Insights into the particle acceleration of a peculiar gamma-ray radio galaxy IC 310

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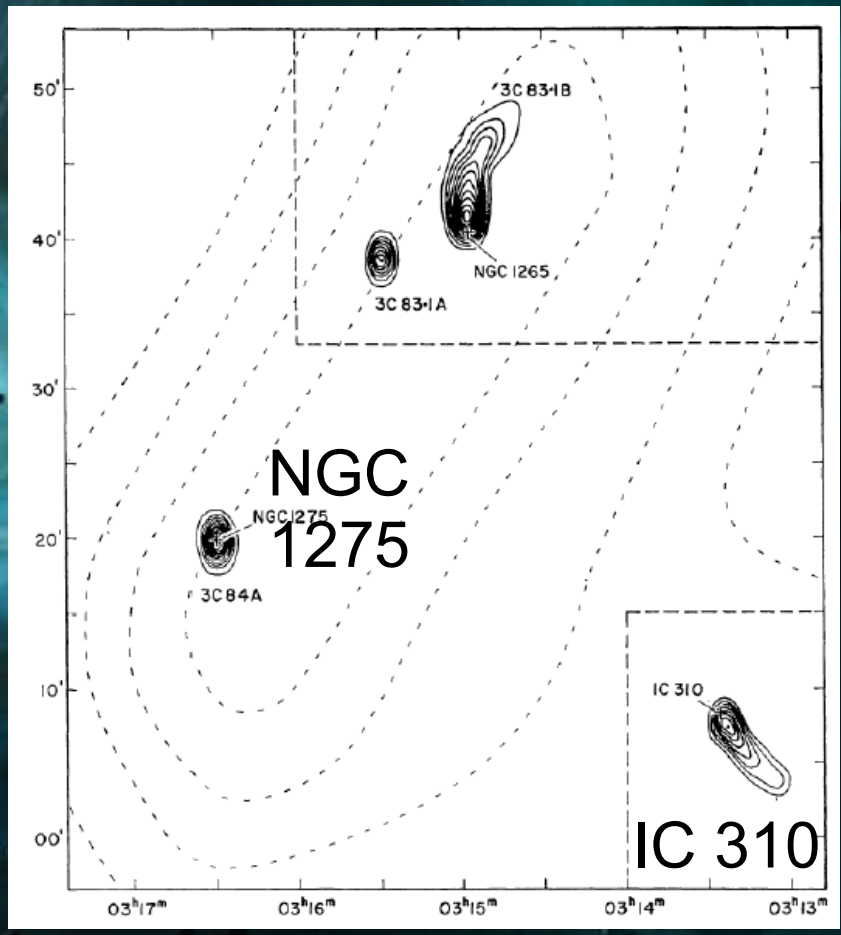
MAGIC telescopes

- Two 17mØ Imaging Atmospheric Cherenkov Telescopes located in La Palma, Spain
- Summer 2012: major upgrade completed

- Detecting gamma-rays with energies above ~50 GeV
- Sensitivity ~0.7% of Crab Nebula flux in 50h of observations (>220 GeV)

IC 310: a blazar or a radio galaxy ?

