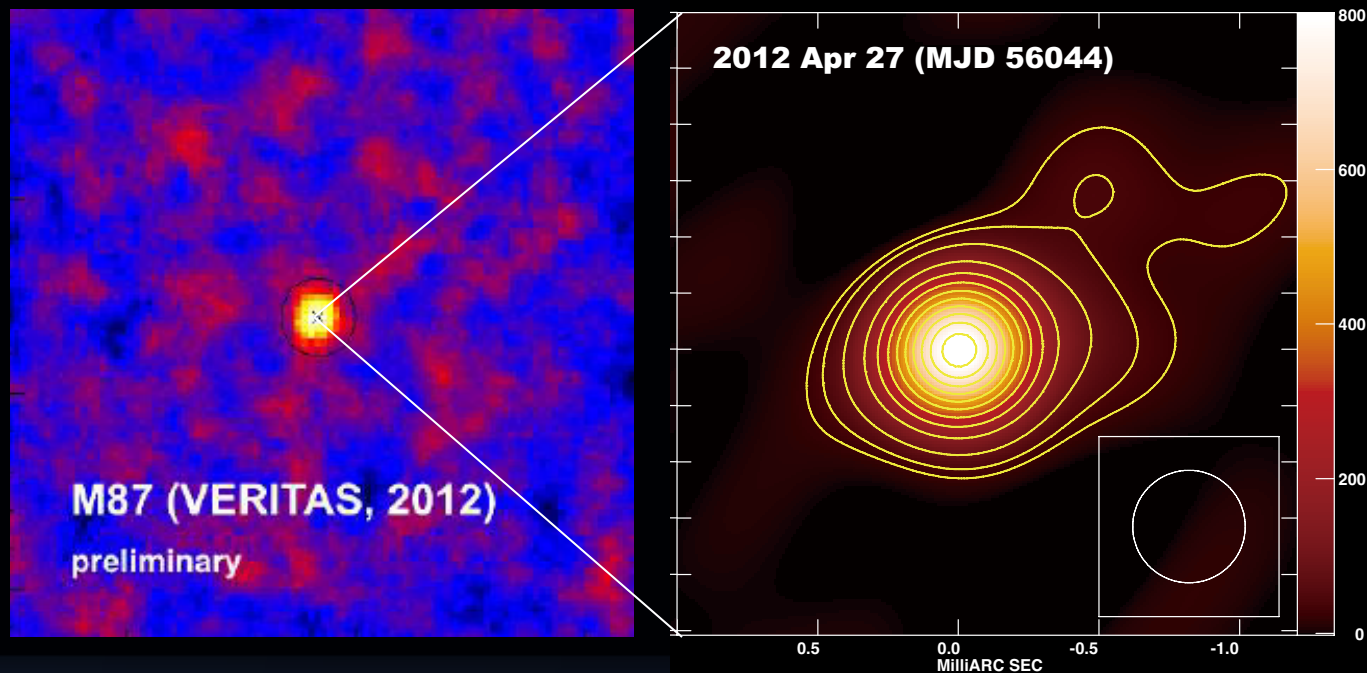


# A strong radio brightening at the jet base of M87 during the elevated VHE $\gamma$ -ray state in 2012

Hada et al. 2014 ApJ 788,165



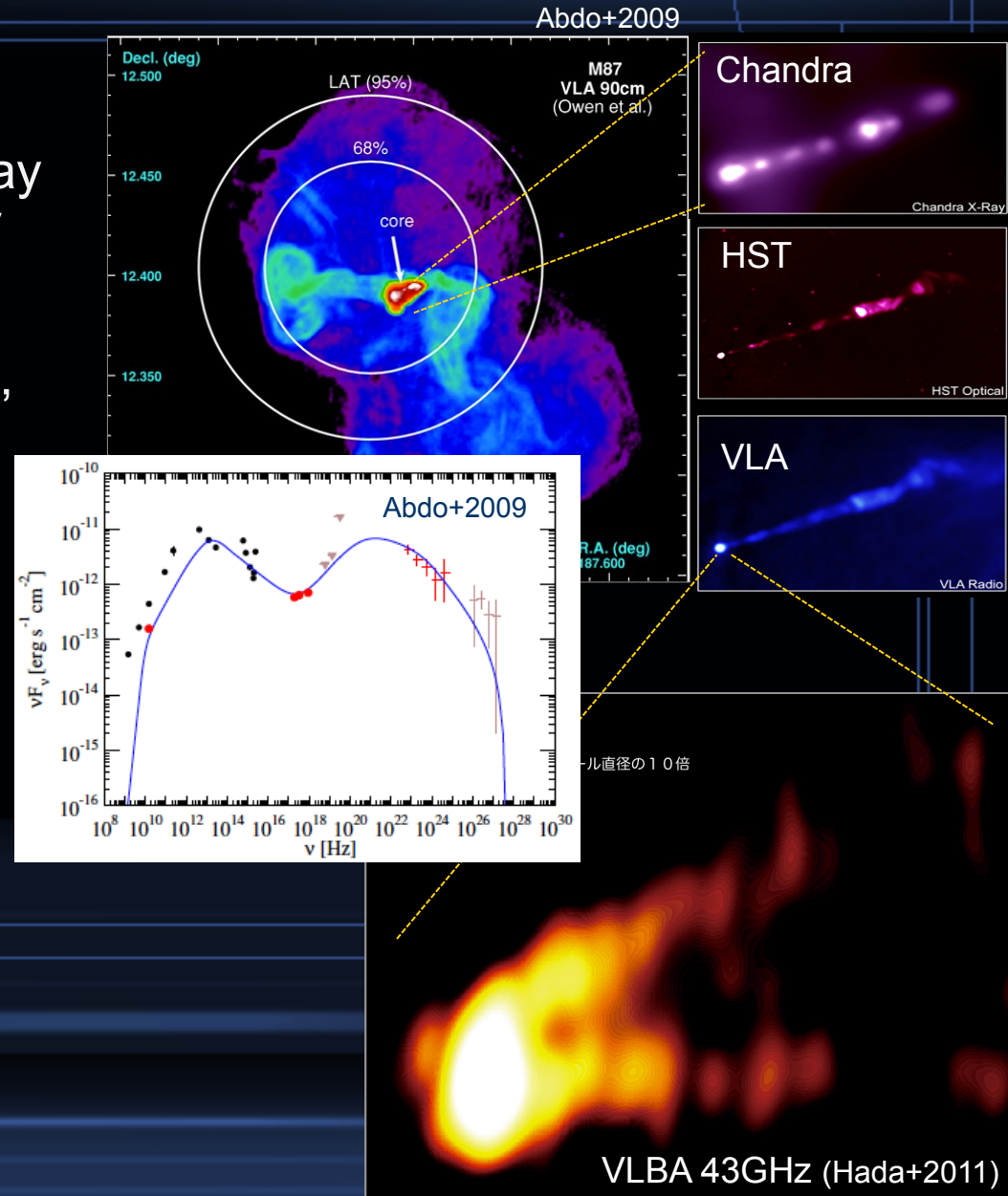
The 5<sup>th</sup> Fermi International Symposium, Oct/2014, Nagoya

