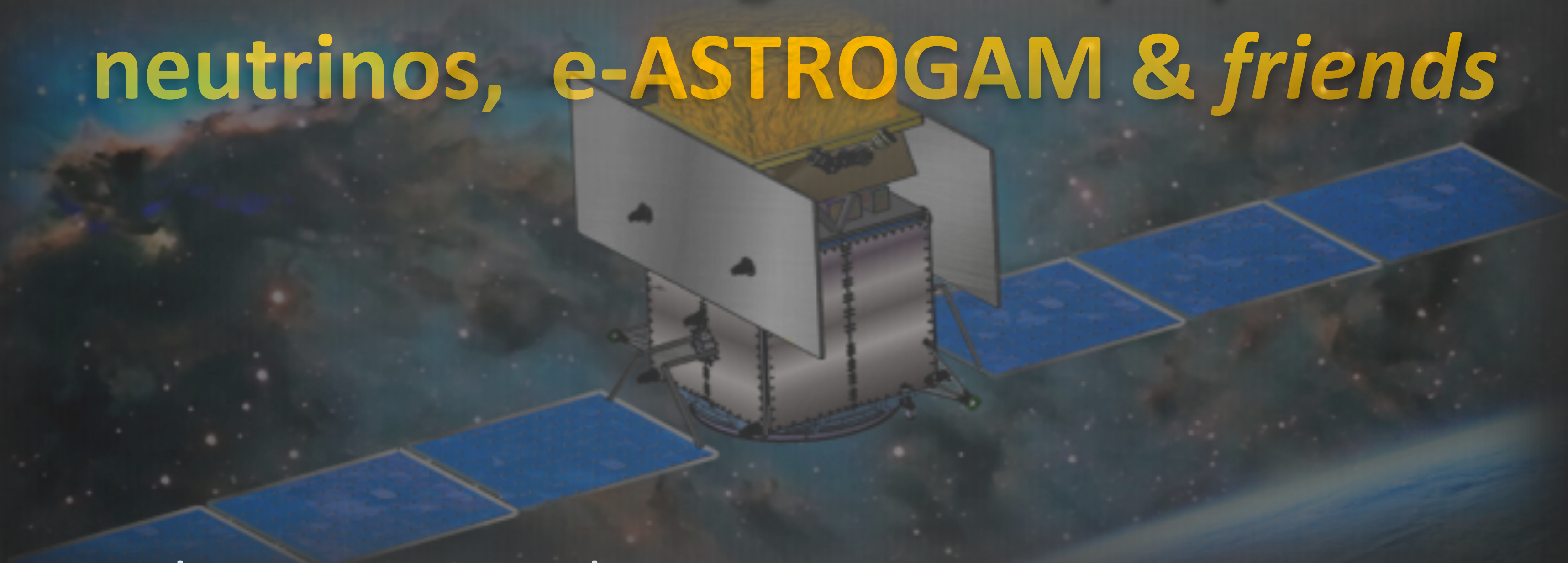
Multi-messenger astrophysics: neutrinos, e-ASTROGAM & *friends*



a.k.a. SYNERGIES between NEUTRINO TELESCOPES and e-ASTROGAM/AMEGO

Sara Buson[1], Elisa Bernardini[2], Alexis Coleiro[3]

