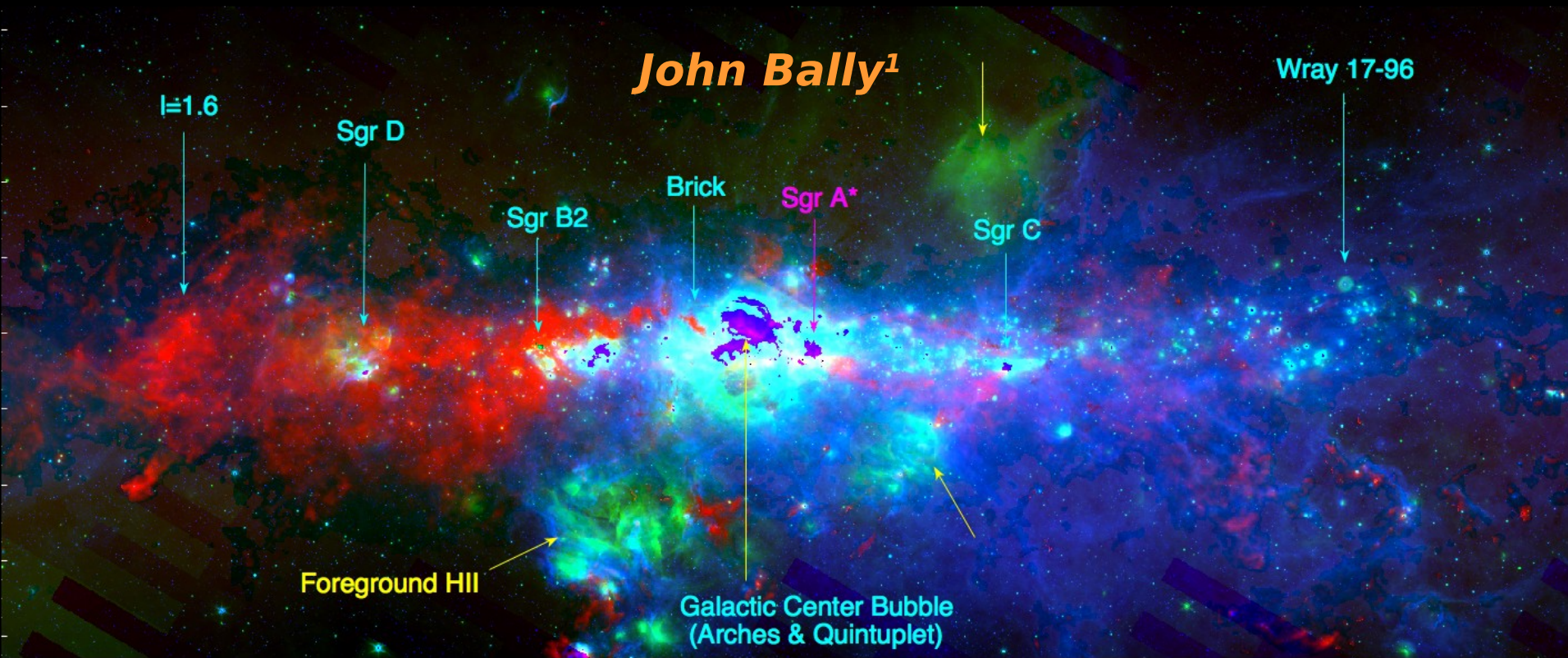


The CMZ Asymmetries: Feeding or Feedback?

Or Small Number of Bound Clouds which Resist Tidal Shear?

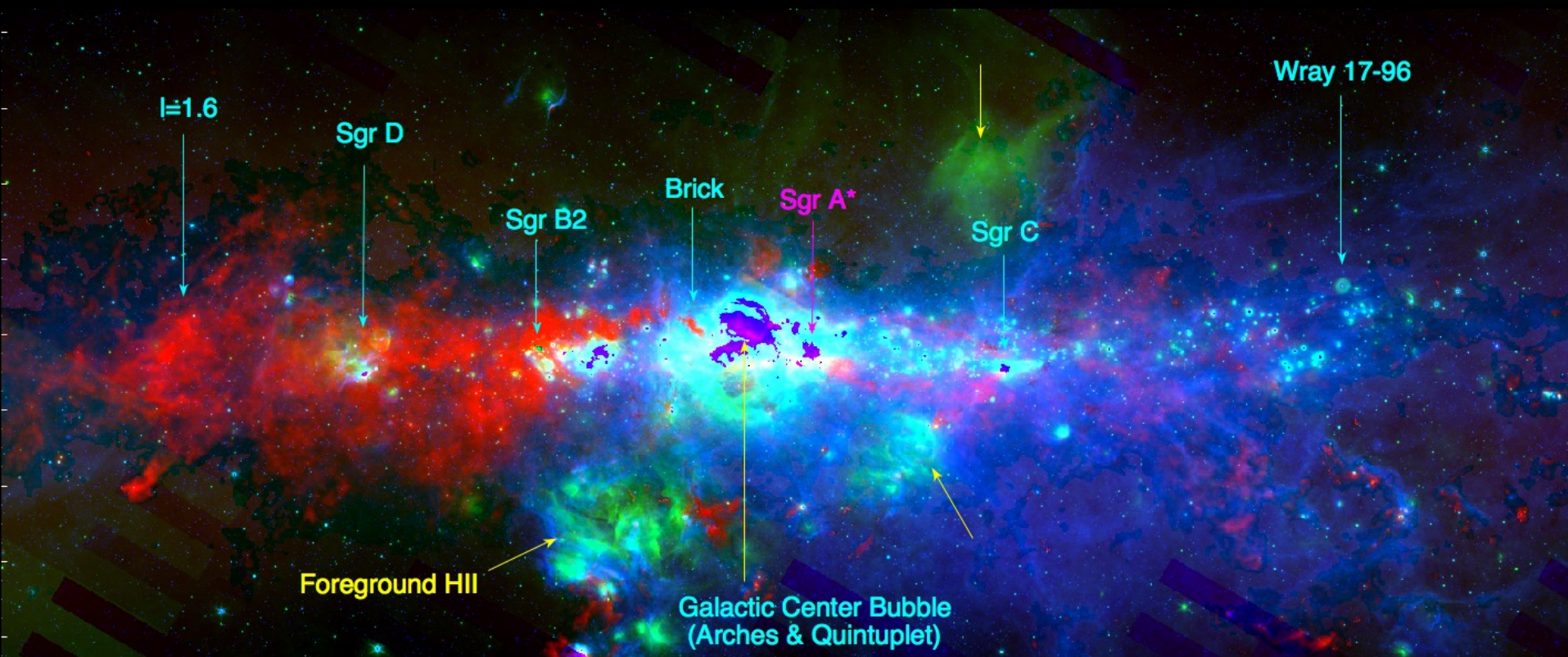


**¹Center for Astrophysics and Space Astronomy (CASA)
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The Inner CMZ

$N(H_2)$

8 μm 24 μm



+2.0°

-2.0°

Central Molecular Zone (CMZ)

Denser, more turbulent than disk GMCs: $M_{\text{gas}} \sim 2 - 5 \times 10^7 M_{\odot}$

Star Formation Rate (SFR): $\sim 0.04 \text{ to } 0.1 M_{\odot} \text{ yr}^{-1}$

Infall Rate from Disk: $\sim 1 M_{\odot} \text{ yr}^{-1}$

- **The Two Asymmetries:**

Gas & dust: $> 3/4$ at **POSITIVE** longitude, + velocity

24 m sources: $> 2/3$ at **NEGATIVE** longitude

- **Short orbit times & Shear :** $t_{\text{orbit}} \sim 3 \text{ Myr } R_{100 \text{ pc}} / V_{200 \text{ km/s}}$
(1 to 10 Myr)

Asymmetries:

Feedback disrupted quadrant of CMZ?

Compact 24 μm sources a sheared super star cluster?

MYSO ($t < 0.1$ Myr)

O/B stars (Compact HII regions)

Post-Main-Sequence (3 to 30 Myr old stars

(Jang & An+ 2022)

Dissociate, “puff-up” a CMZ sector?

Recent Infall of GMC along one bar dust lane ?

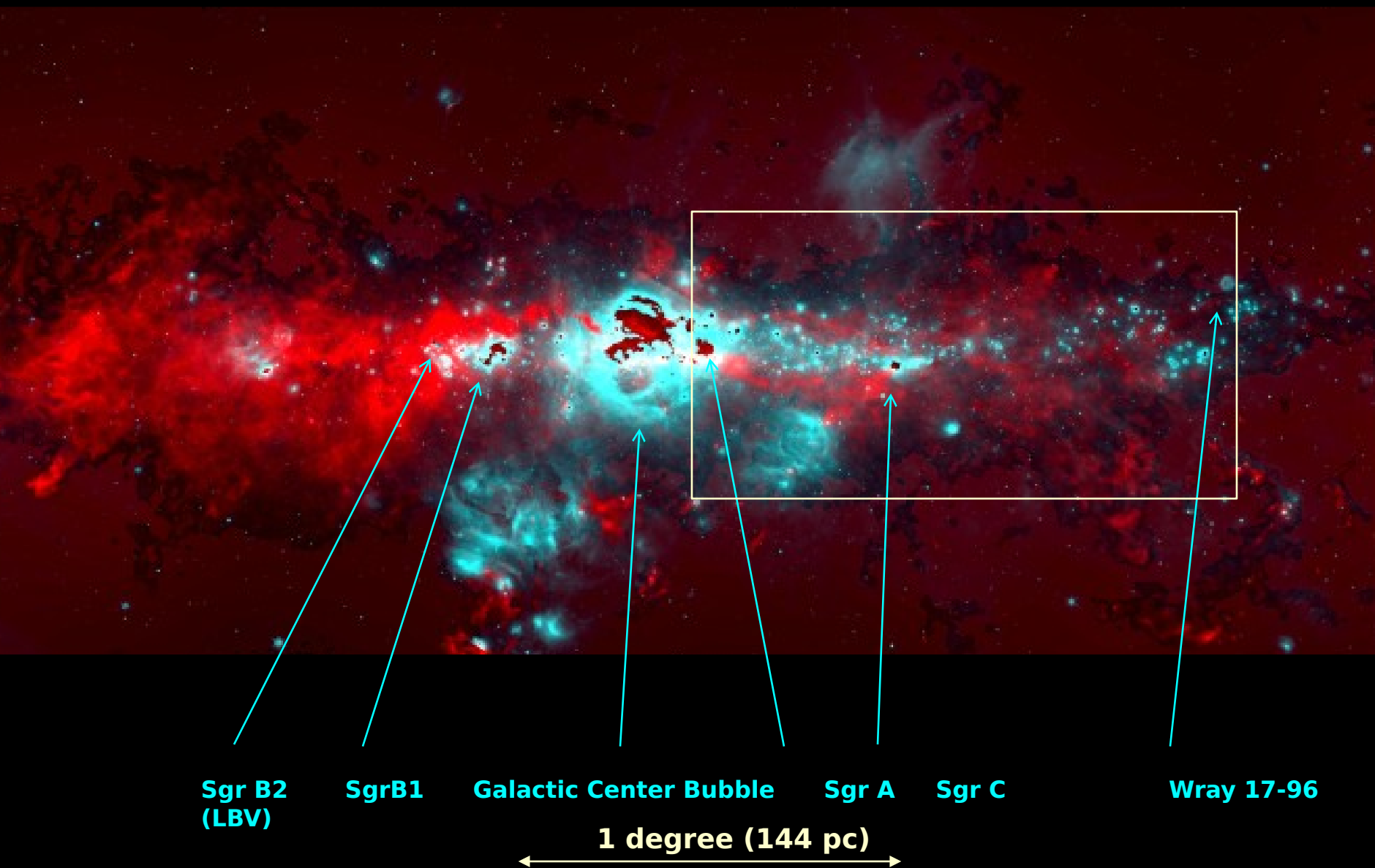
Bania's Clump2 (G3.3), G1.3, G5, ...

