cta cherenkov telescope array

Neutrino Target of Opportunity for the Cherenkov Telescope Array

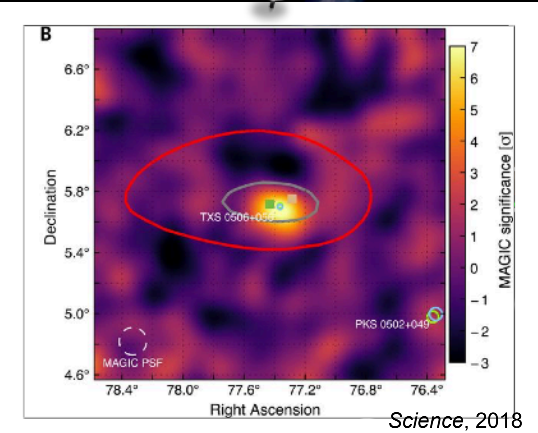
CTA Key Science Program

Konstancja Satalecka on behalf of the CTA Consortium
Anthony M. Brown, Alberto Rosales de Leon, Olga Sergijenko (CTA)
Chun Fai Tung, Theo Glauch, Rene Reimann, Ignacio Taboada (FIRESONG)

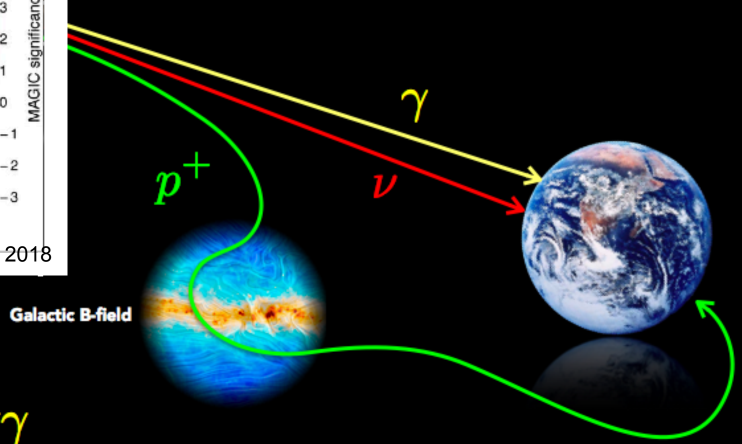
AHEAD 2020
INTEGRATED ACTIVITIES FOR THE HIGH-ENERGY ASTROPHYSICS DOMAIN

Motivation

~3σ correlation of IC-170922A (~300 TeV) with the flaring **gamma-ray blazar** TXS 0506+056 (*Science*, 2018)



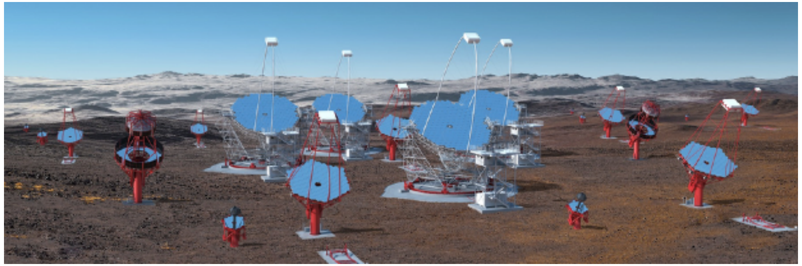
Science, 2018



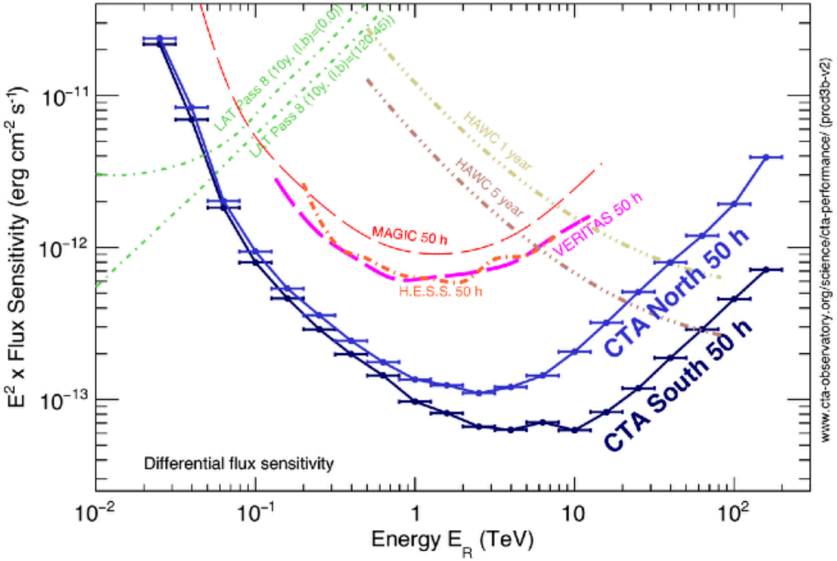
$$p + p/\gamma \to X + \pi^0 \to \gamma\gamma$$
$$\to X + \pi^+ \to \mu^+ + \nu_\mu$$
$$\mu^+ \to e^+ + \nu_e + \bar{\nu}_\mu$$ **(oscillates to ~1:1:1)**

