GALACTIC ASTROPHYSICAL ACCELERATORS: an overview

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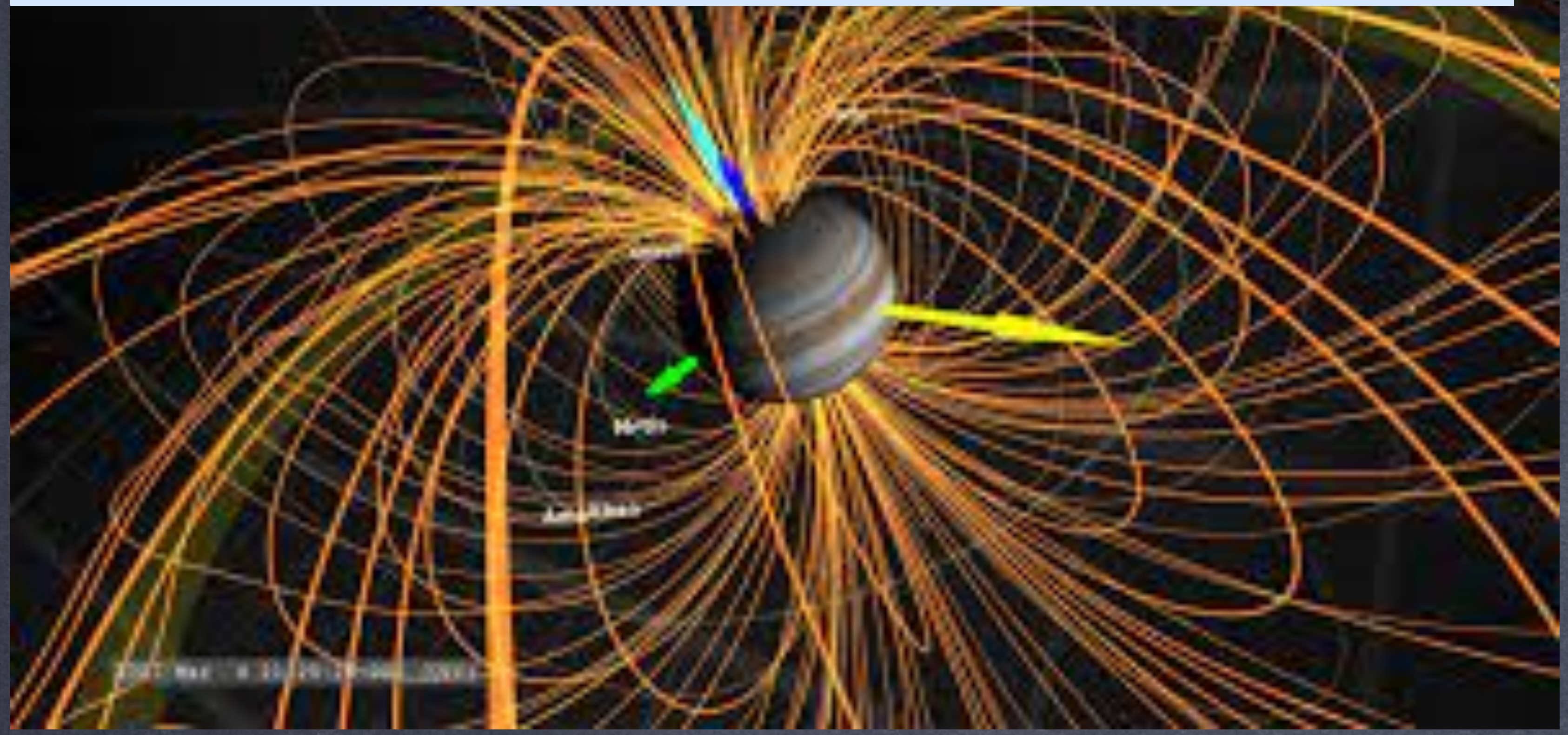
INAF-OSSERVATORIO ASTROFISICO DI ARCETRI

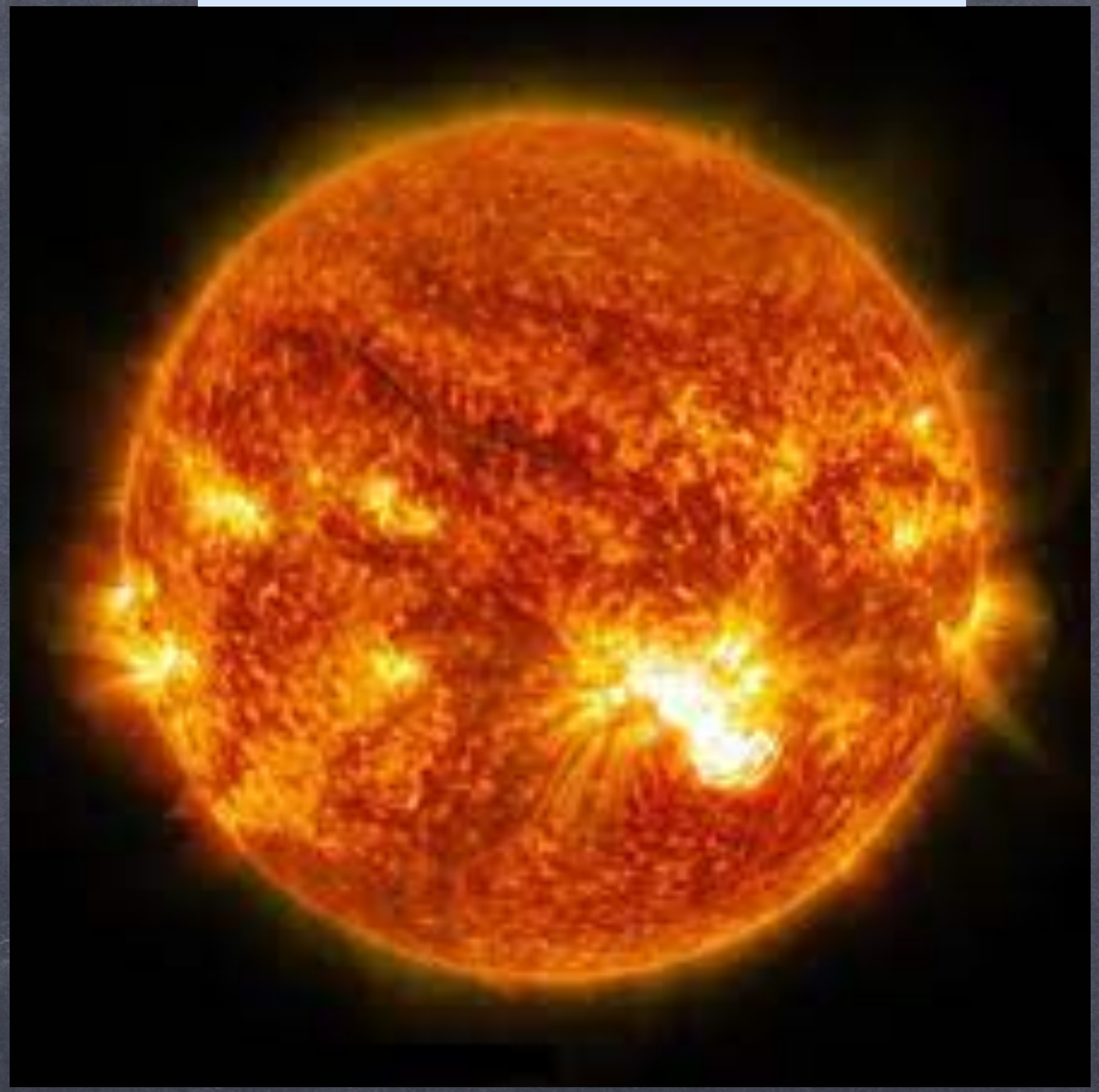
GALACTIC ACCELERATORS

NEW BORN AND LIVING OBJECTS

PLANETARY MAGNETOSPHERES

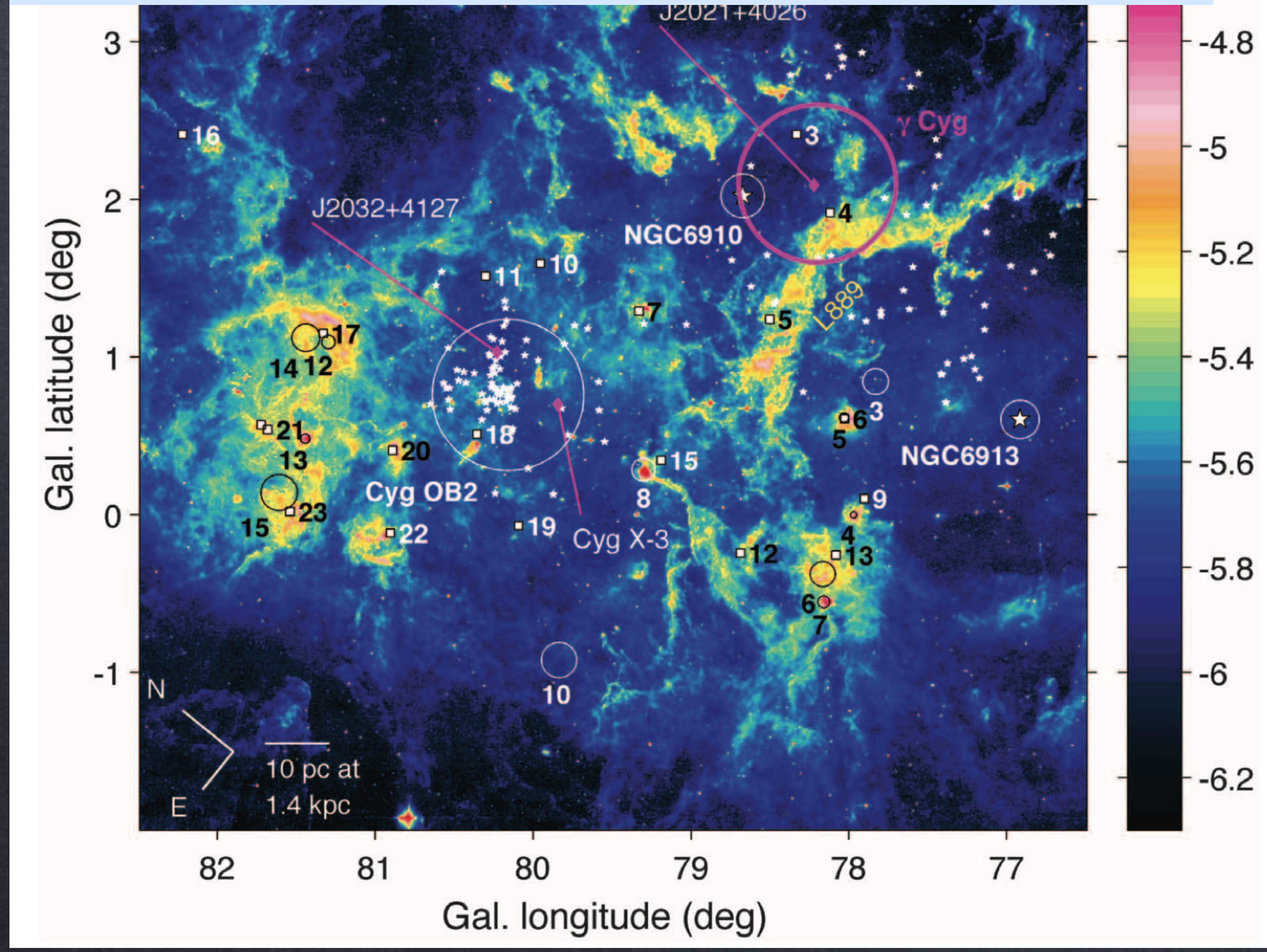


SUN AND STARS

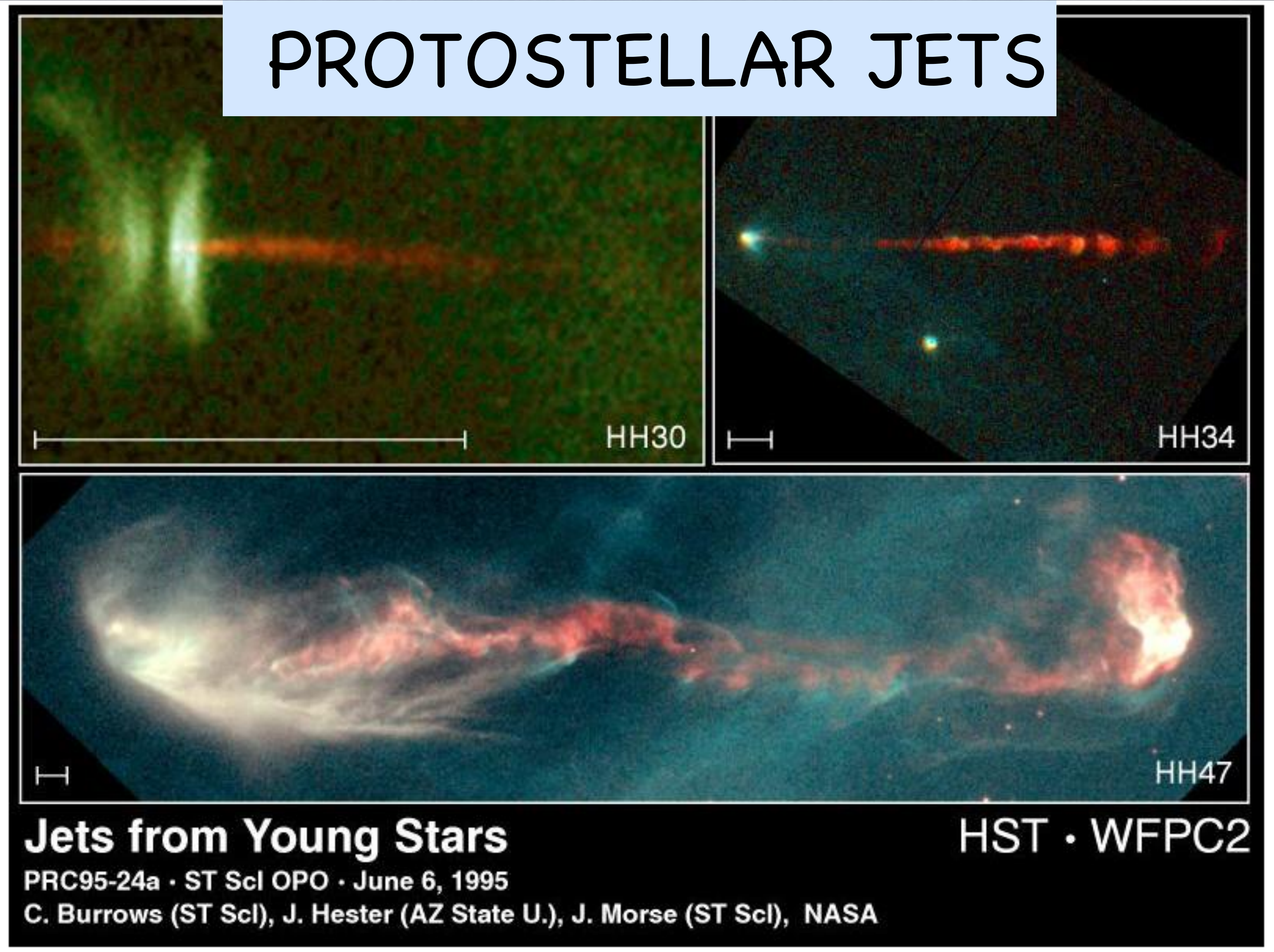


COLLIDING STELLAR WINDS

STAR FORMING REGIONS



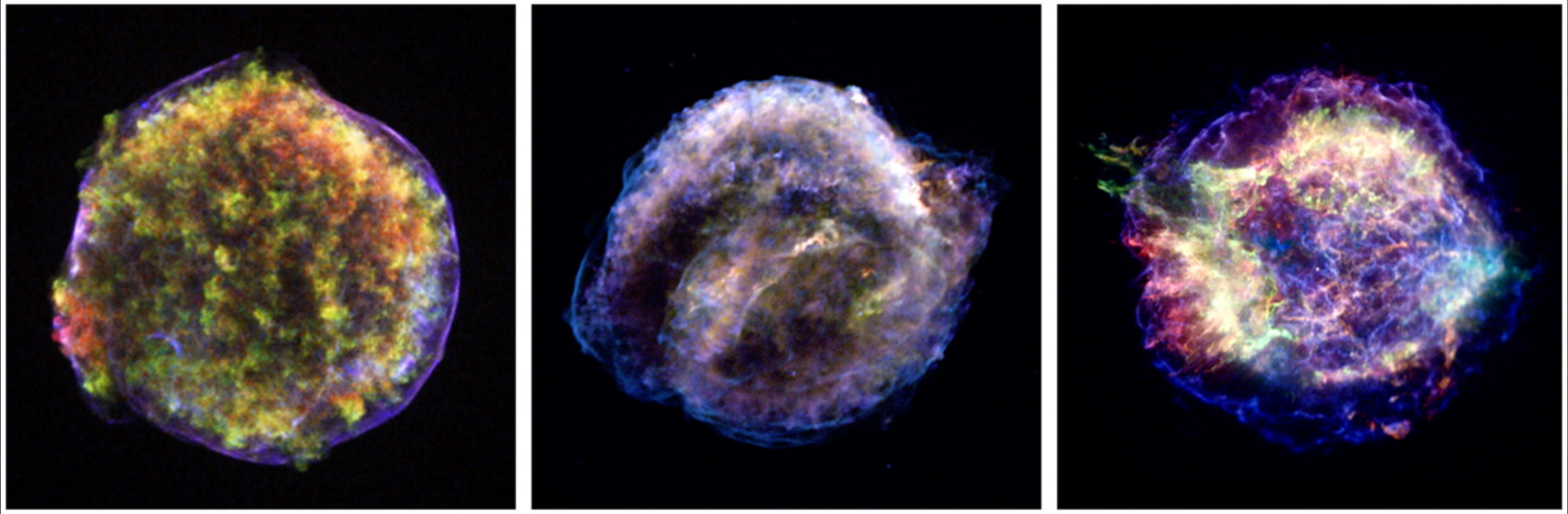
PROTOSTELLAR JETS



GALACTIC ACCELERATORS

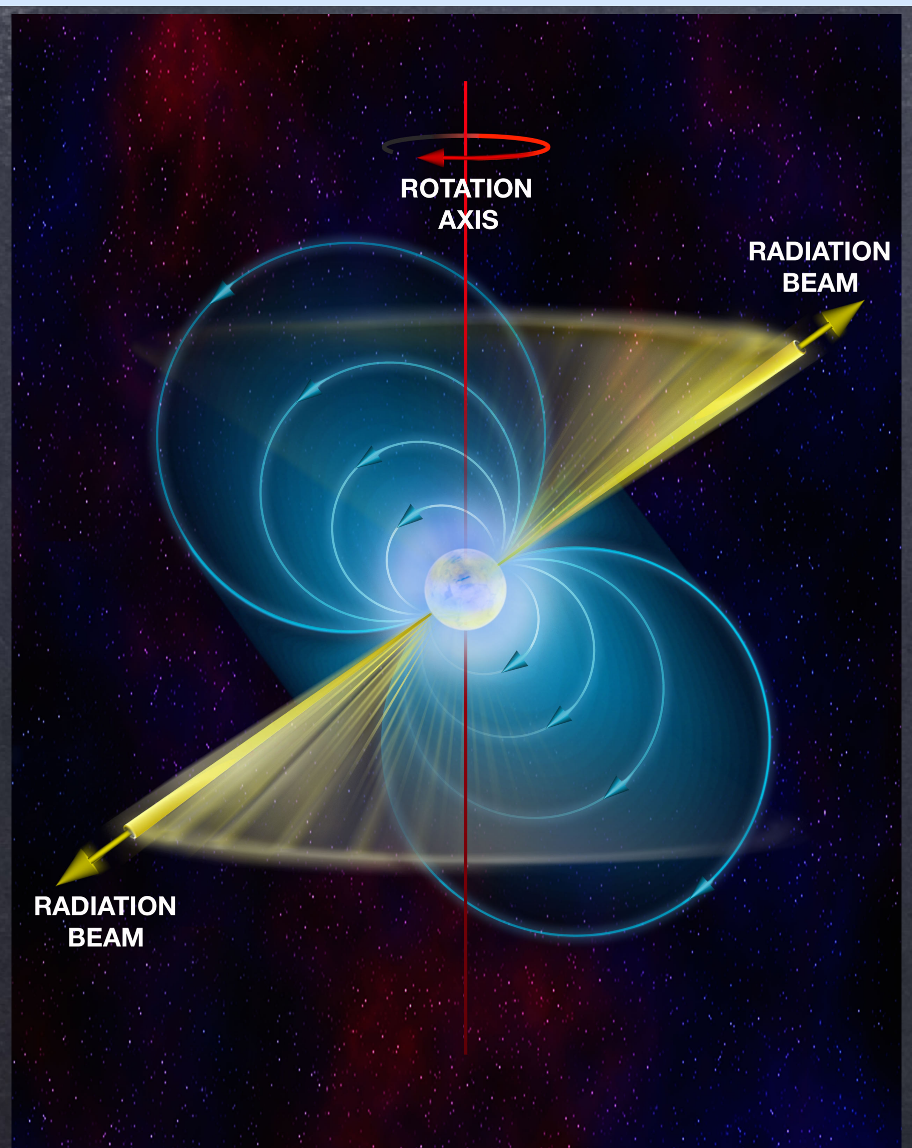
DEAD OBJECTS

SUPERNOVA REMNANTS



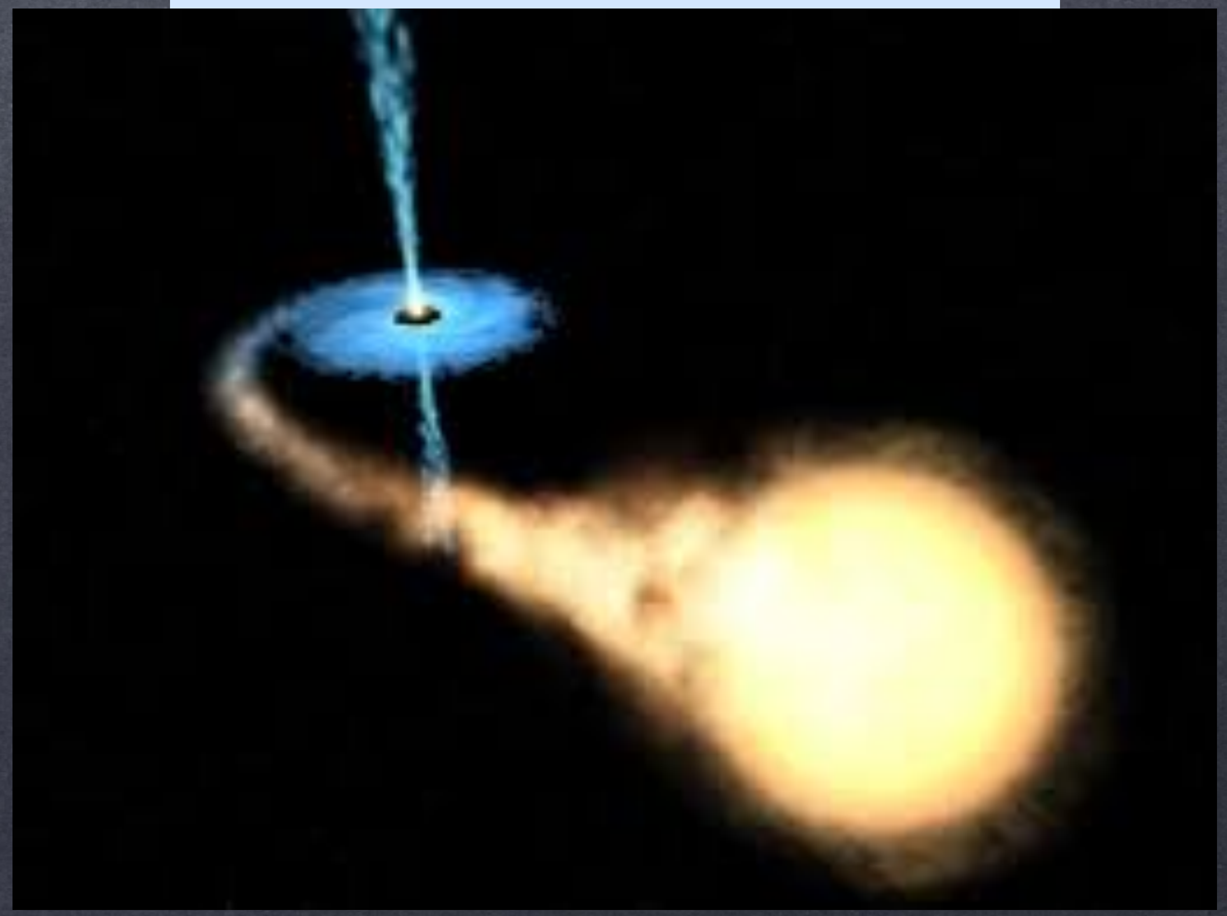
PULSAR WIND NEBULAE

PULSARS AND MAGNETARS



NOVAE

MICROQUASARS



PROPERTIES OF THE ACCELERATOR

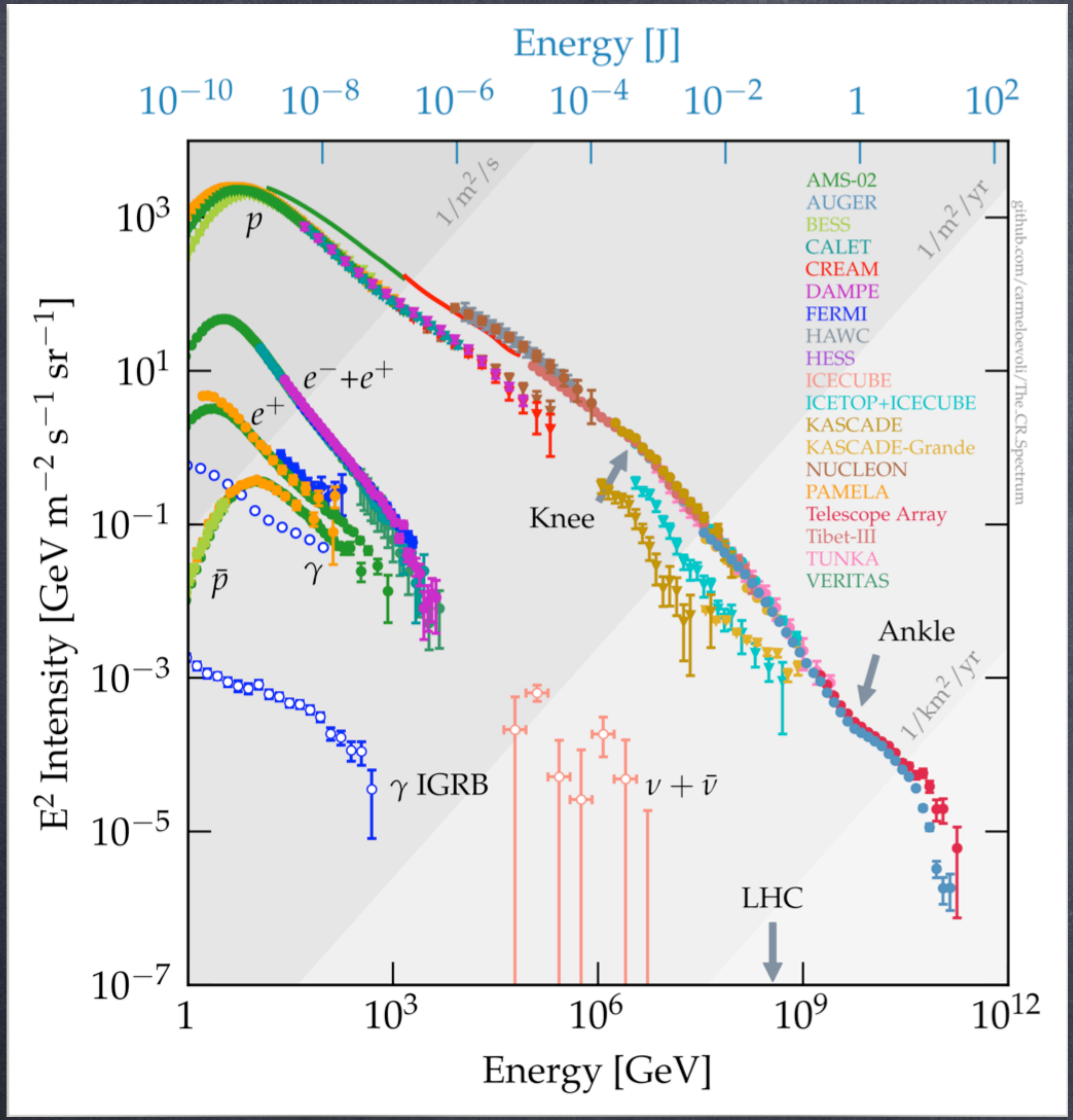
BROAD VARIETY OF ACCELERATION MECHANISMS

- SHOCK ACCELERATION
- MAGNETIC RECONNECTION
- UNIPOLAR INDUCTION
- WAKE FIELD ACCELERATION
- RESONANT WAVE ABSORPTION

DIFFERENT PROPERTIES OF THE PLASMA IN THE SOURCE

- RELATIVISTIC VS NON-RELATIVISTIC
- COMPOSITION: $p+e^-$, e^-+e^+, N
- MAGNETIZATION AND B-FIELD ORIENTATION

COSMIC RAYS



98% PROTONS AND NUCLEI

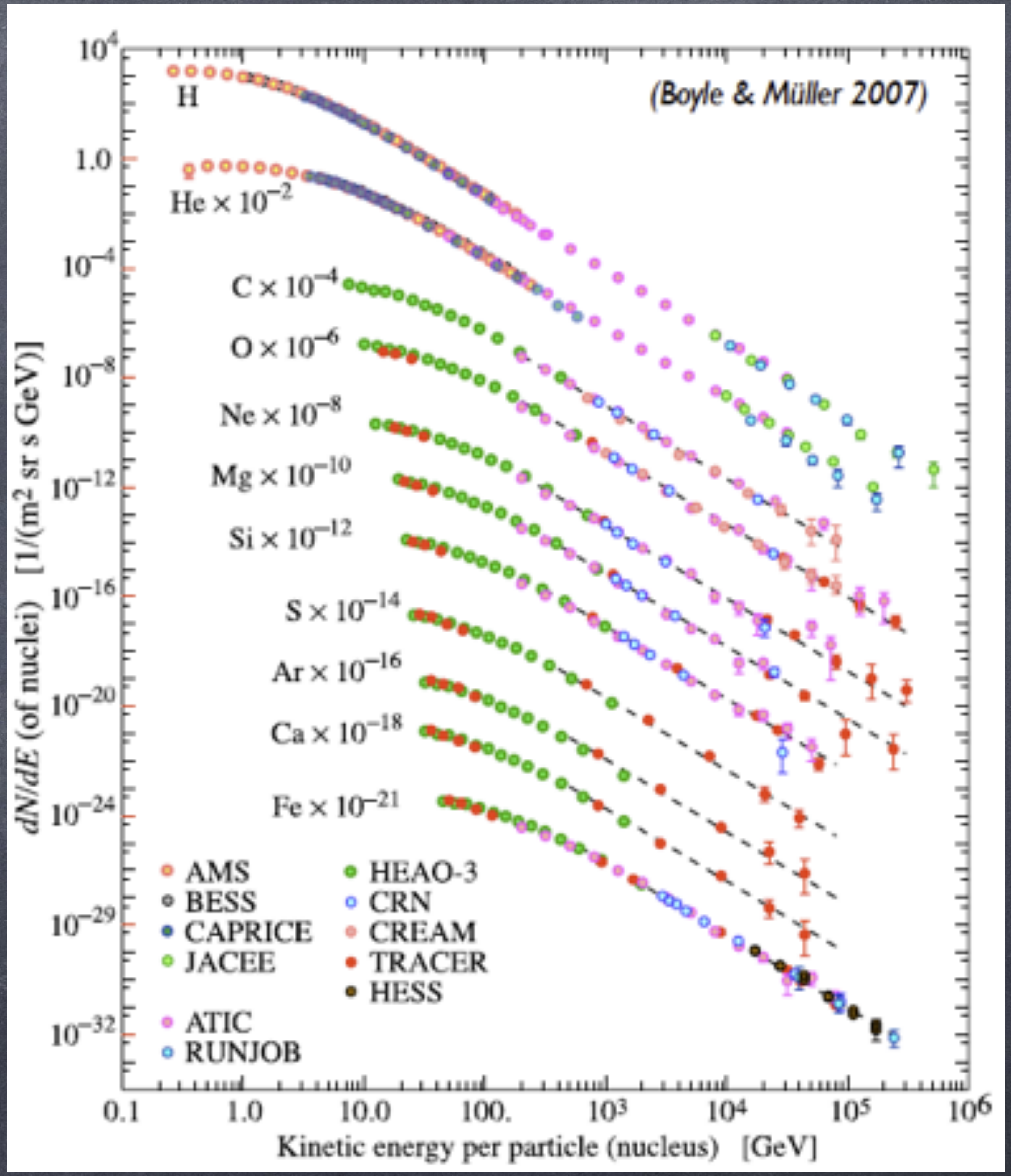
87% PROTONS

12% He

1% HEAVIER NUCLEI

2% ELECTRONS

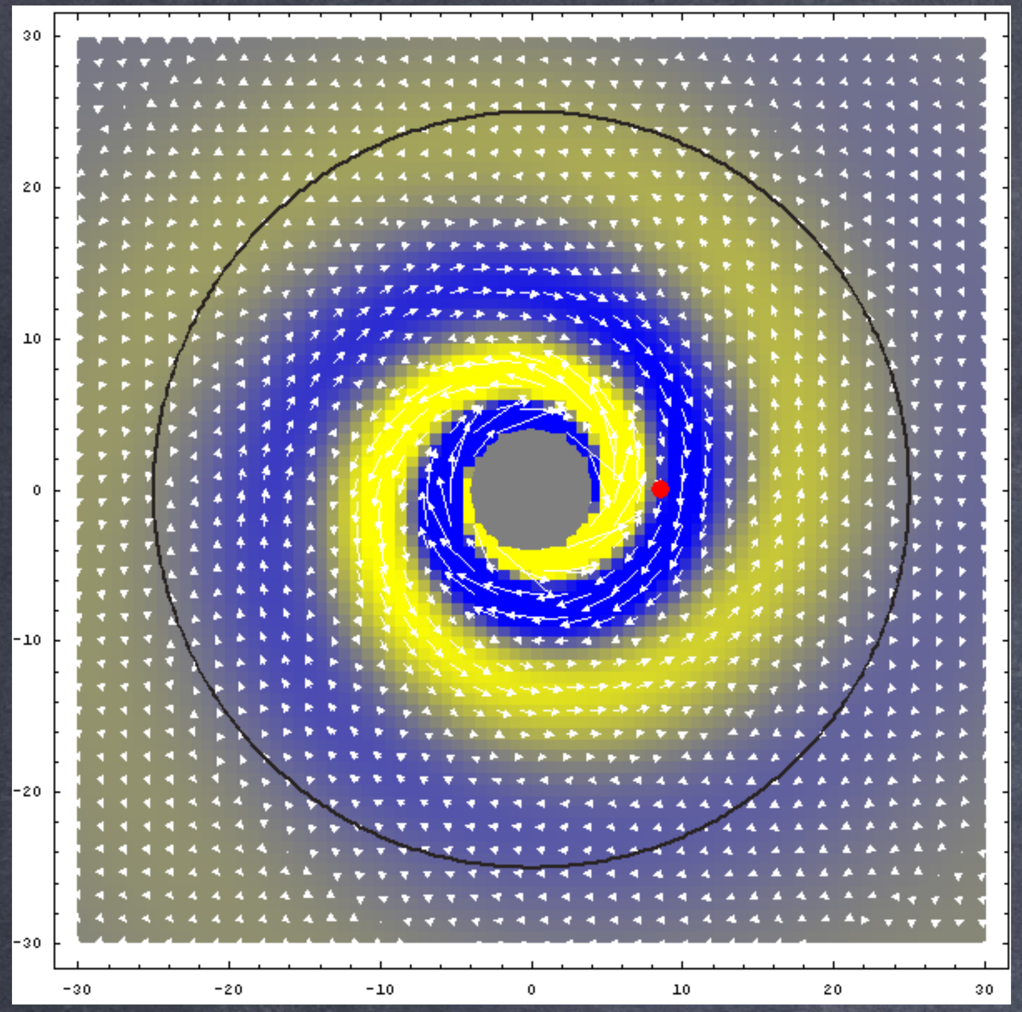
0.1% ANTIMATTER (POSITRONS AND ANTI-PROTONS)

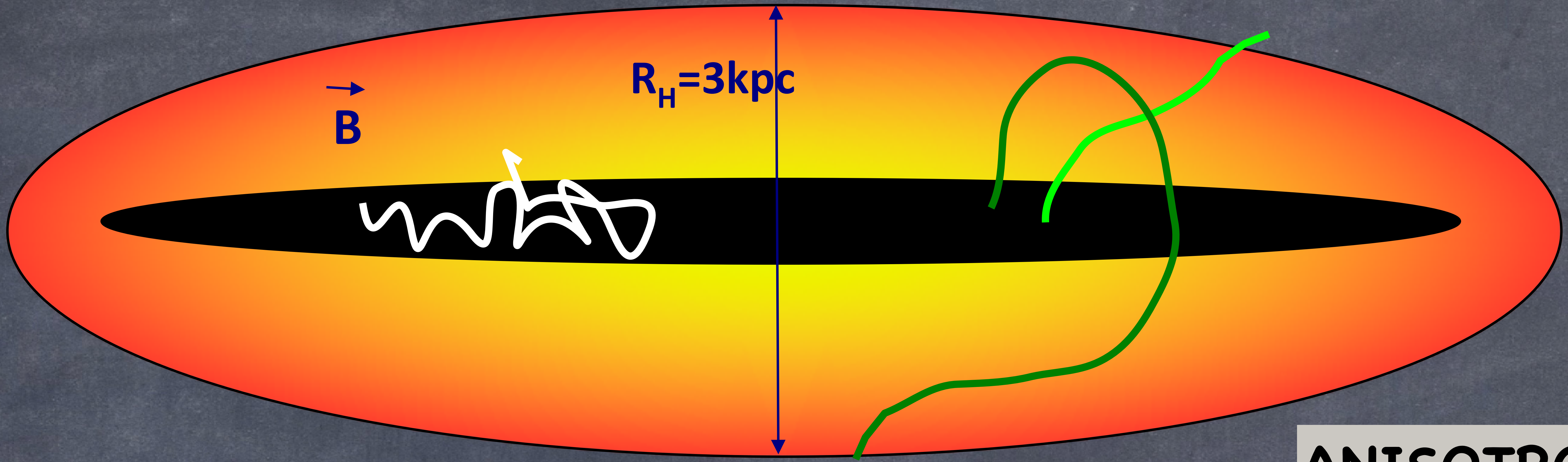


A FUNDAMENTAL COMPONENT OF THE ISM

ENERGY DENSITY: $0.5\ eV \approx U_{CR} \approx U_{CMB} \approx U_B \approx U_{th} \approx \approx U_{sl}$

