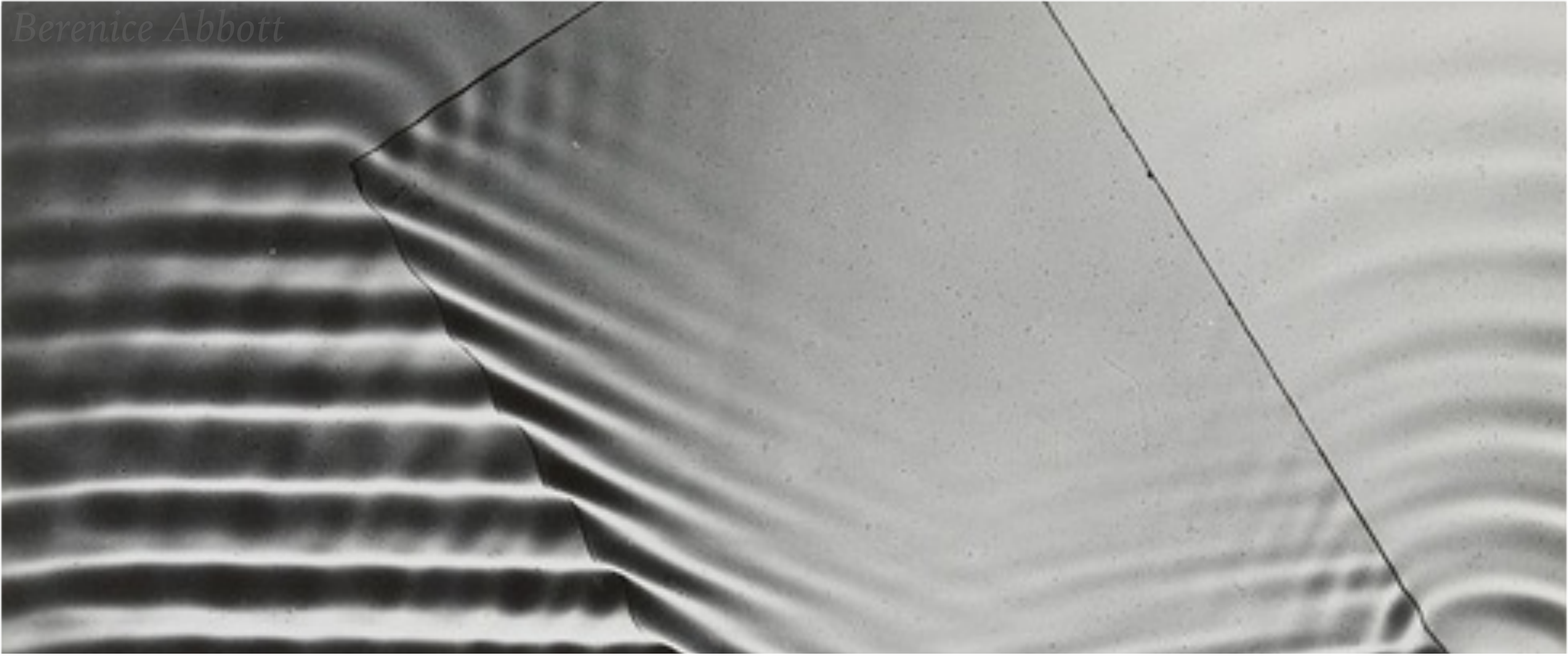


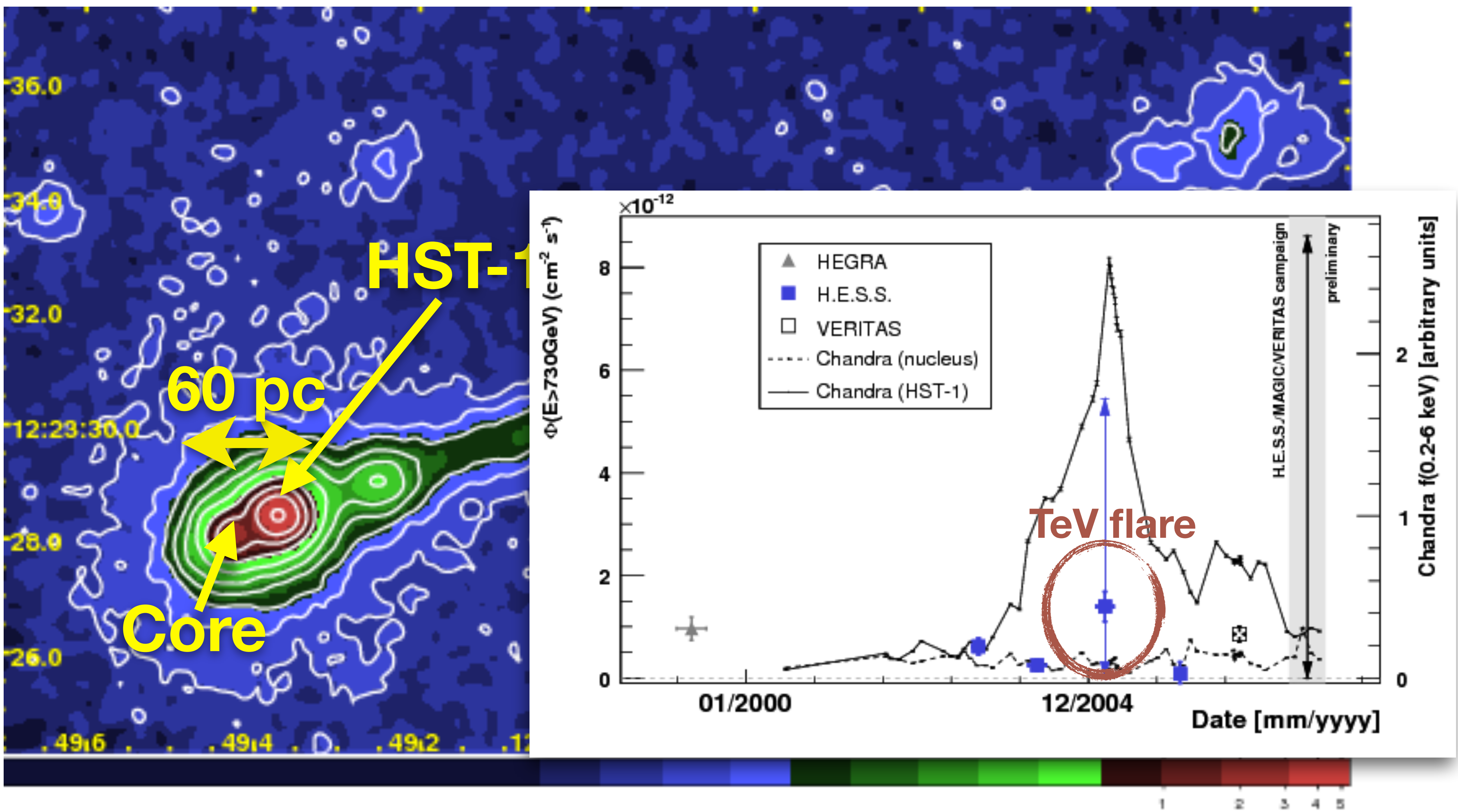
THE STORY OF STRONGLY LENSED JETS AND COSMOLOGY

