ST3G

"Stègue"

Self-**t**riggering **T**PC **T**elescope for **G**amma-rays

Deirdre Horan, Conseil Scientifique du LLR, 21.11.2016

Outline

- Gamma-ray astrophysics in the MeV range
- ST3G - the prototype detector
- Our plan

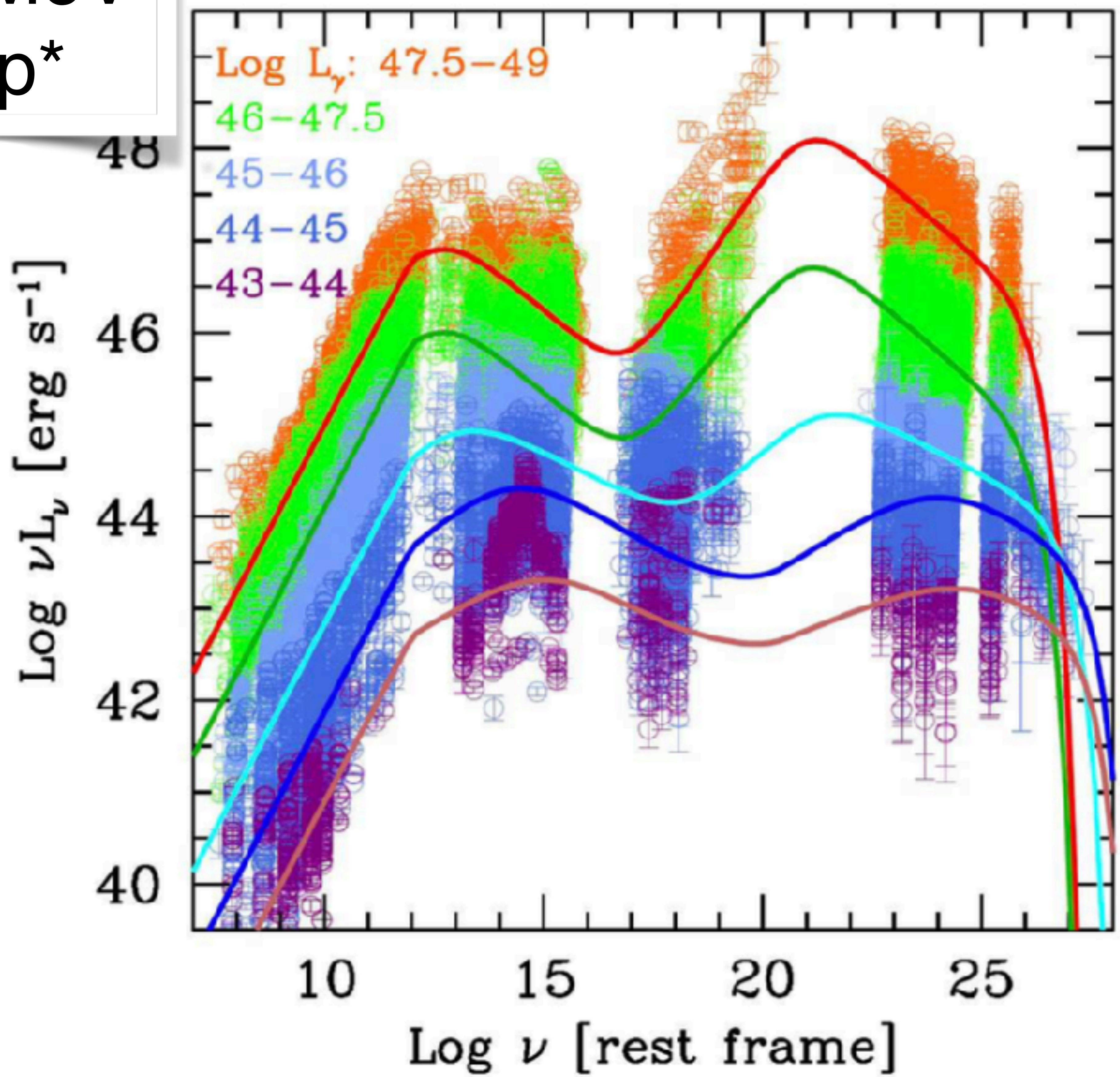
ST3G - key characteristics

- Energy range: a few MeV - a few GeV
- Polarisation capabilities
- High angular resolution:
  - 0.4 deg at 100 MeV

    (4 deg at 100 MeV for *Fermi* LAT)

The MeV Gap

The MeV Gap*



Ghisellini arXiv:1609.08606

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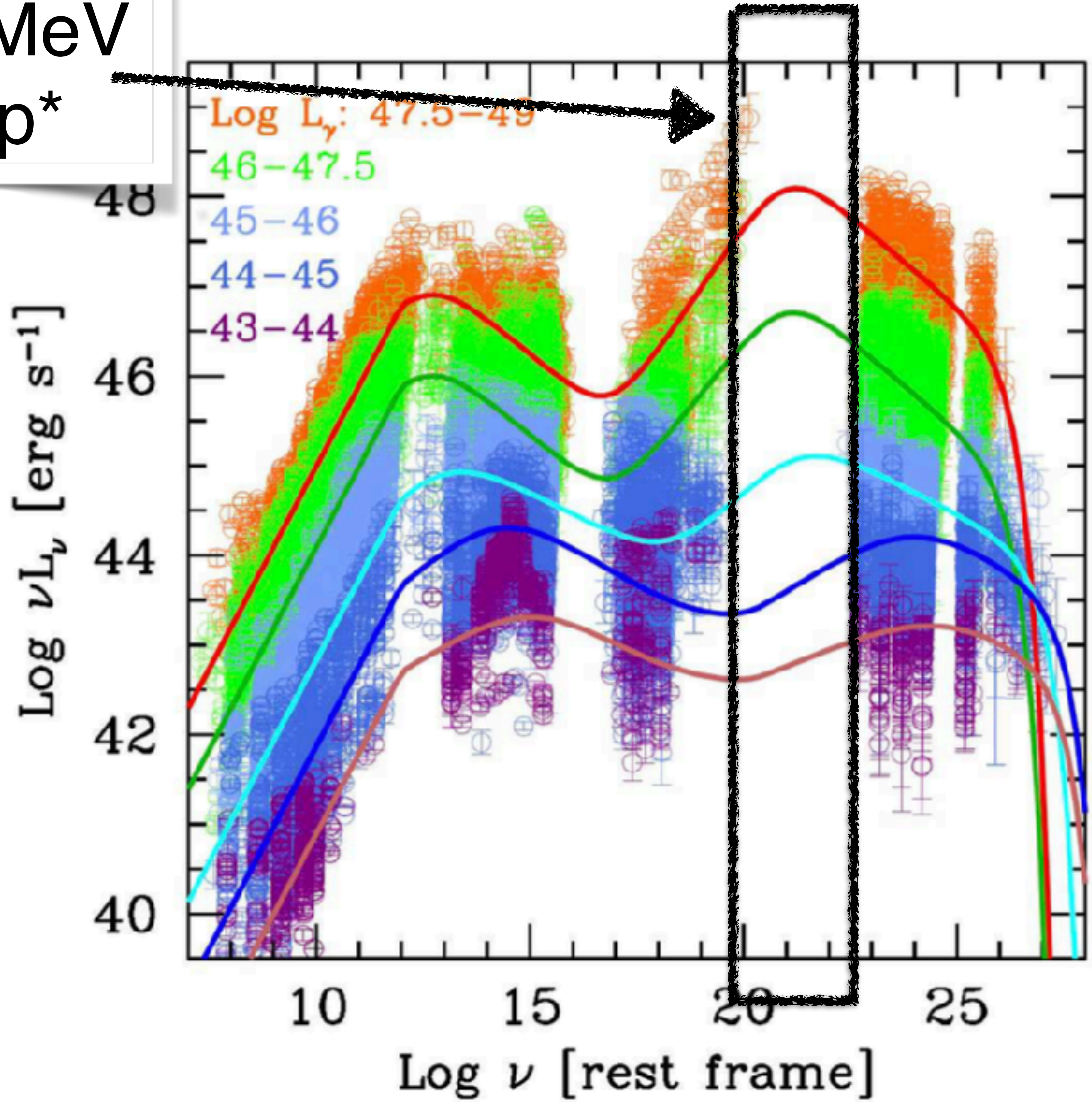

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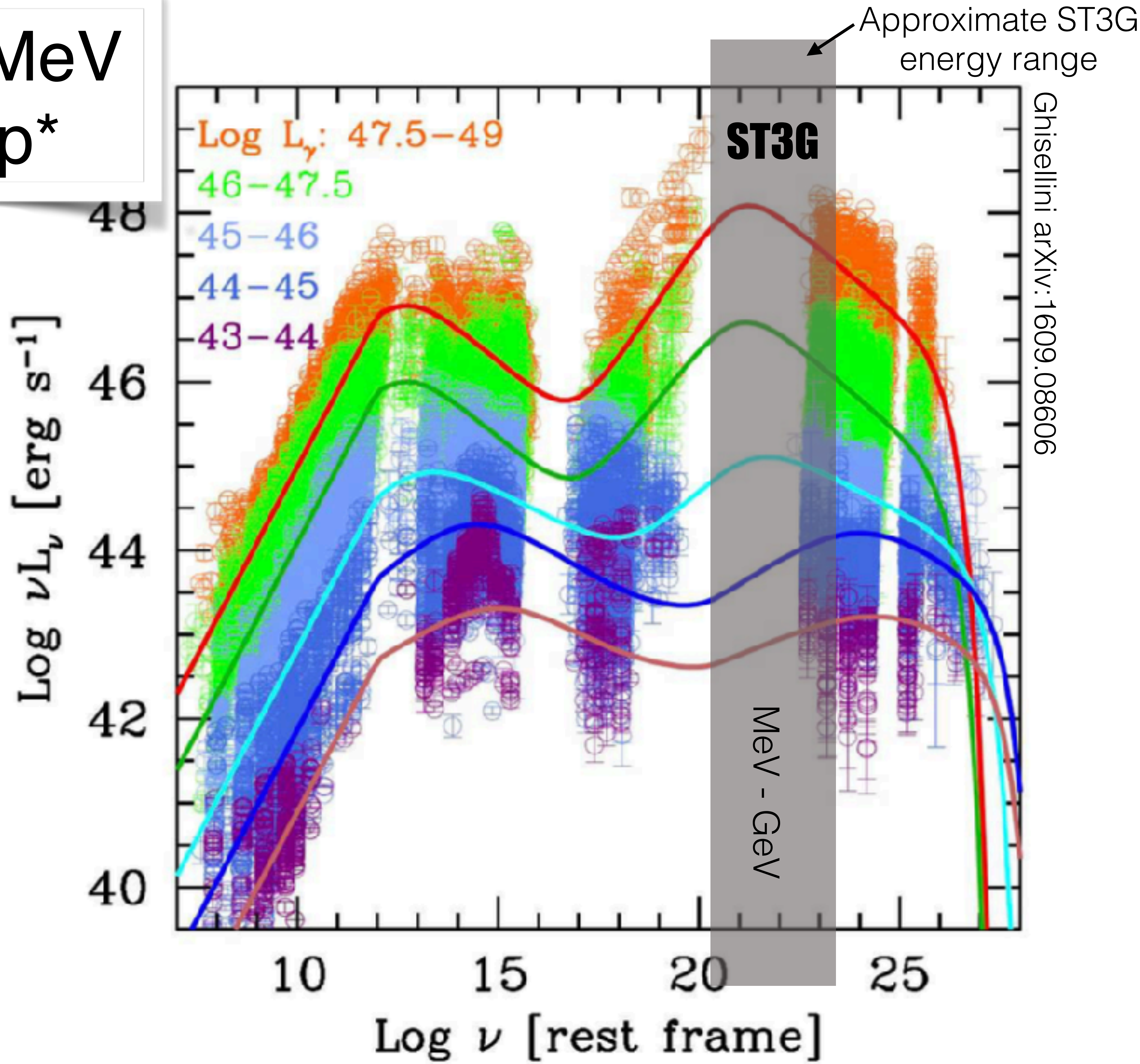

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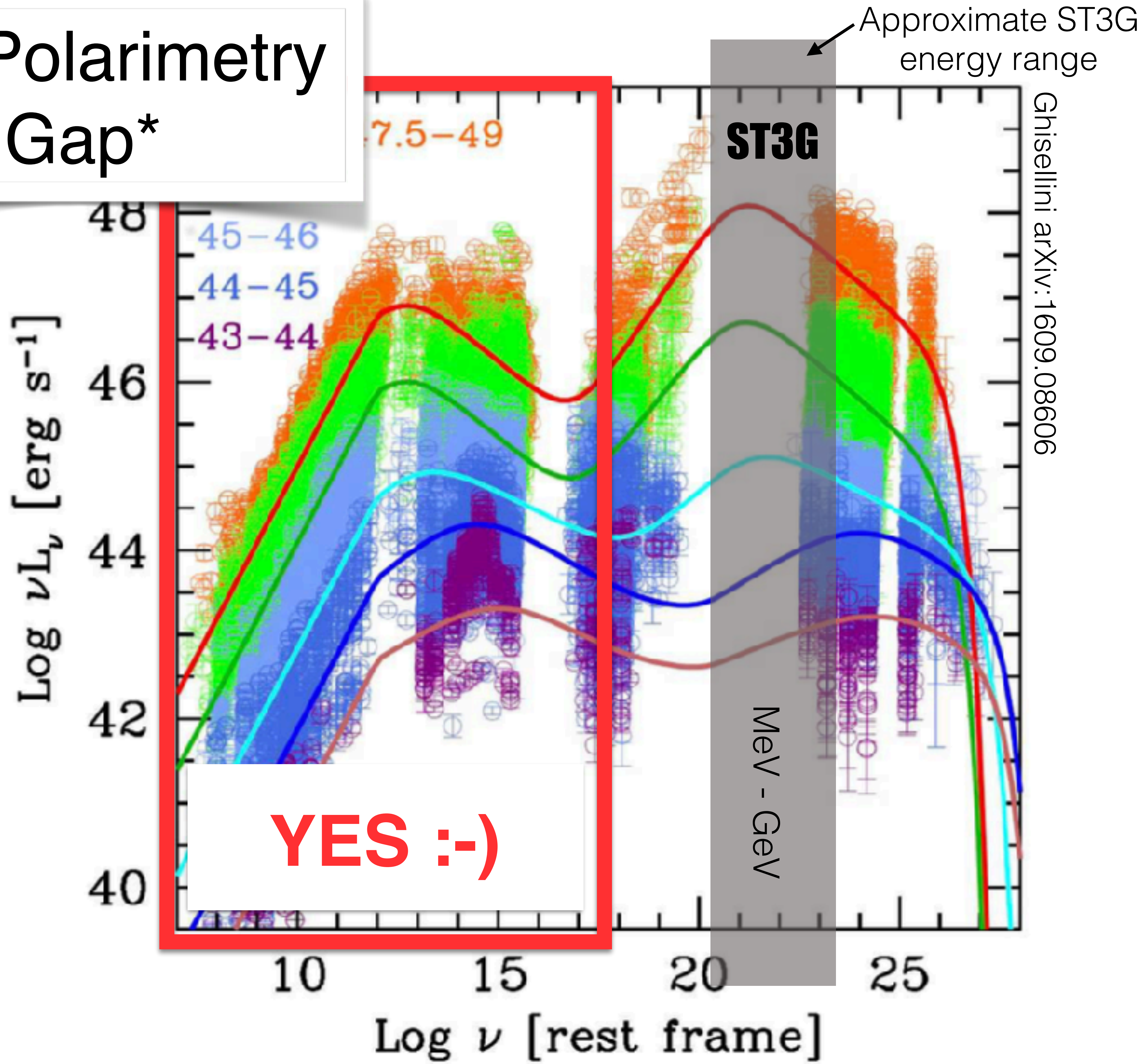

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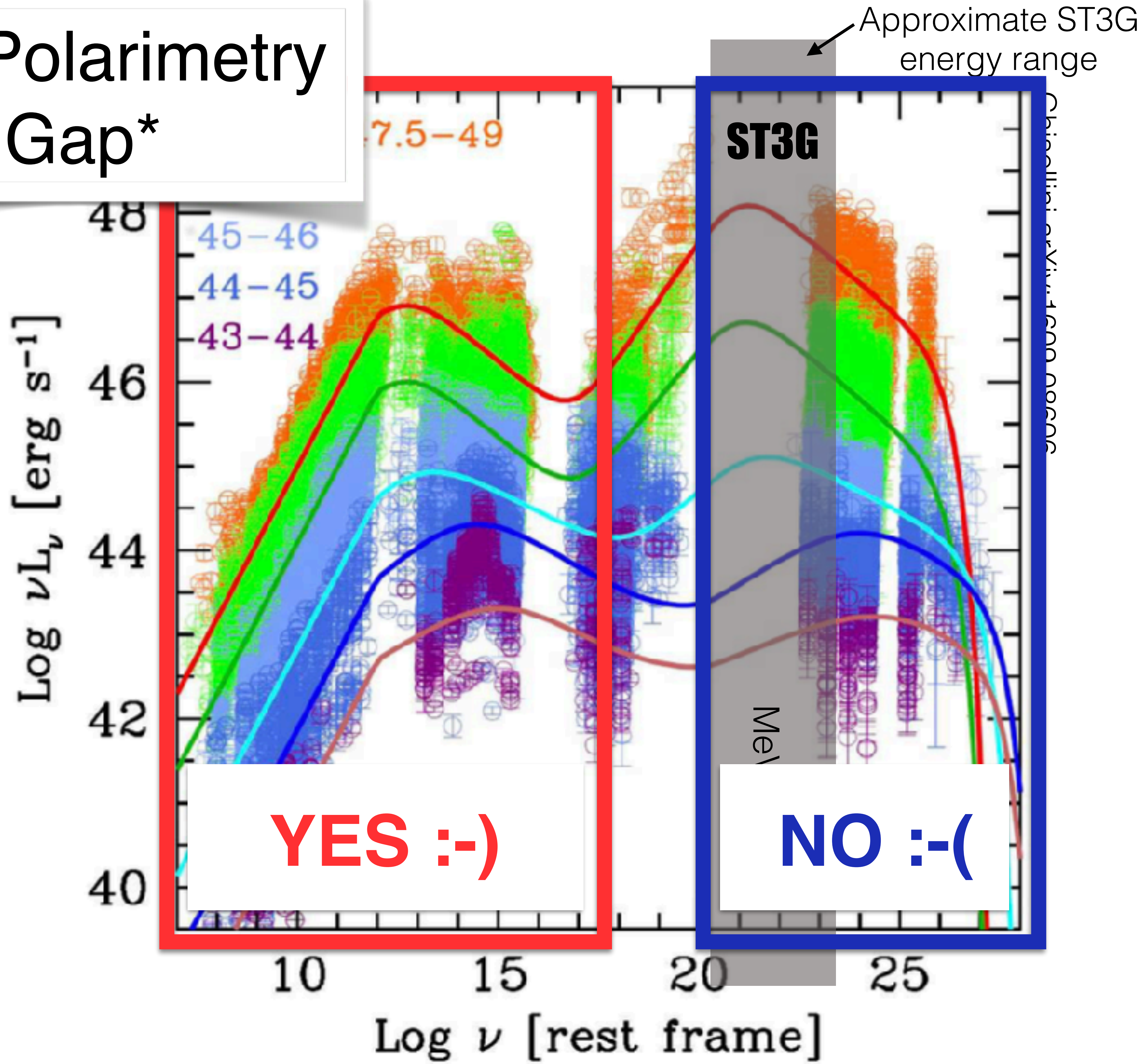

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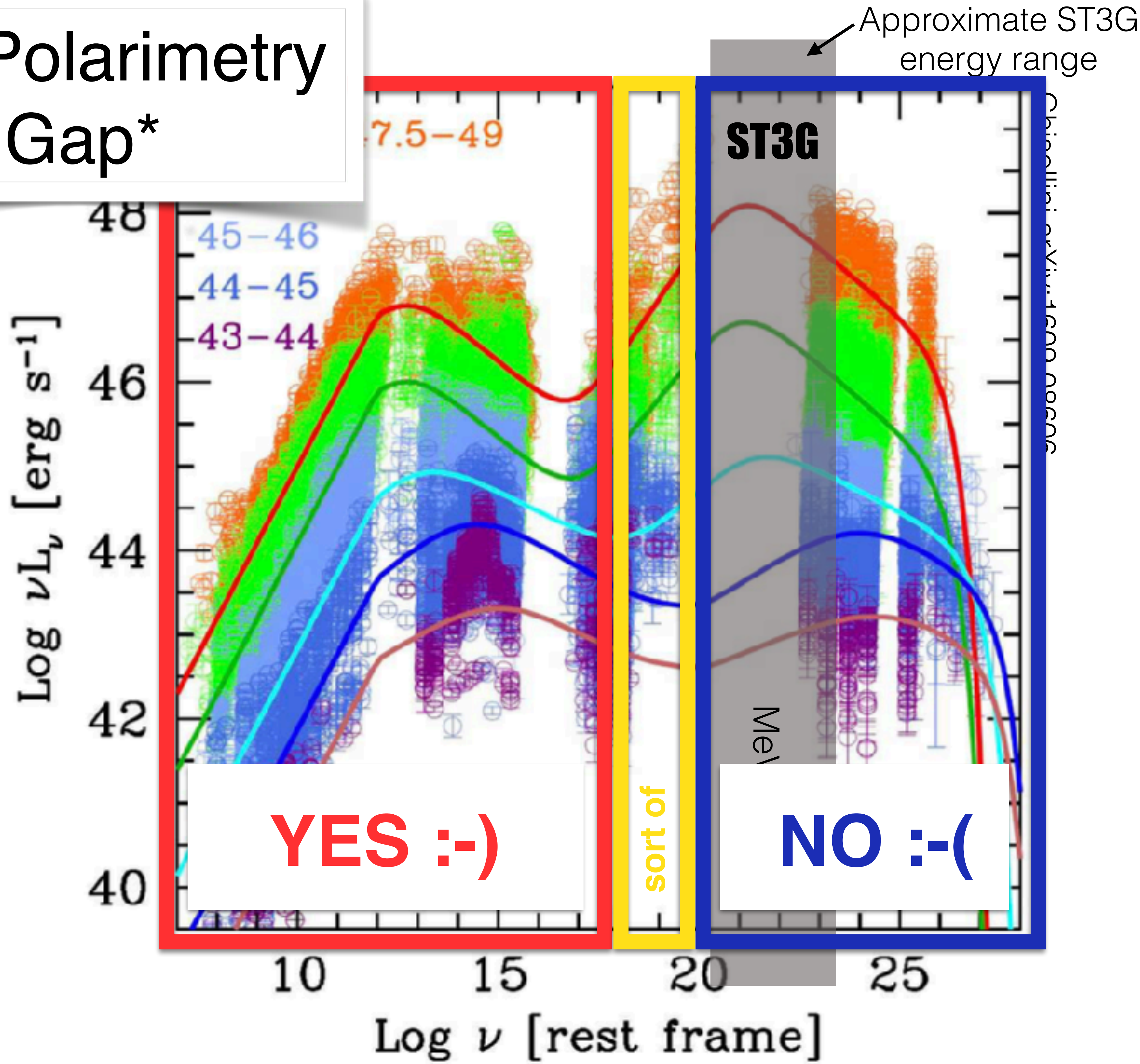

