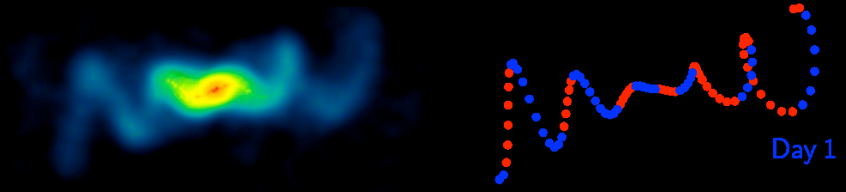
Jet-launch in SS433: before, during & after a major flare

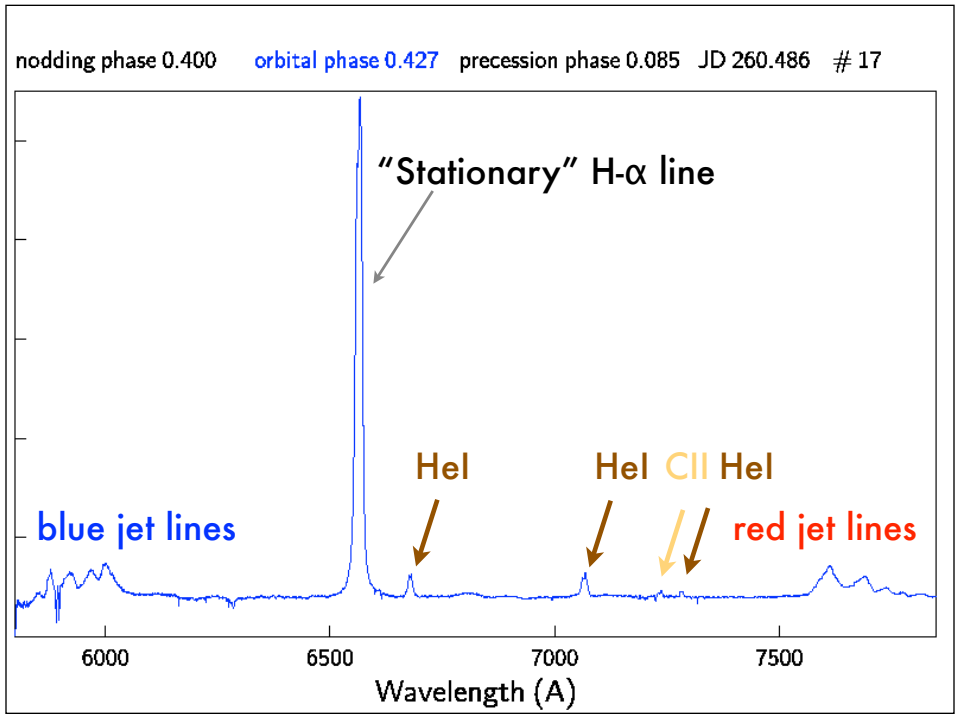


Katherine Blundell

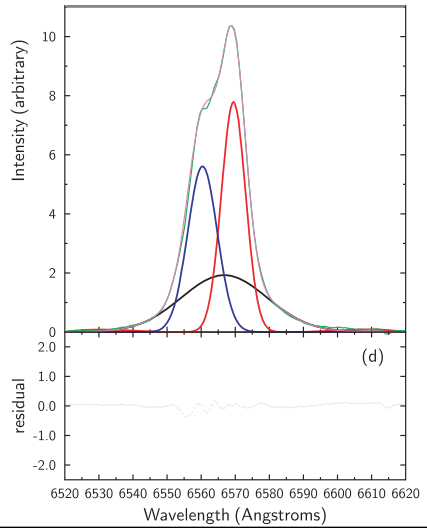
UNIVERSITY OF
OXFORD

In quiessence (long before a flare) there are *thr*ee modes of mass-loss

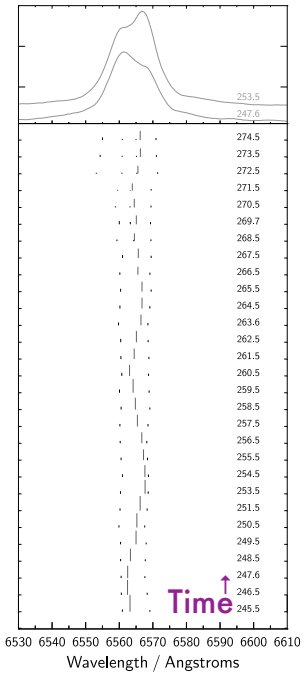
1. The famous jets (precessing & nodding)
2. Accretion disc wind (poloidal)
3. Circumbinary disc wind ("sideways")


nodding phase 0.400
orbital phase 0.427
precession phase 0.085
JD 260.486
17
"Stationary" H-α line
HeI
HeI
CII
HeI
blue jet lines
red jet lines
6000
6500
7000
7500
Wavelength (A)

During quiescence "stationary Hα" line fitted by 3 gaussians



The wind speed also seems to show a 6.5-day periodicity with the same phase as the nodding - this, together with the dependence on precession phase, closely associates it with the accretion disc.

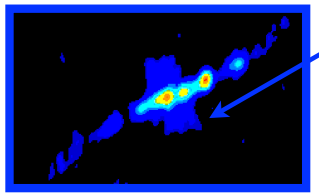


- During quiescence "stationary Hα" line fitted by 3 gaussians
- Ideagram encodes positions & FWHM
- One fat gaussian: the *accretion disc wind*
  - position moves with ~orbital period
  - speed changes with precession phase
  - speed knows about 6.5-day nodding

Blundell, Bowler & Schmidtobreick 2007↑ & 2008↓

- Two (really) stationary lines: *circumbinary disc*
  - stationary in wavelength
  - intensity varies with orbital period
  - matter orbiting at 200 km/s
  - implies 40 solar masses enclosed
  - seen in direct imaging...

The wind speed also seems to show a 6.5-day periodicity with the same phase as the nodding – this, together with the dependence on precession phase, closely associates it with the accretion disc.

