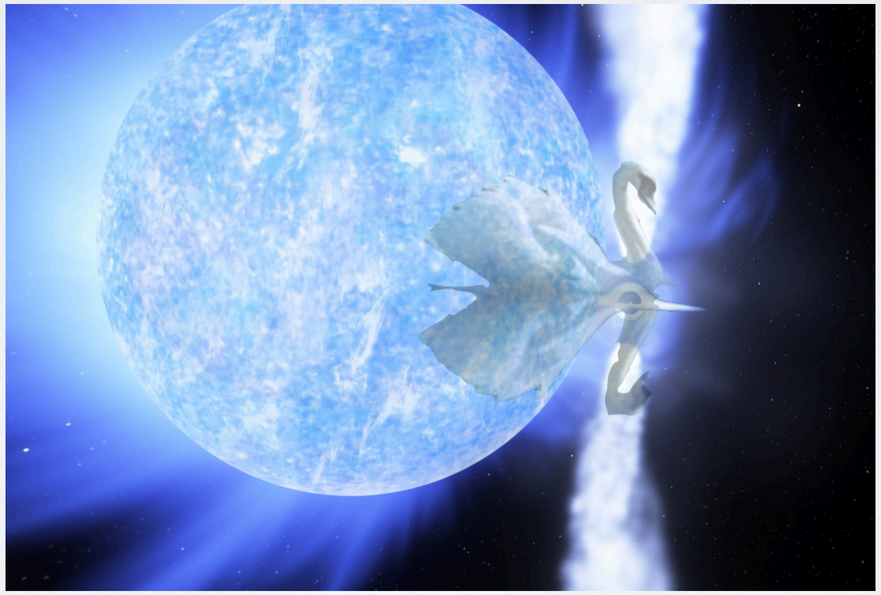
Investigating the mini and giant radio flares of the enigmatic microquasar Cygnus X-3



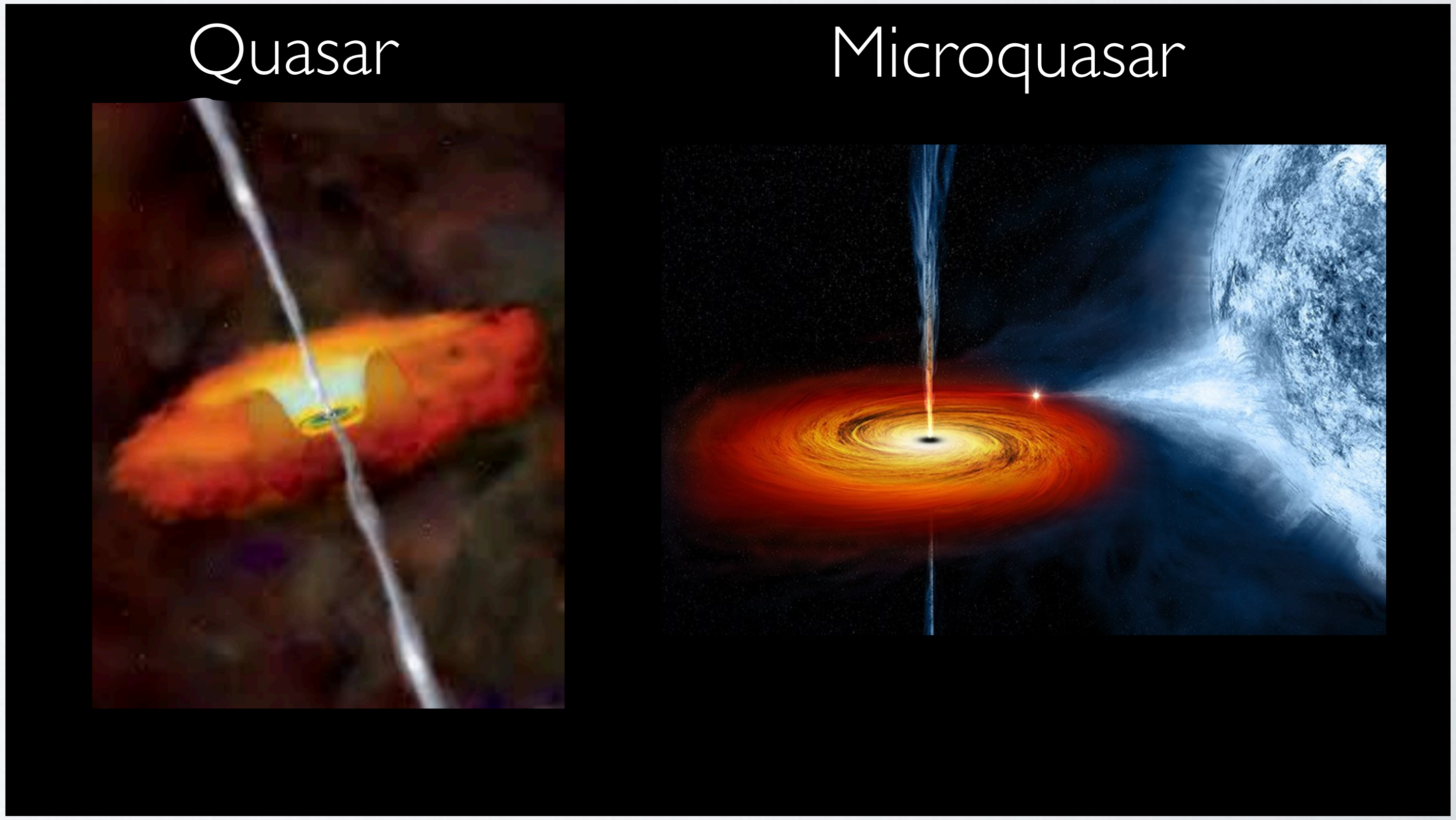
E. Egron (INAF-Observatory of Cagliari)

In collaboration with:

A. Pellizzoni, M. Giroletti, S. Righini, S. Trushkin, K. Koljonen, K. Pottschmidt, M. Stagni, A. Orlati, C. Migoni, A. Melis, M. Pilia, S. Loru, R. Concu, L. Barbas, S. Buttaccio, P. Cassaro, P. De Vicente, M.P. Gawronski, M. Lindqvist, G. Maccaferri, C. Stanghellini, P. Wolak, J. Yang, G. Surcis, J. Rodriguez, J. Wilms, V. Grinberg, S. Corbel, S. Markoff et al.

Microquasars

* Microquasars are X-ray binaries launching relativistic jets
* About 20 microquasars are ***now*** known (7% of X-ray binaries)
* 1rst microquasar observed in 1992 (Mirabel et al., Nature1992)
* Scaled-down version of quasars



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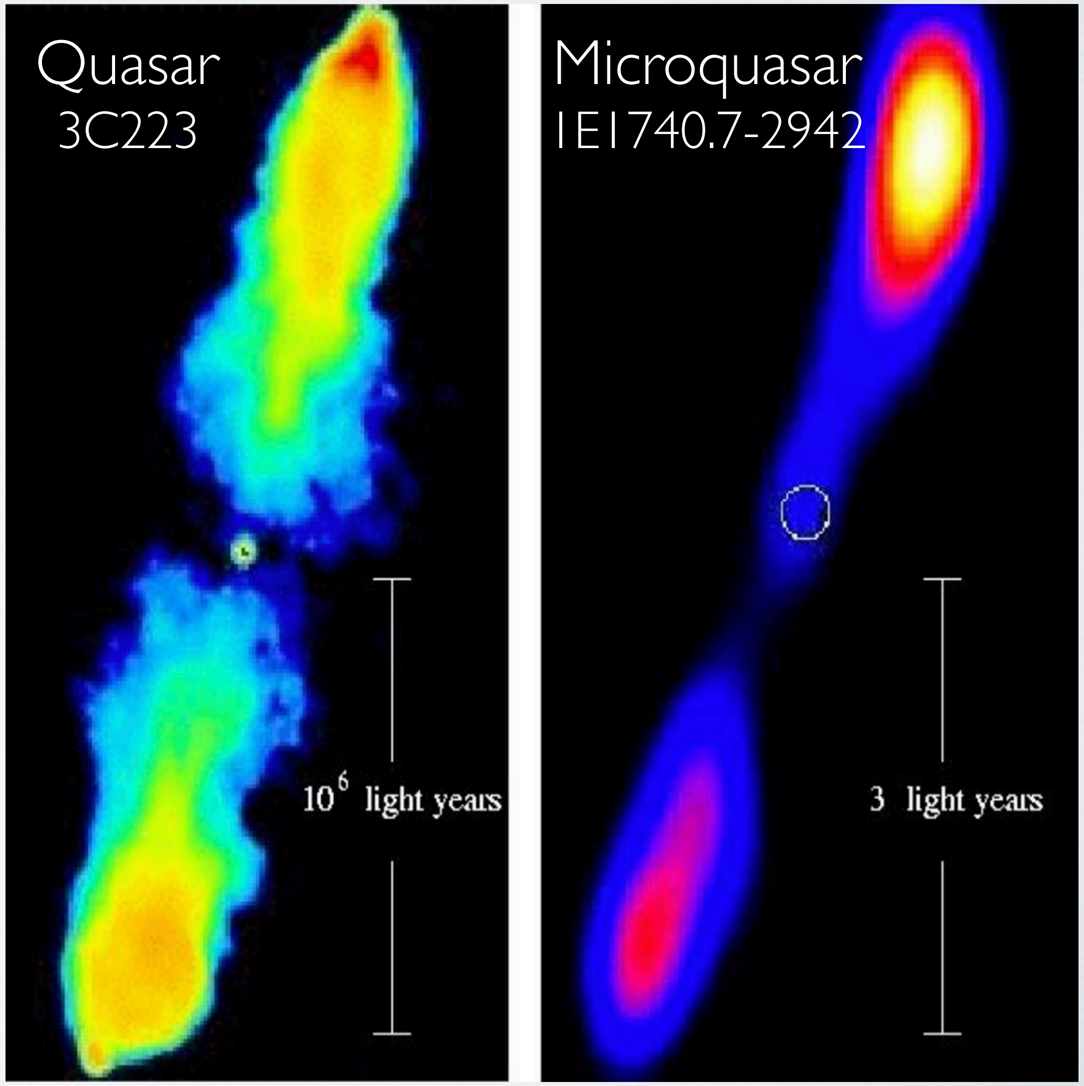

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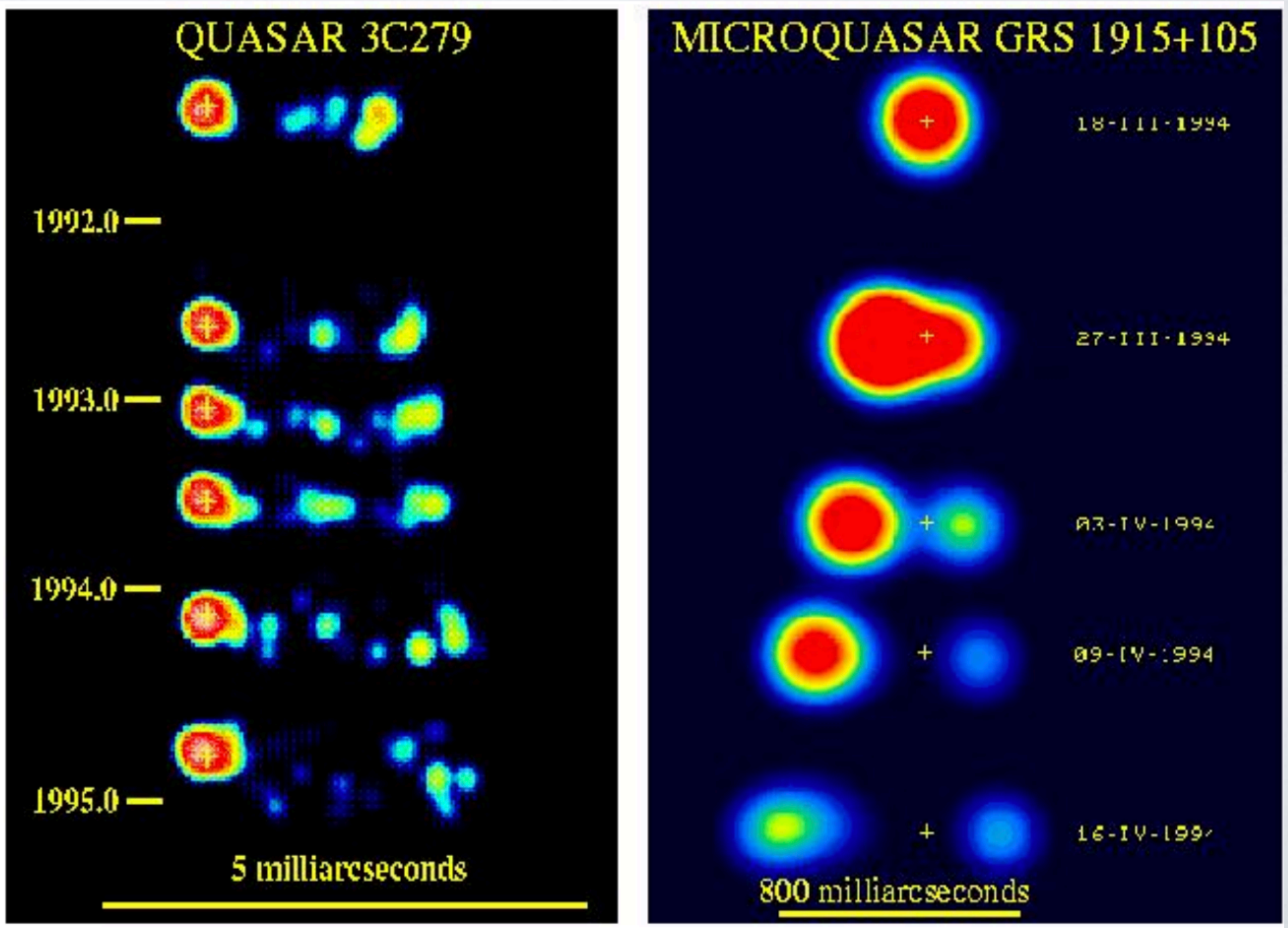
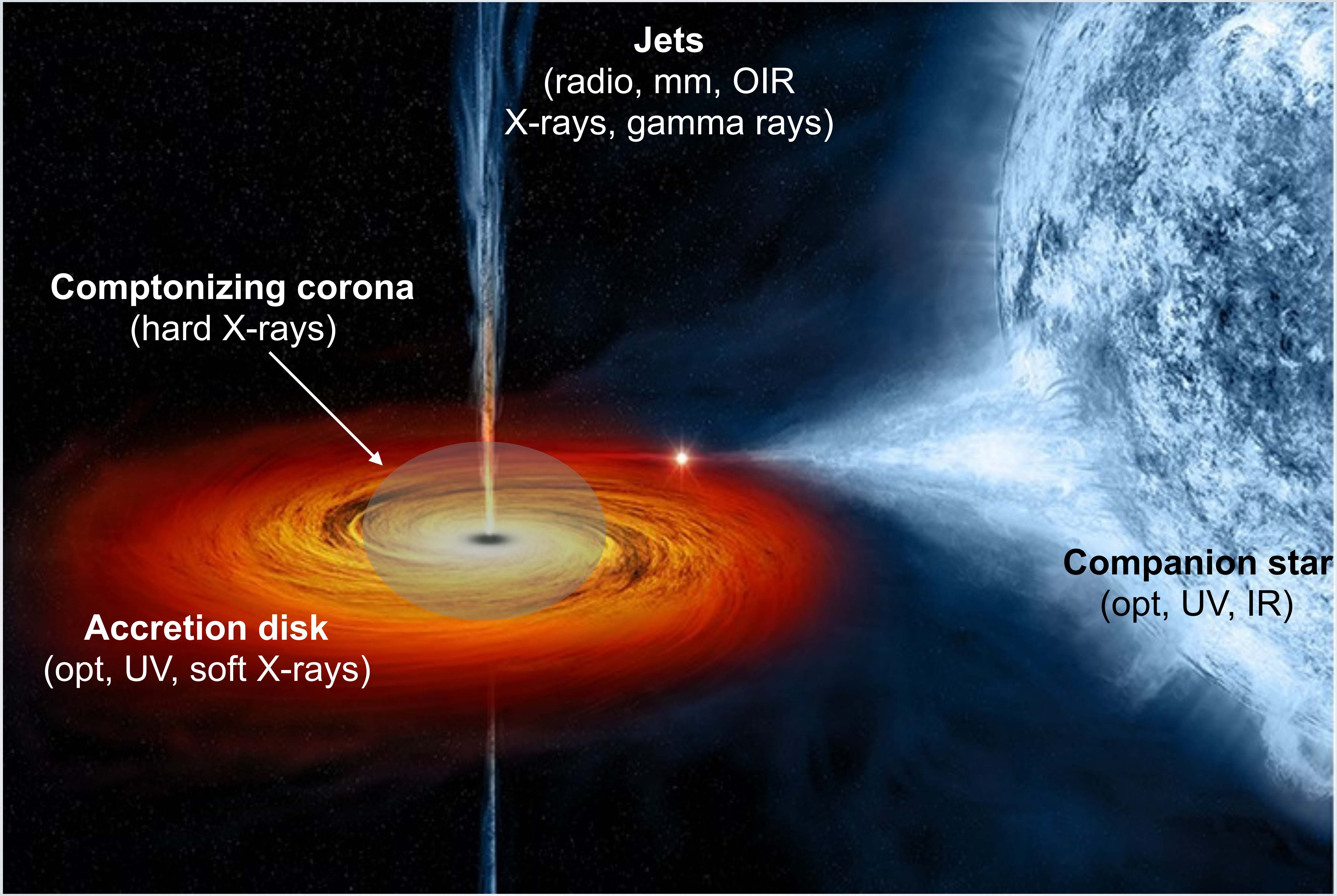


=> Microquasars evolve on much faster time scales

Microquasars



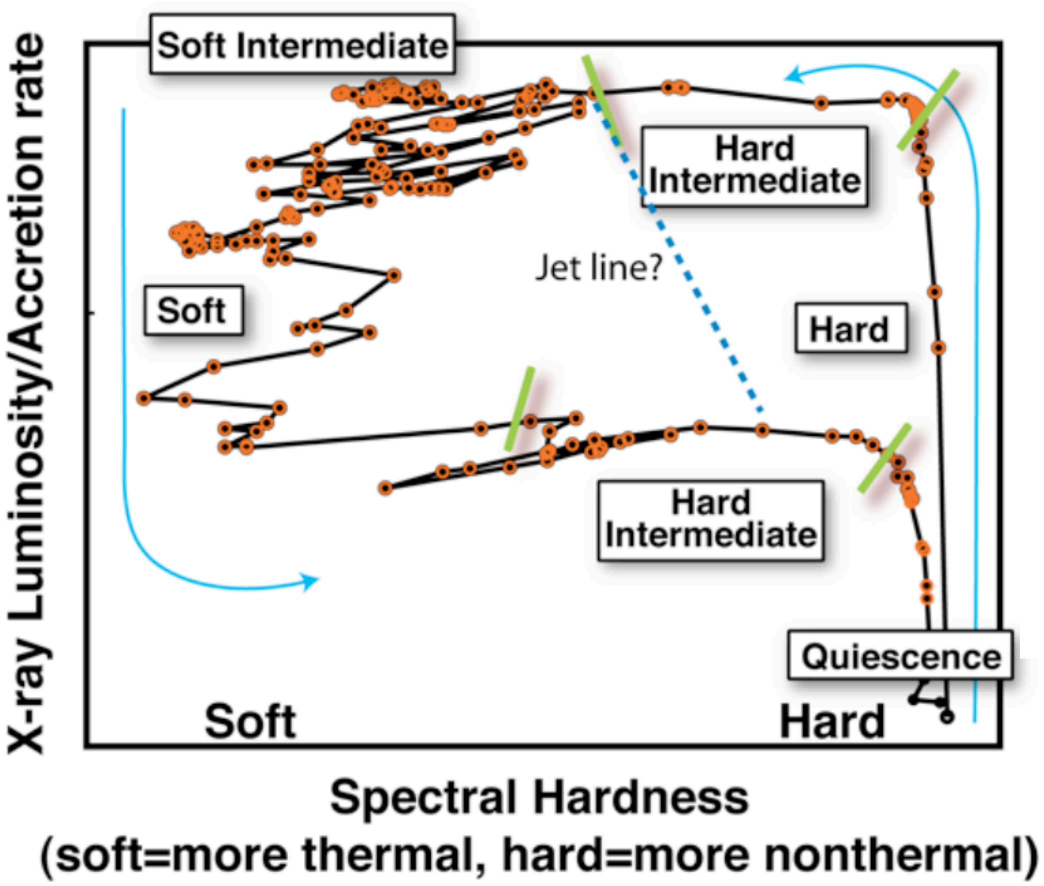
Key questions

* Do all X-ray binaries launch jets? Sensibility?
* How are jets launched ?
* What causes in-situ acceleration of particles in a jet?
* How are the properties of jets (power, speed, shape, etc.) related to accretion?
* What conditions are necessary in the accretion flow ?
* What is the role of the corona?
* How do the properties of jets vary between BHs and NSs ?
* What impact do the jets have on their environment ?

