CTA-Oz Meeting #2 2022, Adelaide

The peculiar gamma-ray phenomenology of Terzan 5

Roland Crocker

Australian National University

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…work in progress with
Mark Krumholz, Jim Hinton, and others

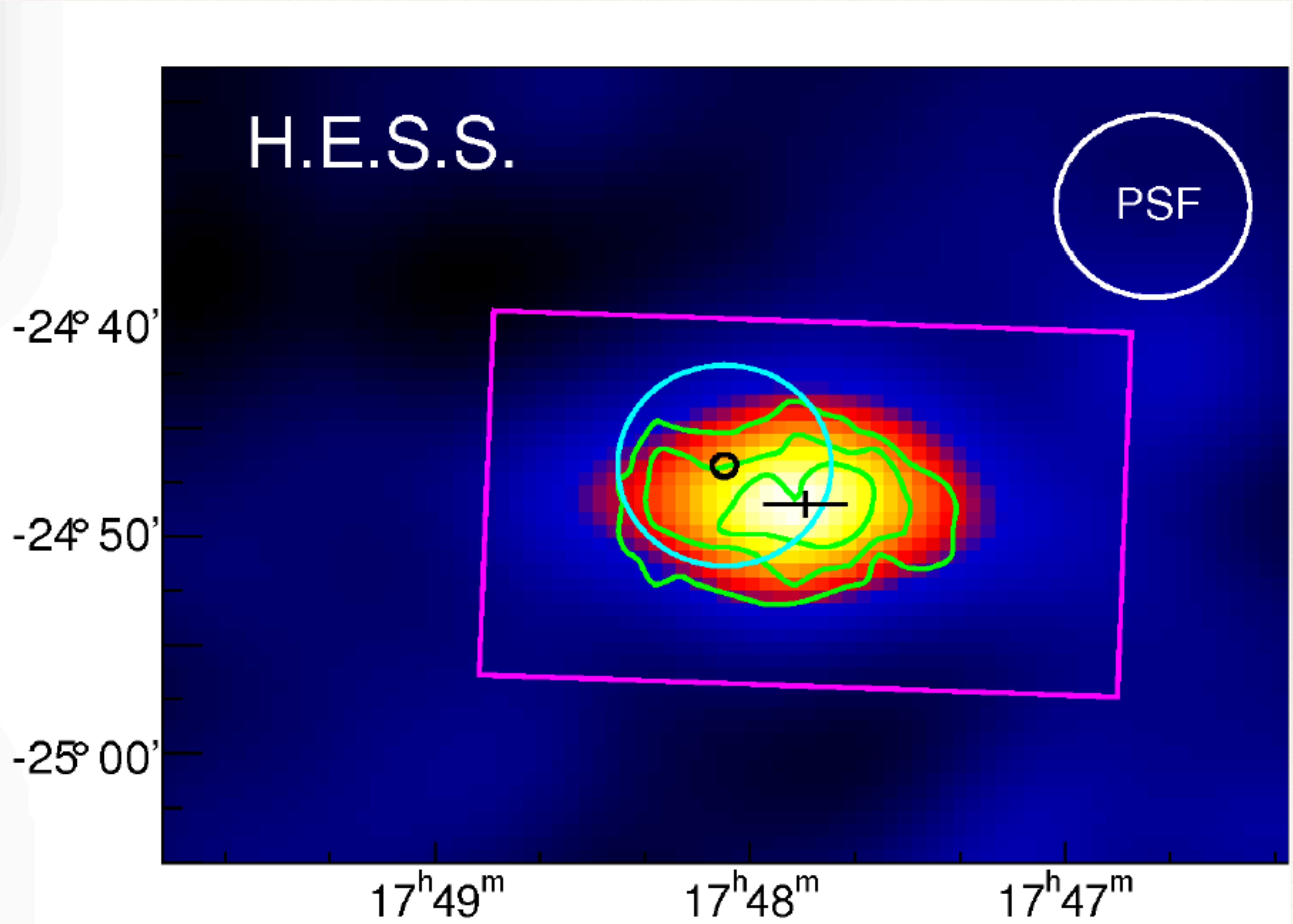
Terzan 5 Globular Cluster (GC)

- One of the Milky Way's most massive GCs
- Largest MSP population of any GC
- Brightest gamma-ray (GeV band) GC
- Located in the Galactic Bulge, only 200 pc above plane

Terzan 5 Globular Cluster

- About 30 Galactic MSPs detected in ~GeV band with *Fermi* data
- Terzan 5, uniquely amongst GCs, detected in the TeV band by HESS (Abramowski+2011)
- The Terzan 5 associated TeV source is semi-resolved and extended
- The centroid of the extended TeV emission is displaced off GC centre (where the MSPs concentrate)

Terzan 5 @ TeV (Abramowski+2011)



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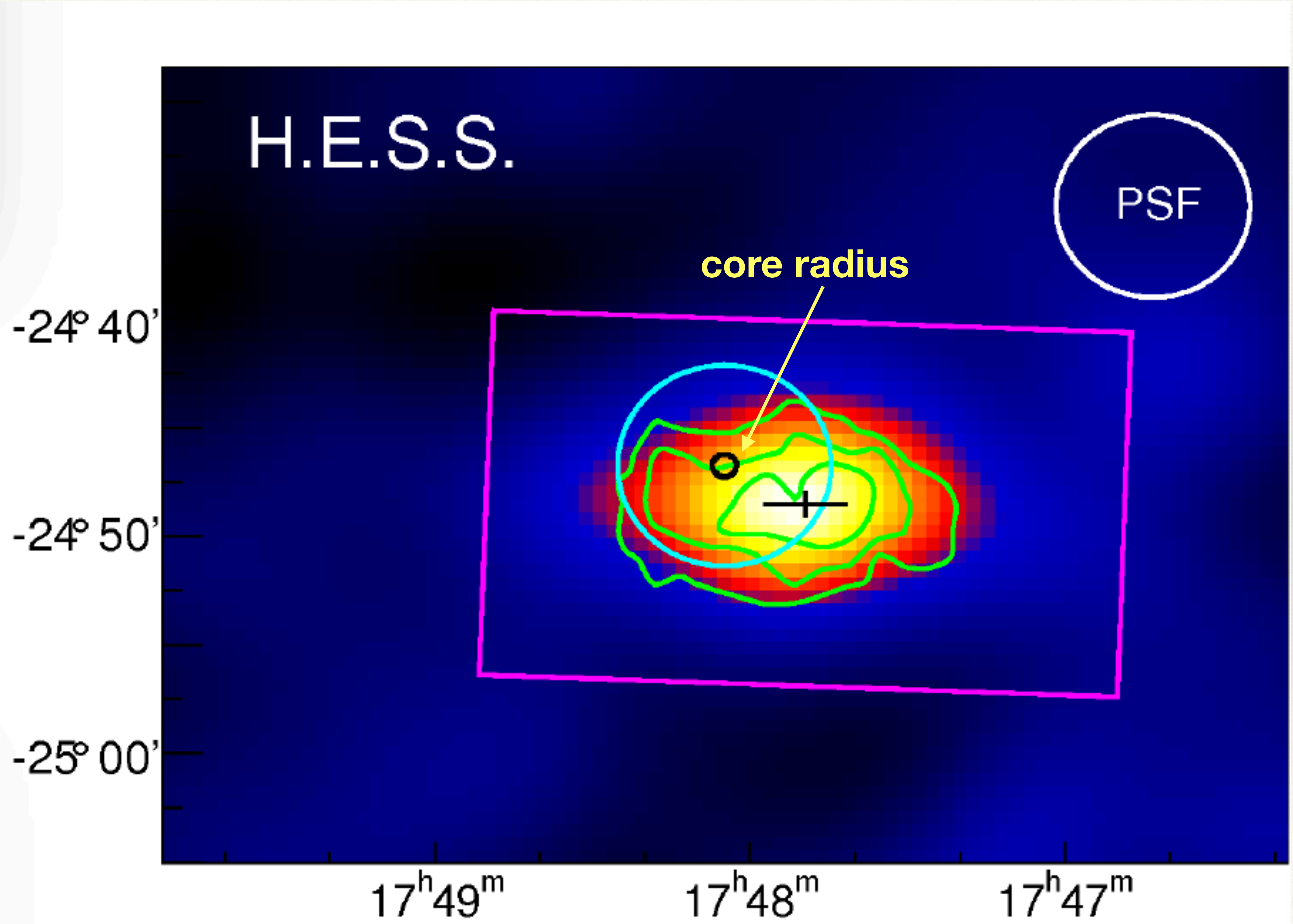
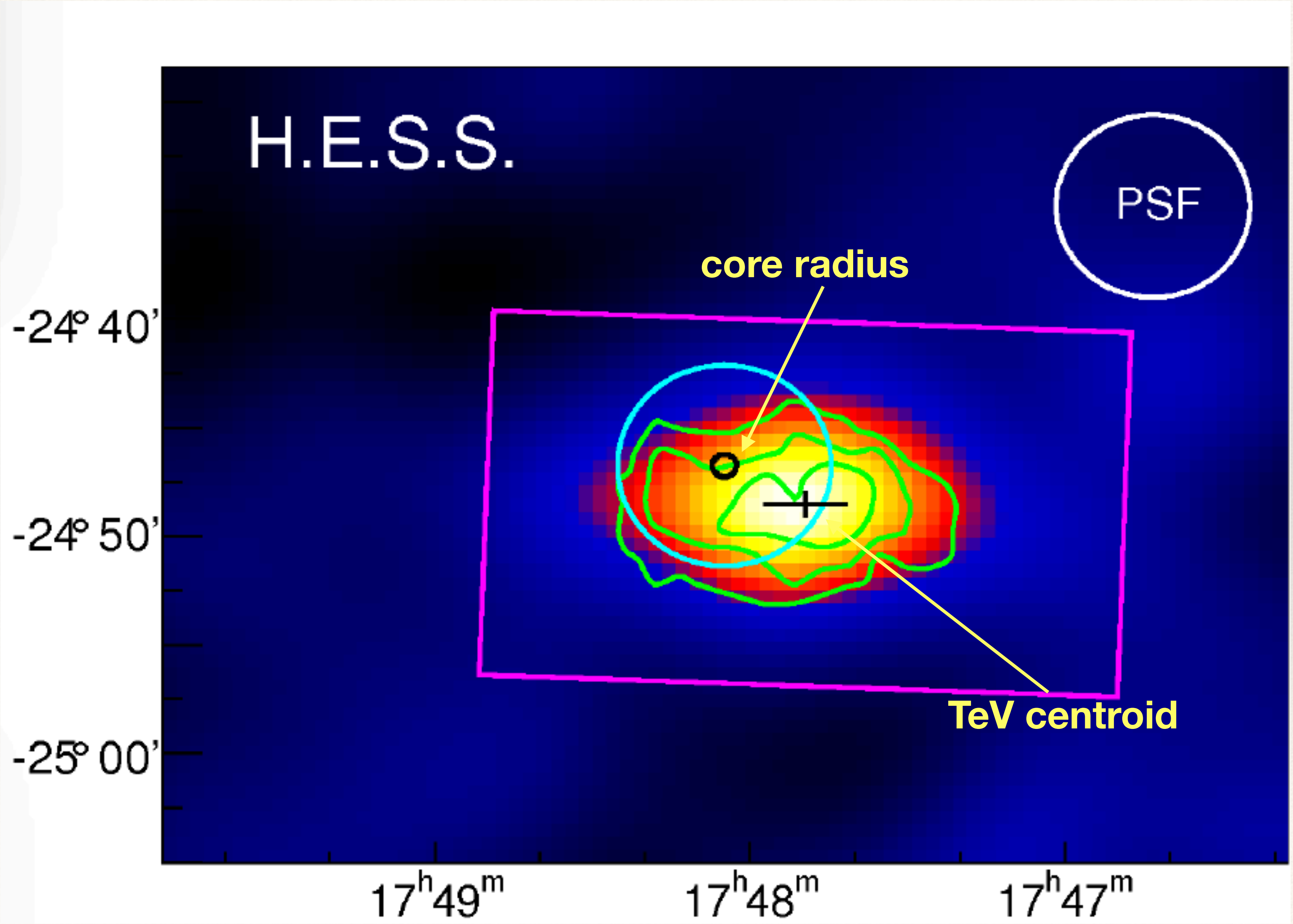


