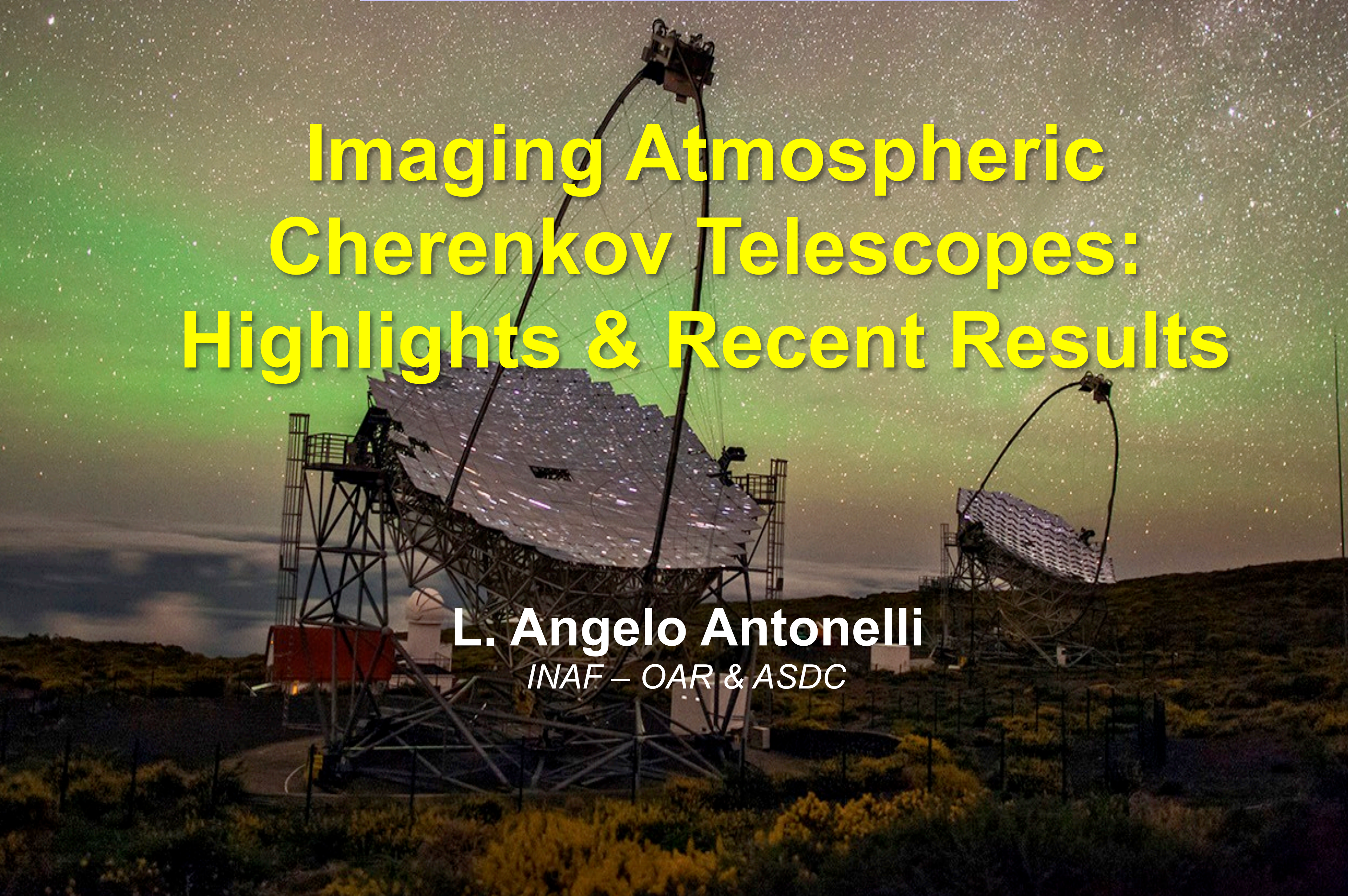


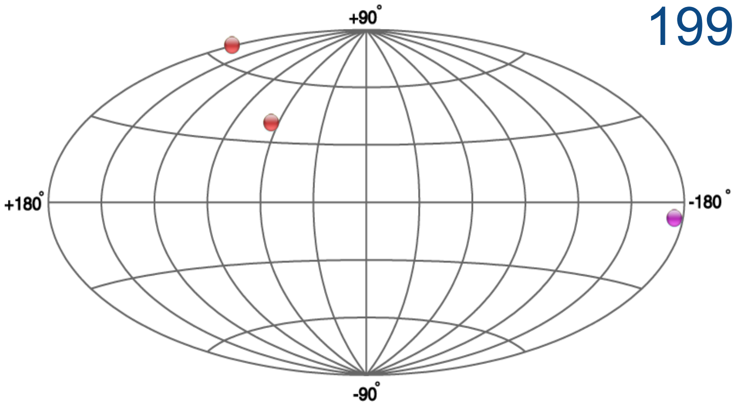
Imaging Atmospheric Cherenkov Telescopes: Highlights & Recent Results

L. Angelo Antonelli

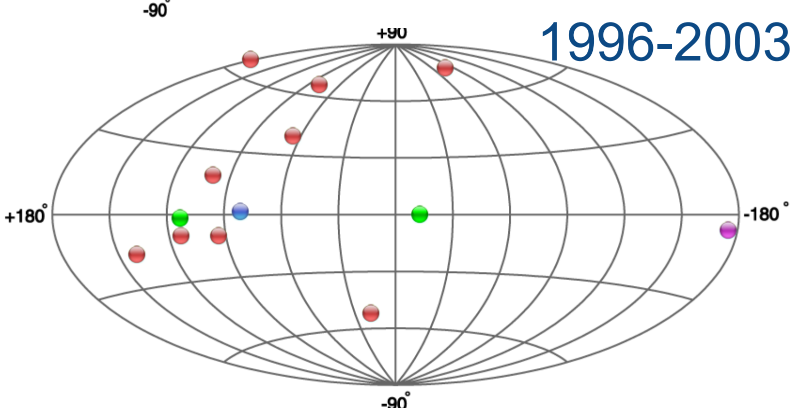
INAF – OAR & ASDC

The 1996-2017 TeV Sky

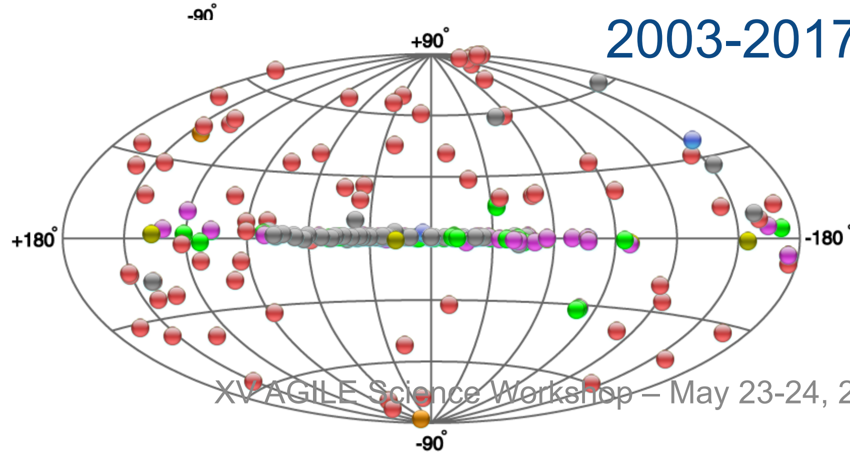
1996



1996-2003



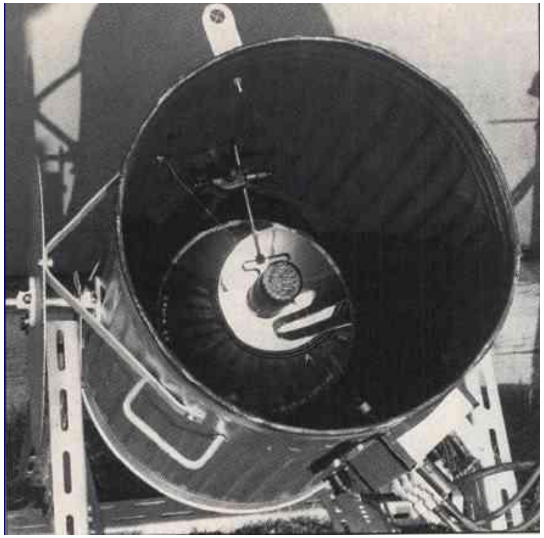
2003-2017



If we consider the first object observed in the TeV band (Crab observed in 1989 by Whipple) we had a very fast increment in the number of VHE sources (>160 in 2017).

