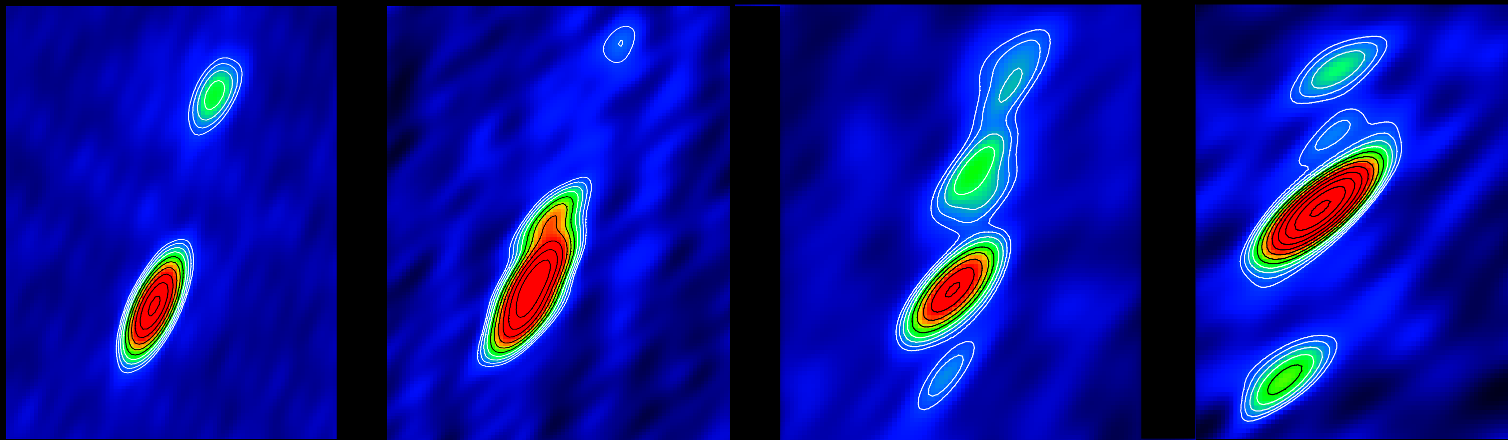

Extreme Jet Ejections from the Black Hole X-ray Binary V404 Cygni: The Unique (Sub-) Millimetre Perspective

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University of Alberta

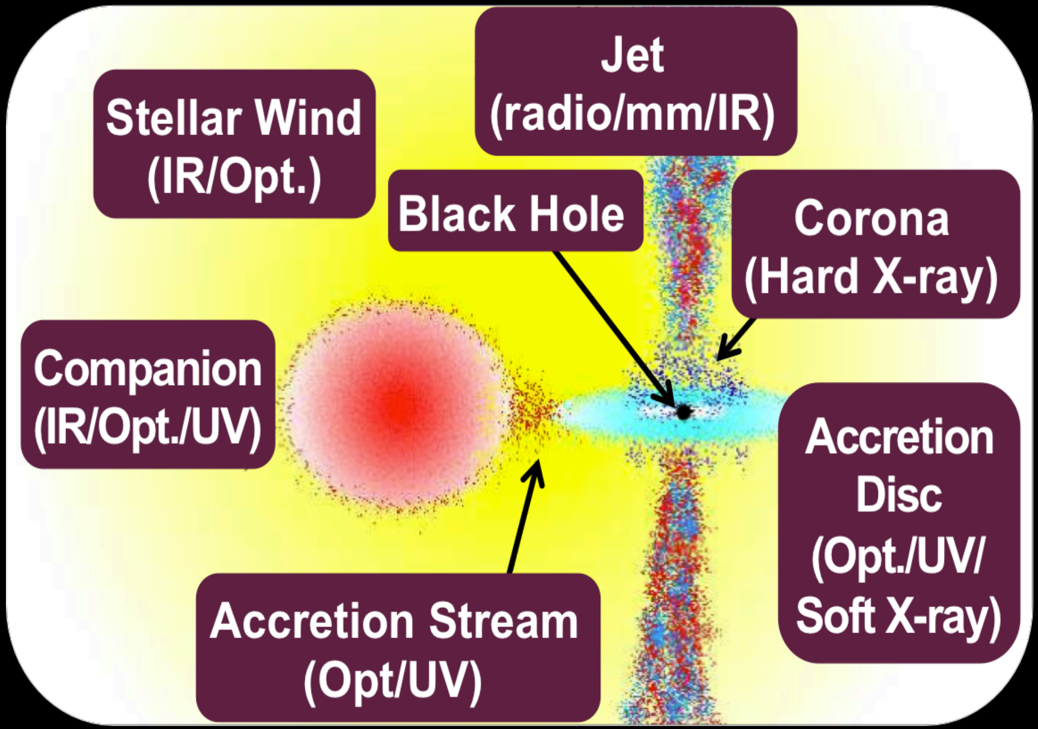
J.C.A. Miller-Jones (ICRAR), G.R. Sivakoff & E. Rosolowsky (UAlberta), on behalf of a Larger X-ray Binary Collaboration

UNIVERSITY OF ALBERTA

EAO Seminar
February 16, 2016

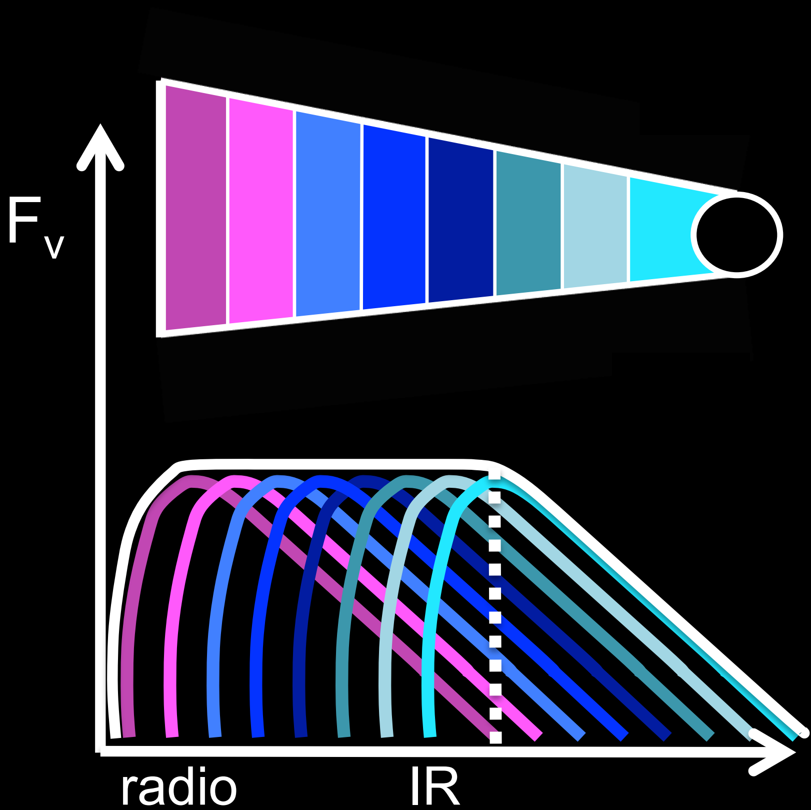
Black Hole X-ray Binaries (BHXBs)