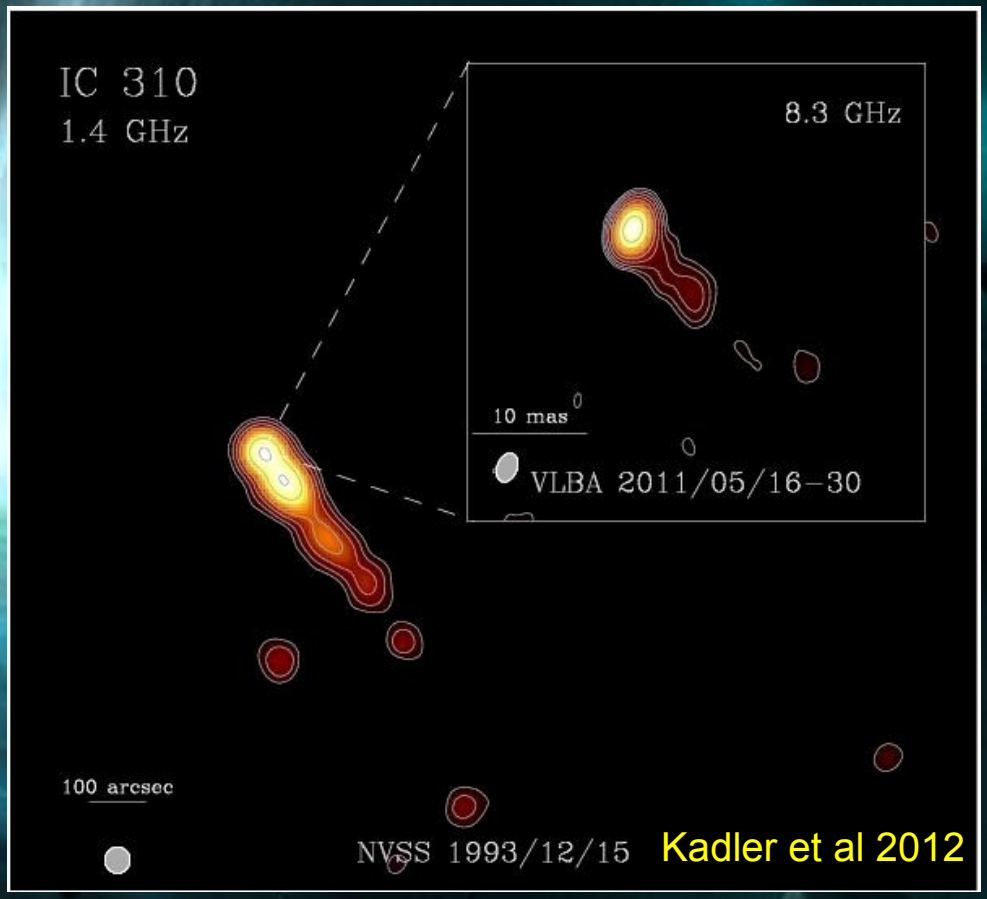
- AGN in the outskirts of the Perseus cluster (z=0.018) with central BH with mass ≈3 x 10^8 M_{sun}
- Radio, optical and X-ray properties are a mixture of those of FR I and blazars
- But:
  - Intrinsic, isotropic luminosity is 2-3 orders of magnitude below the ones of typical blazars
  - Clear radio jet, and de-projecting it, the viewing angle >10^o
- IC 310 might be an intermediate object of the two classes



Ryle & Windram (1968)

