29th Rencontres de Blois, 29/5-2/6 2017 - Blois, Loire Valley, France

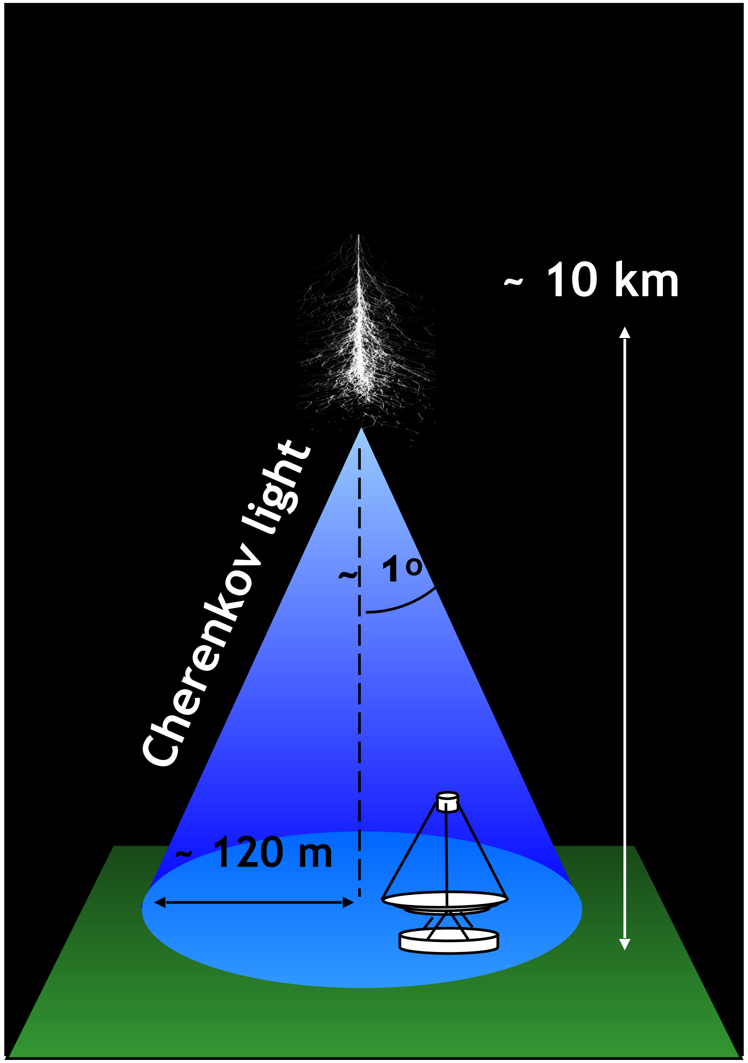
Exploring the cosmic Middle Age with MAGIC

Giacomo Bonnoli on behalf of the MAGIC Collaboration
Università degli Studi di Siena & INFN Pisa

Outline

- MAGIC in a nutshell
- Briefs on FSRQs
- Grazing the z=1 horizon with MAGIC
- Conclusions

How: Imaging Air Cherenkov Telescopes (IACT)



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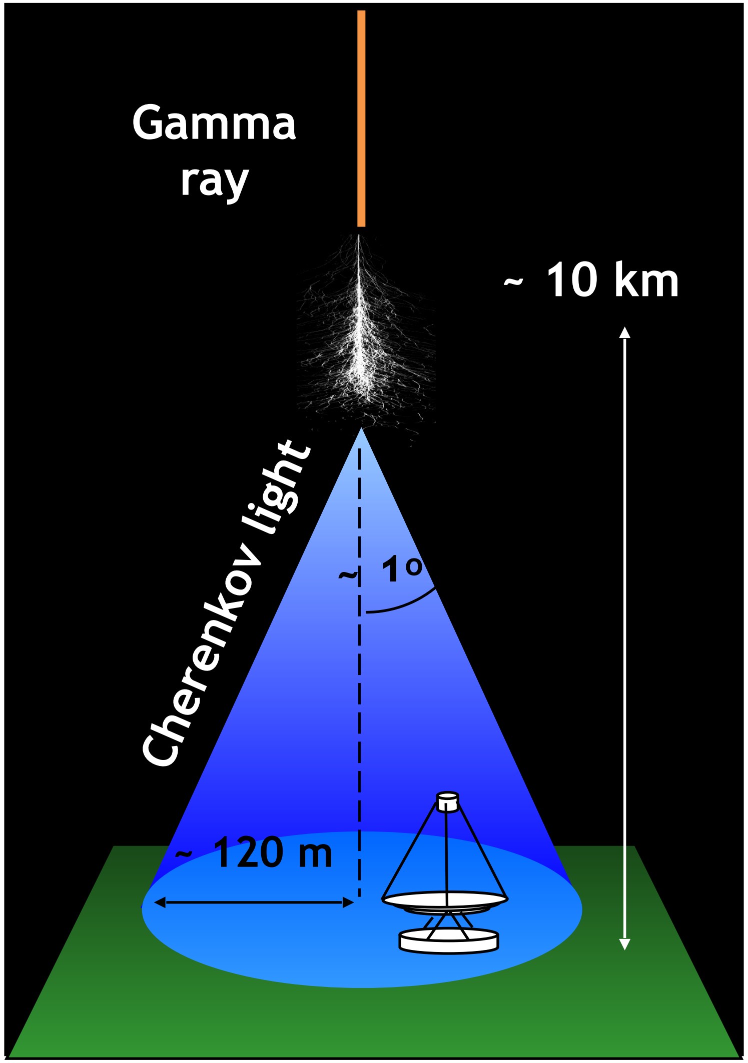

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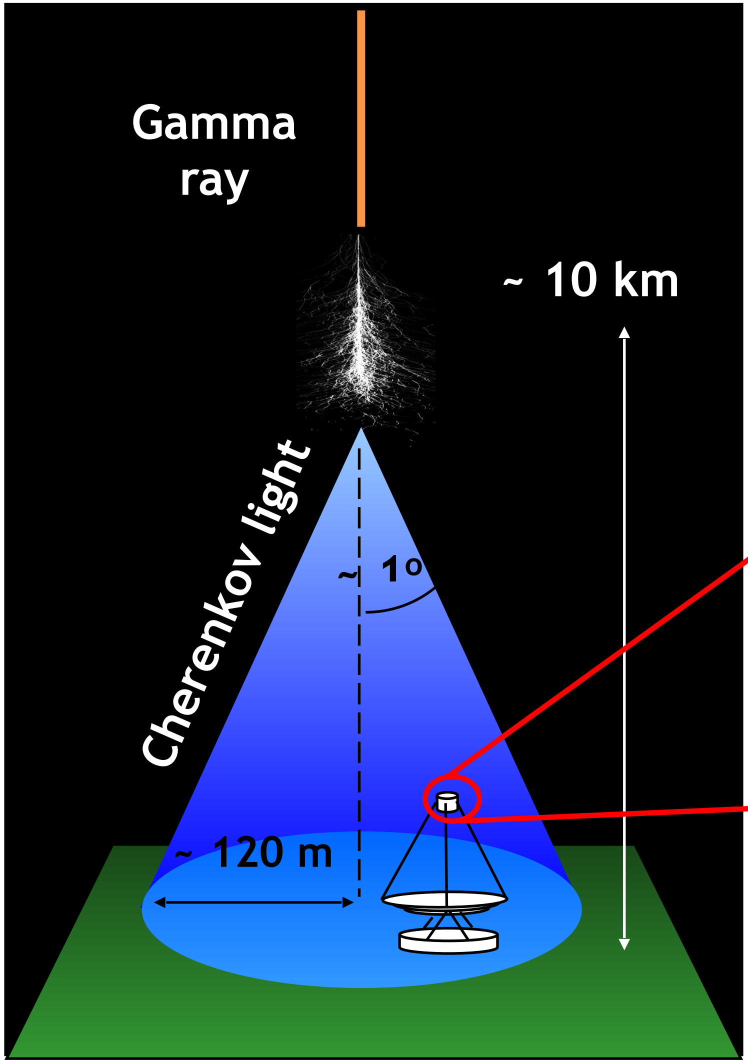
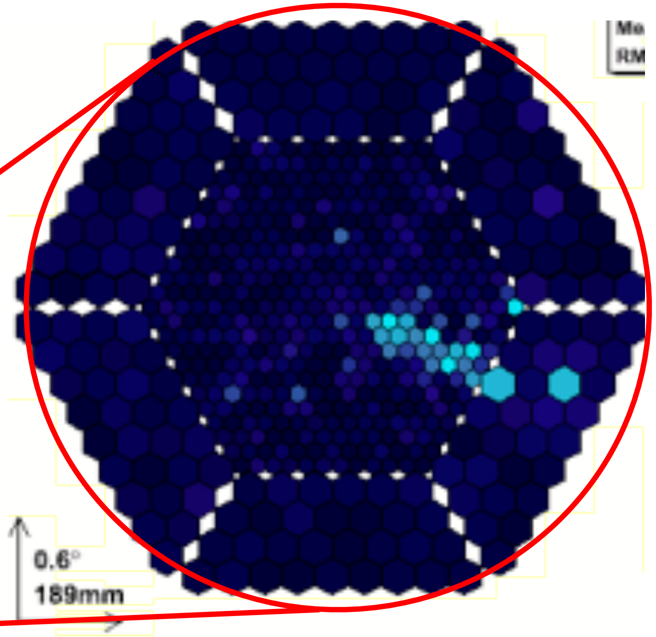


Image of Cherenkov flash on the camera



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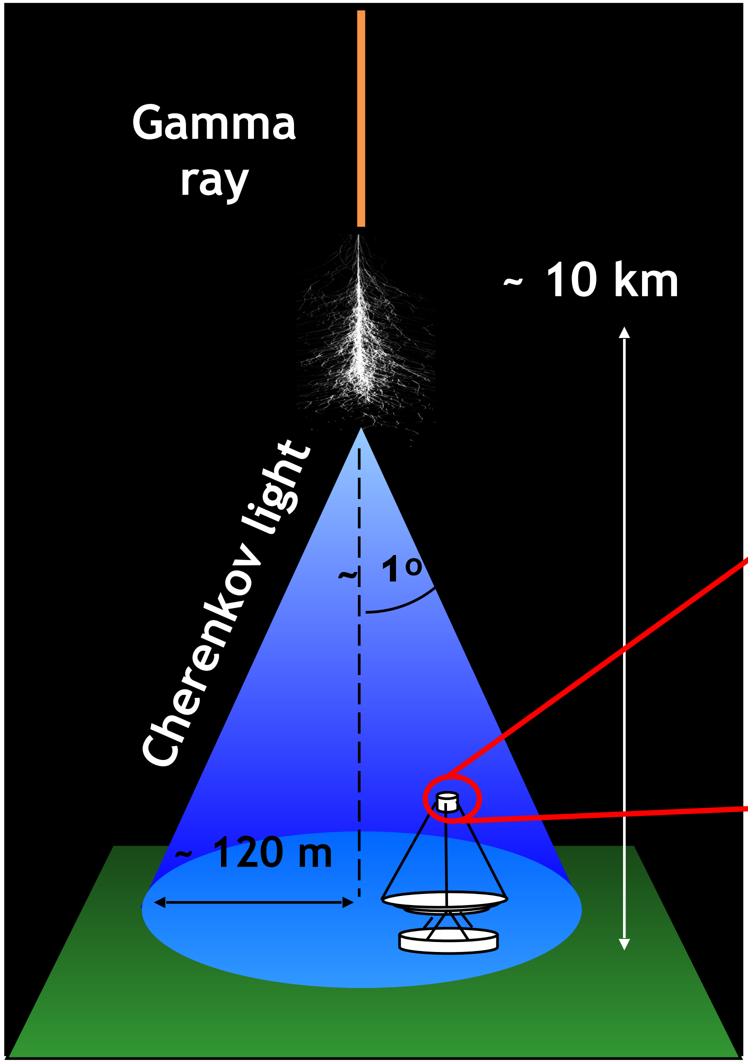

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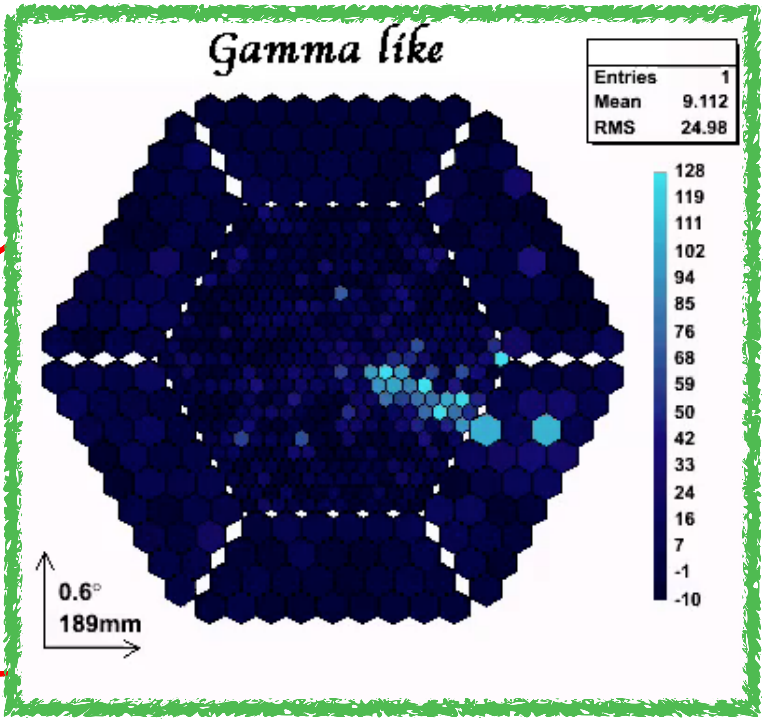

