VHE emission from extragalactic sources

open issues from MWL observations

On behalf of MAGIC

Major Atmospheric Gamma Imaging Cherenkov Telescopes

The MAGIC telescopes

- **VHE range** - Energy threshold **~50 GeV** (up to 10 TeV)
- Energy Resolution ~20%
- FOV: 3.5º
- Angular Resolution ~0.1º
- Sensitivity (5 σ in 50 hours): ~1% Crab Nebula flux (@~200 GeV)

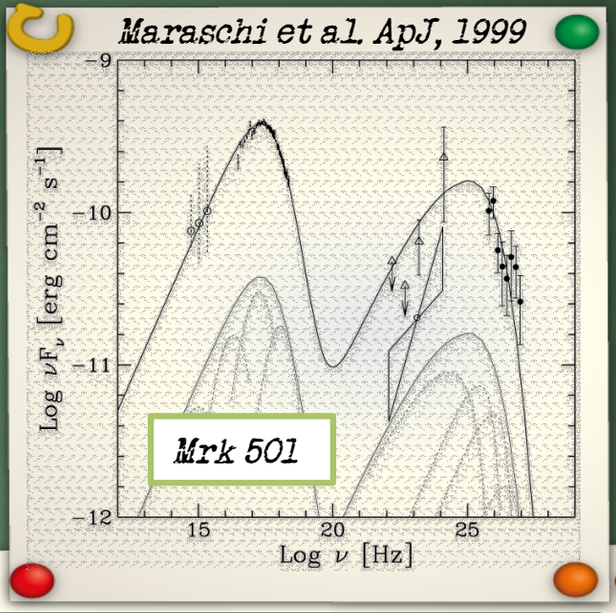
The plot

- A single scenario for blazars?
  - the single-zone SSC
  - the blazar sequence
- An obscure scene of the crime
  - where gamma rays come from
- Evidences from far-far away
  - EBL EGMF and axions

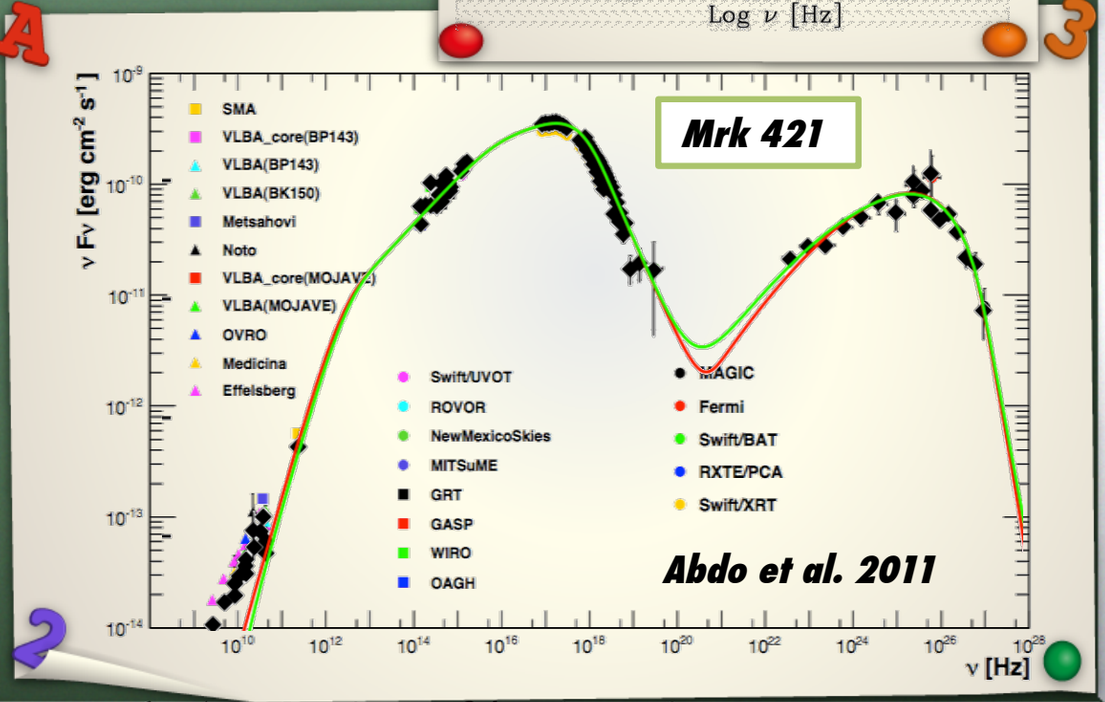
Once upon the time...

- First simultaneous VHE SED (5 hours integration time)

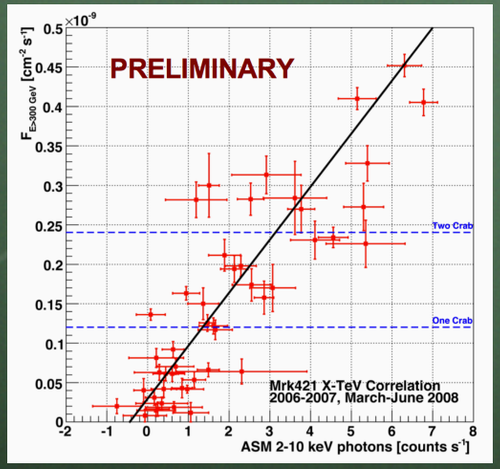
one-zone SSC model



- Best sampled SED:



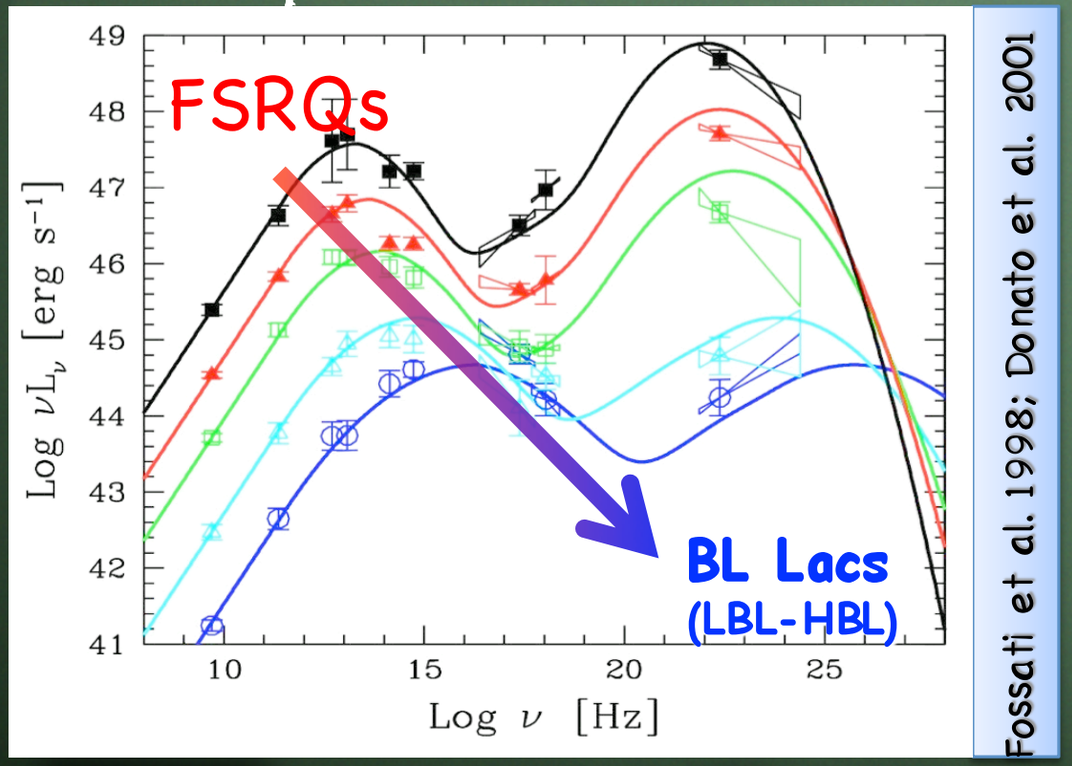
correlation X-ray vs TeV



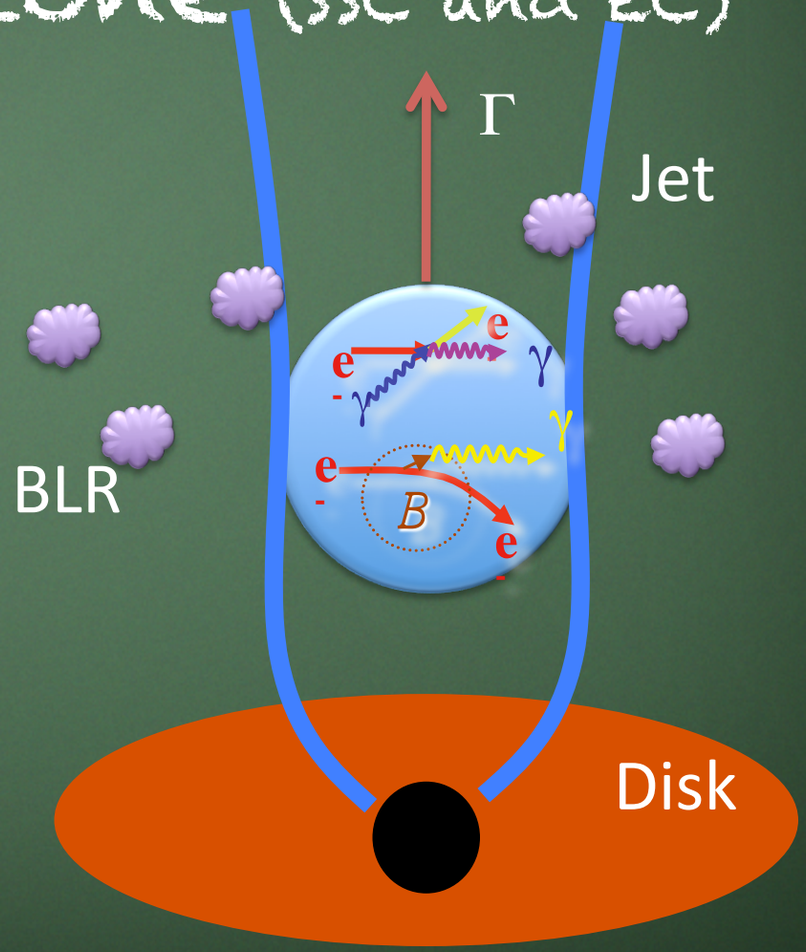
... in a fairyland

reigned by

- Single zone (SSC and EC)
- Sequence



Fossati et al. 1998; Donato et al. 2001

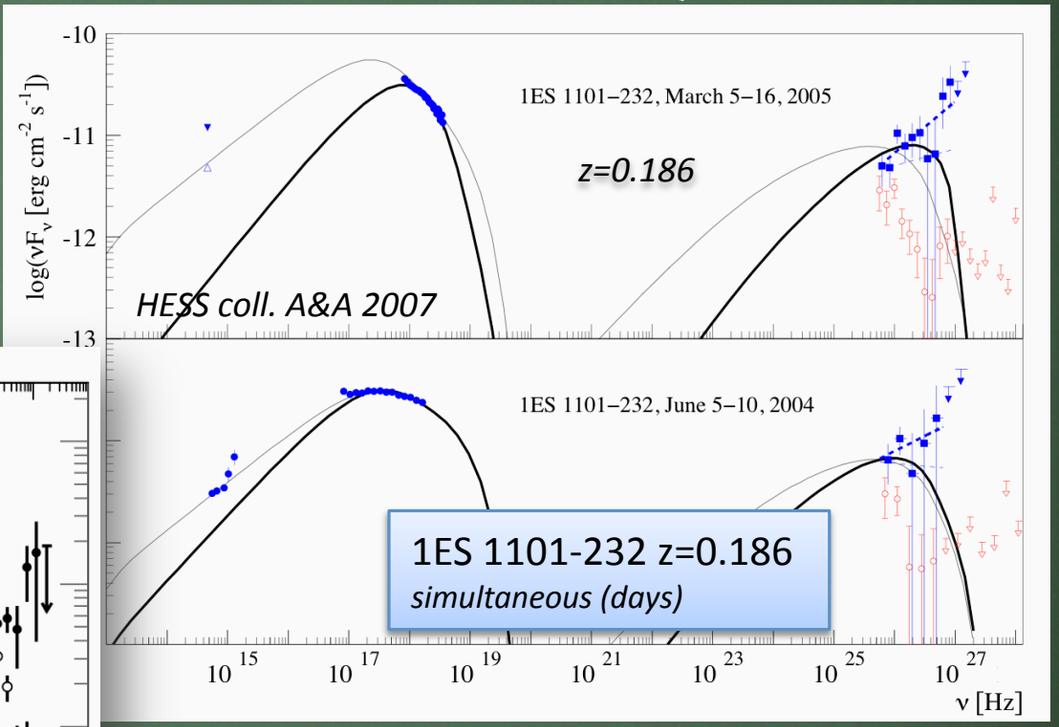


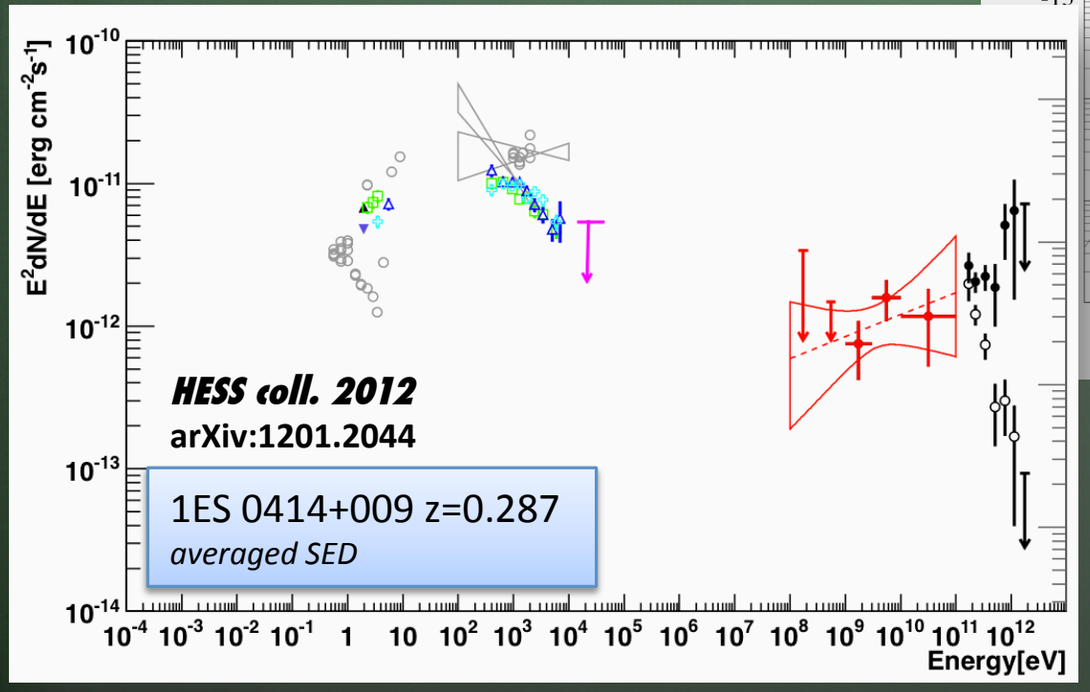
The bad...

"Extreme" blazars: (too) hard TeV spectra?

A distance effect?

EBL, EGMF, exotic effects,...



