Modeling TXS 0506+056: Multimessenger Blazars and the MeV

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TDAMM Initiative Workshop - Jetted Transients SMBH I

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SPACE FLIGHT CENTER

An active galaxy has a nucleus at least 100 times brighter than all the light from its stars combined.

A fraction of active galaxies have bipolar jets.

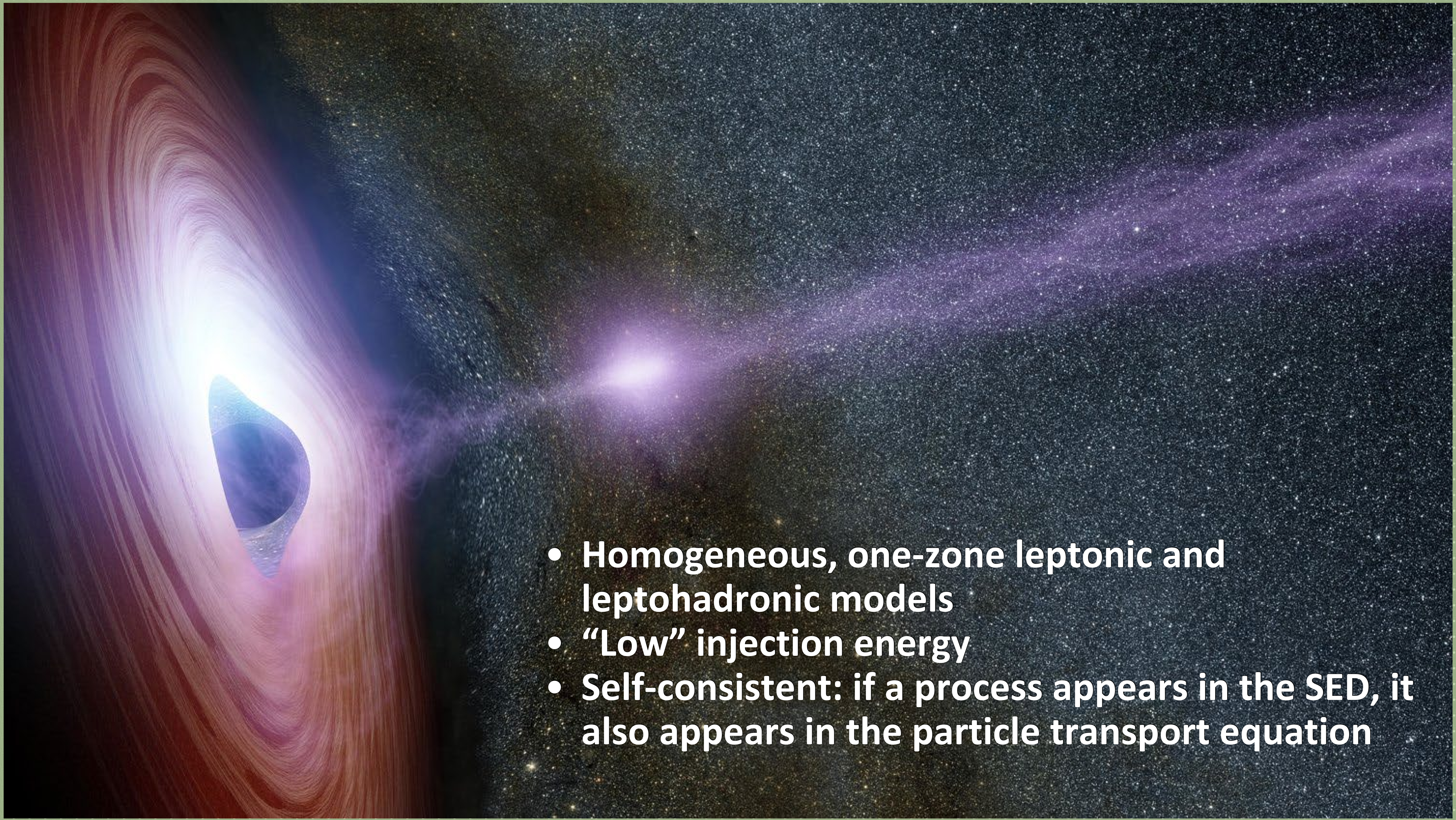
A blazar is a jetted, active galaxy, which is also pointed at Earth.

Simulation by NASA Goddard Space Flight Center Conceptual Image Lab

Blazars are the most energetic sustained sources in the known Universe.

WallPaper-House (https://wallpaper-house.com/wallpaper-id-425029.php)

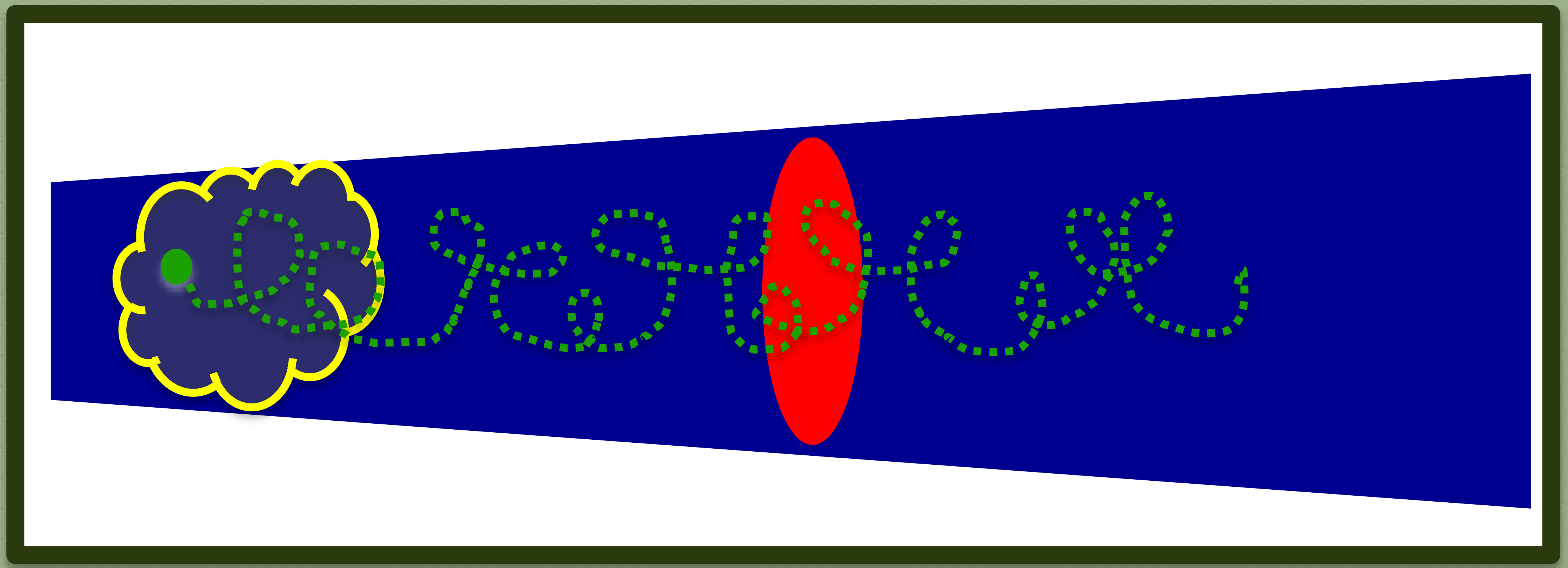
Models for Blazar Jets



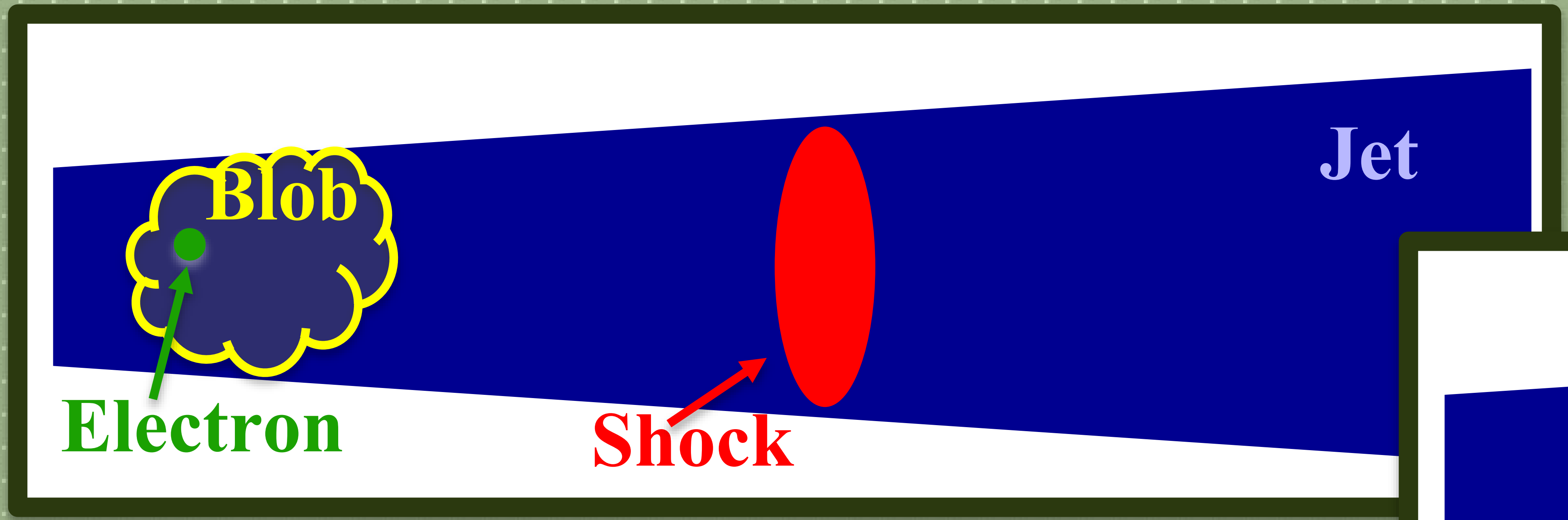
- Homogeneous, one-zone leptonic and leptohadronic models
- “Low” injection energy
- Self-consistent: if a process appears in the SED, it also appears in the particle transport equation

