When MAGIC met IceCube

Gamma-Ray Astronomy with Neutrino Event Reconstruction Techniques

Jarred Green

Copenhagen, HAMLET-PHYSICS 2025

20 August 2025

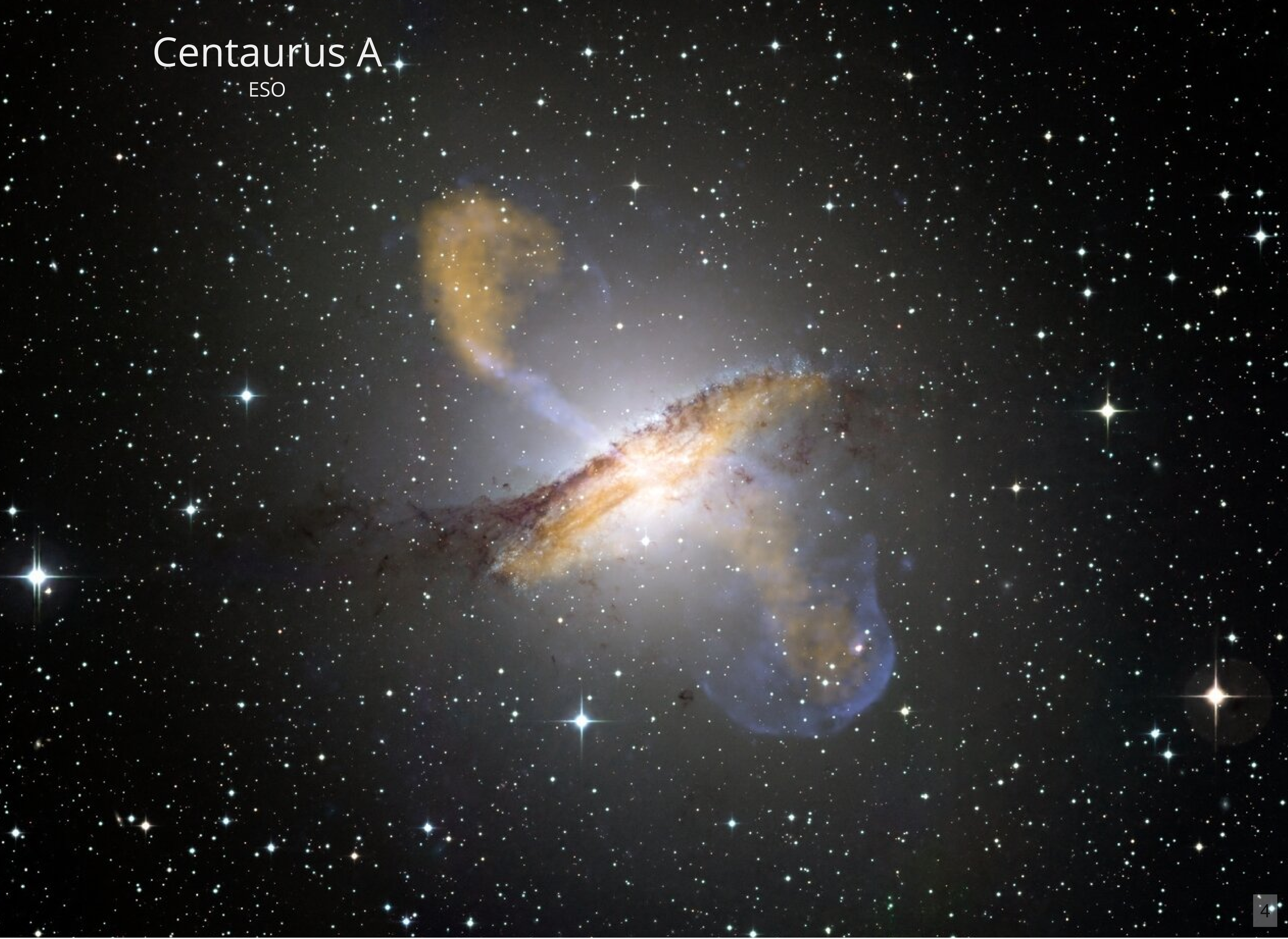
Max Planck Institute for Physics

jgreen@mpp.mpg.de

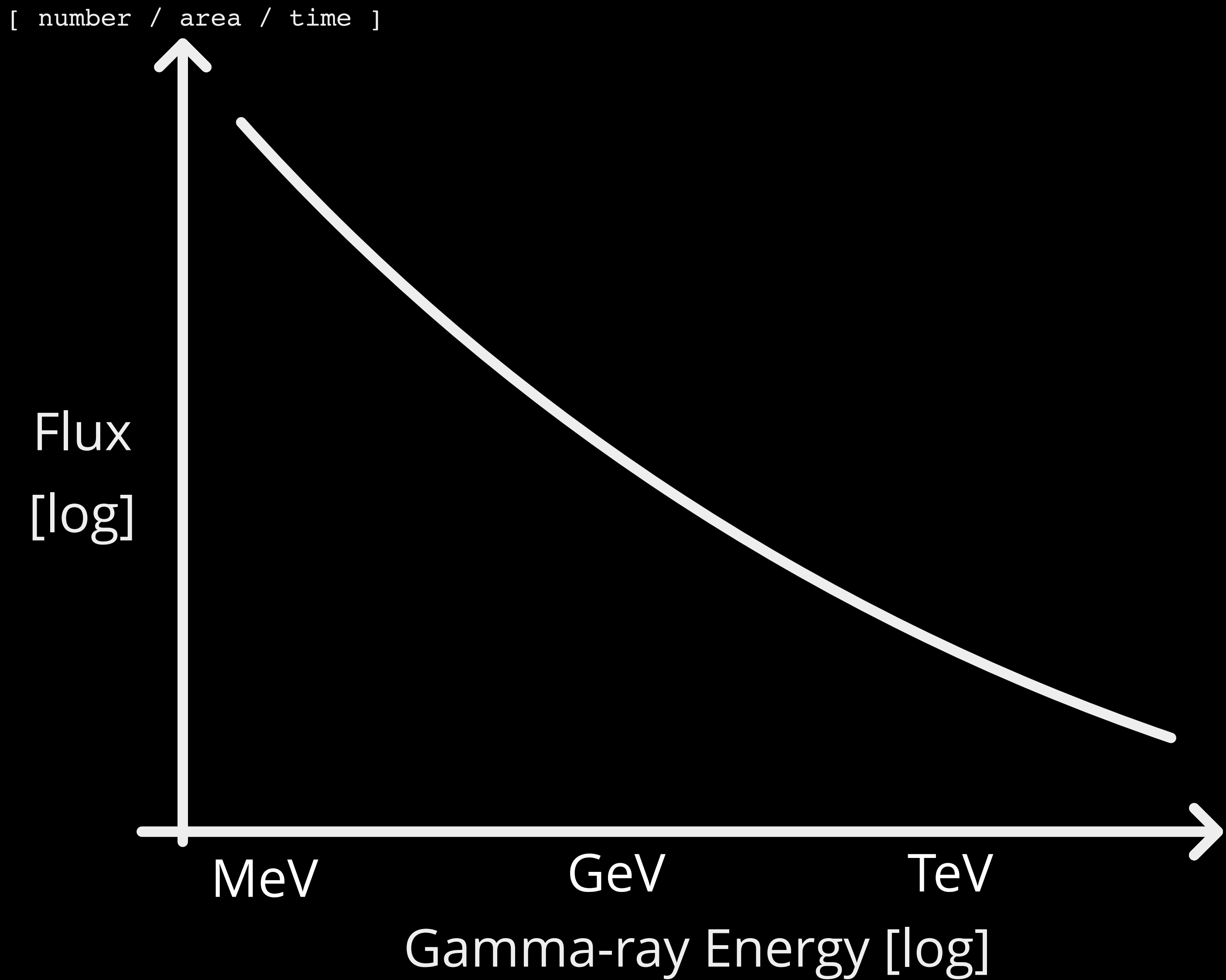
MAX-PLANCK-INSTITUT FÜR PHYSIK

Outline


Crab Nebula
NASA (JWST)


Centaurus A
ESO

1. The Gamma-Ray Sky



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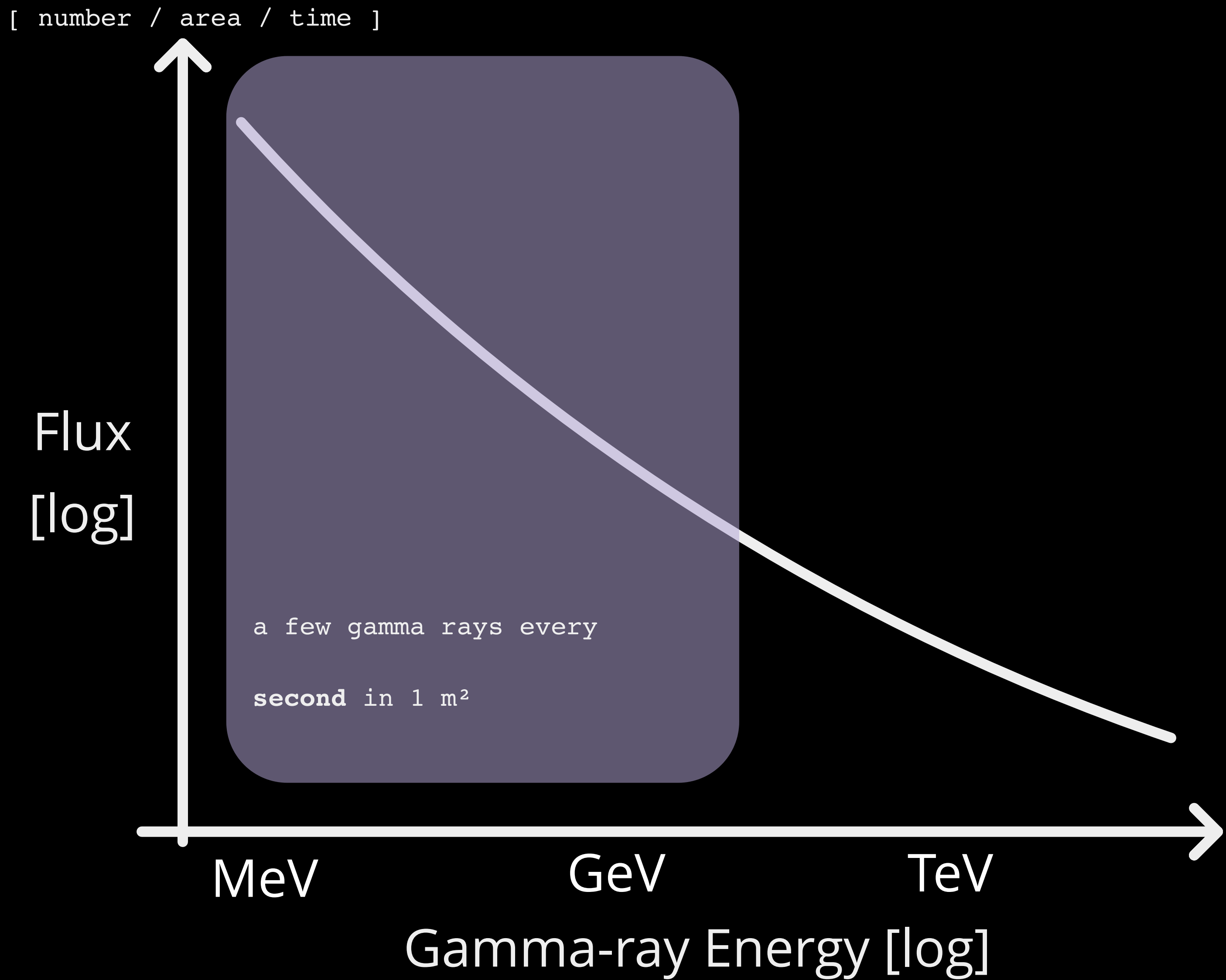

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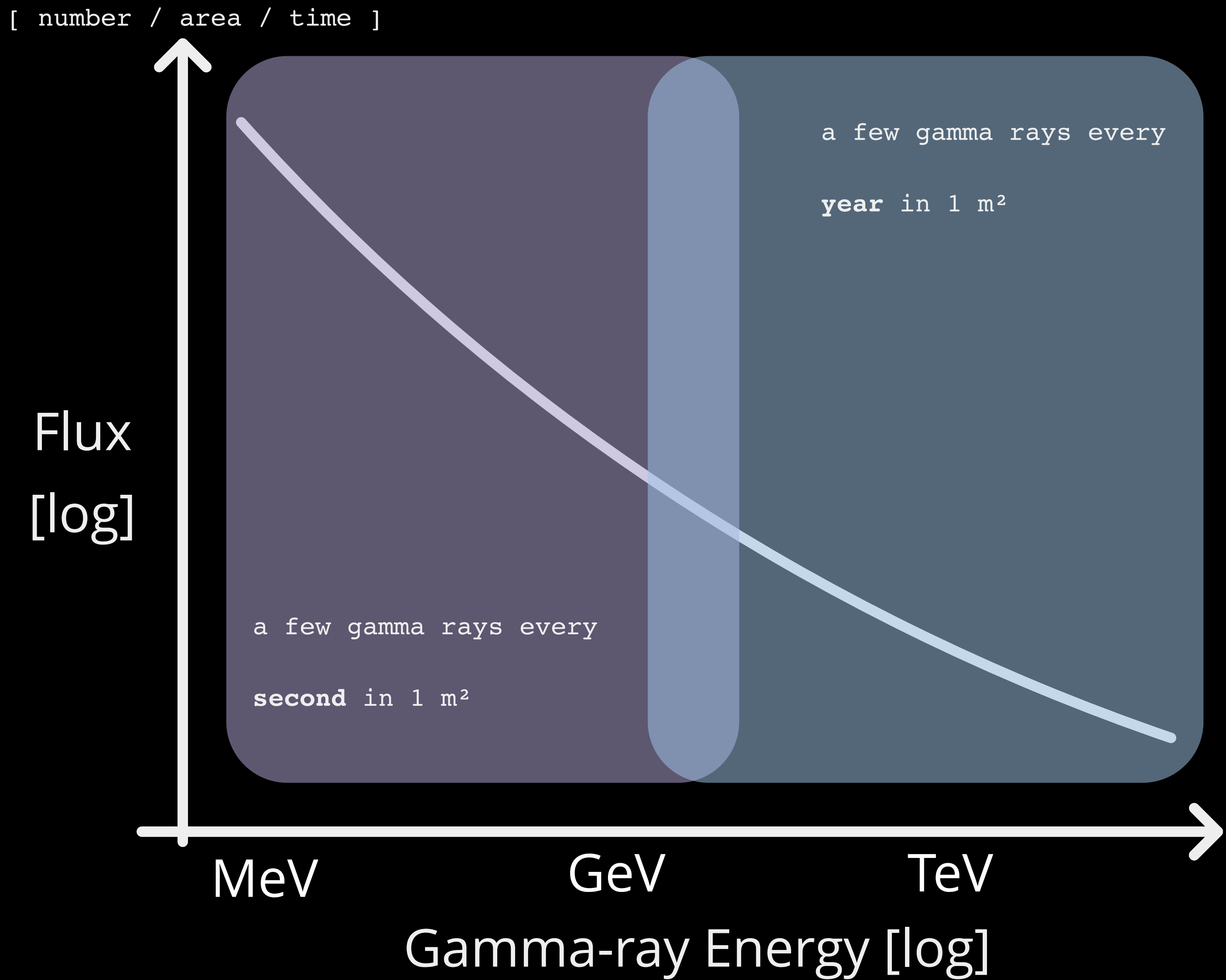

