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Expected gamma-ray emission from Stellar Clusters acting as Galactic PeVatrons

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Abstract

Galactic cosmic rays may be accelerated up to PeV energies due to collective stellar winds surrounding stellar clusters. Further particle acceleration may occur due to supernova remnants within the wind-blown bubble. We apply a model of particle acceleration accounting for the stellar cluster wind termination shock and supernova remnant shocks to young and massive stellar clusters catalogued in Gaia DR2. The resulting gamma-ray and neutrino emission and size of the wind-blown bubble are predicted, from which we identify the most suitable candidates for future observations of stellar clusters. Detection prospects for future experimental facilities, taking the flux and angular size into account, are evaluated, along with the flux range allowed due to model assumptions and uncertainties.

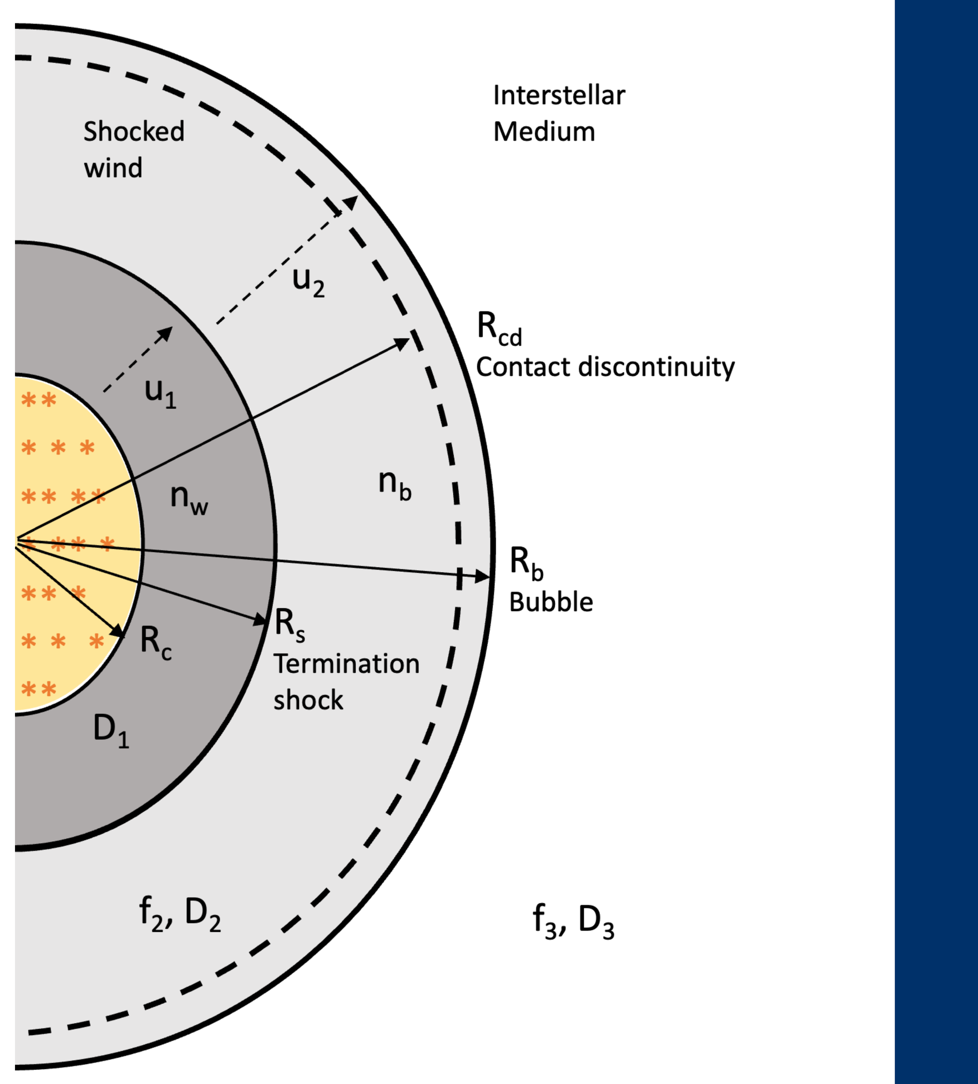

Fig. 1 Stellar cluster model schematic.
A collective wind region (1) drives a termination shock at radius R_s, beyond which there is a wind-blown bubble region (2) of radius R_b within the ISM (3).