Image Credit: IPAC CalTech

Particle Acceleration Mechanisms: 1st Order Fermi Interactions



Particles gain energy from shock crossings in proportion to the energy they already have, and can pass through a shock region multiple times



Shock Acceleration (+)
& Adiabatic Expansion (-)

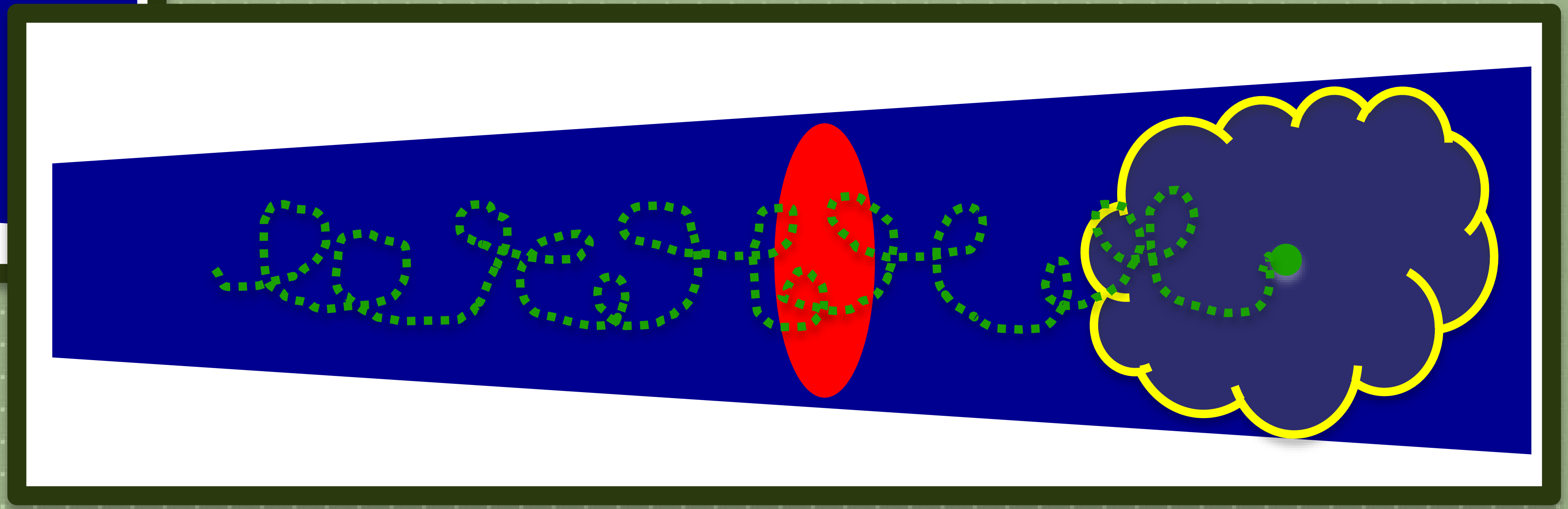
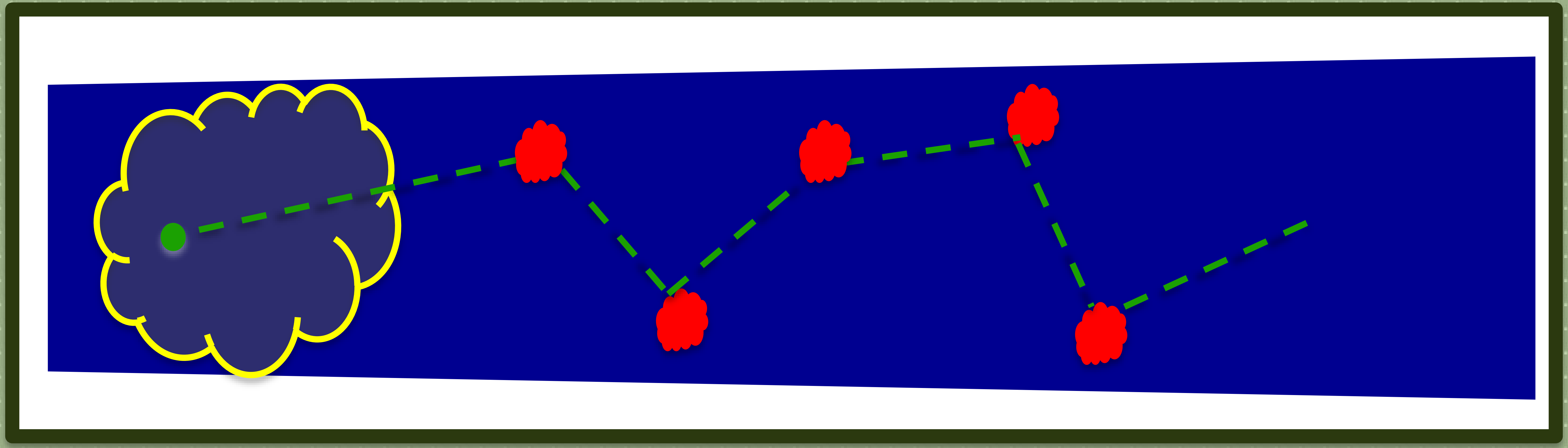
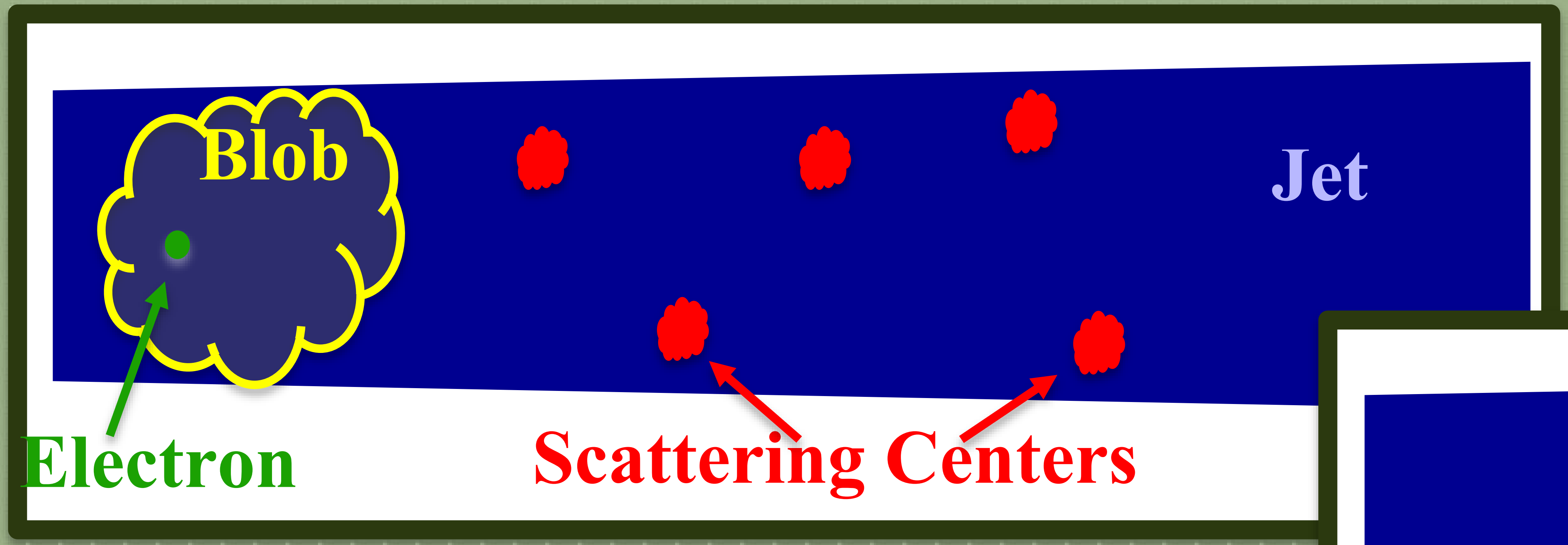


Illustration: Tiffany Lewis

Particle Acceleration Mechanisms: 2nd Order Fermi Interactions



Particles always gain energy from stochastic scatterings in the head-on approximation due to the bulk motions in the jet.



