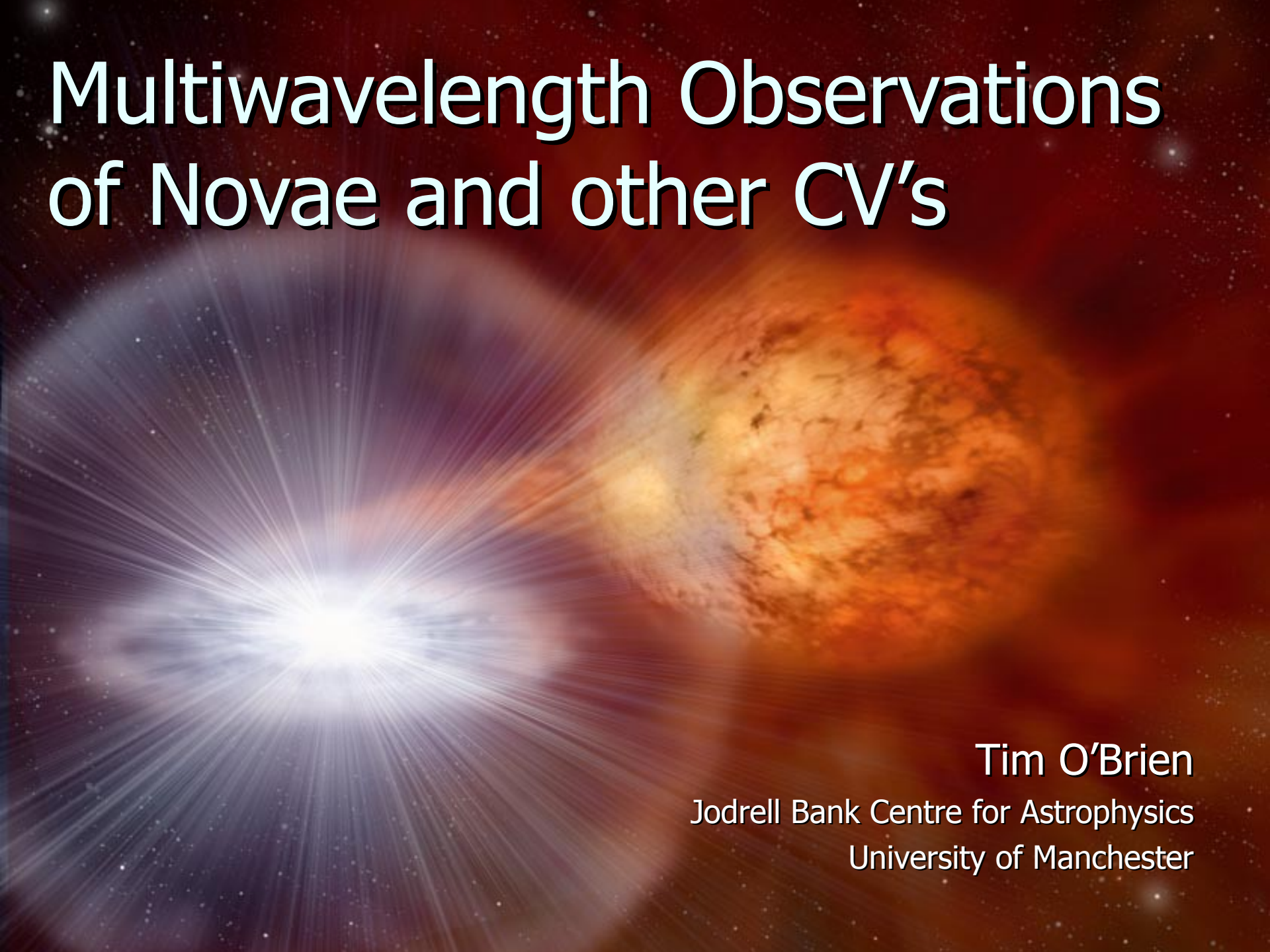
Multiwavelength Observations of Novae and other CV's



Tim O'Brien
Jodrell Bank Centre for Astrophysics
University of Manchester

Summary

- What are Cataclysmic Variables?
- Radio emission from CV's
- A few recent examples:
  - RS Oph
  - SS Cyg
  - V445 Pup
- TOO campaigns on outbursts of CV's e.g. Swift group + example of U Sco

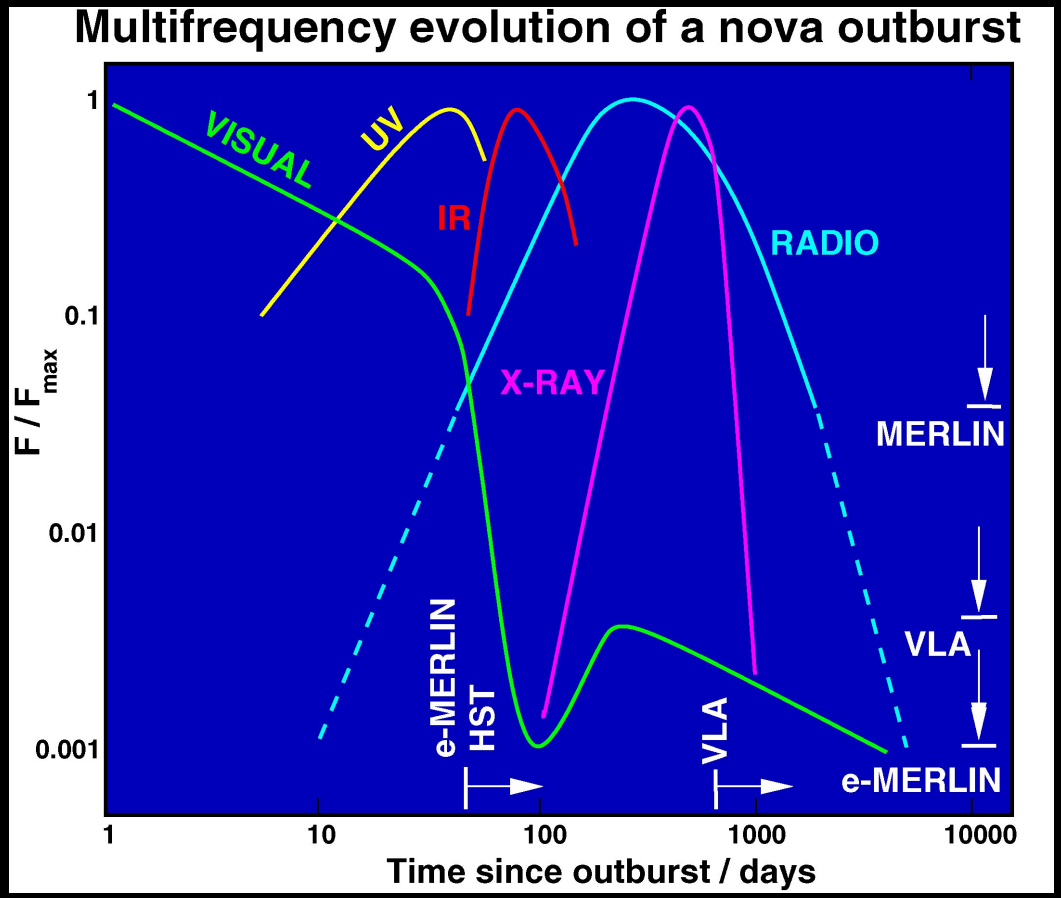
Cataclysmic Variables

- Interacting binaries (P ~ few hours – *few years*)
- White dwarf + low-mass main sequence star *or red giant*
- Accretion onto WD
- Wide range of behaviour – variation on timescales of secs to hours to weeks to years
  - Novae – classical & *recurrent*, thermonuclear
  - Dwarf novae – accretion disk driven outbursts
  - Magnetic CV's – polars, asynchronous polars and intermediate polars
  - *Symbiotic stars*

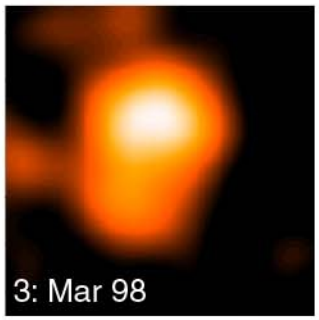
Radio emission from CV's

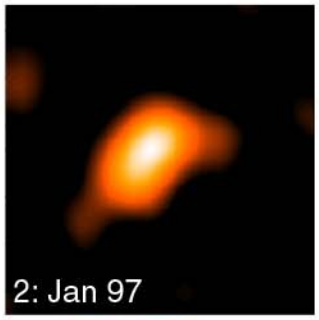
- Non-magnetic –
  - no persistent radio sources (e.g. Cordova et al 1983, Nelson & Spencer 1988, Furst et al 1986)
  - However 18 classical novae have been detected in outburst – free-free from expanding shell (e.g. Seaquist & Bode 2008)
  - One unconfirmed dwarf nova in outburst (SU UMa – Benz et al 1983) plus one recent one (SS Cyg, see later)
  - One recurrent nova – RS Oph, see later