Small number of $>10^6 M_{\odot}$ GMCs ?

$$r_{\text{GMC}} < R_{\text{tidal}} = R_{\text{orbit}} (m_{\text{GMC}} / 2 M_{\text{gal}})^{1/3}$$

$$n(\text{H}) > 1.3 \times 10^4 V_{200 \text{ kms}}^2 R_{100 \text{ pc}}^{-2} (\text{cm}^{-3})$$

$N(H_2)$ from Herschel Hi-GAL **24 μm**
Snitzer



1 GHz 24 μ m 8 μ m

Negative longitudes

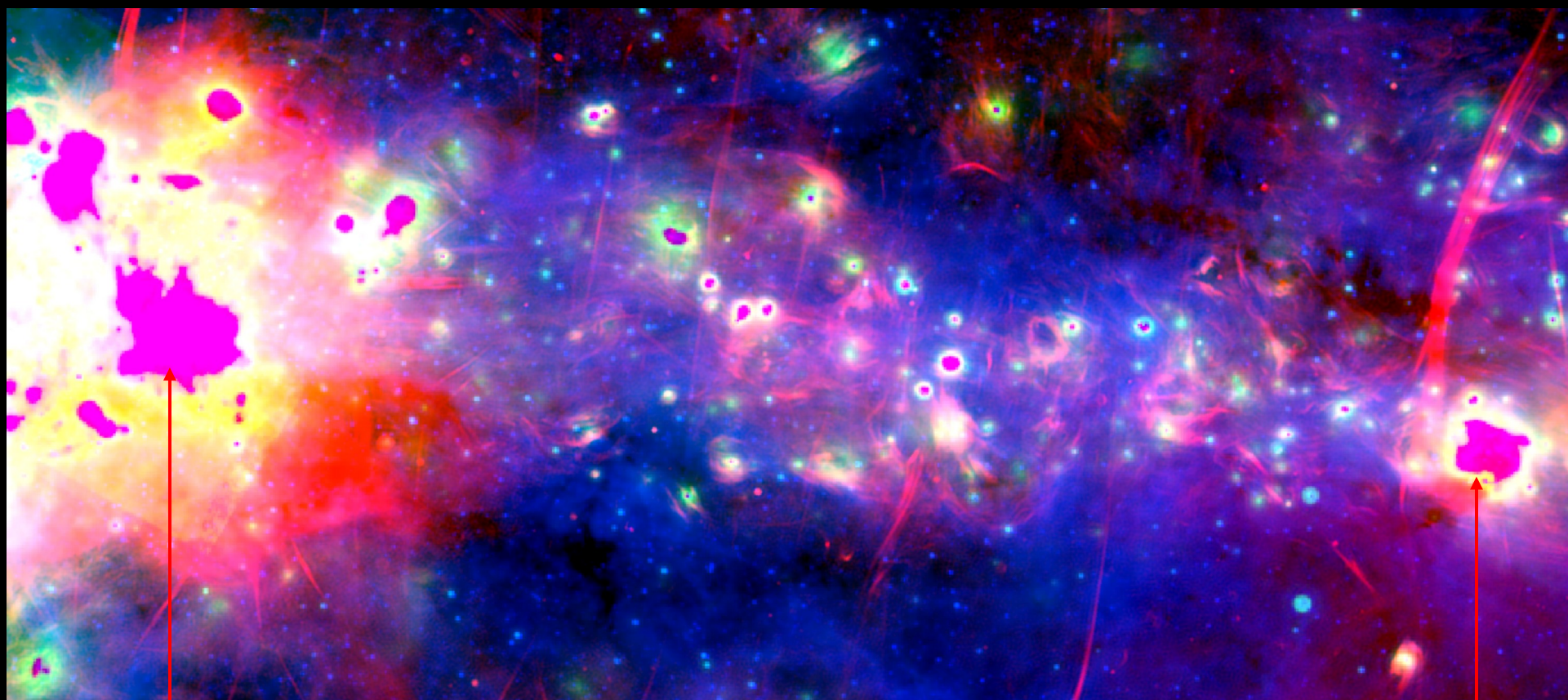


Sgr A

Sgr C

1 degree (144 pc)