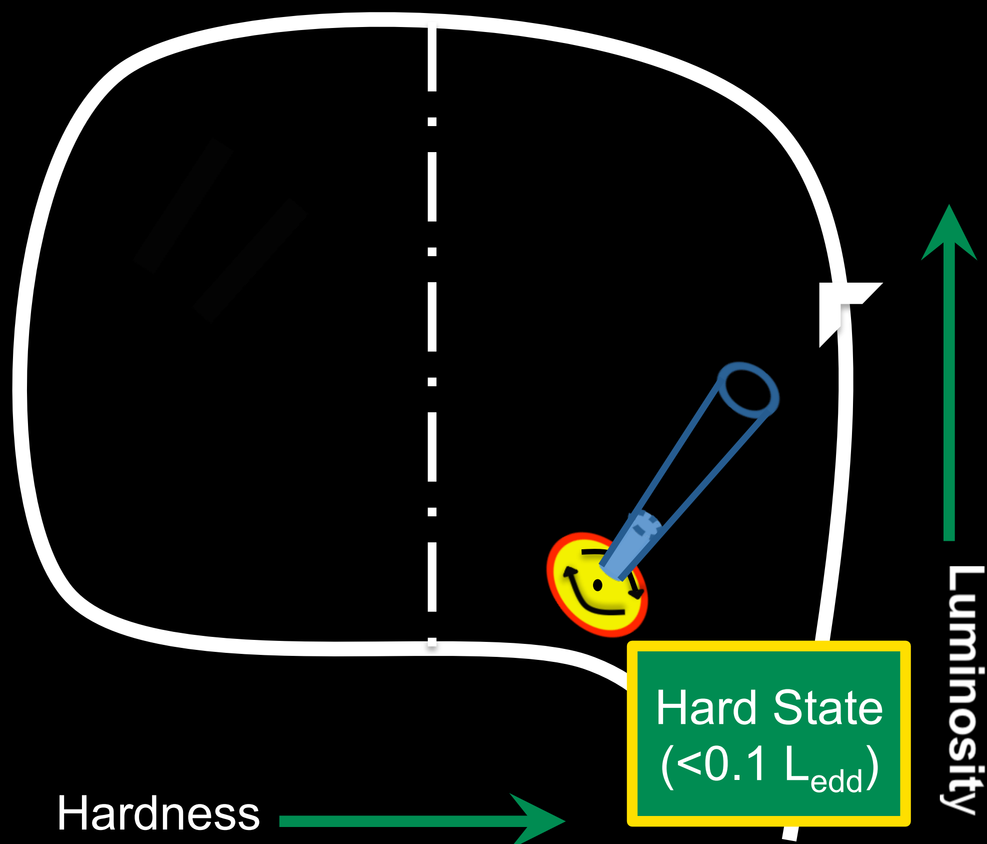
- Compact object accreting from less-evolved companion
- Two phases:
  - Quiescence
  - Outburst
- Jet best detected during outburst
- Outbursts vary on short timescales



