Physical Origins of Outflowing Cold Clouds in Local Star-forming Dwarf Galaxies

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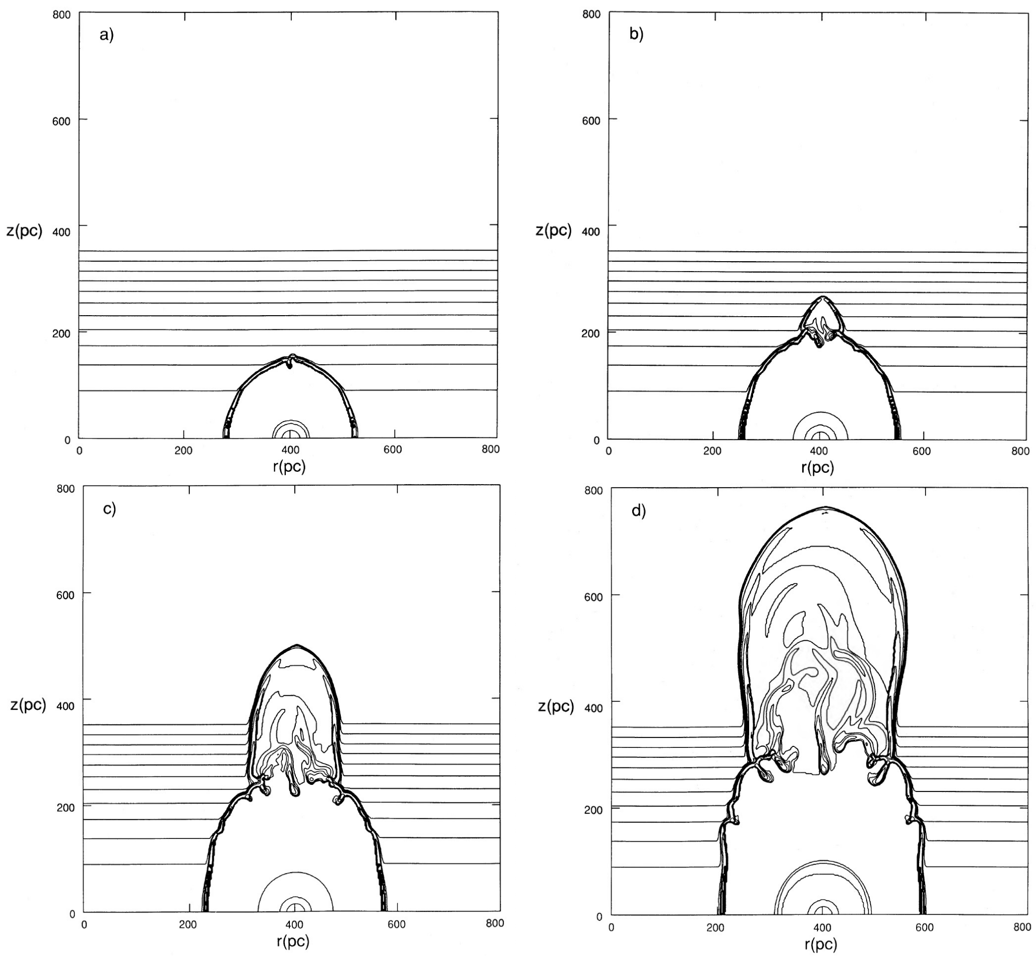
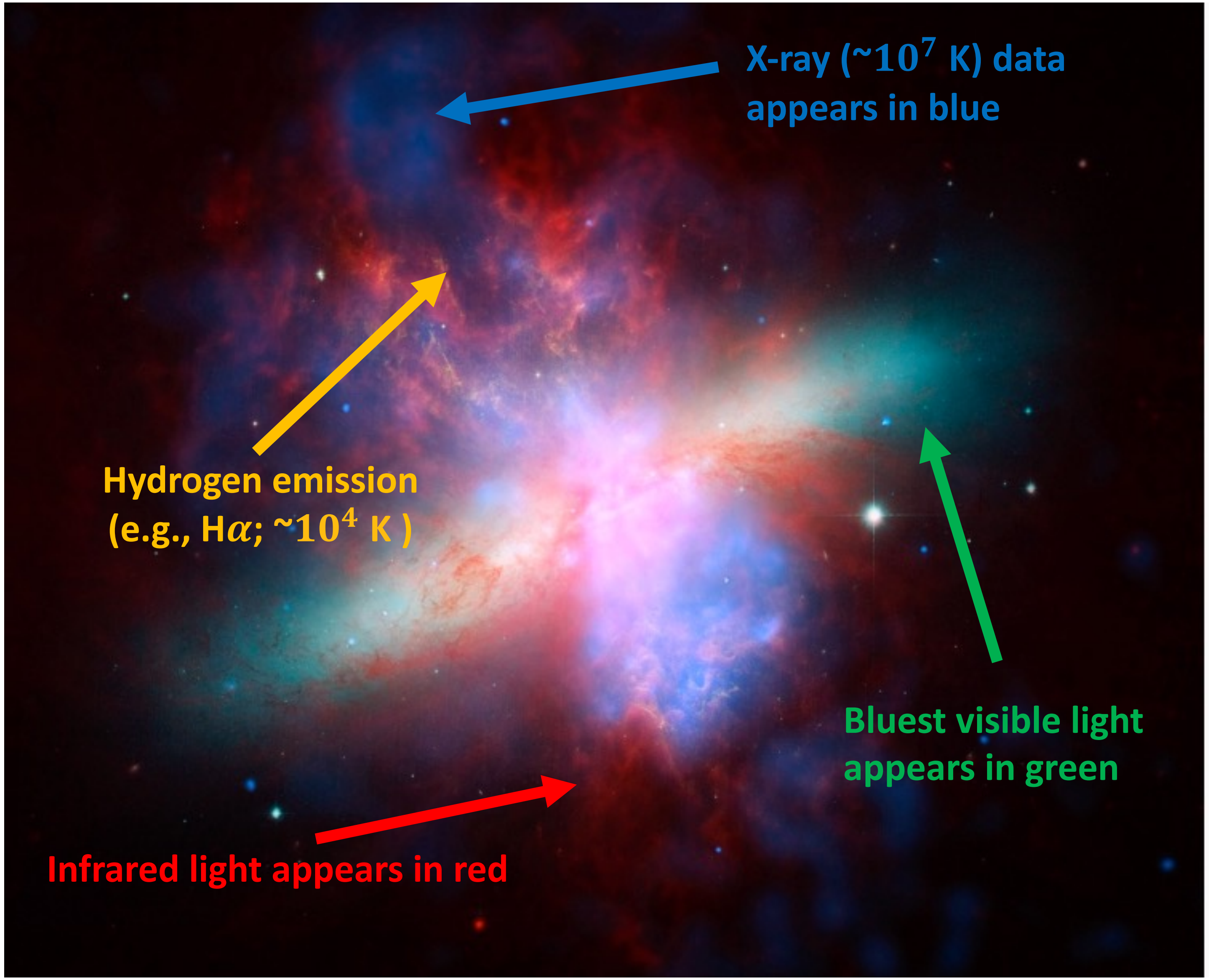
Image Credit: NASA/JPL-Caltech/STScI/CXC/UofA/

Superbubble Expansion & Blowout



Mac Low & McCray (1989)



Credit: NASA/JPL-Caltech/STScI/CXC/UofA/

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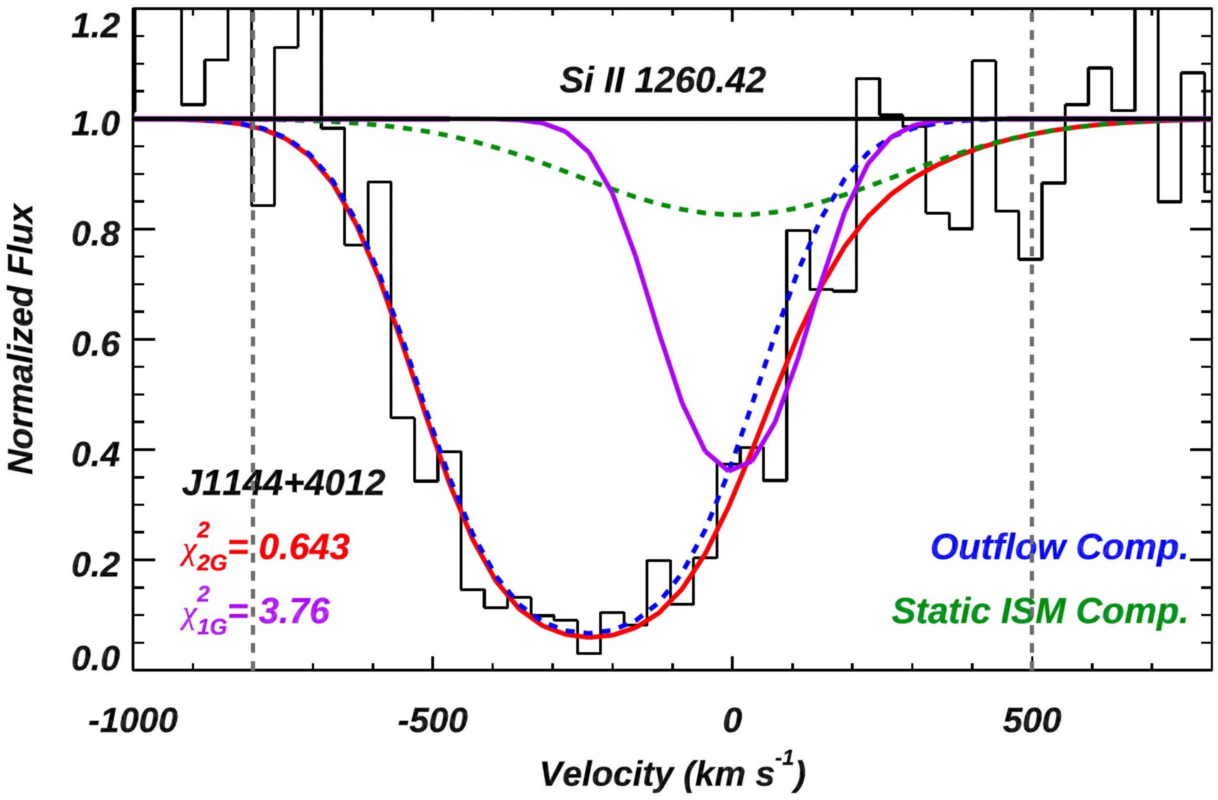
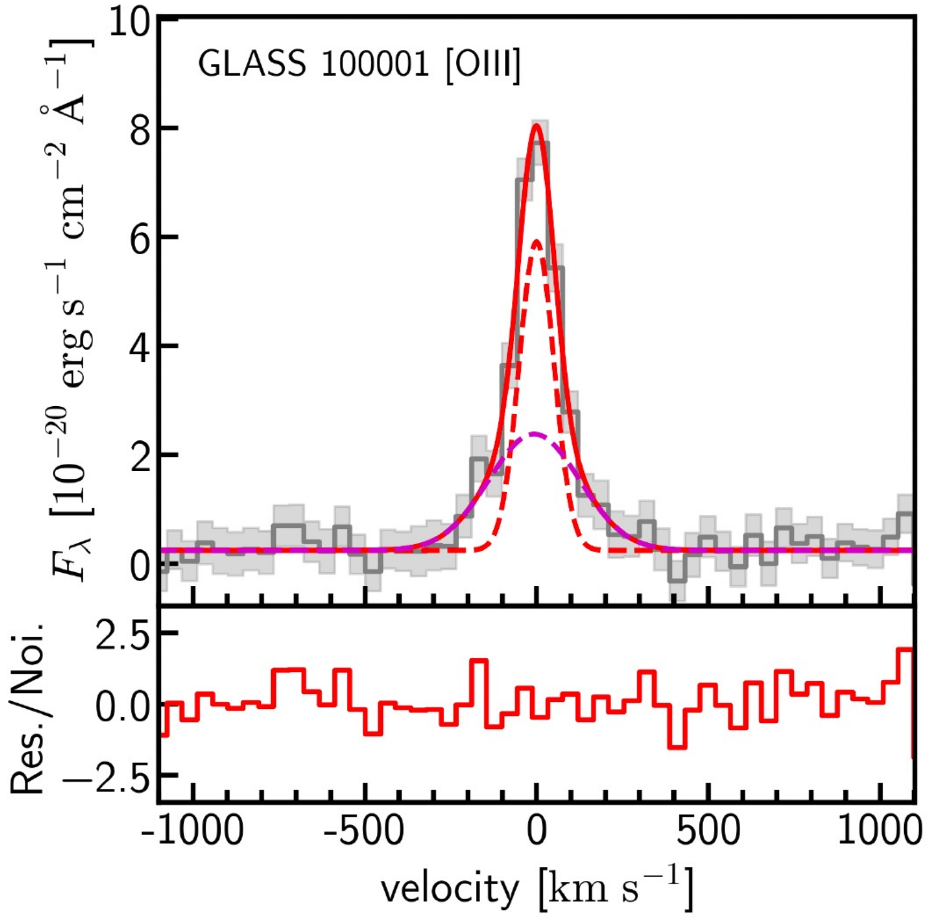
Detection of Superbubble Expansion & Blowout



