From MAGIC-I to MAGIC-stereo: filling the gap with HE satellite experiments.

Michele Doro (Universitat Autonoma Barcelona) michele.doro@uab.cat

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MAGIC

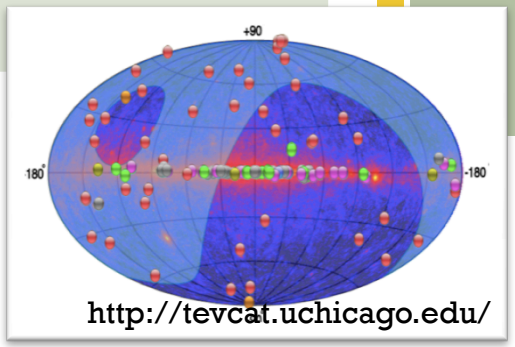
UAB
Universitat Autònoma de Barcelona

Outline of the talk

- From one to two telescopes
- Why low energies?
- Highlights on recent MAGIC-I result and M-stereo results
- Conclusion

→See also R. Wagner Wed talk

+ Where, when.

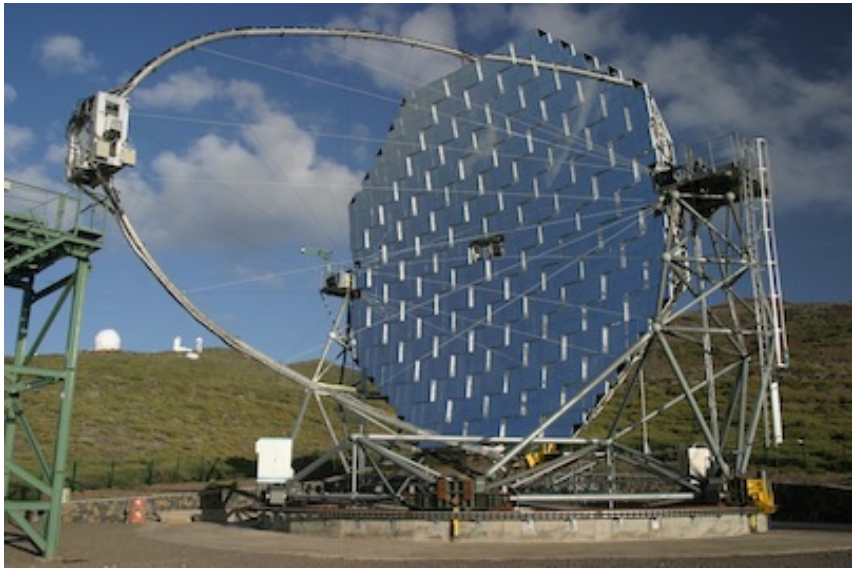


- Canary Island La Palma, 2200 m. asl. (**northern hemisphere**)
- Best suited for **extragalactic objects**

- Fall **2003** → MAGIC-I telescope built
  - 2006 From 300MHz to 2GHz readout
- Fall **2008** → MAGIC-II telescope commissioned

A twin but not a clone!

The telescope(s)



Design

- Solar power-plant design
- 17-m diameter
- F/D=1
- ~500kg camera
- Signal digitization off-telescope
- 64 tons total moving weight
- Fast-movement (GRBs): 20 sec ptp

Performance

- Energy threshold ~50 GeV (~ 25 GeV with a special trigger)
- FOV 3.5deg
- Energy Resolution ~16% (E>300 GeV)
- Angular Resolution ~0.07deg (E>300 GeV)
- Sensitivity (5 σ in 50 hours) ~0.8% Crab Nebula flux (> 250 GeV)

Colin, ICRC 2009

Several "firsts"

- Worldwide largest mirror dish.
- Lightweight CFRP tubes for structure
- Diamond milled light weight all-aluminum sandwich mirrors
- Active mirror control
- Low gain hemispherical PMTs with diffuse lacquer coating
- Transmission over 160 m by optical
- 2 GHz FADCs

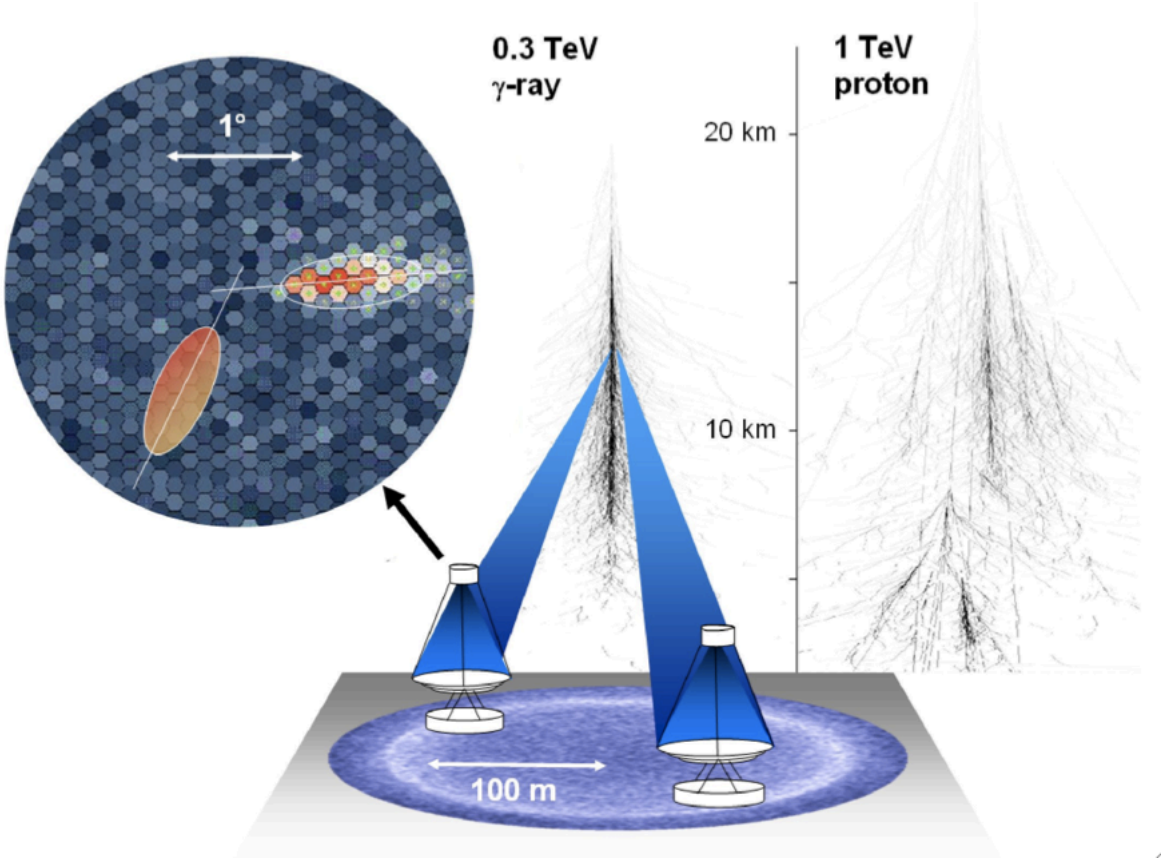
MD, ICAPTT 2008

So run MAGIC run..!

Fast-motion is used only after satellite alerts for possible GRBs (1-2/ month). Telescopes move at v_max=13-16 deg/sec.

M. Garczarczyk 2011

Why stereo?

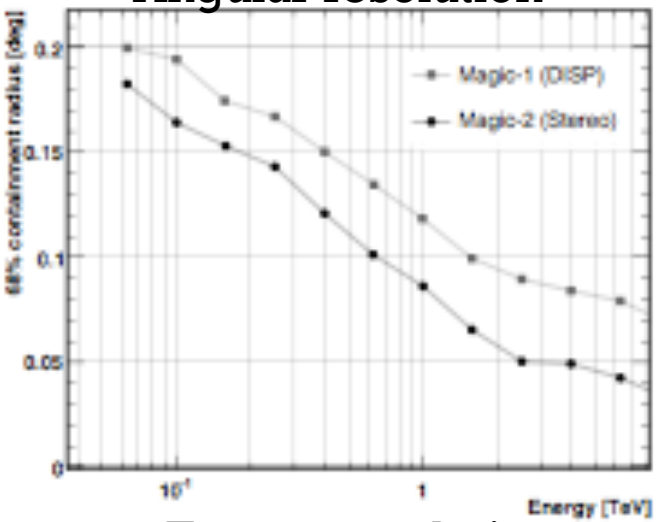


Adapted from Hinton and Hofmann 2009

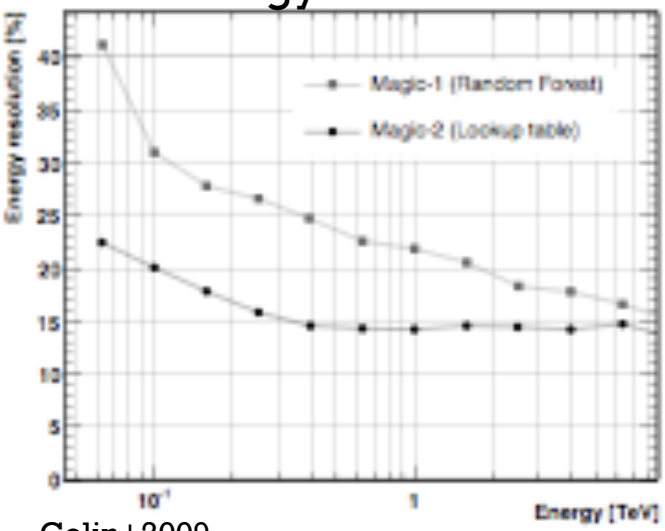
- Two telescope see same shower
- Two new parameters wrt MAGIC-I:
  - Impact parameter
  - Shower maximum height
- Better **background estimation** specially at **low energies**
- Possible **morphological studies**

