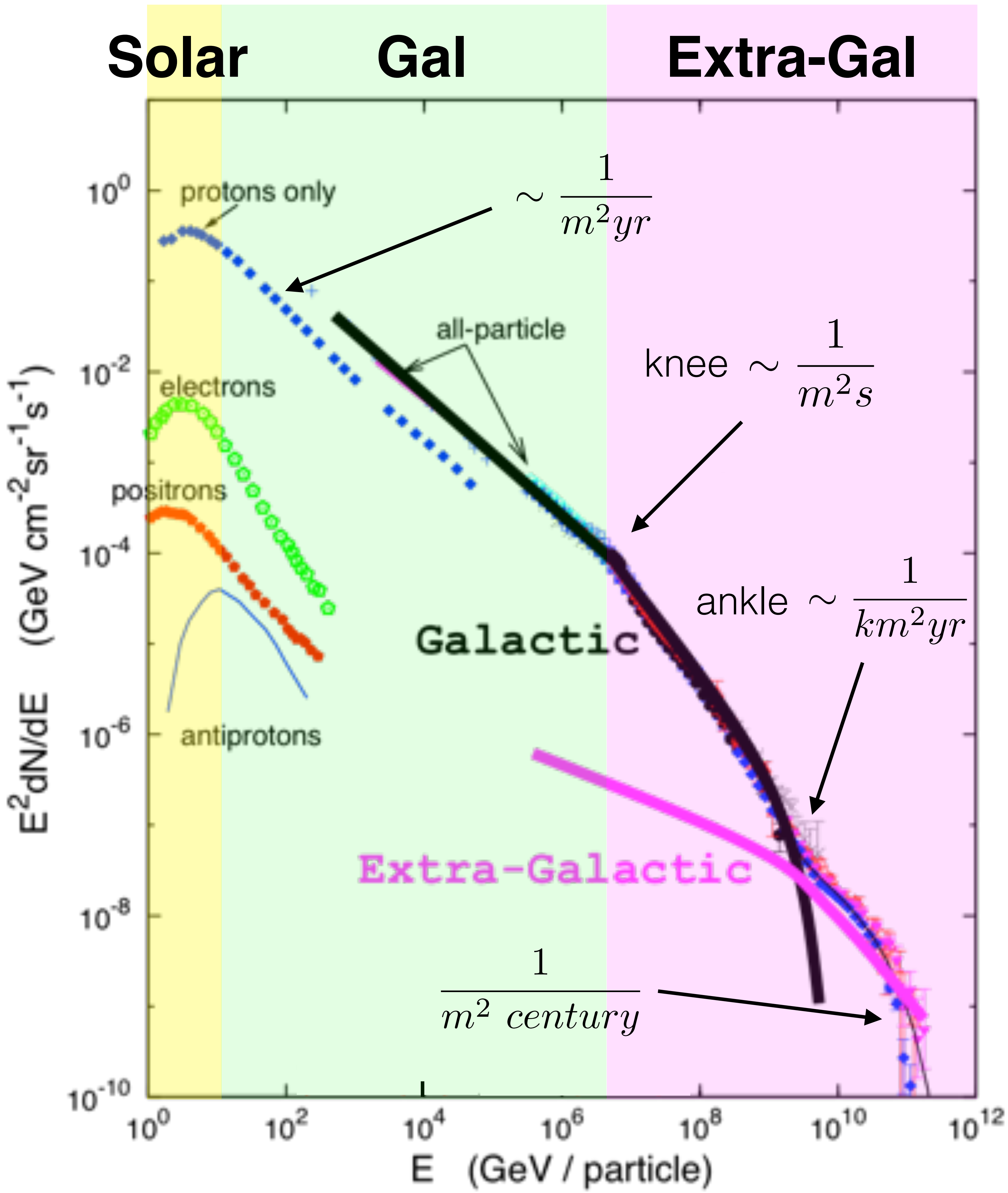
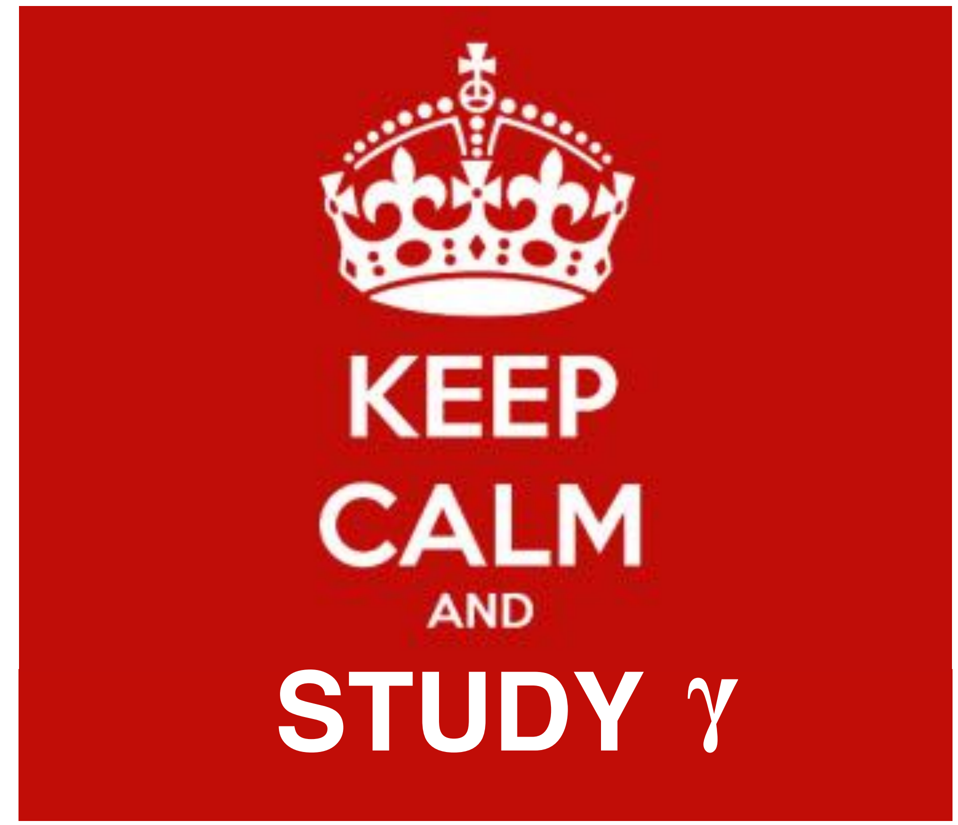
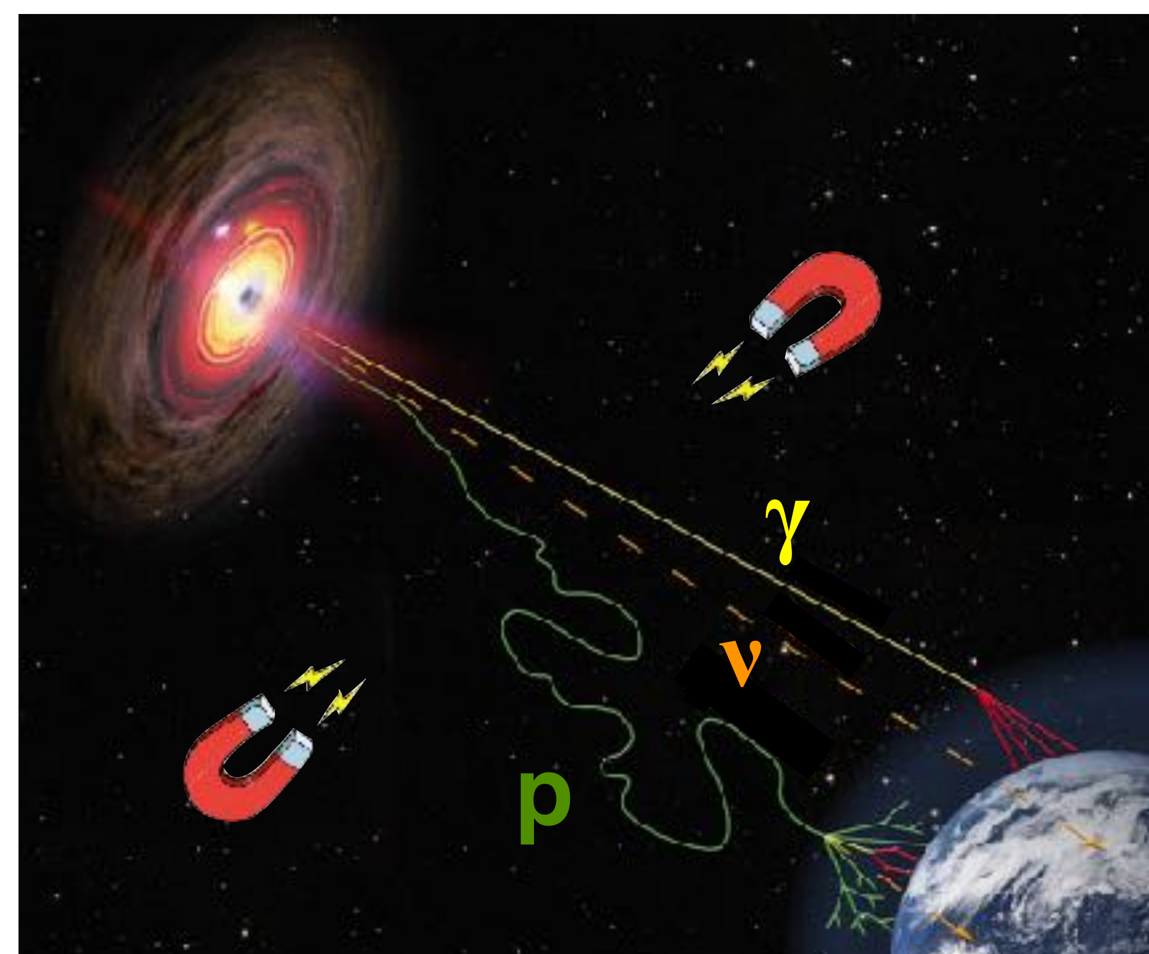
Cosmic rays



Solar
Gal
Extra-Gal
protons only
electrons
positrons
antiprotons
all-particle
Galactic
Extra-Galactic
$\sim \frac{1}{m^2 yr}$
knee $\sim \frac{1}{m^2 s}$
ankle $\sim \frac{1}{km^2 yr}$
$\frac{1}{m^2\ century}$
$E^2 dN/dE \quad (GeV\ cm^{-2} sr^{-1} s^{-1})$
E (GeV / particle)
10^0
10^{-2}
10^{-4}
10^{-6}
10^{-8}
10^{-10}
10^0
10^2
10^4
10^6
10^8
10^{10}
10^{12}

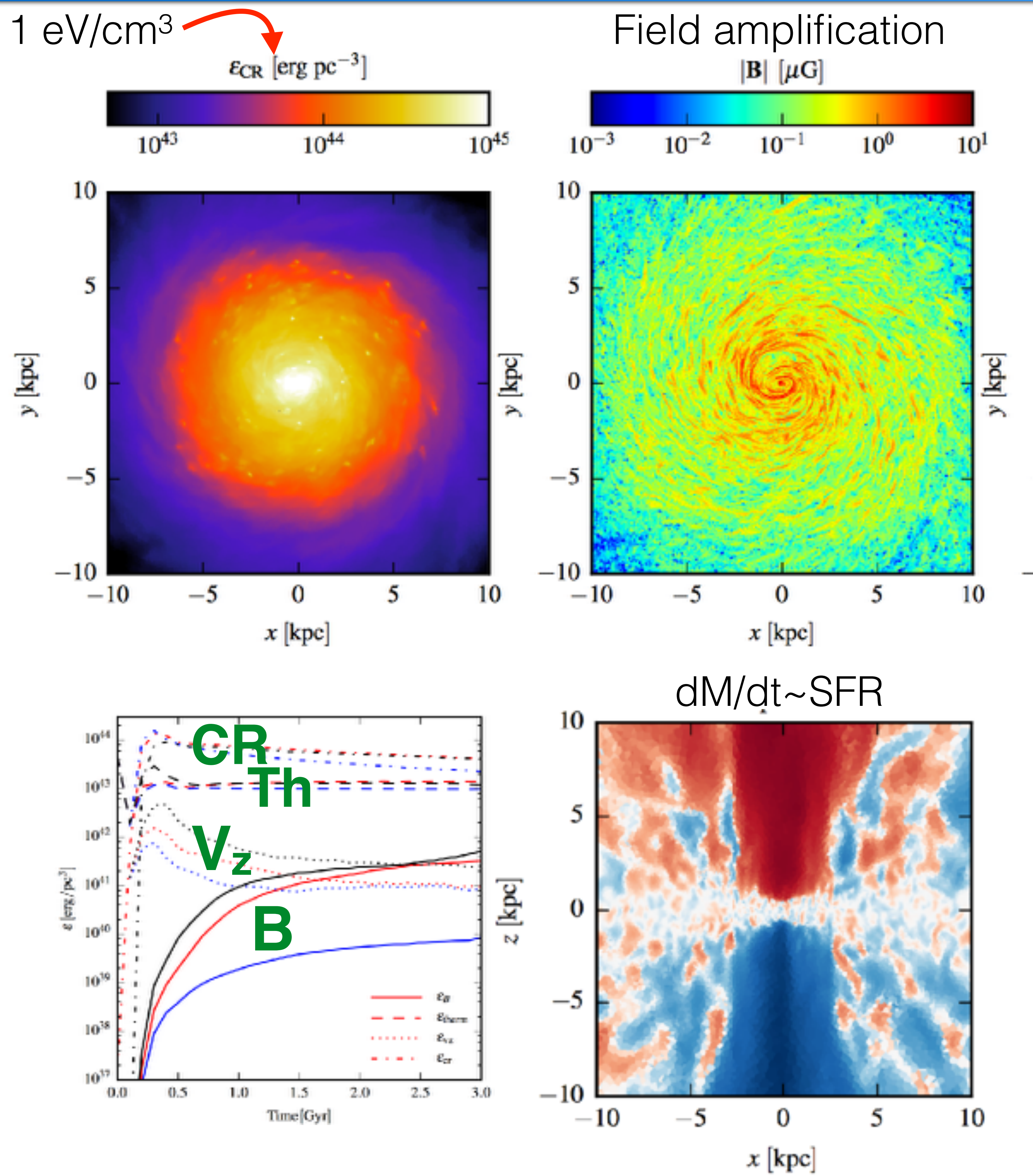


KEEP
CALM
AND
STUDY γ

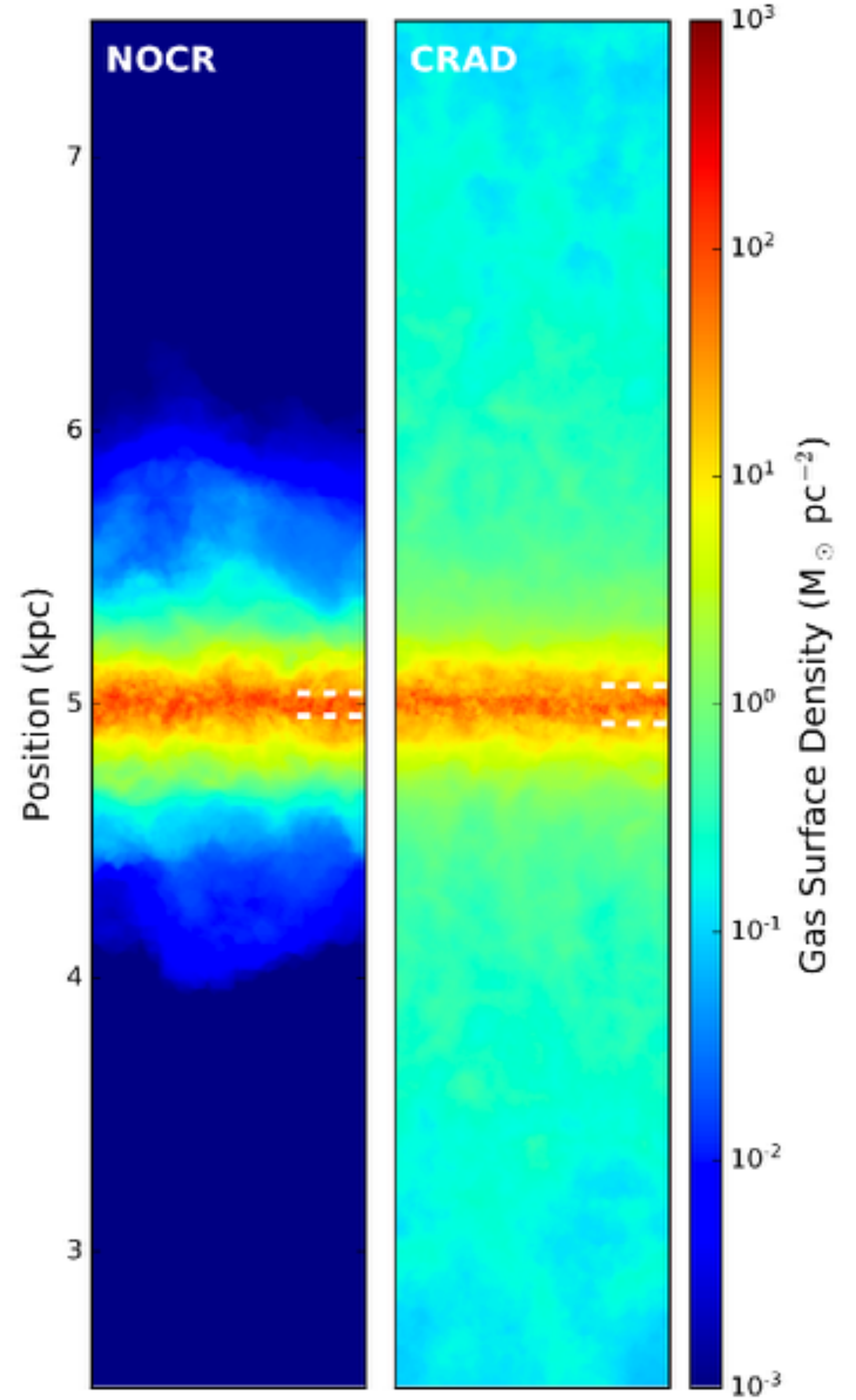


γ
ν
p

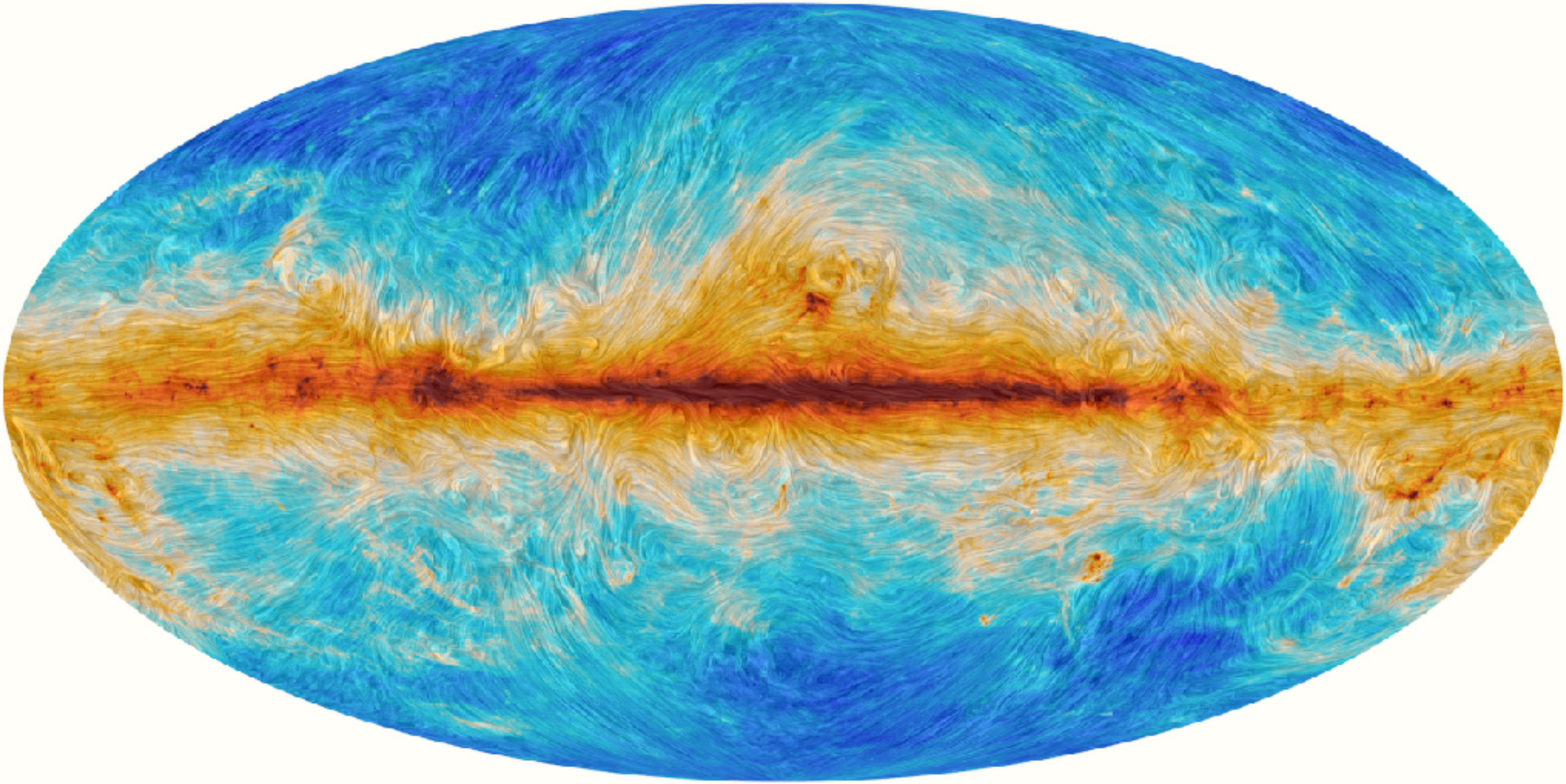
Anisotropic CR diffusion



(Pfrommer & Springel groups, 2016)