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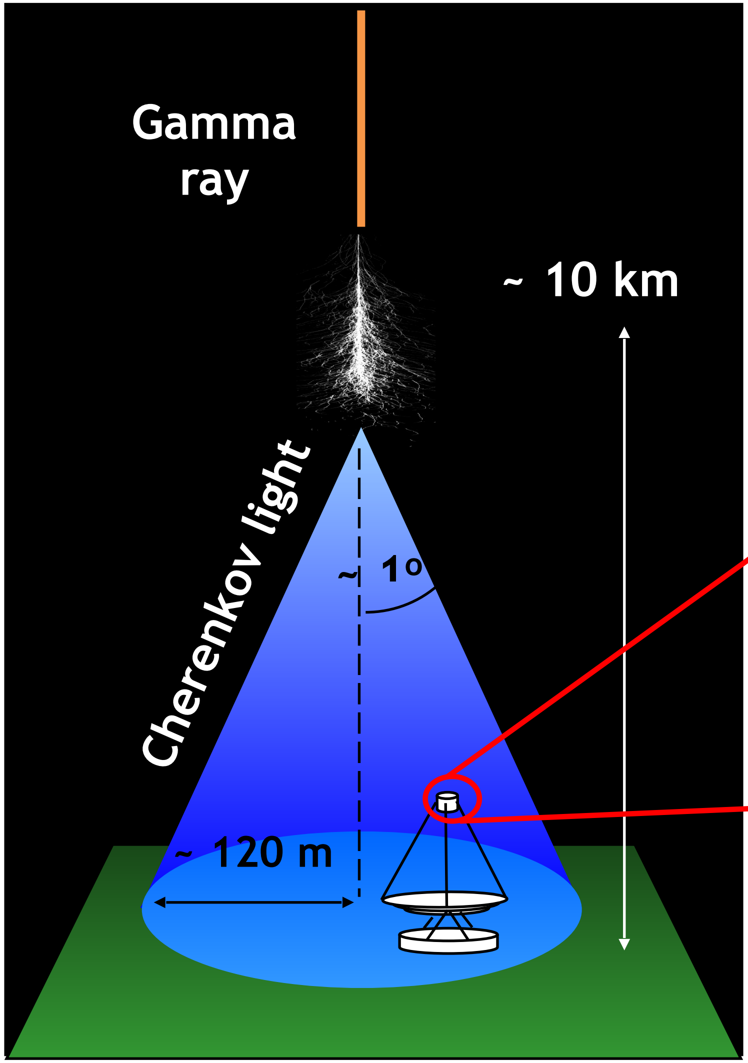

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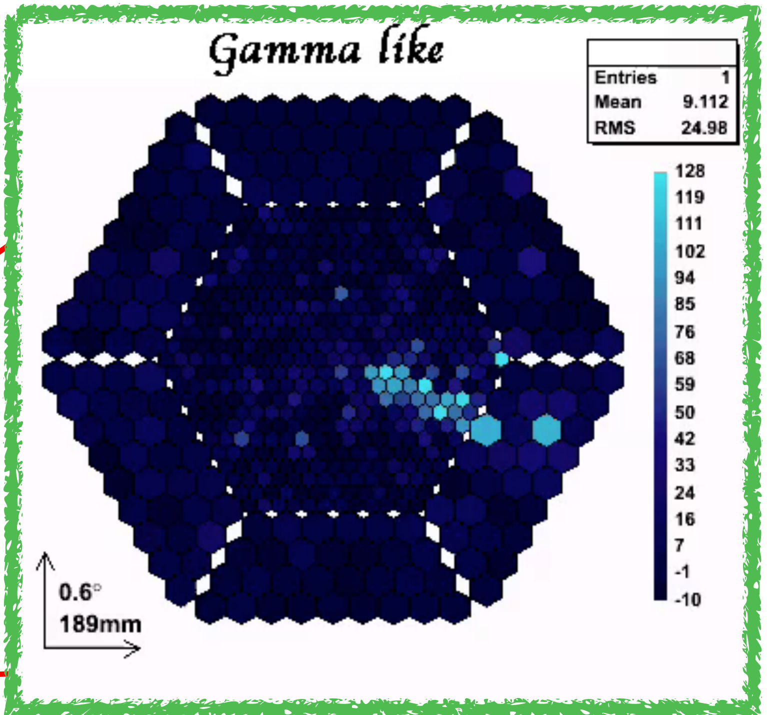
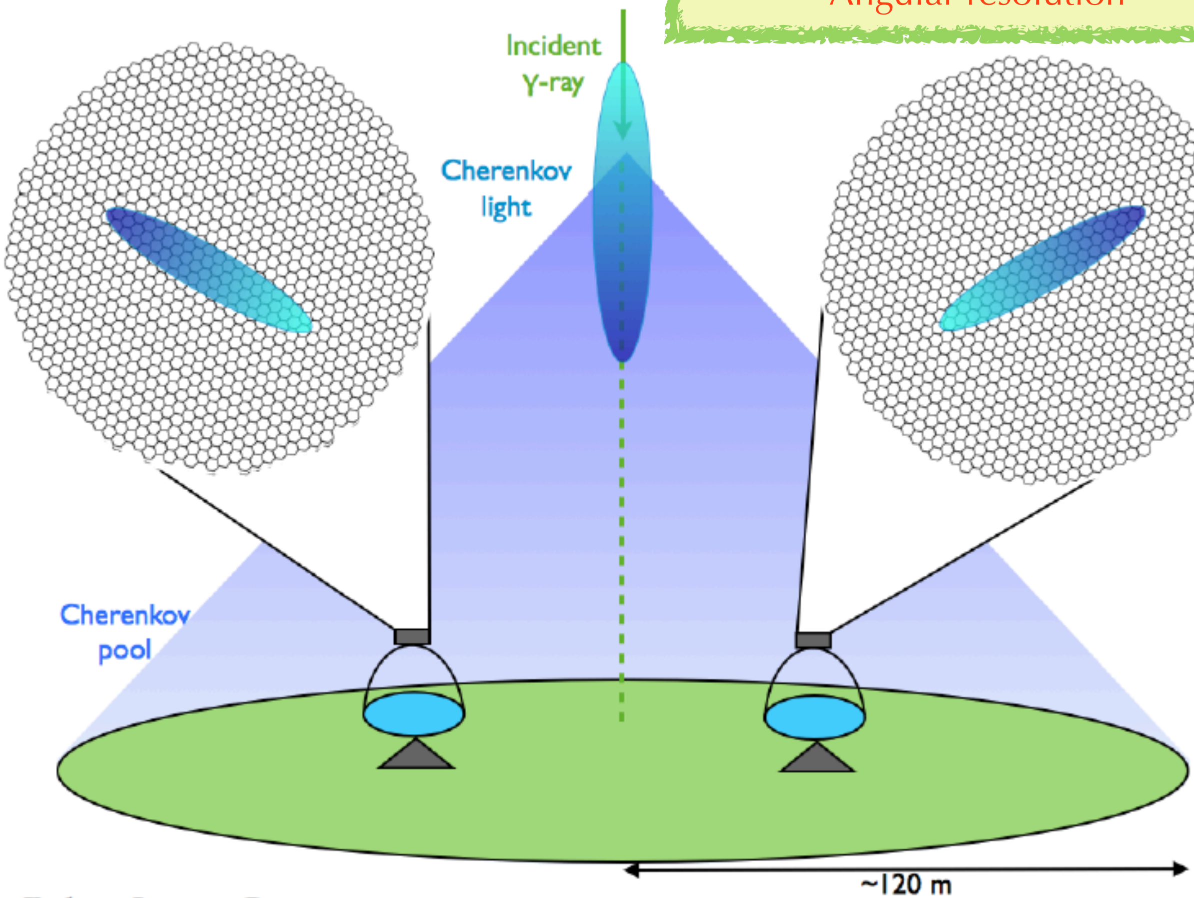


reconstruction of the energy and direction of the primary photon

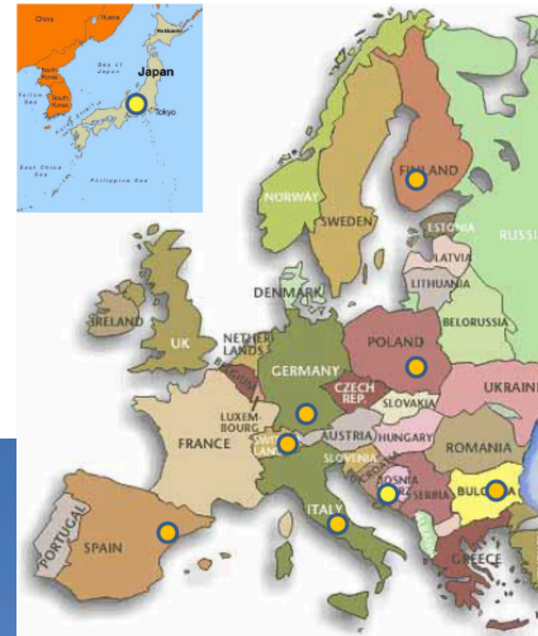
IACT Stereo Tecnique

Improving background rejection
Energy resolution
Angular resolution

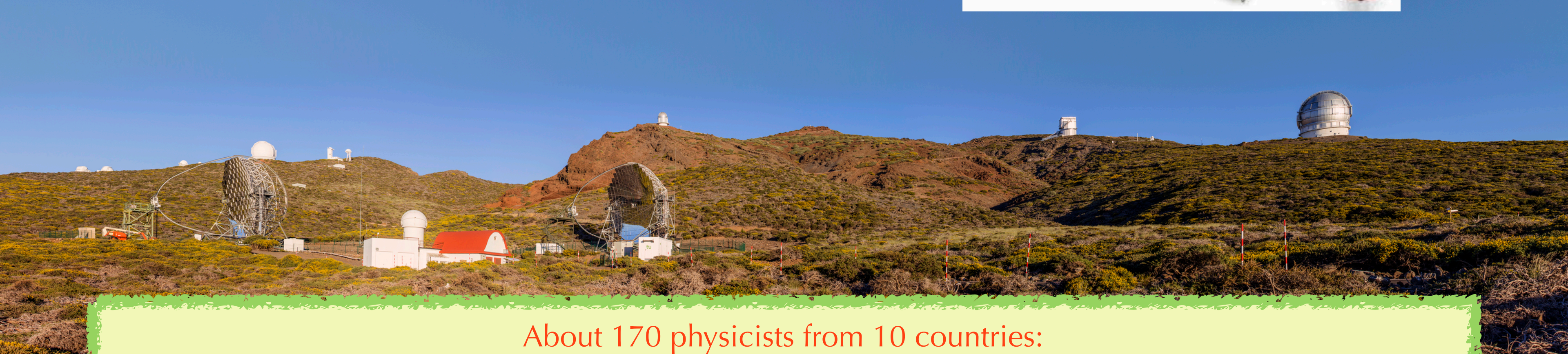


credit: Rubén López Coto

Who, Where and When?



MAGIC
@ORM (La Palma, Canary Islands)
Since 2004



About 170 physicists from 10 countries:
Bulgaria, Croatia, Finland, Germany, India, Italy, Japan, Poland, Spain, Switzerland

The MAGIC telescopes in a nutshell

- Energy threshold ~50 GeV
- FOV 3.5°
- Energy Resolution ~16% (E>300 GeV)
- Angular Resolution ~0.06° (E>300 GeV)
- Sensitivity (5 σ in 50 hours) ~0.8% Crab Nebula flux (> 250 GeV)

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Fast repositioning
~ 25s/180°

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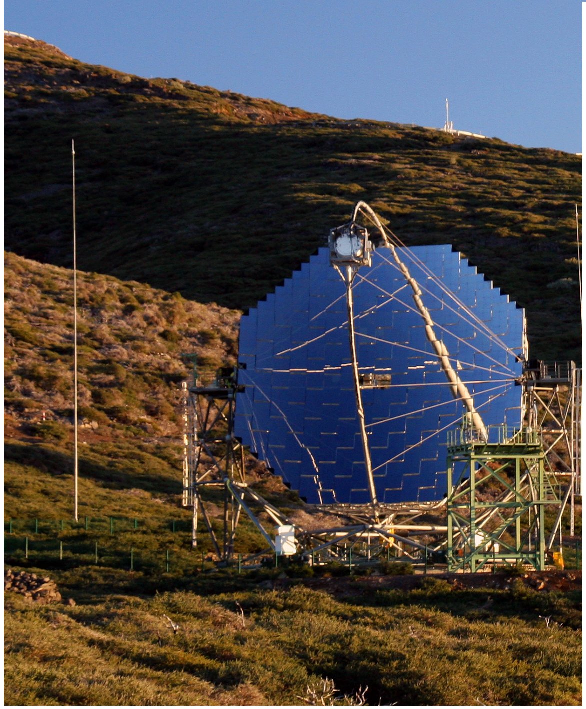