MeerKAT 1.3 GHz, Spitzer 24 μ m, 8 μ m

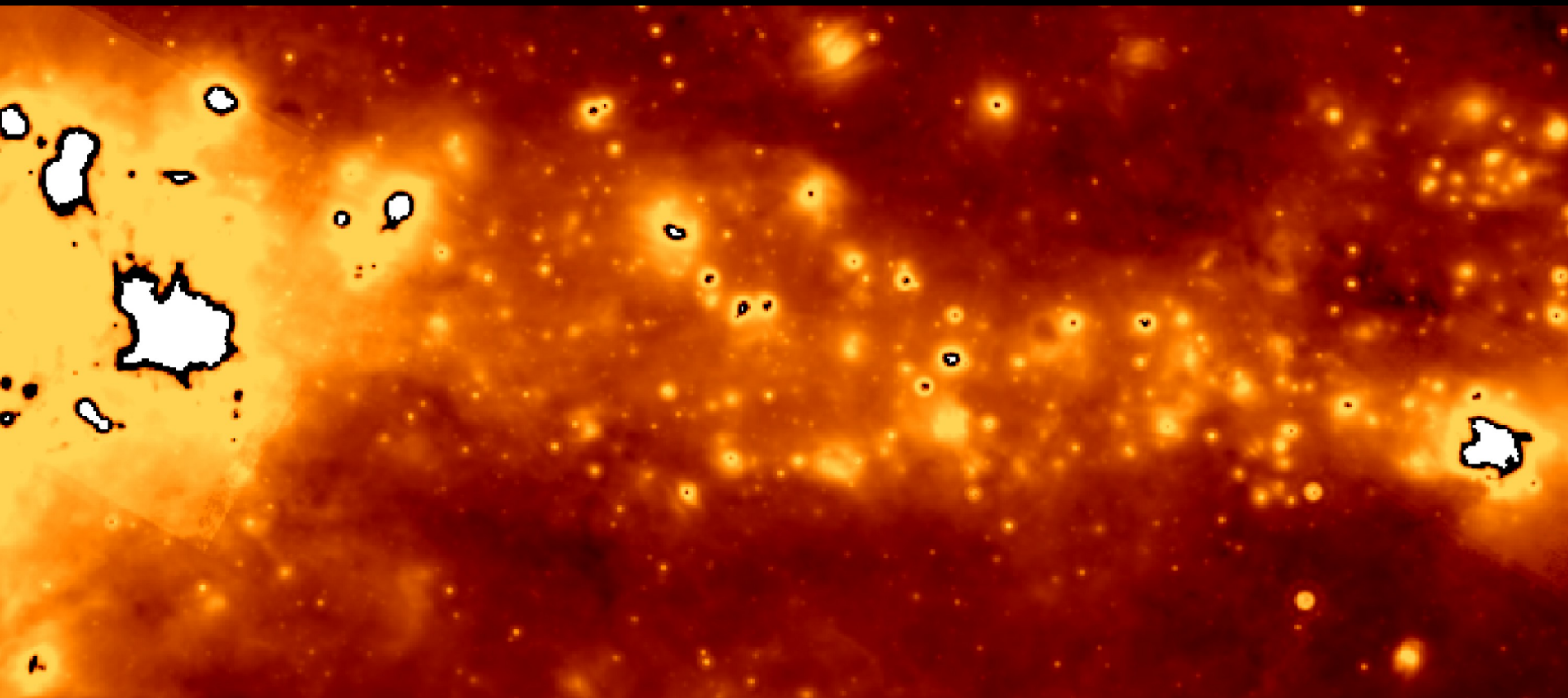


Sgr
A*

Sgr C

Spitzer

24 μ m

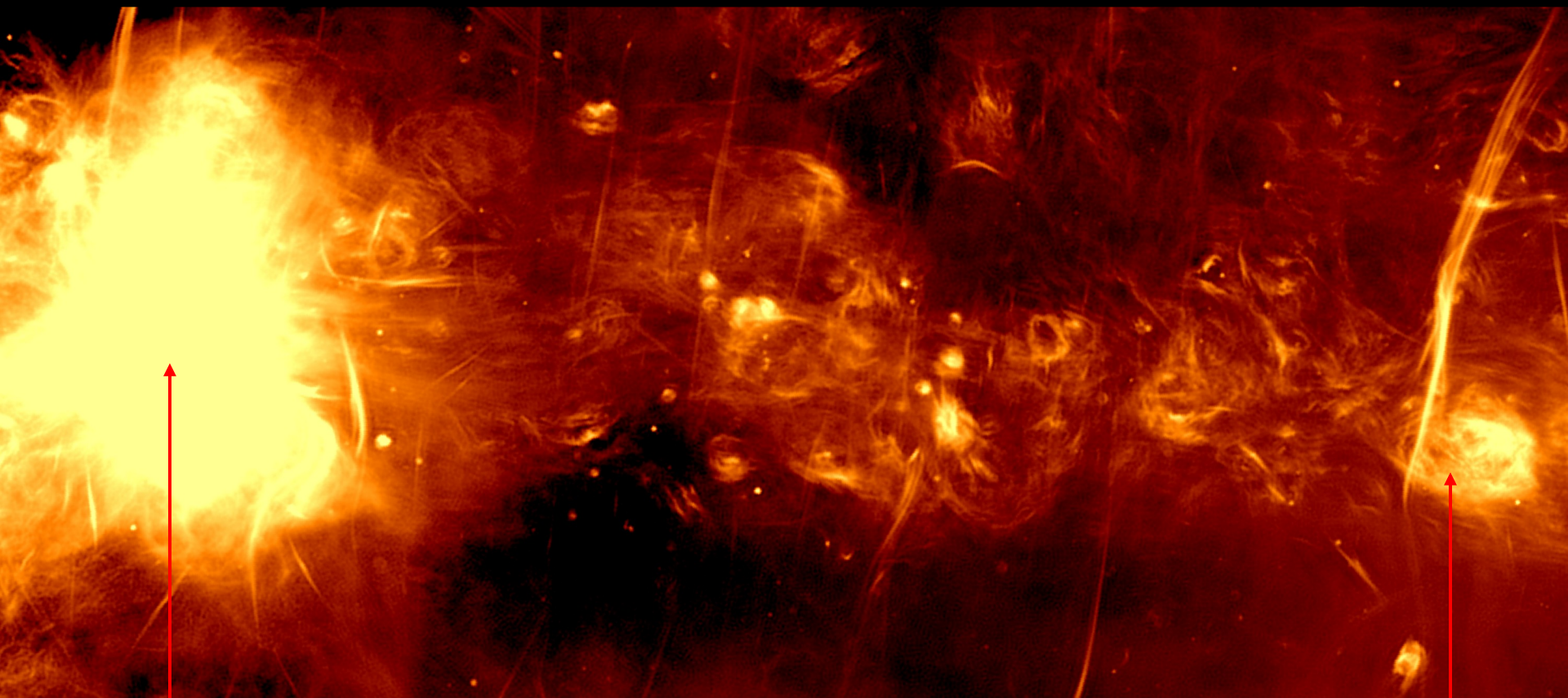


**Sgr
A***

Sgr C

MeerKAT

1.3 GHz continuum



**Sgr
A***

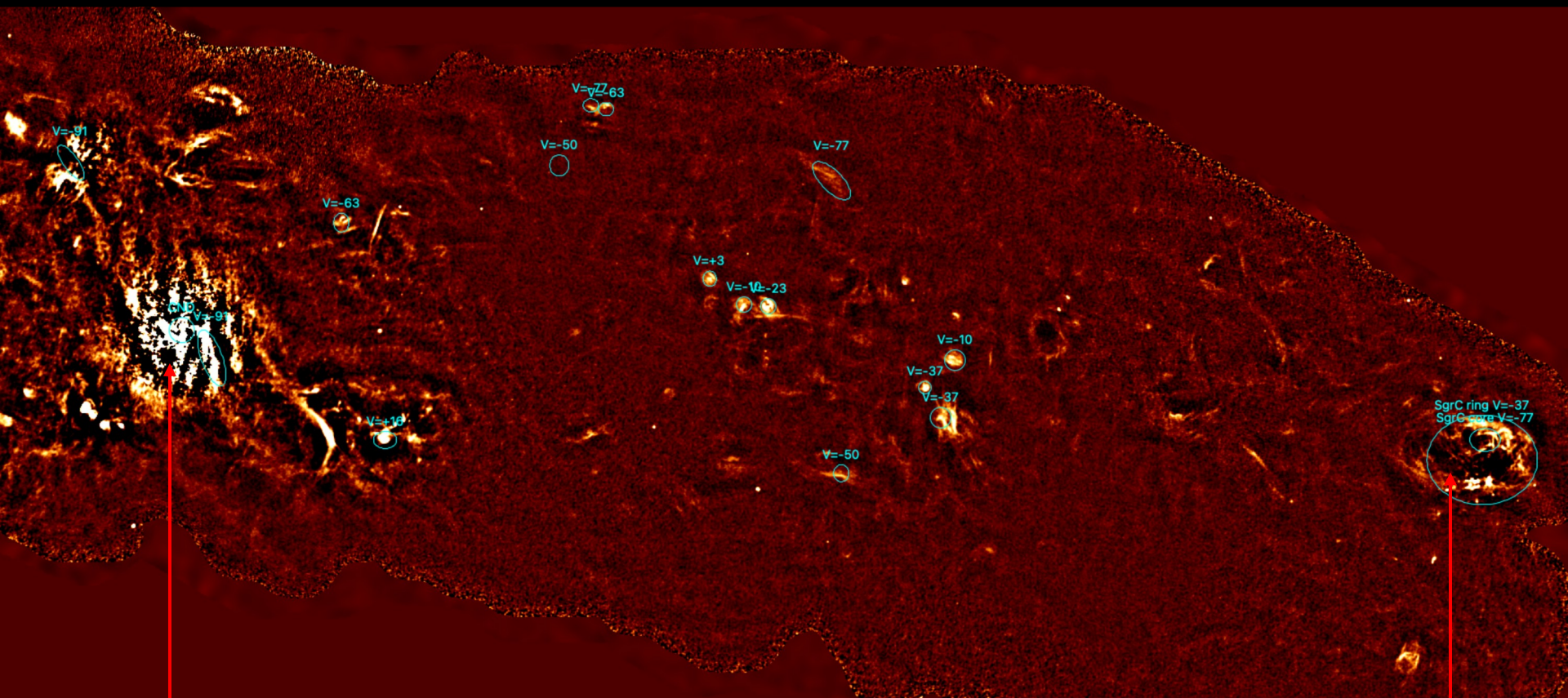
Sgr C

ACES

3 mm continuum

Compact HII region LSR radial velocities from

H40 α



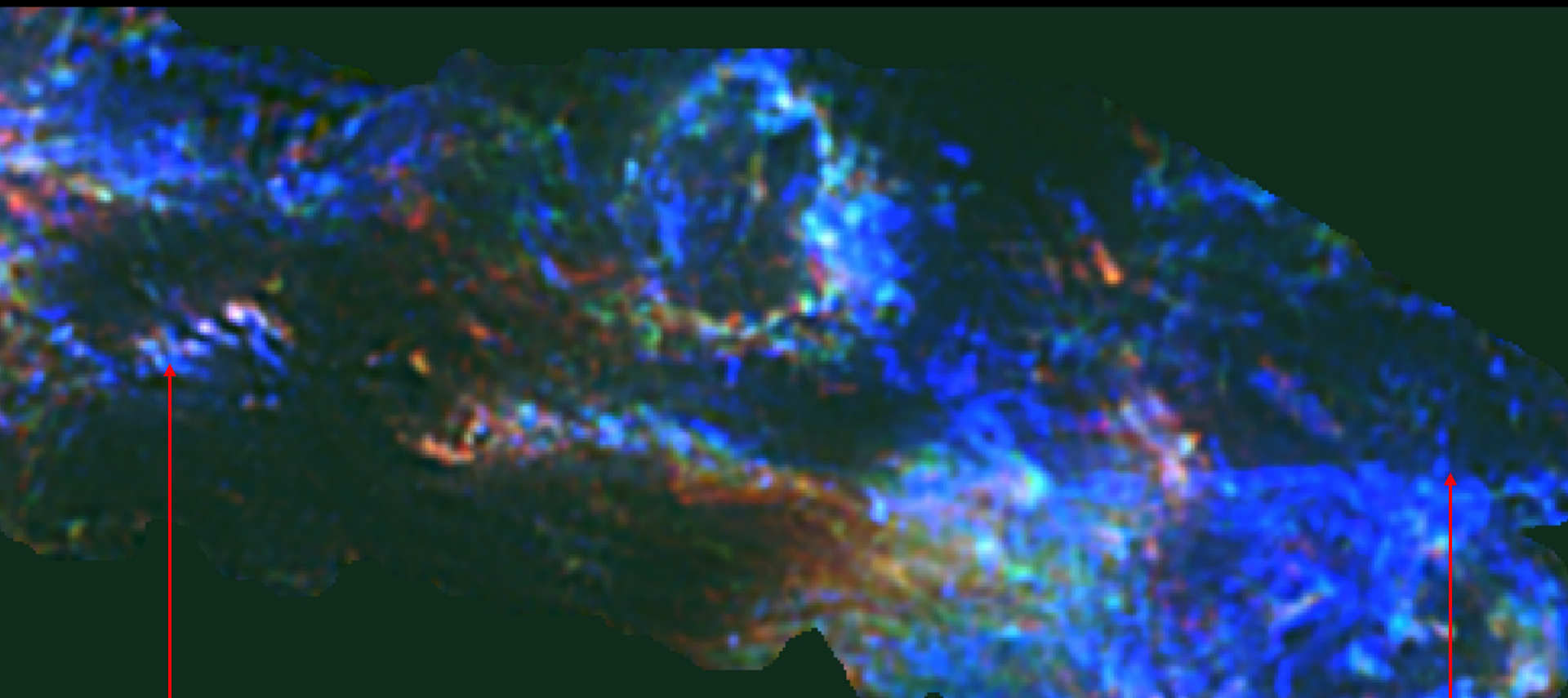
**Sgr
A***

Sgr C

ACES
1

CS J=2-

V = -24 to -30 km/s
= -31 to -37 km/s
= -38 to -44 km/s



Sgr
A*

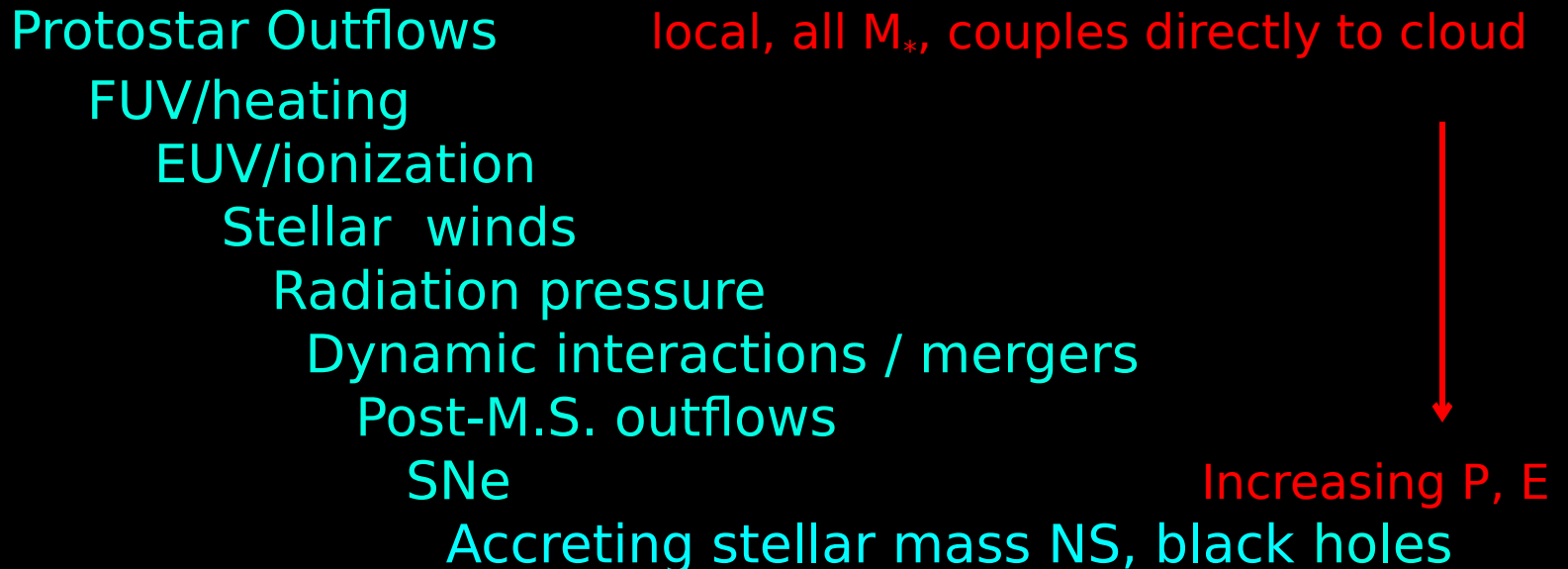
Sgr C

Feedback?

Blow out a sector of the CMZ?

The Feedback Ladder

Progression of ever stronger stellar feedback impacts



Feedback failure => High SFE, bound clusters?

