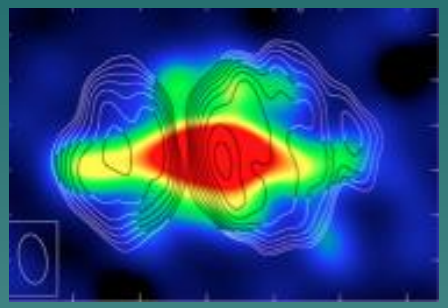
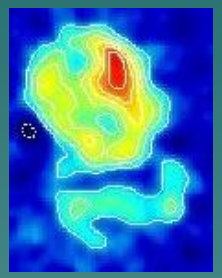
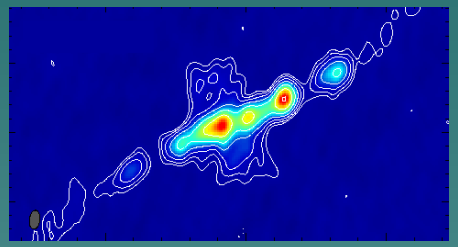
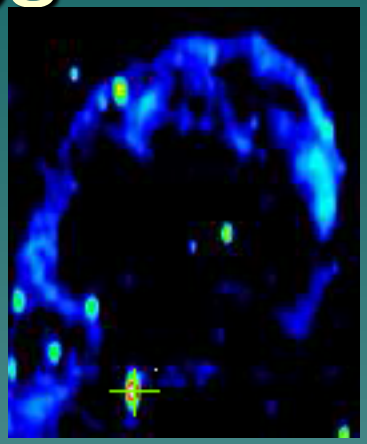
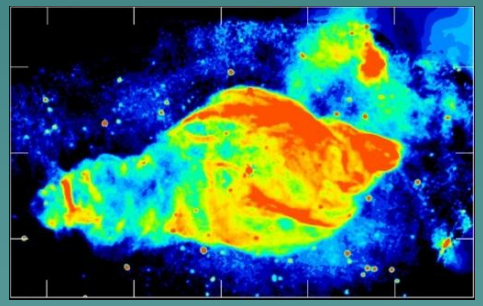
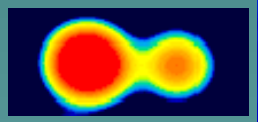
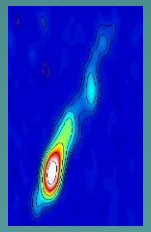
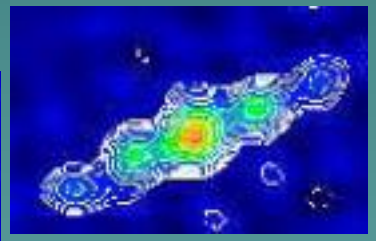
Jets and Outflows in Compact Stellar Binaries

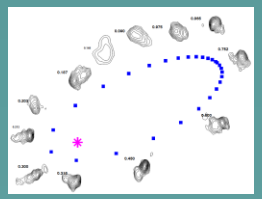


Michael P. Rupen

NRAO/Socorro

5 March 2012



Inspiration and insight from…

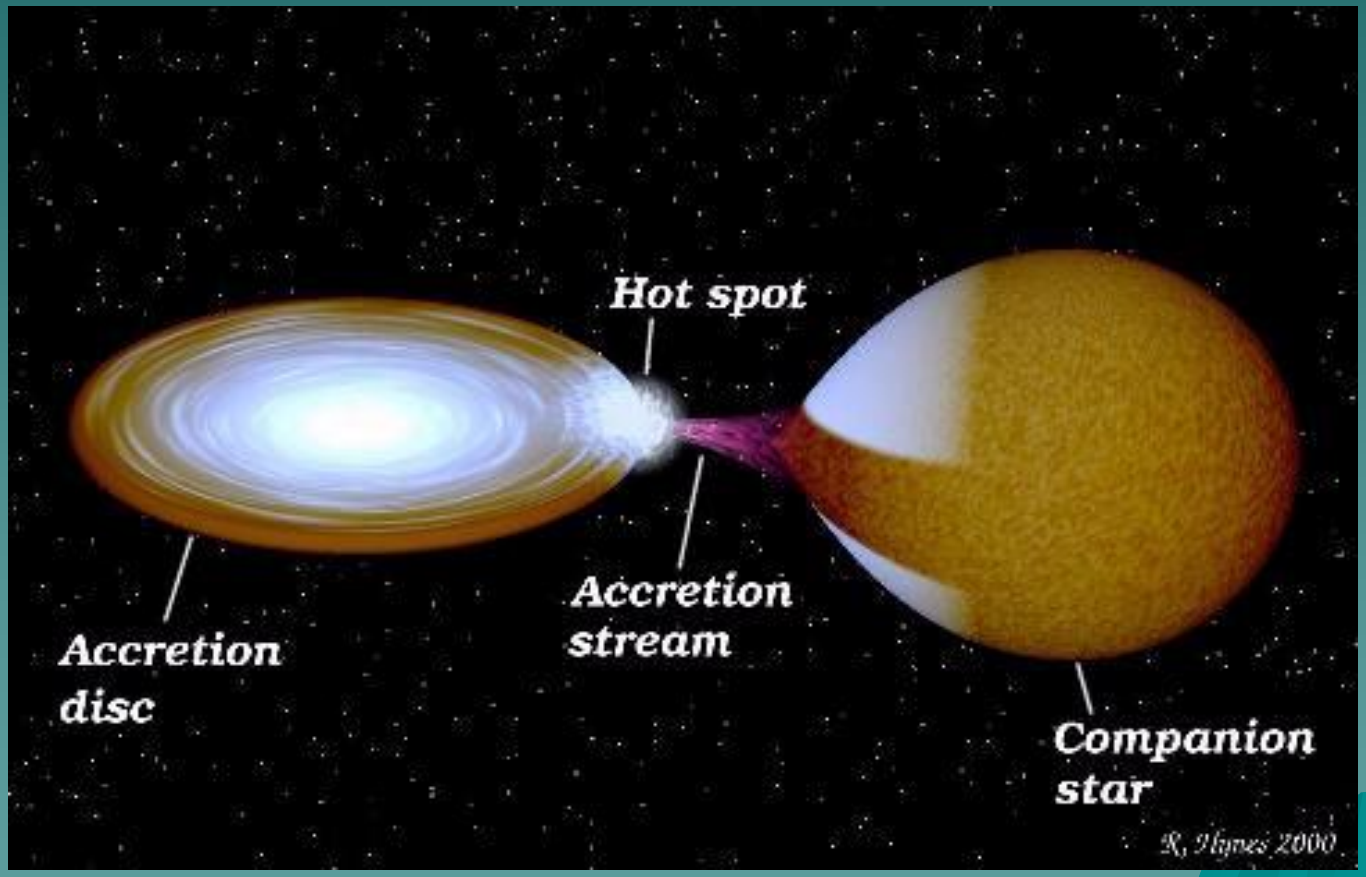
- Amy Mioduszewski & Vivek Dhawan (NRAO)
- James Miller-Jones (Curtin Inst.)
- Elmar Kording (Nijmegen), Christian Knigge (Southampton)
- Jeno Sokoloski (Columbia) & the eNova team (Laura Chomiuk, Miriam Krauss, Traci Johnson, Tommy Nelson, Koji Mukai)
- Jon Miller (Univ. of Michigan)
- Bob Hjellming (NRAO)

…plus many others

Why study accreting stellar binaries?

- Well understood
- Richly varied: statistical samples and fabulous individuals
  - Many repeating sources too
- **Tie accretion to outflow**

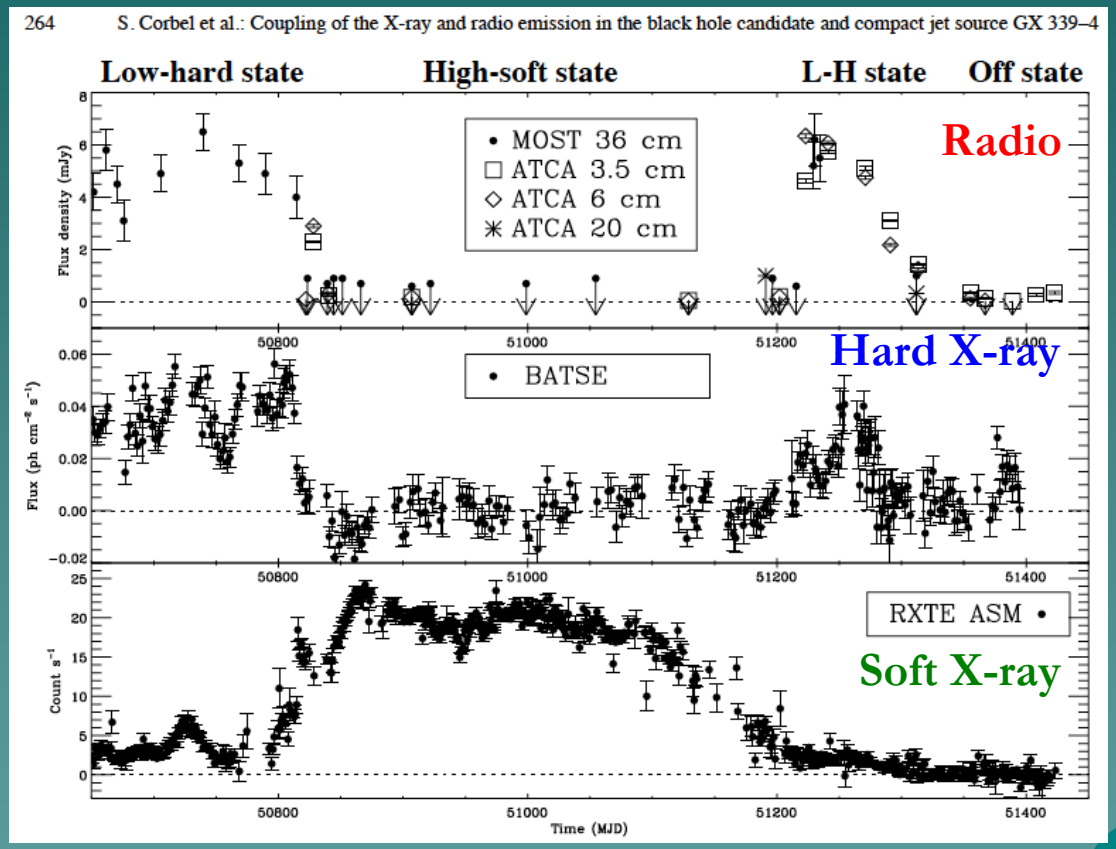
Accreting stellar binaries



BH/NS at low luminosities: small & steady

BH low Lx/Ledd

- High/soft X-ray state: no radio
- Low/hard X-ray state (up to ~2% L_{edd}): steady radio with flat/rising spectrum