http://tevcat.uchicago.edu/

Imaging Atmospheric Cherenkov Telescopes (IACTs)



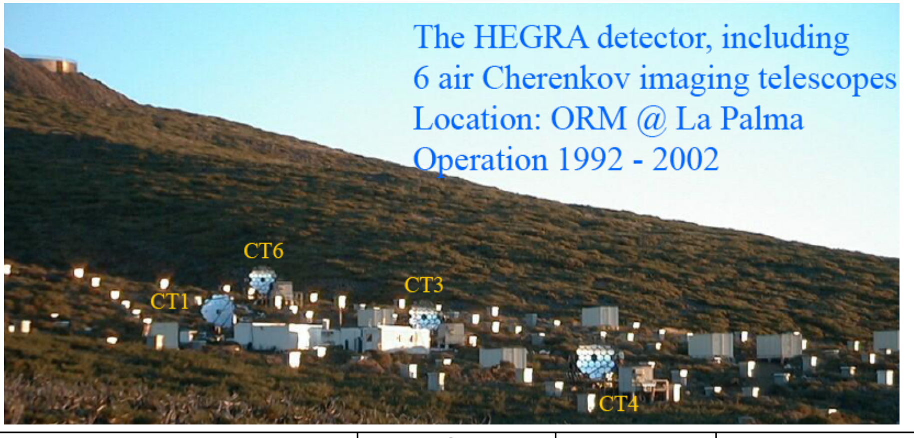
1953 Galbraith & Jelly:

A garbage can, a 60 cm diameter mirror in and a PMT in the focus. Discovery of Cherenkov light pulses from extensive air showers due to leptonic Cosmic Rays.

Crimea Experiment 1959-1965,

1969 Trevor Weeks @ Mt. Hopkins

IACTs' 2nd Generation



Telescope	Whipple	CAT	HEGRA	CANGAROO
Mirror diameter (m)	10	5	5	3.8
Mirror area (m^2)	74	18	8.4	11.3
Number of pixels	151	546+54	271	256
Pixel deg	0.25	0.12	0.25	0.18

IACTs' 3rd Generation

MAGIC Telescopes in La Palma (Canary Islands)

2 Telescopes (17 m)
E_{th} ~ 30 GeV, Sens. ~ 0.6% Crab/50h
Unique instrument in 50 < E [GeV] < 200

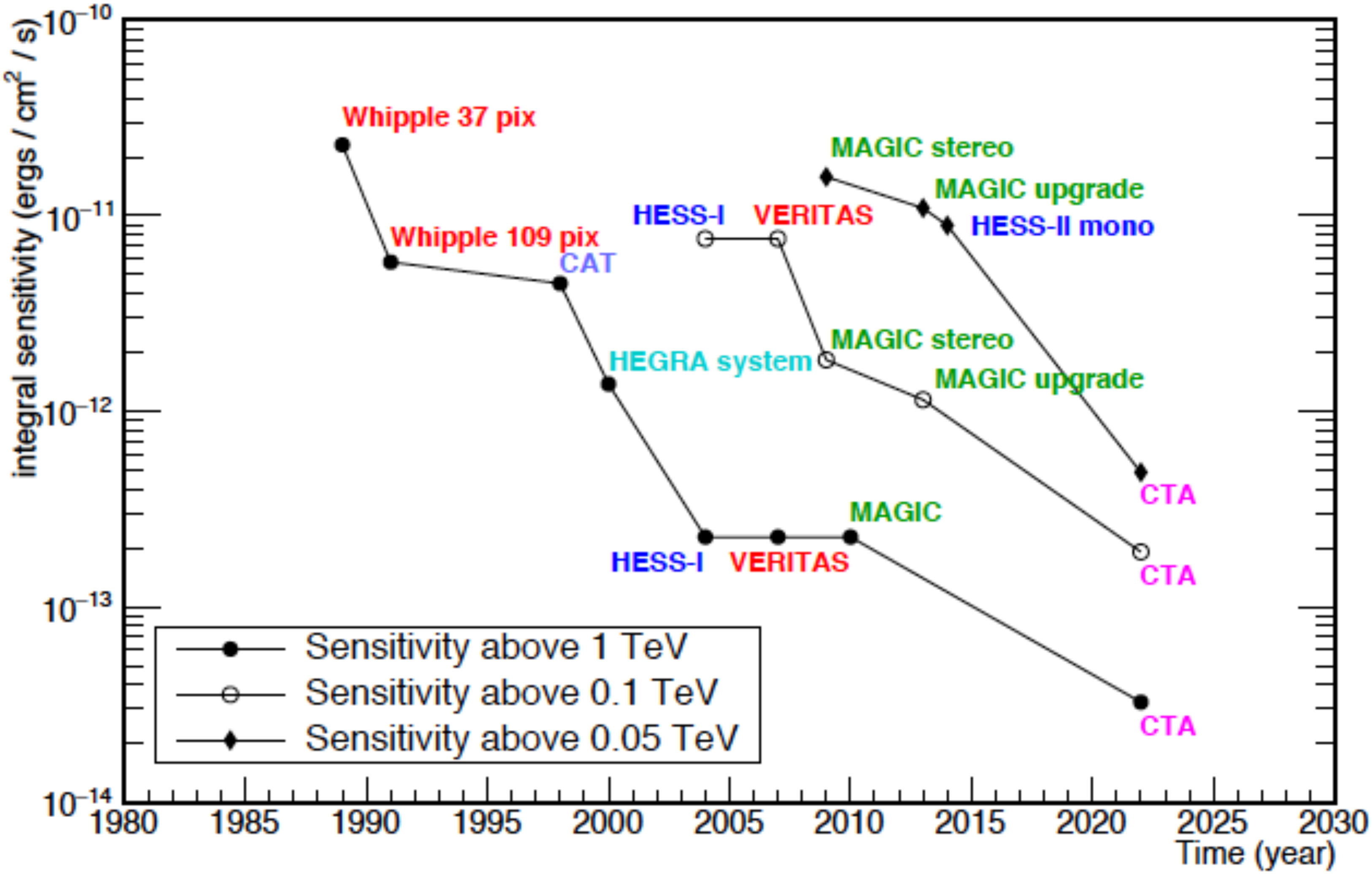
VERITAS Telescopes Arizona (USA)

4 Telescopes (12 m)
E_{th} ~ 150 GeV
Sens. ~ 0.7% Crab/50h

HESS Telescopes (Namibia)