Hard-Sphere Scattering off of Stochastic MHD Waves

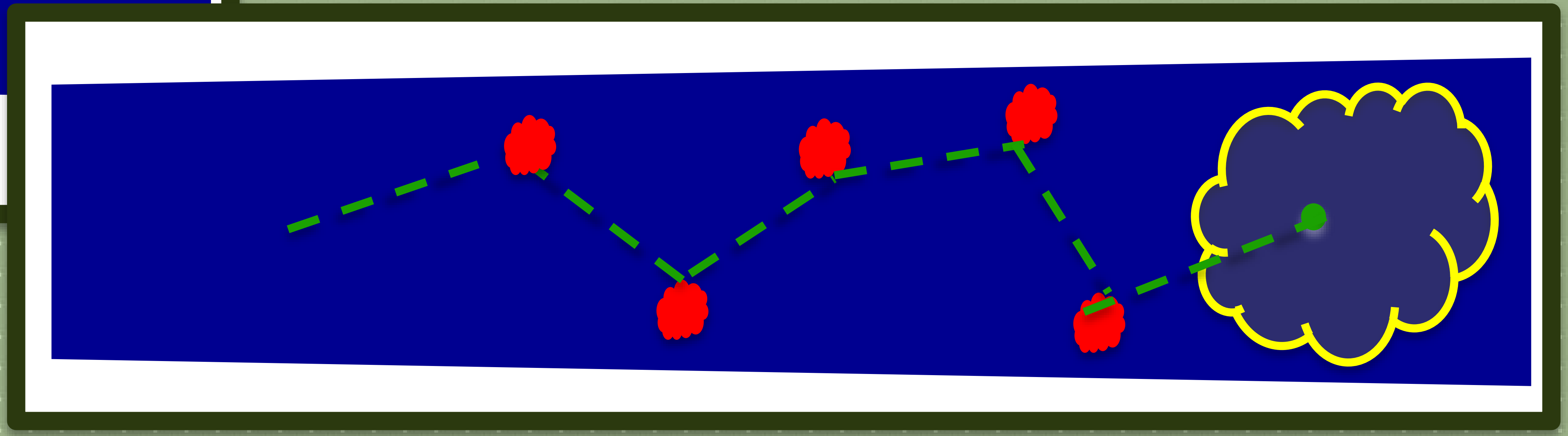
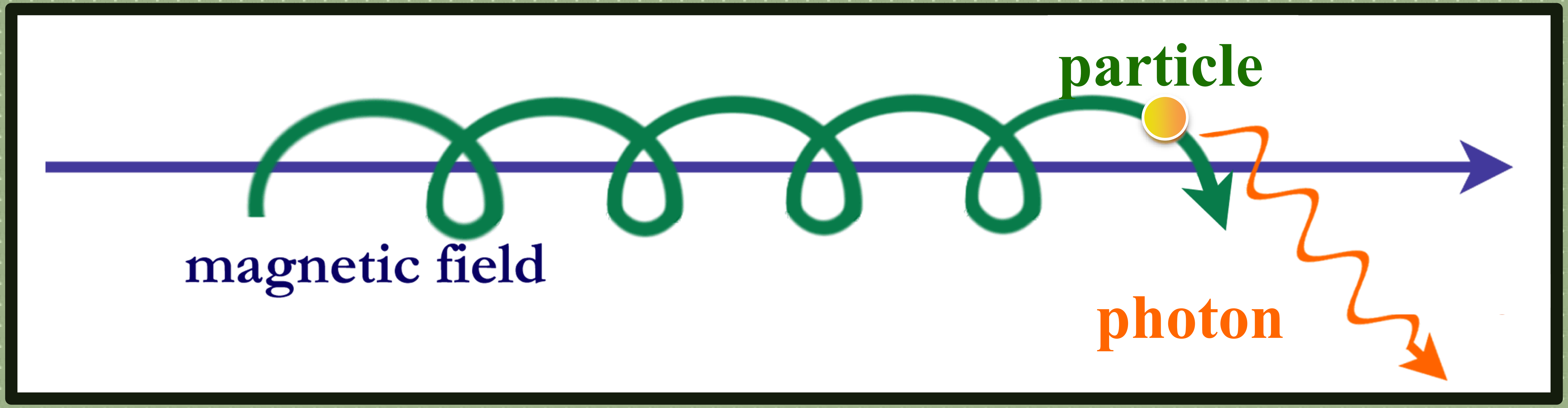


Illustration: Tiffany Lewis

Particle Energy Loss Mechanisms: Synchrotron



- Both electrons and protons populations can cool through synchrotron radiation.
- The rate of synchrotron cooling depends on the strength of the magnetic field.

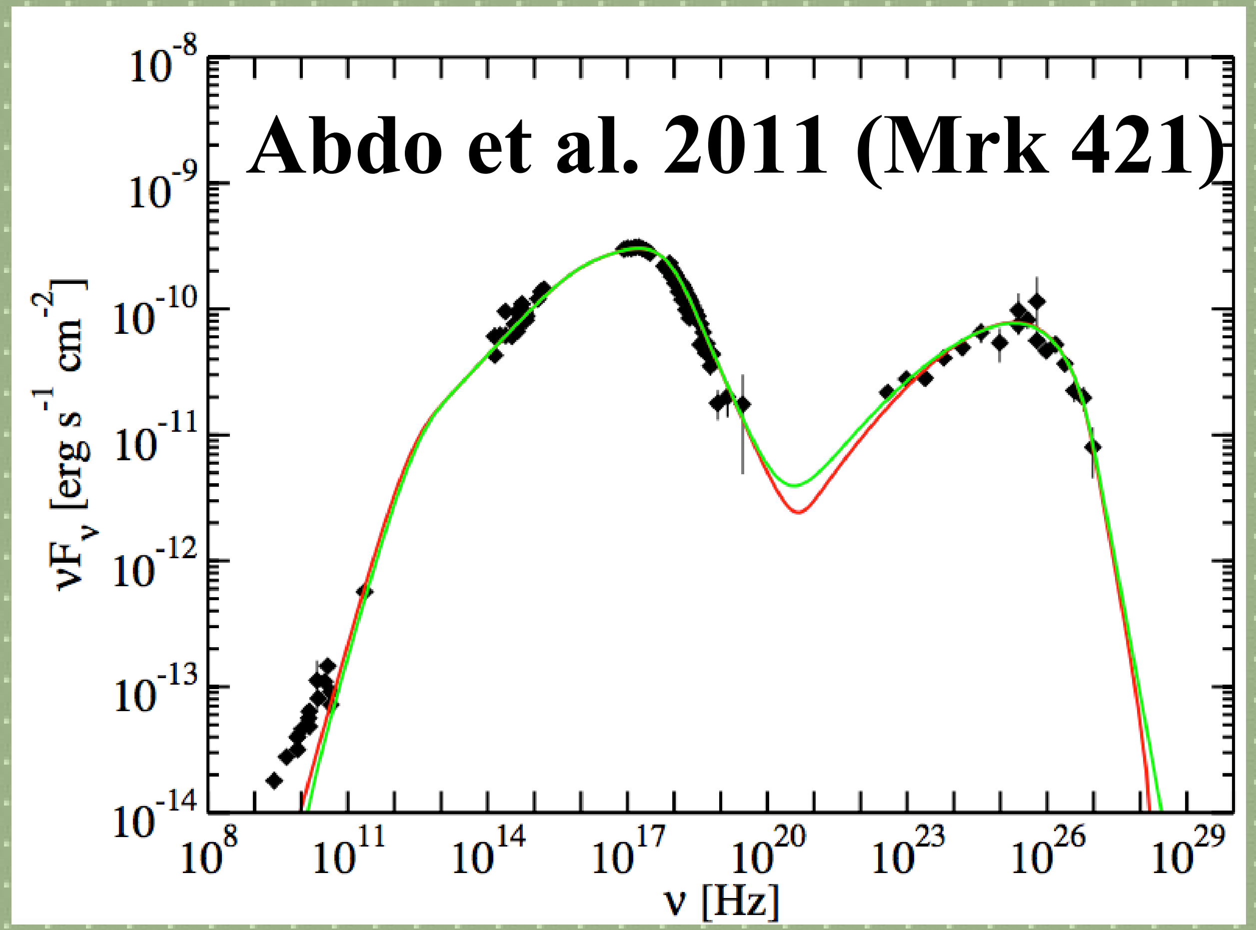
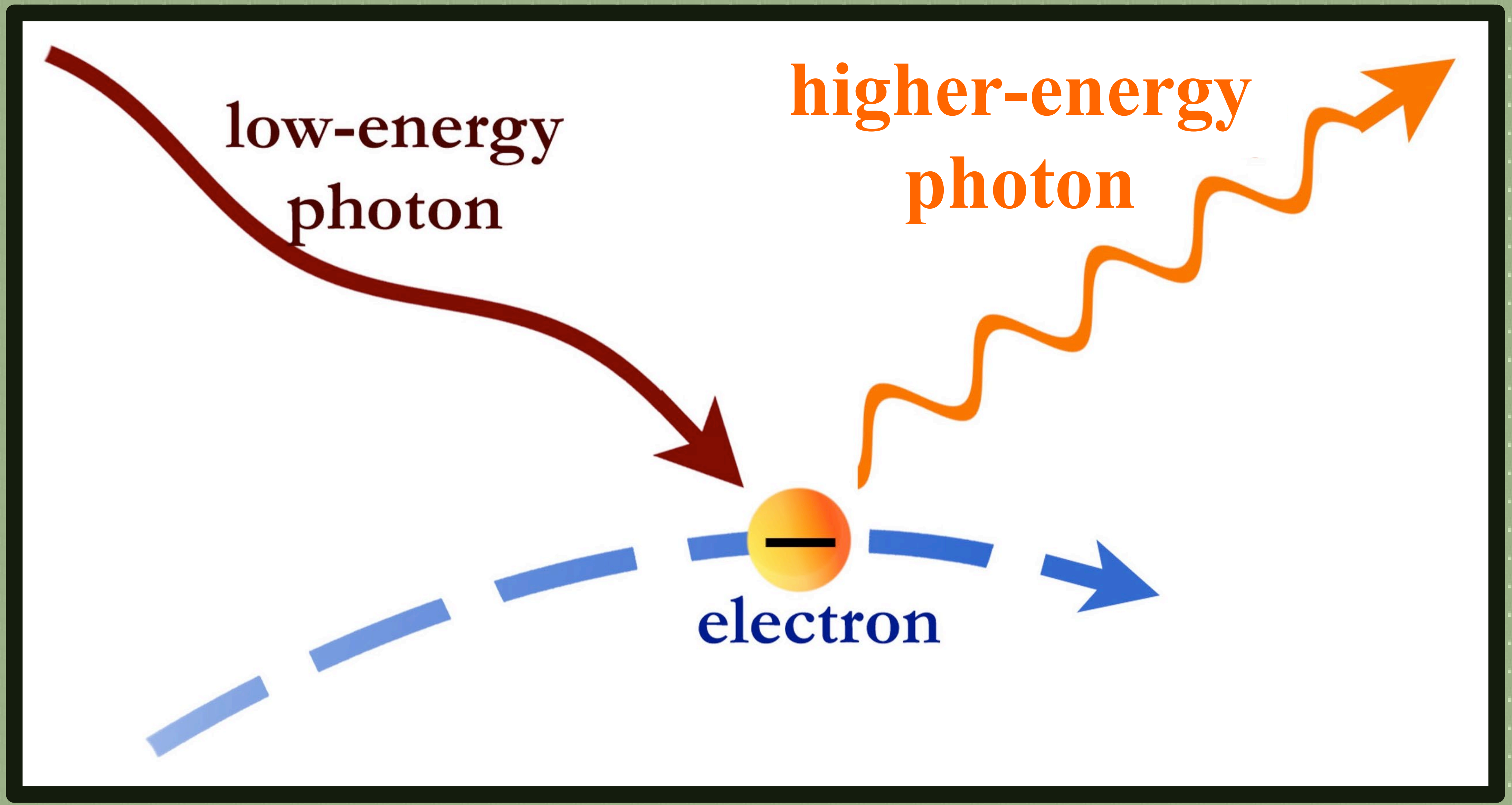
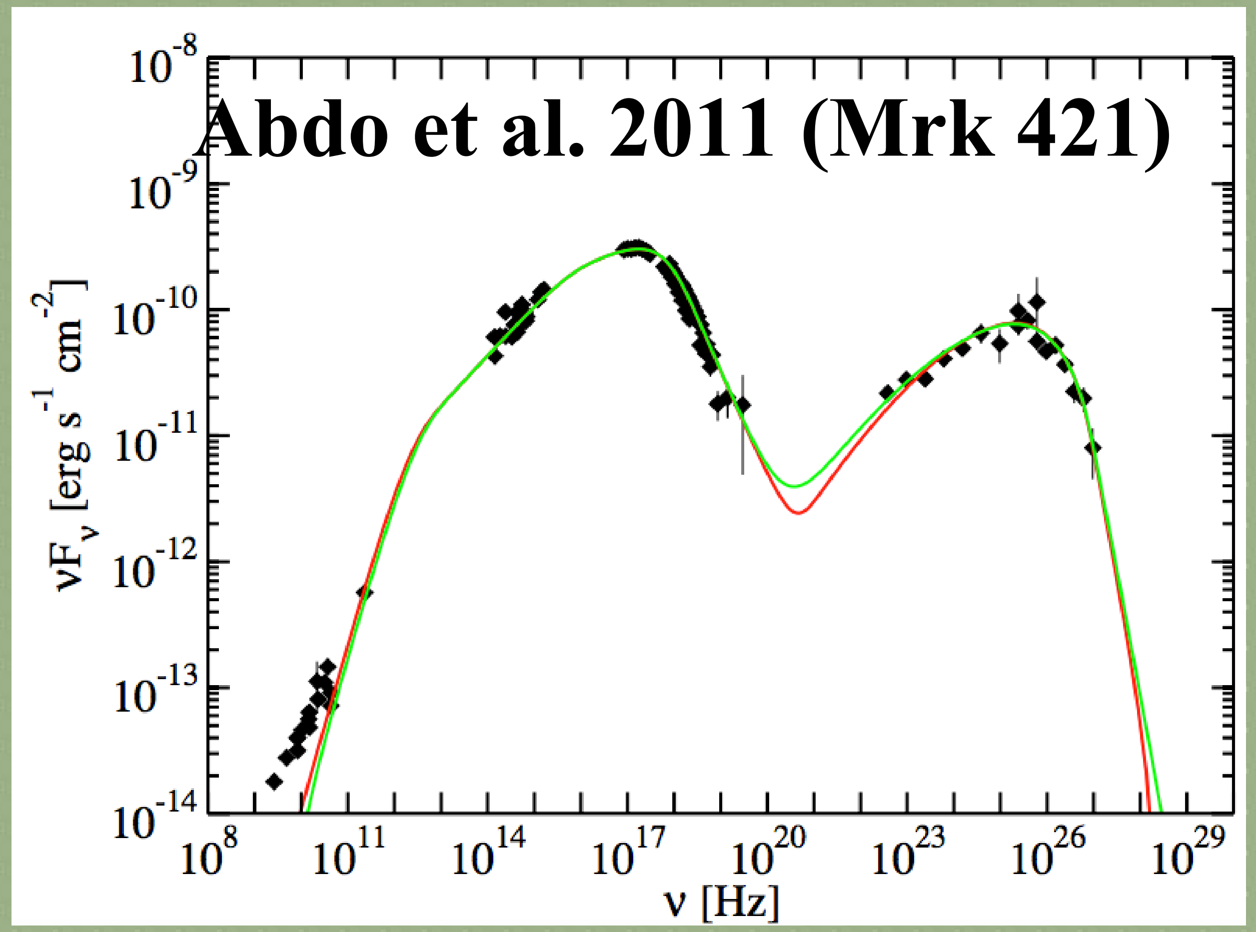