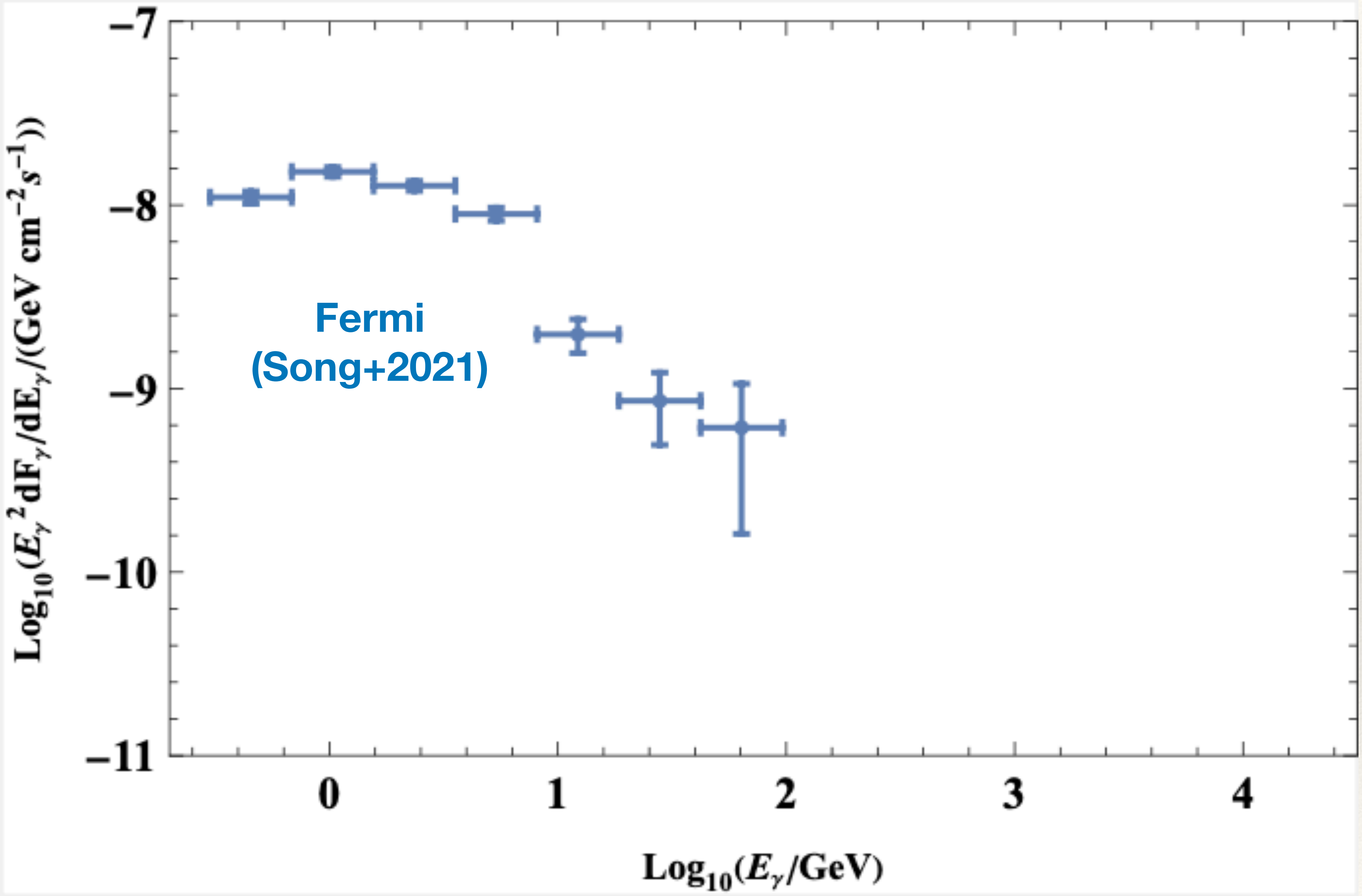
Terzan 5 @ TeV (Abramowski+2011)



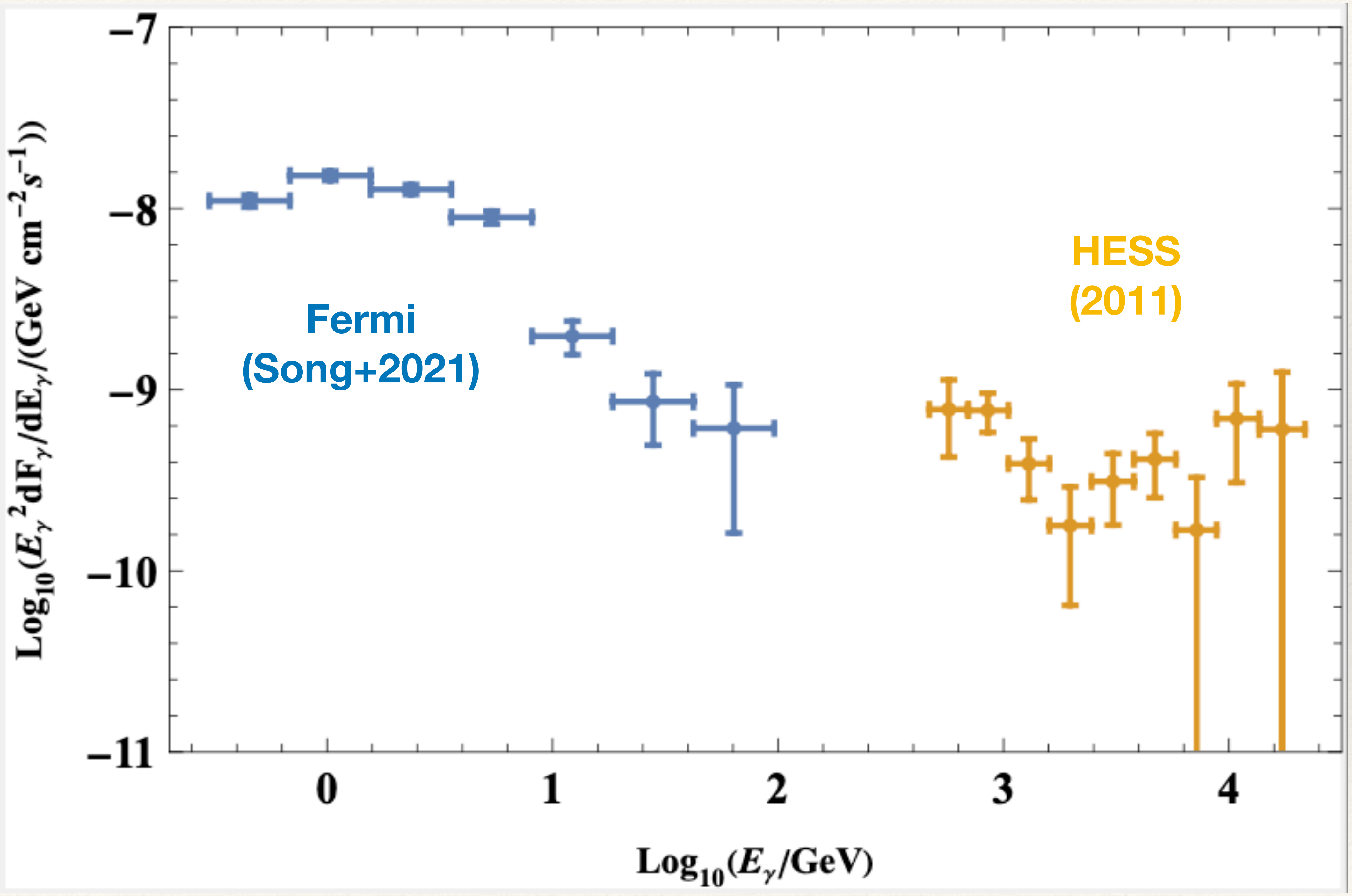
Is the TeV source really associated to Ter 5?

- Abramowski+2011 calculate the chance overlap probability as $\sim 10^{-4}$
- The GeV and TeV spectral data points match well

