Resolving the High Energy Universe with Strong Gravitational Lensing

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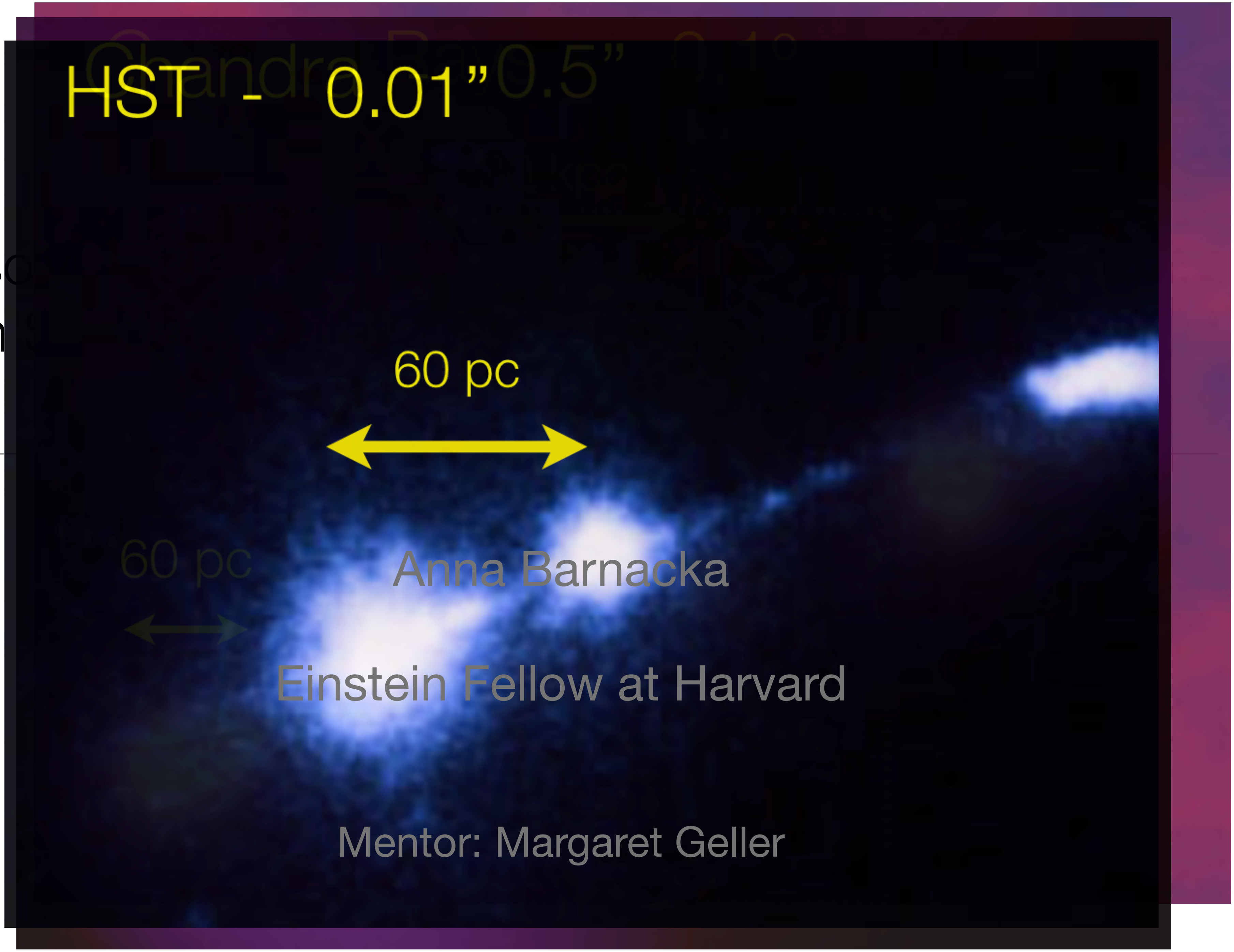
Reso
with


HST - 0.01"
60 pc
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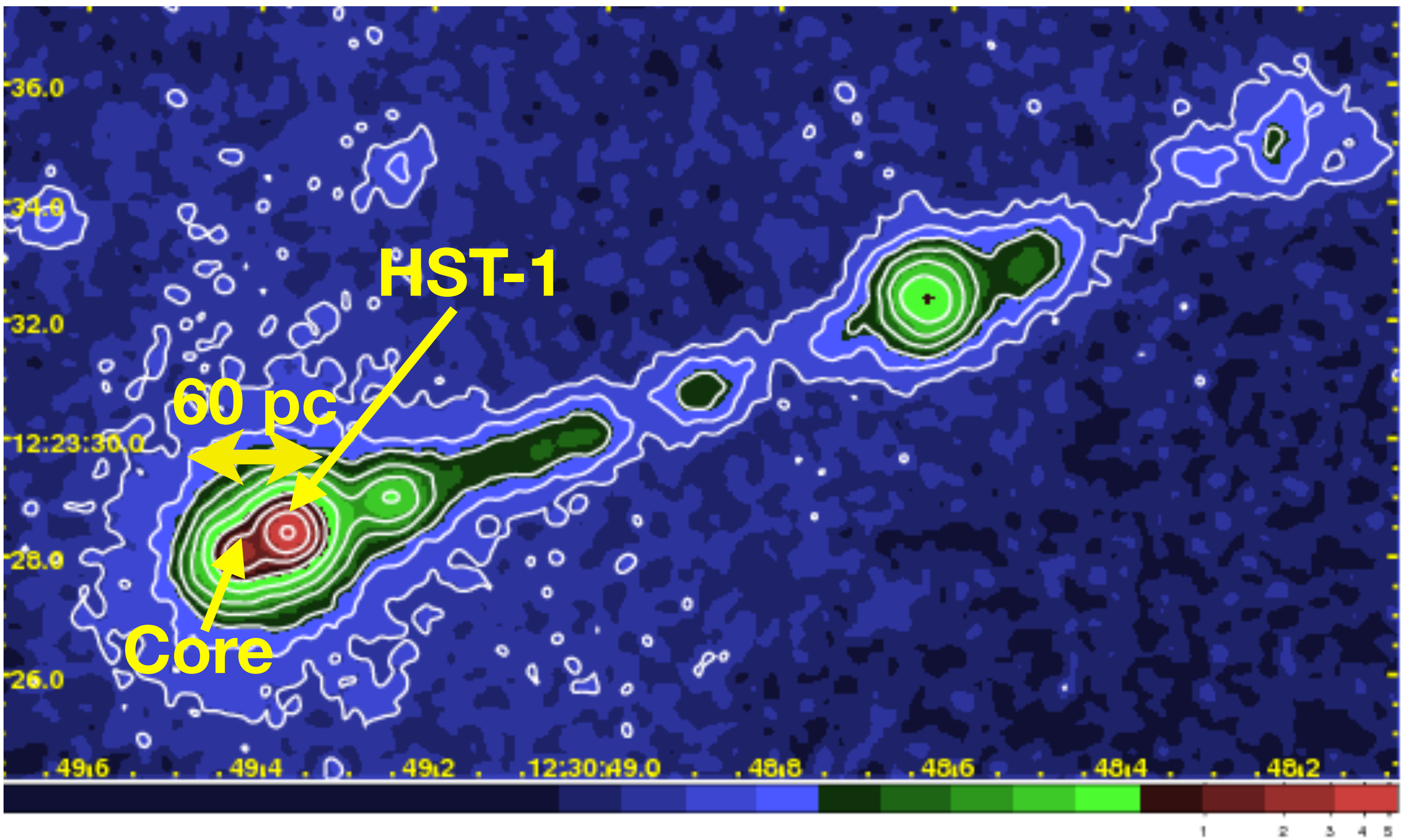
X-Ray Jets - Lessons from Chandra

