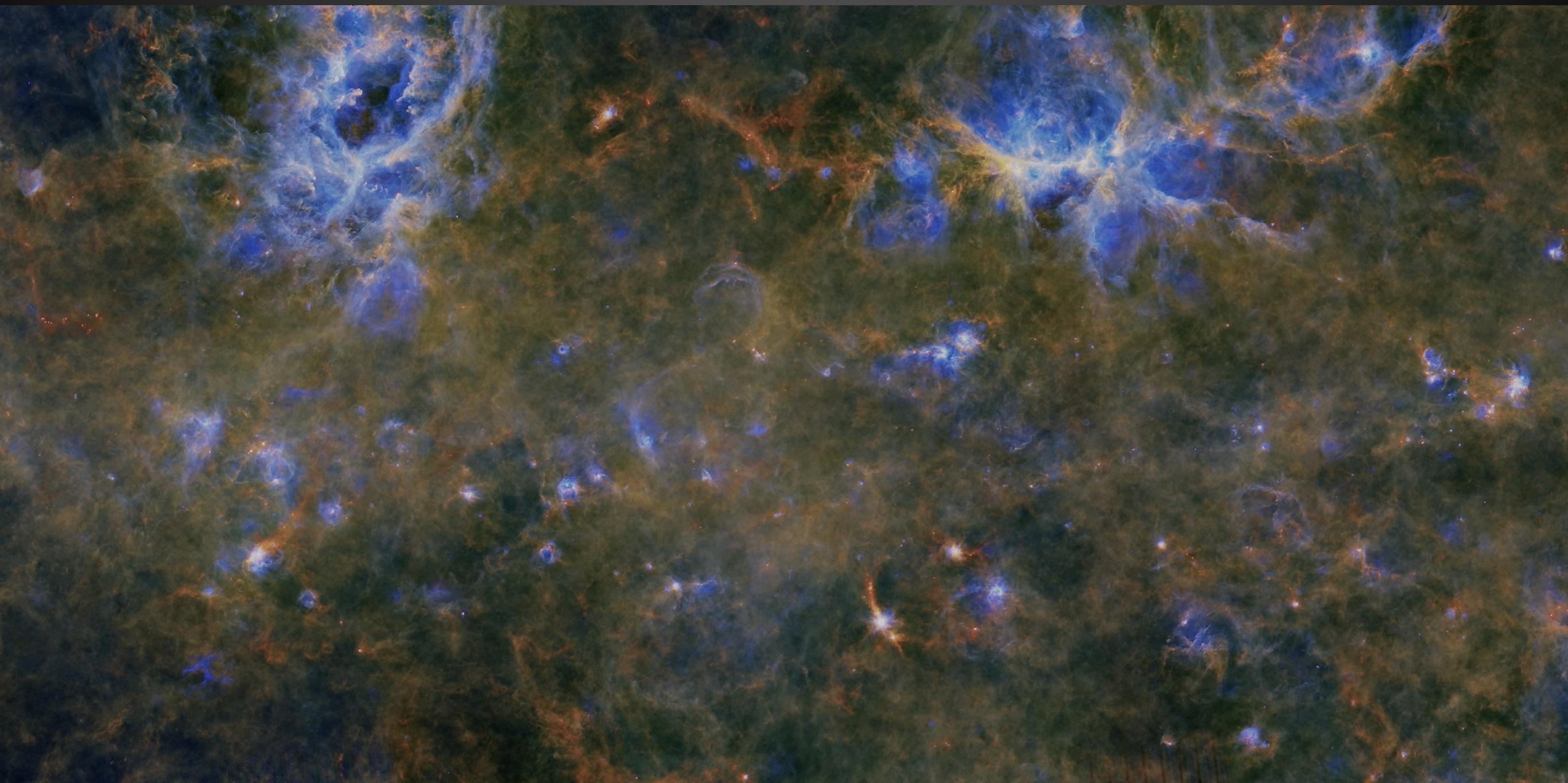
| LONGITUDE |

SPIRAL ARM TANGENT POINTS IN THE MILKY WAY



HI-GAL: HERSCHEL INFRARED GALACTIC PLANE SURVEY

- *Simultaneous five band (70, 160, 250, 350 & 500μm) continuum mapping of Milky Way plane ($| \ell | < 1^\circ$) PI: Sergio Molinari
- *Compact source catalogue (10^5 sources in $| \ell | < 70^\circ$; Elia et al. 2017)