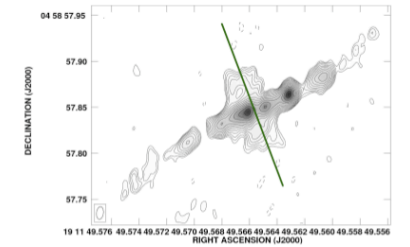


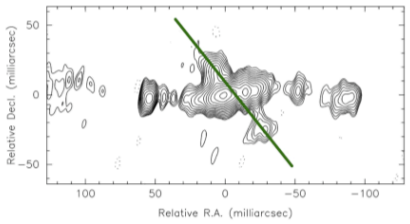
Blundell, Mioduszewski, Muxlow, Podsiadlowski, Rupen 2001

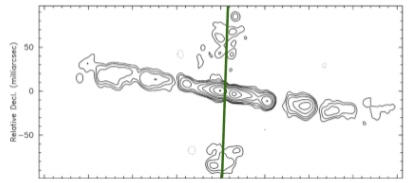
VLBA image of SS433

ruff

Mass-loss from the circumbinary disc feeds the ruff

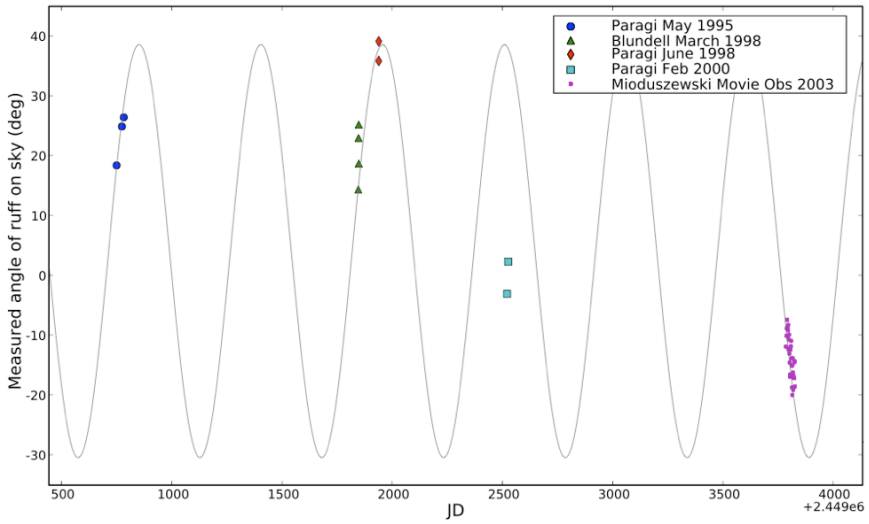






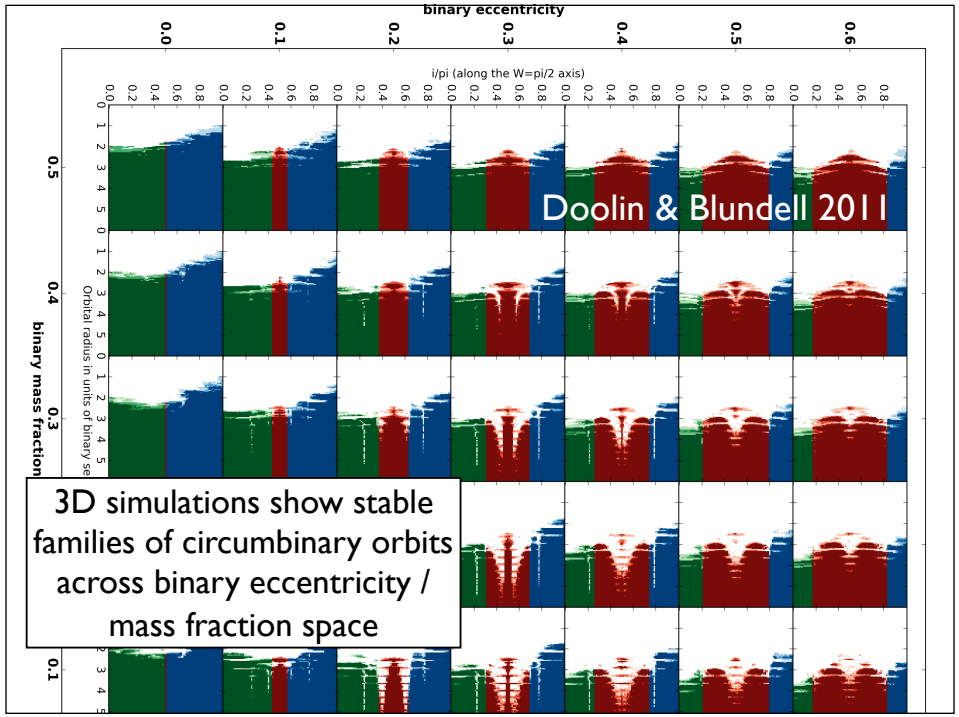
The orientation of the ruff axis changes with time

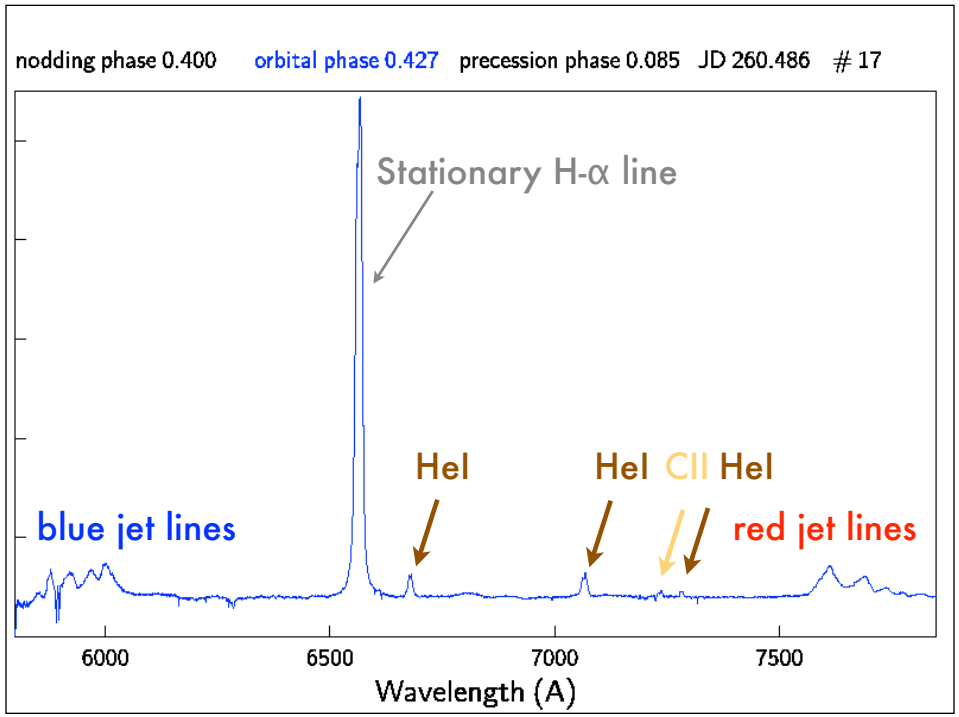
Doolin & Blundell 2009



Apparent periodicity of ~550 days (42 orbital periods)

