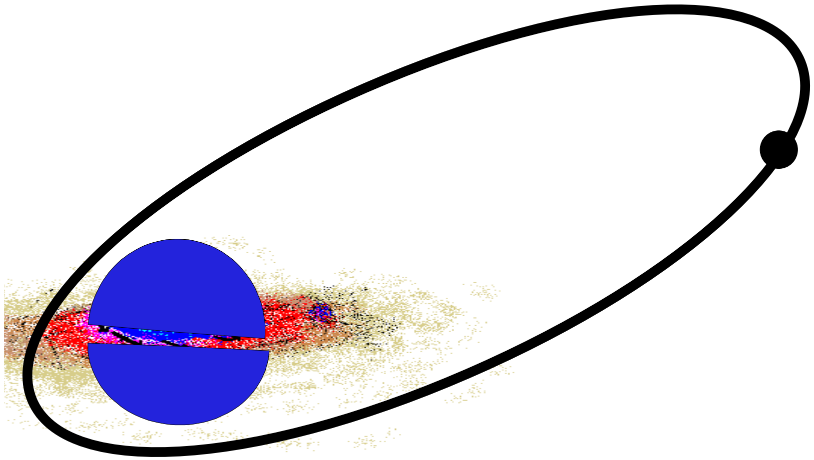
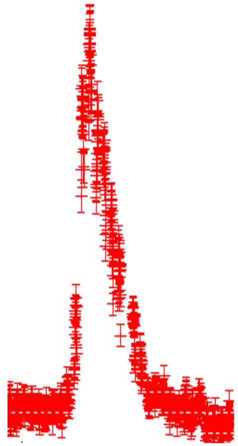
# *Characteristics of the Periodic Outburst of LS I +61303*


Maria Massi

• (MPIfR)



*Variable Galactic Gamma-ray Sources – Heidelberg 2015*

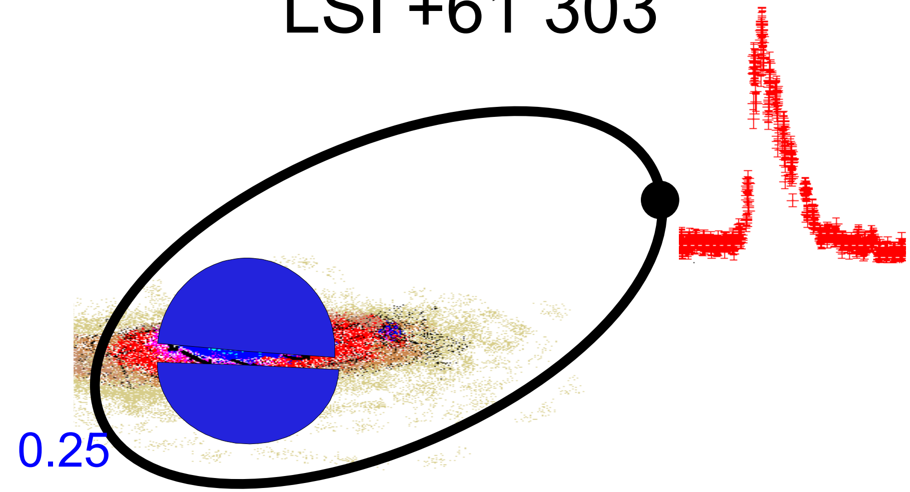
# *Characteristics of the Periodic Outburst of LS I +61303*

I. Periodic radio outburst

II. Long-term periodicity

# LSI +61 303

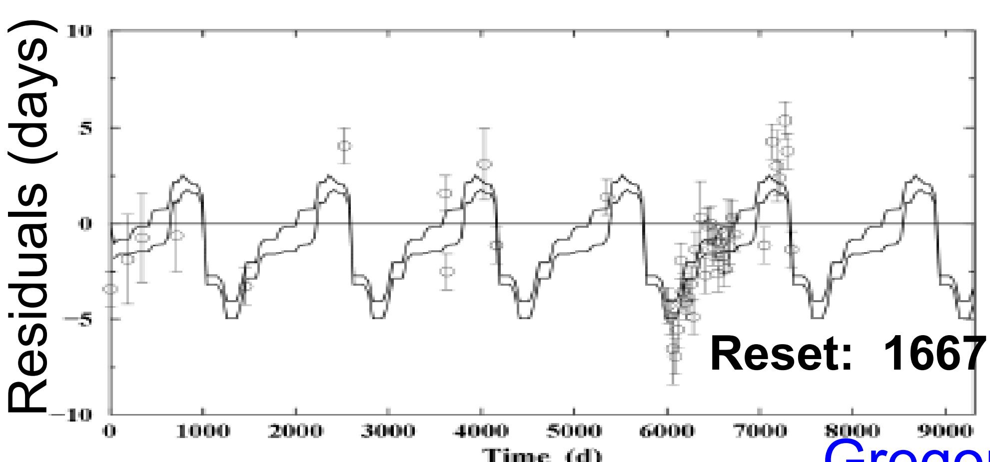
1 - periodic radio outburst toward apastron




2 - Hypothesis that compact object undergoes a periodical increase in accretion at a particular orbital phase along an eccentric orbit around the **Be star** was suggested and developed by several authors
Taylor et al 1992, Marti & Paredes 1995
Bosch-Ramon et al. 2006, Romero et al 2007

3- Orbital Period $P_1$= 26.496 +/- 0.08d
Gregory 2002

*Periodic* radio outburst towards apastron,
*nearly* but not exactly $P_1$

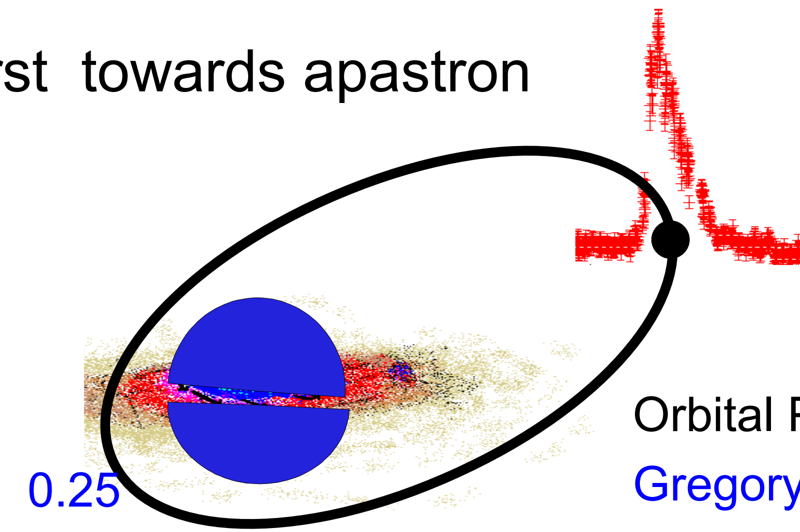



**Reset: 1667 days**

Gregory et al 1999

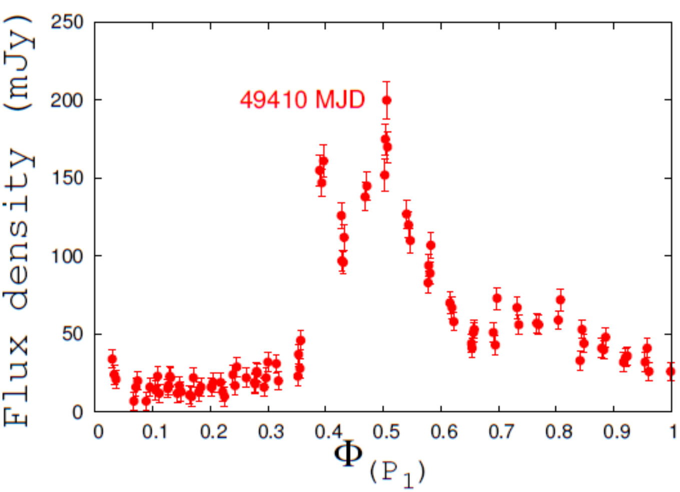
Timing residuals: Gregory et al 1999
Orbital shift: Paredes et al 1990

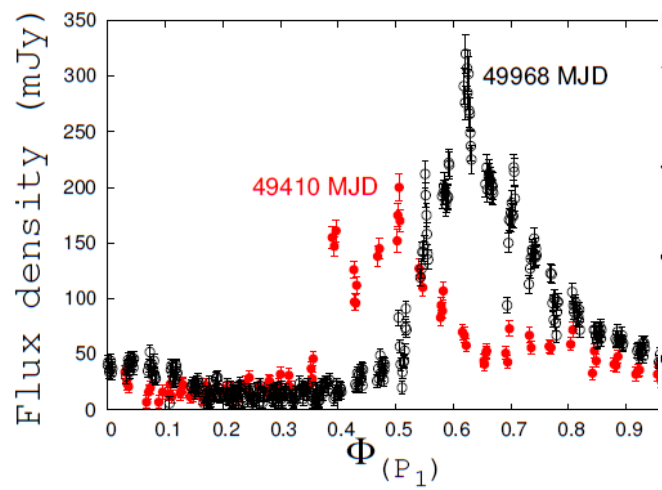
# Periodic radio outburst towards apastron