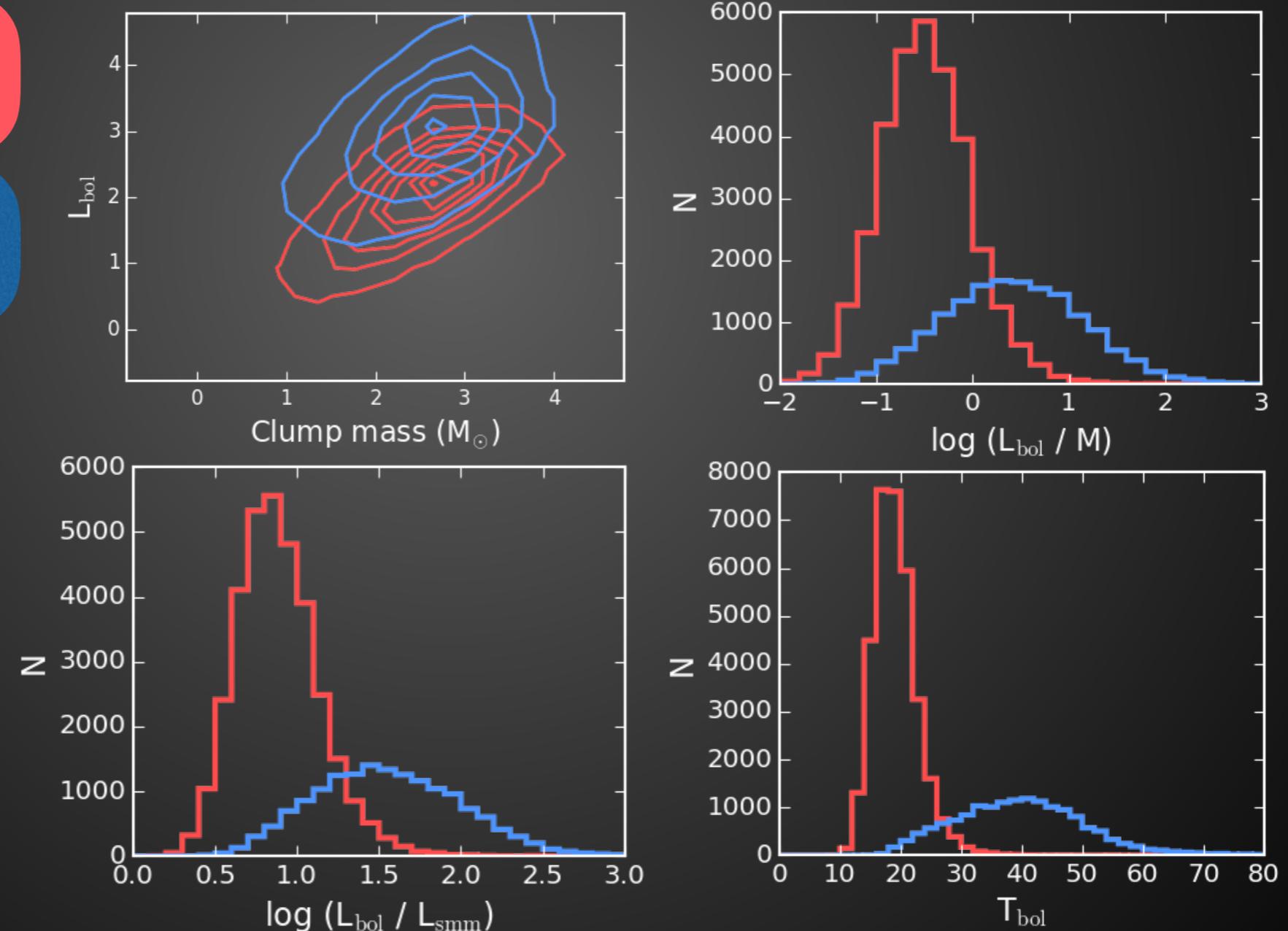


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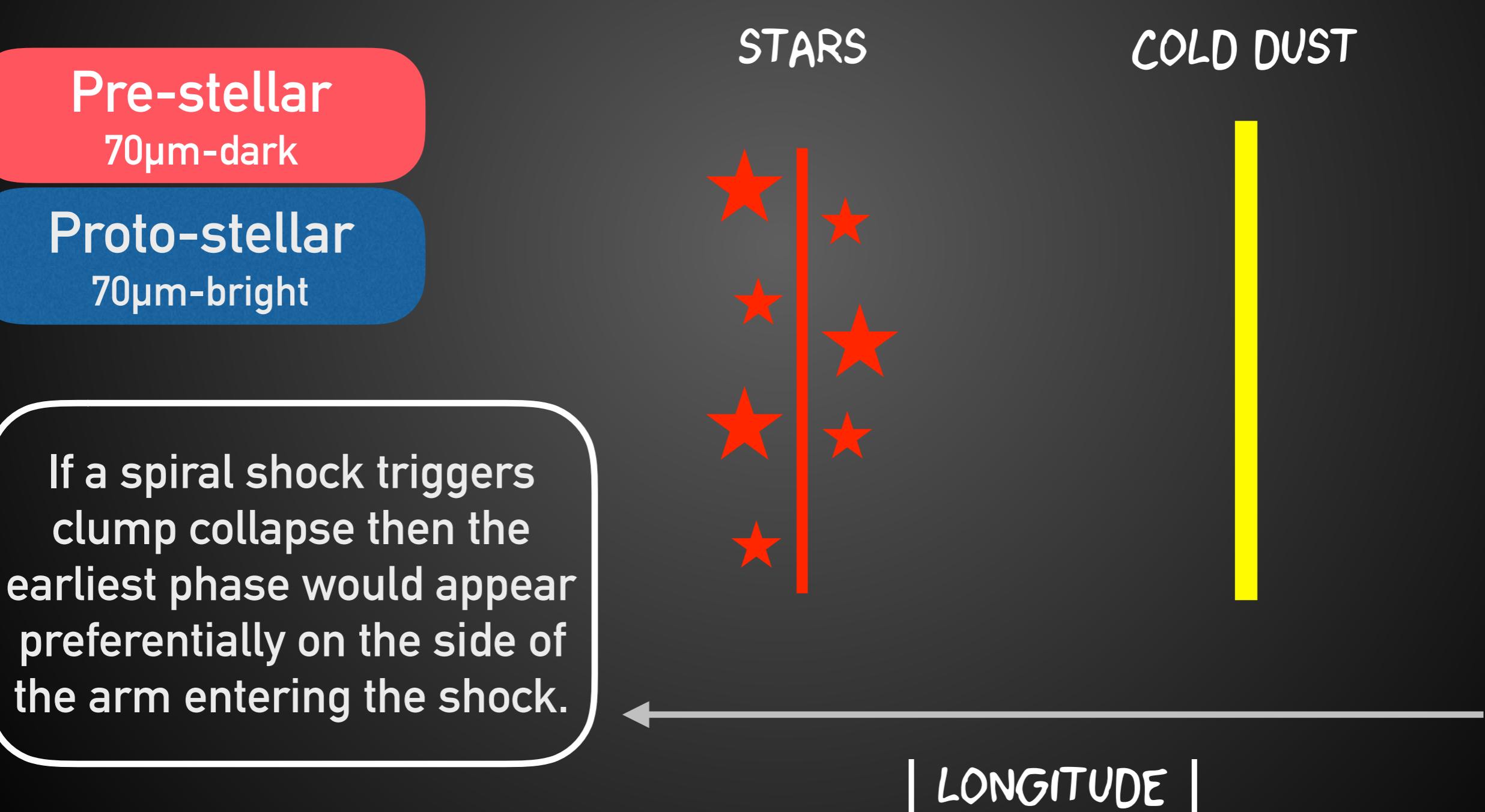
Pre-stellar
70 μ m-dark

Proto-stellar
70 μ m-bright



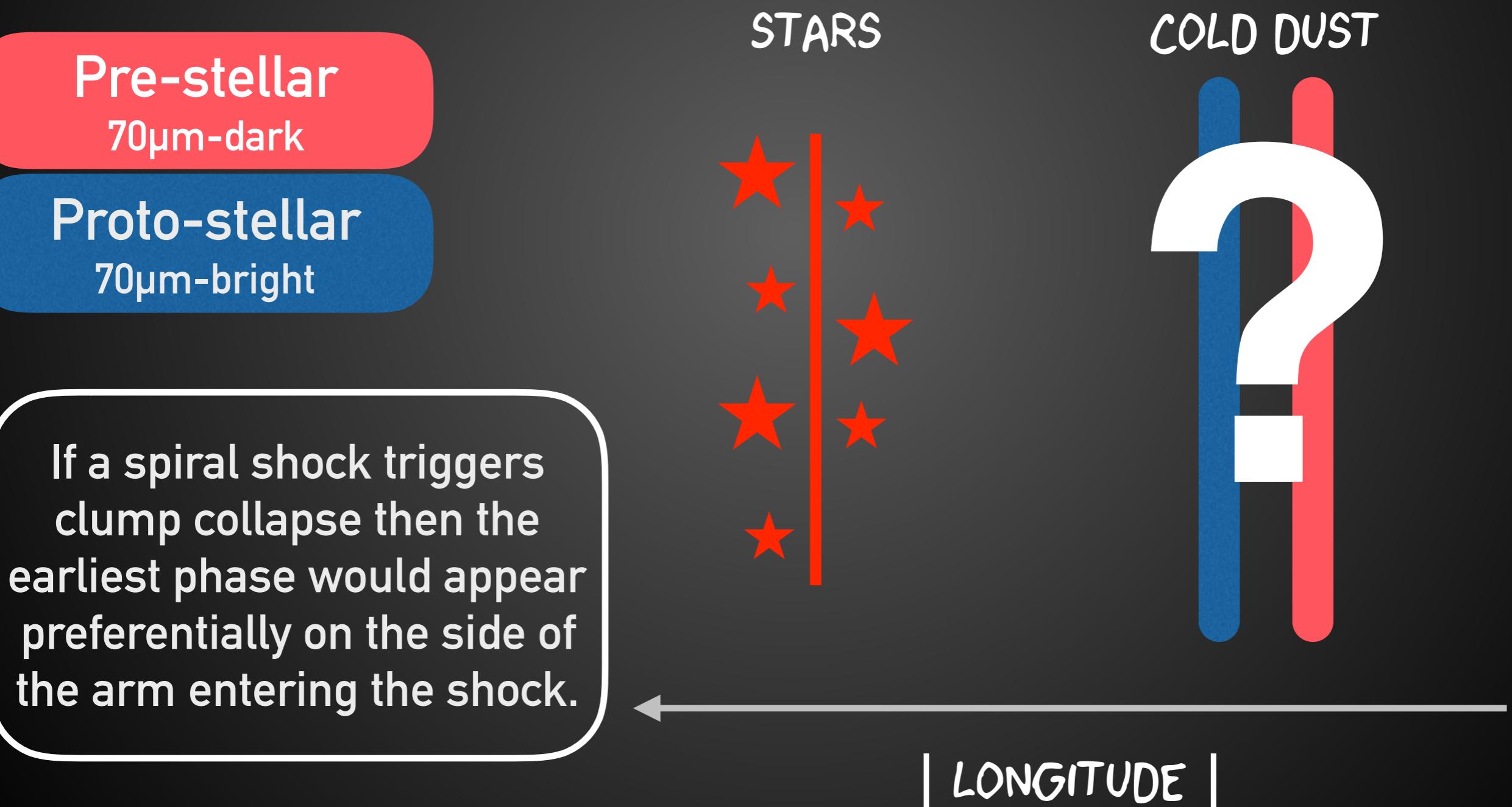
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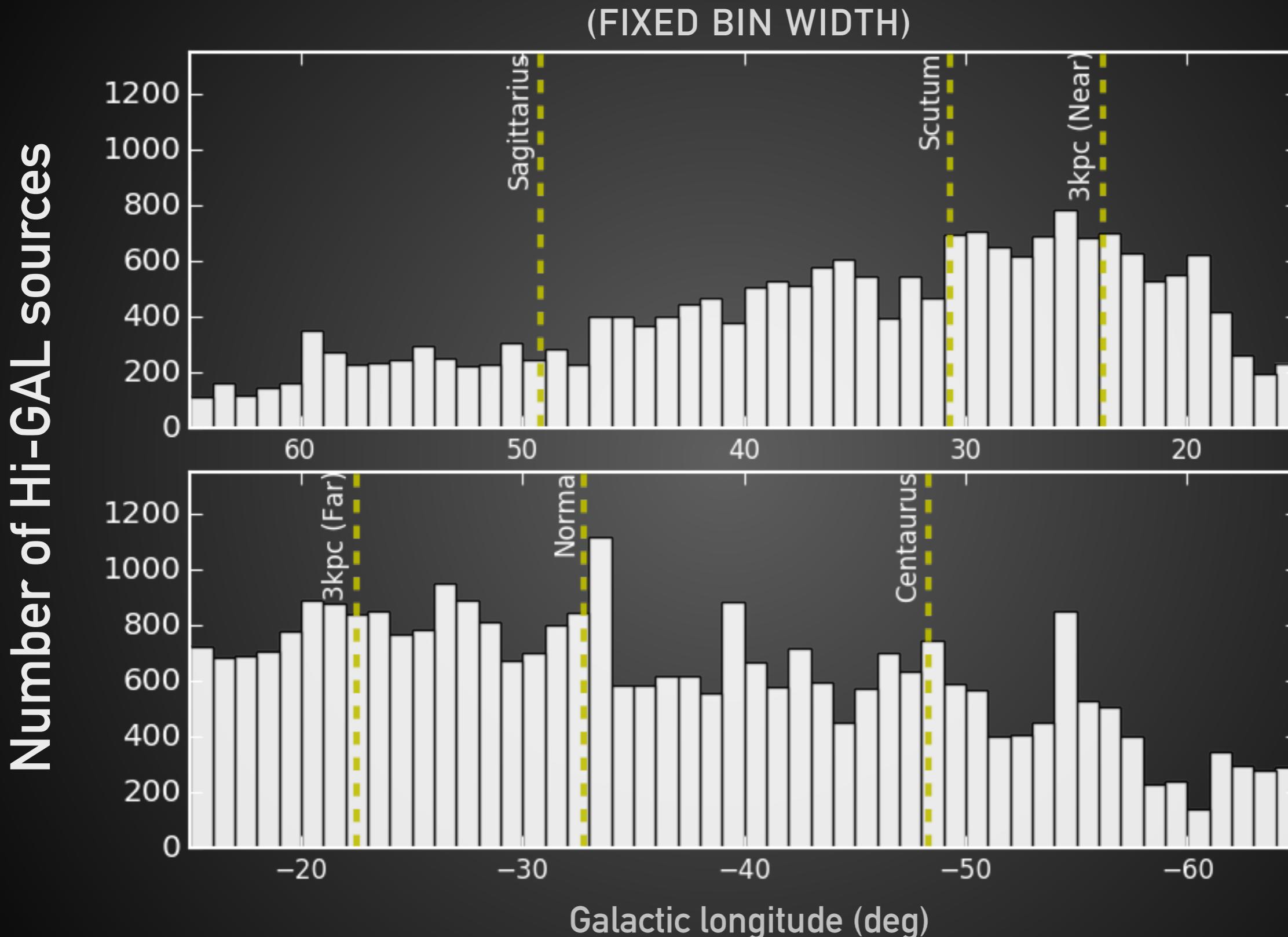