X. Xu et al. (2022)

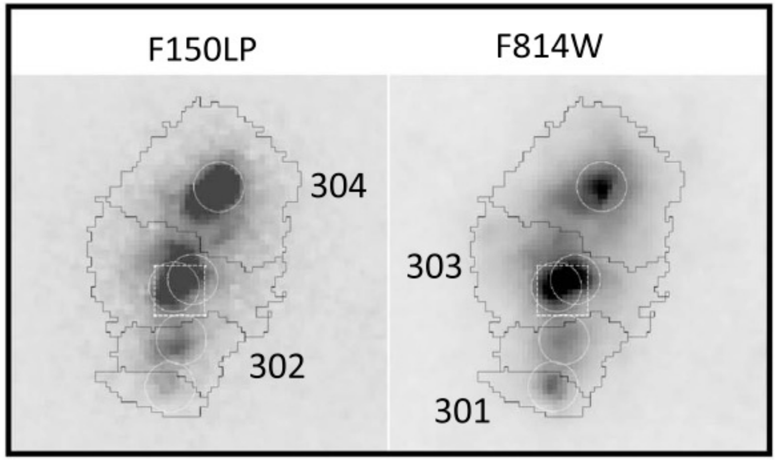


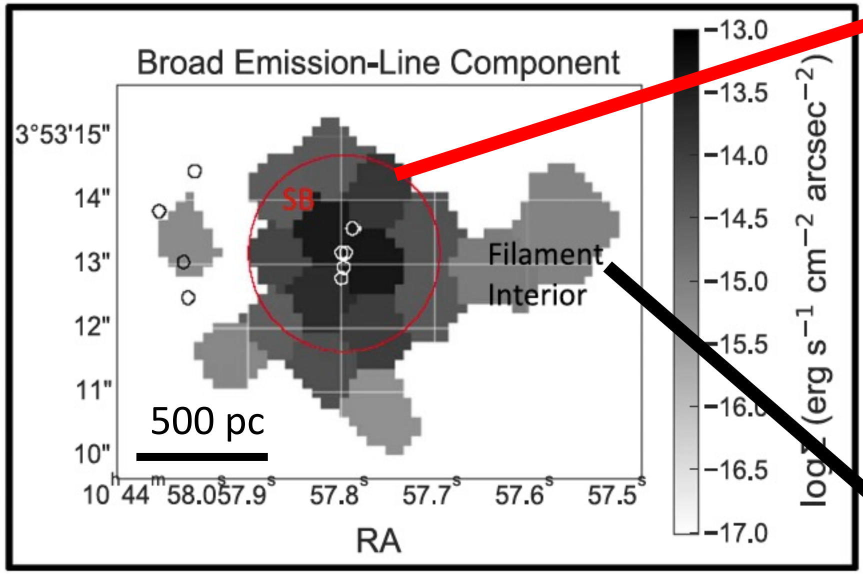
Y. Xu et al. (2024)

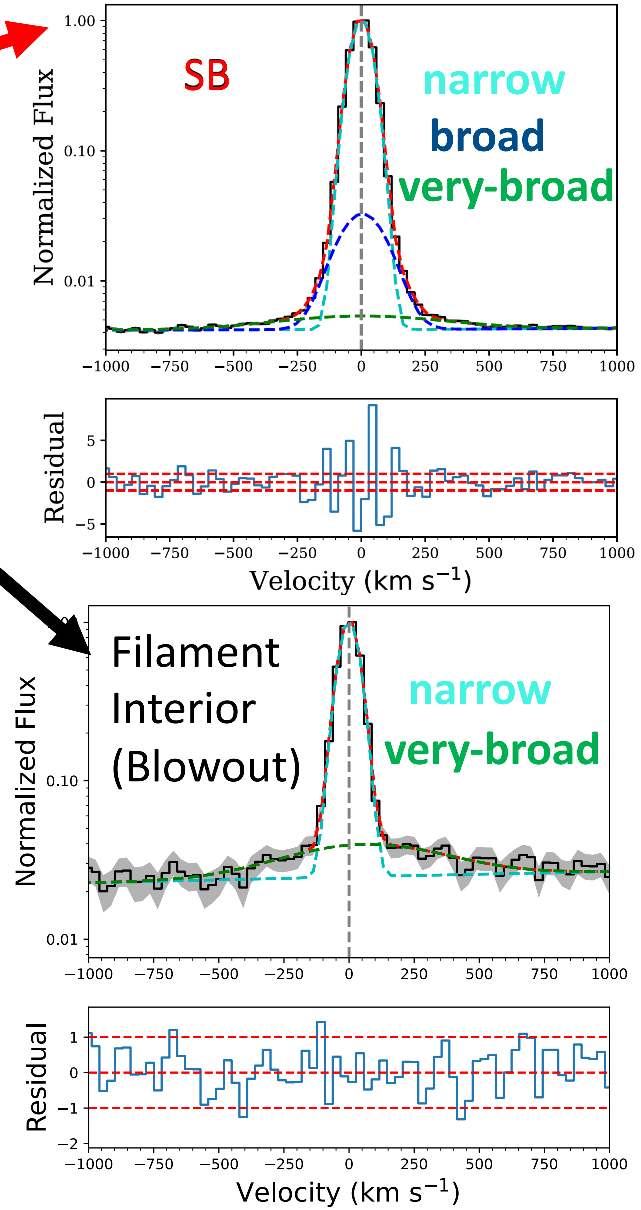
- **What are the physical origins of the blueshifted components in UV absorption lines and broad components in optical emission lines (galactic winds? expanding superbubble shells?)**

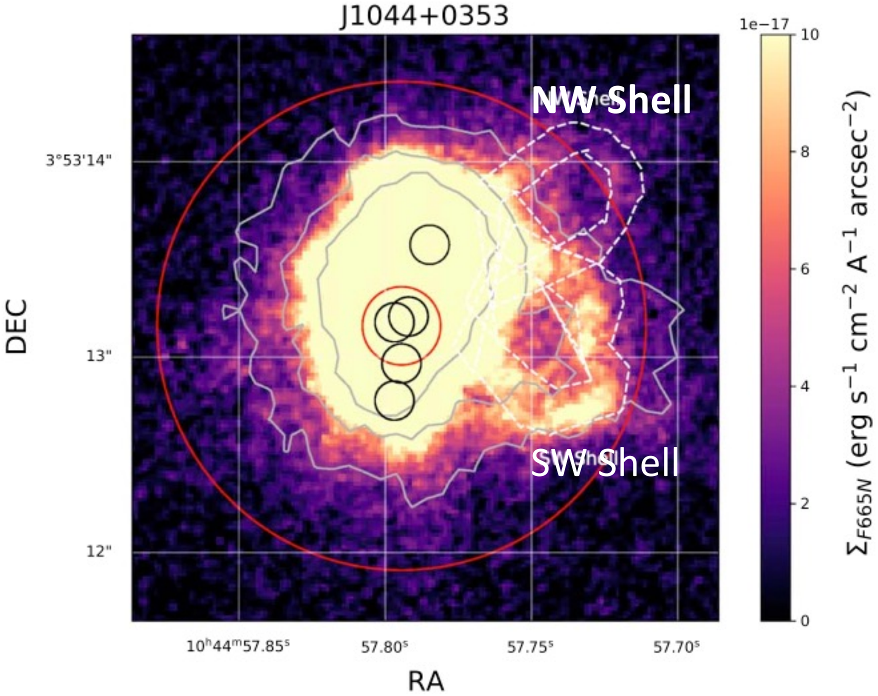
Insights from an Extreme-emission-line Dwarf Galaxy

z = 0.013; $\log\left(\frac{M_*}{M_\odot}\right) = 6.80$; $Z_g = 0.05\,Z_\odot$









FWHM (broad) ~ 210 km s^{-1} (expanding superbubble shells)

FWHM (very broad) ~ 750 km s^{-1} (galactic winds from blowouts)

Martin, Peng, and Li (2024)

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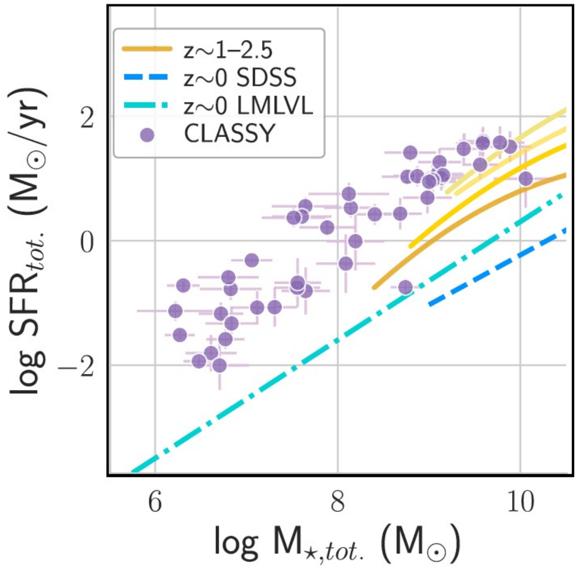
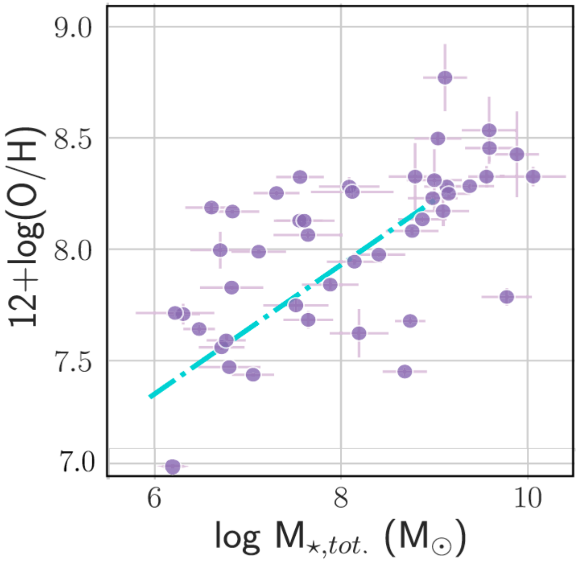
Outflowing Components in Local SF Dwarf Galaxies