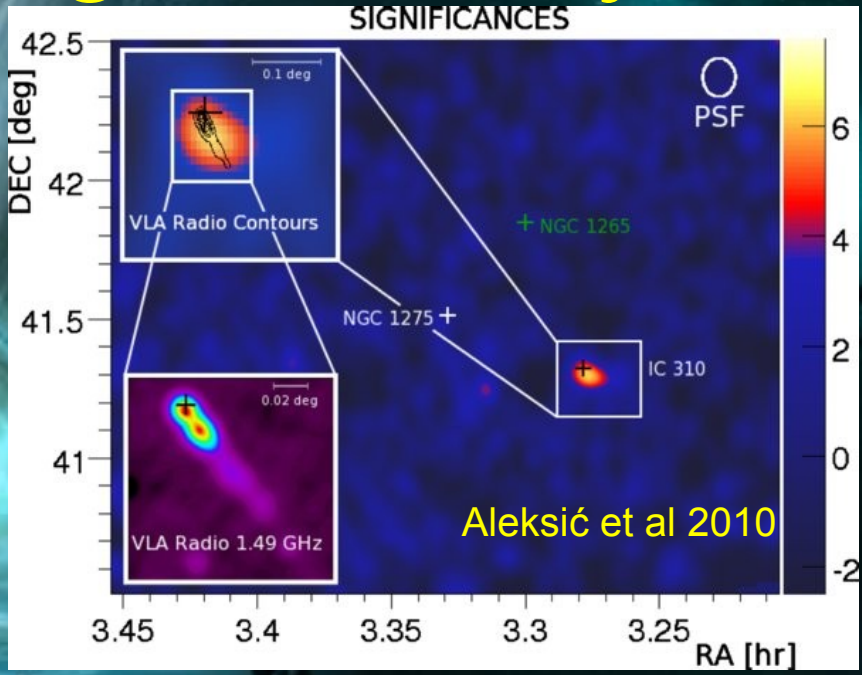
pc-scale jet structure

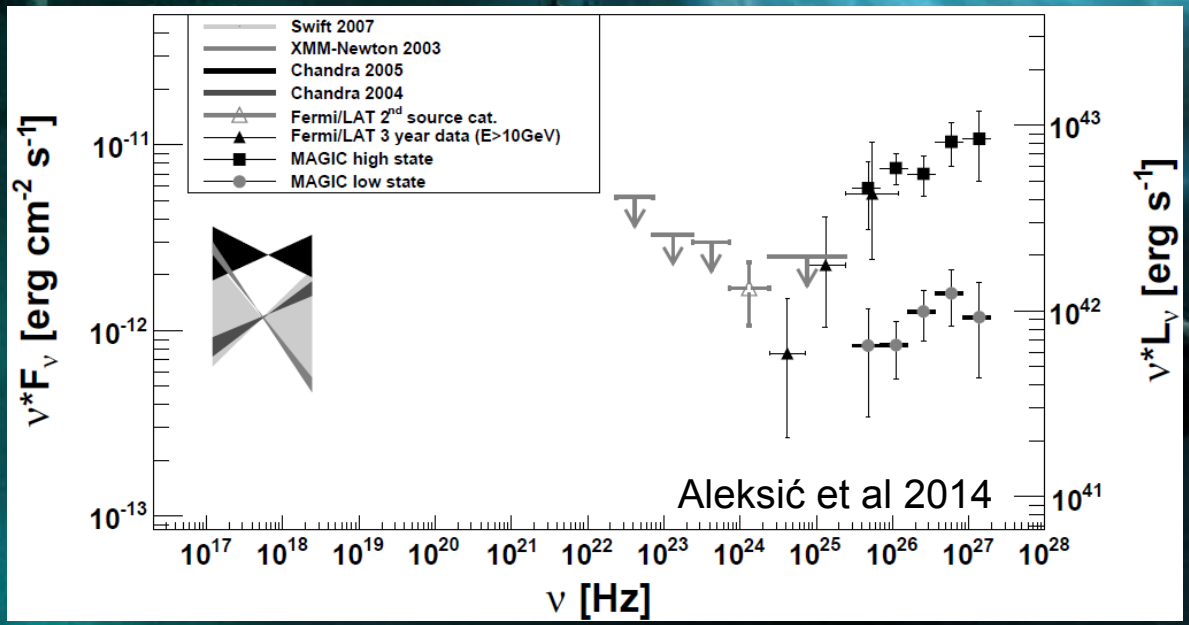
- A close look with VLBI reveals a pc scale inner jet structure
- The position angle is consistent within errors with the one of the 350 kpc jet – no hints of any bending

