



# An Exceptional Radio Flare in Markarian 421

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# Acknowledgements

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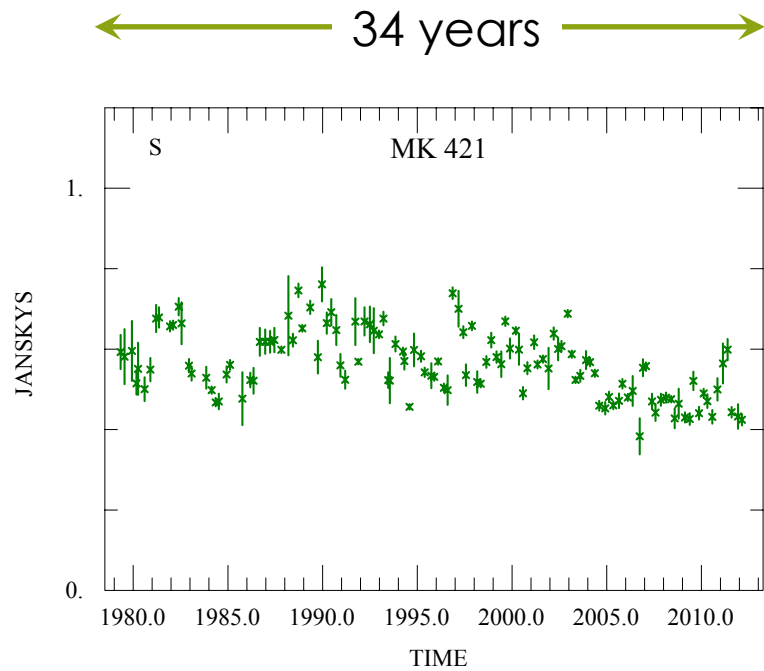
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UMRAO was supported in part by NSF grant AST-0607523, and NASA Fermi GI grants NNX09AU16G, NNX10AP16G, and NNX11AO13G.

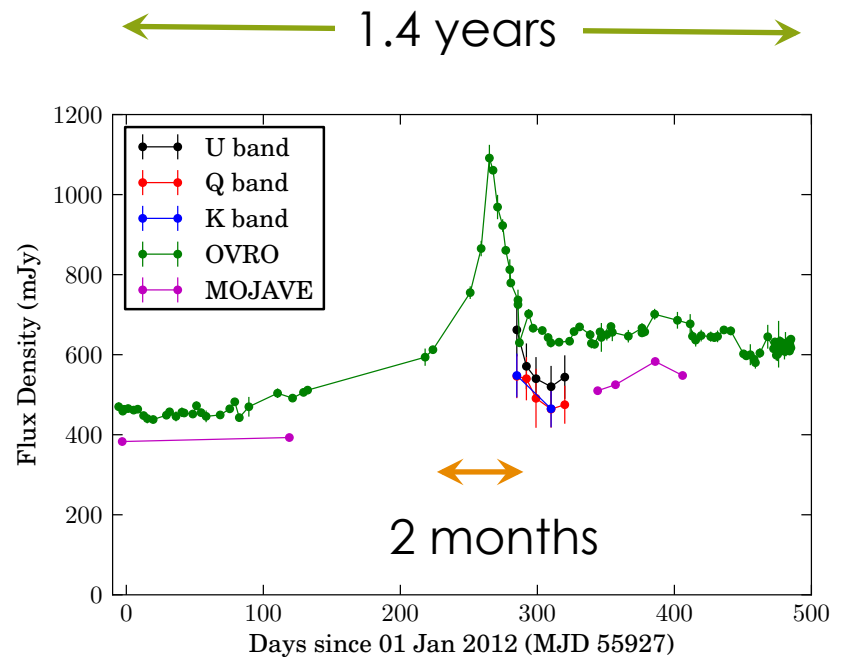
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Conceptual Image Lab