Acceleration and feedback



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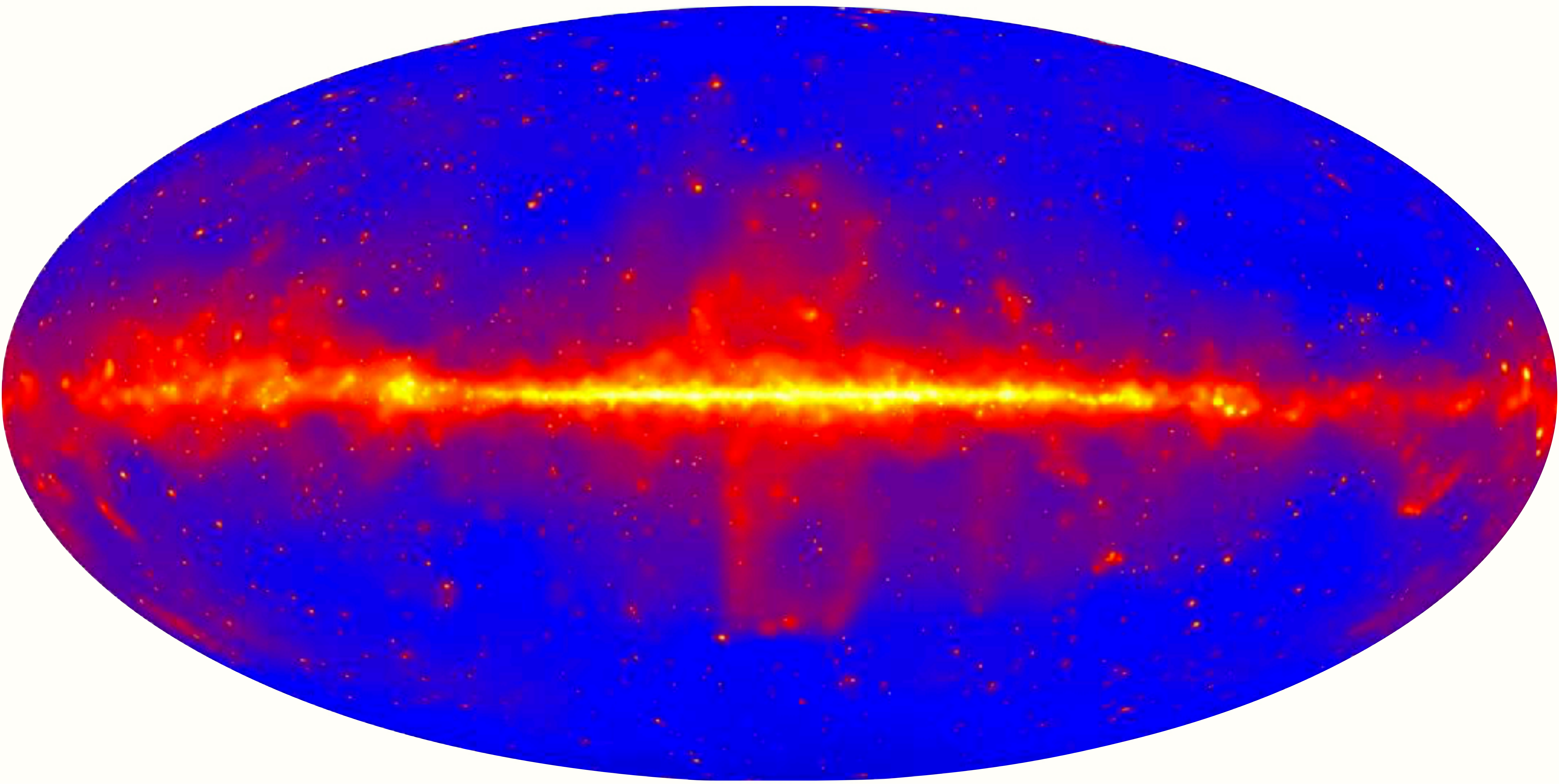
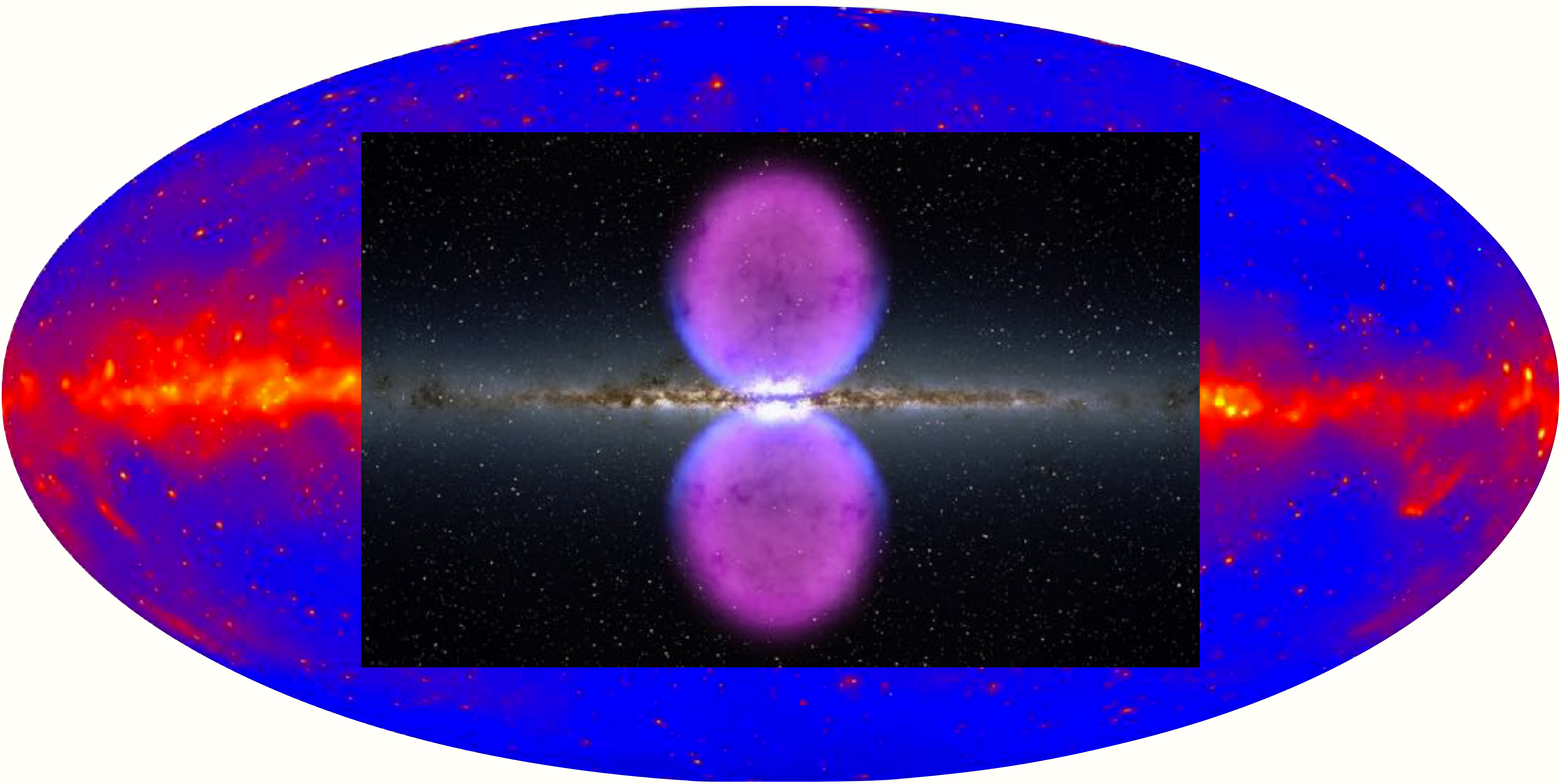
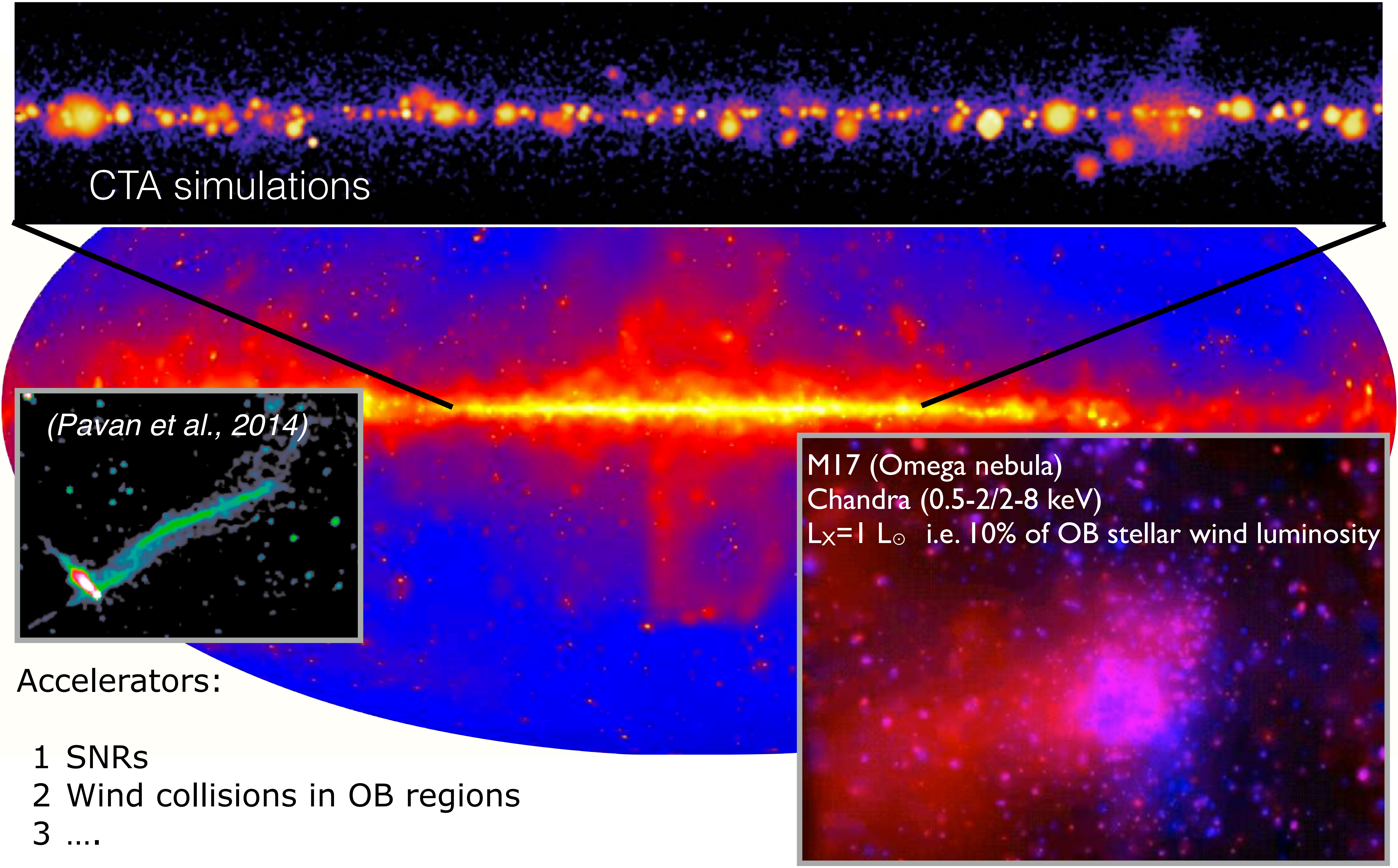


Acceleration and feedback



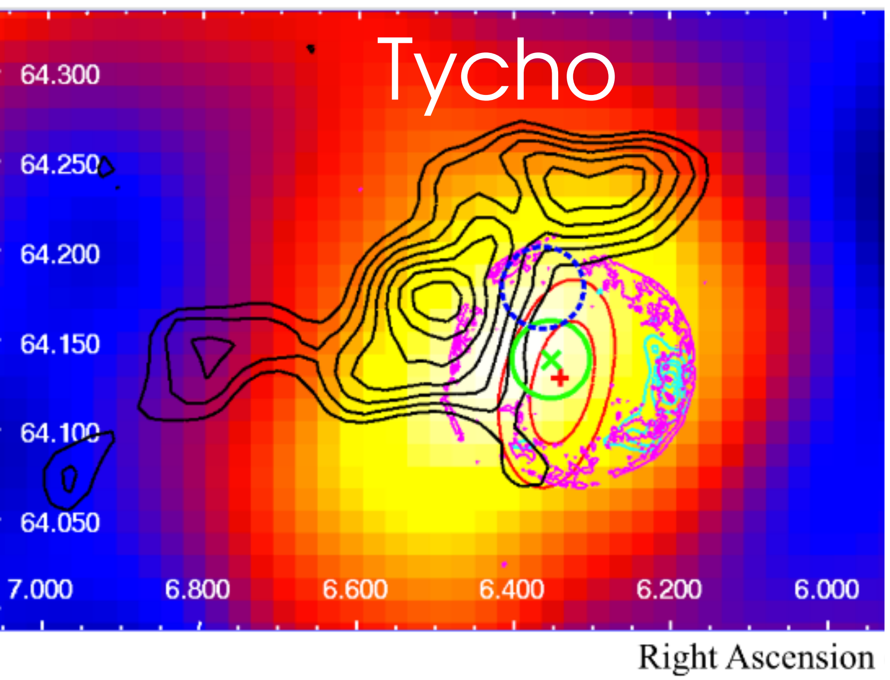
Acceleration and feedback

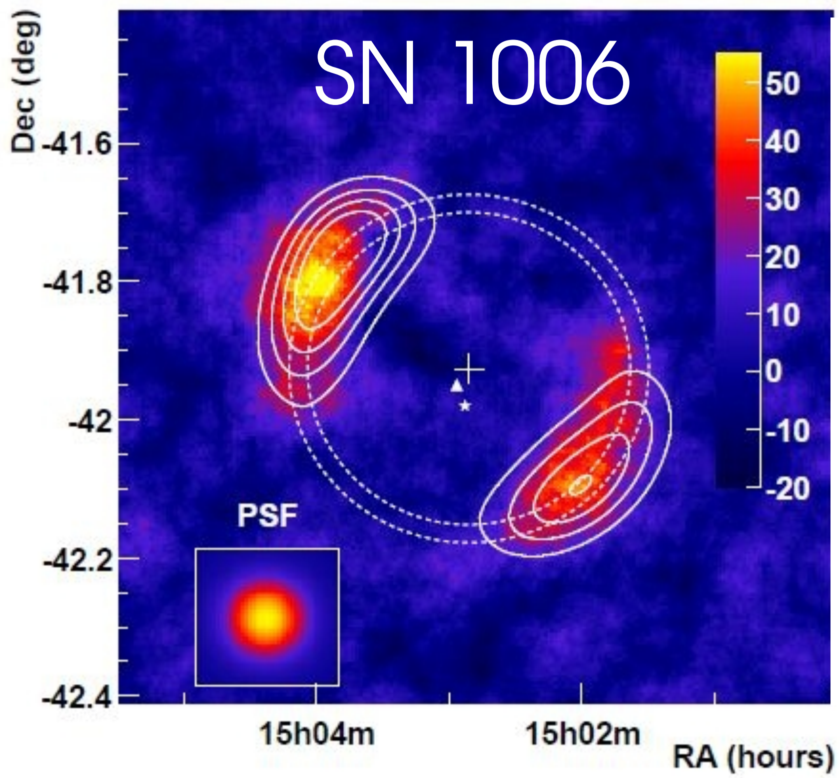


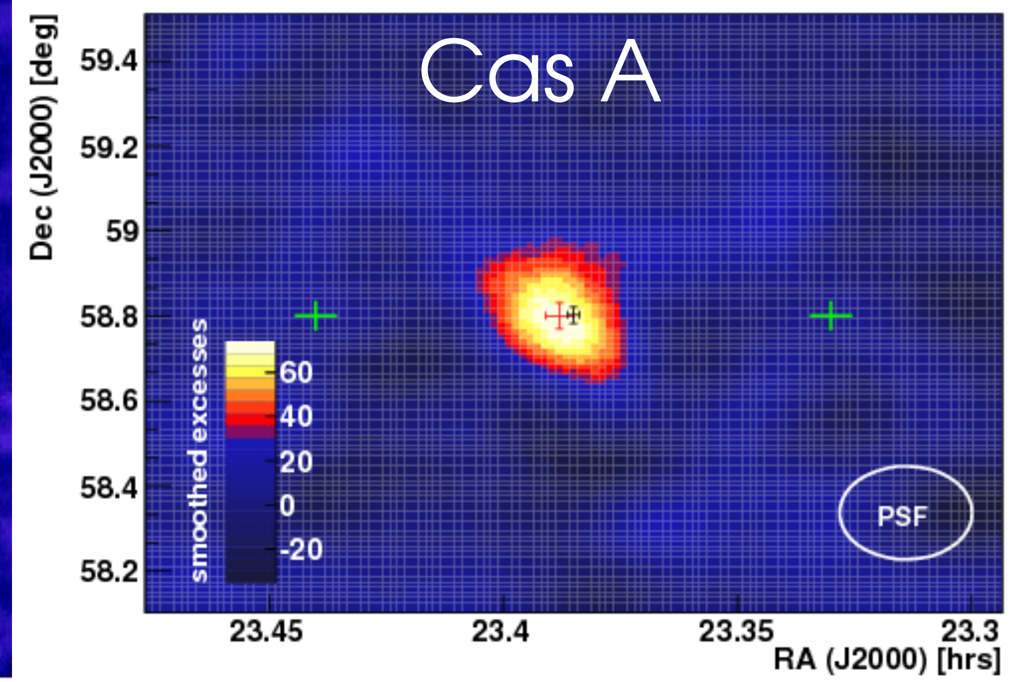
Accelerators:

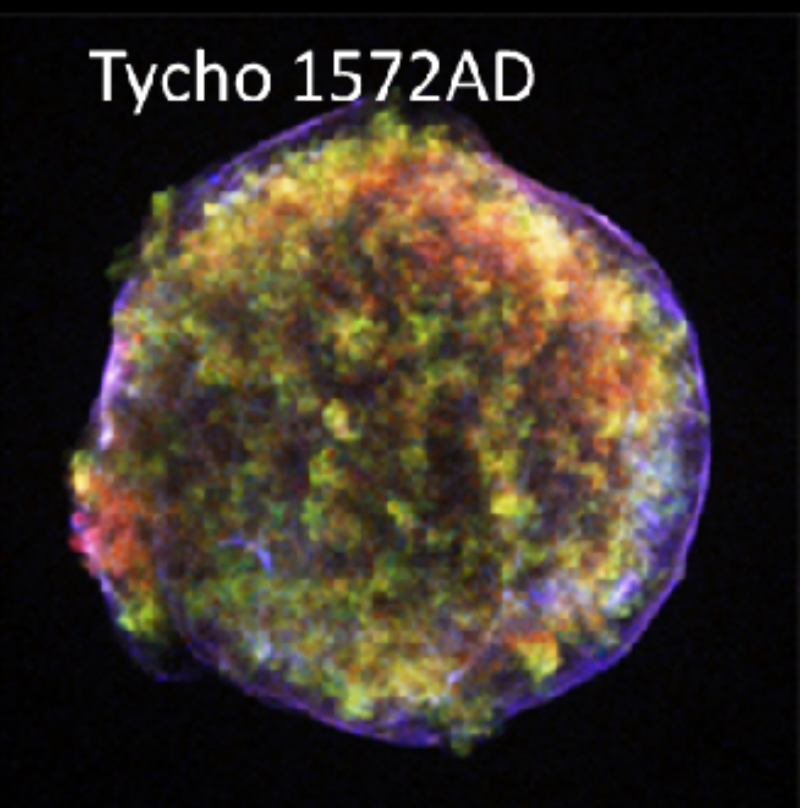
1 SNRs
2 Wind collisions in OB regions
3 ....