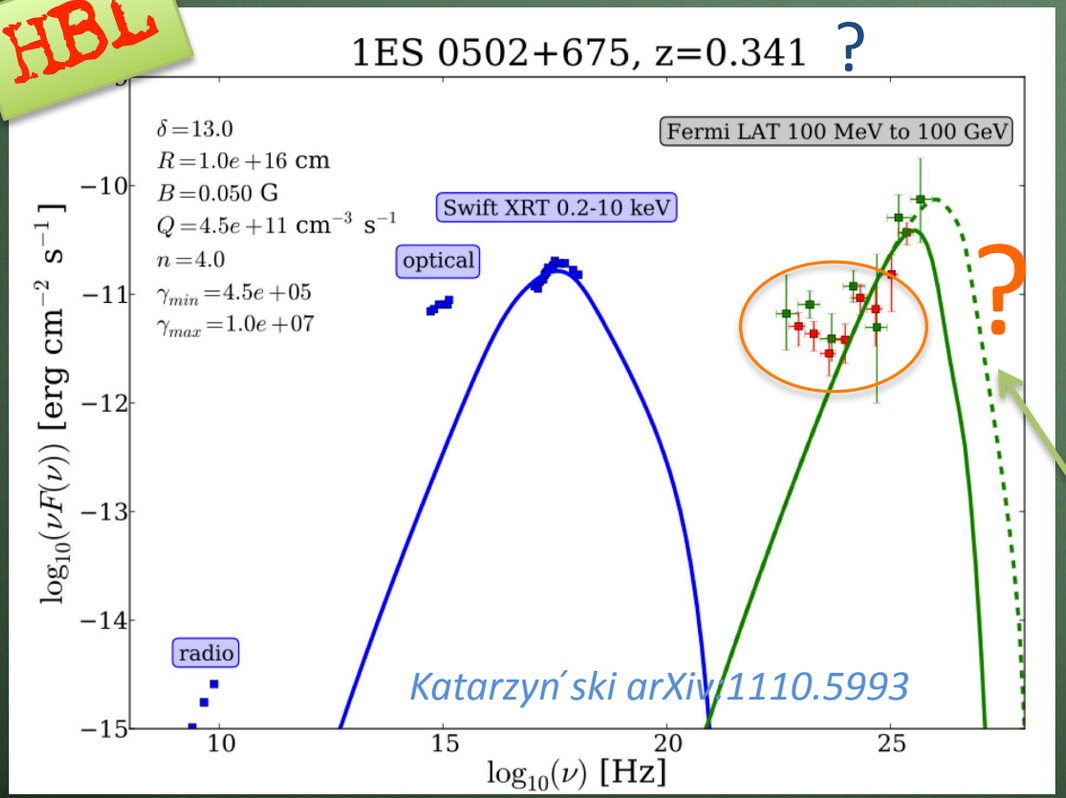


... and the ugly

"Extreme" blazars

Just a distance effect?

HBL



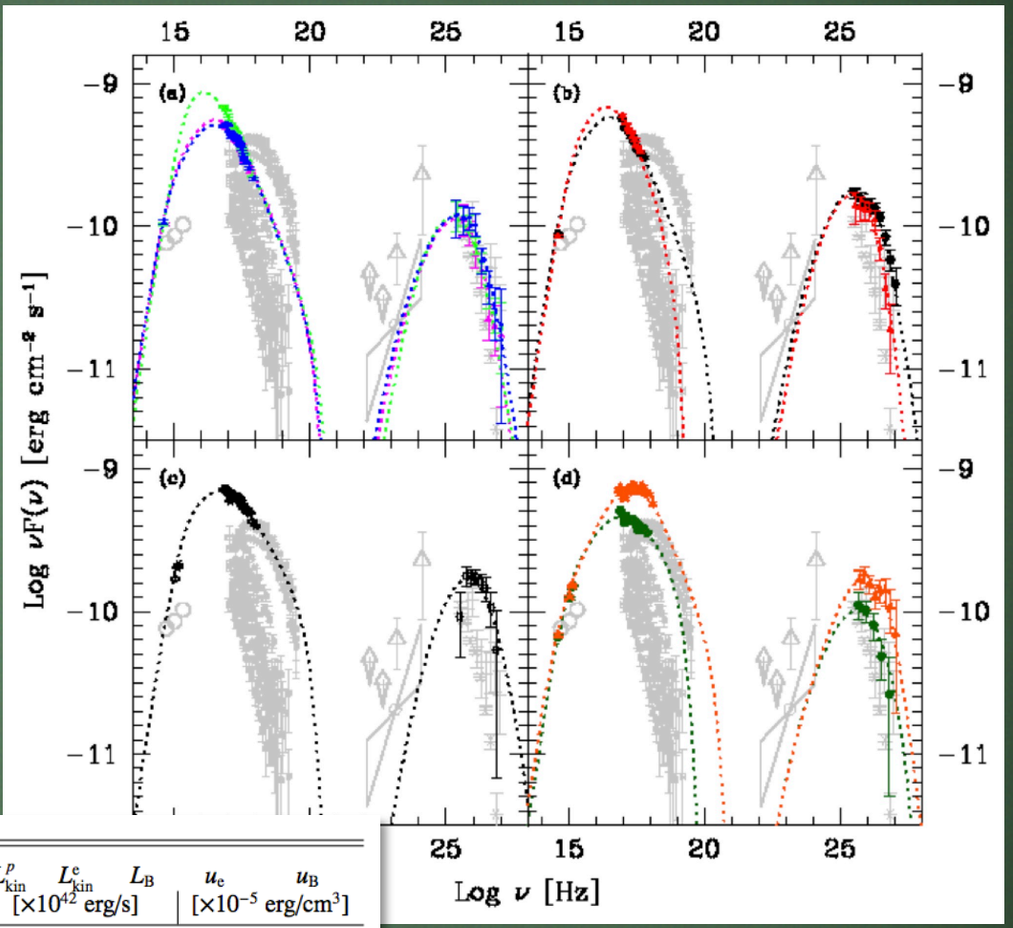
VERITAS detection - *ATel #2301 (2009)*
No published spectrum
slope 3.92+/-0.35 Benbow *arXiv:1110.0040*

The single zone SSC crisis

Mrk421 z=0.031

strictly simultaneous SEDs

- Extreme doppler factors "δ-crisis"
- ➢ Structured jet? Spine-layer? small jets in a jet?



Night yyyy-mm-dd	γ_{min} [×10³]	γ_b [×10⁴]	γ_{max} [×10⁶]	n_1	n_2	B [G]	K [cm⁻³]	R [×10¹⁵cm]	δ	t_{var} [h]	L'_{kin} [×10⁴² erg/s]	L^e_{kin}	L_B	u_e [×10⁻⁵ erg/cm³]	u_B
2008-01-08	7.0	6.0	3.0	2.0	4.0	0.050	1700	9.0	45	1.8	5.41	91	1.61	420	9.9
2008-01-09	10	2.9	3.0	2.0	4.0	0.043	3700	5.0	85	0.5	7.37	136	1.25	600	7.4
2008-01-10	6.0	5.7	3.0	2.0	4.0	0.037	3300	5.0	70	0.7	8.83	131	0.63	850	5.4
2008-01-16	8.3	6.7	3.0	2.0	4.0	0.025	4000	5.0	80	0.6	9.97	197	0.38	980	2.5
2008-01-17	10	6.0	0.7	2.0	4.2	0.037	2600	7.2	60	1.1	6.18	138	0.96	590	5.4
2008-02-11	11	6.9	3.0	2.0	3.7	0.020	2400	6.6	85	0.7	6.86	187	0.47	470	1.6
2008-04-02	8.0	3.2	1.0	2.0	3.5	0.050	5900	3.9	70	0.5	5.24	80	0.46	1200	9.2
2008-04-03	17	20	3.0	2.0	4.0	0.040	2000	8.5	40	2.0	5.47	120	0.62	520	3.6

MAGIC coll.
Aleksic et al. 2012

The single zone SSC crisis

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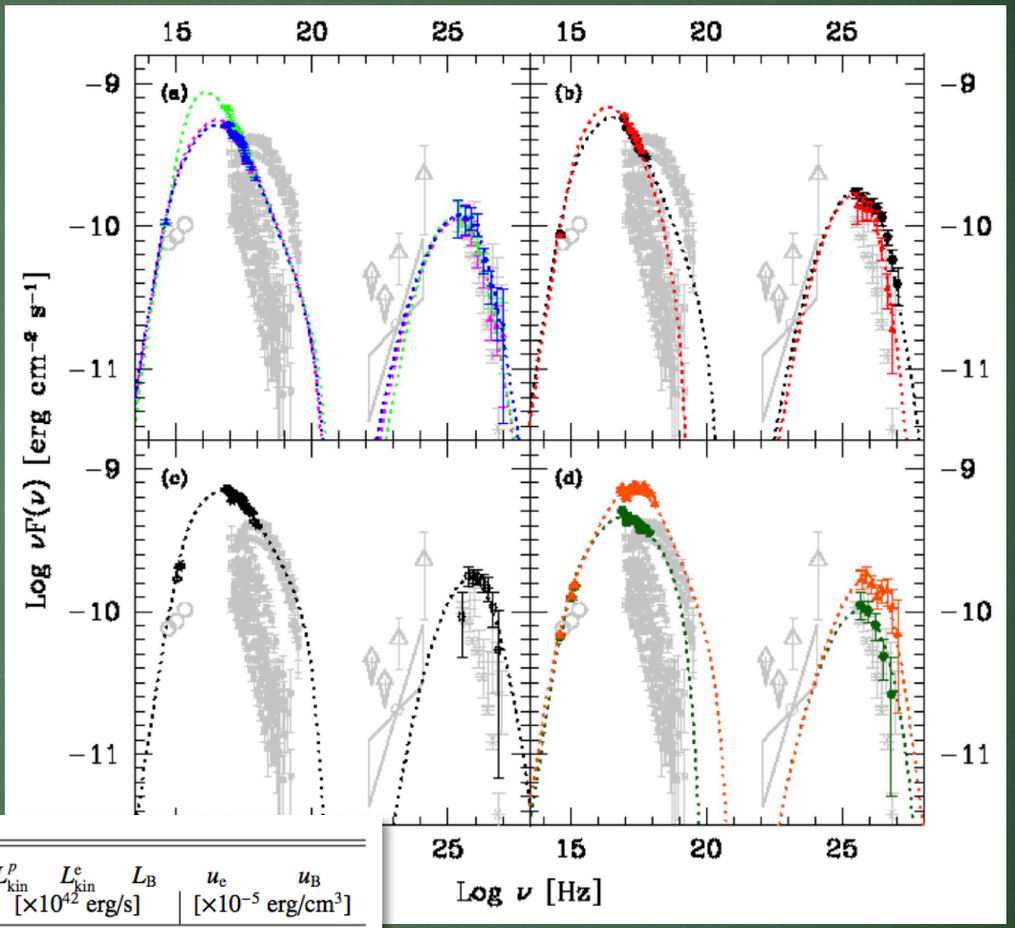
- ➢ Structured jet? Spine-layer? small jets in a jet?



Night yyyy-mm-dd	γ_{min} [$\times 10^3$]	γ_b [$\times 10^4$]	γ_{max} [$\times 10^6$]	n_1	n_2	B [G]	K [cm^{-3}]	R [$\times 10^{15}$c	δ	L'_{kin}	L^e_{kin} [$\times 10^{42}$ erg/s]	L_B	u_e	u_B [$\times 10^{-5}$ erg/cm^3]
2008-01-08	7.0	6.0	3.0	2.0	4.0	0.050	1700	9.0	45	5.41	91	1.61	420	9.9
2008-01-09	10	2.9	3.0	2.0	4.0	0.043	3700	5.0	85	7.37	136	1.25	600	7.4
2008-01-10	6.0	5.7	3.0	2.0	4.0	0.037	3300	5.0	70	8.83	131	0.63	850	5.4
2008-01-16	8.3	6.7	3.0	2.0	4.0	0.025	4000	5.0	80	9.97	197	0.38	980	2.5
2008-01-17	10	6.0	0.7	2.0	4.2	0.037	2600	7.2	60	6.18	138	0.96	590	5.4
2008-02-11	11	6.9	3.0	2.0	3.7	0.020	2400	6.6	85	6.86	187	0.47	470	1.6
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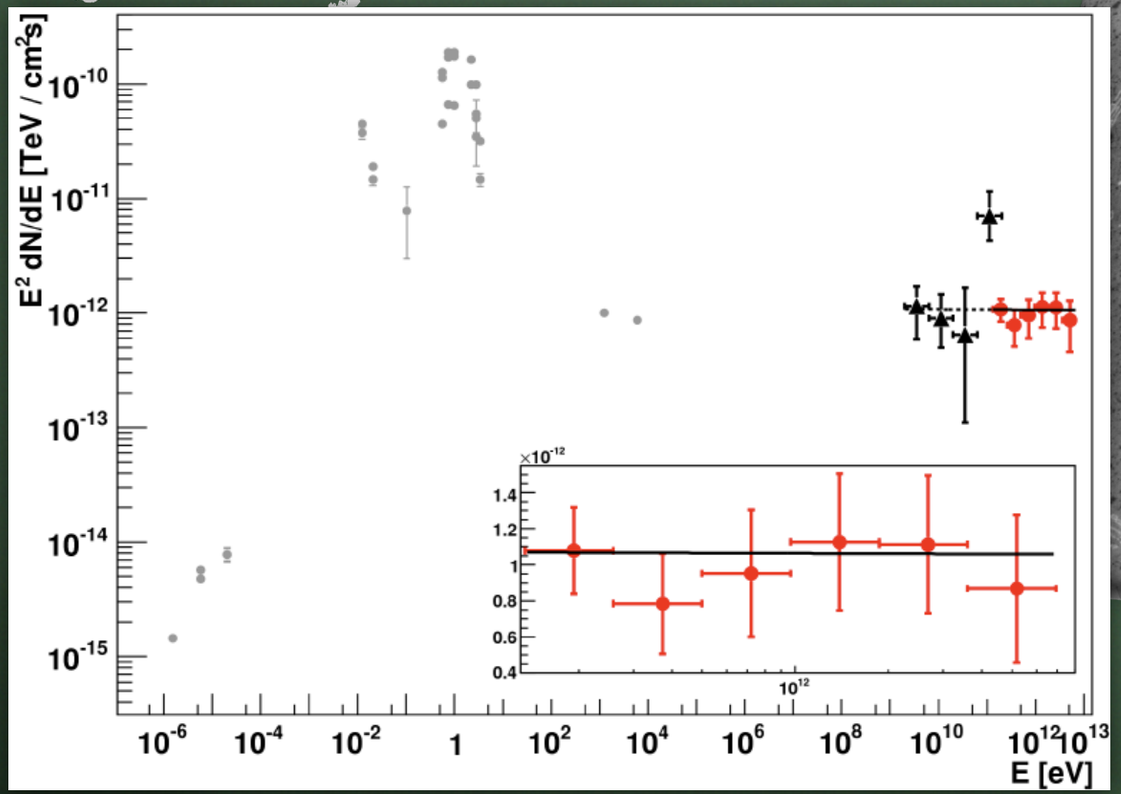
2008-04-03	17	20	3.0	2.0	4.0	0.040	2000	8.5	40	5.47	120	0.62	520	3.6

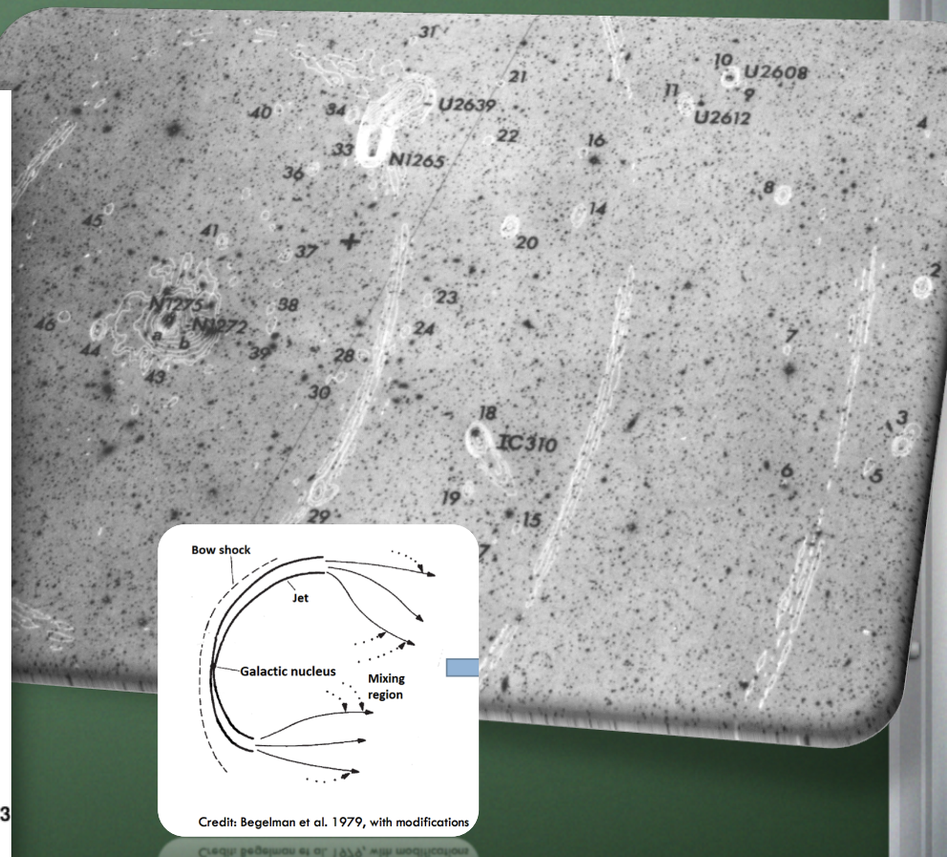
MAGIC coll.
Aleksic et al. 2012

The single zone SSC crisis

the unexpected guest

- IC 310: a flat GeV-TeV peak
- γs from bow shock of the head-tail galaxy? *(Neronov et al. 2010)*