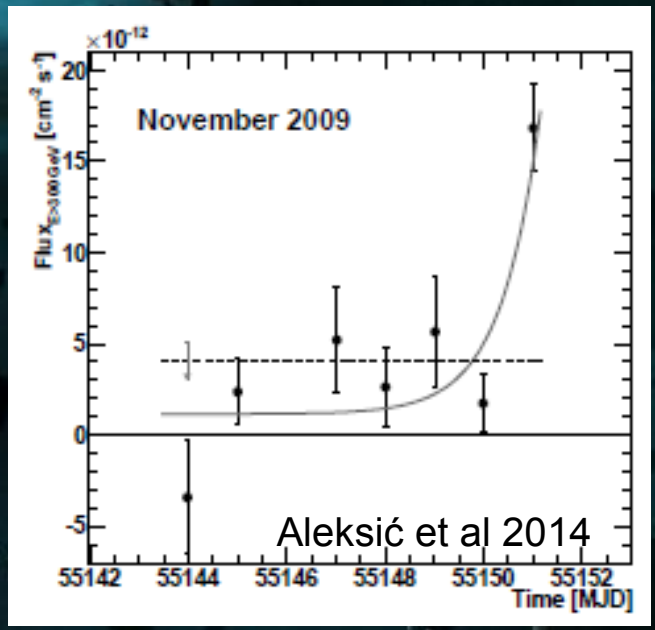


IC 310 in HE & VHE gamma-rays

- Detected above 30 GeV in Fermi data (Neronov et al 2010)
- Hard Fermi-LAT spectrum (slope 1.3+/-0.5), Aleksić et al 2014
- Detected in VHE by MAGIC (Aleksić et al 2010) with night-to-night variability (Aleksić et al 2014)



