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Flaring Episodes of Cyg X-3 with KVN (Korean) & VERA (Japanese) VLBI Facilities

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VERA & KVN collaboration with

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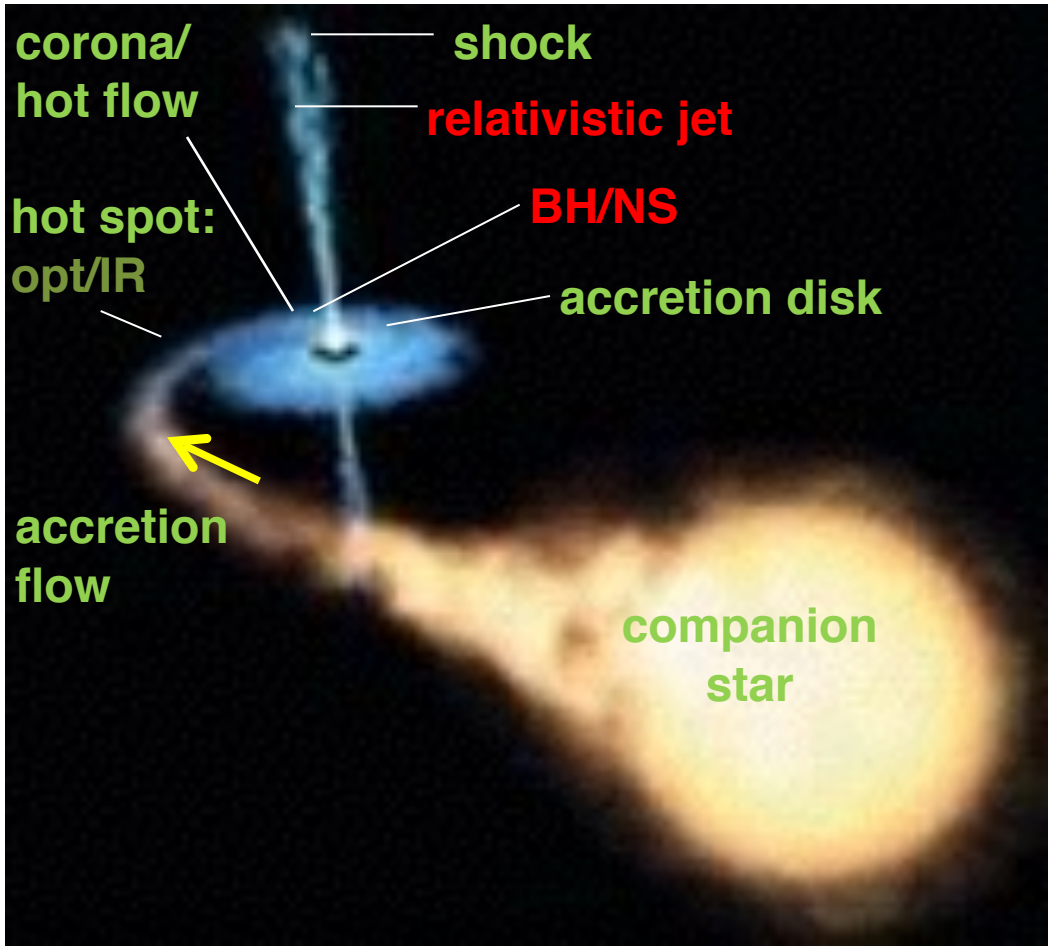
Introduction: Micro-quasars & Cygnus X-3