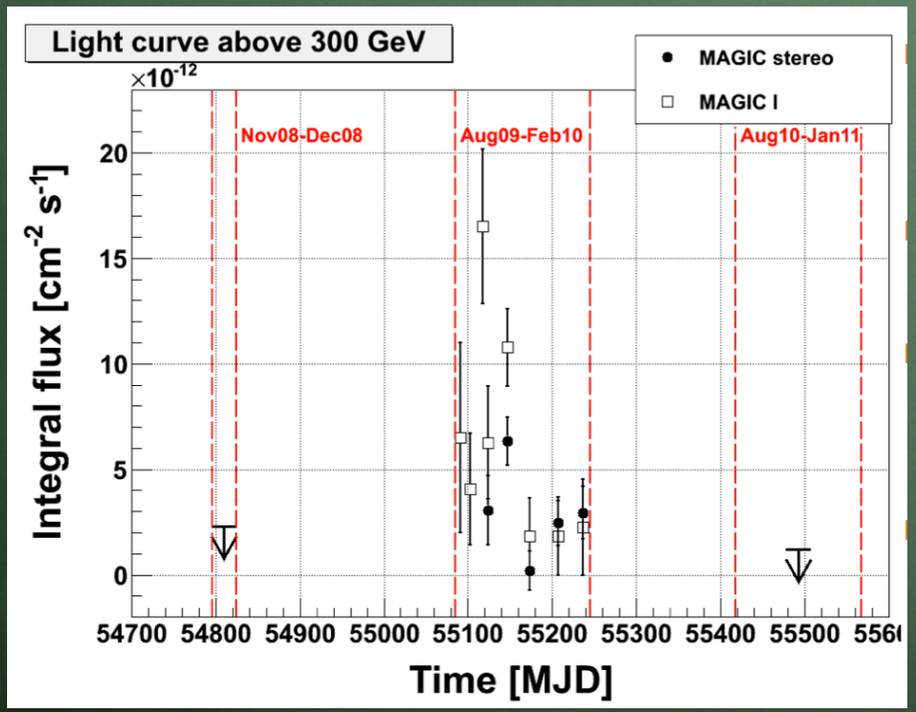


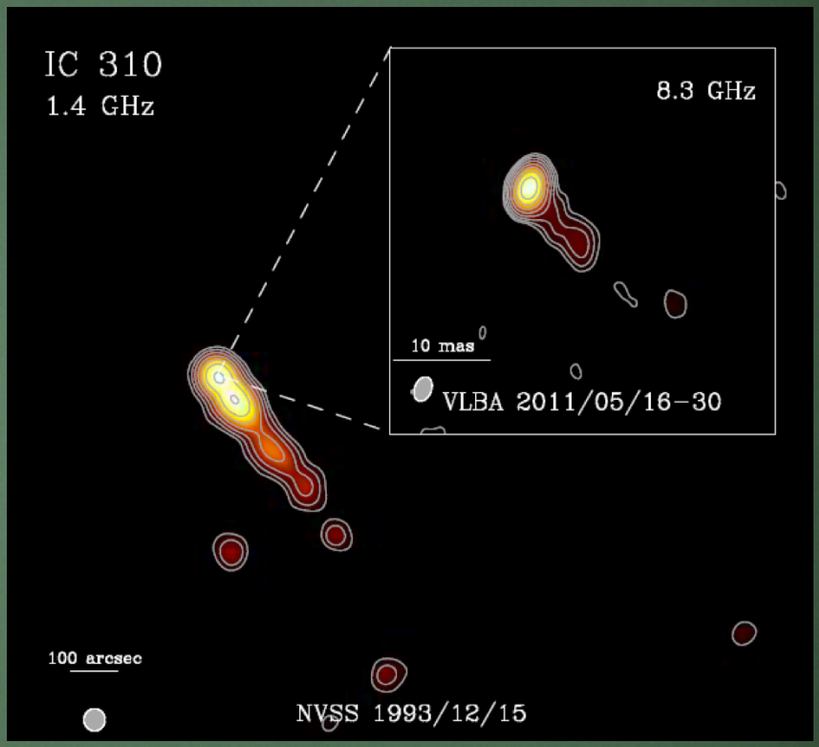


The single zone SSC crisis

the unexpected guest

- A blazar structure
- jet angle <30 deg
- TeV variability





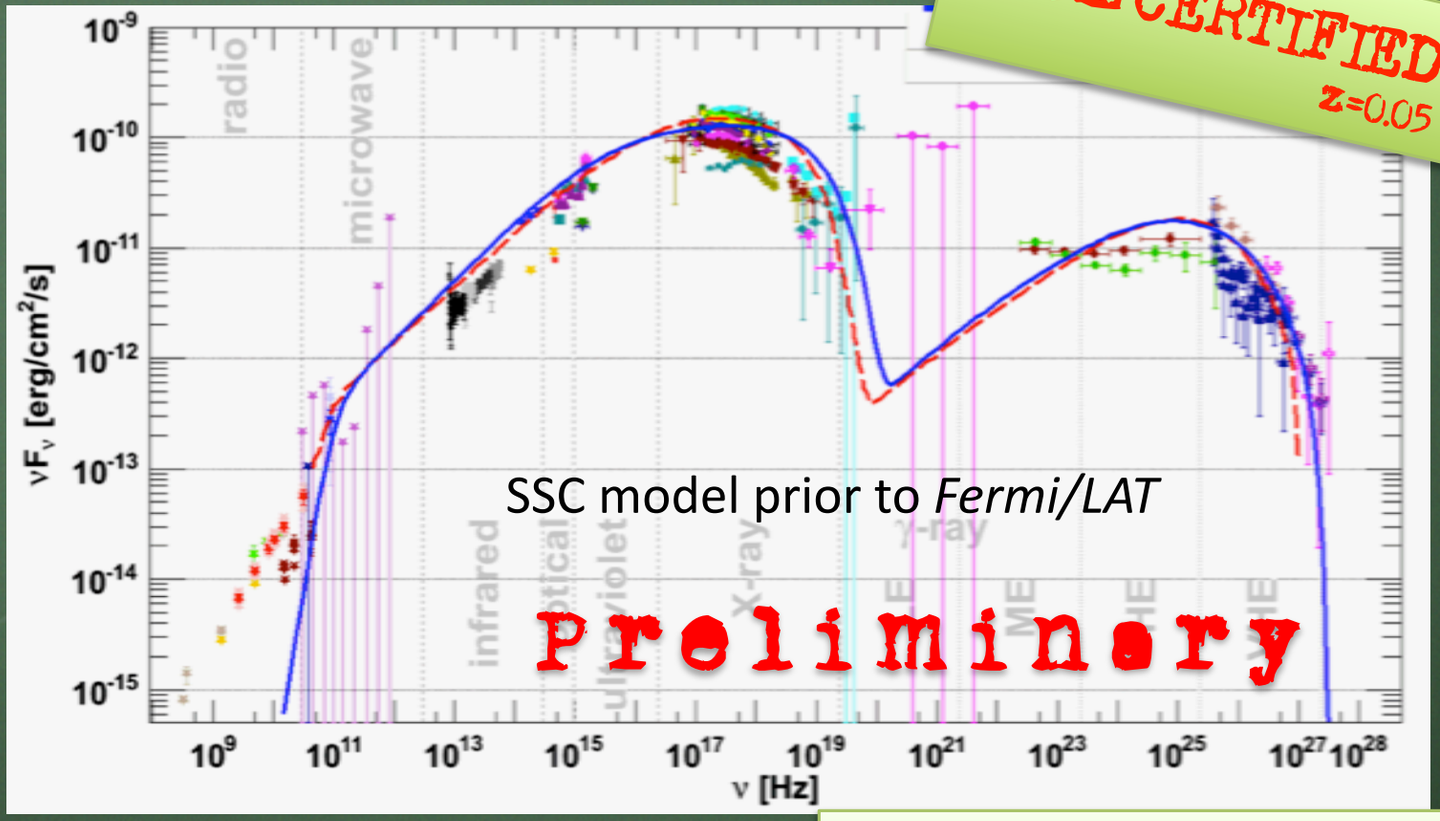
Kadler et al. 2012

MAGIC coll.
A&A 539 (2012)
ApJL 723 (2010)
more to come...

IC 310 is a blazar!

The single zone SSC crisis

- A HBL with an hadronic VHE bump?

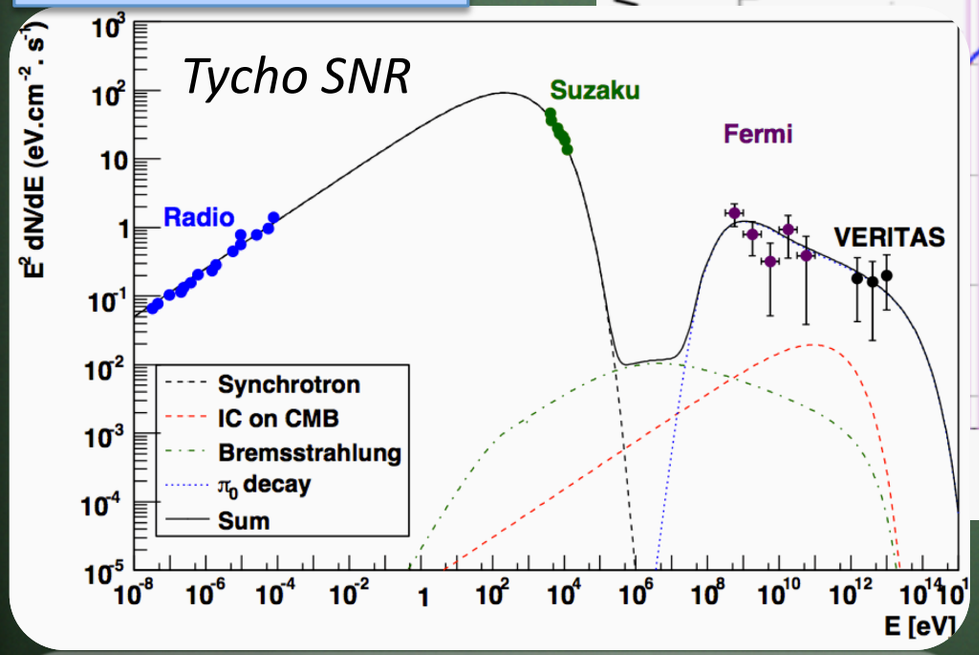


Credit: **M. Backes**, PhD thesis
http://hdl.handle.net/2003/29464

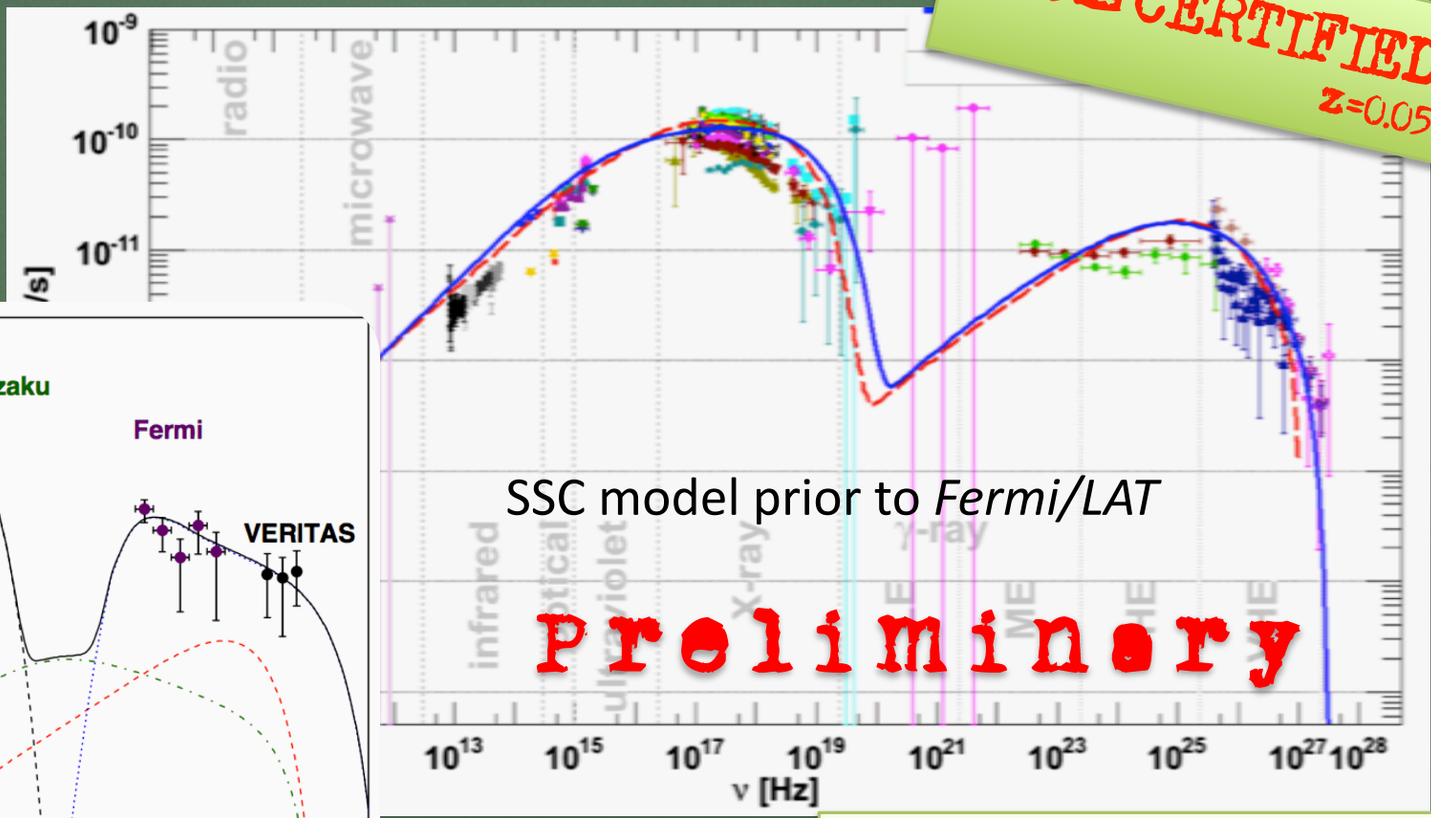
The single zone SSC crisis

- A HBL with an hadronic VHE bump?

