MAGIC highlights, and a look toward CTA

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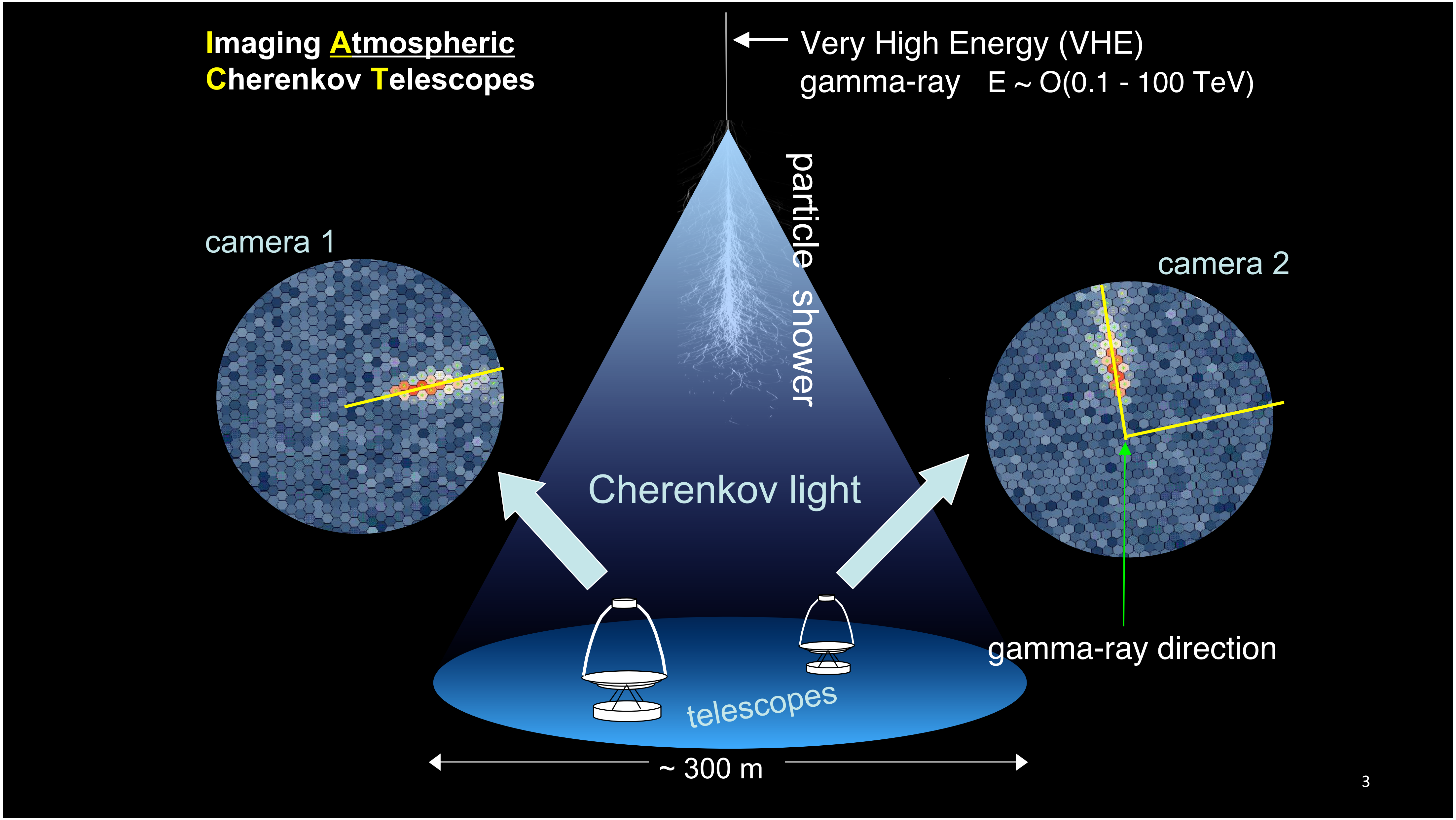
Outline

- The instrument
- Science (disclaimer: personal taste selection)
  - 0: GW-counterpart detector
  - 1: gamma-ray detector
  - 2: cosmic-ray detector
  - 3: exotic-physics detector
- Conclusions


Imaging Atmospheric
Cherenkov Telescopes
Very High Energy (VHE)
gamma-ray E ~ O(0.1 - 100 TeV)
particle shower
camera 1
camera 2
Cherenkov light
gamma-ray direction
telescopes
~ 300 m

MAGIC Facts

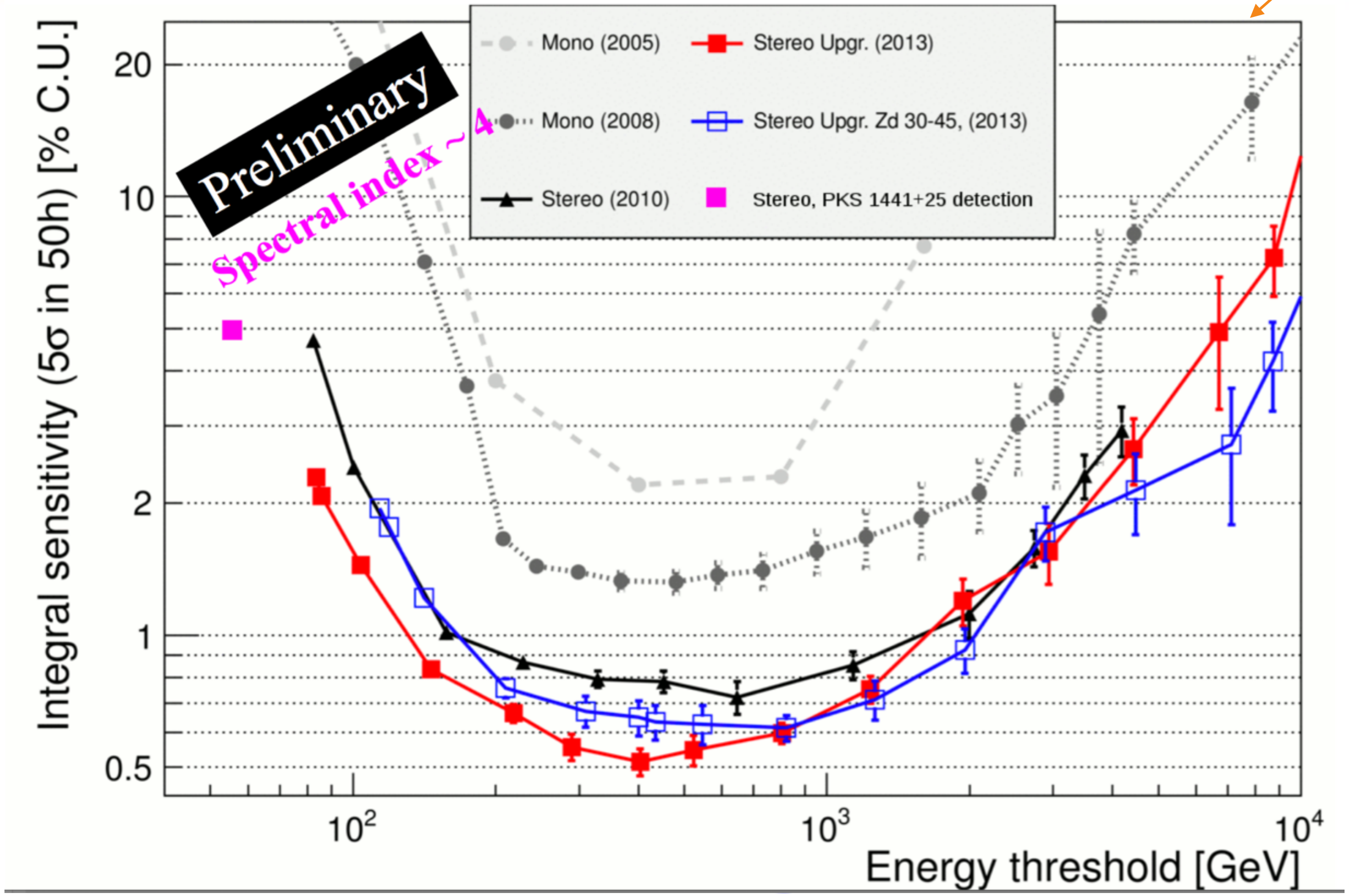
- Started as **a single telescope** in 2004
- Operating in **stereo-mode** since 2009
- Designed optimized for: **low-energy, fast repositioning**

- ❖ Collaboration of **~160 scientists** from Germany, Spain, Italy, Switzerland, Finland, Croatia, Bulgaria, Poland, India and Japan
- ❖ 17m diameter dish
- ❖ Energy range: 70 GeV-30 TeV (with standard trigger) and down to 30 GeV (with *sumtrigger*)
- ❖ **Angular resolution**: <0.08°; **Energy resolution**: ~15-25%
- ❖ **Pointed mode** observations (Field of View: ~3.5°)

Astronomic Observatory of Roque de Los Muchachos (~2200 m a.s.l.), La Palma (Spain)

A continuous effort

See R. Coccia talk this morning



- **Mono**:
  - Light Gray circles: first installation (2005)
  - Dark gray: different readout system (2008)
- **Stereo**-phase:
  - **Black** triangles: stereo phase 1 (2010)
  - Squares: stereo after camera upgrade:
    - **zenith angle below 30◦ (red, filled),**
    - **30 – 45◦ (blue, empty)**
- **Sum-trigger** allowed <50 GeV

4-fold improvement in sensitivity over the last decade

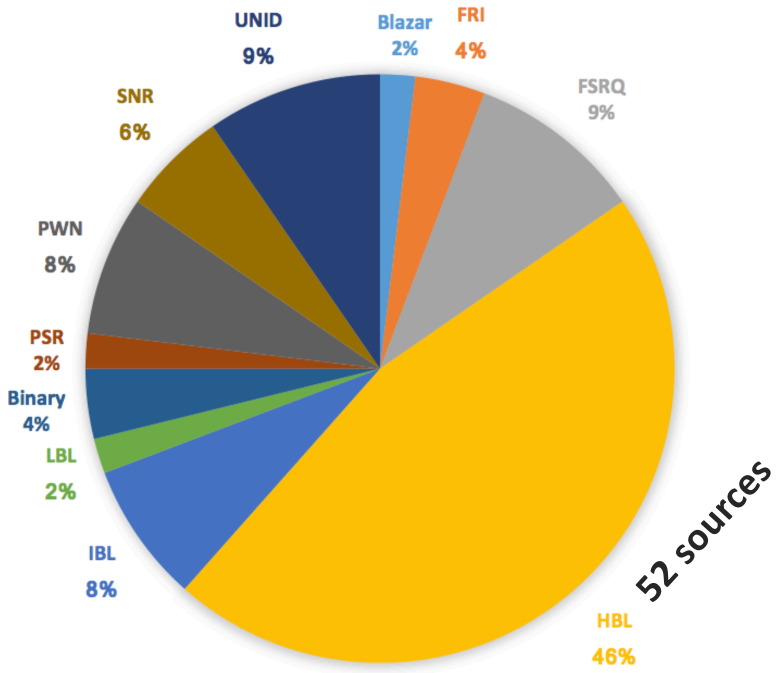
→ ~10-fold improvement at the lowest energies !!

← 16 times less needed observation time!

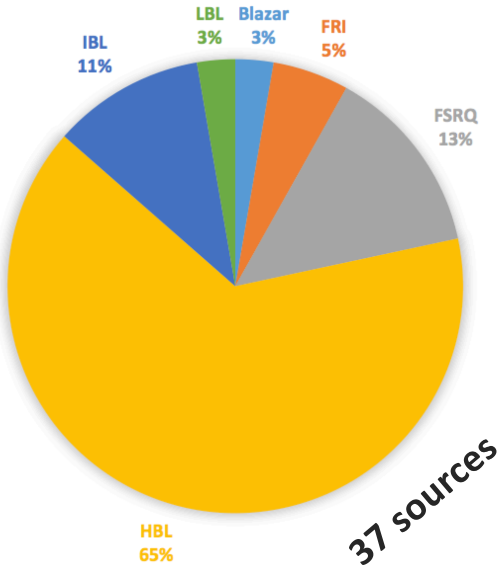
The MAGIC “catalogues”

From TeVCat 2.0 http://tevcat2.uchicago.edu/

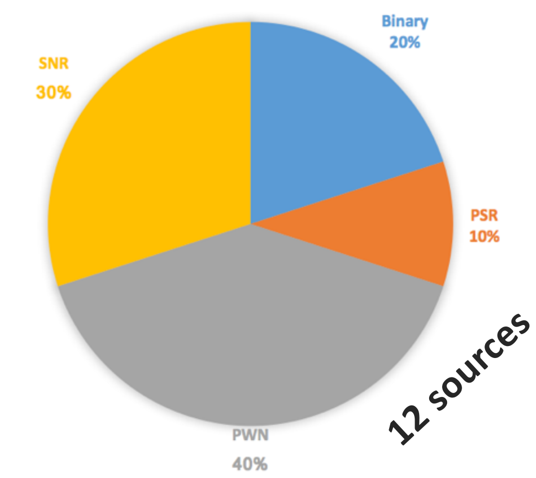
MAGIC SOURCE CATALOGUE



MAGIC EXTRAGALACTIC SOURCES



MAGIC GALACTIC SOURCES



Dark Catalogue (many sources pointed and not detected)

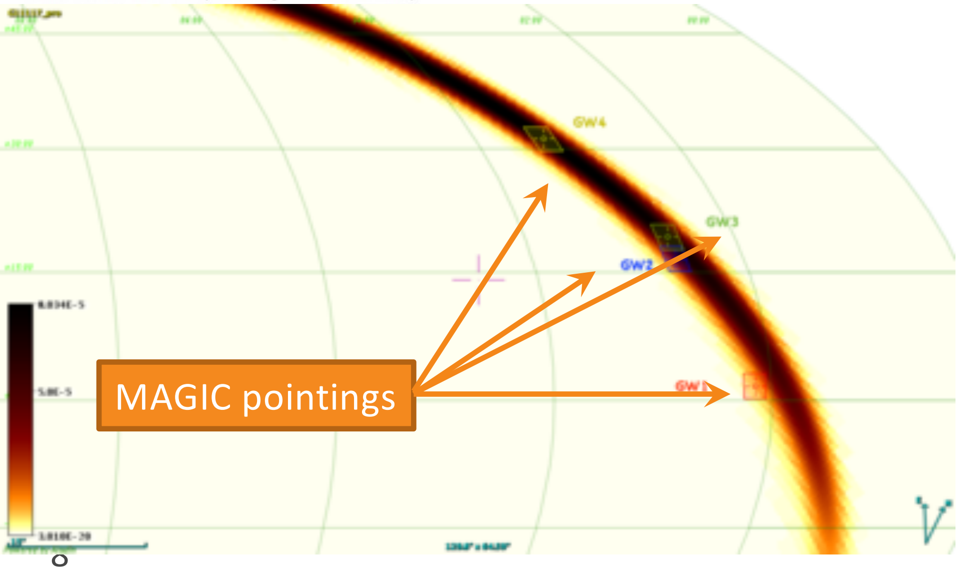
- MAGIC is in the N-hemisphere: optimized for extra-gal. physics
- MAGIC hunts the farthest objects due to lowest energy threshold


PART 0
MAGIC and GW counterparts

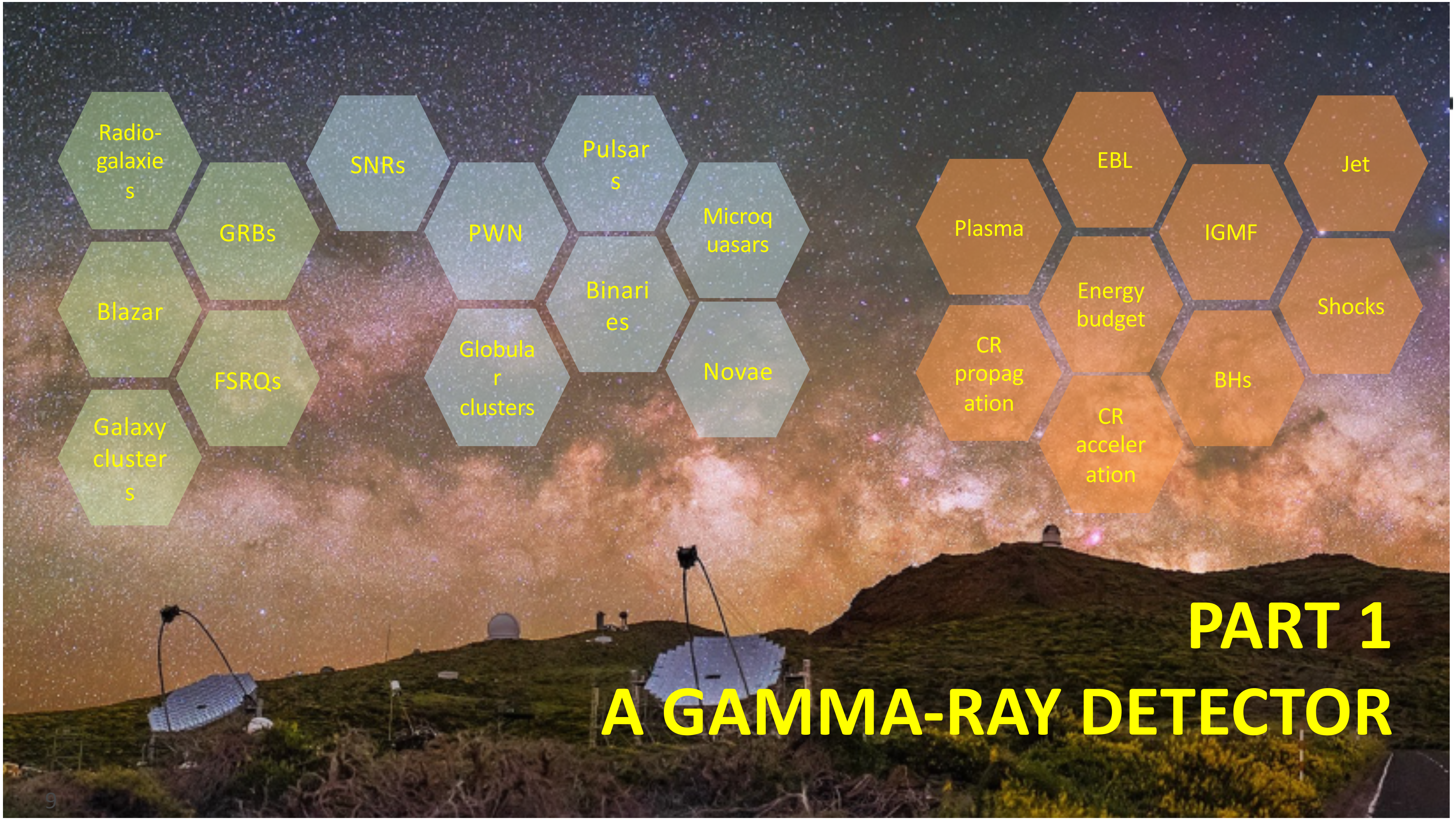
MAGIC observed GW151226

See P.Evans talk at this conf.

```
TITLE:   GCN CIRCULAR
NUMBER:  18776
SUBJECT: LIGO/Virgo G211117: MAGIC very-high energy gamma-ray observations
DATE:    15/12/30 16:14:44 GMT
FROM:    Antonio Stamerra at INAF-OATo/SNS-Pisa  <antonio.stamerra@sns.it>

Angelo Antonelli (INAF-OaR), Alessandro Carosi (INAF-OaR), Barbara de Lotto
(Univ. Udine), Razmik Mirzoyan (MPI-Müenchen) and Antonio Stamerra (INAF-
OaTo and SNS-Pisa) on behalf of the MAGIC collaboration

The MAGIC system of Cherenkov Telescopes, sensitive to high-energy gamma-
ray above ~50 GeV, performed observations of 4 regions in the strip of the
bayestar GW map for the trigger G211117.
Observations started on  December 28,  21 UT. Each observation covers a
region of ~2.5x2.5 deg. Analysis is on-going.
The list of targets is the following:

Target 1:  PGC1200980 (OT MASTER GCN#18729)
RA,Dec (J2000):  02:09:05.8,  +01:38:03.0
Duration: 42 min

Target 2: strip from GW map
RA,Dec (J2000):  02:38:38.93, +16:36:59.27
Duration: 56 min (moonlight conditions)
```



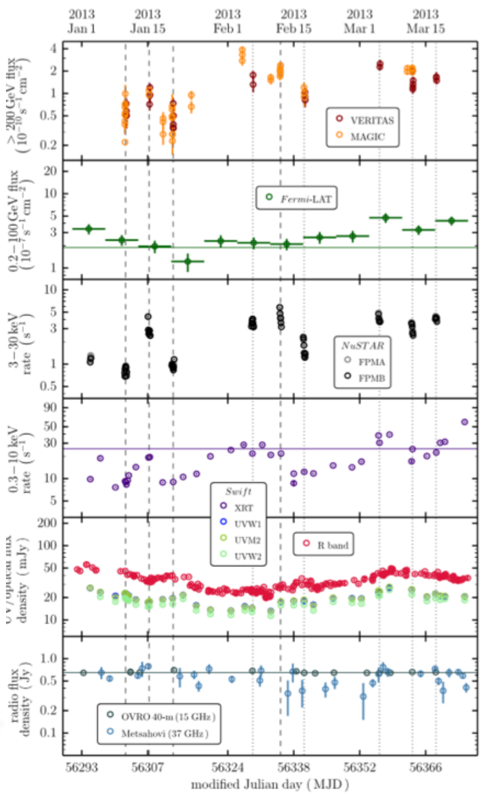
- MAGIC signed in 2014 an **MoU** with the LVC to join the **follow-up program** of GW event candidates.
- On the Dec 28th 2015, MAGIC followed-up the second GW discovery event (see our **GCN #18776**), pointing four 2.5x.2.5deg regions (2x max prob, 2x known targets). No excesses found.
  - Consider that MAGIC FOV is roughly 3x3deg
- For LVC O2 run, we are discussing **our "reaction" and "pointing" criteria**:
  - 1. immediate repositioning or later follow-up?
  - 2. Scanning mode (e.g. n positions) or association mode (closeby galaxies)?
  - 3. trigger acceptance (rate and value)
- Learning period to optimize observation modes
- The expected number of highly significant events during the O2 run is between 6 and 25.



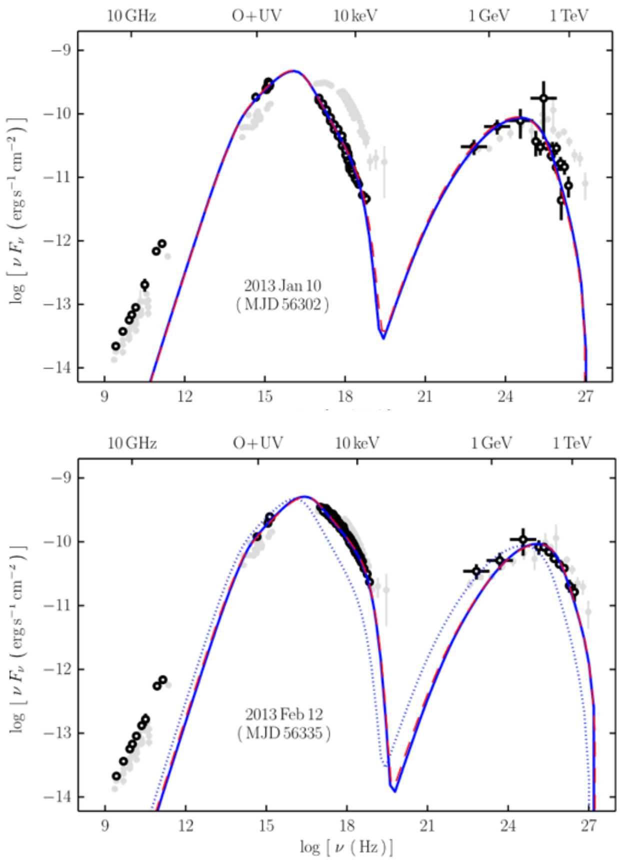
Radio- galaxie s
GRBs
Blazar
FSRQs
Galaxy cluster s
SNRs
PWN
Globula r clusters
Pulsar s
Binari es
Microq uasars
Novae
Plasma
EBL
Energy budget
CR propag ation
CR acceler ation
IGMF
BHs
Jet
Shocks
PART 1
A GAMMA-RAY DETECTOR
9

#1.1 Large projects: Multi-wavelength/multi-year

- The importance of multi-w campaign has become utter, MAGIC had developed several monitoring campaigns + ToO.