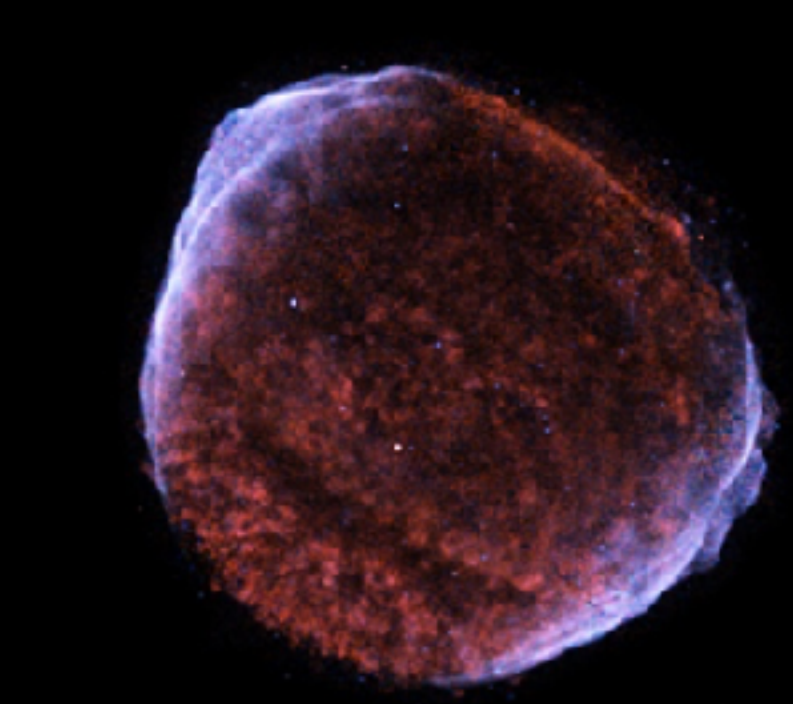
Shell-like SNR



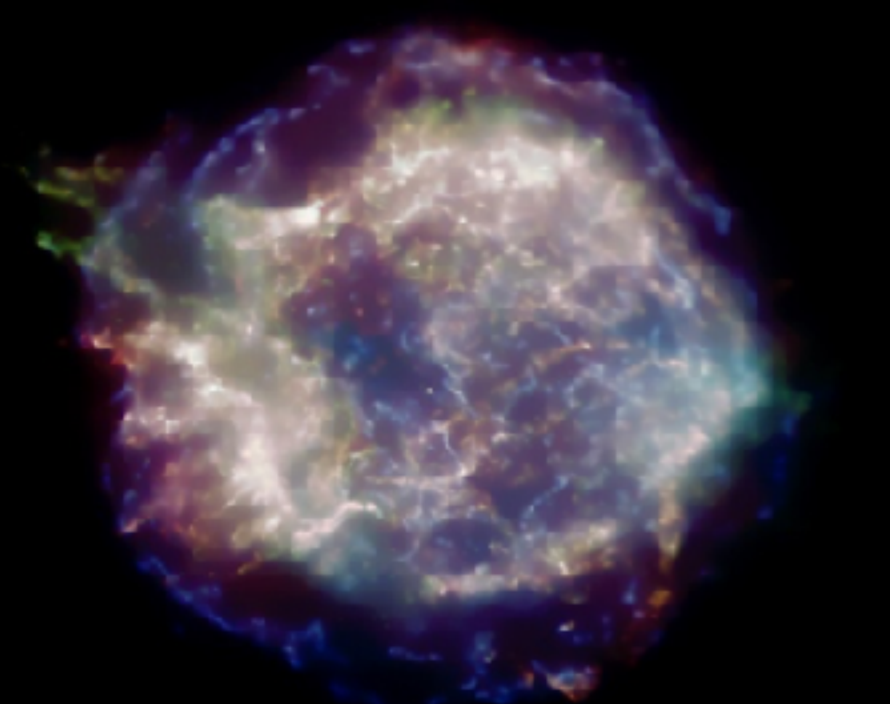






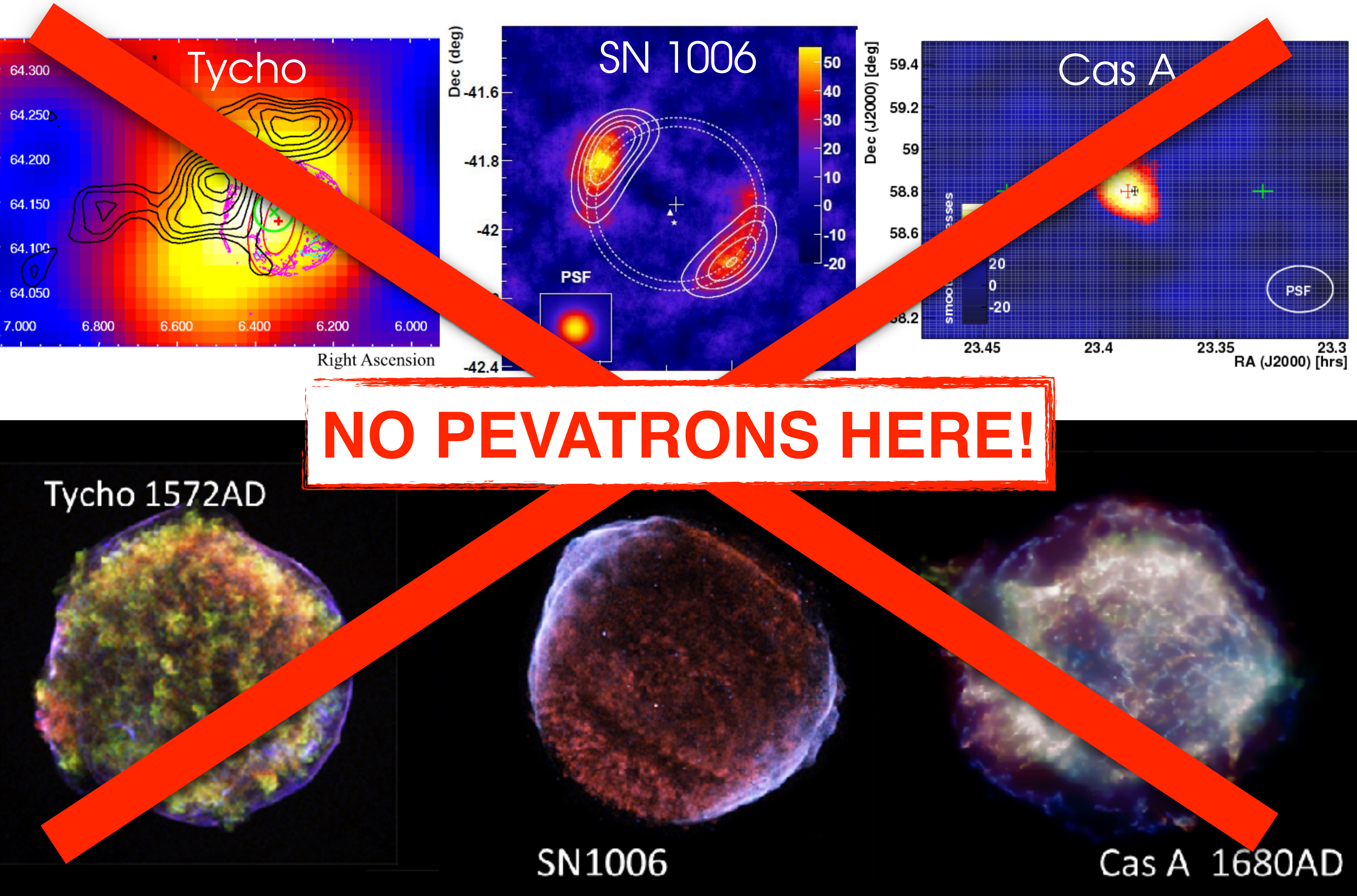


SN1006

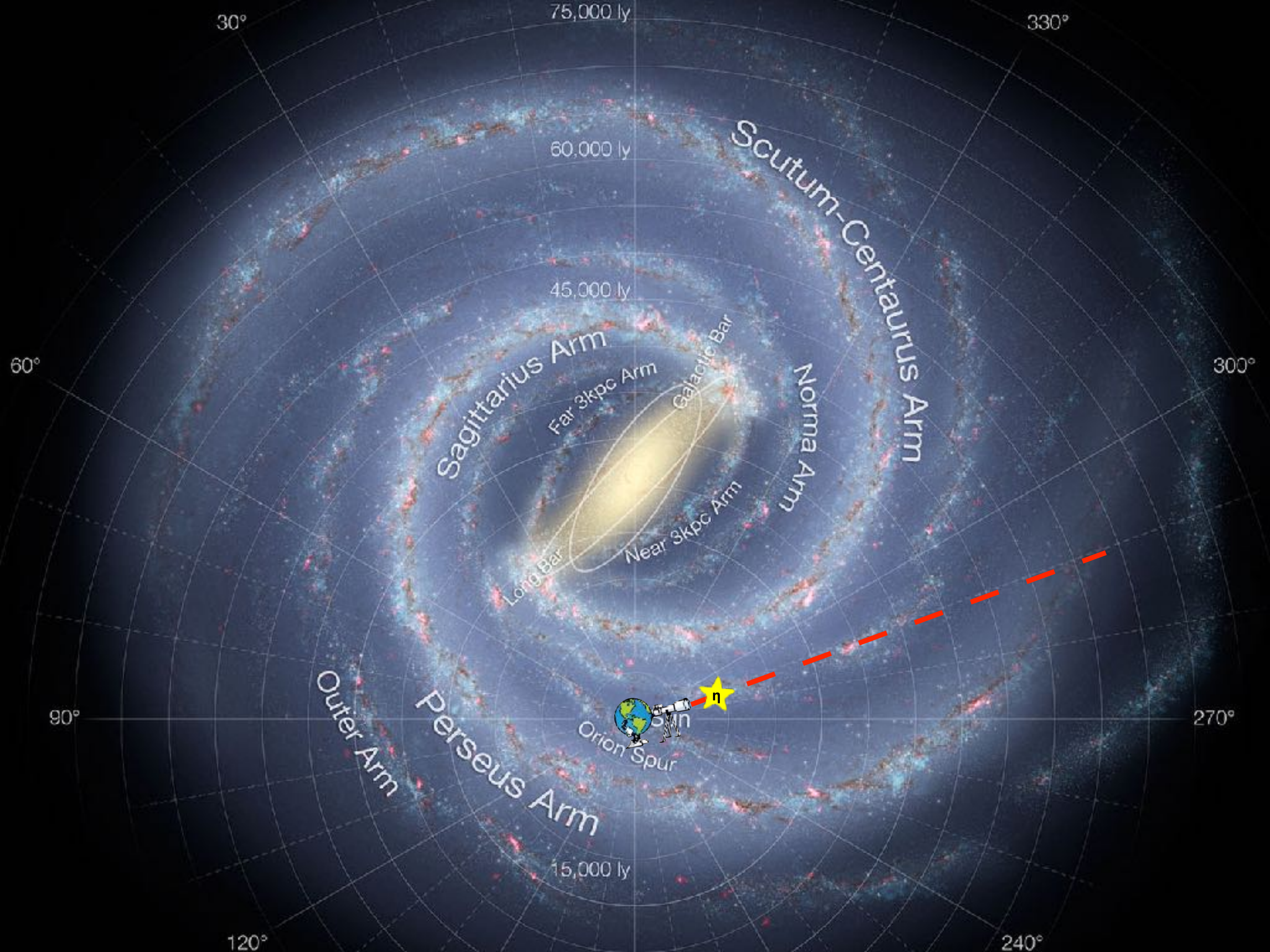


Cas A 1680AD

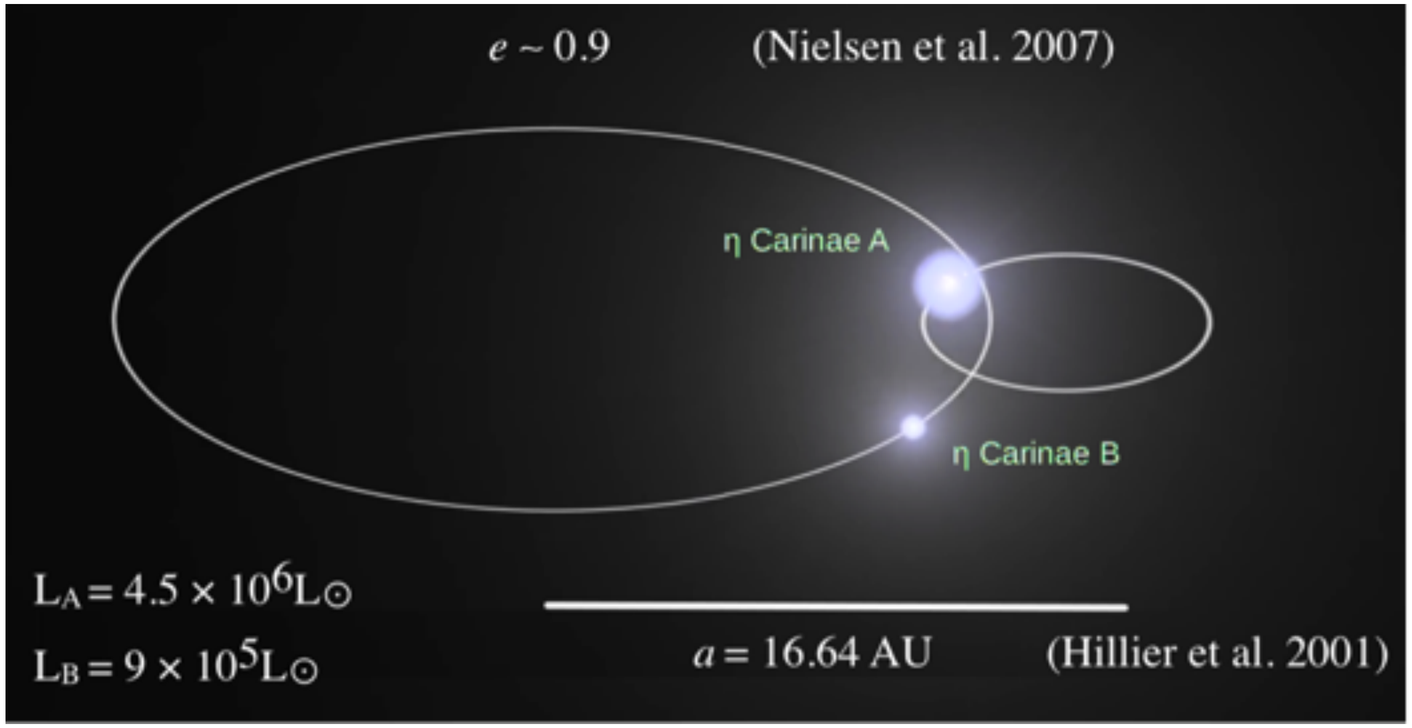
Shell-like SNR

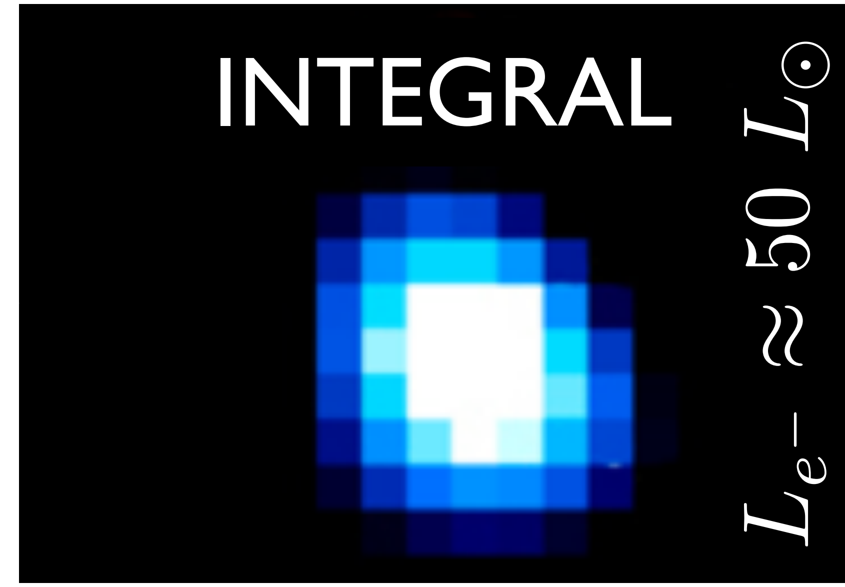


NO PEVATRONS HERE!


75,000 ly
30°
330°
60,000 ly
Scutum-Centaurus Arm
45,000 ly
Galactic Bar
Sagittarius Arm
Far 3kpc Arm
Norma Arm
60°
300°
Near 3kpc Arm
Long Bar
Outer Arm
Perseus Arm
η
Orion Spur
90°
270°
15,000 ly
120°
240°

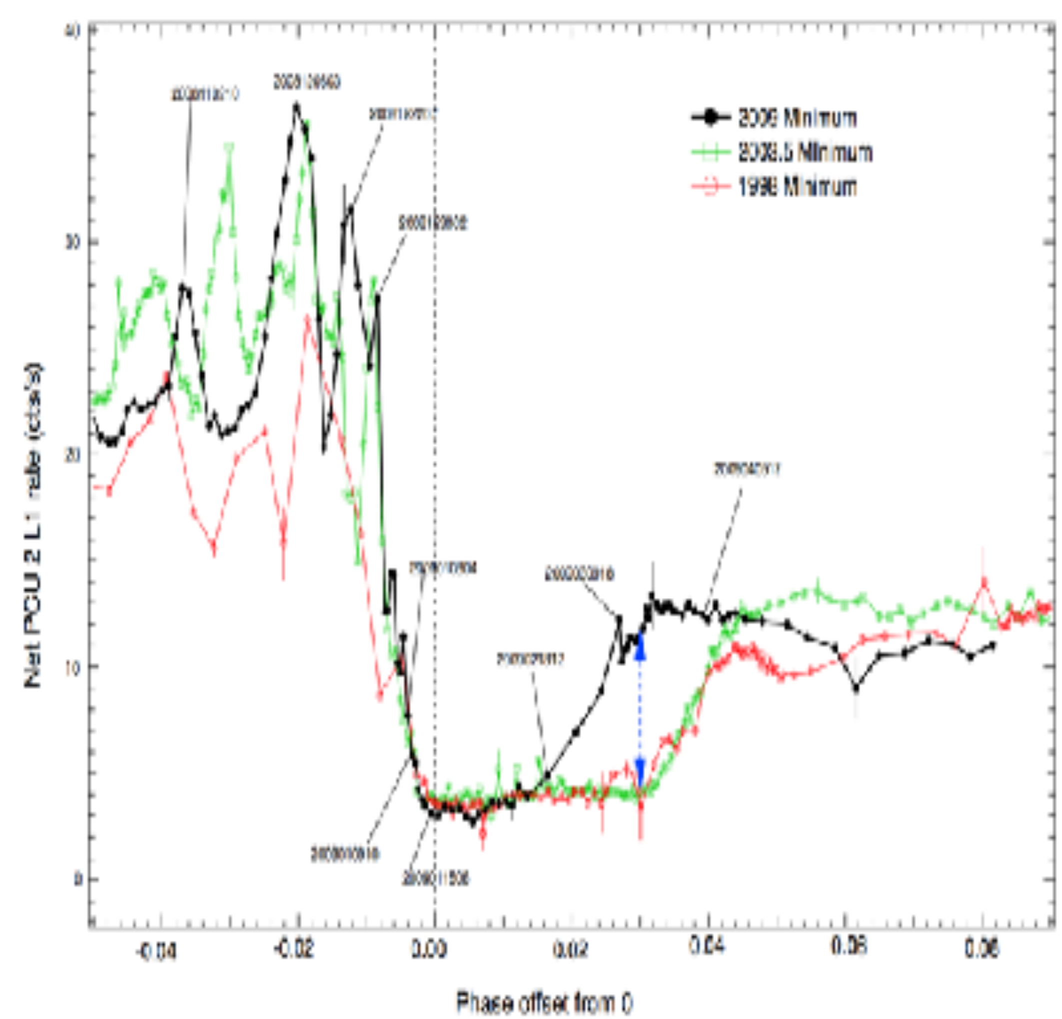
Who is ηCar?



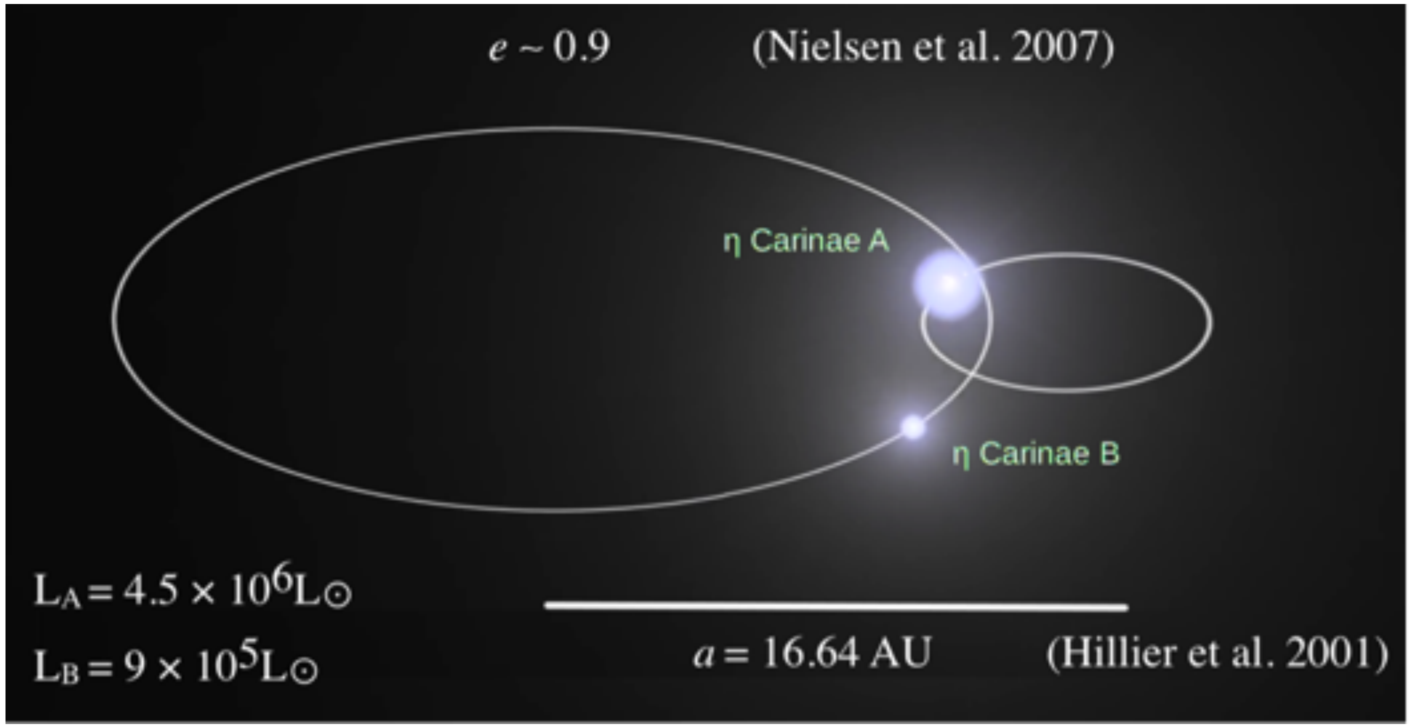


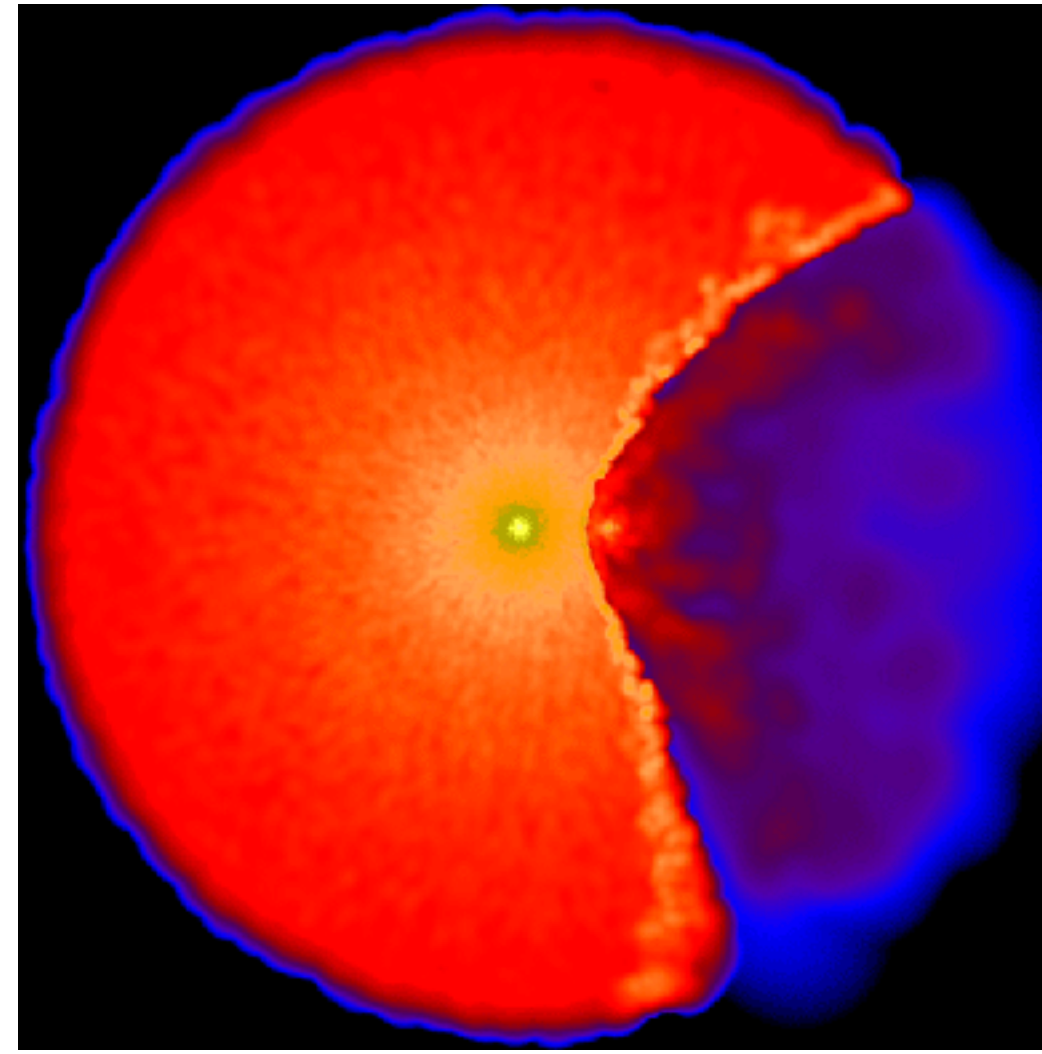
(Walter at al., 2008, 2010)

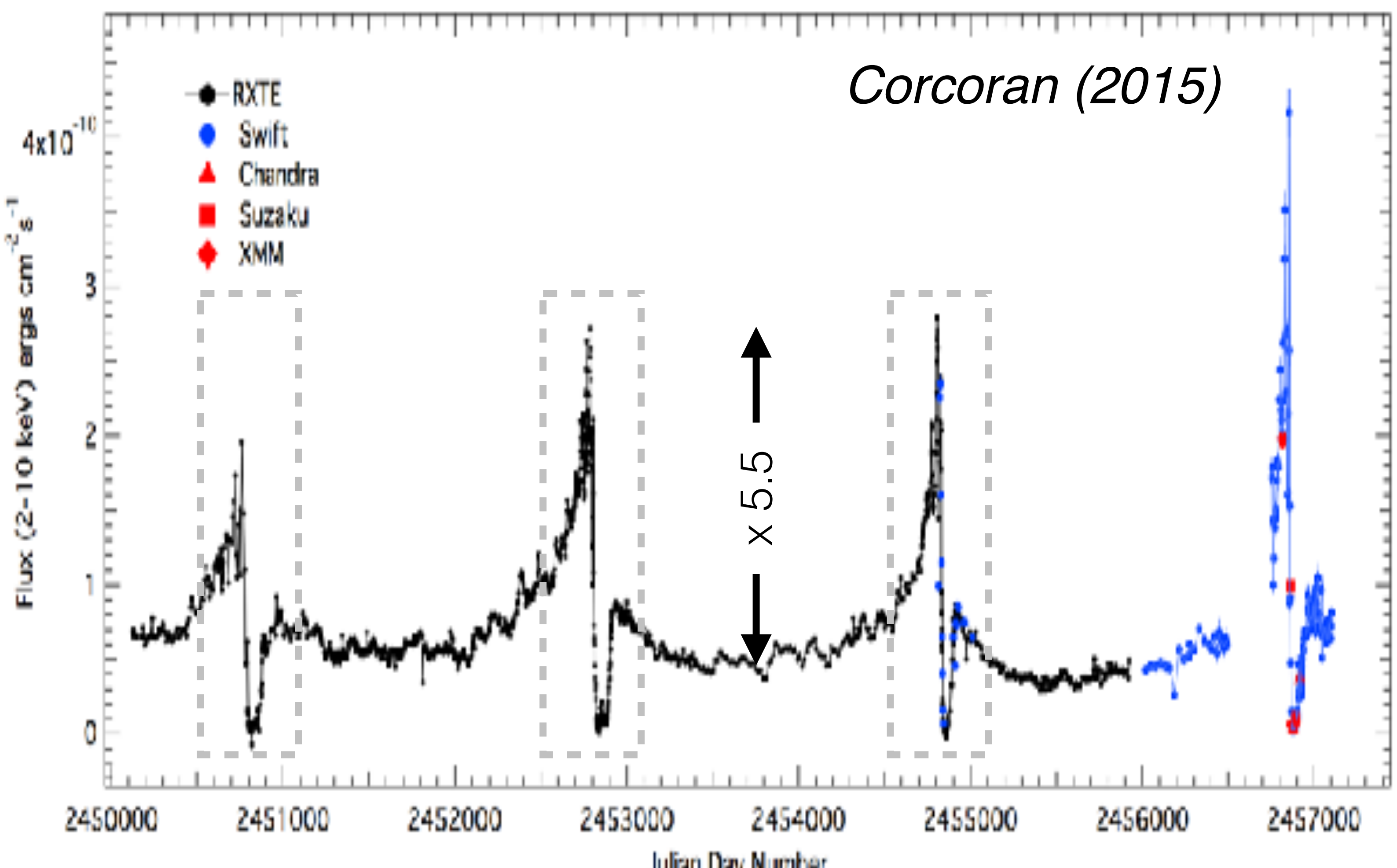
Parameter	Value	Reference
d	2.3±0.1 kpc	Davidson & Humphreys (1997)
P	2024±2 d	Corcoran et al. (2005)
i	45°	Okazaki et al. (2008)
e	0.9	Smith et al. (2004)
Φ	27°	Okazaki et al. (2008)
	0-30°	Parkin et al. (2009)
a	15.4 AU	Corcoran (2001)
M_A	90 $M_\odot$	Hillier et al. (2001)
M_B	30 $M_\odot$	Verner et al. (2005)
$\dot{M}_A$	$10^{-3}\ M_\odot yr^{-1}$	Hillier et al. (2001)
	$2.5 \times 10^{-4}\ M_\odot yr^{-1}$	Pittard & Corcoran (2002)
$\dot{M}_B$	$10^{-5}\ M_\odot yr^{-1}$	Pittard & Corcoran (2002)
	$1.5 \times 10^{-5}\ M_\odot yr^{-1}$	Parkin et al. (2009)
$V_{\infty,A}$	500 kms^{-1}	Hillier et al. (2001)
$V_{\infty,B}$	3000 kms^{-1}	Pittard & Corcoran (2002)

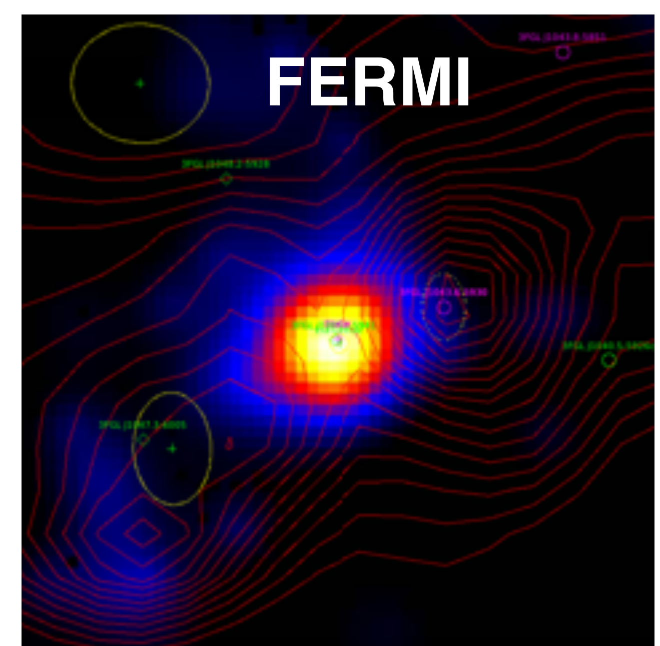


Who is ηCar?