Giordano et al. 2011
Morlino&Caprioli 2011
Atoyan&Dermer 2012



HBL CERTIFIED
z=0.05



SSC model prior to *Fermi/LAT*

Preliminary

Credit: **M. Backes**, PhD thesis
http://hdl.handle.net/2003/29464

The scene of the crime

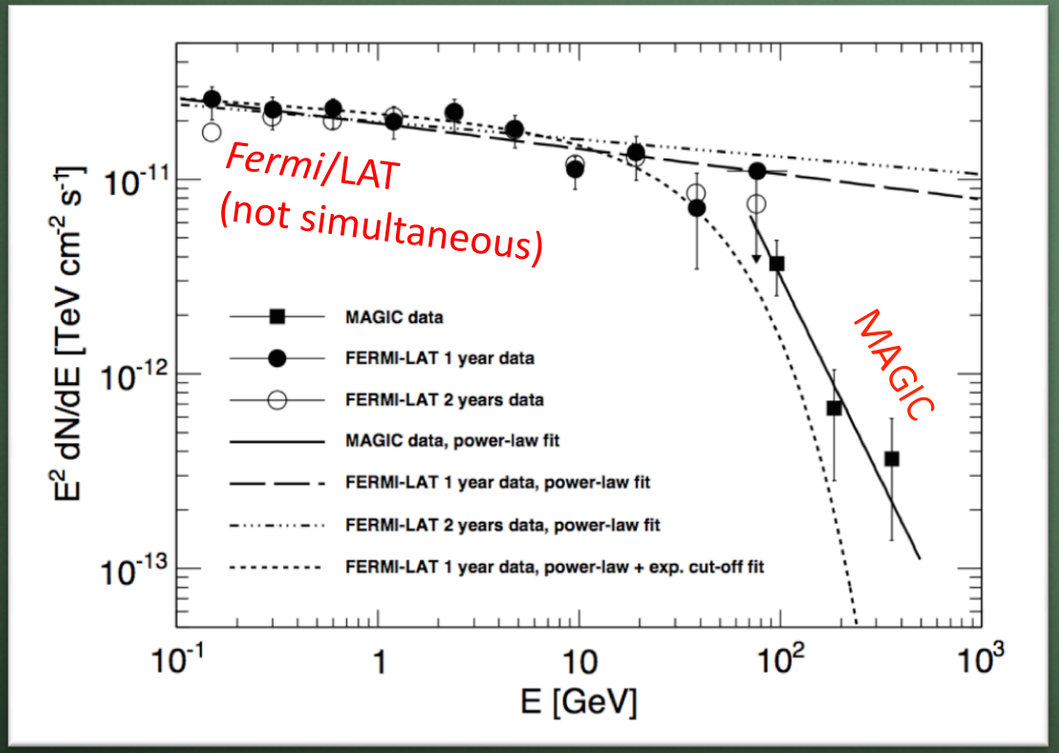
Identify the blazar zone

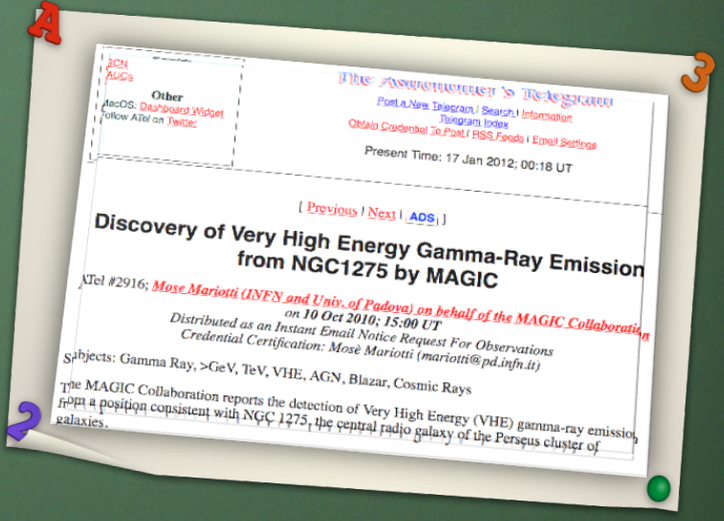
- MWL connections
  - radio / gamma correlations
  - X-ray / gamma correlations
  - polarization
- Variability + internal absorption features

The radio-gamma correlation

An example: NGC 1275

- MAGIC detection 2010 (3rd radio galaxy in TeV)
- MWL campaign 2010-2011 (*paper in prep.*)




The Astronomer's Telegram

Discovery of Very High Energy Gamma-Ray Emission from NGC1275 by MAGIC

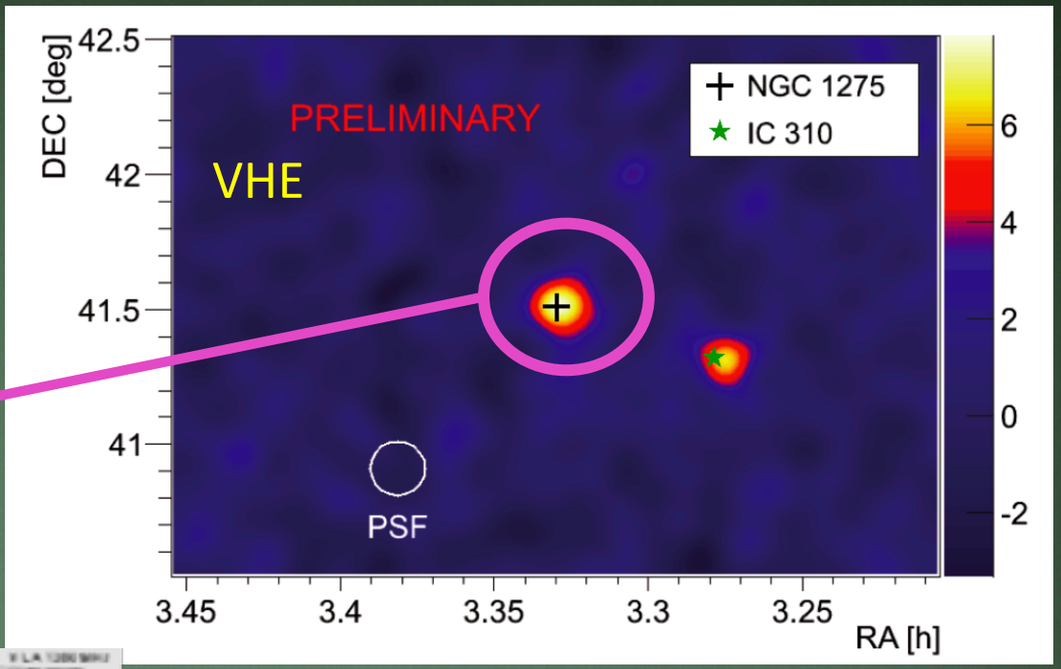
ATel #2916; Mose Mariotti (INFN and Univ. of Padova) on behalf of the MAGIC Collaboration
on 10 Oct 2010; 15:00 UT
Distributed as an Instant Email Notice Request For Observations
Credential Certification: Mosè Mariotti (mariotti@pd.infn.it)

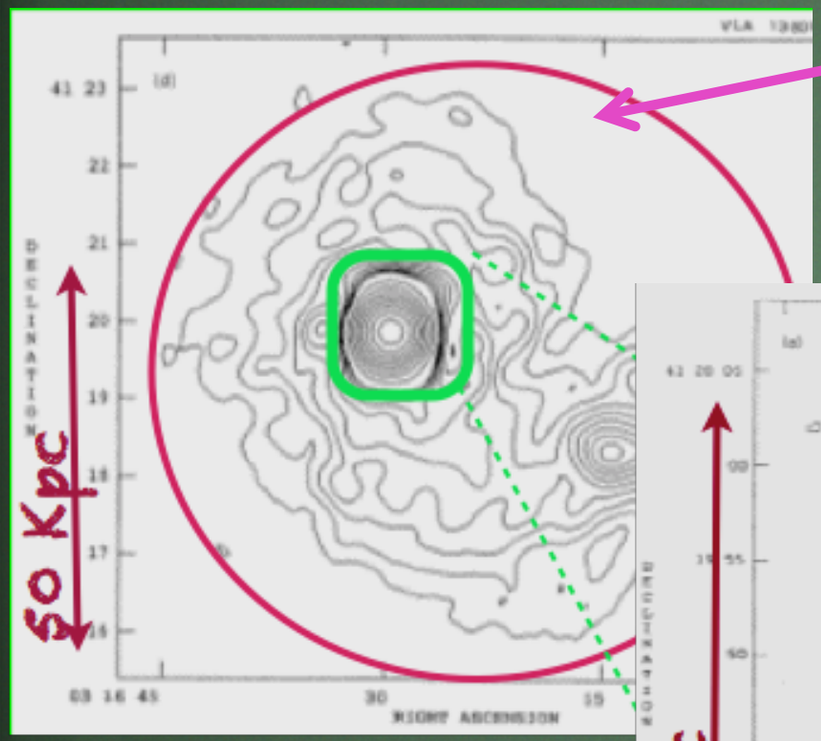
Subjects: Gamma Ray, >GeV, TeV, VHE, AGN, Blazar, Cosmic Rays

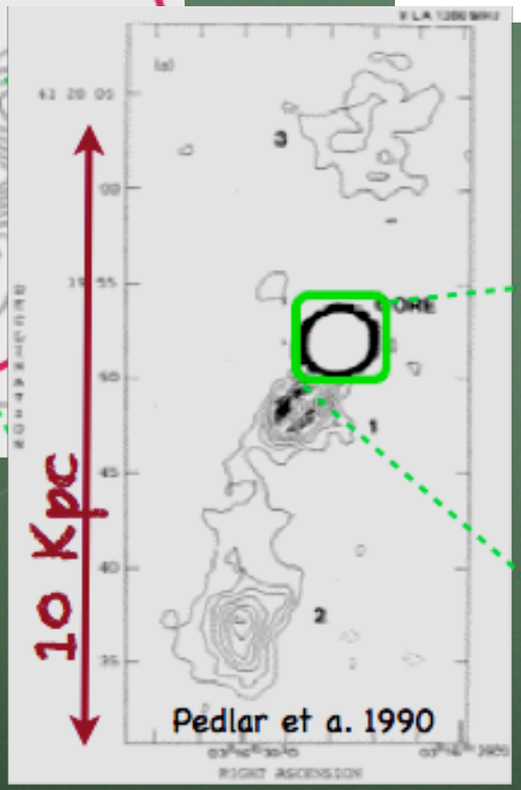
The MAGIC Collaboration reports the detection of Very High Energy (VHE) gamma-ray emission from a position consistent with NGC 1275, the central radio galaxy of the Perseus cluster of galaxies.

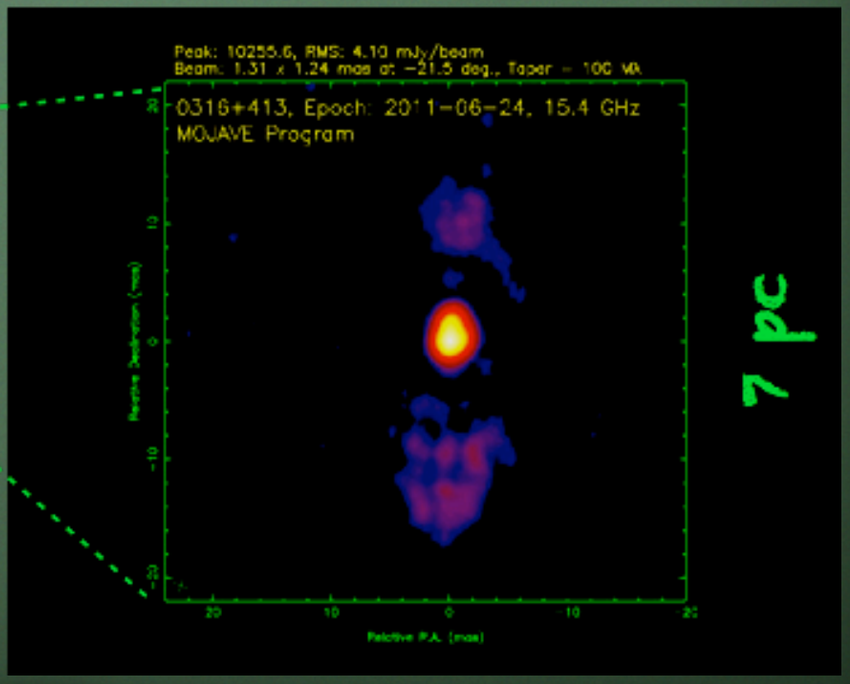
MAGIC Coll. A&A, 539 (2012)

