MAGIC EXTRAGALACTIC HIGHLIGHTS FROM A MEV PERSPECTIVE

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for the MAGIC Collaboration

INTEGRAL looks AHEAD
Geneva 13.02.2019

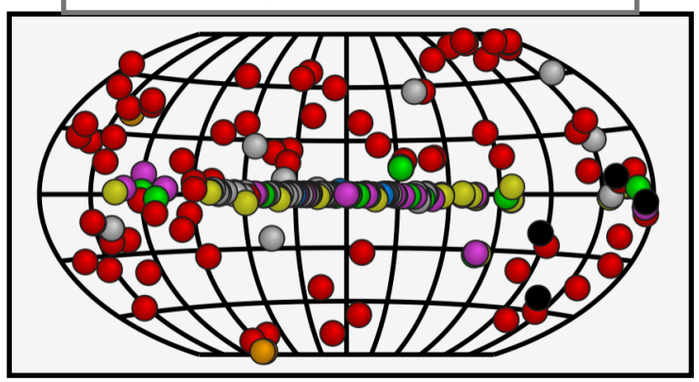
OUTLINE

- The extragalactic MAGIC sky
- The MAGIC telescopes for VHE gamma-ray observations
- Highlight results:
  - The neutrino blazar
  - Extreme blazars
  - Flat spectrum radio quasars
  - Transients
- Conclusions

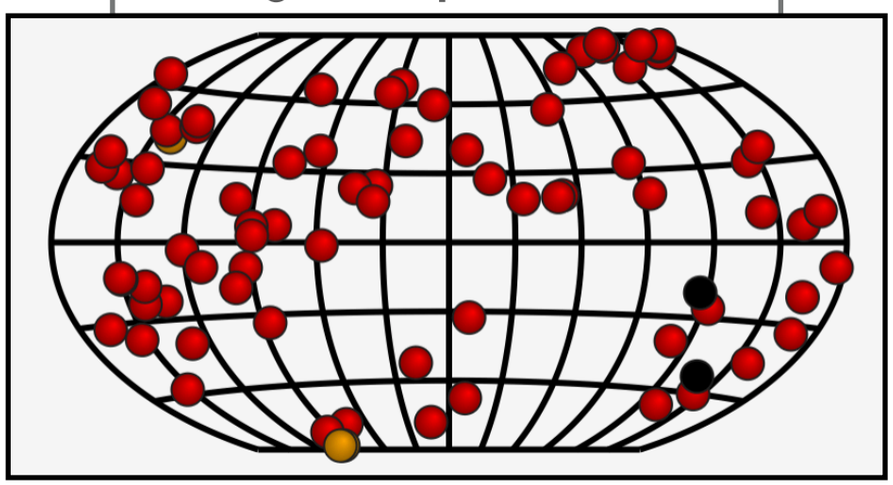
TeVCat2.0

MAGIC EXTRAGALACTIC SOURCES

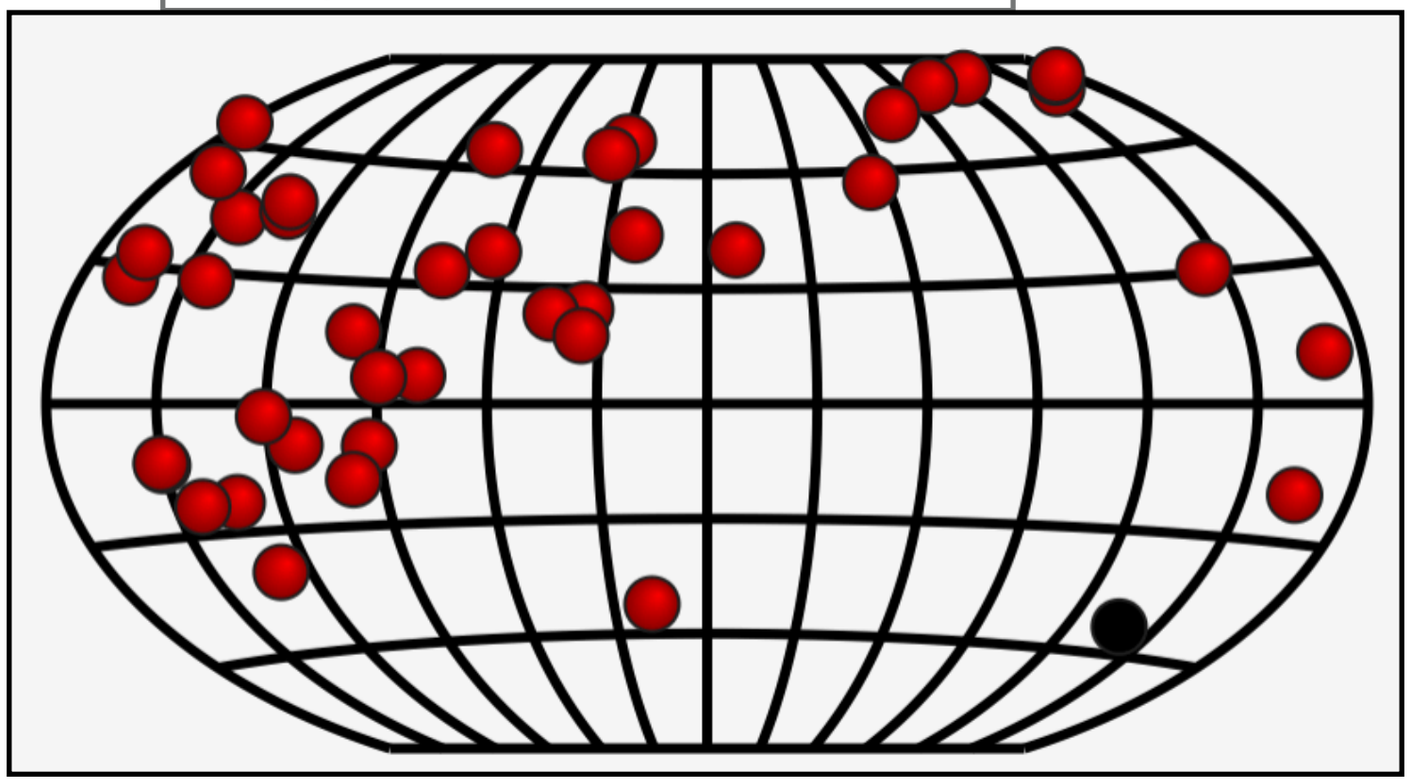
TeV map: 231 sources



TeV Xgal map: 80 sources



TeV Xgal MAGIC map: 42 sources

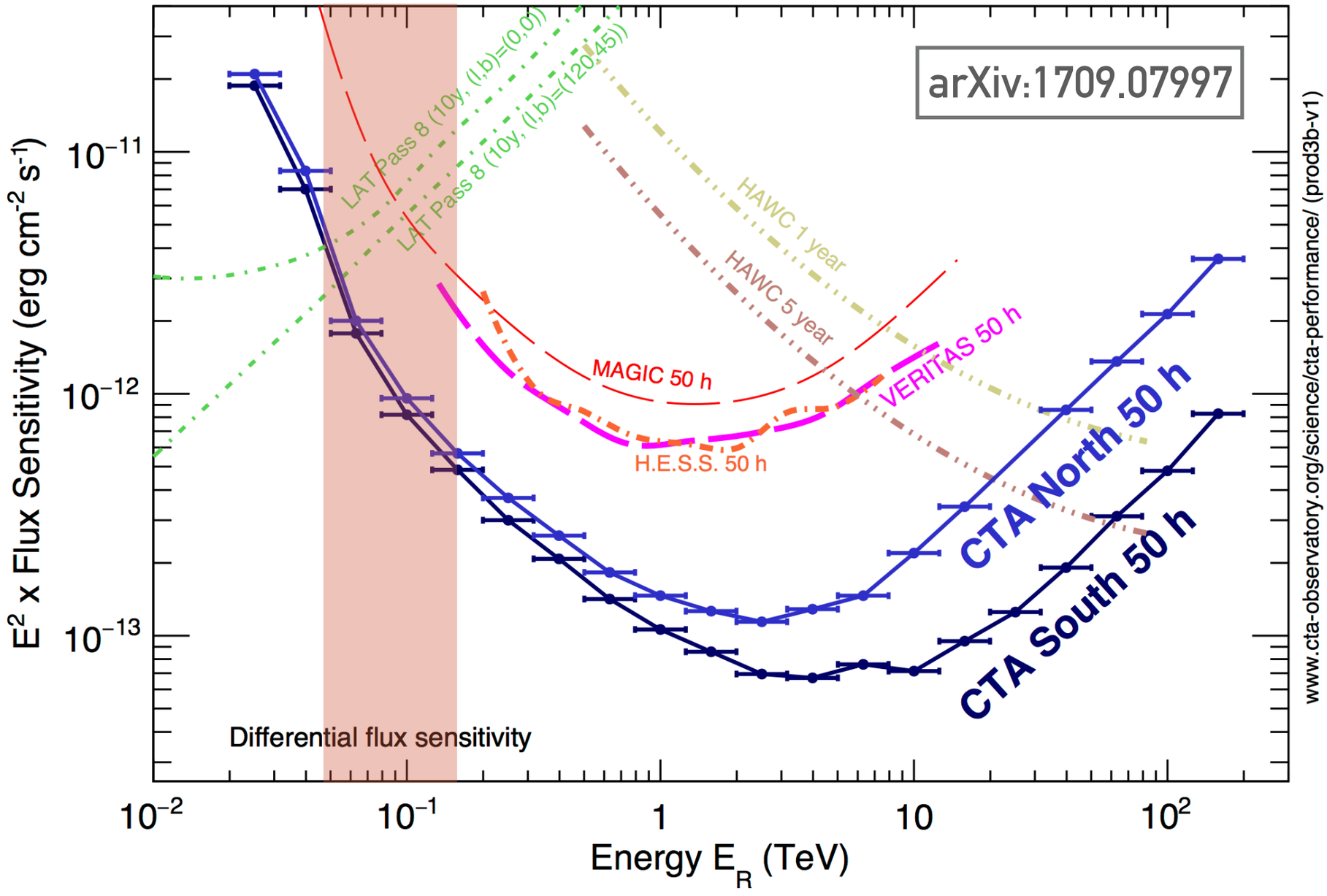


OBSERVATION STRATEGY

- Always pointing mode
- Monitoring campaigns of known objects
- Scheduled observations (one call per year, open to external scientists)
- ToO observations

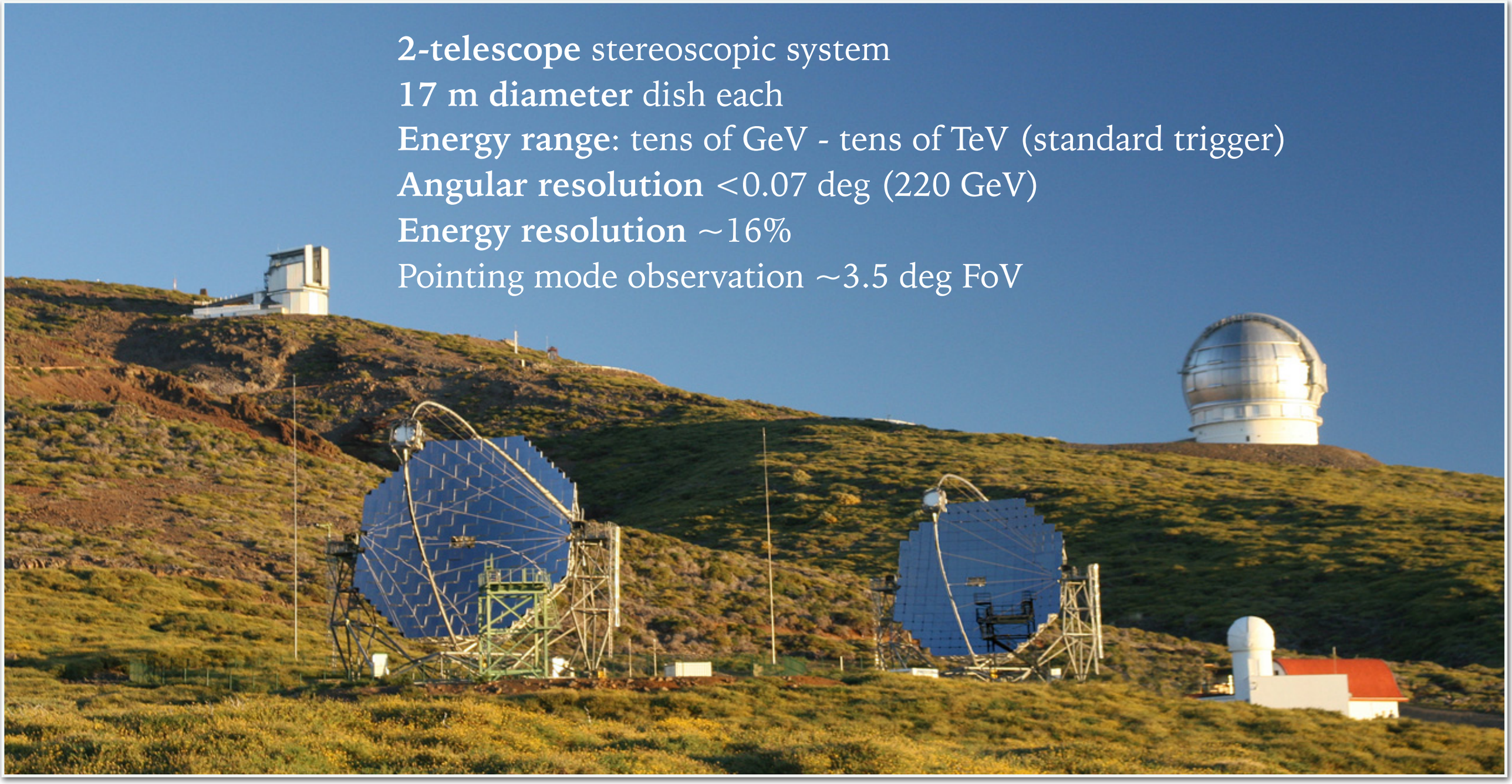
MAGIC TELESCOPES SENSITIVITY

Best instrument around 100 GeV



Current MAGIC sensitivity above 220 GeV: 0.66 % Crab Nebula flux in 50 hours

THE MAGIC TELESCOPES



THE MAGIC STORY

First MAGIC design meeting, 1995, in The Eng, Austria

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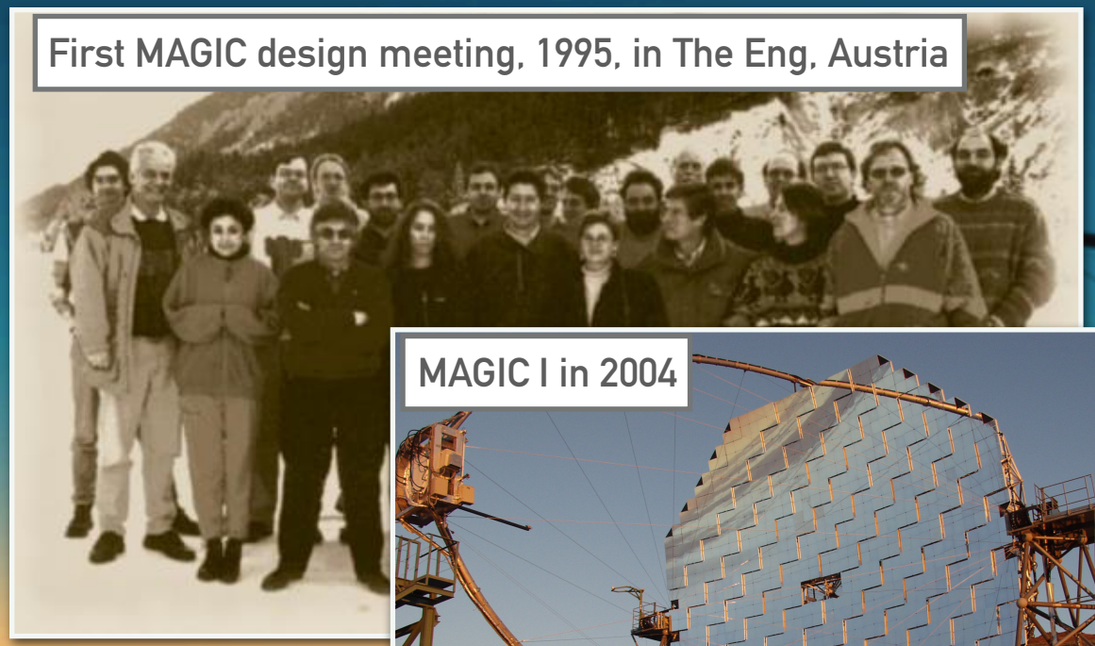

