Monitoring of the Radio galaxy M87 during a low emission state from 2012 to 2015 with MAGIC and *Fermi*

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and

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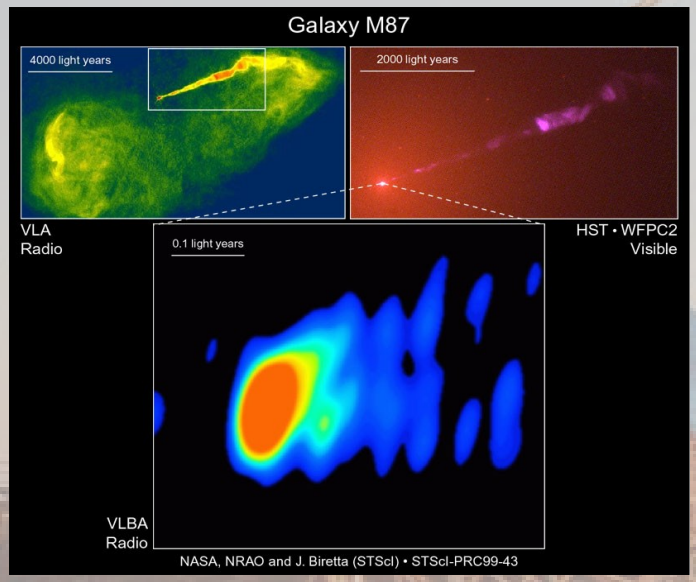
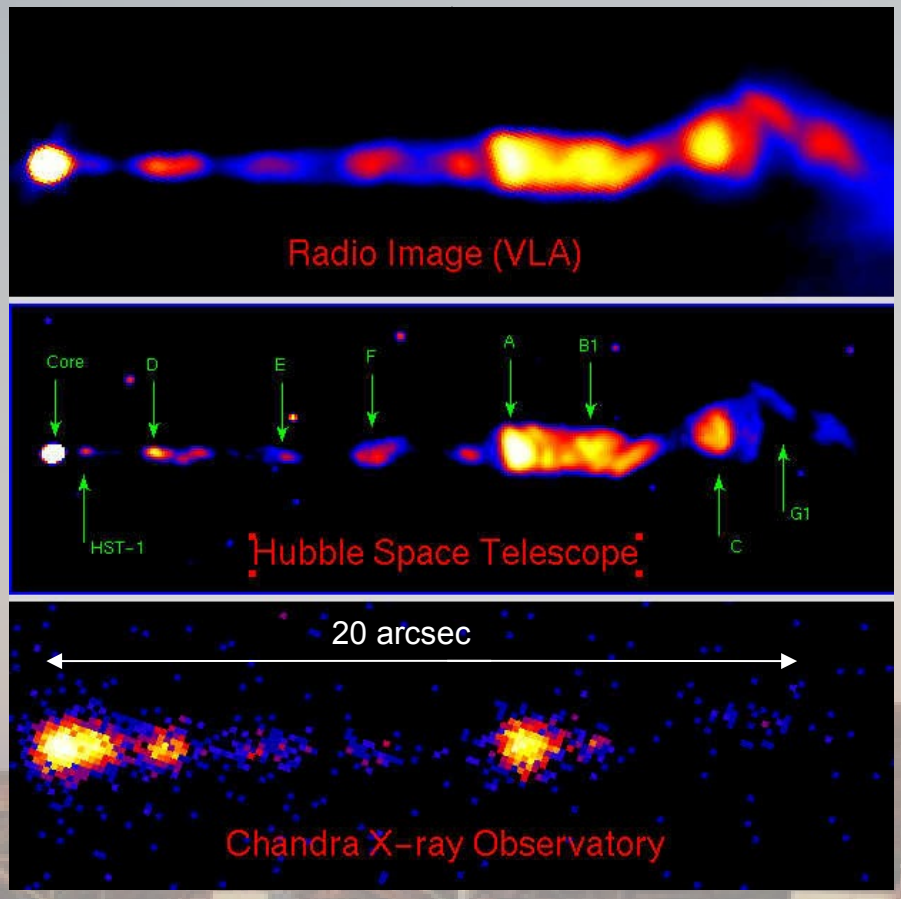