GALACTIC COSMIC RAYS



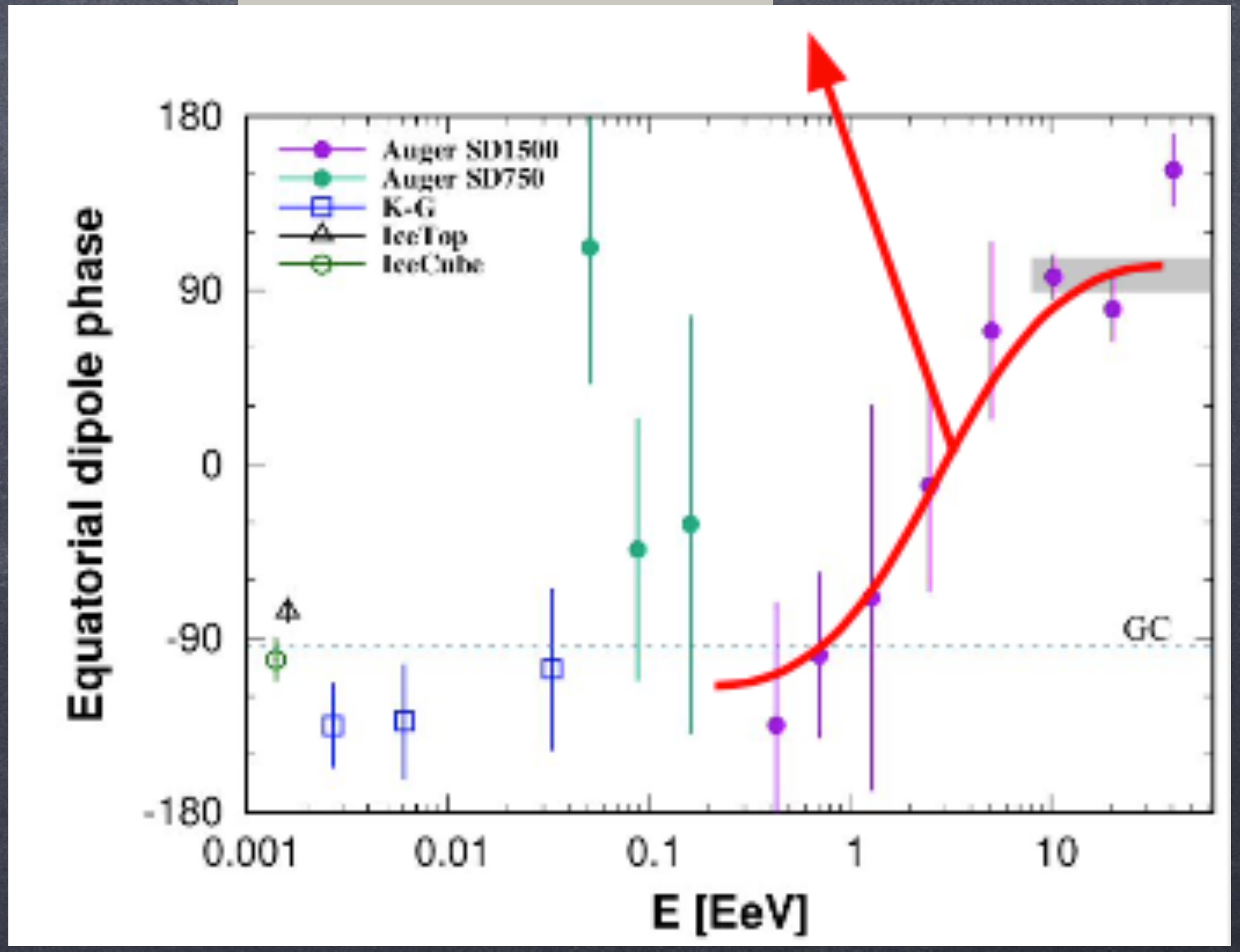


$$R_L(E) \approx R_H$$

$$E[eV] \approx 300\ B[\mathrm{G}]\ R_H[\mathrm{cm}]$$

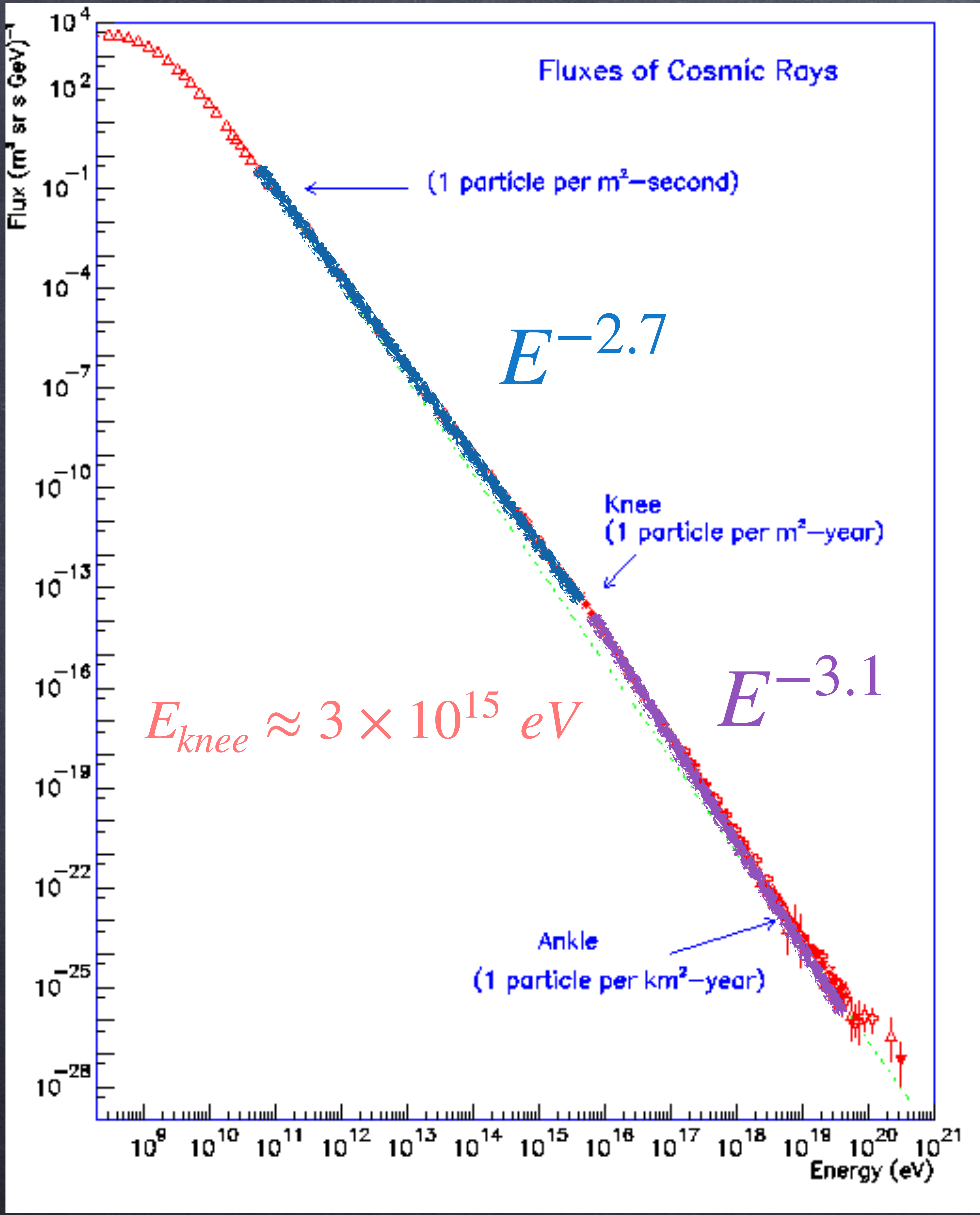
$$E_{\mathrm{trans}} \approx 5 \times 10^{18}\mathrm{eV}$$

ANISOTROPY



Auger 20

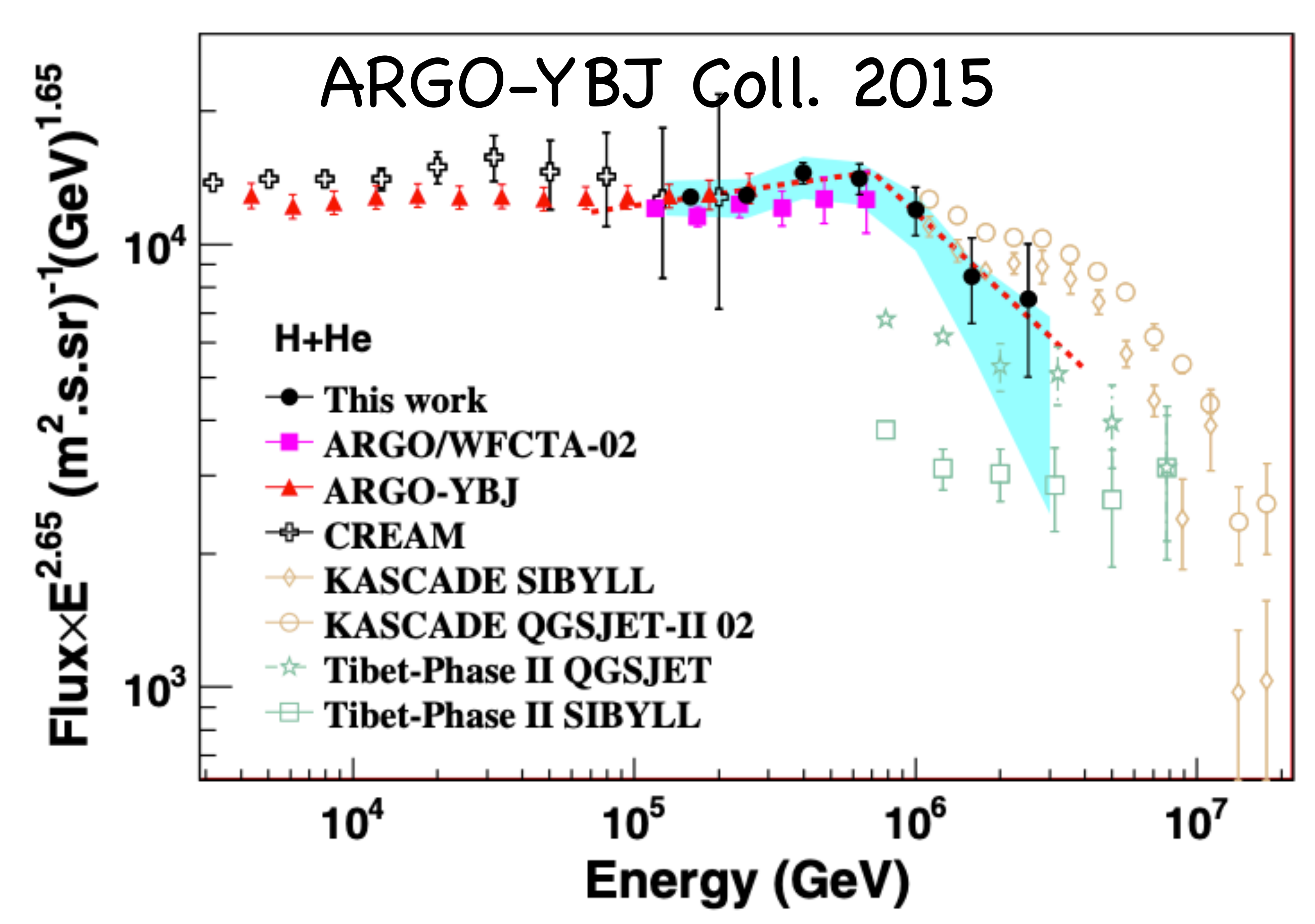
GALACTIC COSMIC RAYS



RIGIDITY DEPENDENT ACCELERATION

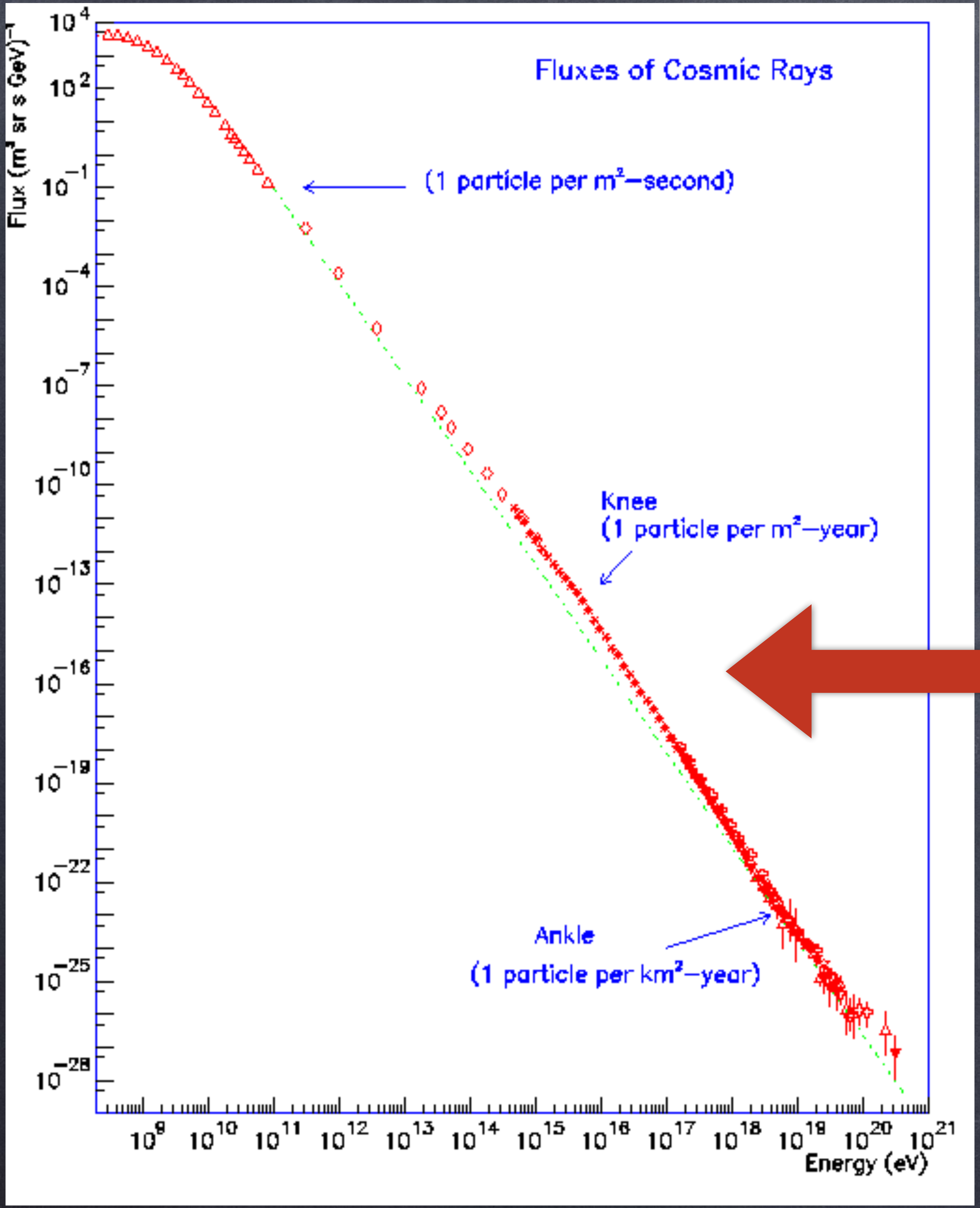
KNEE=END OF GALACTIC PROTON SPECTRUM

BUT REMEMBER....



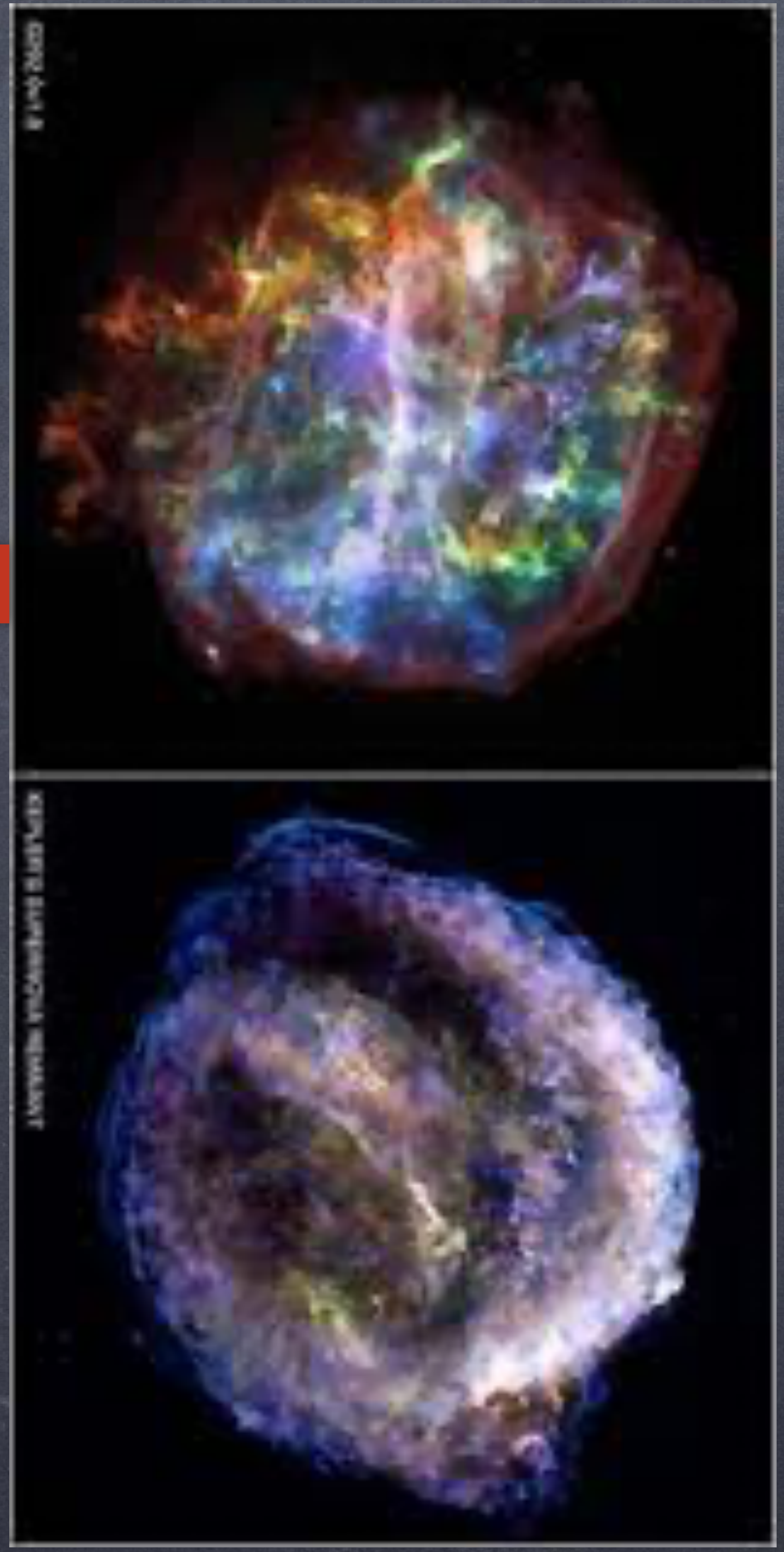
THE SNR/CR CONNECTION

THE SNR/CR CONNECTION



QUALITATIVE SUGGESTION IN BRILLIANT PAPER

Baade & Zwicki 1934



$$L_{CR} = \frac{W_{CR} V_{CR}}{\tau_{res}} \approx (3-10) \times 10^{40}\ erg/s$$

$$L_{SN} = \mathscr{R} E_{SN} \approx (3-10) \times 10^{40}\ erg/s$$

$$\frac{L_{CR}}{L_{SN}} = 0.03 - 0.3$$

$$V_{CR} \approx \pi R_d^2 H \approx \pi\ (15\ kpc)^2\ ((1-3)\ kpc)$$

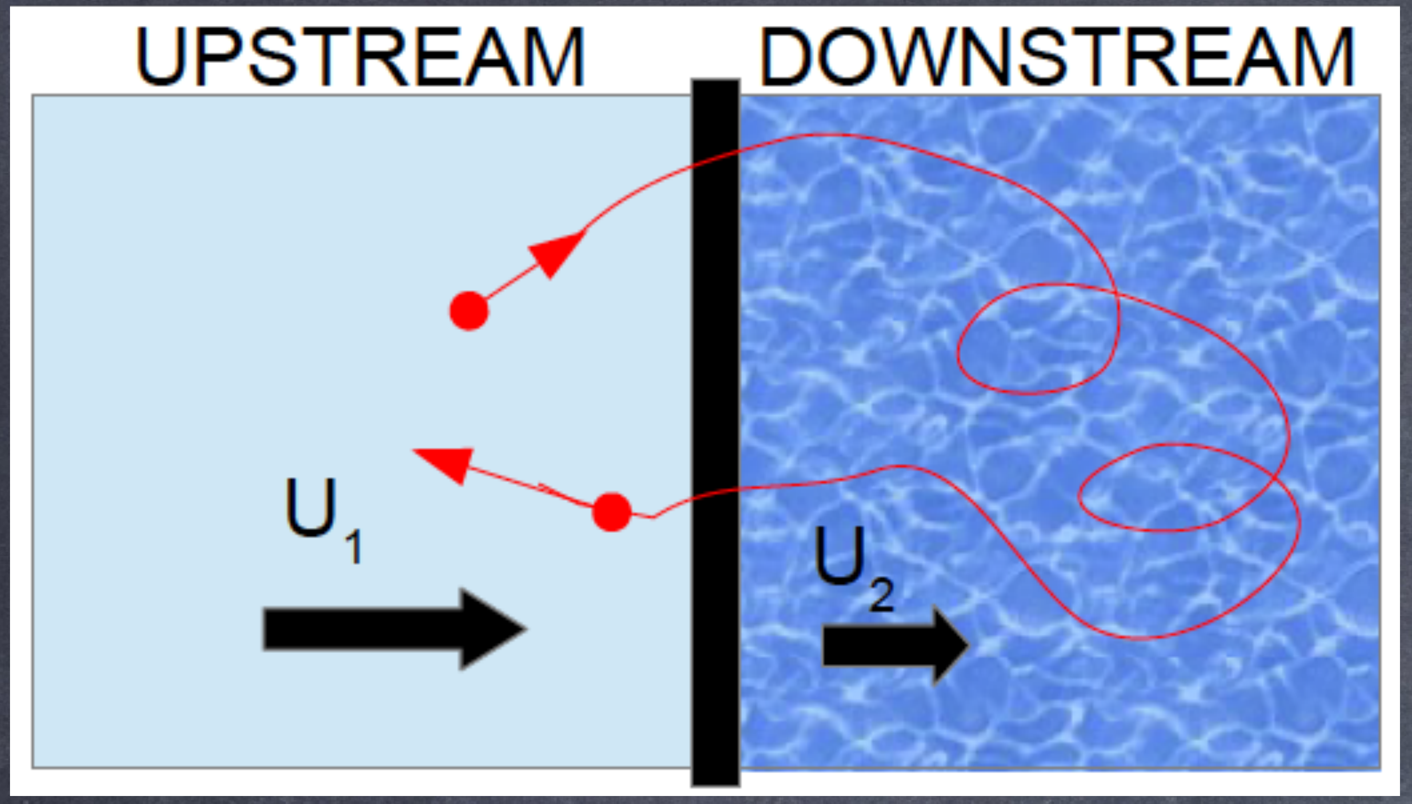
$$W_{CR} \approx 0.5 eV/cm^3$$

$$\mathscr{R} \approx \frac{1}{(30-100)\ yr} \qquad E_{SN} \approx 10^{51} erg$$

QUANTITATIVE SUGGESTION

Ginzburg 1960s

SHOCK ACCELERATION



NOTE: IT IS THE ELECTRIC FIELD THAT DOES THE WORK!!!!

VELOCITY DIFFERENCE BETWEEN REGIONS IN THE PLASMA LEAVES UNSCREENED ELECTRIC FIELD

RELATIVISTIC PARTICLE SPECTRUM ONLY DEPENDS ON COMPRESSION RATIO:

$$N(E) \propto E^{-\gamma} \qquad \gamma = \frac{R+2}{R-1} \longrightarrow 2$$ FOR STRONG SHOCKS

$$\frac{\Delta E}{E} = \frac{4}{3}\frac{V}{c}$$

E_{max} DEPENDS ON VELOCITY AND SCATTERING EFFICIENCY

$$E_{max} \Leftarrow t_{acc}\left(E_{max}\right) = min\left[t_{age}, t_{loss}\left(E_{max}\right)\right]$$

$$t_{acc} = \frac{E}{dE/dt} = \frac{\tau_{diff}}{\Delta E/E} = \frac{3}{U_1 - U_2}\left(\frac{D_1}{U_1} + \frac{D_2}{U_2}\right) \approx \frac{8D_1(E)}{V_s^2}$$

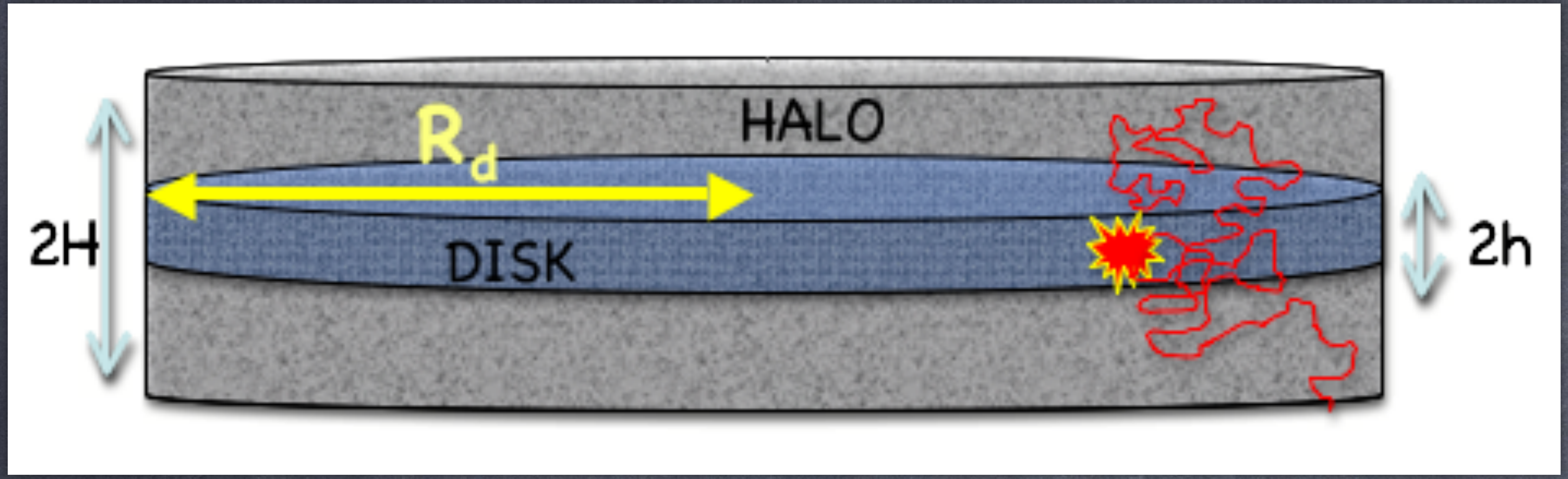
$t_{acc} < t_{age} \Rightarrow$

$E_{max} \sim GeV$ IF SAME D AS IN ISM

$E_{max} \sim 10^3 - 10^4 GeV$ IF SAME $\delta B \sim B_0$ AT RELEVANT SCALES....

(Lagage & Cesarsky 83)

PROPAGATION EFFECTS

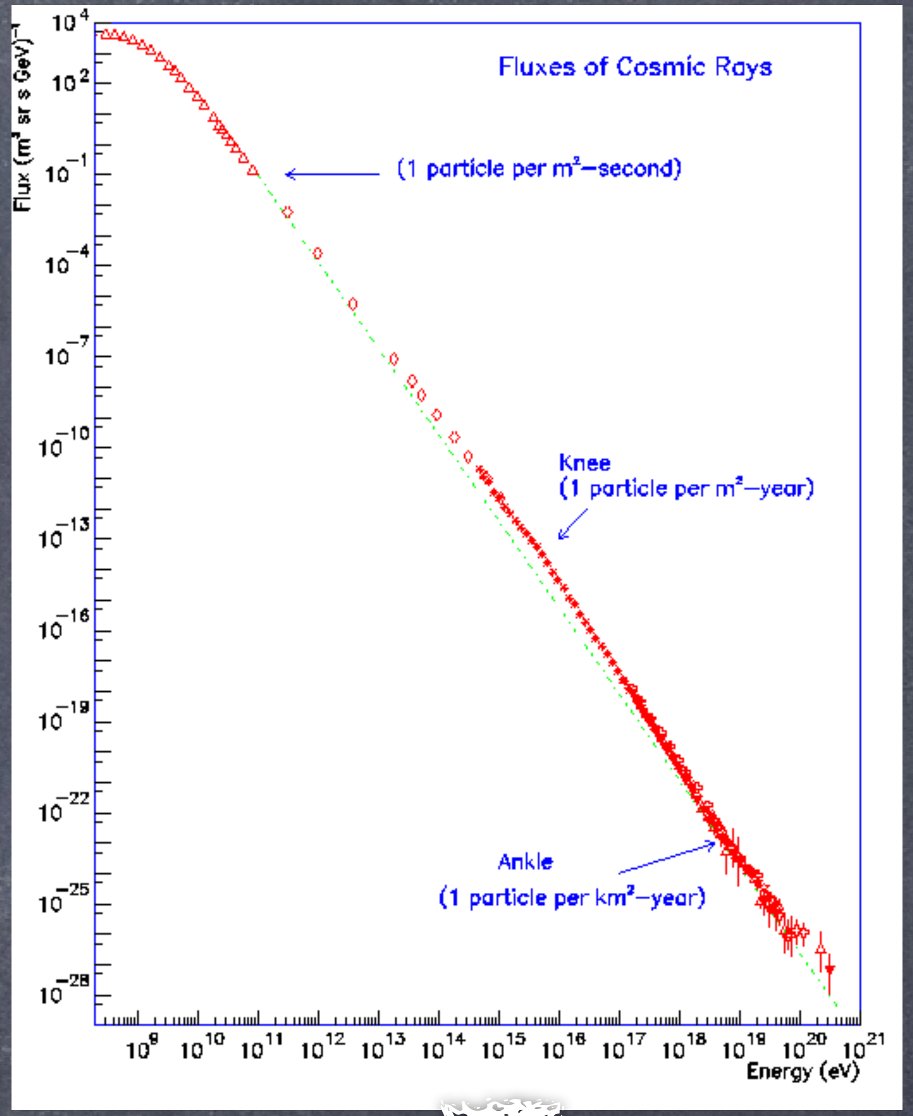


INJECTION

$$Q(E) \propto E^{-\gamma_{inj}}$$

PROPAGATION

$$D(E) \propto E^{\delta_E}$$



$$\frac{dN(E)}{dt} = Q(E) - \frac{N(E)}{\tau_{esc}}$$ STEADY STATE → $$N(E) = Q(E)\ \tau_{esc}$$

LEAKY BOX MODEL $$\tau_{esc}(E) \approx \frac{H^2}{D(E)} \propto E^{-\gamma_{inj}}$$

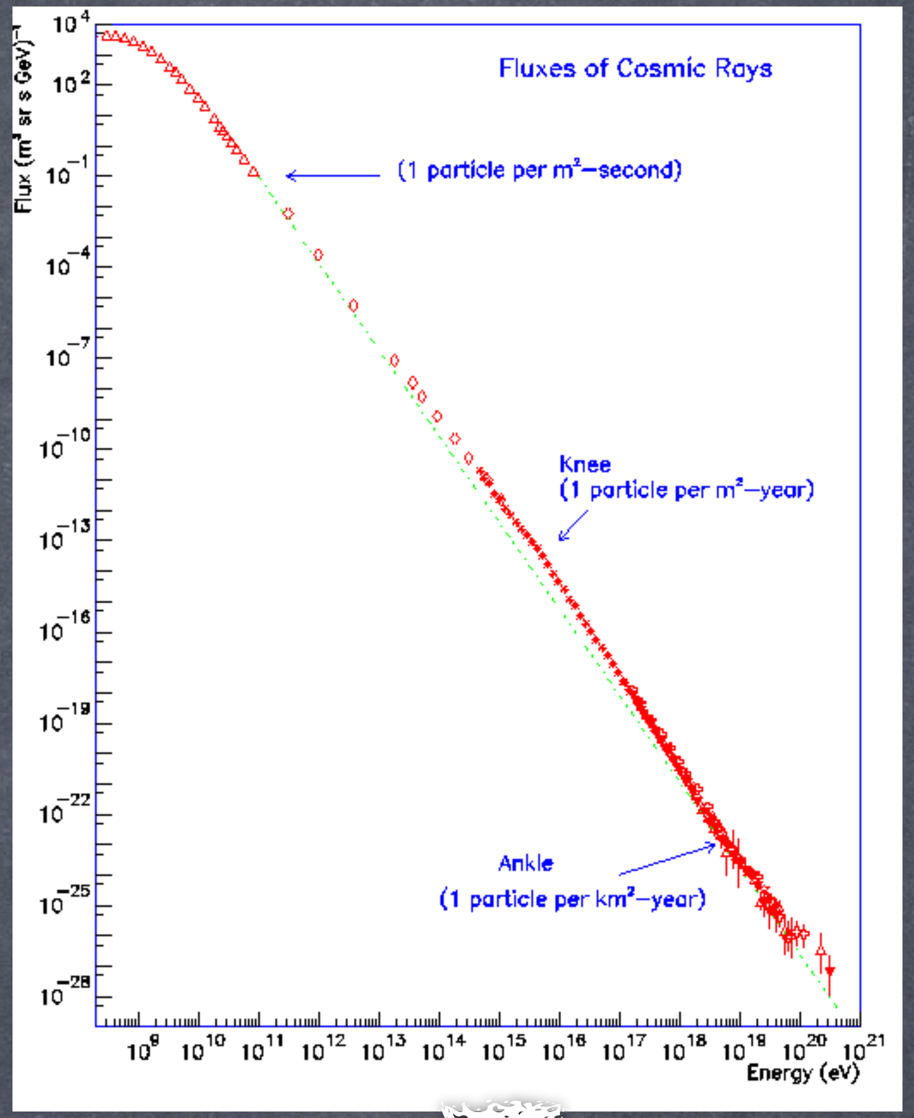
PROTON SPECTRUM $$N(E) = \frac{N_S(E)\mathscr{R}}{2\pi R_d^2 H}\ \tau_{esc} \propto E^{-\gamma_{inj}-\delta_E}$$

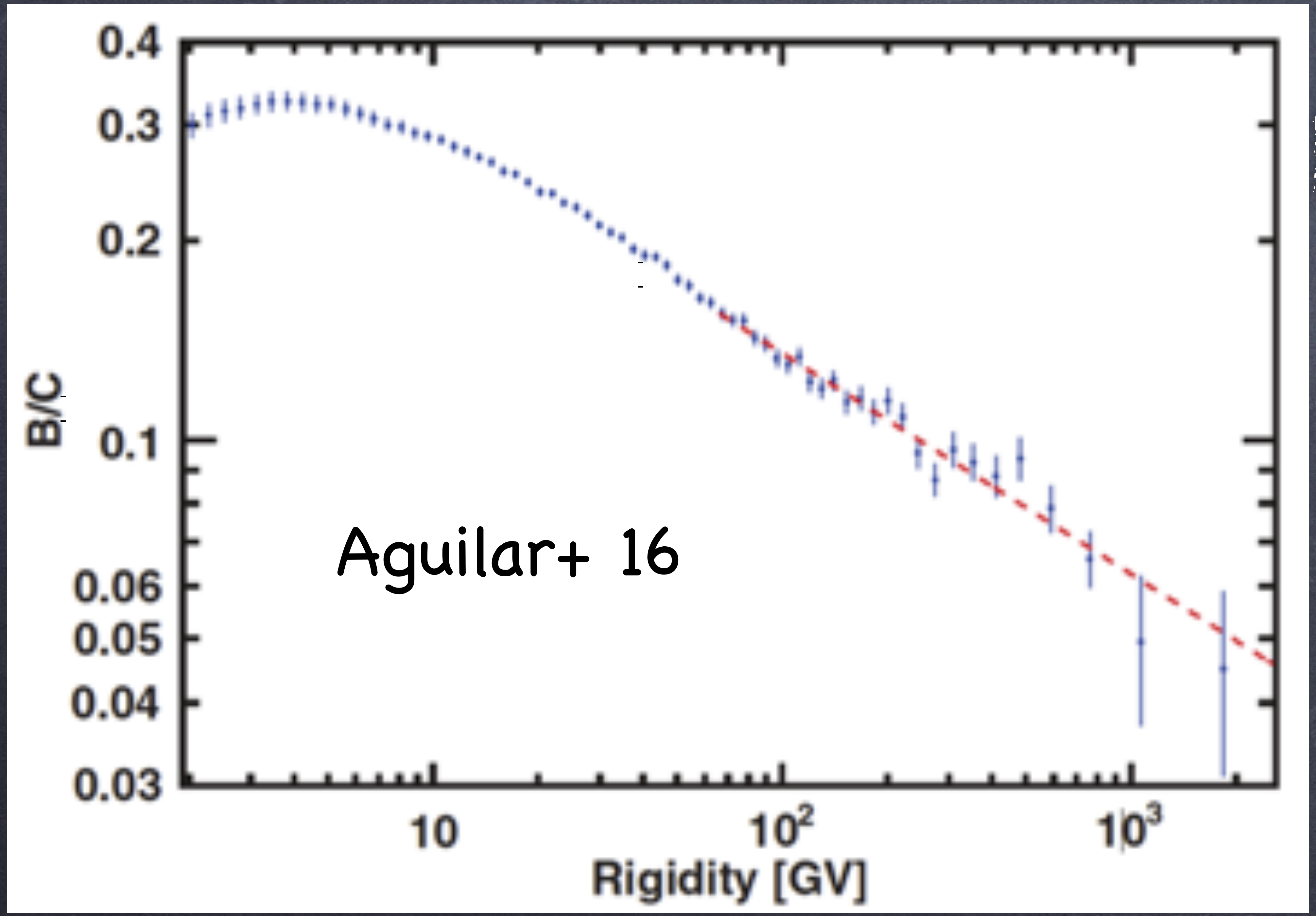
$$\gamma_{inj} + \delta_E \approx 2.7$$

THE INJECTION SPECTRUM OF CRs

$$N_{sec}(E) \propto N_{prim} c n_H \sigma \tau_{esc} \propto Q(E)\, \tau_{esc}^2$$