Stellar Feedback in the CMZ

OB stars

$$\begin{aligned} M_{\text{gas, CMZ}} &\sim 2\text{-}5 \times 10^7 M_{\odot} & V_{\text{gas}} &\sim 10 - 20 \text{ km/s} \\ M_{\text{GMC}} &\sim 10^{5-6} M_{\odot}, & R_{\text{gmc}} &\sim 3 - 10 \text{ pc} \end{aligned}$$

$$\text{Self-gravity (1 GMC)} \quad \sim 3 \times 10^{50} \text{ to } 10^{52} \text{ erg / GMC}$$

$$(E_{\text{G}} \sim GM_{\text{g}}^2/R_{\text{c}}):$$

Molecular binding energy

$$(E_{\text{mol}} \sim M_{\text{gmc}} [4.8 \text{ eV}] / \mu m_{\text{H}}) \quad \sim 3 \times 10^{50} \text{ erg / GMC}$$

$$\text{Energy to disrupt } 10^{5-6} M_{\odot} \text{ GMC:} \quad \sim 10^{51-52} \text{ erg} \quad (\sim 1 - 10 \text{ SNe})$$

$$\text{Energy to disrupt } 10^7 M_{\odot} \text{ of CMZ :} \quad \sim 10^{52-53} \text{ erg} \quad (\sim 100 - 1000 \text{ SNe})$$

$$\text{To eject from } R_{100} \text{ pc to infinity:} \quad \sim 10^{55} \text{ erg} \quad (10^4 \text{ SNe})$$

Bubbles stall:

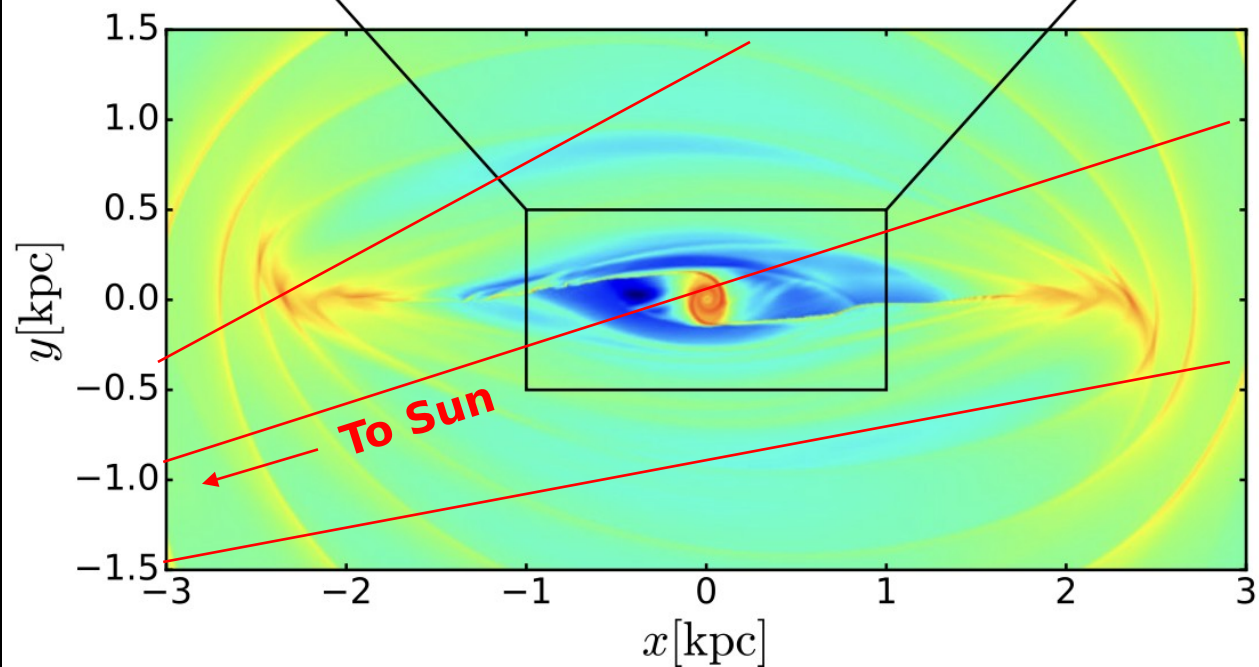
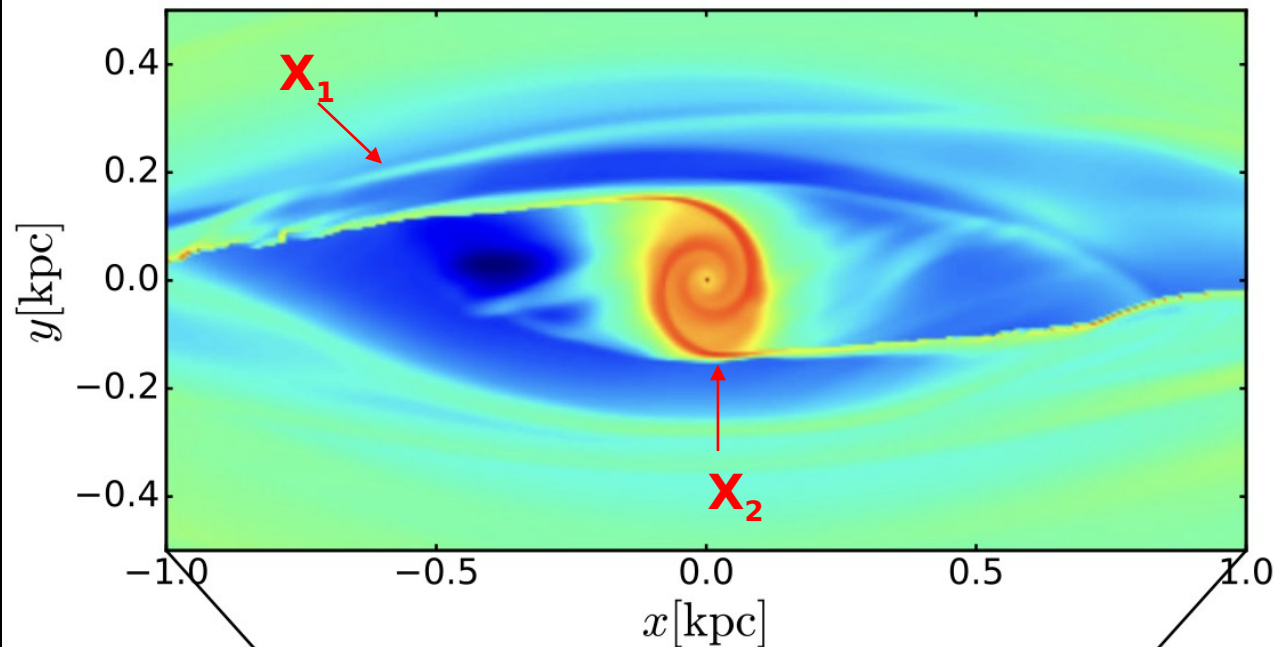
Need B + Cosmic Ray pressure to eject from

CMZ!

Life in a



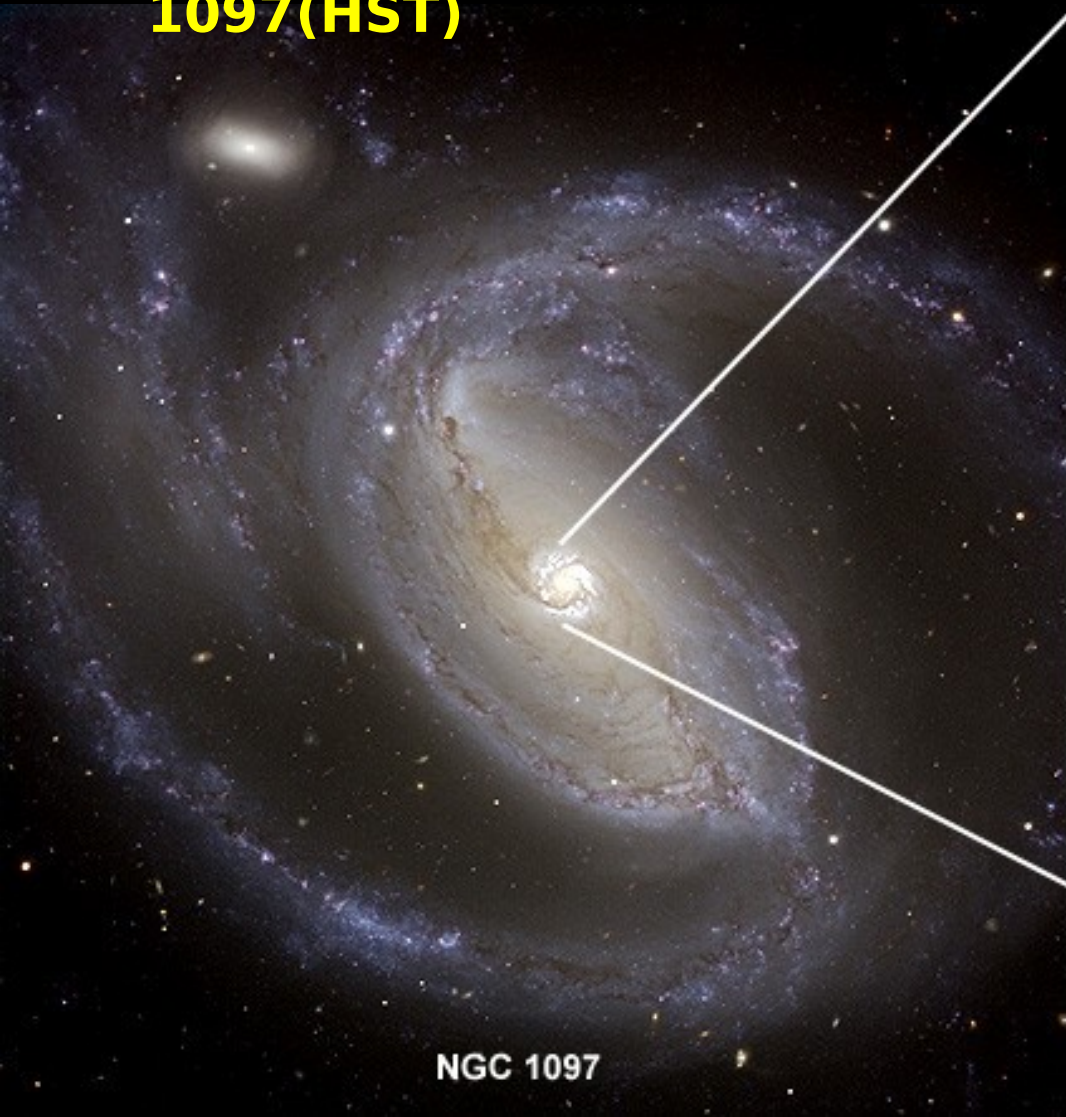
**X_1 to X_2
orbits**



(Ridley+ 2017)