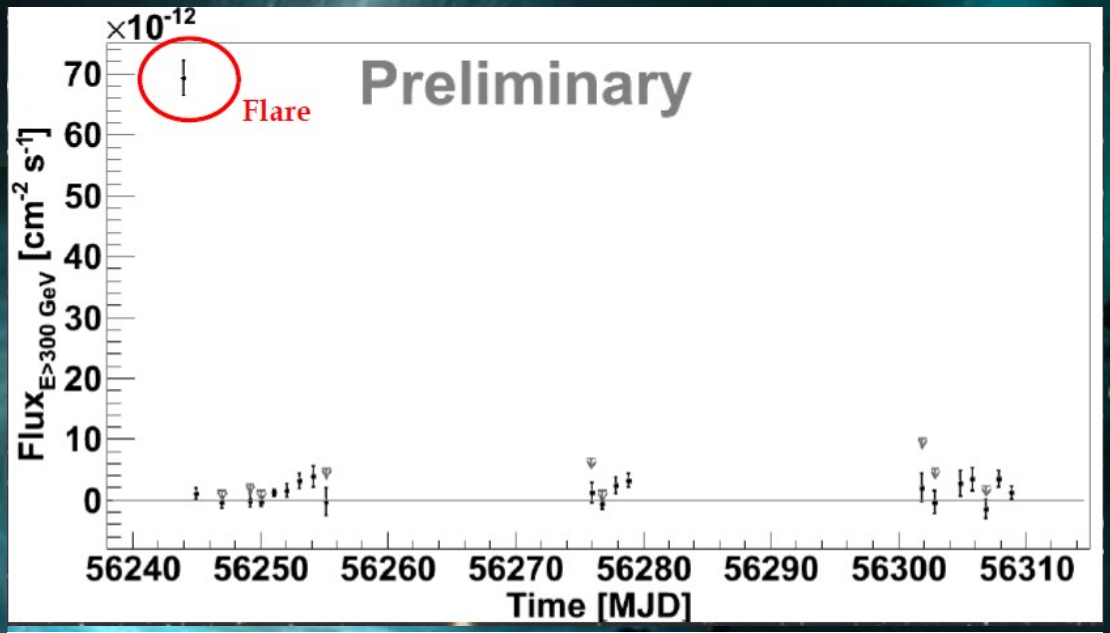


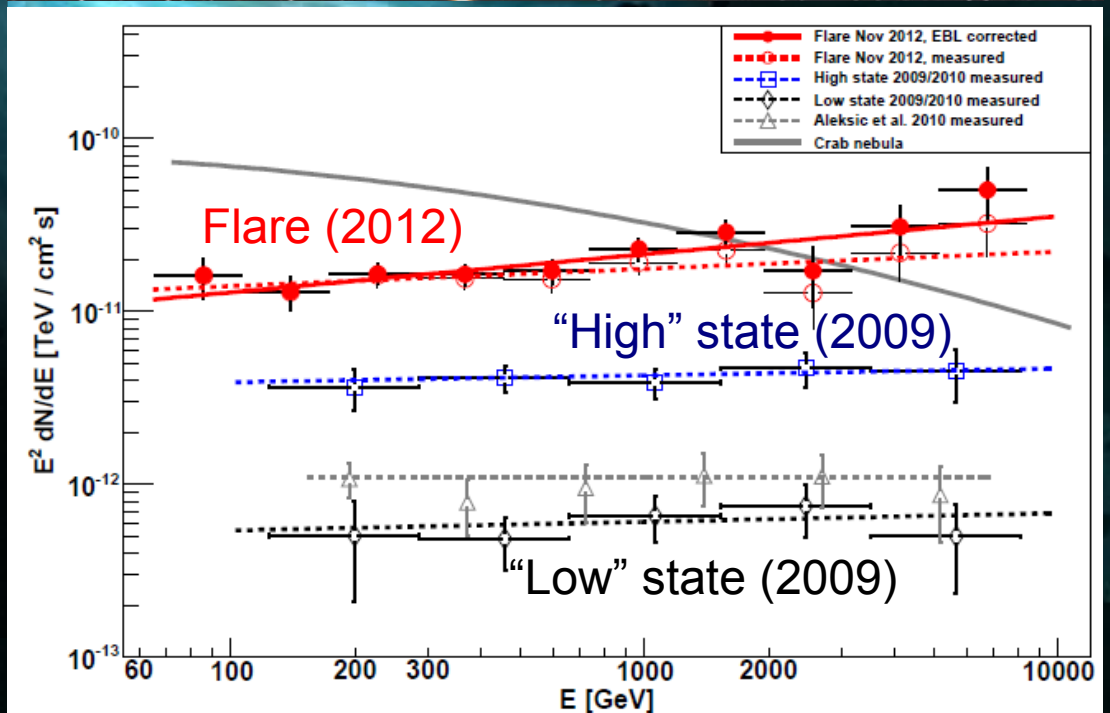


IC 310 in Nov 2012 – Jan 2013