$$\frac{N_{sec}}{N_{prim}} \propto \tau_{esc} \propto E^{-\delta_E}$$



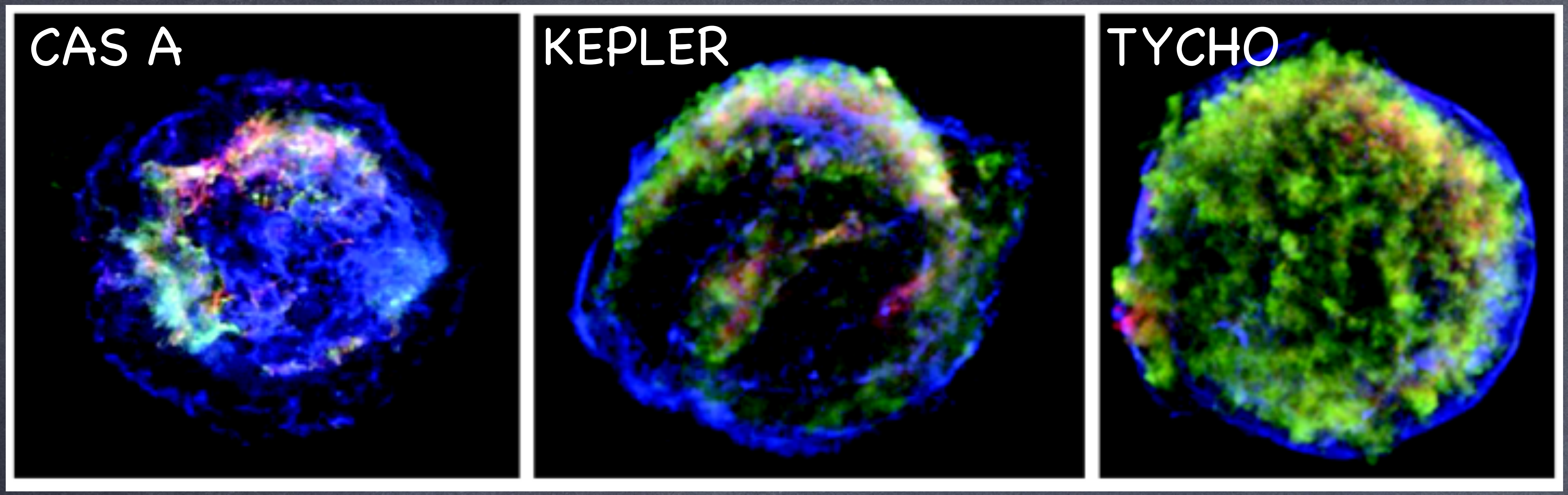


$$\delta_E \approx 0.33 - 0.45$$

$$\gamma_{inj} + \delta_E = 2.7 - 2.8$$

$$\gamma_{inj} \approx 2.3 - 2.4$$

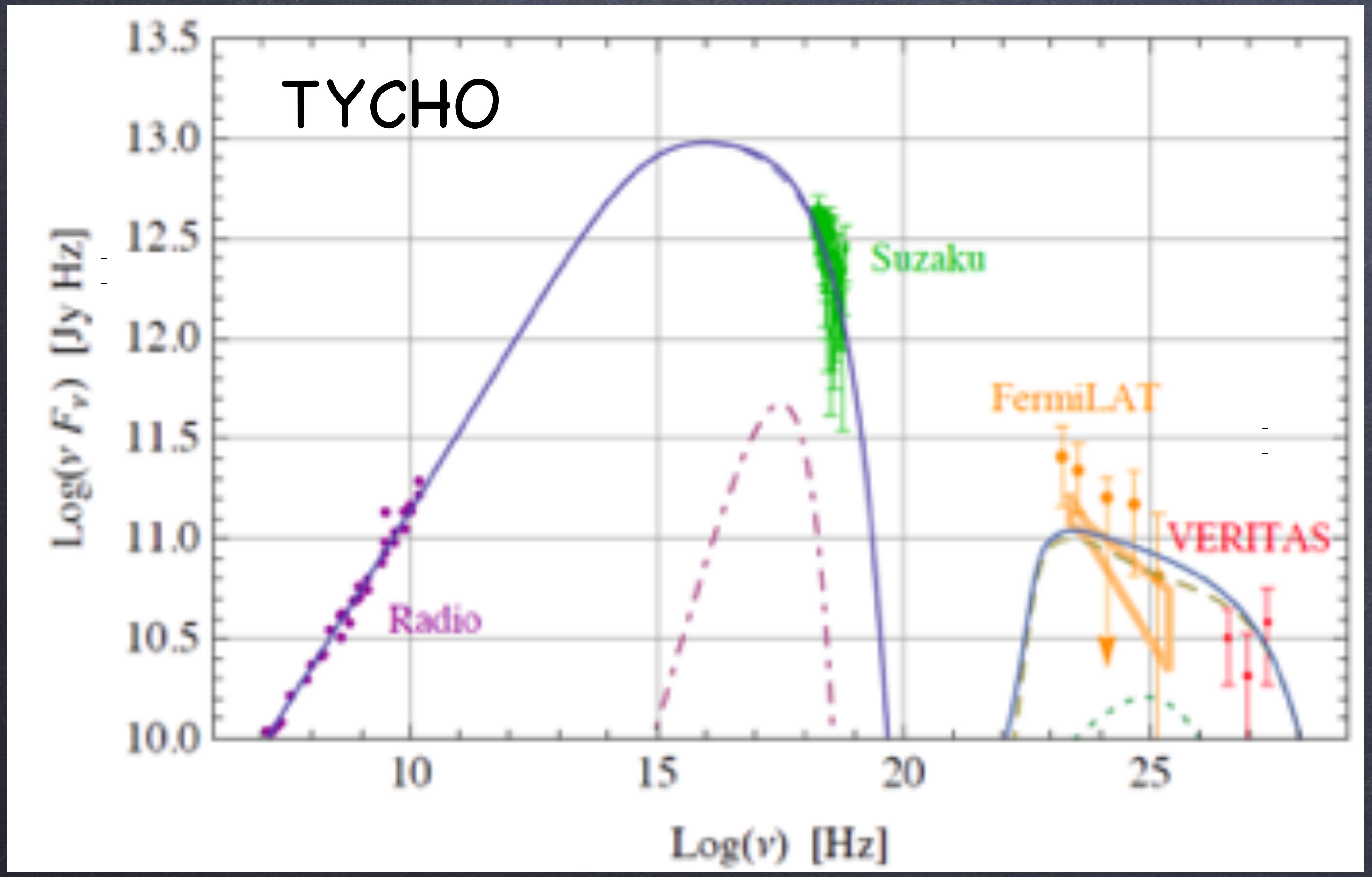
FERMI MECHANISM AT SNR SHOCKS



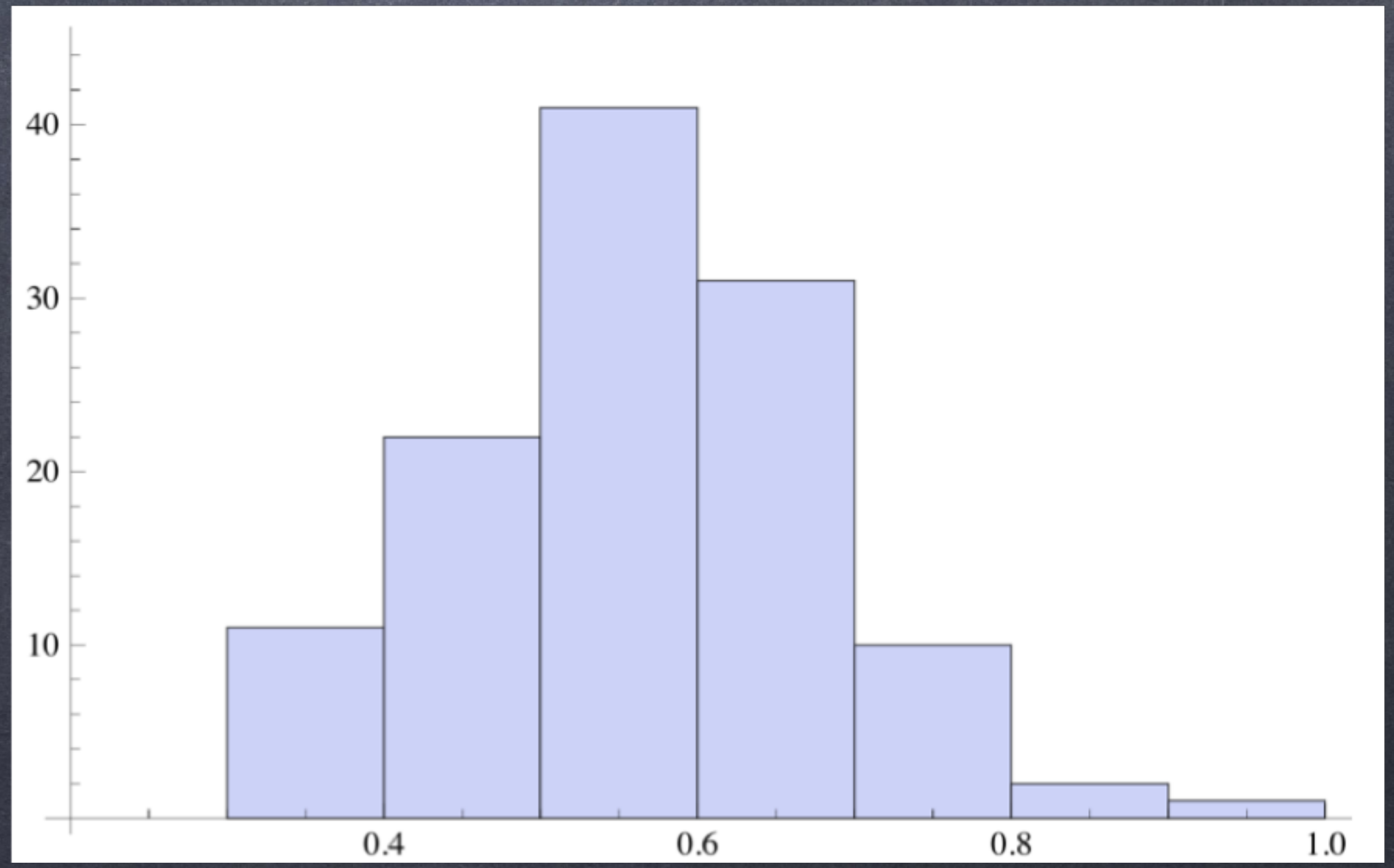
$$V_{ej} \approx \sqrt{\frac{2E_{SN}}{M_{ej}}} = 10^4 E_{51}^{1/2}\ M_{ej,\odot}^{-1/2}\ km/s$$

$$M_s = V_{ej}/c_s \approx 10^3$$

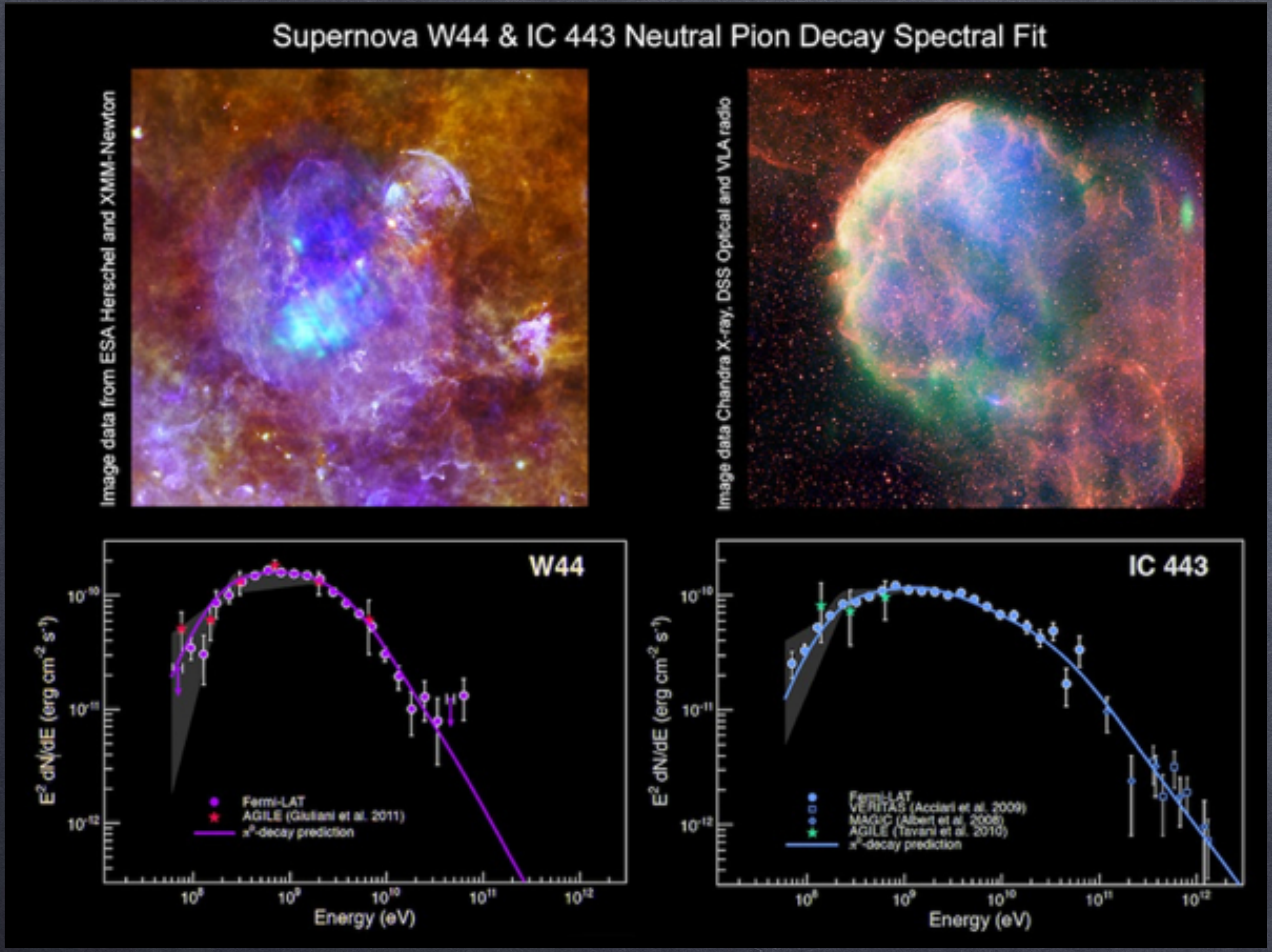
VERY STRONG SHOCKS IN YOUNG SNRs!!!!



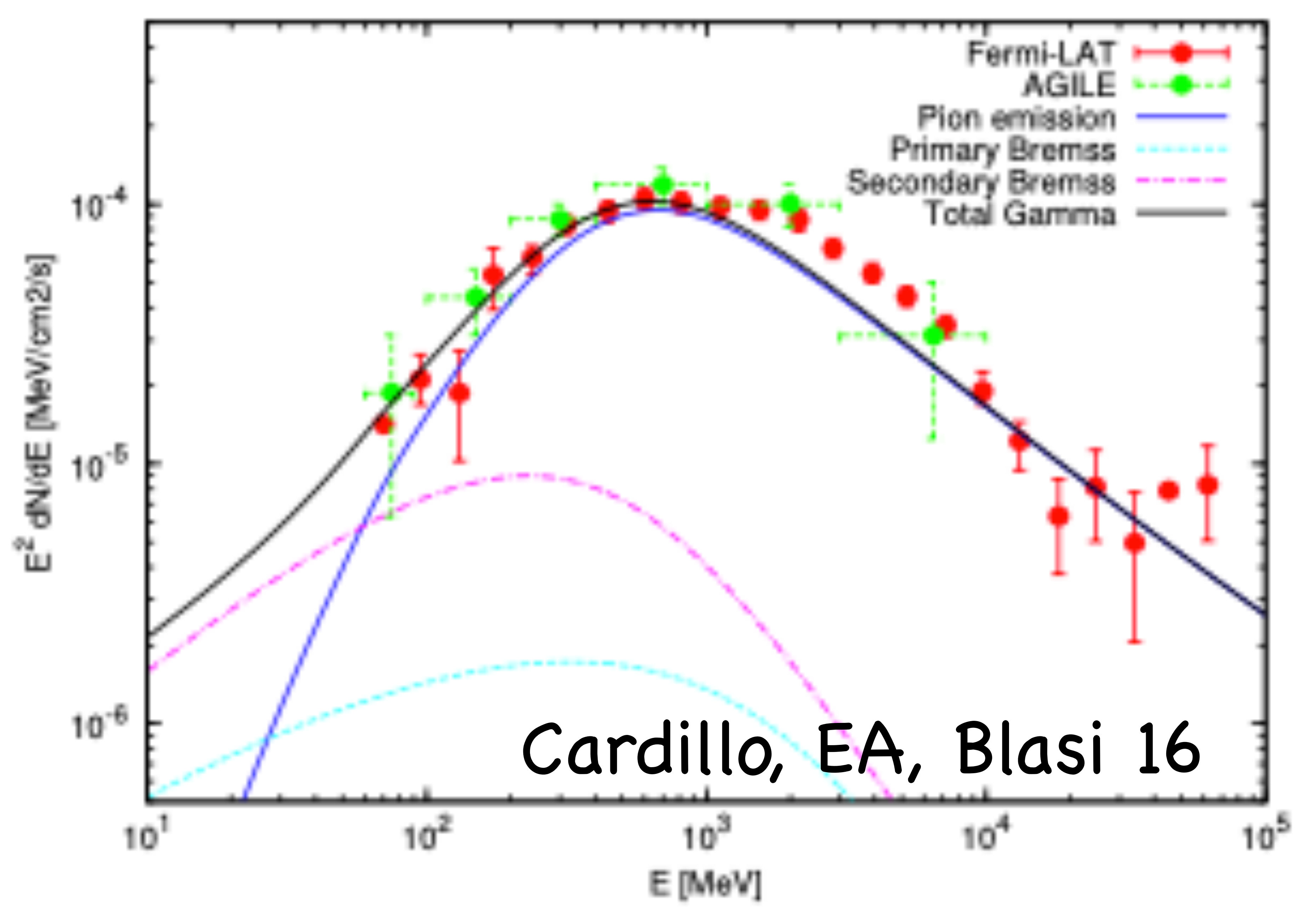
RADIO SPECTRAL INDEX OF GALACTIC SNRs



GAMMA-RAY OBSERVATIONS



Ackermann+13

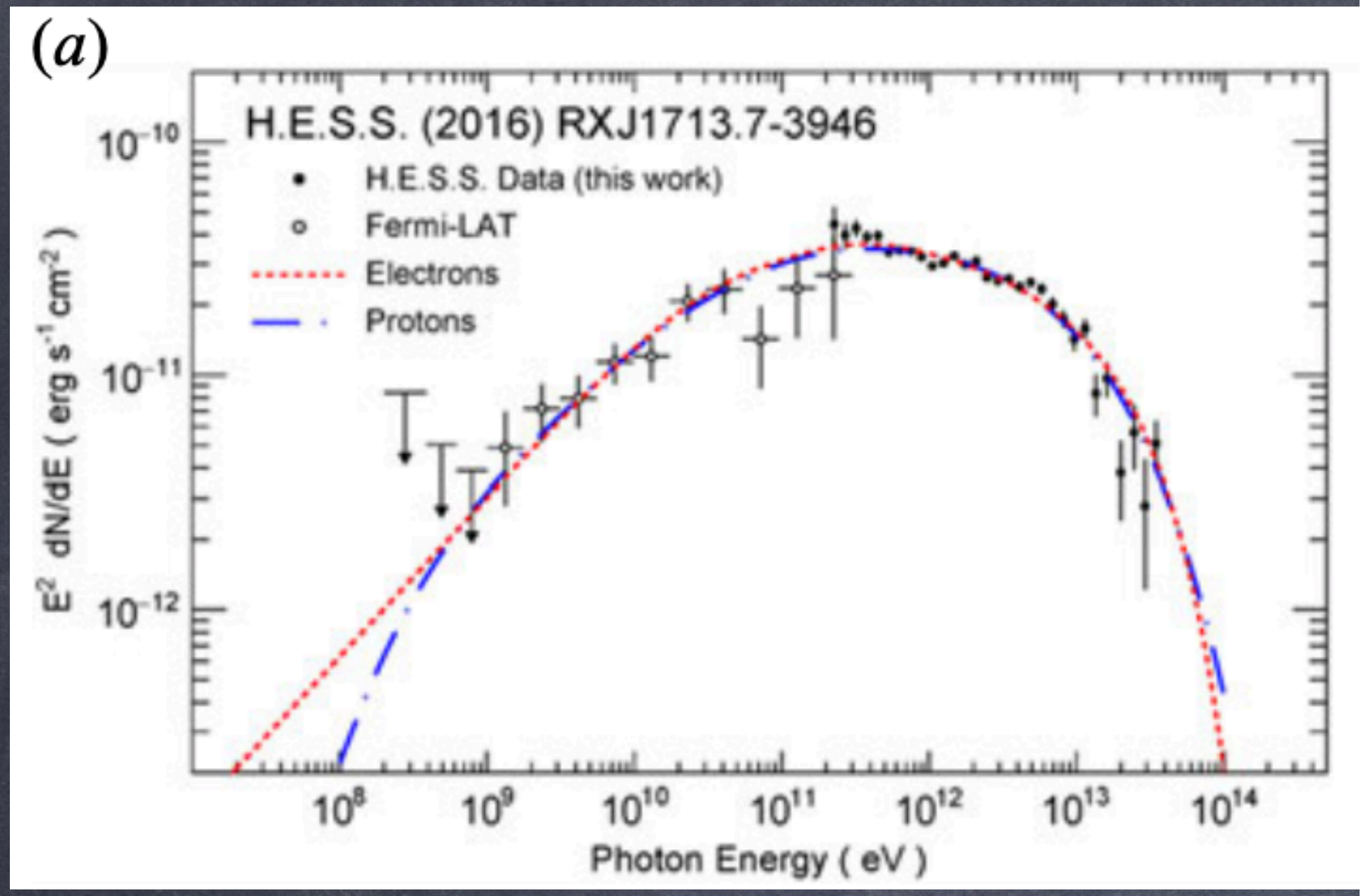


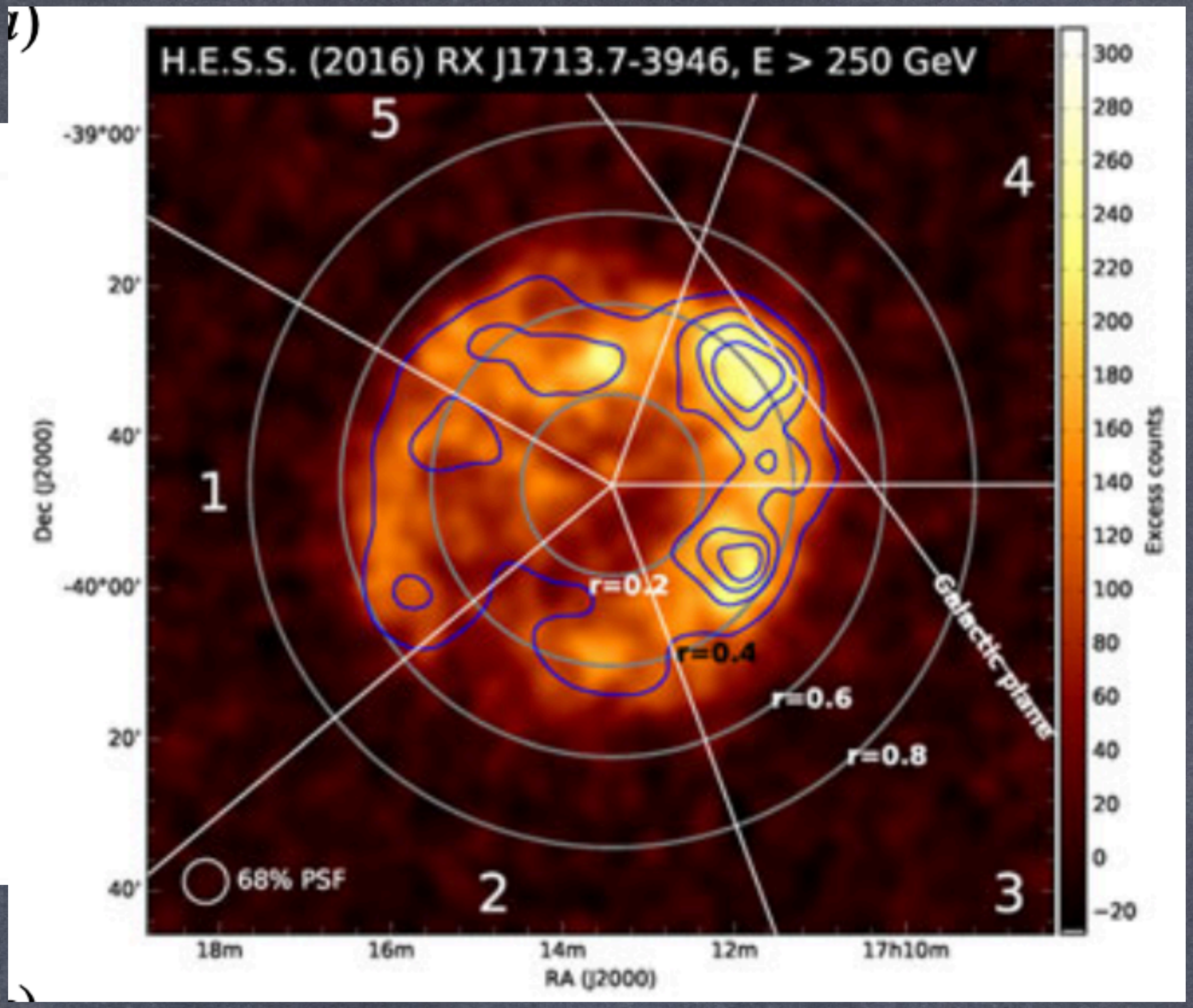
Cardillo, EA, Blasi 16

- PION BUMP IN MIDDLE AGED SNRs
- PROTON MAXIMUM ENERGY TENS OF TeV
- MOSTLY REACCELERATION OF AMBIENT CRs AT LEAST FOR W44 (Cardillo, EA, Blasi 16)

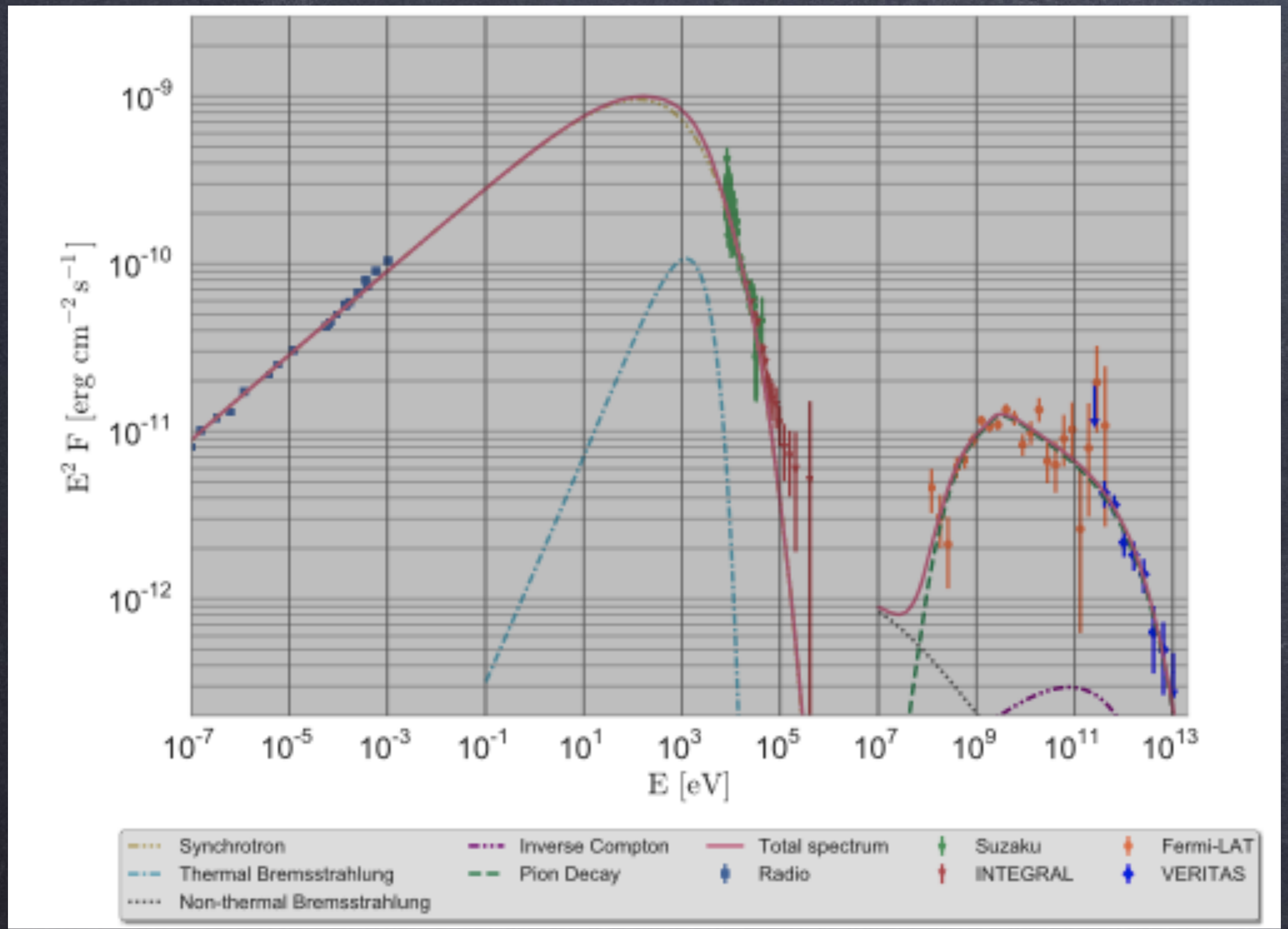
YOUNG SNRs

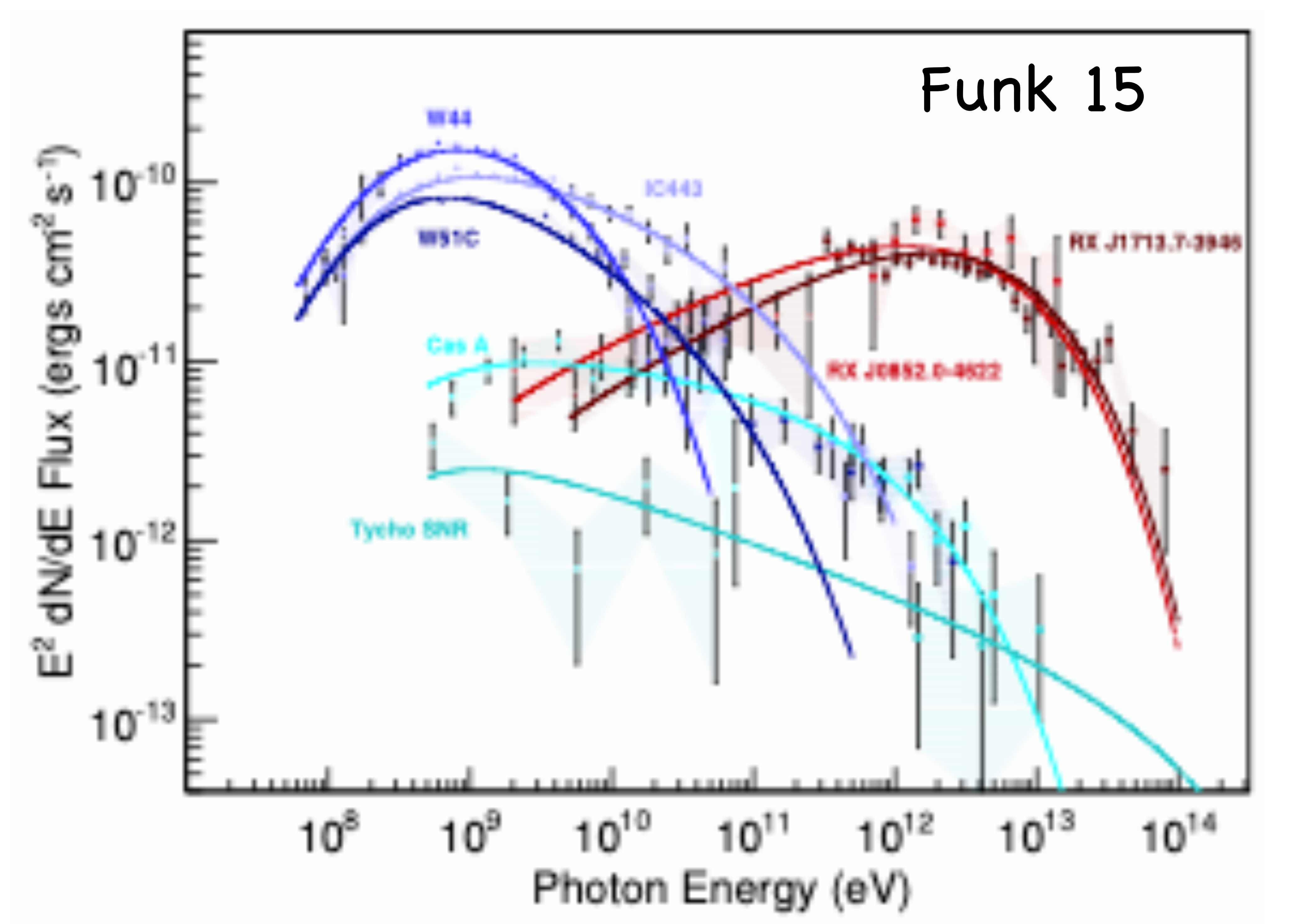
EA & Casanova 21





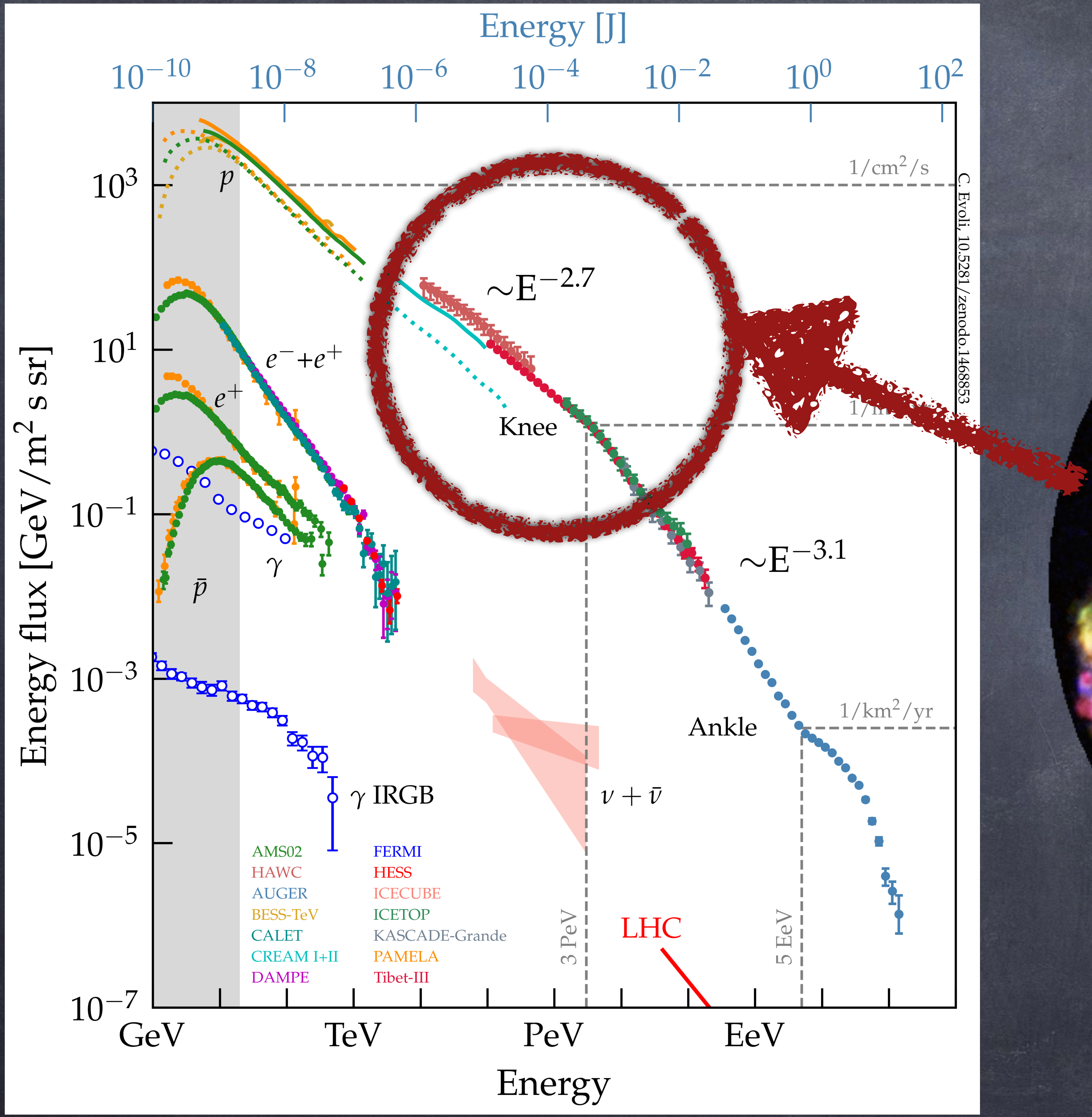
Abeysekara+ 20

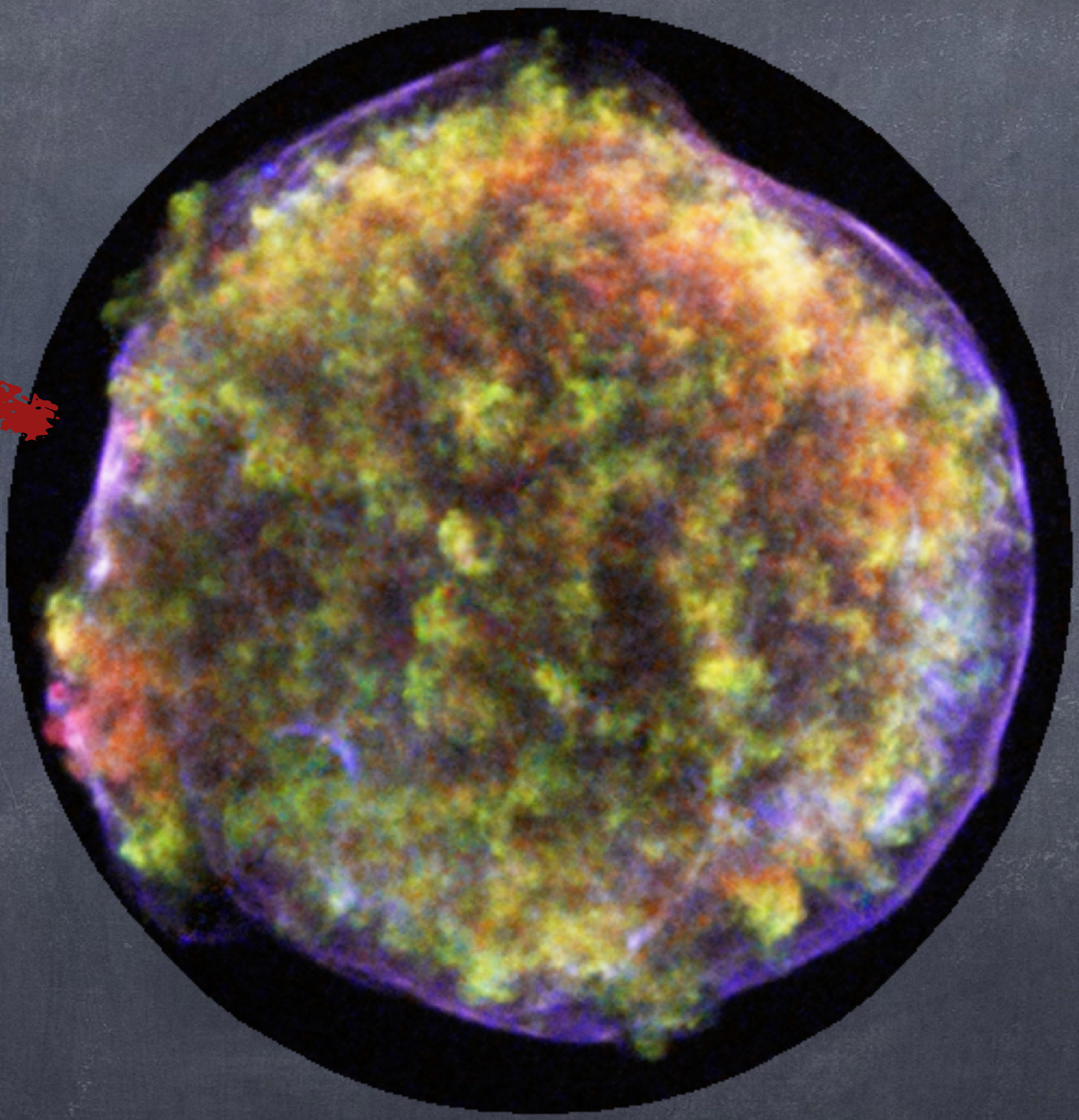




- PROTON SPECTRUM $E^{-2.2/2.3}$
- MAXIMUM PROTON ENERGY ~ 10-50 TeV

MAIN CHALLENGE TO THE CR-SNR PARADIGM

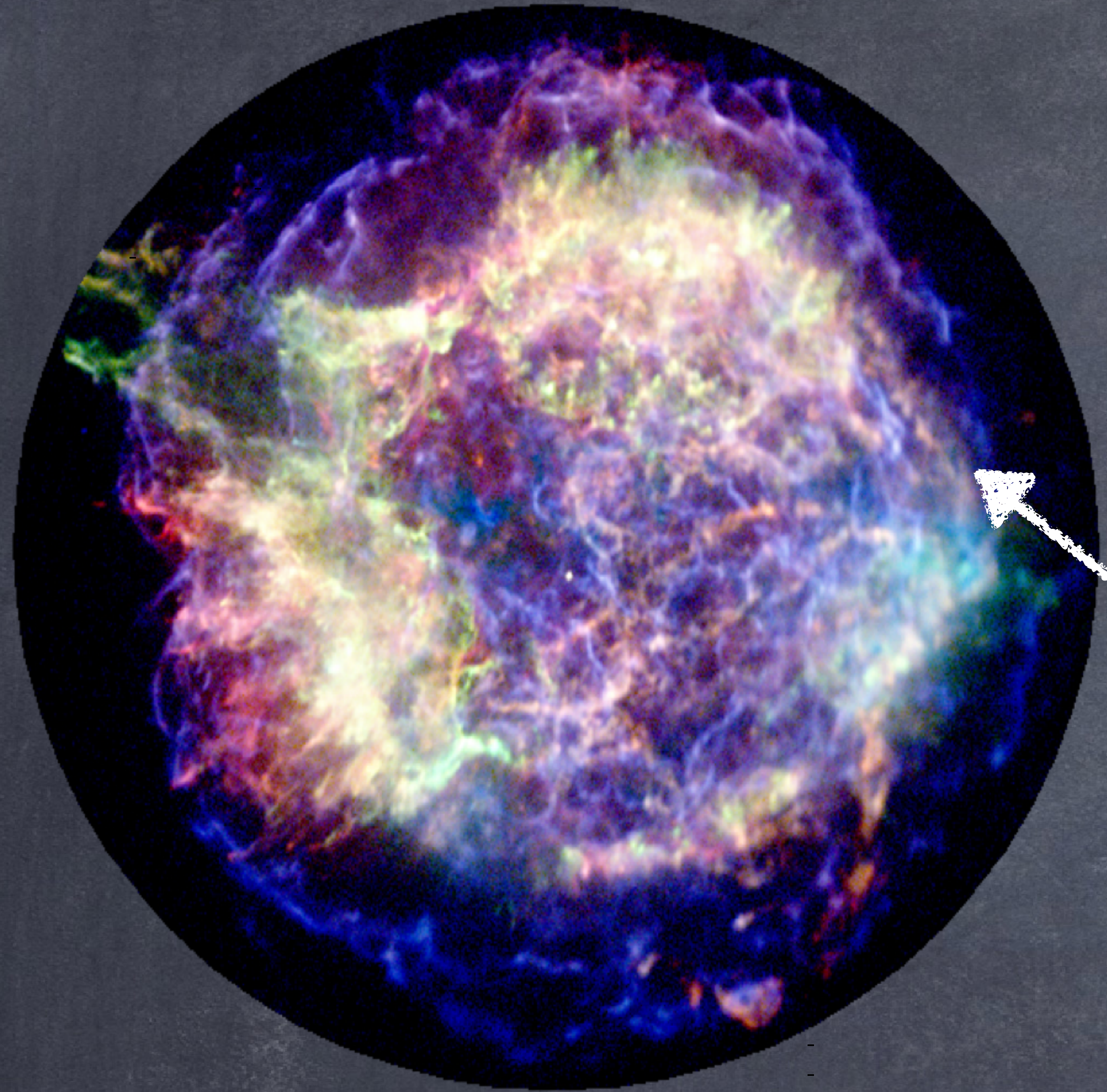




GALACTIC CRS COME FROM SNRS

SNRS MUST BE PEVATRONS

MAGNETIC FIELD AMPLIFICATION



e.g. Vink 12 for a review

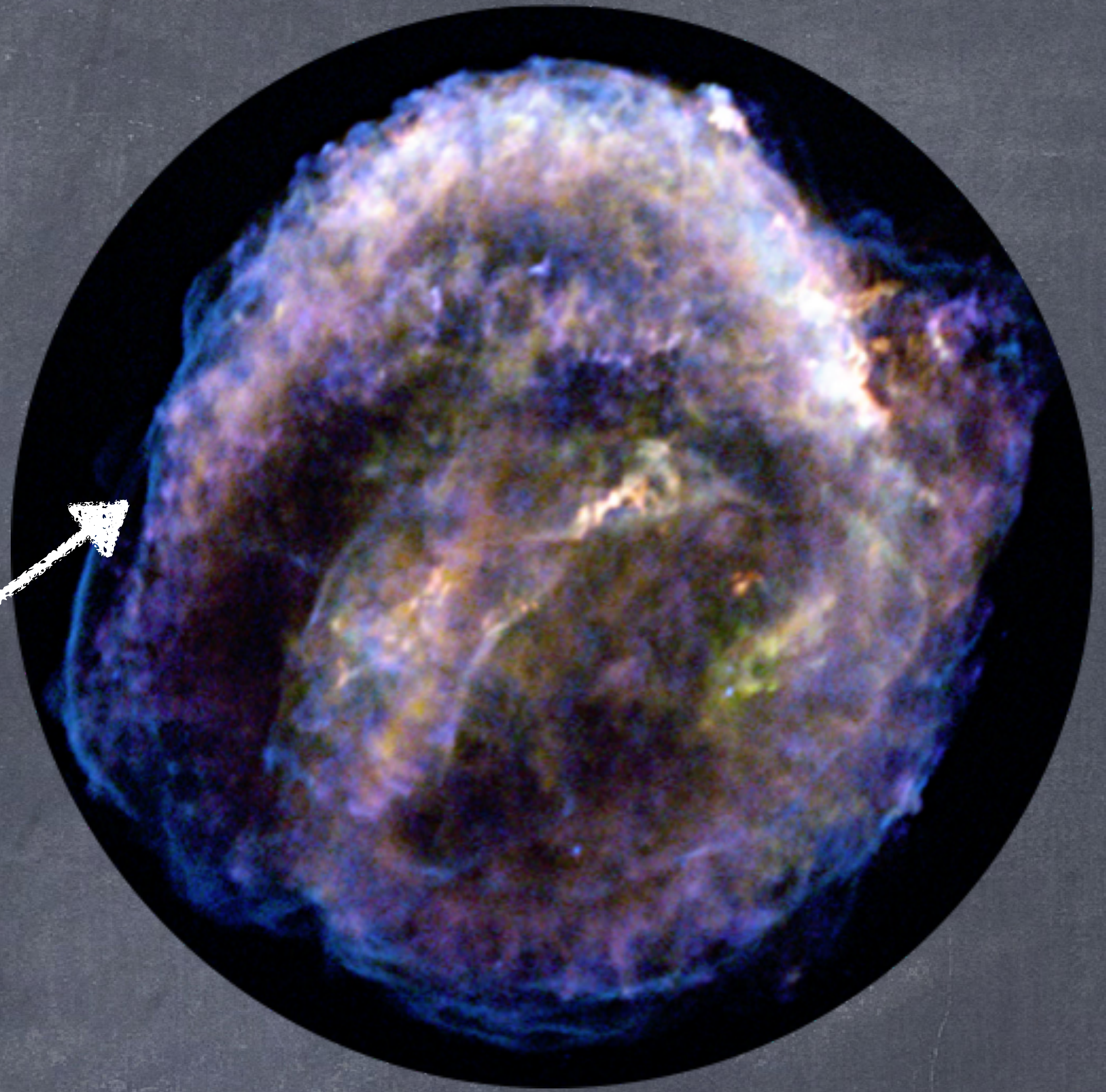
$$\Delta x = \sqrt{D_B \, \tau_{sync}} = 0.04 B_{100}^{-3/2} \; pc$$