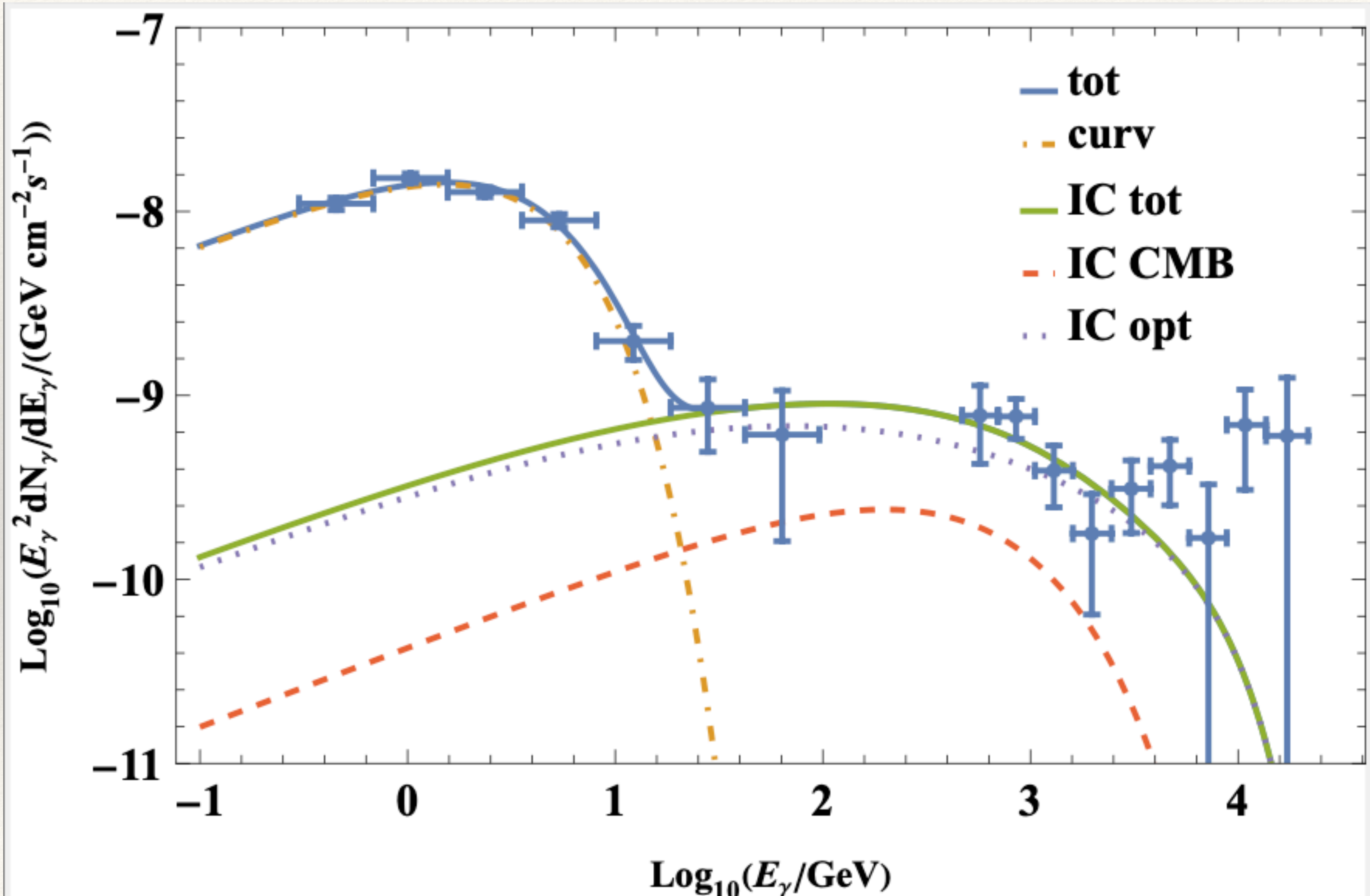
Spectrum Ter 5



Spectrum Ter 5



Spectrum well fit as curvature radiation + inverse Compton



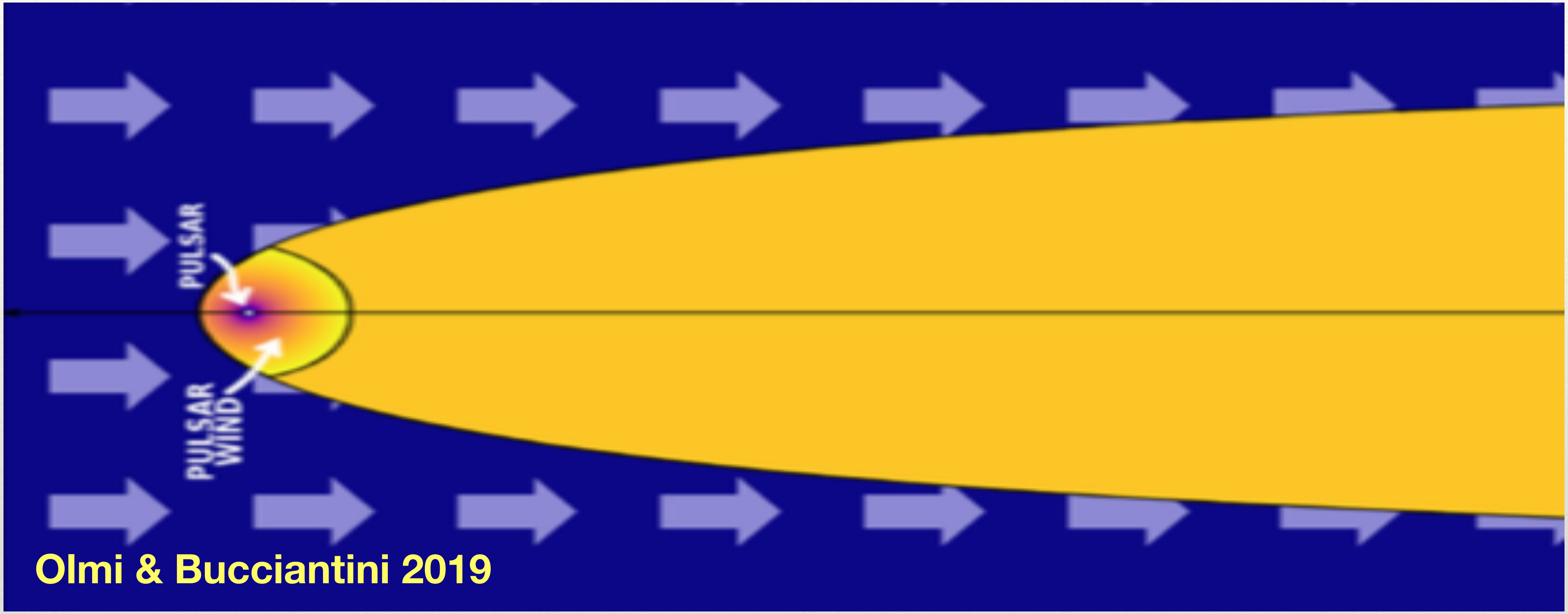
The Big Mystery: why the displacement?

- Lightfield energy density and (naively) CR electron/positron energy density should peak in the centre of the GC, so why doesn't the surface brightness peak here?

The Big Mystery: why the displacement?

- A cosmic ray transport effect?
- Point: the TeV+ radiation is produced by CR $e^{\pm}$ with energies > 10 TeV, or Lorentz gamma factors > 10^7 ; if $e^{\pm}$ are not moving in our direction, we do not see the radiation they emit
- The GC is moving super-sonically through the disk ISM
- It has a bow shock and a magnetotail in the direction opposite its motion in the local ISM gas rest frame

The Big Mystery: why the displacement?



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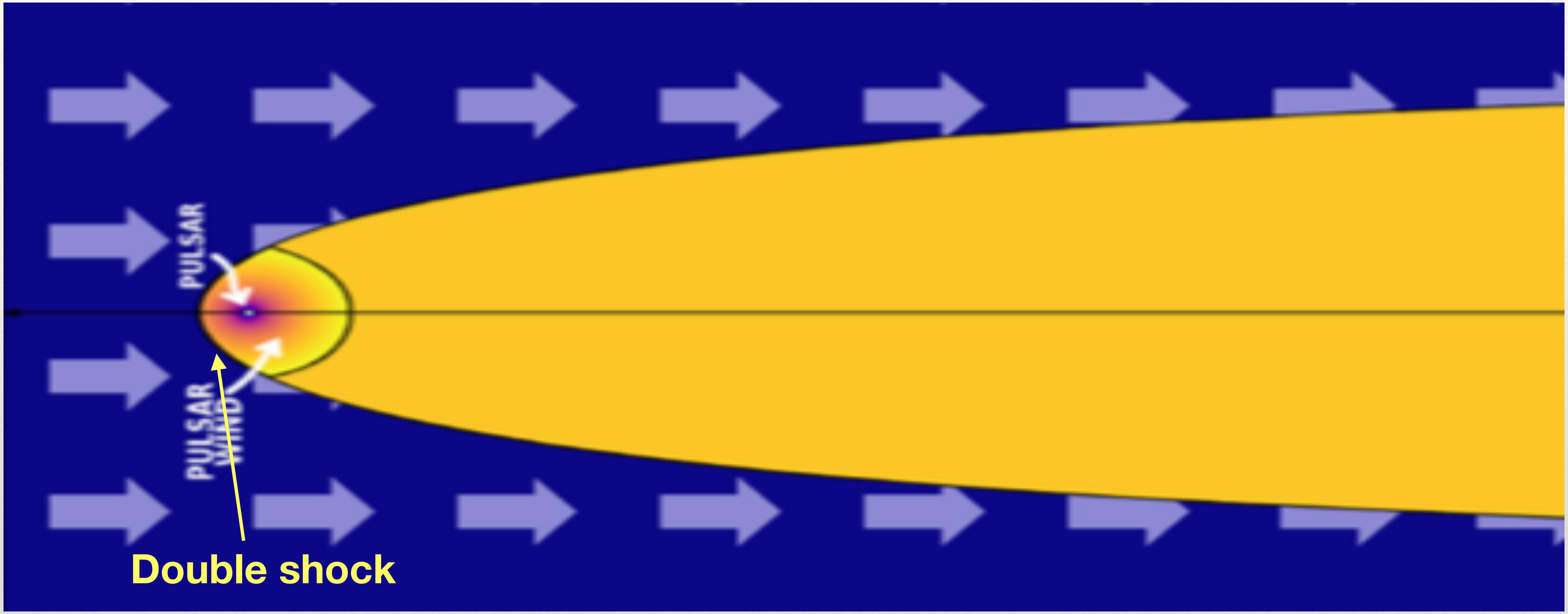

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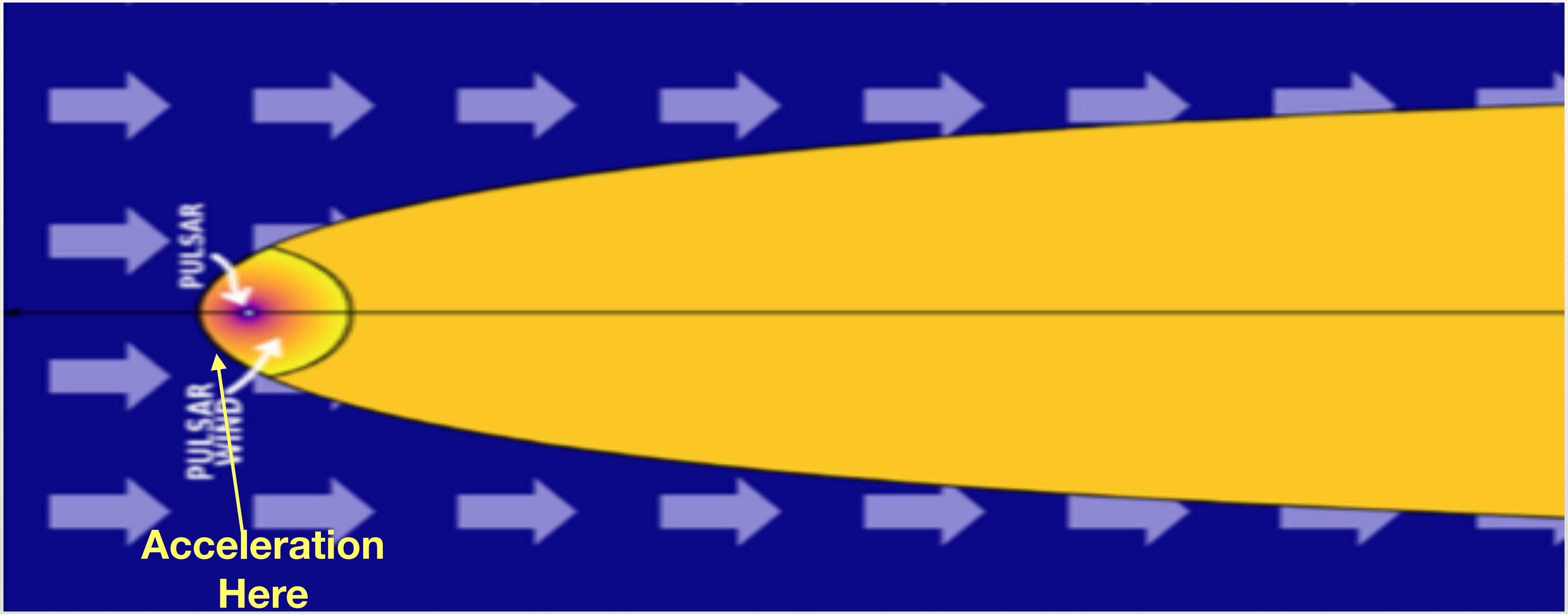