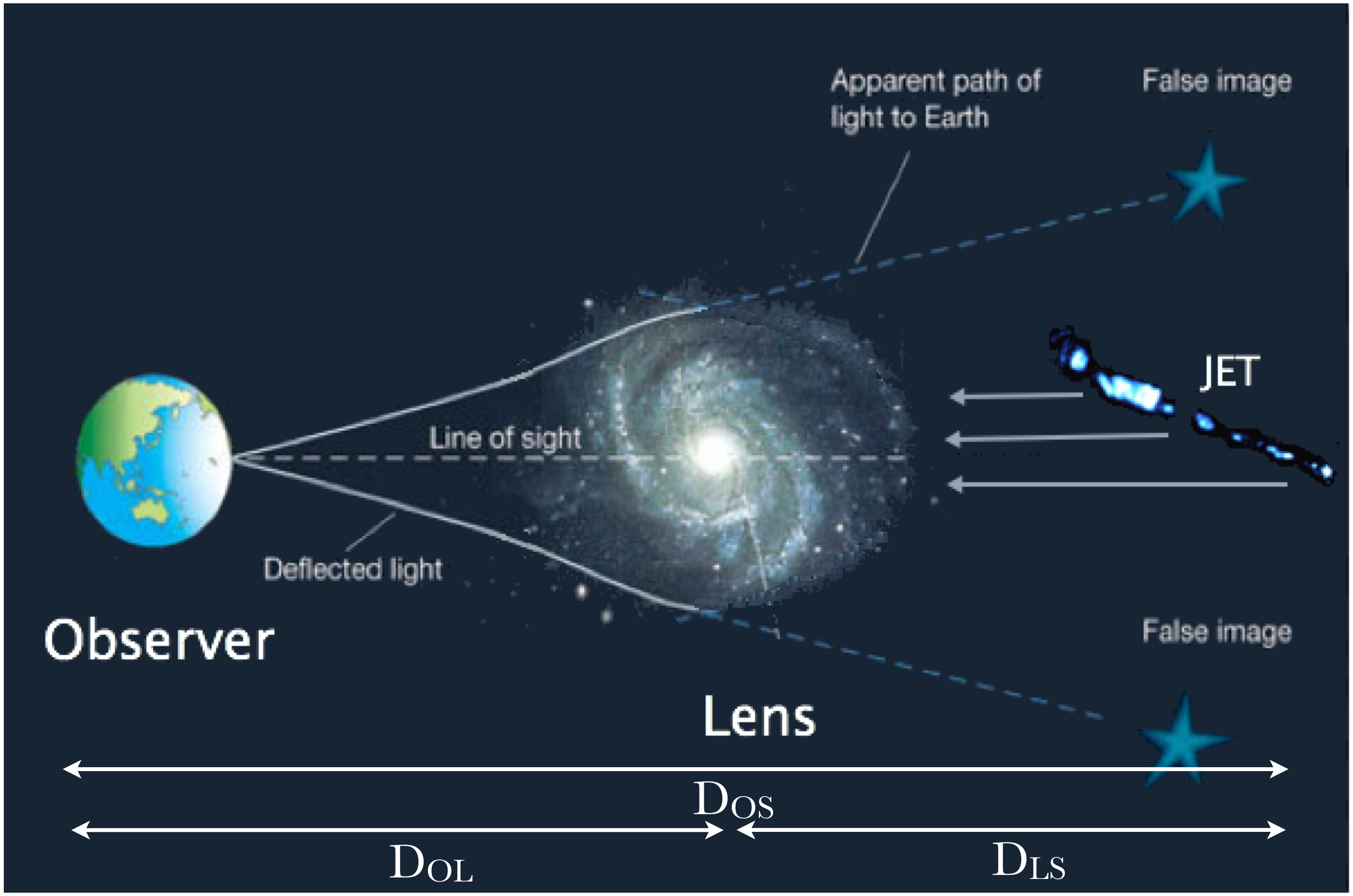
Increased x-ray emission by a factor of 50 from the HST-1 knot (Harris et al. 2006,2009)

Core and HST-1: Separation ~ 60 pc



Flares from knots along the jets

M87 Gravitationally Lensed?



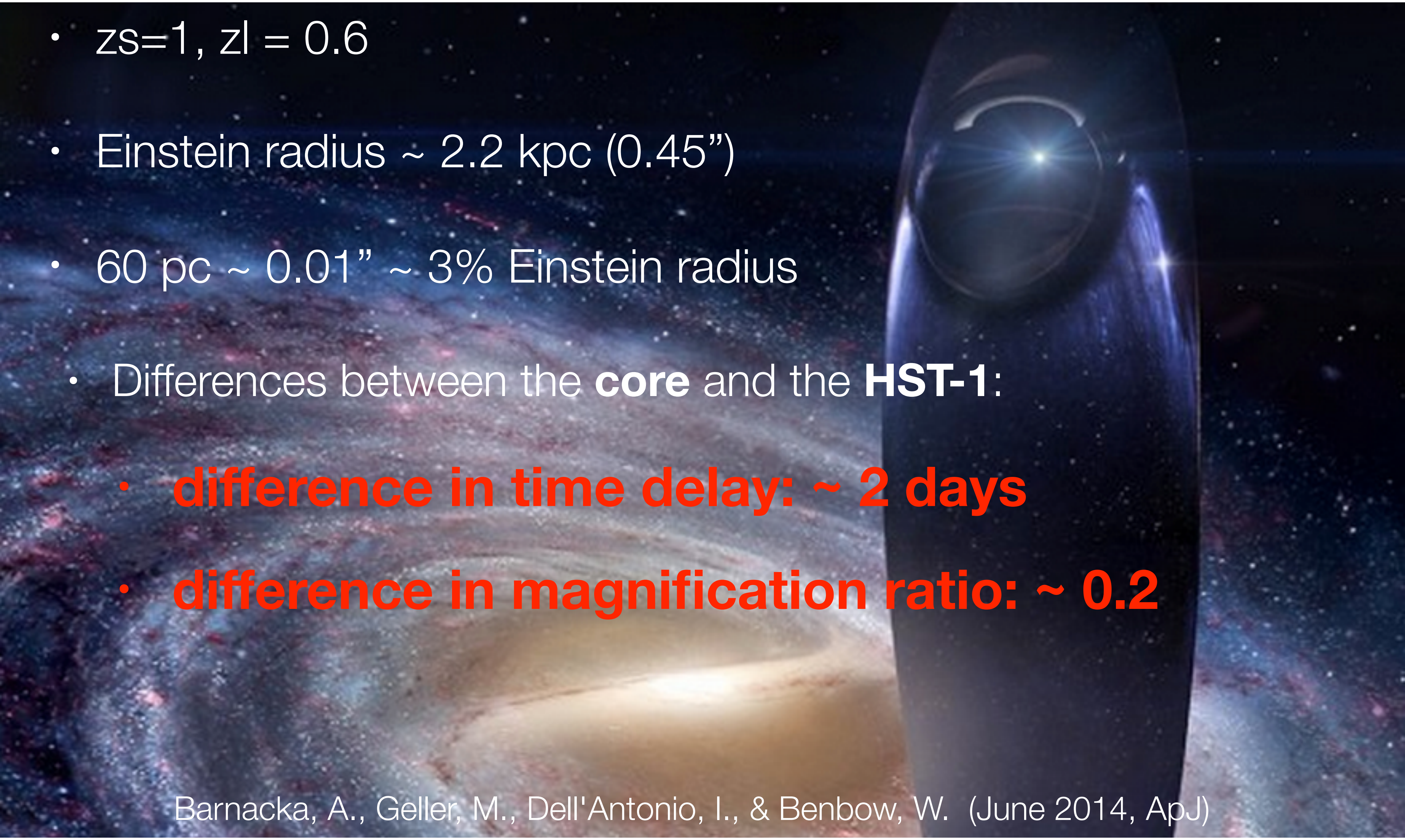
Deflection angle:

$$\alpha = \frac{4GM(r)}{c^2}\frac{1}{r}$$

Images separation - a few arcseconds

time delay **magnification ratio**

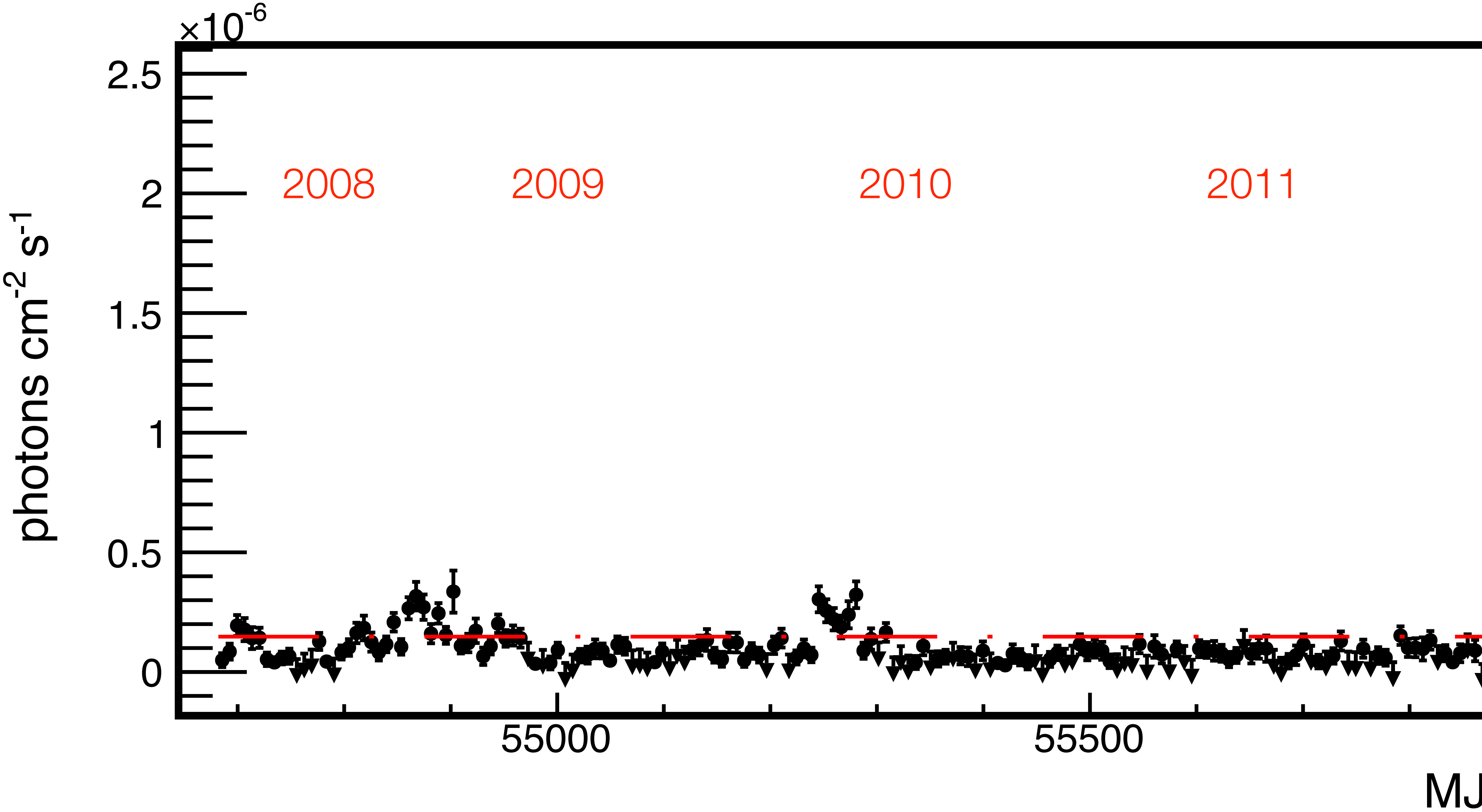
M87 as a Toy Model



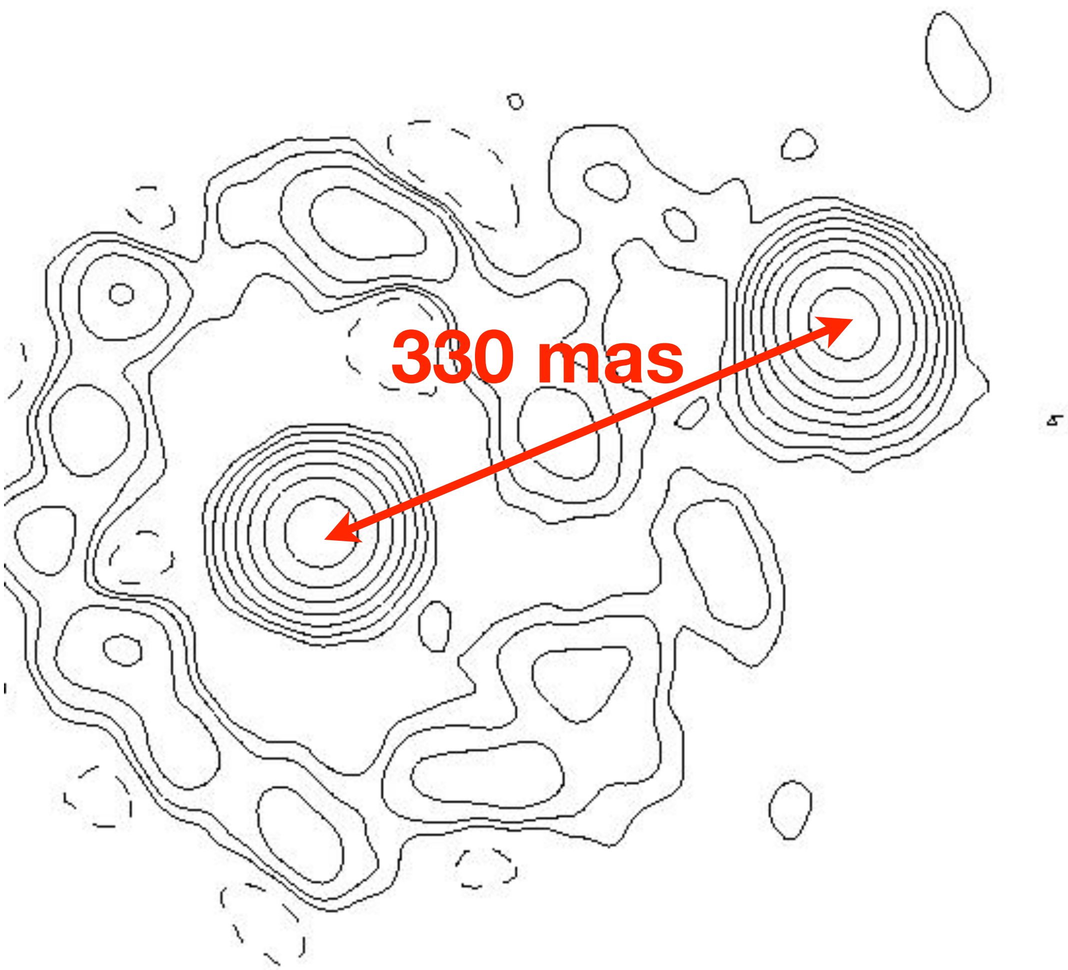
- zs=1, zl = 0.6
- Einstein radius ~ 2.2 kpc (0.45”)
- 60 pc ~ 0.01” ~ 3% Einstein radius
- Differences between the **core** and the **HST-1**:
  - **difference in time delay: ~ 2 days**
  - **difference in magnification ratio: ~ 0.2**