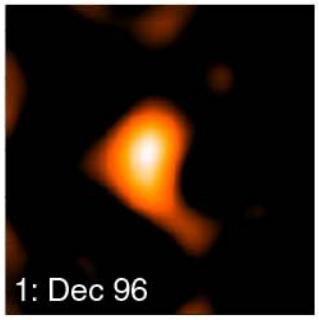
Radio Emission from CNe

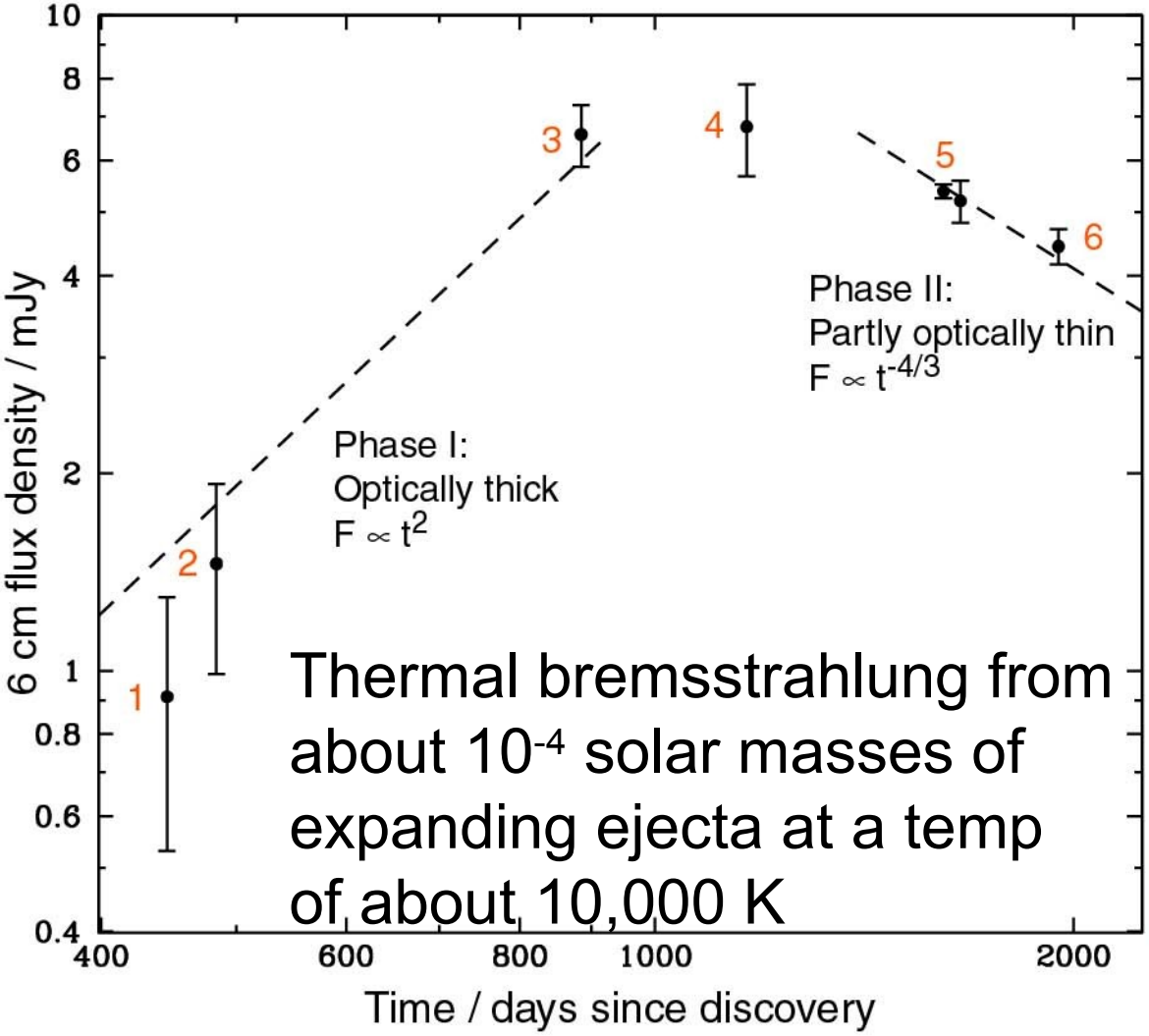


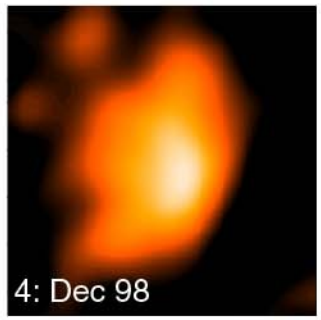
MERLIN Imaging – V723 Cas

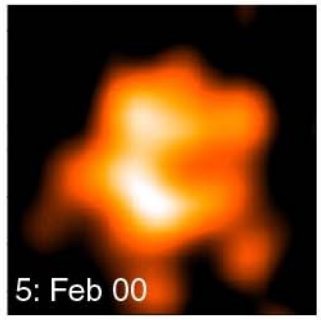


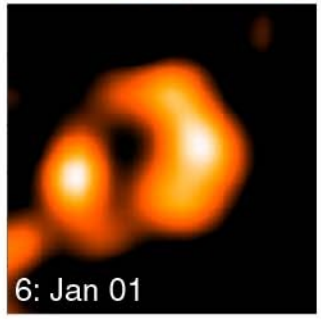












Heywood et al (2005)

Radio emission from CV's

- Non-magnetic –
  - no persistent radio sources (e.g. Cordova et al 1983, Nelson & Spencer 1988, Furst et al 1986)
  - However 18 classical novae have been detected in outburst – free-free from expanding shell (e.g. Seaquist & Bode 2008)
  - One unconfirmed dwarf nova in outburst (SU UMa – Benz et al 1983) plus one recent one (SS Cyg, see later)
  - One recurrent nova – RS Oph, see later

Radio emission from CV's

- Magnetic –
  - only 3 persistent radio sources
  - VLA survey of all magnetic CV's out to 100pc – Mason & Gray (2007)
  - Detected AR UMa, AM Her, AE Aqr (+ pre-CV V471 Tau)
  - Sporadic detections of flares in a few others: V834 Cen, ST LMi, DQ Her, BG CMi

Radio emission from CV's

- Non-magnetic CV's not radio-loud BUT isolated magnetic WD's are not radio sources so it is not this alone that explains CV radio emission
- Persistent emission has not been detected in any CV with a disc outside of outburst, so maybe the disc prevents radio emission
- Possible model requires a magnetized secondary and radio emission arises from gyrosynchrotron in the combined magnetosphere (e.g. Uchida & Sakurai 1983, Lim et al 1996, Nicholls & Storey 1999)

Some recent examples

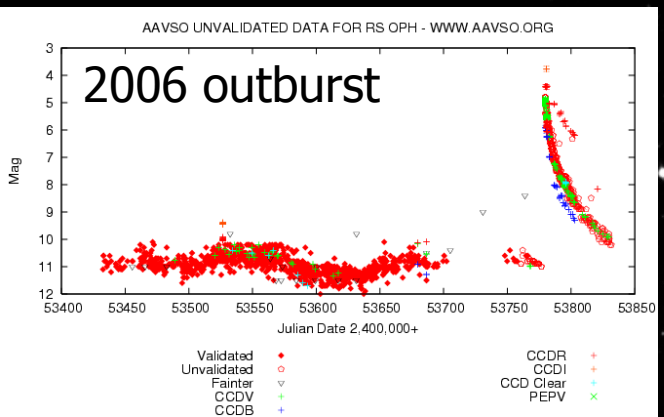
- RS Oph – Recurrent Nova, WD + RG
- SS Cyg – Dwarf Nova
- V445 Pup – first helium nova
- U Sco – Recurrent Nova, WD + MS

RS Oph – A Recurrent Nova

- Observed outbursts 1898, (1907), 1933, 1958, 1967, 1985, 2006

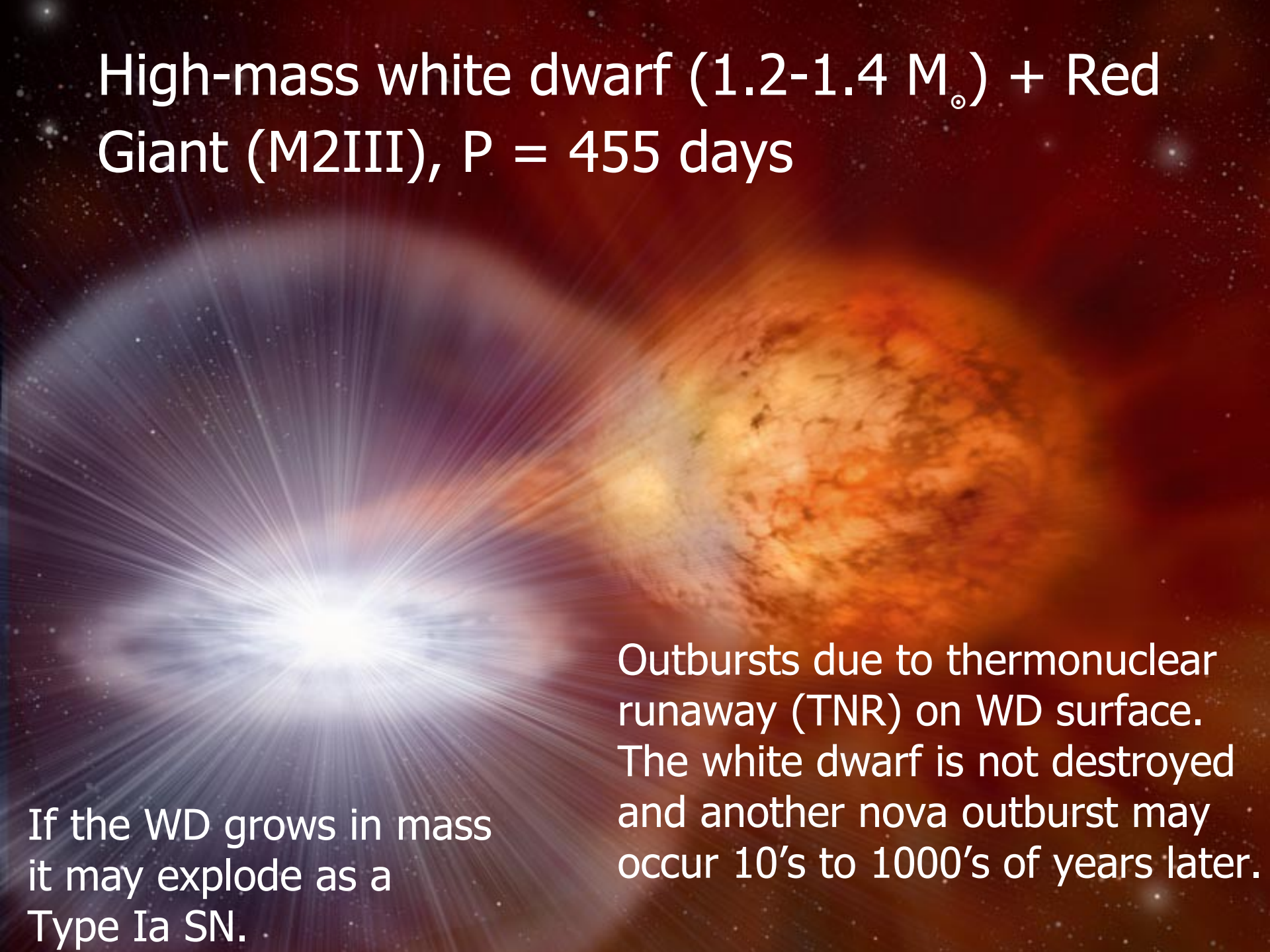
Nova Stella = New Star

Brightens from ~11th mag to ~4th mag in less than a day.



