cherenkov telescope array

The Cherenkov Telescope Array view of extra-galactic jetted sources

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Outline

- The Cherenkov Telescope Array
- Narrow-line Seyfert 1 galaxies
- Extreme HBL & Hadron beams

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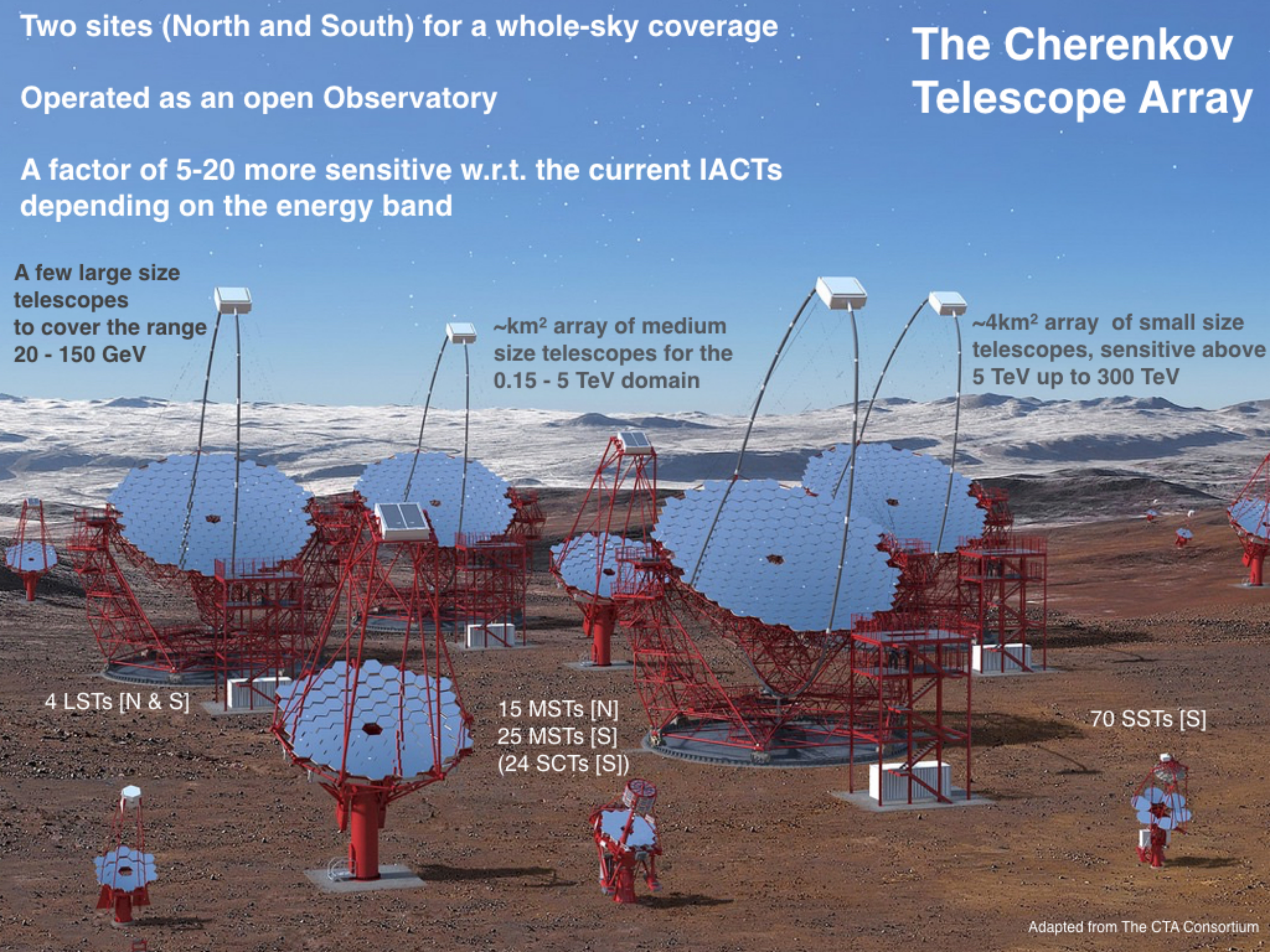
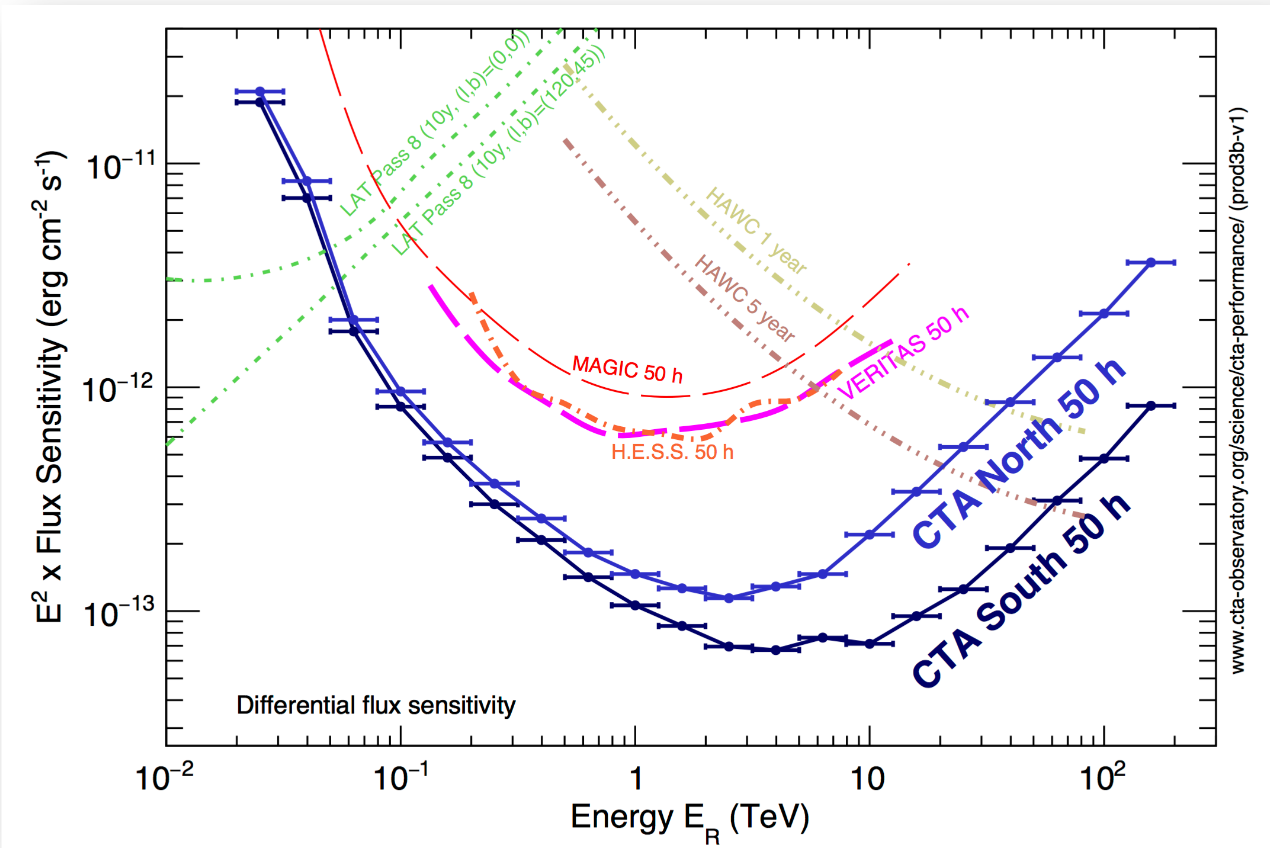