Barnacka, A., Geller, M., Dell'Antonio, I., & Benbow, W. (June 2014, ApJ)

Temporal Resolution at Gamma Rays



Lensed Gamma-Ray Jets: B2 0218+35



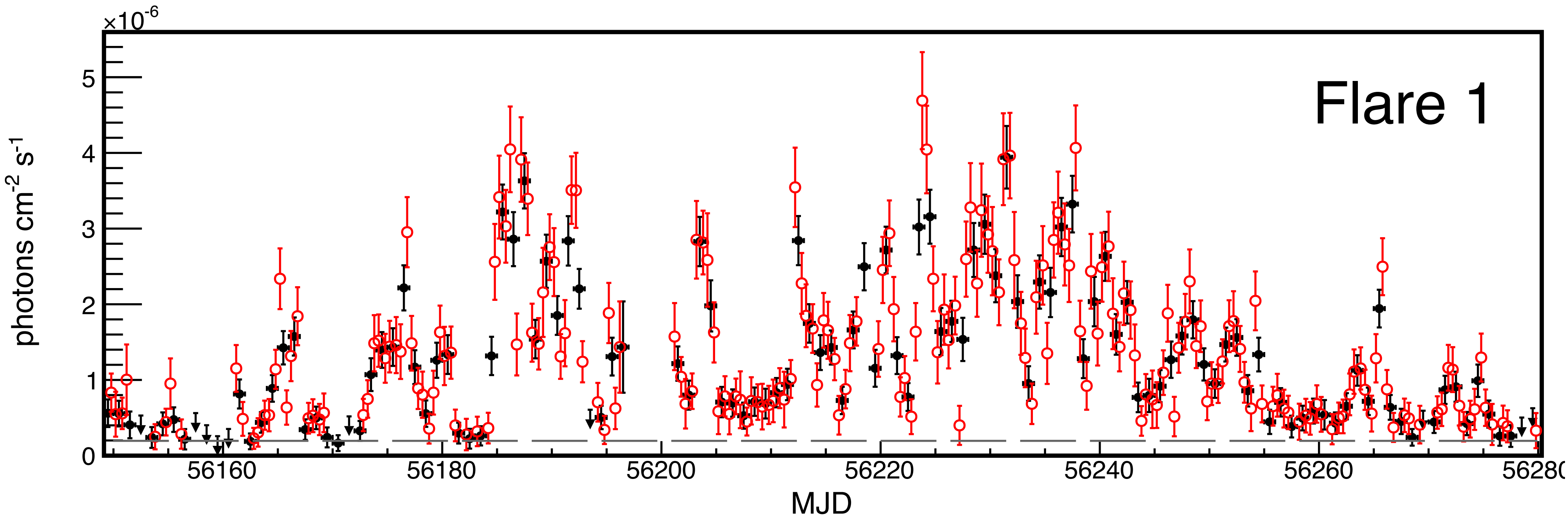
1.687 GHz, Patnaik et al. (1992)