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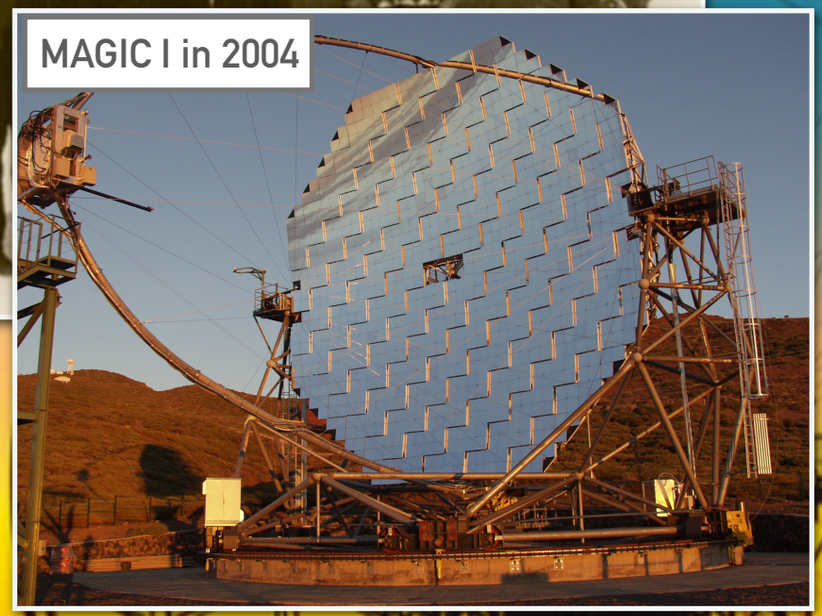
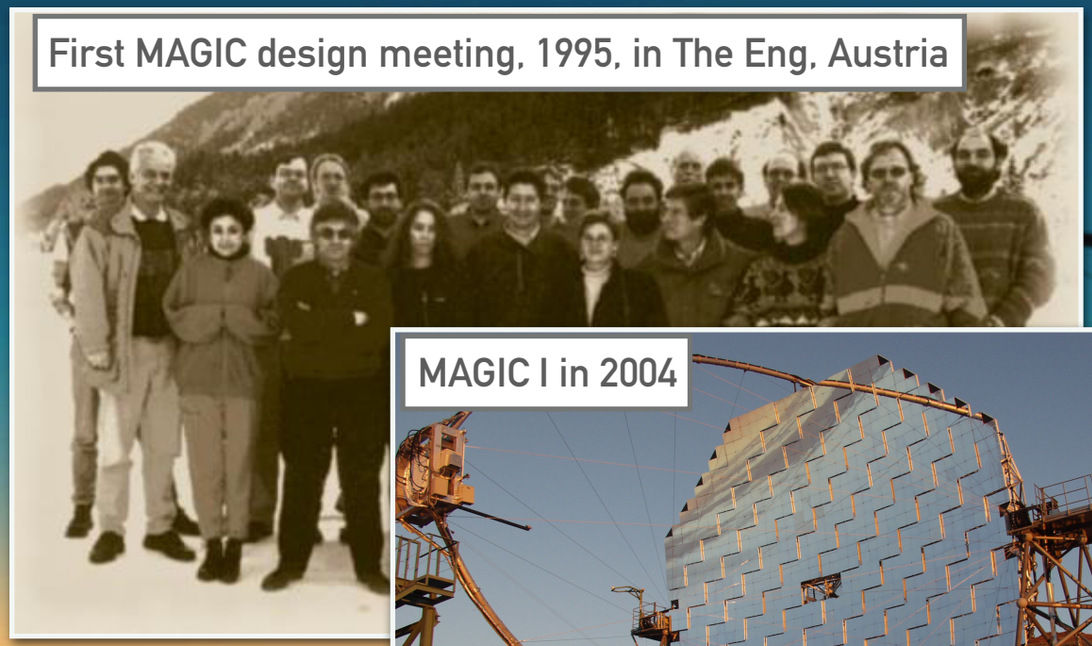


MAGIC I in 2004

THE MAGIC STORY

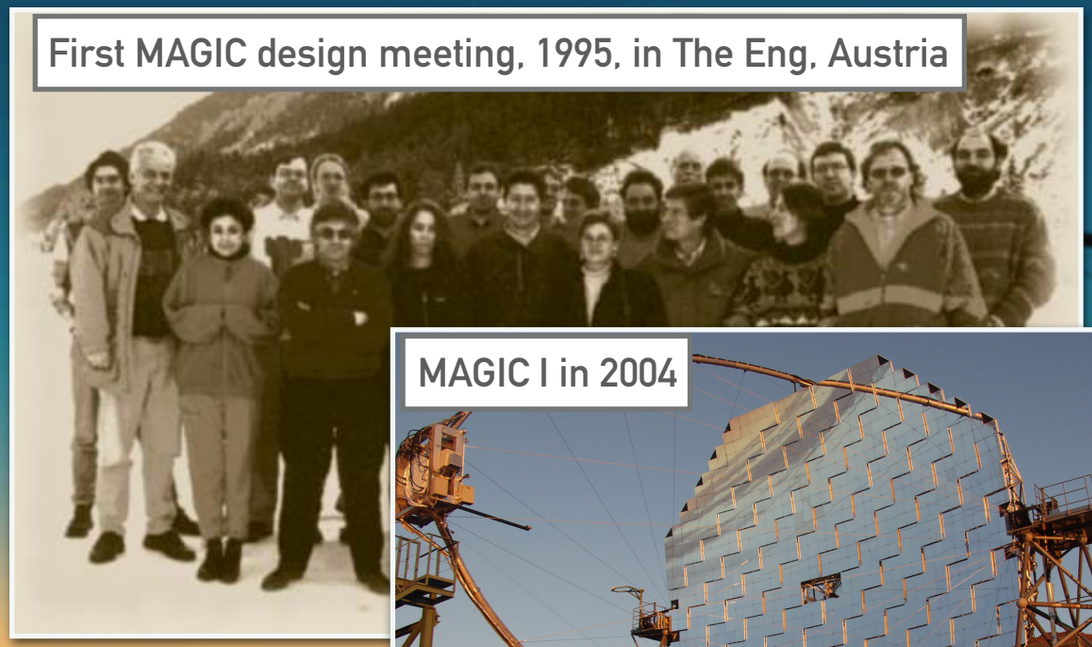


First MAGIC design meeting, 1995, in The Eng, Austria

MAGIC I in 2004

MAGIC I and II in 2009

THE MAGIC STORY



First MAGIC design meeting, 1995, in The Eng, Austria

MAGIC I in 2004

MAGIC I and II in 2009

MAGIC and LST 2018

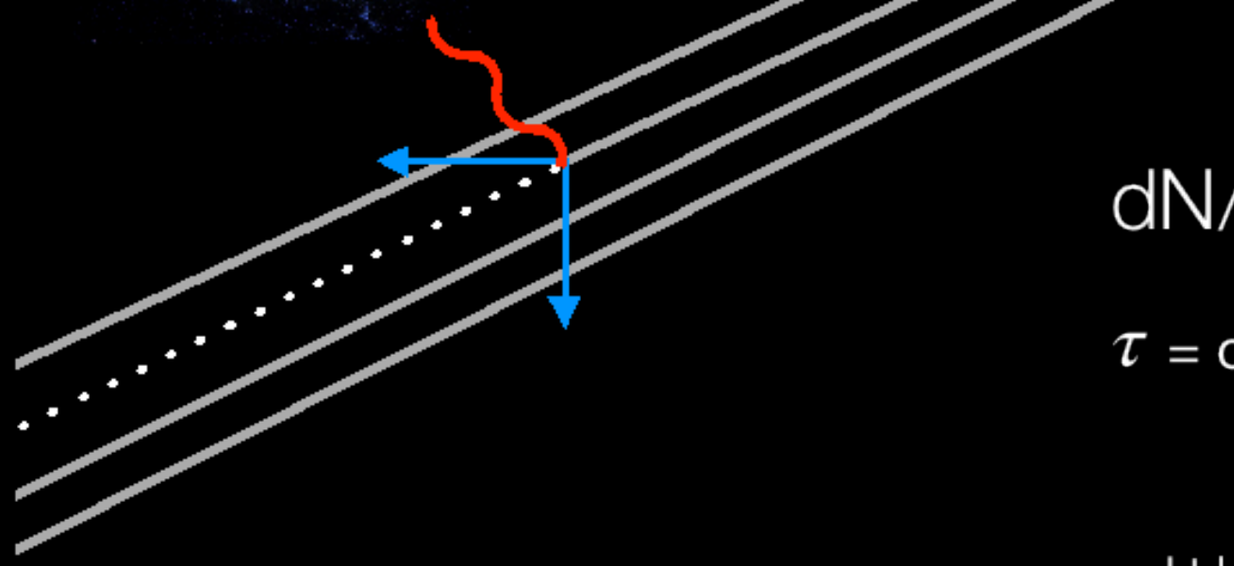
MAGIC OBSERVATION STRATEGY

Average time per year:
1000 h dark
500 h moon

Several Scientific topics:

- ***Extragalactic:*** aligned and misaligned AGNs
- ***Transients:*** Multimessenger Alerts (GRBs, neutrinos, FRBs, GWs)
- ***Galactic:*** SNRs, PWNs, pulsars
- ***Fundamental Physics:*** dark matter, tau neutrinos, LIV

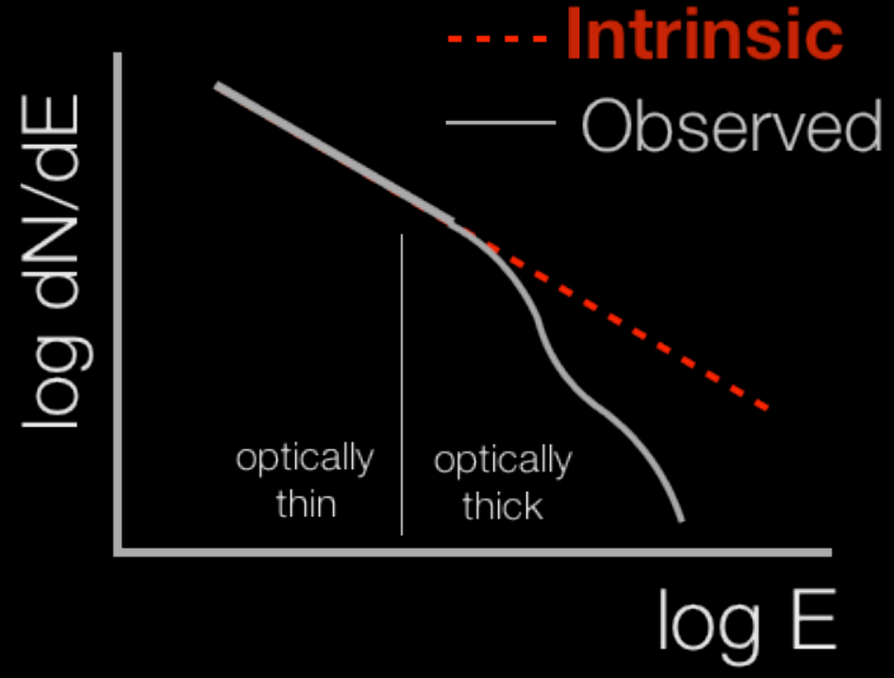
THE EFFECT OF INTERACTION WITH THE EXTRAGALACTIC BACKGROUND LIGHT (EBL)



$dN/dE_{obs} = dN/dE_{int}\ e^{-\tau(z,E)}$

τ = optical depth

VHE photons and EBL photons: pair creation —> VHE flux absorption (e.g. Franceschini et al. 2008, A&A 487, 837–852)

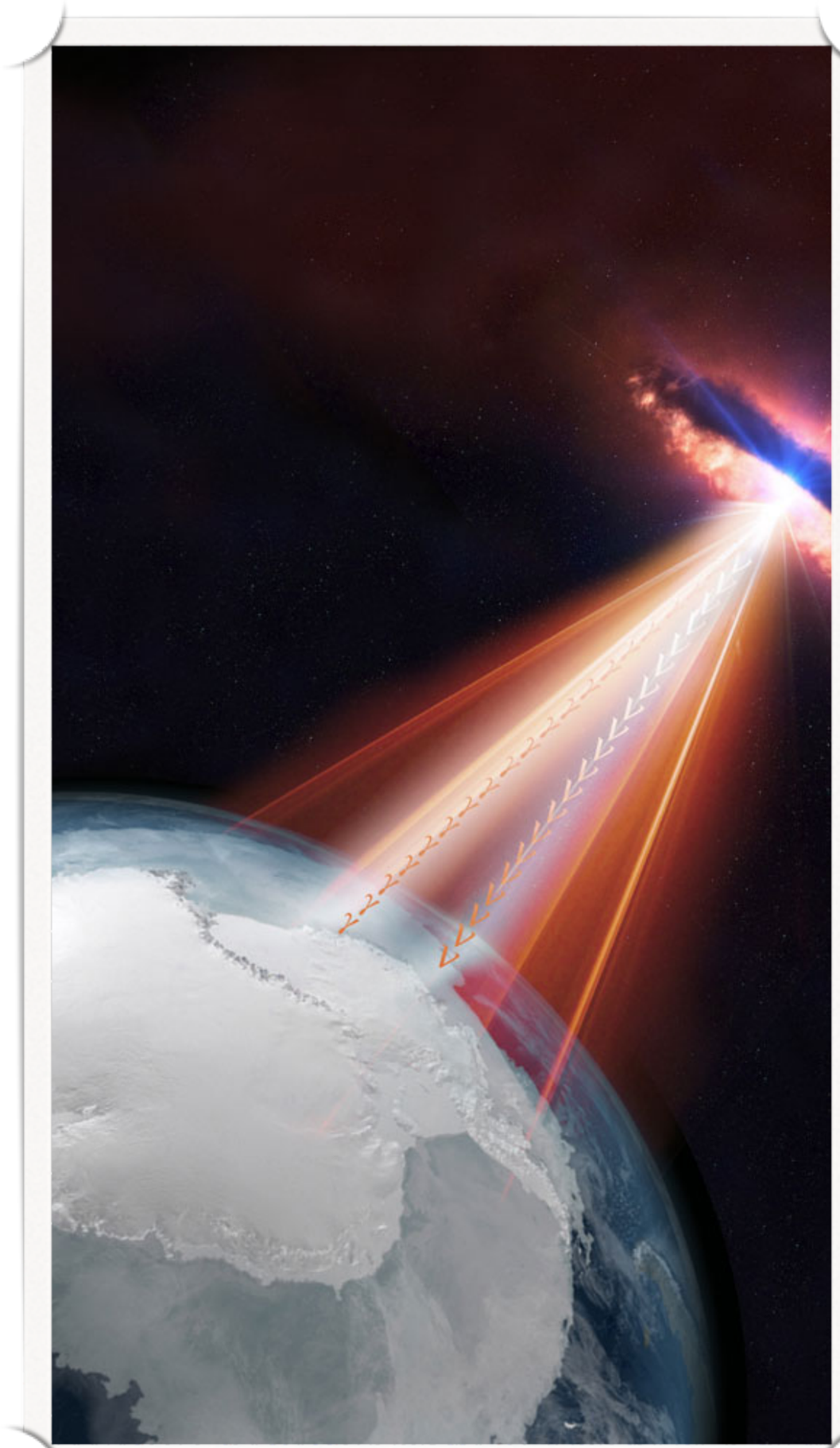


For detecting distant sources at VHE a low energy threshold is essential!

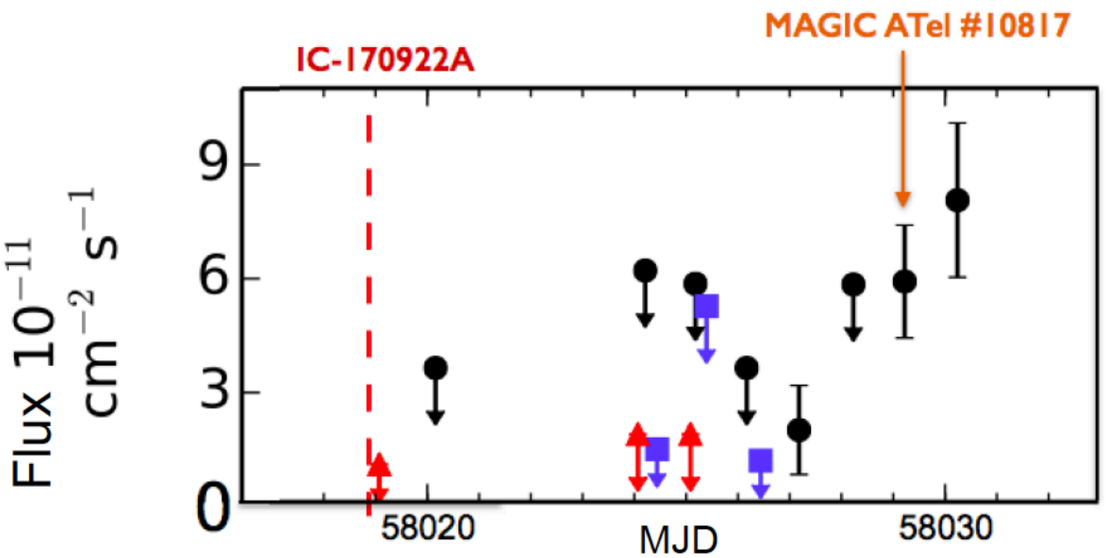
HIGHLIGHTS RESULTS

TeV–Neutrino Connection

The dawn of multimessenger astronomy



TEV PHOTONS FROM A NEUTRINO EMITTING BLAZARS



MAGIC (E>90 GeV)
VERITAS (E>195GeV) H.E.S.S. (E>195GeV)

On September 22nd, 2017:

- Trigger alert from IceCube of a high energy neutrino event
- *Fermi*-LAT detects a blazar in a high gamma-ray state in the neutrino field of view
- IACTs observations triggered