6th *Fermi* Symposium, Washington DC

10th Nov. 2015

Introduction

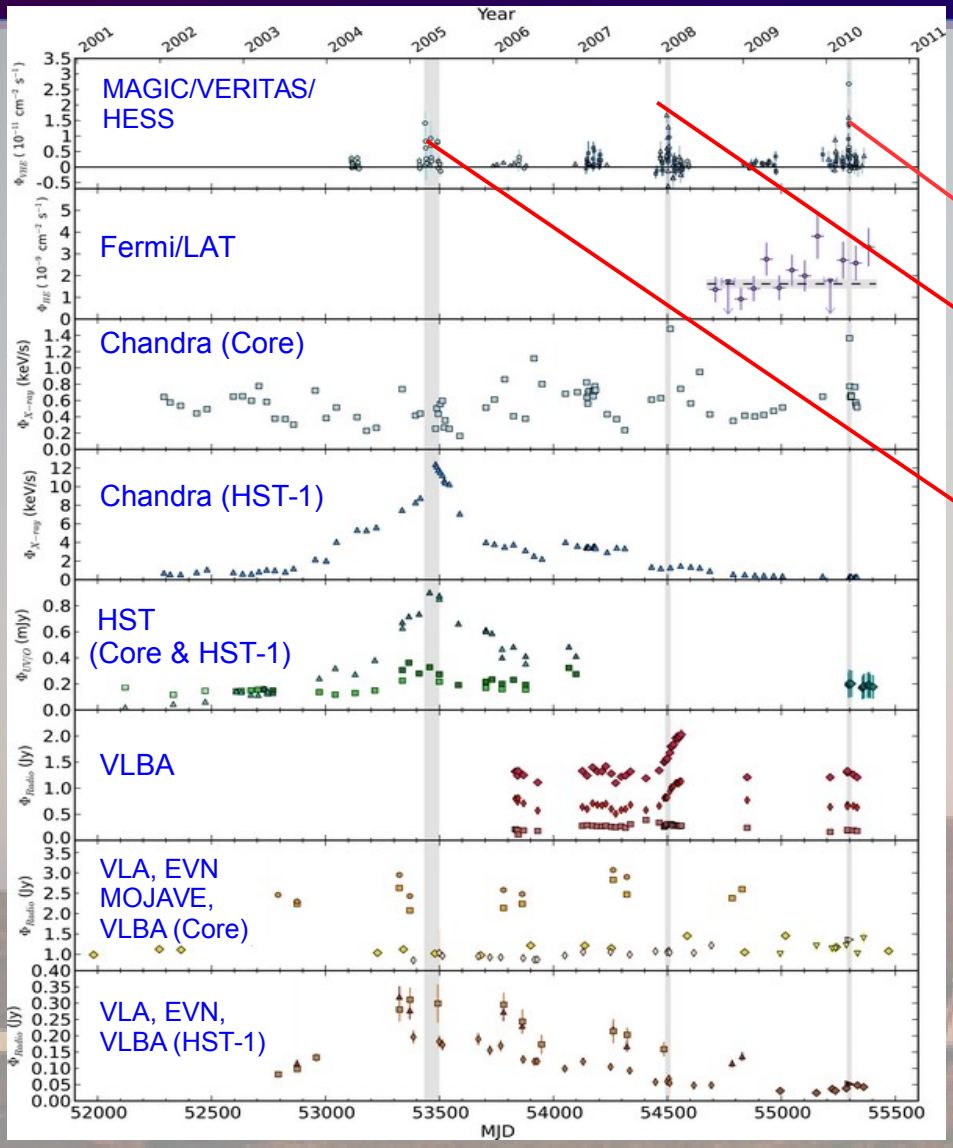
MAGIC PSF (68% containment) : 201”



Credit: X-ray: NASA/CXC/MIT/H.Marshall et aal.,
Radio: F.Zhou, F.Owen (NRAO), J.Biretta (STScI),
Optical: NASA/STScI/UMBC/E.Perlman et al.

- **First radio galaxy detected at TeV**
  [HEGRA, Aharonian et al., A&A, 703 (2003)]
- **Distance ~ 16.7 Mpc**
  [Mei et al., ApJ, 655, (2007)]
- **Jet inclined (10º – 45º) with respect to our line of sight**
  [Biretta et al., ApJ, 520 (1999), Ly et al., ApJ, 660 (2007)]
- **Central black hole: M_{BH} ~ (3-6) x 10^9 M_{sun}**
  [Macchetto et al., ApJ, 486 (1997),
  Gebhardt & Thomas, ApJ, 700 (2009)]
- **Highly structured jet resolved in radio, optical and X-rays**
- **Proximity of M87 makes it unique laboratory for detailed study of different parts of the jet**

