The January 2017 Orphan Gamma-ray Flare from the Radio Galaxy NGC 1275: VERITAS and Multiwavelength Results

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[1]University of Minnesota

NGC 1275 (3C 84, Perseus A)

Radio galaxy, Giant Elliptical Galaxy, FR I, Seyfert 2 (Narrow line)

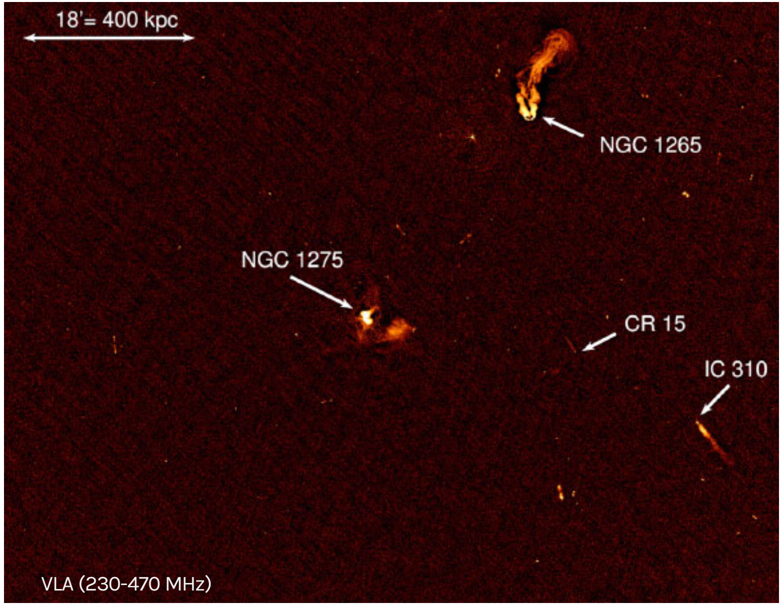
$z = 0.0176$; D~75Mpc; 1mas=0.34 pc = $4500R_s$

$M_{SMBH} = (0.8\text{-}2)\times10^9 M_\odot$ [1]

3C 84 is one of the brightest compact radio sources in the sky → long history of radio observations

R. Jay Gabany (https://apod.nasa.gov/apod/ap090508.html)

Brightest cluster galaxy in Perseus



Gendron-Marsolais et al (2020)

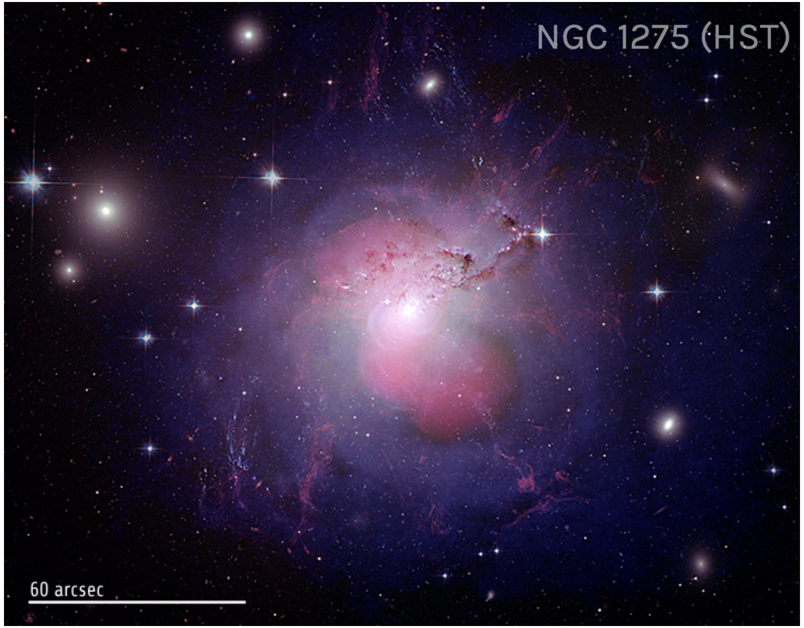
[1] Giovannini et al 2018

Current VHE catalog of Radio Galaxies

Name	Cross-ID	Type	Distance	BH mass [10^8 Msun]
Cen A	NGC 5128	FR I	3.7 Mpc	(0.5-1)
M87	NGC 4486, Virgo A	FR I	16 Mpc	(20-60)
NGC 1275	3C84, Perseus A	FR I	70 Mpc	3-4
IC 310	B0313+411	FR I/BL Lac	80 Mpc	3 [0.3?]
3C 264	NGC 3862	FR I	95 Mpc	4-5
PKS 0625-35	OH 342	FR I/BL Lac	220 Mpc	~10

Rieger & Levinson 2018

VERITAS detected



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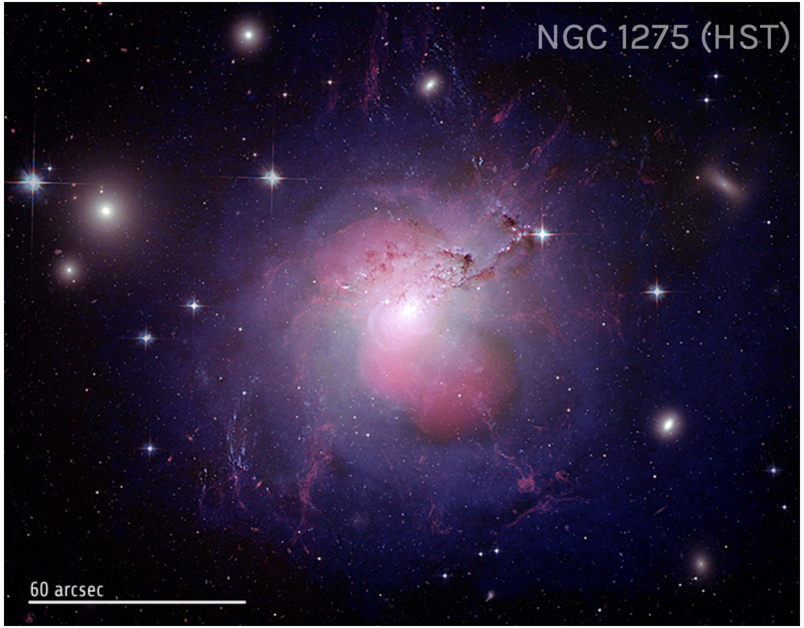