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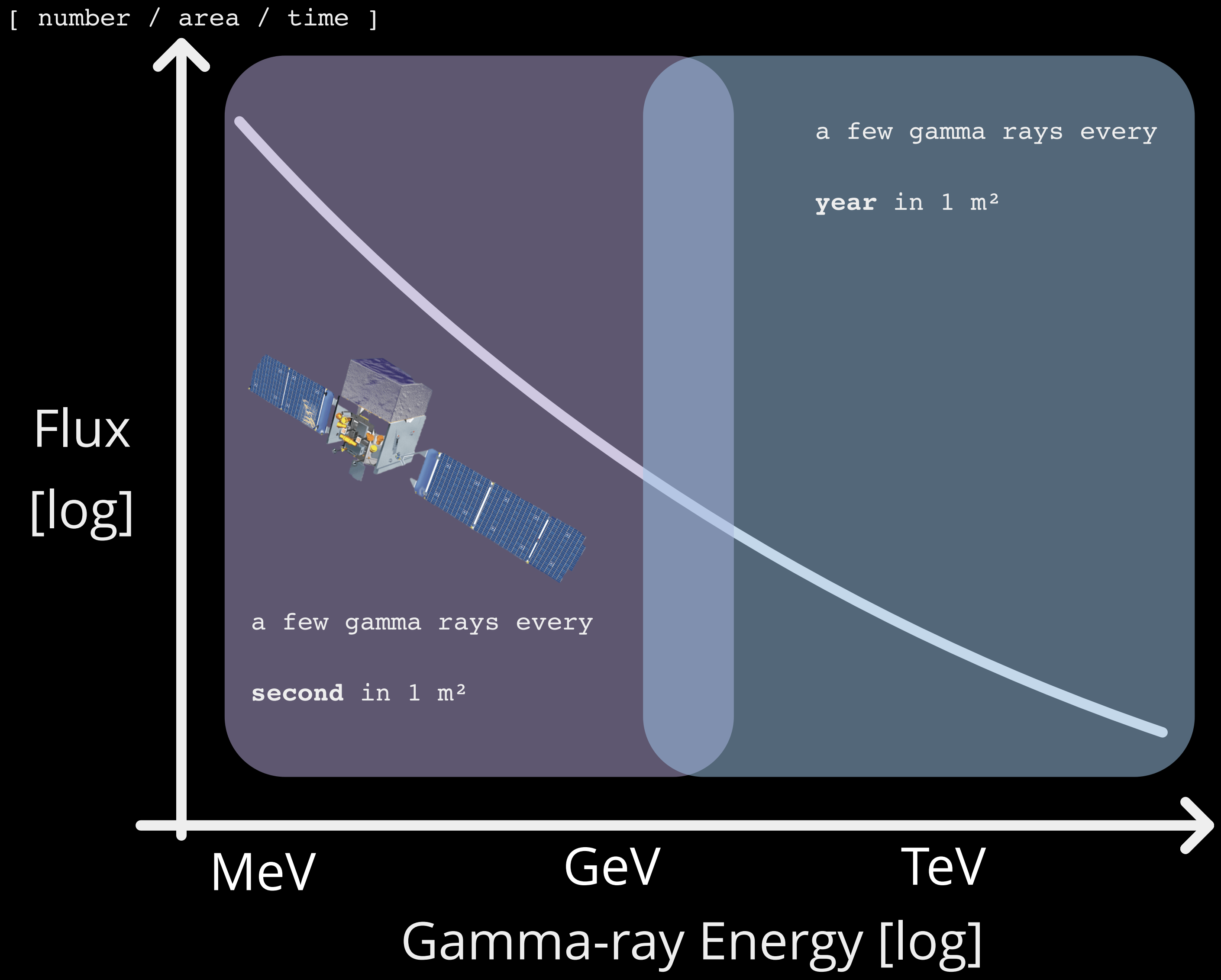

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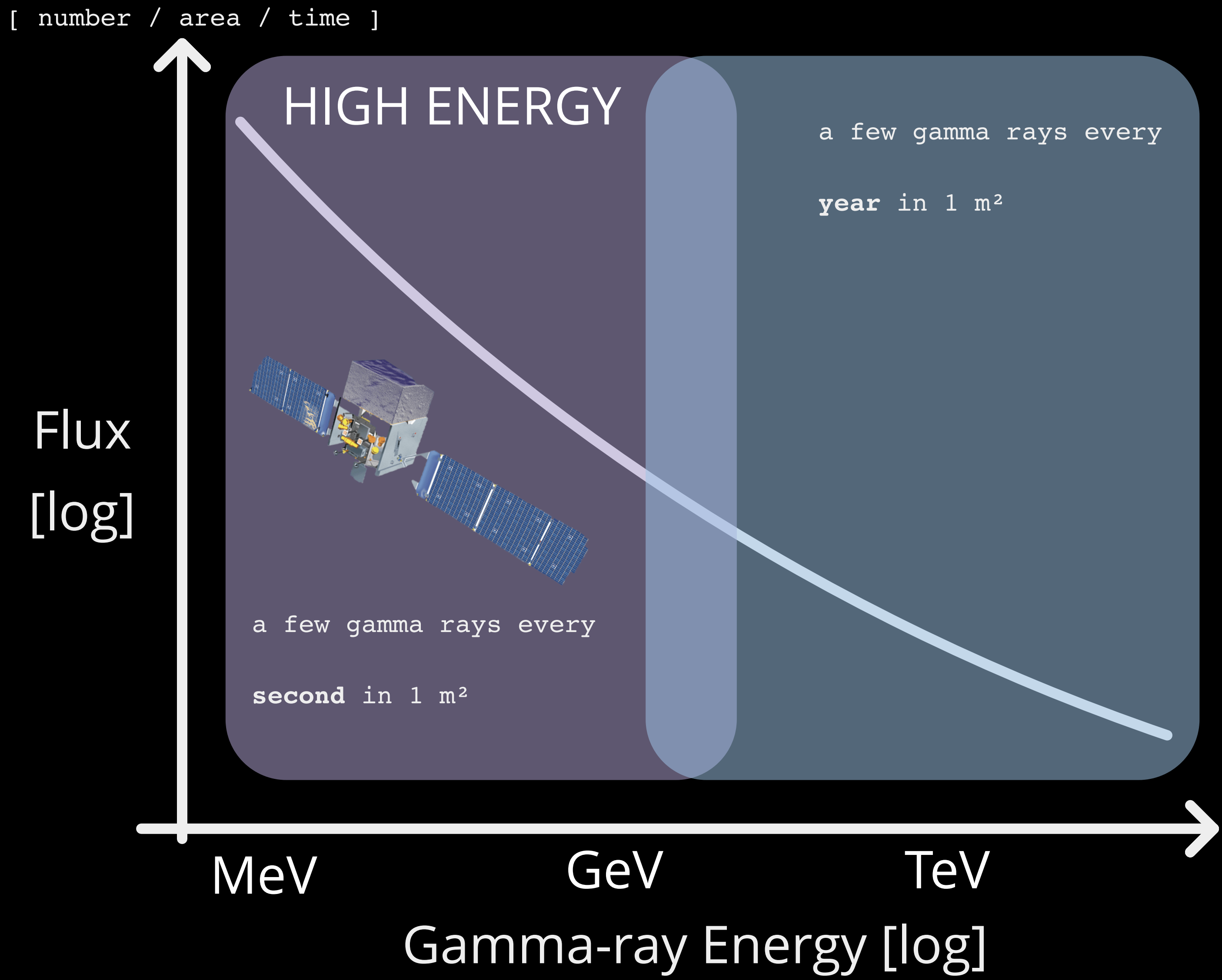

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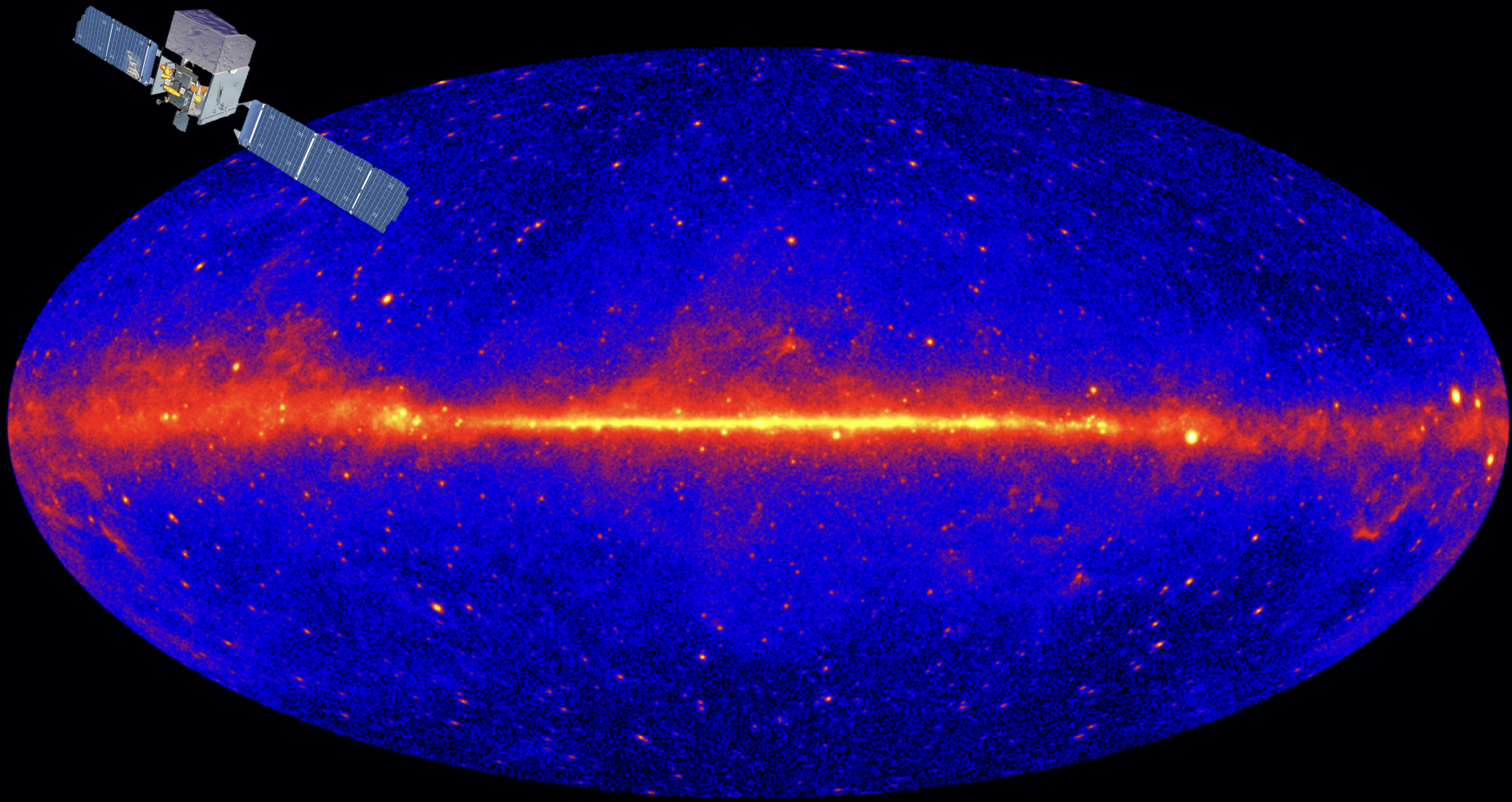

Our galaxy (Fermi)

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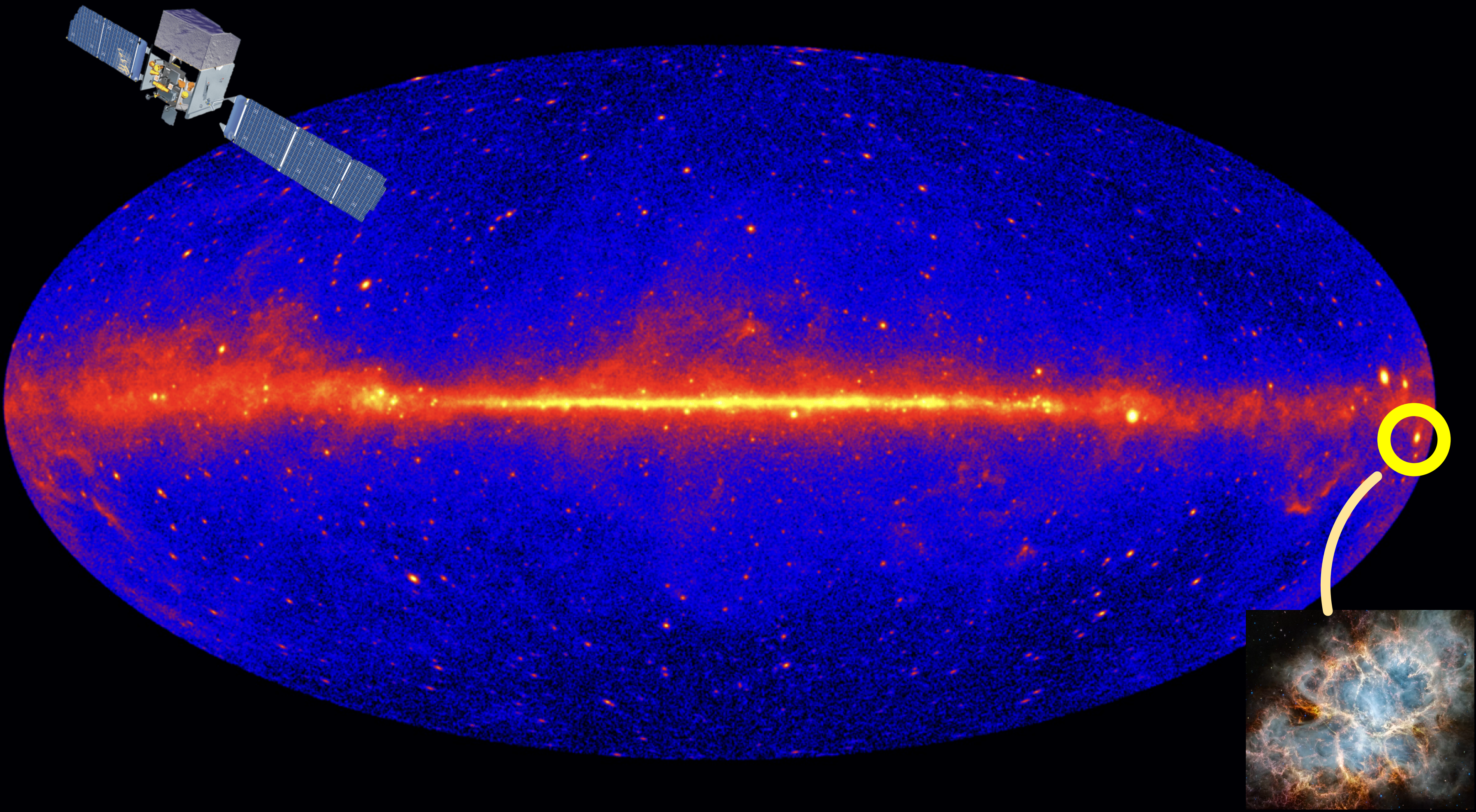