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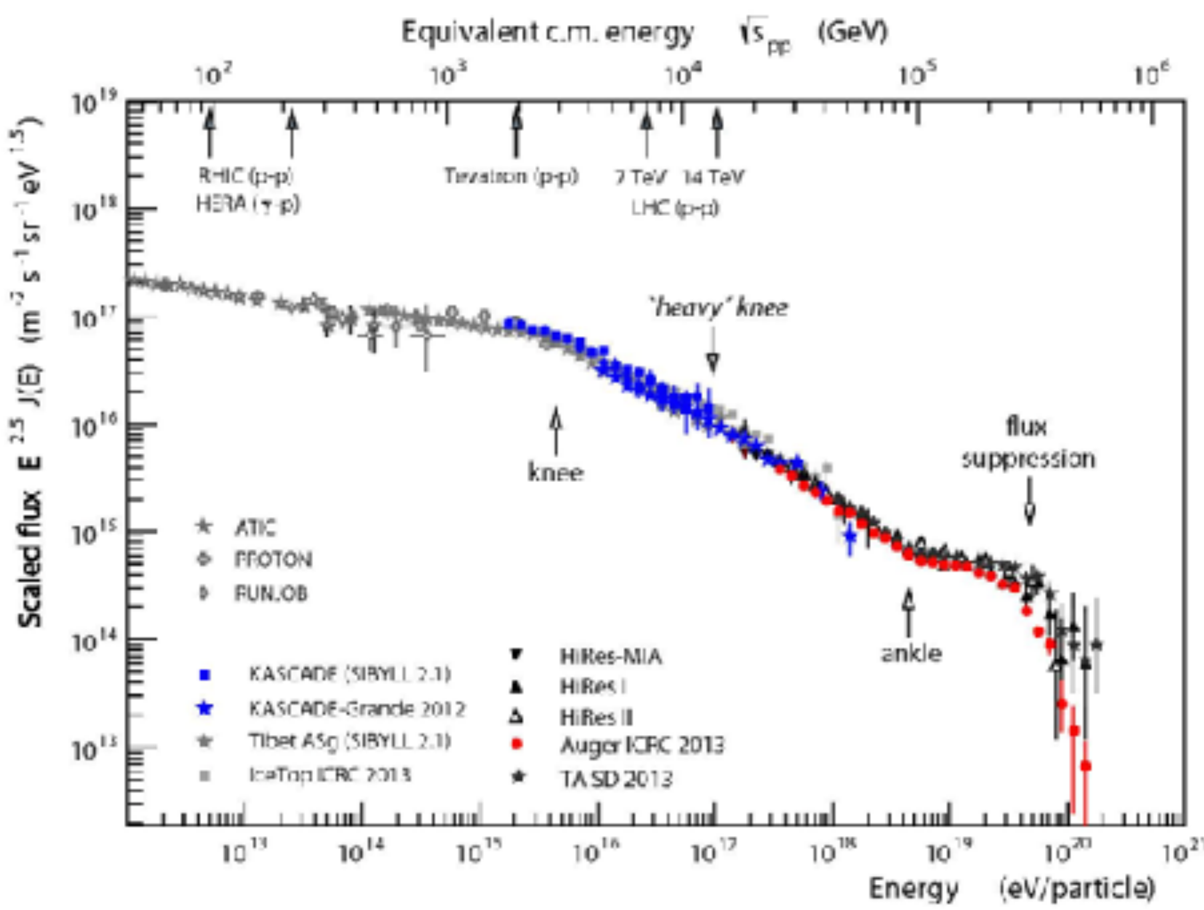
Gamma-ray Astrophysics at MeV energies

a few key questions ...

- Where do the UHECRs come from?
- How do supermassive black holes form?
- Is Lorentz invariance violated?

Where do the UHECRs come from?



The measured spectrum of cosmic rays taken from Andreas Haungs' talk at APPEC 2016

- Today, 100+ years after their discovery, the origin of the ultra-high energy cosmic rays (UHECRs; E > 10^{17}eV), remains one of the greatest unsolved mysteries in astrophysics
- Exquisite measurements of the spectrum of cosmic rays have been made
- No individual source or population of sources has been identified as the accelerator of the UHECRs

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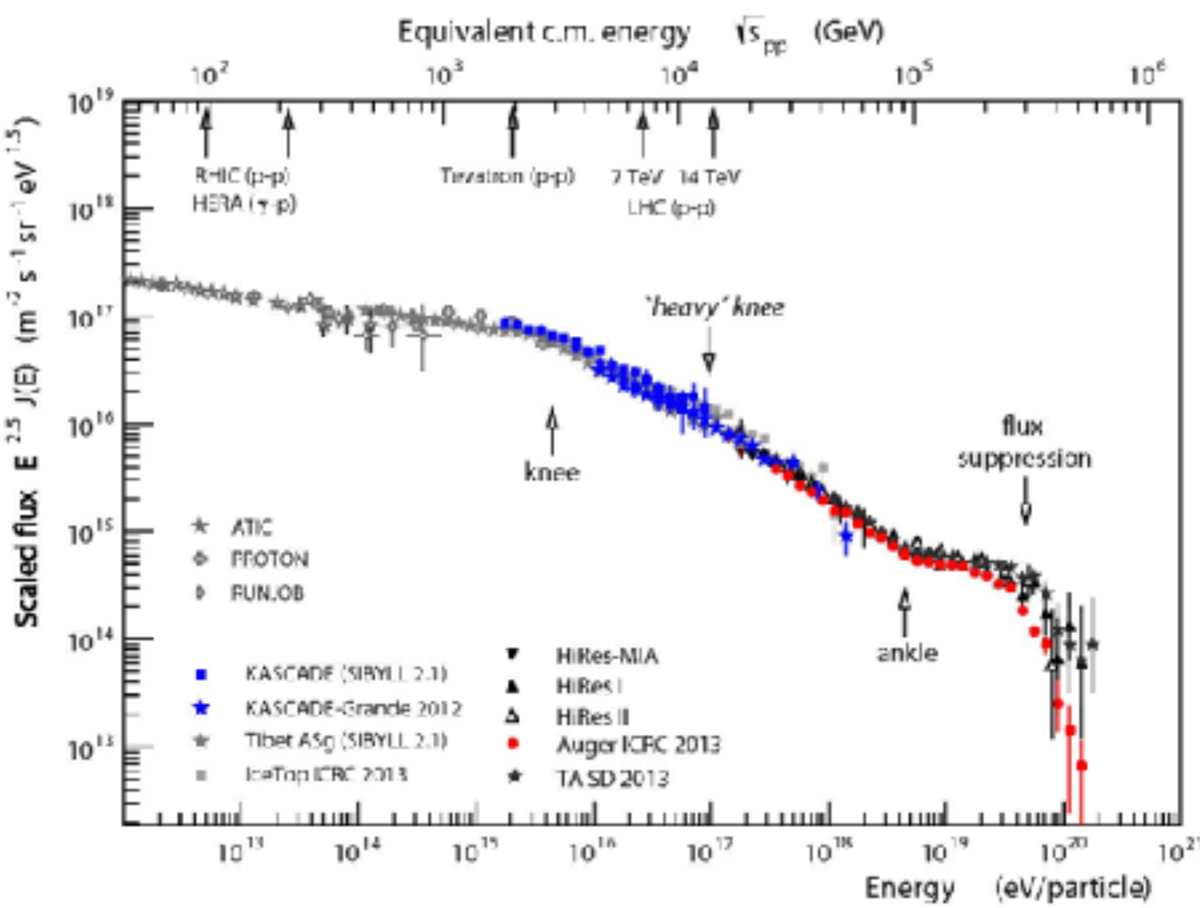

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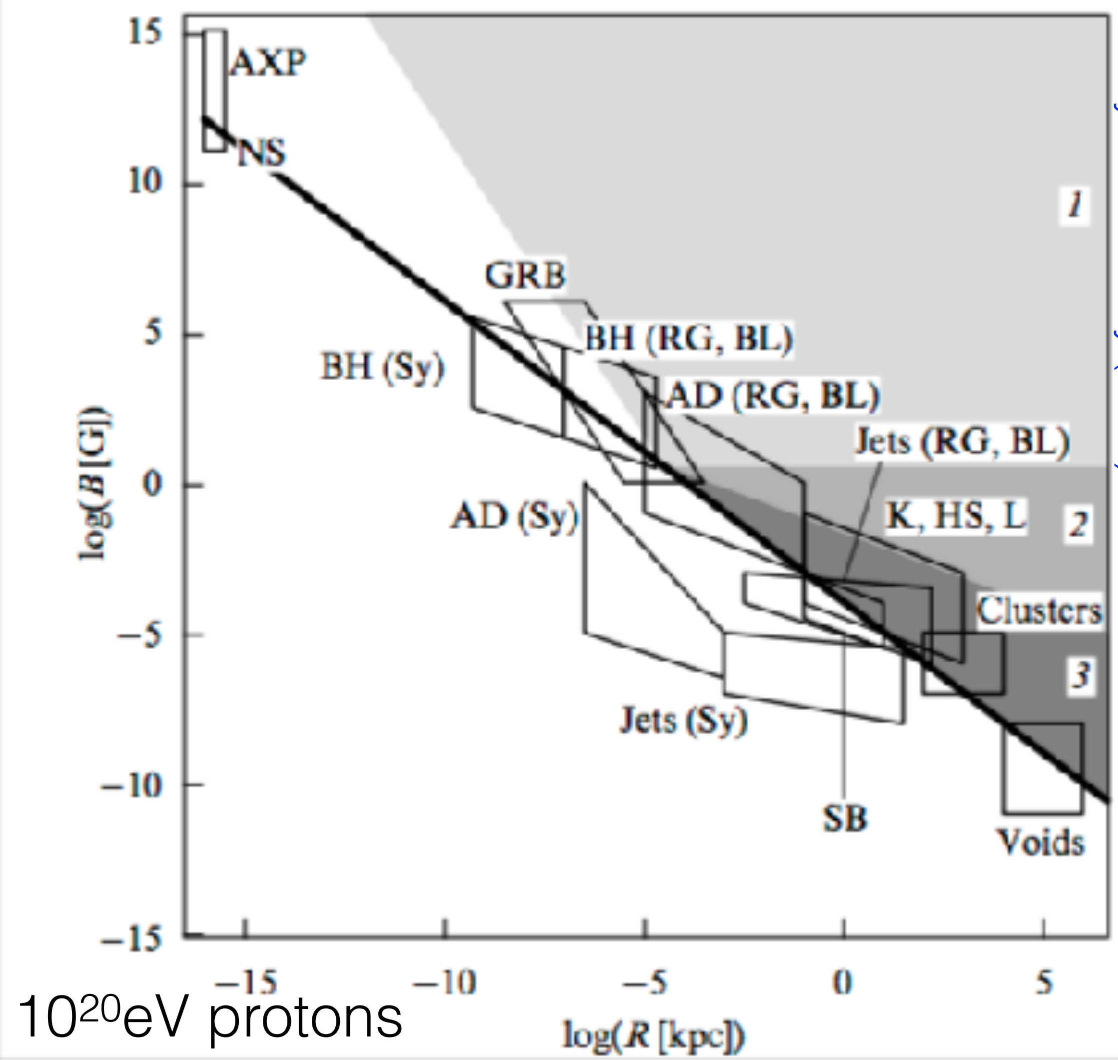

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- Exquisite measurements of the spectrum of cosmic rays have been made
- No individual source or population of sources has been identified as the accelerator of the UHECRs
- Many theories exist and can be summarised by looking at the updated version of the famous Hillas diagram from 1984

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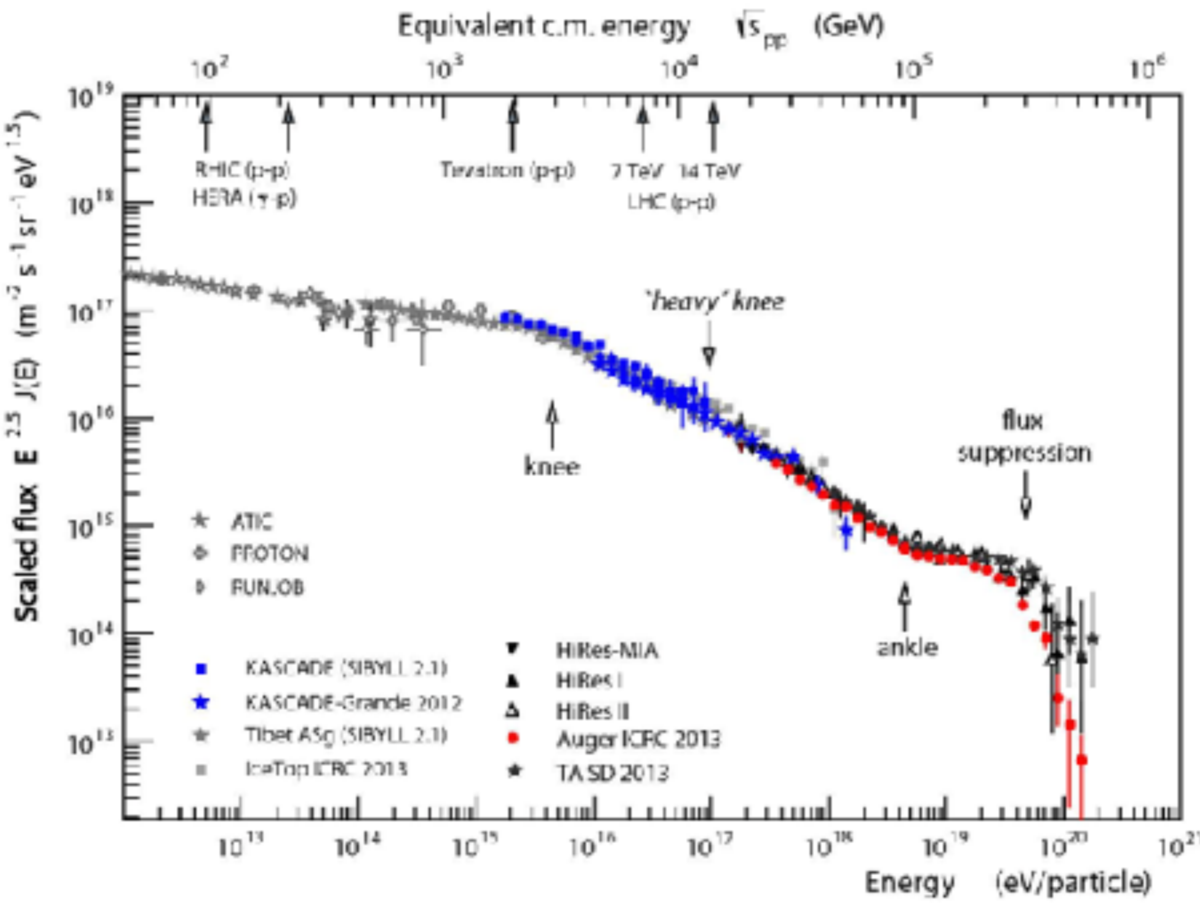

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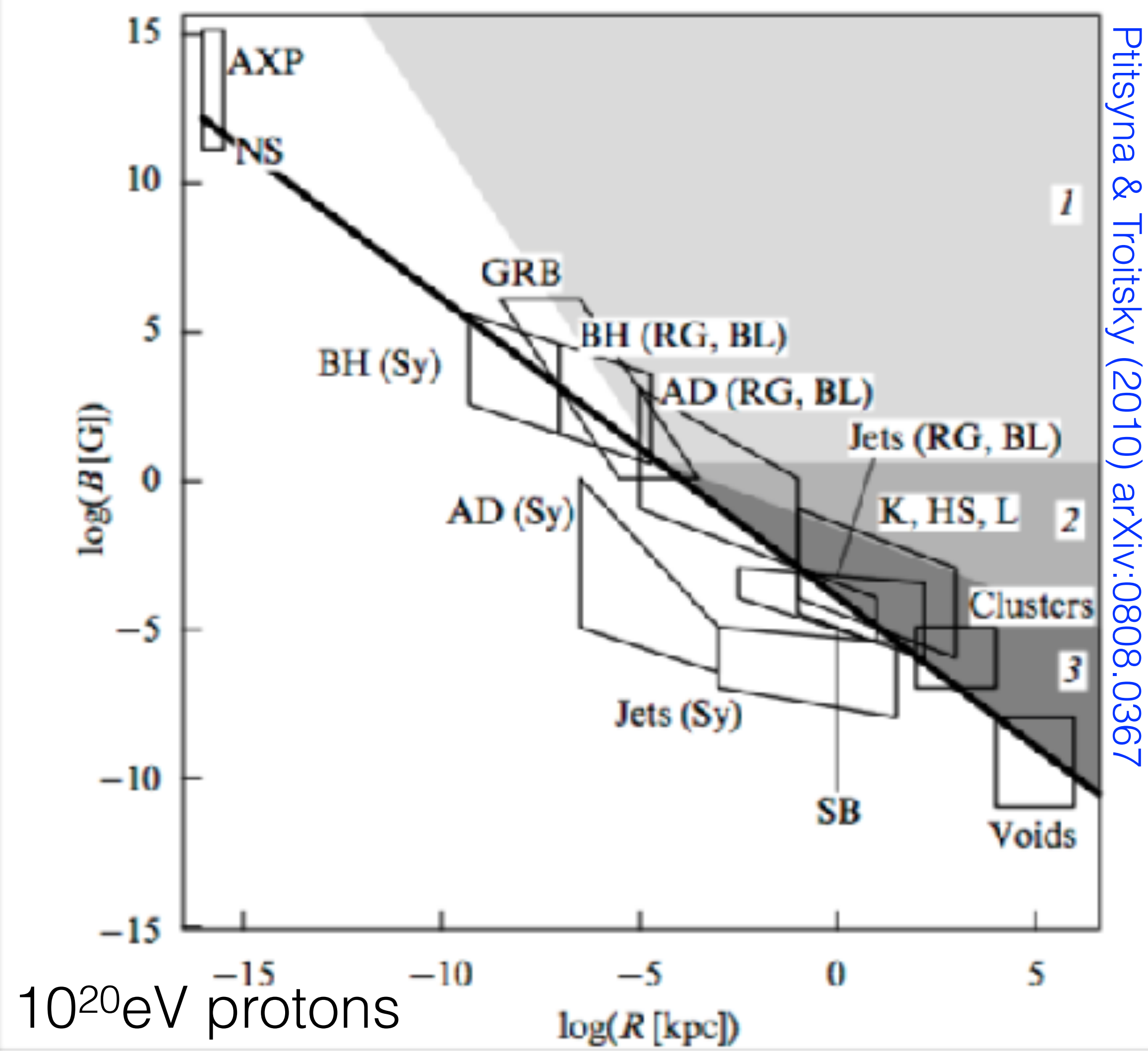

- Since the particle must acquire its energy before leaving the accelerator, and, since the particle is presumed to be accelerated by the while being confined by the magnetic field, the Larmor radius of the particle must not exceed the linear size of the accelerator
- This is known as the Hillas criterion and is represented graphically in the Hillas plot (Hillas 1984)
- The acronyms are defined as follows: BH - black hole; RG - radio galaxy; BL - blazars; AD - central parsec; K - knots; HS - hot spots; L - lobes; SB - starbursts;

Where do the UHECRs come from?