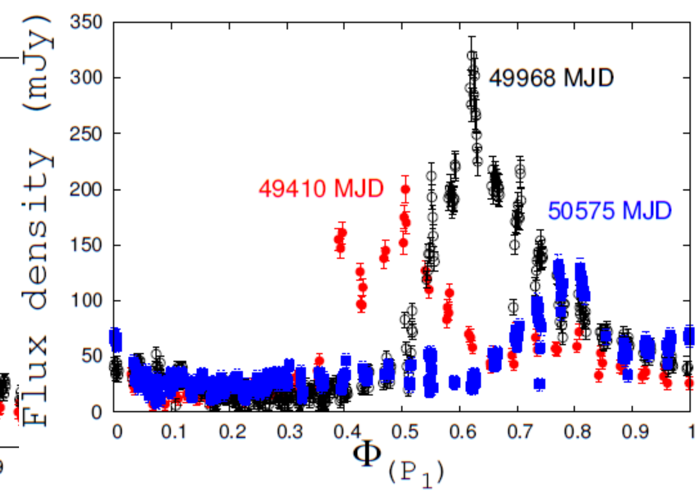



Orbital Period $P_1$ = 26.496 +/- 0.08d

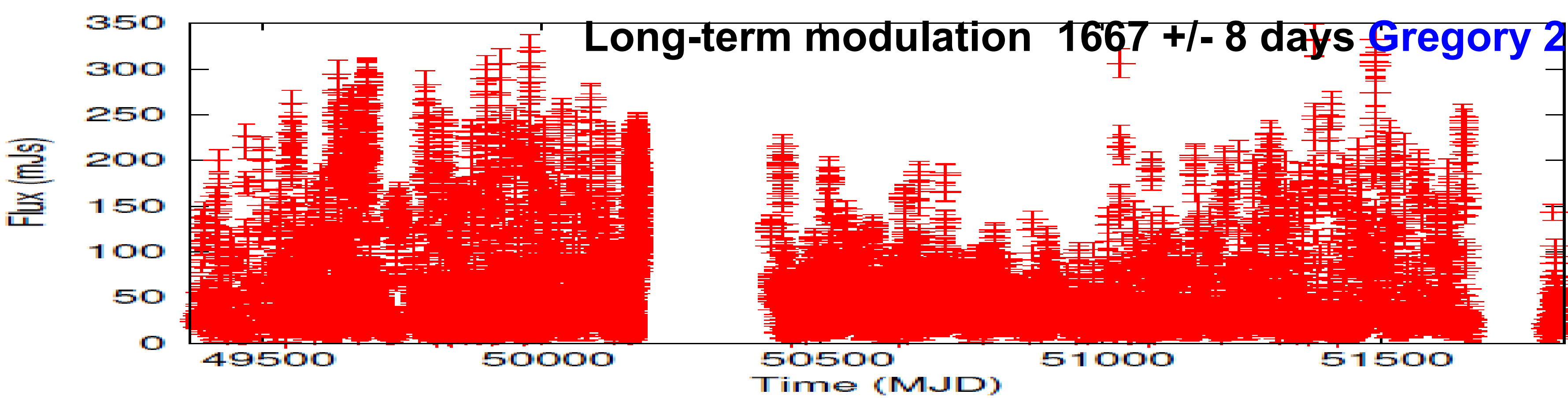
Gregory 2002

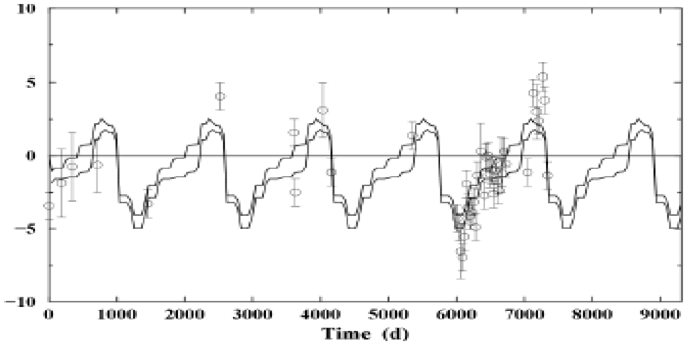



**Long-term modulation 1667 +/- 8 days Gregory 2002**






Residuals affected by a **systematic error** with a sawtooth pattern

Period= $P_1$ = 26.4960 +/- 0.0028 =Orbital Period

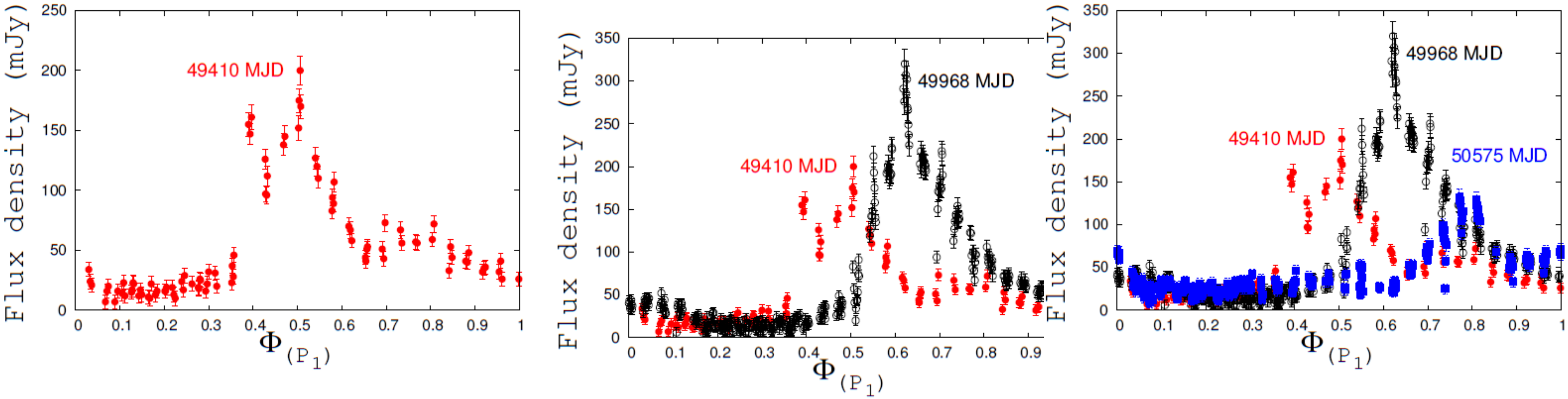
Not the period of the radio outburst

Ray et al 1997

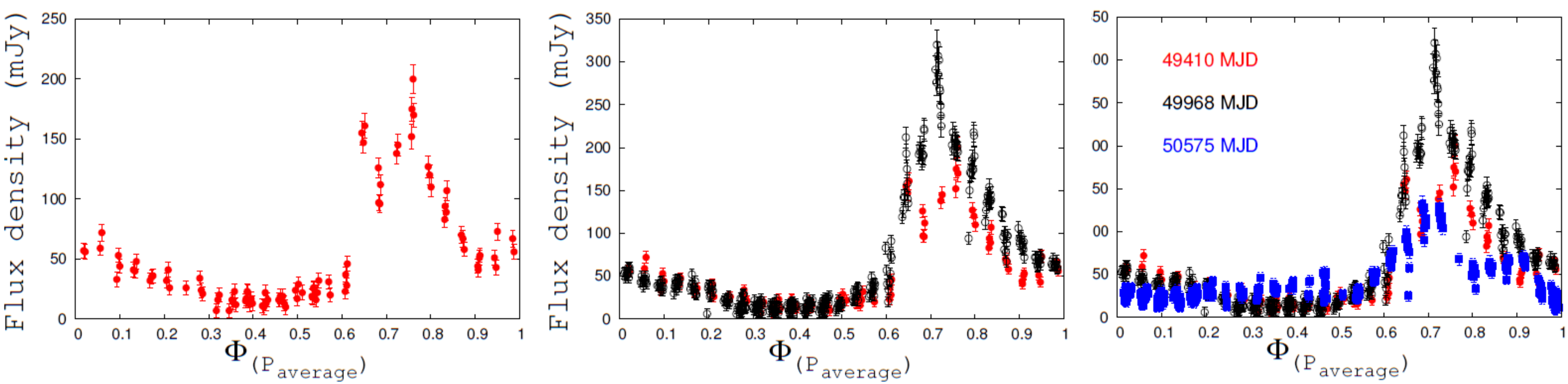
Period for radio outburst 26.69 +/- 0.02