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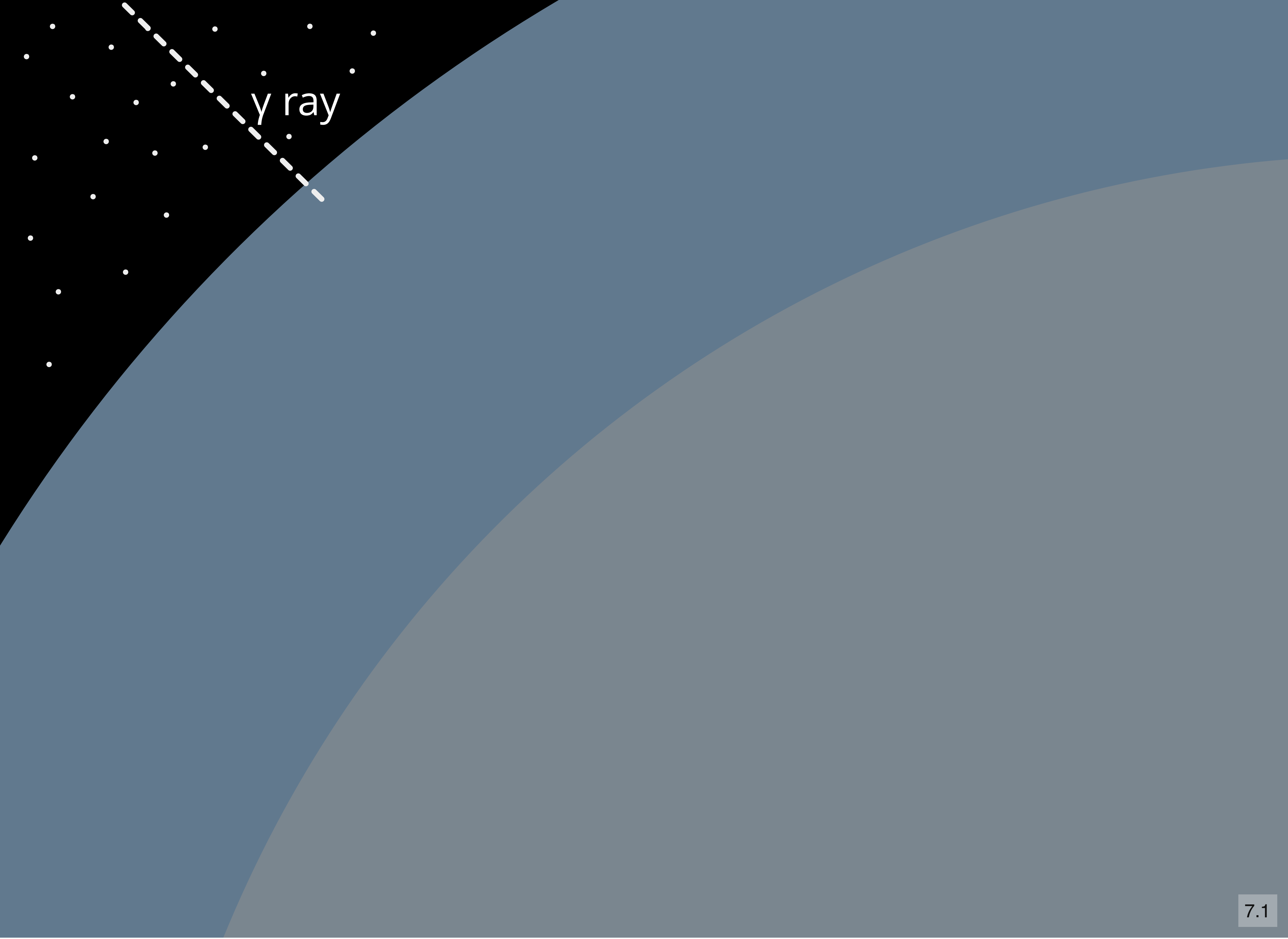
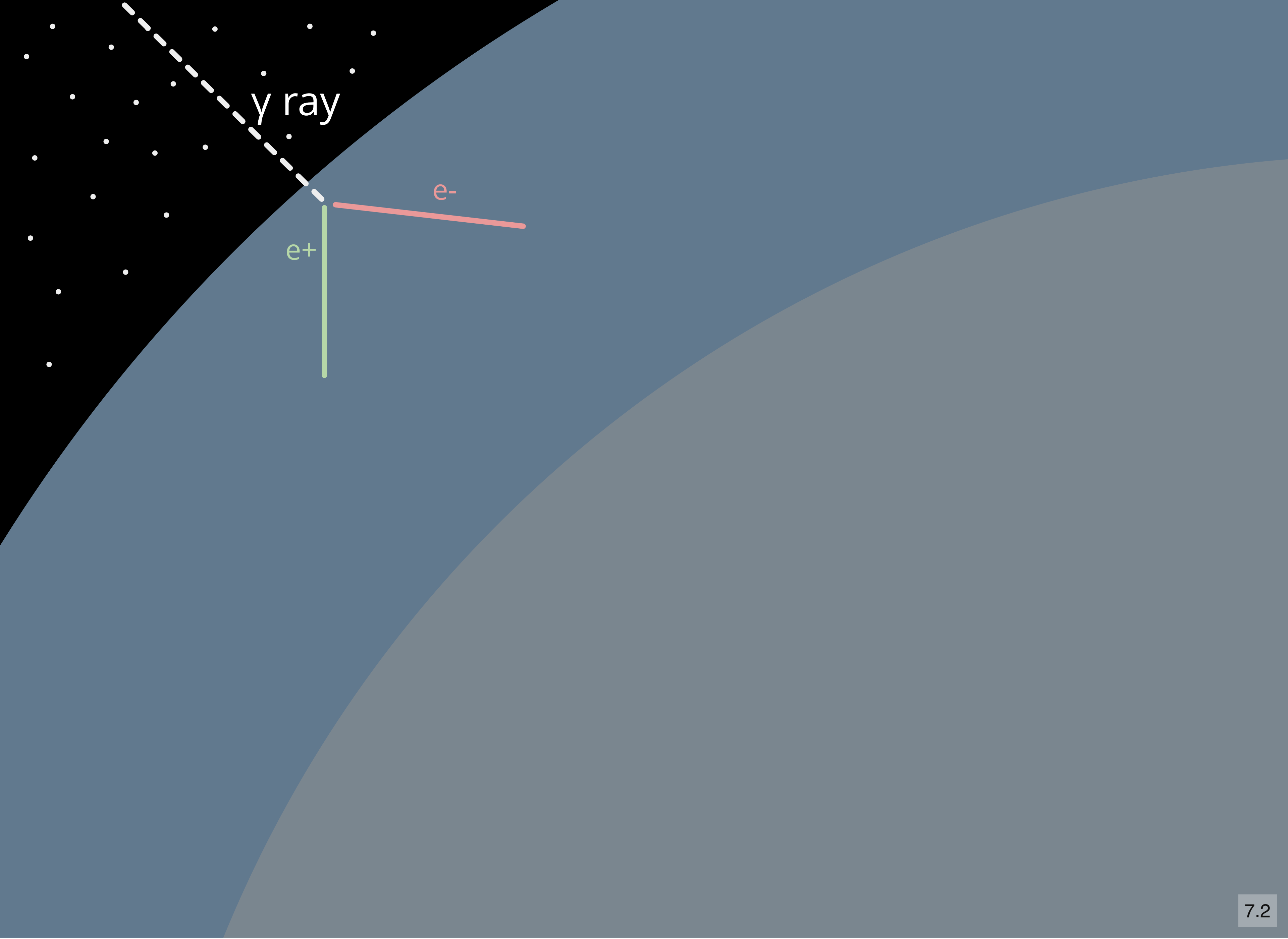
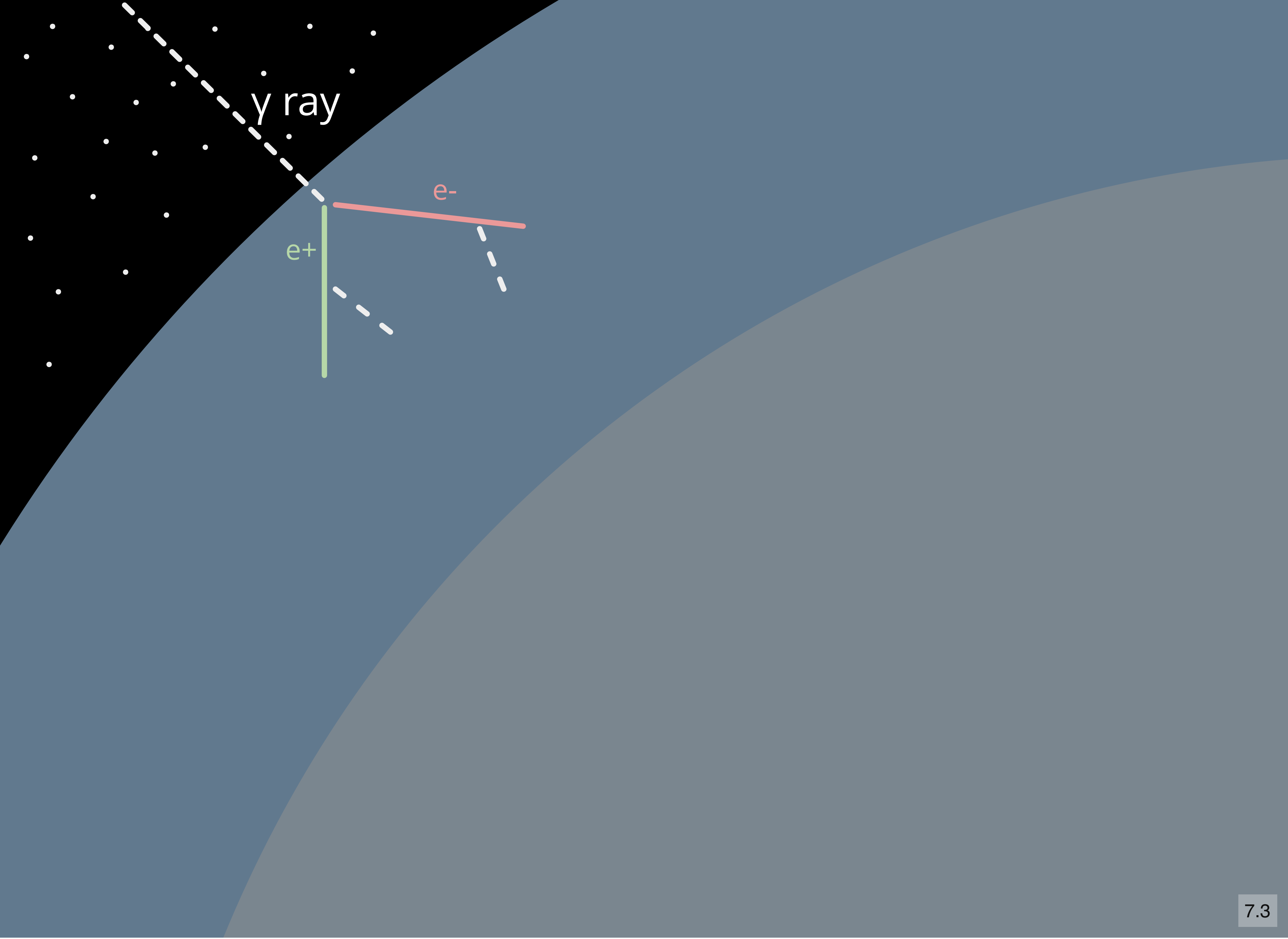
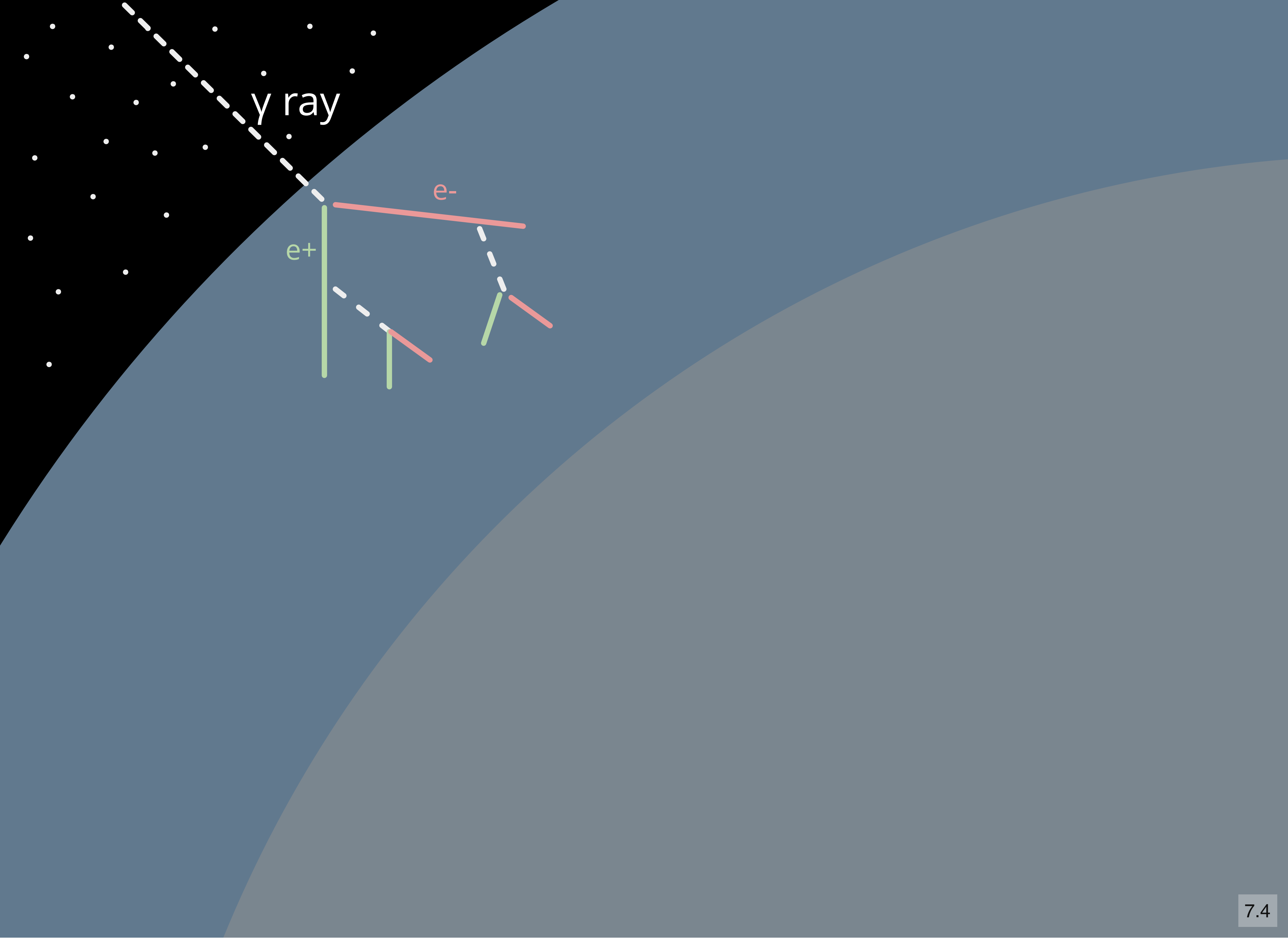