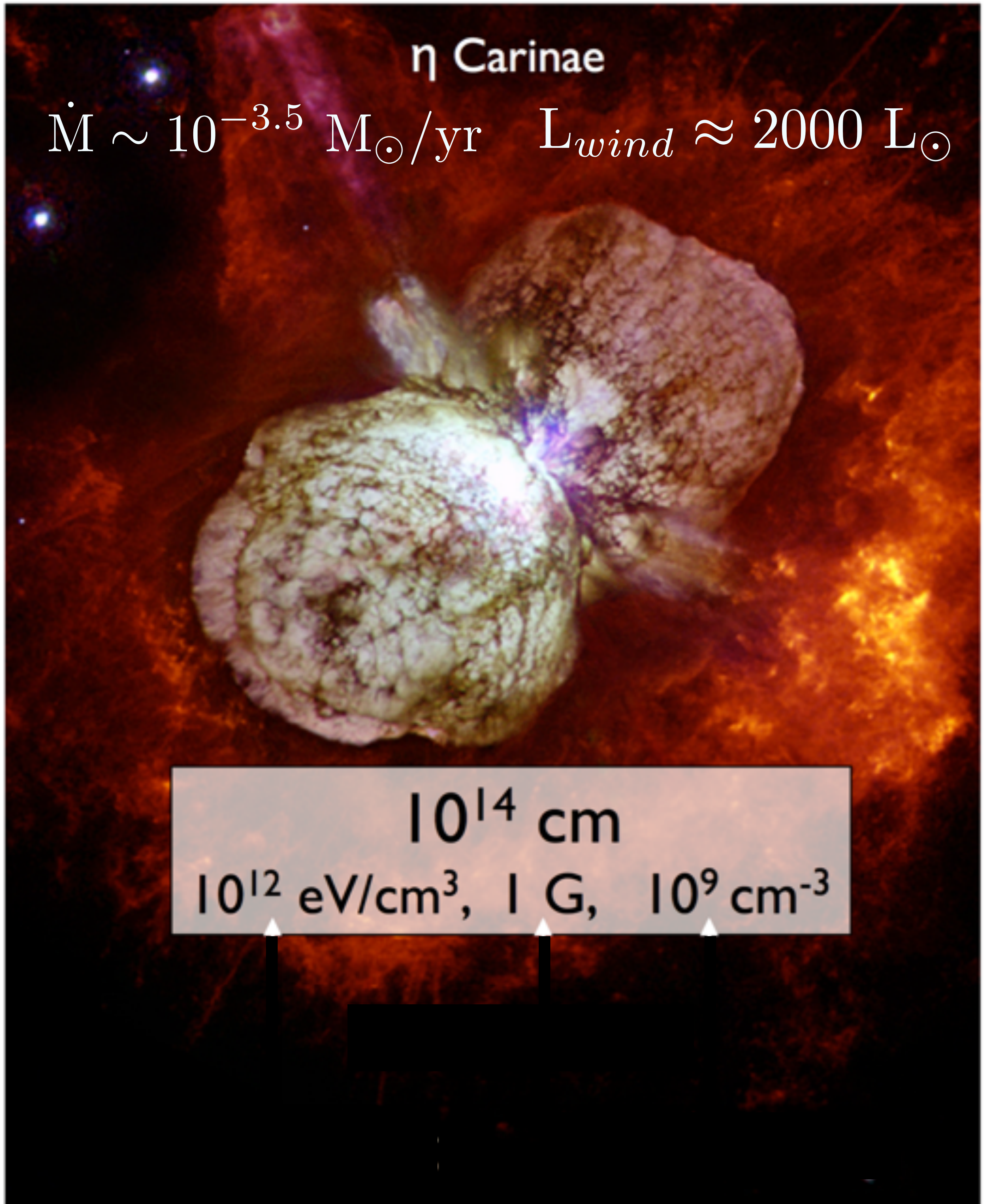


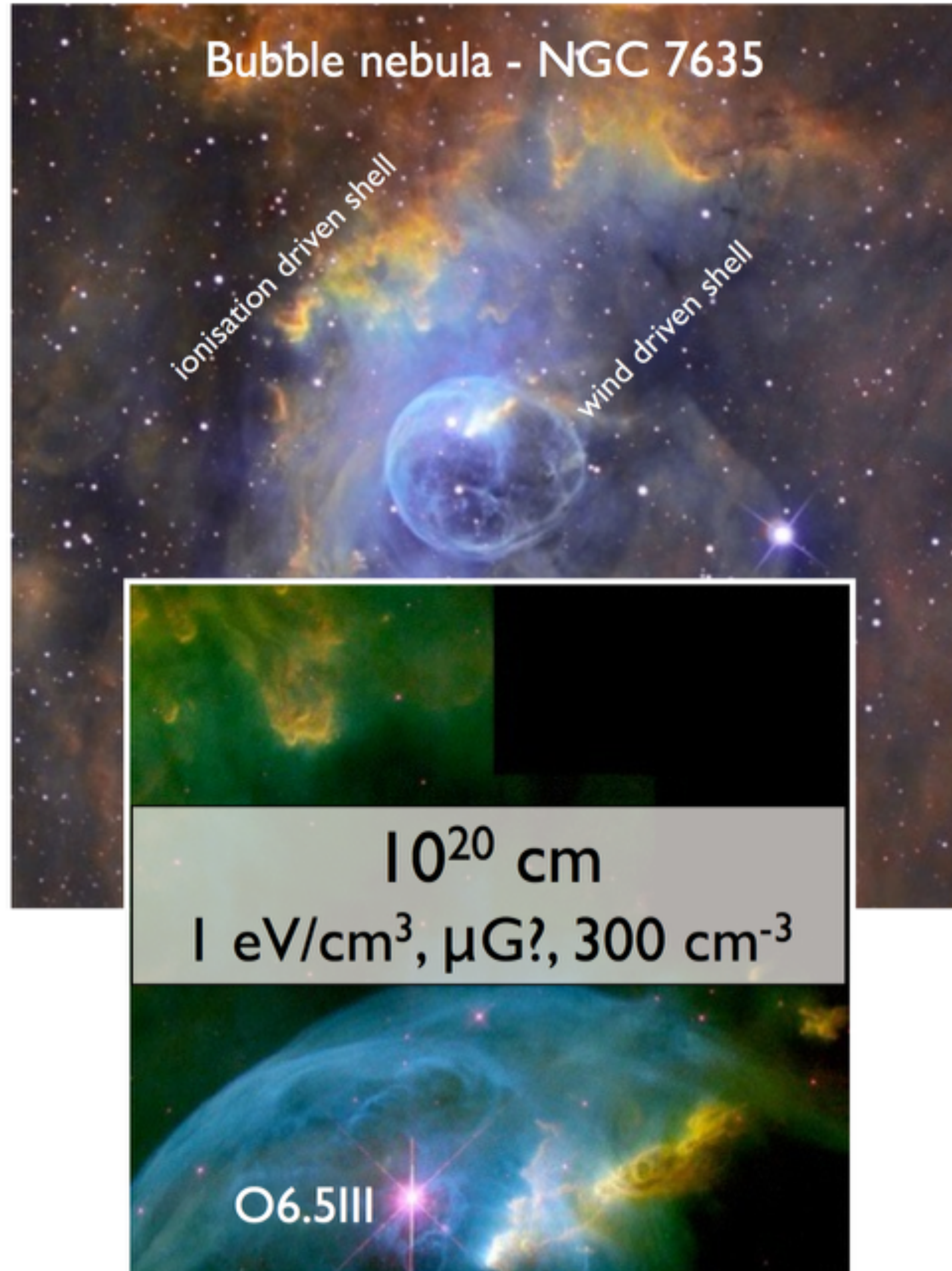




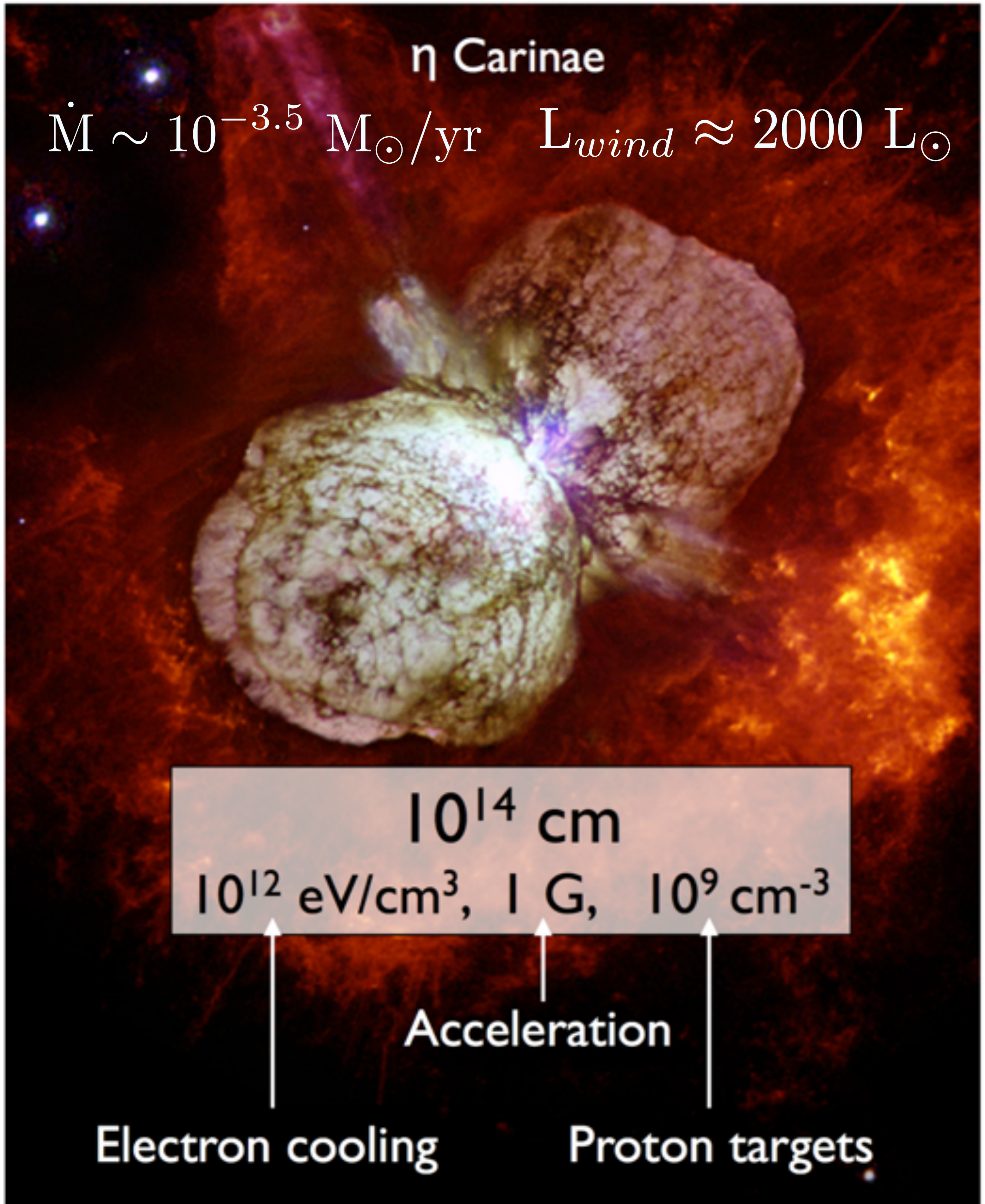
$L_{\pi^0} \simeq 10\, L_\odot$

Particle acceleration





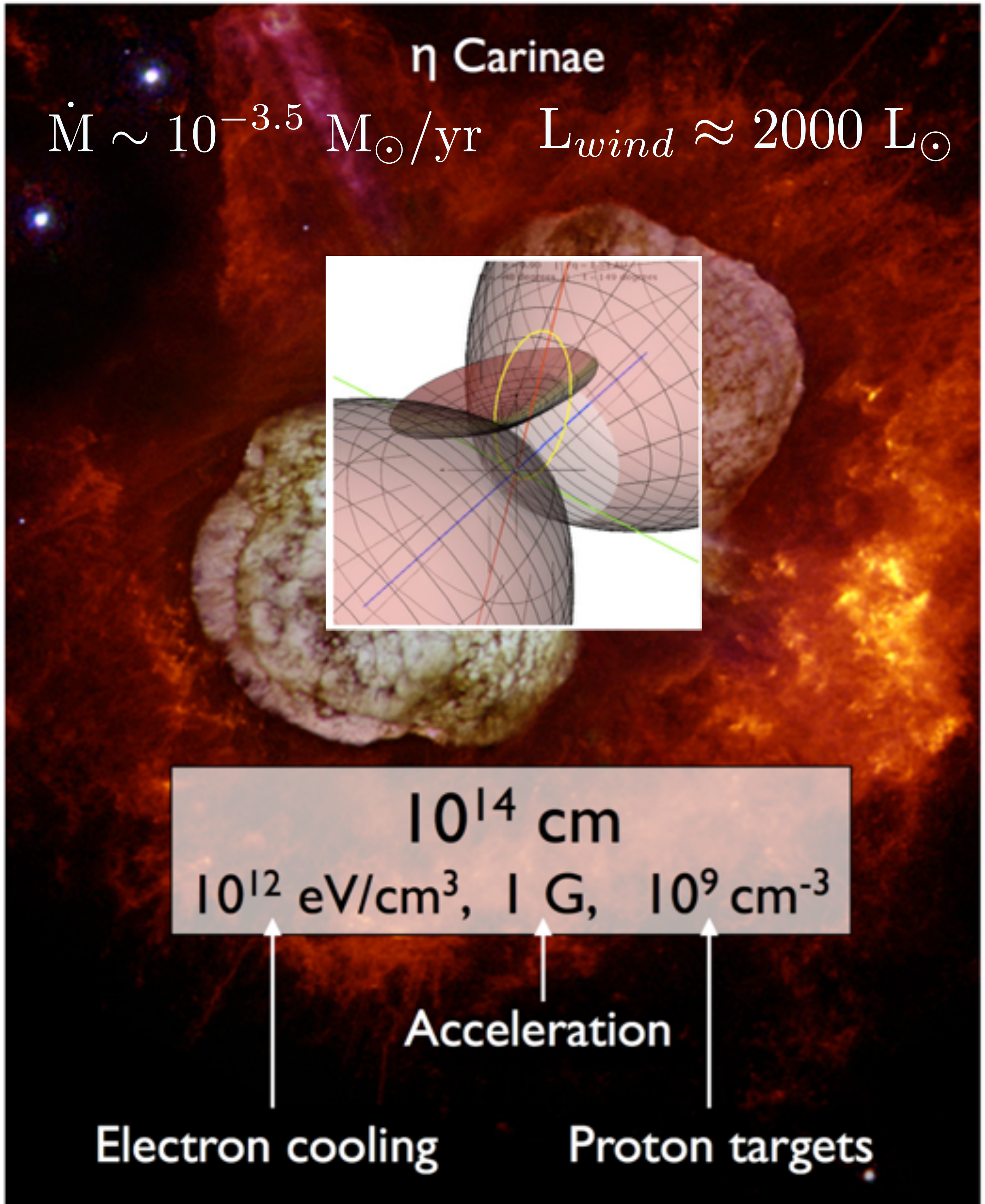
Particle acceleration



Colliding Wind Binaries are predicted to be potential sites of HE γ-ray emission through strong shocks due to colliding winds

Eichler & Usov (1993) ApJ 402, 271

Particle acceleration



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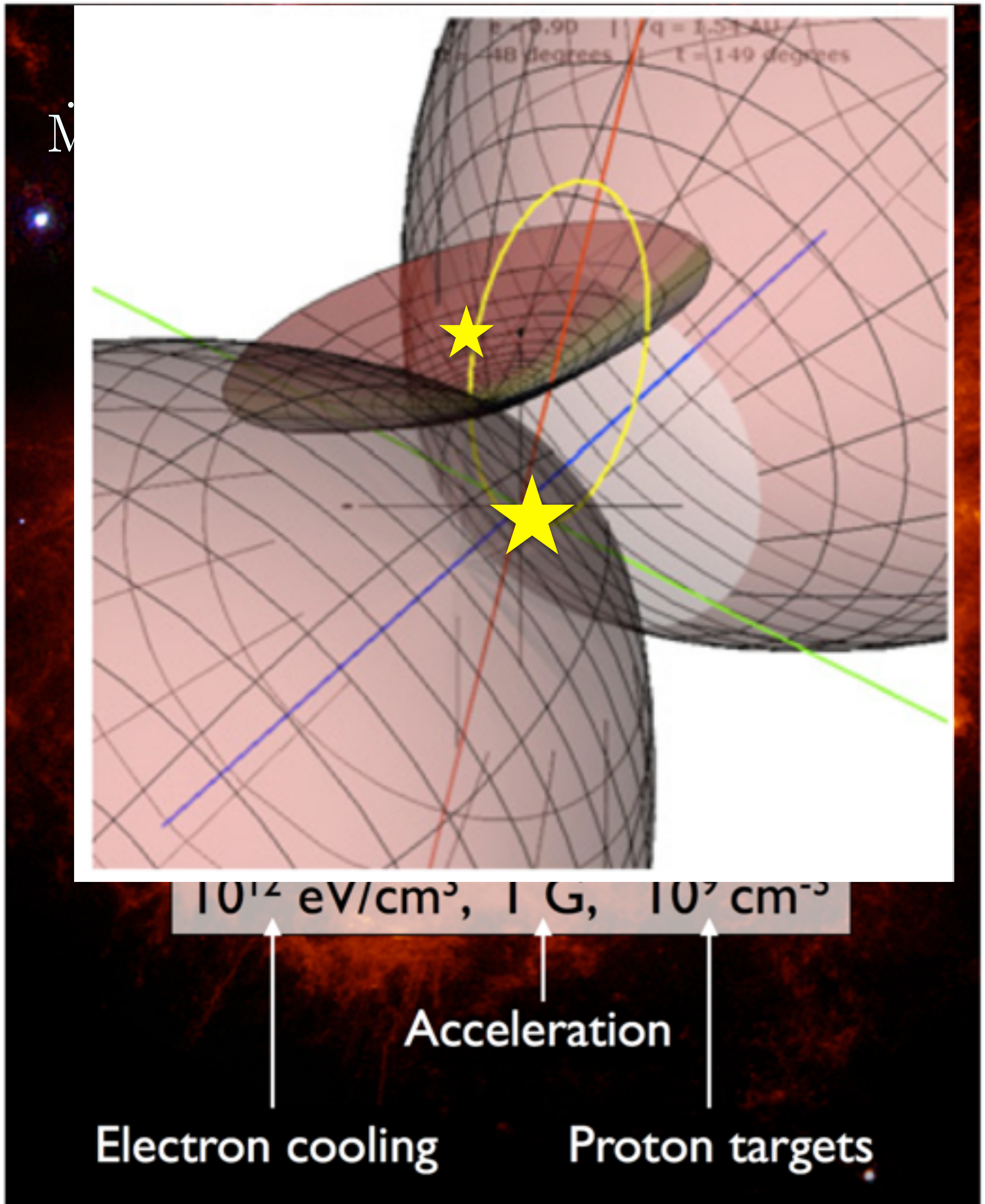
Particle acceleration



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Eichler & Usov (1993) ApJ 402, 271

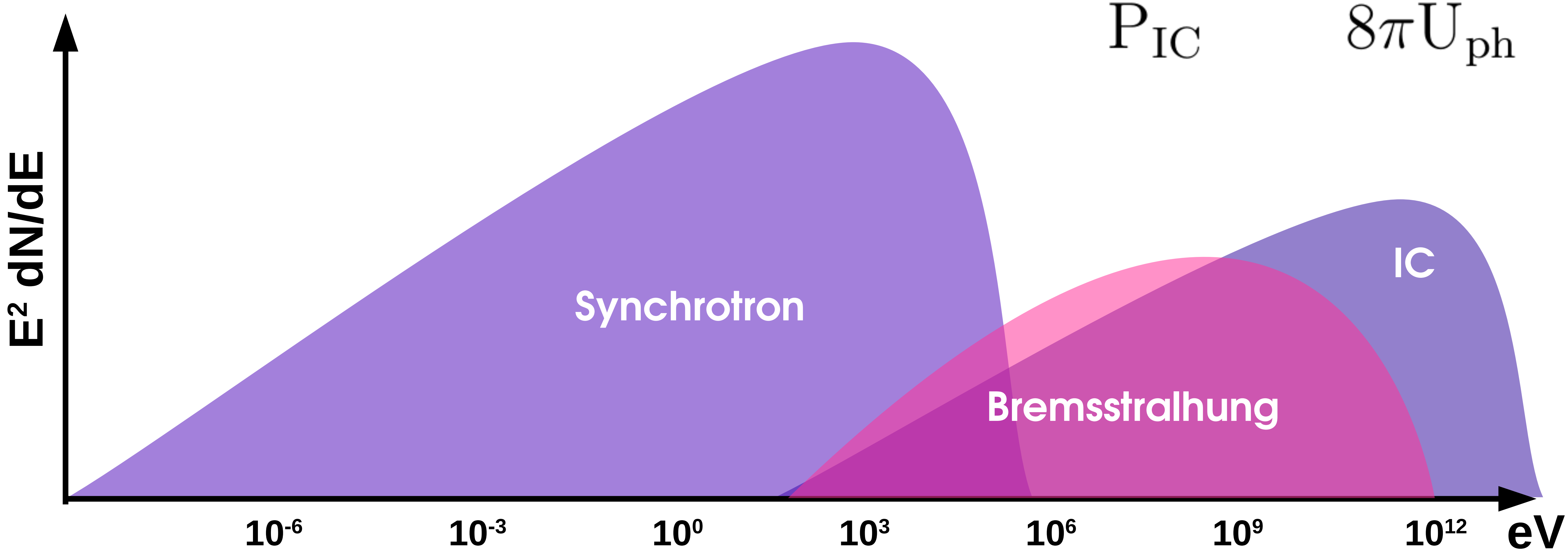
Physical processes

Produced by ultra-relativistic charged particles

Leptons:

- Inverse Compton on ambient radiation field
- Bremsstrahlung (surrounding material)

$$\frac{P_{\rm sync}}{P_{\rm IC}} = \frac{B^2}{8\pi U_{\rm ph}}$$



Physical processes

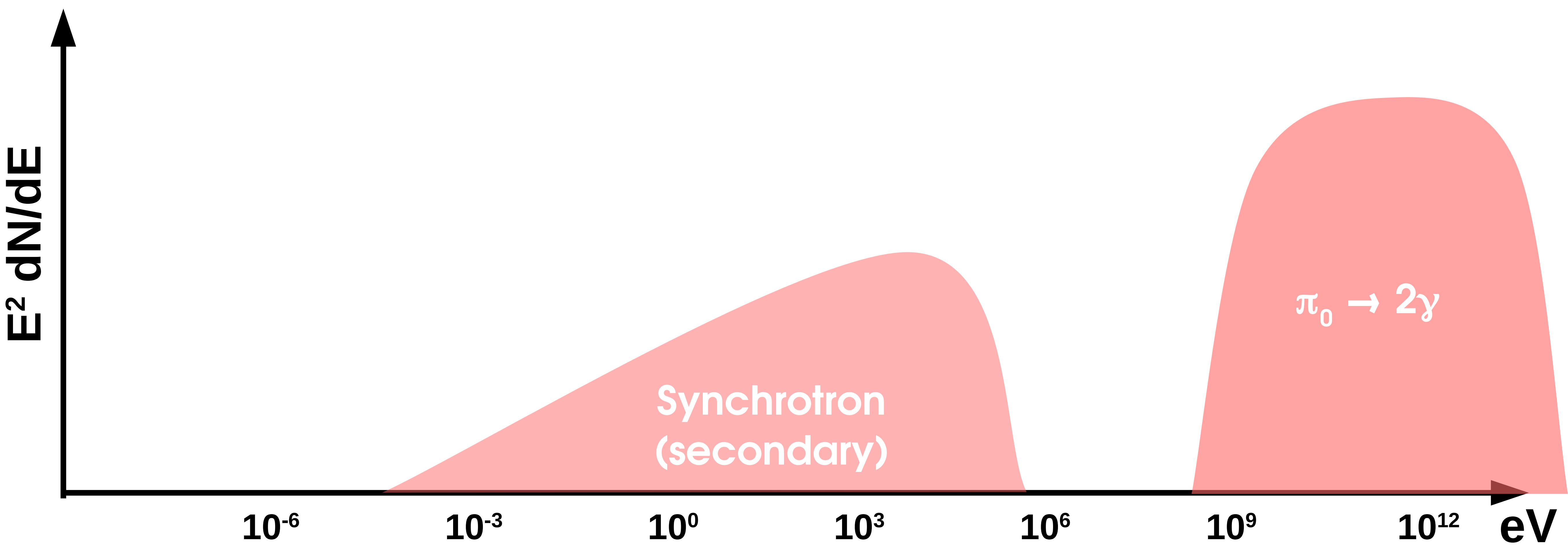
Produced by ultra-relativistic charged particles

Leptons:

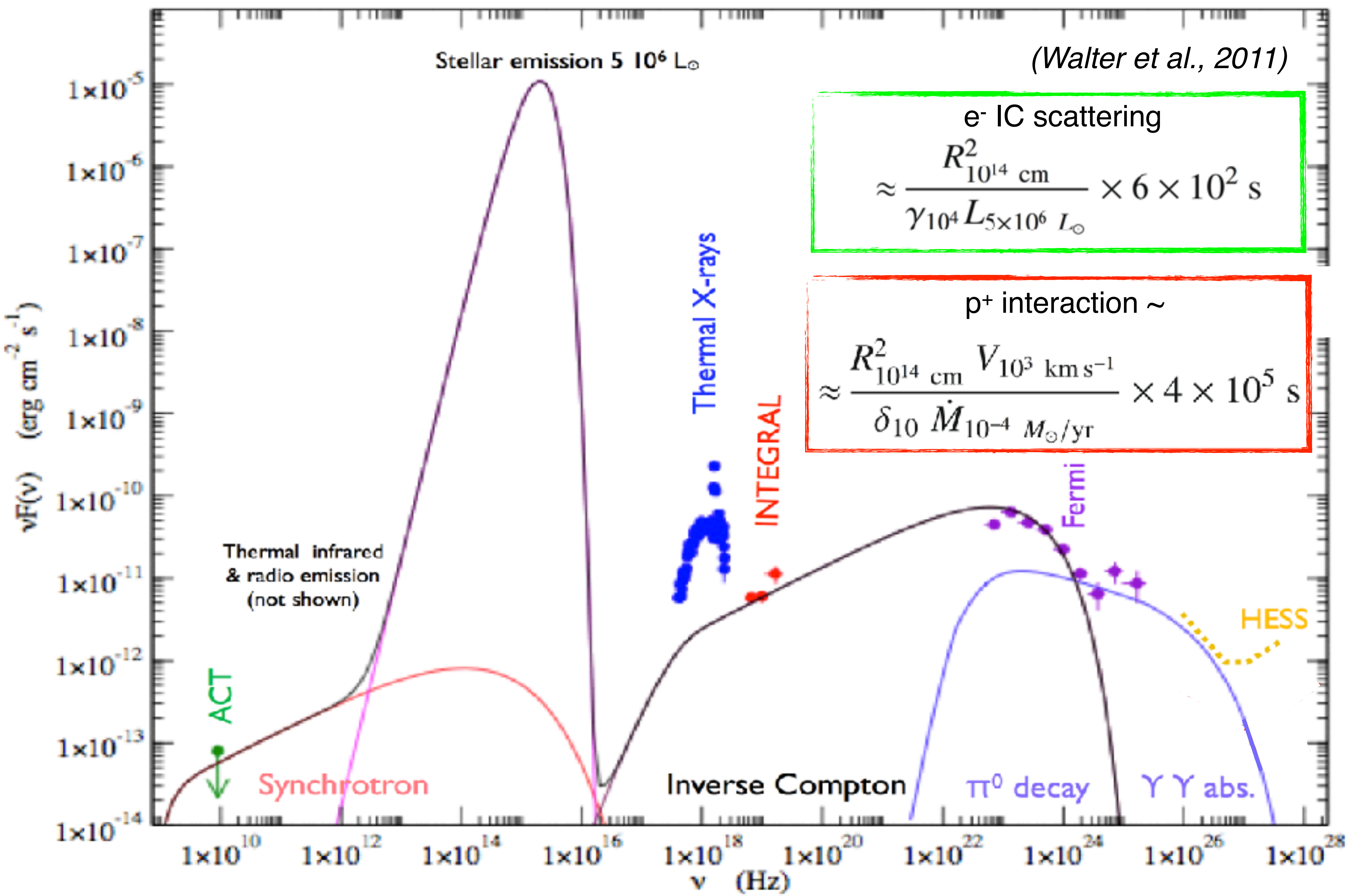
- Inverse Compton on ambient radiation field
- Bremsstrahlung (surrounding material)

Hadrons:

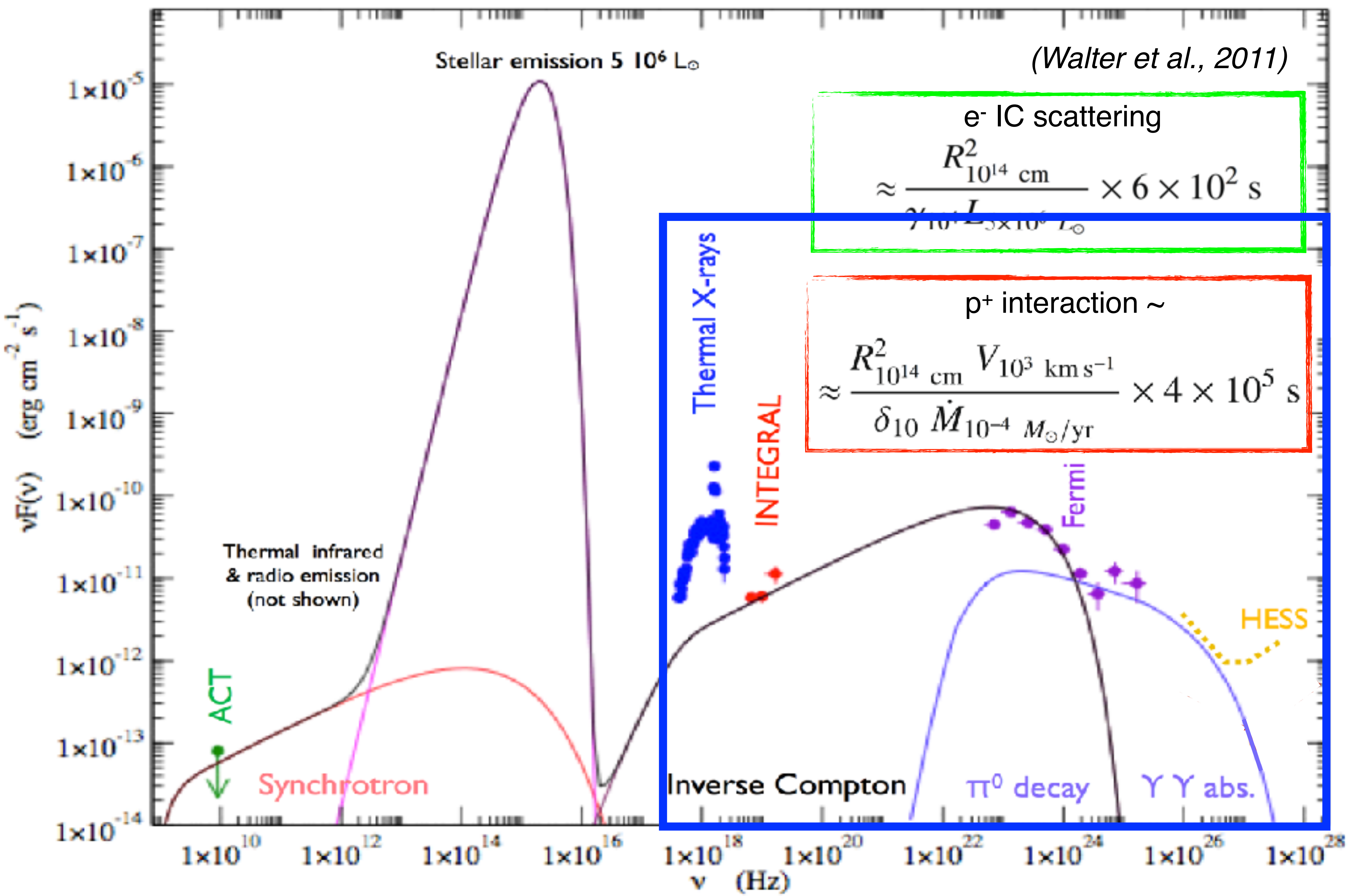
- neutral pion decay (surrounding material)
- Bremsstrahlung (surrounding material)



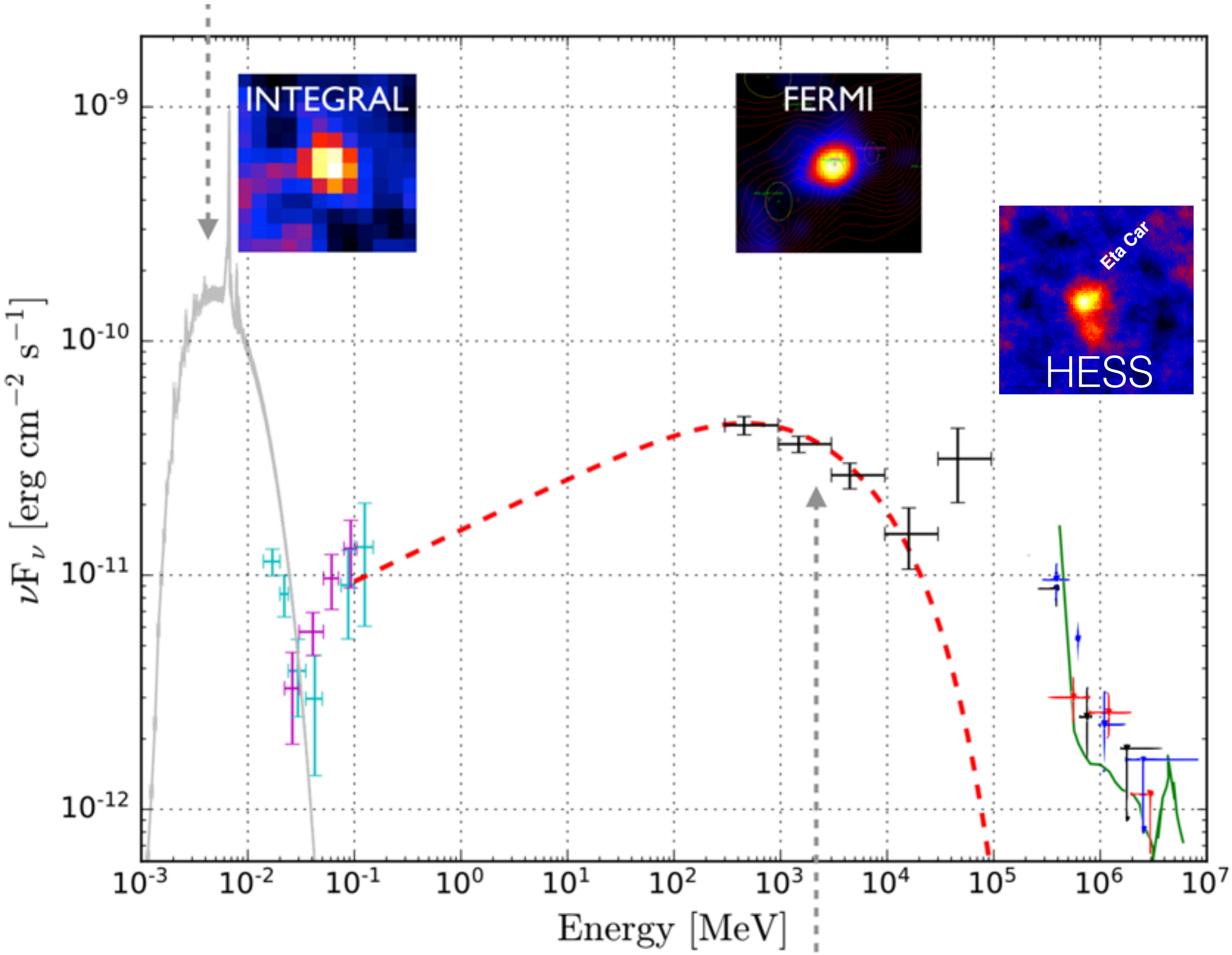
The physics behind ηCar



The physics behind ηCar



Spectral Energy Distribution



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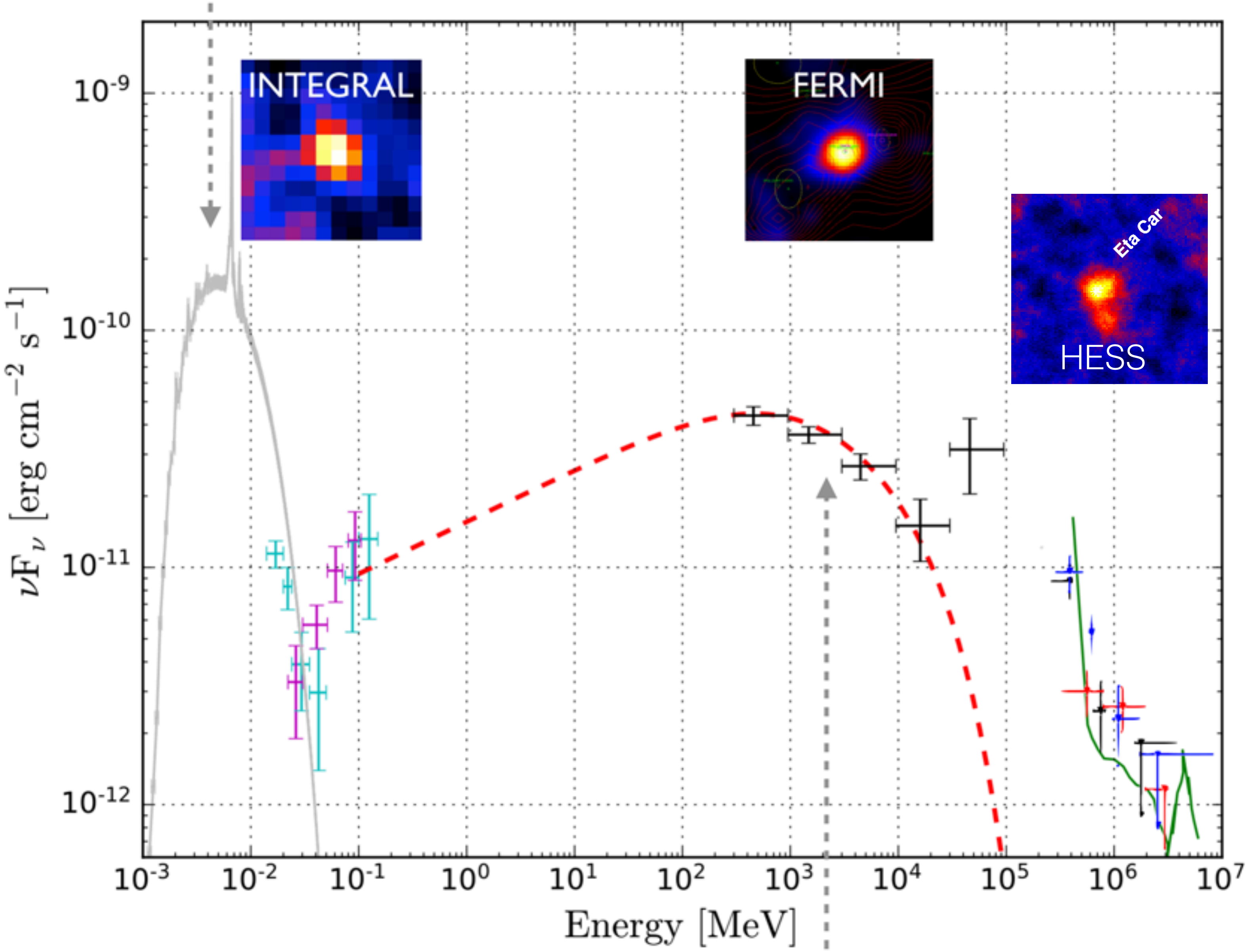
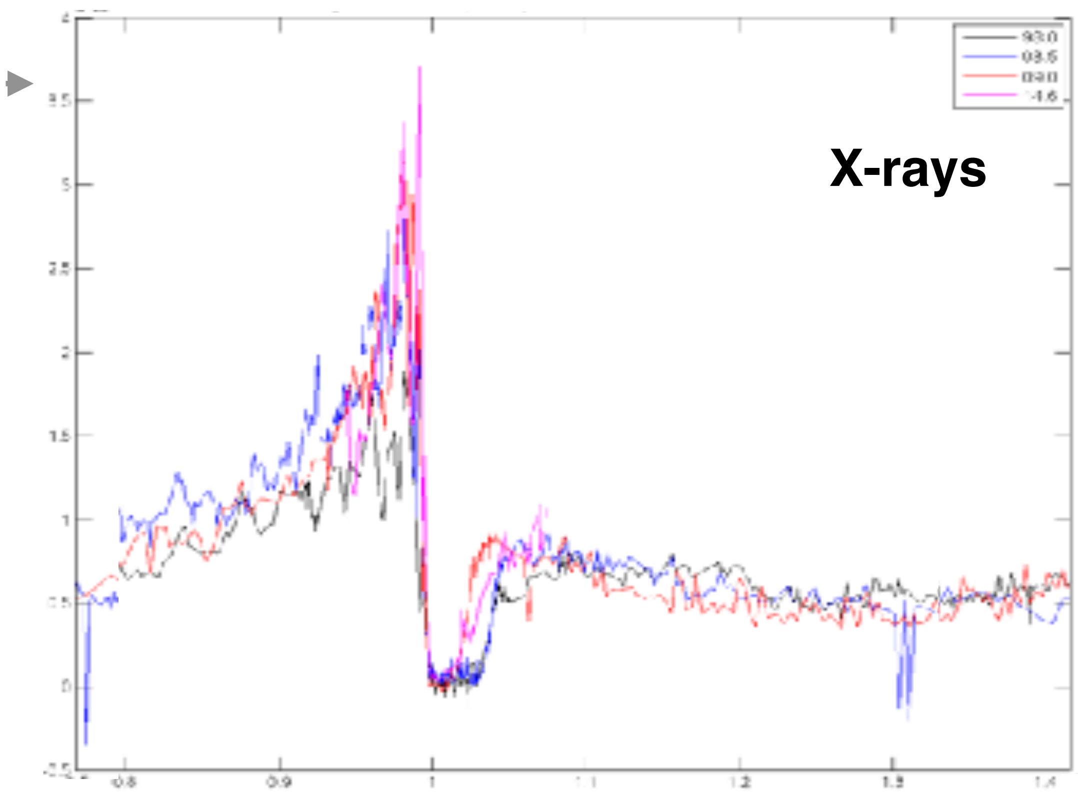
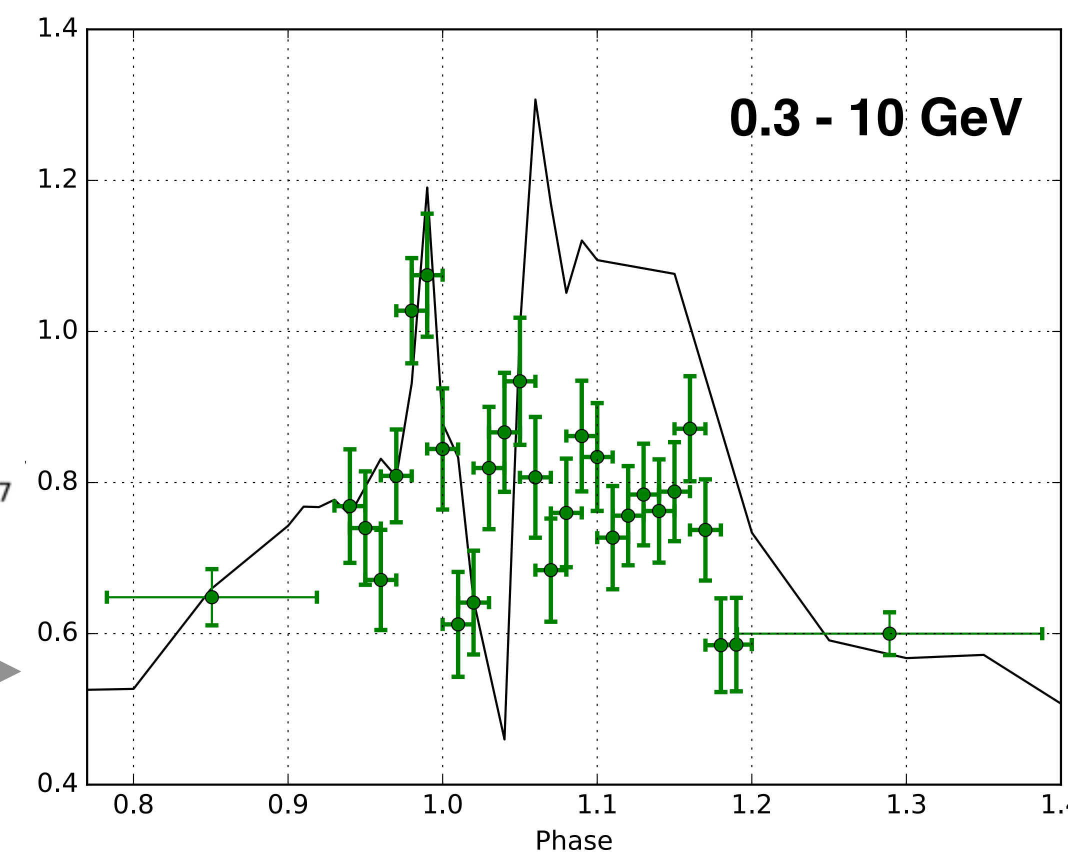
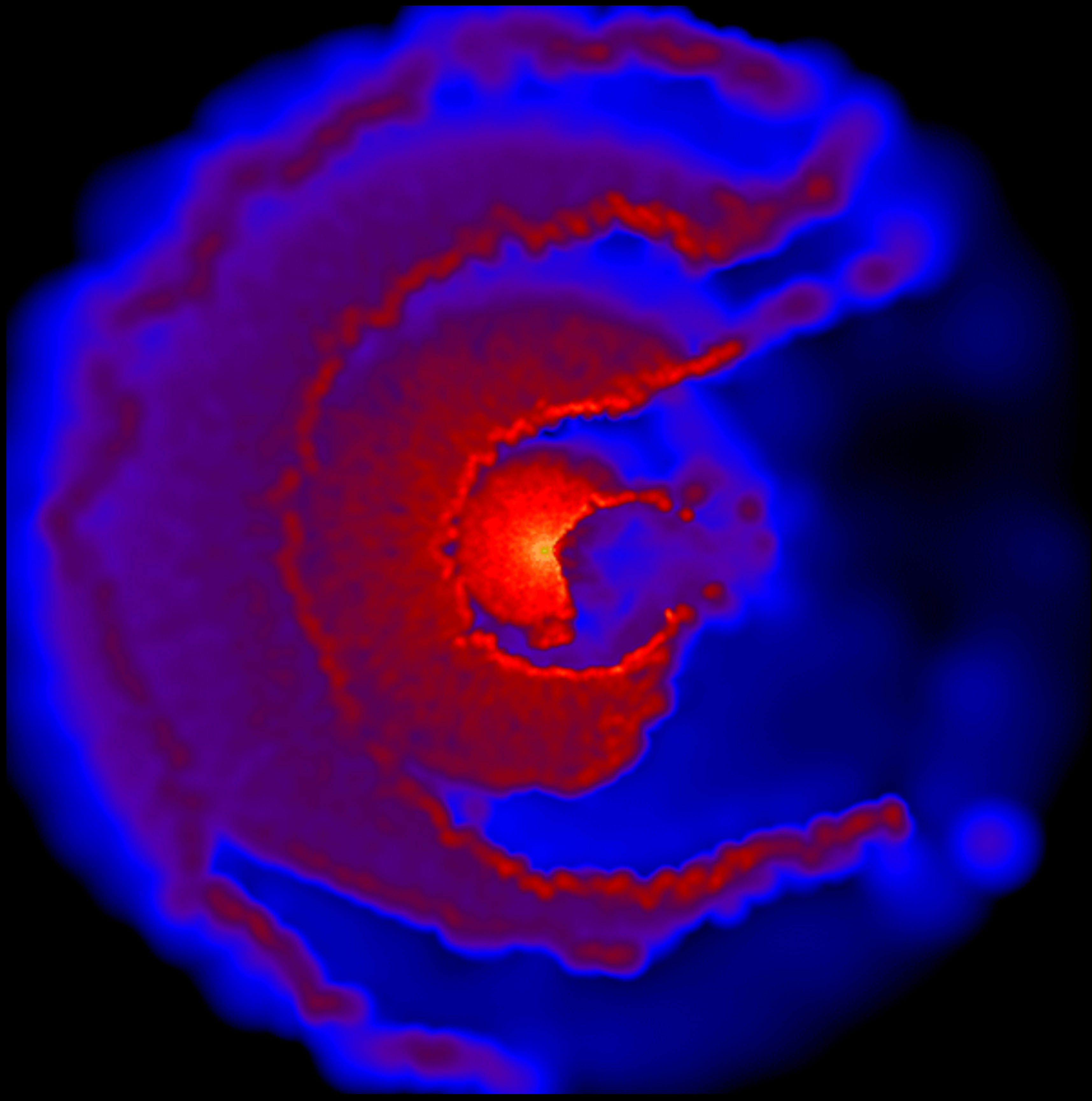






(MB and R. Walter, 2017 A&A)



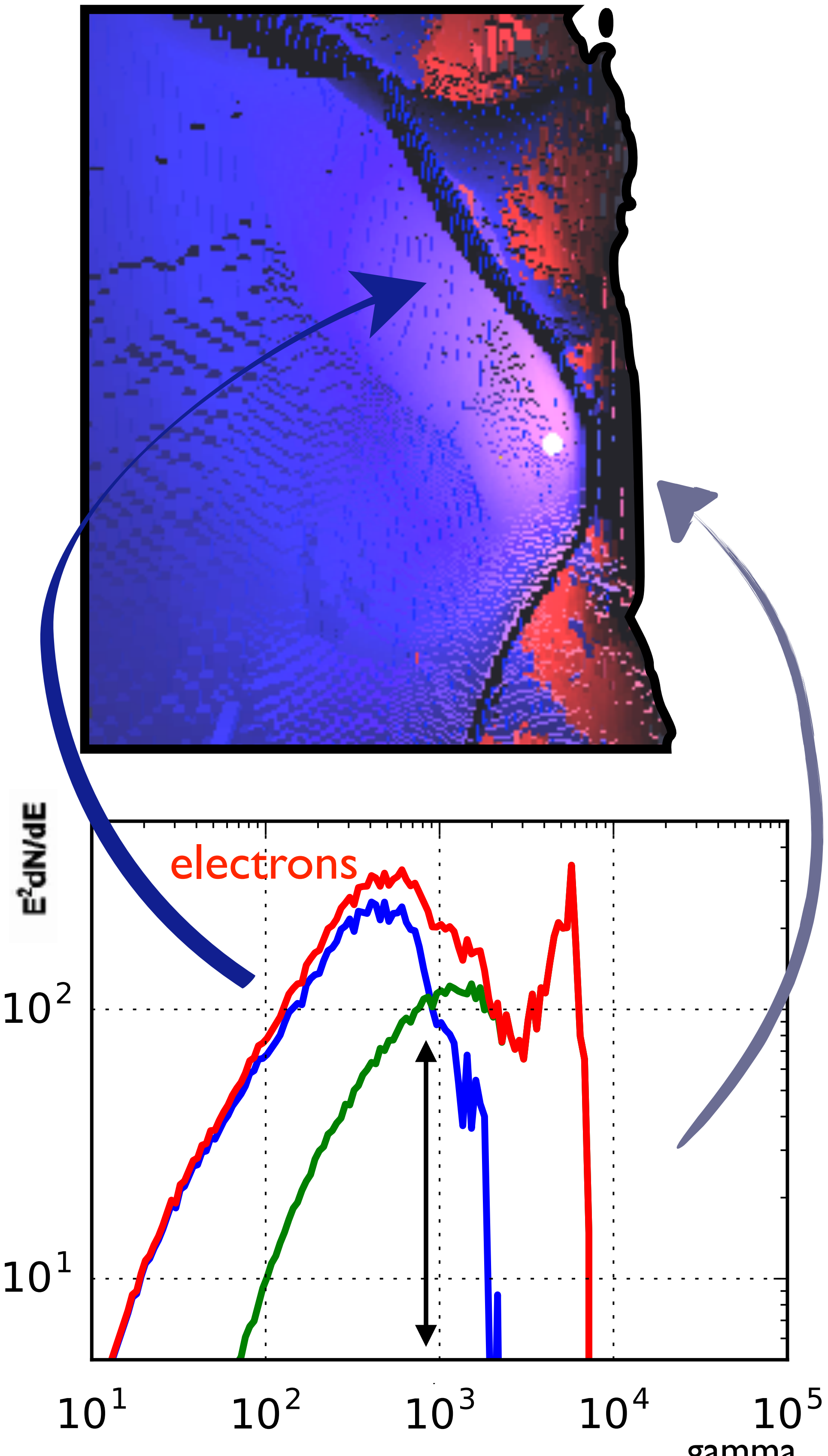
UNIVERSITÉ DE GENÈVE

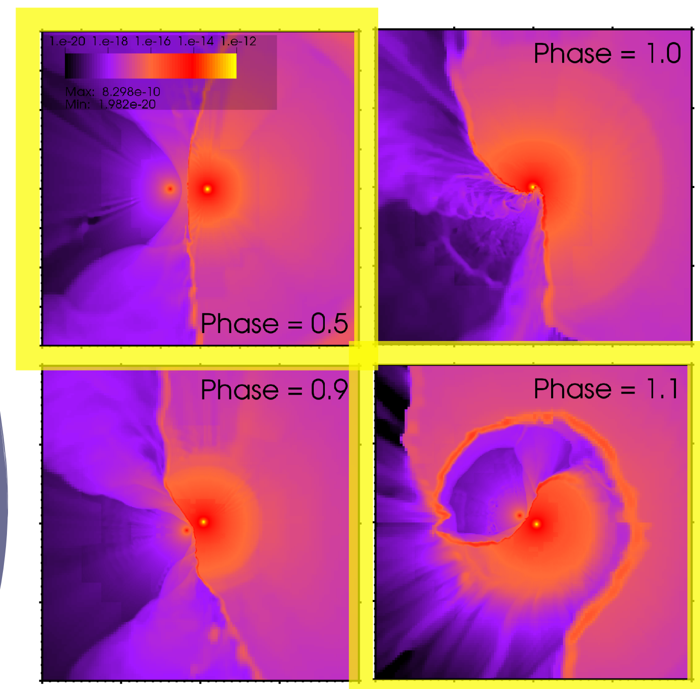
3D hydro simulations (Flash)

iSDC

(MB and R. Walter, 2017 A&A)

Parameter	Primary	Secondary
M ($M_\odot$)	120	30
R_* ($R_\odot$)	100	20
$T_{\rm eff}$ (K)	25,800	30,000
L_* ($10^6 L_\odot$)	4	0.3
k	0.30	0.50
α	0.52	0.68
$\dot{M}$ ($M_\odot\,{\rm yr}^{-1}$)	4.8×10^{-4}	1.4×10^{-5}
v_∞ (km s^{-1})	500	3000
B (G)	2000	