Cherenkov Telescope Array

CTA North (La Palma island, Spain):
4x LST (23m) + 15 x MST (12m)



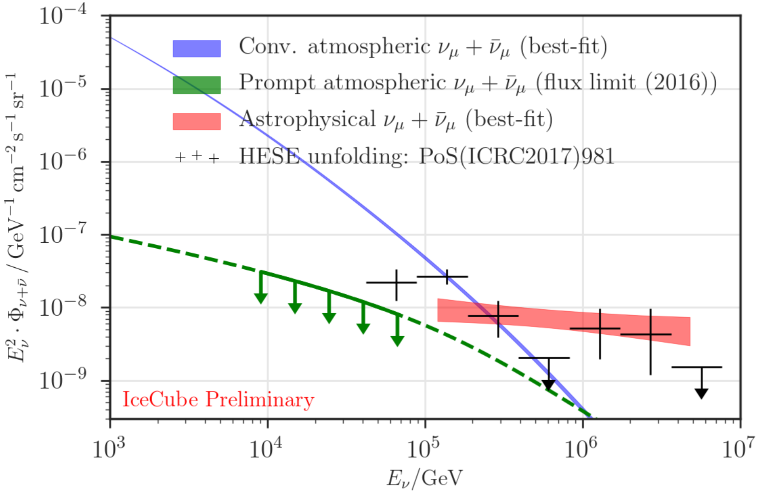
CTA South (Atacama, Chile):
4x LST (23m) + 25 x MST (12m) + 70 x SST (4m)



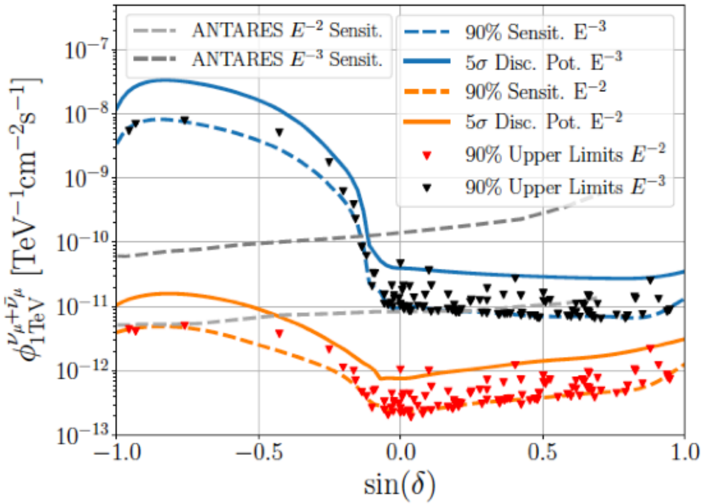
5-10° field of view
30s to point anywhere
>20 GeV
10x current IACT sensitivity

What do we know about neutrino sources?

Observational evidence



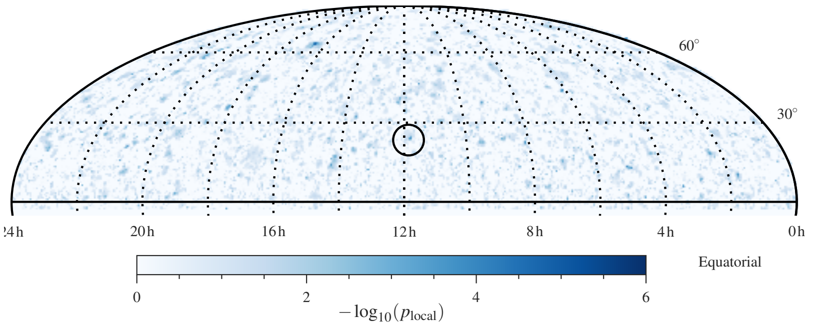
M.G. Aartsen at al., Phys. Rev. Lett. 124, 051103 (2020)