Doolin & Blundell 2009


binary eccentricity
0.0
0.1
0.2
0.3
0.4
0.5
0.6
i/pi (along the W=pi/2 axis)
binary mass fraction
0.5
0.4
0.3
0.1
Orbital radius in units of binary se
Doolin & Blundell 2011
3D simulations show stable families of circumbinary orbits across binary eccentricity / mass fraction space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Stationary H-α line
HeI
HeI CII HeI
blue jet lines
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6000
6500
7000
7500
Wavelength (A)

Blundell & Bowler 2005

$$z_{\pm} = -1 + \gamma[1 \pm \beta \sin\theta \sin i \cos\phi \pm \beta \cos\theta \cos i]$$

"the kinematic model"

Blundell & Bowler 2005

$$
\begin{aligned}
z_{\pm} &= -1 + \gamma[1 \pm \beta \sin\theta \sin i \cos\phi \pm \beta \cos\theta \cos i] \\
z_{+} &= -1 + \gamma[1 + \beta \sin\theta \sin i \cos\phi + \beta \cos\theta \cos i] \\
z_{-} &= -1 + \gamma[1 - \beta \sin\theta \sin i \cos\phi - \beta \cos\theta \cos i]
\end{aligned}
$$

Blundell & Bowler 2005

$$
\begin{aligned}
z_{\pm} &= -1 + \gamma[1 \pm \beta \sin\theta \sin i \cos\phi \pm \beta \cos\theta \cos i] \\
z_{+} &= -1 + \gamma[1 + \beta \sin\theta \sin i \cos\phi + \beta \cos\theta \cos i] \\
z_{-} &= -1 + \gamma[1 - \beta \sin\theta \sin i \cos\phi - \beta \cos\theta \cos i] \\
z_{+} + z_{-} &= -2 + 2\gamma
\end{aligned}
$$

Blundell & Bowler 2005

$$
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z_{-} &= -1 + \gamma[1 - \beta \sin\theta \sin i \cos\phi - \beta \cos\theta \cos i] \\
z_{+} + z_{-} &= -2 + 2\gamma \\
\beta &= \left[1 - \left[1 + \frac{z_{+} + z_{-}}{2}\right]^{-2}\right]^{1/2}
\end{aligned}
$$

The sum of the two redshifts tells us the jet speed,
if the jets are symmetric

Blundell & Bowler 2005

$$z_{\pm} = -1 + \gamma[1 \pm \beta \sin\theta \sin i \cos\phi \pm \beta \cos\theta \cos i]$$

Blundell & Bowler 2005

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Blundell & Bowler 2005

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z_{-} &= -1 + \gamma[1 - \beta \sin\theta \sin i \cos\phi - \beta \cos\theta \cos i] \\
z_{+} - z_{-} &= 2\gamma[\beta \sin\theta \sin i \cos\phi + \beta \cos\theta \cos i]
\end{aligned}
$$

Blundell & Bowler 2005

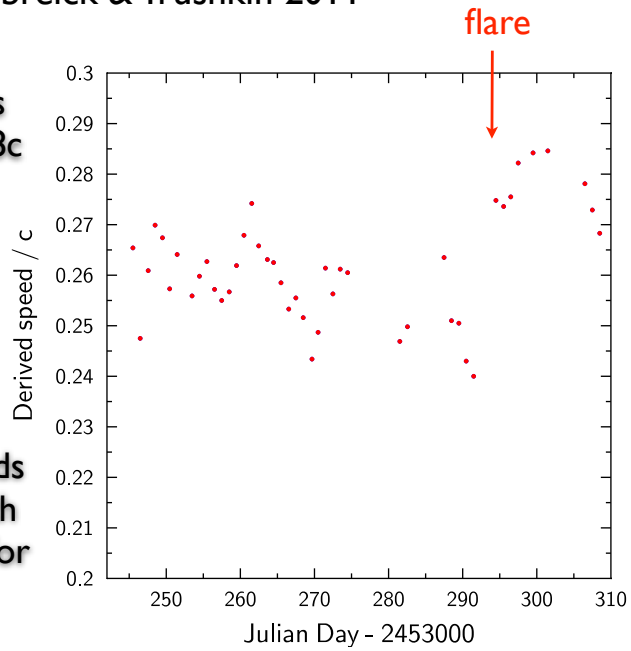
$$
\begin{aligned}
z_{\pm} &= -1 + \gamma[1 \pm \beta \sin\theta \sin i \cos\phi \pm \beta \cos\theta \cos i] \\
z_{+} &= -1 + \gamma[1 + \beta \sin\theta \sin i \cos\phi + \beta \cos\theta \cos i] \\
z_{-} &= -1 + \gamma[1 - \beta \sin\theta \sin i \cos\phi - \beta \cos\theta \cos i] \\
z_{+} - z_{-} &= 2\gamma[\beta \sin\theta \sin i \cos\phi + \beta \cos\theta \cos i] \\
\frac{z_{+} - z_{-}}{2\beta\gamma} &= \sin\theta \sin i \cos\phi + \cos\theta \cos i
\end{aligned}
$$

The difference of the two redshifts tells us about the angle of the jet axis,
if the jets are symmetric

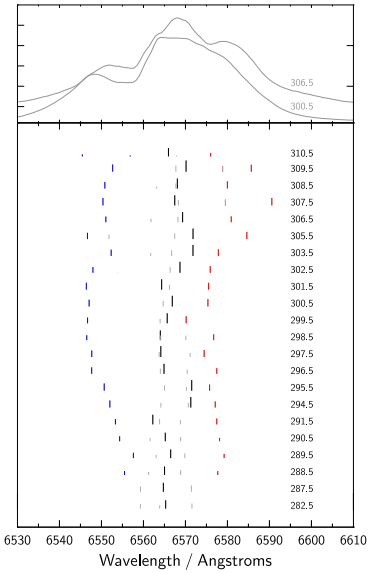
Blundell, Schmidtobreick & Trushkin 2011

Jet speed increases from 0.24c to ~0.28c

Enhanced jet speeds are associated with *all* flares in SS433 for which data exist

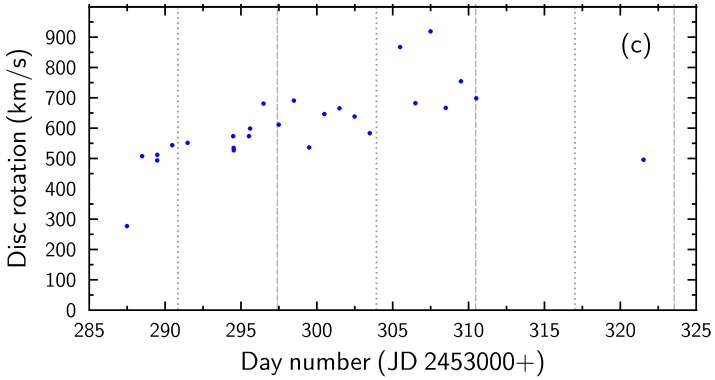


Blundell, Schmidtobreick & Trushkin 2011



- After an extended period of quiescence, SS433 exhibits a flare
- "Stationary" H-α line now fitted by 5 gaussians
- Two widely separated lines appear, that veer to the blue: spiralling-in material within the accretion disc?