**Kazuhiro Hada (INAF-IRA/NAOJ)**

M.Giroletti, M.Kino, G.Giovannini, F.D'Ammando, T.Cheung, M.Beilicke, H.Nagai, A.Doj, K.Akiyama, M.Honma, K.Niinuma, M.Orienti, C.Casadio, H. Krawczynski, J.L.Gomez, S.Sawada, S.Koyama, A.Cesarini, S.Nakahara and M.Gurwell

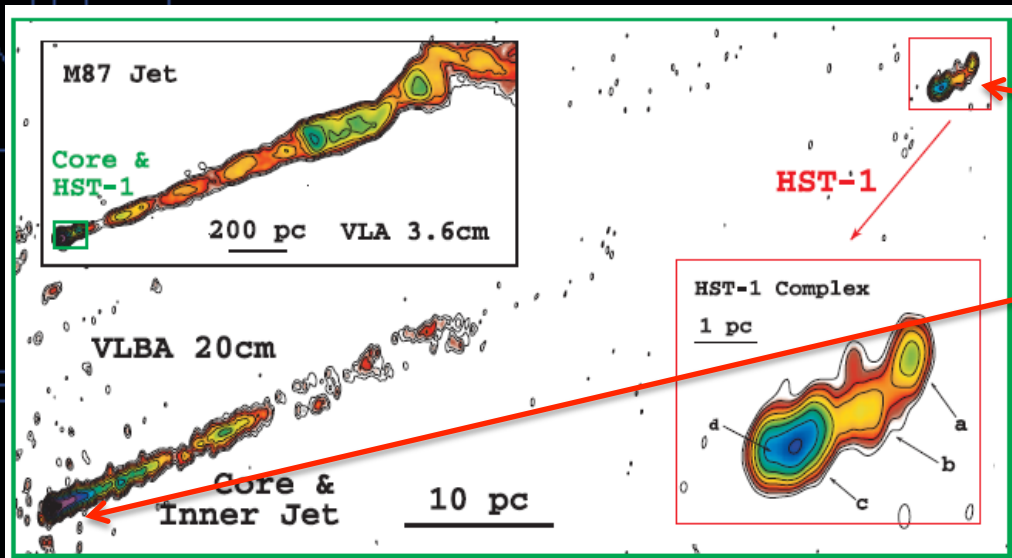
# M87

- One of the nearest (16Mpc)  $\gamma$ -ray detected AGNs up to GeV, TeV
- Well-studied jet at radio, optical, and X-ray
- Subpc/mpc-scale jet imaging with VLBI
  - $1\text{mas} = 0.08\text{pc} = 140R_s$
- Ideal source to probe the origin of  $\gamma$ -ray emission by resolving detailed substructures



# Where is the $\gamma$ -ray production site in M87?

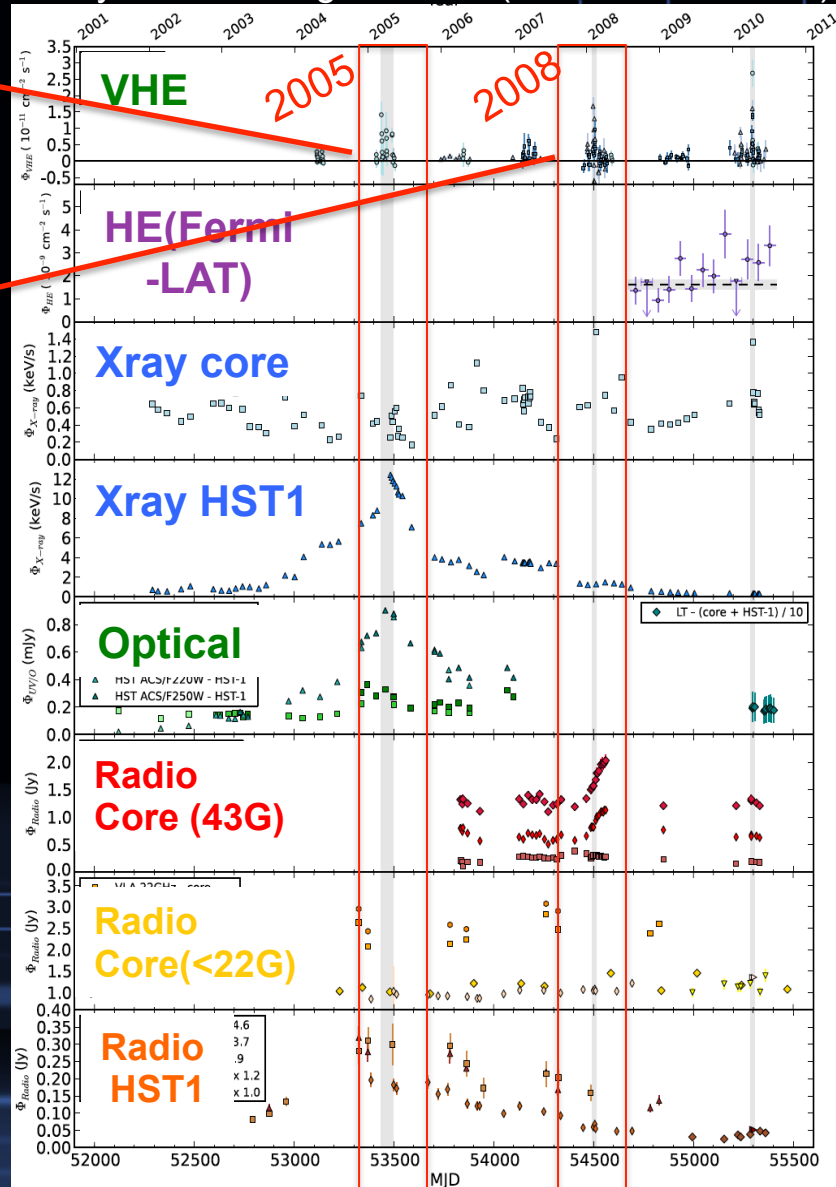
## Two candidates



VLBA 1.7GHz (Cheung+2007)