$$D_B = \frac{c}{3} r_L = \frac{c}{3} \frac{E}{eB}$$

$$\Delta x \approx 0.01 \; pc$$

↓

$$B \approx 100 - 300 \; \mu G$$

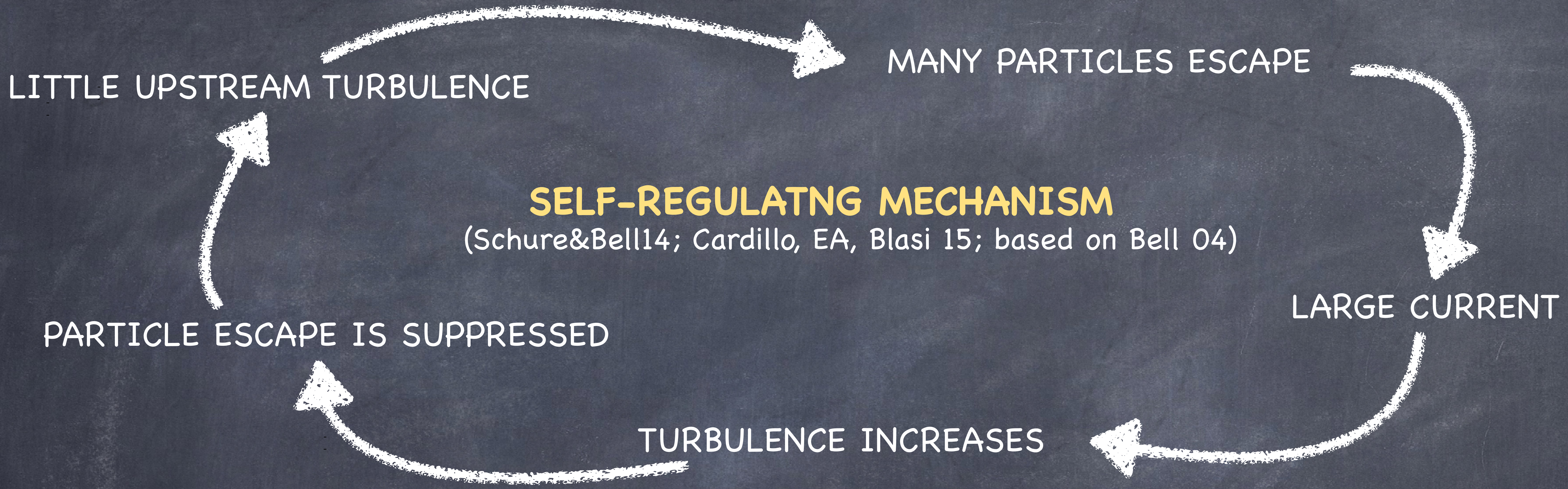


$$E_e \approx 10 \text{ TeV} \; \epsilon_{\gamma,\text{keV}} \; B_{100}^{-1/2}$$

ϵ_γ=1 keV → 30 TeV ELECTRONS

- ELECTRONS ARE LOSS-LIMITED
- PROTONS COULD REACH HIGHER ENERGIES
- MFA A SIGN OF EFFICIENT PROTON ACCELERATION ITSELF

MAXIMUM ENERGY AND PARTICLE ESCAPE



$$E_M \approx 130 \left(\frac{\xi_{\rm CR}}{0.1}\right)\left(\frac{M_{\rm ej}}{M_\odot}\right)^{-\frac{2}{3}}\left(\frac{E_{\rm SN}}{10^{51}{\rm erg}}\right)\left(\frac{n_{\rm ISM}}{{\rm cm}^{-3}}\right)^{\frac{1}{6}} {\rm TeV}$$

TYPE I

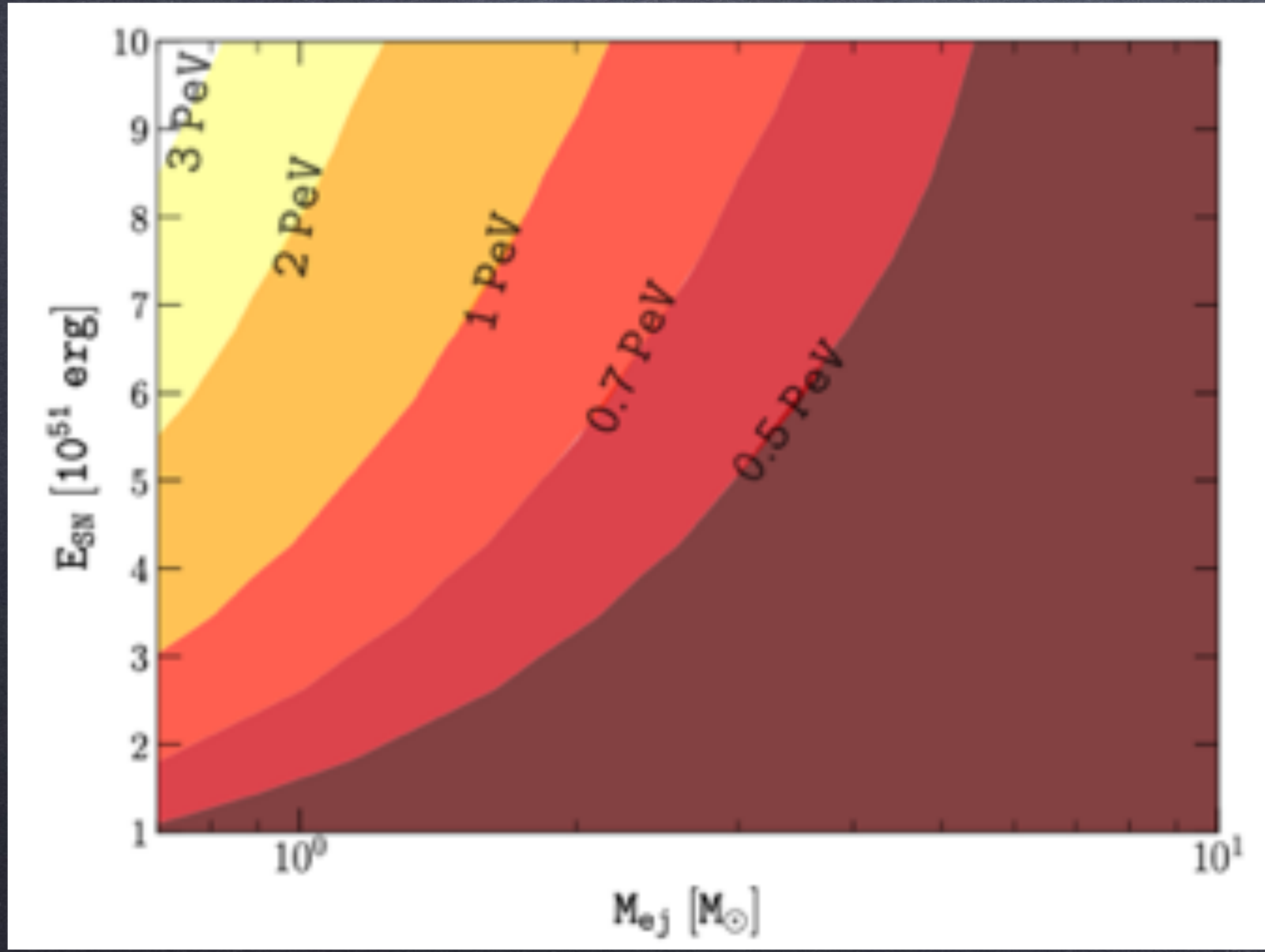
$$E_M \approx 1 \left(\frac{\xi_{\rm CR}}{0.1}\right)\left(\frac{M_{\rm ej}}{M_\odot}\right)^{-1}\left(\frac{E_{\rm SN}}{10^{51}{\rm erg}}\right)\left(\frac{\dot{M}}{10^{-5} M_\odot {\rm yr}^{-1}}\right)^{\frac{1}{2}}\left(\frac{v_w}{10{\rm km/s}}\right)^{-\frac{1}{2}} {\rm PeV}$$

TYPE II

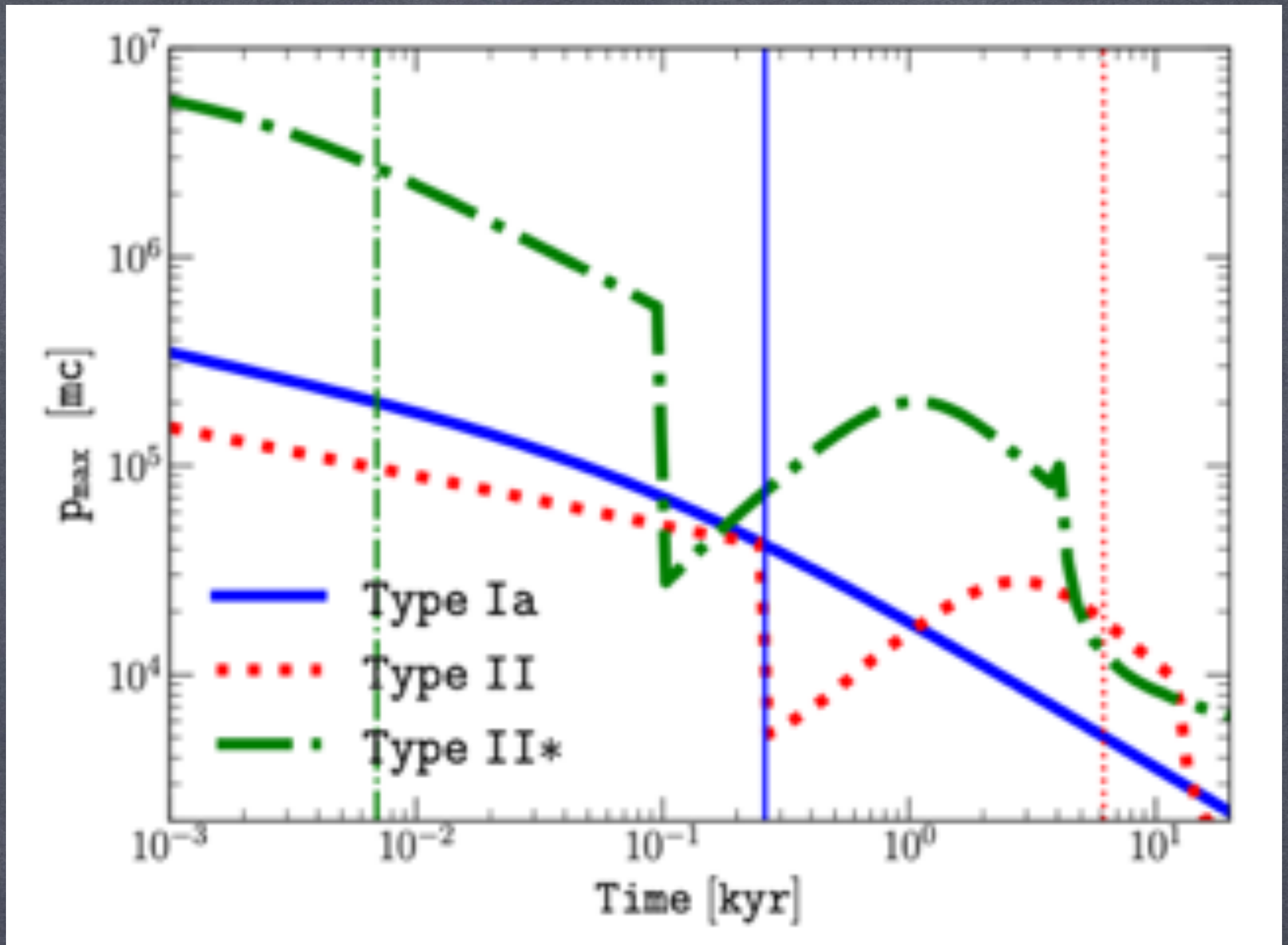
PEVATRON SNRs?

Type	Ia	II	II*
M_{ej} [$M_\odot$]	1.4	5	1
E_{SN} [10^{51} erg]	1	1	10
$\dot{M}$ [10^{-5} $M_\odot$/yr]	–	1	10
u_w [10^6 cm/s]	–	1	1
r_1 [pc]	–	1.5	1.3

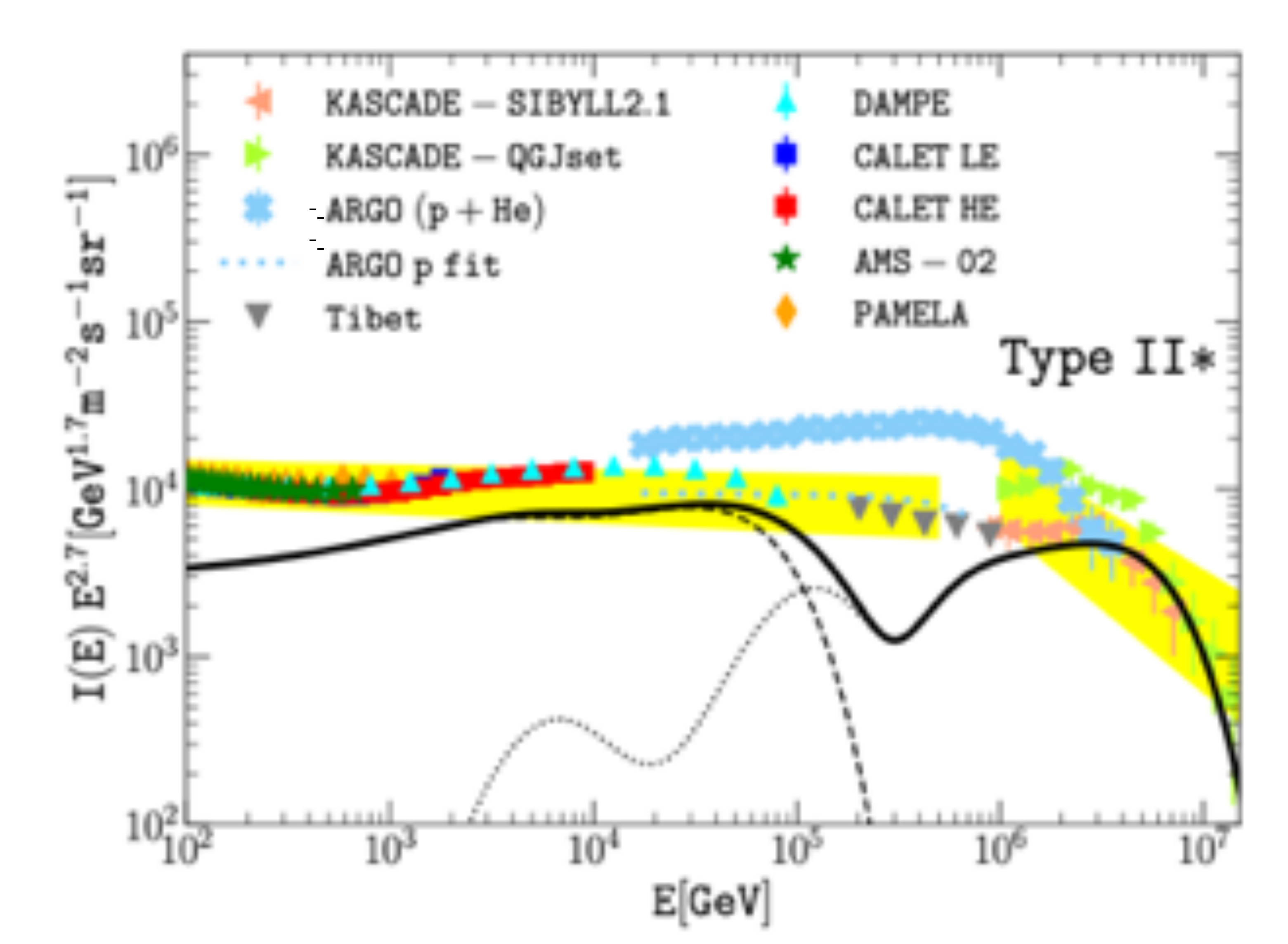
TYPE II*



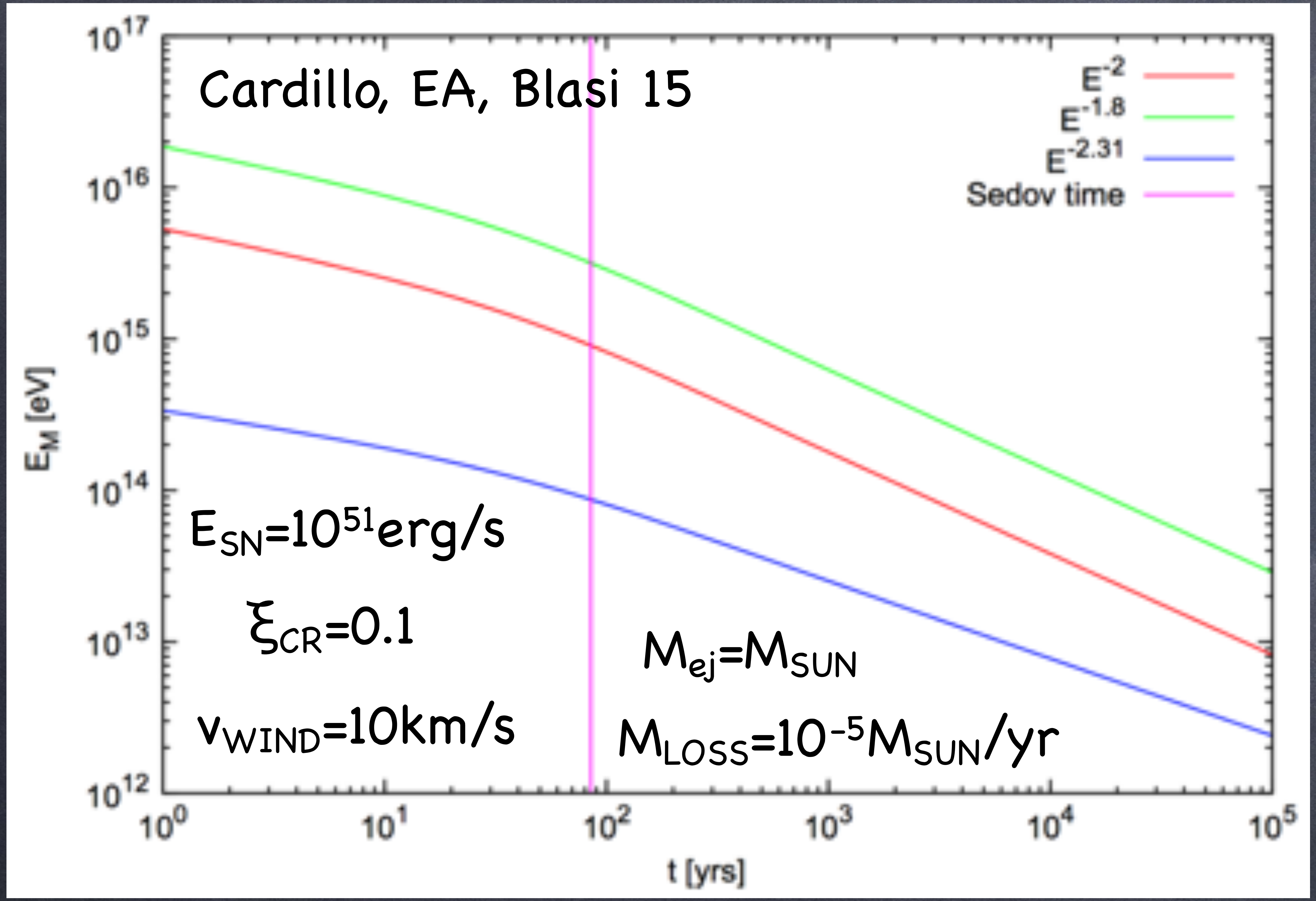
Cristofari, Blasi, EA 20



TYPE II* WOULD DOMINATE ALSO AT 10^2–10^4 GeV



STEEP PARTICLE SPECTRA MAKE IT WORSE!



RARE (<1/10000 yr^{-1})

EXTREME EVENTS ($E_{SN}>10^{52}$erg)

EXTREME EFFICIENCY ($\xi_{CR}>30\%$)

NO HOPE IF SPECTRUM STEEP

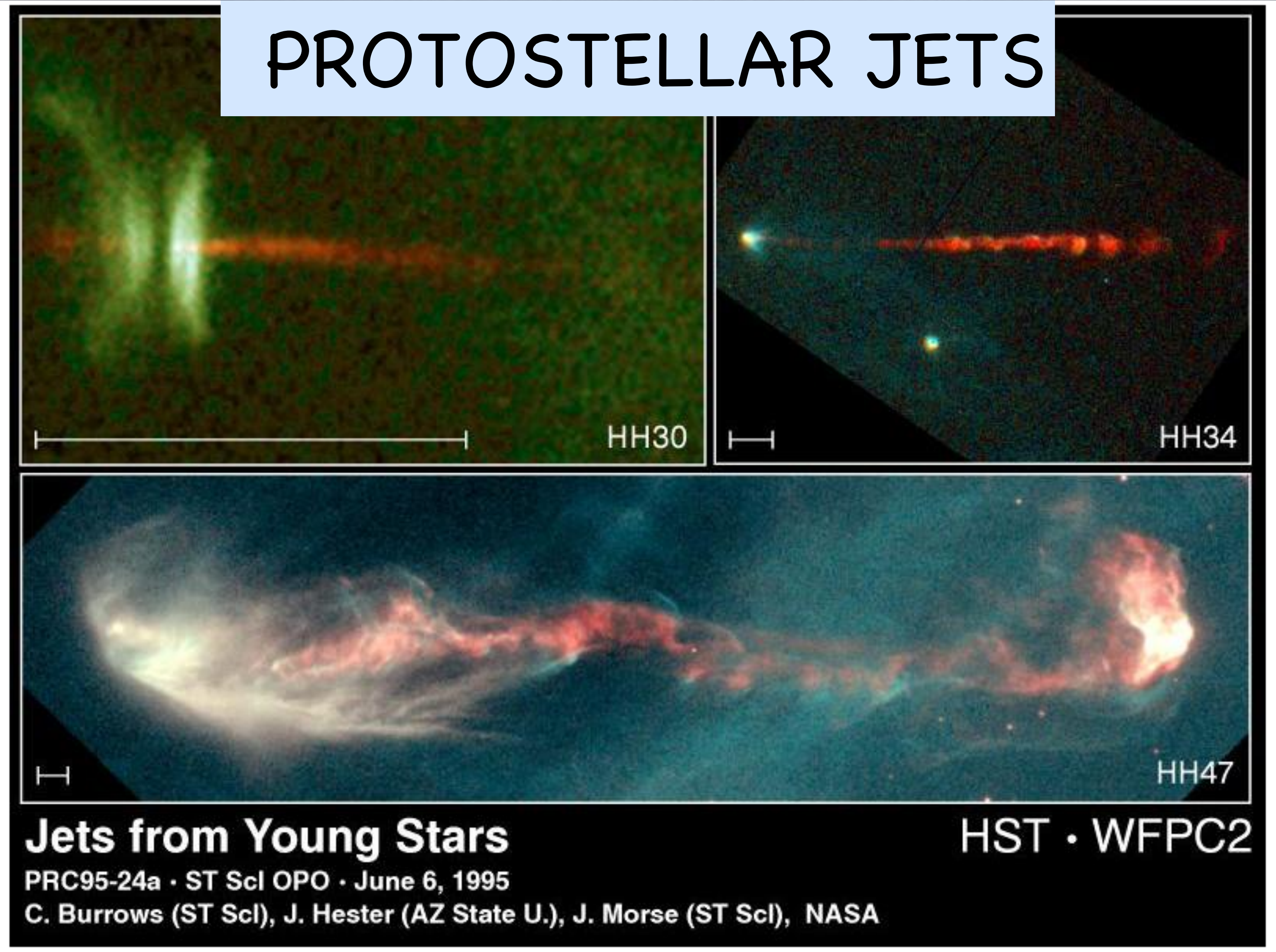
- PROPAGATION POINTS TO STEEP INJECTION SPECTRA (Aguilar+ 16; EA & Blasi 18)
- INJECTED PARTICLE SPECTRA STEEP ONLY IF SOURCE SPECTRA STEEP (Schure & Bell 14; Cardillo, EA, Blasi 15)

ALTERNATIVE SOURCES

GALACTIC ACCELERATORS

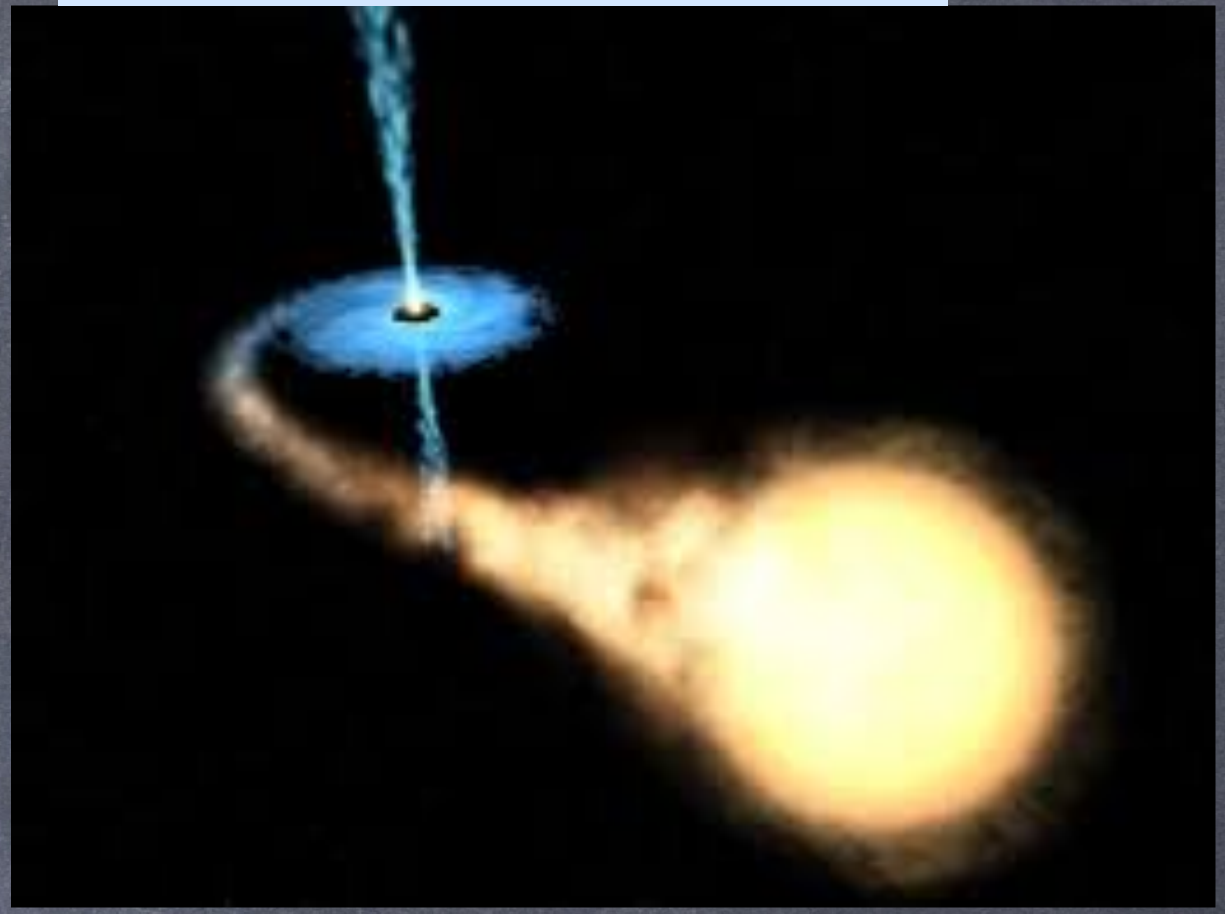
NEW PROPOSALS

PROTOSTELLAR JETS

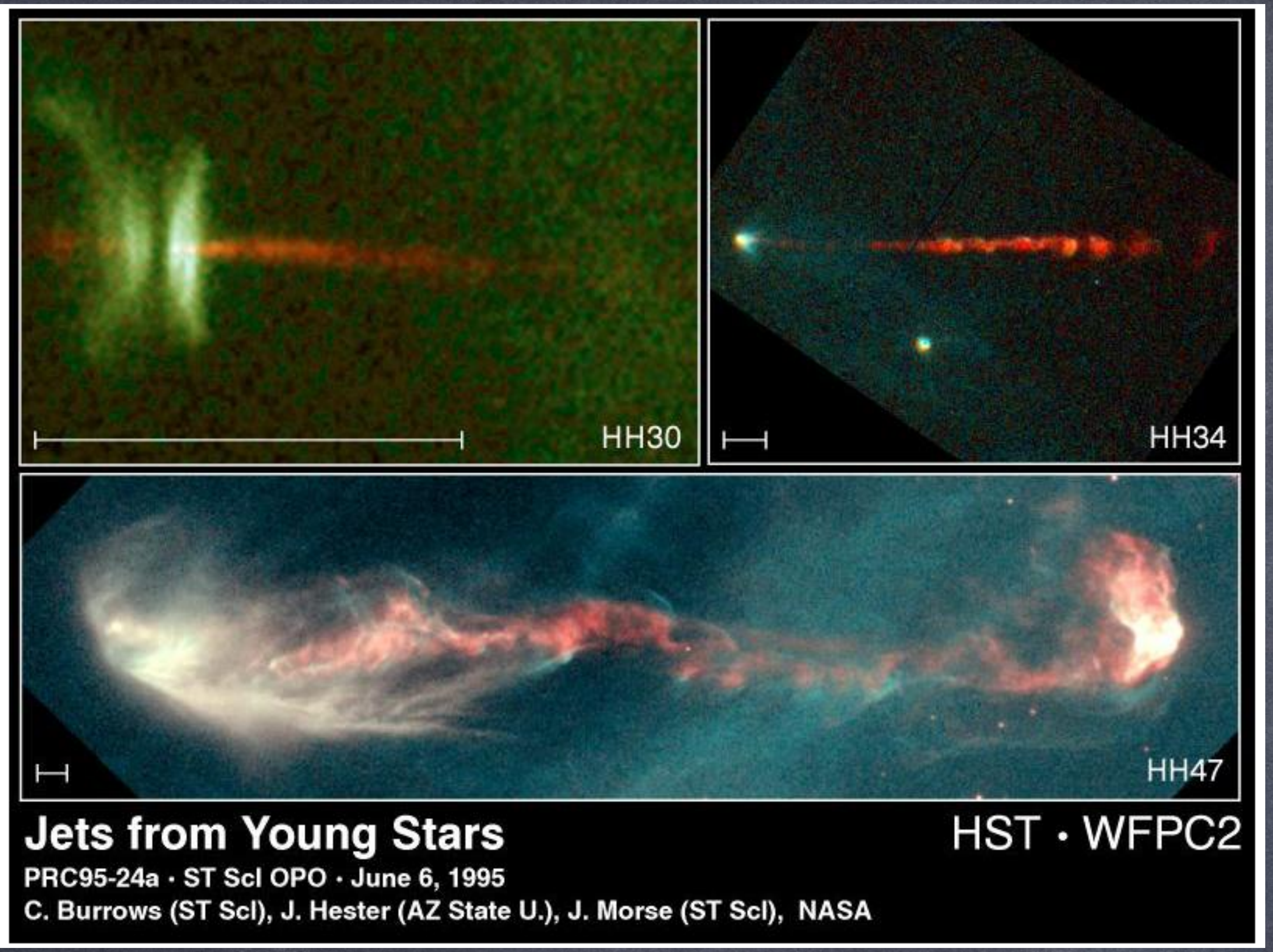


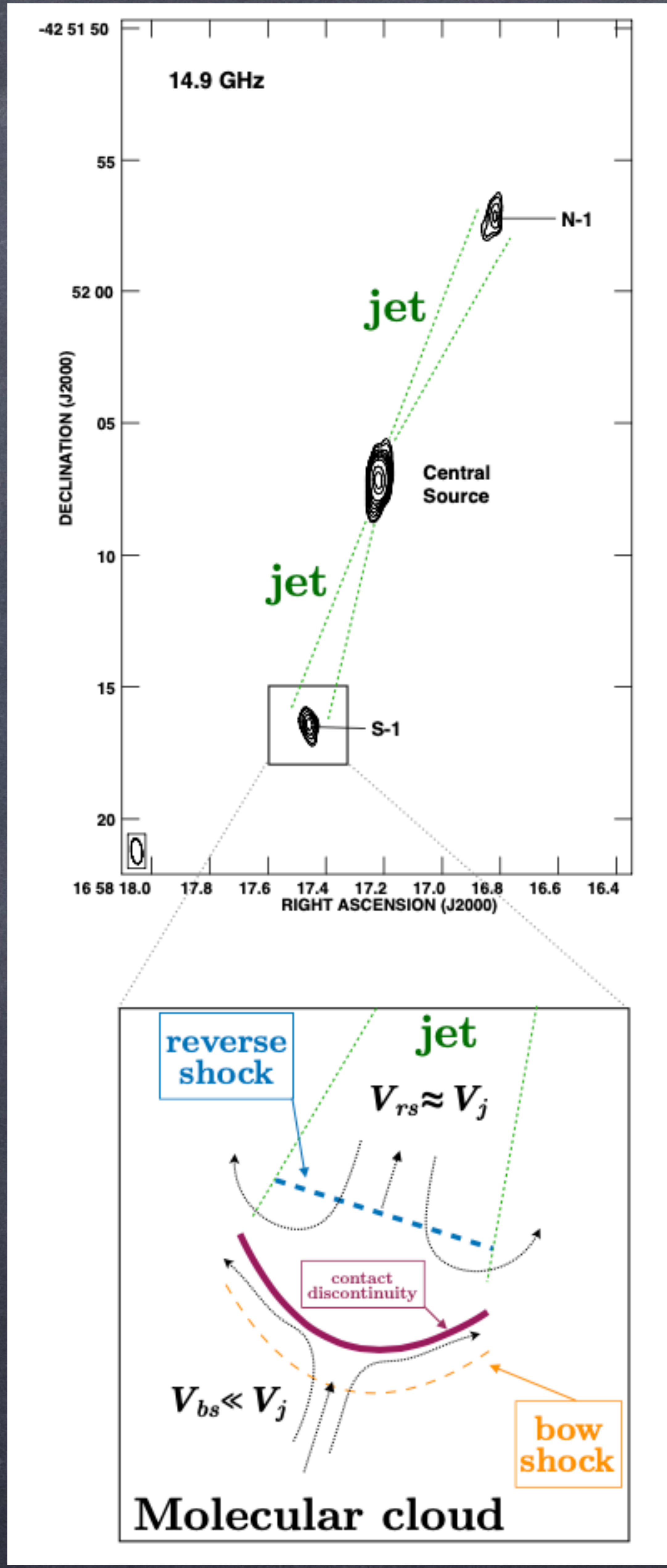
NOVAE

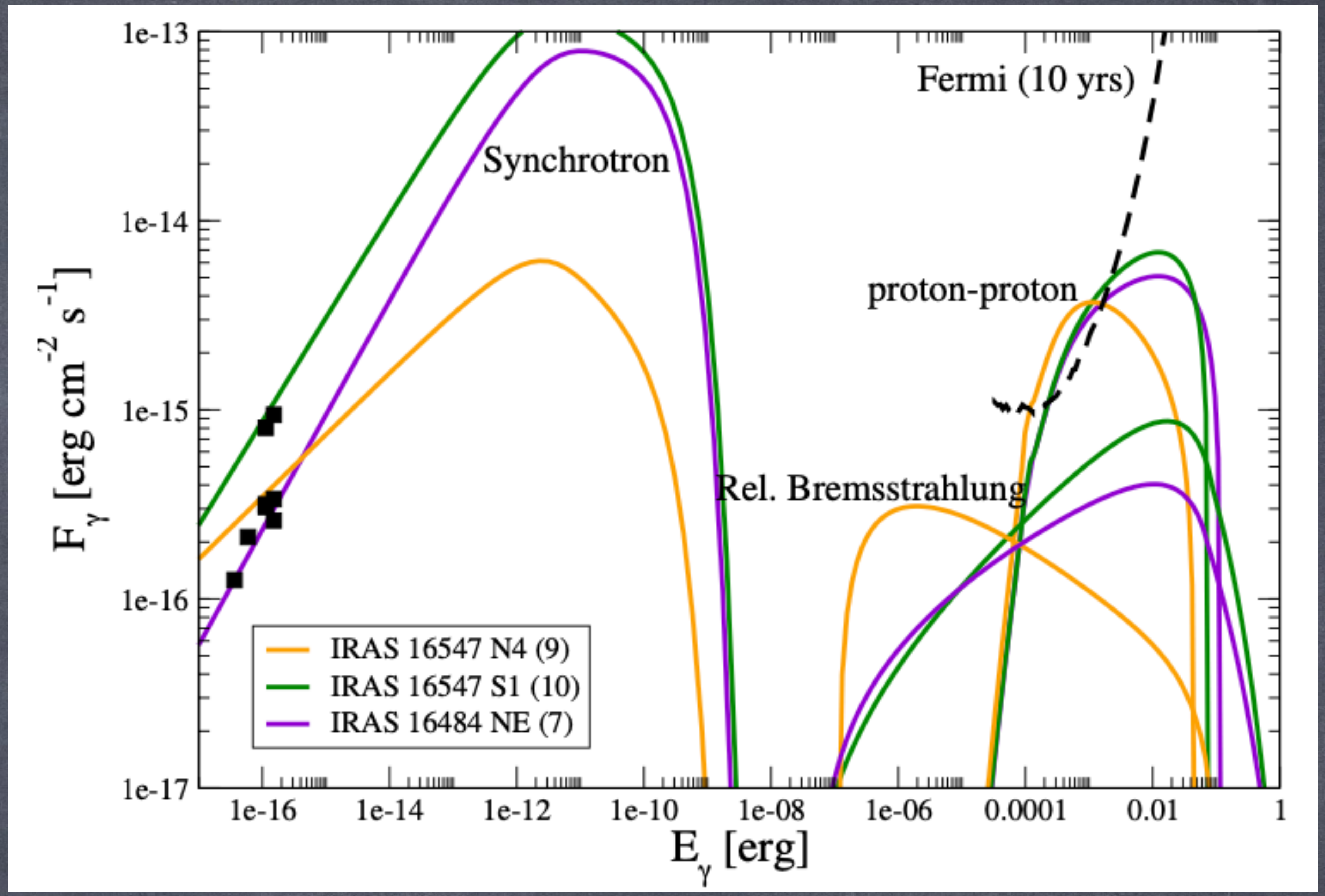
MICROQUASARS



PROTOSTELLAR JETS







(Araudo, Padovani, Marcowith 21)