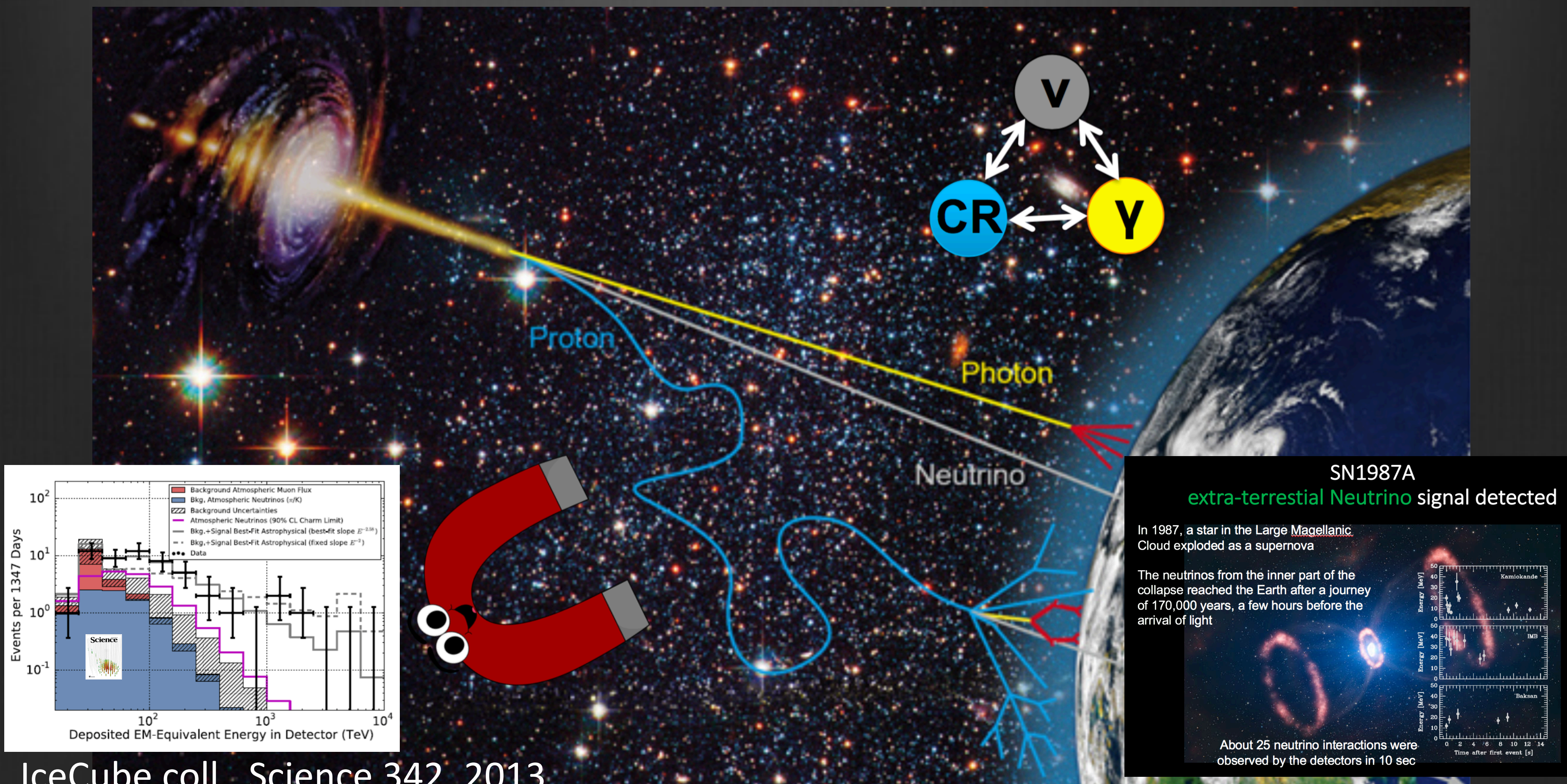
[1]NASA/Goddard Space Flight Center; [2]DESY, Humboldt-Univ. Berlin; [3]APC PARIS & IFIC VALENCIA

e-ASTROGAM/AMEGO workshop:

Towards a White Book on MeV Gamma-ray Astrophysics

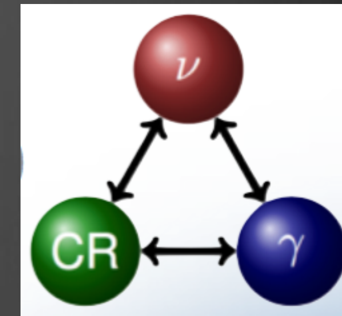
Munich, Oct. 2017

Neutrinos
-an exciting step forward-



IceCube coll., Science 342, 2013

HE NEUTRINO PRODUCTION PROCESSES



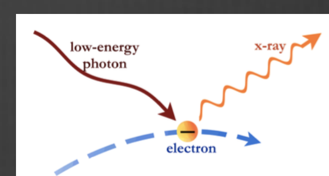
- **Hadronuclear**

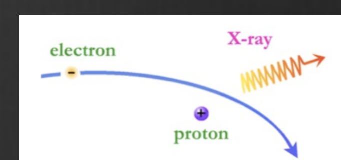
$$pp \rightarrow \begin{cases} \pi^0 \rightarrow \gamma\, \gamma \\ \pi^+ \rightarrow \mu^+ \nu_\mu \rightarrow e^+ \nu_e \nu_\mu \bar{\nu}_\mu \\ \pi^- \rightarrow \mu^- \bar{\nu}_\mu \rightarrow e^- \bar{\nu}_e \bar{\nu}_\mu \nu_\mu \end{cases}$$