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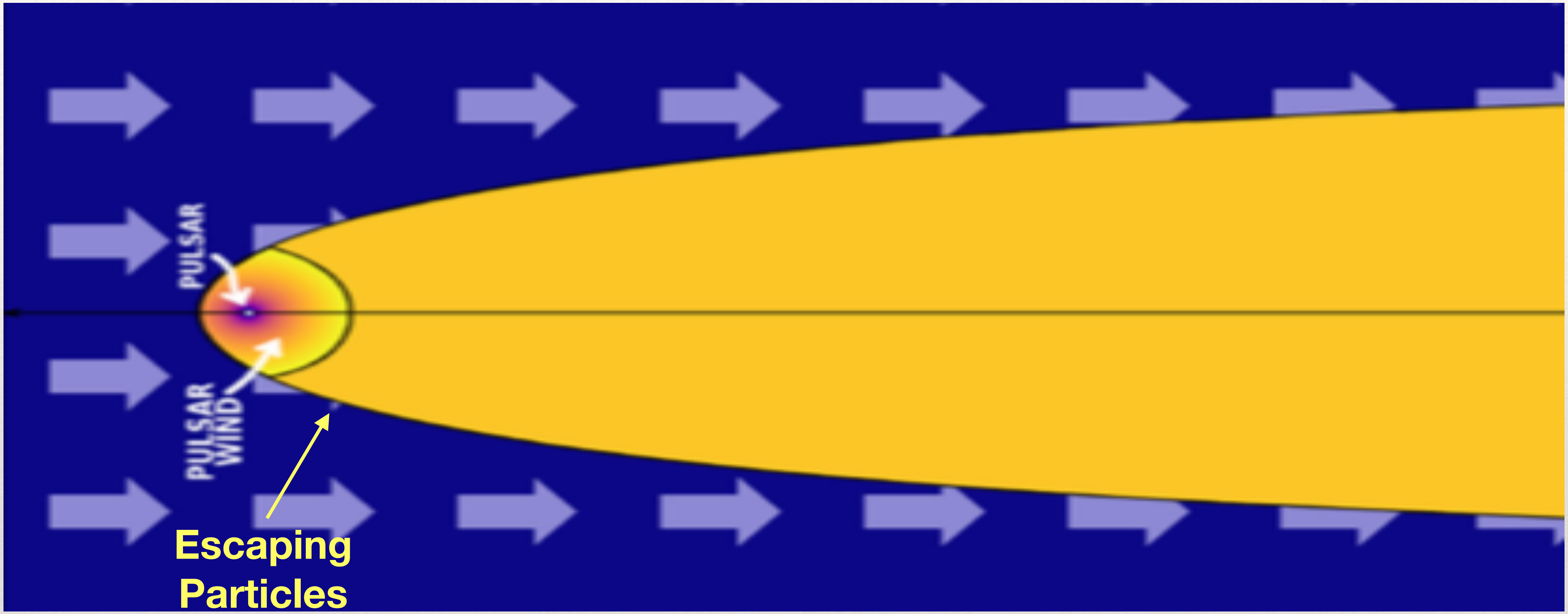

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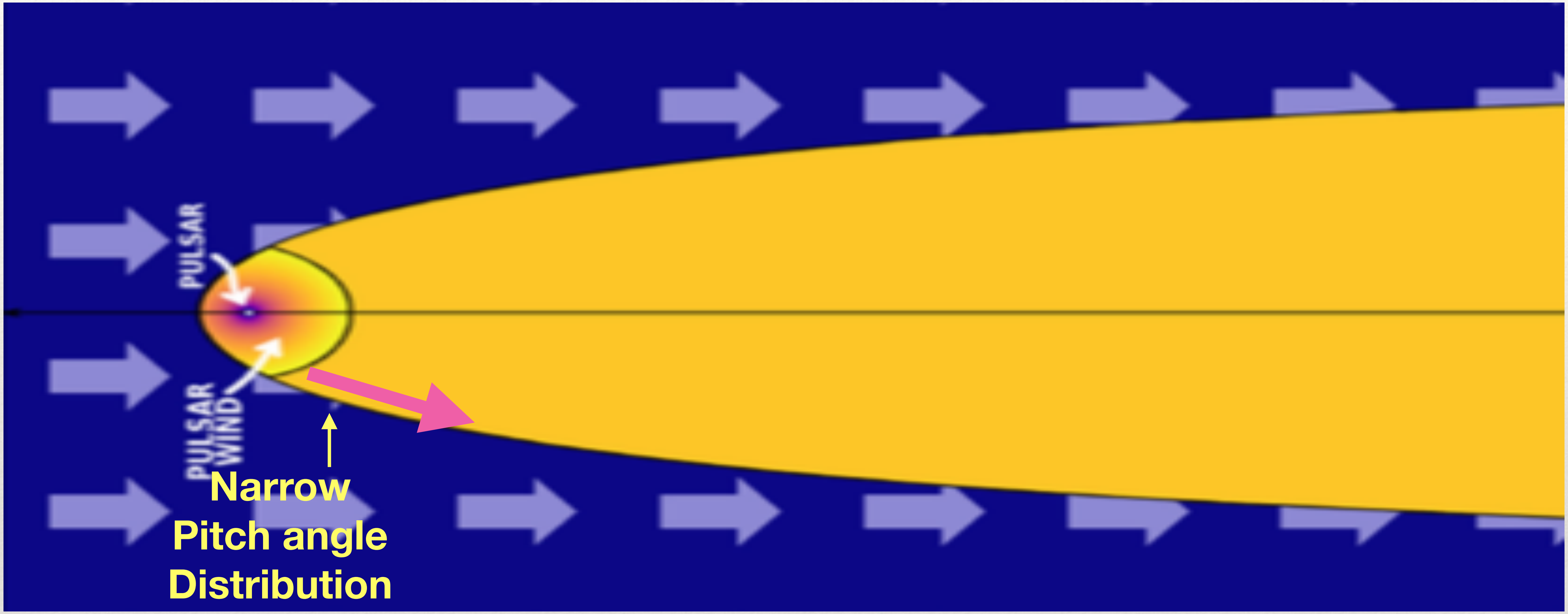

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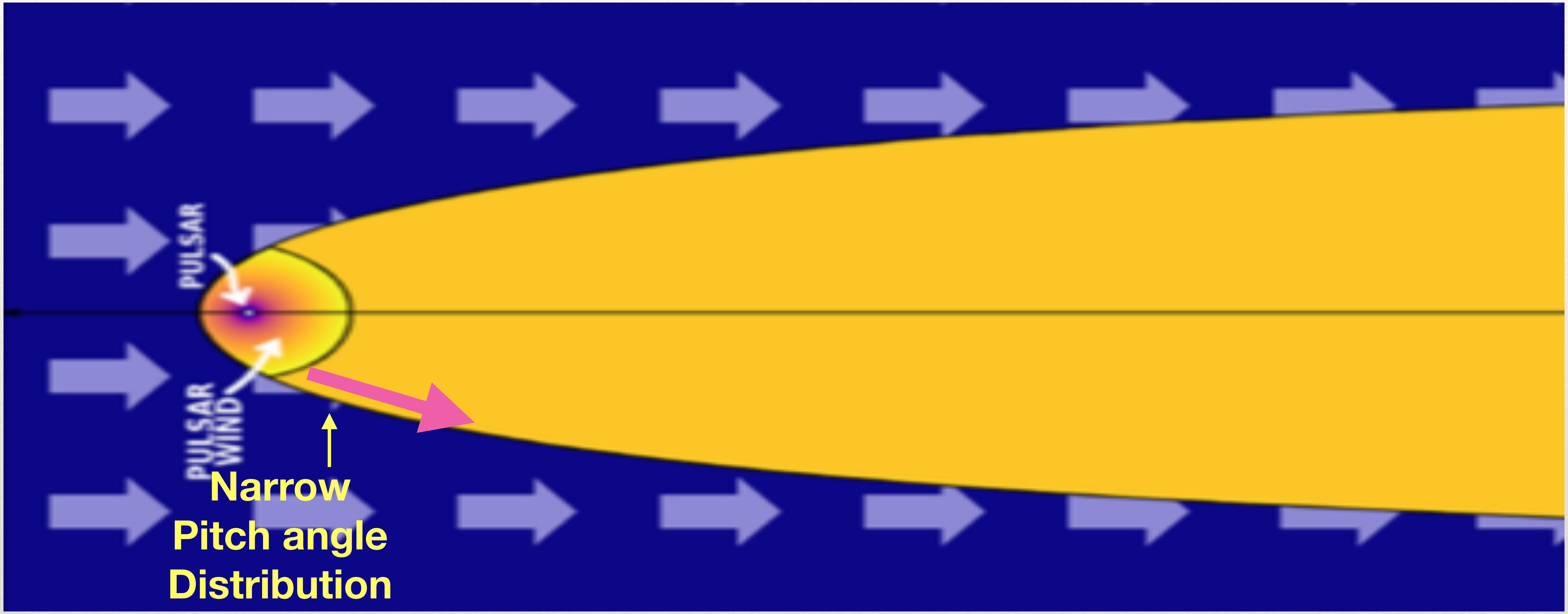
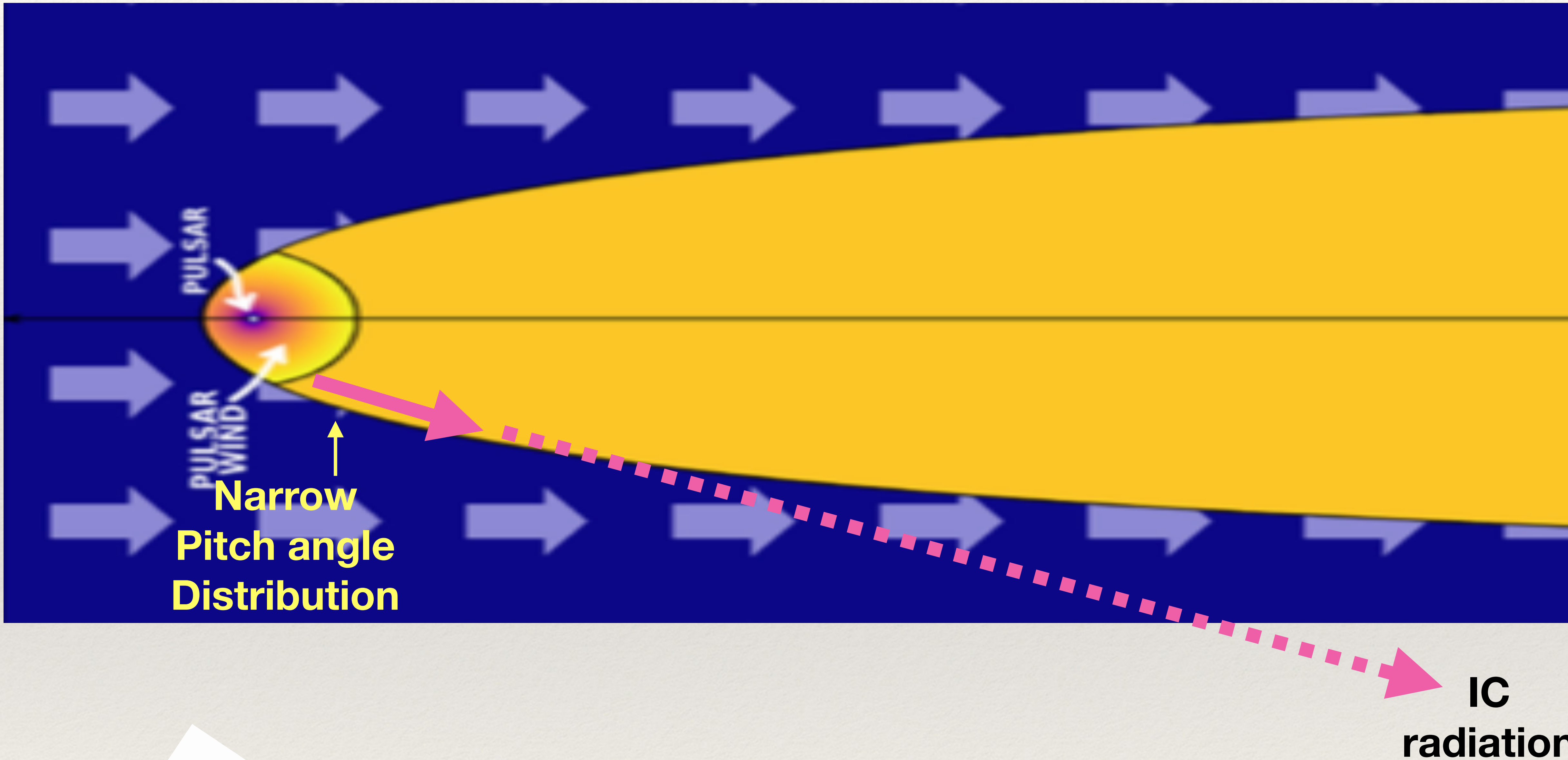
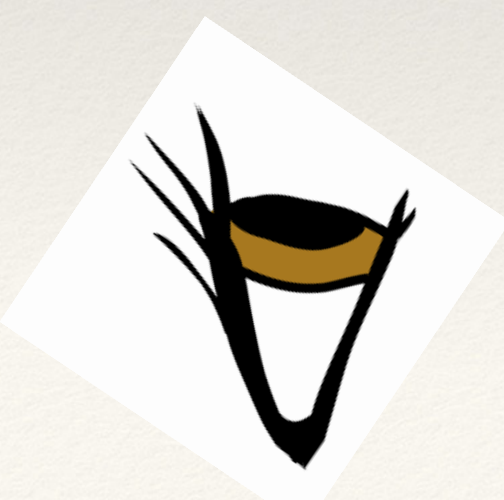


These particles
moving at
speed light

The Big Mystery: why the displacement?