γ ray


γ ray
e-
e+



7.3



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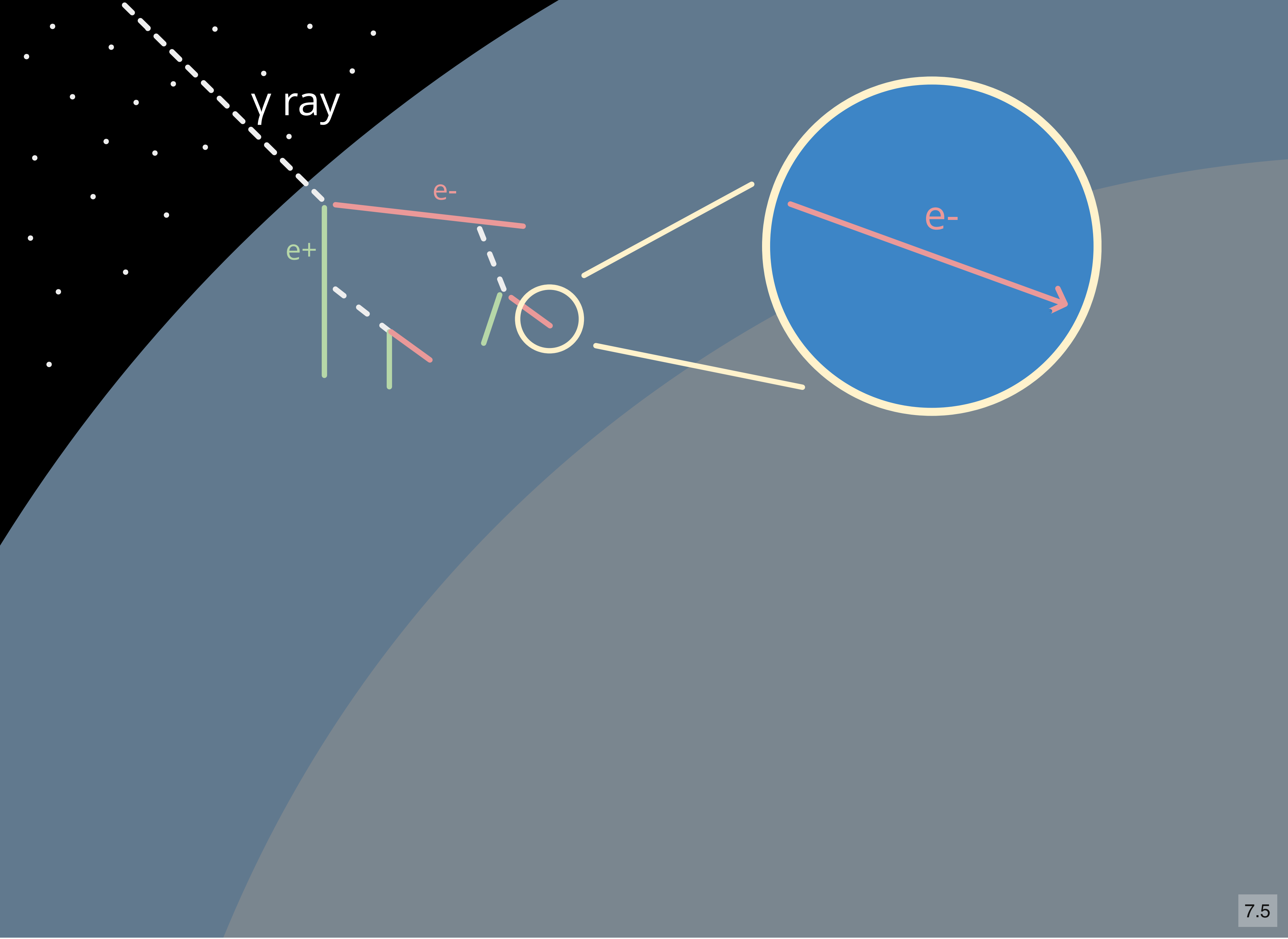
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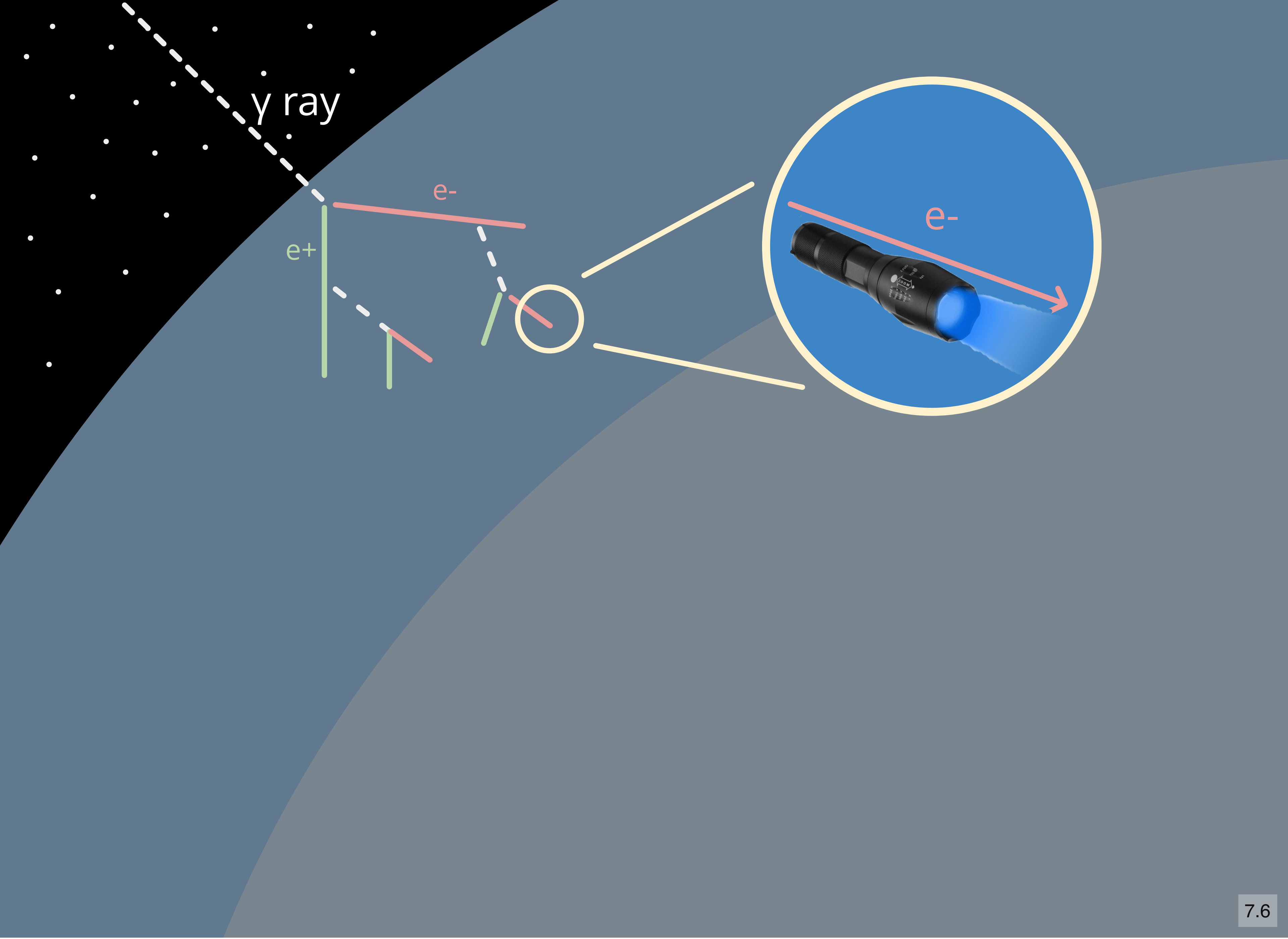

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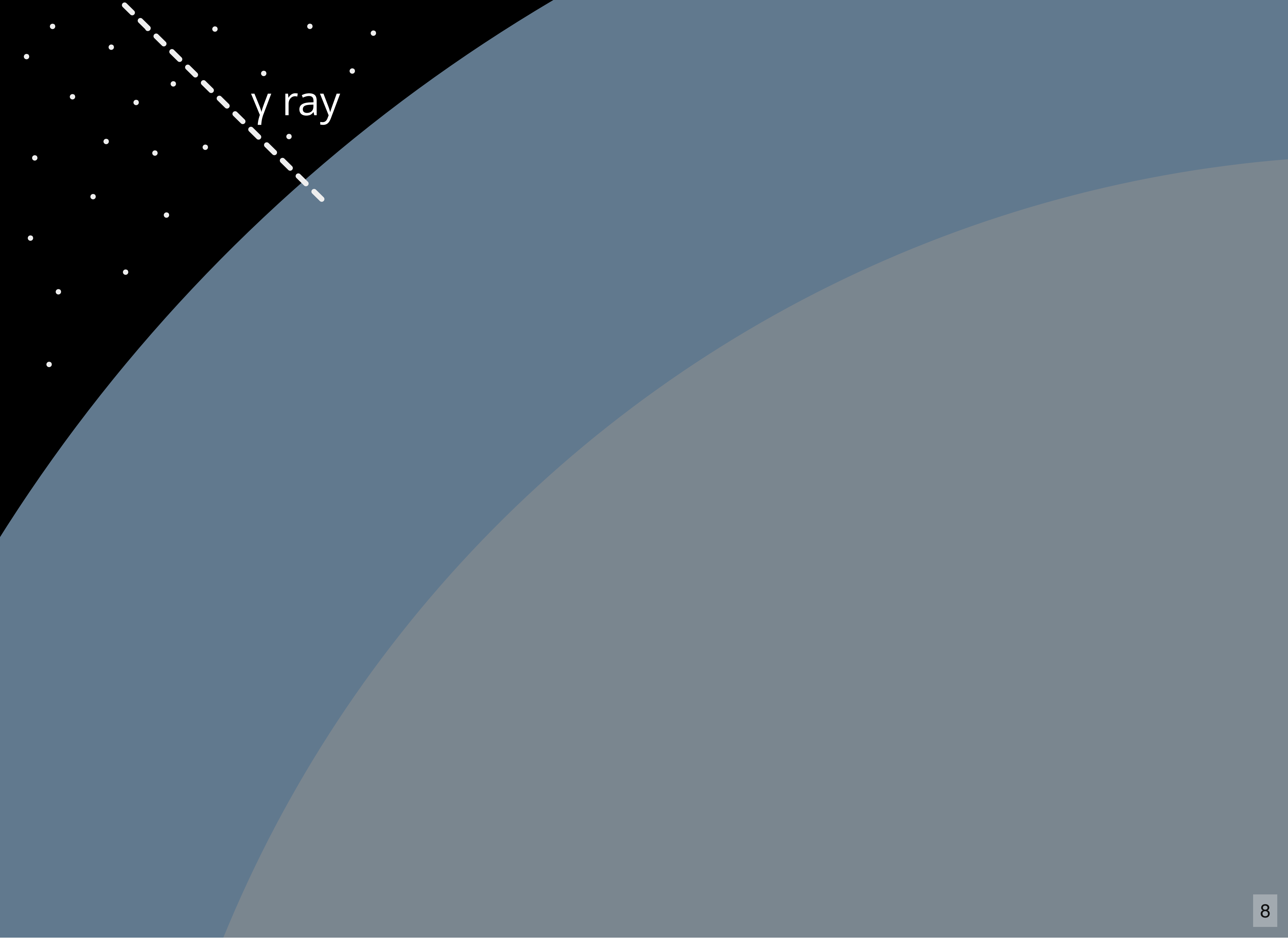
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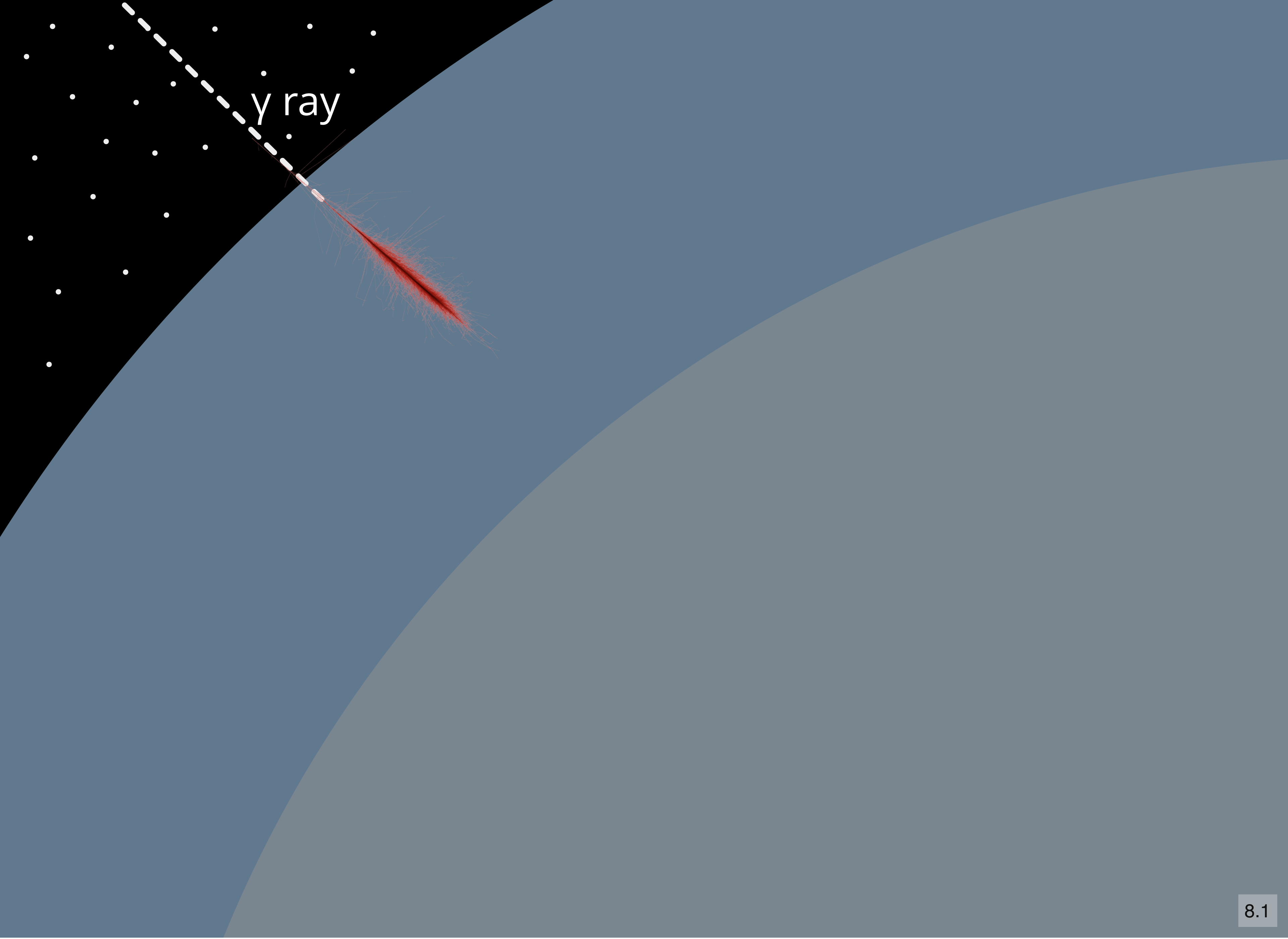
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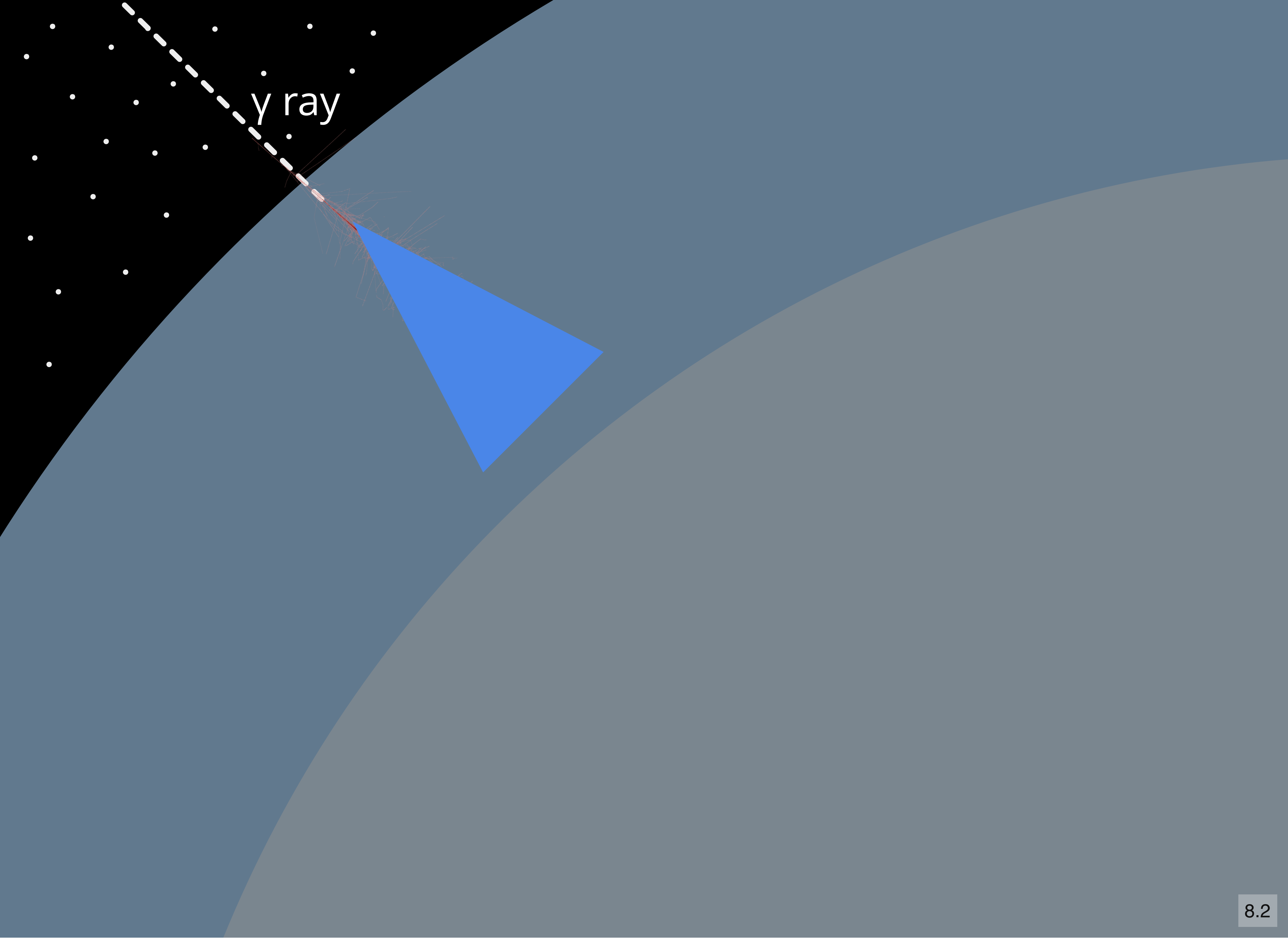

