Gamma-ray Emission from the Young Galactic Star-Forming Region RCW 38

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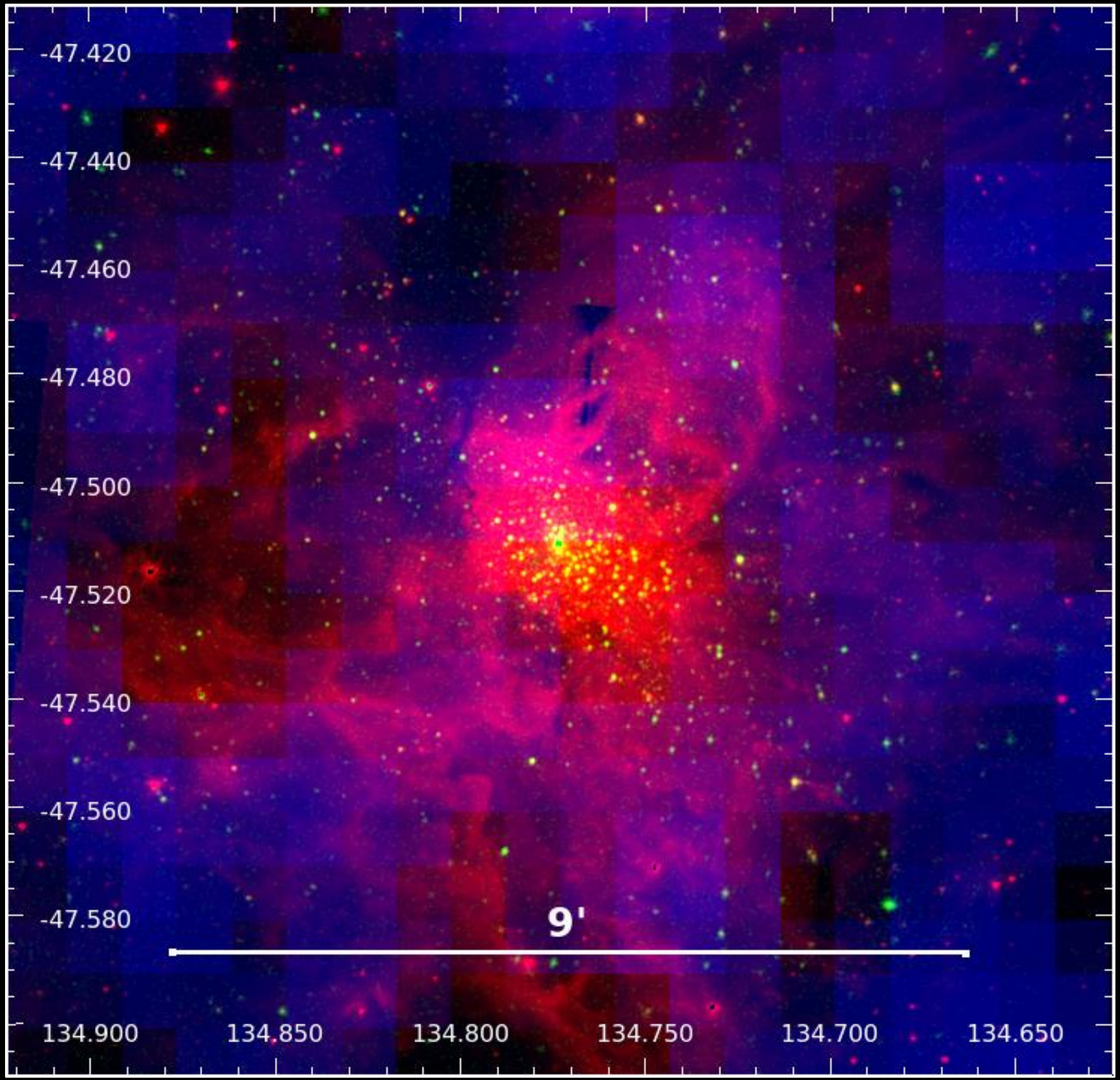
Topical Overview on Star Cluster Astrophysics (TOSCA)

Siena, Italy, October 2024

arXiv



RCW 38

Age	0.5 Million years old	No Supernovae have occurred
Position	One degree south of galactic plane	No nearby supernova remnants
Stars	20 confirmed OB stars	$M_\star = 2200\ M_\odot$

