HIGHLIGHTS OF THE VERY-HIGH ENERGY GAMMA-RAY SKY AS SEEN BY MAGIC

Serena Loporchio

For the MAGIC Collaboration

RICH 2022

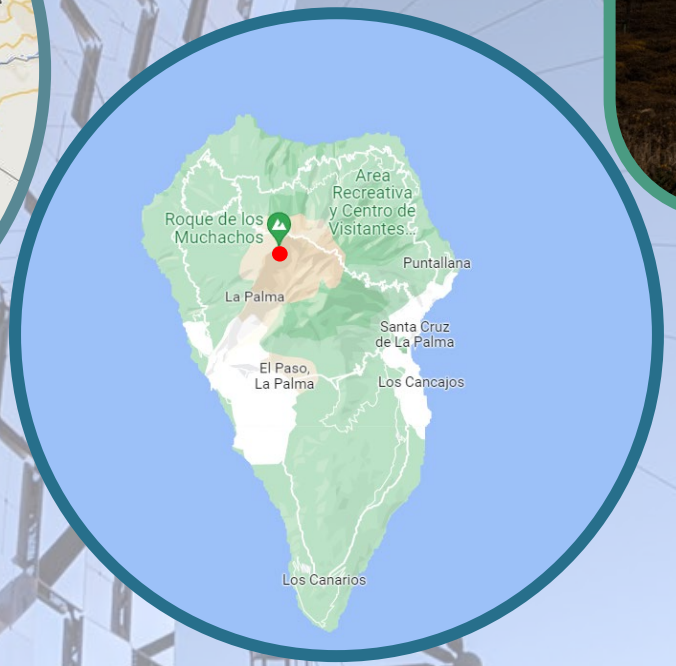
Edinburgh, 12-16 Sept 2022

INFN BARI Istituto Nazionale di Fisica Nucleare Sezione di Bari

MAGIC Major Atmospheric Gamma Imaging Cerenkov Telescope

THE MAGIC TELESCOPES

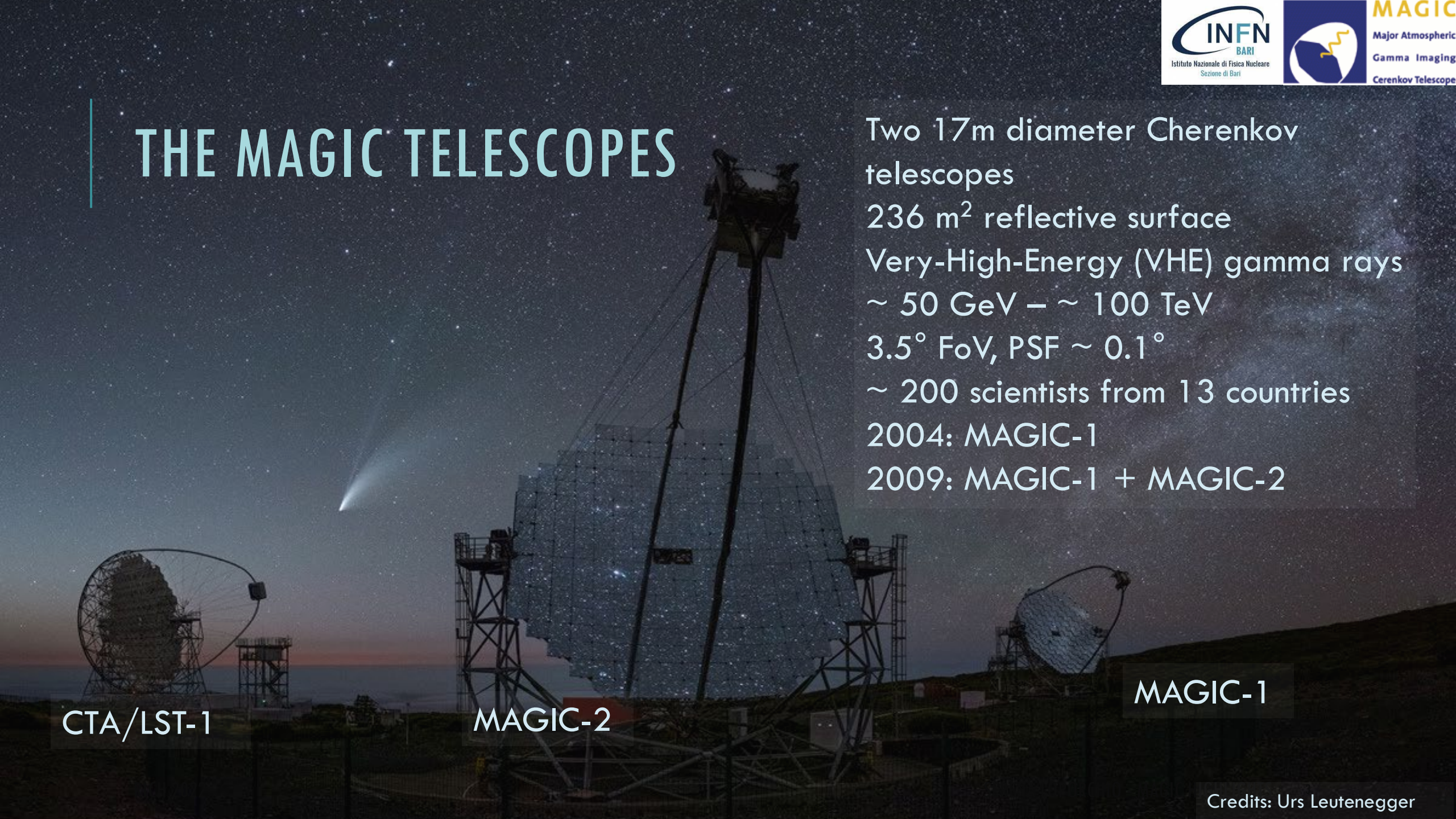
Major Atmospheric
Gamma Imaging
Cherenkov



Observatorio del Roque de los Muchachos
La Palma, Canary Islands
2200 m asl

THE MAGIC TELESCOPES

Two 17m diameter Cherenkov telescopes
236 m^2 reflective surface
Very-High-Energy (VHE) gamma rays
~ 50 GeV – ~ 100 TeV
3.5° FoV, PSF ~ 0.1°
~ 200 scientists from 13 countries
2004: MAGIC-1
2009: MAGIC-1 + MAGIC-2



Credits: Urs Leutenegger

TARGETS OF THE MAGIC TELESCOPES

Transients:
GRB, Neutrino,
FRB, GW

Galactic sources:
Pulsars, SNRs,
GC, PeVatrons

AGNs:
BL Lacs, FSRQs,
radio galaxies

APFP:
Dark Matter, LIV,
cosmic rays

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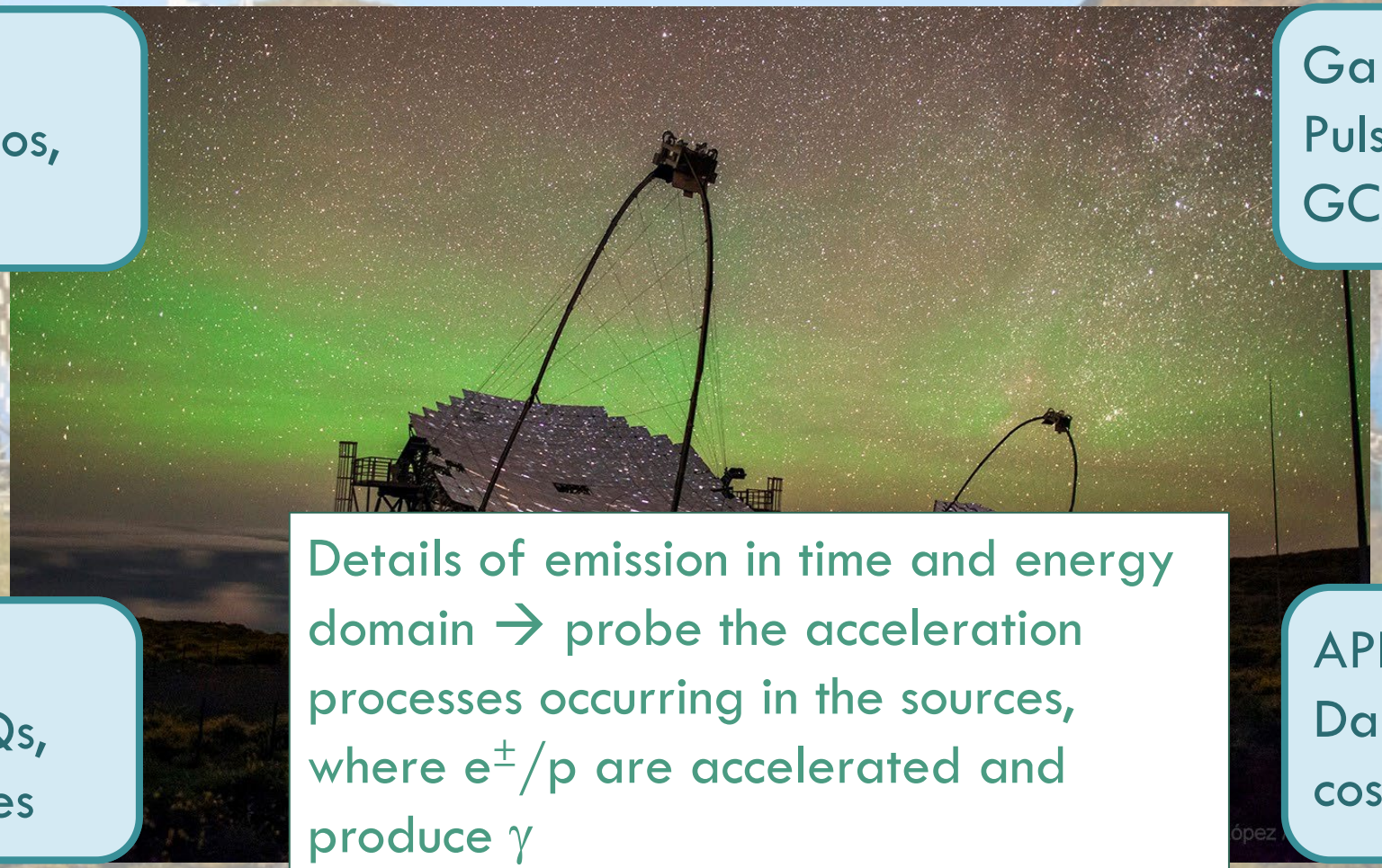