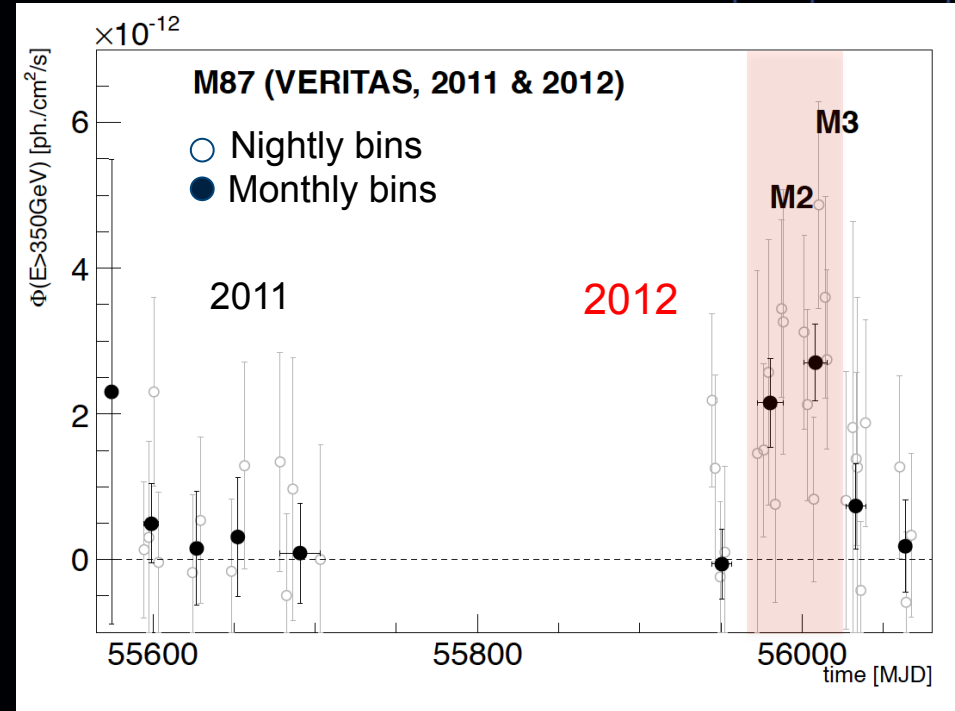
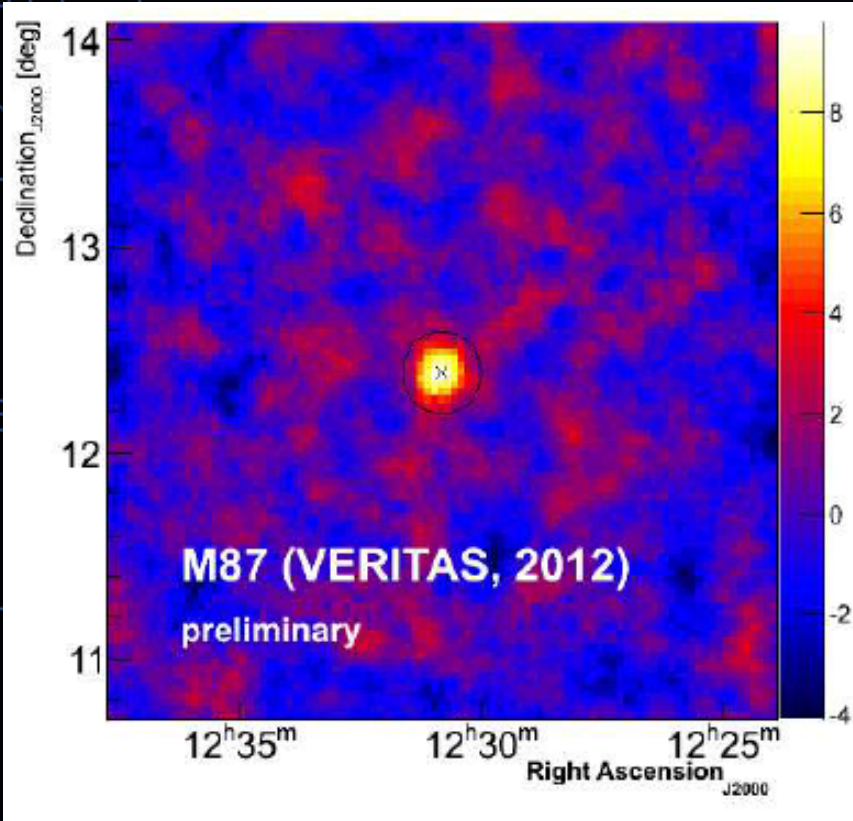
- HST-1 (peculiar knot at  $>120$ pc from the nucleus)
  - 2005 radio/TeV event (Cheung+2007)
- Core (jet base near BH)
  - 2008 radio/TeV event (Acciari+2009)

10-year multi- $\lambda$  light curves (Abramowski+2012)



# A new TeV activity detected in Feb/Mar 2012

(Beilicke & VERITAS Collaboration 2012)



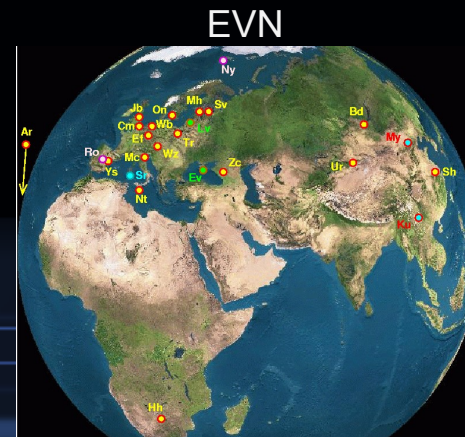
- Not extreme, but clearly elevated TeV state (a factor of 2)
- To see the MWL behavior, and to examine the location of this event, we report our VLBI monitoring results of M87 around 2011/2012, together with contemporaneous LAT light curves



