Monitoring of the radio galaxy M87 at Very High Energy with MAGIC during a low emission state between 2012 and 2015

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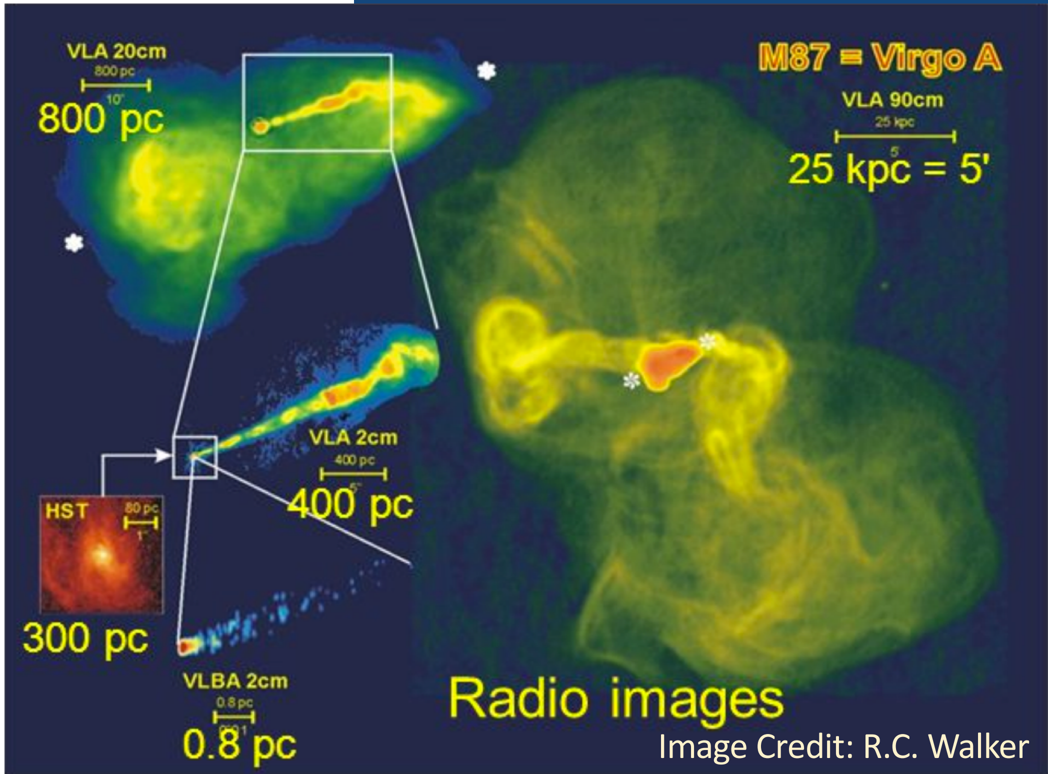
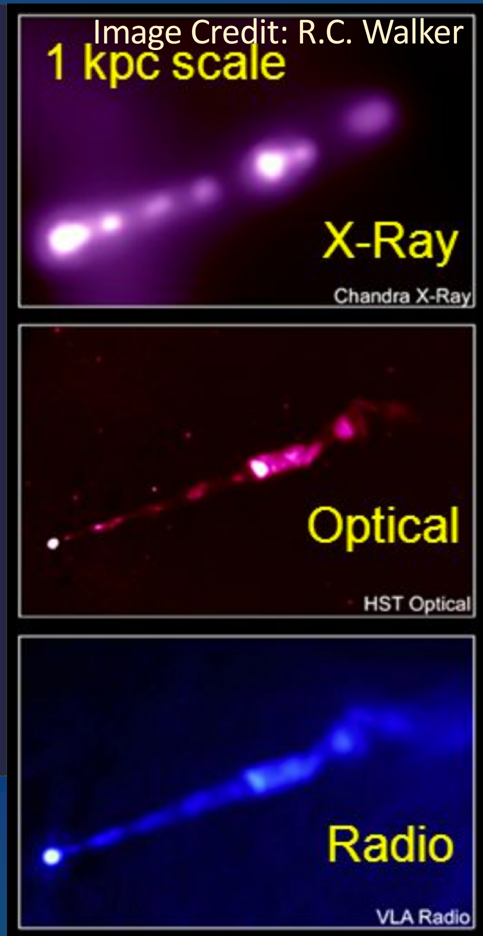
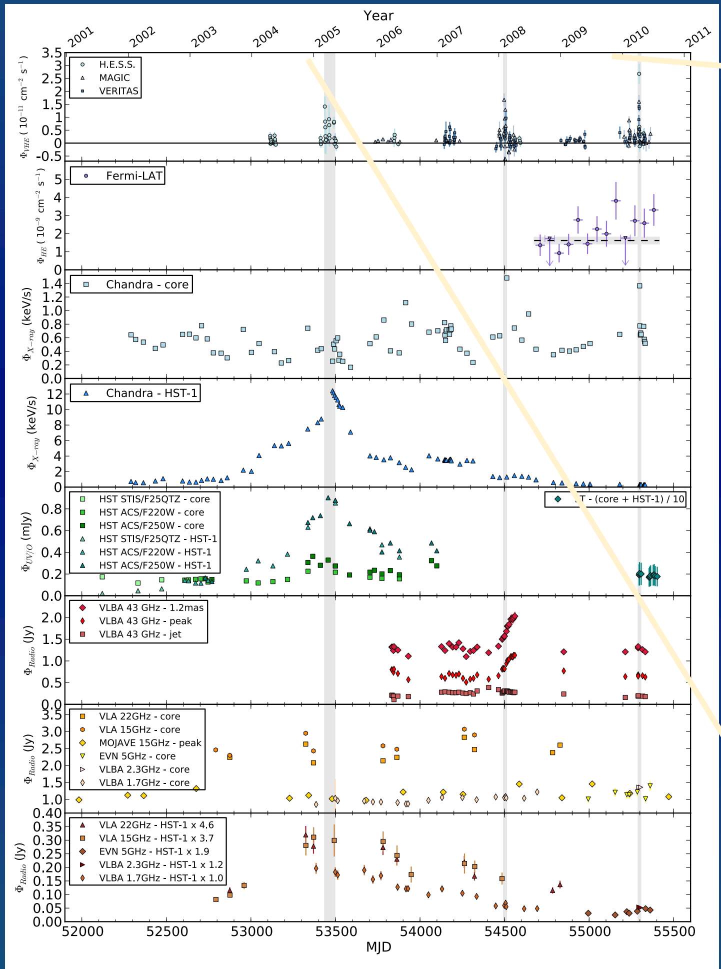
Messier 87

