



Black Hole Lightning from the Peculiar Gamma-Ray Loud AGN IC 310

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Relativistic Jets: Creation, Dynamics, and
Internal Physics, April 23, 2015

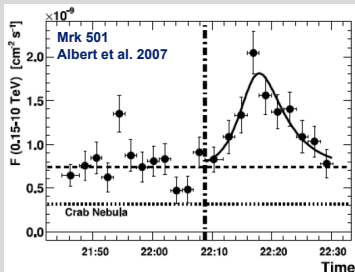
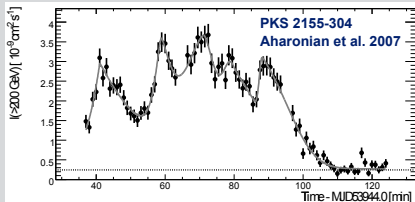


- Particle acceleration to extreme energies – origin of UHE cosmic rays ($E > 10^{18}$ eV)?
- Black hole – jet connection ?
- Jet structure & jet formation ?
- Emission mechanisms at high energies: hadronic or leptonic ?
- Location of the emission region ?



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Rapid variability at VHE

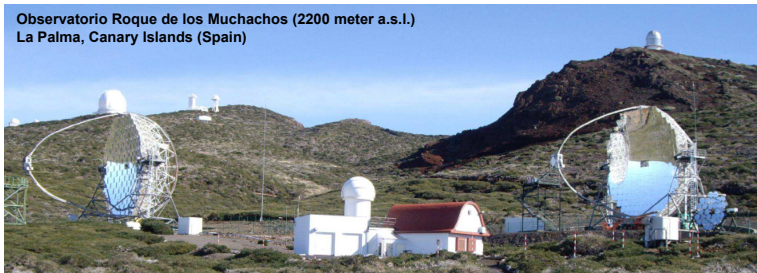




MAGIC: Major Atmospheric Gamma-Ray Imaging Cherenkov Telescopes

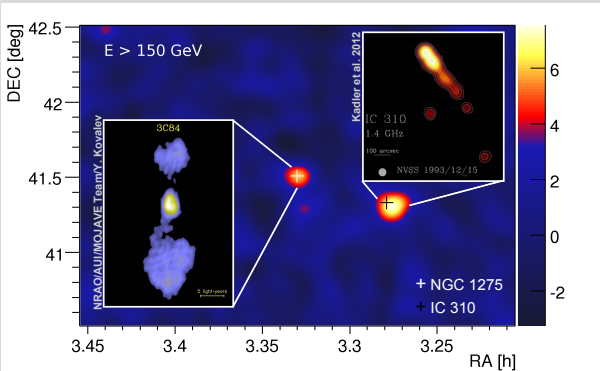
- Two IACTs of 17 m diameter mirror dish, MAGIC-I since 2003, MAGIC-II in 2009
- 2011 and 2012: major upgrade of the telescopes, new camera for MAGIC I, readout system in both telescopes replaced by DRS 4 chips
- 2014: new mirrors for both telescopes, downsampling
- Sensitivity: $\sim 0.6\%$ C.U. 5σ in 50 h (at 400 GeV)

Observatorio Roque de los Muchachos (2200 meter a.s.l.)
La Palma, Canary Islands (Spain)