# M87 joint monitoring 2011/2012

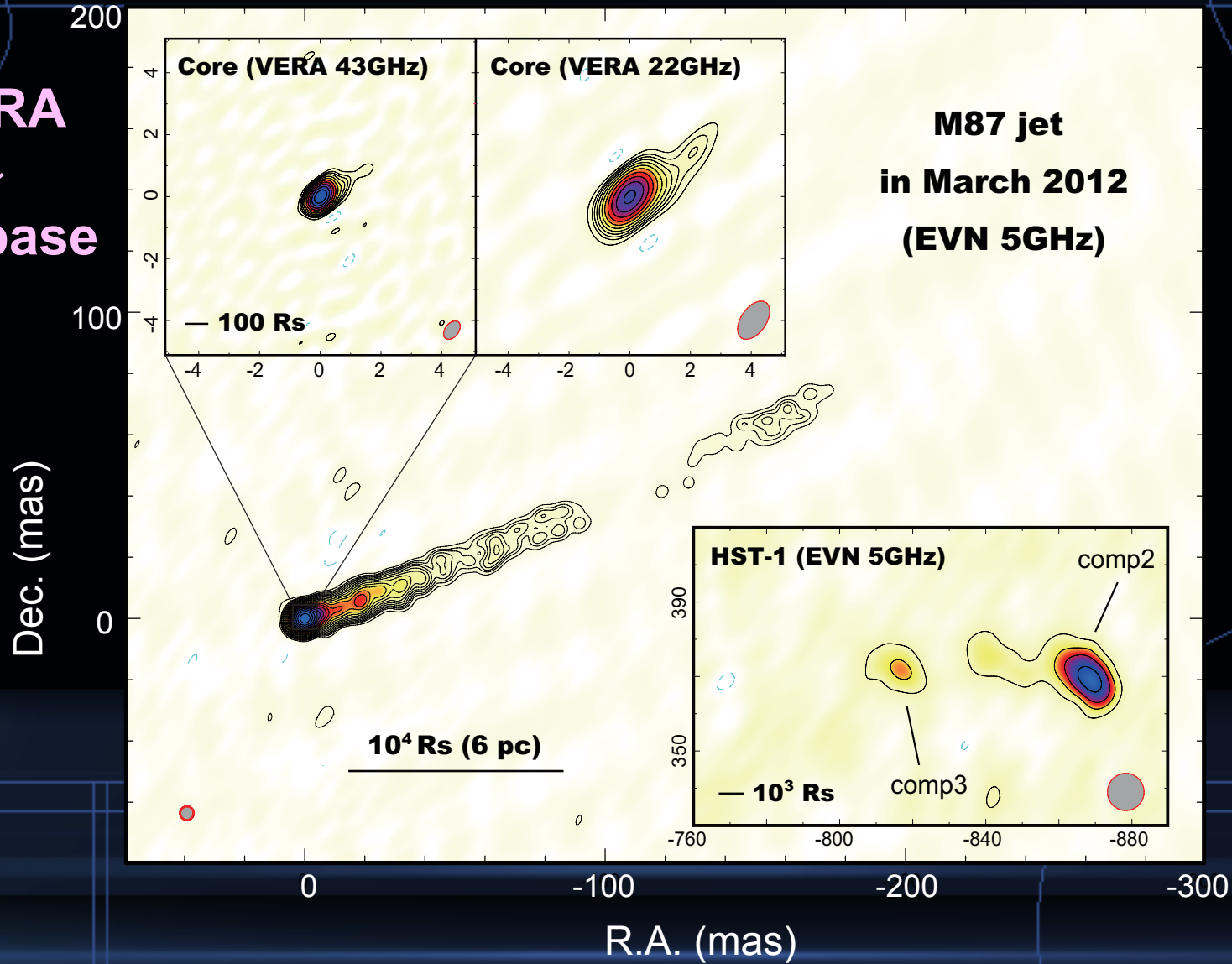
VERA (VLBI Exploration of Radio Astrometry)

- VERA @ 22GHz (~1mas)
  - 24 epochs in Sep/2011-Sep/2012
- VERA @ 43GHz (~0.5mas)
  - 6 epochs in Feb-May/2012
- EVN @ 5GHz (~2mas)
  - 9 epochs in Mar/2011-Oct/2012
  - To image HST-1 region at a better sensitivity
- Fermi-LAT (0.1-100GeV)
  - Feb/2011-Sep/2012
  - Light curves were created with 1&2month bins (M87 is a weak source for Fermi)