Model We follow the model of [1] together with the gamma-ray flux conversion of [2]:

- The radius of the wind termination shock and of the wind-blown bubble evolve with time
- The particle distribution within the bubble:

$$f_2(r,p) = f_s(p) e^{\alpha(r)} \frac{1+\beta(e^{\alpha(R_b)} e^{-\alpha(r)} - 1)}{1+\beta(e^{\alpha(R_b)}-1)} + f_{\mathrm{Gal}}(p) \frac{\beta\left(e^{\alpha(r)}-1\right)}{1+\beta(e^{\alpha(R_b)}-1)}$$

- We account for SNR explosions occurring within the cluster and contributing to particle acceleration, with an average distribution over the bubble volume:

$$\langle f_{snr}\rangle = N_{sn}(t_{esc}) \frac{\xi_{cr} n_b u_{st}^2}{4} \frac{R_{st}^3}{R_b^3}$$

- Where the ratio can be parameterised

$$R \equiv \frac{\langle f_{snr}\rangle}{f_{ts}} = 1.74 N_{sn}(t_{esc}) \left(\frac{E_{sn}}{10^{51} erg}\right)\left(\frac{L_w}{10^{37} erg/s}\right)^{-1}\left(\frac{t_{age}}{3\,Myr}\right)^{-1}$$

Data We select young stellar clusters from the Gaia DR2 [3,4], obtain their mass, mass-loss rate and wind luminosity via [5] and evaluate their properties in the above model.

- The resulting bubble size, gamma-ray flux and maximum energy can be derived (***Fig. 2, 4***)
- The model can be further refined for specific individual clusters (***Fig. 3***)

