Gamma-ray emission from young stellar clusters

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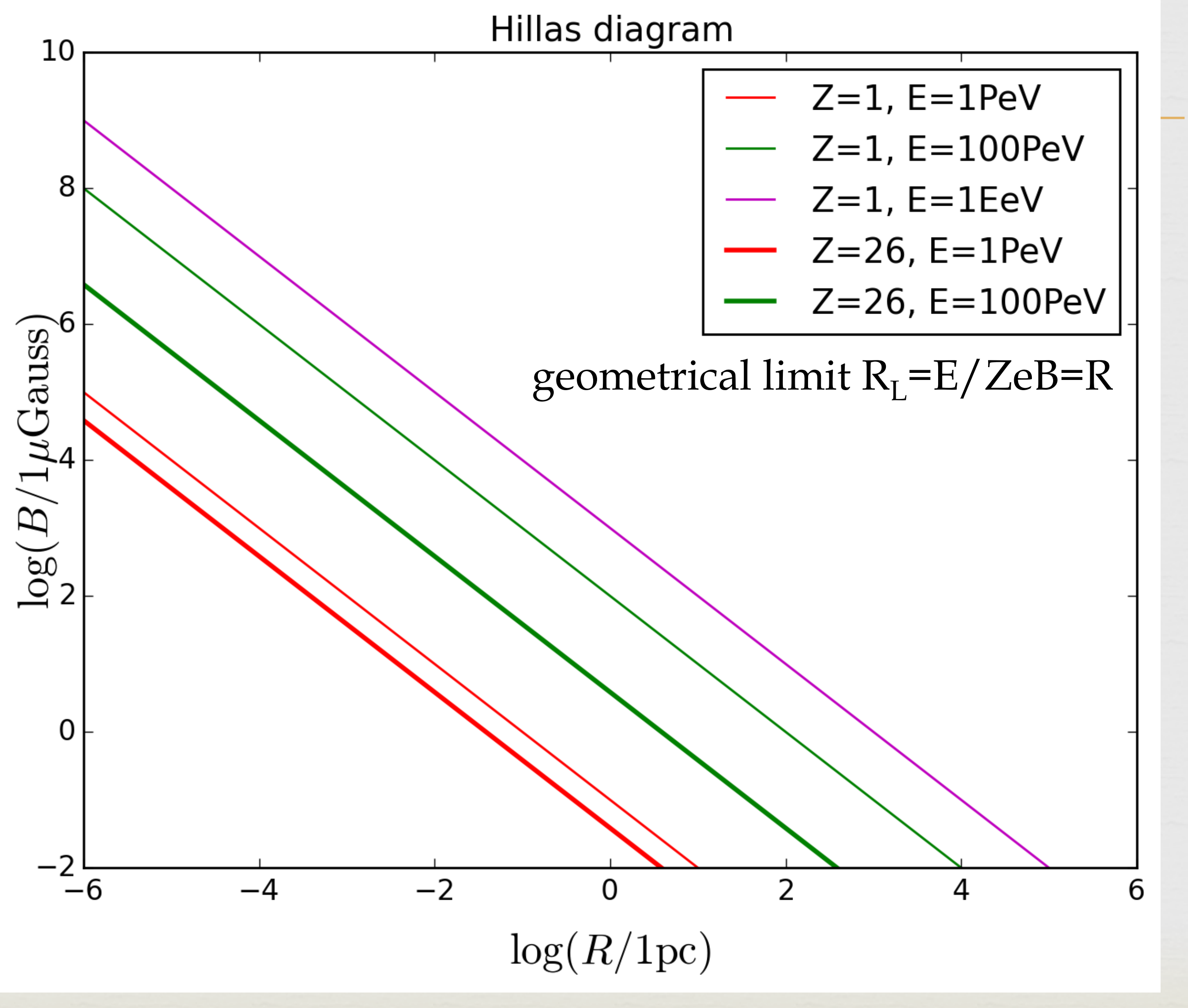
based on G.Maurin et al A&A 2016 arXiV 1605.04202.