1 Telescope (28 m)
4 Telescopes (13 m)
E_{th} ~ 150 GeV
Sens. ~ 0.5% Crab/50h

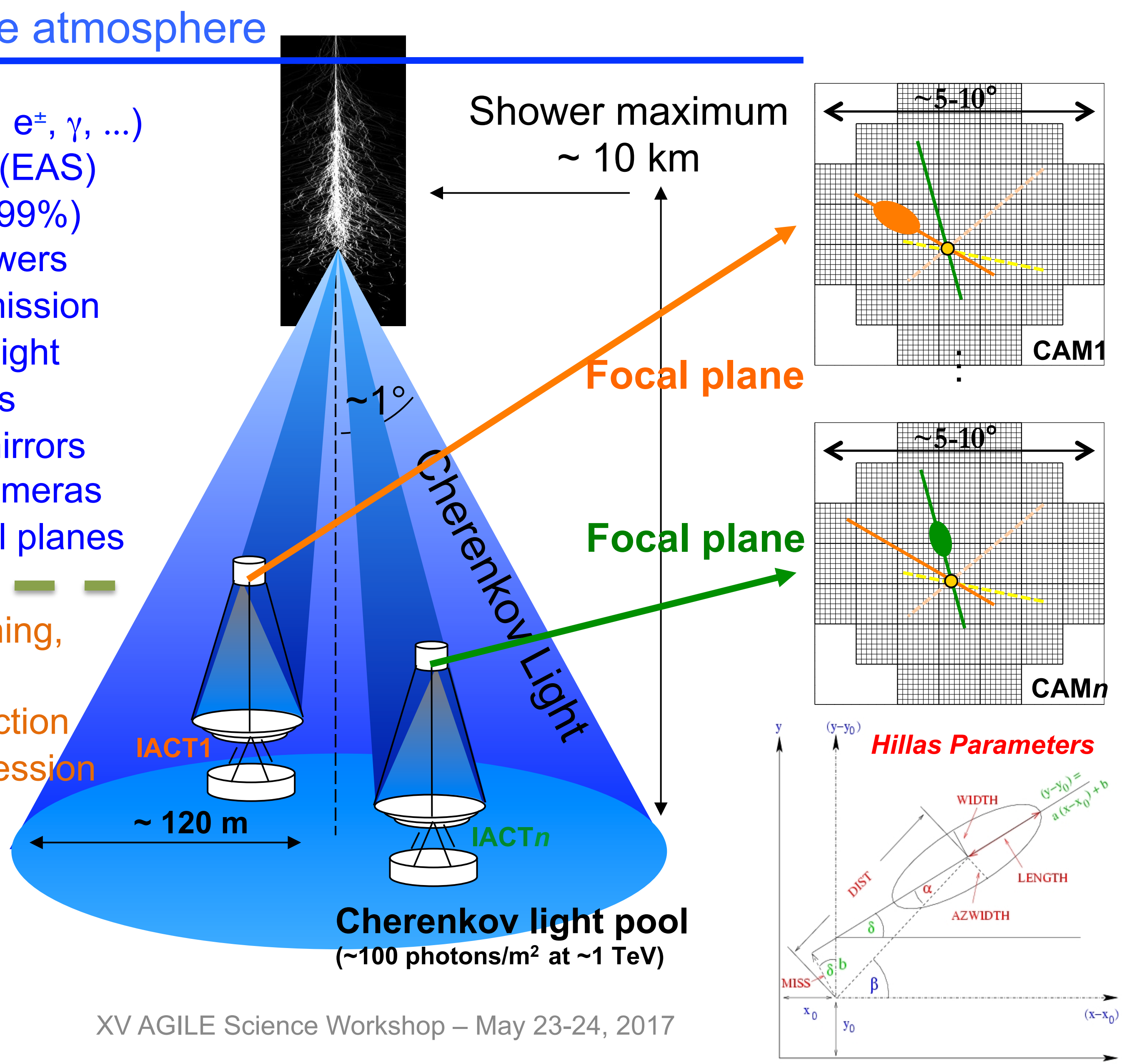
IACT sensitivities



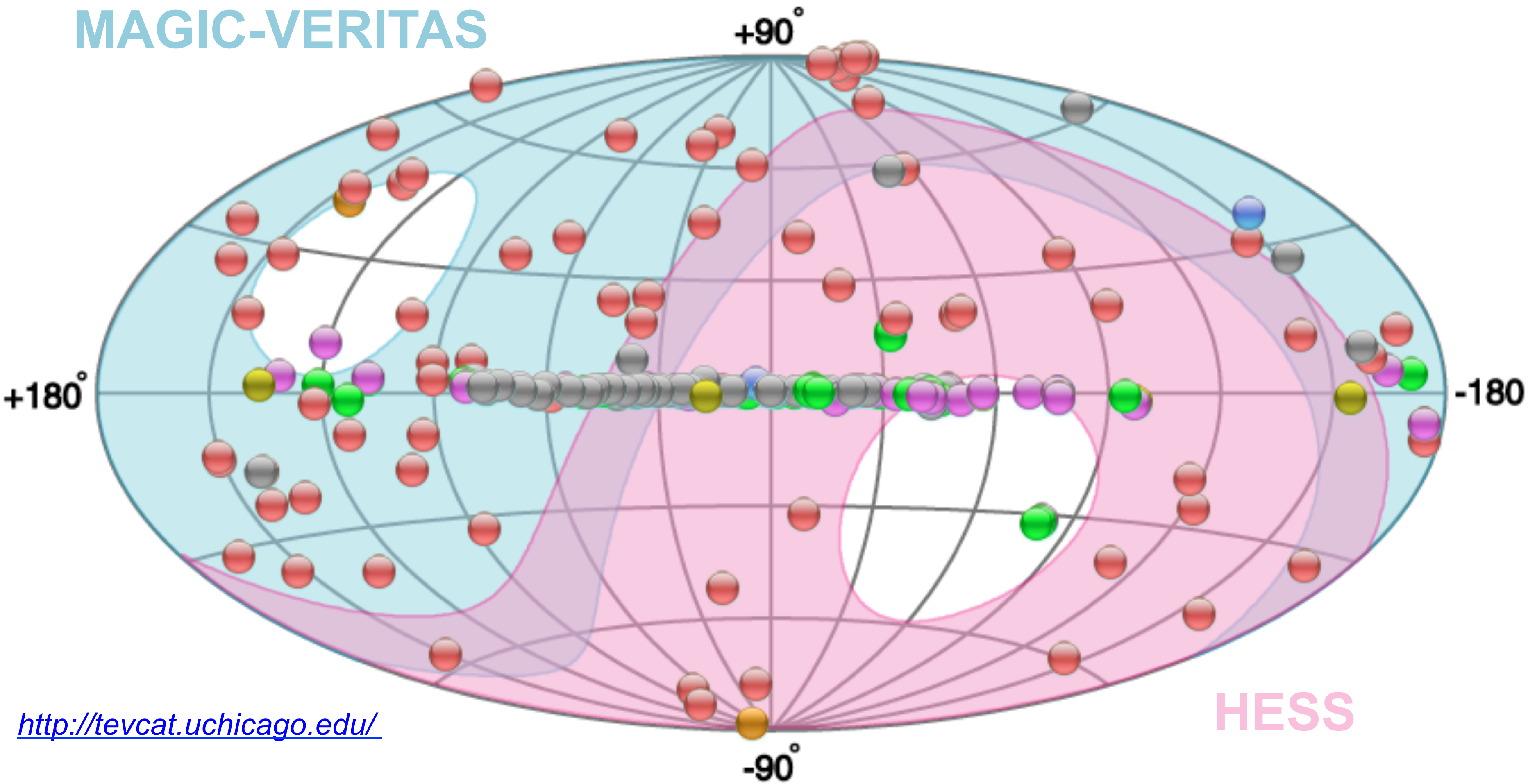
The Imaging Atmospheric Cherenkov Technique

- ✧VHE primary CRs (p, α, e±, γ, ...)
- ✧Extended Air Showers (EAS)
  - Hadronic showers (>99%)
  - Electromagnetic showers
- ✧Cherenkov radiation emission
  - optical and near-UV light
  - flash duration ~few ns
- ✧Light collected by the mirrors
- ✧Light focalized in the cameras
- ✧EAS images in the focal planes

- ✧Image calibration, cleaning, and parameterization
- ✧Stereoscopic reconstruction and background suppression
- ✧MC simulations
- ✧Scientific analysis
- ✧Science products
- ✧Observatory products



The Present TeV Sky

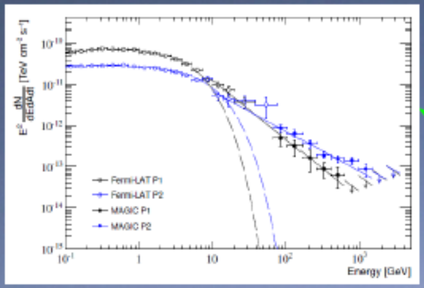


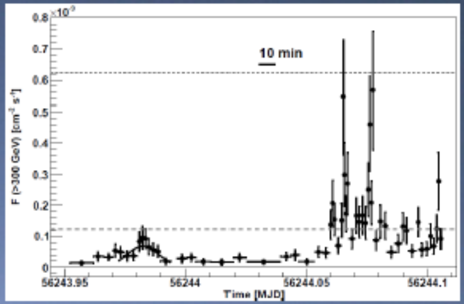
http://tevcat.uchicago.edu/

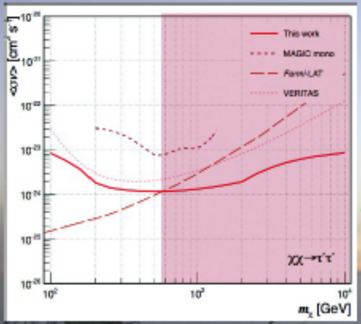
IACTs' Science

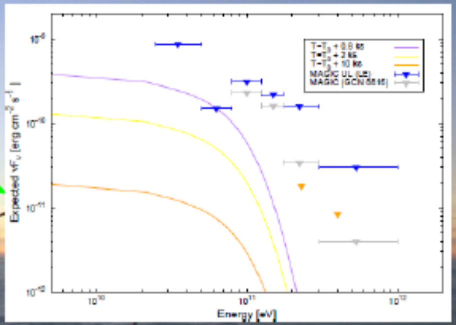
Galactic sources:
Pulsars, PWN, SNR, Binaries

AGNs: Blazars, Radio Gal., …
Galaxies & RQ AGNs: RC accel.