NGC 1275 – VERITAS long-term monitoring campaign

Paper in preparation

VERITAS

The Very Energetic Radiation Imaging Telescope Array System

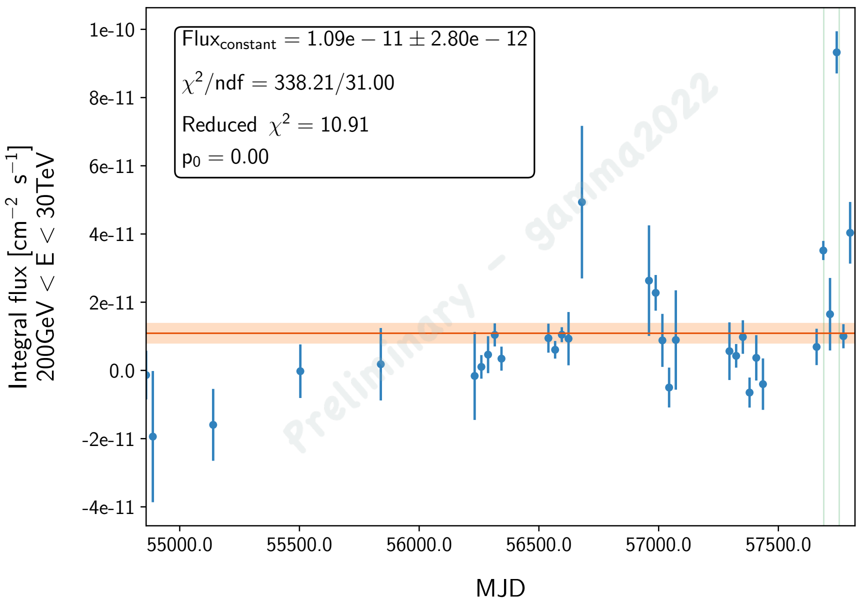
- An array of four 12m-diameter imaging atmospheric Cherenkov telescopes
- Located at the Fred Lawrence Whipple Observatory in southern Arizona
- Energy range: 85 GeV to >30 TeV — Energy resolution: 17%
- Angular resolution: ~0.08 @ 1 TeV — Source location accuracy: error < 50 arcsec
- Sensitivity: 1% Crab in ~25h

NGC 1275 – VERITAS 8 years of data

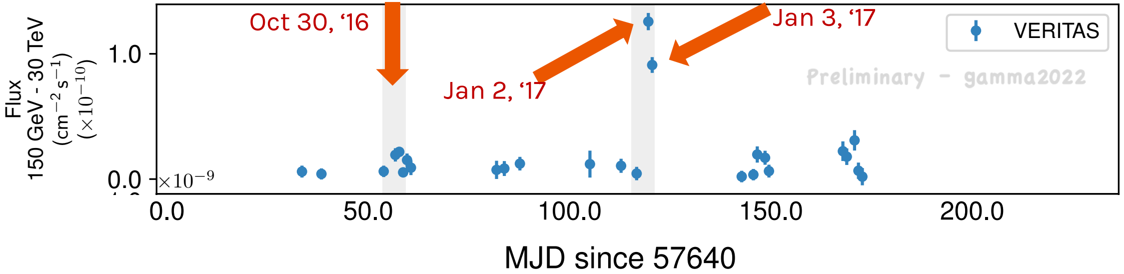
VERITAS analysis separated into four states based on 8 year lightcurve:

- Low state: < 3σ mean flux
- High: > 3σ mean flux (without below flare points)
- Jan 2, 2017 flare
- Jan 3, 2017 flare decline

28-day binned VERITAS light curve
2009-2017 seasons



Zoom in on 2016-17 season →



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- Low state: < 3σ mean flux
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- Jan 2, 2017 flare
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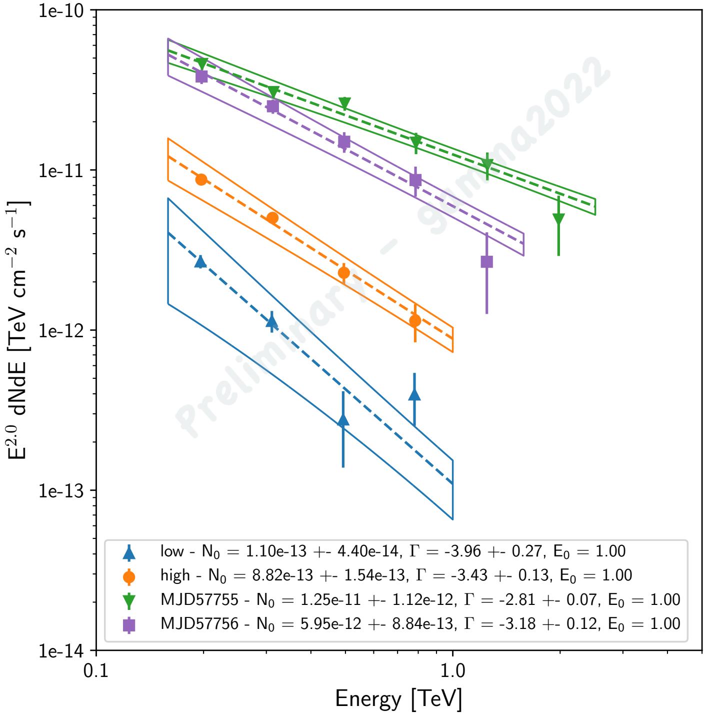
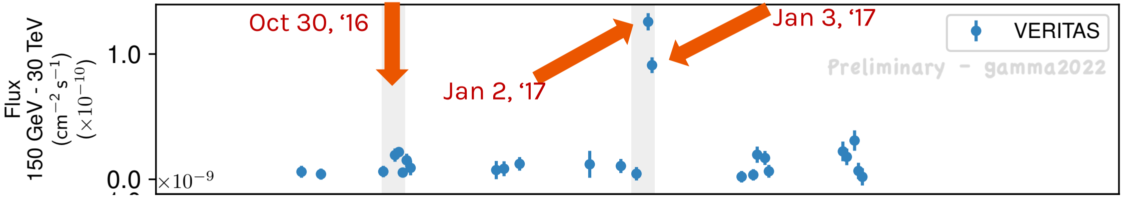
- **Observed events > TeV**

- **Low state very soft**
- **Trend to harder when brighter**
- **Joint Log P fit between Fermi-LAT and VERITAS spectra**