Galactic sources:
Pulsars, SNRs,
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AGNs:
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radio galaxies

Details of emission in time and energy domain → probe the acceleration processes occurring in the sources, where $e^{\pm}$/p are accelerated and produce γ

APFP:
Dark Matter, LIV,
cosmic rays

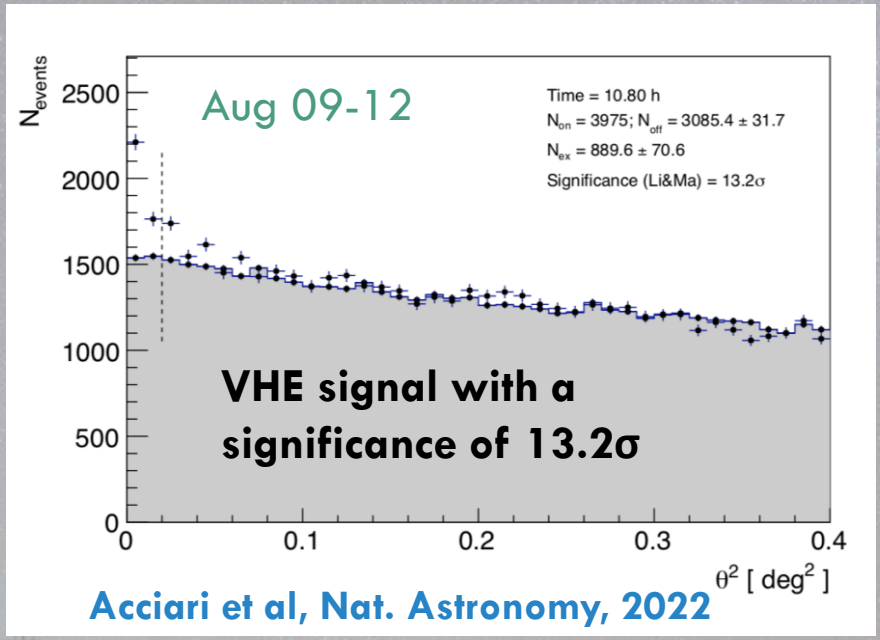
VHE GAMMA RAYS FROM RS OPHIUCHI

RS Ophiuchi is a recurrent symbiotic nova (WD + RG)

Accumulation of material on the surface of the WD
→ thermonuclear explosions, latest August 2021

Detected in the HE γ-ray → HE processes, 2 scenarios

Novae established as a new type of VHE emitter



Acciari et al, Nat. Astronomy, 2022

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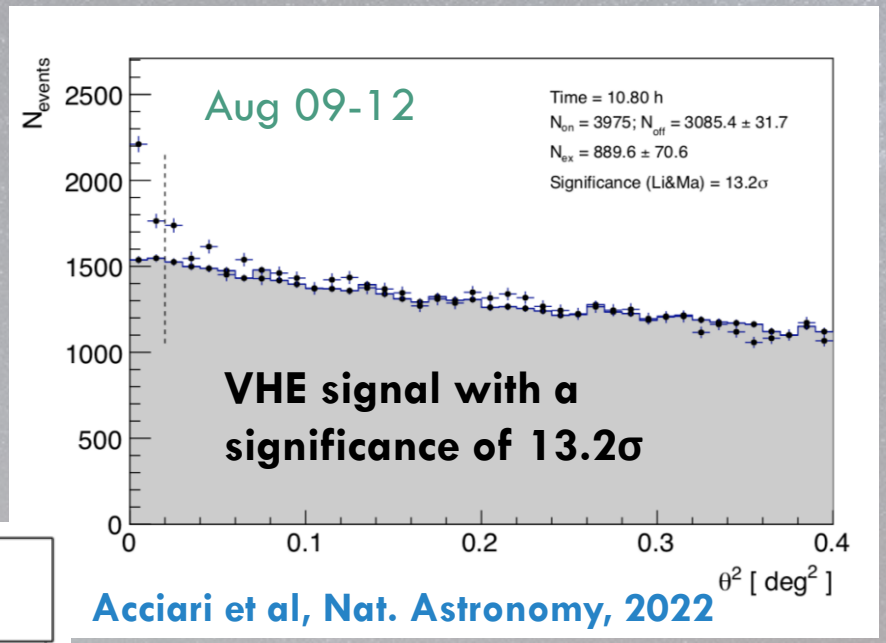
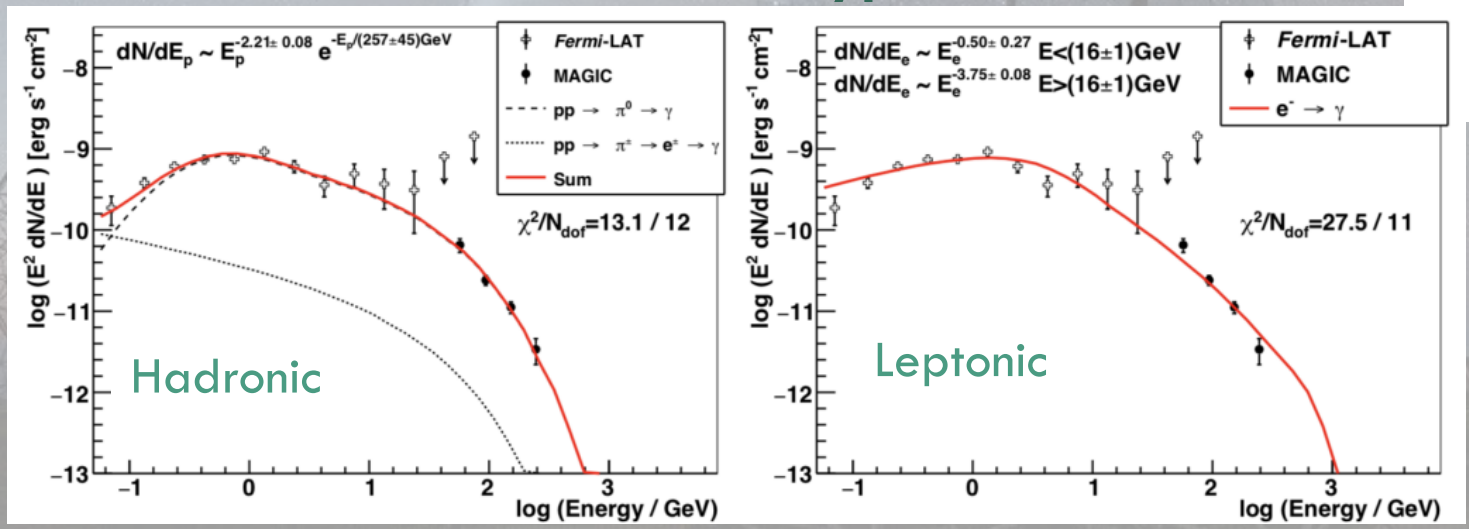