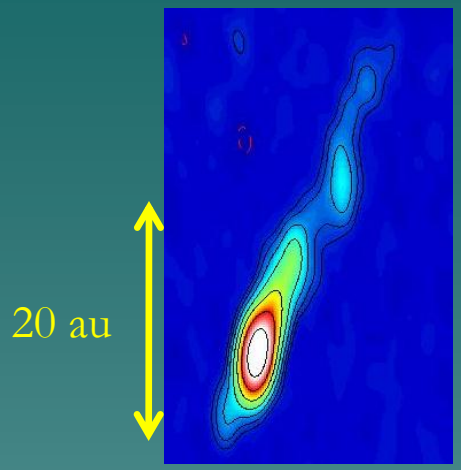


800 days

GX 339-4

BH low Lx/Ledd

- Low/hard state imaging
  - Most are unresolved (e.g., V404 Cyg <1.4au, Miller-Jones et al. 2009)
  - Two are small steady highly collimated jets
  - Symmetry indicates low beta (0.1 for GRS 1915+105)
- Some show low, stable linear pol'n
- Emission is synchrotron



Stirling et al. 2001

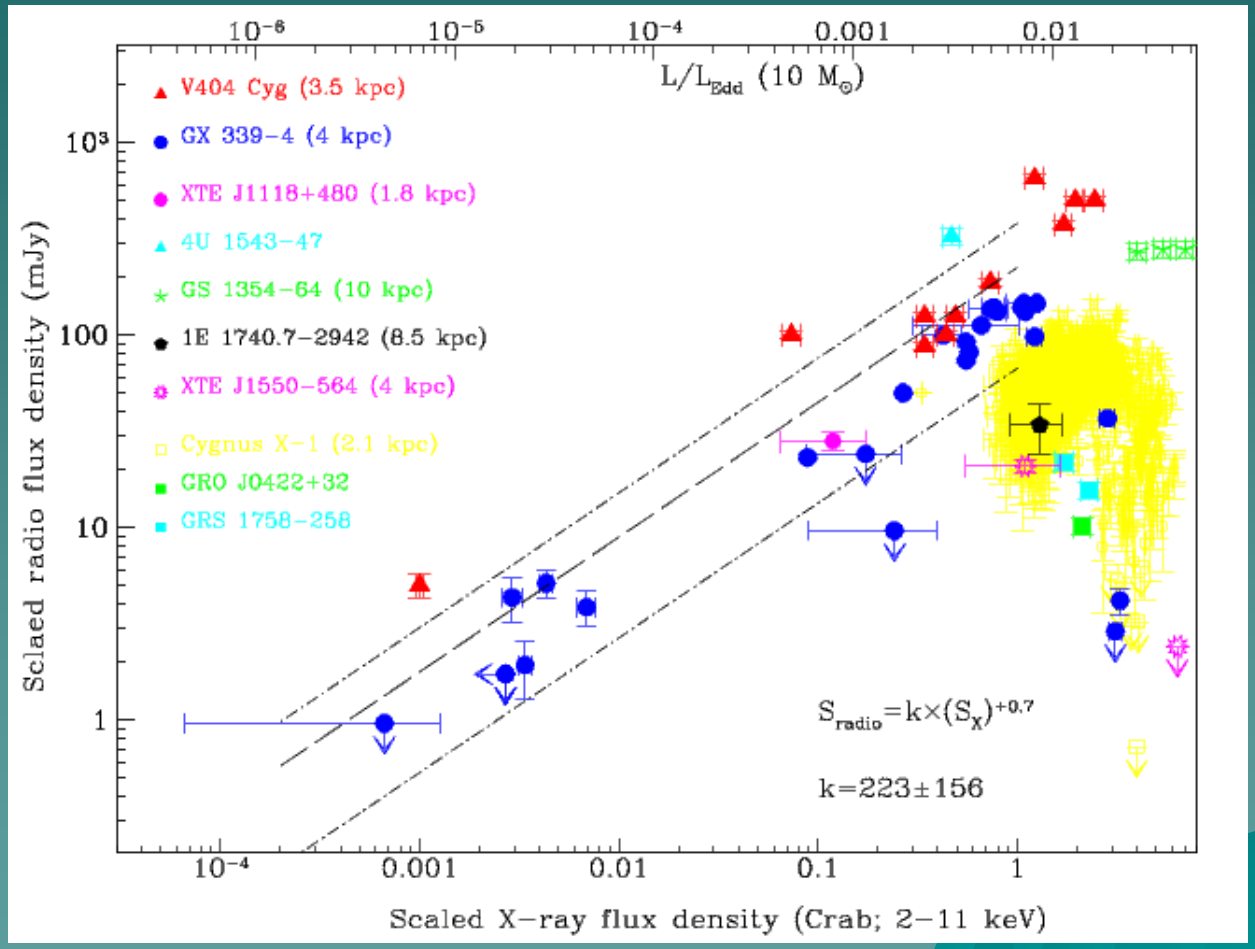
Cyg X-1 @ 1.86 kpc
15 Msun i= 27.1d
(Reid et al. 2011)