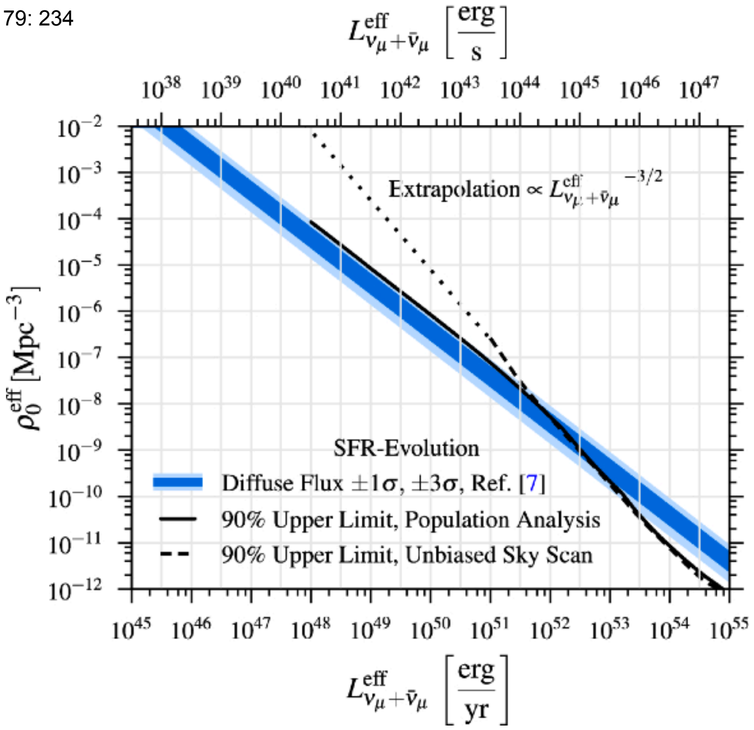


- IC measures astrophysical neutrinos diffuse flux [PoS(ICRC2017)1005], spectral index: 2.19 +/- 0.1
- No cosmic neutrino source discovered so far (steady or transient) > 5 sigma
- TXS 0506+056: ~3.0 sigma association of HE neutrino; 2014-15 neutrino flare, also ~3.5 sigma
- Recent limits on IC point-source search [PRL,124, 051103 (2020)]
  - Hot-spots emerging at AGN locations: NGC 1068, TXS 0506+056, etc… (all <3.0 sigma after trials)
- No other firm identification of any MWL counterpart.

Observational evidence - steady sources

Aartsen et al., *EPJC* (2019) 79: 234





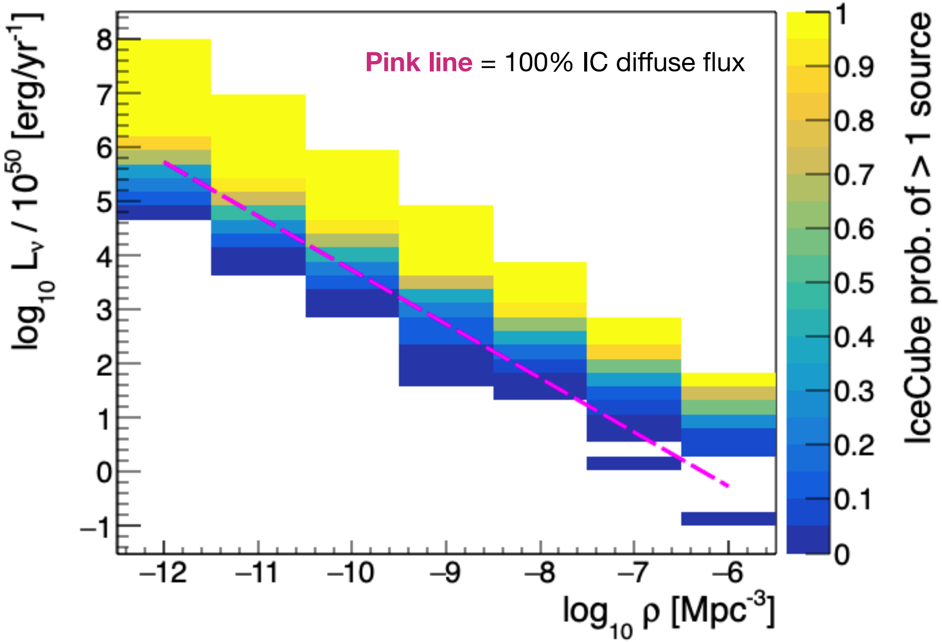
- We can use IC results (non-detection) to set limits on the general properties of allowed neutrino source populations (L vs ρ)
- **Blue shaded band:** populations that are compatible at the $1\sigma/3\sigma$ level with the observed diffuse flux
- **Black**: non-detection limits (*Exclude populations which produce spots hotter than the hottest one observed)*
- Very high L vs very low ρ corner basically excluded