Source z = 0.944,
Lens z = 0.6847

Radio Time Delay
10.5±0.5 days

Magnification Ratio
3.62±0.06

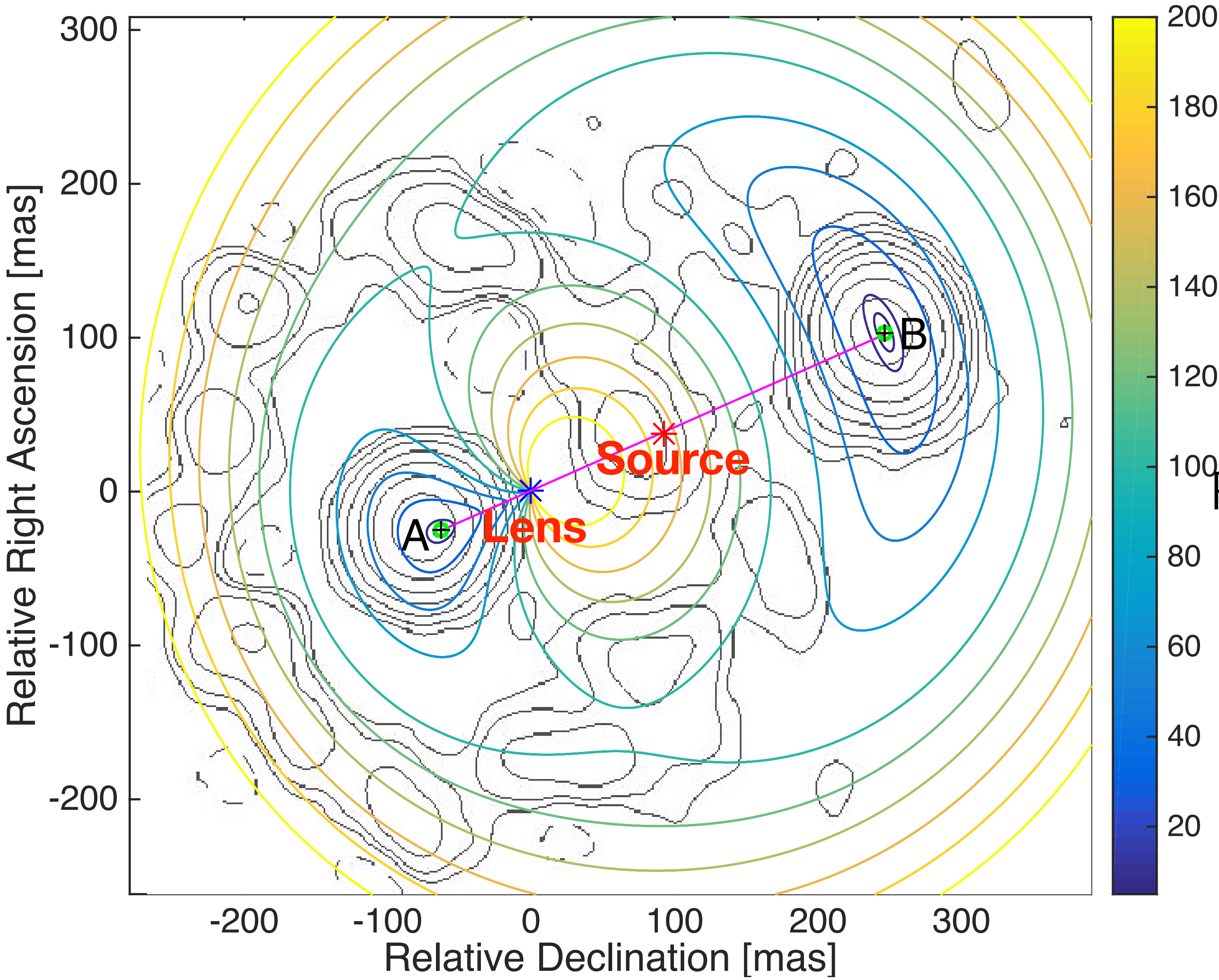
Gamma-Ray Time Delay



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

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

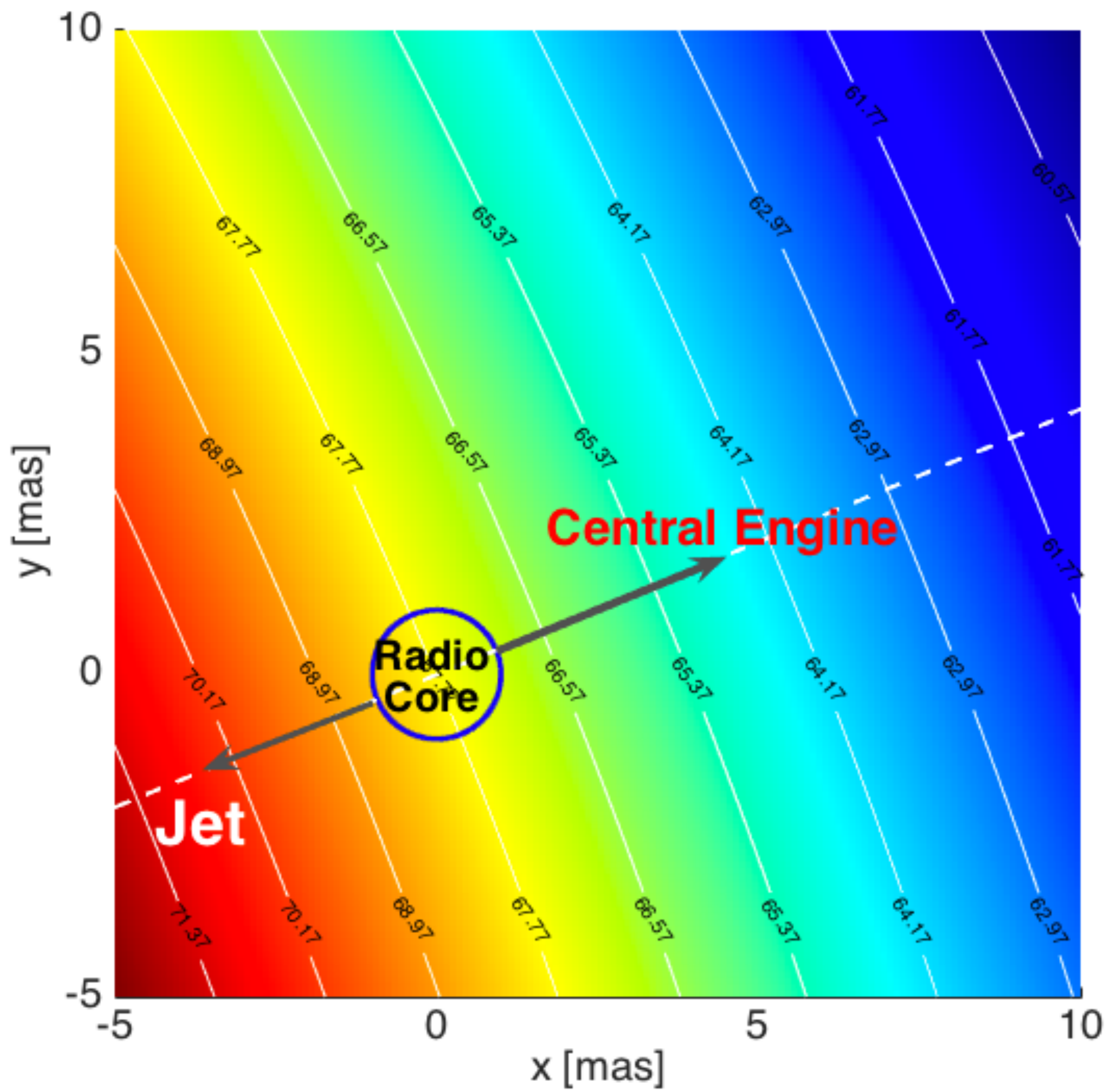
Lens Modeling



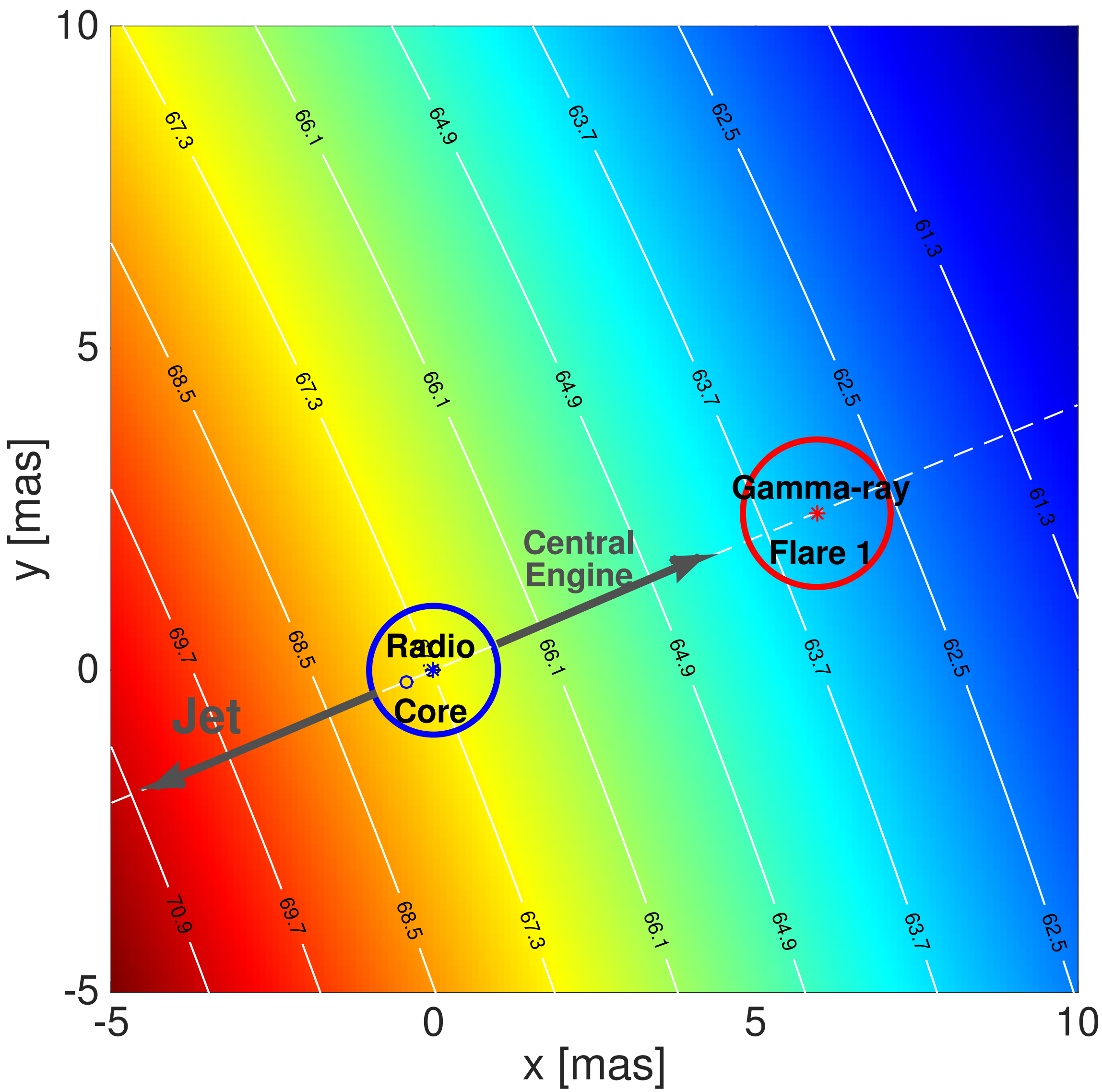
Reconstruction
~ 1 milliarcsecond

Radial Jet Projection

The Hubble Parameter Space



The Origin of Gamma-ray Flare



Gamma-ray flare occurred

51±8 pc

from the 15 GHz core toward the central engine.