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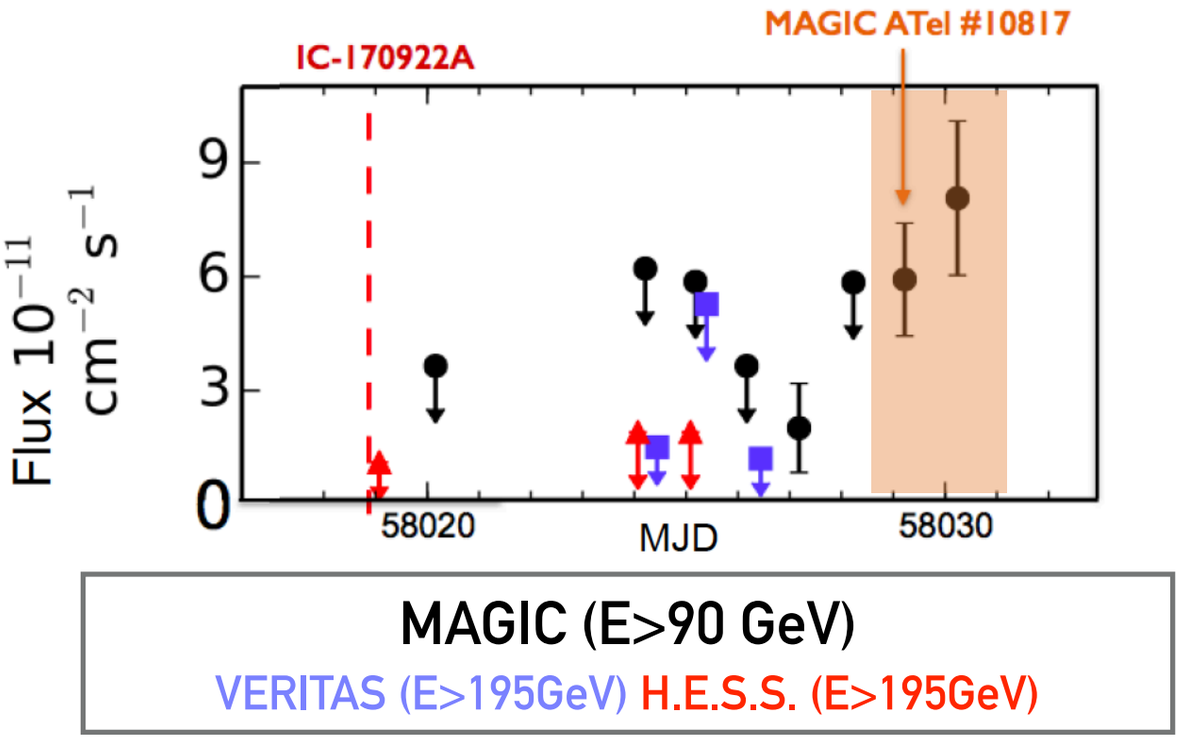

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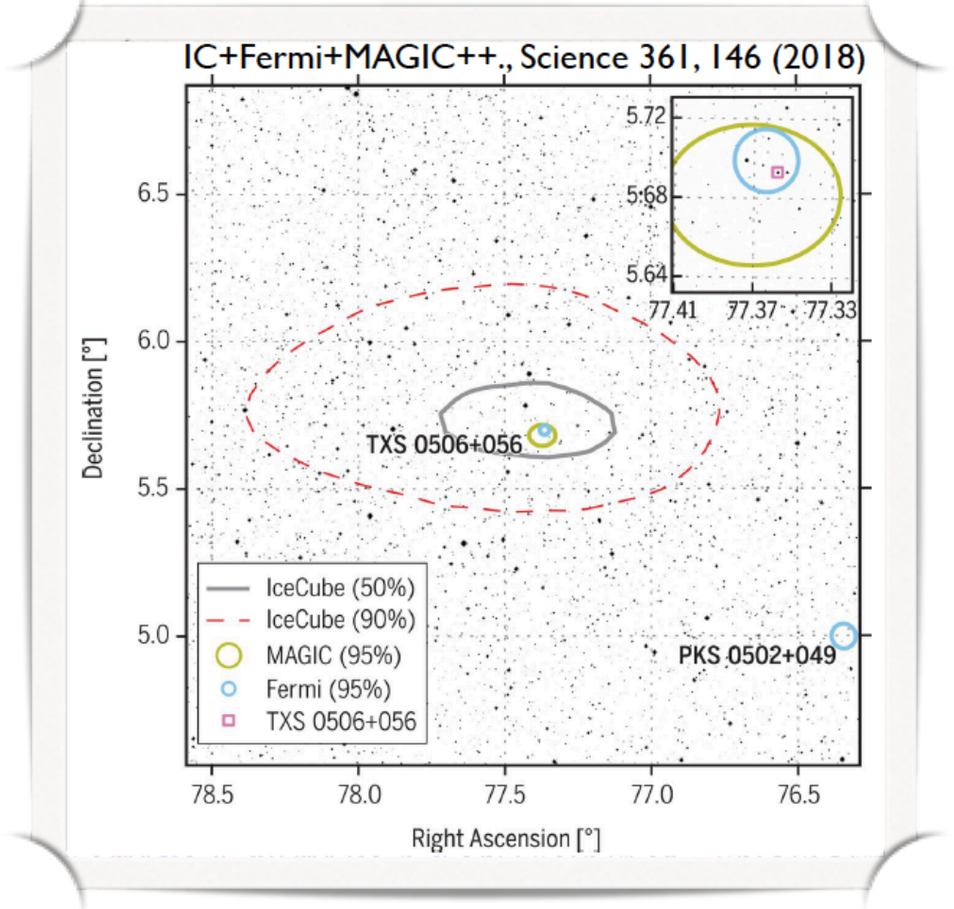

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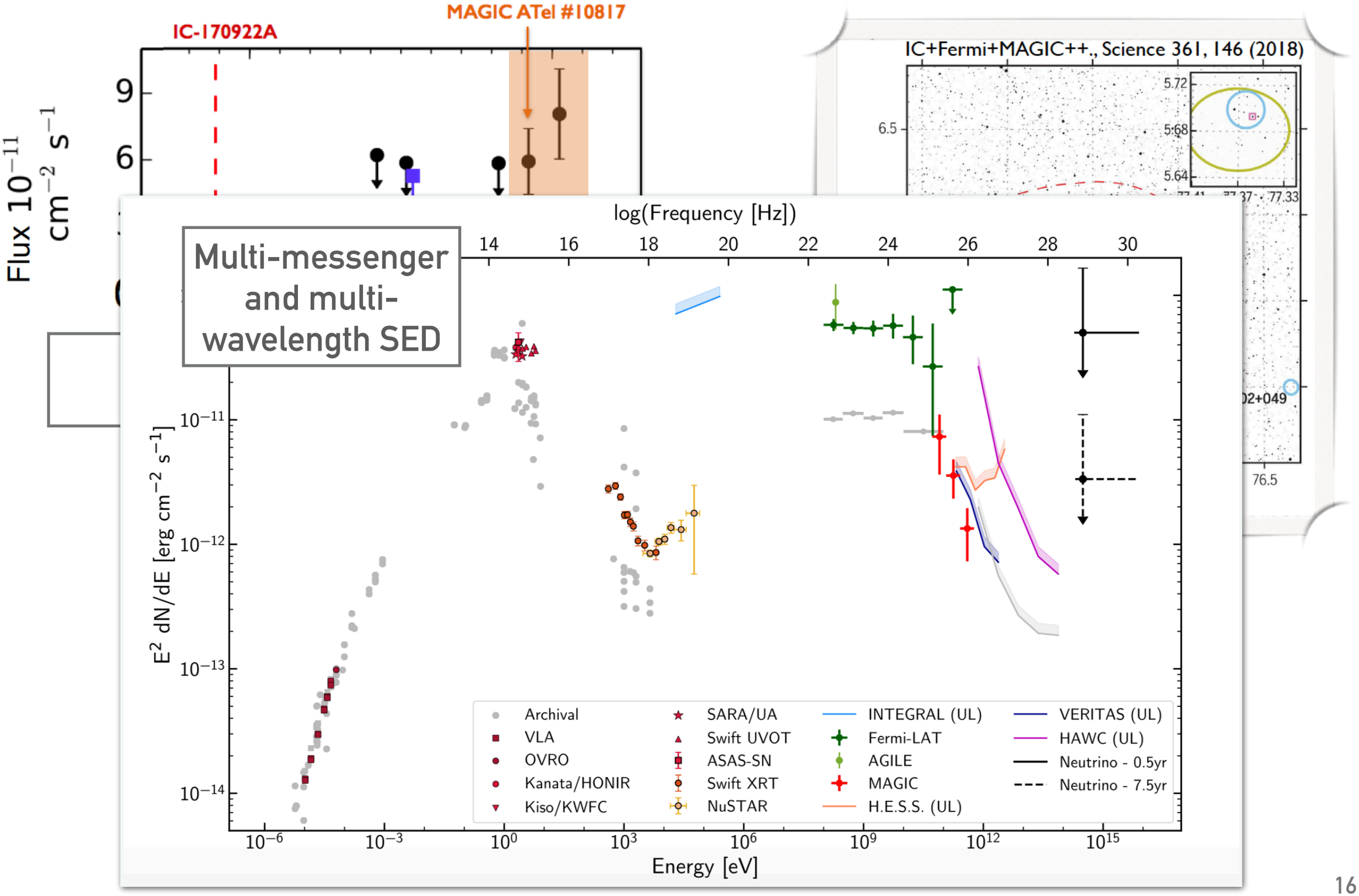
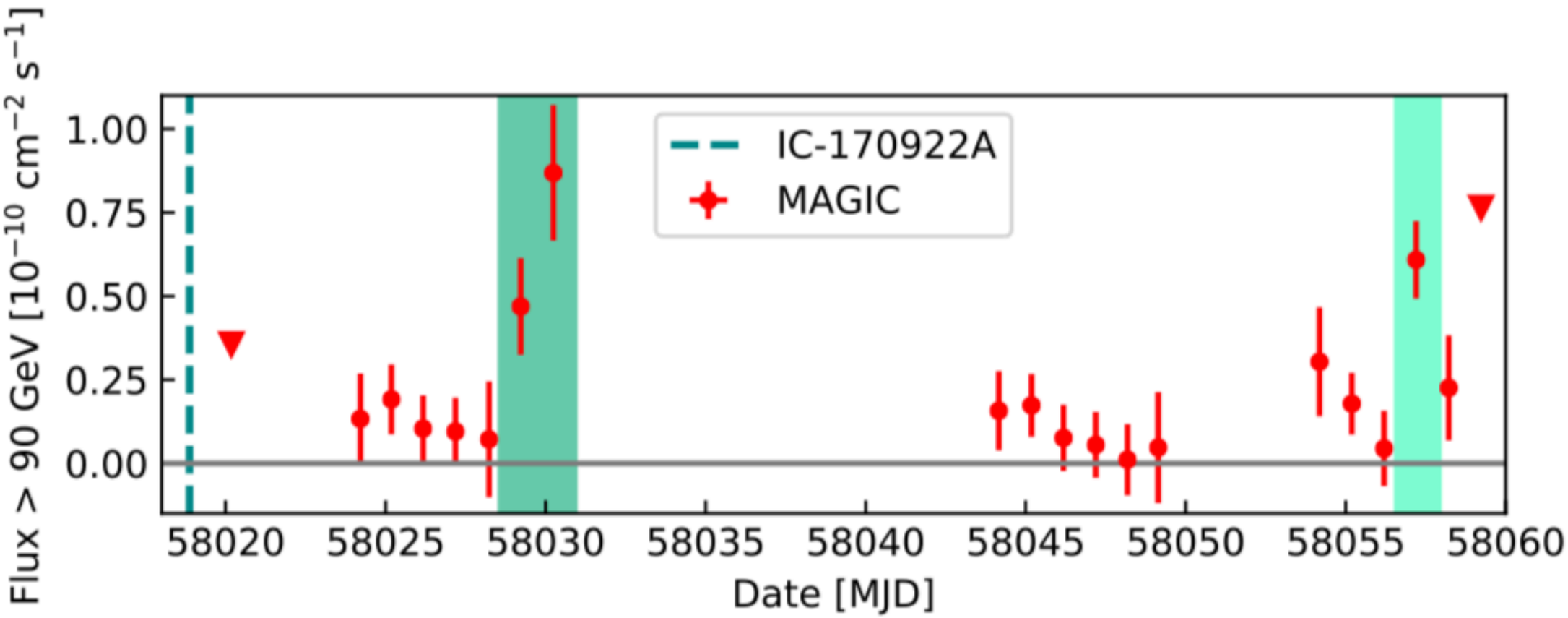
- Trigger alert from IceCube of a high energy neutrino event
- *Fermi*-LAT detects a blazar in a high gamma-ray state in the neutrino field of view
- IACTs observations triggered
- MAGIC detected a **significant signal** (just before the full moon break)

TEV PHOTONS FROM A NEUTRINO EMITTING BLAZARS



MAGIC FOLLOW UP OBSERVATIONS



- The blazar was monitored by the three IACTs
- Light curve with the lowest energy threshold: **MAGIC**
  - Variable TeV emission clearly detected

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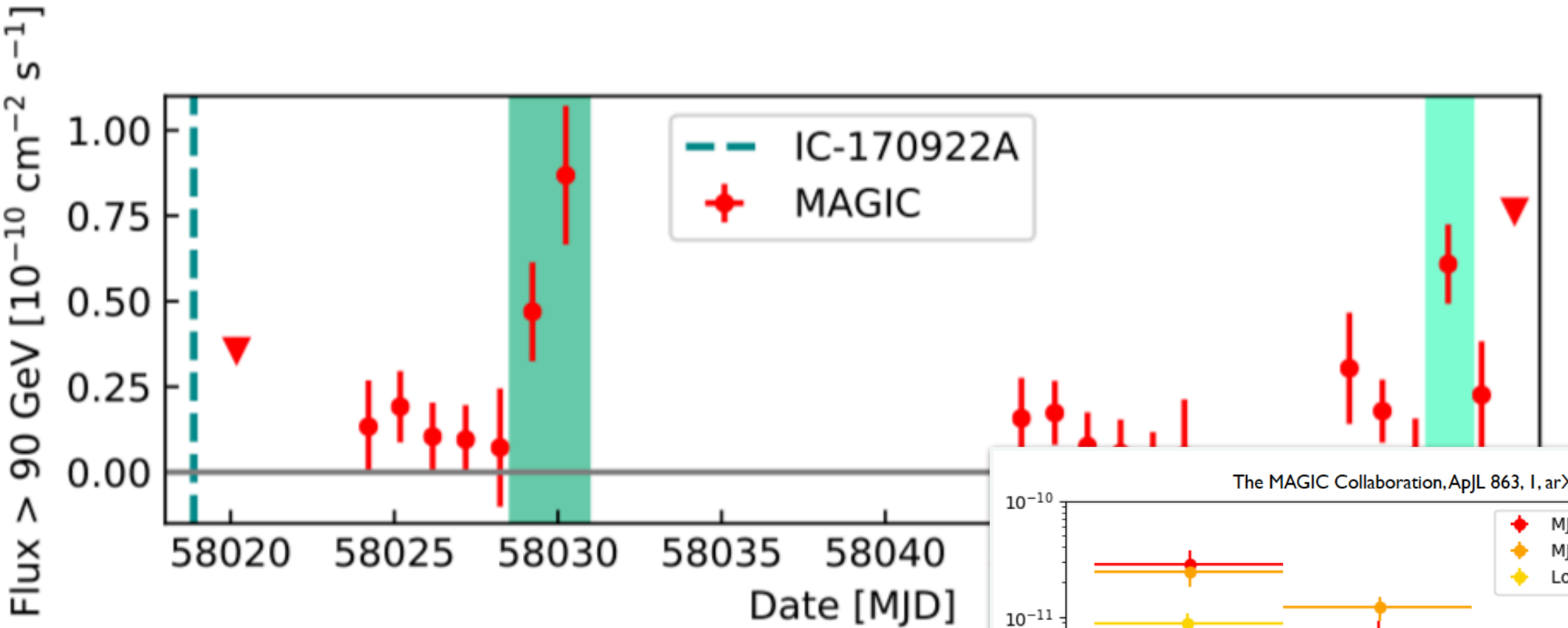
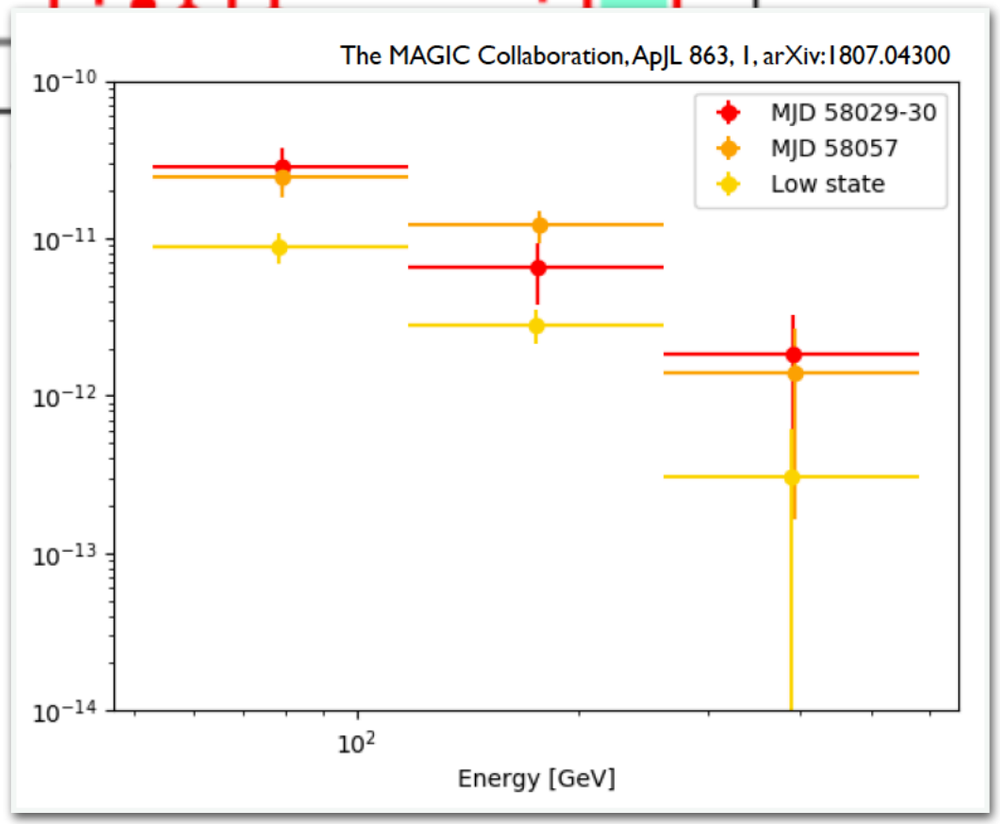