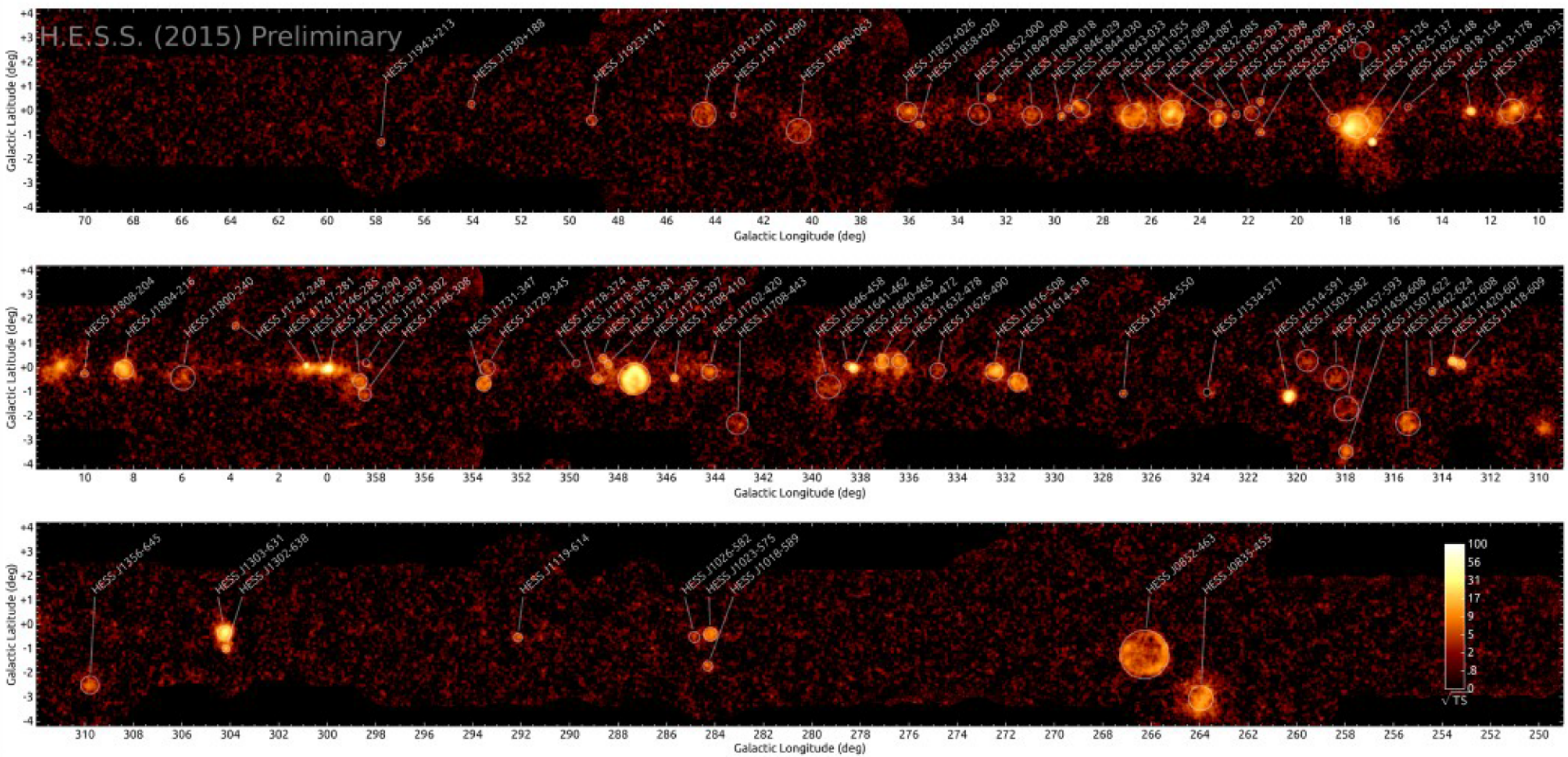


Fundamental physics:
Dark matter, LIV, EBL, IGMF & cosmology

GRBs, GW, Transients

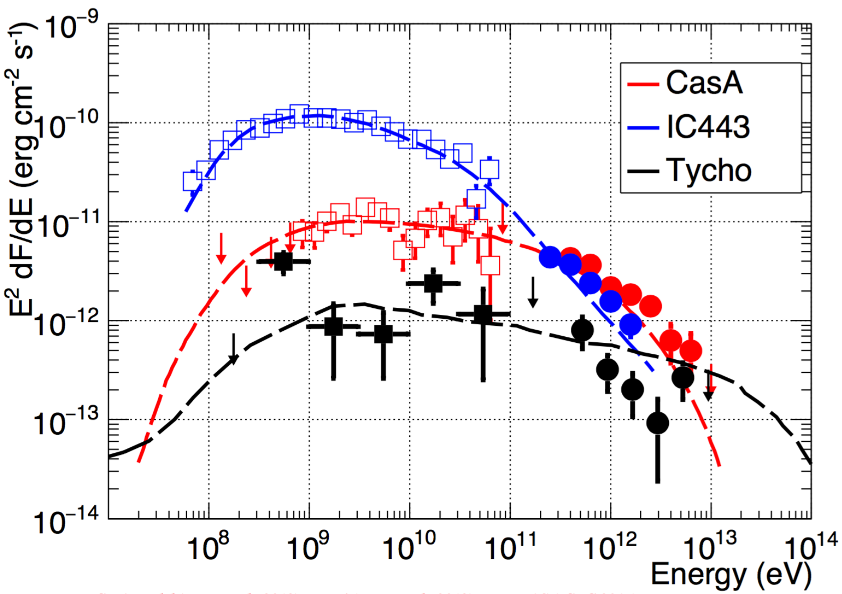
Galactic Plane's Survey by HESS

Gamma-rays from the survey made with 3000 hrs of HESS.
64 sources + 13 complex source regions (PWN, SNR, Binaries) + extended emission