Typical evolution of microquasars during outbursts

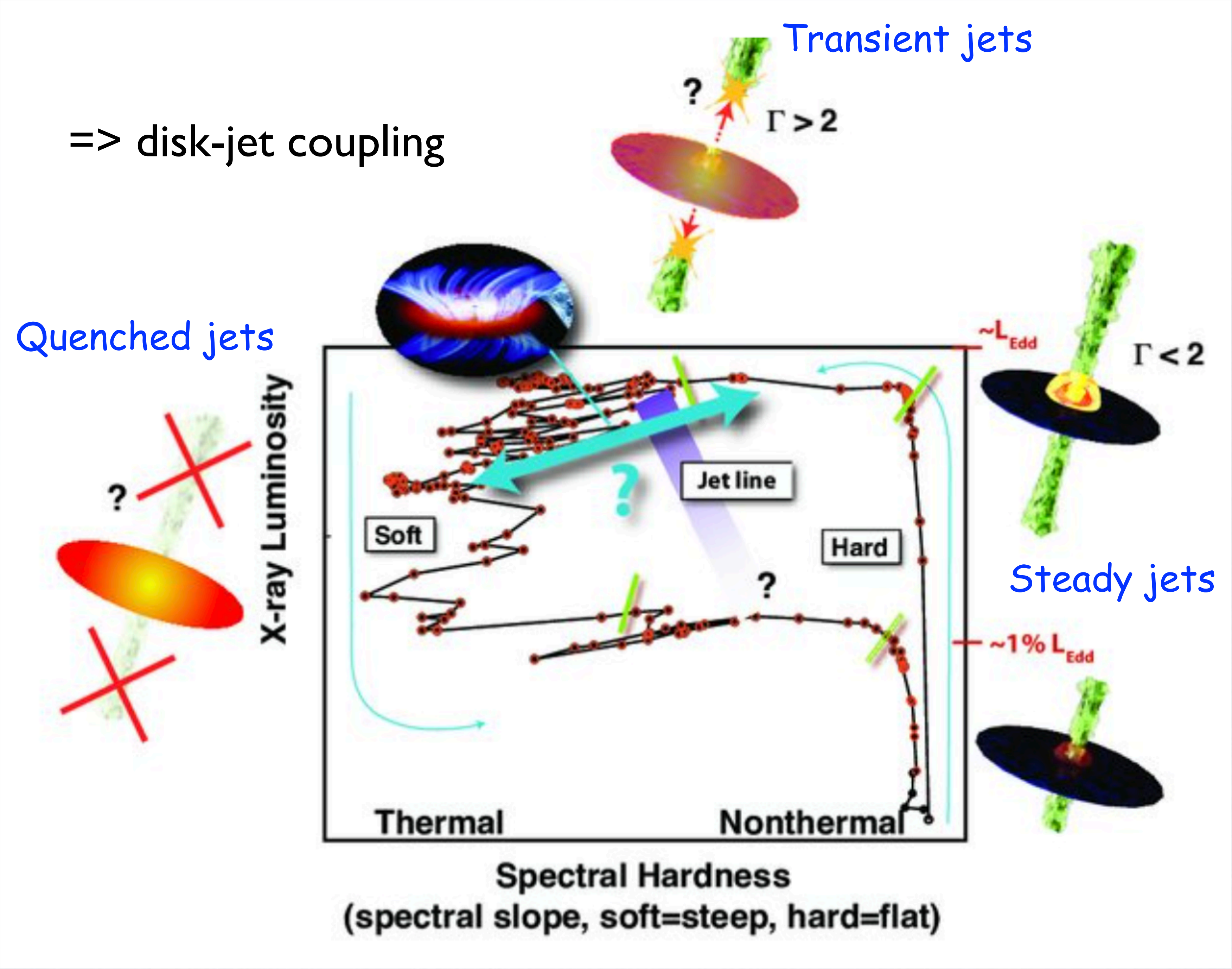
Hardness-Intensity Diagram

Inner accretion-flow variability :
=> X-ray state changes



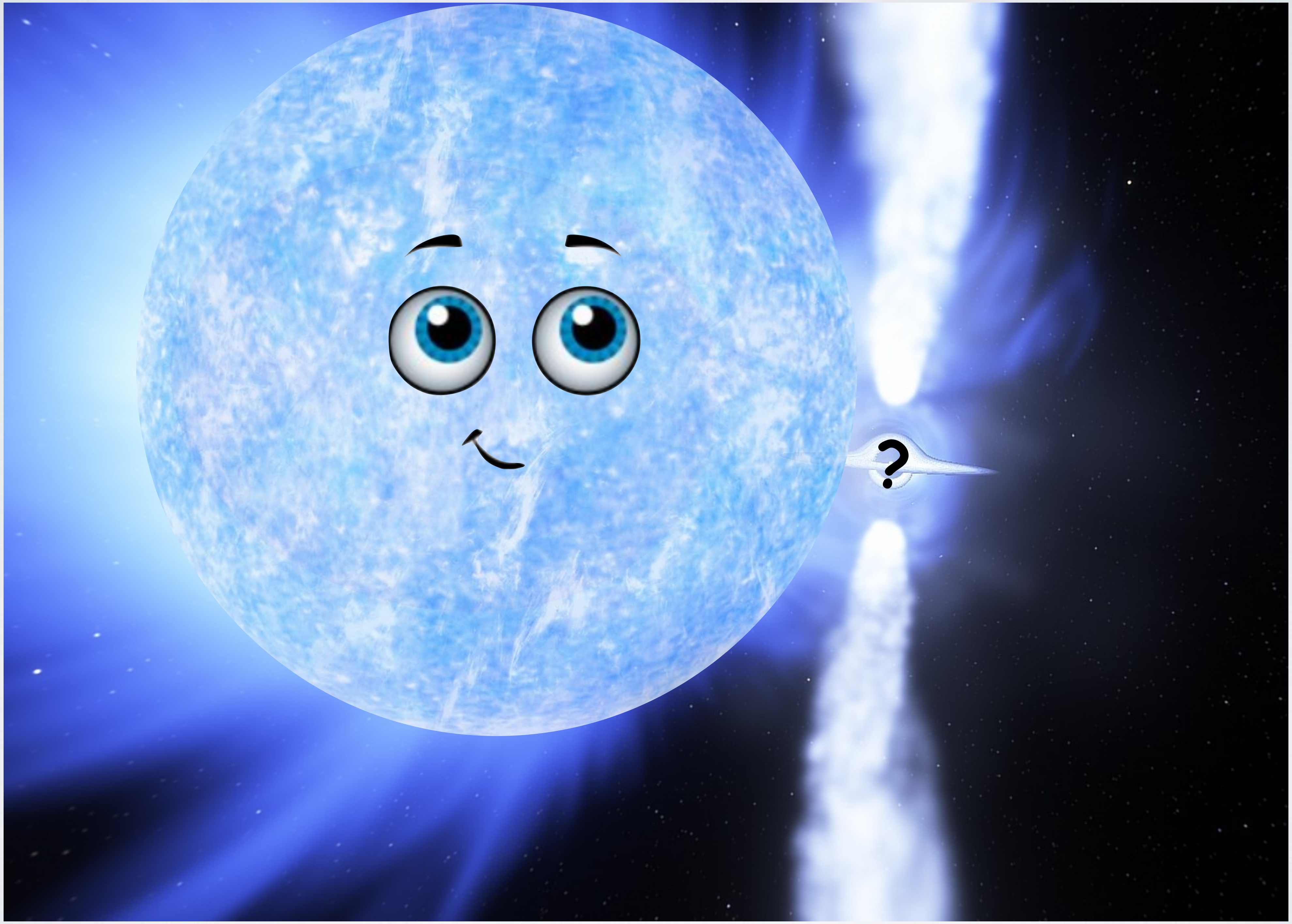
Romero et al. 2017

Typical evolution of microquasars during outbursts



Romero et al. 2017

The case of Cygnus X-3



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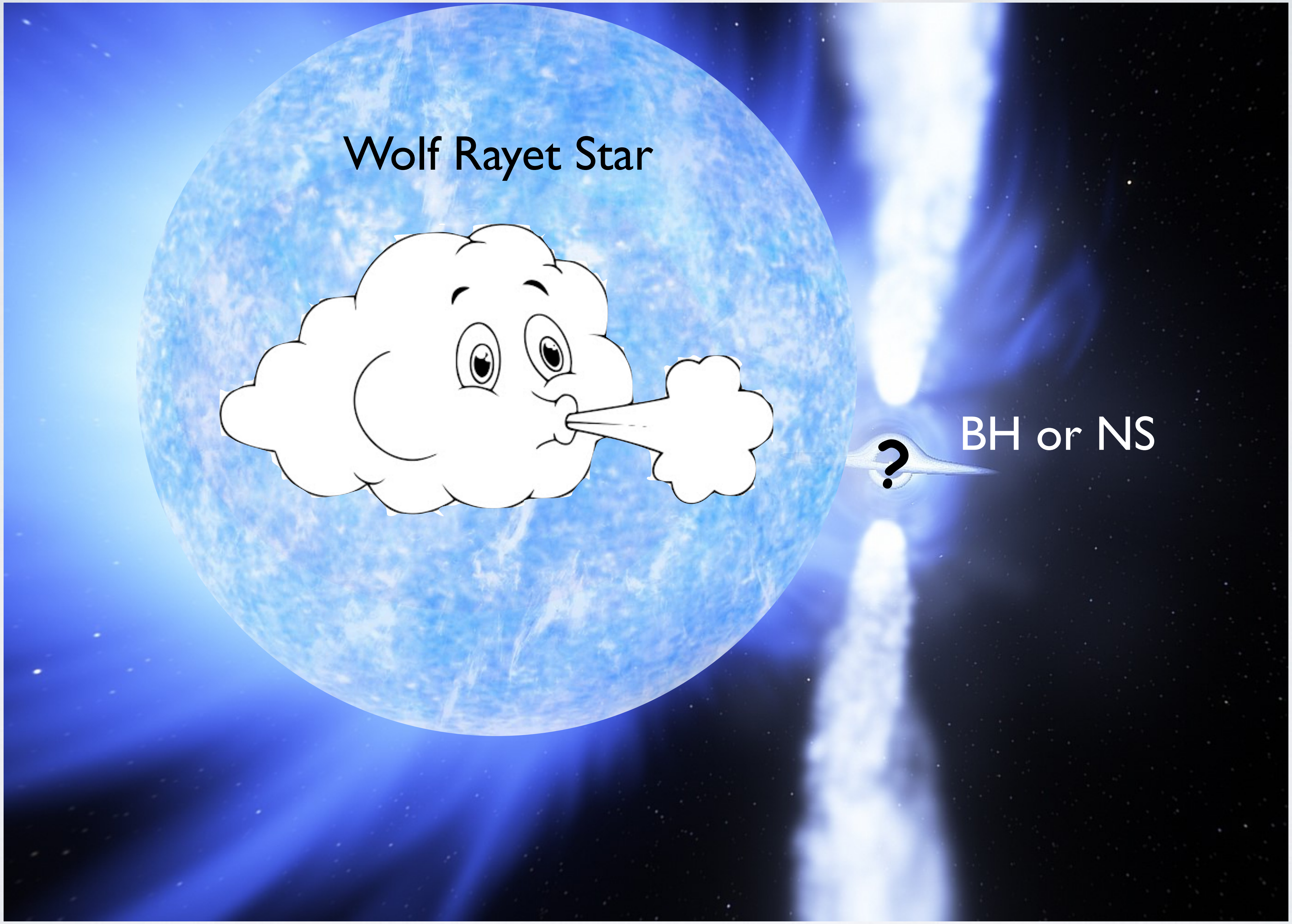


Cyg X-3: a very peculiar microquasar

* HMXB, a black hole or a neutron star wind-fed by a Wolf-Rayet star

* Short orbital period: 4.8 hr, distance 7.4 kpc (McCollough+16)

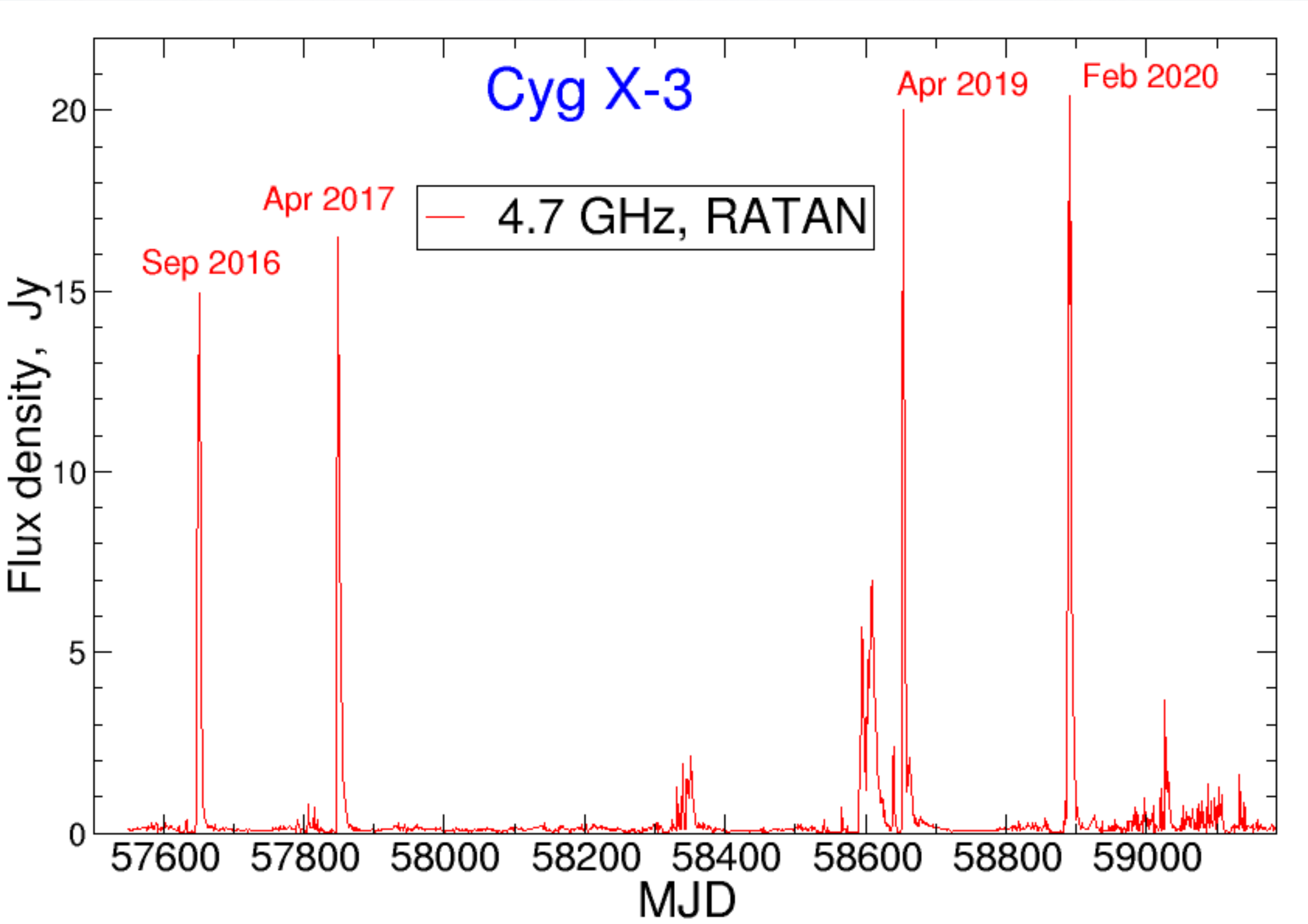
* The brightest X-ray binary in radio :

=> Giant radio flares of 10-20 Jy after quenched radio state (< 30 mJy)
(Waltman+95; Mioduszewski+01; Miller-Jones+04; Corbel+12)

=> Transition from the hypersoft X-ray state to a harder state
(Szostek+08; Koljonen+10; Koljonen+18)

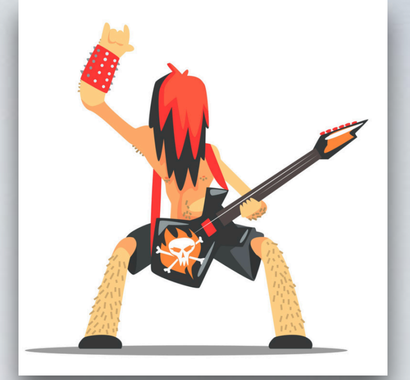
* Gamma-ray emission observed with AGILE and Fermi (Tavani+09, Fermi/LAT collab. 2009)