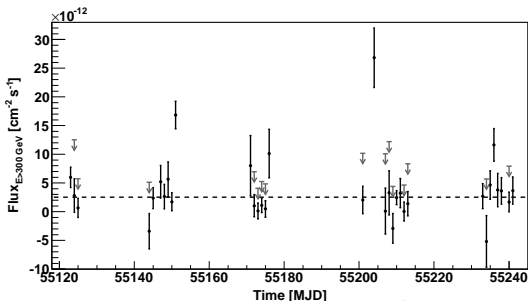
Detection of two AGN



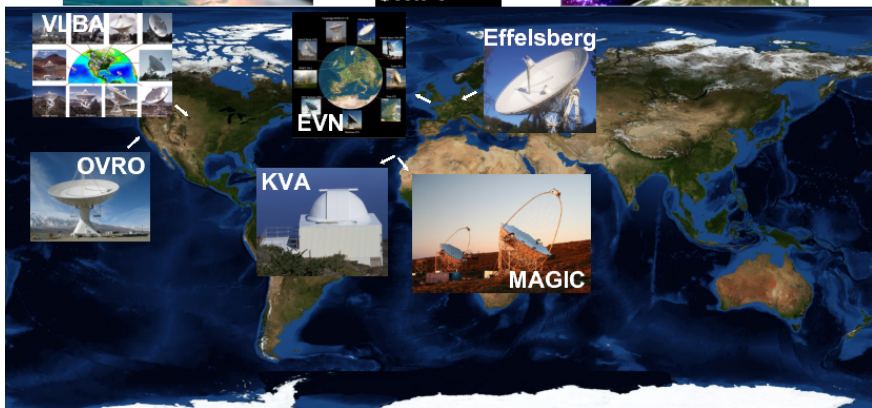
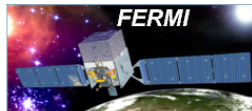
IC 310: Aleksić et al. 2010, ApJ, 723, L207
 NGC 1275: Aleksić et al. 2012, A&A, 539, L2

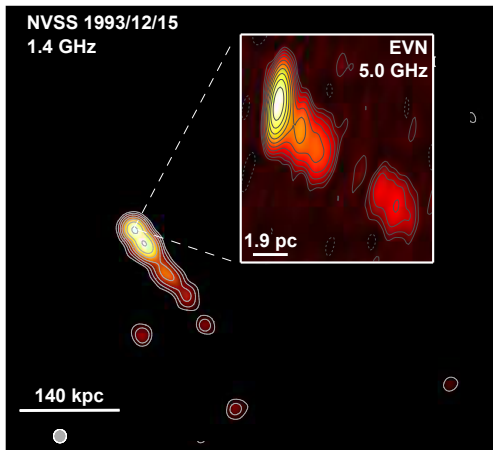


- Original: head-tail radio galaxy with a large projected radio jet (Ryle & Windram 1968; Miley 1980)
- But: VLBI image shows blazar-like parsec-scale structure, same position angle as kpc jet (Kadler, Eisenacher et al. 2012)
- Flux variability in the soft X-ray and VHE band
→ blazar-like properties (Aleksić... Eisenacher... et al. A&A 2014)

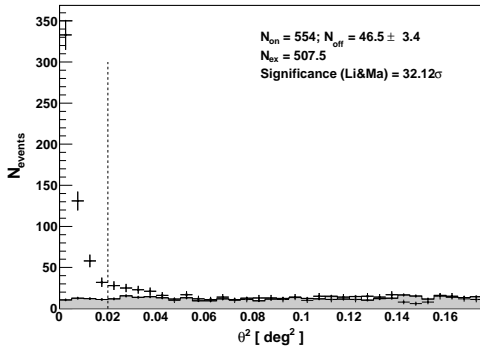


see Aleksić... Eisenacher... et al. A&A 2014





- VLBI observation at 5.0 GHz on Oct. 29, 2012 using the European VLBI Network
 - $\theta \lesssim 20^\circ$
- Large de-projected length of kpc radio structure:
 - $10^\circ \lesssim \theta$
- Rather large angle → no strong (blazar-like) boosting



Aleksić... Eisenacher... et al. 2014, *Science*

- Dramatic TeV flare on Nov 12/13, 2012
- Clear detection in 3.5 h with 32σ above 300 GeV
- Further observations until early 2013: only weak signal detected

ATel #4583

MAGIC detection of renewed activity from the radio galaxy IC 310

ATel #4583; *Juan Cortina for the MAGIC collaboration*
 on 16 Nov 2012; 19:17 UT
 Credential Certification: *Juan Cortina (cortina@fiae.es)*