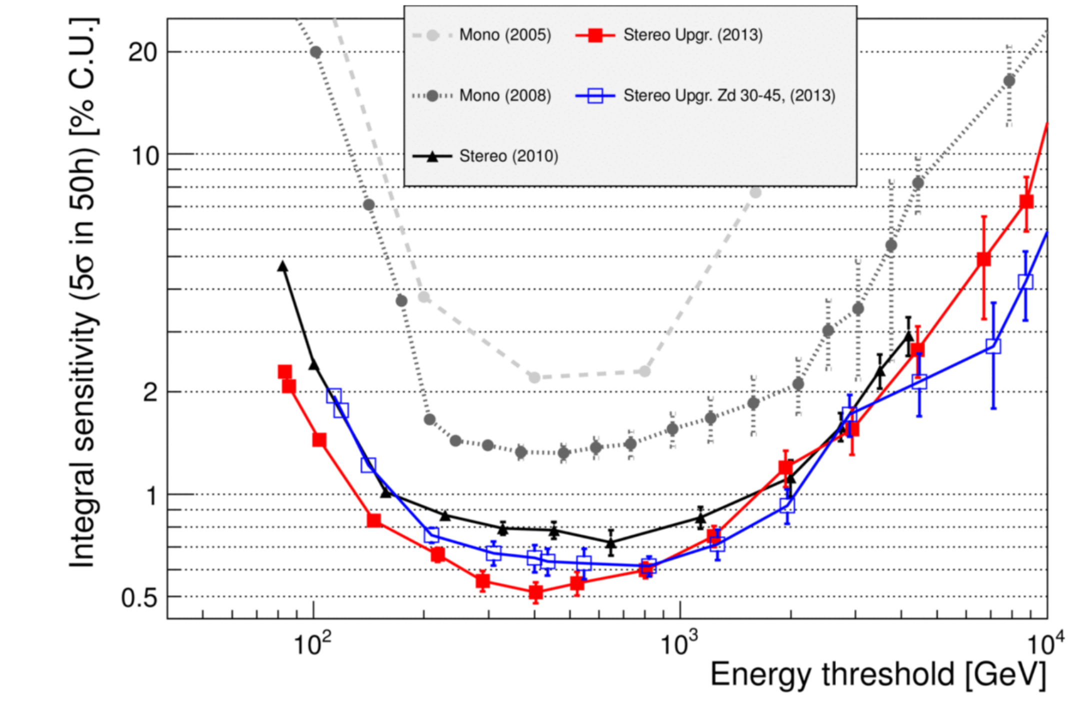

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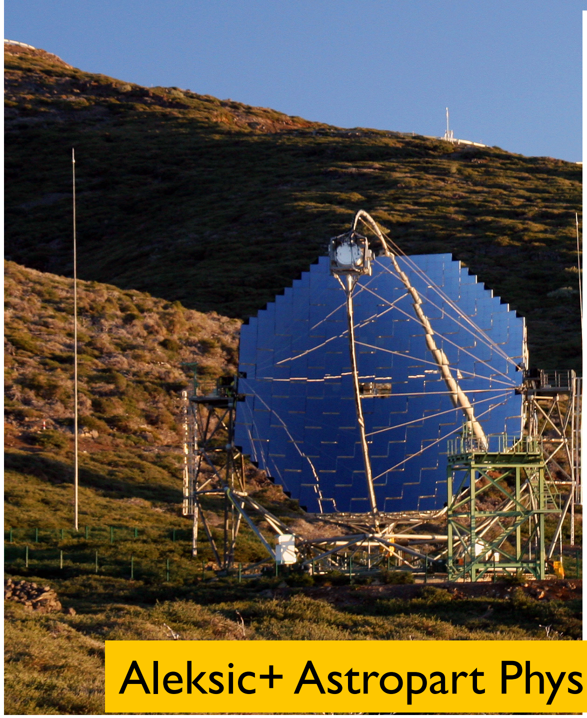

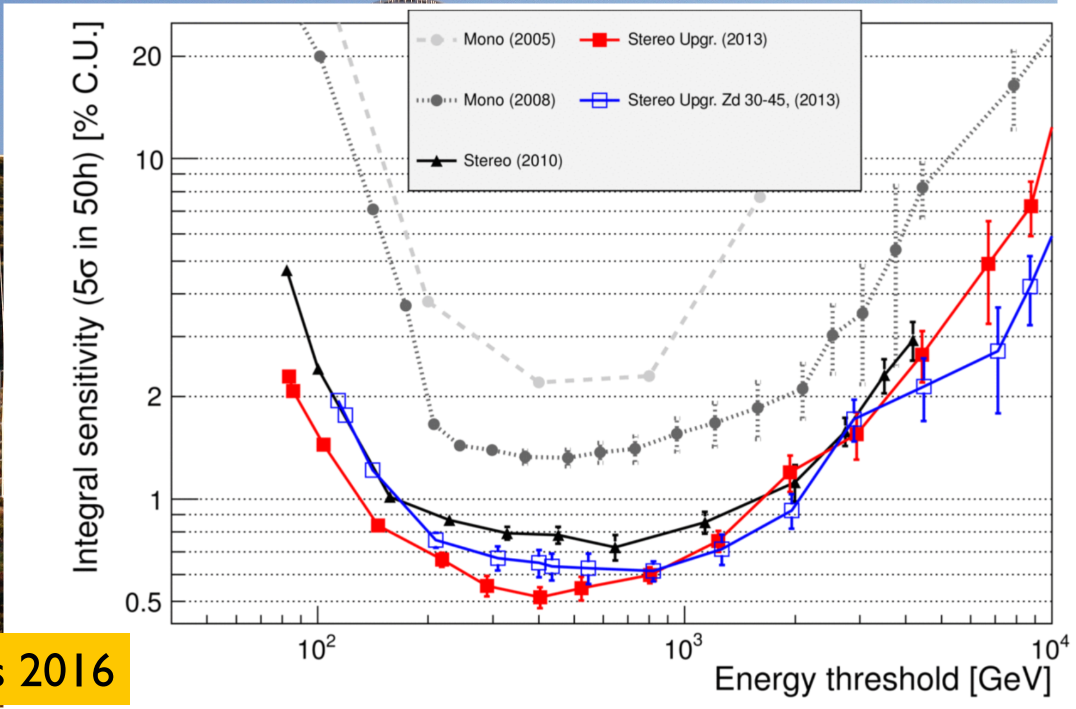

Aleksic+ Astropart Phys 2016

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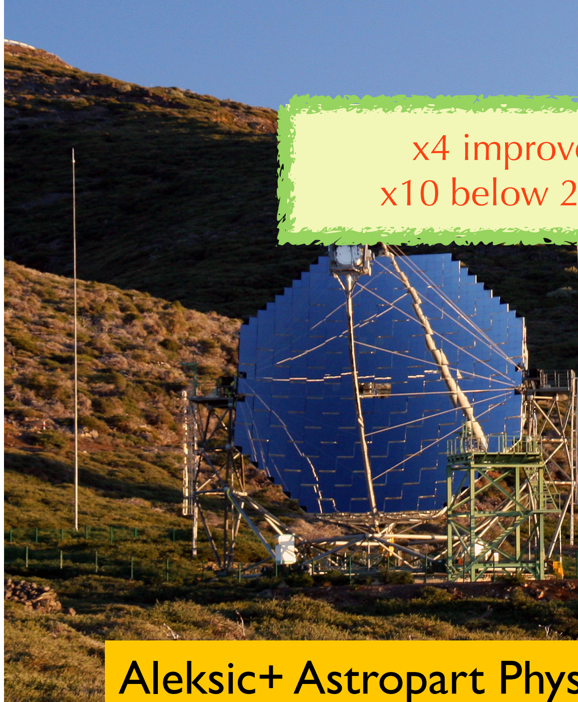
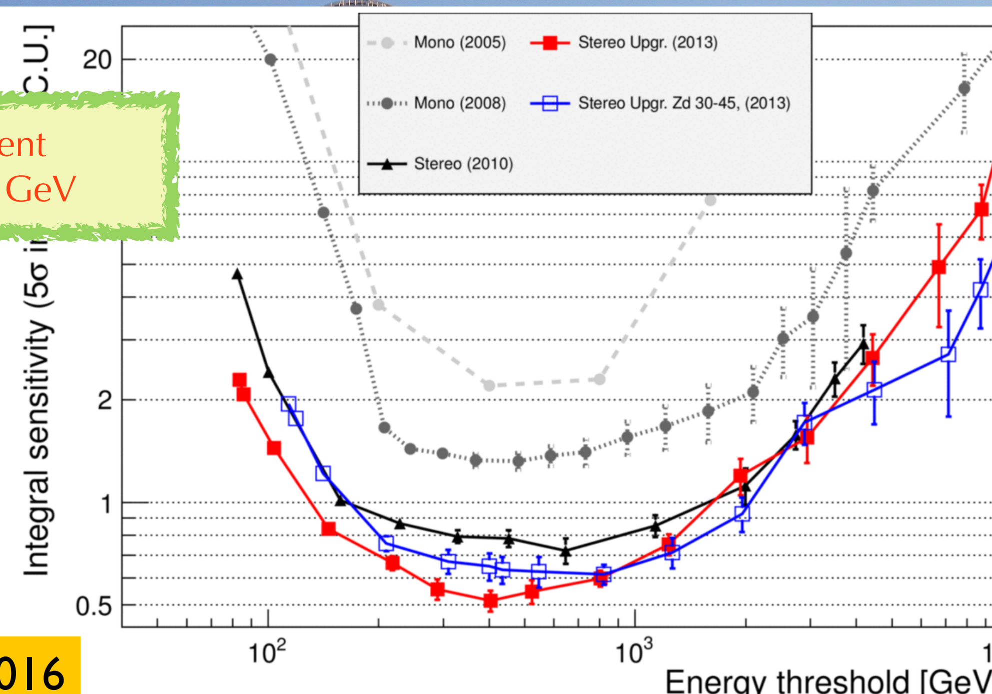
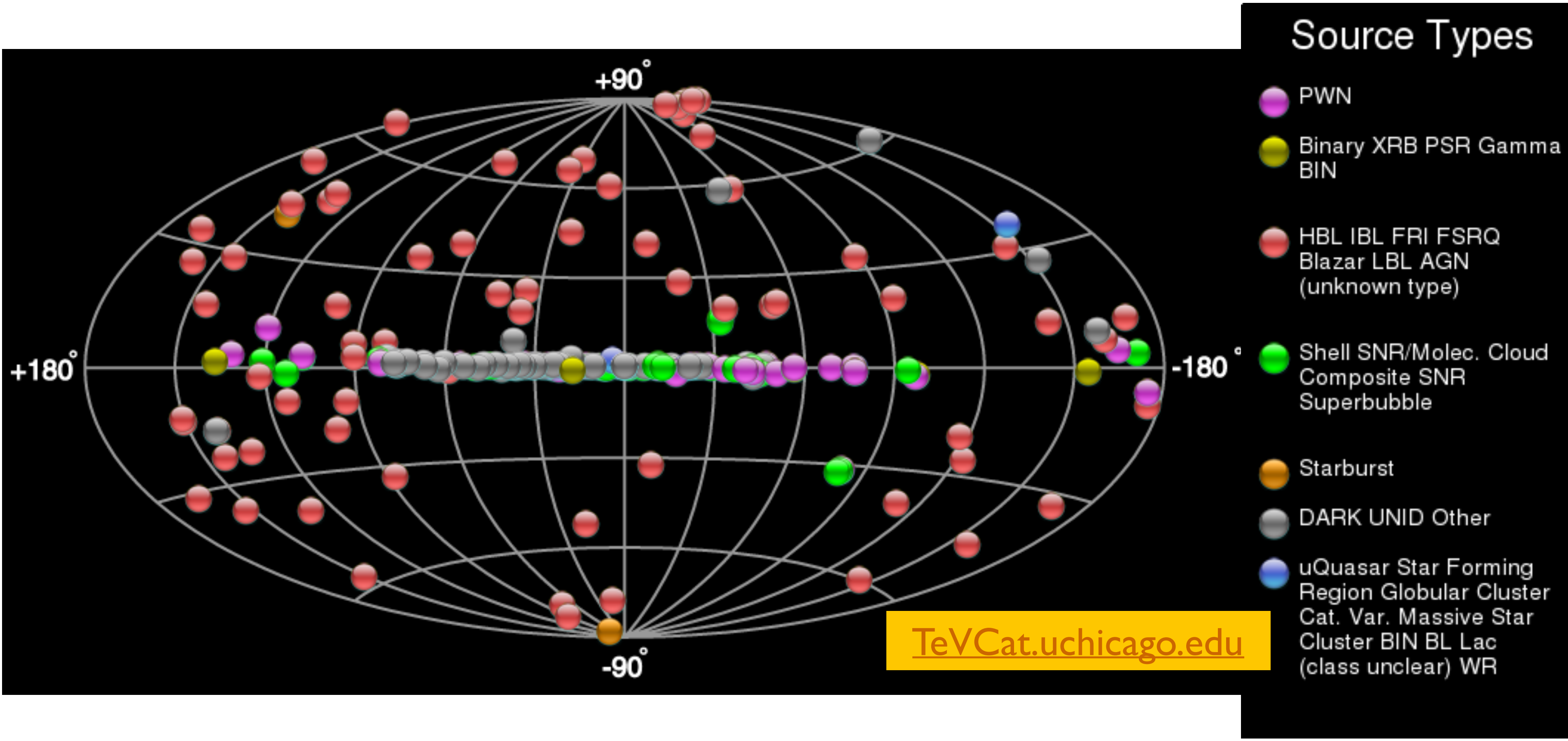