- AGN and their various constituent parts occupy a large portion of this diagram and thus, comprise the physical conditions necessary to accelerate protons to UHE
- The authors of this plot claim that only the most powerful AGN, i.e., radio galaxies, quasars and BL Lac type objects, are capable of accelerating protons to such energies
- They list jets, lobes, knots and hot spots of the powerful AGN as other possible acceleration sites

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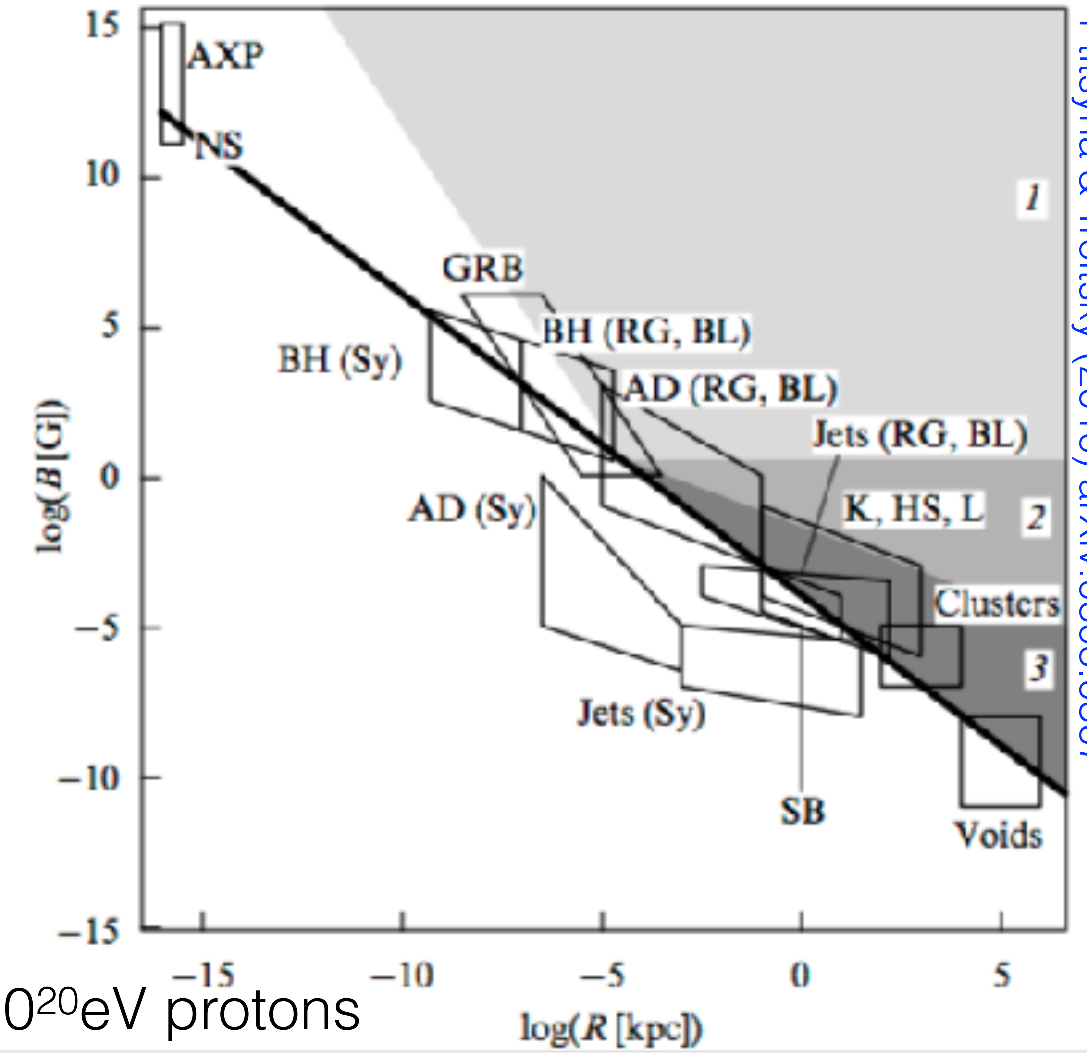

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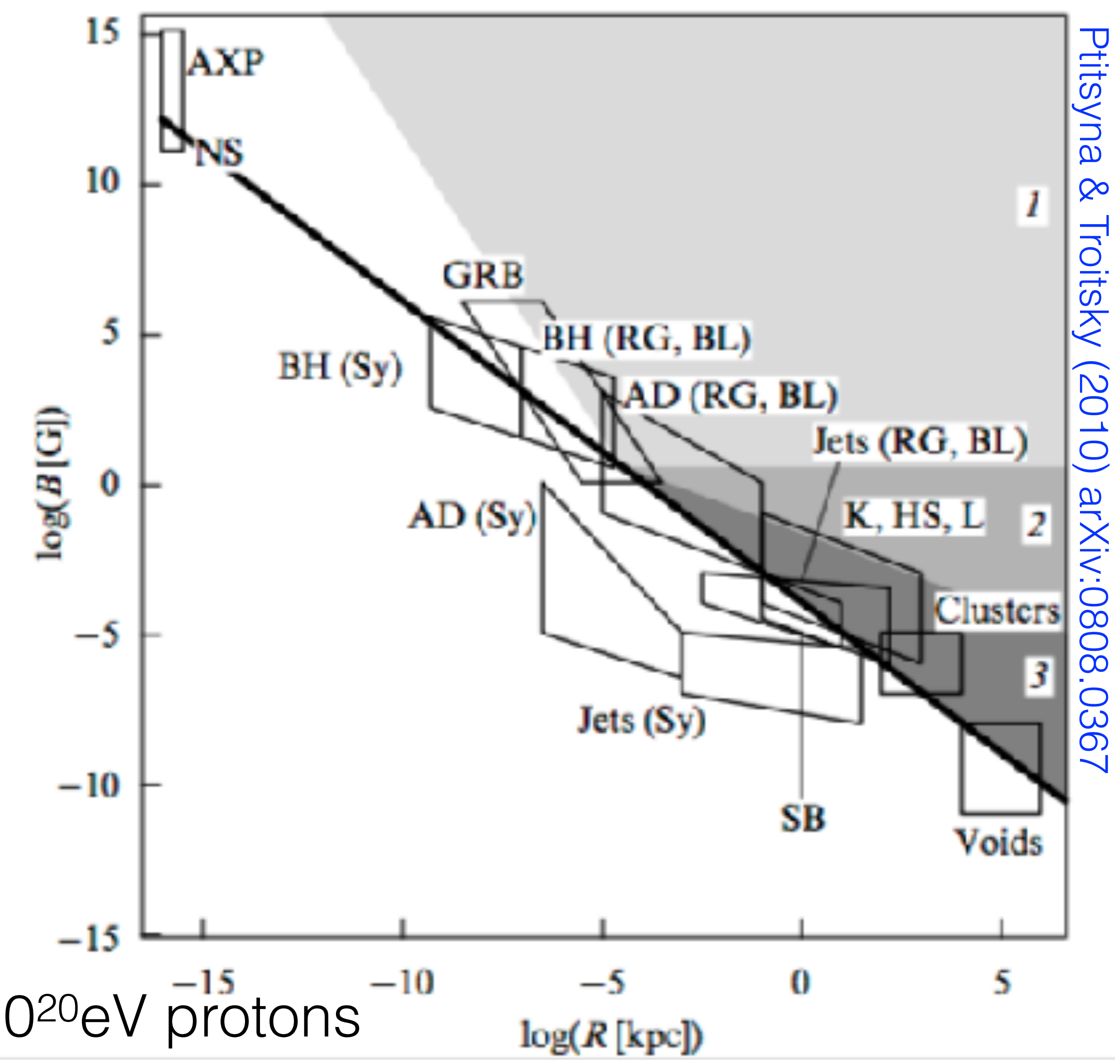

➡ Given that AGN are the most luminous persistent sources of electromagnetic radiation in the Universe (Murase 2015), it is not surprising that they are (Dermer 2012, …) and have been (Burbidge 1962, ...) considered as prime candidates for the acceleration of the UHE by many authors since their initial discovery in 1943 (Seyfert 1943)

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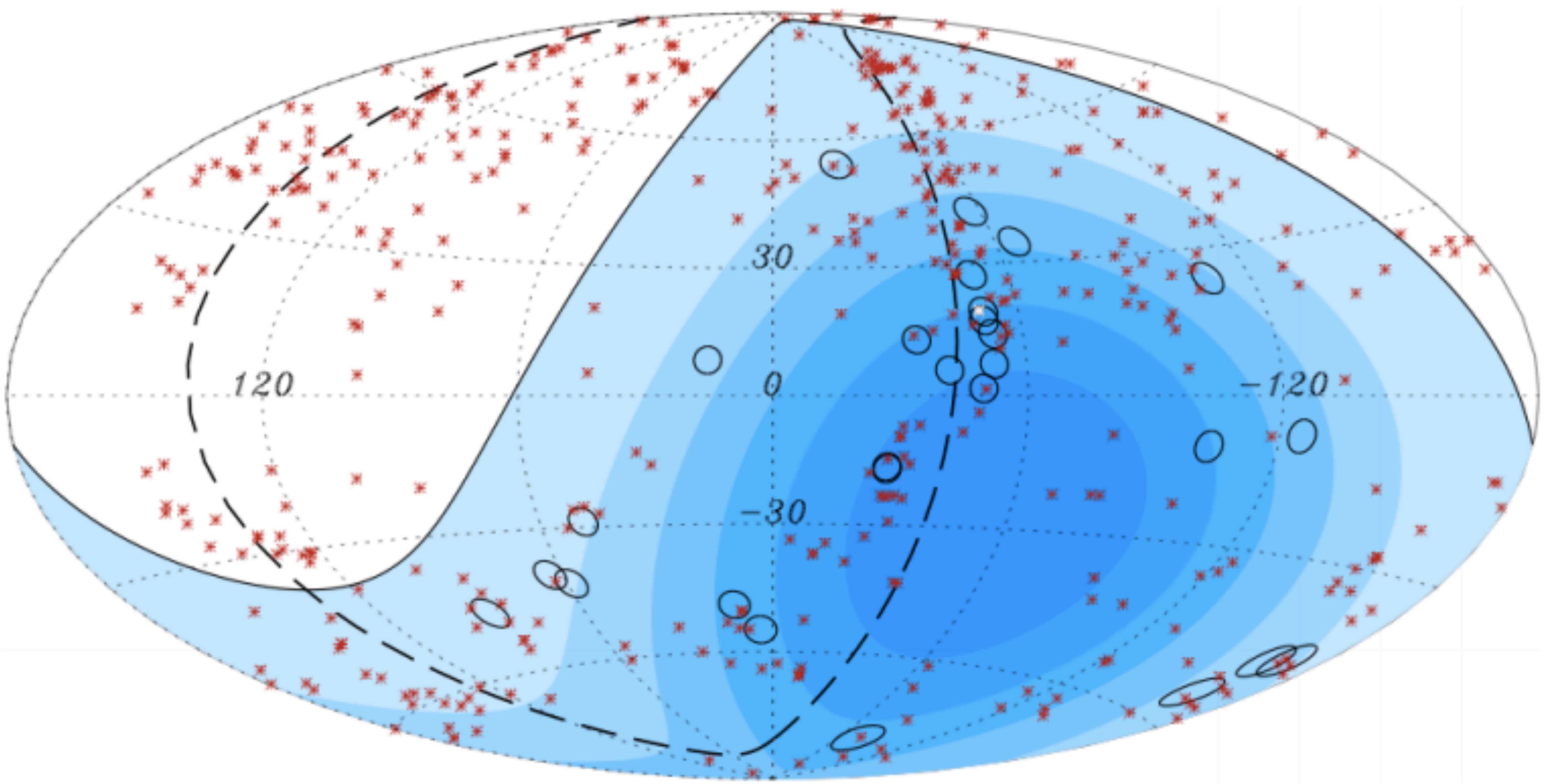

Auger Collaboration (2007) arXiv: 0712.2843

Distribution of nearby AGN from 12th Véron-Cetty & Véron Catalogue (red asterisks) with Auger HE events (black circles) and exposure (blue) from Auger Collaboration (2007)

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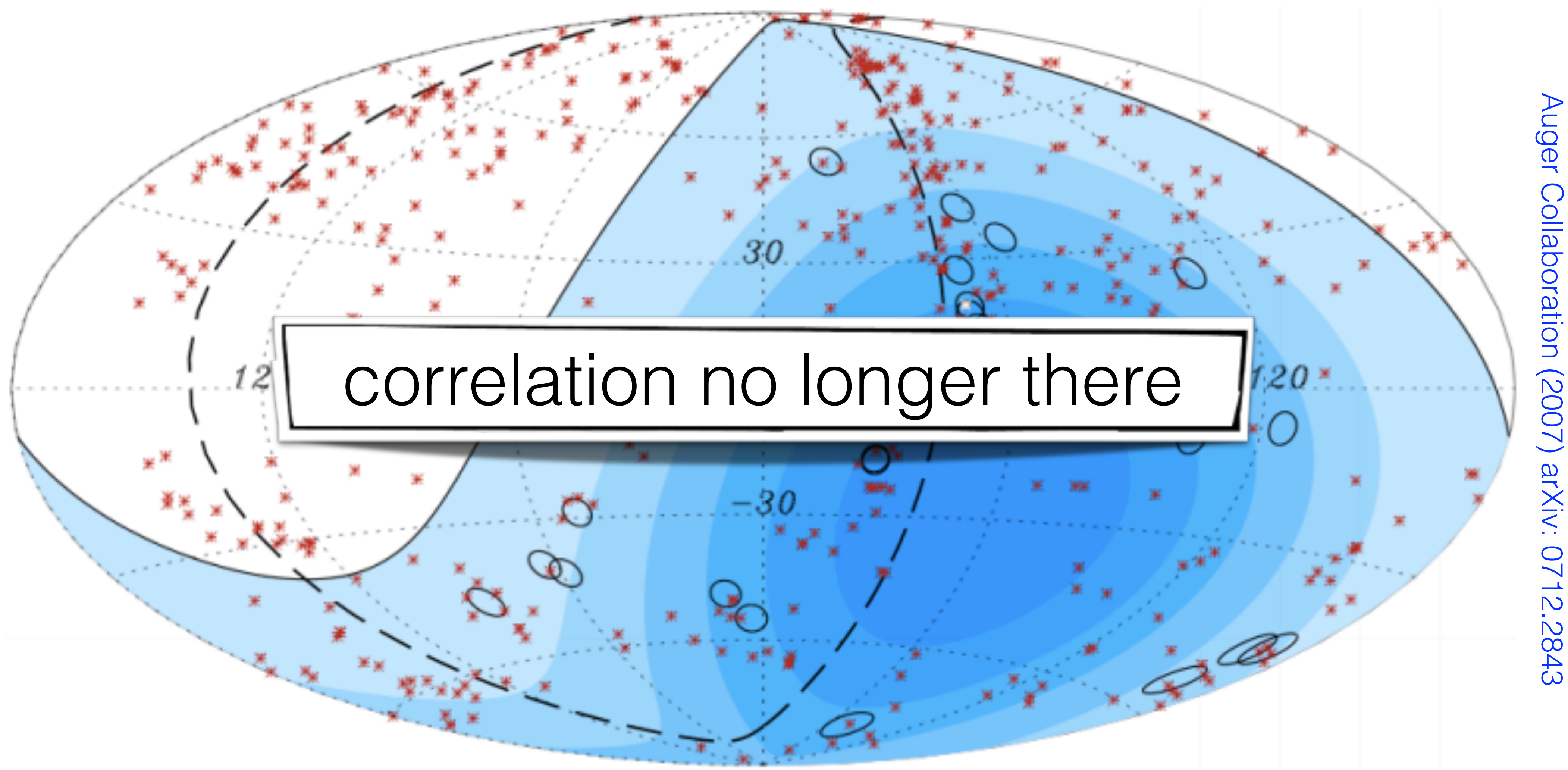

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- look directly - neutrinos … promising in the years to come

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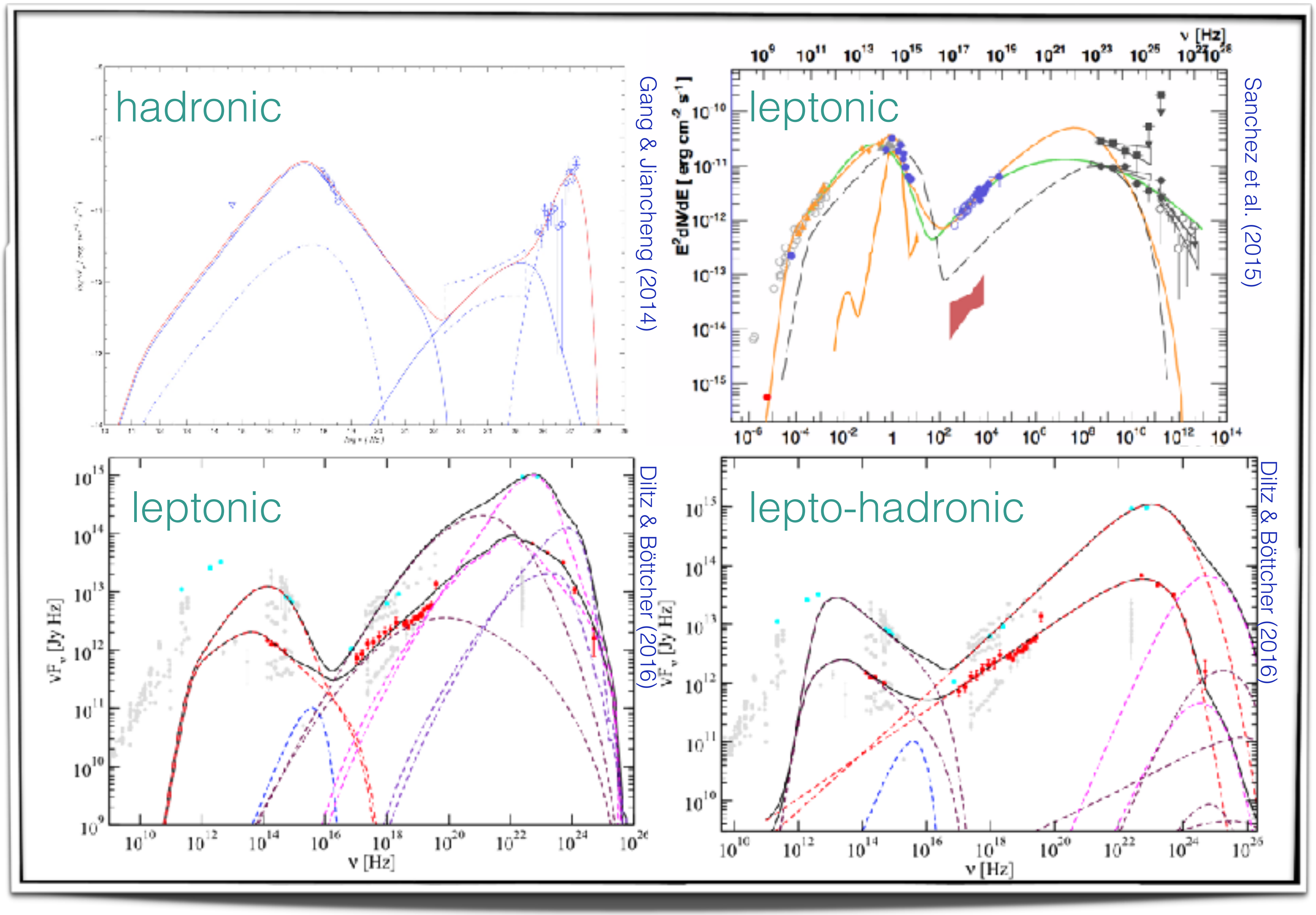

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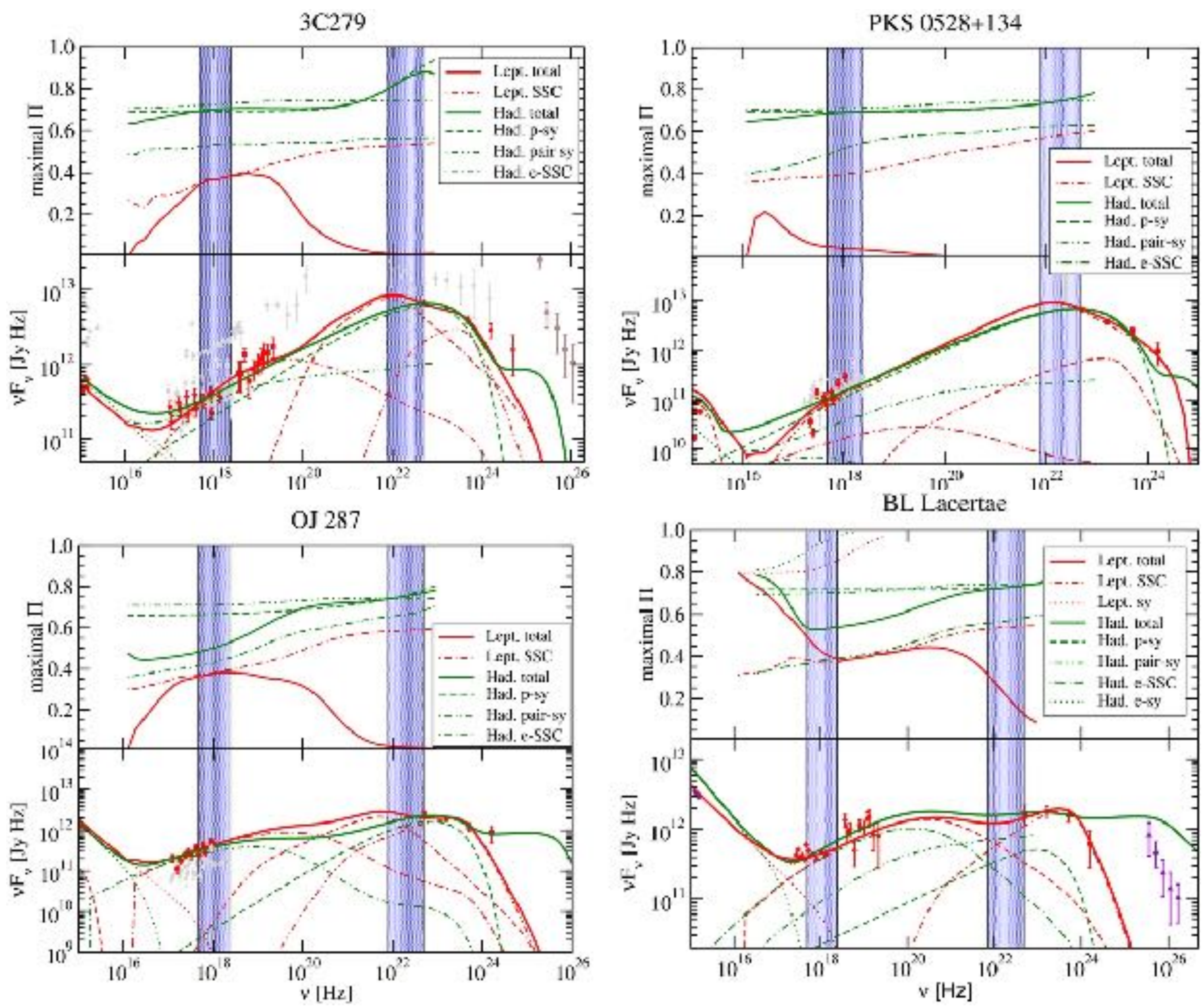