Period= $P_{average}$ =26.704 +/- 0.004

Massi & Jaron 2013
Jaron & Massi 2014




Period= P$_1$ = 26.4960 +/- 0.0028 =Orbital Period

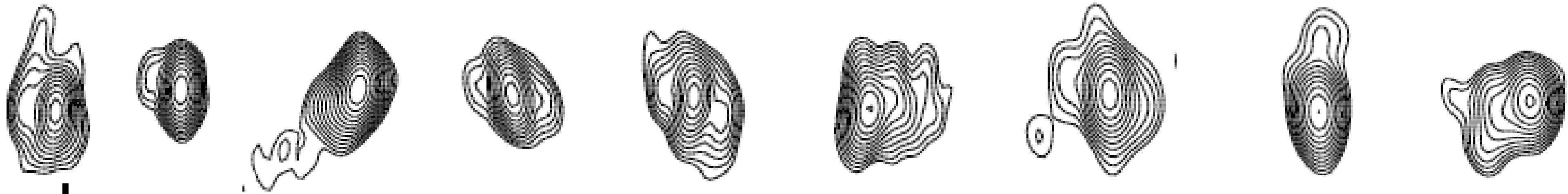



Period= P$_{average}$ =26.704 +/- 0.004 =Radio Outburst Periodicity

# *Characteristics of the Periodic Outburst of LS I +61303*

I. Periodic radio outburst $P_{average}$ = 26.704 +\- 0.004

II. Long-term periodicity 1667 +\-8 days

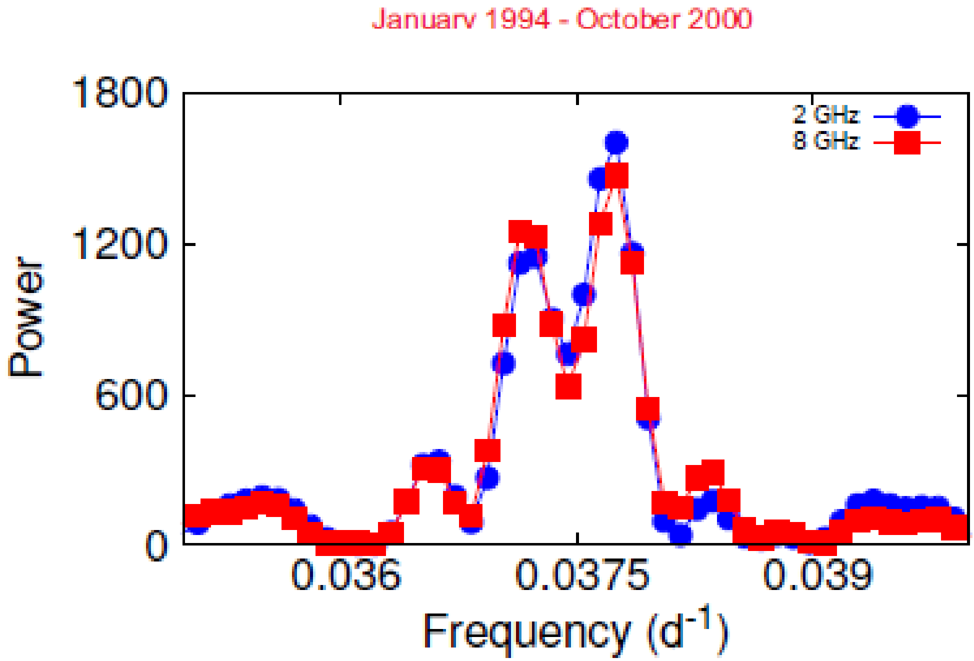


$$S_{\mathrm{a}}(t)(\delta_{\mathrm{a}}(t))^{\kappa-\alpha}$$

Doppler boosting

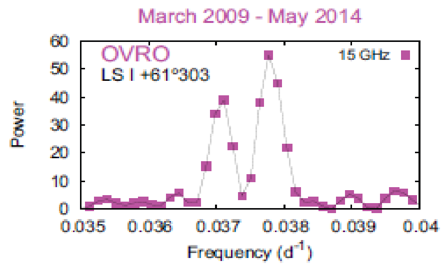
$$\delta_{\mathrm{a}} = \frac{\sqrt{1-\beta^2}}{1-\beta\ \cos\eta}$$

# Timing Analysis of 6.7 years Green Bank Interferometer (GBI) data at 2.2 Ghz and 8.3 GHz




Massi & Jaron 2013 (GBI)

Figure : Lomb-Scargle periodogram of the GBI data



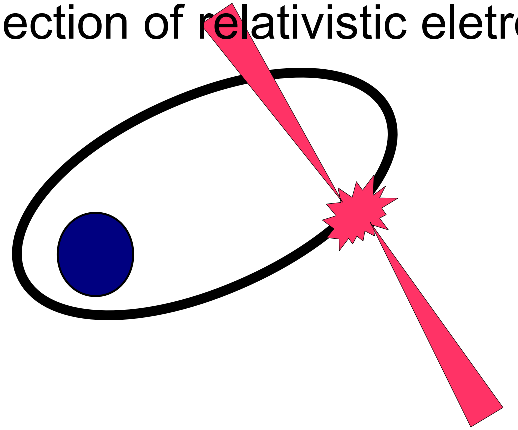

Massi,Jaron,Hovatta 2015 (OVRO)

- Two periodicities:

$$P_1 = 26.49 \pm 0.07\,\mathrm{d}$$
$$P_2 = 26.92 \pm 0.07\,\mathrm{d}$$

- $P_1$ is the known orbital periodicity.
- $P_2$ agrees well with the precessional periodicity previously determined from VLBA Astrometry (27-28 d) (Massi, Ros, Zimmermann 2012)

P1: ejection of relativistic eletrons at a particular orbital phase



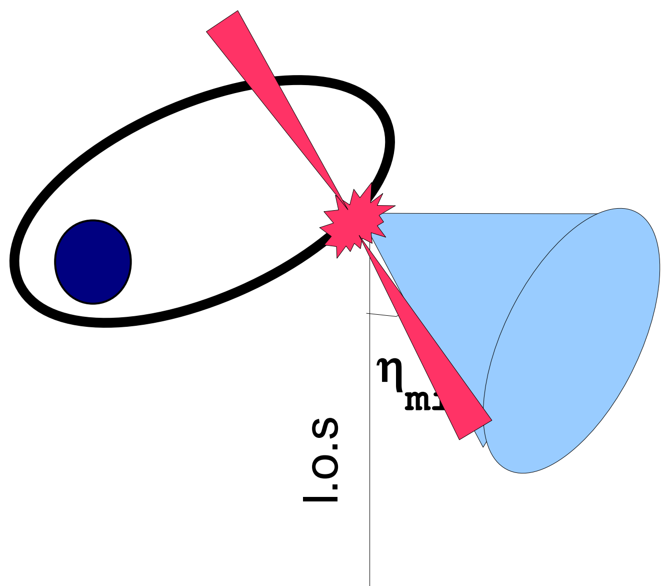
P1: Hypothesis that compact object in LSI+61303 undergoes a periodical (P1) increase in accretion at a particular orbital phase along an eccentric orbit was suggested and developed by several authors
Taylor et al 1992, Marti & Paredes 1995.
Bosch-Ramon et al. 2006, Romero et al 2007

- $P_2$ agrees well with the precessional periodicity previously determined from VLBI images.

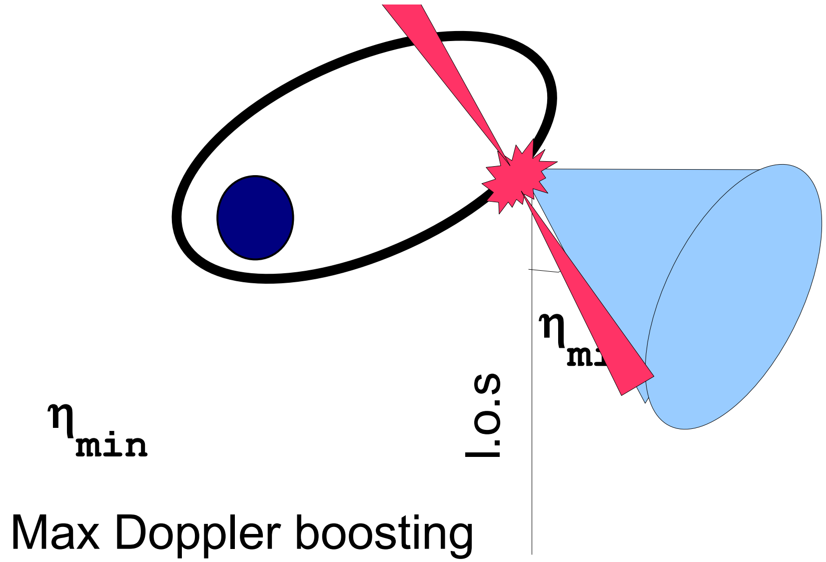
VLBA Astrometry 27-28 d
(Massi, Ros, Zimmermann 2012)