NGC 1275

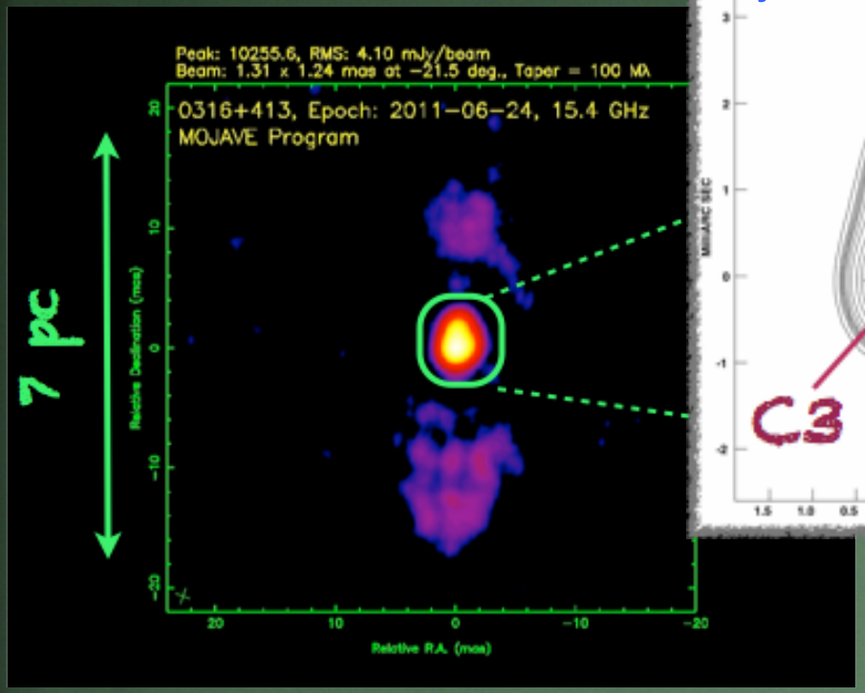


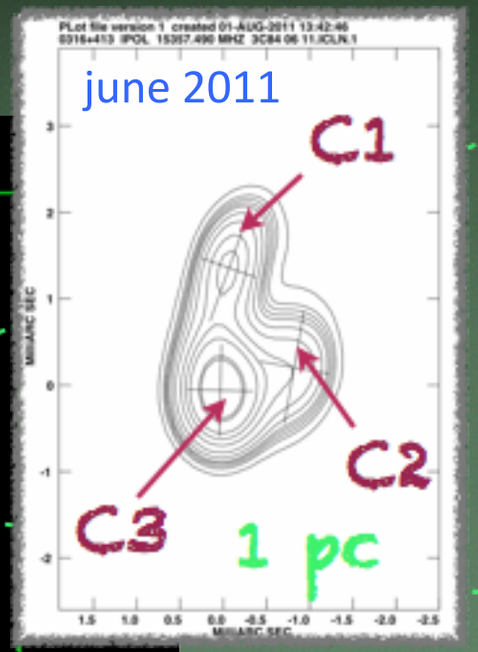




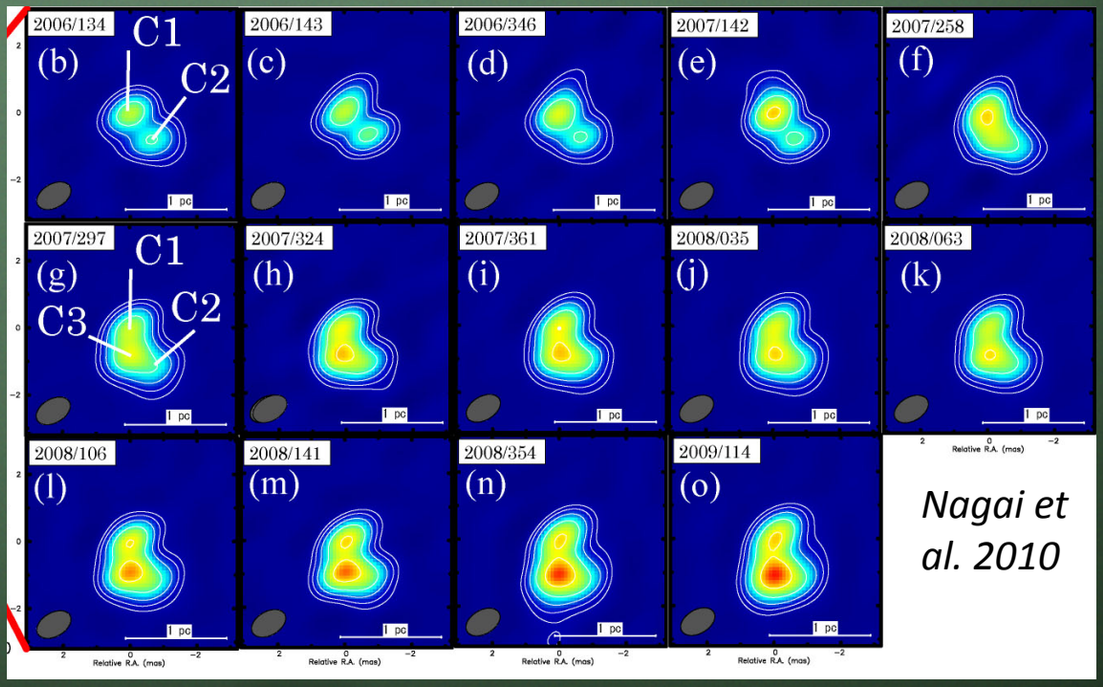


Credits: S. Partini

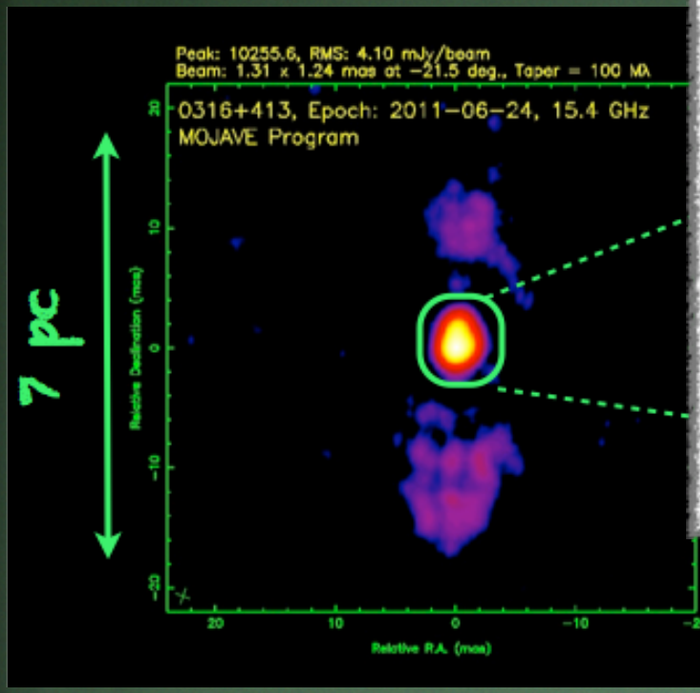


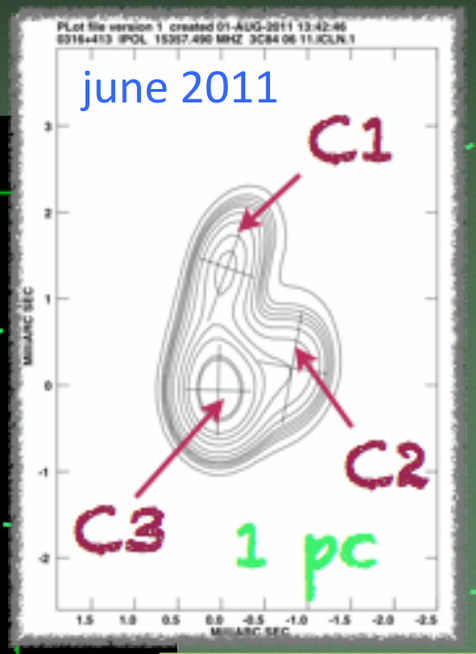


- Radio core in the <1 pc region

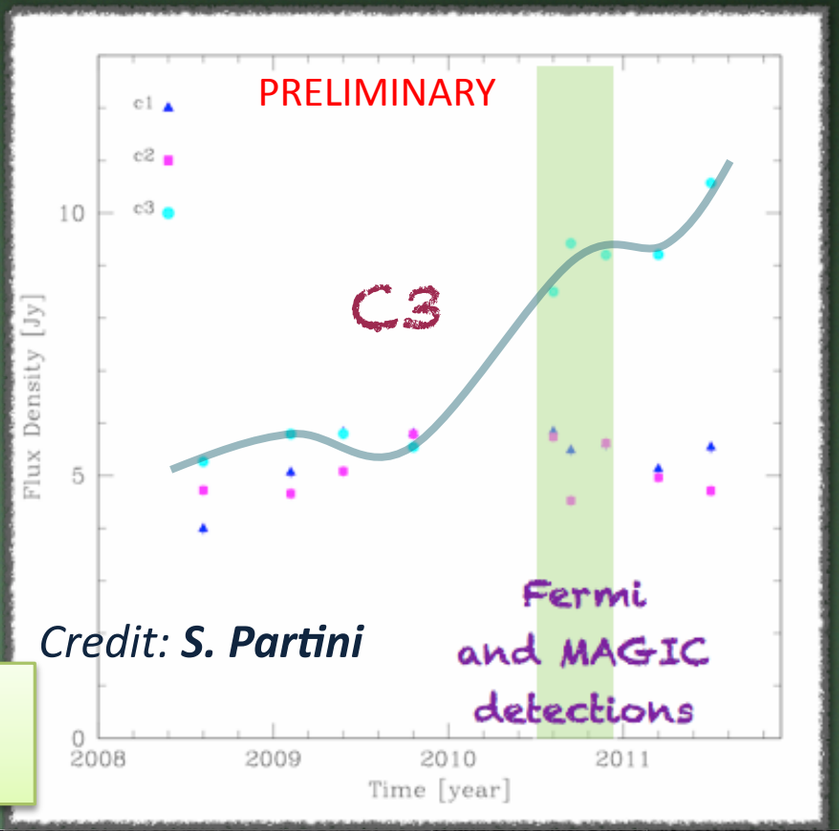


Nagai et al. 2010

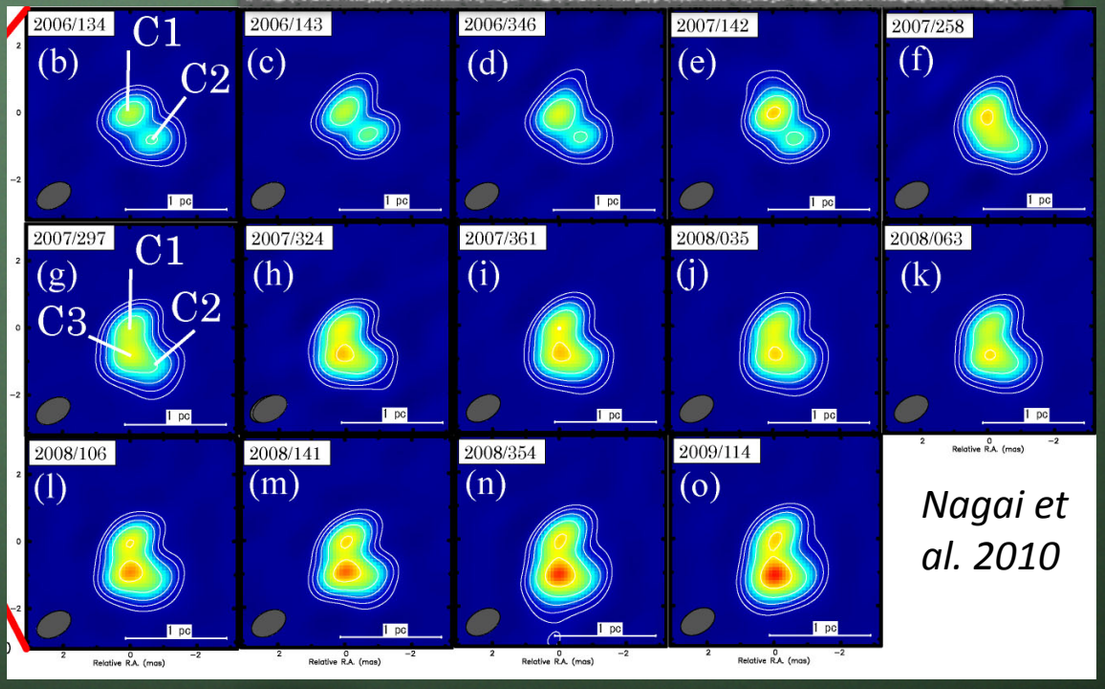




also
Nagai et al. 2012



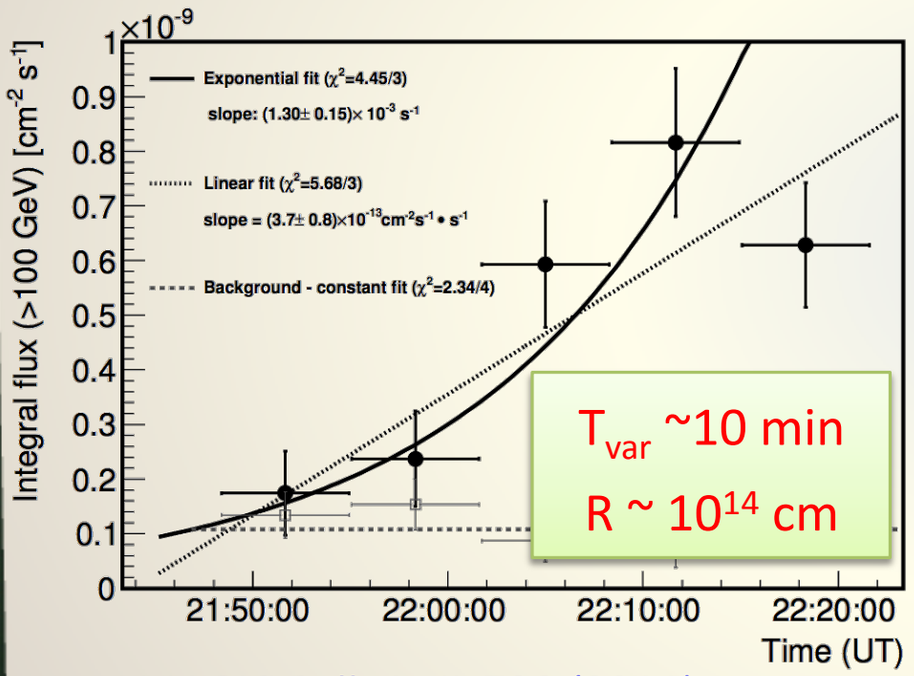
- Radio core in the <1 pc region
  - ➢ Is C3 the blazar zone?
    - ➢ work in progress...

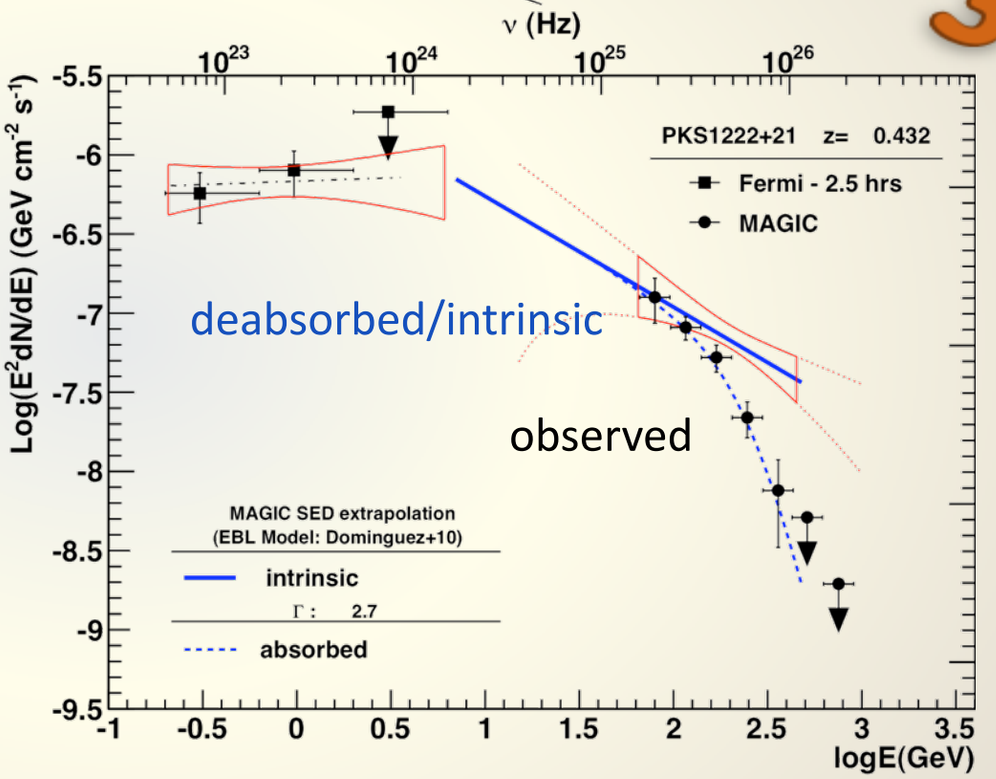


Nagai et al. 2010

The scene of the crime

- PKS 1222+21 (4C 21.35, z=0.435)
- Variability + internal absorption





MAGIC Coll. ApJL 730 (2011)

Stamerra et al. (2011) arXiv:1111.0077

The scene of the crime

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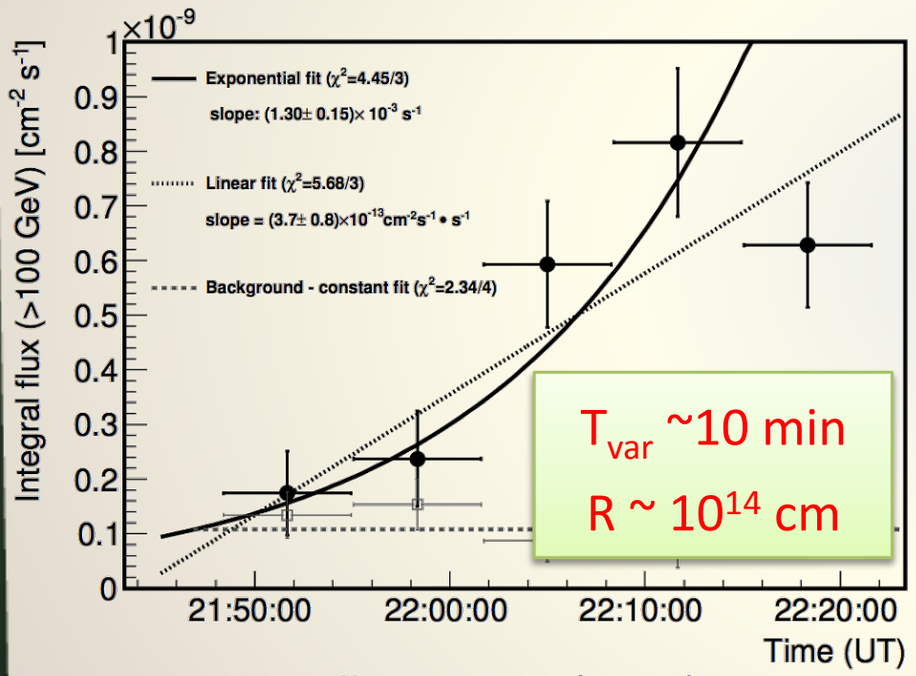
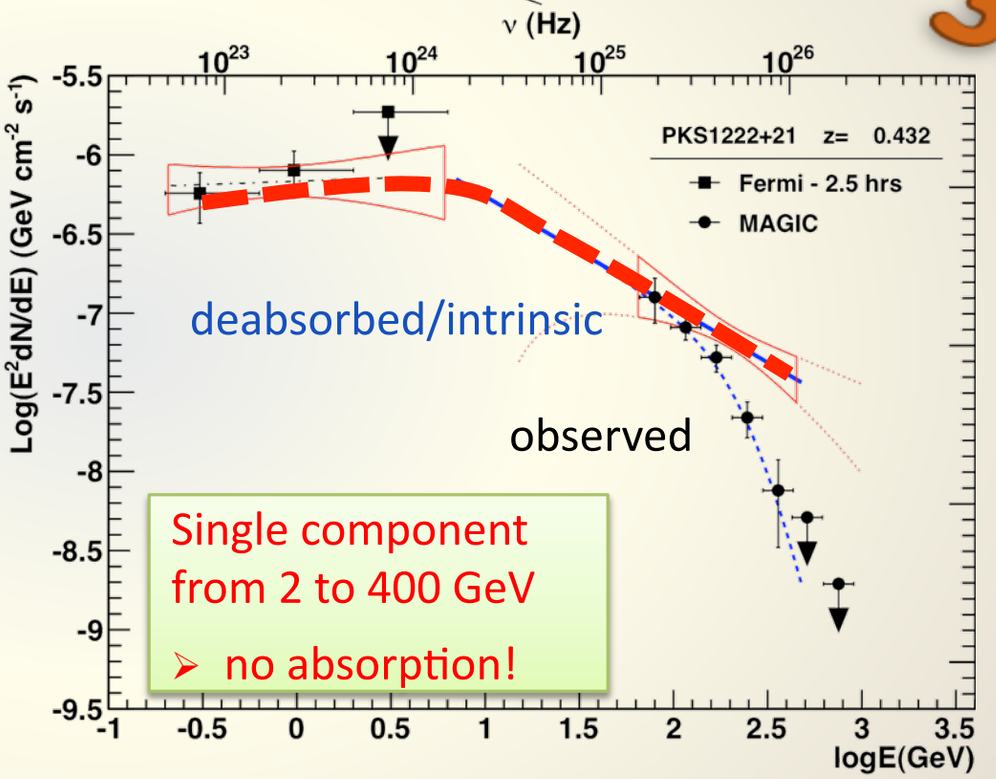