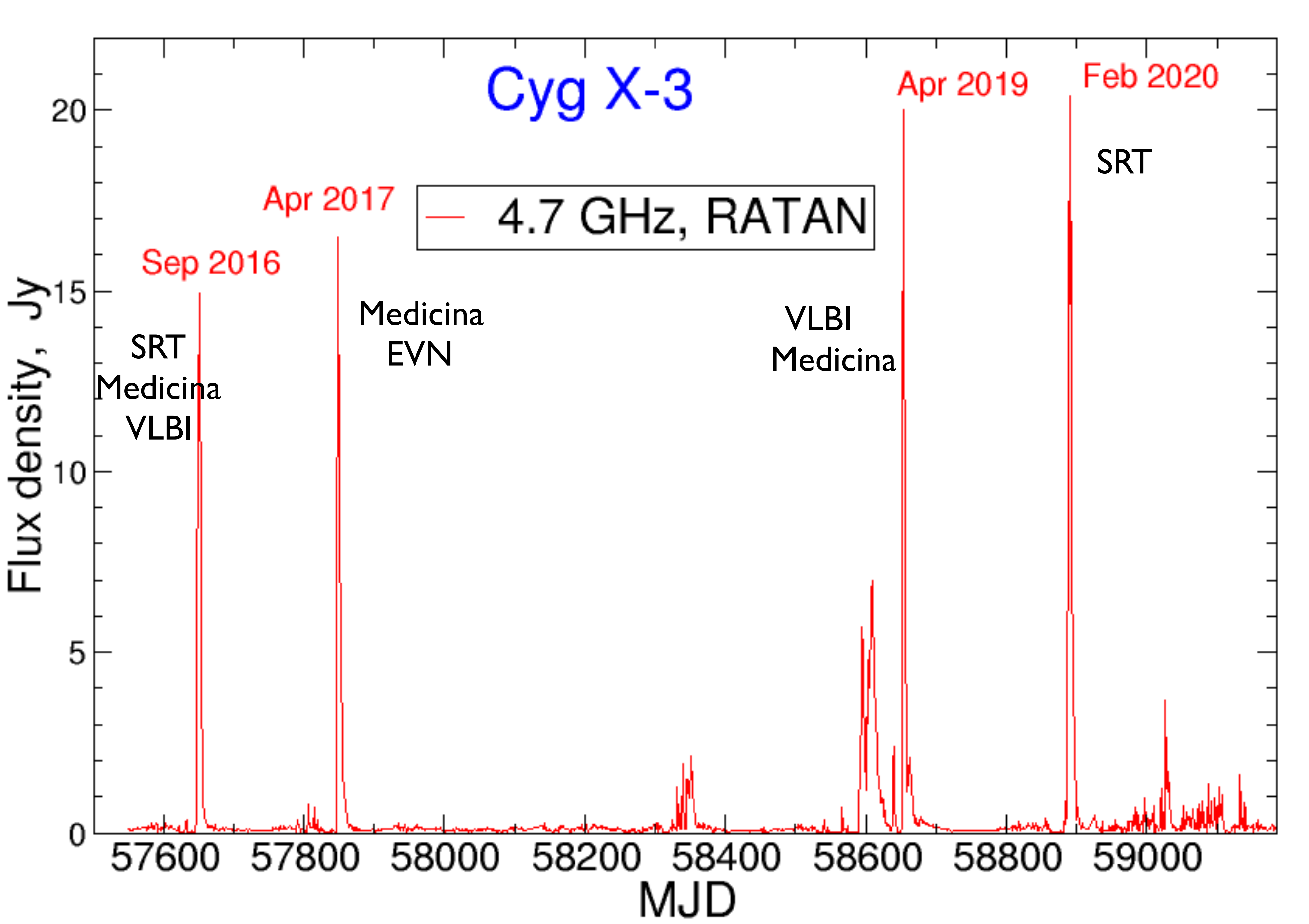
The giant flares of Cyg X-3



Courtesy of S. Trushkin

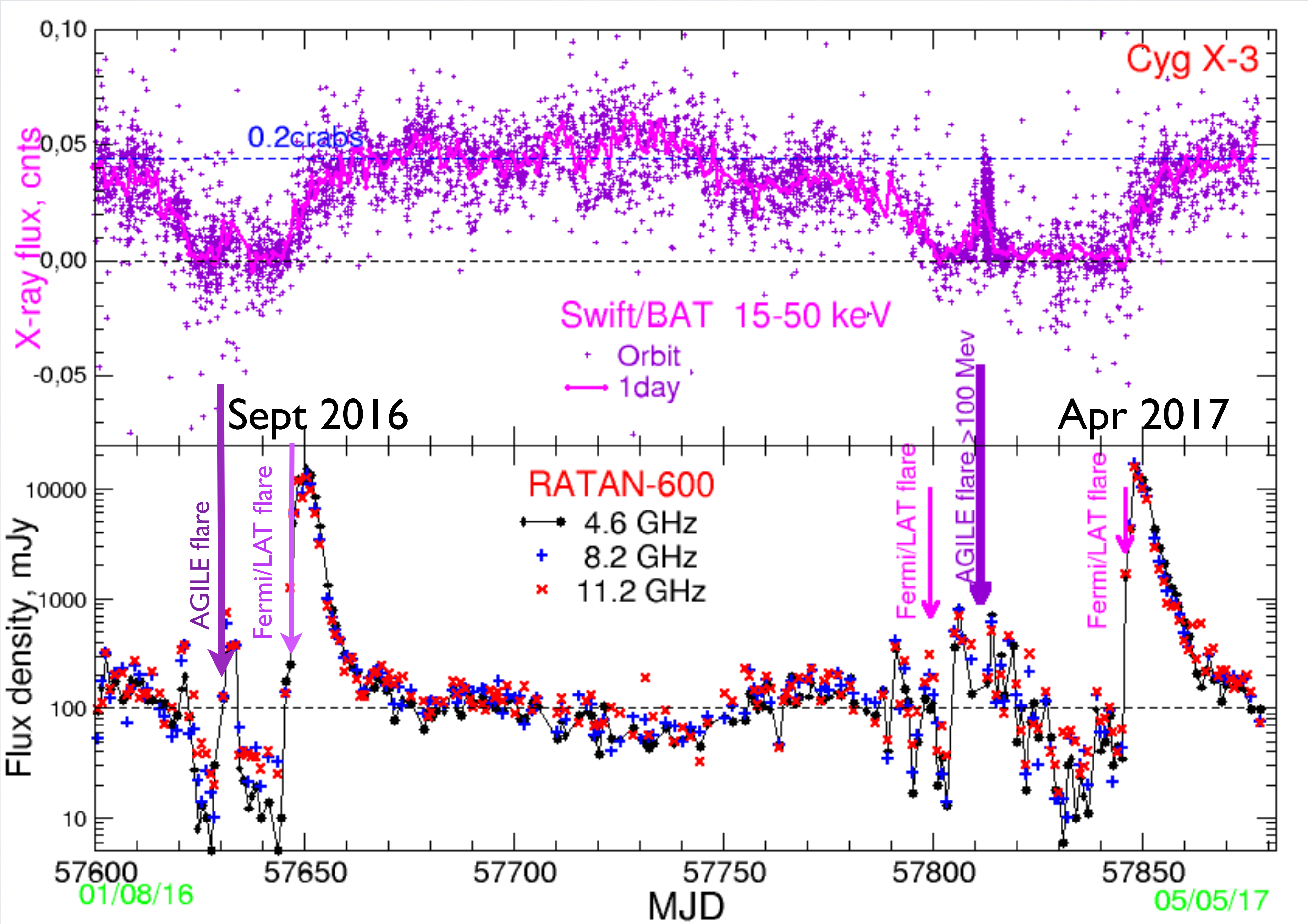
The giant flares of Cyg X-3





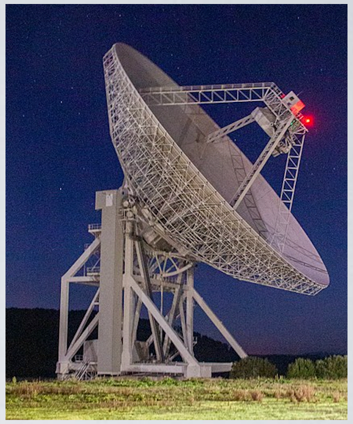
Courtesy of S. Trushkin

Radio, X-ray, gamma-ray monitoring



S. Trushkin

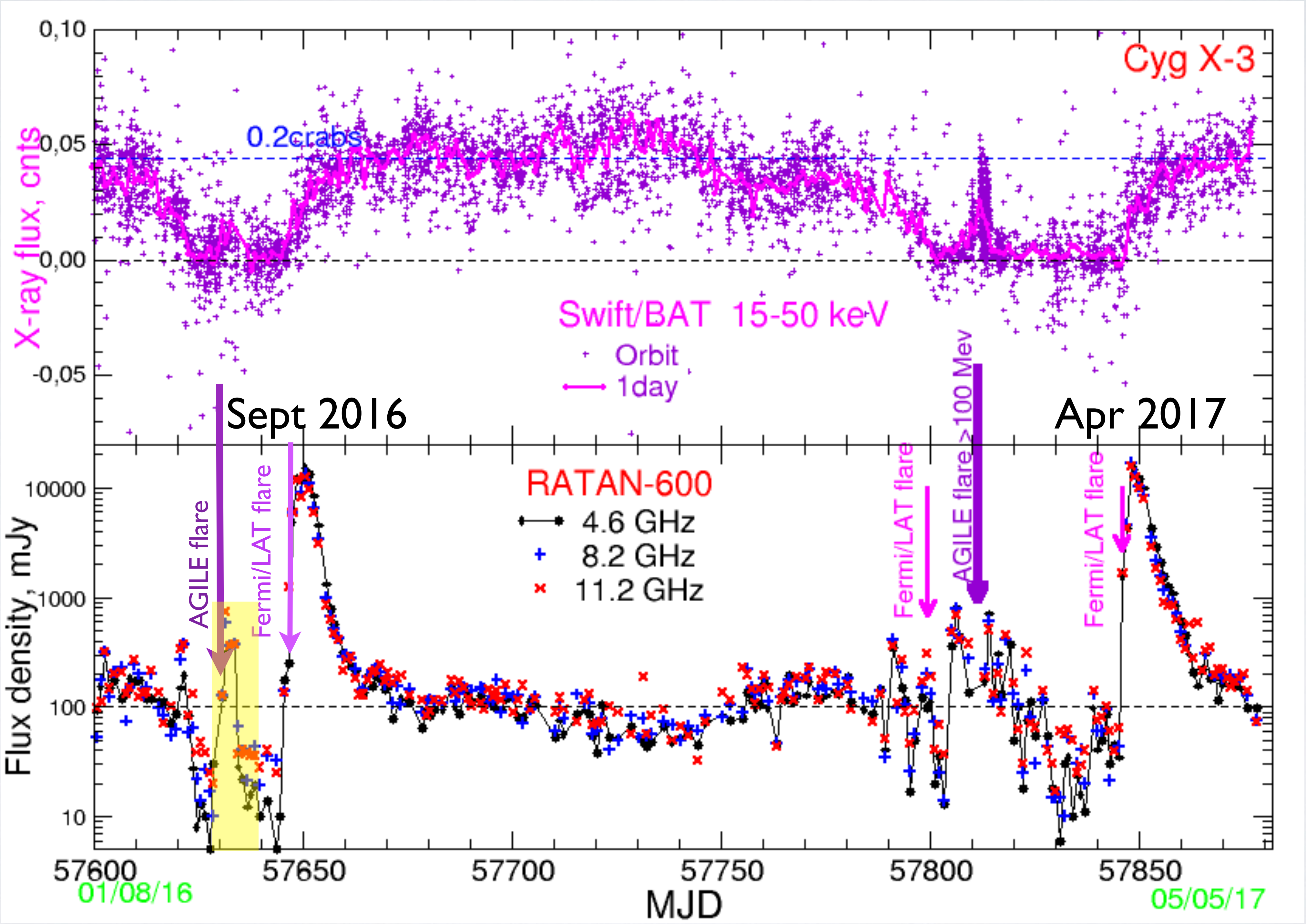
Radio multifrequency monitoring + VLBI observations



* SRT and Medicina : multifrequency observations, evolution of the giant flares (flux density, spectral index) during several consecutive days

* VLBI provides speed, direction, evolving morphology of the jets, more difficult to schedule quickly

A mini-flare during the quenched radio state



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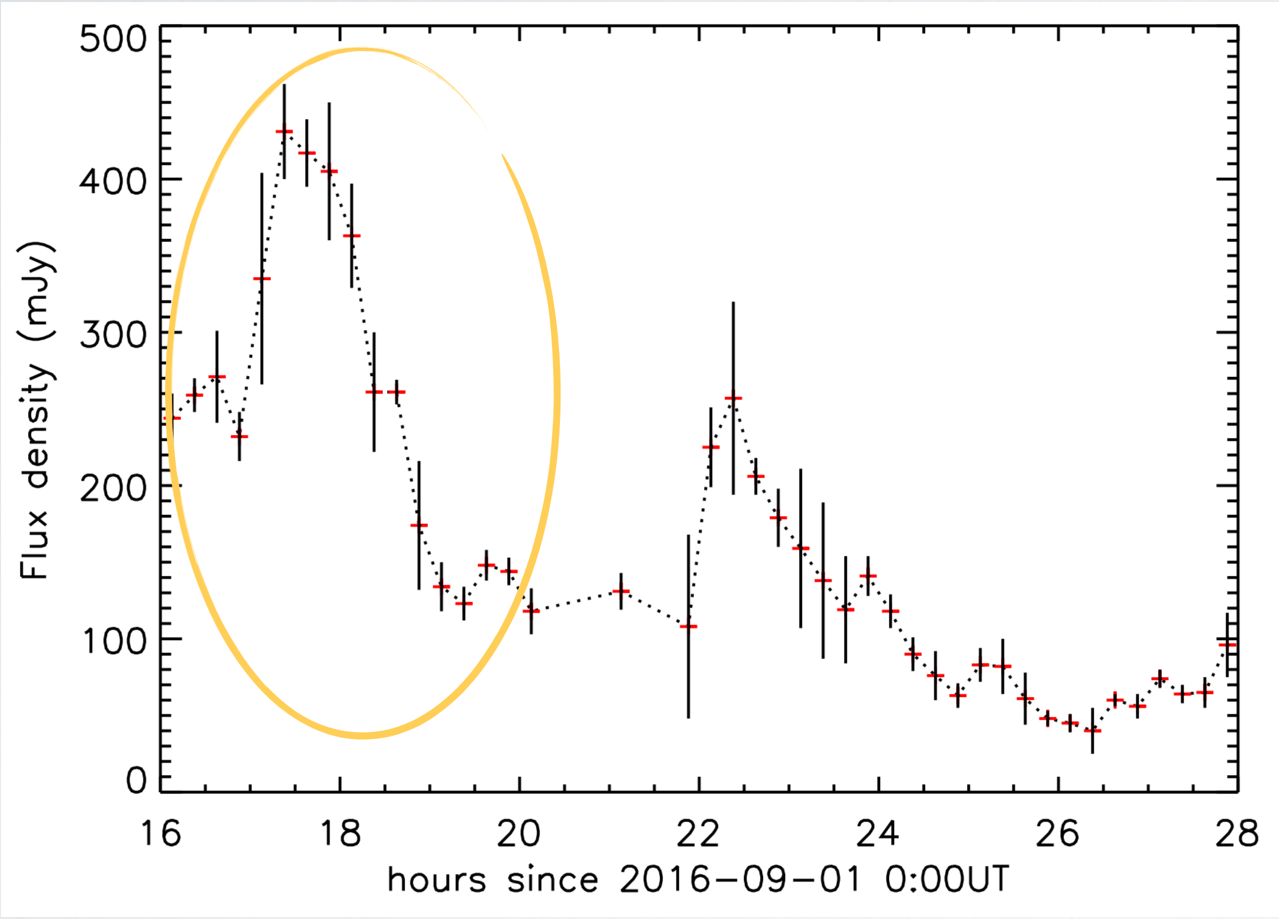
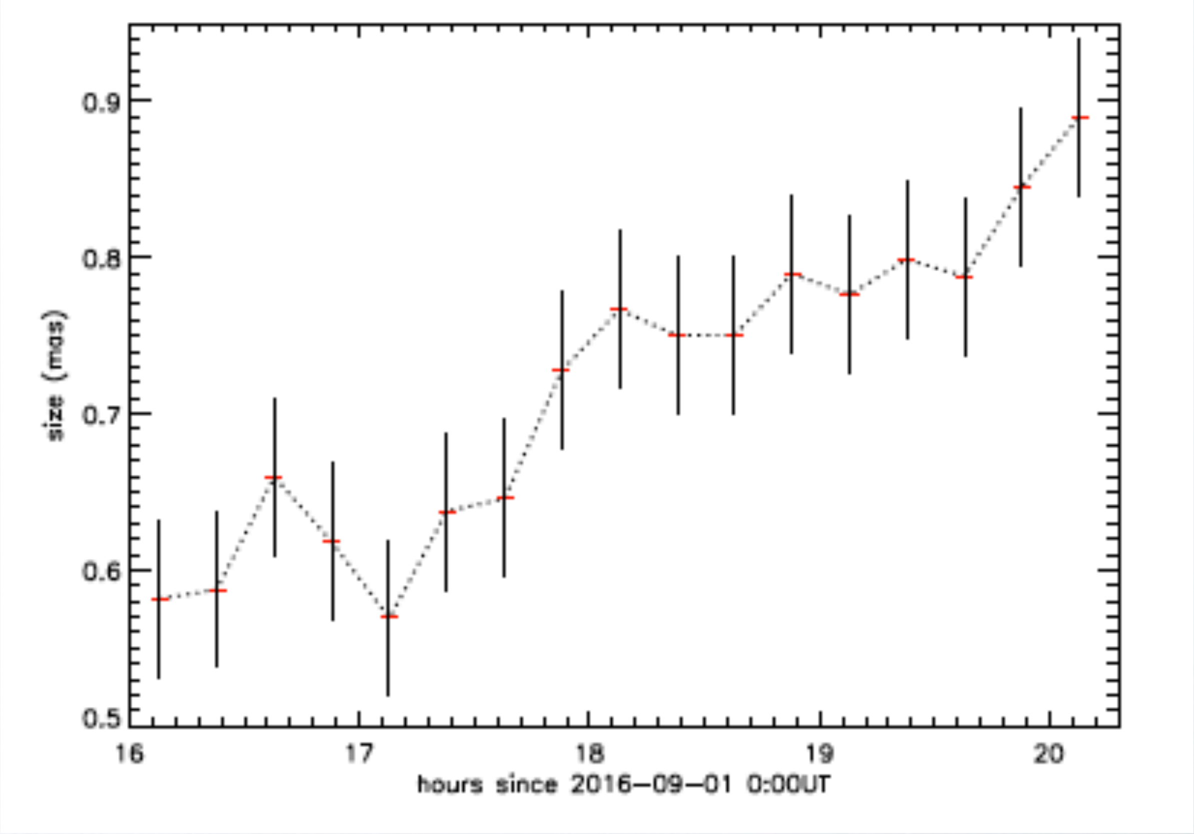
Mini-flare on 1st Sept 2016

*VLBI light curve obtained at 22 GHz with Sr, Md, Nt, Tr, Ys



* Radius in mas of the emitting component
=> expansion of the region from 0.6 to 0.9

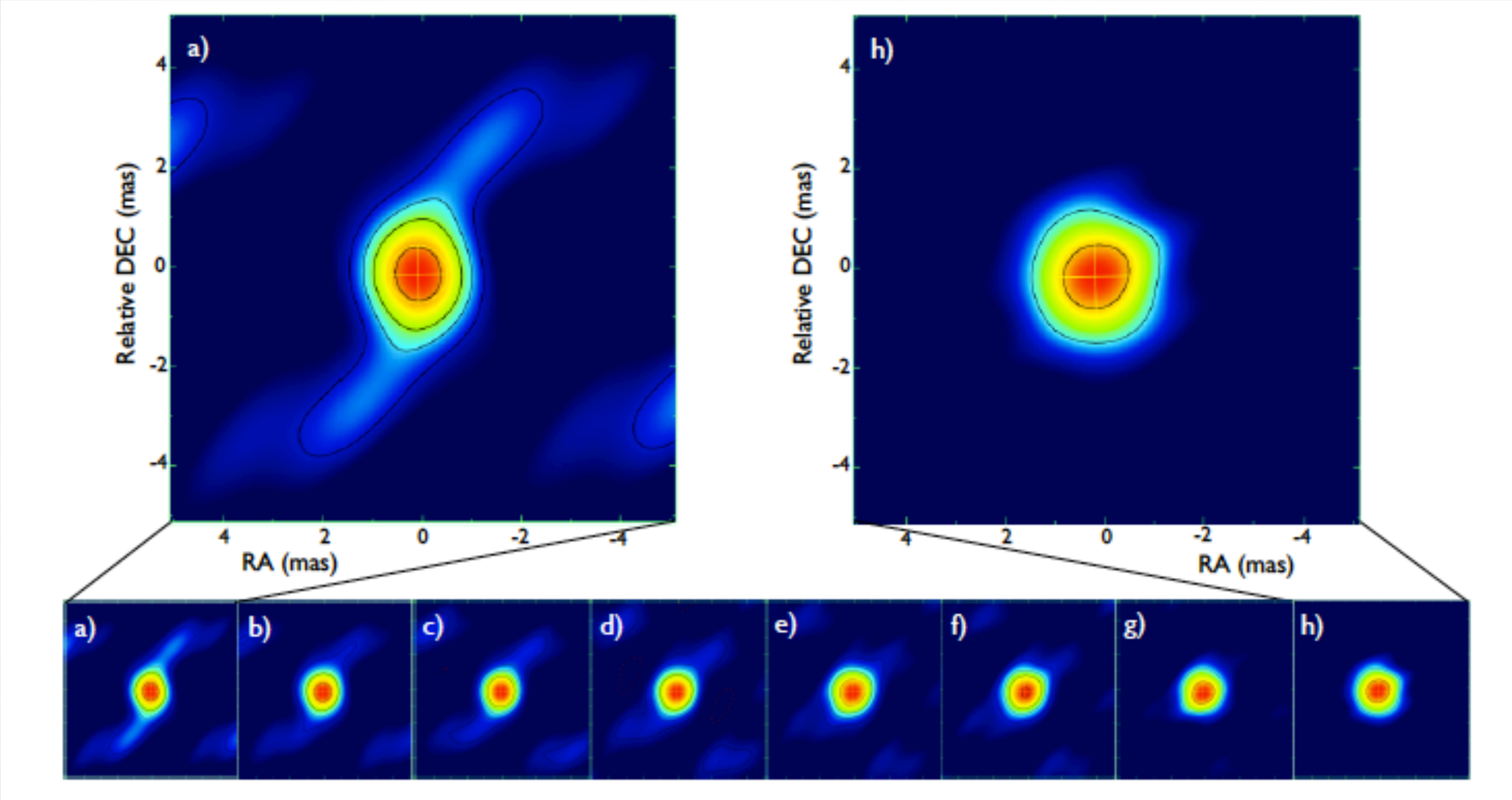


Egron et al. 2017

Mini-flare on 1st Sept 2016

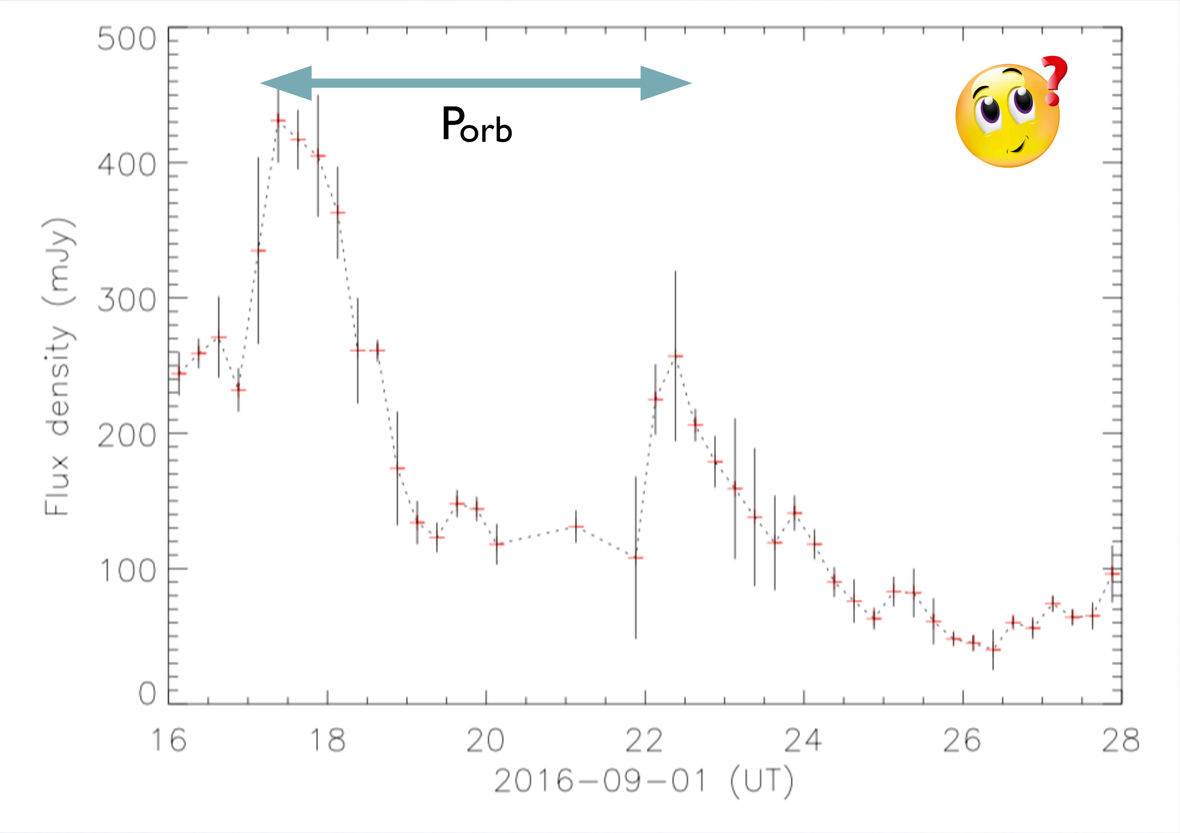
* Evolution of the size of the emitting component during the 4 first hrs
  => expansion at the velocity 0.06c assuming d = 7 kpc