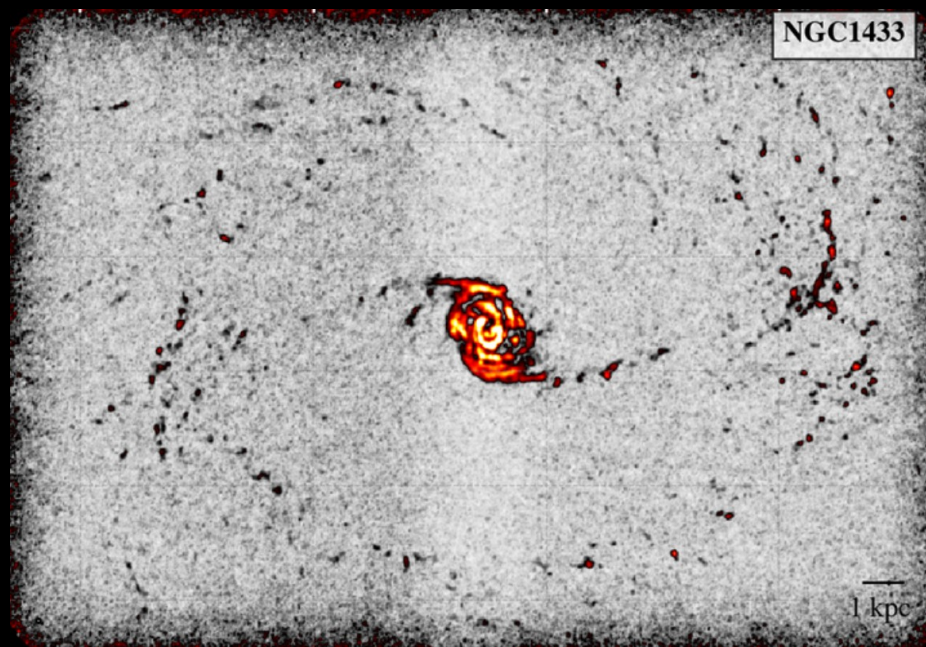
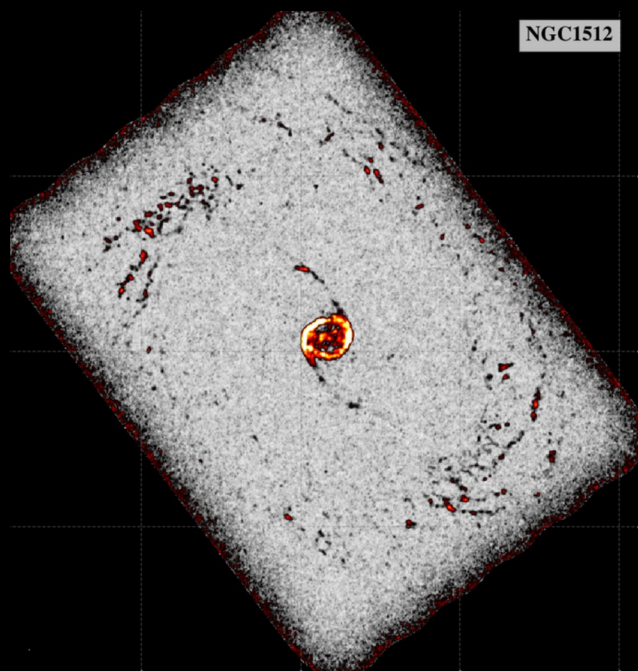
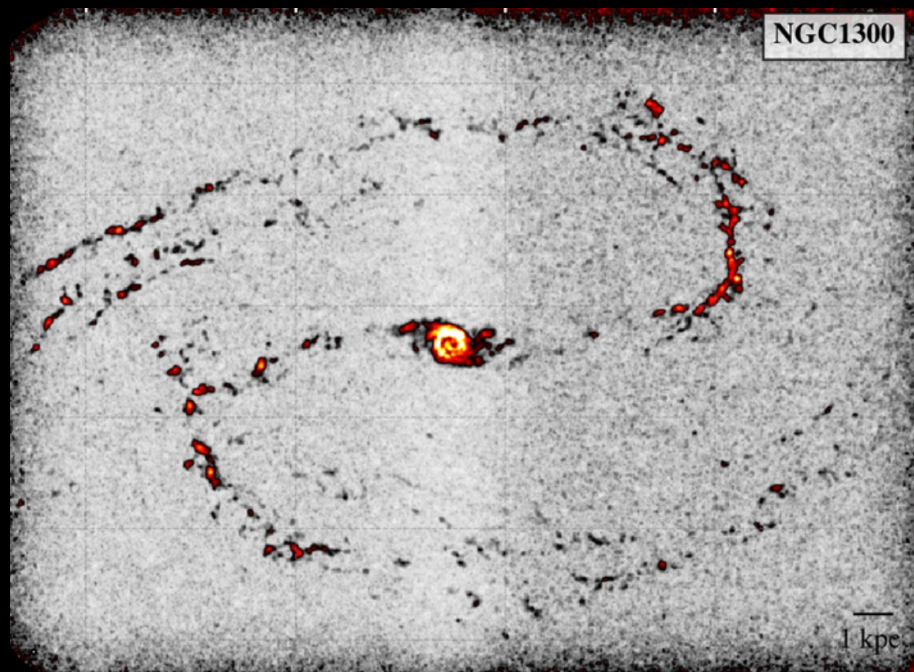
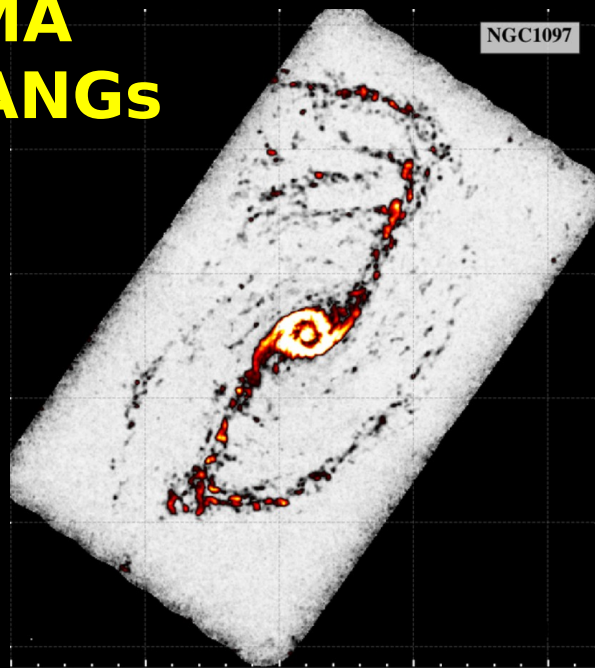
**NGC
1097(HST)**

Most CMZs are symmetric

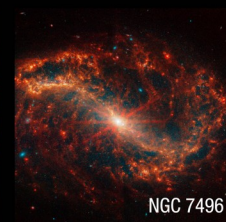
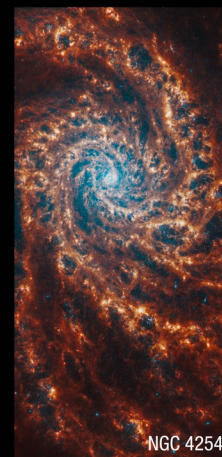
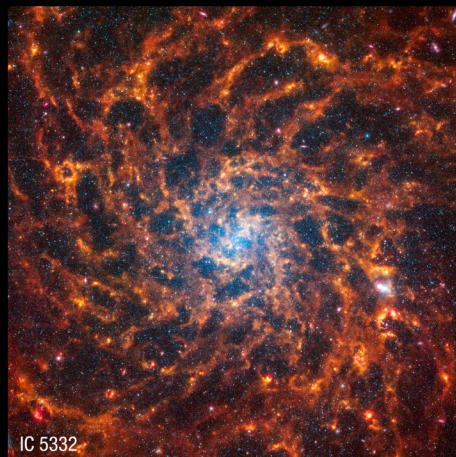