# In September, 2012, Mrk 421 flared in radio like never before



UMRAO

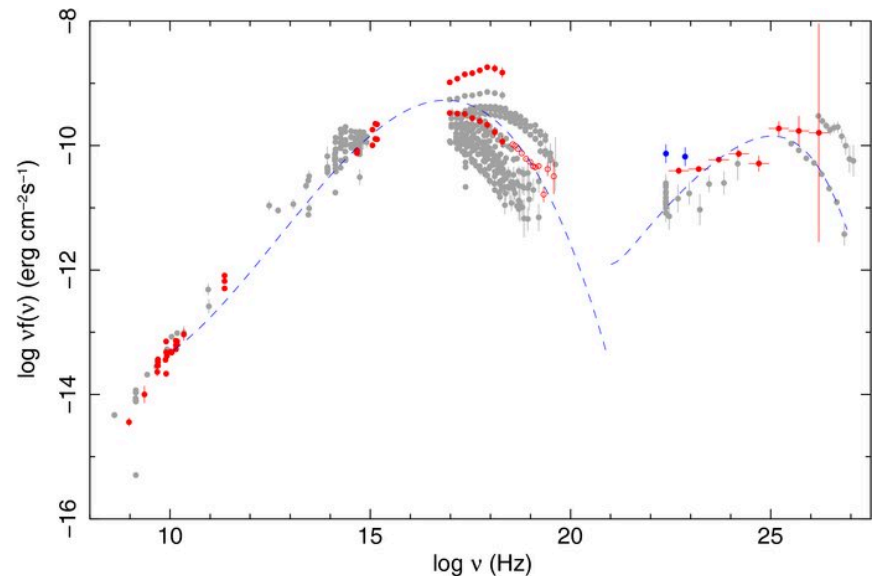


OVRO + VLBA

# Background on Mrk 421

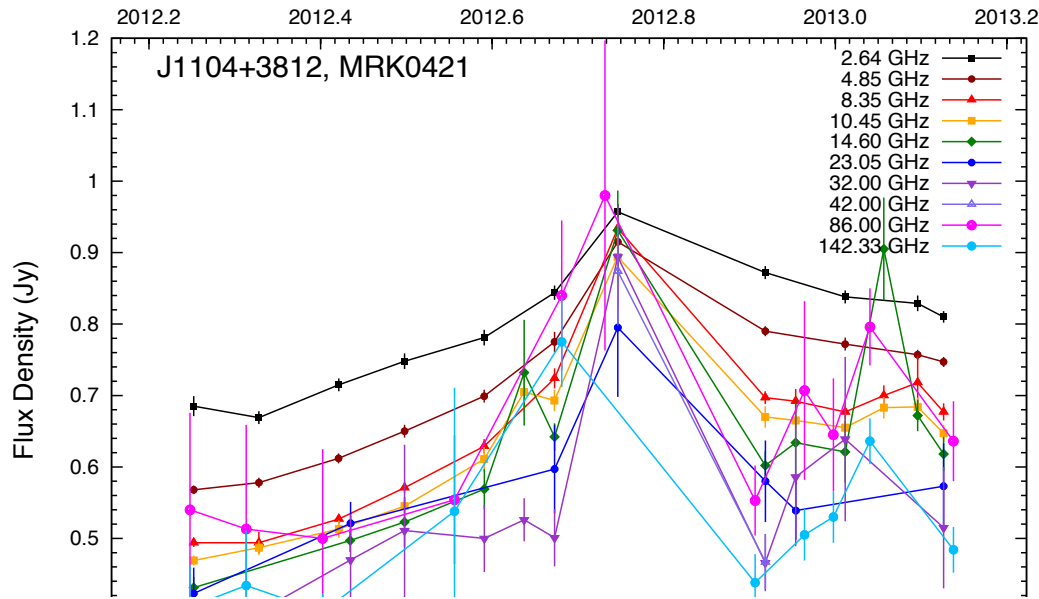
- HSP BL Lac object
- TeV  $\gamma$ -ray-loud
- Subluminal\* radio jet
- Viewing angle  $\sim 2^\circ$ – $5^\circ$   
(Lico et al. 2012, A&A, 545, A117)
- Doppler factor: TeV  $\Rightarrow \sim 20$ , radio  $\Rightarrow \sim 3$
- $z=0.031$  (133 Mpc)

\* Except for recent tentative detection by  
Niinuma et al. (2012, ApJ, 759, 84)