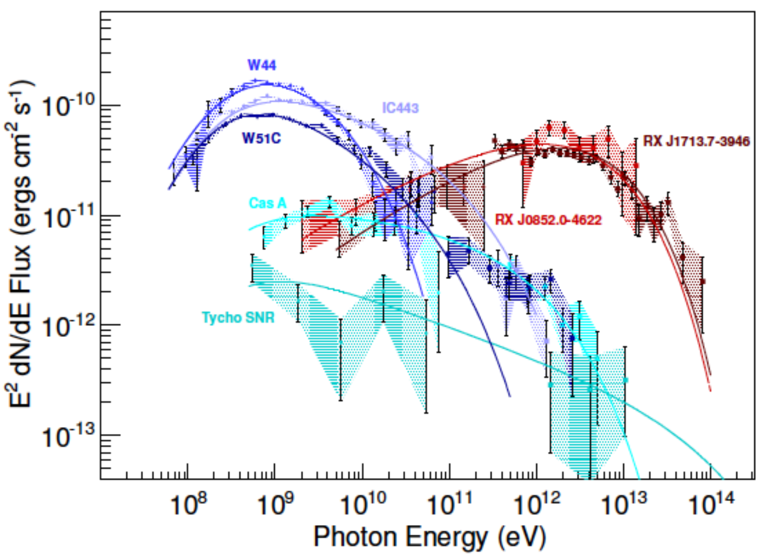


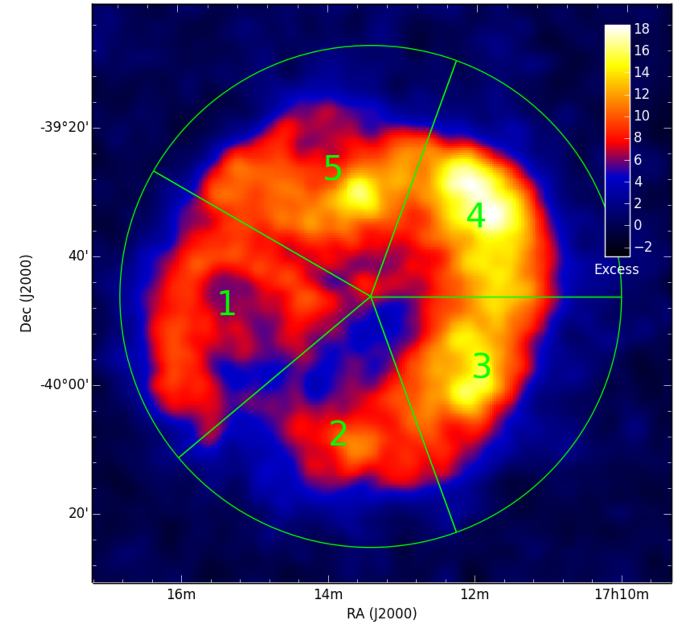
Deil et al. @ICRC 2015

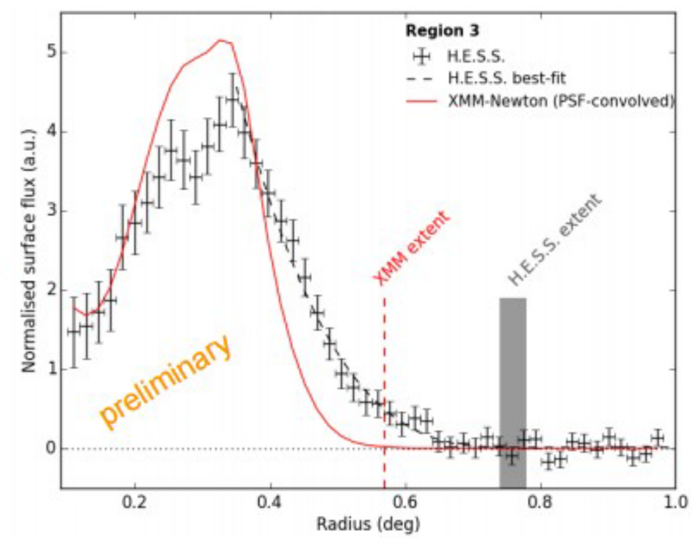
SNRs as CR factories



CasA model (Yuan et al., 2013), Fermi (Yuan et al., 2013), VERITAS (ICRC 2015)
IC443 model (Ackermann et al., 2013), Fermi (Ackermann et al., 2013), VERITAS (ICRC 2015)
Tycho model (S

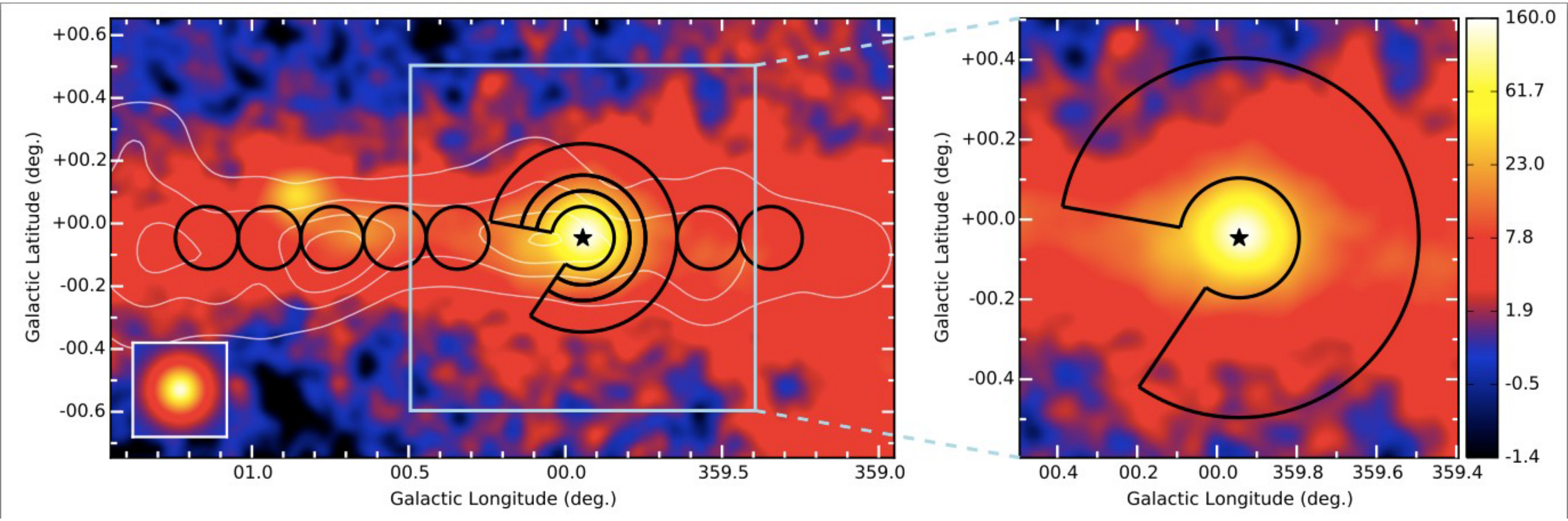


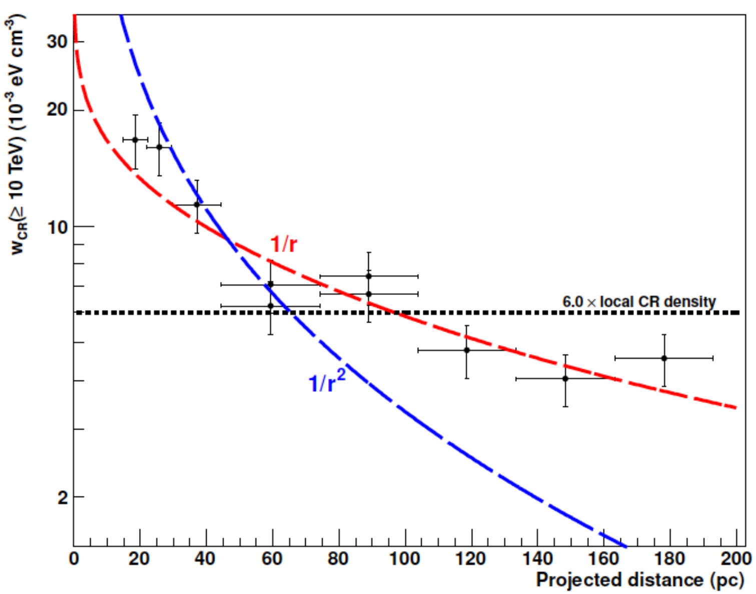


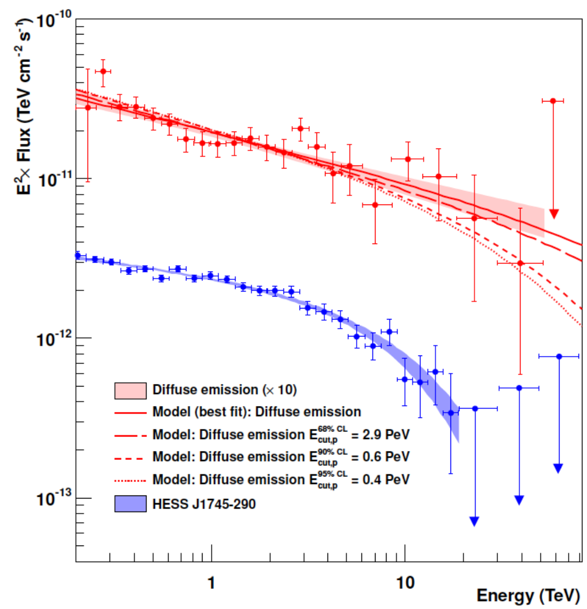


Quadrants used in the H.E.S.S.VHE γ-ray image of RX J1713.7-3946 to investigate possible particle escape.