Dhawan et al. 2000, ApJ, 543

GRS 1915+105 @ ~9kpc

BH low Lx/Ledd

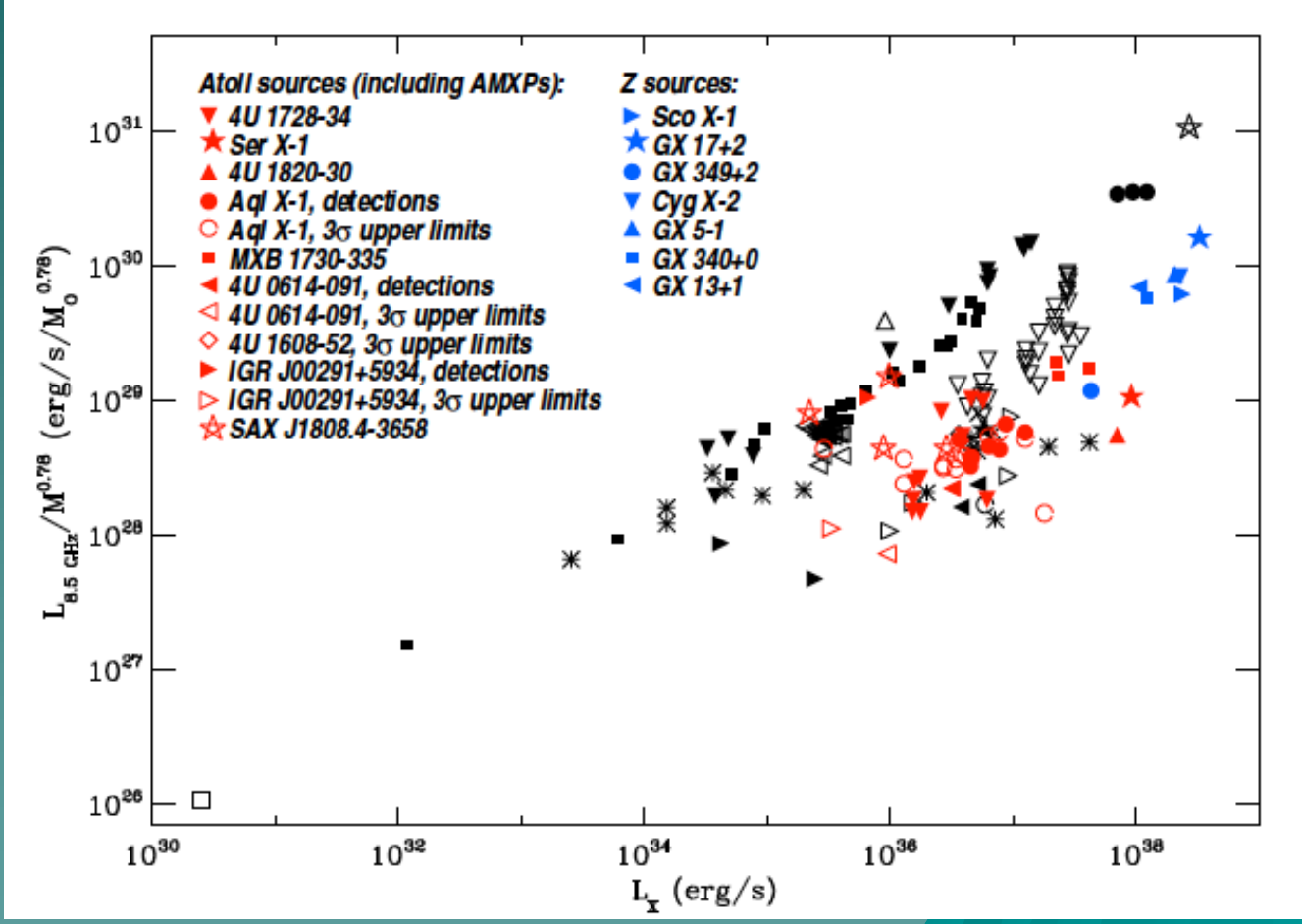
- Radio scales as $F_x^{0.7}$



Gallo, Fender, & Pooley 2003

Neutron star binaries: low Lx/Ledd

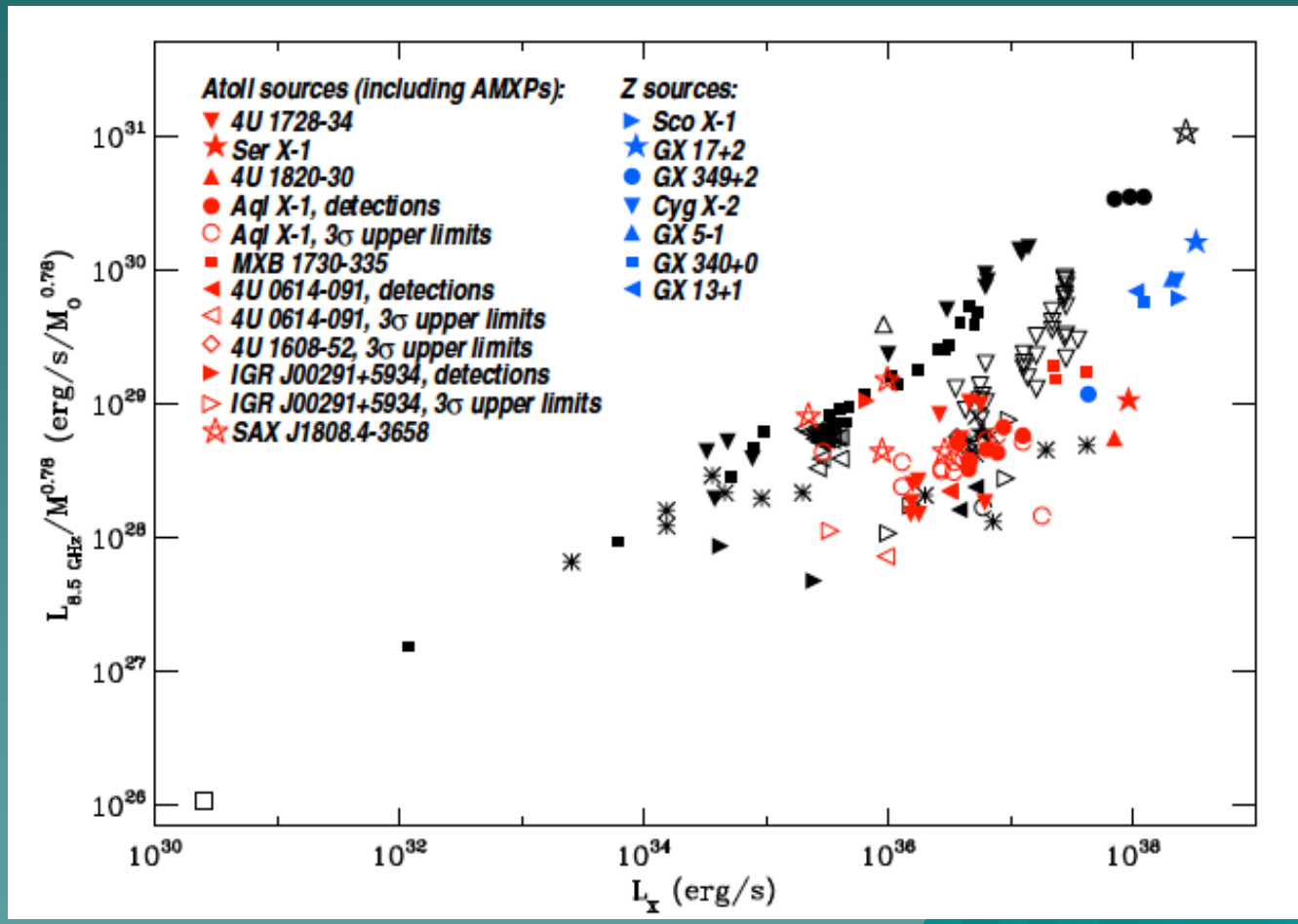
- Only low-B NS XRBs detected (in ANY state)
- Radio x30 fainter at given L_X
  - goes as $L_X^{1.4}$ (Migliari et al. 2004)
- Only x10 fainter in soft state (Migliari et al. 2004)



Soleri & Fender 2011

BH+NS, low Lx/Ledd

- More recent BH are also faint!
- Note A0620-00: 1e-8.5 Ledd (Gallo 2007)

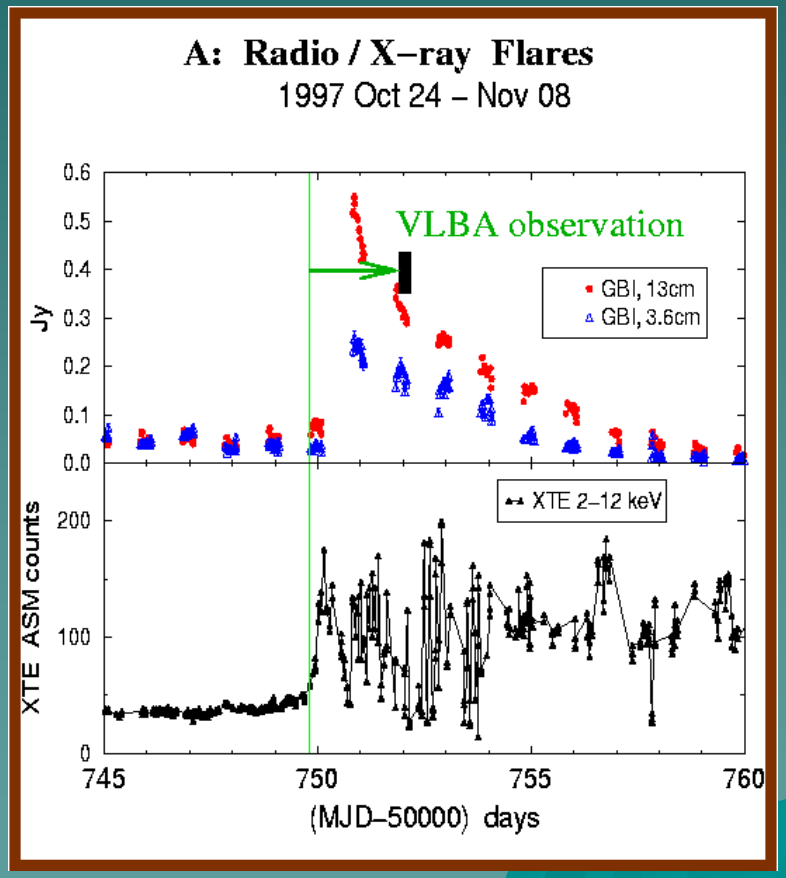


Soleri & Fender 2011

BH/NS hard to soft transtions: fast ejecta

BH state transitions

- Hard-to-soft (X-ray) transitions produce radio flares
  - Optically thin (falling synchrotron spectra)
  - Can be highly polarized

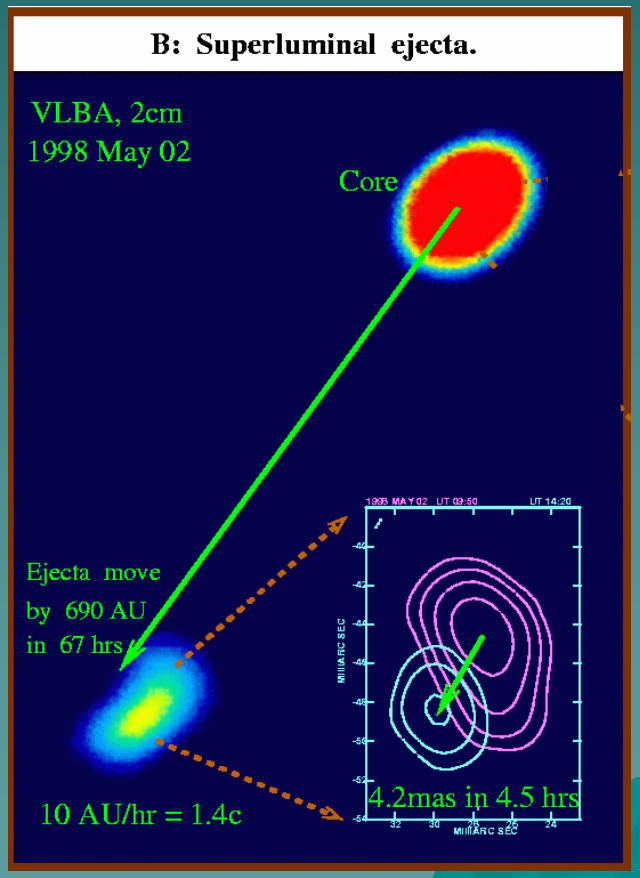


Dhawan et al. 2000, ApJ, 543

GRS 1915+105

BH state transitions

- Imaging (often) shows O(c) (even superluminal) jets
  - n.b. core re-appears in a few days
  - Record is V4641 Sgr: 0.4 arcsec/day at >7.4 kpc (Gamma>10)

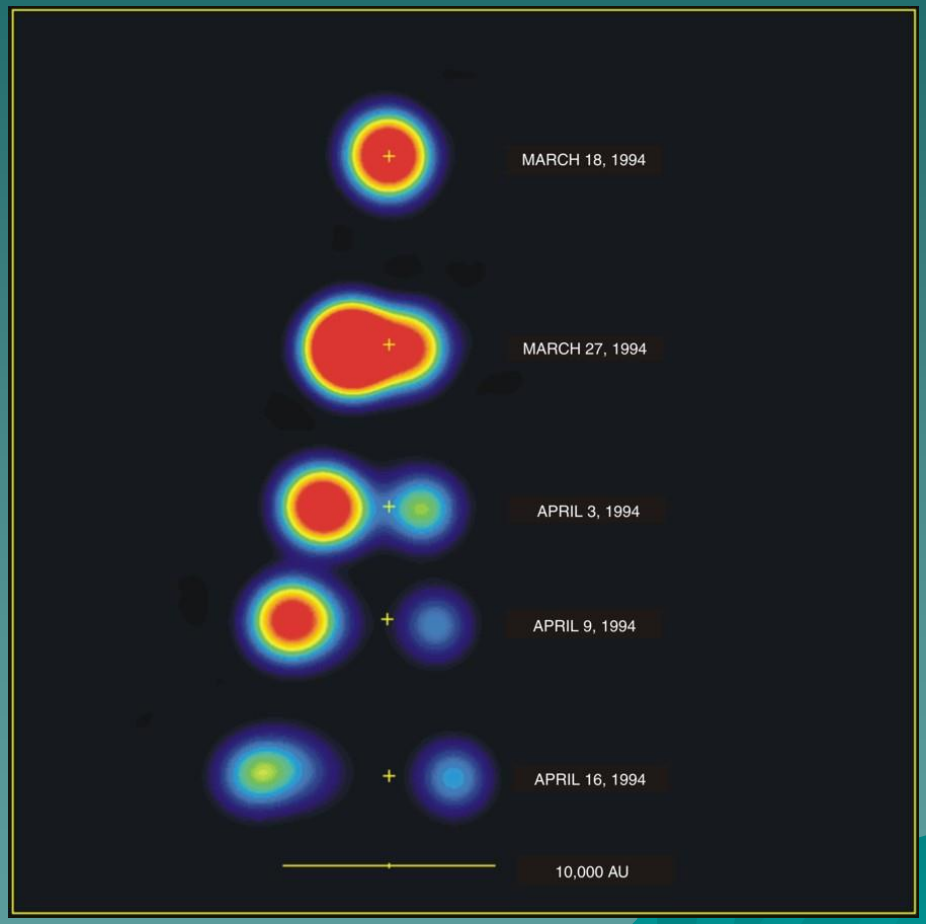


Dhawan et al. 2000, ApJ, 543

GRS 1915+105

BH state transitions

- Some remain bright, with no deceleration
  - GRS 1915+105
  - SS433
  - Cyg X-3 (sometimes)