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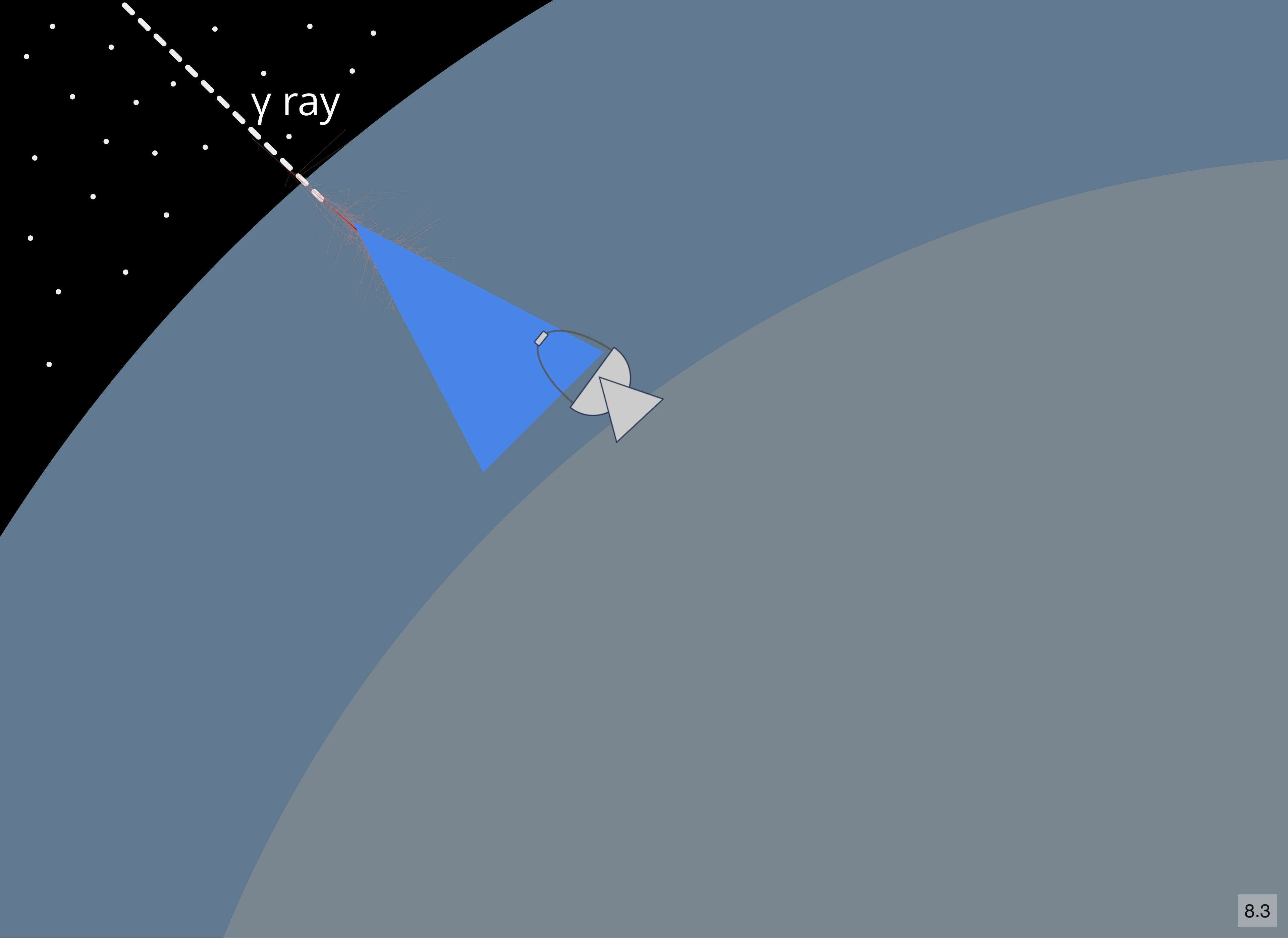
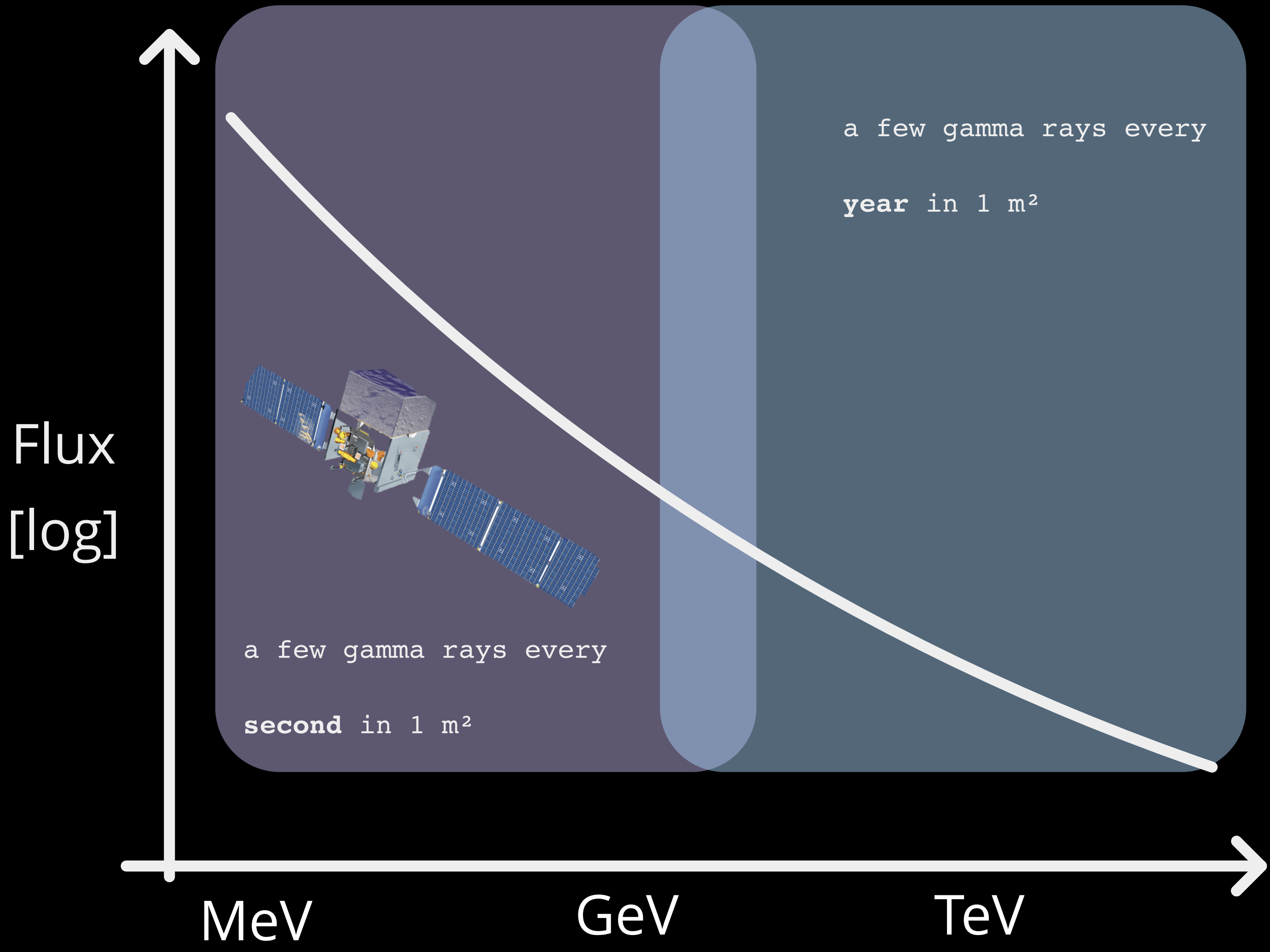

γ ray

"Imaging Atmospheric Cherenkov Telescopes"



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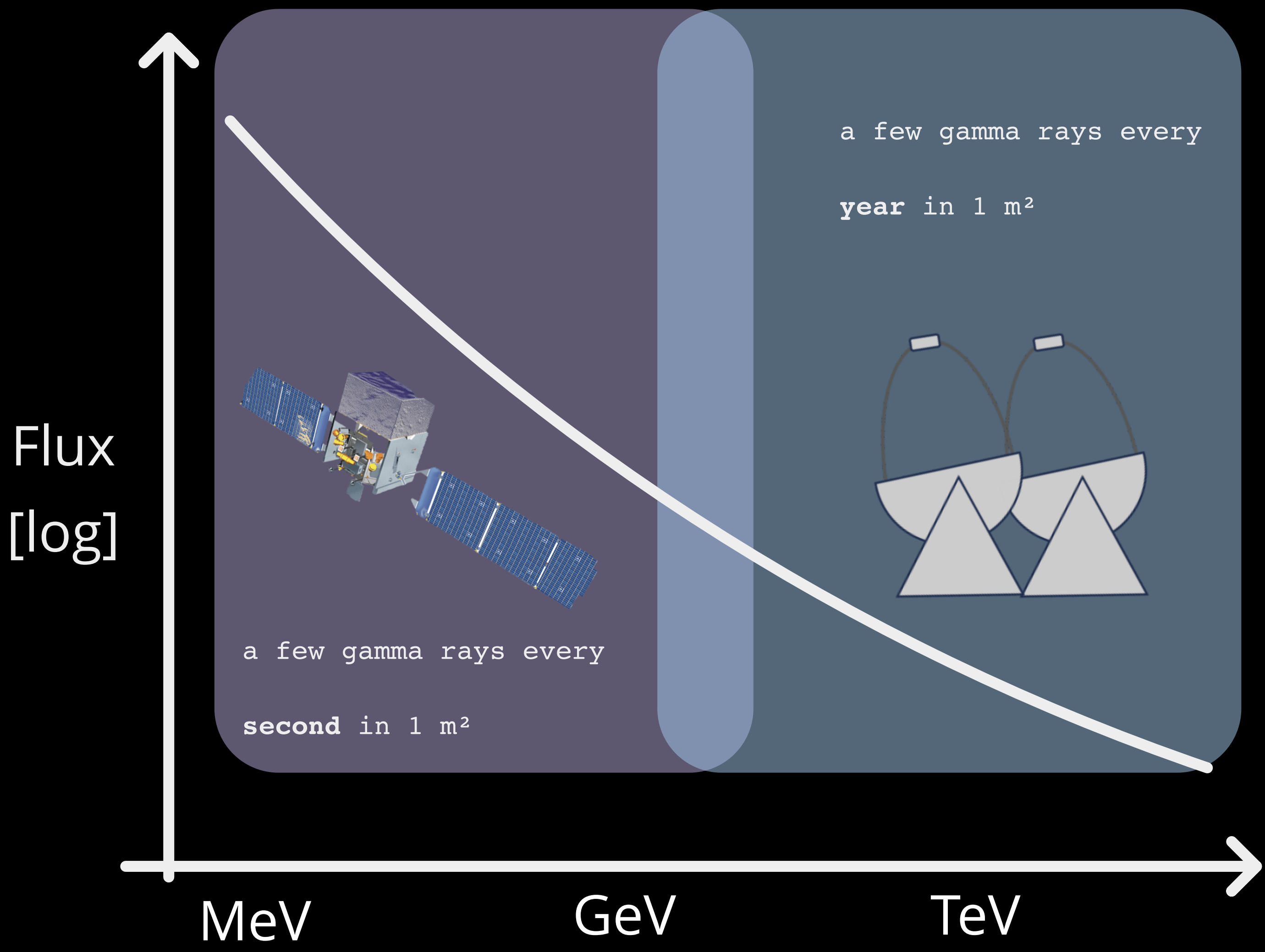

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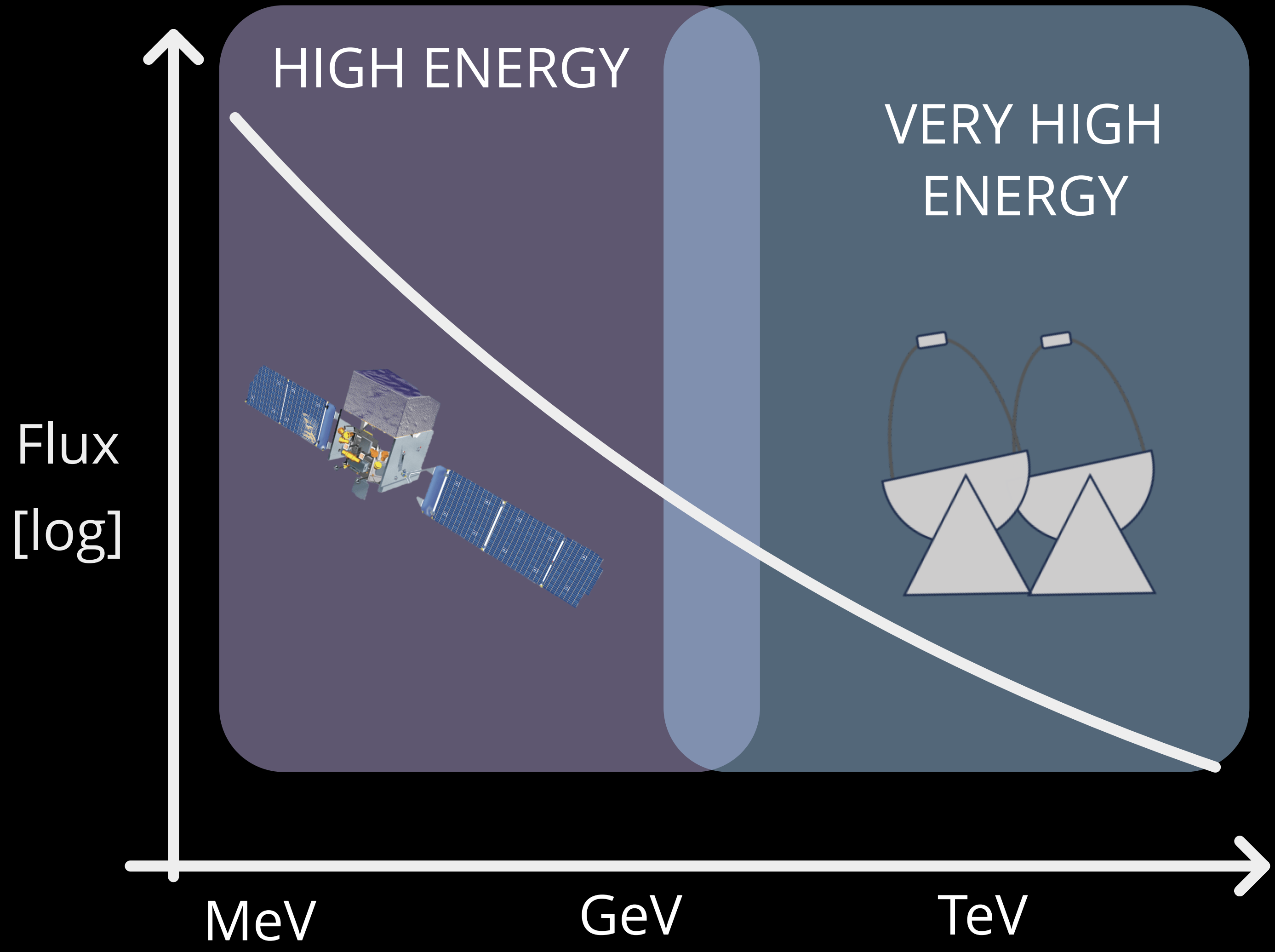