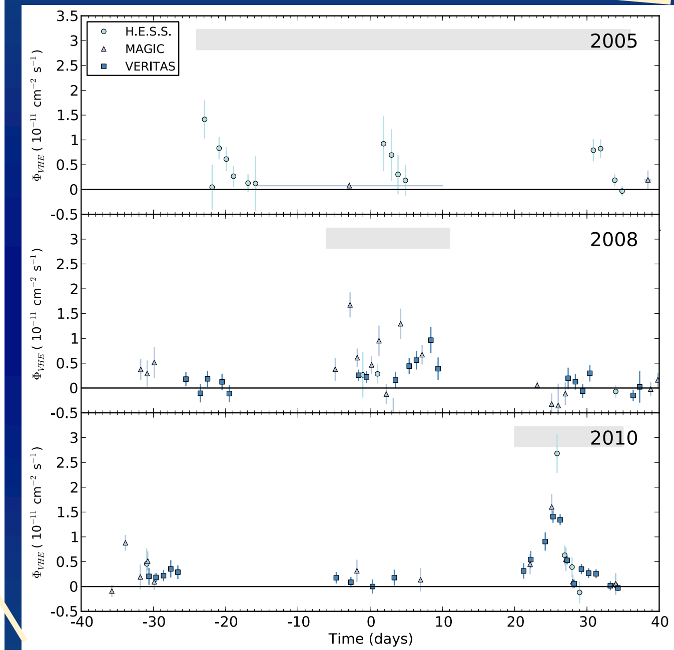




- Nearby radio galaxy (16.4 Mpc) in the Virgo cluster
- Based on gas-dynamical/ stellar-dynamical modeling central black hole with $M_{BH} \simeq (3\text{-}6) \times 10^9 M_\odot$ (*Walsh et al. 2013, ApJ, 770, 86*;*Gebhardt et al. 2011, ApJ, 729, 119*)
- Jet inclined by 5°-15° w.r.t. to observer's line of sight
    - First discovered AGN jet
    - Excellent laboratory to study formation processes of relativistic jets/high energy particls
- Highly structured jet, knots resolved in radio, optical and X-rays
- Jet is variable: flares in radio, optical and X-rays
- Monitoring for 10 years from radio to VHE (E > 100 GeV) gamma rays