Neutrino sources simulations
with
FIRst **E**xtragalactic **S**imulation **O**f **N**eutrinos and **G**amma-rays
(FIRESONG)

FIRESONG

Developers: Chun Fai Tung, Rene Reimann, Theo Glauch, Ignacio Taboada

https://github.com/ChrisCFTung/FIRESONG



Example: steady sources following SFR

- **FIRESONG** software used to simulate source populations in the (L vs ρ) plane
- Most recent cosmological models [Planck 2016, 2018]
- Cosmological evolution: Star Formation Rate (SFR) [Hopkins and Beacom 2006,Dickinson and Madau 2014], no evolution
- Luminosity L: standard candles
- Local source density ρ: free parameter 10^{-4} – 10^{-12} (transients [bursts Mpc^{-3} yr^{-1}] or steady [Mpc^{-3}])
- Total neutrino flux normalized to IC diffuse flux [PoS(ICRC2017)1005] (only ν_{μ} alerts, 1:1:1 flavor composition)

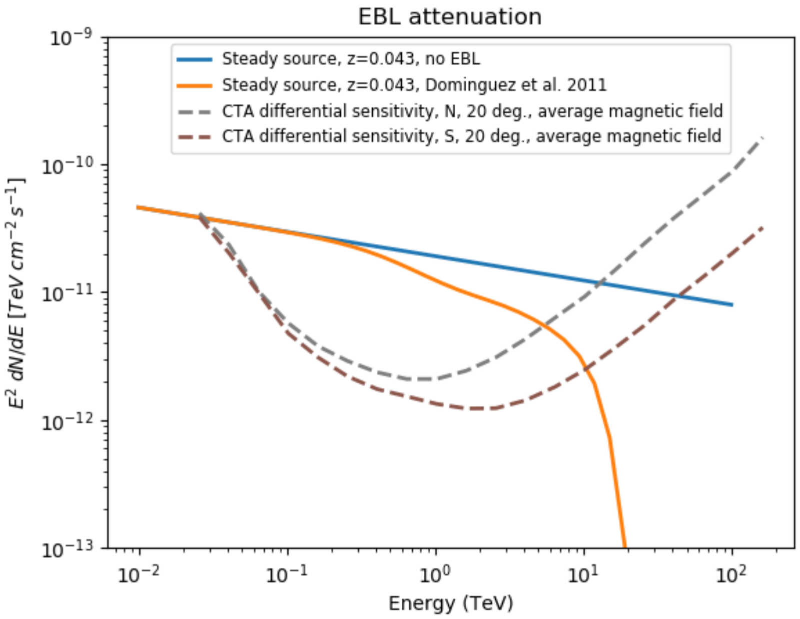
What about gamma-rays?

If we add gamma-ray emission, can we detect those sources with CTA? Set limits on L vs ρ?

What is the best observational strategy?

CTA simulations - steady sources

CTA Neutrino Task Force:
Anthony M. Brown, Alberto Rosales de Leon, Olga Sergijenko, KS



Example: steady source gamma-ray spectra

Basic scaling for g-ray flux:

p-gamma: K = 2
pp: K = 1

$$\frac{1}{3}\sum_{\alpha} E_\nu^2 Q_{\nu_\alpha}(E_\nu) \simeq \frac{K_\pi}{4}\left[E_\gamma^2 Q_\gamma(E_\gamma)\right]_{E_\gamma=2E_\nu}$$

Use the **Instrument Response Functions** (effective area, energy migration matrix, PSF…) of **CTA** + **EBL absorption** (Domiguez et al., 2011) to calculate, if the source is detectable in gamma-rays.