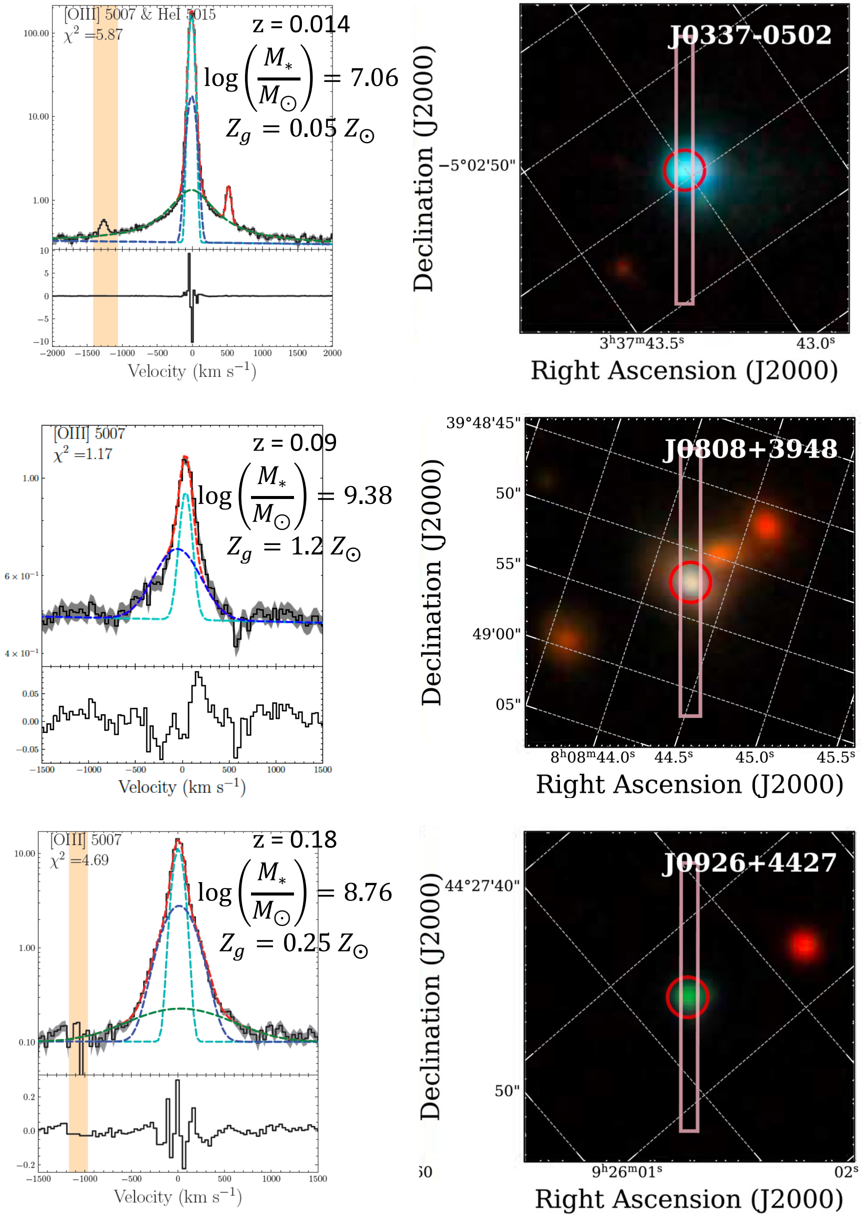
Peng et al. (2025): 14 CLASSY galaxies with Keck/ESI

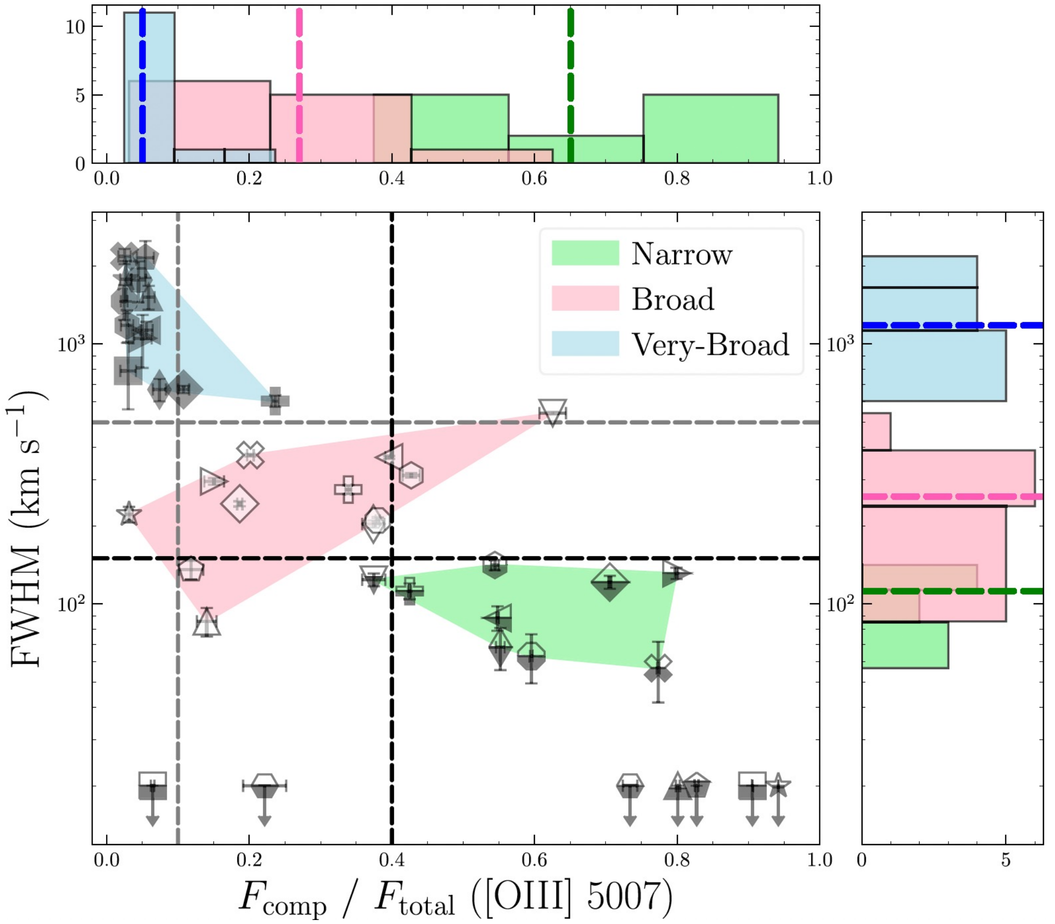
Velocity Components' Demarcation Map

CLASSY (Berg et al. 2022)









FWHM (narrow) ~ 100 km s^{-1}

FWHM (broad) ~ 260 km s^{-1}

FWHM (very broad) ~ 1200 km s^{-1}

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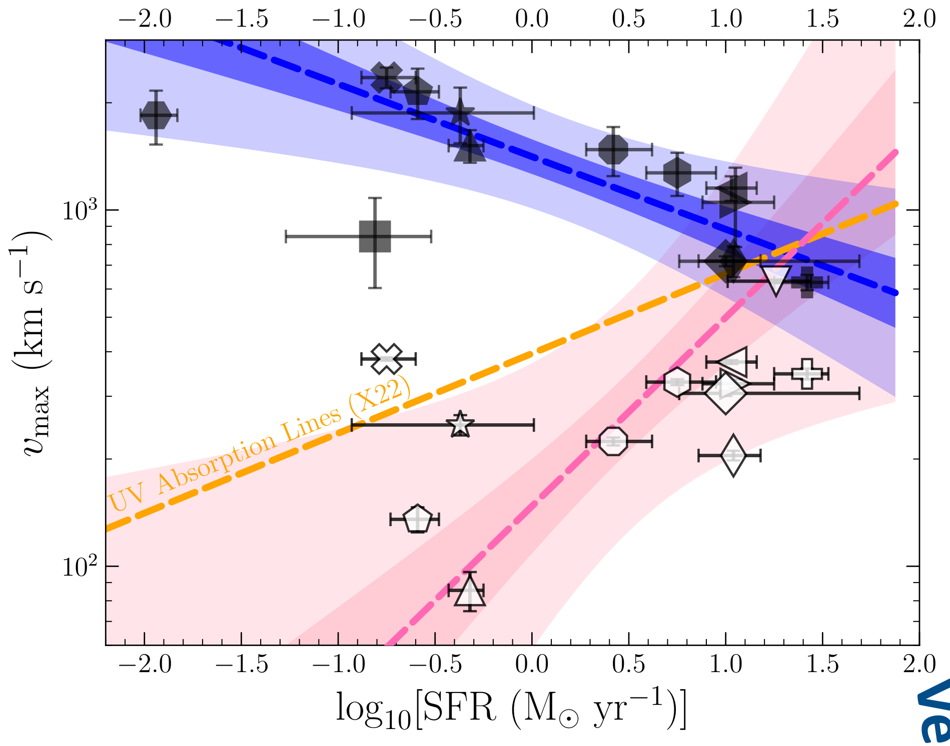
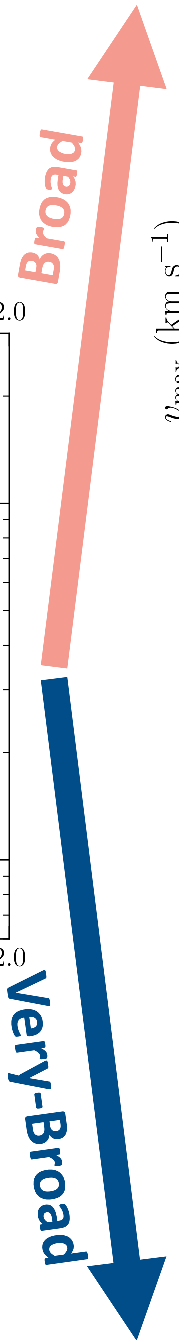
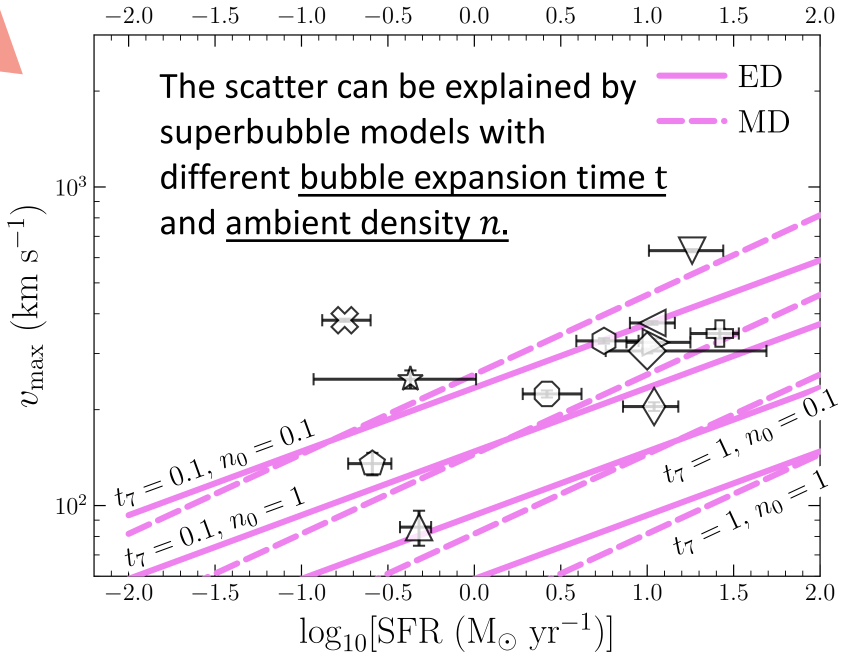
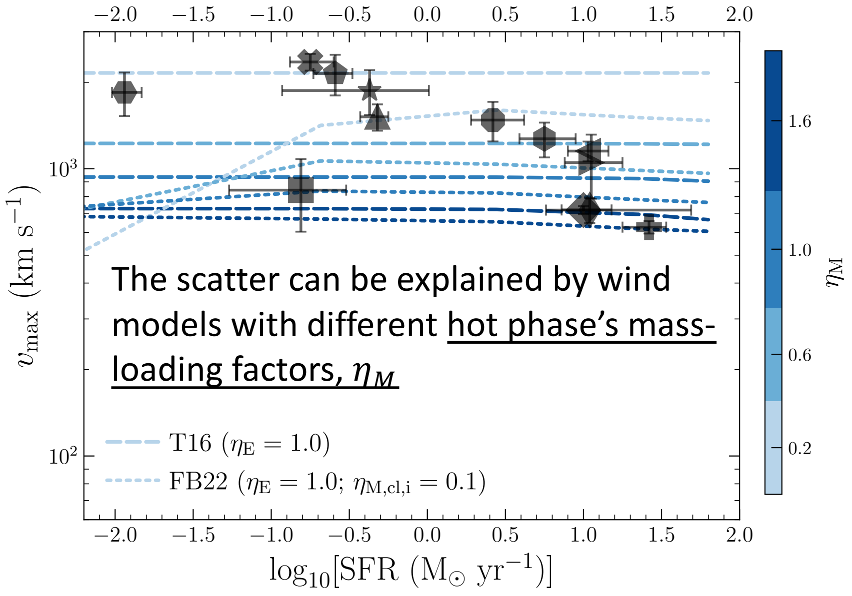
Scaling Relations with Galaxy Observables