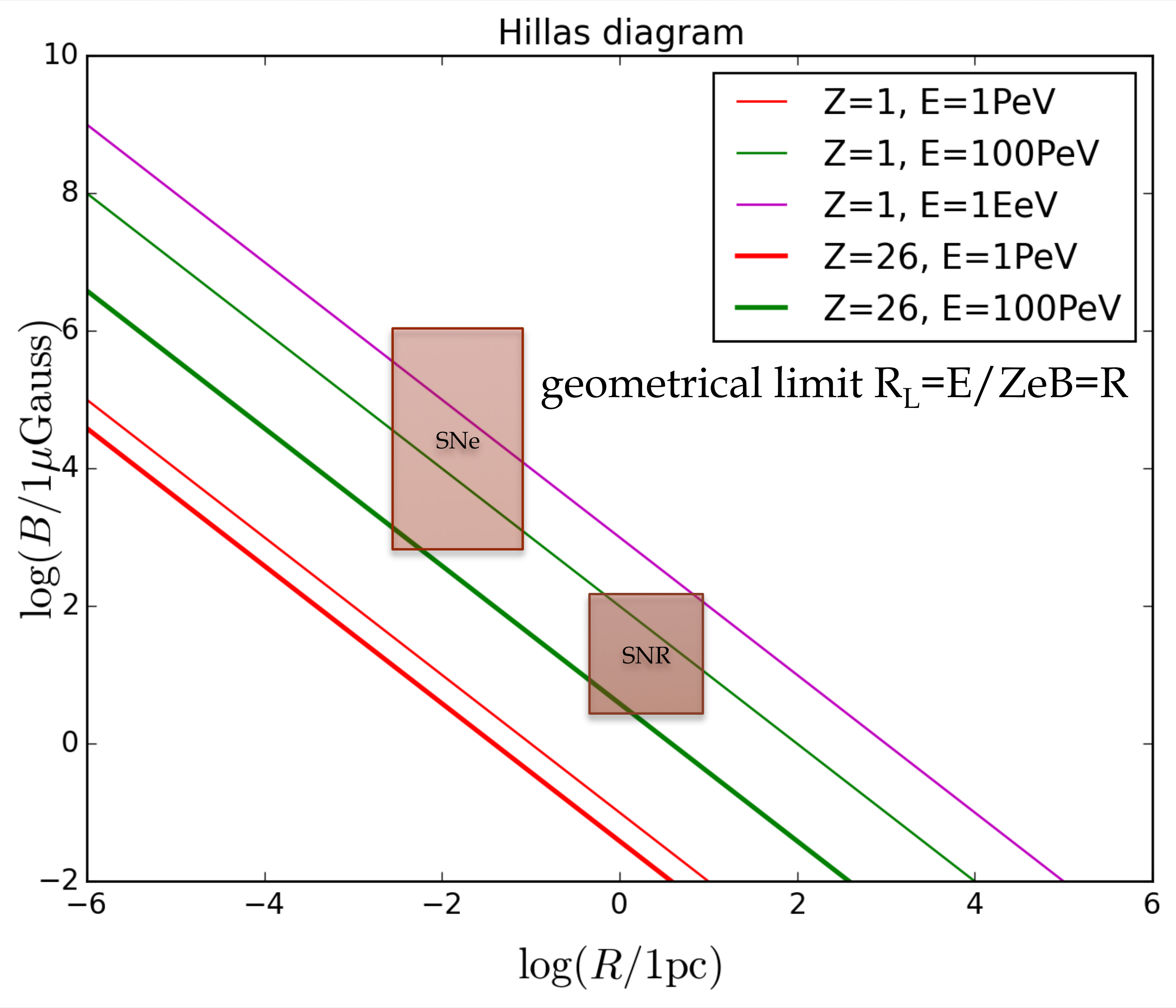
Outlines

- Context: the origin of Cosmic Rays
- The Stellar Wind OB stars model.
- Stellar wind cluster catalogue selection.
- Gamma-ray emissivity and perspectives for C.T.A.
- Conclusions.