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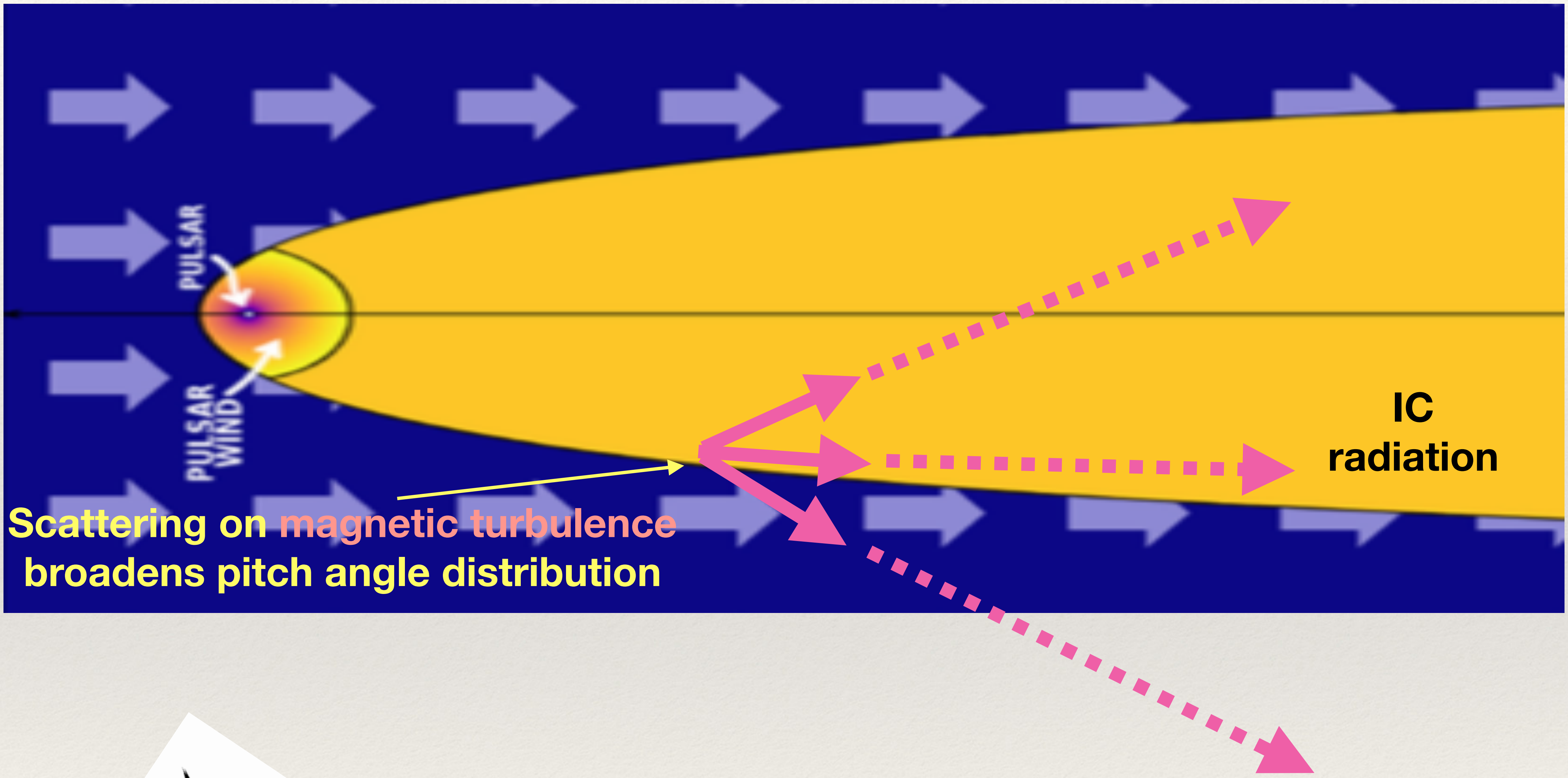

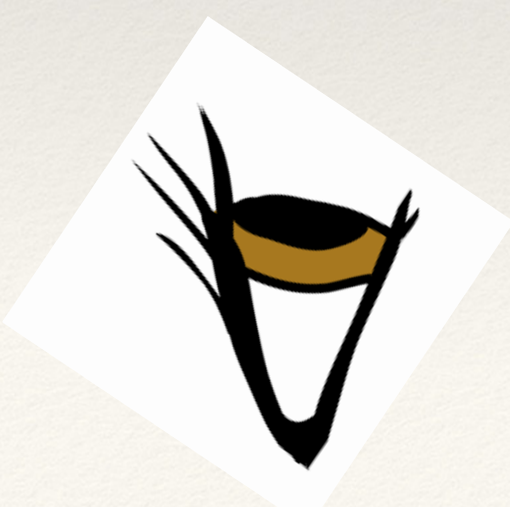

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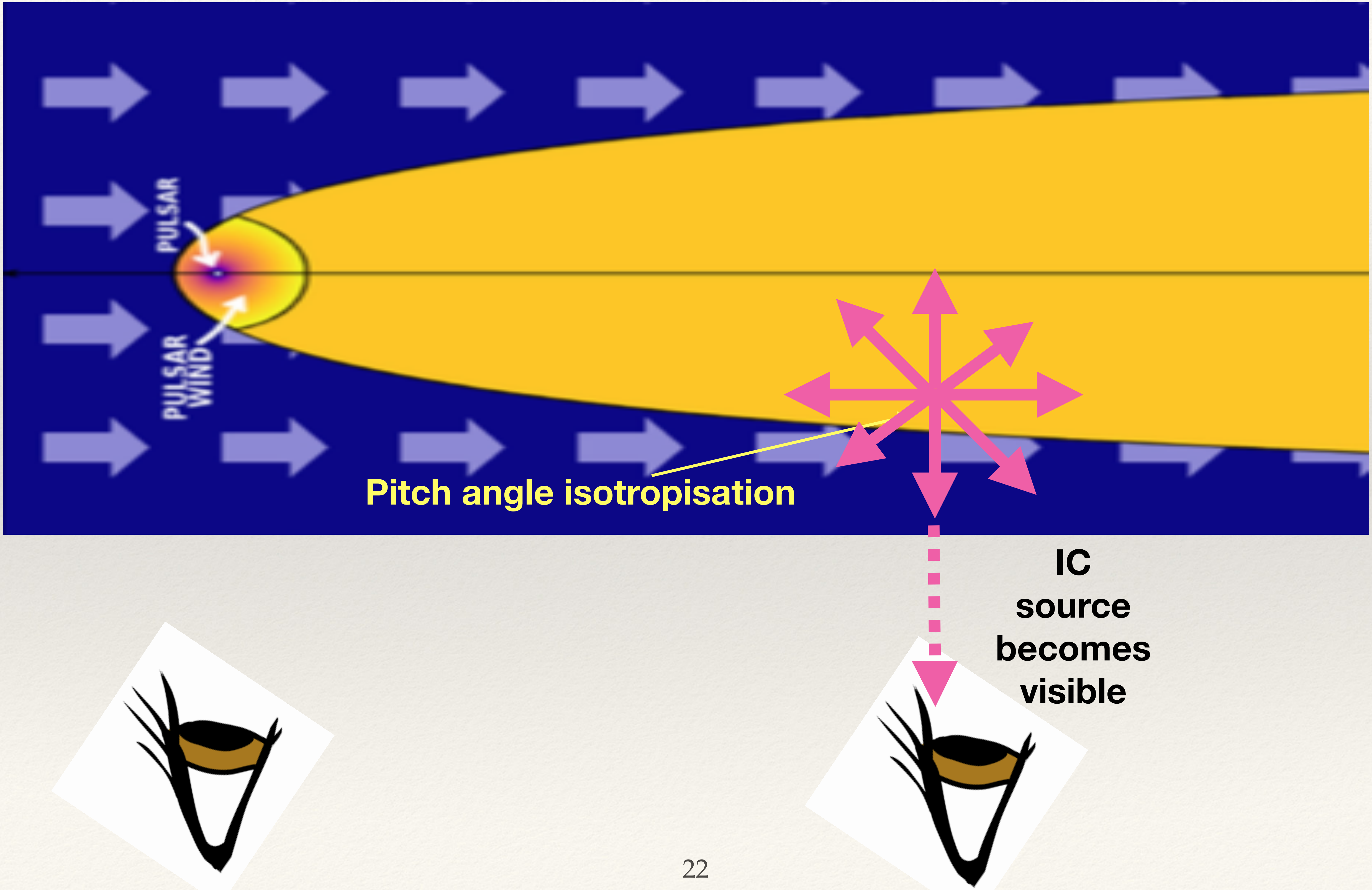
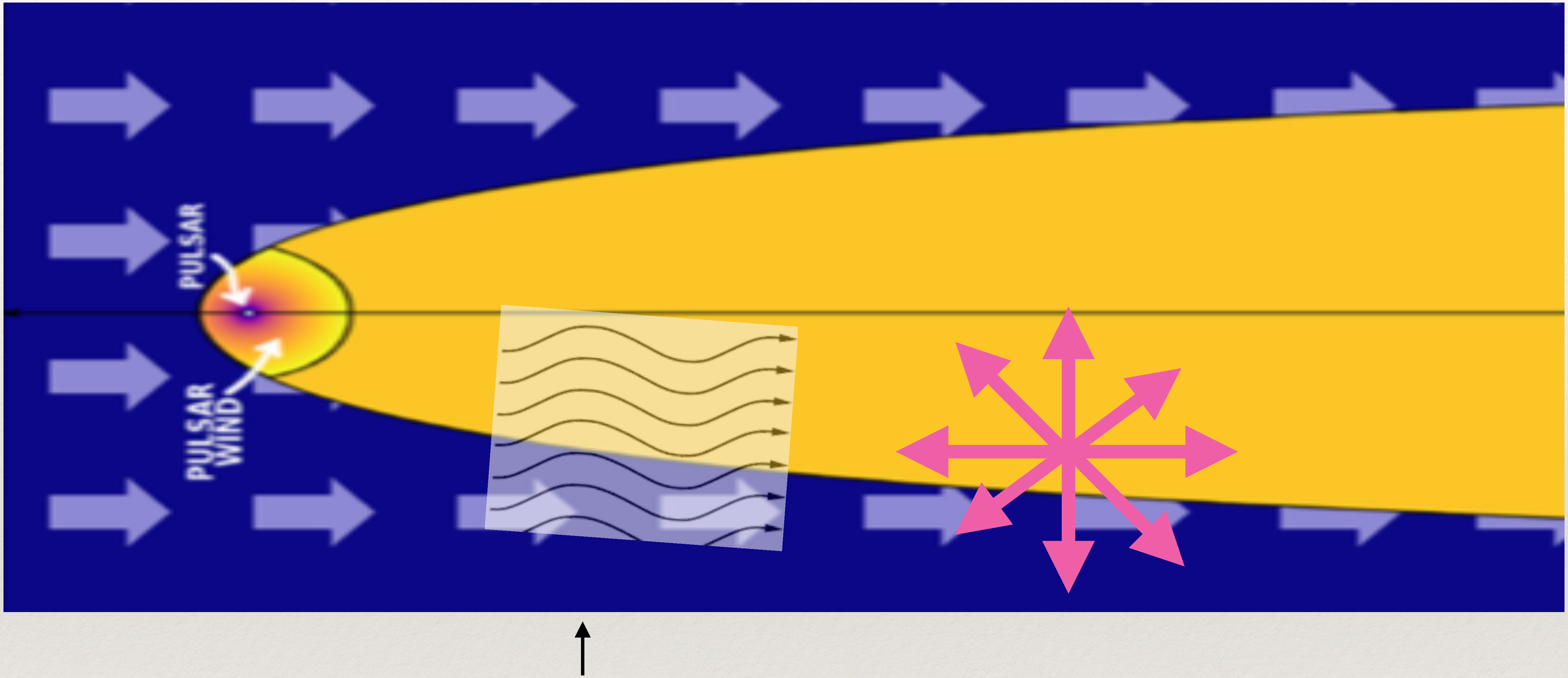


What creates the pitch-angle-scattering magnetic turbulence?