PeVatron from GC





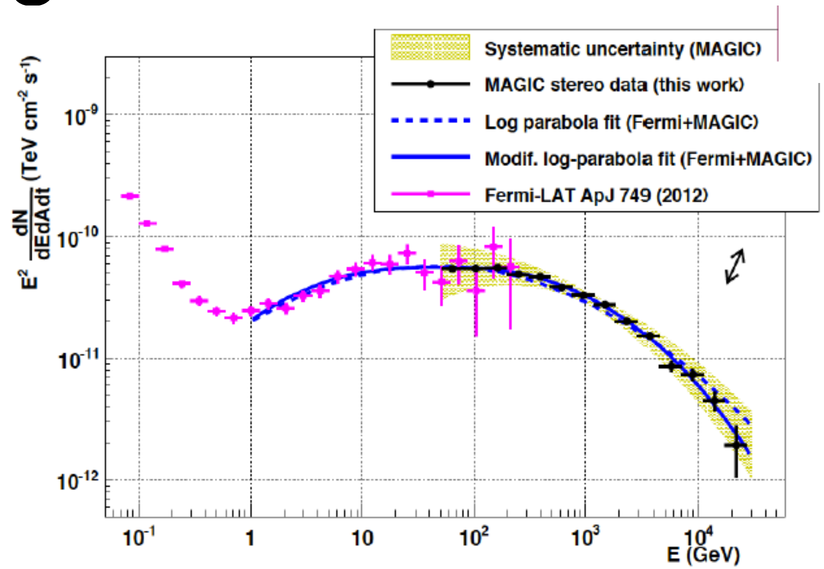


H.E.S.S. coll.
Nature, 531,
(2016)

The amazing CRAB

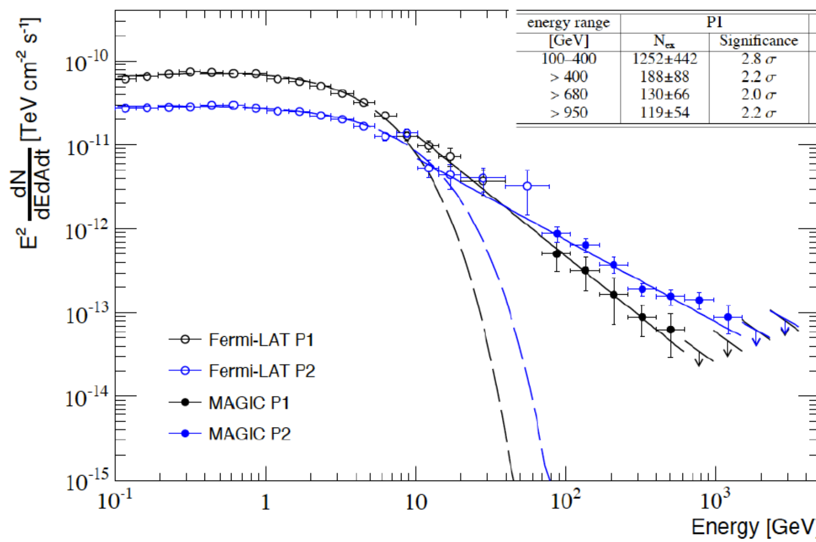
CRAB Nebula:

- High precision energy spectrum: 50 GeV to ~30 TeV, 5 bins per decade.
- Observations at E > 80 TeV (high-Zd) are allowing the K-N regime exploration.
- Combined fit with Fermi data yields the most precise measurement of the IC peak: 52.5 +/- 1.6 GeV



CRAB Pulsar:

- First detection of Crab Pulsar at VHE back in 2008 (E>25 GeV).
- 320 hours of observation led to the detection of pulsation above 400 GeV up to 1,5 TeV with spectrum extending at TeV energies.
- A VHE emission "bridge" also detected up to 400 GeV.



energy range	P1		P2	
[GeV]	N_{ex}	Significance	N_{ex}	Significance
100–400	1252±442	2.8 σ	2537±454	5.6 σ
> 400	188±88	2.2 σ	544 ± 92	6.0 σ
> 680	130±66	2.0 σ	293±69	4.3 σ
> 950	119±54	2.2 σ	190±56	3.5 σ

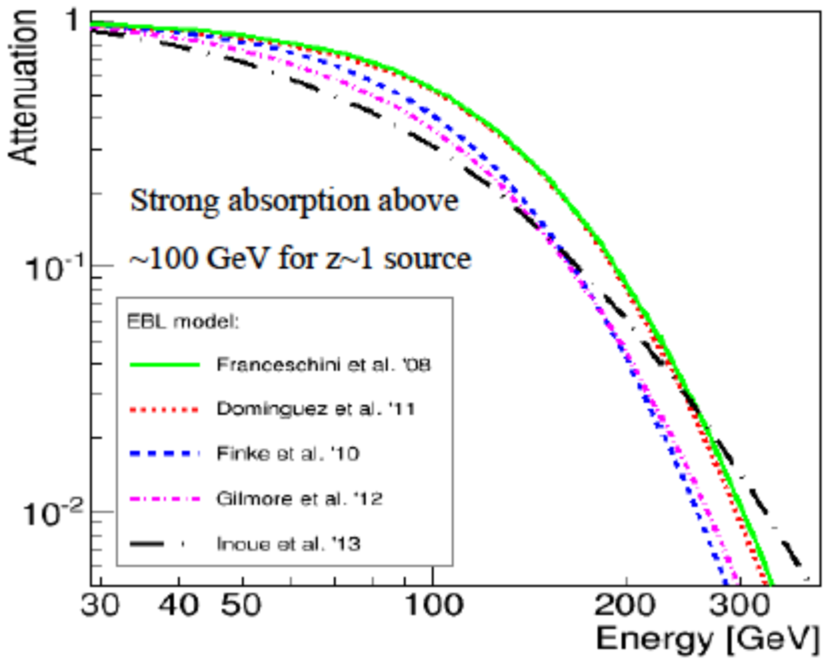
Aliu et al., 2008, Science, 322 [MAGIC]; Aliu et al, 2011, Science, 334 [VERITAS];
Aleksic et al., 2011, ApJ, 742; 2012, A&A,540; 2014, A&A,565; 2016, A&A, 582 [MAGIC]

Extragalactic Astrophysics

- The MAGIC Low-Energy Threshold allows to observe also objects at high redshift otherwise absorbed by Extragalactic Background Light.

- Farthest objects ever observed at VHE are FSRQ, most part of them has been discovered by MAGIC.

- At present the farthest FSRQ detected at VHE is at z=0.939.