$P_1$ $P_2$

$$S_a(t)(\delta_a(t))^{k-\alpha}$$

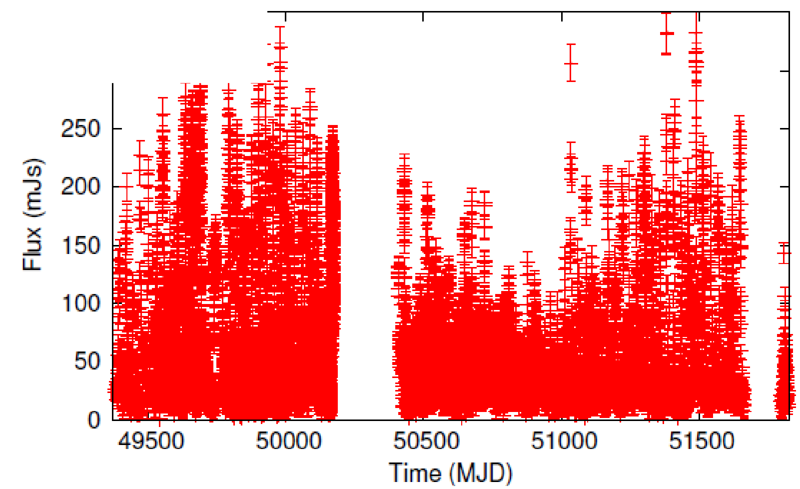


$$P_1 = 26.49 \pm 0.07\,\mathrm{d}$$
$$P_2 = 26.92 \pm 0.07\,\mathrm{d}$$




# The long-term modulation

**1667 +/- 8** Gregory 2002




$$1/P_{long} = \nu_1 - \nu_2$$

Massi & Jaron 2013

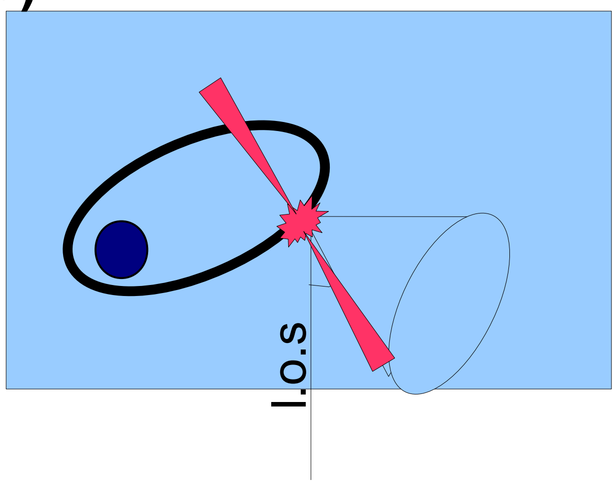
$$1/P_{average} = (\nu_1 + \nu_2)/2$$

# BEATING

**Starting (Intrinsic) frequencies**

1/P1 →

1/P2 →




**Resulting (Observed) frequencies**

1/ P average $= \nu_1 + \nu_2 \;\; / 2$

1/ P long $= \nu_1 - \nu_2$

**LS I +61 ◦303 seems to be one more case in astronomy of a "beat"**

The first astronomical case was that of a class of Cepheids, afterwards called **beat Cepheids** (Oosterhoff 1957).

# The Model
Massi & Torricelli-Ciamponi 2013

$$S_{\mathrm{model}}(t) = S_{\mathrm{a}}(t)(\delta_{\mathrm{a}}(t))^{k-\alpha} + S_{\mathrm{r}}(t)(\delta_{\mathrm{r}}(t))^{k-\alpha}$$

Kaiser (2006) **Conical jet**

$$\kappa = \kappa_0 l^{-a_3}$$

The number density of the relativistic electrons $N_{\mathrm{rel}} = \kappa E^{-p}$.

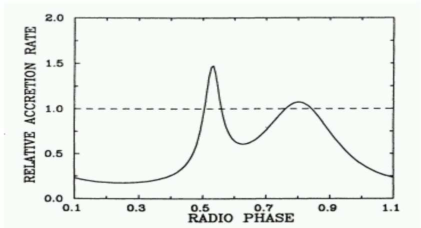
$$B = B_0 l^{-a_2}$$

$$S_{\mathrm{a}} = \int_1^L r_0 x_0 I_{\nu_{\mathrm{a}}}(\eta, l) \frac{\sin(\eta - \xi)}{D^2} l \mathrm{d}l \qquad I_\nu(\eta, l) = \int_0^{\tau_{\mathrm{end}}(l)} \frac{J_\nu}{\chi_\nu} e^{-\tau'/\cos\eta} \mathrm{d}\left[\frac{\tau'}{\cos\eta}\right]$$

$$J_0 = 2.3\ 10^{-25}(1.3\ 10^{37})^{(p-1)/2} a(p) B_0^{(p+1)/2} \kappa_0 \qquad \chi_0 = 3.4\ 10^{-9}(3.5\ 10^{18})^p b(p) B_0^{(p+2)/2} \kappa_0.$$

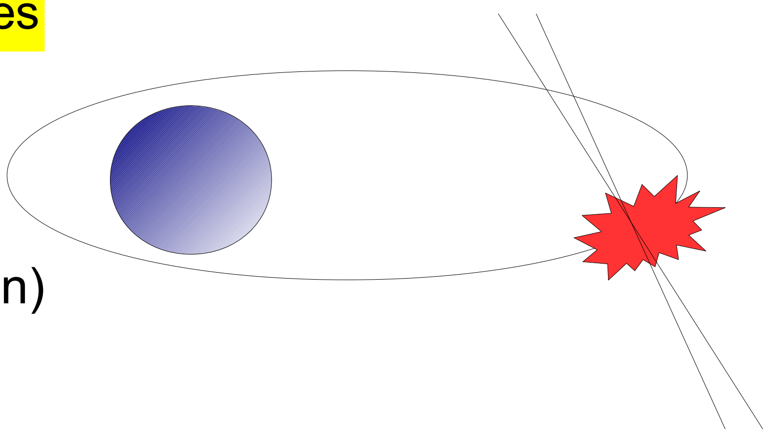
Precessing jet with periodical variations of emitting particles

$$\kappa_0 = A(\sin^2[\pi(\Phi - \Phi_{\mathrm{r}} + 0.5)])^n.$$



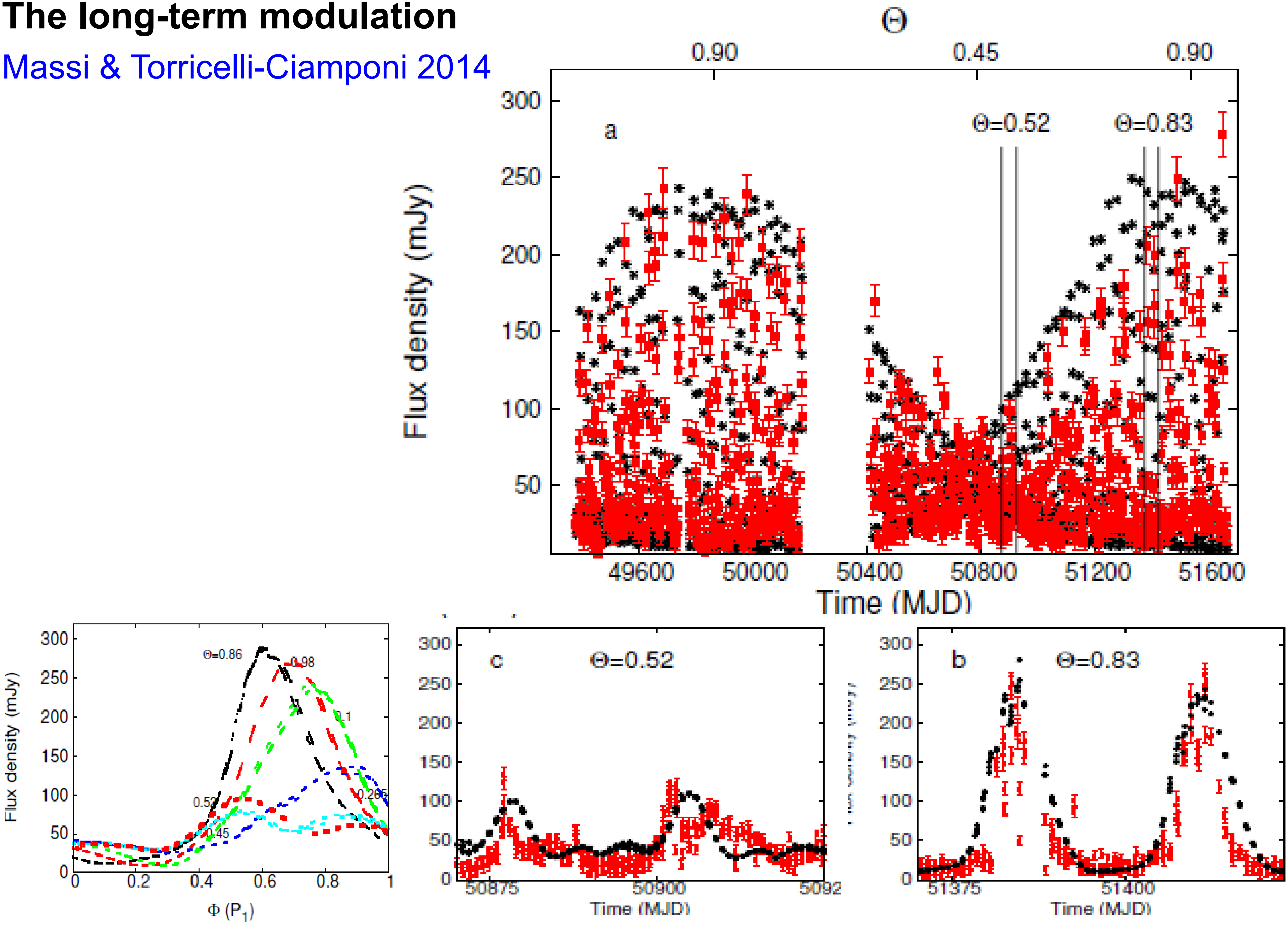

$P_1$ (o r b i t a l)