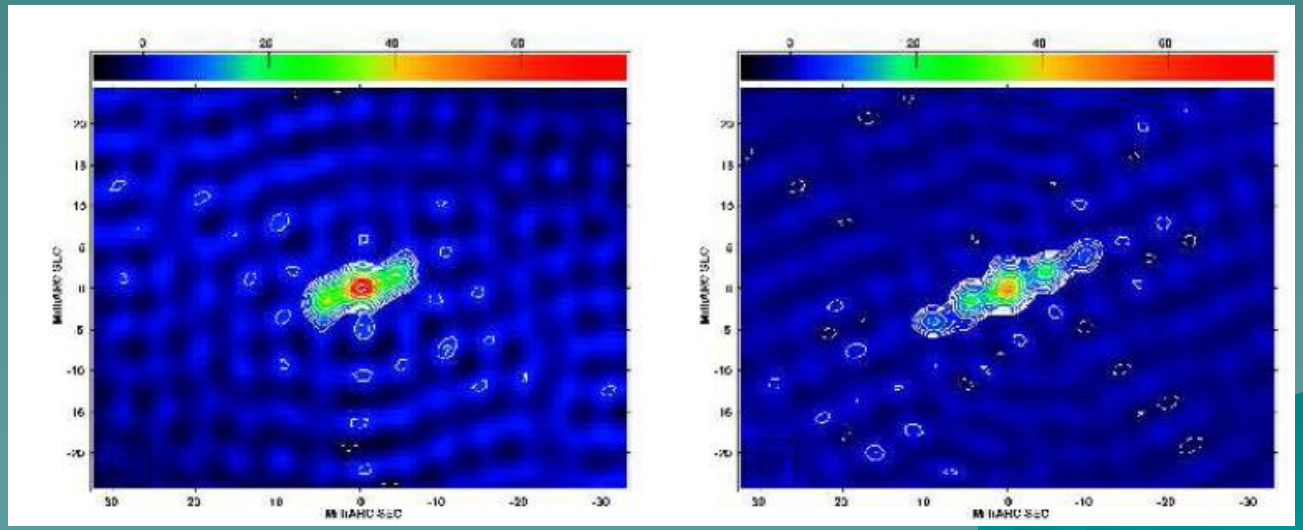


GRS 1915+105

Mirabel & Rodriguez 1995

NS state transitions

- Very few NS XRBs have been imaged, even in outburst
- X-ray/radio light curves seem similar (esp. Z sources, e.g., GX 17+2 Migliari et al.)
- Cir X-1 VLBI: sep'n about 1.6c @ 7.8 kpc

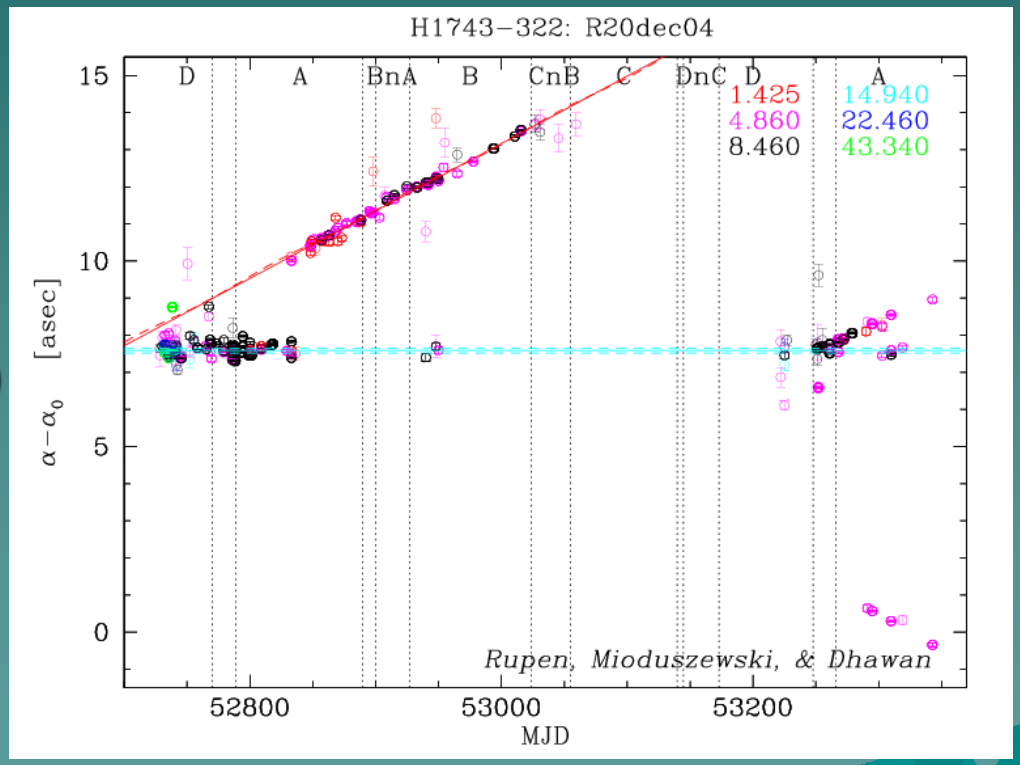


Miller-Jones et al. 2011

Cir X-1

BH state transitions

- Some fade, then **re-appear without decelerating**
  - H1743-322 (with synchrotron X-rays!)
  - Note disappearance of core…

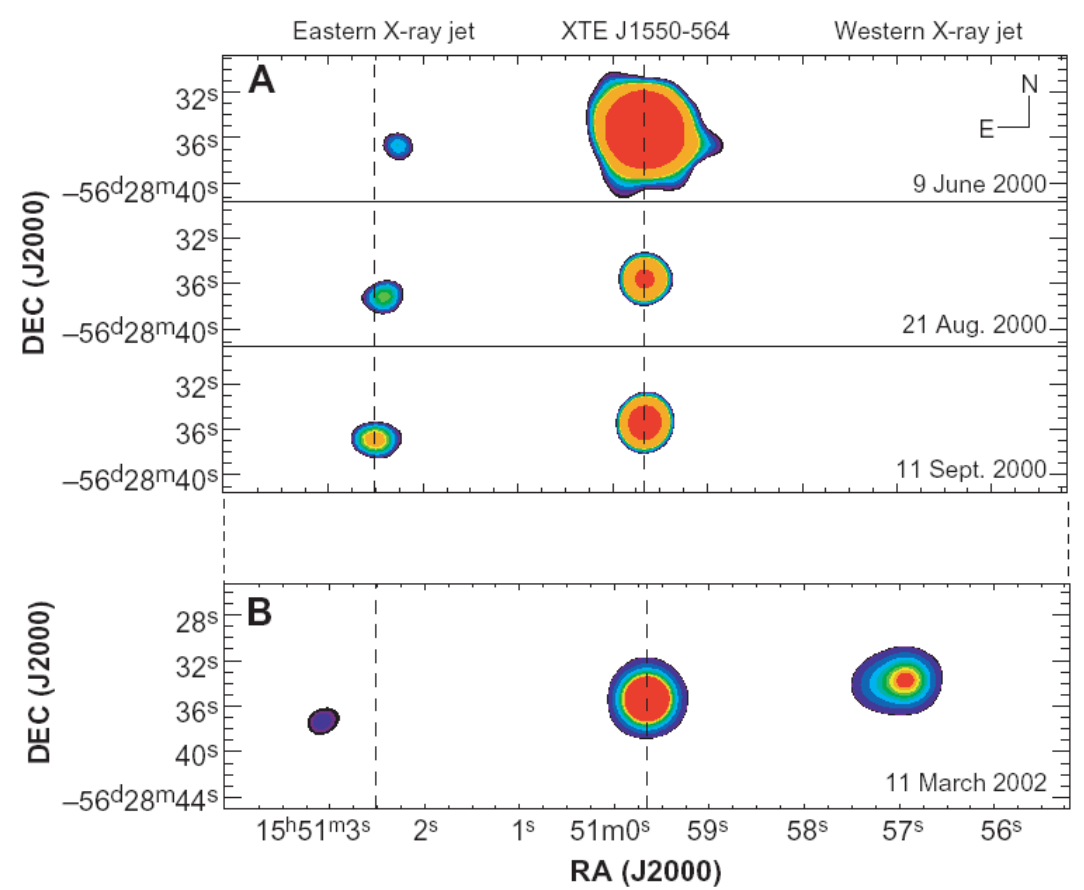


Rupen, Midouszewski, & Dhawan

H1743-322

BH state transitions

- Others fade, then re-appear & decelerate
  - X1550-564 (with synchrotron X-rays!)
  - Initial beta_app~2