Before & after 2006

High-mass white dwarf (1.2-1.4 $M_\odot$) + Red Giant (M2III), P = 455 days



Outbursts due to thermonuclear runaway (TNR) on WD surface. The white dwarf is not destroyed and another nova outburst may occur 10's to 1000's of years later.

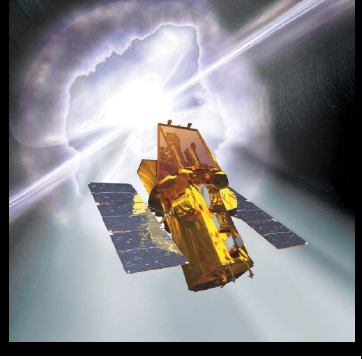
If the WD grows in mass it may explode as a Type Ia SN.

2006 Outburst

- Discovered Feb 12.83 UT ($t = 0$)
- Within a few days, ToO's granted on *Swift, XMM, Chandra, MERLIN, VLA, VLBA, EVN, Liv Tel, UKIRT,* plus *HST*, *GMRT, OCRA* and *Spitzer* later.
- Monitoring with MERLIN from day 4.5, combined with VLBA and EVN imaging and Swift X-ray spectroscopy.

The University of Manchester
Jodrell Bank
Observatory

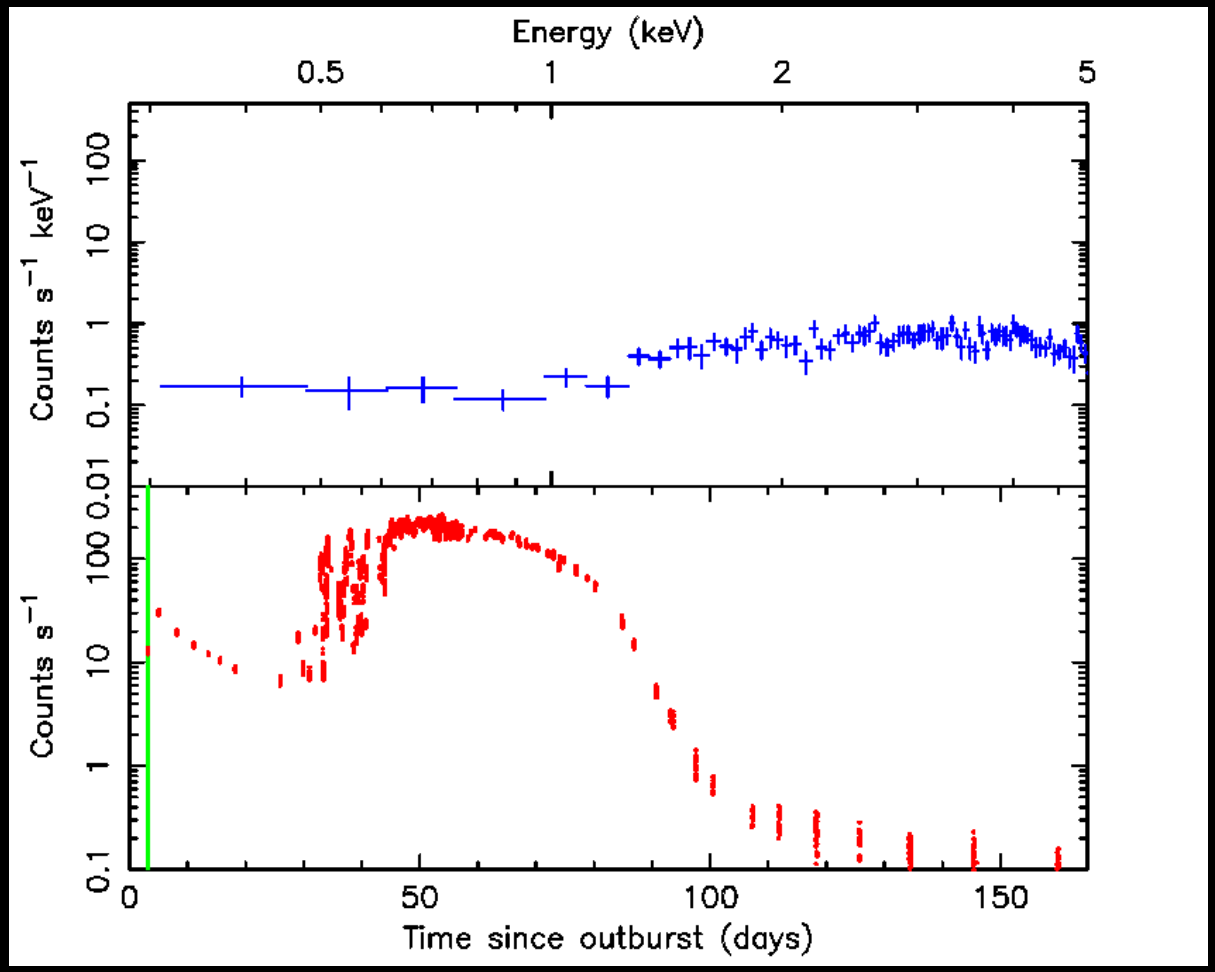
Swift X-ray Observations



Two components:

1. Shock providing higher-energy emission visible at early and late times.

2. Bright soft component from nuclear burning on white dwarf.

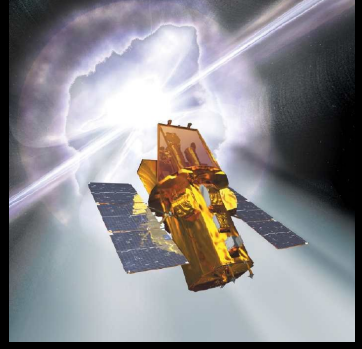


Bode et al (2006), Osborne et al (2007)

The University of Manchester
Jodrell Bank
Observatory

MANCHESTER 1824

Swift X-ray Observations



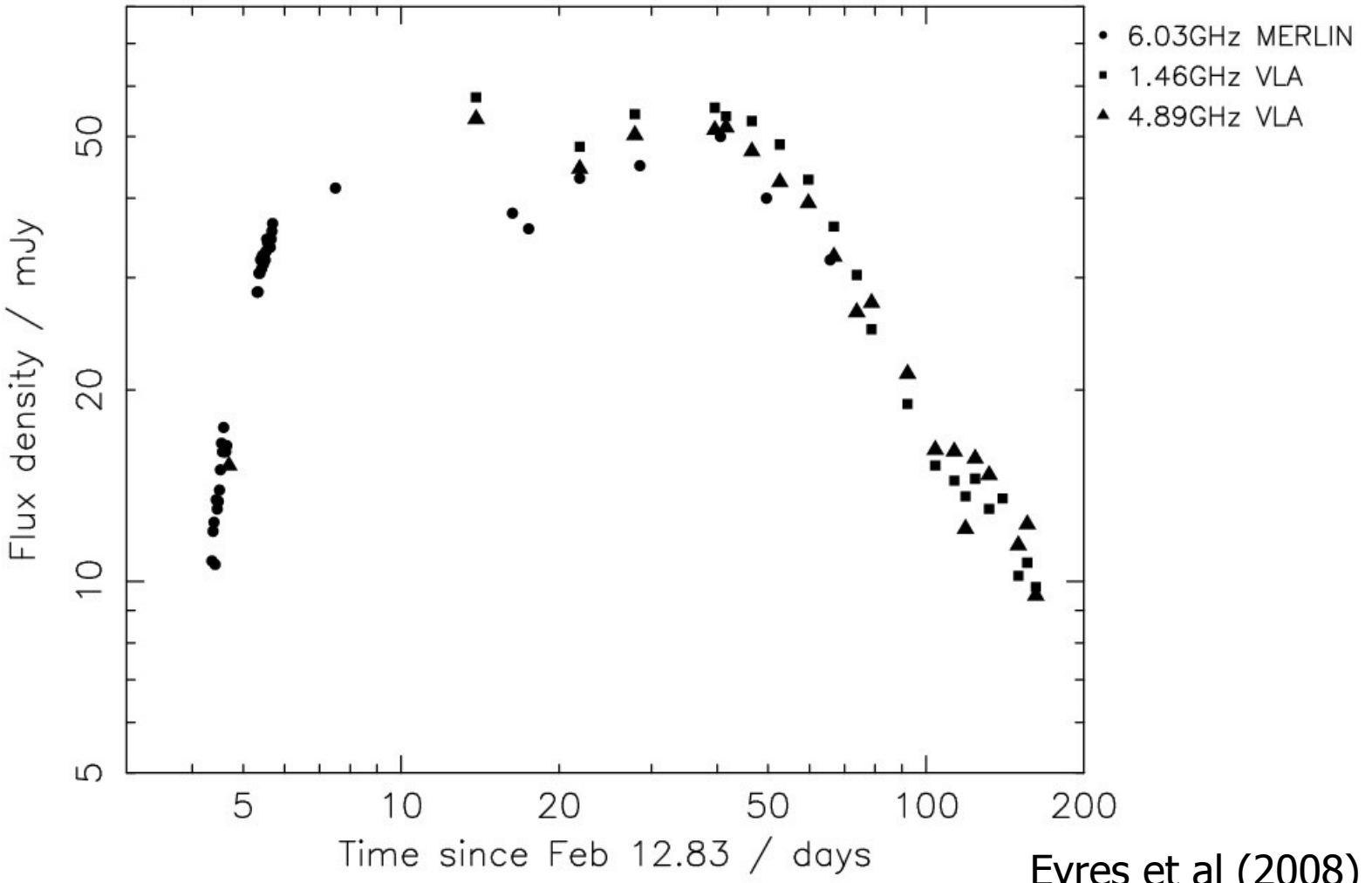
Two components:

1. Shock providing higher-energy emission visible at early and late times.

2. Bright soft component from nuclear burning on white dwarf.

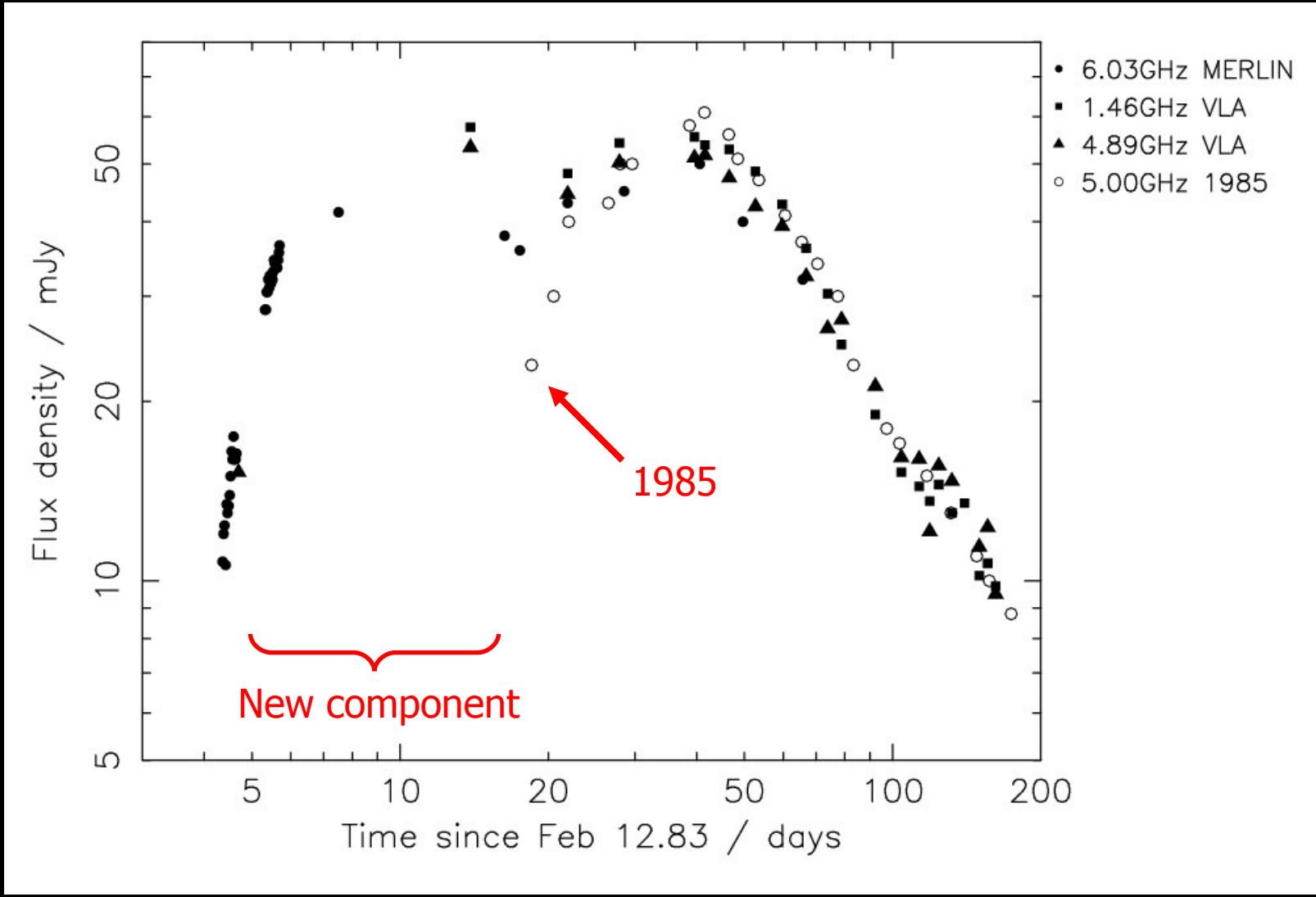
Bode et al (2006), Osborne et al (2007)

Radio Lightcurve – MERLIN/VLA

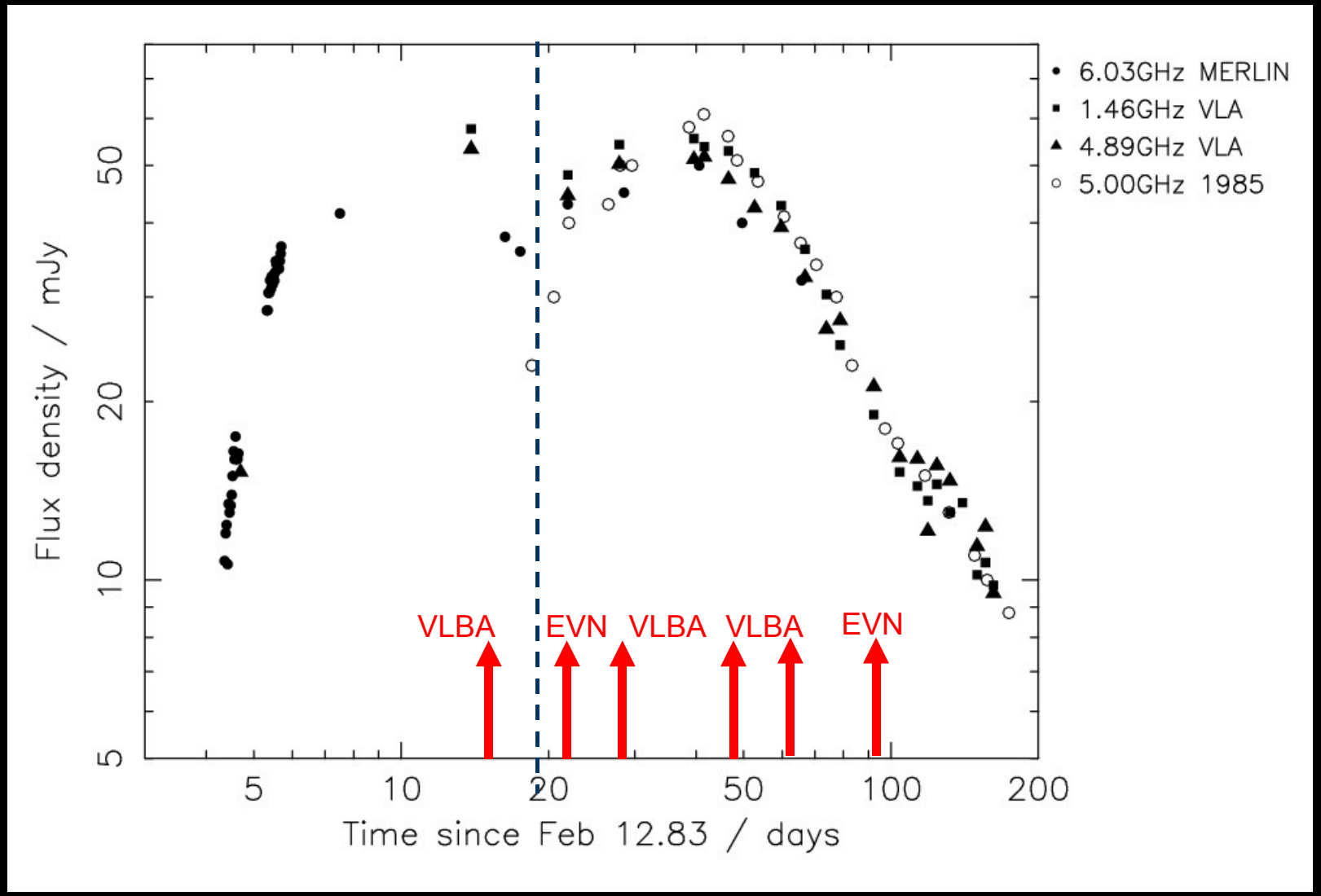


Eyres et al (2008)