+ Improvements

Angular resolution

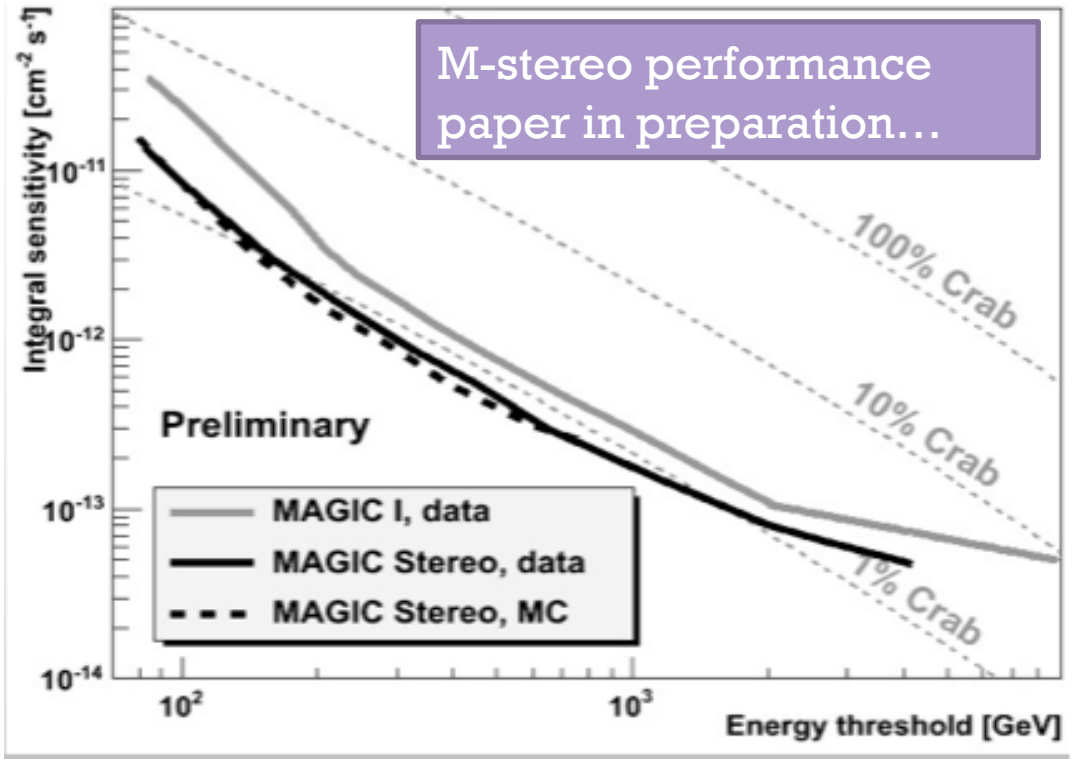


Energy resolution



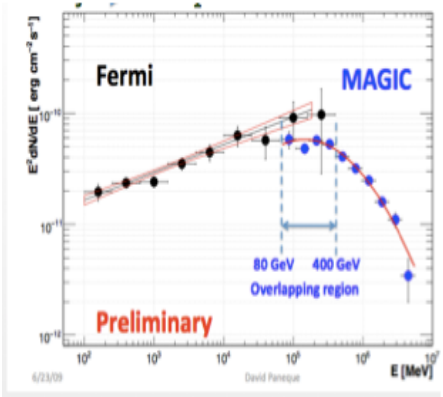
Colin+2009

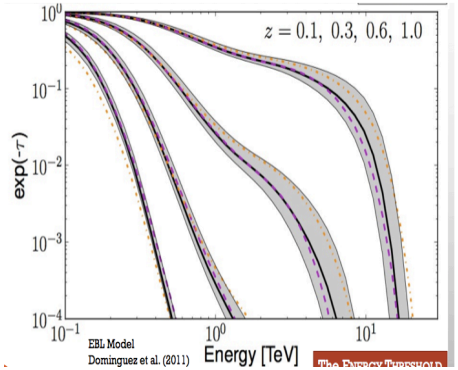
- Extended sources and morphology now possible
- **Sensitivity improved of 100%** over most of the energy range
- Better performance specially at low energy (<100 GeV)

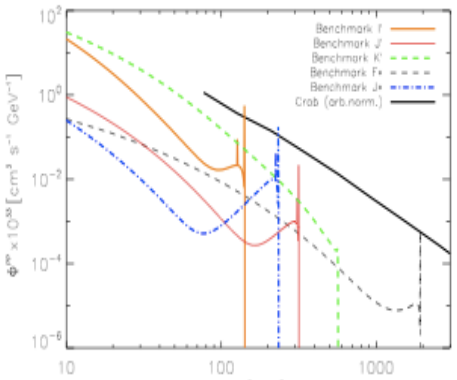


But why low energies?

Why low energies



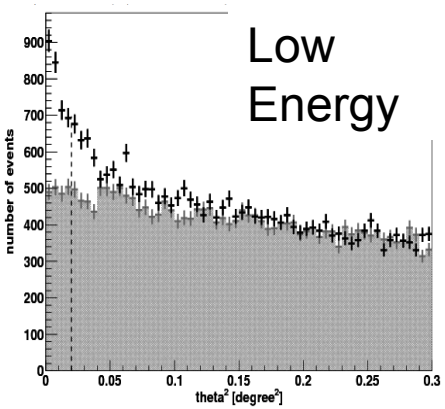


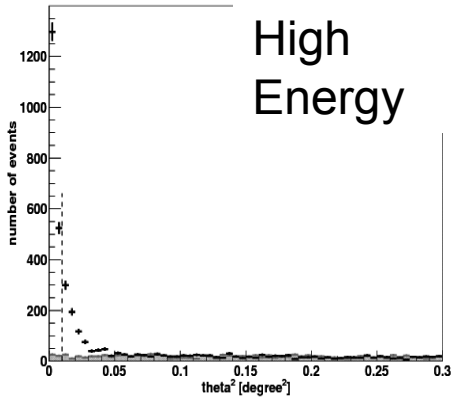


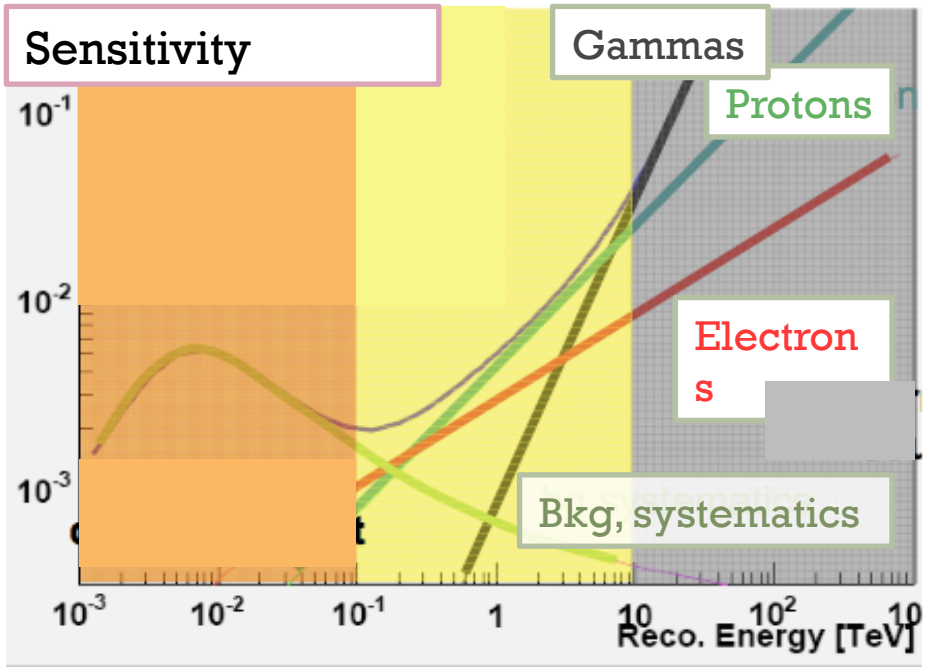
- Despite Fermi is sensitive up to 300 GeV, it runs into lack of statistics above few tens of GeV. Filling the gap means:
  - All physics in the 10 GeV – 100 GeV range
  - Energy/flux intercalibration of (uncalibrated) IACTs with (calibrated) Fermi

- Physics wanted at HE-VHE window:
  - "HE bump" for galactic and extragalactic objects to prove acceleration mechanisms
  - Pulsed emission in pulsar (polar-cap vs outer-gap)
  - Blazar population discrepancy between HE and VHE (intrinsic cutoff or EBL-absorption)
  - Dark Matter models with low-mass WIMPs
  - …

Low Energy in the real world







Adapted from W. Hofmann 2009

- IACT runs of 3 regimes:
  - **> 10 TeV**: almost no background but limited by statistics
  - **1-10 TeV:** best suited, bkg rejection > 99%
  - **< 100 GeV**: electrons background is important, bkg systematics, bkg rejection drops to 50-60%
- Effective area drops rapidly below 100 GeV➔ **analysis is tougher (specially for faint sources)**

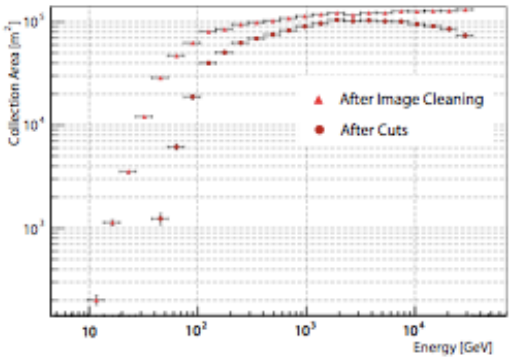
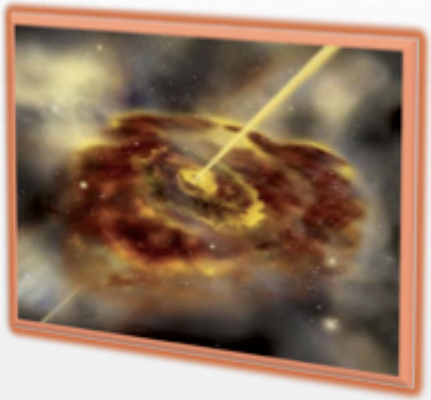


FIG. 9.— Collection area after image cleaning and after cuts for low zenith angle observations (< 20°).