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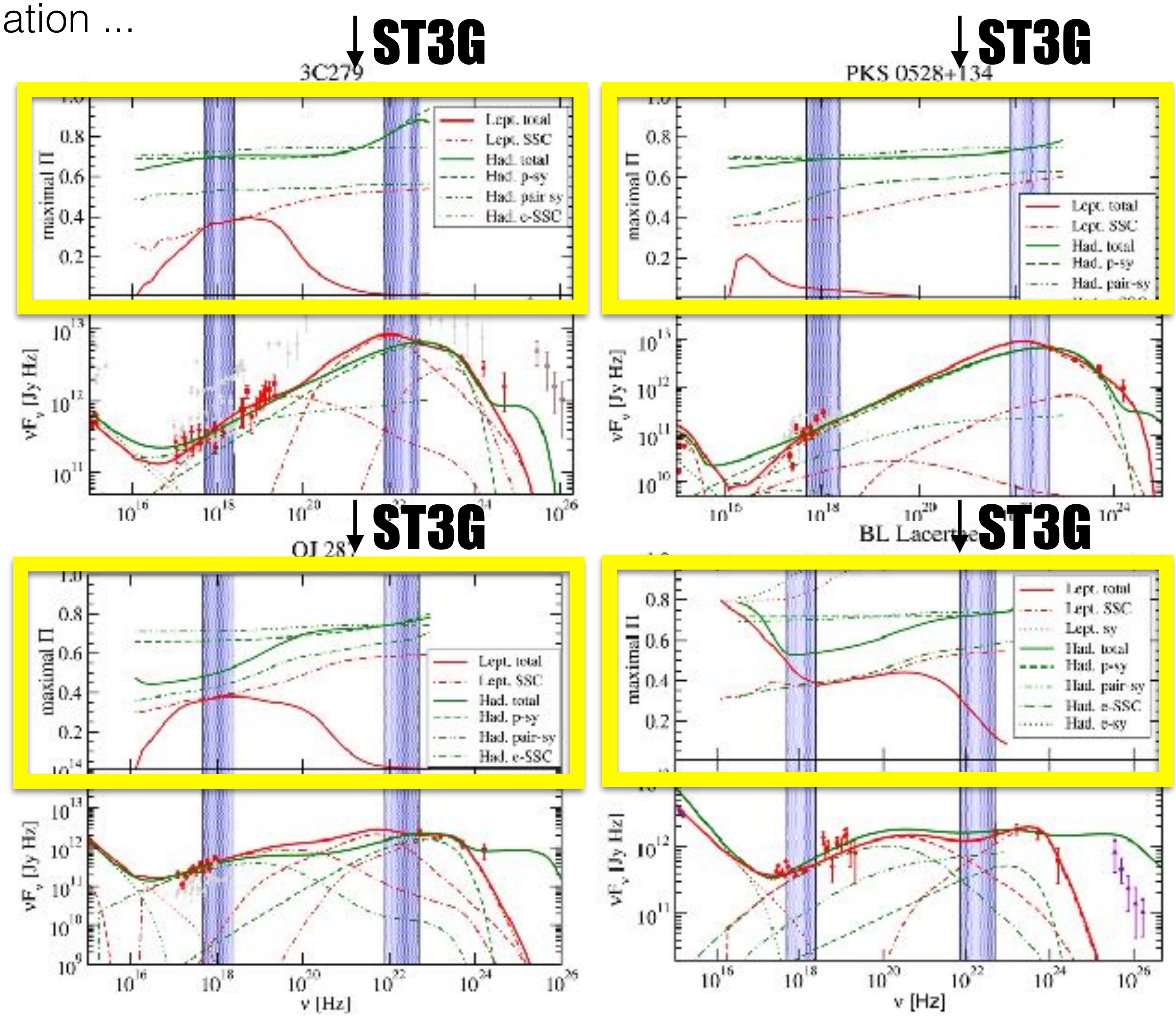

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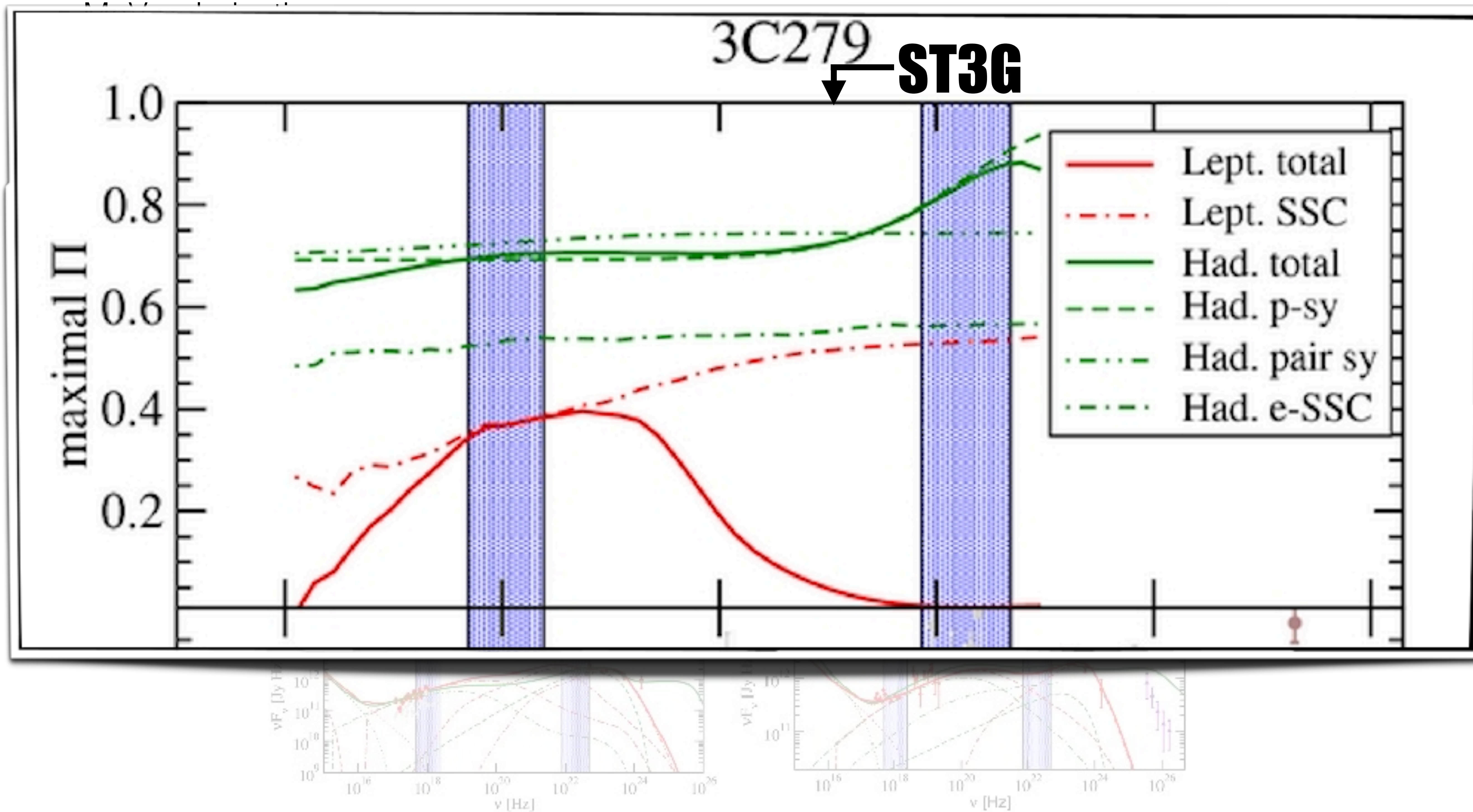

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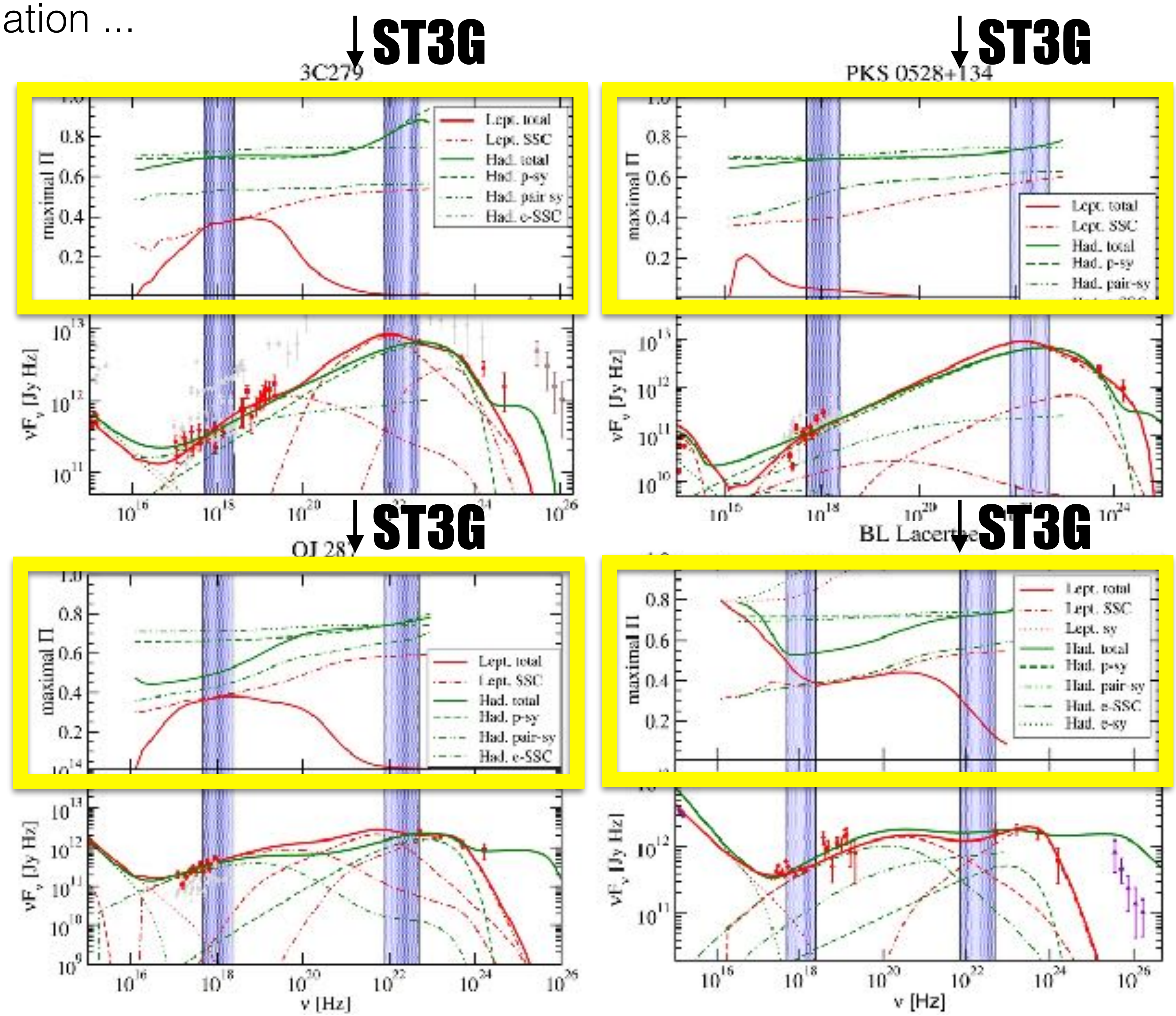

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How do supermassive black holes form?

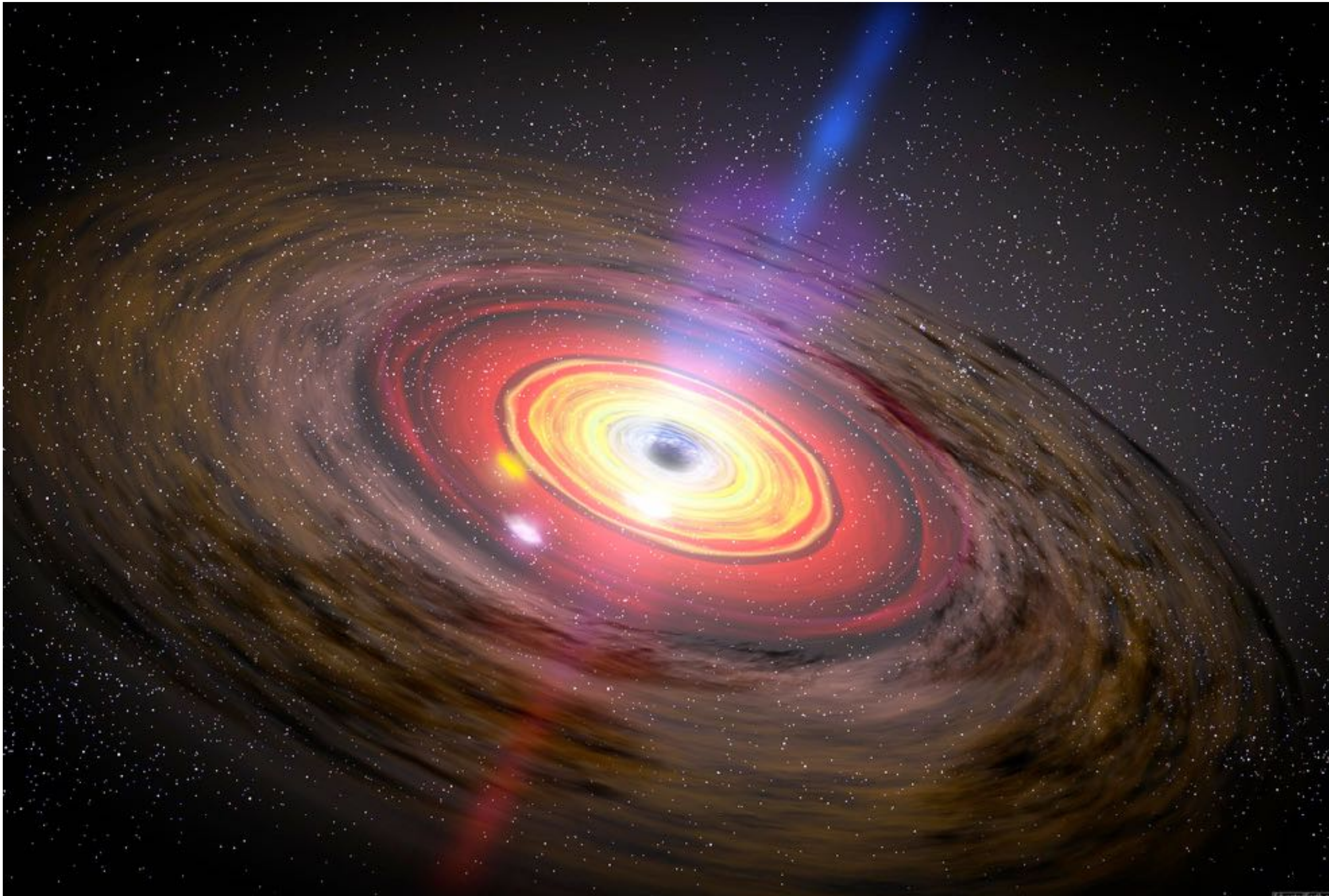
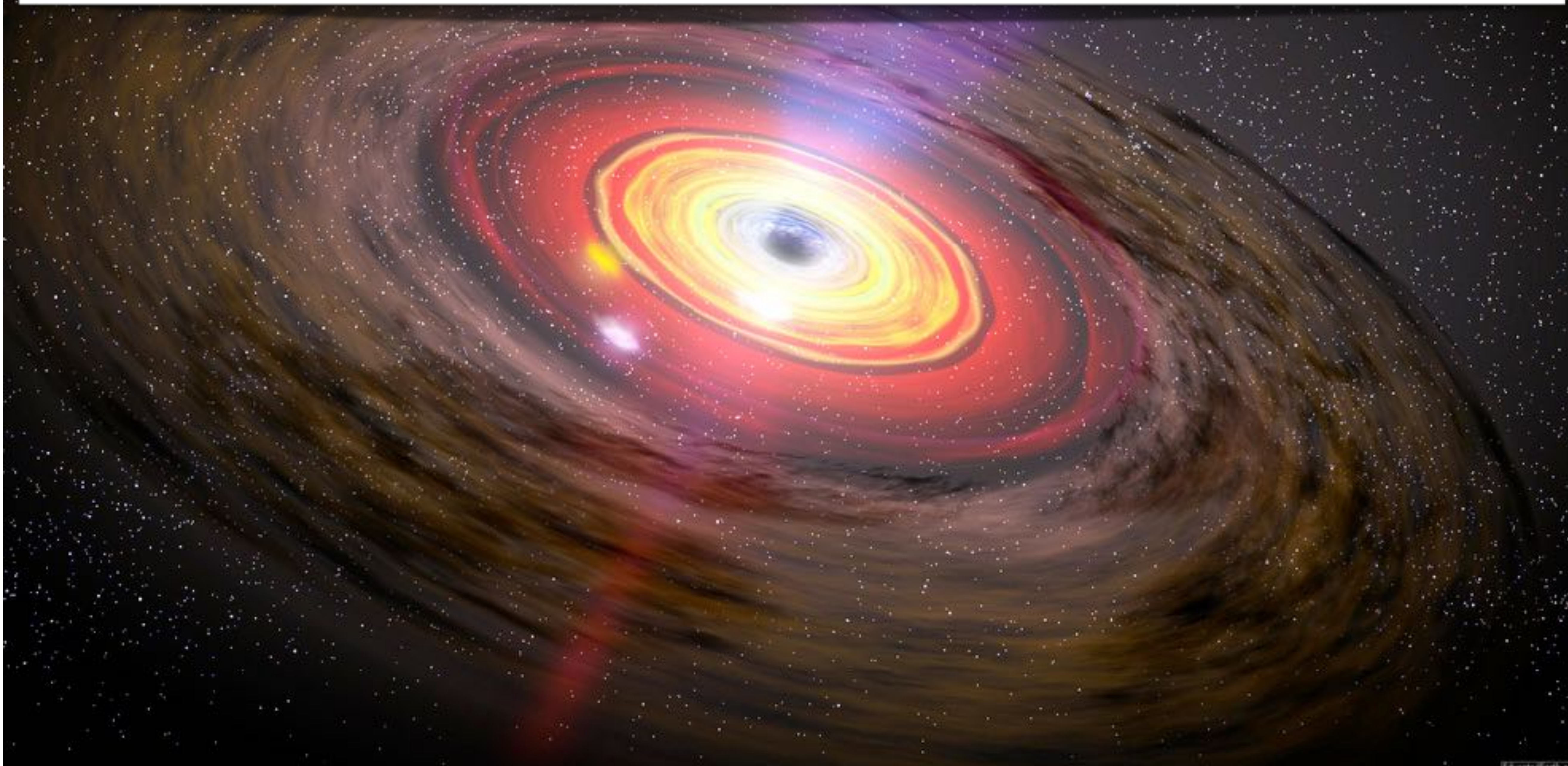


Image credit: NASA

How do supermassive black holes form?

“Recent observations of quasars at z >~ 6 suggest that some supermassive black holes (SMBHs) quickly achieve masses of M• >~ 10^9 M⊙ , even before the Universe is a billion years old. The origin of these SMBHs, located in galactic centers and serving as energy sources for active galactic nuclei (AGN), is one of the unsolved mysteries of contemporary astrophysics” (Choi, Shlosman & Begelman, 2016)



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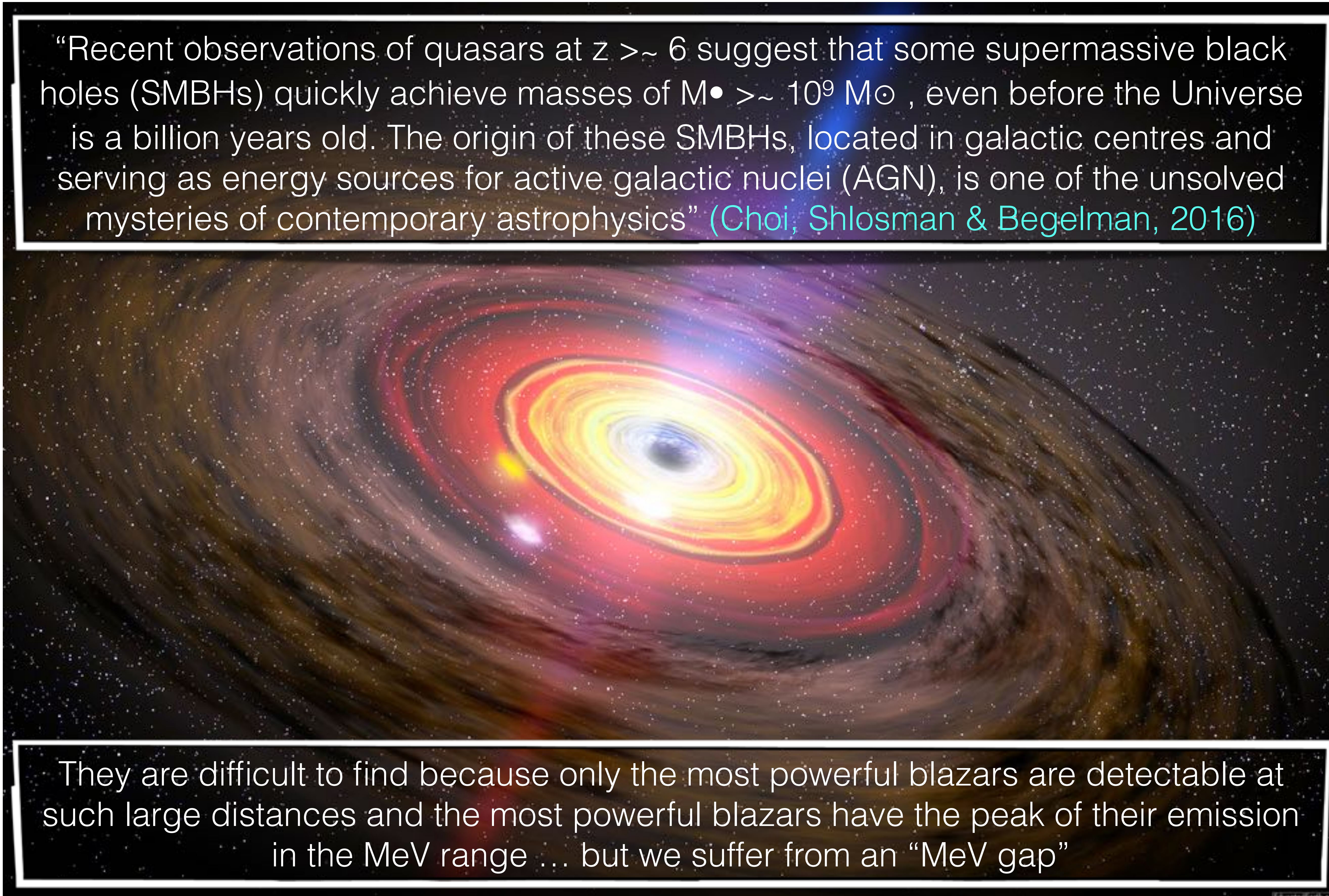

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They are difficult to find because only the most powerful blazars are detectable at such large distances and the most powerful blazars have the peak of their emission in the MeV range … but we suffer from an "MeV gap"

Image credit: NASA

How do supermassive black holes form?

