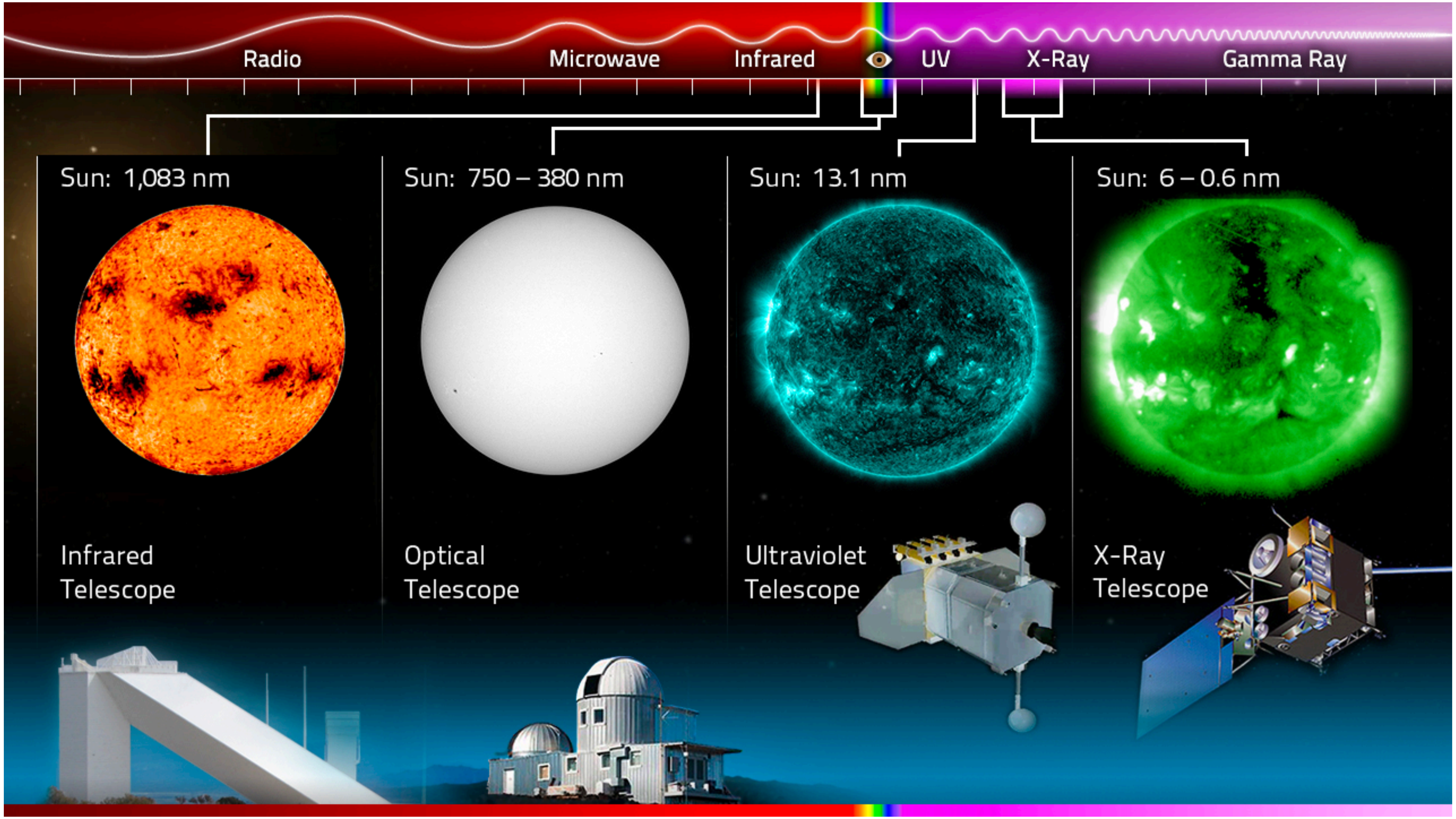
Data analysis for gamma-ray astronomy

Ruo-Yu Shang

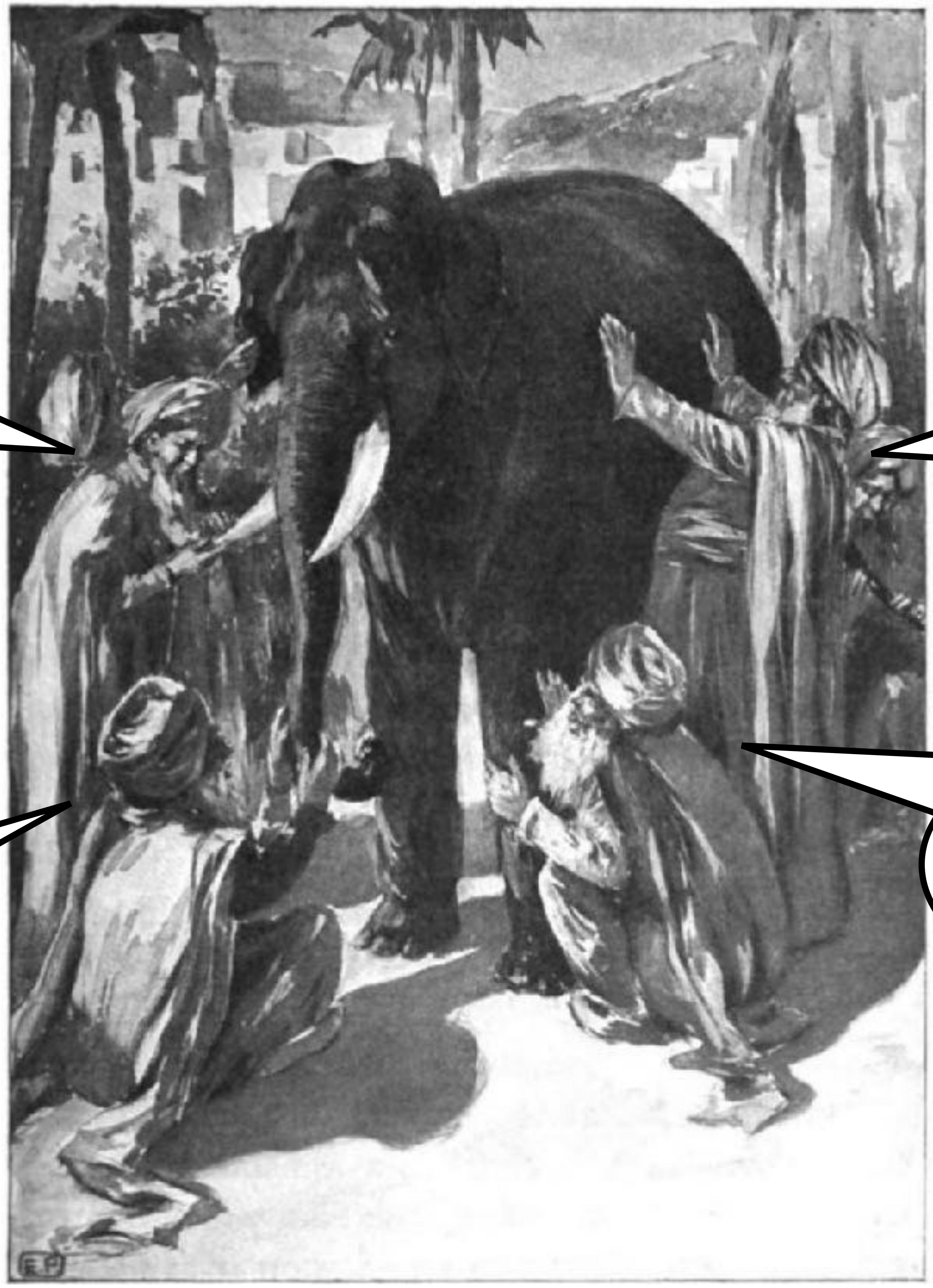
Why do we need gamma-ray telescopes?
(or many other different types of telescopes?)



Blind men and an elephant

The elephant is pointy.

The elephant is a wall.



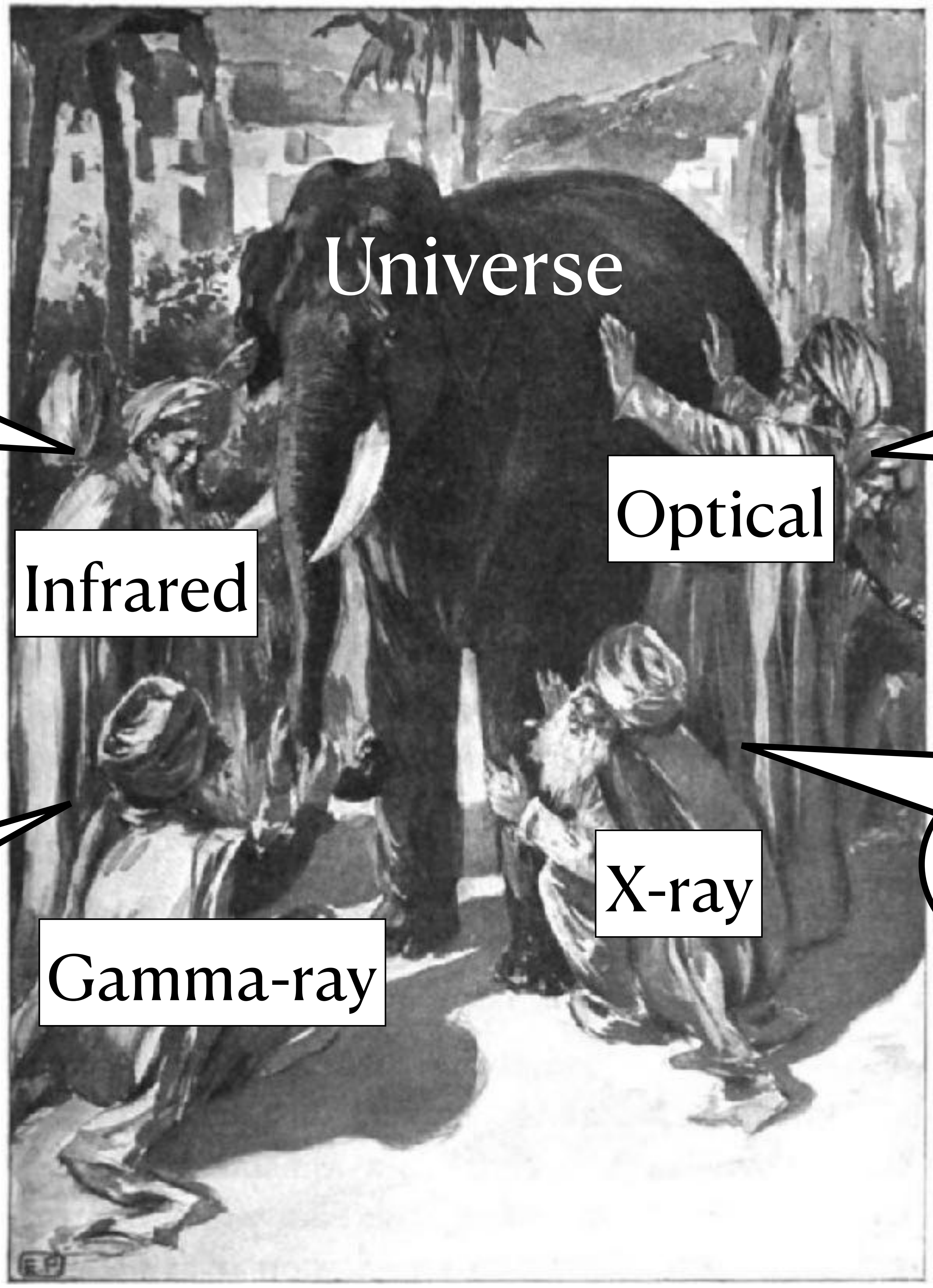
This being is like a thick snake!

The elephant is a pillar like a tree-trunk.

Blind men and an elephant

The elephant is pointy.

This being is like a thick snake!



The elephant is like a wall.

The elephant is a pillar like a tree-trunk.

Galactic plane in optical band

Solar stars: optical light coming from stars of size similar to Sun.