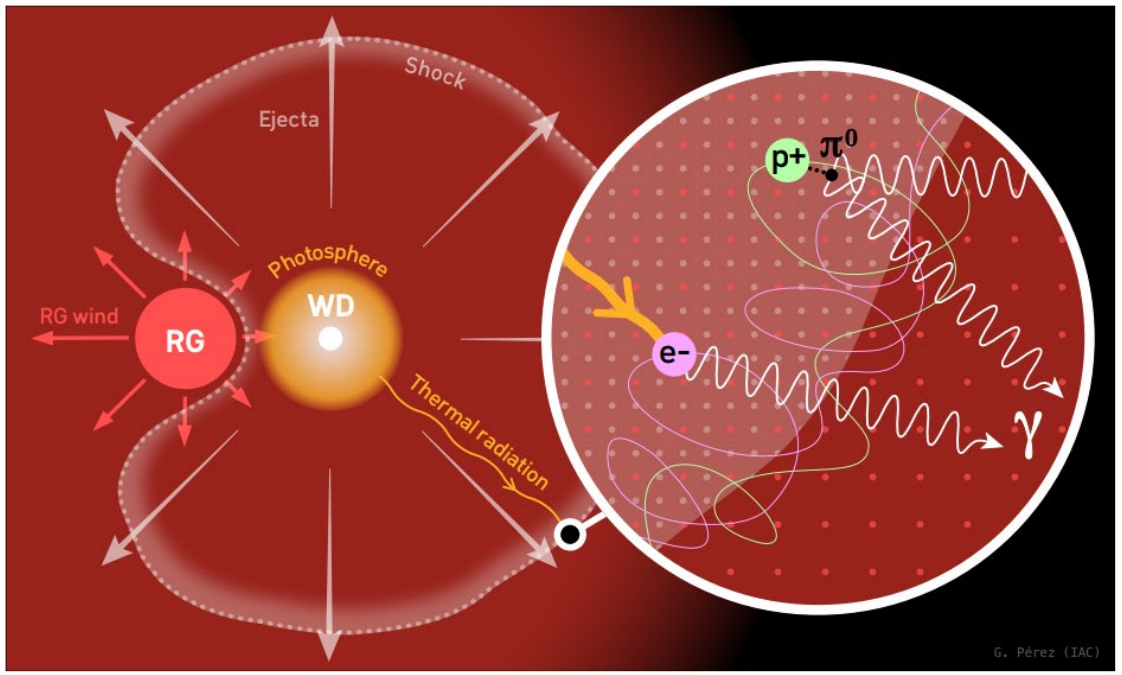
Acciari et al, Nat. Astronomy, 2022



Hadronic scenario is favoured:
proton acceleration to
hundreds of GeV
in the nova shock

NOVAE EXPLOSIONS AS PROTON ACCELERATORS

HE data alone: not enough to disentangle electron and proton scenarios.



Acciari et al, Nat. Astronomy, 2022

Novae were established as HE emitters (E>100 MeV) → HE emission explained with either pp interaction or leptonic models.
MAGIC + *Fermi*-LAT strongly suggest hadronic scenario (proton acceleration)

$e^{\pm}$: strong radiation field, large cross-section → rapid cooling and limited maximum energy

p: lower cross section → higher energies and thus possible second component

VHE EMISSION FROM GRB190114C

GRB190114C

Rapid, variable prompt + longer afterglow

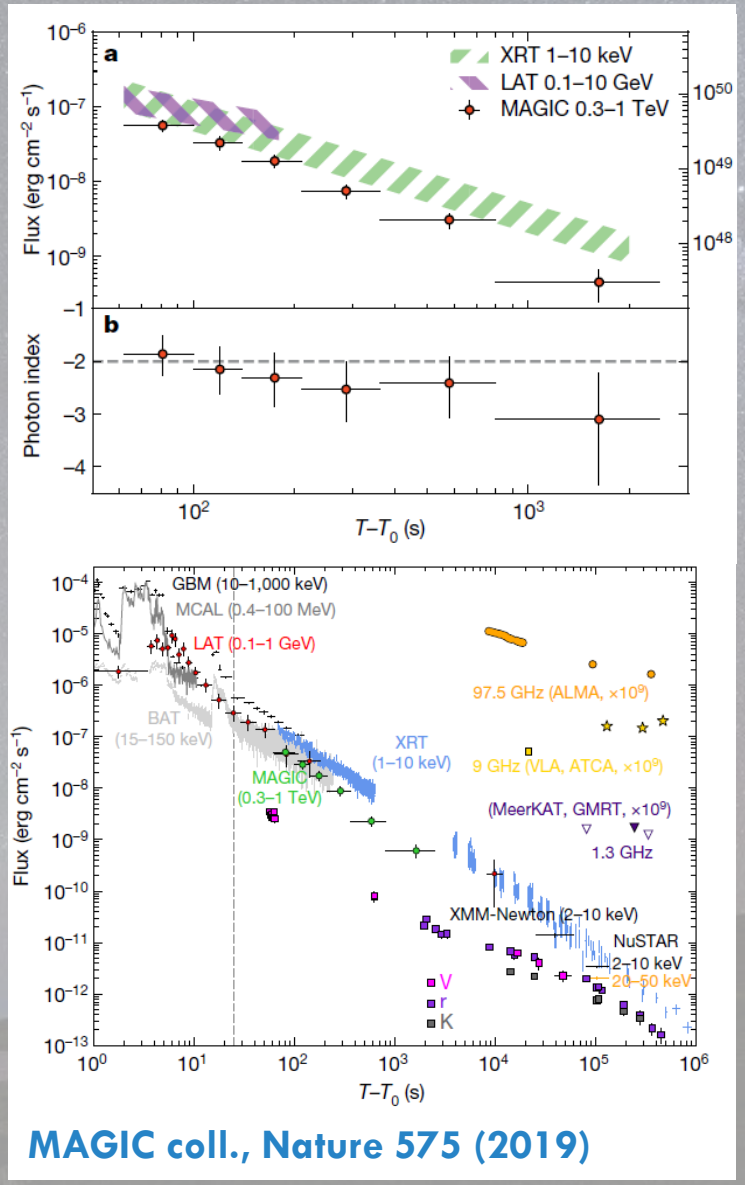
First detection of VHE emission from long GRBs (>50σ)

Trigger by *Swift*-BAT and *Fermi*-GBM at
T_0 = 20:57:03 UT

T_0 + 22s: MAGIC received the alert
T_0 + 50s: MAGIC started tracking
T_0 + 57s: MAGIC started data acquisition
(**35s after the alert**)
T_0 + 62s: MAGIC data acquisition stabilised

Exhaustive MWL coverage

VHE emission associated with the afterglow component



MAGIC coll., Nature 575 (2019)

SSC FROM GRB190114C

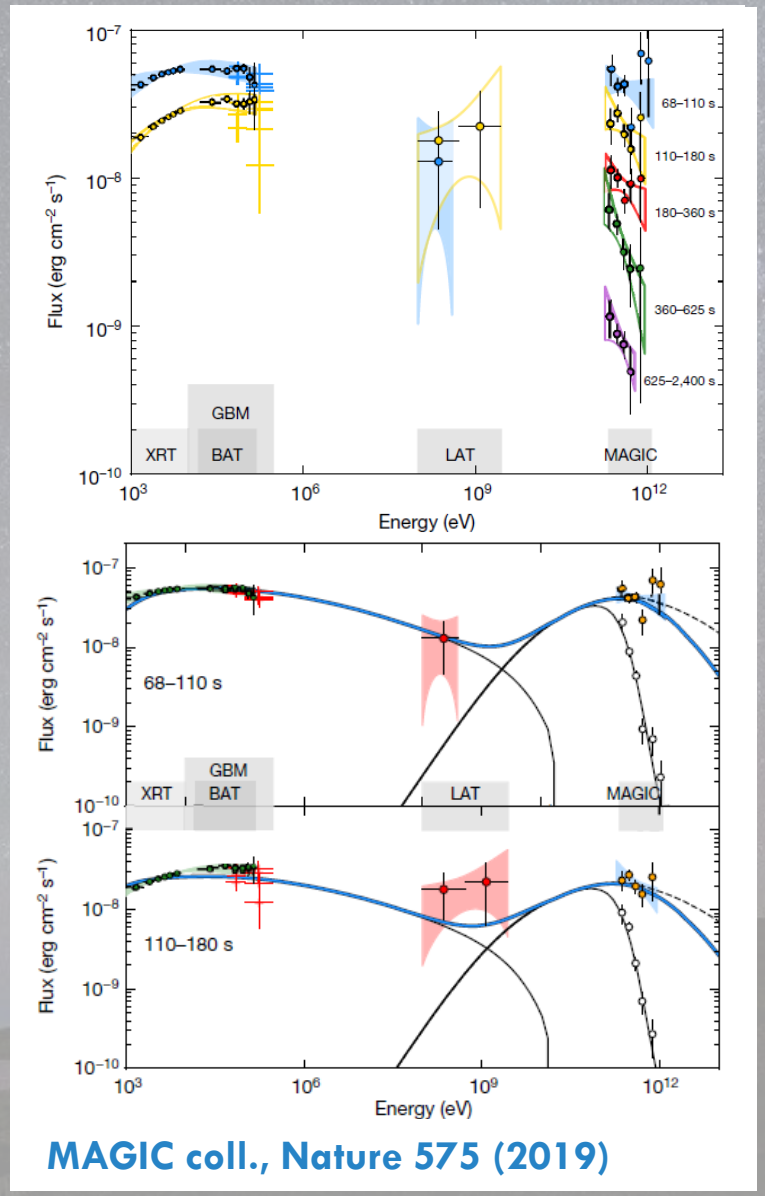
MAGIC spectra in 5 different time intervals, first two with GeV and X-ray coverage

