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High-energy particle interactions in blazar jets

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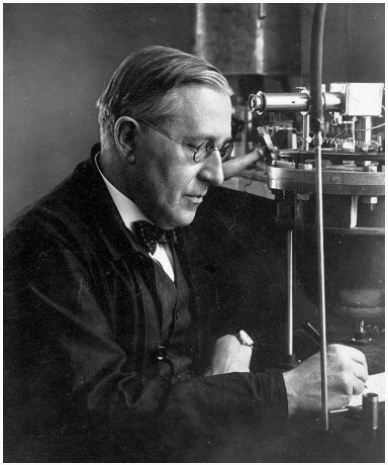
Introduction

110-years-old riddle

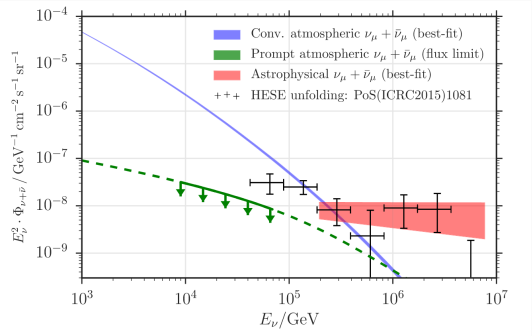


Victor Hess

Particles with highest ever observed energies were detected in cosmic rays.

- ◇ Where these particles come from?
- ◇ How are they accelerated?
- ◇ Composition, properties, search for new physics?

2013: Neutrinos from space



Observation of astrophysical neutrinos with 6 years of IceCube data

Astrophysical neutrinos were discovered in 2016 with the IceCube Neutrino Observatory. As for now, more than 100 high-energy cosmic neutrinos with energies between 100 TeV and 10 PeV were detected by IceCube.

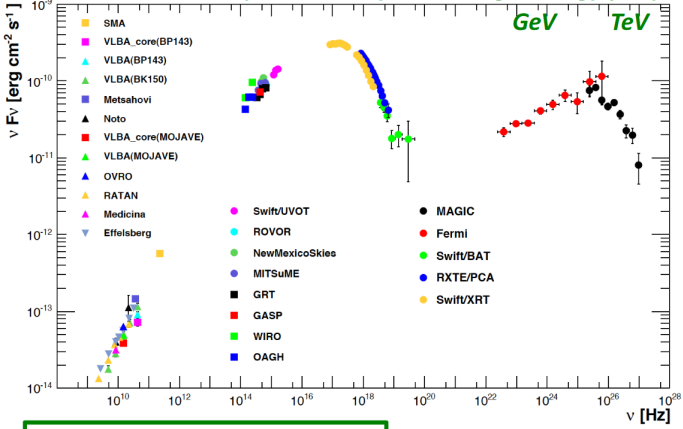
- ◇ What are neutrino sources?
- ◇ How high-energy neutrinos are produces?
- ◇ What information do they carry about physical processes in the source?

Blazars

Extremely powerful sources

- Powered by the central engine, supermassive black hole, active galactic nuclei (AGNs) outshine the host galaxy
- Some of AGNs launch relativistic jets
- AGN pointing towards Earth (blazar) $\longrightarrow$ efficient Lorentz boosting

Spectral energy distribution: similarities in blazars



Abdo et al 2011, ApJ 736, 131

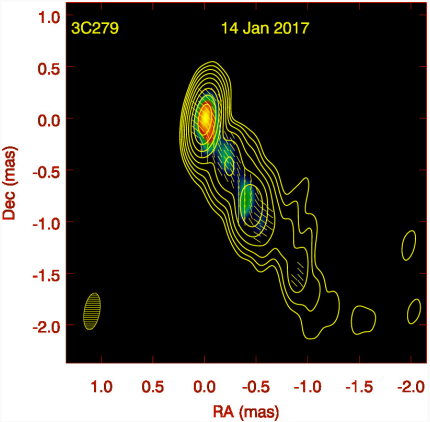
Blazars as neutrino sources

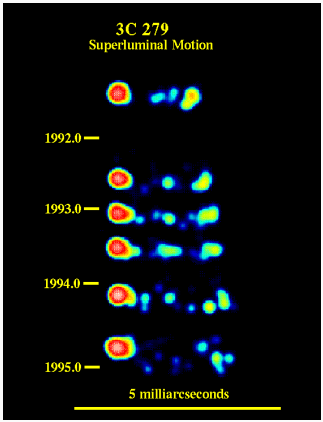
By now, there are three known blazars that are neutrino sources:

- TXS 0506+056
  2017: IceCube-170922A, 290 TeV;
  2014-2015: 13±5 more event from IceCube, 10-20 TeV, 3.5σ atmospheric background excess
- PKS 1502+102
  2019: IceCube-190730A, 300 TeV
- PKS 0735+178
  2021: IceCube-211208A, 172 TeV
  3.5 hours after IceCube event: Baikal-GVD, 43 TeV
  4 days before IceCube event: Baksan Underground Scintillation Telescope, $\sim$ 10 GeV