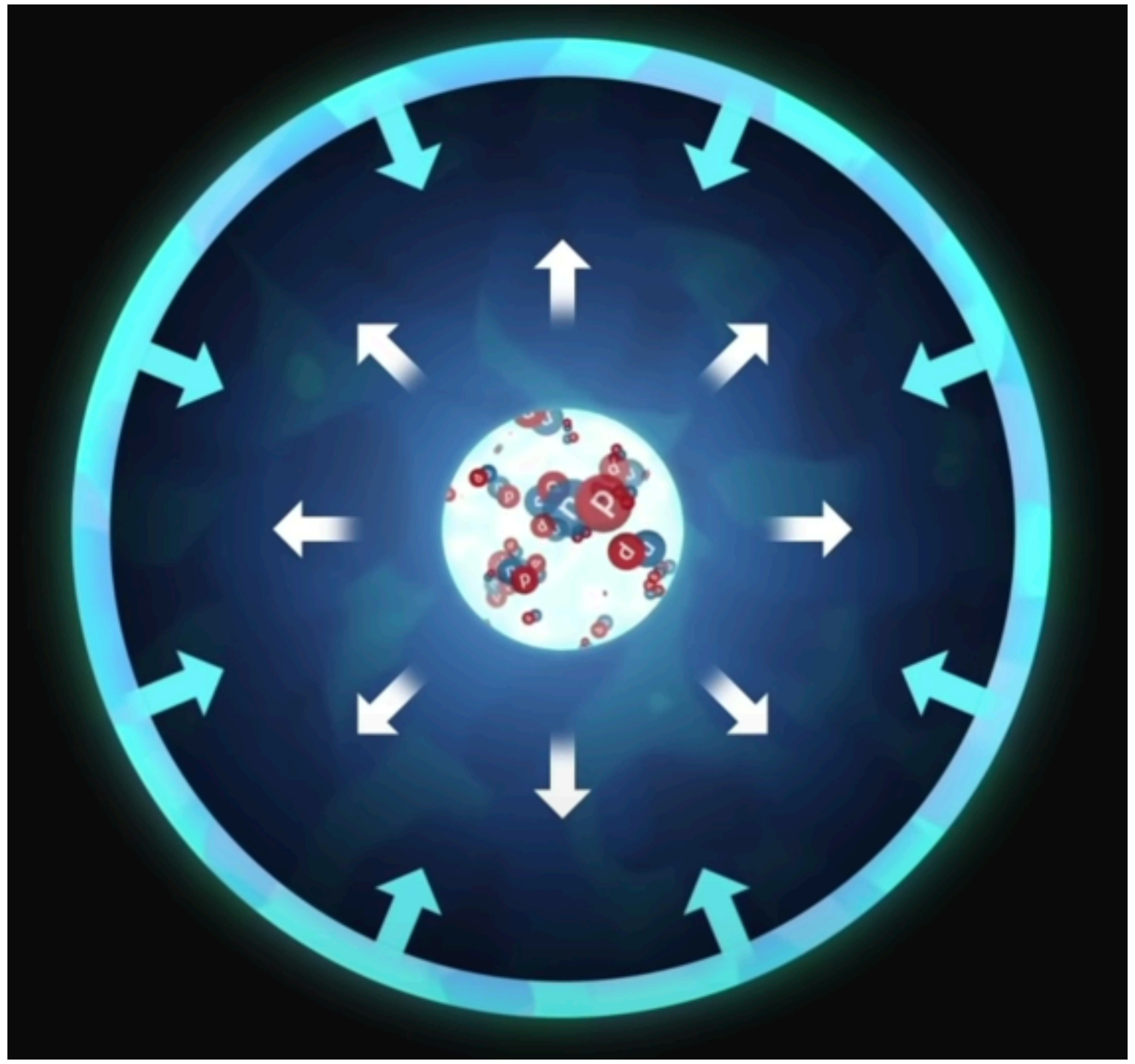
Galactic plane in radio band

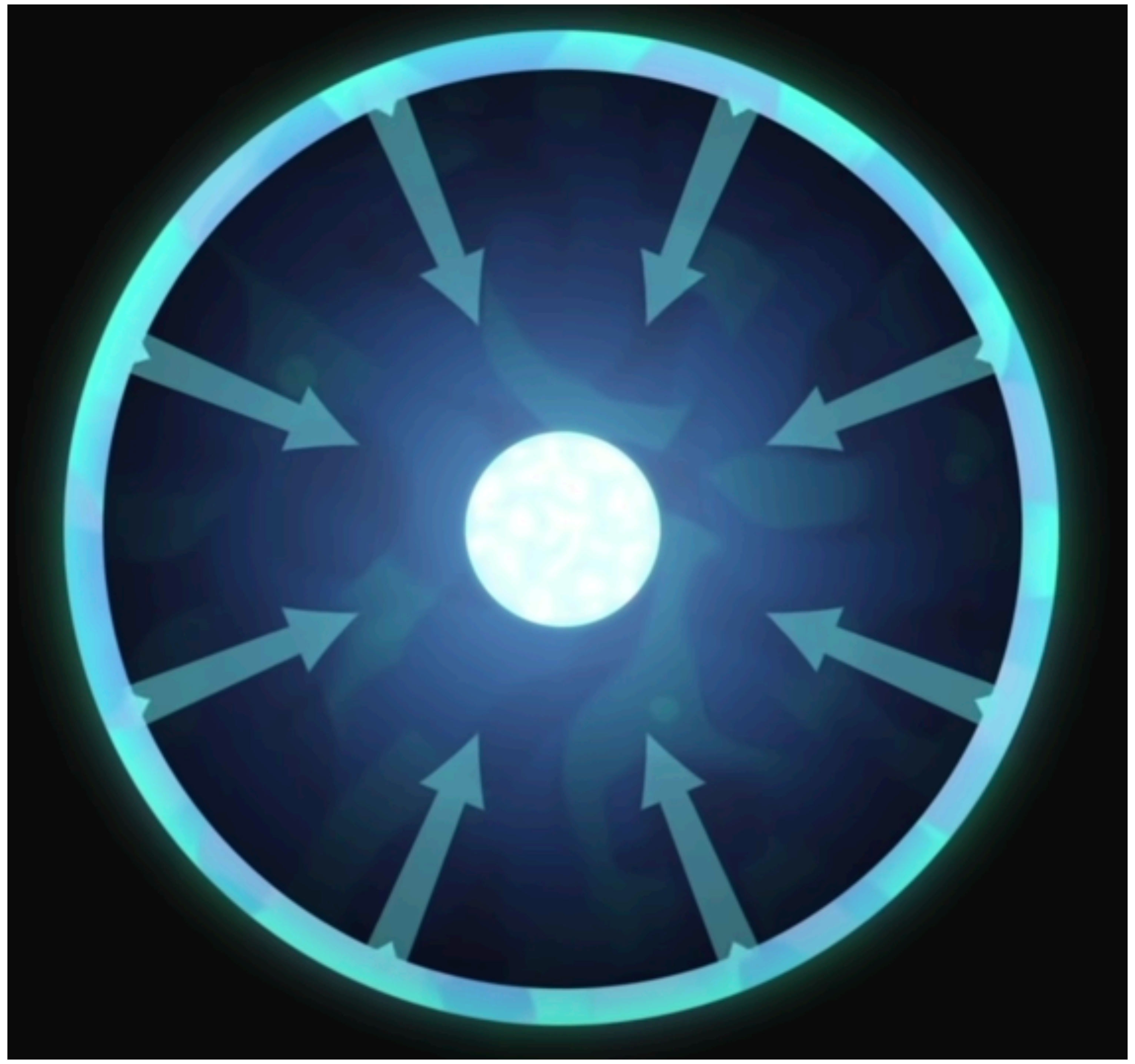
Cold gas: radio waves reveal region of cool gas where CO_2 molecules can exist.

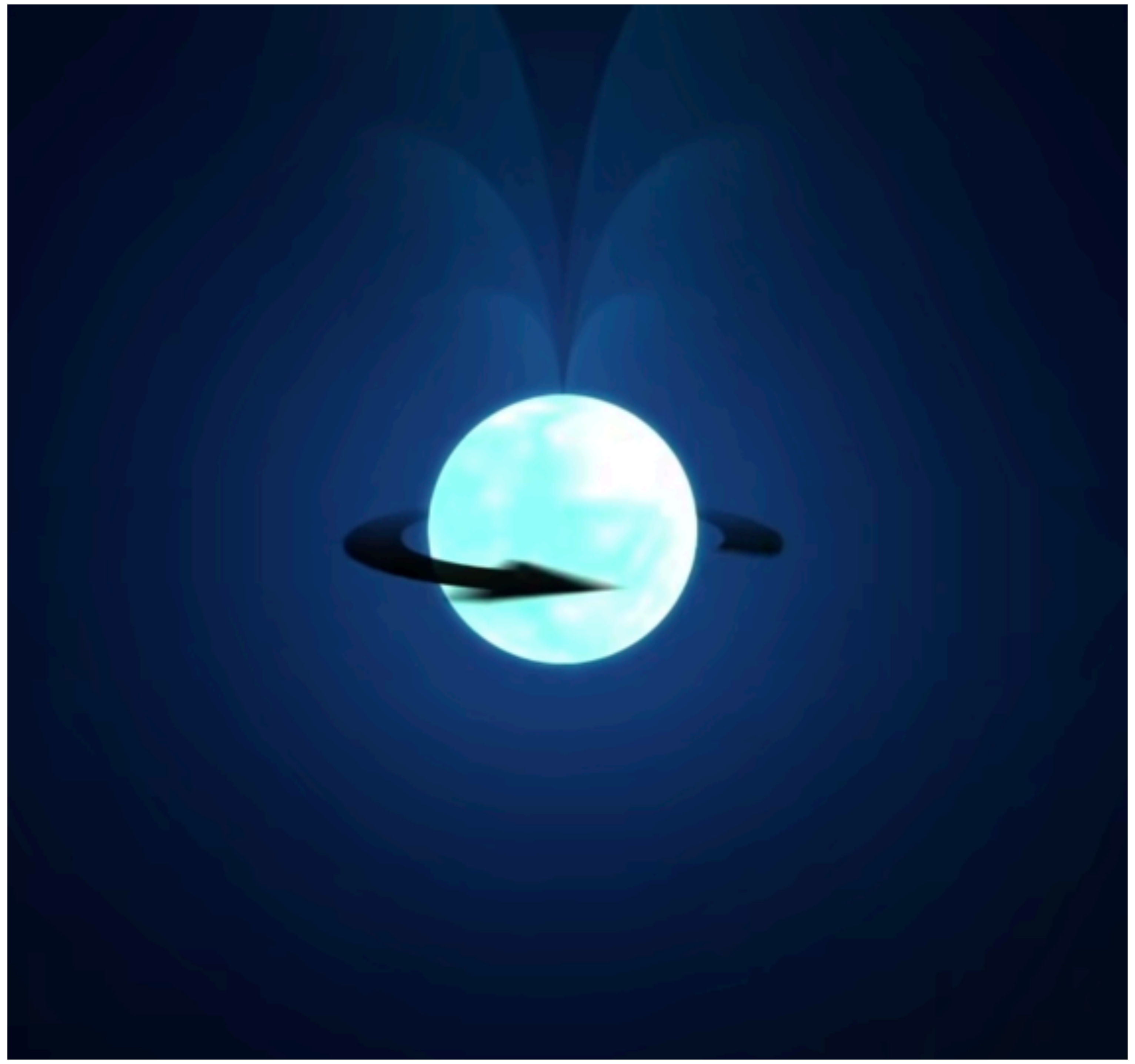
Galactic plane in gamma-ray band

Exploding stars: gamma rays show the sites of most-violent events, including black holes, supernova remnants, and pulsar wind nebulae.