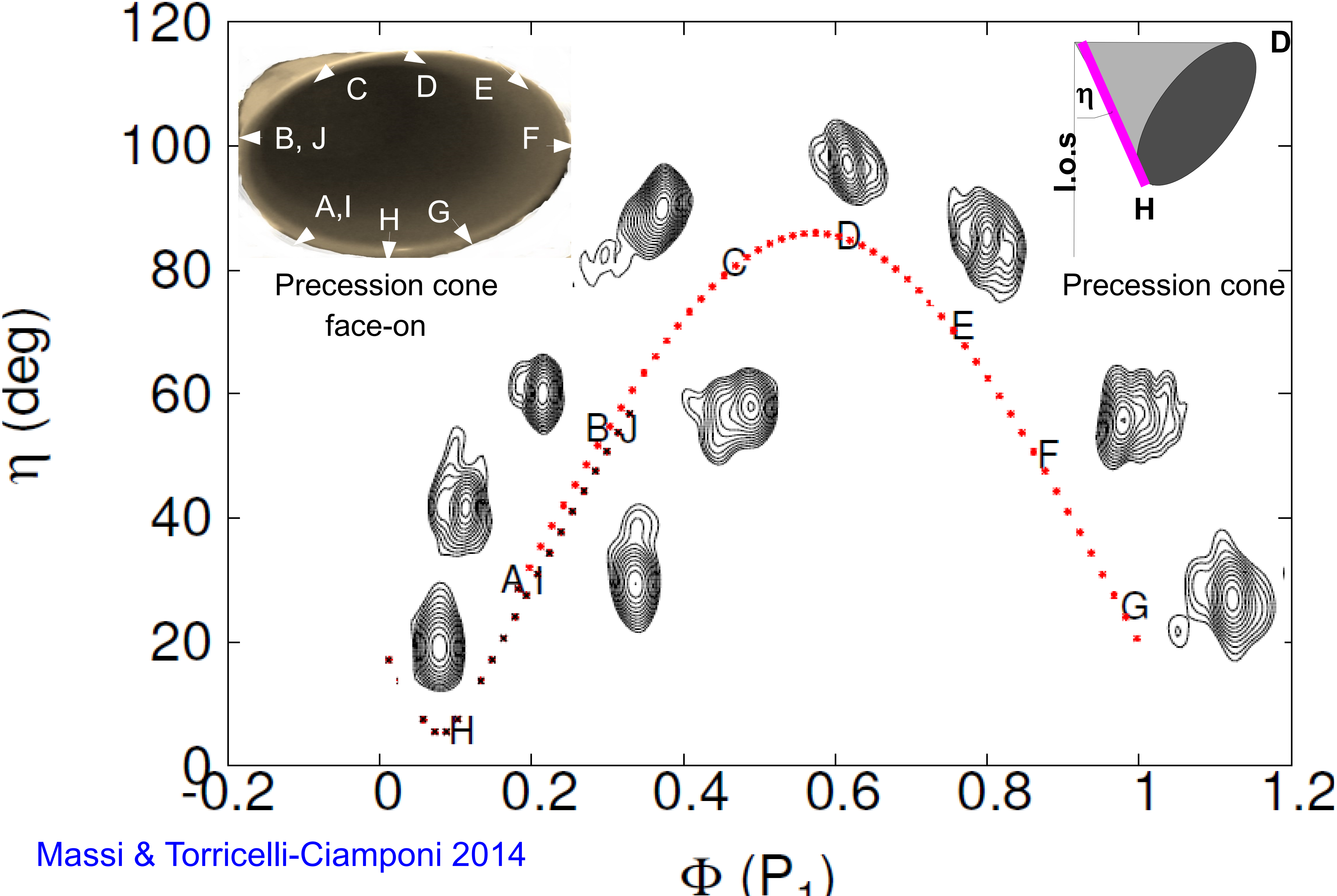
$P_2$ (precession)