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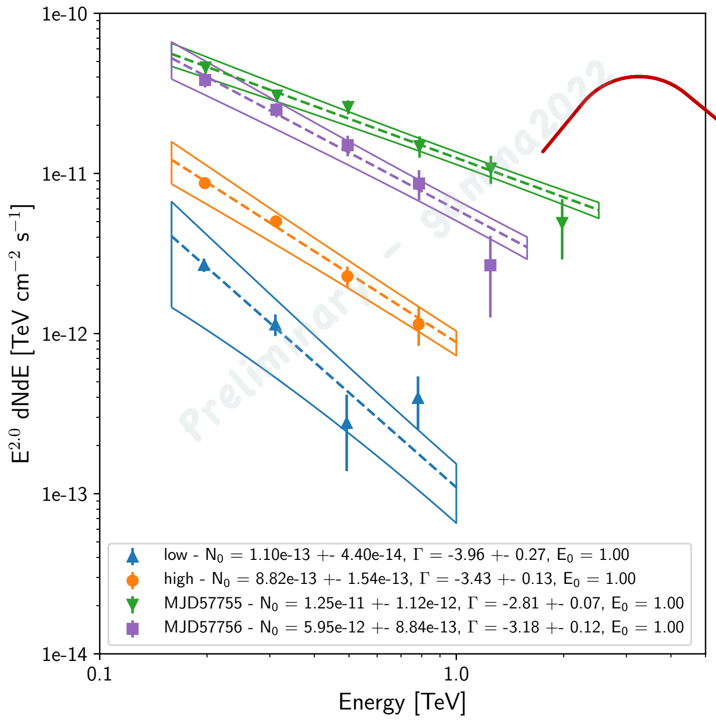
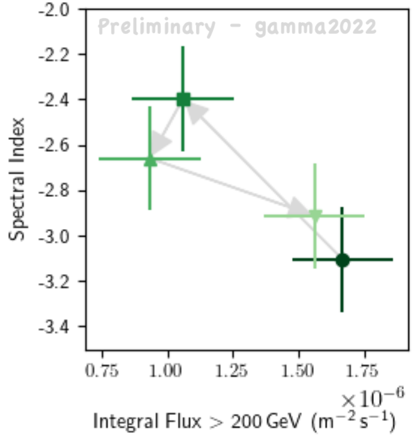
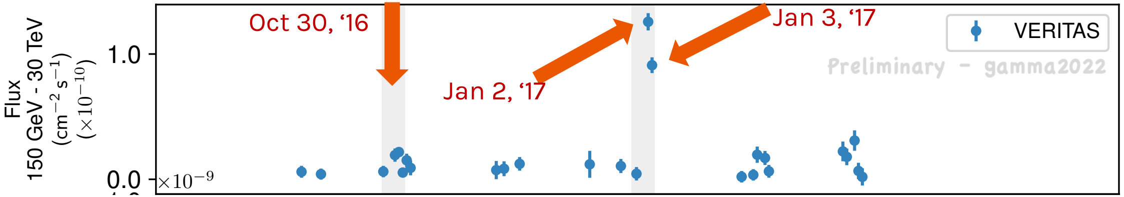
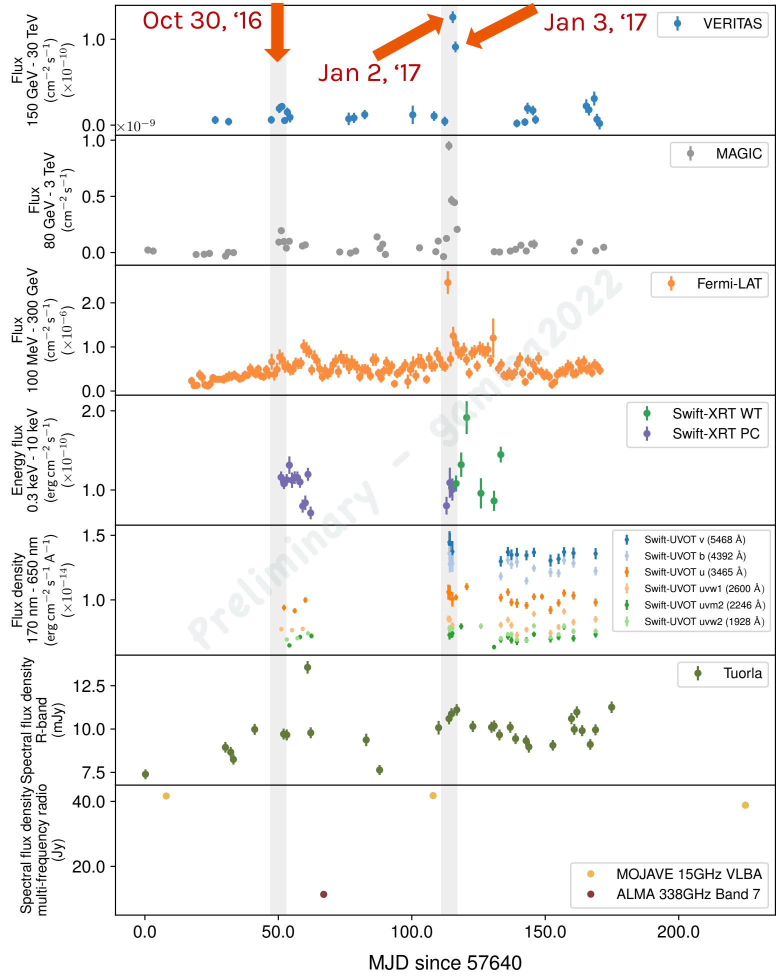






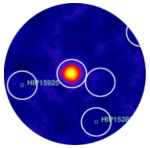
Some evidence for softer-when-brighter evolution during Jan 2, 2017 flare night.