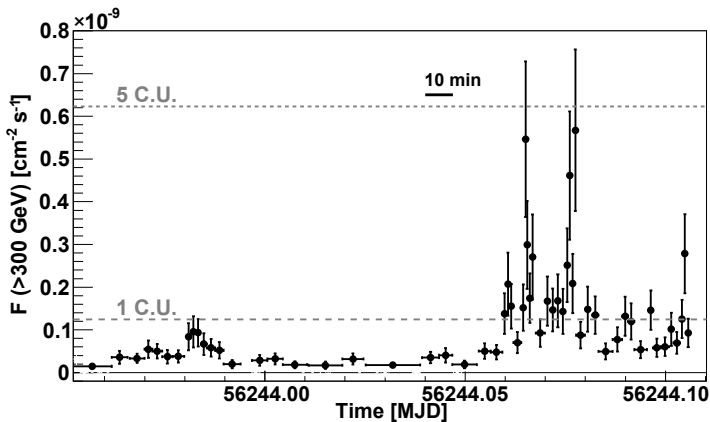
Subjects: Gamma Ray, TeV, VHE, Request for Observations, AGN

ATel #4581

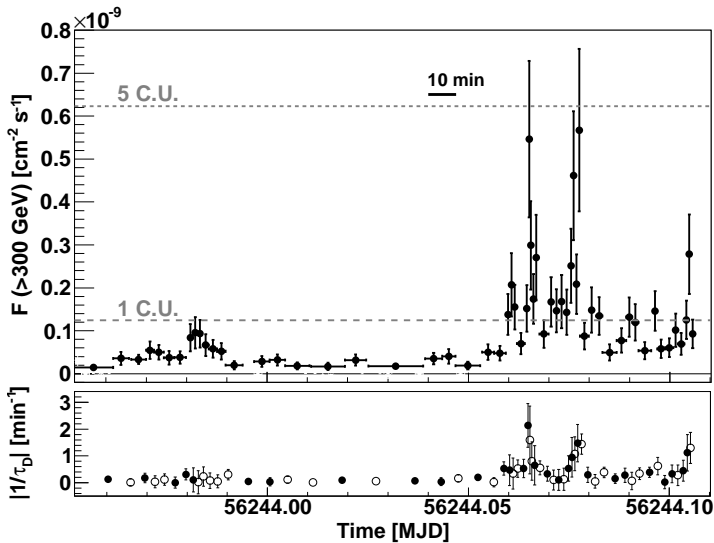
Swift Observation of IC 310

ATel #4581; *Felicia Krauss (ECAP/FAU Erlangen/Univ. Wuerzburg), Dorit Eisenacher (Wuerzburg), Matthias Kadler (Wuerzburg), Joern Wilms (ECAP), Dominik Elsaesser (Wuerzburg), Karl Mannheim (Wuerzburg), Neil Gehrels (GSFC)*
 on 16 Nov 2012; 17:27 UT
 Credential Certification: *Joern Wilms (j.wilms@sternwarte.uni-erlangen.de)*