How a star dies: gravitational collapse

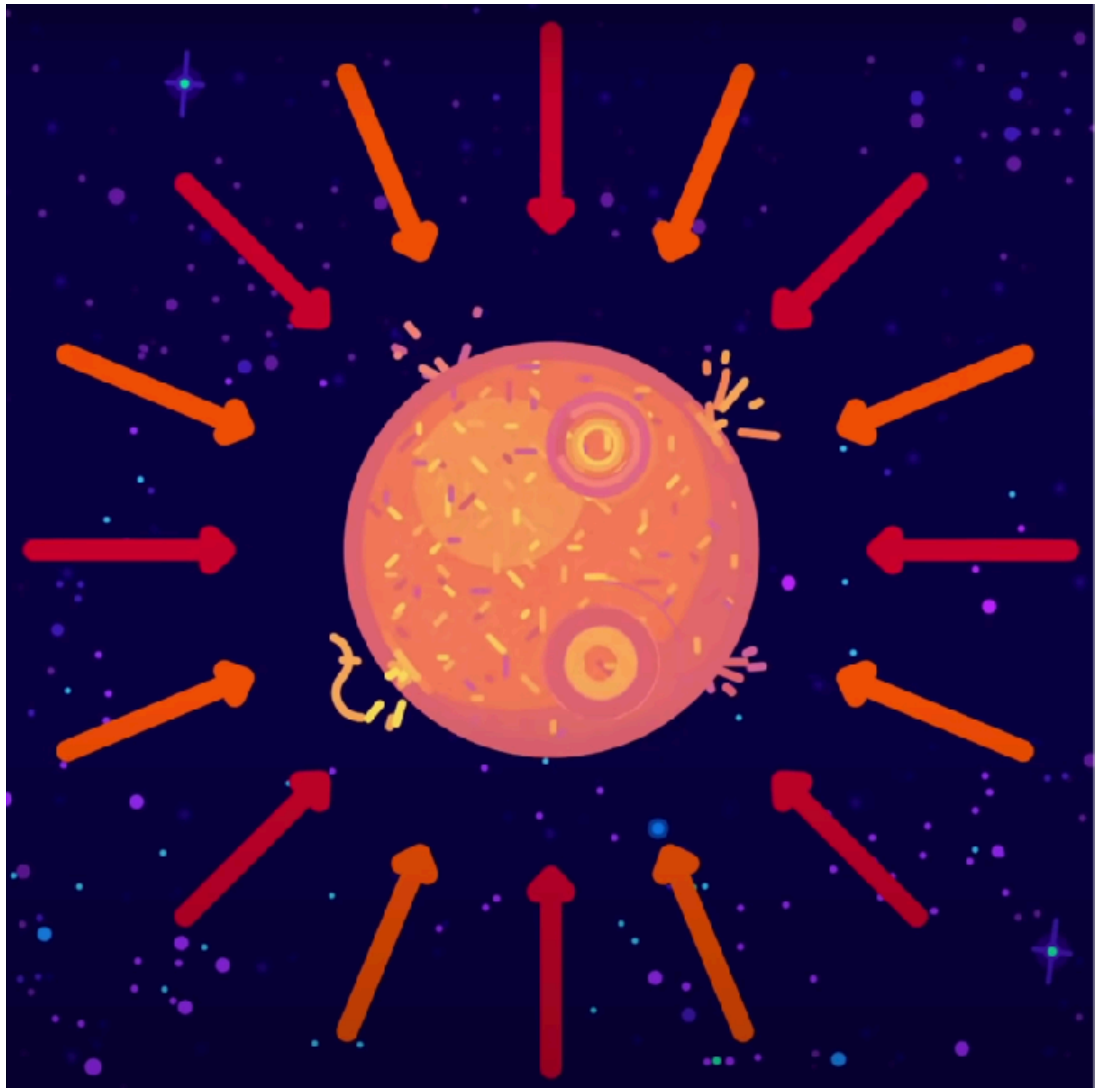


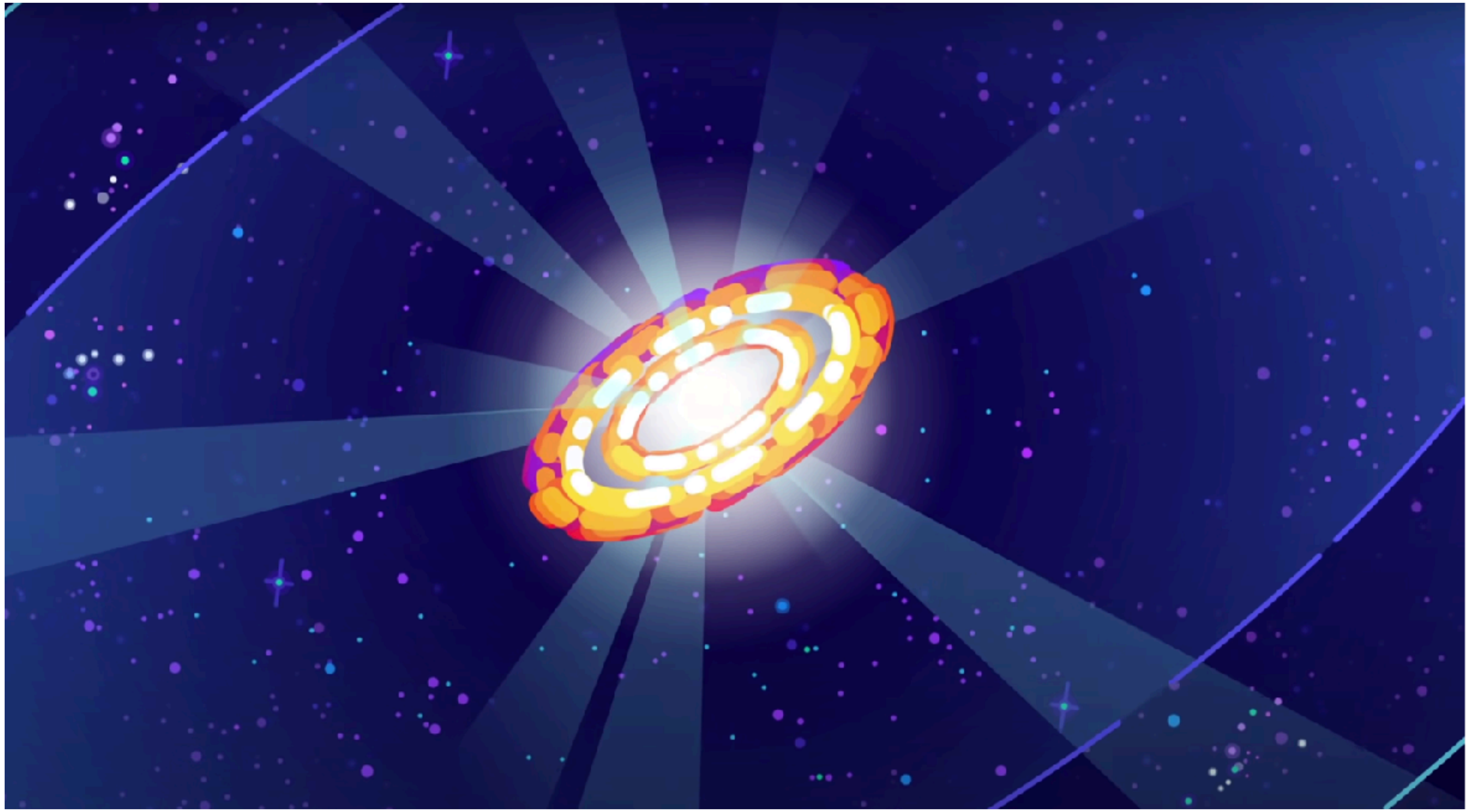




Credit: https://www.youtube.com/ScienceClicEN

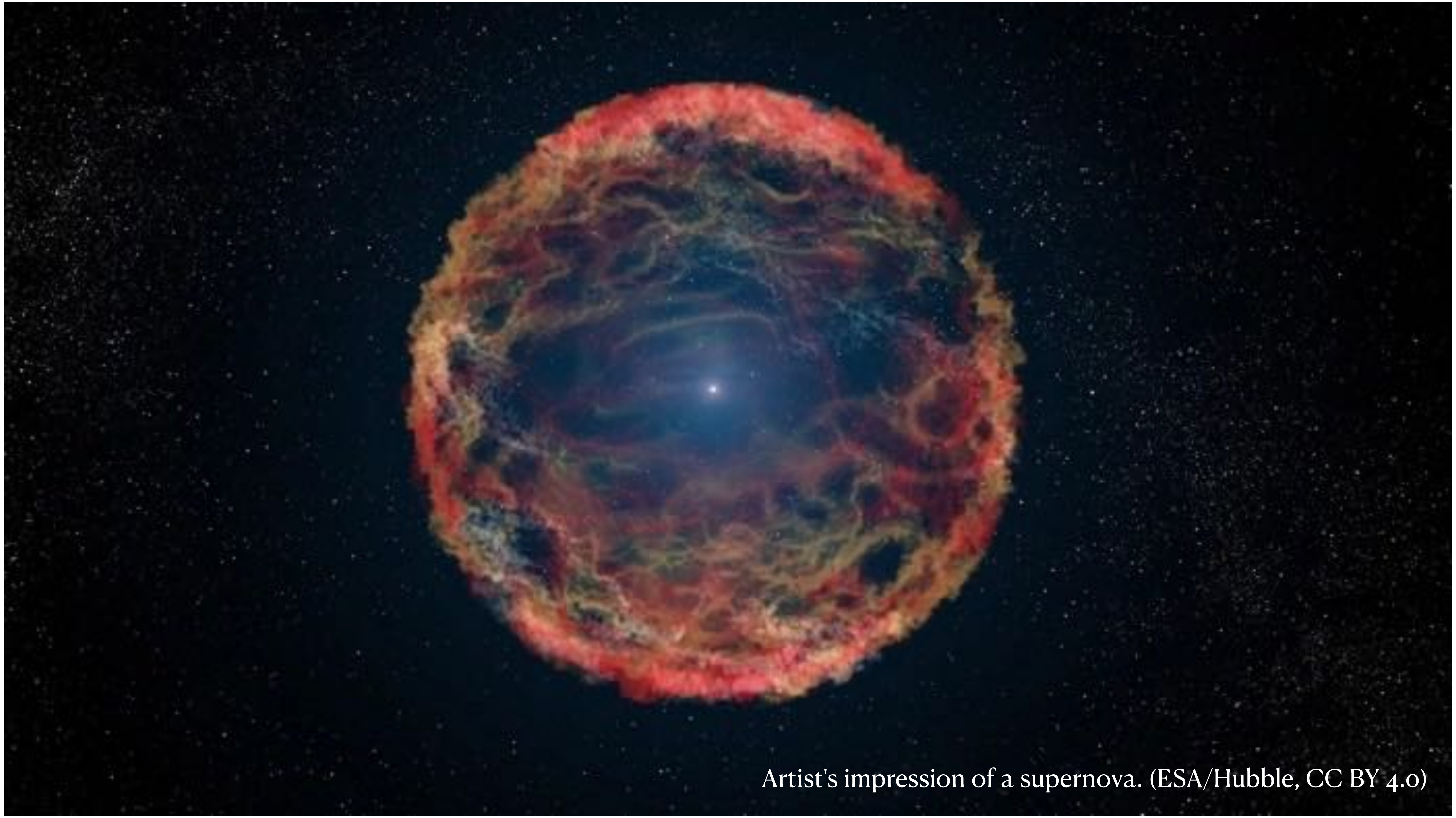
How a star dies: gravitational collapse





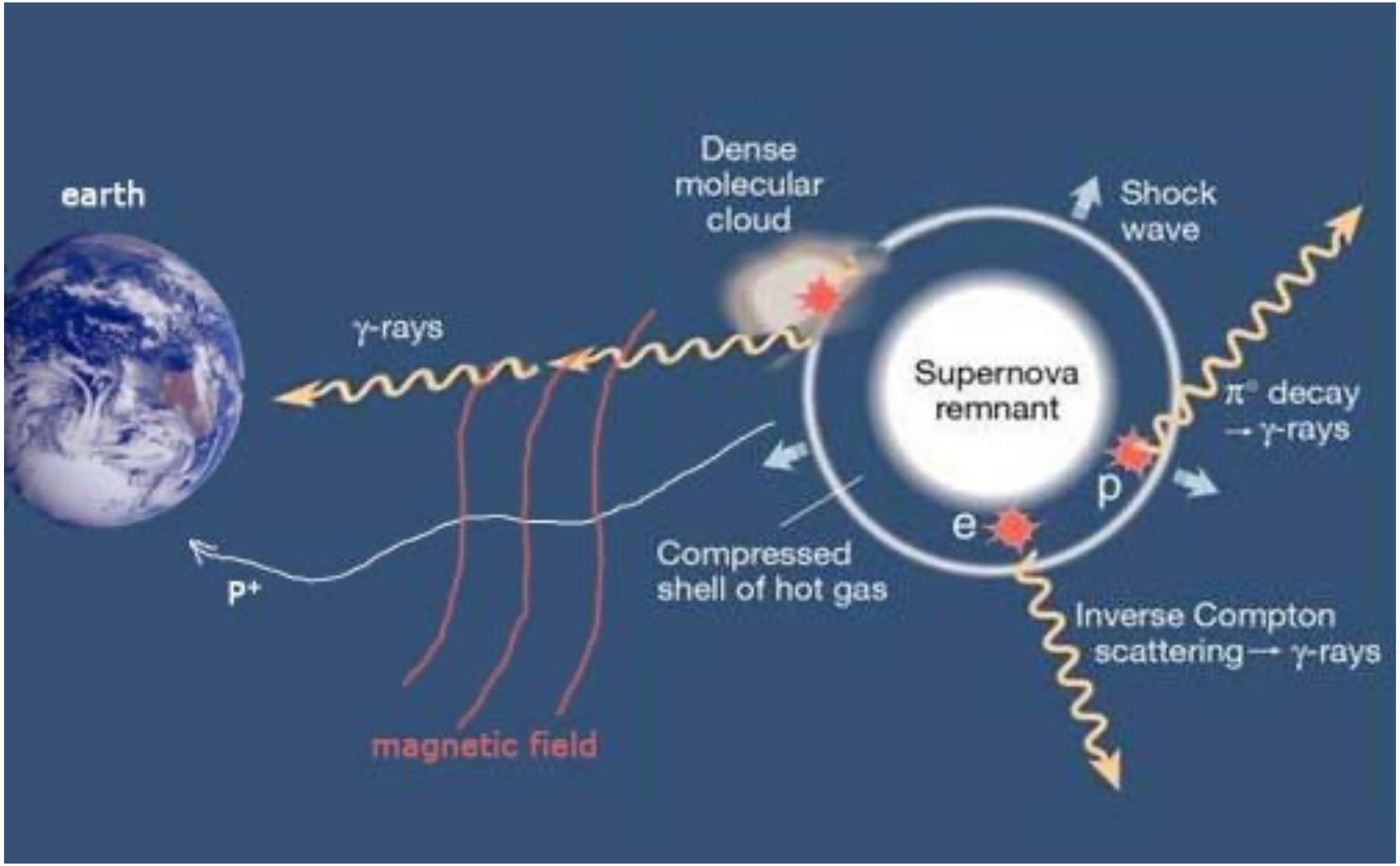
Credit: https://www.youtube.com/@kurzgesagt