OBSERVATIONS

-SYNCHROTRON RADIO EMISSION

-AMPLIFIED MAGNETIC FIELDS $B \sim 0.5 - 3\ mG$

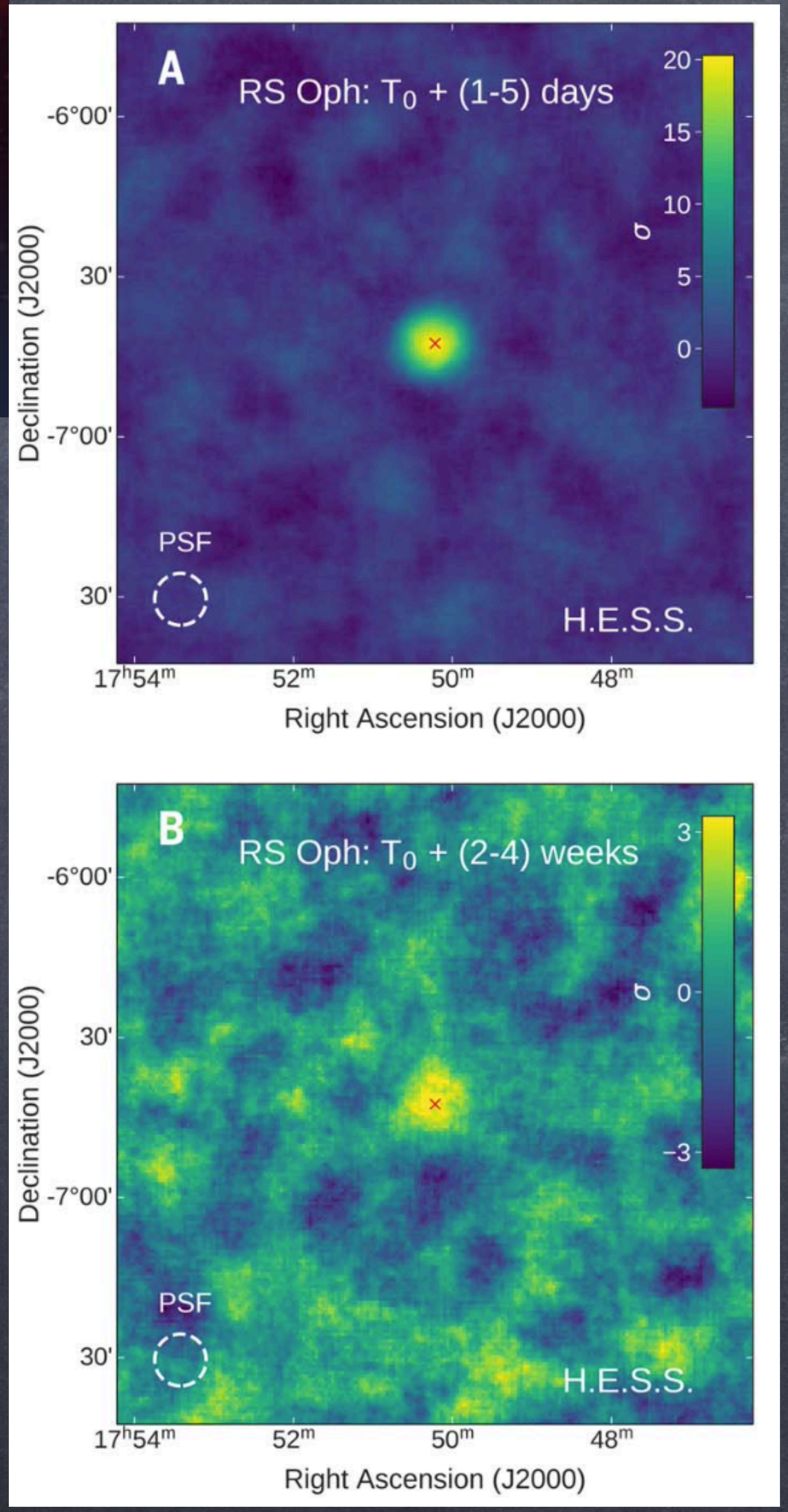
INFERENCE

-SHOCK ACCELERATION WITH MFA AT REVERSE SHOCK

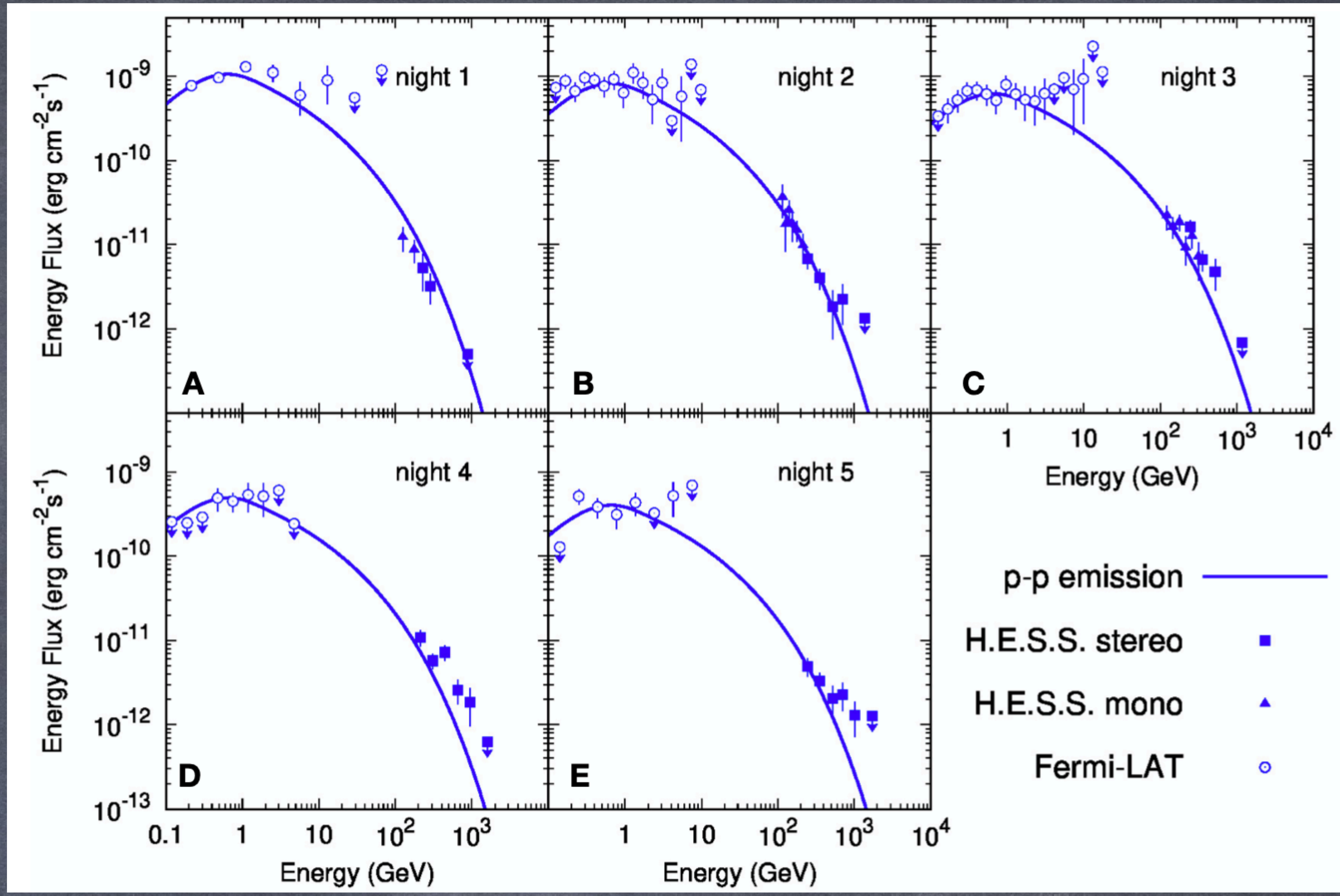
- $E_{max} \sim TeV, \gamma_p = 2.1, \epsilon \approx 0.1$

-NEW GAMMA-RAY SOURCES

NOVAE



HESS Coll 22



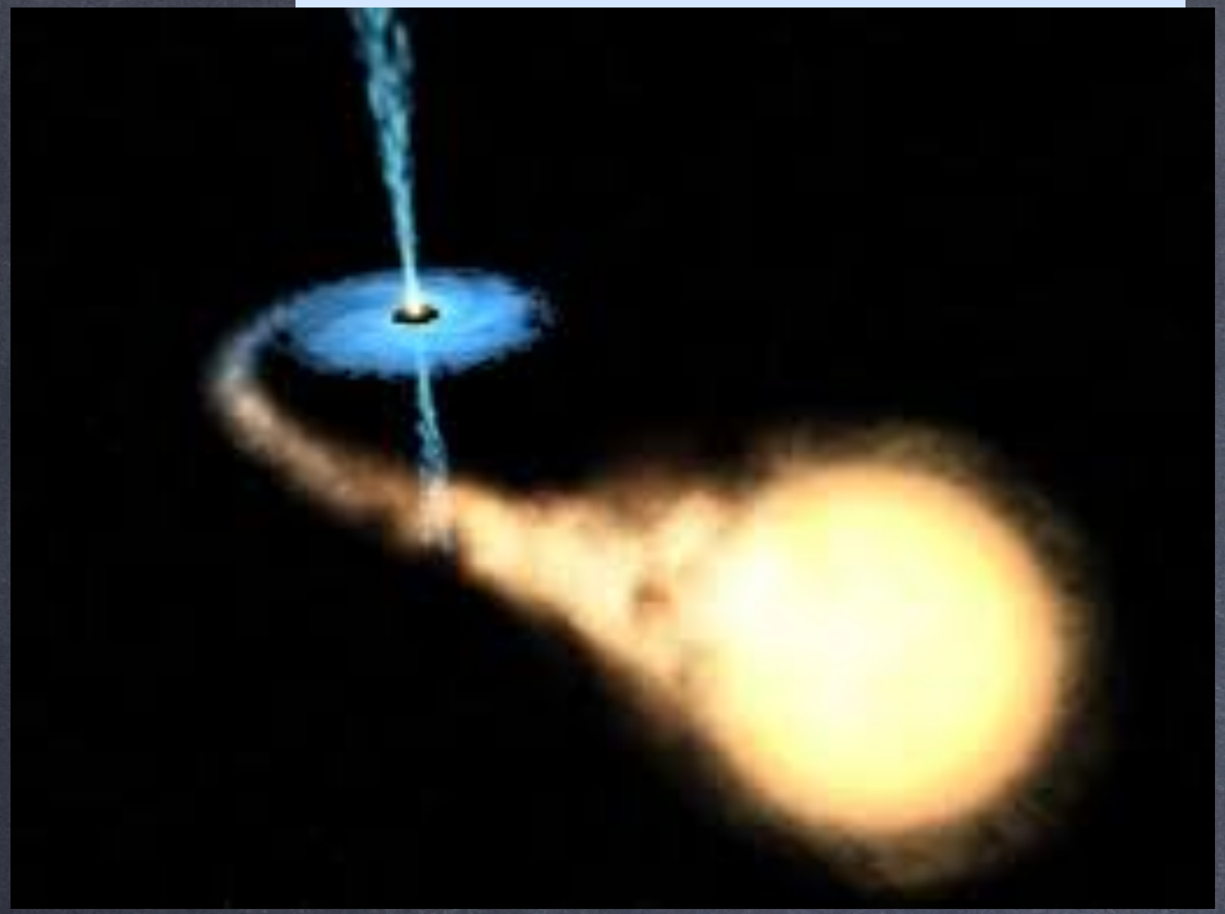
-ACCELERATION AT $4-5\times10^3\ km/s$ SHOCK IN DENSE RED GIANT WIND WITH $E_{max}\sim 10\ TeV$

-DIRECT EVIDENCE OF MFA ACCORDING TO NRH (Bell) INSTABILITY

-10% ACCELERATION EFFICIENCY, $\gamma_p = 2.2$, $E_{max}\sim 10\ TeV$, $E_{tot}\approx 10^{42}\ erg$

MICROQUASRAS

MICROQUASARS



(Escobar, Pellizza, Romero 22)

-HADRONIC CONTENT PROVEN IN SOME CASES

-INTERNAL SHOCKS ACCELERATE PROTONS

-p-p INTERACTIONS PRODUCE NEUTRONS FREE TO ESCAPE

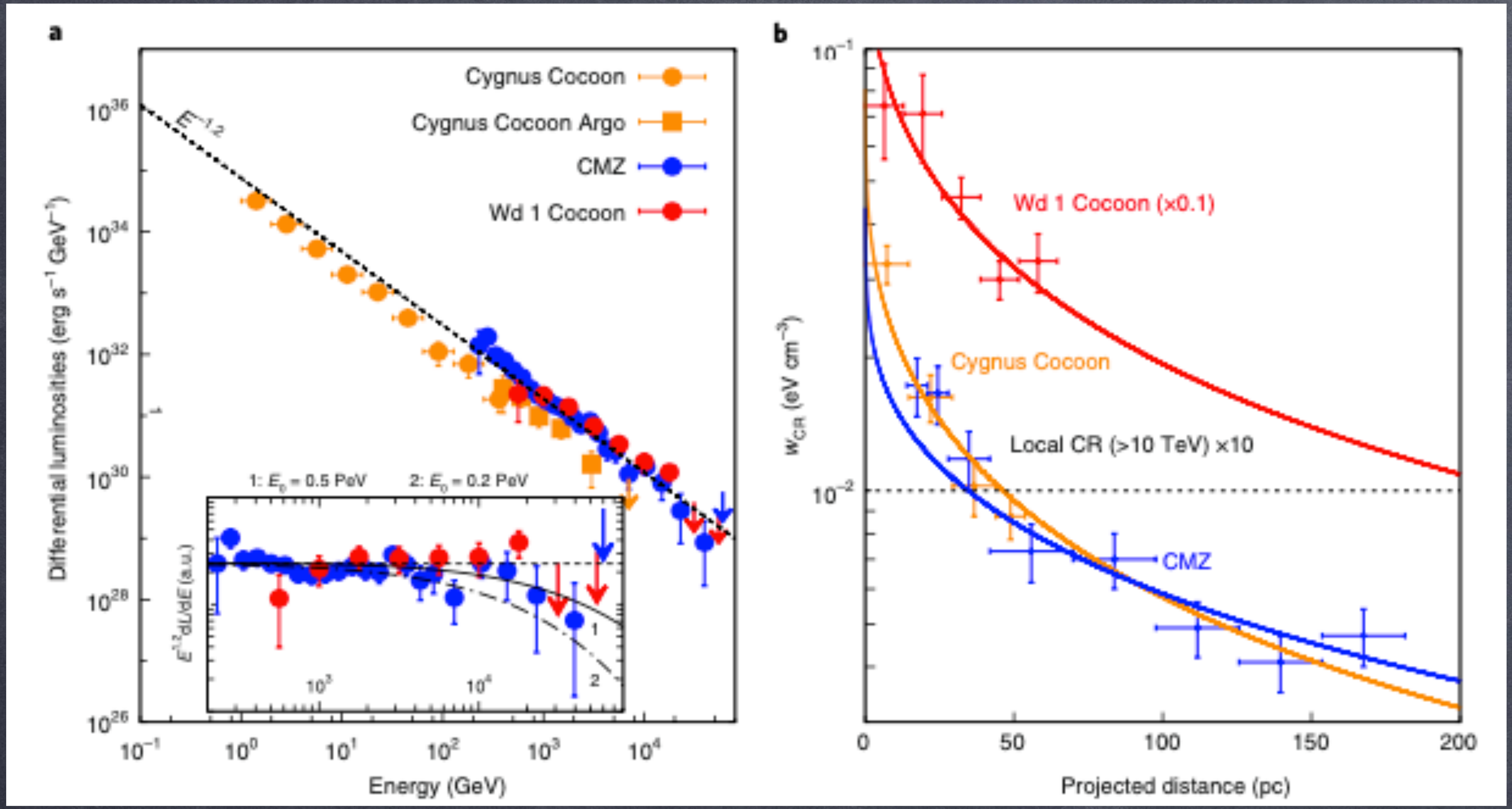
-USUAL POWER OUTPUT: $10^{48} - 10^{49}\ erg$ INTEGRATED OVER LIFETIME

-COLLIMATION $\Rightarrow$ 100X MORE AND $E_{max} \sim 10\ PeV$

-STEEP SPECTRUM: $E^{-\gamma}, \quad \gamma > 2.5$

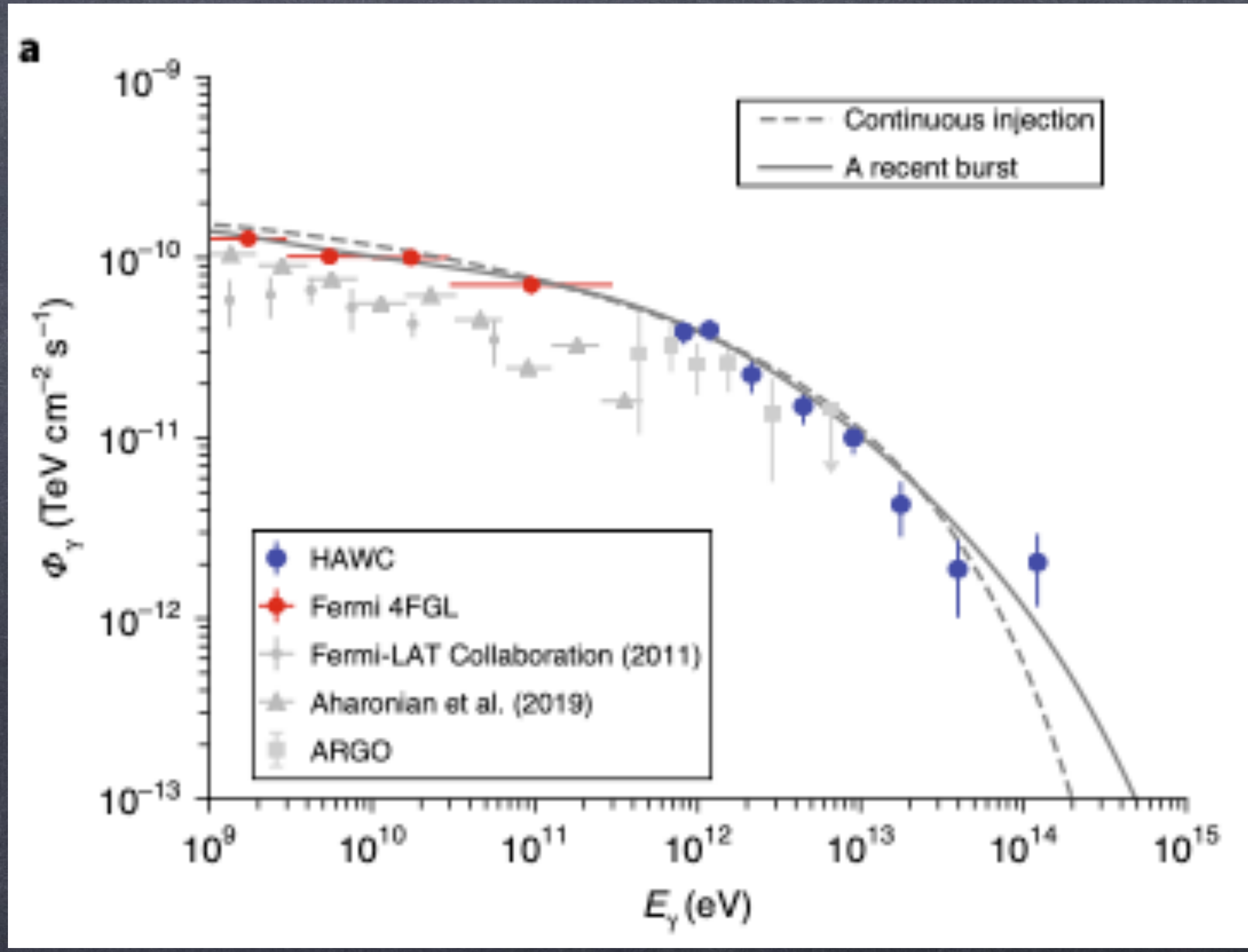
ALTERNATIVE PEVATRONS

STAR FORMING REGIONS?



Aharonian+ 19

$$E_p \approx 300\ TeV$$



Abeysekara+ 21

LEPTONIC OR HADRONIC PEVATRONS?

12 SOURCES DETECTED BY LHAASO ABOVE 100 TeV

Table 1 | UHE γ-ray sources

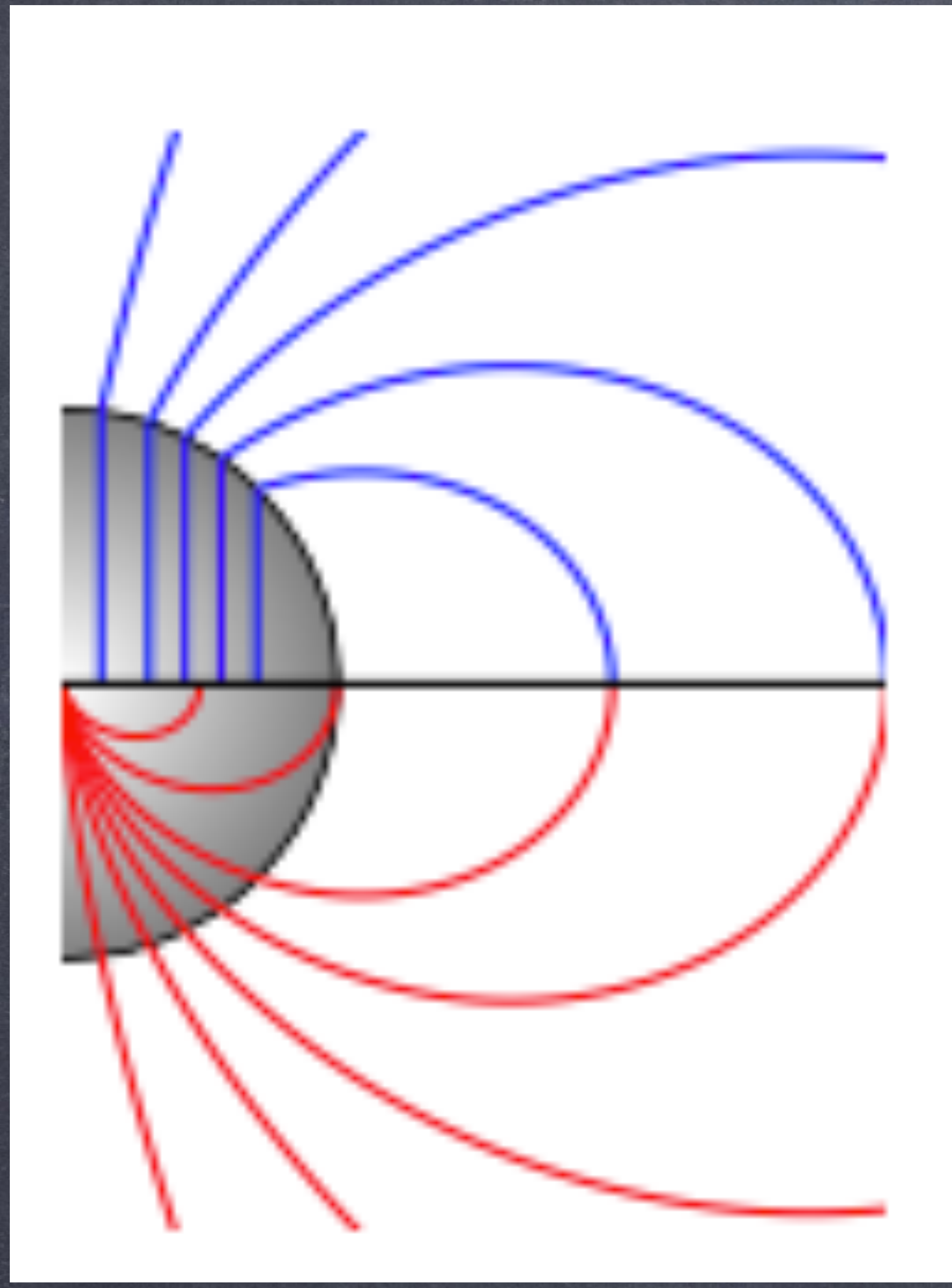
Source name	RA (°)	dec. (°)	Significance above 100 TeV (×σ)	E_{max} (PeV)	Flux at 100 TeV (CU)
LHAASO J0534+2202	83.55	22.05	17.8	0.88 ± 0.11	1.00(0.14)
LHAASO J1825-1326	276.45	−13.45	16.4	0.42 ± 0.16	3.57(0.52)
LHAASO J1839-0545	279.95	−5.75	7.7	0.21 ± 0.05	0.70(0.18)
LHAASO J1843-0338	280.75	−3.65	8.5	$0.26_{-0.10}^{+0.16}$	0.73(0.17)
LHAASO J1849-0003	282.35	−0.05	10.4	0.35 ± 0.07	0.74(0.15)
LHAASO J1908+0621	287.05	6.35	17.2	0.44 ± 0.05	1.36(0.18)
LHAASO J1929+1745	292.25	17.75	7.4	$0.71_{-0.07}^{+0.16}$	0.38(0.09)
LHAASO J1956+2845	299.05	28.75	7.4	0.42 ± 0.03	0.41(0.09)
LHAASO J2018+3651	304.75	36.85	10.4	0.27 ± 0.02	0.50(0.10)
LHAASO J2032+4102	308.05	41.05	10.5	1.42 ± 0.13	0.54(0.10)
LHAASO J2108+5157	317.15	51.95	8.3	0.43 ± 0.05	0.38(0.09)
LHAASO J2226+6057	336.75	60.95	13.6	0.57 ± 0.19	1.05(0.16)

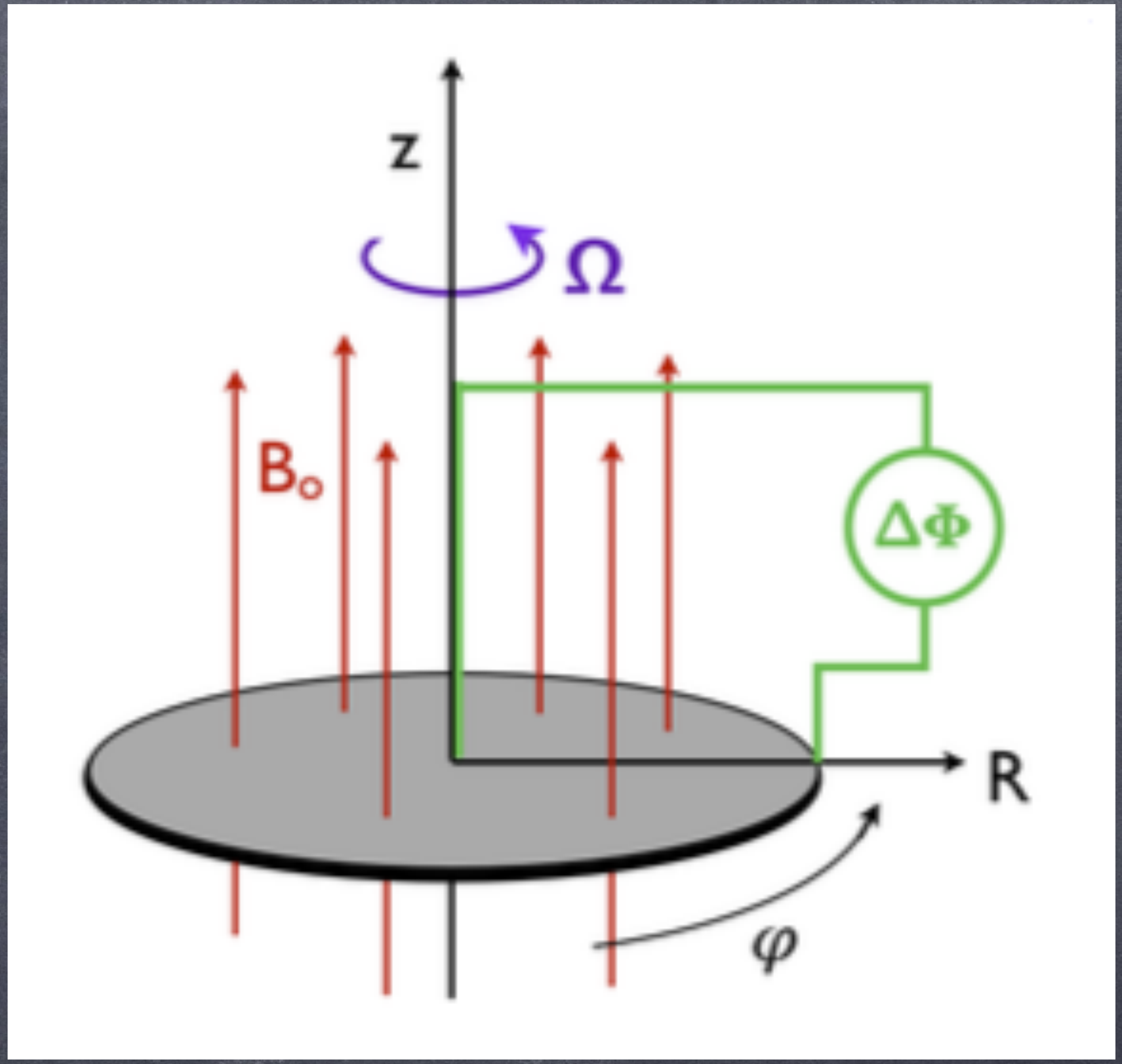
Cao+ 2021

PeV PROTONS OR ELECTRONS?

ALL SOURCES BUT ONE HAVE A PSR IN THE FIELD….

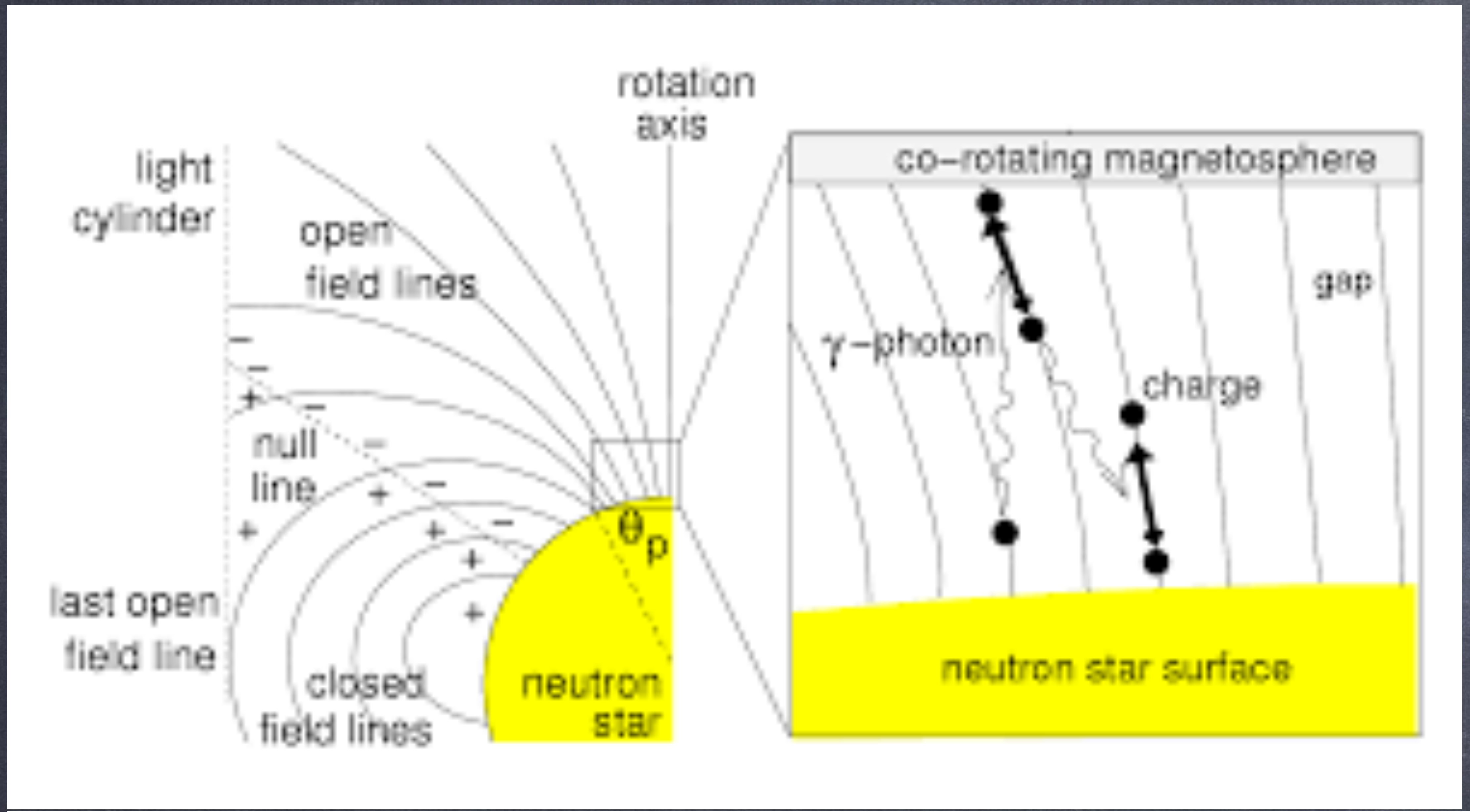
PSR: A SIMPLE PROBLEM...

