UNIVERSITÄT HEIDELBERG ZUKUNFT SEIT 1386

Observational constraints on the coupling efficiency of mechanical stellar feedback

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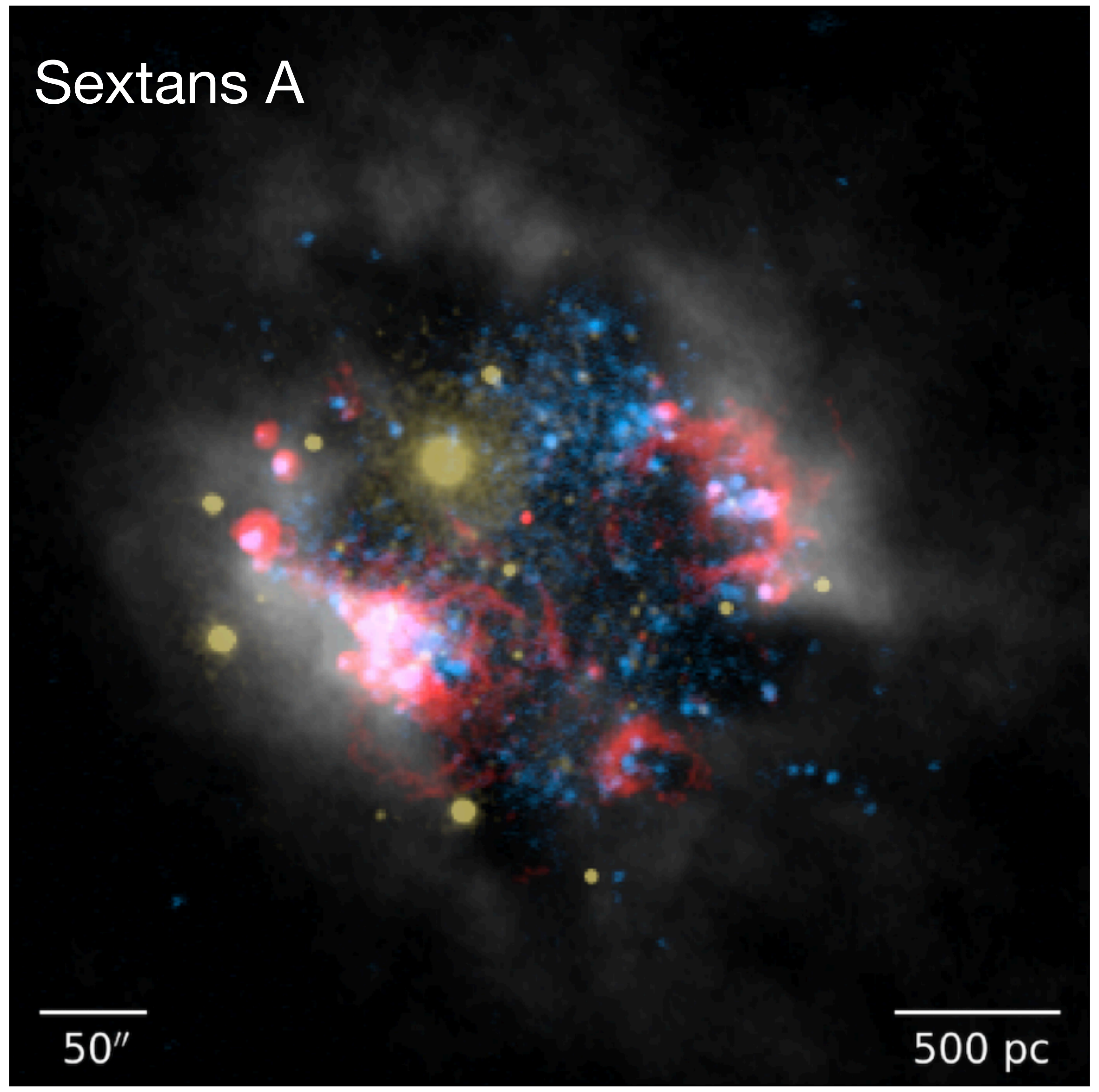
phangs + Local Volume Mapper

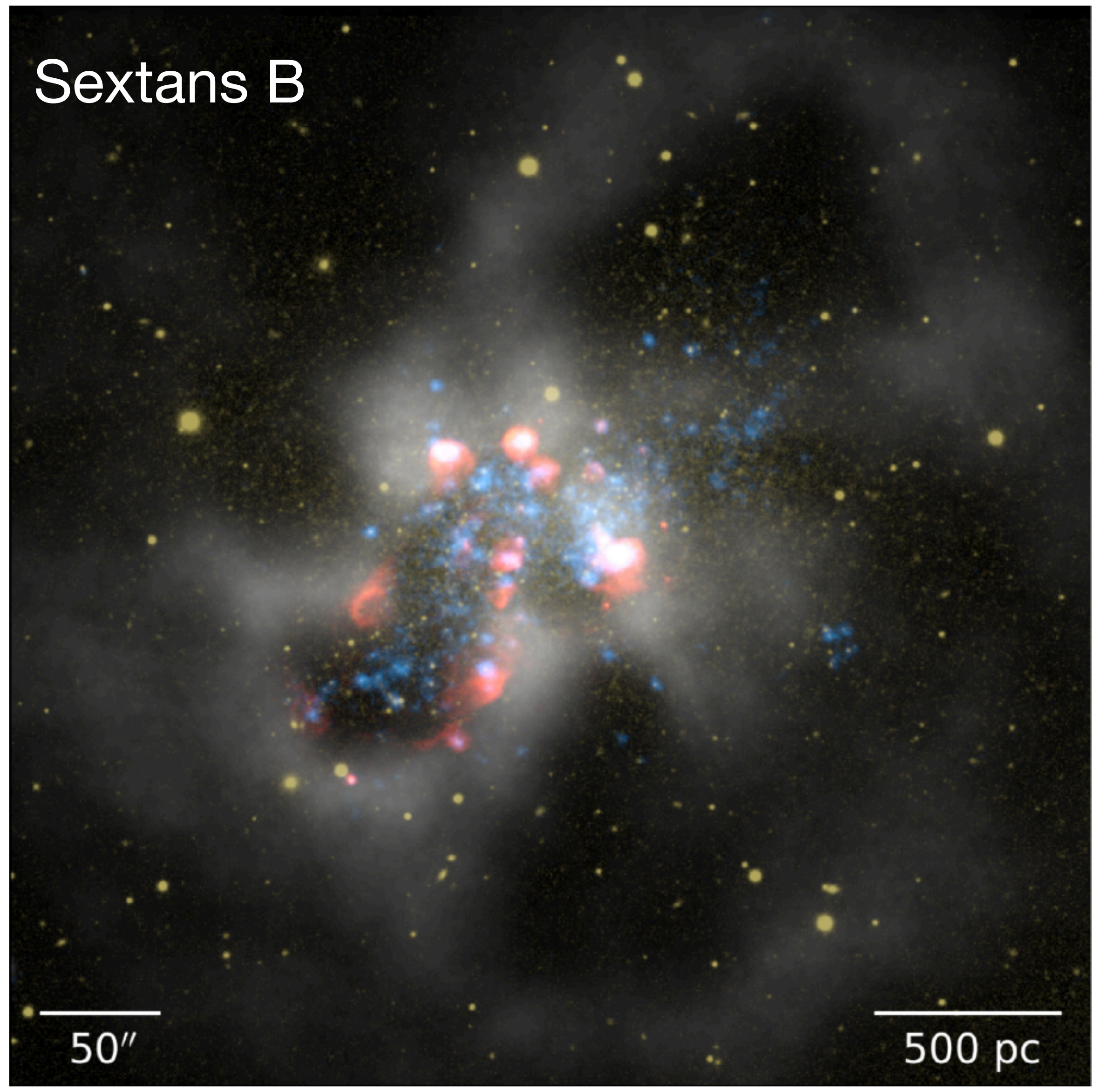
Resolving the Physics Driving Galaxy Formation

Stellar feedback in the ISM

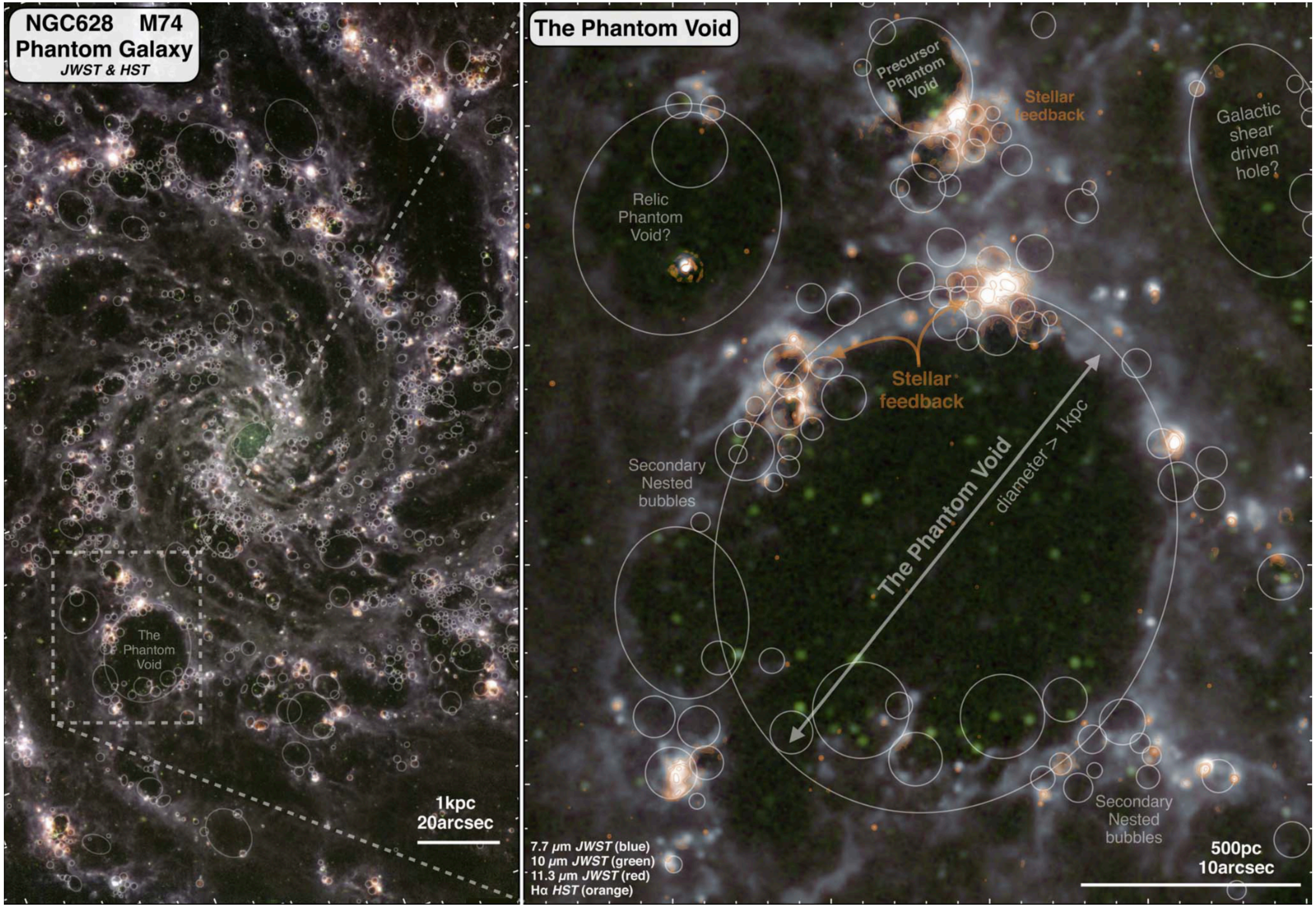
Schinnerer & Leroy, Ann.Rev 2024

Stellar feedback shapes the ISM of the galaxies



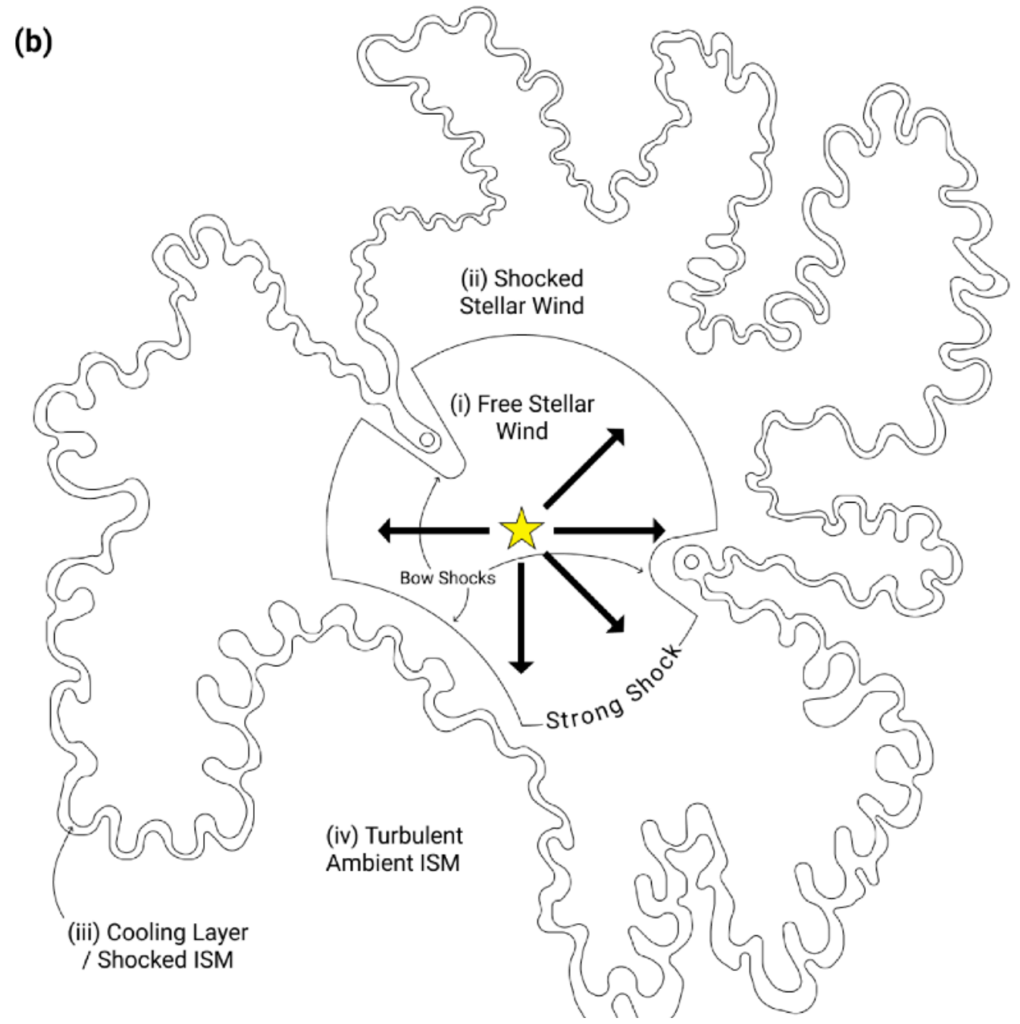


Gerasimov, OE et al. 2023, 2024



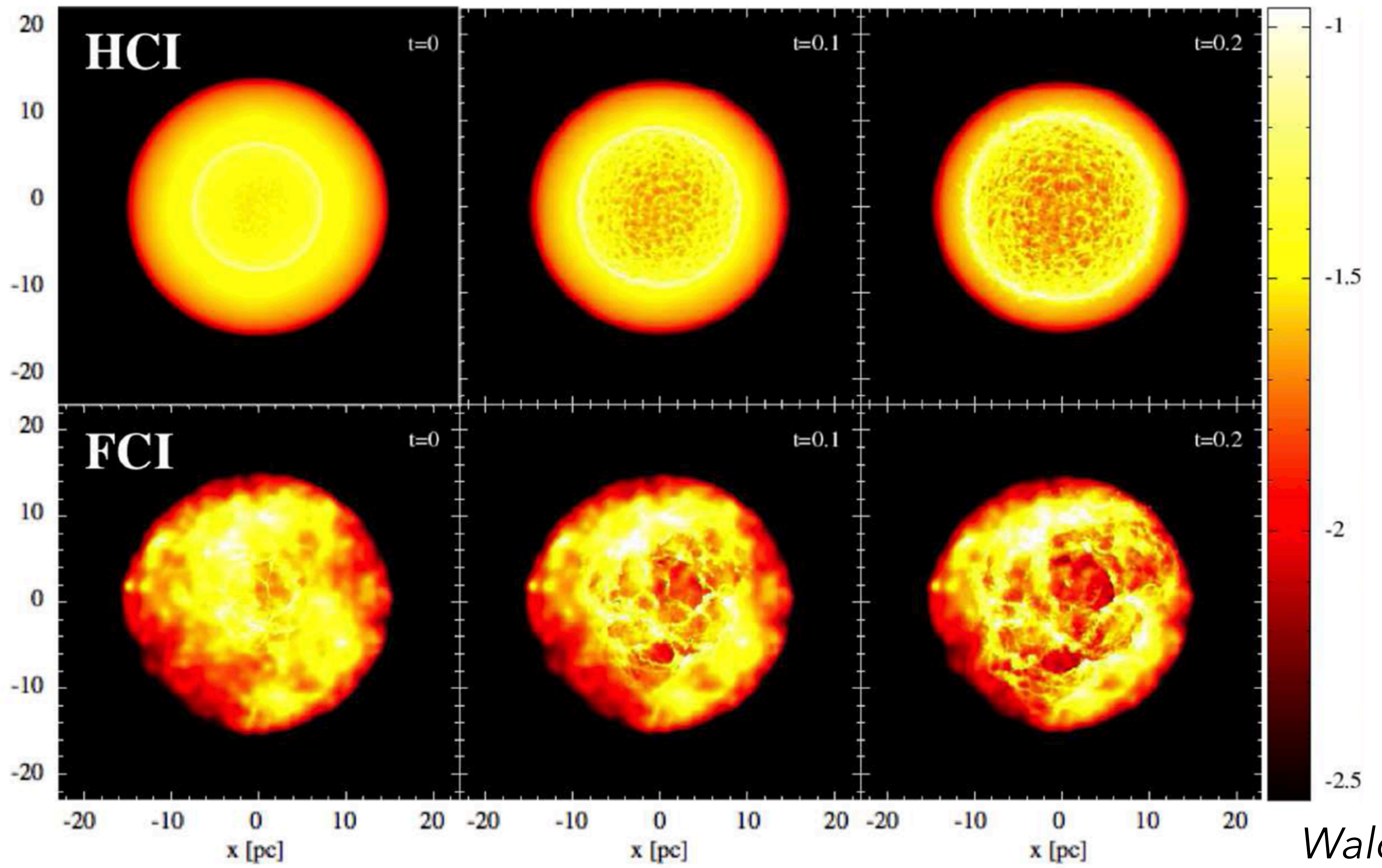
Barnes et al. 2023, Watkins et al. 2023

Evolution of the superbubbles in the ISM



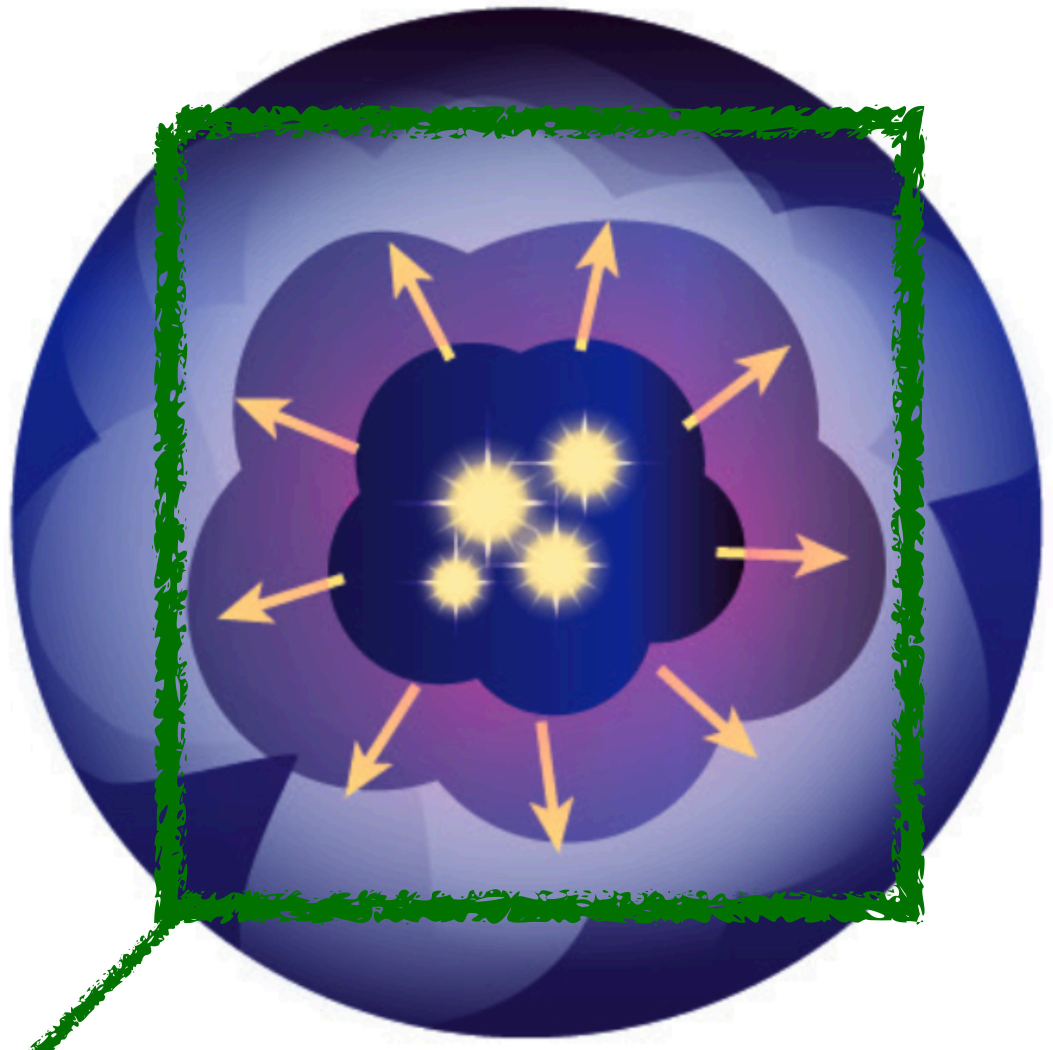
Lancaster et al. (2021)