MWL context



VERITAS sky maps

10/30/16



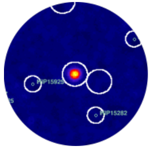
~15% Crab

1/1/17

MAGIC detects flare

~150% Crab

1/2/17



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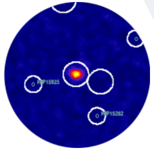
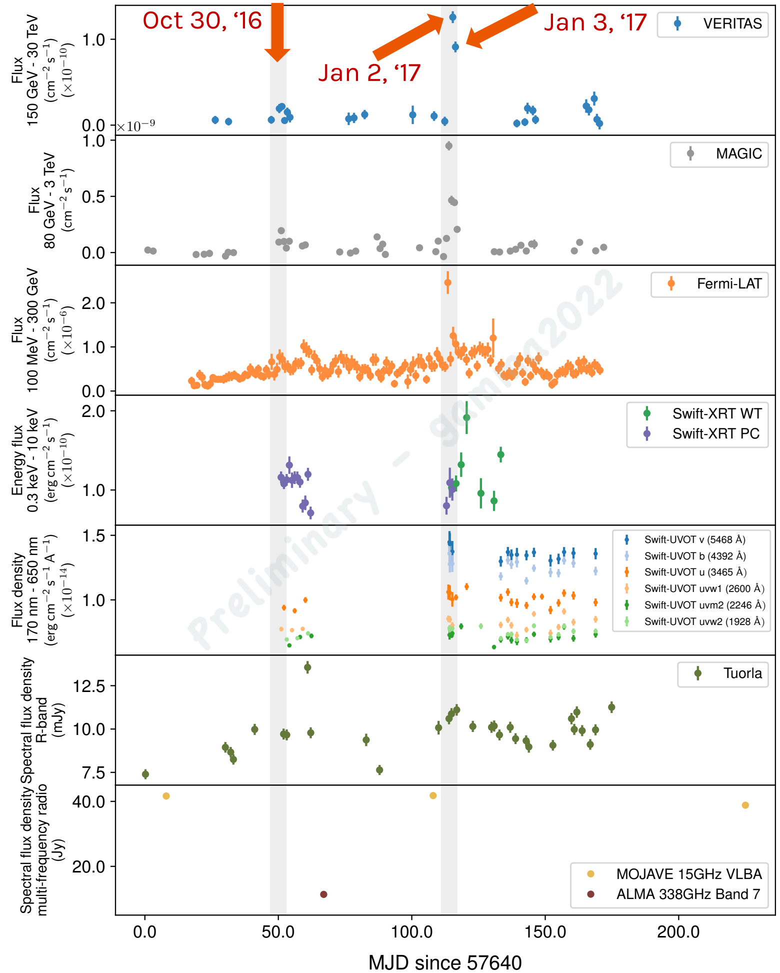


~60% Crab

MWL context



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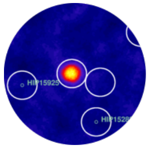

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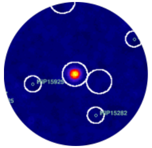

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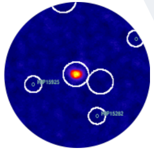

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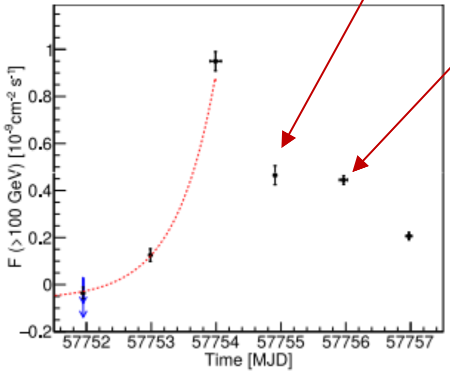
VERITAS overlap with MAGIC

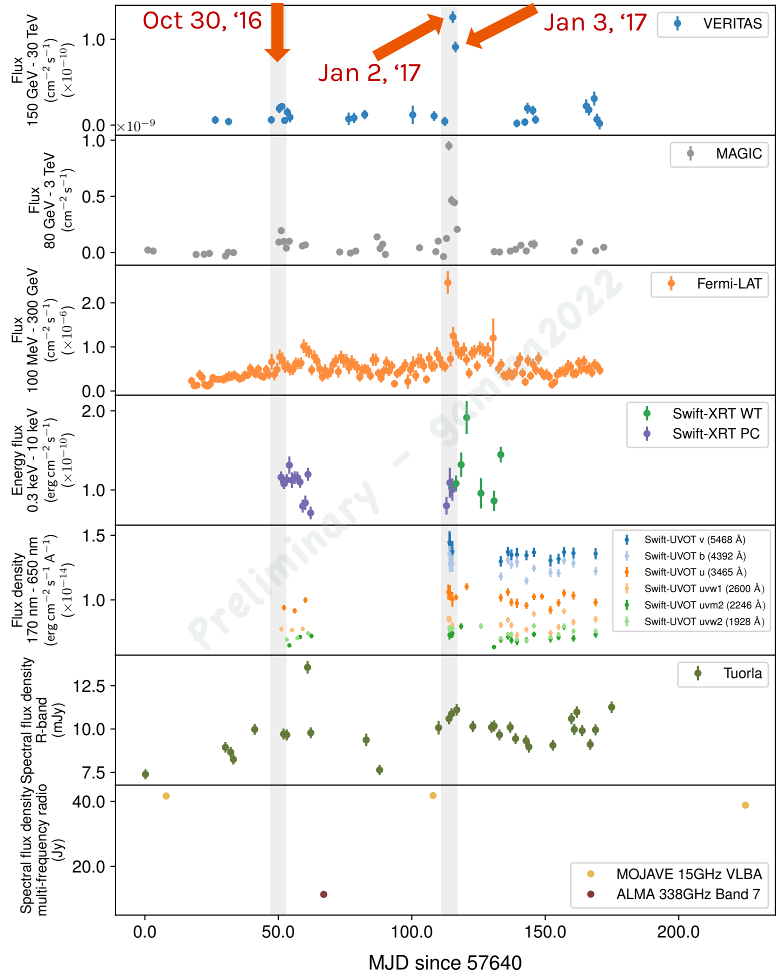


Zoom on MAGIC lightcurve

Minimal variability for doubling flux: (10.2 ± 1.7) h

(MAGIC Collaboration, 2018, A7A, 617, A91)

MWL context



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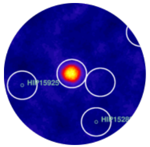

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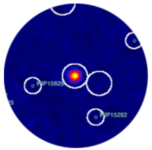

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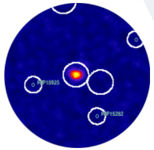

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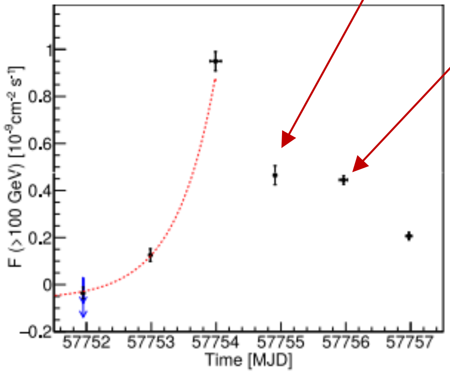