Highlights on M-stereo results (and other recent M-1 results)

MAGIC Astrophysics



Source detection and monitoring

Populate the TeV sky

Origin of the emission (and CRs)

γ-ray propagation

Dark Matter and new physics

Cosmology and fundamental physics

7

Extragalactic

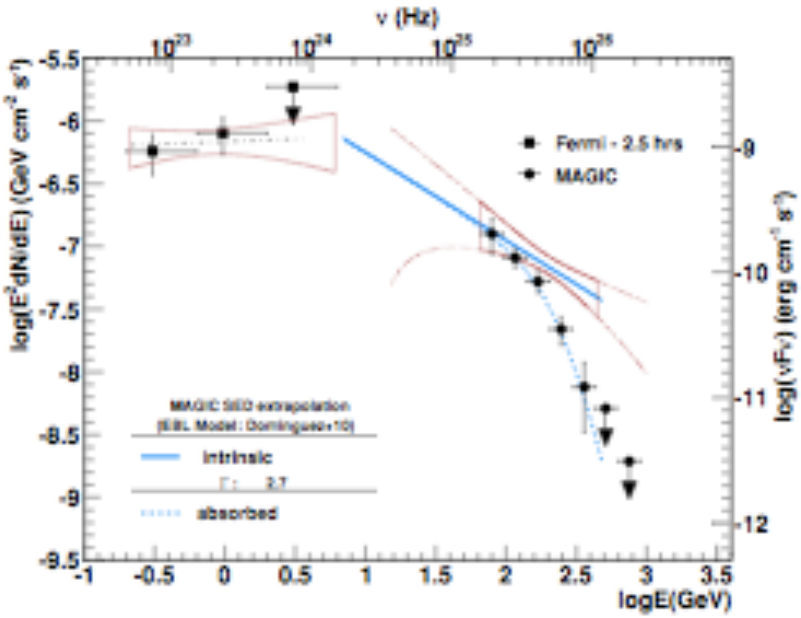
+ FSRQ PKS 1222+21 (4C21.35)

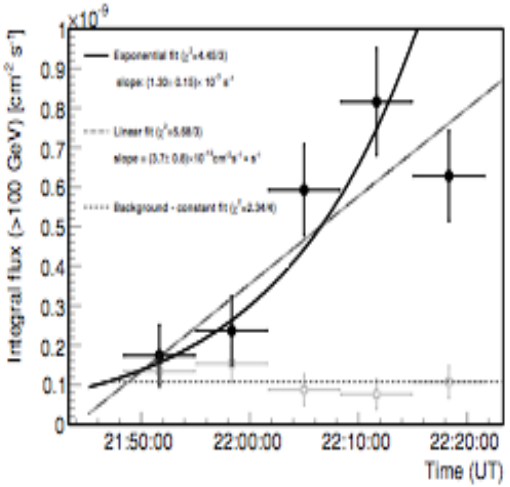
- Very good example of collaboration Fermi-IACTs (hard sources)
- Fermi Atel 2584 triggers MAGIC: 10.2 sigma detection in 0.5 h (1 Crab)
- 2nd farthest VHE source: z=0.432

- MAGIC+Fermi: can fit to single power-law -2.7(0.3) between 3 and 400 GeV
- No-sign of any cutoff
- Most rapid variation ever observed at VHE: Flux doubling-time 8.6min!

- Single spectrum → emission due to unique component
- No GeV cutoff → emission outside the BLR region, in the relativistic jet?
- Flux rapid variability→compact emission

- CHALLENGE TO EMISSION MODELS!

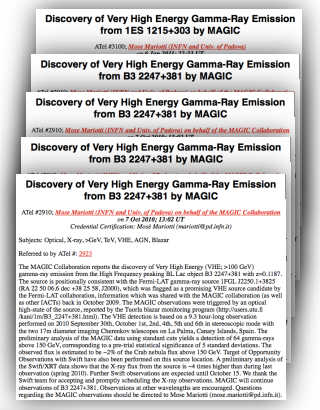


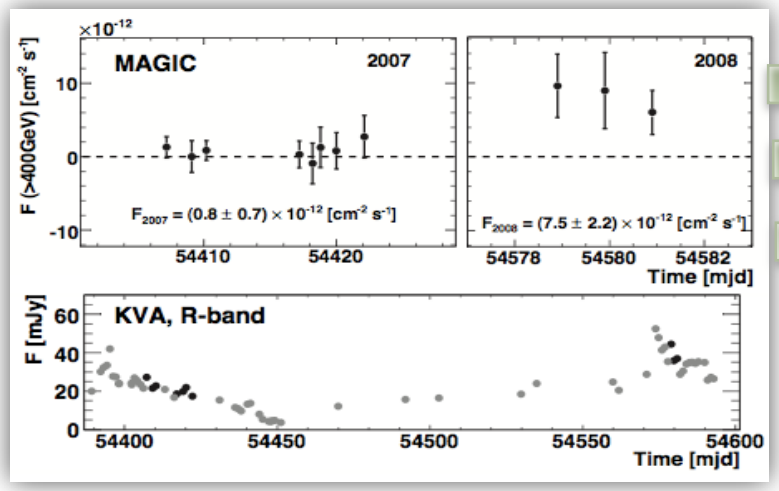


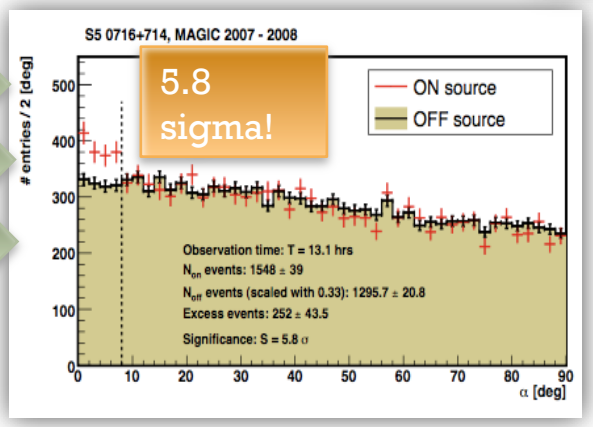
ApJL 730:L8 2011

Optically triggered discoveries

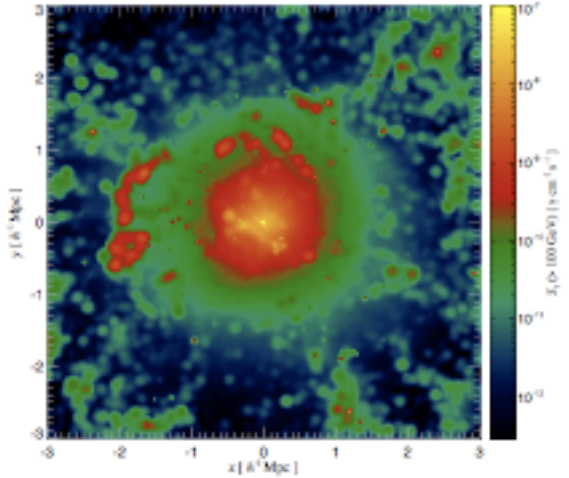
- MAGIC operates together with two optical telescopes: 60cm KVA (La Palma) and Tourla blazar monitoring program
- Connection optical to gamma is still unknown but proven useful for discoveries:
  - M-1 observation of HBL S50716+714 (ApJ 704 (2009) L129)
  - M-stereo observation of BL-lac 3C 66A (ApJ 726 (2011) 58)
  - M-stereo discoveries:
    - HBL B3 2247+381 ATEL #2910, Oct.2010,
    - HBL 1ES1215+303 (ON325) ATEL#3100, Jan.2011.

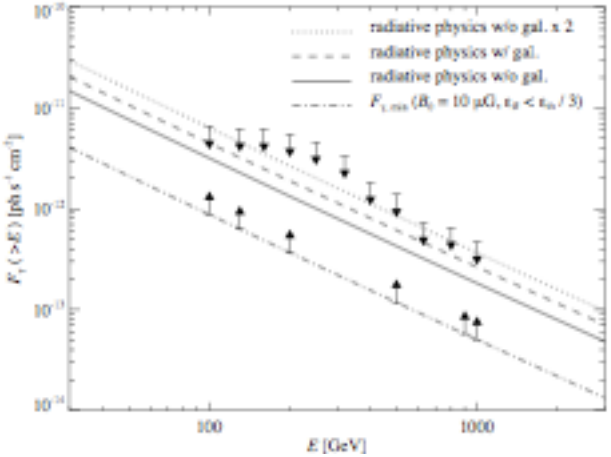






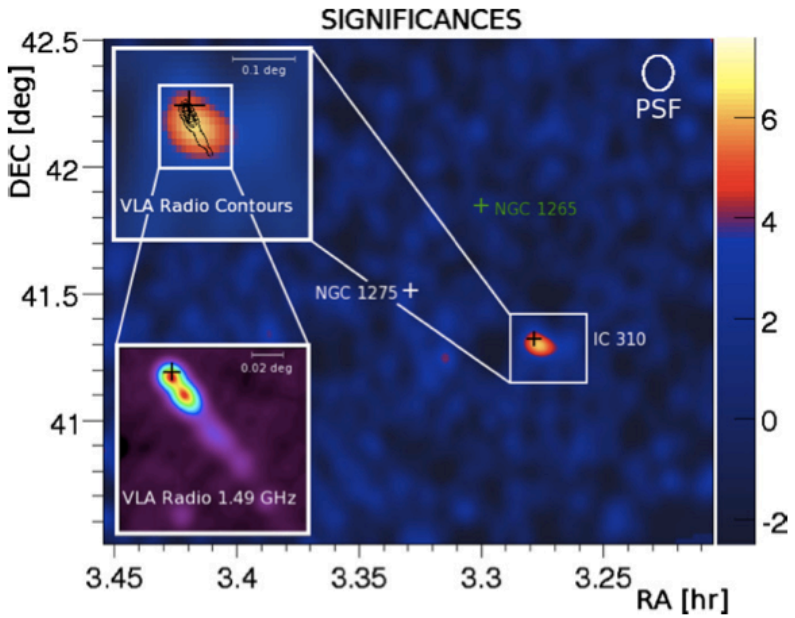
Perseus galaxy cluster region





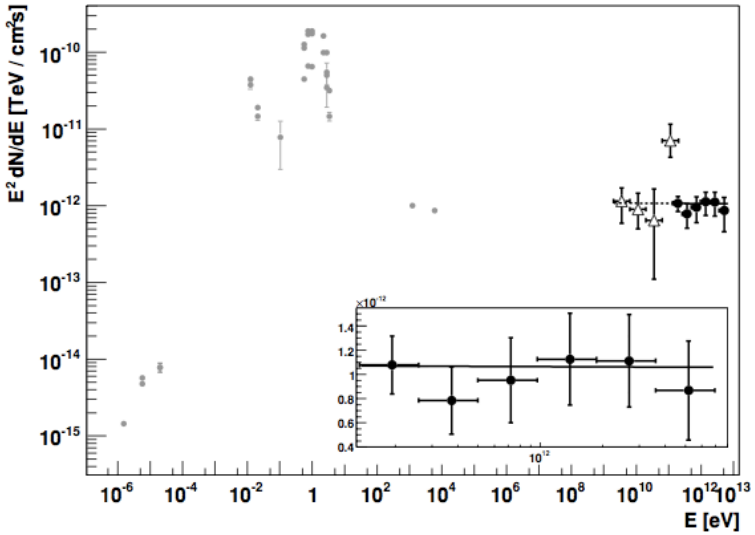
- Galaxy clusters are micro-universe → much astrophysics:
  - Many galaxies
  - Extended CR emission from central core
  - Huge DM content (despite large distance)
- Monitored by MAGIC since 4 years
  - Upper limits with M-1 ApJ 710 (2010) 634-647)
  - Around 60 h collected now with M-stereo data.
- M-stereo observation very fruitful:
  - Discovery of IC310 head-tail radio galaxy (ATEL#2510, Mar 2010, ApJL, 723:L207–L212, 2010)
  - Discovery of VHE emission from NGC1275 (ATEL#2916, Oct 2010,Pubs. in Prep.)