Possible sites for VHE emission



10-year multi wavelength light curve
[Abramowski et al., ApJ, 746, (2012)]

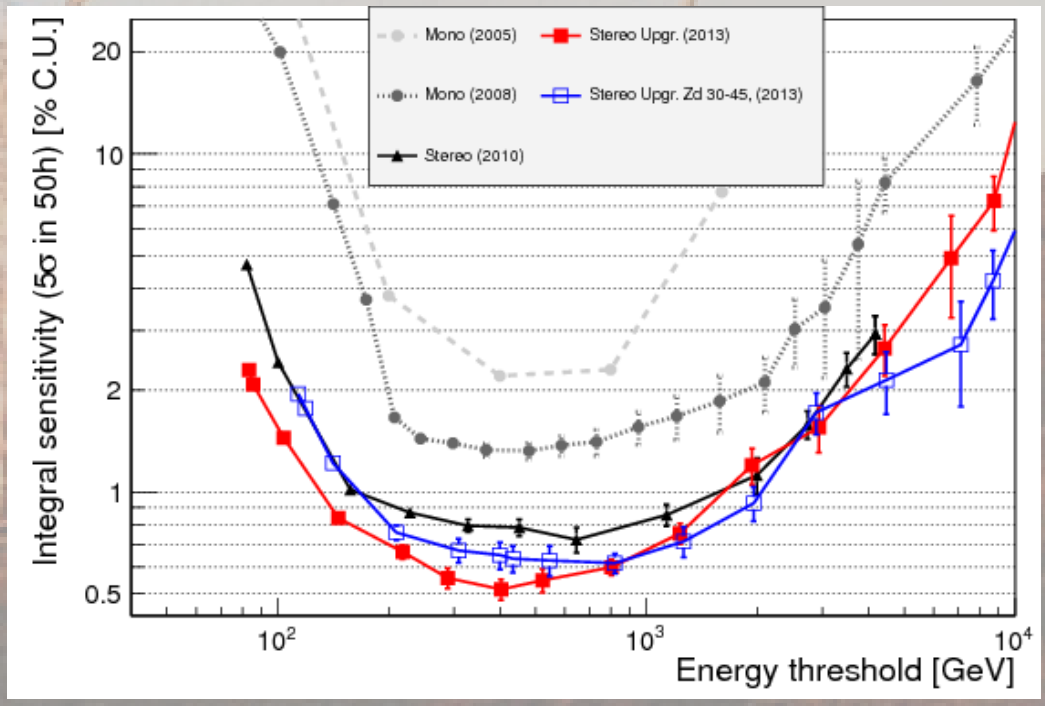
- **Short term variability (short as a day) places strong constraints on possible sites**
  [Aharonian et al., Science , 314, (2006)]
  - **The Core Region:**
    - **2010 X-ray/TeV event**
      [Abramowski et al., ApJ, 746, (2012)]
    - **2008 Radio/X-ray/TeV event**
      [Acciari et al., Science, 325 (2009)]
  - **The HST-1 knot:**
    - **2005 Radio/X-ray//TeV event**
      [Stawarz et al., MNRAS, 370, (2006), Cheung et al., ApJ, 663, (2007), Harris et al., ApJ, 699, (2009)]
- **Most of the spectral modeling was done to interpret high or flaring states**
- **Thus it is important to study the quiescent or low (baseline) emission state in order to understand the flare**