- Qualitatively, the evolution of superbubbles is well described by the classical Weaver et al. (1977) model
- However, it doesn't agree well with observations quantitatively
- **Only a small fraction of injected energy should retain in a superbubble** to support its expansion (*Sharma+2014; Krause&Diehl 2014; Vasiliev+2015; Yadav+2017*)
- **Different models predict coupling efficiency of mechanical feedback to be 1-40%** (depending on the density, clustering of SNe, age of the clusters, resolution of the simulations)



Walch & Naab (2015)

Measuring coupling efficiency from observations



Optical IFUs
(e.g.MUSE)

- Morphology, density
- Ionization condition
- Metallicity
- Local kinematics
- **Kinetic energy of the ionzied gas**

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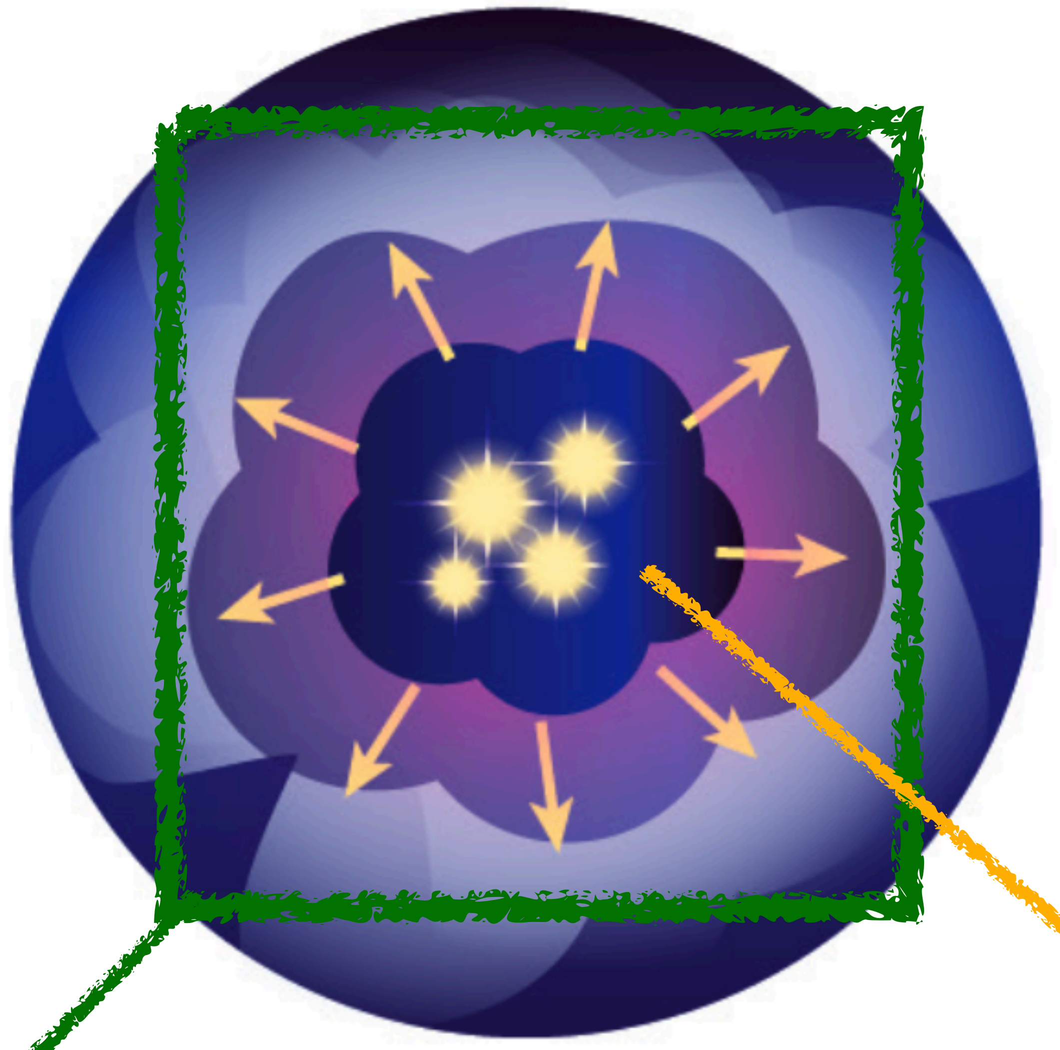

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- Morphology, density
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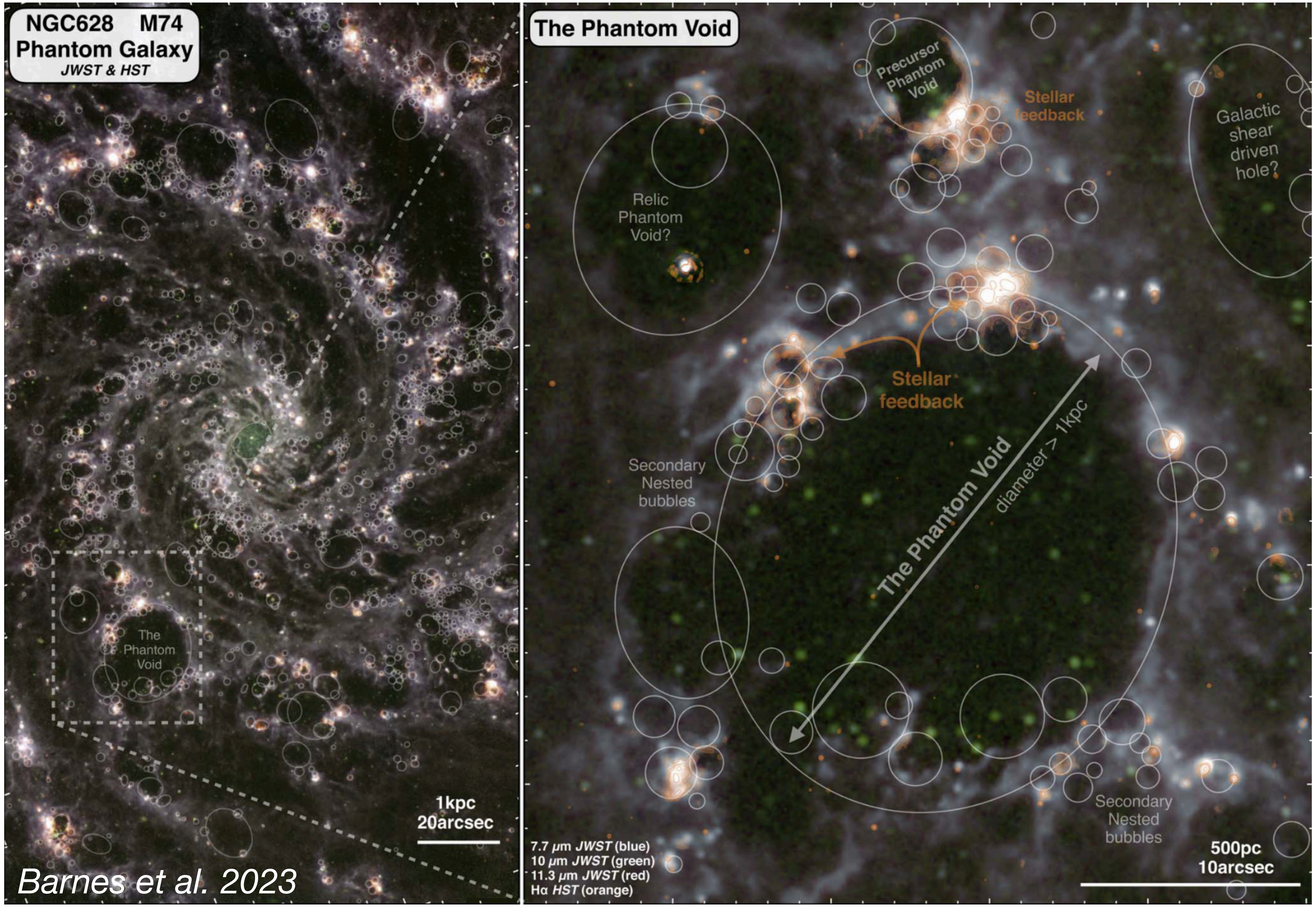
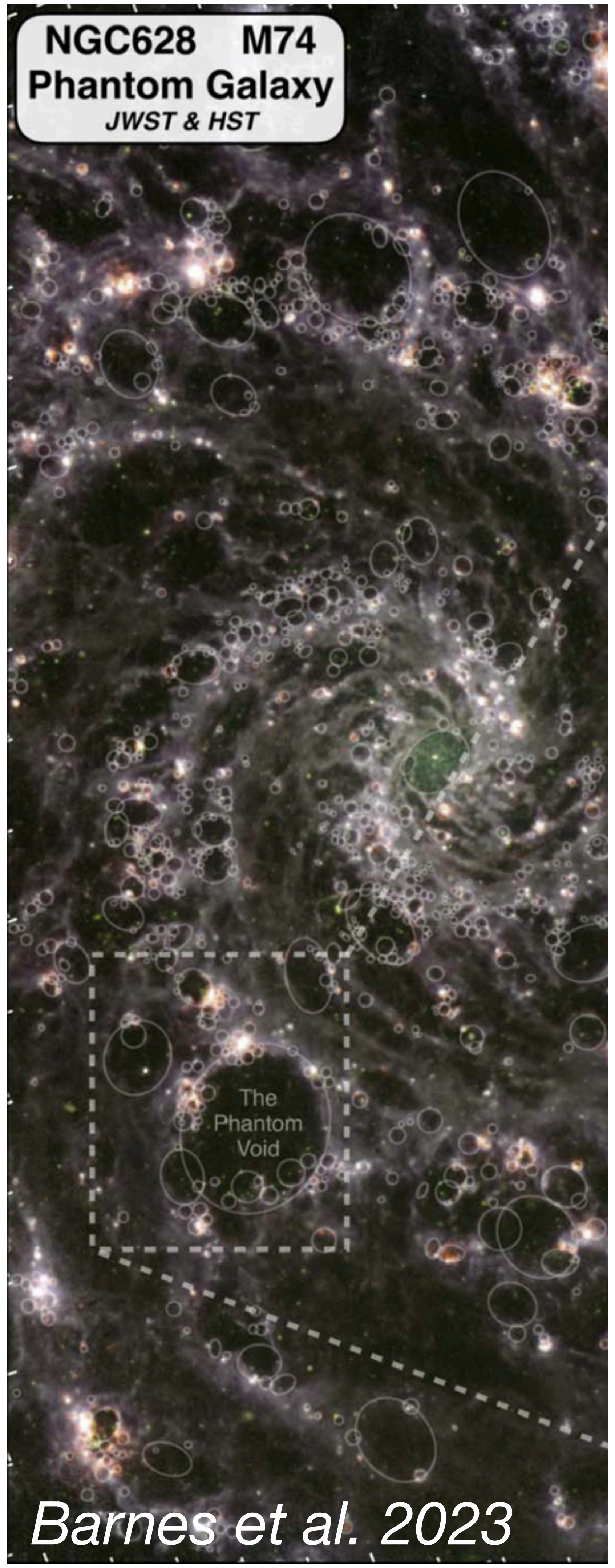
HST (+JWST/AstroSat)

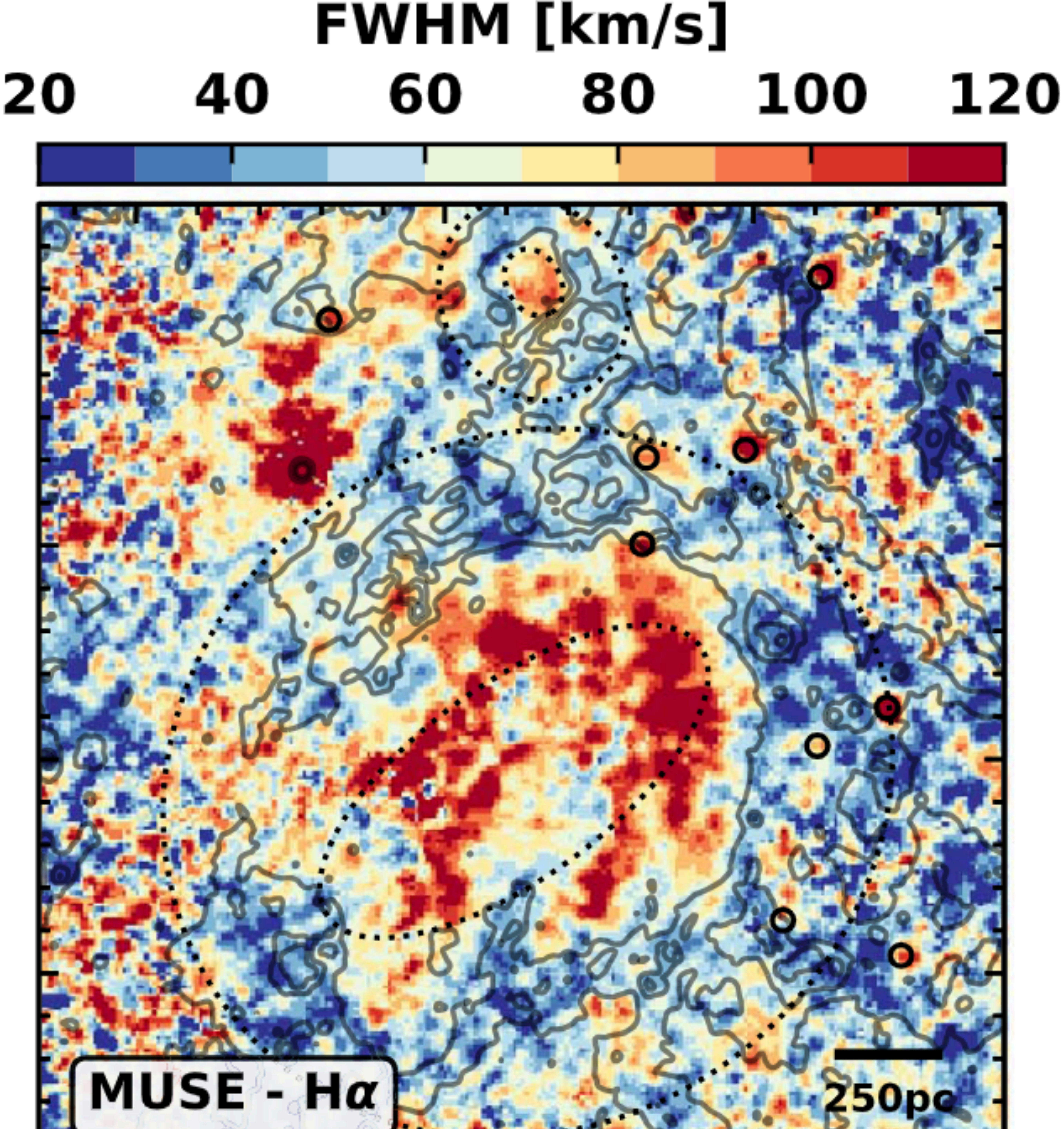
- Ages and masses of the young stars
- **Mechanical luminosity**

Searching for expanding super bubbles

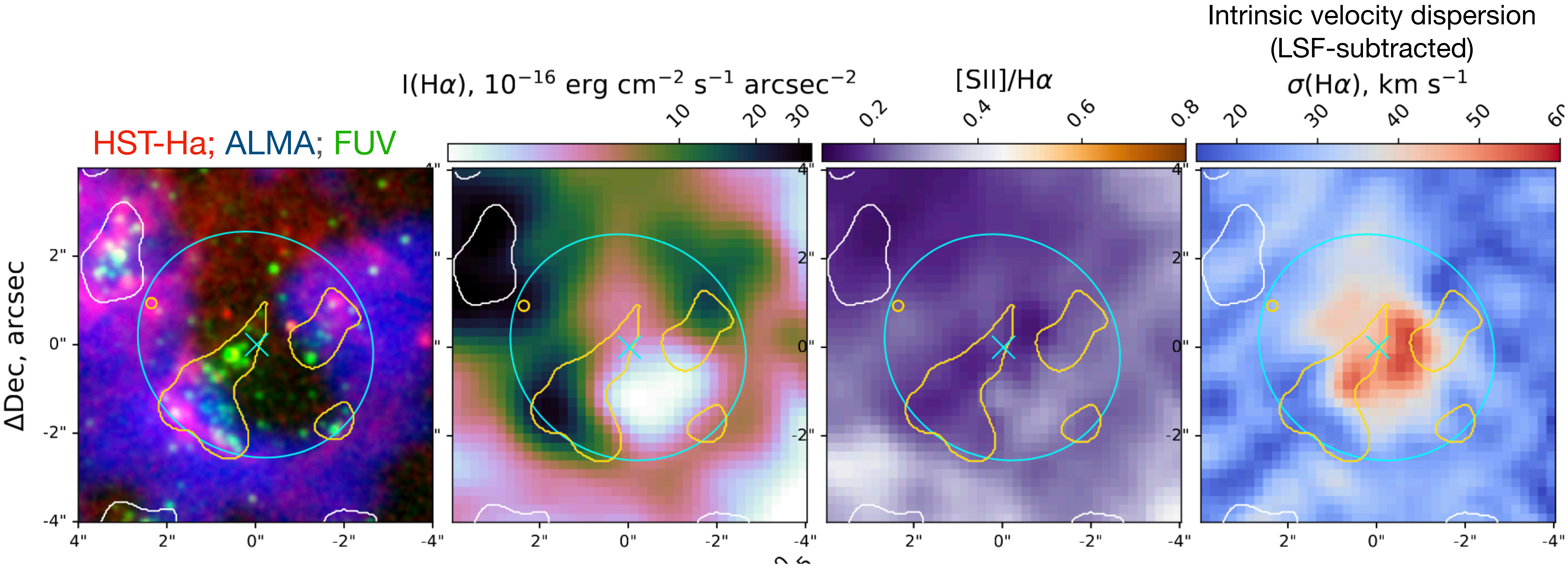


Searching for (





Searching for expanding superbubbles in 19 PHANGS-MUSE galaxies



511 regions with high velocity dispersion linked with at least one young star cluster / OB association

(Expanding superbubbles or regions with turbulent ionized gas motions)

Egorov et al. (2023)

Quantifying the energy balance

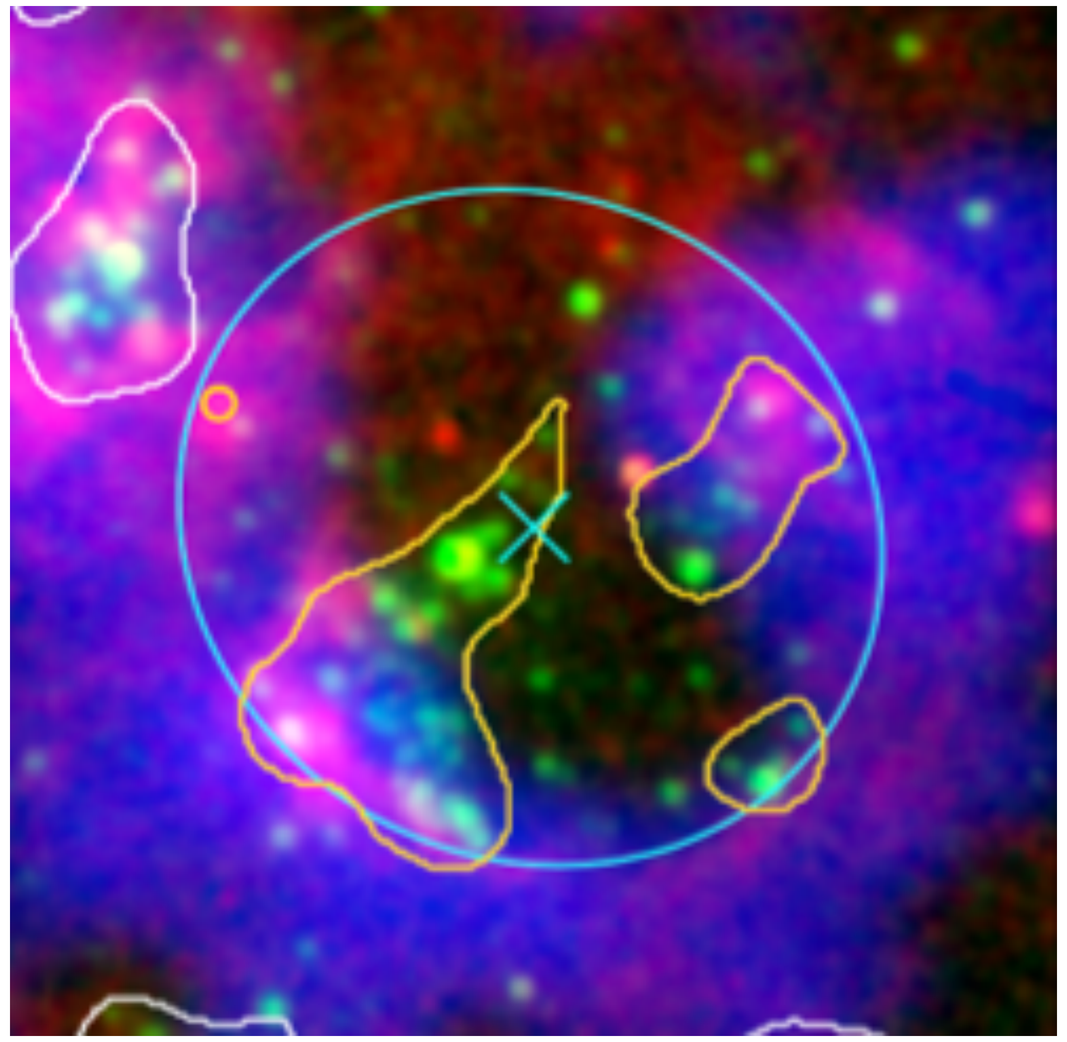
Kinetic energy of the ionized gas:

$$E_{\rm kin} \simeq E_{\rm turb} \simeq \frac{3}{2} M_{\rm ion} (\sigma({\rm H}\alpha)^2 - \sigma({\rm H}\alpha)_m^2).$$