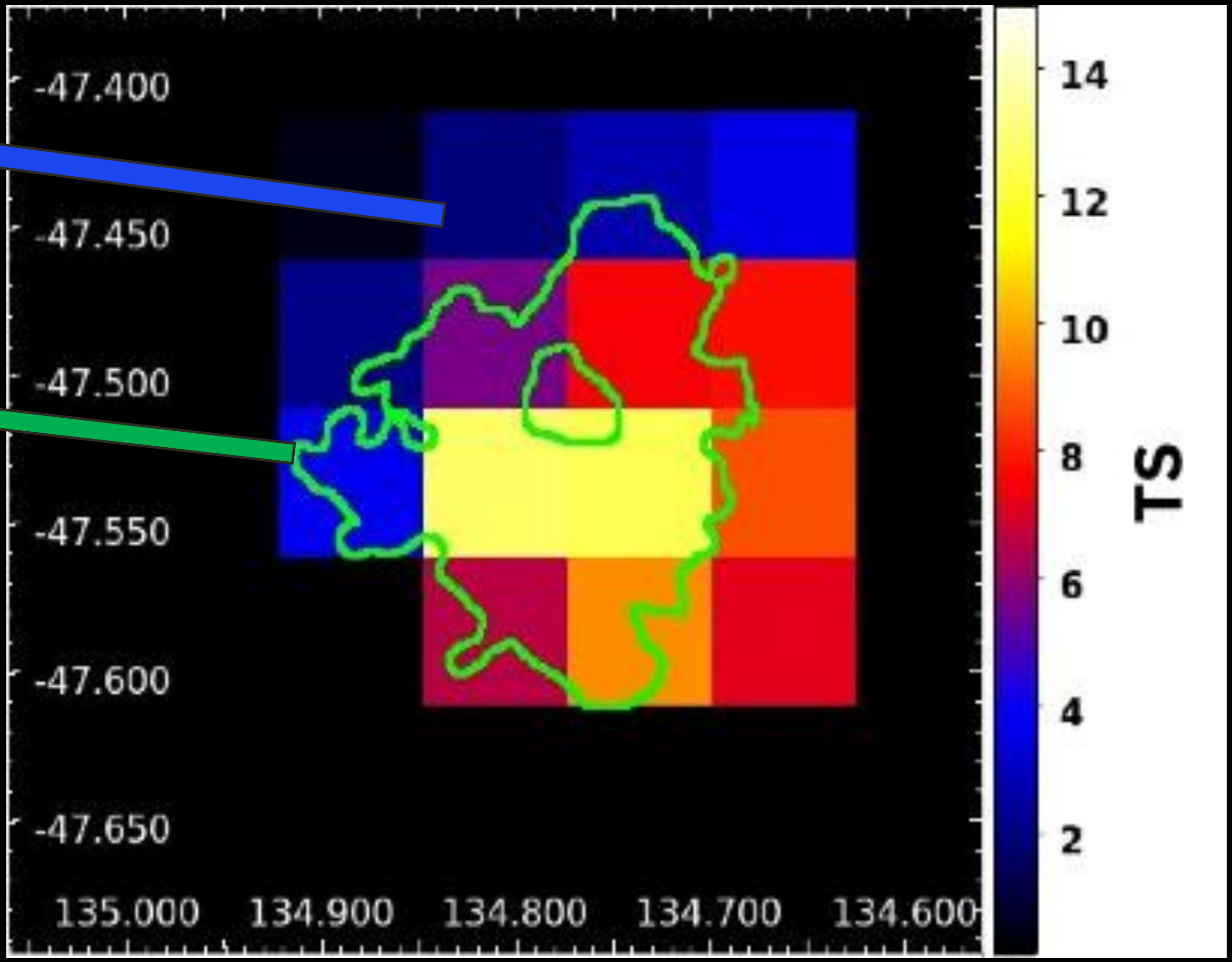
3.6 μm Spitzer IR
Chandra X-ray (0.5-7.0 keV)
2-300 GeV Fermi-LAT