The afterlife of a star: SNR, pulsar, and PWN

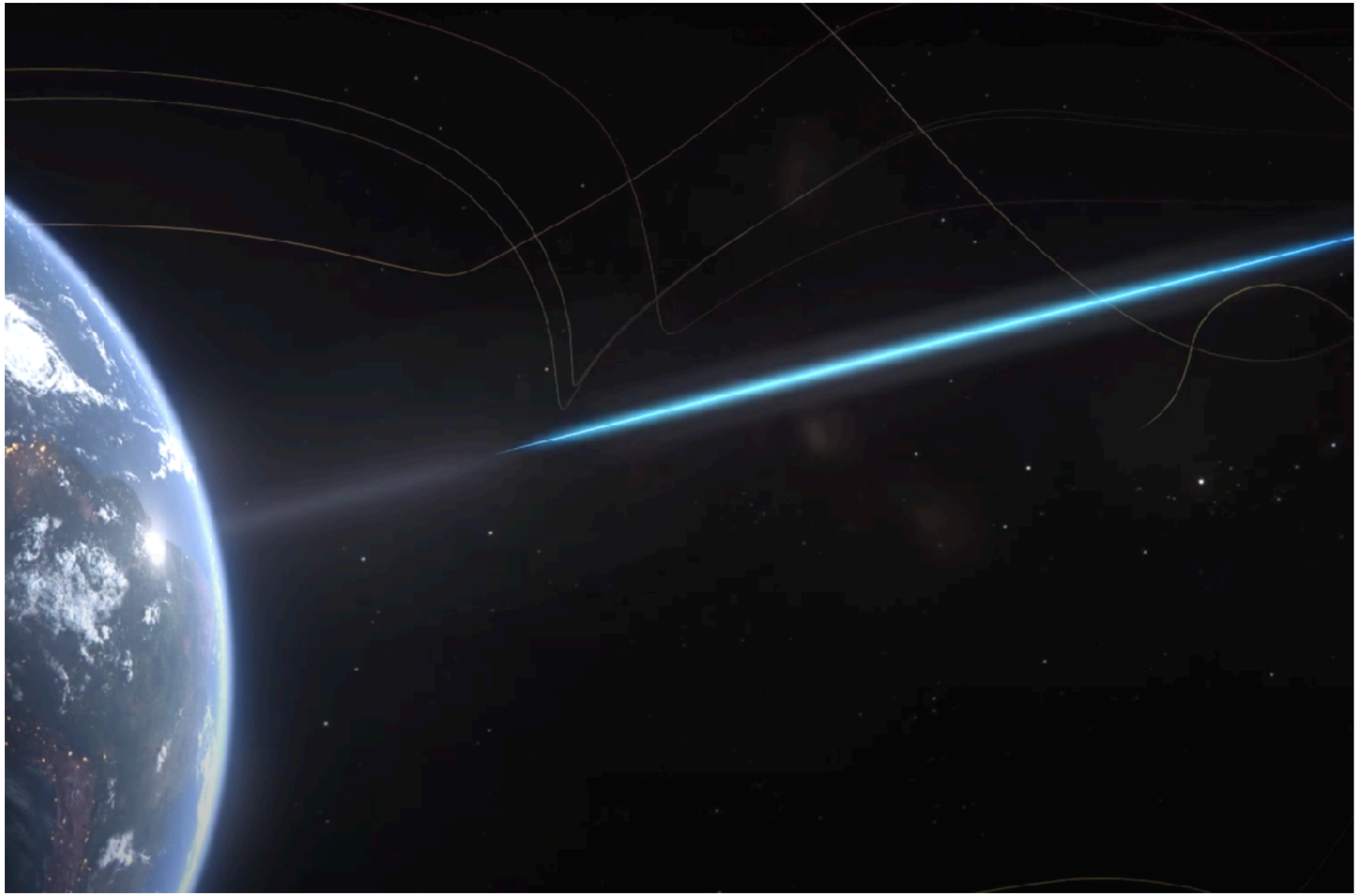


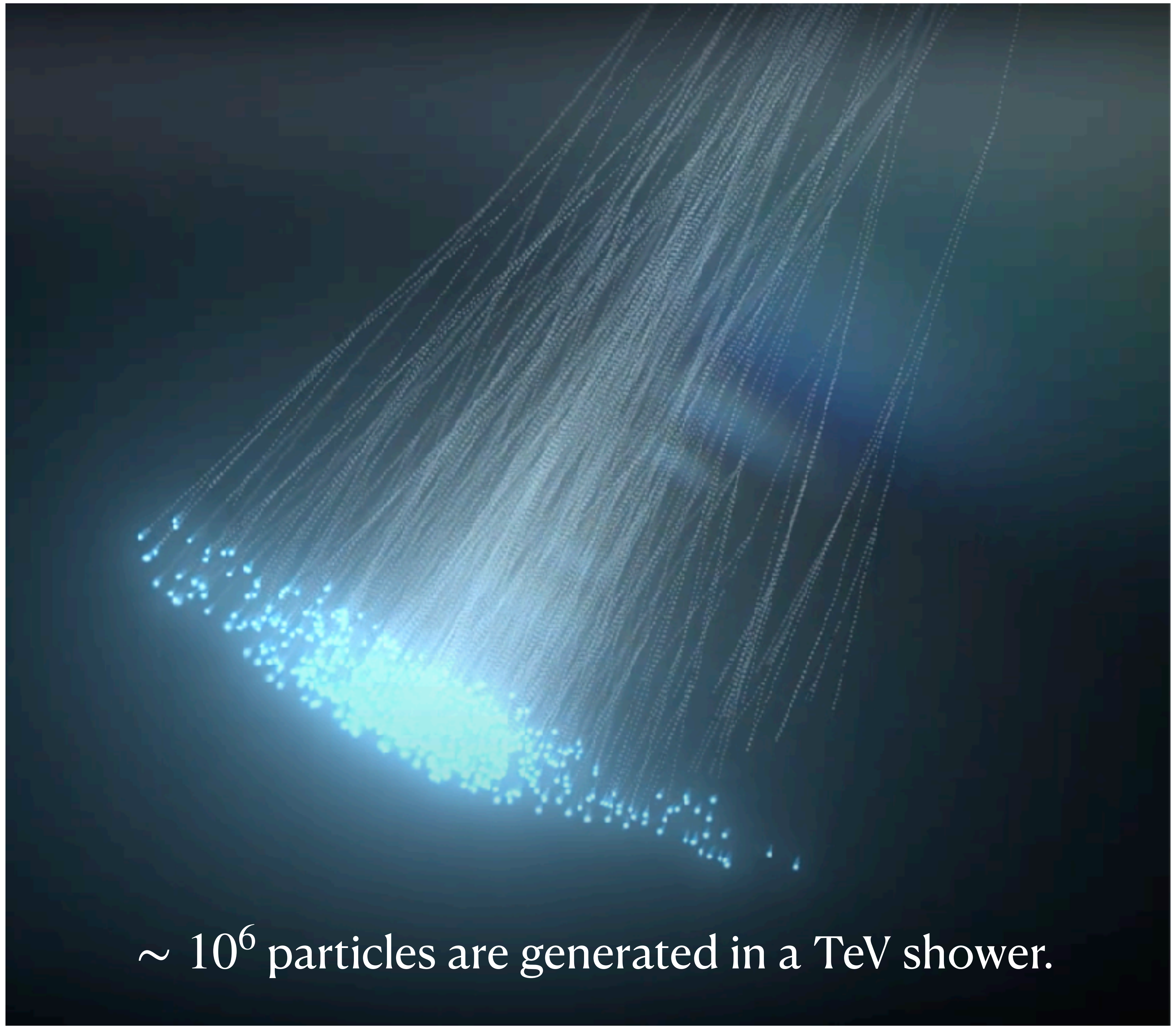
Artist's impression of a supernova. (ESA/Hubble, CC BY 4.0)

Gamma rays from supernova remnant

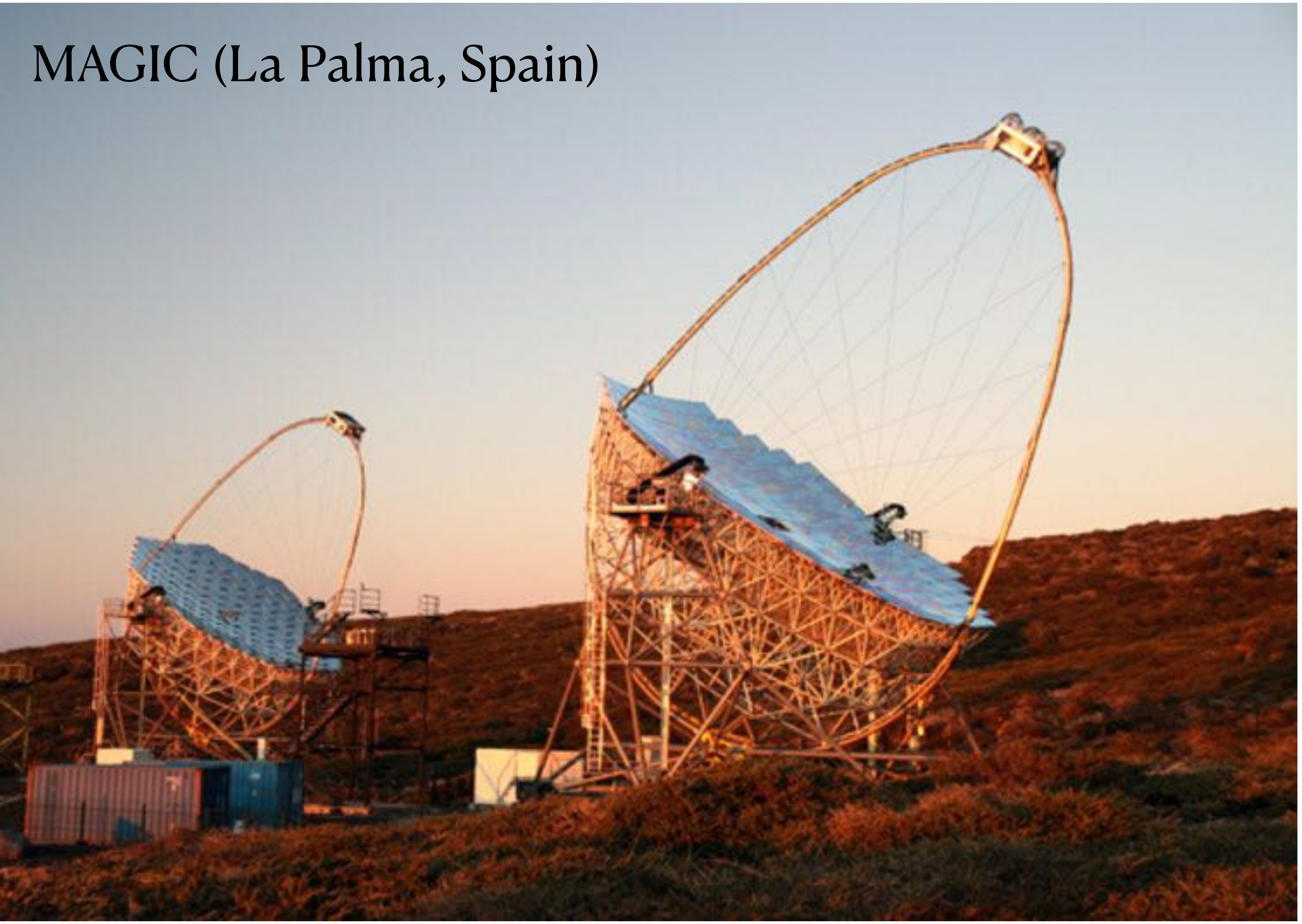


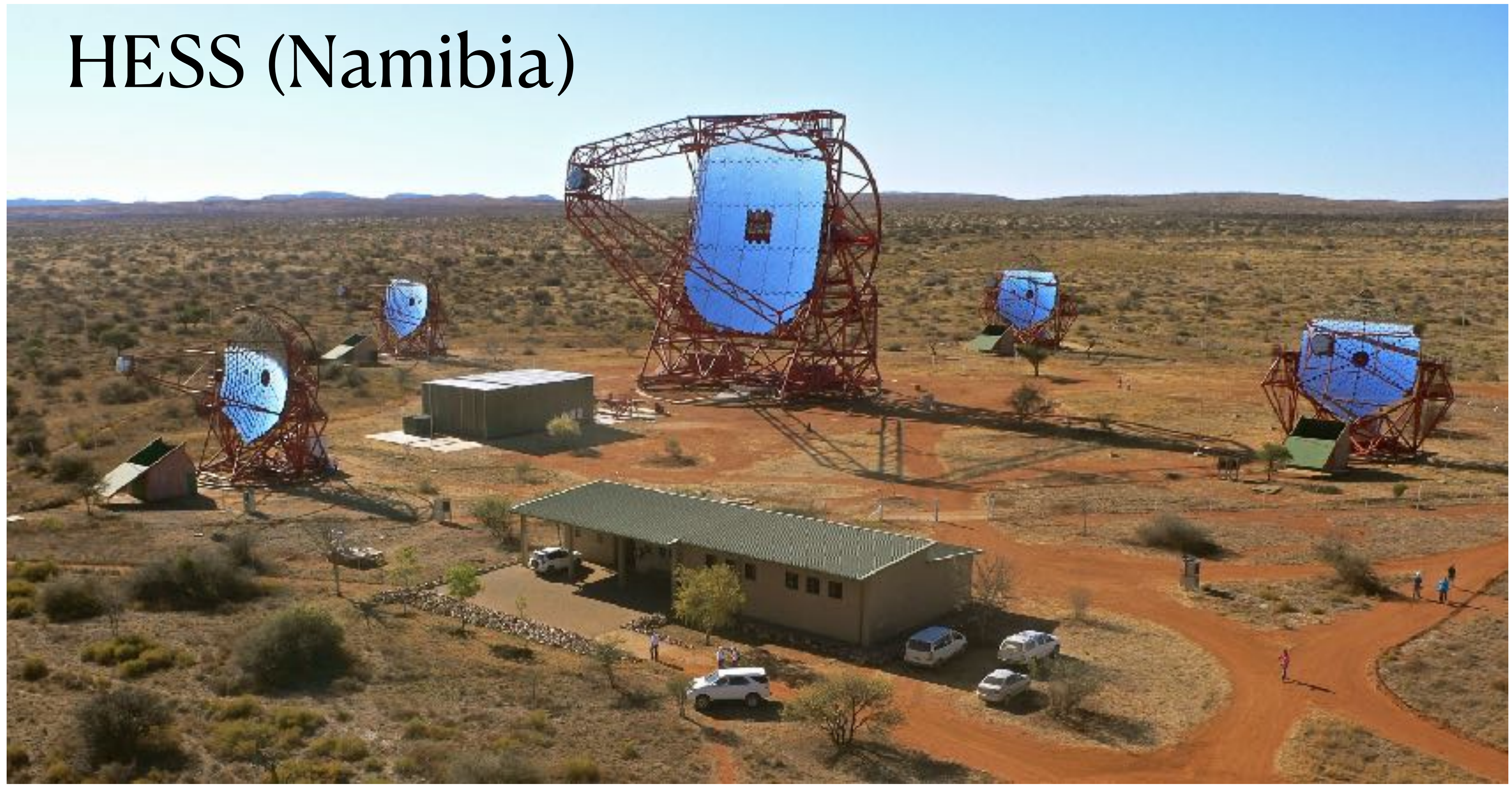
Seeing violent events in the Universe: Gamma-ray astronomy





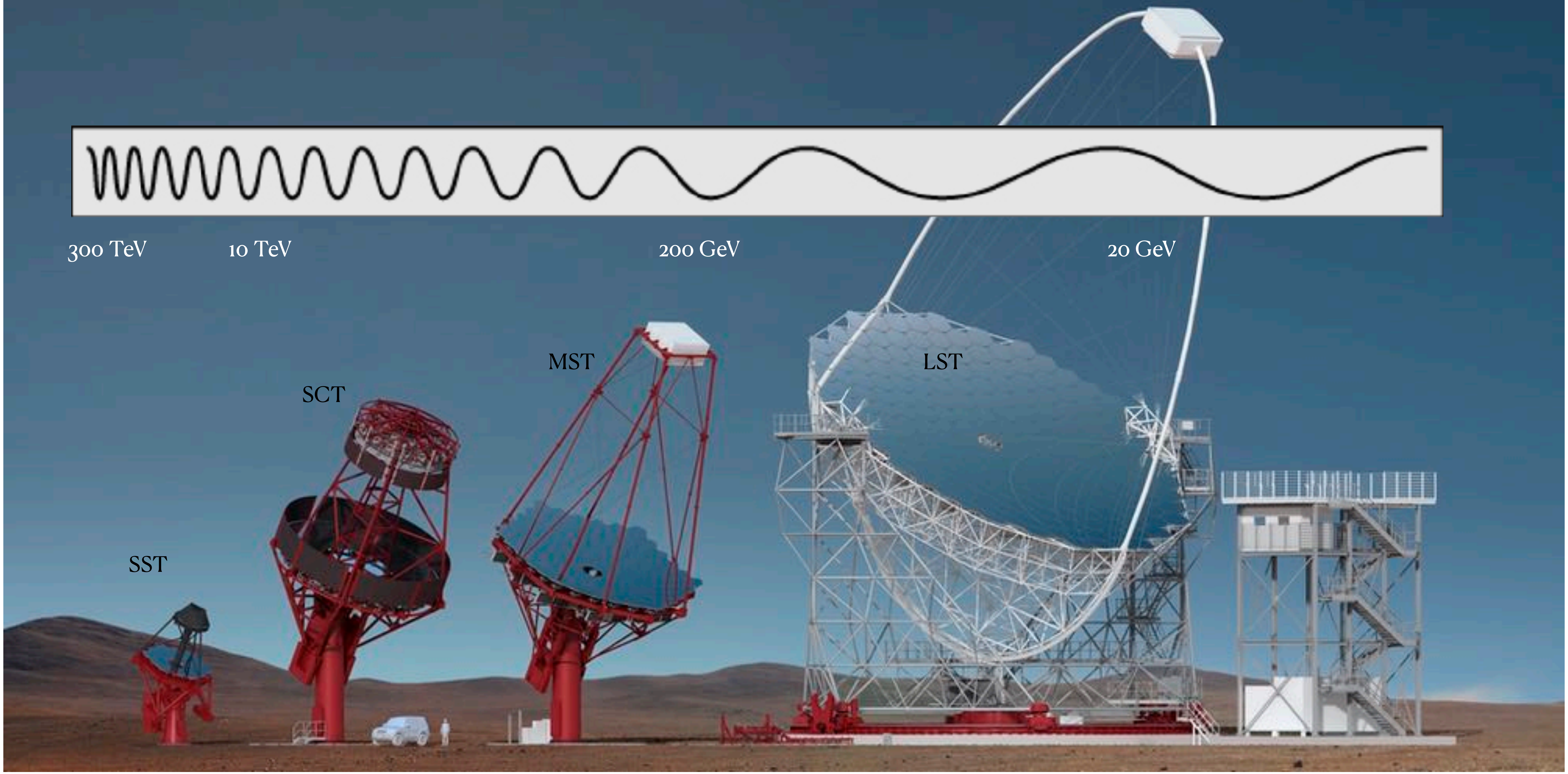
Current Ground-based Gamma-ray experiments