* Short radio flare close to the core of the source : compact jets



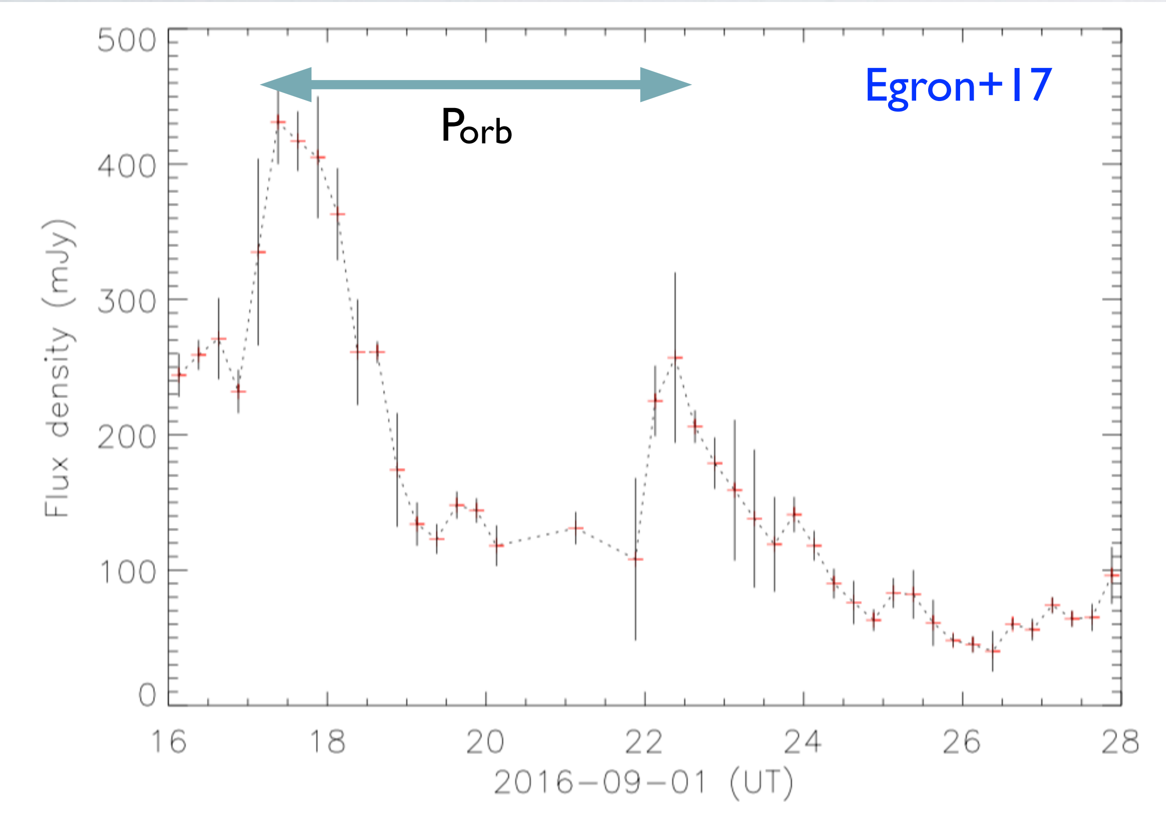
Egron et al. 2017

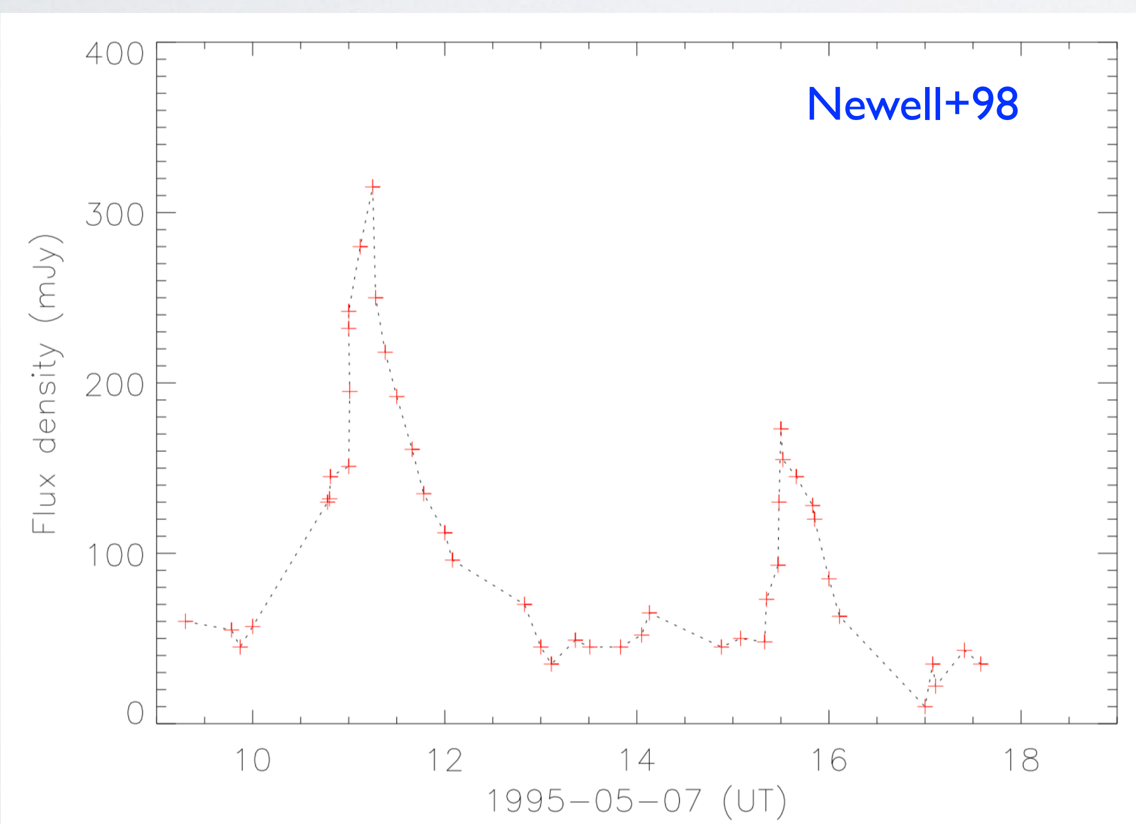
Radio orbital modulation ?



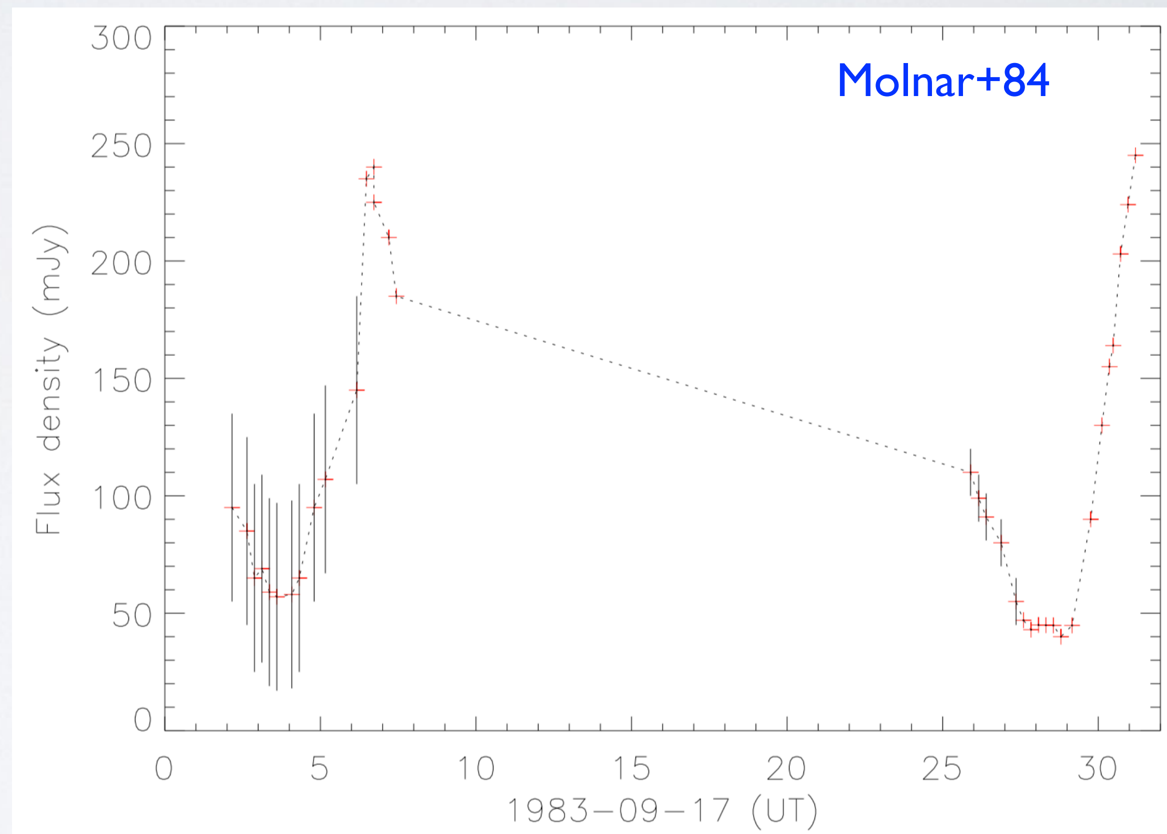
- A modulation of the radio emission from the jet is expected by variable free-free absorption in the wind from the companion star along the orbit.
- Mini flares: compact jets, perhaps easier to detect the orbital modulation ?

Mini flares observed with the VLA and VLBI





* The peak separation observed during mini-flares at 15-22 GHz seems to correspond to the orbital period: 4.8 hrs.

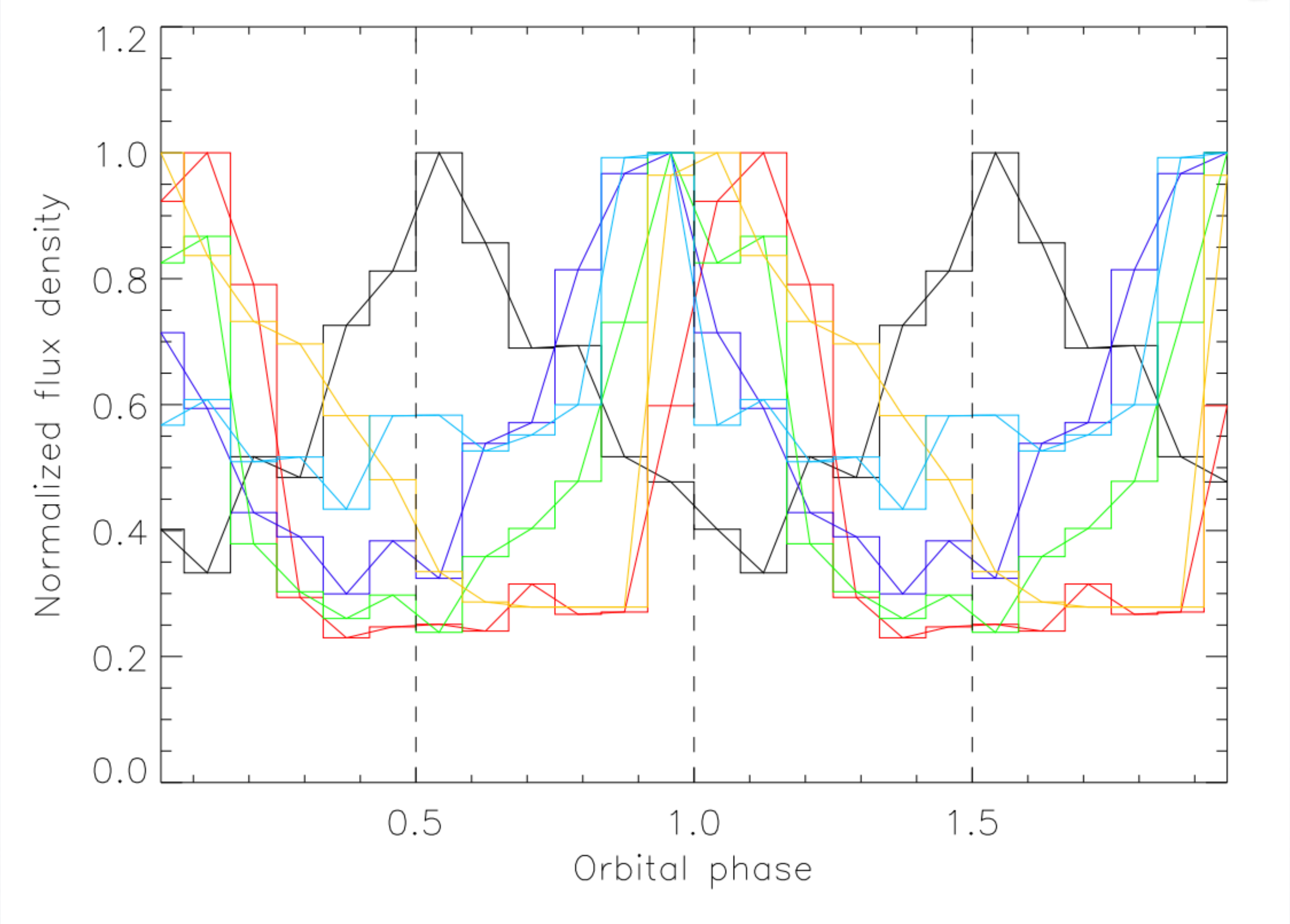


* See also Zdziarski+18

Radio orbital modulation

* Phase folding renormalized light curves corresponding to 6 mini-flare datasets observed between 1983 and 2016 using the X-ray ephemeris from Bhargava+17.

* The 2016 light curve peak is shifted of 0.5 w.r.t. the other ones.



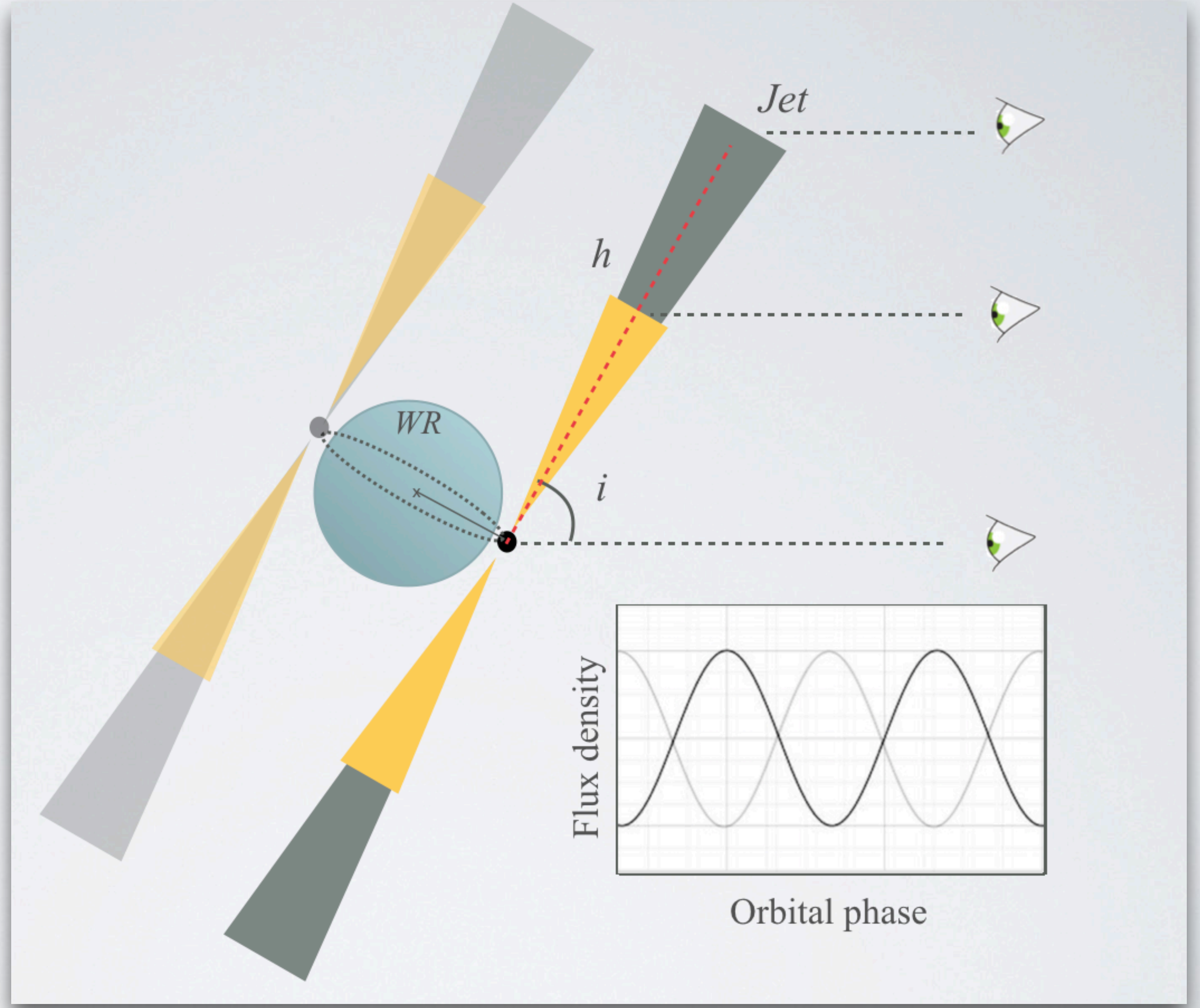
Egron et al. 2020

Phase shift in 2016

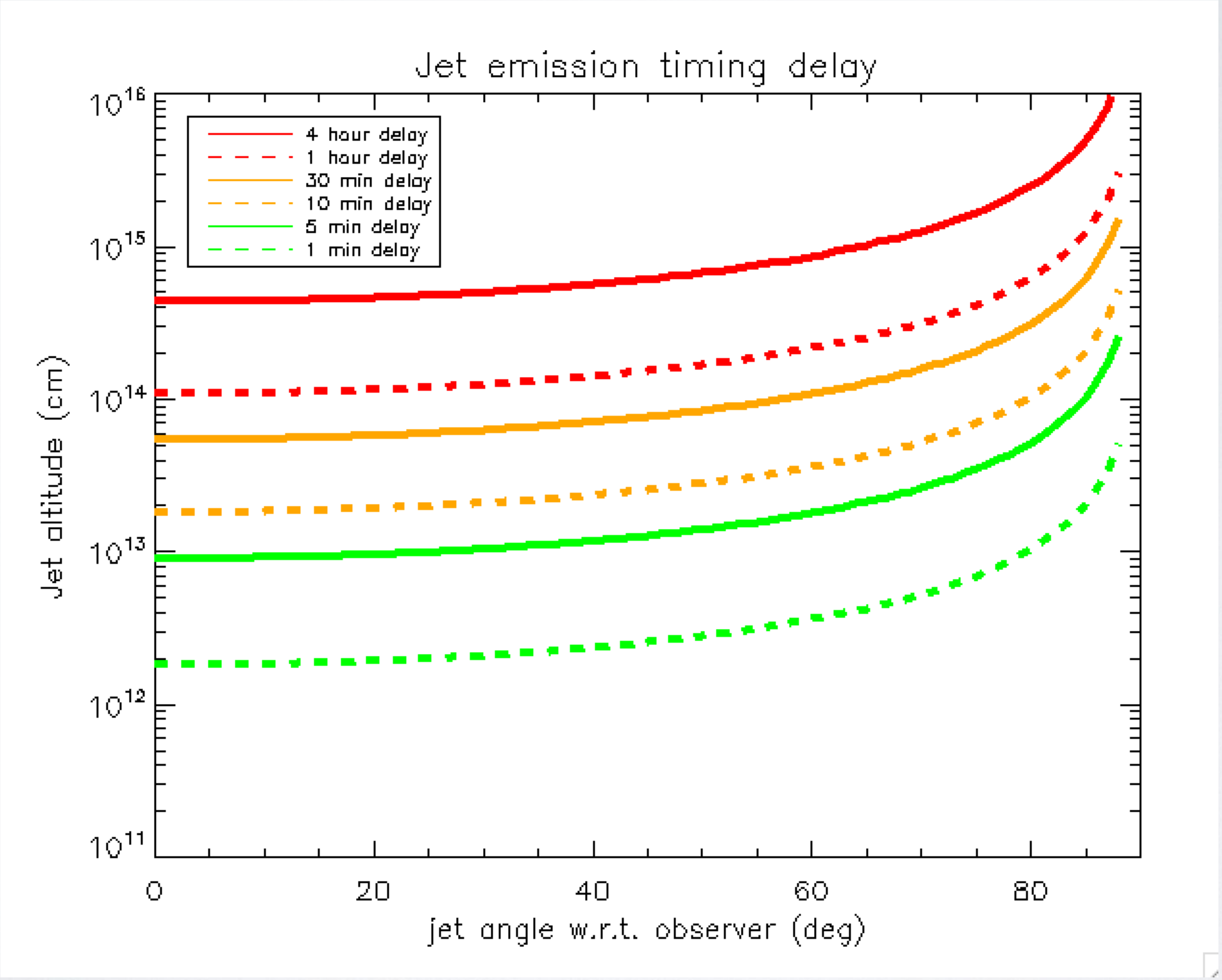
* The phase shift is most likely attributed to a different location of the radio emitting region along the jet.
* Emitting jet with bulk emission at altitudes ≥10^14 cm (1 mas angular separation) can provide an emission delayed up to about 1 hour => phase shift > 0.2.