MAGIC observations imply a spectral hardening at TeV

Emission up to TeV → one order of magnitude above synchrotron cut-off (burnoff limit E >100 GeV)

Extension of the synchrotron emission excluded
Separate spectral component → synchrotron and SSC scenario

Also: probes of QG models on energy dependence of the speed of light in vacuum



MAGIC coll., Nature 575 (2019)

OTHER GRB DETECTIONS WITH MAGIC

GRB 201216C: MAGIC detection in very high energy gamma rays

ATel #14275; *Oscar Blanch (IFAE-BIST) on behalf of the MAGIC Collaboration*
*on **17 Dec 2020; 17:23 UT***
Credential Certification: Oscar Blanch (blanch@ifae.es)

Subjects: Gamma Ray, >GeV, TeV, VHE, Gamma-Ray Burst

Referred to by ATel #: 14277

GRB201216C detected with high significance (>5σ), publication coming soon

Hint of signal from GRB201015A.

```
TITLE:   GCN CIRCULAR
NUMBER:  28659
SUBJECT: MAGIC observations of GRB 201015A: hint of very high energy gamma-ray signal
DATE:    20/10/16 16:48:37 GMT
FROM:    Oscar Blanch at MAGIC Collaboration  <blanch@ifae.es>
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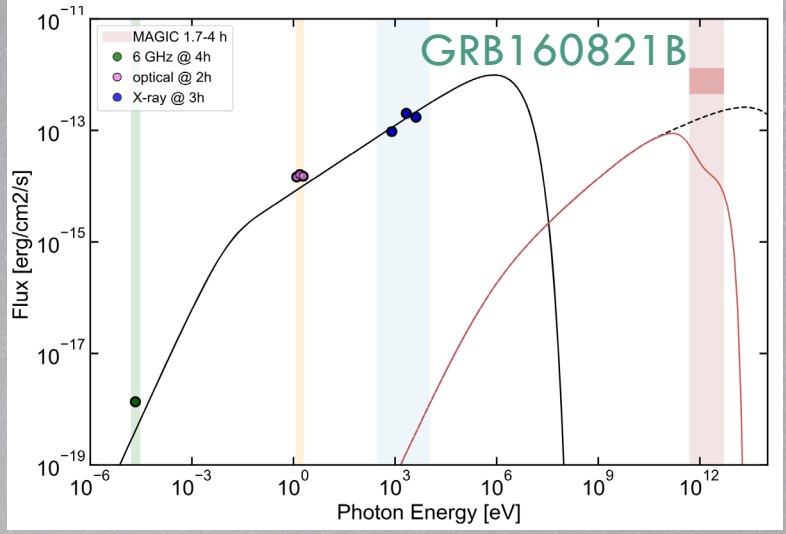