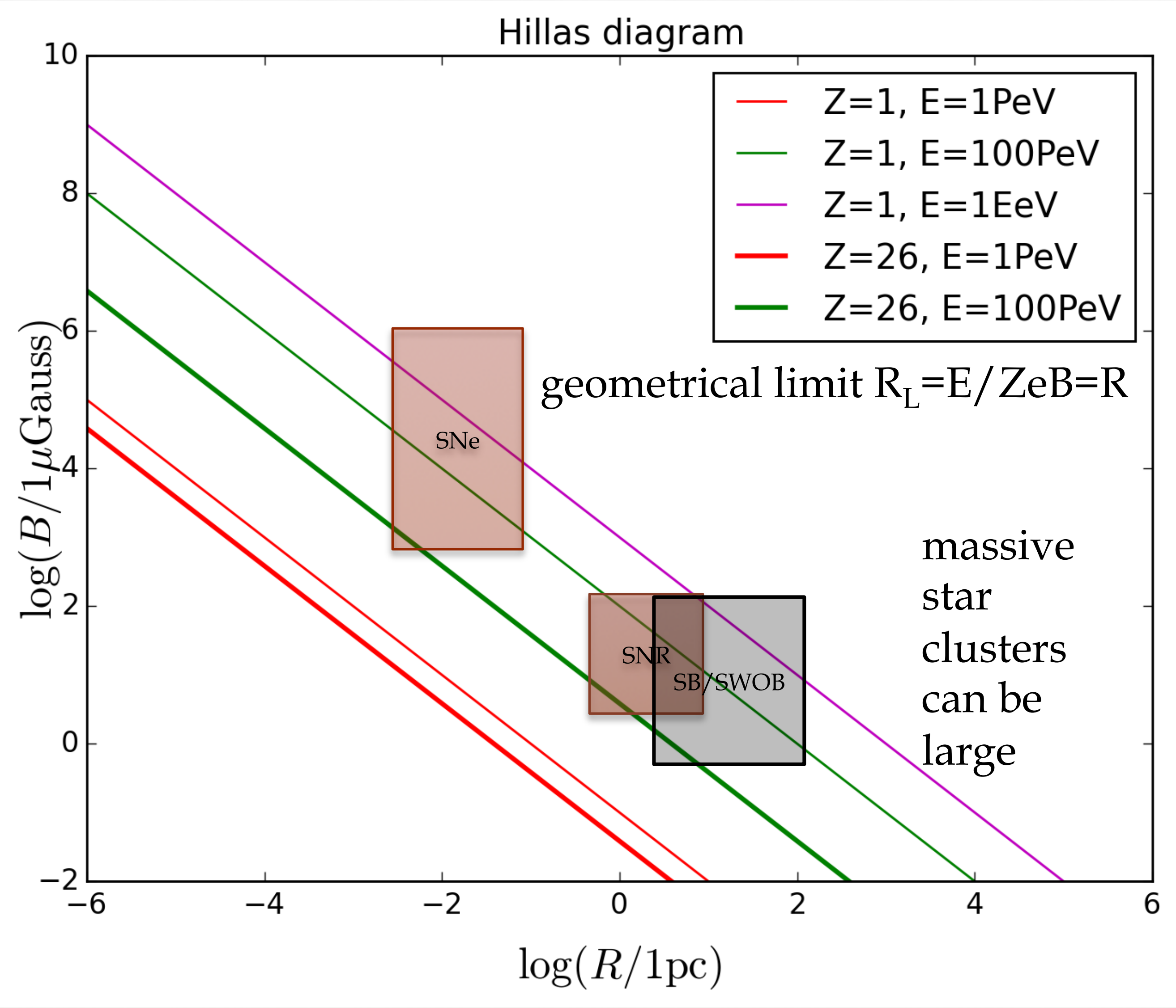
Origin of (galactic) cosmic rays



Origin of (galactic) cosmic rays



Origin of (galactic) cosmic rays



geometrical limit R_L=E/ZeB=R

massive star clusters can be large

Stellar Wind OB model

- Idea similar to the SNOB model (Montmerle & Cesarsky'79'83):
  - Convert a fraction of massive star wind power into energetic particles.
  - Particle escape from the stellar cluster and interact with dense HII regions => gamma-rays.

Our purpose

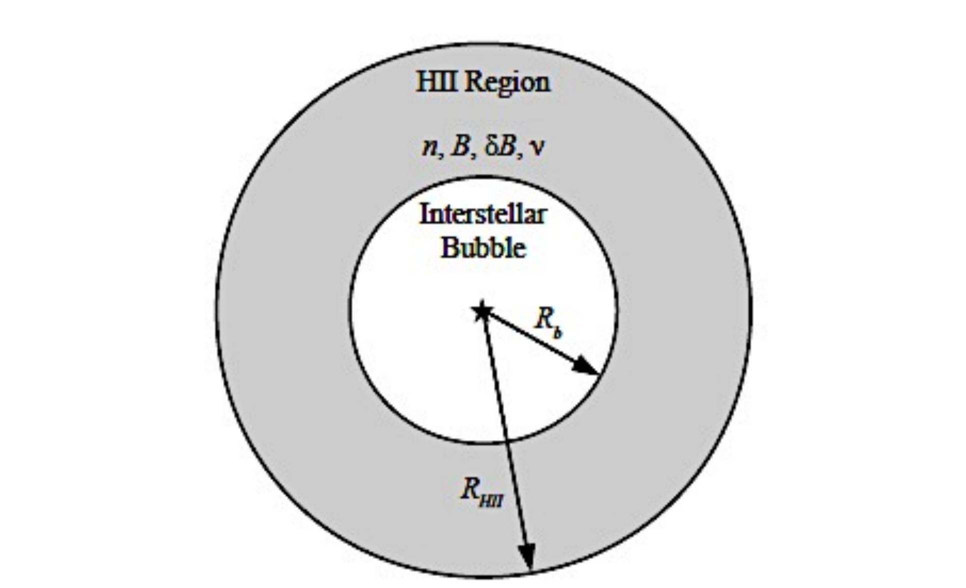
- Test the capacity of SW and SW in interaction to accelerate particles. (Selection of young stellar clusters with no SN explosion yet (< a few M years).)using current facilities.