Two sites (North and South) for a whole-sky coverage
Operated as an open Observatory
A factor of 5-20 more sensitive w.r.t. the current IACTs depending on the energy band
The Cherenkov Telescope Array
A few large size telescopes to cover the range 20 - 150 GeV
~km² array of medium size telescopes for the 0.15 - 5 TeV domain
~4km² array of small size telescopes, sensitive above 5 TeV up to 300 TeV
4 LSTs [N & S]
15 MSTs [N]
25 MSTs [S]
(24 SCTs [S])
70 SSTs [S]
Adapted from The CTA Consortium

CTA Performance

Differential Sensitivity



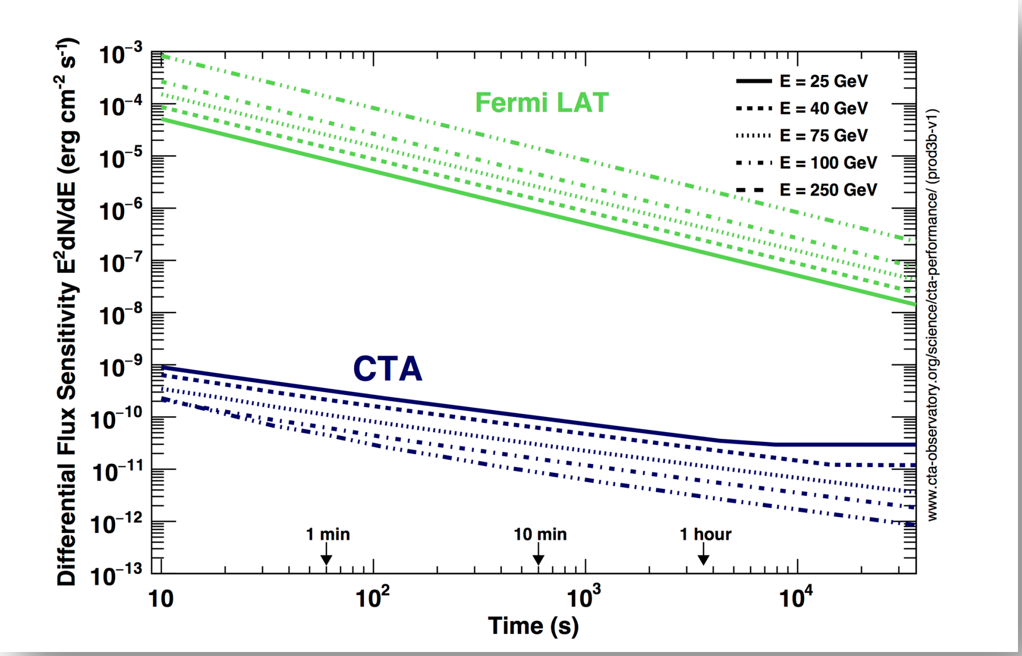
A factor of **5-20 improvement** in sensitivity depending on energy, relative to current IACTs.

Extension of the accessible energy range from **well below 100 GeV to above 100 TeV**.

https://www.cta-observatory.org/science/cta-performance/

CTA as a *transient factory*

- **Huge advantage over Fermi** in energy range of overlap for ~minute to ~day timescale phenomena
  - Explosive transients
  - AGN flares
  - Binary systems
  - ***Real-time analysis SW is crucial***



- **Disadvantage over Fermi**
  - Limited FoV (compared to Fermi)
  - Prompt reaction to external trigger is critical

Science with CTA

arXiv:1709.07997

To be published as a book & open-access online version by World Scientific.

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NLS1 galaxies as VHE sources ???

- **Evidence for possible VHE emission from NLS1 galaxies**
  - About 7% (4%) are **radio-loud** [Komossa+06, VCV] ([Cracco+16, SDSS, z<0.345]) and present **flat radio spectrum** [Oshlack+01, Zhou+03, Yuan+08] **resembling jetted sources**
  - Hard component in some X-ray spectra observed with *Swift*/XRT and **flux and spectral variability in the hard X-ray** observed with INTEGRAL/IBISand Swift/BAT [Foschini+09]
  - See **reviews** by [Foschini+15, D'Ammando+16] on the properties of jetted NLS1

A positive detection with CTA (>20GeV) would allow us to put constraints on location of the gamma-ray emitting zone

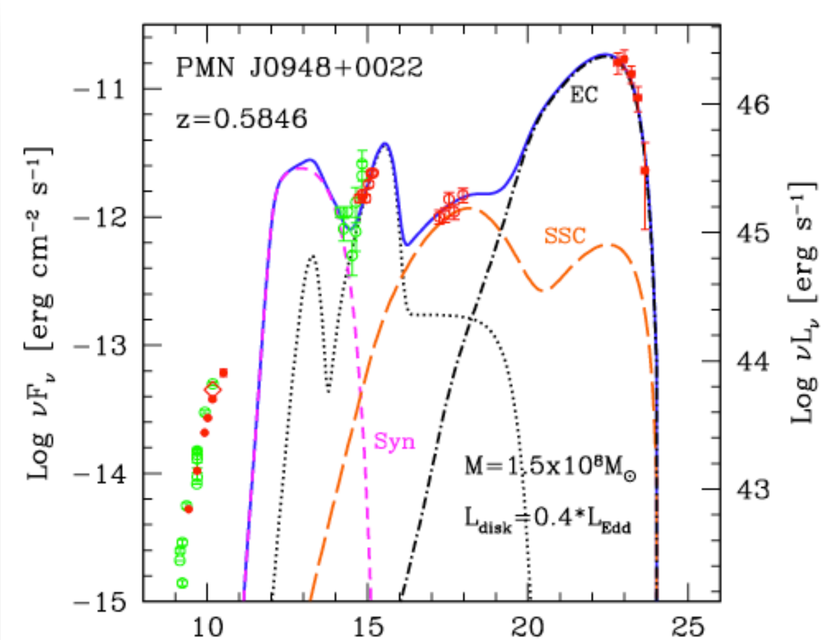
NLS1 galaxies as high-energy sources !!!