© Urs Leutenegger 2020 Nightscape Photography

2. Event Reconstruction

0. Raw data

1. Calibration

2. Cleaning

3. Parameterization

4. ML

5. Science

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$\left.\begin{array}{l}\text{0. Raw data}\\\text{1. Calibration}\\\text{2. Cleaning}\\\text{3. Parameterization}\end{array}\right\}$ Dimensionality Reduction

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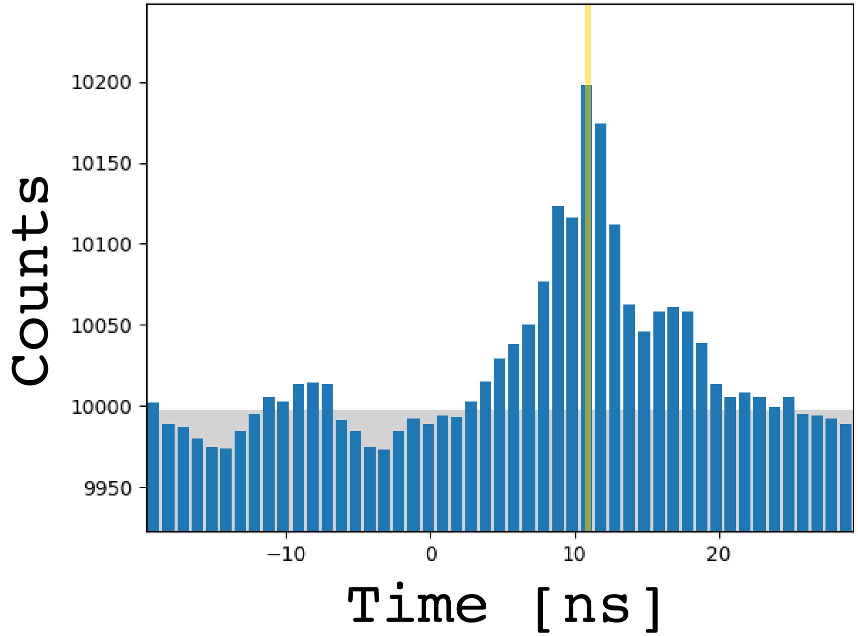
One Pixel, 30ns



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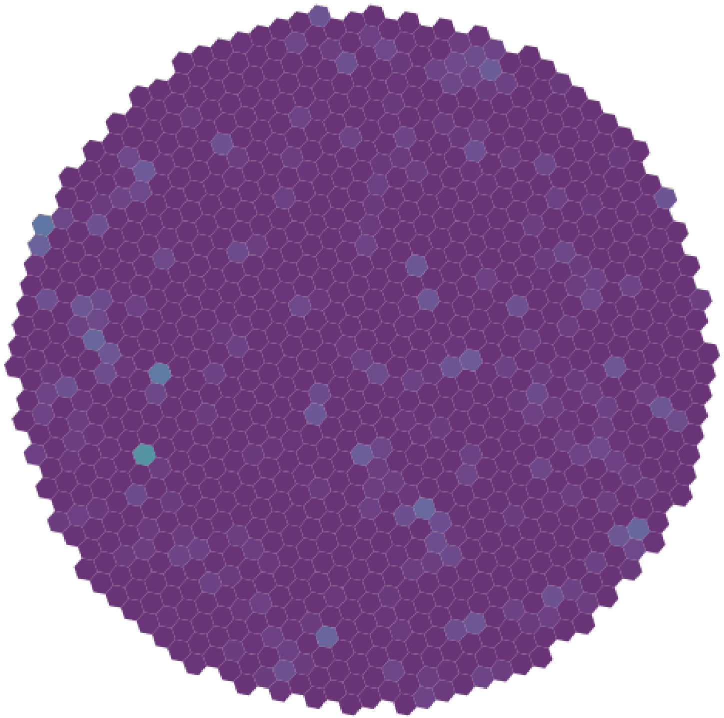

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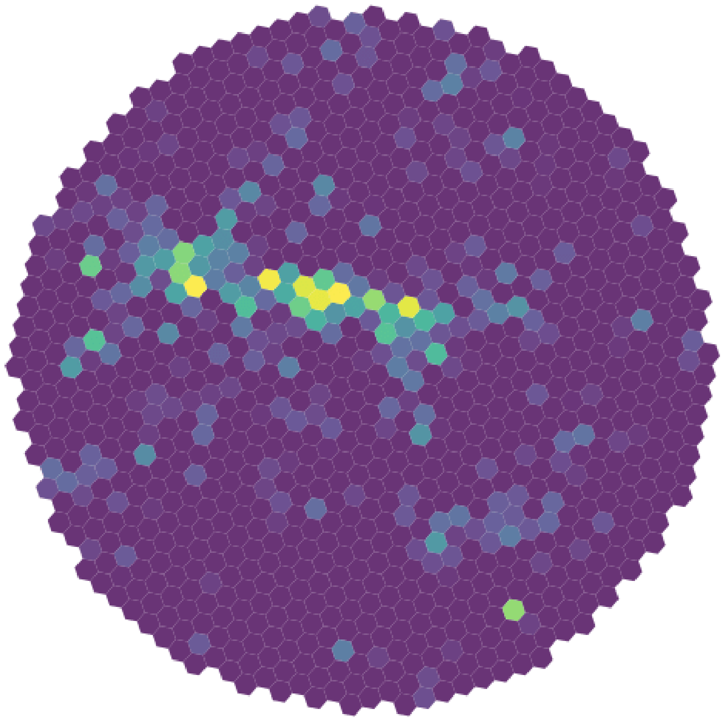

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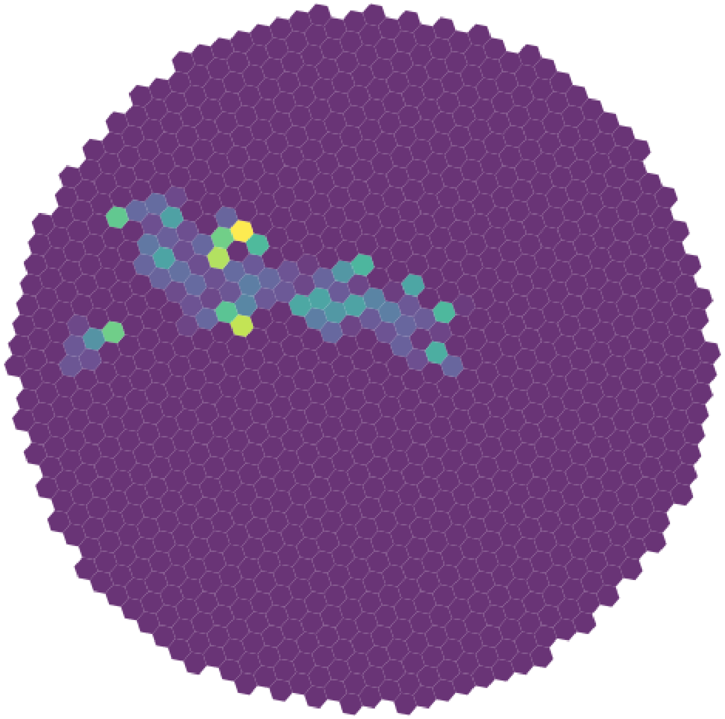

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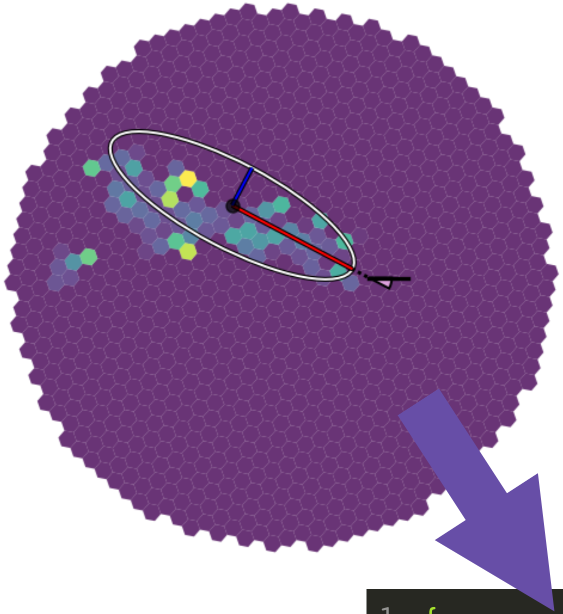