Anna Barnacka
Einstein Fellow at Harvard

EXTRAGALACTIC JETS – M87

Increased x-ray emission by a factor of 50 from the HST-1 knot (Harris et al. 2006,2009)

Core and HST-1: Separation ~ 60 pc

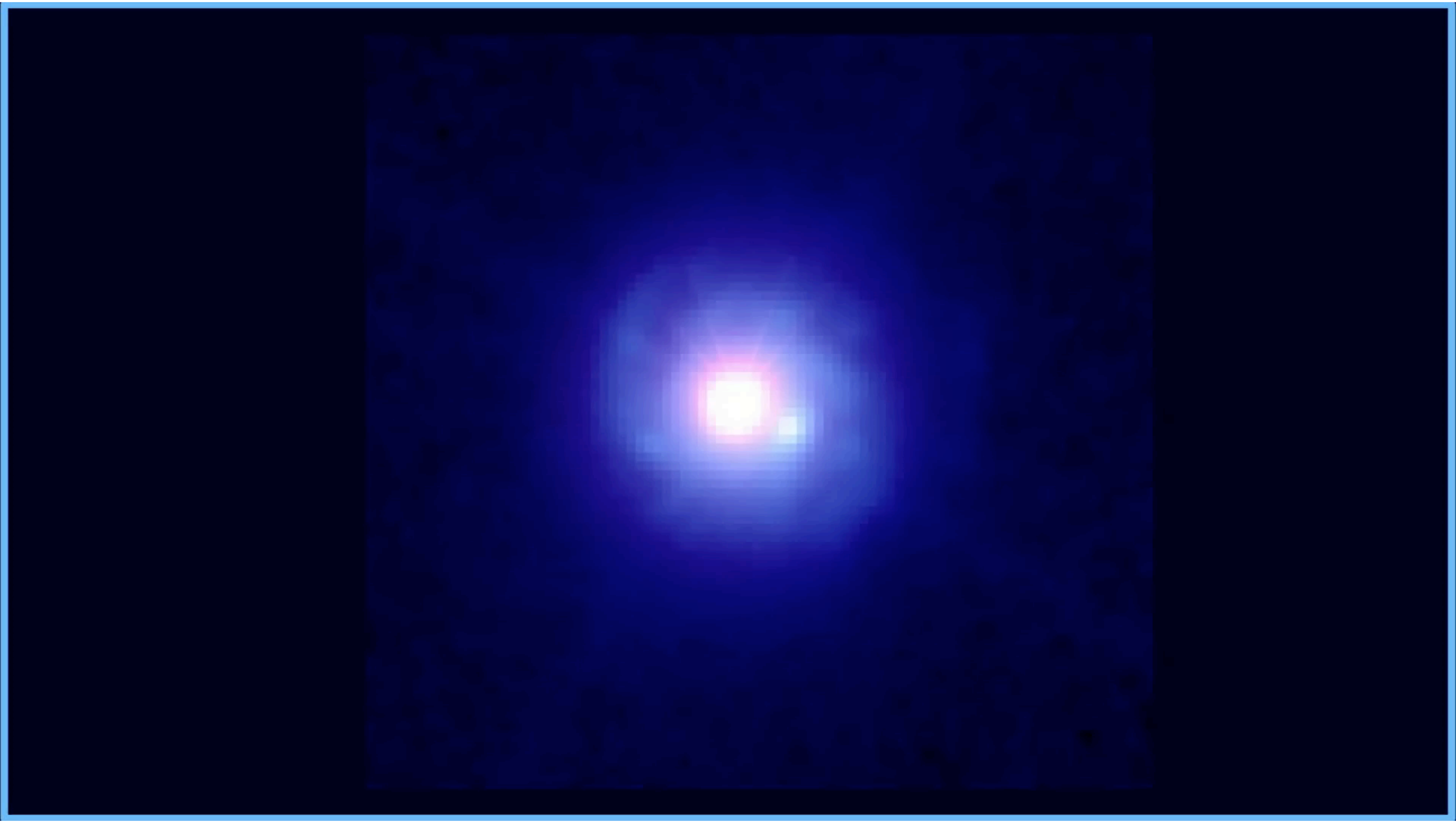


Flares from knots along the jets

SCIENTIFIC CHALLENGES

- Frequency of M87-like variability
- Origin of gamma-ray flares

GRAVITATIONALLY LENSED JETS



Credit: NASA's Goddard Space Flight Center

M87 AT Z=1

*Differences between the **core** and the **HST-1**:*

difference in time delay: ~ 2 days

GAMMA-RAY SPATIAL RESOLUTION

- Einstein Symposium 2015: **PKS 1830-211**
  Effective Spatial Resolution ~ **0.02”** (~ HST)
  Barnacka, A., et al. (2015, ApJ, 809, 100)

- What if we could resolve gamma-ray emission with resolution of radio telescopes: ~**0.001”**?