IC310 Head-Tail galaxy



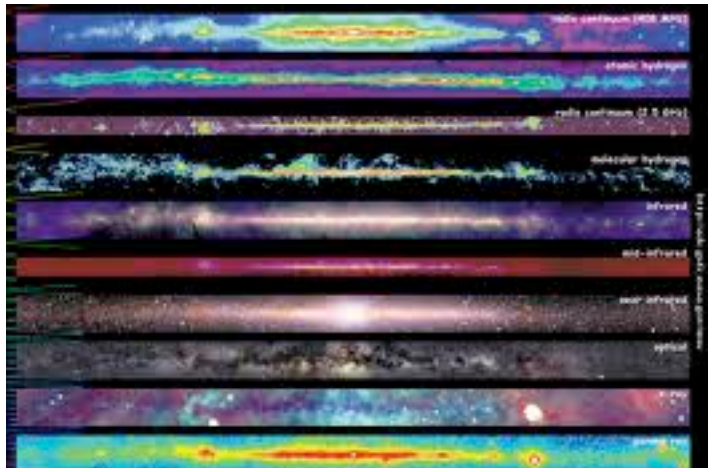
- 1Mpc from Perseus central NGC1275 (0.6deg)
- IC310 show radio-optical head and radio tail
- Only few radio galaxies seen at TeV
- Jet interaction with flow of intracluster medium
- Serendipity active during Perseus survey: 20.6h M-stereo, 7.6σ

- Not enough spatial resolution for emission location: head or tail?
- Radid variability (10 days)
- Flat spectrum: powerlaw Γ=-2 can feature leptonic or hadronic models



Astrophysical Journal Letters, 723:L207–L212, 2010

+ Multi-wavelength campaigns

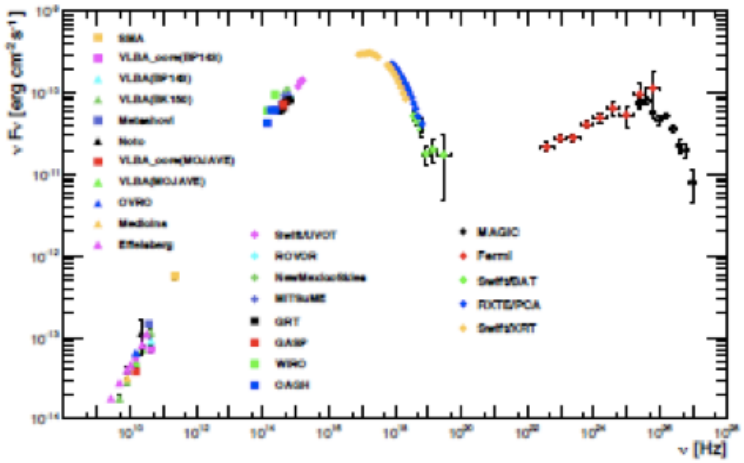


Radio: VLBA, OVRO, Effelsberg, Metsahovi..
mm: SMA, IRAM-PV
Infrared: WIRO, OAGH
Optical: GASP, GRT, MITSuMe, Kanata...
UV: Swift-UVOT
X-ray: Swift-XRT, RXTE-PCA, Swift/BAT
Gamma-ray: Fermi-LAT
VHE: MAGIC, VERITAS, Whipple

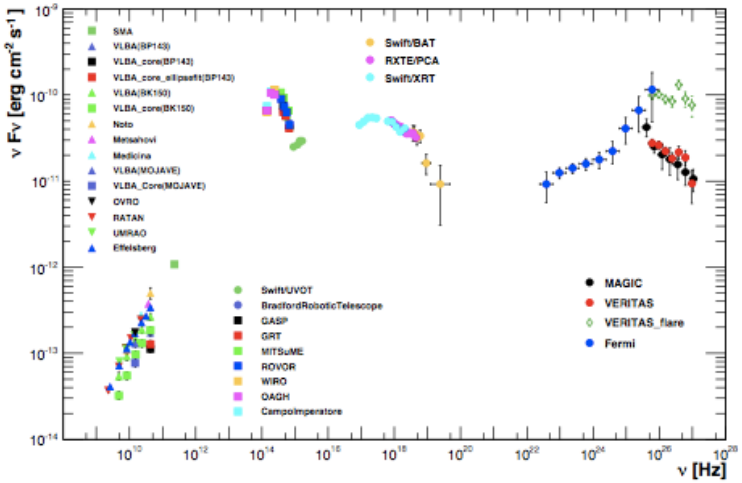
- In 2010, MAGIC participated in several multi-w campaigns.
- Targets: Mrk421, Mrk501, M87
- In general, proven very fruitful. For the future, need more prolonged contemporary monitoring to dig more into physics

The Markarians 421 and 501

Mrk 421

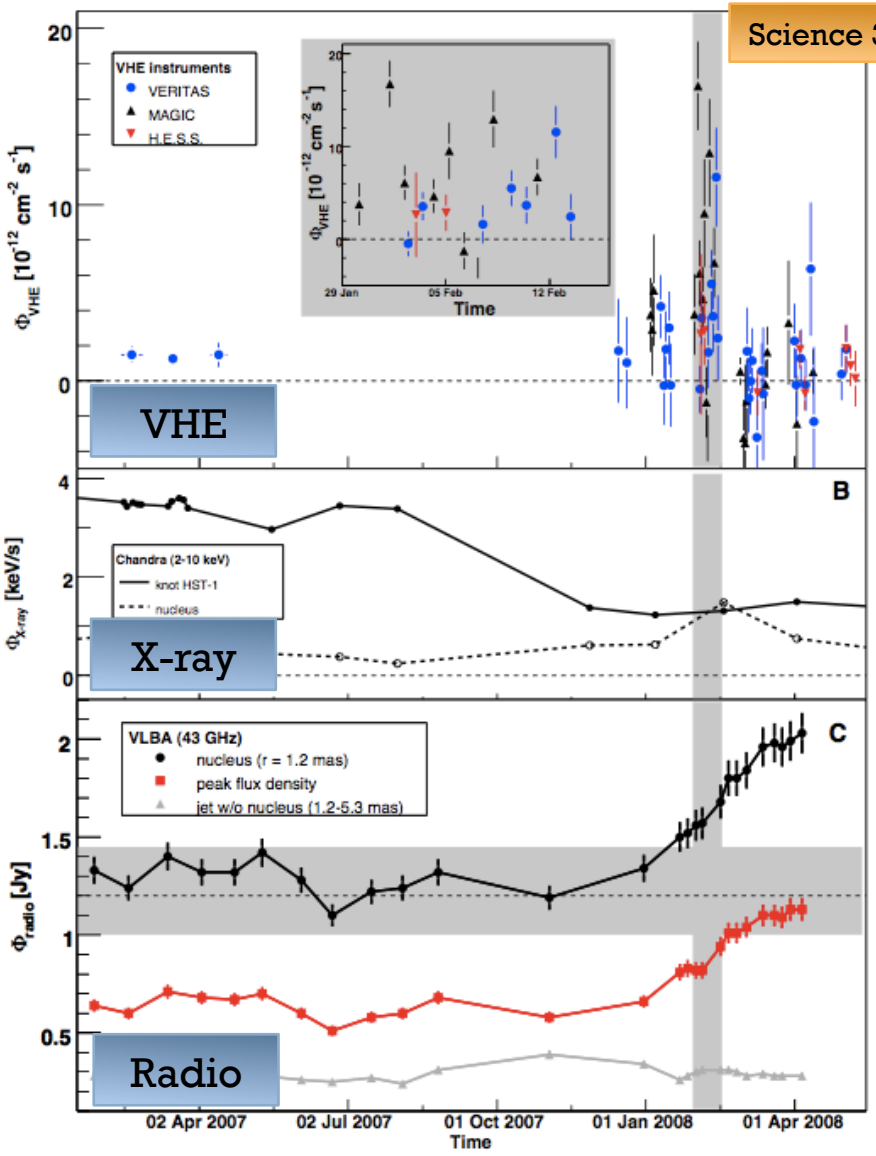


Mrk 501

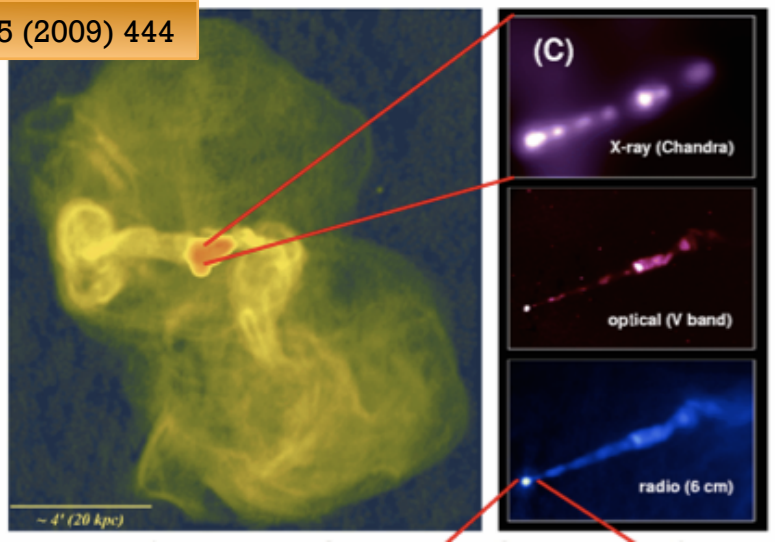


- Most **complete SED** ever collected for Mrk 421 and Mrk 501
- Total **Fermi-MAGIC overlap** over 5 decades in energy! ➔ HE-VHE connection
- Sources monitored in low-high states, detailed light-curves, multi-wavelength coverage: lots of physics possible!:
  - Insights Into the High-Energy Gamma-ray Emission of Markarian 501 from Extensive Multifrequency Observations in the Fermi Era FERMI, MAGIC, VERITAS and MAGIC, accepted Astrophys. J. 2010
  - MAGIC TeV Gamma-Ray Observations of Markarian 421 during Multiwavelength Campaigns in 2006, J. Aleksić et al. (MAGIC Coll.), Astron. Astrophys. 519 (2010) A32
  - Simultaneous Multiwavelength Observation of Mkn501 in a Low State in 2006, H. Anderhub et al. (MAGIC Coll.), Astrophys. J. 705 (2009) 1624
  - Simultaneous Multiwavelength Observations of Markarian 421 During Outburst , V. A. Acciari et al., Astrophys. J. 703 (2009) 169
  - …