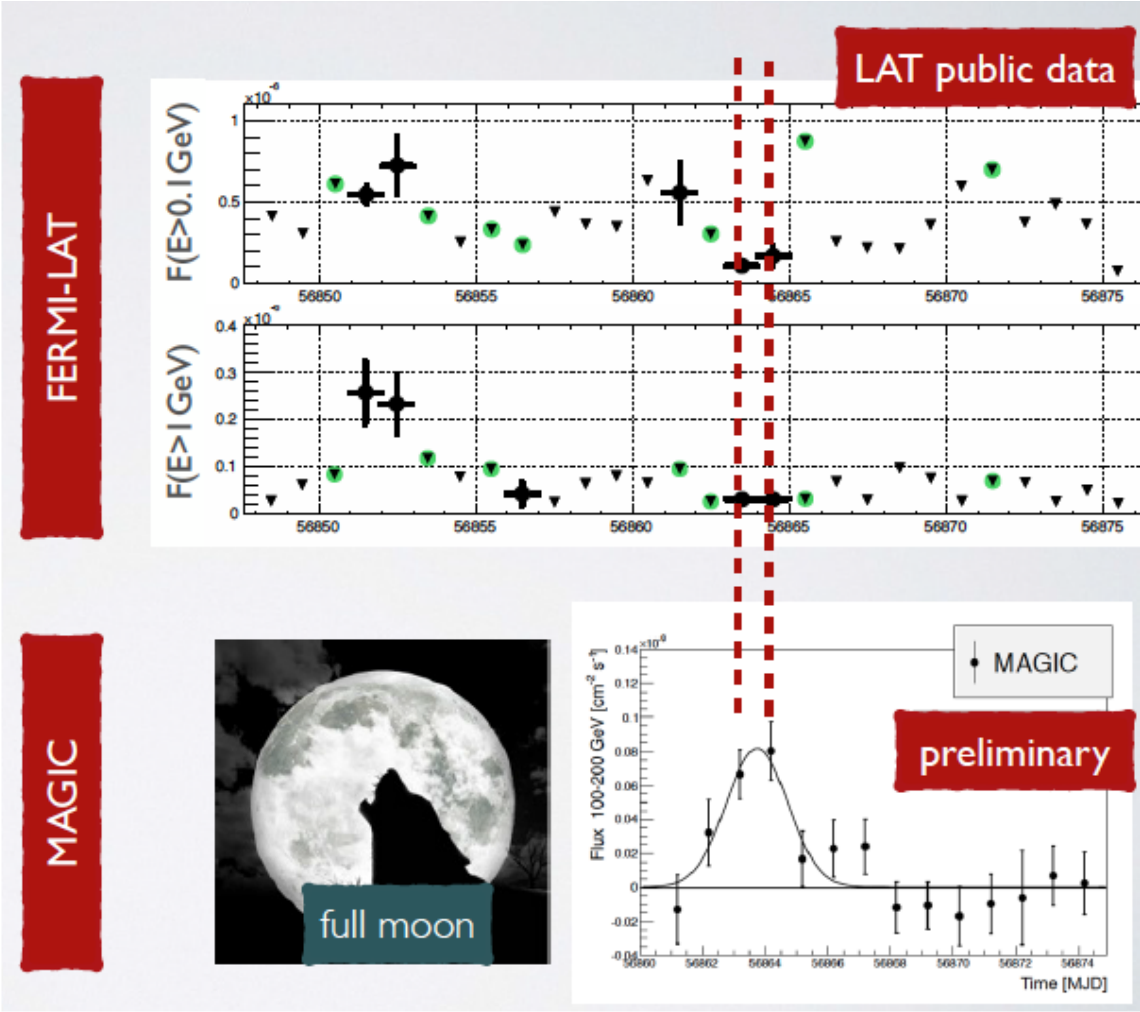
FSRQ	Redshift	First VHE detection by:	Year
3C 279	0.536	MAGIC	2006
PKS 1510-089	0.361	HESS	2009
PKS 1222+216 (4C +21.35)	0.432	MAGIC	2010
B0218+35	**0.944**	MAGIC	**2014**
PKS 1441+25	**0.939**	MAGIC	**2015**
S4 0954+65*	0.368	MAGIC	**2015**

Detection of the first gravitationally lensed VHE emission: the blazar S3 0218+357

LAT-observations in July ‘14:
spectral hardening
(Buson et al. ATel #6316)

A real pity:
no MAGIC observations right
at the flare (full moon)

but ~10 days later:
  => delayed emission!
signal with >5σ
in 4 consecutive nights,
point-like source

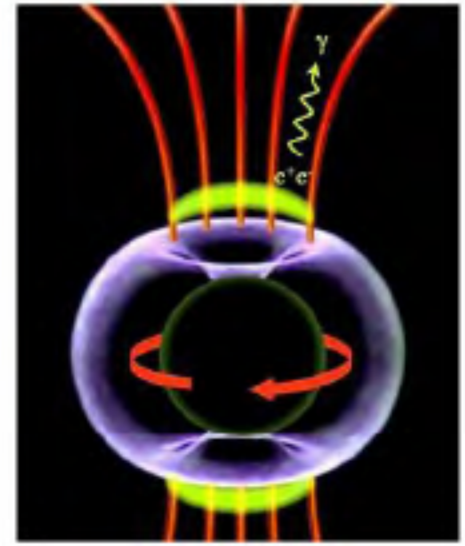


ATel#6349
MAGIC discovery

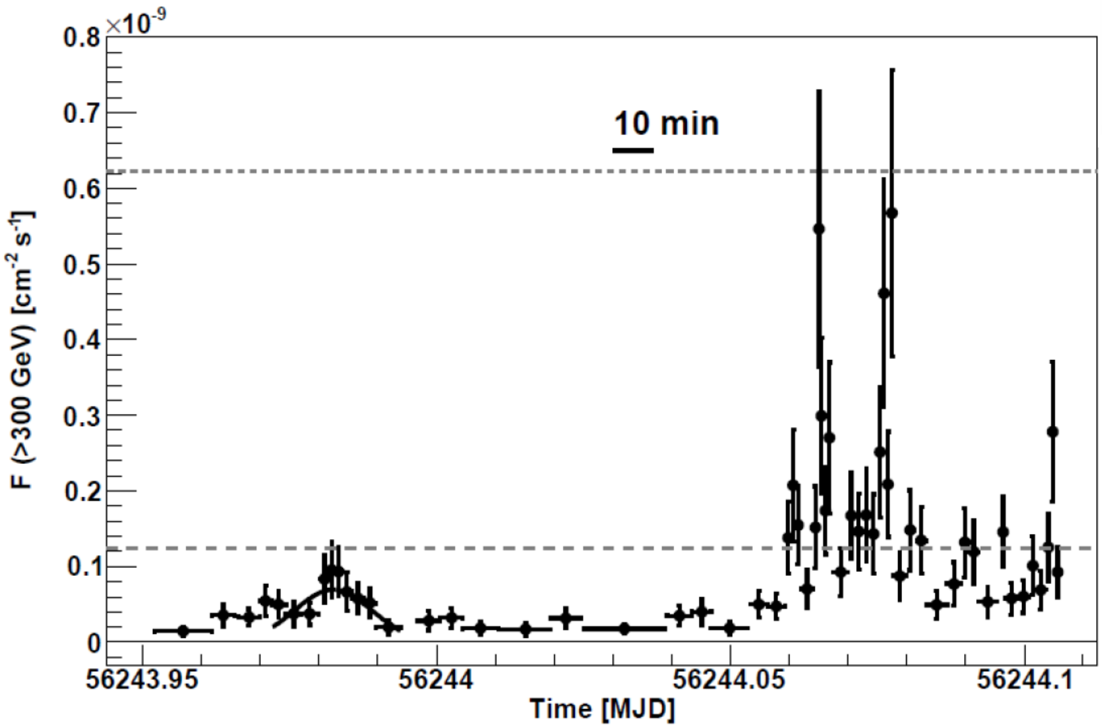
Extreme Flares: the case of IC310

Flaring activity with ultra-fast variability (< 5 min) detected in 2012 by MAGIC => sub-horizon variability challenges shock-in-jet models. Possible scenarios:

- mini-jet
- jet-cloud interactions
- magnetospheric origin of gamma-rays



Aleksić et al. (MAGIC) Science 346, 2014

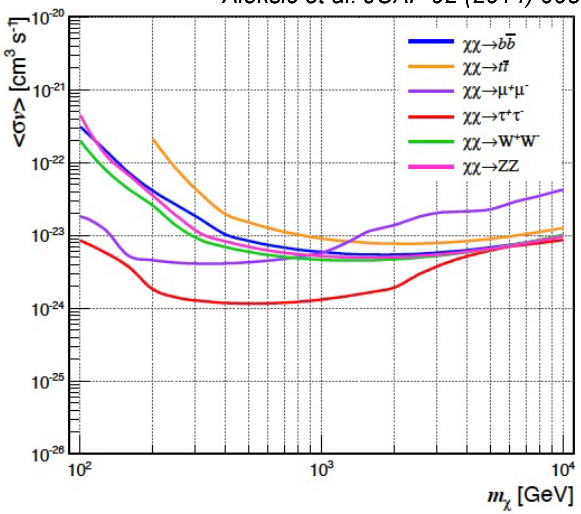


Dark Matter Sarches

MAGIC set most stringent limits on cross section annihilation and decay life time, in the WIMP mass range m_χ(~100 GeV up to tens of TeV), through deep observations of dwarf spheroidal satellite galaxies (dSphs) and the Perseus cluster.