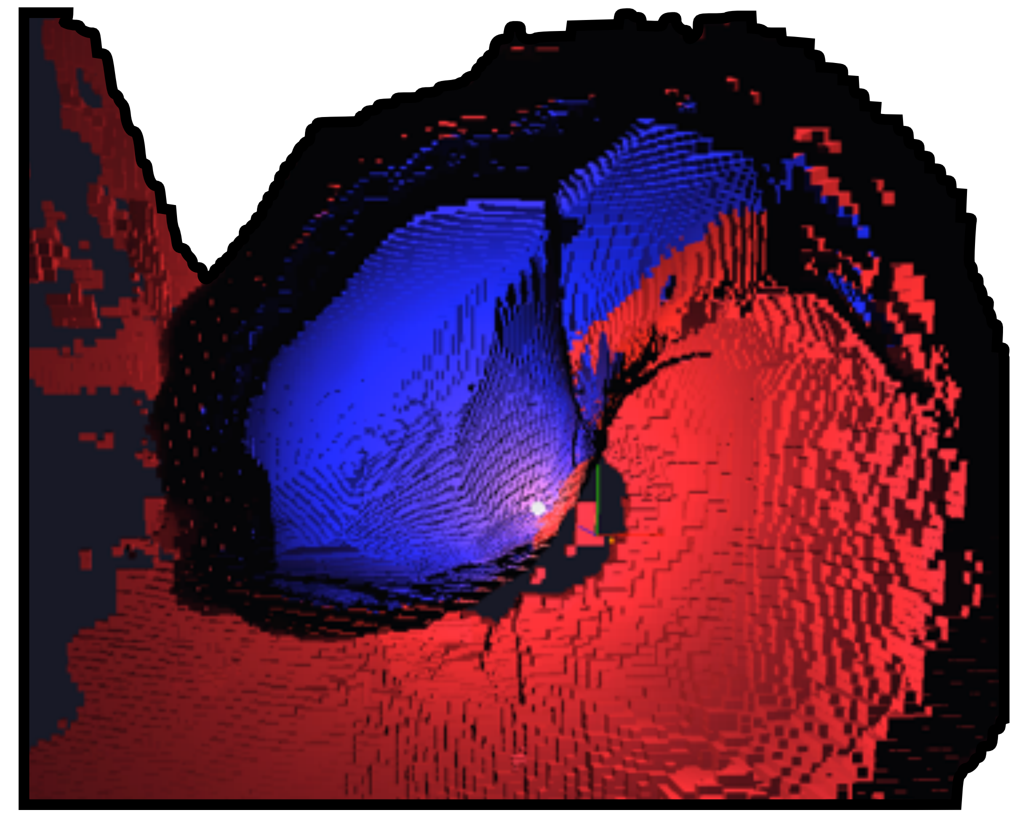


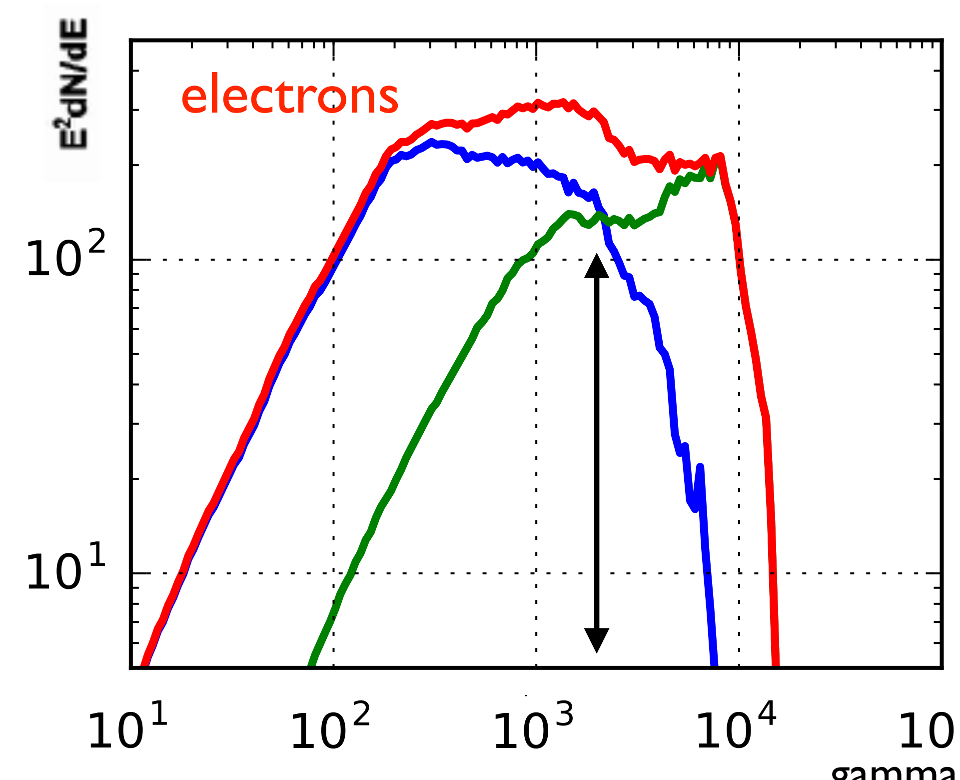


Parkin et al, 2011

e⁻ spectrum

smooth IC spectrum





UNIVERSITÉ DE GENÈVE

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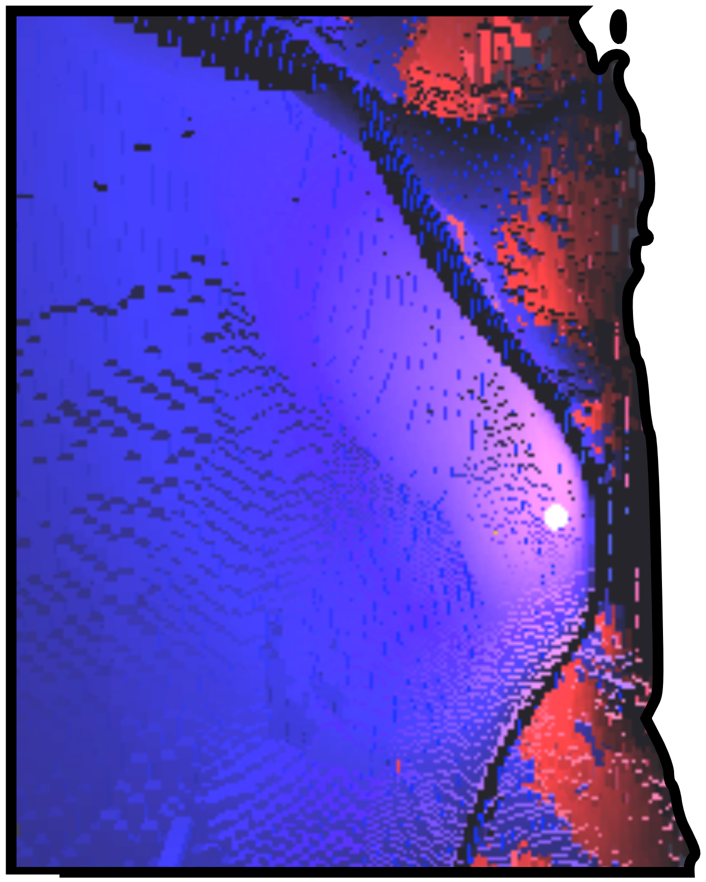

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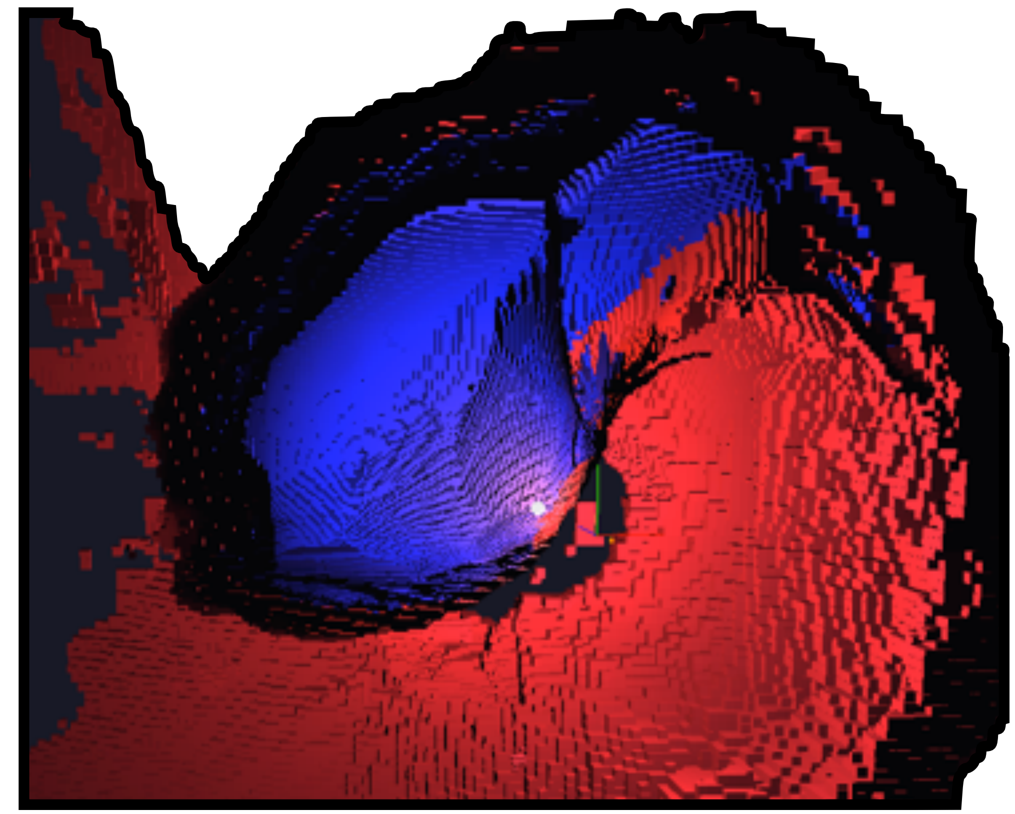
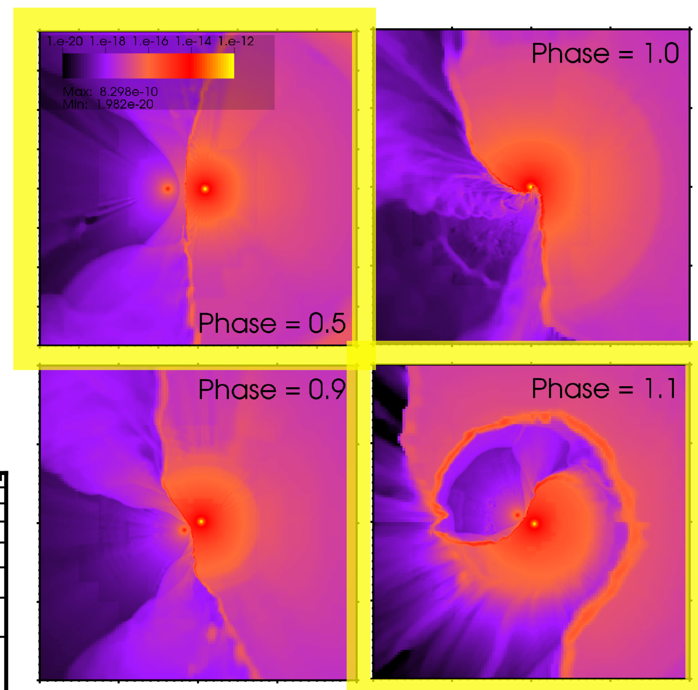
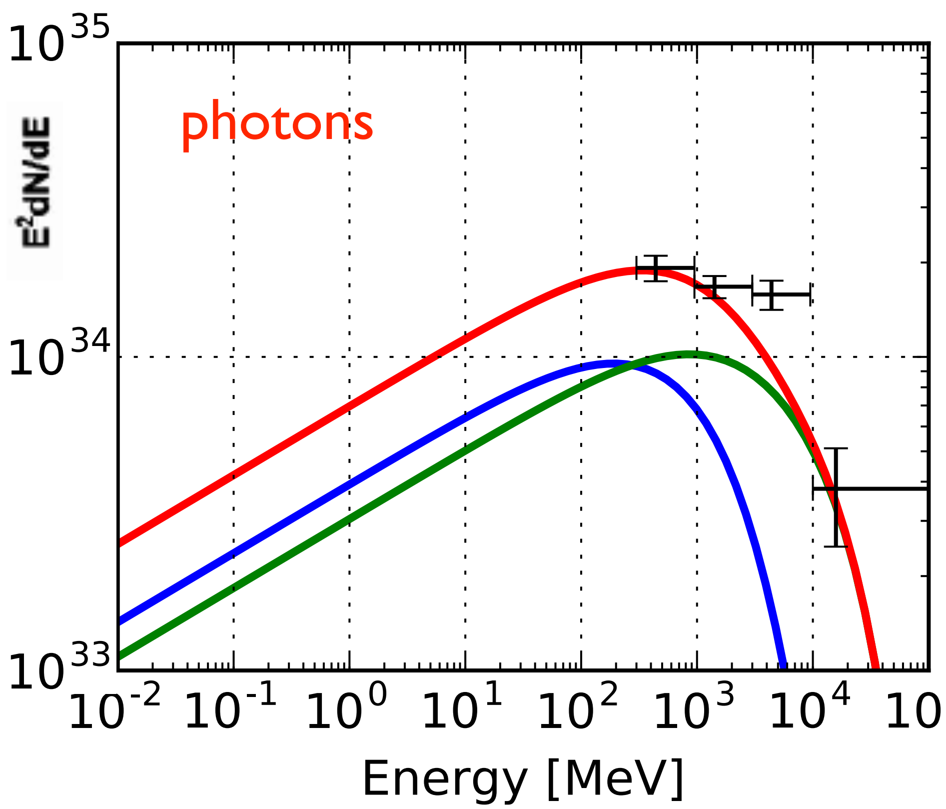




Parkin et al, 2011



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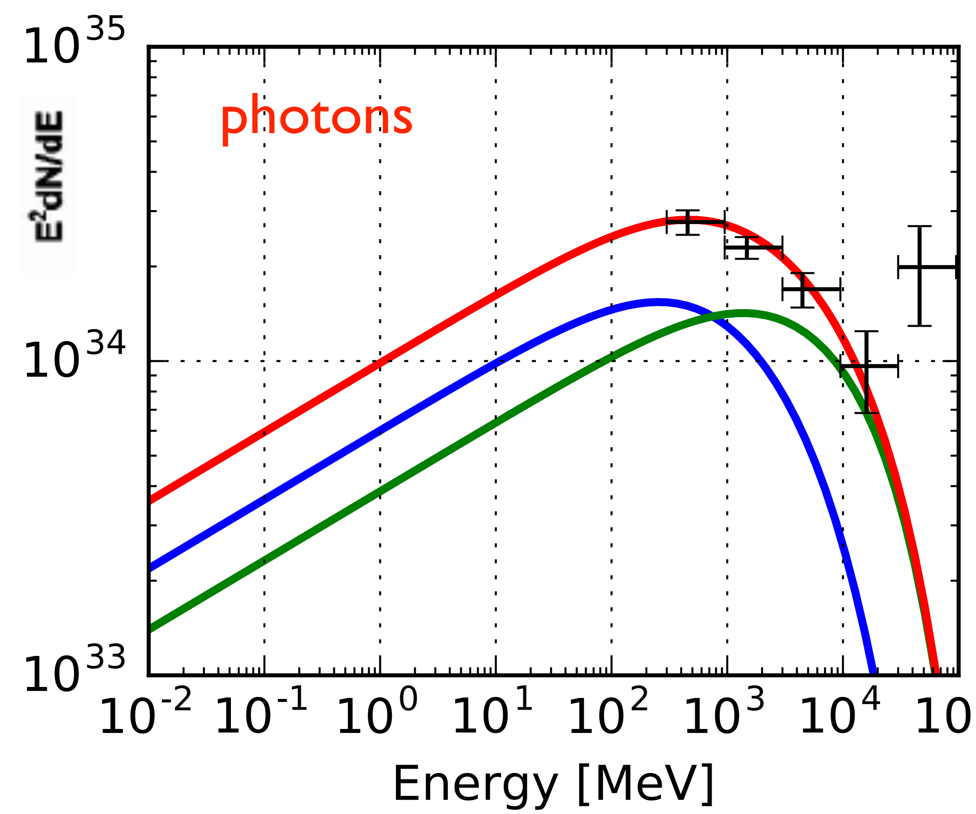
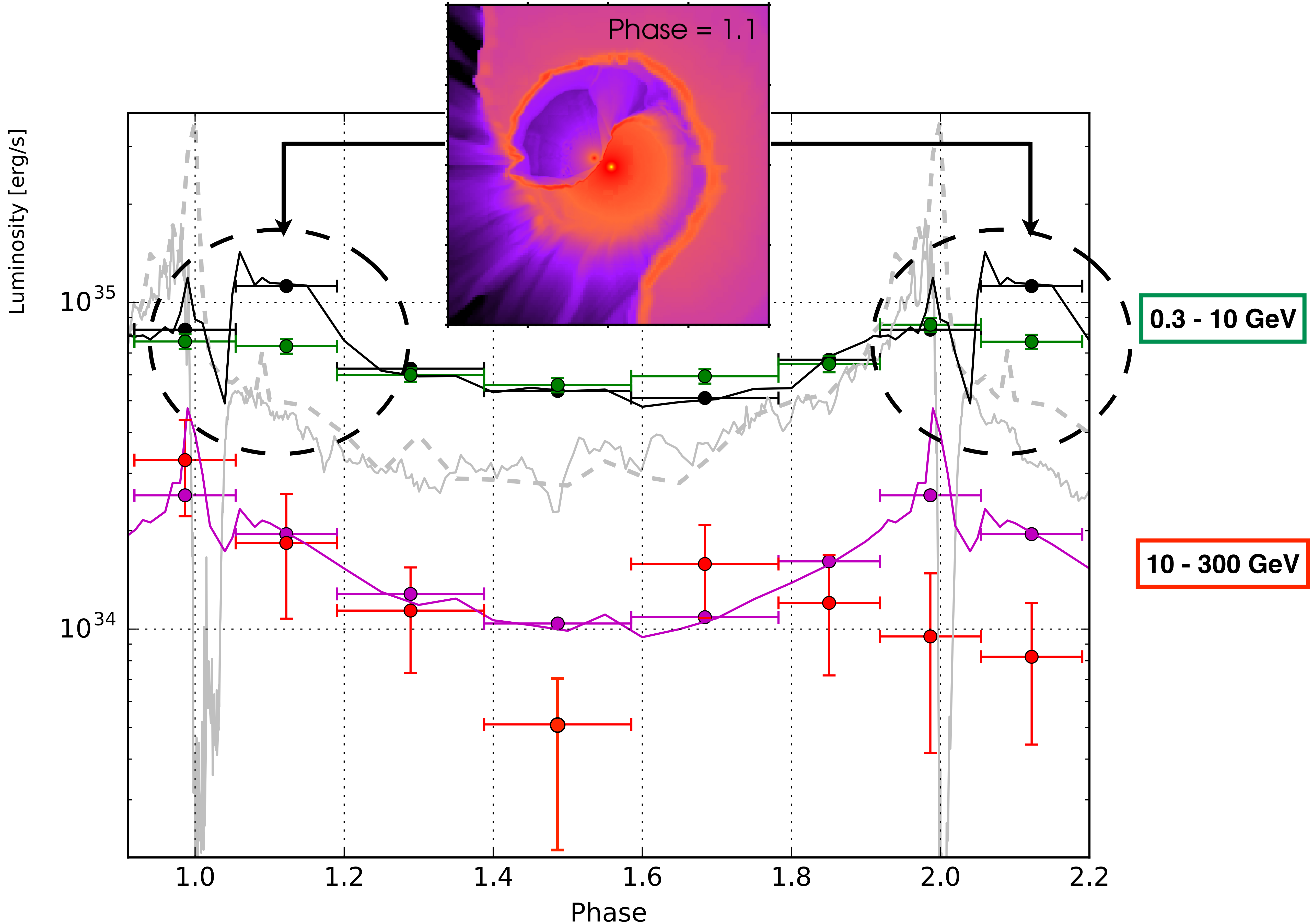
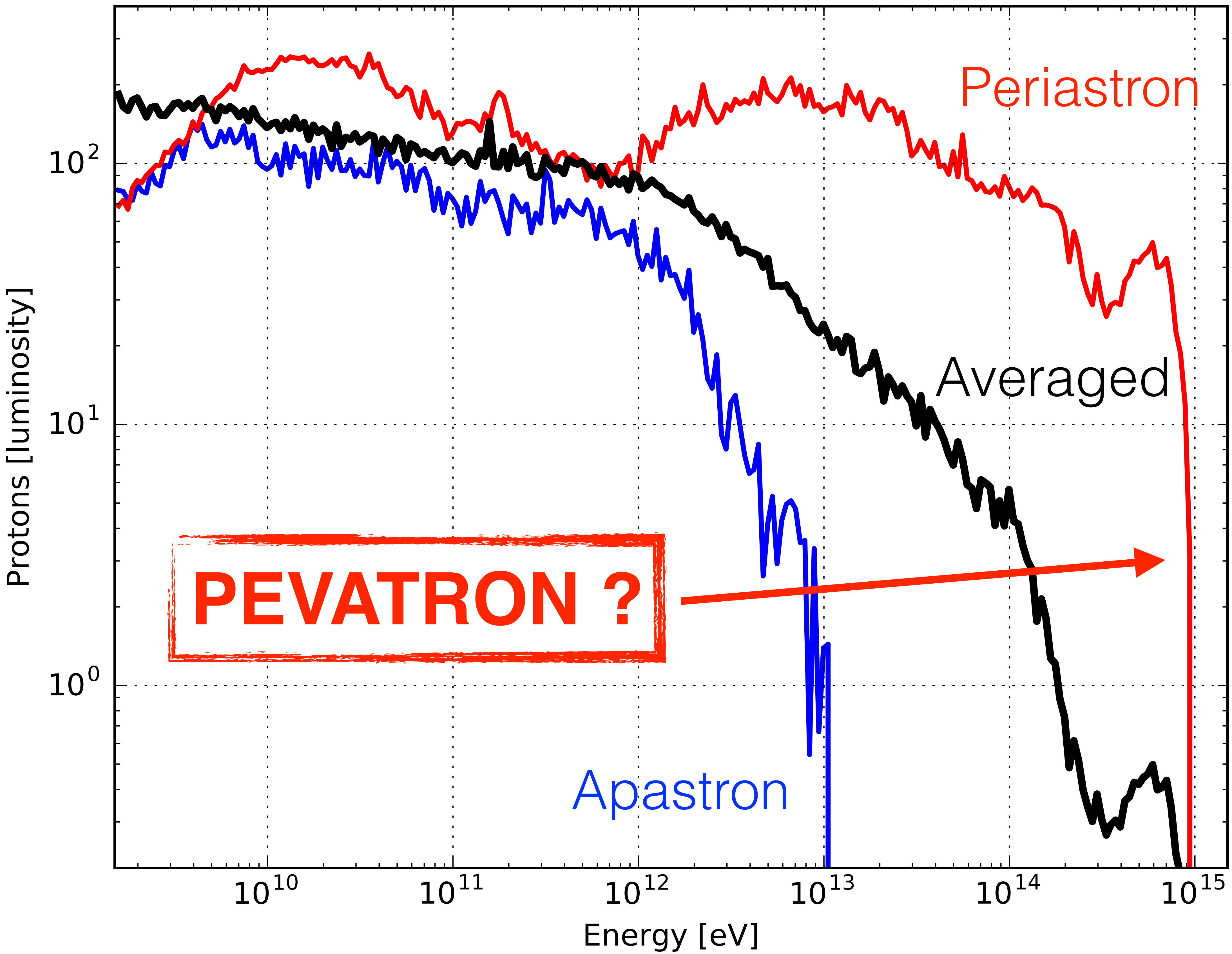
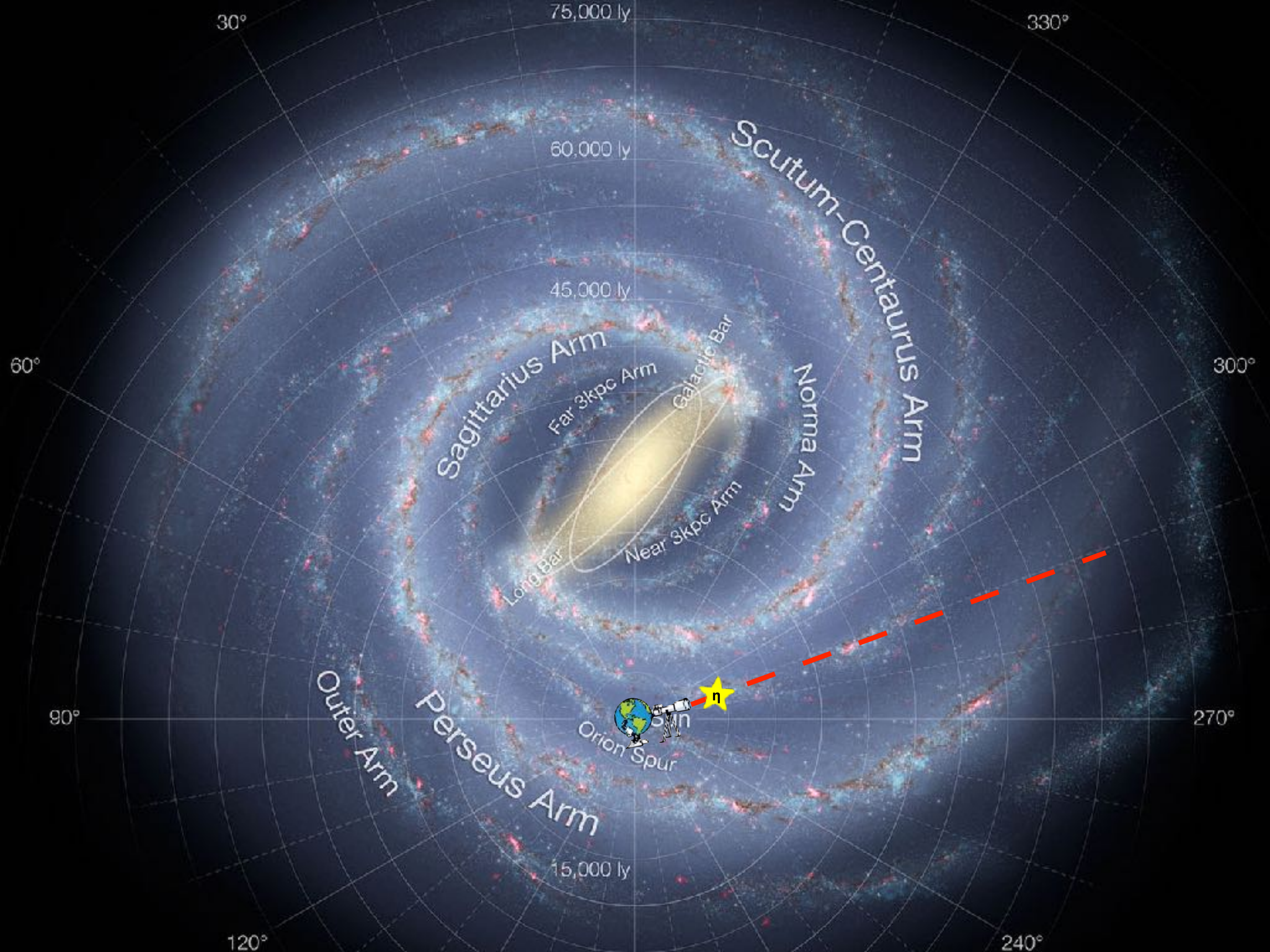