Active Galactic Nucleus

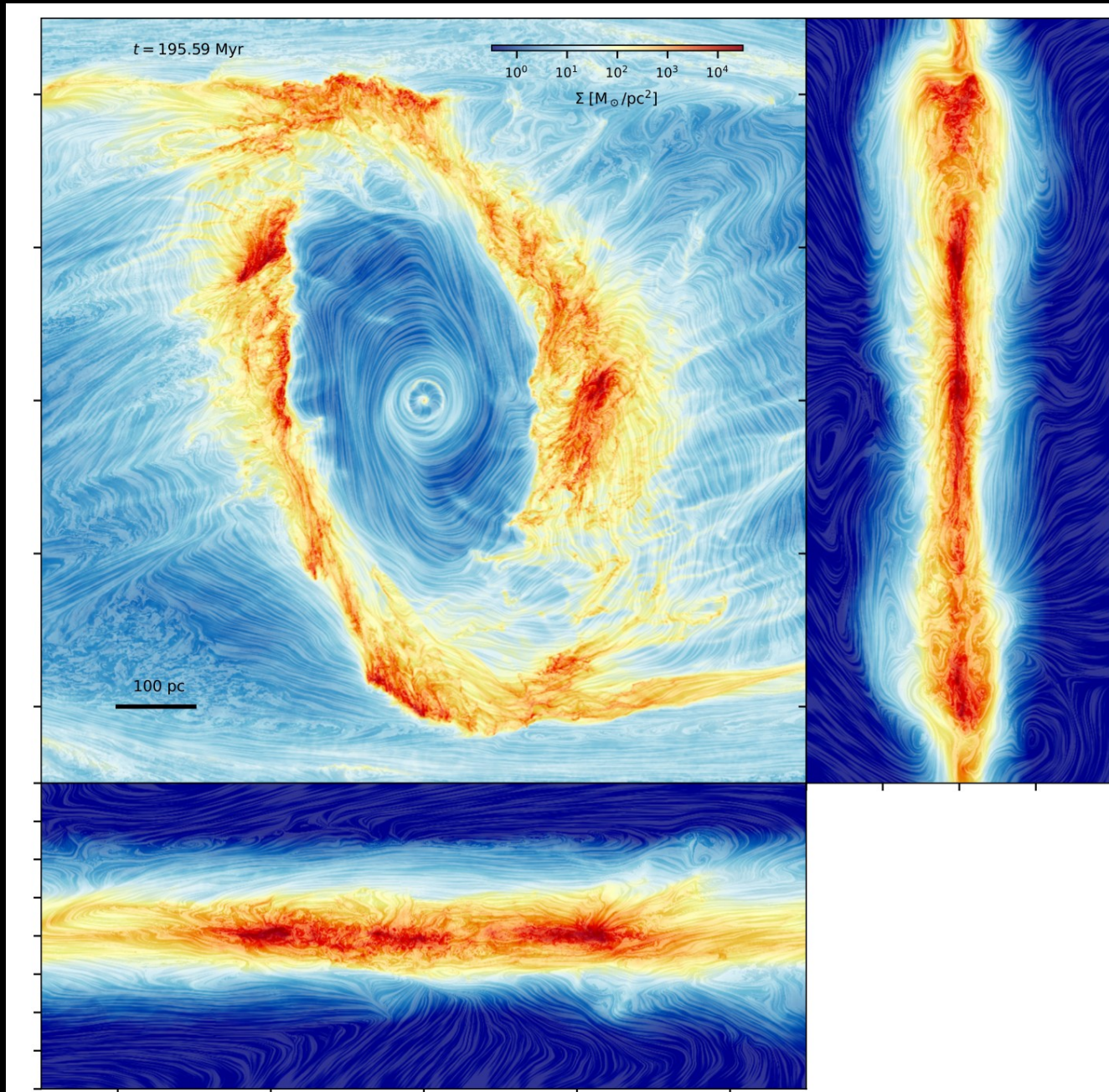
ALMA PHANGs CO

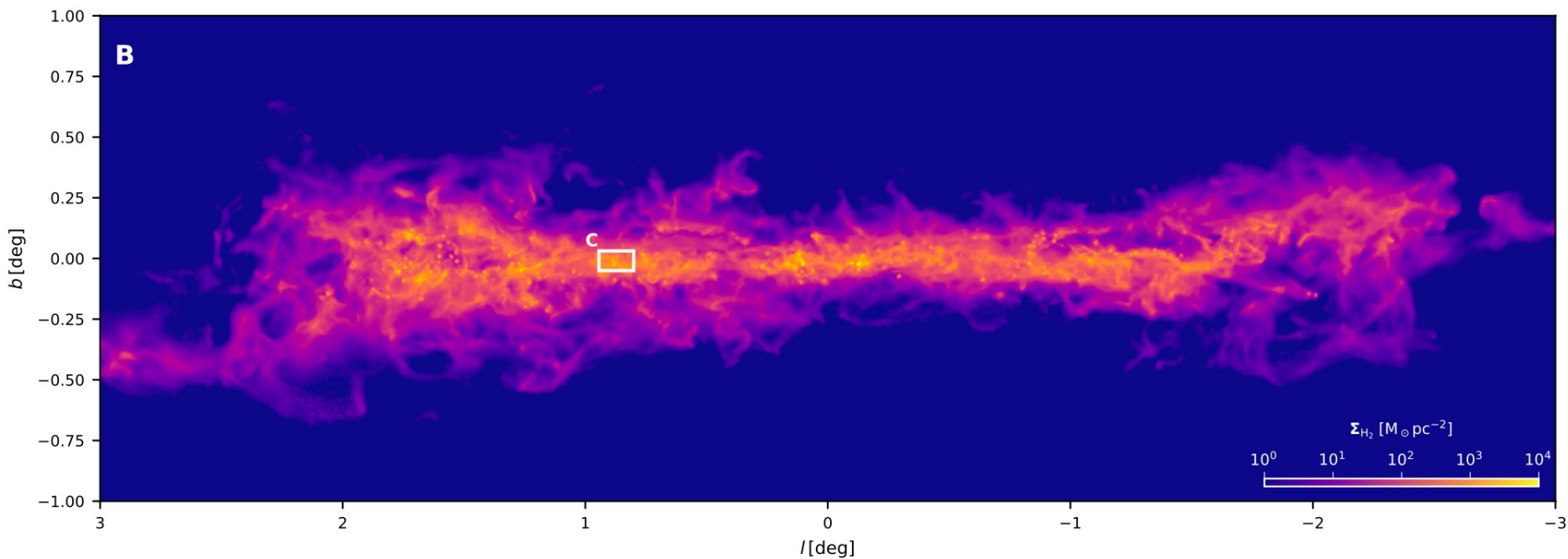
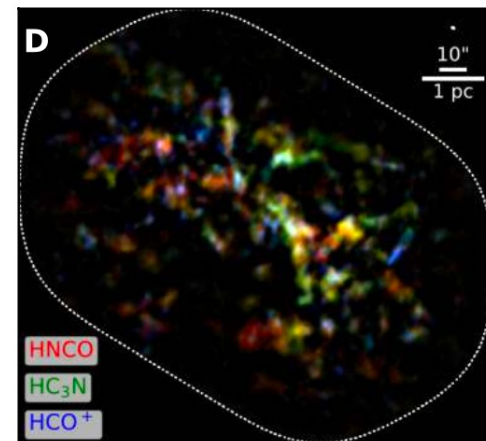
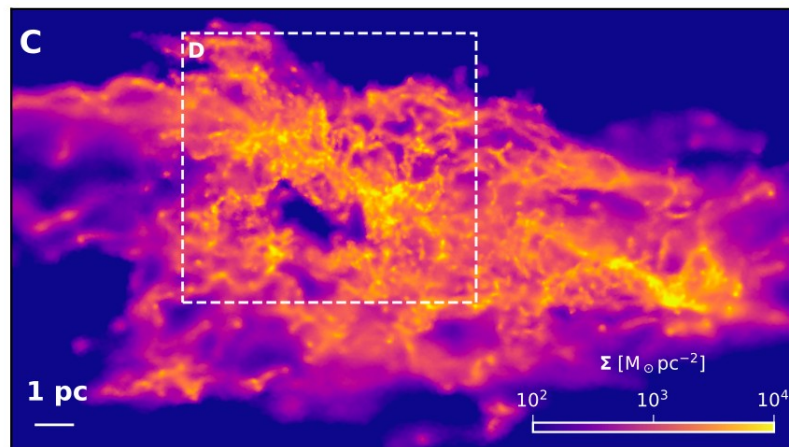
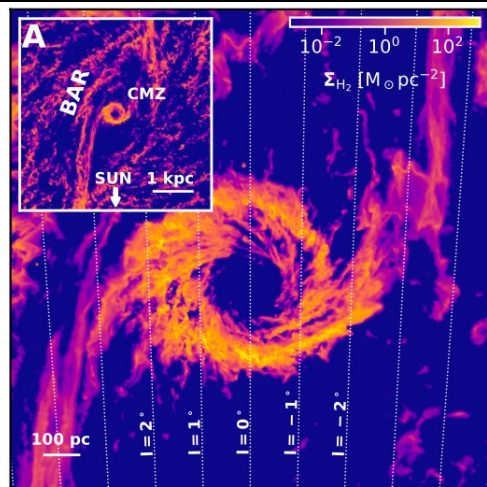


JWST NIRCam PHANGS



Magnetized CMZ Models (Tress+ 2023)

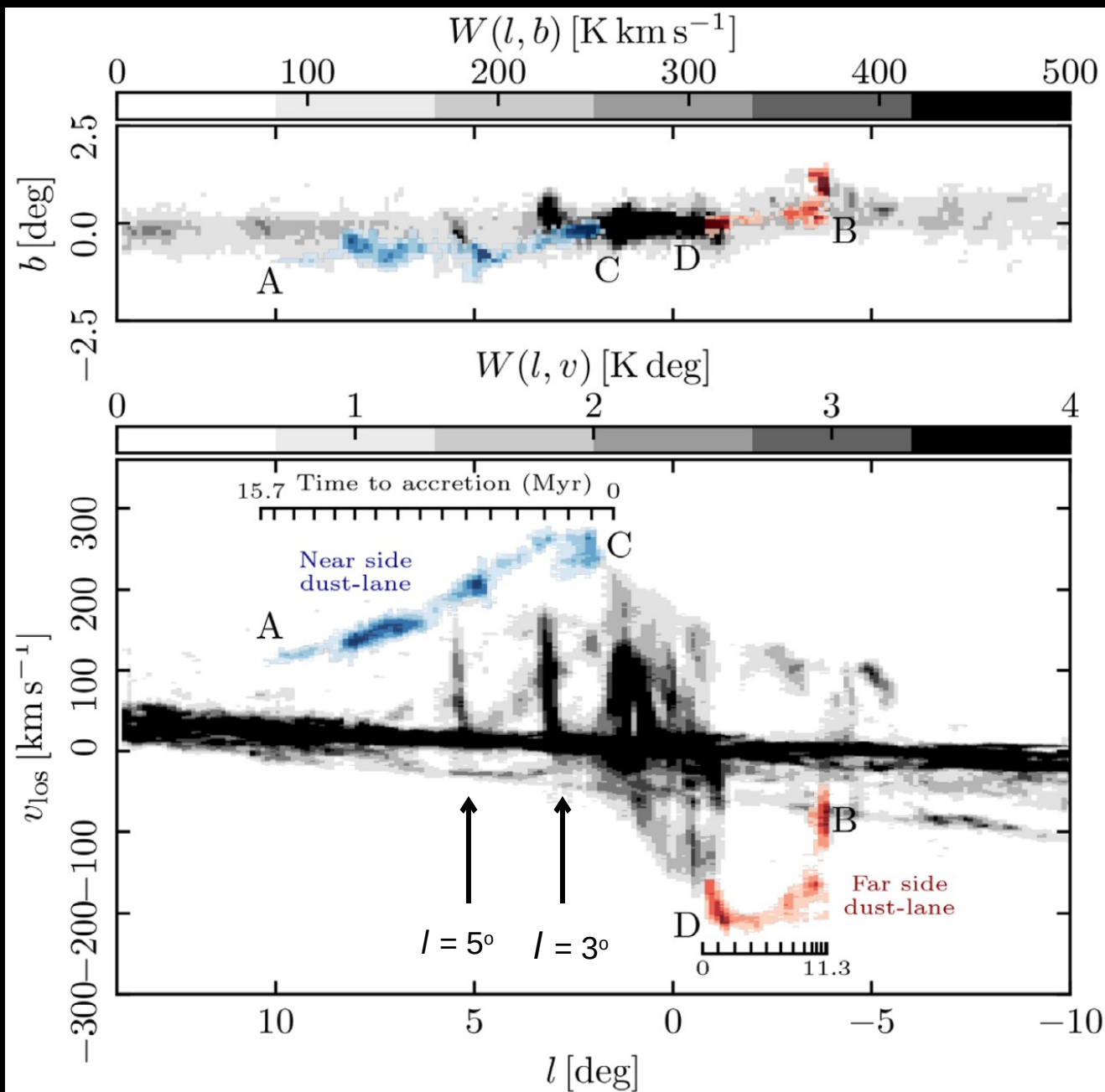




Petkova 2023; Longmore+ 2026)

Milky Way bar-shock / leading-edge dust lanes (Sormani, Barn

2019)