MAGIC Telescopes

- Stereoscopic system of two 17 m diameter Imaging Atmospheric Cherenkov telescopes (IACTs)
- Location: La Palma, Canary Islands (28.75ºN, 17.86ºW, 2200 m asl)
- Energy threshold 50 GeV

- Integral sensitivity: (0.66 ± 0.03) % Crab Unit above 220 GeV in 50 hours
- Energy resolution ΔE/E ~ 16%
- Angular resolution: 0.07º

[Aleksić et al., Astropart. Phys, 72, (2016)]



10 Years VHE Monitoring with MAGIC

- Monitoring started in 2005
- 2005-2007 low emission state [Aleksić et al., A&A, 544, (2012)]
- Flare in 2005 (observed only by HESS, missed by MAGIC), 2008 and 2010 (observed by MAGIC, VERITAS and HESS) with rapid variability as short as a day [Acciari et al., Science, 325 (2009), Abramowski et al., ApJ, 746, (2012)]
- No flare since 2010
- Monitoring continues with MAGIC (~ 40hrs/year)
- Here we present results from 2012-2015 MAGIC data

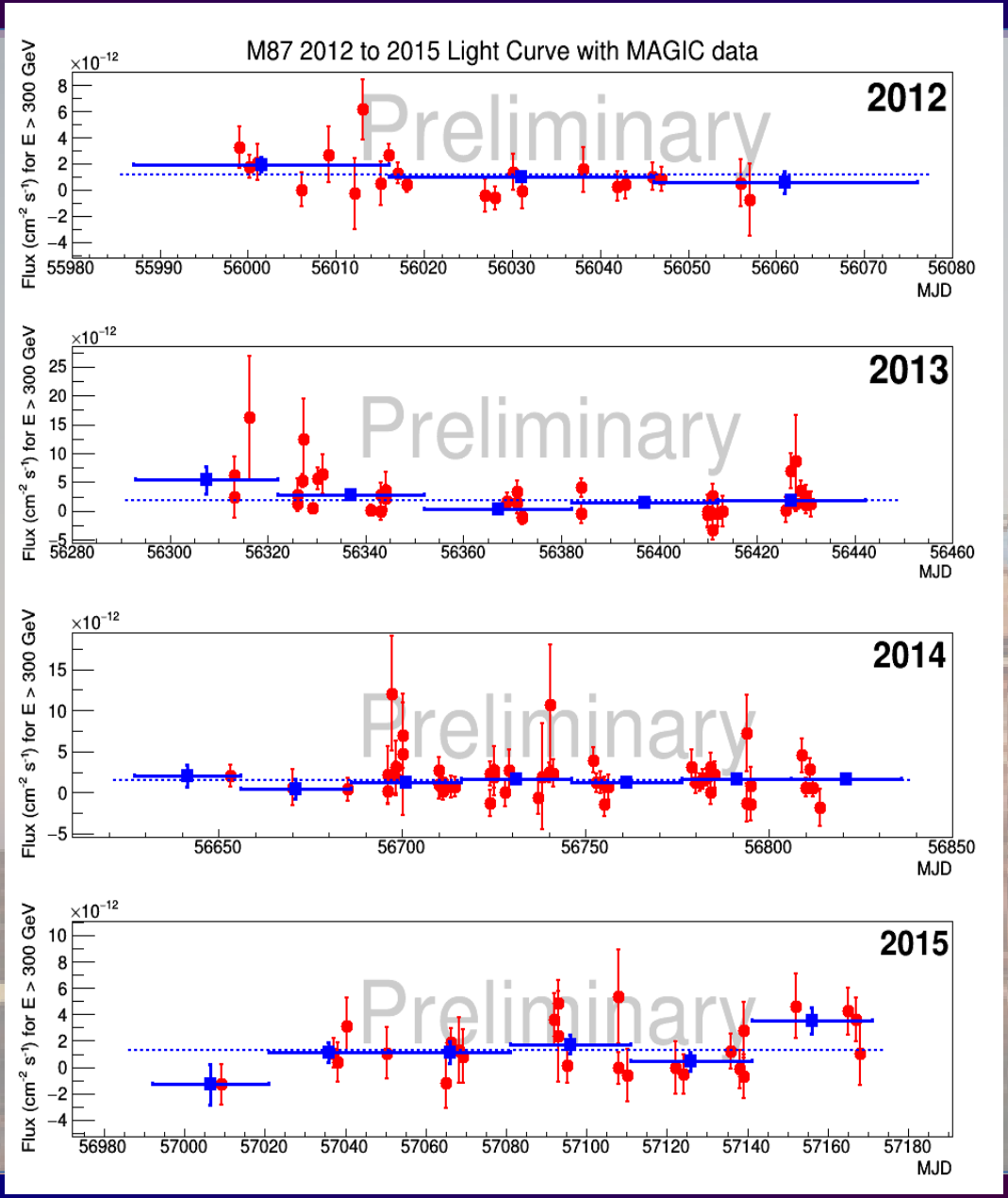
M87 Observations with MAGIC

- Observations: 2012 to 2015
- Visibility from La Palma: Dec. to July
- Data taking ~ 156 hrs (after quality cuts)
- Zenith range 15º - 50º

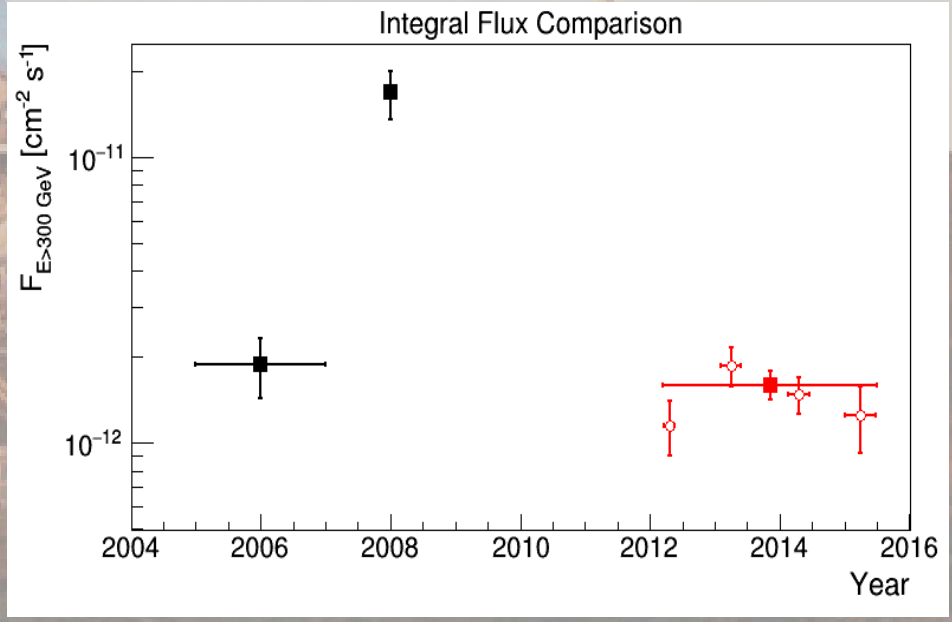
Year	T_{eff} [h]	Significance [σ]
2012	39.1	5.4
2013	34.8	8.8
2014	49.9	7.3
2015	32.7	5.9