<u>160 h observations on dwarf satellite galaxy Segue 1: point-like analysis and fullikelihood method</u>

Aleksić et al. JCAP 02 (2014) 008



Upper limits on $<\sigma_{ann}v>$ for secondary photons produced from different final state SM particle

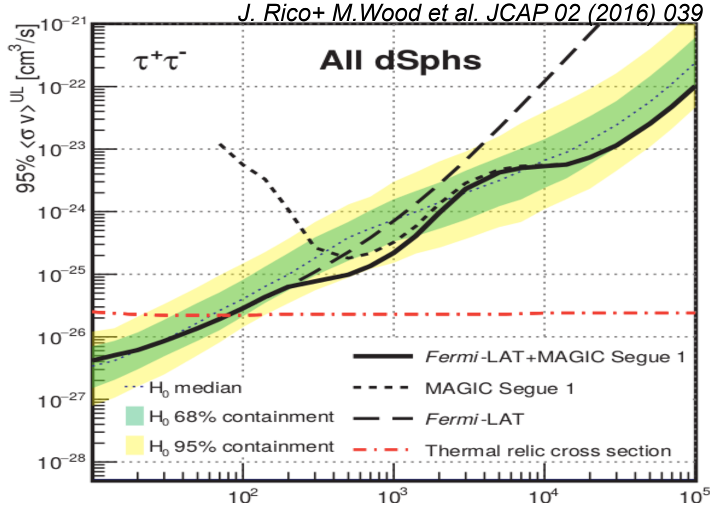
The strogest limit (95% c.l.) is of order:

$<\sigma_{ann}v>\sim 1.2 \times 10^{-24}$ cm^3 s^{-1}

Corresponding to a m_χ~500GeV dark matter particle annihilating in τ+τ-

<u>The first MAGIC/*Fermi*-LAT joint dark matter annihilation signal search from dSphs : fullikelihood approach</u>

J. Rico+ M.Wood et al. JCAP 02 (2016) 039



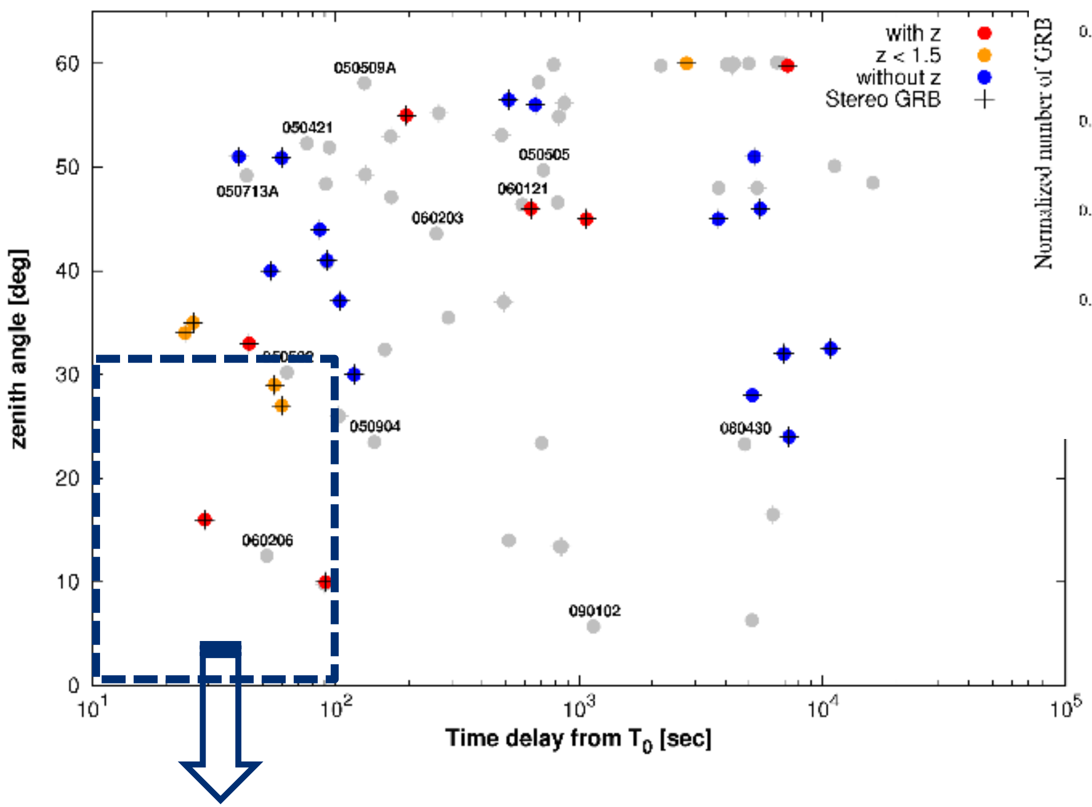
160 h Segue1
by MAGIC
+
6-years obs.
of 15 dSphs
by *Fermi*-LAT

Combined achieved limits on the annihilation cross-section for dark matter particle masses between 10 GeV and 100 TeV (the widest range so far explored)

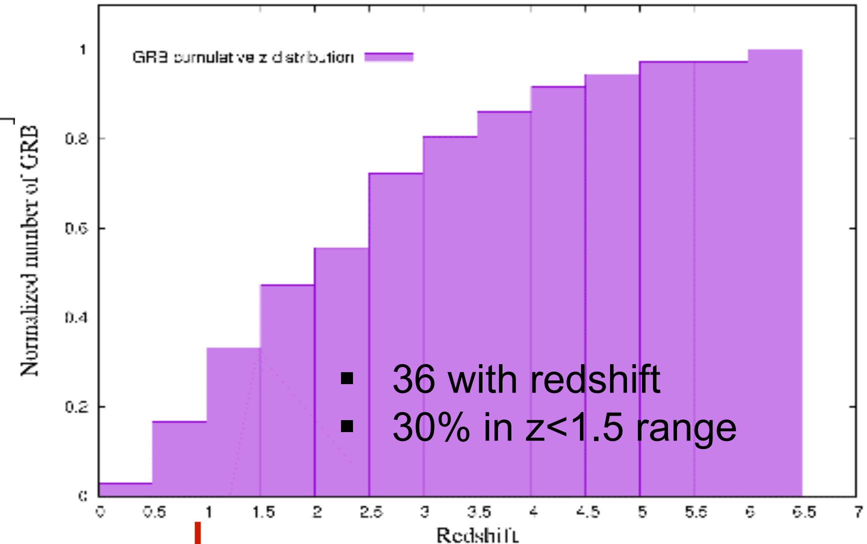
Maximum improvement of the combined limits with respect to the individual ones by a factor 2 at a mass of 500 GeV (for bbbar) and 3 TeV (for τ+τ-, here shown)

Gamma Ray Bursts & other transients …

- 90 GRBs observed so far (since 2005)
- No detection until now



Still poorly-populated region (~10% of GRBs)



- 36 with redshift
- 30% in z<1.5 range

SOURCE	REDSHIFT	DISCOVERER	YEAR
B 0218+35	**0.944**	**MAGIC**	2014
PKS 1441+25	**0.939**	**MAGIC**	2015
3C 279	0.536	**MAGIC**	2006

MAGIC almost doubled the VHE horizon in the past 2 years

redshift ~ 1 is not a limit anymore!

Conclusion

IACTs are presently at a very productive time in terms of physics.
Available sensitivity allows the/to:

- Population studies at VHE
- Disentangle Cosmic Ray acceleration processes and origins
- Comprehension of acceleration mechanism in pulsars
- Long term behaviour of binary systems and AGNs
- Access the ultra fast variability in AGNs (min scale): LIV probe
- Increase the accessible volume of the Universe (up to z~1)
- Measurements on the EBL density at different redshifts
- Dark matter searches leading to best limits on dark matter cross-section from dSph.
- CR acceleration in normal galaxies and RQ AGNs.
- Effectively search for GRBs or fast transients.

INAF MAGIC TEAM