Peng et al. (2025)

Superbubble Models

Energy-Driven (ED)

$$v_{ED} \propto n^{-1/5} t^{-2/5} \mathrm{SFR}^{1/5}$$

Momentum-Driven (MD)

$$v_{MD} \propto n^{-1/4} t^{-1/2} \mathrm{SFR}^{1/4}$$

Galactic Wind Models

$$v_{max} \propto (\eta_E/\eta_M)^{1/2}$$

(**NOT** depend on SFR)

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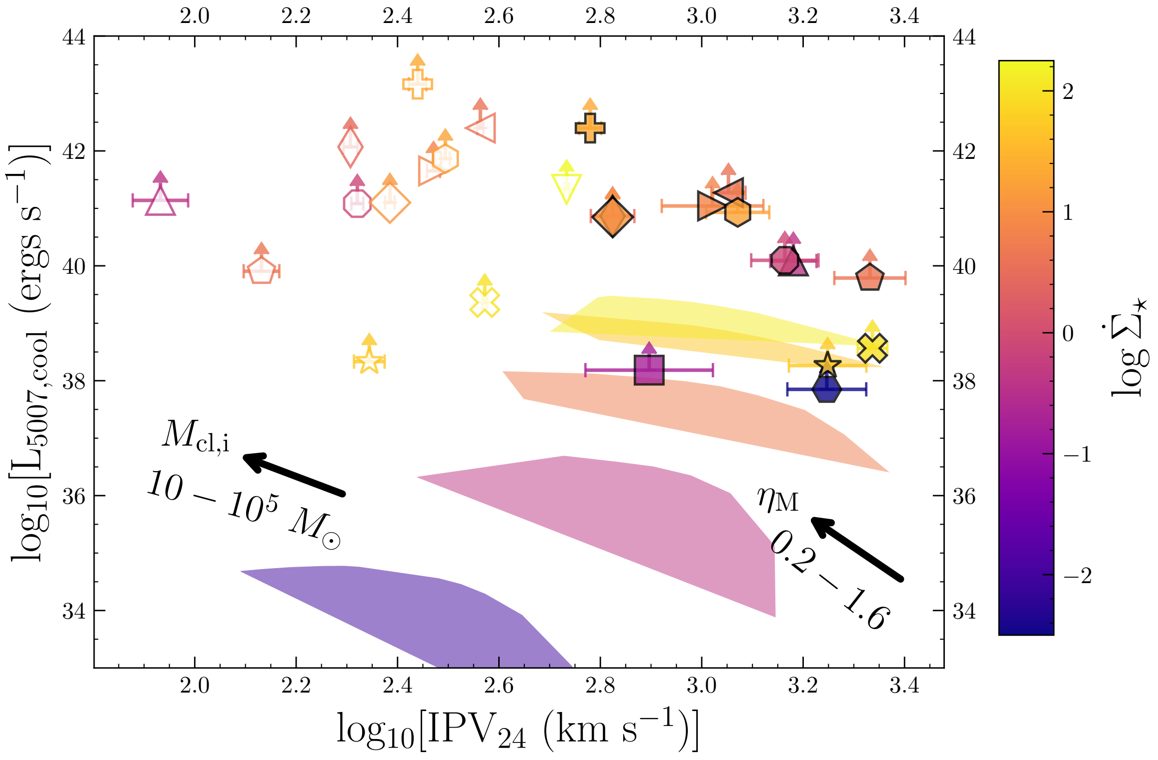
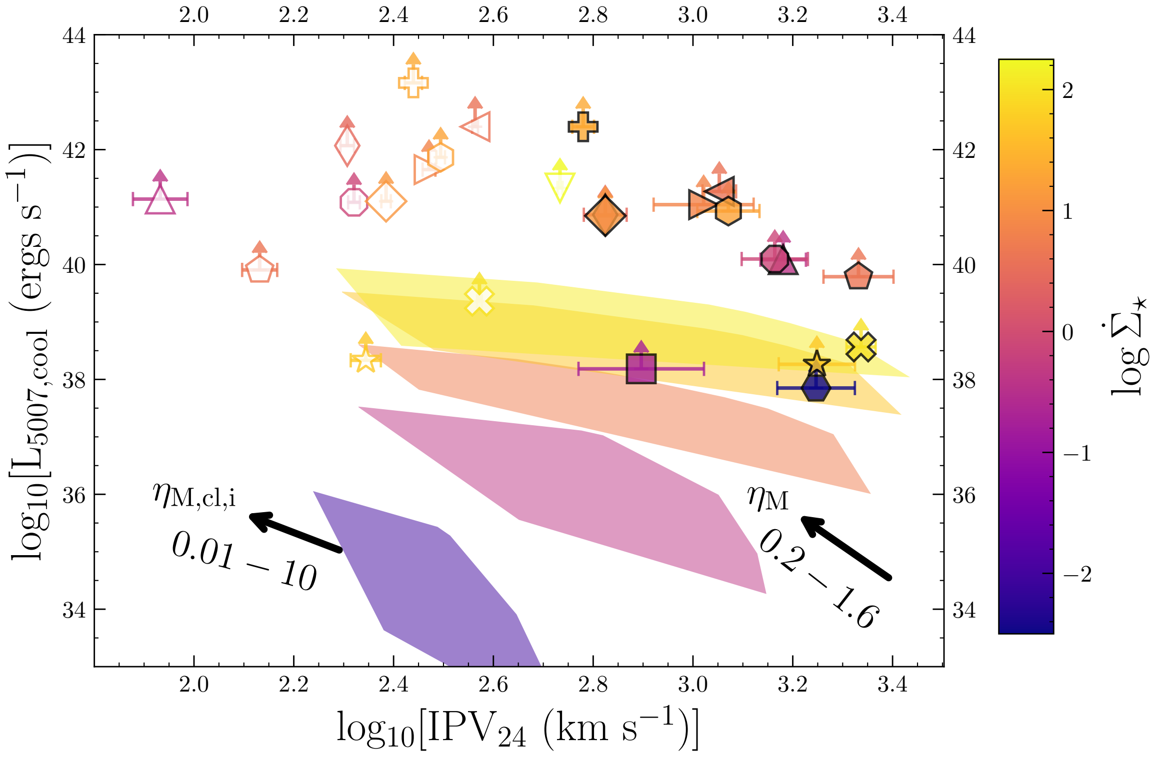
Luminosity-Deficit Issue of Wind Models

CCSN-driven Multiphase Galactic Wind Model (Fielding & Bryan 2022)





❑ CCSN-driven galactic wind models can **reproduce the velocity widths** of these outflowing components but **underestimate most [OIII] 5007 luminosities by at least one dex**.

Peng et al. (2025)

Main Takeaways from Peng et al. (2025)

1. Different physical origins of outflowing components (**superbubble shells vs. galactic winds**)
2. Star-forming galaxies can power galactic winds with **FWHM $\gtrsim$ 1000 km s^{-1}**

Harikane et al. 2023:

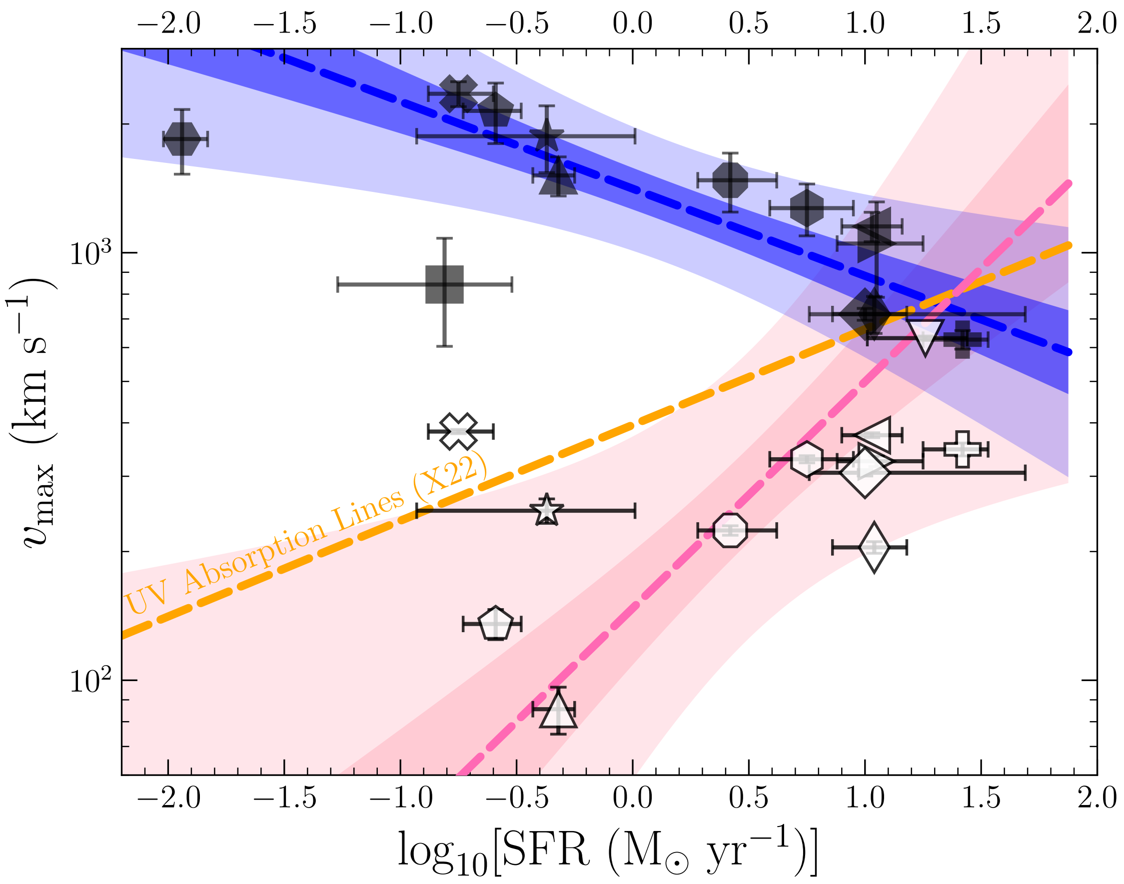
> We choose the threshold value of $>1000\,\mathrm{km\,s^{-1}}$ for the definition of the broad line made by an AGN because such a high-velocity component is seen in AGNs (e.g., Vanden Berk et al. 2001; Reines & Volonteri 2015) but not seen in star-forming galaxies (typically FWHM $<400\,\mathrm{km\,s^{-1}}$, e.g., Freeman et al. 2019; Swinbank et al. 2019; Xu et al. 2022). This threshold value is also used in Stern & Laor (2012), and is more stringent than those used in other studies at $z\sim0$ (e.g., Reines & Volonteri 2015; Liu et al. 2019).