Subjects: X-ray, AGN, Blazar

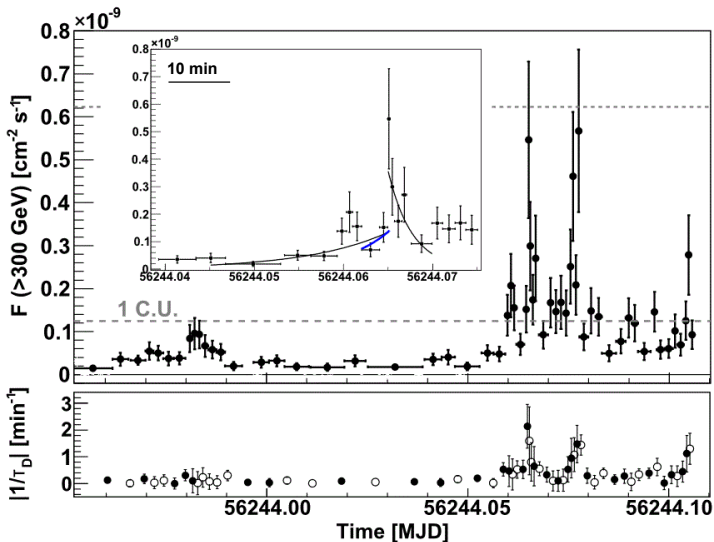


Aleksić... Eisenacher... et al. 2014, *Science*



Aleksić... Eisenacher... et al. 2014, *Science*

Light Curve on Nov 12/13, 2012

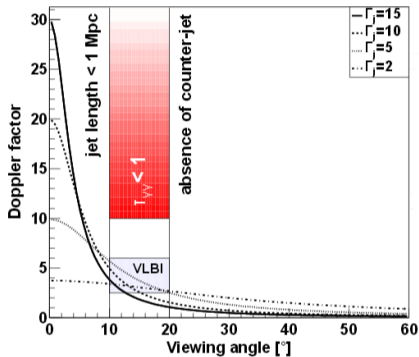


Aleksić... Eisenacher... et al. 2014, *Science*

Variability on time scales faster than $\sim 4.8 \text{ min} \hat{=} 0.2 R_G$ (conservative) !



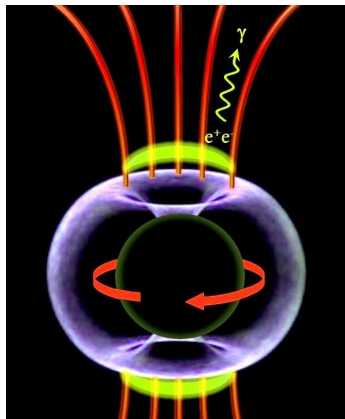
- $R < \delta c \tau_{\text{var}} = \delta \cdot 0.2 \cdot R_g$ (for 4.8 min, $M_{\text{BH}} = 3 \times 10^8 M_{\odot}$)
- Opacity problems: typically solved by $\Gamma \sim 50$ (Begelman et al. 2008)
- Here: $\tau_{\gamma\gamma}(10 \text{ TeV}) = \delta^6 \cdot 1.2 \times 10^5$ (for 4.8 min, $L_{\text{syn}} \sim 10^{42} \text{ erg/s}$)
 $\rightarrow \delta \gtrsim 10$ required
- Bend in jet? Relatively improbable as kpc jet and pc jet are aligned. Difference is 10° (probability is $\sim 11\%$).
- Jets-in-jet models based on relativistic reconnection?



see Aleksić... Eisenacher... et al. 2014,
Science



- **“Magnetospheric models”**:
by e.g. Levinson & Rieger 2011;
Aleksić et al. 2014, *Science*
- Similar to aligned magnetic rotator models for pulsars
- e^+e^- accelerated in an electric field in vacuum gap regions
- Low accretion rate \rightarrow small gap height \rightarrow fast variability
- Unsaturated EM cascades \rightarrow stable hard power-law
- Particle multiplication in cascades leads to mass loading of jet
- Anisotropic particle beams at angles 10° - 20° to the jet axis



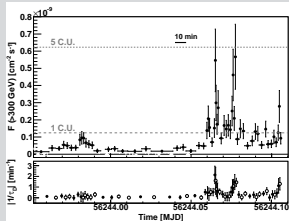
see Aleksić... Eisenacher... et al. 2014,
Science