Intrinsic velocity dispersion

Surrounding unperturbed ISM

HST-Ha; ALMA; FUV



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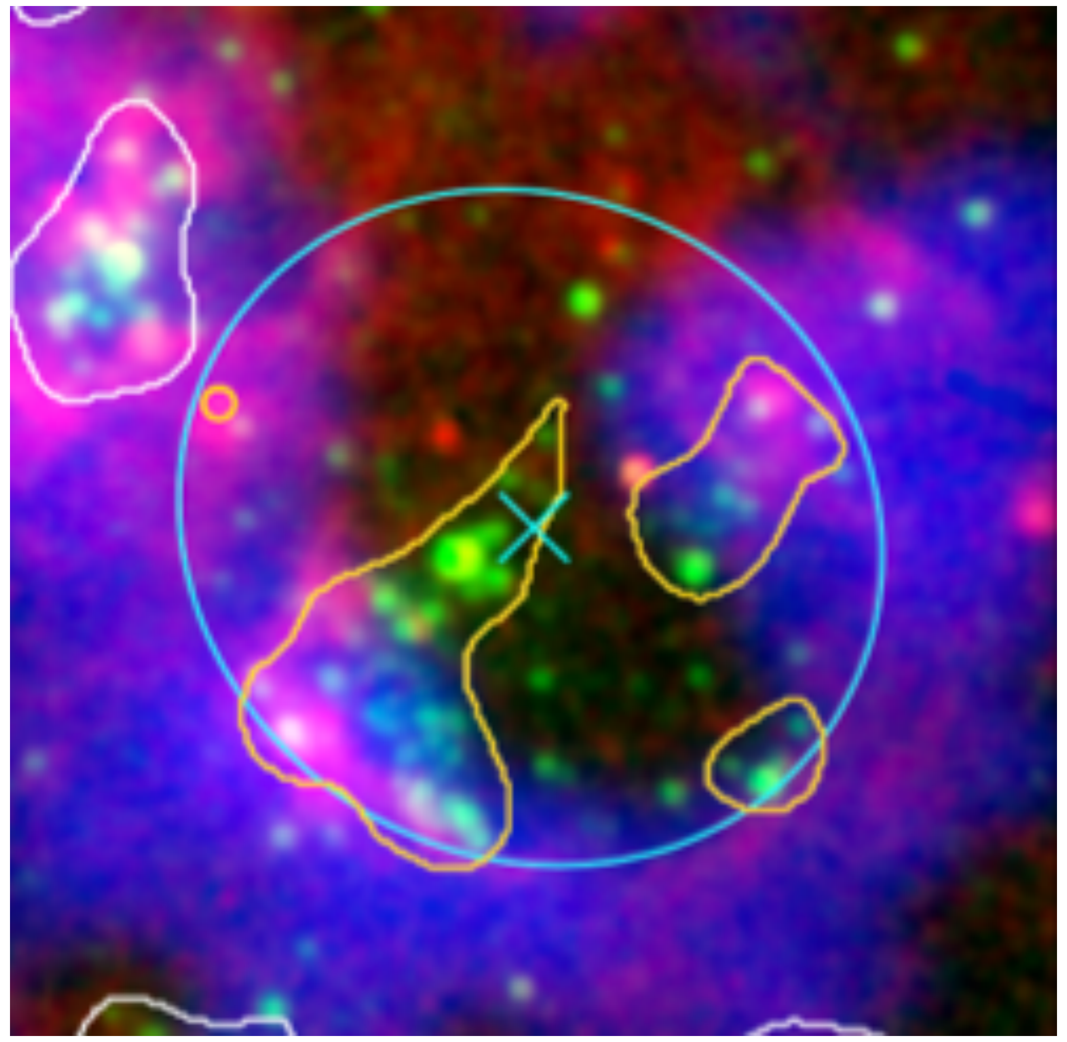

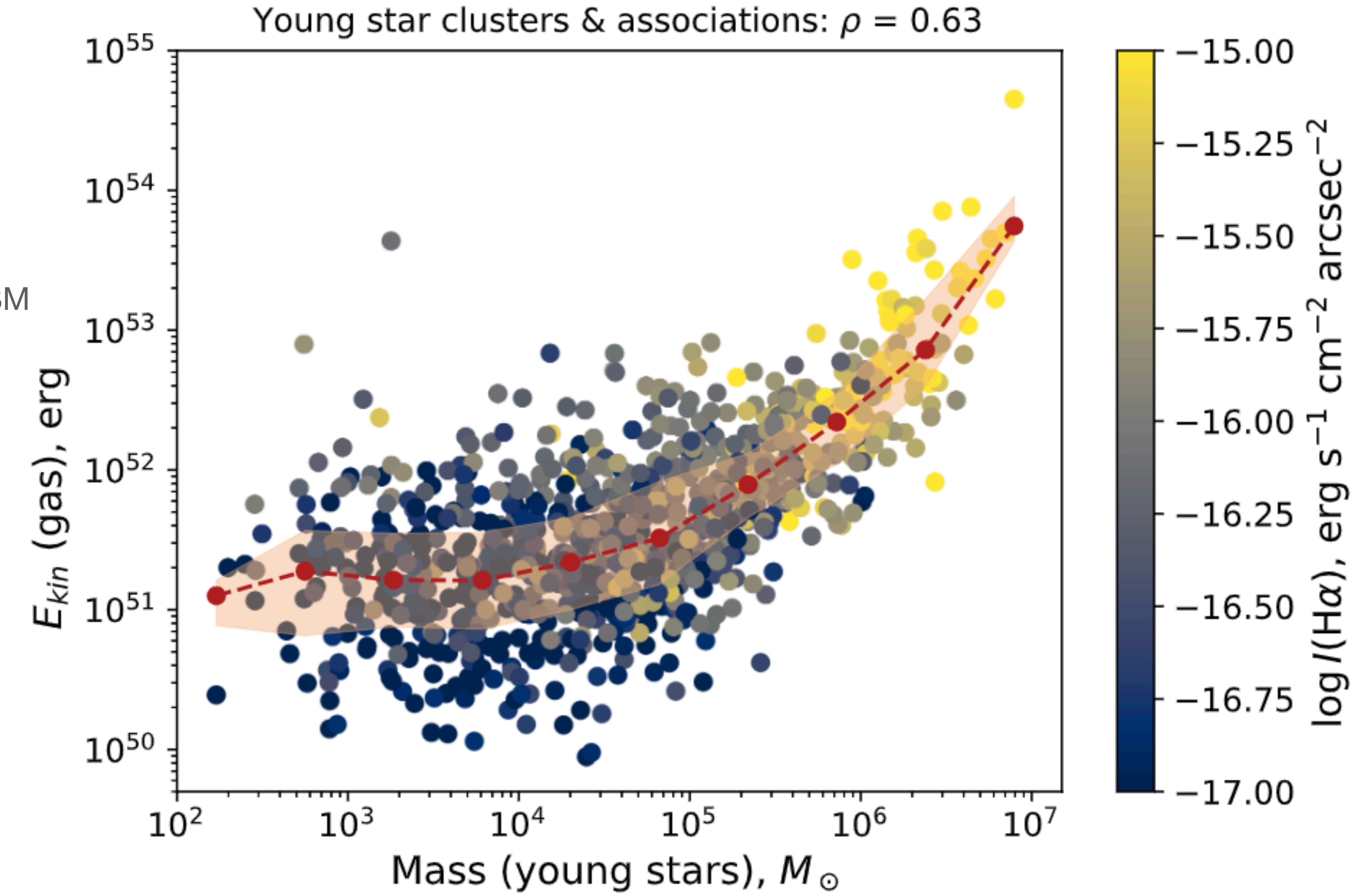

Strong correlation with the mass of the young star clusters and associations => feedback from massive stars is crucial

Egorov et al. (2023)

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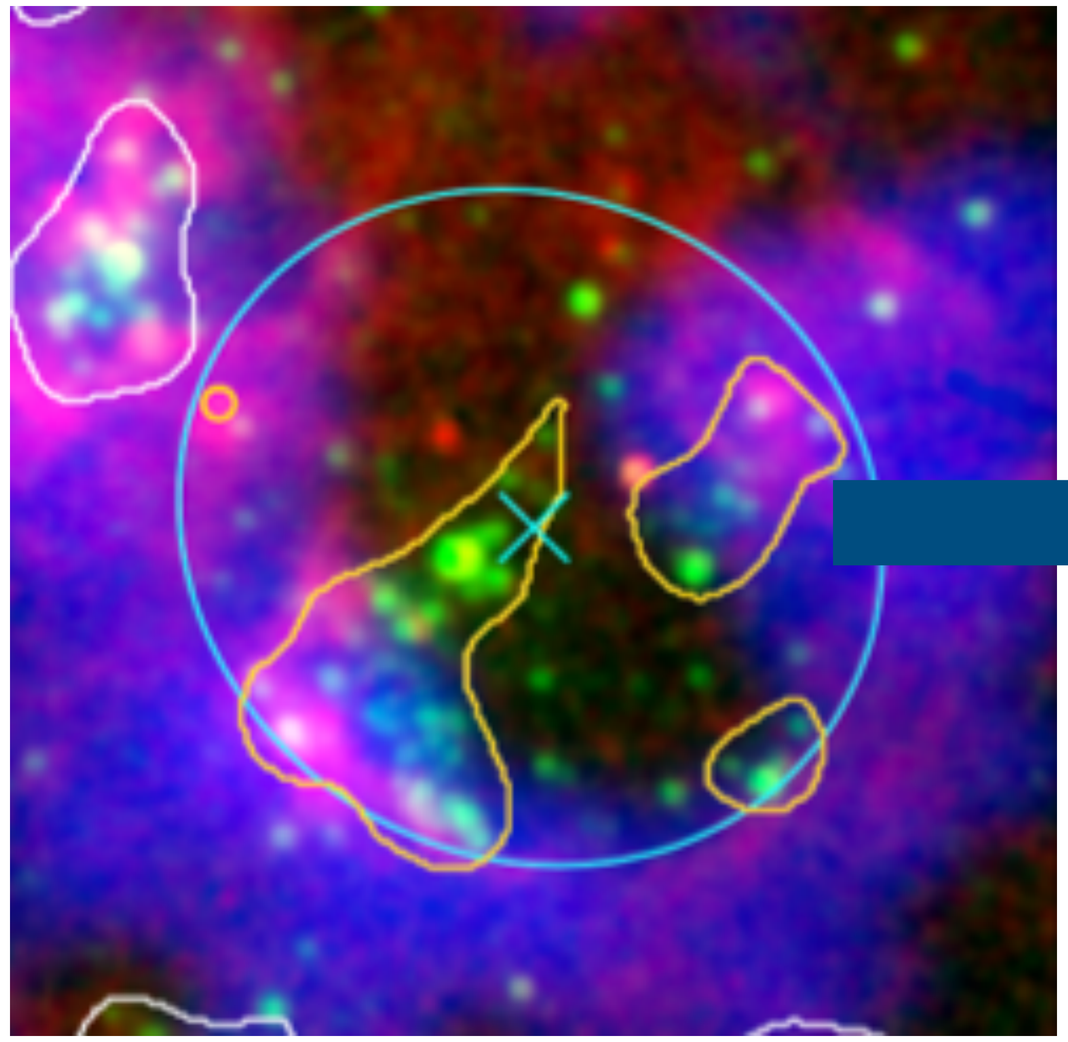
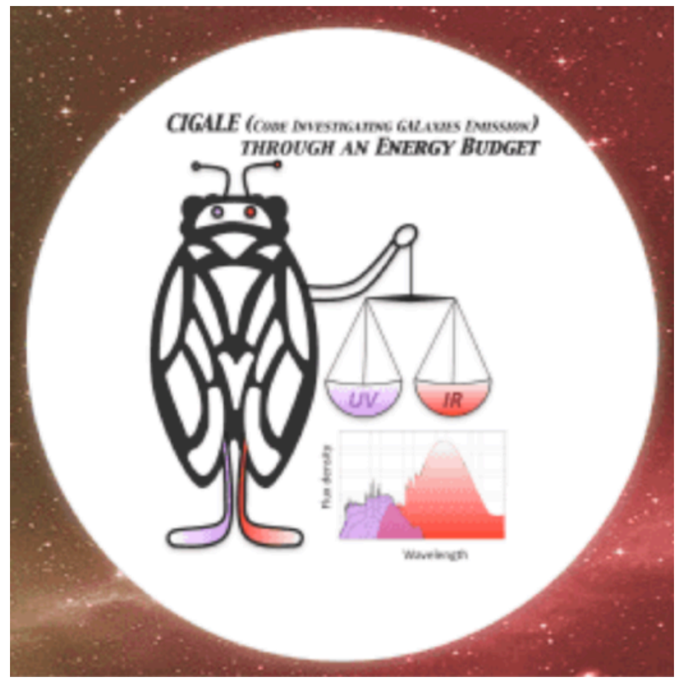


Stellar associations:
Larson et al. (2022)

SED fitting with CIGALE

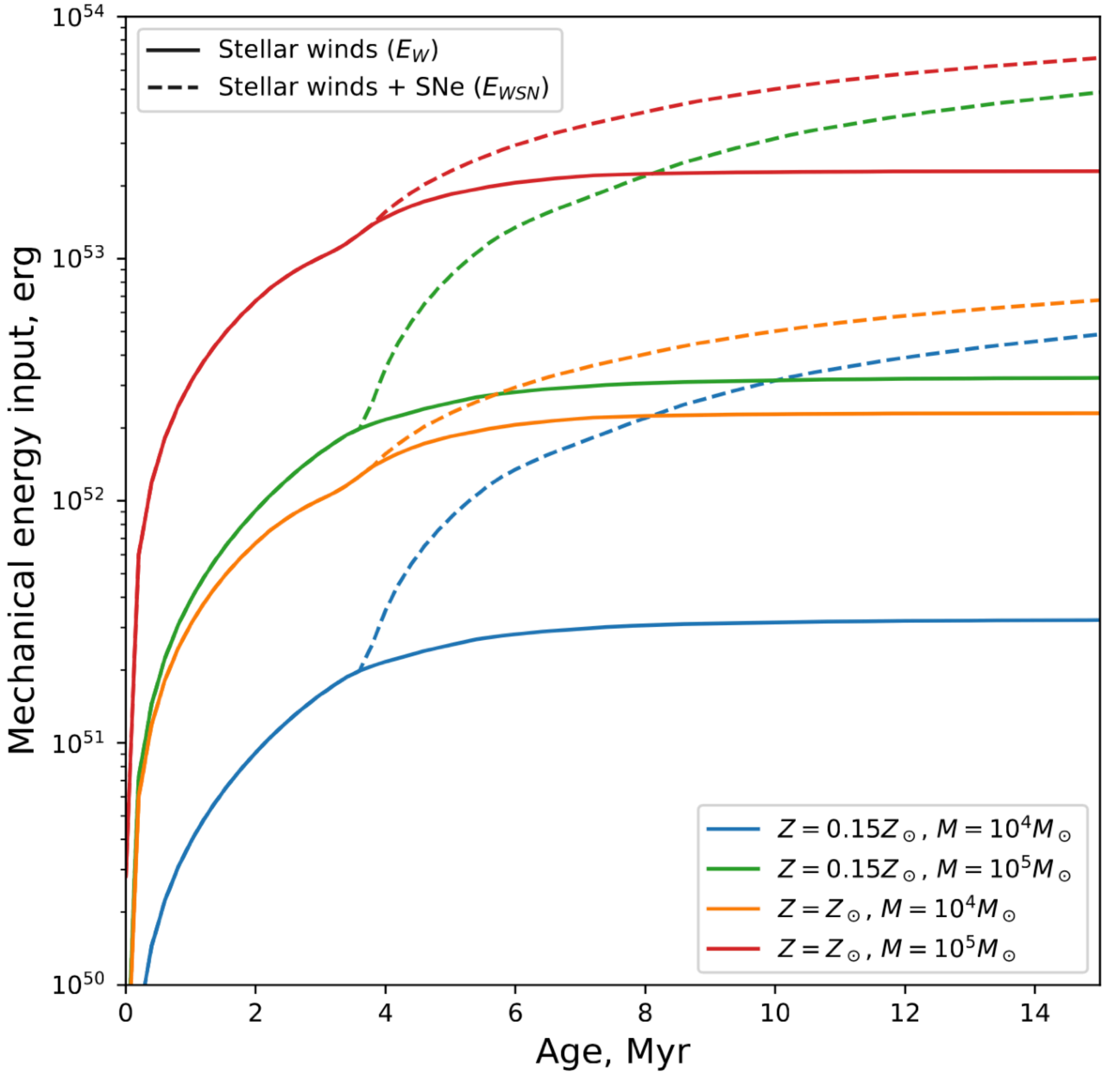


Boquien et al. (2019)

Age & Mass

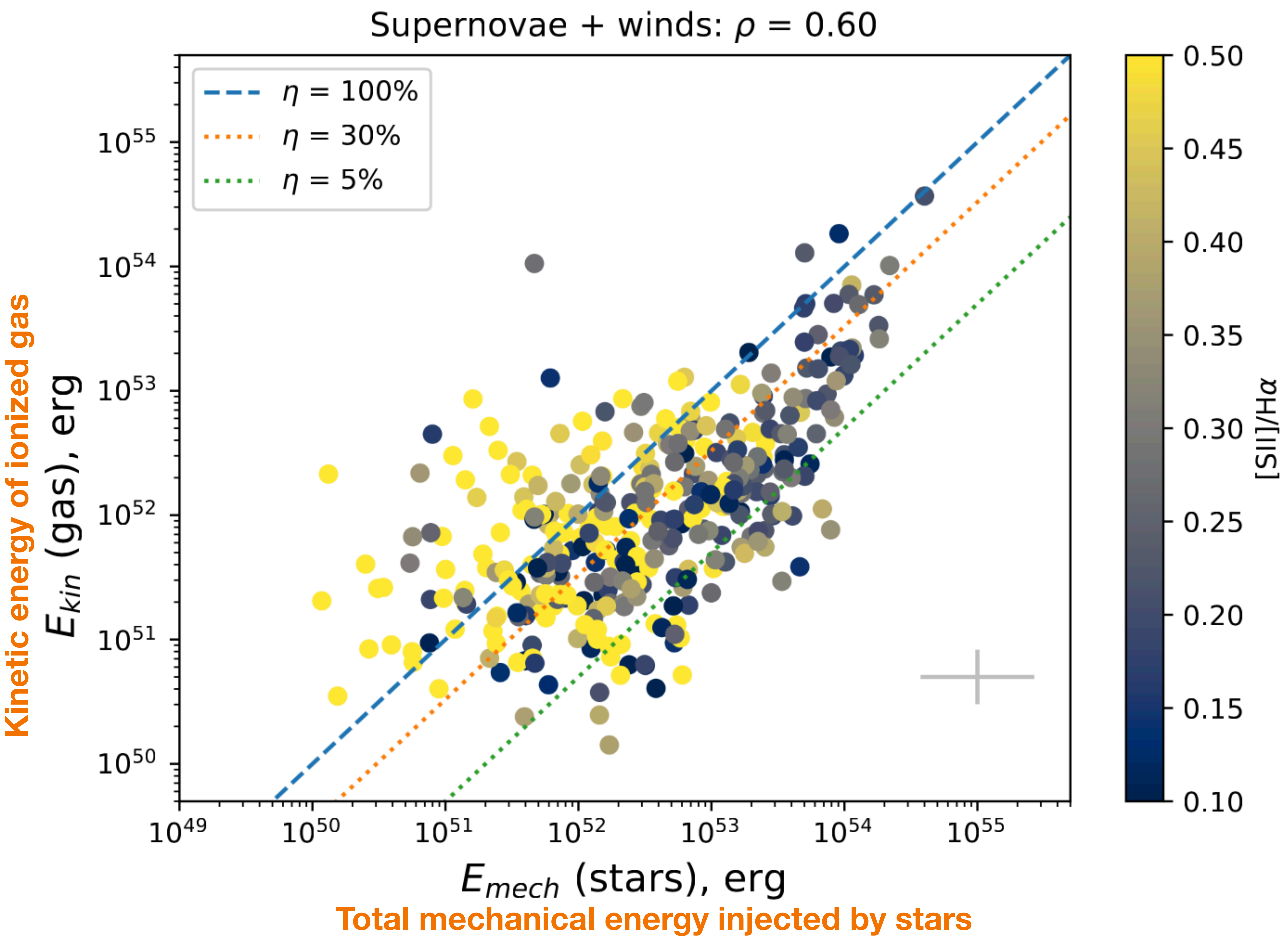
Mechanical energy input
from supernovae and winds:

Starburst99 *(Leitherer et al. (1999, 2014)*



Contribution from stellar winds and SNe from all star clusters in the region during the last 10 Myr

Energy balance between turbulent ionized ISM and massive stars



10-20% of the total mechanical energy injected by stars should retain in the superbubbles or turbulent ISM surrounding the stars.