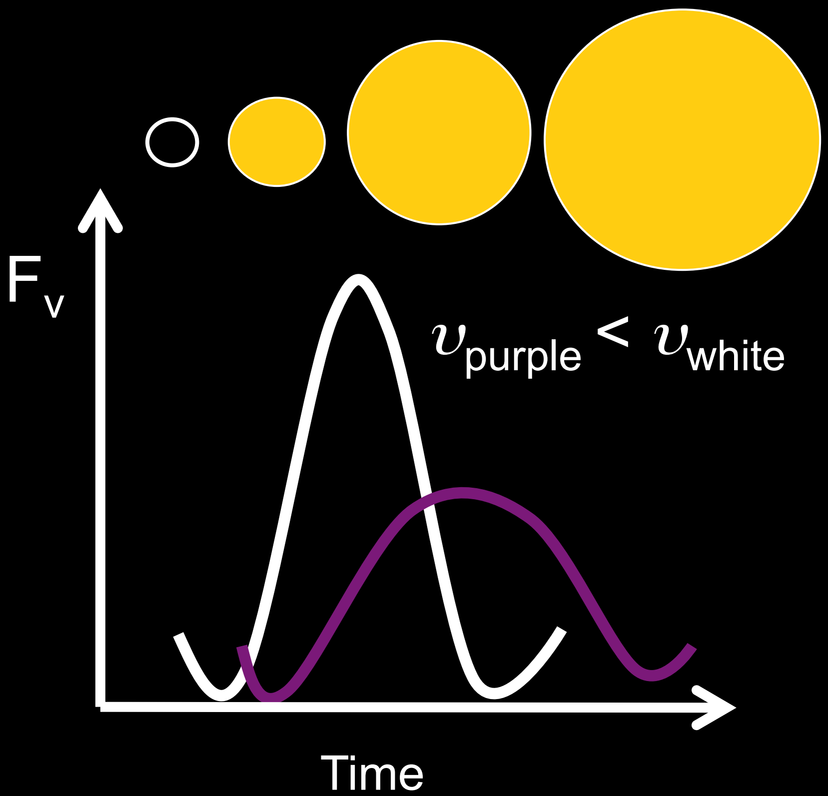
Adapted from Fender, 2000

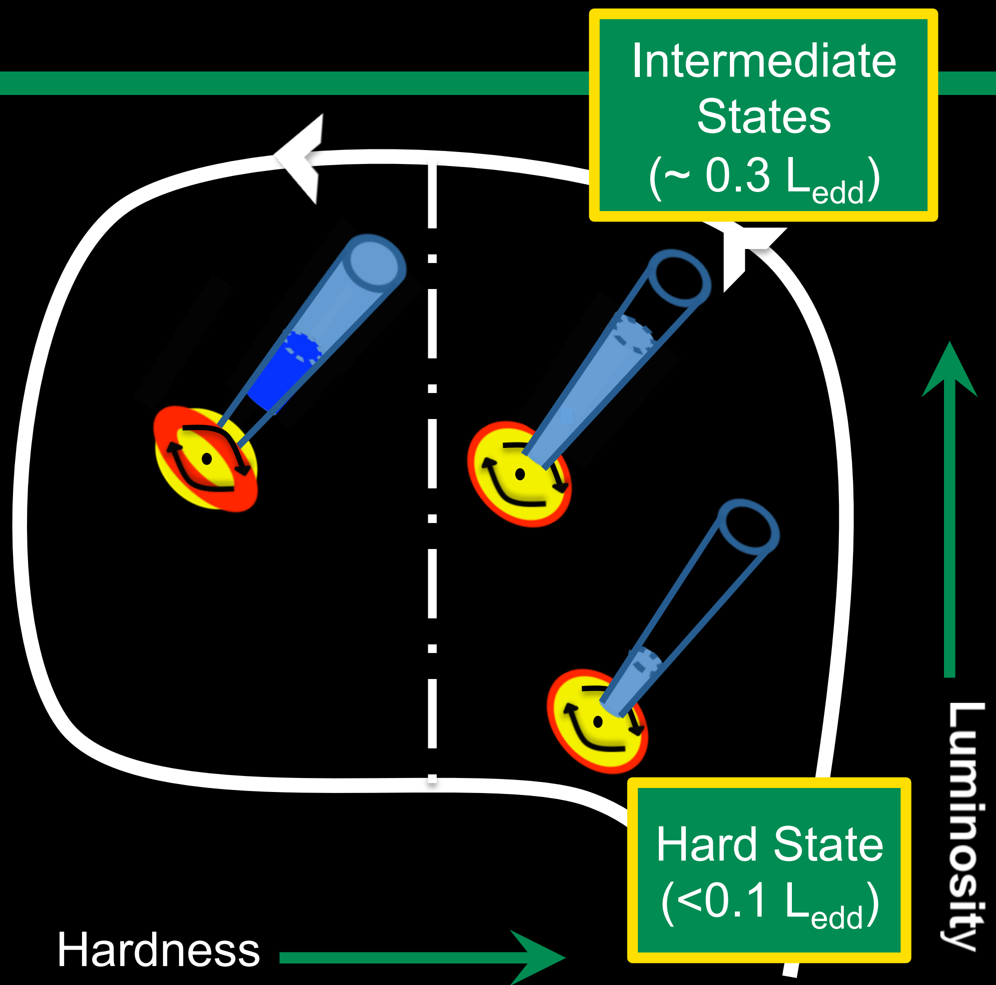
Outburst and Jet Behaviour



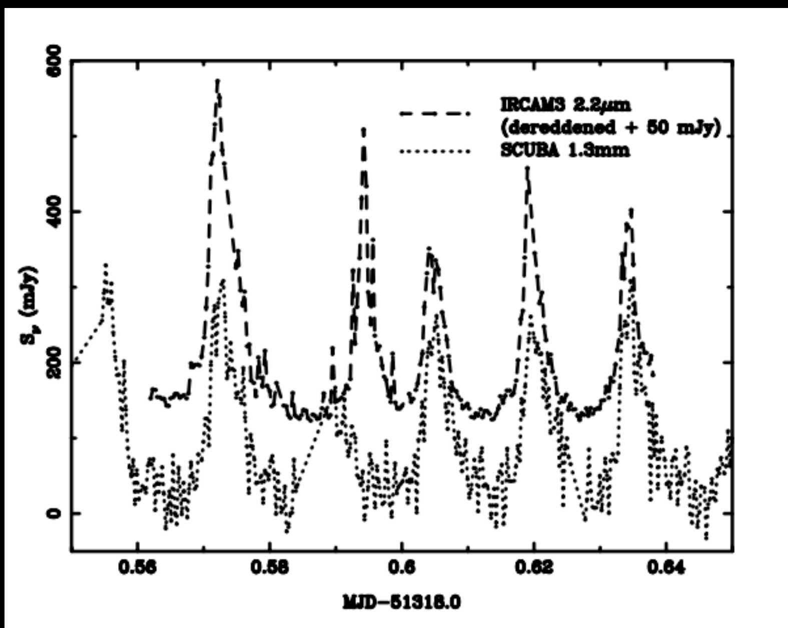


Outburst and Jet Behaviour

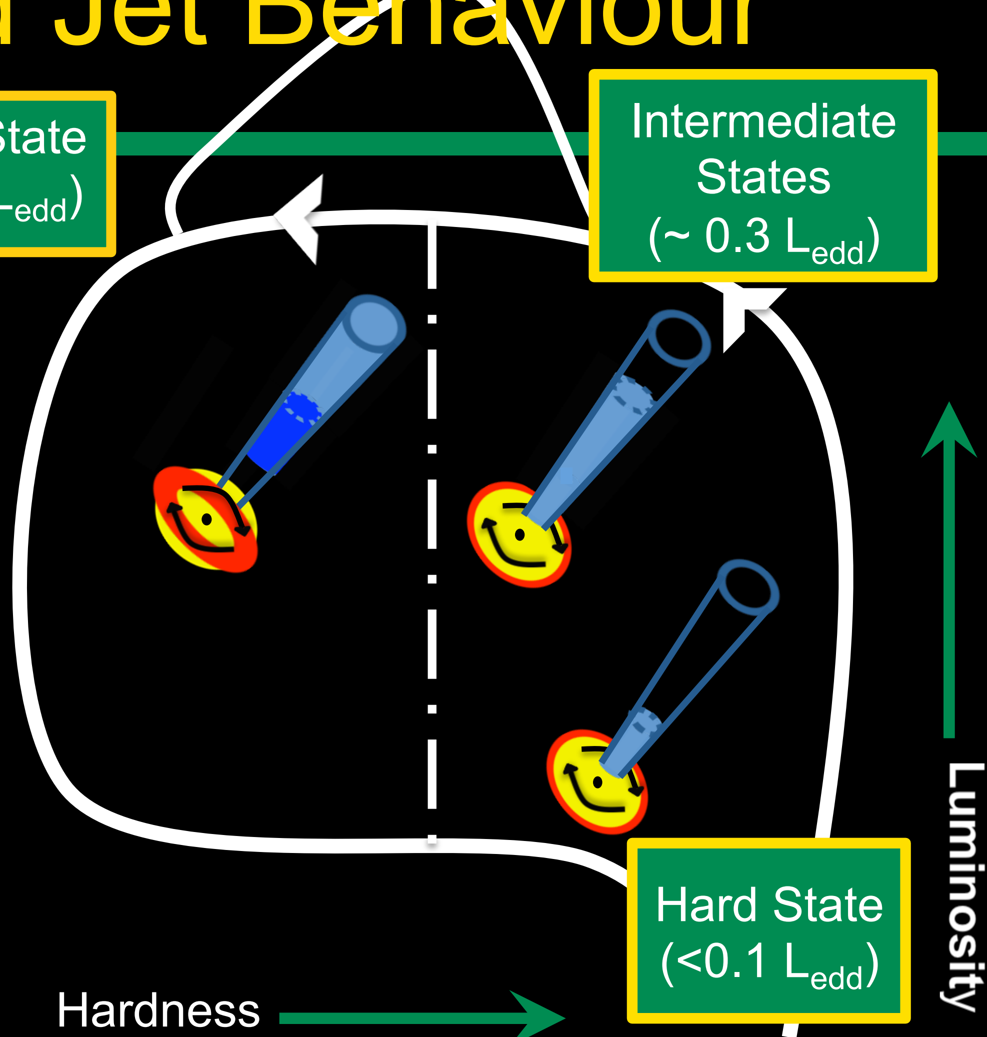




Outburst and Jet Behaviour