~**3 sigma** effect

(Barnacka et al. submitted)

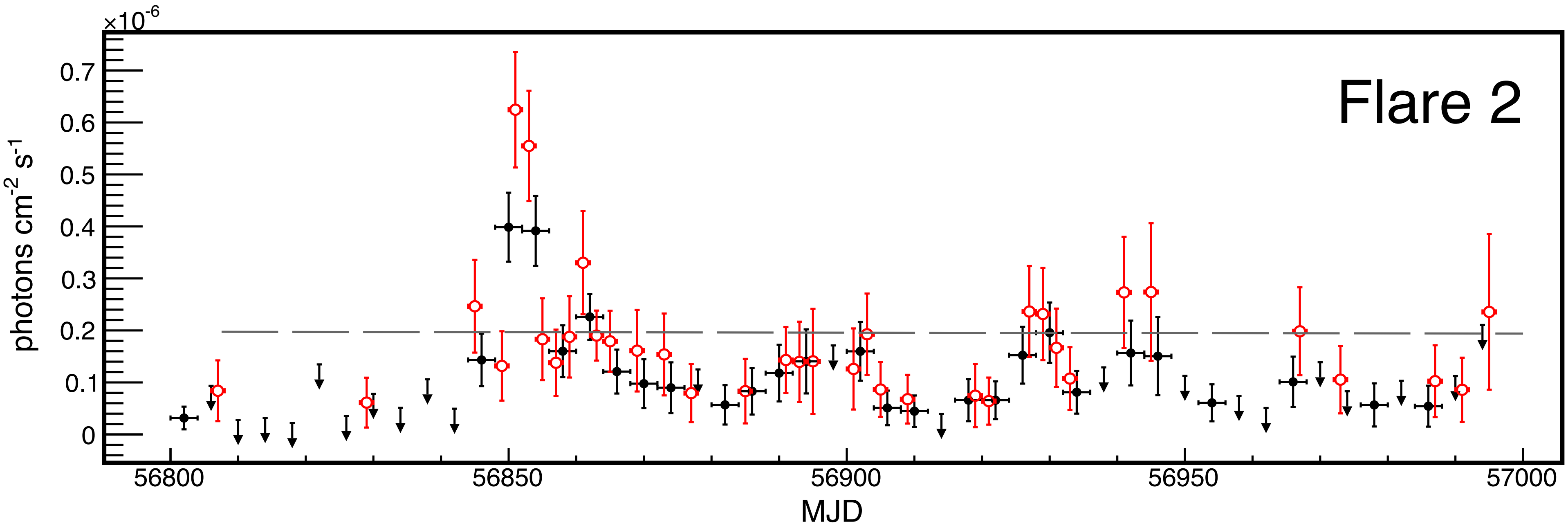
Summary

- **Strong Lensing:**
  - **Powerful Tool to Resolve High Energy Universe**
  - **Effective Spatial Resolution ~ 1 =miliarcsecond - improvement x 10,000,000**