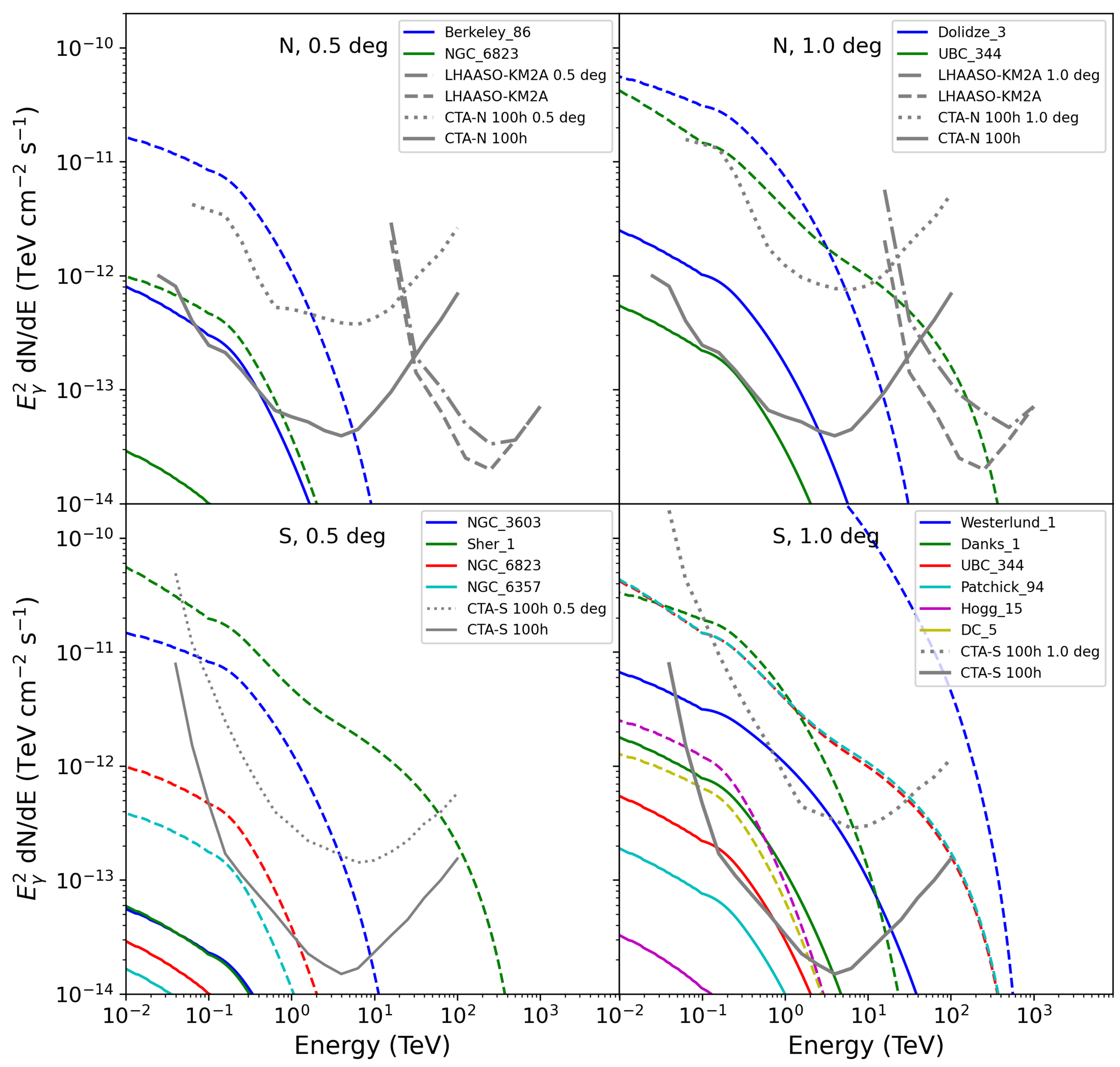

Fig. 2 Gamma-ray flux predictions for wind-blown bubbles from stellar clusters. Solid lines indicate the baseline scenario and dashed lines the most optimistic case.

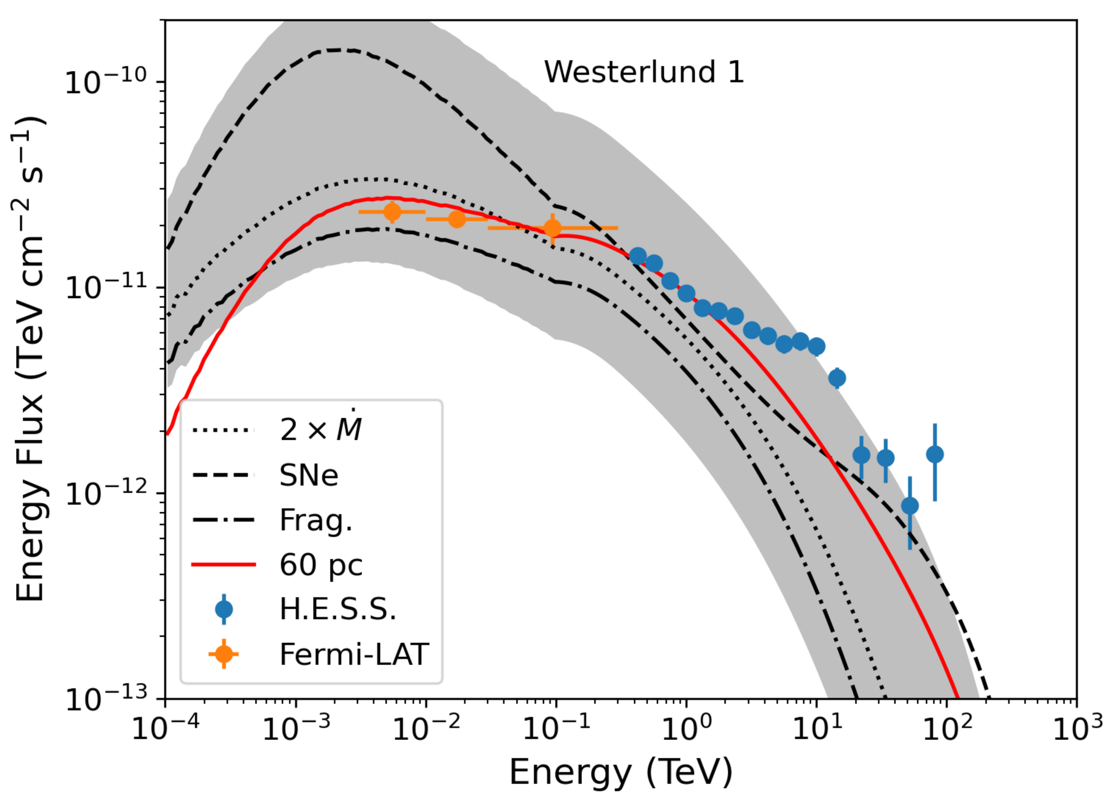

Fig. 3 Westerlund 1 model compared to gamma-ray data. A smaller 60 pc bubble consistent with TeV data can be accounted for by using Bohm diffusion and a higher ISM density