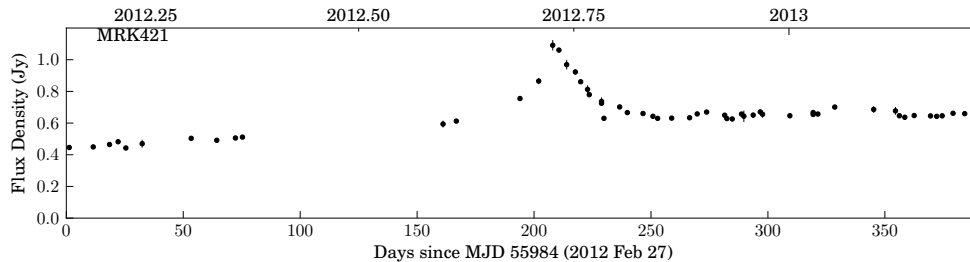


Abdo et al. 2010,  
ApJ, 716, 30

# The radio flare was a wideband phenomenon



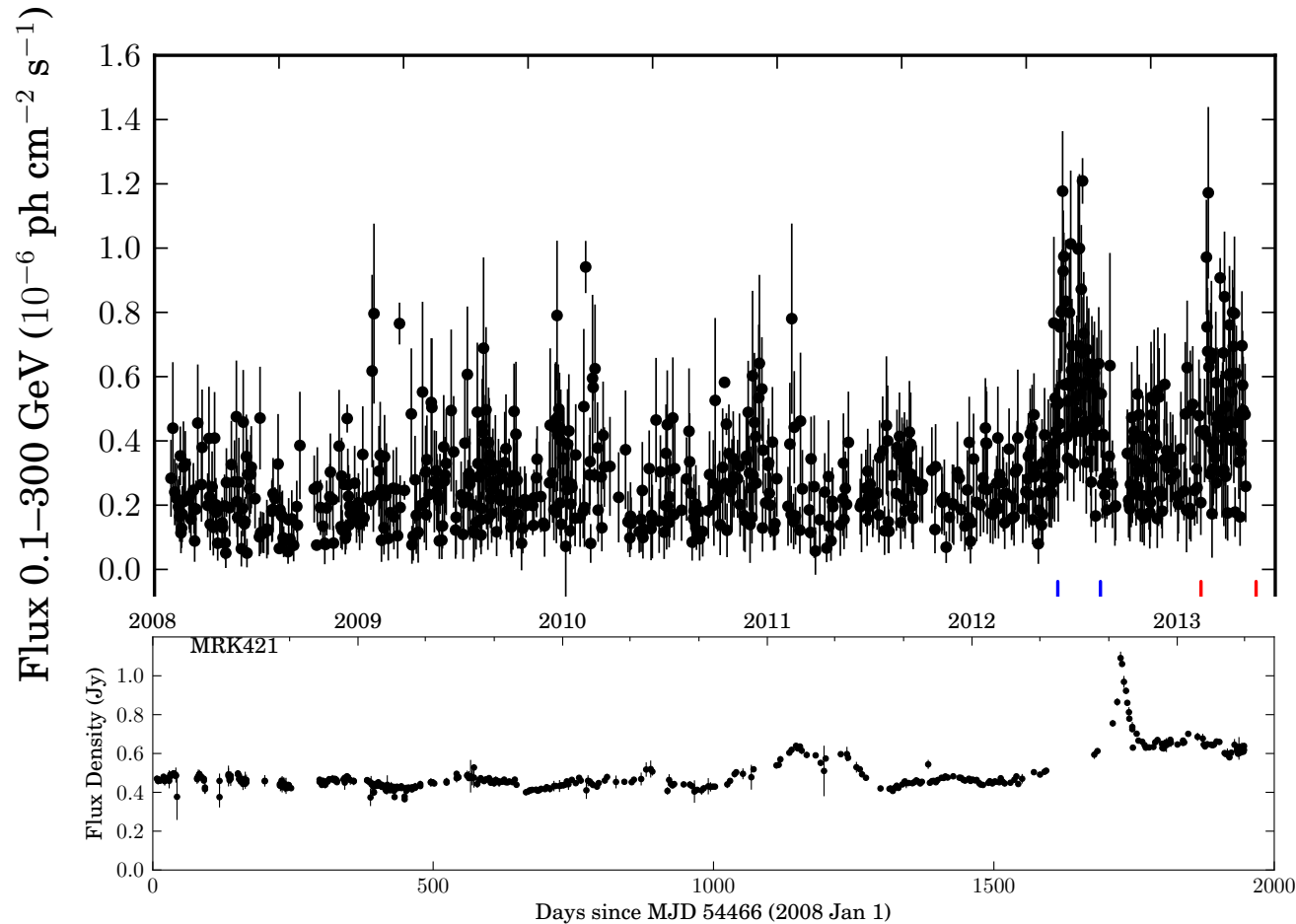
2.6–142 GHz radio  
light curves  
from F-GAMMA



OVRO  
15 GHz

[.de/div/vlbi/fgamma](http://de/div/vlbi/fgamma)