- Scientific case for CTA.

- Evaluate the contribution to cosmic ray spectrum.

Main assumptions

- Spherical geometry for the cluster and the HII region.
- Evolution model (Weaver+77 : $R_b(t)$, Freyer+03 $R_{HII}(t)$).
- HII region is turbulent (δB, index=5/3, 3/2): diffusive transport of particles.

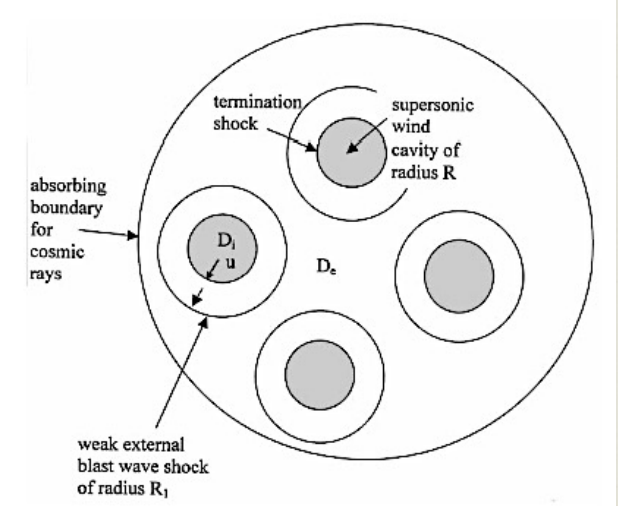


Model for particle acceleration

- Important parameter ξ = fraction of the wind power imparted into energetic particles (electron/proton): $\xi_e = K_{ep}\,\xi_p$

$$\frac{\xi L_w}{V_b(t)} = \int_{E_{inj}}^{E_{max}} Q_0 \left(\frac{E}{E_{inj}}\right)^{-s} E\,\mathrm{d}E$$

collective shock acceleration model



- E_{max}, s based on Klepach+00: $E_{max,p}$= 1-10 PeV, $E_{max,e}$=10-100 TeV, s=2.
- E_{inj} =1 GeV

=> $Q_0(t, s, E_{max}, \xi) = t^{-6/5}$ (Weaver+77)

Solution in the HII region

- One-zone model (Aharonian & Atoyan'00)

$$N(E,t) = \frac{1}{P(E)} \int_0^t P(E_t)\, Q(E_t, t')\, \exp\left(-\int_{t'}^{t} \frac{dx}{\tau_{esc}(E_x)}\right) dt'$$

P(E) = energy loss rate dE/dt : synchrotron/Inverse Compton,Bremsstrahlung for electrons, pp interaction for protons.

τ_{esc}= escape time from HII region due to diffusive isotropic transport

$$\tau_{esc}(E,t) = \frac{R_{HII}(t)^2}{6\,D(E)}$$

D=diffusion coefficient controlled by turbulence parameters:
1) Amplitude δB 2) index ν 3) coherence length l_c

Cluster selection

- From Galactic O-star catalog (Apellaini'11)
  - Young enough age < 10 Myrs
  - No evolved star in the cluster
  - No supernova explosion yet
  - HII shape almost spherical
  - Known astrophysical properties: population of O-type stars, radius and density of the HII region, cluster distance.