Backup Slides

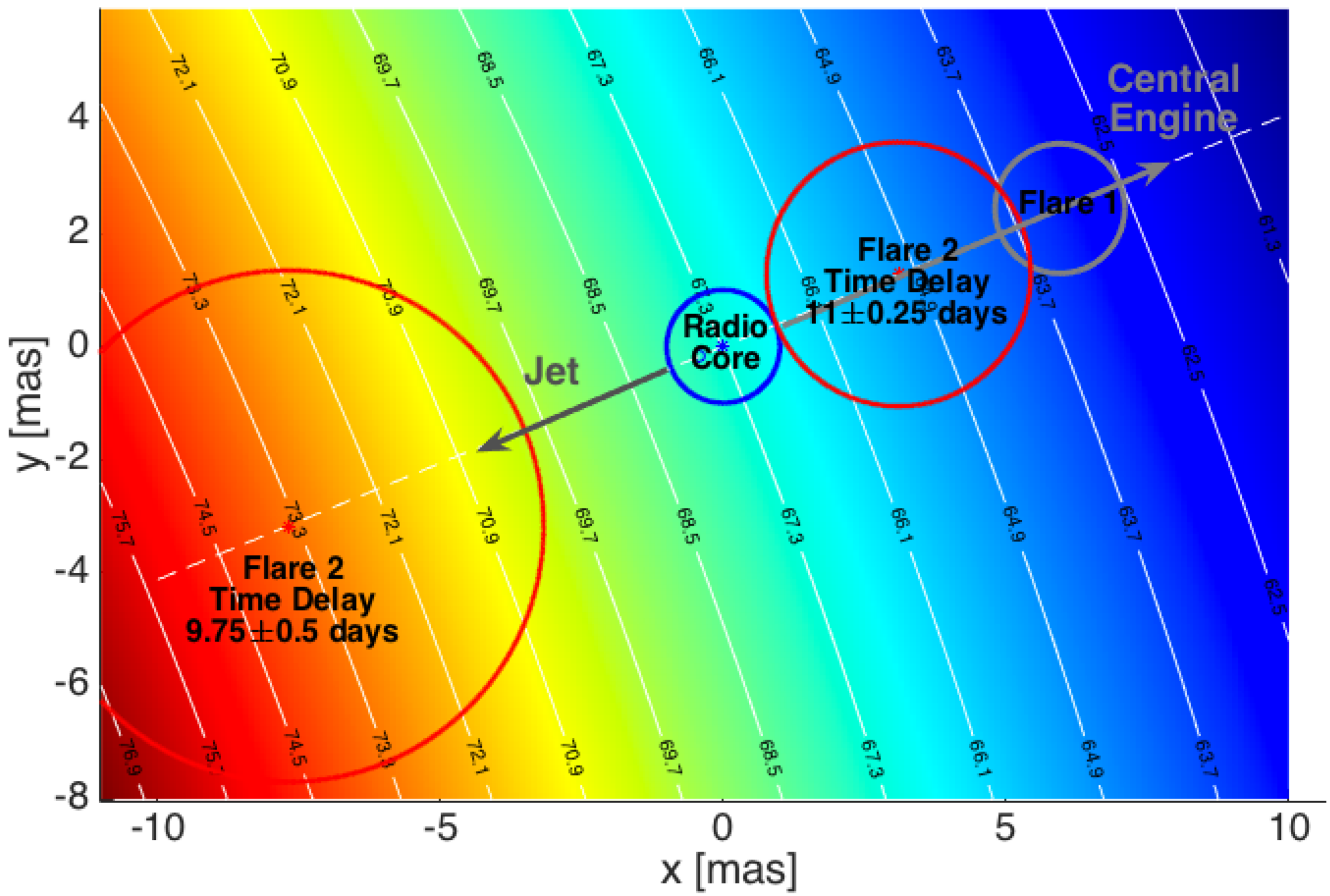
Flare 2

Gamma-ray Flare 2: Time Delays

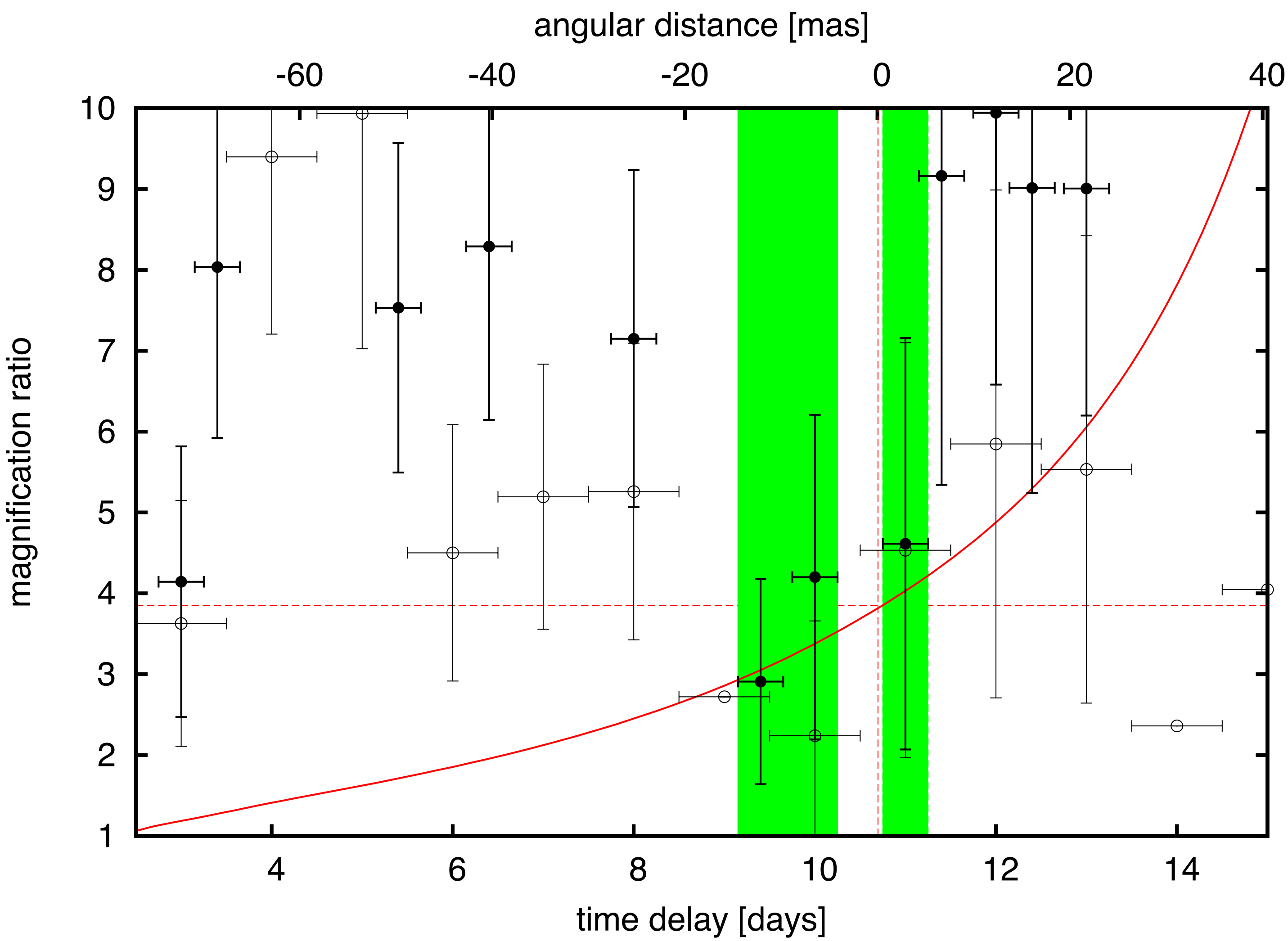


Time delay:9.75±0.5 or 11.0±0.25 days

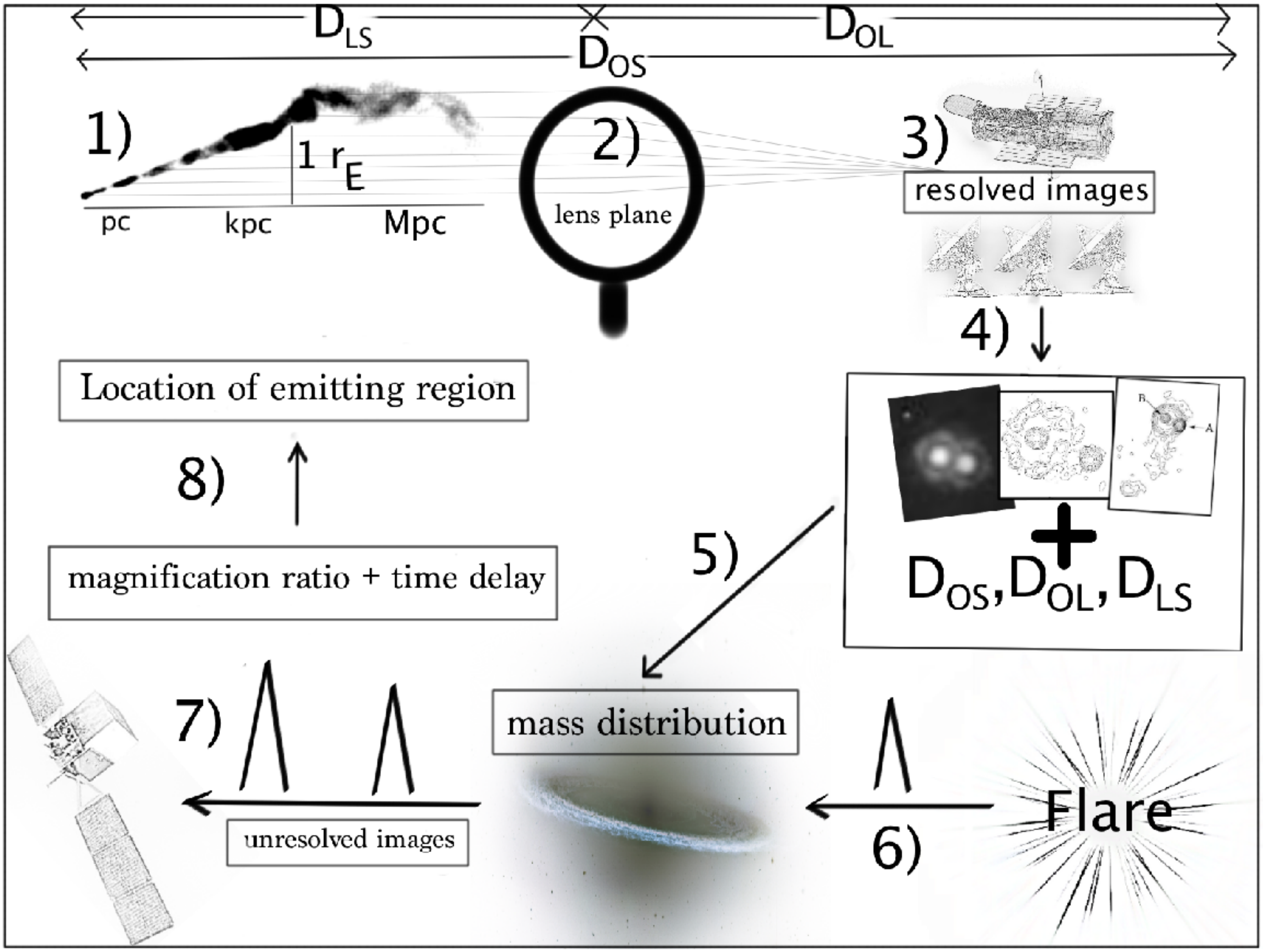
Spatial Origin of Flare 2



Gamma-ray Flare 2: The Maximum Peak Method