# The radio flare followed a period of intense gamma-ray emission



*Fermi-LAT*  
public light  
curve

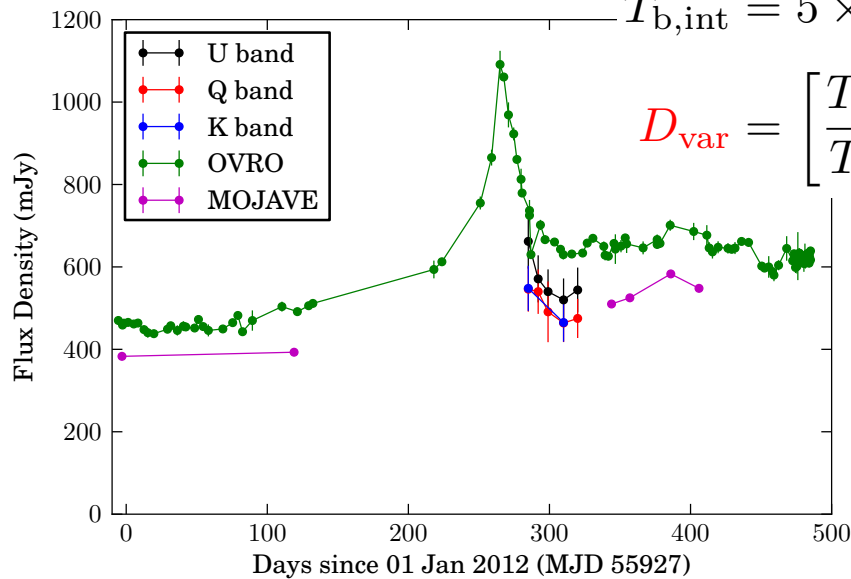
*OVRO*  
15 GHz

# Radio flare requires only a modest Doppler factor

$$T_{b,\text{var}} = 1.548 \times 10^{-32} \text{ K} \frac{\Delta S d_L^2}{\nu^2 \tau^2 (1+z)} \approx 3.3 \times 10^{12} \text{ K}$$

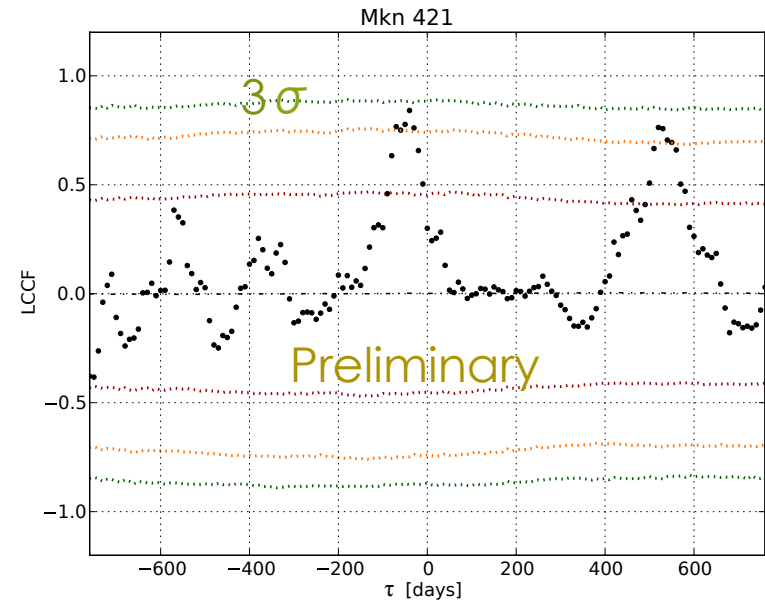
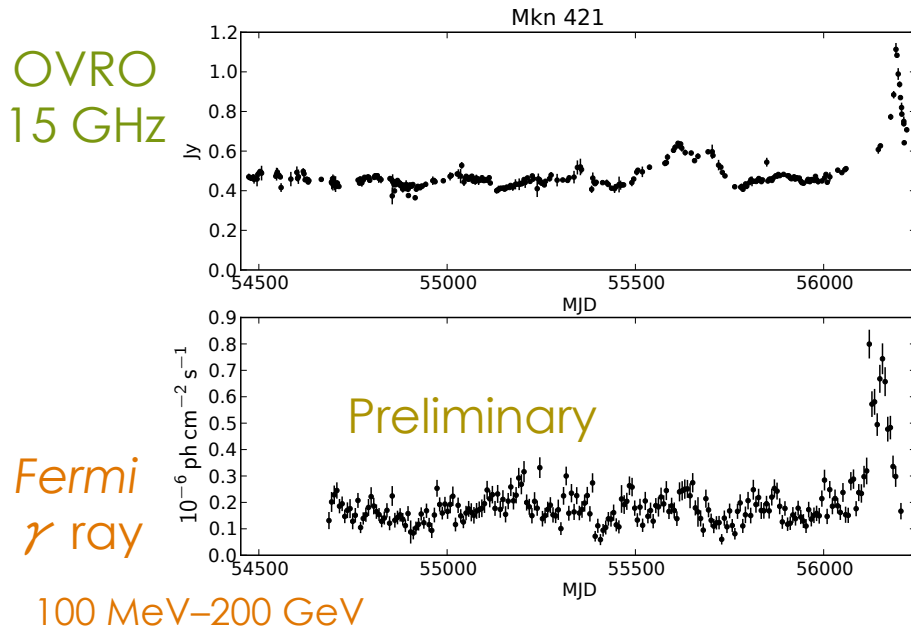
$$T_{b,\text{int}} = 5 \times 10^{10} \text{ K}$$

$$D_{\text{var}} = \left[ \frac{T_{b,\text{var}}}{T_{b,\text{int}}} \right]^{1/3} \approx 4.1$$



Hovatta et al. 2009,  
A&A, 494, 527

# The radio / gamma-ray cross-correlation peaks are significant



Max-Moerbeck et al. and the  
*Fermi*-LAT collaboration, in prep.