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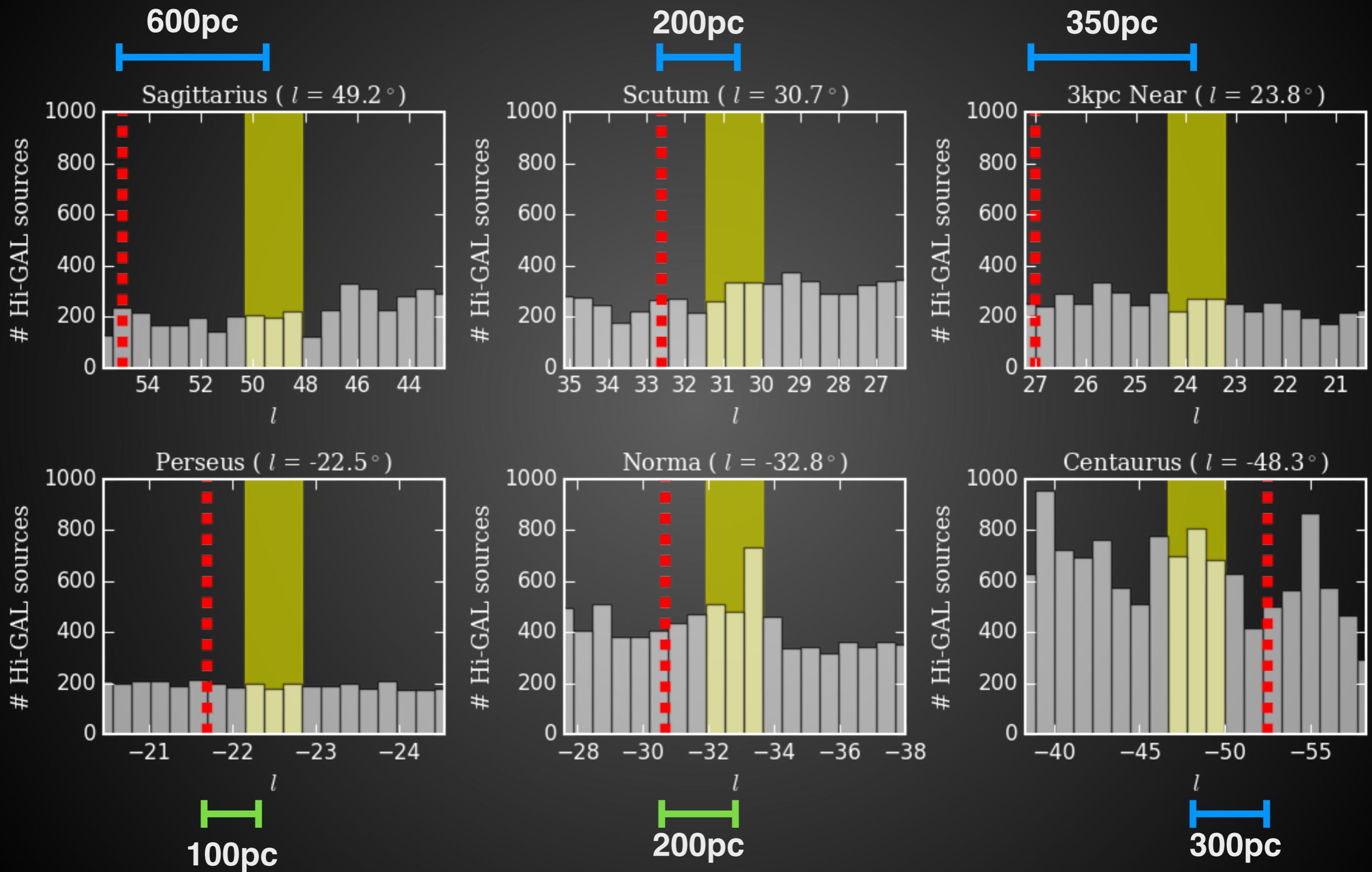
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HI-GAL SOURCE DISTRIBUTION WITH LONGITUDE



