HESS J1507–622: A Galactic Kilonova Remnant Candidate and Its r-Process Gamma-Ray Signatures

Origin of Elements and Cosmic Evolution” (OECE2026), NOV 2-6, 2026, Beihang University, Beijing

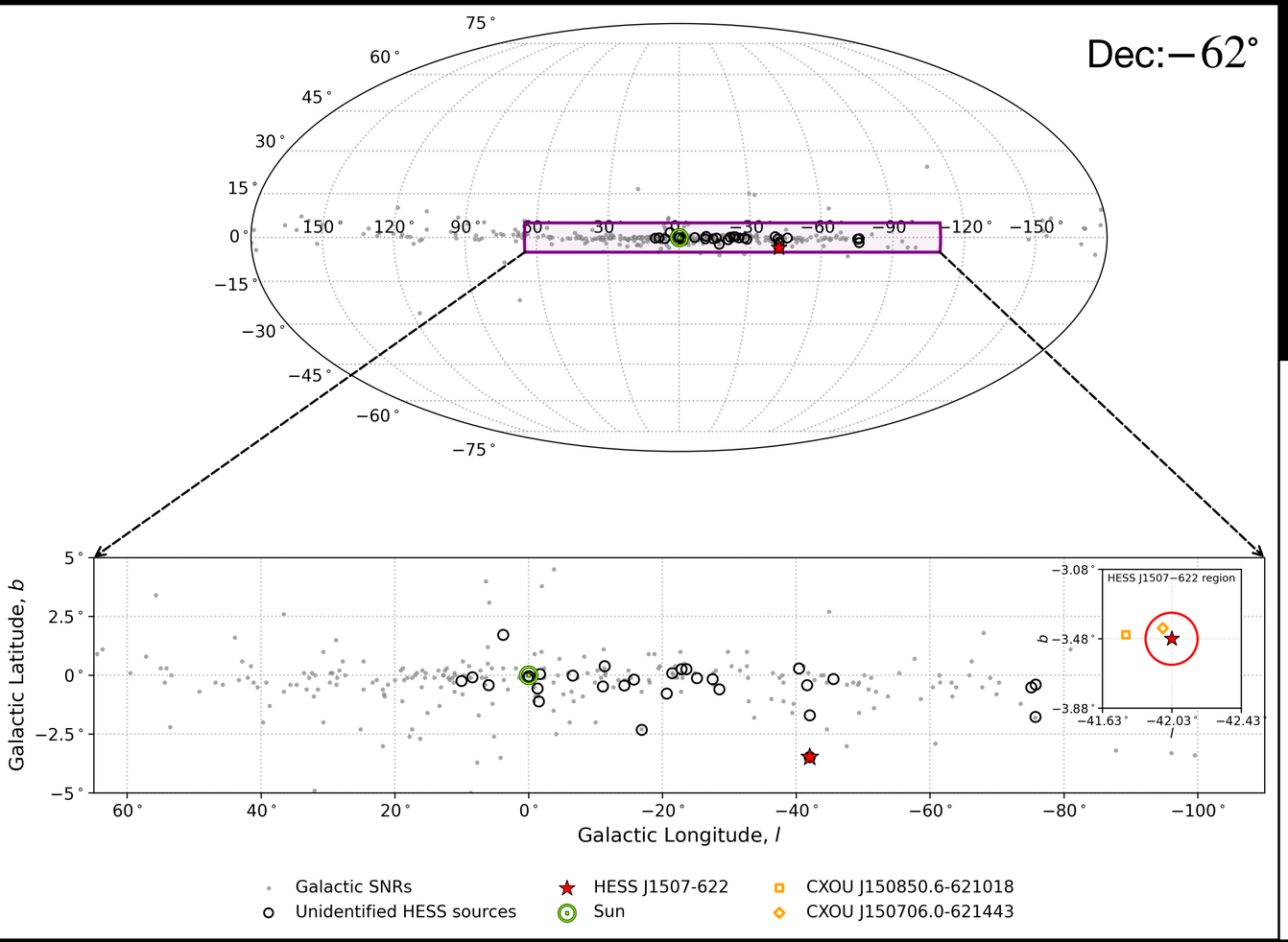
Prantik Sarmah
IHEP, Beijing, China
Email: prantiksarmah@ihep.ac.cn
arXiv: 2609.38341
Collaborators: Xilu Wang, Myles Carley, Shu-Xu Yi, Ming-Yu Ge, Rebecca Surman

Image source: Google

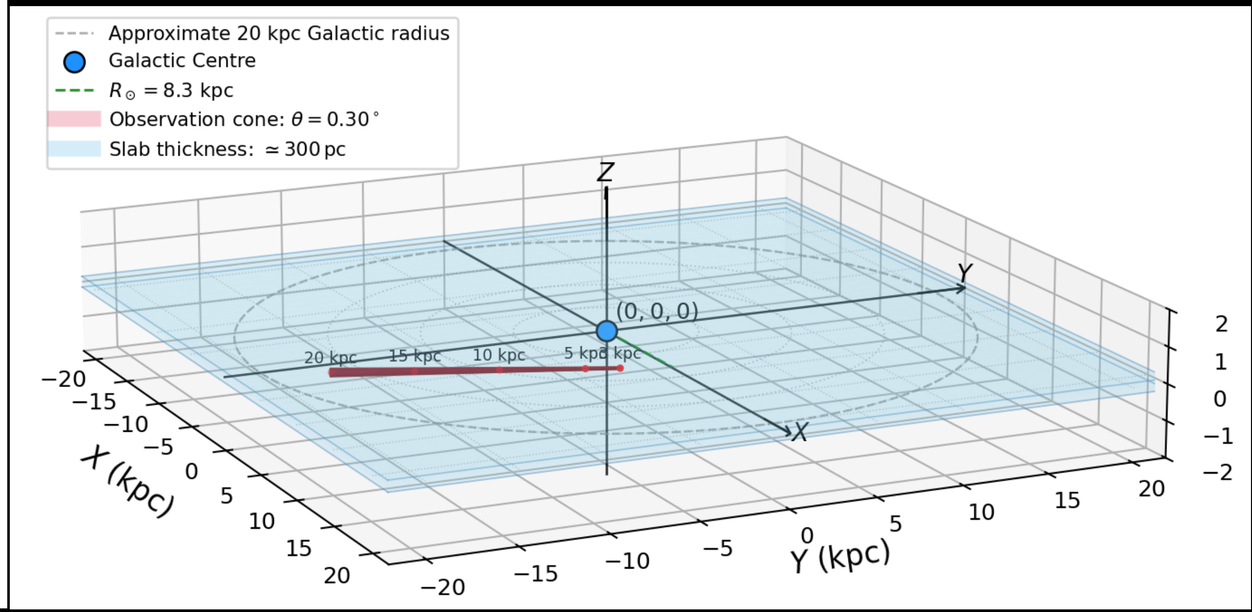
Plan of the talk

- ✦ Details of the HESS J1507-622.
- ✦ Limitations of the existing PWN and SNR interpretation.
- ✦ Why could HESS J1507-622 be a Kilonova Remnant?
- ✦ Results