Next generation: Cherenkov Telescope Array

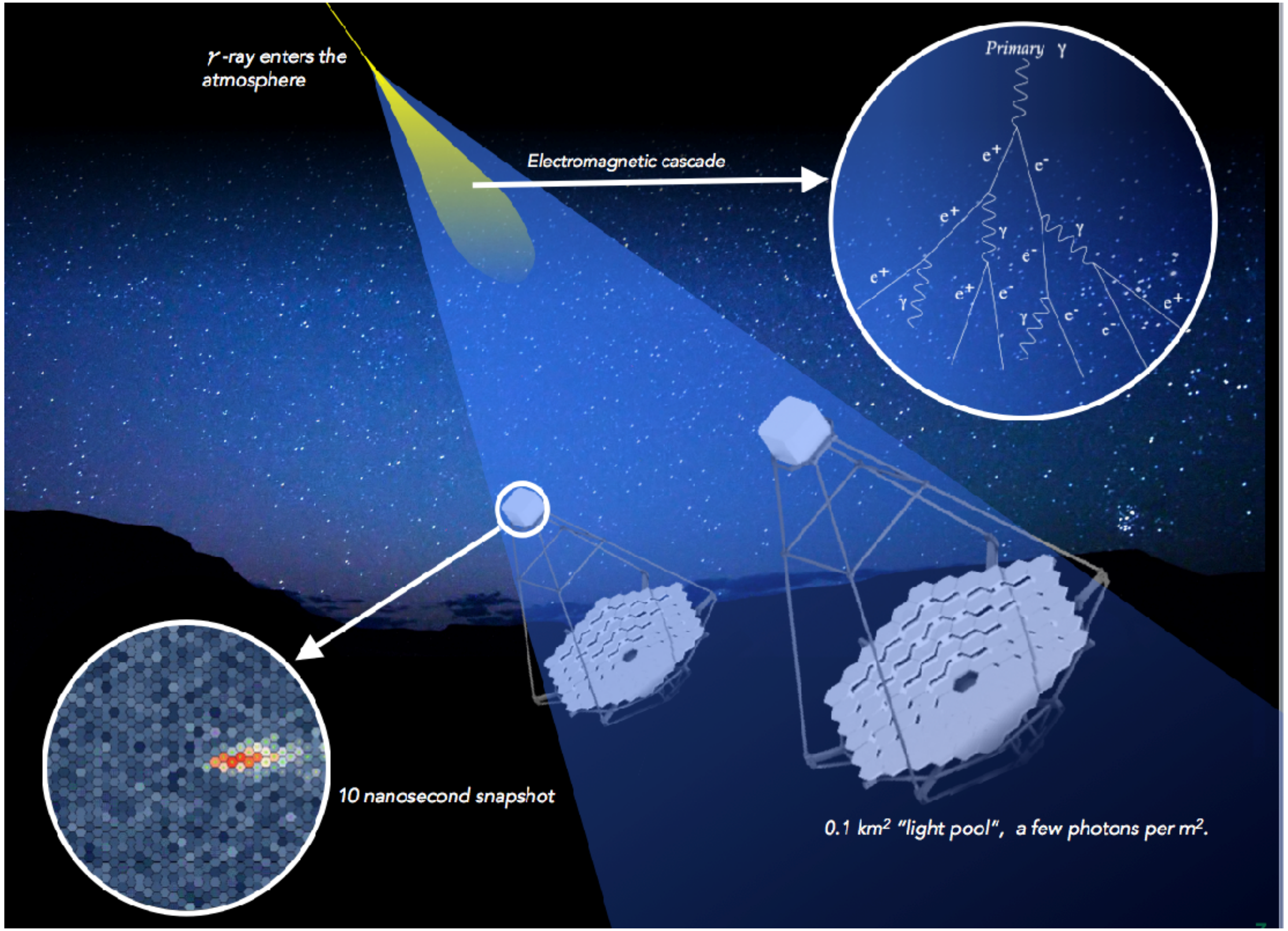
Three types of telescopes to see γ rays of different energies



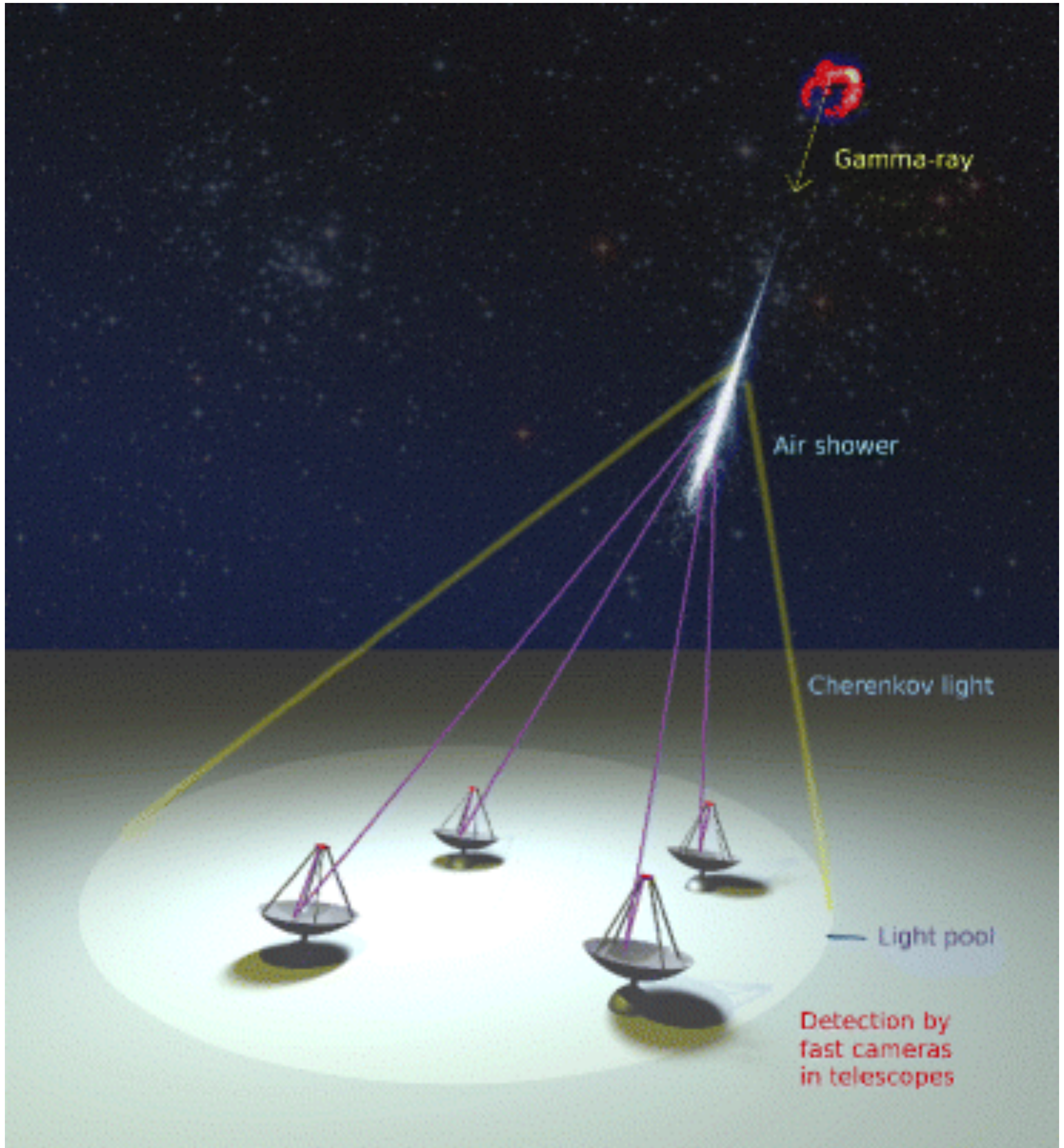
Prototype Schwarzschild-Couder Telescope in Arizona

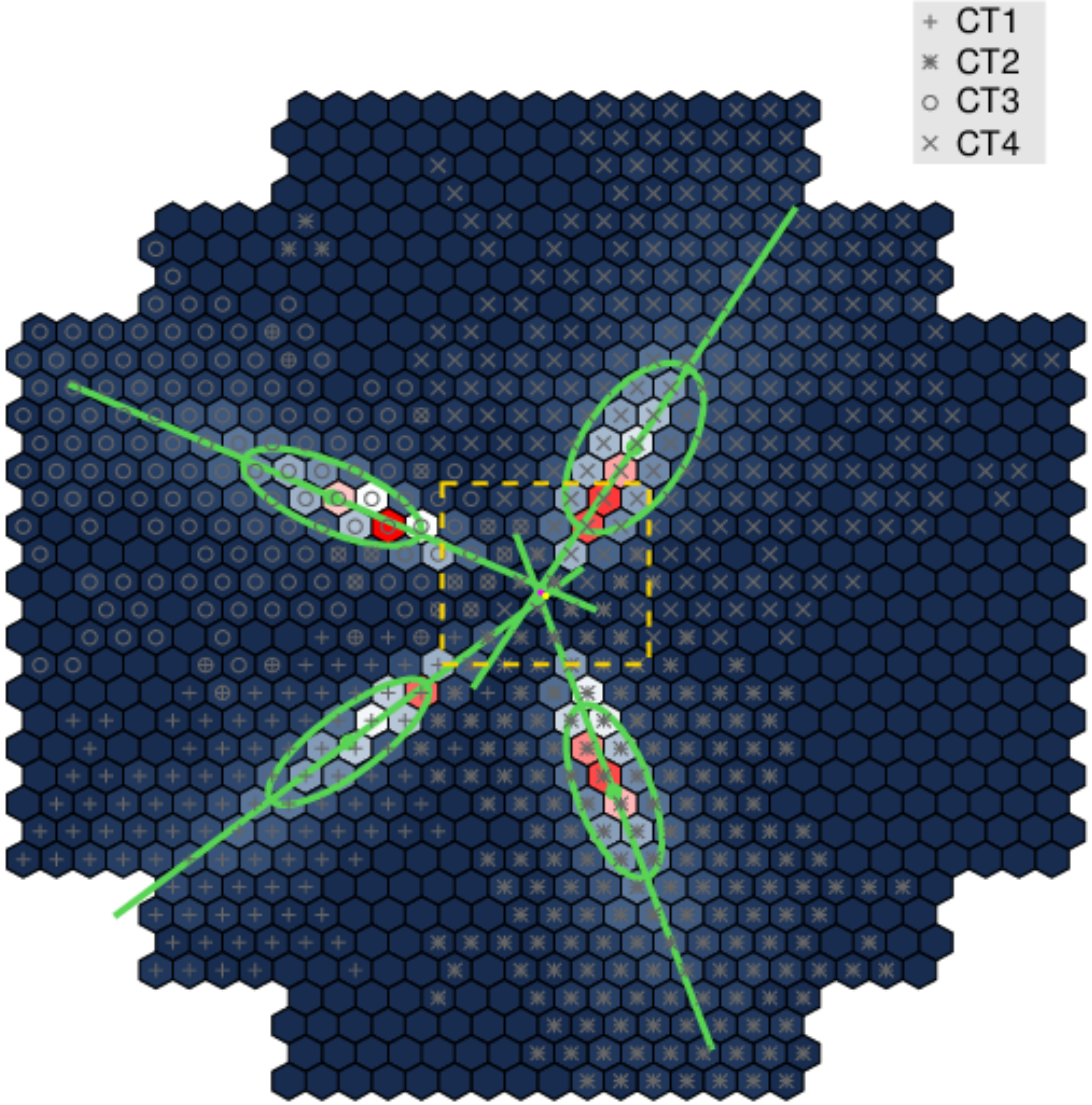
Visit https://www.cta-observatory.org/ to learn more!