Illustration: CXC/S. Lee

Particle Energy Loss Mechanisms: Inverse-Compton

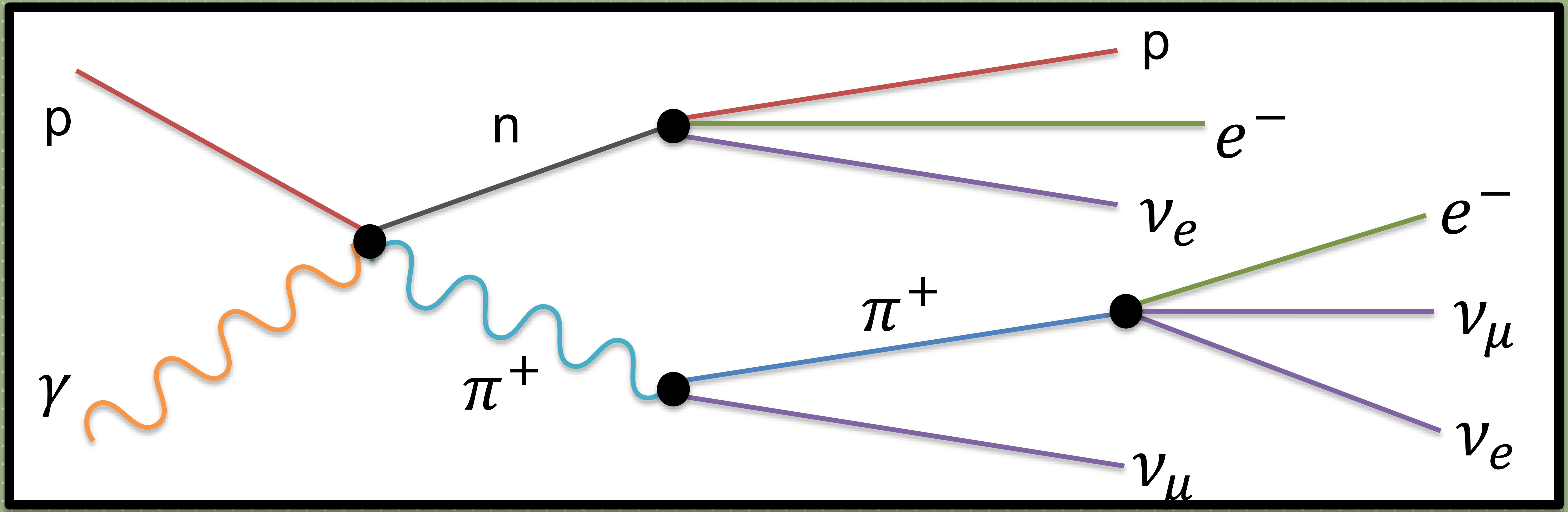




- Compton cooling describes the high-frequency SED bump in the leptonic picture.
- The Compton cooling rate depends on the energy density of the 'low-energy' photon field

Illustrations: CXC/S. Lee

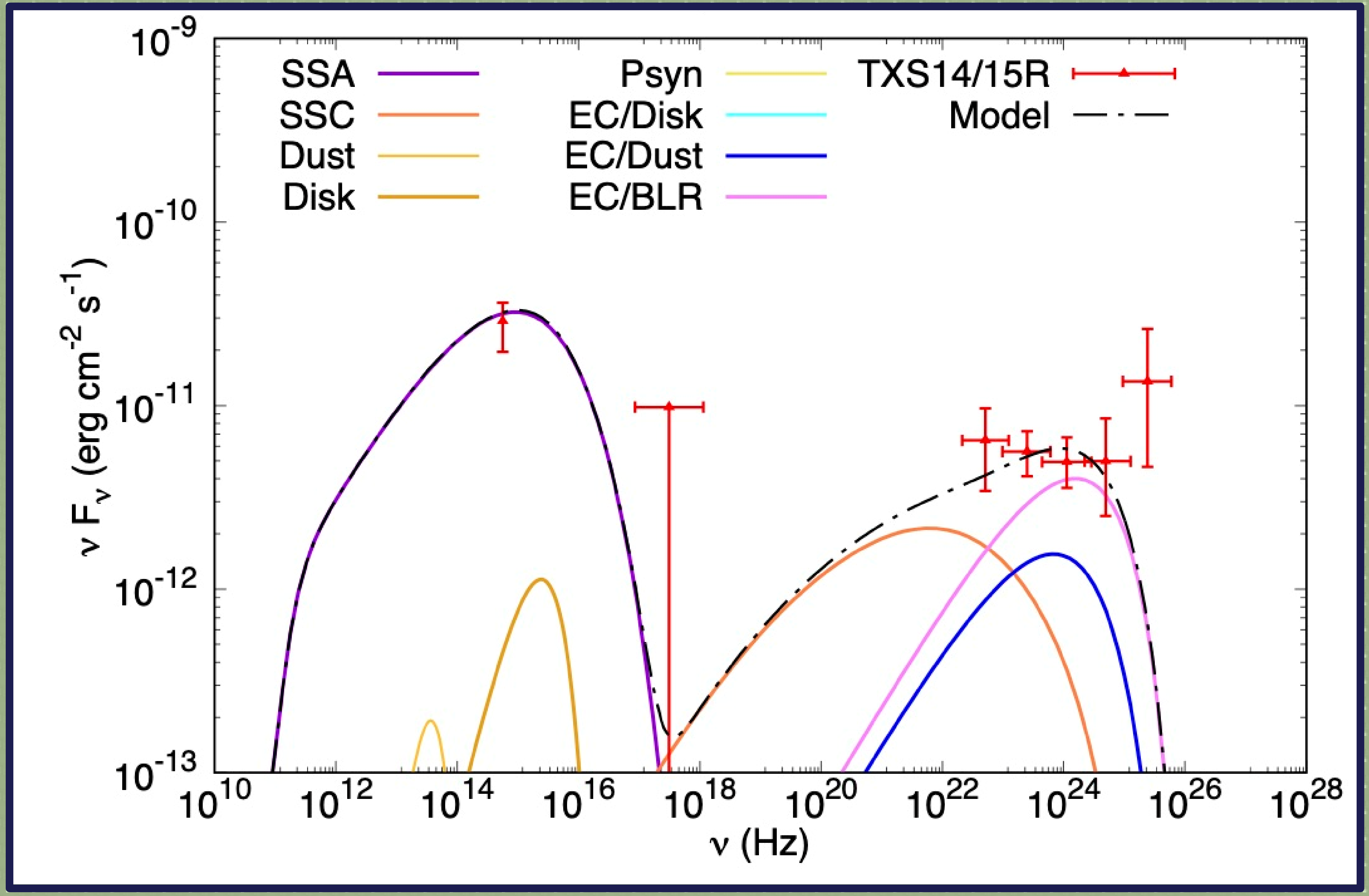
Particle Energy Loss Mechanisms: Photo-pion Production - Delta Resonance