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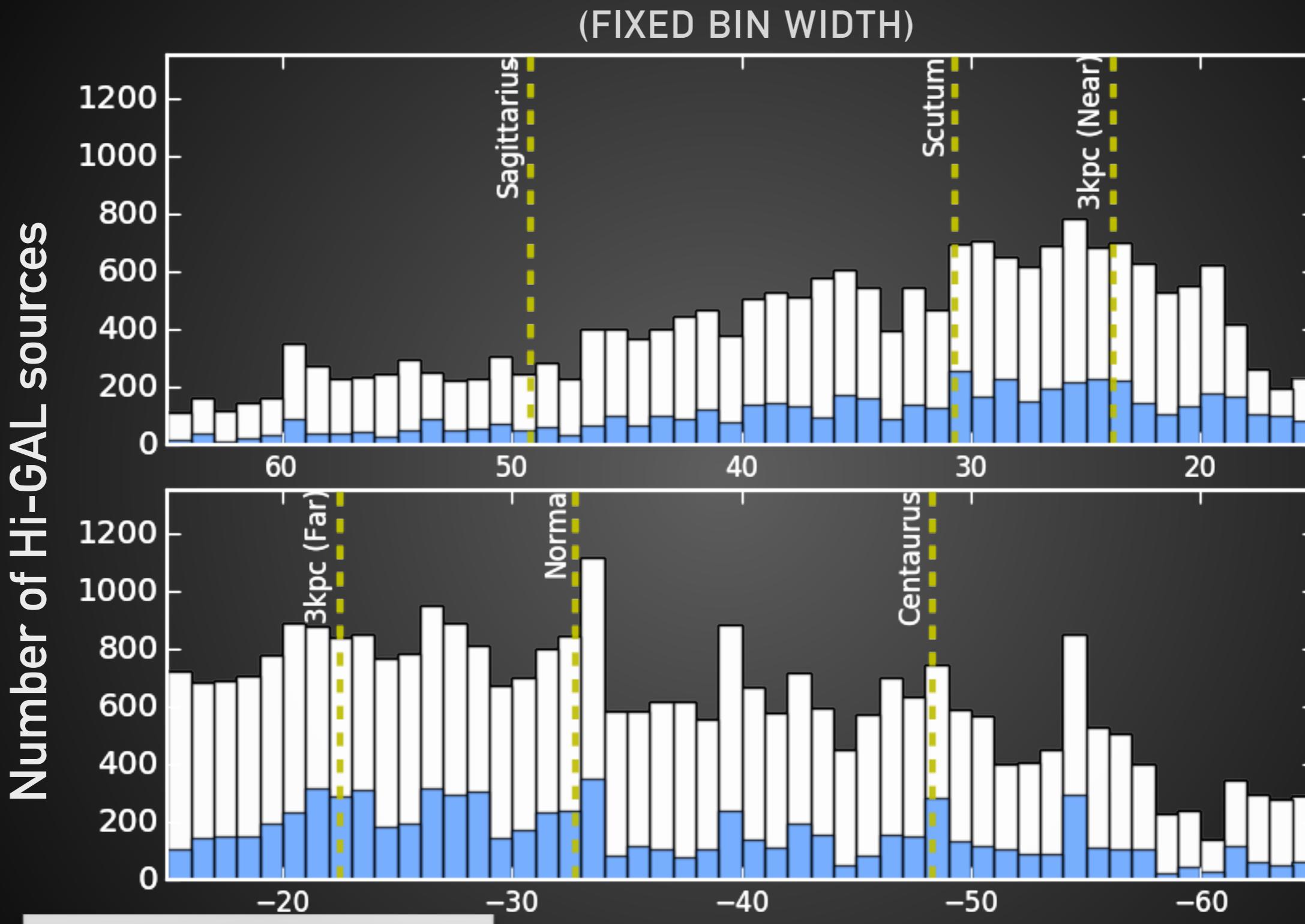


(ARM WIDTH FROM REID ET AL. 2014)

(PEAK STAR LONGITUDE FROM HOU & HAN 2015)

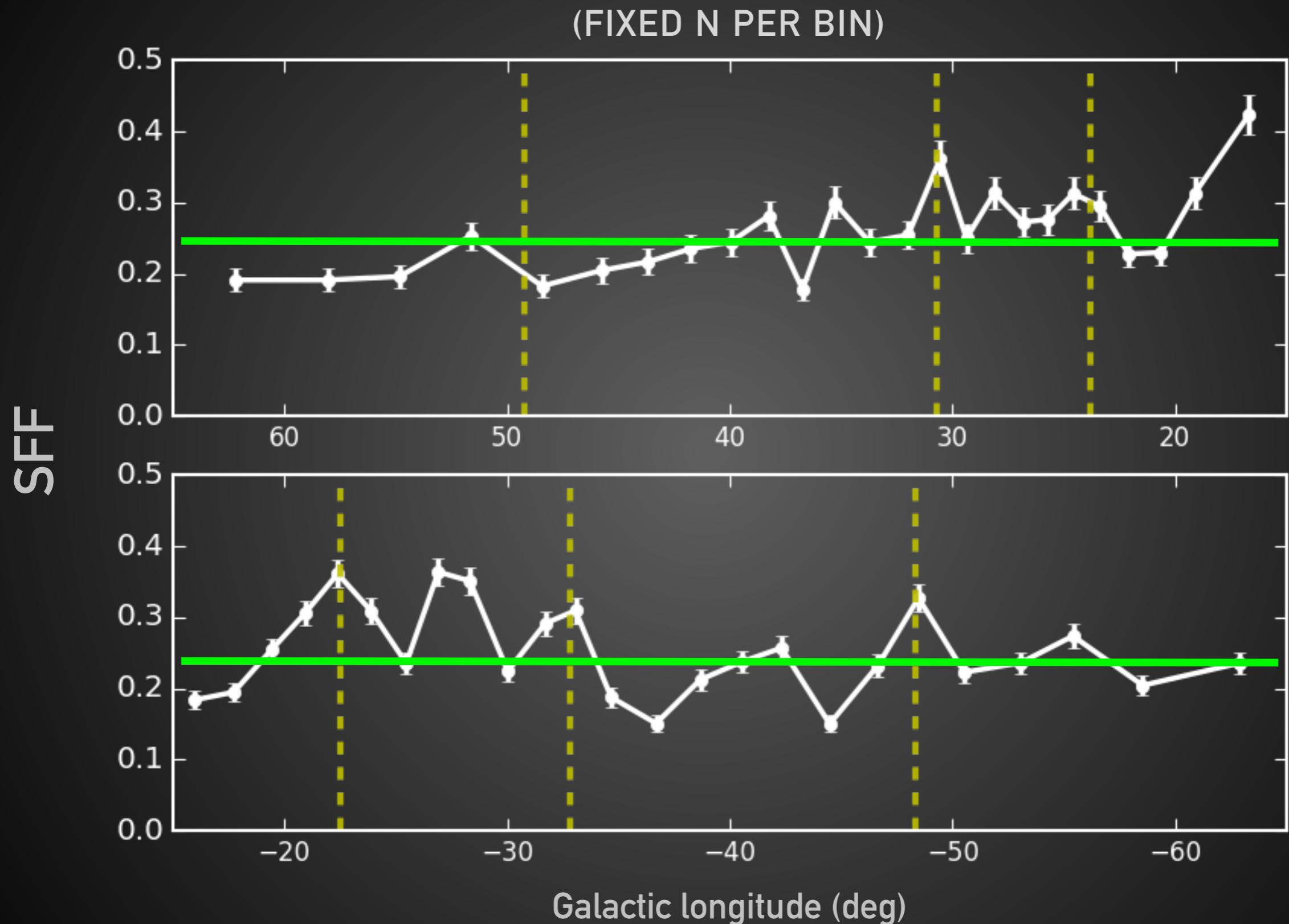
THE STAR-FORMING FRACTION (SFF)