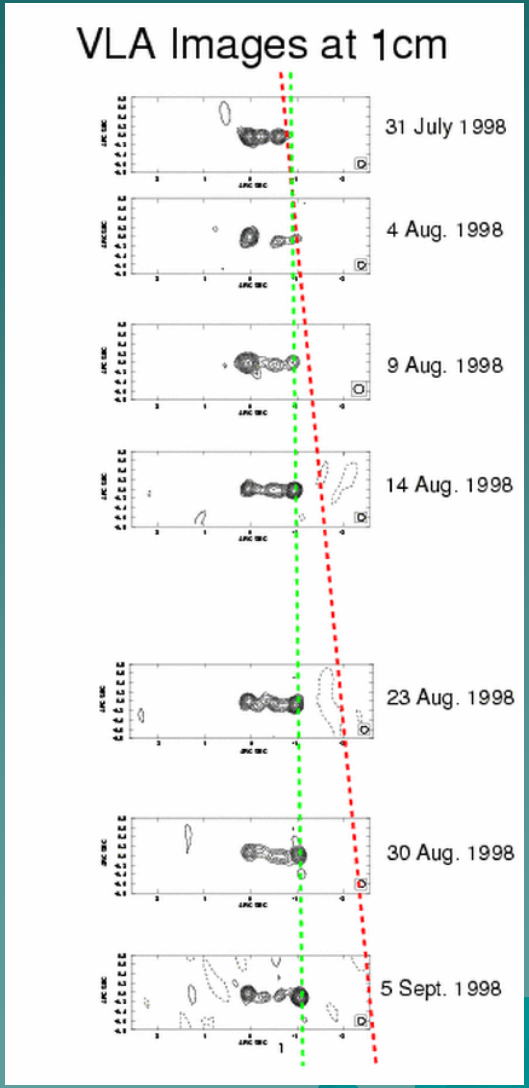


Corbel et al. 2002

X1550-564

BH state transitions

- Some are smothered at birth

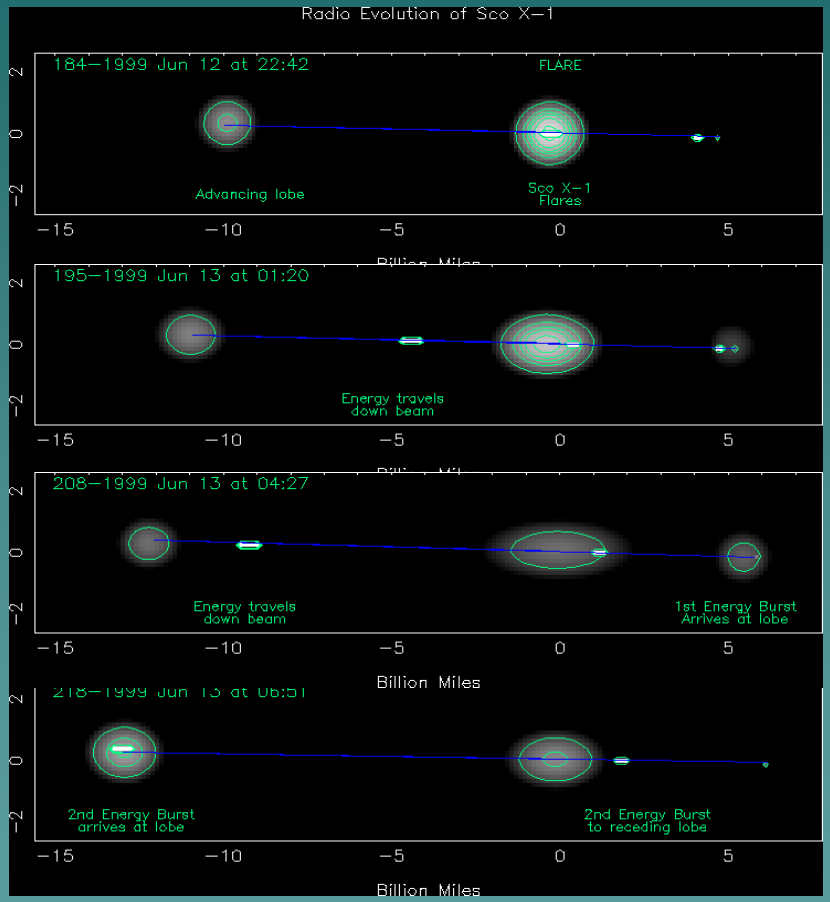


Hjellming & Rupen

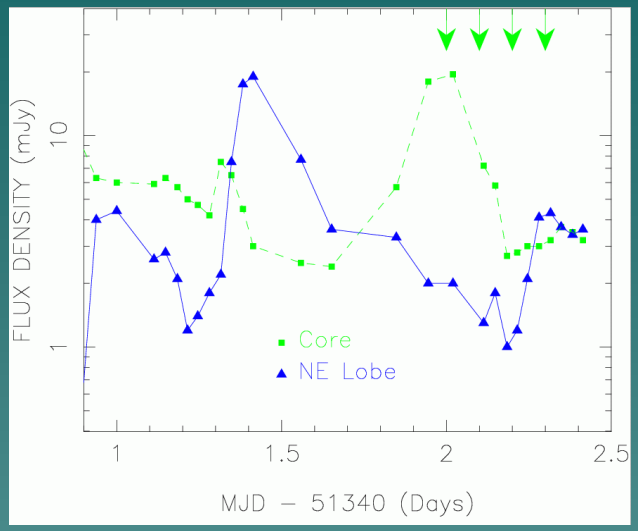
X1748-288

NS state transitions

Fomalont, Geldzahler, & Bradshaw 2001



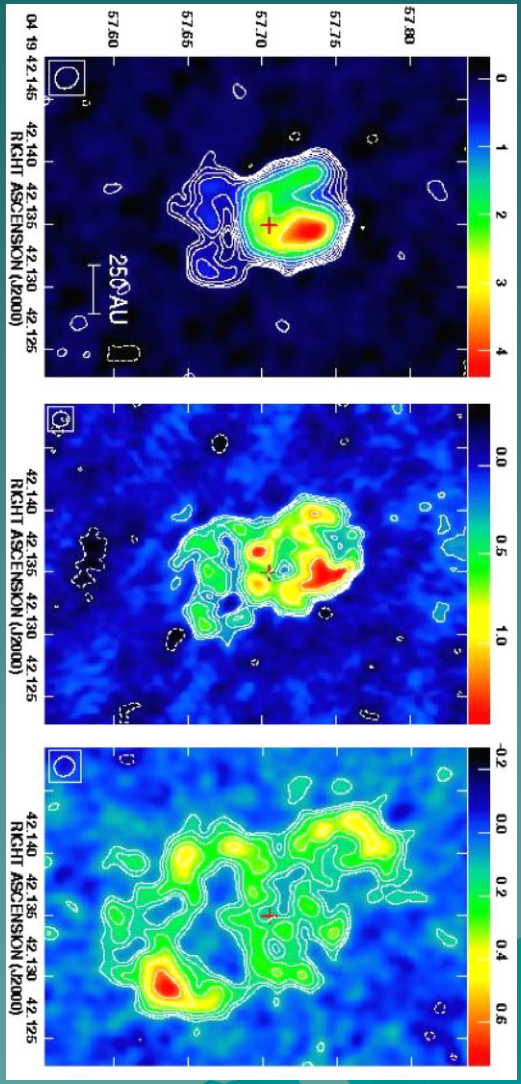
Sco X-1



- β_{blob}~0.3-0.6
- β_{flow}≥0.95
- Also see transverse expansion
- cf. Cir X-1: Γ_{flow}≥21? *(Fender et al. 2003)*

BH state transitions

- CI Cam had **no discernible jet at all**
  - KE of jet was comparable to integrated luminosity of entire outburst

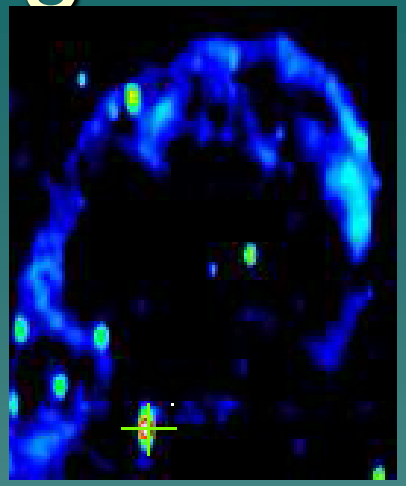


Mioduszewski & Rupen 2004

CI Cam

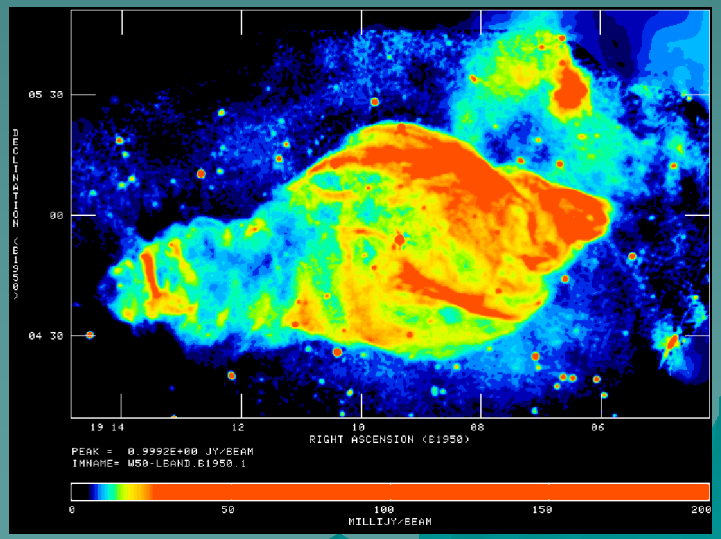
Smothered jets on large scales

- KE of jets is quite significant, of order the total radiated luminosity → quite efficient (>5%)
- Alas, there are examples (cf. Heinz etc.)



Galloet al. 2005

Cyg X-1: 0.7e49 ergs over ~1e5yrs

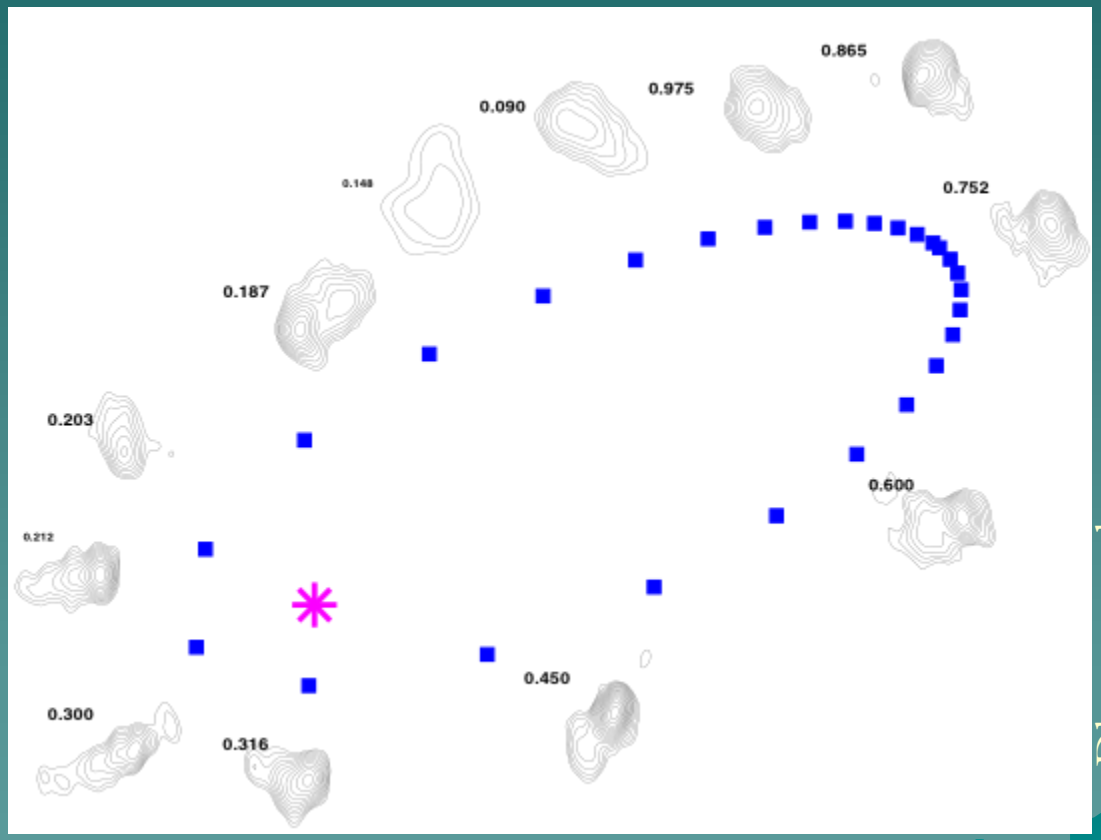


Dubner et al. 1998

W50/SS433: 3e49 ergs episodically over 1e4 yrs (Lockman et al. 2007; Goodall et al. 2011)

Not everything is a jet…

- Smothered pulsar (pulsar wind nebula) – see Paredes later today



Dhawan et al.