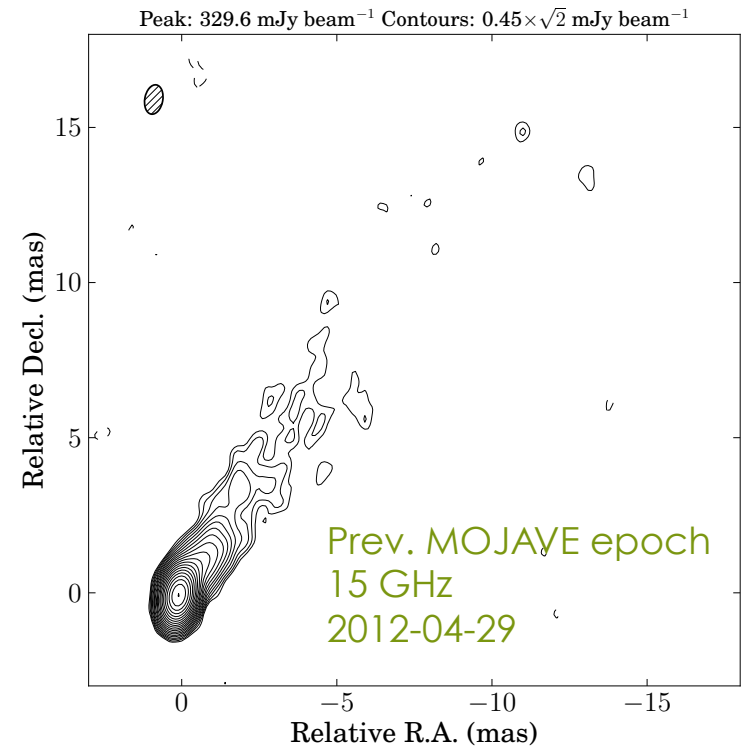
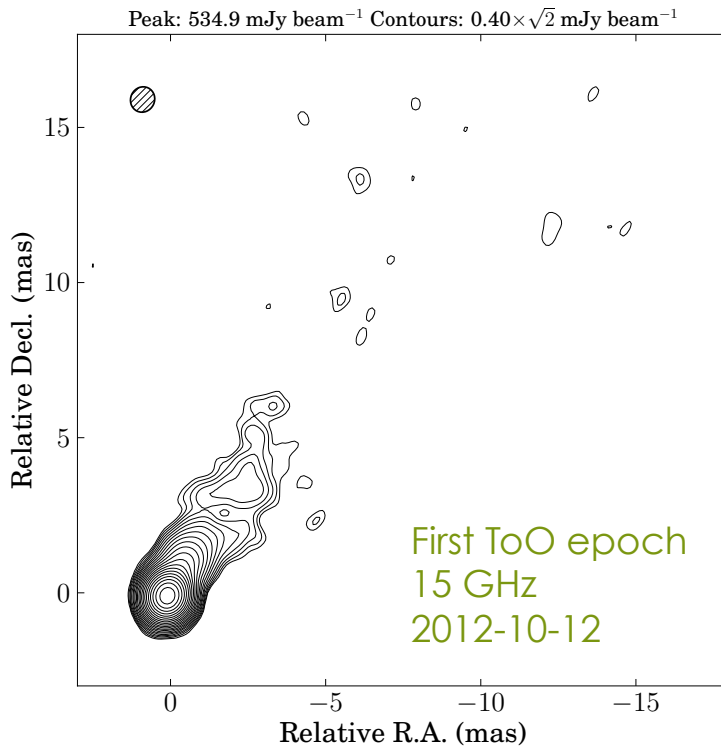