Egorov et al. (2023)

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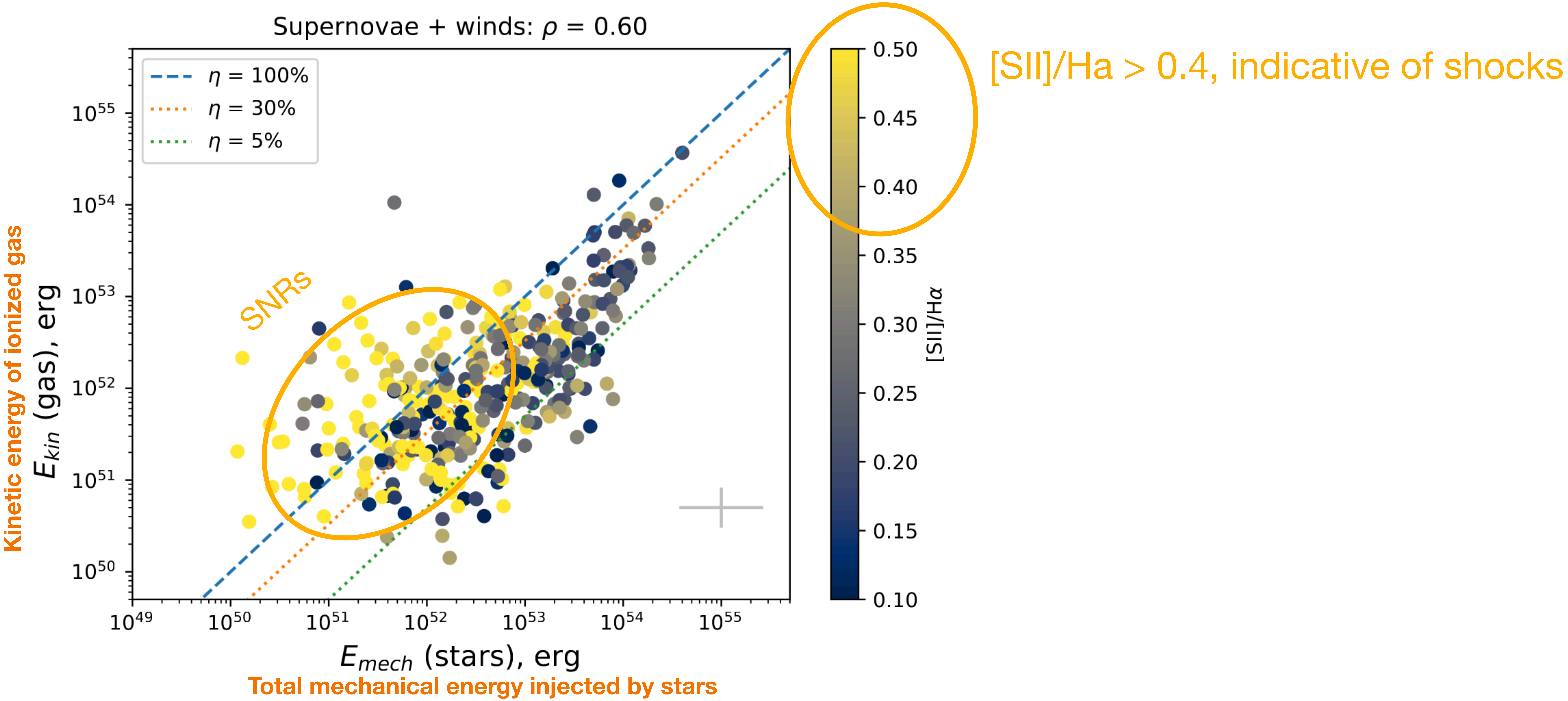

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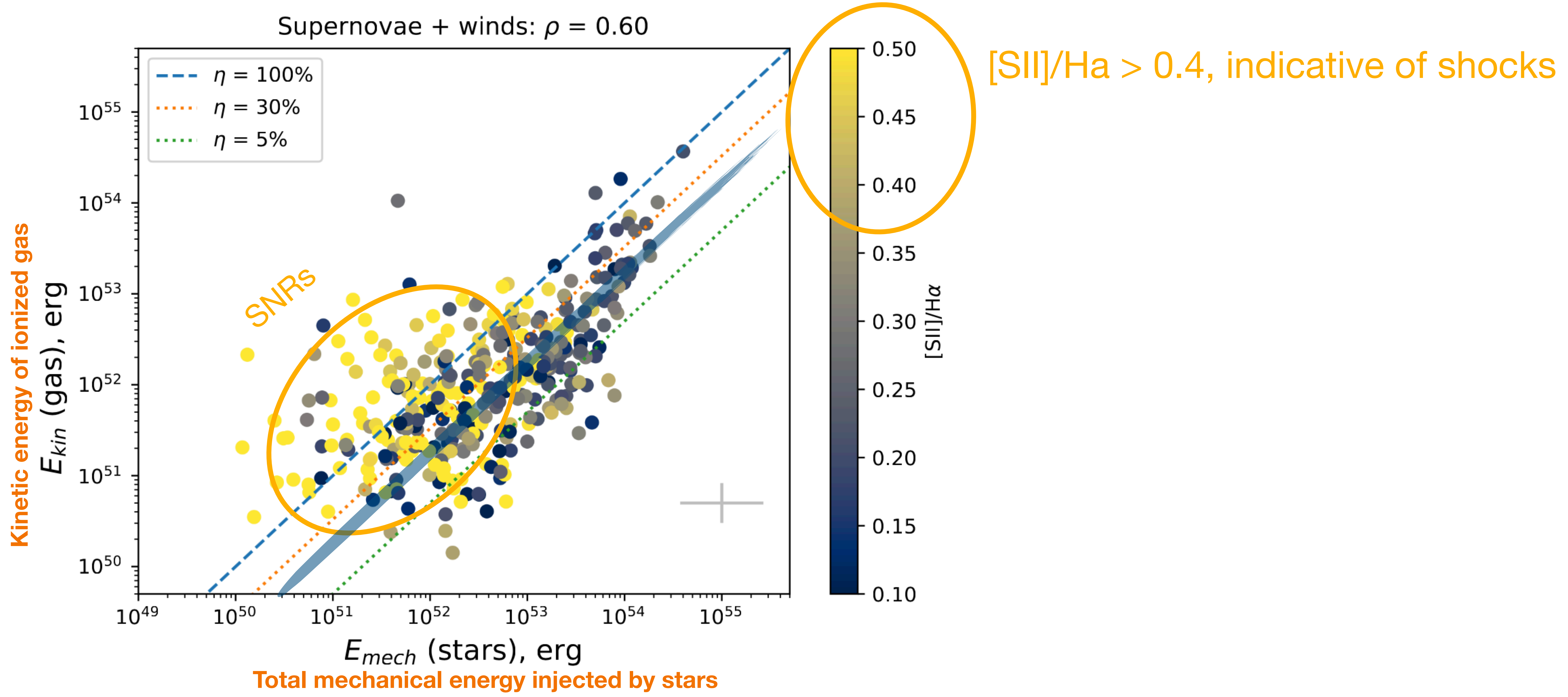

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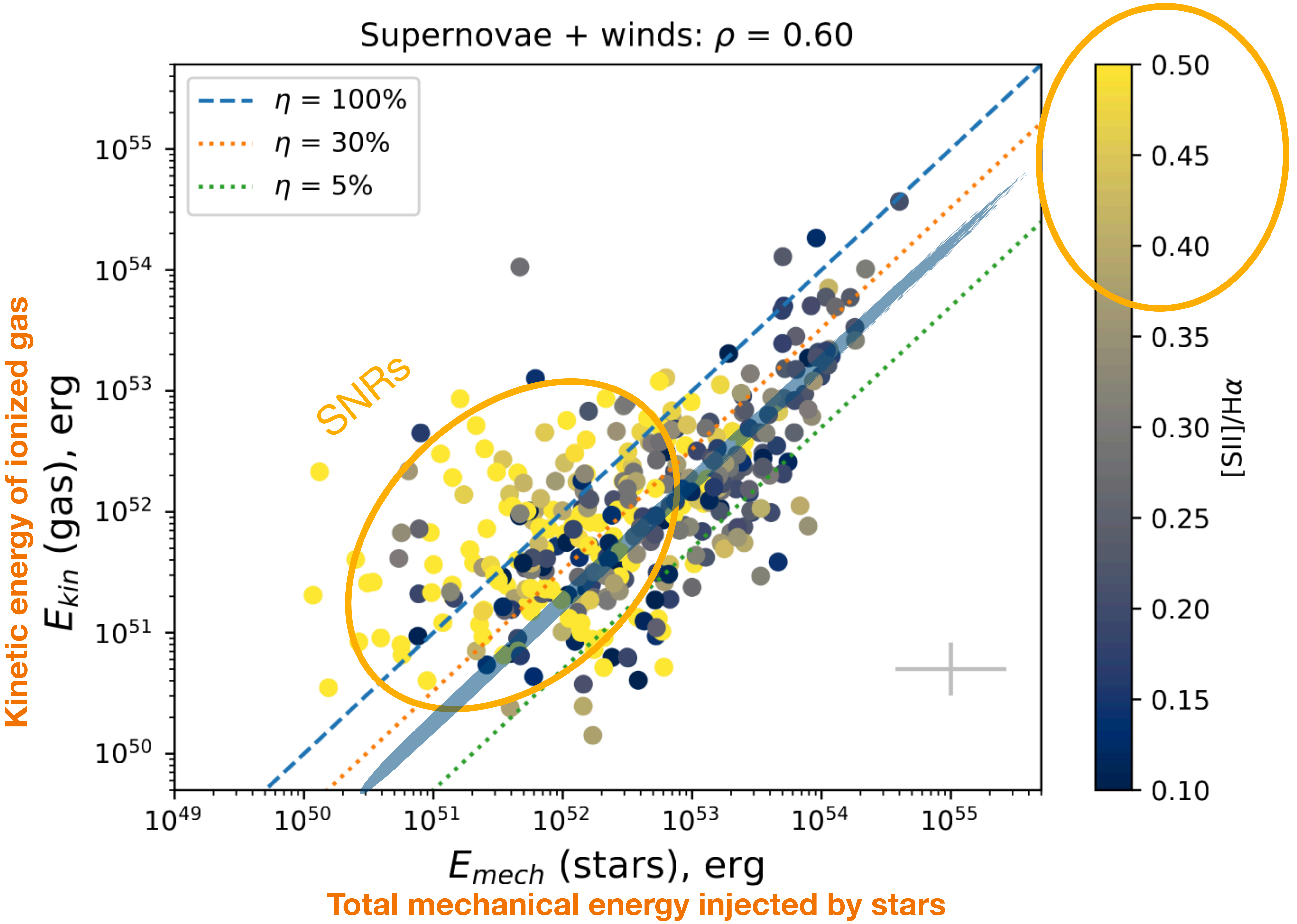

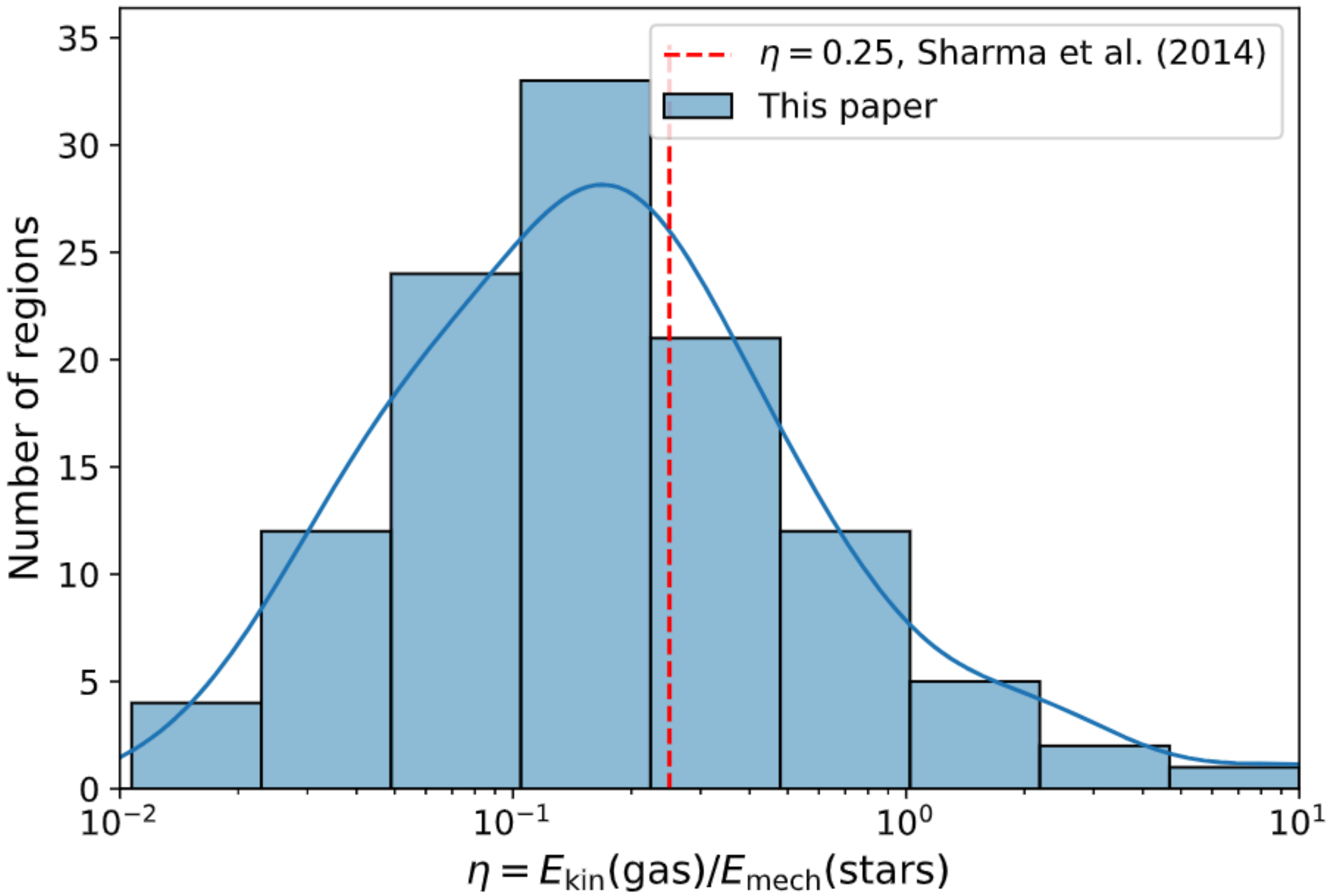

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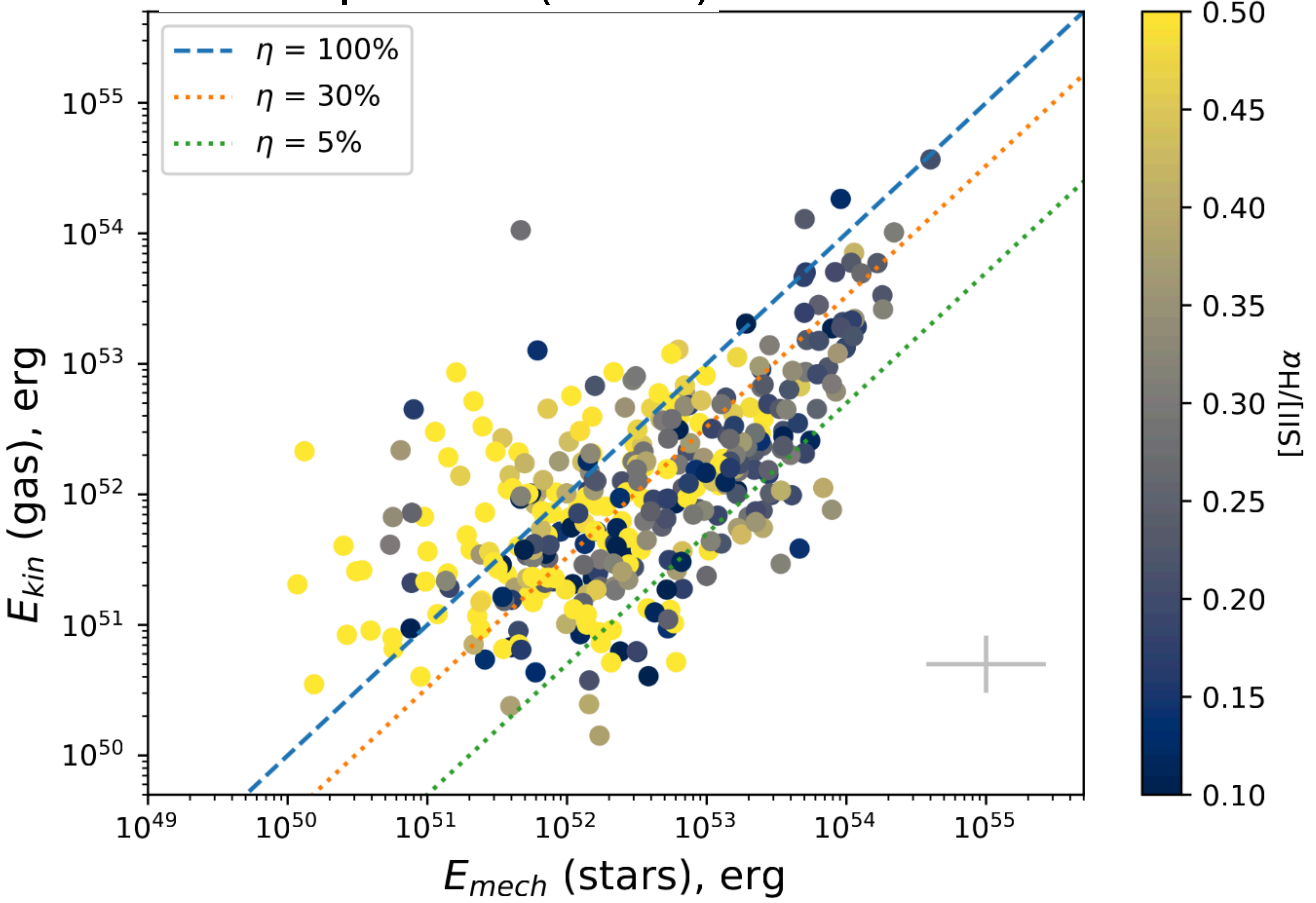
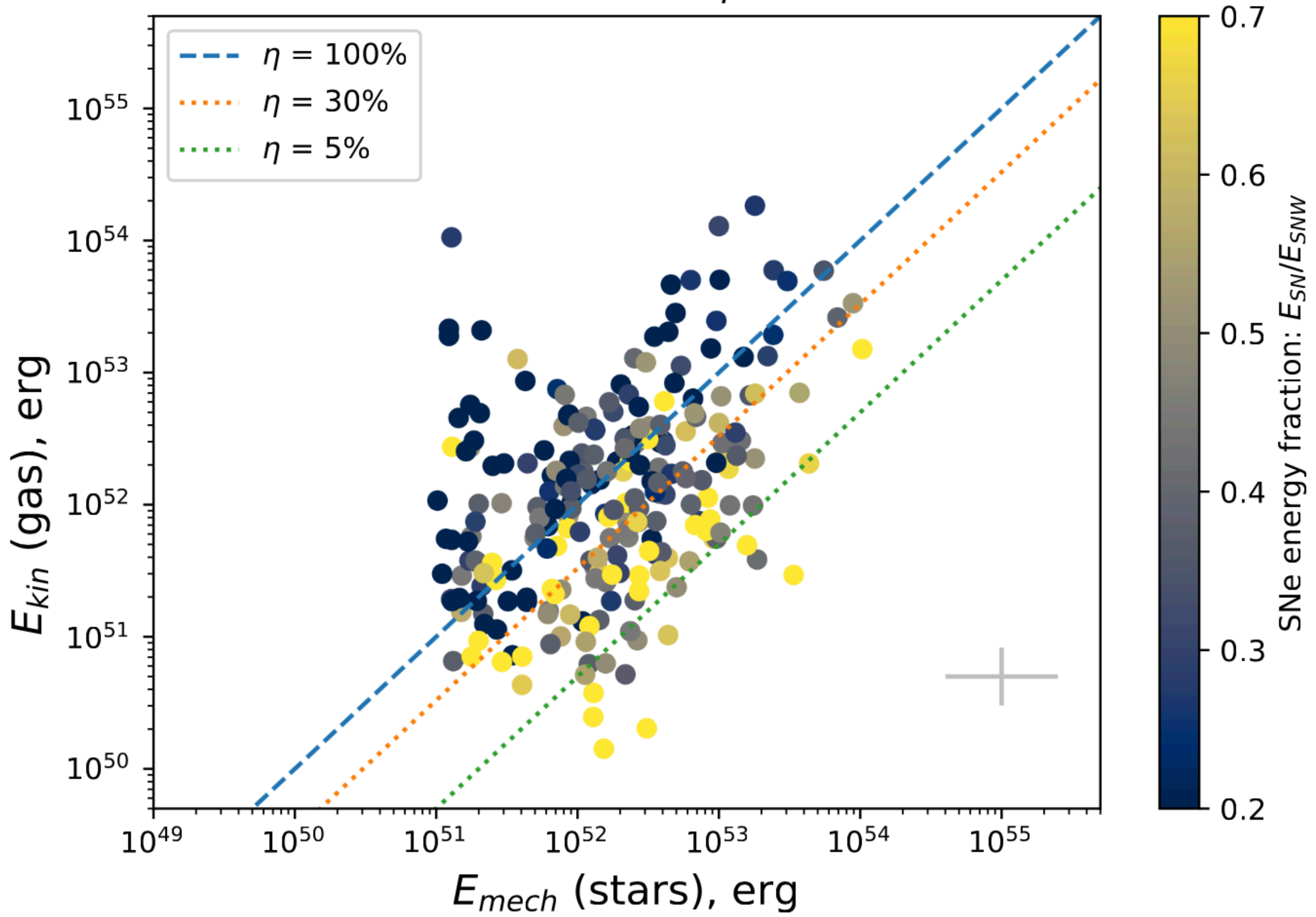
Egorov et al. (2023)