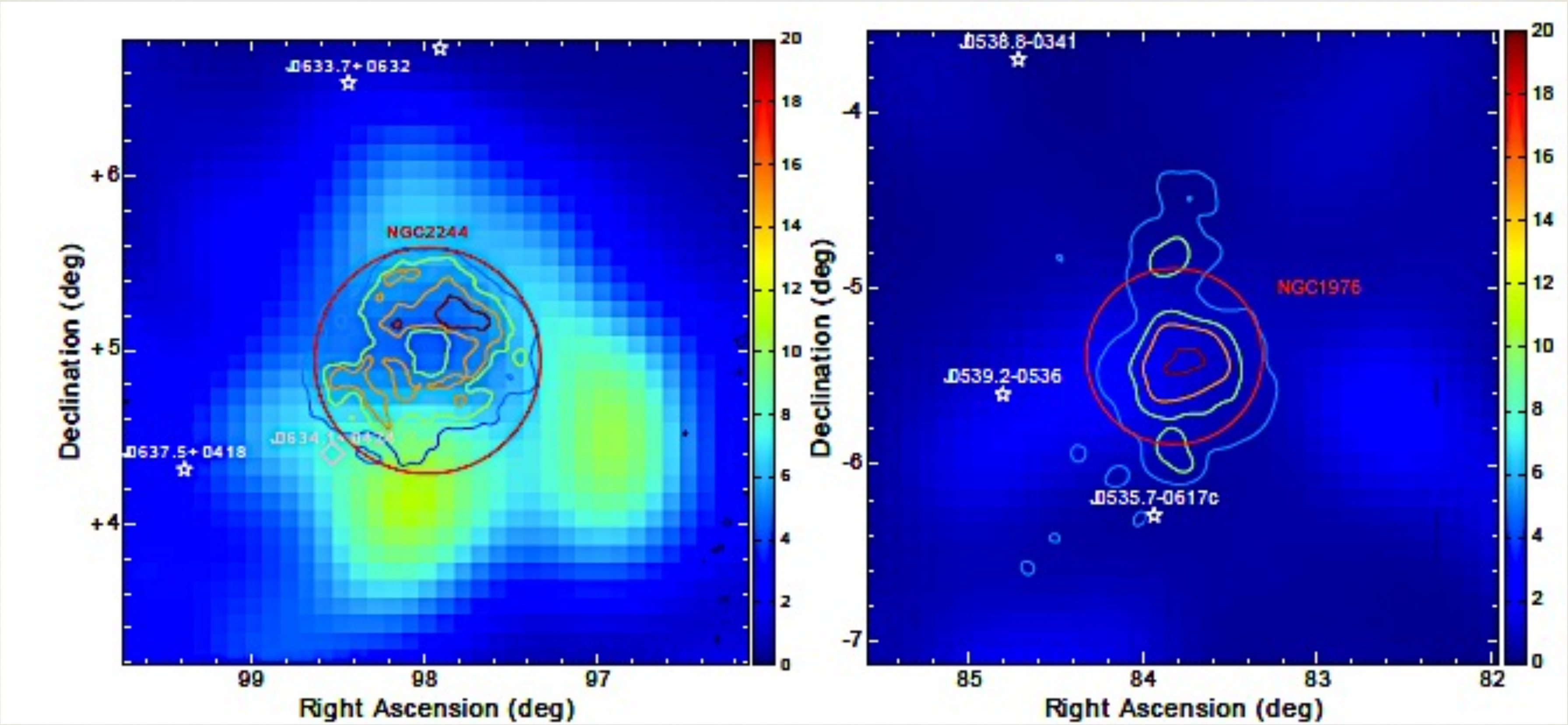
Cluster selection

Cluster name	O stars (most massive)	Luminosity (erg s^{-1})	R_{HII} (pc)	R_b (pc)	n_{HII} (cm^{-3})	Log(Age) Log(years)	D (kpc)
NGC 2244	4 (O4)	1.0×10^{37}	16.9	6.2	15	6.28	1.55
NGC 1976	4 (O7)	1.5×10^{36}	3.7	2	8900	6.4	0.4
NGC 2175	1 (O6.5)	1.3×10^{36}	12	2.56*	13	6.3	2.2
NGC 3324	2 (O6.5)	1.6×10^{36}	6.5	2.32*	33	6.4	3
RCW 8	2 (O8.5)	4.8×10^{35}	2.2	1.86*	91	6.78	4.2
RCW 62	10 (O6)	9.2×10^{36}	25.6	2.59*	430	6.8	2.2
NGC 6618	17 (O4)	3.3×10^{37}	4	1.69*	470	6	1.6
NGC 2467	3 (O3)	1.4×10^{37}	4	1.51*	550	6.3	4.1

NGC 2244=Rosette nebula, NGC 1976=Orion nebula = sample the gas density.
R_b with a star have calculated from Weaver+77 (so are not deduced from observations.