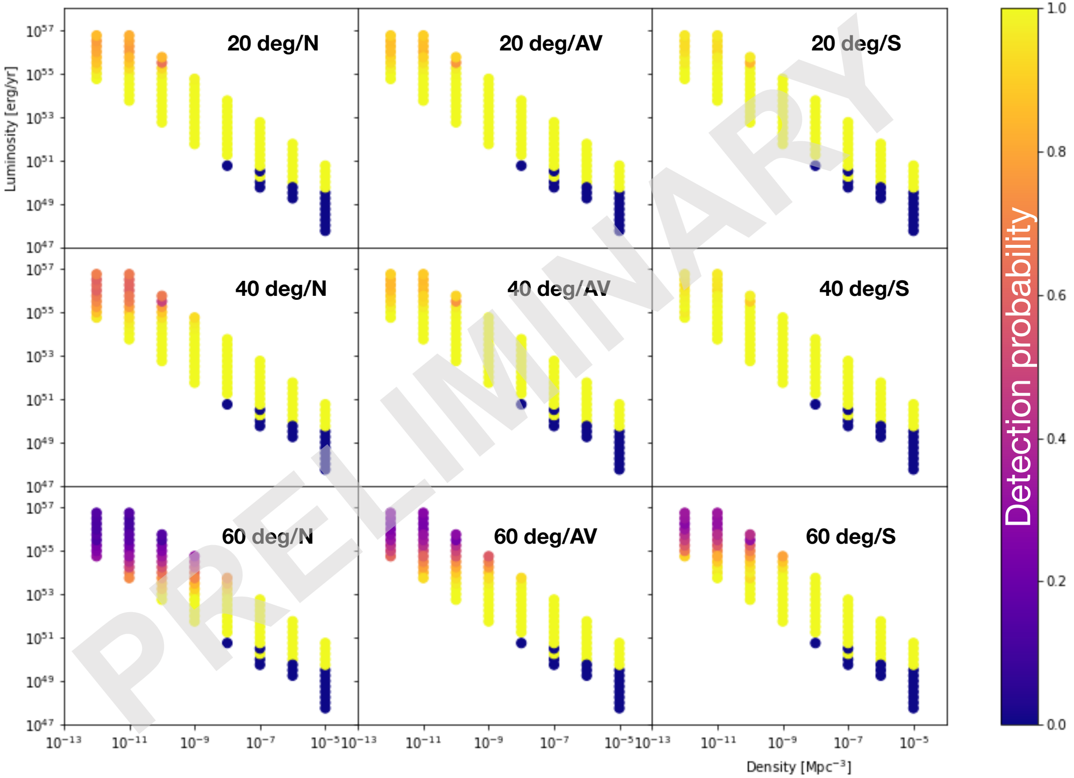
Simulation software: `ctools`

Criteria for detection: Test Statistics > 25

Detection probability = (Sources with TS > 25)/ (All sources)