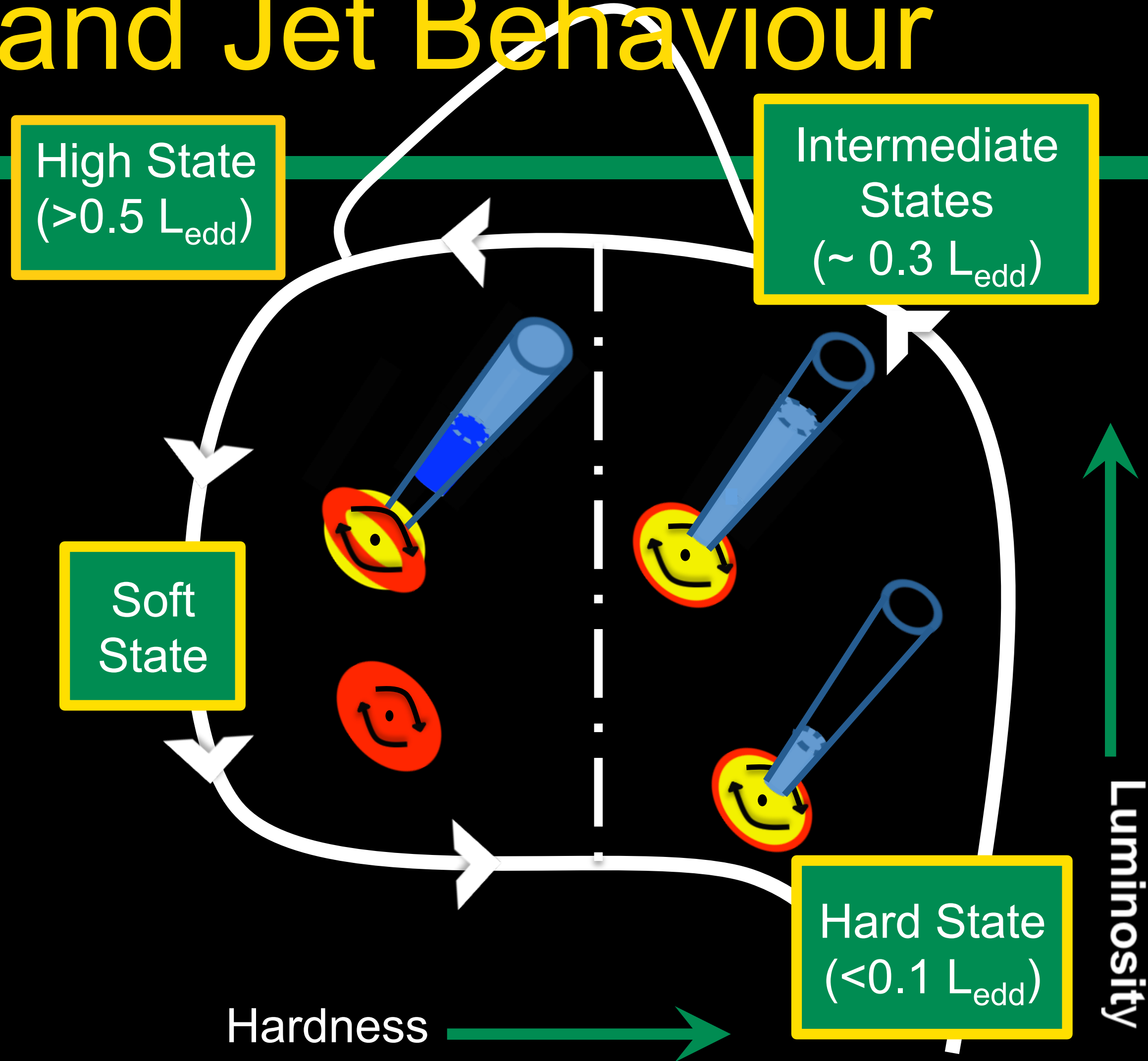


Fender & Pooley, 2000



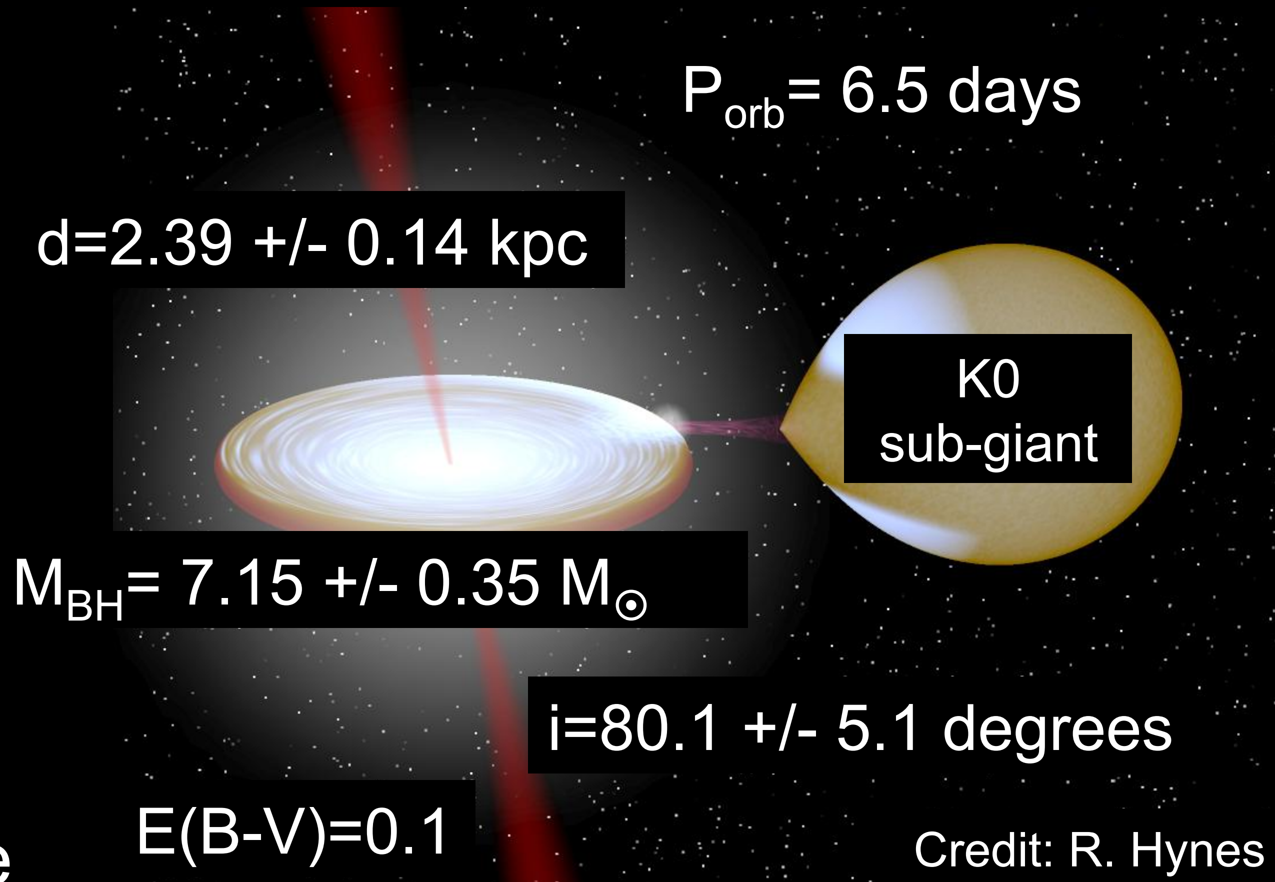
Outburst and Jet Behaviour

Jet quenched in soft state



V404 Cygni

- Prolonged quiescent period of 26 yrs.
- Well determined system parameters
- Low optical extinction