MAGIC detected M87 in every year between 2012 and 2015

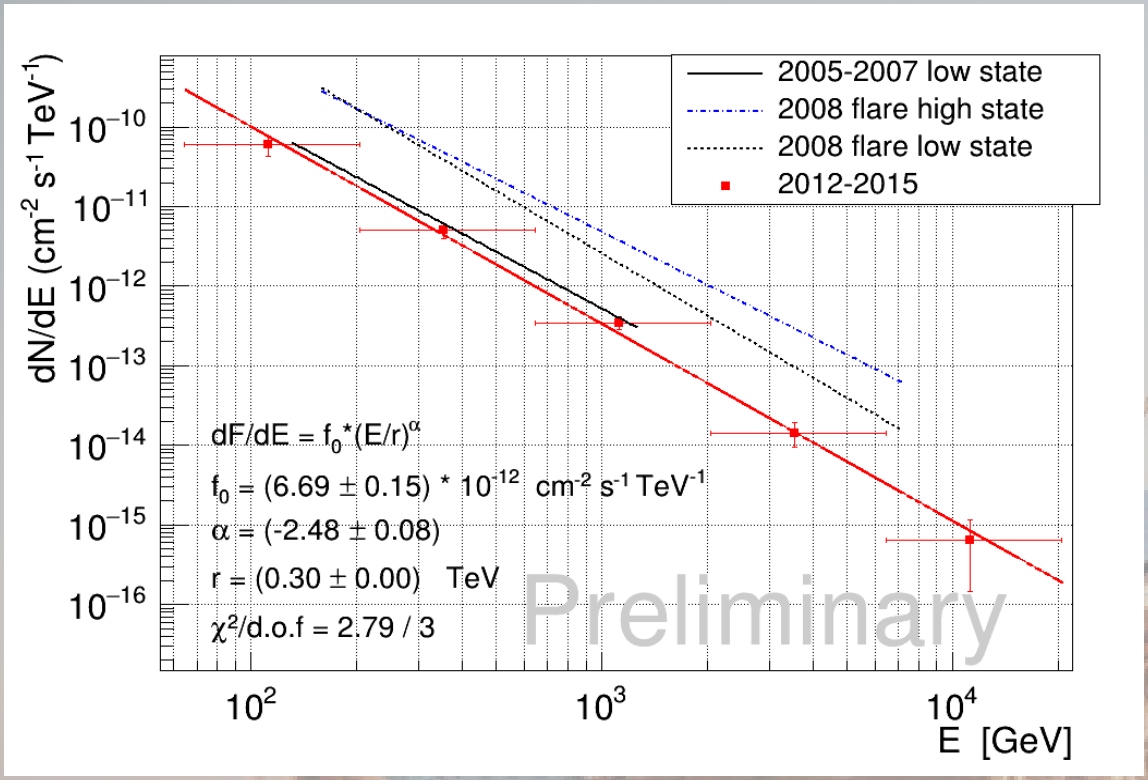
Multi-year VHE Light Curve



- **No sign for variability in 2012, 2014 and 2015 on monthly or daily timescales (probability for fit with constant flux > 40%)**
- **3σ hint for variability on daily timescale in 2013 (probability for fit with constant flux < 0.3%)**
- **integral flux above 300 GeV observed at similar state as in 2005-2007 campaign**



Averaged differential spectrum of M87 for 2012 to 2015 MAGIC data

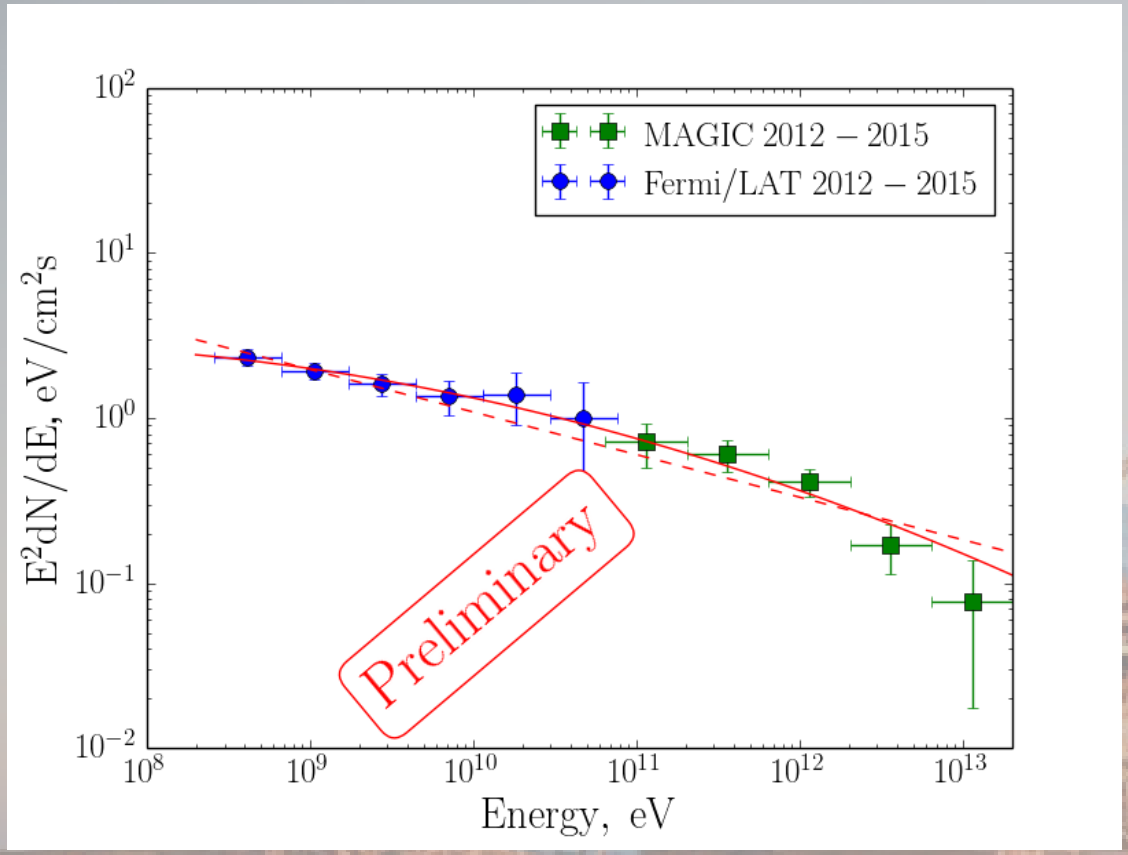


First time precise measurement with spectrum over two decades of energy

Year	α	$f_{0(E=300\ GeV)}$ [cm^{-2} s^{-1} TeV^{-1}]
2005-2007	-2.21 +/- 0.21	(7.7 +/- 1.3) x 10^{-12}
2008 flare low state	-2.60 +/- 0.30	(59.0 +/- 30.0) x 10^{-12}
2008 flare high state	-2.21 +/- 0.18	(68.8 +/- 21.0) x 10^{-12}
2012-2015	-2.48 +/- 0.08	(6.9 +/- 0.1) x 10^{-12}

- Spectral slope is consistent within errors
- Flux is clearly lower but compatible with low state from 2005 to 2007

MAGIC & *Fermi* combined SED



- **MAGIC & *Fermi*/LAT Pass 8 data: 2012 to 2015**
- **First time gap less HE/VHE spectrum from MAGIC and *Fermi* observations**