L/C-Band Lightcurve



VLBI Imaging



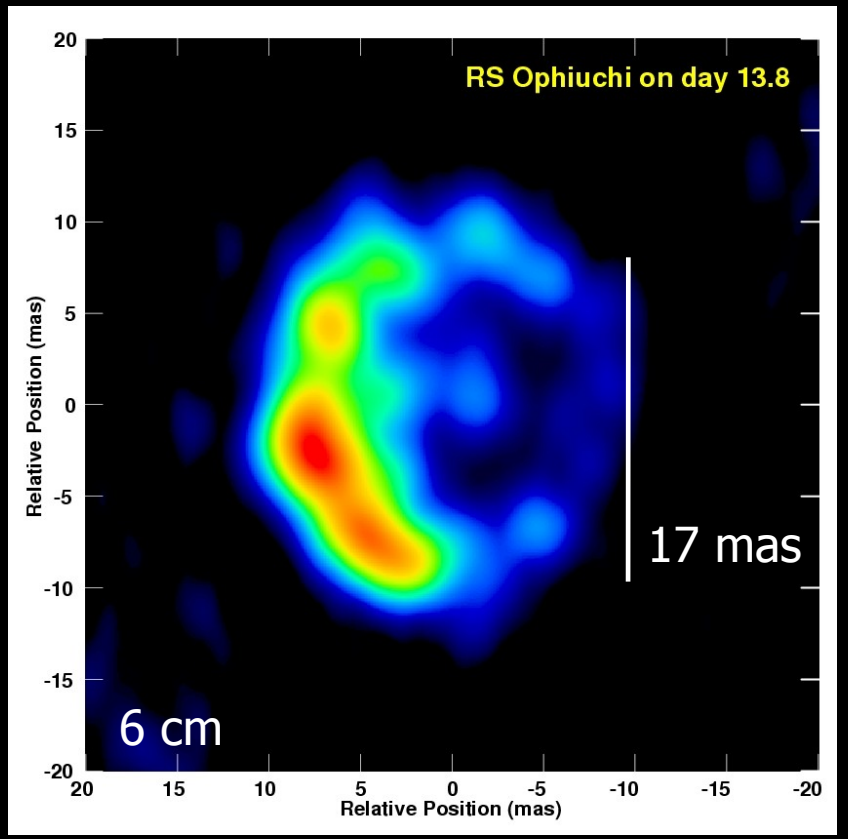
The University of Manchester
Jodrell Bank
Observatory

First VLBI image – Day 13.8

VLBA image reveals the shock wave for the first time. Earliest resolution of structure in any such explosion.

Res'n ~ 3 mas (5 AU)
Peak T_b ~ 4×10^7K

Significant contribution from synchrotron.
X-ray temp consistent with shock expansion speed



O'Brien et al (2006)

The University of Manchester
Jodrell Bank
Observatory

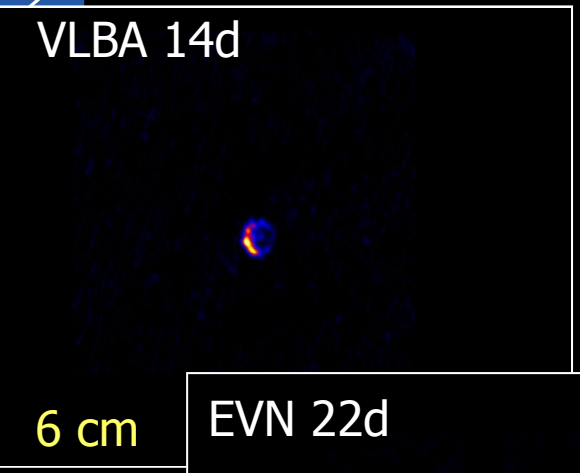
MANCHESTER 1824

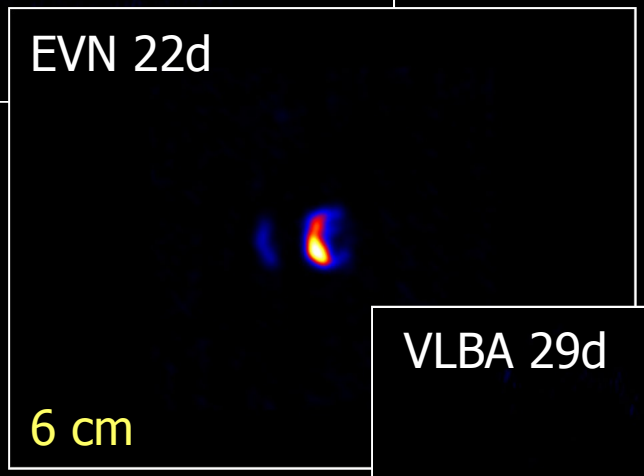
MERLIN imaging

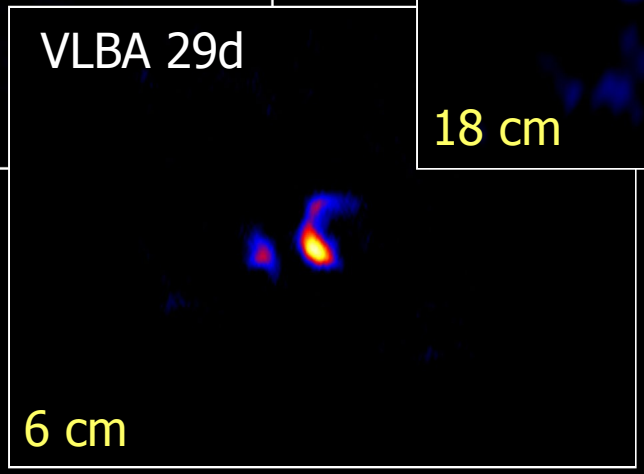
- Second component clearly visible from day 21 onwards.
- Third component to west visible around day 50.
- Source evolves into E-W structure.

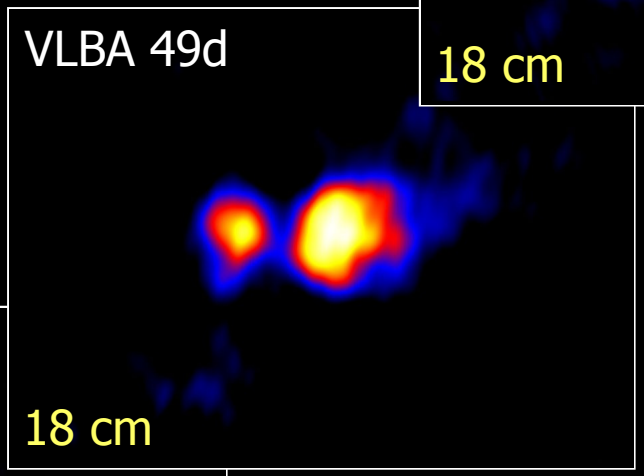
The University of Manchester
Jodrell Bank
Observatory

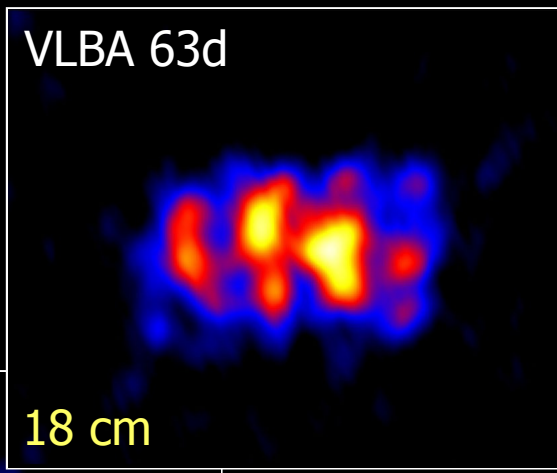
VLBI Sequence







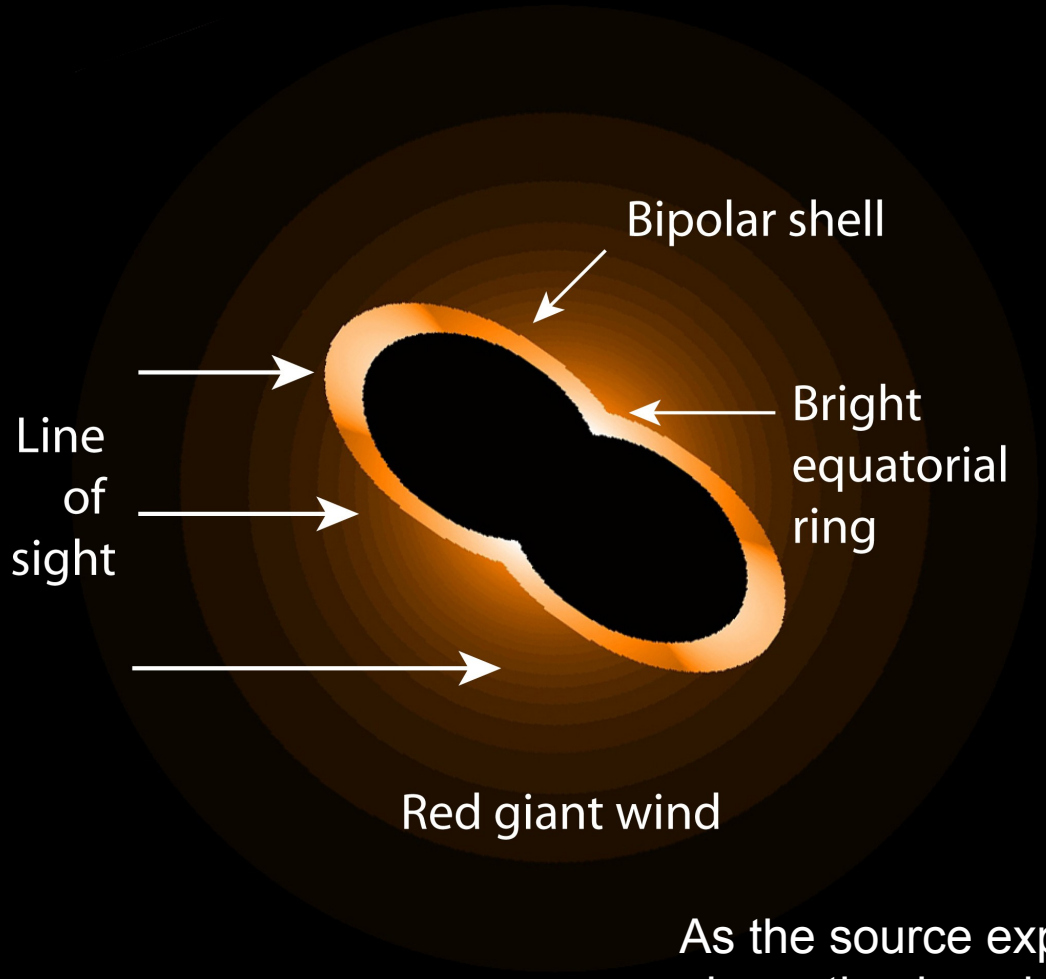




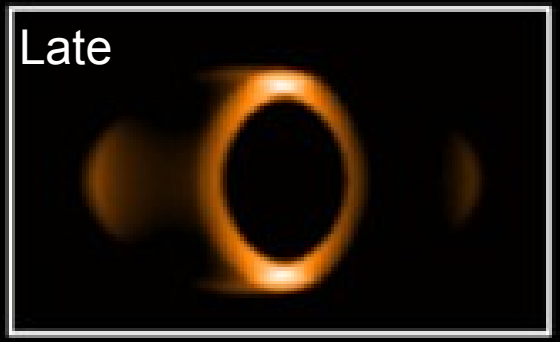
O'Brien et al (2007)