HESS J1507-622

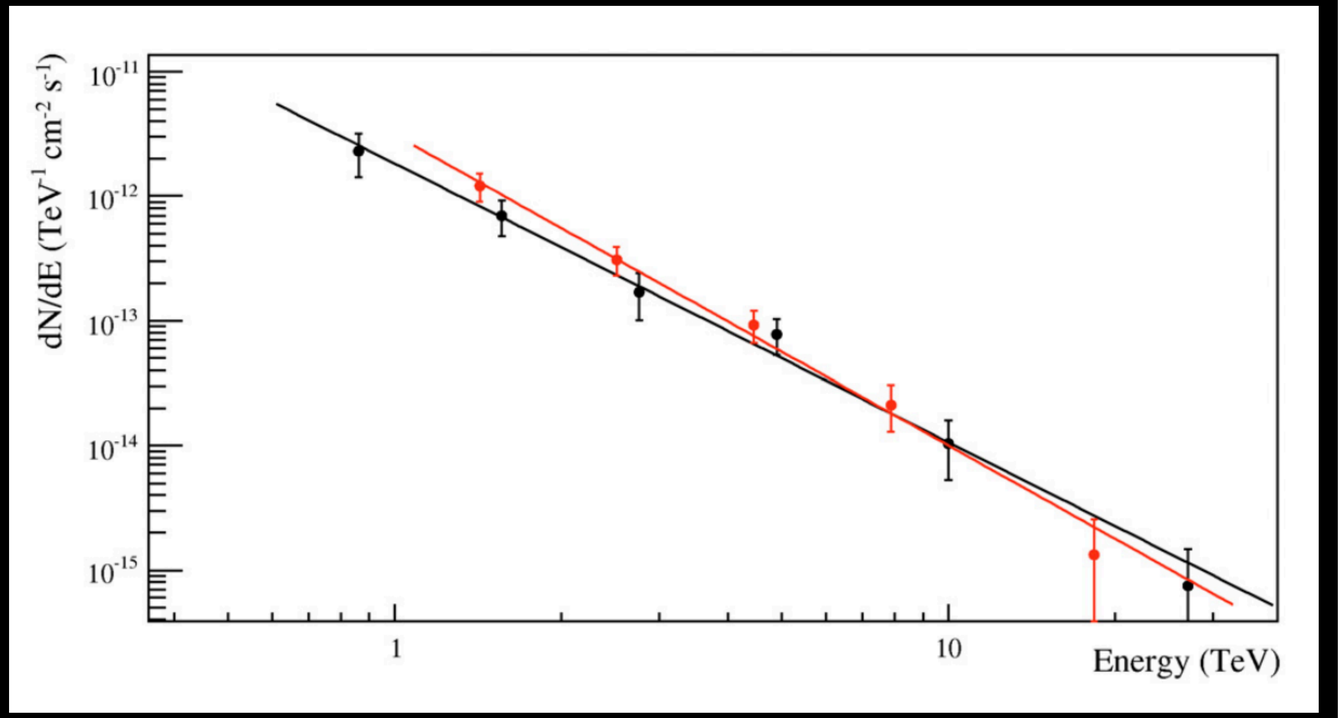


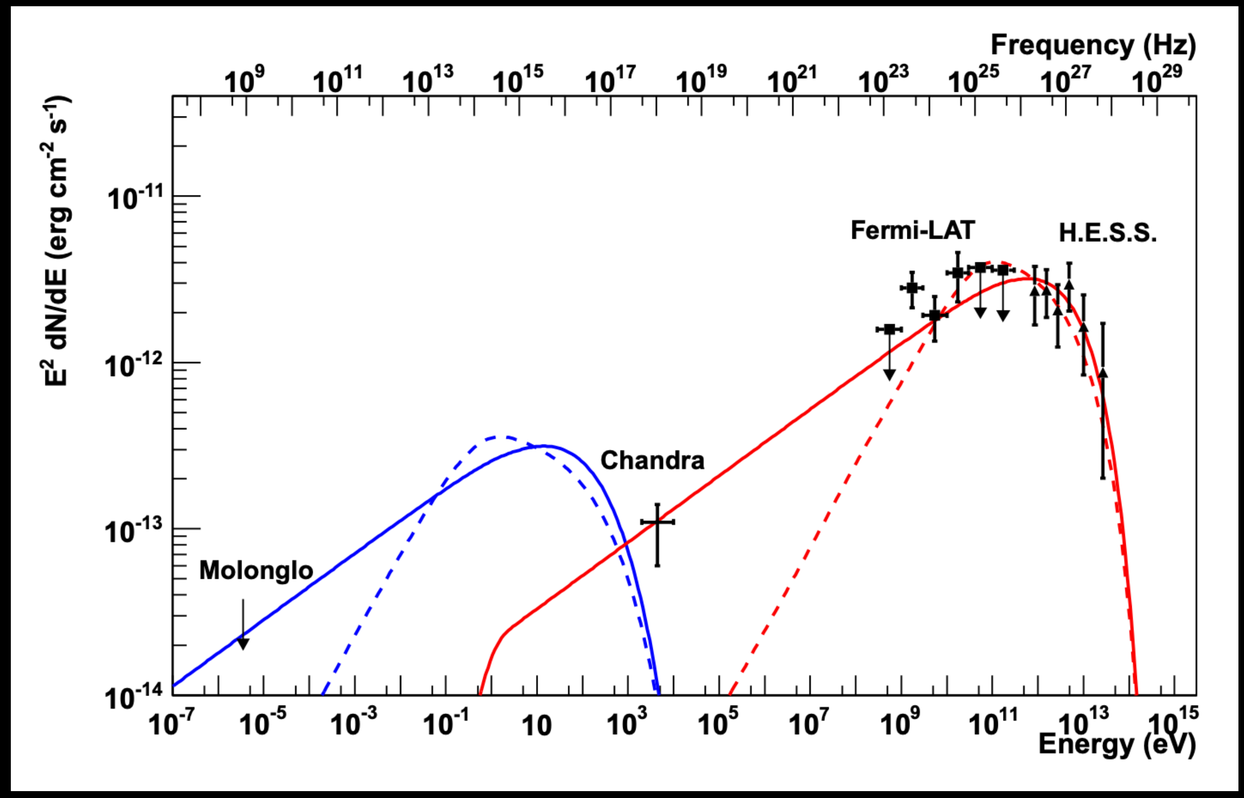
- From HESS Galactic Plane Survey.
- 3.5 degree below the Galactic plane.
- Angular size ~ 0.30 degree.
- Distance not known.



H. E. S. S. Collaboration, Acero, F., Aharonian, F., et al. 2011, A&A, 525, A45

HESS J1507-622





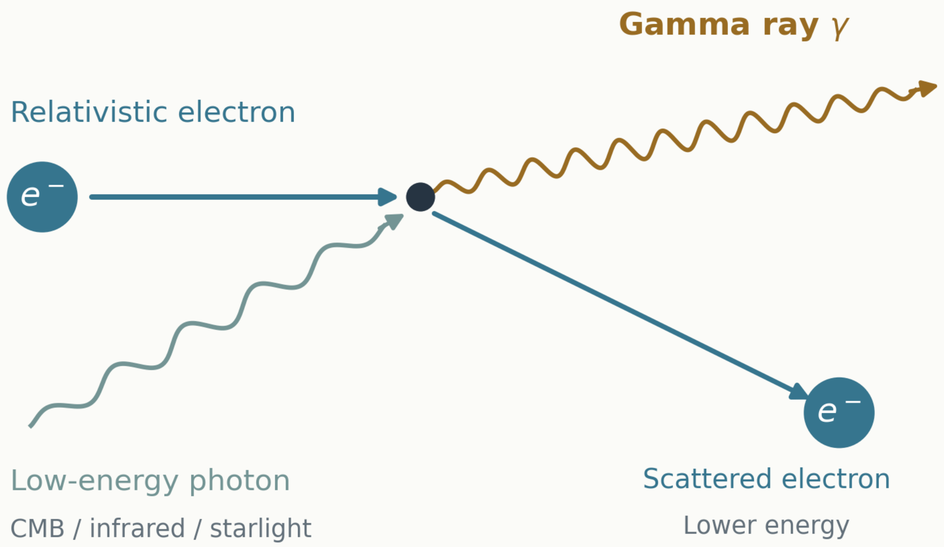
- ✦ Detected in GeV by Fermi-LAT.
- ✦ No radio-X-ray counterparts, means low synchrotron emission.
- ✦ Suggest far below (several 100 pc) the Galactic plane where magnetic field is weak.

H. E. S. S. Collaboration, Acero, F., Aharonian, F., et al. 2011, A&A, 525, A45
Domainko, W., & Ohm, S. 2012, A&A, 545, A94

Hadronic or Leptonic?

A INVERSE COMPTON

Leptonic emission

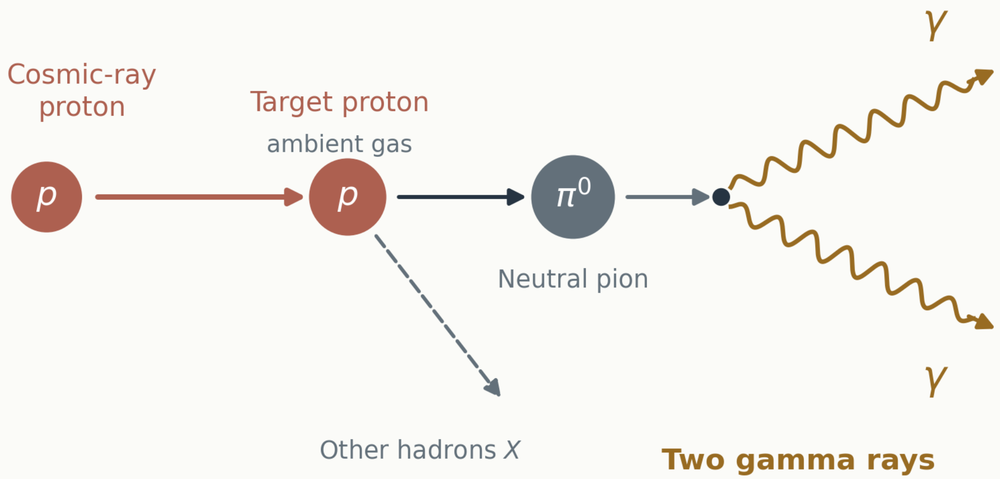


$$e^-_{\text{rel}} + \gamma_{\text{soft}} \longrightarrow e^- + \gamma_{\text{high}}$$

Electron energy is transferred to the photon.

B PROTON–PROTON COLLISION

Hadronic emission



$$p + p \longrightarrow \pi^0 + X, \qquad \pi^0 \longrightarrow \gamma + \gamma$$

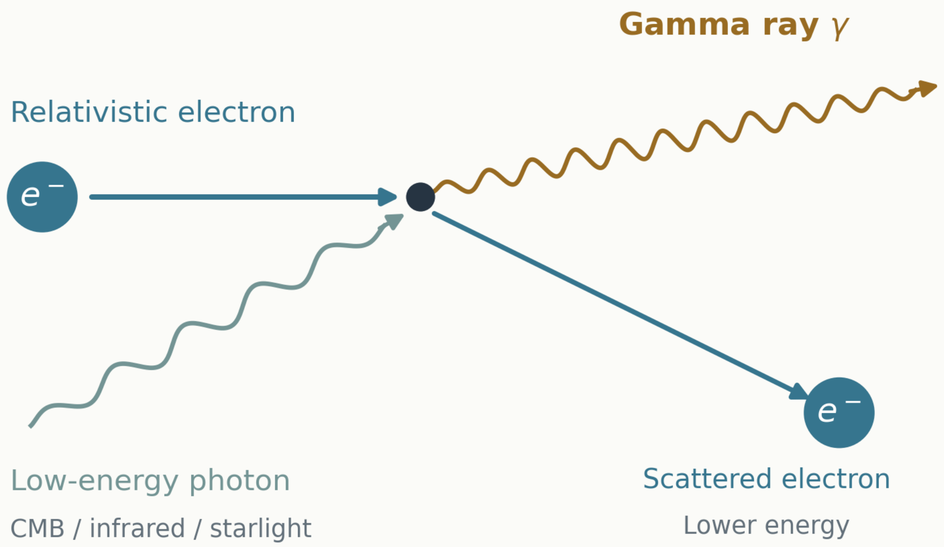
Gamma rays are produced by neutral-pion decay.