M87 Radio Galaxy



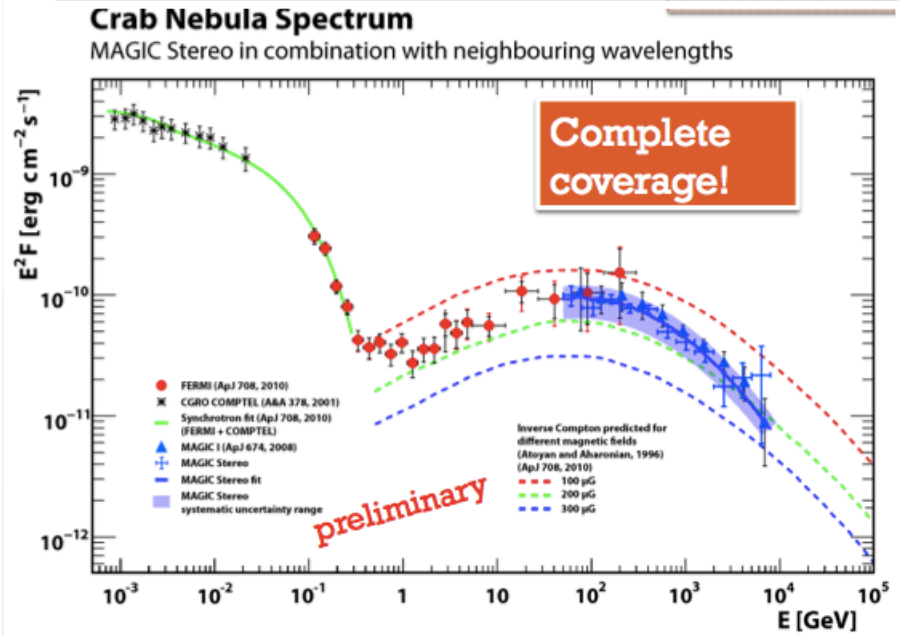
Science 325 (2009) 444

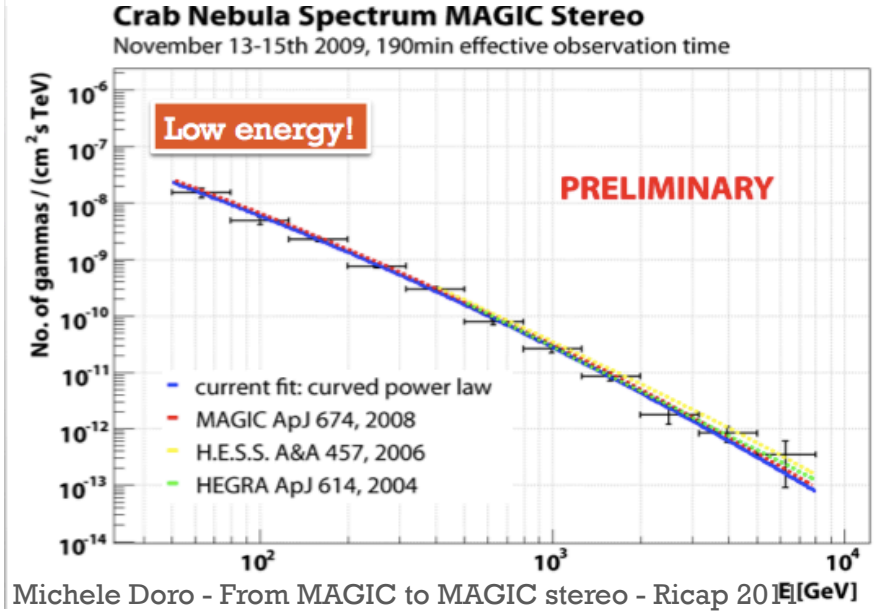


- 16.7 Mpc, ~20deg tilted jets
- Shared monitoring HESS, MAGIC VERITAS and VLBA (radio) and Chandra (X-ray) in 2007-08
- Day-scale variability at VHE
- Very interesting radio delay wrt VHE
- Acceleration should be close to black hole (not HT1 knot) but no strong clue on acceleration mechanism.

Galactics

Crab Nebula HE-VHE coverage

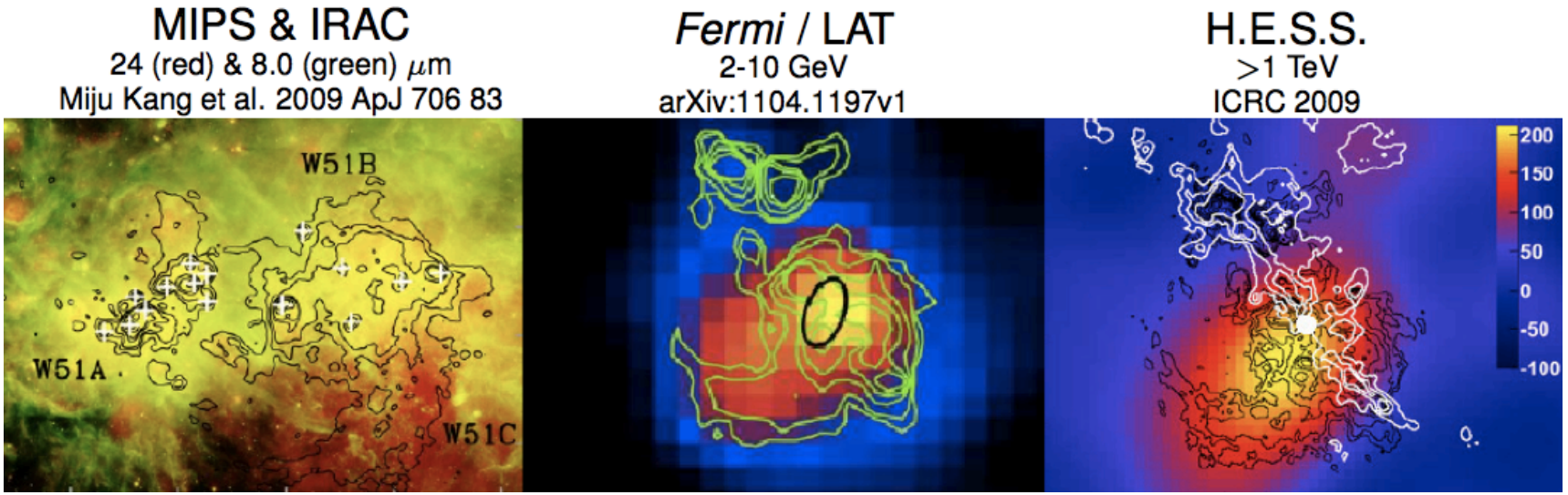




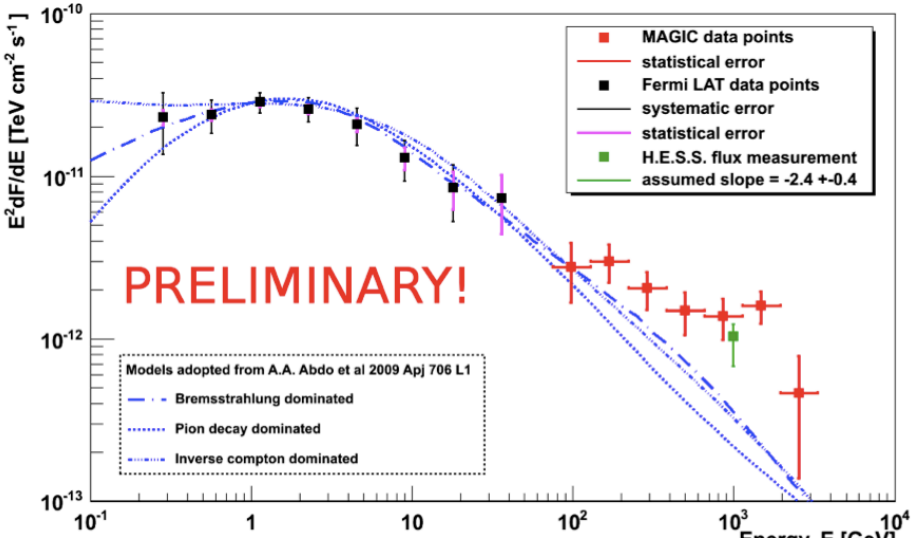
- 3.2 h of good data in Nov. 2010
- Complete overlap with Fermi
- Spectrum measured from 40-50 GeV to 30-40 TeV
- Test source for M-stereo
  - Technical Crab paper in prep.
  - Physics Crab paper in prep.
- Improved estimation of HE bump will be provided
- Regarding first HE flare (Agile, Fermi), MAGIC-stereo did not detect significant VHE flares (ATEL#2967, sep.2010)
- We monitor Fermi data for flares