# The long-term modulation

Massi & Torricelli-Ciamponi 2014

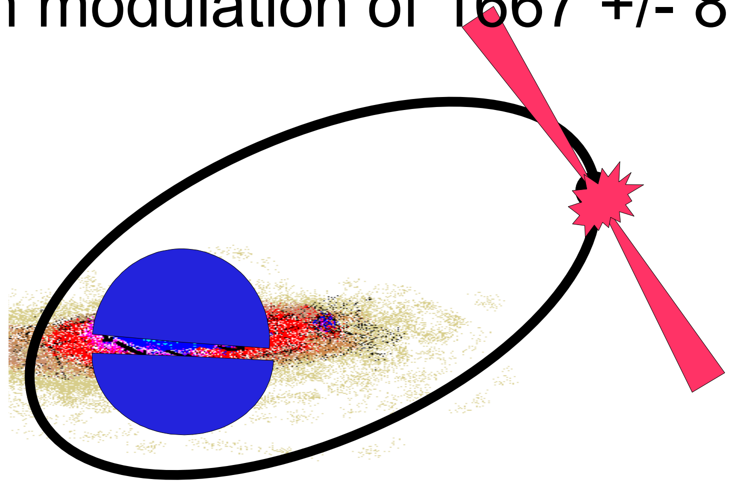




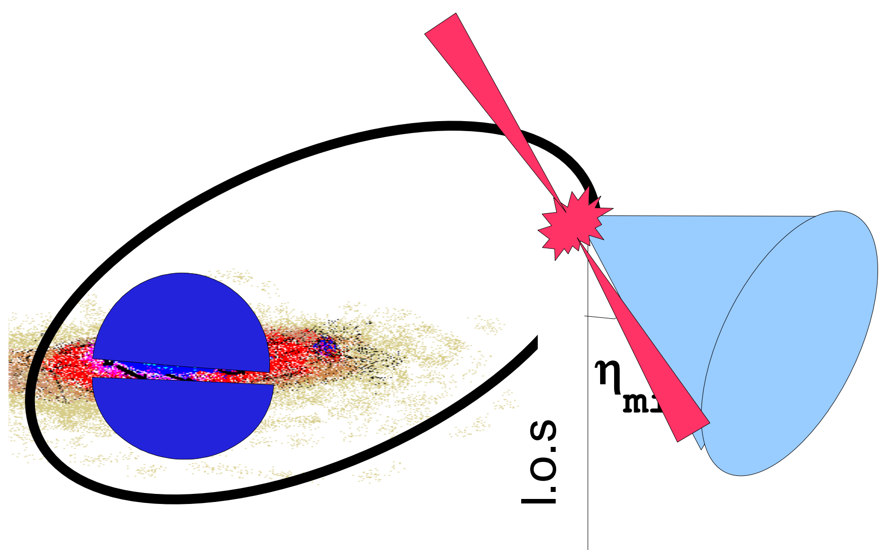

Massi & Torricelli-Ciamponi 2014

Results: the rapid rotation in position angles of VLBA maps

# Origin of the long-term modulation of 1667 +/- 8 days



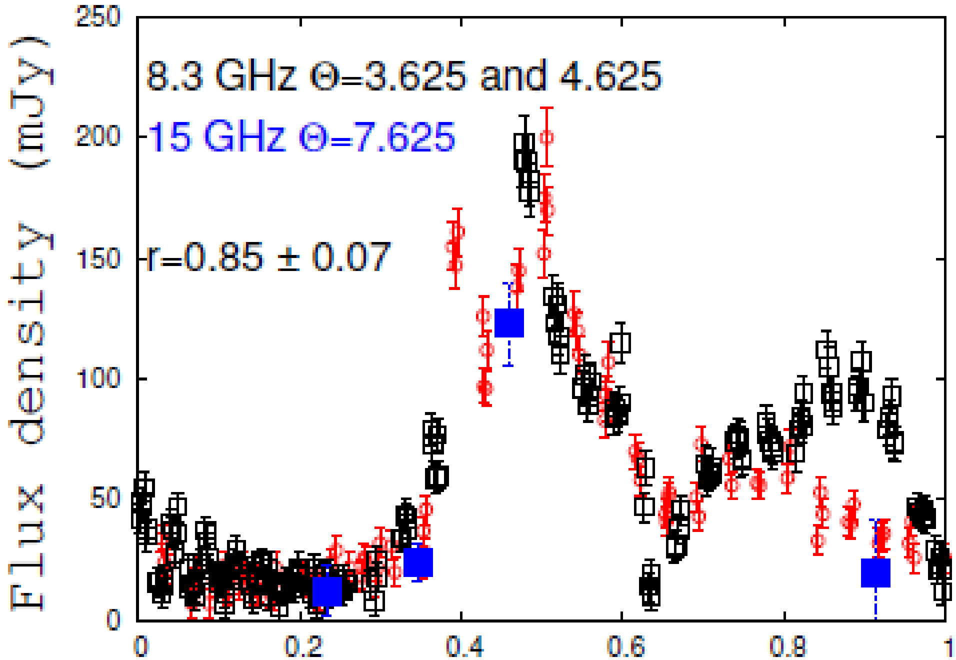
Hypothesis I:
Induced by Identical variations in the mass loss of the Be star?



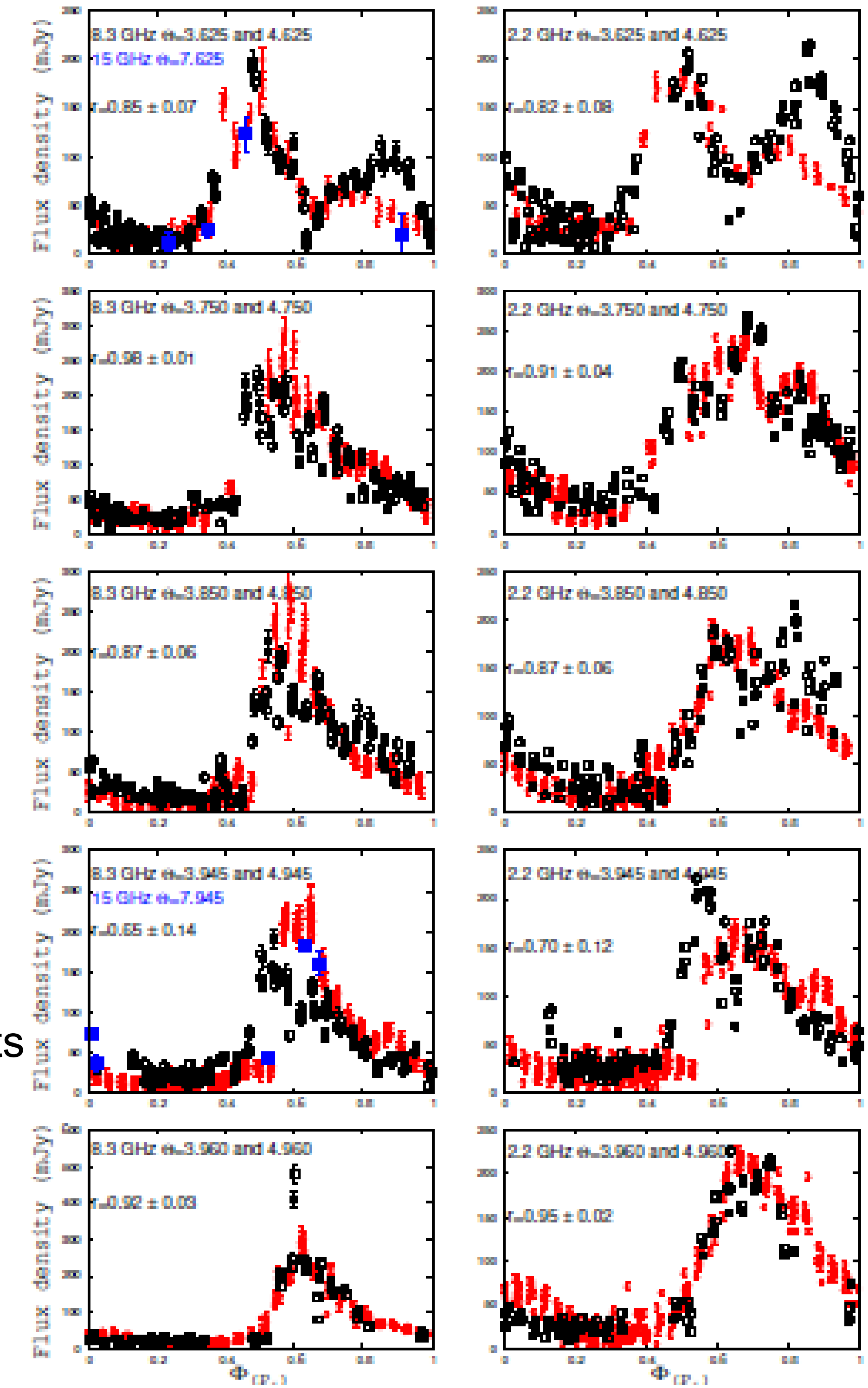

Hypothesis II: Doppler boosting

Origin of the long-term modulation:
Doppler Boosting  vs  Be variations

*“The cycle lengths in variable Be stars are not constant, but vary from cycle to cycle”*
*(Rivinius et al 2013)*