LSI +61 303

BH/NS XRBs: spin

- Spin is not obviously important for X-ray binary jets (Fender et al. 2010; Migliari et al. 2011)
  - but spin measurements are controversial for BH XRBs, and observations are especially sparse for NS XRBs

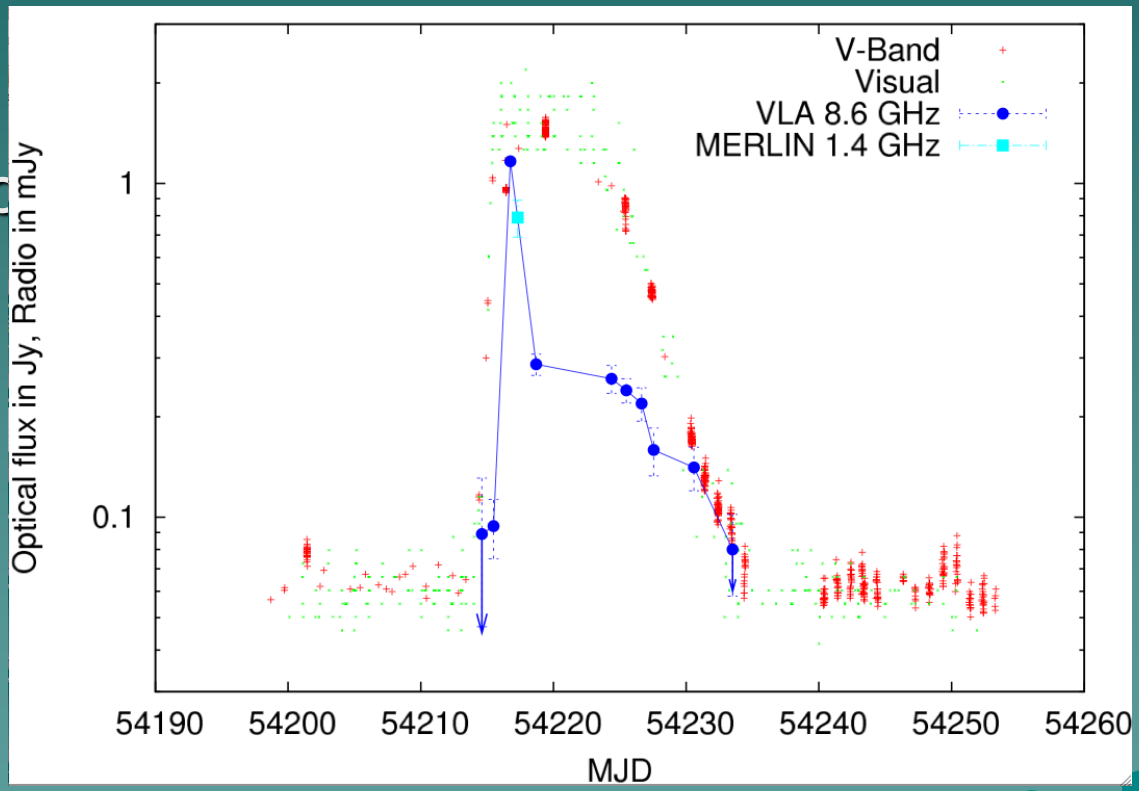
White dwarf binaries

Accreting White Dwarfs

	Cataclysmic Variables (CVs)	Supersoft Sources	Symbiotics
Size	Small	Medium	Large
Mass donor	Dwarf	Evolved	Giant
$\dot{M}$	Low	High	High
L_{WD} (L_{sun})	Few	1e4	1e3
$\dot{M}$ Mech	Stable RL overflow	Unstable RL overflow	Wind
Jets?	YES	YES	YES

Cataclysmic variables: non-magnetic

- SS Cyg
  - Dwarf nova
  - Non-magnetic
  - Nearby (100pc) & bright
- Unresolved with VLBA
- Also detected V3885 Sgr, but not Z Cam (higher Mdot)

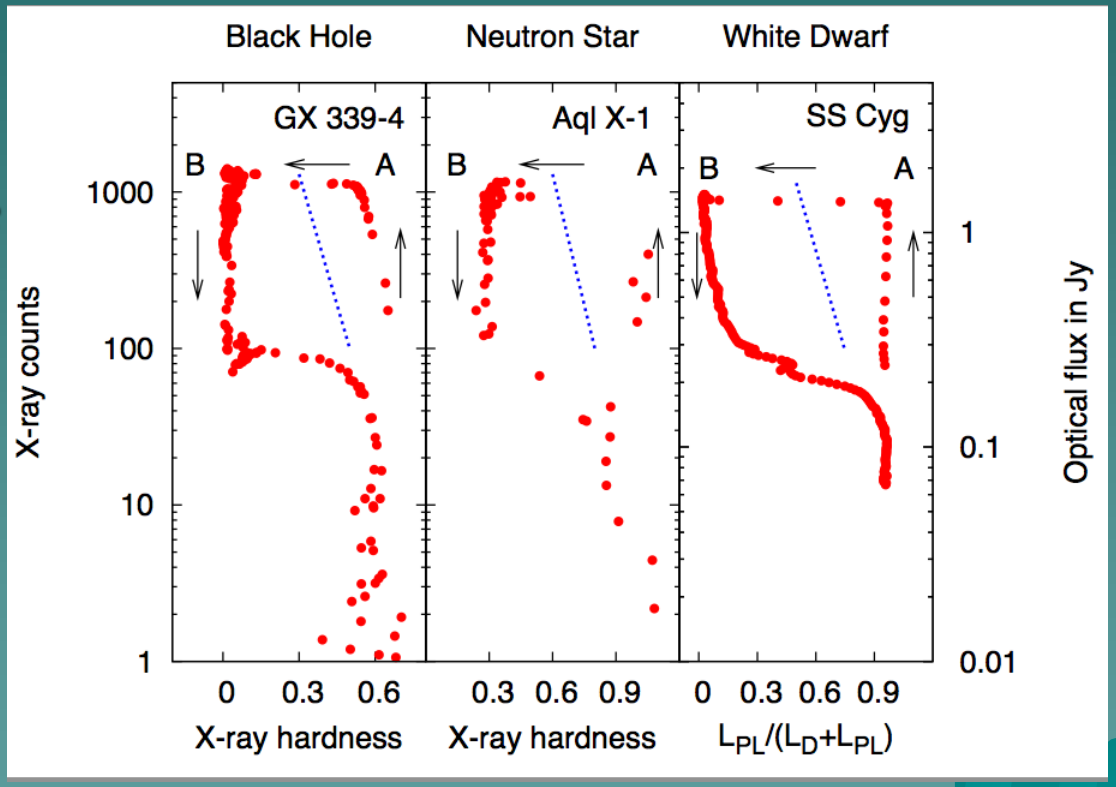


Kording et al. 2008

SS Cyg

Cataclysmic variables: non-magnetic

- SS Cyg broadly fits the state transition/outflow paradigm
- Not detected in quiescence

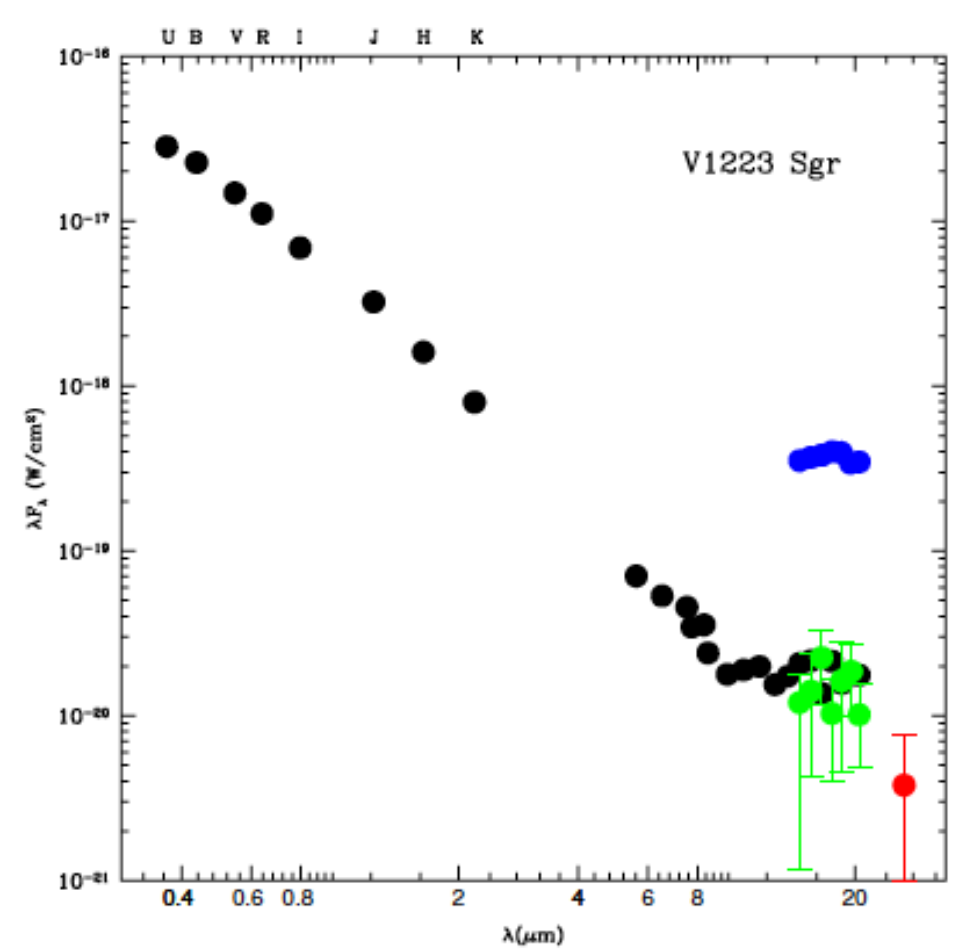


Kording et al. 2008

SS Cyg

Cataclysmic variables: intermediate polars

- AE Aqr (e.g., Dubus et al. 2007): persistent with flares
- V1223 Sgr (Harrison et al. 2010): optically-thin synchrotron flares (to mid-IR)