- SMBHs "conventionally" postulated to be born when a massive star (100 -1000 $M_\odot$) collapses ... then they grow slowly by accreting surrounding gas and merging with other structures

- There is, however, growing evidence for a population of SMBHs at large redshifts whose formation could not have followed this channel
  ➡ it is not efficient enough for them to have been so massive at such an early epoch: the universe was not old enough for them to have grown by accretion

- Many theories exist to explain their formation and a **crucial input** for such studies is the space density of these distant supermassive black holes

we need to find more of these early (large z) supermassive black holes

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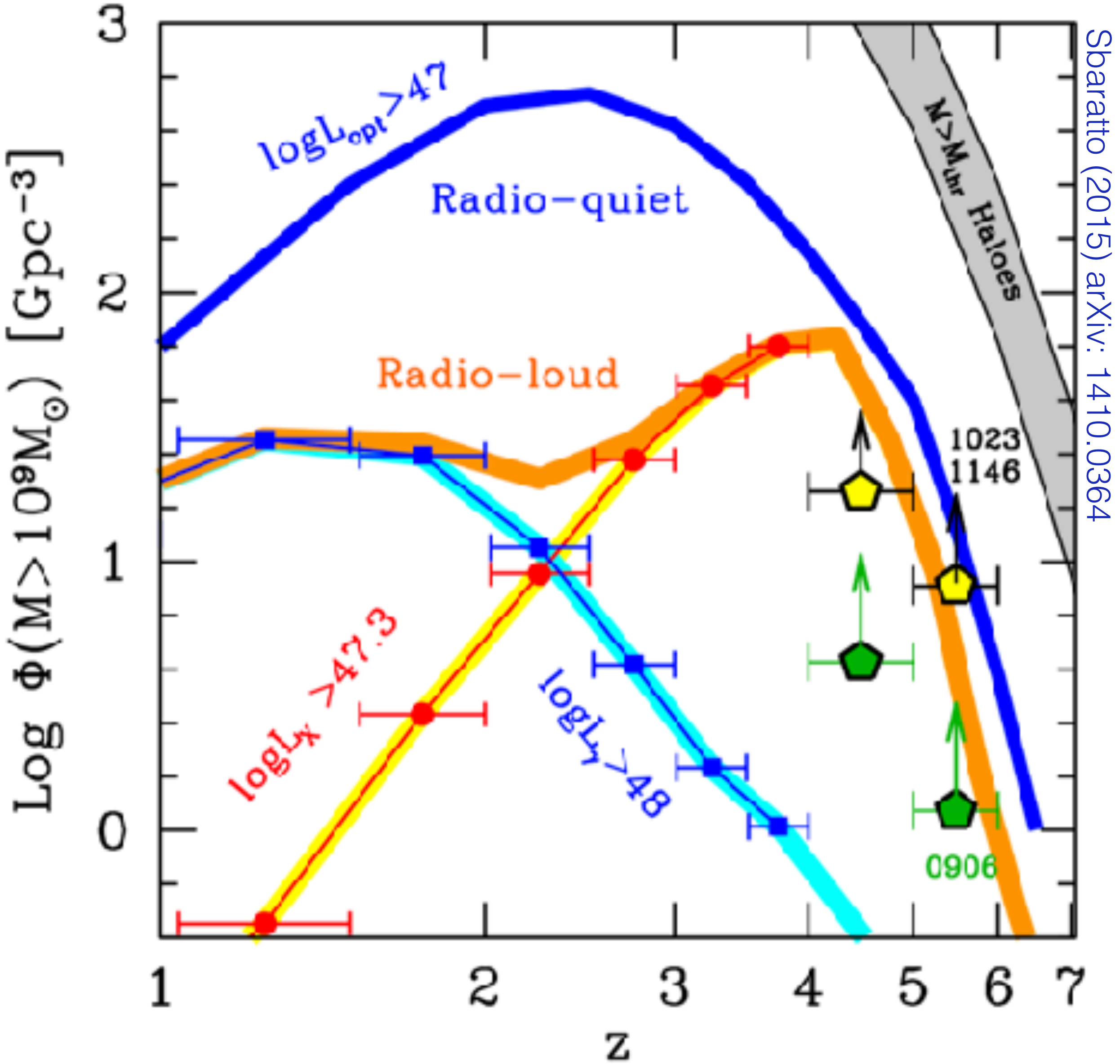
The space density of SMBHs
as a function of redshift



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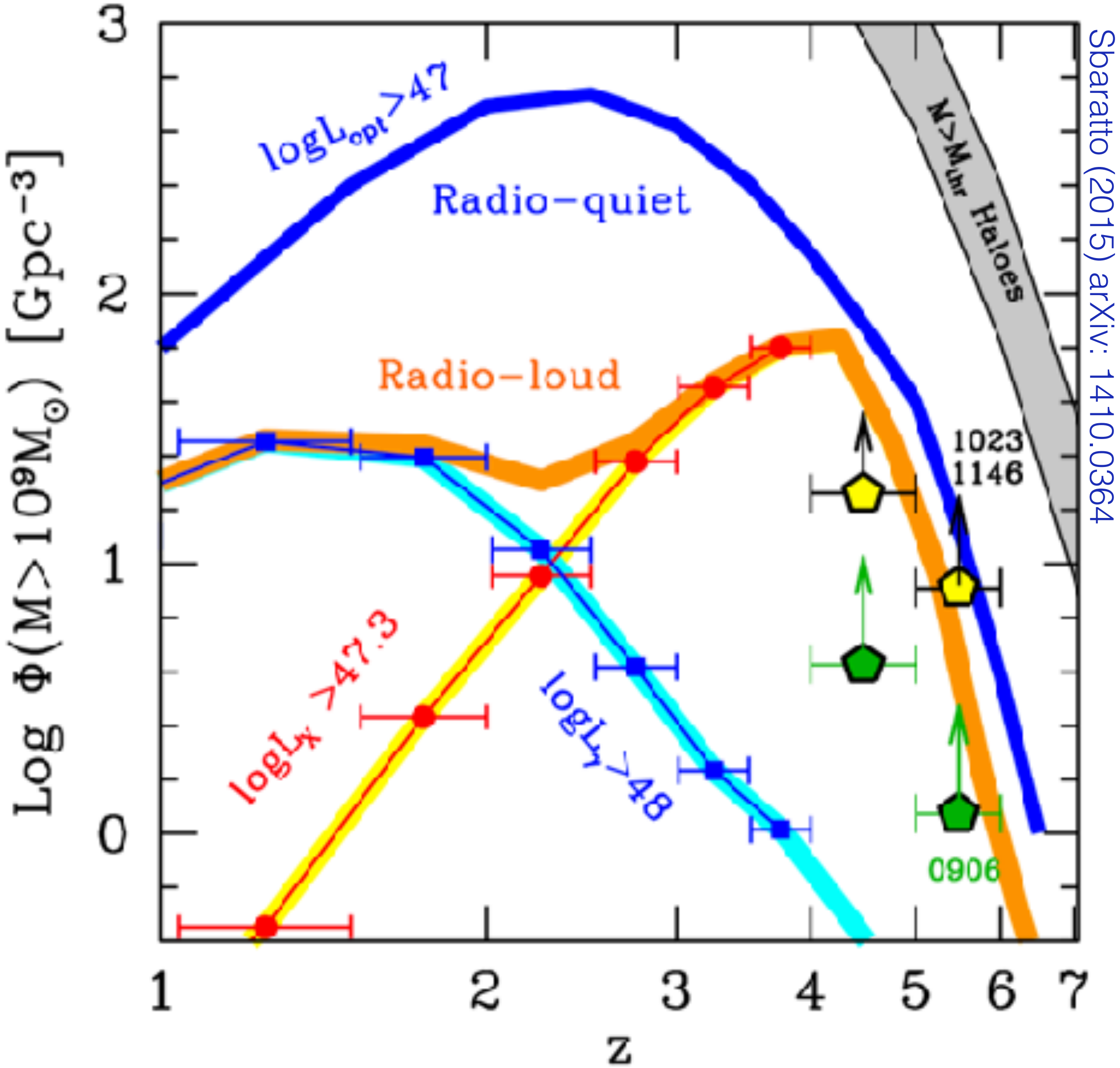
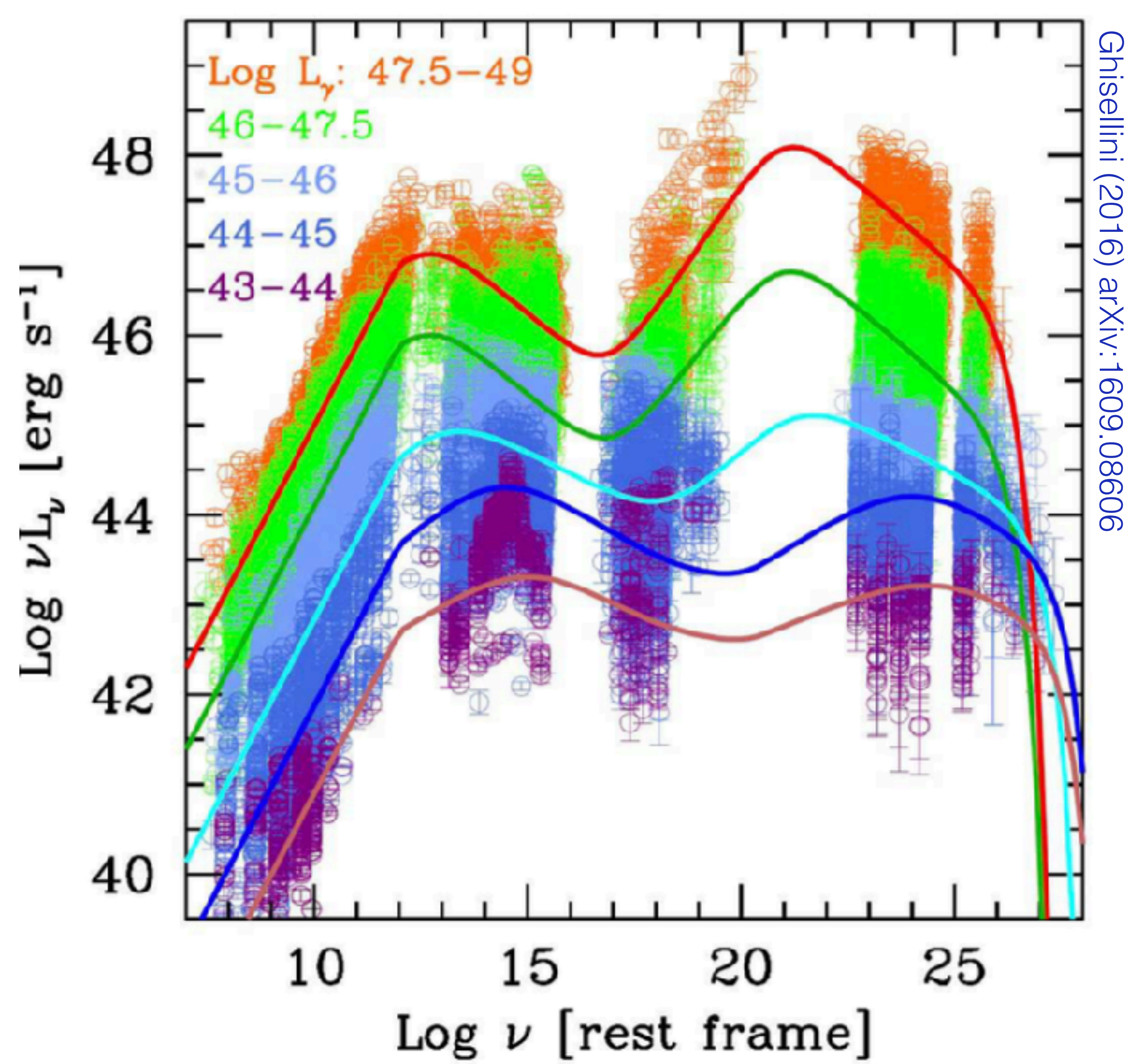


The radio-loud AGN - power as a function of energy



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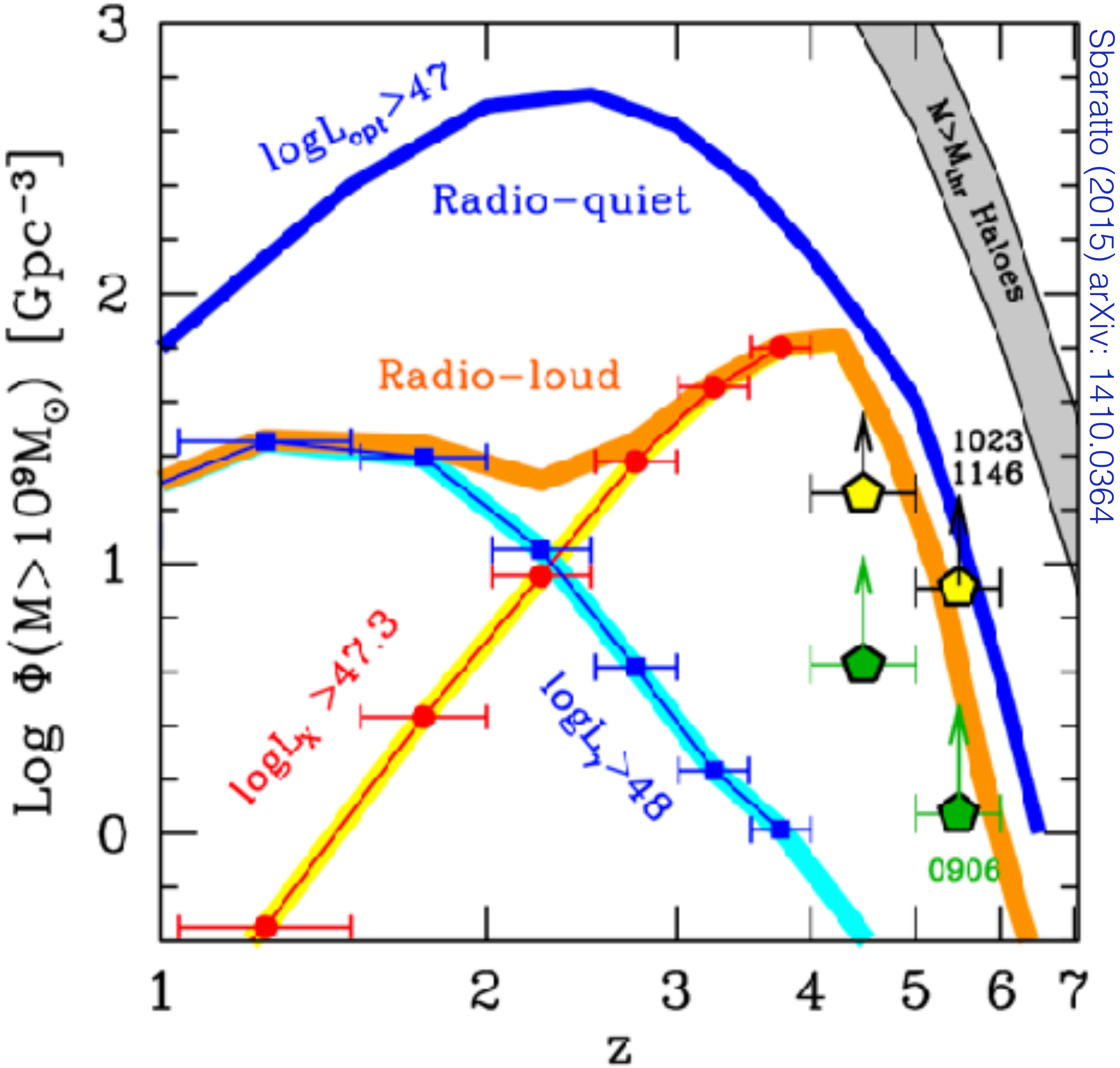

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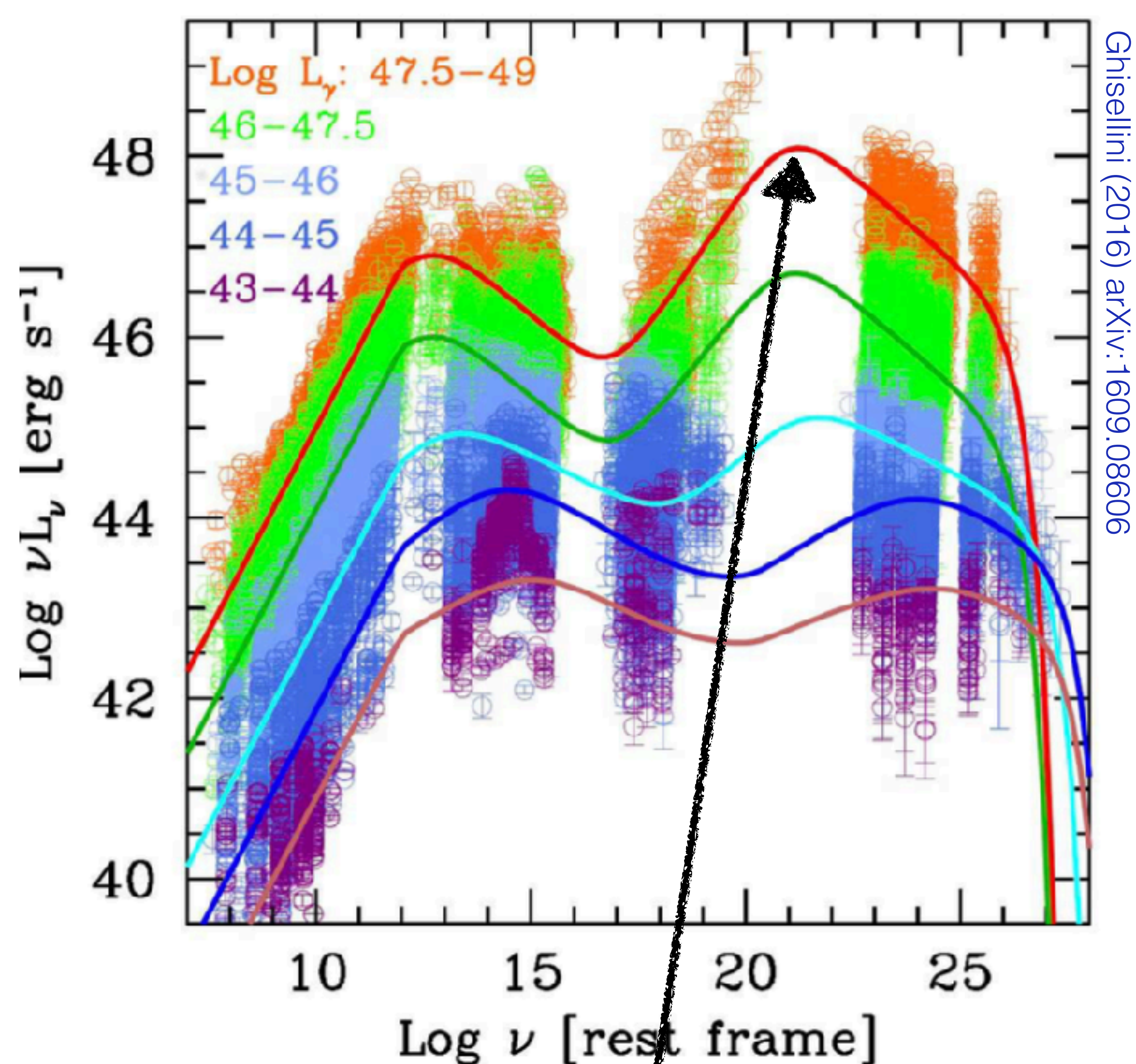

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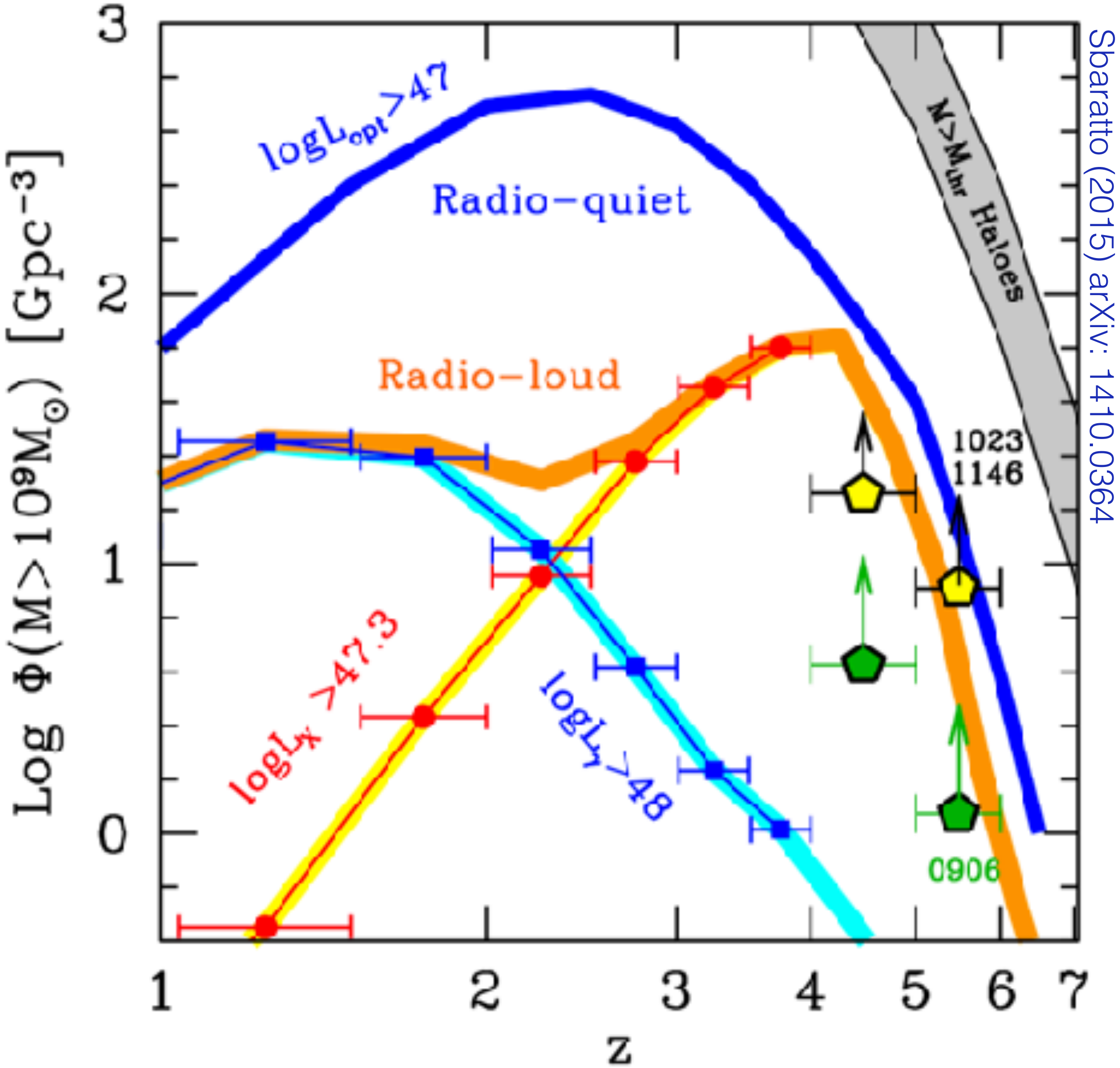