M87 in VHE gamma rays





Abramowski et al., 2012, ApJ, 746, 151

3 flares

- 2005 (H.E.S.S.); Radio/optical/X-ray/TeV emission
- 2008 (MAGIC & VERITAS); Radio/X-ray/TeV emission
- 2010 (H.E.S.S., MAGIC & VERITAS); X-ray/TeV emission
- Variability of timescales of days constrains possible sites to compact emission (R ~ 10^{15} cm)

Recent VHE gamma-ray observations

MAGIC telescopes

- Stereoscopic system of two 17 m diameter Imaging Atmospheric Cherenkov Telescopes
- Energy threshold 50 GeV
- Integral sensitivity of 0.6% Crab Nebula in 50 of observations for E > 250 GeV (see *Aleksić et al. 2016, AP, 72, 76* for details*)*

Observations 2012-2015

- Visibility from December to July at the MAGIC site
- 156 h of data
- 15° - 50° Zenith range
- Observations carried out under moderate moon light requiring non-standard analysis and higher energy threshold
- Significant detection in each year

Year	T_{eff} [h]	Significance (E>300 GeV)
2012	38.8	**5.4 σ**
2013	34.8	**8.8 σ**
2014	49.9	**7.3 σ**
2015	32.7	**6.0 σ**

VHE gamma-ray light curves

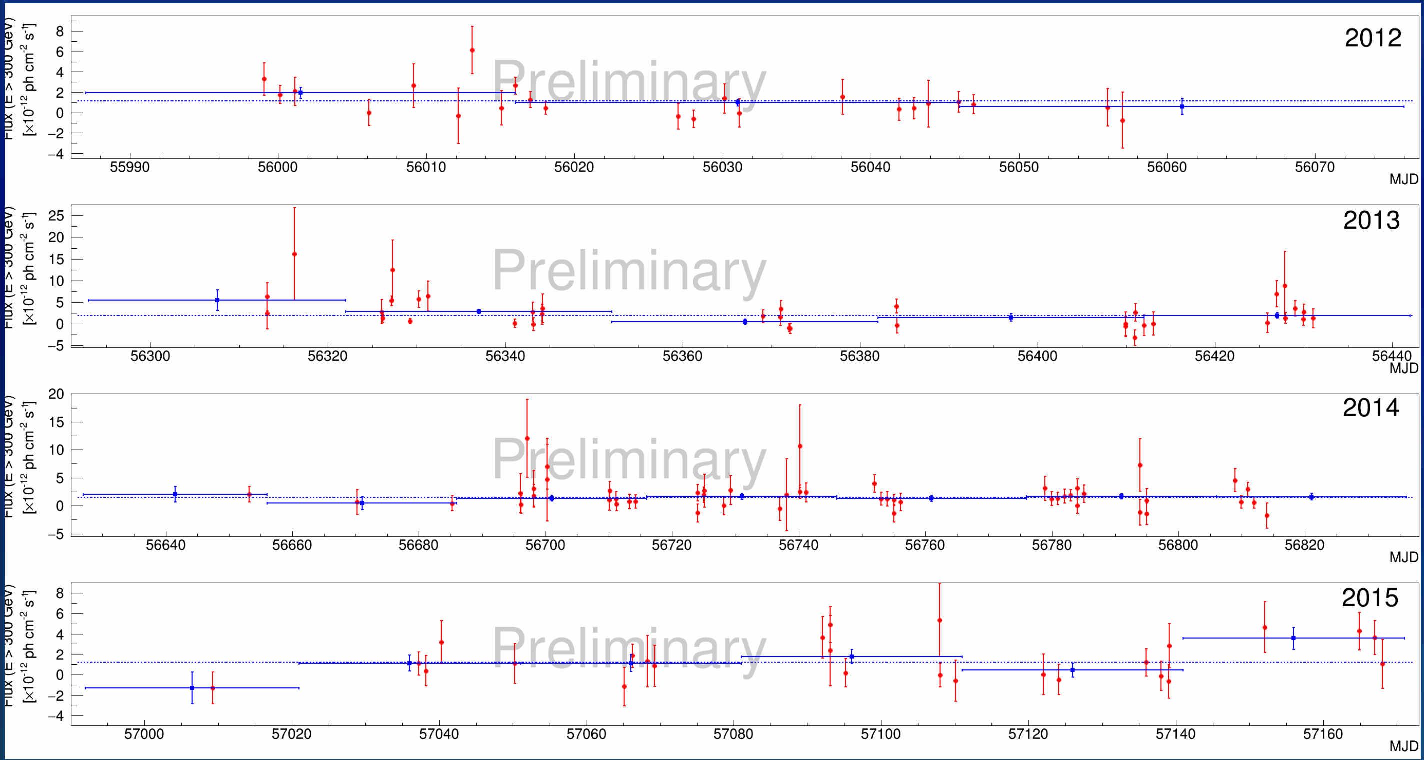
Year	$F_{E>300\ GeV}$ [10^{-12} cm^{-2} s^{-1}]
2012	1.16 ± 0.25
2013	1.88 ± 0.30
2014	1.49 ± 0.23
2015	1.21 ± 0.34
2012-2015	1.42 ± 0.13