Pre-supernova feedback is crucial

SNe + pre-SN (winds)



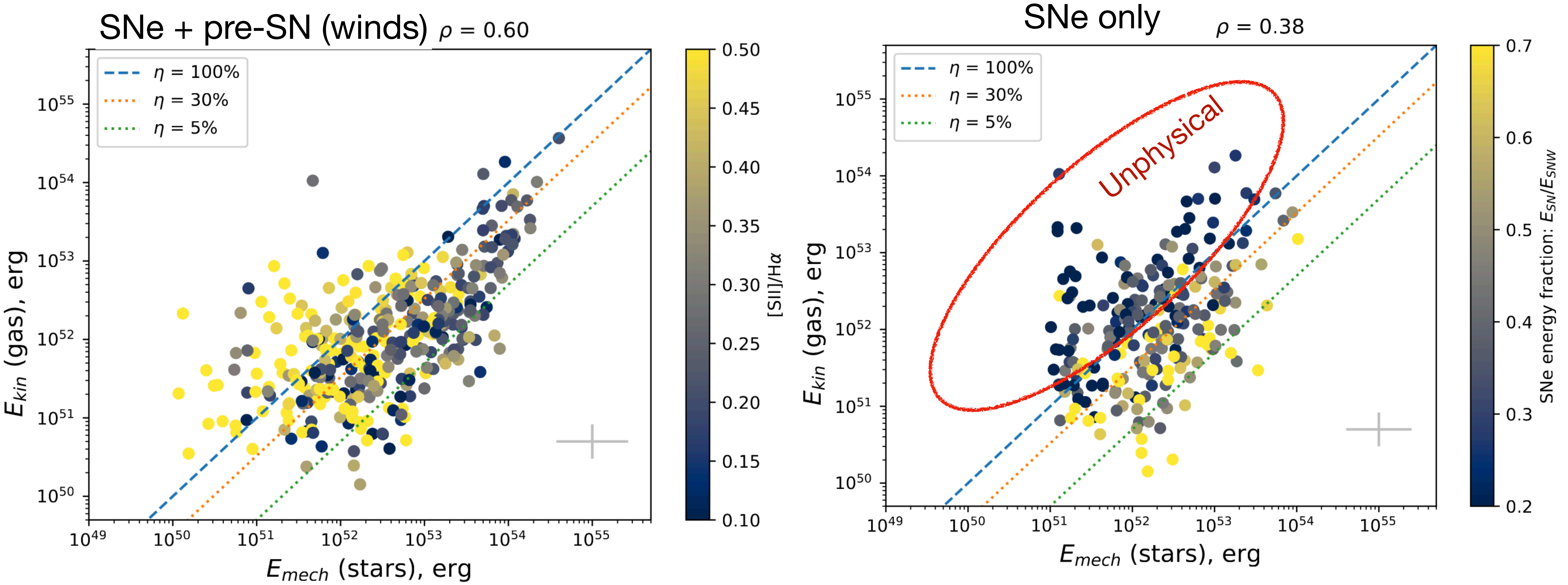
SNe only



Supernovae alone do not produce sufficient mechanical energy to support the turbulent motions or superbubbles expansions for ~50% regions in our sample. Accounting for pre-SN feedback is crucial

Egorov et al. (2023)

Pre-supernova feedback is crucial



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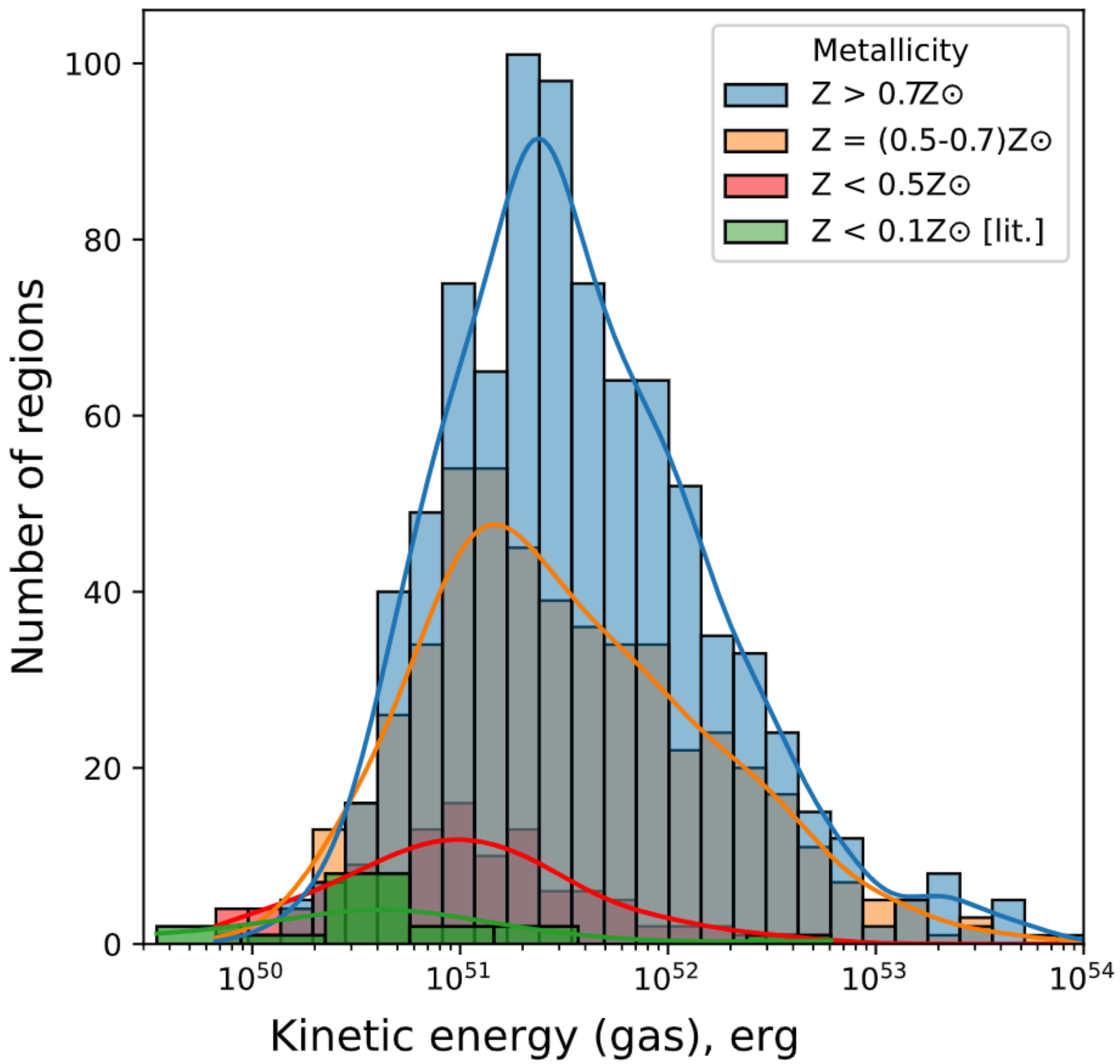
Egorov et al. (2023)

Energy of the turbulent ionized gas at different metallicities

- PHANGS-MUSE observations: the energy of ionized gas in the regions of high velocity dispersion declines with metallicity
- FPI-based measurements for 2 nearby metal-poor (Z<0.1Zsun) dwarfs galaxies (Egorov et al. 2021, Gerasimov, OE et al. 2022)
- Need more homogeneous data at low metallicity.



Egorov et al. (2023)

Some caveats and solutions

Caveats…

Electron density measurements

- From [SII]6717/6731 measurements: $n_{e,[SII]}$ ($\sim n_e^{(max)}$)
  - *Overestimates density and mass due to clumping*

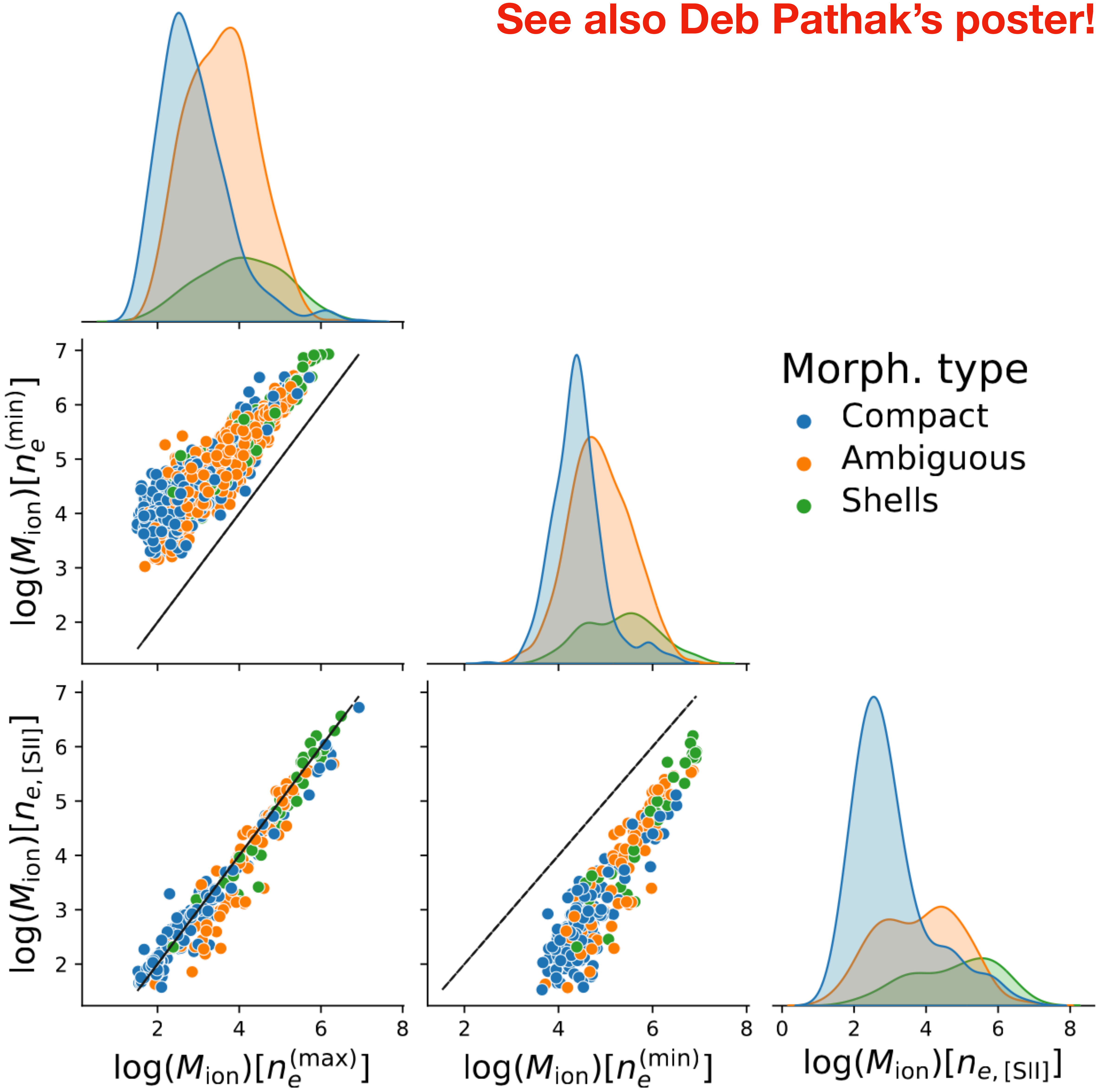
- From Strömgren sphere approximation

$$n_e^{(min)} = \sqrt{\frac{3Q(H^0)}{4\pi R_{eff}^3 \alpha_B}} \simeq 1.42 \times 10^{-16} \left(\frac{L(H\alpha)}{\text{erg s}^{-1}}\right)^{0.5} \left(\frac{R_{eff}}{\text{pc}}\right)^{-1.5} \text{cm}^{-3}$$

  - *Better trace volume-average density;*
  - *Sensitive to precision of size measurements and deviation from spherical geometry*

Adopting [SII]-based density (high limit) leads to and order of magnitude lower coupling efficiency (-> low limit)

See also Deb Pathak's poster!



Egorov et al. (2023)

Caveats…

Accounting for cold gas mass

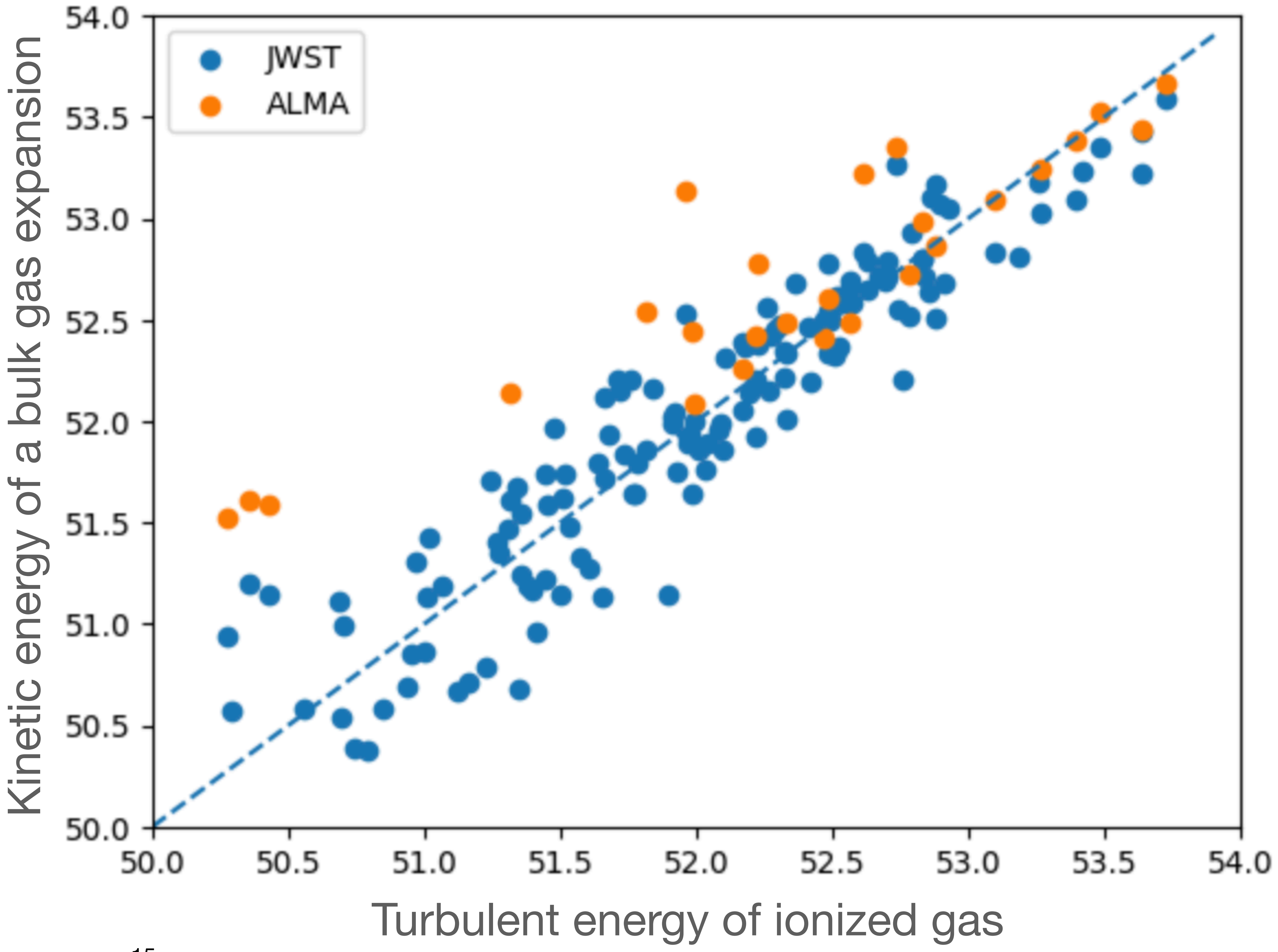
See also Deb Pathak's poster!

- Ionized gas is a dominant contributor to the mass of HII regions (Pathak+in prep), but this is not necessarily true for superbubbles

- Total gas mass and bulk expansion velocities for ~100 expanding bubbles with shell-like morphology in JWST/MIRI or ALMA CO images

Accounting for cold gas does not affect the measurements

- Watkins+2023: coupling efficiency ~5-12% is required for establishing agreement between age of molecular gas bubbles and star clusters



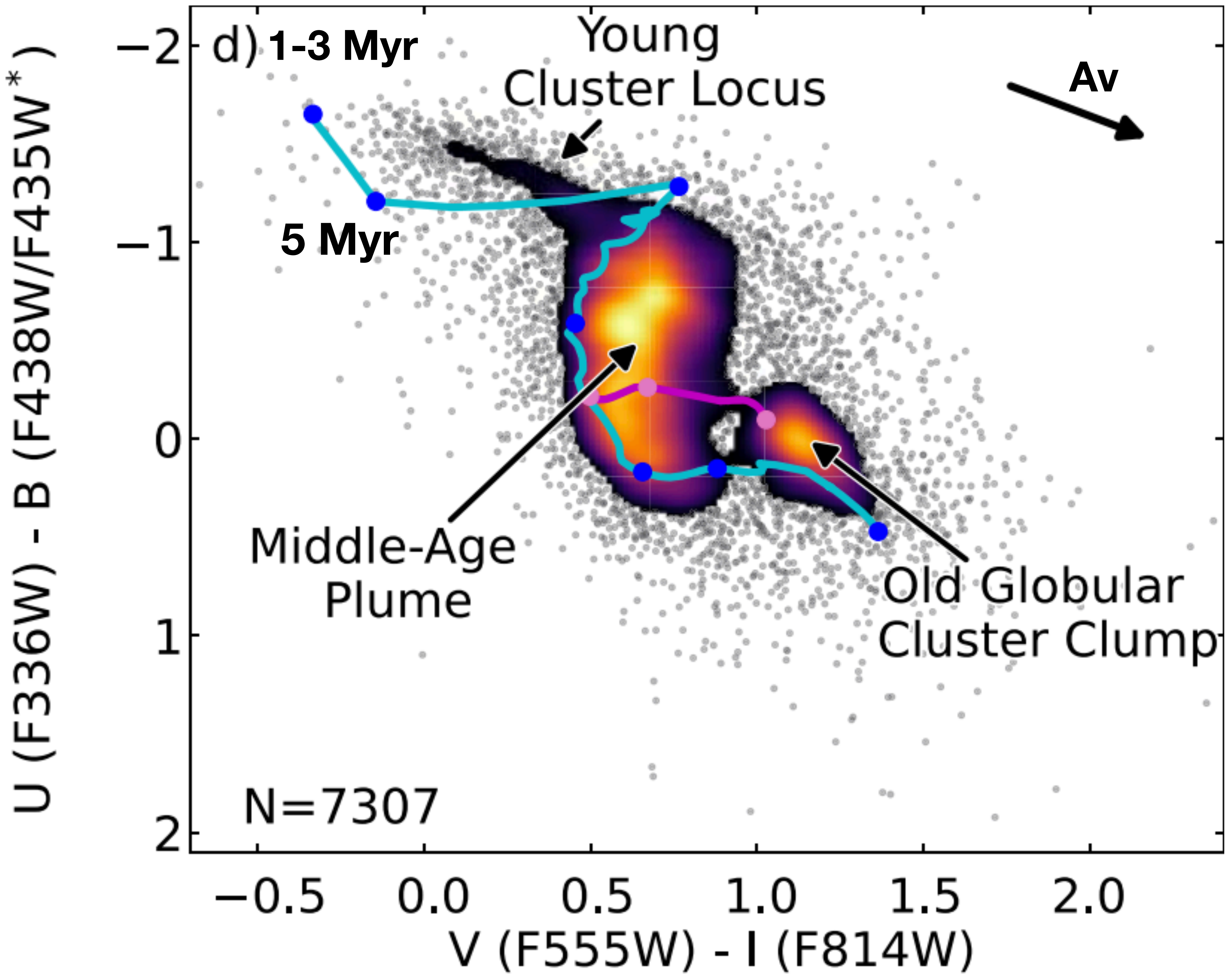
Caveats…

Ages of stellar population

- Precise estimates of the cluster age <3 Myr are challenging.
- Additional information is required (e.g. HST-Ha, or JWST PAHs bands; see, e.g. Whitmore+2024)