- Parallax distance

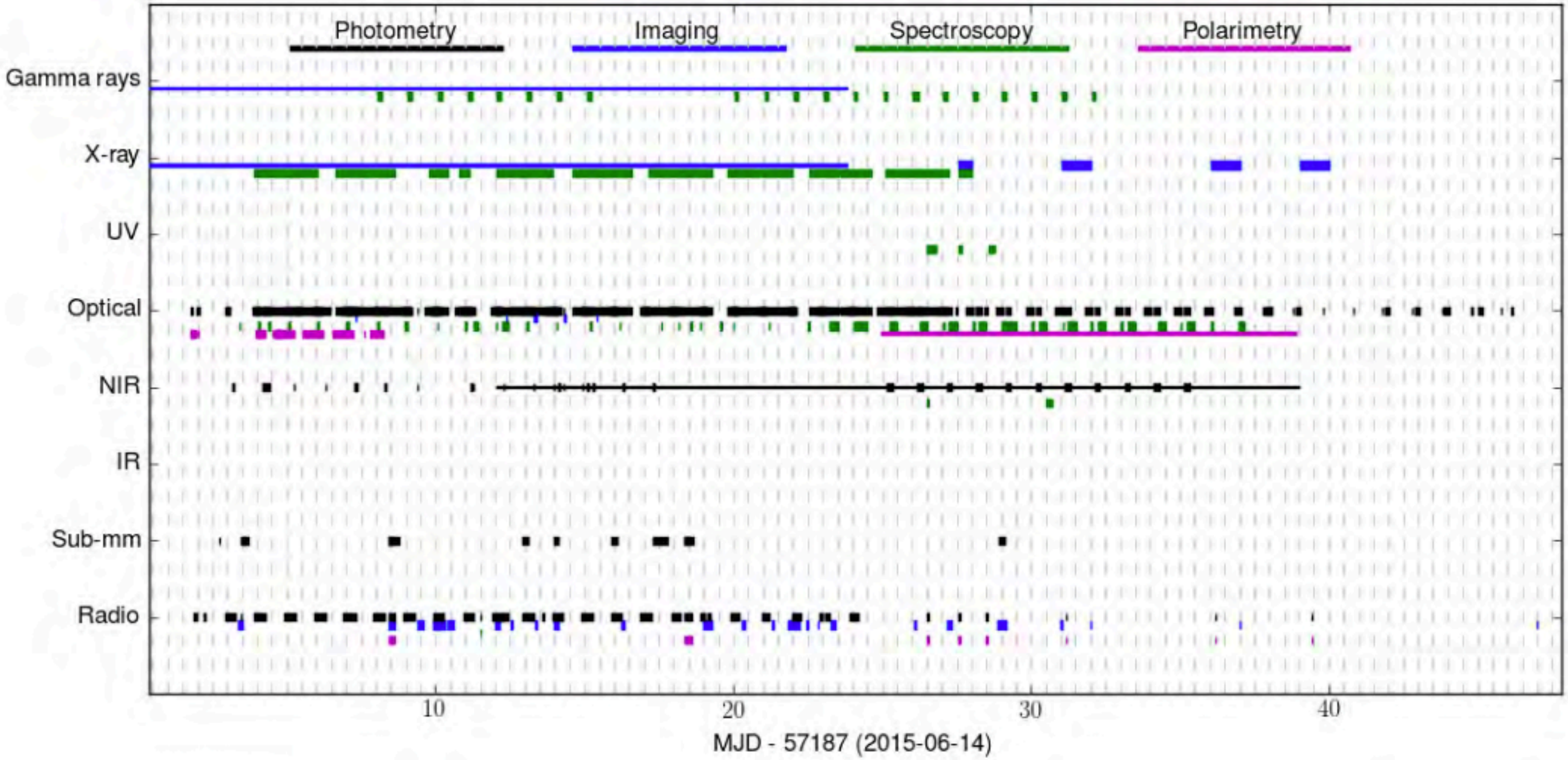


June 2015 Outburst

- On June 15, 2015 X-ray flaring activity detected by Swift BAT, MAXI and INTEGRAL
- Extraordinary mutli-wavelength flaring activity followed
- Brightest BHXB outburst in the past decade