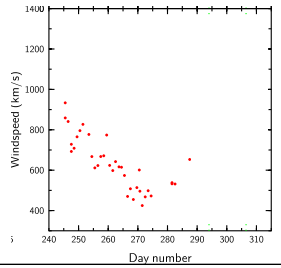
Blundell, Schmidtobreick & Trushkin 2011



Accretion disc speed from H-α increases
from 500 km/s to 700 km/s
before and during onset of flare

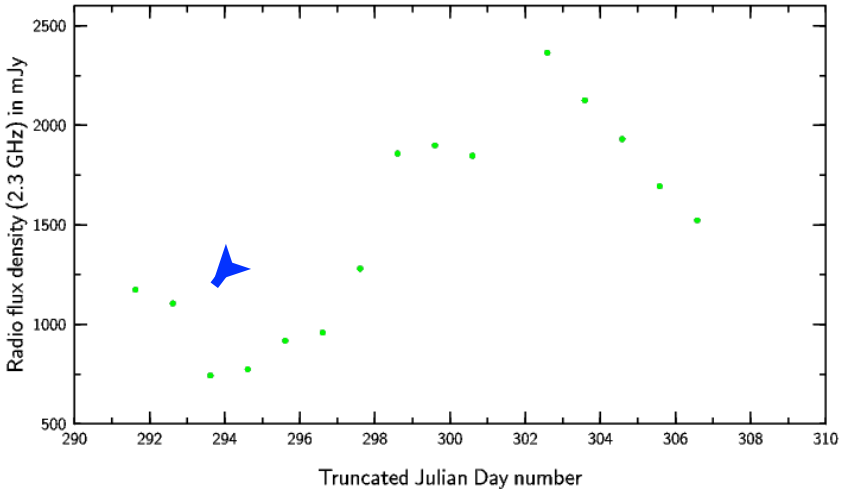
Blundell, Schmidtobreick & Trushkin 2011

Dependence of wind speed on precession phase

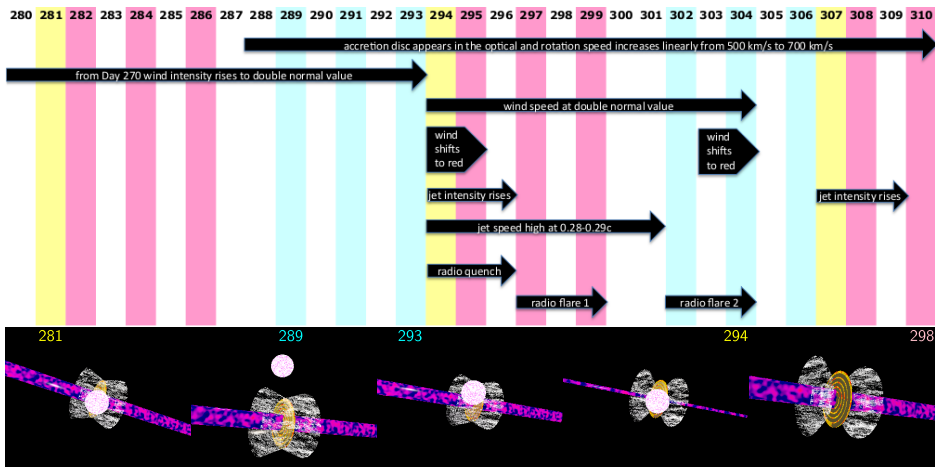


And a leap in the intensity of the wind just before the speed increase...