<u>Solutions:</u>

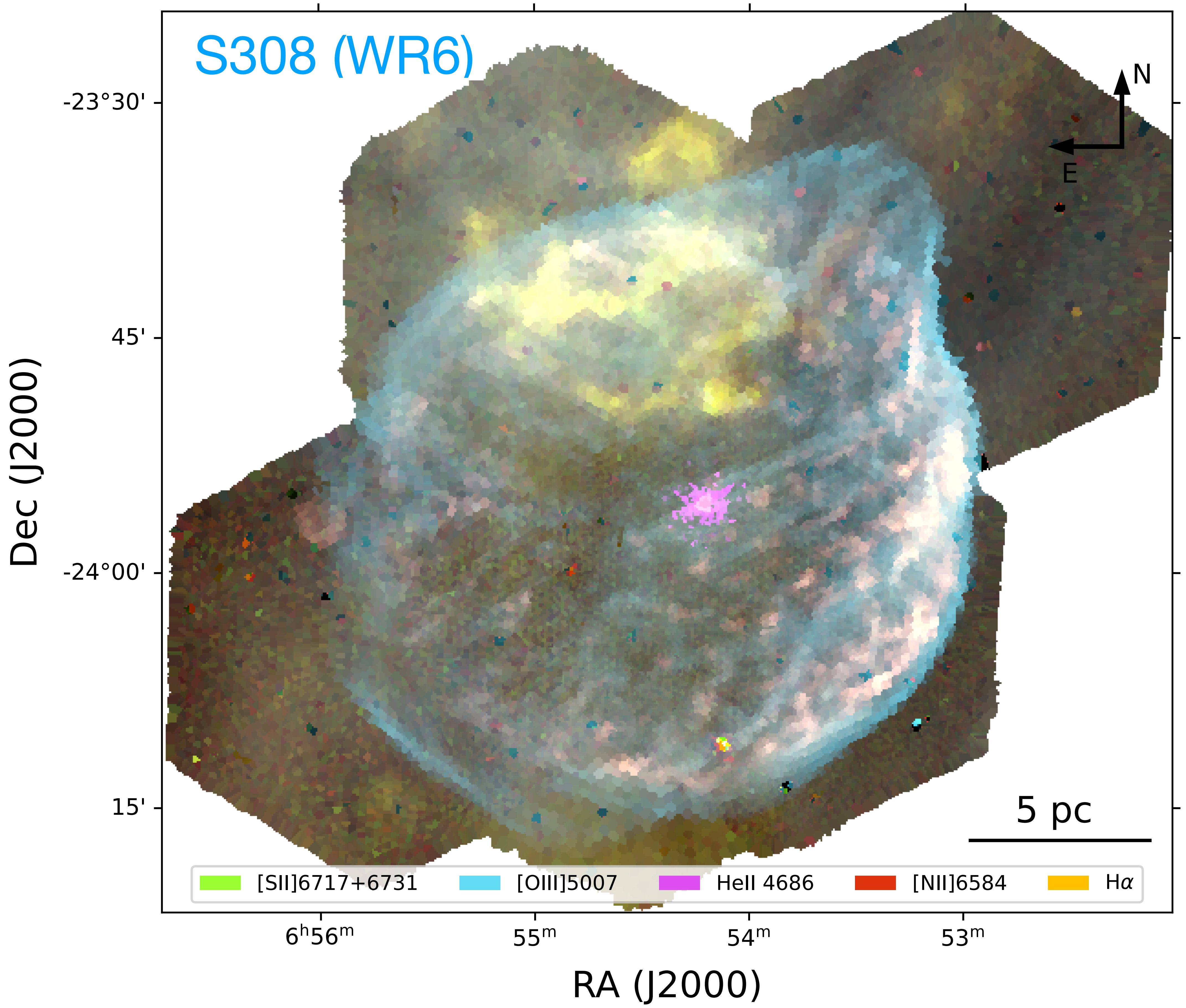
- HST-Ha are now available for all 19 PHANGS-MUSE galaxies (Chandar+2025) => improvements of age measurements
- **Studying bubbles around single stars with precisely measured properties?**

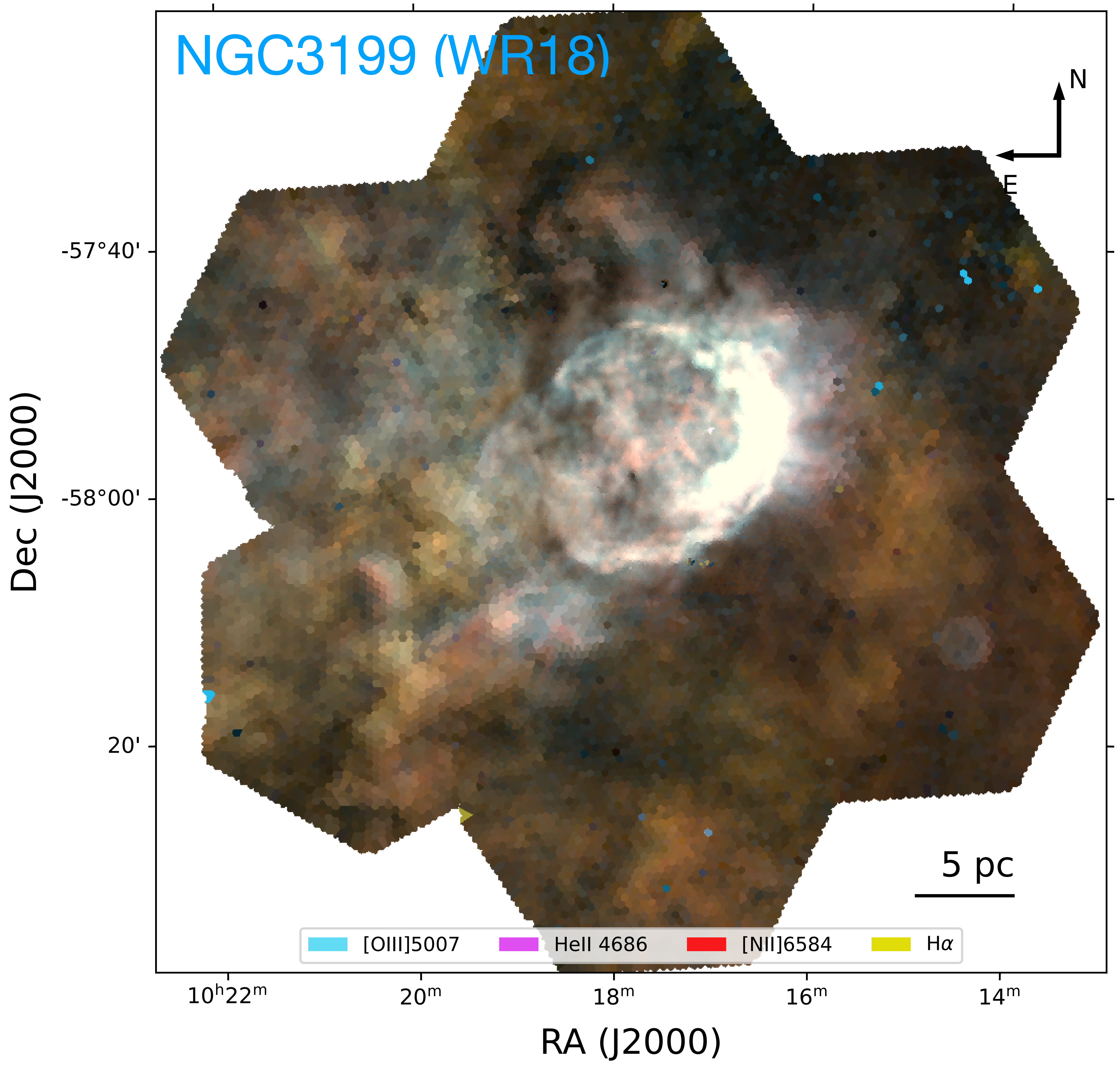


Maschmann et al. (2024)

Galactic WR bubbles

-> See Kathryn Kreckel's talk





Mechanical luminosity of the central WR stars: $L_w = \frac{1}{2}\dot{M}V_\infty^2 \sim 5.7 - 8.0 \times 10^{37} \mathrm{erg/s}$ (Hamann et al. 2019)

Egorov et al. (in prep)

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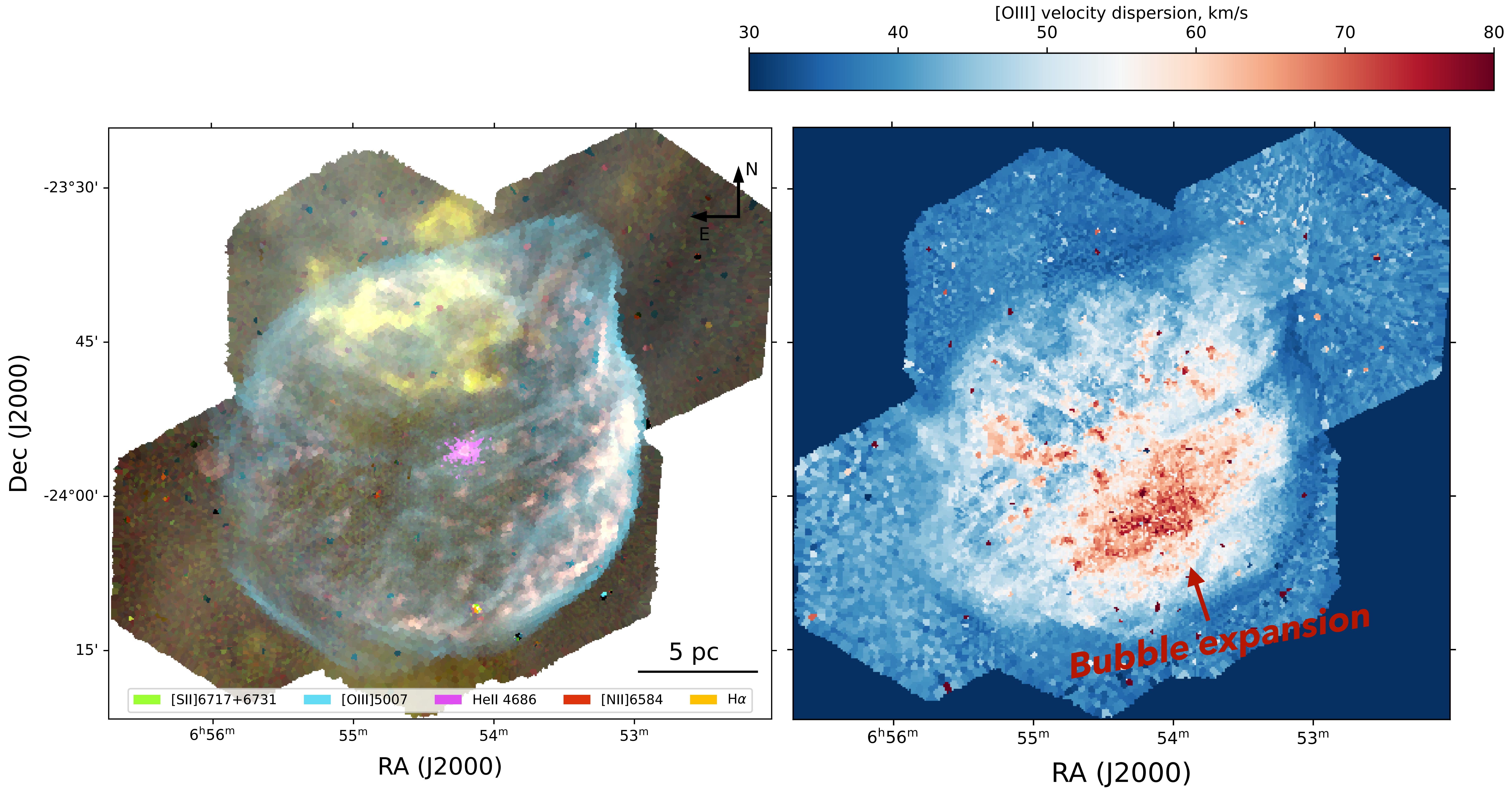

Kinetic energy of the bubbles: ~ $4 - 5.5 \times 10^{48}\mathrm{erg}$: **1-3% of the total mechanical energy injected by central WR star**

Egorov et al. (in prep)

Local Volume Mapper
Resolving the Physics Driving Galaxy Formation

Galactic WR bubbles

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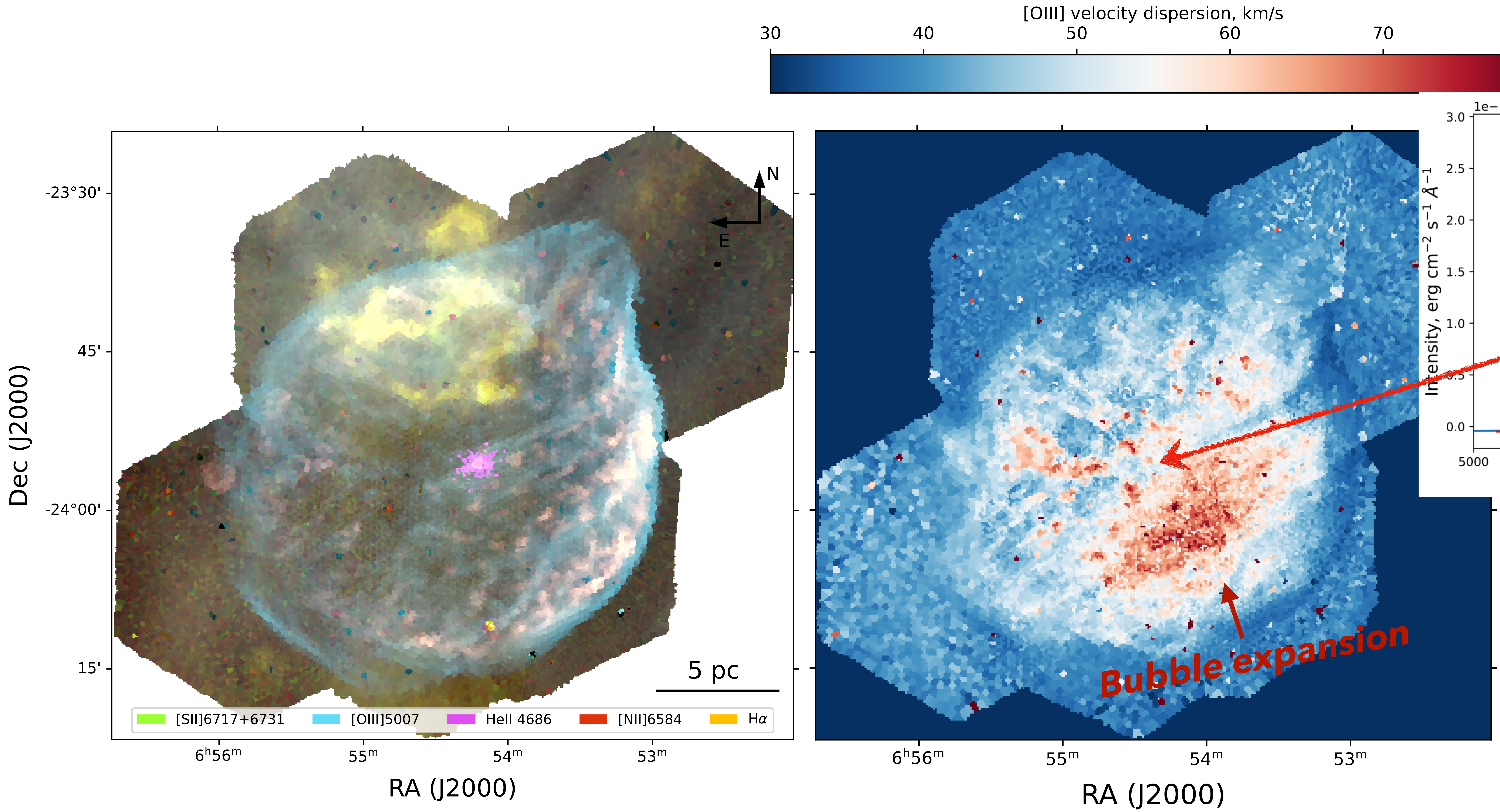

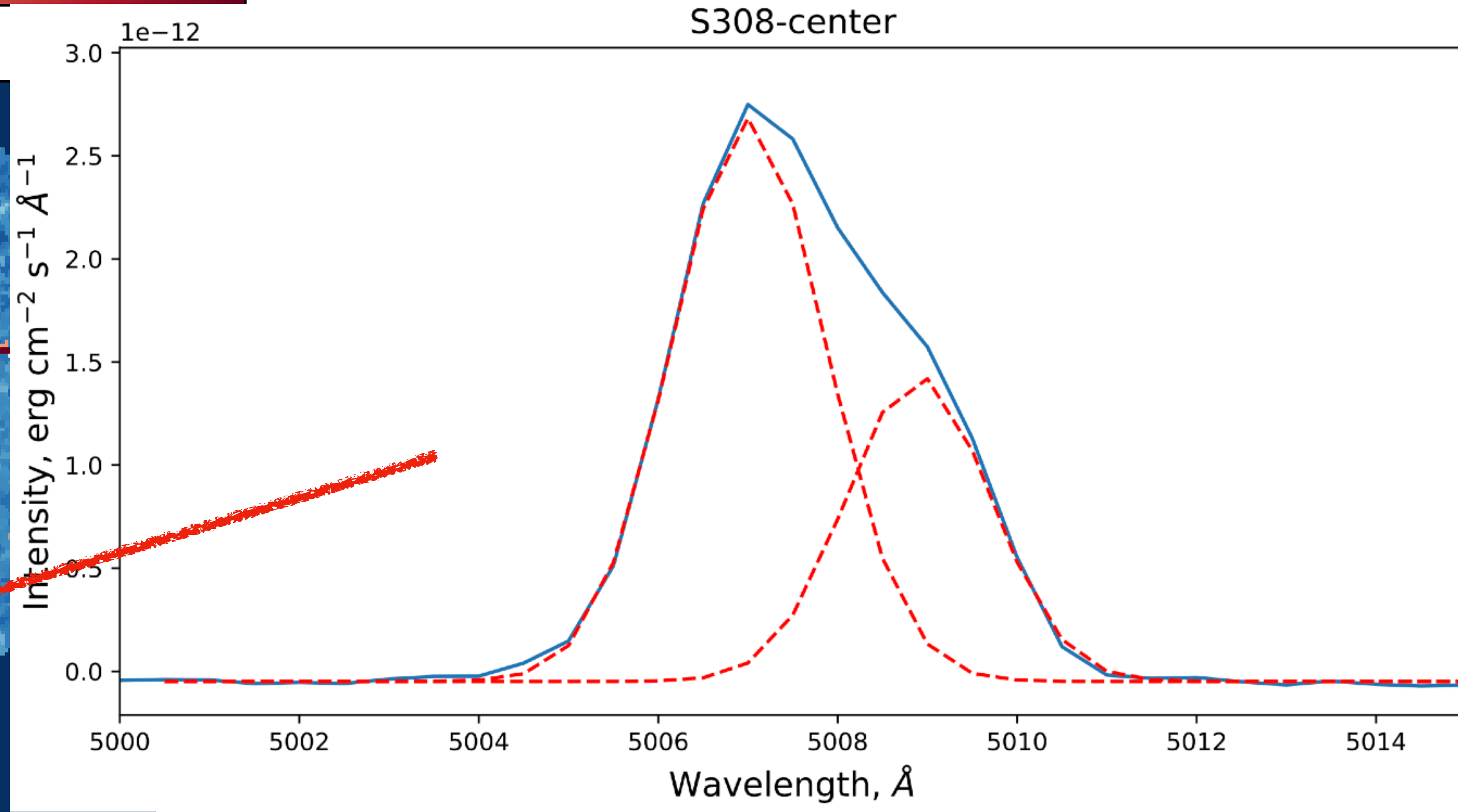

Vexp ~57 km/s
From Weaver et al. (1977) model, dynamical age ~ 0.1 Myr
(In agreement with the estimates by Chu+2003)

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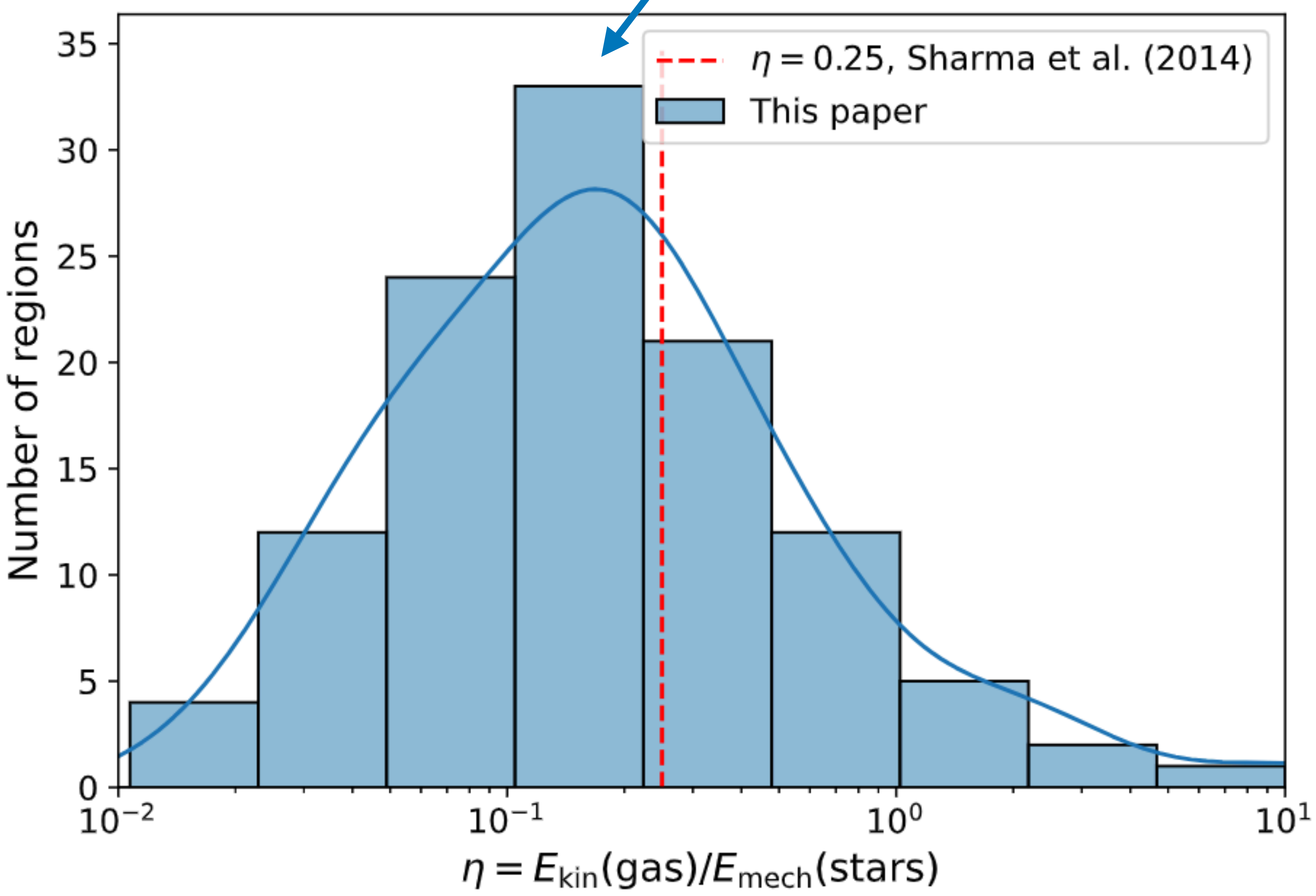
Egorov et al. (in prep)