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Hadronic or Leptonic?

A INVERSE COMPTON

Leptonic emission

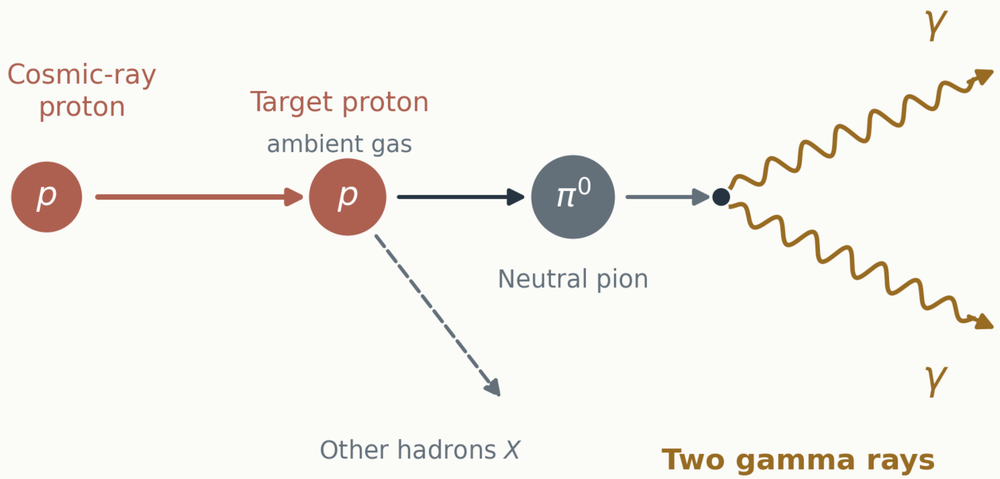


$$e^-_{\mathrm{rel}} + \gamma_{\mathrm{soft}} \longrightarrow e^- + \gamma_{\mathrm{high}}$$

Electron energy is transferred to the photon.

B PROTON–PROTON COLLISION

Hadronic emission



Disfavoured due to low ISM density at off-plane location.

$n_{\mathrm{ISM}} \sim 10^{-2} - 10^{-3}\ \mathrm{cm}^{-3}$.

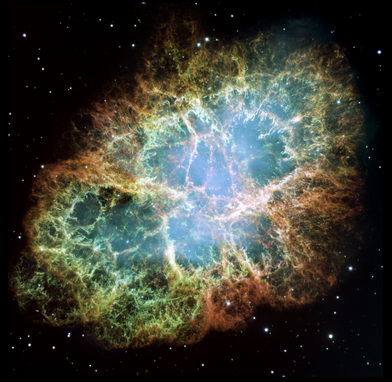
Plausible Sources

Pulsar Wind Nebula (PWN)



- ✦ Explored well.
- ✦ Several limitations.

Supernova Remnant (SNR)



- ✦ Disfavoured by observations.

Kilonova Remnant (KNR)



- ✦ Not explored.
- ✦ We exlpore in great detail.

H. E. S. S. Collaboration, Acero, F., Aharonian, F., et al. 2011, A&A, 525, A45
Domainko, W., & Ohm, S. 2012, A&A, 545, A94

Limitations of PWN

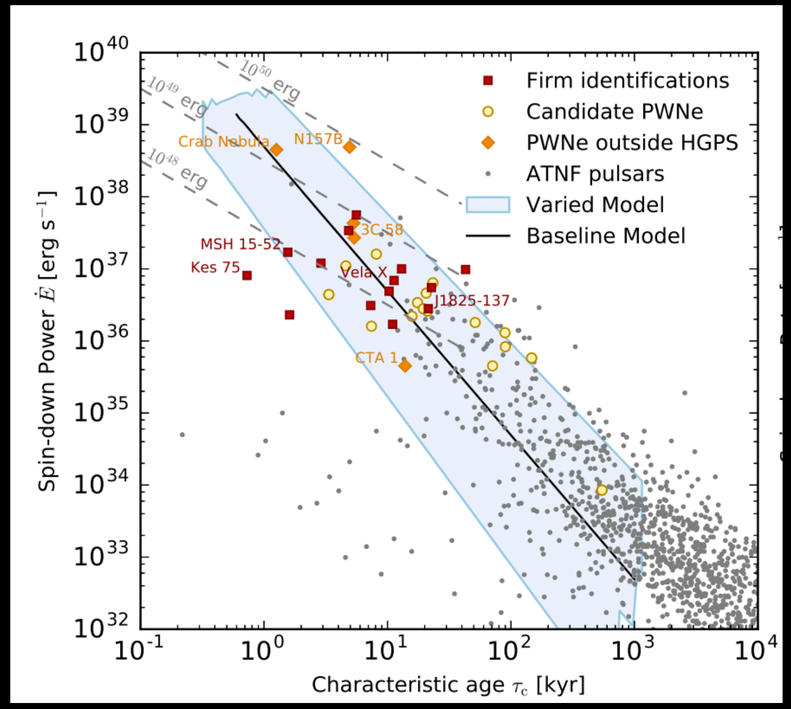
Constraints from Energy Budget

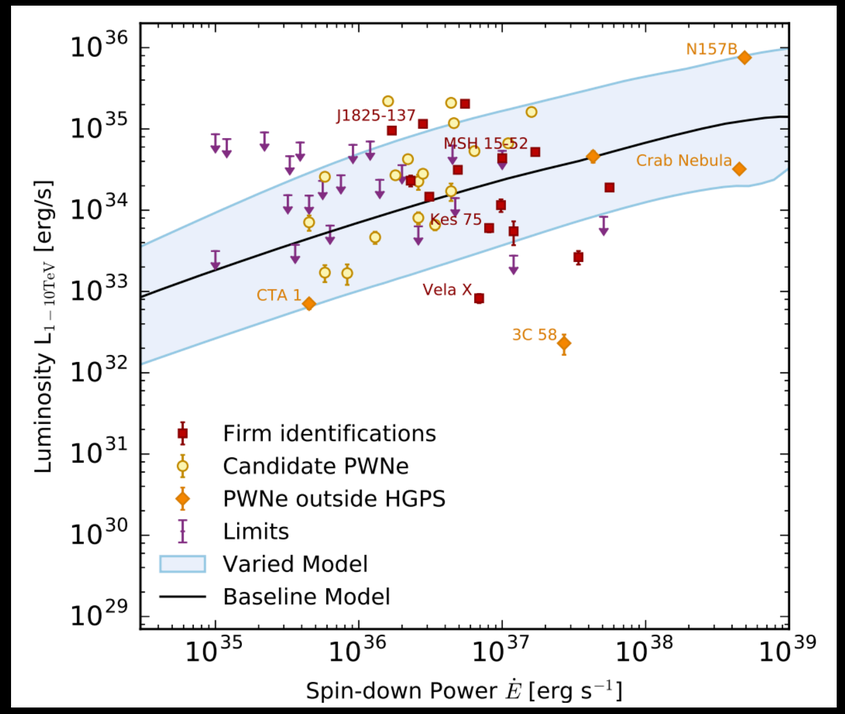
- ✦ Typical Pulsar Rotational Energy $\sim 10^{48} - 10^{50}$ erg.
- ✦ Electron energy budget: a fraction of this rotational energy.
- ✦ Required electron energy for the observed gamma-ray flux $\sim 2 \times 10^{47}\ (d/\mathrm{kpc})^2$ erg .
- ✦ At 6 kpc, electron energy required $\sim 10^{49}$ erg.
- ✦ Limited energy available.