RCW 38: Gamma-Ray TS Map > 2 GeV

Pixel size of 0.05° × 0.05°

IR contour of the distribution of the star cluster observed by Spitzer

22σ detection in 0.2 – 300 GeV
3.6σ above 2 GeV



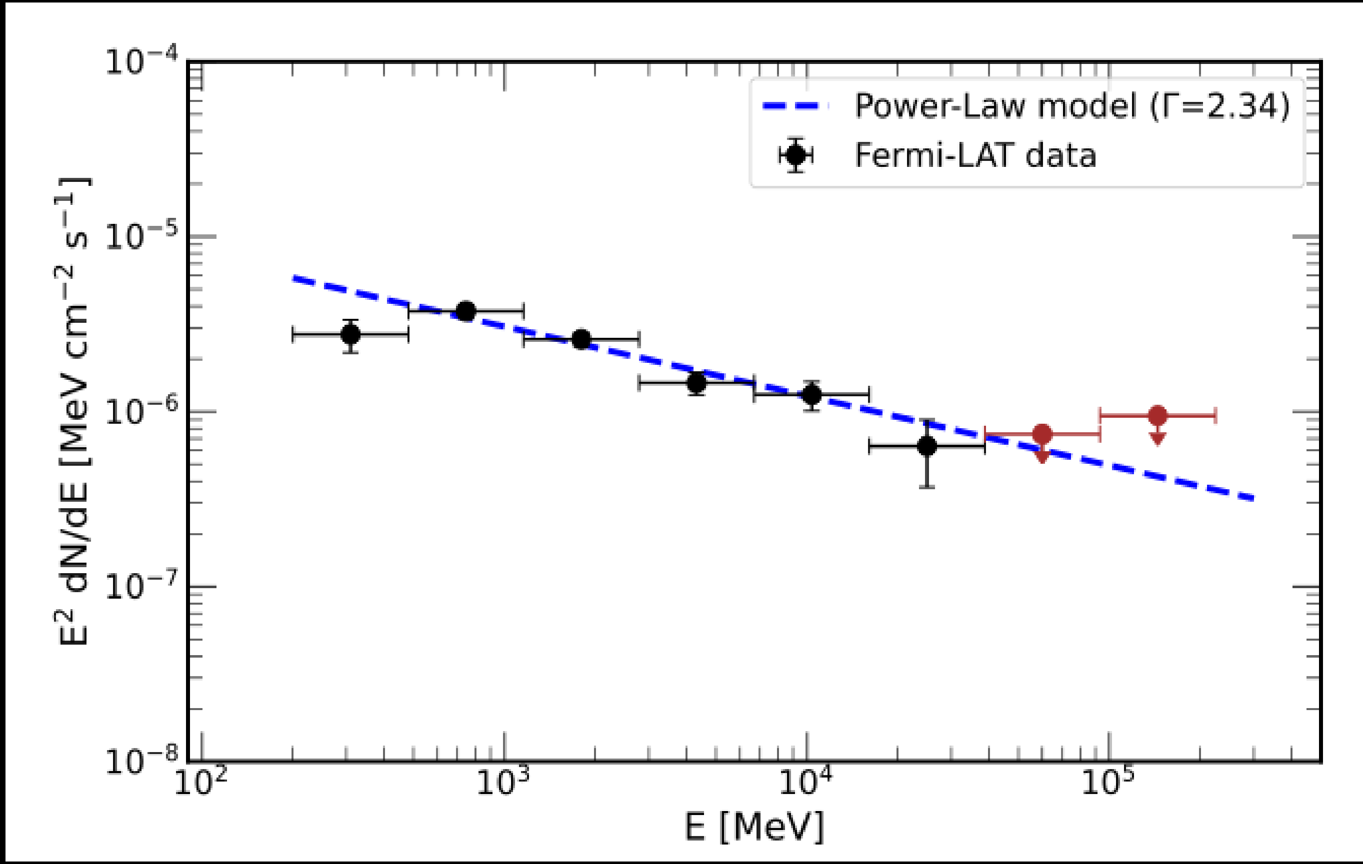
1° × 1° TS Map above 2 GeV of RCW 38

Fermi-LAT Analysis

- Gamma-ray Luminosity
  $L\gamma = 2.6 \times 10^{34}$ erg s^{-1}
  (0.1 - 500 GeV)