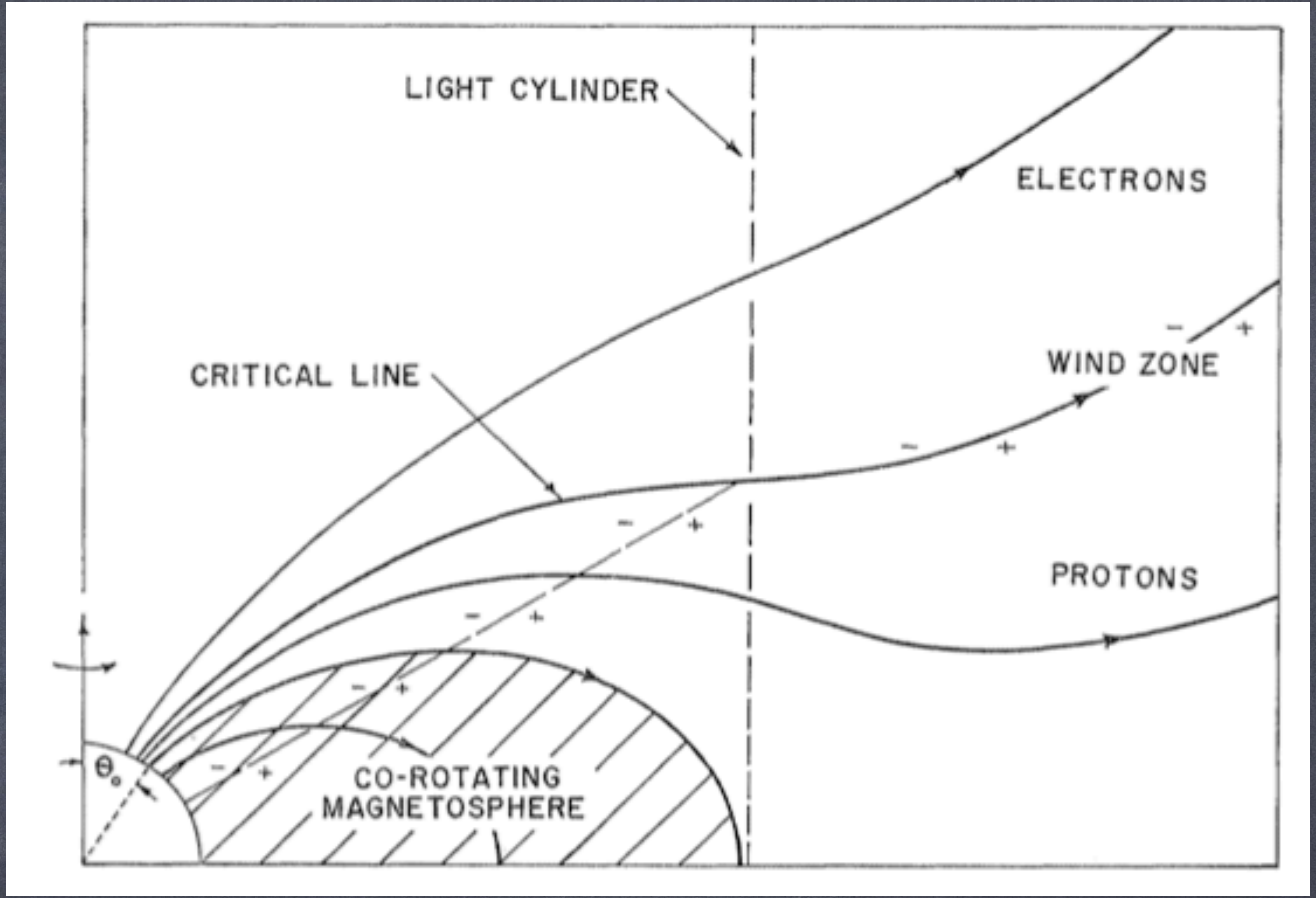




$$\Delta\Phi^{PSR} \approx \frac{B_\star \Omega R_\star^2}{c}\frac{R_\star}{R_L} \approx \sqrt{\frac{\dot{E}}{c}}$$

PULSARS





e^- ⇒ **Curvature or ICS on star X-rays** ⇒ γ (E_γ>50 MeV) ⇒ $\gamma + B \rightarrow e^+ + e^-$

$\gamma_{primary} \sim 10^7$

$\gamma_{secondary} \sim 10^{2-3}$

↓

γ-RAYS

MAXIMUM ENERGY IN A PWN

IN YOUNG ENERGETIC SYSTEMS ACCELERATION IS LOSS LIMITED

$$t_{acc} = \frac{E}{e\eta_E Bc} < t_{loss} = \frac{6\pi(mc^2)^2}{\sigma_T c B^2 E}$$

$$E_{max} \approx 6\ PeV\ \eta_E^{1/2}\ B_{-4}^{1/2}$$

STRICT LIMIT FROM THE PSR POTENTIAL DROP $\Phi_{PSR} = \sqrt{\dot{E}/c}$

$$E_{max,abs} = e\eta_E B_{TS}\ R_{TS}$$

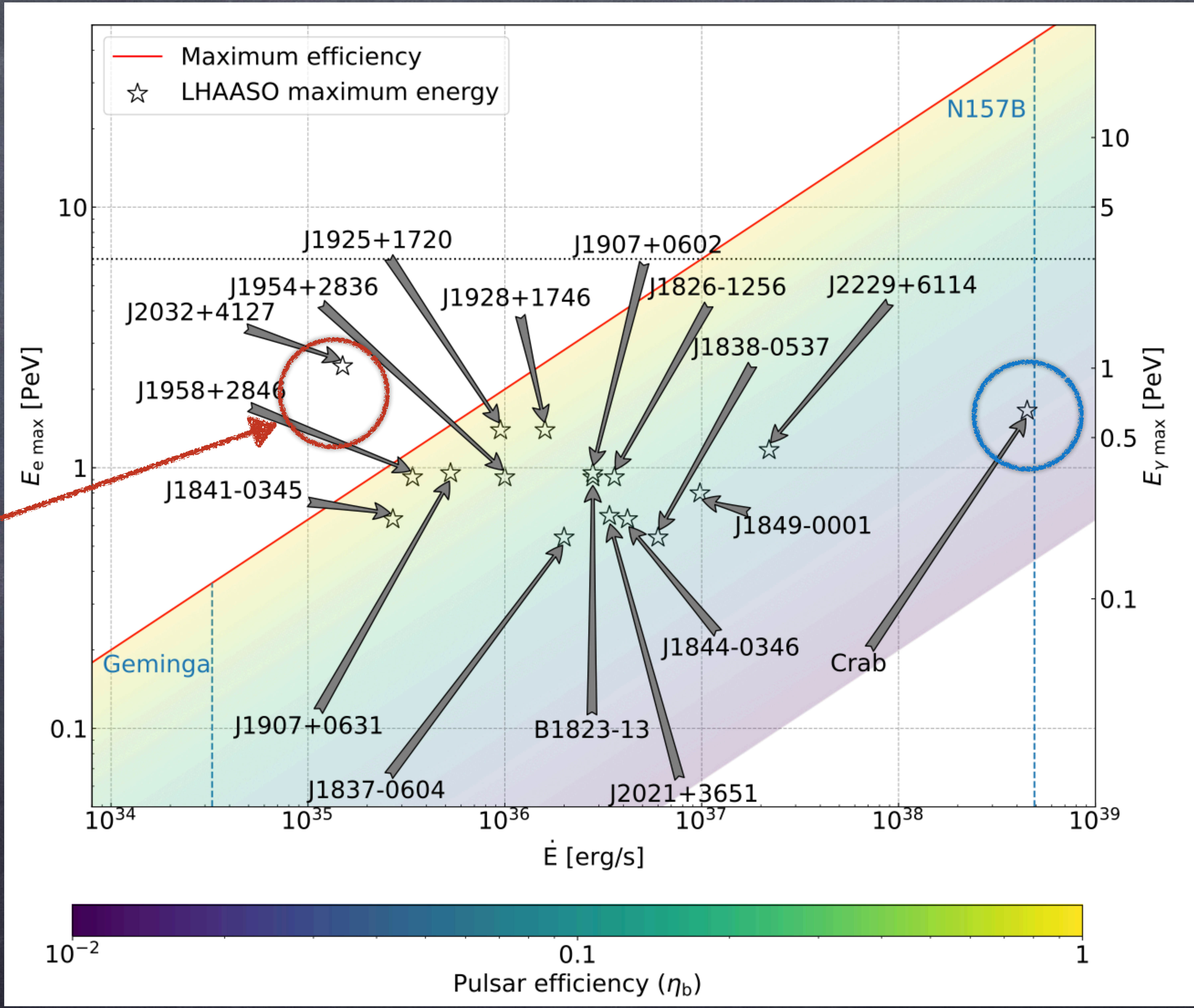
$$\frac{B_{TS}^2}{4\pi} = \eta_B \frac{\dot{E}}{4\pi R_{TS}^2 c}$$

$$E_{max,abs} = e\eta_E\ \eta_B^{1/2}\sqrt{\dot{E}/c} \approx 1.8\ PeV\ \eta_E\ \eta_B^{1/2}\ \dot{E}_{36}^{1/2}$$

LHAASO PEVATRONS AND PWNe

MAXIMUM
ELECTRON ENERGY
AS A FUNCTION
OF PSR POTENTIAL DROP
AND LHAASO SOURCES

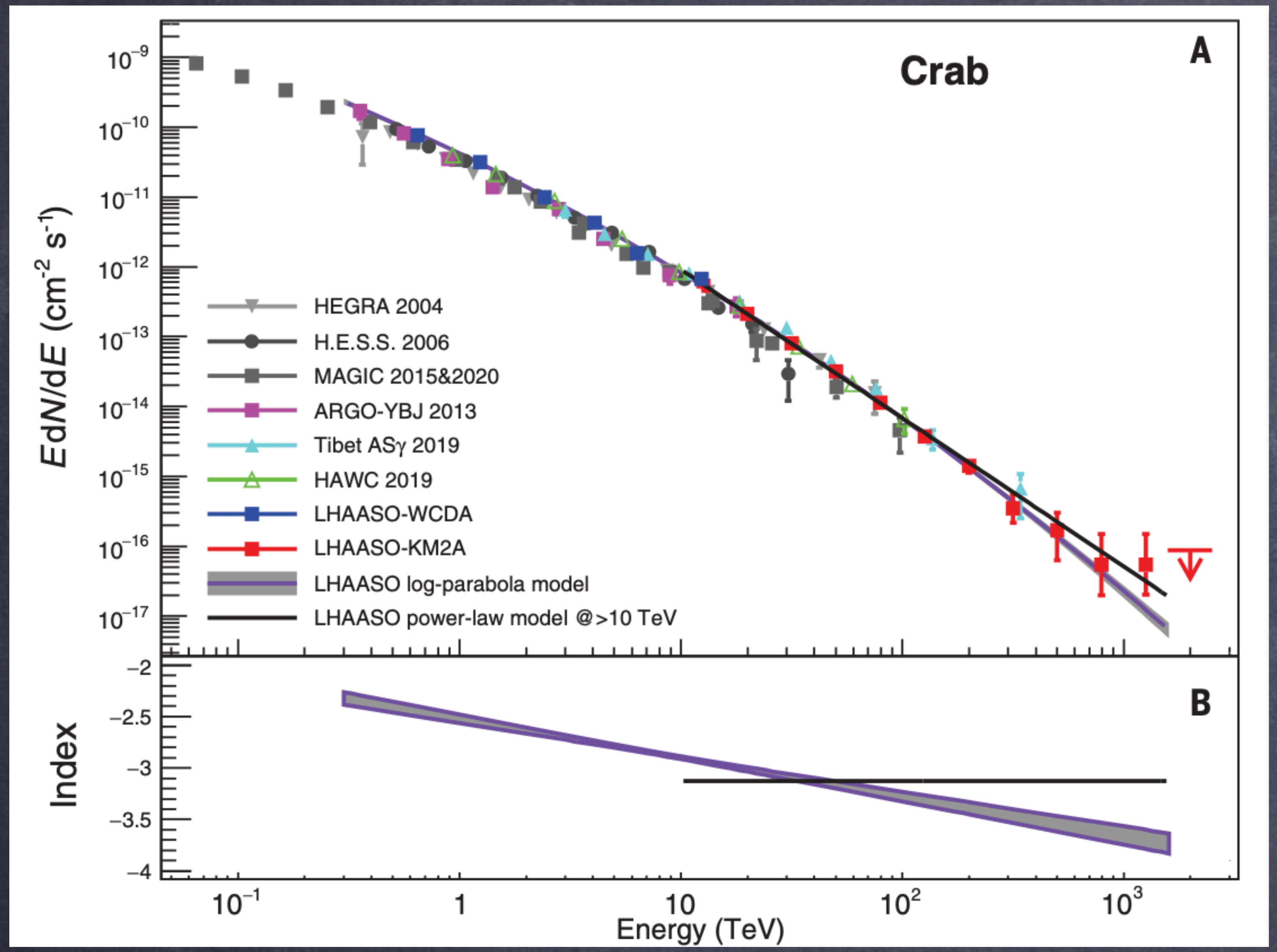
CYGNUS



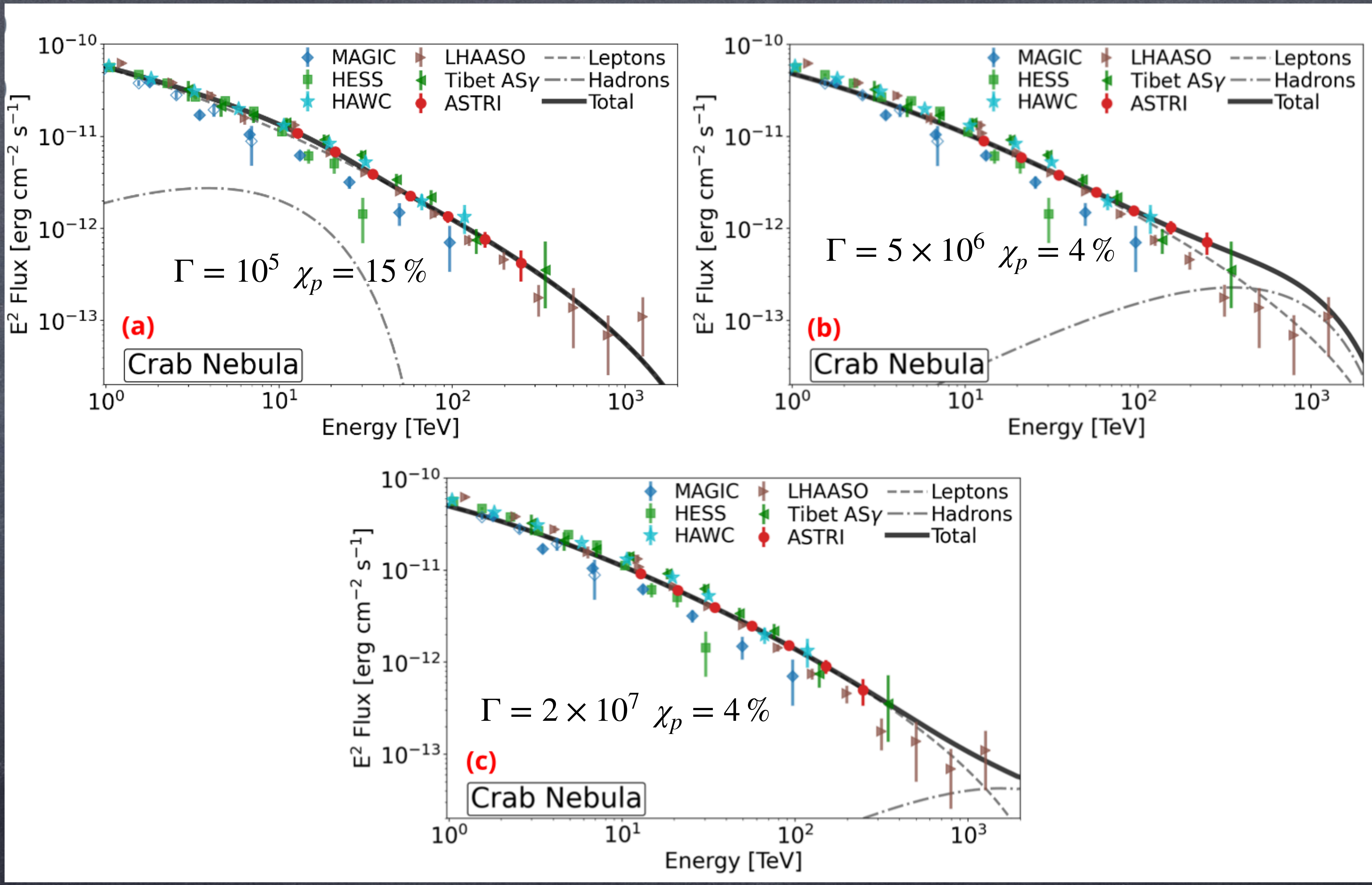
de Ona Wilhelmi + 2022

HADRONS FROM PULSARS?

HADRONS IN CRAB?



Cao+, LHAASO Coll. 21

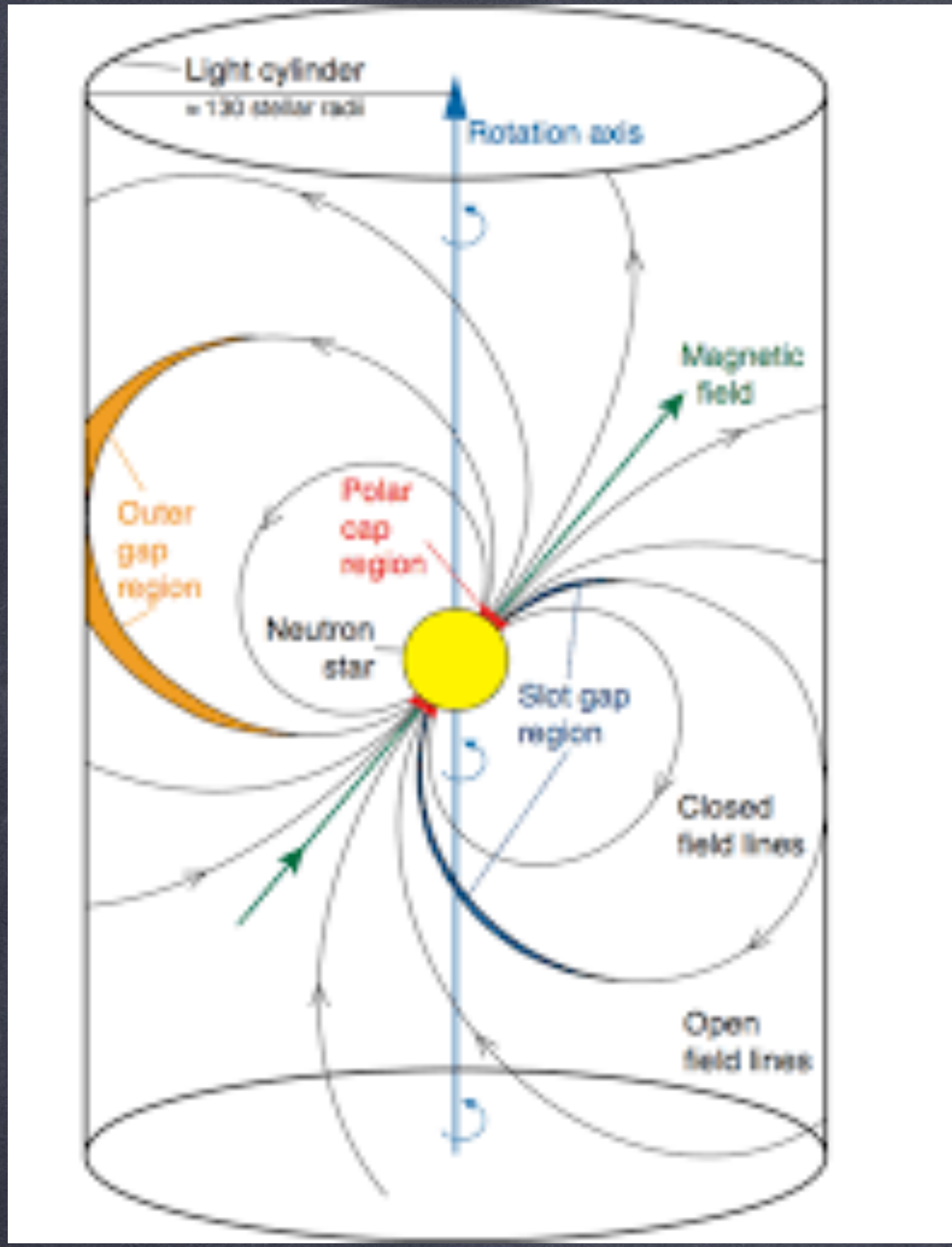


Vercellone+ 22; Fiori, EA + in prep.

$Q_p(E) \propto \delta(E - m_p c^2 \Gamma)$ (EA & Arons 06; EA, Guetta, Blasi 03)

UHCRs FROM NEW BORN MAGNETARS

ACCELERATION IN MAGNETARS



DIRECT E-FIELD ACCELERATION IN GAP OF SIZE ξR_L
WITH POTENTIAL DIFFERENCE Φ VS CURVATURE

$$\frac{d\gamma}{dt} = \frac{Ze\Phi}{Am_pc^2}\frac{2\pi}{\xi P} - \frac{8\pi^2}{3cP^2}\frac{Z^2e^2}{Am_pc^2}\gamma^4$$

$$\gamma_{curv} = \left(\frac{3\pi B R_\star^3}{2ZecP\xi}\right)^{1/4} \sim 1.1\times 10^8 Z_{26}^{-1/4}\xi^{-1/4}B_{13}^{1/4}P_{-3}^{-1/4}R_{\star,6}^{3/4}$$

$$\gamma_{max} = \max(\gamma_w, \min(\gamma_\Phi, \gamma_{curv}))$$

PURE IRON EXTRACTION
+ PHOTODISINTEGRATION

$$\frac{dN_A}{dt} + \frac{N_A}{t_A} = \frac{N_{A+1}}{t_{A+1}}$$

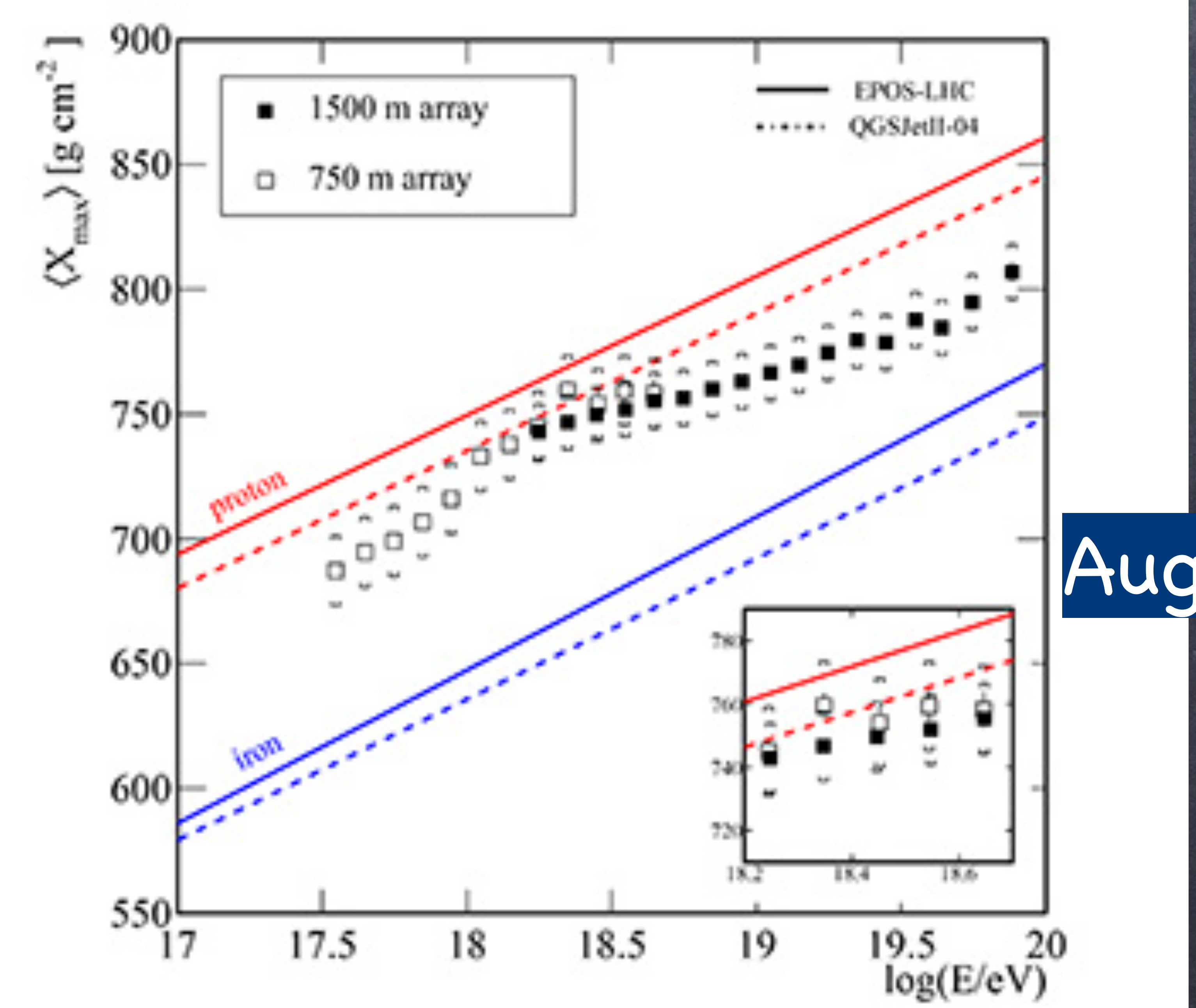
AUGER CORRELATIONS: AGN:2.7σ; AGN+SBG: 3.7σ; SBG: 4σ

PARTICLE SPECTRUM

$$E_{\rm CR}(t) = E_0\,(1+t/t_{\rm sd})^{-1} \sim 1.2\times10^{20}\,{\rm eV}\,\eta A_{56}\kappa_4 I_{45} B_{13}^{-1} R_{\star,6}^{-3}\, t_{7.5}^{-1} \quad \text{for} \quad t > t_{\rm sd}.$$

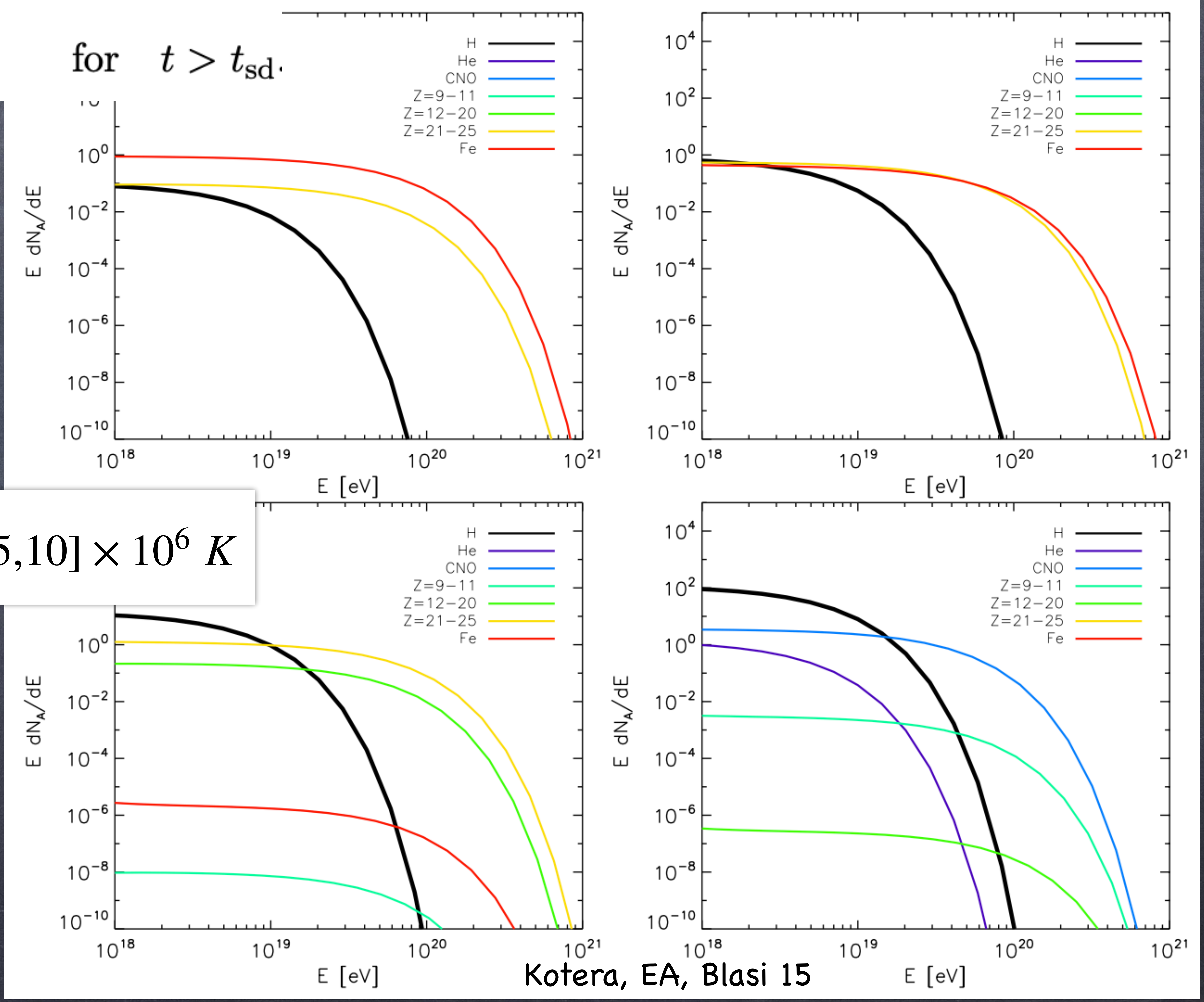
$$\frac{{\rm d}N_{\rm CR}}{{\rm d}E} = \int_0^\infty {\rm d}t\,\dot N_{\rm GJ}(t)\,\delta\left(E - E_{\rm CR}(t)\right) = \frac{\dot N_{\rm GJ}(0)\,t_{\rm sd}}{E}$$

$$t_{\rm sd} = \frac{9Ic^3P_{\rm i}^2}{8\pi^2B^2R^6} \sim 3.1\times10^7\,{\rm s}\,I_{45}B_{13}^{-2}R_{\star,6}^{-6}P_{\rm i,-3}^2$$



Auger 20

$$T_{NS} = [1,2,5,10]\times10^6\ K$$

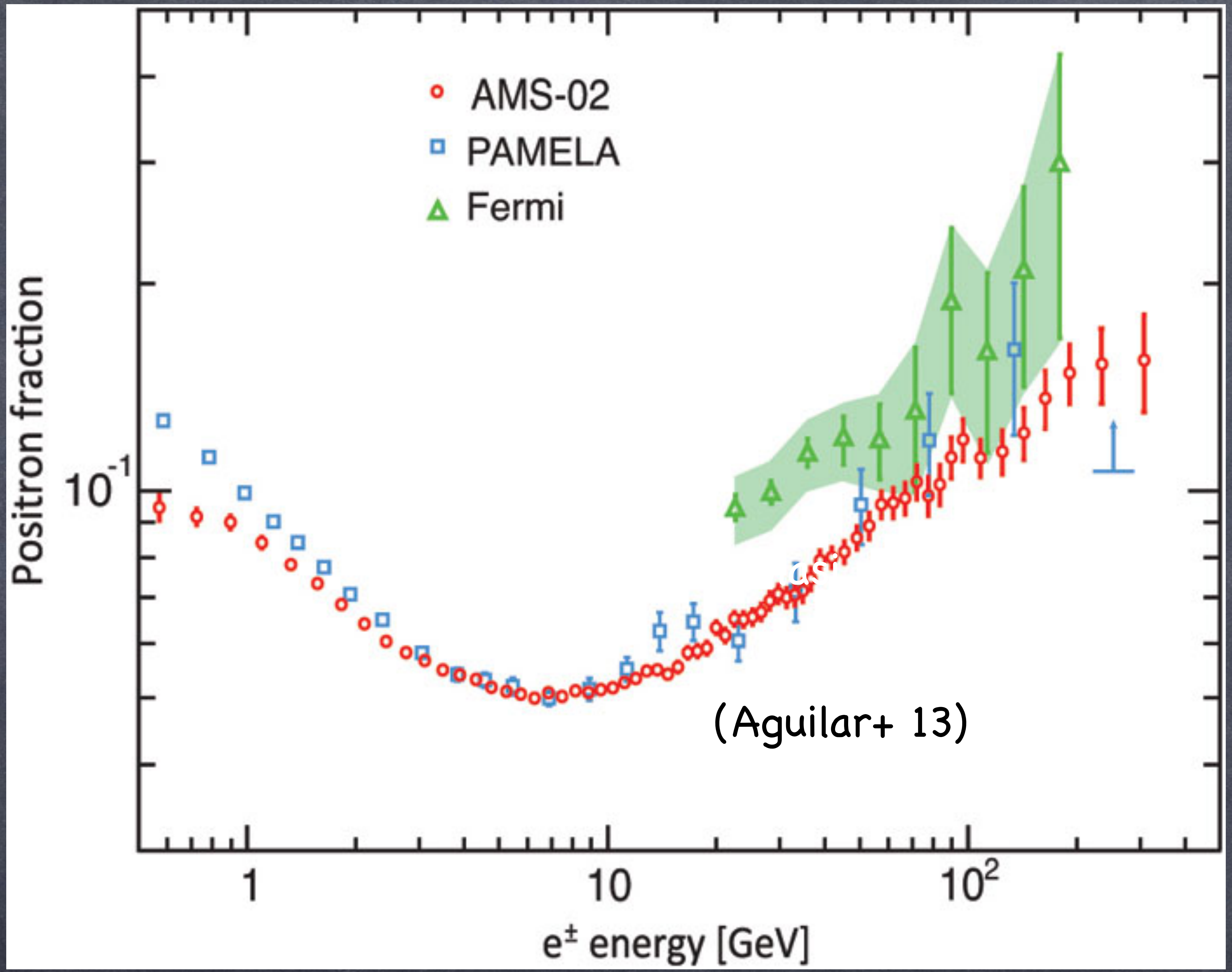


Kotera, EA, Blasi 15

THE SOURCES OF GALACTIC POSITRONS

THE POSITRON EXCESS

$$\frac{\Phi_{e^+}}{\Phi_{e^+} + \Phi_{e^-}} \approx \frac{\Phi_{e^+}}{\Phi_{e^-}}$$



- IF POSITRONS ONLY SECONDARY, FRACTION SHOULD DECREASE WITH INCREASING ENERGY
- PWNe EARLY SUGGESTED AS BEST CANDIDATES TO EXPLAIN THE EXCESS (Blasi & EA 11)

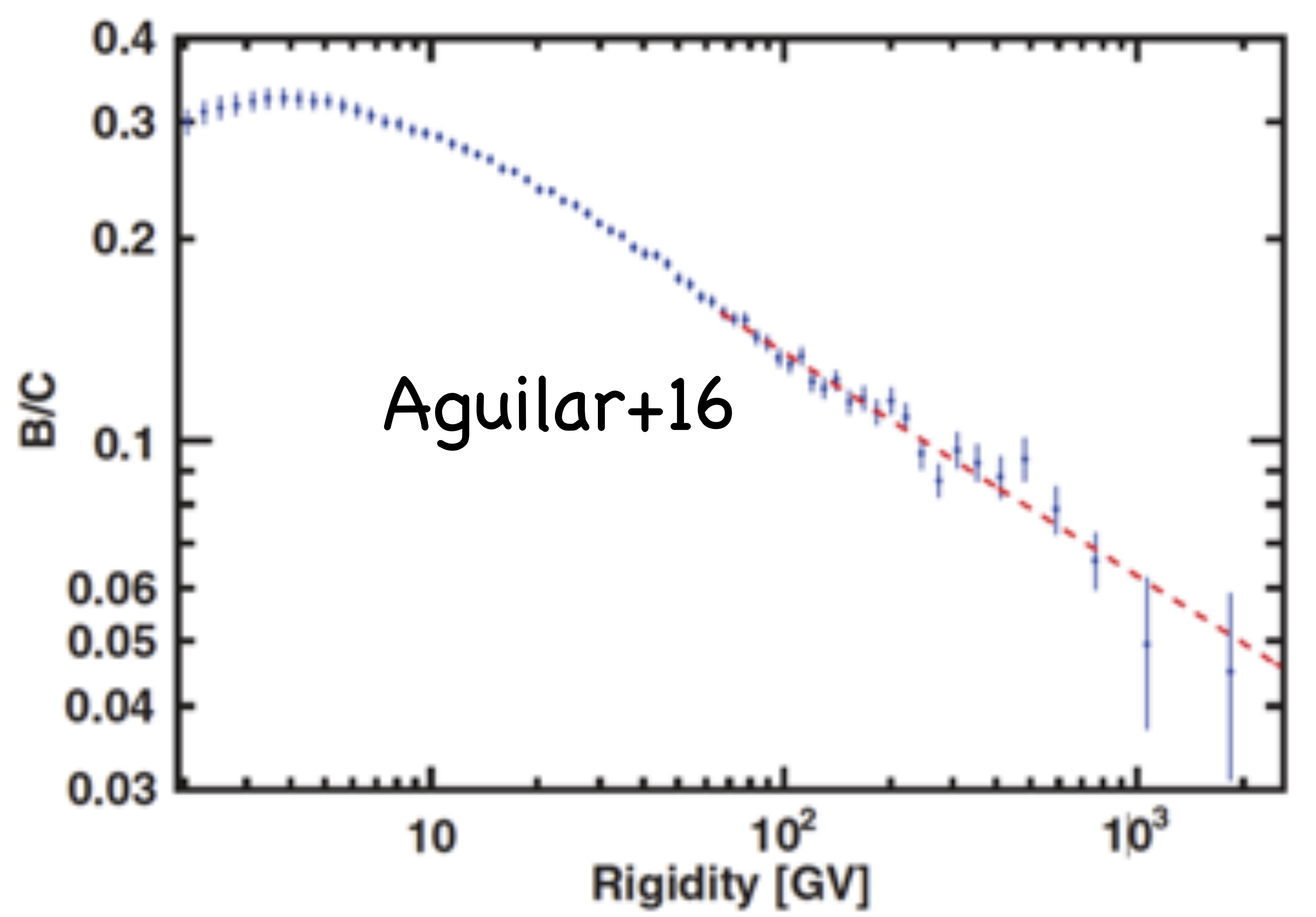
THE ODDITIES OF ANTI-MATTER

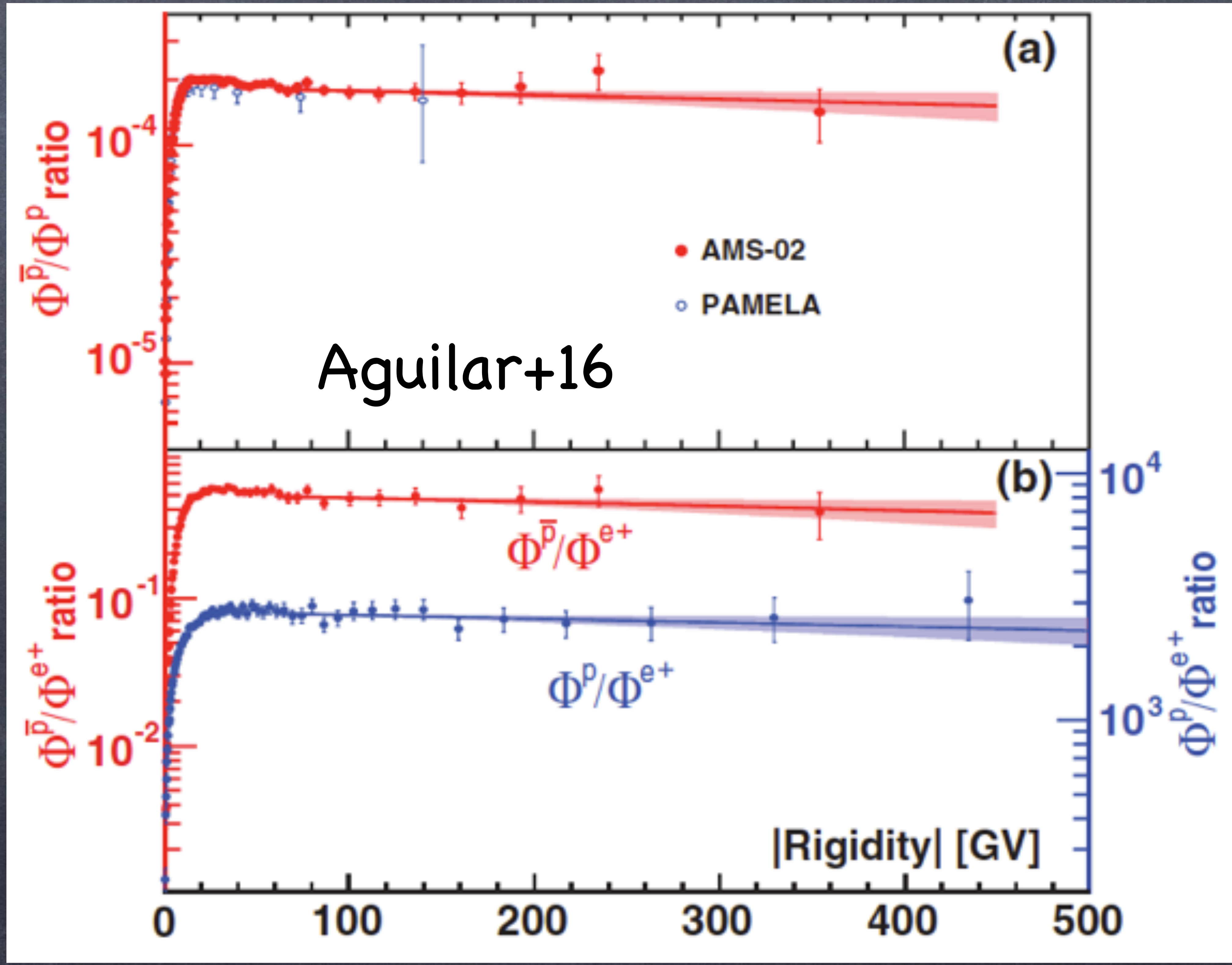
$$\frac{N_{sec}}{N_{prim}} \propto \tau_{esc} \propto E^{-\delta_E} \Rightarrow \frac{\Phi_B}{\Phi_C} \propto E^{-\delta_E}$$

BUT ALSO $\frac{\Phi_{\bar{p}}}{\Phi_p} \propto E^{-\delta_E}$

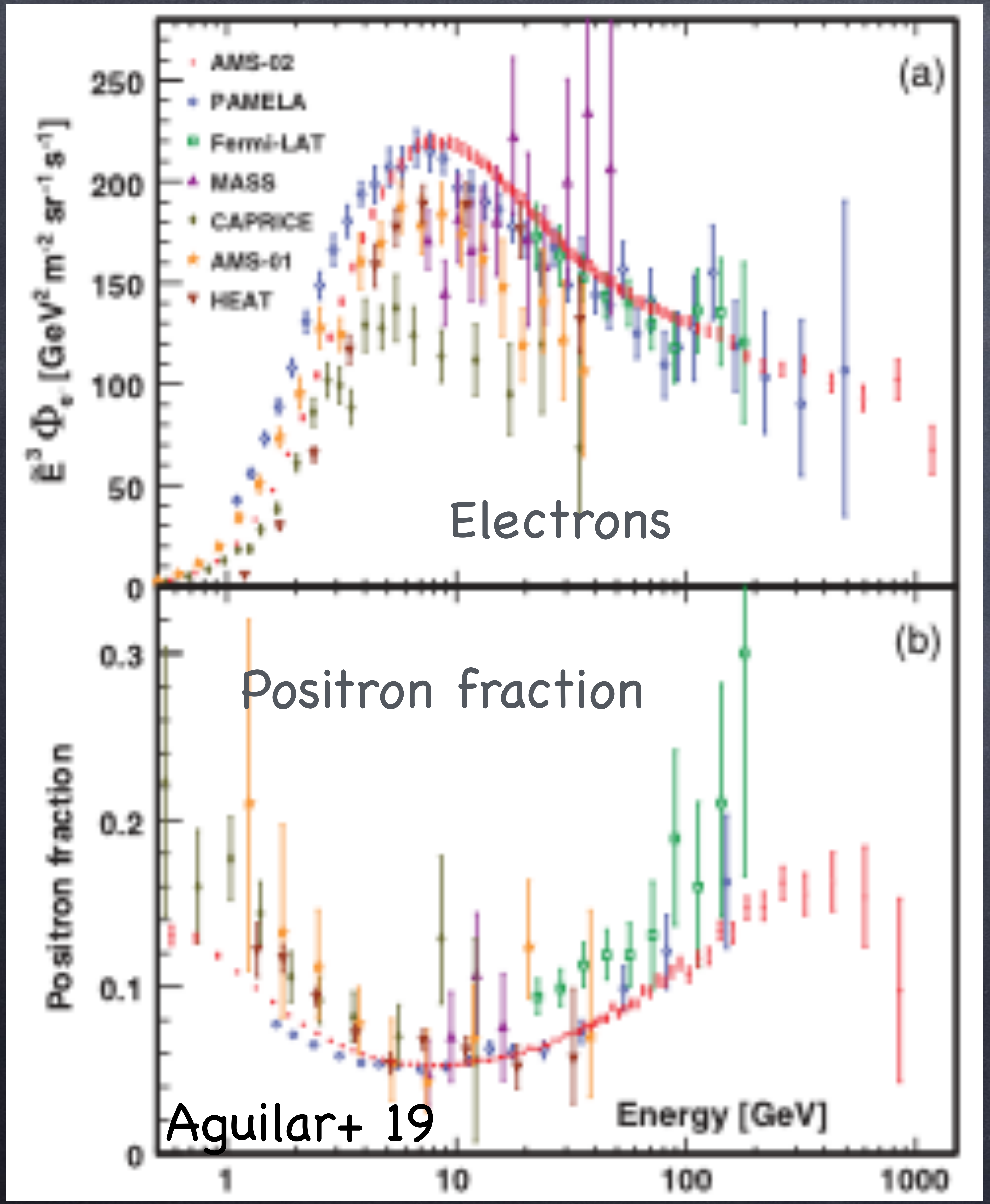
AND IF $\gamma_{inj}(e^-) = \gamma_{inj}(p)$