# Milliarcsec-scale images

VERA  
⇓  
Jet base

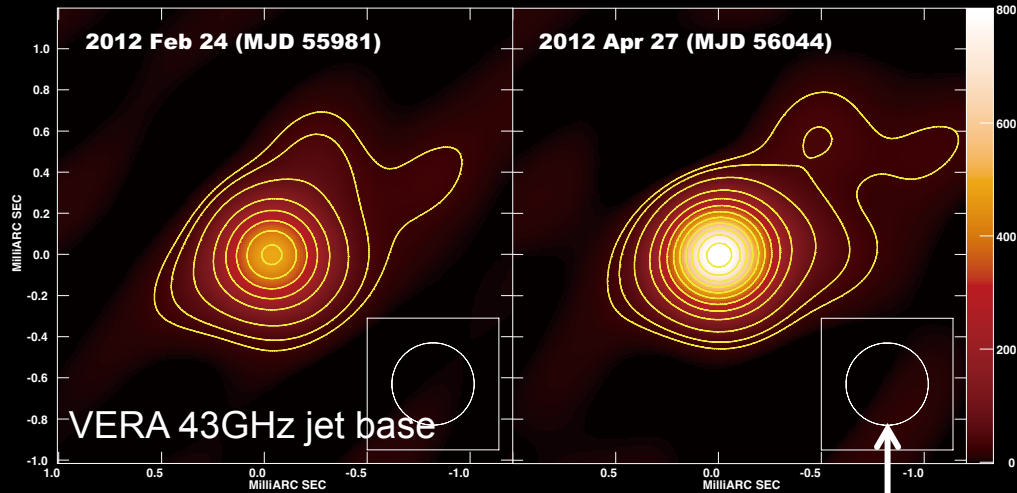


EVN  
⇓  
HST-1

# MWL light curves

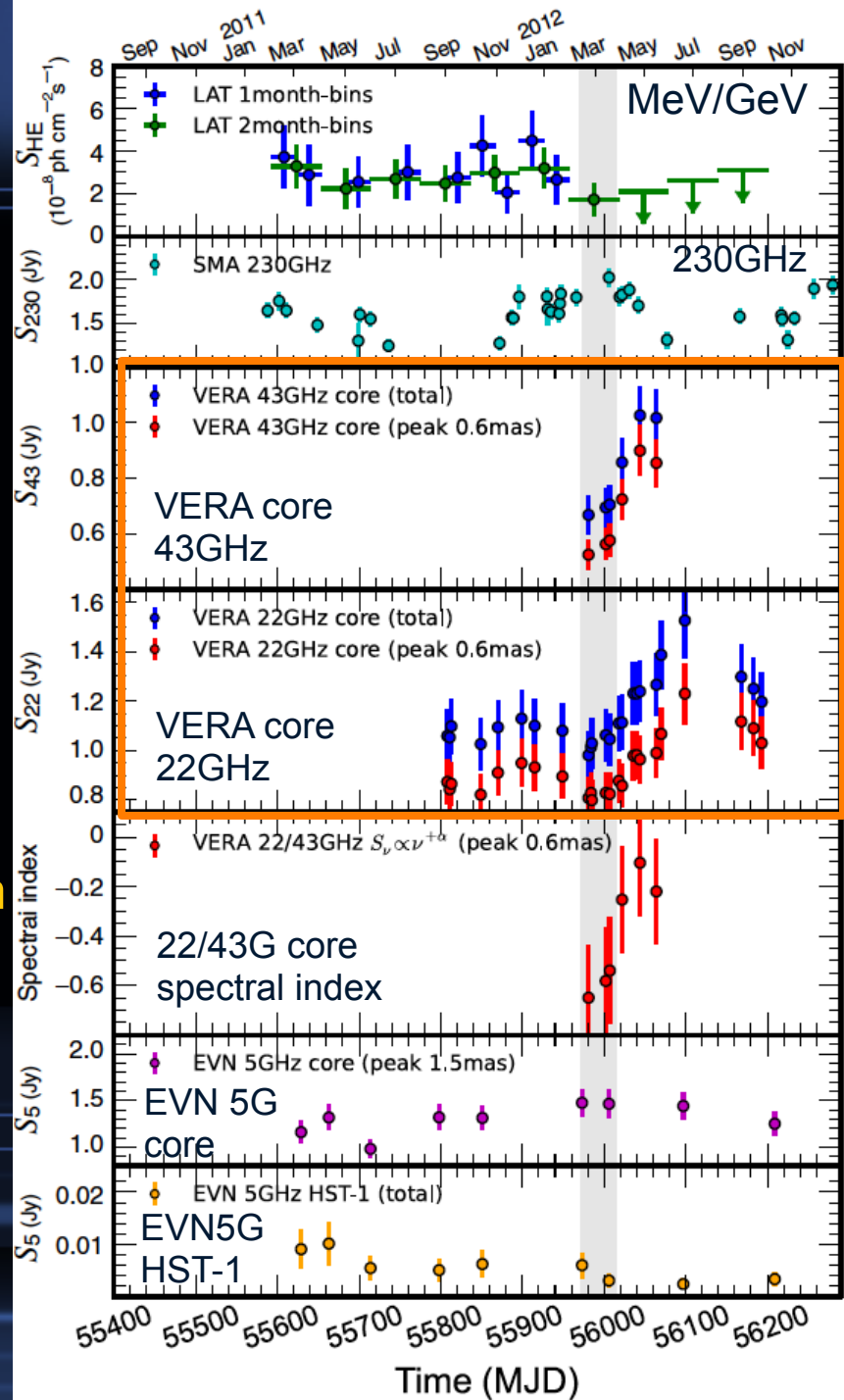
Before TeV event

After TeV event



0.4mas/0.03pc/56Rs

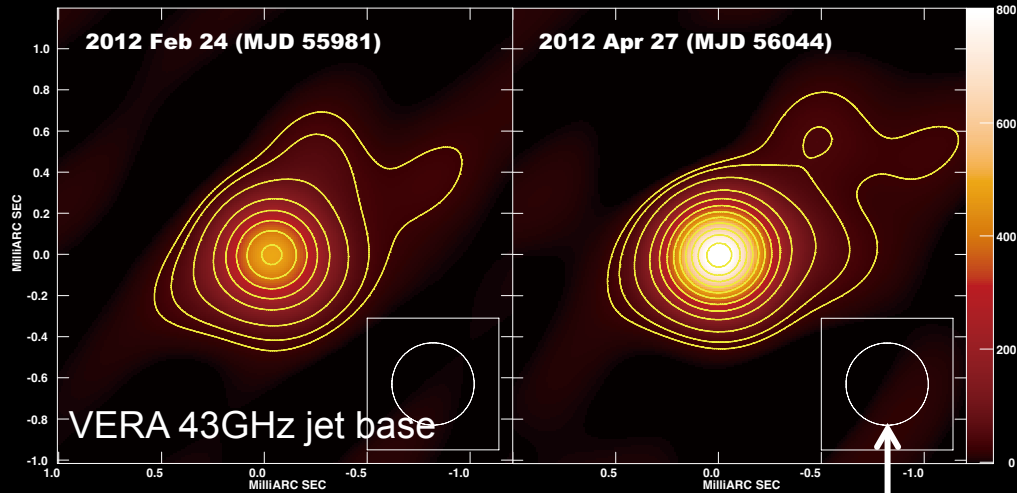
- Remarkable flux increase ( $\sim 70\%$ ) from the radio core (22/43GHz) coincidentally with the TeV event
- HST-1 remained quiescent
- LAT light curves - no significant enhancement, but a possible state change after the TeV event?