Acciari et al, ApJ 908 (2021)



Hint of signal (3σ) from GRB160821B putative VHE emission difficult to explain with one zone SSC

MULTIMESSENGER: TXS 0506+056

AGNs are the most promising candidate ν emitters

First multimessenger observations: VHE γ rays in coincidence with a 300 TeV neutrino → 3σ association

First multimessenger SED

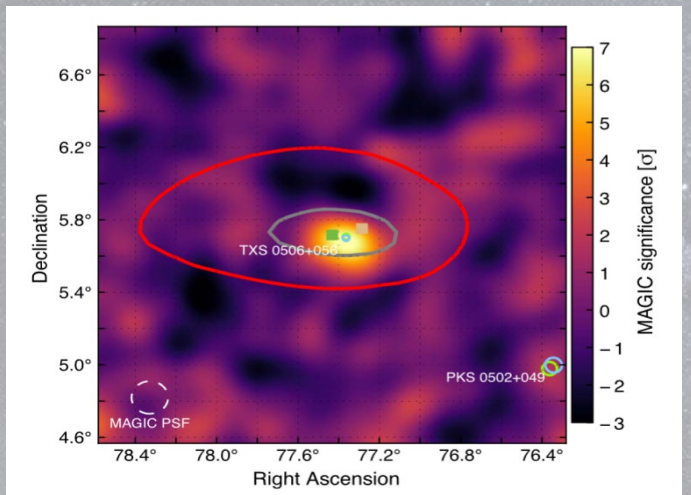
Insights into extragalactic jets & CR acceleration

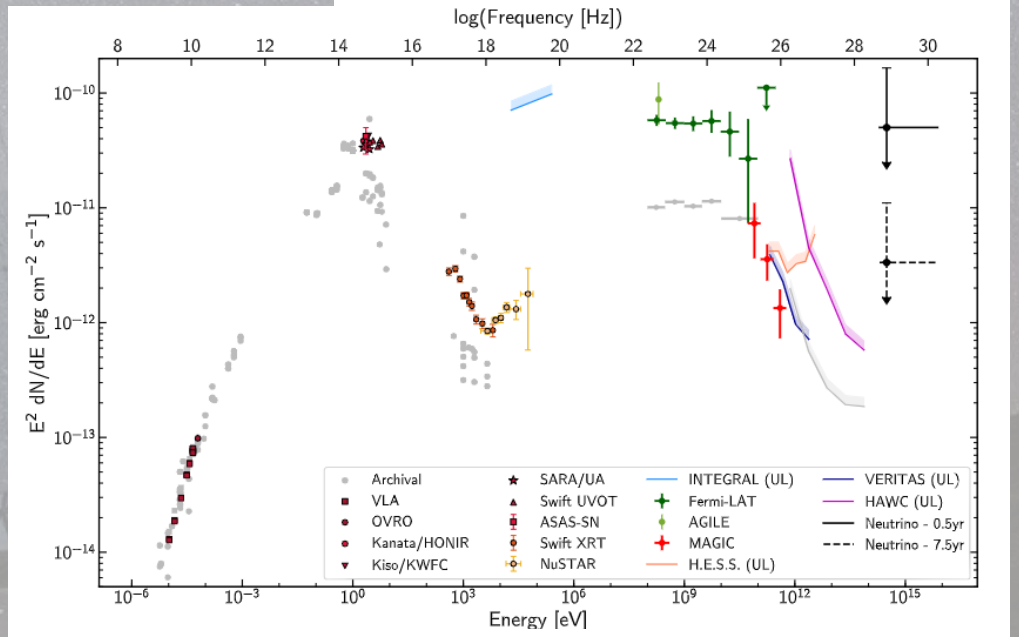
Jet-sheath scenario with $E_{p,max} = 10^{16}$ eV

Leptonic scenario + hadronic component

Deep monitoring with MAGIC: several flares detected, no neutrino counterpart

Acciari et al, ApJ 927 (2022)





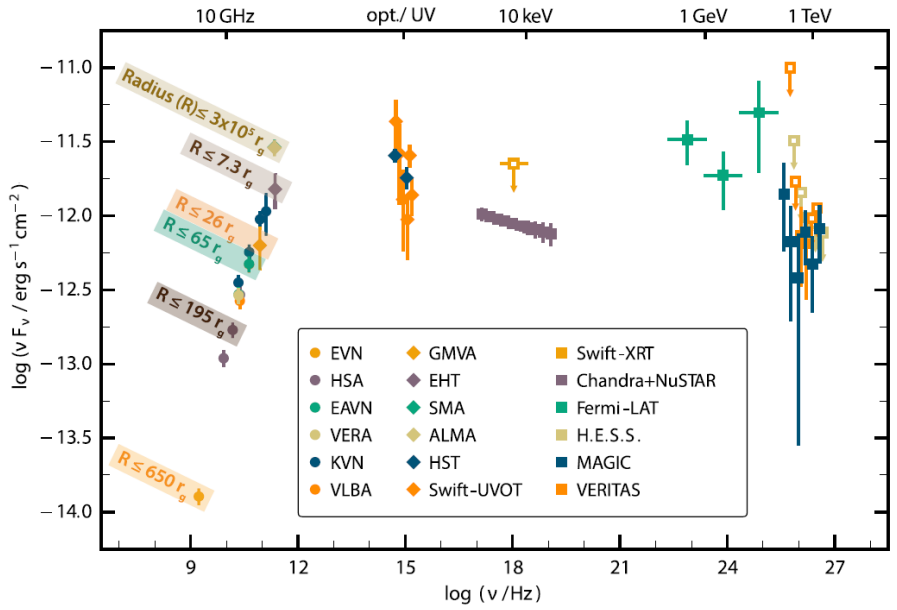
The IceCube coll. et al, Science 361 (2018)

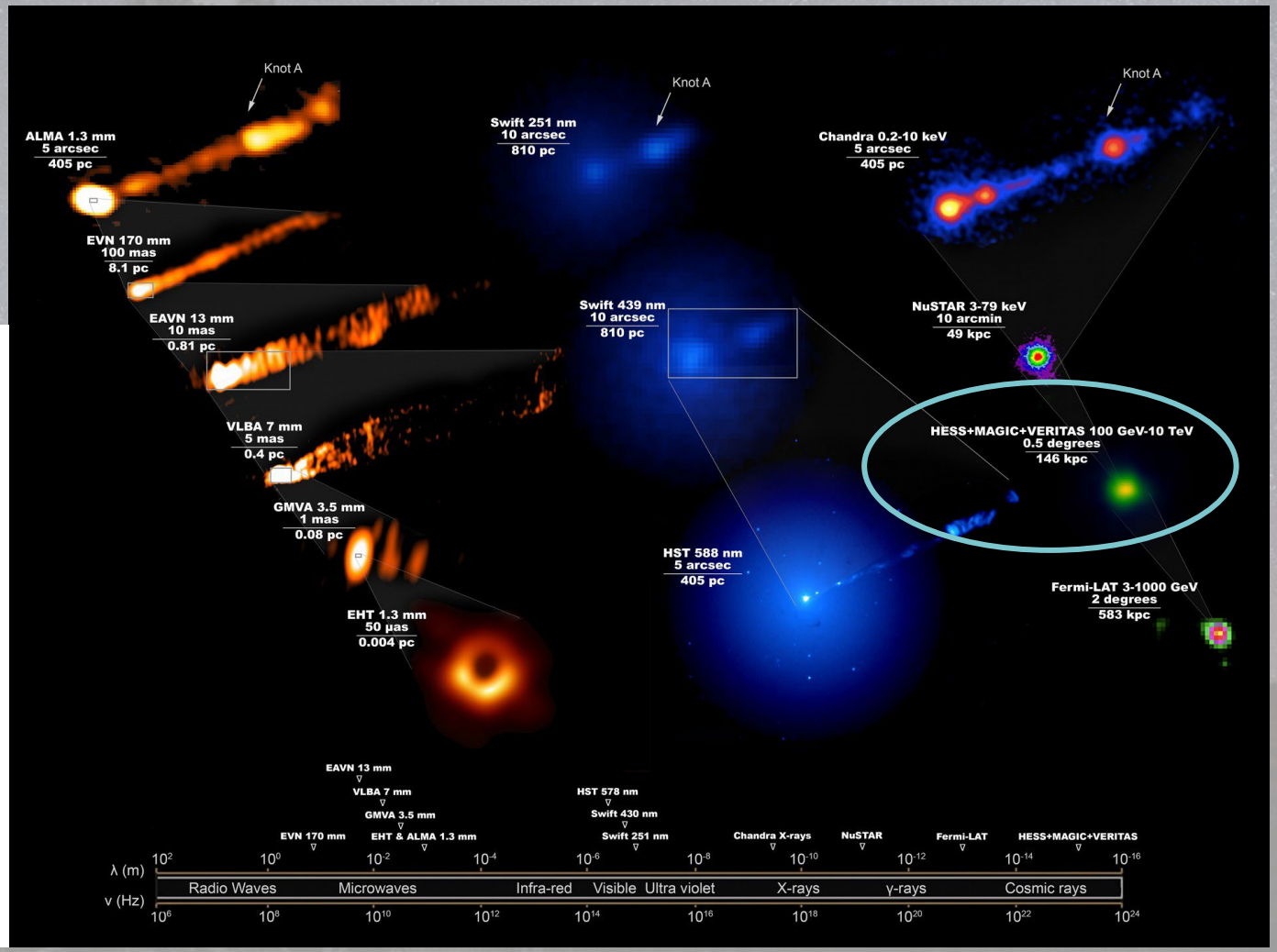
BROADBAND MWL EMISSION FROM M87

Coordinated observations in all the e.m. spectrum during quiescent state

Resolved jets from radio to X-rays

Algaba et al, ApJL 911 (2021)





EXTREME SOURCES

High synchrotron peak frequency exceeding soft X-rays band: $\nu_s > 10^{17}$ Hz, IC peak in the VHE range

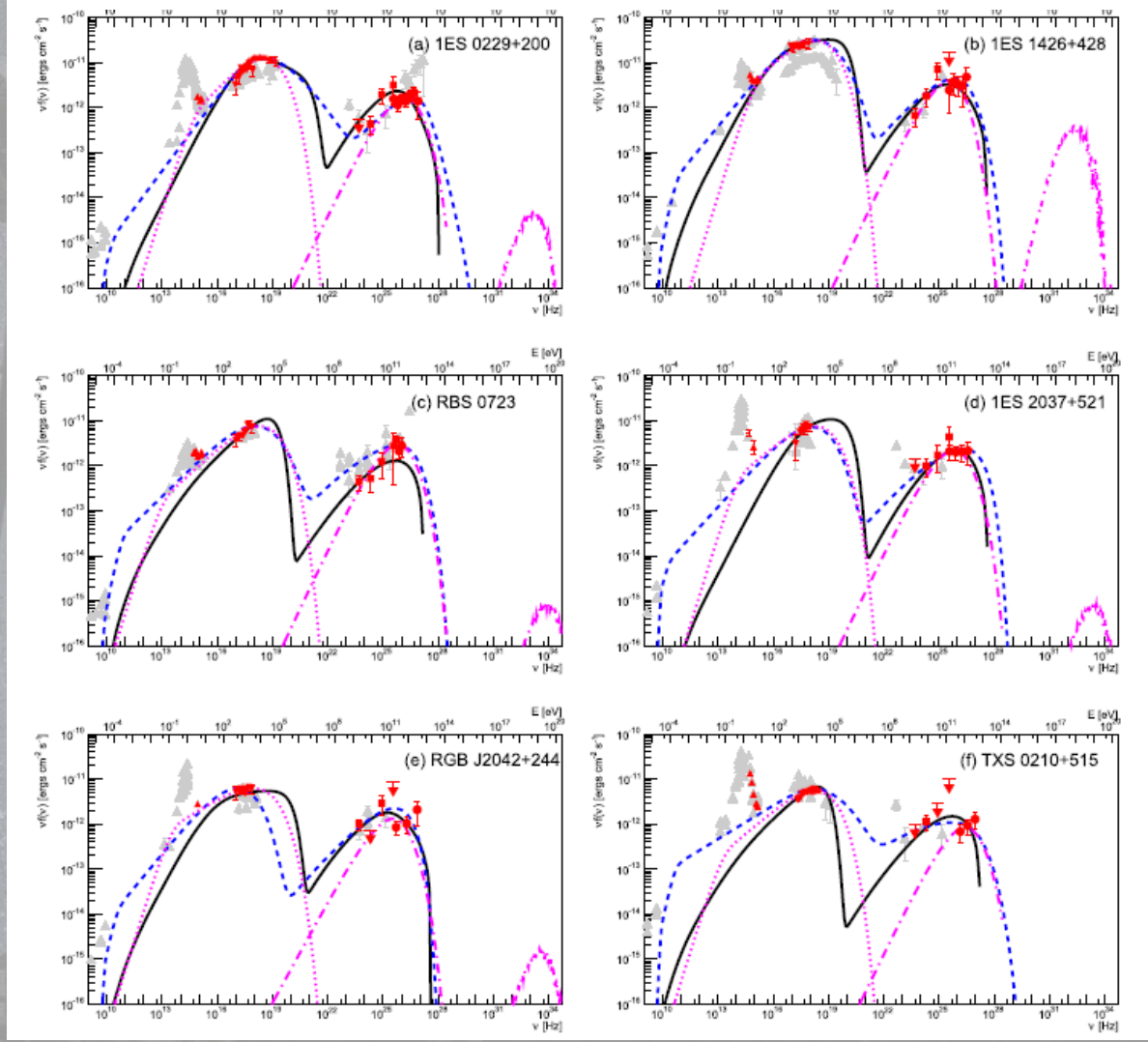