- **The smoking gun**

  – Discovery of **gamma-ray emission** (E>100MeV) with *Fermi*-LAT from PMN J0948+0022 [Abdo+09a, Foschini+10]

  – The **SED** fit with the model by [Ghisellini & Tavecchio 09] clearly resembles that of a **blazar-like source**

  – Gamma-ray emission is **variable** too, on time-scales as low as a few hours [Abdo+09b, Calderone+11, Paliya+14]



Abdo+09a

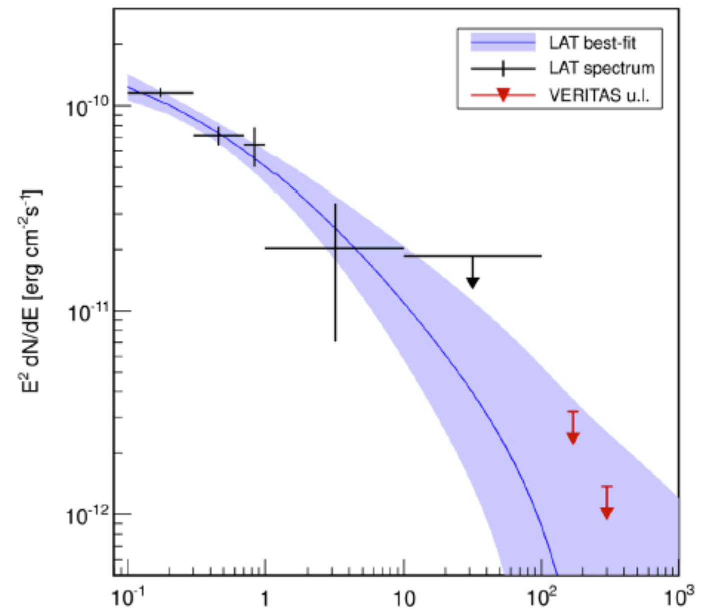
Current sample

- About **20 sources** have been recently discovered as gamma-ray emitters [see recent results presented at the NLS1s Symposium in Padova].

- At the time of writing, **none of them** have been **detected at VHE** by current imaging atmospheric Cherenkov telescope.

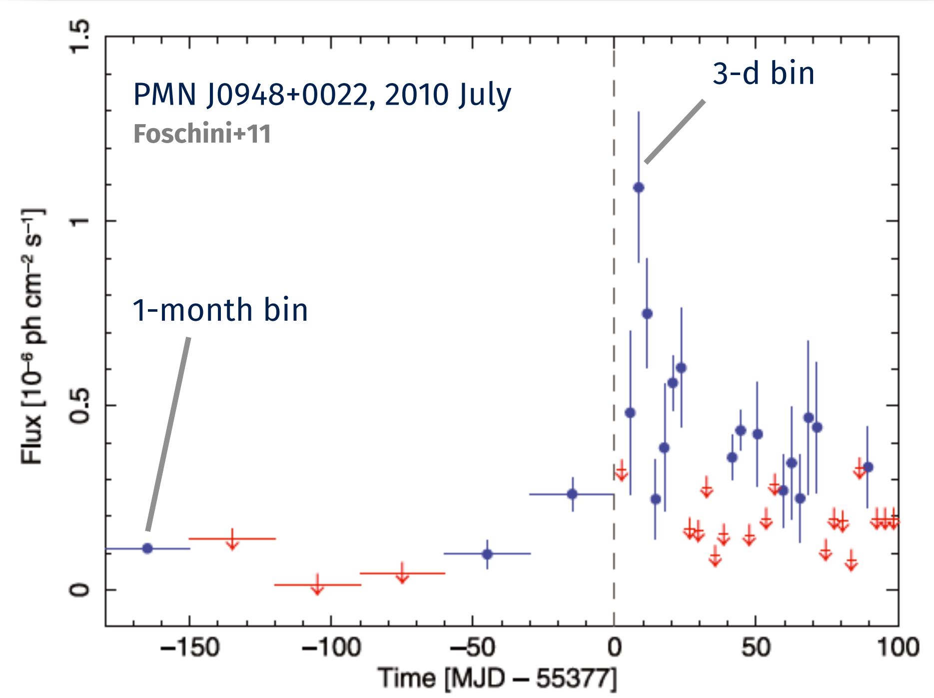
- **VERITAS** observations (5.25 h) on PMN J0948+0022 obtained **only UL** (also on nightly and 30m time-scales) for **E>100 GeV**.

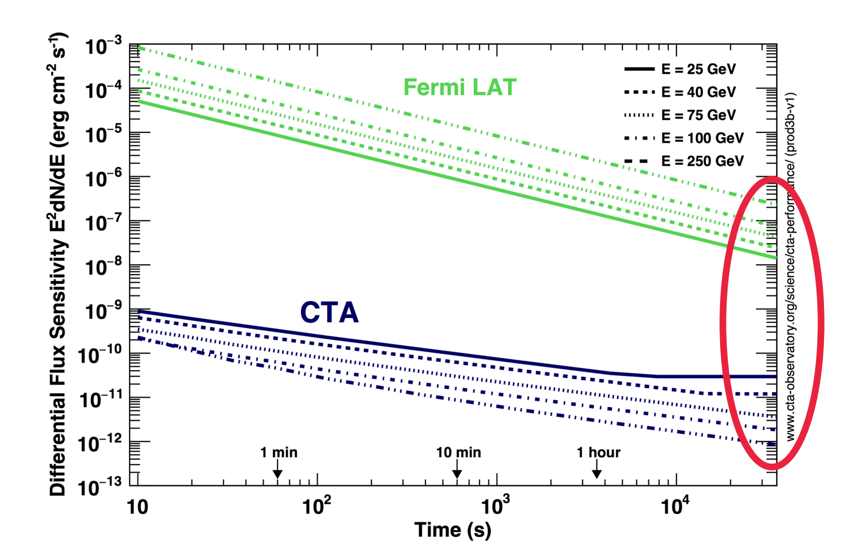
- **VERITAS** started observations a **few days after the gamma-ray peak**, monitoring the flare decay.