Astrophys.J. 819 (2016) 156

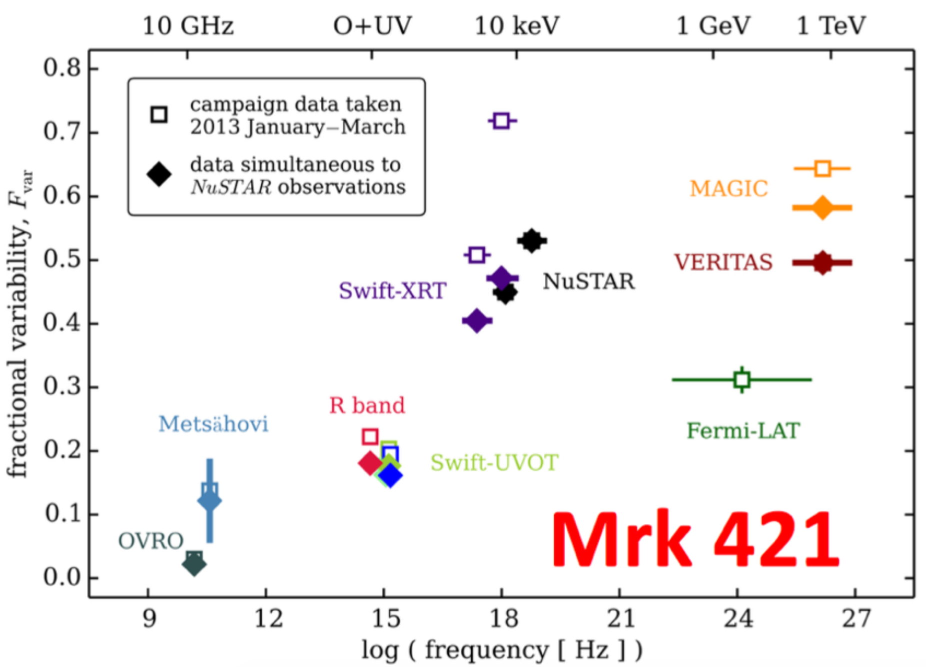


- ← Mrk421 Swift-UVOT, Swift-XRT, NuSTAR, Fermi-LAT, MAGIC, and VERITAS [MAGIC+ 2016 Apj 819]
  - Coverage issue + integration

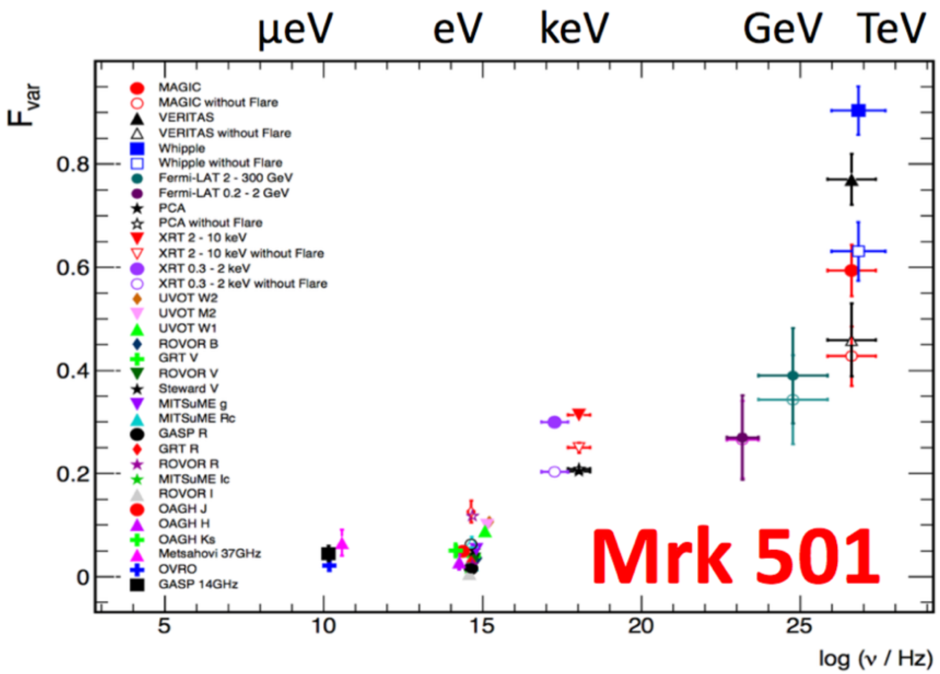
- Flares cause not only increased flux, but also (correlated) peak-shifts. SSC mechanisms seems at work, but:
  - A different (than baseline) electron population swept-up?
  - Same population received boost?

Fractional variability: a global picture of dynamics

Balokovic et al., 2016 *ApJ* 819, 156

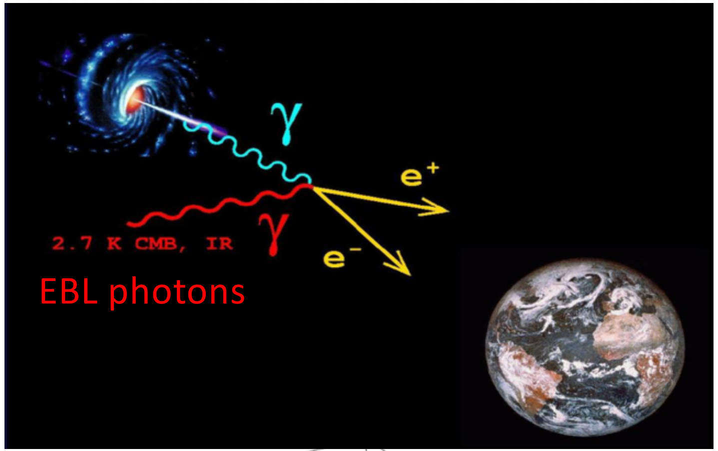


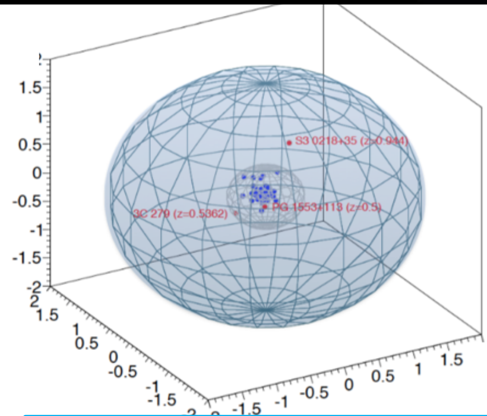
Ahnen et al. Submitted to A&A



- Fractional variability requires large coverage, but guarantees connection between two bumps:
  - Information on particle populations, acceleration efficiency…
- IACT data are now important to be made public in astronomical format in science archives..

#1.2 Expanding the TeV universe





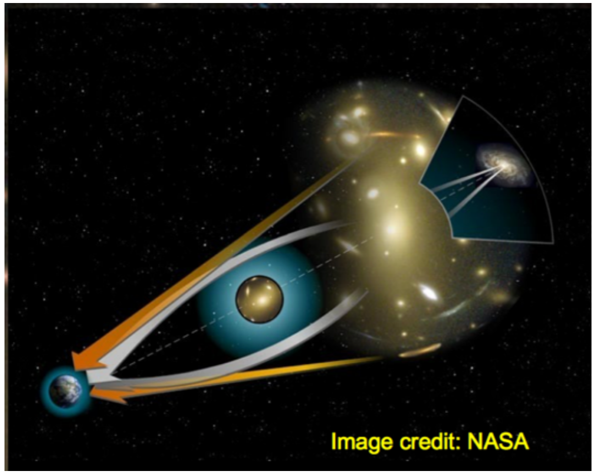
Almost doubled the TeV universe reach in past 2 years

- Gamma-ray flux is depleted through inter-galactic space by pair-production
- Interaction with low-energy (UV-IR photons) of the Extragalactic Background Light: a proxy for modeling the evolution of Universe
- MAGIC has a design focus in the low-energies: **optimized for far-away (extragalactic) sources**

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

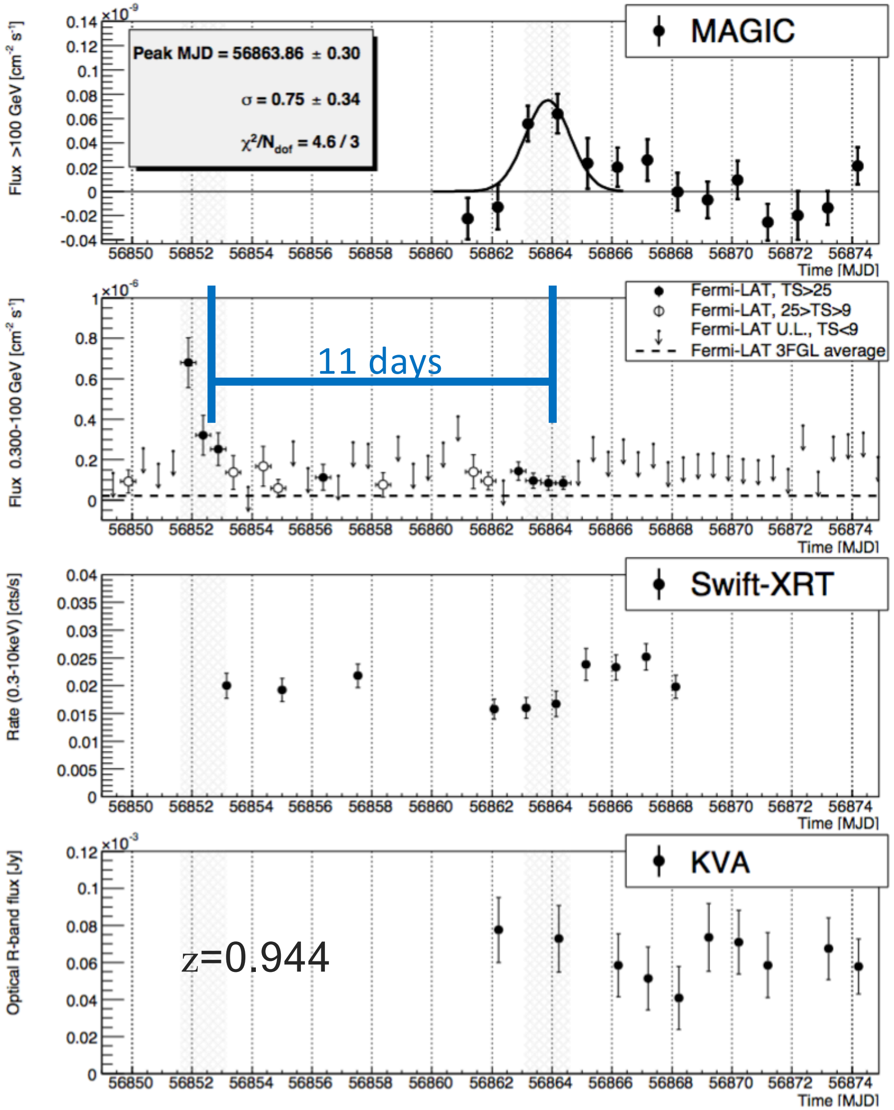
Farthest objects ever observed in TeV sky!

Gravitational lensed gamma-rays



QSO B0218+357 is a gravitationally lensed blazar at redshift: 0.944 where the lens is probably a spiral galaxy B0218+357G at z=0.68

11-days is the time-delay

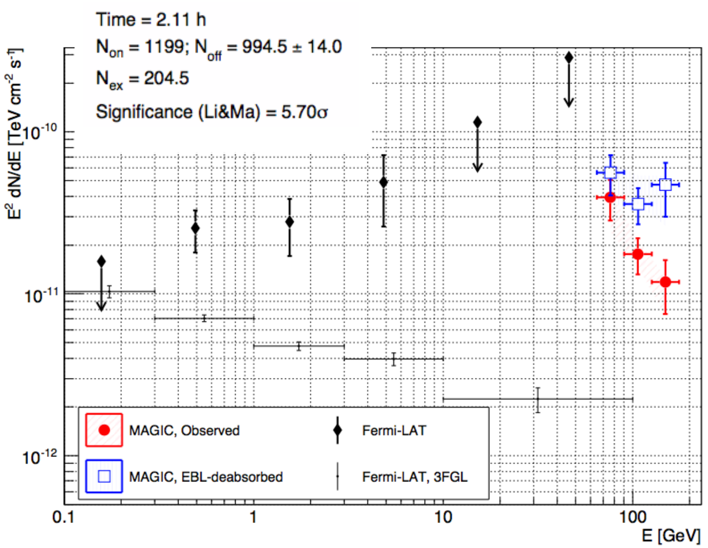


In 2014, Fermi got the first flare, and 11 days after, MAGIC detected the afterlight

- MAGIC could not observe the leading image due to the Full Moon.
- First gravitationally-lensed VHE gamma rays ever observed
- 2hours, 6 sigma significance

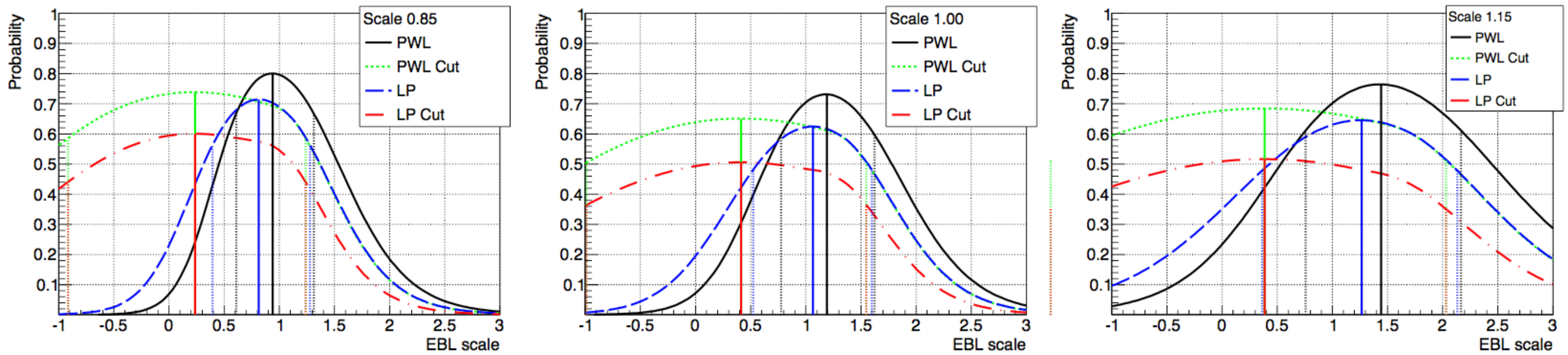
Detection of very high energy gamma-ray emission from the gravitationally-lensed blazar QSO B0218+357 with the MAGIC telescopes
MAGIC Collaboration (M.L. Ahnen *et al.*). Sep 5, 2016. 11 pp.
e-Print: **arXiv:1609.01095** **[astro-ph.HE]** | **PDF**

Constraints on EBL from the farthest objects



- Joint spectral fit combining *Fermi*-LAT and MAGIC points using a set of possible spectral shapes.
- Scaling parameter α of the optical depth.

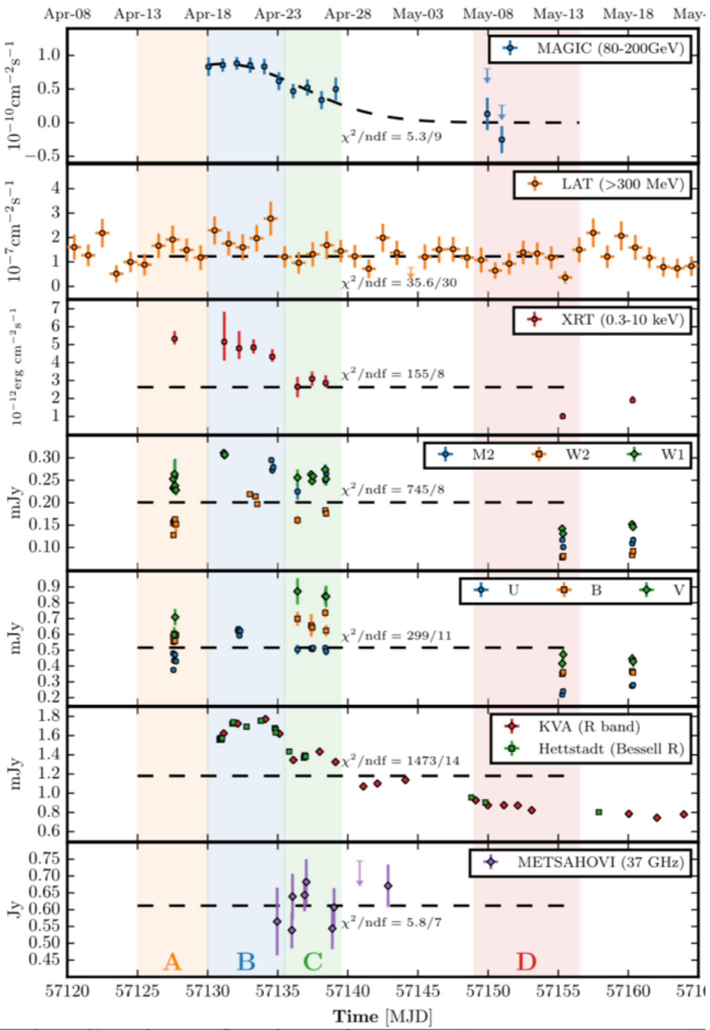
Model	α (PWL)	α (all)
Franceschini et al. (2008)	$1.19 \pm 0.42_{stat} \pm 0.25_{syst}$	< 2.8
Finke et al. (2010)	$0.91 \pm 0.32_{stat} \pm 0.19_{syst}$	< 2.1
Domínguez et al. (2011)	$1.19 \pm 0.42_{stat} \pm 0.25_{syst}$	< 2.7
Gilmore et al. (2012)	$0.99 \pm 0.34_{stat}\,{}^{+0.15\,syst}_{-0.18\,syst}$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

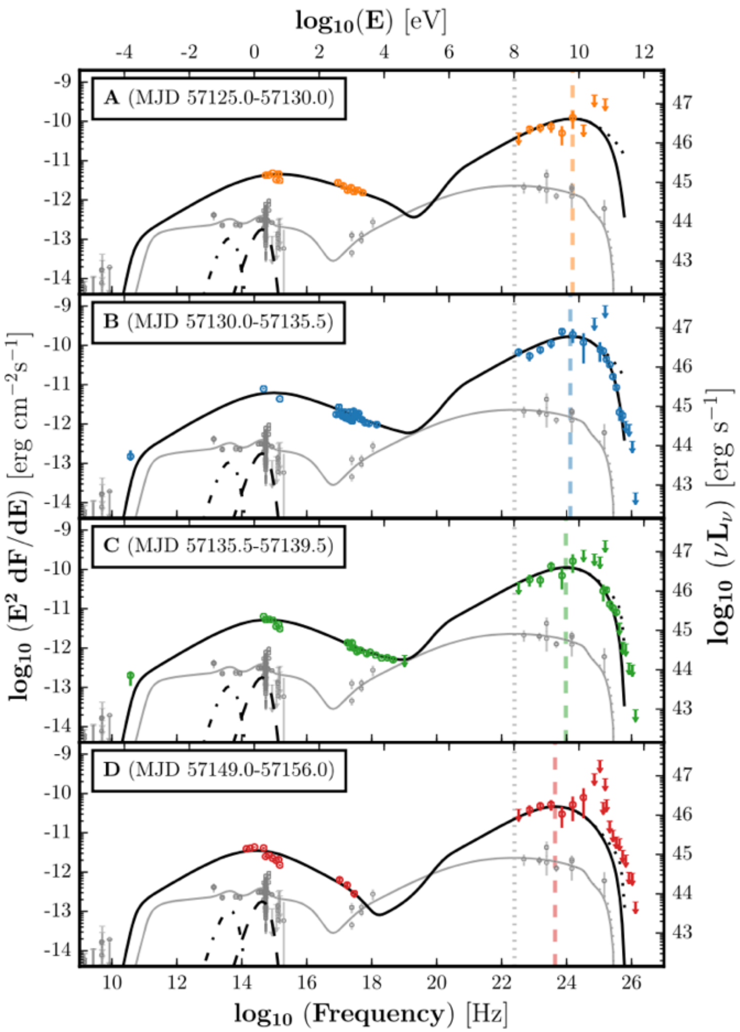


Detection of very high energy gamma-ray emission from the gravitationally-lensed blazar QSO B0218+357 with the MAGIC telescopes
MAGIC Collaboration (M.L. Ahnen *et al.*). Sep 5, 2016. 11 pp.
e-Print: arXiv:1609.01095 [astro-ph.HE] | PDF

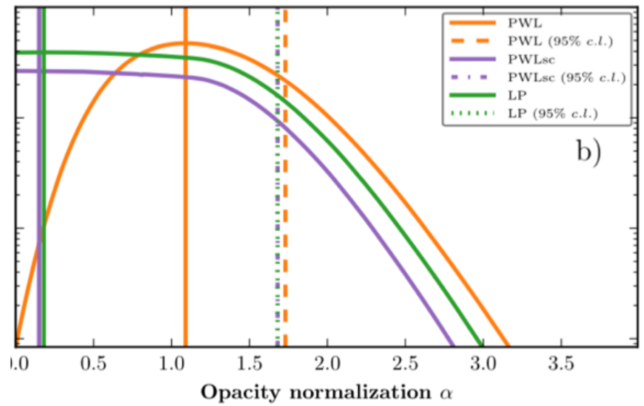
FSRQ PKS 1441+25 (z=0.94)

The Astrophysical Journal Letters, 815:L23 (8pp), 2015 December 20

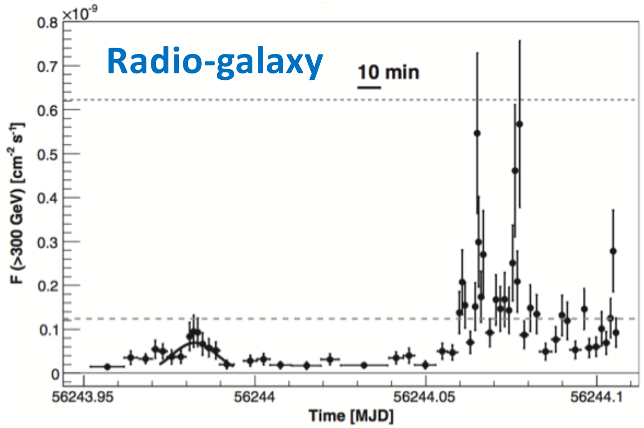




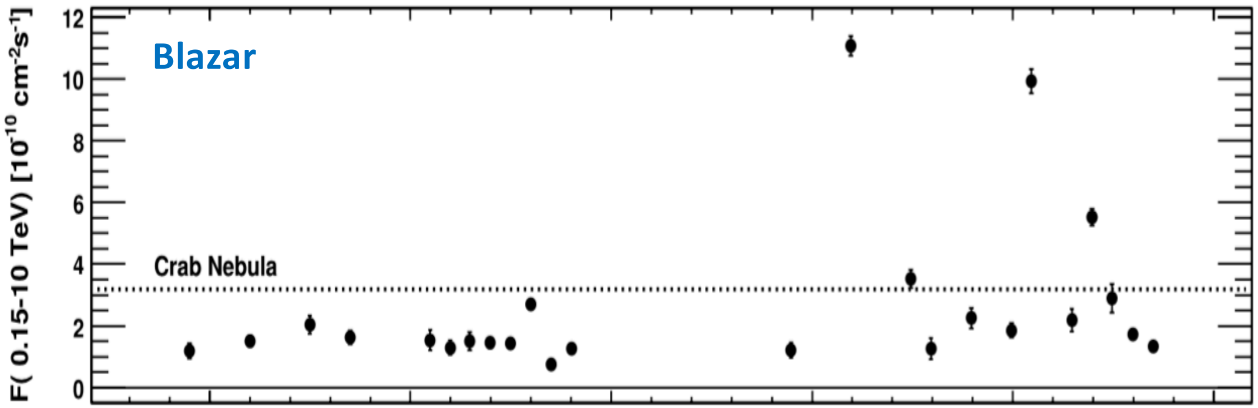
- 25.5σ from periods A,B
- Shift of both S- and IC-peaks to higher energies → emission from within BLR to outside BLR ?
- Even with more statistics, EBL constraints are not surprising



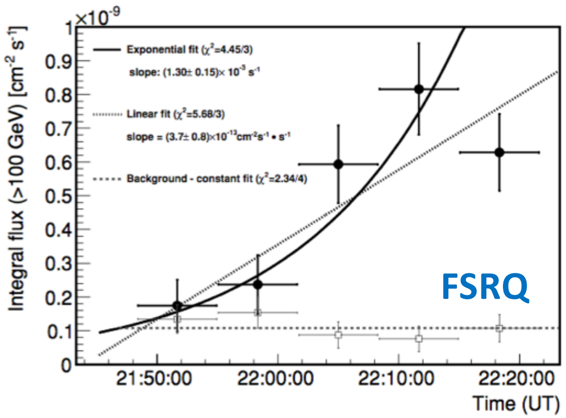
#1.3 Flares provides insight on BH or jets mechanisms



IC310. Doubling time 4.8 min



Mrk501 2005. Flux doubling time ~2min

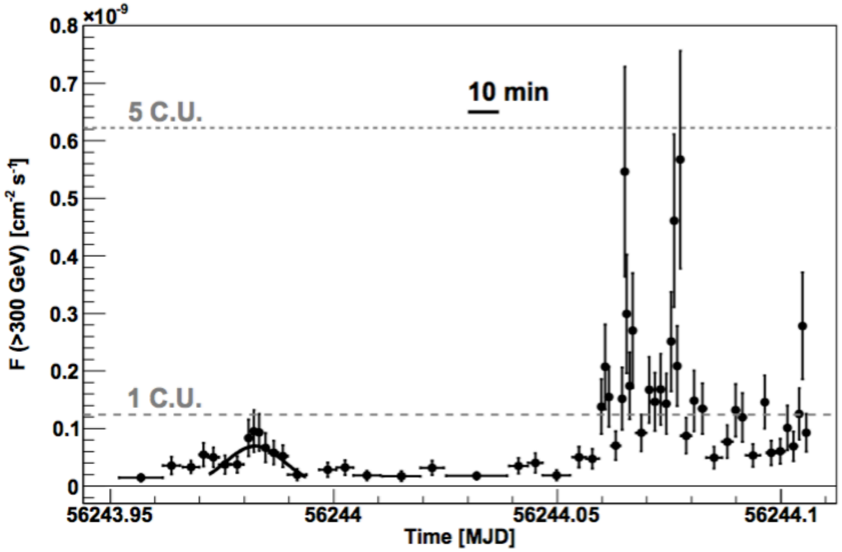


PKS1222. Doubling time 10 min

- MAGIC has detected extremely fast variability in all classes: Radio-galaxy, Blazars and FSRQ.
- Useful probe:
  - One can infer size of emission region with indirect better “angular resolution” than any other instrument
- However, still unclear whether emission scenarios is:
  - Close to the central engine
  - Far out emission region

A thunderstorm in the BH of IC310

Aleksic et al., SCIENCE (2014)

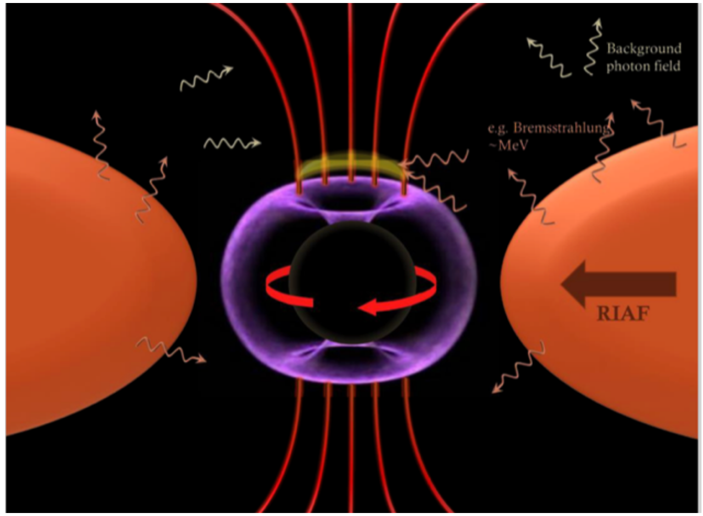


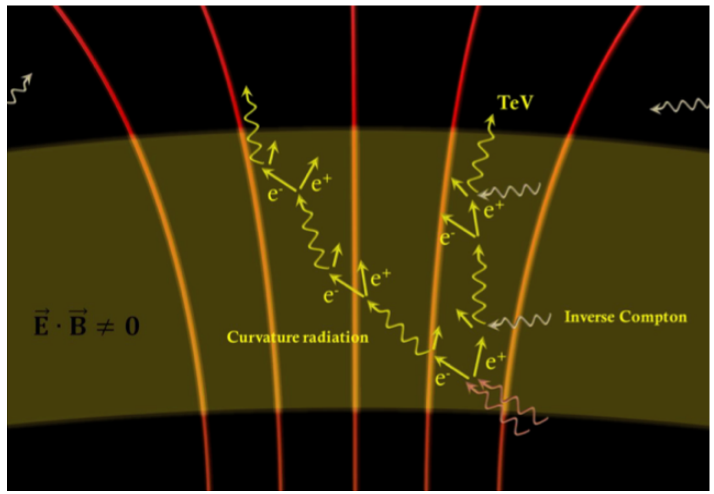
Aleksić et al. 2014, *Science*

In 2014, MAGIC saw an impressive flare of the radio-galaxy **IC310**

Flux-flare was 2x in 4.8 minutes!