T_{var} ~10 min

R ~ 10^{14} cm



Single component from 2 to 400 GeV

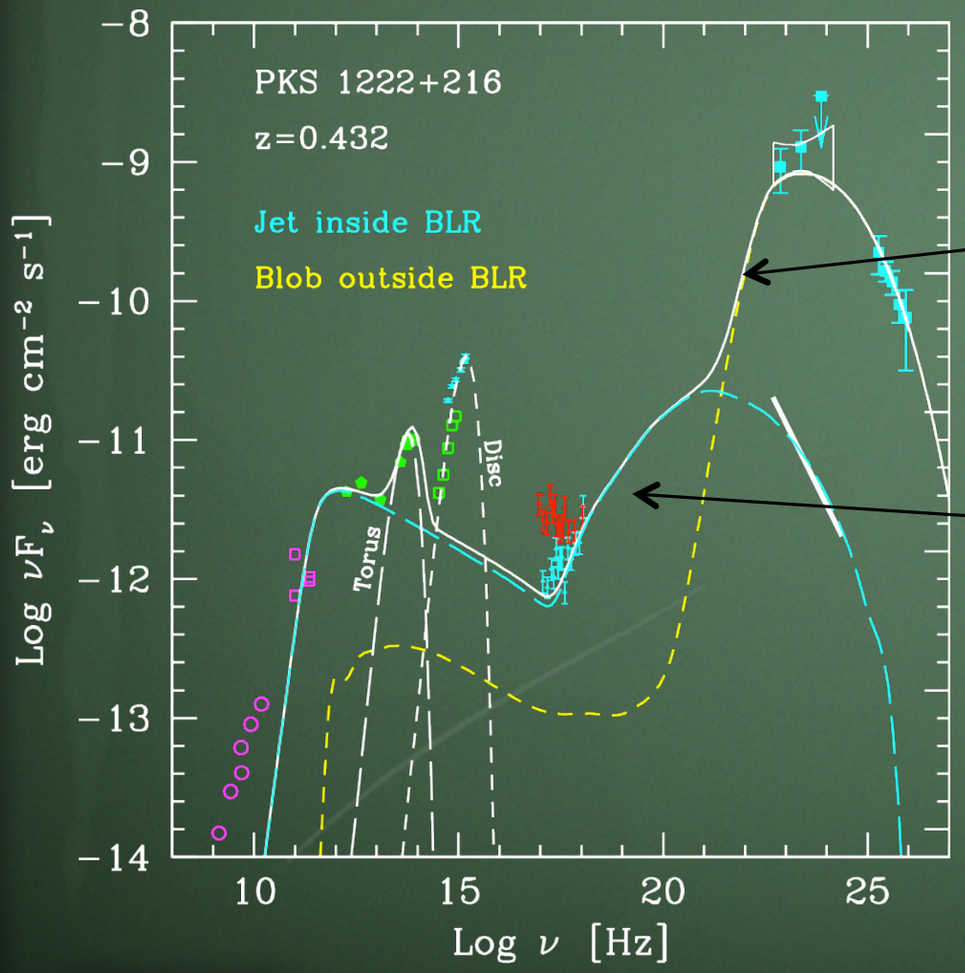
➢ no absorption!

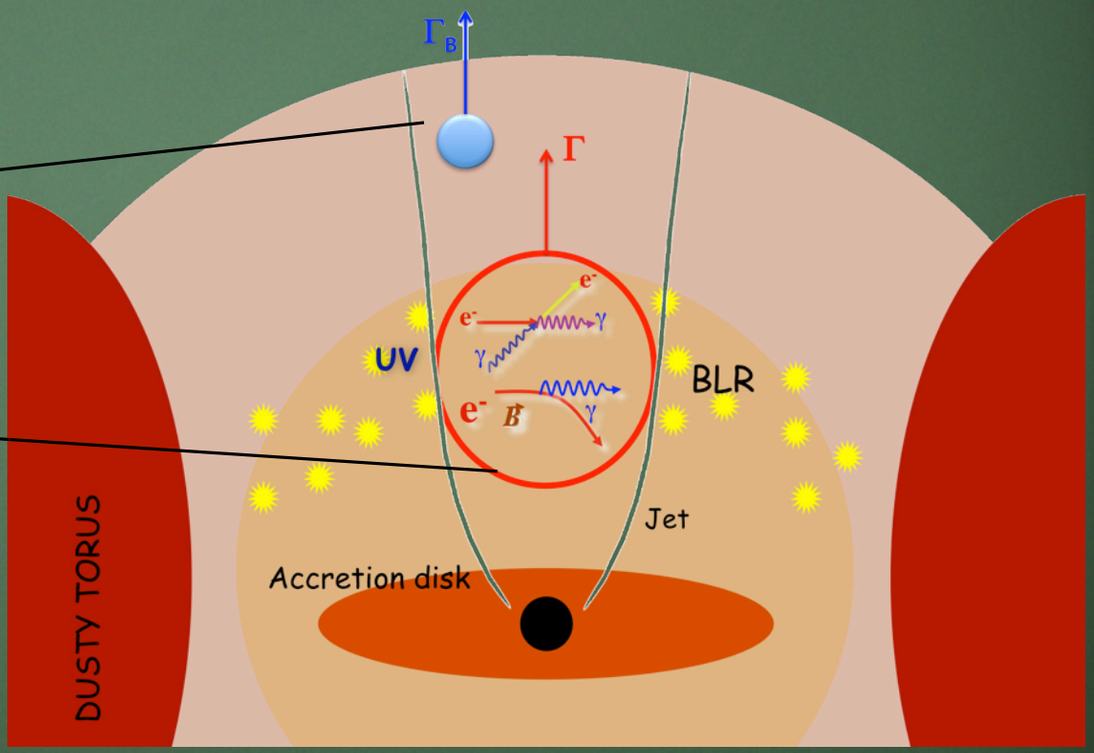
MAGIC Coll. ApJL 730 (2011)

Stamerra et al. (2011) arXiv:1111.0077

The scene of the crime

- A way out: a two zones EC



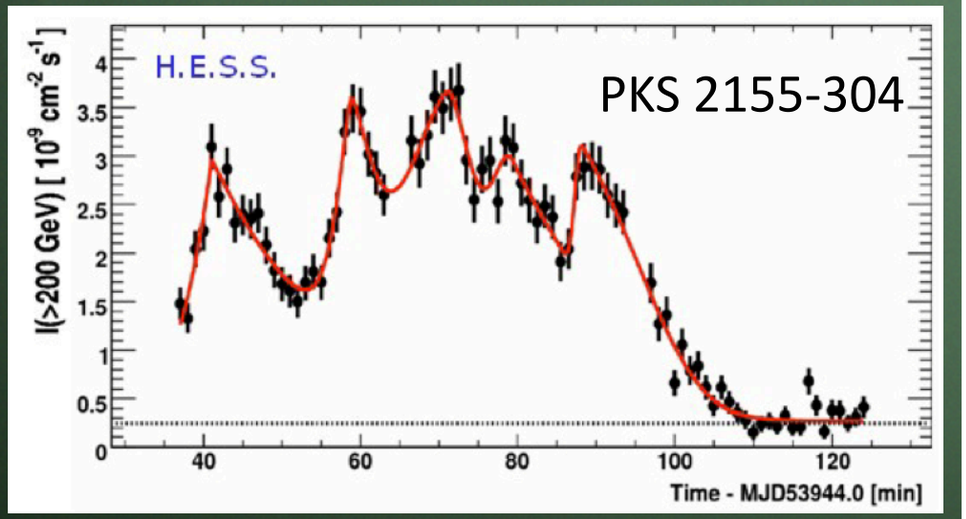


Tavecchio et al. 2011, A&A

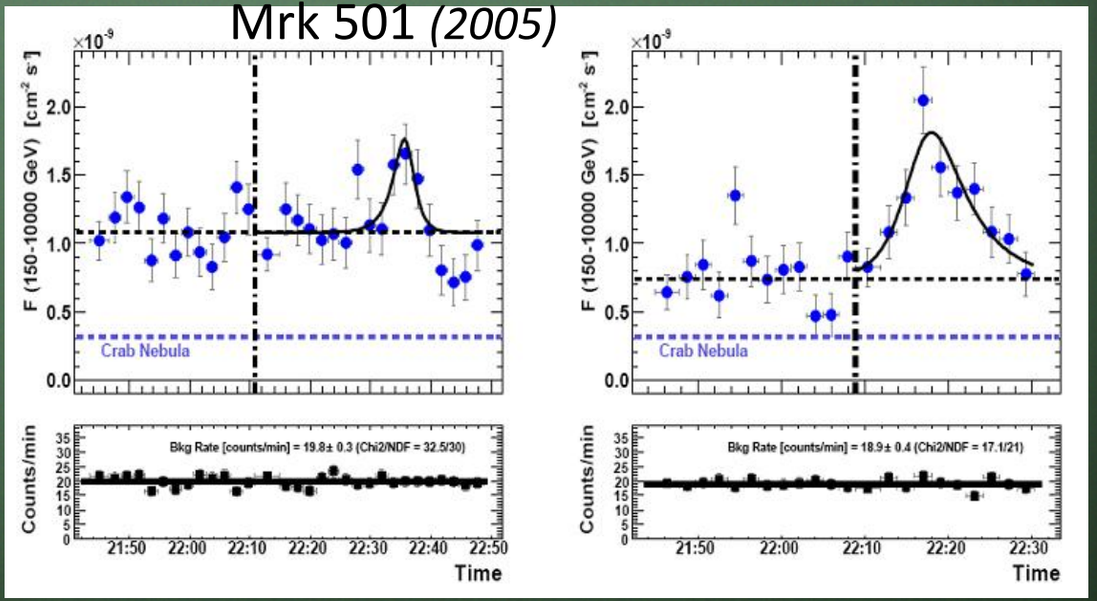
The scene of the crime

Evidence of substructures?

- since 2005: sub-flares on top of major flares
  - ➢ Time evolution of SZ-SSC models?
  - ➢ How are the regions connected?

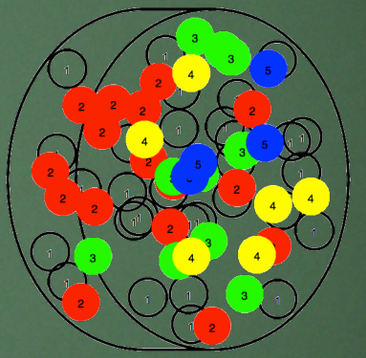


Mrk 501 *(2005)*

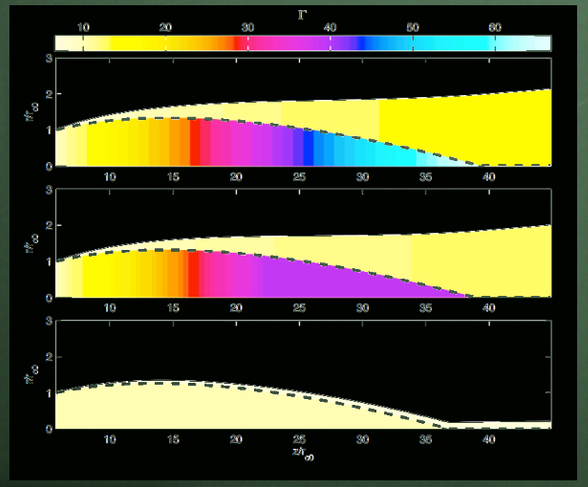


Hints

- *A single homogeneus zone is unable to describe the MWL SED of many HBLs*
  - small emitting regions over a bigger (hadronic?) jet producing the quiescent emission? -> variability
    - collimation?
  - suggested solutions:



Marscher&Jorstad 2010

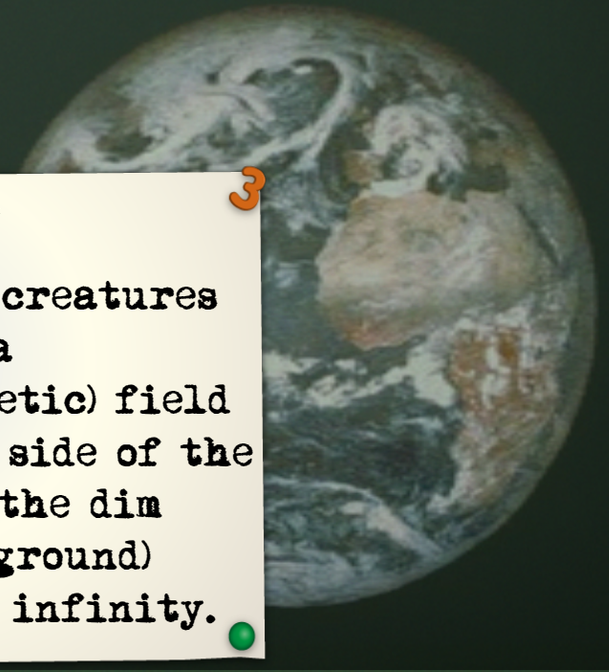


Bromberg & Levinson 2009

- Needle/Jet model *(Ghisellini, Tavecchio 2008MNRAS.386L..28G)*
- Jets in a jet *(Giannos, Uzdensky, Begelman 2009)*
- Relativistic turbulence *(Narayan, Piran 2012MNRAS.420..604N)*
- Kinetic beaming *(Cerruti, Werner, Uzdensky, Begelman 2012)*
- Hydrodynamic collimation *(Bromberg & Levinson 2009)*
- UHE neutral beams *(Dermer et al 2012)*
- Magnetic reconnection *(Nalewajko&Sikora 2009, Stawarz 2006)*

The kingdom of far far away

- EBL features
- EGML, axions



A

== Far far away ==

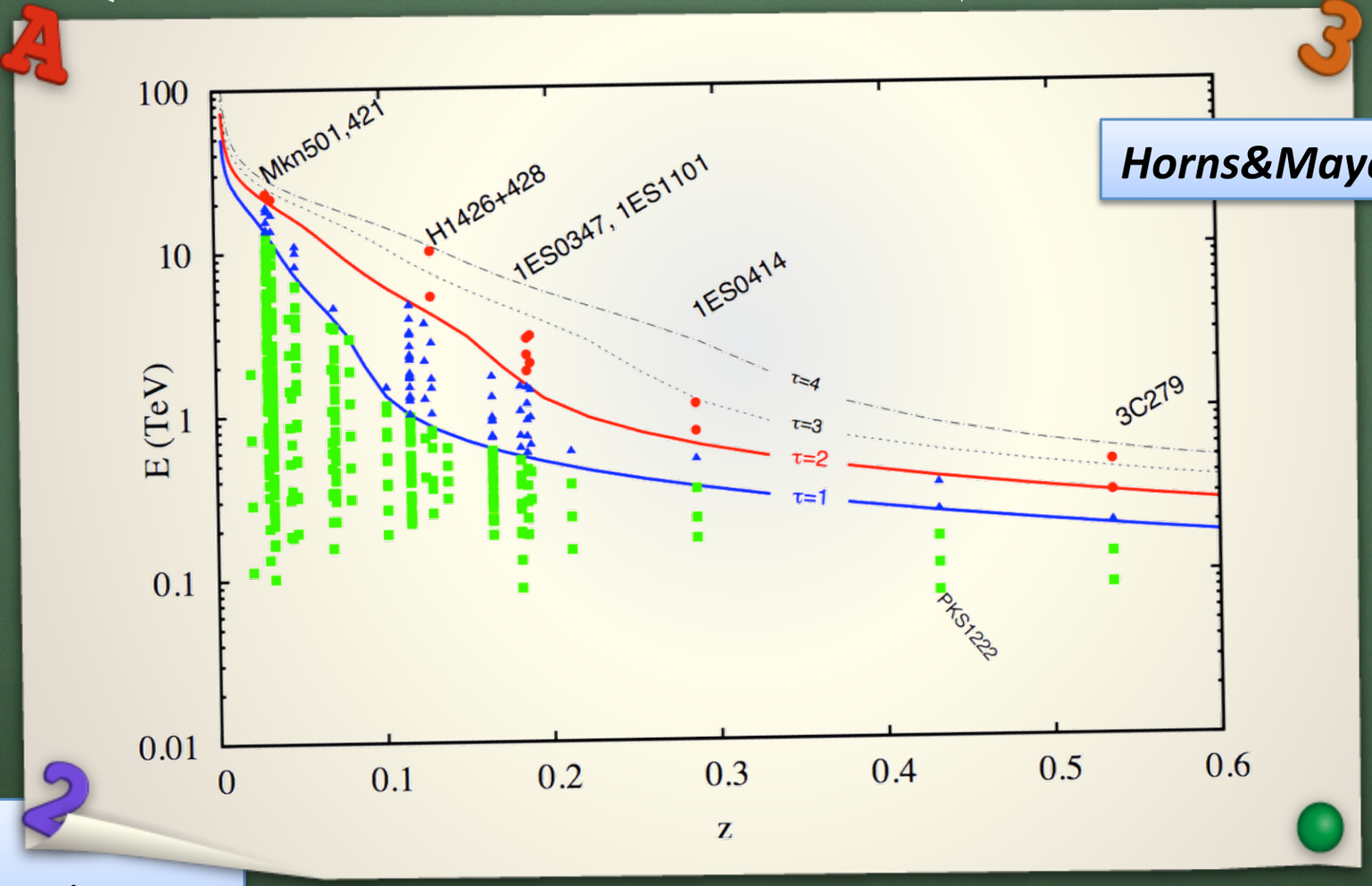
The realm of exotic creatures (axions) grazing at a (extragalactic magnetic) field on the dark (matter) side of the Universe, filled by the dim (extragalactic background) light of the fading infinity.