# VLBA Target of opportunity follow-up campaign

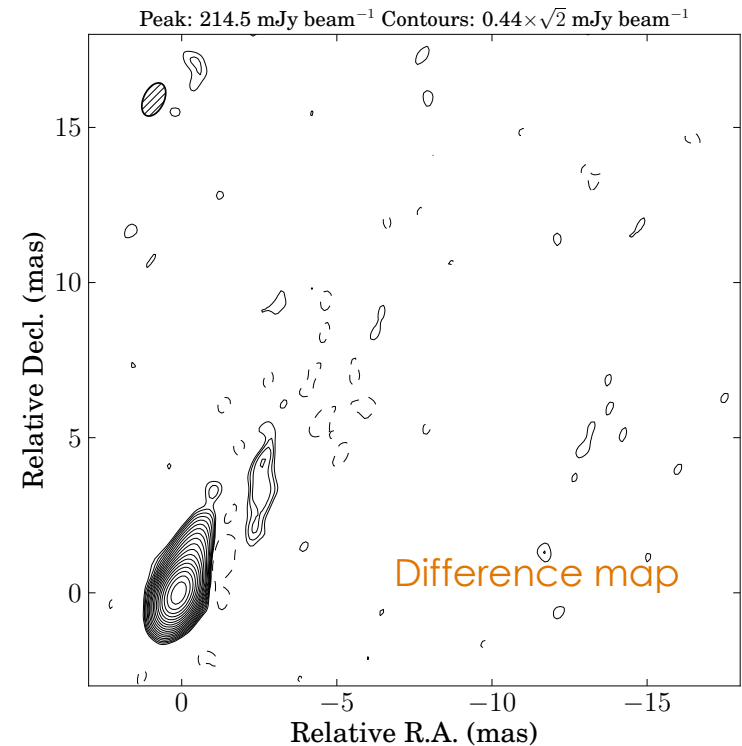
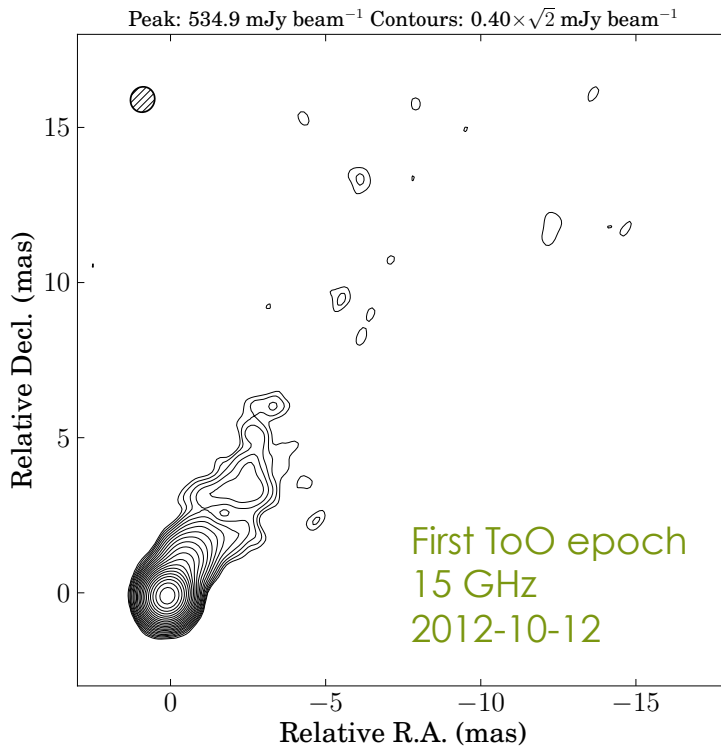
- Five epochs in October/November 2012
- U, K, and Q bands
  - W band in first epoch
- Full polarization

We aimed to pinpoint the radio flare location and detect any short-lived superluminal components