- Effective number density
  $n_{eff} = 1000$ cm^{-3}

- Size of gamma-ray emission
  R = 7 pc



Stellar Wind Luminosity

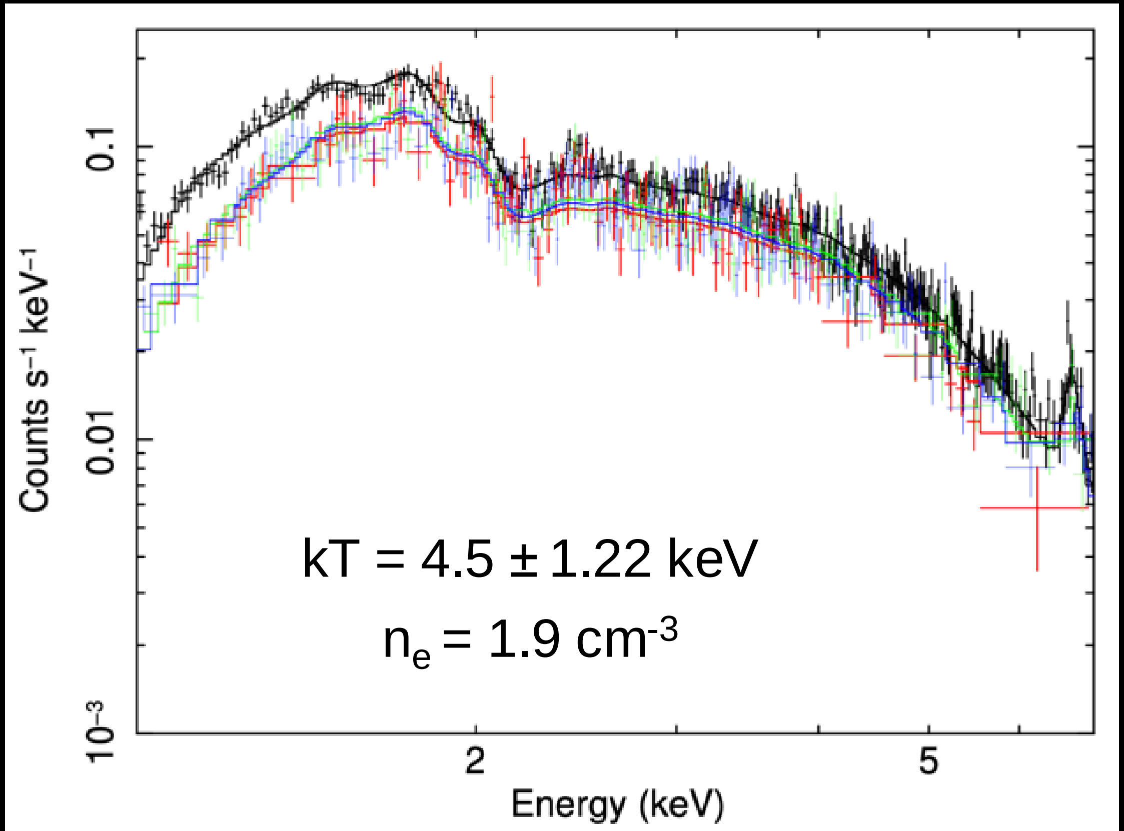
$$L_W = \frac{1}{2}\sum_i^N \dot{M}\, v^2$$