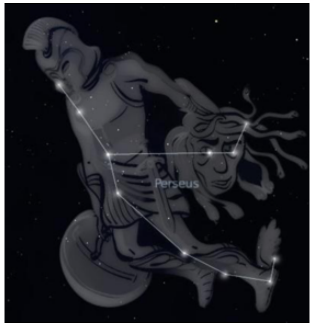
What mechanisms could provide such boost?
Emission region must have size smaller than the 20% of BH





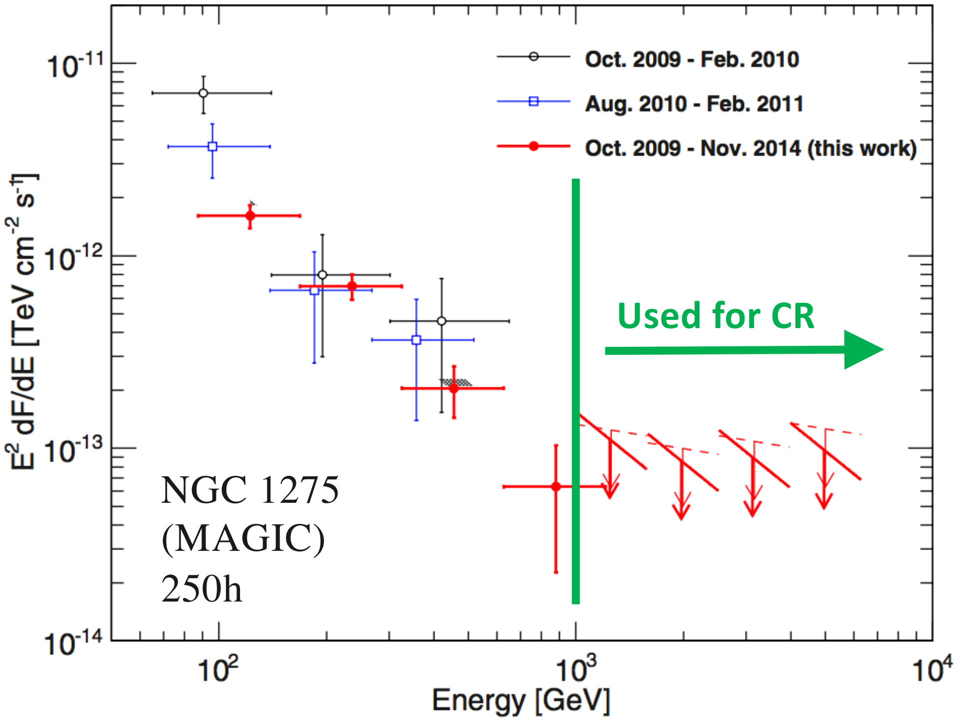
Explanation (pulsar-like):
particle acceleration by the electric field across a magnetospheric gap at the base of the radio jet. Electric fields can exist in vacuum gaps when the density of charge carriers is too low to warrant their shortcut.

#1.4 Energy budgets in the Perseus galaxy cluster



- Galaxy clusters are expected to show a diffuse gamma-ray emission due to the interaction of accelerated CR with the ambient intracluster medium
- **Perseus** is a cool-core clusters, brightest in X-ray→optimal lab (*D*=78 Mpc, *z* = 0.018)
- MAGIC observed for 250 h (selected) in 4 years, providing several (model-dep) constraints

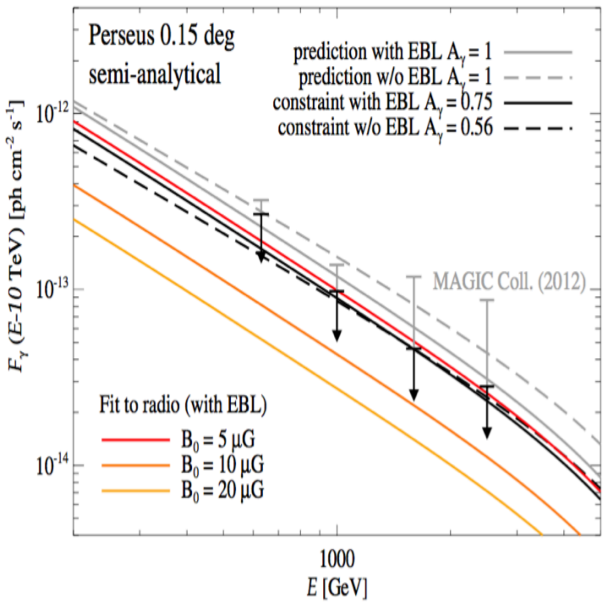
- Explanation for the origin of radio halos is more challenging → TeV gamma-ray best probe
- TeV Gamma rays expected:
  - Hadronic model: radio-emitting electrons are secondaries produced by CR protons interacting with the protons of the ICM
  - Re-acceleration model: seed population of CR electrons re-accelerated by interacting turbulent waves



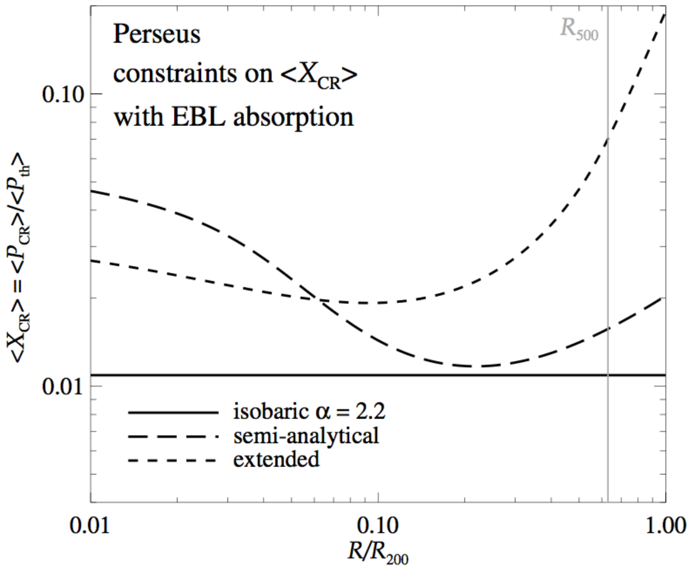
A&A 589, A33 (2016)
DOI: 10.1051/0004-6361/201527846

Constraining energy budget

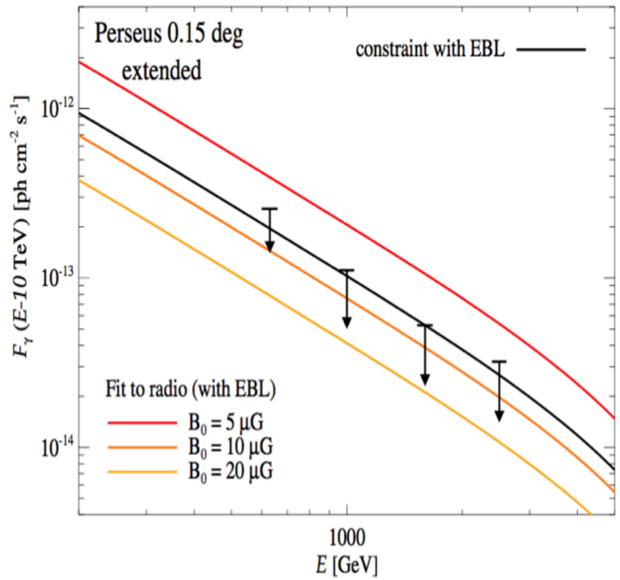
Q1: What fraction of the energy dissipated in structure formation shocks goes into particle acceleration?
Following Pinzke & Pfrommer (2010, no CR transport) model: not more than 37% of energy is converted



Q2: how is the cosmic-ray to thermal-pressure ratio?
Three models, ratio is smaller than between 2 and 20%.



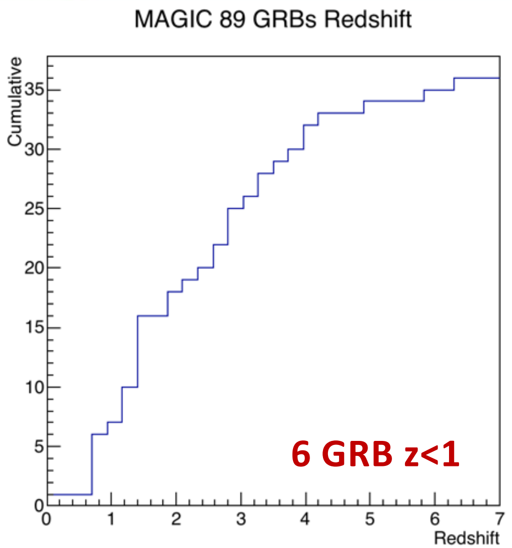
Q3: how intense is the magnetic fields that produce the observed sync-emission from secondary electrons?
Zandanel model (2015, assume CR transportaion). B is smaller than ~10 μG

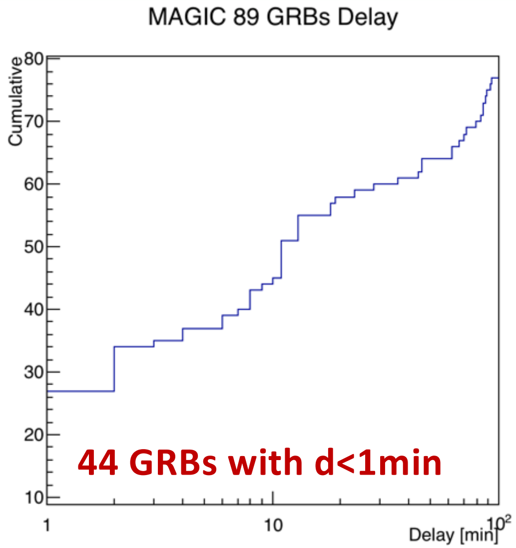


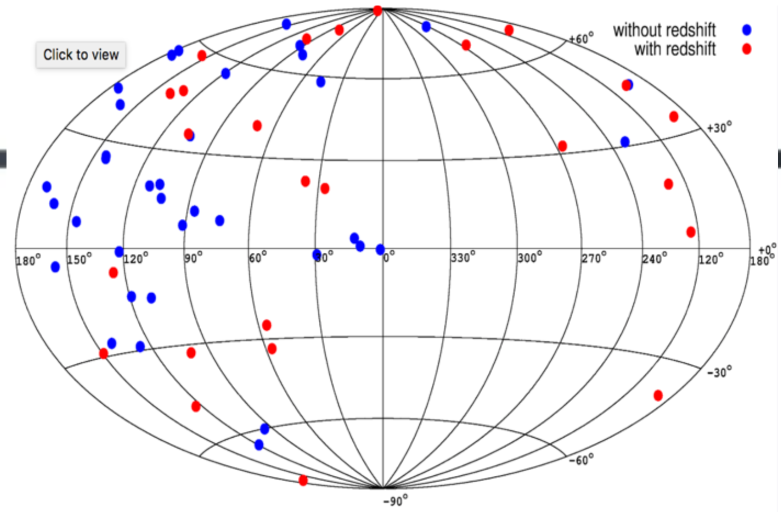
At this point…only CTA can do better

1.4 GRB program

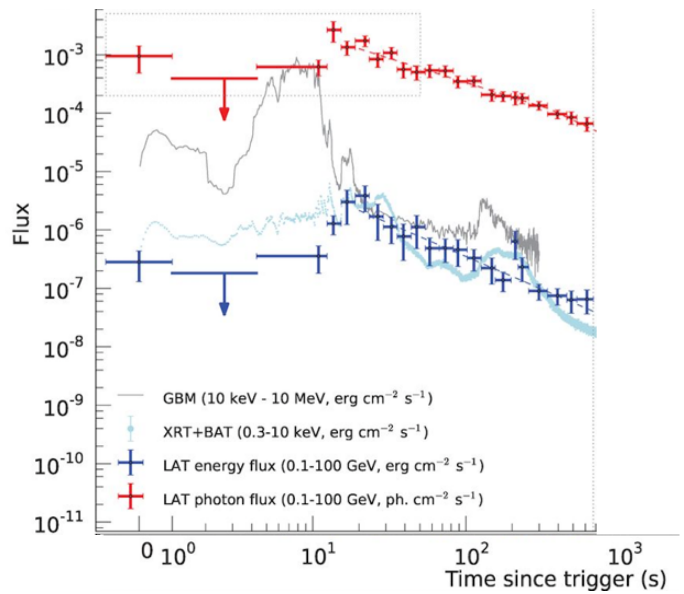
http://www.asdc.asi.it/tegrbcat/





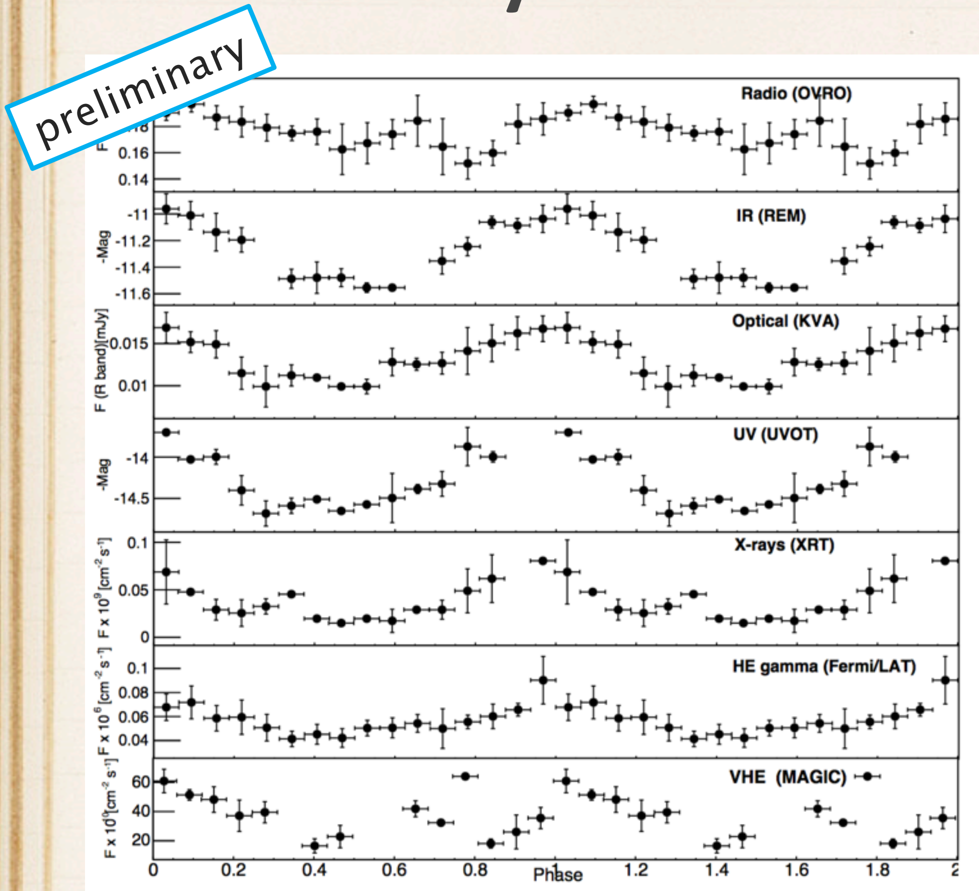


Ackermann, M. et al., 2014, Science, 343, 42



- MAGIC was built to fast-reposition to GRB alert (20sec between any pos) and to get the lowest energy threshold
  - Although late VHE signal may be expected→
- **89 GRBs** observed by MAGIC
- No significant hints at any target ☹, however, our eye is keen now

Periodicity of 1553 – very long-term monitoring



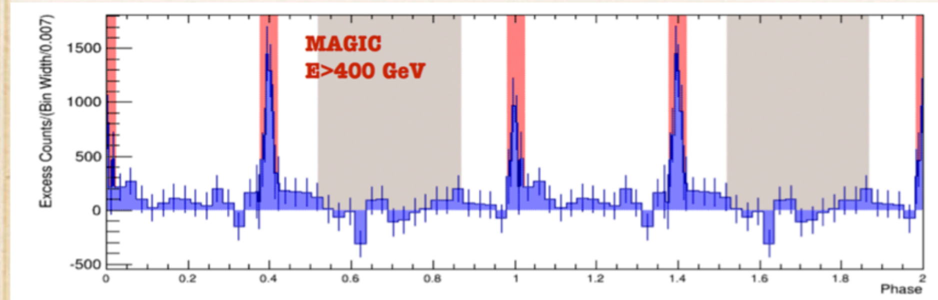
Da Vela+ Proc. Gamma2016

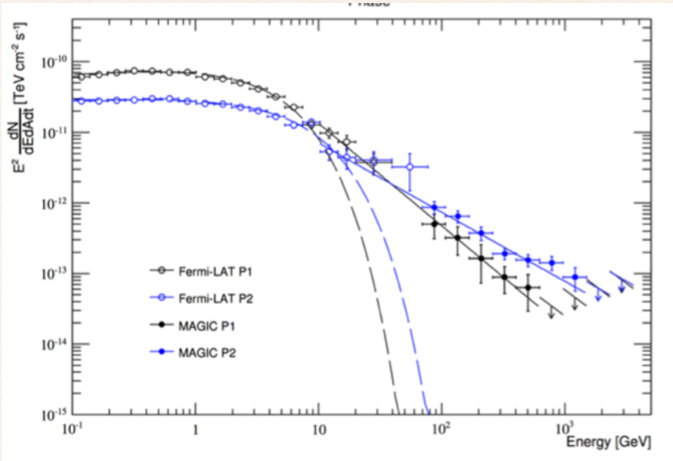
- **PG 1553+113** is the first gamma-ray blazar with a compelling evidence of **quasi-periodic modulation** (2y) in the correlated gamma-ray and optical light curves.
- Can be interpreted as **periodic changes in jet geometry or feeding processes**
  - The presence of a secondary black-hole in a sub-parsec orbit respect to the primary SMBH
  - Different mechanisms as jet precession, internal jet rotation, or helical jet motion may be invoked.
- Current MAGIC data still lack discrimination power, MAGIC will be densely monitoring the source

Pulsar hunts

Crab

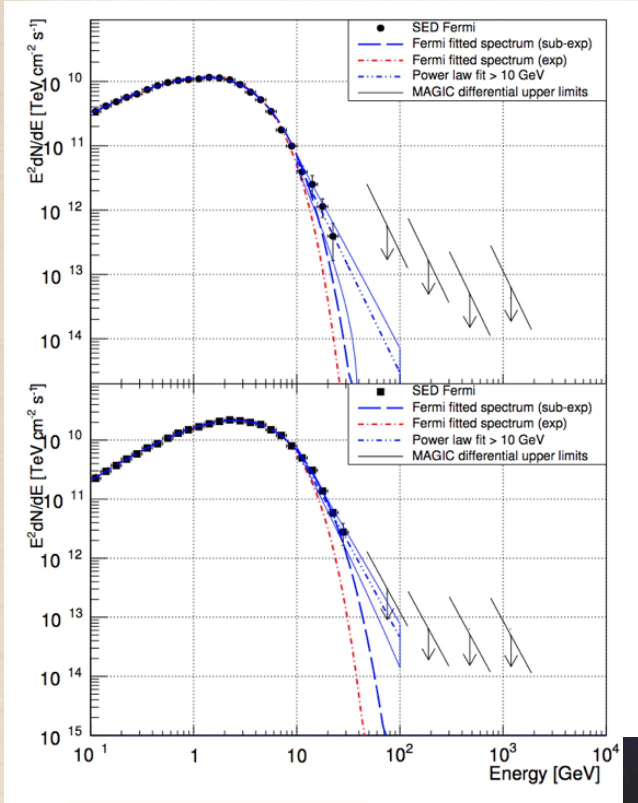
MAGIC (300h) detected pulsed emission close to 1 TeV on the Crab Pulsar





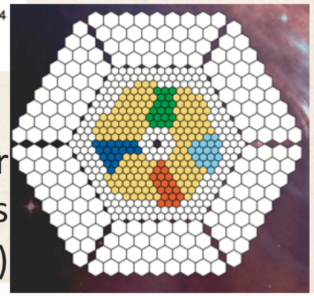
Teraelectronvolt pulsed emission from the Crab pulsar detected by MAGIC
MAGIC Collaboration (M.L. Ahnen *et al.*). Oct 23, 2015. 6 pp.
Published in **Astron.Astrophys. 585 (2016) A133**

