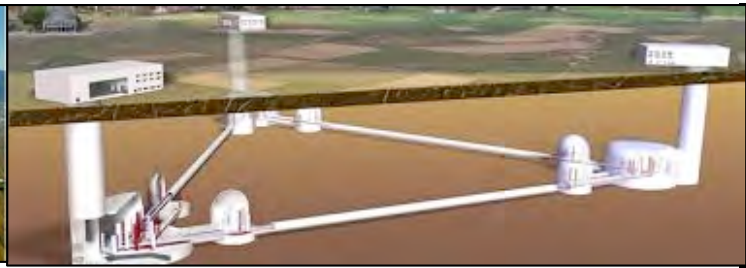
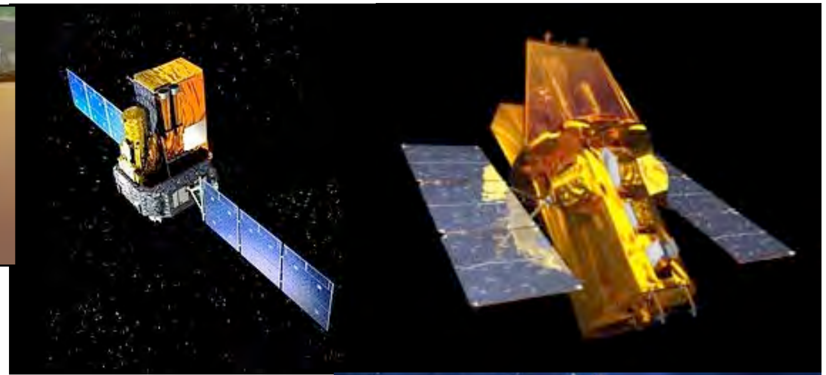
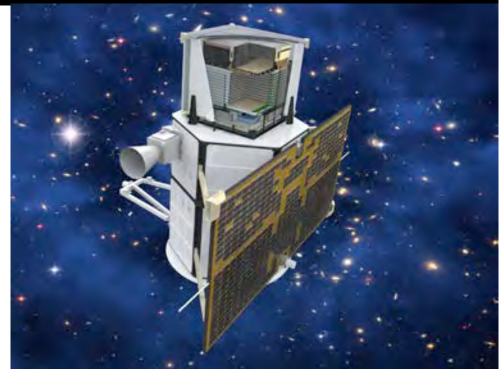




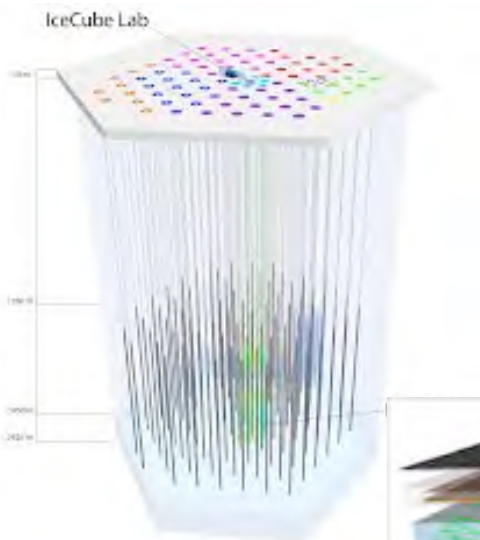
Large-FoV gamma-ray detectors with threshold ~100 MeV and Multimessenger Astronomy



Alessandro De Angelis

INFN, INAF, LIP/IST, Univ Ud/Pd

Praha, May 2018



The problem

- Do we expect to see gamma rays with LATTES in conjunction with
  - neutrino and/or
  - gravitational wave events
  - and/or … ?

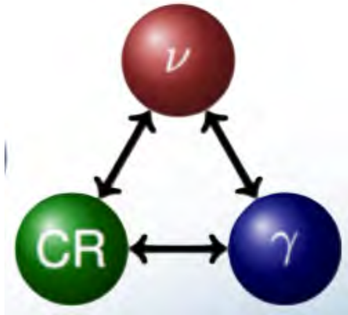
- If we see them, what can we say?