Constraints on coupling efficiency from observations and simulations

Ionized gas superbubbles
across 19 nearby galaxies



Studying more Local Volume targets is necessary

Egorov et al. (2023; +in prep)

Constraints on coupling efficiency from observations and simulations

Ionized gas superbubbles
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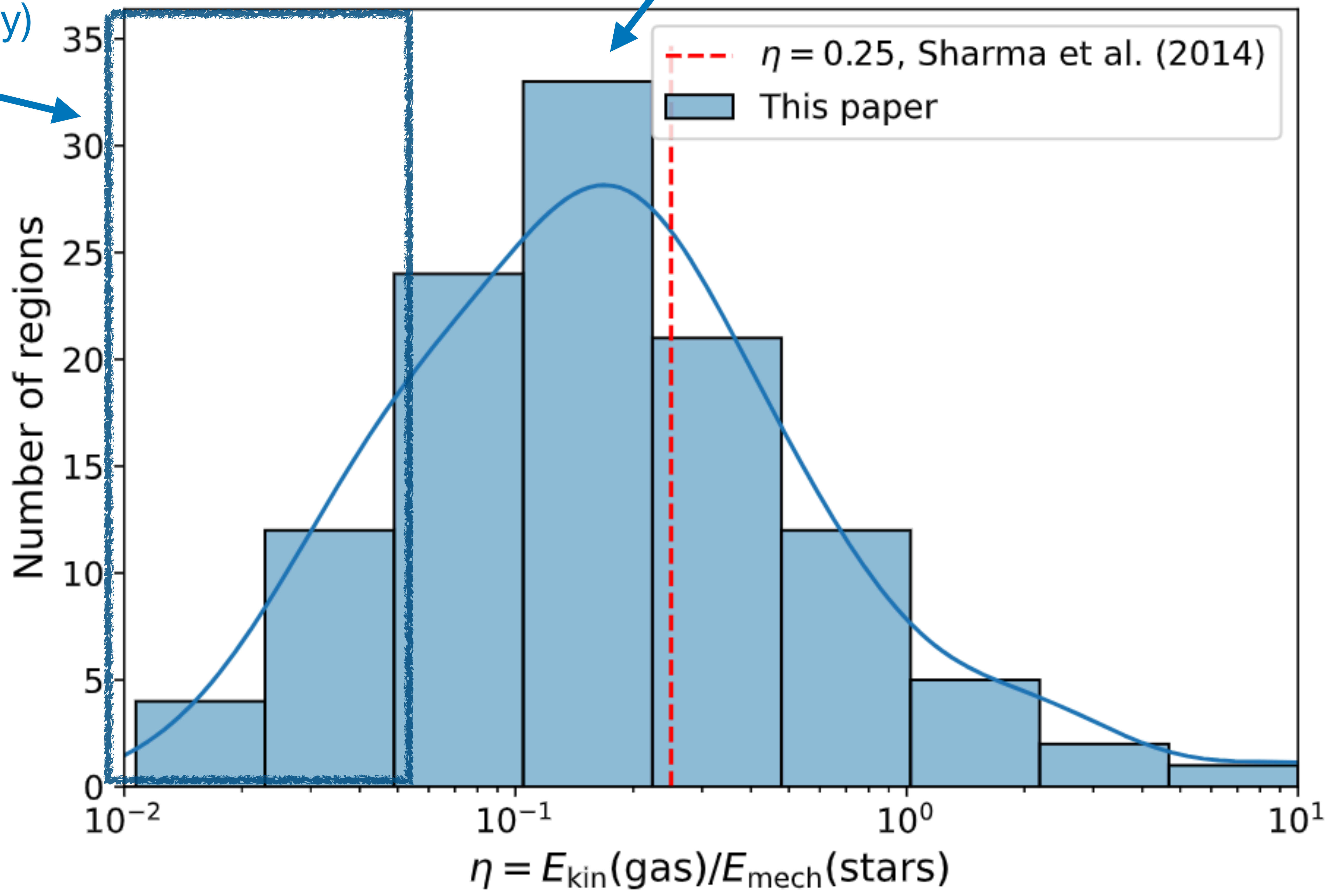
Ionized gas superbubbles
(Lower limit: overestimated density)



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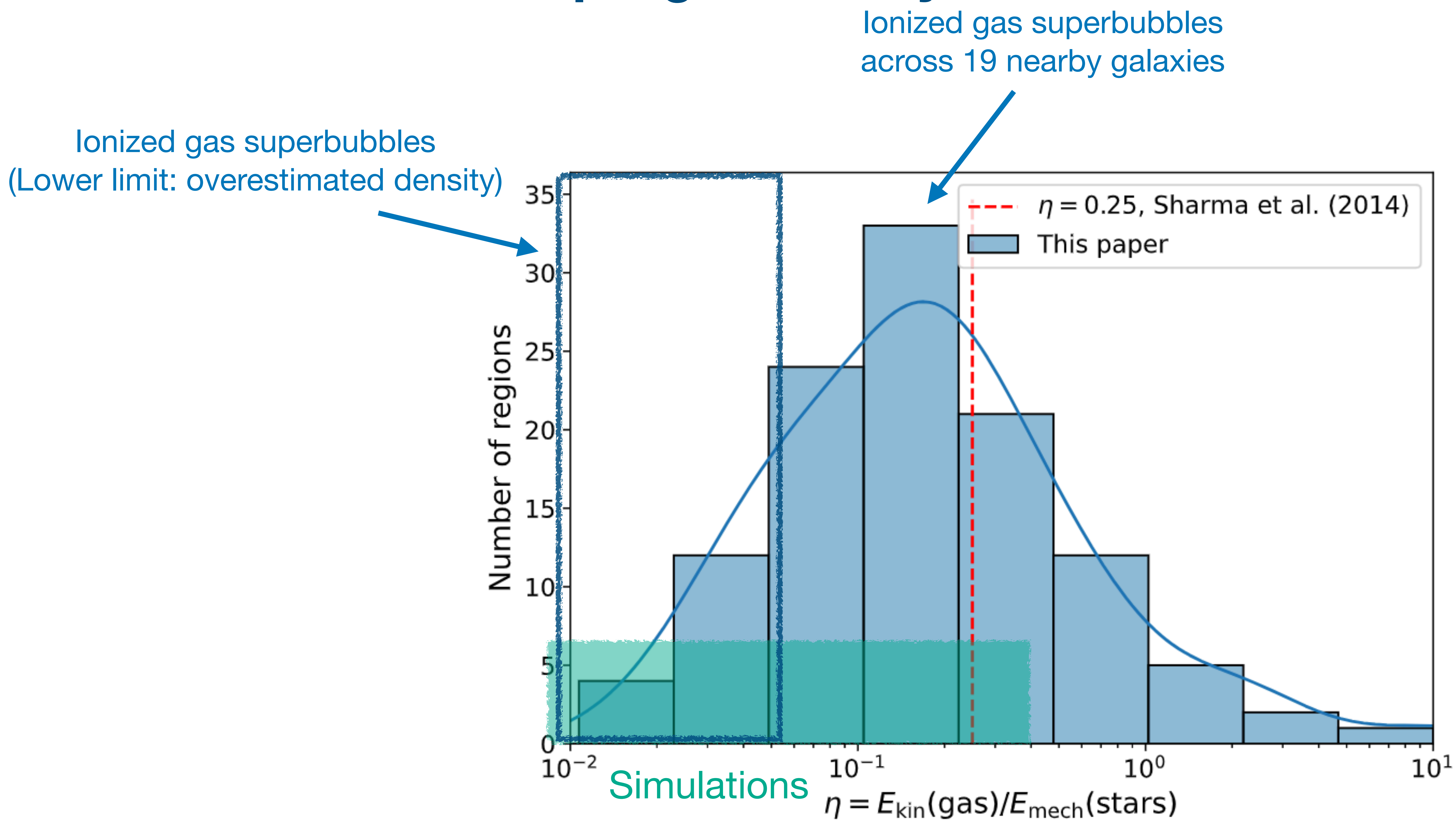

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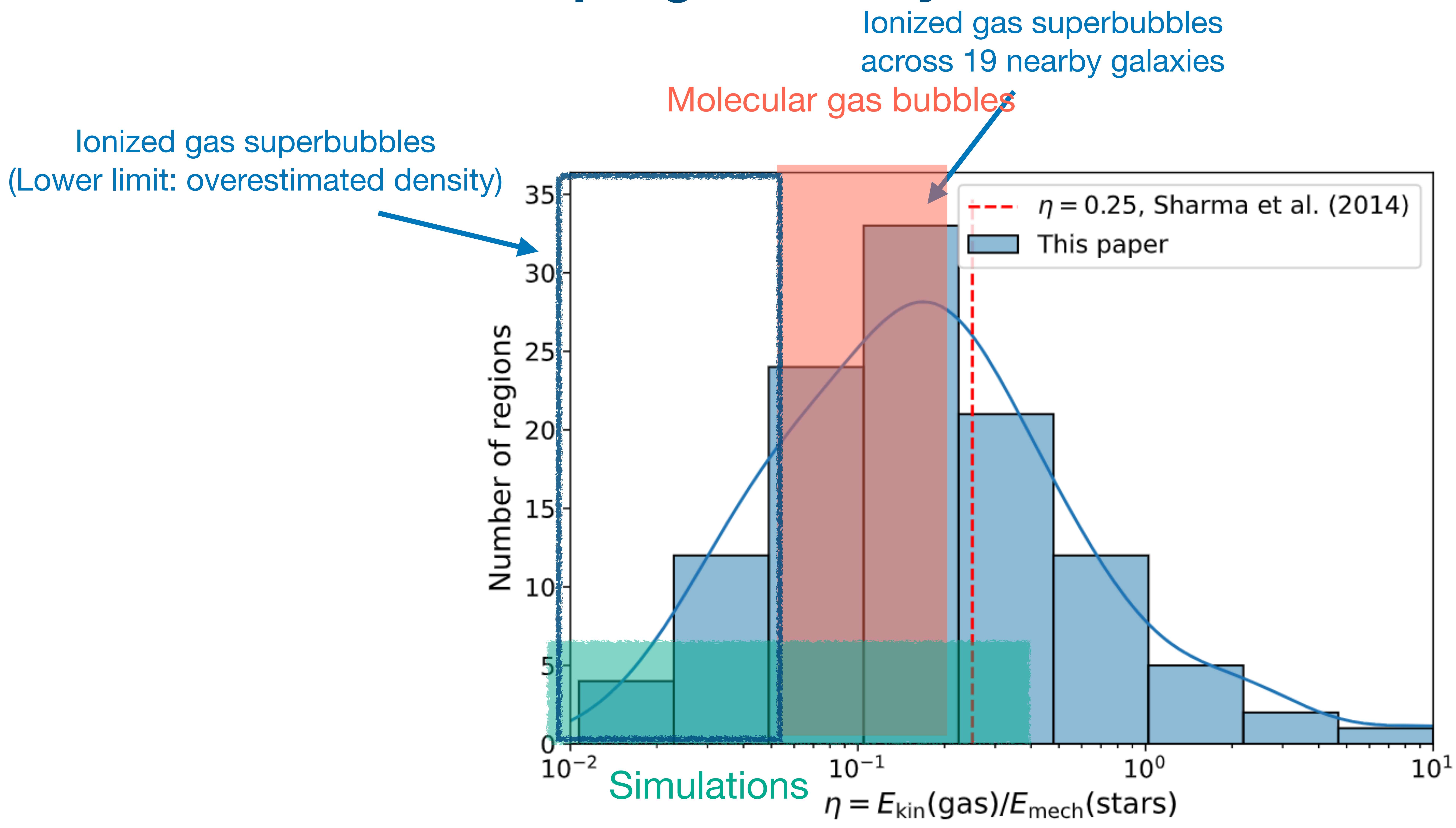

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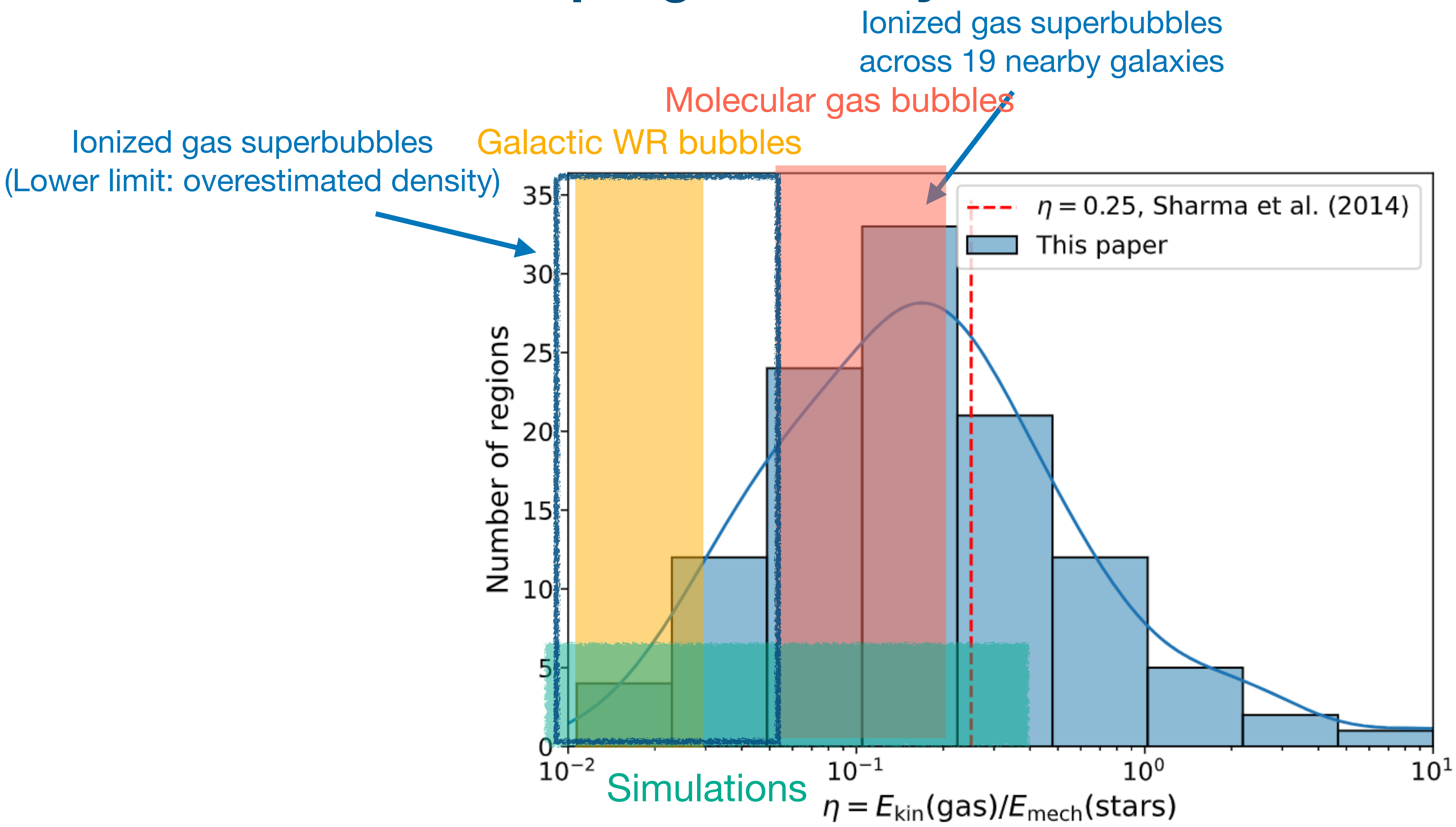

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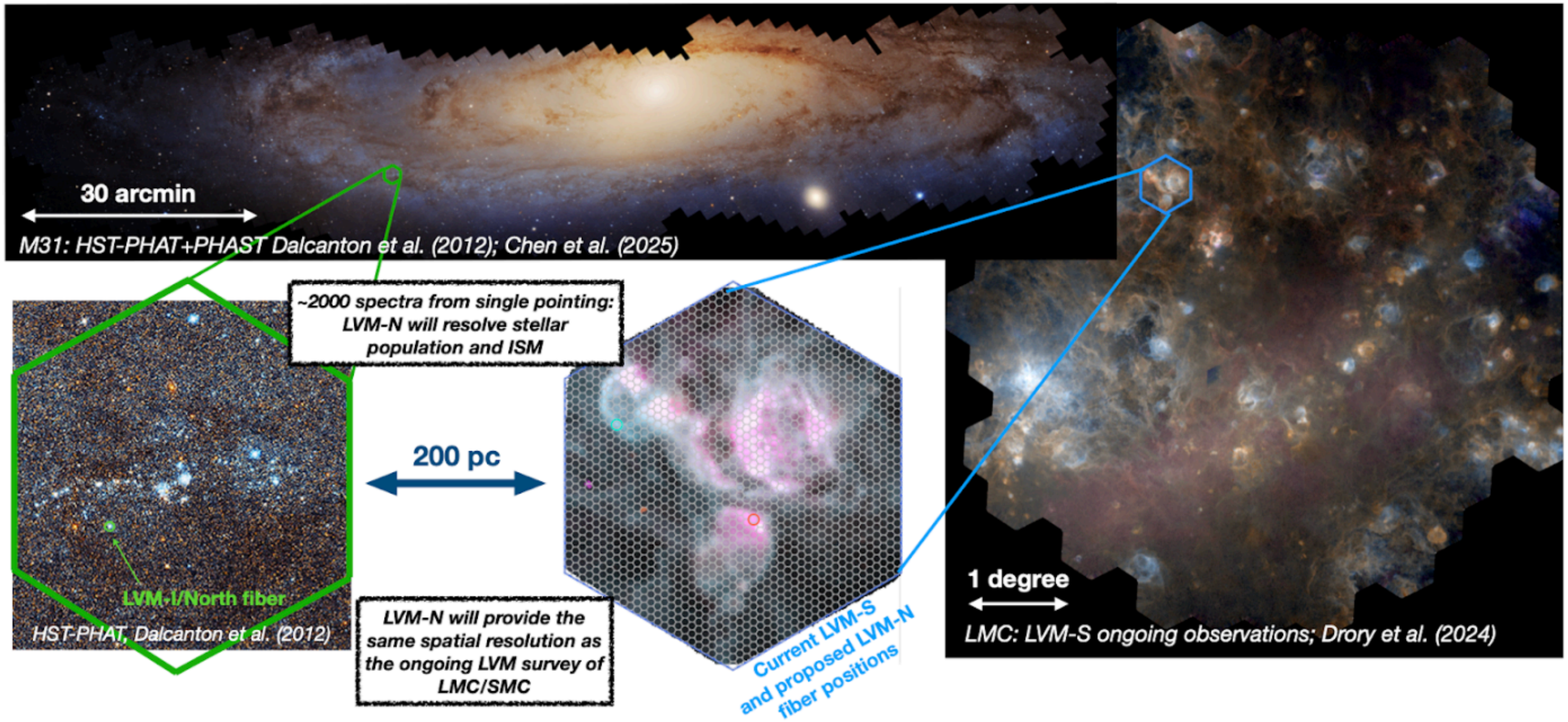
AS5 Local Group Explorer (expected 2027-…)

LVM-N: Optical wide-field IFU spectroscopy of M31, M33, dwarfs and more

LVM-N is the only project capable of mapping all northern Local Group galaxies. Following a strategy well-proven in the ongoing LVM survey of the Milky Way, LMC and SMC, we will provide the unprecedented view on the ISM and stellar population in M31, M33 and nearby dwarf galaxies.