The start of a massive radio flare

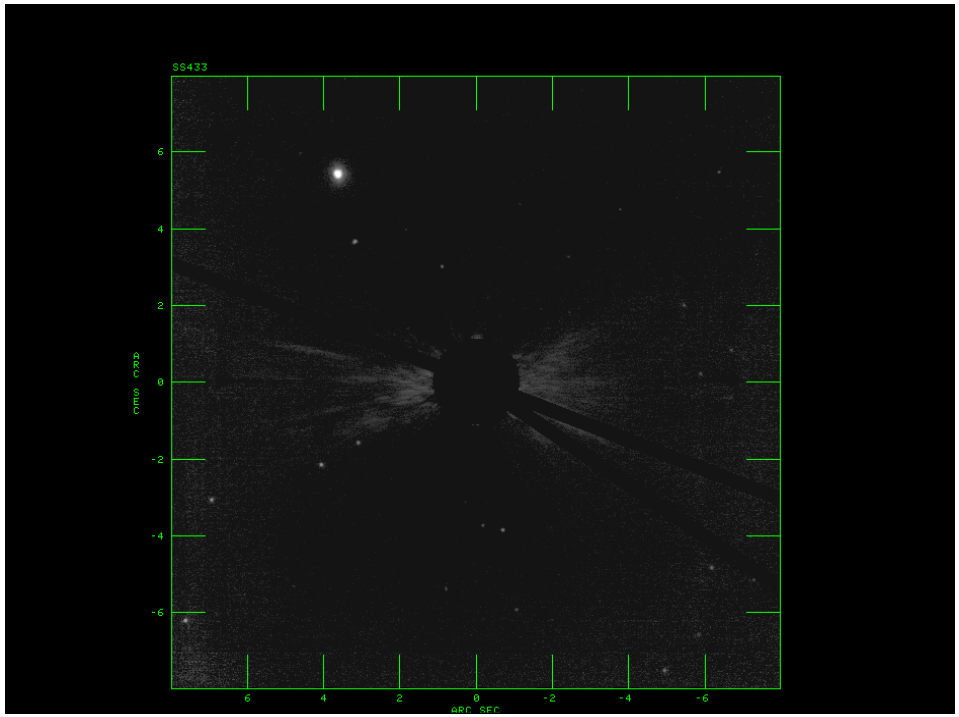


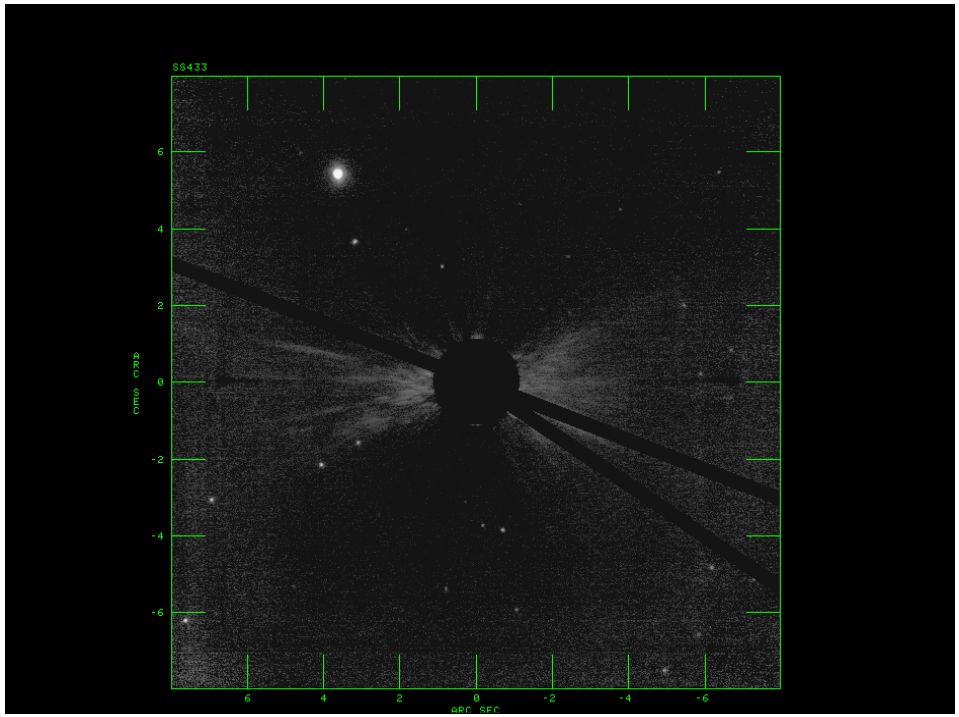
Blundell, Schmidtobreick & Trushkin, MNRAS 2011

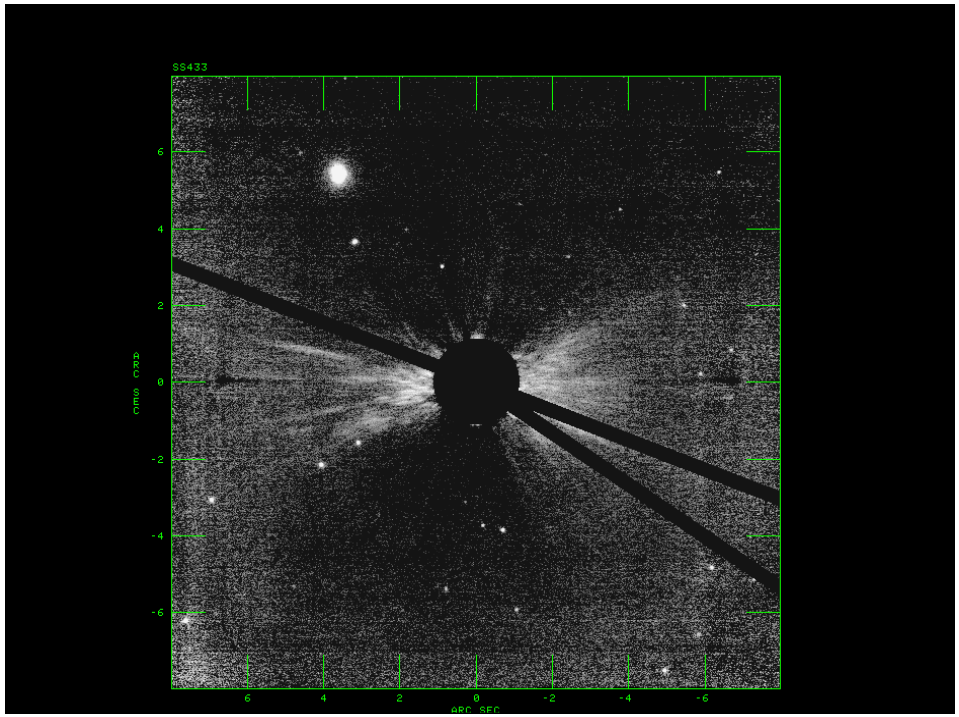


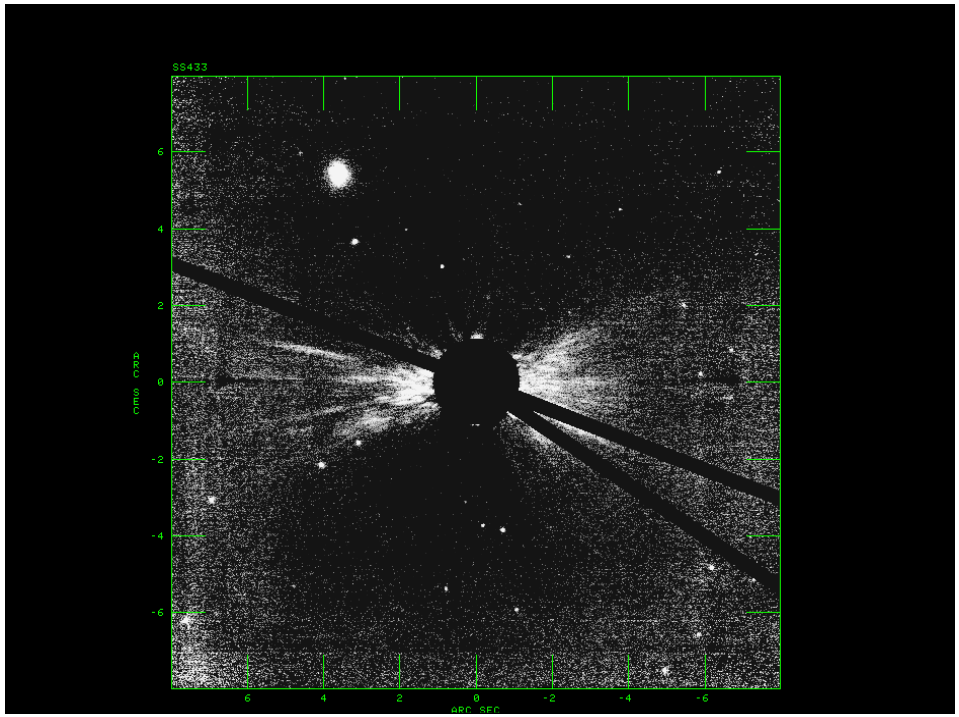
Blundell, Schmidtobreick & Trushkin, MNRAS 2011

10 months later...