Galactic winds??? Or just expanding superbubble shells!?

Does our argument hold for more targets?

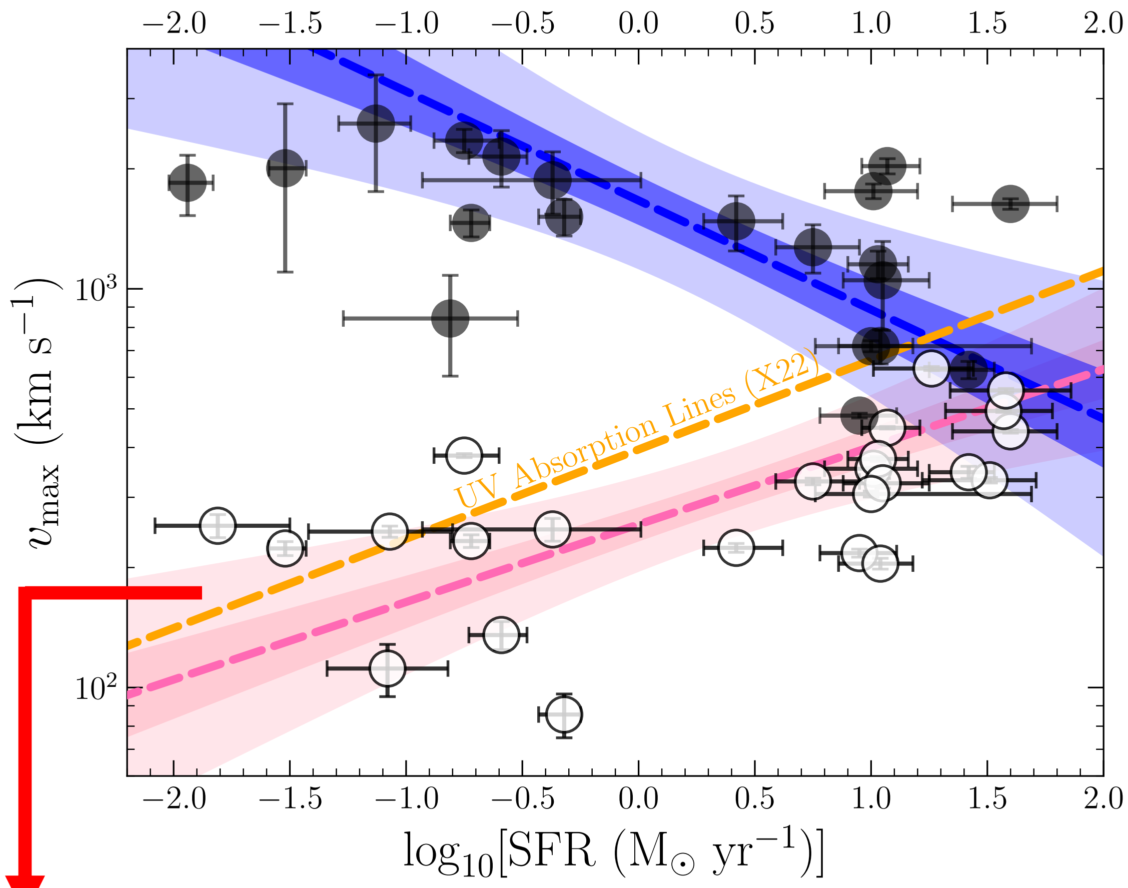
14 Targets

(Keck/ESI; Peng et al. 2025)



27 Targets

(14 Keck/ESI + 13 Keck/KCWI; Peng et al. in prep.)



UV absorption lines have a similar scaling relation as broad components, but with a slightly higher $v_{\rm max}$ ($N(v) \equiv \int n(v)dl$, $EM(v) \equiv \int n(v)^2 dl$; Xu et al. 2025)

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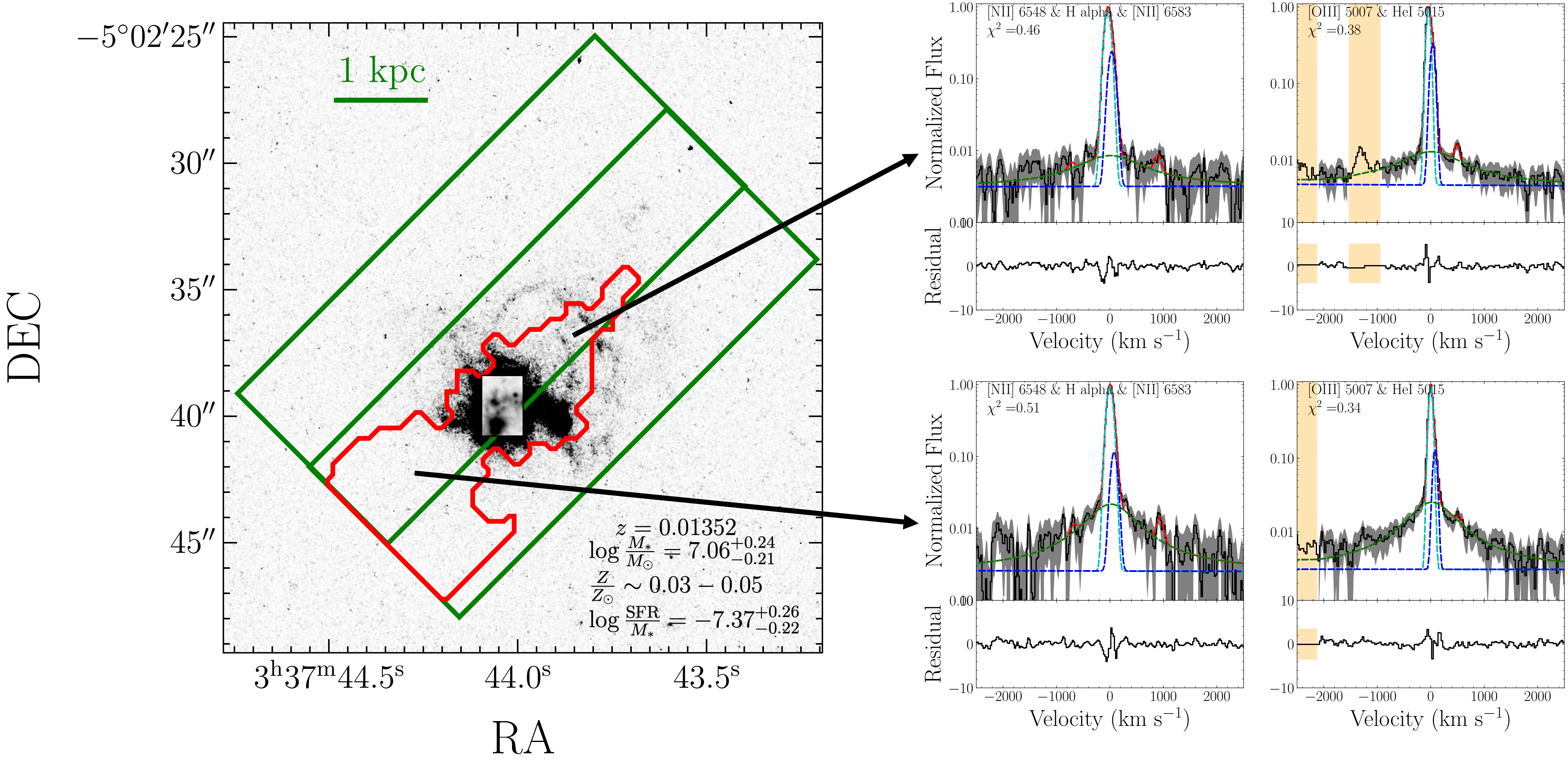
Spatially Resolved Study Using KCWI/KCRM: Kinematics



Peng et al. (in prep.)