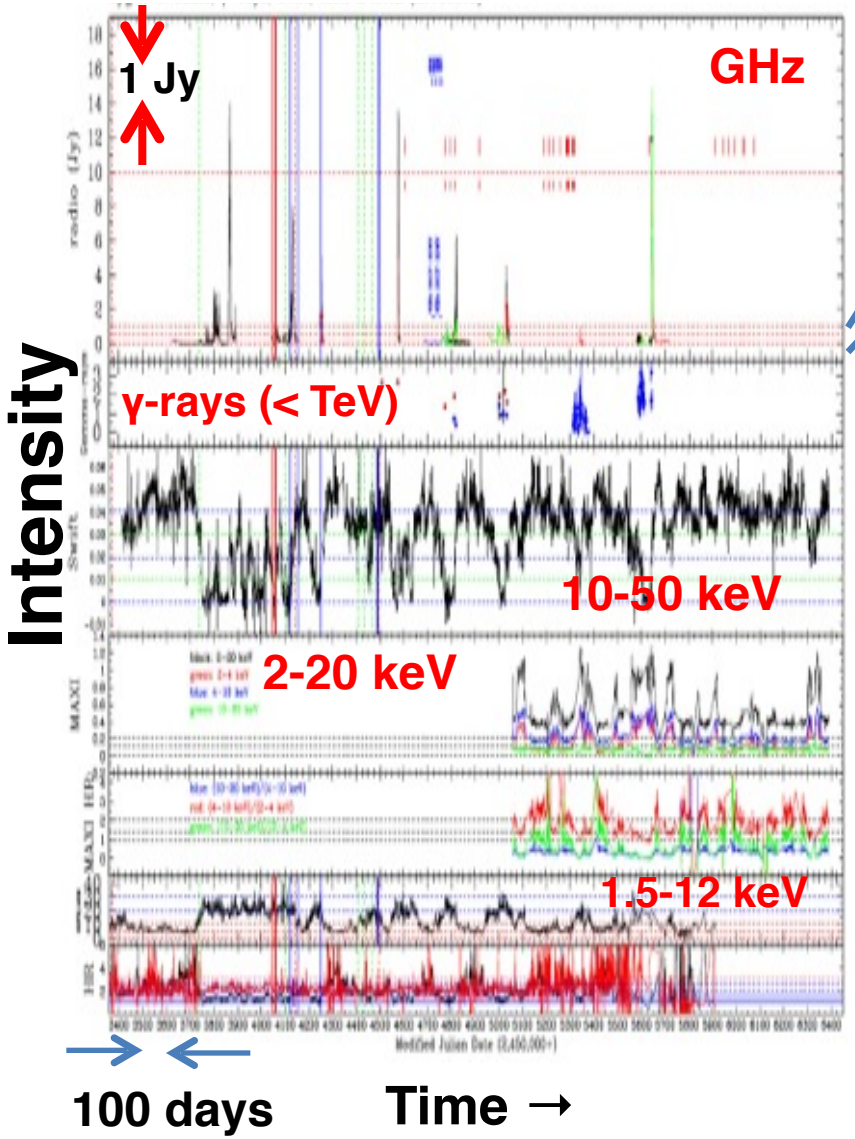


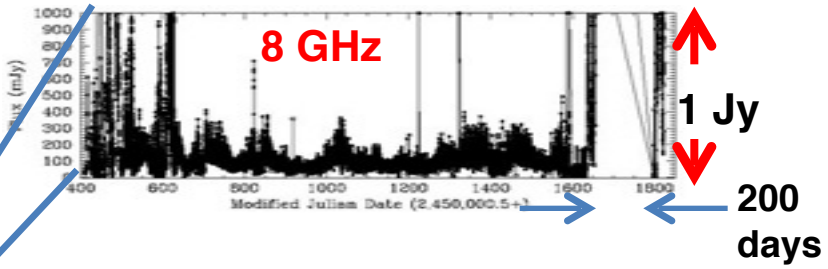
- "**microquasars**" (late 1980s): X-ray binaries (BH/NS) with relativistic jets (> 0.9c)
- micro-scale to quasars/AGN: but, jet production is as efficient as those in SMBH

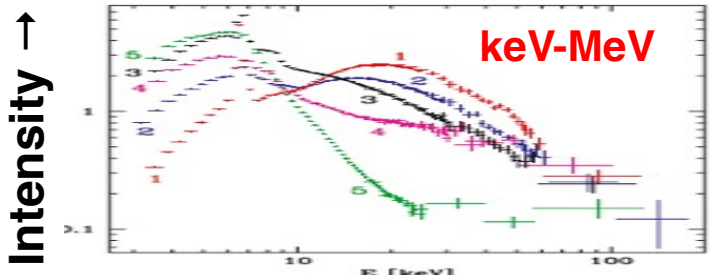
- MQs in our Galaxy (a dozen known): flares/ jets once a few-tens of yrs (but, with irregular recurrences); hard to catch a radio flare, even with ToO, esp. in the rise of a day or two.