Geminga

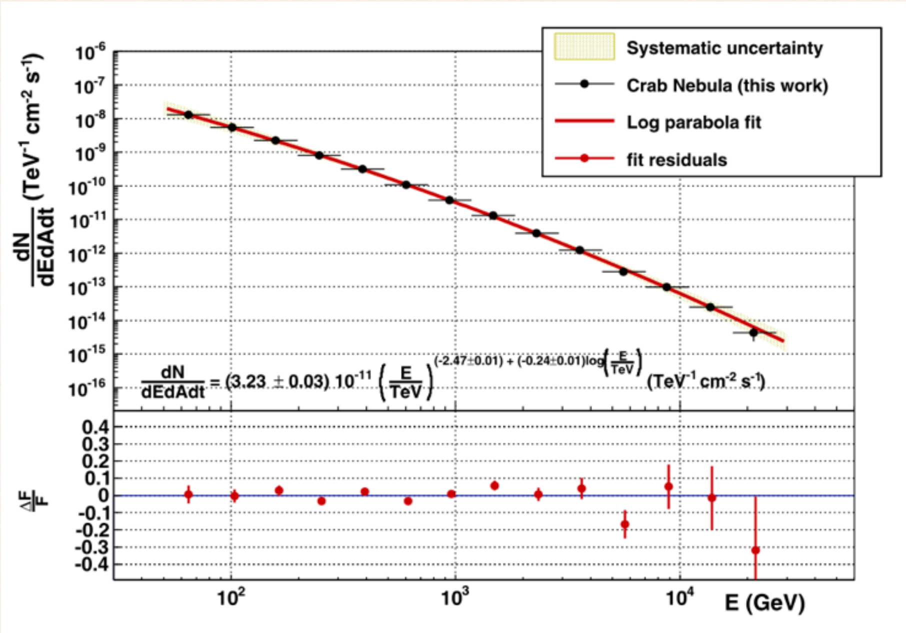


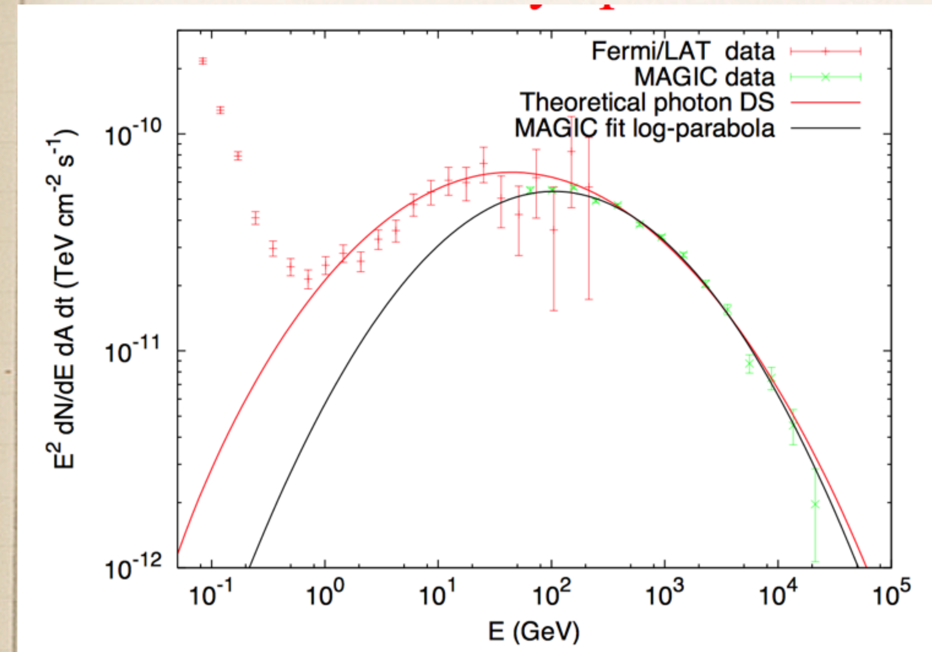
Nothing from the **Geminga pulsar** (nor Nebula) in 70h of data [MAGIC 2016]

Developed a new trigger concept for low-energies ("sumtrigger")



Crab Nebula





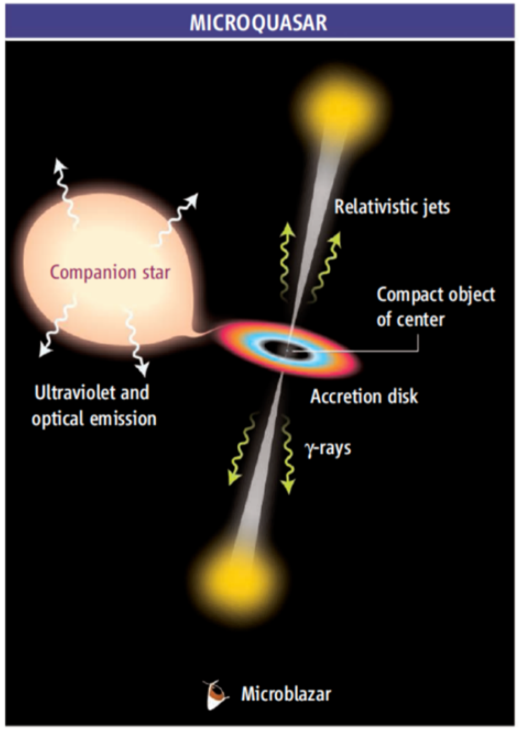
- MAGIC Crab Nebula results extend from 70 GeV to 30 TeV (higher range is in prep.) and fits well with log-parabola.
- When connected with Fermi: log-parabola is not good for both

Fraschetti+ theorized that the probability for TeV electrons of remaining in the acceleration region at mildly relativistic shock weakly decreases with energy; thus, the distribution in momentum of emitting particles is not a power-law

- However, uncertainty 10% in Fermi-MAGIC energy

Galactic jets (microquasars)

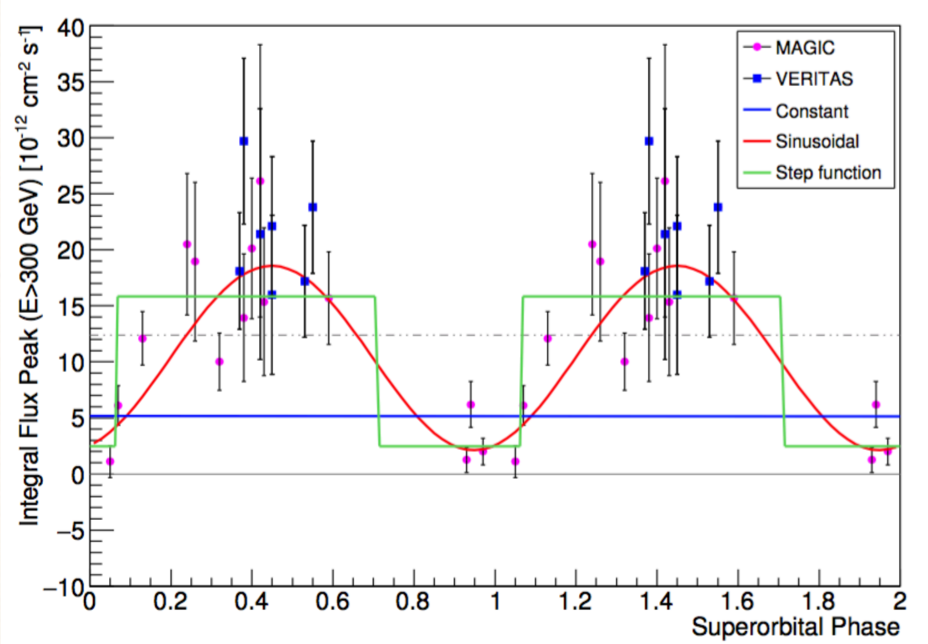
Candidates	Distance	Year	Obs. [h]	Detection	References
Cygnus X1	1.86 kpc	2006	1.3	4sigma	APJL 665
		2006-14	80	No hints	1510.03101
Cygnux X3	7kpc?	2006-09	70	No hints	APJ 721
Scorpius X1	2.8 kpc	2010	8	No hints	APJ 735
GRS1915		2005-06	14	No hints	0907.1017
V404 Cyg	2.4 kpc	2015	11	No hints	EWASS 2016



- MAGIC did not detect any VHE signal from well-established microquasars

- VHE flux is suppressed:
  - Synchrotron losses in the magnetic field present in the jets?
  - The fraction of kinetic energy transferred to plasma is low?

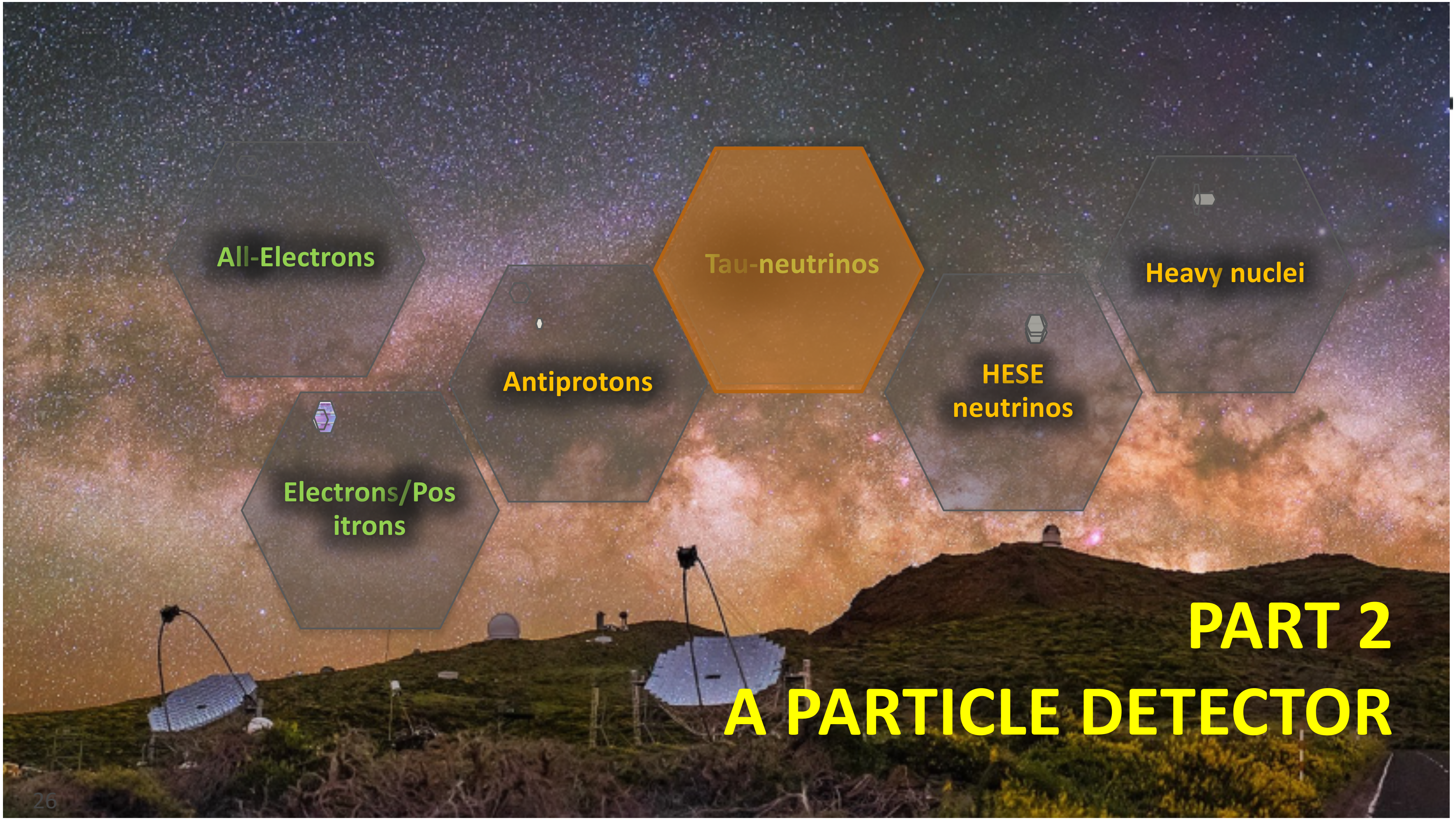
LSI +61 303



Astron.Astrophys. 591 (2016) A76

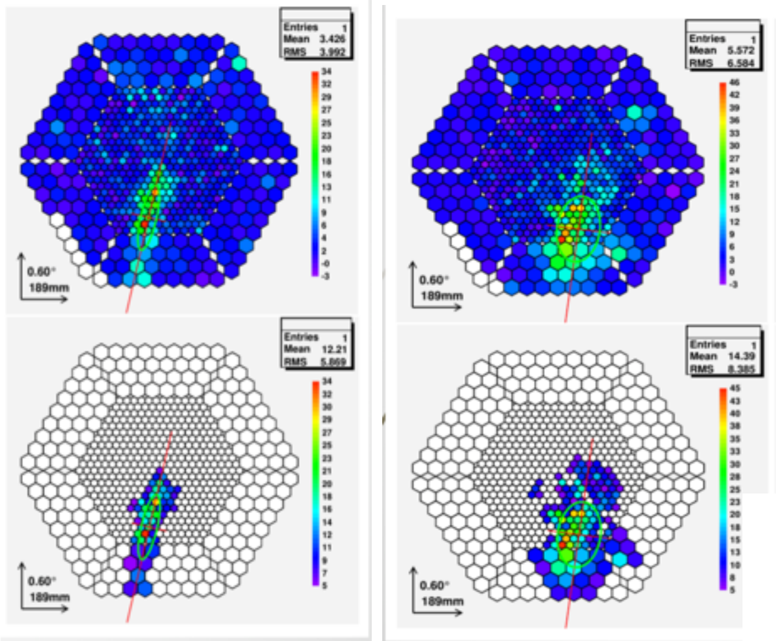
Function	Fit probability	χ^2/d.o.f.
Constant	4.5×10^{-12}	114.8/20
Step function	0.07	26.4/17
Sinusoidal	0.08	27.2/18

- LS I +61∘303 is a system of a Be star and a compact object of unknown nature co-rotating with a period of 26.5 days [MAGIC Science 312 (2006)] and conjuction at ϕ = 0.23.
- LSI observed for 4 years at ϕ = 0.5–0.75
- → **First detection of super-orbital variability** (1667 days) in the TeV regime compatible with radio data witin 8%
- The **flip-flop model** (Zamanov et al. 2001; Torres et al. 2012; Papitto et al. 2012) considers LS I +61∘303:
  - Accretion state changes from a propeller regime during periastron to an ejector regime at apastron.


All-Electrons
Tau-neutrinos
Heavy nuclei
Antiprotons
HESE neutrinos
Electrons/Positrons
PART 2
A PARTICLE DETECTOR

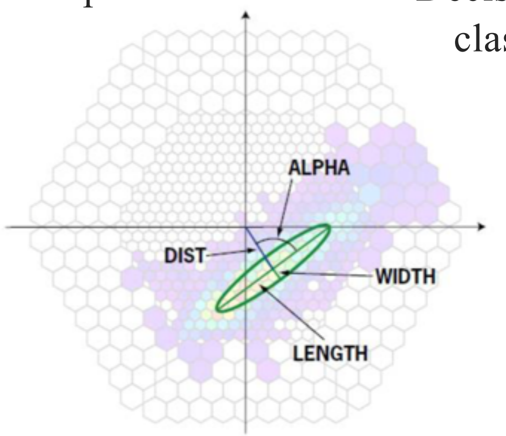
Events classification

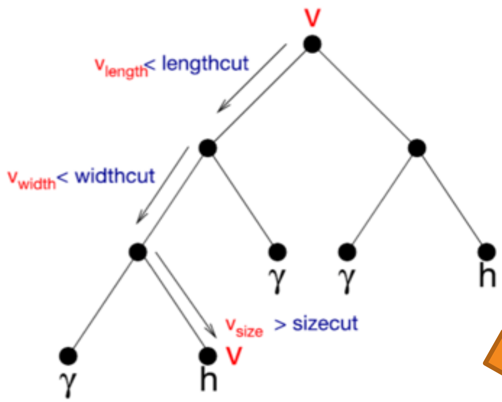
Gamma Hadron



Shape and time evolution can change between event classes

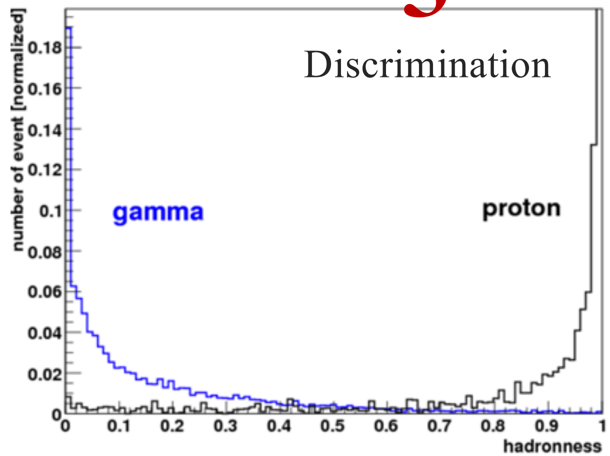
1
Image parameters



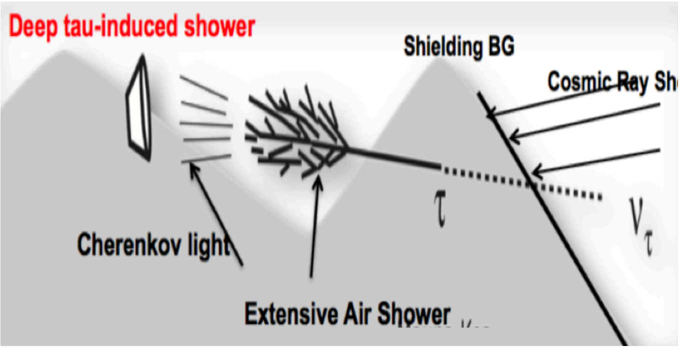


2
Decision trees for classification

3
Discrimination



#2.1 Neutrinos



- **Tau neutrinos may** reach Earth from space from energetic engines (AGNs, GRBs) from decay of charged pions. At Earth

$$\nu_e : \nu_\mu : \nu_\tau \sim 1:1:1$$

- If crossing the right amount of matter, nu_tau **can convert to tau-lepton in ground** and if exiting the ground again, can **generate atmospheric showers**

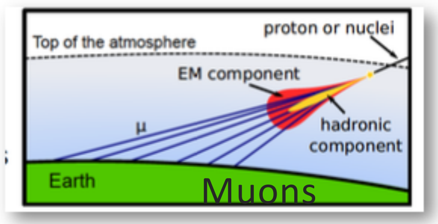
- MAGIC has a **sea window** observable (sometimes) when clouds are high in the sky and prevent cosmic observation
- **Complexity in MC simulations** (atmosphere, shower model, interactions, orography)
- All solved ☺ in Gora+ Astropart.Phys. 26 (2007) 402-413

D. Fargion, Astrophys.J. 570, 909 (2002).
X. Bertou et al., Astropart.Phys. 17, 183 (2002).
E. Zas, New J.Phys. 7, 130

Discrimination

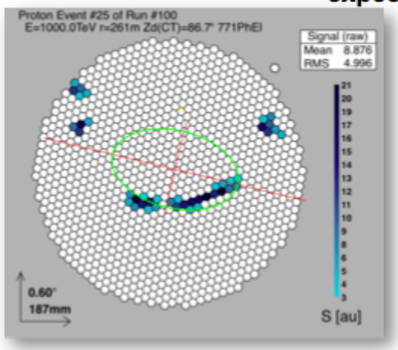
- Observations performed at 85 deg ZA
- Tau-lepton induced showers happen much closer to MAGIC: they produce a cascade or muon ring(s)

Proton injected at the top of the atmosphere
(X_{inj} < 50 g/cm², ~1000 km to detector for 87 deg)

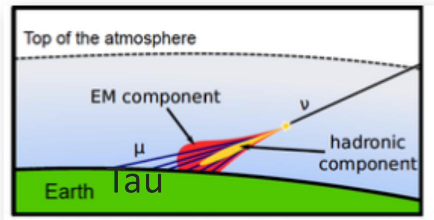


E_{muon}= 1 PeV

Background expectation

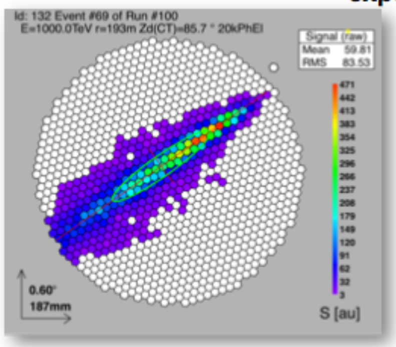


Deep tau-induced shower
(X_{inj} = 760 g/cm², ~50 km to the detector)



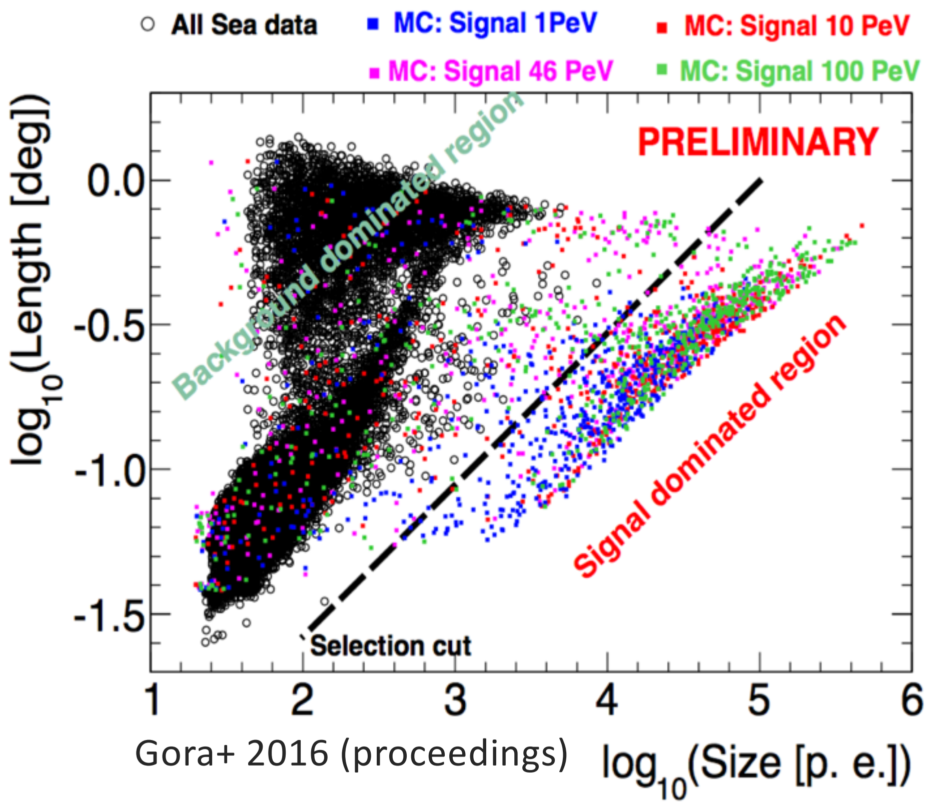
E_{tau}= 1 PeV

Signal expectatio



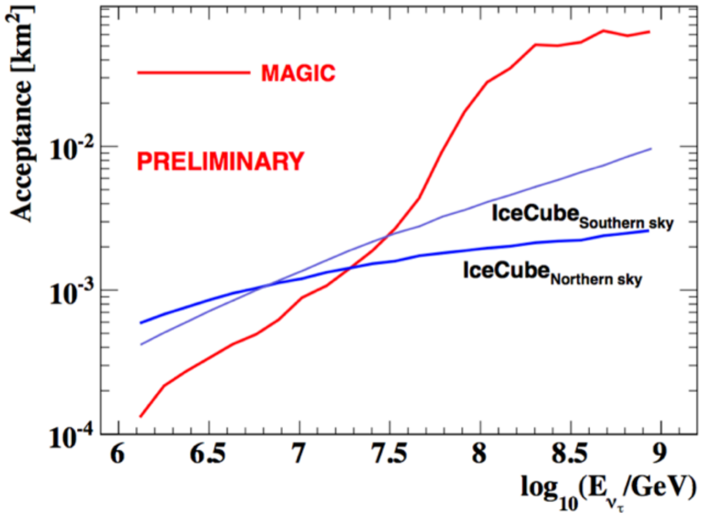
Gora+ 2016 (Gamma16 poster)

- Discriminated by (larger) Size and Length of the images



Gora+ 2016 (proceedings)

Performance and Expectations



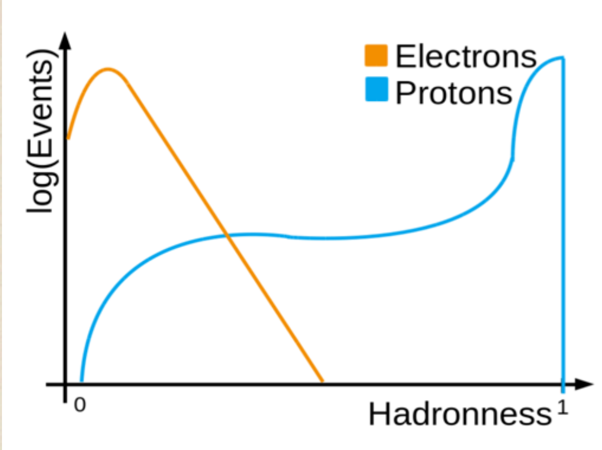
Results to be published soon

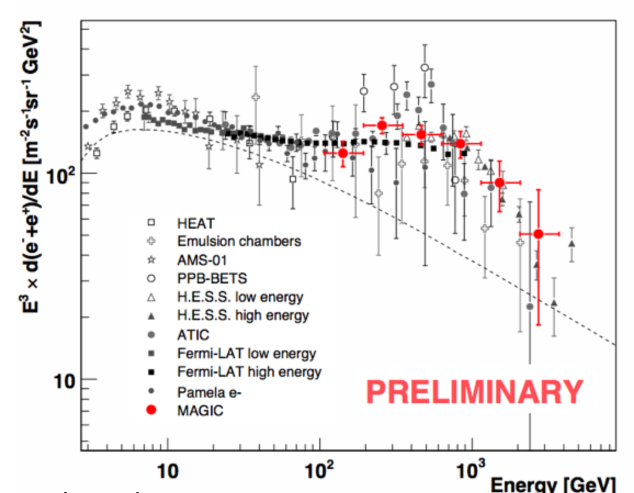
- Sensitivity above the PeV is good (due to combination of large acceptance window and large number of photons)
- However, events are very rare
  - **Diffuse neutrino** flux is low, but MAGIC constraints in the PeV could be the strongest (300h achievable)
  - **Bright flares** from can be observed when the source passes through the "sea window"
    - GRBs possible in case of late neutrino emission (Phys. Rev. D 93, 083003 (2016))
    - AGNs?
    - GW?