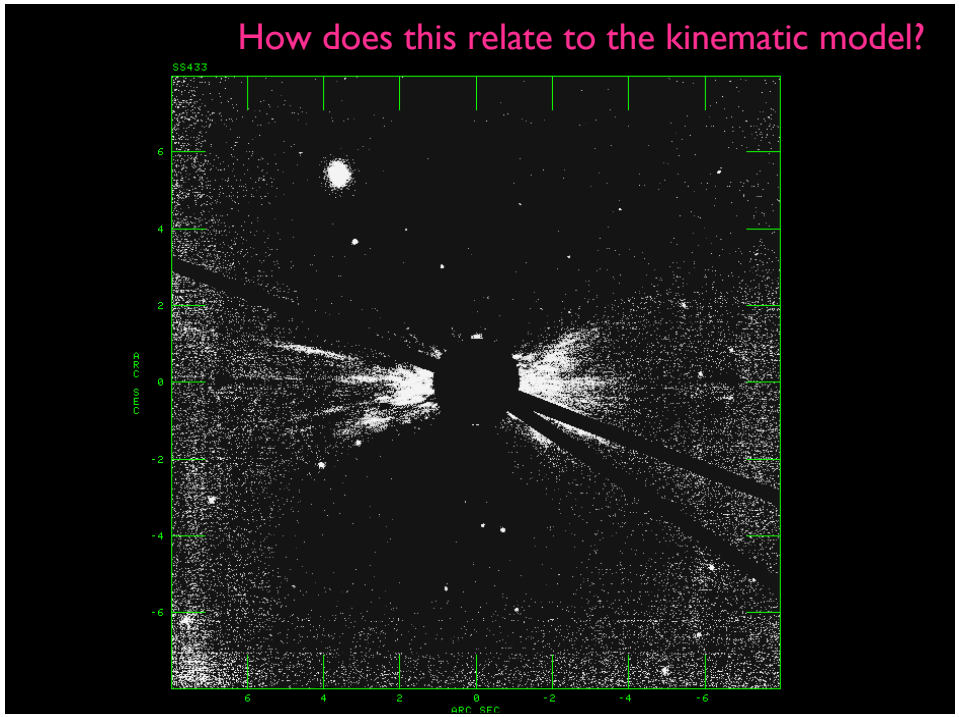

SS433
6
4
2
0
-2
-4
-6
DECL (B1950)
6
4
2
0
-2
-4
-6
ARC SEC

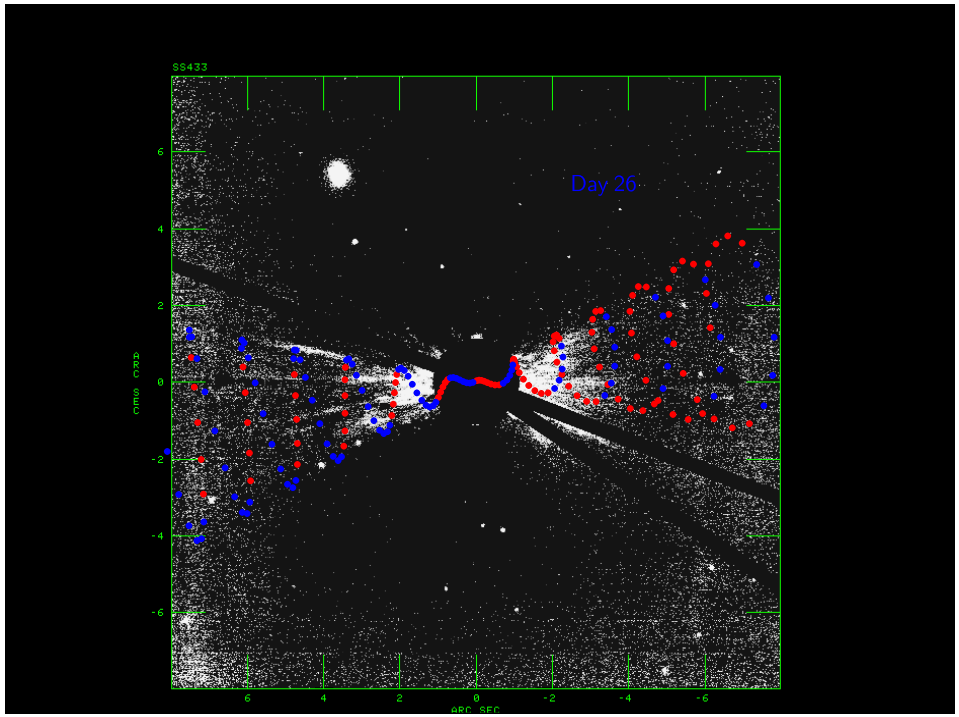

SS433
6
4
2
0
-2
-4
-6
DECL OFFSET
6
4
2
0
-2
-4
-6
ARC SEC

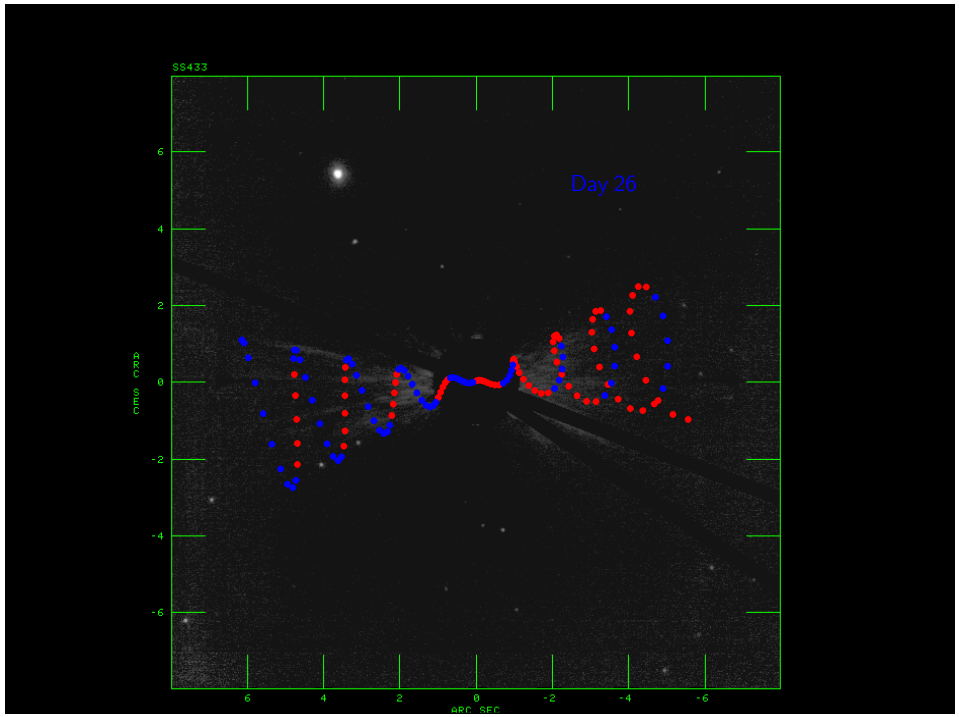