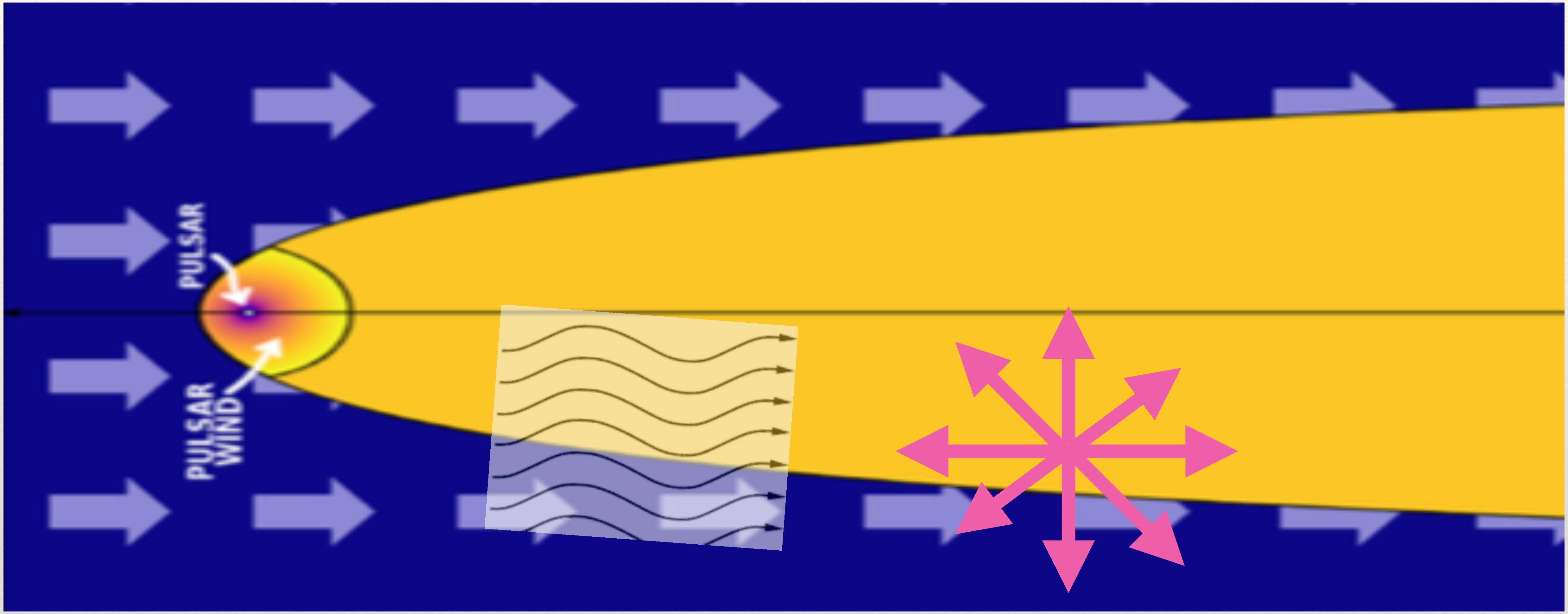
- …the cosmic rays themselves!
- Streaming instability: cosmic rays excite co-travelling Alfven waves with a wavelength equal to the CRs' gyroradius
- The Alfven waves pitch angle scatter the CRs
- *At a population level* the CRs end up travelling down the field lines at the local Alfven speed, with an isotropic pitch angle distribution in this frame (Kulsrud 1968)

The Big Mystery: why the displacement?



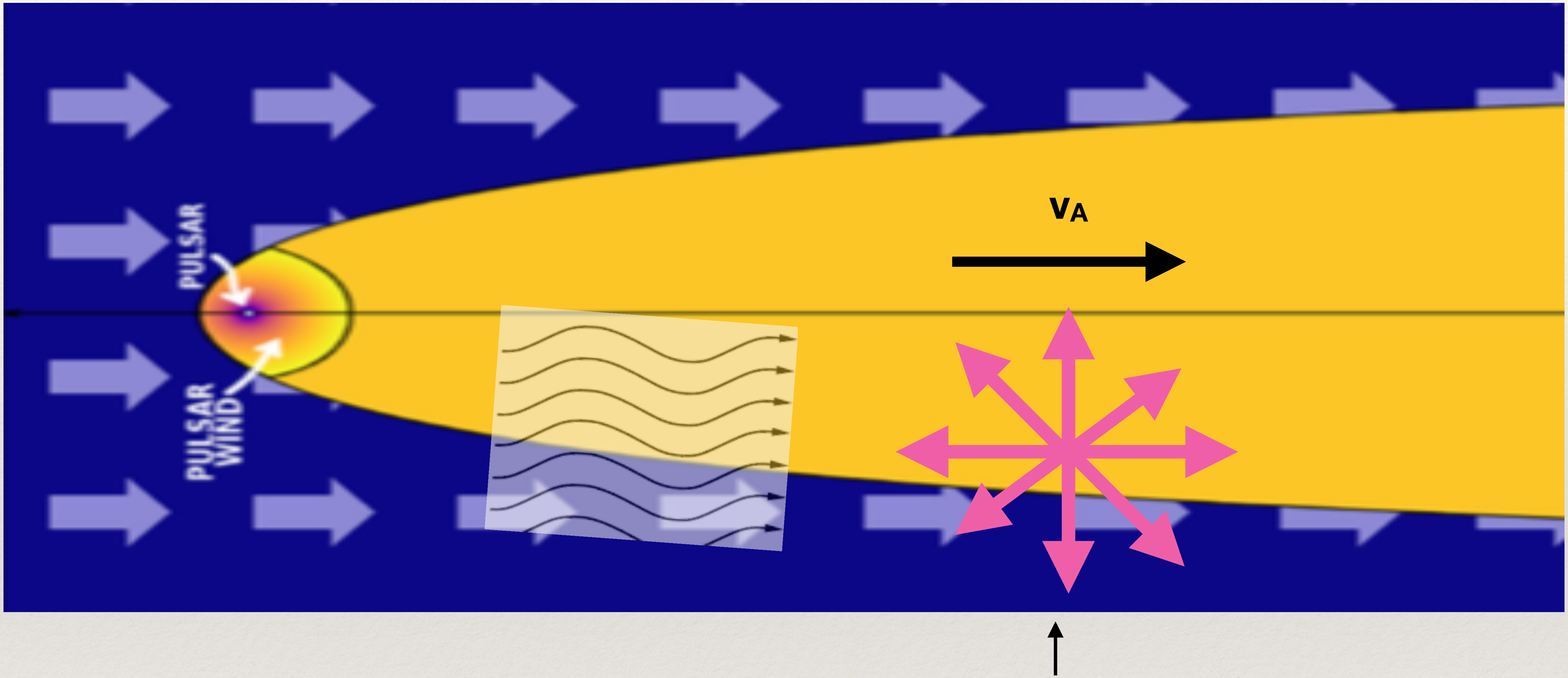
Streaming particles excite Alfven waves

The Big Mystery: why the displacement?



Waves scatter pitch angles of particles

The Big Mystery: why the displacement?



Scattering back and forth constrains the particle packets to move at Alfven speed down the field lines

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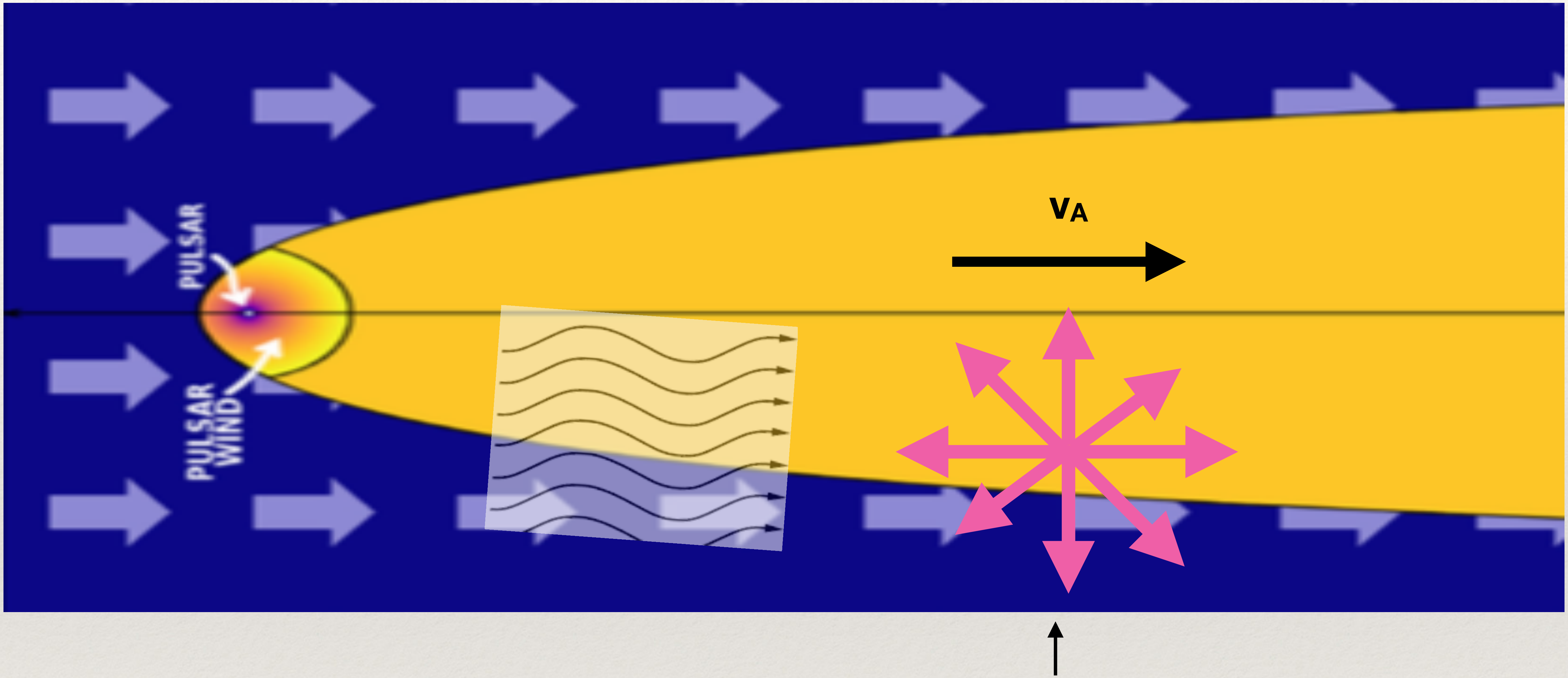

[Individual particles still moving at c]

Transport model

$$\frac{\partial f(t,z,\mu)}{\partial t} + v\mu \frac{\partial f(t,z,\mu)}{\partial z} = \frac{\partial^2}{\partial \mu^2}\left(\mathcal{D}(\mu) f(t,z,\mu)\right) - \frac{f(t,z,\mu)}{t_{\mathrm{c}}} + q(t,z,\mu)$$