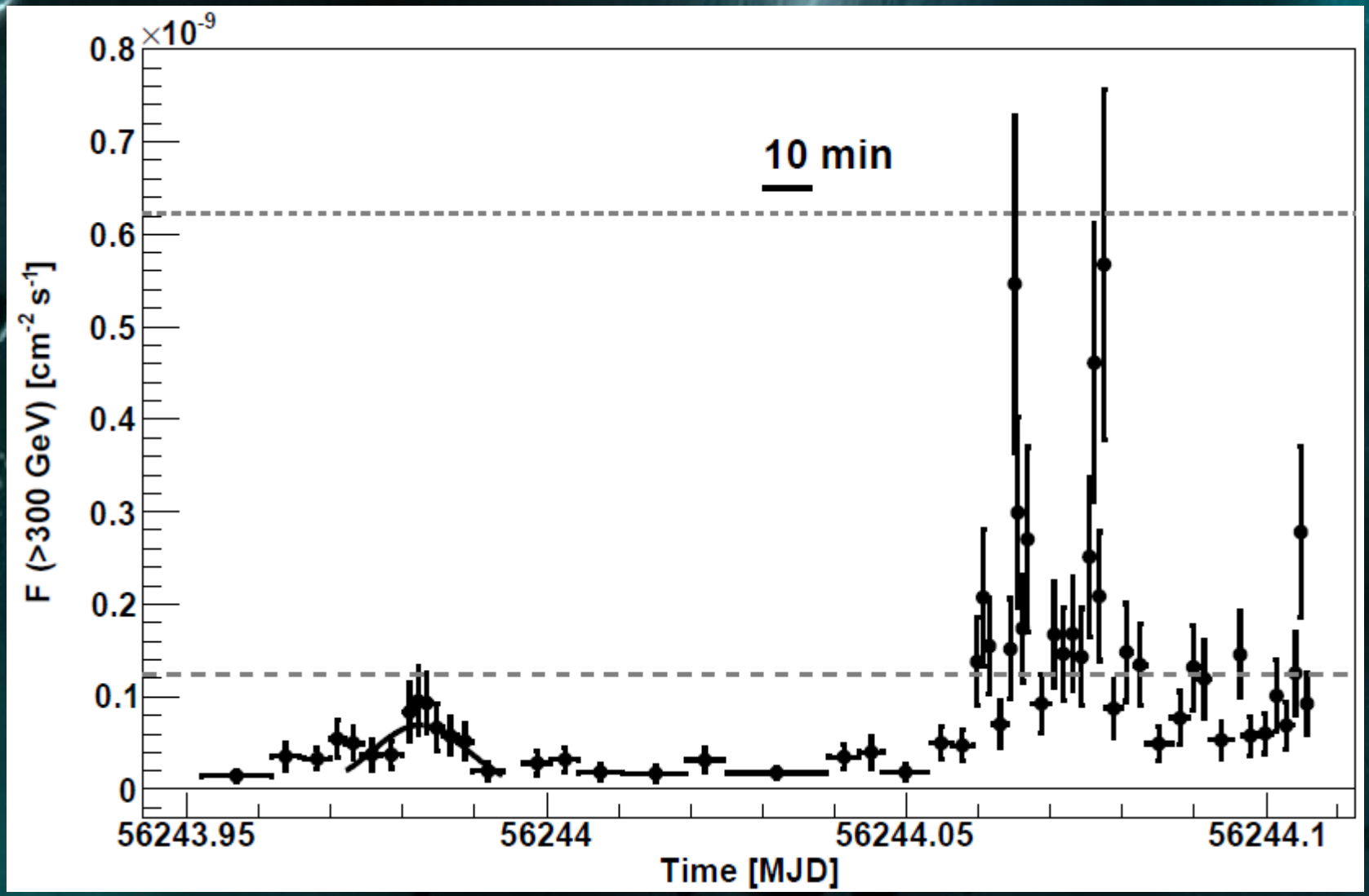
- Impressive flare on the night of Nov 12/13, 2012