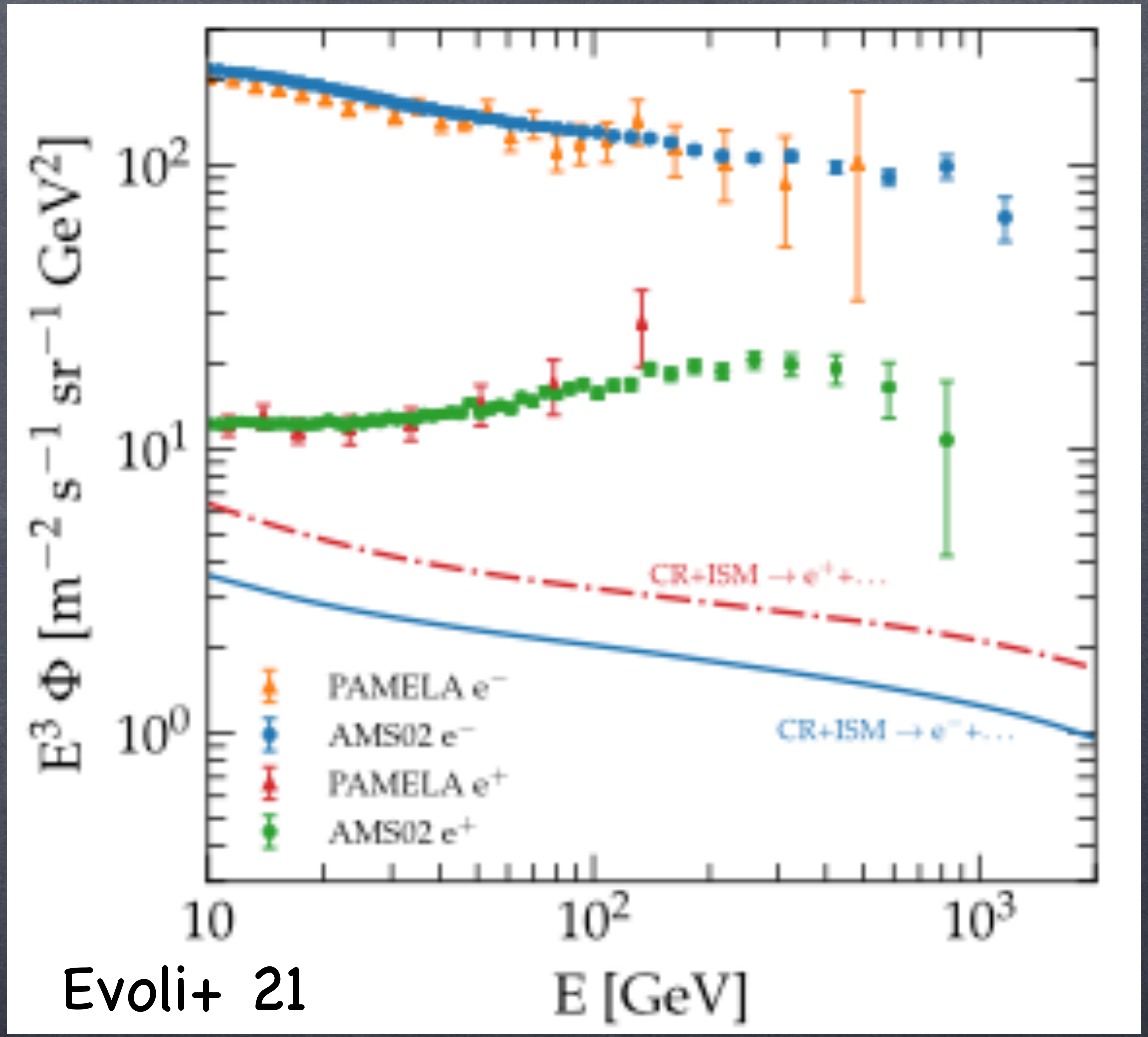
$$\frac{\Phi_{e^+}}{\Phi_{e^+} + \Phi_{e^-}} \approx \frac{\Phi_{e^+}}{\Phi_{e^-}} \propto E^{-\delta_E}$$



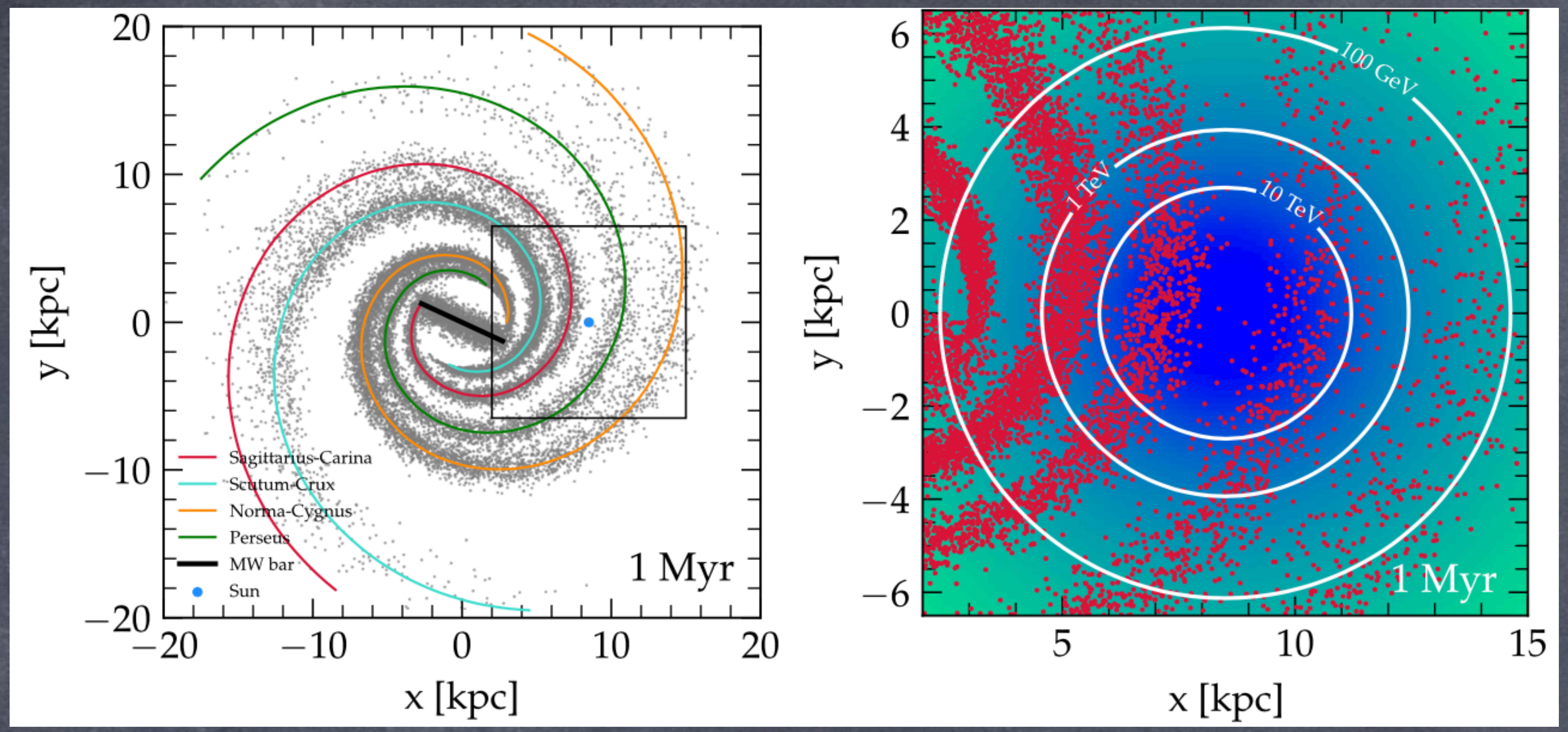


COSMIC POSITRONS

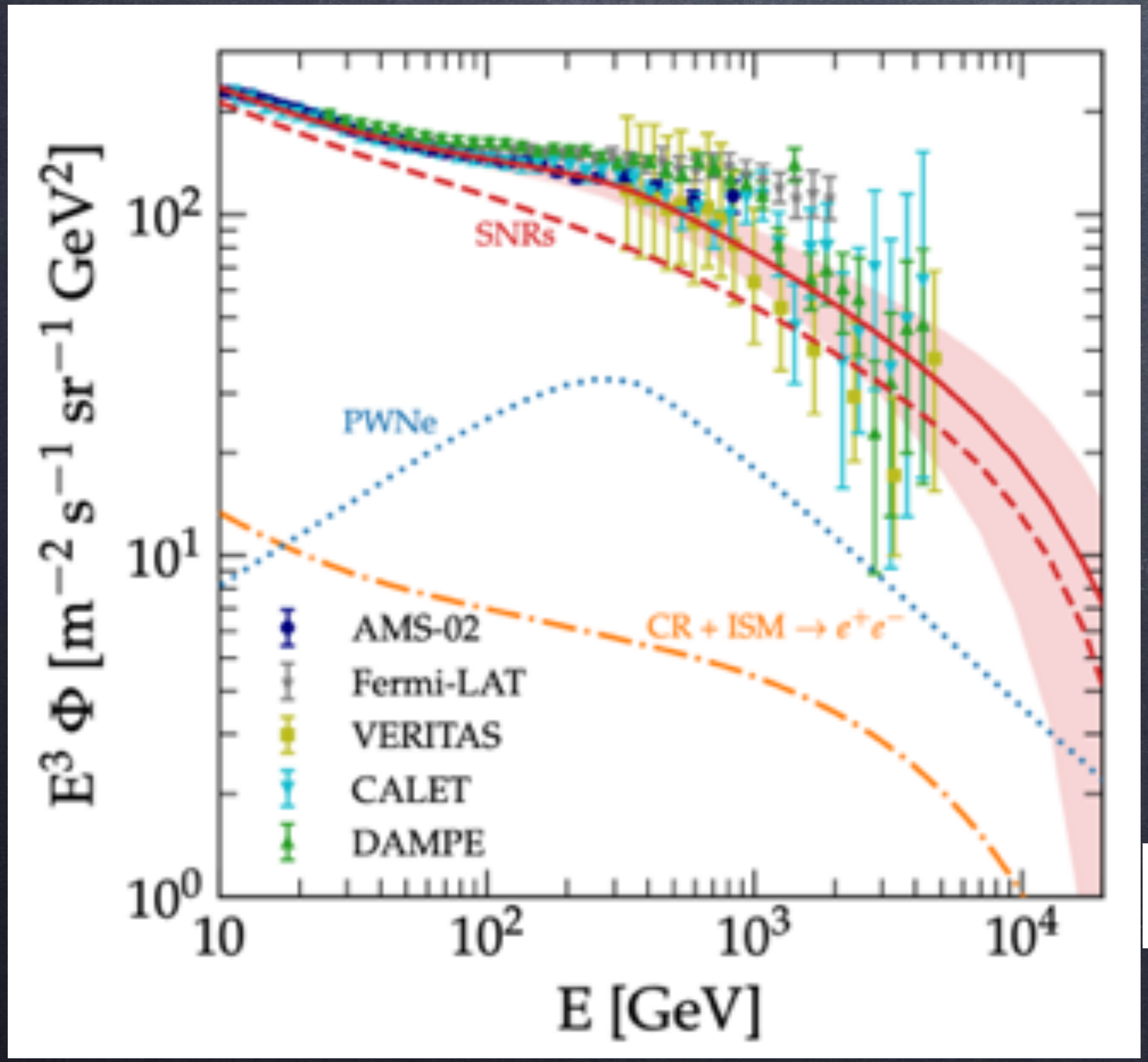




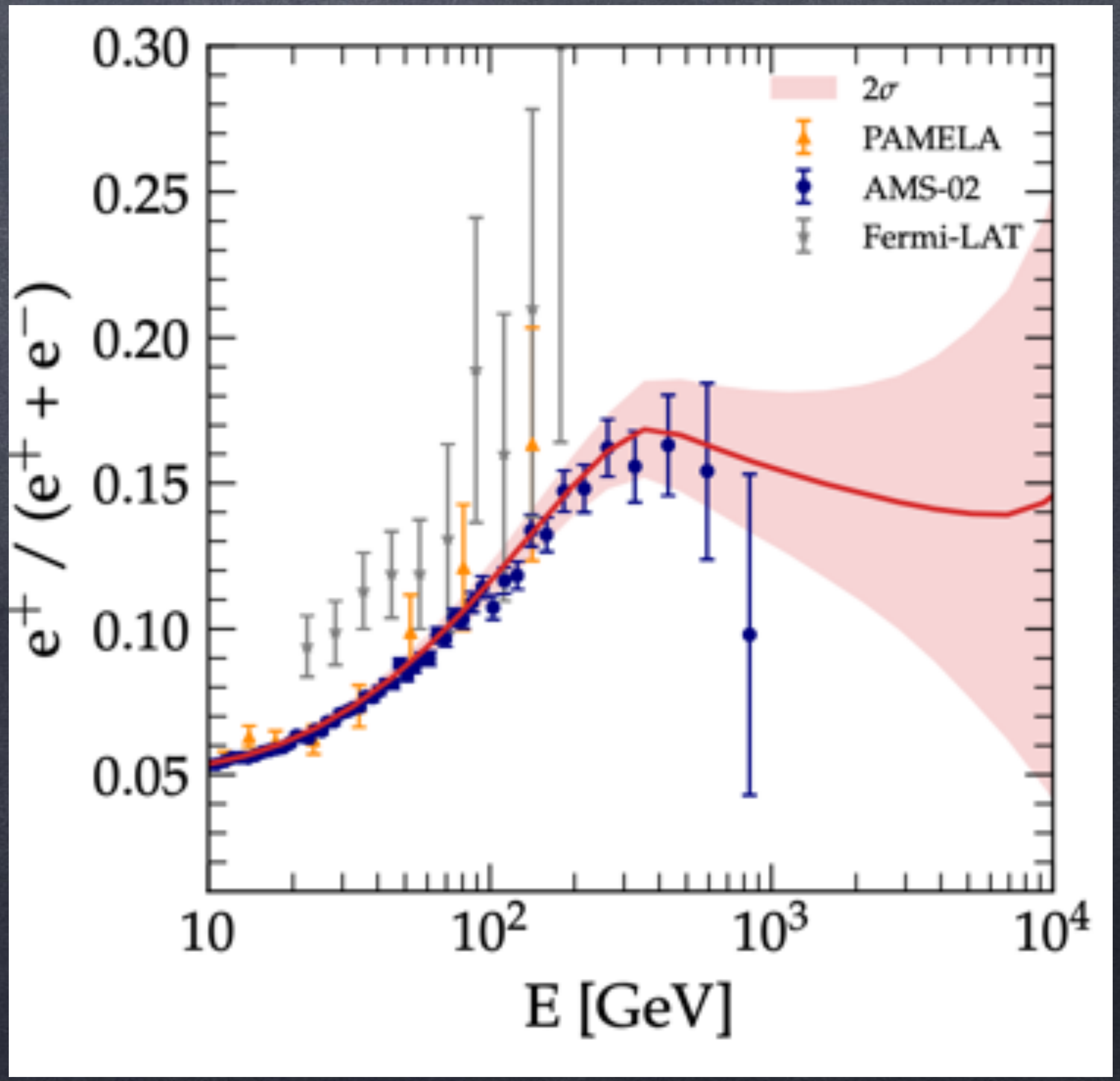
THE POSITRON EXCESS



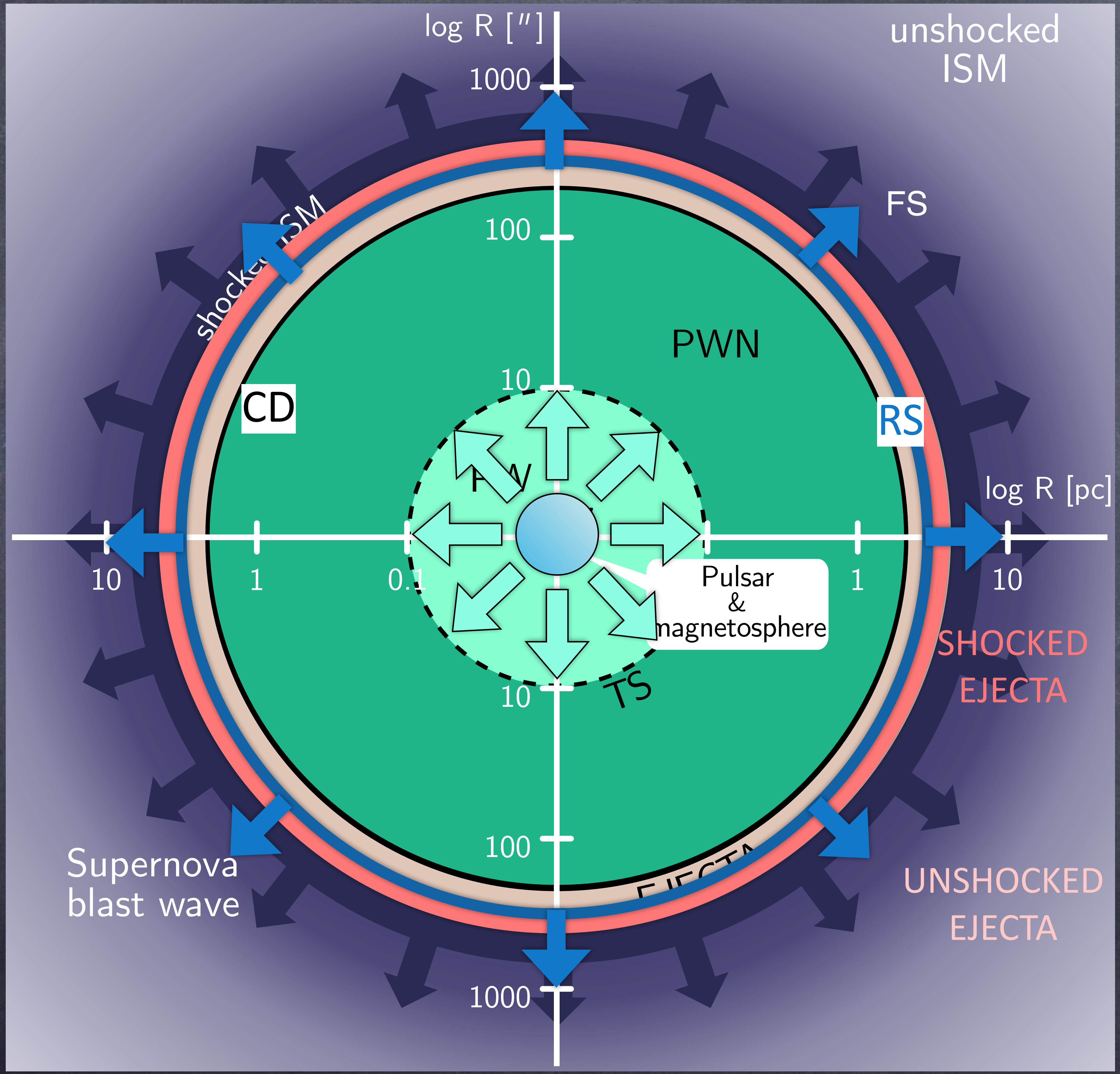
- PSR PARAMETERS ACCORDING TO Faucher-Giguere & Kaspi 06
- BROKEN POWER-LAW SPECTRUM STEEPENING AT ~500 GeV
- PROPAGATION PARAMETERS THAT FIT ALL AVAILABLE DATA



Evoli+ 21

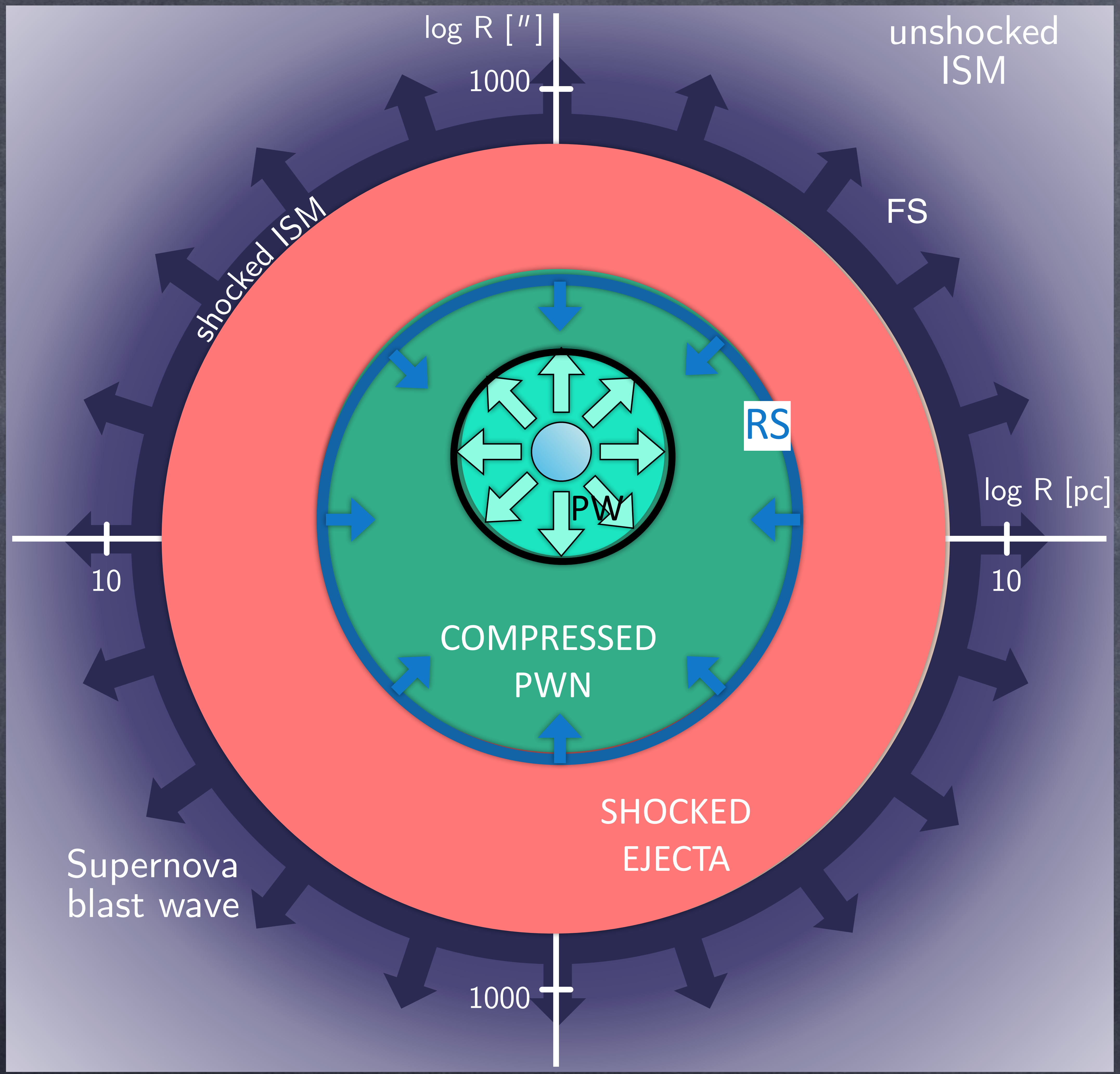


BASIC PICTURE FOR YOUNG PWNE



Adapted from Kennel & Coroniti 1984
[Del Zanna & Olmi 2017]

PWN EVOLUTION



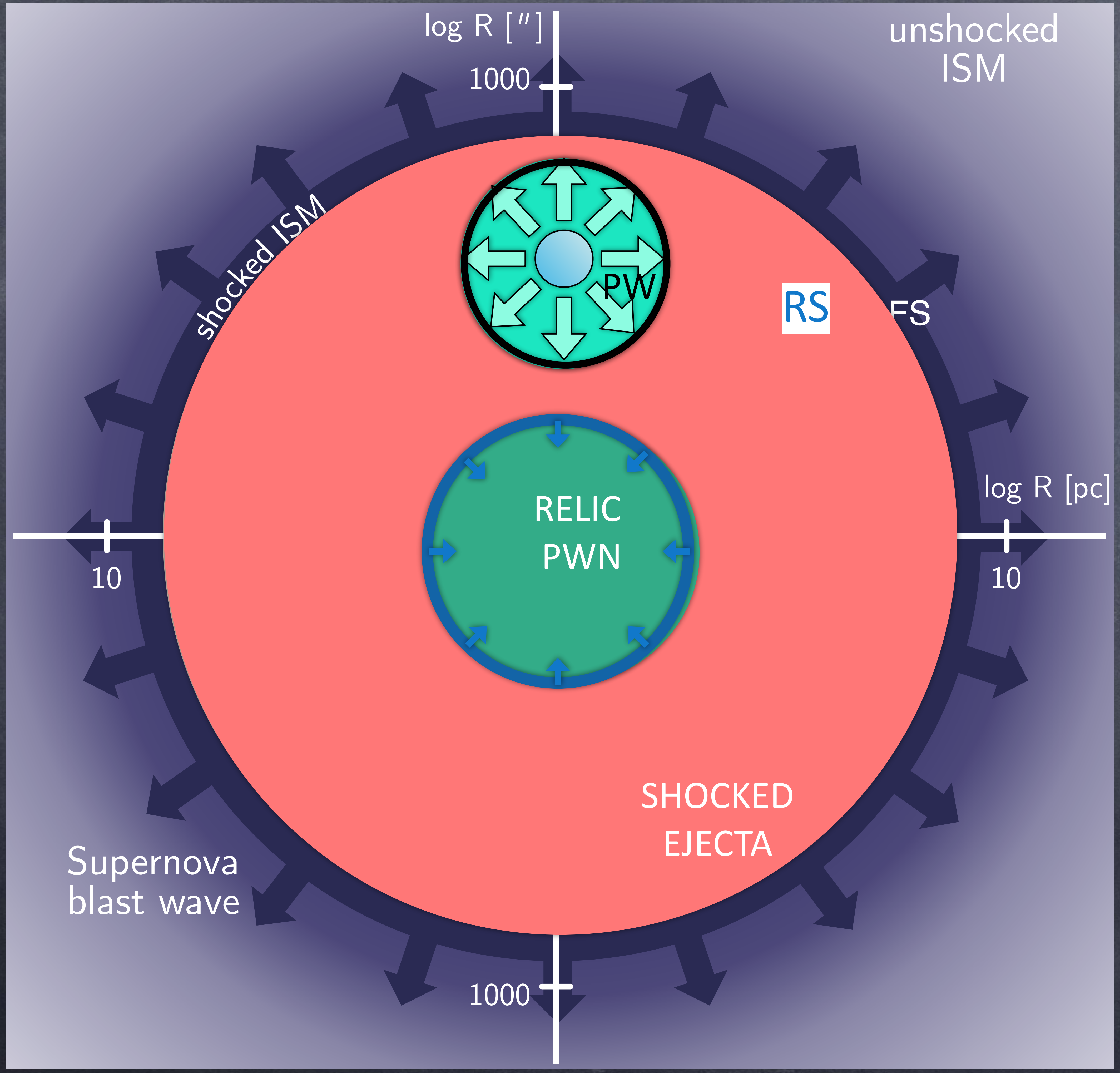
SNR EXPANSION
SLOWS DOWN
+
LARGE FRACTION OF
ALL THE PULSARS
BORN WITH
HIGH KICK VELOCITY

COMPRESSED PWN
OFFSET PW

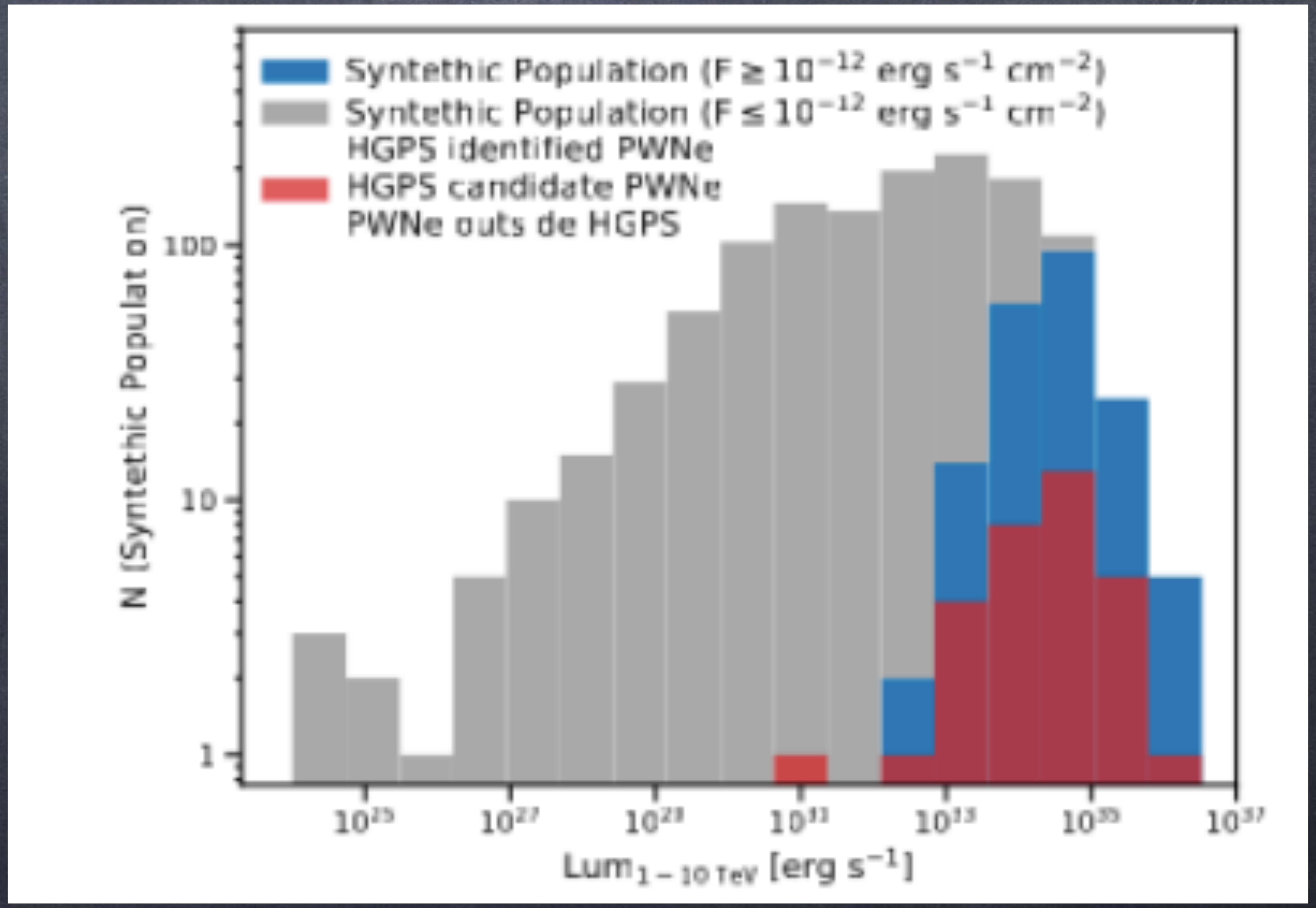
REVERBERATION PHASE

RELIC NEBULAE

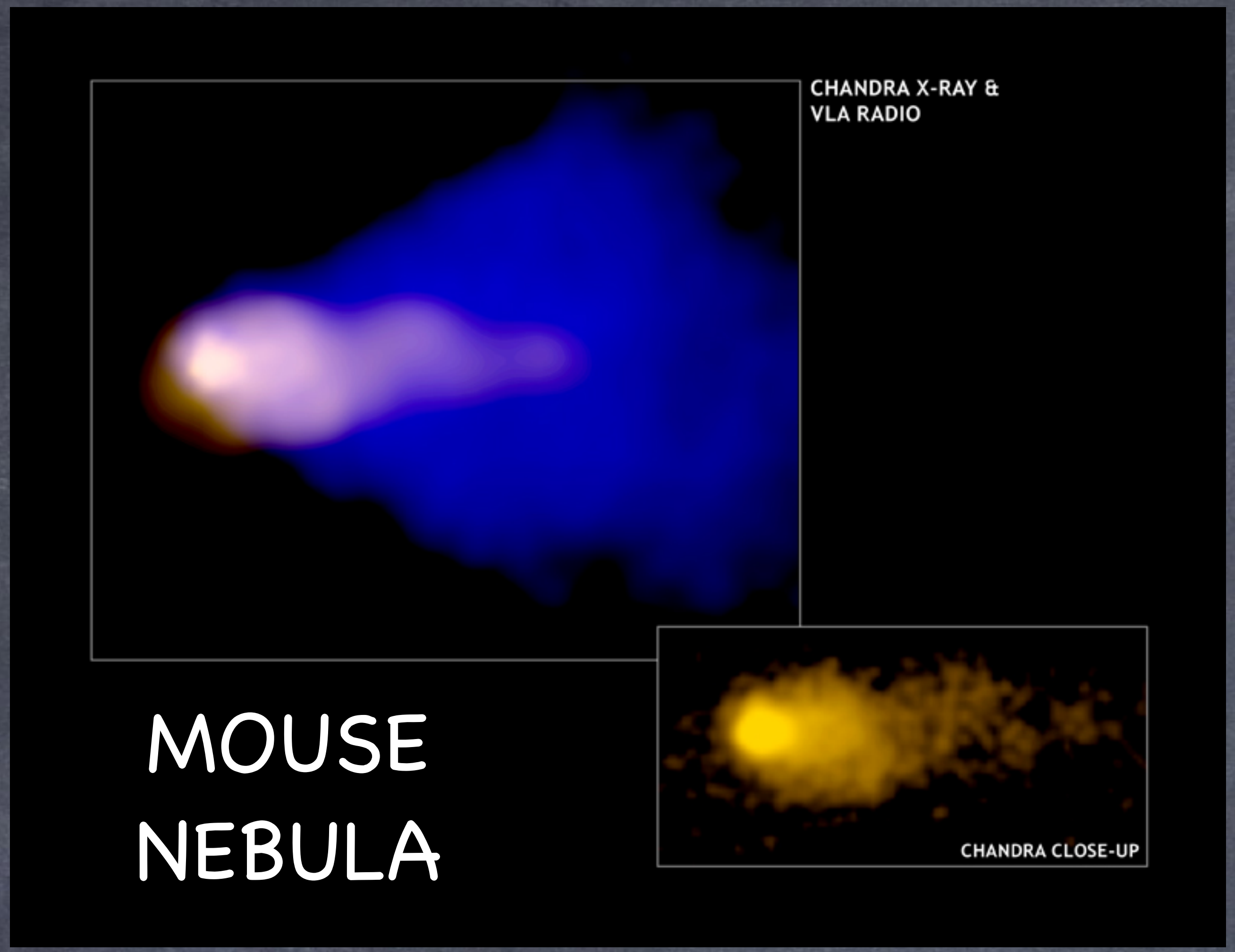
PSR MAY CROSS RS DURING COMPRESSION
AND LEAVE A RELIC

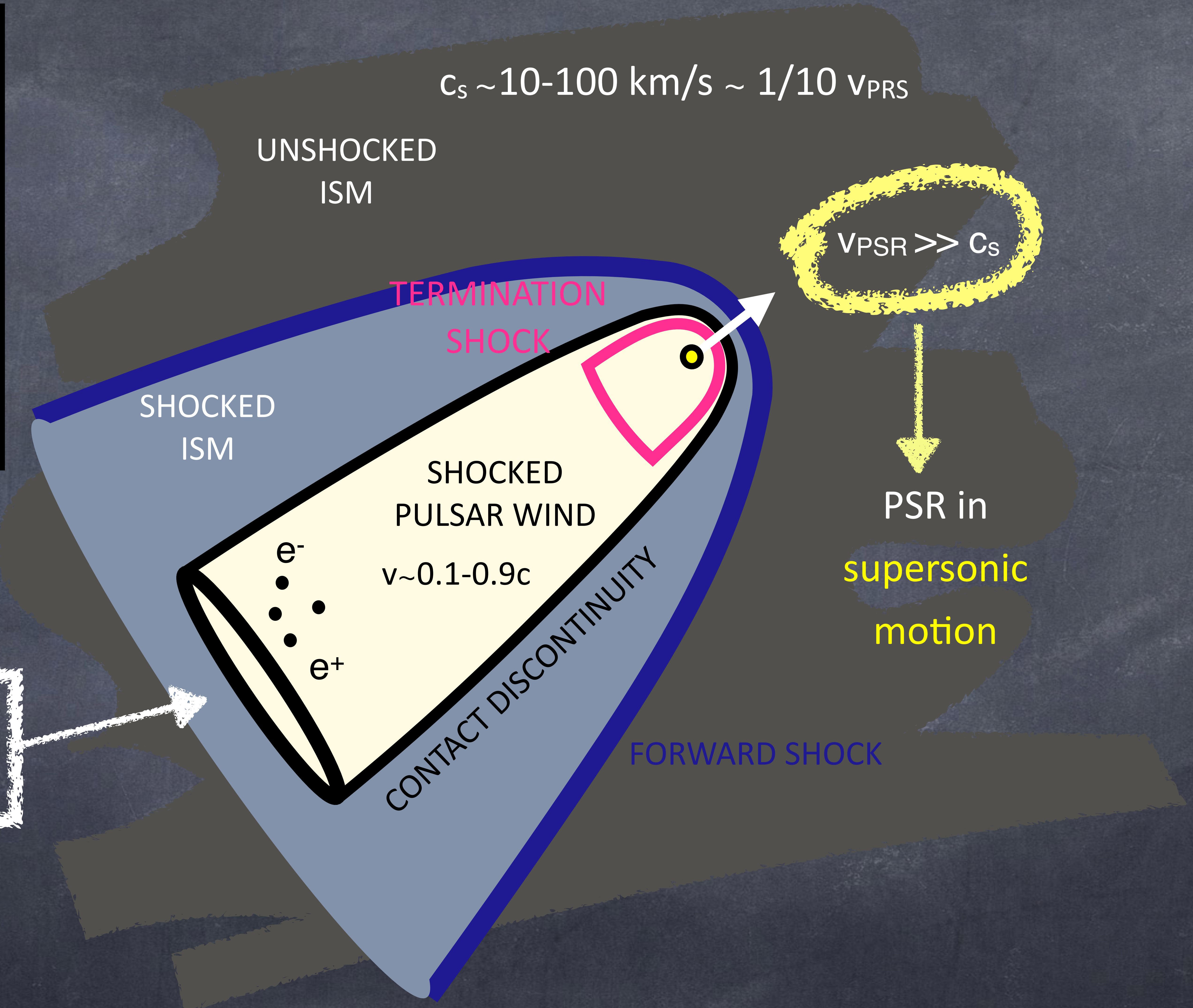


EVENTUALLY
MOST GAMMA-RAY BRIGHT
X-RAY DIM PWNe
[Fiori+ 2022]