# MWL light curves

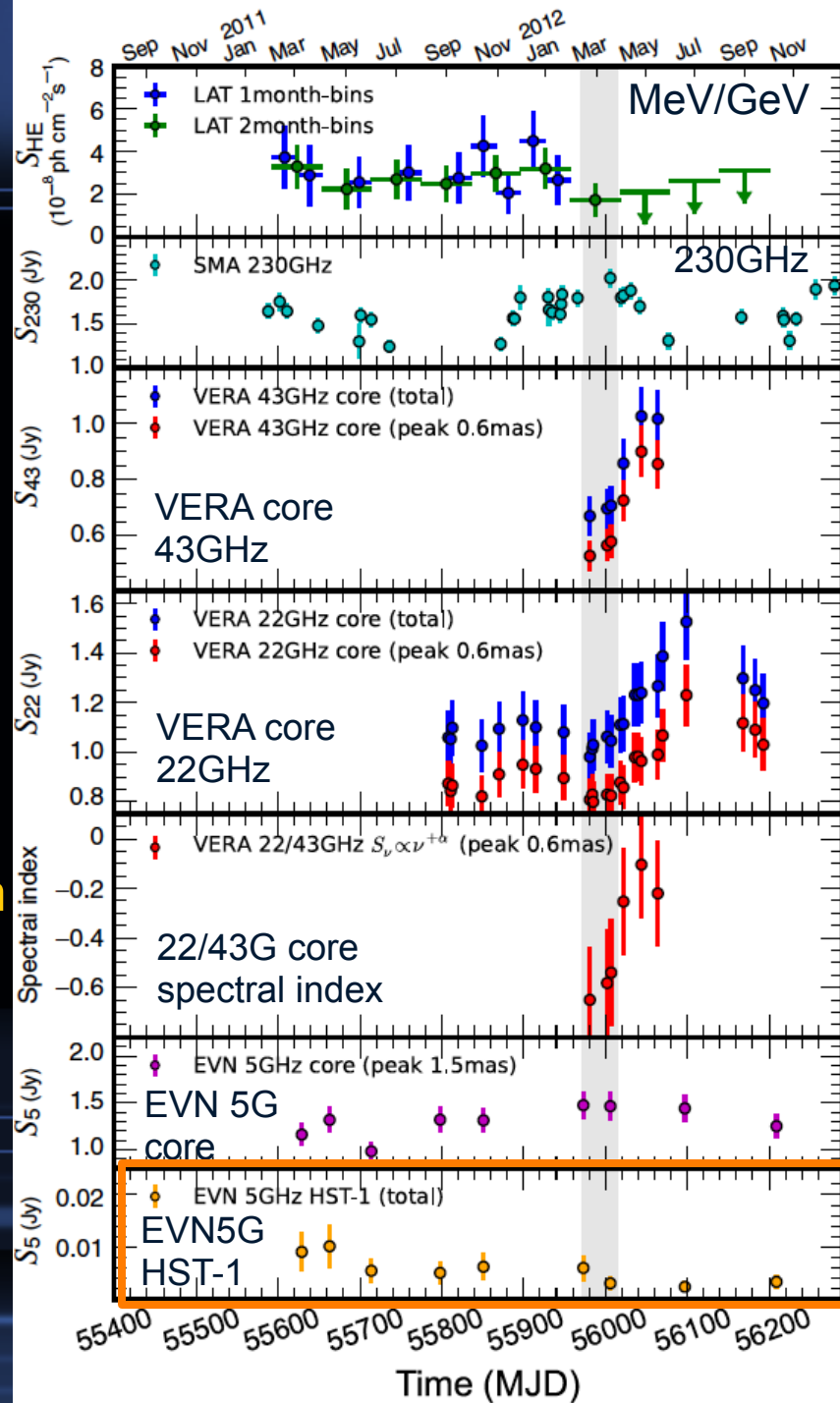
Before TeV event

After TeV event



0.4mas/0.03pc/56Rs

- Remarkable flux increase ( $\sim 70\%$ ) from the radio core (22/43GHz) coincidentally with the TeV event
- HST-1 remained quiescent
- LAT light curves - no significant enhancement, but a possible state change after the TeV event?