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     ...
}
```

"Hillas Parameters" (1977!)

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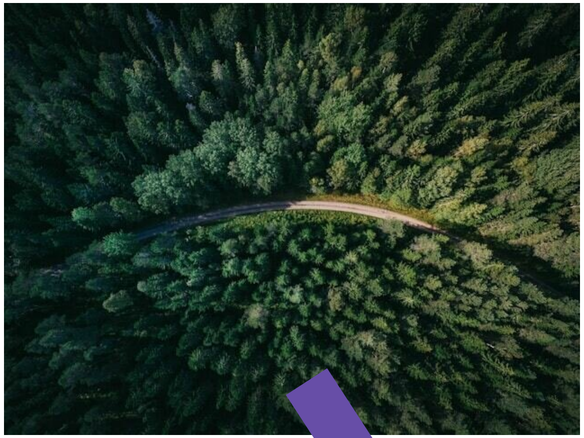


- Particle Type
- Energy
- Arrival Direction

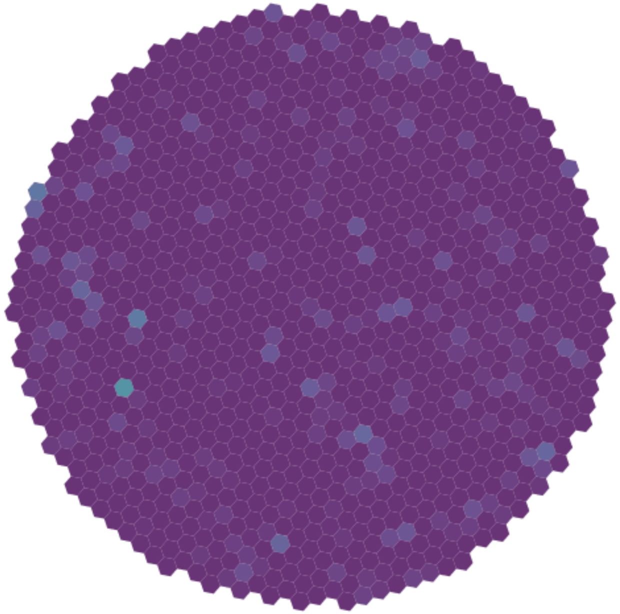
Detections

Skymaps

Spectra

2. Event Reconstruction

tl;dr



Dimensionality reduction

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ML

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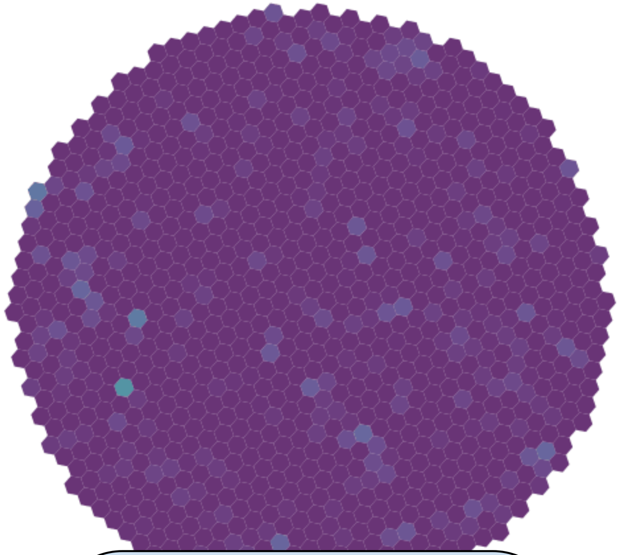

$$1039 \text{ pixels} \times 50 \text{ time slices} \times 2 \text{ telescopes} = 103900 \text{ params}$$

Dimensionality reduction

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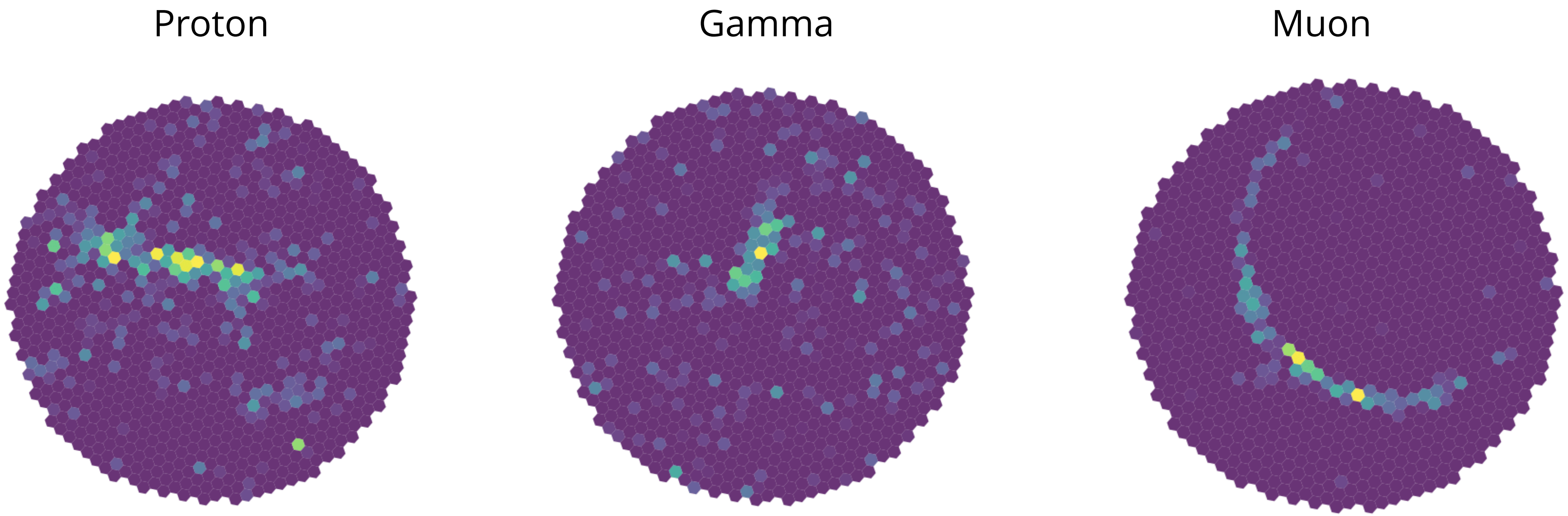

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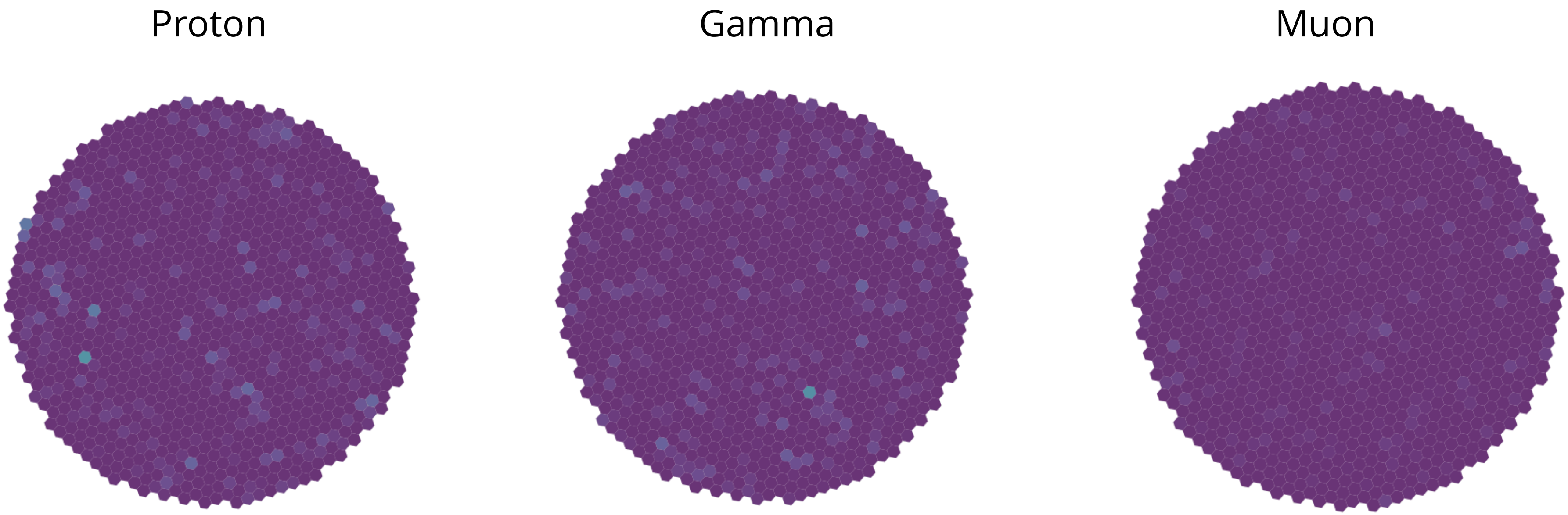

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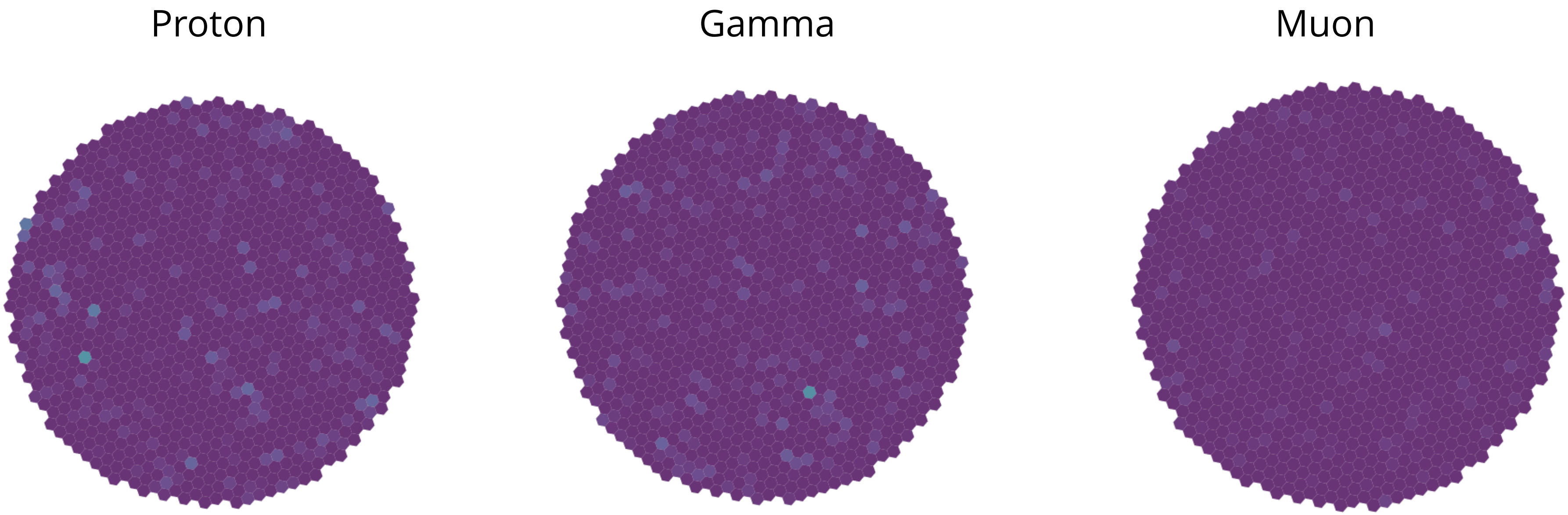

103900 params per event (raw)

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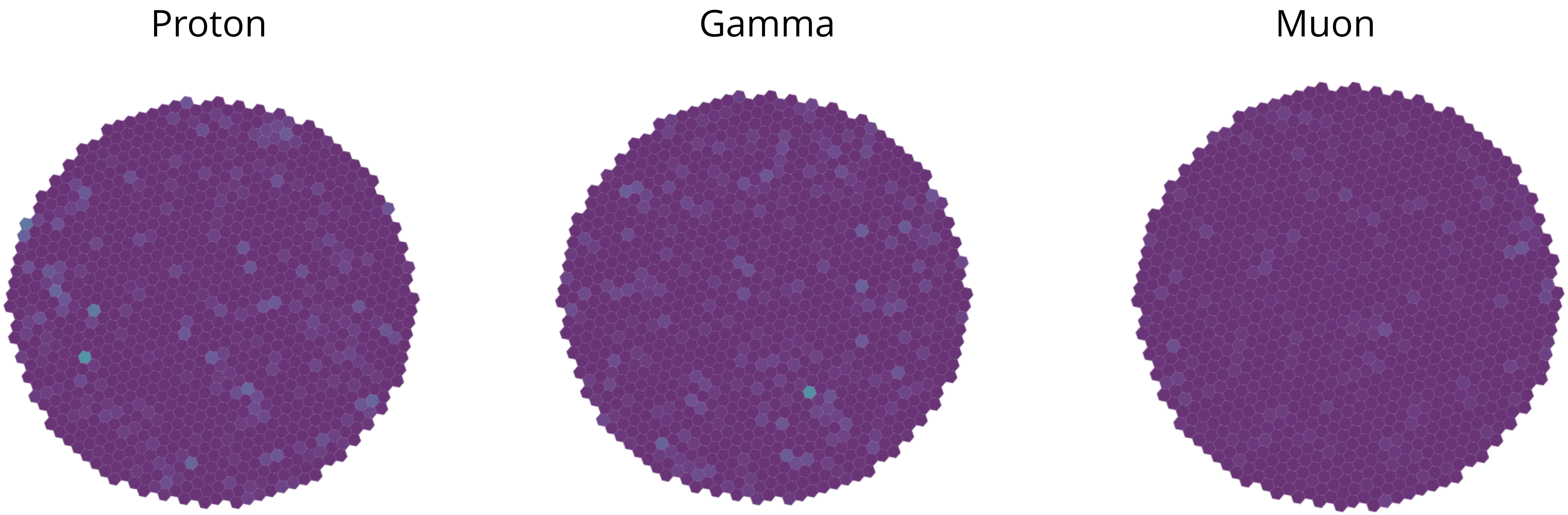
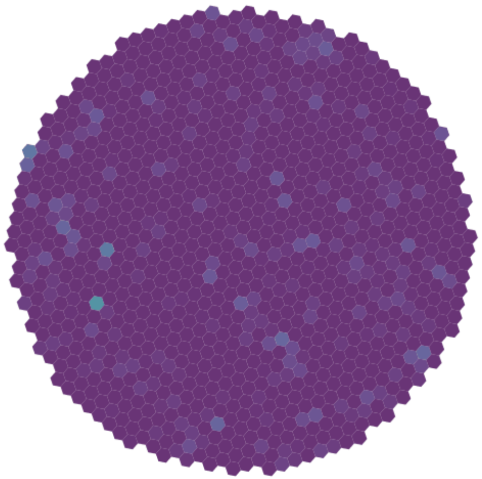


$$103900 \text{ params per event (raw)}$$

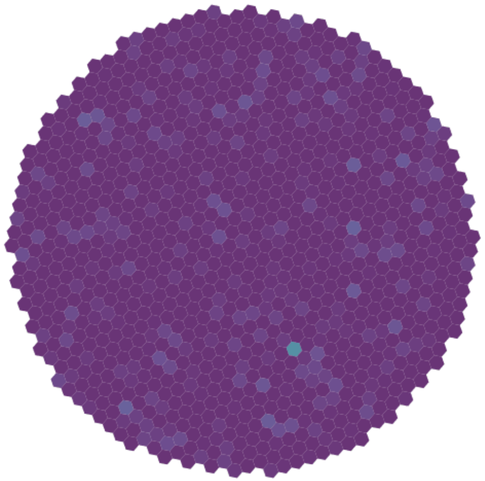
$$\sim 300 \frac{\text{triggers}}{\text{s}}$$

3. Graphs for MAGIC?

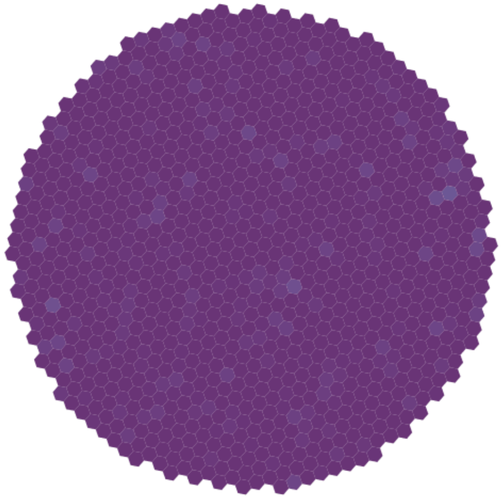
Proton



Gamma



Muon



$$103900 \text{ params per event (raw)}$$

$$\sim 300 \, \frac{\text{triggers}}{\text{s}}$$

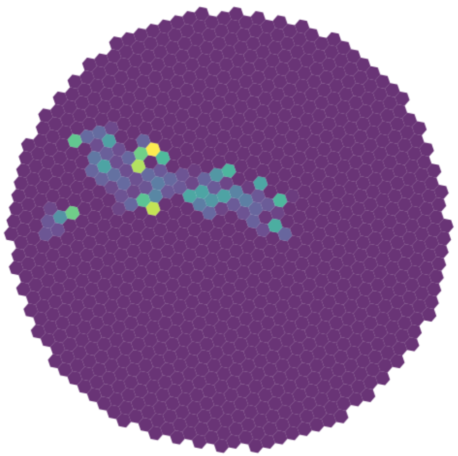
$$\text{S/N ratio} \sim \frac{1}{10000}$$

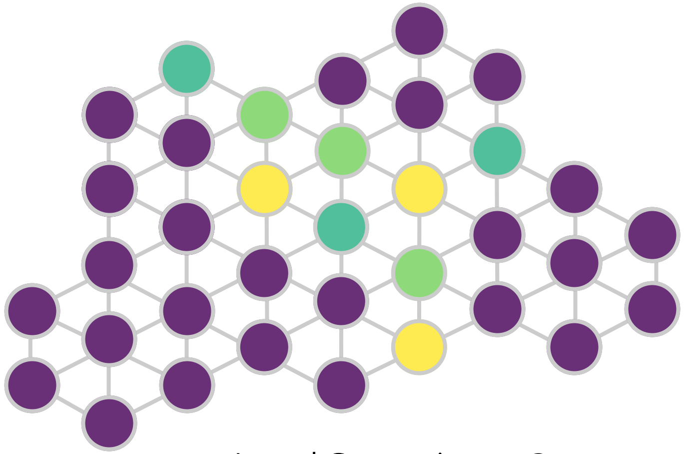
3. Graphs for MAGIC

Why Graphs?

We effectively deal with:

- irregular camera geometry
- sparse data
- non gridlike pixels
- arrays with different camera types





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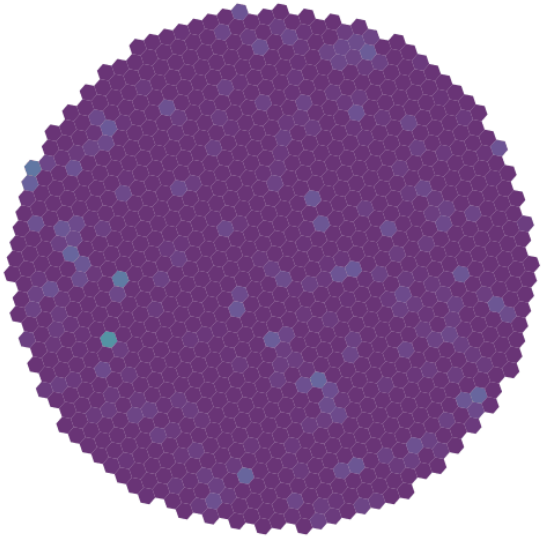