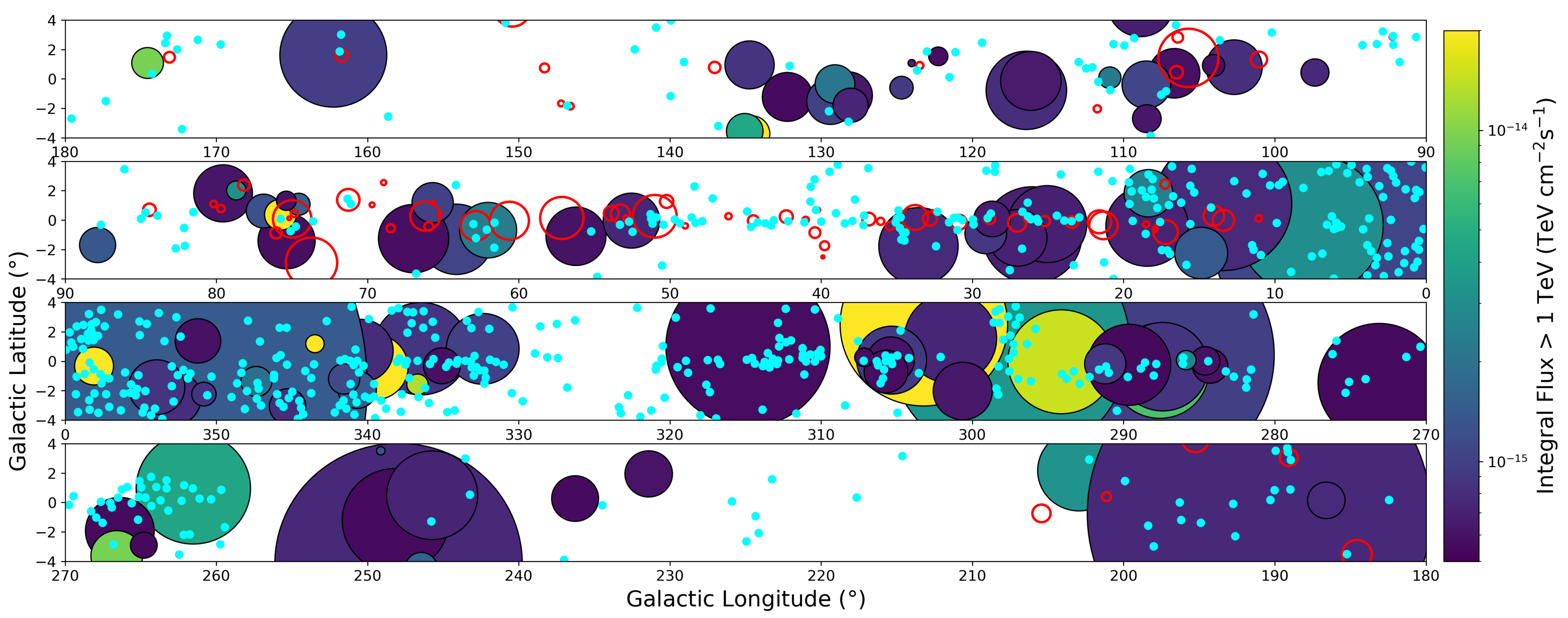

Fig. 4 Stellar clusters in the galactic plane – predicted gamma-ray emission from the wind-blown bubble. The size of the coloured circles correspond to the bubble size. Red circles indicate ultra-high-energy LHAASO sources [6] and cyan points sources detected by Fermi-LAT in the 4FGL catalog [7].

References

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Conclusions

We anticipate that many stellar clusters generate gamma-ray fluxes detectable by forthcoming facilities. Given their large angular size, a good sensitivity to extended emission is required. Our model is flexible, can be adapted to individual stellar clusters, and describe the measured gamma-ray emission well. However, several input parameters of the model have large uncertainties, such that multiwavelength data is necessary to further constrain details for each individual stellar cluster in turn.