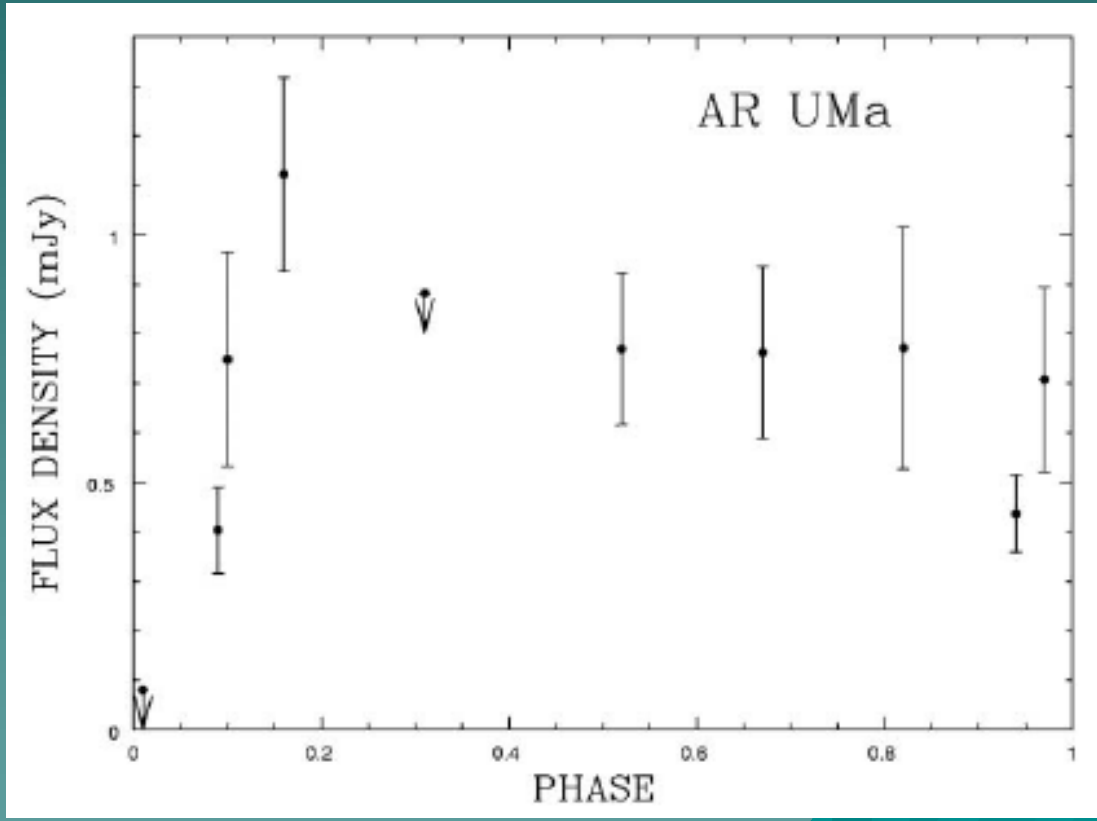


Harrison et al. 2010

AE Aqr

Cataclysmic variables: polars

- No emission from isolated magnetic WDs
- AR UMa (230 MG), AM Her
  - Persistent but variable
  - Seen even in low accretion state



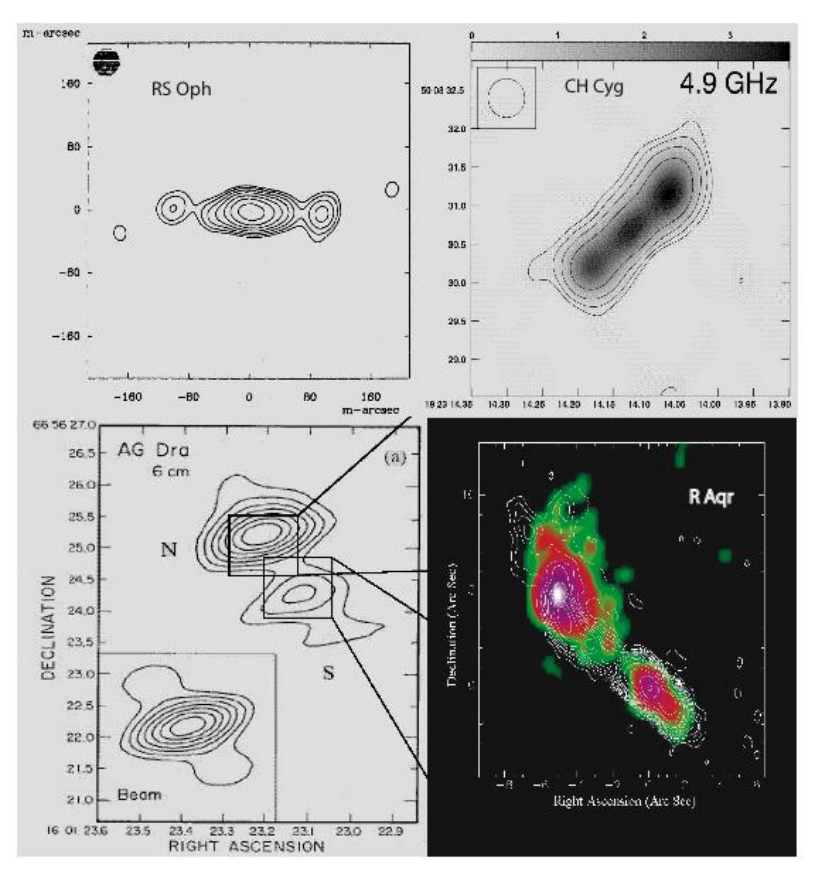
Mason & Gray 2007

AR UMa

- Suggest accretion STOPS outflow in these systems!

Symbiotics

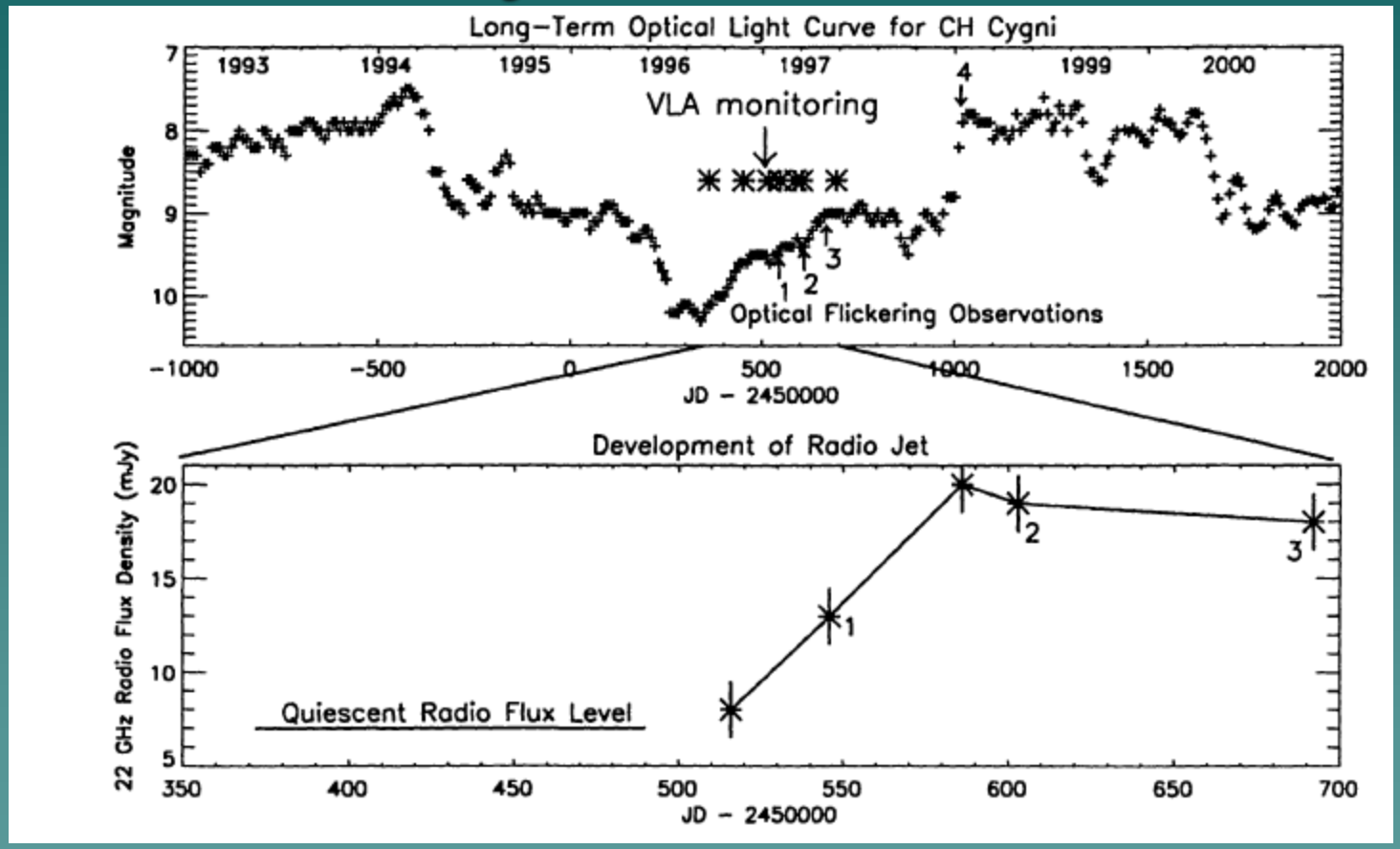
- >5% have some evidence for collimated flows
- Often transient
- 10s of mas to 10s of arcsec (10s to 1000s of au)
- 100s to 1000s km/s
- Thermally-powered synchrotron



Symbiotics & Supersofts: which give jets?