- Proposed also to make "muon tomography" of mountains [N. Lesparre et al. 2010, Geophys. J. Int, 183 O. Catalano et al. 2016,]

2.2 All-electrons

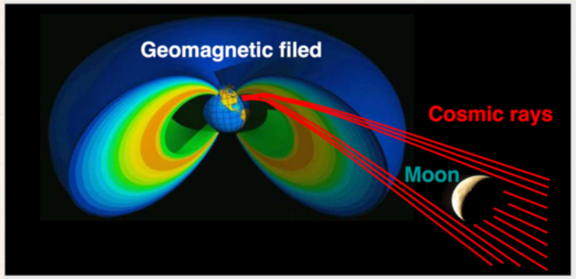
- MAGIC can measures cosmic-electron induced showers
  - totally similar to that of g-ray
  - Discrimination possible when comparing “background only” regions
- Preliminary results in 2011 (40h), took a long way to update them
  - It is hard to gain control on systematics

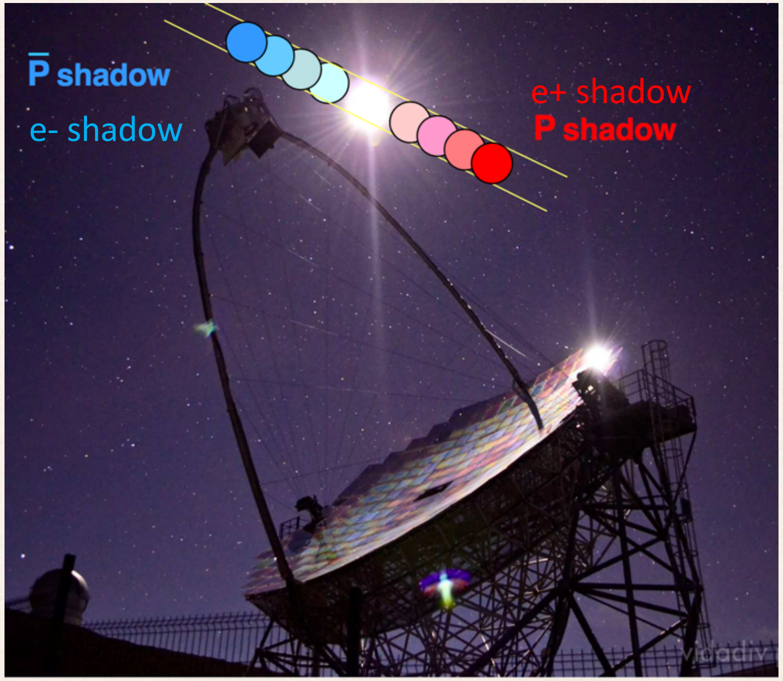




Borla Tridon+ ICRC 2011

#2.2 Electron/positrons – antiprotons





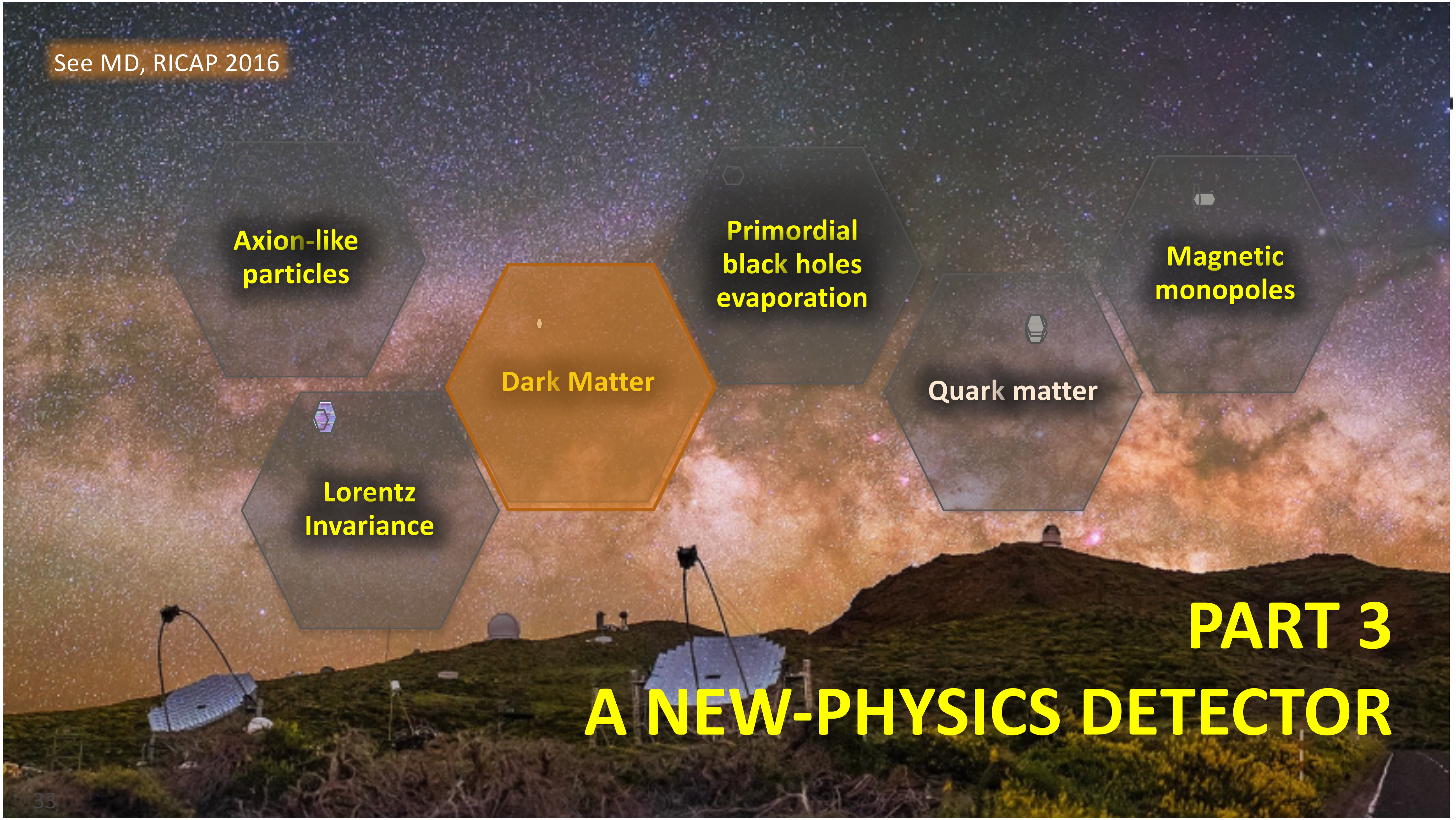
Credit: P.Colin

1342

- Is it possible to charge-separate cosmic-rays?
- By means of the moon-shadow:
  - deficit charge-dependent at one side to the moon
  - Deficit shift in distance following particle energy
- MAGIC collected several h in few years → very bright moon analysis (not standard). Also during a lunar eclipse
- *Paper in prep.*

Colin+ ICRC 2015

Composition hypothesis	Missing flux 300-700 GeV	Detection time with MAGIC
MAGIC spectrum [5]:		
100% e-	5.4%	~30 h
80% e-	4.3%	~50 h
60% e-	3.3%	~90 h
40% e+	2.2%	~200 h
20% e+	1.1%	~800 h
ATIC spectrum [3] :		
100% e-	7.2%	~20 h
80% e-	5.7%	~30 h
60% e-	4.3%	~50 h
40% e+	2.9%	~100 h
20% e+	1.5%	~400 h


See MD, RICAP 2016
Axion-like particles
Dark Matter
Primordial black holes evaporation
Quark matter
Magnetic monopoles
Lorentz Invariance
PART 3
A NEW-PHYSICS DETECTOR
33

Dark matter search at all targets

Target	Year	Time	Experiment	Ref.
Globular Clusters				
M15	2002	0.2	Whipple	[5]
	2006–2007	15.2	H.E.S.S.	[6]
M33	2002–2004	7.9	Whipple	[5]
M32	2004	6.9	Whipple	[5]
NGC 6388	2008–2009	27.2	H.E.S.S.	[6]
Dwarf Satellite Galaxies				
Draco	2003	7.4	Whipple	[5]
	2007	7.8	MAGIC	[7]
	2007	18.4	VERITAS	[8]
Ursa Minor	2003	7.9	Vhipple	[5]
	2007	18.9	VERITAS	[8]
Sagittarius	2006	11	H.E.S.S.	[9]
Canis Major	2006	9.6	H.E.S.S.	[10]
Willman 1	2007–2008	13.7	VERITAS	[8]
	2008	15.5	MAGIC	[11]
Sculptor	2008	11.8	H.E.S.S.	[12]
Carina	2008–2009	14.8	H.E.S.S.	[12]
Segue 1	2008–2009	29.4	MAGIC	[13]
	2010–2011	48	VERITAS	[14]
	2010–2013	158	MAGIC	[15]
Boötes	2009	14.3	VERITAS	[8]
Galaxy Clusters				
Abell 2029	2003–2004	6	Whipple	[16]
Perseus	2004–2005	13.5	Whipple	[16]
	2008	24.4	MAGIC	[17]
Fornax	2005	14.5	H.E.S.S.	[18]
Coma	2008	18.6	VERITAS	[19]
The Milky Way central region				
MW Center	2004	48.7	H.E.S.S.	[20]
MW Center Halo	2004–2008	112	H.E.S.S.	[21]
Other searches				
IMBH	2004–2007	400	H.E.S.S.	[22]
	2006–2007	25	MAGIC	[23]
Lines	2004–2008	112	H.E.S.S.	[24]
	2010–2013	158	MAGIC	[15]
UFOs	–	–	MAGIC	[25]
	–	–	VERITAS	[26]
All-electron	2004–2007	239	H.E.S.S.	[27,28]
	2009–2010	14	MAGIC	[29]
Moon-shadow	–	–	MAGIC	[30]

- MAGIC and IACTS searched everywhere for Dark Matter
  - Galactic Center, dSphs, Galaxy Clusters, UFOs,+

Single-telescope (MAGIC-I alone) results

- Galactic Center
  - **(17 h)** ApJ Lett. 638 (2006) L101
- Galaxy clusters
  - **Perseus (25 h)** ApJ 710 (2010) 634
- Dwarf Galaxies:
  - **Draco (8 h):** ApJ 679 (2008) 428
  - **Willman 1 (16 h):** ApJ 697 (2009) 1299
  - **Segue 1 (30 h):** JCAP 06 (2011) 035

A decade ago, we were investing few hours per source.

MAGIC has now moved to 100h+ campaigns.

AIM is detection of course, but also legacy robust results

← *MD, NIM A 742 (2014)*

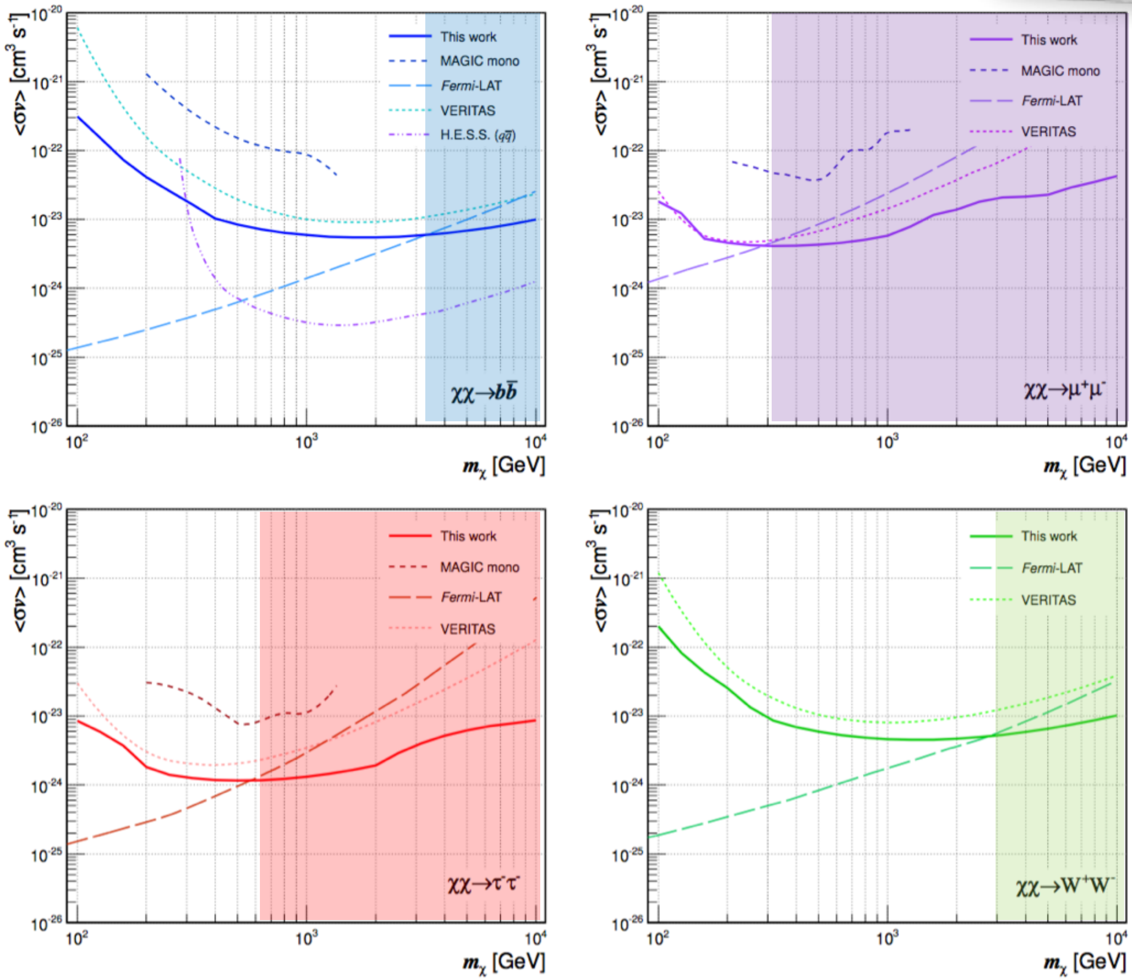
#3.1 Segue 1 Deep Scan with MAGIC stere

Best limits from dwarfs in high-mass range

- MAGIC decided to perform the **longest exposure on a single dSph**: Segue 1
- **160 hours** of good-quality data between 2011 and 2013.

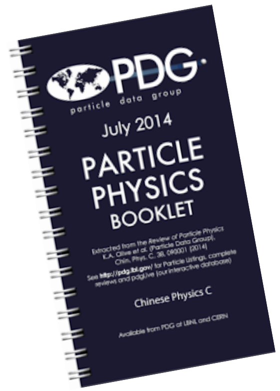
- Optimized statistical treatment allowed performance boost

See Aleksic+ *JCAP* 1210 (2012) 032



- Strongest constraints above few hundreds GeV according to channel

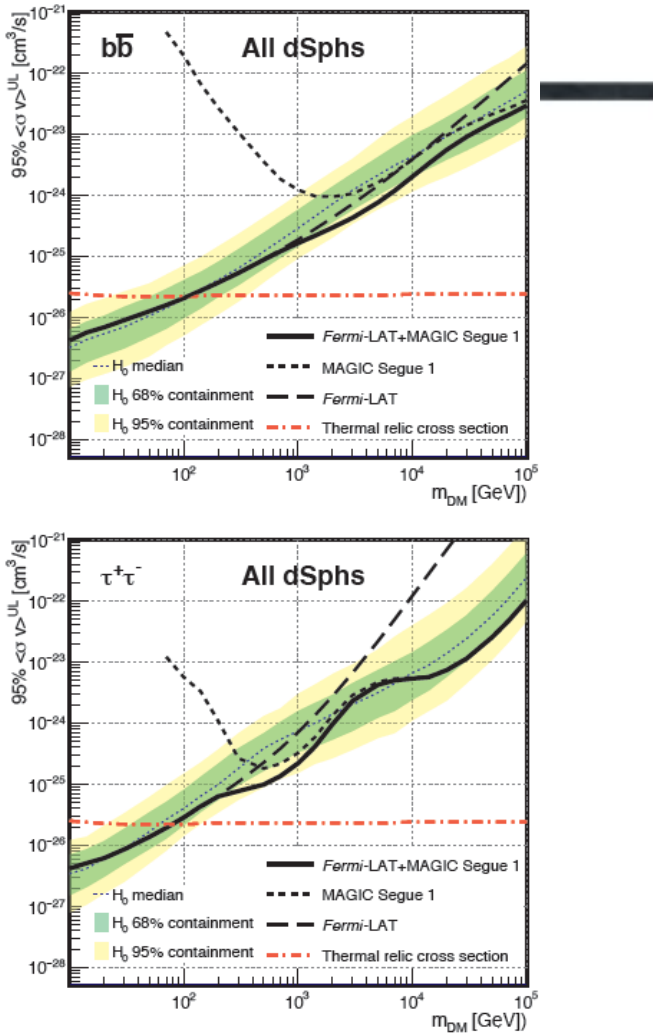
- Results made into the PDG



MAGIC + Fermi combined

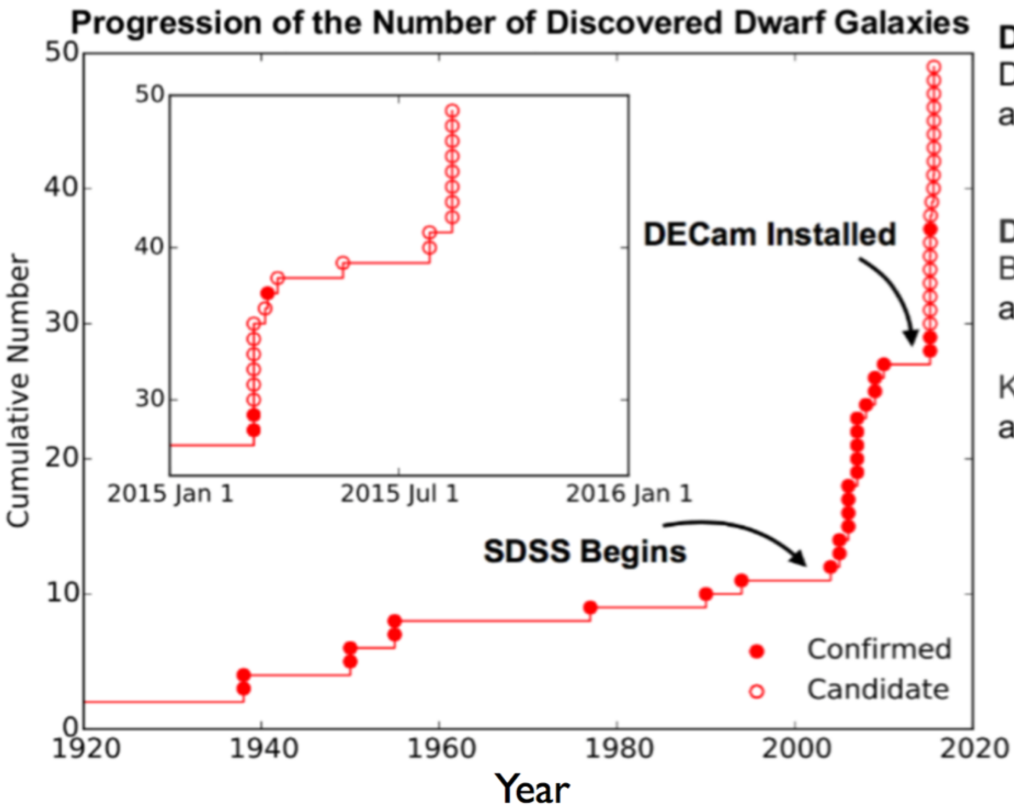
- MAGIC: Segue 1 (158 h) and Fermi-LAT: 15 dwarfs (6 years, Pass8)
- **Coherent limits** between 10 GeV and 100 TeV (widest range so far explored)
  - Annihilation limits for DM particle masses below O(1) TeV dominated by Fermi-LAT, above O(1) TeV by MAGIC (and IACTs, in general)
- **Effective combination (2x stronger constraints) in the range 300-500 GeV**
- *Possible to add additional indirect detection instruments (a call was raised by MAGIC)*

JCAP 02 (2016) 039



JCAP02(2016)039

MAGIC program



DES Year 2 Data:
Drlica-Wagner+,
arXiv:1508.03622

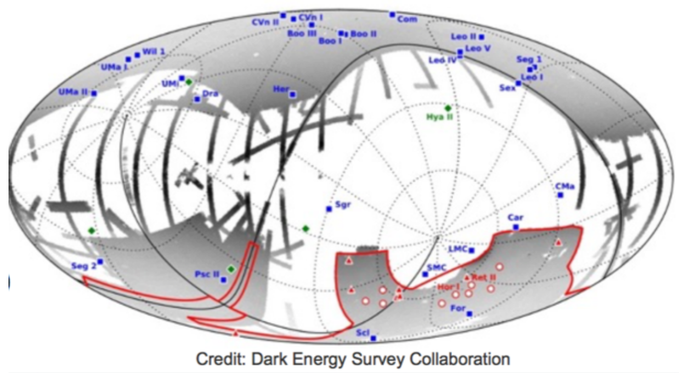
DES Year 1 Data:
Bechtol+:
arXiv:1503.02584

Koposov+:
arXiv:1503.02079

New instruments are discovering new dSphs: some very promising.

Expect results from MAGIC!

Catching up with ΛCDM predictions:
until 2004: 9 "classical"
2005: +15 (SDSS)
2015: +>20 (DES + Pan-Starrs)



Decaying DM in Cluster of galaxy

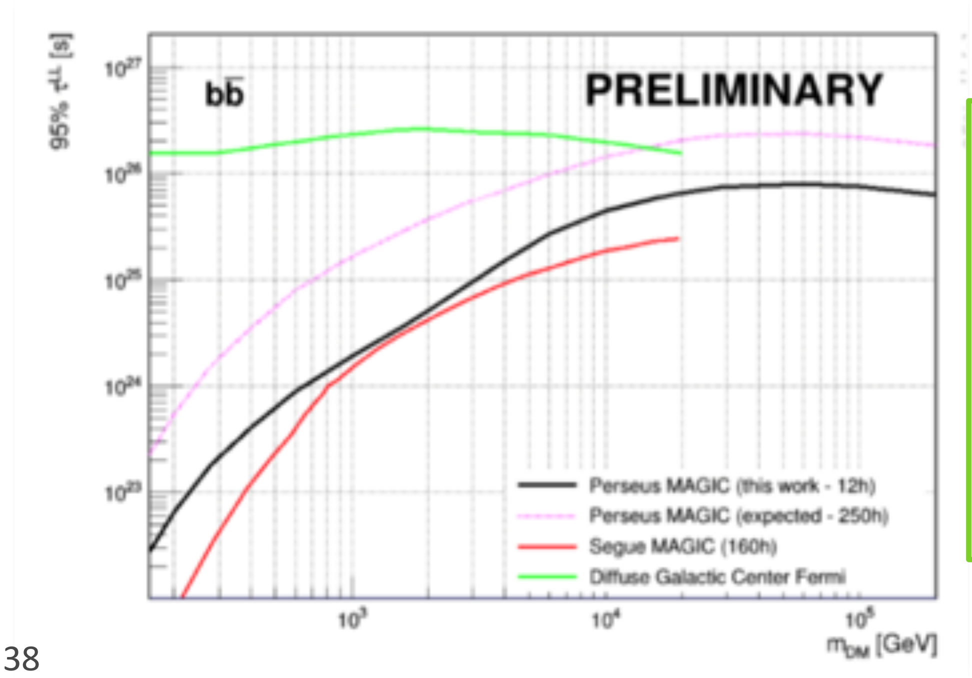
$$\frac{d\Phi_\gamma}{dE} = \frac{d\Phi_\gamma^{PP}}{dE} \times J(\Omega)$$

Decay

$$\frac{d\Phi_\gamma^{PP}}{dE} = \frac{1}{4\pi m_\chi \tau_\chi} \frac{dN_\gamma}{dE}$$

$$J(\Omega) = \int_\Omega \int_{los} \rho(r) dr d\Omega$$

- **Galaxy clusters** are very far-away
  - Cannot compete (probably) with closer object in terms of annihilating DM (where DM density-square matters)
  - **Are optimum targets for decaying DM**
- We used the **large campaign** on a Perseus

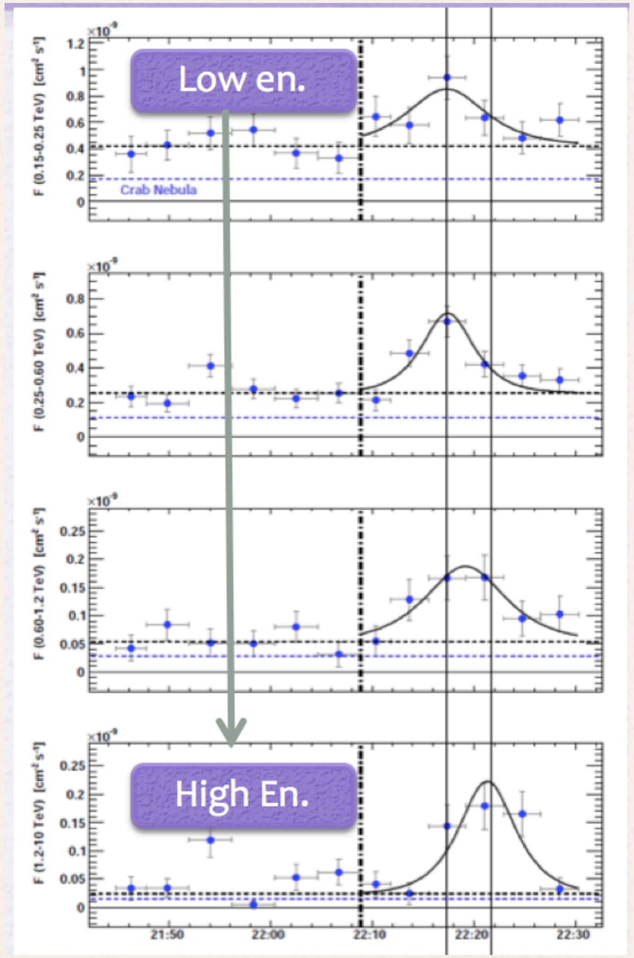


We are obtaining excellent results in the decaying DM case

Lower limits on DM particle decay lifetimes (*with ONLY 12 hours !!*) Best limits for X→Tau+Tau- for DM masses above 2 TeV

Publication soon!