ηCar γ-ray lightcurve

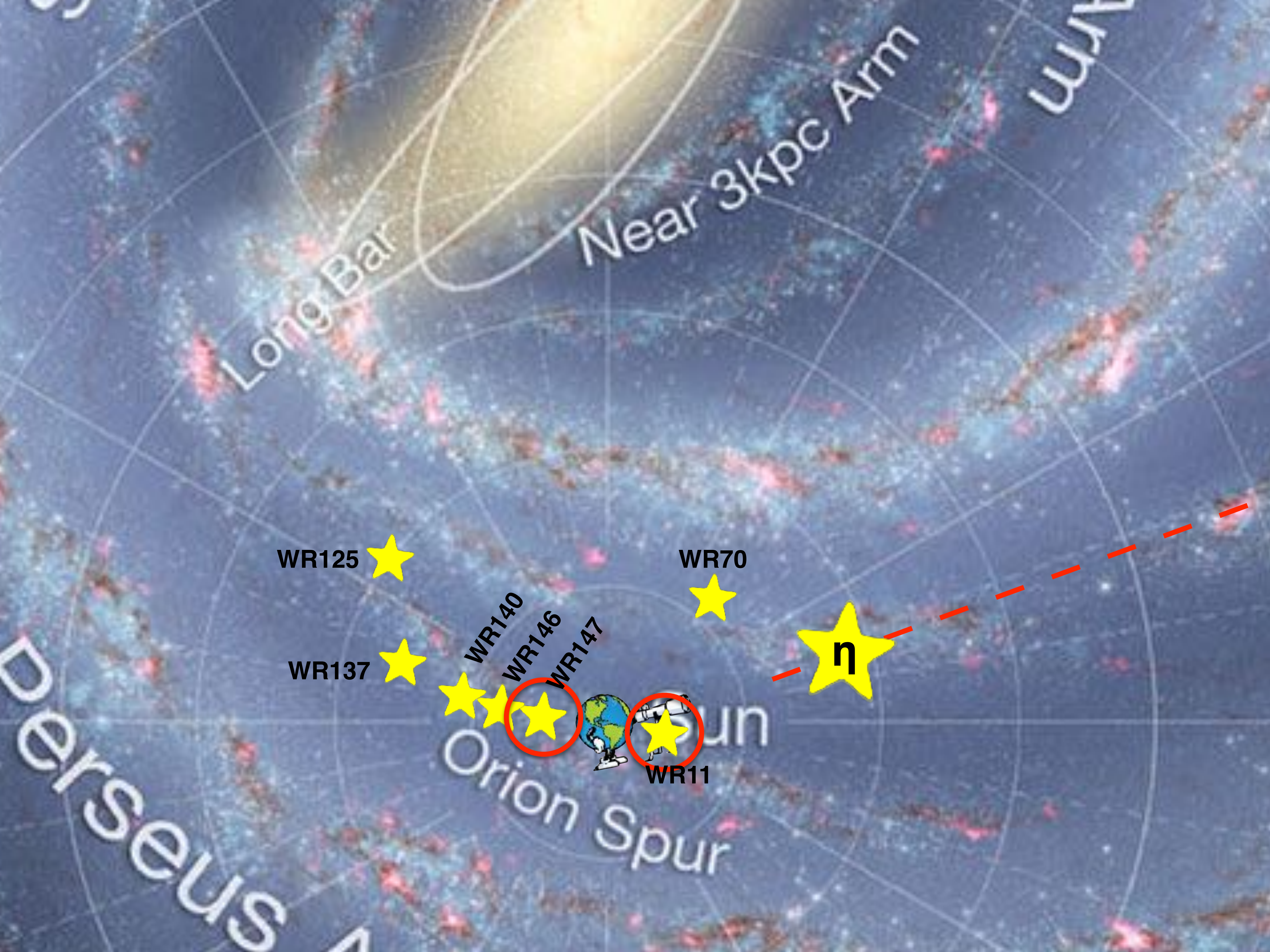


Protons spectrum



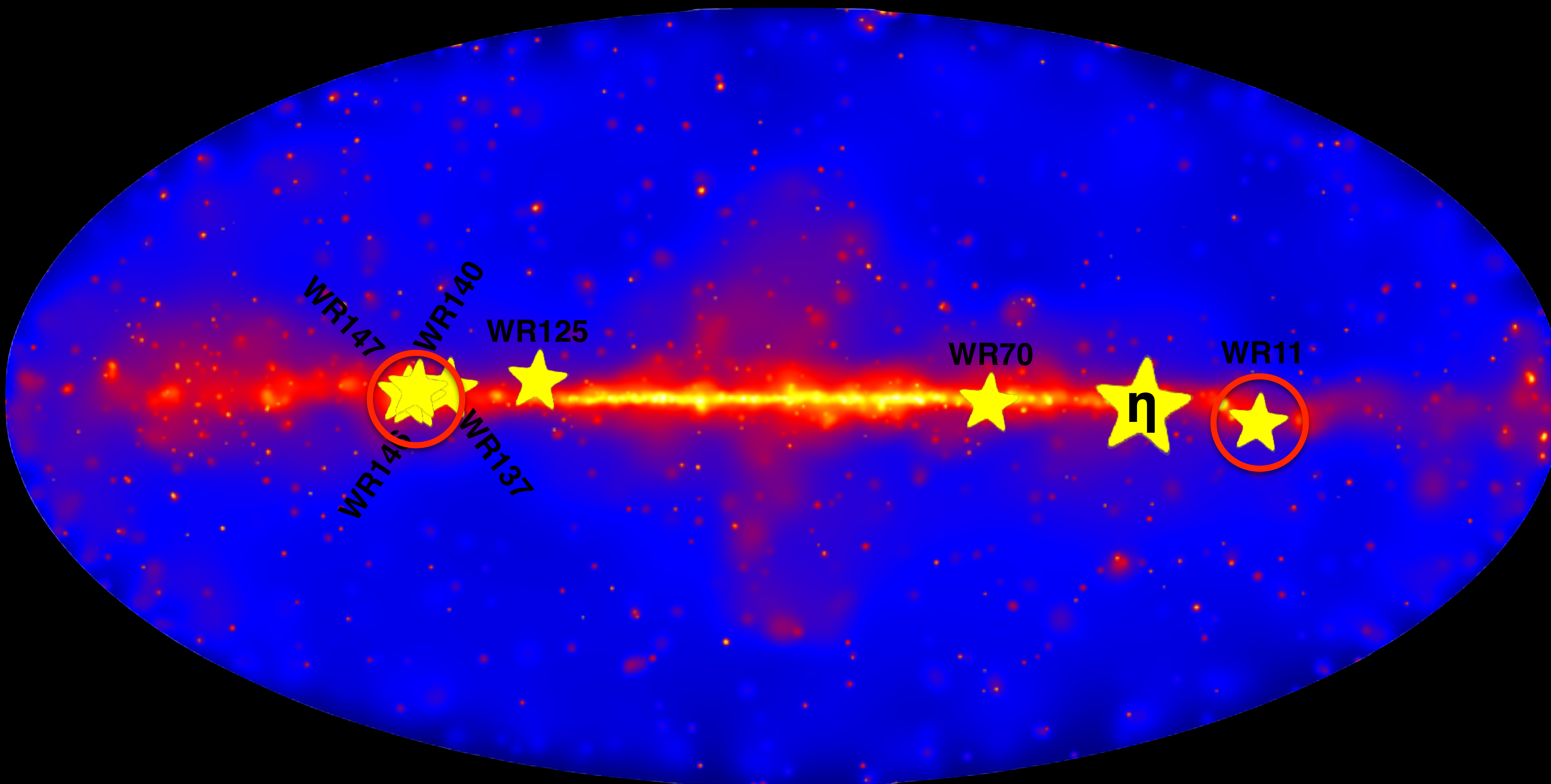


75,000 ly
30°
330°
60,000 ly
Scutum-Centaurus Arm
45,000 ly
Galactic Bar
Sagittarius Arm
Far 3kpc Arm
Norma Arm
60°
300°
Near 3kpc Arm
Long Bar
η
Outer Arm
Perseus Arm
Sun
Orion Spur
90°
270°
15,000 ly
120°
240°

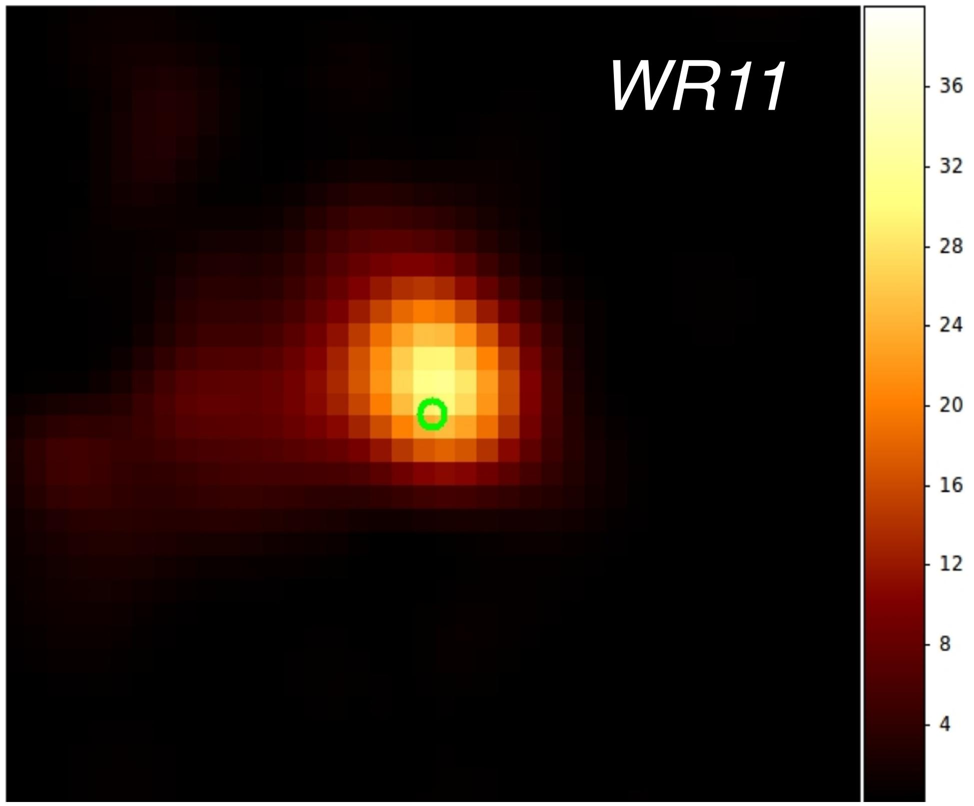


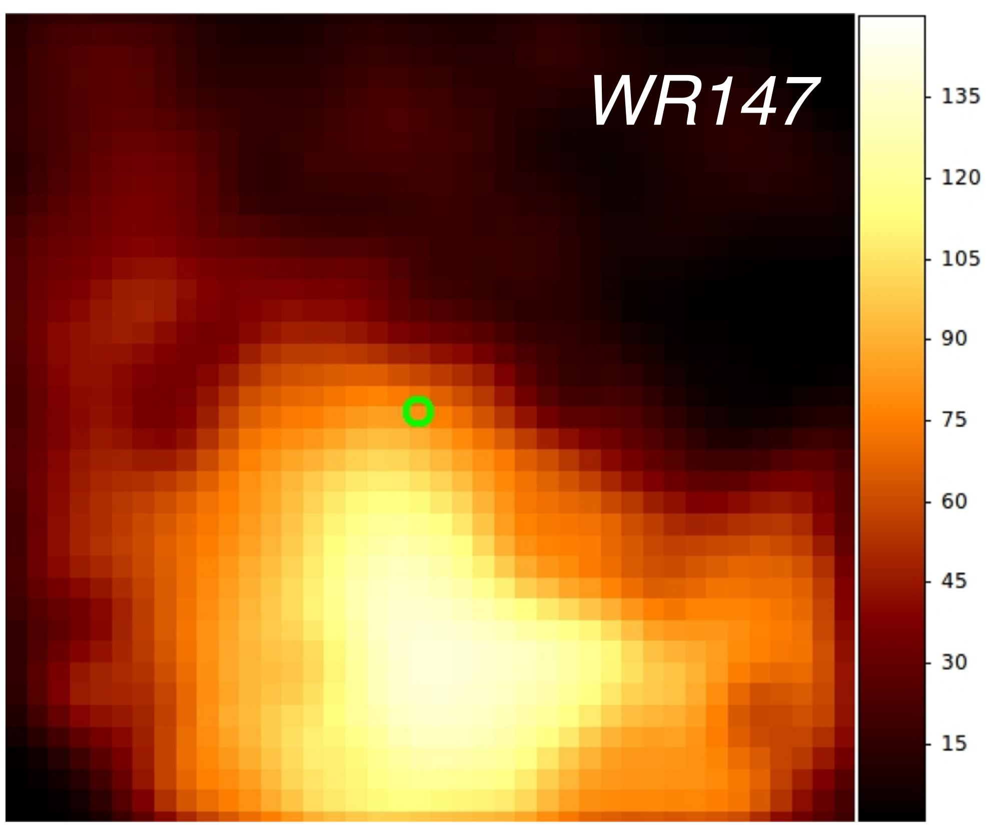
Near 3kpc Arm
Long Bar
Arm
WR125
WR70
WR140
WR146
WR147
WR137
η
Sun
WR11
Orion Spur
Perseus

Other candidates



γ-ray candidates in CWB





(Pshirkov, 2016)

Name	$l(^\circ)$	$b(^\circ)$	Distance (kpc)	*TS*
WR 11	262.80	−07.69	0.34	37.7
WR 70	322.34	−1.81	1.9	1.2
WR 125	54.4[illegible]	[illegible]1.0[illegible]	3.1	41.0
WR 137	74.33	+1.10	2.4	23.3
WR 140	[illegible]0.9[illegible]	[illegible]4.18	1.7	0.1
WR 146	80.56	+0.44	1.2	15.0
WR 147	79.85	−0.31	0.65	54.9

UPPER LIMITS

(De Marco et al., 1999) *(North at al., 2007)*

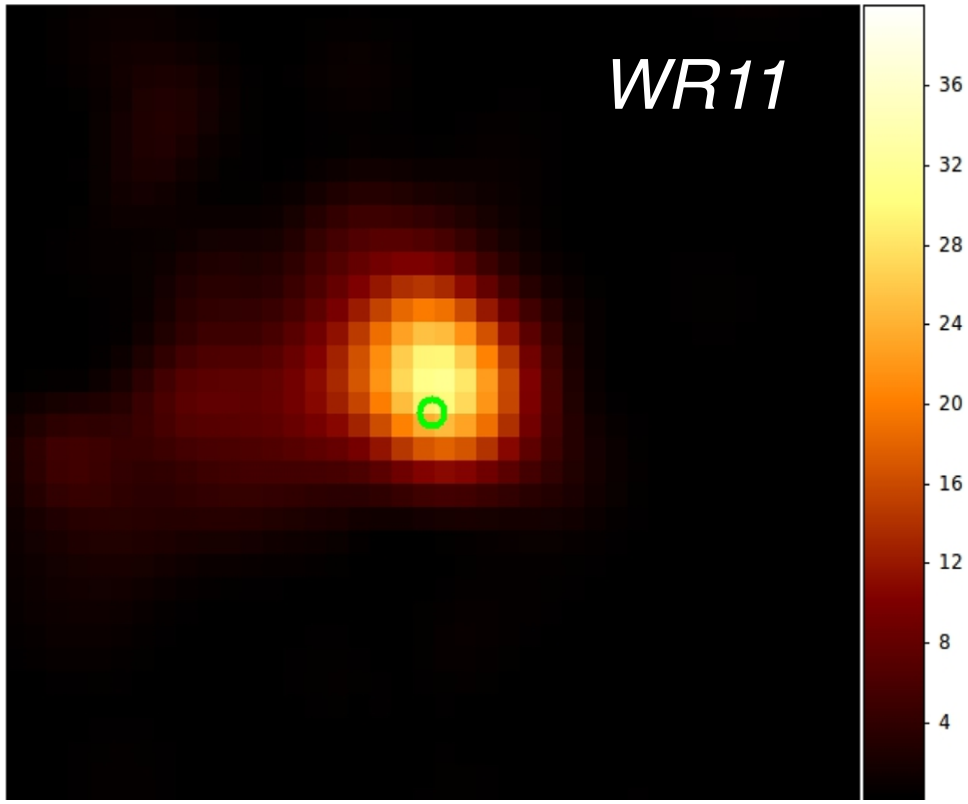
Parameter	Unit	WC8	O7.5
Mass, M	$M_\odot$	9.0	29.0
Mass-loss rate, $\dot{M}$	$10^{-7}\ M_\odot\ yr^{-1}$	80	1.8 (1)
Terminal wind velocity, v^∞	$km\ s^{-1}$	1450	2500 (1)
Luminosity, L	$10^5\ L_\odot$	1.7	2.8

$$\eta = \frac{\dot{M}_O v_O^\infty}{\dot{M}_{WR} v_{WR}^\infty} = 0.04$$

(De Becker & Raucq, 2013)

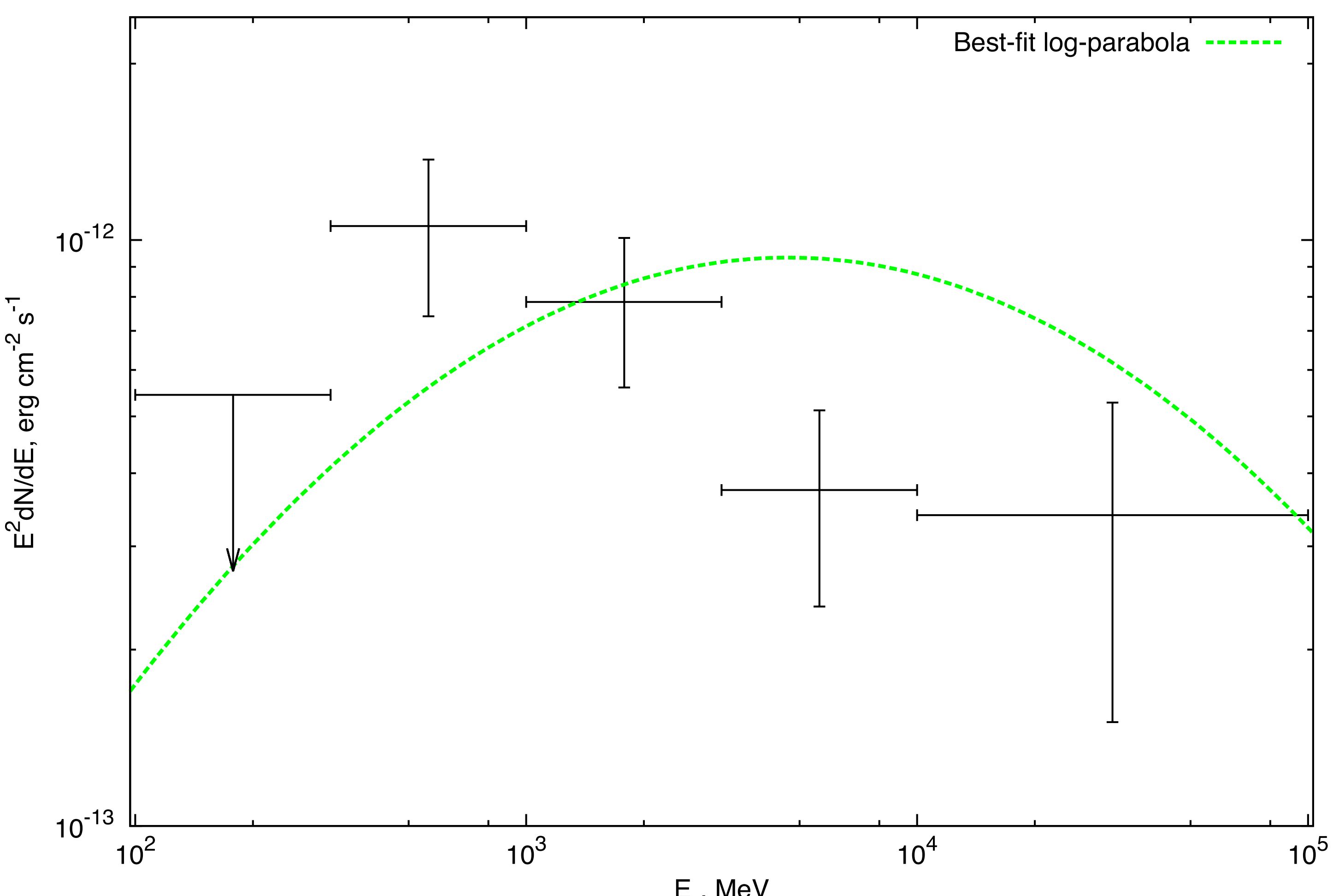
$$L_{cwz} = \eta L_w = 2.3 \times 10^{35} \mathrm{ergs}^{-1}$$

γ-ray candidates in CWB



Name	$l(^\circ)$	$b(^\circ)$	Distance (kpc)	TS
WR 11	262.80	−07.69	0.34	37.7

- $L_{rad} = 1.8 \times 10^{28}$ erg s^{-1} *(Leitherer, 1997)*
- $L_x = 10^{33}$ erg s^{-1} *(Schild, 2004)*
- $L_\gamma = (3.7 \pm 0.7) \times 10^{31}$ erg s^{-1}



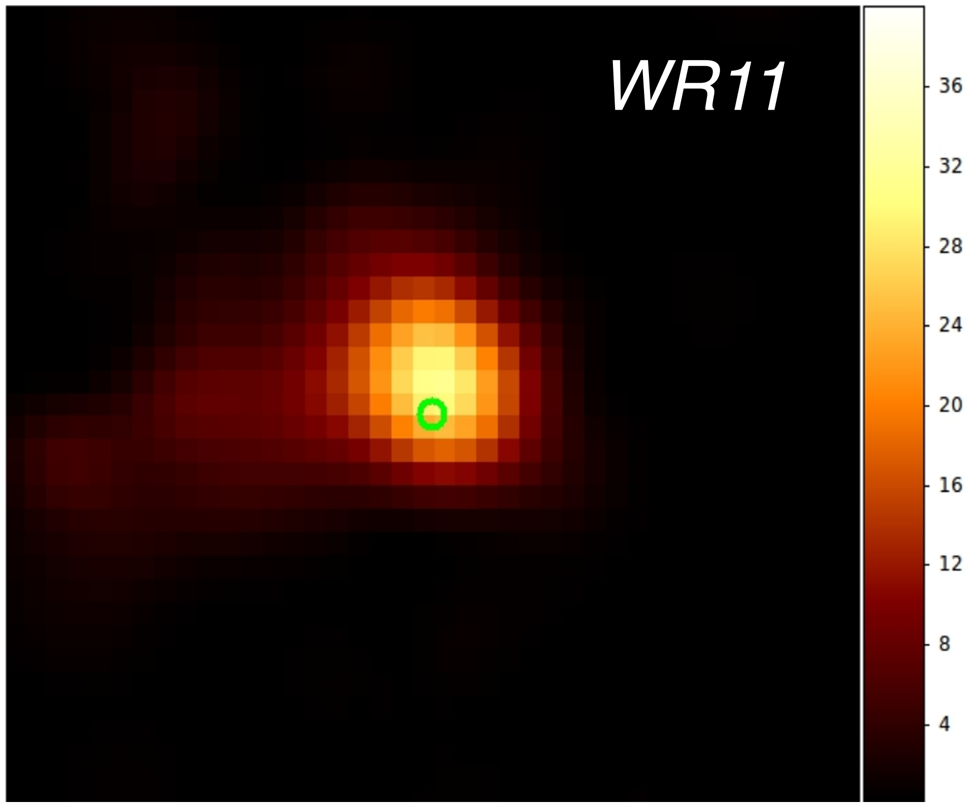
➡ Hadronic

- small dist ~ 10^{13} cm
- flat spectrum @ low E

➡ Leptonic

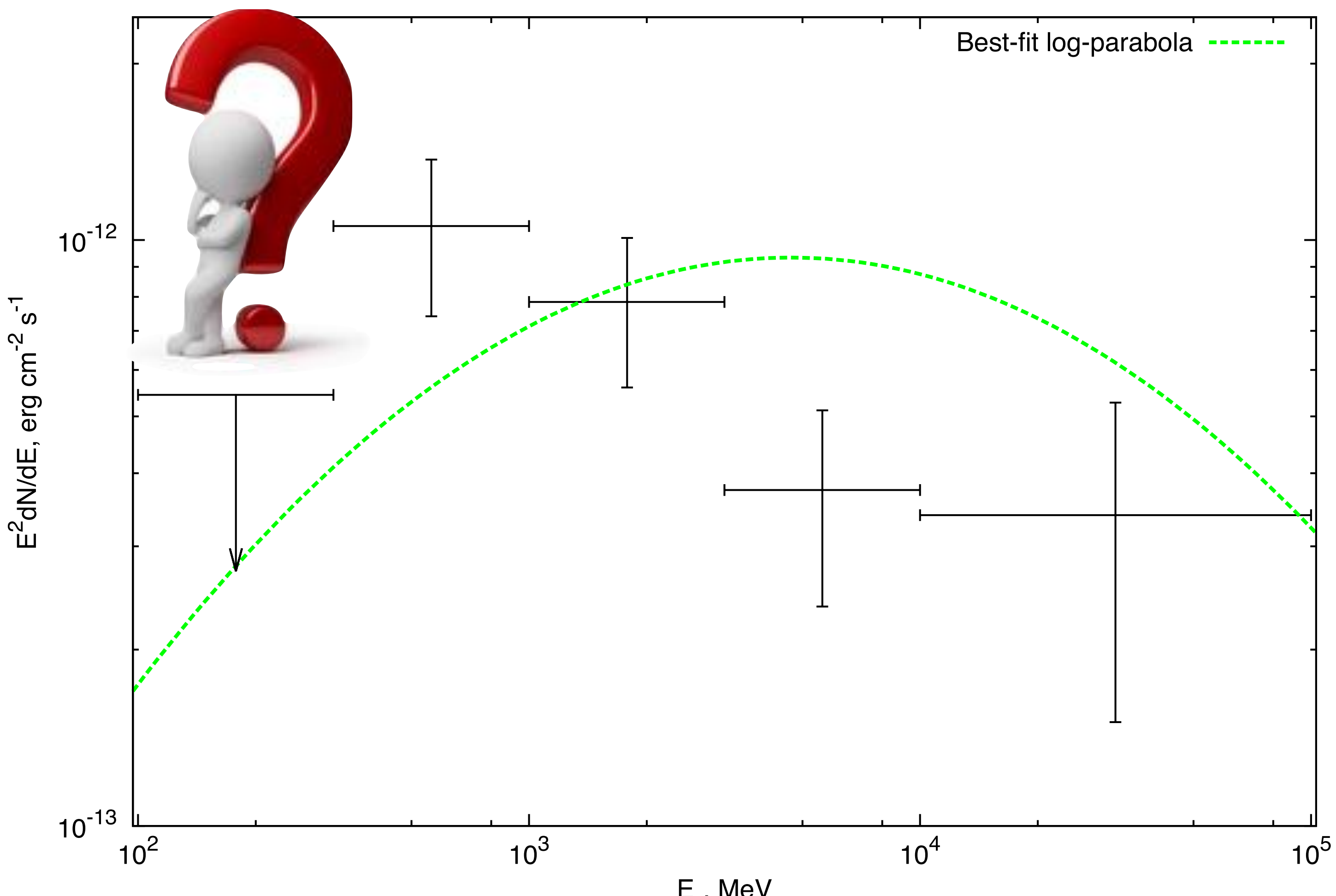
- $B_{cwz} \sim 1.7$ G
- $B_{surf} \sim 100$ G
- $\gamma \sim 10^4$