Rare, bright accretion state + Well-known system parameters + Close Proximity

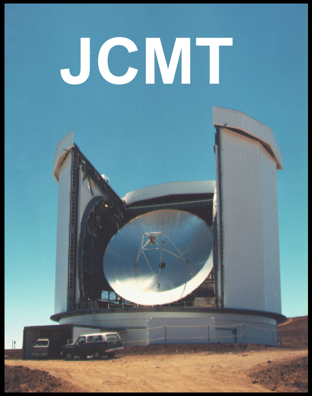
June 2015 Outburst



http://deneb.astro.warwick.ac.uk/phsaap/v404cyg/data/

The “Golden Data Set”

+



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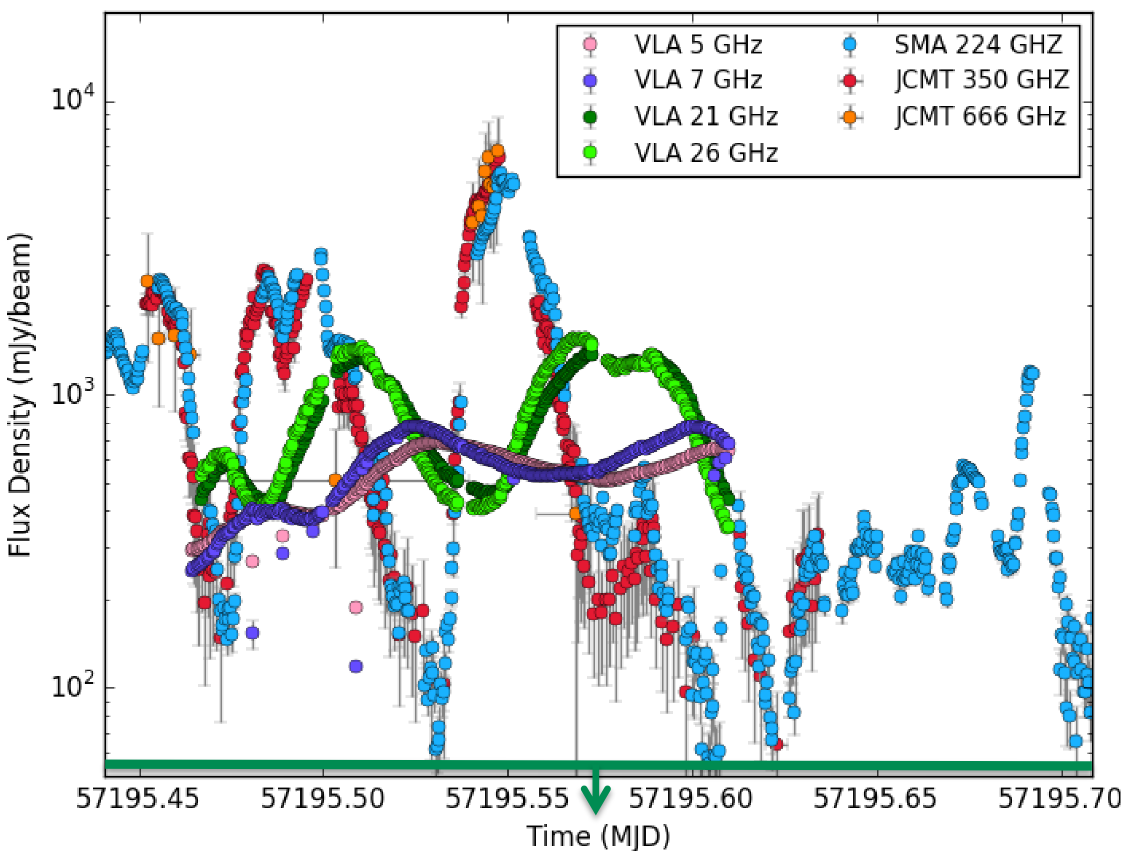
Unprecedented multi-wavelength view