SS433
6
4
2
0
-2
-4
-6
DECL ARCSEC
6
4
2
0
-2
-4
-6
ARC SEC

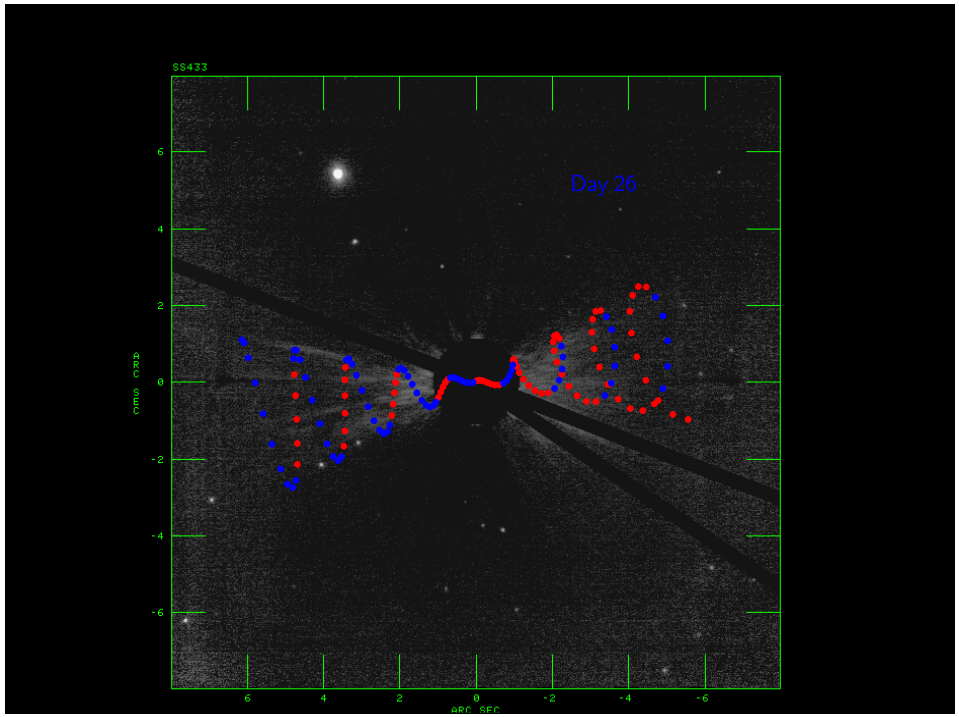

SS433
6
4
2
0
-2
-4
-6
DECL (B1950)
6
4
2
0
-2
-4
-6
ARC SEC

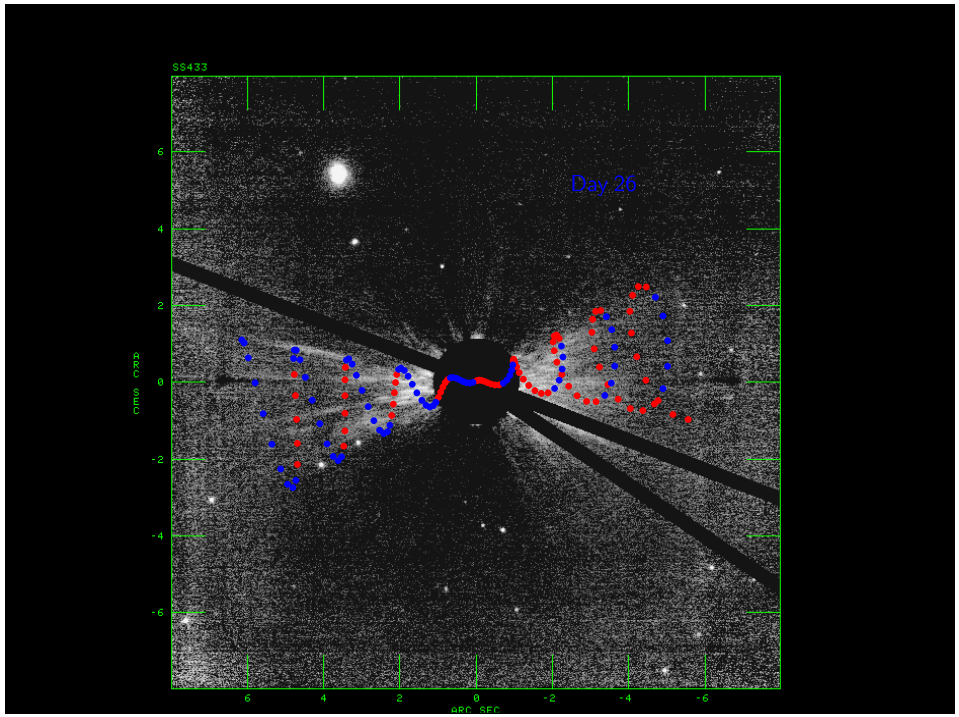
How does this relate to the kinematic model?