D'Ammando+15

Transient NLS1s and CTA performance





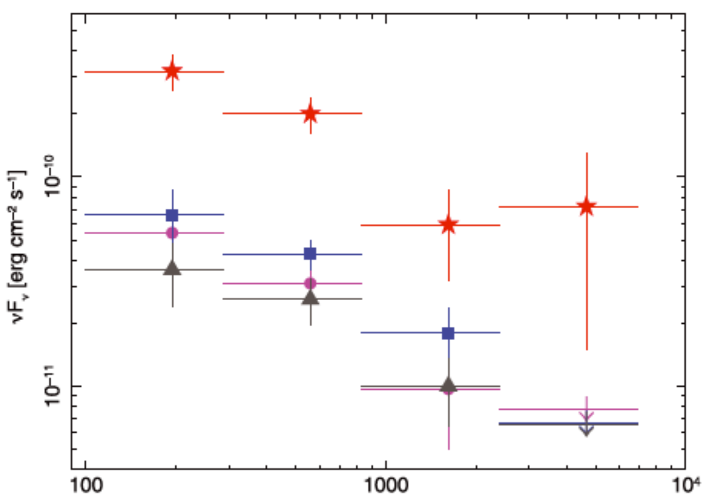
High and flaring states can last **1-3 days, a promising time-scale for CTA**, when compared with Fermi-LAT in the overlapping energy ranges.

Work status

- We make use of the ***ctools* (v1.4.2)** simulation and analysis software package **[Knödlseder+16]**
  - http://cta.irap.omp.eu/ctools/
- IRFs: public **prod3b-v1, averaged**
  - https://www.cta-observatory.org/science/cta-performance/
- A paper is in preparation on the whole sample **[Romano+18]**

PMN J0948+0022: simulations setup

- We simulated three gamma-ray states:
  - **quiescence → grey triangles**, broken PL **[Abdo+09]** with $\Gamma_1 = 2.3$, $\Gamma_2 = 3.4$, $E_b = 1$ GeV
  - **high-state → red stars**, PL **[Foschini+11]** with $\Gamma = 2.55$
  - **flaring-state →** not observed, assumed to be 3 x the high-state



Foschini+11

Time period	$F_{E>100\,\mathrm{MeV}}$	Γ	TS
Jun 01–30	0.23 ± 0.01	2.77 ± 0.06	98
Jul 07–10	1.02 ± 0.02	2.55 ± 0.02	140
Aug 1–Sep 14	0.26 ± 0.01	2.74 ± 0.03	140

During the high gamma-ray state, the spectrum becomes harder than that of low and quiescence periods

harder-when-brighter: promising for CTA observations

PMN J0948+0022: simulations setup

J0948+0022 ("Flare" State)	N	North_z20_average_5h	3	1000	20–150	3	3	1000	20–30, 30–50, 50–150
	S	South_z20_average_5h	3	1000	20–150	3	3	1000	20–30, 30–50, 50–150
	N	North_z20_average_5h	5	1000	20–150	3	5	1000	20–30, 30–50, 50–150
	S	South_z20_average_5h	5	1000	20–150	3	5	1000	20–30, 30–50, 50–150
	N	North_z20_average_5h	10	1000	20–150	3	10	1000	20–30, 30–50, 50–150
	S	South_z20_average_5h	10	1000	20–150	3	10	1000	20–30, 30–50, 50–150
J0948+0022 (High State)	N	North_z20_average_5h	5	1000	20–150	3	5	1000	20–30, 30–50, 50–150
	S	South_z20_average_5h	5	1000	20–150	3	5	1000	20–30, 30–50, 50–150
	N	North_z20_average_5h	10	1000	20–150	3	10	1000	20–30, 30–50, 50–150
	S	South_z20_average_5h	10	1000	20–150	3	10	1000	20–30, 30–50, 50–150
	N	North_z20_average_50h	50	1000	20–150	4	50	1000	20–30, 30–50, 50–150, 20–50
	S	South_z20_average_50h	50	1000	20–150	4	50	1000	20–30, 30–50, 50–150, 20–50
J0948+0022 (Quiescent)	N	North_z20_average_50h	100	1000	20–150	1	100	1000	20–50
	S	South_z20_average_50h	100	1000	20–150	1	100	1000	20–50

- We simulated observations for both the Northern and the Southern **sites**
- IRFs were selected according to the simulated **exposure time**
- Input spectral models were derived **extrapolating the best-fit Fermi spectra** to the CTA energy range, including **the effects of the gamma-ray absorption** both inside the source (PL + Exponential cut-off at ~30 GeV) and the EBL **[Dominguez+11]**
- To reduce the impact of variations between individual realisations we performed sets of **N=1000 statistically independent realisations** by adopting different seeds for the randomization

PMN J0948+0022: simulations results

CTA should be able to detect this source on different flux states and at different time-scales. In particular, assuming that **dissipation region is inside the BLR:**

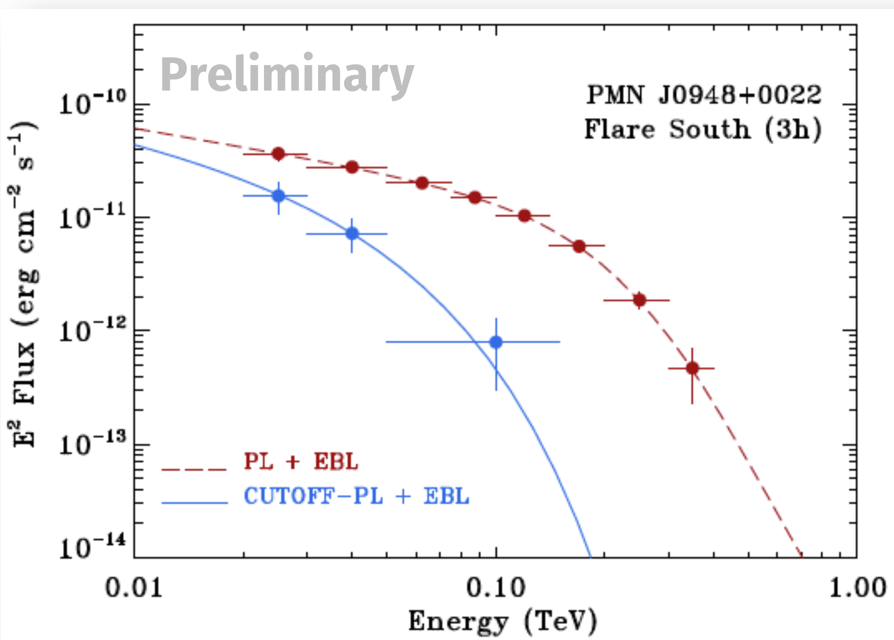
- **“Flare” state**
  - all bands in 10 hr
  - up to 50 GeV in 3 hr
- **High state** [Foschini+11a]
  - all bands in 50 hr
  - up to 50 GeV in 10 hr
- **Quiescence** [Abdo+09a]
  - in the 20-150 and 20–50 GeV bands in 100 hr.