x4 improvement
x10 below 200 GeV



Aleksic+ Astropart Phys 2016

The TeV sky today



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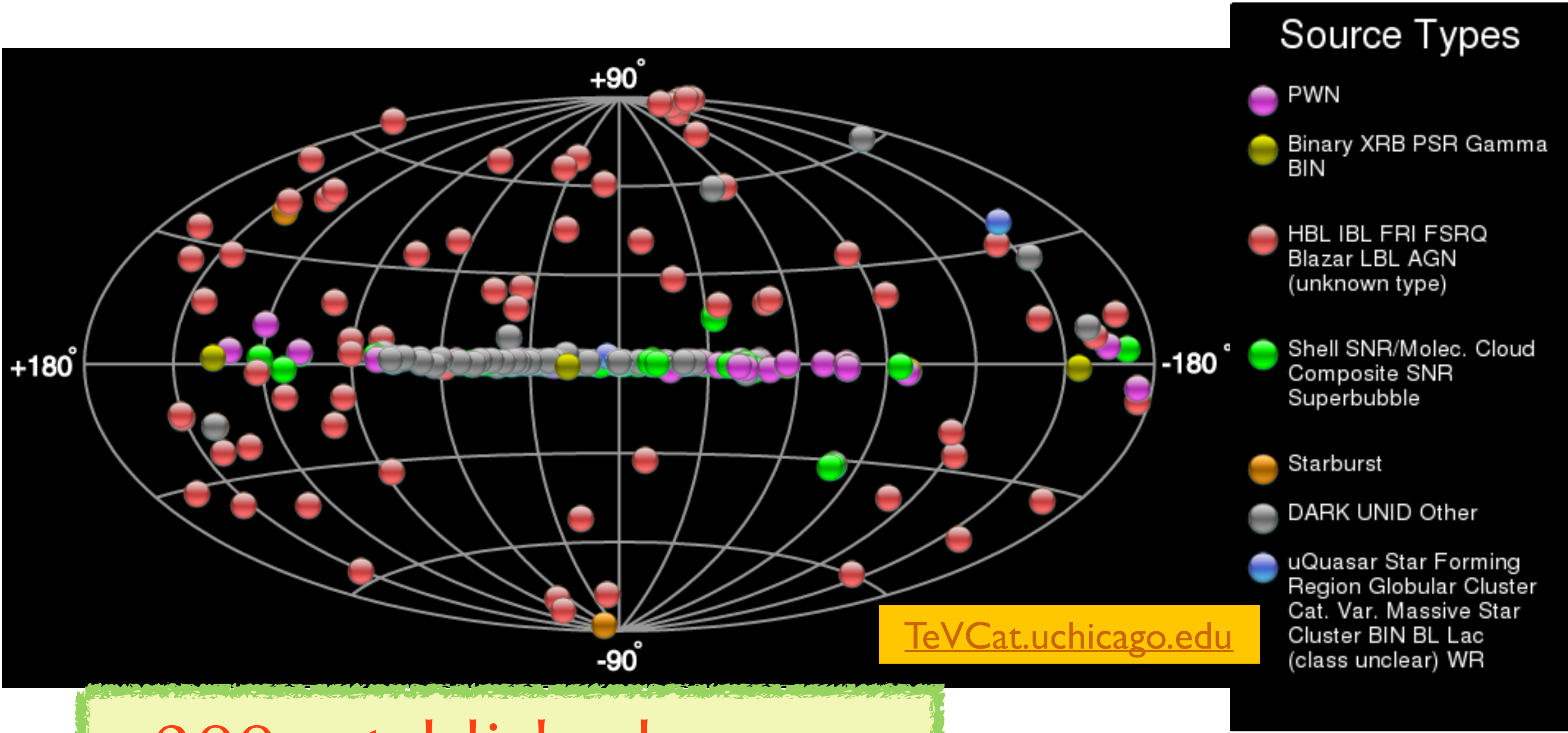
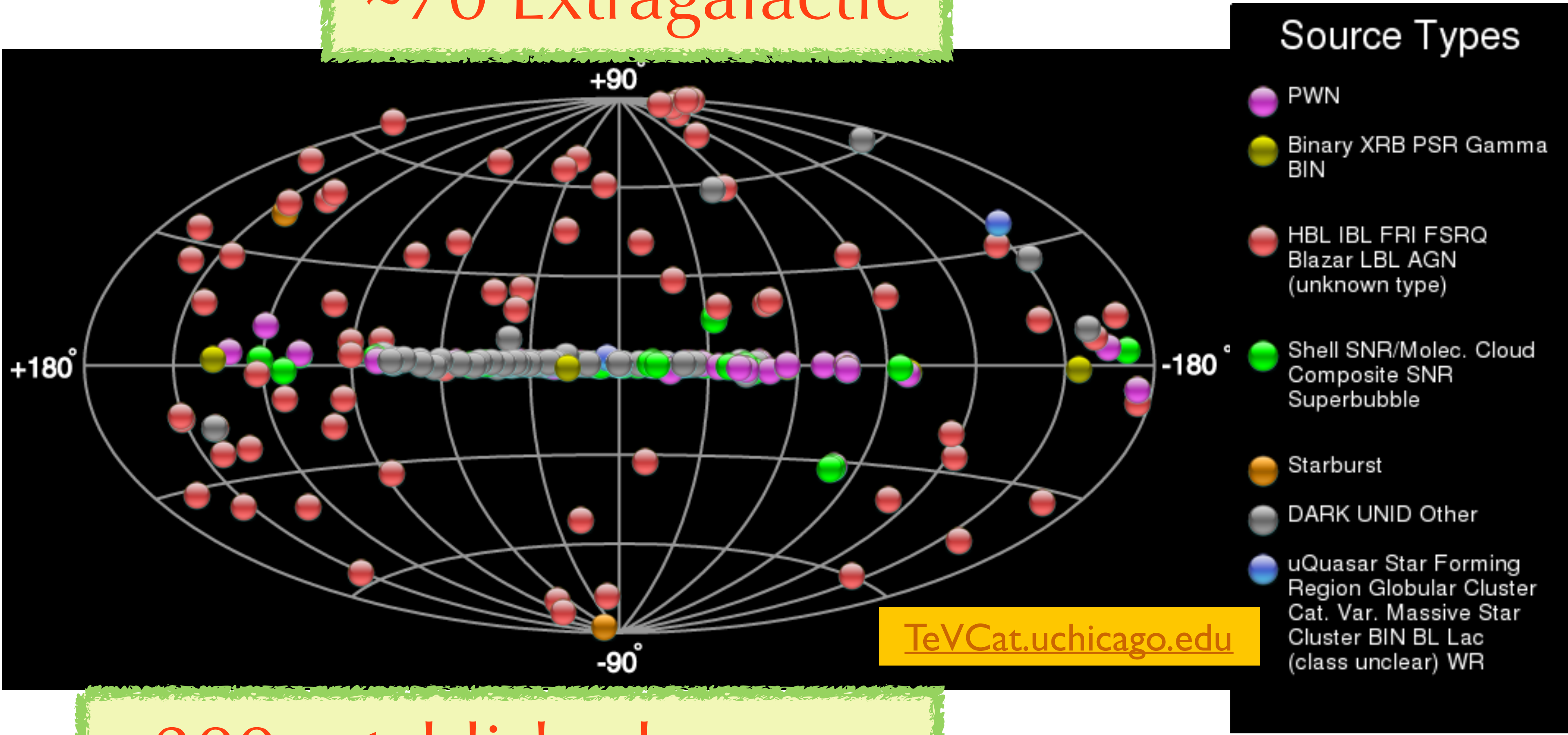