- **Photohadronic**

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

- **Gamma-rays are not exclusively produced in hadronic processes**





Astrophysical Extragalactic Scenarios

Cosmic-ray Accelerators

- **Gamma-ray bursts**
  (e.g. Waxman & Bahcall 97, KM et al. 06 // (Cholis & Hooper 13, Liu & Wang 13, Murase & Ioka 13, Winter 13, Senno, Murase & Meszaros 16)
- **Active Galactic Nuclei**
  (e.g. Stecker et al. 91, Mannheim 95 // Kalashev, Kusenko & Essey 13, Stecker 13, Murase, Inoue & Dermer 14, Dermer, KM & Inoue 14, Tavecchio et al. 14, Kimura, Murase & Toma 15, Padovani et al. 15, Wang & Li 1)

Cosmic-ray Reservoirs

- **Starburst galaxies**
  (Loeb & Waxman 06, Thompson+ 07; Murase, Ahlers & Lacki 13, Katz et al. 13, Liu+ 14, Tamborra, Ando & Murase 14, Anchordoqui+ 14, Senno+ 15
- **Galaxy groups/clusters**
  (Berezinsky+ 97, KM et al. 08, Kotera+ 09 // Murase, Ahlers & Lacki 13, Fang & Olinto 16)

γ - ν connection: strategies

- **Looking for excess at high energies:**

  ➜ Decomposing the diffuse g-ray bkg.

  Time + Space domain

- **Looking for anisotropies (clusters of events) in the sky:**

  ➜ **point source searches**

  Space domain

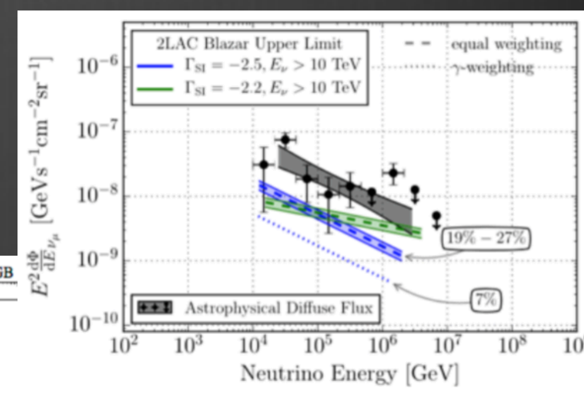
- **Looking for coincidences with other astrophysical signals:**

  ➜ **multi-messenger searches**; requires temporal coincidences with other probes (GW, photons)

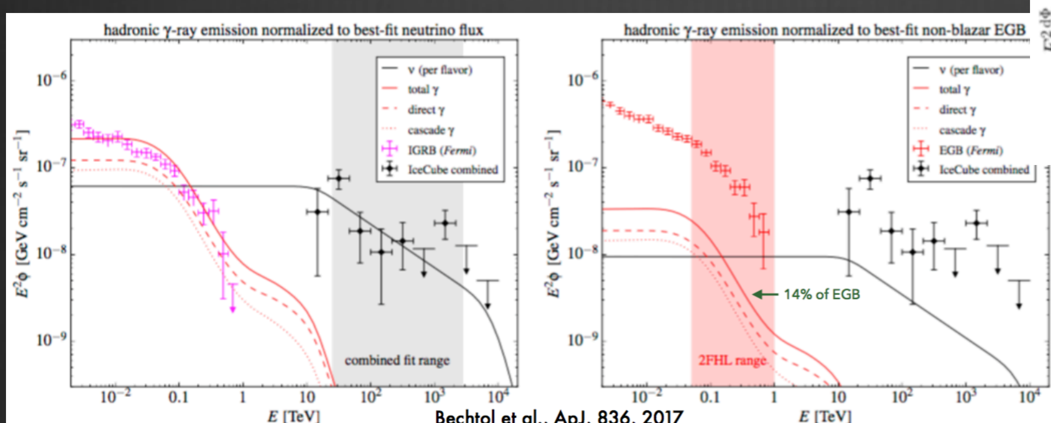
  Time domain

Lessons learned

- **Decomposing the diffuse gamma-ray / neutrino bkg.**
  - Latest results on the IGBR by Fermi and IC provide strong constraints on source populations
  - IceCube flux:
    - Blazars <30%
    - Star Forming Galaxies <30%
  - Less room for pp scenarios