Imaging Atmospheric Cherenkov Telescopes



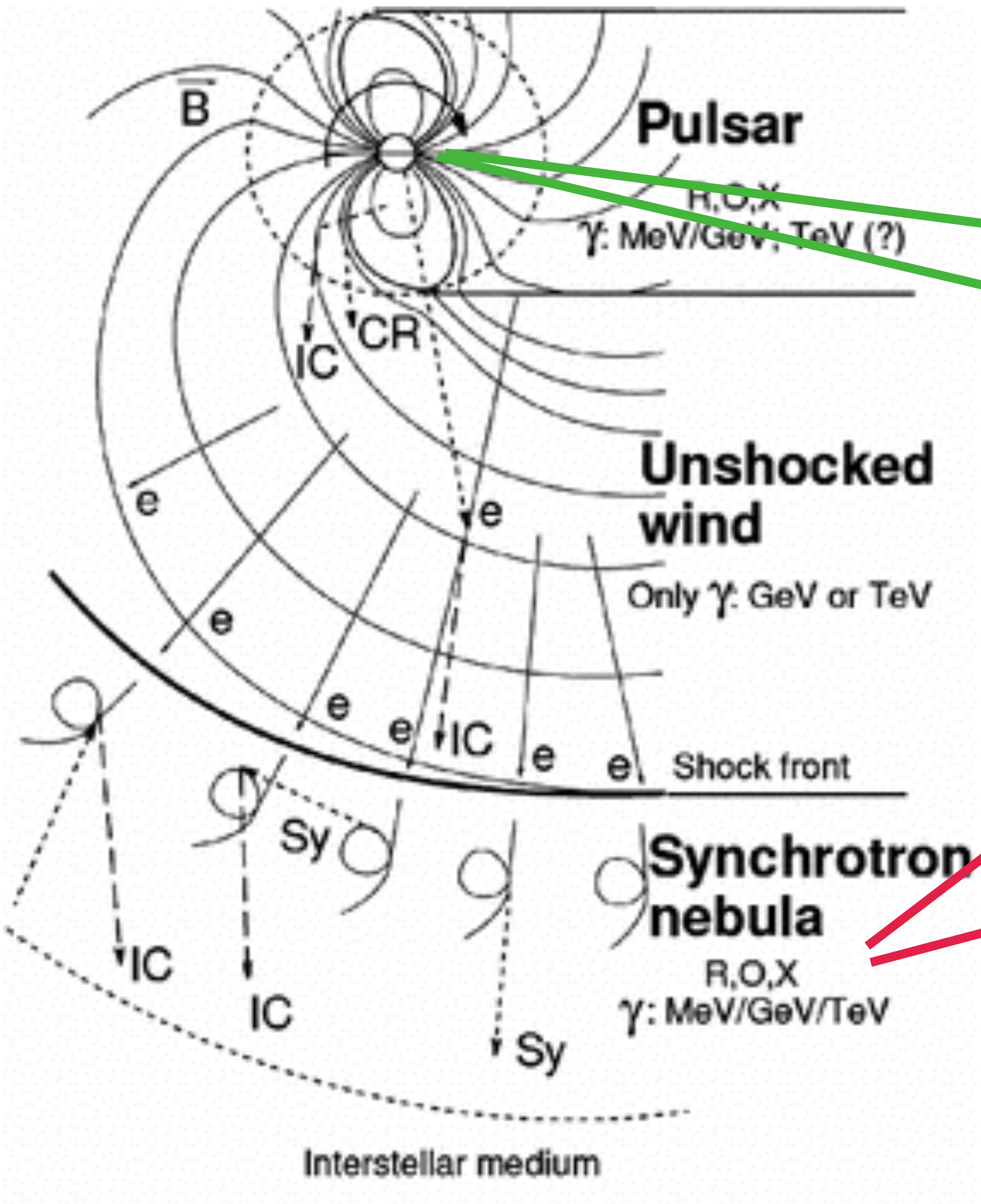
Reconstruct Gamma-ray arrival direction



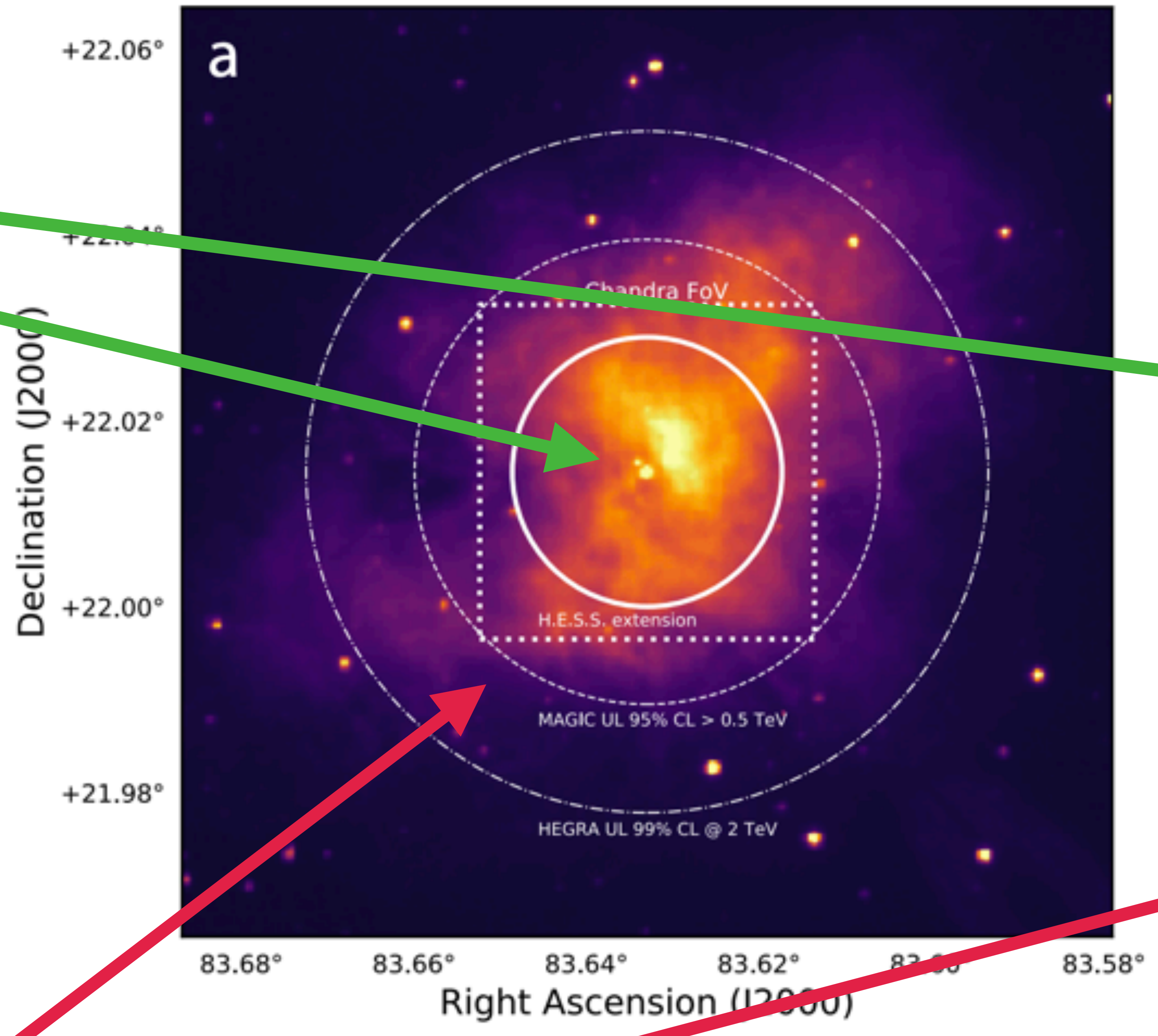



Locating the gamma-ray sources!
HESS J1857+026
HESS J1858+020
HESS J1852-000
HESS J1848-018
HESS J1846-029
HESS J1843-033
HESS J1841-055
HESS J1837-069
HESS J1834-087
HESS J1833-105
HESS J1825-137
HESS J1826-148
HESS J1813-178
HESS J1809-193
HESS J1804-216
HESS J1747-281
HESS J1745-290
HESS J1745-303
HESS J1731-347
HESS J1713-381
HESS J1714-385
HESS J1718-385
HESS J1713-397
HESS J1708-410
HESS J1708-443
HESS J1646-458
HESS J1634-472
HESS J1632-478
HESS J1640-465
HESS J1616-508
HESS J1614-518
HESS J1514-591
HESS J1507-622
HESS J1442-624
HESS J1420-607
HESS J1418-609
HESS J1356-645

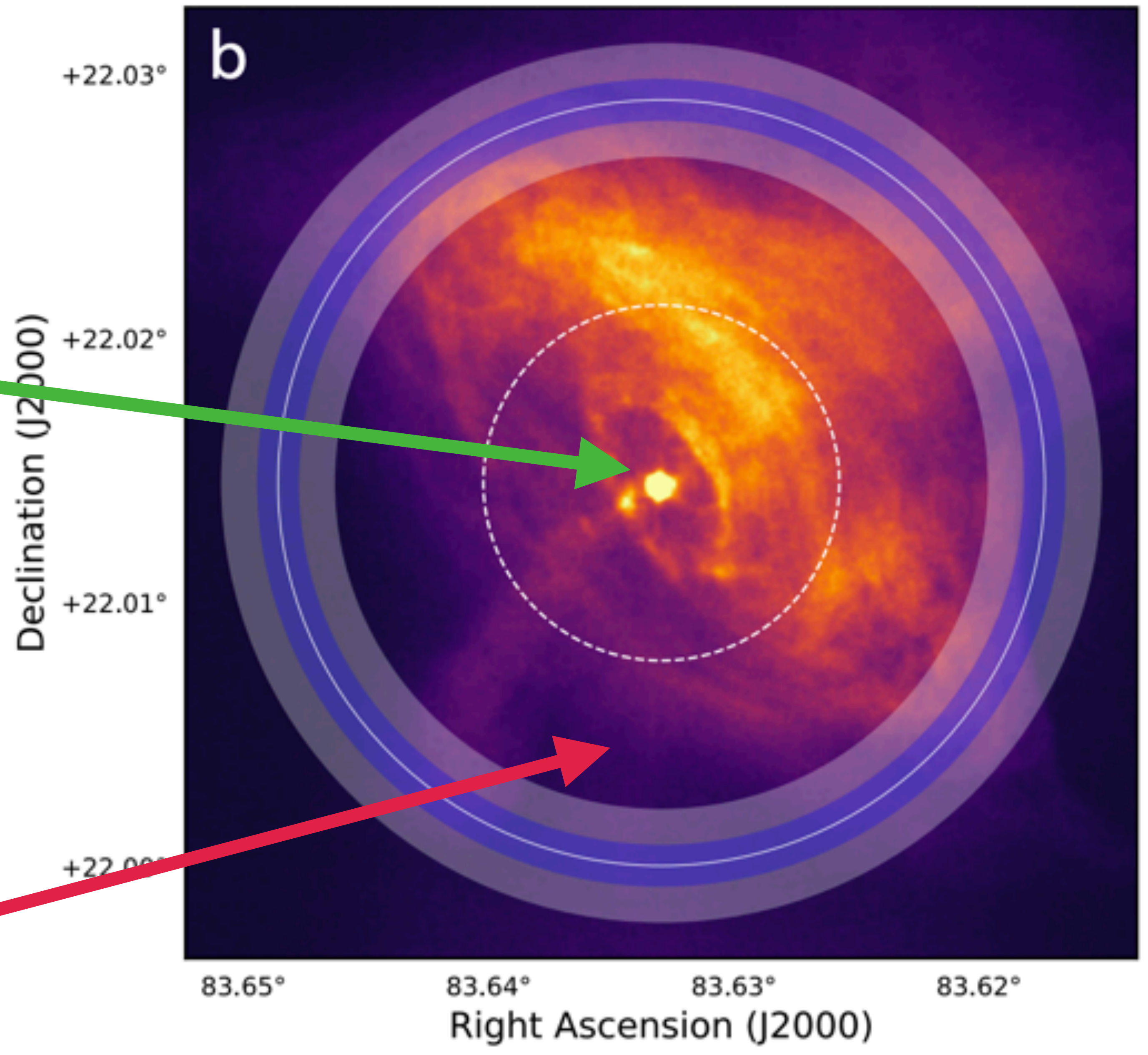
Multi-wavelength observation of extended emission