~200 established sources

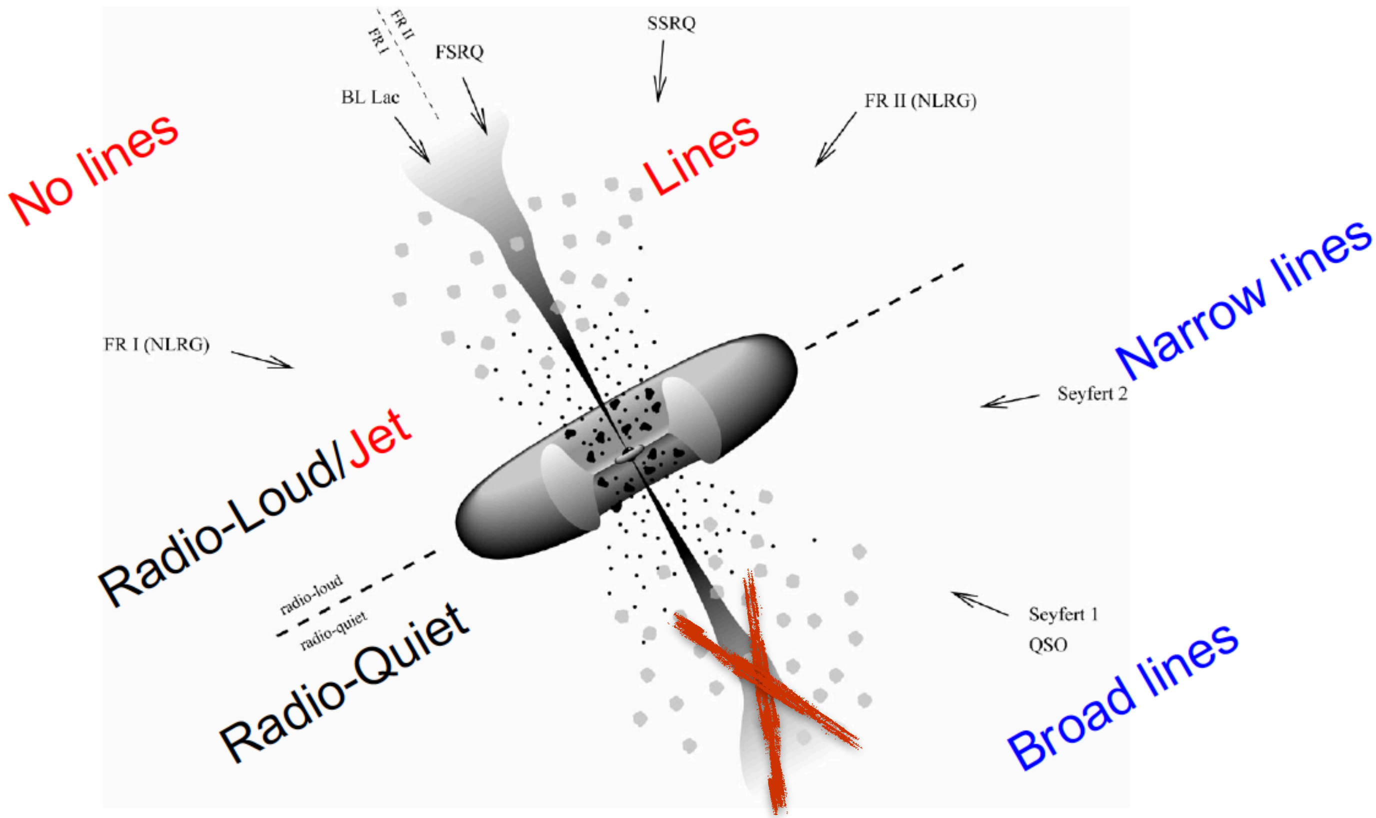
The TeV sky today

~70 Extragalactic

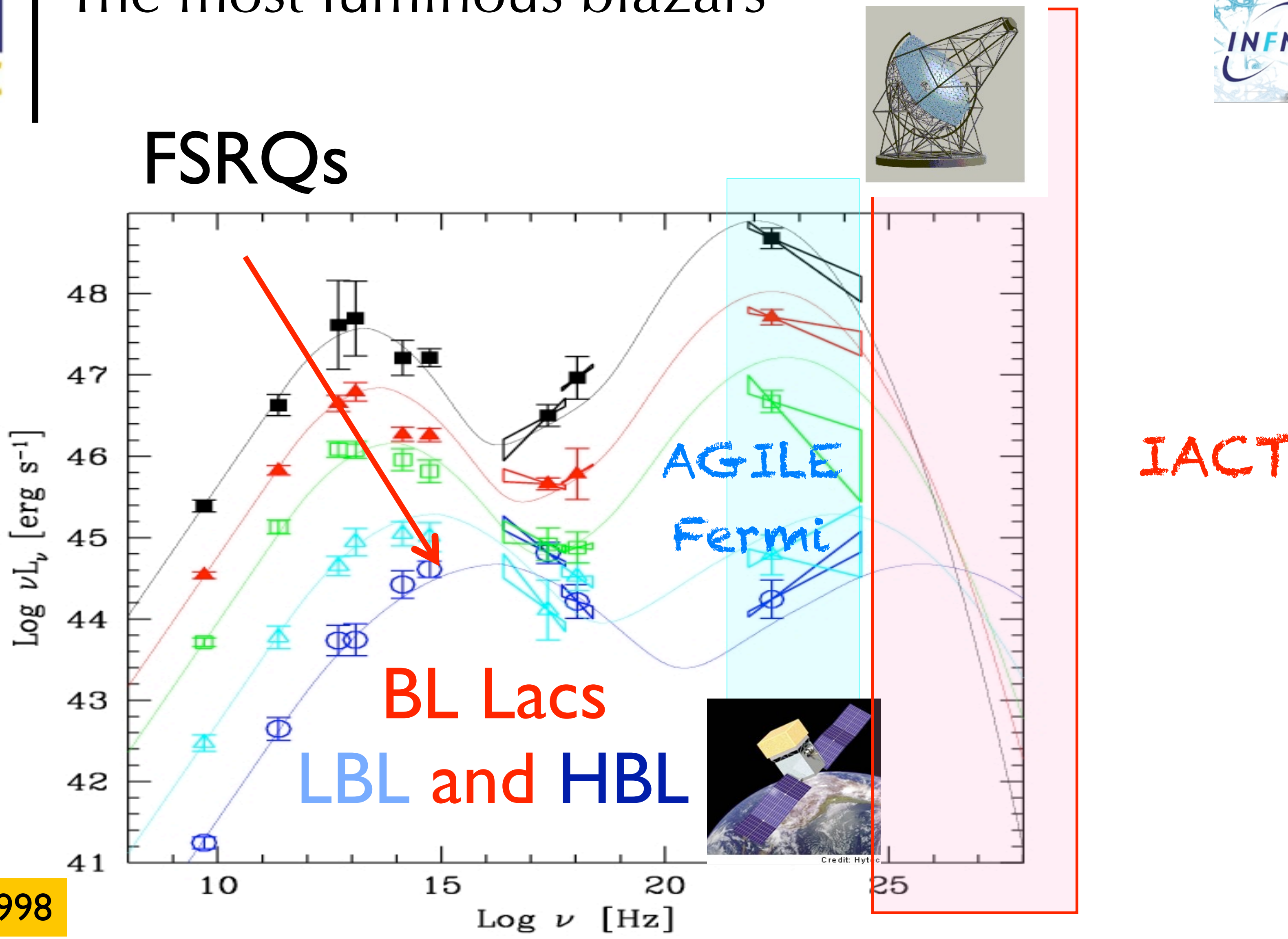


~200 established sources

Flat Spectrum Radio Quasars in the blazar zoo



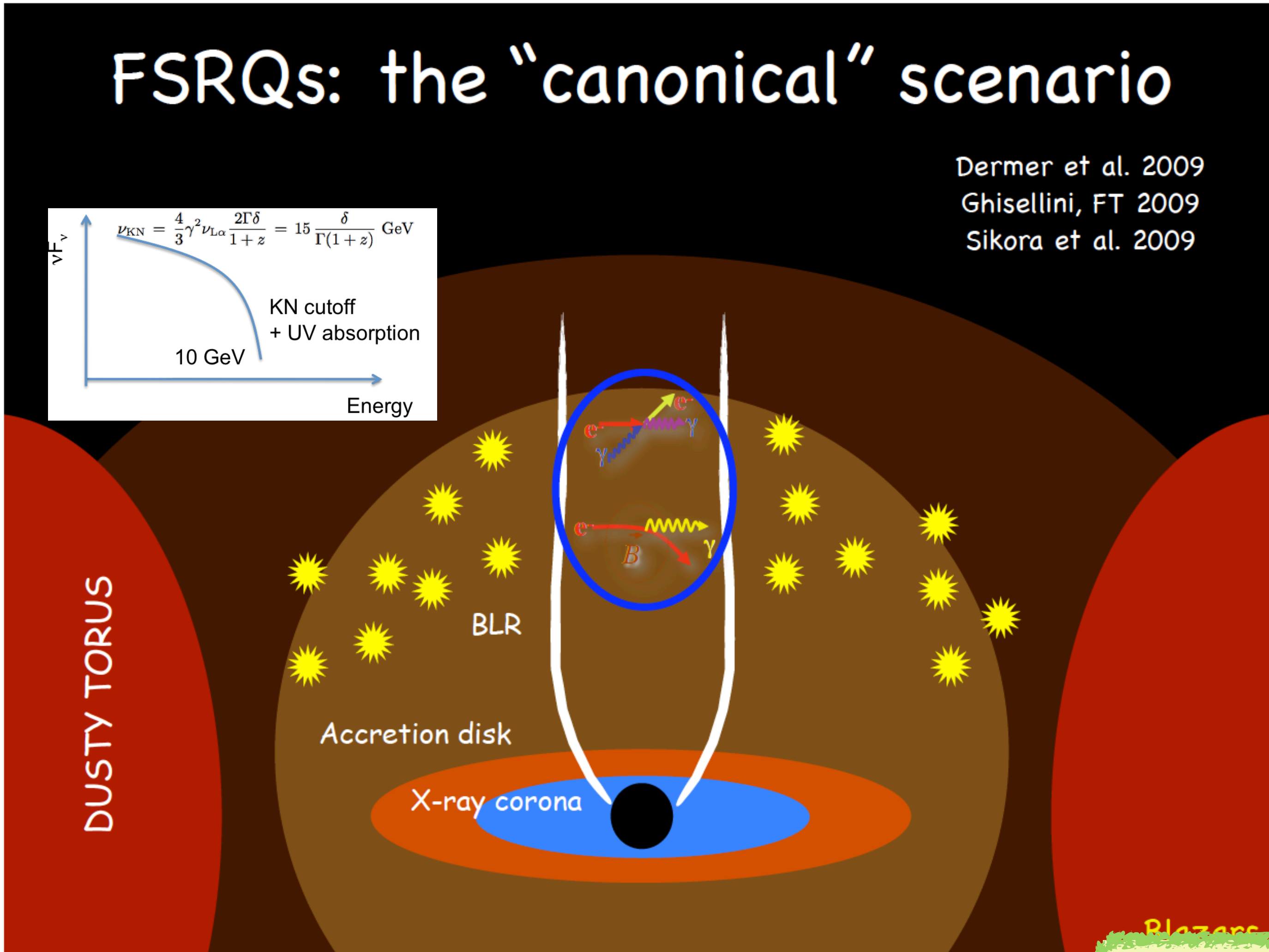
The most luminous blazars



Fossati+ 1998

Debated unification model of blazars; "cooling"

External Compton models for FSRQ



Credits: F. Tavecchio

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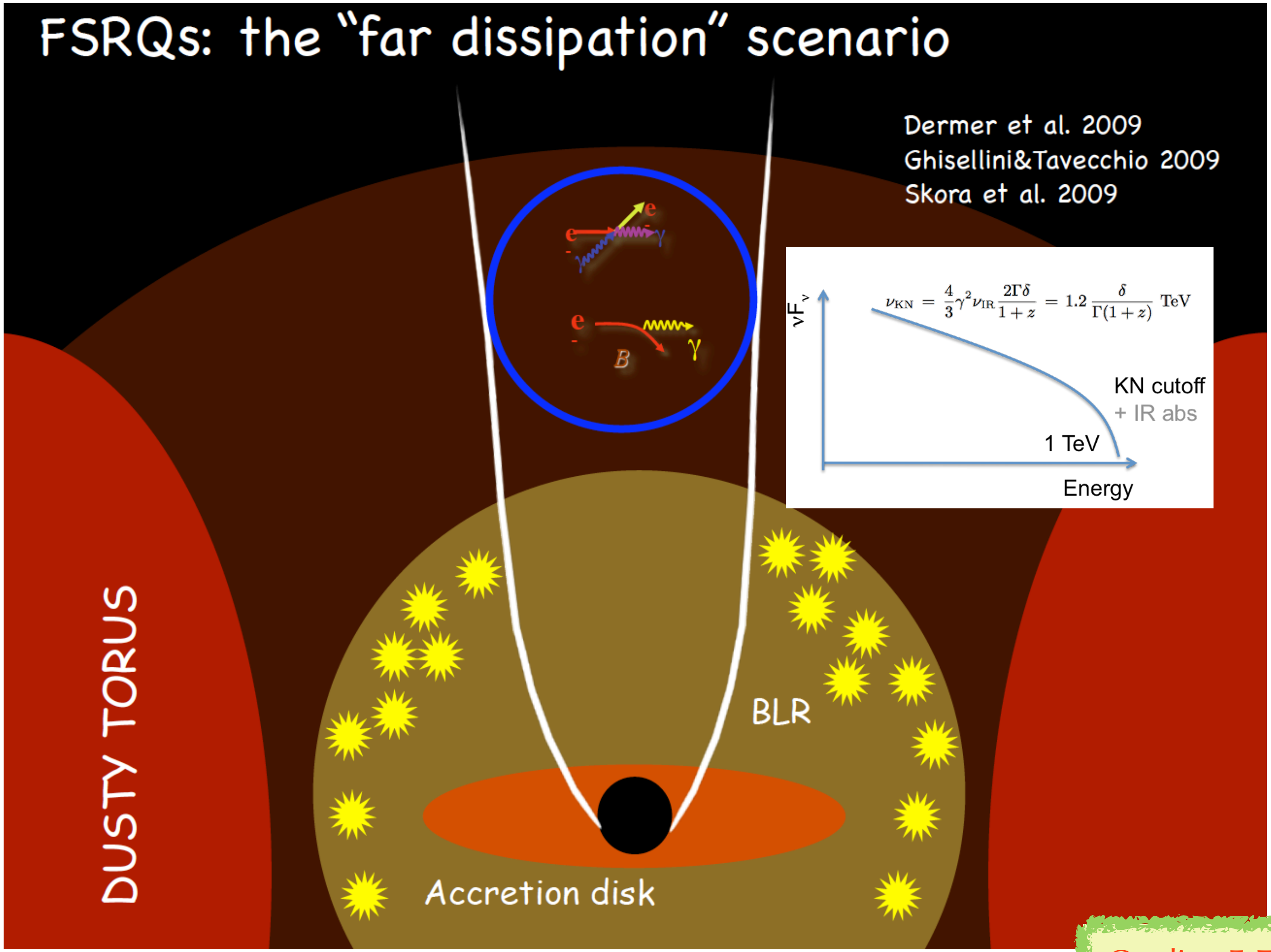
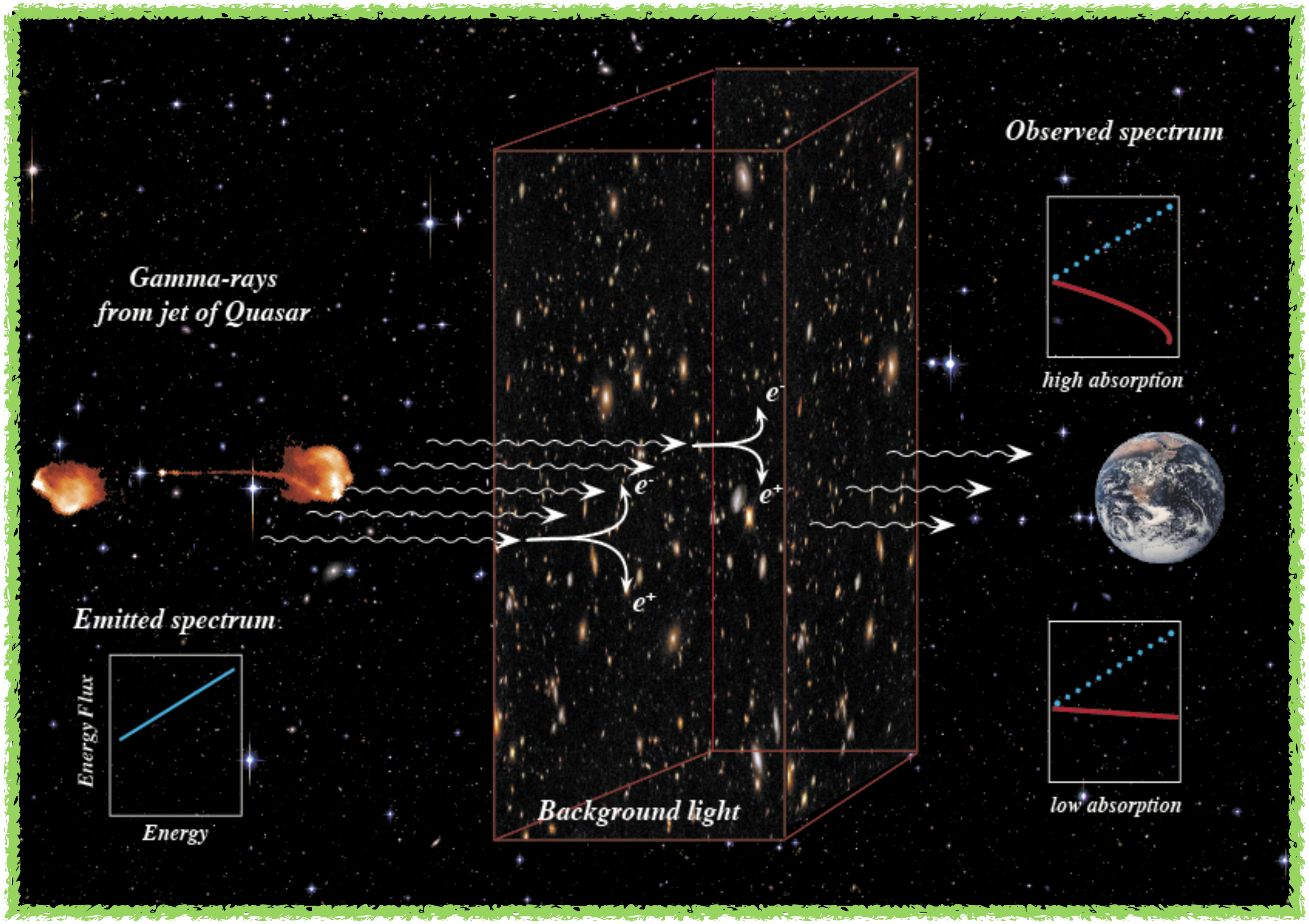
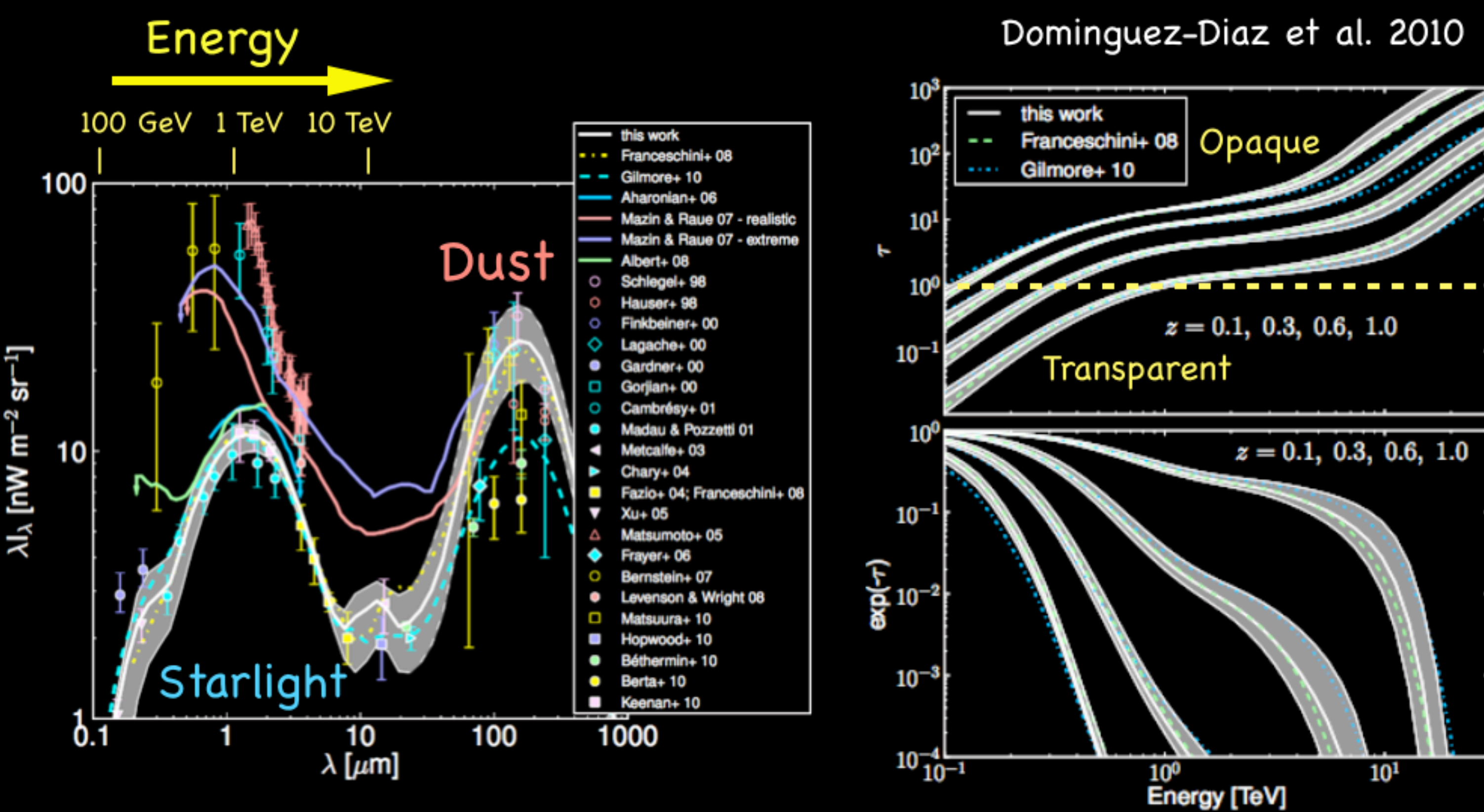