* 2016 mini-flare: 0.6-0.9 mas
* 1985 and 1995: 2.0-2.5 mas

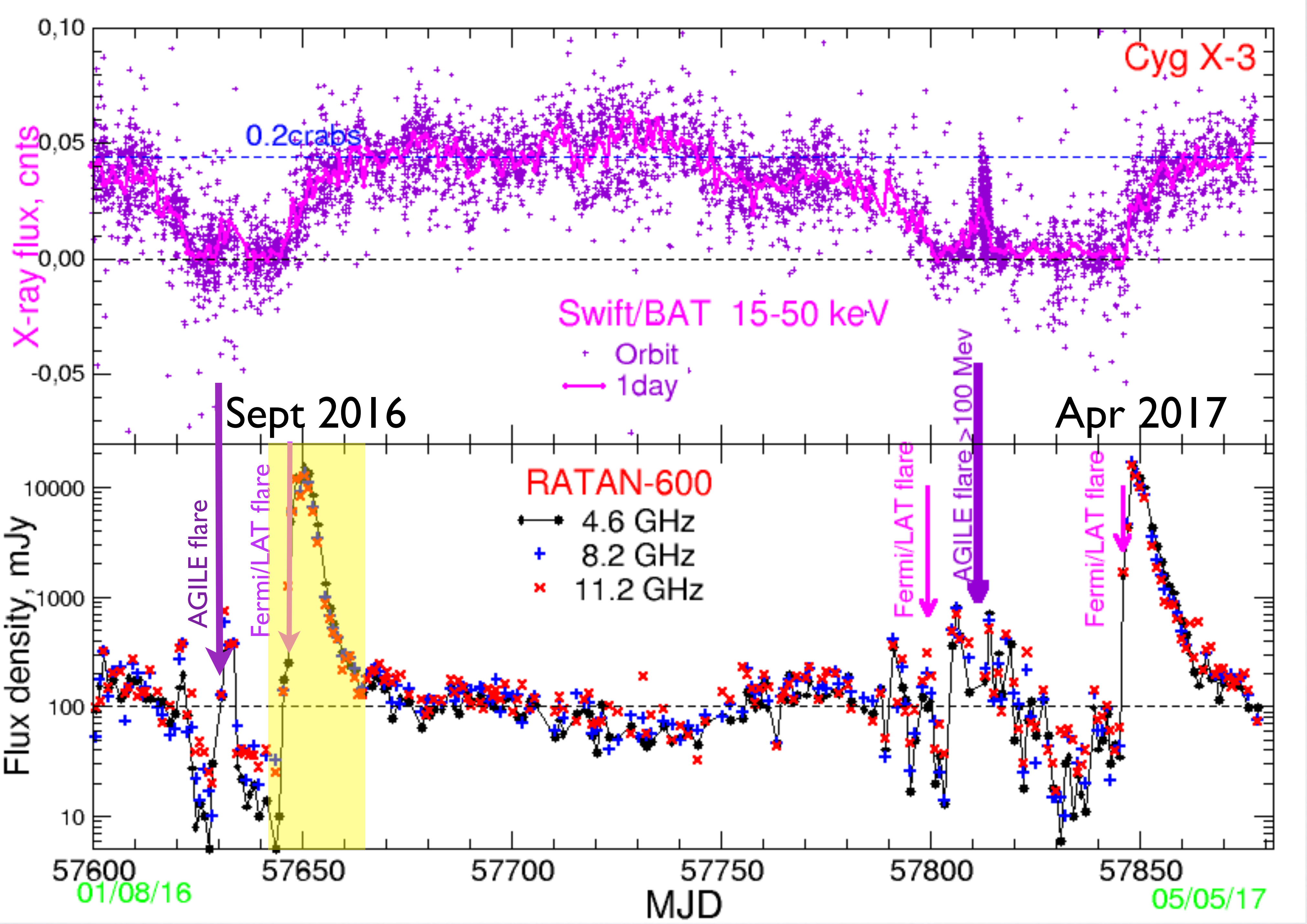
* Jet position, extension
* Inclination, precession



Timing delay



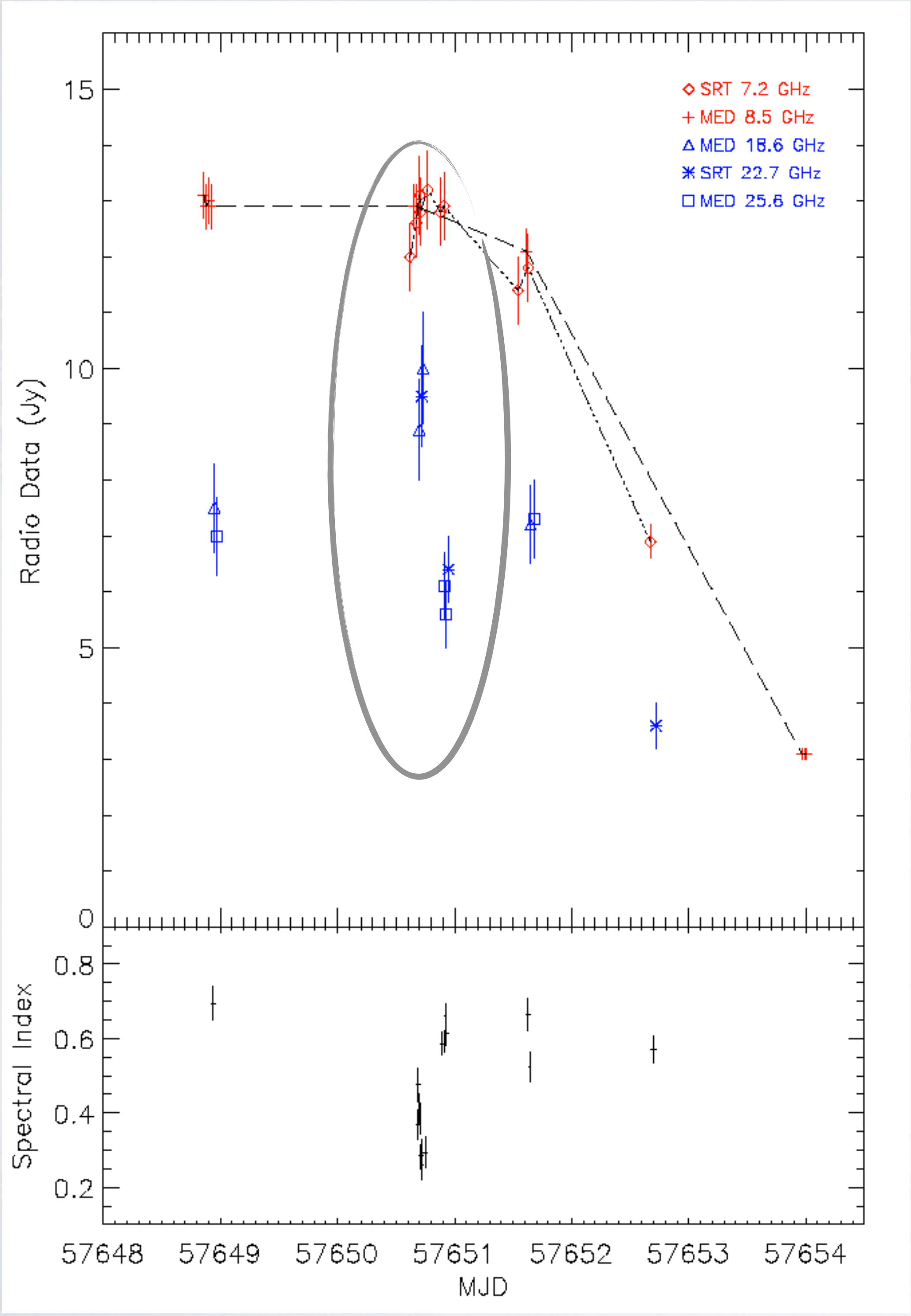
The giant flare in September 2016



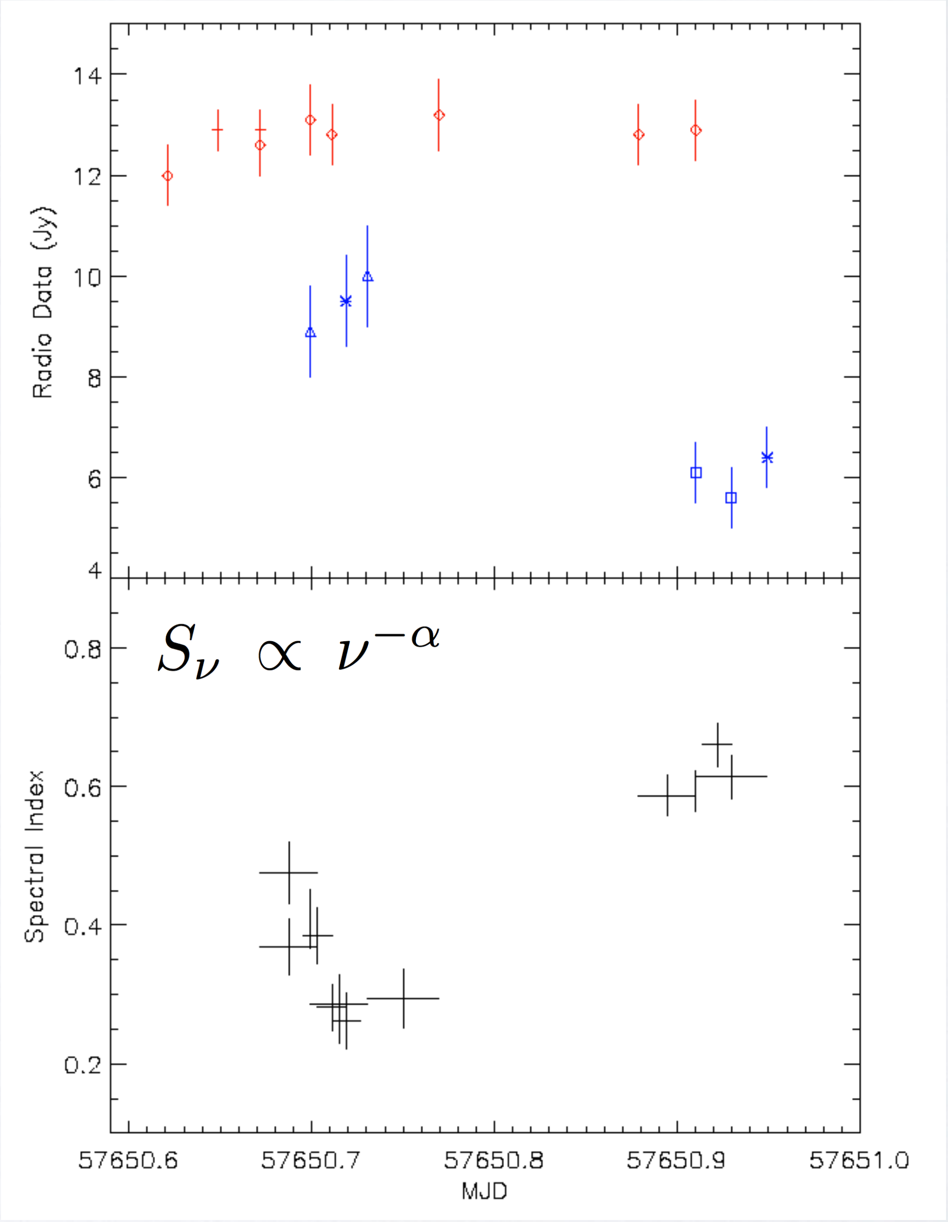
S. Trushkin

Single dish observations

* Observations at 7.2, 8.5, 18.6, 22.7 and 25.6 GHz with SRT and Medicina



=> Clear spectral index change
at the peak of the flare on 5 hrs!



Egron et al. 2017

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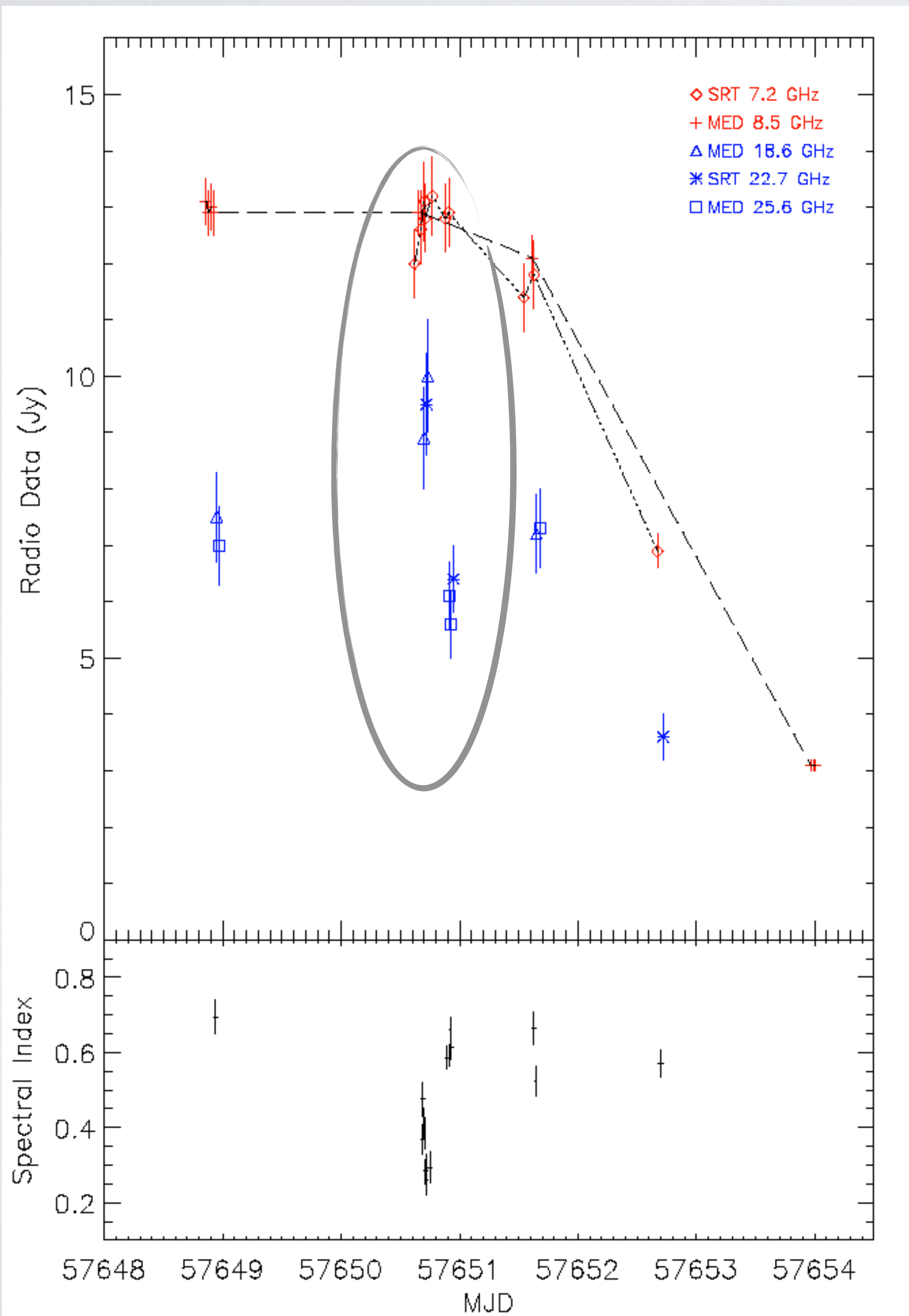
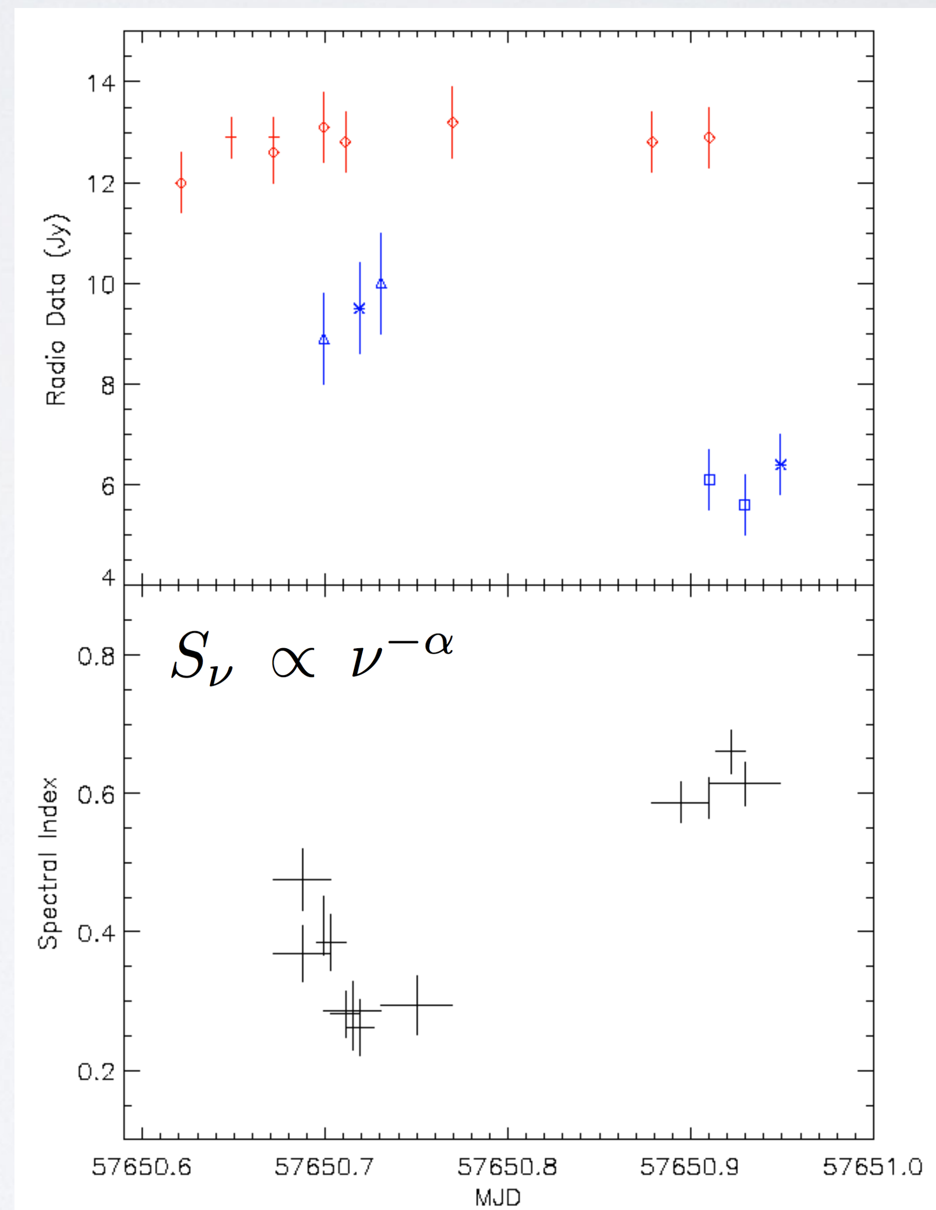
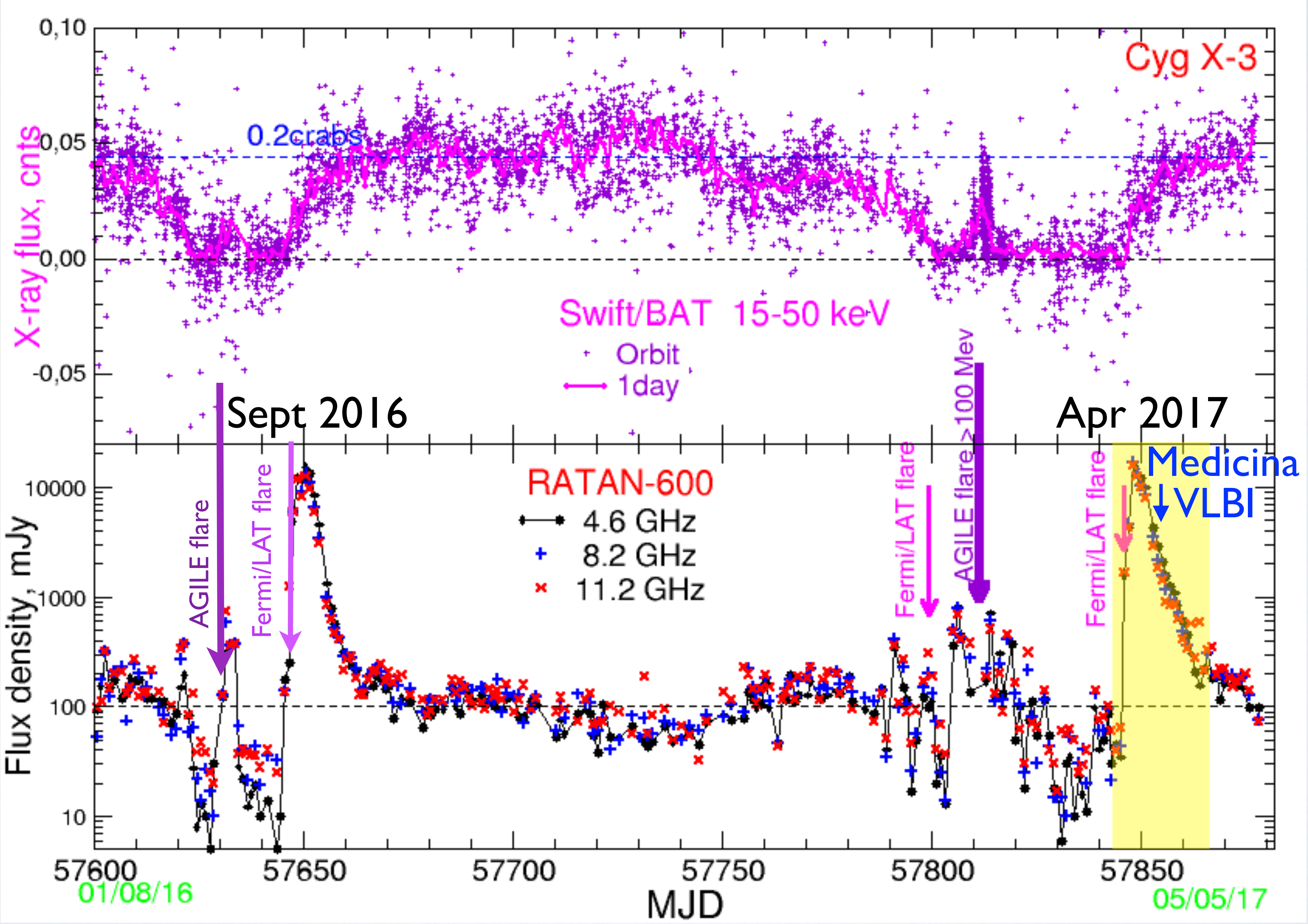