COSMIC SCALE

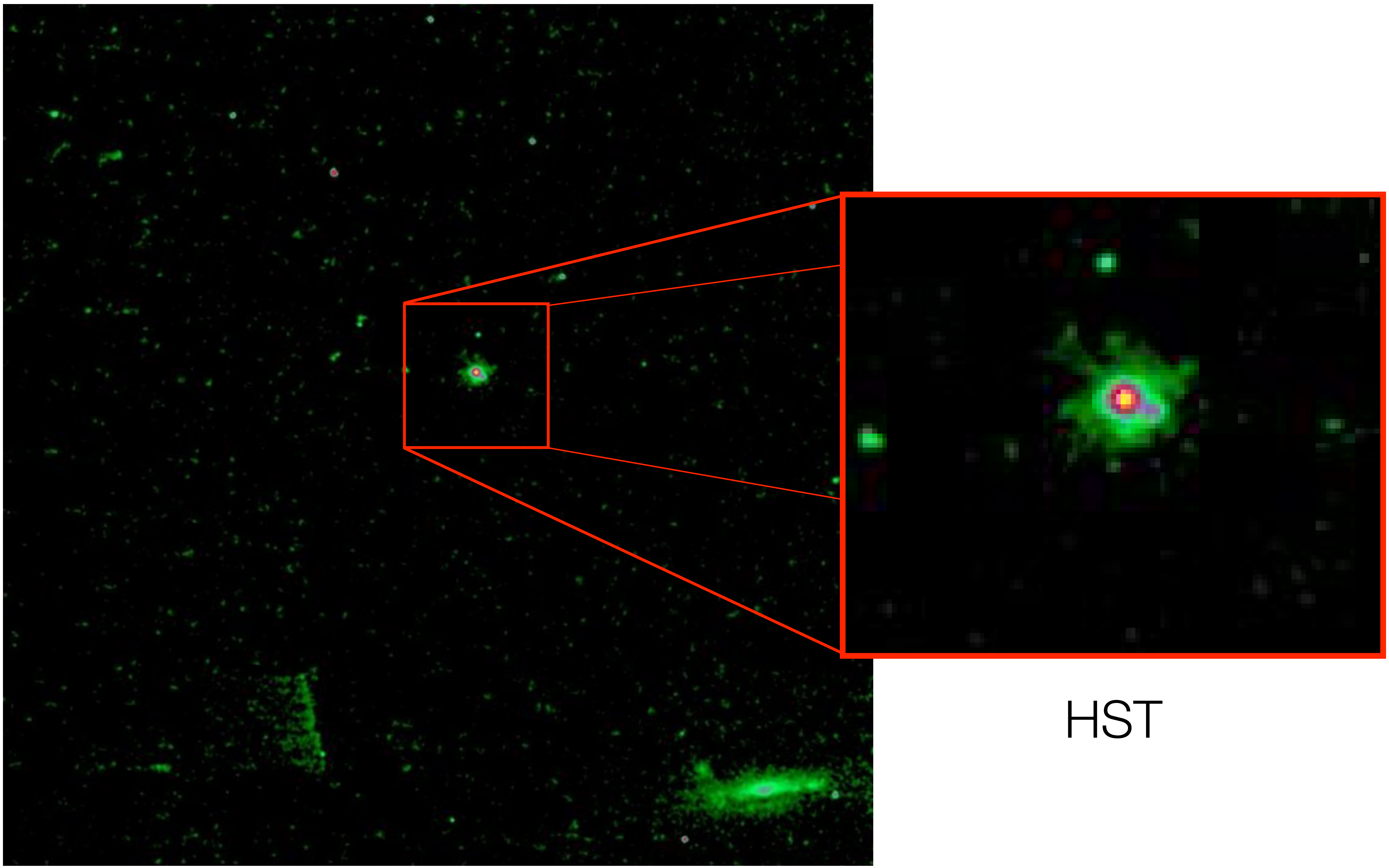
Time Delay + Position of the Images + Lens Model