NEUTRINOS

Astrophysical neutrino production

- Proton-hadron

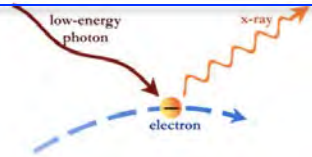
$$pp \rightarrow \begin{cases} \pi^0 \rightarrow \gamma\,\gamma \\ \pi^+ \rightarrow \mu^+ \nu_\mu \rightarrow e^+ \nu_e \nu_\mu \bar{\nu}_\mu \\ \pi^- \rightarrow \mu^- \bar{\nu}_\mu \rightarrow e^- \bar{\nu}_e \bar{\nu}_\mu \nu_\mu \end{cases}$$

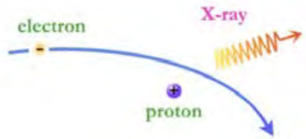


- Photoproduction

$$p\gamma \rightarrow \Delta^+ \rightarrow \begin{cases} p\,\pi^0 \rightarrow p\,\gamma\,\gamma \\ n\,\pi^+ \rightarrow n\,\mu^+ \nu_\mu \rightarrow n\,e^+ \nu_e \bar{\nu}_\mu \nu_\mu \end{cases}$$

$$E_\nu^2 \frac{dN_\nu}{dE_\nu}(E_\nu) \sim \frac{3}{4} K E_\gamma^2 \frac{dN_\gamma}{dE_\gamma}(E_\gamma)\,;\; K = 1/2\ (2)\ \text{for}\ \gamma p\ (pp)$$





- HE gamma rays can also come from purely leptonic mechanisms (SSC)
- The production rate of γ-rays is not necessarily the emission rate observed: photons can be reprocessed

Hadroproduction

$$pp \rightarrow \begin{cases} \pi^0 \rightarrow \gamma\,\gamma \\ \pi^+ \rightarrow \mu^+ \nu_\mu \rightarrow e^+ \nu_e \nu_\mu \bar{\nu}_\mu \\ \pi^- \rightarrow \mu^- \bar{\nu}_\mu \rightarrow e^- \bar{\nu}_e \bar{\nu}_\mu \nu_\mu \end{cases}$$

$$N_\pi \sim 3 \left(\frac{E_p - E_{th}}{\text{GeV}} \right)^{1/4} \sim 3 \left(\frac{E_p}{\text{GeV}} \right)^{1/4} , \tag{10.15}$$

where E_{th} is the threshold energy for pion production, less than 1 GeV - we can neglect it at large proton energies. Consequently, the average pion energy at the source is related to the proton energy, in the direction of flight of the proton, by

$$\langle E_\pi \rangle \sim \Gamma \sqrt{\frac{2}{9}} \left(\frac{E_p}{\text{GeV}} \right)^{1/4} \sim \frac{1}{3} \left(\frac{E_p}{\text{GeV}} \right)^{3/4} .$$

The generic pion distribution from the hadronic collision, assuming equipartition of energy among pions, can be written as

$$q_\pi \simeq n_H l \sigma_{pp} \int_{E_{th}}^{\infty} dE_p \, j_p \left(\frac{E_p - E_{th}}{3\text{GeV}} \right)^{3/4} \delta(E_\pi - \langle E_\pi \rangle) , \tag{10.16}$$

where n_H is the density of hadrons in the target, l is the depth, j_p is the proton rate. If the differential proton distribution per energy and time interval at the source is

$$j_p(E_p) \propto E_p^{-p} . \tag{10.17}$$

making in the integral (10.16) the substitution $E_p \rightarrow E_\pi^{4/3}$ the pion spectrum at the source is

$$q_\pi(E_\pi) \propto E_p^{-\frac{4}{3}p + \frac{1}{3}} . \tag{10.18}$$

The photon (and the neutrino) spectra become

$$q_\gamma(E_\gamma) = A_\gamma E_p^{-\frac{4}{3}p + \frac{1}{3}} ; q_\nu(E_\nu) = A_\nu E_p^{-\frac{4}{3}p + \frac{1}{3}} , \tag{10.19}$$

Photoproduction

- Although $\sigma_{\gamma p} \sim 0.3$ mb $\sim \sigma_{pp}/100$, photoproduction is favored in jets because the photon density is expected to be larger

$$p\gamma \rightarrow \Delta^+ \rightarrow \begin{cases} p\,\pi^0 \rightarrow p\,\gamma\,\gamma \\ n\,\pi^+ \rightarrow n\,\mu^+\,\nu_\mu \rightarrow n\,e^+\,\nu_e\,\bar{\nu}_\mu\,\nu_\mu \end{cases}$$

- This process has obviously a threshold, and is dominated by the Δ pole:

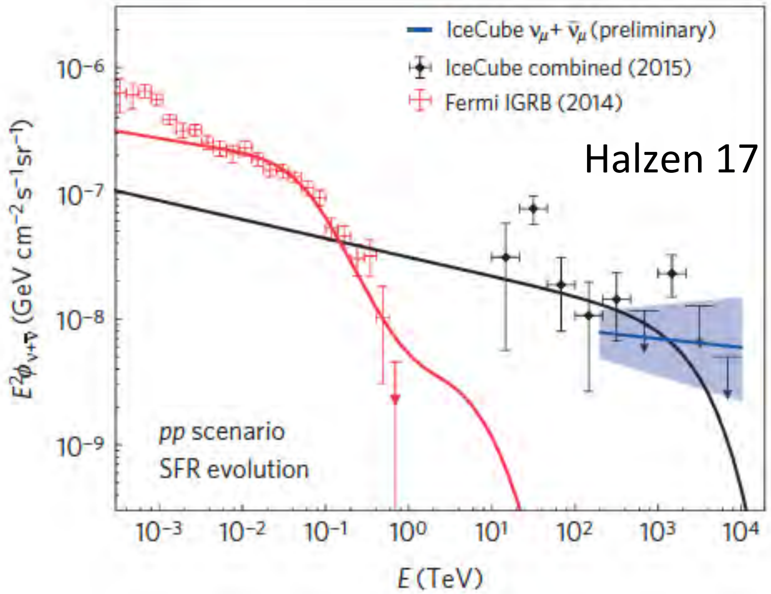
$$E_p \sim 350 \text{ PeV} / (\varepsilon/\text{eV})$$

=> The creation of a neutrino (or gamma ray) from a photon gas at 10 eV requires protons at $E_p > 35$ PeV

- E^{-p} in protons => E^{-p} in photons and neutrinos, rescaled by a factor 10 (20)

Reprocessing

- Gamma rays are likely to be reprocessed in the photon gas, to shower and
  - Degrade they energy - this explains the shift in the E distribution of the extragalactic background of γ vs. ν



  - Arrive later
  - This is again an estimator of the column density

First detection of (HE, VHE) gamma-ray excess positionally and temporally consistent with an IceCube EHE neutrino (EHE170922). Astronomer telegrams:

IceCube-170922A: IceCube observation of a high-energy neutrino candidate event

Fermi-LAT detection of increased gamma-ray activity of TXS 0506+056, located inside the IceCube-170922A error region.