Heterogeneous population: extreme during flares, steady hard synchrotron but no hard-TeV, hard synchrotron and hard TeV, intermittent sources…

Expected to be very faint according to the blazar sequence

Both leptonic and leptohadronic scenario

Tests of γ-ray propagation: probes for EBL, IGMF and fundamental physics

Acciari et al, ApJS 247 (2020)



PULSED SIGNAL FROM GEMINGA

Detection between 15 GeV and 75 GeV

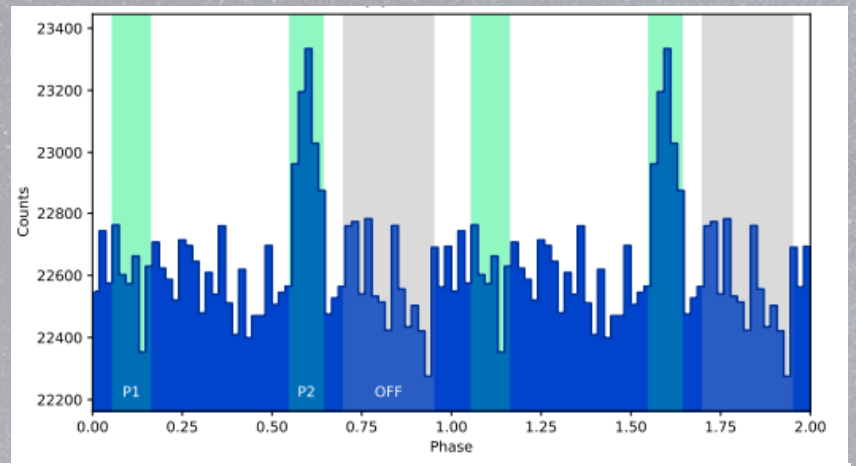
6.3σ detection in 80h of very low energy trigger threshold thanks to SumTrigger

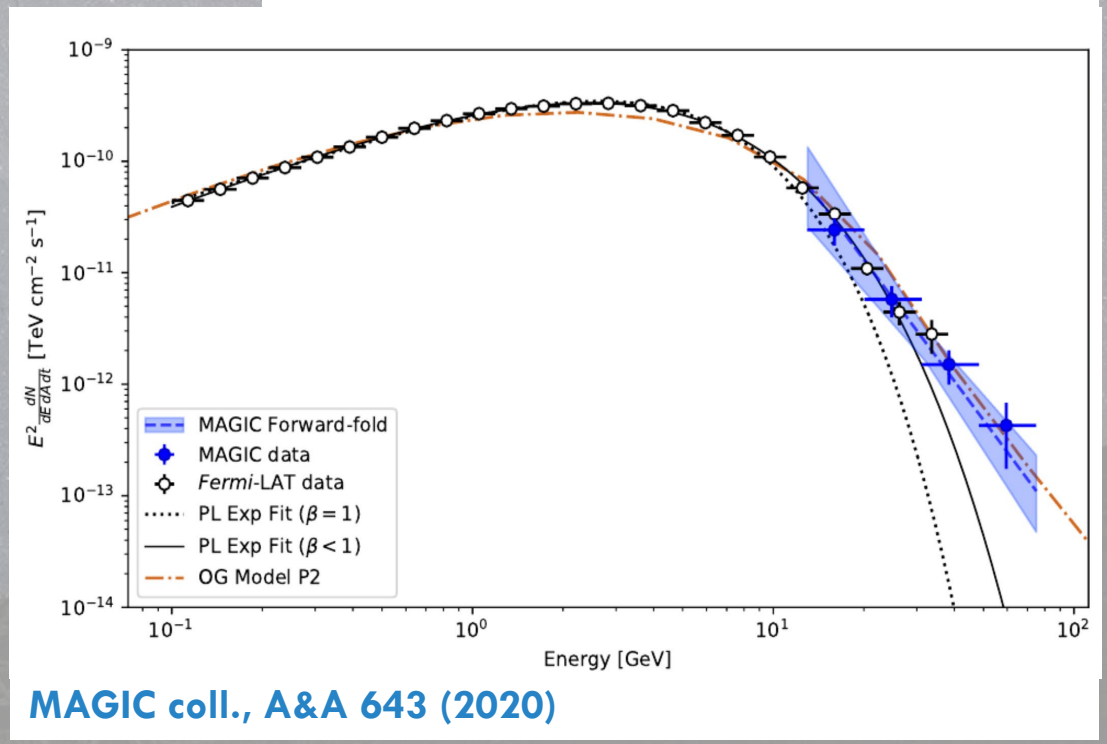
Power-law tail emission above 15 GeV (cut-off disfavored)

Transition from Curvature Radiation to IC scattering?

E<40 GeV curvature rad of outward e^+

E>40 GeV IC scattering of inward e^-





MAGIC coll., A&A 643 (2020)

VLZA OBSERVATIONS: HIGH ENERGY THRESHOLD

Observations at energies above 10 TeV have low event rate

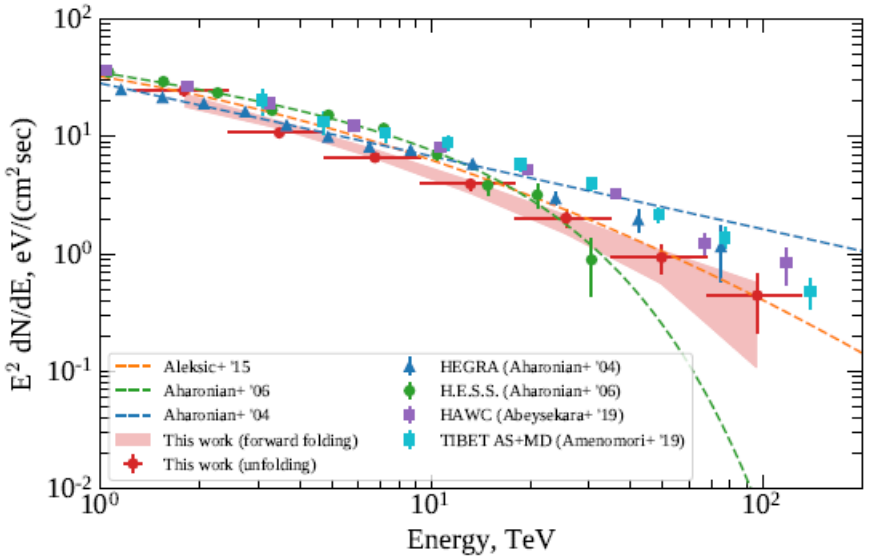
Large collection area needed: larger number of telescopes or larger collection area at higher zenith angles (> 70°)

Increase in the Cherenkov pool size + reduction in photon density → **higher energy threshold**