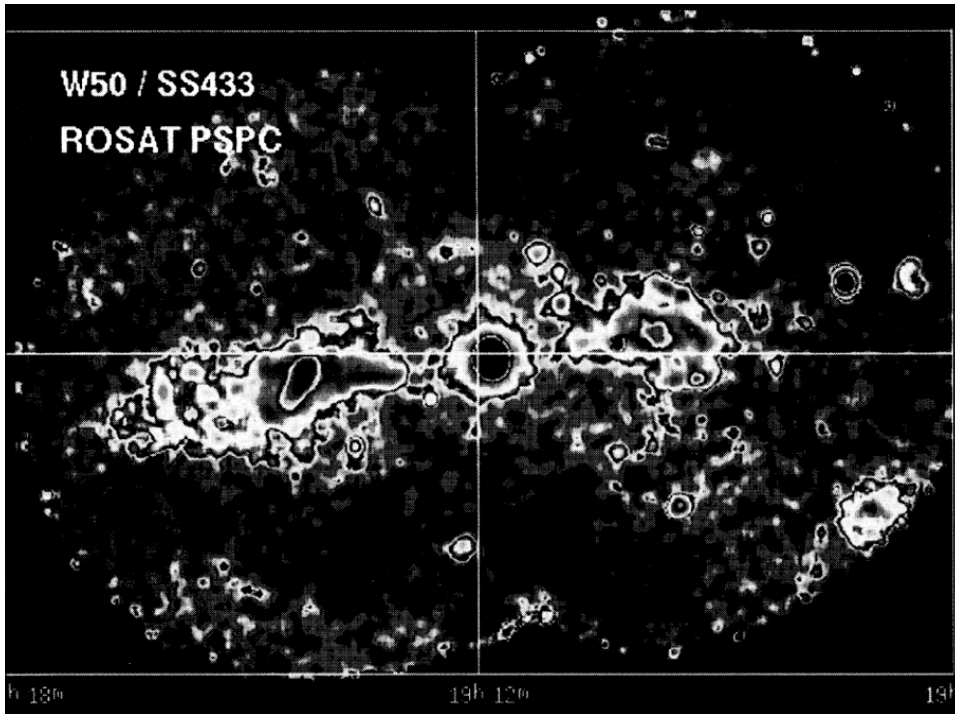


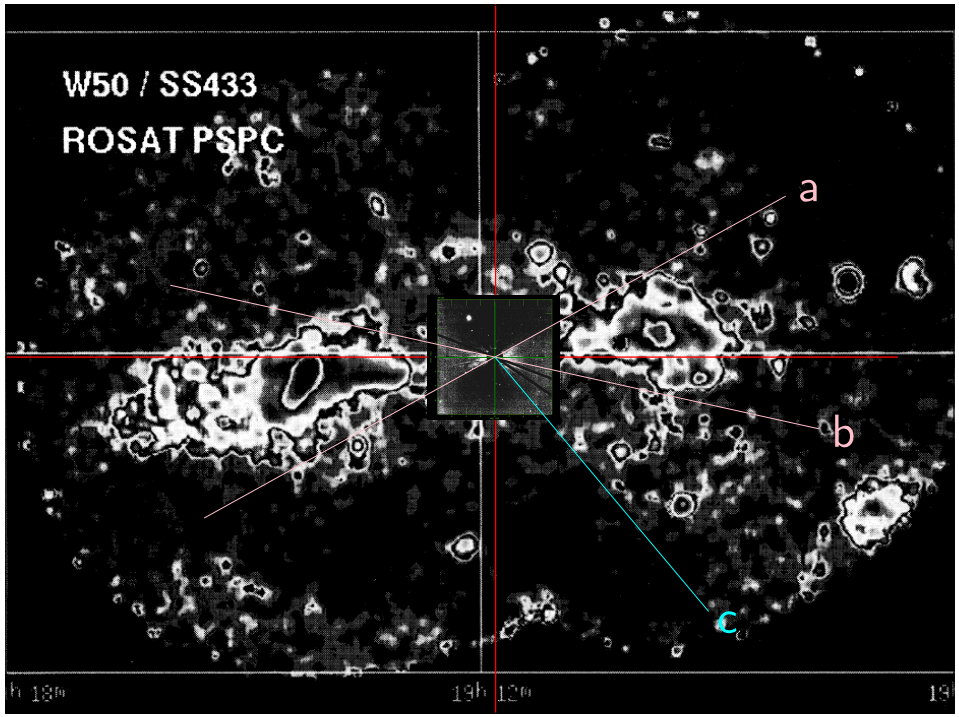

SS433
Day 26
6
4
2
0
-2
-4
-6
6
4
2
0
-2
-4
-6

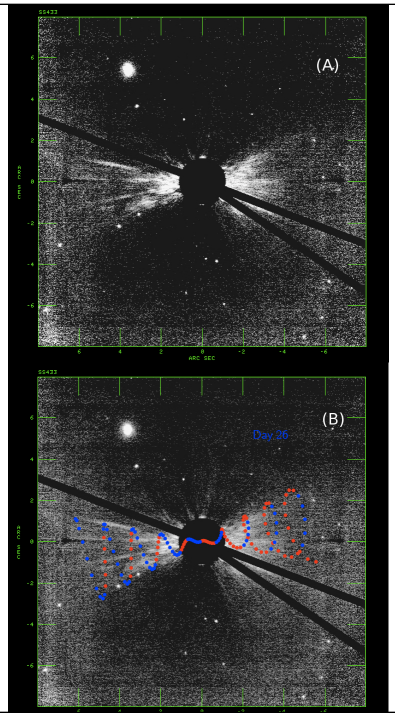

SS433
Day 26
6
4
2
0
-2
-4
-6
DECLINATION
6
4
2
0
-2
-4
-6
ARC SEC


SS433
Day 26
6
4
2
0
-2
-4
-6
DECL (ARC SEC)
6
4
2
0
-2
-4
-6
ARC SEC


SS433
Day 26
6
4
2
0
-2
-4
-6
6
4
2
0
-2
-4
-6


W50 / SS433
ROSAT PSPC
h 18m
19h 12m
19


W50 / SS433
ROSAT PSPC
a
b
c
h 18m
19h 12m
19



- Blundell & Hirst 2011 ApJ Lett
- Wind ejecta snow-ploughed out by precessing jet
- Enhanced wind ejected in a major *flare*

Summary

- Three modes of mass-loss in both quiescence and in flaring
- SS433 has a poloidal disc wind (70% of Brγ - Perez & Blundell 2009)
- SS433 has a circumbinary disc that precesses
- Ruff precesses with ~550 day period
- Just before a flare, accretion disc revealed in Hα (500 → 700+ km/s)
- Jets can snow-plough out wind ejecta
- Flare sequence:

  ➡ accretion disc appears in the optical, wind intensity doubles, radio quenches, wind speed doubles, *jets increase in speed and intensity*, 3 days later radio flaring, 10 months later enhanced wind ejecta has been snow-ploughed out