Number of protostellar $\text{H}\alpha\text{-GAL}$ sources

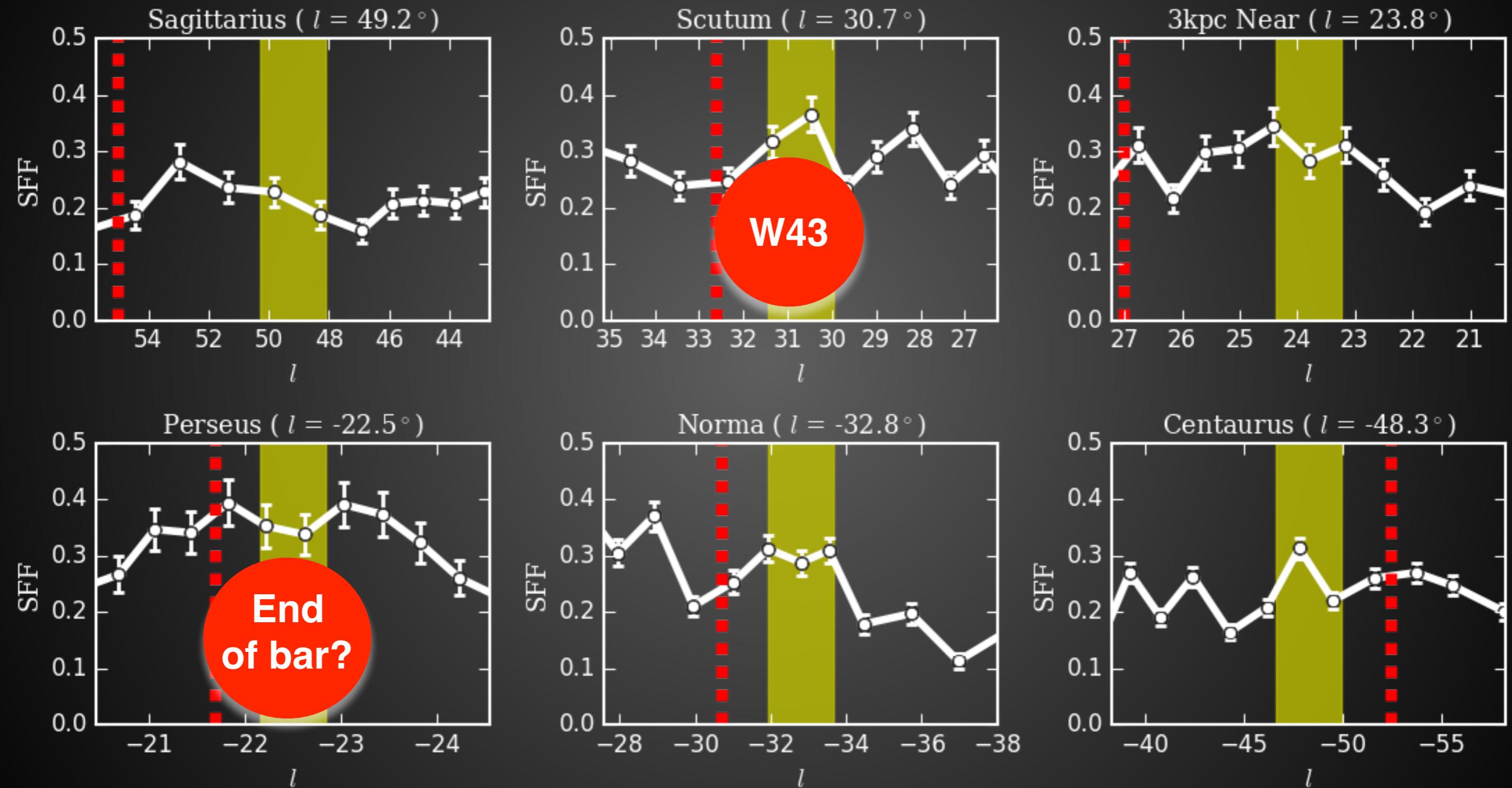


$$\text{SFF} = \frac{N_{\text{protostellar}}}{N_{\text{total}}}$$

SFF DISTRIBUTION WITH LONGITUDE

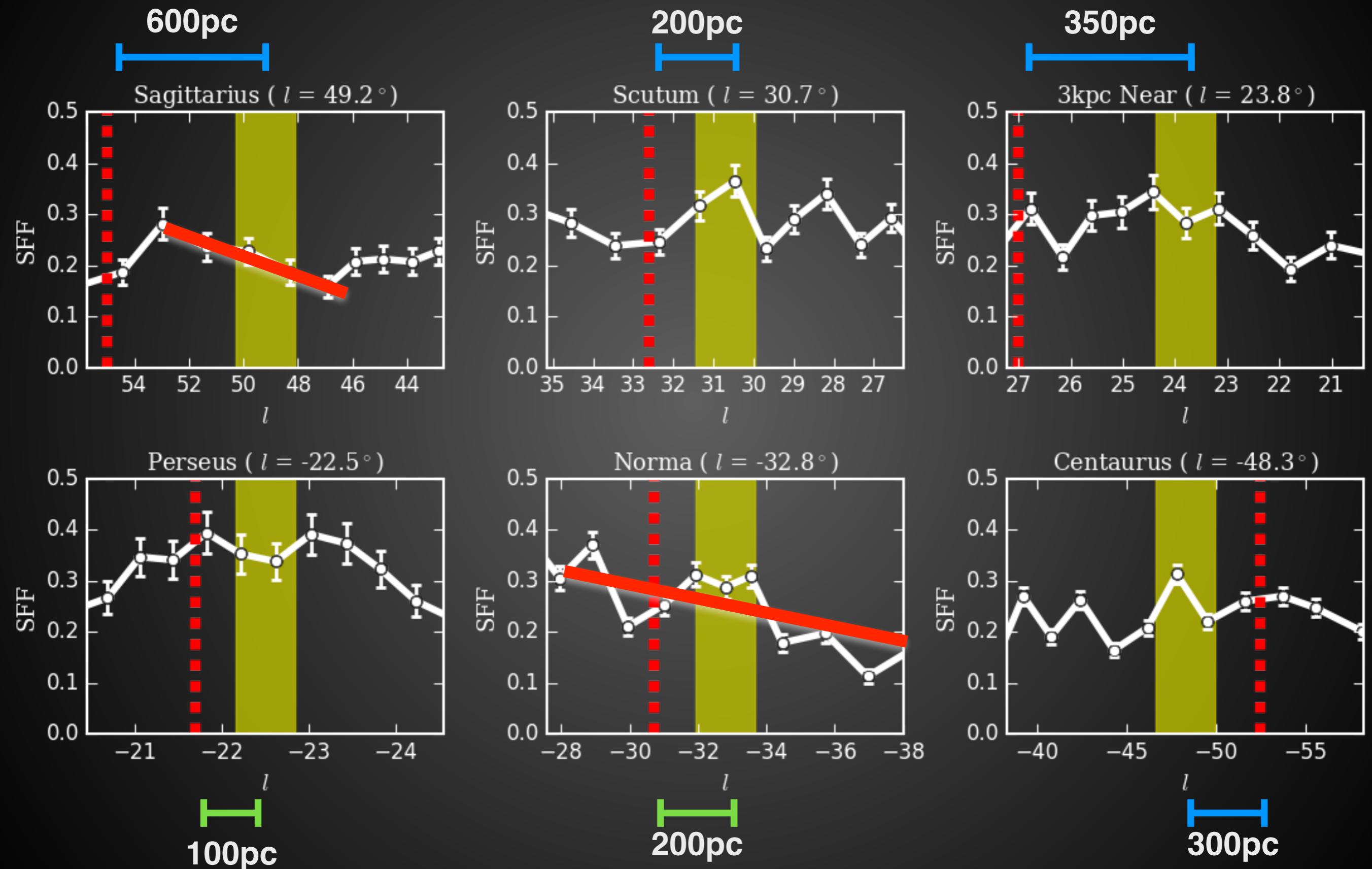


DO SPIRAL ARMS AFFECT STAR FORMATION?



- Significant peak (Scutum arm, top middle) is completely due to the W43 star-forming complex.
- Broad SFF excess at Perseus arm / bar end

DO SPIRAL ARMS AFFECT STAR FORMATION?



SUMMARY: SFF AT SPIRAL ARM TANGENTS

- * Weak / no evident patterns of clump evolutionary stage near tangent lines of sight (Ragan et al., 2018)
 - * Spiral arms accumulate clouds but show no strong evidence of enhanced star formation per unit mass
 - * Agrees with previous studies (e.g. Moore et al. 2012, Eden et al. 2012, 2013, Urquhart et al. 2014)

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A clump's position relative to the arm potential has no bearing on whether it is or will become star-forming.