=> Evolution from optically thick to optically thin plasmons in expansion moving outward from the core



Egron et al. 2017

The giant flare in April 2017



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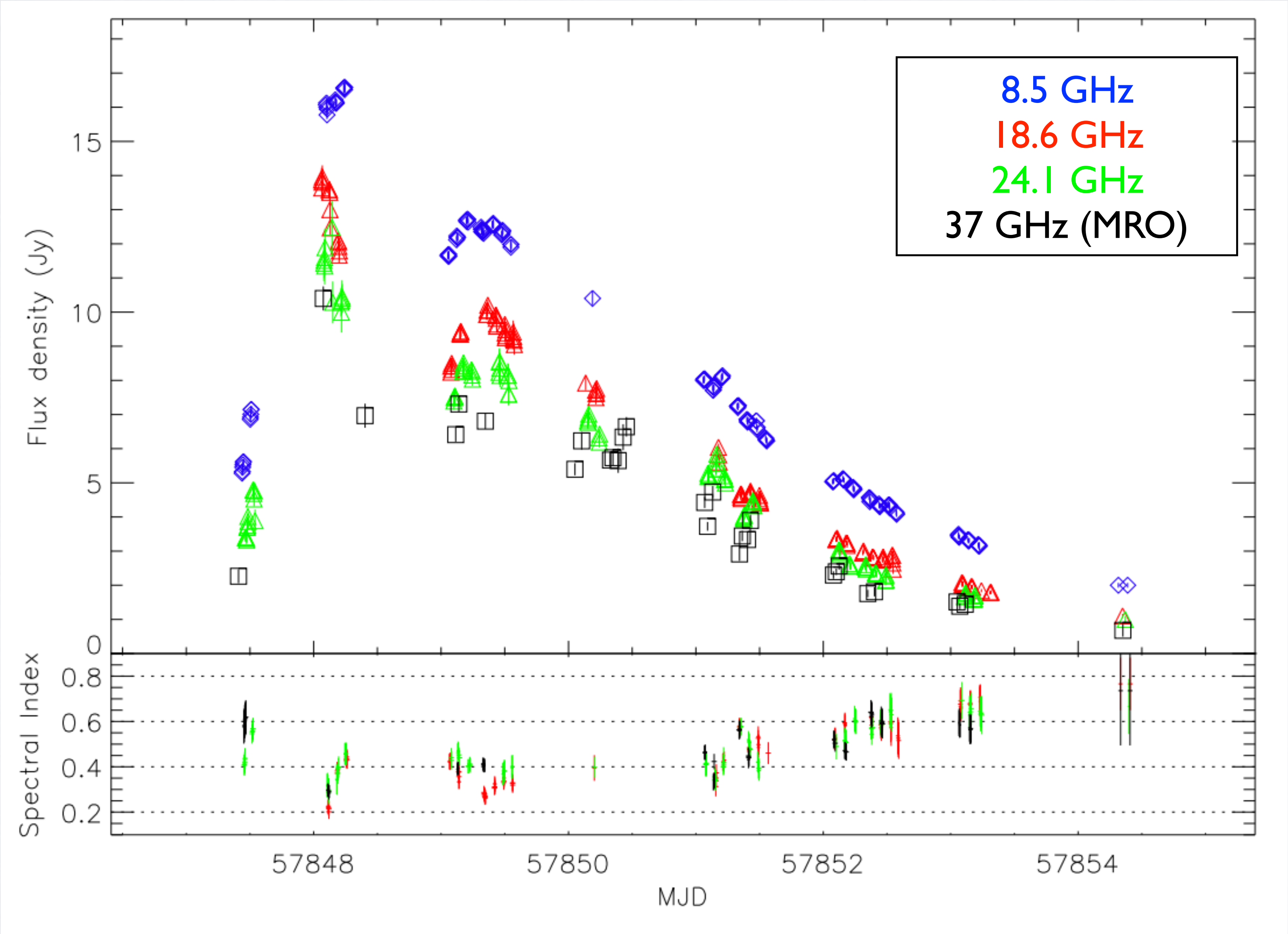
Multifrequency monitoring with Medicina

* Evolution of the spectral index over 8 days from 4 April 2017 (sessions 3-13 hrs/day)

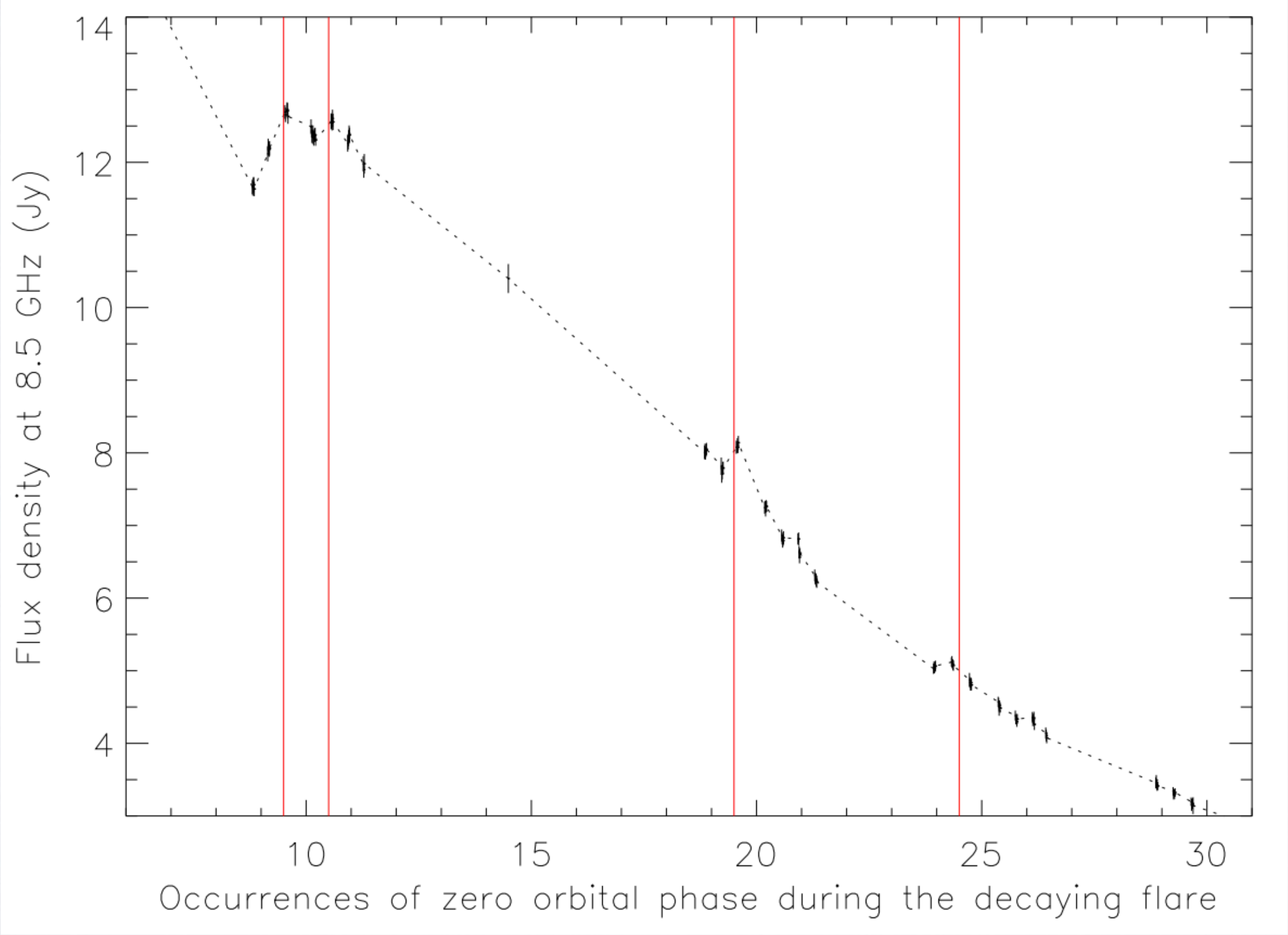
* Spectral steepening at the maximum of the flare with $S_\nu \propto \nu^{-\alpha}$



Egron et al. 2020

Radio orbital modulation

* The enhanced emissions at 8.5 GHz seem to correspond to the orbital phase 0.5.
* Modulation of the base of the jet at Porb most likely by from free-free absorption by thermal electrons from the wind of the WR.

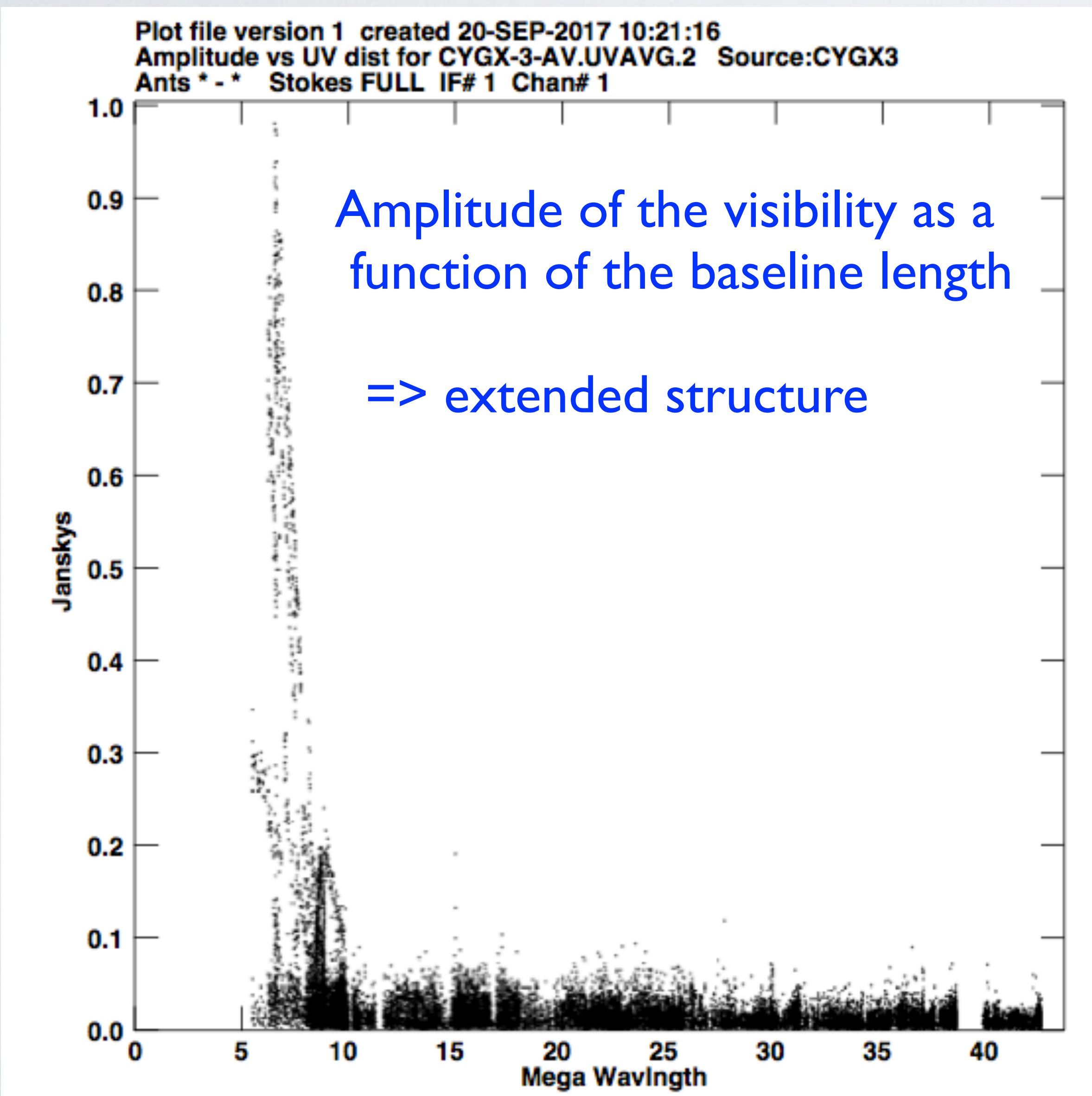


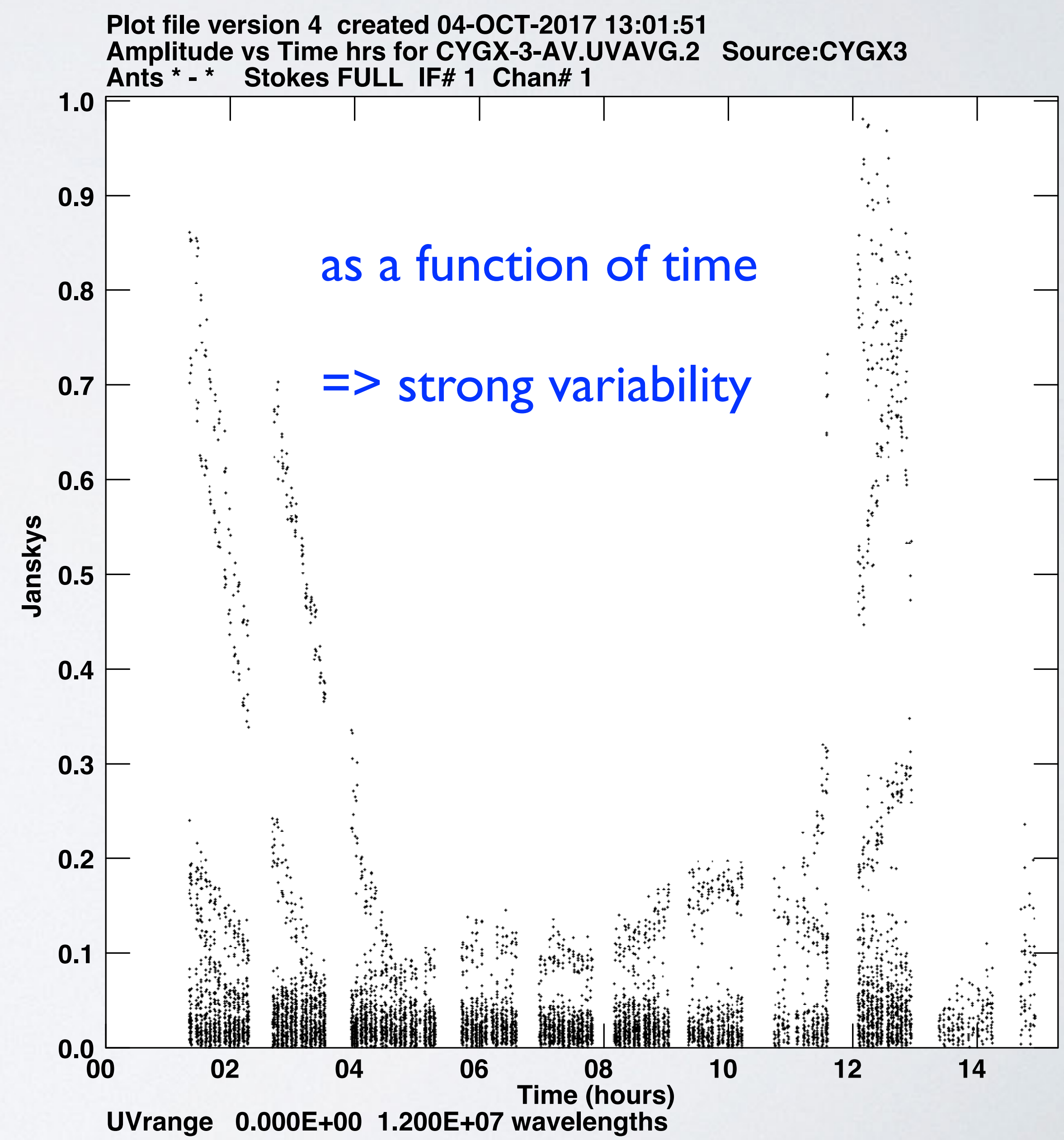
Egron et al. 2020

EVN observations in April 2017

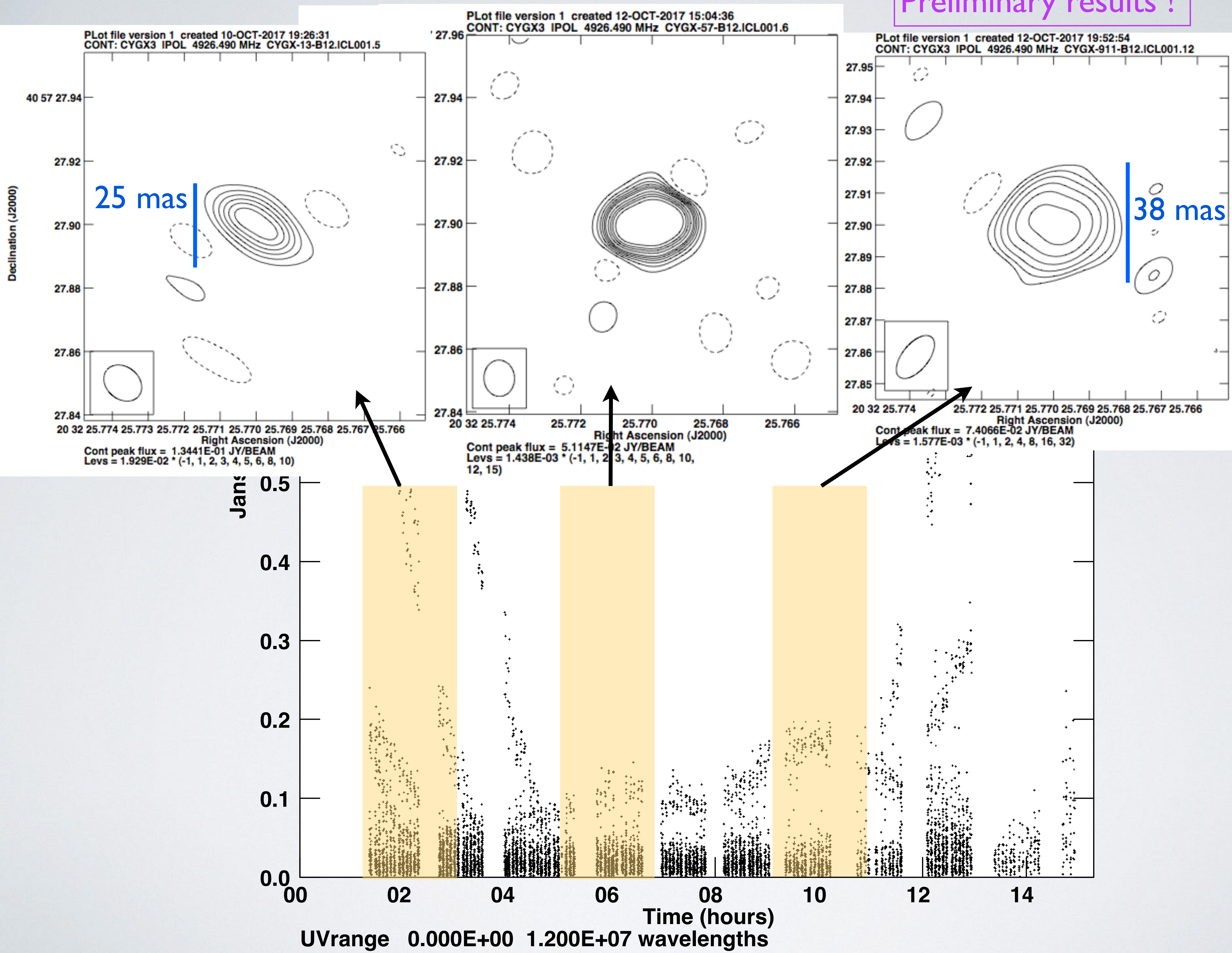
* 2 runs e-EVN triggered at 5 GHz on 10 and 13 April for 15 hrs each