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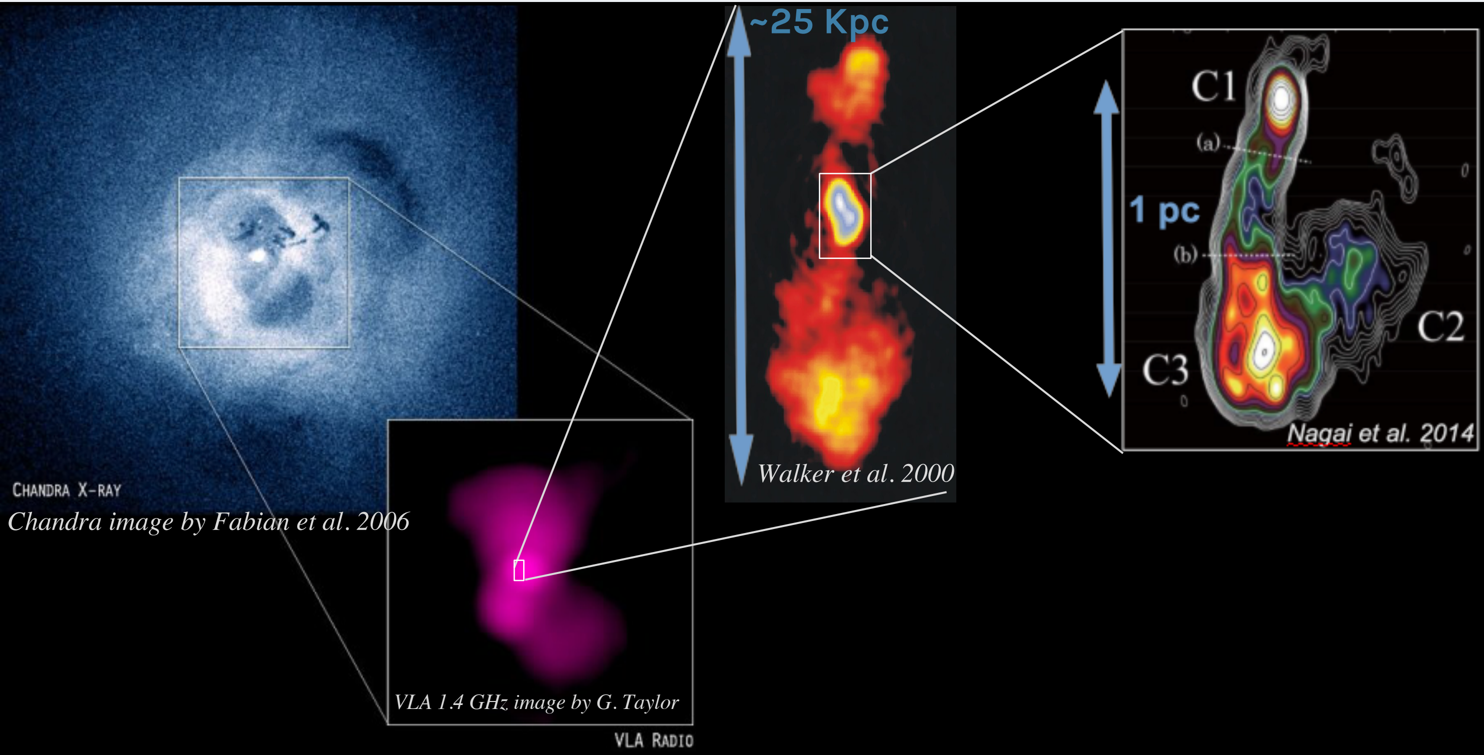
Good MWL data around flare periods

- No significant variability detected in Opt-UV-X during the gamma-ray flare.

"Orphan-flare" conditions

Complex morphology and X-ray environment



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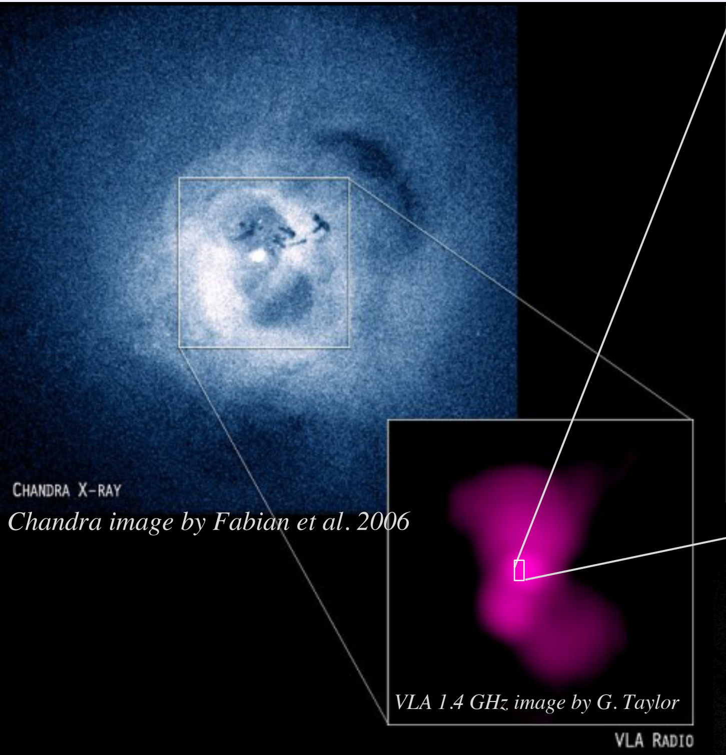
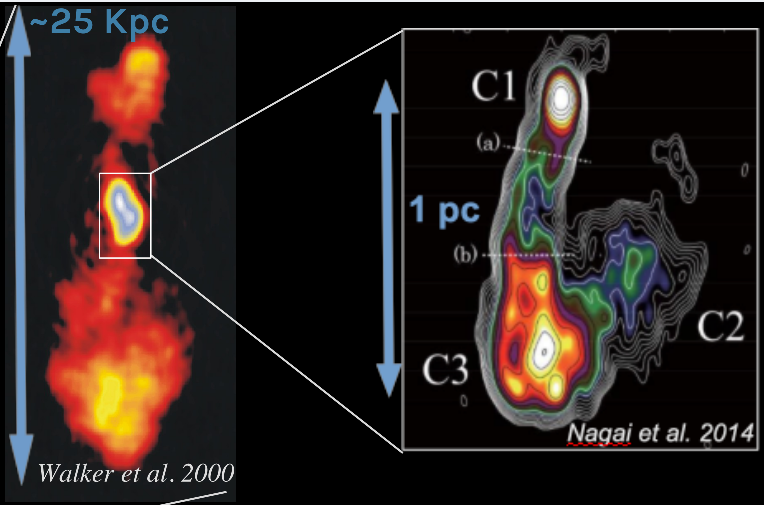