The University of Manchester
Jodrell Bank
Observatory

A model for the radio imaging



Synthetic images



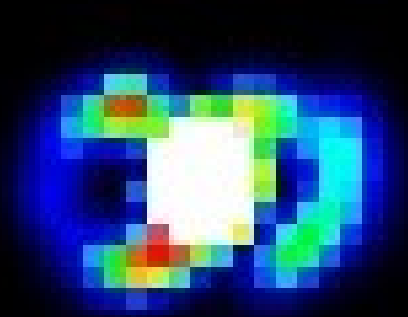
As the source expands the overlying free-free absorption is reduced and it becomes symmetrical.

O'Brien et al (2006)

The University of Manchester
Jodrell Bank
Observatory

MANCHESTER 1824

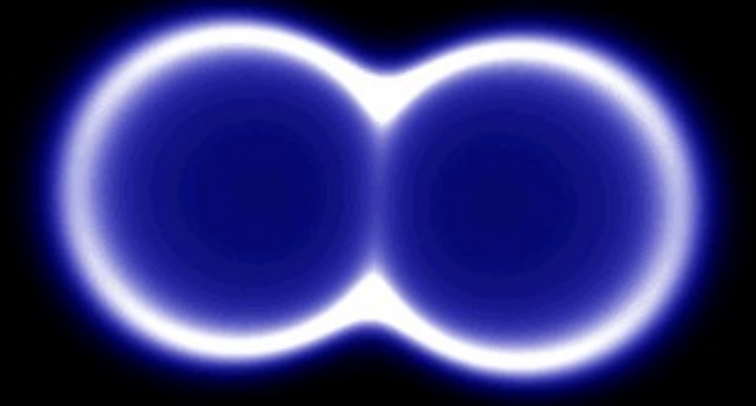
Deconvolved HST [OIII]



Scale consistent with expanded radio nebula (Harman et al 2008)

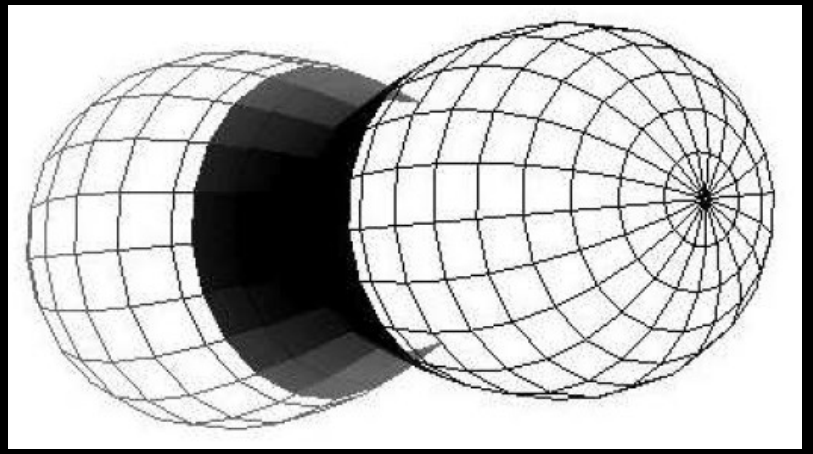
MANCHESTER 1824

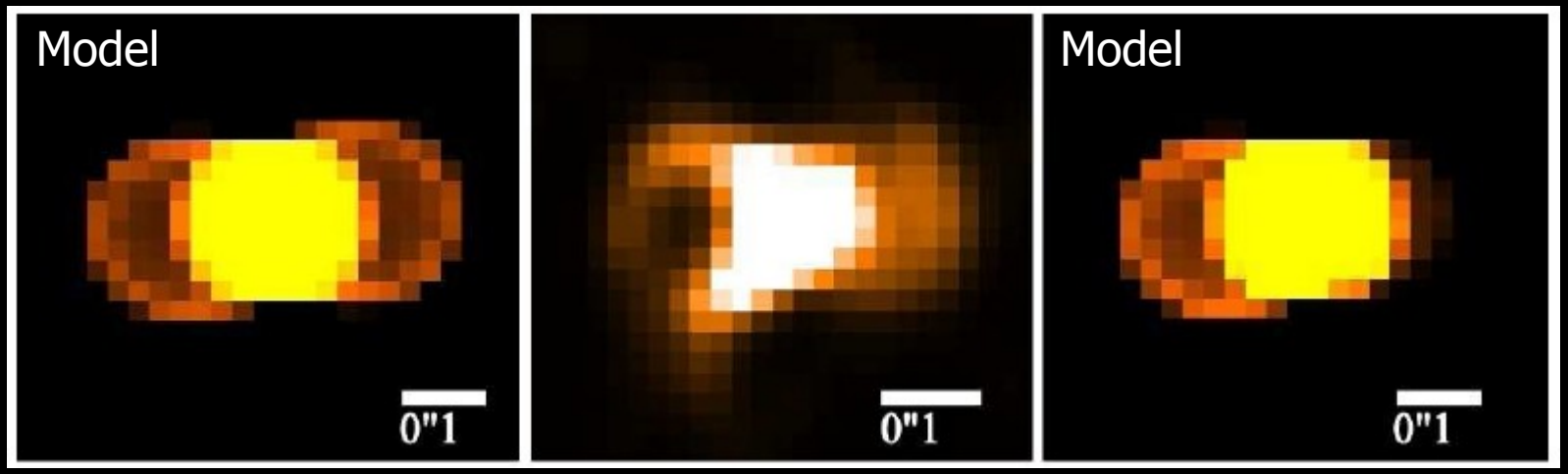
Simple model



Spatiokinematic modelling

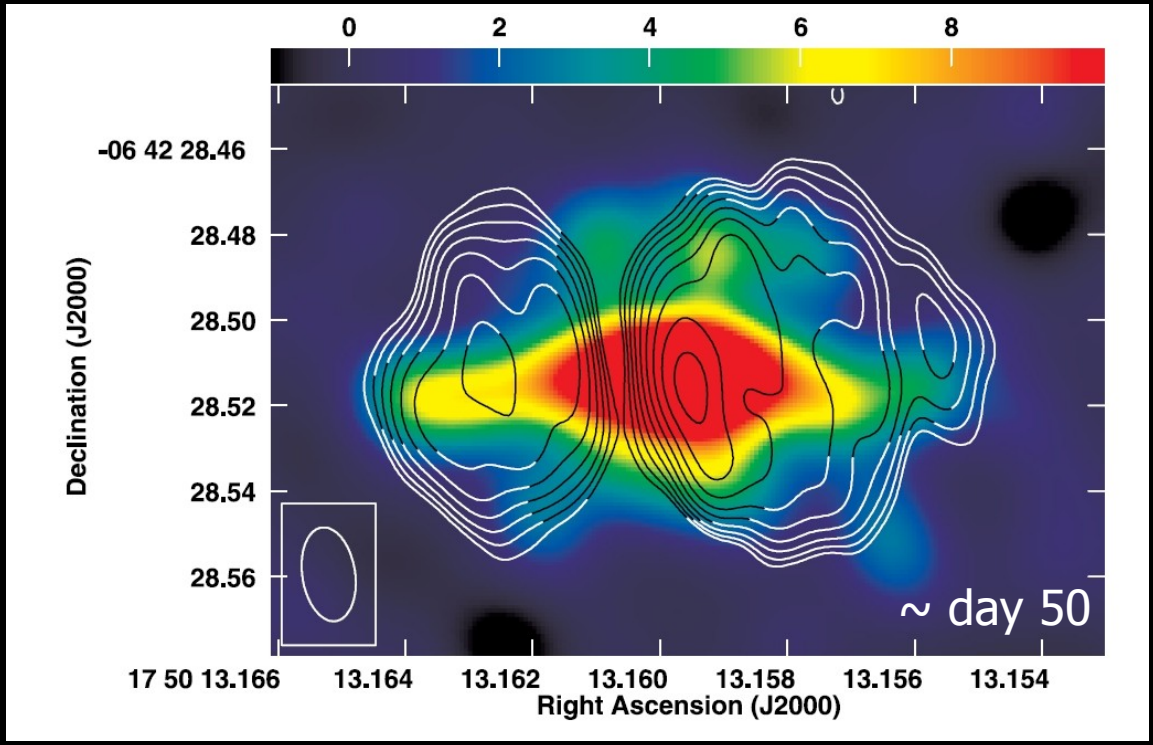
- Ribeiro et al (2009)
  - HST imaging at day 155
  - West lobe nearest





Jets in RS Oph?

- Sokoloski et al (2008)
  - Jets collimated by disc (?)
  - Powered by residual TN burning on WD or by accretion?