LIV contraints from AGN



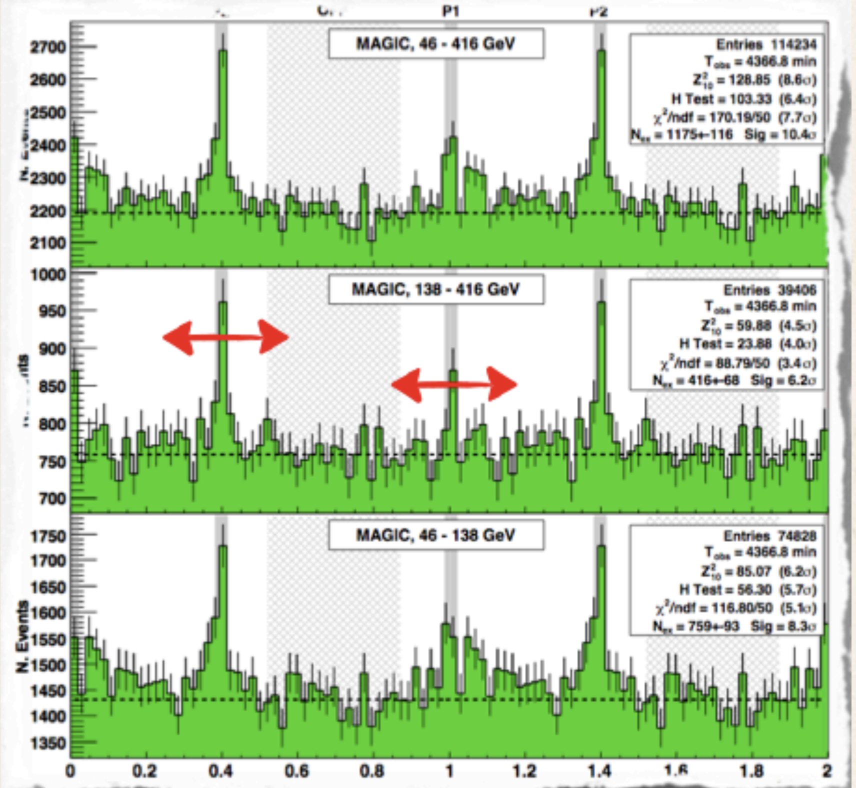
- ←In 2007, MAGIC saw a great delay of arrival times of photons at different energies....however simple **intrinsic effects** cannot be excluded
- Since then, several flares observed
- Effort now is to combine all flare into a single limit (also with other instruments in the filed)

LIV contraints from pulsars

- **Intrinsic effect can be excluded** in pulsar, where there is a first derivative of the frequency with time (need long time-lag)
- MAGIC has the Crab pulsar observed for a decade
- Paper to be published soon

Limits obtained with g-rays but things will improve soon…

Telescope	M_P/ξ [GeV]	M_P/ζ [GeV]
MAGIC	0.03×10^{19}	5.7×10^{10}
H.E.S.S.	0.21×10^{19}	6.4×10^{10}
Fermi-LAT	1.50×10^{19}	3.0×10^{10}

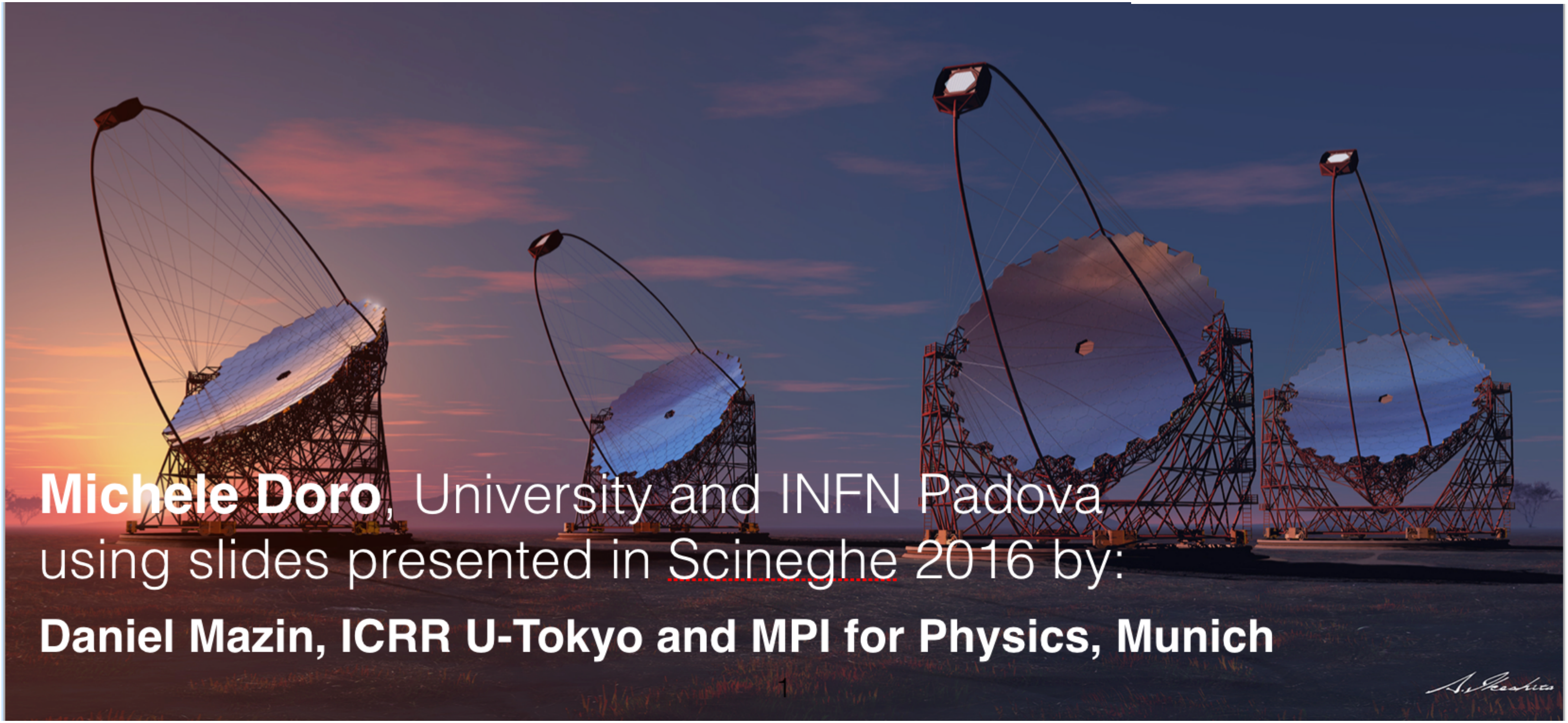


(Aleksic et al., 12)

cta cherenkov telescope array

an observatory for ground-based gamma-ray astronomy

Status and Perspective of CTA

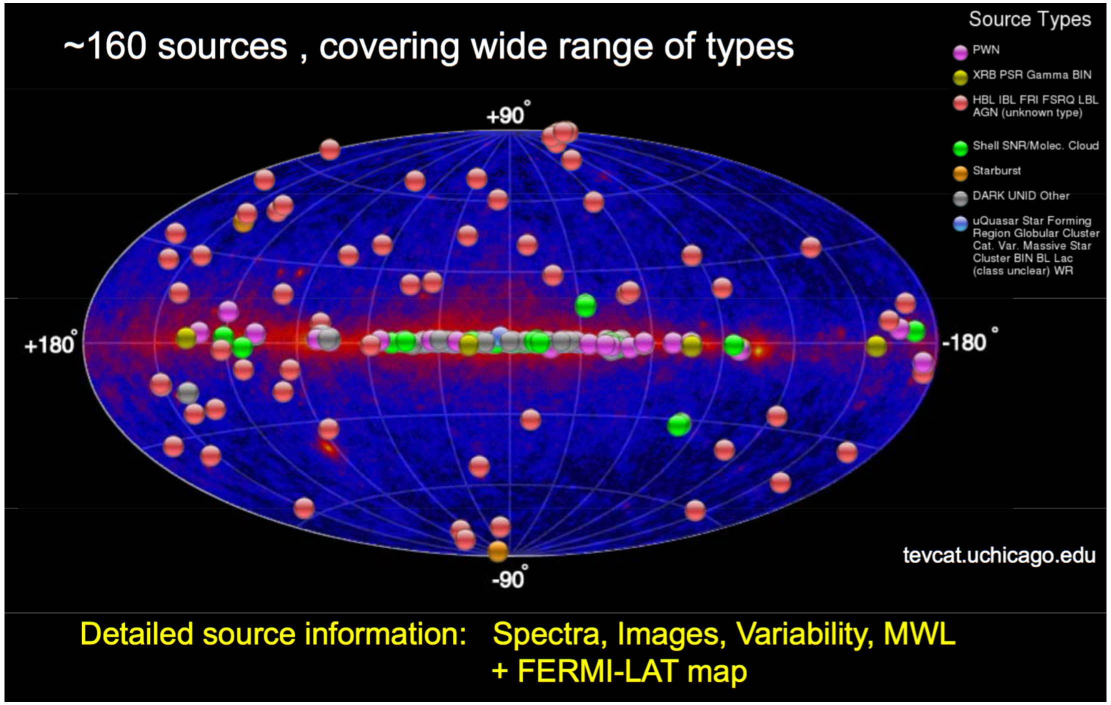


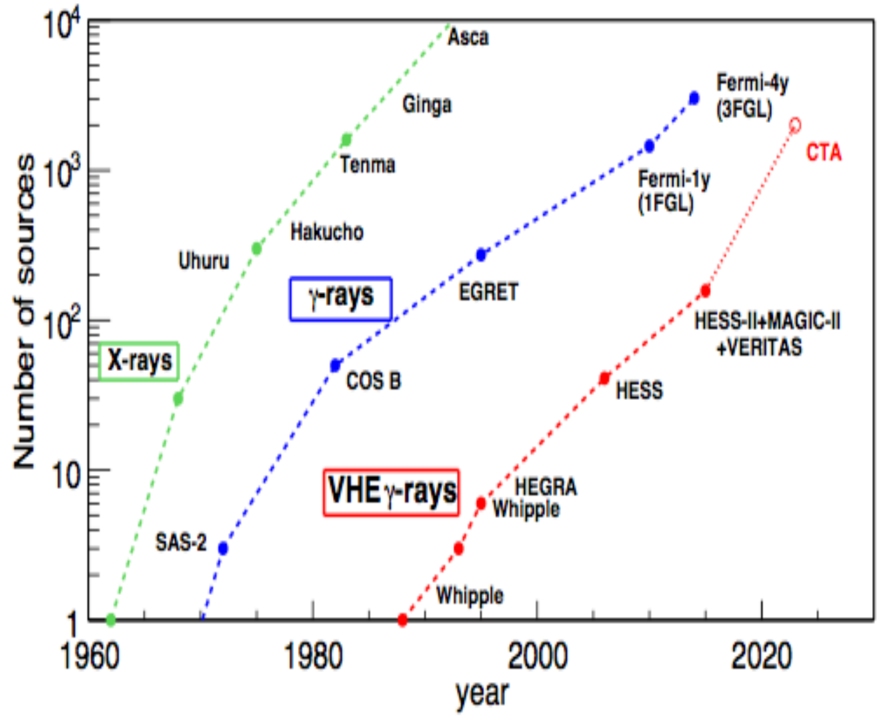
Michele Doro, University and INFN Padova

using slides presented in Scineghe 2016 by:

Daniel Mazin, ICRR U-Tokyo and MPI for Physics, Munich

All IACTs: many sources + many details





- CTA aims at 1000 sources in 3-years
  - First time possible TeV unbiased population studies

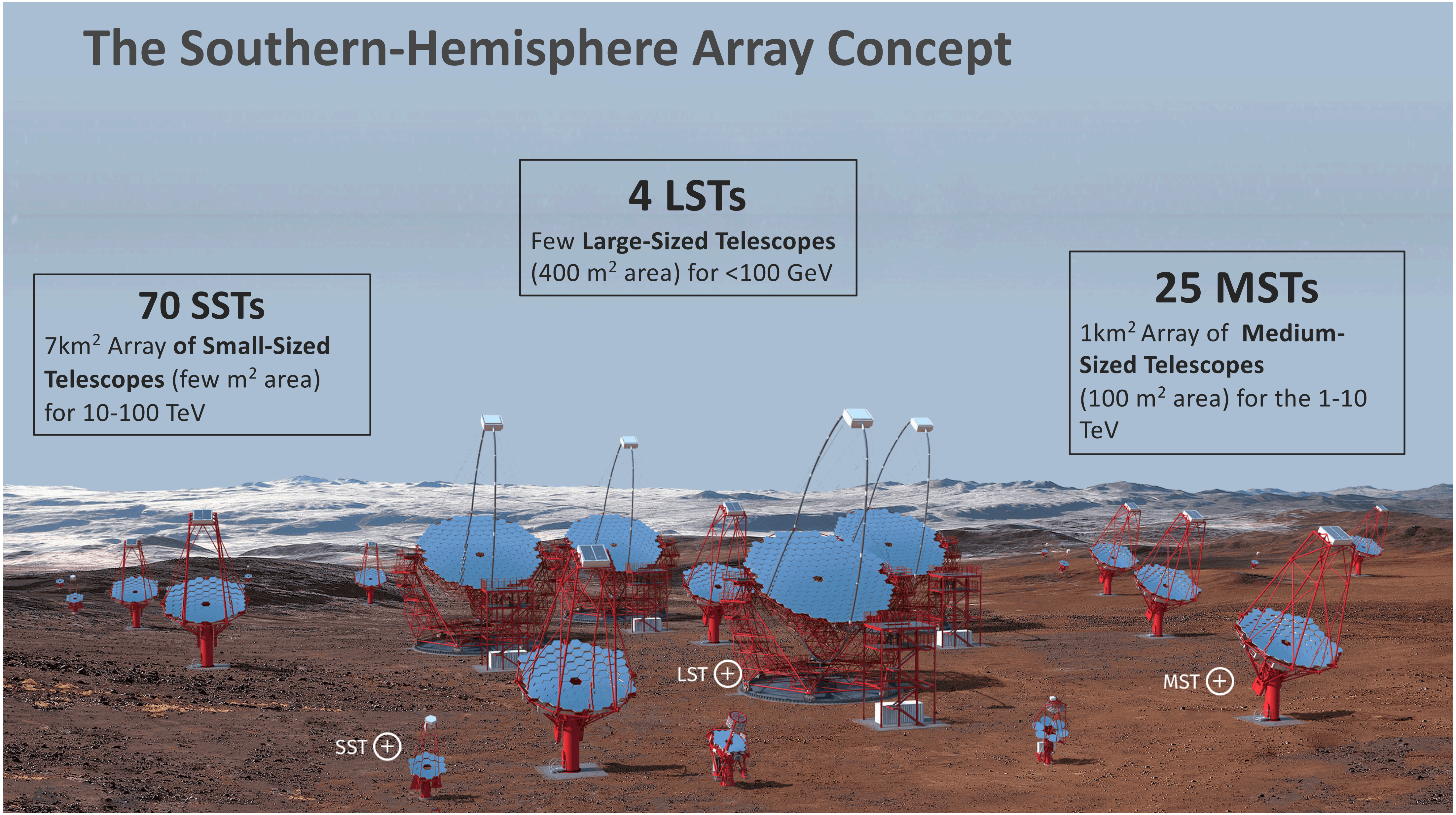
Highly successful, but …

- Some key object classes still elusive, e.g.
  - **Galaxy clusters** as cosmological storehouses of Cosmic Rays
  - Very high energy emission from **GRB**
  - **Dark Matter** annihilation signatures
- Some key mechanisms remain to be understood, e.g.
  - Supernovae as sources of cosmic rays: do they provide sufficient peak energy & energy output?
  - Cosmic ray escape from accelerators and propagation
  - Energy conversion in pulsars
- **Energy range & angular resolution** of current instruments insufficient to probe details

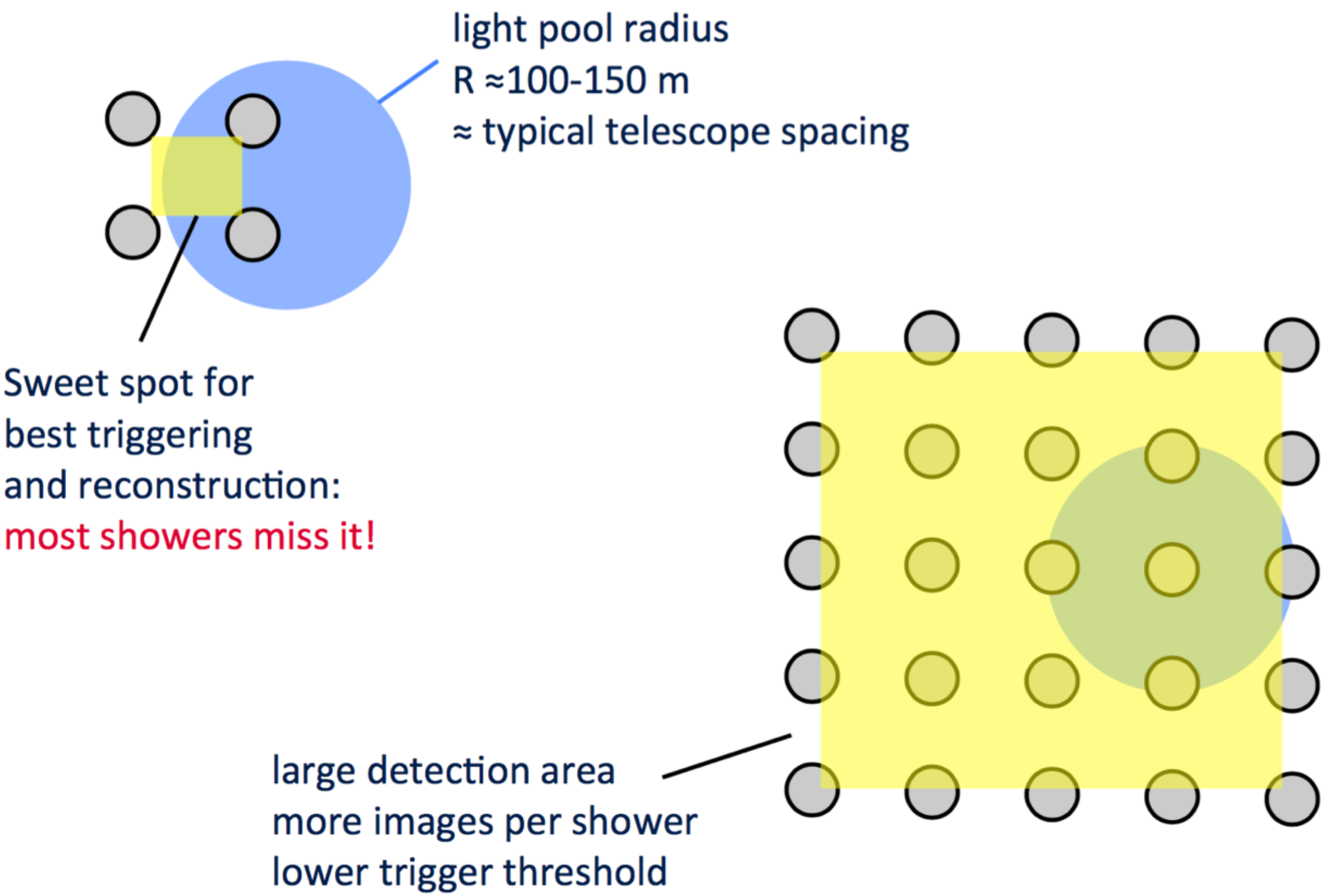
What do we want?

- **High sensitivity**
  - 3 orders of magnitude dynamic range in flux, down to 1“mCrab”
  - Wide spectral range
  - Over three decades, ~20 GeV to ~300 TeV 10-15% energy resolution
- Resolved **source morphology**
  - ~5’ angular resolution
  - 10-20” source localization
- Unprecedented **energy resolution**
  - Spectral features give good physics (especially for fundamental physics)
- **Survey** capability
  - H.E.S.S. Galactic Plane Survey:
    better than 2% Crab sensitivity, 77 sourced detected -> goal is 2mCrab
  - Extragalactic survey
- **Well-resolved light curves**
  - Minute-scale variability of AGN

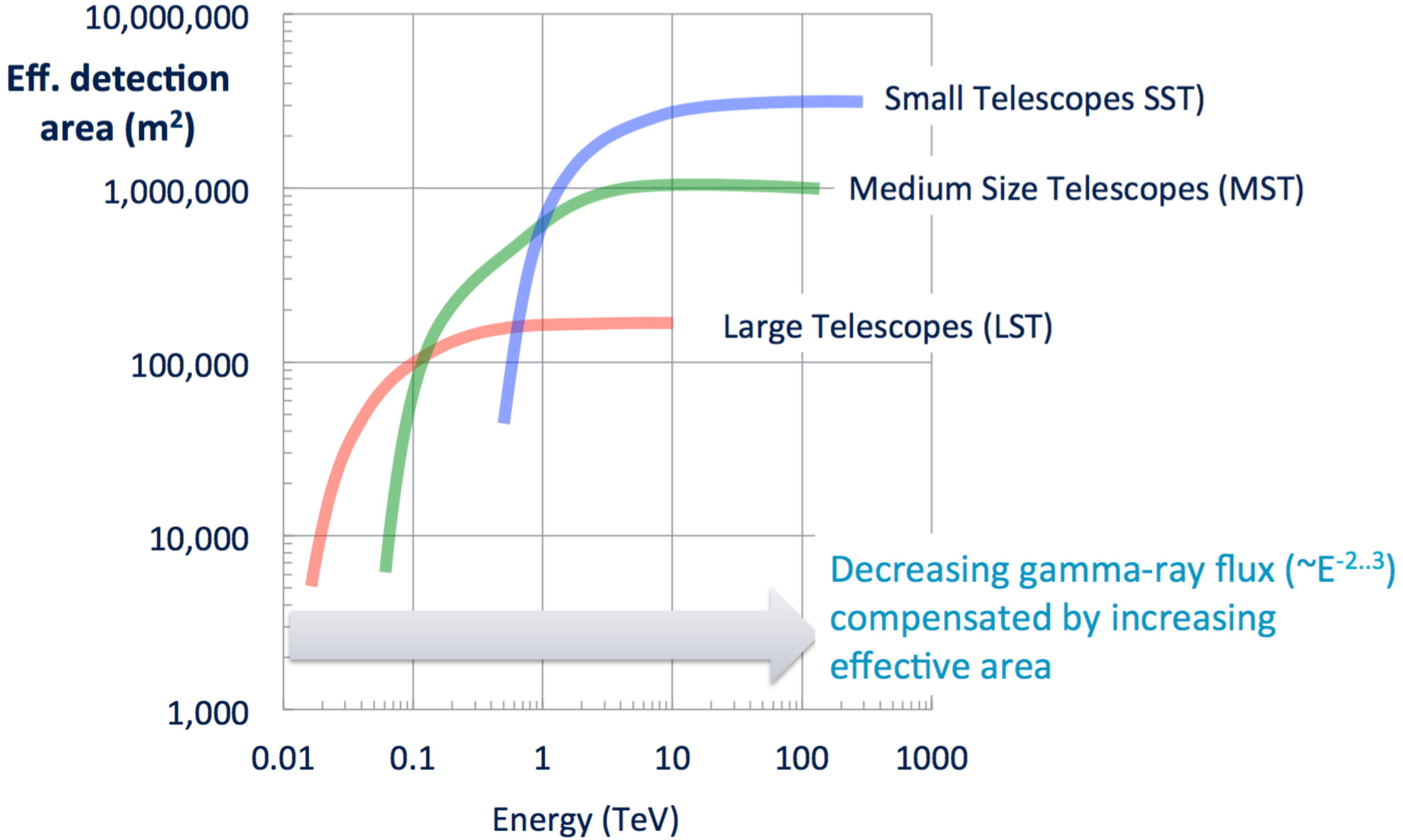
HOW?