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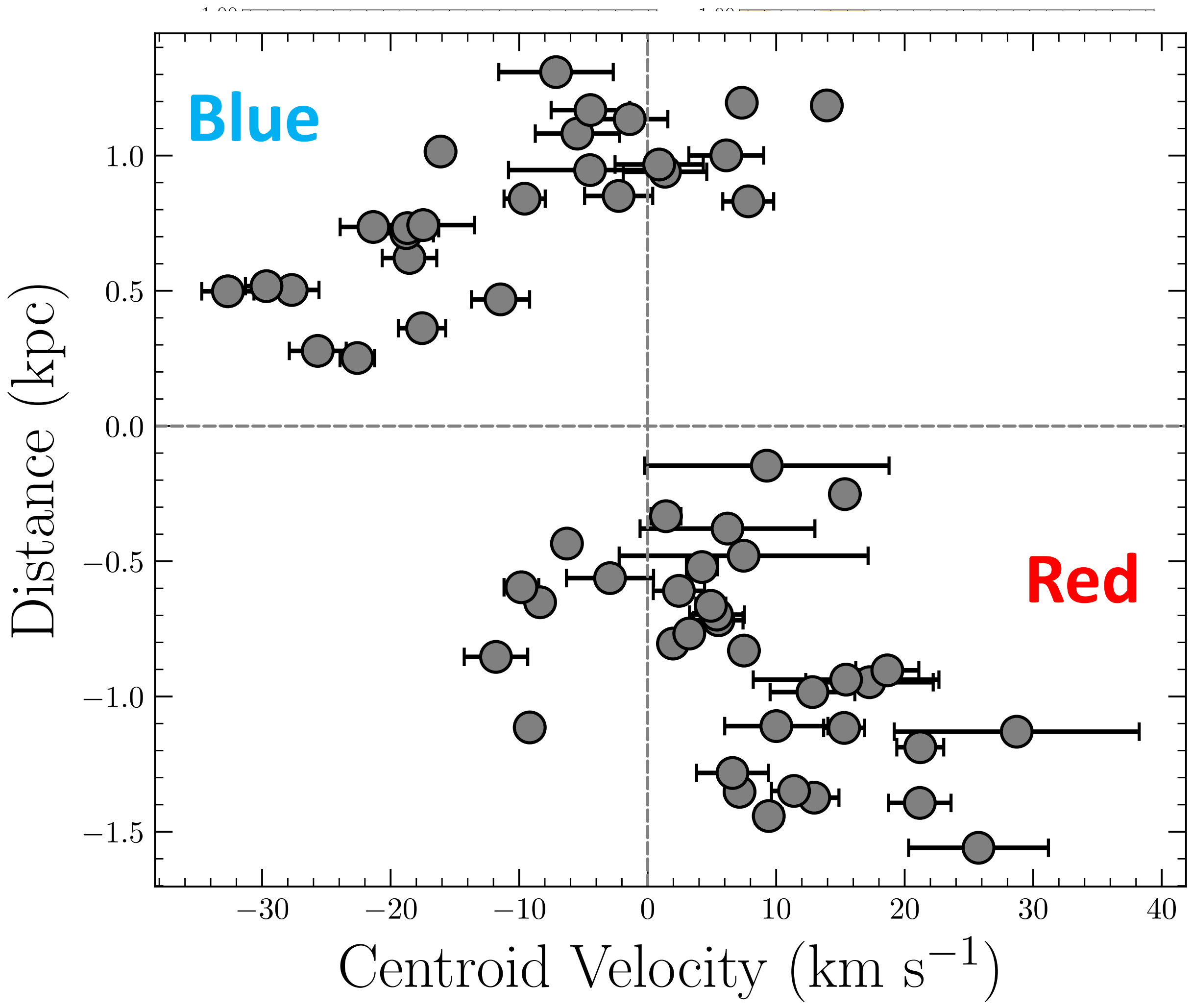
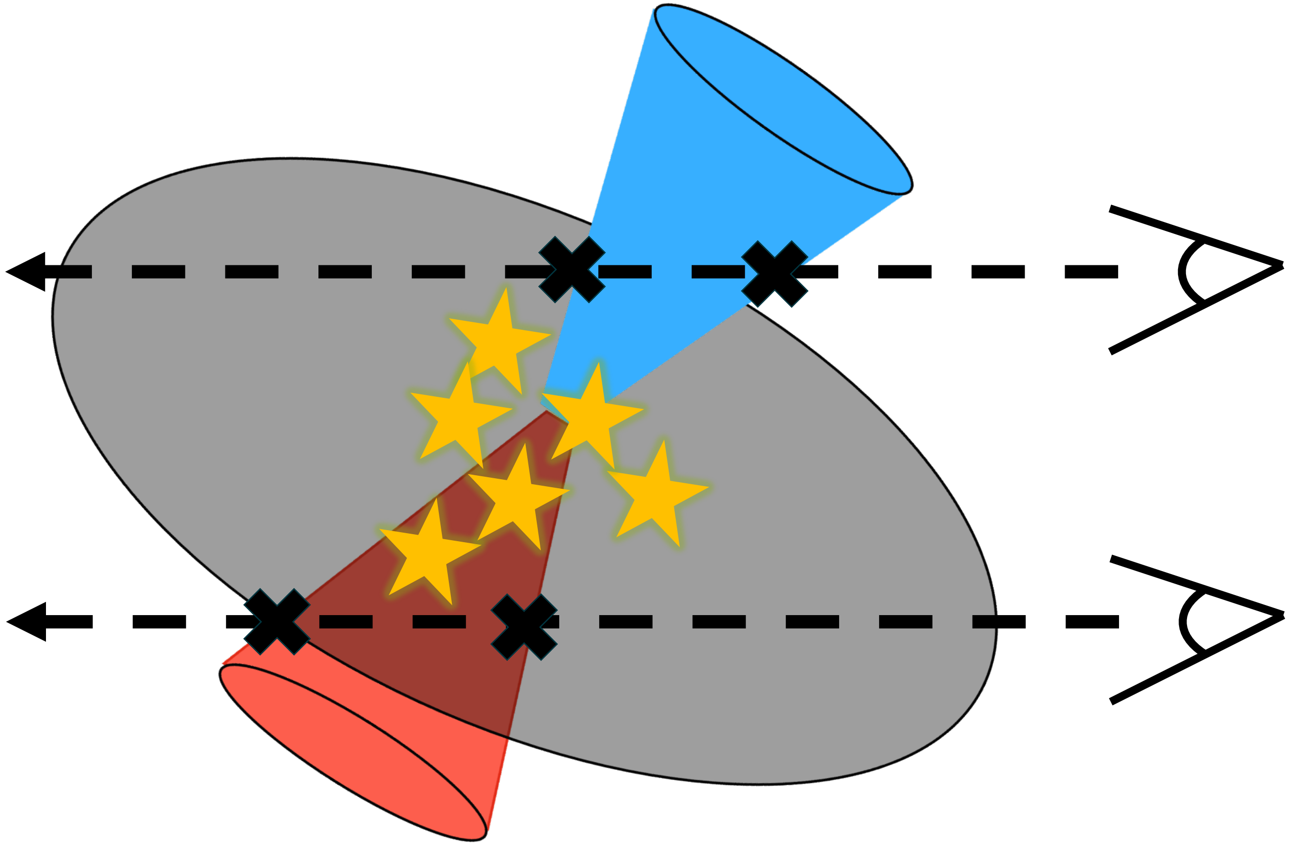
Spatially Resolved Study Using KCWI/KCRM: Kinematics



RA



Peng et al. (in prep.)

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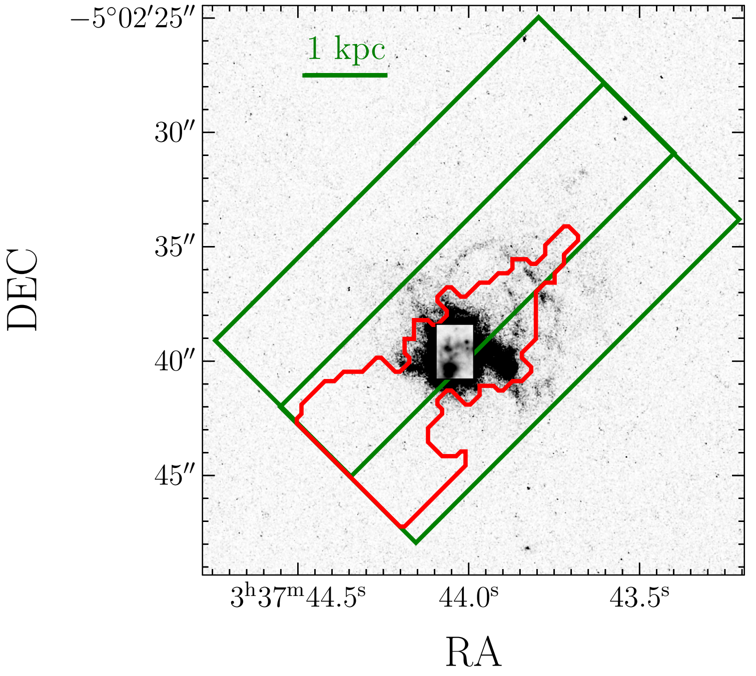
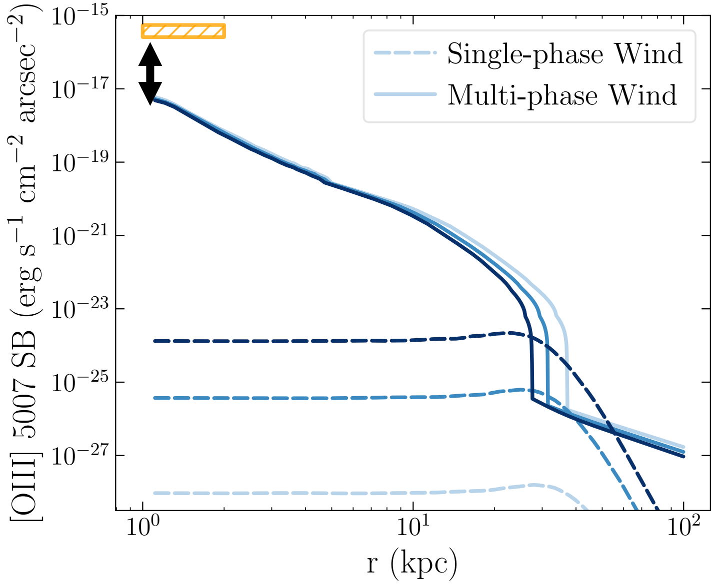
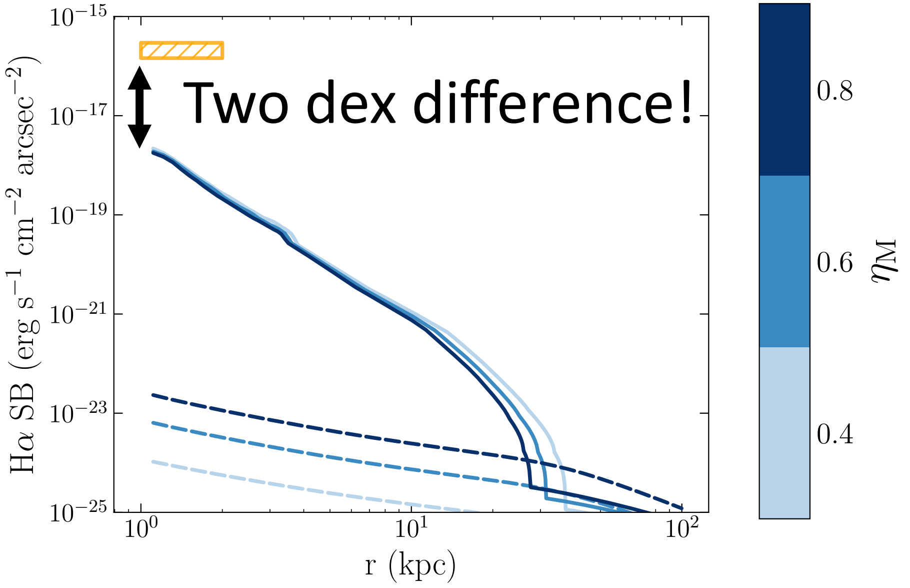
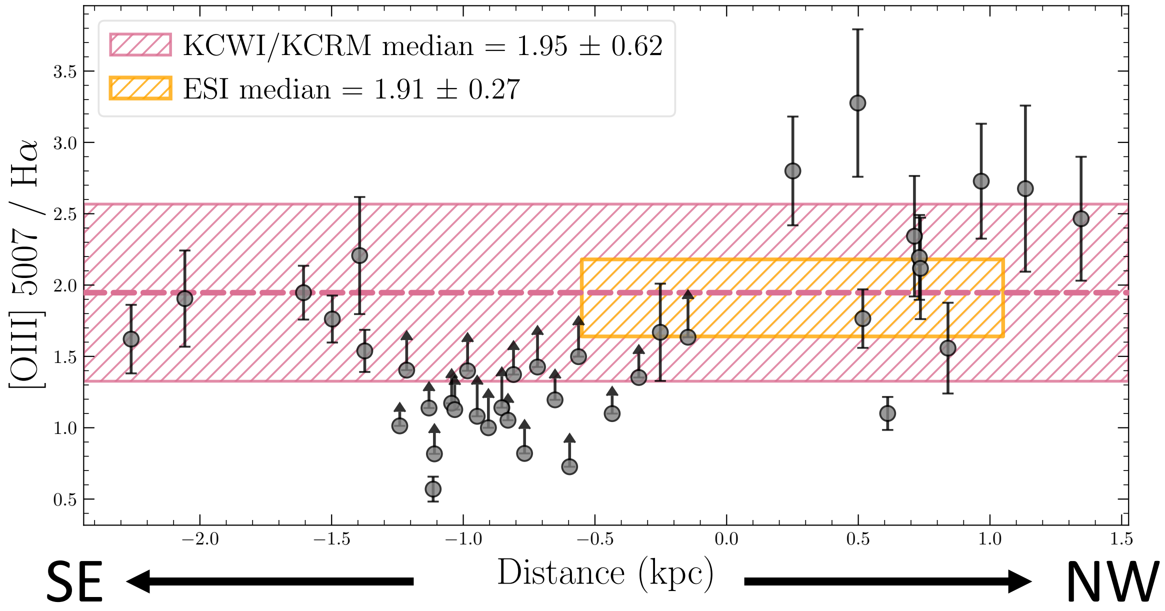
SB Predictions of Analytical Galactic Wind Models

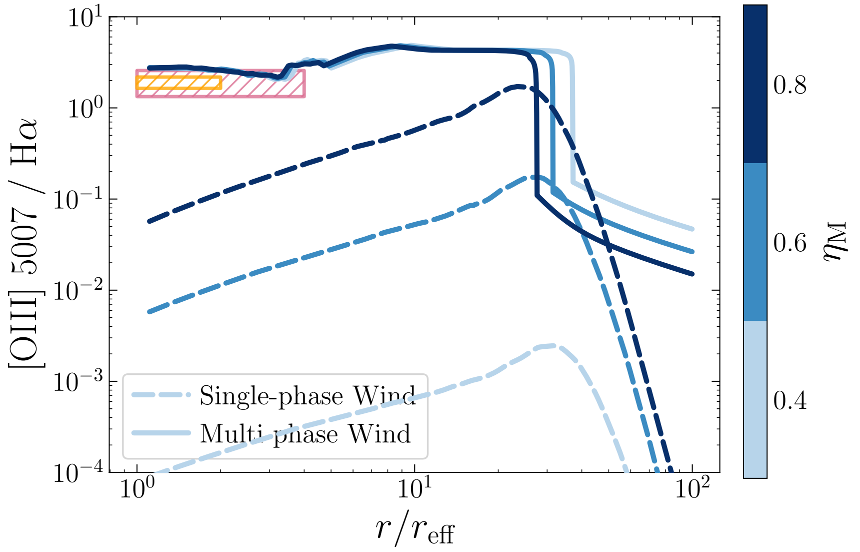
$\eta_{M.cl.i} = 1.0;\ M_{cl.i} = 10^5\ M_{\odot}; \eta_E = 1.0$