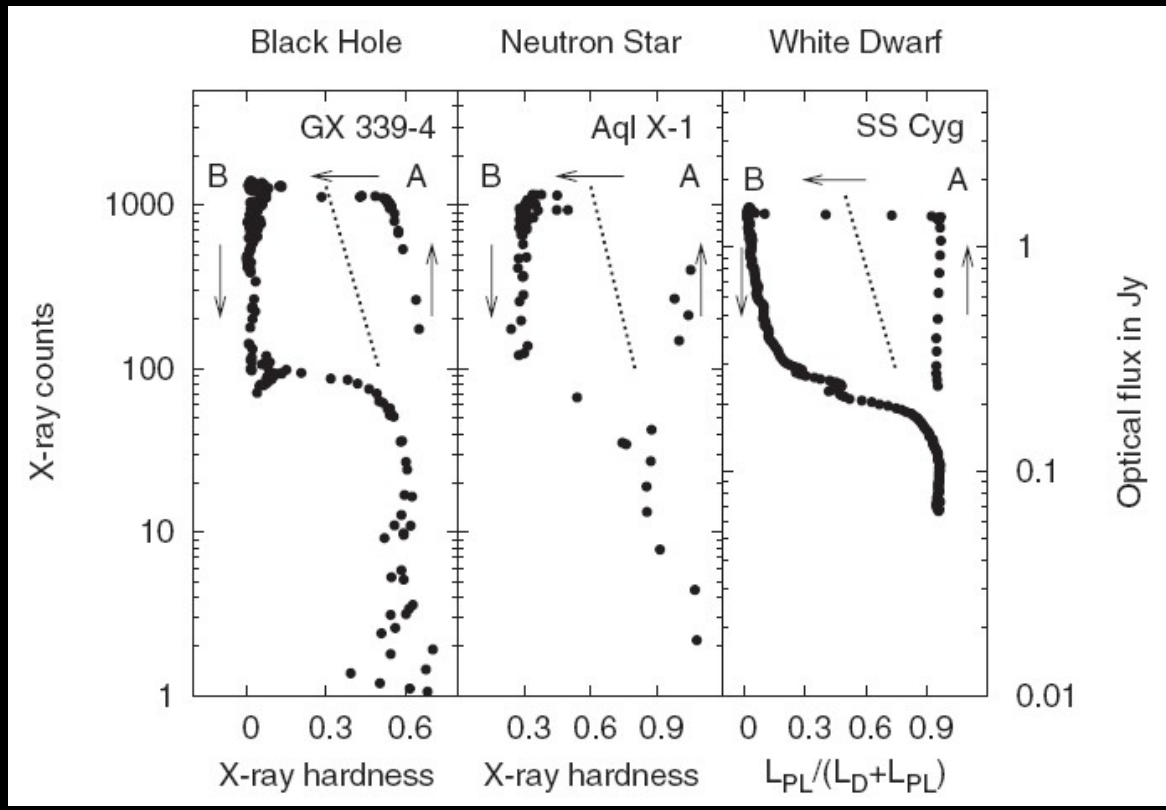


Contours: 1.7GHz VLBA Thermal

Colour: 43GHz VLA Synchrotron

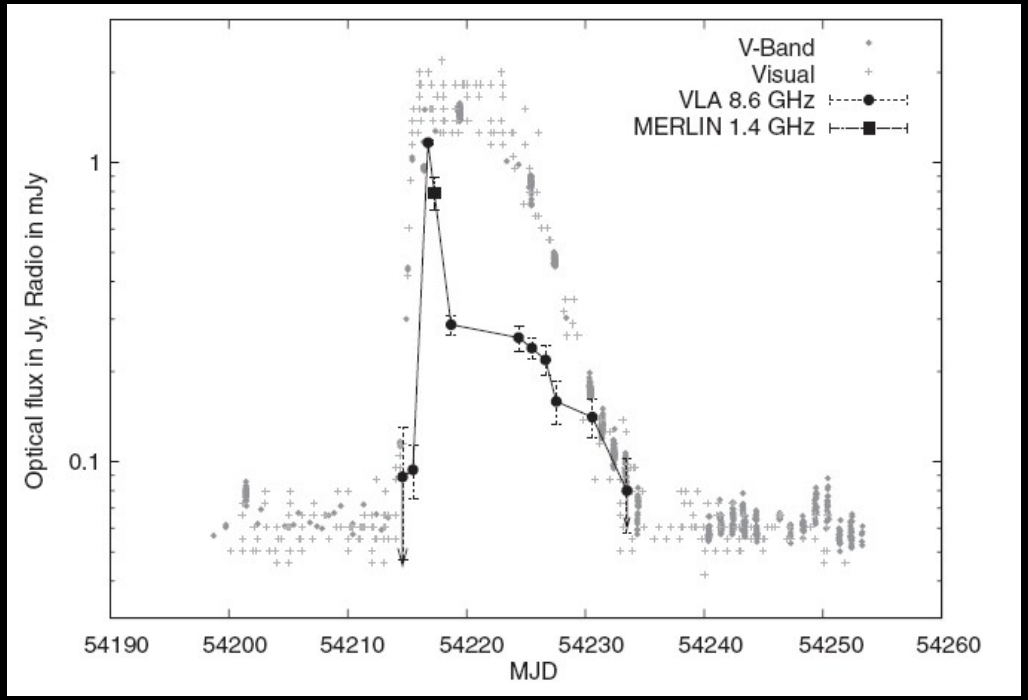
Jets in SS Cyg? A dwarf nova

- Körding et al (2008) compare to XRB's
  - Hardness-intensity diagram
  - A: hard state shows radio jets
  - B: soft state radio reduced
  - SS Cyg shows Fast rise (~24h)



Jets in SS Cyg? A dwarf nova

- AAVSO provided optical trigger for radio observations
- Synchrotron
- Suggestive of jets similar to N* XRB (shows radio in soft state)
- But not resolved
- Currently monitoring Z Cam, YZ Cnc and EM Cyg



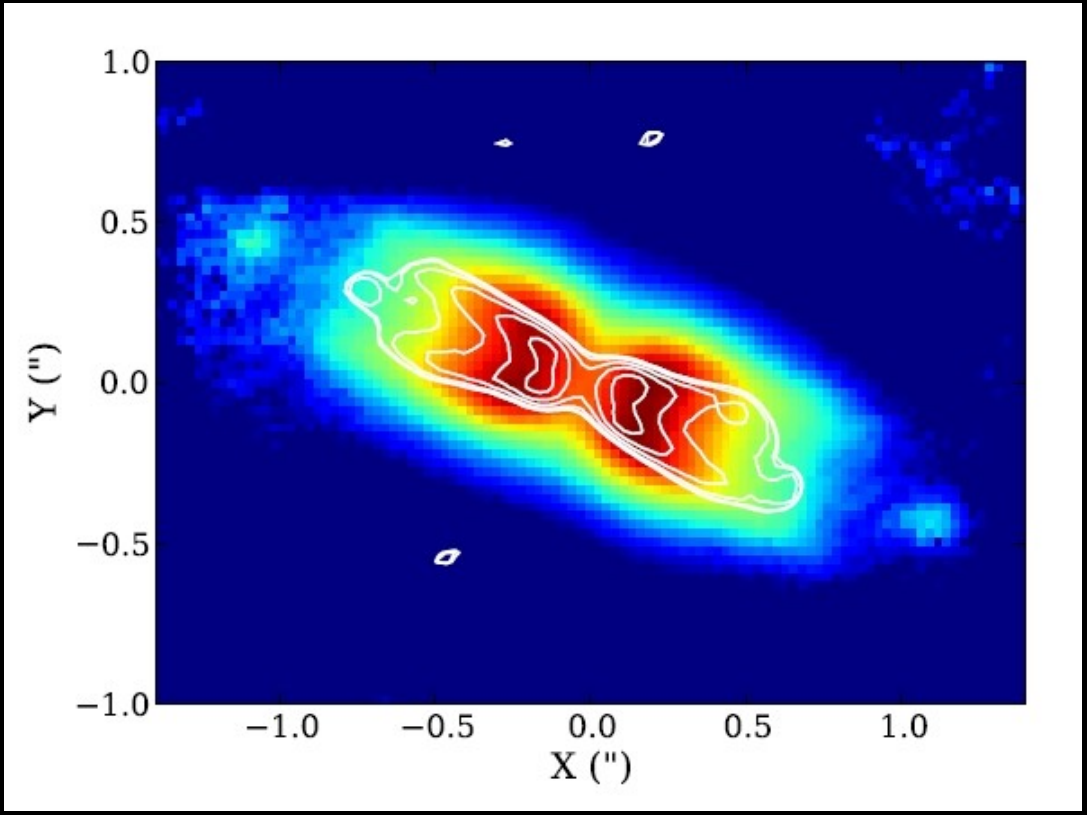
V445 Pup – Helium Nova

- Massive WD accreting from He star – Outburst in 2000 suggests it's the first Helium Nova to be observed
- Woudt et al (2009) obtained adaptive optics NIR imaging on VLT with NAOS/CONICA

V445 Pup – Helium Nova

- Woudt et al (2009)