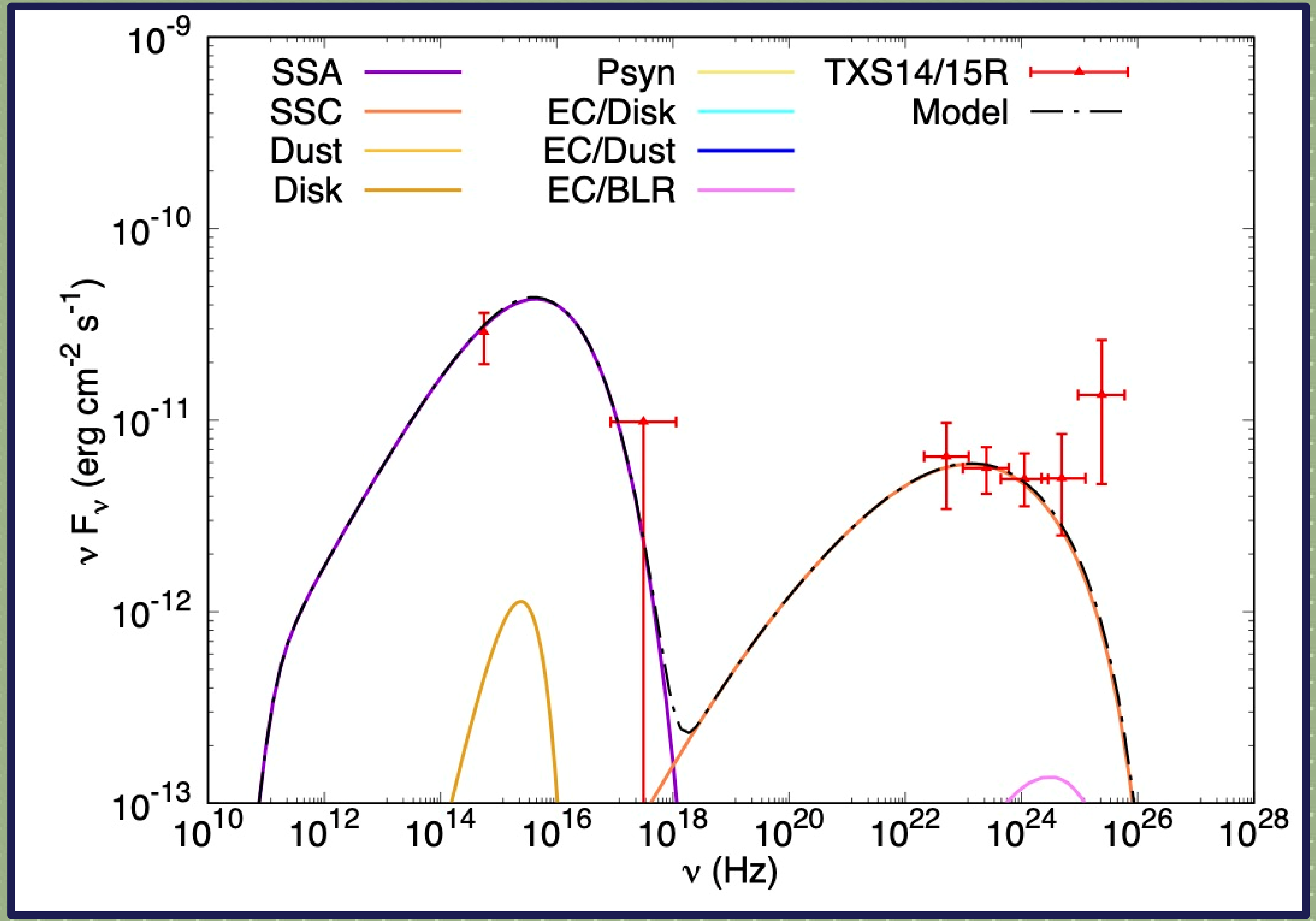


- **Photo-pion production contributes to cooling for the proton population**
- **It also has the potential to produce observable neutrinos, but I will not be showing neutrino spectra today.**

Illustration adapted from: Jonas Heinze

TXS 0506+056 Data: the 2014-2015 Neutrino Flare



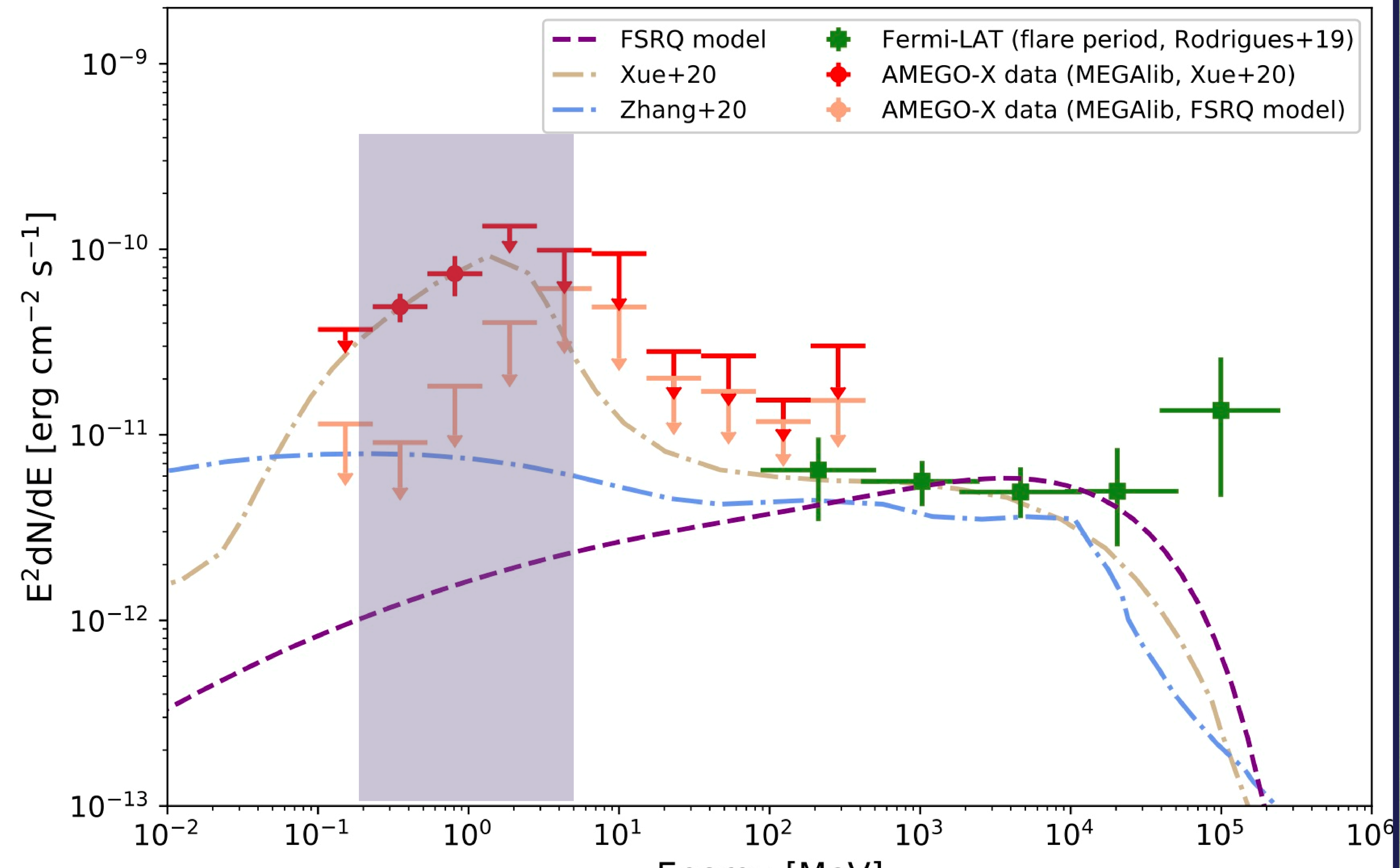


- Comparison of the FSRQ leptonic model to multiwavelngth flare data
- The model is tuned such that external Compton dominates in the γ-rays.