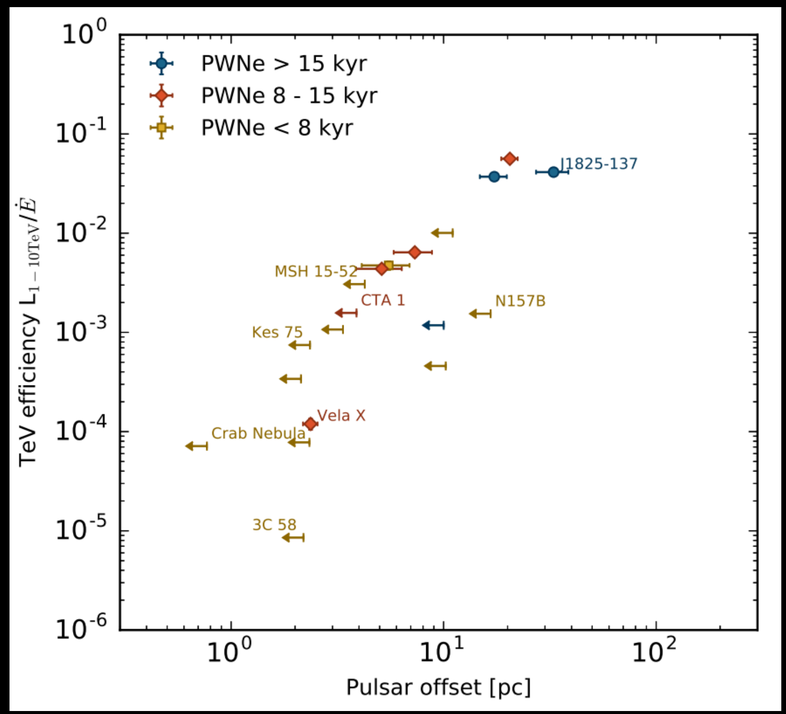
H. E. S. S. Collaboration, Acero, F., Aharonian, F., et al. 2011, A&A, 525, A45
Domainko, W., & Ohm, S. 2012, A&A, 545, A94

Limitations of PWN

Contraints from Correlation between Spin-down power, Pulsar age, TeV luminosity, and pulsar offset.







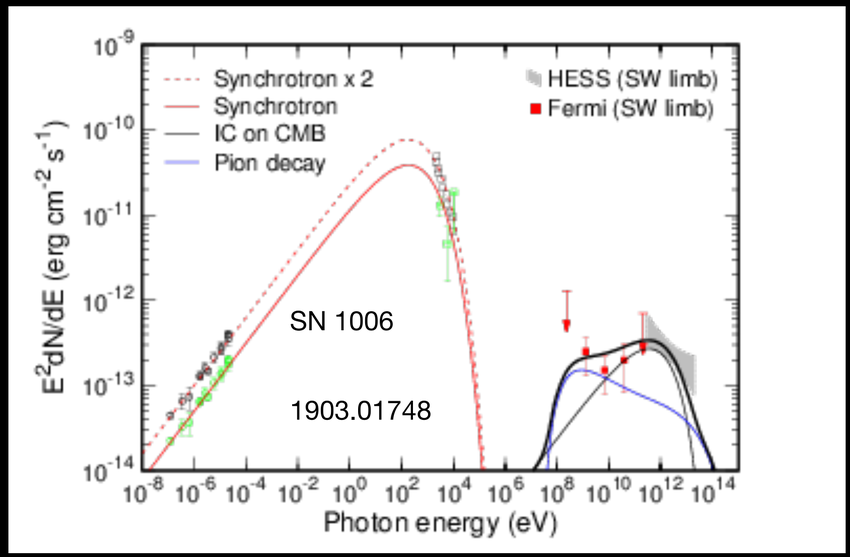
- ✦ HESS J1507-622 requires 10^2 kyr $\Longrightarrow$ $10^{33} - 10^{36}$ erg/s .
- ✦ TeV luminosity $\Longrightarrow$ $10^{31} - 10^{33}$ erg/s .
- ✦ With this luminosity, the PWN requires to be within 2 kpc.

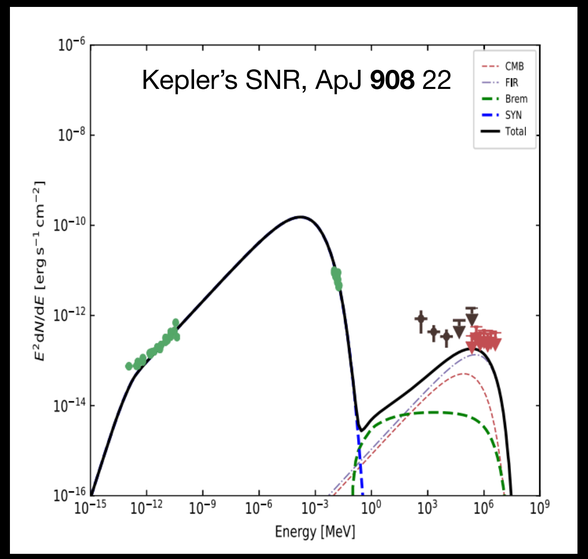
- ✦ Off-plane location cannot be explained.
- ✦ No pulsar is detected.

Abdalla, H., et al. 2018, Astron. Astrophys., 612, A2

Limitations of SNR

- ✦ Absence of a supernova shell.
- ✦ Most of the observed SNRs are closed to the Galactic plane.
- ✦ Difficult to explain off-plane location.
- ✦ Most SNRs show stronger emissions.

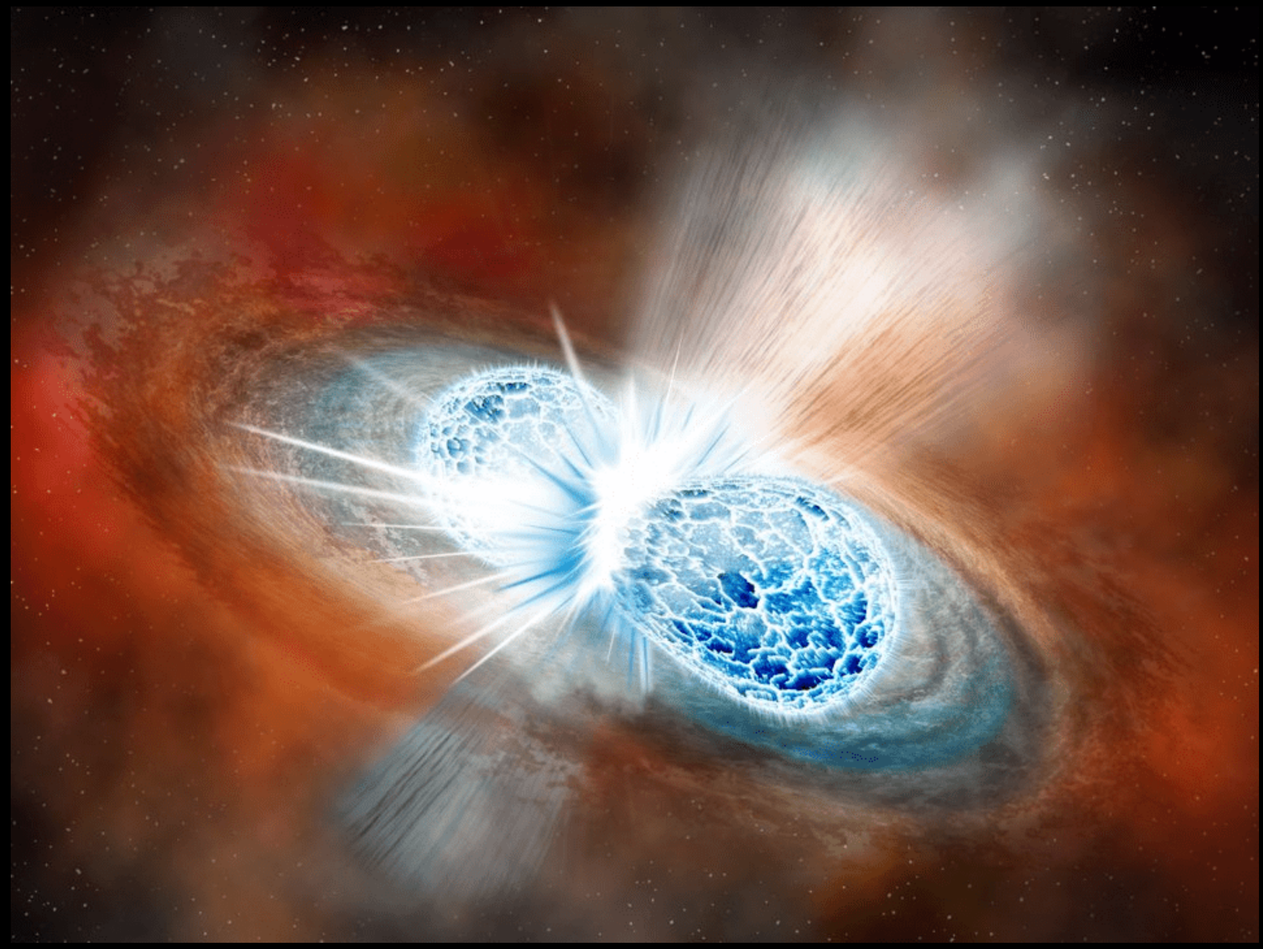




H. E. S. S. Collaboration, Acero, F., Aharonian, F., et al. 2011, A&A, 525, A45
Domainko, W., & Ohm, S. 2012, A&A, 545, A94

What is a Kilonova?

- ✦ Merger of Binary neutron stars or Blackhole-Neutron star system.
- ✦ Often associated with Short Gamma-Ray Bursts.
- ✦ Example: GW/GRB 170817.
- ✦ Sites of r-process (rapid neutron capture) nucleosynthesis.
- ✦ Creates elements heavier than the Iron.