Credits: F. Tavecchio

Propagation of VHE gamma rays



An Horizon for VHE gamma rays



$$\tau(E,z) = \int_0^z dl(z) \int_{-1}^{1} d\cos(\theta) \frac{1-\cos(\theta)}{2} \int_{\frac{(2(m_e c^2))^2}{E(1-\cos(\theta))}}^{\infty} d\epsilon(z)\eta_\epsilon(\epsilon(z),z)\sigma_{\gamma\gamma}(E(z),\epsilon(z),\theta)$$

VHE FSRQs: very few so far!!

FSRQs are luminous, but HE spectra are steep.

- Synchrotron peak shifted to low energies (IR)
- IC peak shifted to HE gamma
- Evidence for intrinsic absorption cutoff in some (e.g. 3C454.3) but with remarkable exceptions (e.g. PKS 1222+216)
- Typical redshift larger than for BL Lacs

To catch them IACTs need:

- sensitivity below 100 GeV
- prompt reaction to flares

Source	Discoverer	Year	Redshift
3C279	**MAGIC**	2006	0.536
PKS 1510-089	H.E.S.S.	2009	0.361
PKS 1222+216	**MAGIC**	2010	0.432
B 0218+35	**MAGIC**	2014	**0.944**
S4 0954+65	**MAGIC**	2015	0.368
PKS 1441+25	**MAGIC**	2015	**0.940**
PKS 0736+017	H.E.S.S.	2016	0.189

The very beginning: 3C279 (z=0.536)

The MAGIC Coll.
Science 2008

to prepare ordered mesoporous metals of other elements, disordered alloys, or even ordered intermetallics. Furthermore, this discovery also cre-

156 (2007).
22. S. Creutz, P. Teyssie, R. Jerome, Macromolecules 30, 6 (1997).
23. See SOM on Science Online.

References
2 May 2008; accepted 29 May 2008
10.1126/science.1159950

Very-High-Energy Gamma Rays from a Distant Quasar: How Transparent Is the Universe?

The MAGIC Collaboration*

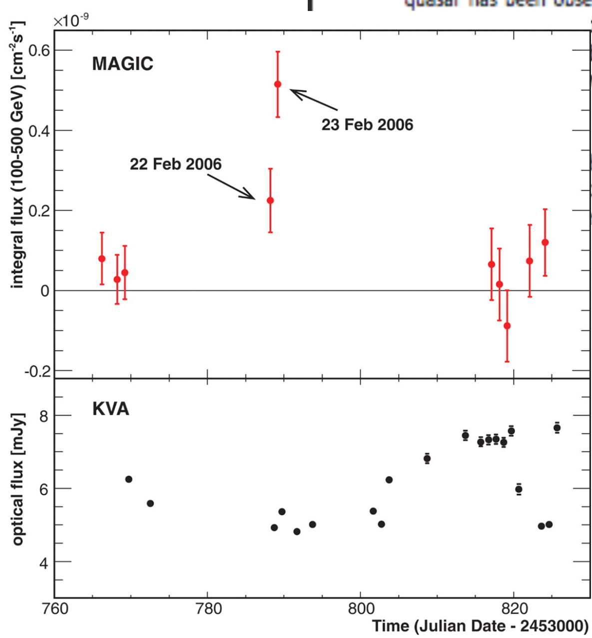
The atmospheric Cherenkov gamma-ray telescope MAGIC, designed for a low-energy threshold, has detected very-high-energy gamma rays from a giant flare of the distant Quasi-Stellar Radio Source (in short: radio quasar) 3C 279, at a distance of more than 5 billion light-years (a redshift of 0.536). No quasar has been observed previously in very-high-energy gamma radiation, and this is also the most … emitting gamma rays above 50 gigaelectron volts. Because high-energy gamma … by interacting with the diffuse background light in the universe, the observations … amount for such light, consistent with that known from galaxy counts.

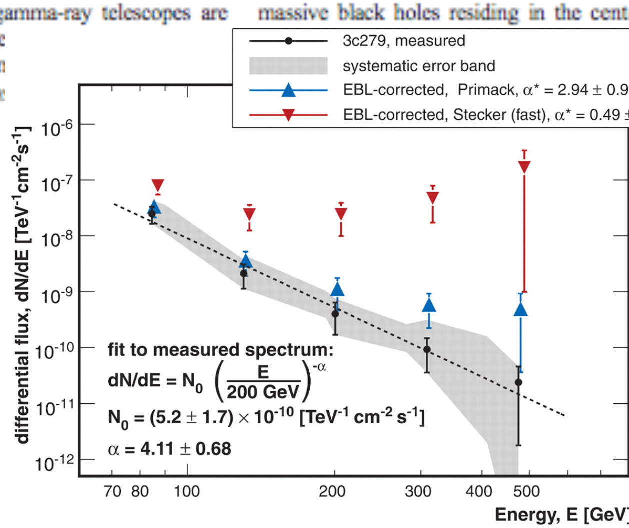
… gamma-ray telescopes are … massive black holes residing in the centers of …

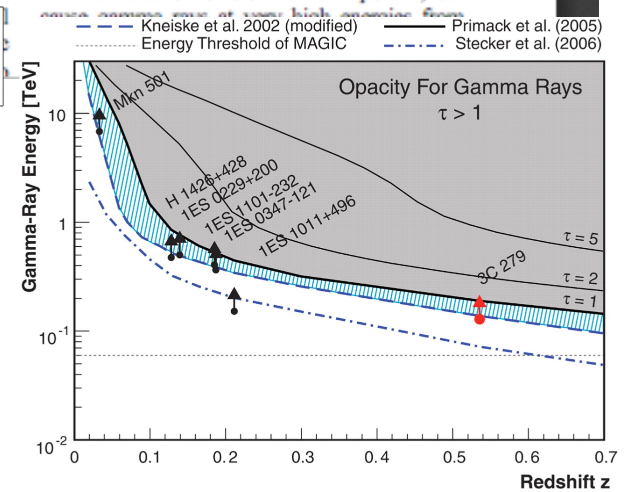
Observatory (CGRO) had measured gamma rays from 3C 279 (2) and other quasars, but only up to energies of a few GeV, the limit of the detector's sensitivity. An upper limit for the flux of very-high-energy (VHE) gamma rays was derived in (3).

Using MAGIC, the world's largest single-dish gamma-ray telescope (4) on the Canary island of La Palma (2200 m above sea level, 28.4°N, 17.54°W), we detected gamma rays at energies from 80 to >300 GeV, emanating from 3C 279 at a redshift of 0.536, which corresponds to a light-travel time of 5.3 billion years. No object has been seen before in this range of VHE gamma-ray energies at such a distance [the highest redshift previously observed was 0.212 (5)], and no quasar has been previously identified in this range of gamma-ray energies.

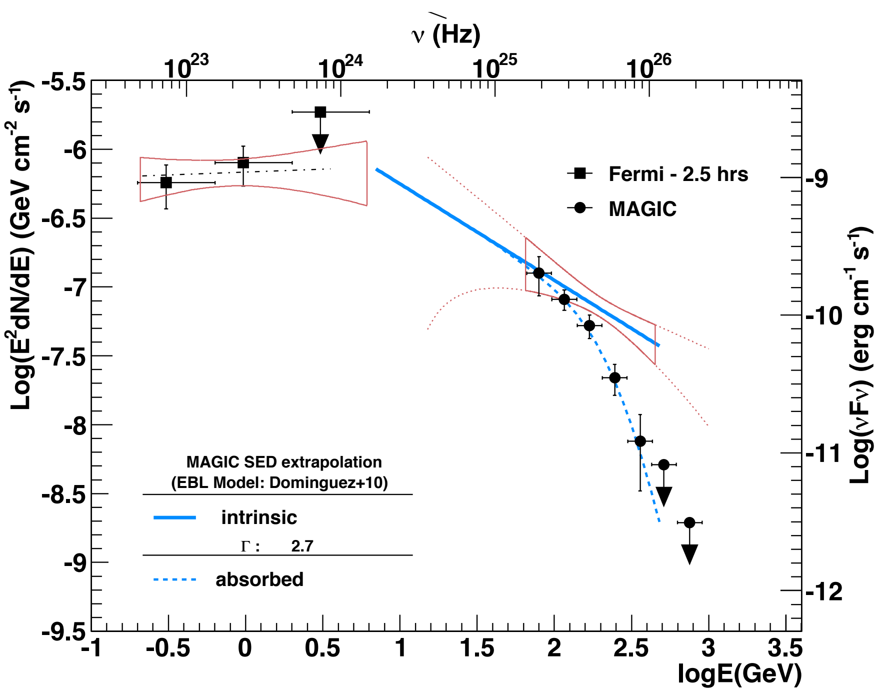
The detection of 3C 279 is important, be-

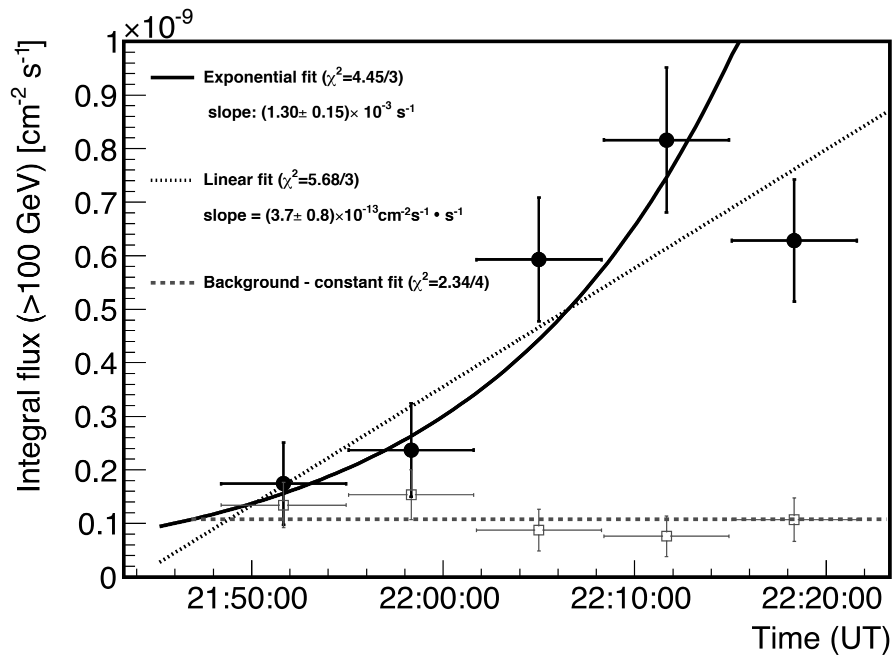






PKS 1222+216: surprises on the emitting region!