Flaring Activities in Cygnus X-3

Cyg X-3: multi-wavelength light curves



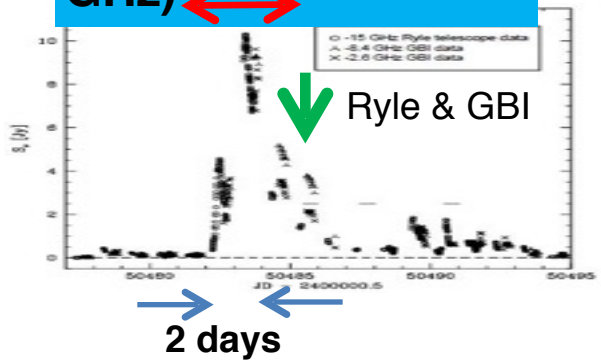




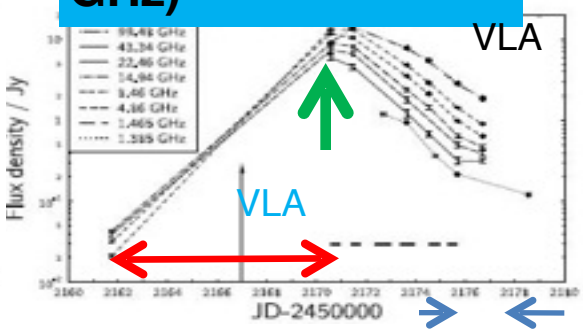
- Exceptions: **GRS 1915+105** & **Cyg X-3** – ***restless*** flaring activities ~ mins-yrs in the radio; *no real quiescence.*
- **GRS 1915+105**: extensively observed for last decades with VLBI – leaving more homework than understanding
- **Cyg X-3**: much poorly explored;
  BHC, massive but tight (P_{orb}~4.8 hr)
  XRB with an unusual companion, WR.

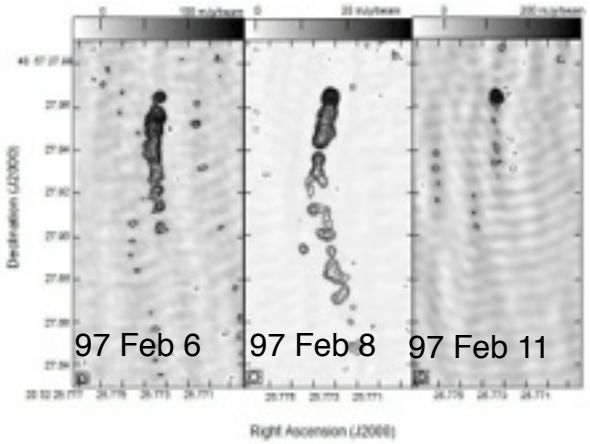
Two VLBI Observations during Large Flares

1997 (VLBA @15 GHz)



2001 (VLBA@22 GHz)

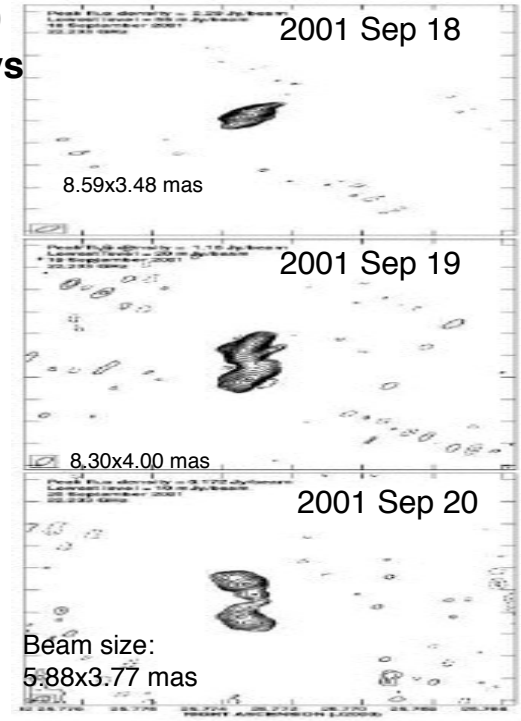




200 days

Bean size (mas): (a) 3.98x3, (b) 4.66x4.13, (c) 4.29x3.81

[Mioduszewski et al. 2001]