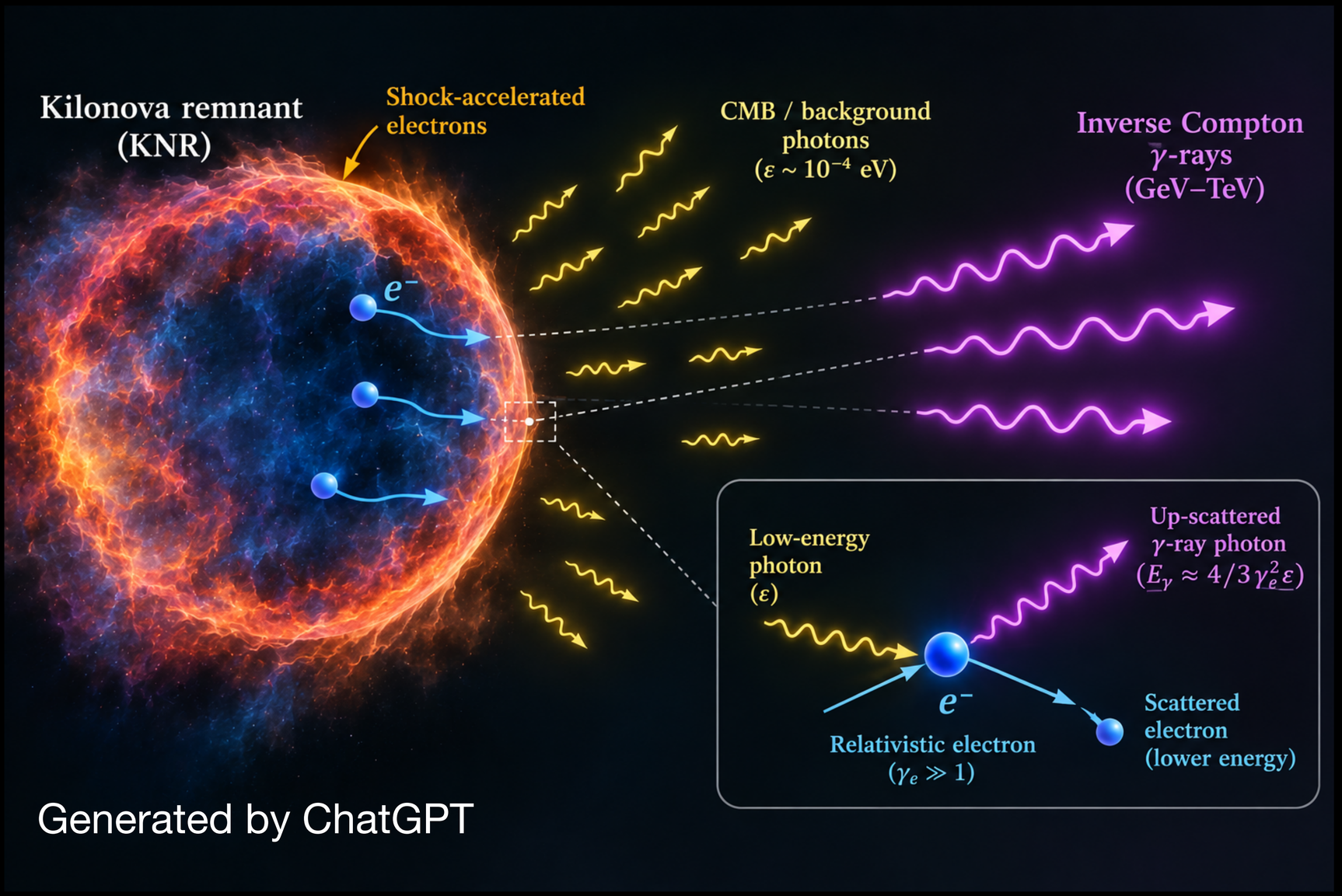
Berger, E. 2014, Annual Review of Astronomy and Astrophysics, 52, 43
Pian, E., et al. 2017, Nature, 551, 67

Why Kilonova Remnant Works?

- ✦ Binary neutron stars receive natal kick $10 - 100\ \mathrm{km/s}$ during their birth.
- ✦ Explains the off-plane location ($b \approx -3.5^{\circ}$) of HESS J1507-622.
- ✦ KN ejecta energy $\sim 10^{51}\ \mathrm{erg}$.
- ✦ Gamma-rays can be produced via Inverse Compton.