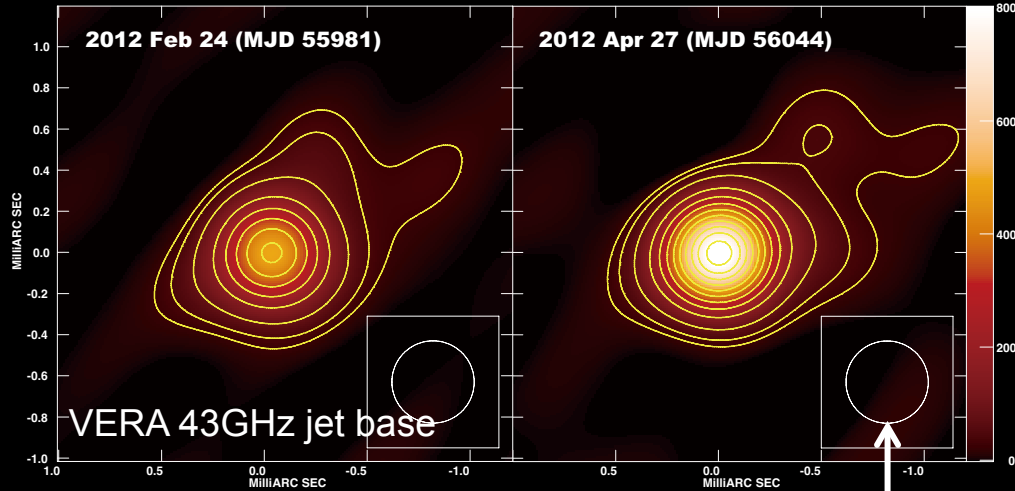




# MWL light curves

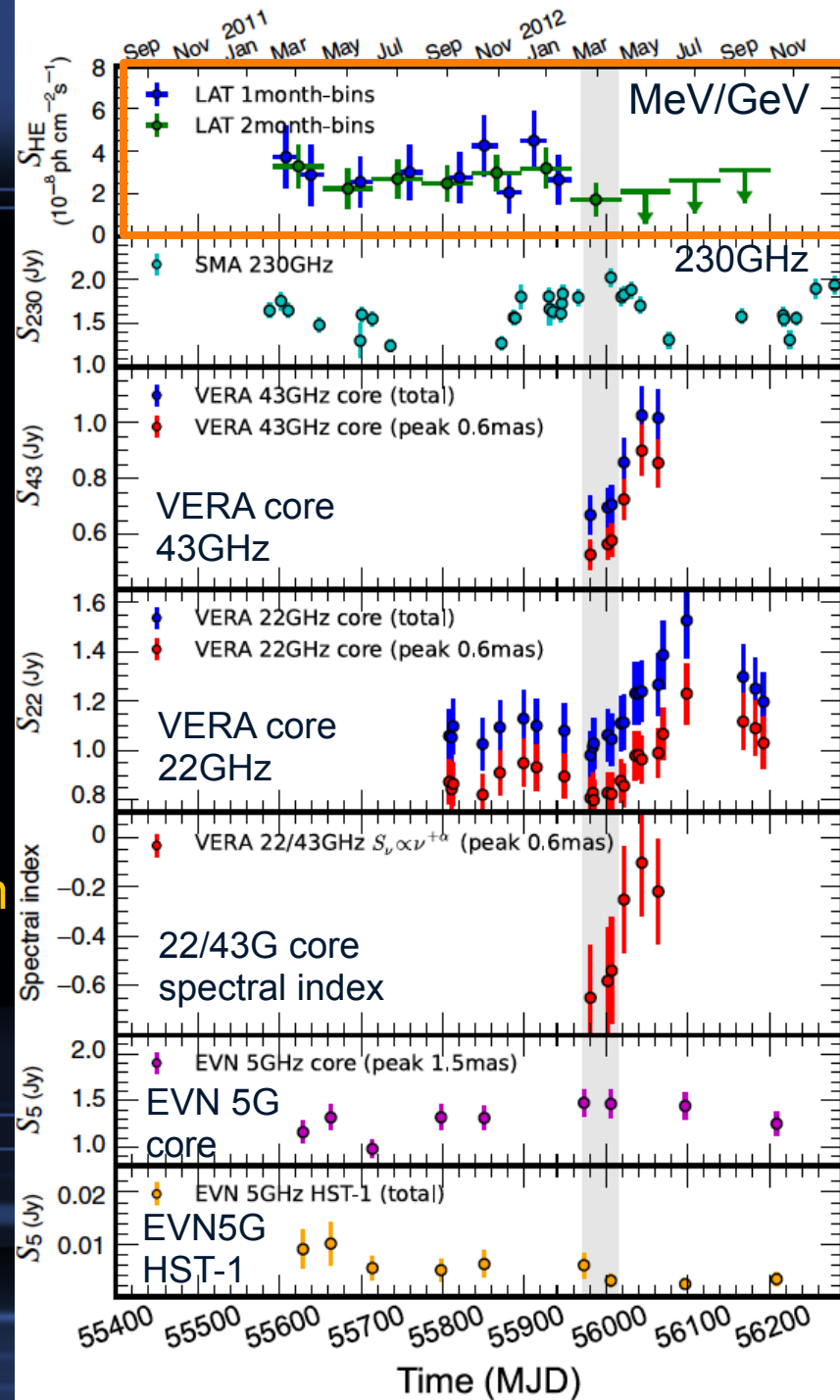
Before TeV event

After TeV event



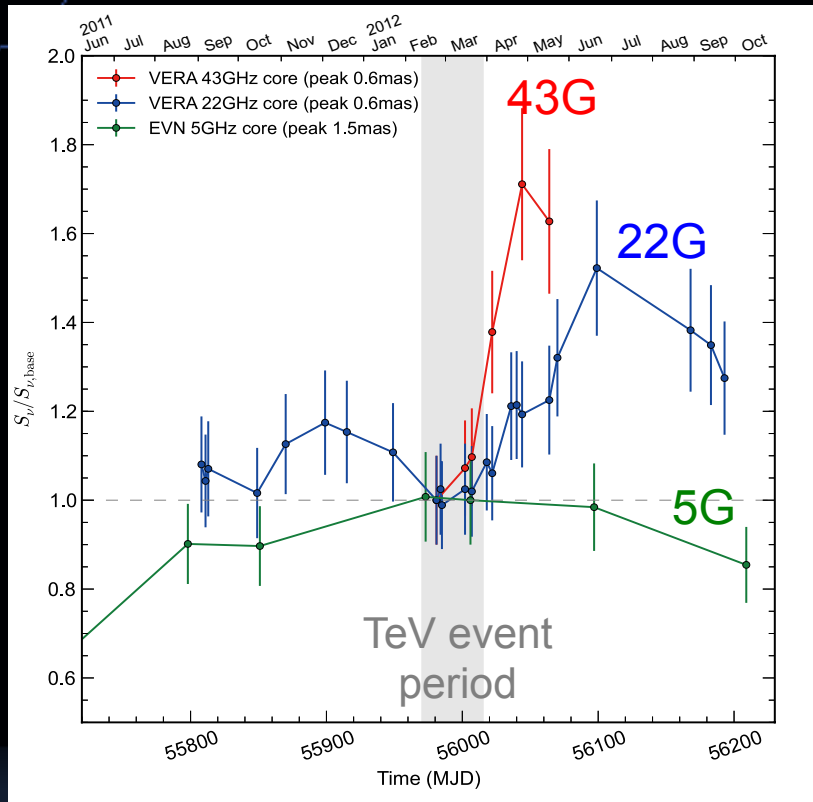
0.4mas/0.03pc/56Rs

- Remarkable flux increase (~70%) from the radio core (22/43GHz) coincidentally with the TeV event
- HST-1 remained quiescent
- LAT light curves - no significant enhancement, but a possible state change after the TeV event?

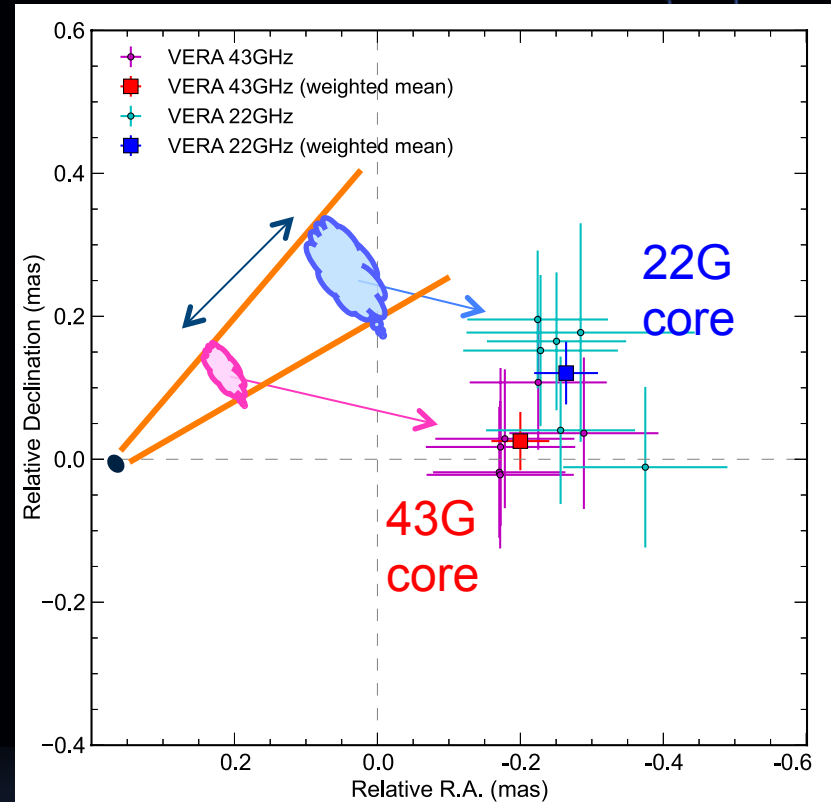


# Radio flare at jet base

## Radio core light curves



## Core positions on the sky with VERA 22/43G astrometry

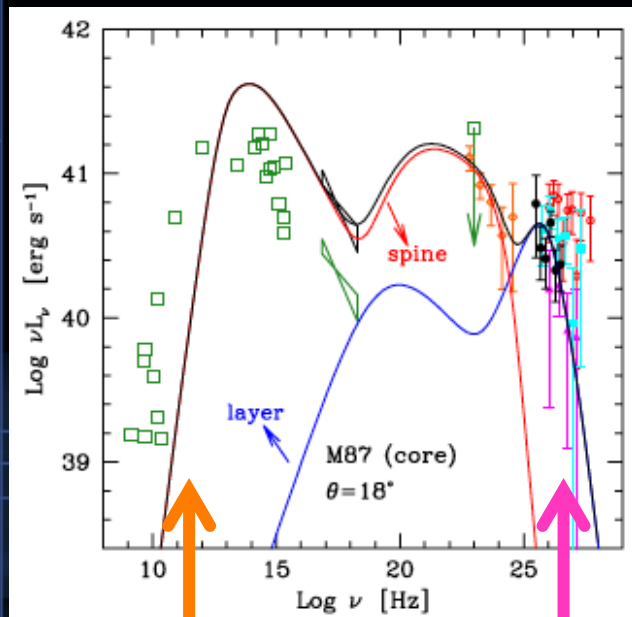


- Frequency-dependent flare evolution (time-lag, amplitude)
- Detection of “core-shift” during the radio flare
- The active event originates in an optically-thick region at these radio frequencies

# The location of the 2012 event

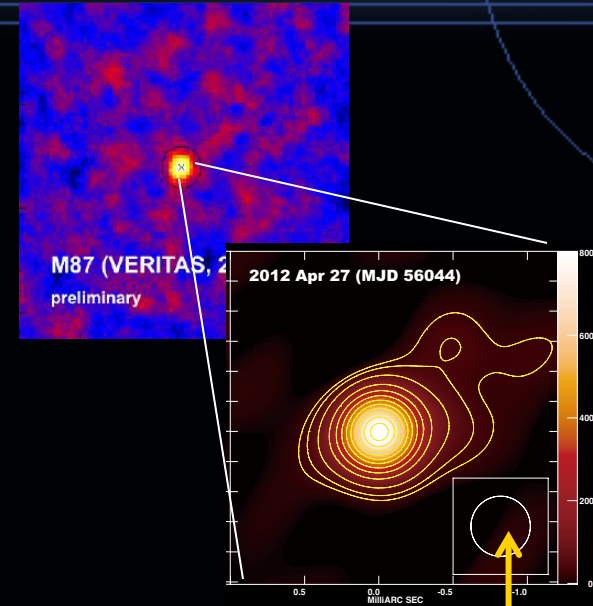
- Core/TeV joint enhancement
- ~70% rise of radio flux is very rare in M87 core (only seen in the 2008 event)
- Quiescent HST-1 (flux&structure)
  - favor the 2012 TeV event originates in the jet base (within  $\sim 0.03\text{pc}$  or  $\sim 56R_s$ )