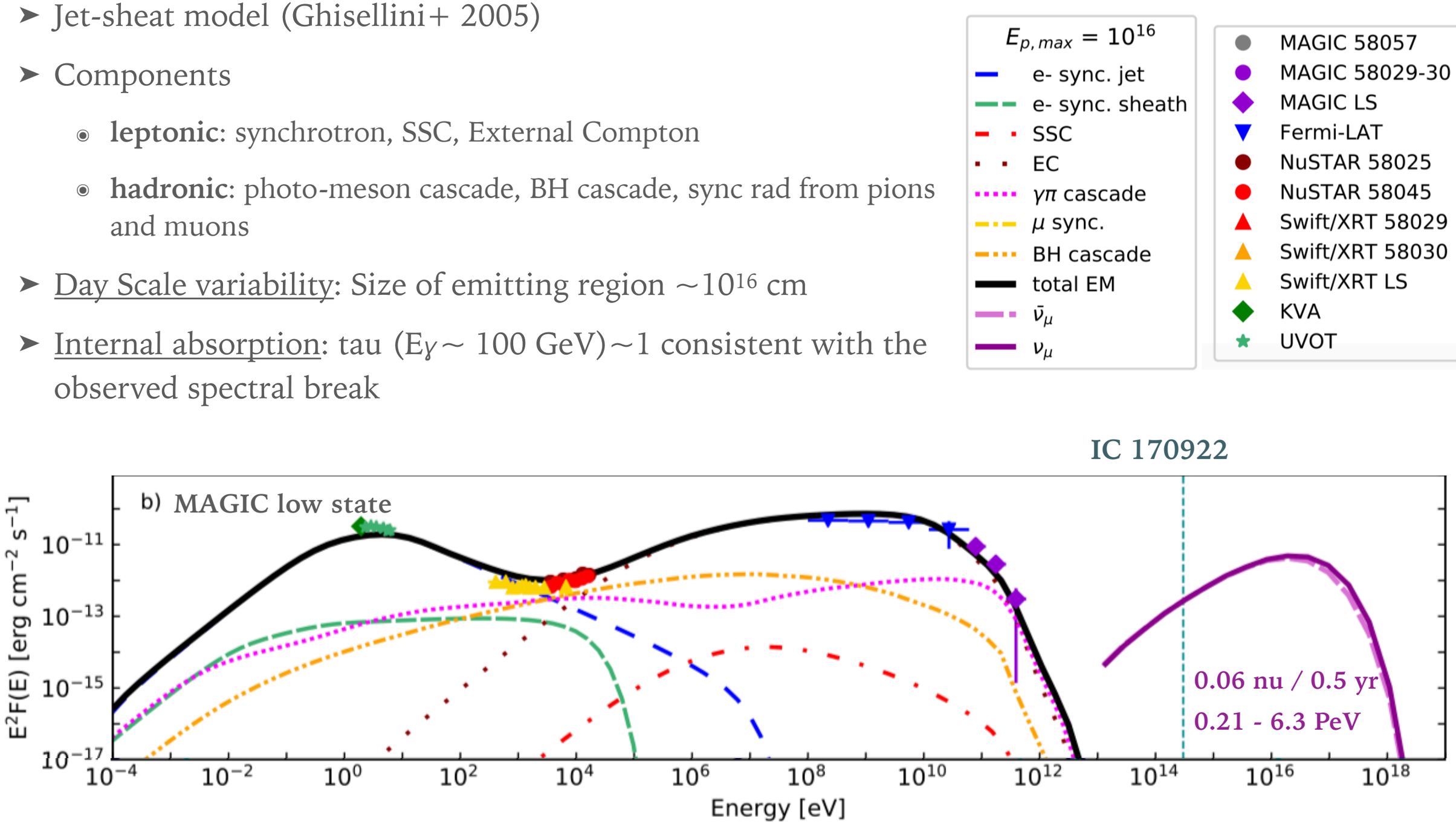


- The blazar was monitored by the three IACTs
- Light curve with the lowest energy threshold: **MAGIC**
  - Variable TeV emission clearly detected
  - No significant changes in the spectral shape

MAGIC Coll. 2018

MODELING THE NEUTRINO BLAZAR

- Jet-sheat model (Ghisellini+ 2005)
- Components
  - **leptonic**: synchrotron, SSC, External Compton
  - **hadronic**: photo-meson cascade, BH cascade, sync rad from pions and muons
- Day Scale variability: Size of emitting region $\sim 10^{16}$ cm
- Internal absorption: tau ($E_\gamma \sim$ 100 GeV)$\sim$1 consistent with the observed spectral break



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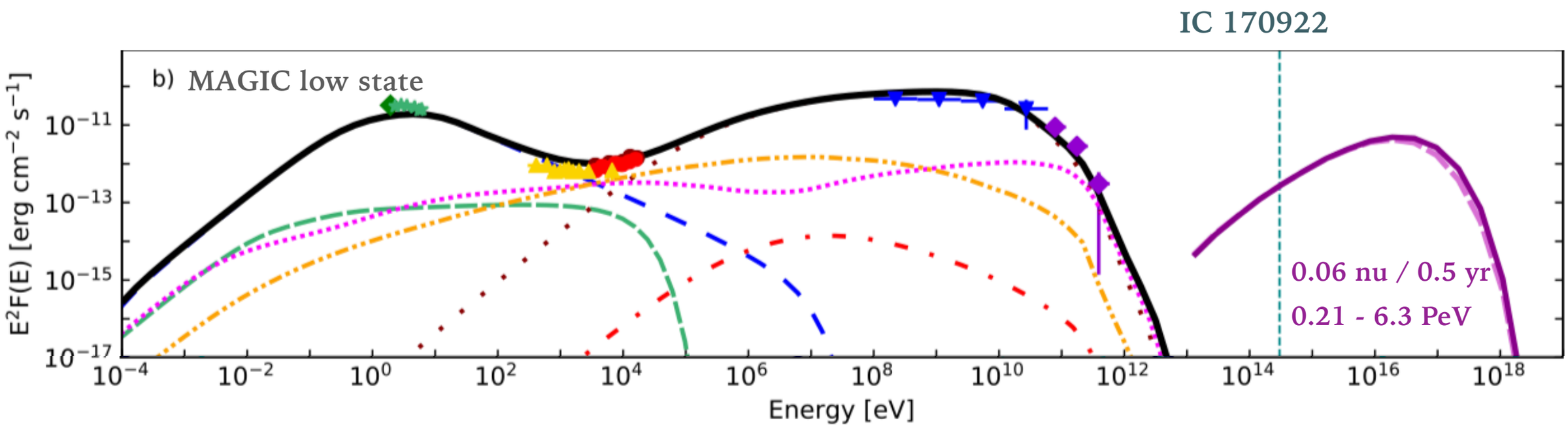
- **X-ray and VHE gamma-ray data set tight constraints on max. proton energy $E_{p,max}$**
- **Scan of $E_{p,max}$: 10^{14}–10^{18} eV (co-moving frame)**
  - **TXS 0506+056 able to accelerate CR to UHE!**



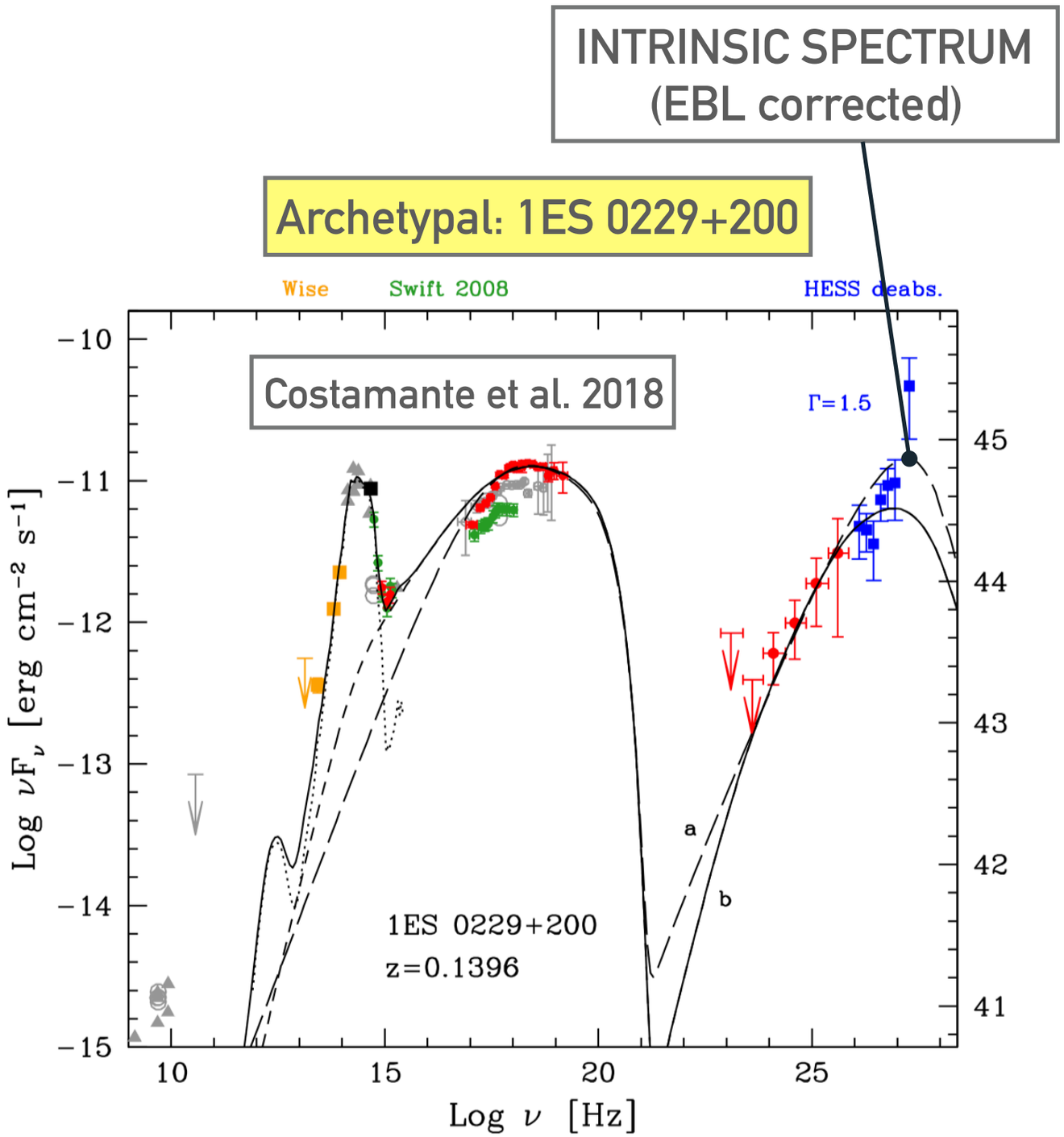
Extreme Blazars

Testing the limit of acceleration in jets

EXTREME BLAZARS

- EHBLs: extreme synchrotron peak BL Lac objects (nu peak above 10^{17})
- MeV and TeV data probe two different peaks
  - **MeV observations are crucial since they test the limit of particles acceleration**
- The problem is that extreme blazars are **relatively faint**
  - difficult to detect in a single snapshot by current generation of instruments

In some extreme blazars a hard TeV spectrum was detected: ideal probes for cosmological studies



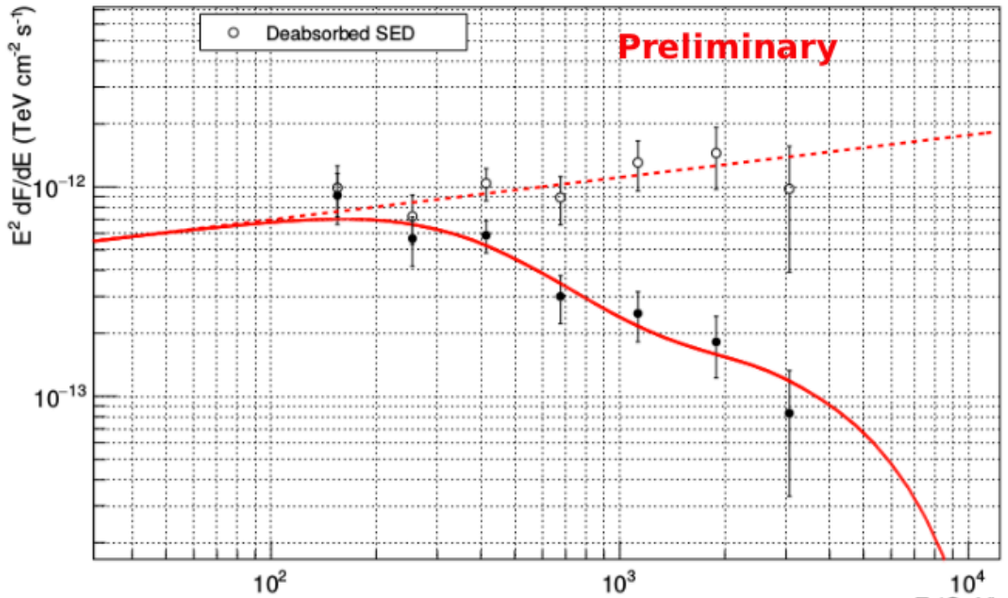
1ES 0229+200 MULTI-YEAR CAMPAIGN WITH MAGIC

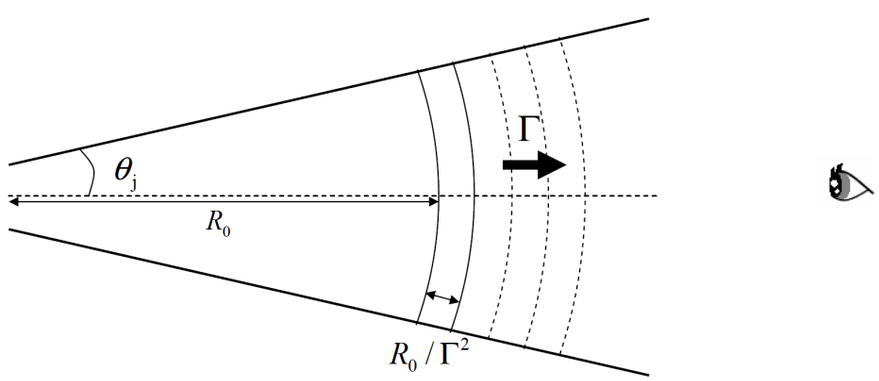
- 1ES 0229+200 is extremely interesting since the intrinsic (EBL corrected) spectrum extends to several TeV without breaks

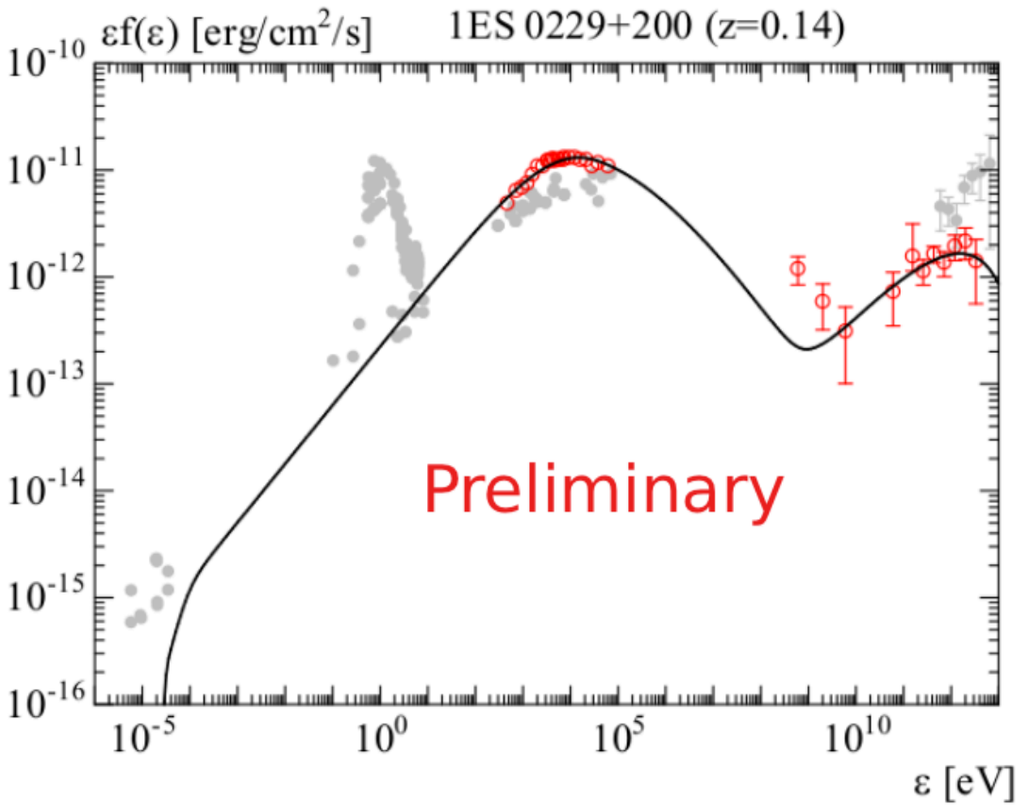
- It was observed with MAGIC for 117.5 hours from 2012 to 2017

- The flux detected was 40% lower than in previous observations

- Modelled with SSC model (1D steady model, Asano et al. 2014)