Transport model

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$$\mu \equiv \cos(\theta)$$

Transport model

Pitch angle diffusion

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Energy loss

Transport model

Pitch angle diffusion

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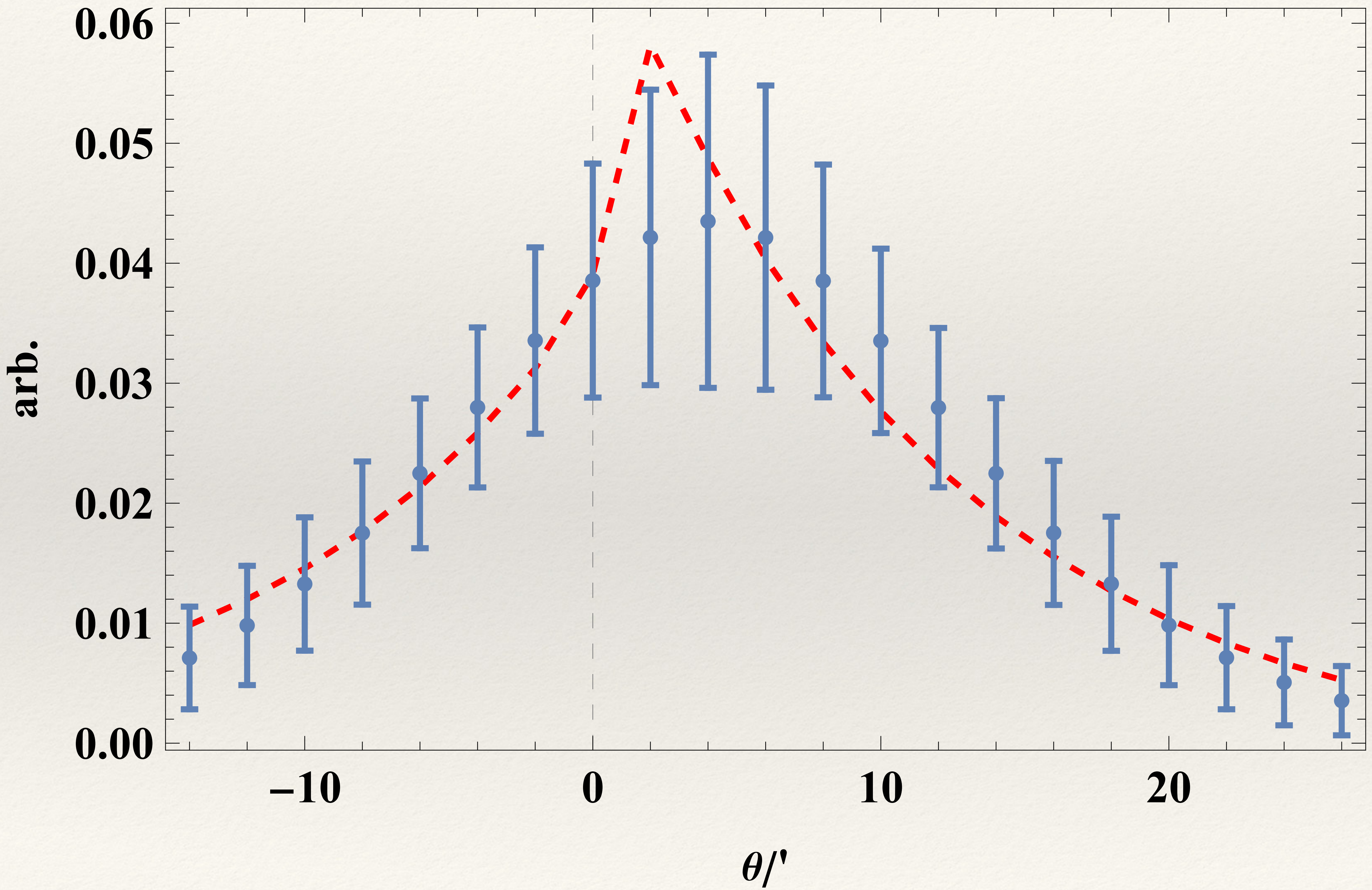
Source

Energy loss

Numerical experiments



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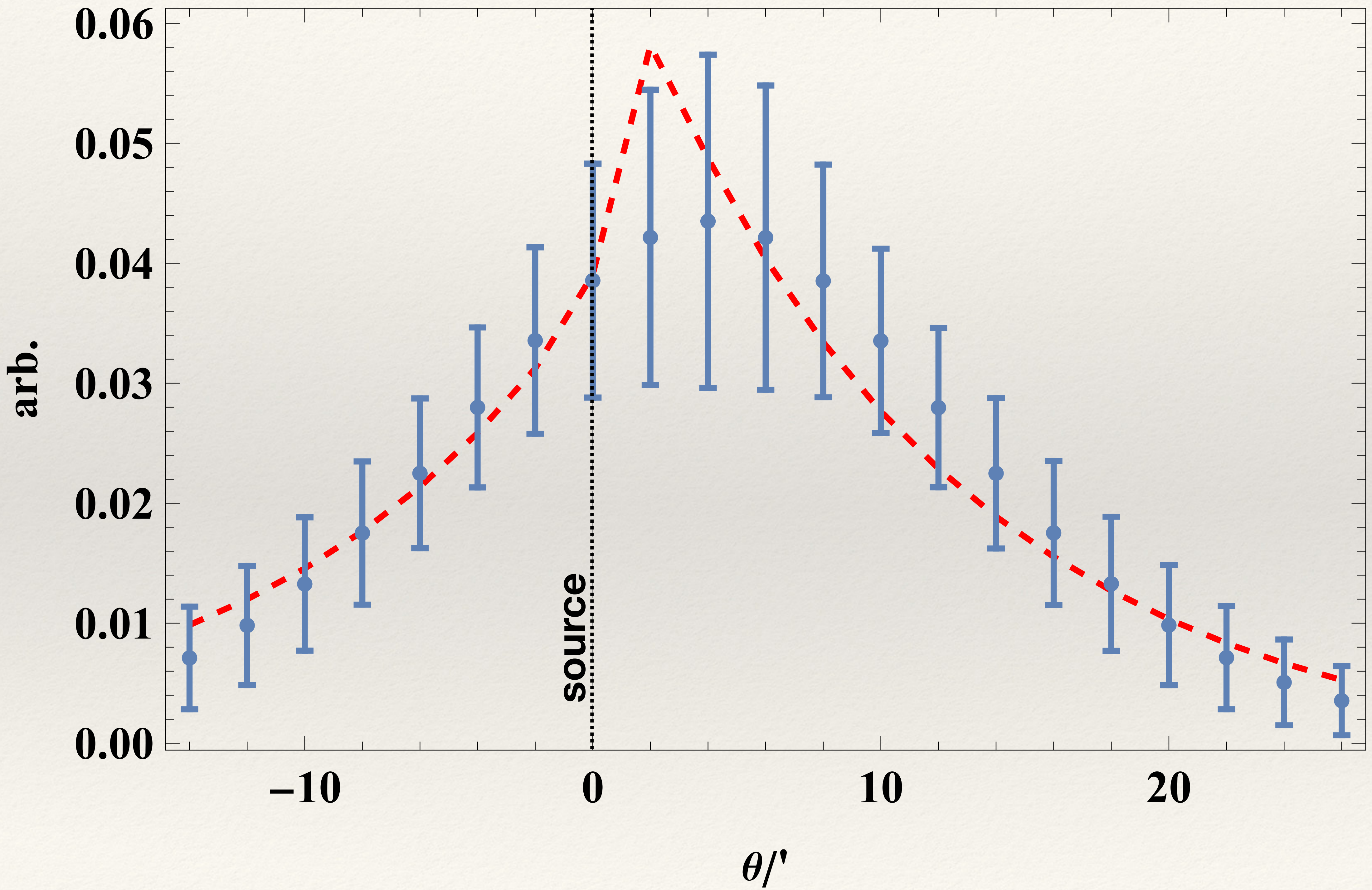

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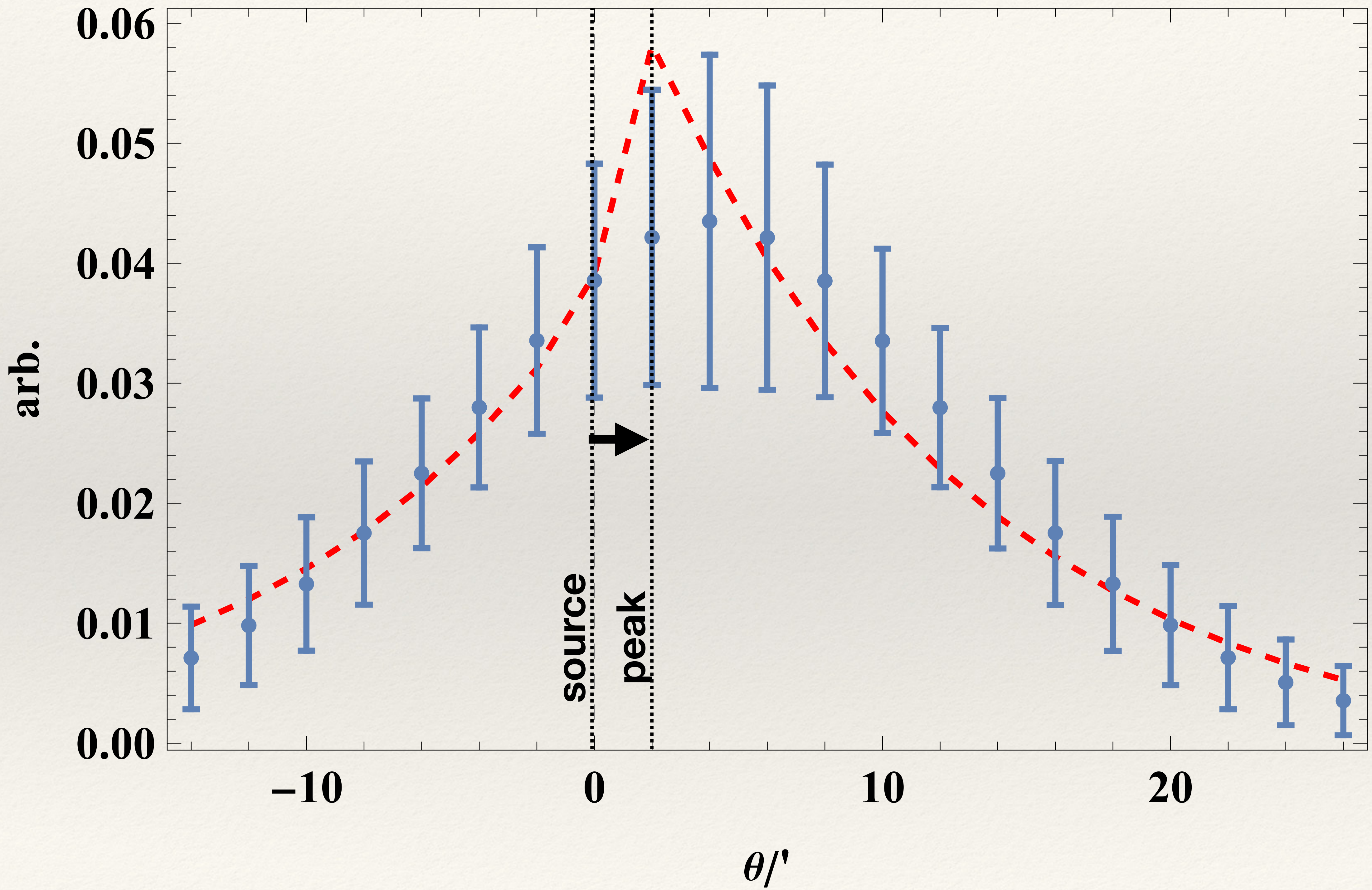

