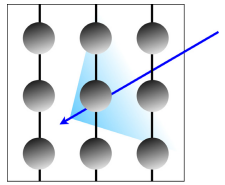
History Multi-Messenger Astrophysics

Event	EM	CR	GW	ν	Date
Solar Flare	yes	yes			1940
Supernova	yes		pred	yes	1987
NS merger	yes		yes	pred	aug 2017
Blazar	yes	pred		yes	sep 2017

- Optical very old, new fields in last hundred years
- Importance and History of Multi Messenger Astrophysics
- Solar Flare in 1940
- SN1987A in Large Magellanic Cloud in 1987
  - 25 neutrinos at 3 observatories
  - confirmed model core-collapse (neutrinos carry 99% Energy)
  - Nobel Prize 2002
- NS merger
  - big in the news
- Blazar
  - not so big in the news
  - what we will talk about

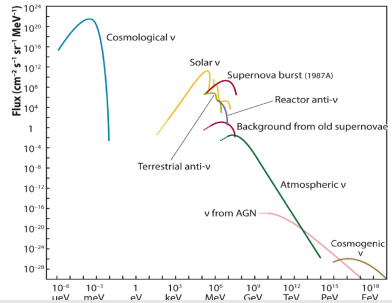
Neutrino Basics

- Neutrino interacts in atmosphere, ice or water
- Charged particle gets into the ice or water
- Cherenkov photons detected by DOMs in the matter



- Interactions
  - Neutral Current: energy into e^-, ν_e flies off
  - Charged C: ν_μ on e^- goes to ν_e with μ
- Cherenkov light
- Digital-Optical Modules
- Recap: idea of telescope

Astrophysical vs Atmospheric Neutrino

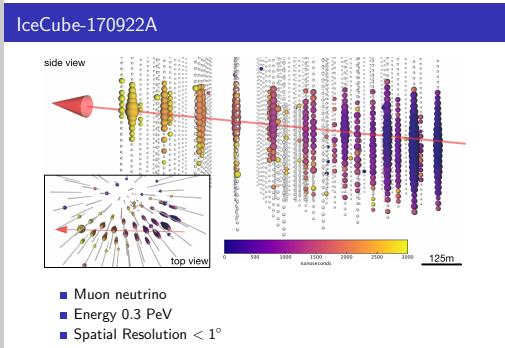


- Distinction Atmospheric vs Astrophysical
  - steep decline for ¿ TeV
  - lower energies
  - solar flare, sn1987A only because of flux
- Observatories: IceCube, ANTARES
  - IceCube: 100 GeV - several PeV
  - ANTARES: 10 GeV - 100 TeV
- Types of events
  - Tracklike (through-going)
  - Showerlike

Possible Multi-Messenger Astrophysics on a Blazar

IceCube-170922A

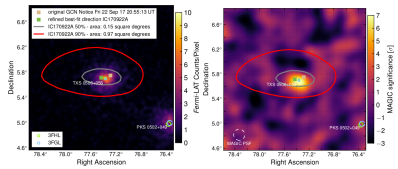
IceCube-170922A



- 22 sept 2017 Icecube
- Muon detection (automated analysis)
- real-time alert system
- 43 secs initial direction and energy

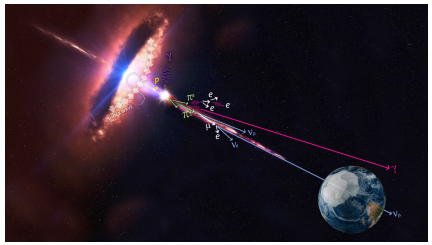
- Muon track
- $\rightarrow$ zenith angle 5.7 ± 0.5
- $\rightarrow$ interaction outside
- $\rightarrow$ simulations

- IC robust $>$ PeV, individual atmospheric not excluded ~ 100TeV
- followup ANTARES data
  - no candidates (± 1 day)
  - sensitivity 1/10 of IceCube at declination
- $\Rightarrow$ EM observation needed

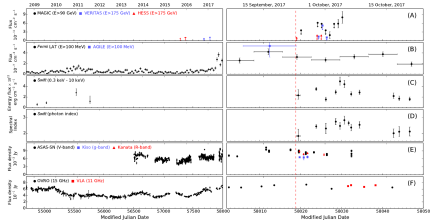


- γ-ray blazar TXS 0506+056 within 0.1° of IC event

- Fermi-LAT instrument
  - 20 MeV to 300 GeV + pair-conversion ($e^- + e^+$)
  - all-sky survey (entire sky every 3h)
- Fermi-LAT observation
  - object 0.1° from best-fitting direction known source
  - brightening since April 2017, confirmed by AGILE (italian)
  - automated processing $\rightarrow$ previous flare $\rightarrow$ because neutrino
- MAGIC instrument
  - telescope on La Palma
  - 50 GeV to 30 TeV
- MAGIC observation
  - observation non-optimal 2h $\rightarrow$ nothing
  - observation good 13h $\rightarrow$ 374 ± 62 excess photons
- VERITAS, HESS no observations $\rightarrow$ upper limits (coming slide)
- HAWC no source above 1TeV in (archival) data
- $z < 1$ from flux and extragalactic background light interaction



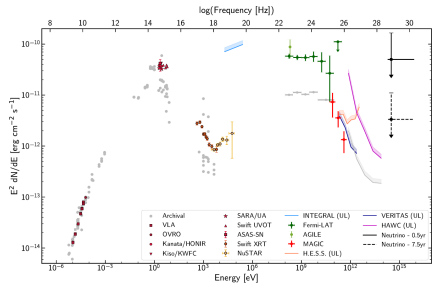
- Active Galactic Nucleus
- early optical and radio detections
- Jet from Central BH
- Blazar = jet pointed at us
- Joke: earth wrongly rotated for current event



- Not only Gamma Rays: X-ray to Radio
- dates: left: 22 Aug 2008 to 6 Sept 2017
  right: 6 Sept 2017 to 22 Sept 2017

- VHE γ: flare, difference because of Energy and Exposure
- γ: flare (AGILE confirmation), earlier flare
- X-Ray: 9 sources within 2.1 sq deg

Broadband Spectrum of TXS 0506+056



- observations within 14 days of IC-170922A
- archival data
- UL is upper limit
- double bump structure (characteristic of non-thermal emission)
- redshift difficult non-thermal outshines spectral lines
- later redshift measurement from optical data ($z = 0.3365 \pm 0.0010$)
- Extrapolated Spectra connect smoothly

- 3σ non-random coincidence $\rightarrow$ inconclusive
- ν detection in 2014 in vicinity of TXS $0506+056$

- IC-170922A not enough for science
  - neutrino production models
  - neutrino to gamma
- real-time alert system since Apr 2016
- 41 archival events also tested with TXS
- neutrino 2014 - points to Blazar - lower energy