Our current understanding of blazar emission

Radiation zone



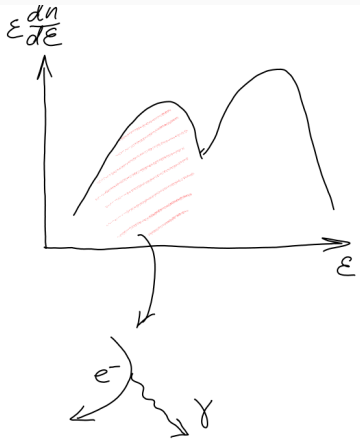


Radiation zone is a spherical blob. This is motivated by:

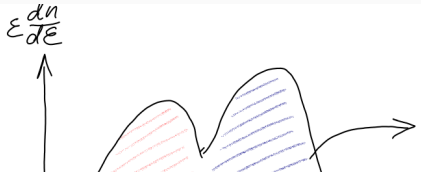
- ◇ radio observations
- ◇ ideas from plasma physics

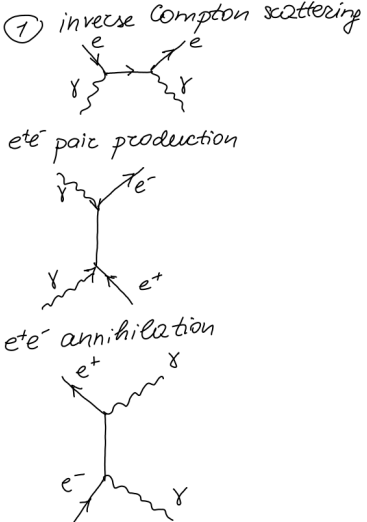
Particle interactions

Particle interactions

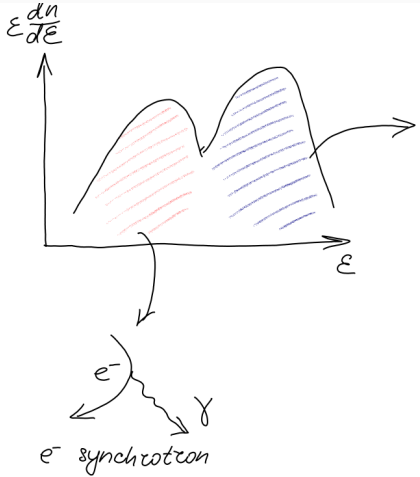


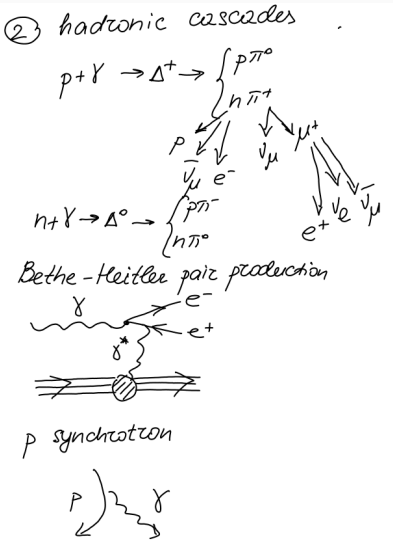
Particle interactions





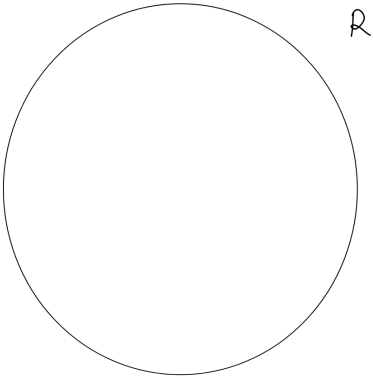
Particle interactions



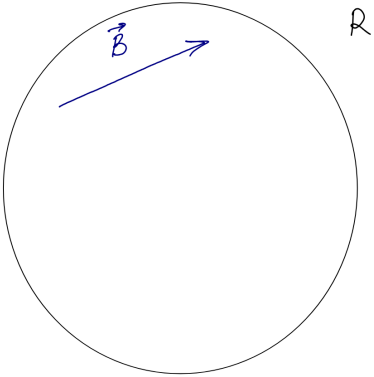


Modeling particle interactions in jets

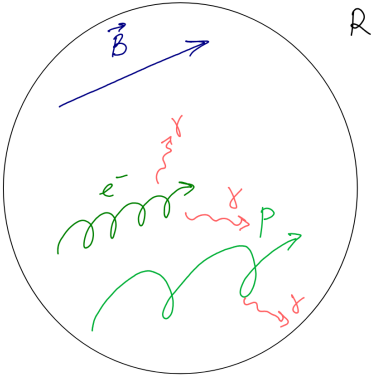
Modeling setup



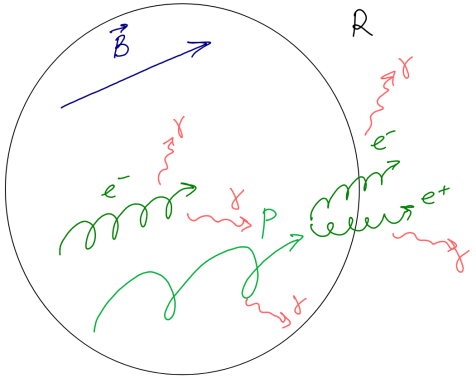
Modeling setup



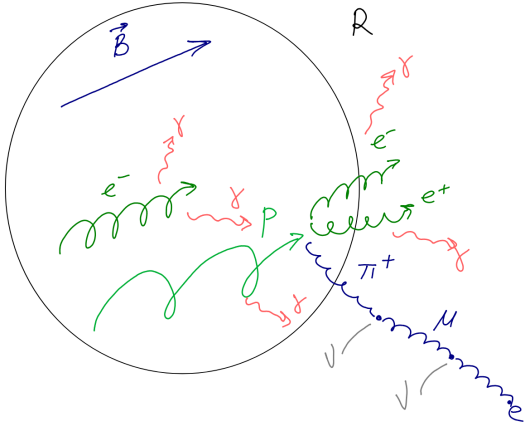
Modeling setup



Modeling setup

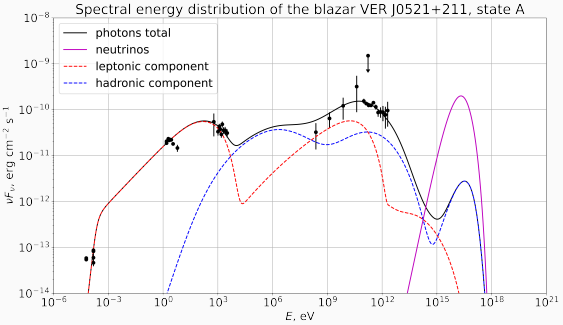


Modeling setup



γ-ray flare of blazar VER J0521+211

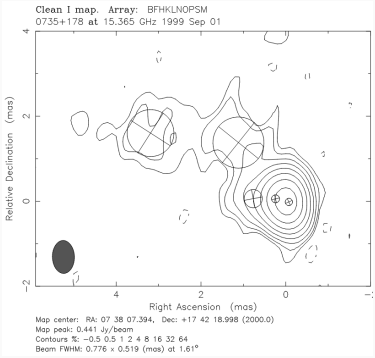
Preliminary

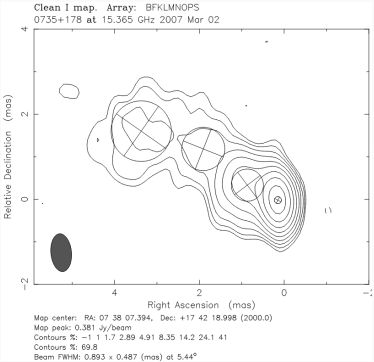


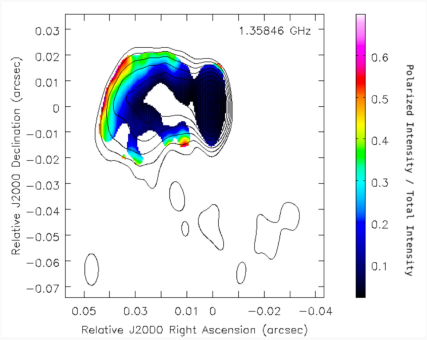
MAGIC Collaboration + AO, Xavier Rodrigues, Anna Franckowiak (in preparation)

- TeV photons observed in February 2020 by MAGIC telescope
- simultaneously, mutli-wavelength data was collected in different bands
- gamma-rays produced in hadronic interaction in one radiation zone can explain the origin of this extreme activity

PKS 0735+178