CTA response - steady sources

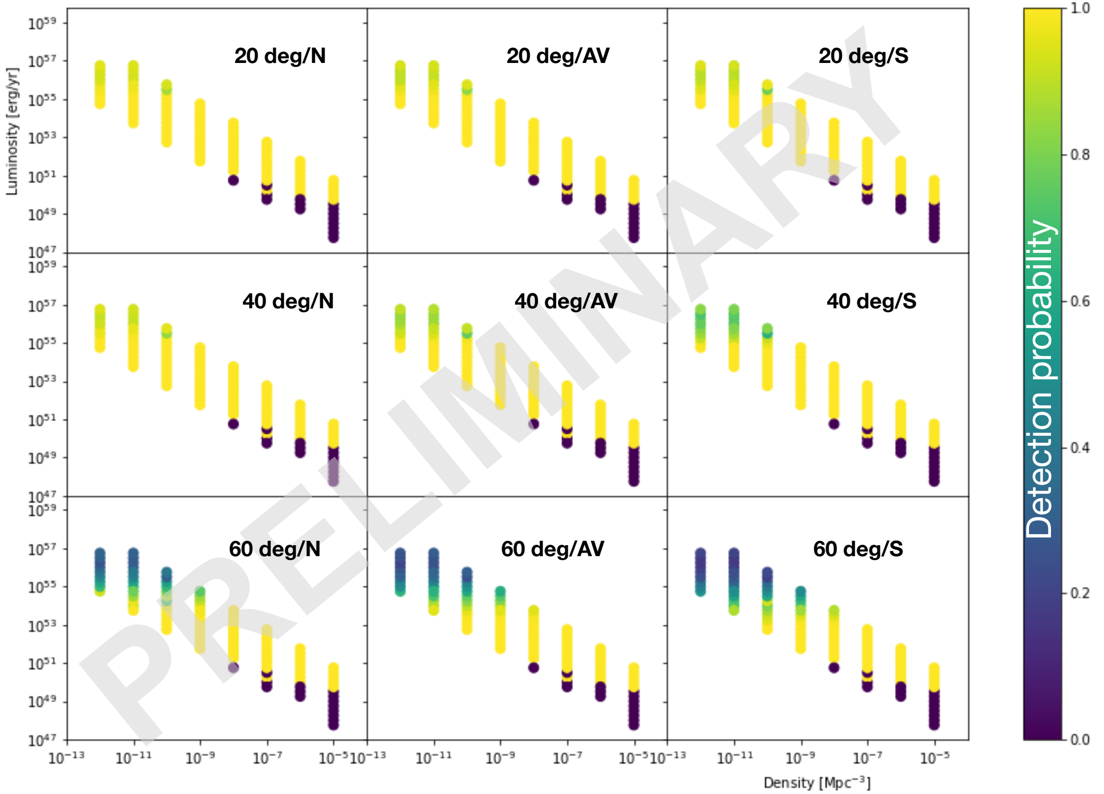
Example: scan of (L vs ρ) for **SFR**, standard candles, **CTA-N response** for different zenith/azimuth, 30 min observation



- With low - mid zeniths (20-40 deg) CTA-N able to **detect all sources up to $\rho = 10^{-9}$ Mpc^{-3}**
- Drastic **performance loss**, up to **65%, at high zeniths** (60 deg)
- Visible **effect of magnetic field: 10 - 30%** difference for low to high zeniths
- For sources with *flat* redshift evolution the trends are similar, but less pronounced

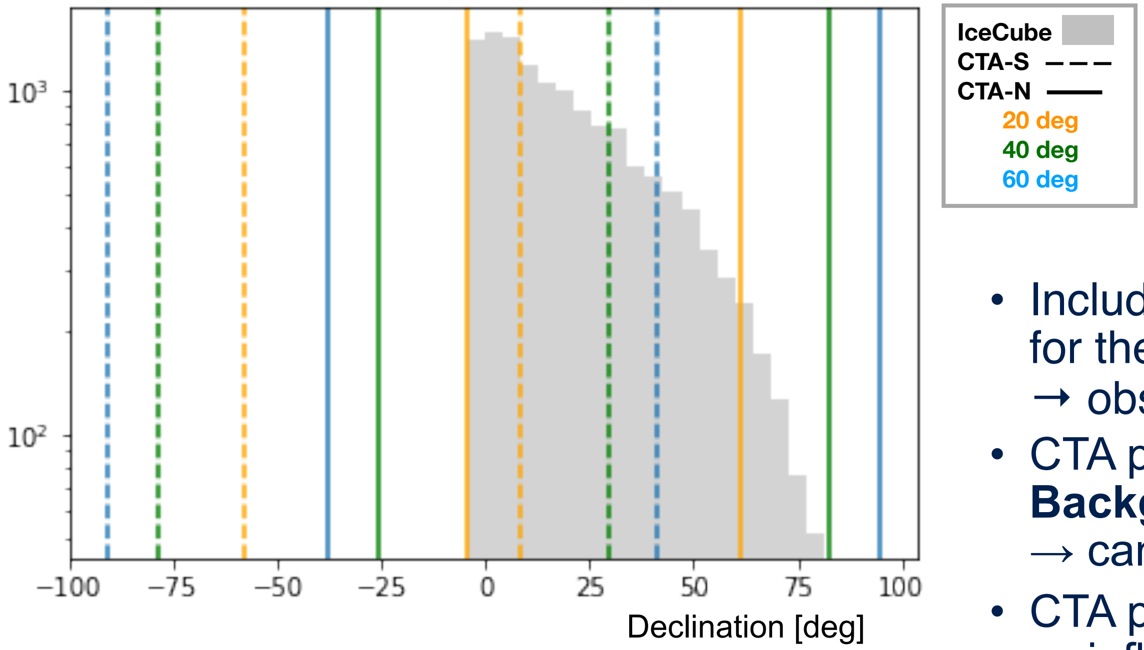
CTA response - steady sources

Example: scan of (L vs ρ) for **SFR**, standard candles, **CTA-S response** for different zenith/azimuth, 30 min observation