Cosmic Scale: Hubble Parameter

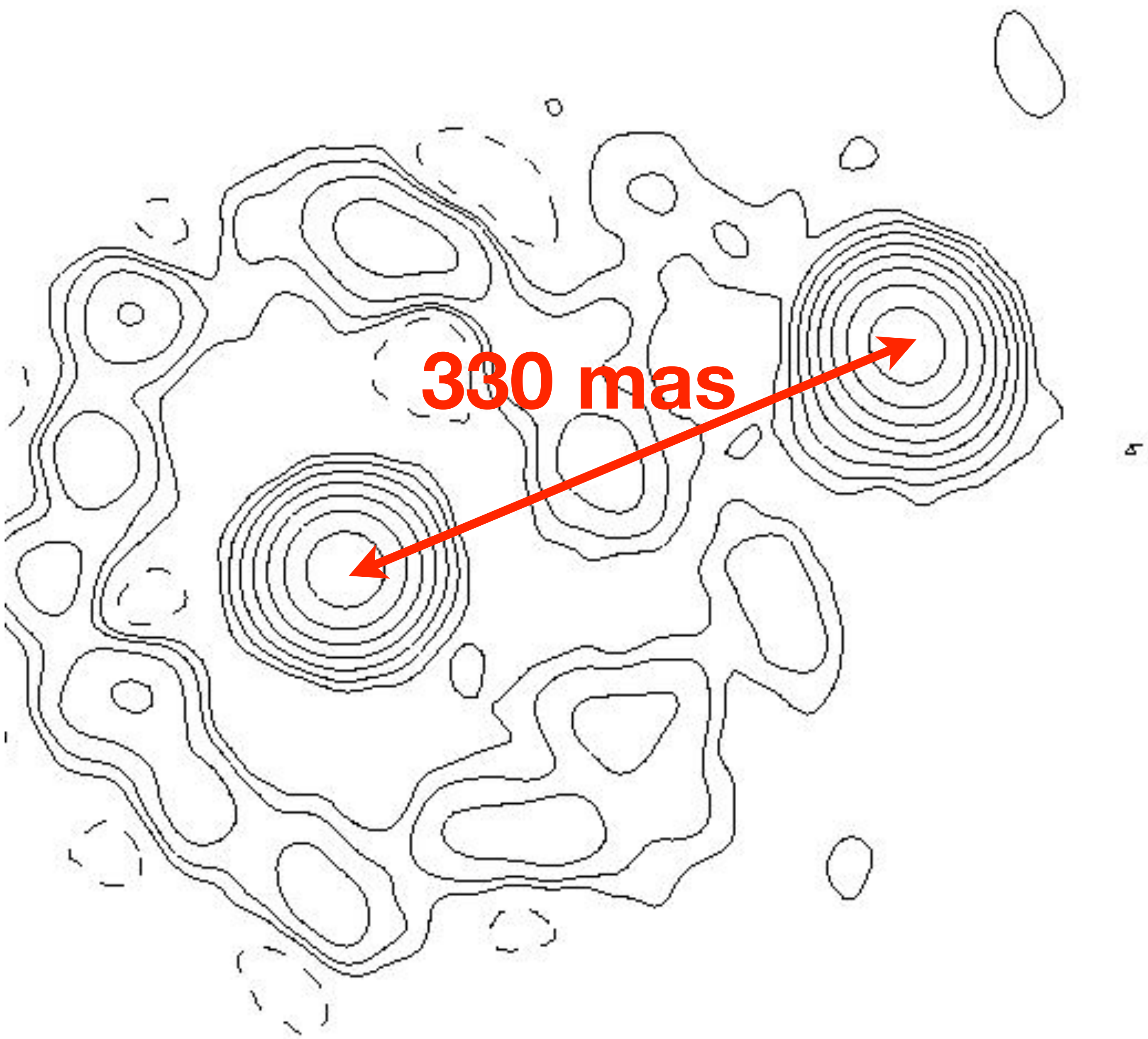
Offset between the resolved emitting region and the variable emitting region

Barnacka, A., Geller, M., Dell'Antonio, I., & Benbow, W. (2015,ApJ,799,48)