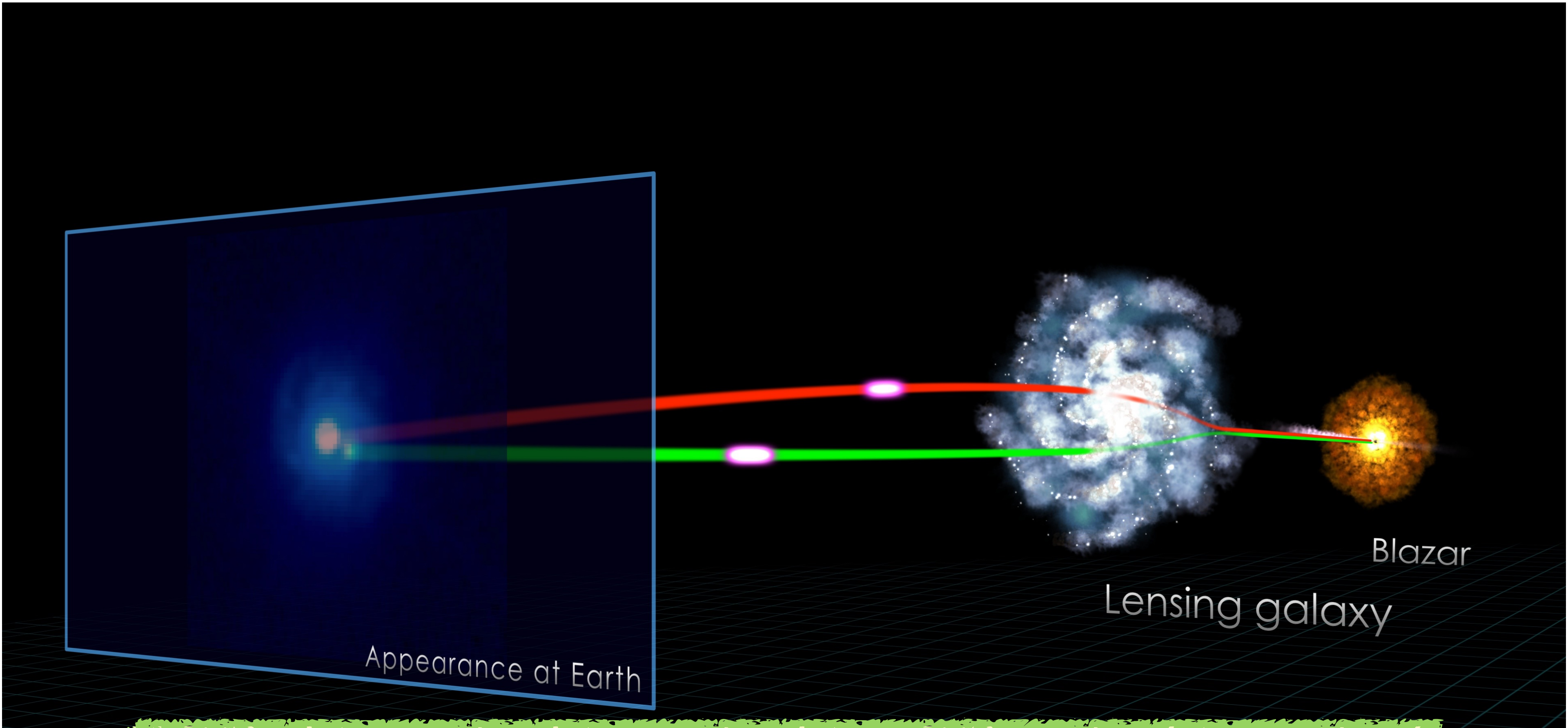




Aleksic+ ApJL 2011

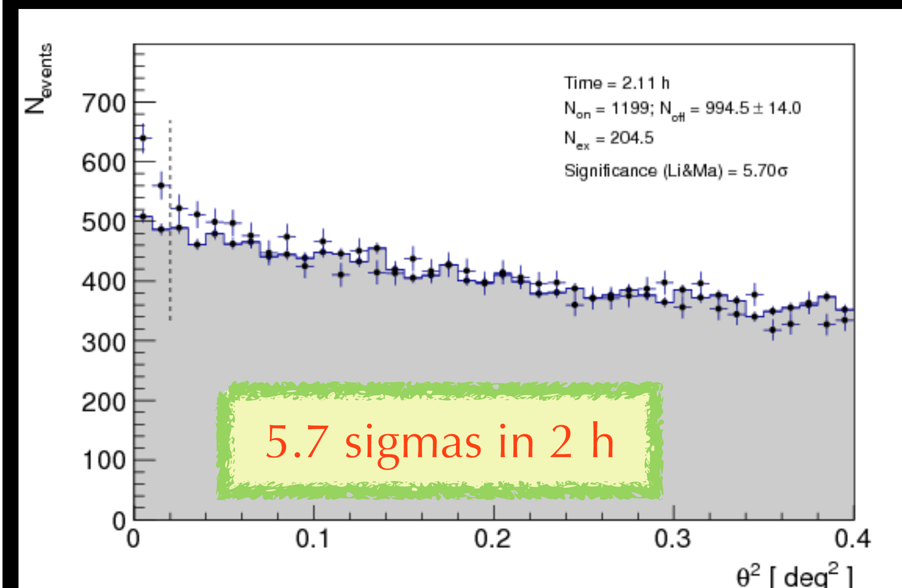
Spectrum extending at hundreds of GeV points to dissipation outside BLR
Minute-scale doubling times points to small regions by causality

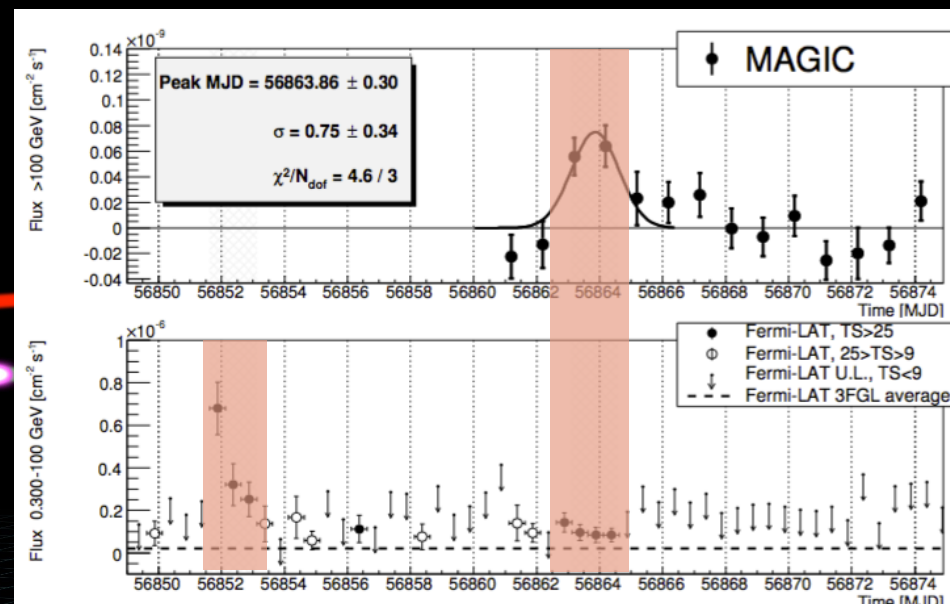
B0218+357 : a TeV grav-lensed FRSQ



B0218+357 is a gravitational lensed blazar located at z=0.944

B0218+357 : a TeV grav-lensed FRSQ



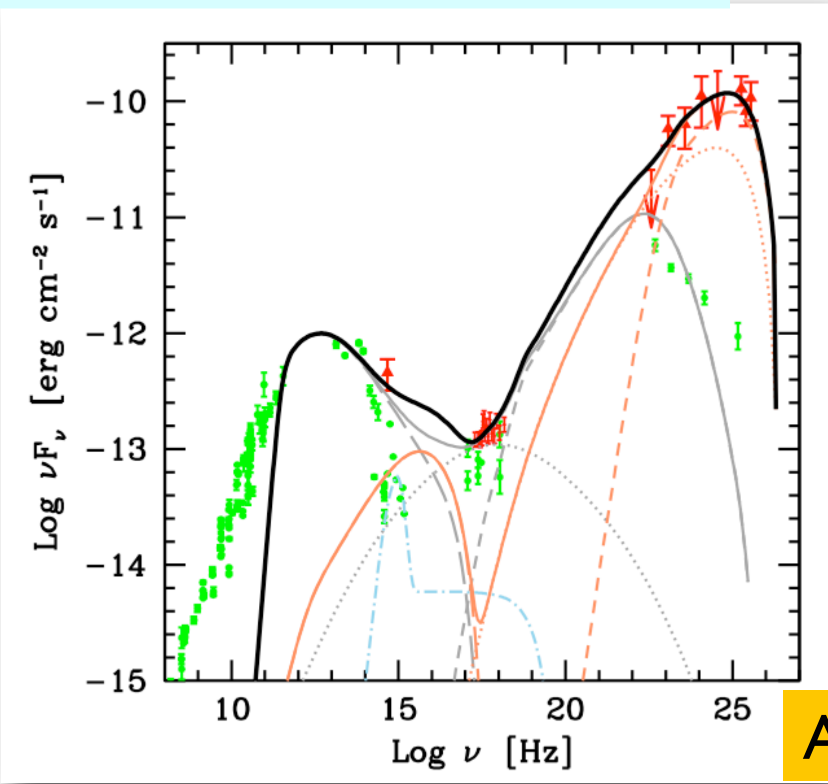


Appearance at Earth

B0218+357 : a TeV grav-lensed FRSQ

Modeled with a two-zone (inside and outside BLR) EC leptonic model

	γ_{min}	γ_b	γ_{max}	n_1	n_2	B [G]	K [cm^{-3}]	R [cm]	R_{dist} [cm]	δ	Γ
Jet in	2.5	300	3×10^4	2	3.9	1.1	1.5×10^5	7×10^{15}	7×10^{16}	20	17
Jet out	10^3	7×10^4	2×10^5	2	4.3	0.03	3×10^7	10^{15}	2×10^{17}	20	17



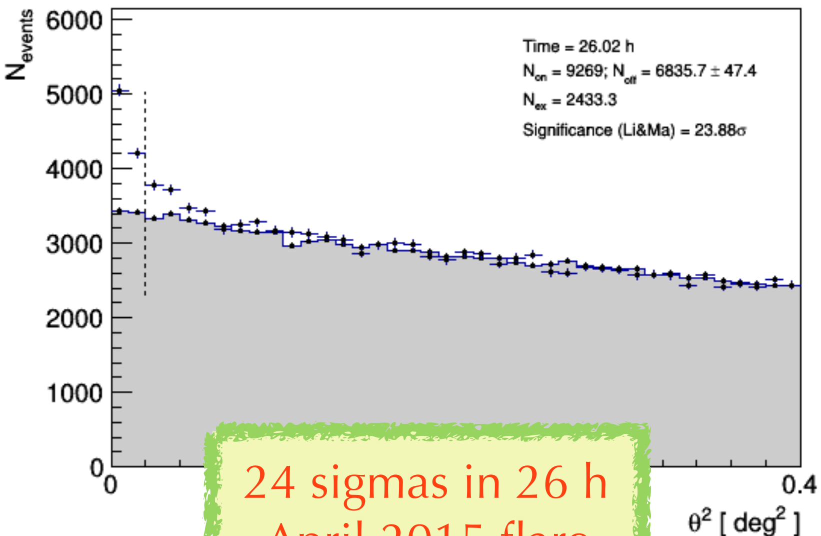
Compatible with EBL models

Model	α (PWL)	α (all)
Franceschini et al. (2008)	$1.19 \pm 0.42_{stat} \pm 0.25_{syst}$	<2.8
Finke et al. (2010)	$0.91 \pm 0.32_{stat} \pm 0.19_{syst}$	<2.1
Domínguez et al. (2011)	$1.19 \pm 0.42_{stat} \pm 0.25_{syst}$	<2.7
Gilmore et al. (2012)	$0.99 \pm 0.34_{stat}\ {}^{+0.15\,syst}_{-0.18\,syst}$	<2.1
Inoue et al. (2013)	$1.17 \pm 0.37_{stat}\ {}^{+0.10\,syst}_{-0.13\,syst}$	<2.2

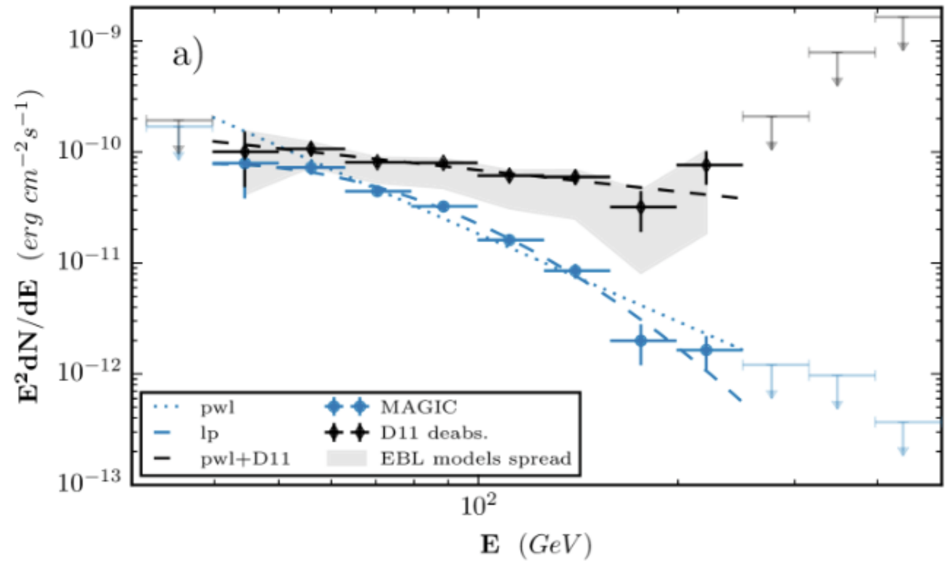
Notes. The second column specifies the limit for the intrinsic spectral model with the highest peak probability from the assumed phenomenological spectral shapes (Eqs. (3)–(6)). For all the EBL models it is the power law shape. The last column specifies the 95% C.L. limit allowing all considered spectral shapes and 15% energy scale systematic uncertainty.