IceCube coll 2017

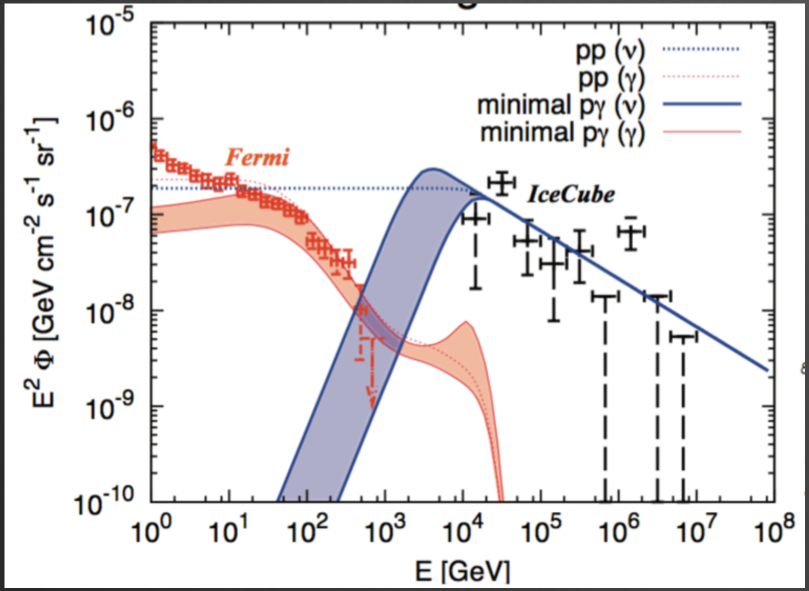


Bechtol et al., ApJ, 836, 2017

(see also subthreshold sources studies, Fermi coll. 16, Lisanti+ 16)

Lessons learned

- **The "medium-energy problem"**



- Best fit spectral indices tend to be as soft as 2.5
- At 10-100 TeV, high flux (~1e-7 GeV cm^{-2} s^{-1} sr^{-1})
- If **γ**-ray transparent → strong tensions w. diffuse **γ**-ray bkg. for both pp & p**γ**

Lessons learned

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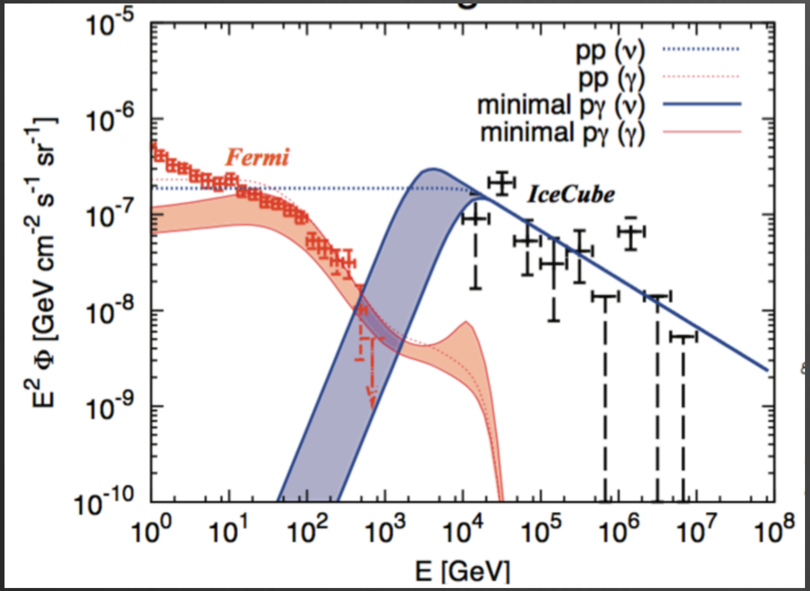