Tavecchio&Ghisellini 2008, Aleksic+ 2012



Radio  
from spine

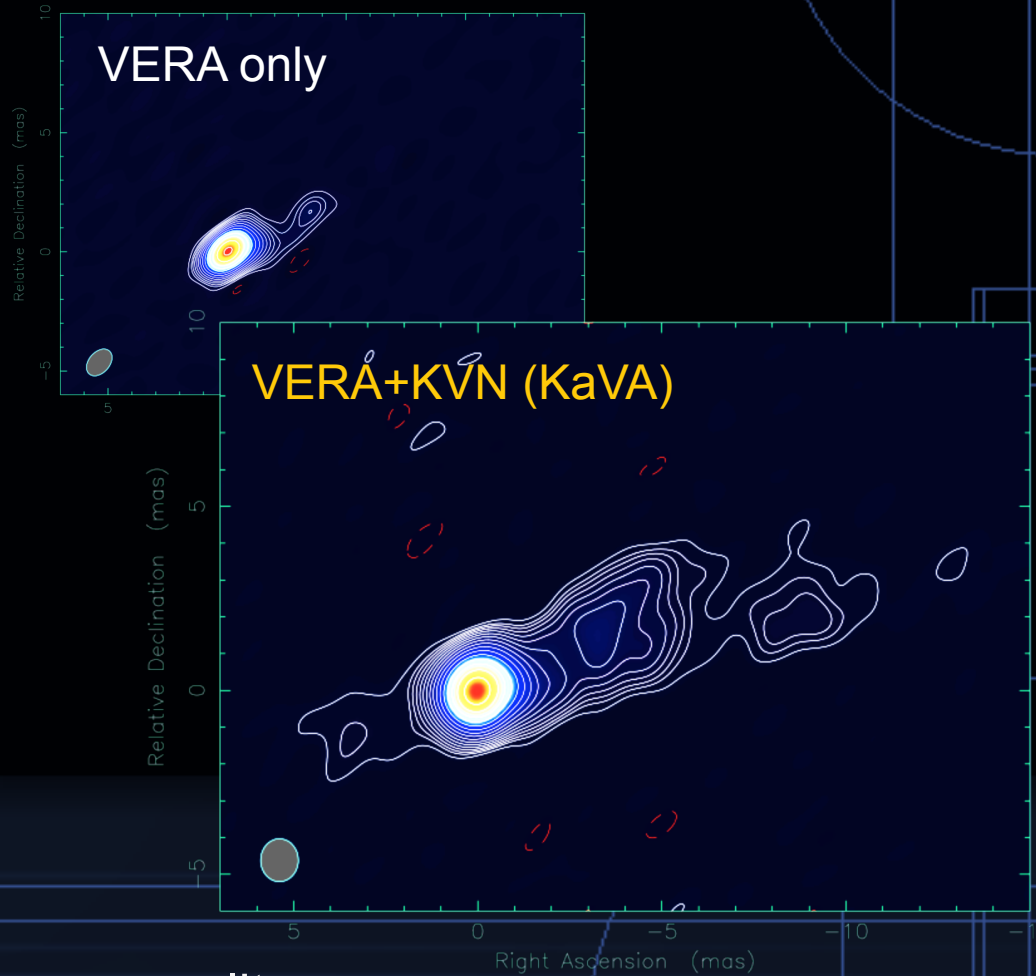
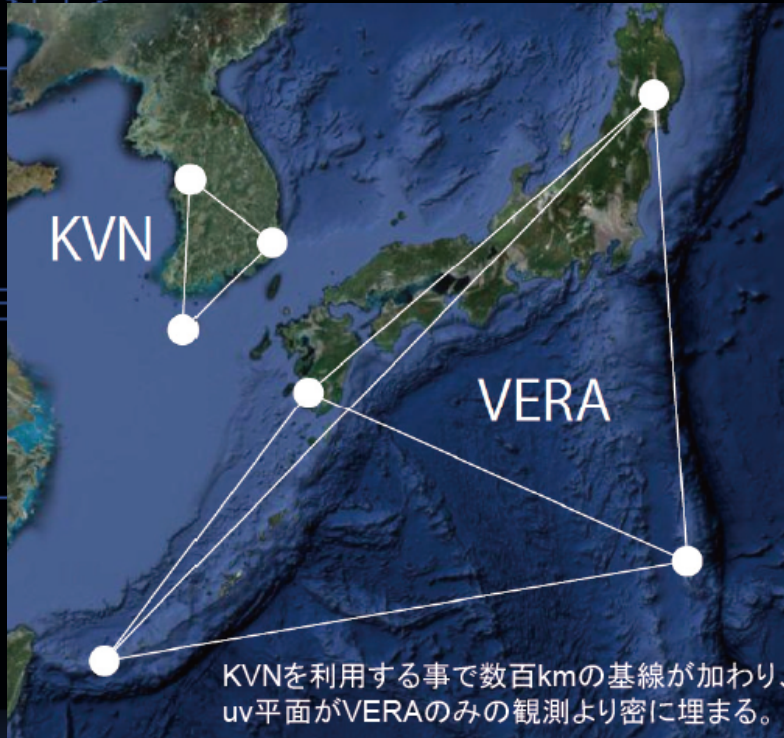
TeV  
from sheath



0.4mas/0.03pc/56Rs

- Spine-sheath structure is often favored in M87 sub-pc jet, but this scenario does not necessarily expect radio/TeV joint flares
- 2008/2012 cases may imply that the radio/TeV regions are spatially not separated

# Project upgrade: Jet base monitor with VERA+KVN joint array



- Dramatic improvement of image quality
- Better constraint on the mas-scale properties of the jet base region



# Summary

- We reported a multi-band radio and MeV/GeV study using VERA, EVN and LAT during the elevated VHE gamma-ray state in 2012
- We detected a remarkable flux increase from the radio core at the jet base coincidentally with the TeV enhancement, while HST-1 was quiescent. These results favors that the TeV event in 2012 originates in the core near the central engine (similar to the case in 2008)
- The LAT light curves did not show any significant flux enhancement during the period of the TeV activity, but could show a possible state change after the TeV period (although the statistics are still low)