γ-ray candidates in CWB



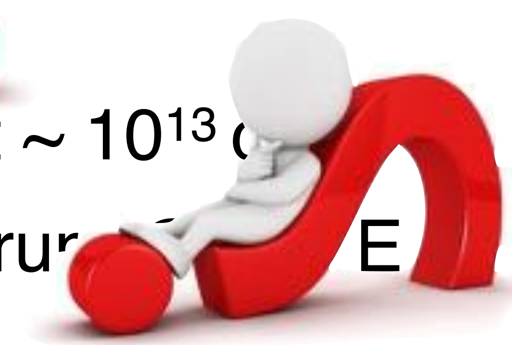
Name	$l(°)$	$b(°)$	Distance (kpc)	TS
WR 11	262.80	−07.69	0.34	37.7

- $L_{rad} = 1.8 \times 10^{28}$ erg s^{-1} *(Leitherer, 1997)*
- $L_x = 10^{33}$ erg s^{-1} *(Schild, 2004)*
- $L_\gamma = (3.7 \pm 0.7) \times 10^{31}$ erg s^{-1}



➡ Hadronic

- small dist ~ 10^{13} c
- flat spectrum ... E



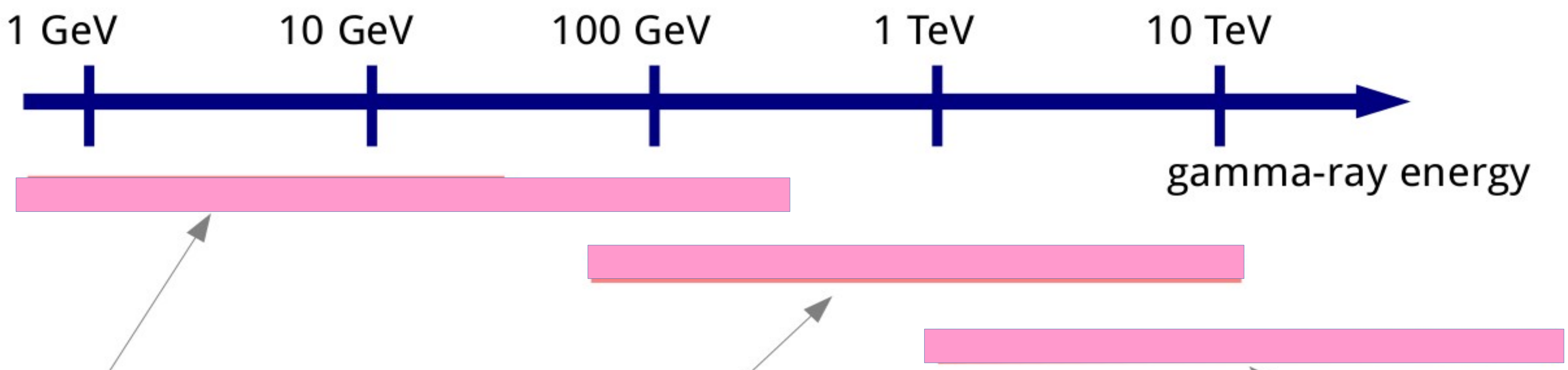
➡ Leptonic

- B_{cwz} ~ 1.7 G
- B_{surf} ~ 100 G
- γ ~ 10^4

Probing higher energies

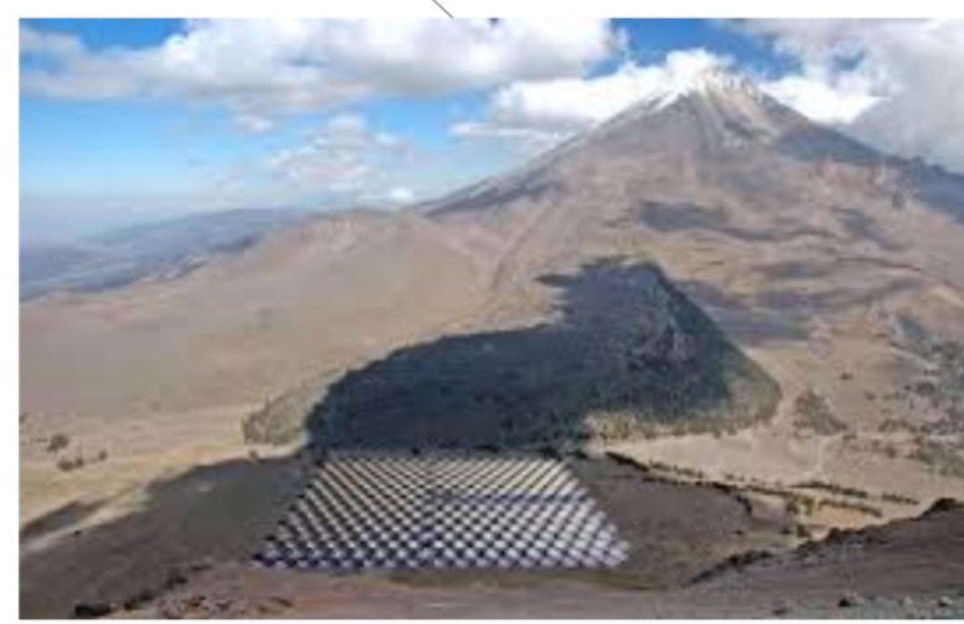
Earth's atmosphere is opaque for gamma-rays

Direct detection in space ⟷ Indirect detection from ground



Satellites

Cherenkov telescopes



Water Cherenkov detectors

Imaging Cherenkov Technique

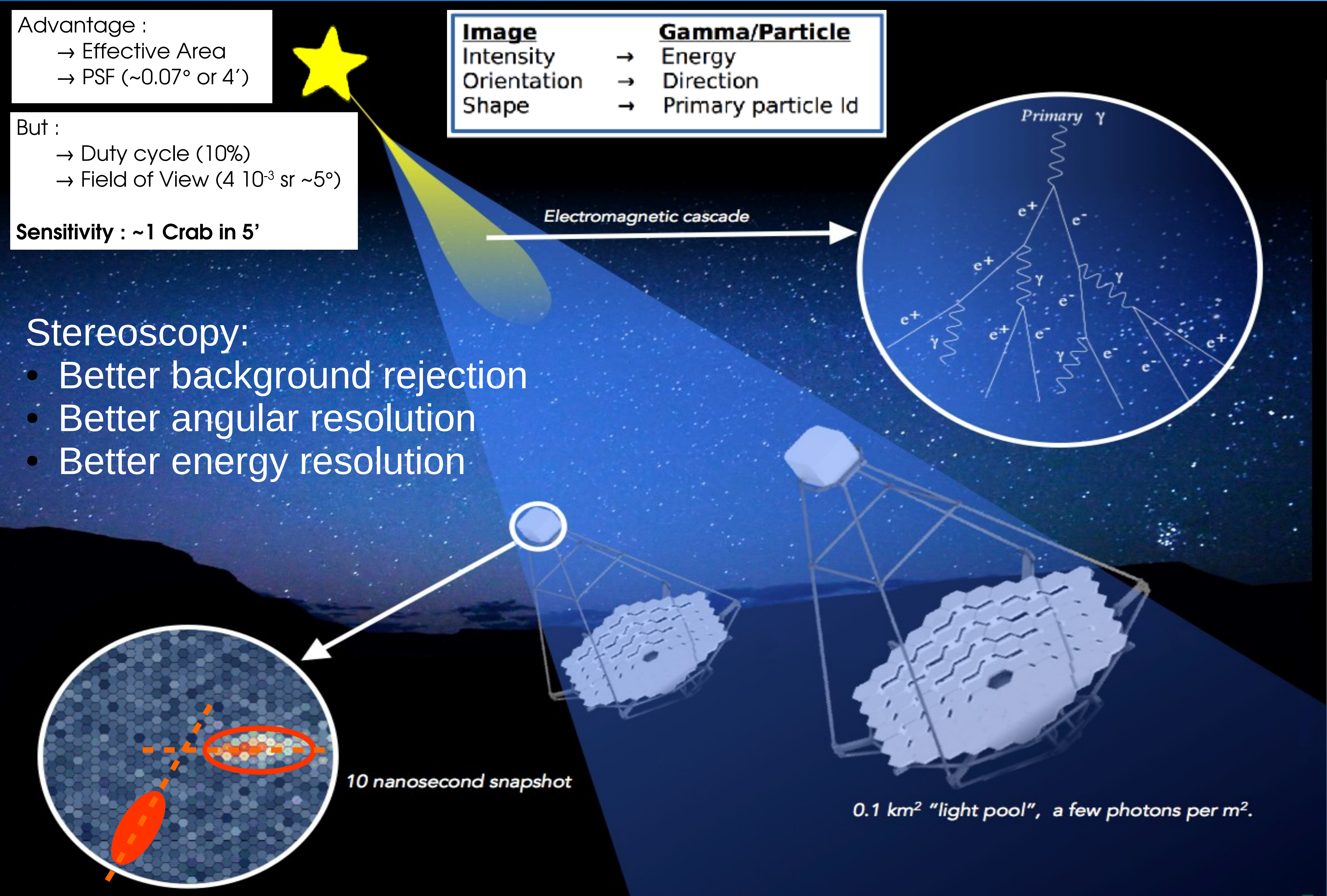
Advantage :
→ Effective Area
→ PSF (~0.07° or 4′)

But :
→ Duty cycle (10%)
→ Field of View (4 10^{-3} sr ~5°)

Sensitivity : ~1 Crab in 5'

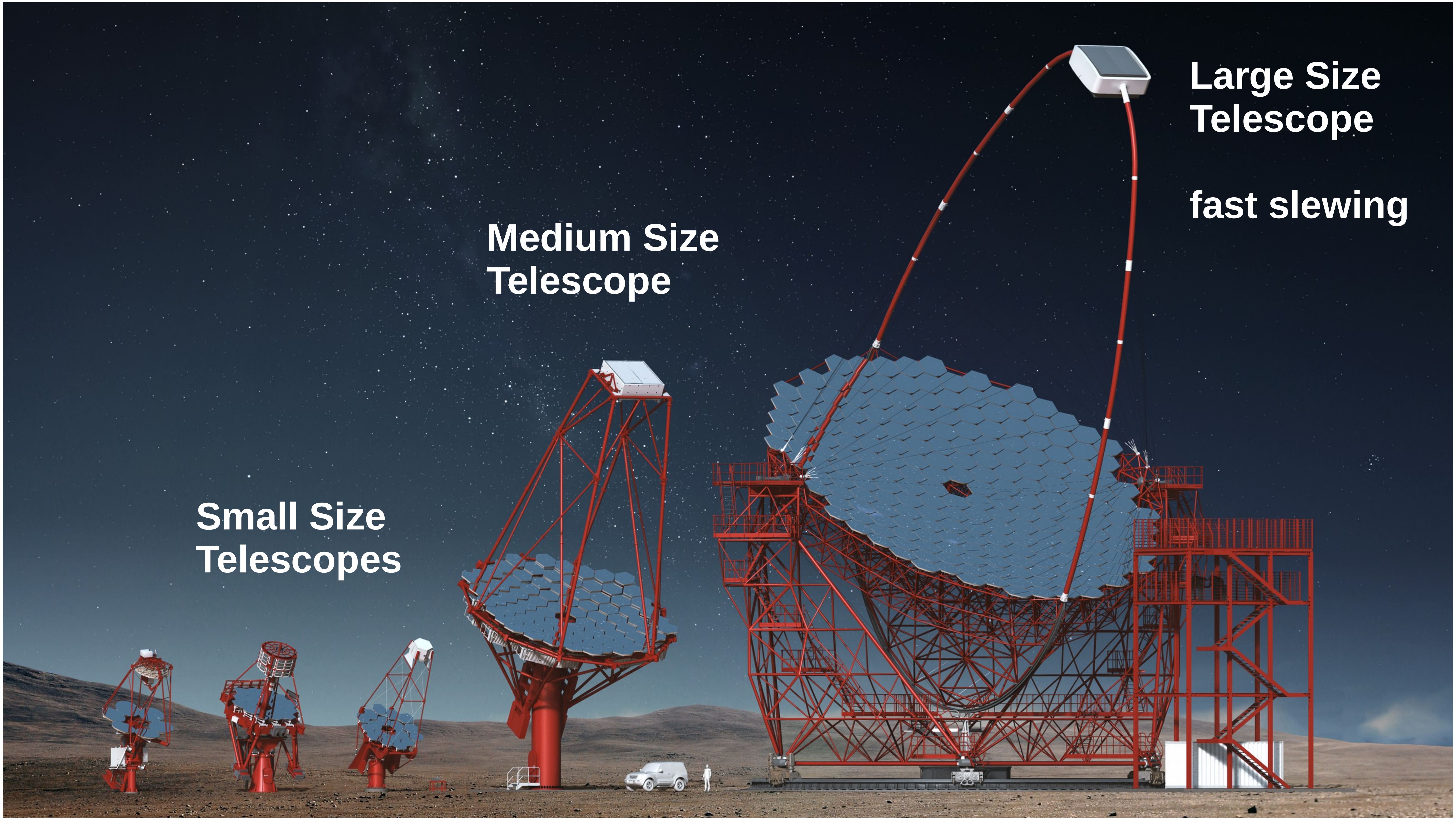
Image		**Gamma/Particle**
Intensity	→	Energy
Orientation	→	Direction
Shape	→	Primary particle Id

Stereoscopy:
- Better background rejection
- Better angular resolution
- Better energy resolution

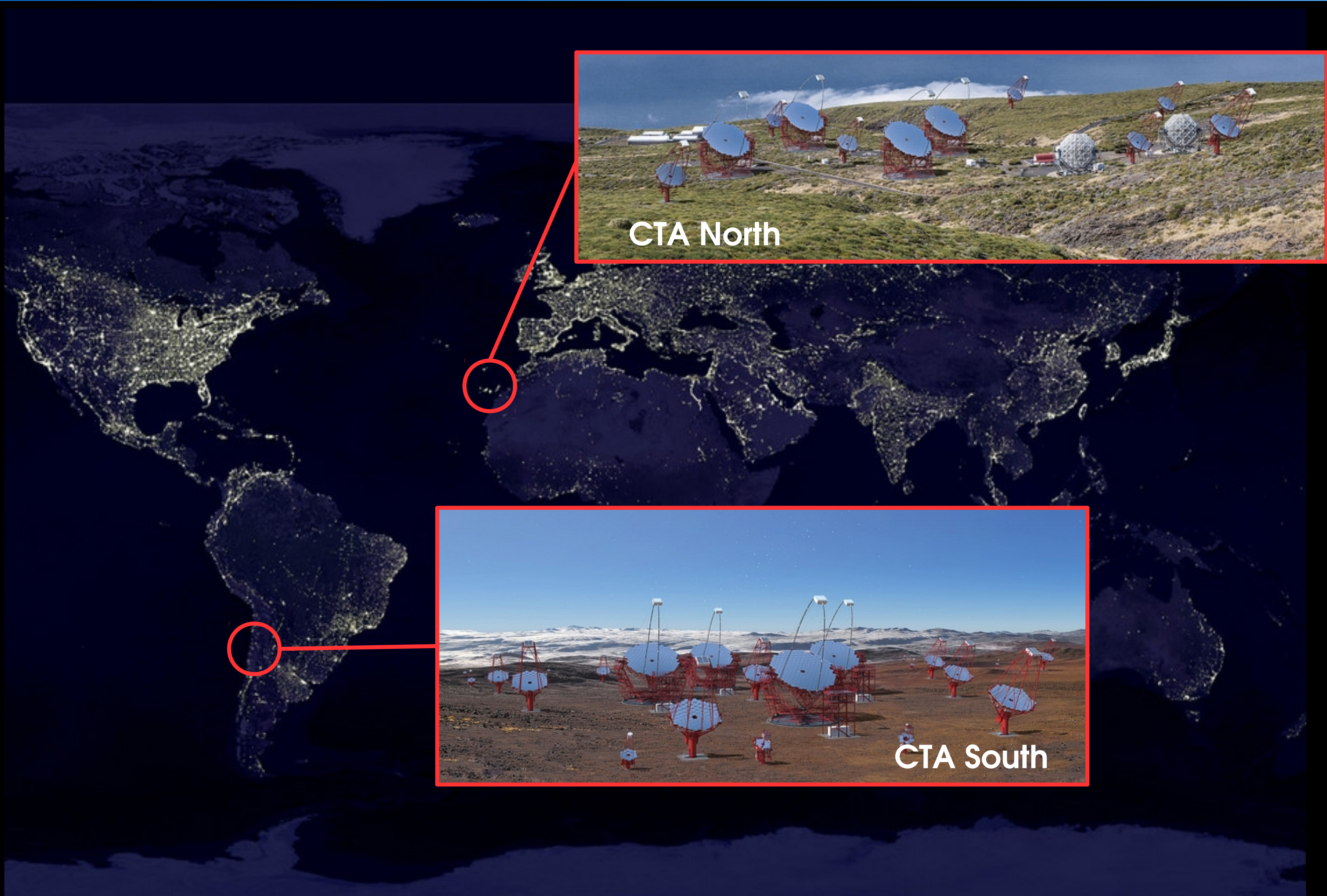


CTA Telescope Types

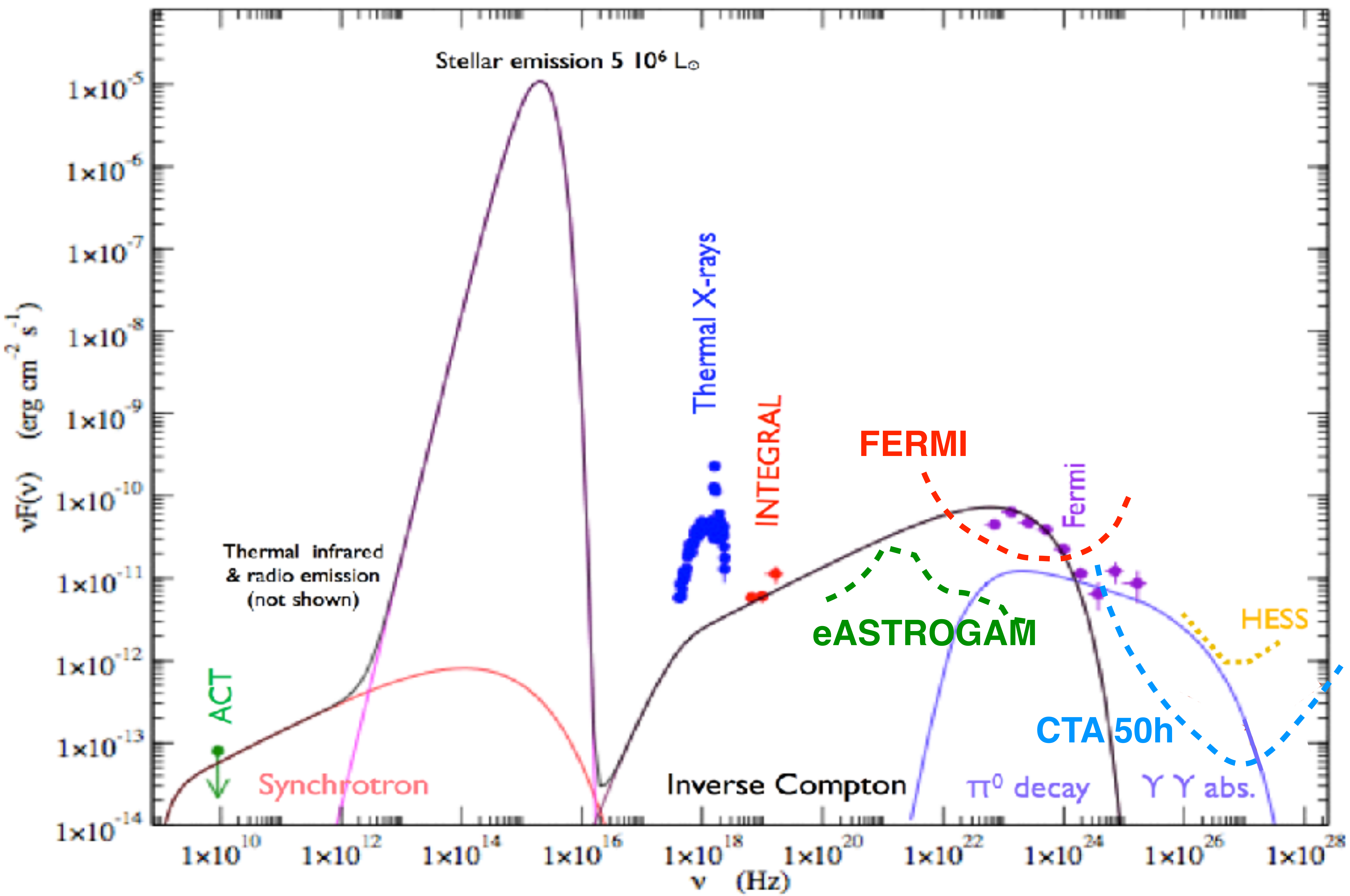
3 different telescope sizes $\Longrightarrow$ 3 different energy ranges



CTA sites



The physics behind ηCar

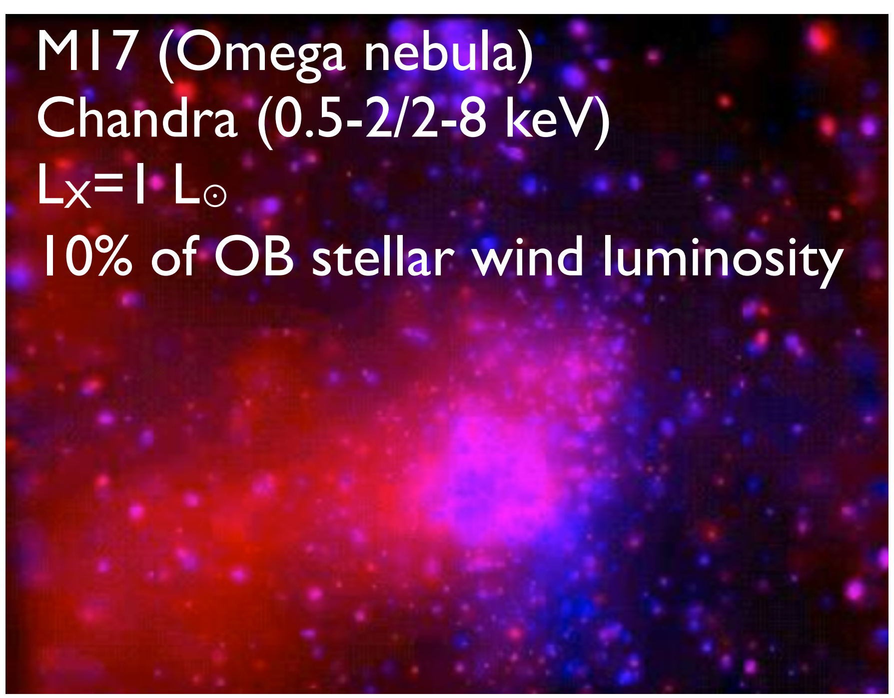


Energetics and conclusion…

- **Thermal X-rays:** 25 $L_\odot$ (~ 2% L_{shock})
- **Synchrotron:** < 0.1 $L_\odot$
- **Electron acceleration:** 50 $L_\odot$ (~ 6% L_{mec})
- **π^0 emission:** 10 $L_\odot$ (~ 1% L_{mec})
- **neutrino:** ~ 10^{-9} GeV s^{-1} cm^{-2} (above 10 TeV)

- **η Carinae** shows evidences for **electronic** and **hadronic** acceleration
- Electron **spectral index** is 2.25
- **Proton cutoff energy** $\gtrsim 10^{13}$ eV, higher than measured in middle aged SNR
- **Efficiency** of particle **acceleration ~ 5%** (Spitkovsky's simulations: 10%)

With this efficiency, a massive star could accelerate $5\% \cdot \dot{M} \cdot t_{WR} \cdot V_w^2 \approx 10^{49\sim50} erg$



(Townsley et al., 2005)


Thank You