+ W51SNR

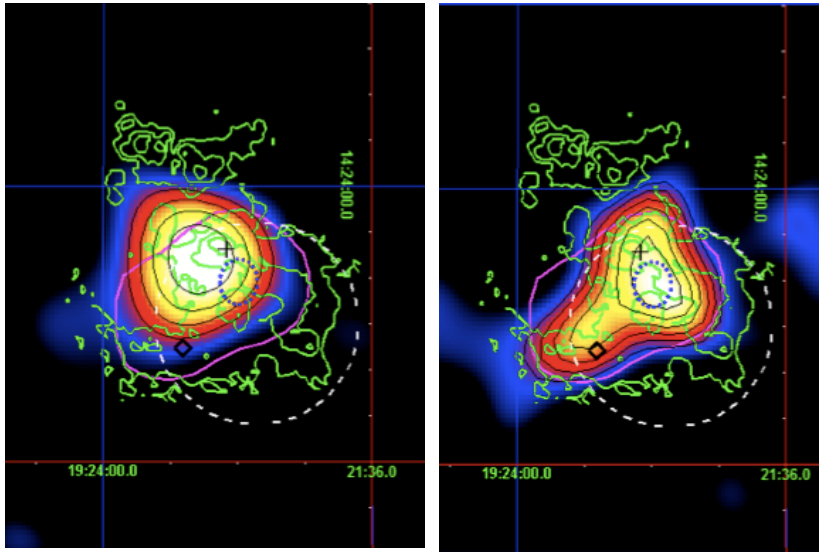
- Presented two weeks ago at Fermi symposium (Krause+)
- Paper soon released
- One of the most luminous star forming regions (distance ~ 6kpc)
- W51C is a medium age (~ 30kyr) supernova remnant interacting with the molecular clouds
- Discovered by Fermi / LAT (~ GeV) and H.E.S.S. (~ TeV)
- First extended source probing M-stereo capabilities
- Promising candidate to test and study cosmic ray acceleration in SNR's



+ MAGIC-stereo on W51



Relative Flux Maps



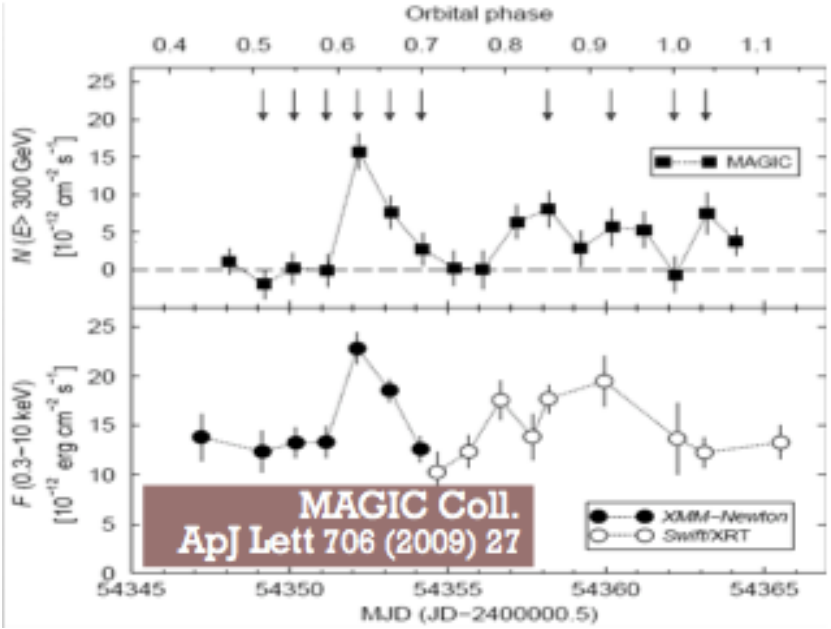
150-700 GeV >700 GeV

- Total of 31.09 h in 2010, extended emission 0.16deg , 8 σ det. > 150 GeV
- Maximum of the emission coincides with the shocked cloud regions
- Models based on Fermi / LAT + radio data predict a too softer spectrum than MAGIC sees
- Morphology suggests hadronic or other mechanisms:
  - particle spectrum hardens at high energies high
  - energy particles penetrate more effectively dense regions
  - other sources > 100 GeV

+ Binary systems confirmed at VHE

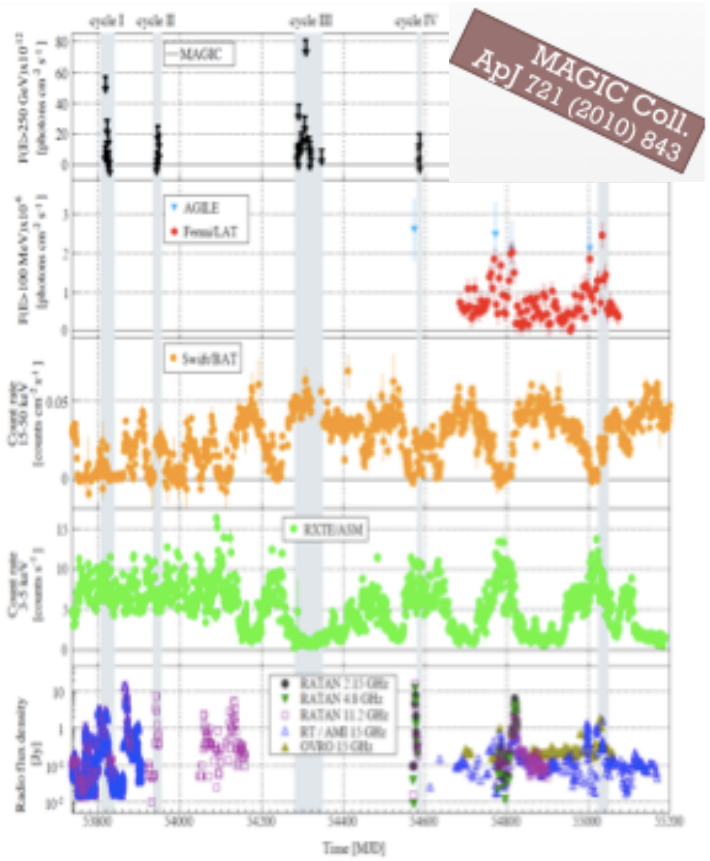
LS I +61 303

- Discovered by MAGIC in 2006 (Science 312 (2006) 1771)
- Correlation between X and VHE gamma-ray emission suggests **leptonic processes are at work.**

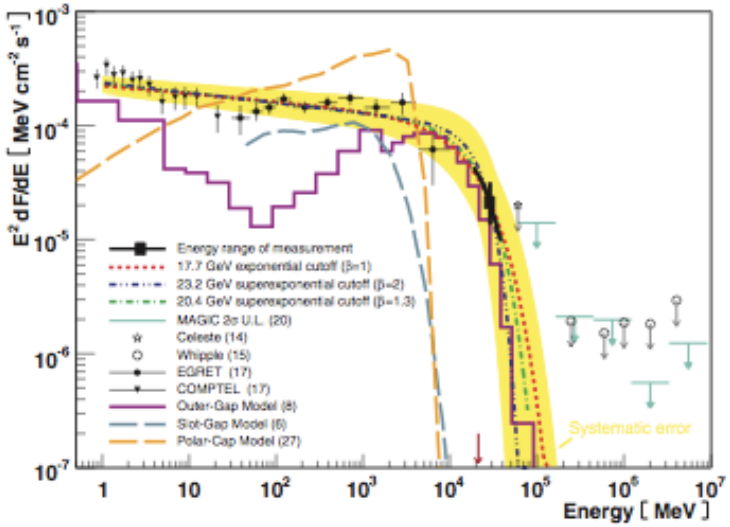


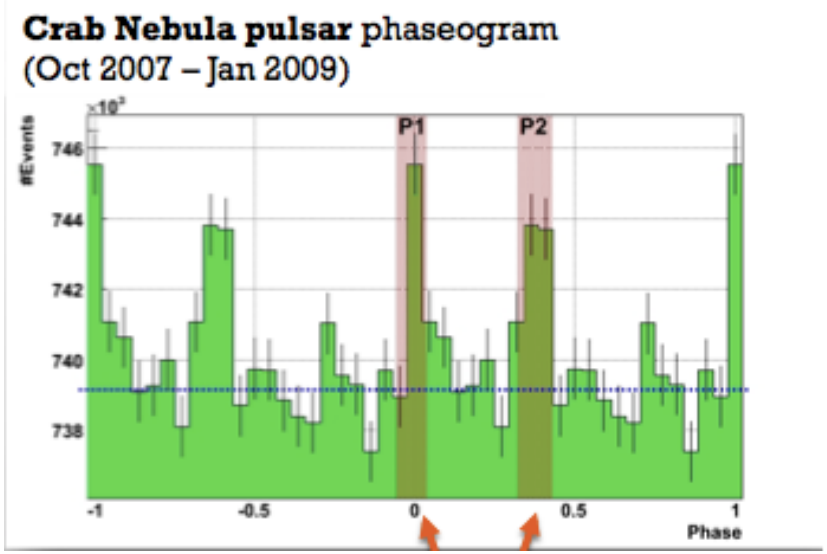
Cygnus X-3

- Large MWL efforts!
- MAGIC measured upper limits



The Crab still beats.