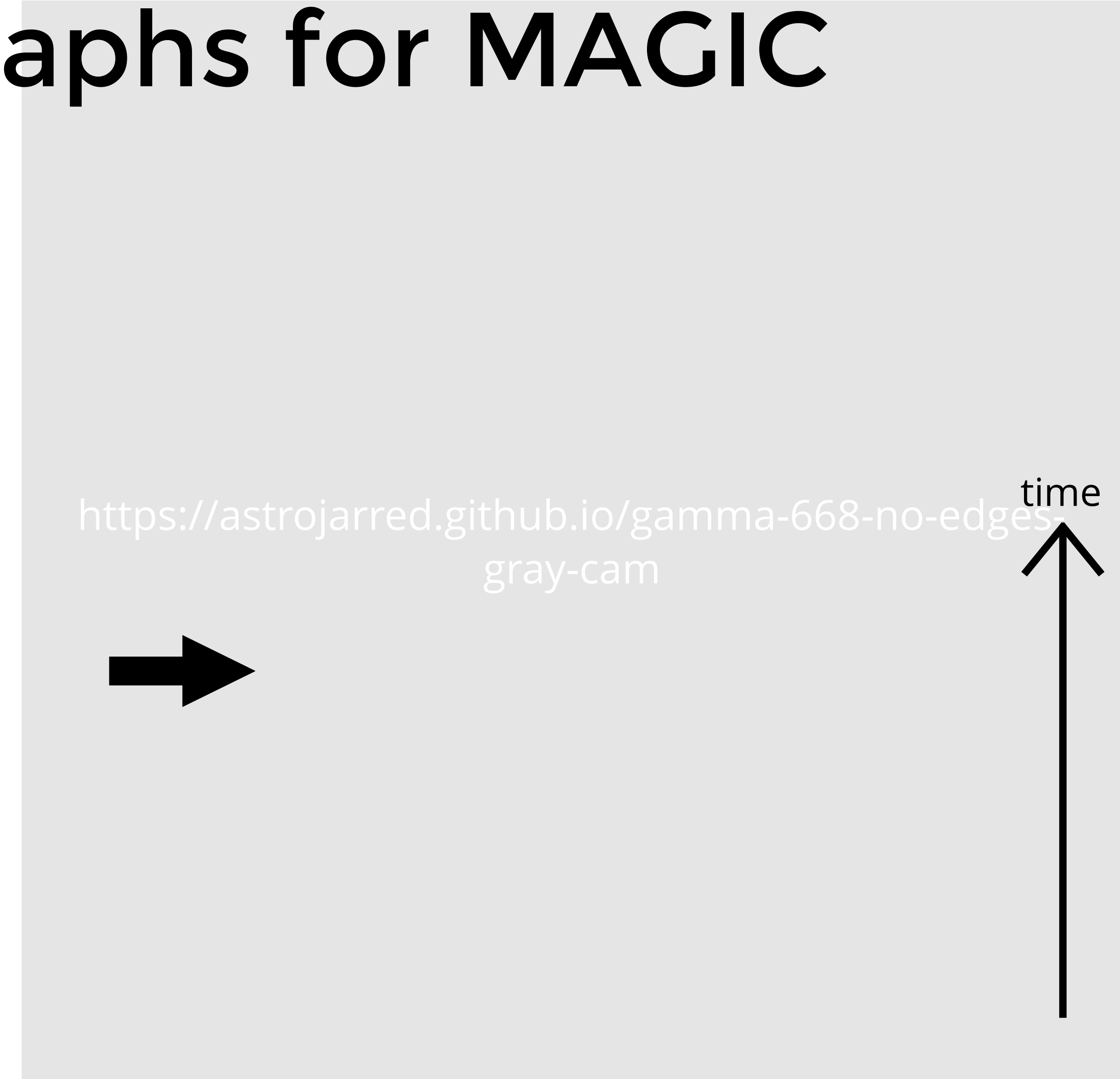
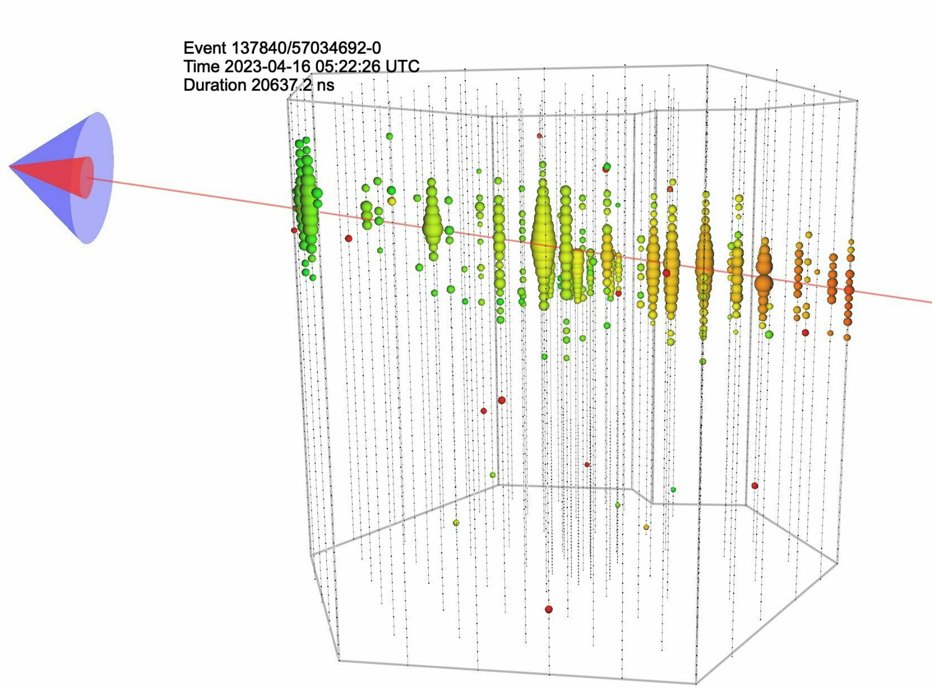




3. Graphs for MAGIC

an IceCube case study



GraphNeT
Deep Learning for Neutrino Telescopes

- A GNN framework for Neutrino observatories
- Easy to adapt to other detectors

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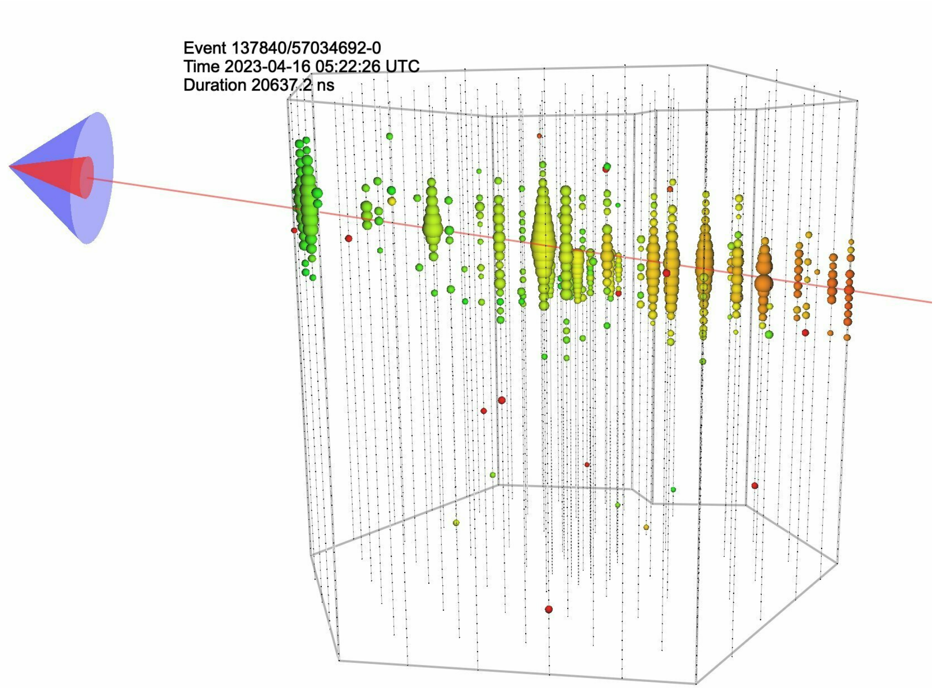

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Proven models | DynEdge | DeepIce

4. ML Playground

Particle Classification with

DynEdge

Model:

- Binary classification
- DynEdge with 12 NN
- Separate each telescope
- Cross-attention
- Only need 5-10% of training data
- z = time

4. ML Playground

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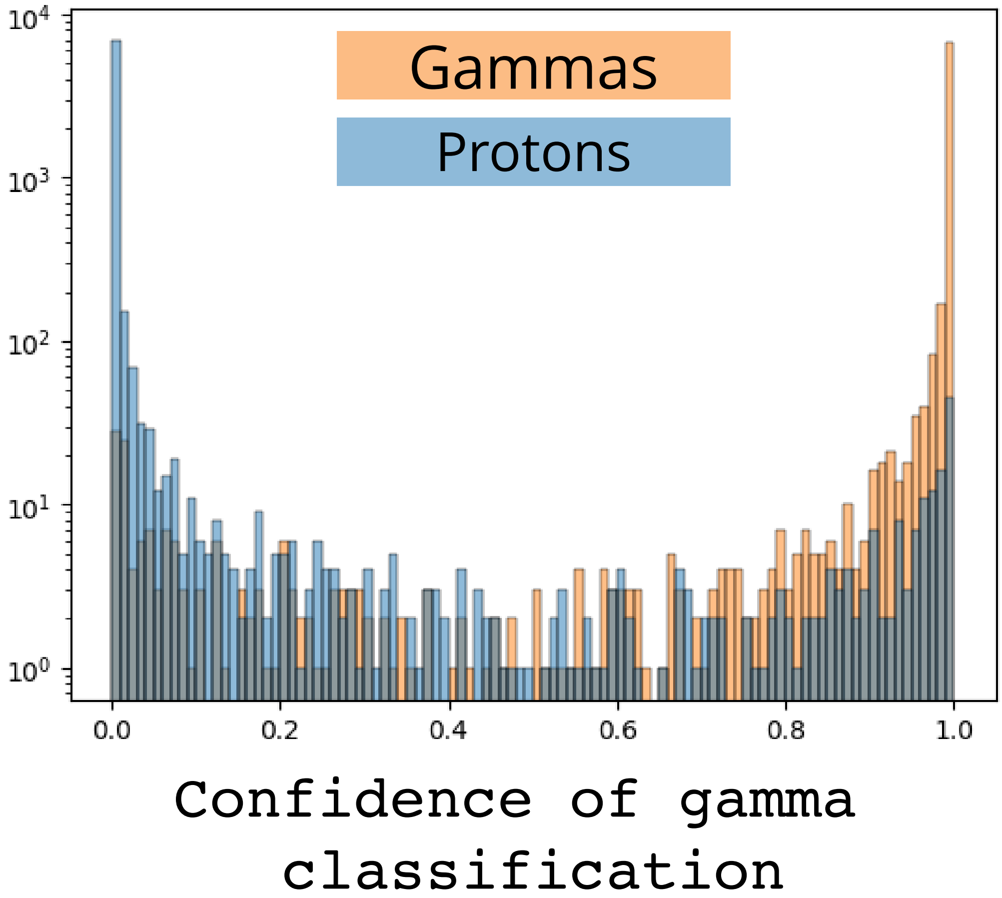

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Direction Reconstruction with

DeepIce

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- Transformer + DynEdge
- Very robust model for neutrino direction reconstruction
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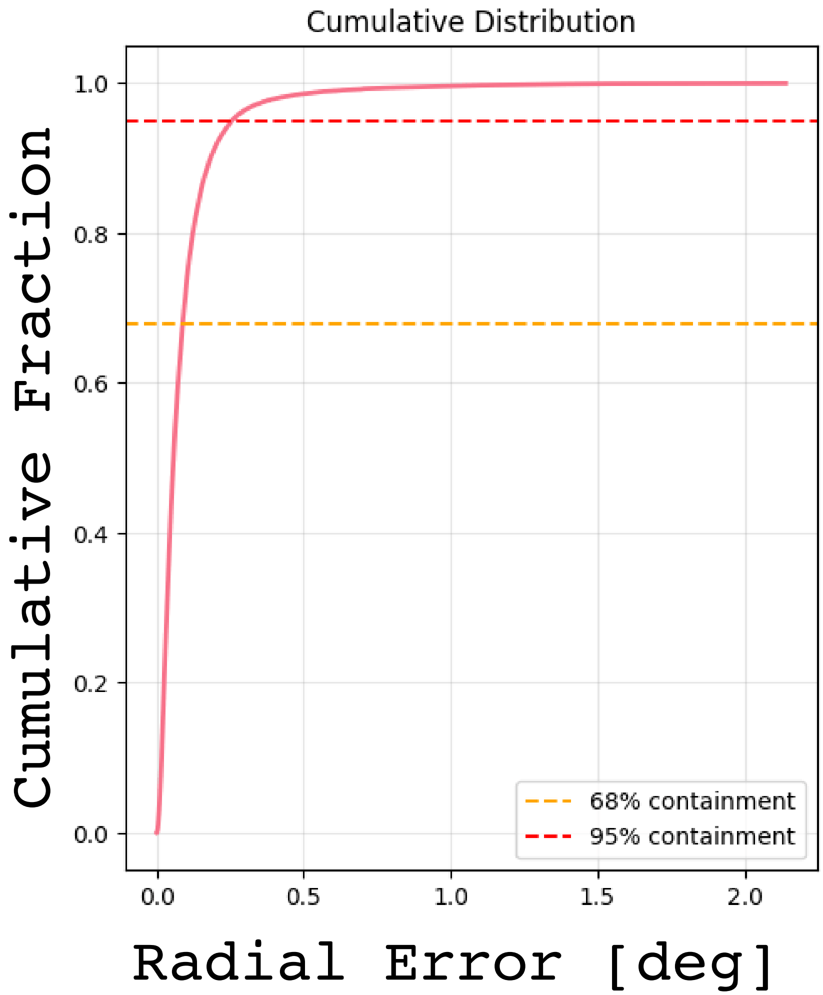

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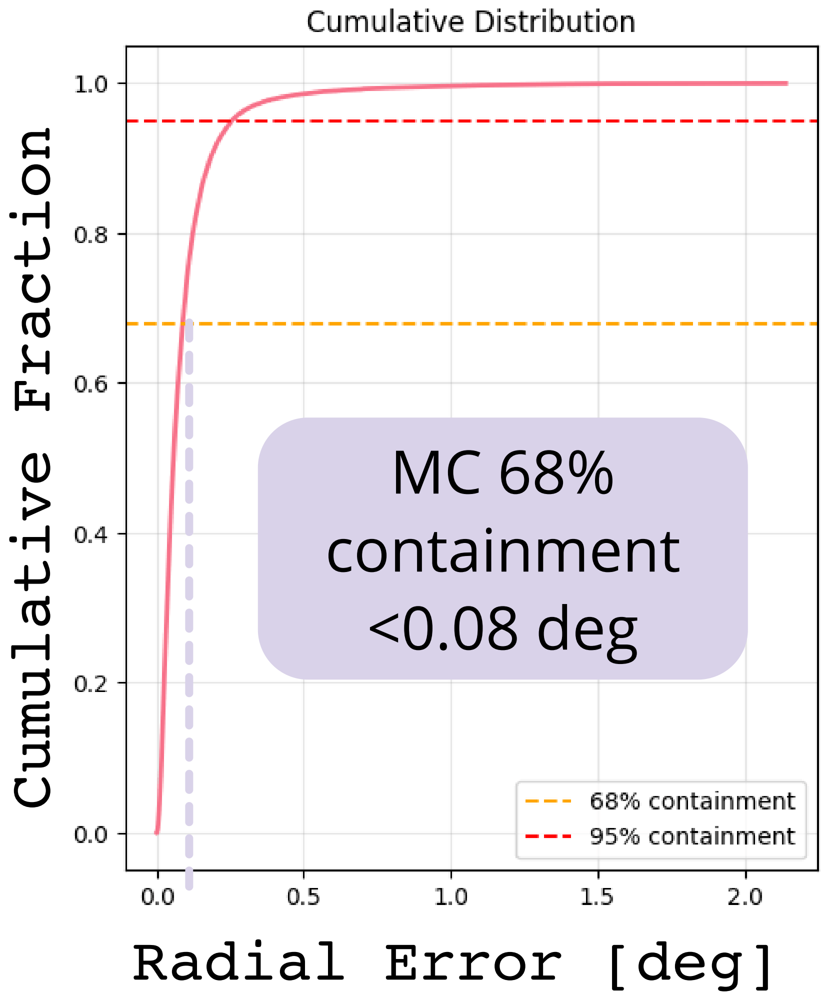

5. Conclusions

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Reconstruction with GraphNET

- Apply domain knowledge from IceCube
- 'Built-in' neutrino models work on gamma-ray data
- Robust performance with minimal modifications

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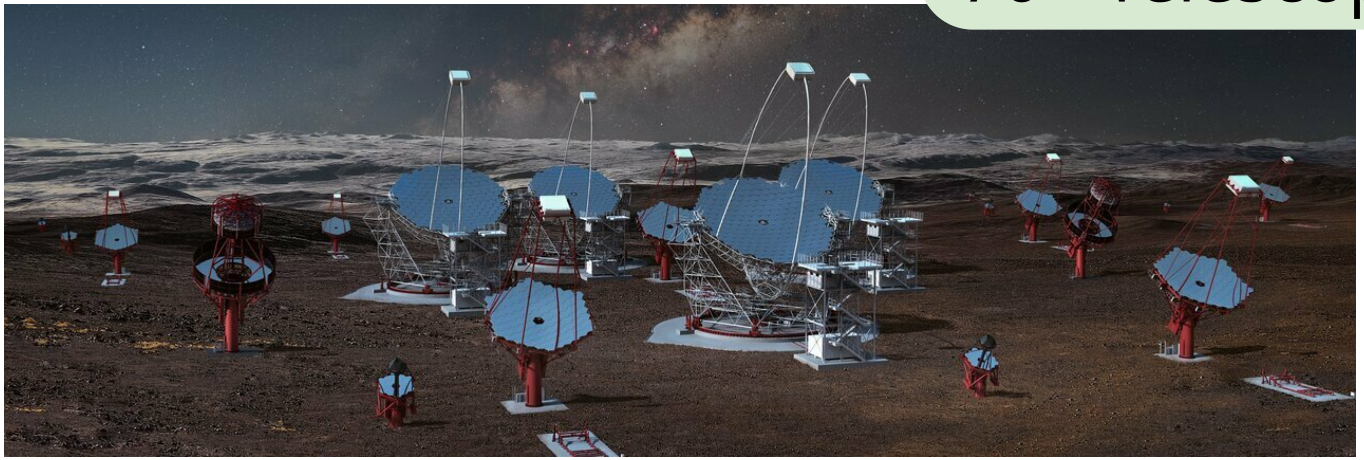
Further evidence for the benefits of cross-domain collaboration

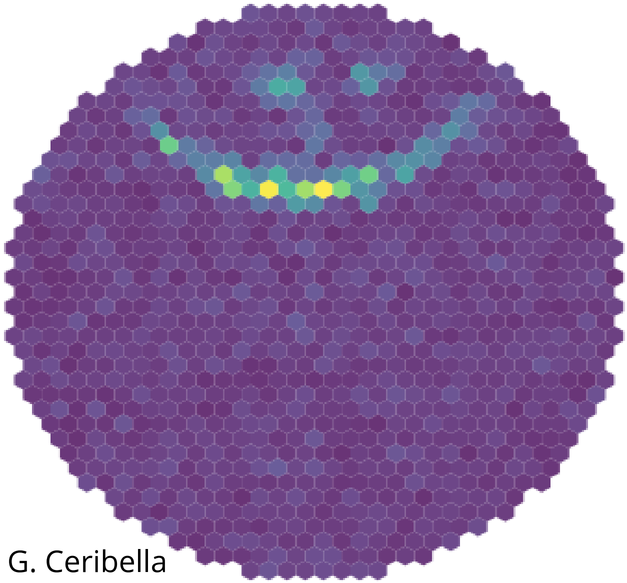
5. Future Motivation

70+ Telescopes!!



Cherenkov Telescope Array

Thank you!


Credit: G. Ceribella