UV image

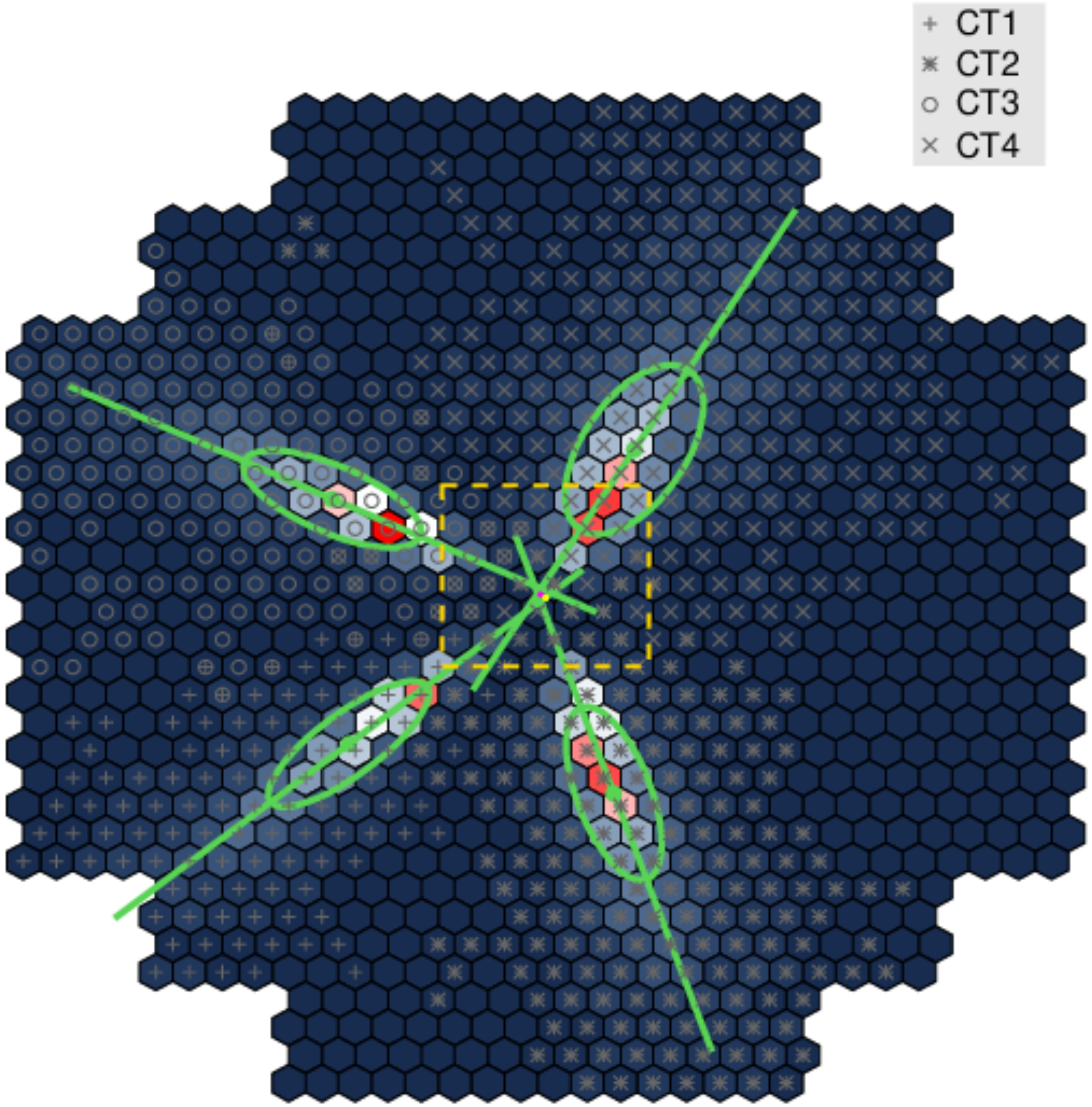


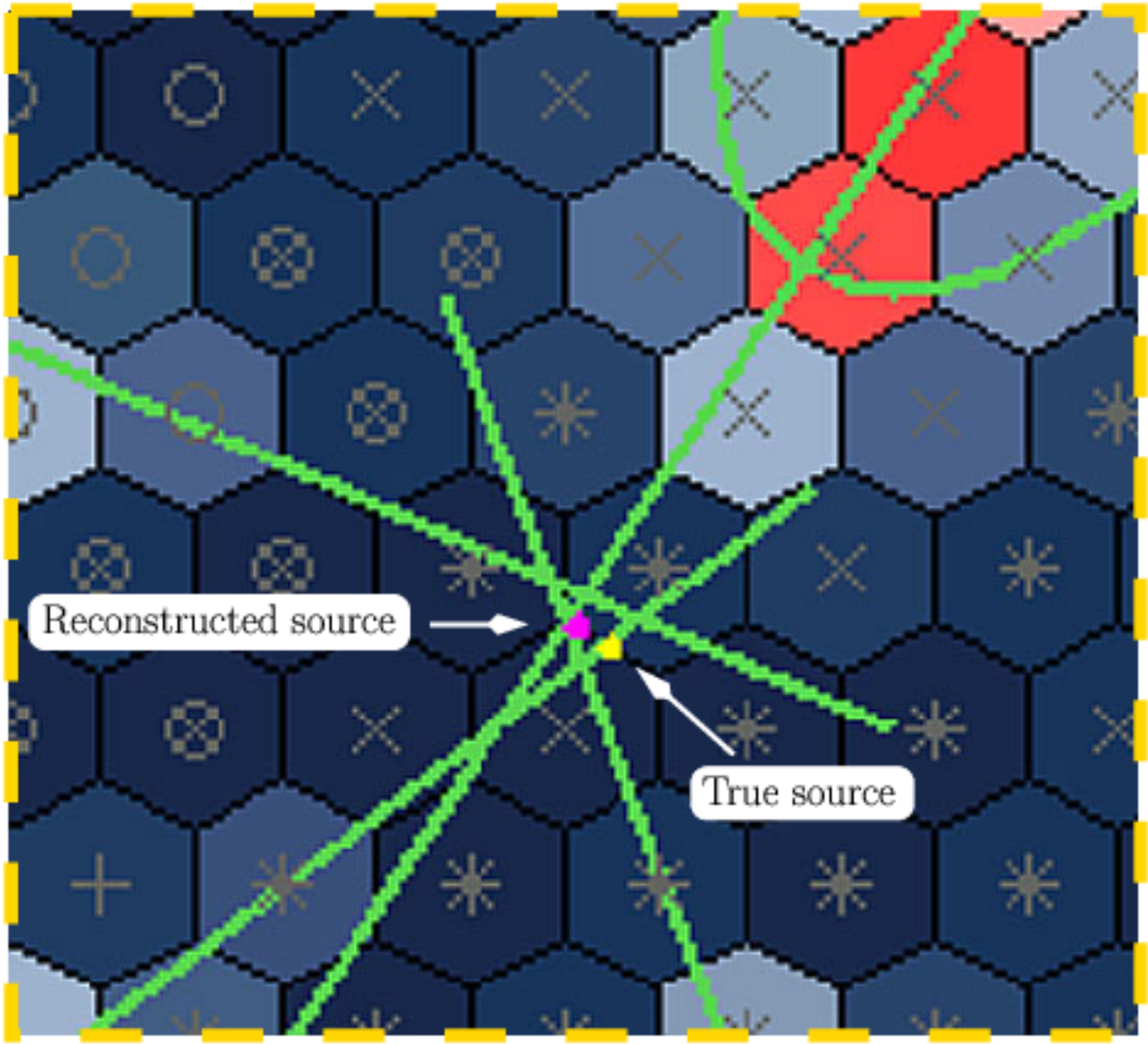
X-ray image



Can gamma-ray telescopes resolve extended emission from the nebula?

Angular resolution: Point-Spread Function

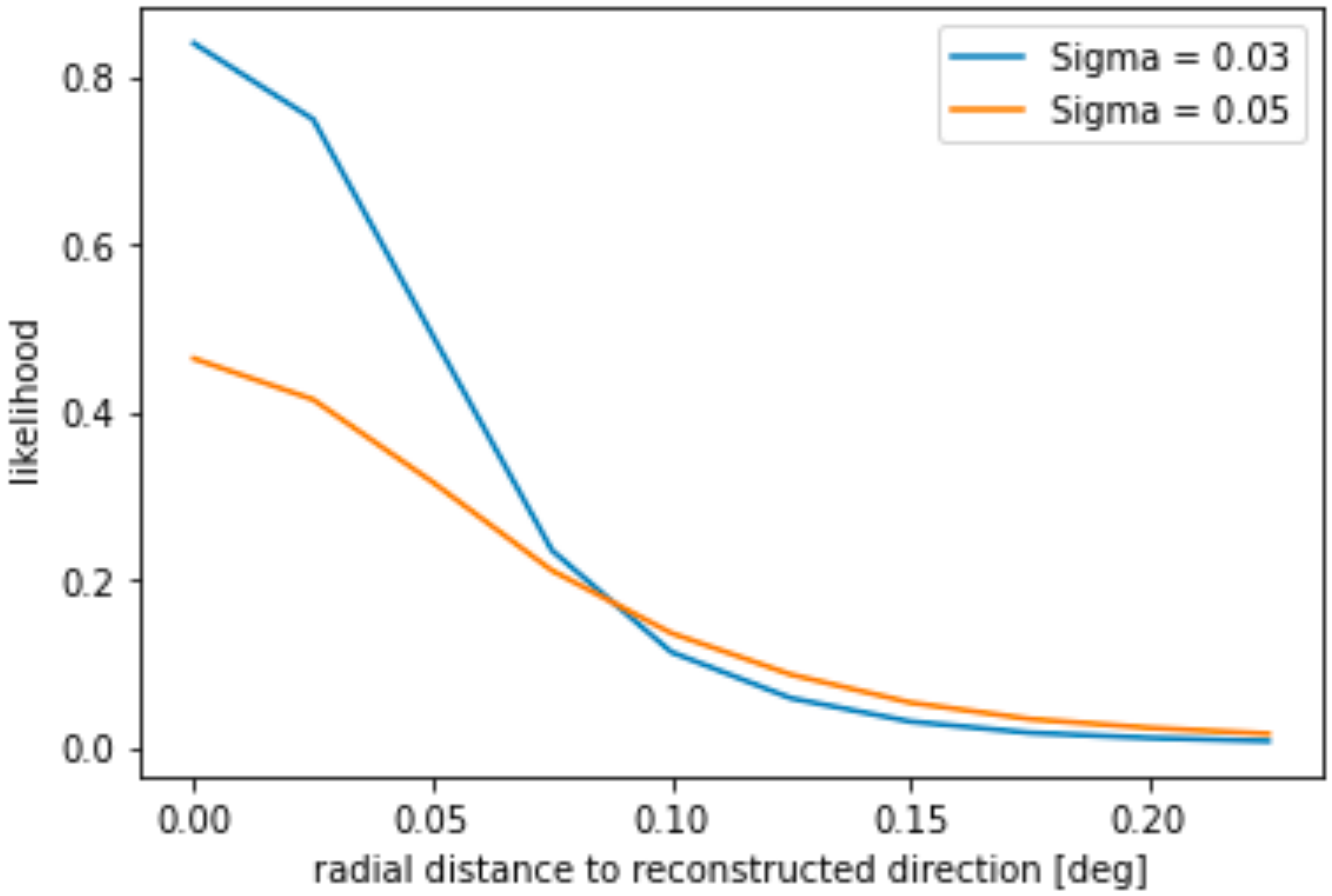




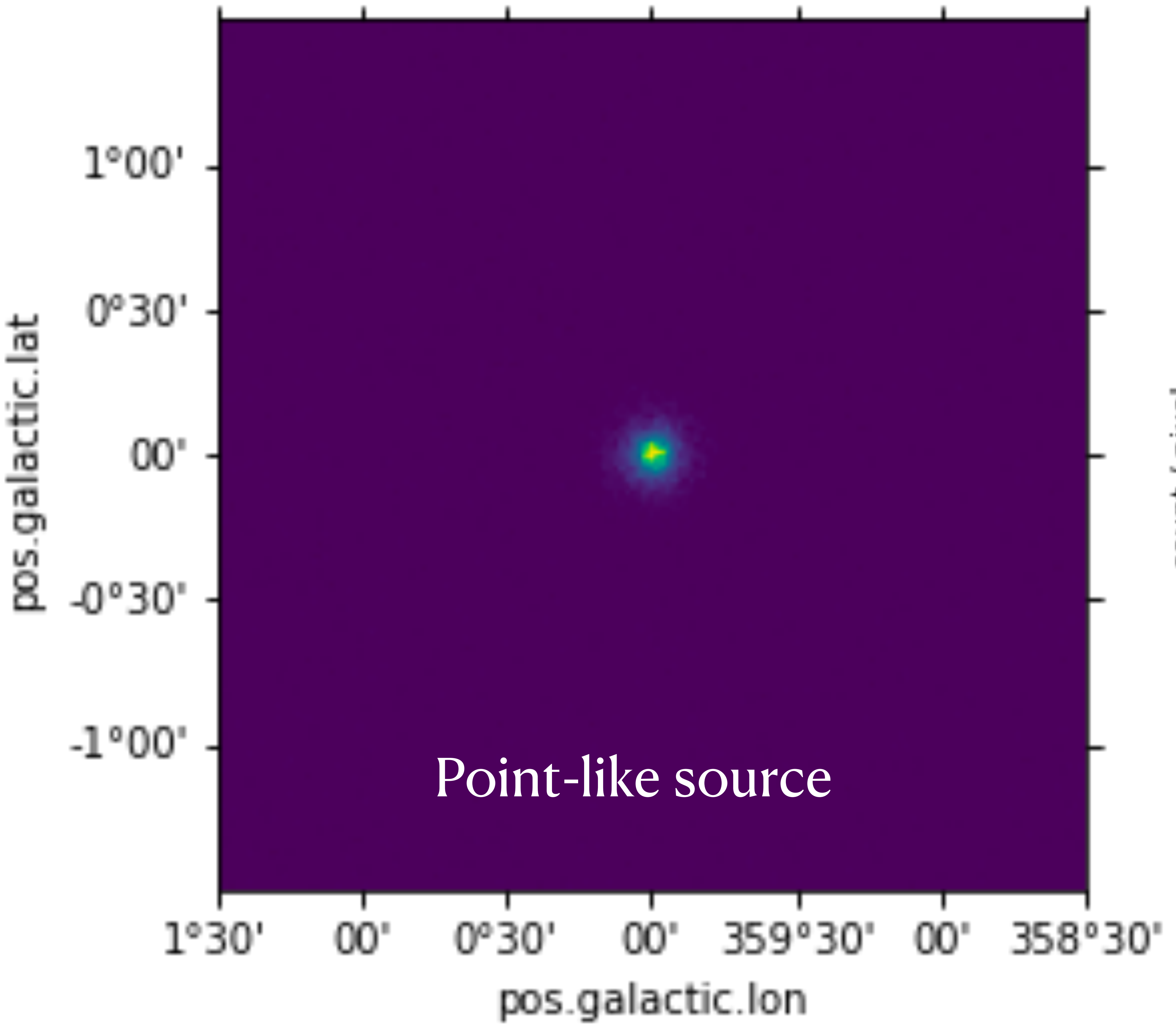
Angular resolution: Point-Spread Function

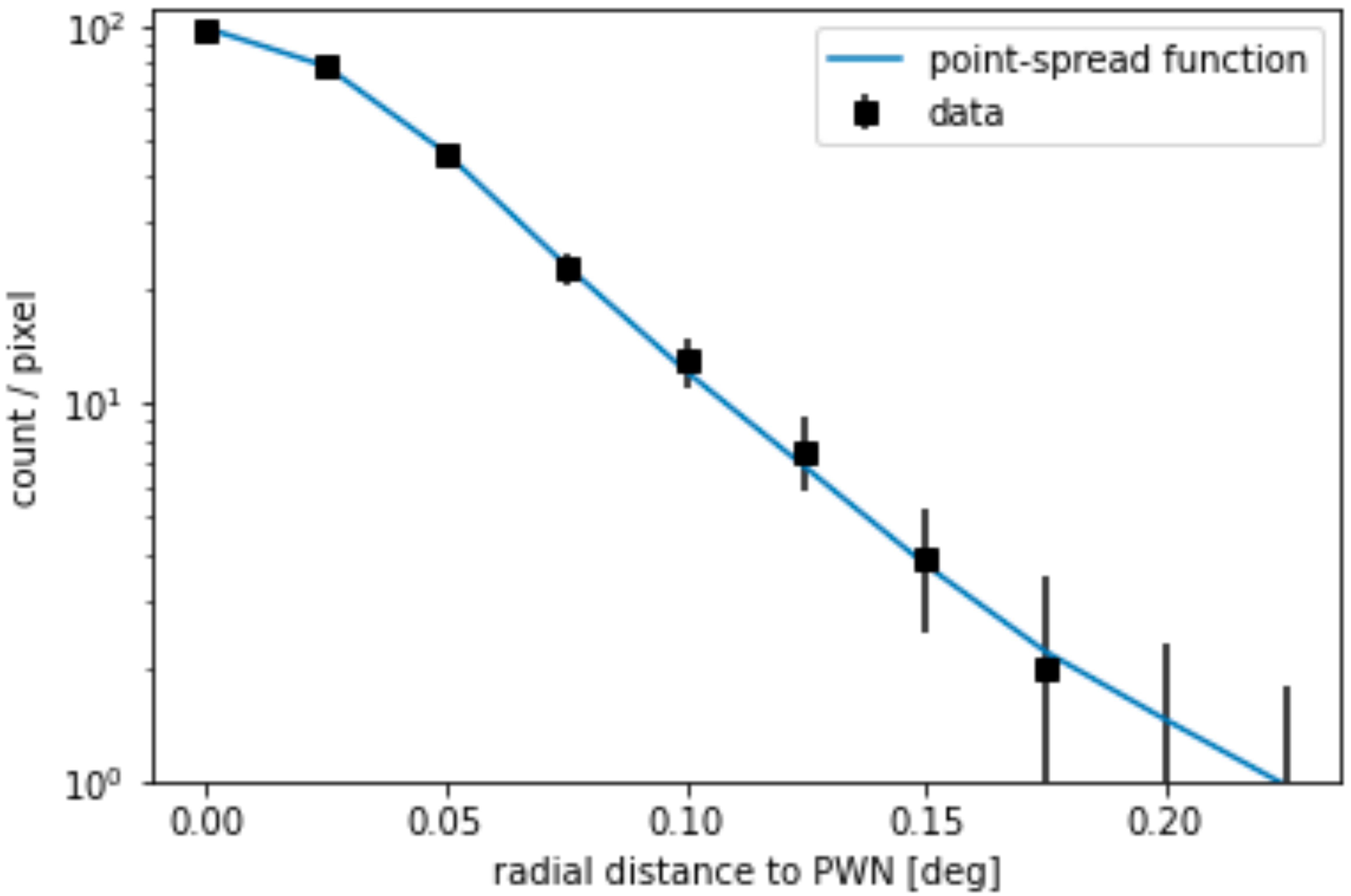
The likelihood the true source location is x-deg away from the reconstructed location:

$$K(x) = \frac{1}{2\pi\sigma^2}\left(1 - \frac{1}{\gamma}\right)\left(1 + \frac{1}{2\gamma}\frac{x^2}{\sigma^2}\right)$$