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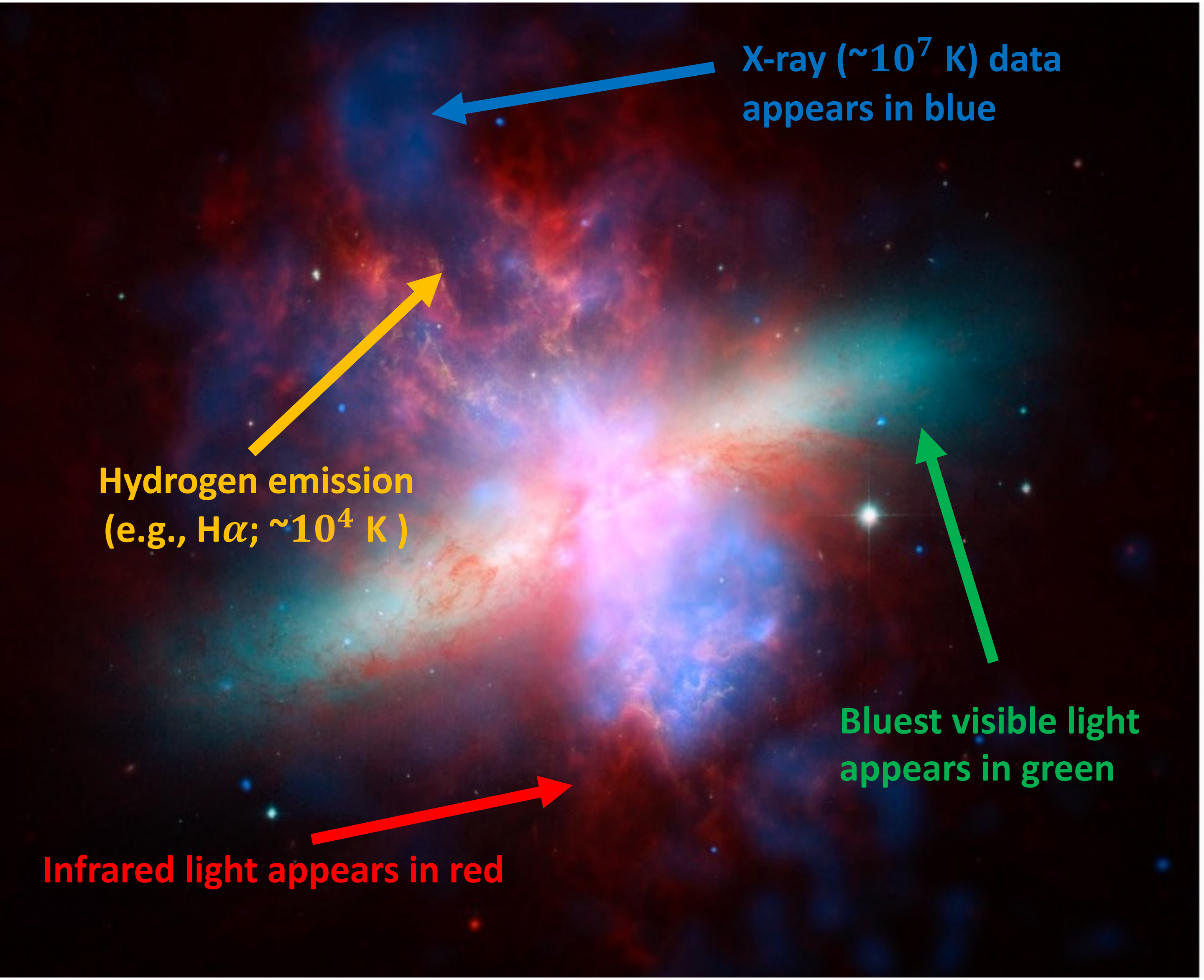
Spatially Resolved Study: Outflow Rates

Multi-phase nature of galactic winds



Credit: NASA/JPL-Caltech/STScI/CXC/UofA/

Thermalization Efficiency Factor:

$$\dot{E}_{\rm hot} = 3 \times 10^{41}\ {\rm erg\ s^{-1}}\ \eta_{\rm E}\ \frac{\rm SFR}{\rm M_{\odot}\ yr^{-1}}$$

Mass Loading Factor:

$$\dot{M}_{\rm hot} = \eta_{\rm M}\ {\rm SFR}$$

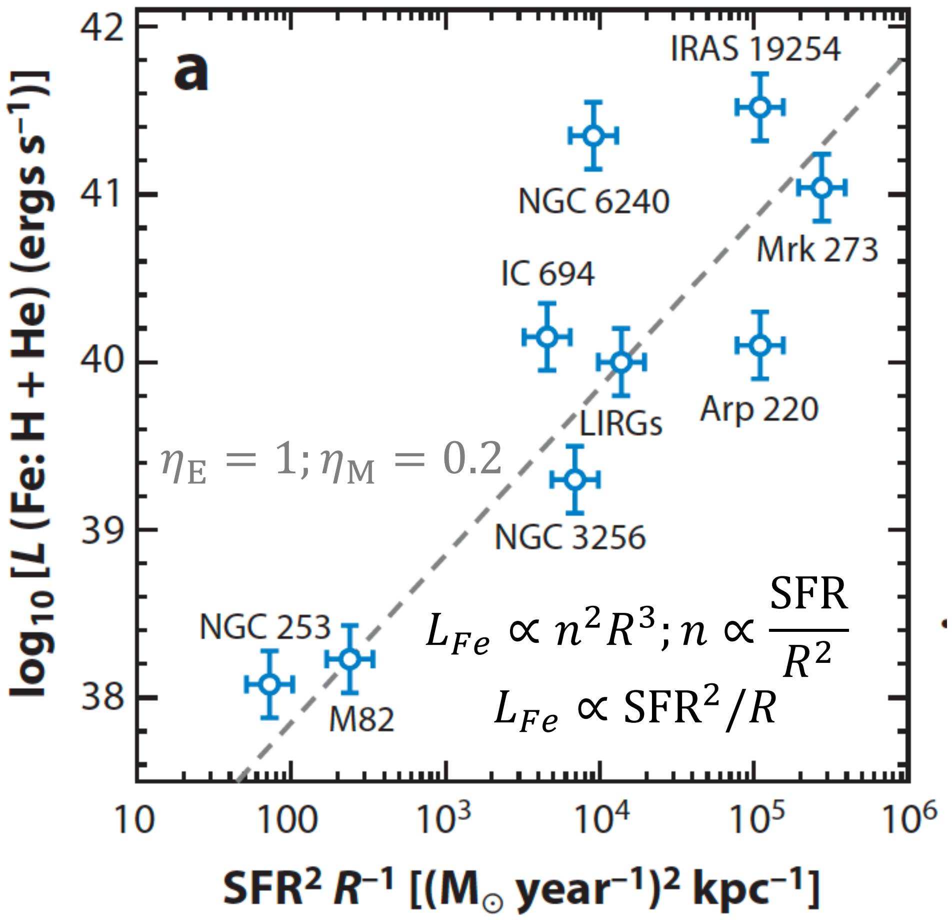
However, both $\eta_{\rm E}$ and $\eta_{\rm M}$ are not well-constrained by observations and simulations/theories

If the cold clouds are pressure confined by the volume-filling hot wind,

$$\dot{p}_{\rm hot} = \left(2\dot{E}_{\rm hot}\dot{M}_{\rm hot}\right)^{1/2} \simeq 5\ (\eta_{\rm E}\eta_{\rm M})^{1/2}\ \frac{L}{c}$$

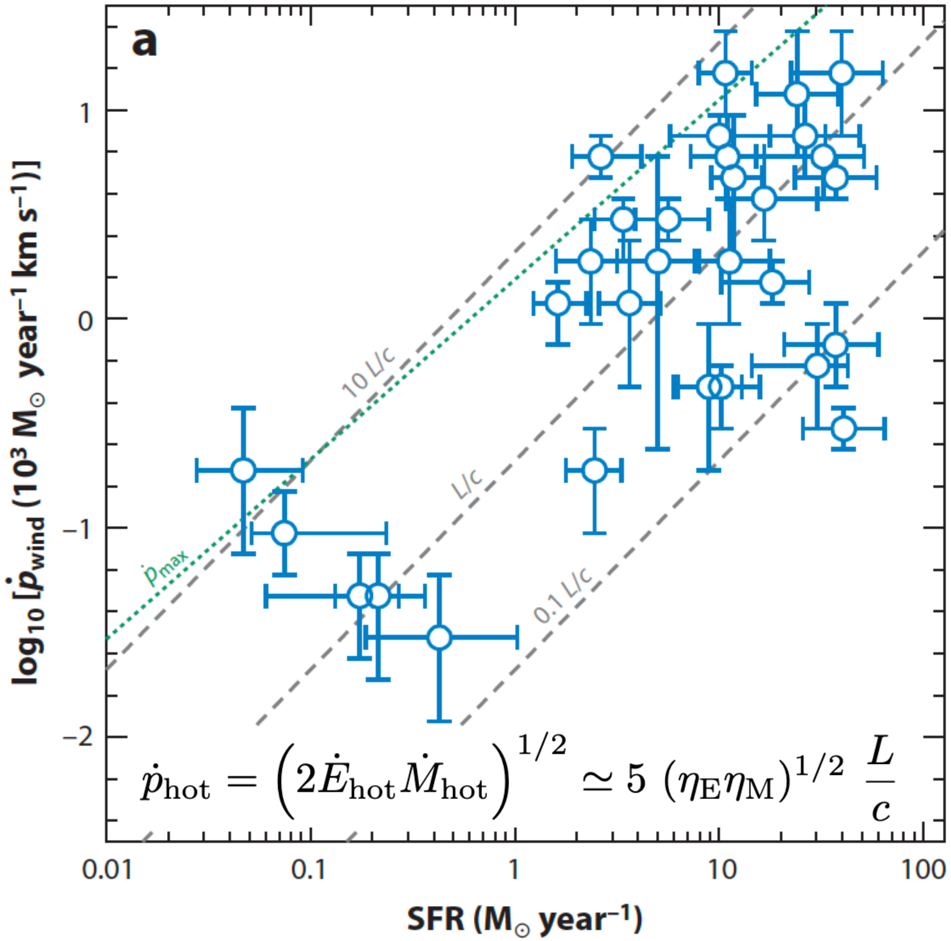
Spatially Resolved Study: Outflow Rates

X-Ray (Fe Kα)



$(\eta_E \eta_M)_X^{1/2} \sim 0.2 - 0.8$

UV Absorptions



$(\eta_E \eta_M)_{abs}^{1/2}$ up to ~ 2 for $\dot{p} \sim 10\ L/c$

Thompson & Heckman (2024)