PRELIMINARY

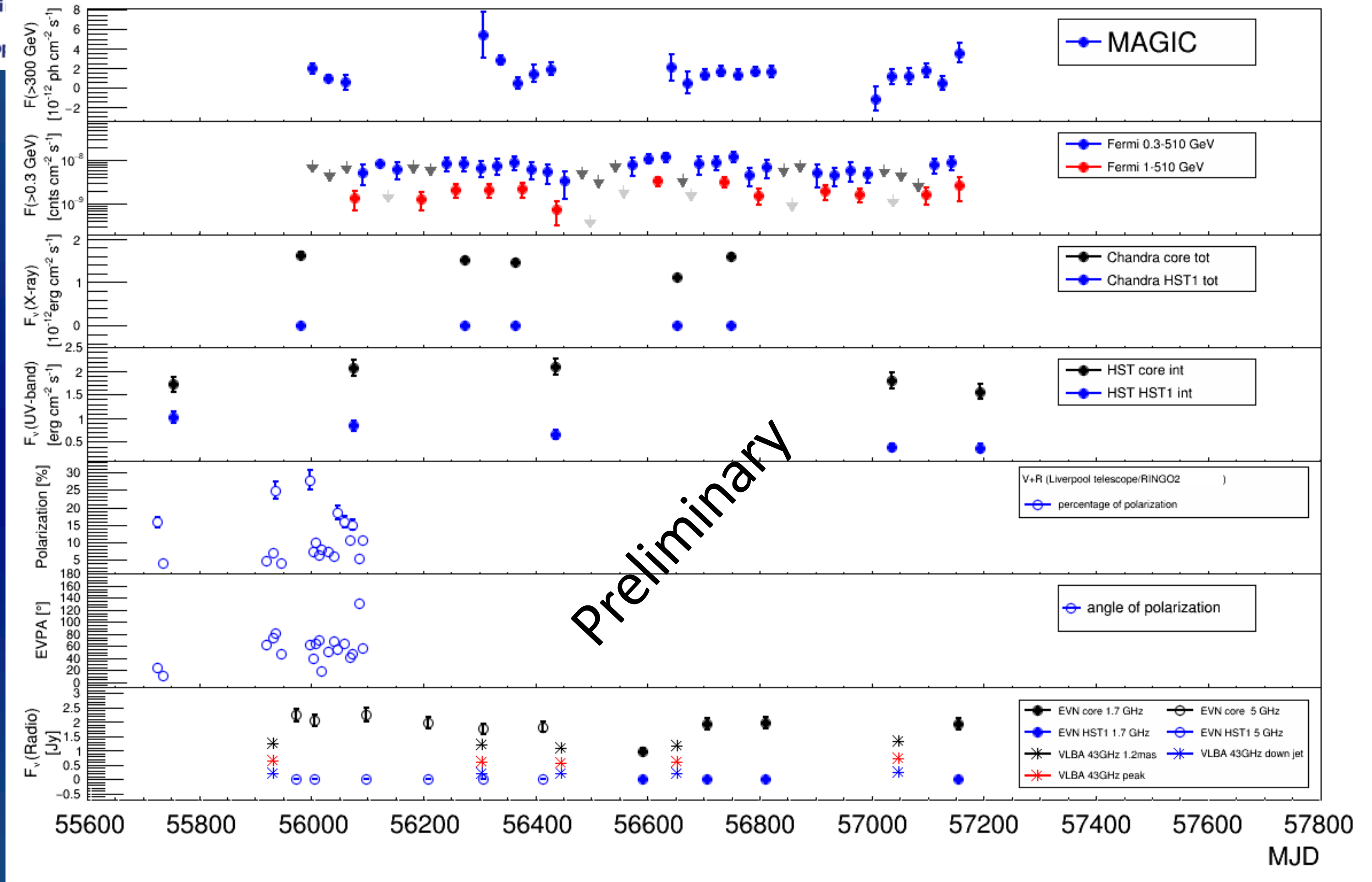
Year	$F_{400\ GeV<E<1TeV}$ [10^{-12} cm^{-2} s^{-1}]
2004 (H.E.S.S.)	0.51 ± 0.19
2005 (H.E.S.S.)	1.97 ± 0.03
2005-2007 (MAGIC)	0.90 ± 0.20
2007 (VERITAS)	1.31 ± 0.26
2008 (MAGIC)	5.09 ± 0.72
2010 (VERITAS)	7.82 ± 0.56
2012-2015 (MAGIC)	0.74 ± 0.06