Fit Parameters	Fit Functions	
	Log parabola	Power law
f_0 [eV cm^{-2} s^{-1}]	0.75 +/- 0.1	0.60 +/- 0.05
α	-2.28 +/- 0.02	-2.25 +/- 0.02
β	-0.014 +/- 0.009	----
χ^2/NDF	2.8/8	5.3/9
Probability [%]	95	80
E_0 [GeV]	100	100

$$\frac{dN}{dE} = f0\left(\frac{E}{E_0}\right)^{\alpha+\beta log(E/E_0)}$$

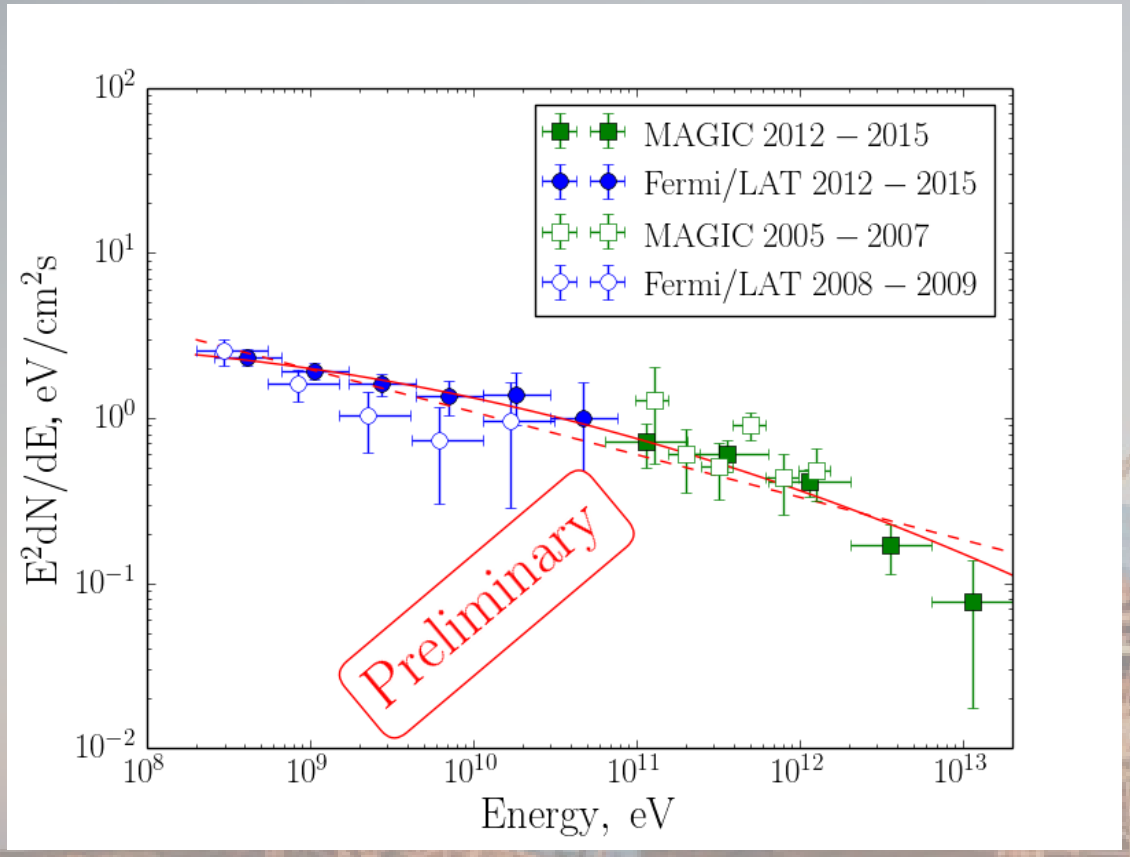
Equation for Log Parabola

$$\frac{dN}{dE} = f0\left(\frac{E}{E_0}\right)^{\alpha}$$

Equation for Power Law