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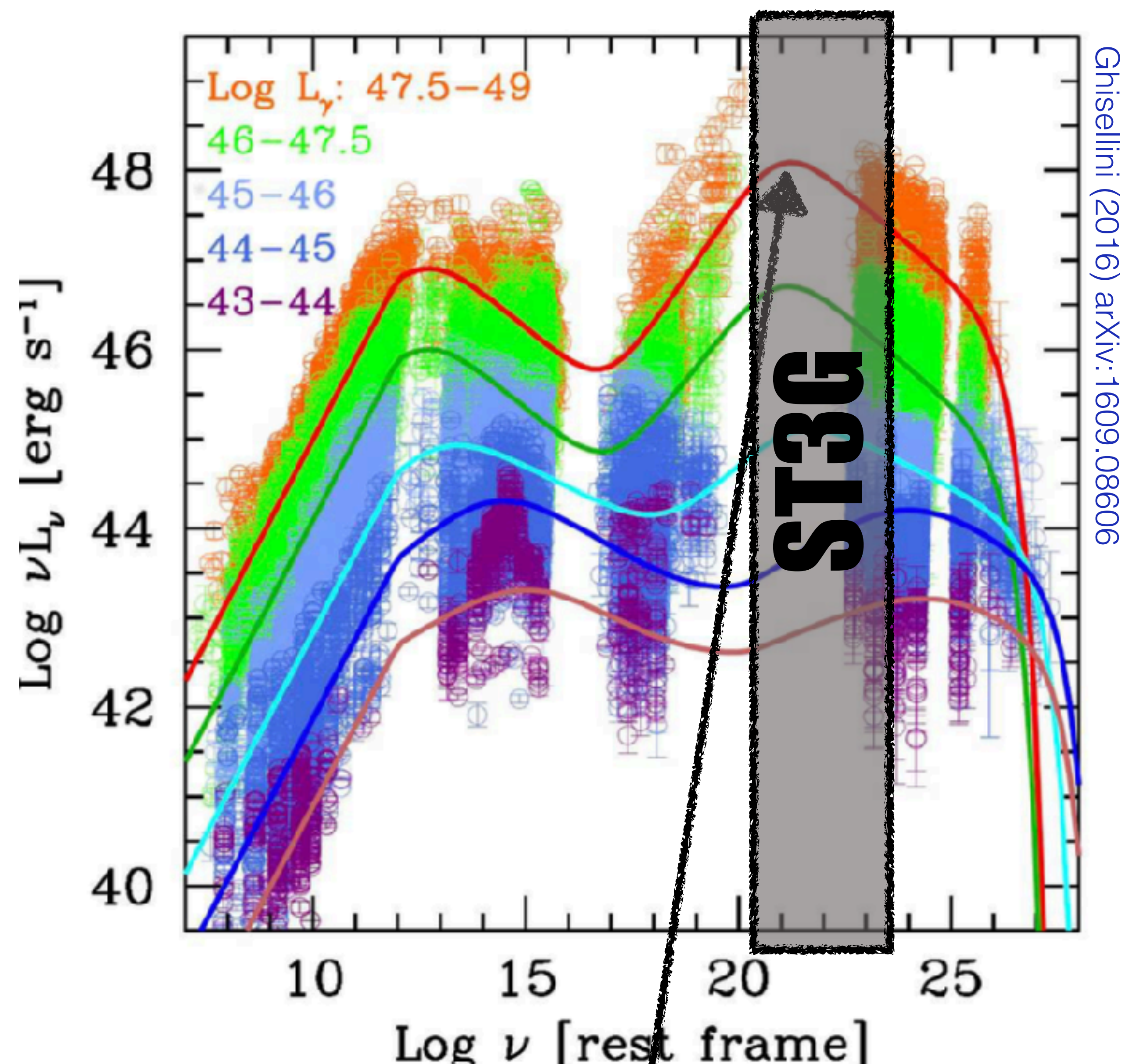

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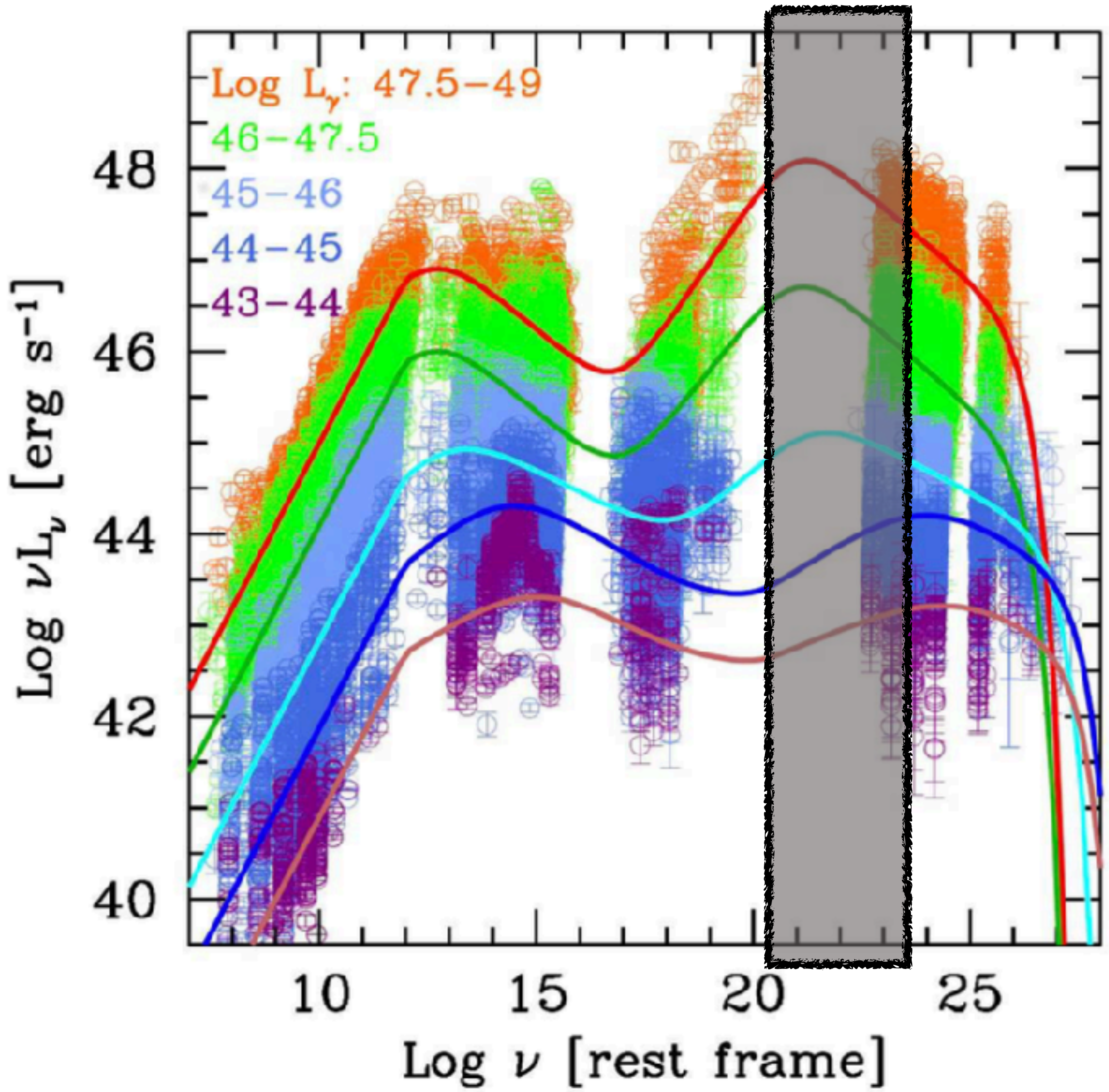

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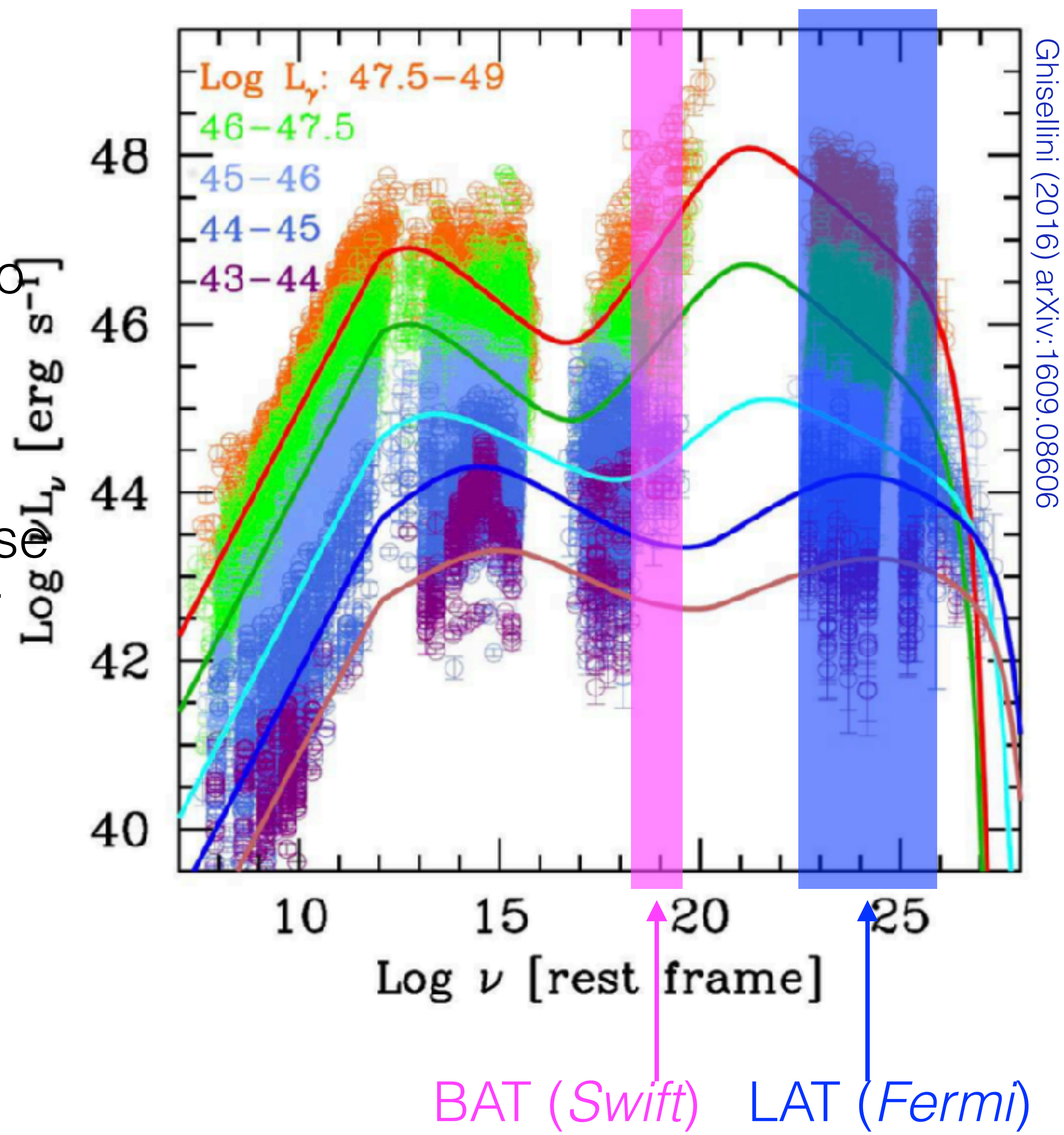

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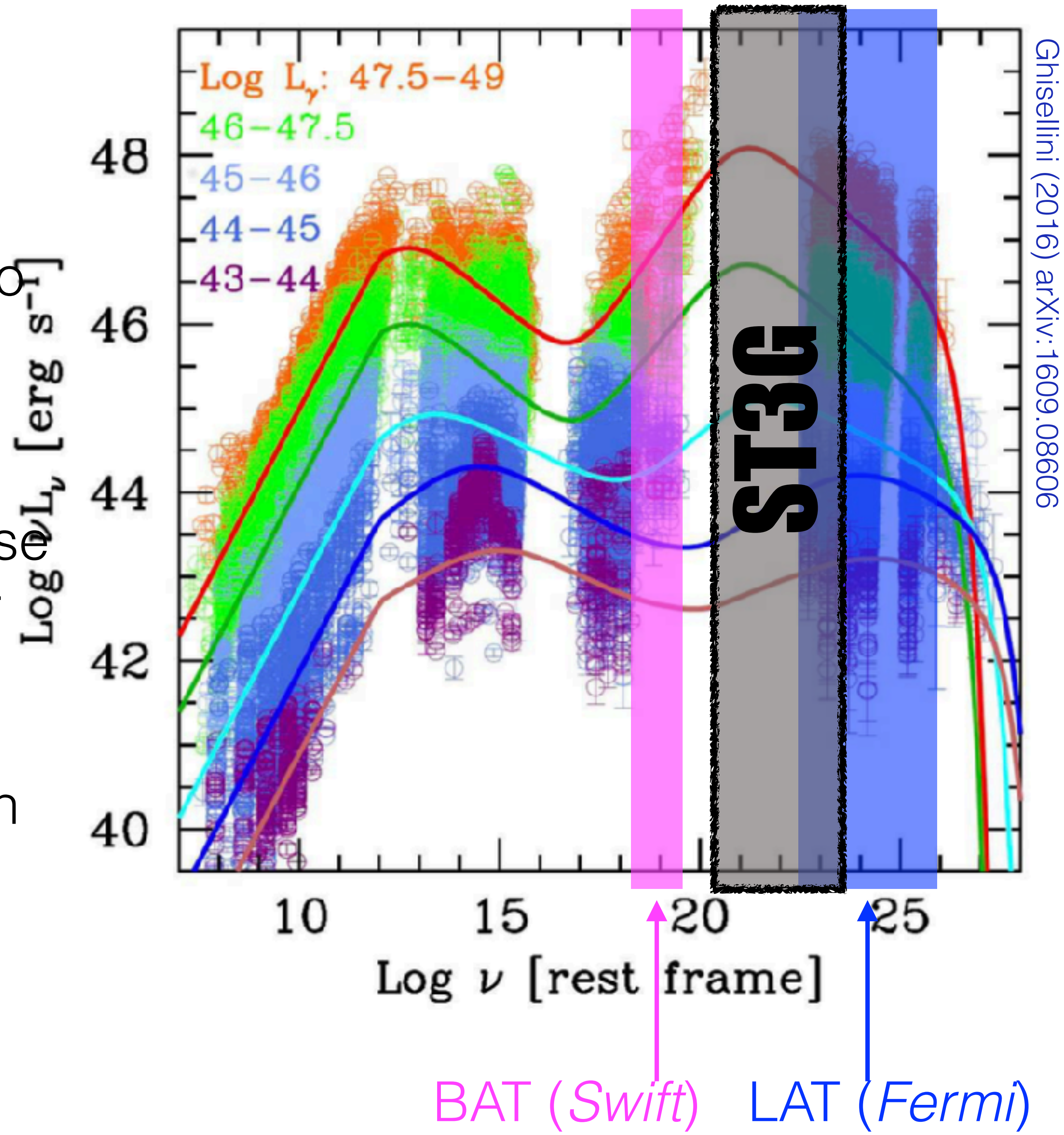

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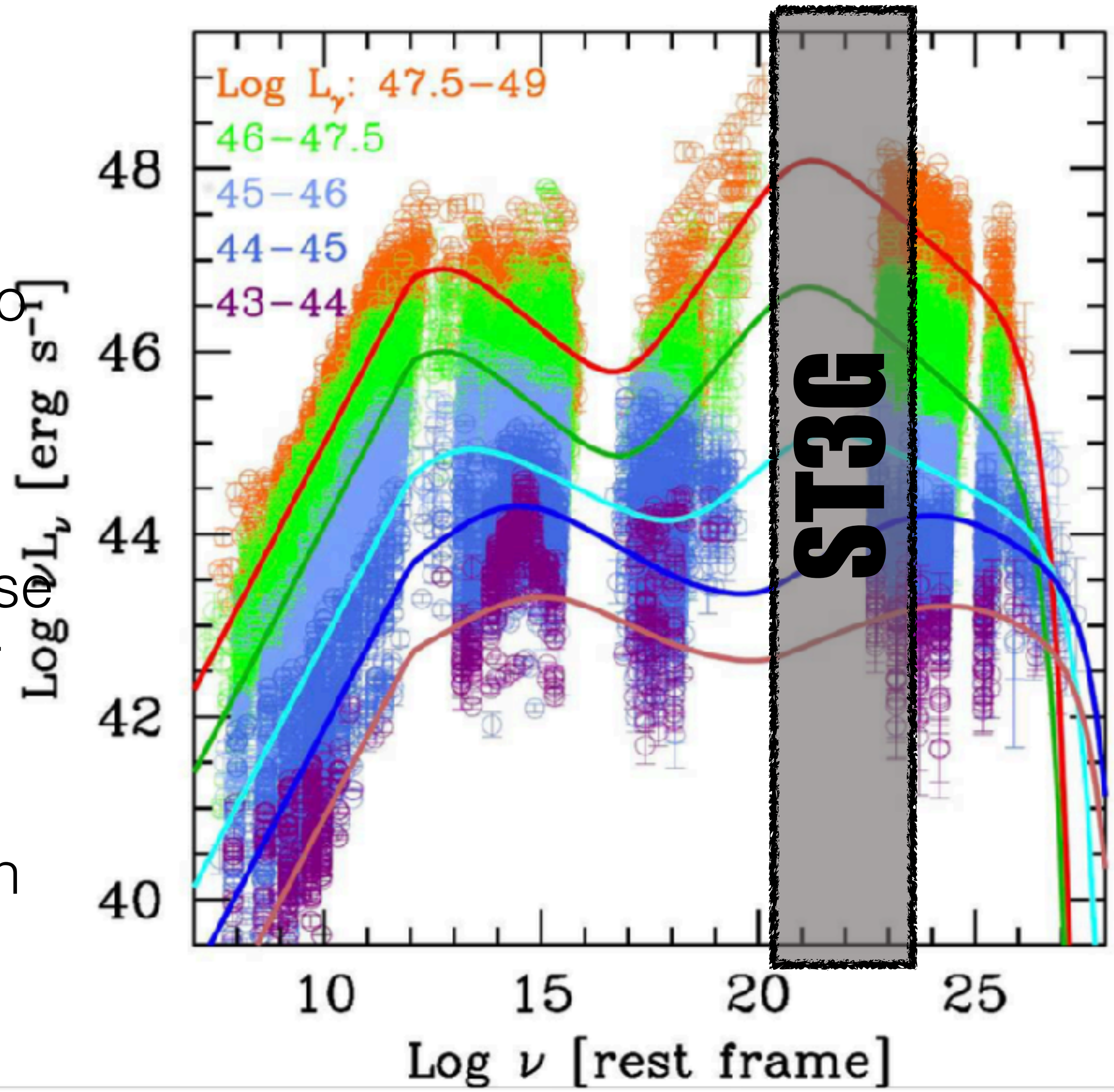

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The discovery of a large number of SMBHs at z > 4 could put strong constraints on theories of their formation

Is Lorentz Invariance violated?

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i.e. the laws of physics remain the same for all observers that are moving with respect to each other at uniform velocity

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- But minute deviations from Lorentz invariance might still be present at much lower energies
  - these deviations can accumulate over large distances
  - this makes **astrophysical measurements** the most sensitive tests of Lorentz symmetry

Is Lorentz Invariance violated?