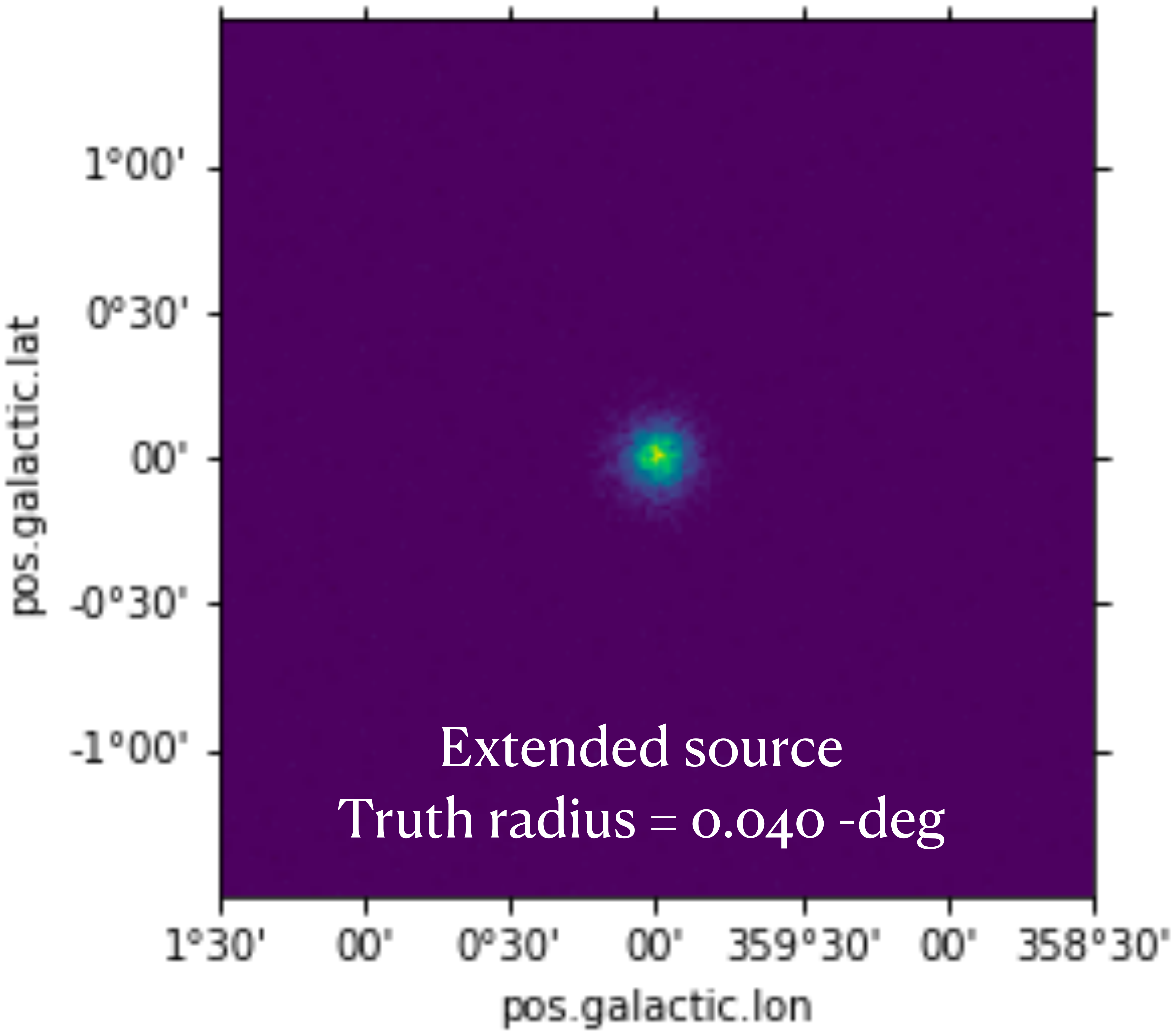


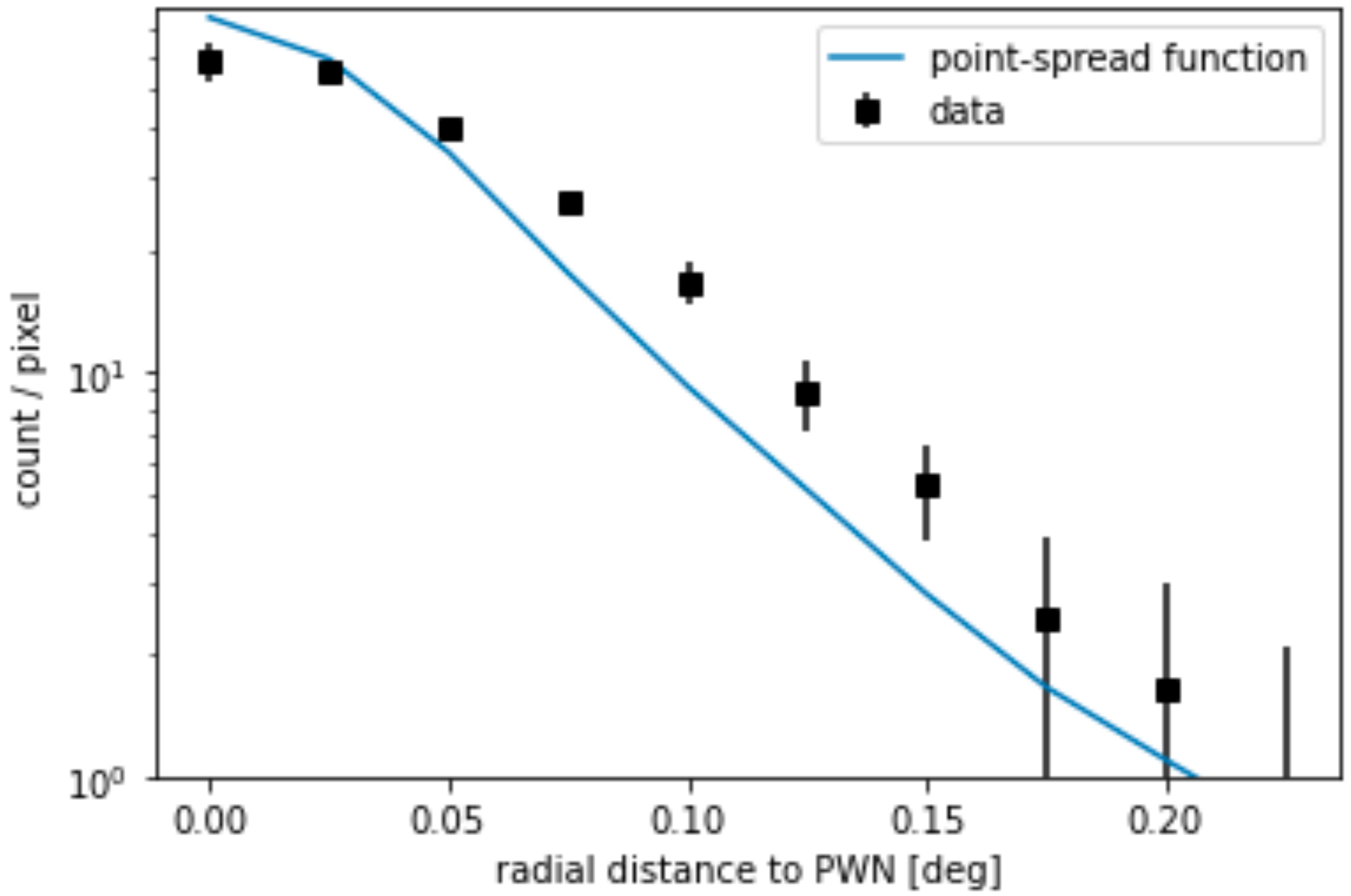
Intrinsic size of a point-like source: PSF



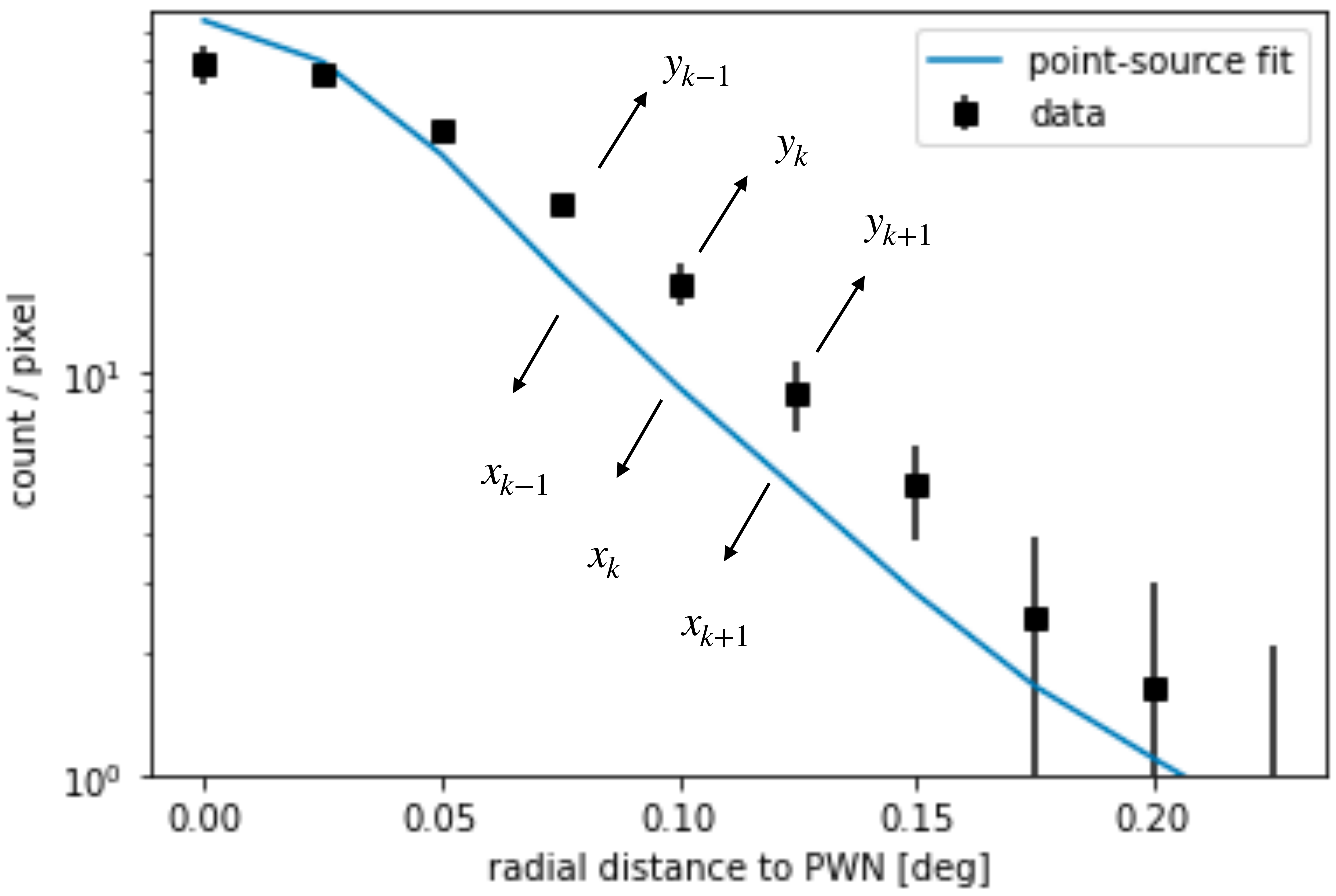


Resolve an extended source





Differentiate point-like and extended profiles



We would like to find out the difference between the radial distribution of an extended source (y_k) and the radial distribution of an point-like source assumption (x_k).

$$\chi^2 = \sum_k \left(\frac{y_k - x_k}{\sigma_k} \right)^2$$

If the errors are normally distributed,
the chance to find $\chi^2 > 1$ is 32% due to noise fluctuation.

Conventionally, scientists use $\chi^2 > 25$ as a threshold to claim detection, which reduces the chance of noise fluctuation to 2.9×10^{-7}.

Analysis: resolve source extension

- Coding exercise link: https://bit.ly/3QRsk6I
- Click the link above.
- Or use the QR code on the right.
- Go to your Google Drive, select “Shared with me” folder.
- Right click “Colab_Notebooks_Extended_Ana”, and select “Add shortcut to Drive”.