Ahnen+ 2016 A&A

PKS 1441+25, at z=0.94



24 sigmas in 26 h
April 2015 flare

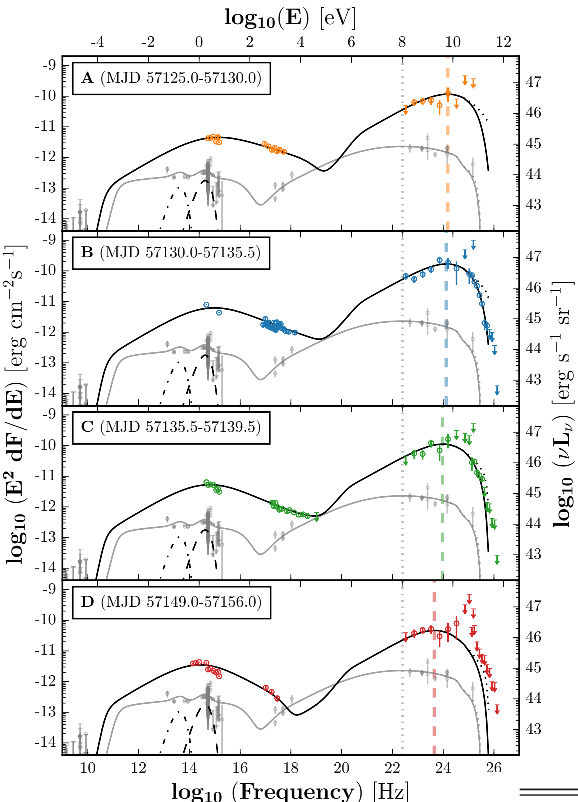


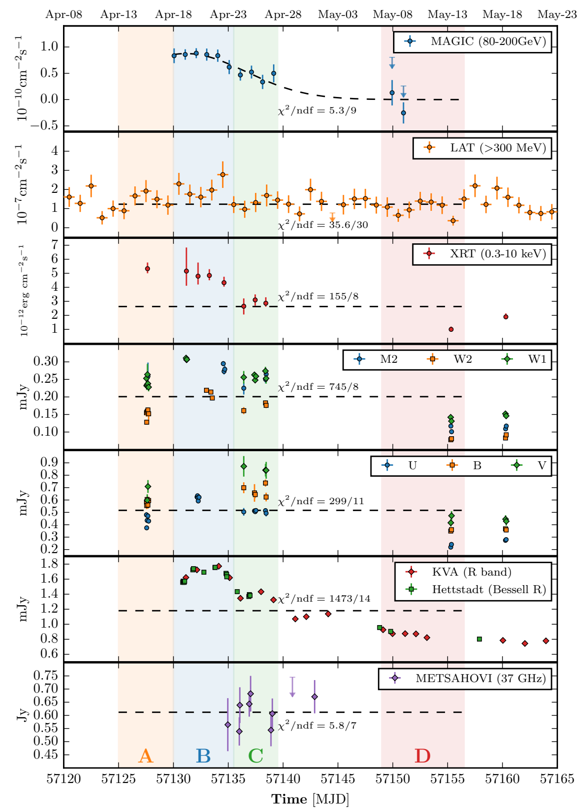
E_{thres} =40 GeV
Detected up to 250 GeV

Ahnen+ 2015 ApJL

γ-rays (E>100 GeV) from the Universe's Middle Age: detection of the Blazar PKS 1441+25 located at redshift 0.936!
Again compatible with EBL models

PKS 1441+25, at z=0.94





Ahnen+ 2015 ApJL

T_{var} =6.4 (1.9) d

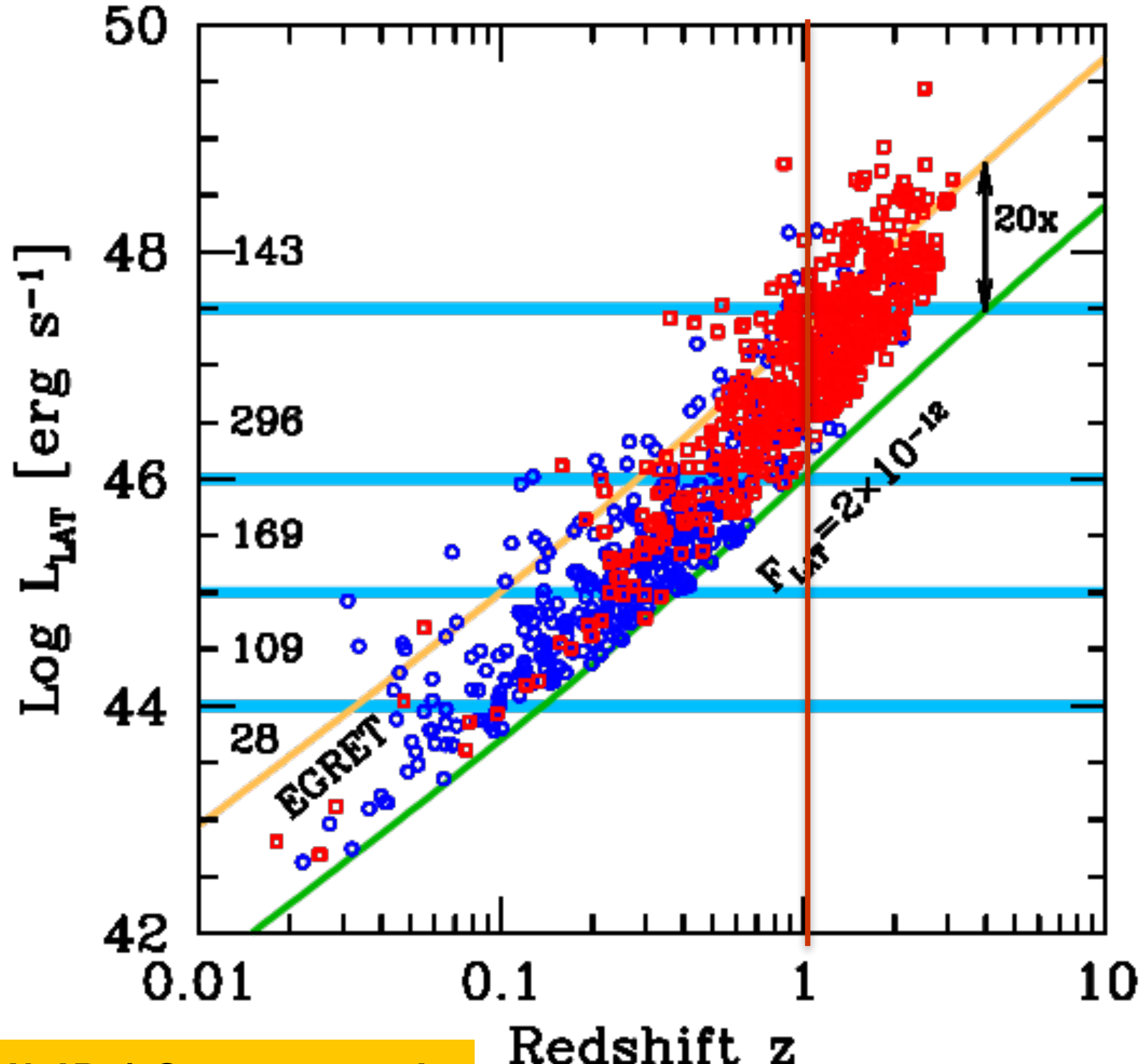
Emission out of the BLR during flare

Period	MJD	γ_{min}	$\gamma_b(10^4)$	$\gamma_{max}(10^6)$	n_2	B (G)	K (10^3 cm^{-3})	$\nu_{IC}[Hz]$	CD
A	57125.0–57130.0	80	1.0	1.0	3.55	0.15	2.80	24.2	24
B	57130.0–57135.5	80	1.0	1.0	3.70	0.15	4.00	24.1	25
C	57135.5–57139.5	50	0.8	1.0	3.75	0.17	3.35	24.0	21
D	57149.0–57156.0	50	0.5	0.2	3.90	0.23	2.00	23.6	13
Archival	-	20	10^{-2}	3×10^{-2}	3.05	0.35	70	22.4	7

The Fermi Blazar sequence

At few tens of GeV, potentially lots of FSRQ can be discovered when FLARING

Low energy treshold
ToOs
Fast reaction crucial!



Ghisellini+ 2017 MNRAS accepted

Conclusions

- The MAGIC telescopes are behaving better than ever!

- Until now the most effective into expanding the gamma-ray horizon, with bright FSRQs in flare
- Measurements in substantial agreement with current EBL models

- Emission mechanism and location more challenging

- Expecting the TeV FSRQ subclass to grow in the near future, and MAGIC will be well into the business

- Great interest for:
  - better understanding these sources
  - probing the cosmic evolution with VHE gamma rays

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see also Franceschini & Rodighiero 2017, A&A accepted

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STAY TUNED!!!

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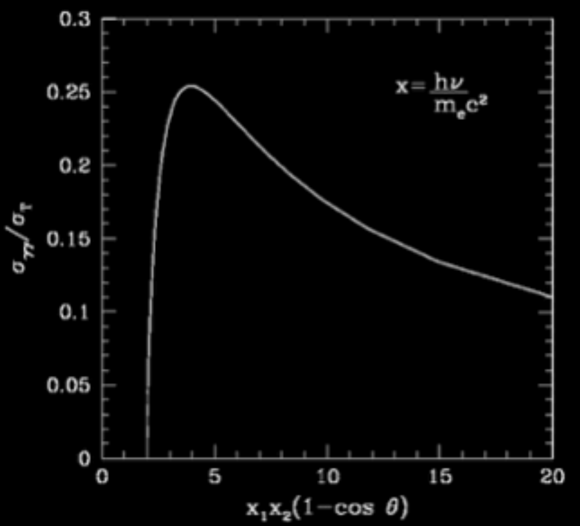
  - probing the cosmic evolution with VHE gamma rays

THANKS!

Absorption of gamma rays by pair prod.

$$\gamma + \gamma \rightarrow e^+ + e^-$$

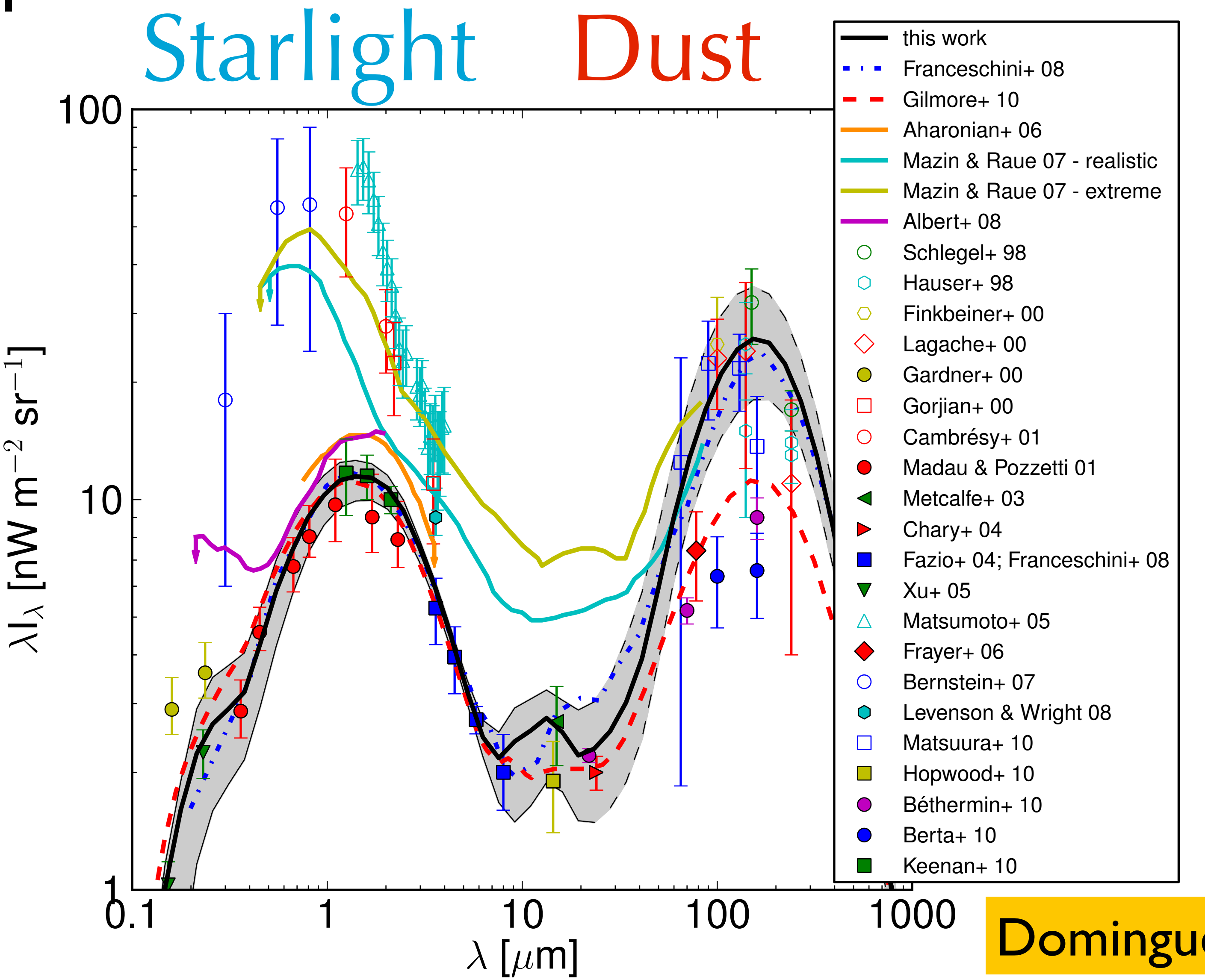


$$\sigma(s) = \frac{3}{16}\sigma_T (1 - s^2)\left[(3 - s^4)\ln\frac{1+s}{1-s} - 2s(2 - s^2)\right]$$

$$s = \left[1 - \frac{2}{x_1 x_2 (1 - \mu)}\right]^{1/2}$$

Rule of thumb: $\nu = 2 \times 10^{15} \left(\frac{E}{100\,\mathrm{GeV}}\right)^{-1}$ *Hz*

The Extragalactic Background Light (EBL)



Dominguez+ 2011