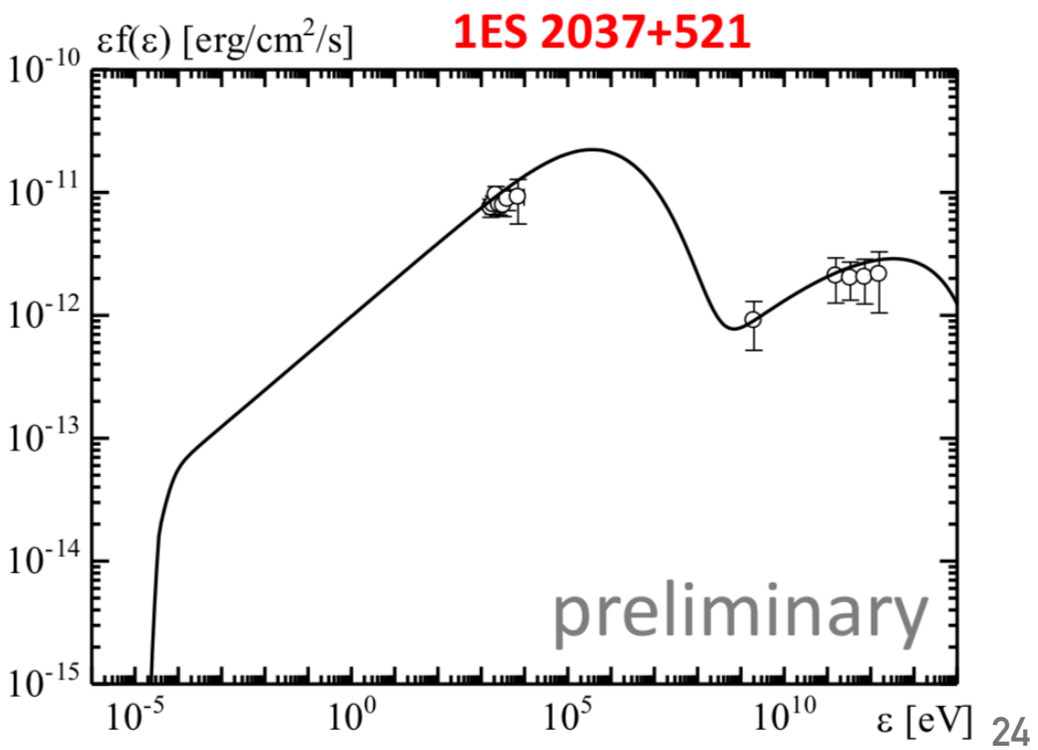


EXTREME BLAZARS WITH MAGIC

Aim of the project: Study of the broad band emission and characterisation of the extreme blazar class

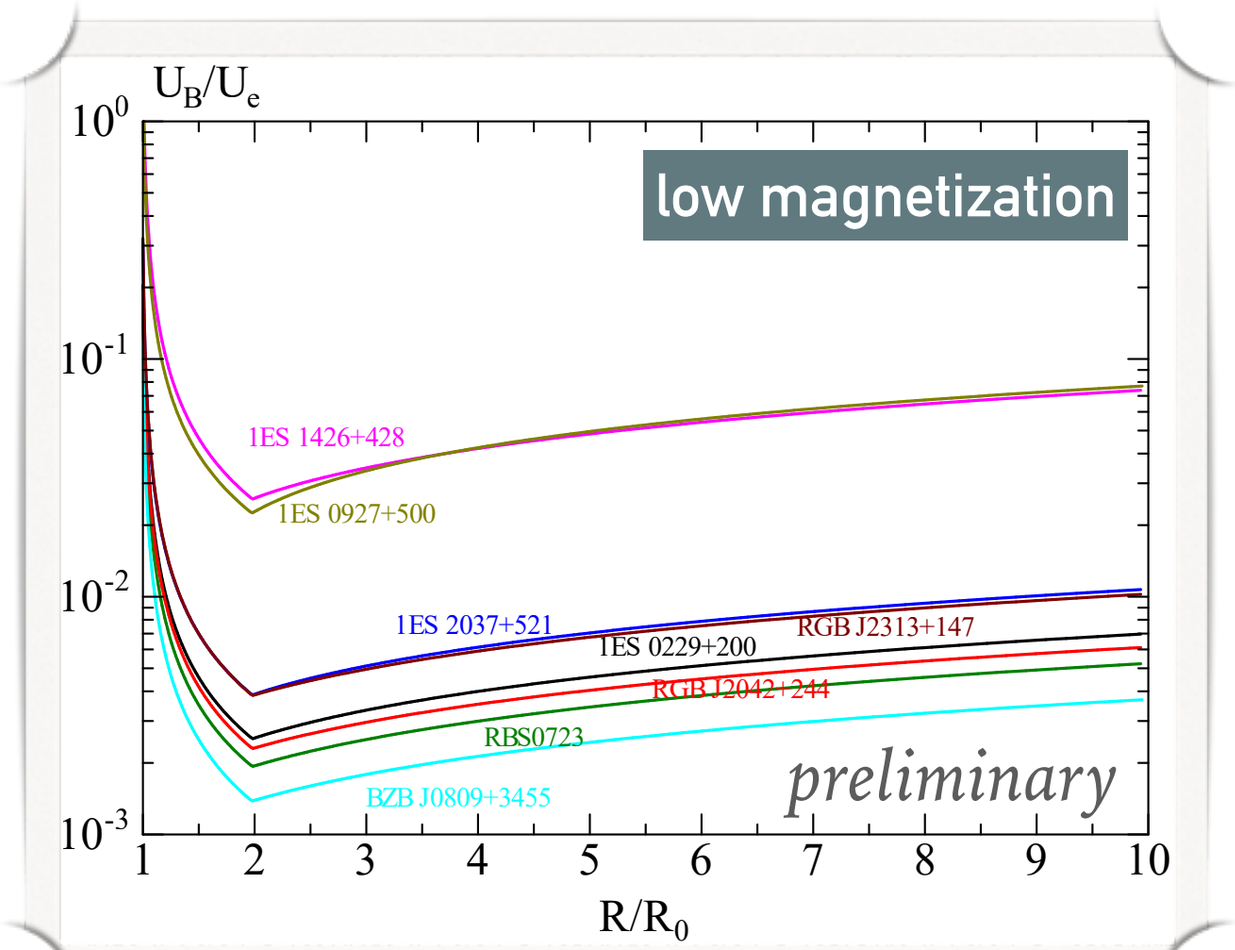
- From January 2011 to April 2018:
  - ~180 h on new sources
  - 11 sources were observed
    - **4 new** TeV emitters discovered
    - **1 known** TeV emitter confirmed
    - **1 hint** of signal
    - **5 no signal**
- Swift-XRT coordinated observations
- Modelled with SSC model (1D steady model, Asano et al. 2014)

Source	z
TXS 0210+515	0.049
PGC 2402248	0.065
BZB J0809+3455	0.083
RBS 0723	0.198
1ES 0927+500	0.187
RBS 0921	0.236
1ES 1426+428	0.129
1ES 2037+521	0.053
RGB J2042+244	0.104
RGB J2313+147	0.163



RESULTS OF SSC MODEL ON EXTREME BLAZARS

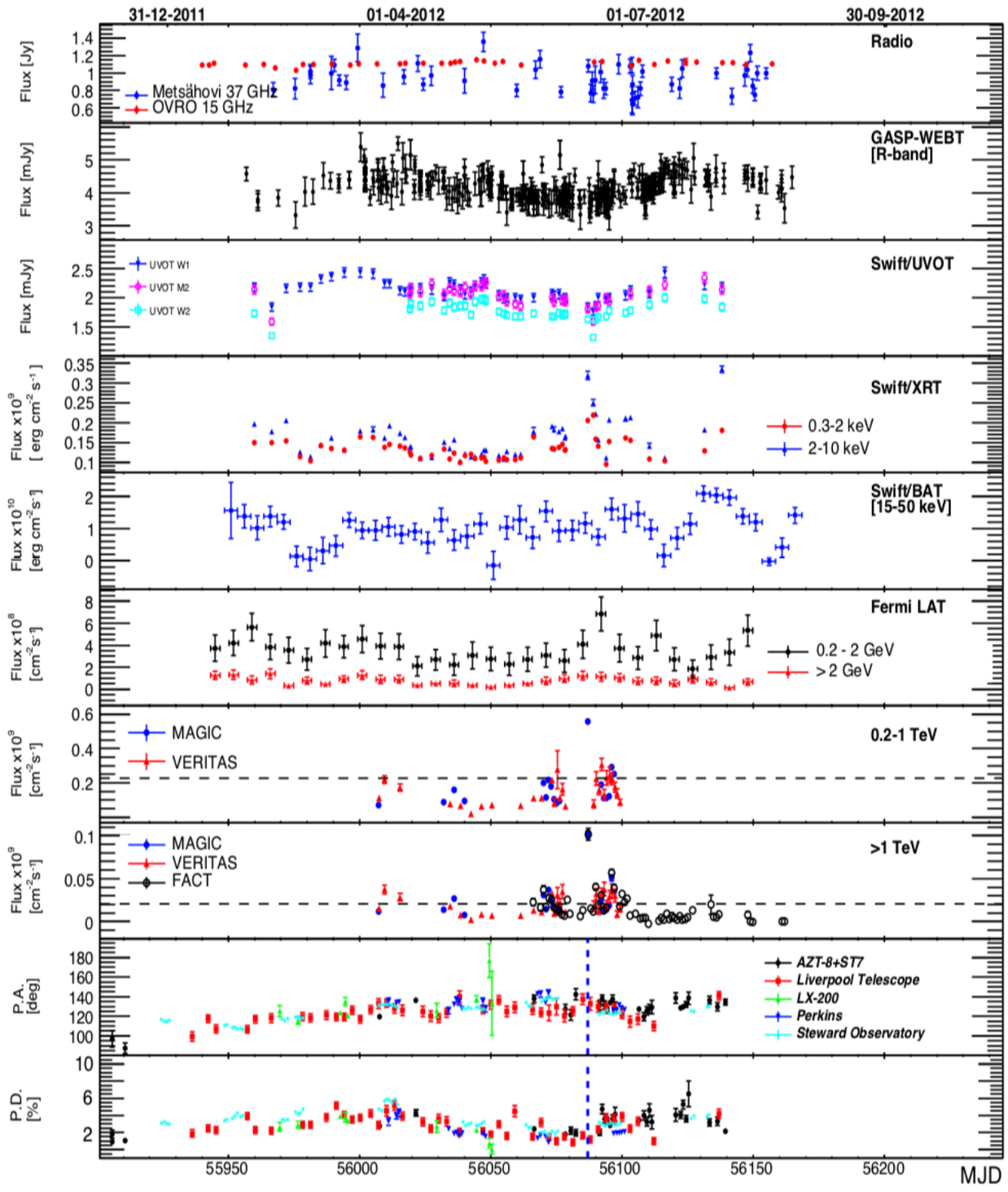
- Extremely low magnetization
- Not all extreme blazars are hard TeV emitters:
  - this class of objects presents different behaviour at gamma-ray frequencies
- Better coverage (in particular at MeV frequencies) and simultaneous modelling is necessary to unambiguously probe the SED



MKN 501: EXTREME BEHAVIOUR IN 2012

MAGIC Coll. 2018

- Some objects behaves as **extreme blazars** only **temporarily**
- Example: Mkn 501
  - **multi-wavelength campaign in 2012**



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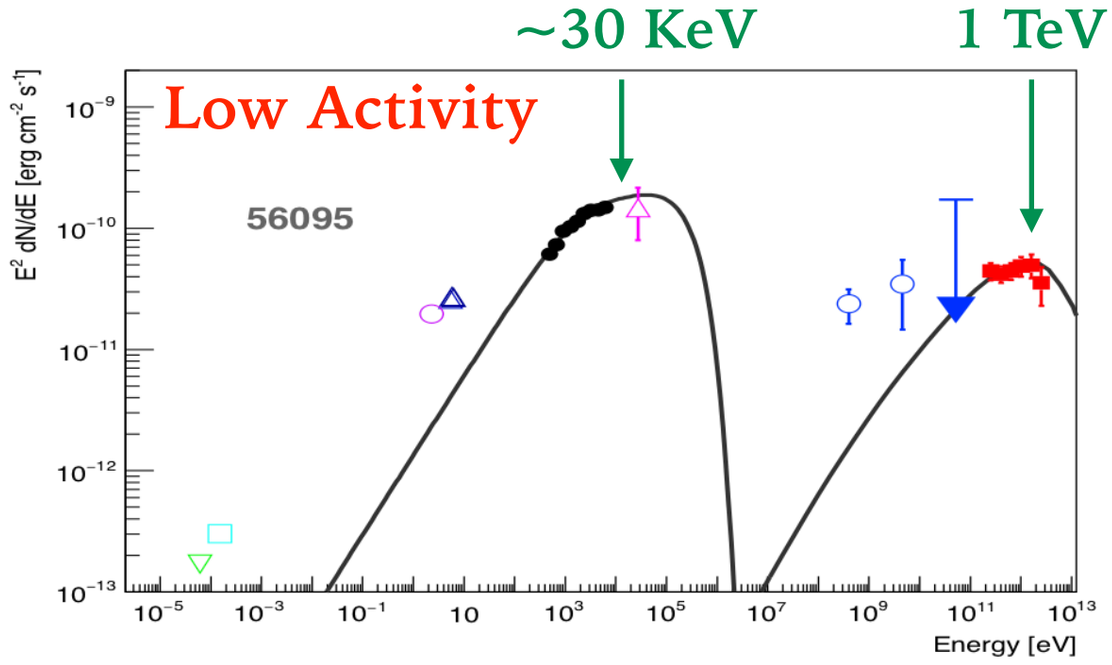
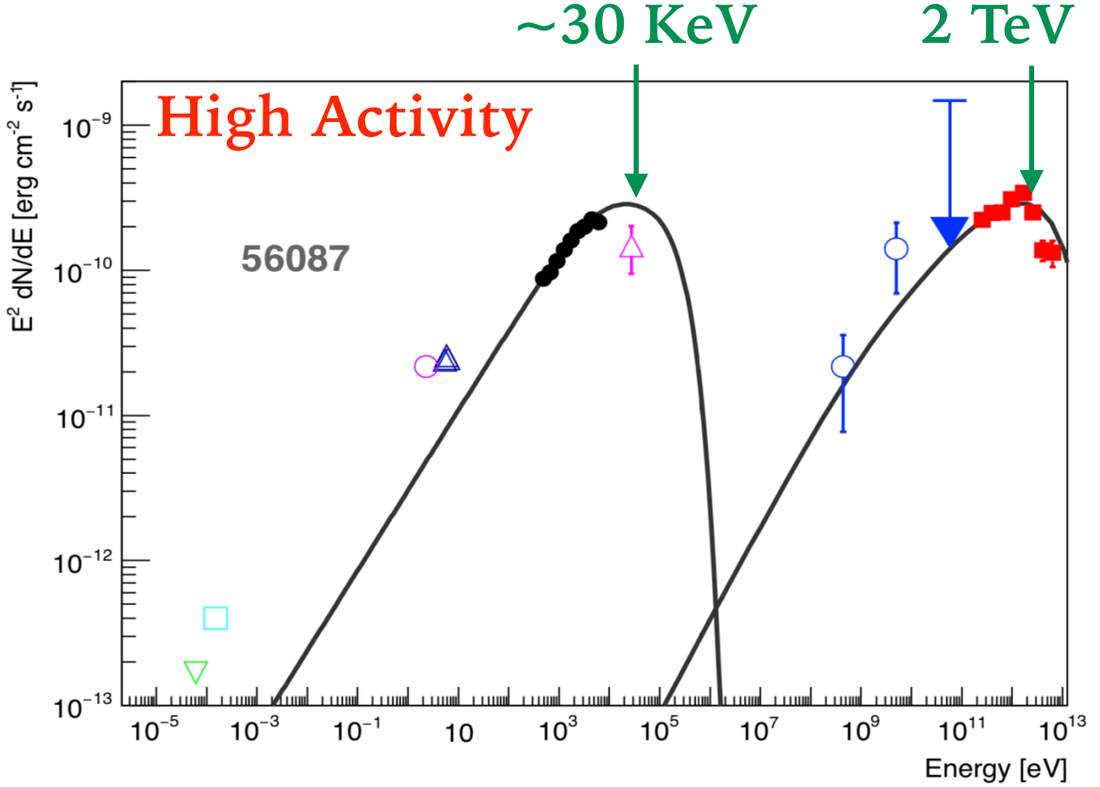
  - extremely hard spectral index in X-rays and VHE gamma rays, and both during low and high state
  - In 2005 the spectrum was soft during the low state