BOW SHOCK NEBULAE

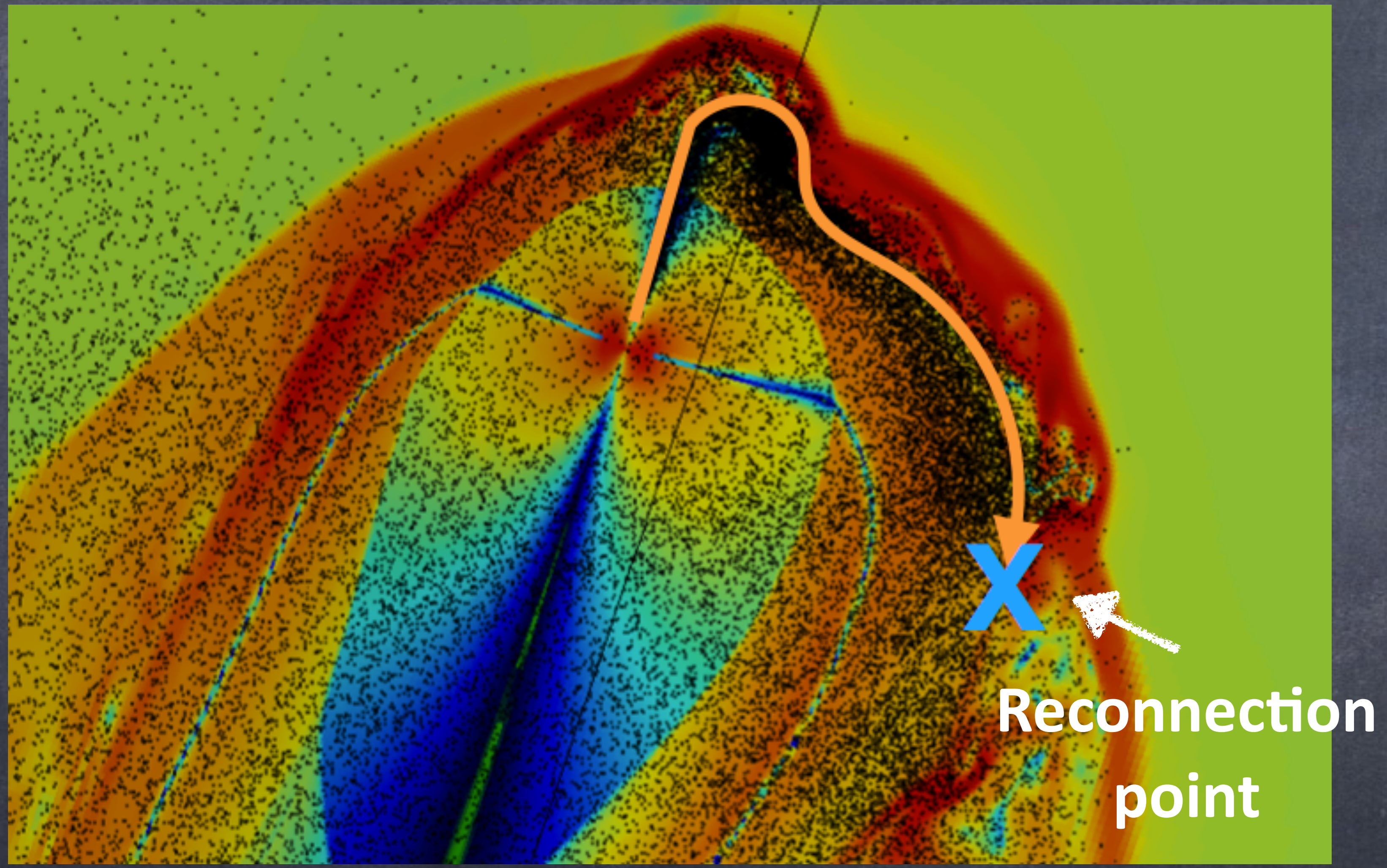


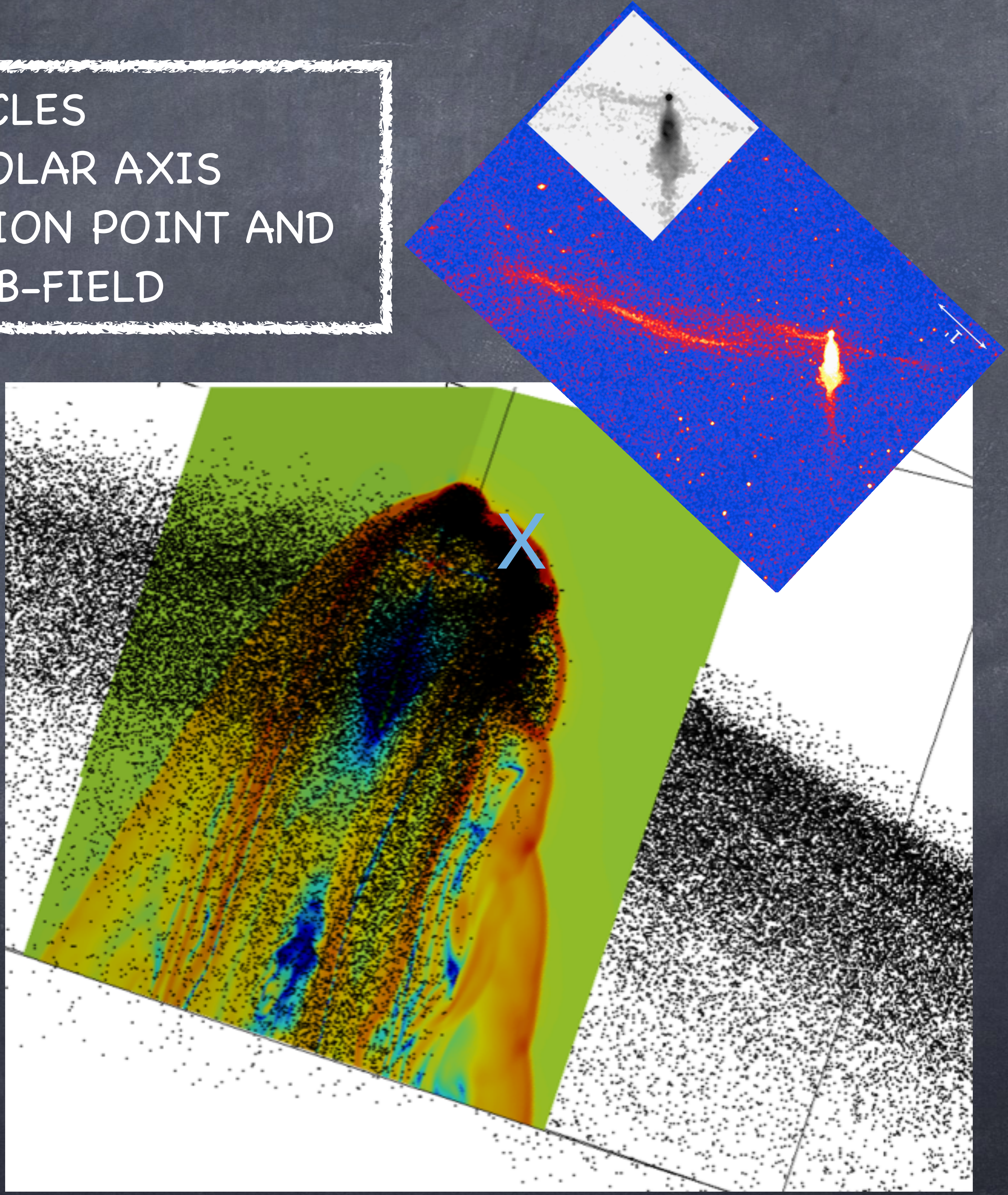


COURTESY OF B. Olmi

PARTICLE ESCAPE FROM BOW SHOCK PWNe

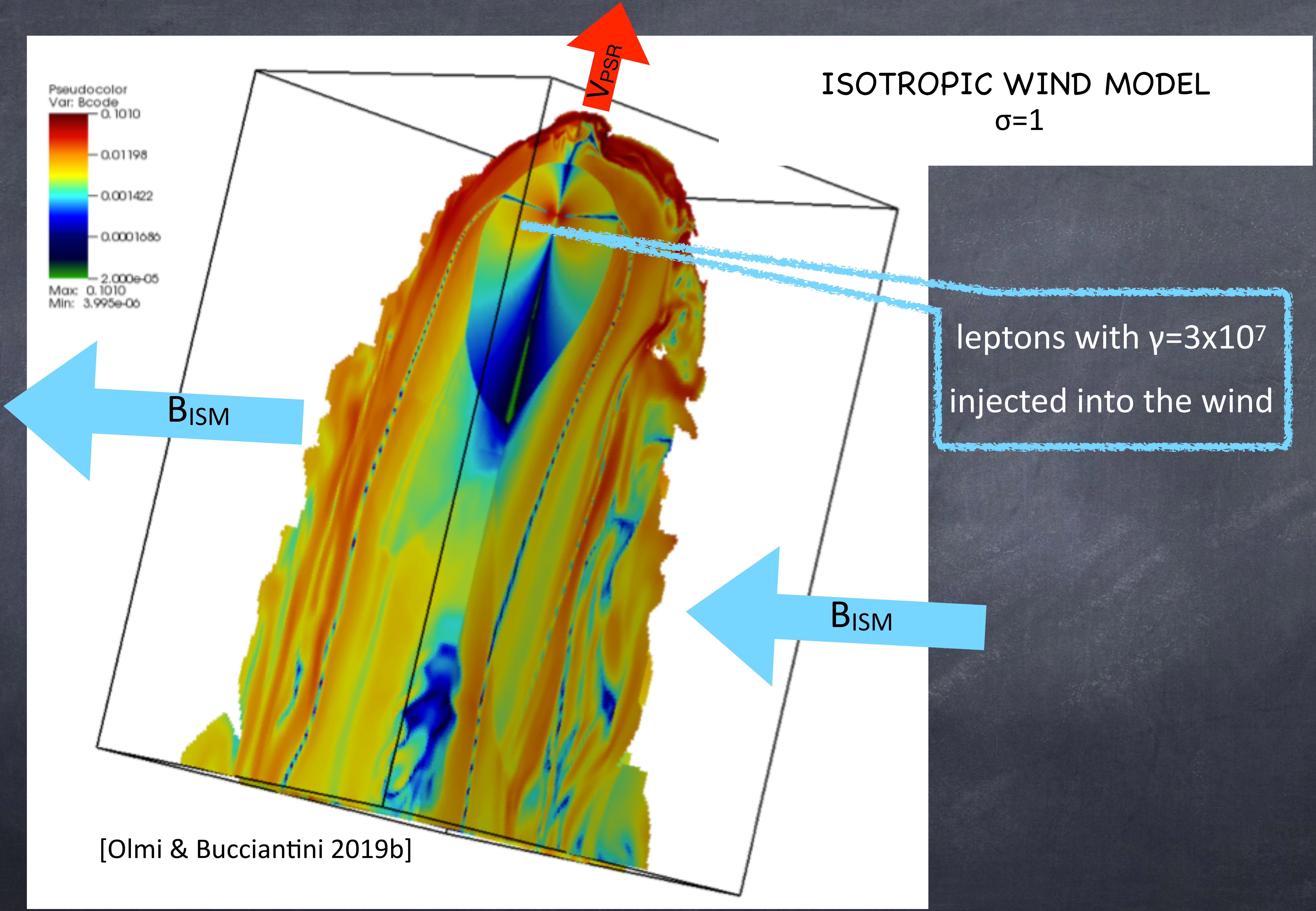
HIGH ENERGY PARTICLES
INJECTED CLOSE TO THE POLAR AXIS
STREAM OUT FROM RECONNECTION POINT AND
FORM JETS IN THE ISM B-FIELD





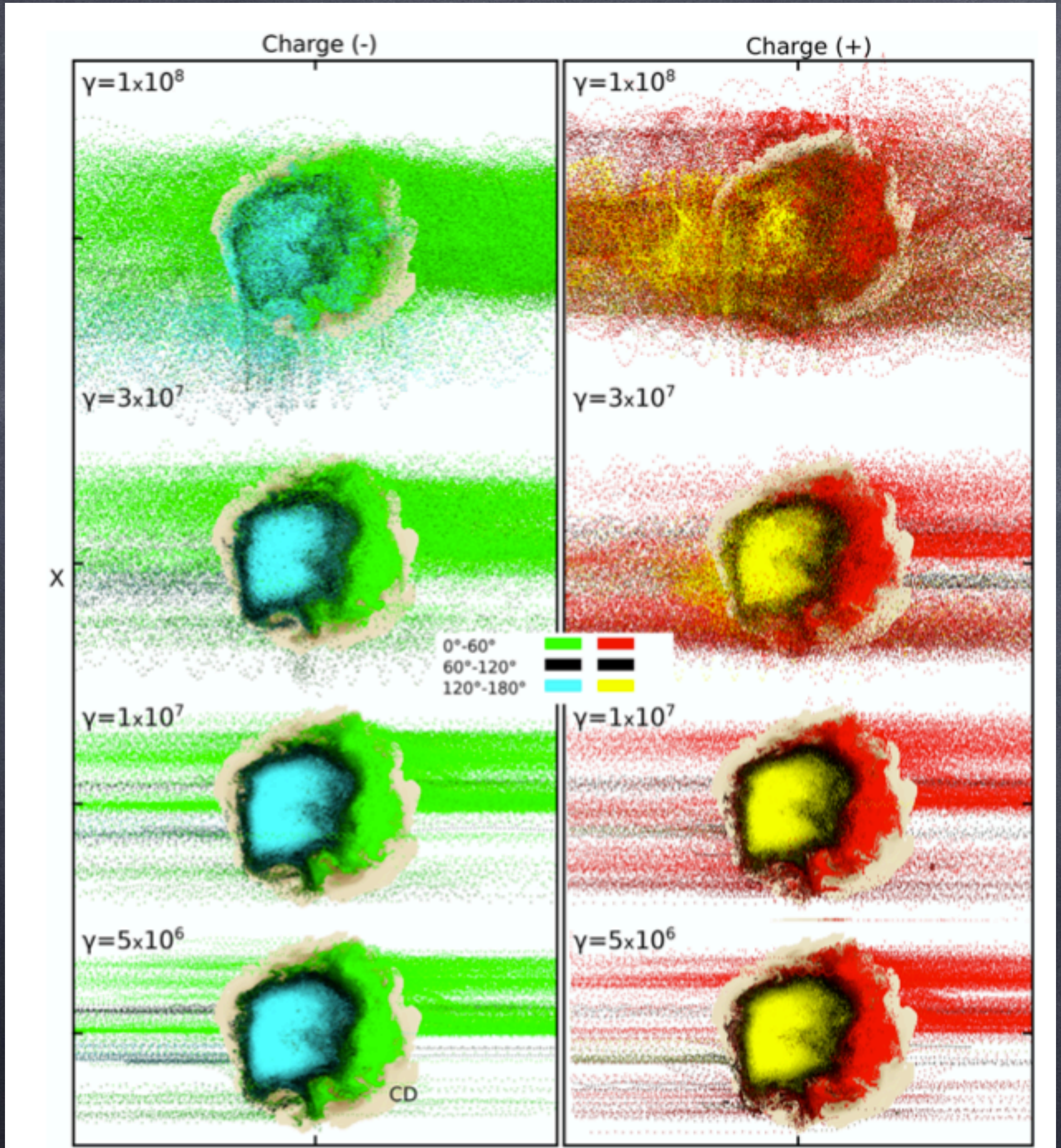
Olmi & Bucciantini 2019b

PARTICLE ESCAPE FROM BSPWN



[Olmi & Bucciantini 2019b]

ENERGY DEPENDENCE OF THE ESCAPE



[Olmi & Bucciantini 2019b]

WITH INCREASING ENERGY:

- LARGER FRACTION OF PARTICLES
- MORE ISOTROPIC RELEASE

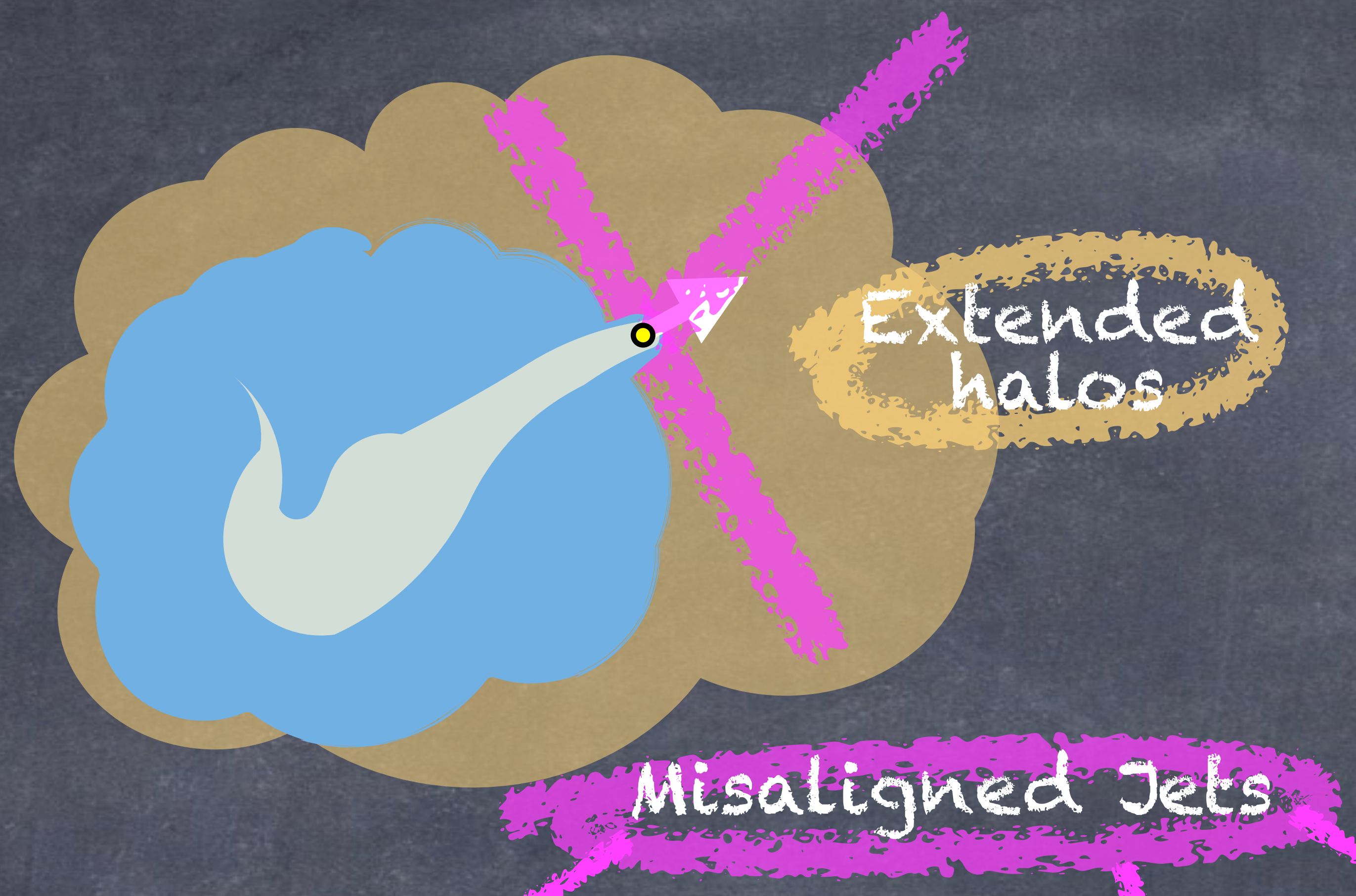
AT GeV ENERGIES:

- ESCAPE EXPECTED ONLY FROM THE TAIL

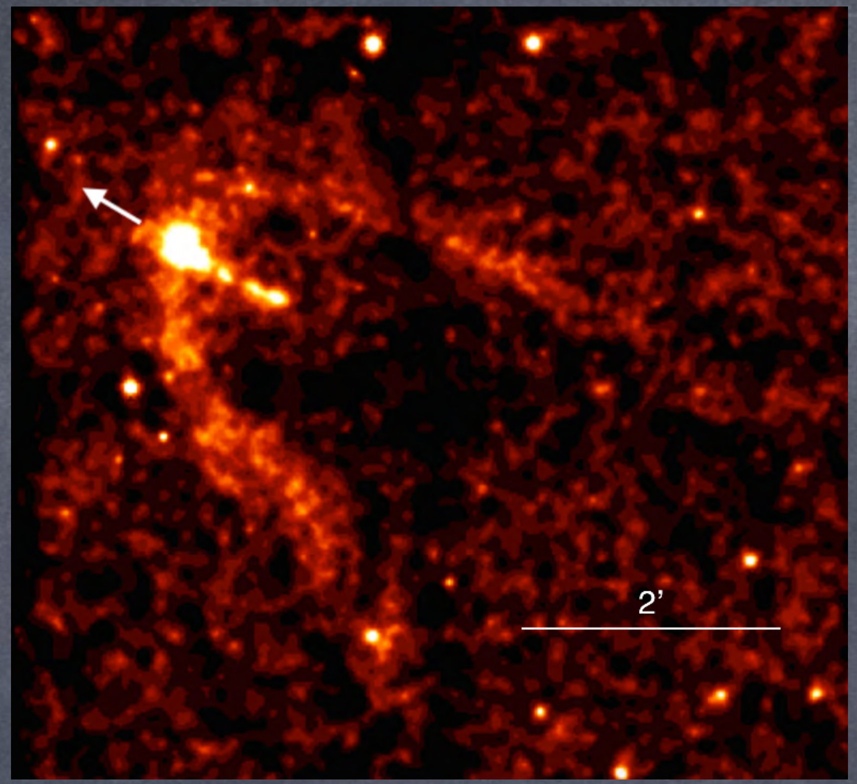
NOTICE THAT:

- ENERGY DEPENDENT ESCAPE PROBABILITY MAKES HALO SPECTRUM NON TRIVIAL
- ESCAPE IS CHARGE SEPARATED!
- IF LOW AMBIENT B BELL INSTABILITY POSSIBLE...

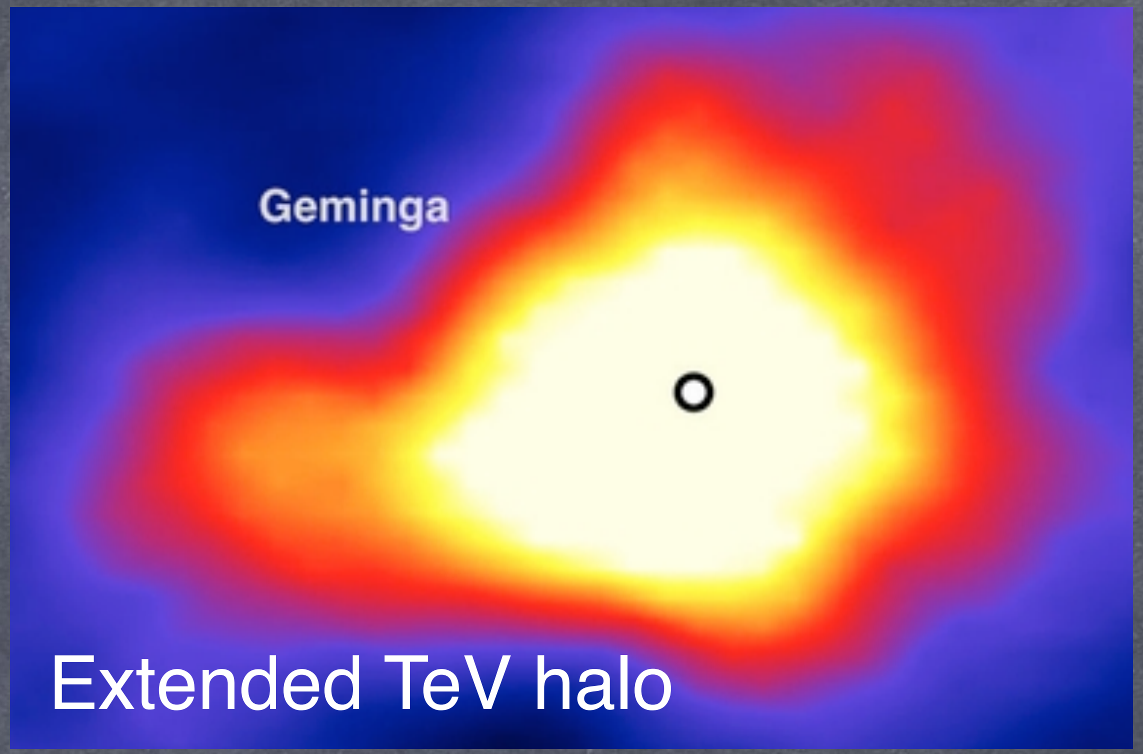
OBSERVATIONS OF JETS AND HALOES



X-ray

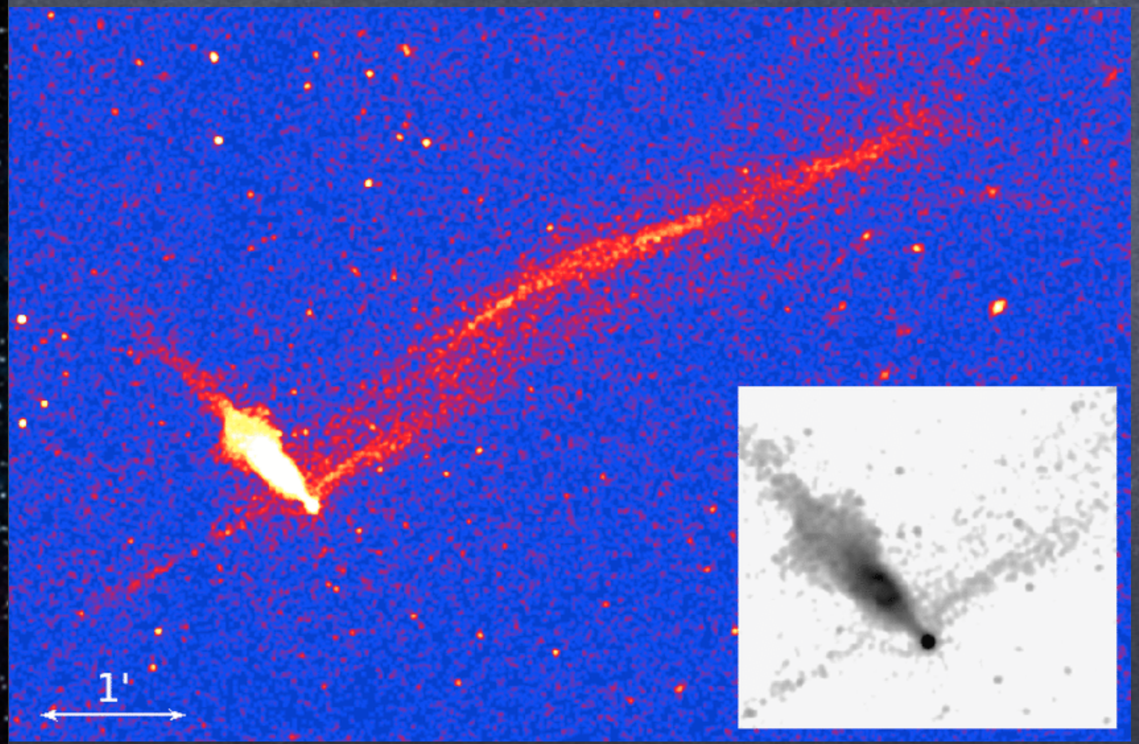


Geminga
[Posselt+ 2017]

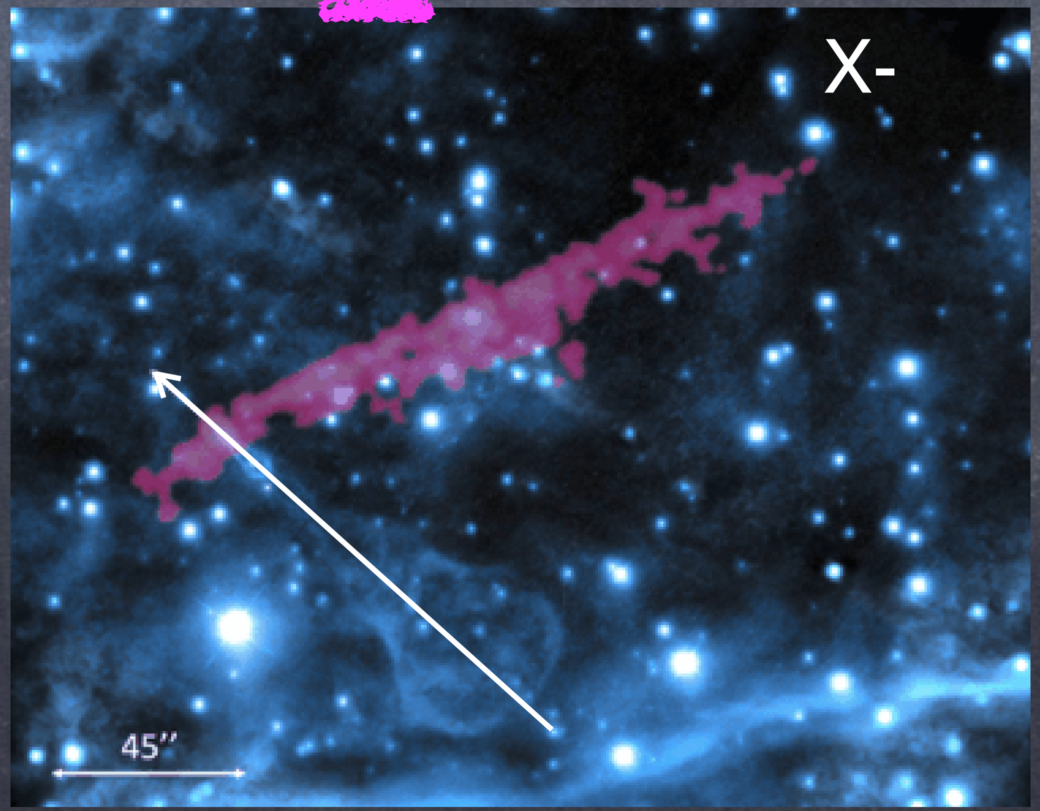


[Abeysekara+ 2017]

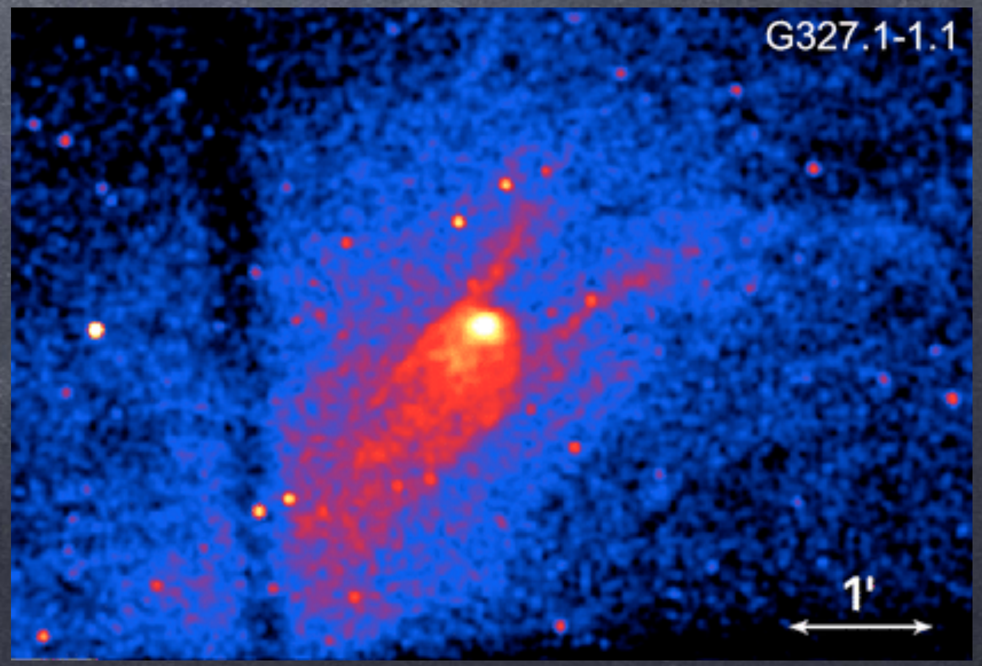
PSR J1509-5850
[Klinger+ 2016]



Lighthouse nebula
[Pavan+ 2016]

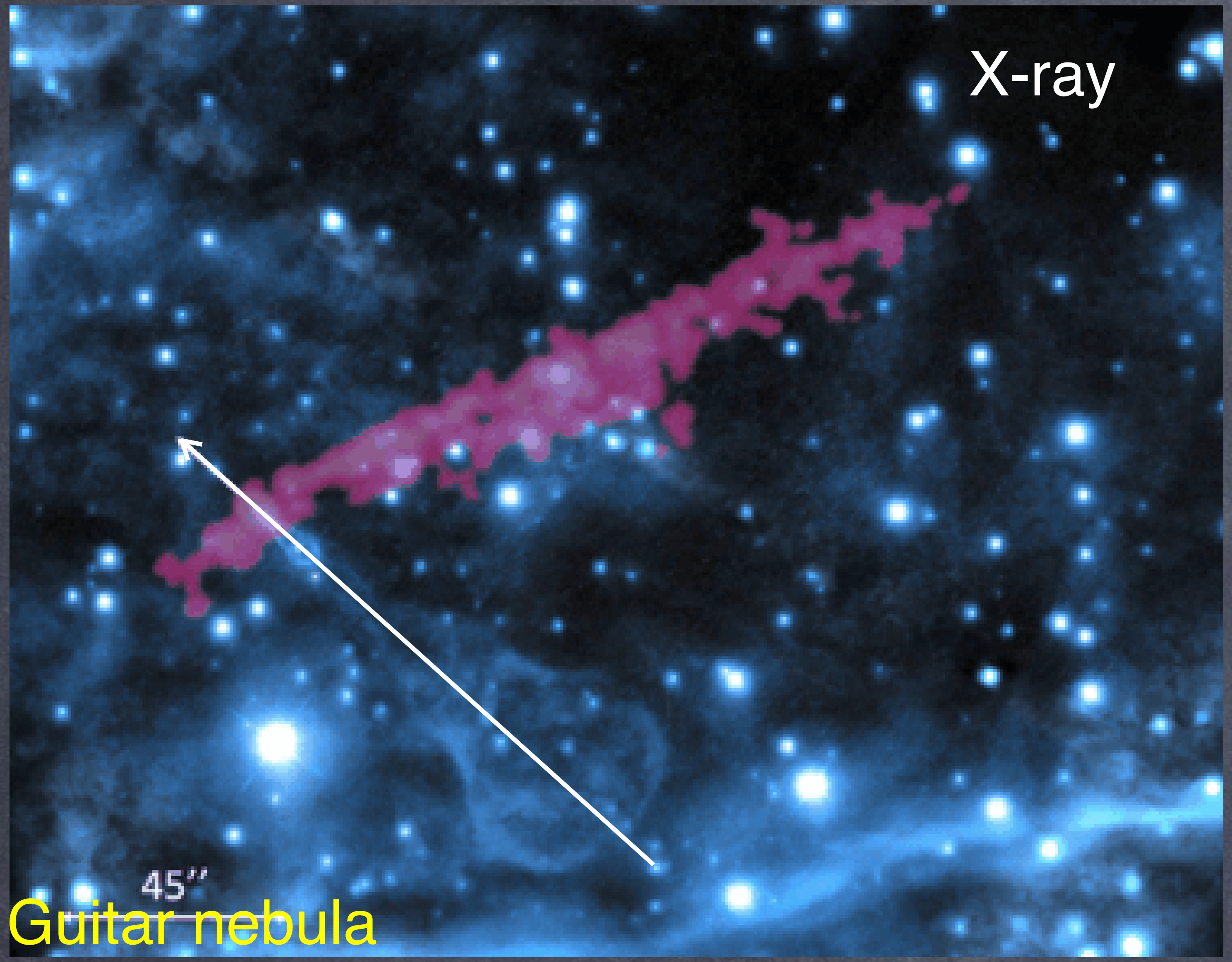


Guitar nebula
[Cordes+ 1993, Wong+ 2003]



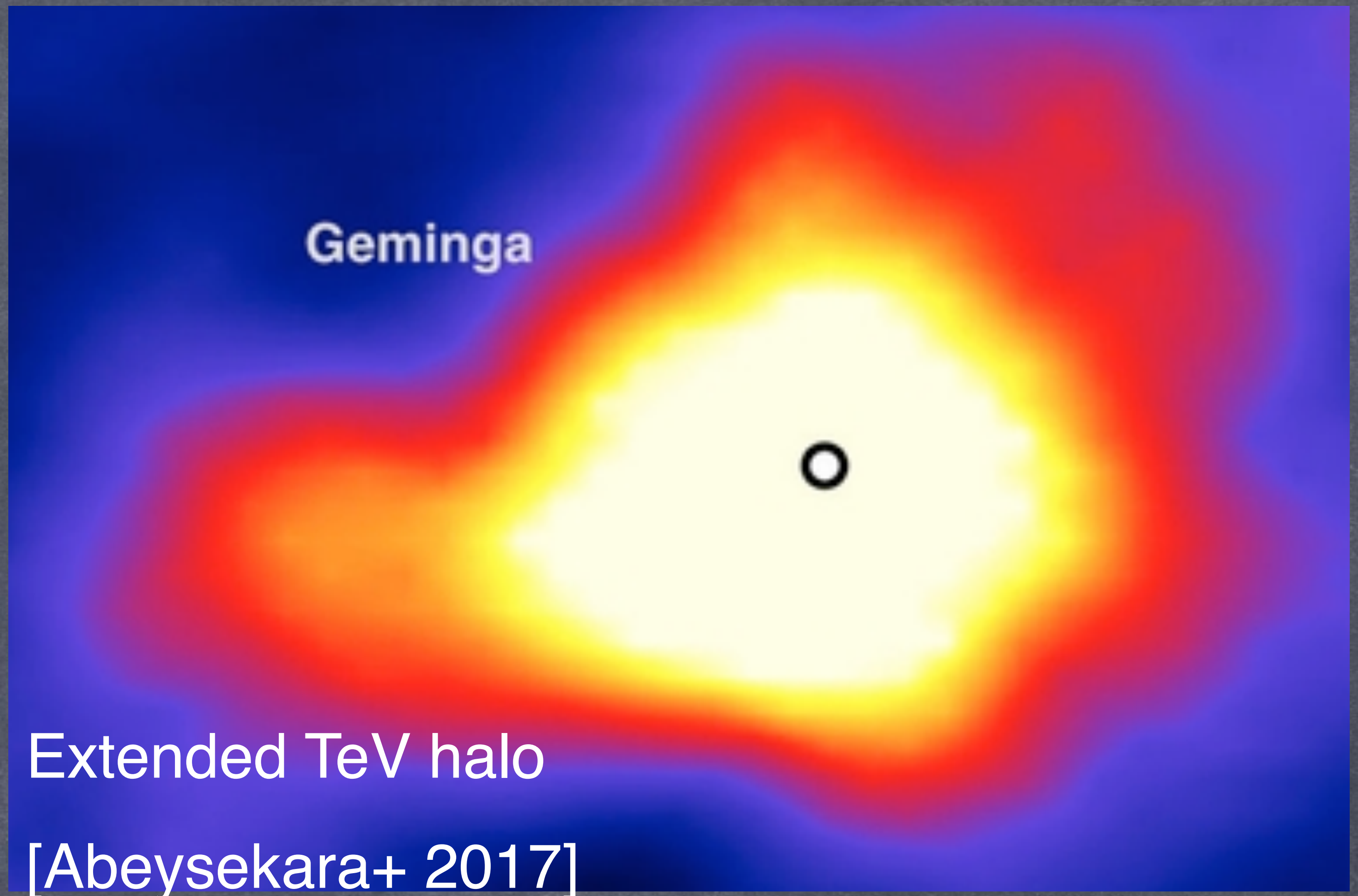
G327
[Temim+ 2009]

INTERPRETATION: JETS AND HALOES



[Cordes+ 1993, Wong+ 2003]

JETS CONSISTENT WITH
SYNCHROTRON EMISSION
OF PARTICLES WITH $E \approx e\Phi_{\rm PSR}$
IN A **FEW X** $10\mu G$ **MAGNETIC FIELD**
[Bandiera 2008]



[Abeysekara+ 2017]

HALOS CONSISTENT WITH
ICS EMISSION
OF PARTICLES WITH $E \approx e\Phi_{\rm PSR}$
IN A $\approx \mu G$ MAGNETIC FIELD
AND $D \approx 10^{-2} D_{gal}$

[Abeysekara+ 2017, Lopez-Coto & Giacinti 2018,
Lopez-Coto + 2021]

SUMMARY

-SNRs STRUGGLE TO REACH THE KNEE IN THEORY AND GAMMA-RAY OBSERVATIONS SO FAR ARE NOT TOO ENCOURAGING

-SEVERAL NEW CLASSES OF GALACTIC ACCELERATORS

-SOME POTENTIAL PEVATRONS

-SOME OBSERVED PEVATRONS

-POSITRON SOURCES ALSO NEEDED!

-IMPORTANT ANSWERS EXPECTED FROM OBSERVATIONS WITH UPCOMING CTA AND ASTRI-MiniArray