Wong, T.-W., Willems, B., & Kalogera, V. 2010, ApJ, 721, 1689

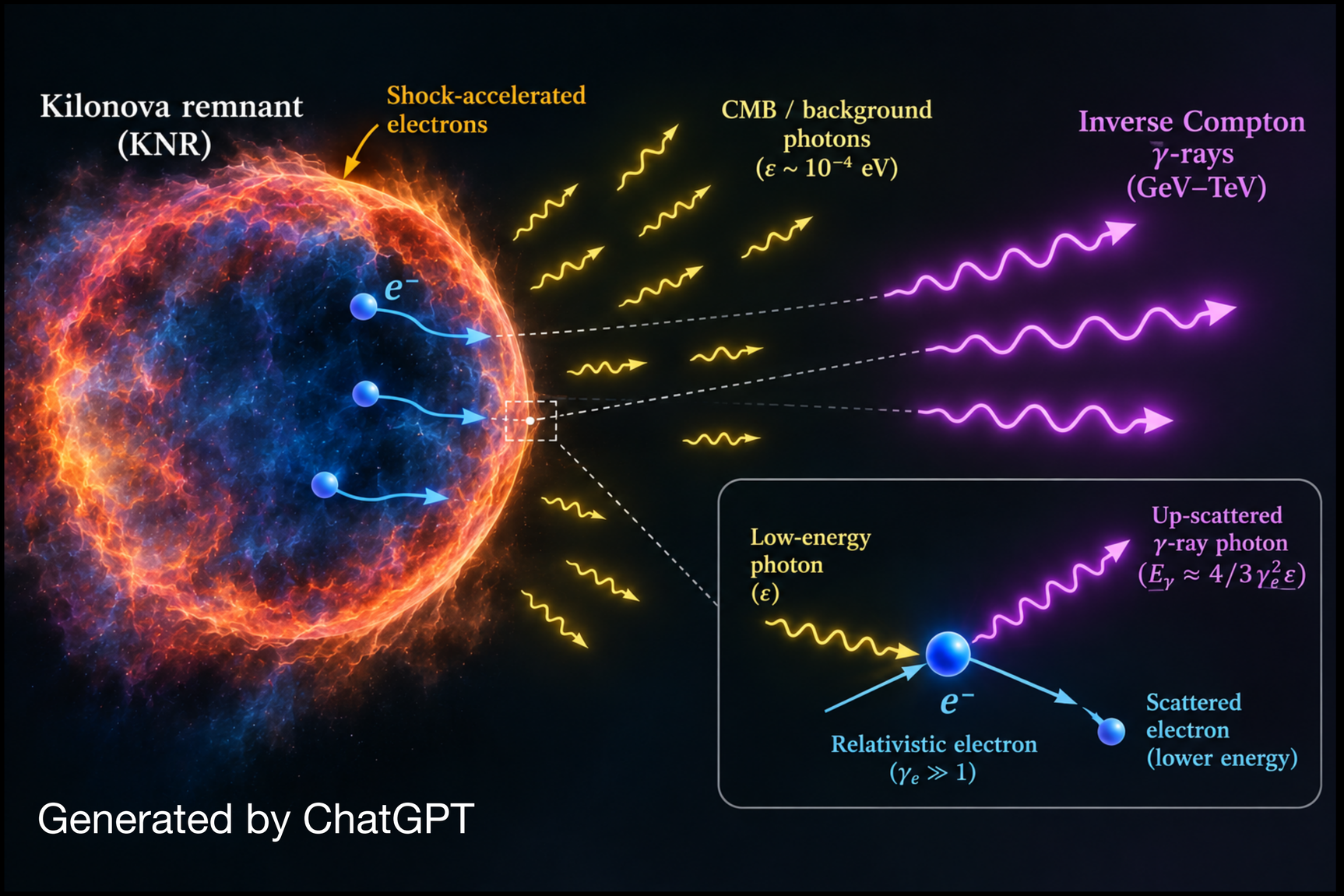
Gamma-Rays From Inverse Compton



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We used GAMERA code

Gamma-Rays From Inverse Compton



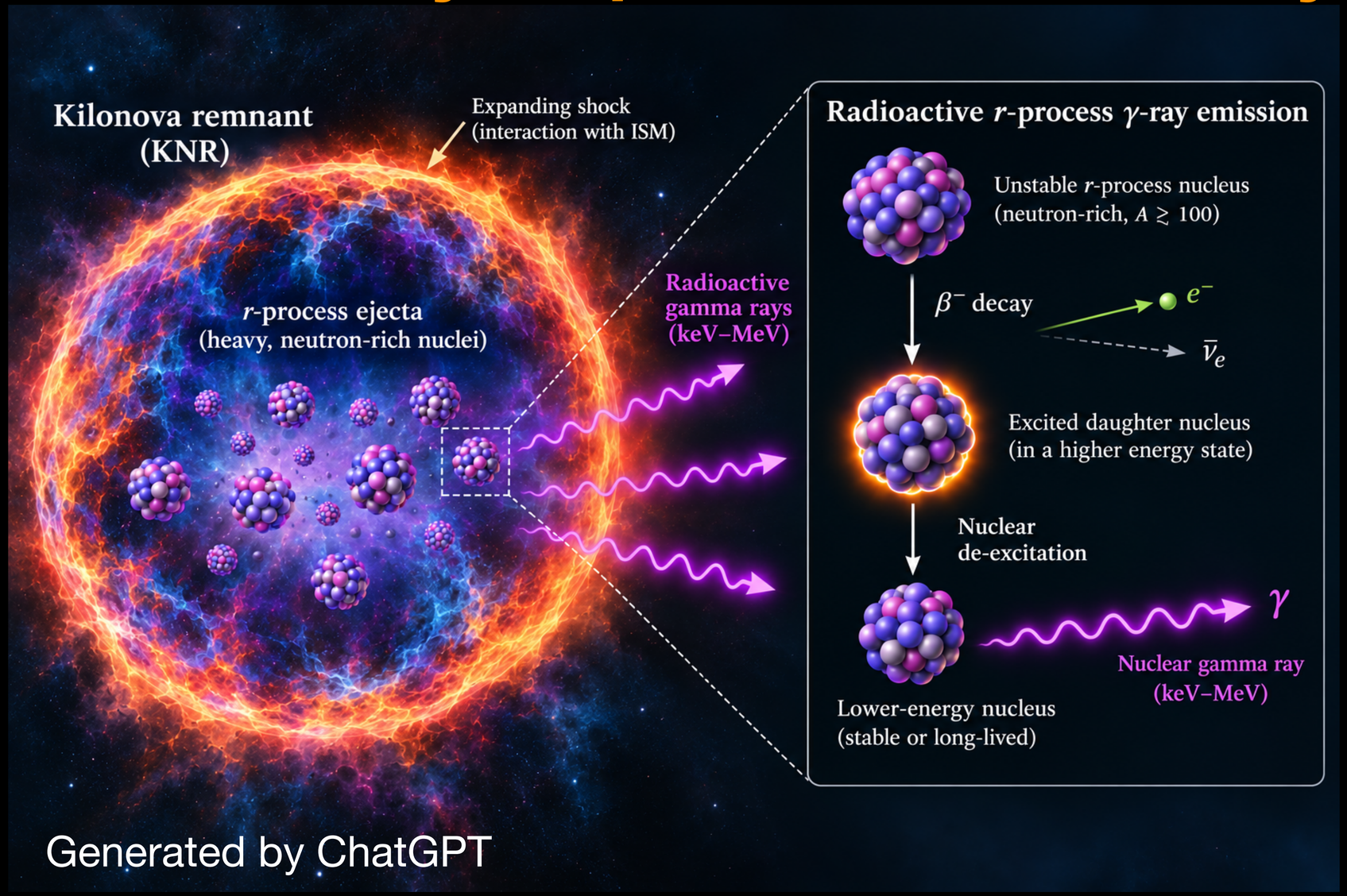
Generated by ChatGPT

✦ Hadronic (pp collision) is disfavoured due to low ISM density

$n_{\rm ISM} \sim 10^{-2} - 10^{-3}\ {\rm cm}^{-3}$.

We used GAMERA code

MeV Gamma-rays r-process Nucleosynthesis



✦ r-process can be crucial for probing the KN origin.

KNR Viability Test

Angular Size ~ $\sim 0.30^\circ$

Observed Gamma-Ray Flux

}

Contrains the parameters: Ejecta Mass ($M_{\rm ej}$), Ejecta Velocity ($V_{\rm ej}$), KNR age ($t_{\rm age}$), and Distance (d).

$$\theta_{\rm HESS} = \tan^{-1}\left(\frac{2r_{\rm KNR}}{d}\right) \approx 0.30^\circ$$

$$r_{\rm KNR} = f[M_{\rm ej}, V_{\rm ej}, t_{\rm age}, n_{\rm ISM}(d)]$$

$$n_{\rm ISM} \sim 10^{-2} - 10^{-3}\ {\rm cm}^{-3}$$

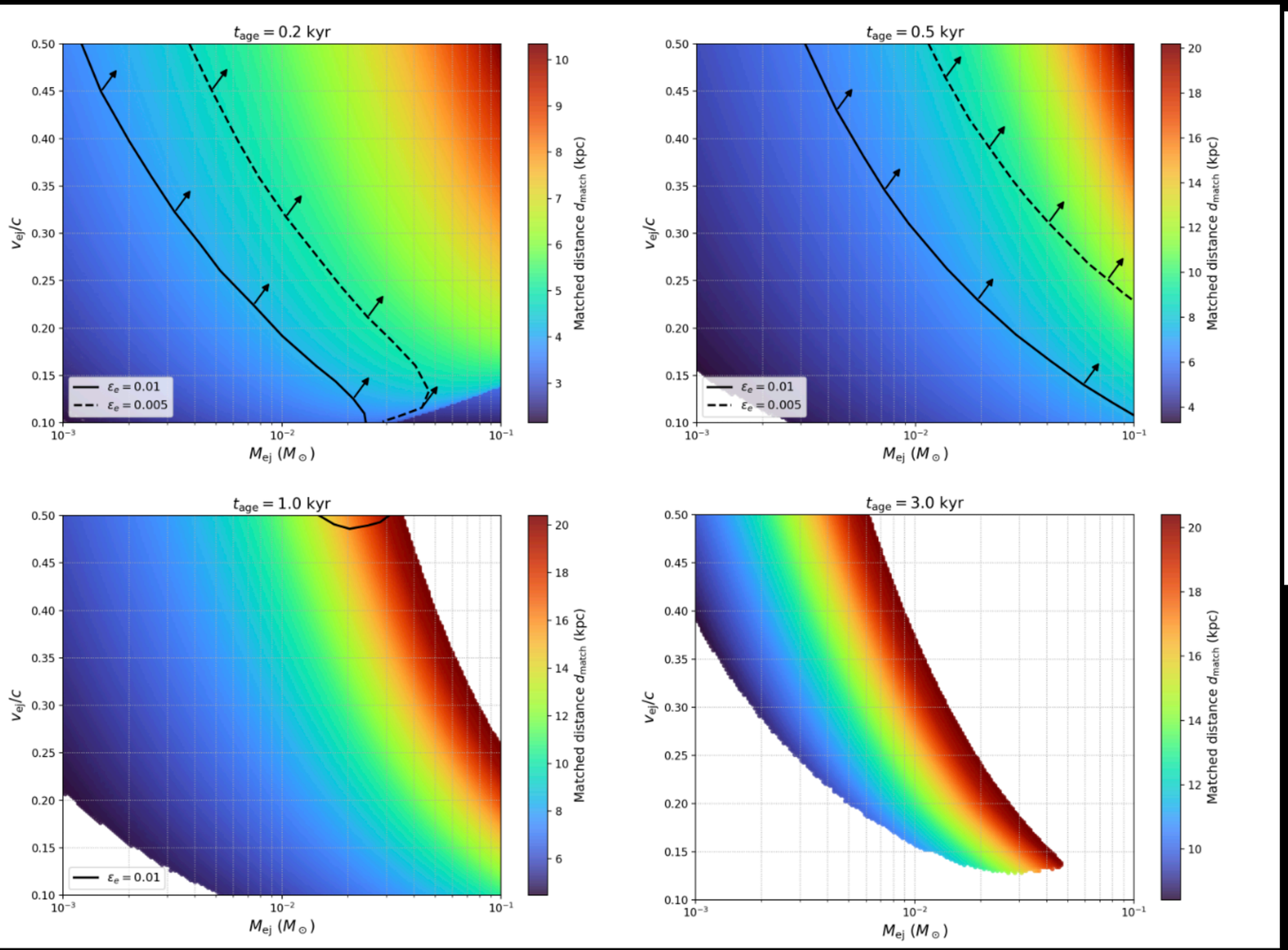
Observed Gamma-Ray Flux $\propto$ Total electron energy

$$= \epsilon_e \times E_{\rm ej}\ ;\ E_{\rm ej} = \frac{1}{2} M_{\rm ej} V_{\rm ej}^2$$

$$E_{\rm ej} \geq 2 \times 10^{50}\ (d/10\ {\rm kpc})^2\ (\epsilon_{\rm e}/0.1)^{-1}$$