- Hard (~1.8 intrinsic) spectrum up to ~8 TeV without any sign of a break/cut-off



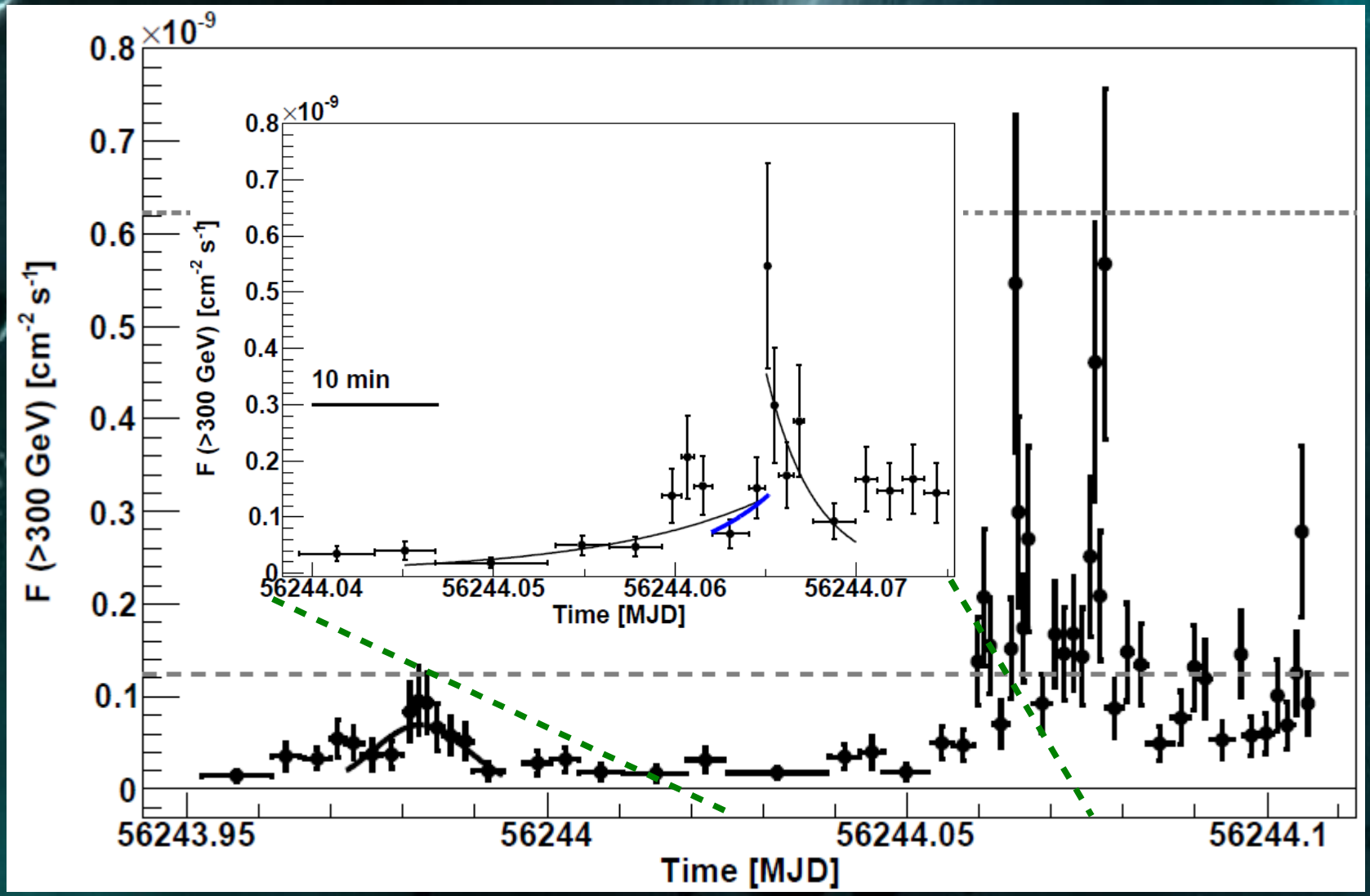


Close-up view of the flaring night



3.7h of observations during the night of the flare
Light curve binned according to fixed number of events

Close-up view of the flaring night



Flux doubling time-scale < 4.8 min at 95% C.L
corresponds to 20% of the light crossing time of gravitational radius

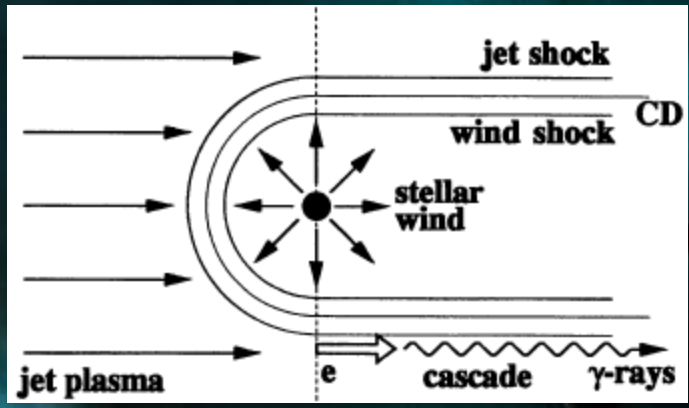
What has happened in IC 310 ?

- Strong flare (nearly 2 orders of magnitude above the low state) with:
  - Hard, stable spectrum without a cut off/break up to at least 8 TeV
  - Very fast variability (below the light crossing-time of the BH horizon)
- Can it be explained by the shock acceleration in the jet ?
  - No, the emission is too fast and the whole cross section of the jet would not be causally connected
  - No, synchrotron radiation naturally produced in this scenario would absorb the multi-TeV emission

Alternative possibilities

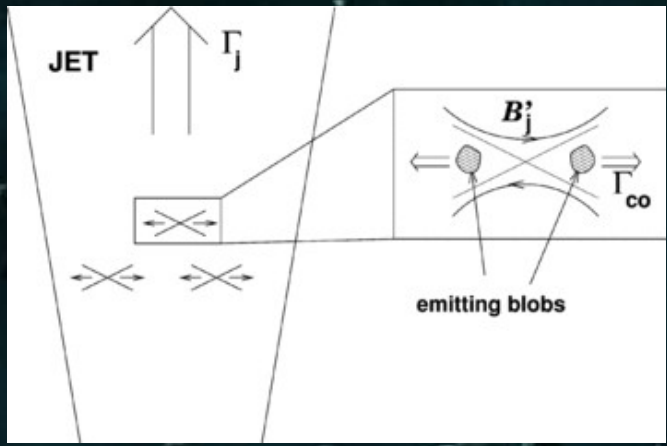
- A cloud/star falling in the jet ?
  - The short time scale and flickering can be explained by the size of the shock irregularities,
  - But the luminosity of IC 310 flare would require an extreme beaming of the emission