Clean I map. Array: BFHKLNOPSM
0735+178 at 15.365 GHz 1999 Sep 01
Relative Declination (mas)
Right Ascension (mas)
Map center: RA: 07 38 07.394, Dec: +17 42 18.998 (2000.0)
Map peak: 0.441 Jy/beam
Contours %: −0.5 0.5 1 2 4 8 16 32 64
Beam FWHM: 0.776 x 0.519 (mas) at 1.61°


Clean I map. Array: BFKLMNOPS
0735+178 at 15.365 GHz 2007 Mar 02
Relative Declination (mas)
Right Ascension (mas)
Map center: RA: 07 38 07.394, Dec: +17 42 18.998 (2000.0)
Map peak: 0.381 Jy/beam
Contours %: −1 1 1.7 2.89 4.91 8.35 14.2 24.1 41
Contours %: 69.8
Beam FWHM: 0.893 x 0.487 (mas) at 5.44°


1.35846 GHz
Relative J2000 Declination (arcsec)
Relative J2000 Right Ascension (arcsec)
Polarized Intensity / Total Intensity

Final remarks

Conclusions

- ◇ Blazars are powerful sources of EM radiation and neutrinos
- ◇ In most of the cases, radiation may be explained by particle interactions in a small region inside the jet
- ◇ Numerical modeling of radiation process in blazar jets helps us to explain the observed multi-messenger data

Outlook

- The exact mechanism of particle acceleration in near supermassive black holes as well as jet formation in general remain interesting open questions
- With the development of new instruments and better quality of data, astrophysical sources can become a new setup for testing fundamental physics at higher energies

Thank you for your attention!