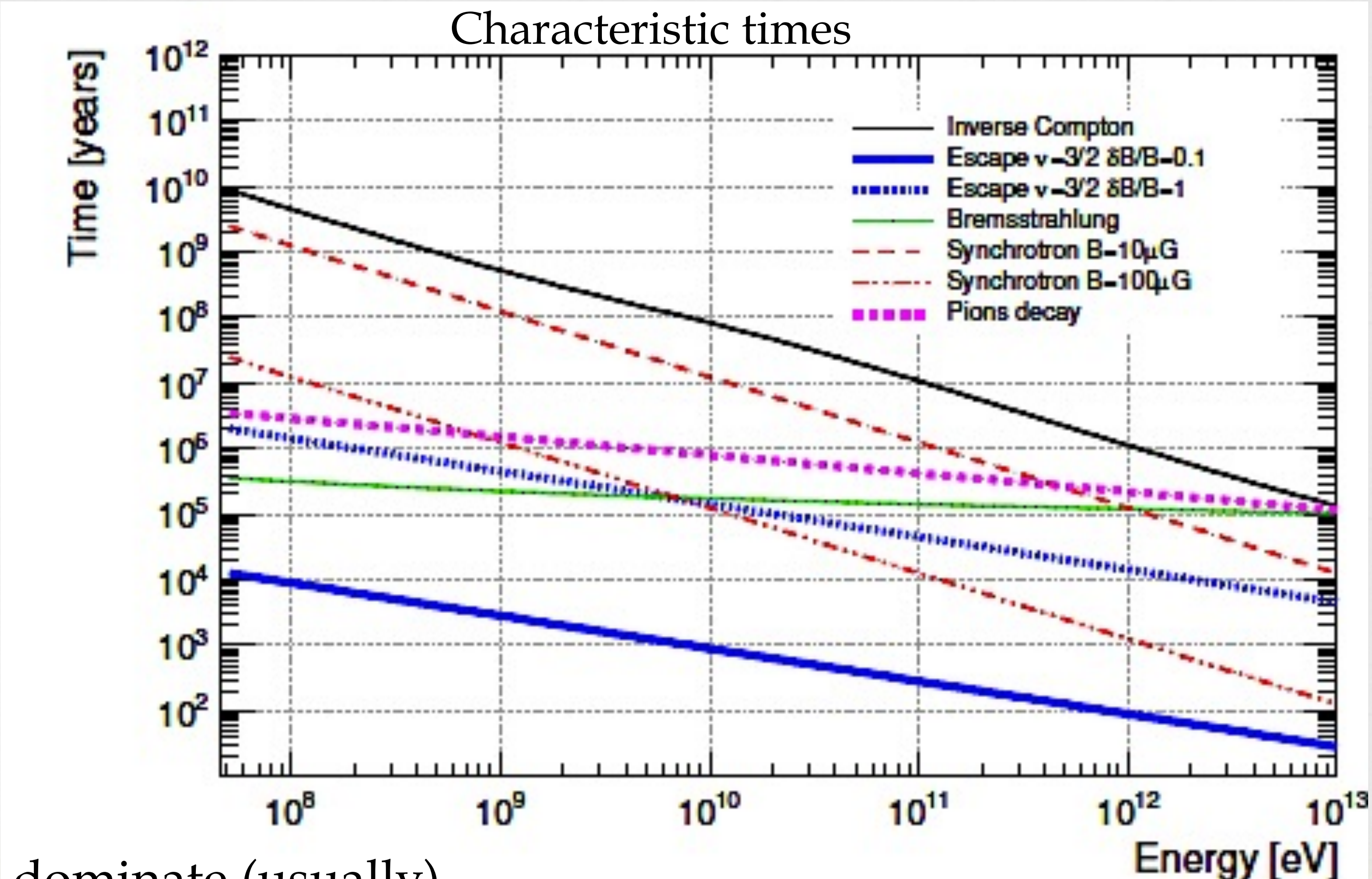
=> Fermi analysis with Pass8.