The Southern-Hemisphere Array Concept
4 LSTs
Few Large-Sized Telescopes
(400 m2 area) for <100 GeV
70 SSTs
7km2 Array of Small-Sized Telescopes (few m2 area) for 10-100 TeV
25 MSTs
1km2 Array of Medium-Sized Telescopes
(100 m2 area) for the 1-10 TeV
LST
MST
SST

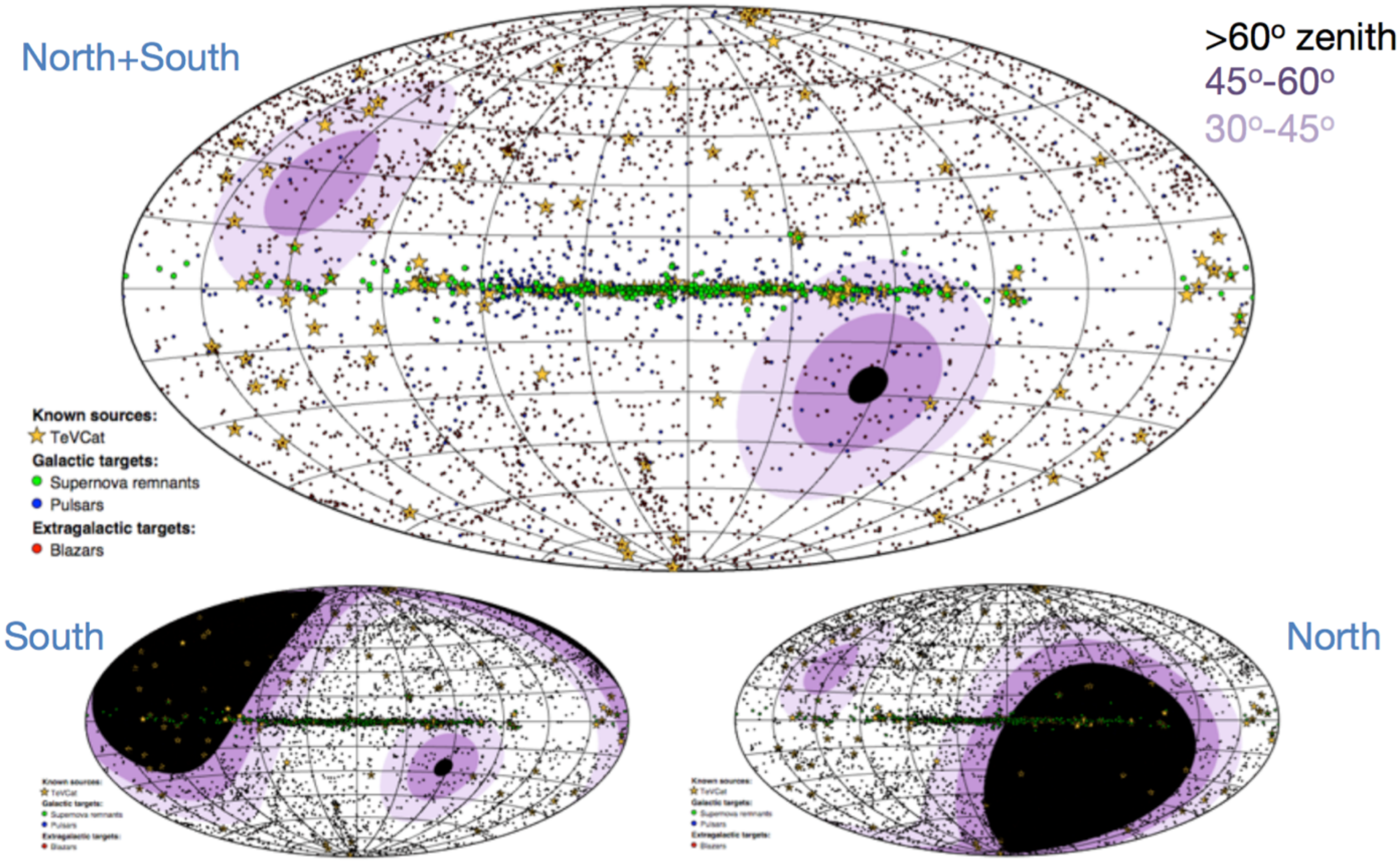
Cherenkov light pool



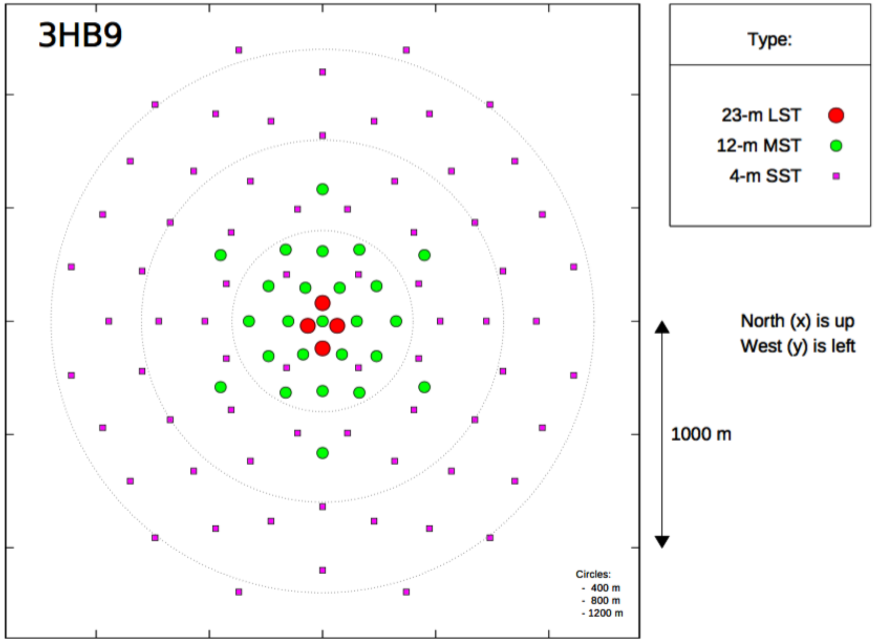
Cherenkov light pool



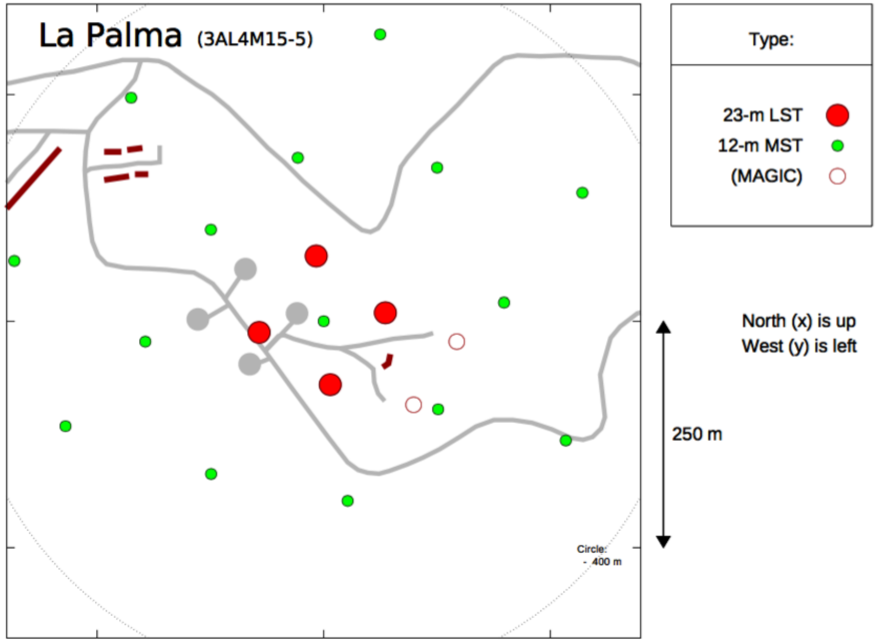
All sky coverage



Array layout (baseline)



4 LSTs, 25 MSTs, 70 SSTs

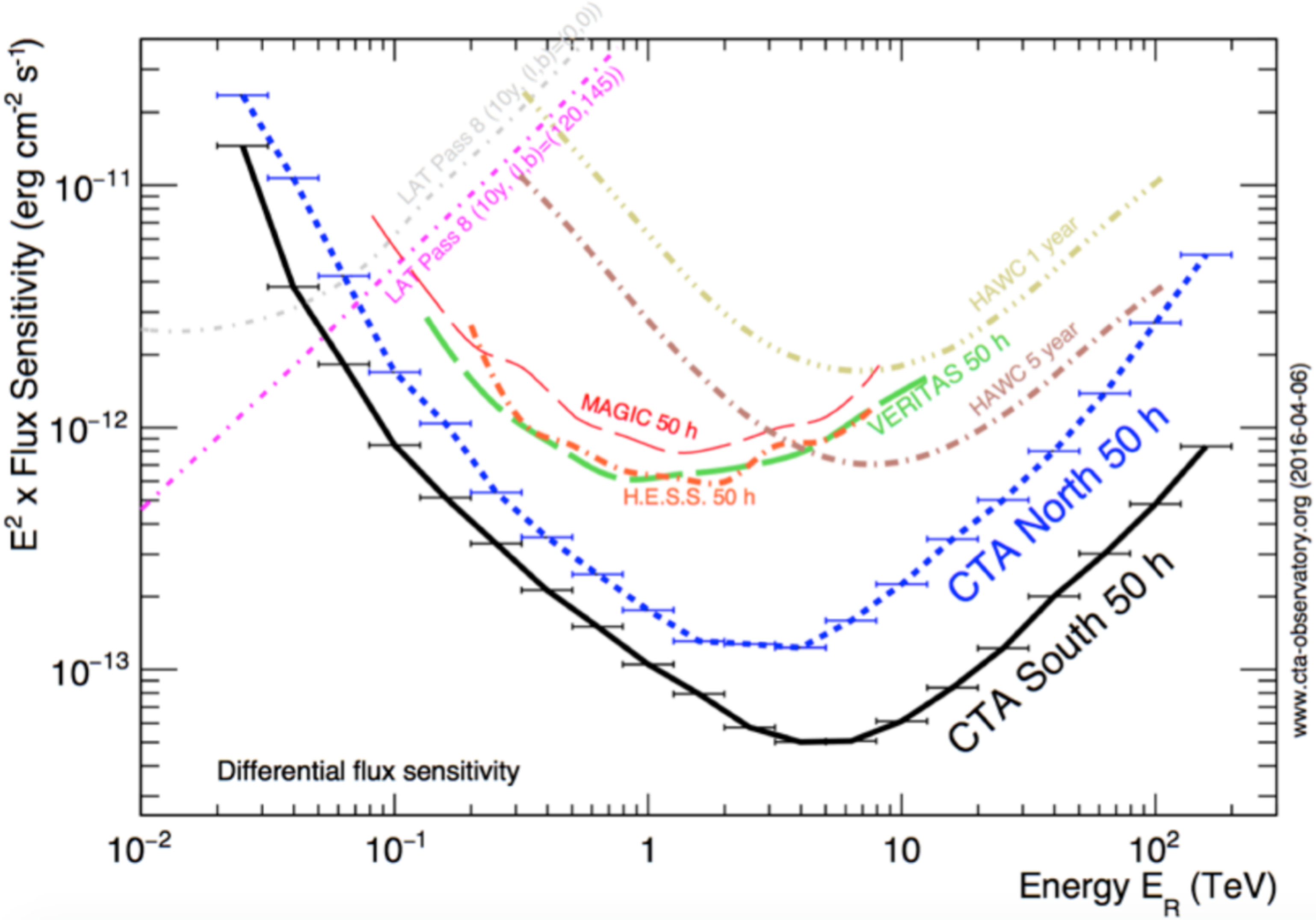


4 LSTs, 15 MSTs

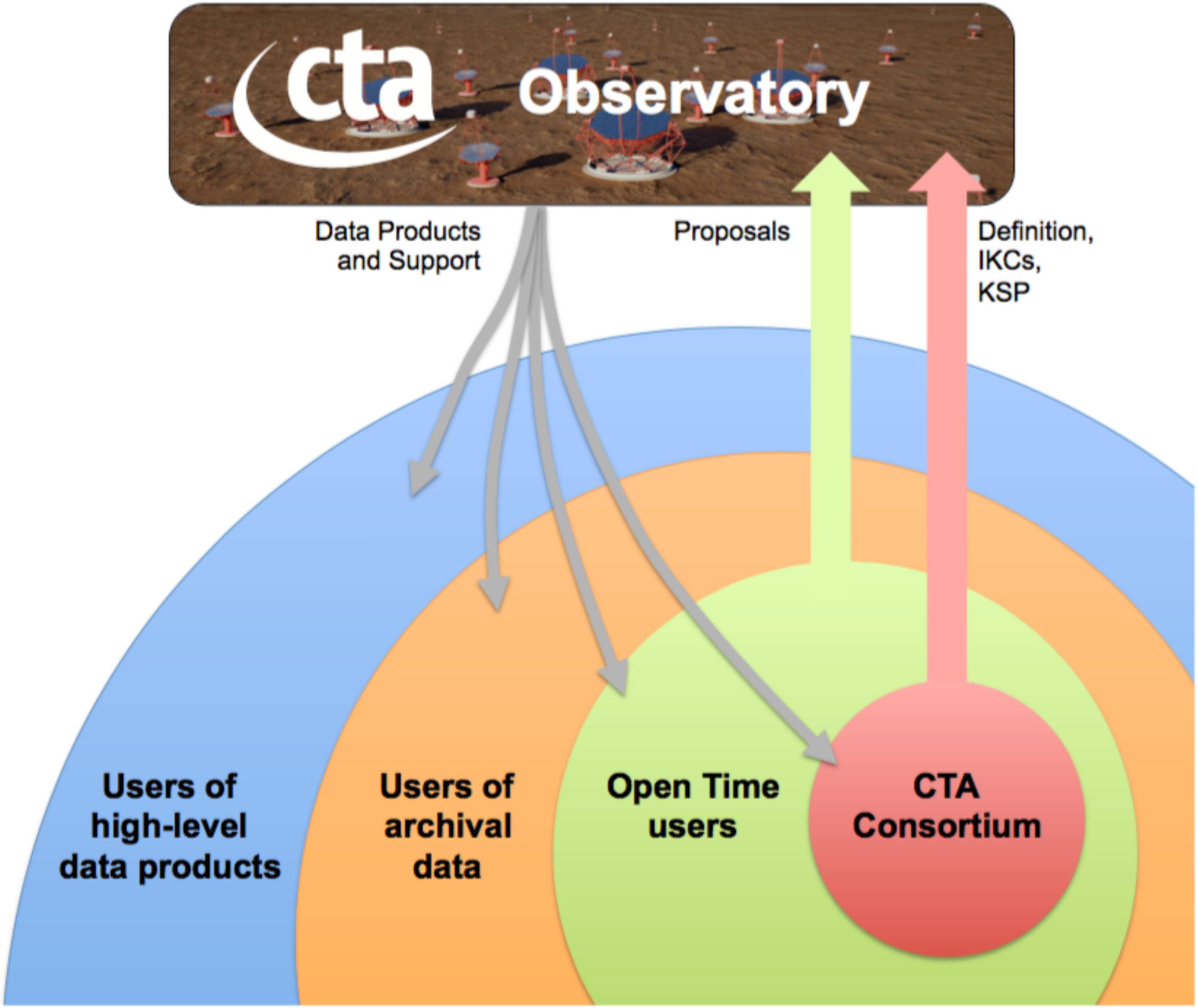
South:
4 LST
25 MST
70 SST

North:
4 LST
15 MST

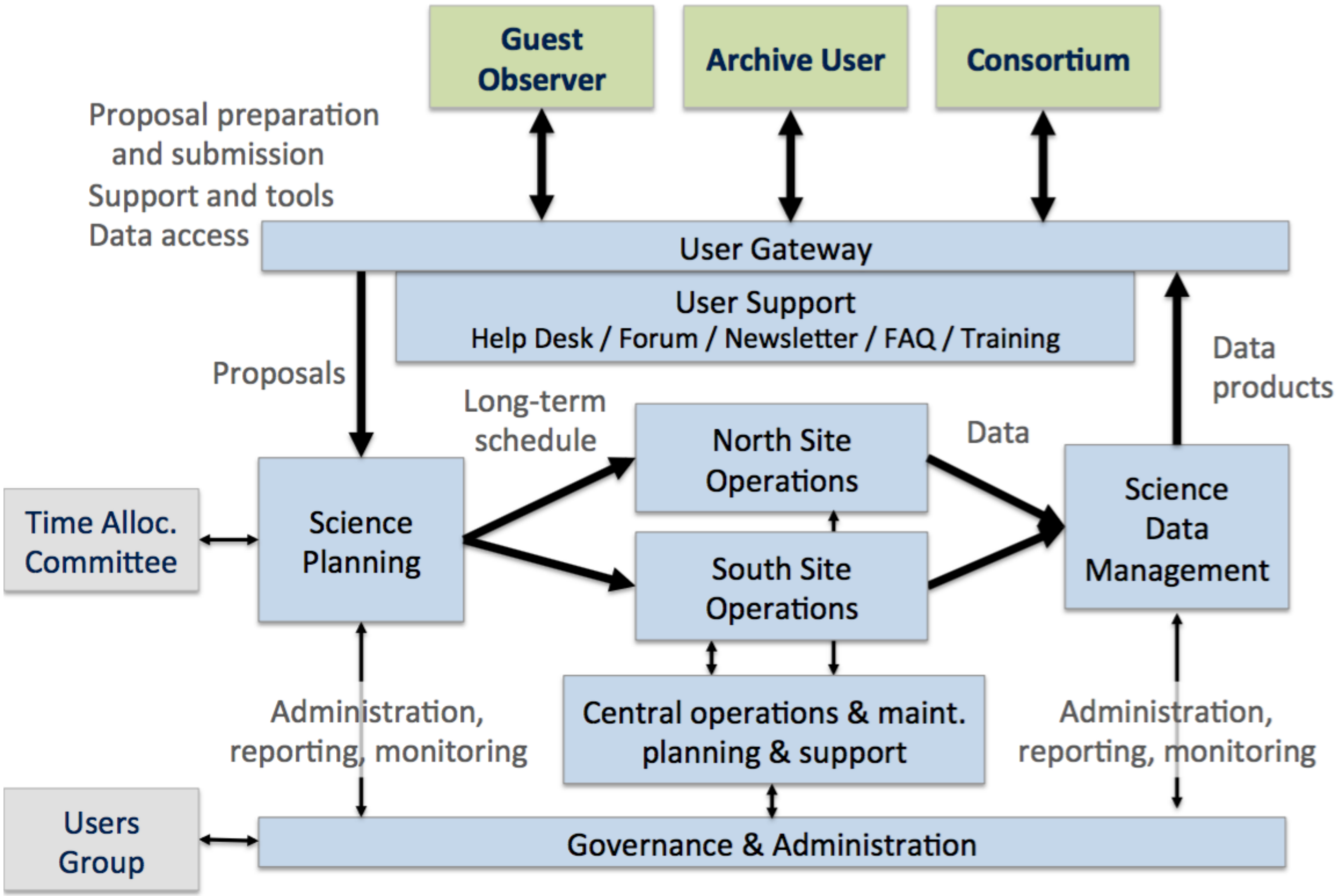
Sensitivity



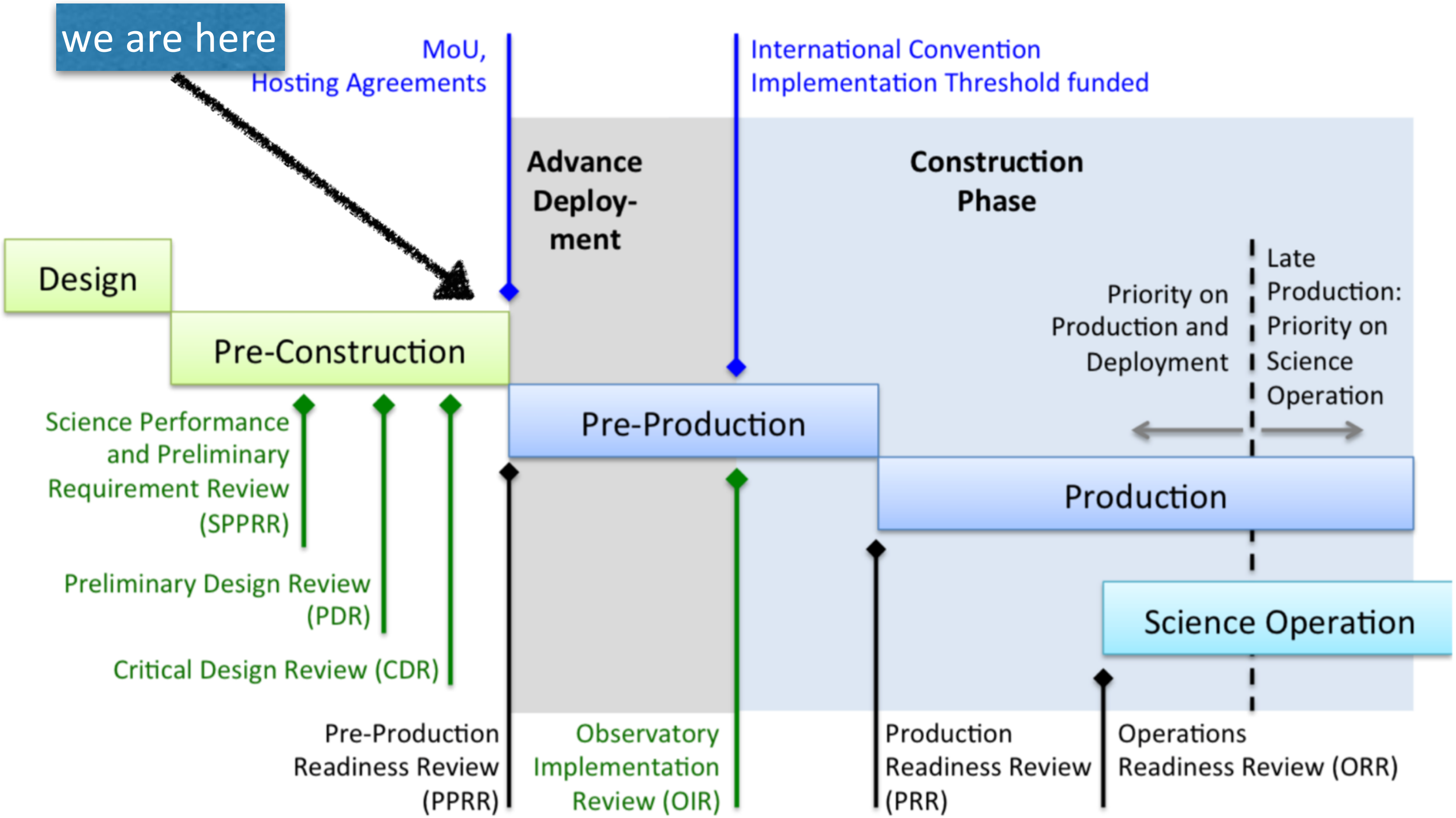
Organization



Organization



Phases



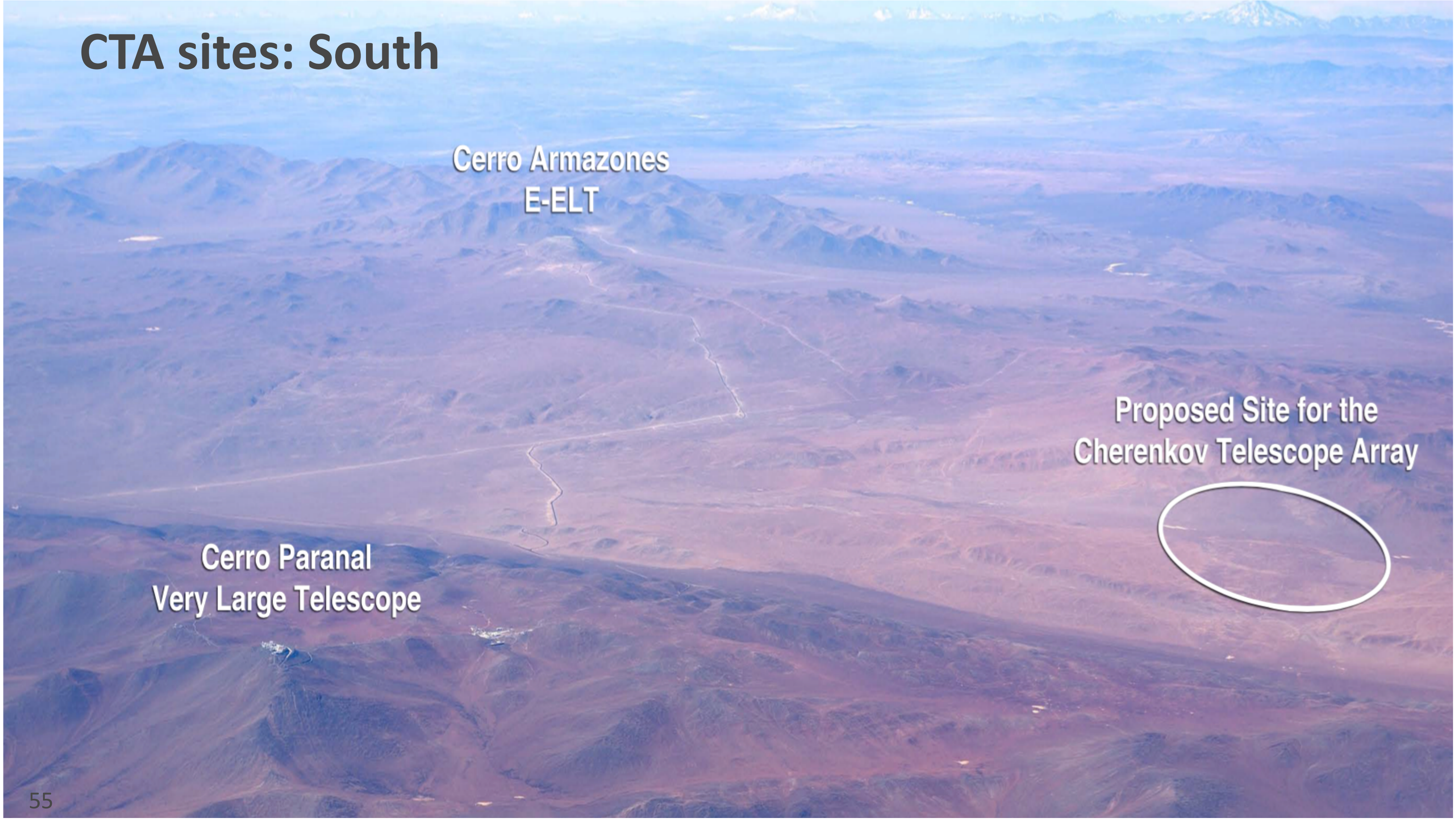
we are here
MoU,
Hosting Agreements
International Convention
Implementation Threshold funded
Advance Deploy-ment
Construction Phase
Design
Pre-Construction
Priority on Production and Deployment
Late Production: Priority on Science Operation
Pre-Production
Production
Science Operation
Science Performance and Preliminary Requirement Review (SPPRR)
Preliminary Design Review (PDR)
Critical Design Review (CDR)
Pre-Production Readiness Review (PPRR)
Observatory Implementation Review (OIR)
Production Readiness Review (PRR)
Operations Readiness Review (ORR)