- **Very similar response as for CTA-N** (within 10% for AV)
- Drastic **performance loss**, up to **70%, at high zeniths** (60 deg)
- **Effect of magnetic field: 5-15%** (much less than for CTA-N)
- For sources with *flat* redshift evolution the trends are similar, but less pronounced

Steady sources - next steps



Distribution of IC hot-spots declination (grey) and CTA IRFs validity wrt the zenith angle (lines)

~100% visible by CTA-N
~80% visible by both

- Include **realistic visibility constraints** for the IceCube hot-spots → observation strategy
- CTA performance with **Night Sky Background x5** dark night level → can we extend our duty cycle?
- CTA performance with **Phase-1 arrays** → influence of smaller arrays on the KSP

What about flaring blazars?

Halzen et al, ApJL, Volume 874, Issue 1, article id. L9, 5 pp. (2019)

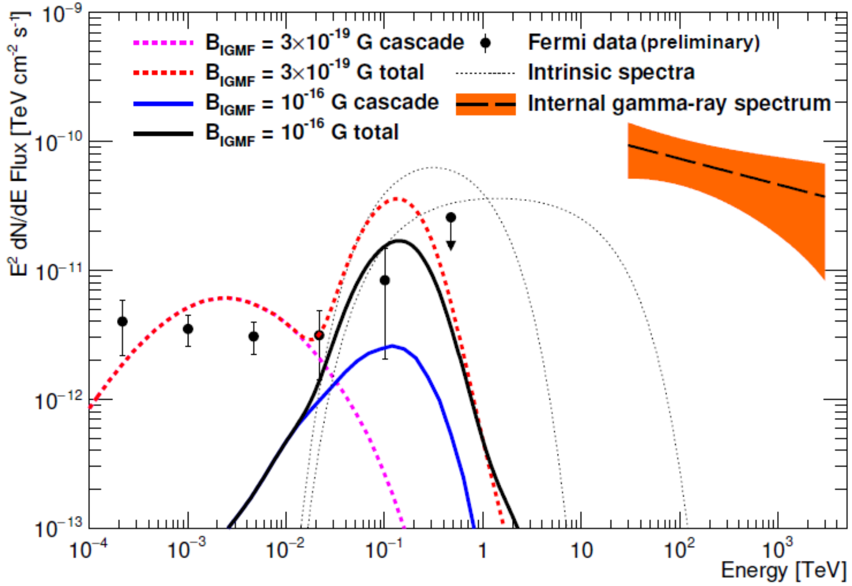


Fig.: Gamma-ray spectrum for TXS 0506+056 flare 2014-2015

- Study based on a model of [Halzen et al., 2019]
- Special class of blazars (a fraction of a total population) that undergo 110-day duration flares like TXS0506+056 once every ~10 years (*Science*, 2018)
- Gamma-ray flux is parametrized as PL with LE and HE cut-offs
- Simulations for flaring sources fraction of 1%, 5% and 10%
- Total neutrino flux normalized to IC diffuse flux from [PoS(ICRC2017)1005]
- Cosmological evolution: no evolution
- FIRESONG simulations - completed!
- CTA response - coming soon!

Summary

- **Real-time alerts** and **MultiMessenger approach** of high interest to the whole astro-community
- **TXS 0506+056** - first (and only…) compelling evidence of a neutrino source (also thanks to IACTs!)
- **IACTs provide essential information on the emission mechanism**
- **Neutrino follow-up is a Key Science Program for CTA**
- New facilities (Km3Net, Baikal GVD, IceCube-Gen2…) & alert channels to come in the nearest future - **great chances, but also many challenges…**

Open questions for CTA:

- How to optimise our follow-up? How fast to react? Where to look? For how long?
- Neutrino point-source non-detection serves as valuable clue to constrain the allowed source populations
- Add gamma-ray emission and test CTA response under different conditions
- Develop observation strategy
- **Steady sources** study almost finished
- **Flaring blazars** study almost finished
- Transient sources - the next exciting topic to investigate!