AGILE confirmation of gamma-ray activity from the IceCube-170922A error region

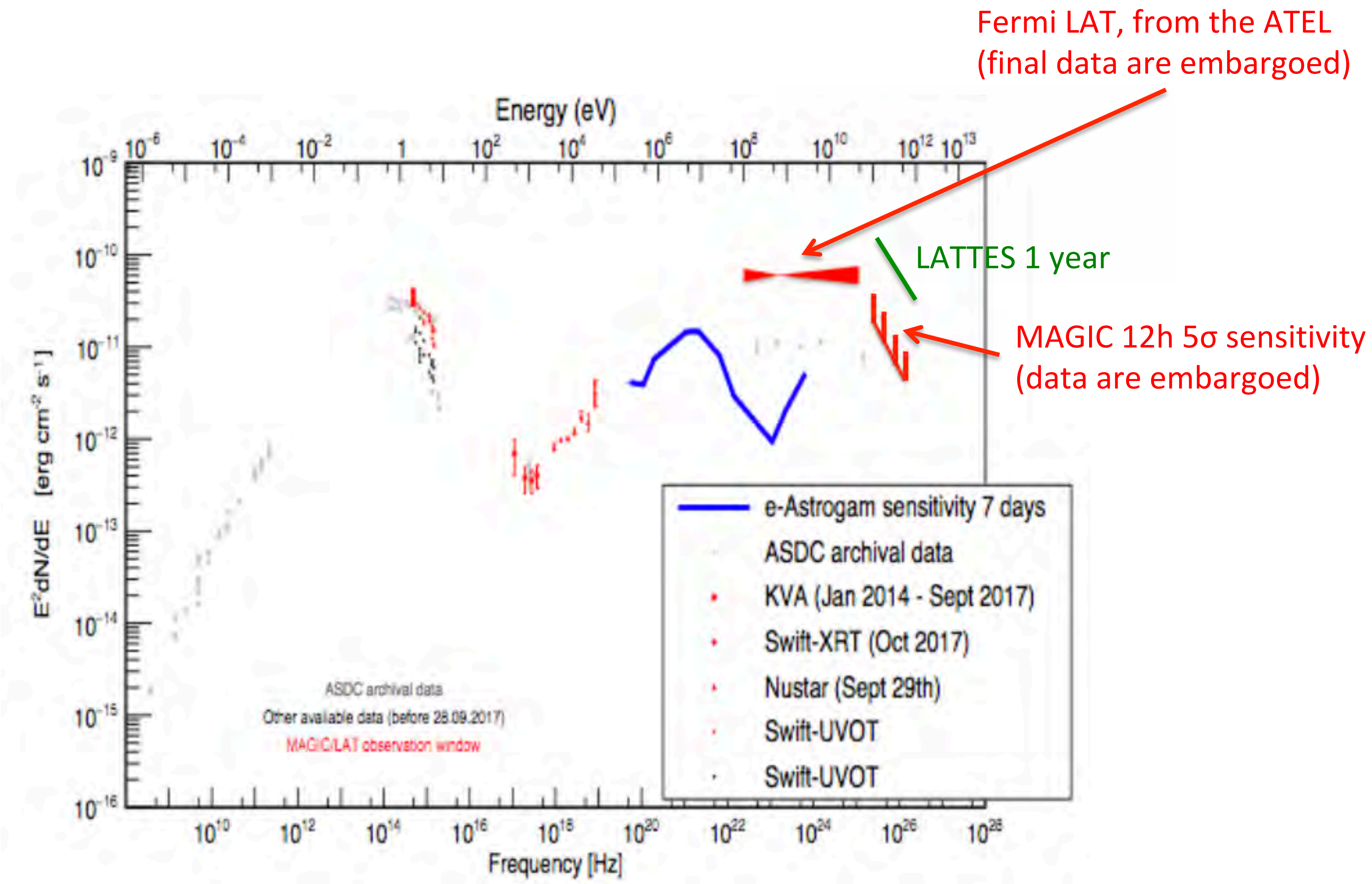
Further Swift-XRT observations of IceCube 170922A

First-time detection of VHE gamma rays by MAGIC from a direction consistent with the recent EHE neutrino event IceCube-170922A

Related

- 10845 Joint Swift XRT and NuSTAR Observations of TXS 0506+056
- 10844 Kanata optical imaging and polarimetric follow-ups for possible IceCube counterpart TXS 0506+056
- 10840 VLT/X-Shooter spectrum of the blazar TXS 0506+056 (located inside the IceCube-170922A error box)
- 10838 MAXI/GSC observations of IceCube-170922A and TXS 0506+056
- 10833 VERITAS follow-up observations of IceCube neutrino event 170922A
- 10831 Optical photometry of TX0506+056
- 10830 SALT-HRS observation of the blazar TXS 0506+056 associated with IceCube-170922A
- 10817 First-time detection of VHE gamma rays by MAGIC from a direction consistent with the recent EHE neutrino event IceCube-170922A
- 10802 HAWC gamma ray data prior to IceCube-170922A
- 10801 AGILE confirmation of gamma-ray activity from the IceCube-170922A error region
- 10799 Optical Spectrum of TXS 0506+056 (possible counterpart to IceCube-170922A)
- 10794 ASAS-SN optical light-curve of blazar TXS 0506+056, located inside the IceCube-170922A error region, shows increased optical activity
- 10792 Further Swift-XRT observations of IceCube 170922A
- 10791 Fermi-LAT detection of increased gamma-ray activity of TXS 0506+056, located inside the IceCube-170922A error region.
- 10787 H.E.S.S. follow-up of IceCube-170922A
- 10773 Search for counterpart to IceCube-170922A with ANTARES

The SED (the flare lasted ~7 days)



Conclusion: on the basis of the only event we know, it can't be done (we are off by ~2-3 orders of magnitude in sensitivity)