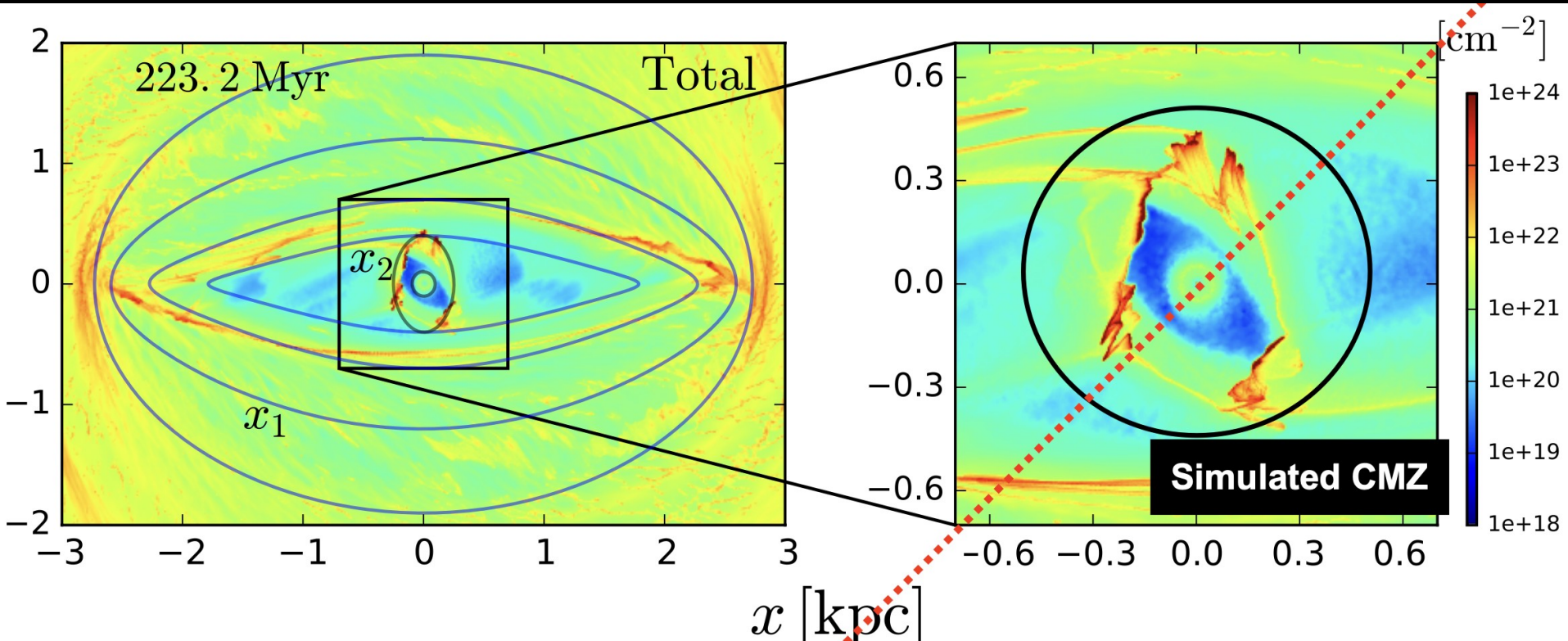


Asymmetric Feeding?

x_1 to x_2 orbits in Bar Models

Asymmetric Infall (GMCs) => Asymmetries?

“Wiggle instabilities” in bar shocks (leading-edge dust lanes)?



(Kim+ 2014; Sormani+ 2017; Sormani+2018; Mandowara, Sormani+ 2022)

Summary

Asymmetries:

Gas-dust: 3/4 at Positive longitude & velocity

Consumption time (no infall) $M_{\text{gas}} / \text{SFR} \gg 10^8 \text{ yr}$

24 μm compact sources: 2/3 at Negative longitude

MYSO ($t < 0.1 \text{ Myr}$)

O/B stars (Compact HII regions)

Post-Main-Sequence (3 to 30 Myr old stars (Jang & An+

2022)

Negative long. $24 \mu\text{m}$ - sheared super star cluster?

Feedback disrupted quadrant of CMZ?

Dissociate, “puff-up” a CMZ sector?

Recent Infall of GMC along bar dust lanes?

Bania's Clump2 (G3.3), G1.3, G5, ...

Small number of $>10^6 M_{\odot}$ GMCs ?

$$r_{\text{GMC}} < R_{\text{tidal}}$$

$$r_{\text{GMC}} = R_{\text{orbit}} (m_{\text{GMC}} / 2 M_{\text{gal}})^{1/3}$$

Questions:

Infall rate from R ~ 3 kpc? $\sim 1 M_{\odot}/\text{yr}$? (Tress+ 2020)

Why so asymmetric? ($t_{\text{orbit } 100\text{pc}} \sim 3 \text{ Myr}$)

Stochastic infall? (Sormani+ 2018) Starburst feedback ?

Star Formation Rate: $\sim 0.04 - 0.1 M_{\odot}/\text{yr}$? (Sormani+ 2020)

Quasi-periodic bursts $\sim 30 - 50 \text{ Myr}$? (Armiglotta+ 2019, 2020)

Negative-longitude 24 μm sources?

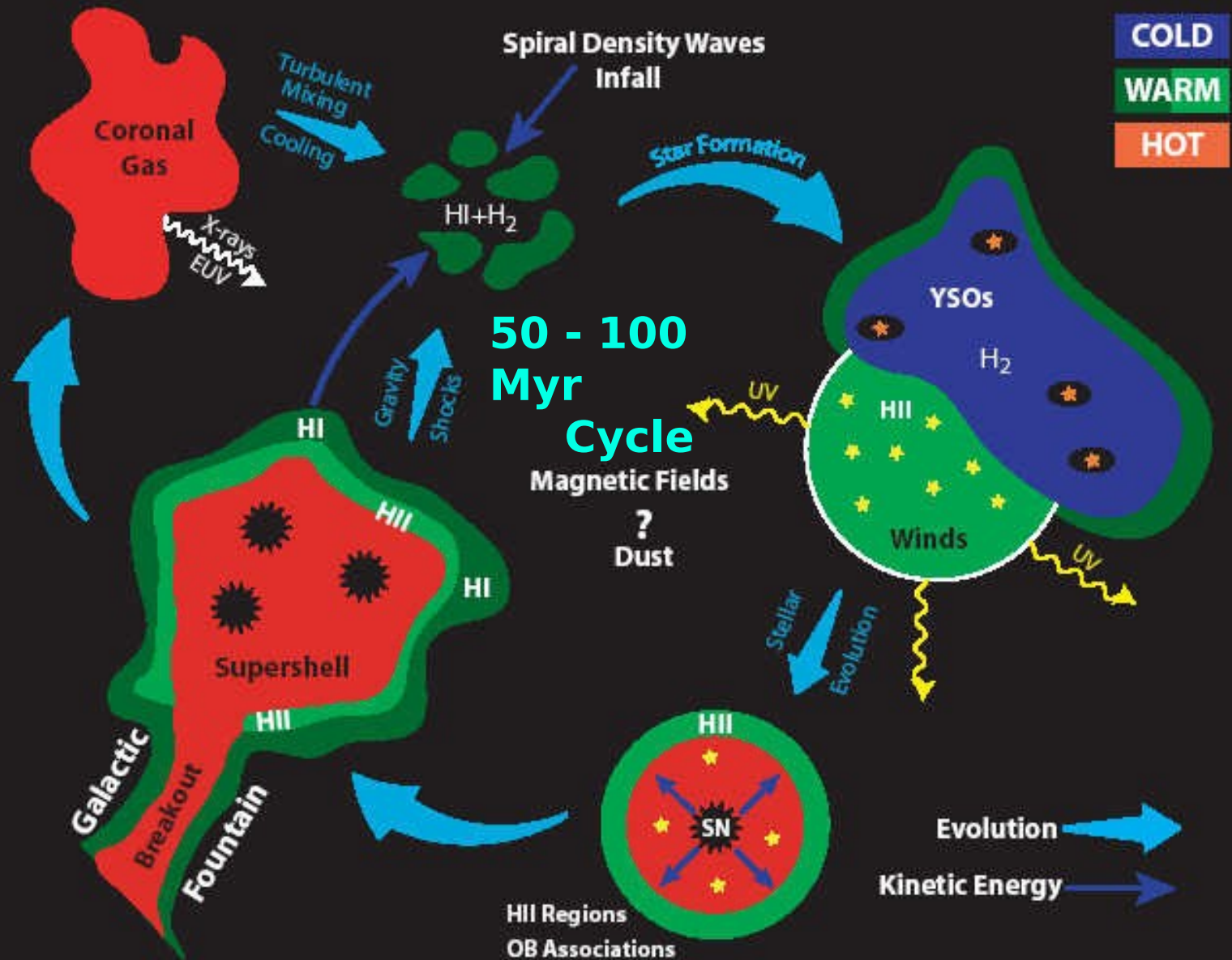
Conveyor-Belt? (Kruijssen, Longmore 2015, 2019)

Where Does Most Gas Go?

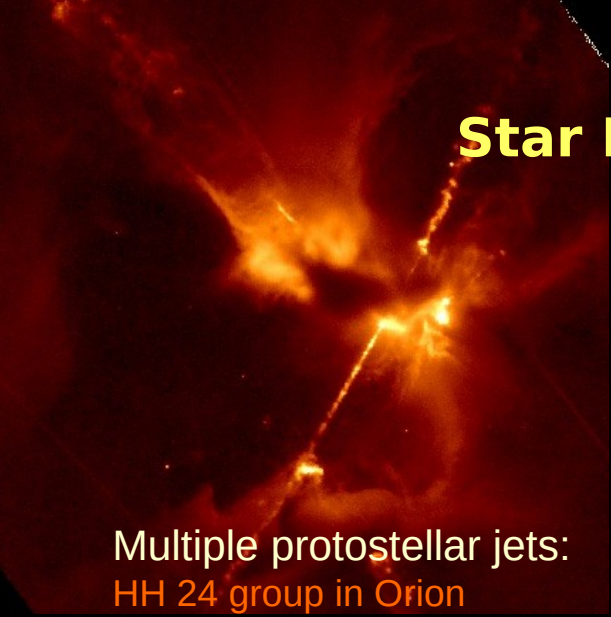
Stars or Ejected ?

What ejects it?

Galactic Ecology: Star Formation & the Interstellar Medium



Feedback Star Formation, a Self-Regulated Process



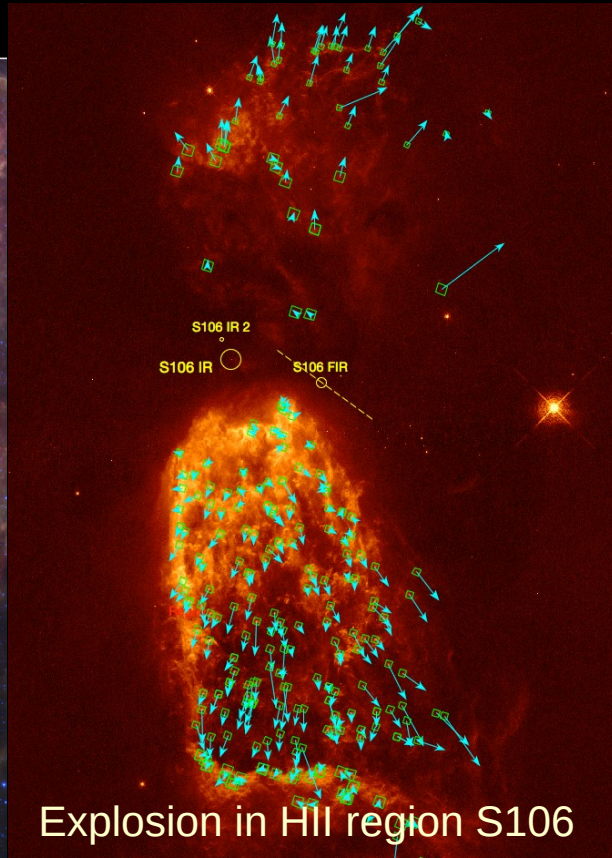
Multiple protostellar jets:
HH 24 group in Orion