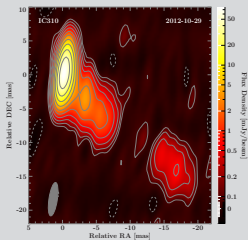
MWL campaign



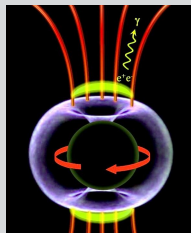
Ultra Fast Variability



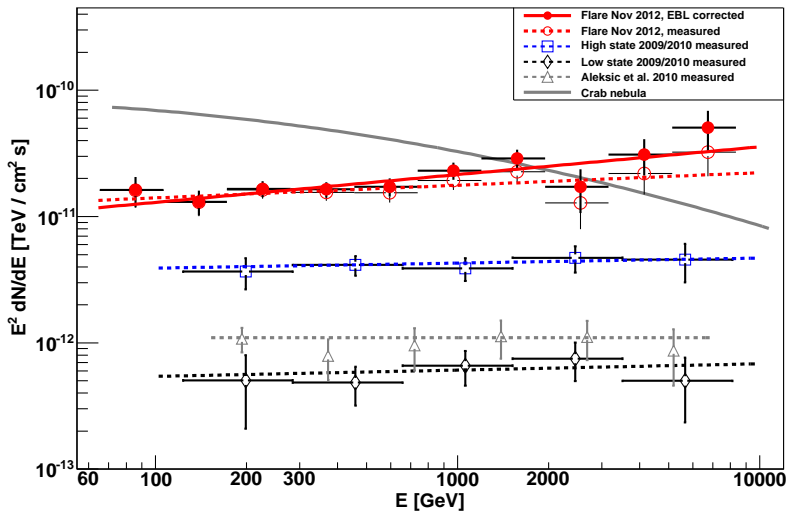
VLBI Jet



Black Hole Lightning

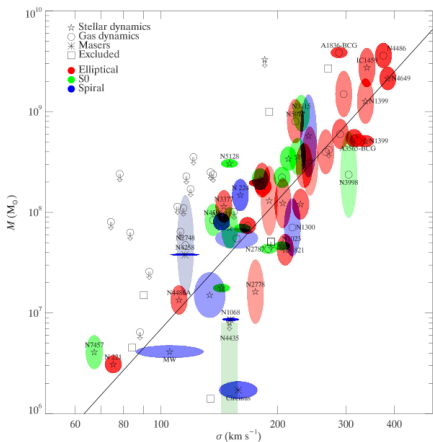




Aleksić... Eisenacher... et al. 2014, *Science*



- Inferred from $M_{\text{BH}}-\sigma$ relation
 $\rightarrow M_{\text{BH,IC 310}} = 3_{-2}^{+4} \times 10^8 M_{\odot}$
- Similar value ($\approx 4 \times 10^8 M_{\odot}$)
 comes from fundamental plane of
 BH activity, but the spread is much
 larger (an order of magnitude)

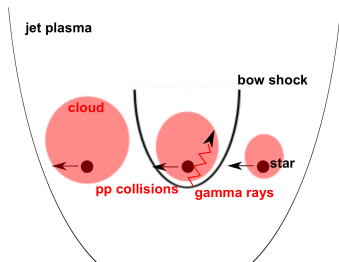


see Gültekin et al. 2009



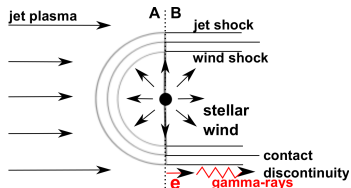
- Radio variability via cloud/star-jet interaction proposed by Blandford & Königl 1979
- Duty cycle unknow (starforming and supernova rate necessary)

- “Cloud-jet-model”:
Barkov et al. 2010/2012



- One cloud produces single peak in LC
- Destroyed cloud → extrem beaming necessary

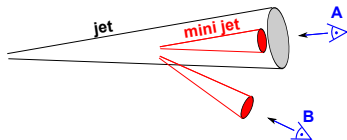
- “Star-jet-model”:
Bednarek & Protheroe 1997



- Fast variability produced by size of shock irregularities
- Stable PL spectrum up to > 10 TeV
- Extreme beaming needed for $L_{\gamma,obs}$



- “Minijets model”:
by Giannios et al. 2010



- $\Gamma_{em} \propto \Gamma_j \Gamma_{mj}$
- Fast variability due to low BH mass
- Luminosity offaxis very low
- Total power of minijets exceed jet power