- Comparison of the BLL leptonic model to multiwavelngth data
- The model is tuned such that synchrotron self-Compton dominates in the γ-rays.

arXiv:2111.10600; submitting to ApJ; Data: Rodrigues et al. 2019

Simulating MeV Spectra for the 2014 Neutrino Flare



arXiv:2111.10600; submitting to ApJ)

In the figure:

- **Fermi LAT data is in green**
- **Simulated AMEGO-X data in red & peach**
- **3 leptohadronic models representing different dominant emission processes.**
    - Purple is Inverse Compton
    - Blue is hadronic cascades
    - Tan is 2 zones with coronal gamma-gamma absorbed cascade emission in the MeV, but inverse Compton in the GeV

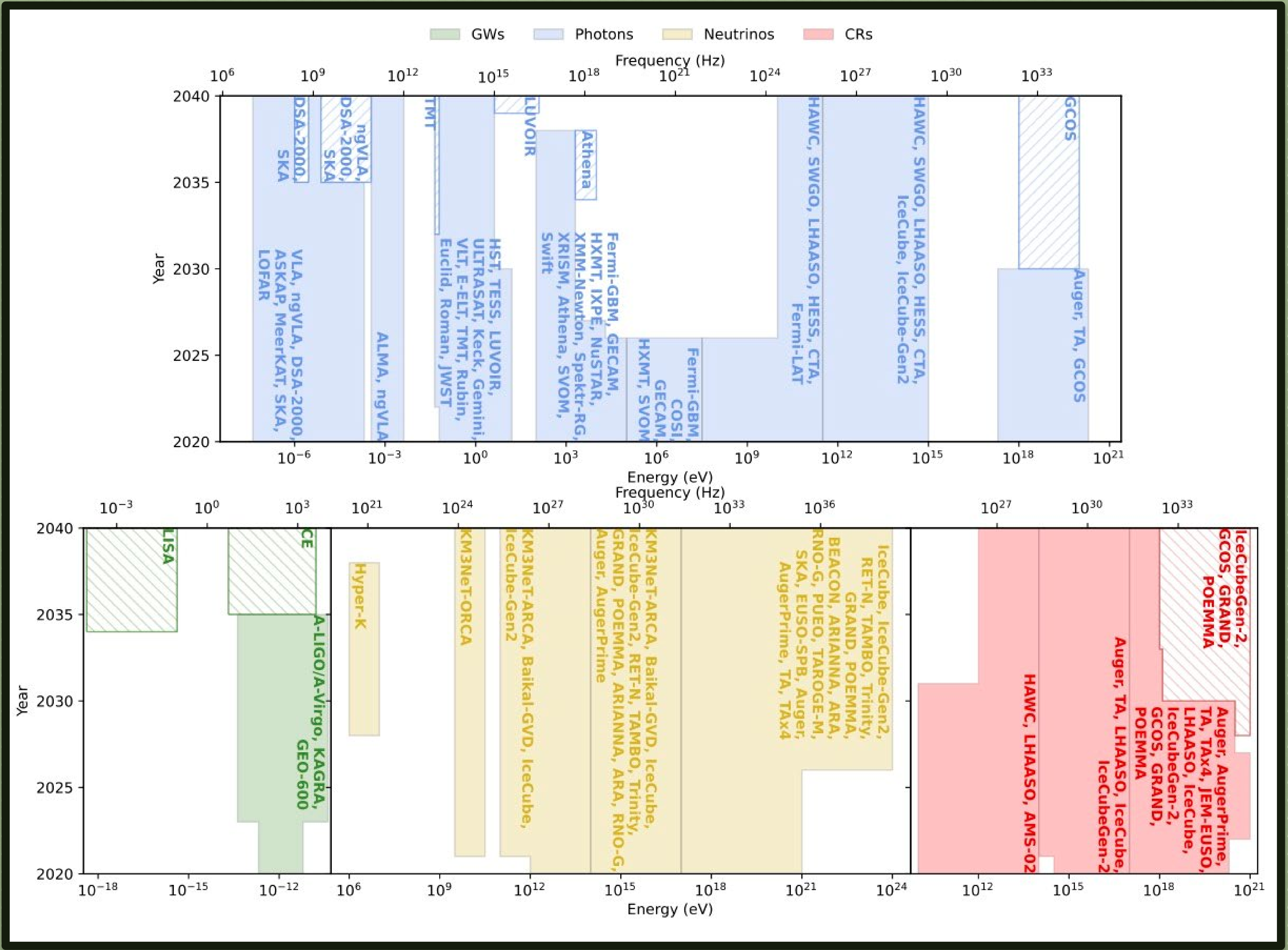
AMEGO-X would have detected the tan model or ruled it out through non-detection.

(arxiv:2208.04990; submitted to JATIS)

The purple box, containing the peak of the tan model, is COSI's sensitivity band.

- COSI is a large field of view 0.2-5 MeV gamma-ray satellite mission planned for launch in 2026 (Tomsick et al., arXiv:1908.04334, arXiv:2109.10403)
- COSI is expected to detect flares from ~35 blazars/year & a correlation study with IceCube events is planned

Multimessenger & Multiwavelength Programatic Balance



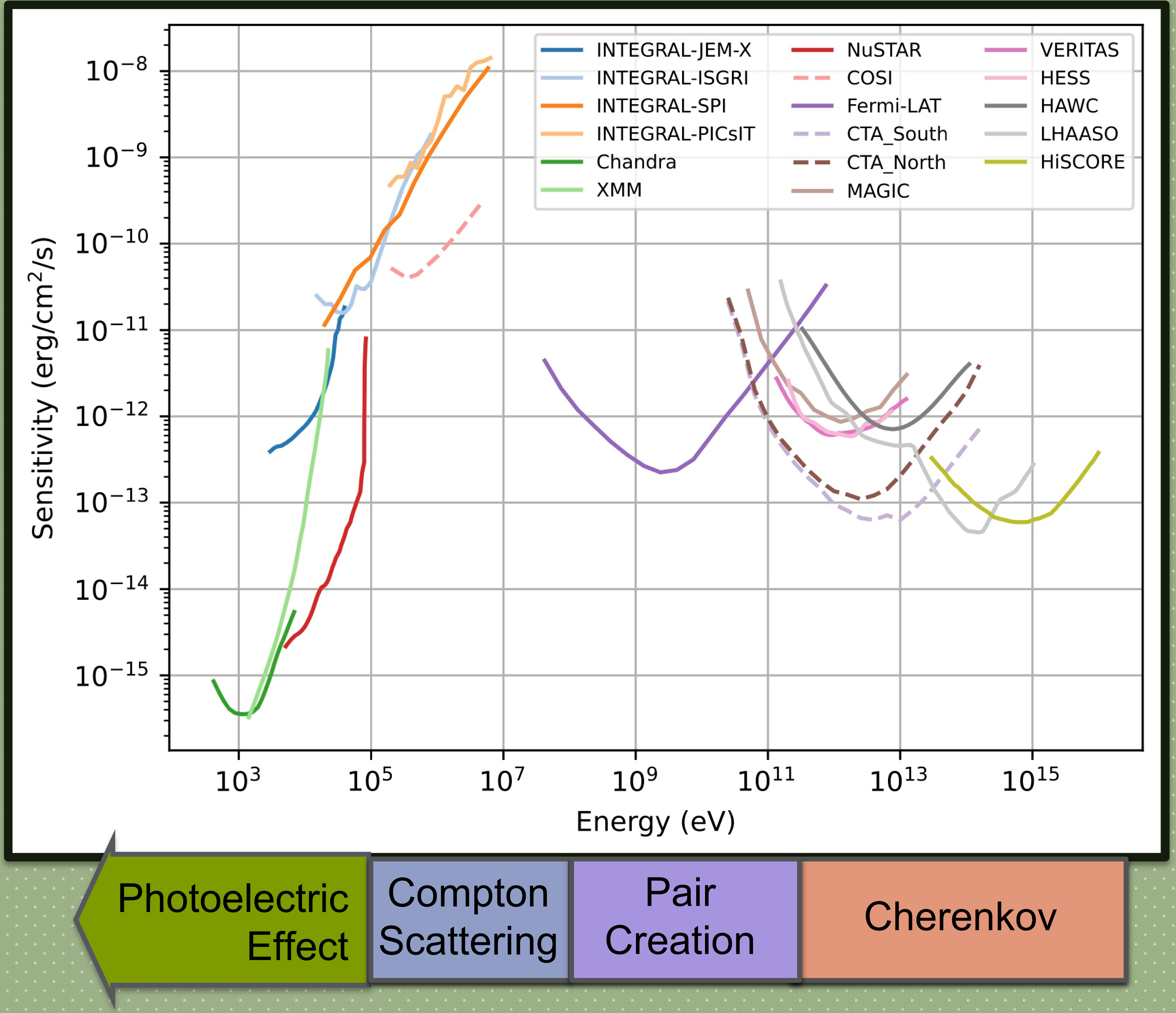
Spectral Timeline for current and planned facilities across all energies and messengers.

Most energies are set to either maintain or increase their coverage over the next 2 decades

- with the notable exception of MeV-GeV gamma-rays, which are historically central to multimessenger discoveries.