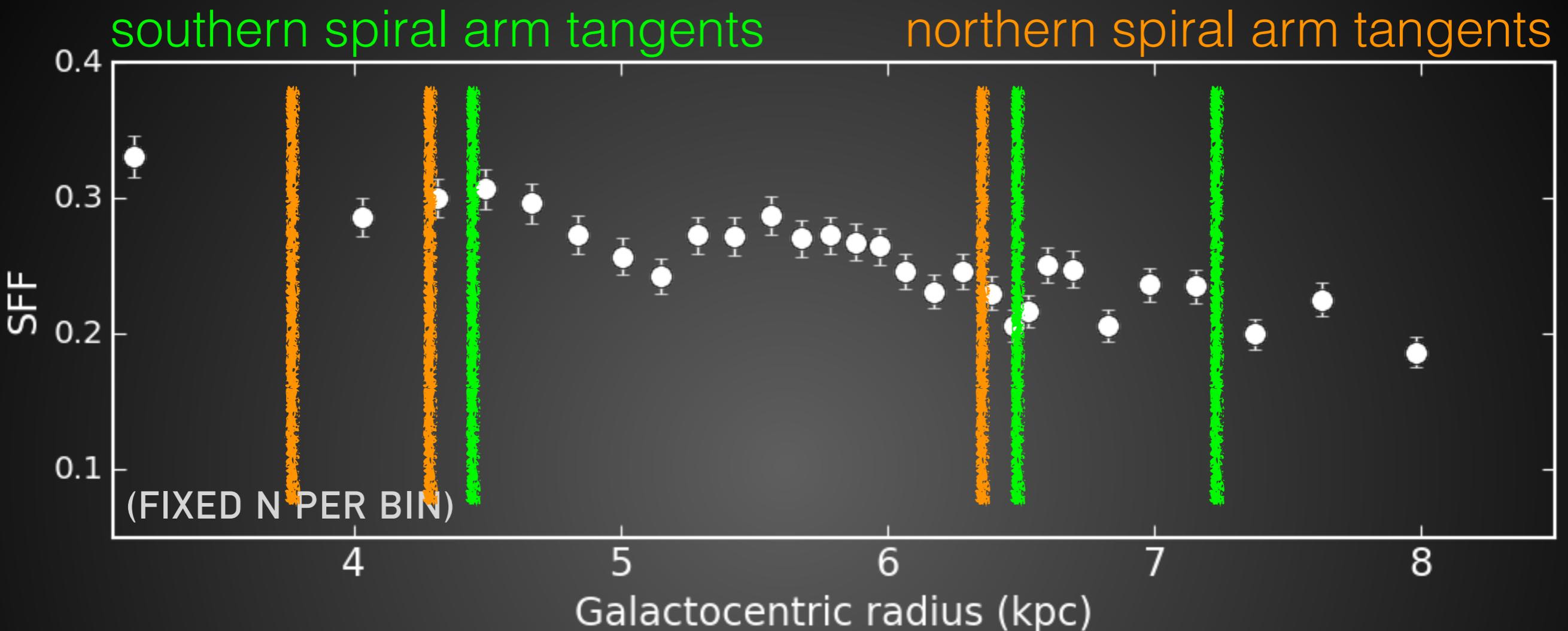
A clump is influenced by passage into the arm, but it is happening over spatial scales smaller than our resolution (< 100pc).

The time between clump formation and the onset of star formation is very short.

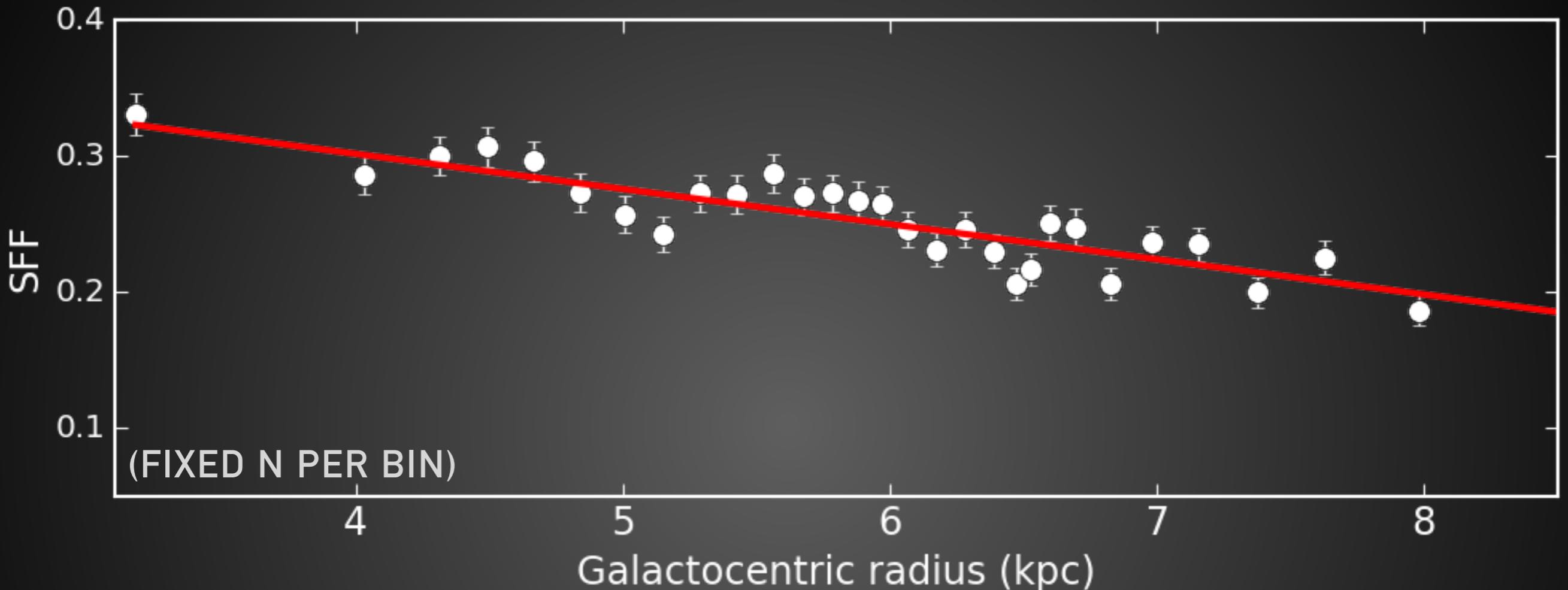
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Lin & Shu (1964), Roberts (1969)