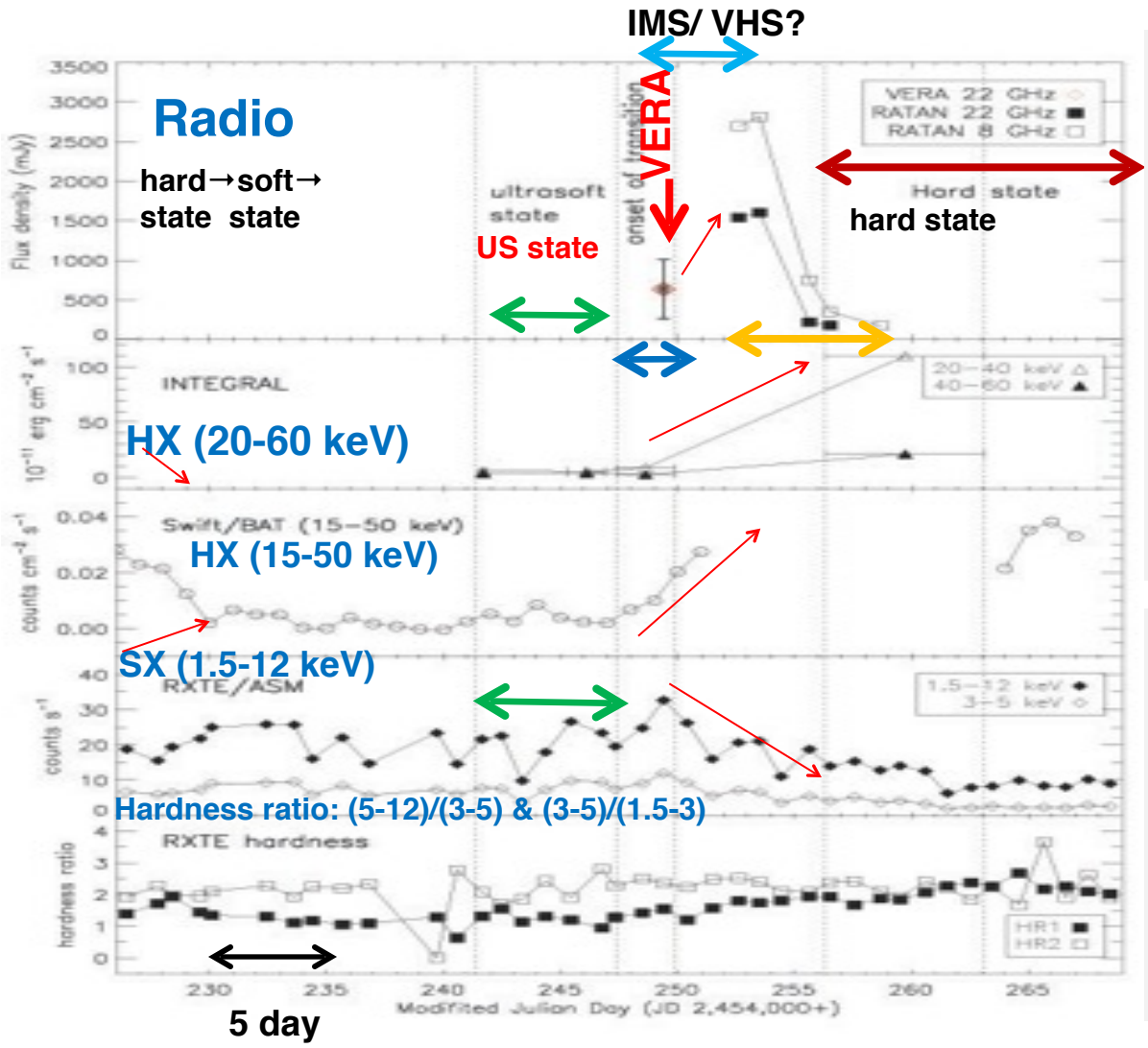


[Miller-Jones et al. 2004]