Fit was done by taking into account the correlation between MAGIC data points

MAGIC & *Fermi* combined SED



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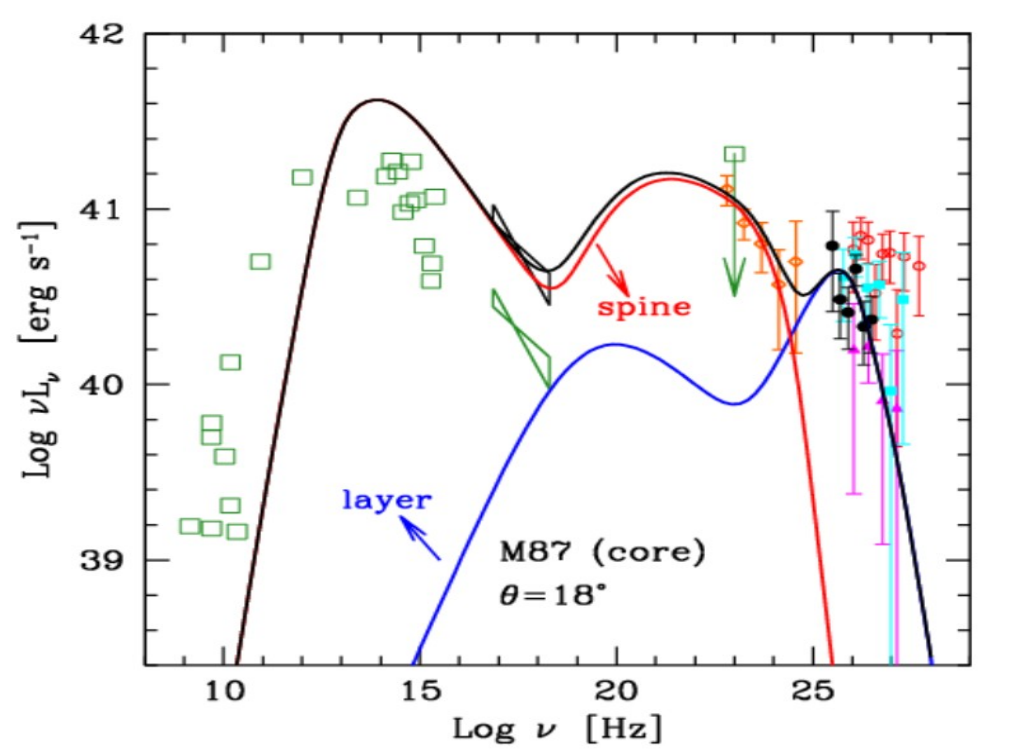
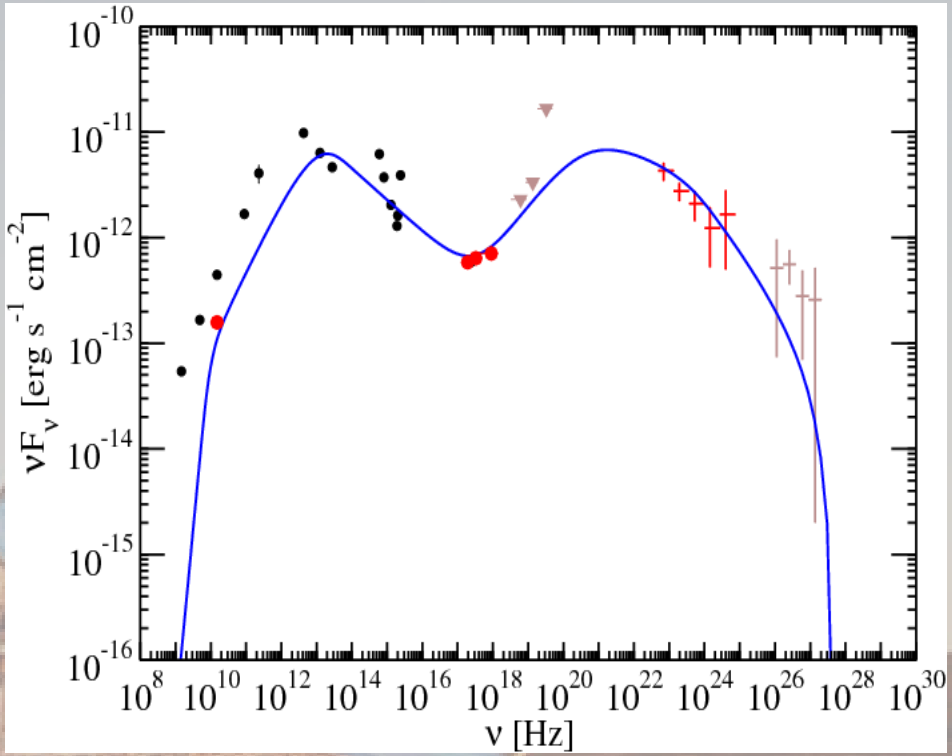
MWL SEDs for 2005-2007 MAGIC and 2009 *Fermi* data





- **MWL SED for 2005-2007 MAGIC low emission state data (Jet & Jet model)**
  [Aleksić et al. A&A, 544, (2012)]

- **MWL SED for *Fermi 2009* data (One zone SSC model)**
  [Abdo et al., ApJ, 707, (2009)]