OBSERVATIONS: B2 0218+35



LENSED BLAZAR: B2 0218+35



1.687 GHz, Patnaik et al. (1992)

Source z = 0.944,

Lens z = 0.6847

Radio Time Delay

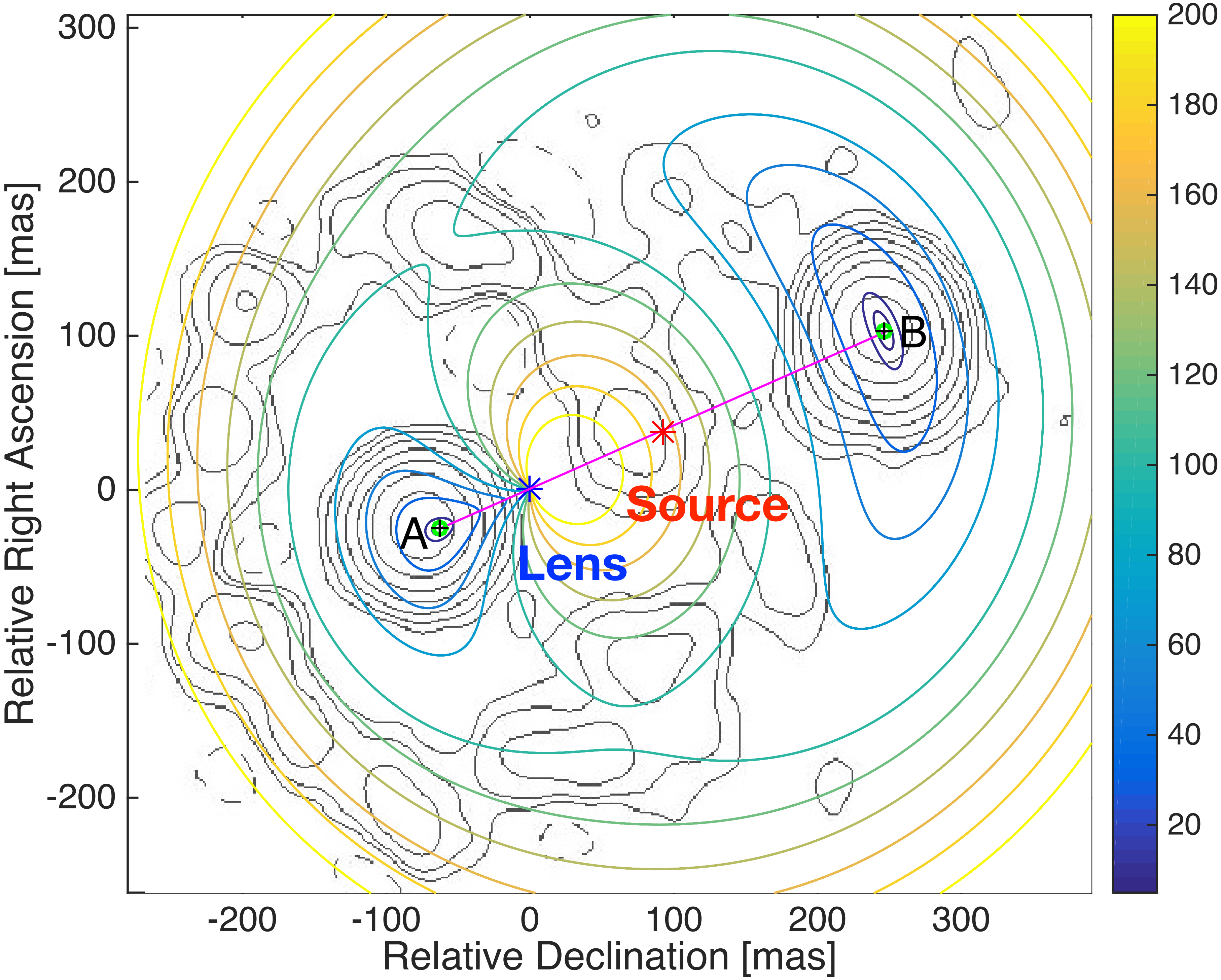
10.5±0.5 days

Magnification Ratio

3.62±0.06

Radial Jet Projection

LENS MODELING

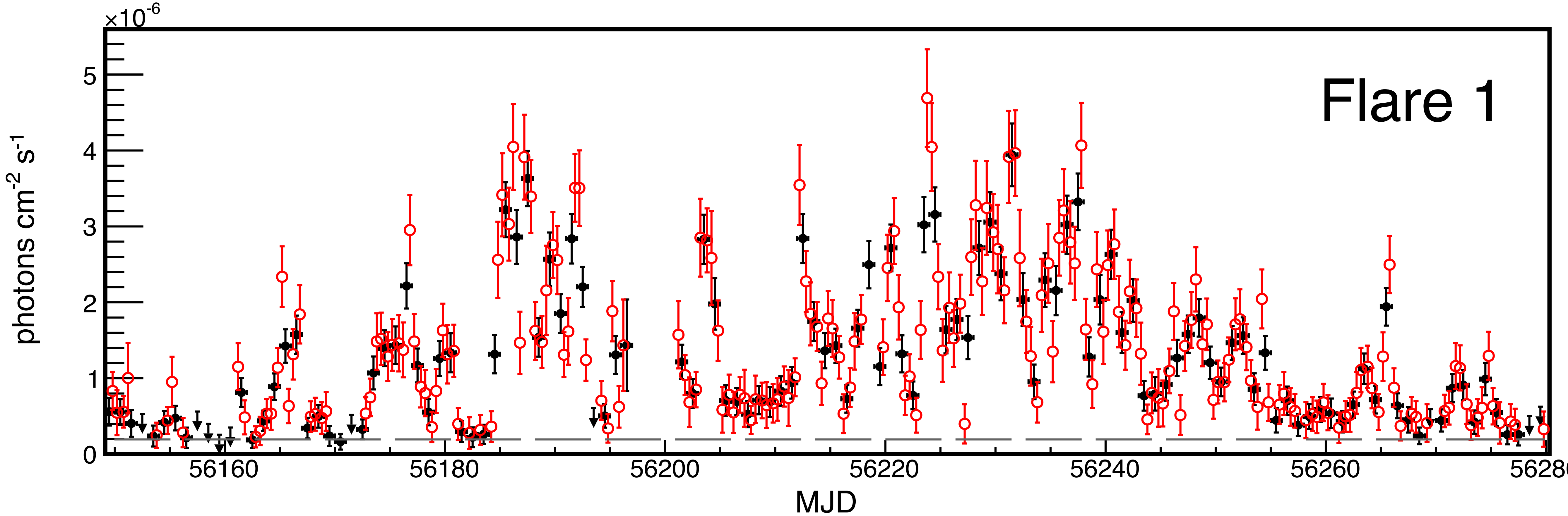


Reconstruction