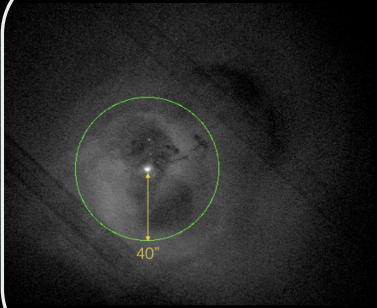


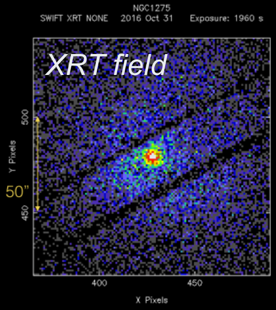
Chandra image by Fabian et al. 2006

VLA 1.4 GHz image by G. Taylor

Walker et al. 2000

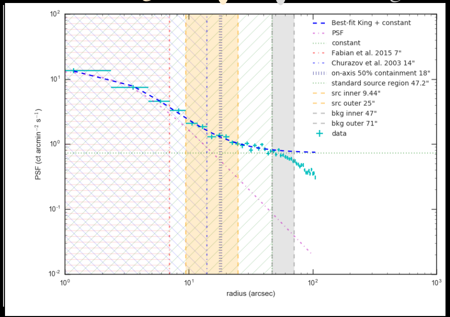
Nagai et al. 2014





Source region

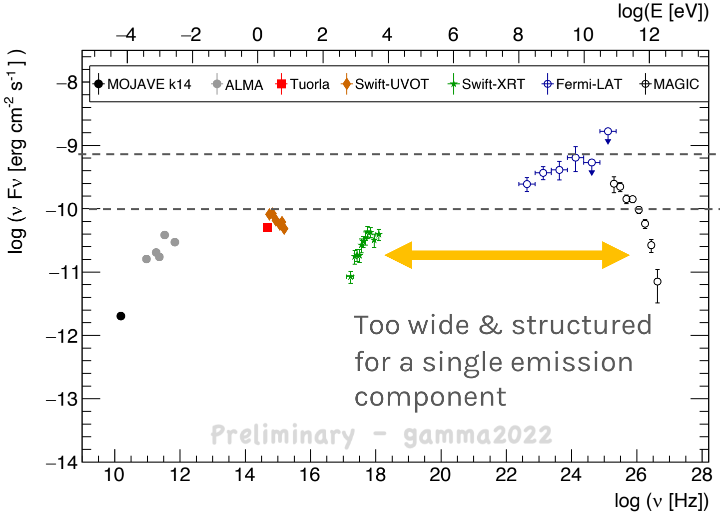
bknd region



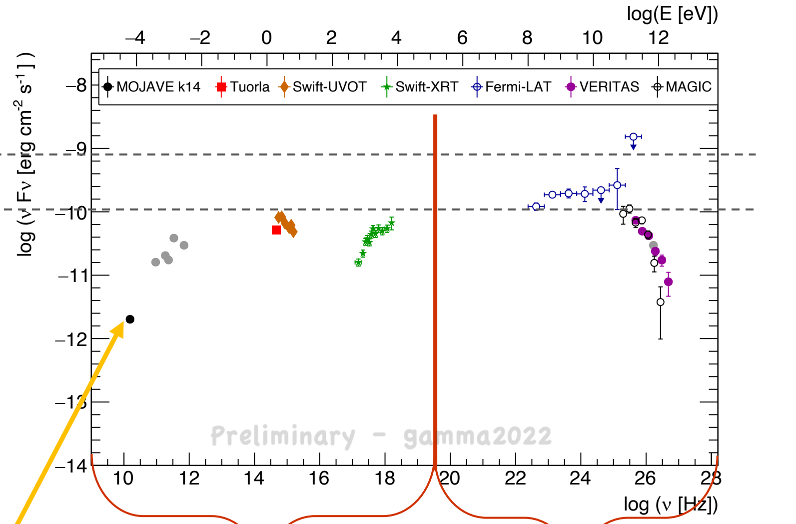
No single PSF function can fit the entire emission

Multiwavelength SEDs of Jan 2017 flare

Dec 31 / Jan 1 (max flare)

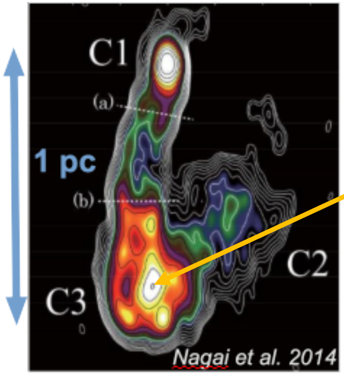


Jan 2 (VERITAS 1st obs.)



Quasi-steady component
→ large/slow zone

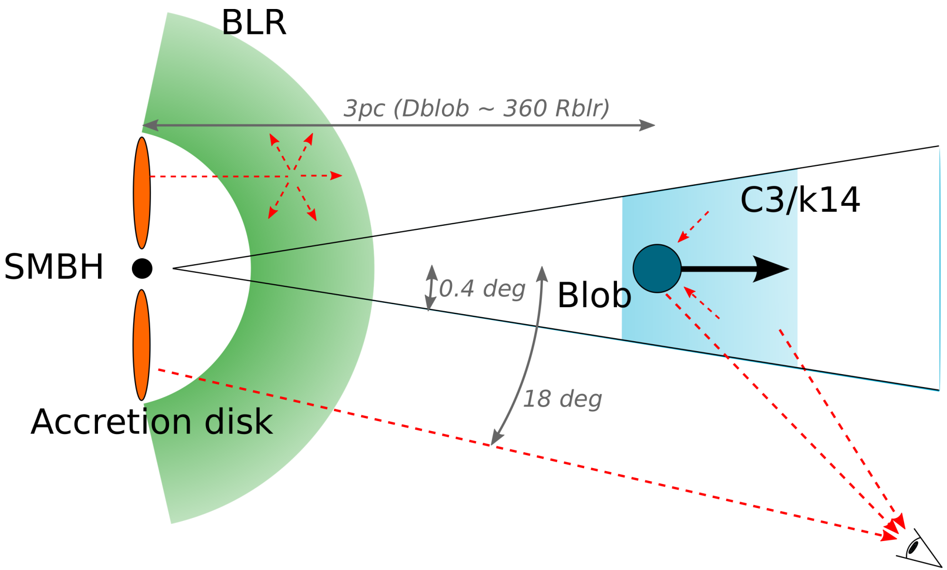
Flaring component
→ compact/fast zone



C3 is the brightest component observed by MOJAVE (k14)