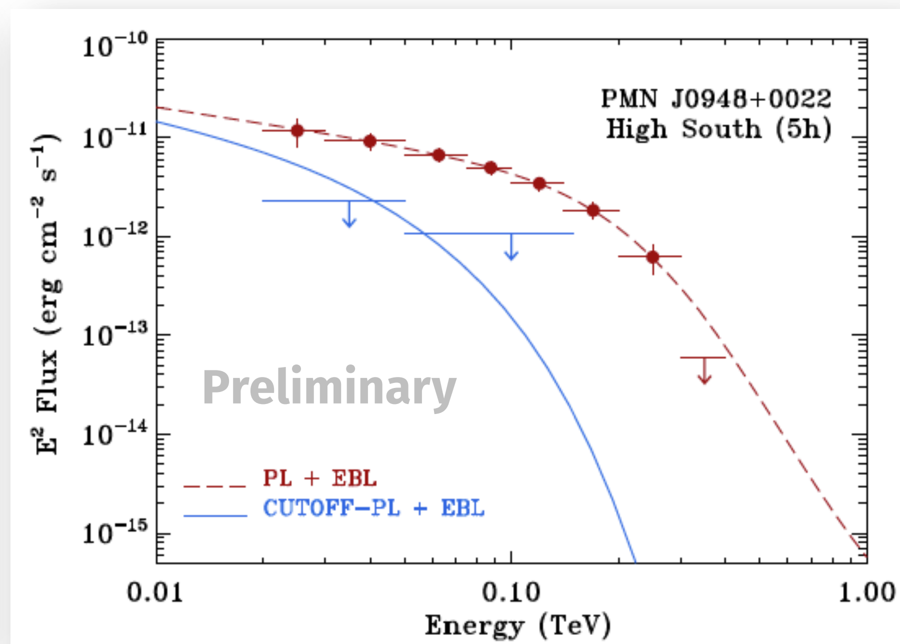
High significance → $TS \geq 25$
Low significance → $10 \leq TS < 25$
Undetected → $TS < 10$

Simulated spectra (flaring & high)

The γ-ray emitting region may not always be placed at the same distance from the central black-hole during different flaring episodes of the same source [Foschini+2011b].

Detection of TeV photons [Albert+08, Ahnen+15] and the dramatic change of the position of the sync. & IC peaks in some blazars during extreme flares [Ghisellini +13, Pacciani+14, Ahnen+15] support the idea of a dissipation region outside the BLR.





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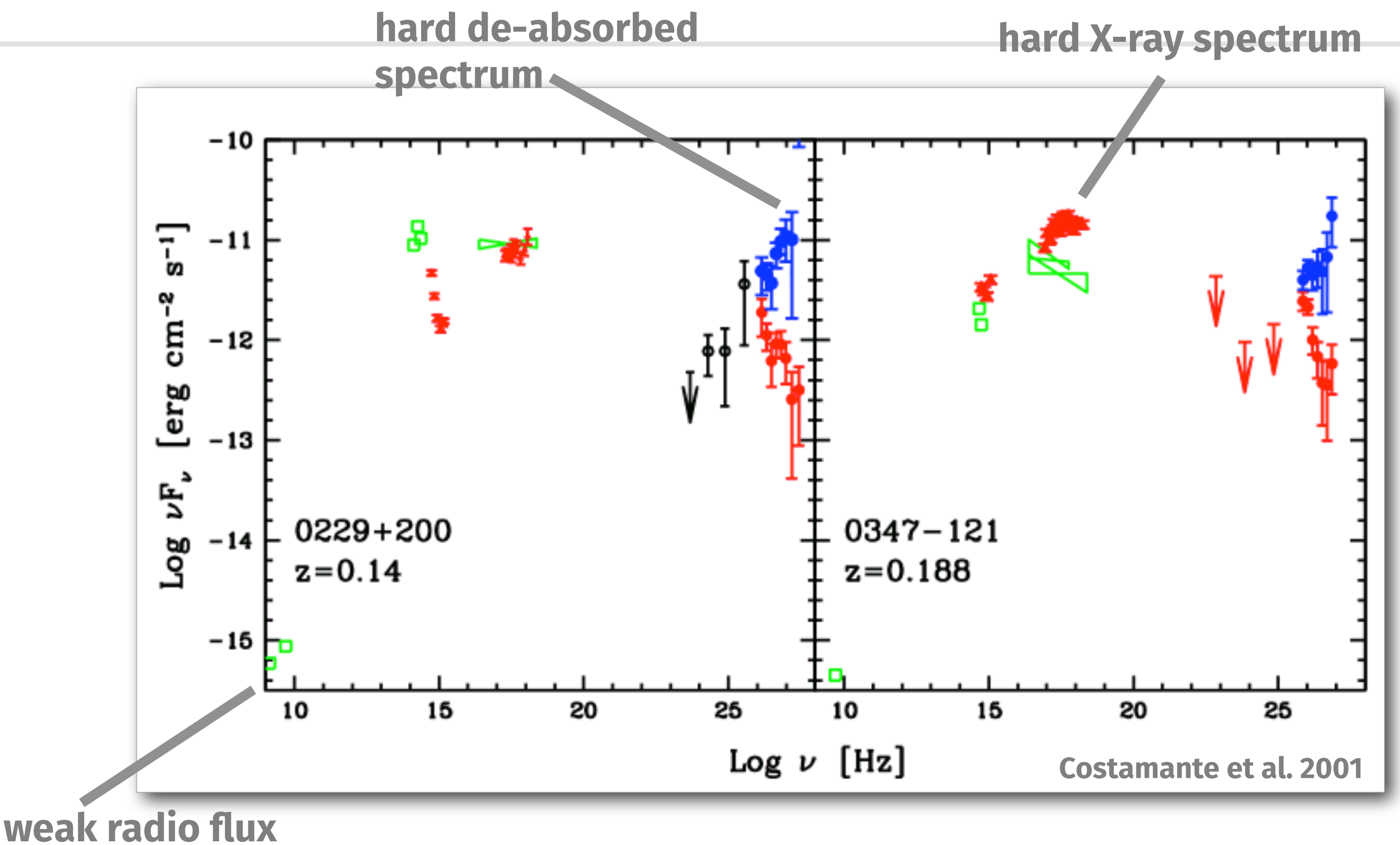
Extreme BL Lacs - properties



- Very **hard** X-ray and gamma-ray (de-absorbed) **spectra**
- Rather **modest variability** at all frequencies
- Synchrotron peak ~ **keV**; IC peak ~ **TeV**