~ 1 milliarcsecond

Barnacka et al. 2016, ApJ, 821, 58

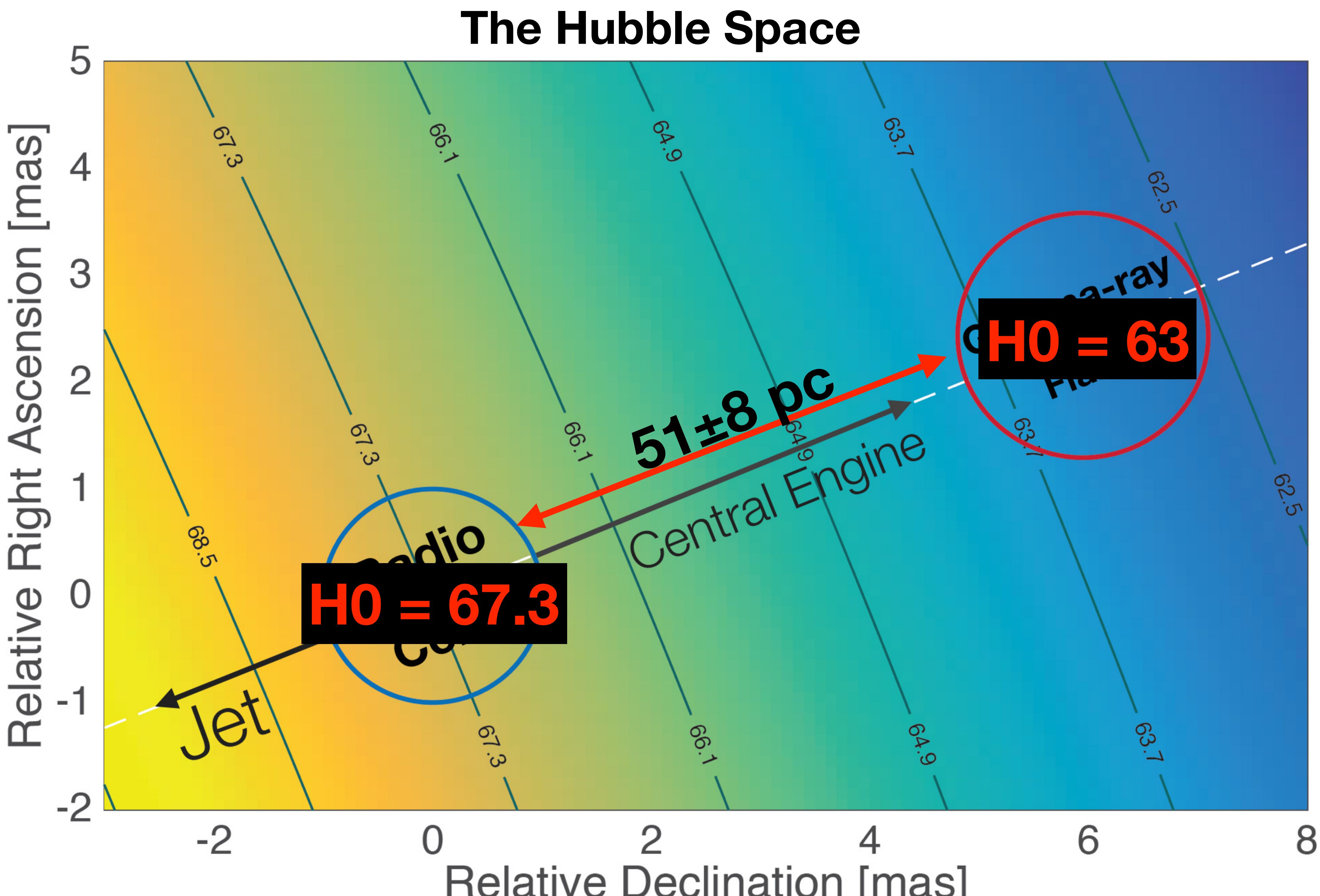
GAMMA-RAY TIME DELAY



Time Delay = 11.38±0.13 days (Barnacka et al.,2016)

Time Delay = 11.46±0.16 days (Cheung et al. 2014)

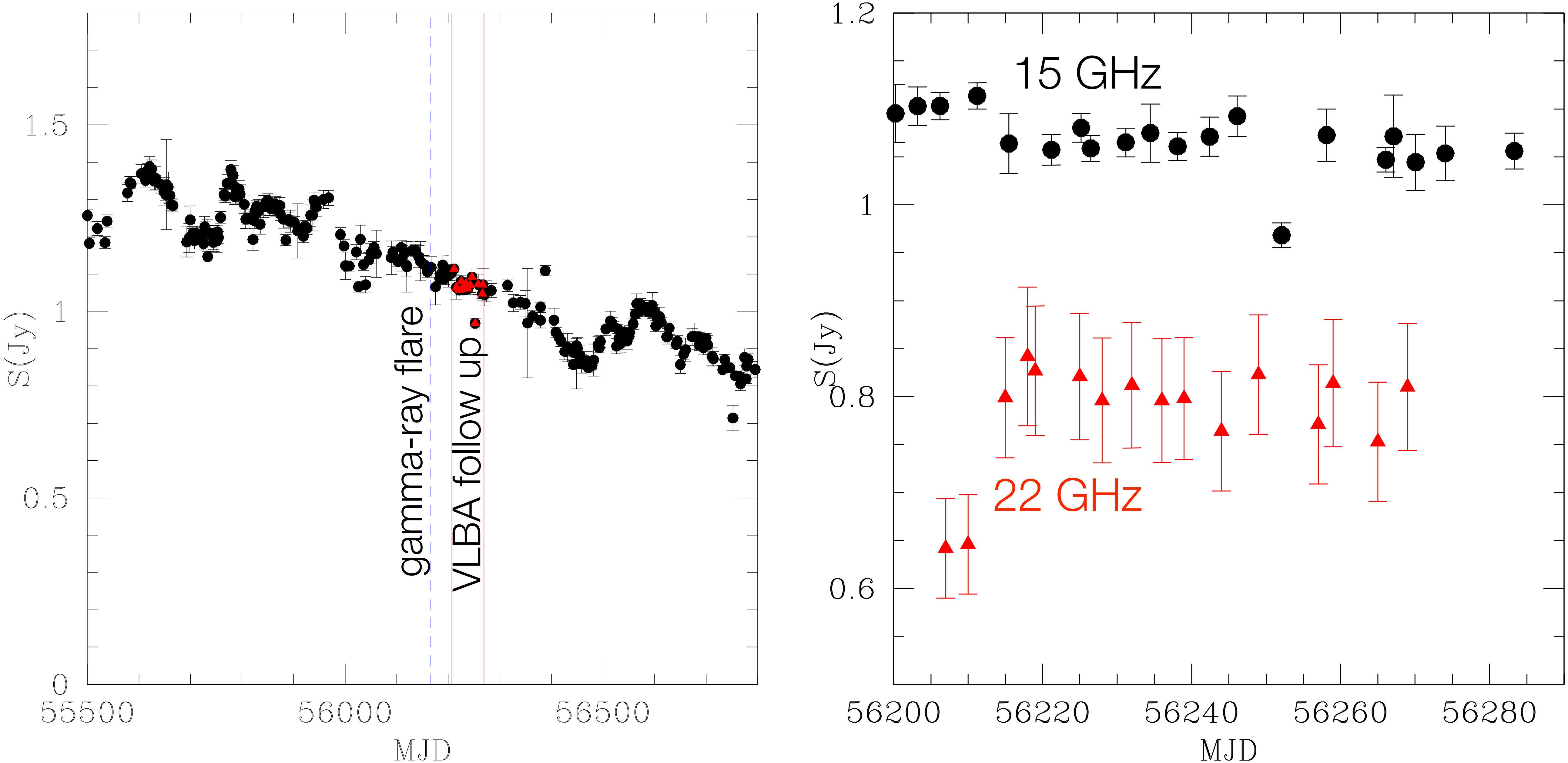
HUBBLE CONSTANT & GAMMA-RAY SOURCE CONNECTION