- Fast moving component ejected from core in 2007
- ~3.5 core flux at 15 GHz Dec 26th 2016

Multizone model: "Blob-in-C3"



Model based on *Hervet et al. 2015*

- Consider **blob within C3** at ~ 3pc from the core for an **angle of 18 deg** (*Tavecchio et al. 2014, Giovannini et al. 2018)*
- Blob well **outside the BLR**, thermal External Inverse Compton (EIC) not favored
- ...but possible strong EIC blob/C3
- Weak Doppler boosting: $\delta_{blob} = 3 \; , \; \delta_{C3} = 2$

Multiwavelength SEDs of Jan 2017 flare

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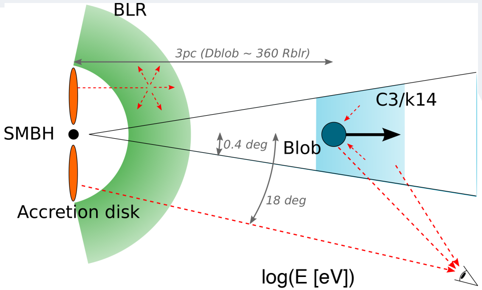
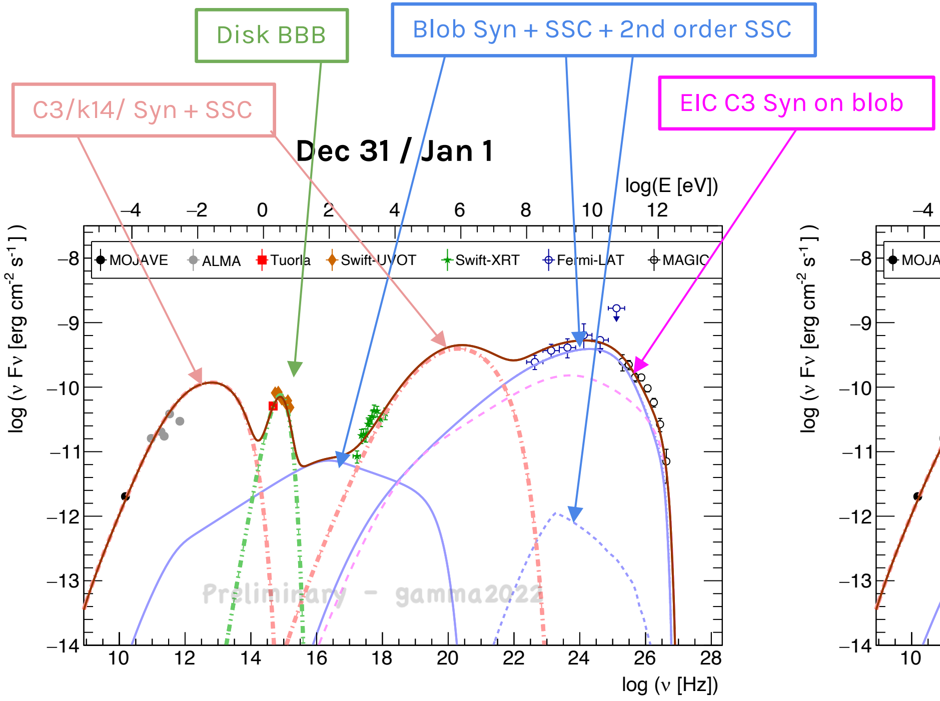
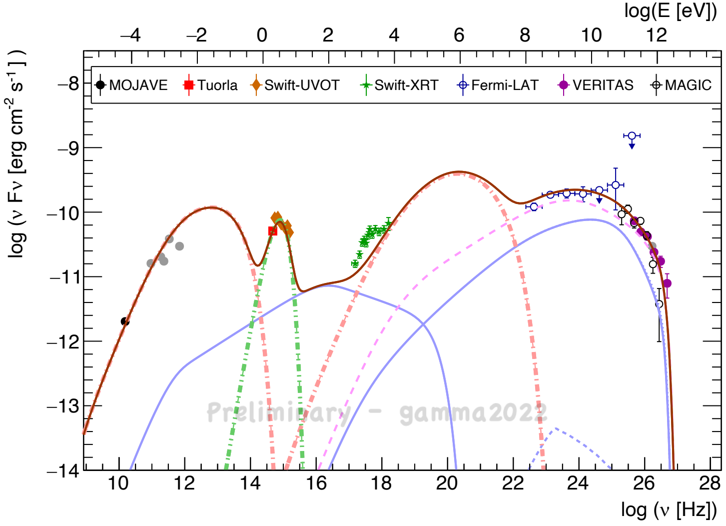