- Nuclear shell burning and not
- Close and wide symbiotics
- With and (mostly) without strong WD magnetic fields
- Some associated with outbursts (e.g. novae), some not
- Some may not have disks (SSS, novae)

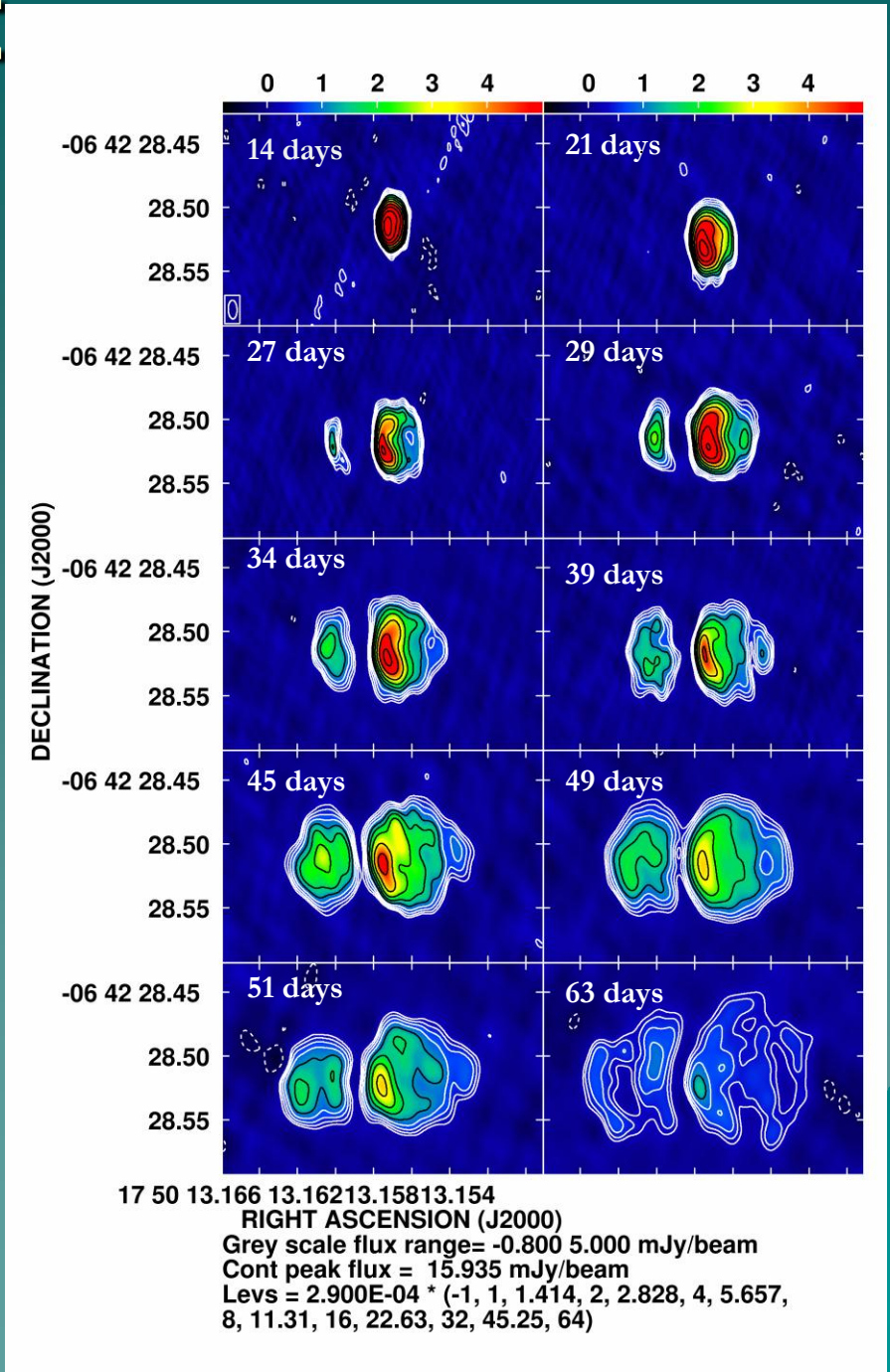
Symbiotics



- CH Cyg: radio jet correlated with lack of optical flickering (Sokoloski & Kenyon 2003)

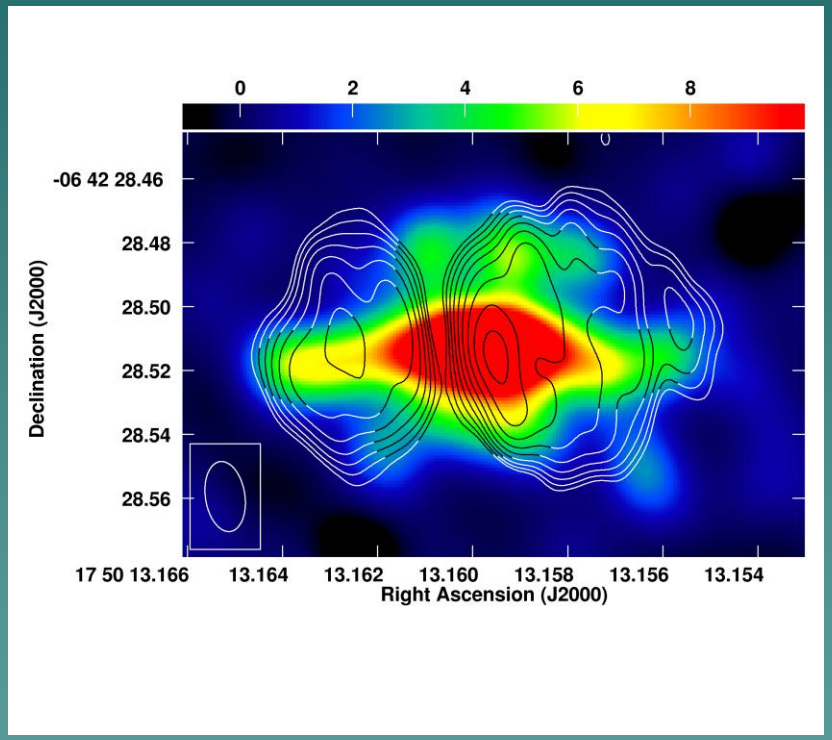
Symbiotic novae: RS Oph

- Synchrotron shell
  - 7500 km/s
  - Asymmetric – red giant wind?



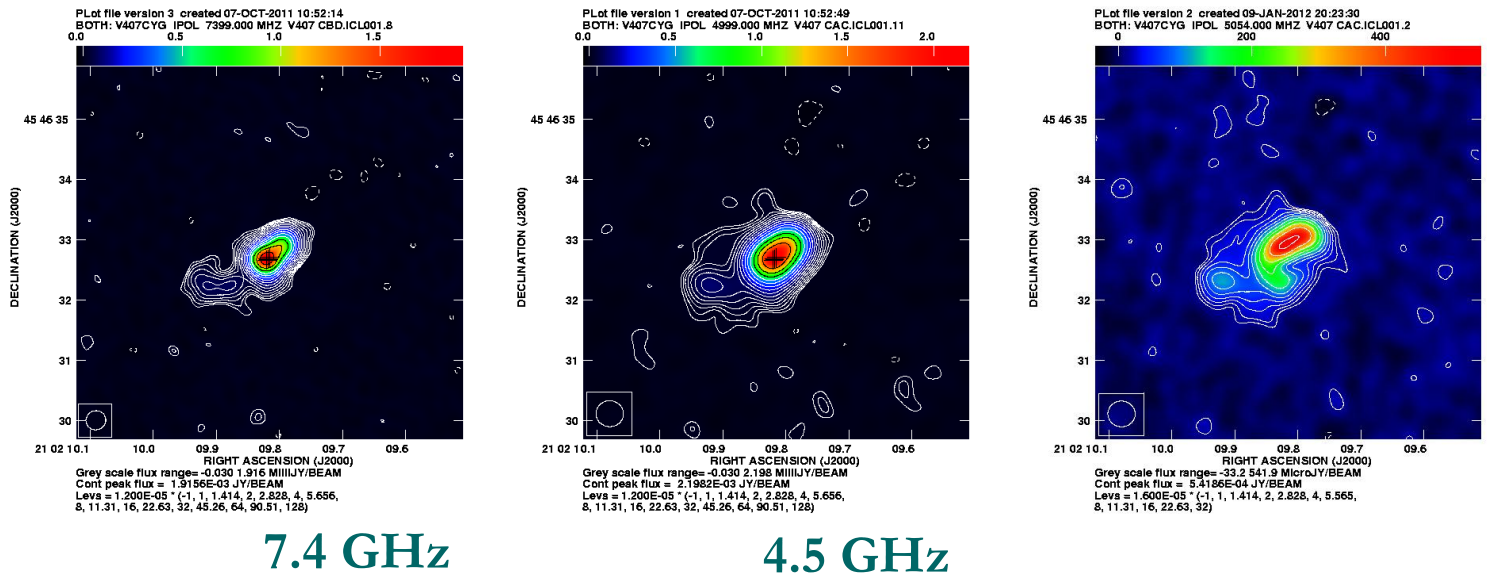
Symbiotic novae: RS Oph

- Thermal jets power the lobes 56 days after explosion
  - Is there a disk??
  - Continuous flow for at least 1 month after eruption
  - Opening angle <4degs
- Jets in quiescence too



Sokoloski, Rupen, & Mioduszewski 2008

Symbiotic novae: V407 Cyg



7.4 GHz

4.5 GHz

Mioduszewski et al.

- EVLA A config at day ~450
- Aligns with early MERLIN

The future

The radio revolution

- ALMA, JVLA…but also eMERLIN and VLBA
  - **Imaging is essential**
- Very wide bandwidths: instantaneous spectral indices

The radio revolution

- Sensitivity = time resolution
- Sensitivity = spatial resolution
- Sensitivity = response time
- Sensitivity = polarization
- Sensitivity = **different sources**
  - Neutron star binaries
  - White dwarf binaries
  - Really test importance of accretion disk, central source, magnetic fields…

The radio revolution

- Sensitivity = serendipity
  - Cf. V407 Cyg
  - Spectral lines (masers, absorption) – esp. with wide bandwidths
  - "invisible" jets
  - Unknown radio transients

New stuff

- Thermal flows: ALMA, but also JVLA
  - radio recombination lines
- Winds from companions
  - maybe from disks, a la SS433 (cf. Blundell)
  - jet powers!
- Synchrotron turn-overs
- Waaaay down in the jet

Stars are GREAT!

…and will soon be even better ☺