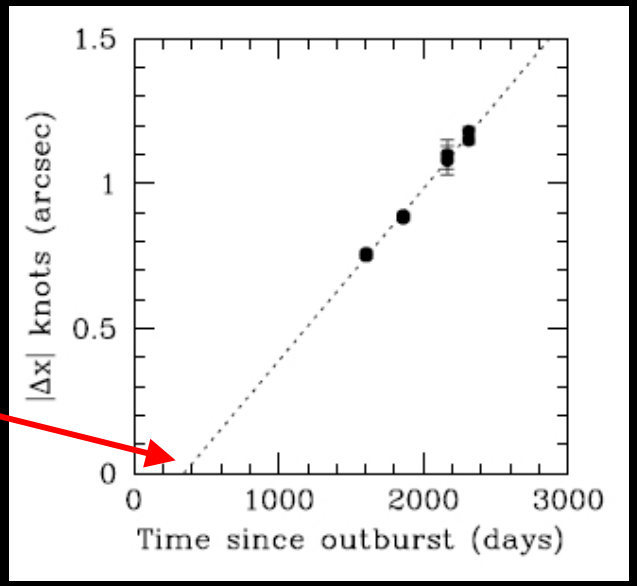
Contours: March 2005
Colour: March 2007

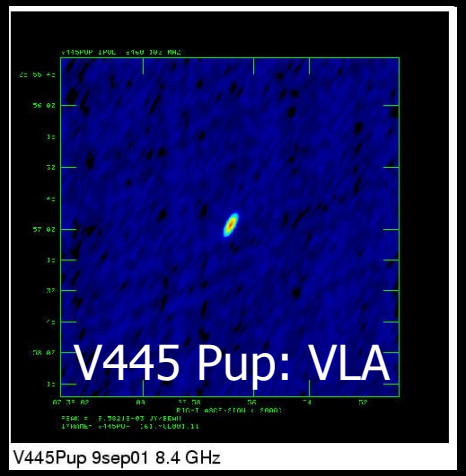


The University of Manchester
Jodrell Bank
Observatory

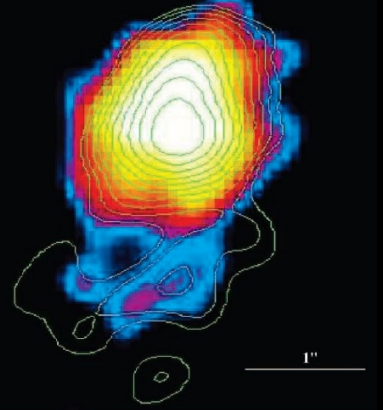
V445 Pup – Helium Nova

- Expansion of blobs at > 8,000 km/s
- Ejection time coincides with drop in optical flux 350d after main outburst (Ashok & Bannerjee 2003) and unresolved radio flare (Rupen et al 2001)
- Cf CH Cyg which ejected radio jets in a similar way (e.g. Karovska et al 2007)





CH Cyg:
Chandra + VLA



The University of Manchester
Jodrell Bank
Observatory

MANCHESTER 1824

TOO Swift Nova-CV group

TOO Swift Nova-CV group

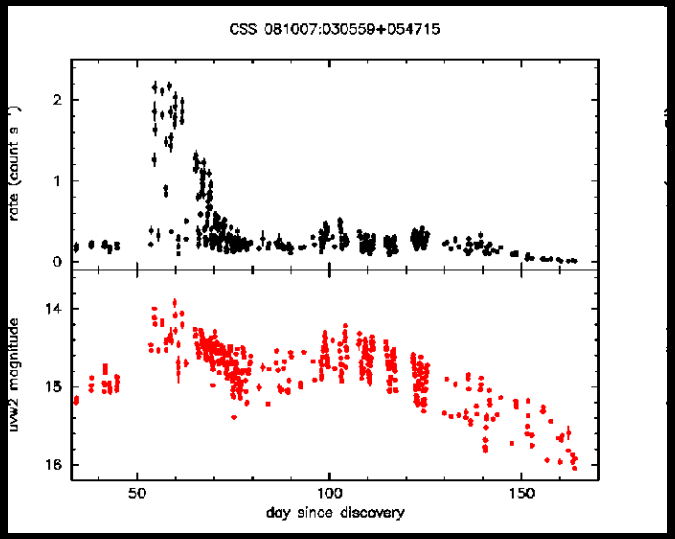
- Set up after success of RS Oph campaign
- Coordinated through UK Swift Science Data Centre (Osborne et al)
- 39 members worldwide, very open access
- E-mail exploder + private group web archive for analysis (data public)
- Coordinate TOO proposals and discussion of strategy

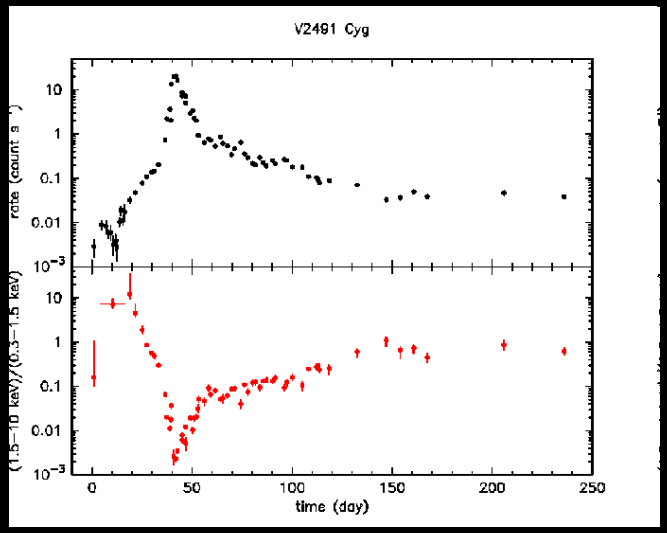
The University of Manchester
Jodrell Bank
Observatory

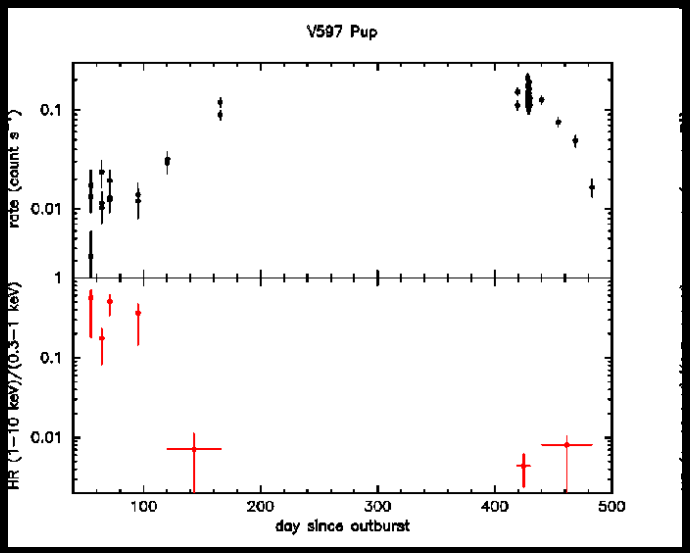
TOO Swift Nova-CV group

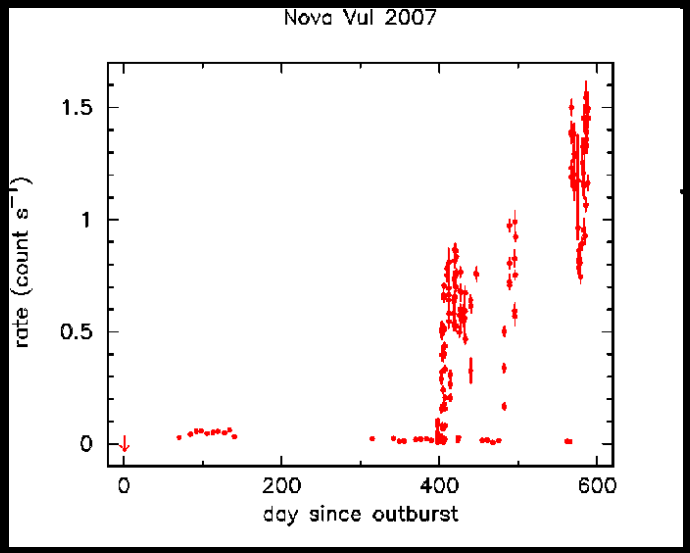
- Guideline observing strategy:
  - For Galactic Novae
    - If Vmax < 5 : Observation daily, day 3 to 10 (or post X-ray peak if earlier)
    - If Vmax < 8 : Observation around 3 mags below maximum
    - If detected :
      - If E(B-V) < 1 : monitor for SSS onset - weekly for fast novae, monthly for slow novae
        - If SSS present : monitor for SSS duration, frequency to depend on observed behaviour
      - Else : monitor monthly to end of emission
    - Else : observe again in nebular phase
      - If detected : monitor monthly to end of emission
  - For Magellanic Cloud Novae
    - Observe MC novae with Vmax < 11.5 at 6 and 9 months
    - All observations to be initially ~2 ks, though later observations may be longer if rapid variability or low quality spectra obtained.

Example Swift Novae...









The University of Manchester
Jodrell Bank
Observatory

MANCHESTER 1824

TOO Swift Nova-CV group

- Swift is ideal TOO instrument
- Building a more complete sample and making a significant impact on understanding of nova eruptions
- 40 novae observed so far
- 11 papers so far
- Keen to bring in other facilities on coordinated campaigns

U Sco

- Fastest known nova
  - Rises from V=17.6 to V=7.5 in 4hrs, falls by 2 mag's in 1.2 days, 3 mag's in 2.6 days
  - Expansion velocities ~ 10,000 km/s
  - Suggestion of jets in optical lines
- Outbursts 1863, 1906, 1917, 1936, 1945, 1969, 1979, 1987, and 1999
  - Next outburst any time now
- Another excellent Type Ia SN candidate
  - WD ~ 1.55 +/- 0.24 $M_{\odot}$ + MS star (Thoroughgood et al 2001)

USCO2009 Campaign

- Coordinated by Brad Schaefer, Ashley Pagnotta, Eric Schlegel
  - AAVSO has U Sco under hourly monitoring
  - ROTSE optical imaging
  - Swift, Suzaku X-rays
  - SMARTS optical photometry/spectroscopy
  - PROMPT optical polarimetry
  - Photometry with SALT, CBA, Liv Tel
  - IRTF/Lick IR spectroscopy
- As yet no radio in place…

Summary

- Some progress in understanding origin of persistent radio emission in CV's
- Growing evidence for ejection of jets in some CV's
  - WD's are an important link between YSO's and N*'s in physics of jet ejection
- Growing evidence that some of these systems are Type Ia SN progenitors
- Rapid-response high-res'n imaging has an important role to play