* extended structure with a strong variability





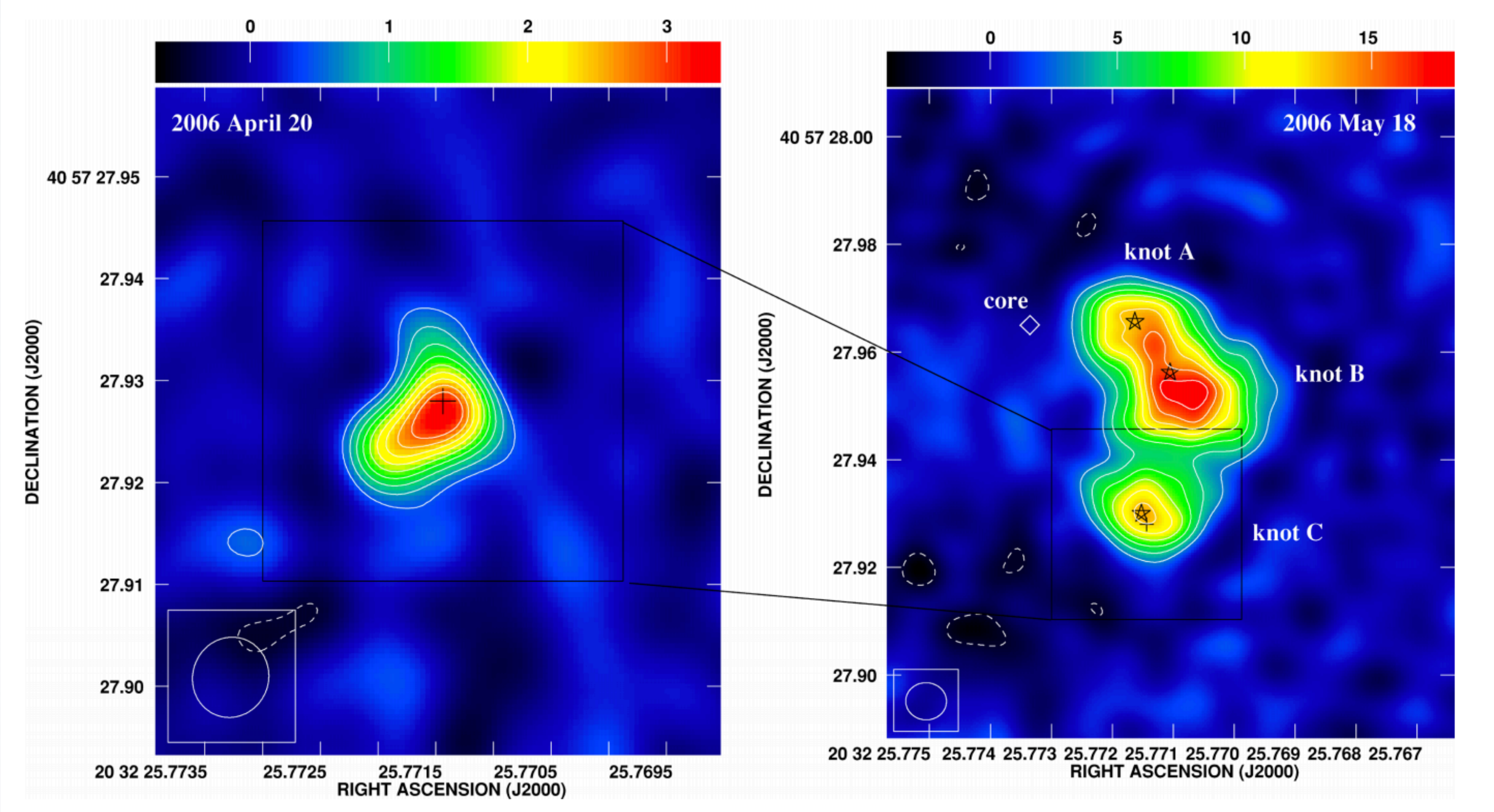
Preliminary results !



Comparison with EVN observations at 5 GHz in April-May 2006

Quiescent state,
several weeks after a flare

1 week days after a major flare



Fading jet, spatially
separated of the core

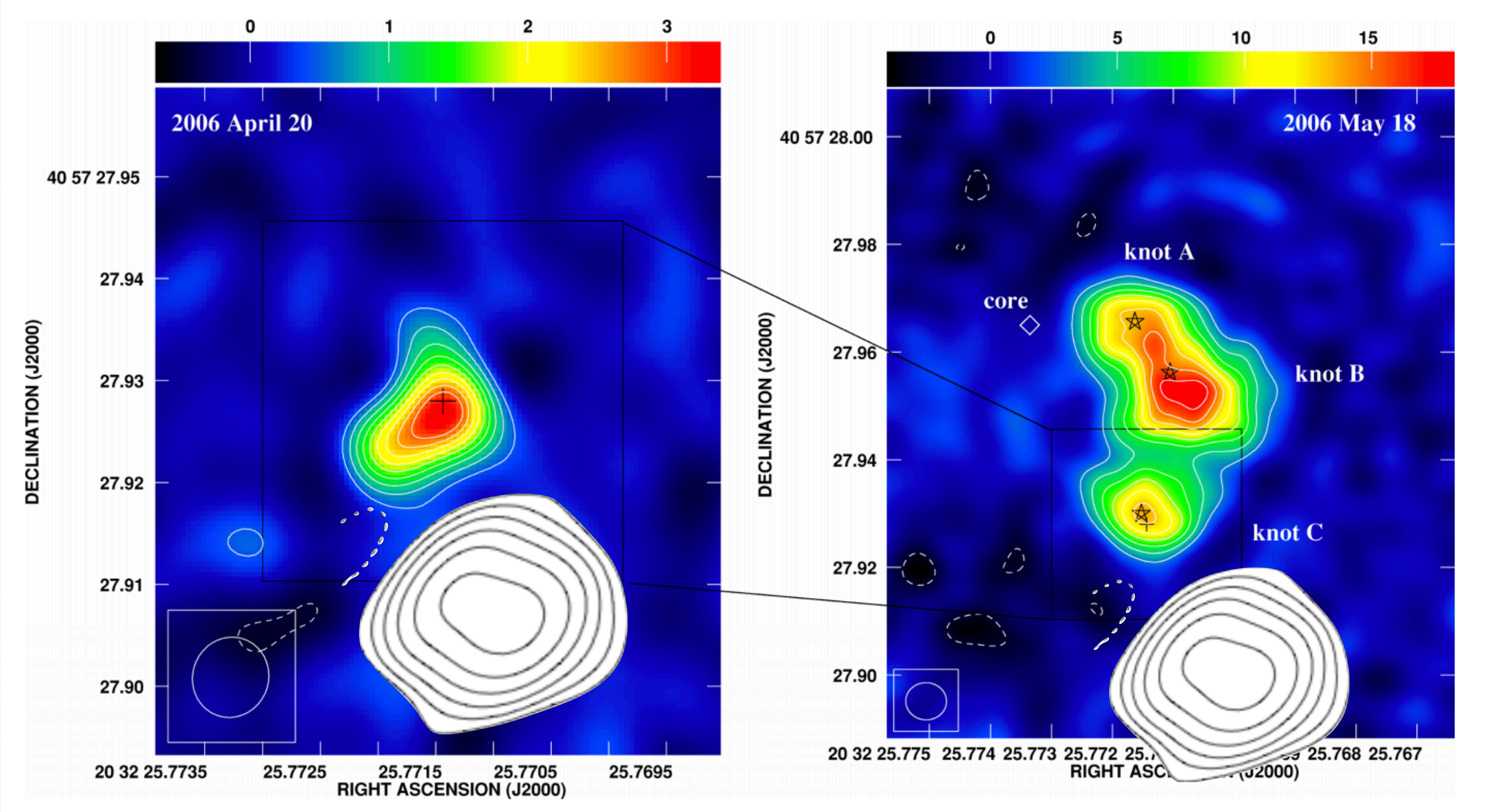
Three bright knots.

Tudose et al. 2007

Comparison with EVN observations at 5 GHz in April-May 2006 with the 2017 flare

Several weeks after a flare

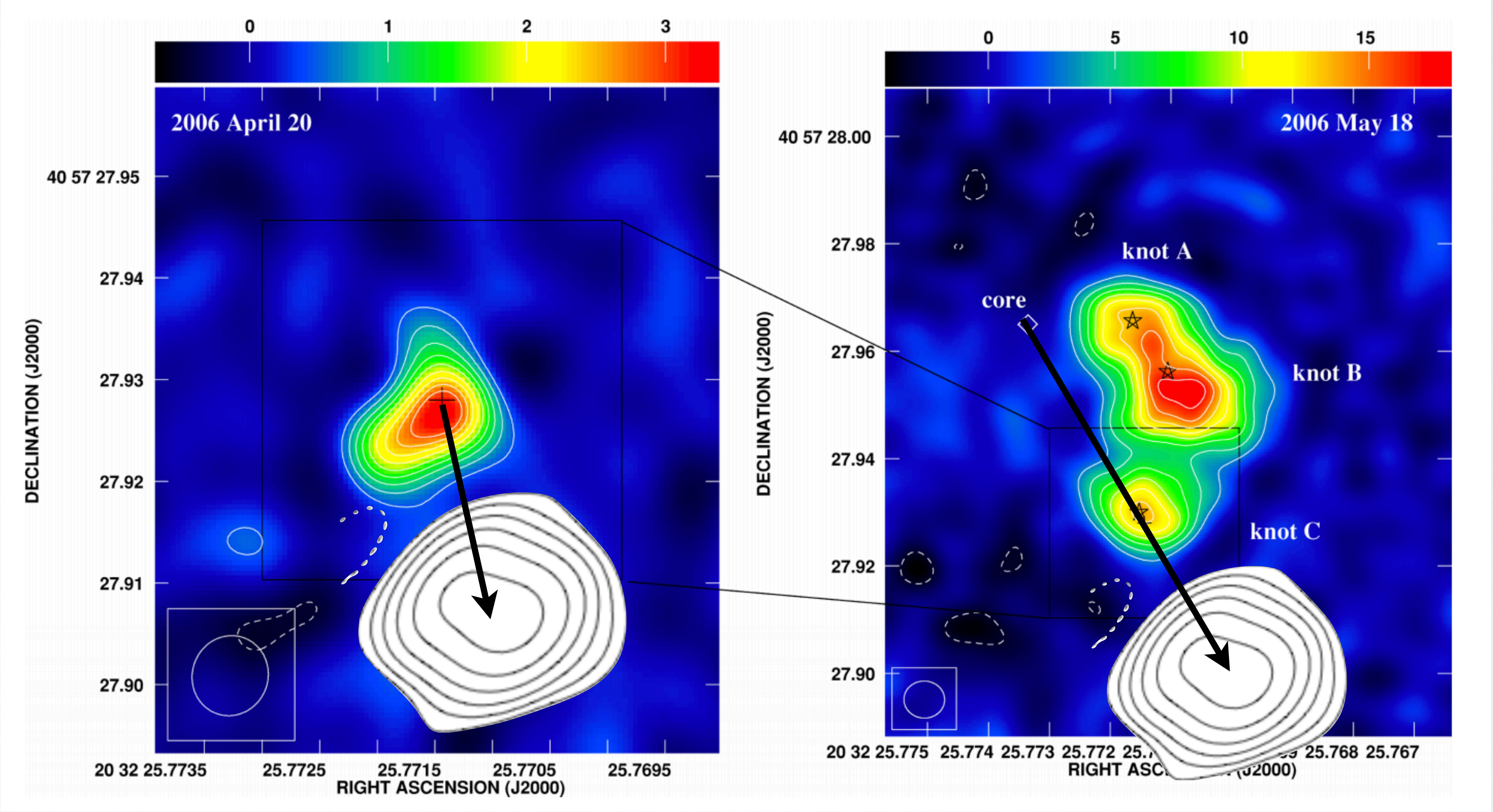
1 week after a major flare of 2006



5 days after the 2017 giant flare

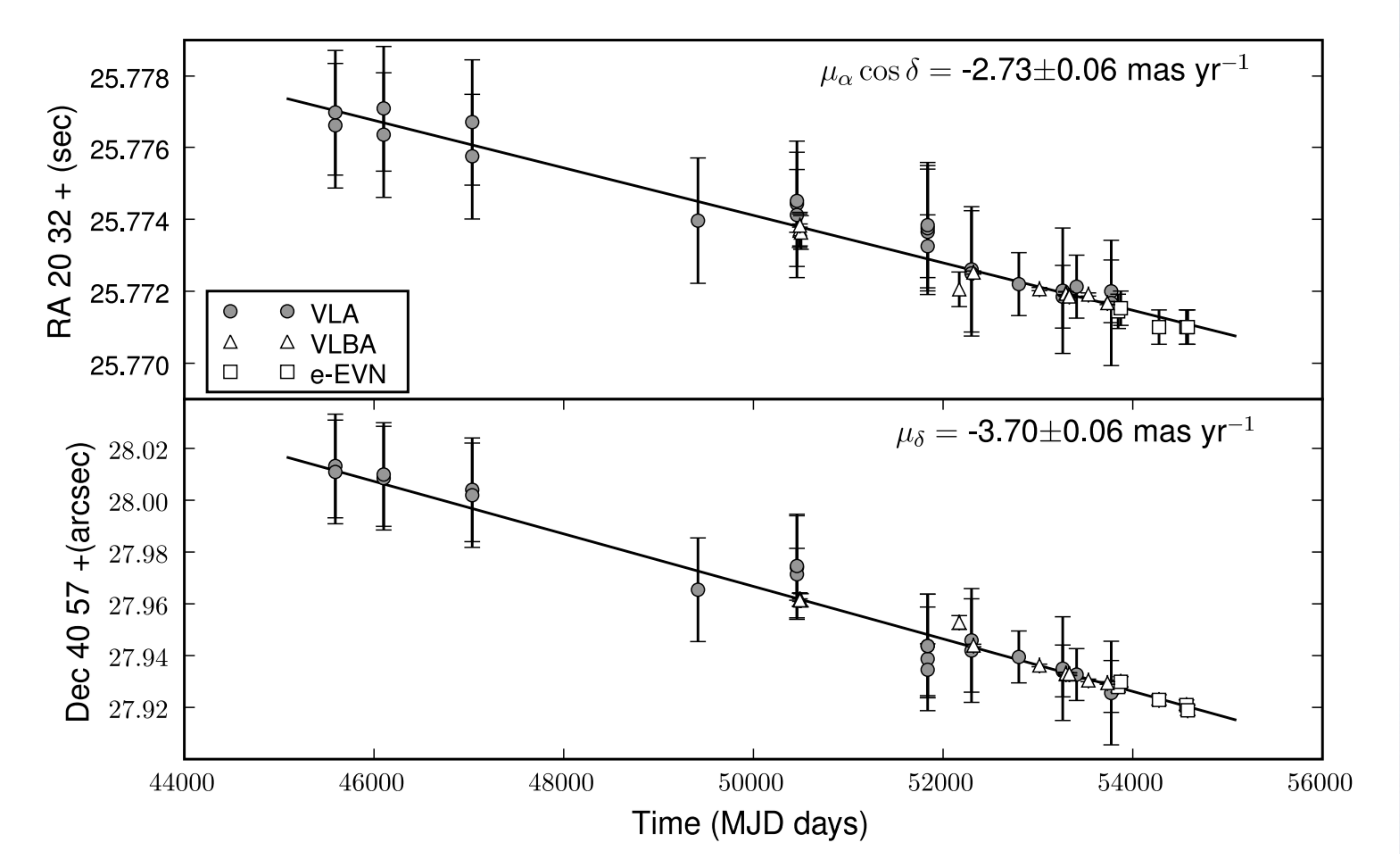
Comparison with EVN observations at 5 GHz in April-May 2006 with the 2017 flare

Several weeks after a flare | 1 week after a major flare of 2006



Proper motion Cyg X-3: 4.6 mas/yr (Miller Jones et al. 2009)

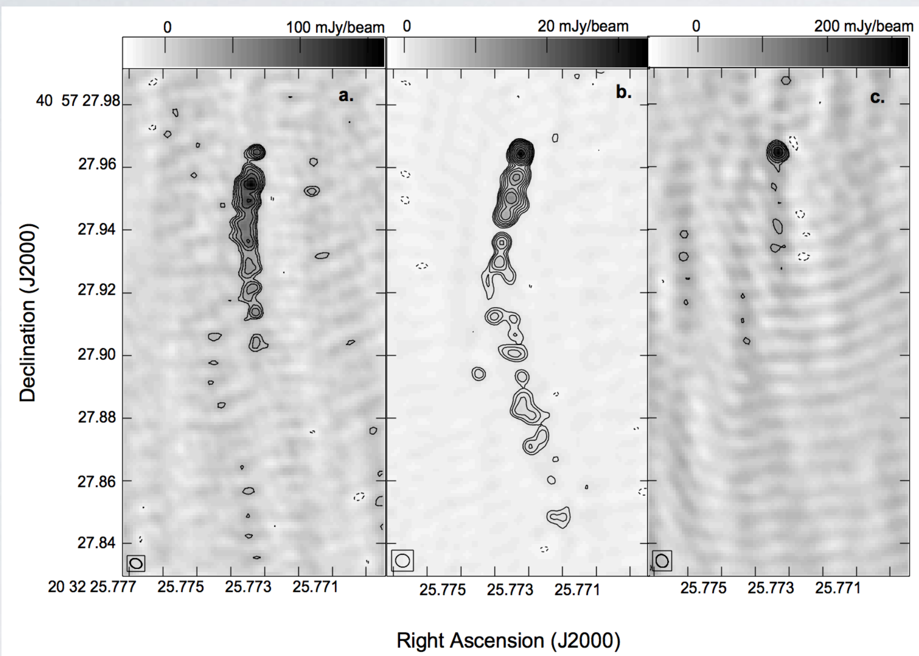
Proper motion of Cyg X-3 using 25 years of data



(Miller Jones et al. 2009)