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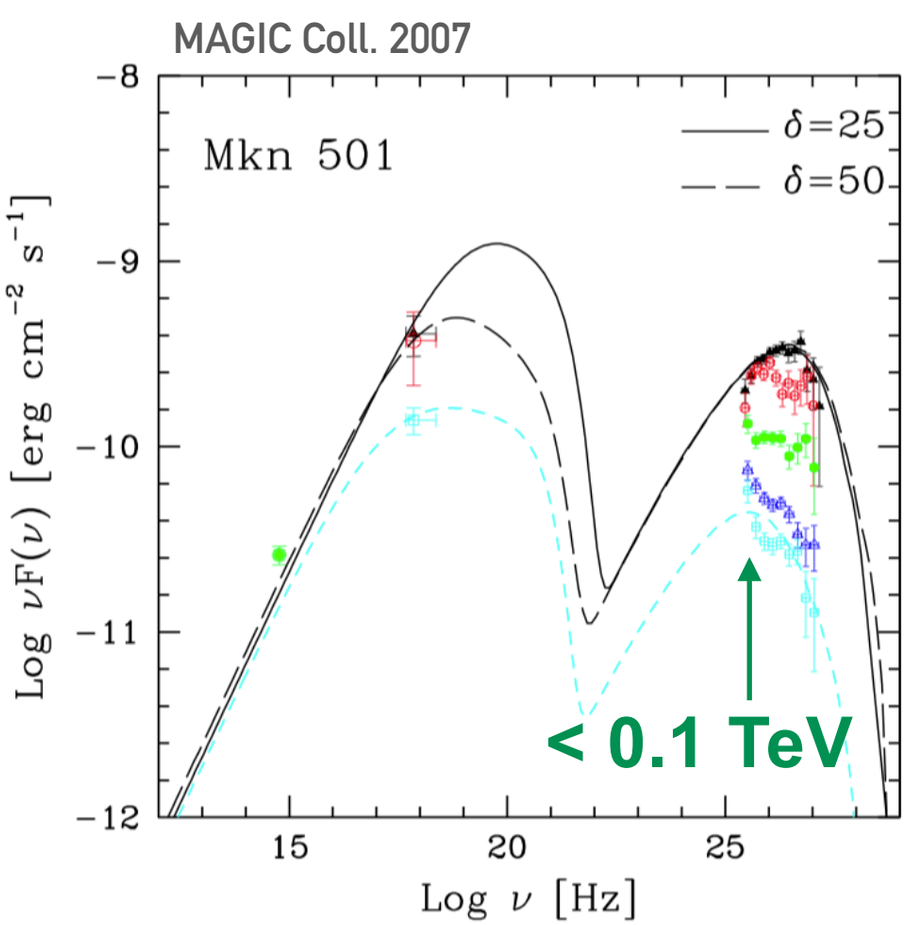
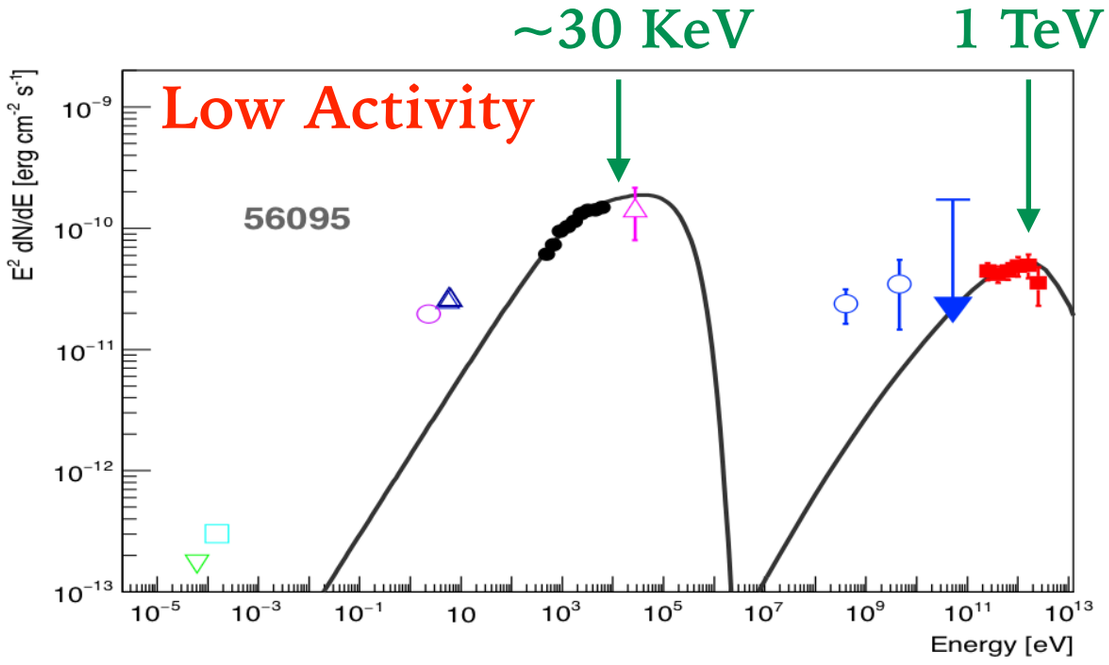
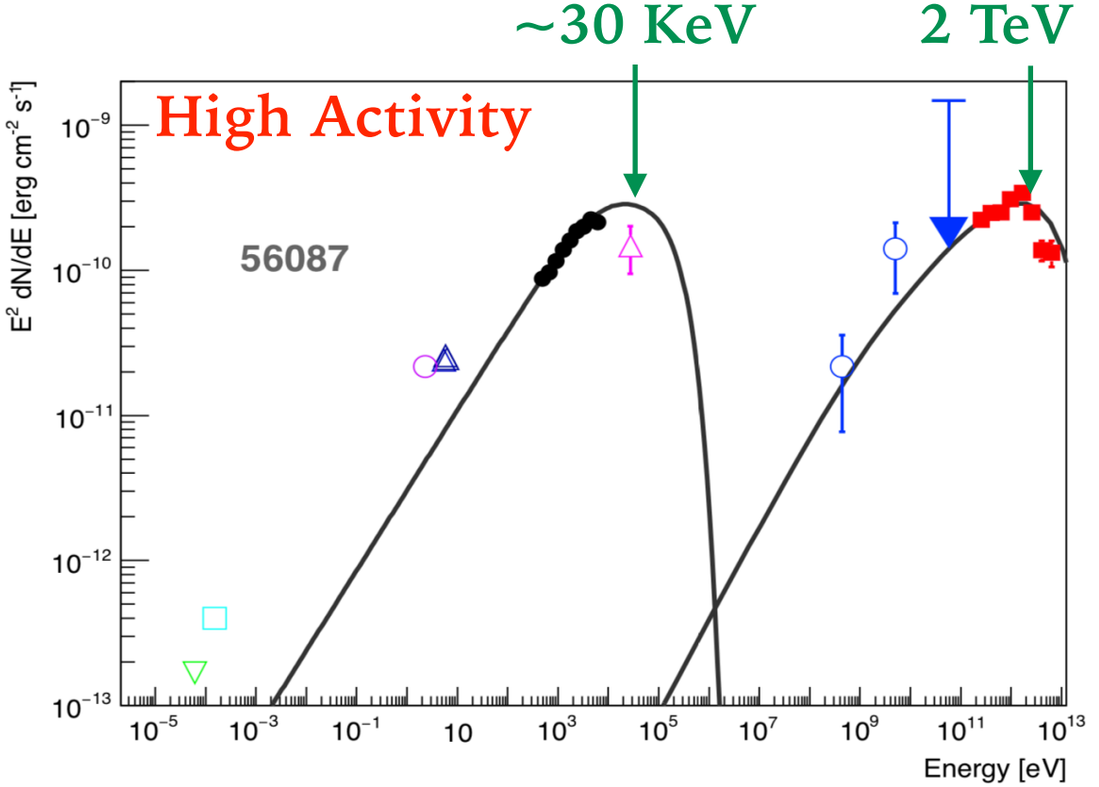
MAGIC Coll. 2007



MAGIC Coll. 2018

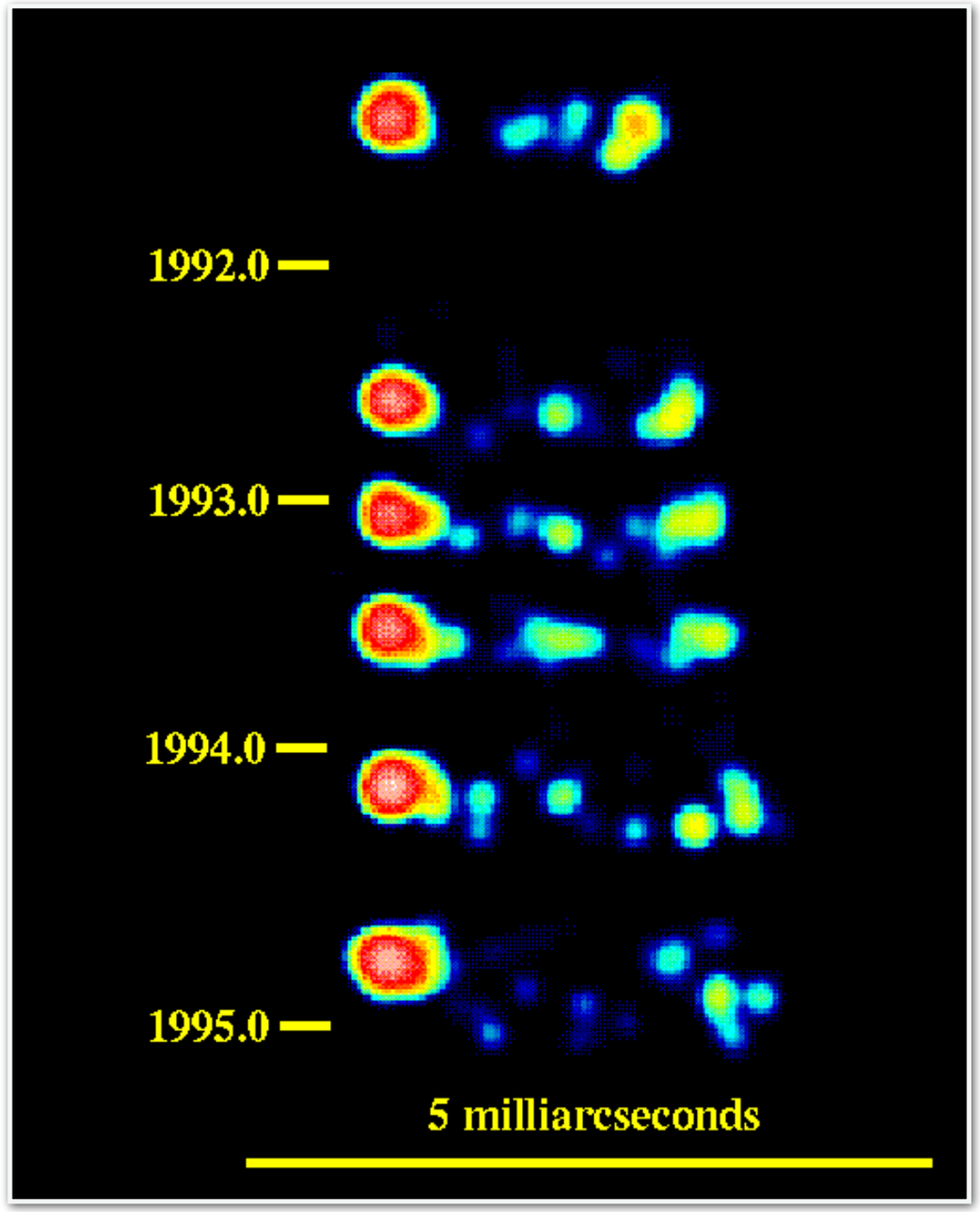




Complex behaviour still not fully understood

FSRQs

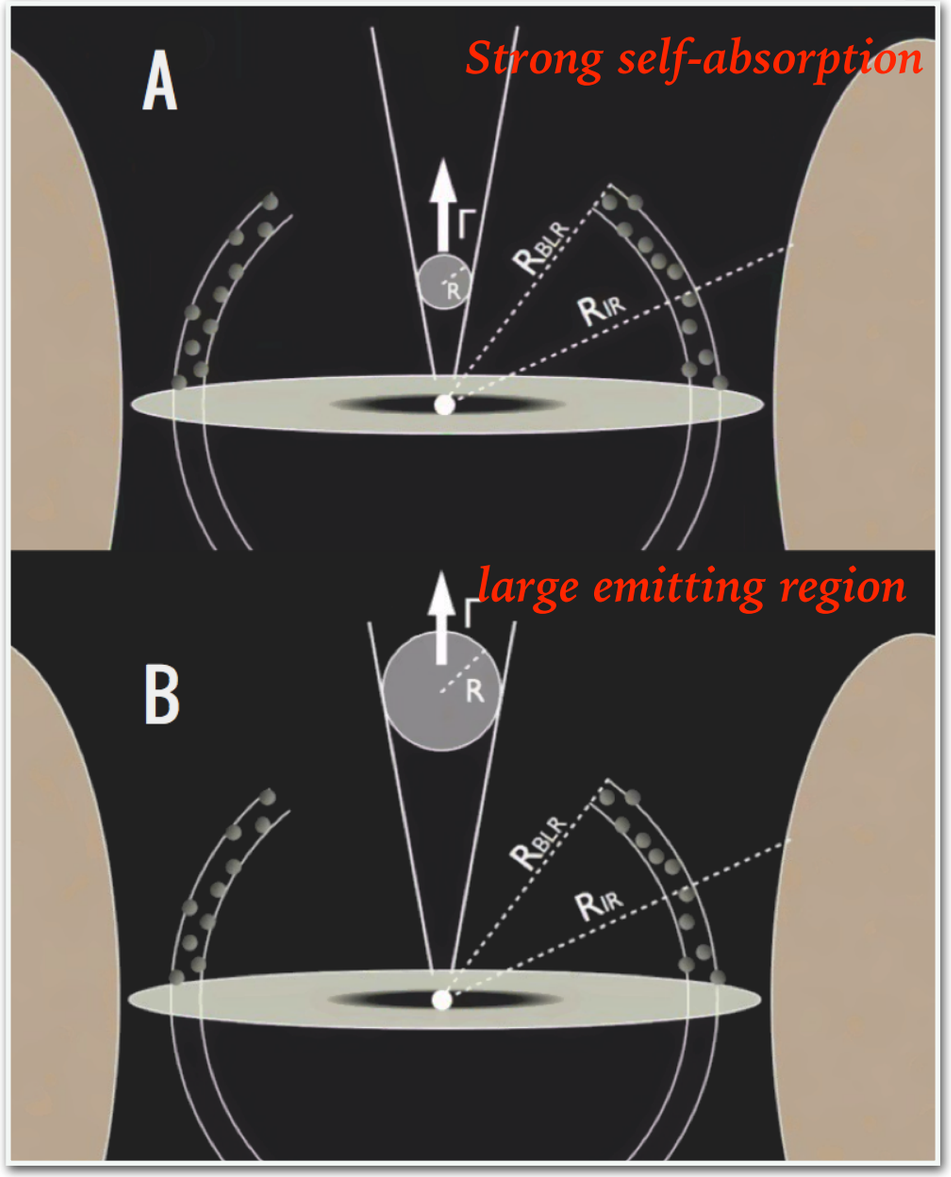
Expanding the gamma ray Universe



TeV FSRQ

Source	z	Discoverer	Year
B0218+367	0.944	MAGIC	2014
PKS 1441+25	0.939	MAGIC	2015
TON 599	0.72	MAGIC	2017
3C 279	0.5362	MAGIC	2006
S4 0954+65*	0.356?	MAGIC	2015
PKS 1222+216	0.432	MAGIC	2010
PKS 1510-089	0.361	HESS	2009
PKS 0736+017	0.189	HESS	2016