- Only a few detailed jet image has been explored for main, large flares, with ***missing rise*** phases, < 2 days.
- Catching **an initiation of jet event in a rise** with VLBI (ToO) is extremely challenging ! (whether large or small flares)
- **Initial rise** & **initiation of jet ejection** are crucial/important to understand **why/how jet forms & accelerated**.
- feedback to AGNs

Topic 1. 2007 Flare with VERA [1]
(during X-ray State Transition from US to Hard State)

[Kim, J.-S., Kim, S.-W. et al. 2013 ApJ 772] - one of J.-S. Kim's Ph.D. works

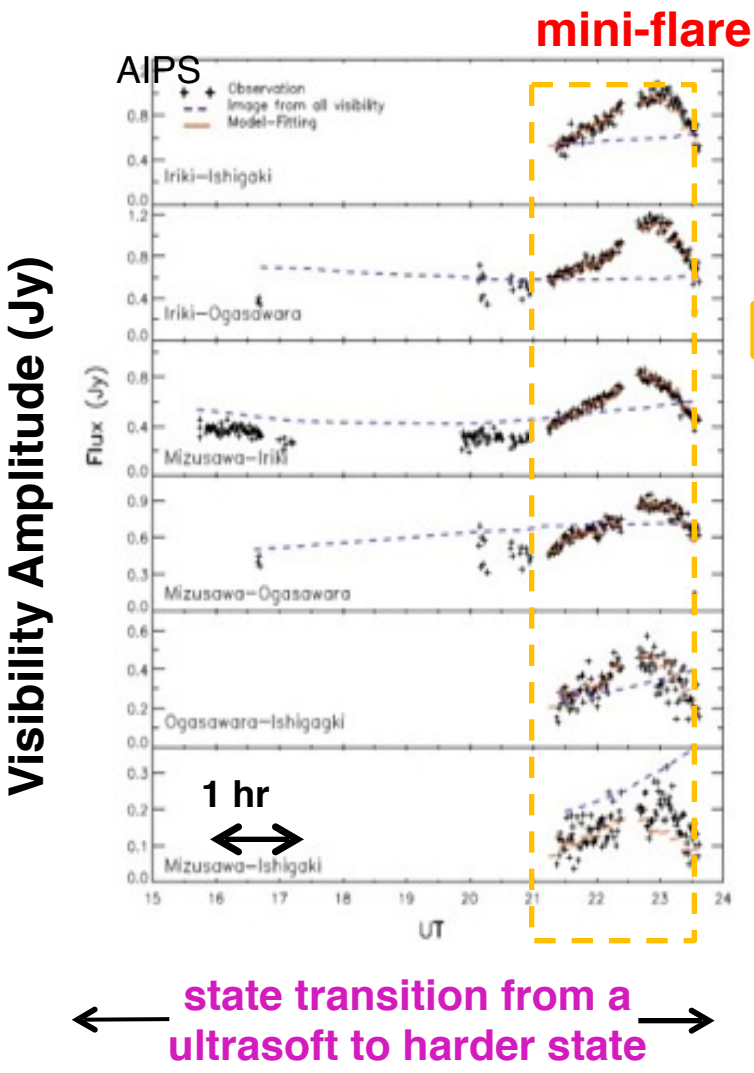


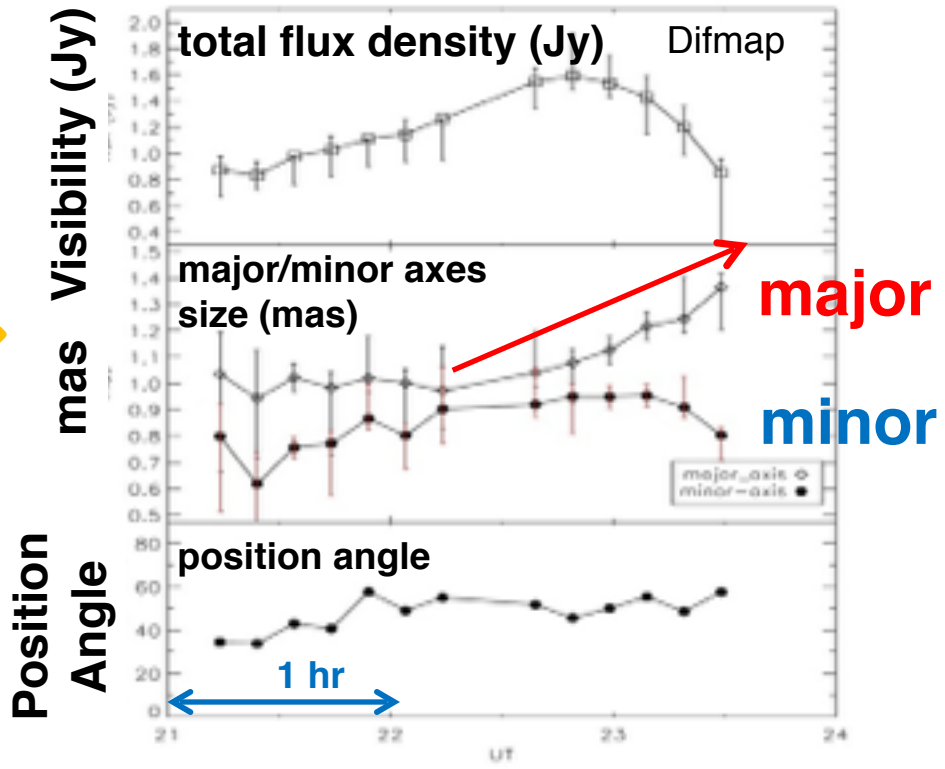
X-rays: (1) In **hard state** (before a major flare), strong correlation of the radio to soft X-rays; (2) In **flaring state**, correlation of the radio to HXs; anti-correlation of the radio & HXs to SXs;

(3) In between, **ultra-soft (transition) state:**

- Soon as it entered the US state [Beckman et al. ATel],
- VERA: in the **early rise** during a state transition from US toward harder states ***for the first time*** (red vertical arrow).

2007 Major Flare with VERA during State Transition [2]





- **~3 hr-long flare (or "mini-flare")** in the course of rise in 2007 large flare
- **model fits: expansion of the major axis → Jet ejection (~0.3c) - proves** rise in the major flare is not simple; a series of **repetitive** flaring activity (i.e. X-rays)

- on-going KVN @22-43-86 GHz (2014-15); VERA proposal for 2015, in prep.

Topic 2. 2013 Small Flare with KVN@22 GHz (polarization with SD & VLBI) [Kim et al., in prep.]

- Polarization in MQs: only a handful of linear polarization in the radio

- **GRO J1655-40**: 1994 large flare, peak to decay (1.38-9.2 GHz) with ATCA → 0-12% [Hannikainen et al. 2000]
- **V404 Cyg**: 1989 large flare (1.49-14.9 GHz) with VLA → 0-6% [Han & Hjellming 1992]
- **GRS 1915+105**: 1997 large flare (4.994 GHz), MERLIN → 3-14% [Fender et al. 1999]
- **SS 433**

- **Cyg X-3**:

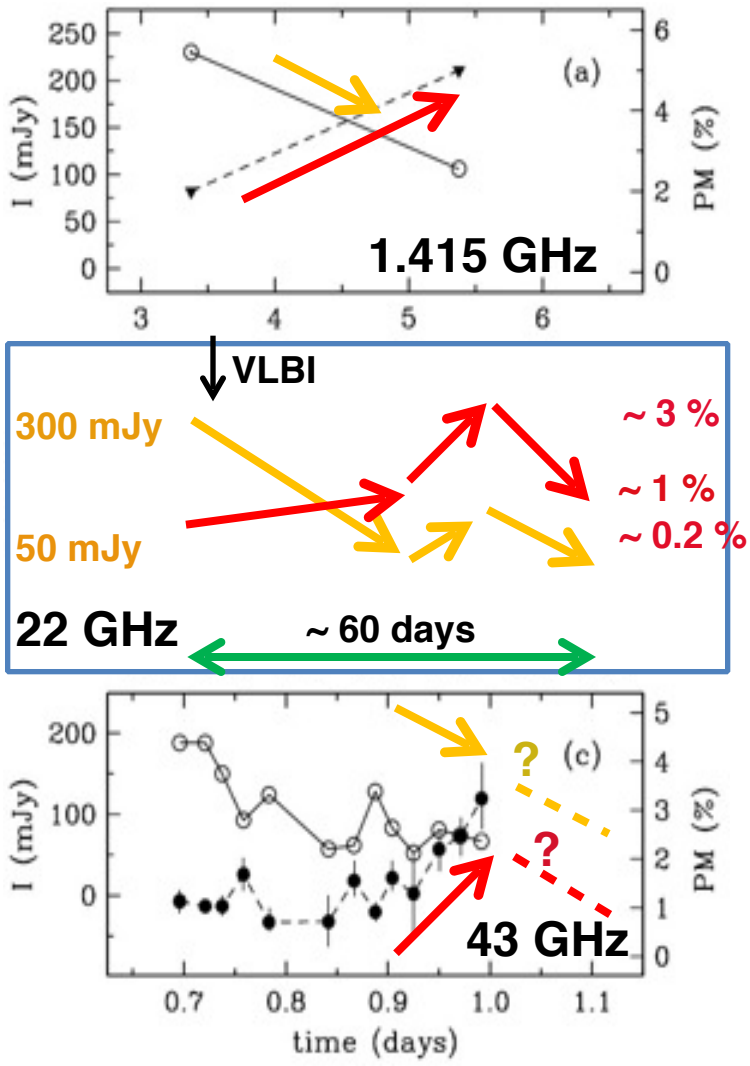
(1) **large flares:** extensively in 1972, 1974 & 1975
- 1972, from rise to decay (2.7, 8 & 10.5 → 0-14% [Dent et al. 1972 (SD), Aller 1972 (SD), Gregory et al. 1972 (SD, Seaquist et al. 1972 (NRAO 4-element interferometer)]
- 1974, from mid-rise to decay (4.2 GHz) with a SD → 5-9% [Kawano & Kawajiri 1975]
- 1975, peak to decay (8 & 14.5 GHz) with a single-dish → 5-25% [Ledden et al. 1976]

(2) **small flares:** covering peak to decay ***only once at 43 GHz***
- 2002, peak to decay (15/43 GHz) with VLA → 0-4% @43 GHz [Miller-Jones et al. 2009]
- 1971, only 2 epochs in decay of a small flare? (1.415 GHz) with Westerbork synthesis telescope → marginal detection [Braes & Miley 1972]

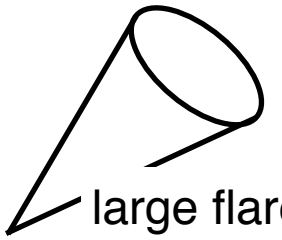
Polarization during 2013 small flare at **22 GHz**, *for the first time*, with KVN.

2013 Small Flare at 22 GHz: [1] Polarization

○ - flux density (mJy)
● - polarization (%)



In their VLA@15 & 43 GHz during 2002 small flare, Miller-Jones et al. (2009) claimed:
1. Opacity effect:



large flare:
large-scale, optically ***thin*** (~peak)
→ **diffusion**

small flare:
compact, optically ***thick*** (~peak)
→ ***thin*** → **diffusion**

2. No detection (lower degree) of pol. at 15 GHz due to greater optical depth: only for > 43 GHz?

2013 small flare at 22 GHz:
1) ~3% at 22 GHz, **comparable to 43 GHz**,
2) similar **enhancement of pol.** in the course of decay is confirmed, plausibly due to a transition of jet from opt. thick to thin, and
3) **VLBI** ob. (~ peak?) in analysis …

- on-going 2014-2015 KVN @22-43 GHz

THANK YOU
감사합니다