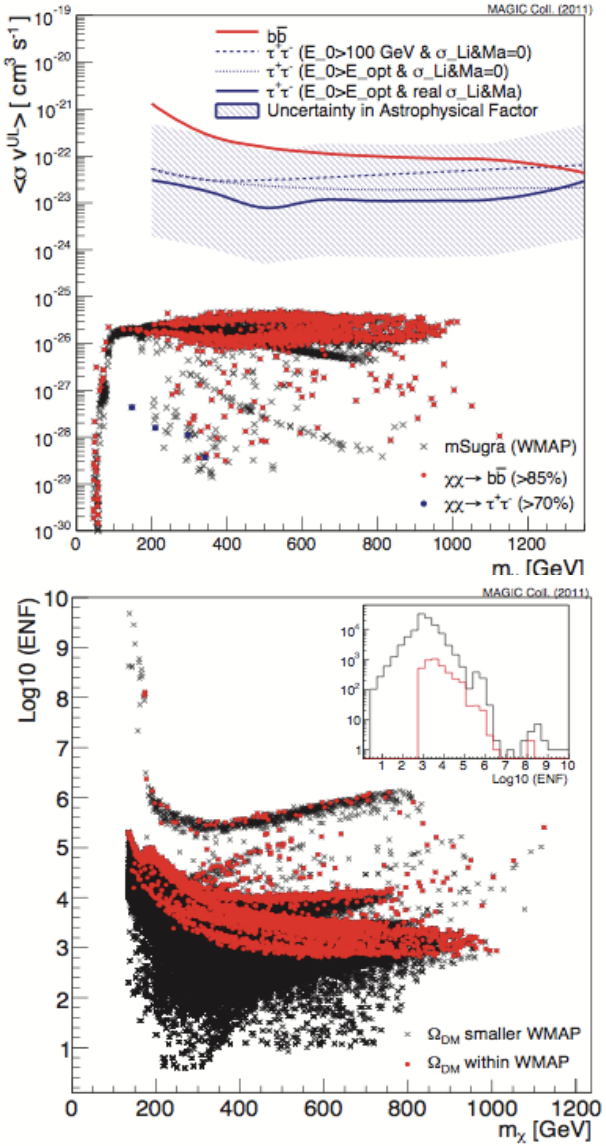


- To reach energy as low as 25 GeV special "sumtrigger" used
- In 2008, Crab pulsar detected at VHE (Science 322 (2008) 21)
- Again observed with M-stereo: publication in draft
  →see next ICRC
- Now used Fermi phaseogram rather than EGRET one
- Veritas showed here the detection above 100 GeV → see Ragan's talk

More fundamentals

$$x = \sqrt{(\log(\exp(x)))^2}$$

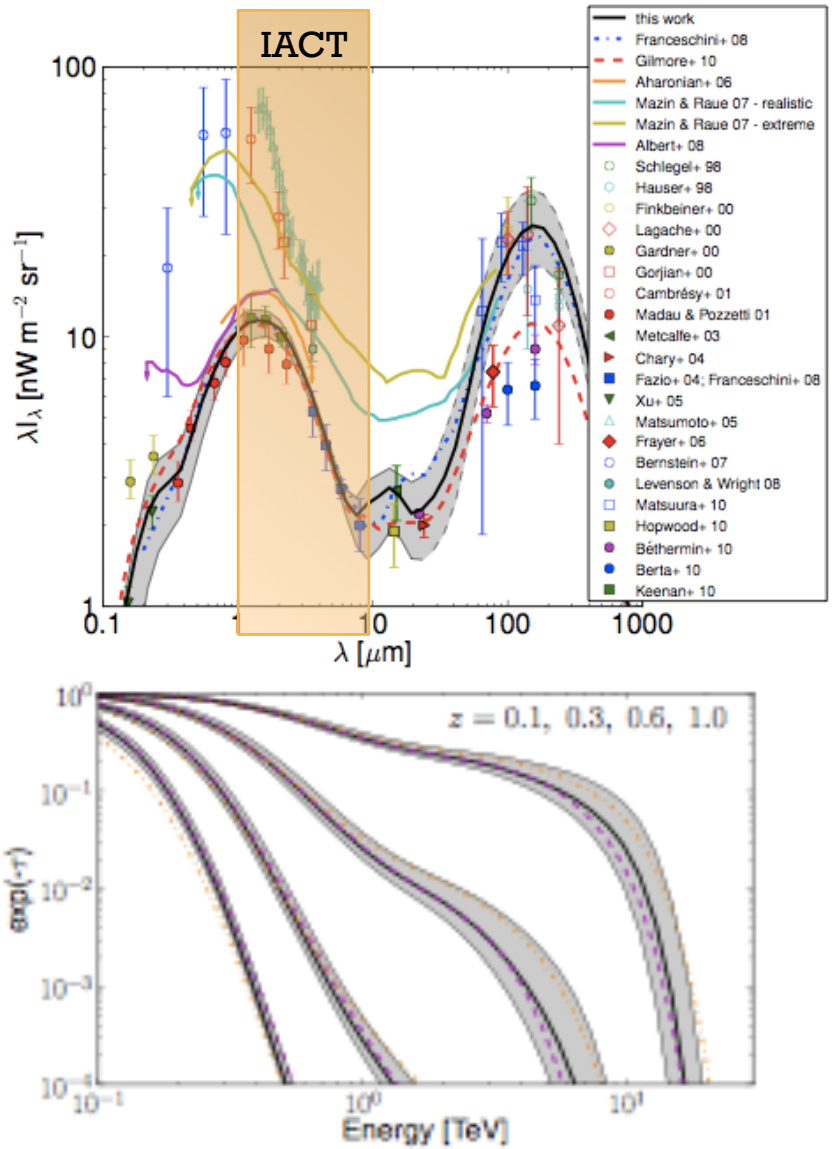
Dark Matter searches at Segue 1



- Recent publication of 30h Segue~1 data with MAGIC-1 (arxiv:1103.0477)
- Segue~1 among the best candidate for DM searches at dsph galaxies.
- Estimation of Upper Limits takes full advantage of **specific gamma-ray spectrum of each model** in a mSUGRA scan
- With current astrophysical factors of dwarf galaxy, we are 3 decades from models, but uncertainty in the astrophysical factor are high

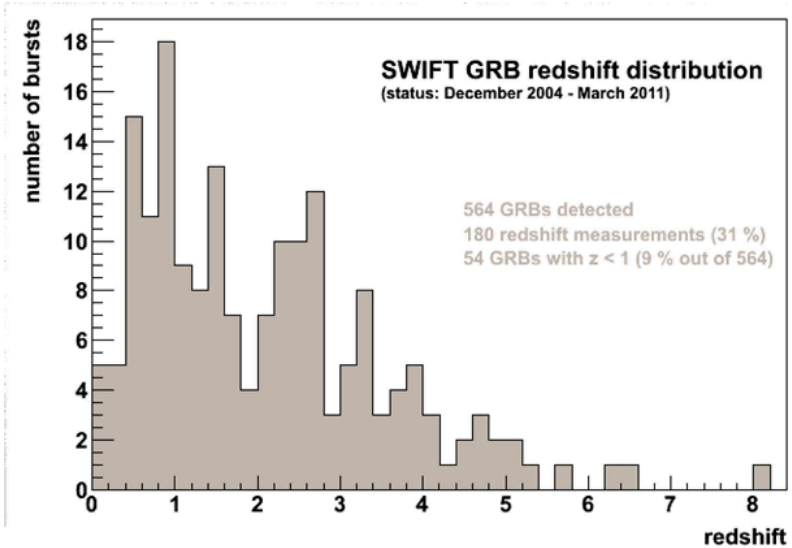
- Future?:
  - mSUGRA may be obsolete after recent direct detection experiment and evidence for low mass WIMP…
  - maybe we can find new ultra-faint denser objects…
  - It is anyhow worth trying to look into the dark…

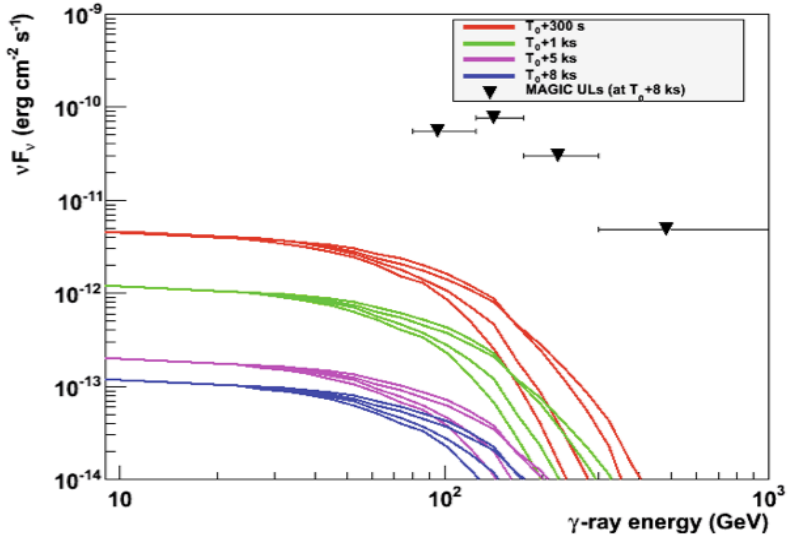
Gamma-ray horizon



- VHE gamma-ray interacting with UV and far-IR photons, may pair produce:
  - Optical depth $\tau=\tau(E,z)$
- Distant AGNs are optimal targets (if distance is known):
  - 3C279 (z=0.536)
  - 3C66A (z=0.444?)
  - PG1553+113 (z=0.4)
  - S5 0716+714 (z=0.310?)
  - …
- Absorption above 100 GeV makes observed spectrum:
  - Softer (steeper)
  - Difficult to observe
- IACT observation already constrained models to their minimum allowance (universe is more transparent)
- Distant AGNs are monitored by M-stereo (PG1553, 3C279)

+ GRBs





- Alerts from Swift & Fermi through GCN alert system
  - 10 alerts/month
  - 1 follow-up/month
  - (6 prompt emission/year)
- Challenges:
  - GRB must not be too far: 9% of GRBs have z<1
  - Prompt emission: we first move the telescope and then check the GRB detail
- Results:
  - In general poorly constraining
  - Detection need luck and persistance.

Conclusions

+ Never stop getting better

Hopefully on solid grounds!