ϵ_e is fraction of $E_{\rm ej}$

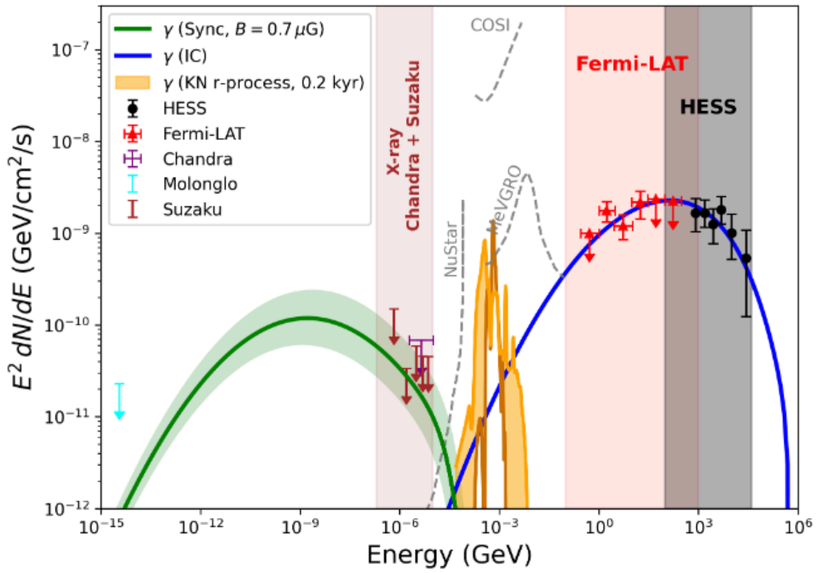
Parameter Space

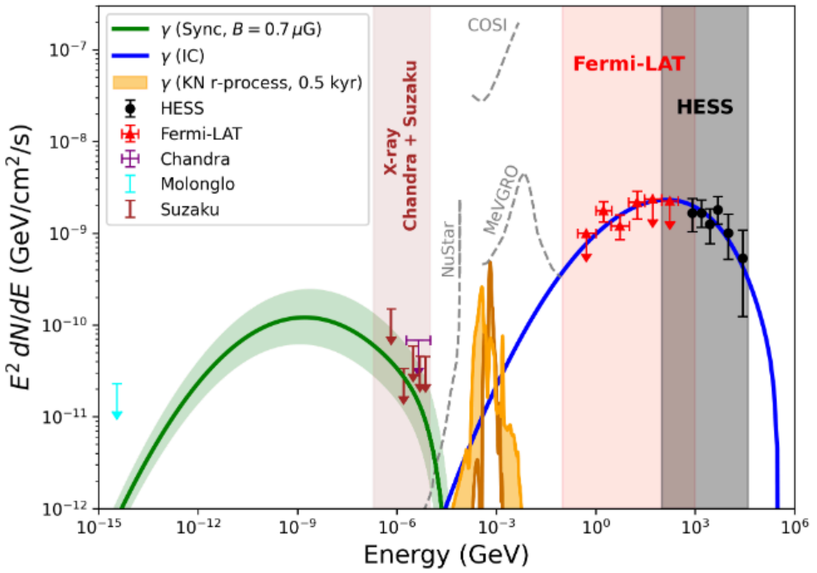


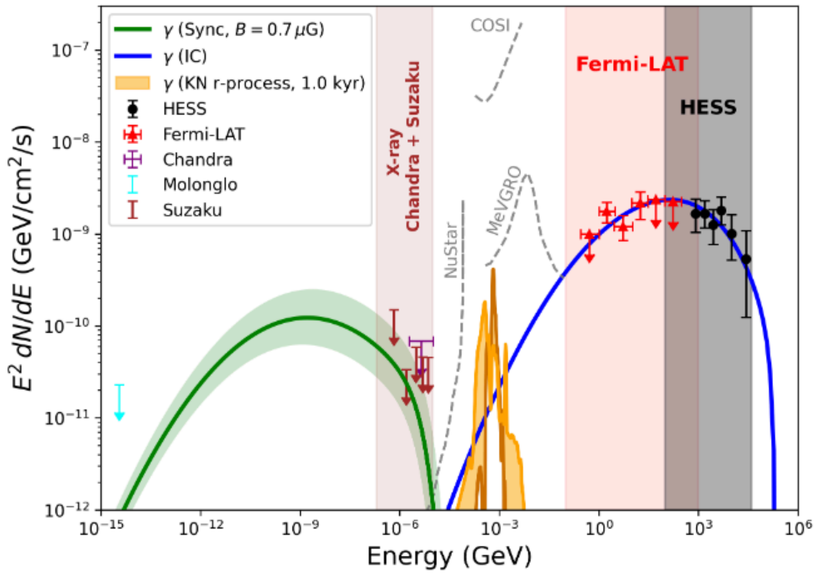
Age (kyr)	d_{min} (kpc)	d_{ml} (kpc)	d_{max} (kpc)
0.2	2.1	3.8	10.3
0.3	2.6	5.0	13.8
0.4	3.0	6.0	17.5
0.5	3.3	6.4	20.0
0.6	3.6	7.2	20.0
0.7	3.8	7.4	20.0
0.8	4.0	6.5	20.0
0.9	4.3	7.3	20.0
1.0	4.5	6.9	20.0
2.0	6.3	9.0	20.0
3.0	8.4	14.3	20.0

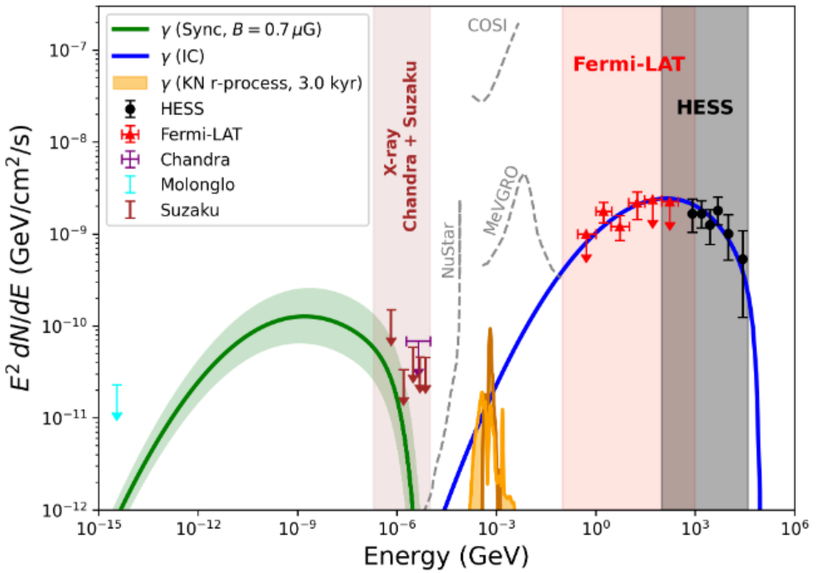
- Most likely distances ~ 3.8-14.3 kpc.
- Preferred age $\lesssim 0.5$ kyr.

KNR reproduces GeV-TeV Gamma-Ray Flux









Electron distribution:

$$\frac{d\phi_e}{dE_e} = \phi_{e,0}\left(\frac{E_e}{E_0}\right)^{-\left[\alpha+\beta\log_{10}(E_e/E_0)\right]}$$

$\alpha = 2.5$ and $\beta = 0.3$

- Most likely distances ~ 3.8-14.3 kpc.
- Preferred age $\lesssim 0.5$ kyr.

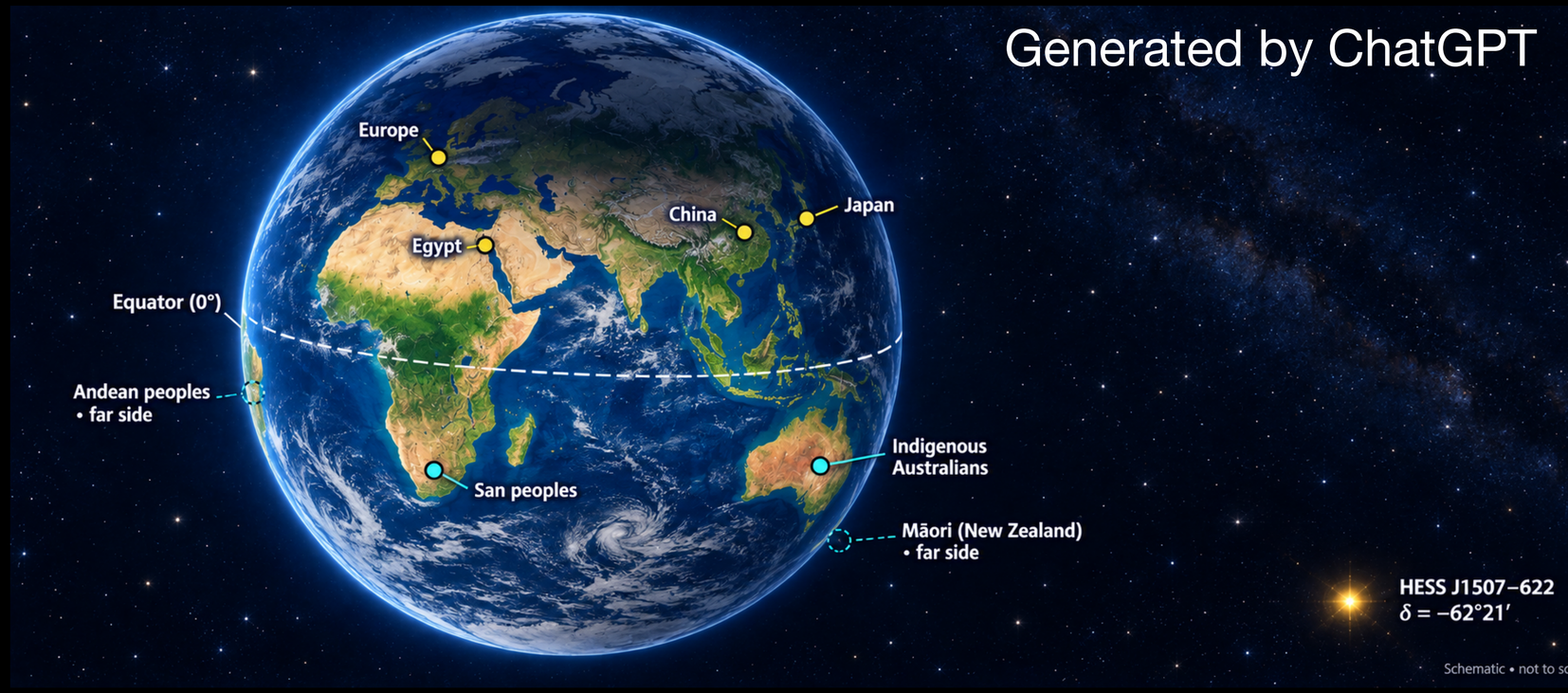
Why is there No Historical Records?