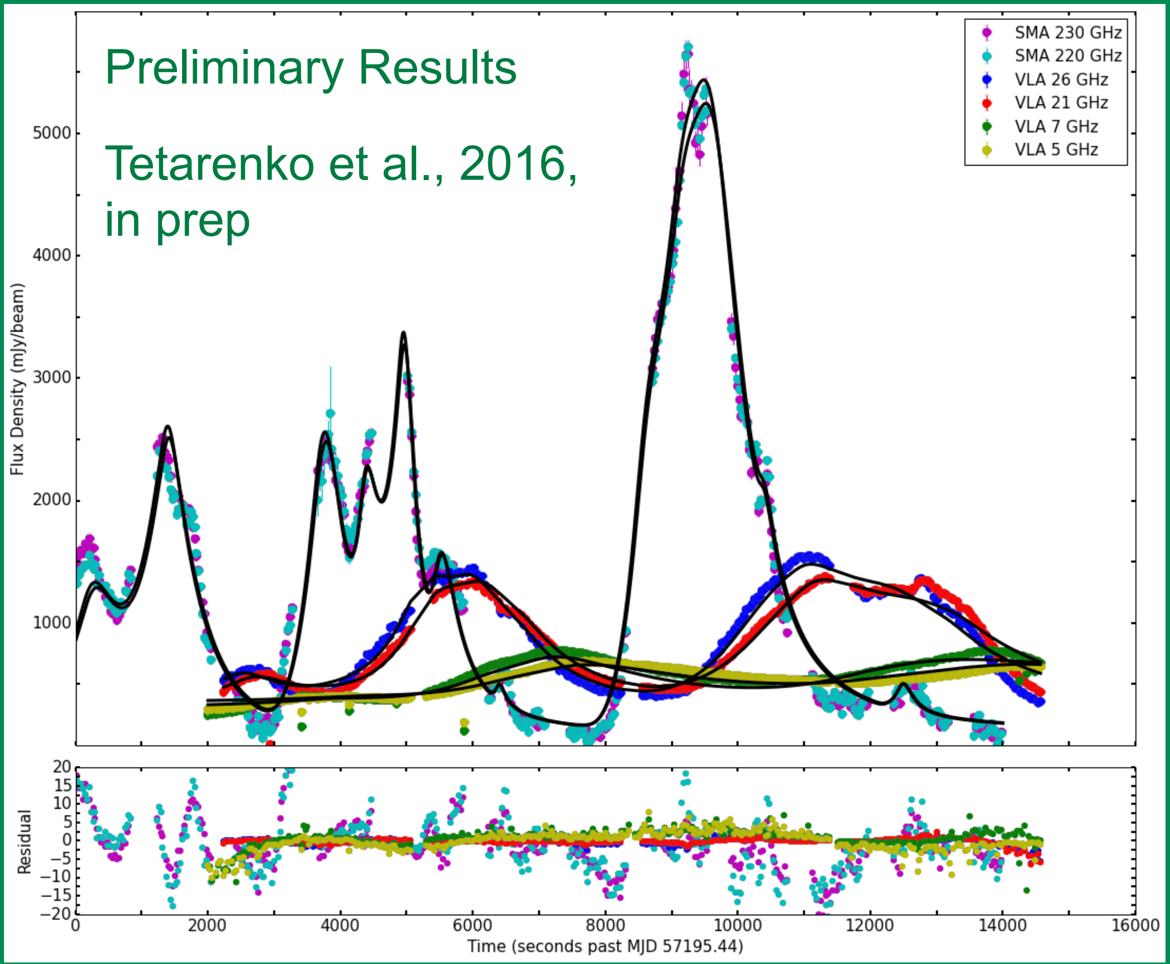
"Golden Data Set" Part 1

Tetarenko et al., 2016, in prep



- Flares reach extremely bright flux levels
- Lower ν are delayed, smoothed version of higher ν
- (sub-)mm substructure not visible in cm emission

Light Curve Modeling

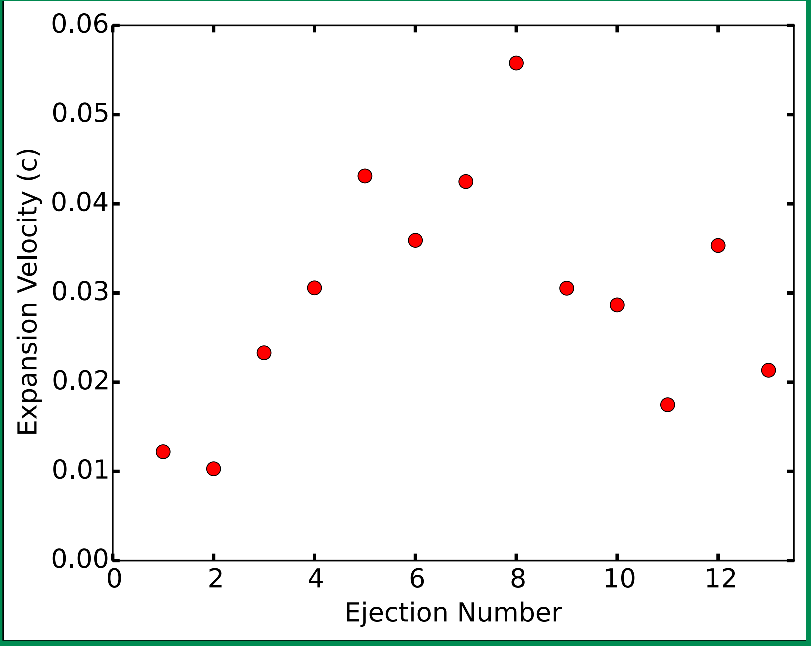


- Simultaneously fit all 6 frequencies with MCMC algorithm
- Light curves well described by van der Laan Models
- 13 ejection events!

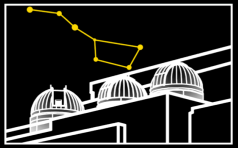
Modeling the Ejecta

- We can model each ejection with,
  - Ejection time
  - Peak Flux
  - Expansion speed
  - Optical depth/p
- We adopt linear expansion model + deceleration

Preliminary Results



$v_{exp} \sim 0.01\text{-}0.05$ c



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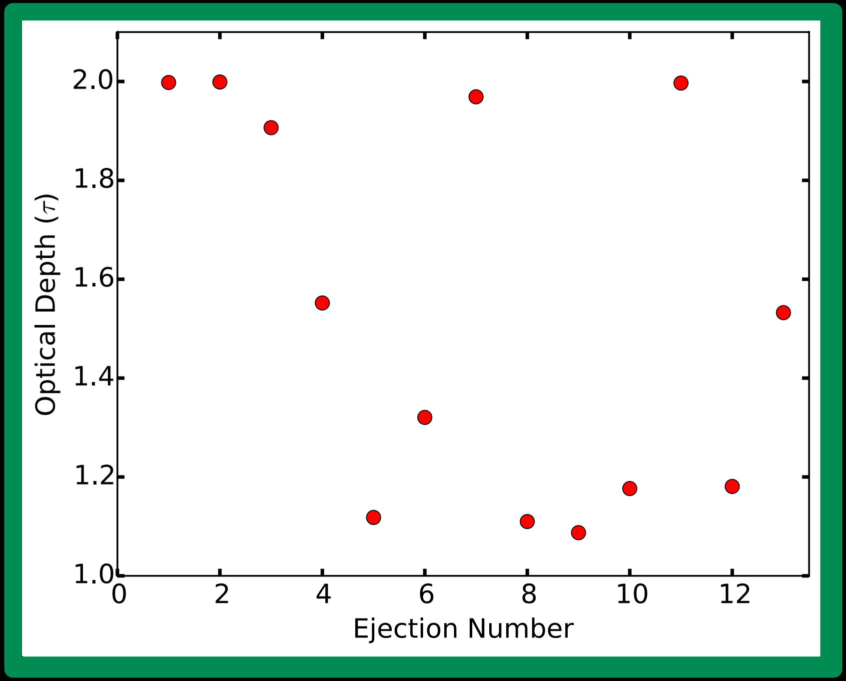

$\tau \sim 1.0\text{-}2.0$

Modeling the Ejecta

- We can model each ejection with,
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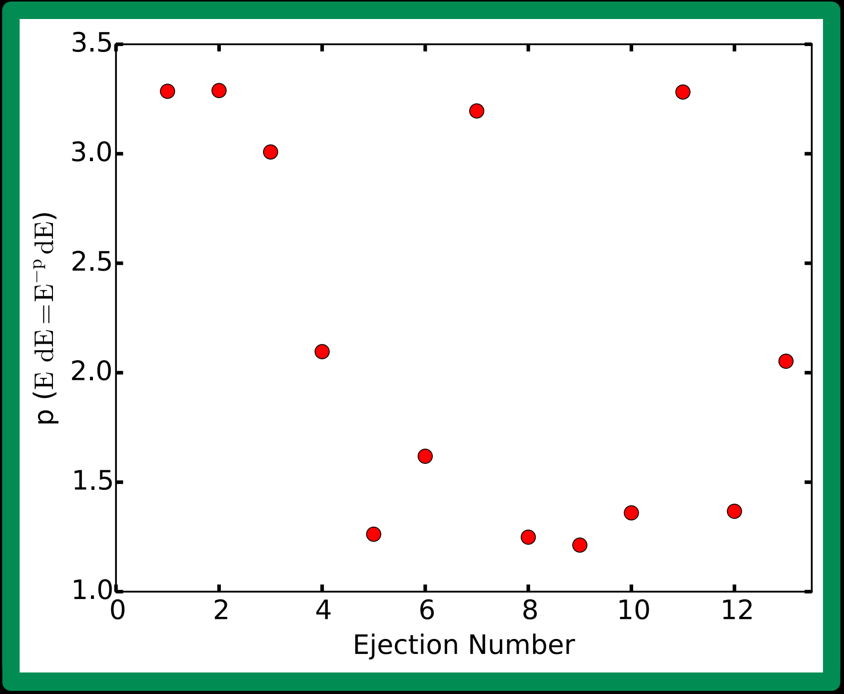
Preliminary Results