GRAVITATIONAL WAVES

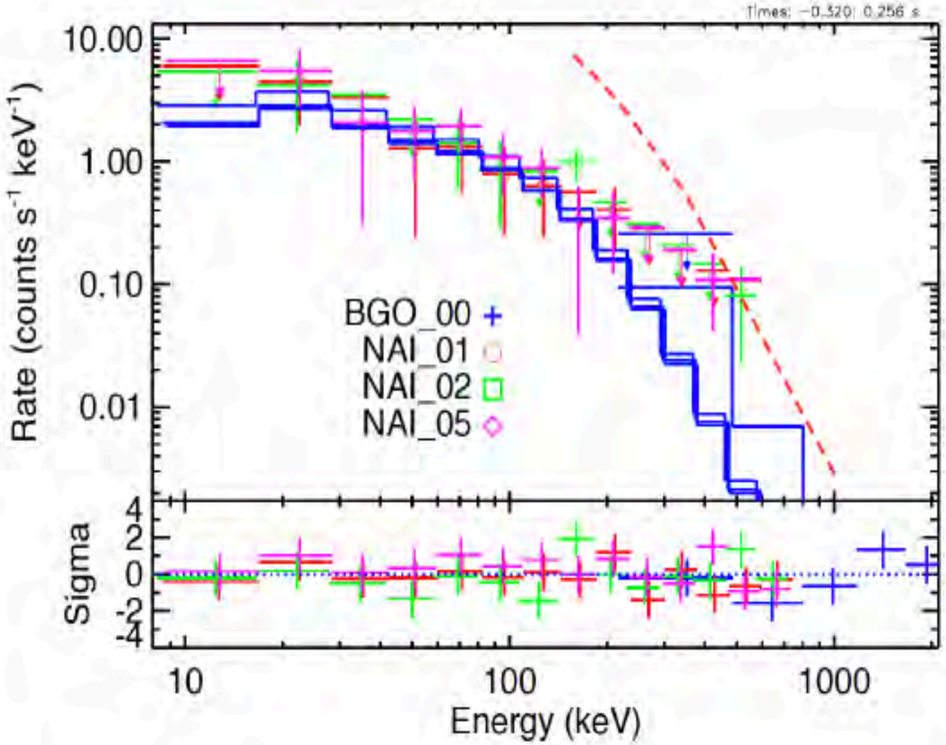
Multimessenger Astronomy: Gravitational Waves

- BH-BH mergers: ~10/year, but no accretion disk, no gamma rays
- NS-NS mergers; ~2-20/year after KAGRA + INDIGO
- GW170817: cutoff at ~200 keV, but largely off-axis (~30 degrees).
- The merger has a mass ~ 2.8 $M_\odot$ close to the maximum possible mass for a NS

  And there is little dynamical space:

  $$1.2\ M_\odot < M_{NS} < 3\ M_\odot$$

- Extrapolation of the electromagnetic counterpart to on-axis gives E ~ 1-10 MeV (no market for EAS)



We are left with BH-NS mergers…

- Never observed, yet
- A case not well studied in the literature
- Rosswog 2005: MHD simulation, one can have accretion disks (=> gamma-ray emission) in the case of a NS coalescence with a BH of 15-30 $M_{\odot}$ (and there are many…)
  - the merger, rather than producing a gamma-ray burst, yields a SN-like transient with a thermal precursor pulse in the gamma-ray band
  - Such a precursor lasts ~10 ms
  - Peak energy at ~ 10 MeV
  - Also based on energetics and scaling from NS-NS, < 100 MeV

Conclusion: on the basis of a fast study, very unlikely. We can invest more effort, but we are off by ~3 orders of magnitude in energy

CHARGED COSMIC RAYS

Positrons+Electrons (Pulsars nearby and gas)

- Important for the studies of indirect production of DM
- Interaction of CRs with molecular clouds; accelerated electrons; gamma rays converted aat the source
- Uses the capability of the detector to image extended sources, and LATTES is better than HAWC thanks to the low energy threshold
- Did not have the time to study, yet
- Worth an investment for the White Book