PRELIMINARY

- No variability between 2012 and 2015 on daily and monthly timescale (E > 300 GeV)
- Lower emission state w.r.t. to flaring epochs (2005 H.E.S.S.; 2007; 2008; 2010)



MWL light curve

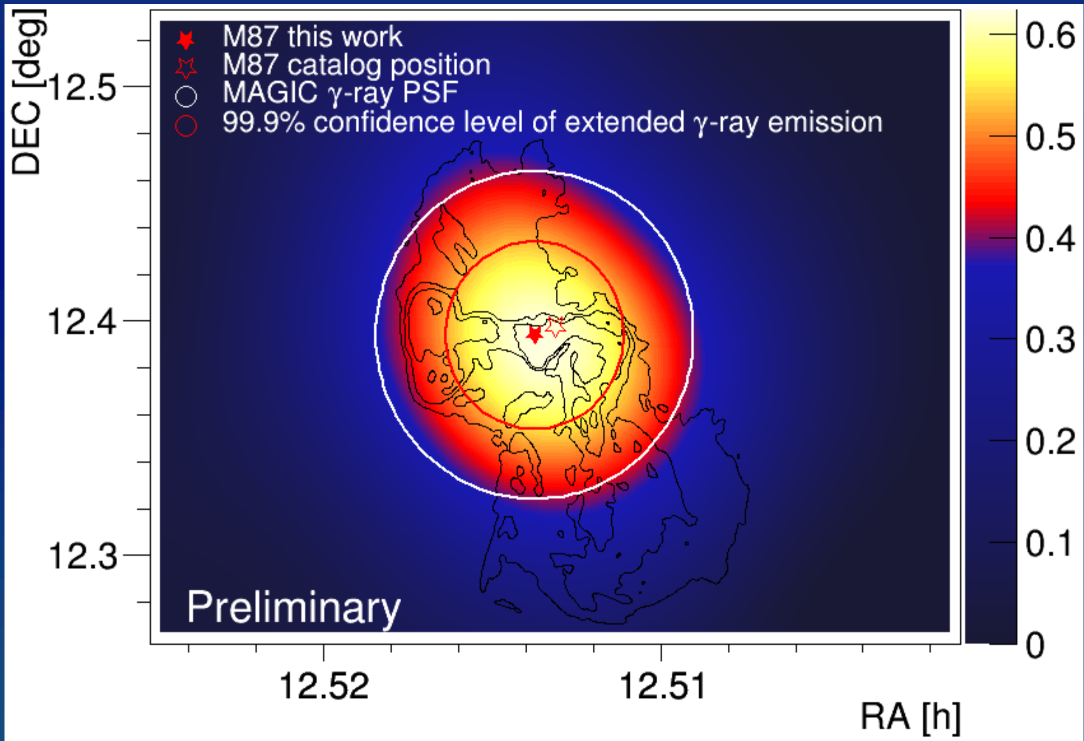


- Low emission state of radio core and HST-1 knot in all observed wavebands

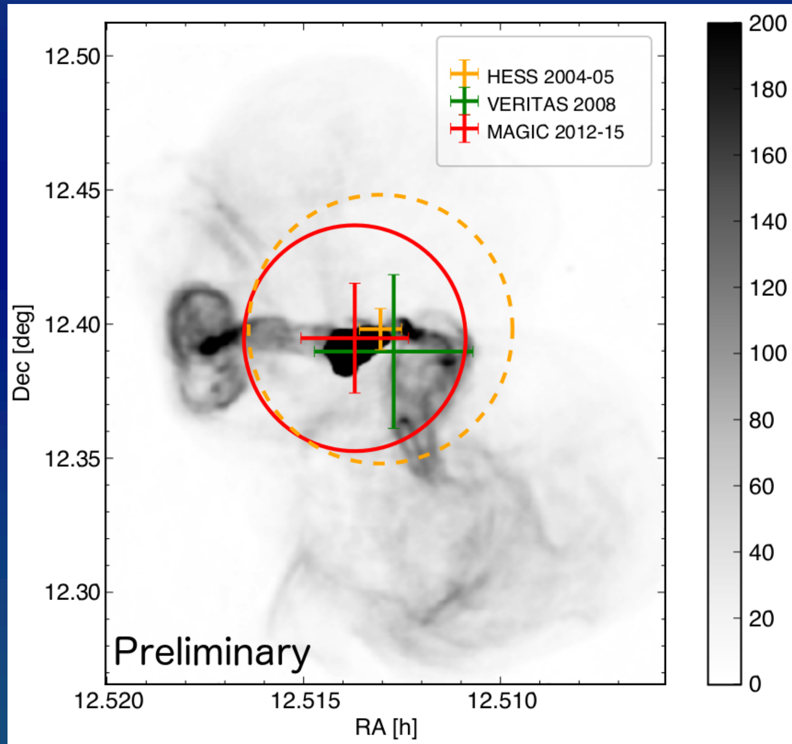
Morphology

- Low state VHE gamma-ray emission from a region close to the radio core?
- Same site from which VHE emission was previously observed.

Relative flux map in C.U. (MAGIC)

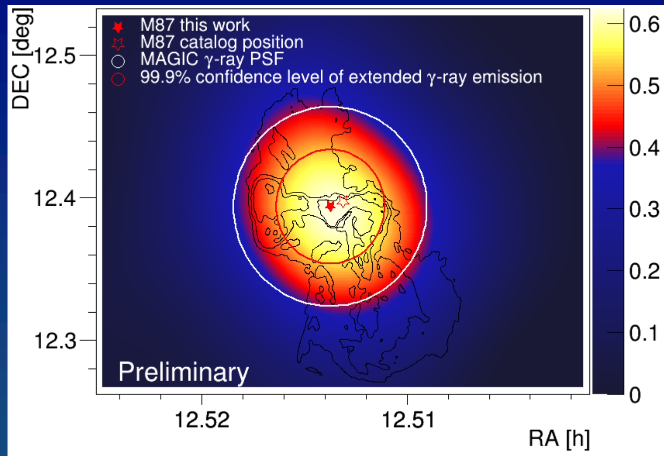


Radio map in a.u.



Summary

- M87 is a known gamma-ray emitter (since 2004)
- After 3 major flares (2005, 2008, and 2010) MAGIC continued monitoring of M87, with about 40 h per year.
- Here we showed results from 2012 to 2015 campaigns
- Source is clearly detected on monthly basis but no flaring activity detected
- Multiwavelength picture remains stable in the last 5 years
- From the VHE sourcemorphology TeV gamma rays seem to come from the same (or close by) site as during previous flares
- Good match between *Fermi*-LAT and TeV data: power law over 5 decades in energy
- Simple homogeneous SSC model cannot describe all the data well; needs to be pushed to a much more extreme parameter regime for that.
- Having more parameters, hadronic model provides better fit to the broadband SED



BACKUP

Model parameters

	γ_{min}	γ_{max}	ν_{min} [Hz]	ν_{max} [Hz]	r_{acc} [cm]	r_{rad} [cm]	$D_{Fermi\ II}$	η	$\eta_{scaling}$	B [G]	proinject [particles/s]	proinjectgamma	elinject [particles/s]	elnjectgamma	compression ratio	shock speed	δ
SSC case	2	2×10^{8}	1×10^{30}	1×10^{10}	1×10^{12}	4.2×10^{15}	0	10	1	0.15	0	10	2.94×10^{43}	2000	3.65	0.1	1.966
Hyb. case	1	1×10^{12}	1×10^{10}	1×10^{36}	3.5×10^{13}	3×10^{16}	0	1	1	3	8.77×10^{42}	10	2×10^{40}	10000	3.5	0.1	5.32