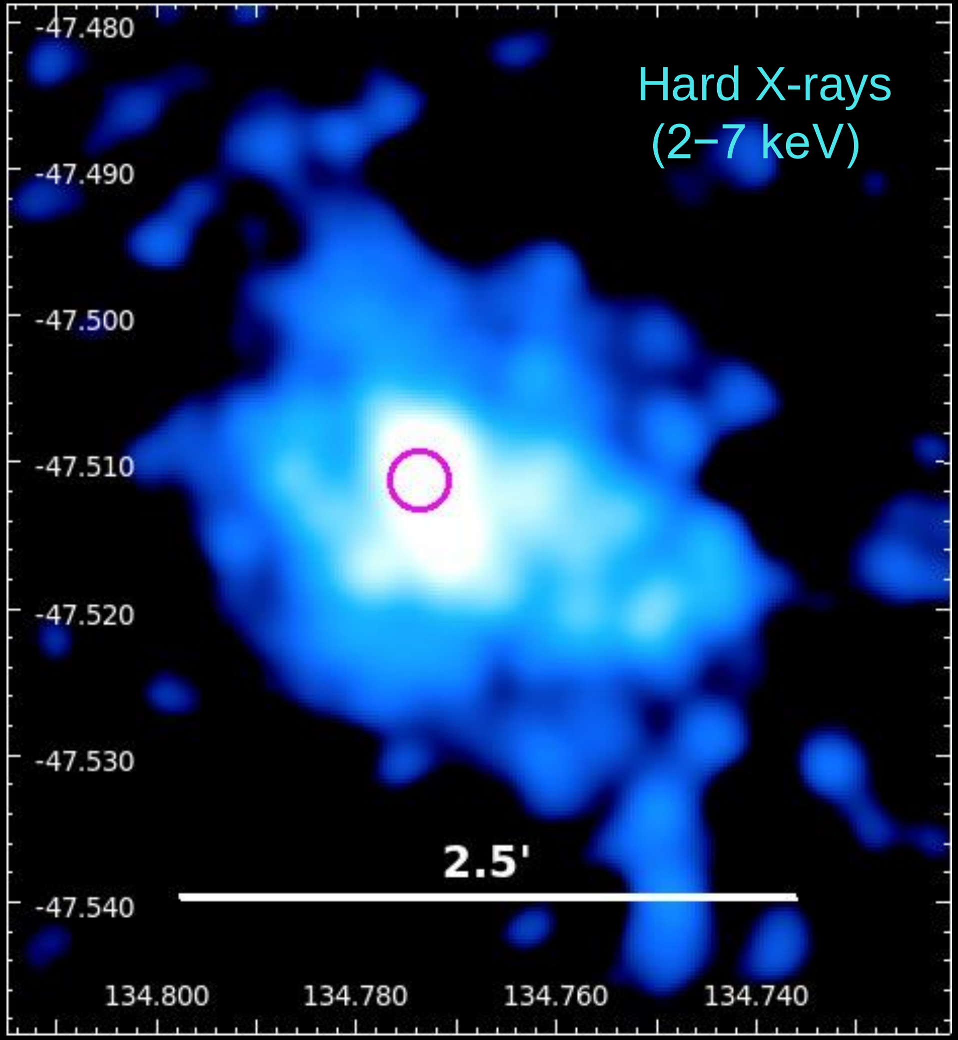
$$\frac{1}{2}\frac{L_{bol}}{c} = \dot{M} v$$