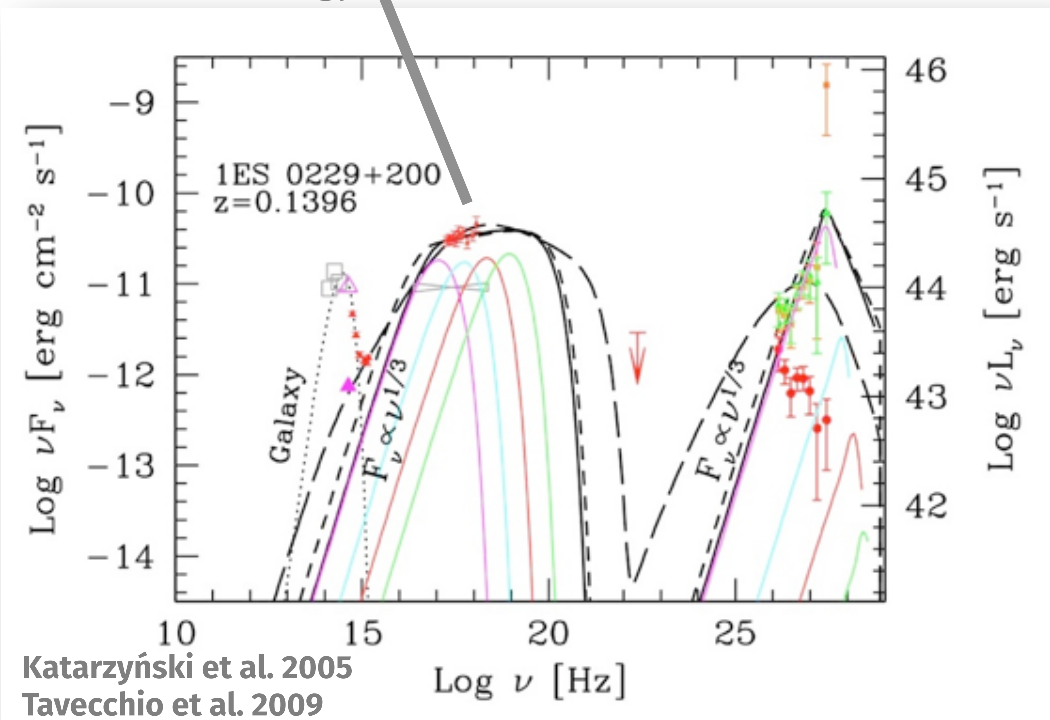
Extreme BL Lacs - properties

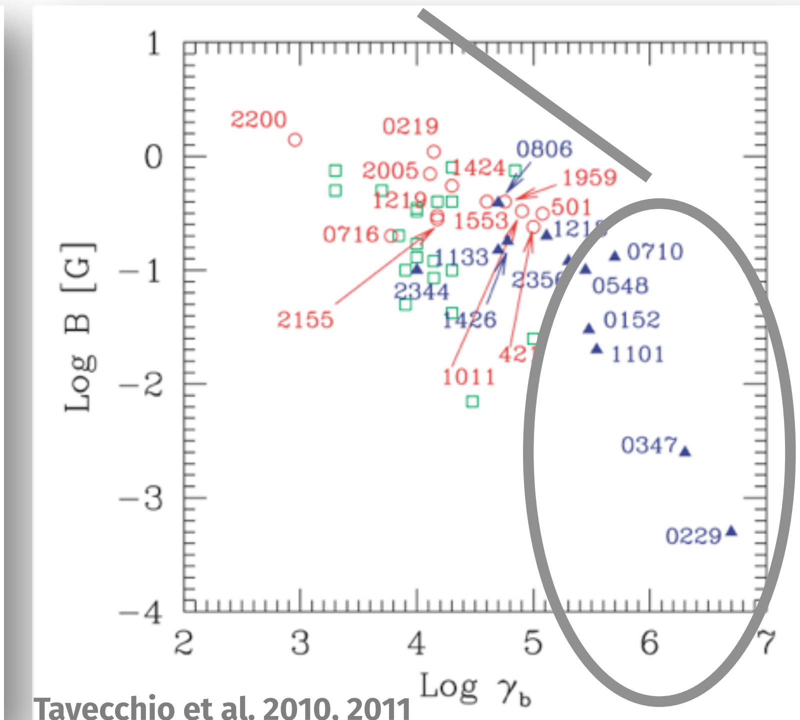
- Acceleration/emission mechanism? Katarzynski+2006, Tavecchio+ 2009 Lefa et al. 2011, Zacharopoulou et al. 2011
- Far-IR EBL-probes and anomalies Franceschini+ 2008 Dominguez+ 2011
  - ALPs De Angelis et al. 2011
  - **Hadron beams** Essey & Kusenko 2010 Murase+ 2012
  - LIV Fairbairn+ 2014 Tavecchio & Bonnoli 2016
- IGMF probes Neronov 2010 Tavecchio+ 2010

Extreme BL Lacs - properties

large minimum
e⁻ energy

very low B
large e⁻ energy

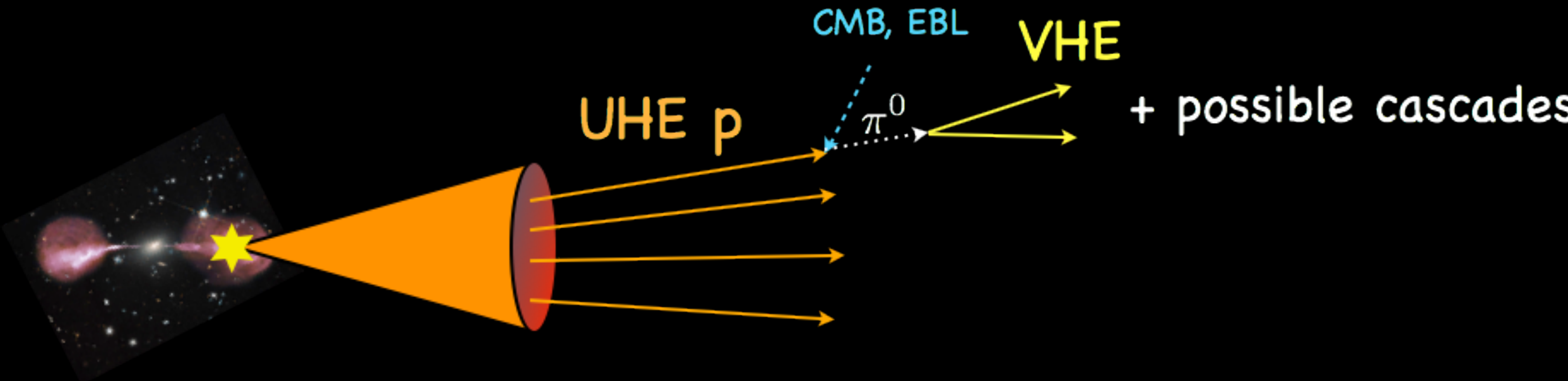




- Acceleration process?
- Why cooling so small?
- Why weakly/slowly variable?

Hadron beams

γ-rays are produced by UHECRs accelerated in the jet and beamed towards the observer.