Crab Nebula γ-ray emission significantly detected up to 100 TeV

None of the existing emission models provides an accurate description in the 1 GeV – 100 TeV range

Acciari et al, A&A 635 (2020)



CONCLUSIONS

Evidence of proton acceleration in novae explosions

Detection of 2 GRBs and 2 hints of detection

Strategies for neutrino follow-up led to multi-messenger observations

+ many more important scientific results: detections of new VHE emitters, Geminga pulsar in the LE range, FSRQ and BL Lacs characterization, long term monitoring, studies on particle acceleration in jets and shocks, searches for DM, MWL and multi-messenger projects

Extended energy range (lower and higher energies)


Credits: Chiara Righi

THANK YOU!

Serena Loporchio

serena.Loporchio@ba.infn.it

DARK MATTER

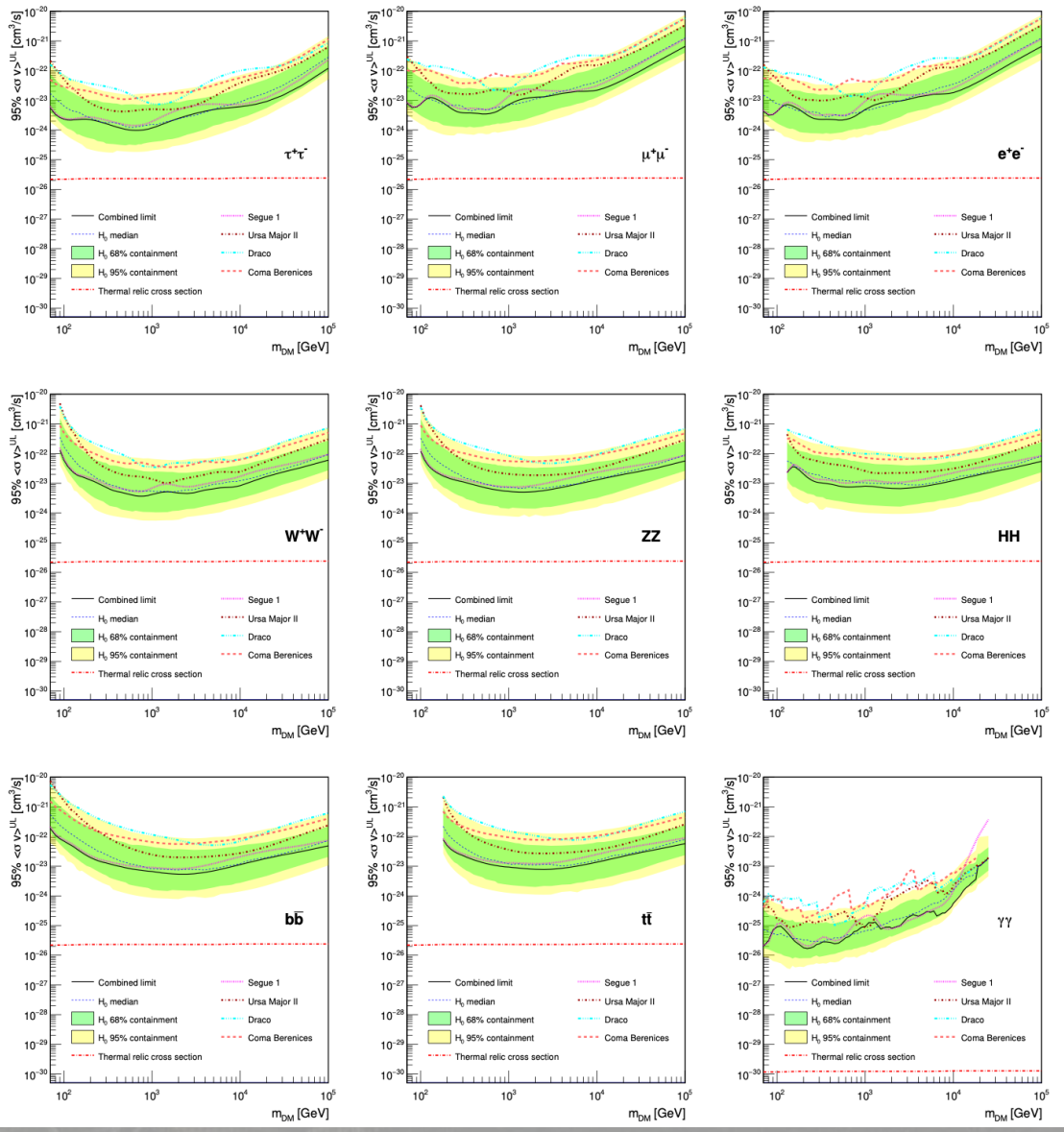
Multi-year (350h) observation program on dwarf spheroidal galaxies (dSph)

Combination of different dSph observations for DM annihilation signal searches

Stringent ULs on the velocity-averaged cross-section of WIMP annihilation

+ many projects: DM lines searches in the Galactic Center, galaxy clusters…