Starburst99

Stellar Wind Luminosity $L_W = 8 \times 10^{36}$ erg s^{-1}

Chandra X-ray Analysis

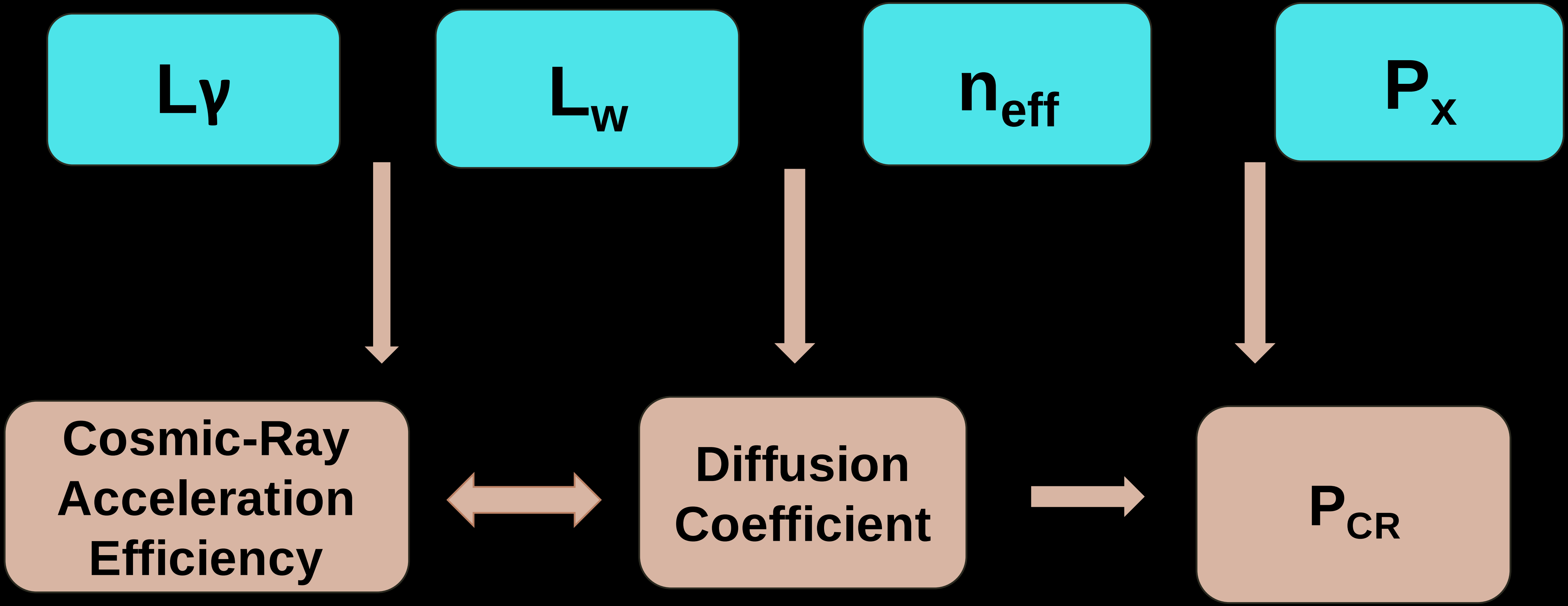




Cosmic Ray Pressure (P_{CR}) ≪ Thermal Pressure (P_X)

10^{-12} erg cm^{-3} 2.7×10^{-8} erg cm^{-3}

What parameters can we constrain?

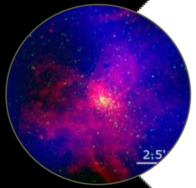


Results

Read my paper here for more information

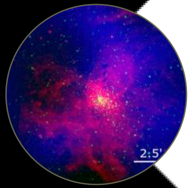
arXiv:2404.19001

Pandey et al. (2024) (accepted in ApJ)



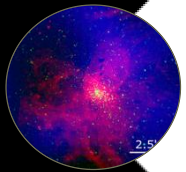
Constraints on efficiency:

10%-40% of the stellar wind energy goes into CR acceleration.



Diffusion coefficient is smaller than the ISM:

CRs are being trapped for longer period of time.



CR pressure is four orders of magnitude lower than thermal pressure.

$$L_{\gamma}^{max} = \eta \, L_w$$

→ Fraction of stellar wind energy that goes into CR acceleration

$$\eta \propto D \cdot n_{eff}^{-1} \cdot R^{-2} \cdot \frac{L_{\gamma}}{L_w}$$

OR

$$D \propto \eta \cdot n_{eff} \cdot R^{2} \cdot \frac{L_w}{L_{\gamma}}$$

If D = 10^{28} cm^2 s^{-1} (ISM)

η = 0.4

If η = 0.1 (SNe)

D = 2.5 x 10^{27} cm^2 s^{-1}

If we use the value of D typical for ISM, we get High efficiency!

For a standard efficiency of 0.1, we get a lower value of D implying CRs being trapped!

$$P_{CR} = \frac{\eta \, Lw}{4\pi R D}$$

For $\eta = 0.1$ and $D = 10^{27}\ cm^2\ s^{-1}$

$P_{CR} = 10^{-12}\ erg\ cm^{-3}$

EXTRA 2: Equations

$$\eta_{\rm CR} \simeq 0.4 \left(\frac{10^3\,{\rm cm}^{-3}}{n_{\rm eff}}\right) \left(\frac{7\,{\rm pc}}{R}\right)^2 \times \left(\frac{D}{10^{28}\,{\rm cm}^2\ {\rm s}^{-1}}\right) \left(\frac{3L_\gamma/L_{\rm w}}{0.011}\right)$$

OR

$$D \simeq 2.5 \times 10^{27}\,{\rm cm}^2\ {\rm s}^{-1} \left(\frac{\eta_{\rm CR}}{0.1}\right) \left(\frac{n_{\rm eff}}{10^3\,{\rm cm}^{-3}}\right) \times \left(\frac{R}{7\,{\rm pc}}\right)^2 \left(\frac{0.01}{3L_\gamma/L_{\rm w}}\right).$$

$$P_{\rm CR} \simeq \frac{\eta_{\rm CR} L_{\rm w}}{4\pi R D} \simeq 1 \times 10^{-12}\,{\rm erg\ cm}^{-3} \left(\frac{\eta_{\rm CR}}{0.1}\right) \times \left(\frac{L_{\rm w}}{10^{37}\,{\rm erg\ s}^{-1}}\right) \left(\frac{7\,{\rm pc}}{R}\right) \left(\frac{10^{27}\,{\rm cm}^2\ {\rm s}^{-1}}{D}\right).$$