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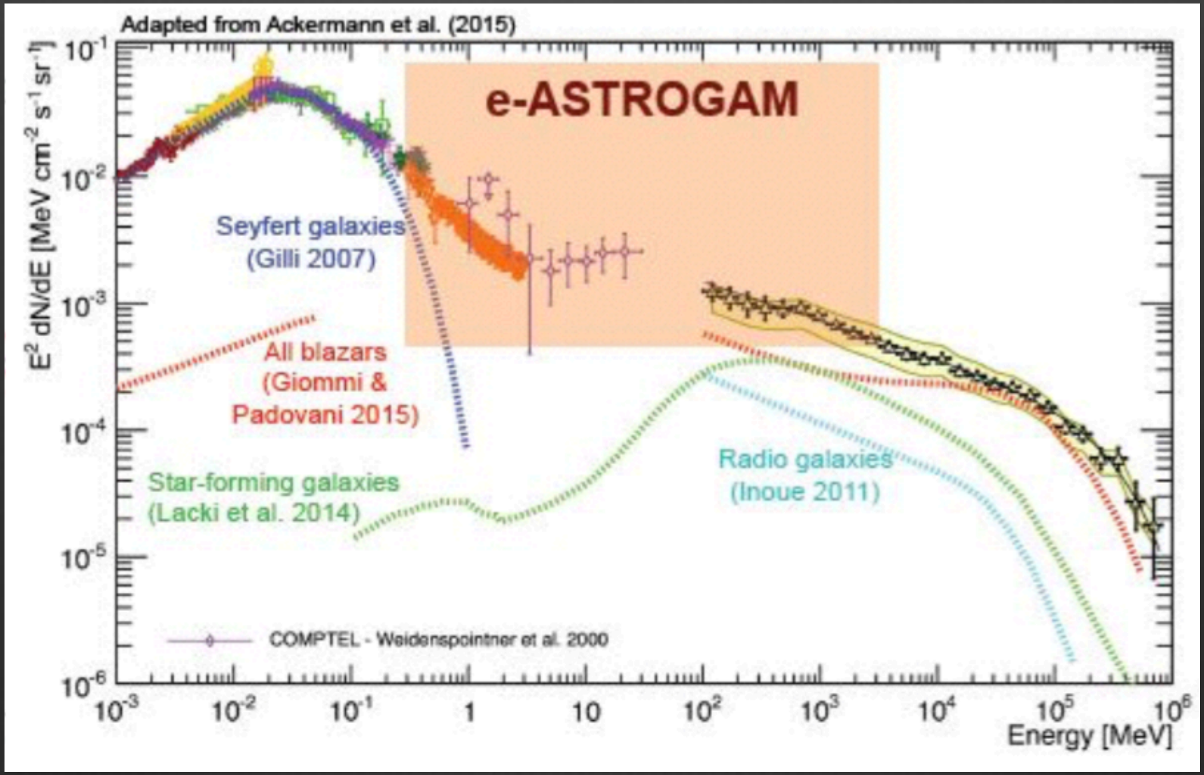
- If **γ**-ray transparent → strong tensions w. diffuse **γ**-ray bkg. for both pp & p**γ**
- **γ -ray dark cosmic-ray accelerators γγ→e+e- inevitable in pγ sources (e.g. GRBs, AGN)**
- **The same target photons prevent γ-ray escape**

Sources originating the astrophysical neutrinos detected by IceCube may be opaque to 1–100 GeV gamma-rays if the neutrino flux originates from photo-hadronic processes (Murase+ 2015, 2016)

Importance of X-ray and MeV ray Searches

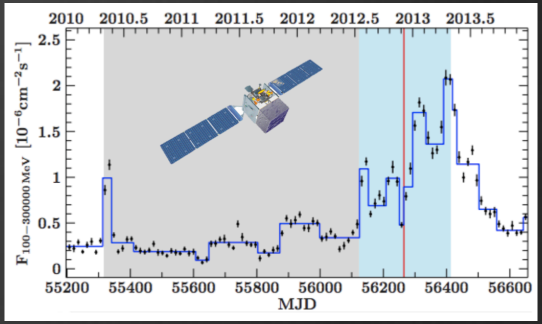
- **searches for X-ray / MeV counterparts are encouraging**



Lessons learned

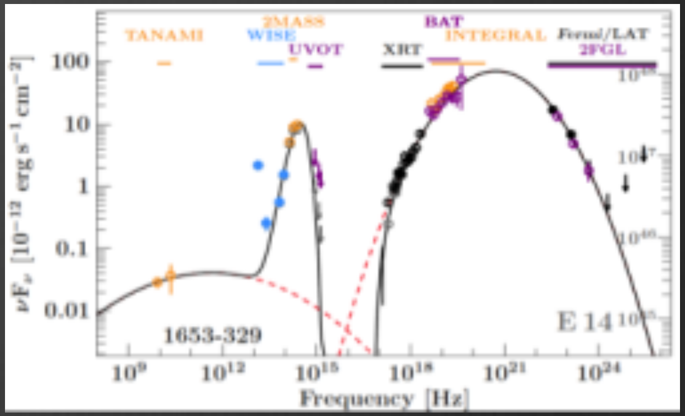
TRANSIENTS!!!