Orion 10^{48} erg explosion &
Stellar ejection ~550 years ago



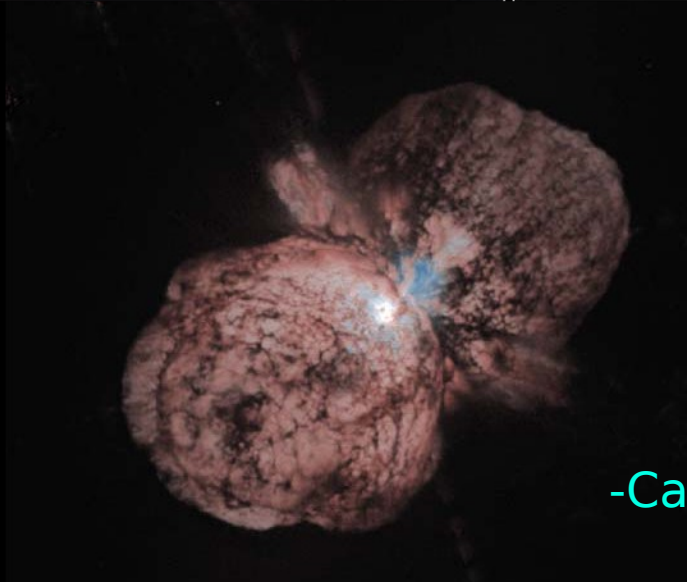
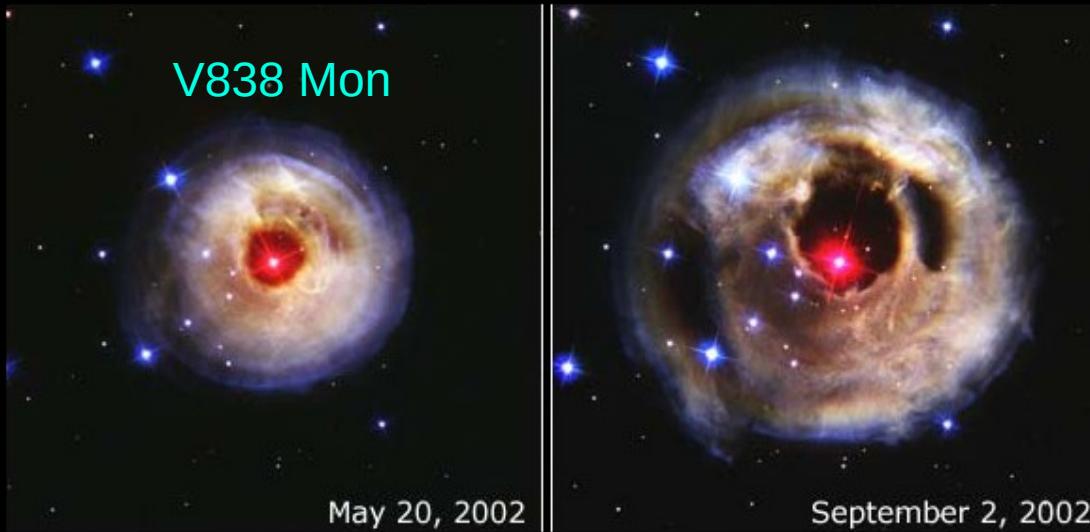
EUV & wind feedback in W5



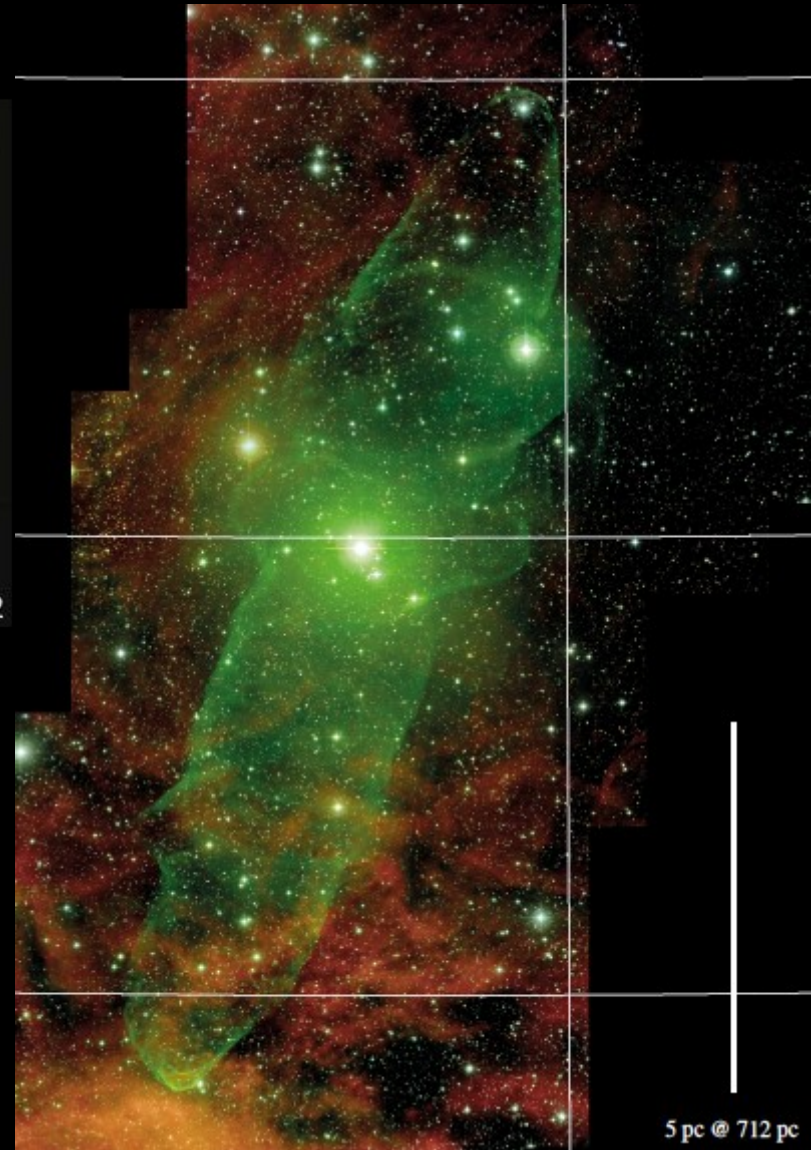
Explosion in HII region S106

Post-Main-sequence Feedback:

WR stars, LBVs, RSGs,

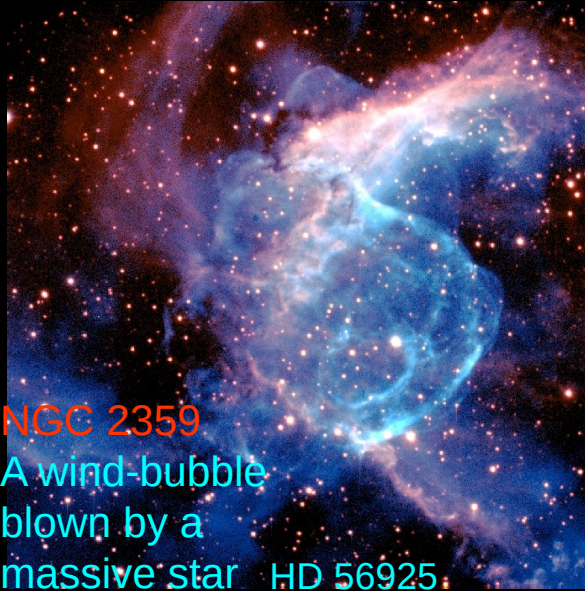


Ou4 (Corradi 2014)
in Sh2-129



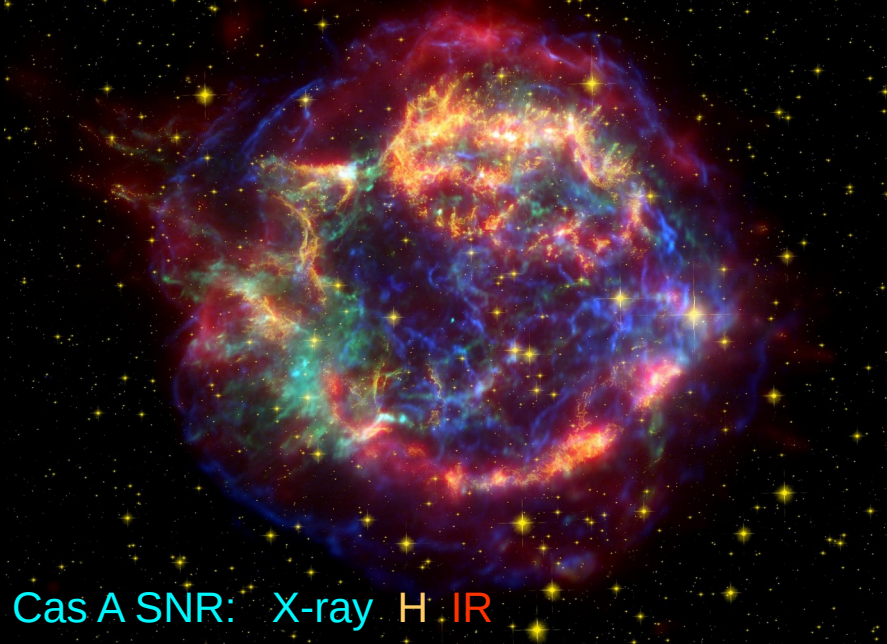
Post-Main-sequence Feedback:

WR stars, SNe, neutron stars, BHs



NGC 2359

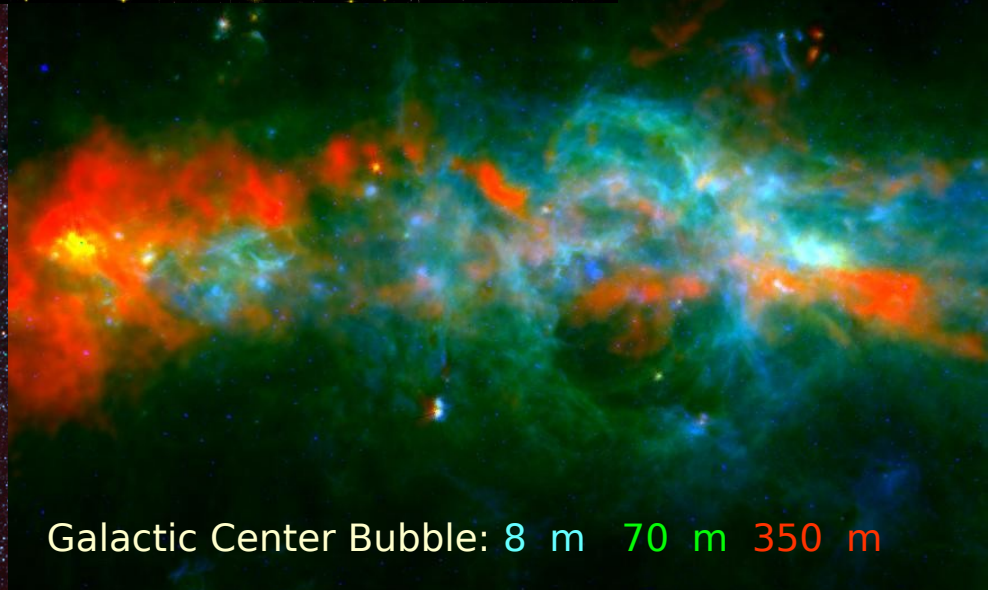
A wind-bubble
blown by a
massive star HD 56925.



Cas A SNR: X-ray H IR



W50 / SS433 relativistic jet



Galactic Center Bubble: 8 m 70 m 350 m