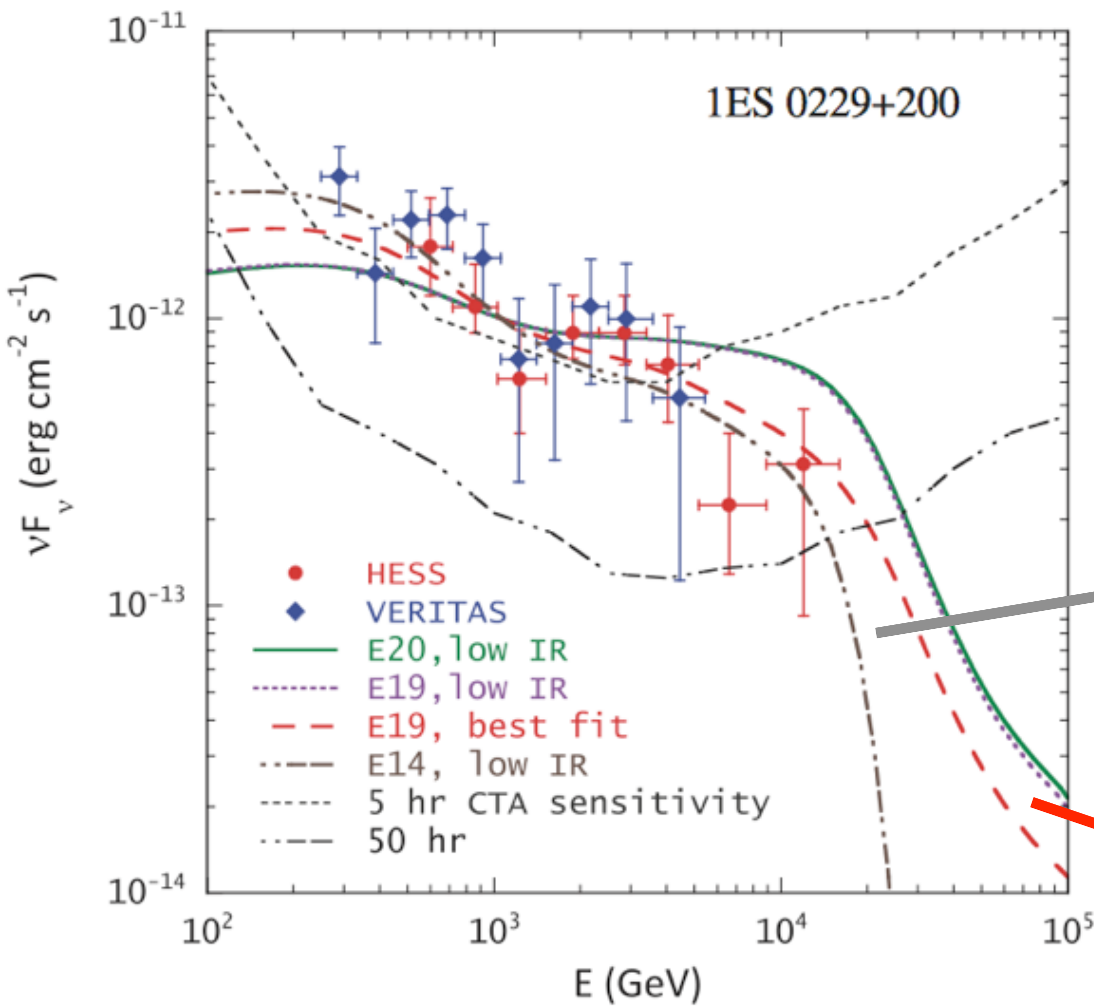


Essey & Kusenko 2010
Murase et al. 2012
Aharonian et al. 2013
Tavecchio 2014

A distinctive prediction of this model is that the observed γ-ray spectrum extends at energies much higher than those allowed by the conventional propagation through the EBL.

An hard tail at 20-30 TeV is considered the smoking gun of this model.