In the photon sector violations of Lorentz symmetry include
vacuum dispersion and **vacuum birefringence**

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$$\delta \phi \propto \omega \delta v L$$

sensitivity gain of **1/ω** compared to time-of-flight measurements

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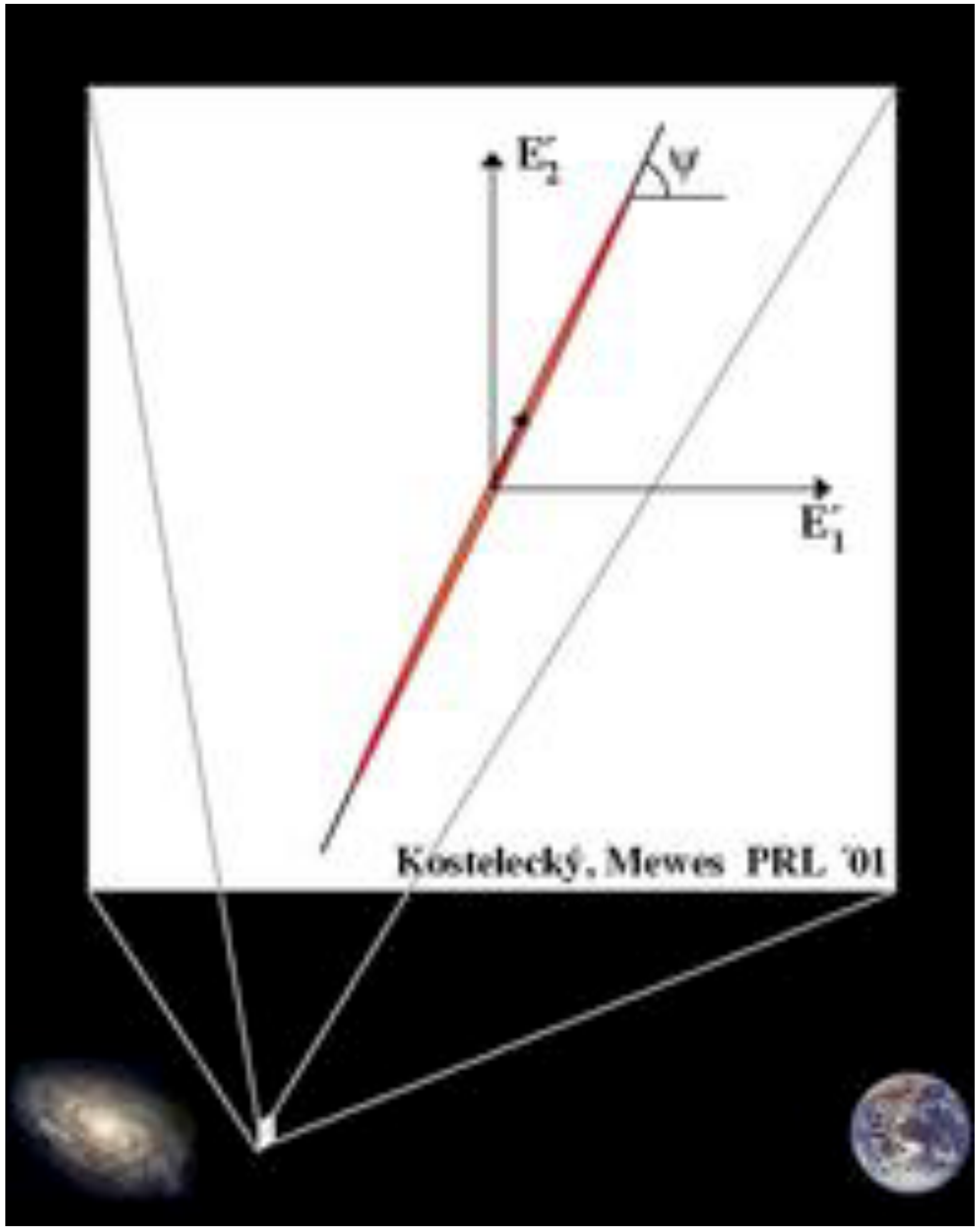
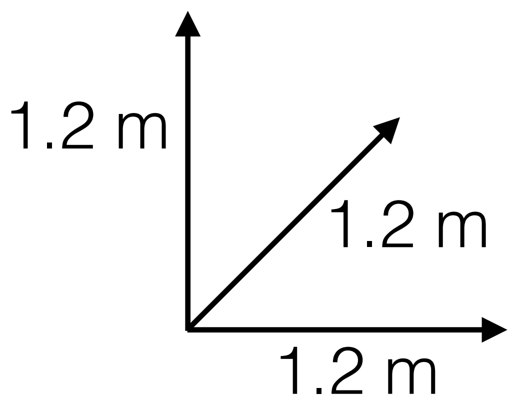


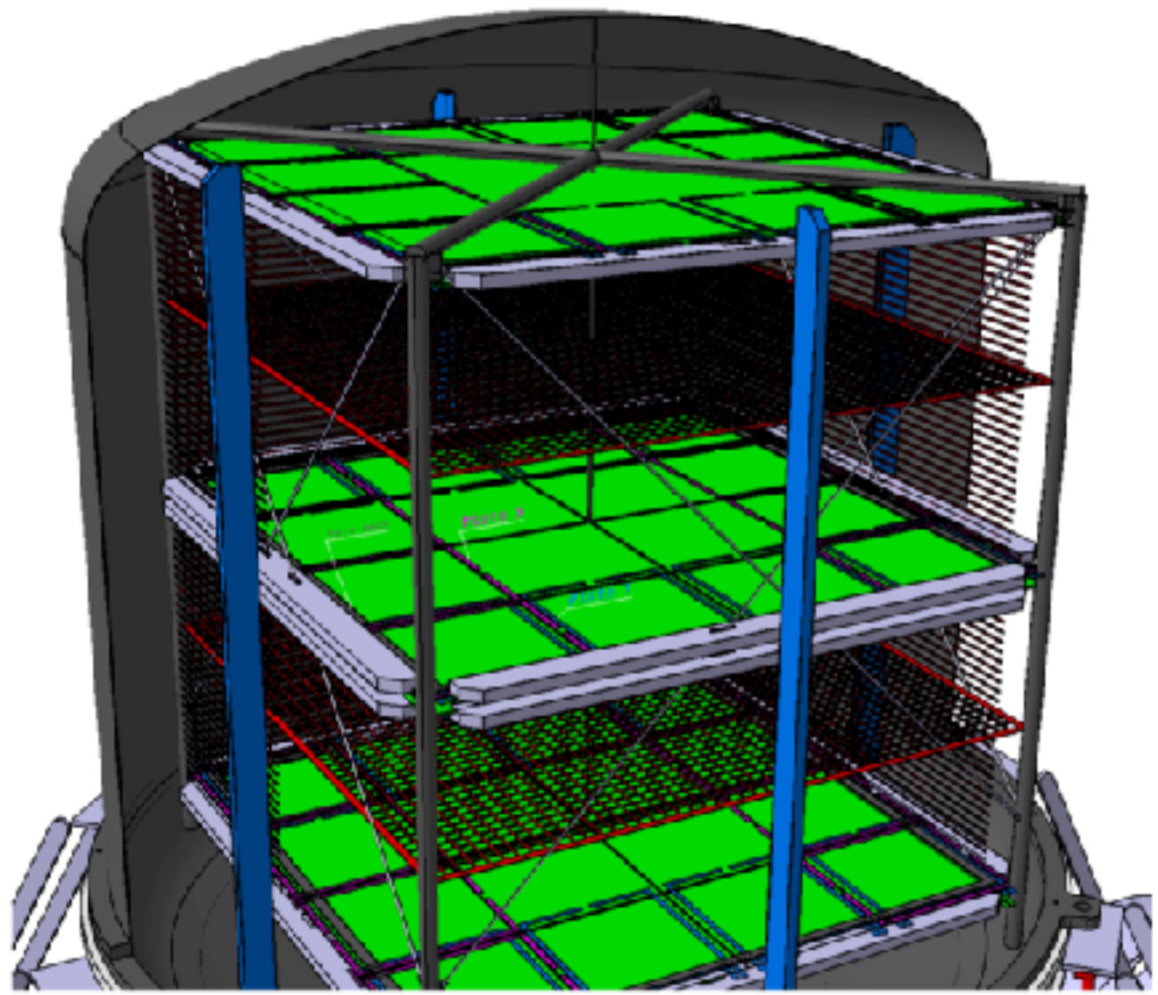
http://www.physics.indiana.edu/~kostelec/mov.html#4

Vacuum birefringence

- light is shown propagating from a distant galaxy to the Earth
- the instantaneous electric-field vector in a plane transverse to direction of motion is shown as a black arrow
- the polarisation of the light is determined by 2 quantities:
  - the orientation of the ellipse (ω)
  - its shape (E1 and E2)
- the breaking of rotation symmetry causes the polarisation and hence the orientation and shape of the ellipse to change as the light travels through space

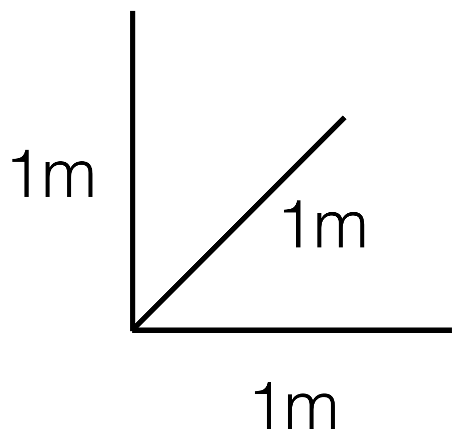
ST3G

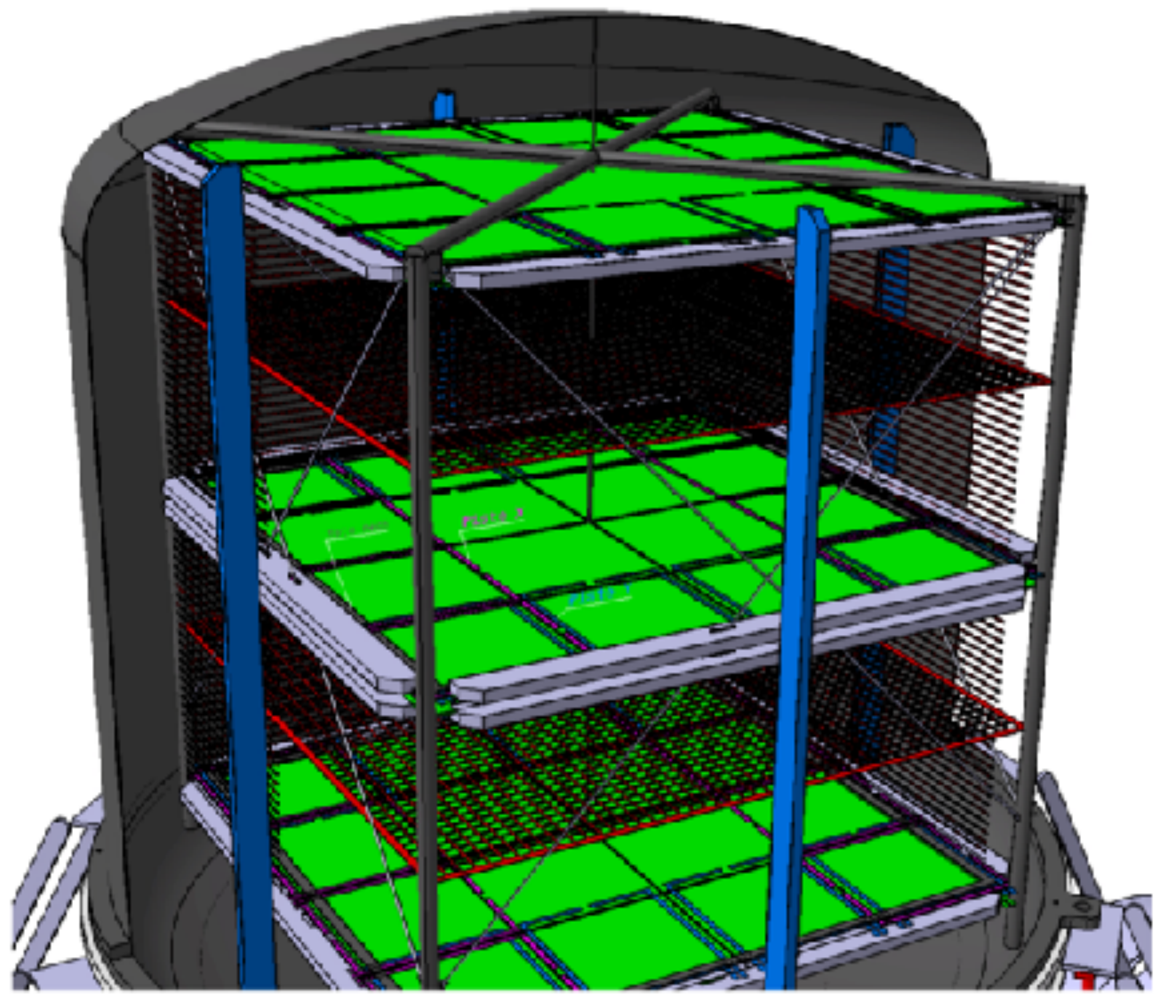




64 modules : 1 module = HARPO
32 TPCs : 2 modules with a common cathode
2 bar Argon gas
Readout chip ASTRE

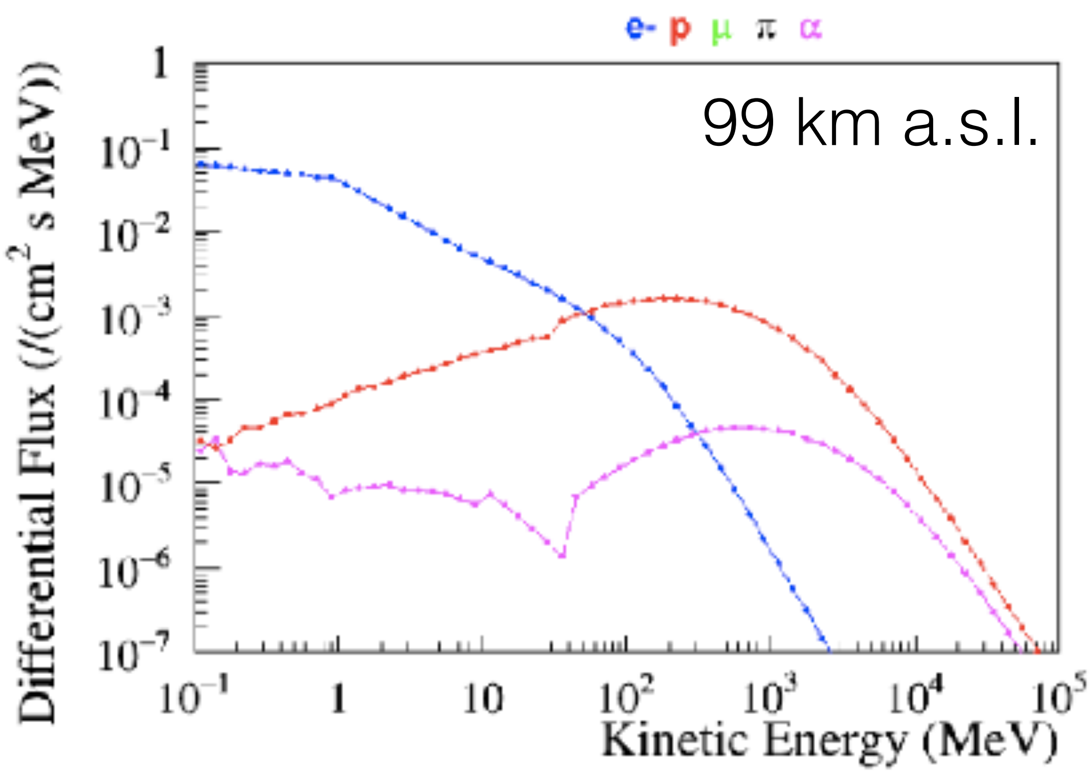
ST3G

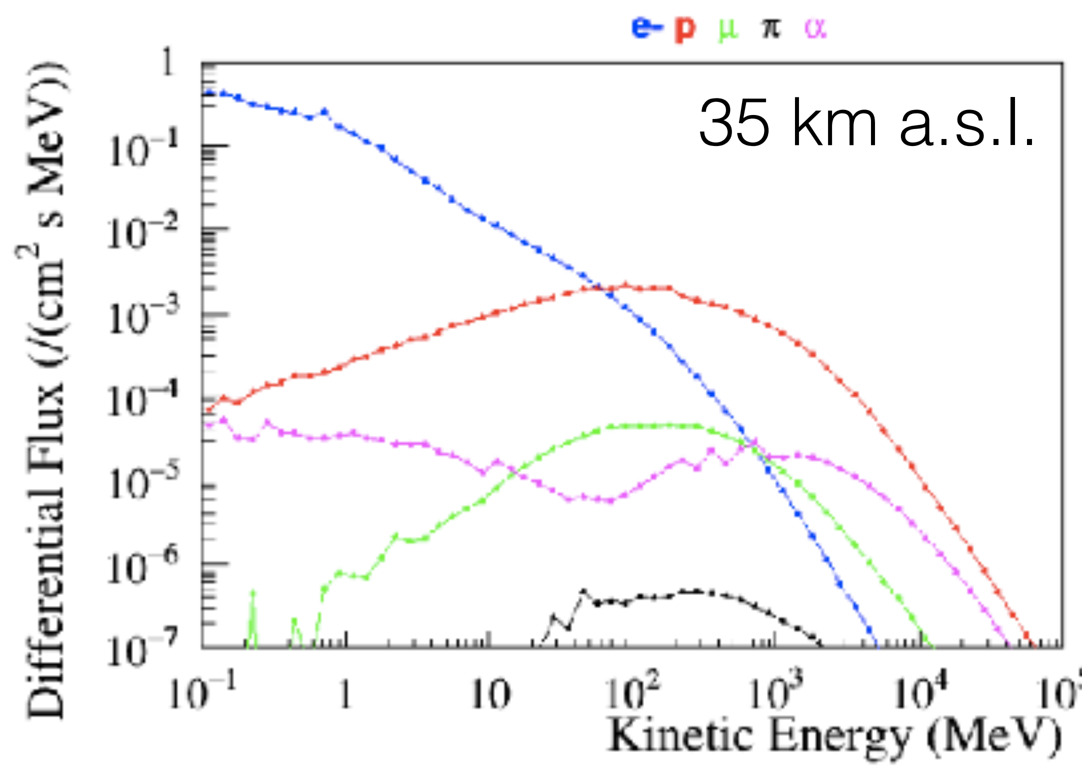


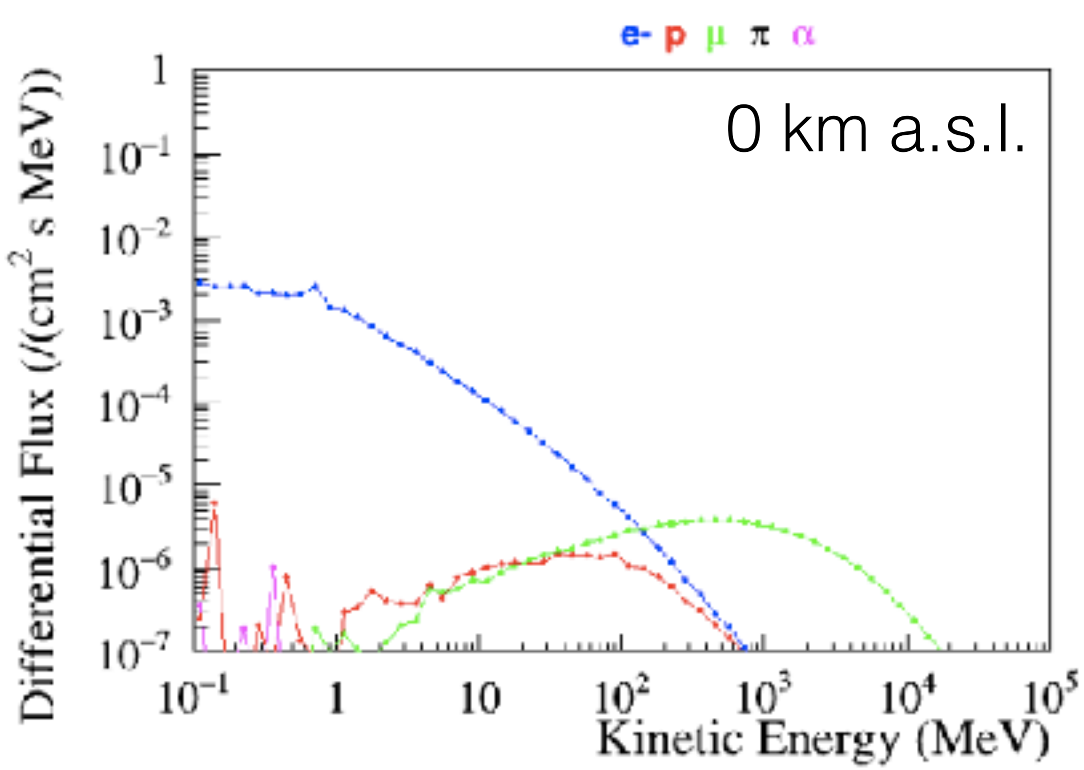


Key challenge: self-triggering ... in real time ... in space

ST3G





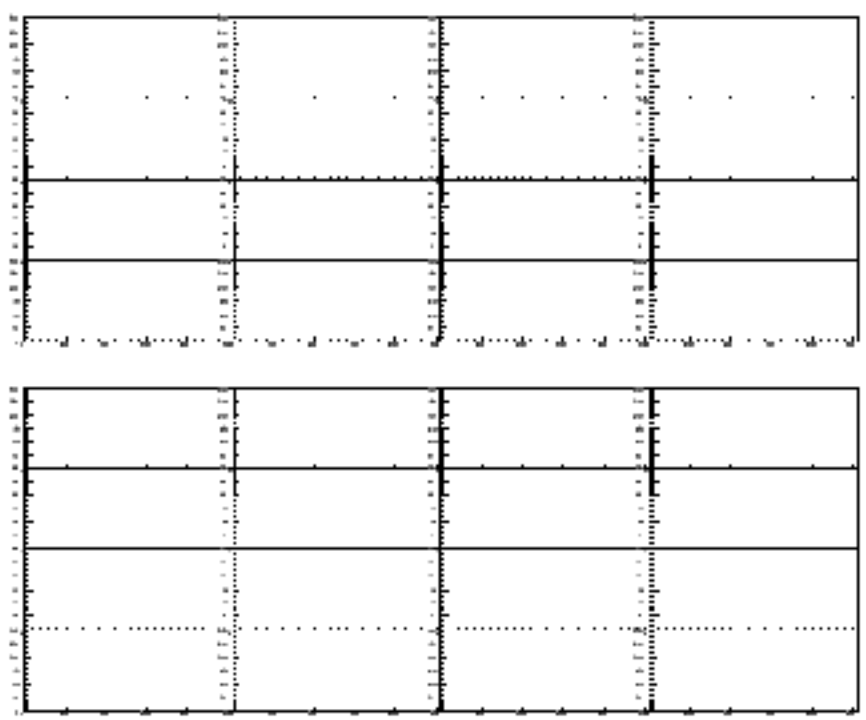


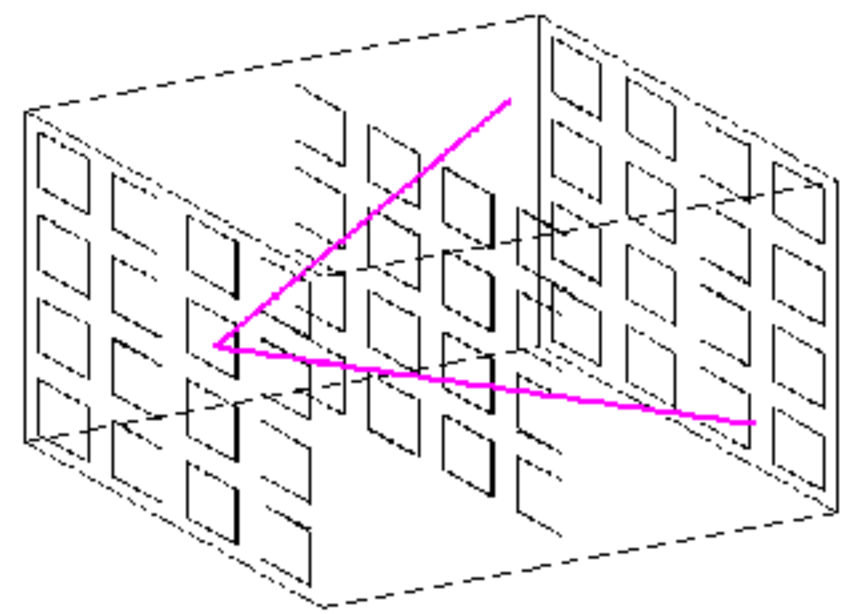
Data recorded at Kirune (Northern Sweden) 20.01.1996
(Quotid Atmospheric Radiation Model (QARM))

a.s.l. = above sea level

ST3G

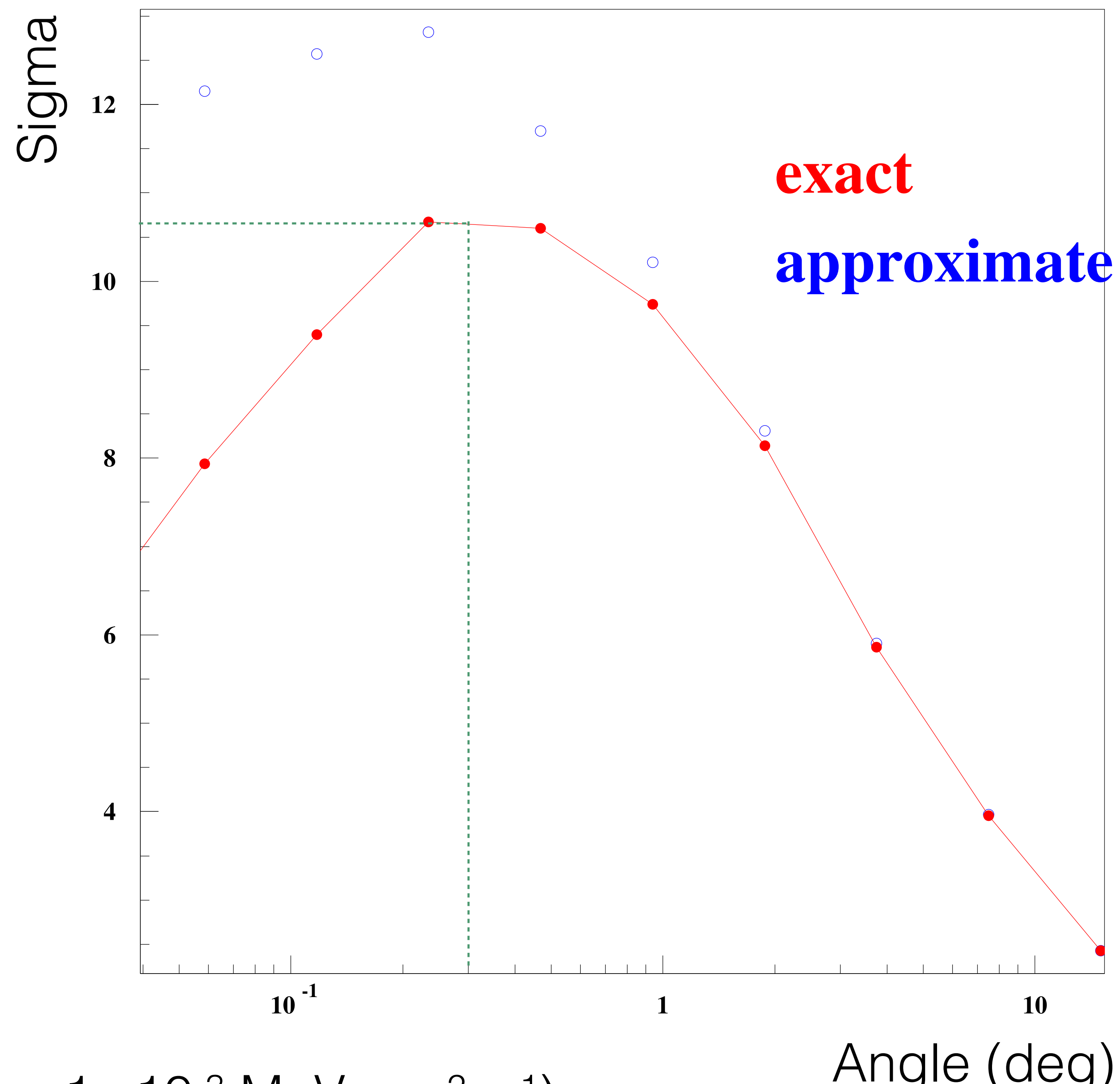
Simulation of event in ST3G





ST3G

Simulation of observation of the Crab Nebula (“standard candle”)