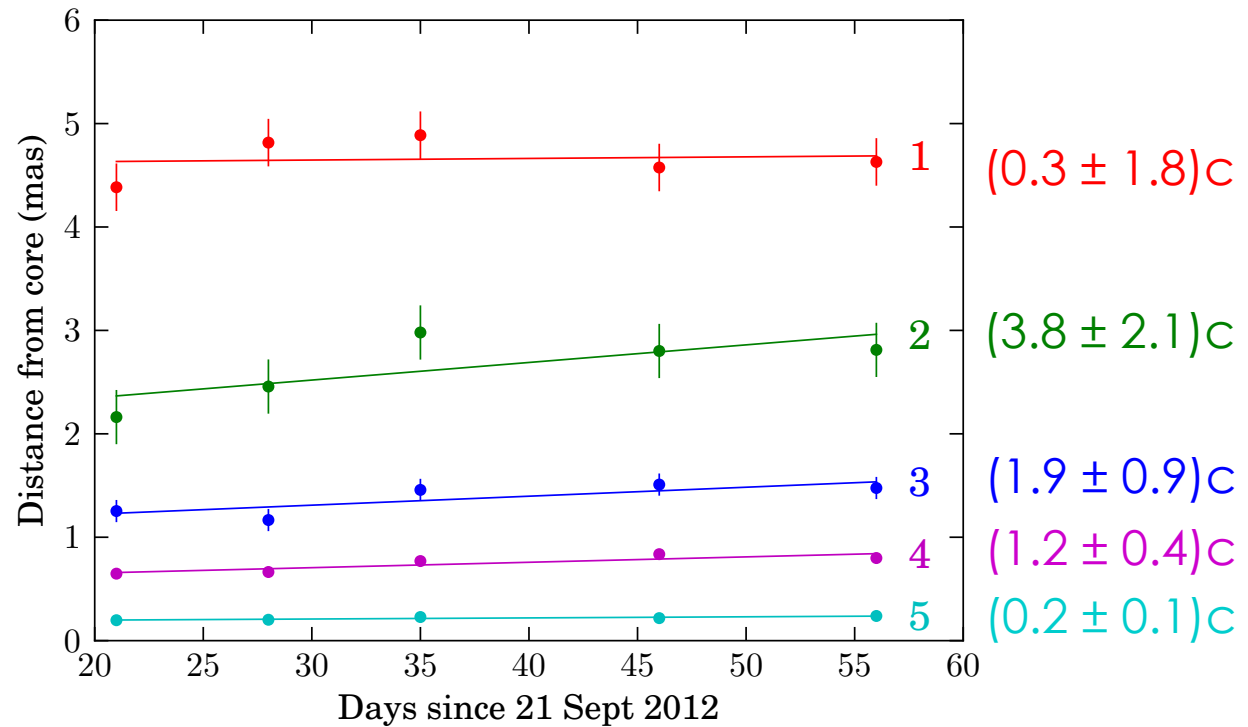
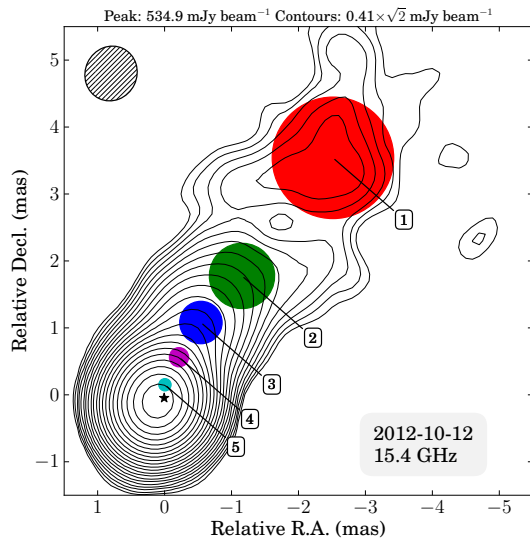
# No major downstream changes associated with the flare



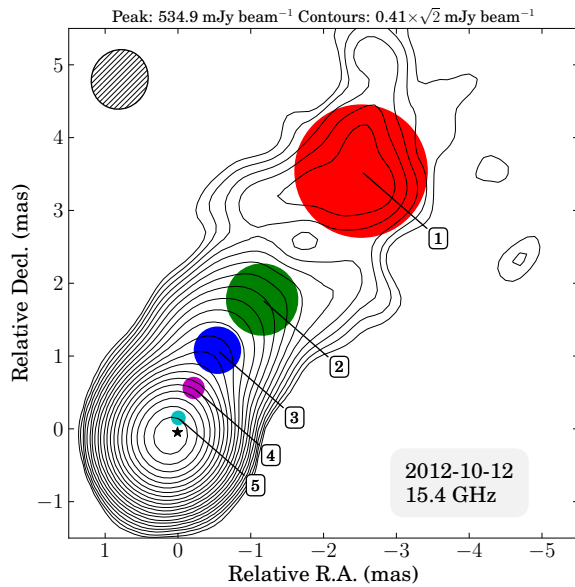
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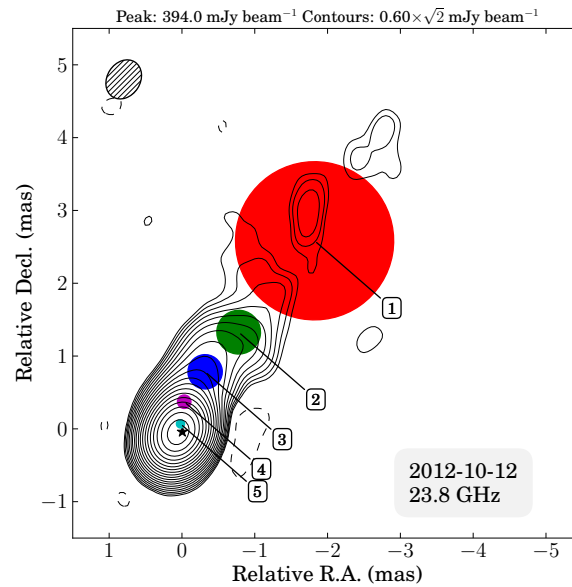
# All components are stationary or subluminal