Fermi TS map



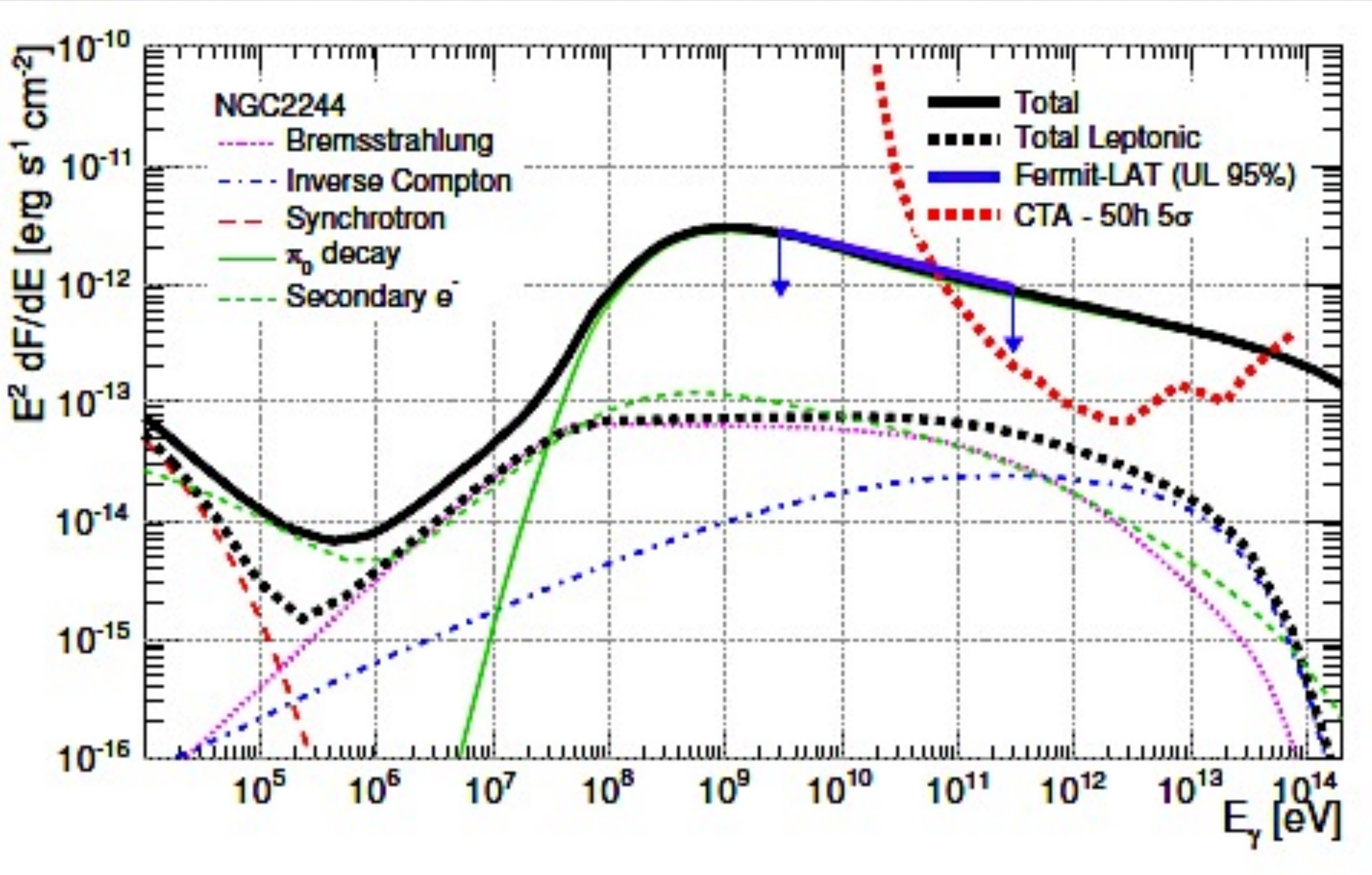
red circle =region used in the analysis
contours=HII regions
stars=sources from the 3FGL catalogue