- ✦ GW 170817 V-band Apparent Magnitude ~ 17
- ✦ At 3.8-14.3 kpc, this would be ~ -3.2 to -0.8
- ✦ Similar to the Brightest planets Venus, Mars, and Jupiter, obsevable to naked eyes.

Historical SN	Modern Remnant	Declination
SN 1006	SN 1006	-42° Wikipedia
SN 1054	Crab Nebula	$+22^\circ$ Wikipedia +1
SN 1181	candidate: Pa 30	$\sim +67^\circ$
SN 1572	Tycho Supernova Remnant	$+64^\circ$
SN 1604	Kepler's Supernova Remnant	-21° Wikipedia
possible: Cassiopeia A supernova	Cassiopeia A	$+58^\circ$

Why is there No Historical Records?

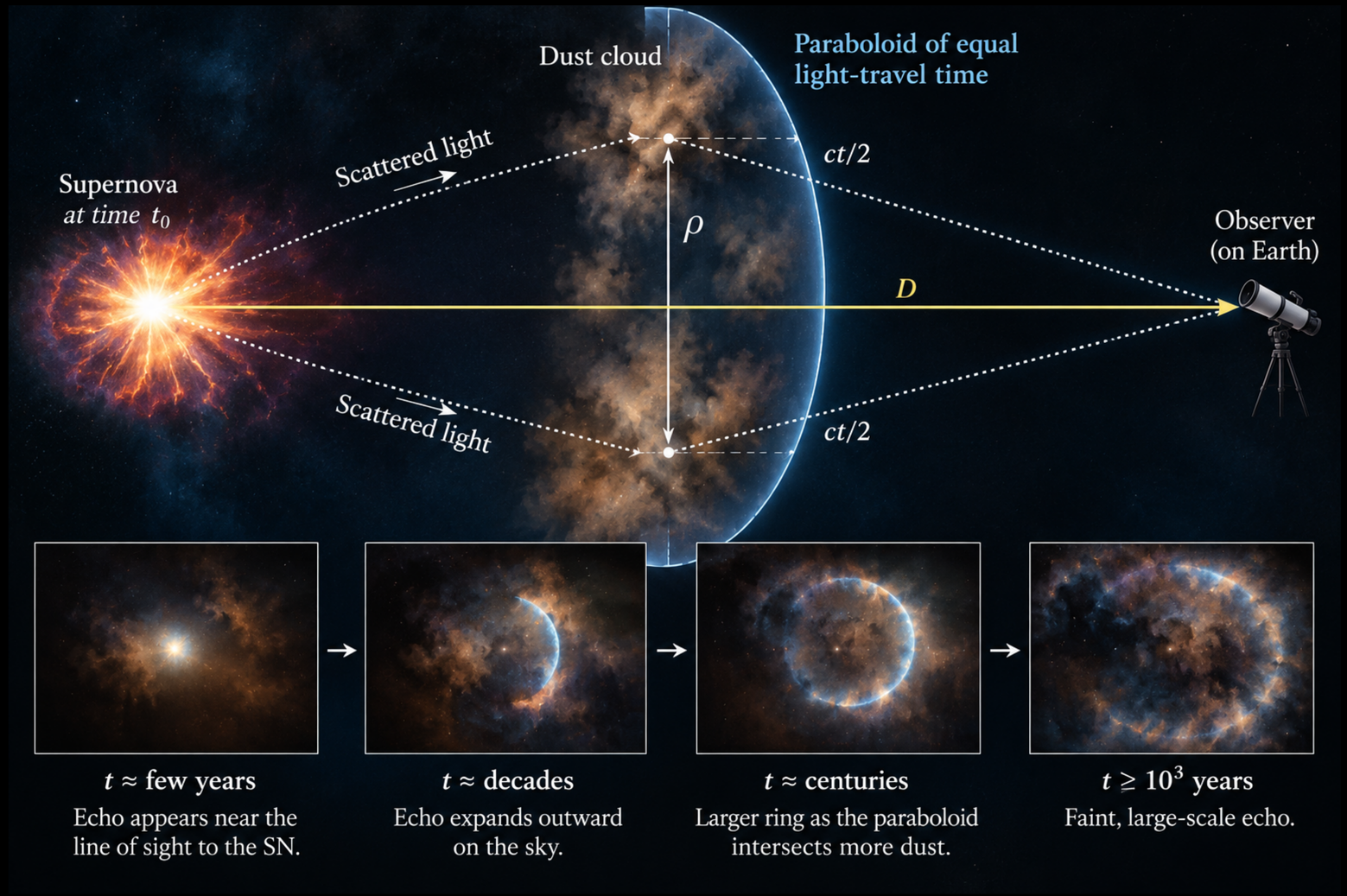
- ✦ KN fades rapidly, ~ 1.1 mag/day.
- ✦ Poor weather or bright lunar phases.
- ✦ Dust extinction.
- ✦ Far southern sky (Dec: -62°).



- ✦ Inaccessible to Northern Hemisphere (China, Japan, Egypt, and Europe).
- ✦ Accessible to Southern Hemisphere (Indigenous Australian, Maori, San, and Andean peoples), but they prioritised seasonal markers, navigational stars, and structural ‘dark cloud’ constellations.

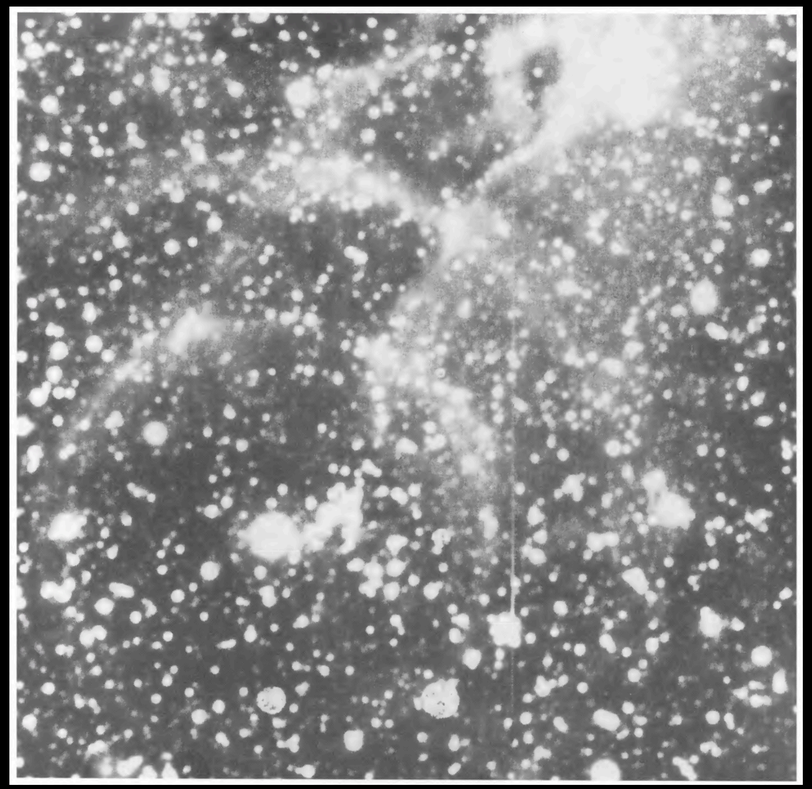
Additional KNR Signatures

Light Echo



Generated by ChatGPT

SN 1987a



Additional KNR Signatures

Light echo detection

- Light Echo Estimates For HESS J1507-622
- Surface brightness: $27 - 33\ \mathrm{mag\ arcsec^{-2}}$.
- VLT/FORS2, Gemini South/GMOS-S, Magellan/IMACS, Blanco/DECam, and Hubble Space Telescope ~ $30\ \mathrm{mag\ arcsec^{-2}}$.
- Large-aperture telescopes with dedicated background control strategies ~ $33\ \mathrm{mag\ arcsec^{-2}}$.
- Vera C Rubin Observatory/LSSTCam ~ $30 - 31\ \mathrm{mag\ arcsec^{-2}}$.

Additional KNR Signatures

Thermal dust emissions

- ✦ Radio, infrared, optical emission from processes free-free emission, thermal bremsstrahlung.
- ✦ Radio band is dominated by non-thermal emission.
- ✦ Optical is uncertain due to uncertainty in dust extinction.
- ✦ We focus on mid-IR band.
- ✦ Flux $10^{-2} - 10^{4}\ \mathrm{MJy\ sr^{-1}}$, based on SN 1006 and Cas A.
- ✦ Suitable for JWST MIRI.

Summary

- ✦ Origin of HESS J1507-622 is not yet known.
- ✦ Conventional PWN and SNR interpretation have several limitations.
- ✦ Our claim: HESS J1507-622 is a young Galactic KNR.
- ✦ 0.2-3.0 kyr old, but $\leq$ 0.5 kyr is favoured.
- ✦ 3.8-14.3 kpc away.
- ✦ It naturally explains the observed properties.
- ✦ Distinct detectable r-process MeV gamma-rays for $\leq$ 0.5 kyr.
- ✦ Light echo and thermal dust emission may be detected.

Thank you for your attention!