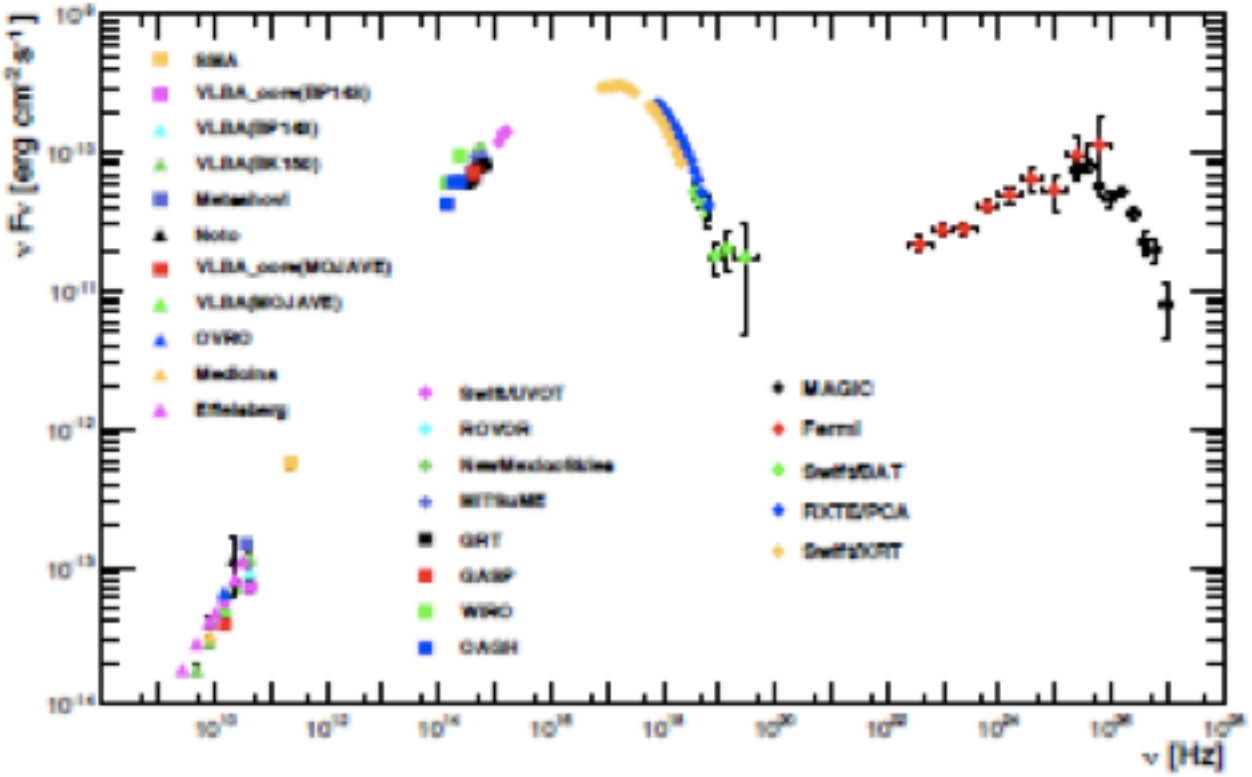
- MAGIC-I (>2003)
  - a challenging experiment → proof of techniques
  - big reflector size → lowest energy threshold of present IACTs at 70GeV (Crab)
  - Timing analysis based on 2GhZ electronics successful
- MAGIC-II (>2009)
  - Many technological improvements compared to MAGIC-I (a twin but not a clone)
- MAGIC-stereo (>2009)
  - Increase sensitivity
  - Also better angular and energy resolution
  - Now possible to study extended sources
  - Energy threshold at ~40-50 GeV (Crab)
- Future plans (>2011-12):
  - Upgrade M-1 camera and readout with (improved) M-II technology
  - To stabilize experiment and homogenize the detectors

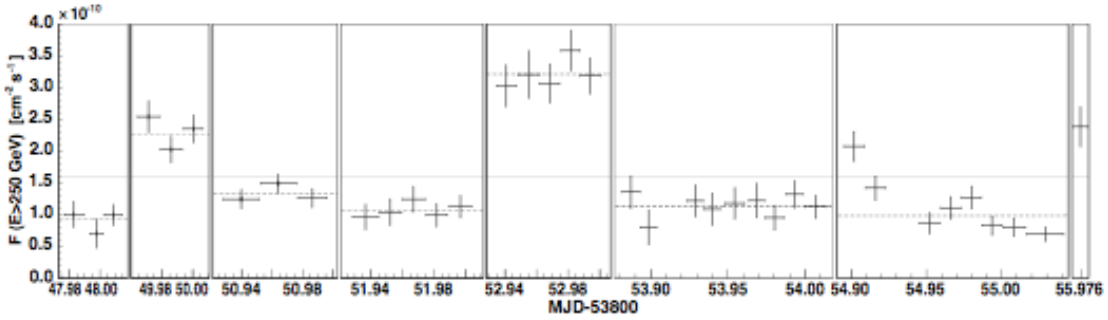
+ Physics

- Extragalactic:
  - Low energy threshold allows for observation of distant blazar (and EBL monitoring)
  - Optical trigger proven successful → many ATELs
  - Multi-wavelength campaigns also proven successful and allow nice physics; now need of denser coverage (mrk421, mrk501, M87)
  - Radio-galaxy catalog increases with IC310
  - PKS1222 sets discussion to acceleration models
- Galactic
  - MAGIC-stereo allow morphological search on SNR W51, maybe probing hadronic acceleration mechanisms
  - Crab spectrum is covered over 3+ decades (close to "IC-peak")
  - Crab pulsed emission is confirmed
- Fundamentals
  - EBL models at minimum in UV, near-IR thanks to IACT
  - Dark Matter is really dark!
  - GRB are challenging too!

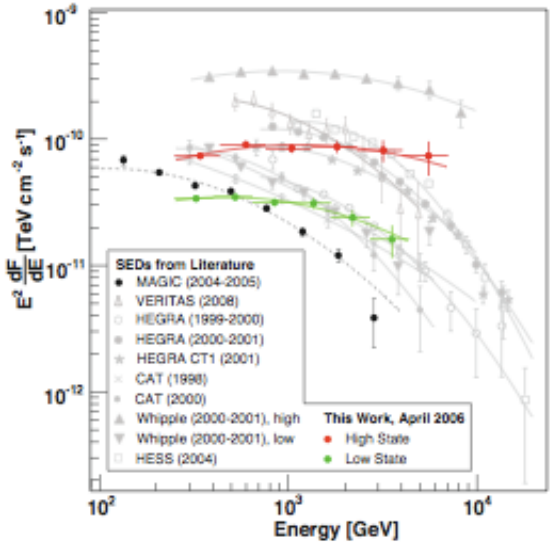
Backup slides

Broadband radio-TeV Mrk421

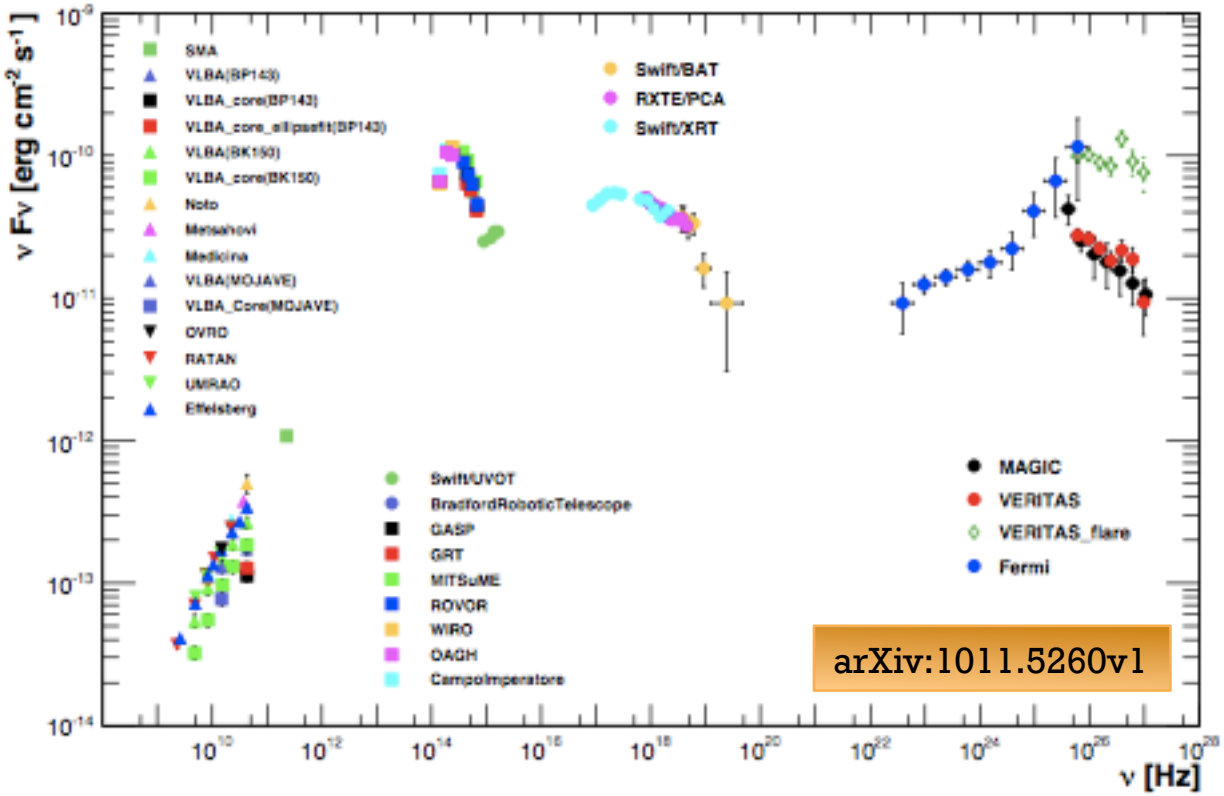




- 4.5 months campaign
- Most complete SED ever collected for Mrk421
- Total Fermi-MAGIC overlap over 5 decades in energy!
- HE-VHE connection!



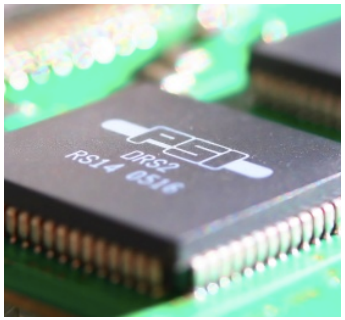
Broadband radio-TeV Mrk501



- Most complete SED ever collected for Mrk501
- Total Fermi-MAGIC overlap over 5 decades in energy!

+ MAGIC-II for MAGIC-stereo

- MAGIC-II features many technological improvements:
  - Domino Ring-Sampler chips
  - Calibration with laser
  - Pixels and the camera
  - Improved AMC adjust
  - 2GhZ readout



+ Optically triggered results

- Make a list of ATEL, publications and shortly discuss results

+ Recent MAGIC results (M-stereo)

EXTRAGALACTIC

- Flat spectrum radio quasars
  - 3C279
  - PKS 1222+21
- Optically triggered discoveries
  - Mrk180, 1ES1011+496, S50716+714, B3 2247+381 ATEL#2910, ON 325 (1ES1215+303) ATEL#3100, 1ES 0806+024 ATEL #3192
- MWL campaigns on Mrk421, Mrk501, M87
- Region of the Perseus cluster of Galaxies
  - NGC1275
  - IC310 (Head-tail radio galaxy)

GALACTIC

- Cygnus X-3
- G65 (0FGL-J1954.4)
- Scorpius X-1
- HESS J0632+057: clear detection (ATel).
- Crab Nebula

FUNDAMENTAL PHYS.

- Dwarf galaxy (Segue1)
- Perseus cluster deep studies
- GRBs