3

2

The kingdom of far far away

- Pair-production anomaly?

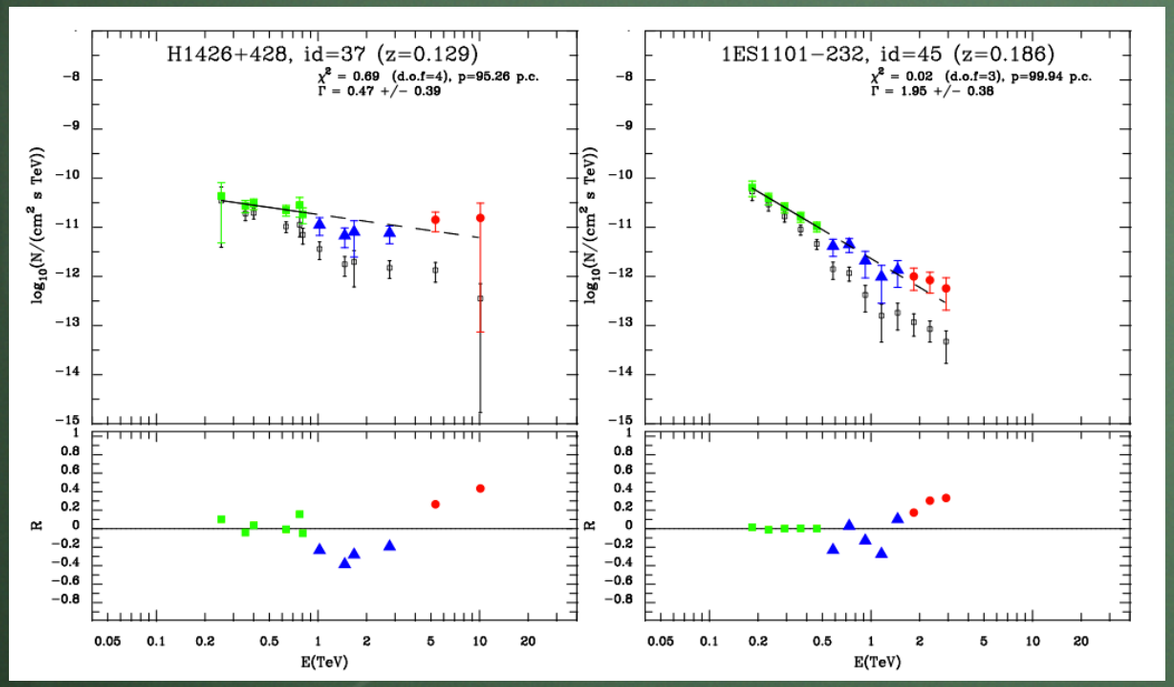


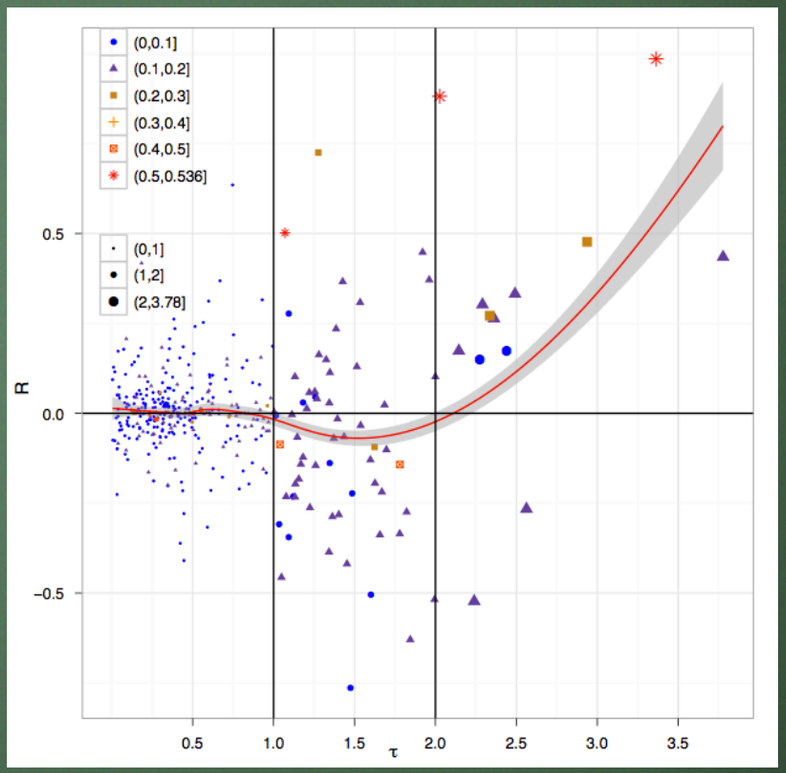
Horns&Mayer 2012

See also:
De Angelis et al. 2009

The kingdom of far far away

- Pair-production anomaly?
- 4.2σ effect





- Systematic effects of VHE measurement?
- How to extract a single clear imprint of EBL absorption?

The farthest HBL

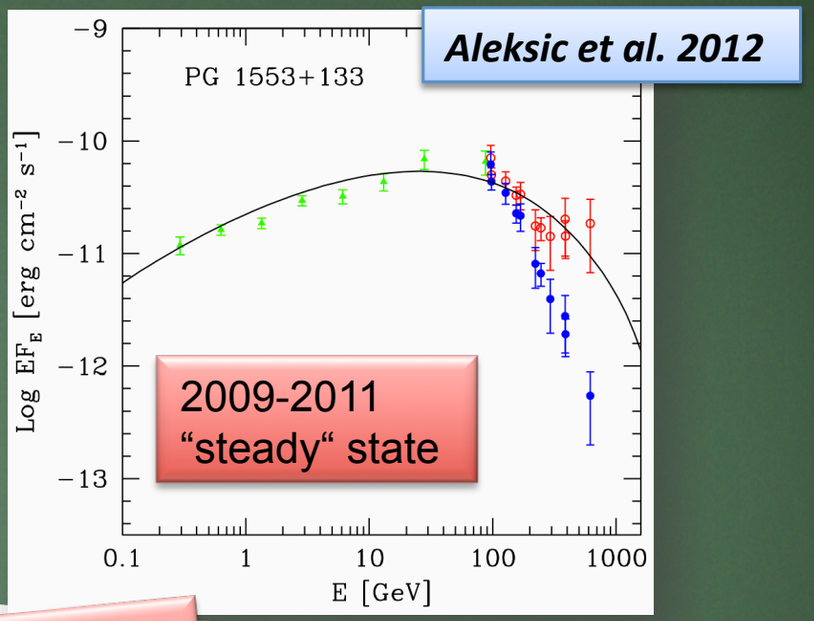
- PG 1553+113
- estimated z~0.45

  Danforth et al. 2010

  also Prandini 2011
- Fermi/LAT hard spectrum; slope~1.6

Huge flare in march-april 2012

- expected EBL features?



march-april 2012
15σ in 1 hr
z~0.5!!

The Astronomer's Telegram

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Present Time: 22 May 2012; 22:09 UT

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MAGIC detects an unprecedented high VHE gamma-ray emission from the blazar PG 1553+113

ATel #4069; *Juan Cortina (IFAE Barcelona) for the MAGIC collaboration*
on 26 Apr 2012; 14:22 UT
Credential Certification: Juan Cortina (cortina@ifae.es)

Subjects: Infra-Red, Optical, X-ray, Gamma Ray, TeV, VHE, Request for Observations, AGN, Blazar

Referred to by ATel #: 4078, 4107

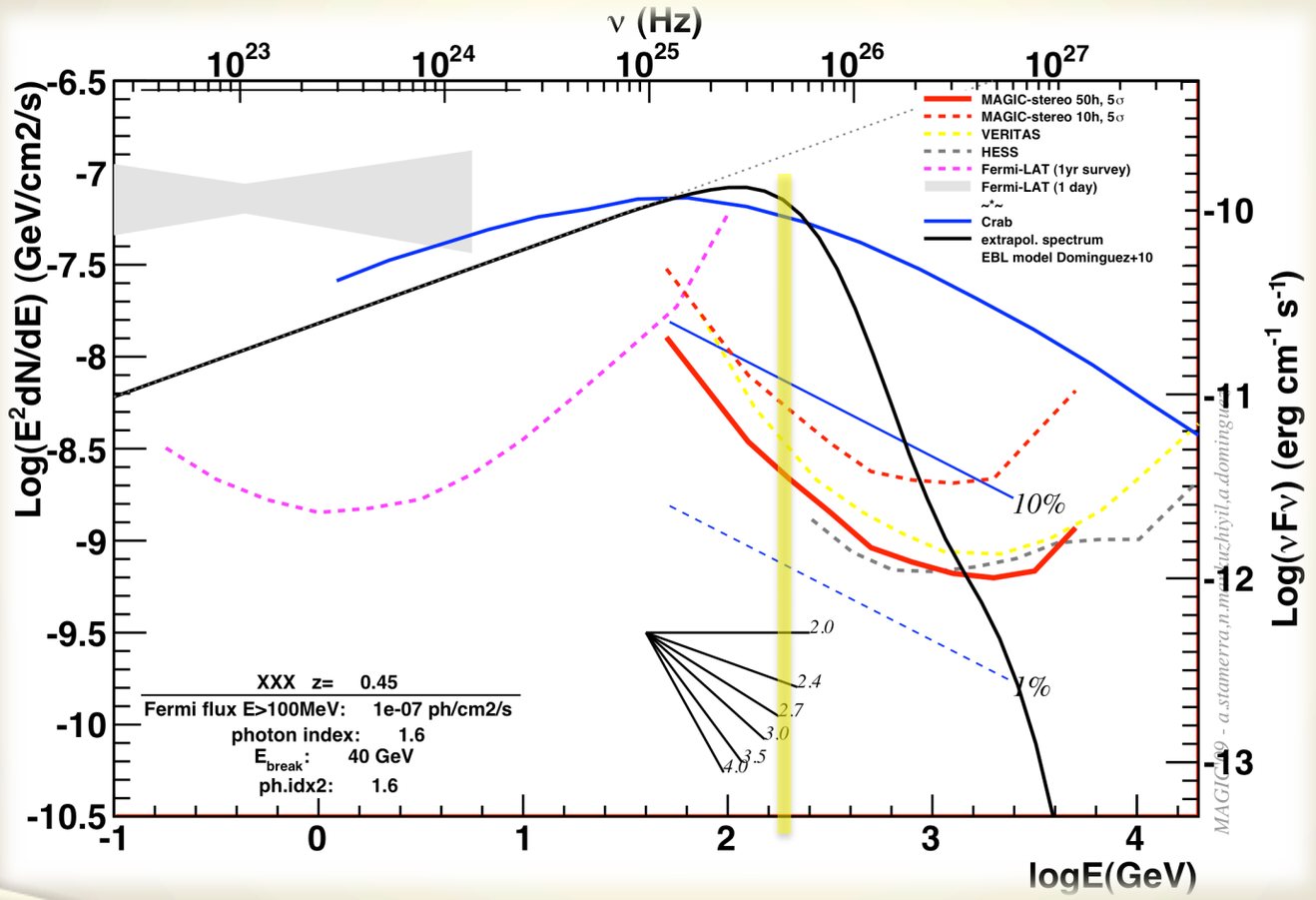
The source PG 1553+113 is a well-known TeV emitter, likely located at redshift 0.4-0.5 (Danforth et al. 2010). Its state has been monitored by MAGIC since February 2005. In March 2012, a high emission state at VHE, X-ray, optical, and infrared wavelengths was reported (ATel #3977).

EBL imprints on VHE spectra

Extreme blazars (hard intrinsic spectrum)

- PG1553 z=0.45; intrinsic slope up to 100 GeV ~1.6

intrinsic VHE slope 1.6

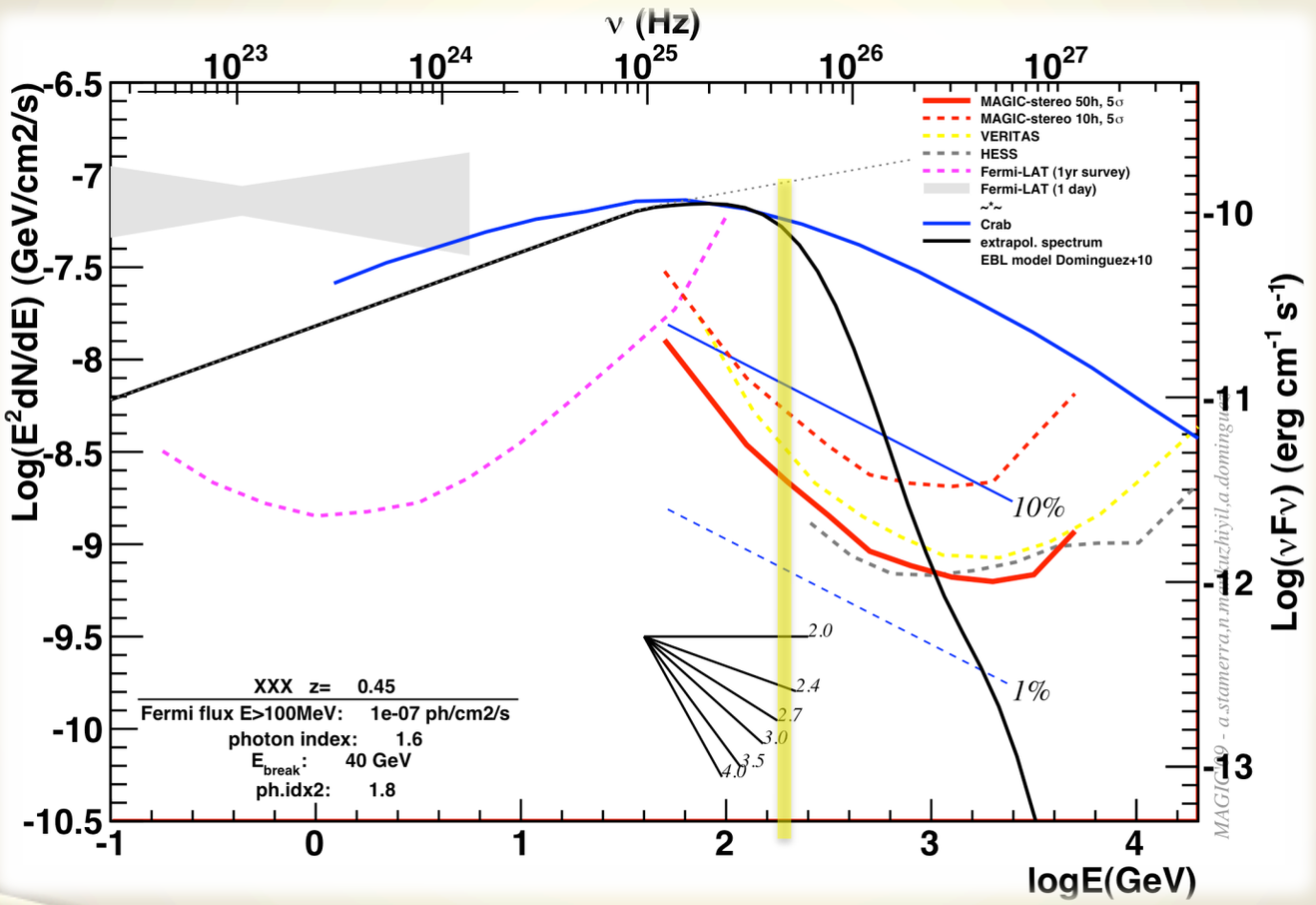


EBL imprints on VHE spectra

Extreme blazars (hard intrinsic spectrum)