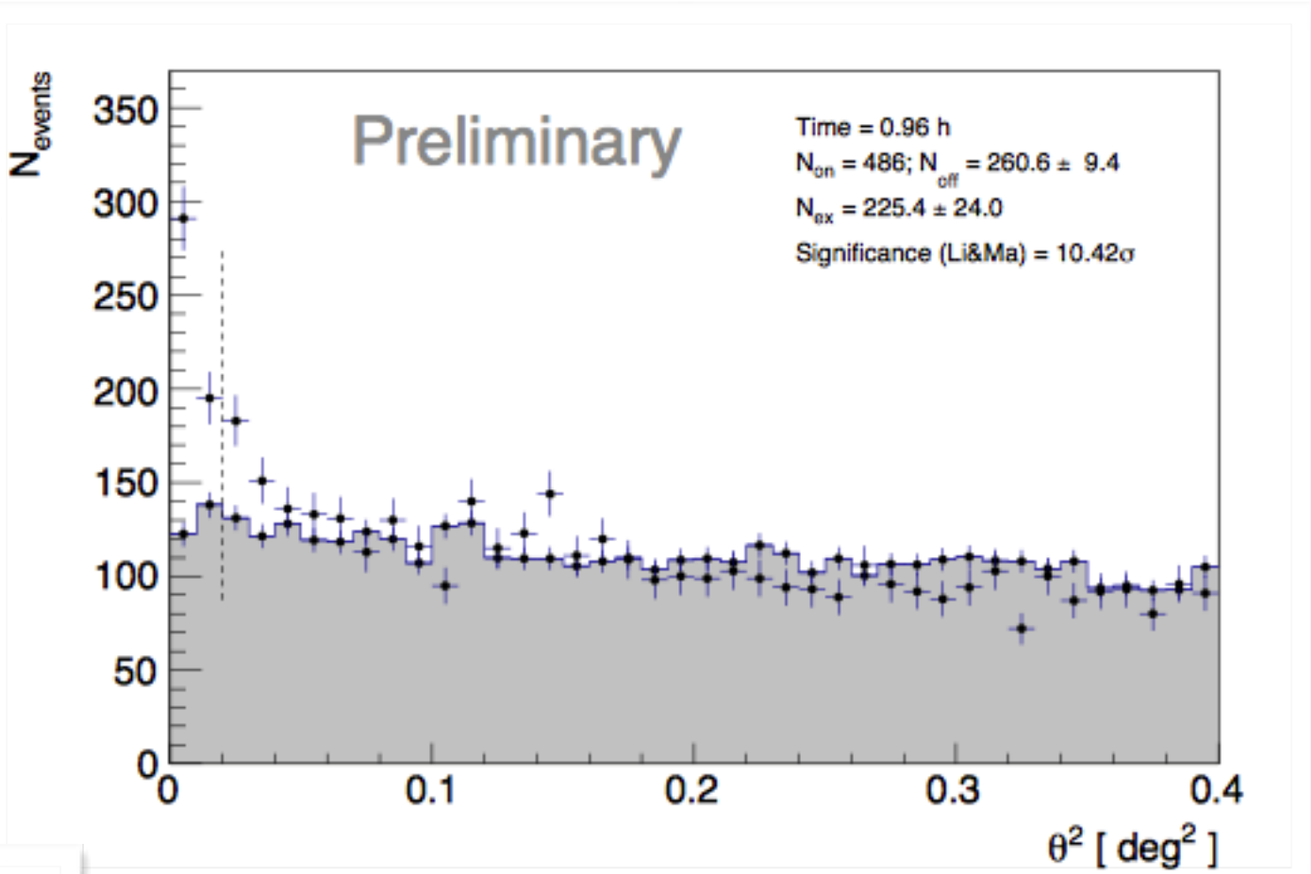
Scenarios for the Emitting region

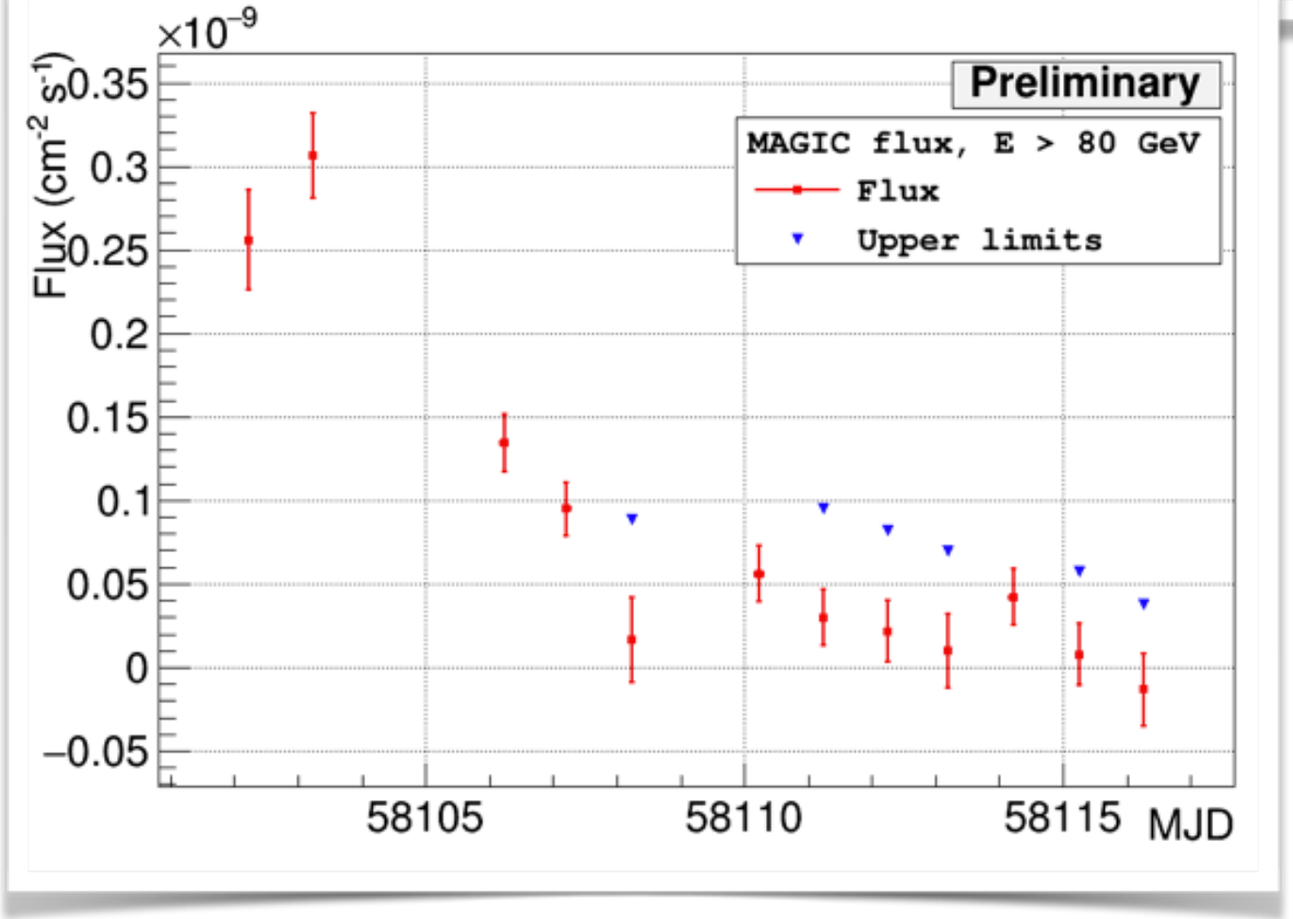


- Bright FSRQs: **distance record** for VHE gamma rays!
- FSRQs are usually detected during flares (role of *alerts* is essential)
- Jet astrophysics: constrain the emitting region size (variability) and location (self absorption arguments)

LATEST RESULT: TON 599

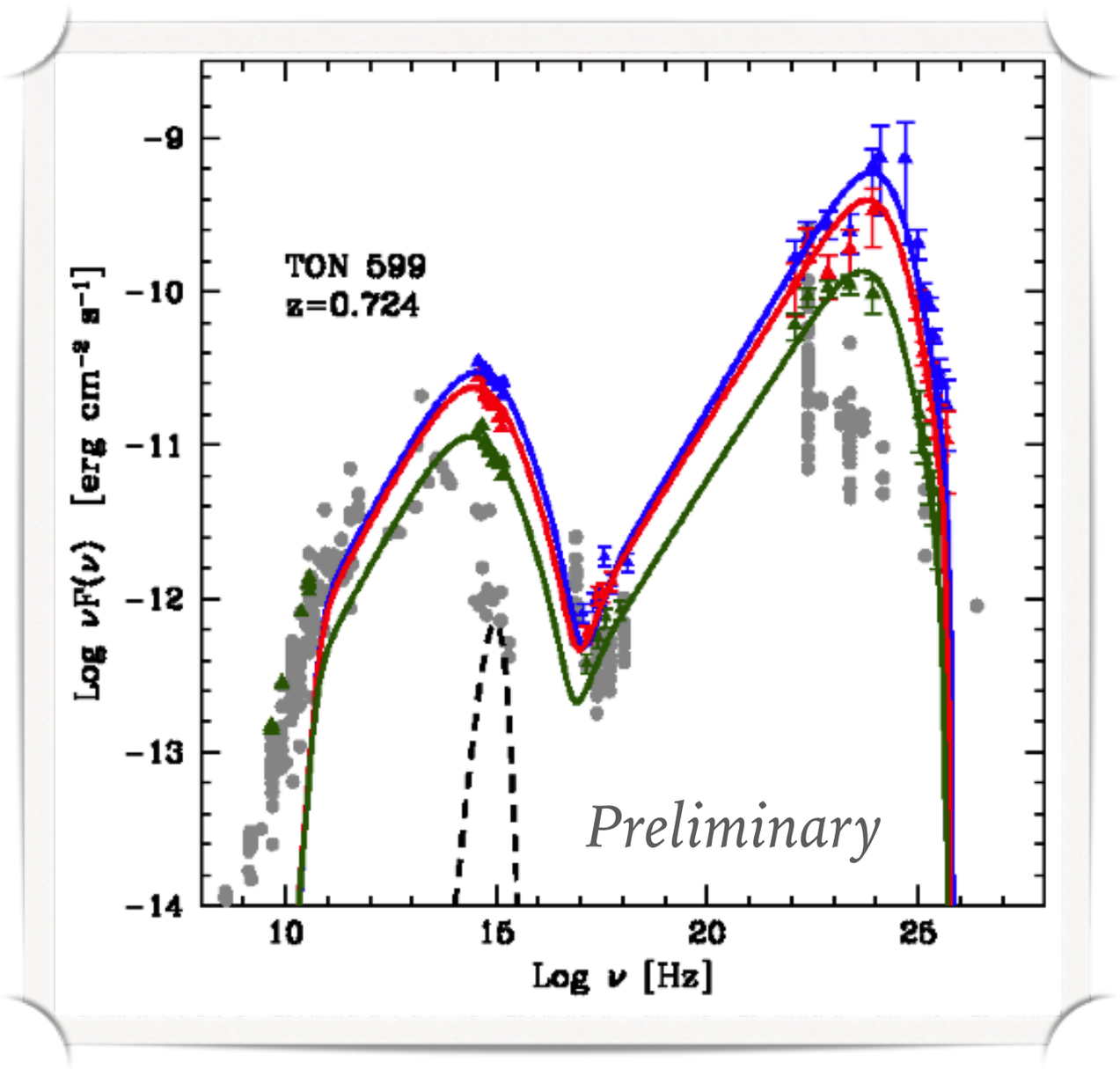
- Third farthest FSRQ (z = 0.72)
- Discovered by MAGIC during a flare in gamma rays



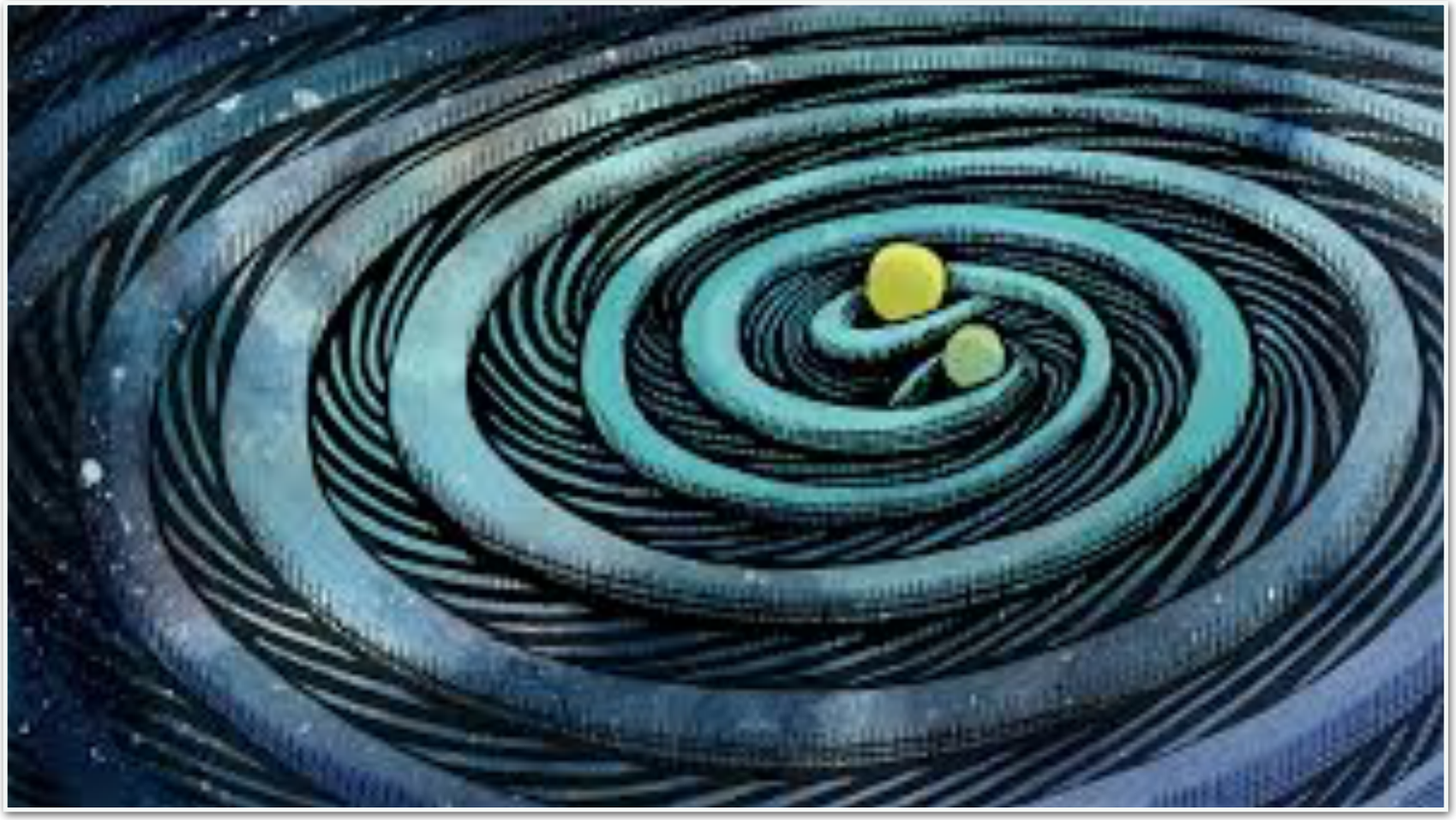


- Flux E > 80 GeV
- Peak flux on 2017-12-16:
  - 51% C.U.

MODELLING THE FSRQ TON 599



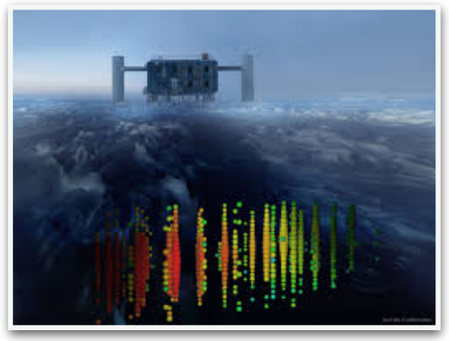
- SSC + External Compton
  - synchrotron emission dominant to the low-energy bump
  - SSC contributes ~50% in X-ray
  - High-energy: External Compton on the torus photons (black body @ 1000 K)
- emission region outside of BLR
- L_{disk} = 3.6e+45 erg/s



TRANSIENTS

Expect the unexpected

THE TRANSIENT PROGRAM IN A SNAPSHOT

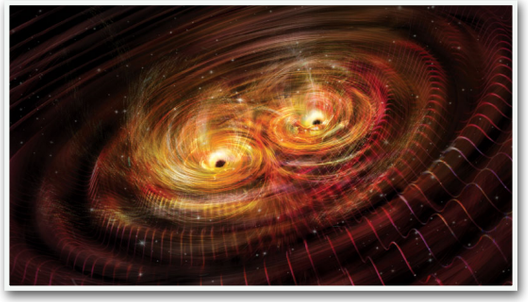


Gamma Ray Bursts

- 100 GRBs pointed with MAGIC
- Automatic (prompt) follow up

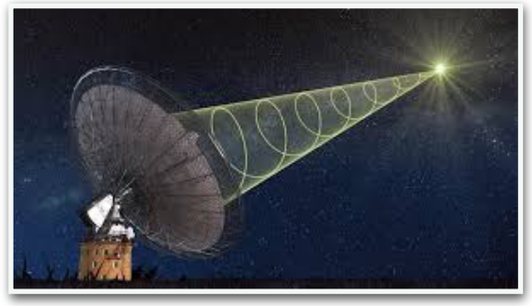
Neutrinos

- Follow-up of alerts of IceCube
- Real-time and archival events
- 60 h per year allocated



Gravitational Waves Counterparts

- Signed MoU with LIGO/Virgo in 2014
- Follow up of GW151226
- Ready for next run!



Fast Radio Bursts

- Observations of FRB 121102 in VHE and optical (MAGIC Coll. 2018)
- Coordination with radio observatories
- Multi wavelength campaign in September 2017

MAGIC DETECTED A GRB ABOVE 300 GEV!

First time detection of a GRB at sub-TeV energies; MAGIC detects the GRB 190114C

ATel #12390; ***Razmik Mirzoyan on behalf of the MAGIC Collaboration***
*on **15 Jan 2019; 01:03 UT***
Credential Certification: Razmik Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de)

Subjects: Gamma Ray, >GeV, TeV, VHE, Request for Observations, Gamma-Ray Burst

Referred to by ATel #: 12395

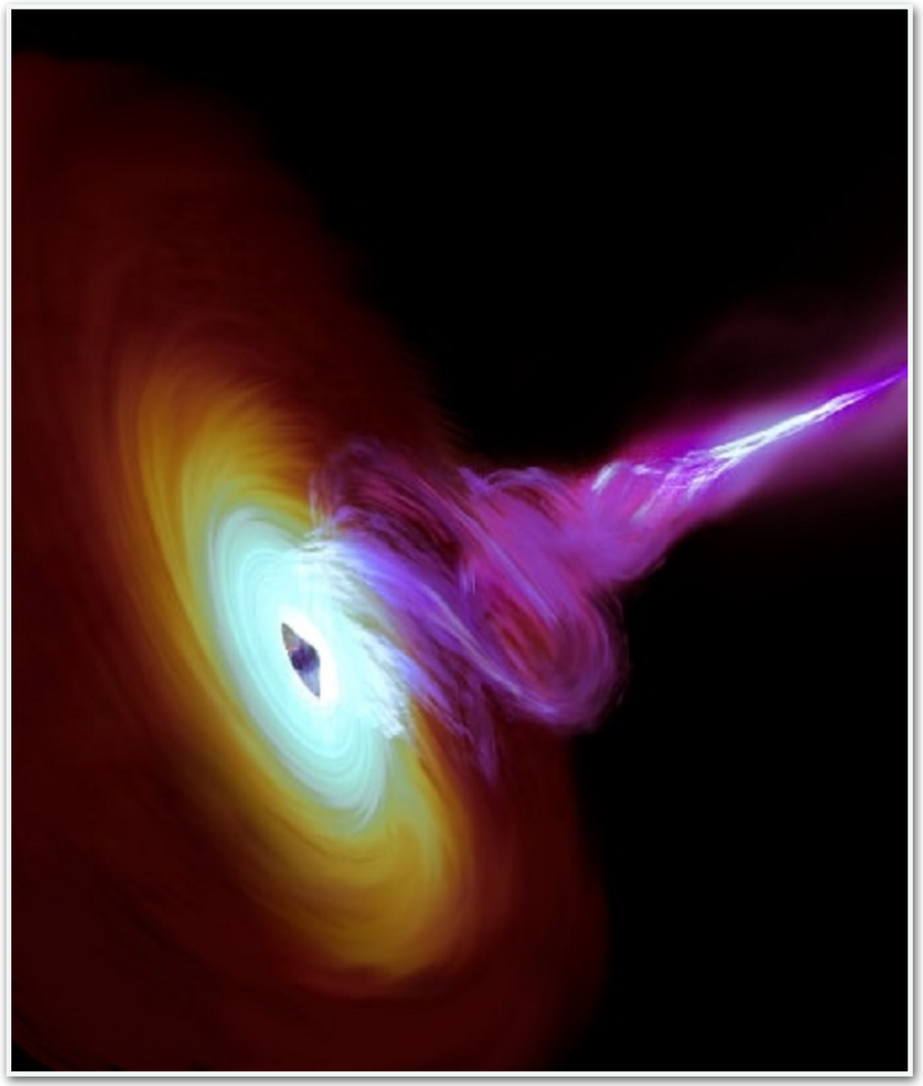
Tweet

The MAGIC telescopes performed a rapid follow-up observation of GRB 190114C (Gropp et al., GCN 23688; Tyurina et al., GCN 23690, de Ugarte Postigo et al., GCN 23692, Lipunov et al. GCN 23693, Selsing et al. GCN 23695). This observation was triggered by the Swift-BAT alert; we started observing at about 50s after Swift T0: 20:57:03.19. The MAGIC real-time analysis shows a significance >20 sigma in the first 20 min of observations (starting at T0+50s) for energies >300GeV. The relatively high detection threshold is due to the large zenith angle of observations (>60 degrees) and the presence of partial Moon. Given the brightness of the event, MAGIC will continue the observation of GRB 190114C until it is observable tonight and also in the next days. We strongly encourage follow-up observations by other instruments. The MAGIC contact persons for these observations are R. Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de) and K. Noda (nodak@icrr.u-tokyo.ac.jp). MAGIC is a system of two 17m-diameter Imaging Atmospheric Cherenkov Telescopes located at the Observatory Roque de los Muchachos on the Canary island La Palma, Spain, and designed to perform gamma-ray astronomy in the energy range from 50 GeV to greater than 50 TeV.