Conclusion: positive; needs work

Correlations with Auger/TA

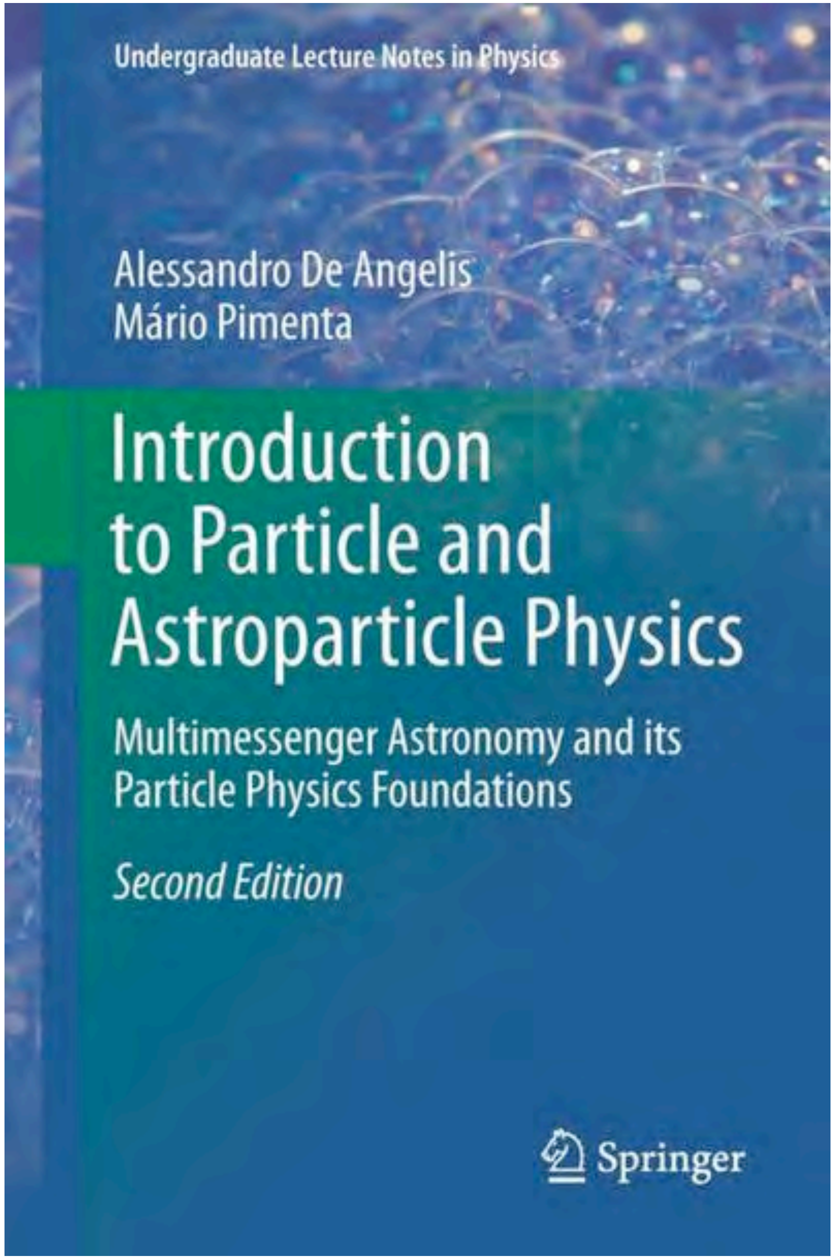
- In this case study we use the highest energy part of the SED…
- Detection of sources ~ 100 TeV, possibly indicating PeVatrons
  - Production of photons above ~10 TeV via leptonic mechanisms very unlikely due to Klein-Nishina suppression of the SSC mechanism
  - 100 TeV photons point to hadrons at E ~ 20x
- Correlations with
  - Galactic asymmetries (we are better than HAWC since we are located in the South)
  - hotspots of extragalactic emission (LATTES is ~equivalent to HAWC, and we'll know more when HAWC's at VHE catalog will be out)

Conclusion: positive; worth detailed work

SUMMARY – TODO FOR A WB

- MW with neutrinos
  - With the present size of neutrino detectors, only flaring AGN can be detected (saw one)
    - LATTES' sensitivity does not allow gamma detections of objects like TXS 0506 +056
  - Re-evaluate with a 3 km^3 Km3NeT (2028)? Space resolution of Km3Net is twice as good as IceCube, but is this relevant? Make a study of the energetics of blazars, but little hope
  - Galactic flares near GC? Very narrow space: no gamma-ray counterparts seen yet
- MW with GW
  - No hope for BH-BH and NS-NS (low energy is not low enough for NS-NS)
  - Prospects for BH-NS don't seem good; can perform independent study, but little hope
- MS with CR
  - Potentially good prospects for electrons/positrons/cosmic ray bubbles. Needs a careful study for a WB. Could exploit large FoV and low threshold
  - Potentially good prospects for spatial association with CR above ~10 PeV. Could use the fact of being South (Galactic sources; to a non-exclusive but independent extent extragalactic). Needs information from HAWC. High energies

ALL THIS… AND MORE IN A BOOK COMING SOON



- On sale from June 16, 2018

- Provides a balanced, university-level introduction to particle physics, astroparticle physics and multimessenger astrophysics

- Exercises site at the web address

  ipap.uniud.it