- PG1553 z=0.45; intrinsic slope up to 100 GeV ~1.6

intrinsic VHE slope 1.8

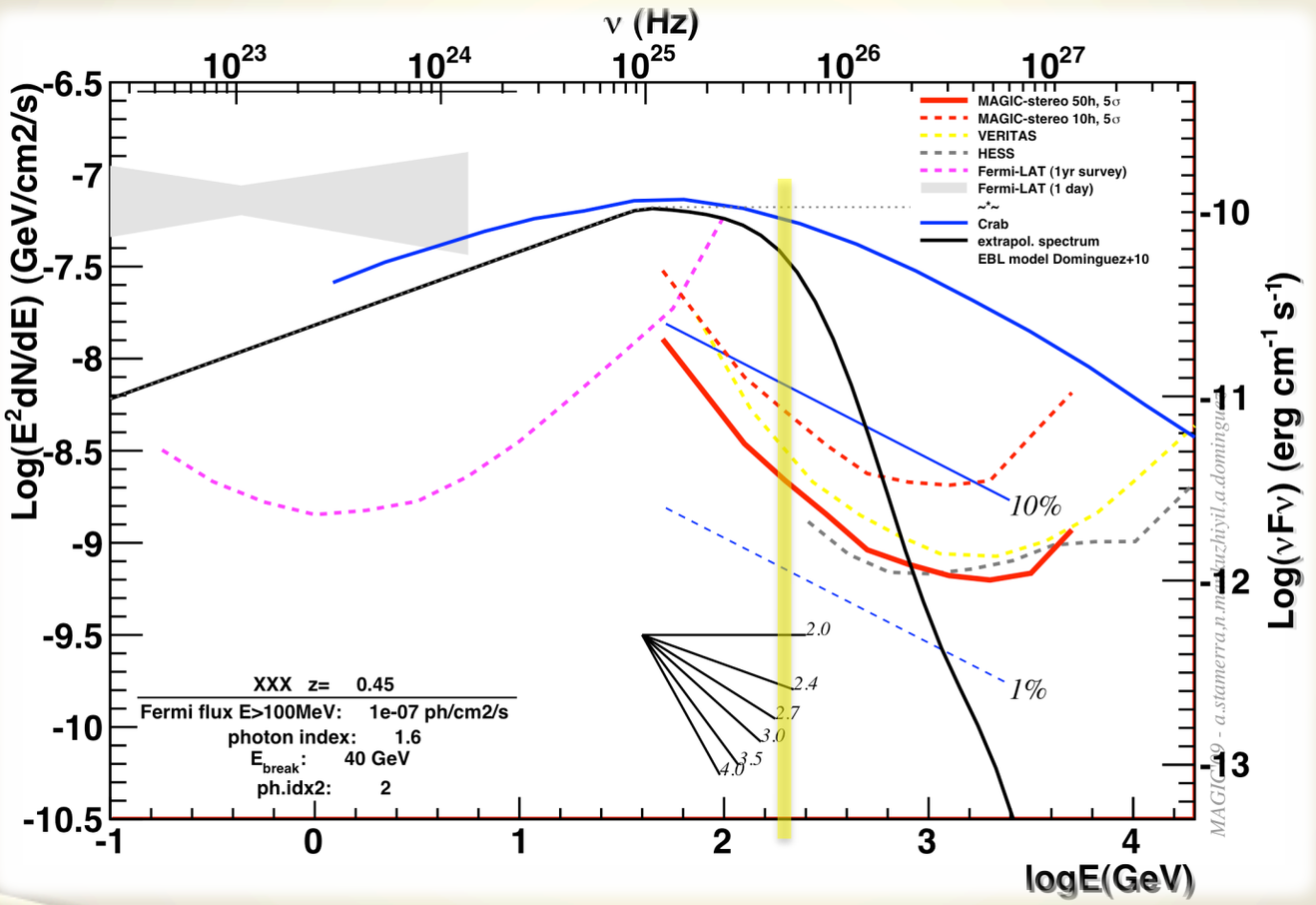


EBL imprints on VHE spectra

Extreme blazars (hard intrinsic spectrum)

- PG1553 z=0.45; intrinsic slope up to 100 GeV ~1.6

intrinsic VHE slope **2.0**

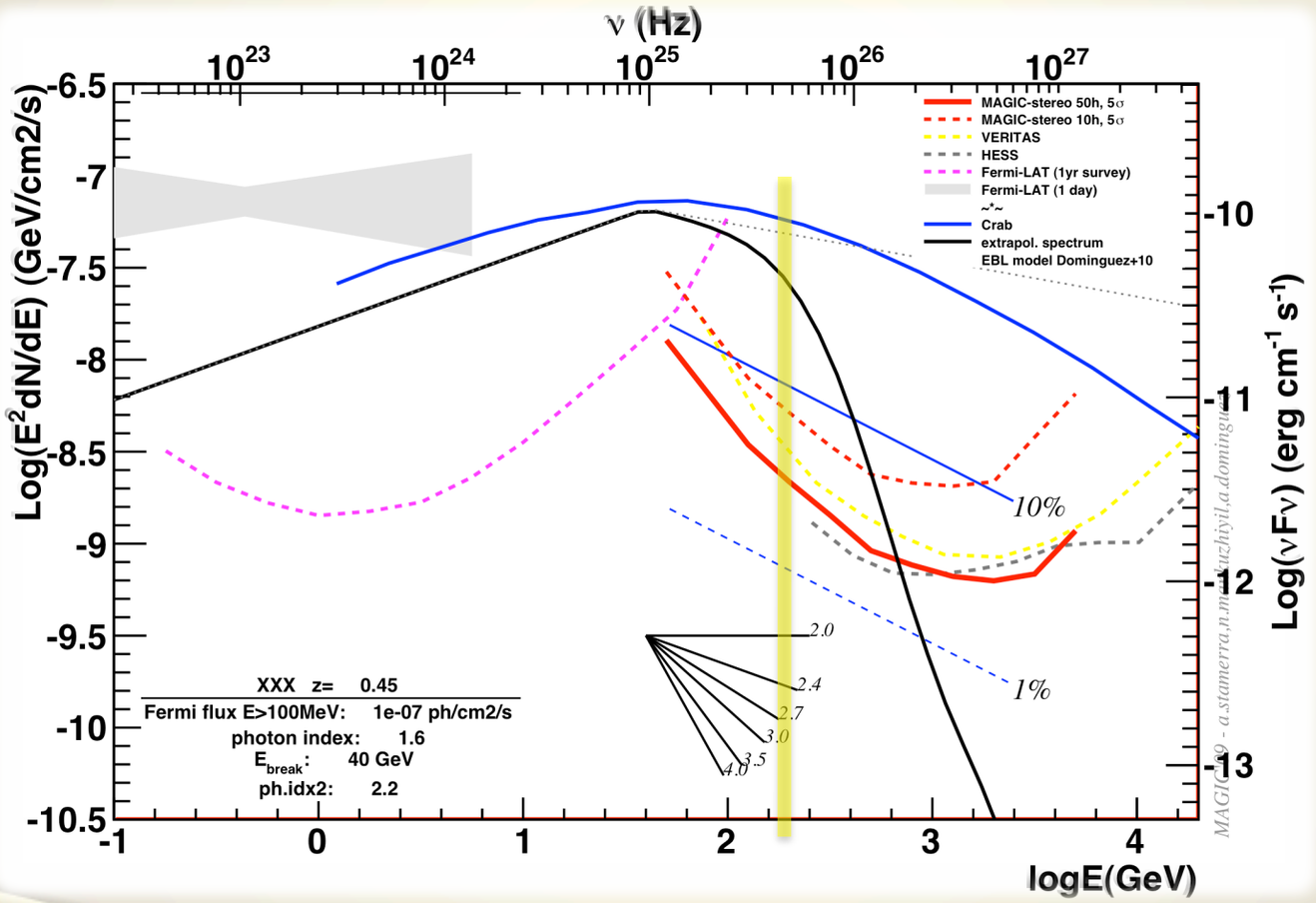


EBL imprints on VHE spectra

Extreme blazars (hard intrinsic spectrum)

- PG1553 z=0.45; intrinsic slope up to 100 GeV ~1.6

intrinsic VHE slope 2.2

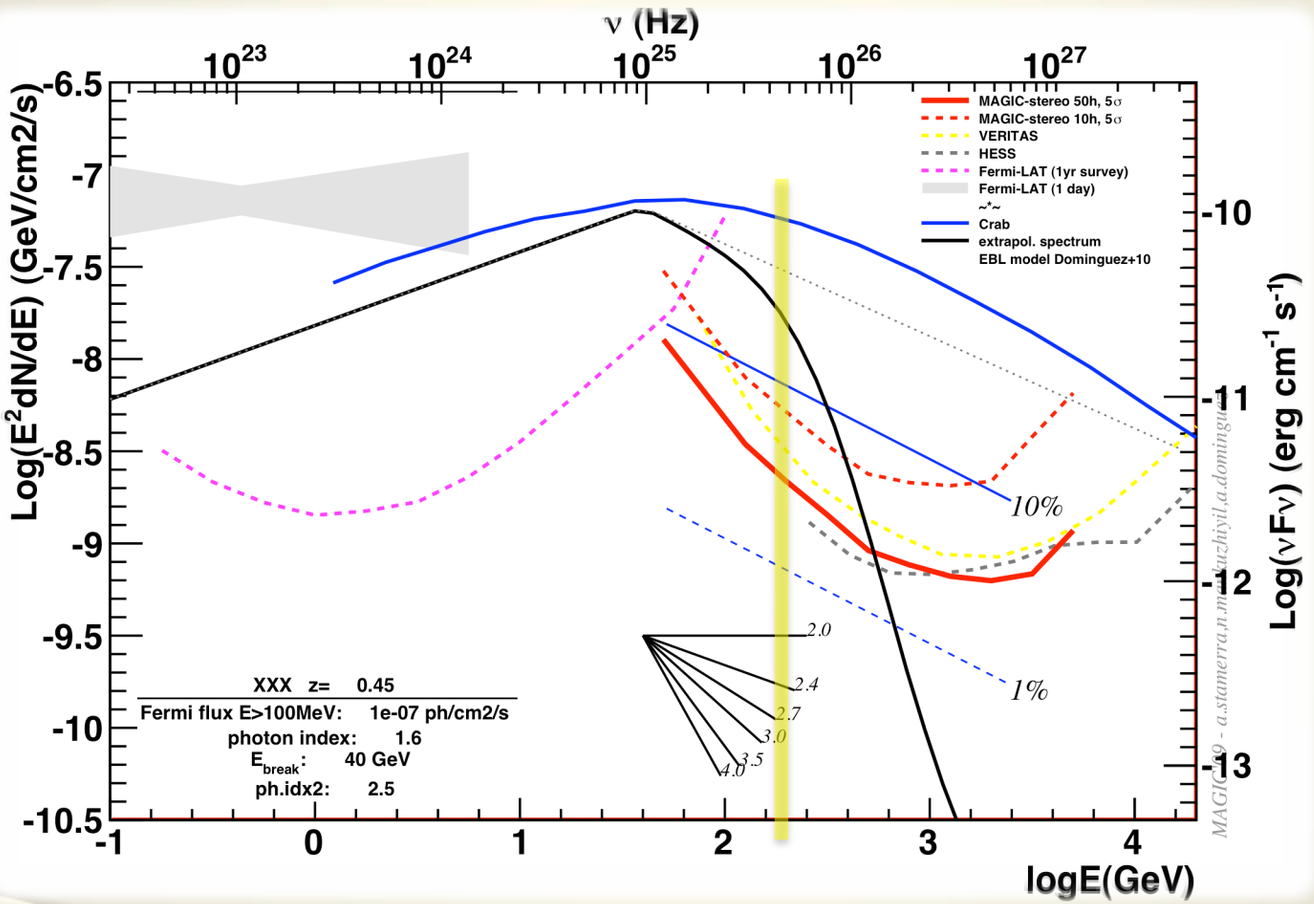


EBL imprints on VHE spectra

Extreme blazars (hard intrinsic spectrum)

- PG1553 z=0.45; intrinsic slope up to 100 GeV ~1.6

intrinsic VHE slope 2.5

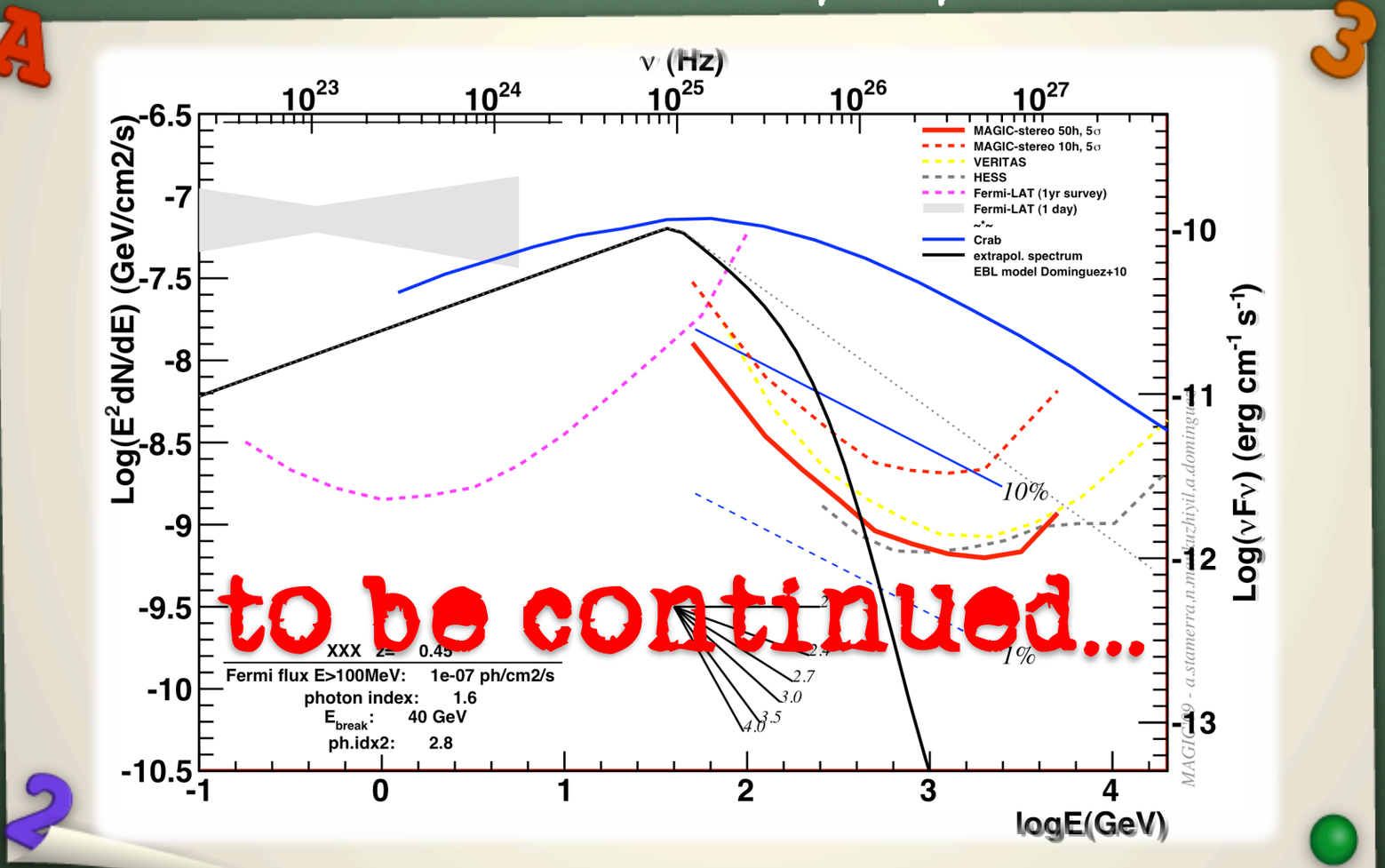


EBL imprints on VHE spectra

Extreme blazars (hard intrinsic spectrum)

- PG1553 z=0.45; intrinsic slope up to 100 GeV ~1.6

intrinsic VHE slope 2.8



End titles

In order of appearance:

- the victim: the single zone (SSC/EC) model
- the unexpected guest: flat HE/VHE SEDs of blazars
- the defendant: multi-zones emission and collimation
- the witness: distance effects (EBL, EGMF, axions...)

Will the present generation of Cherenkov telescopes uncover the plot and solve the "mystery"?

End titles
on the road to a happy end

Will the present generation of Cherenkov telescopes uncover the plot and solve the "mystery"?

- Sensitivity limits reached: ~1% Crab Units in 50 hrs @200GeV!
  - e.g. 1ES 1312-423 by HESS -> ~100 hrs, 0.4% C.U. !!
- ➢ deeeep observations >100 hours? core programs?
- ➢ focus on flaring sources? new classes of sources?
- ➢ Fundamental Physics: DM, EBL, EGMF studies?

discussion on-going

- ✓ MAGIC: best suited instrument (lowest $E_{threshold}$)
- ✓ next future: HESS-II (28 m) and CTA


MAGIC
Major Atmospheric Gamma Imaging Cherenkov Telescope
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IAC
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DIPARTIMENTO DI FISICA
INFN
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di Fisica Nucleare