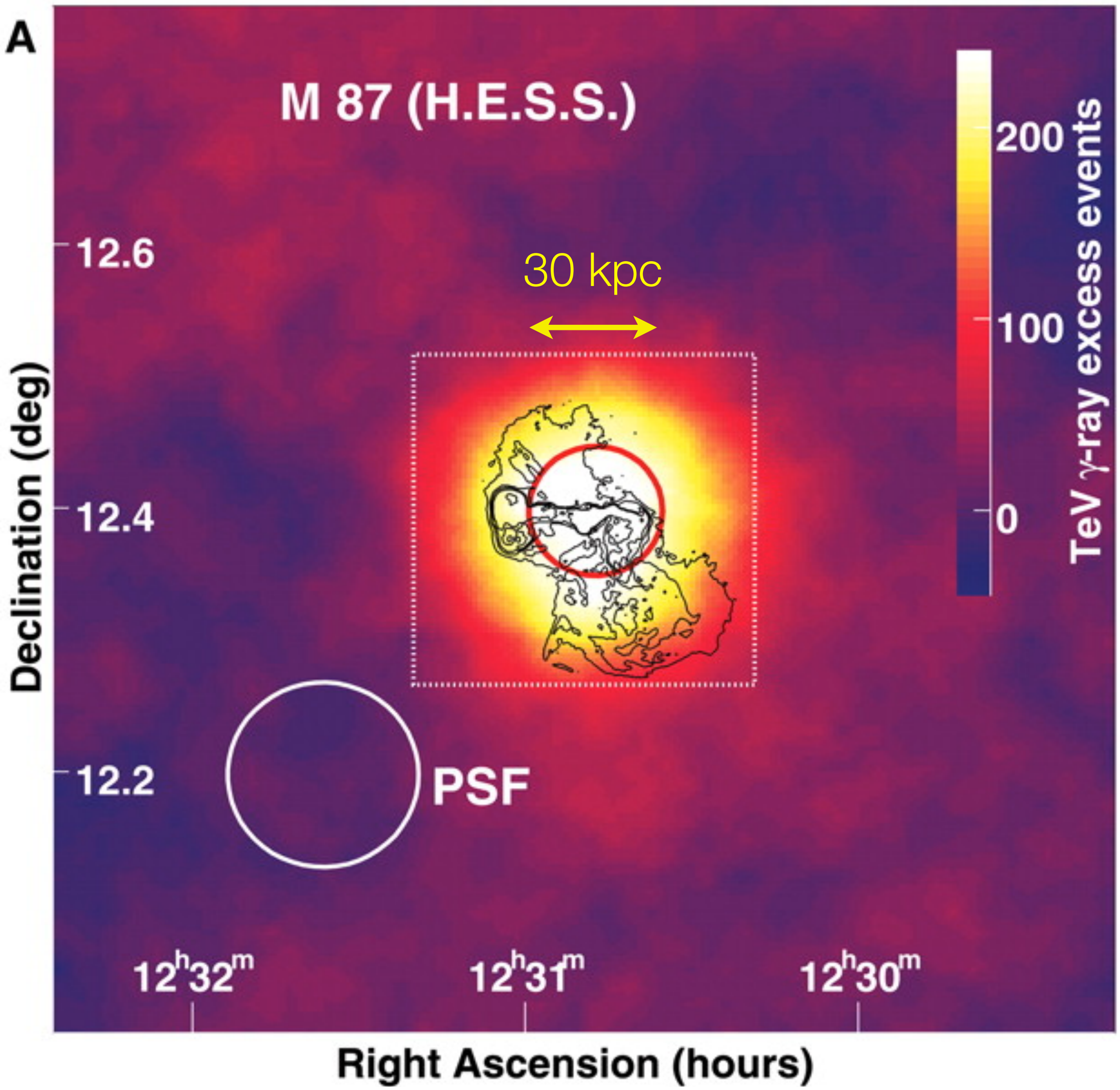


Application of strong lensing

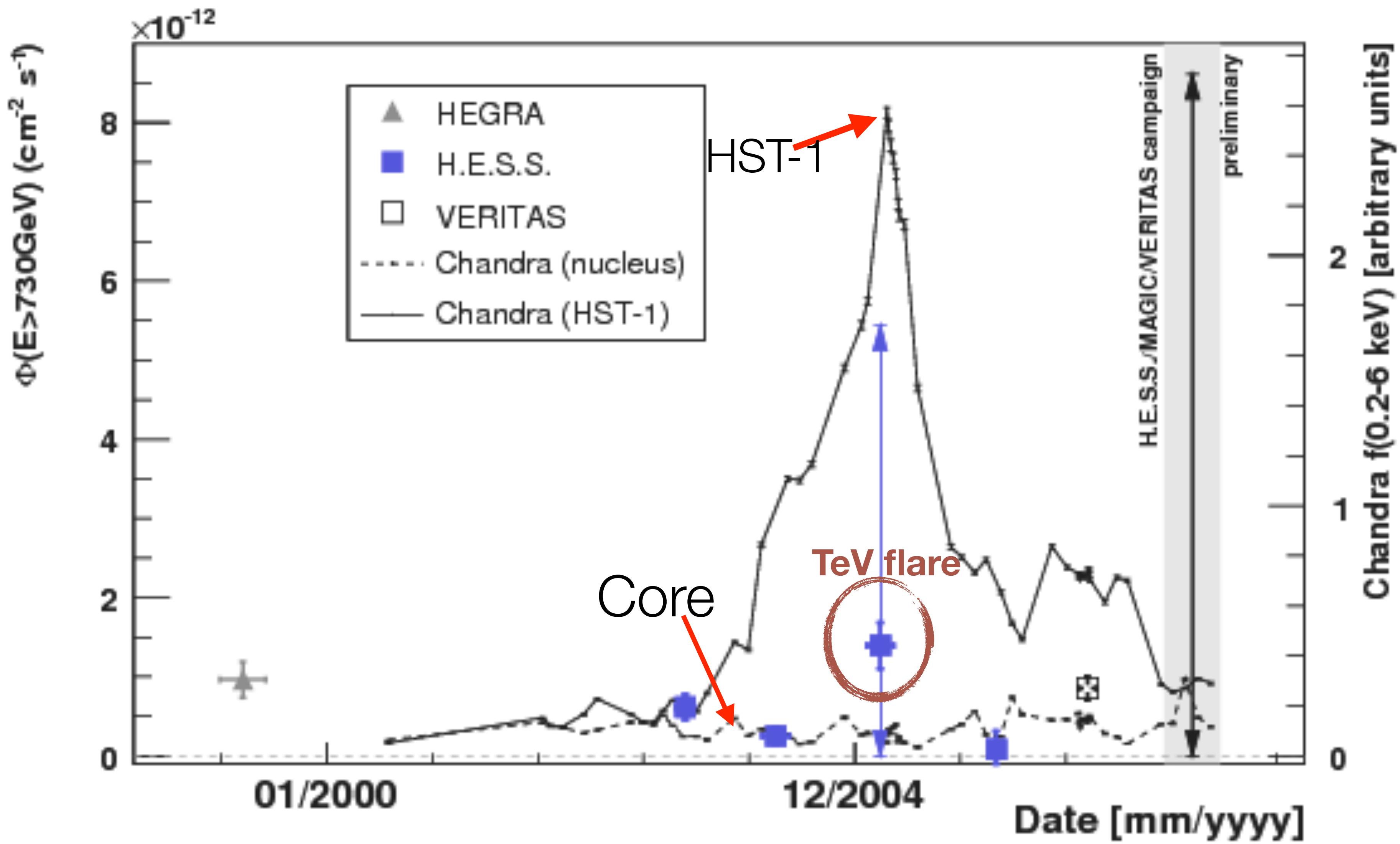


Barnacka, A., Geller, M., Dell'Antonio, I., & Benbow, W. (June 2014, ApJ)

Ambiguity of Gamma-Ray Origin



Spatial Origin of Gamma-Ray Flares



Credit: MAGIC and VERTIAS and H.E.S.S. Collaborations (2009)