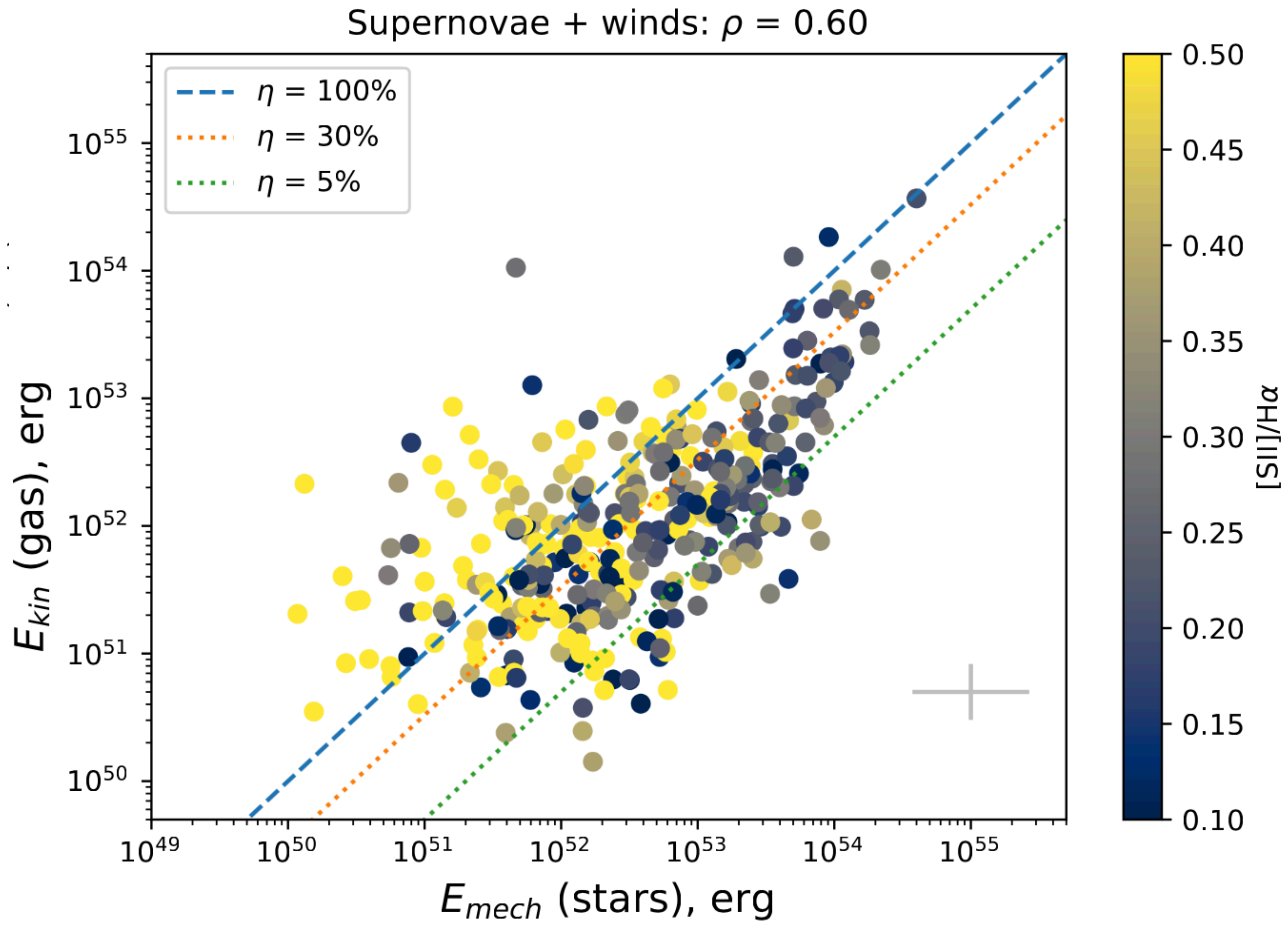
Goal: Spectral mapping of *resolved stellar population* and *ionized gas* in Local Group galaxies at scales of <10 pc. We will measure dozens key lines for physical and chemical diagnostics spread across the entire wavelength range

Summary

1) Energy balance between massive stars and small-scale supersonic motions of ionized gas in the ISM of 19 PHANGS galaxies with the efficiency of 10-20%

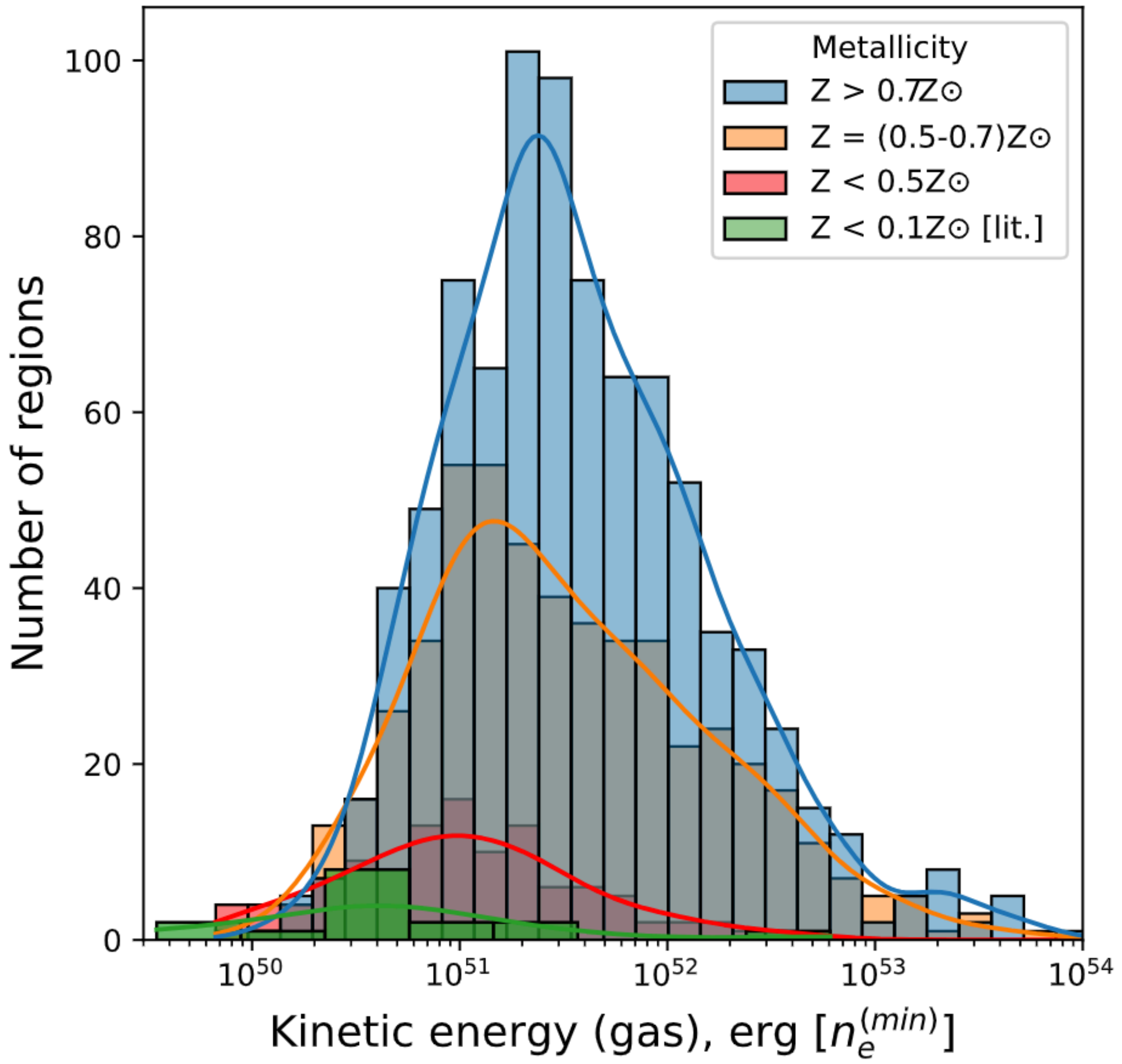
Can be significantly lower: dependent on methods and target selection

Accounting for pre-SN feedback impact is crucial



2) Kinetic energy of the turbulent ionized gas and superbubbles declines in the low-metallicity environment

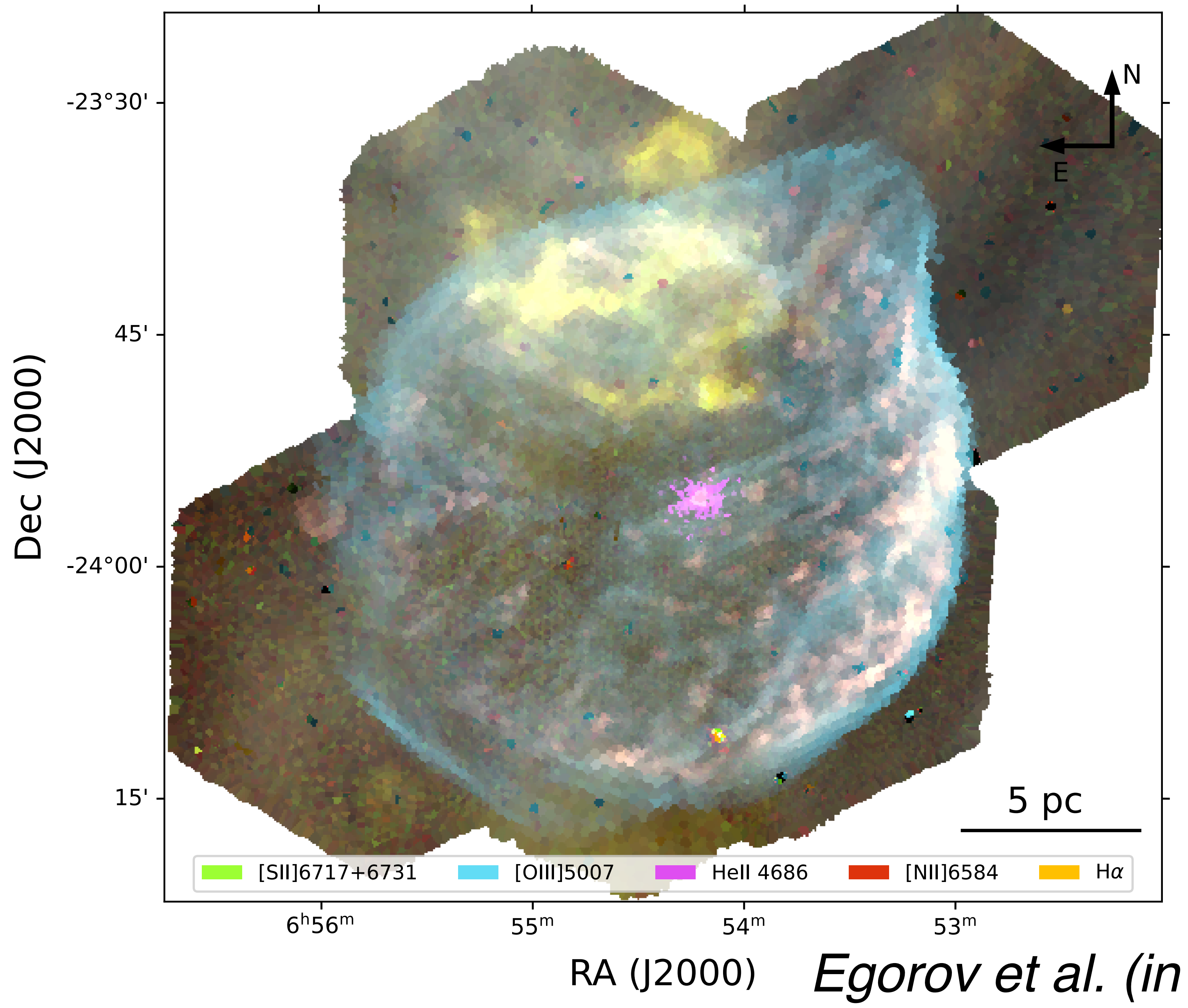
The feedback-driven ionized gas motions are observed even in very metal-poor galaxies



Egorov et al., A&A, 678, A153 (2023)

3) Resolved ionized gas kinematics is crucial to understand how stellar feedback shapes ISM of galaxies

Stay tuned for forthcoming data data



Egorov et al. (in prep)

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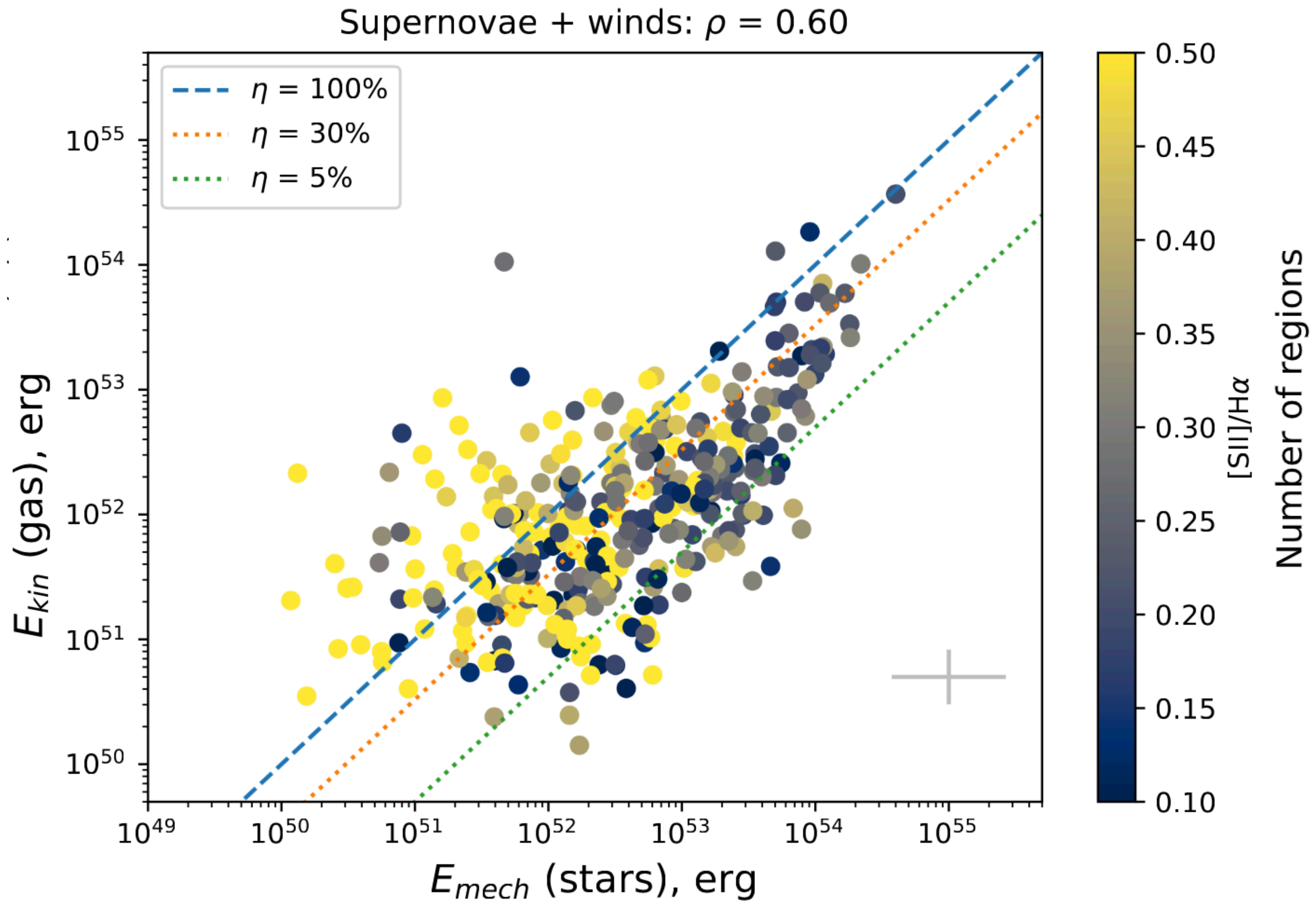

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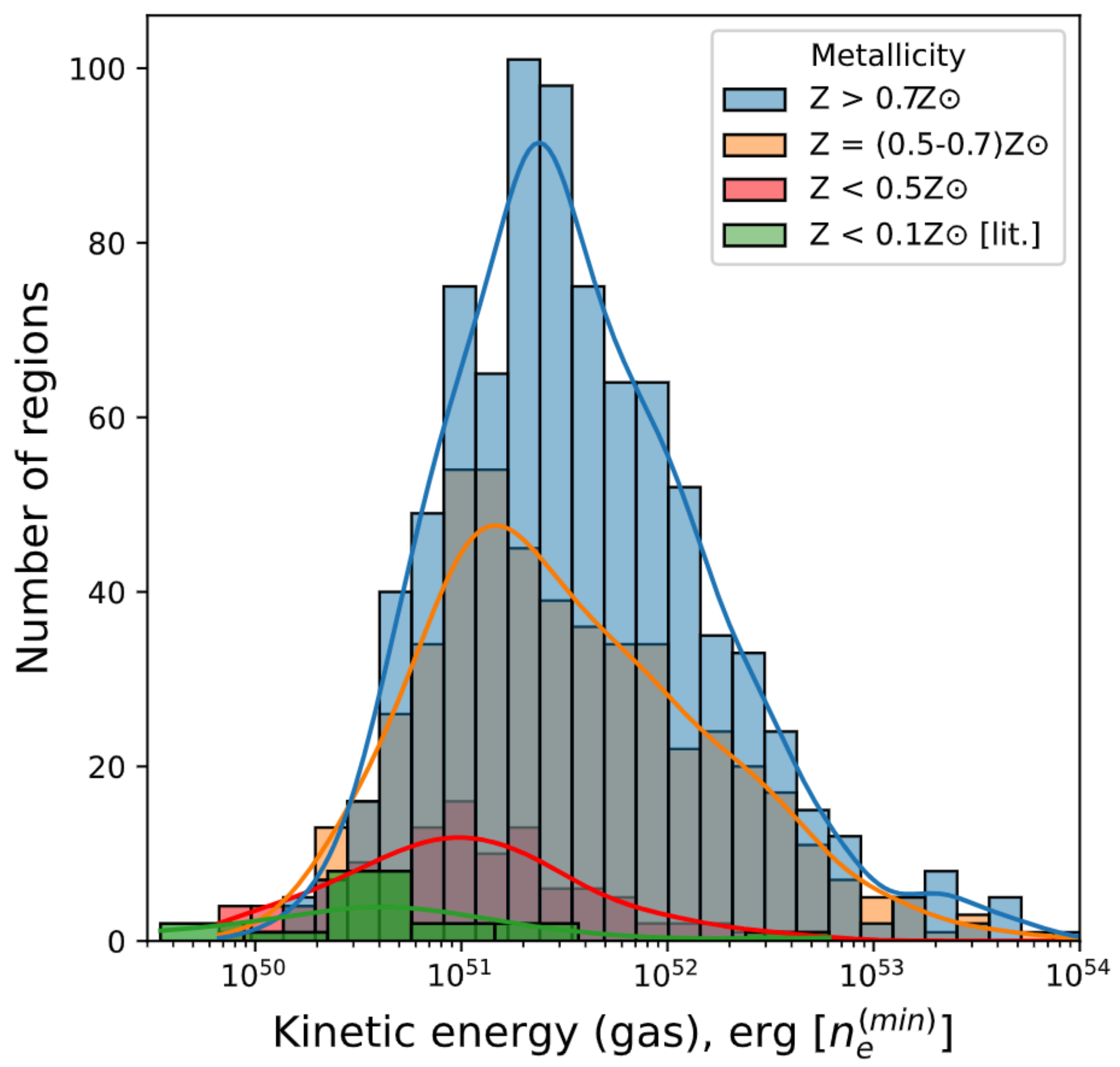

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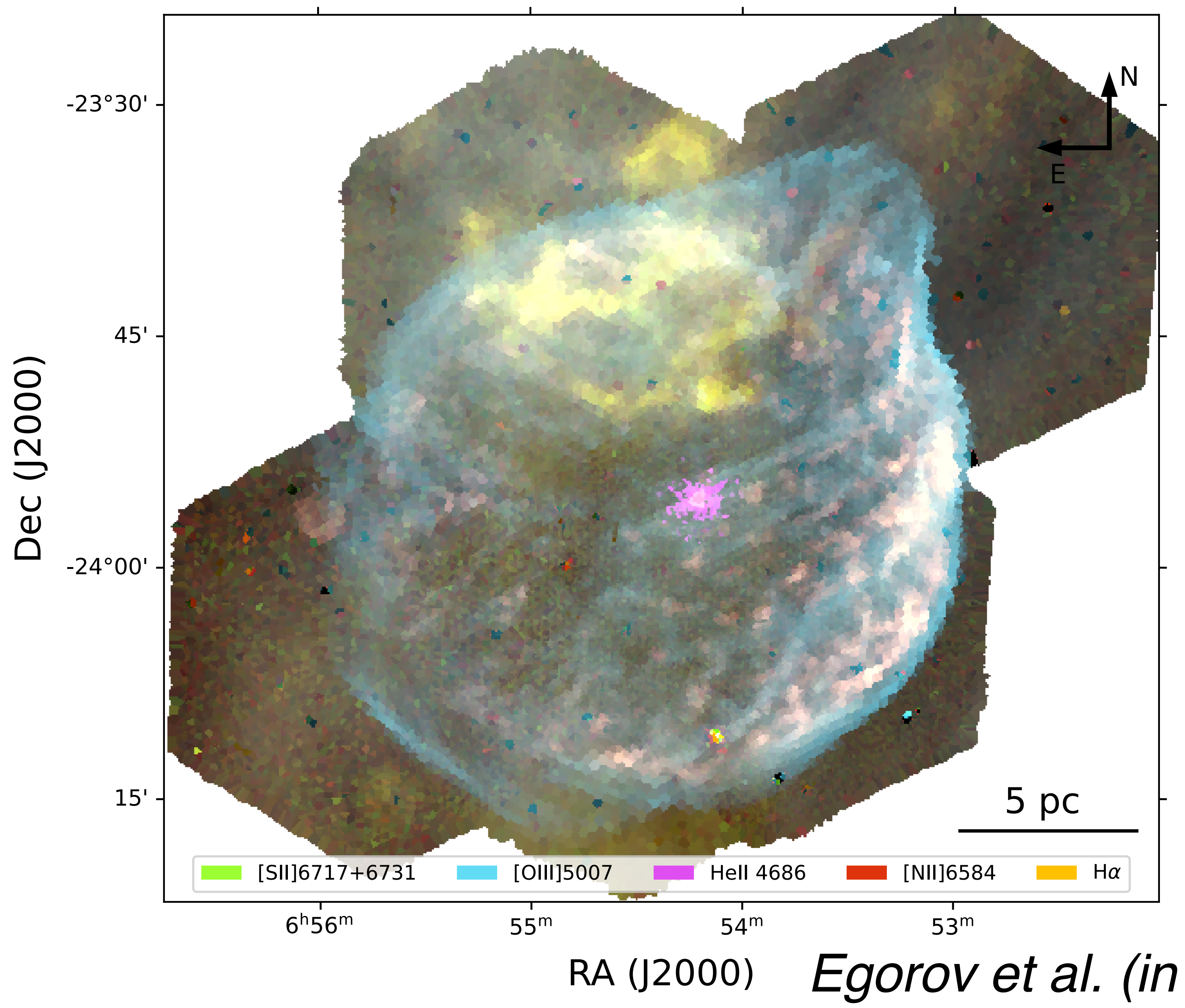

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