Barnacka et al. 2016, ApJ, 821, 58

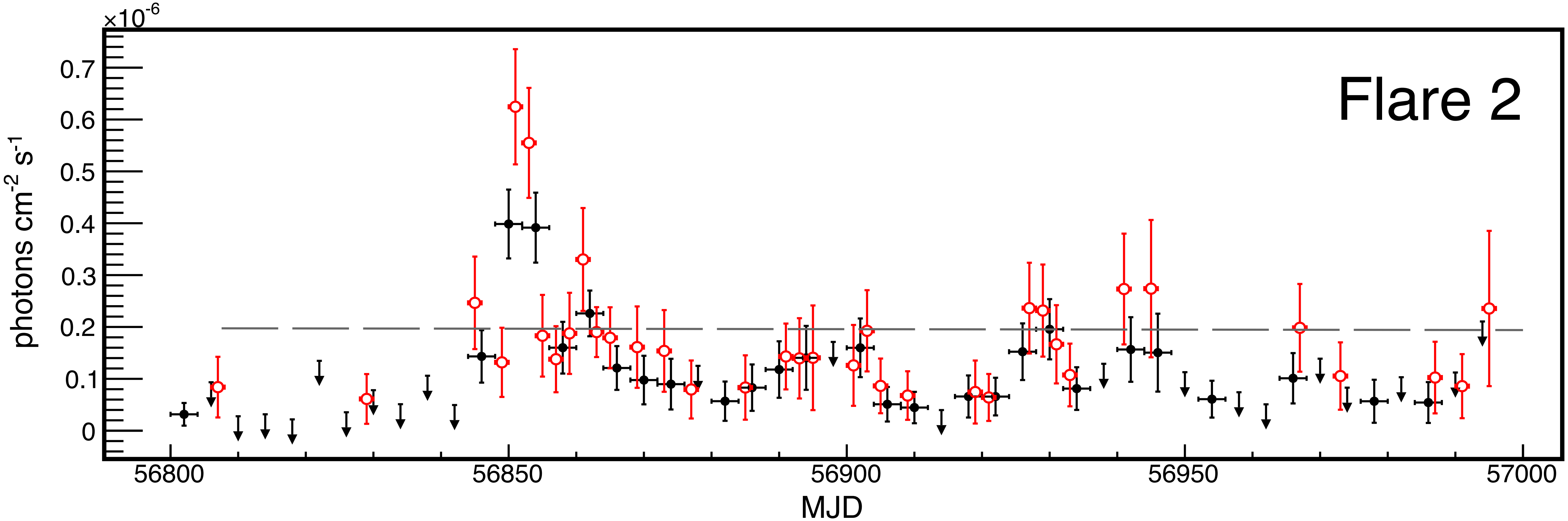
RADIO FOLLOW UP

40 M Telescope at the Owens Valley Radio Observatory (OVRO)



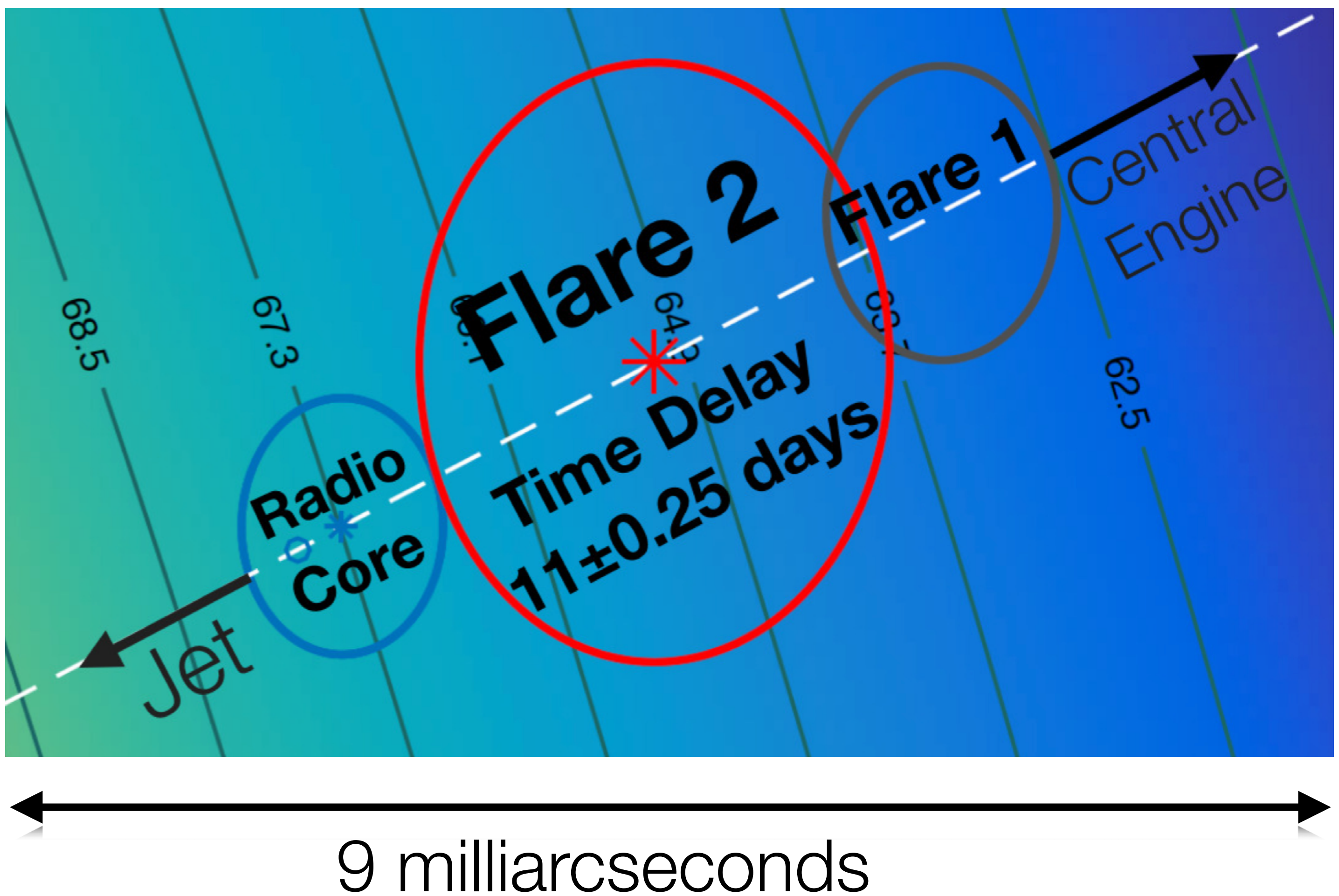
Spingola et al. (2016)