Image Credit: "Advancing the Landscape of Multimessenger Science in the Next Decade" arXiv:2203.10074; submitting to JHEAp

Key Investment in MeV Gamma Rays

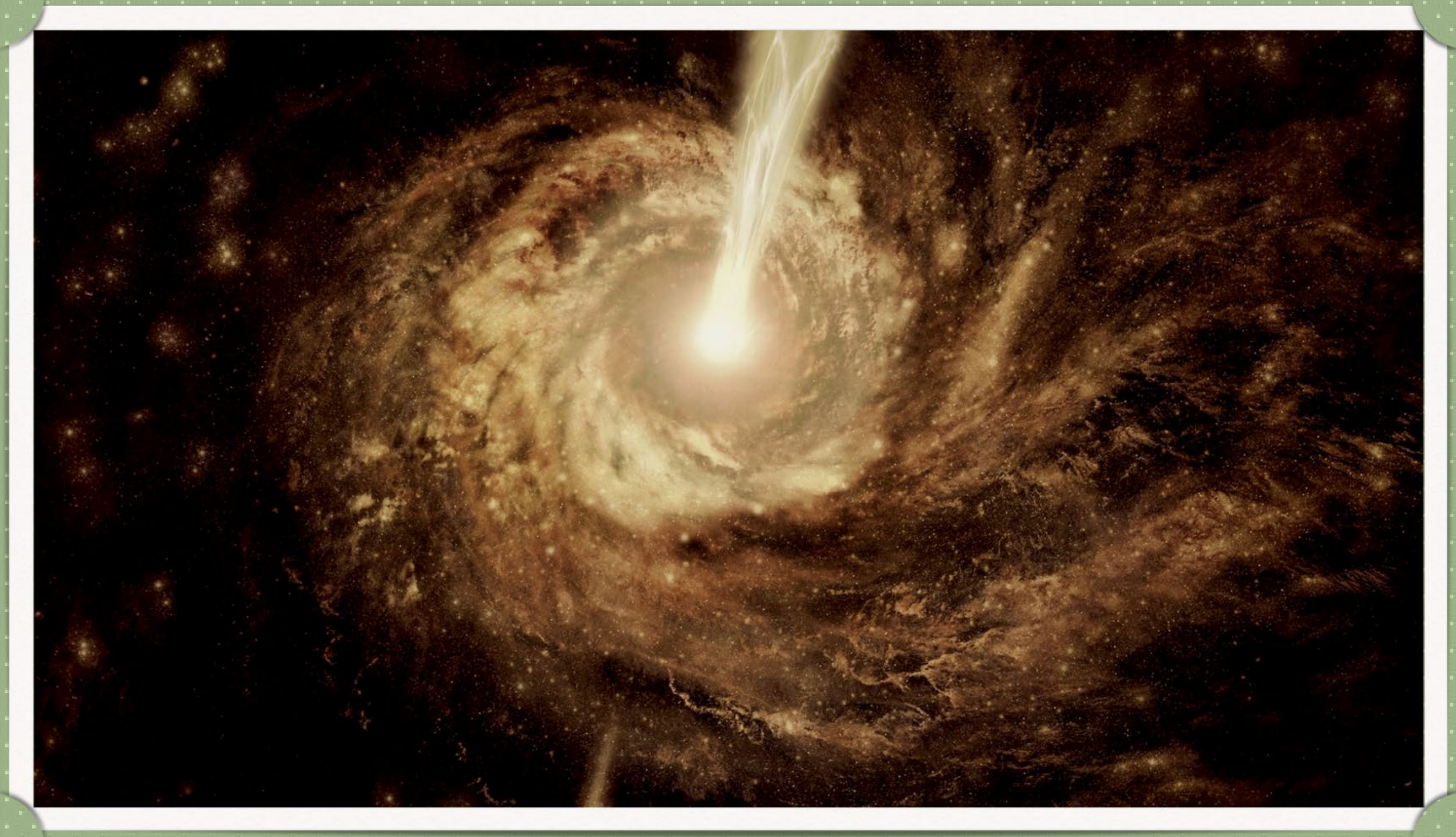


A key opportunity in the next decade is in MeV gamma-ray detector development

- **Unprobed astrophysics - DM, diffuse, AGN, pulsars, etc**
- **Key space for Multimessenger**
- **Relevant to collider detector development**

Also important to establish/maintain support for GeV and UHE gamma ray survey facilities.

Image Credit: "The Future of Gamma-Ray Experiments in the MeV-EeV Range"arXiv:2203.07360; submitting to JHEAp



Questions?

Engagement & Inclusion

DEIA support – providing educational and career development opportunities

Engagement with the general public is a key pillar of support for science in general and funding for astrophysics in particular.

Examining our decisions about admissions, hiring, teaching and mentoring to support excellence through individual achievement of full potential.

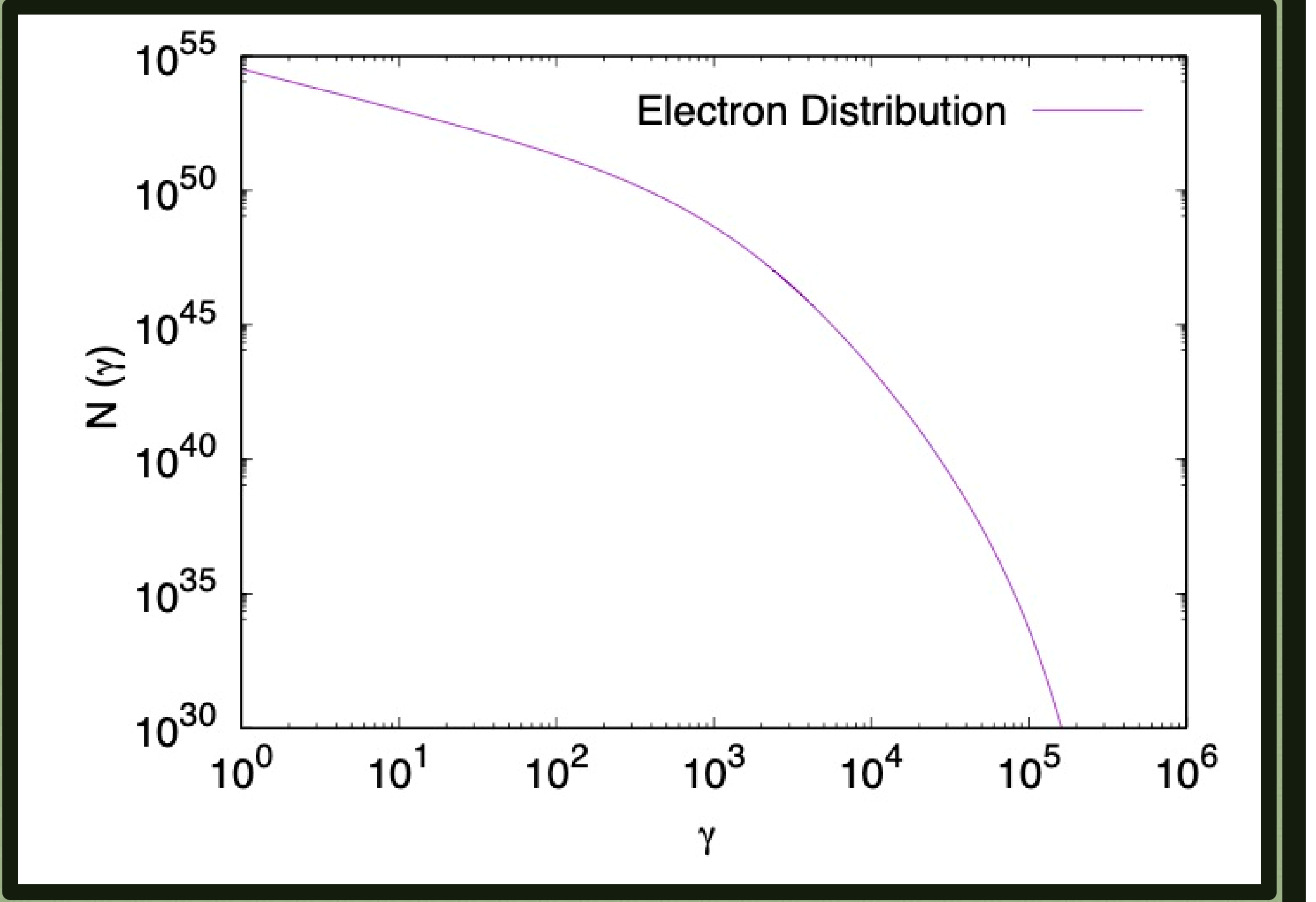
Track demographic information

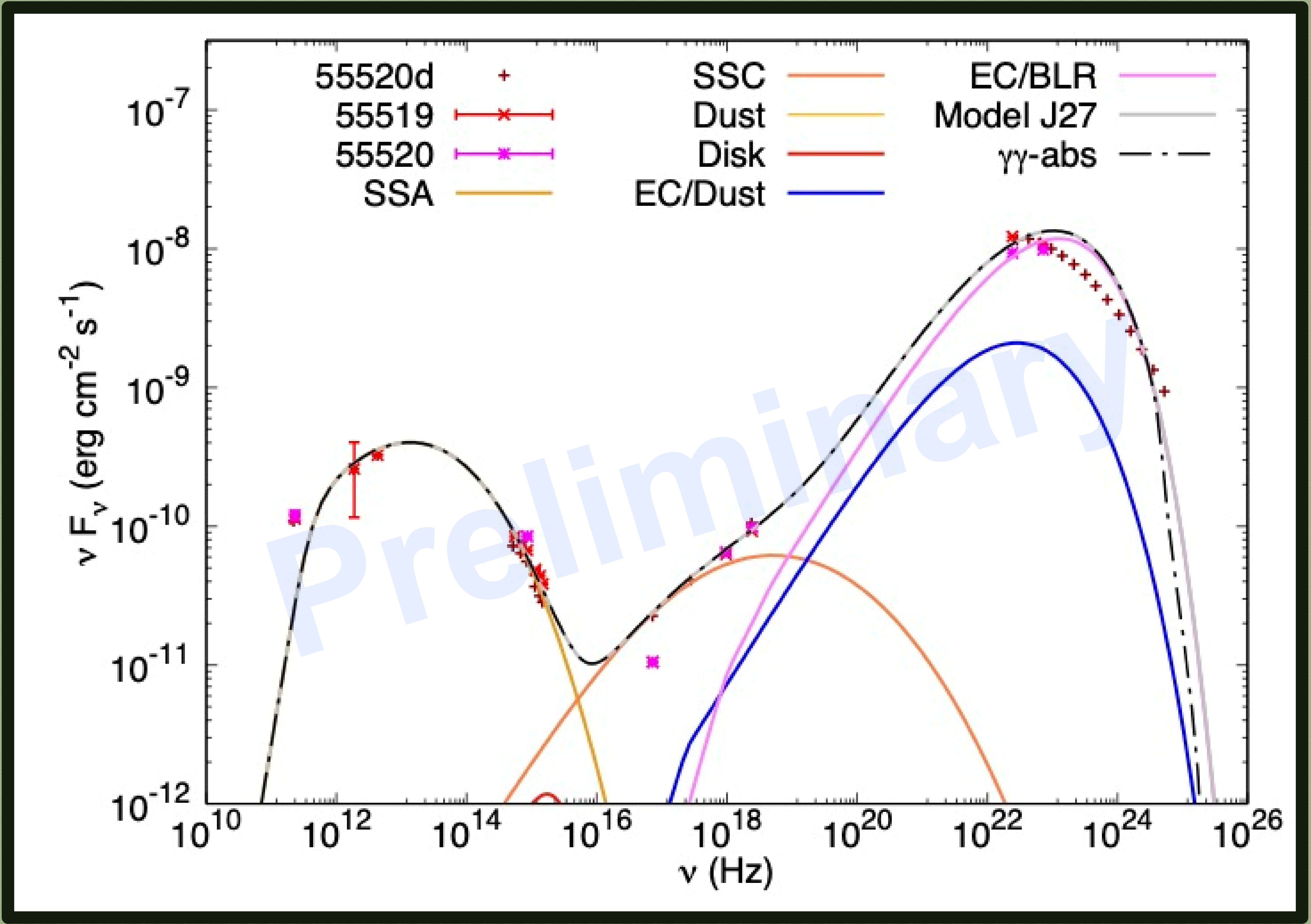
Consider DEIA service in science positions