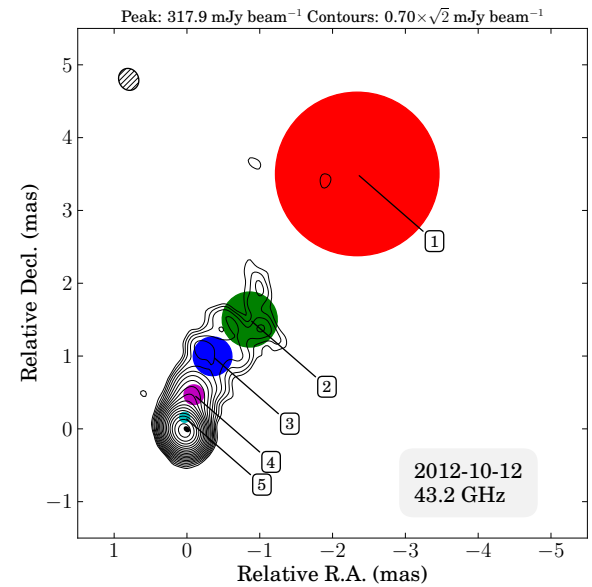
# Parsec-scale structure is similar between radio bands



U band



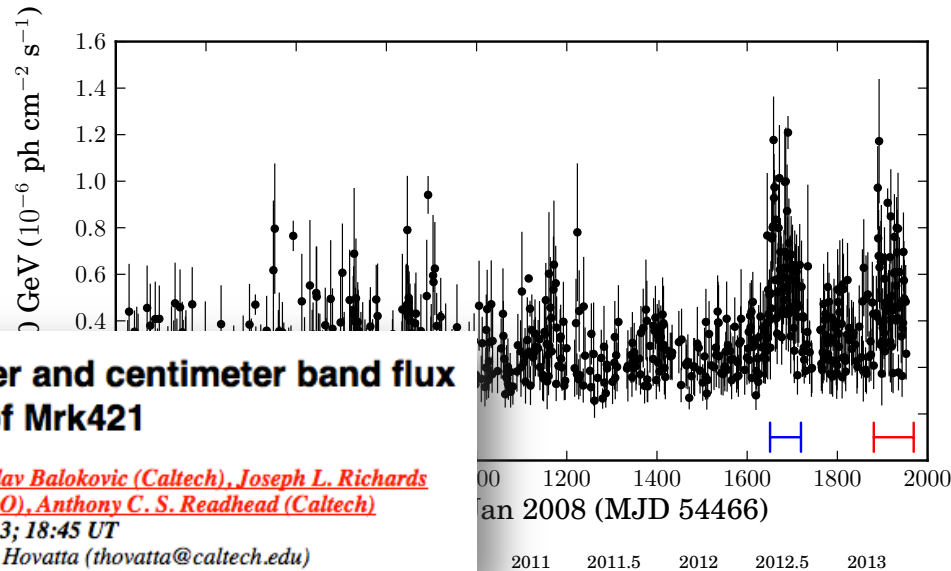
K band



Q band

# Activity continues in 2013

Fermi-LAT  
public light  
curve



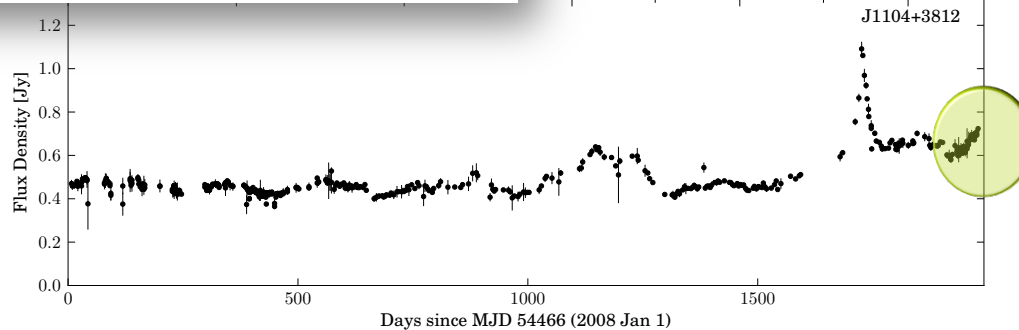
**An increase in the millimeter and centimeter band flux density of Mrk421**

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on 5 Jun 2013; 18:45 UT

Credential Certification: Talvikki Hovatta (thovatta@caltech.edu)

OVRO  
15 GHz



!?!

See Poster:  
M. Balokovic

# Summary and conclusions

An exceptional radio flare occurred in Mrk 421 about two months after a sustained GeV flare.

- Similar duration in radio / GeV
- Cross-correlation analysis supports a physical connection
  - GeV emission  $\sim 0.25$  pc upstream of radio,  $\sim 2$  pc from C.E.
- Flux increase contained in unresolved sub-parsec core
  - No superluminal component ejections
- Radio Doppler factor still in conflict with TeV Doppler factor ( $\sim 4$  vs  $\sim 15$ )





# Radio spectral evolution