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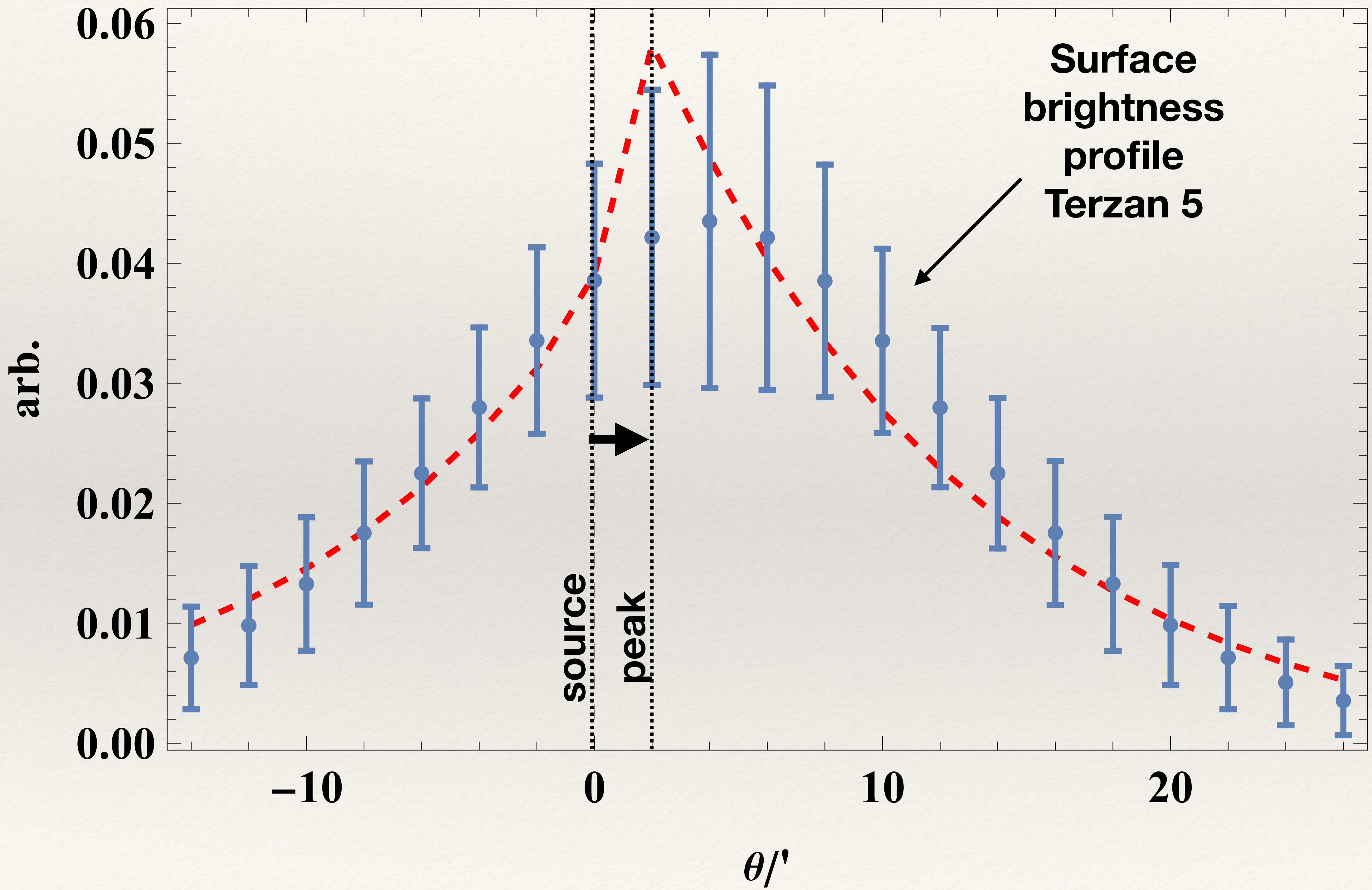

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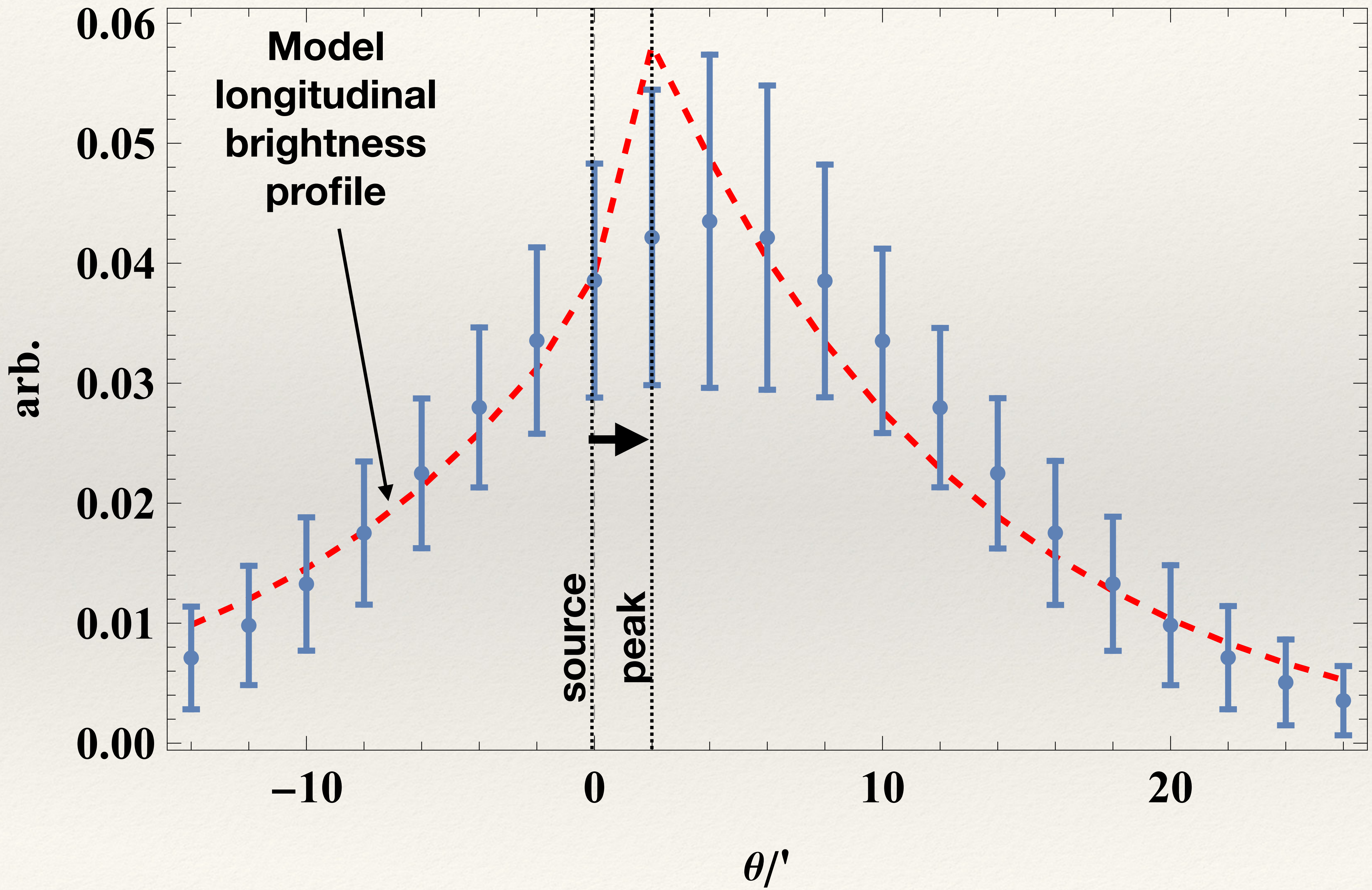

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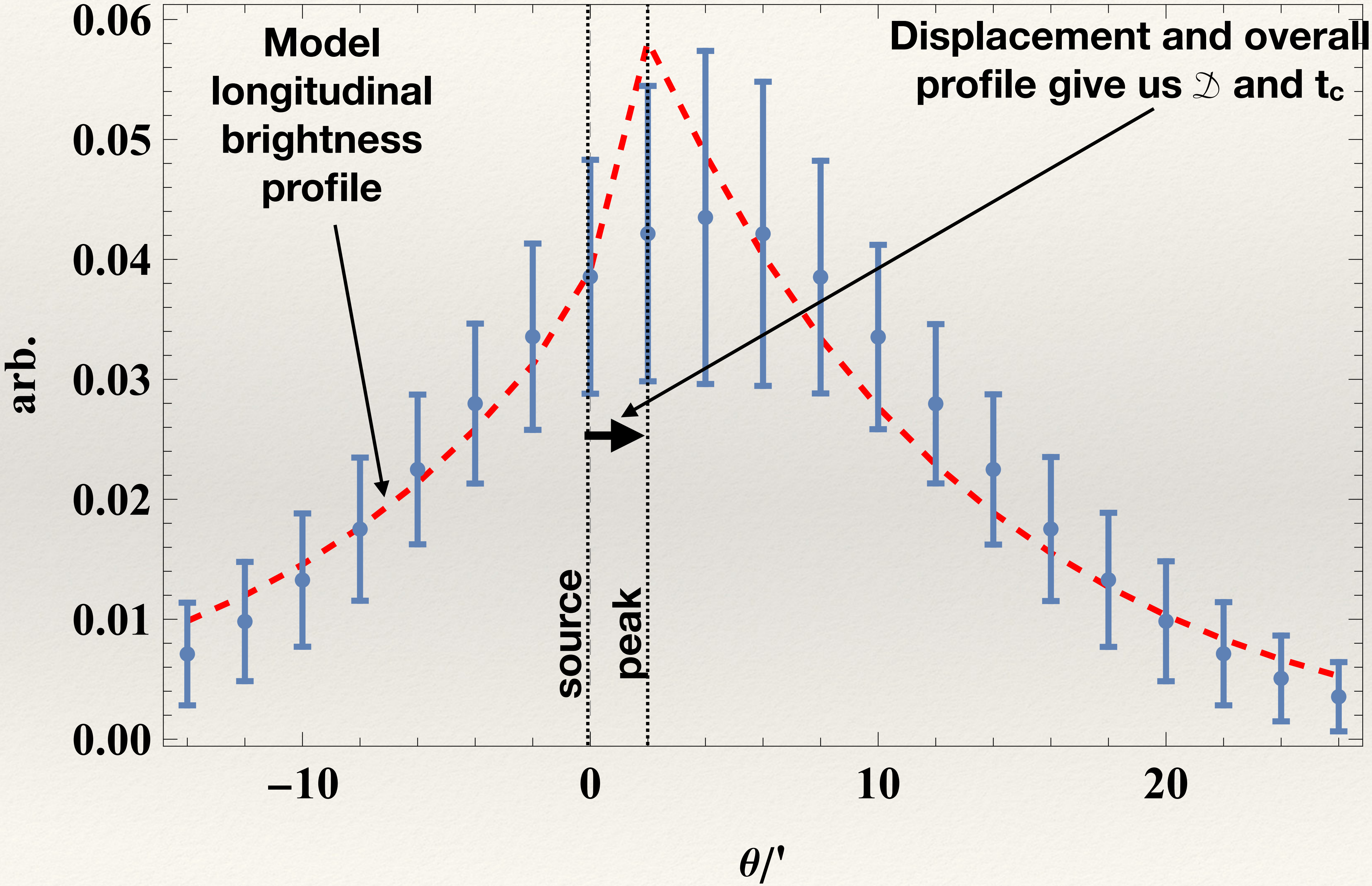

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Find from fitting:

t_c ~ 1/10 $\mathcal{D}$

t_c determined by synchrotron losses

$\mathcal{D}$ ~ 10^{-10}/s

…consistent with streaming instability and known number density of CRs (as determined by IC observations)