Acciari et al, Physics of the Dark Universe 35 (2022)

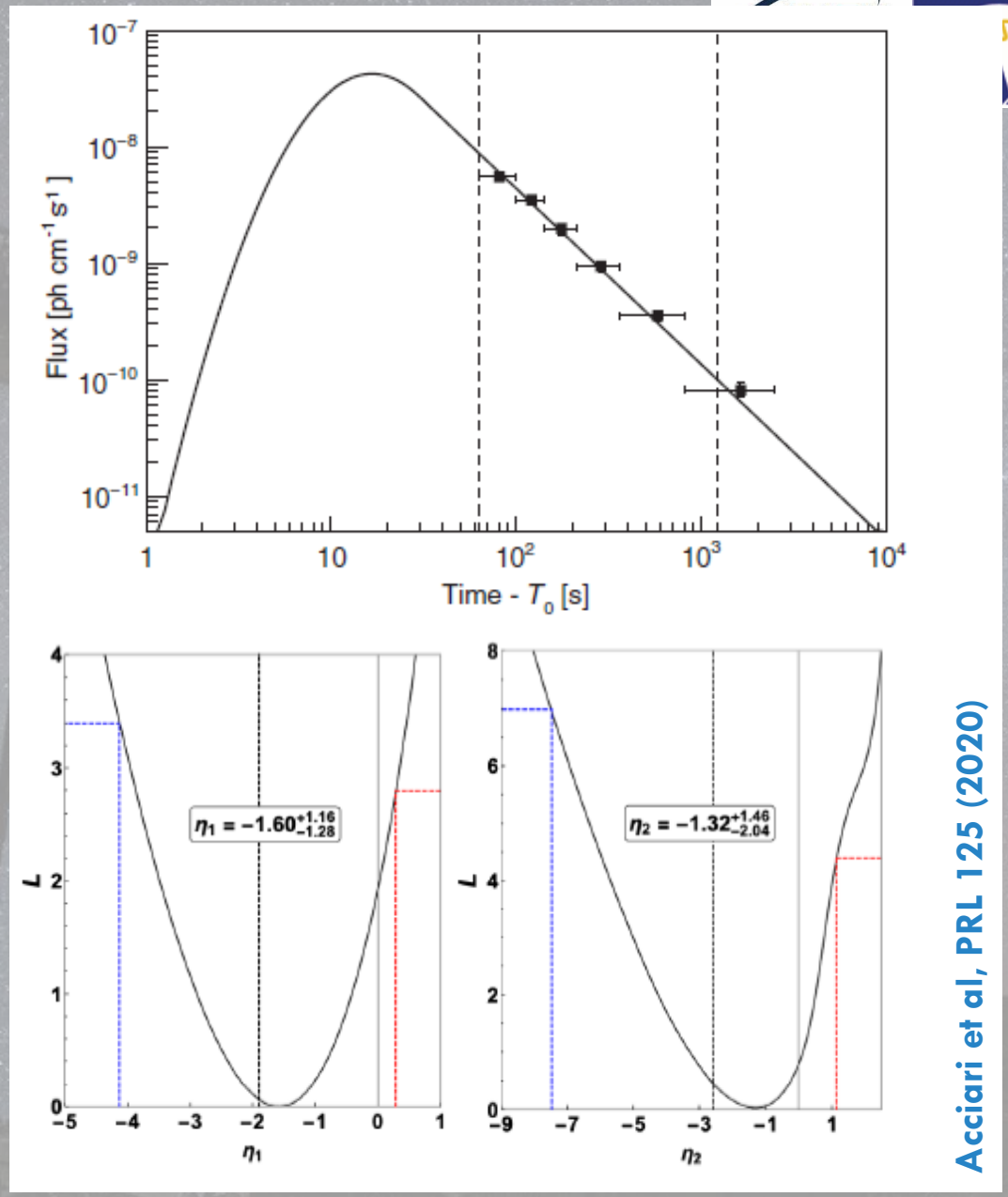


LIV IN GRBS

No dependence of observed light curve on energy for VHE gamma rays

No correlation of photon arrival time with gamma-ray energy

Competitive Lower limits for the QG energy scale derived using an unbinned analysis



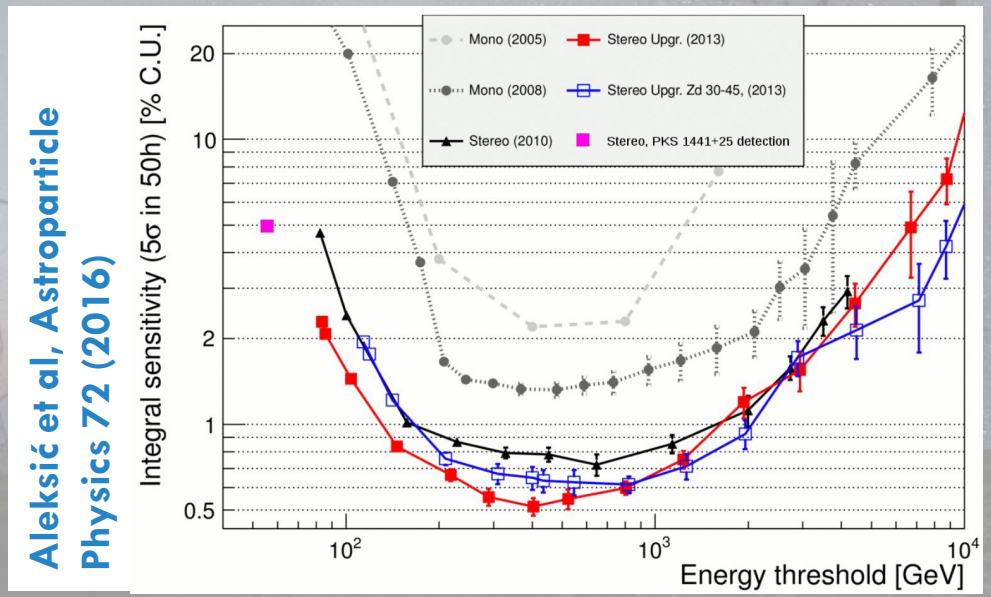
Acciari et al, PRL 125 (2020)

MAGIC PERFORMANCE

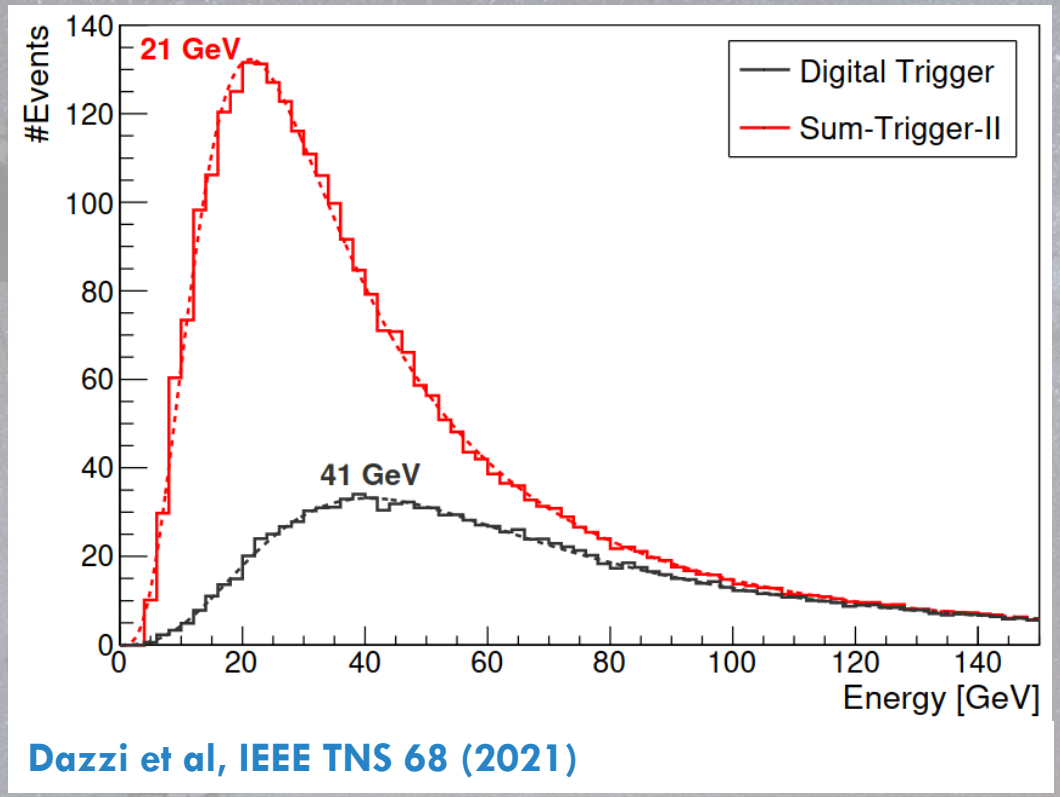
2004: one telescope (mono observations)

2009: two telescopes (stereo)

2012: major upgrade



Aleksić et al, Astroparticle Physics 72 (2016)



Dazzi et al, IEEE TNS 68 (2021)

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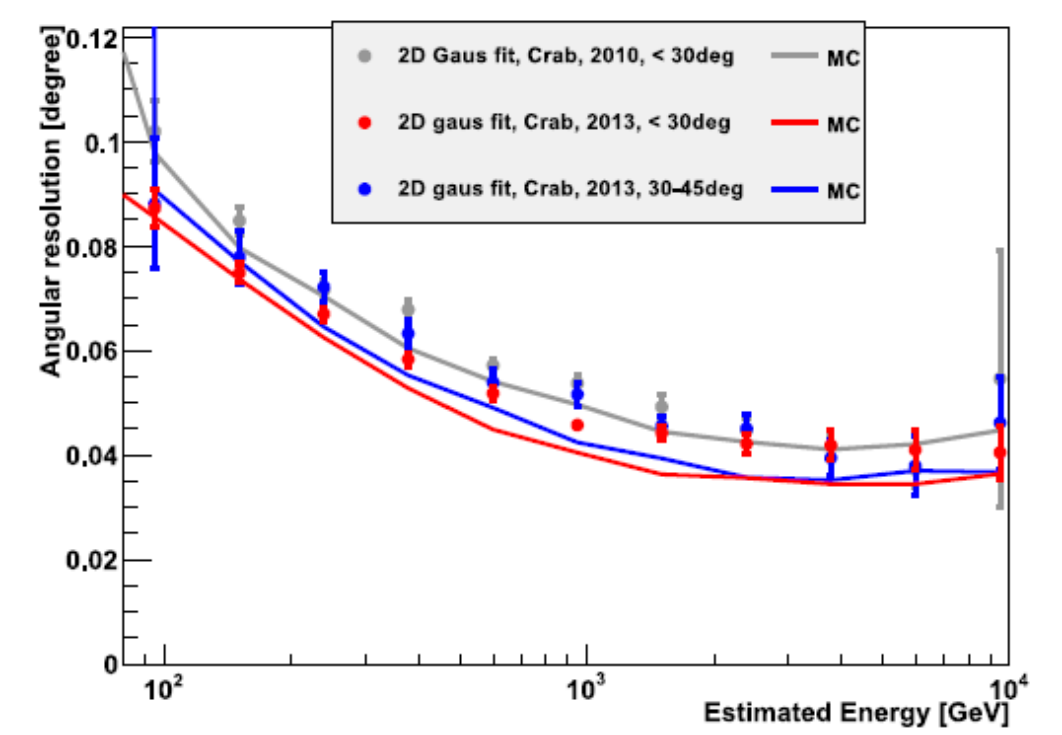

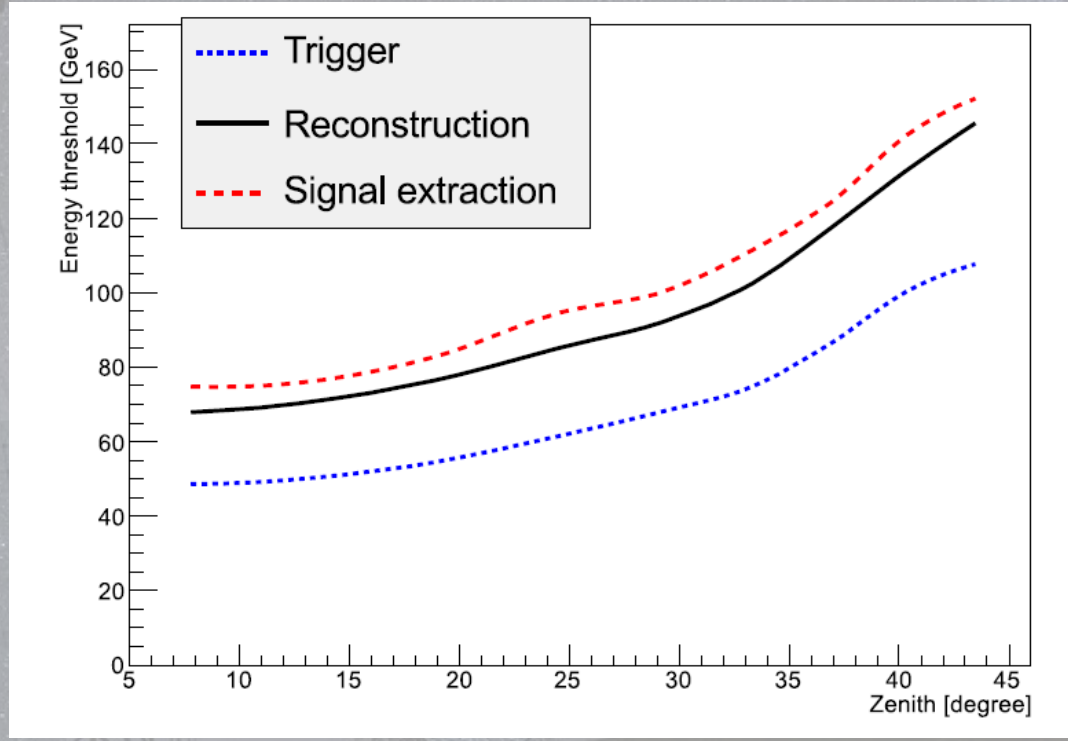

Aleksić et al, Astroparticle Physics 72 (2016)

M87 SED MODELING

SED cannot be modeled using single zone models

γ-ray emission cannot be produced in the same region as mm-band

Structured jets are necessary to explain gamma-ray
emission

Time dependency is also needed for a detailed interpretation

Algaba et al, ApJL 911 (2021)