CTA sites

Site negotiations successfully completed with IAC, La Palma, Spain

Site negotiations progressing with ESO, Chile

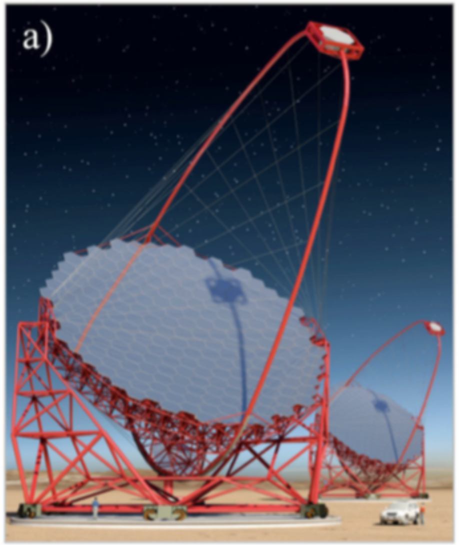
CTA sites: South



CTA site: North
Roque de los Muchachos Observatory, La Palma, Spain

CTA Telescopes

a) LST
b) MST-1M
c) SST-1M
d) SST-2M #1
e) SST-2M #2
f) MST-2M



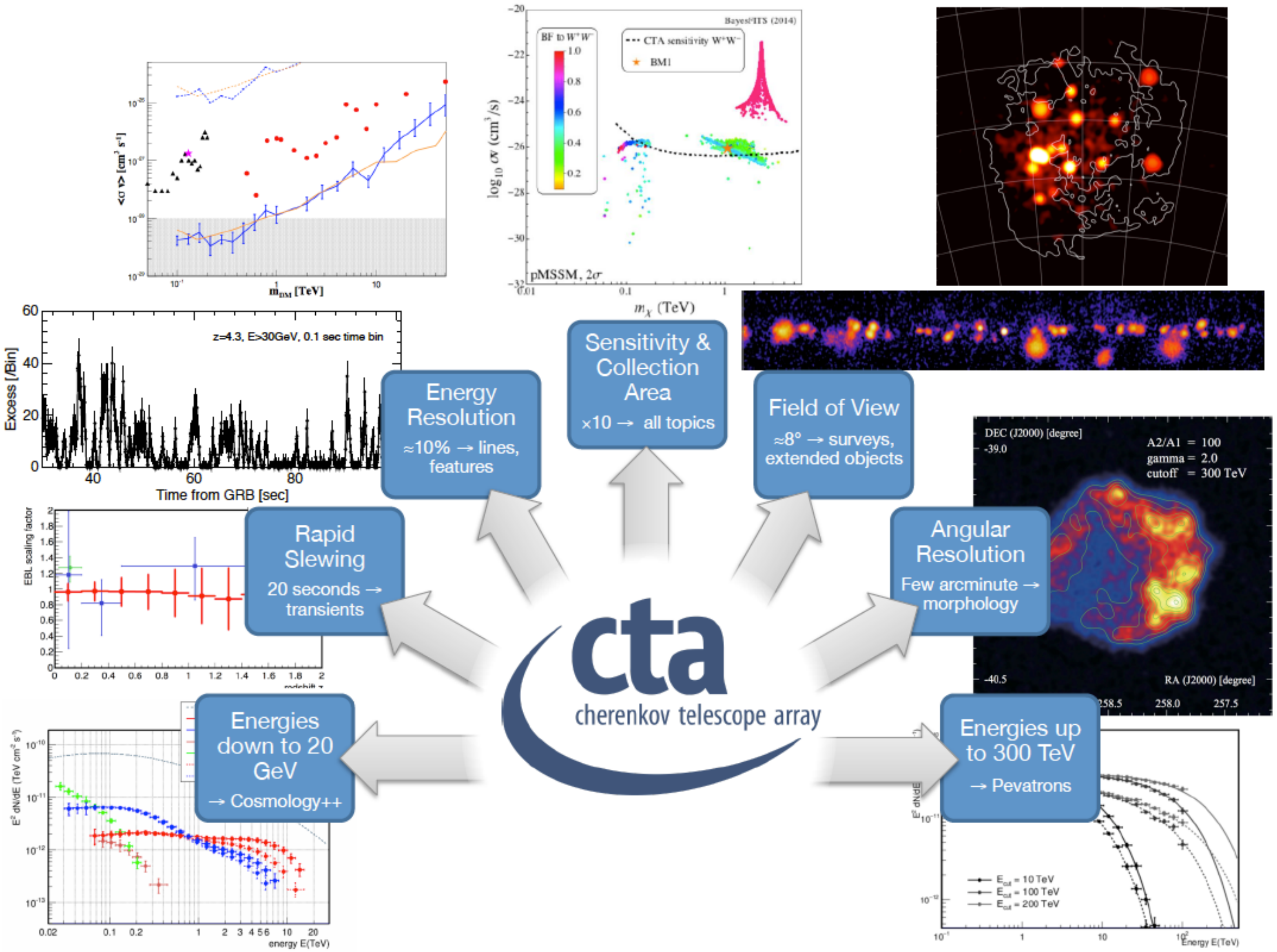
LST corner stone ceremony

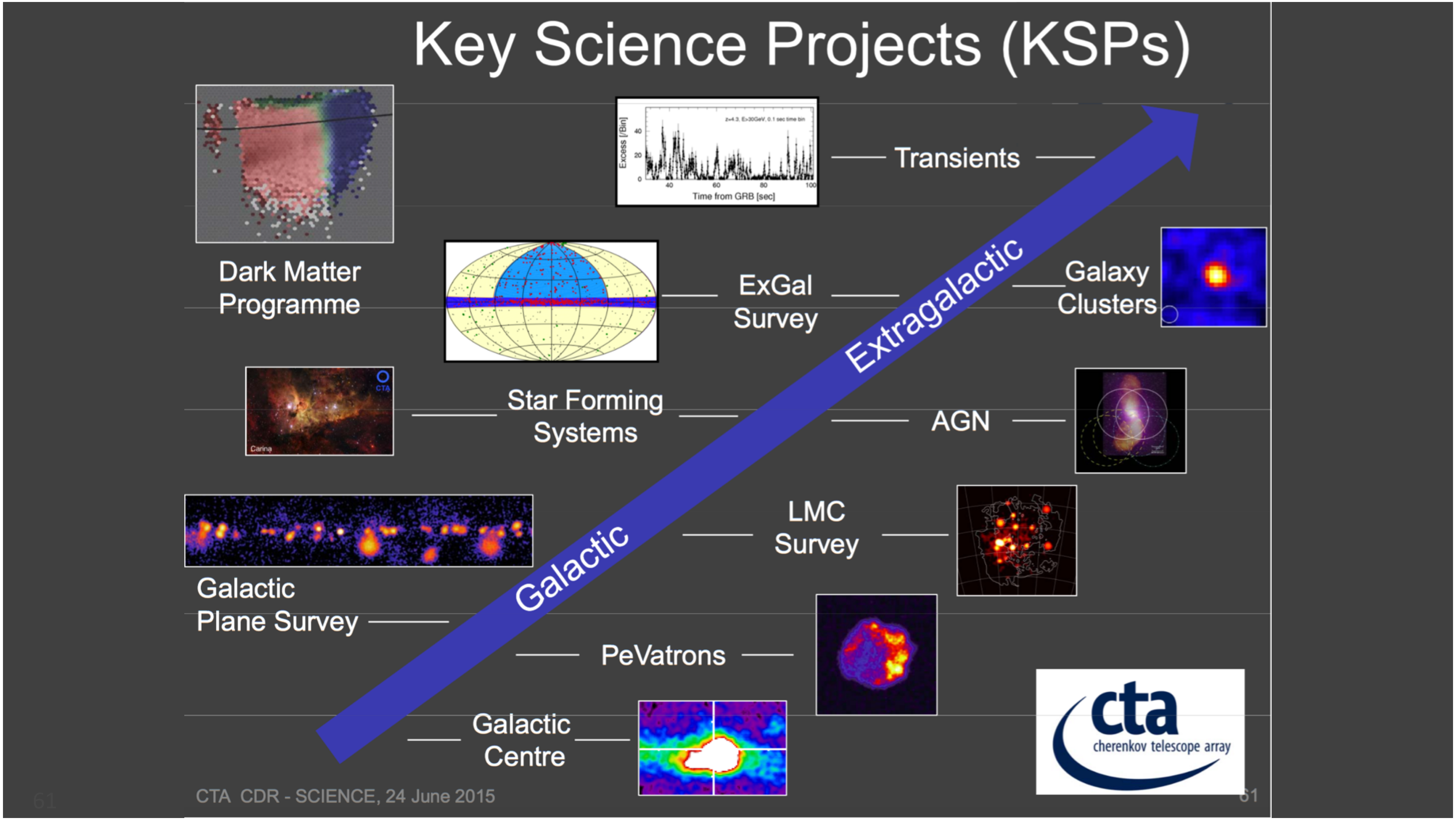
LST prototype status (La Palma)

Oct 2016

CTA Key Science Projects

- **Theme 1:** Understanding the Origin and Role of Relativistic Cosmic Particles
- **Theme 2:** Probing Extreme Environments
- **Theme 3:** Exploring Frontiers in Physics





Key Science Projects (KSPs)
Excess [/Bin]
Time from GRB [sec]
Transients
Dark Matter Programme
ExGal Survey
Galaxy Clusters
Extragalactic
Carina
Star Forming Systems
AGN
LMC Survey
Galactic
Galactic Plane Survey
PeVatrons
Galactic Centre
cta cherenkov telescope array
CTA CDR - SCIENCE, 24 June 2015
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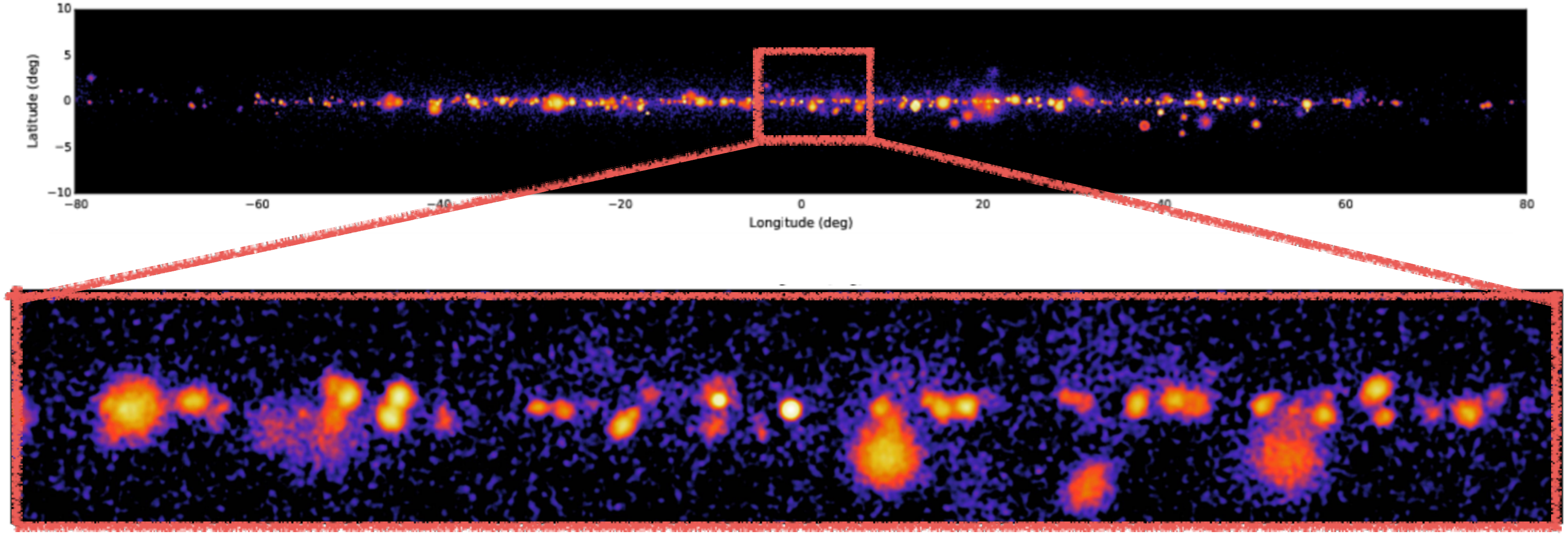
Galactic Plane Scan

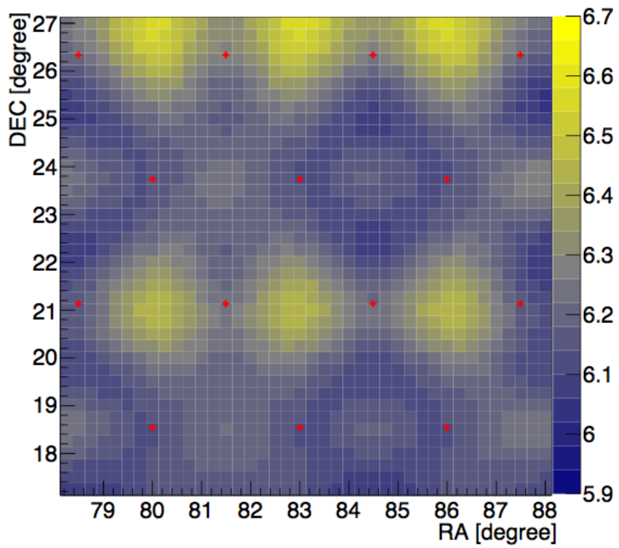
- Simulated Galactic Plane Scan and a zoom in the inner 10 deg
- Sensitivity: 1-3 mCrab (factor 5 better than H.E.S.S)



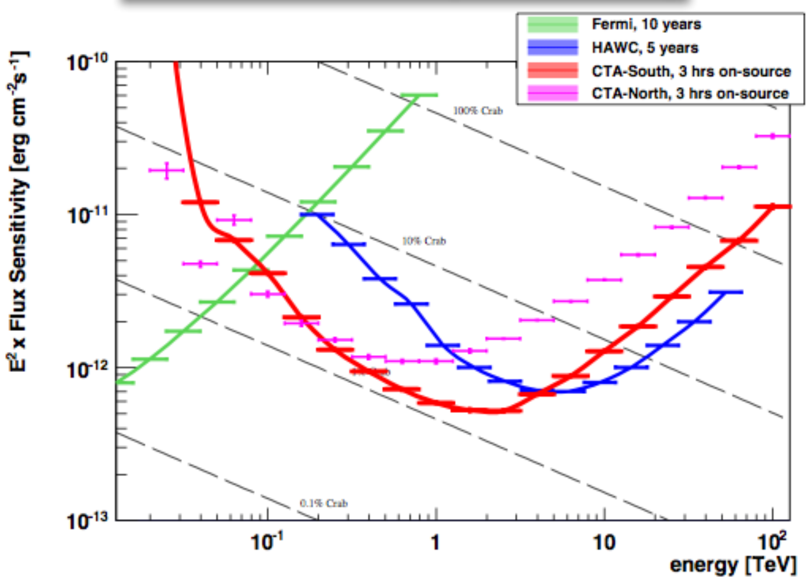
Extragalactic Survey

- Blind survey over 25% of the sky (~10,000 deg^2)
- Overall sensitivity of 6mCrab at energies above 100 GeV
- each field to be observed for few hours, revisit few times over two years to access source variability / persistence
- Divergent pointing is being explored as a possibility

integral sensitivity map in mCrab

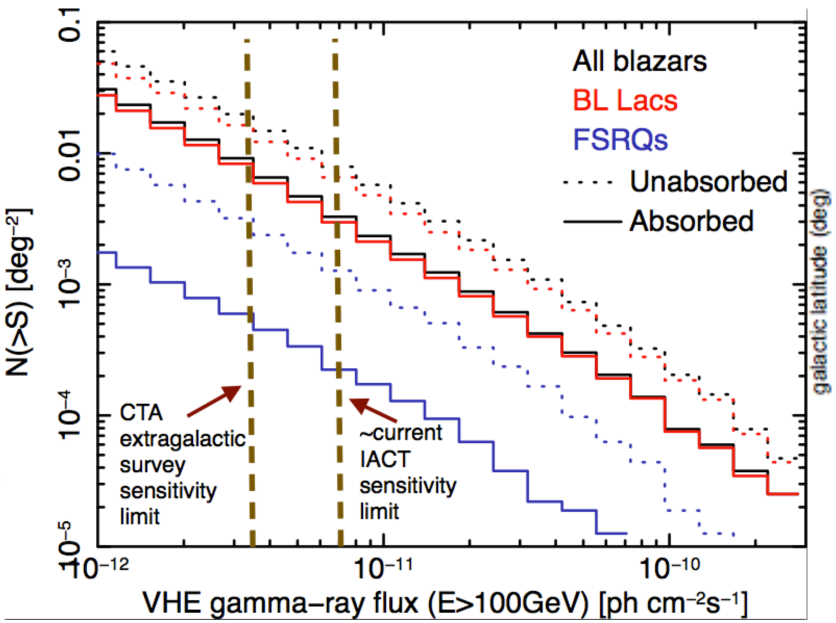


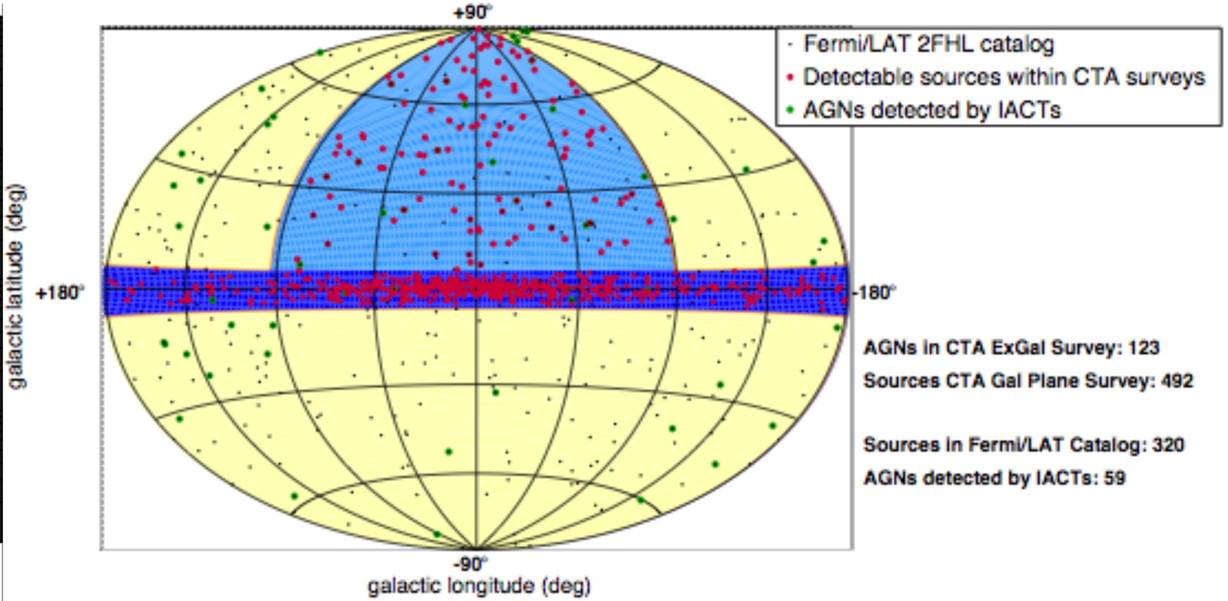
differential sensitivity of the survey



Extragalactic Survey

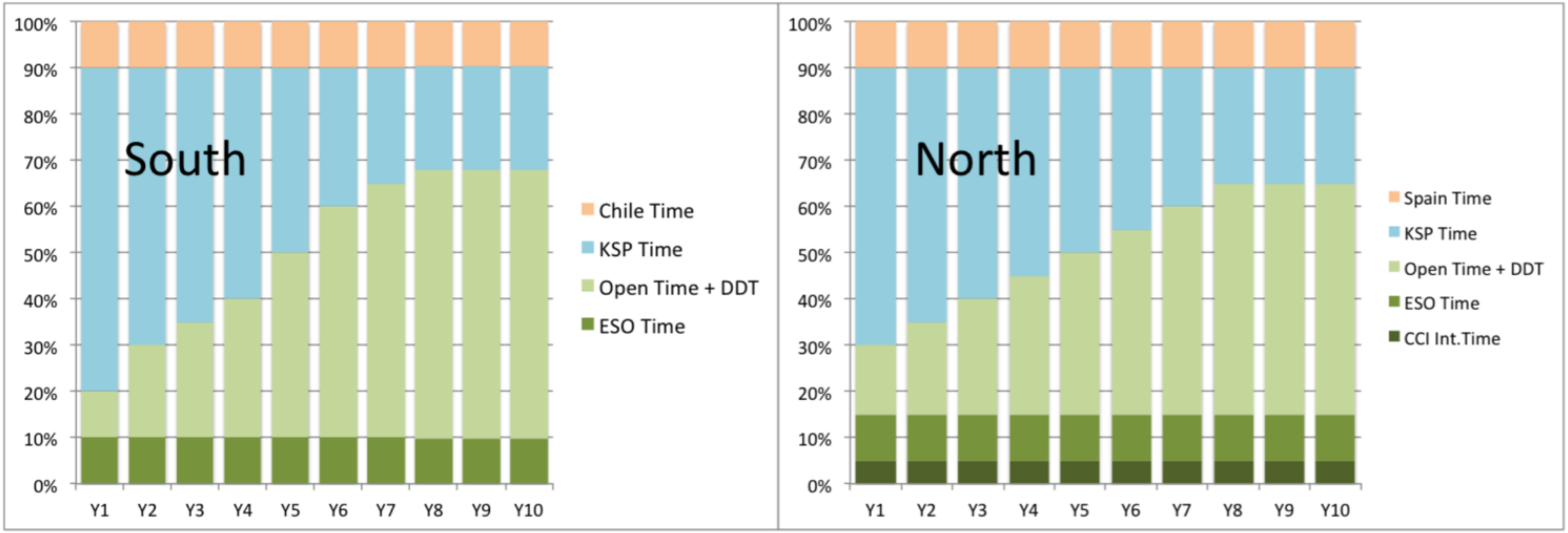
- Expect to detect about 100-150 sources (currently about 20 VHE sources in 25% of the extragalactic sky discovered): this will be enough to construct Luminosity Function
- Hope to find dark emitters: not seen by Fermi/LAT because of hard spectrum and too weak for current IACTs





Time distribution

- Plausible scenario is shown below
- Start with early science (mainly transients and bright objects) in 2018
- Full array aimed for 2021



Summary

- Gamma ray astronomy is a consolidated science with extremely wide science scopes
- CTA will move from current situation to **precision gamma-ray astrophysics:** large energy range + spectral features + morphology power + sensitivity
- **CTA aims are very wide**: observatory structure should be overstructure necessary to make TeV astrophysics a consolidated astronomical branch
- Besides core science, **top-level results are expected**

THANKS!