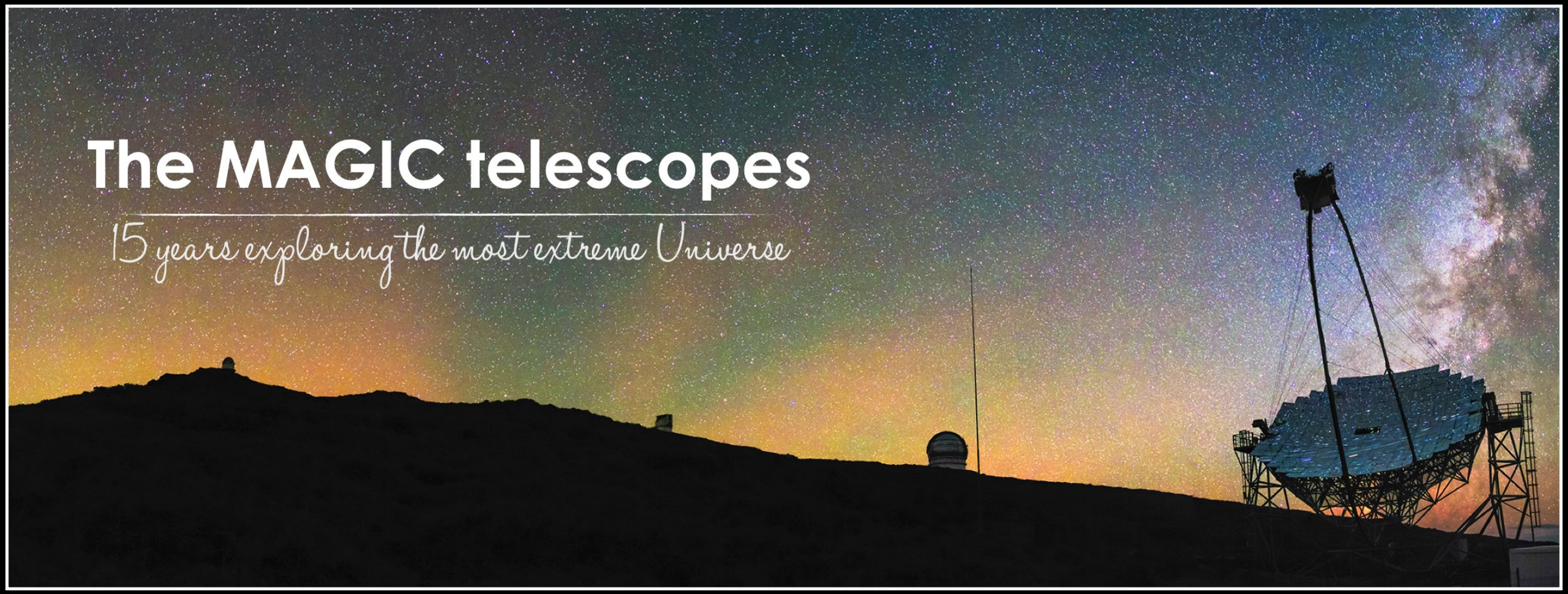
- Triggered by BAT
- Strong detection (20 sigma!)
- Observation started at T0+50s
- Non ideal conditions: high zenith, moon

Analysis ongoing

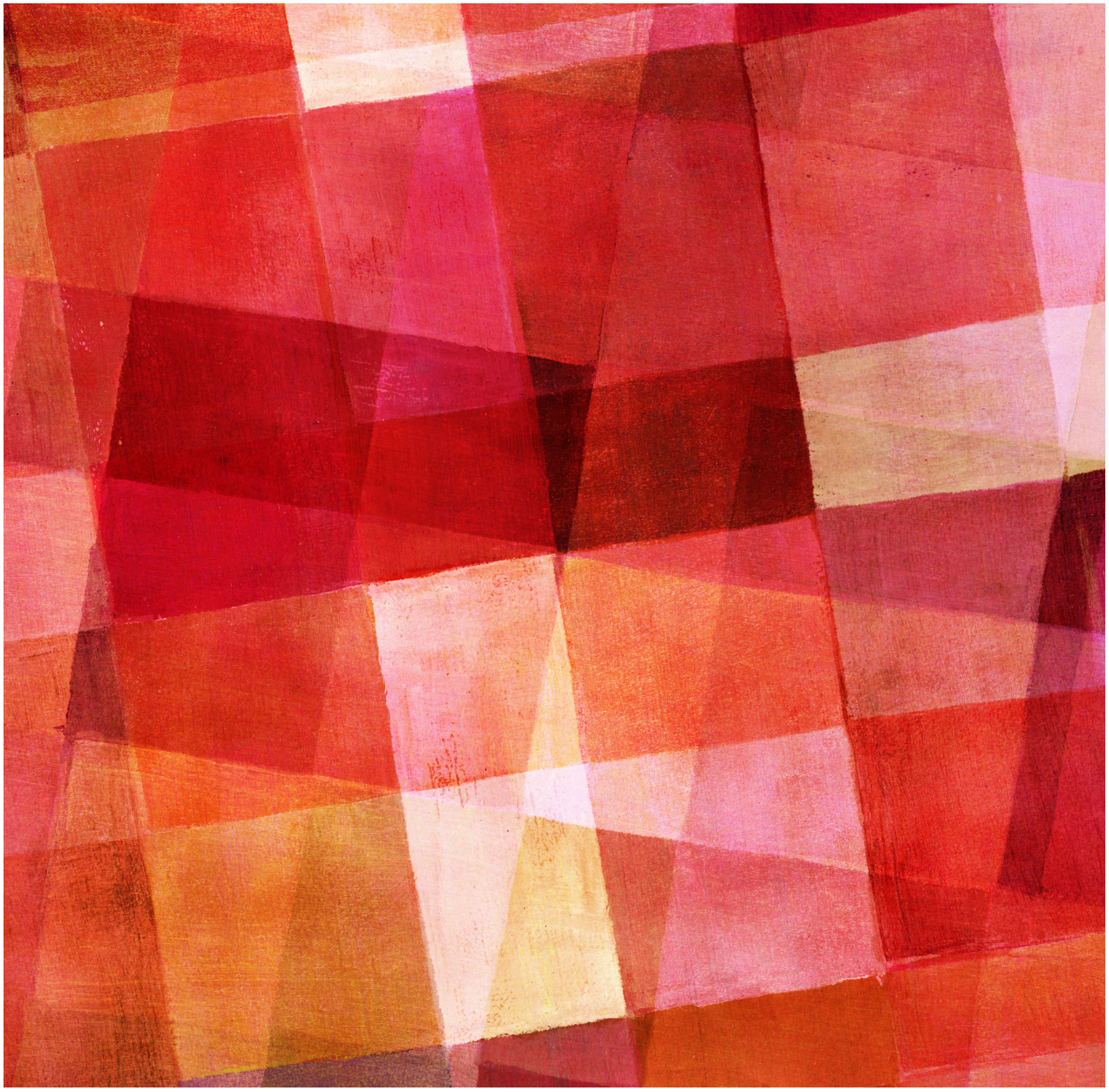
CONCLUSIONS



- After **15 years**, **MAGIC** is in its best shape ever
  - Observations under non-optimal conditions
  - MoU with several facilities
  - ToO observations and fast reactions, multi-wavelength campaigns
- **Rich extragalactic observational program**
  - AGNs
    - blazars (from FSRQs to extreme blazars)
    - radiogalaxies
  - GRBs and other transients
- MAGIC will observe **until 2024 and more**…
  Waiting for the next exciting result!

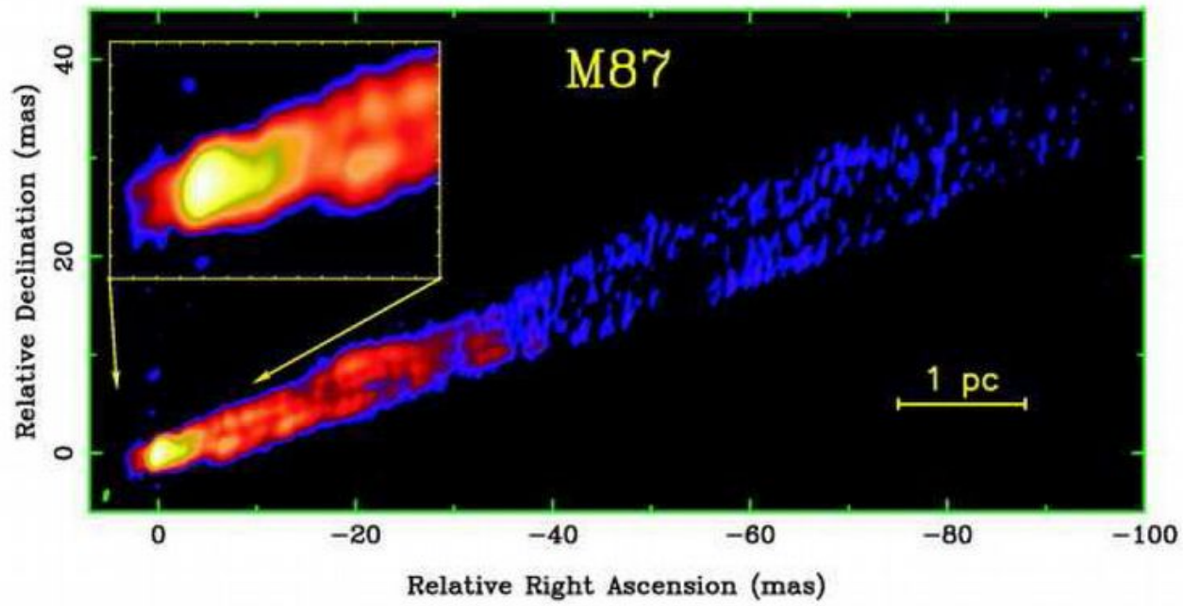

The MAGIC telescopes
15 years exploring the most extreme Universe

Thank you!

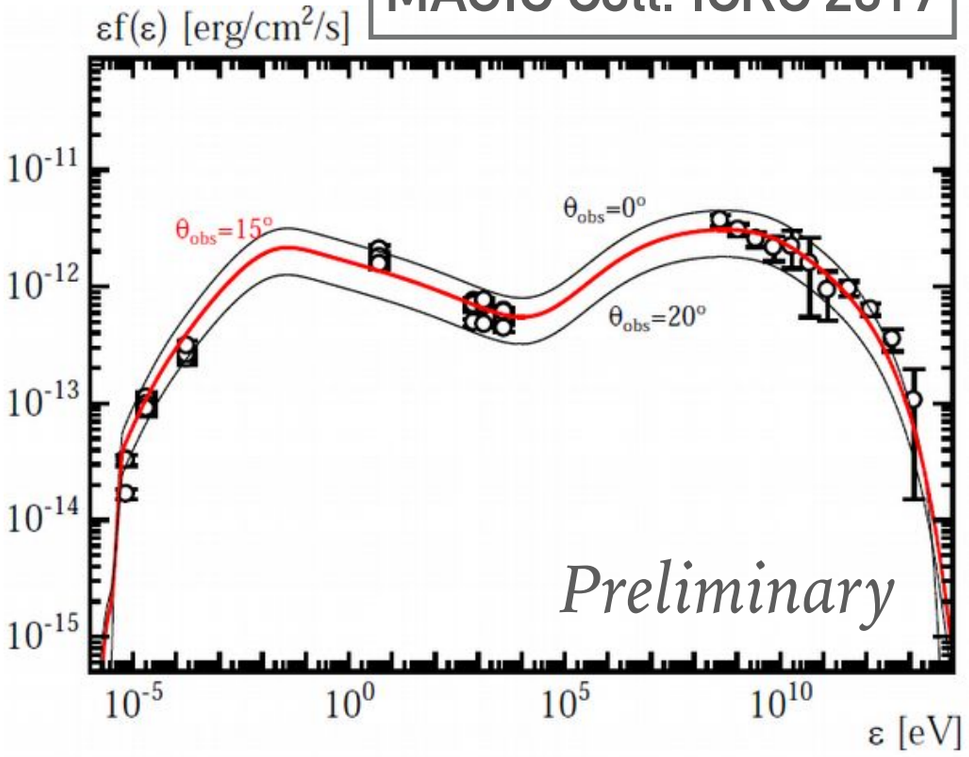


backup slides

M87 MWL OBSERVATIONS



MAGIC Coll. ICRC 2017



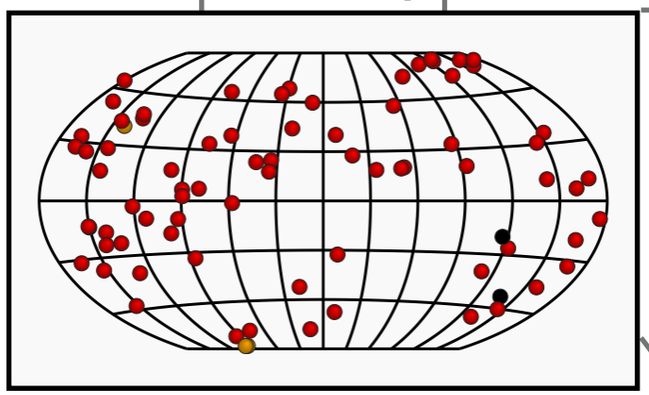
In collaboration with K. Asano

- Best studied radio galaxy in VHE gamma rays
- **Monitored by MAGIC: over 150 h** gathered between 2012 and 2015
- No flares observed in that time
- VHE gamma- ray **spectrum extends up to 20 TeV** and connects smoothly to the GeV spectrum

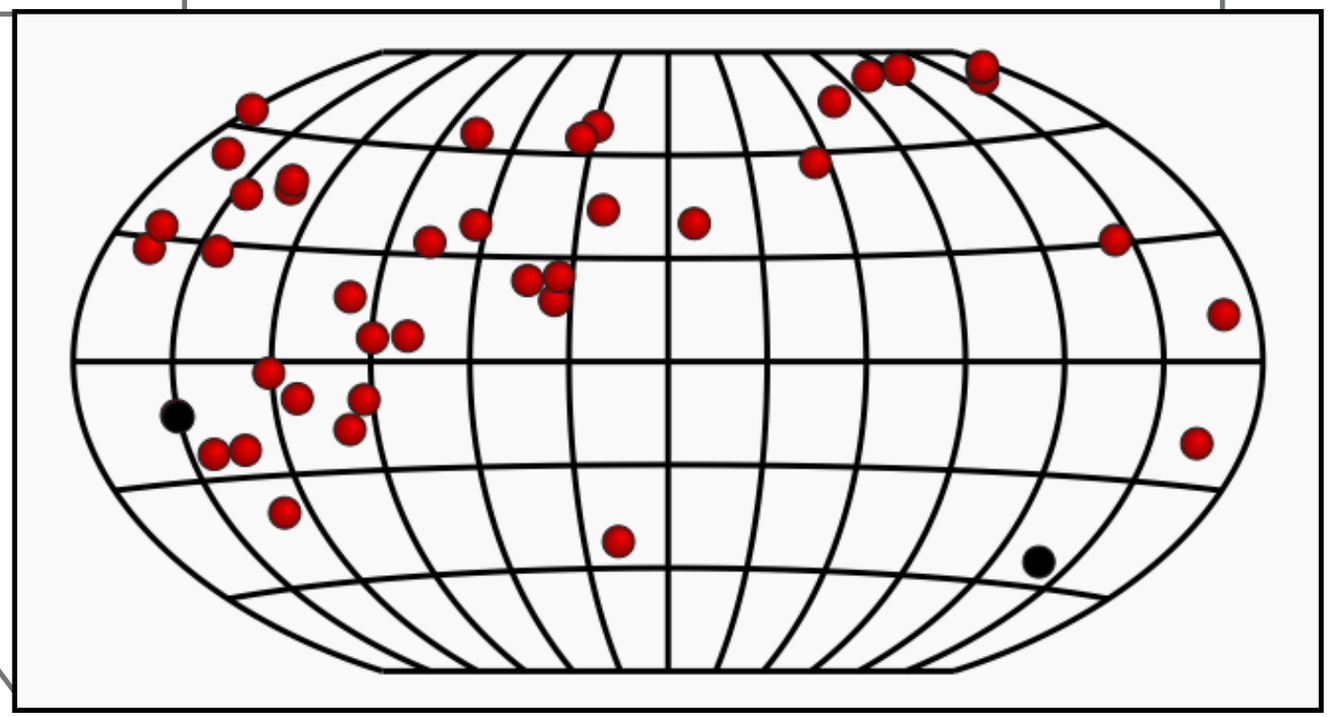
Extremely low magnetisation required

EXTRAGALACTIC TeV SOURCES (FEBRUARY 2019): MAGIC SELECTION

TeV map



TeV map: MAGIC sources are 42 sources



Redshift distribution of MAGIC blazars