- Jets-in-jet models:
  - The short time scale can be explained by a jet composed of smaller sub-jets pointing in the direction of the observer
  - But off-axis luminosity in this model drops fast with $\Gamma_j\theta$, and the jet luminosity is insufficient to explain the flux of IC 310 flare



Star in jet:
Bednarek & Protheroe 1997

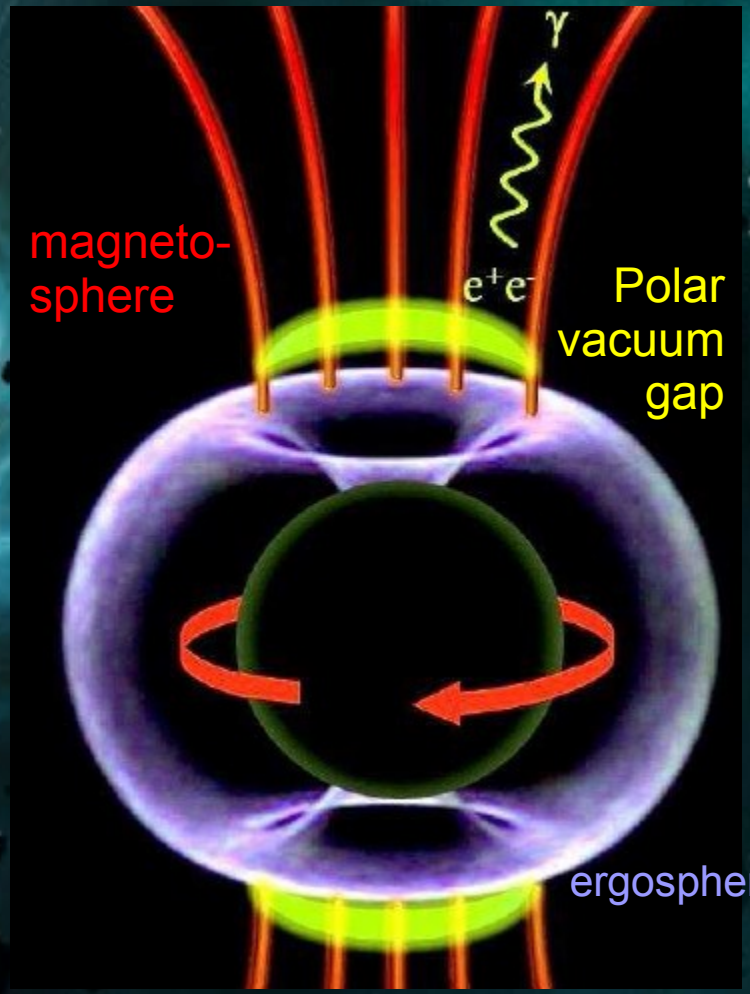
Cloud in the jet:
Barkov et al 2010, 2012



Jets in jet:
Giannios et al 2009

Pulsar-like magnetosphere emission ?

- A scenario similar to the one operating in pulsars with e^+e^- accelerated in an electric field in a vacuum gap region (Levinson & Rieger 2011)
- Hard gamma-ray spectrum comes from electromagnetic cascading
- Variability occurs as the gap varies strongly with plasma turbulence and accretion rate



Summary

- MAGIC has detected an extreme flare from the radio galaxy IC 310
- The hard spectrum without a cut-off up to ~8 TeV energies, and variability time scale smaller than the crossing time of event horizon challenge the shock-in-jet models
- A plausible explanation of the IC 310 flare can be provided by a magnetospheric emission model