SFF VS GALACTOCENTRIC RADIUS



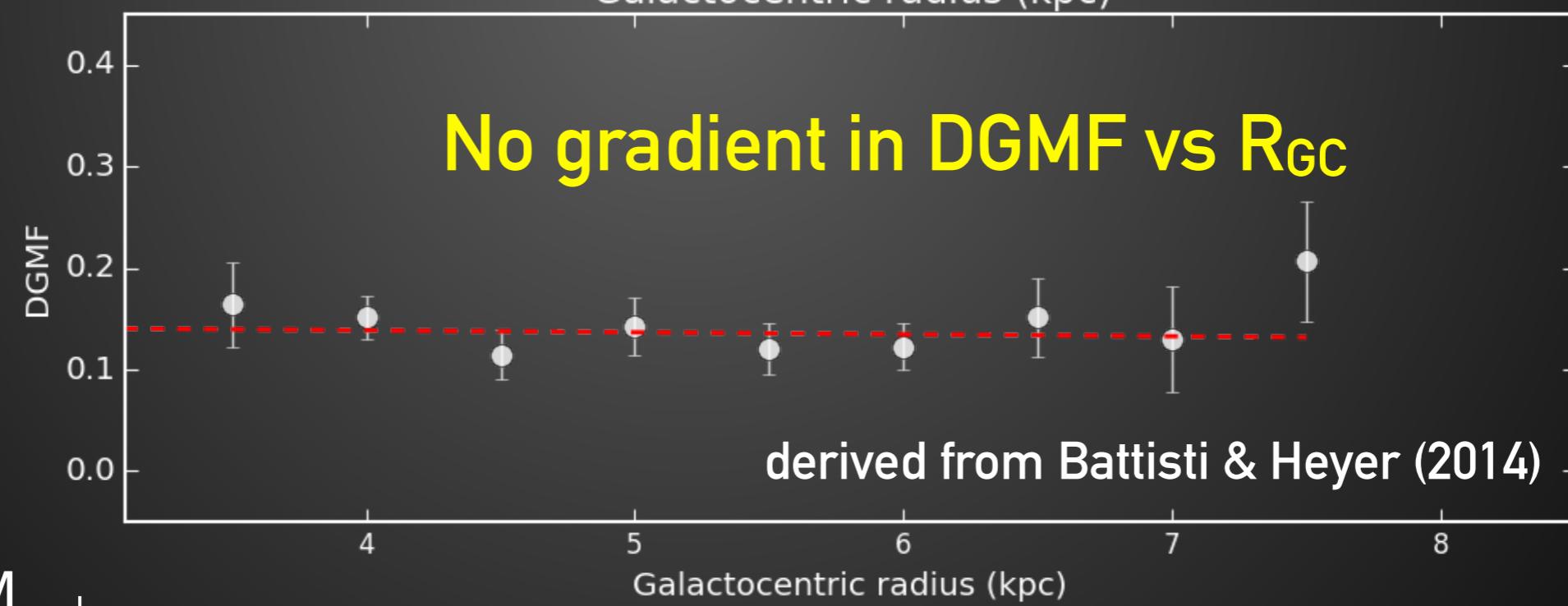
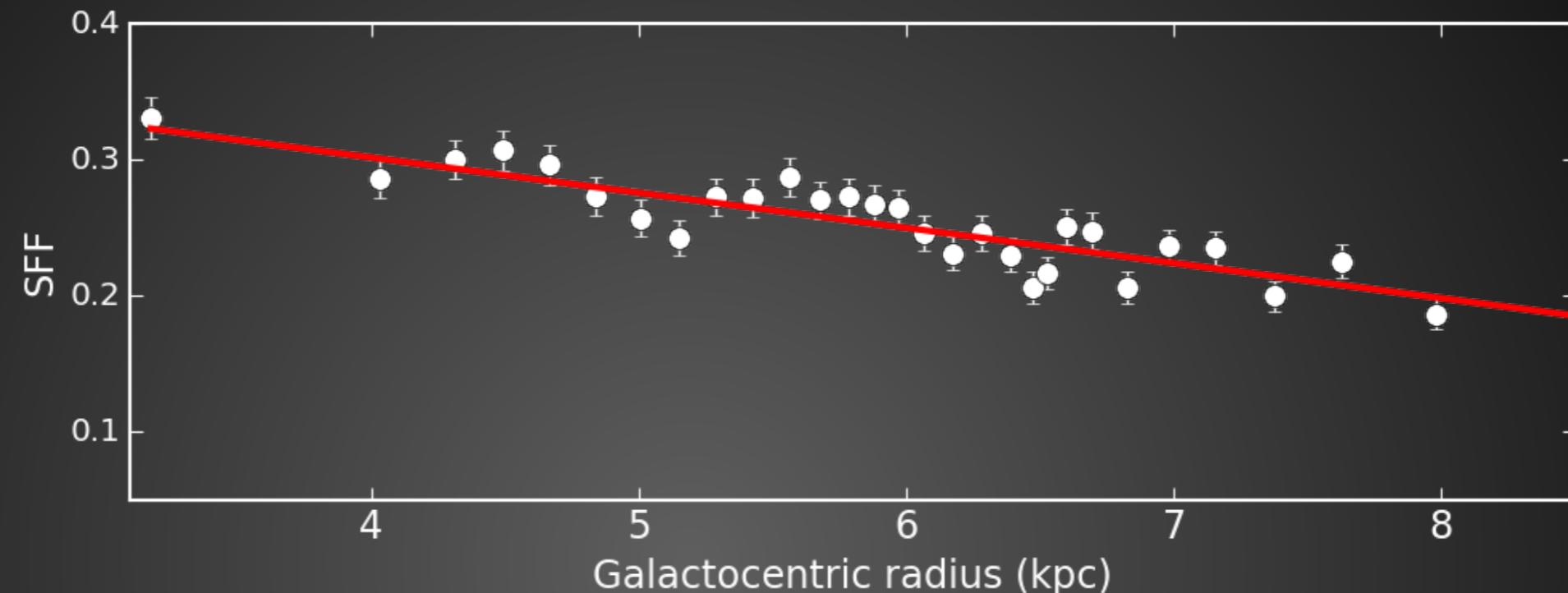
SFF VS GALACTOCENTRIC RADIUS