Blob minimal variability = 12h

C3 minimal variability = 12 days

Jan 2

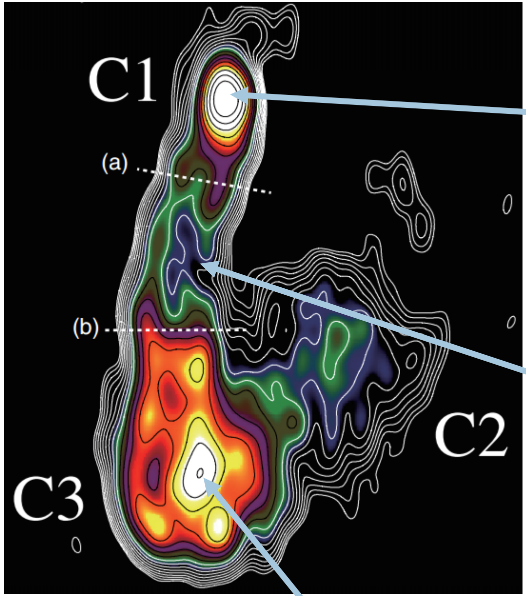


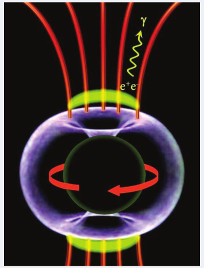
Blob minimal variability = 21h

C3 minimal variability = 12 days

Simple blob adiabatic expansion: $\rho \times V = \mathrm{cst}$

On the gamma-ray origin of NGC 1275





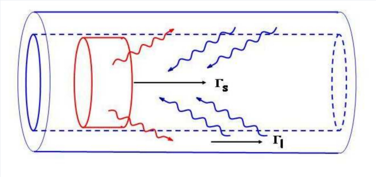
MAGIC Coll. 2018: "black hole lightning"

"The only possibility to fit the enormous luminosity [...] would be an enhancement of the magnetic field threading the BH horizon."

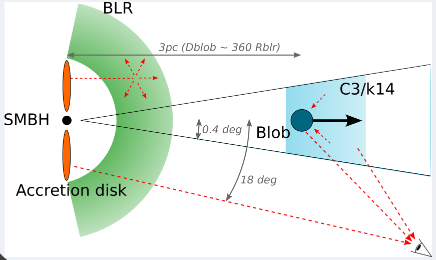
But need a gamma transparent BLR...
No modeling performed.

Tavecchio et al. 2014: "spine-layer"

Produces good SED fit but requires low variability
(>1 week for previous NGC 1275 study)

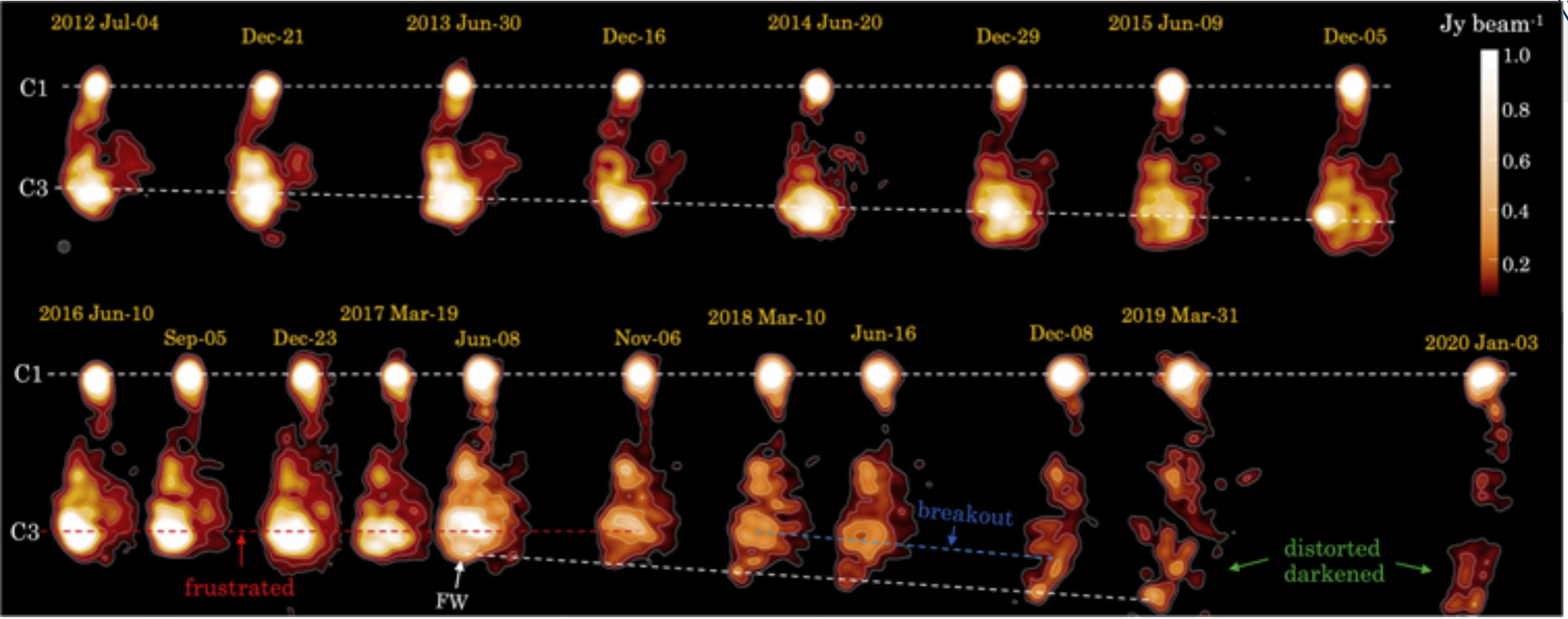


Blob-in-C3 model



- Good SED fit and fast variability with a relatively low power budget
- Geometrically constrained
- Would quickly reach its limits for a larger angle

Link between gamma-ray origin and radio evolution?



Kino et al 2021

1. Hotspot associated with C3 enters ”frustrated” phase for 1.3 years during period of increased gamma-ray flux
2. New component (FW) seen emerging towards end of frustrated phase in data 3 months after Jan ‘17 VHE flare

Could this help explain lack of simultaneous x-ray flare?

Summary

- **VERITAS long-term monitoring of NGC 1275**
  - Enables comparison of low/high VHE states
  - Compiled unprecedented multi wavelength data set over 8 years
- **January 2017 flare**
  - 150% Crab (MAGIC) -> 60% Crab (VERITAS, MAGIC)
  - Simultaneous VHE, HE and X-ray data point to orphan gamma-ray flare
    - Apparent delayed flare in X-ray is still puzzling
  - Multizone blob in jet model can account for ~day-scale evolution of SED with moderate angle to line-of-sight (18 deg)
    - Model difficulties beyond 18 deg – published range for NGC 1275 up to 65 deg
- **Goal: Radio Galaxies as mis-aligned “blazars” for improved understanding of jet physics**
  - The origin of VHE emission from radio galaxies is still not clearly understood, contradictory observations:
    - Large angle with the line of sight = weak (no) Doppler boosting
    - VHE production & fast variability = significant Doppler boosting

Precise estimation of radio galaxy pc-jet direction is critical for understanding the origin of gamma-rays