Hadron beams

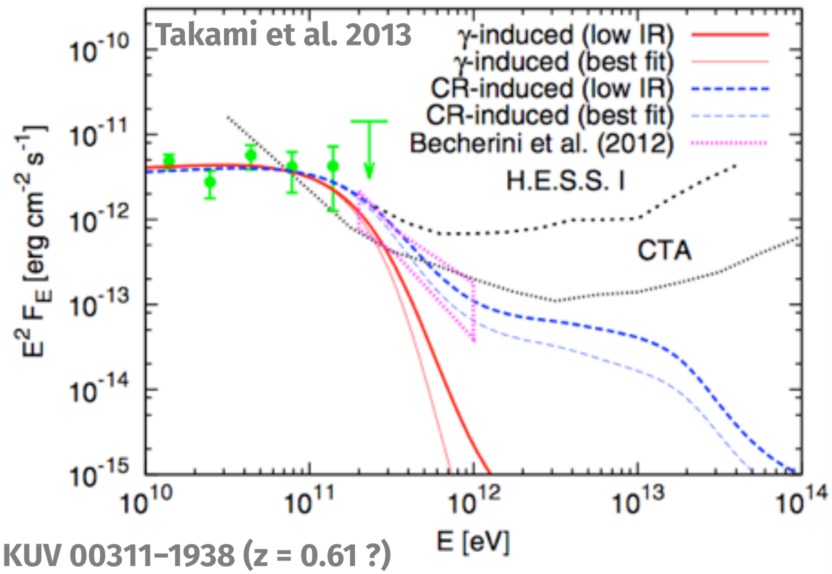


Murase et al. 2012

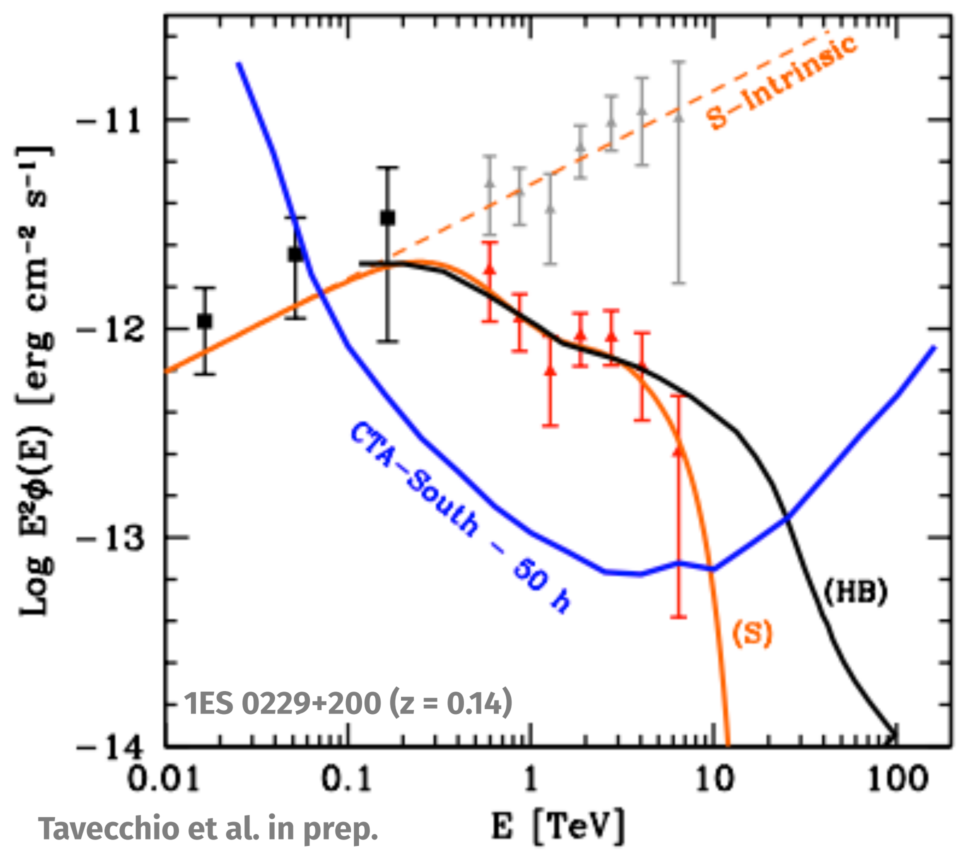
photons

protons

Hadron beams



Prospects for CTA



Data: LAT [Costamante+18], H.E.S.S. [Aharonian+07]

EBL: [Dominguez+11]

(S) – Standard leptonic model

(HB) – Hadron-beams model

E-HBLs simulation setup

1ES 0229+200

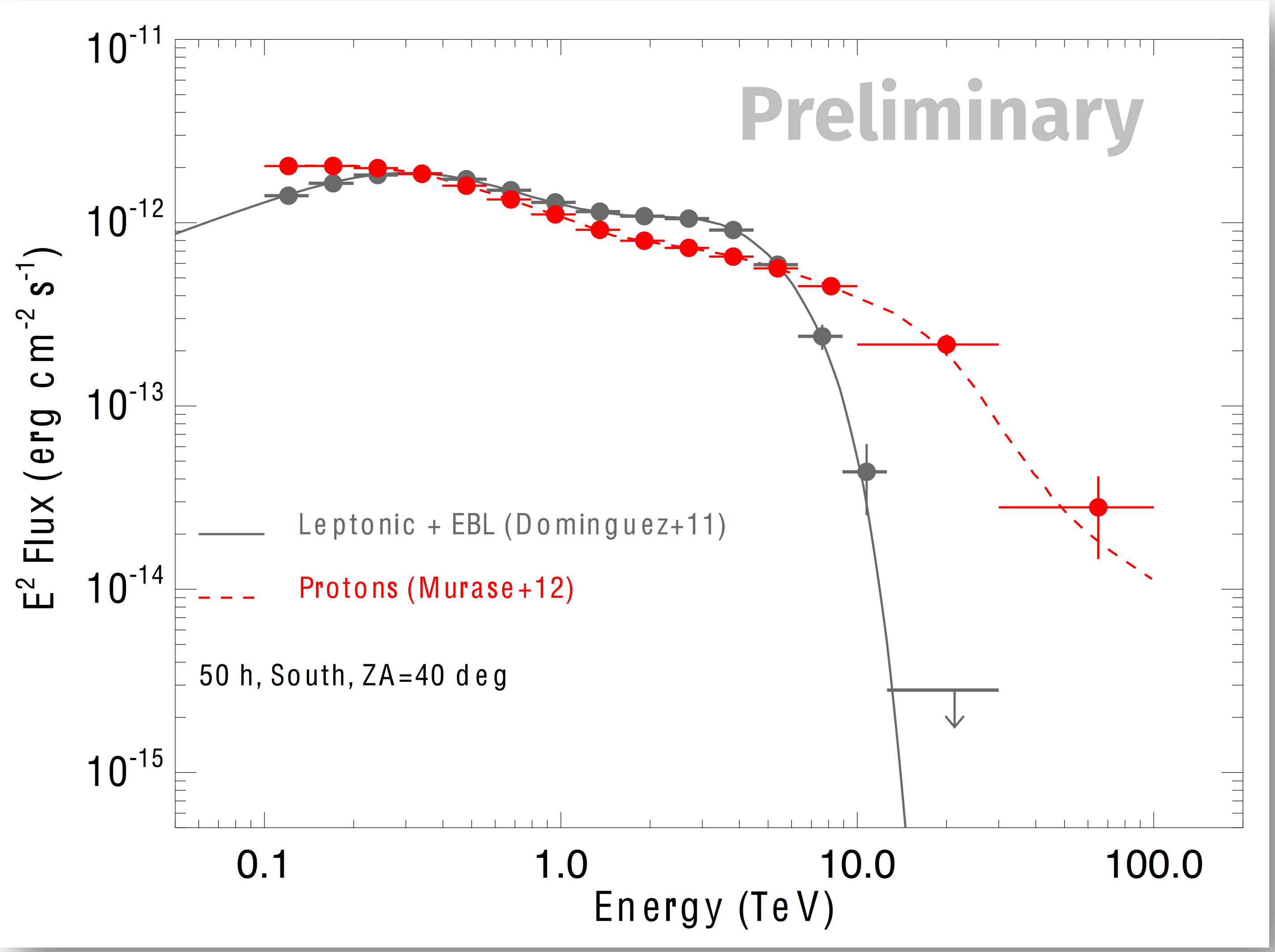
Model	Site	zAngle (deg)	IRF	Expo (h)	Bins	Energy (TeV)	Number	Total
Standard	N	20	North_z20_average_50h	50	15	0.1–30	1000	-
Standard	S	40	South_z40_average_50h	50	15	0.1–30	1000	-
Murase	S	40	South_z40_average_50h	50	15	0.1–100	1000	-
Alp	S	40	South_z40_average_50h	50	15	0.1–100	1000	4000

SW (*ctools*) and IRFs (*public*): same as for the NLS1s

Southern array → **SSTs** to probe **E > 10 TeV**

A paper is in preparation [Tavecchio+18]

1ES 0229+200 – CTA simulations



Conclusions

- **CTA** will be **the next generation** Cherenkov Telescope Array, open to the scientific community
- We simulated **jetted sources** whose spectra lie on **both CTA energy ends**, E<100 GeV and E>10 TeV.
- Preliminary results show that
  - **NLS1s**: detections might be obtained at E < 50 GeV during high/flaring states, while in the highest energy range (50-150 GeV) the EBL and the internal absorption may play a relevant role.
  - **E-HBLs**: the excellent CTA performance at E > 10TeV may help in discriminating among different emission models.