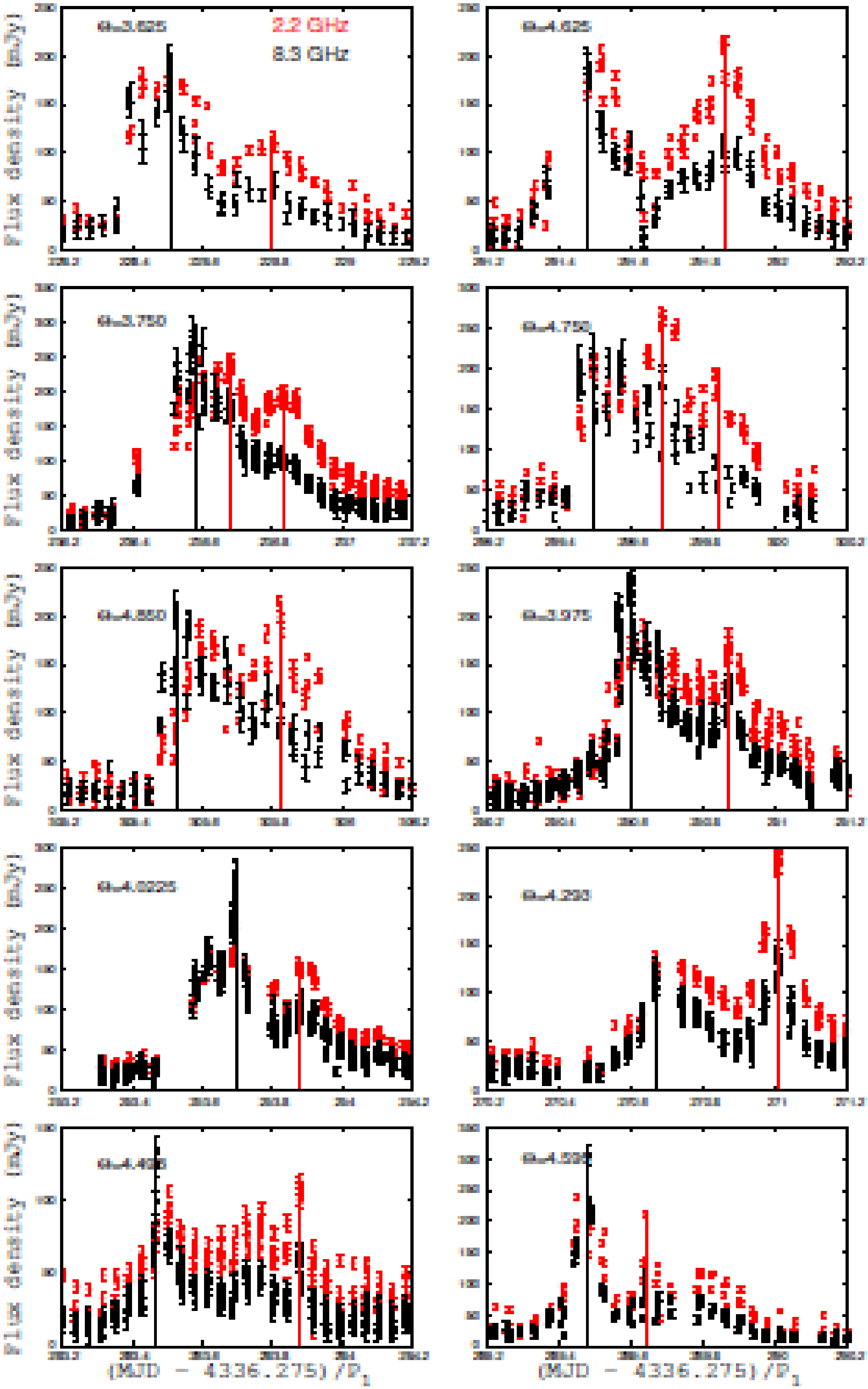

Massi & Torricelli-Ciamponi 2015 preliminary results

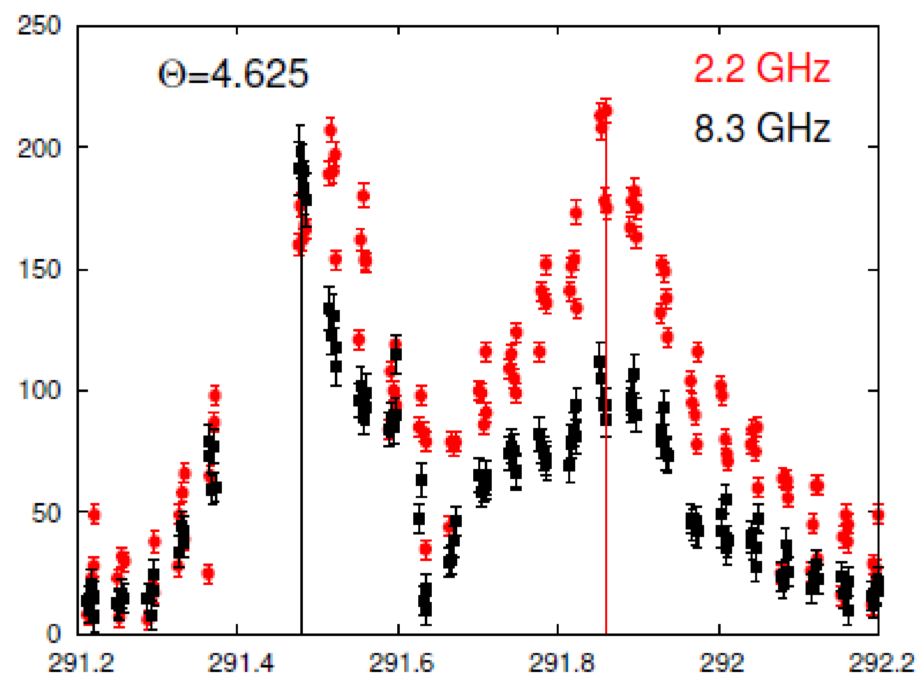


Comparing outbursts separated
GBI-GBI: 1667 days (4.7 yr)
GBI-OVRO:After 1667 x (7-3) days ( ~ 18.3 yr)

**LSI + 61 303**

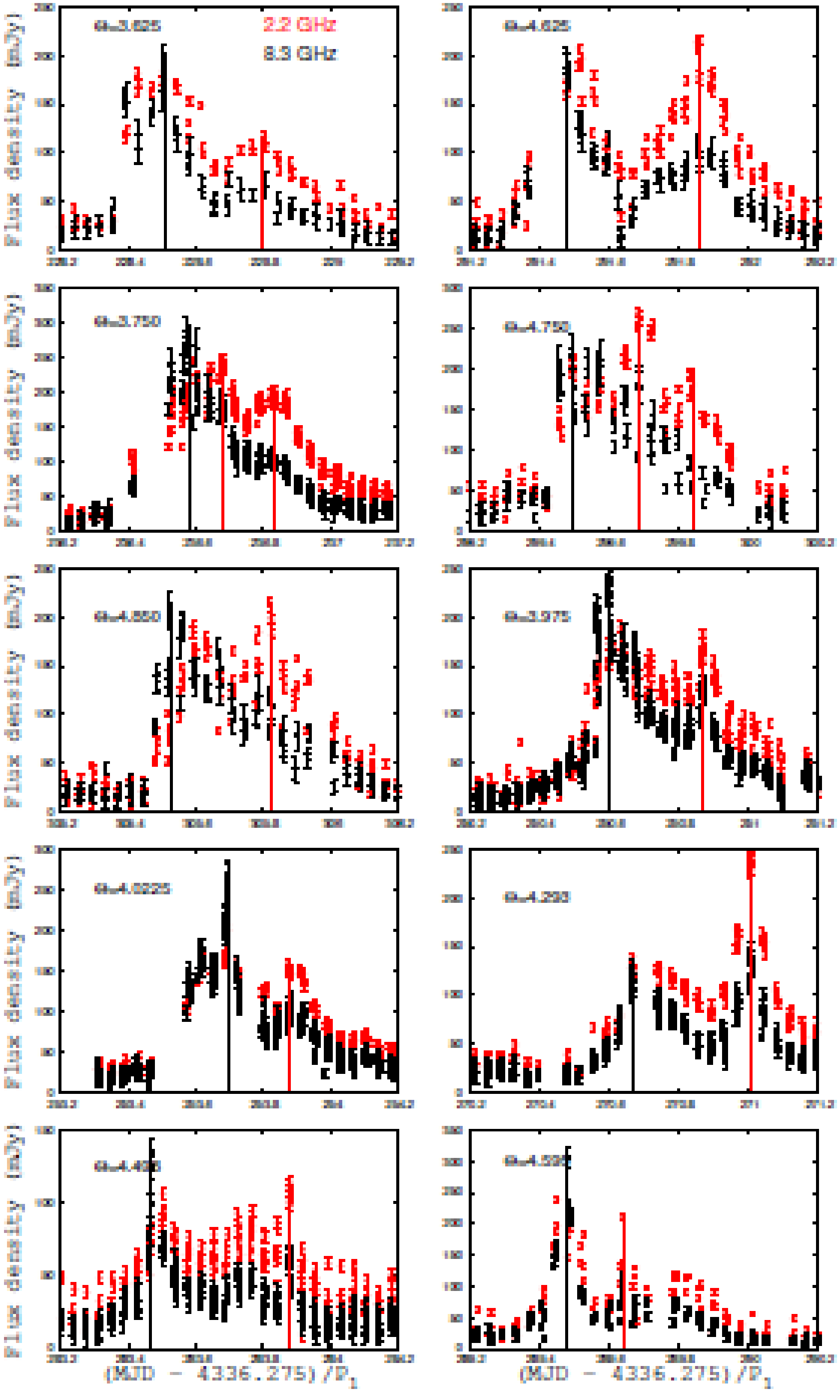
Massi & Torricelli-Ciamponi 2015



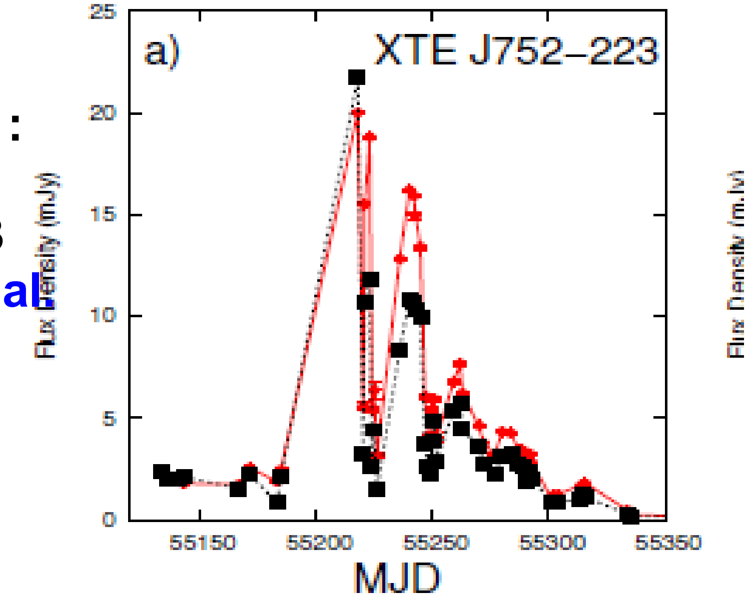

Two outbursts with different spectral characteristics

**LSI + 61 303** Massi & Torricelli-Ciamponi 2015

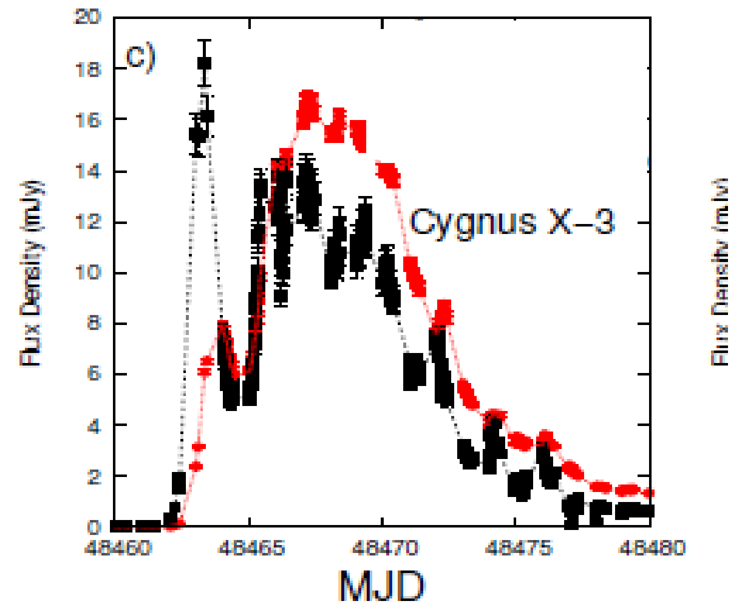



**Microquasars :**

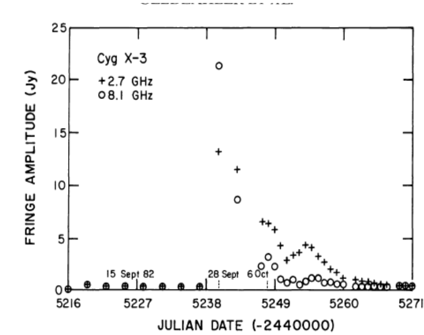
**XTE J752-223**
**Brocksopp et al. 2013**