Rosette Nebula

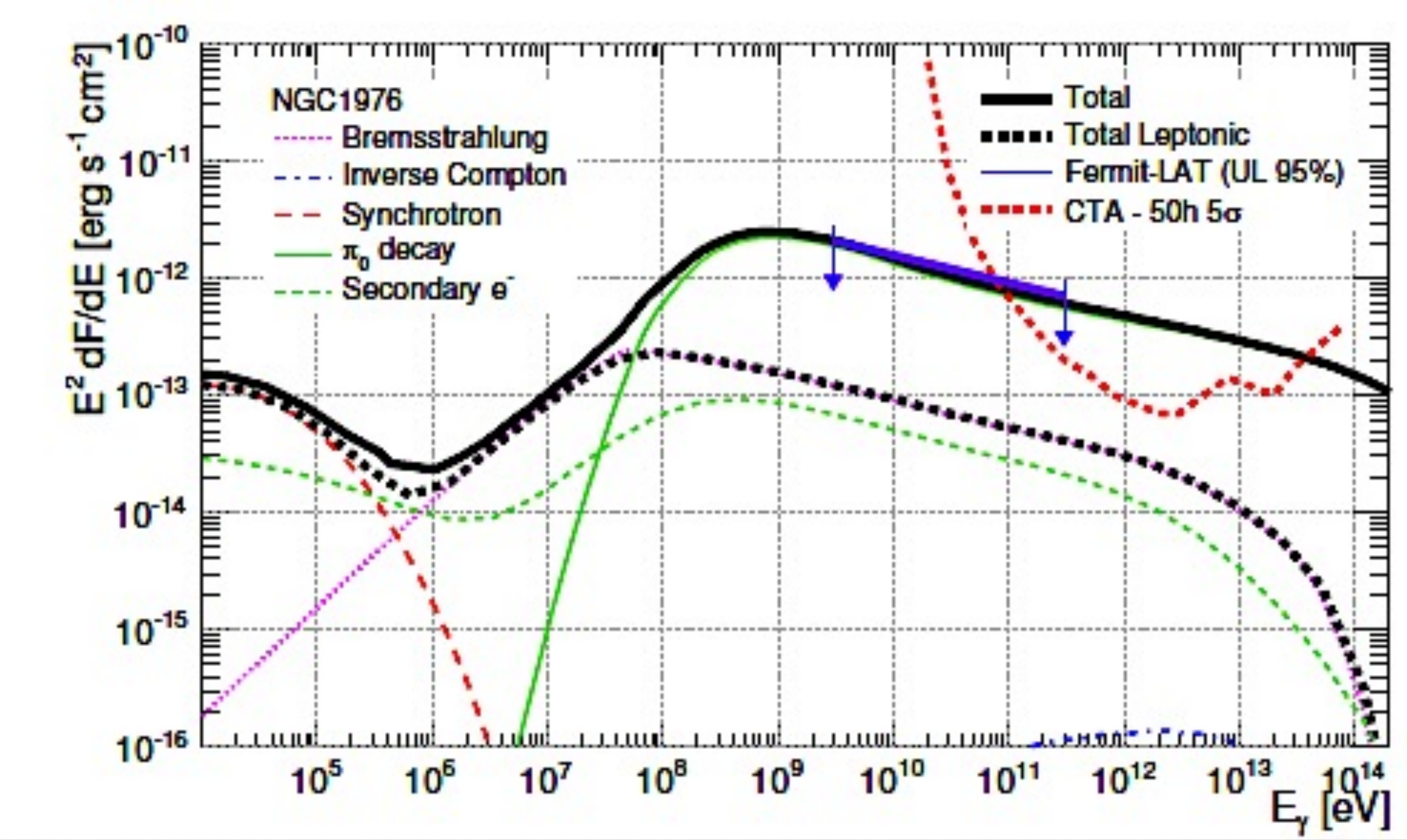


Escape dominate (usually)

Rosette nebula



Orion nebula



Limits for ξ

Cluster name	*Fermi*-LAT analysis TS	$\Phi_{UL}^{95\%}$ ($cm^{-2}s^{-1}$)	ξ_{max} (%)
NGC 2244	22.1	4.61×10^{-10}	5.80
NGC 1976	5.6	3.50×10^{-10}	6.69
NGC 2175	7.1	2.14×10^{-10}	9.81
NGC 3324	2.7	5.54×10^{-10}	100
RCW 8	11.2	1.75×10^{-10}	100
RCW 62	0.1	3.54×10^{-10}	0.13
NGC 6618	1.4	4.20×10^{-11}	0.27
NGC 2467	3.2	9.57×10^{-11}	7.06

(except to 2 objects) Maximum fraction ξ (protons) between 0.1-10% but not more.

CTA detection

Cluster	ξ_{CTA} (%)
NGC 2244	0.72
NGC 2467	4.21
NGC 6618	0.37
RCW 8	N.D.

Cluster	ξ_{CTA} (%)
NGC 1976	1.13
NGC 2175	2.21
RCW 62	0.03
NGC 3324	16.1

Values for ξ for a detection at 5σ in 50h with CTA (sensitivity curves from Becherini+12)

Sensitivity to parameters

Cluster	$\xi_{max}(\%)$					
	$\delta B/B$		l_c		s	
	10^{-2}	10^{2}	0.5 pc	2.0 pc	1.5	2.5
NGC 2244	5.95	5.10	5.88	5.88	16.06	0.85
NGC 1976	7.53	1.28	6.29	7.34	23.12	0.90

Table 2. Influence of the main parameters (magnetic turbulence level $\delta B/B$, coherence length l_c, index of injection s with $E_{max} = 10$ PeV) on the upper limit of the fraction of mechanical energy converted into accelerated particles ξ_{max} for NGC 2244 (Rosette Nebula) and NGC 1976 (Orion Nebula).

Conclusions

- A conservative selection of 8 young star clusters based on the completeness of their properties.
- Only u.l. obtained with Fermi-LAT (pass8 analysis).
- Pion decay dominate the gamma-ray emission.
- Upper limit on ξ only: maximum 10% of the total wind power.
- Selected clusters could be detected by CTA with ξ close to 0.01.
- Young stellar wind cluster are not (likely) strongly contributing to the CR background spectrum.