Crab (index: 2; flux:1 x10^{-3} MeV cm^{-2} s^{-1})
1 week effective exposure with ST3G @35 km (Kirune)
10.5 sigma for angular cut of 0.3 deg

ST3G

- We want to fly ST3G on a balloon to:
  - calibrate the instrument with actual cosmic data
  - understand the background
  - run the trigger in its real environment
    - ➡ measure the combined sensitivity of the trigger/detector system

Our plans

- CNES April 2017
  - seek approval for balloon flight (BSO)
  - flight duration of approx. 1 week
- ERC September 2017
  - fund several CDDs and postdocs
  - fund hardware
- Organise a workshop at LLR early in 2017
  - accrete more people to join our team
- PhD thesis proposed for 2017 (CNES/CNRS)

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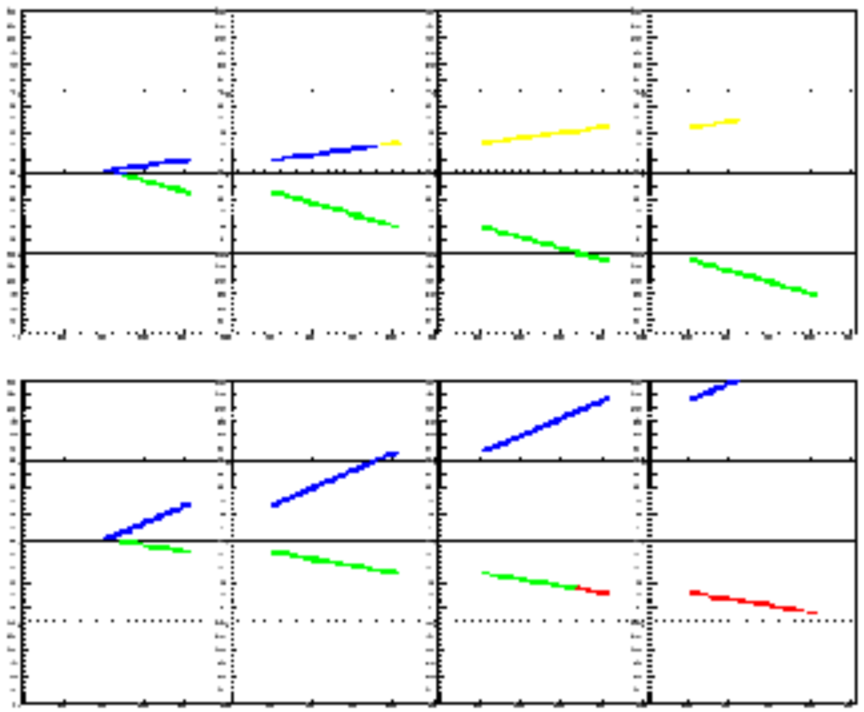
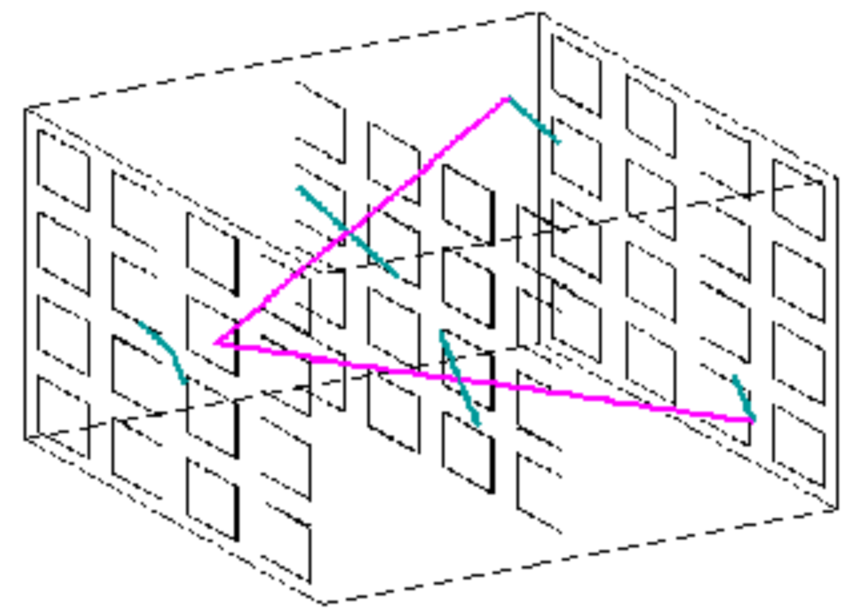
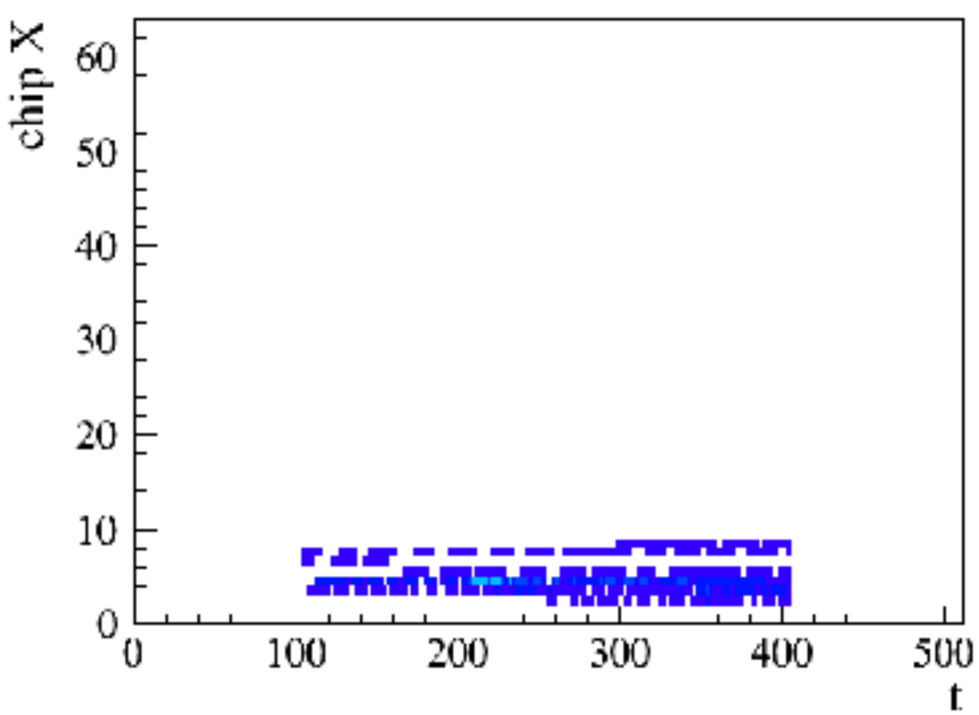
… for these we request the continued support of LLR

Thank you for your attention

ST3G







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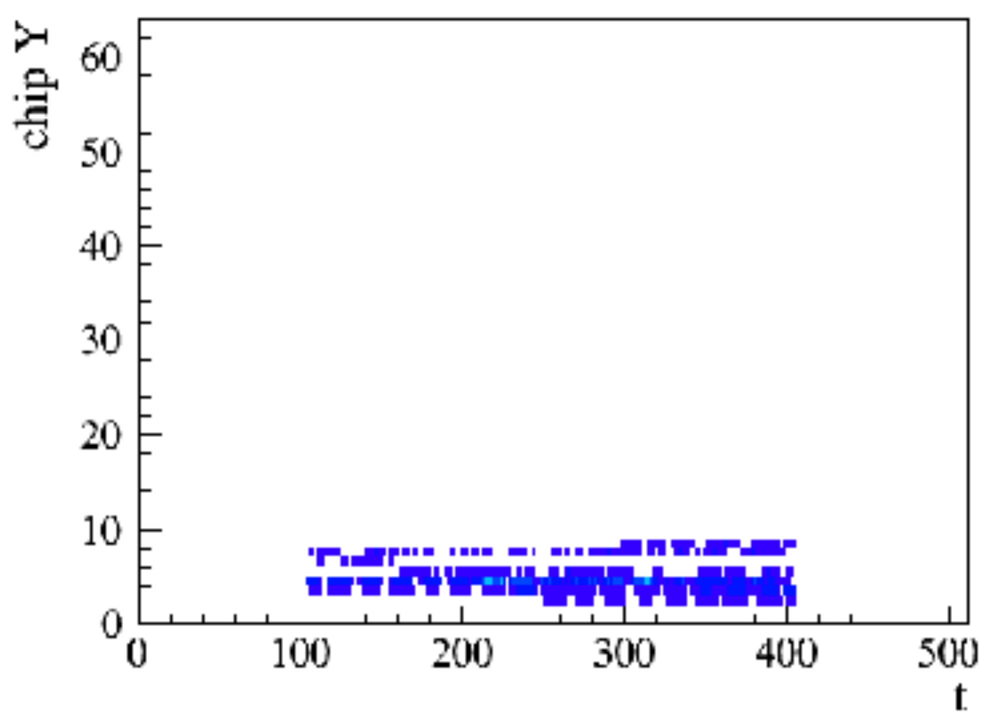

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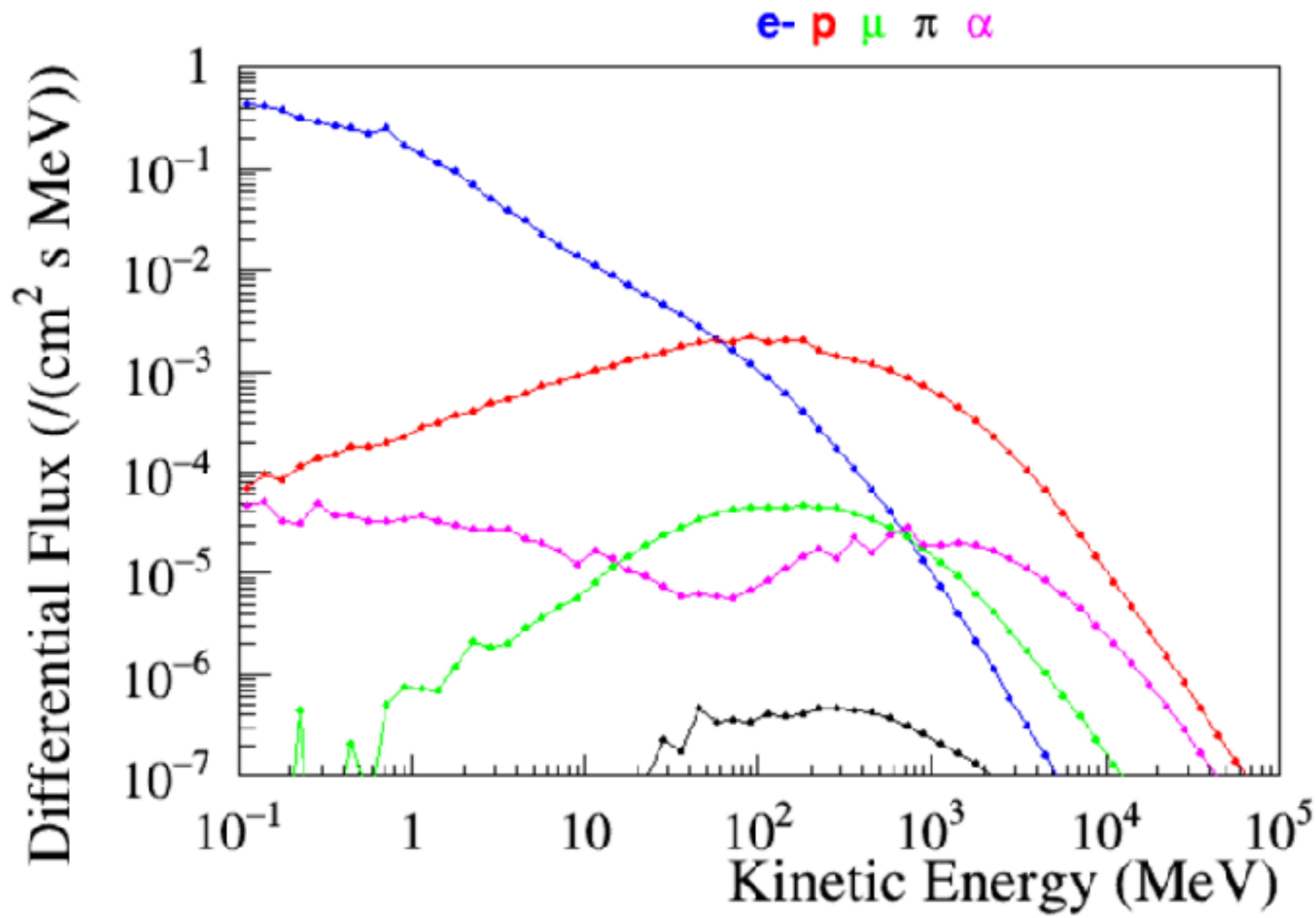
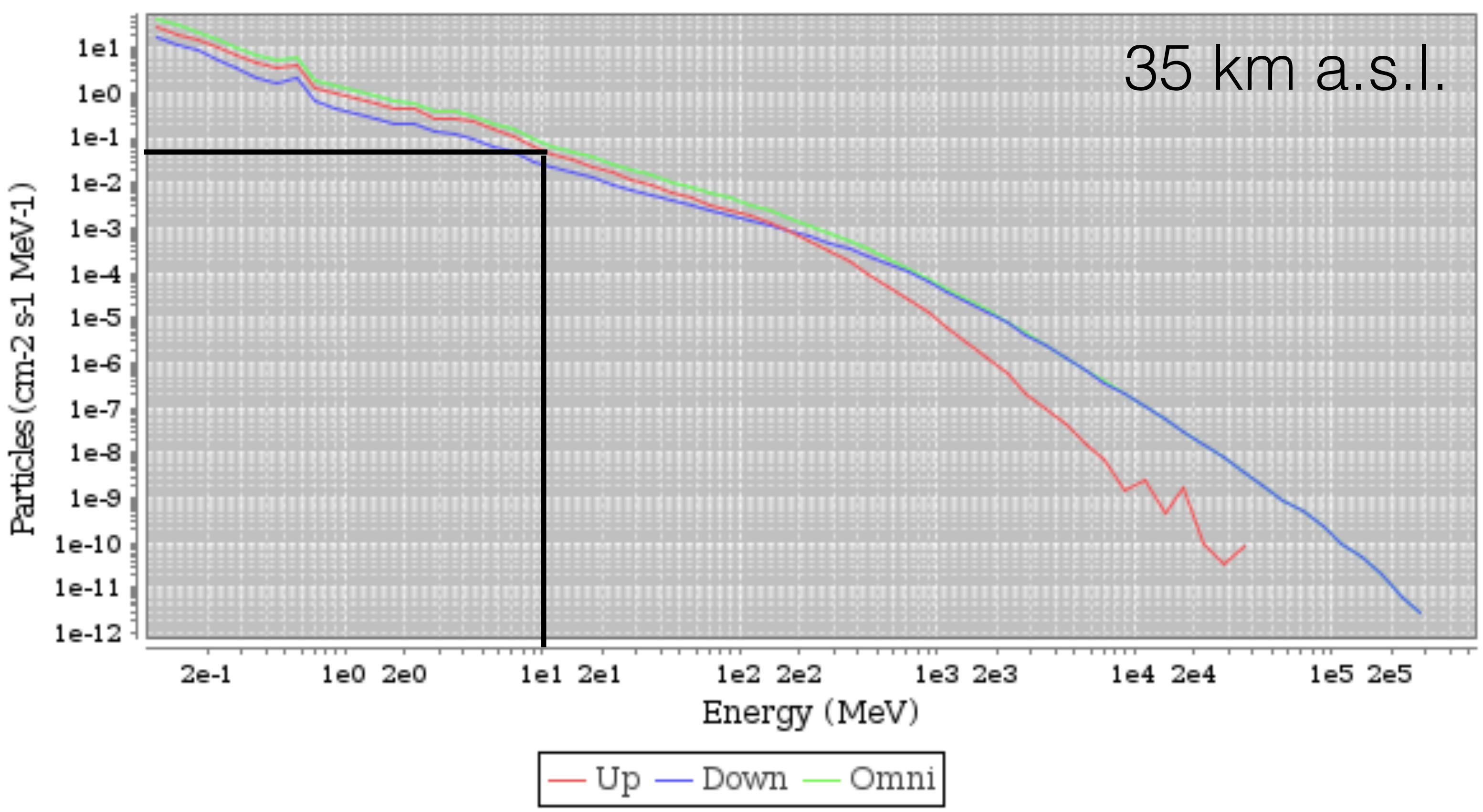
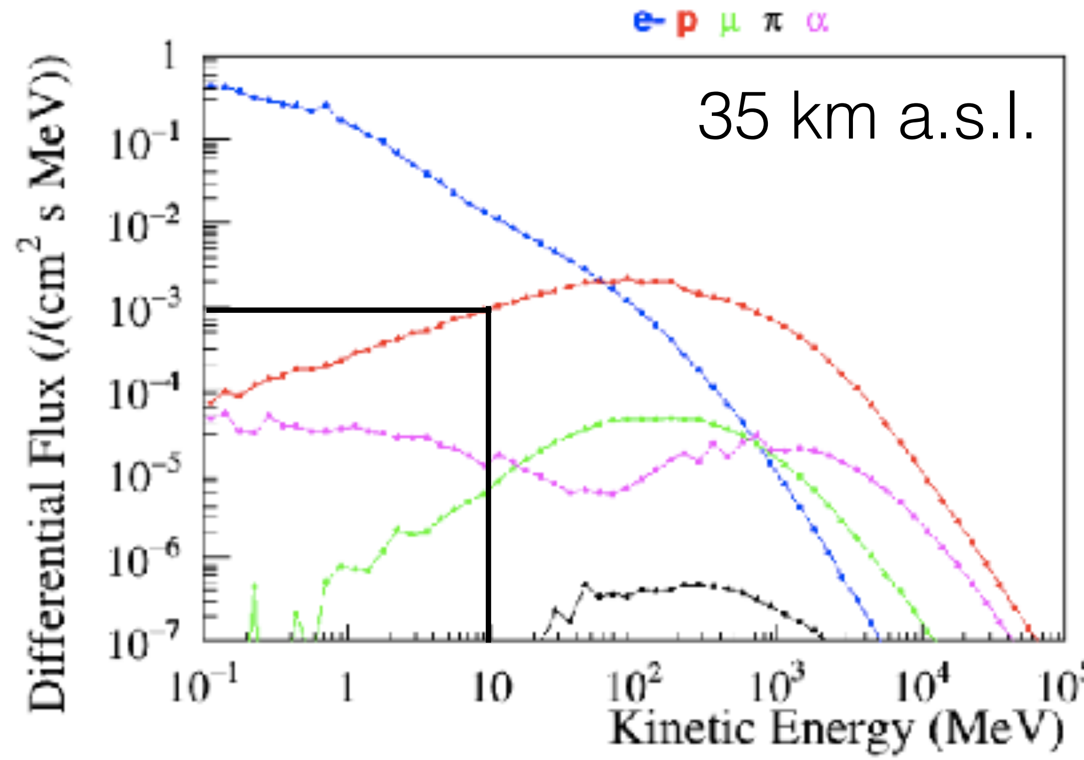
ST3G



Key challenge: self-triggering ... in real time ... in space

ST3G





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