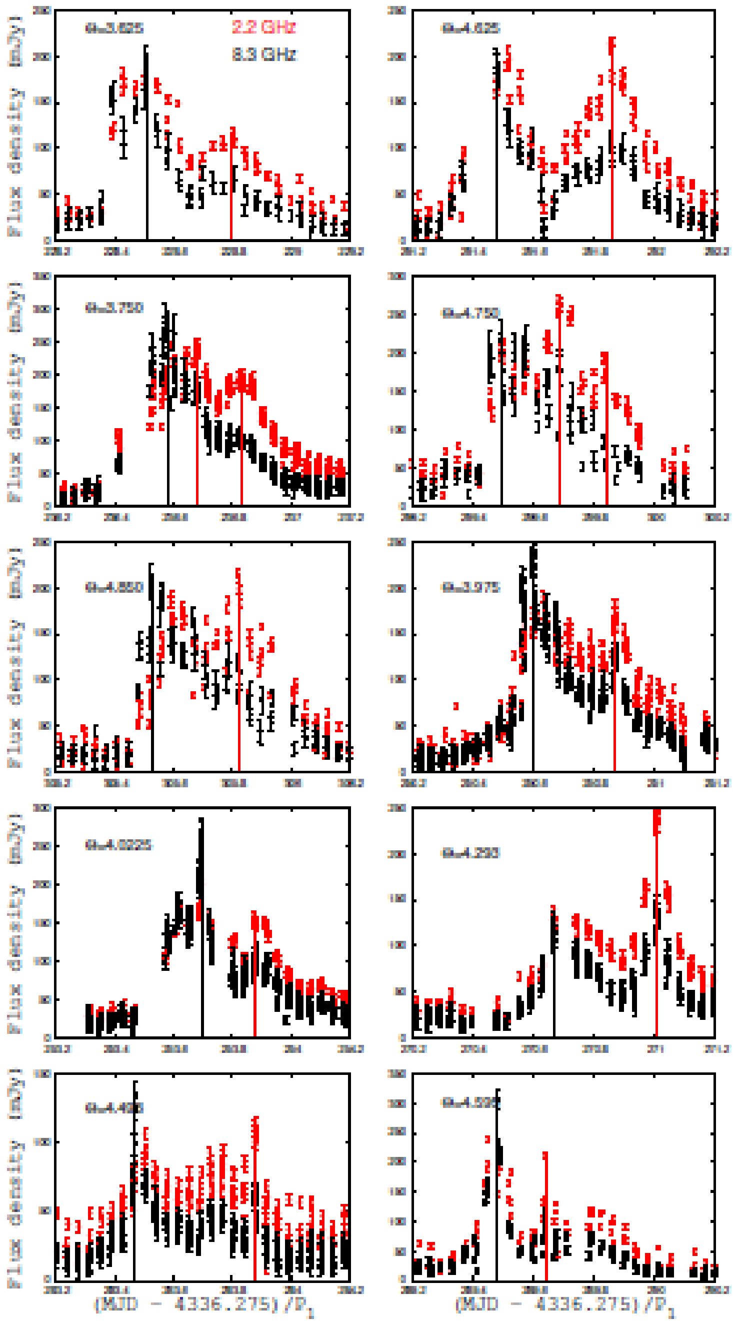

**Cygnus X-3**
**Waltman et al. 1995**




**Cygnus X-3**
**Geldzahler et al. 1983**



## LSI + 61 303 Massi & Torricelli-Ciamponi 2015

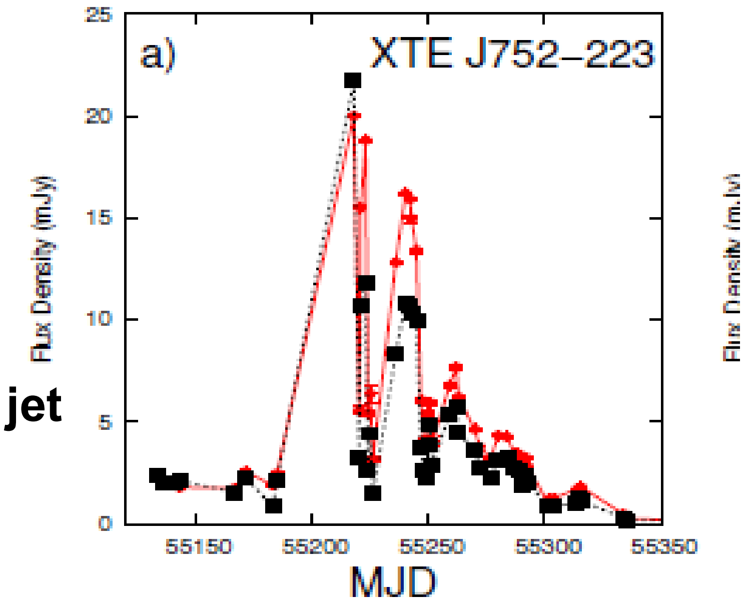



**Microquasars :**

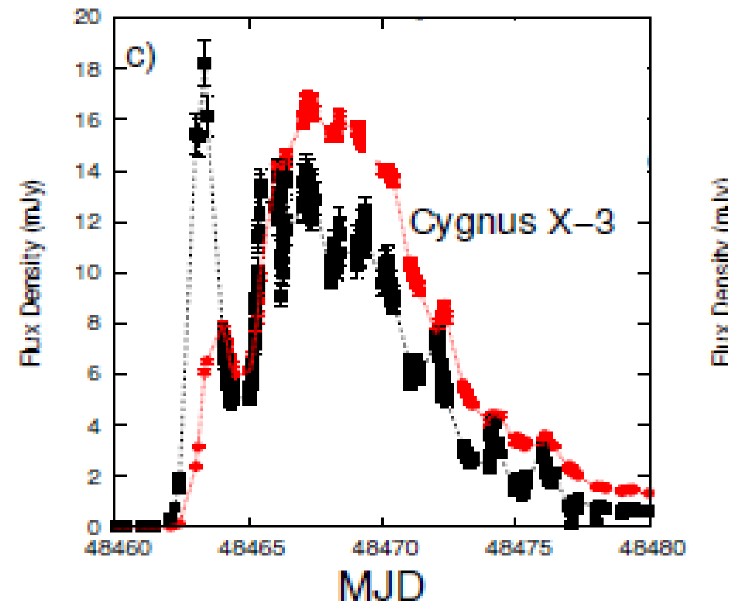
**XTE J752-223**
**Brocksopp et al. 2013**

**-first outburst: compact jet**

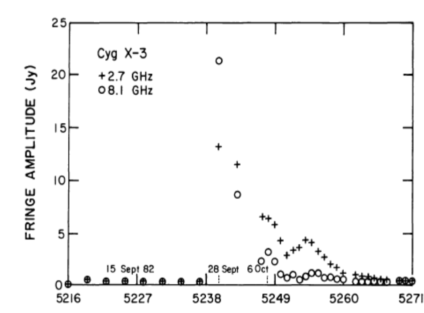
**-optically thin outburst: associated to <u>shocks</u>**




**Cygnus X-3**
**Waltman et al. 1995**




**Cygnus X-3**
**Geldzahler et al. 1983**



# *Conclusions*

1) Radio outburst periodicity: 26.704 +/- 0.004 days

2) Stability of the outburst after 1667 d

*The cycle lengths in variable Be stars are not constant, but vary from cycle to cycle (Rivinius et al 2013)*
i.e, the 1667 d periodicity could just reflect the periodical Doppler boosting induced by precession

3) Two consecutive outbursts with same spectral characteristics as microquasars XTE J1752-223 and Cygnus X-3:
One optically thick outburst (compact jet) followed by an otically thin one (transient jet)