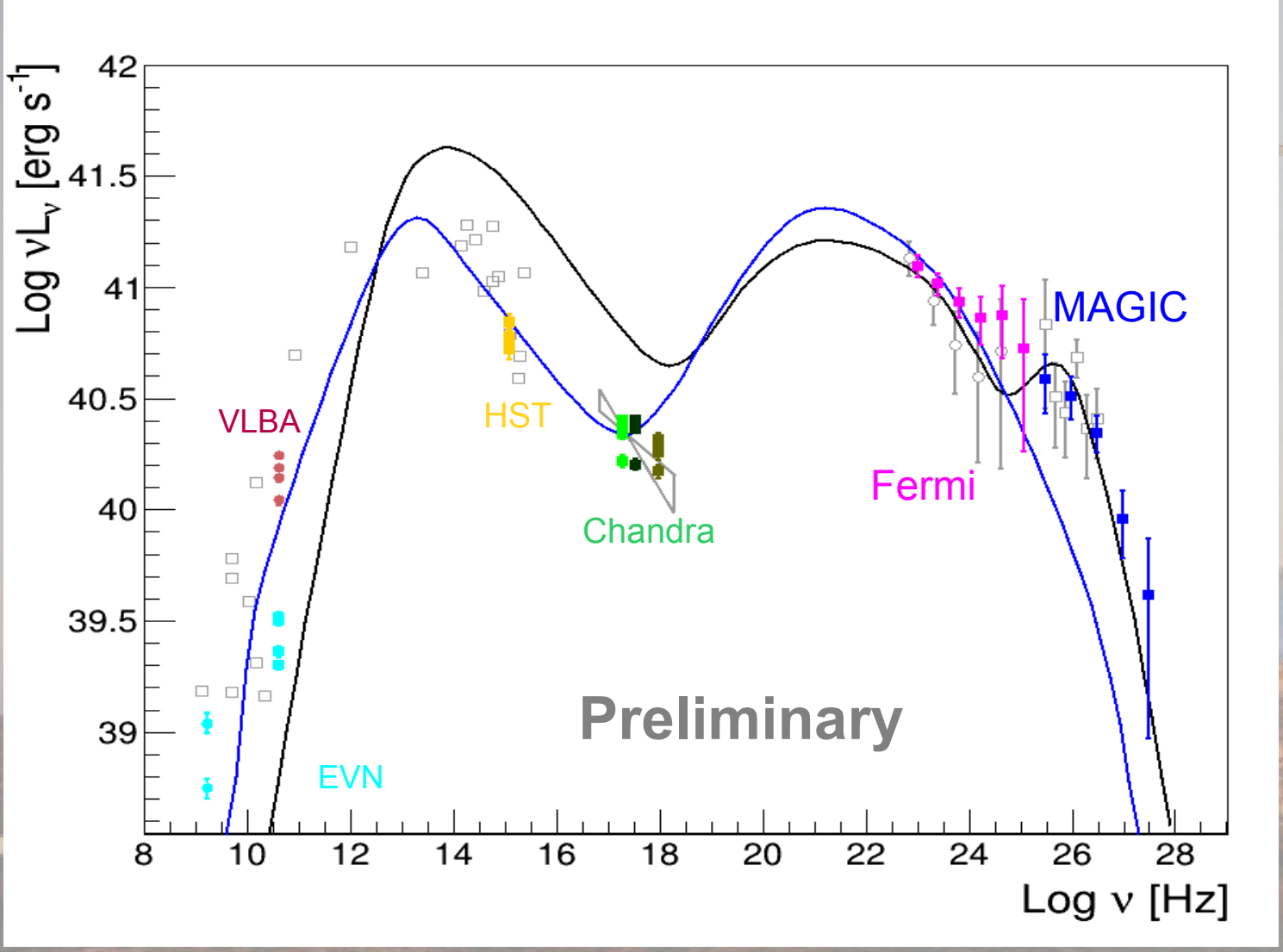
- **Caveat:**

  The MWL data used for modeling was not simultaneous

MWL Data

- MAGIC >100 GeV (2012-2015)
- *Fermi*/LAT 200 MeV - 100 GeV (2012-2015)
- HST UV filter (2364.8 Å) for M87 core (2011-2015)
- Chandra X-ray 0.5-1, 1-2 and 2-7 keV for core region (2012-2014)
- VLBA 43 GHz (1.2 mas, Radio) for core region (2012-2015)
- EVN 1.7 and 5 GHz (Radio) for core region (2012-2015)

MWL SED for 2012-2015 MAGIC data

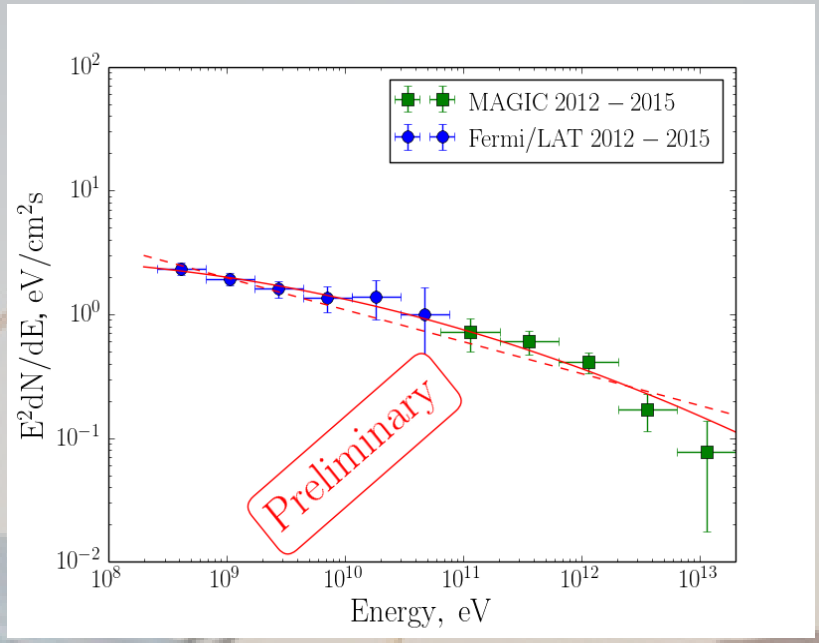


- **Black line:**
  Model used for 2005-2007 MAGIC data
  [Aleksić et al. A&A, 544, (2012)]
- **Blue line:**
  Model used for *Fermi* 2009 data
  [Abdo et al., ApJ, 707, (2009)]
- **Contemporaneous MWL data are in colors & archival data are in gray**
- **Previous models do not seem to fit**

→ **Work in progress..**

Conclusions

- MAGIC detected M87 in every yearly campaign between 2012 and 2015 but no flare detection
- No variability observed in 2012, 2014 and 2015 light curves on daily and monthly timescale
- 3σ hint for variability in 2013 light curve on daily timescale
- Flux and spectral index is consistent with the low emission state observed between 2005 and 2007



- First time gap less HE/VHE spectrum from MAGIC and Fermi observations
- Models used for Magic 2005-2007 low state and Fermi 2009 data are disfavored by the new data
- Work on modeling of the 2012-2015 MWL data is ongoing


Thank You