GAMMA-RAY FLARE 2



FUTURE FLARES

If Flare 1 and Flare 2 connected:



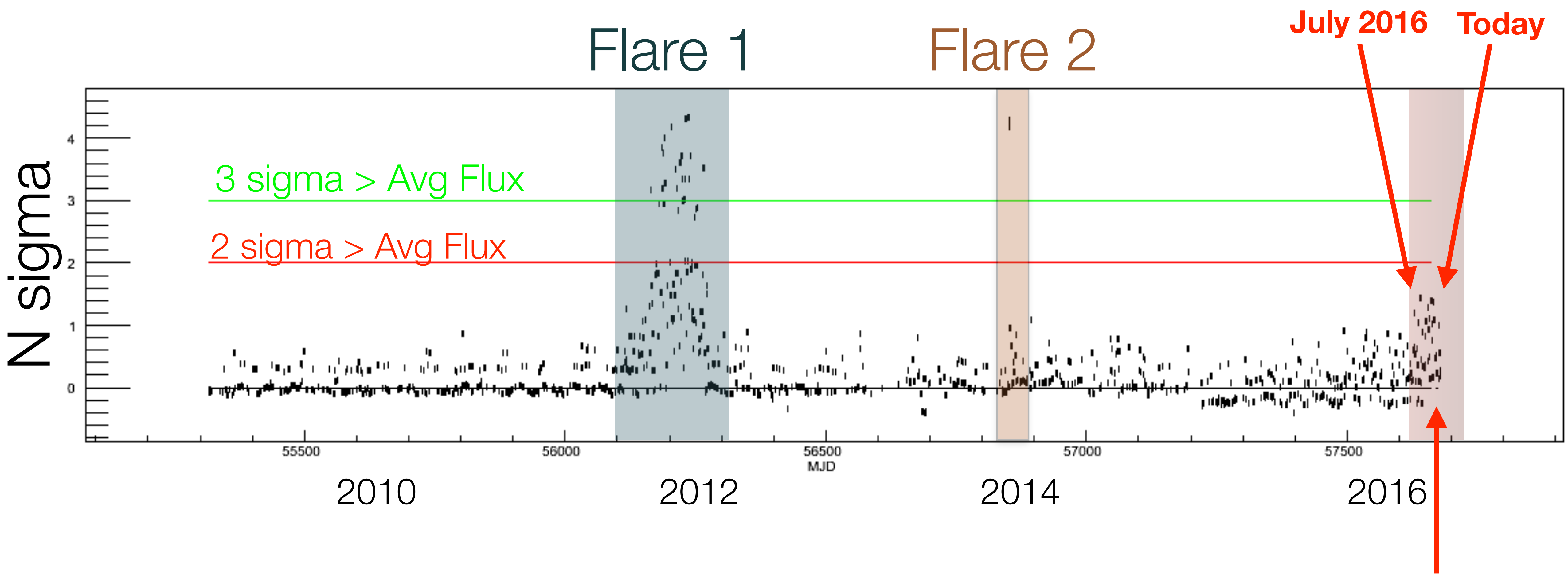
$$\beta_{app} = \frac{D_{projected}(1+z_S)}{c\,\Delta t_{obs}}$$

$$\approx 70\left(\frac{D_{projected}}{24\,\mathrm{pc}}\right)\left(\frac{\Delta t_{obs}}{690\,\mathrm{days}}\right)$$

If plasmoid continues its motion:

interaction with radio core ~ **July 2016**

MONITORING OF B2 0218+35 AT GAMMA RAYS



Since July 2016, 3 x more gamma-ray photons

THE TOOLS

- Radio:
    - Excellent Angular Resolution
- Gamma Rays:
    - Excellent Temporal Resolution
- Hubble Parameter:
    - Cosmic Scale
- Gravitational Lensing:
    - **Combines the Above**

THE RESULTS

- Multiple Time Delays: Source of Systematics for H0
- Spatial resolution at gamma rays:
    - ~1 milliarcsecond
- Gamma-ray Flares not from Radio Core
- Radio Core not at Central Engine
- Prediction of Future Flares

Backup Slides

THE HUBBLE PARAMETER TUNING APPROACH

The Hubble parameter enters into distance ratio in the time delay calculation:

$$D \equiv \frac{D_{OL} D_{OS}}{D_{LS}} = h d$$

where: $\mathrm{H}_0 = h \times 100\,\mathrm{km\,s^{-1} Mpc^{-1}}$

For an Singular Isothermal Sphere gravitational potential :

$$h = \frac{d(1+z_L)(\theta_B^2 - \theta_A^2)}{2c\,\Delta t}$$

Mirage Image B

Mirage Image A

Time Delay between mirage image A and B