$$SFF = (0.406 \pm 0.003) - (0.026 \pm 0.002)R_{GC}$$

$$\rho_s = -0.91$$

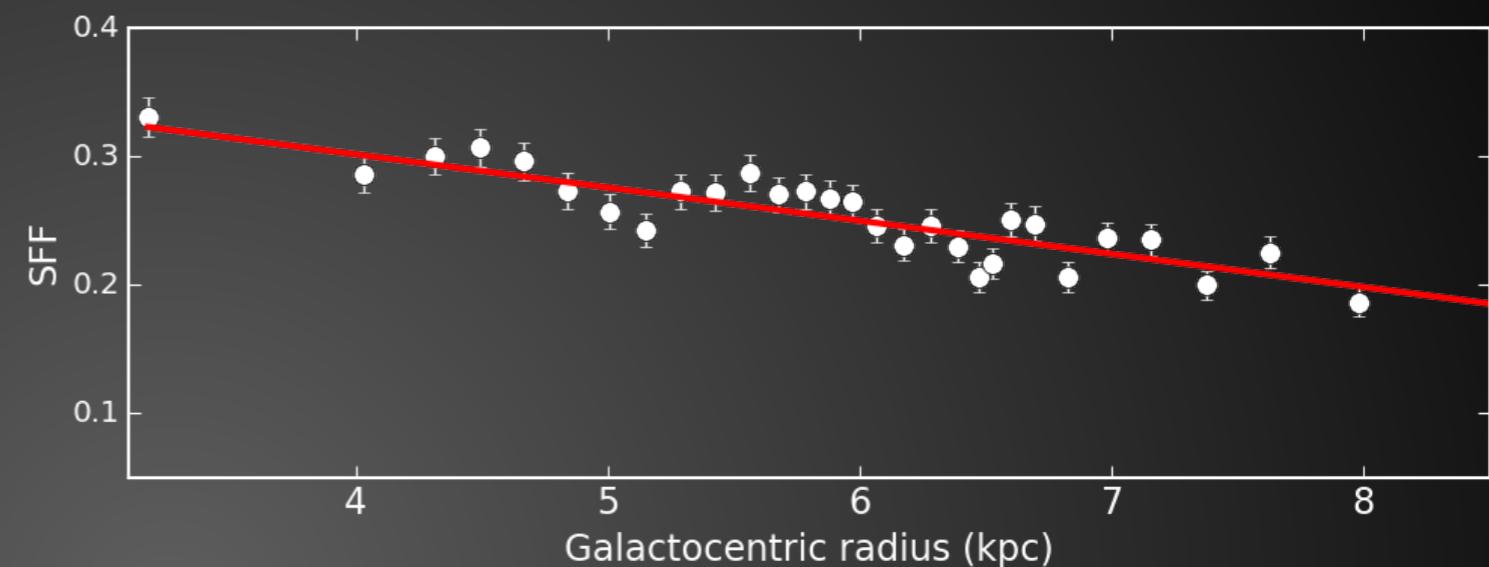
SFF & DGMF VS GALACTOCENTRIC RADIUS



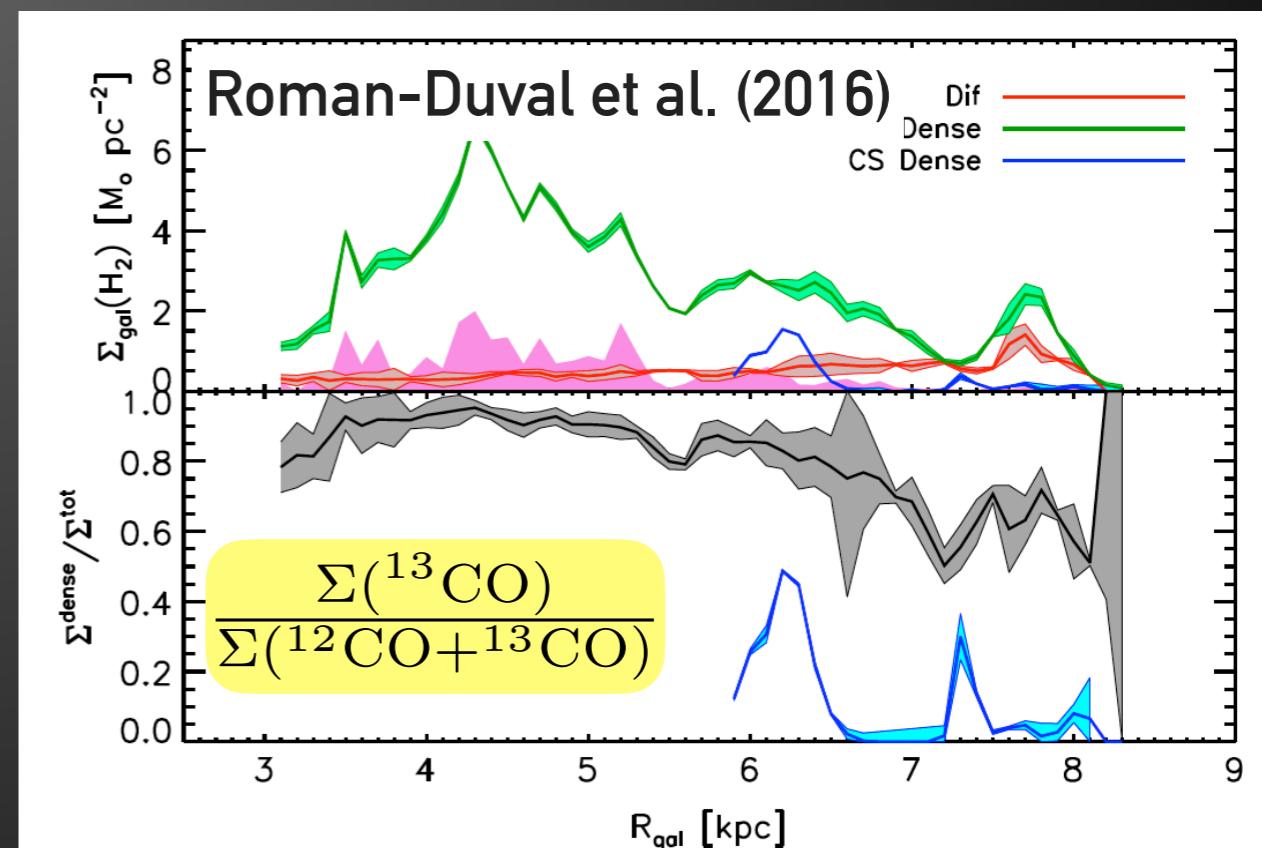
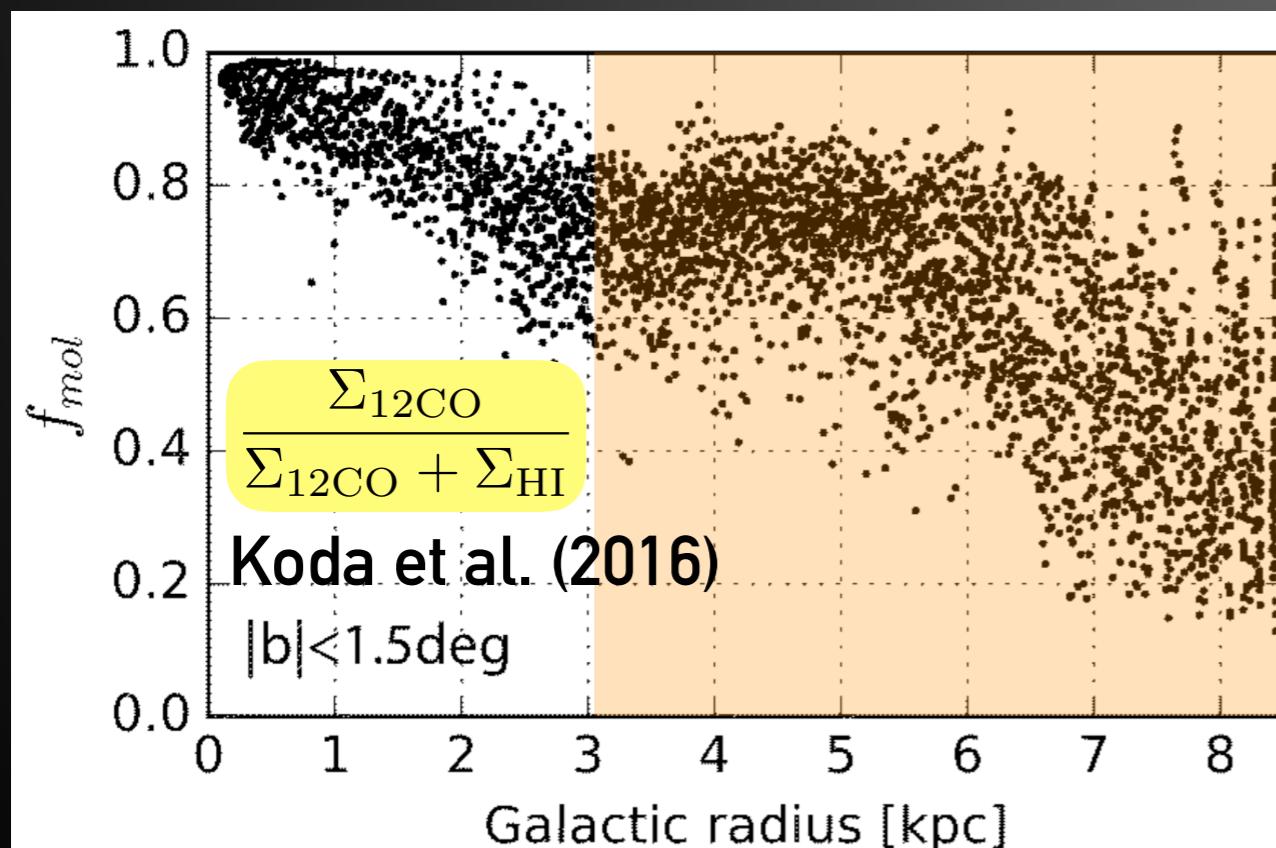
$$DGMF = \frac{M_{\text{sub-mm}}}{M_{13\text{CO}}}$$

KILOPARSEC SCALE GRADIENTS IN THE MILKY WAY

Is the SFF “set” by large-scale physical conditions?



ISRF? Metallicity? External pressure?



Ragan et al. (2016)

SUMMARY

- * Weak / no evident patterns of clump evolutionary stage near tangent lines of sight (Ragan et al., 2018)
 - * Spiral arms accumulate clouds but show no strong evidence of enhanced star formation per unit mass
 - * Agrees with previous studies (e.g. Moore et al. 2012, Eden et al. 2012, 2013, Urquhart et al. 2014)
- * We observe a robust gradient in SFF with R_{GC} in the inner Galaxy ($3\text{kpc} < R_{\text{GC}} < 8\text{kpc}$) of $-2.6\%/\text{kpc}$ (Ragan et al. 2016)
 - * Dense Gas Mass Fraction does not vary with R_{GC}
 - * Is the SFF determined by / inherited from large-scale physics?

OUTLOOK

- * We tried looking for the obvious thing. It didn't work.
- * We are still bedevilled by imperfect tracers
- * The continued effort to bring disparate datasets together will help us do better.