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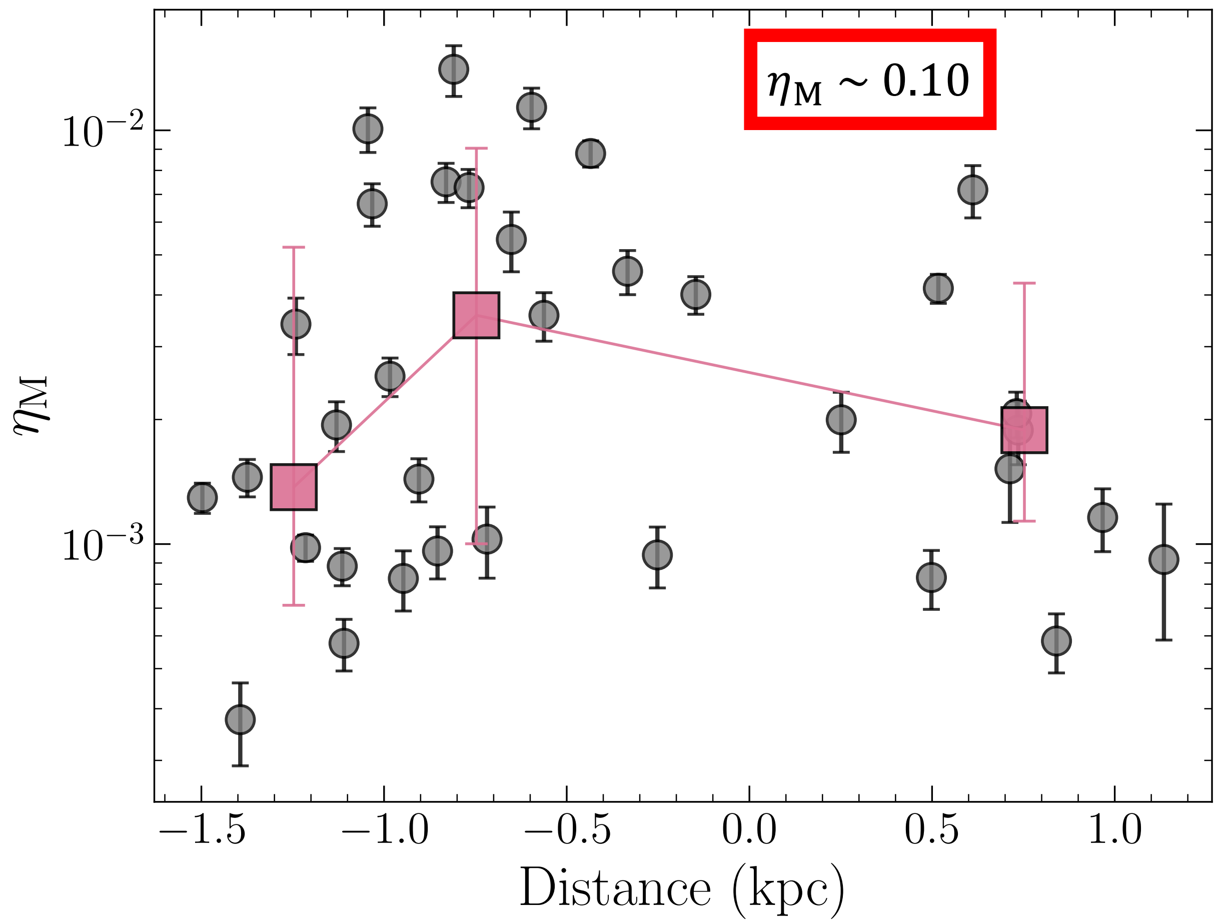
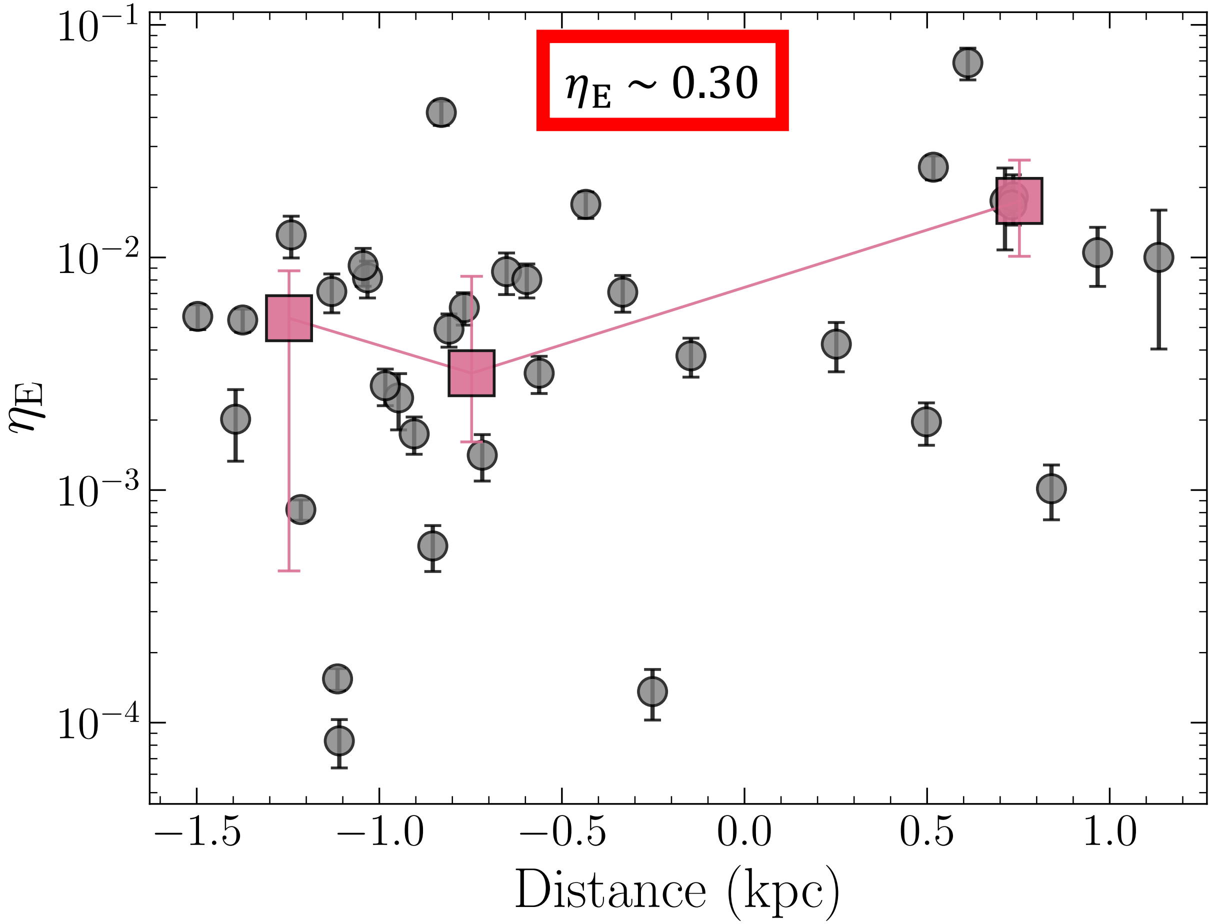
Spatially Resolved Study: Outflow Rates



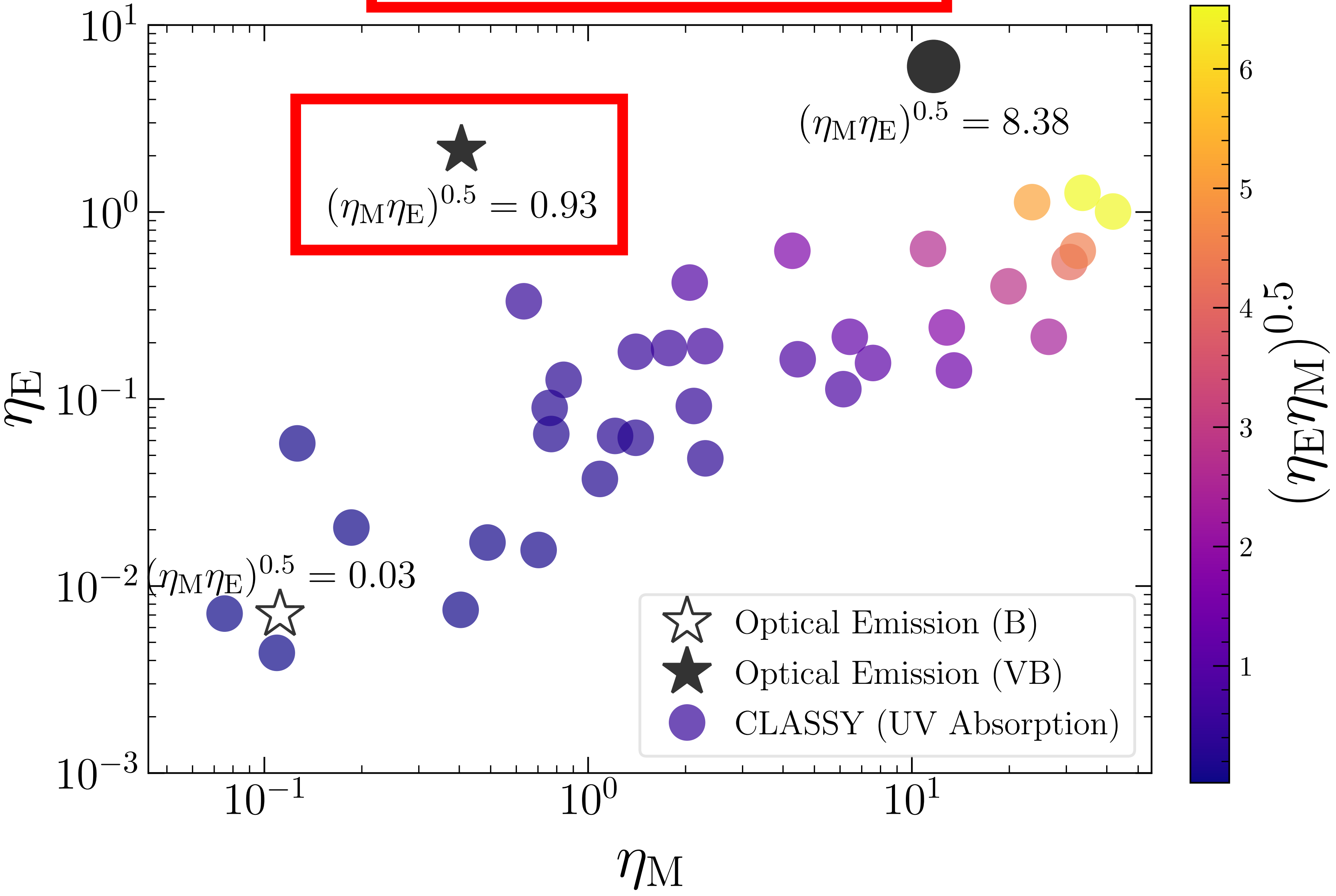


$(\eta_E \eta_M)^{1/2}_{VB} \sim 0.20$ consistent with $(\eta_E \eta_M)^{1/2}_{X} \sim 0.2 - 0.8$

Peng et al. (in prep.)

Spatially Resolved Study: Outflow Rates

$\boxed{(\eta_E \eta_M)_X^{1/2} \sim 0.2 - 0.8}$



Peng et al. (in prep.)

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Discussion & Summary

- Emission-line observations of outflowing cold clouds (27 galaxies), distinguishing
  - **very-broad (VB) components (FWHM ~ 1200 km s^{-1}): galactic winds**
  - **broad components (FWHM ~ 260 km s^{-1}): expanding superbubble shells**

Peng et al. (2025)

- Most VB components' [OIII] 5007 luminosity come from **stellar photoionization** but not mechanical energy of CCSN.

- VB components' surface brightness ratios of [OIII] 5007 and Hα can be explained by our **multi-phase** galactic wind model.

- The $(\eta_{\mathrm{E}}\eta_{\mathrm{M}})^{1/2}$ of **VB components** are more similar to **X-ray data** compared to those of broad components and UV absorption lines.

Martin, Peng, and Li (2024)

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