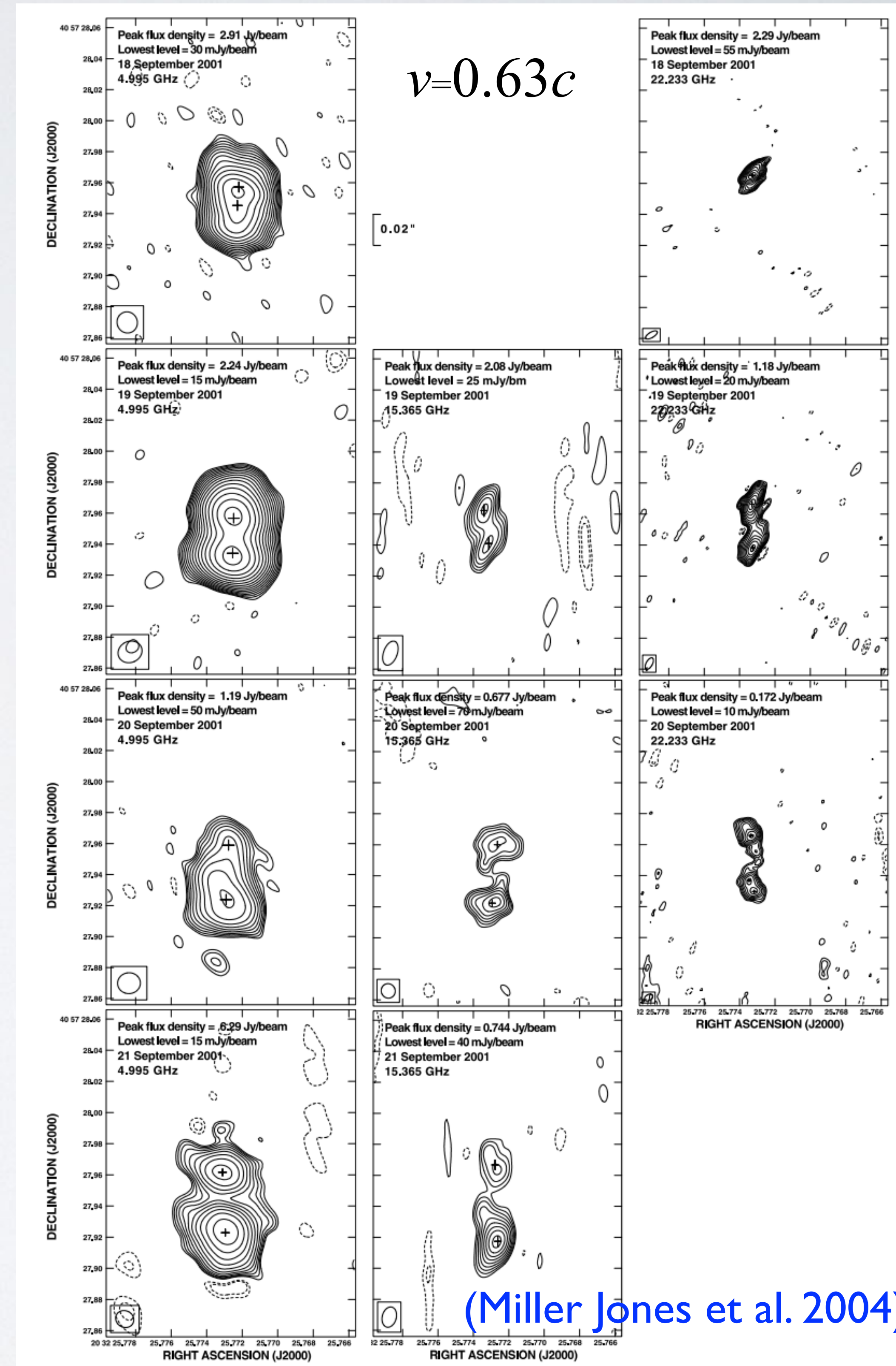
The changing jet morphology of Cyg X-3

VLBA: 2, 4 and 7 days after the 1997 giant flare



v=0.81c

VLBA: 4 days from the 2001 giant flare

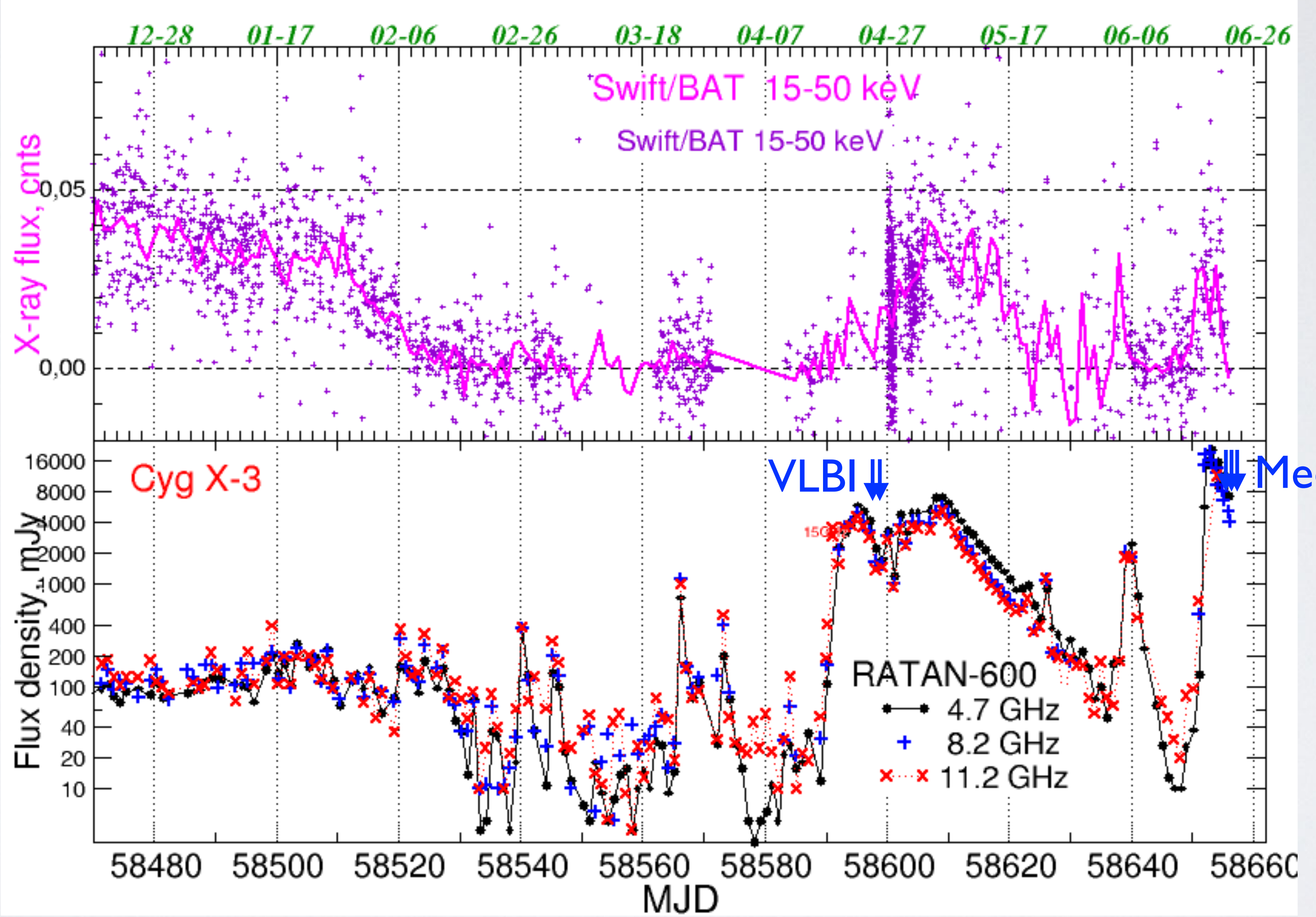


(Miller Jones et al. 2004)

The jet orientation varies with time, the jet is precessing (5-60d) and probably close to the line of sight (i: 10-30°).

The giant flare of June 2019

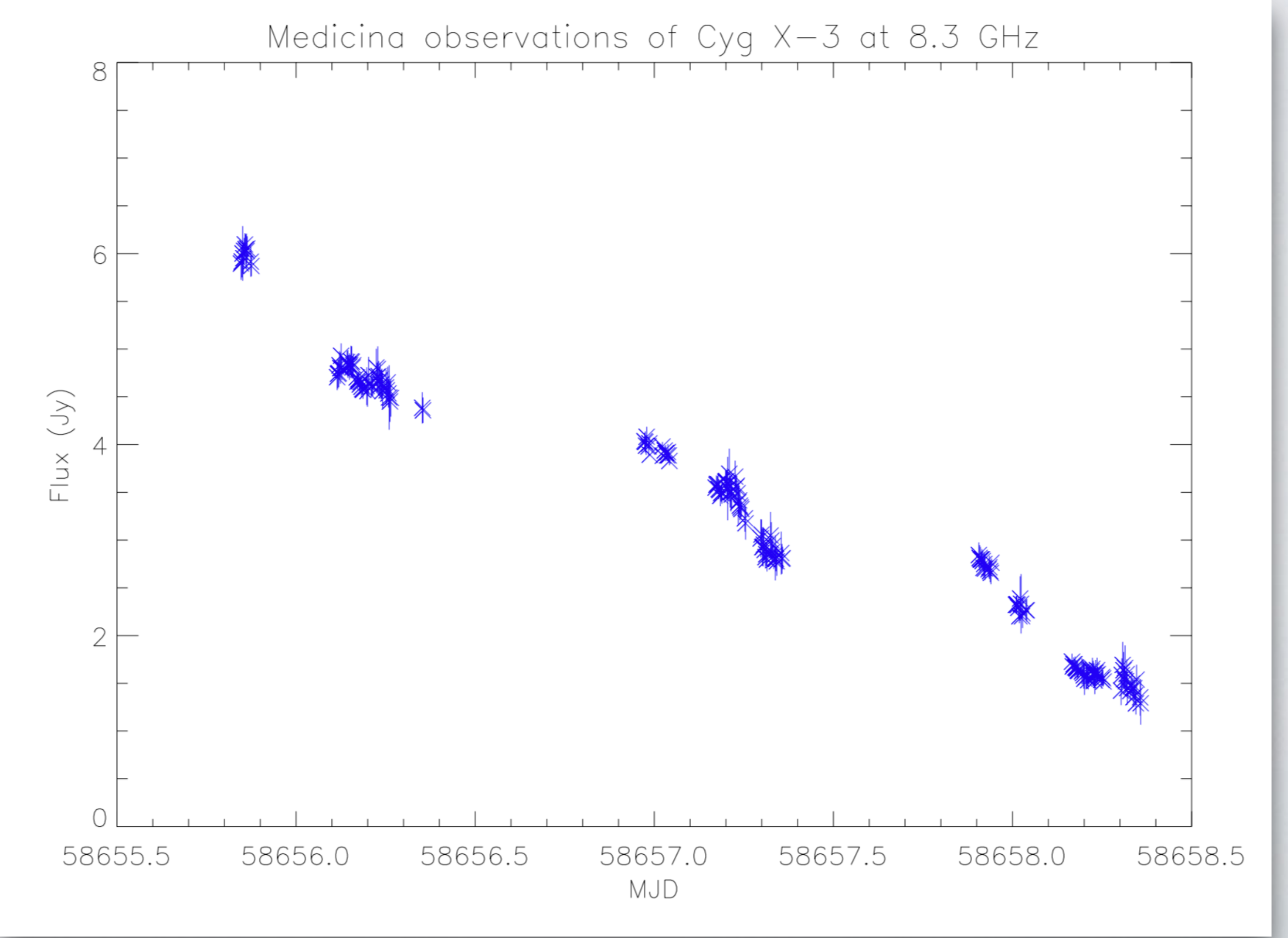
Swift/BAT and RATAN-600 daily monitoring of Cyg X-3



https://www.sao.ru/hq/lran/XB/CygX-3/CygX-3_lc_rat_sw_2019f.png

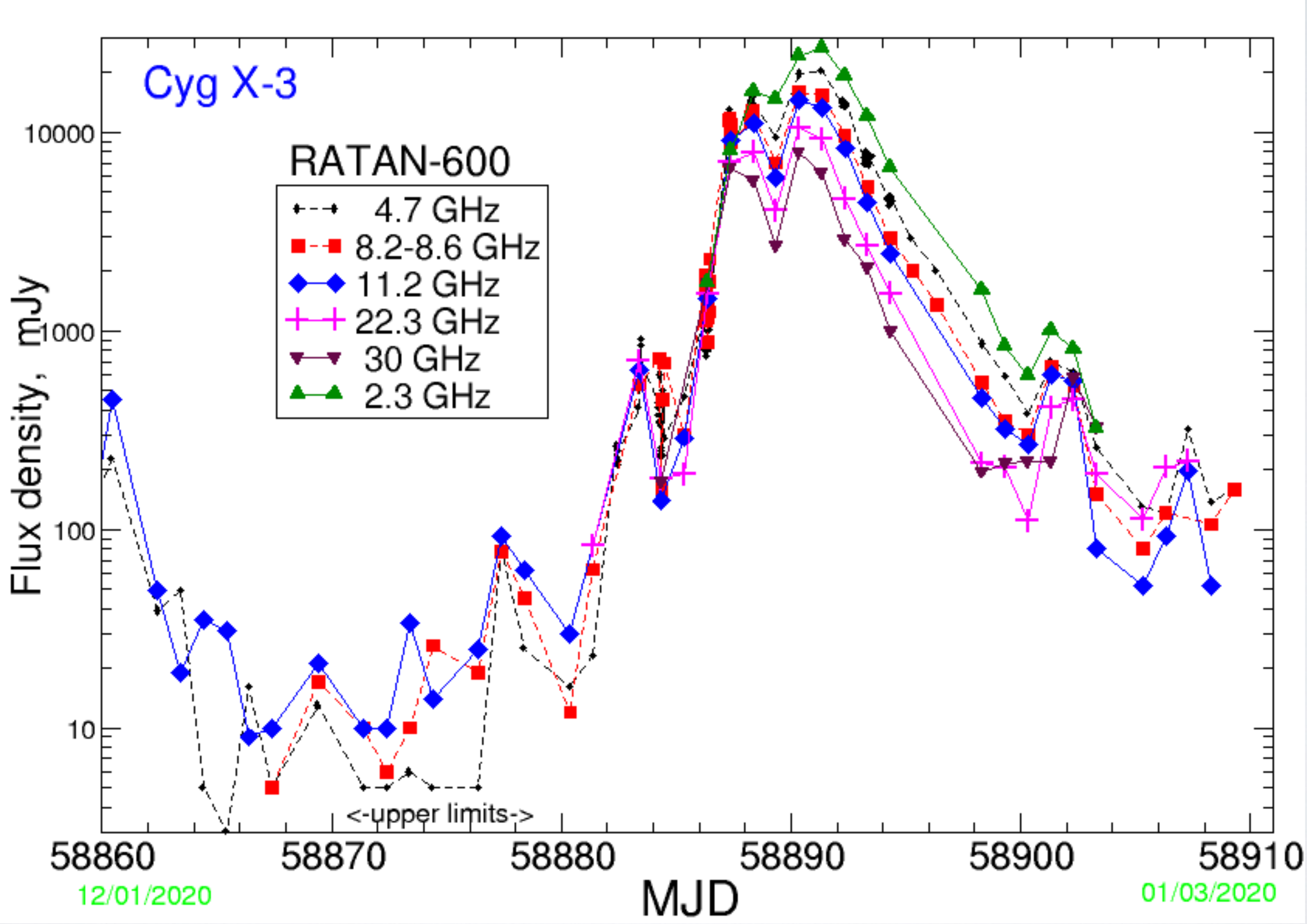
The giant flare of June 2019

- Flares of strong intensity in April 2019, then a giant flare in June 2019
- Coordinated multi-wavelength obs: radio (AMI, RATAN, VLA, **VLBI**, KaVN, Metsähovi), submillimeter (SMA, JCMT), X-rays (Swift, NuSTAR, NICER), gamma rays (AGILE)
- - VLBI obs triggered: Sr, Md, Nt, Ib, On, Tr, Ys at 5 GHz (8 hrs x 2 days) on April
  - Medicina obs on 21-23 June at 8.5 and 25 GHz



The giant flare of February 2020

* Multifrequency monitoring with the RATAN-600

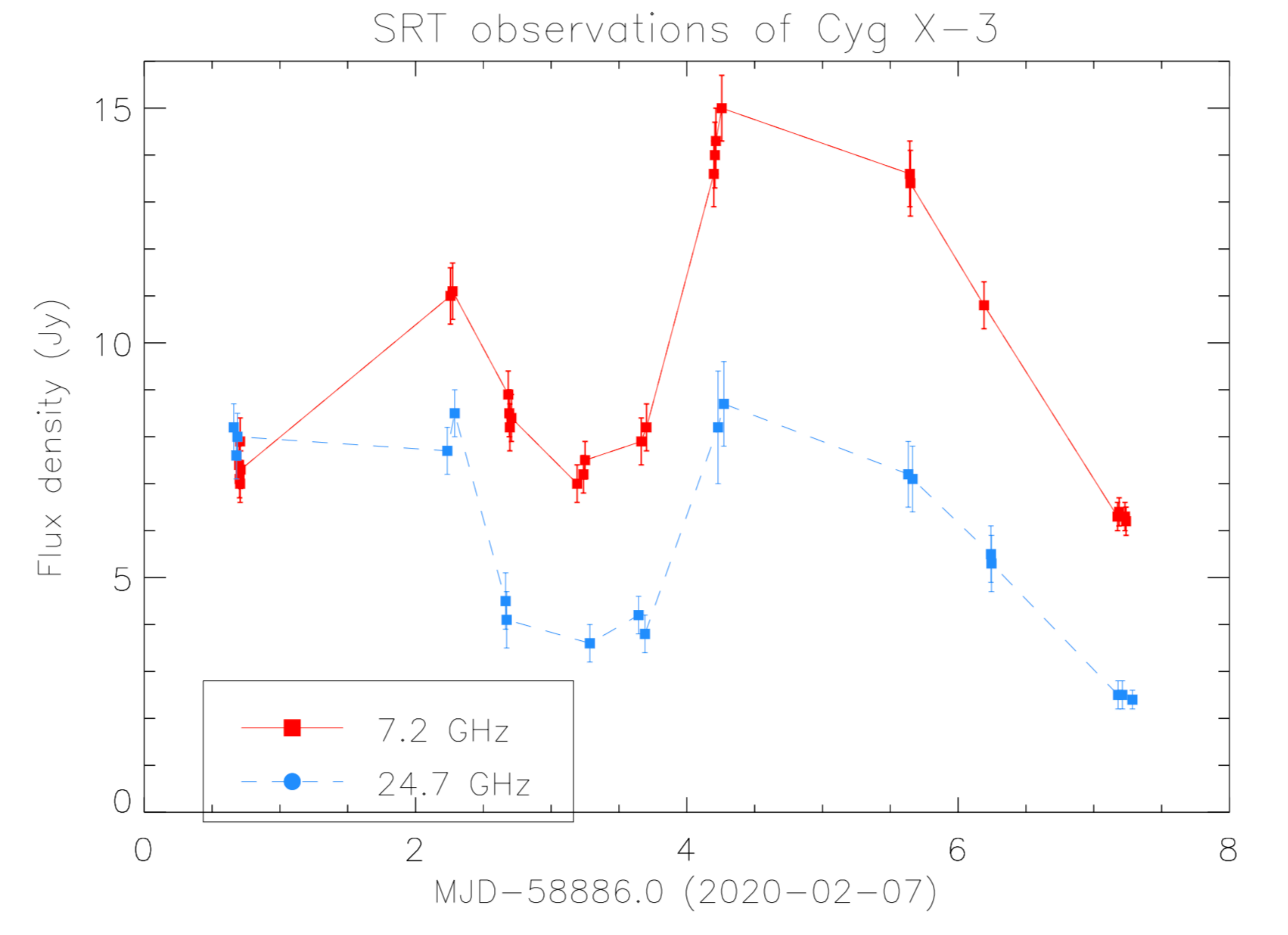


Trushkin et al. (ATel #13461)

The giant flare of February 2020

* SRT observations at 7.2 and 24.7 GHz

* Medicina and Noto were in maintenance



Egron et al. (ATel #13475)

Summary

- Cyg X-3: a complex and very interesting target for the study of accretion/ejection
- Radio orbital modulation detected during the mini-flares
- Need more data during the giant flares to better understand the orbital modulation and what is going on in the multi-wavelength context
- Difficult but essential to trigger observations very quickly
- Nice future for the Italian antennas : new receivers at higher frequency are coming, in particular a multifrequency band receiver 22, 43 e 86 GHz …

Microquasar workshop to be held
in Cagliari in September 2020 => 2021…
https://sites.google.com/inaf.it/microquasar-2020/home

Thank you for your attention !