Astronomy that is invisible and physics that is inaccessible poses specific challenges to communication with the public - we have to do it anyway, and a lot.

Set aside expert time and funding to produce accessible explanations of key topics and distribute them broadly.

Leptonic Analysis of 3C 454.3



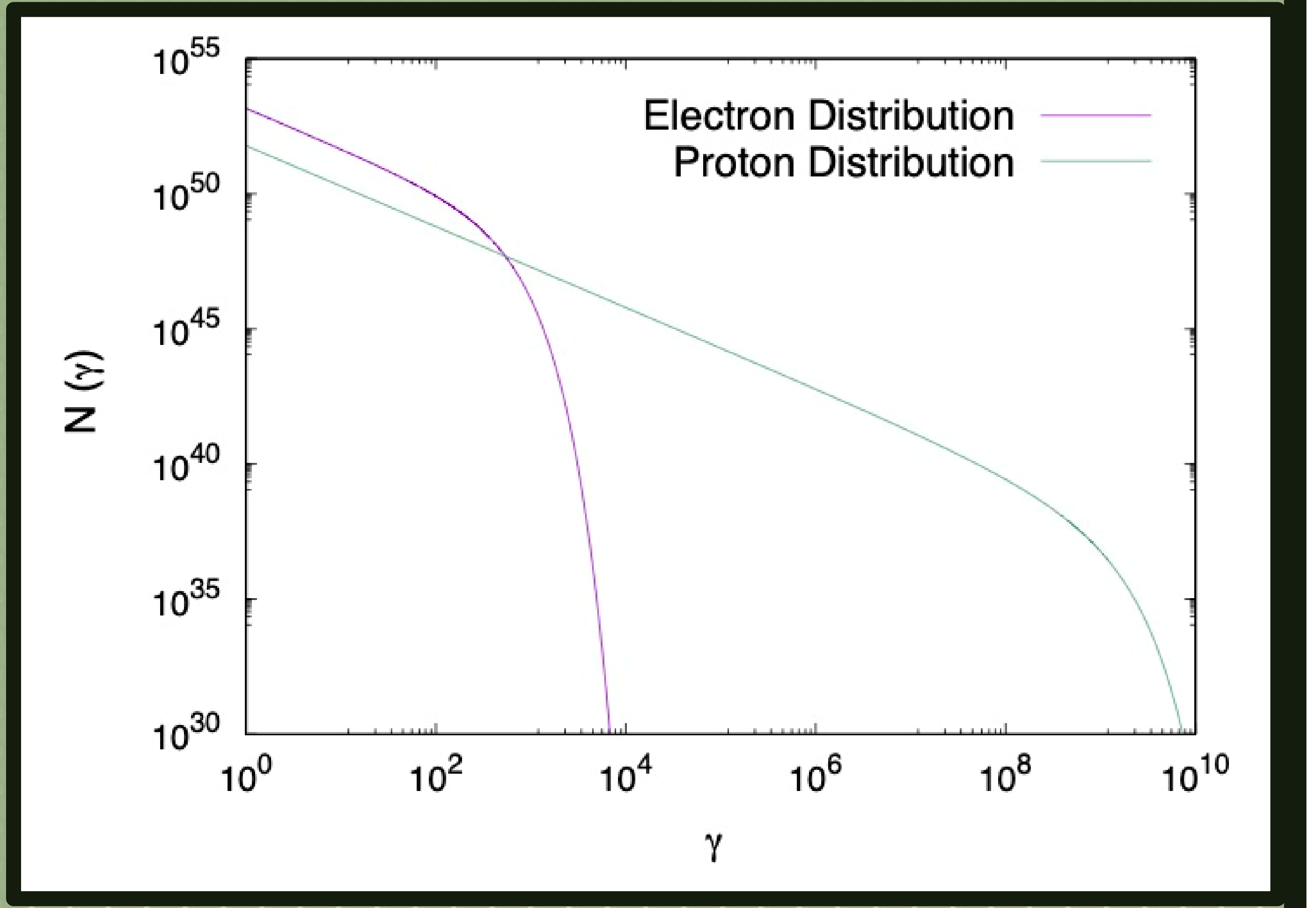


Data: Wehrle et al. (2012)
Flare on 19-20 Nov 2010
(or 55519-20)

There are 3 different representations of the MWL data in the paper.

- **Blob is located toward the outer edge of the BLR**
- **Jet is slightly field dominated**
- **Accretion driving ratio indicates magnetically arrested accretion**
- **Maximum magnetization parameter - reconnection possible**

Leptohadronic Analysis of 3C 454.3



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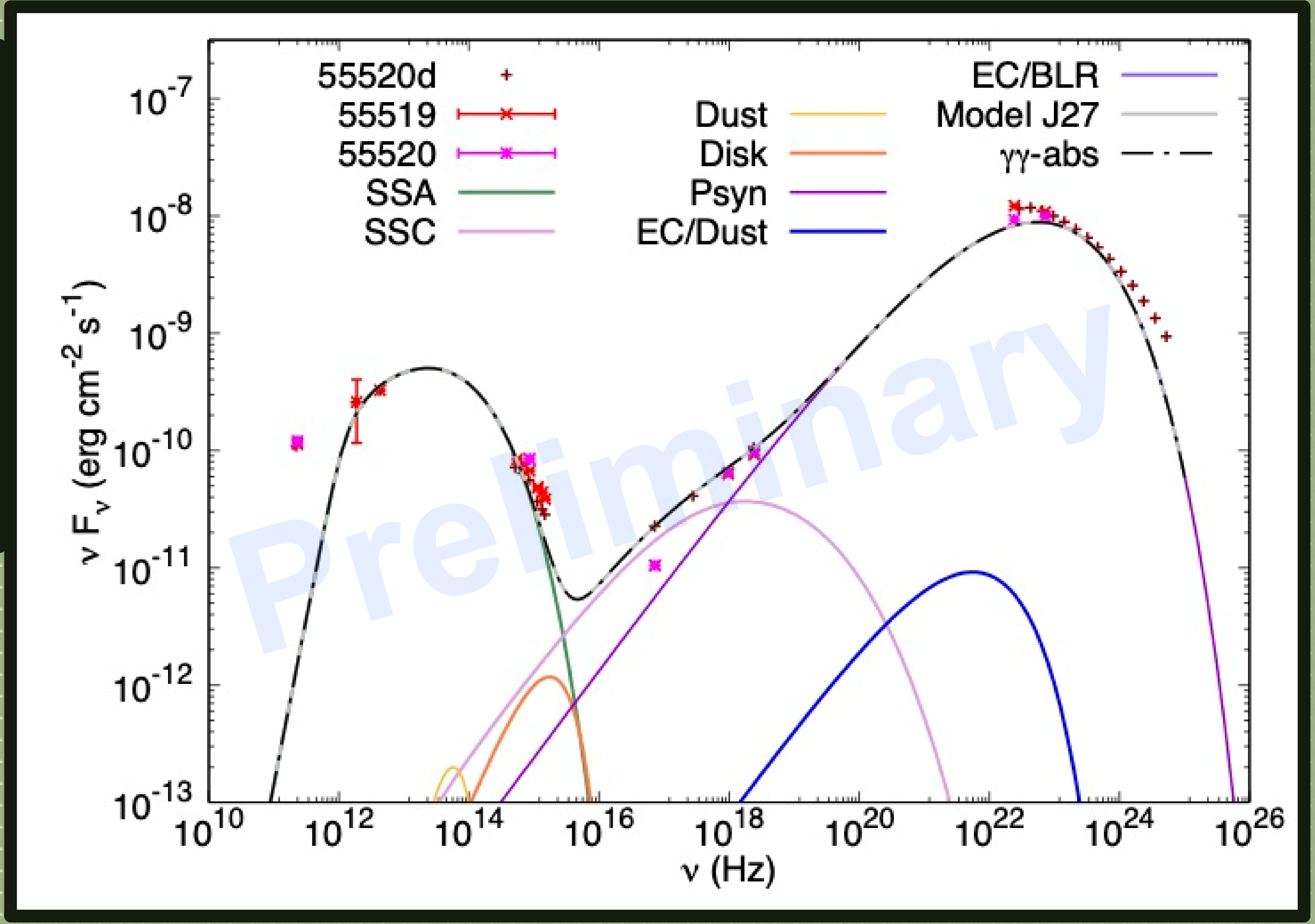

- Blob is located well outside the BLR (3-4pc) - total external energy density lower
- Jet power is proton dominated - SS73 accretion not sufficient
- Moderate magnetic field for a LH model (B=9 G)

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