- Three PeV-ν may be associated with blazars (Padovani & Resconi 14)
- ~2σ association 2 PeV-ν with a FSRQ flare (Kadler+ 15, but see also Gao+ 2017)
- No single class of sources can be connected the IceCube events
- *Flaring sources remain an interesting target (Dermer, KM & Inoue 14)*
  - *Candidate gamma-ray precursor to* to IC-160731 (*AGILE coll., Lucarelli+ 2017)*



Flaring blazars and neutrinos

- Blazars have their emission max. in the MeV range
- In the photo-hadronic scenario:
  - $F_{\gamma} \approx F_{\nu}$ in the keV-GeV range (Mücke+ 2000; Krauss+ 2014)
- **MeV photons = good proxy for neutrino emission**
- **Bonus:**
  - Hadronic models predict high level of **polarization** in the MeV band **detectable by e-ASTROGAM!**



J1653-329 a candidate PeV neutrino emitter (Krauss et al 2014)

Flaring blazars and neutrinos

The Astronomer's Telegram

- **First detection of gamma-ray excess positionally and temporally consistent with an IC EHE neutrino!**

H.E.S.S. follow-up of IceCube-170922A

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

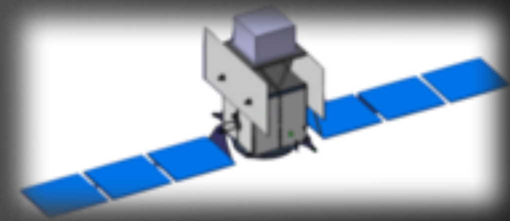
VERITAS follow-up observations of IceCube neutrino event 170922A

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

MeV GAMMA-RAYS and NEUTRINOS

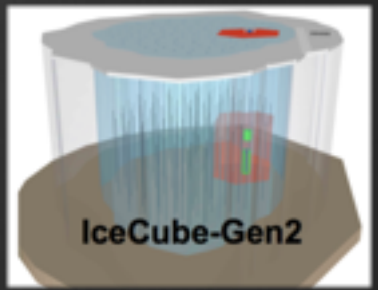
TRANSIENTS!!!



- Neutrino telescopes have a large field-of-view
  - Increase the discovery potential (smaller bkg)
  - Increase the sensitivity + significance of a discovery

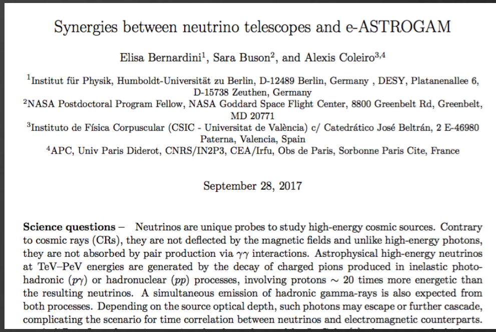
- E-ASTROGAM can play a crucial role:
  - the ToO capabilities should allow for a repointing of the instrument within 6–12hrs (goal 3–6hrs)
  - its large field-of-view will maximize the detection probability and provide an accurate sky localization.

next-generation neutrino telescopes (KM3NeT + IceCube Gen-2)



Summary

- **Understanding g-ray source populations is critical for MM**
- **No smoking gun, but stacking/correlation studies may pave the path, while flares and transients remain interesting targets**
- ***Missing multi-messenger relationship:***
  - ***e-ASTROGAM can play a decisive role!***



Synergies between neutrino telescopes and e-ASTROGAM

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September 28, 2017

Science questions – Neutrinos are unique probes to study high-energy cosmic sources. Contrary to cosmic rays (CRs), they are not deflected by the magnetic fields and unlike high-energy photons, they are not absorbed by pair production via $\gamma\gamma$ interactions. Astrophysical high-energy neutrinos at TeV–PeV energies are generated by the decay of charged pions produced in inelastic photo-hadronic ($p\gamma$) or hadronuclear (pp) processes, involving protons $\sim$ 20 times more energetic than the resulting neutrinos. A simultaneous emission of hadronic gamma-rays is also expected from both processes. Depending on the source optical depth, such photons may escape or further cascade, complicating the scenario for time correlation between neutrinos and electromagnetic counterparts.

- *Draft for white book available*
- *Looking forward to your suggestions and interest in contributing!*

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BACK UP