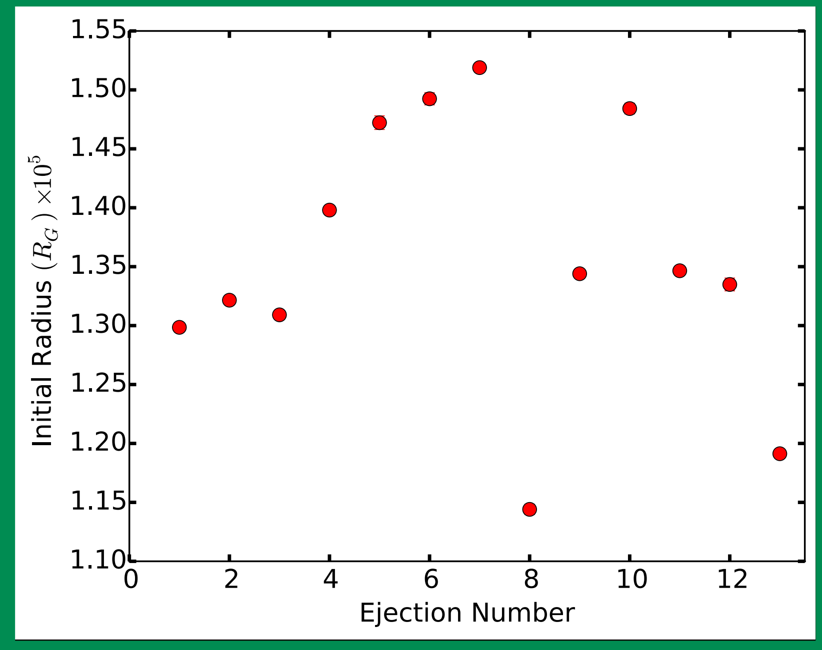


p ~ 1.0-3.0

Modeling the Ejecta

- Estimate ejecta size scales
  - Initial radius at moment of particle injection
  - Track changes as a function of time and frequency

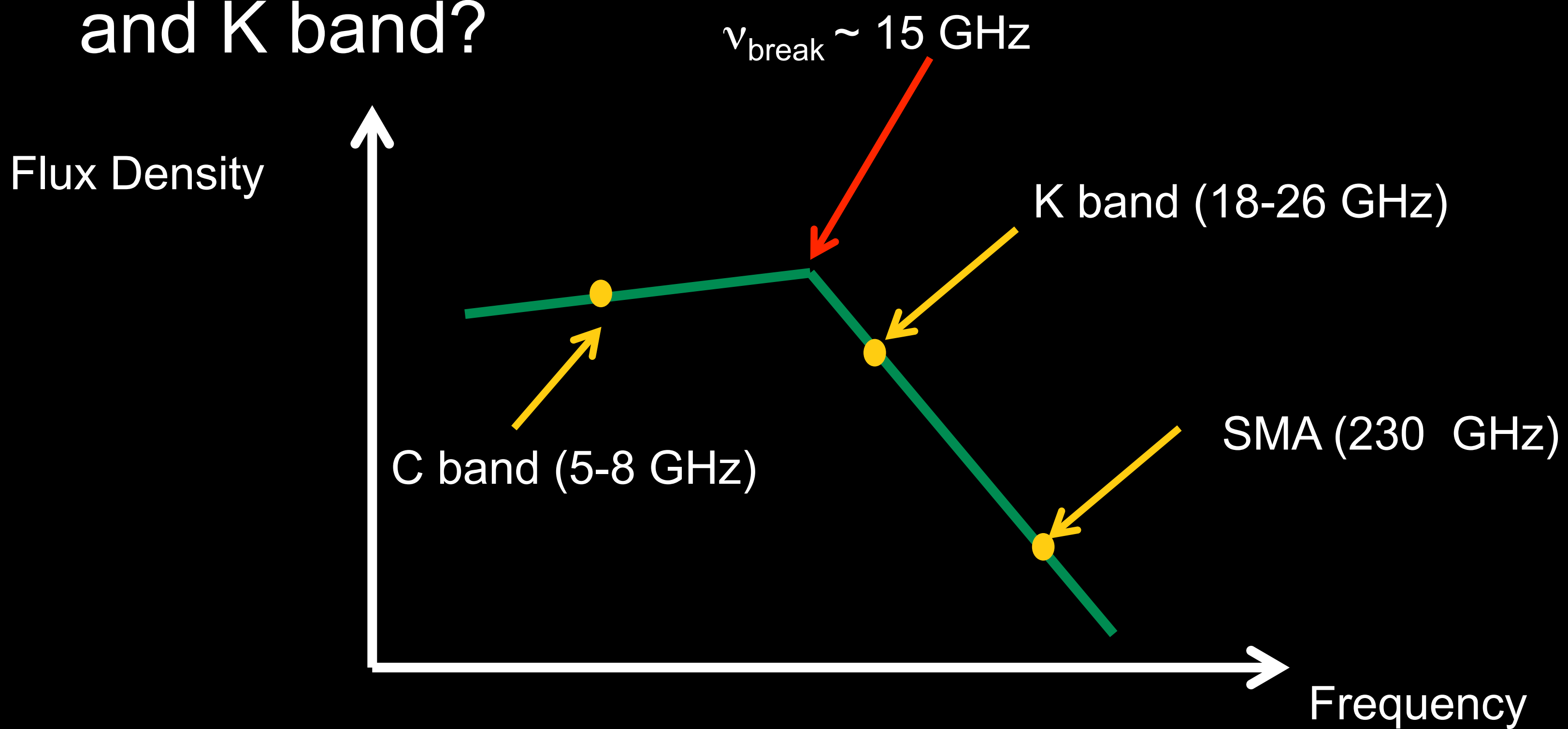
Preliminary Results



Initial Radii ~ 10^5 R_G

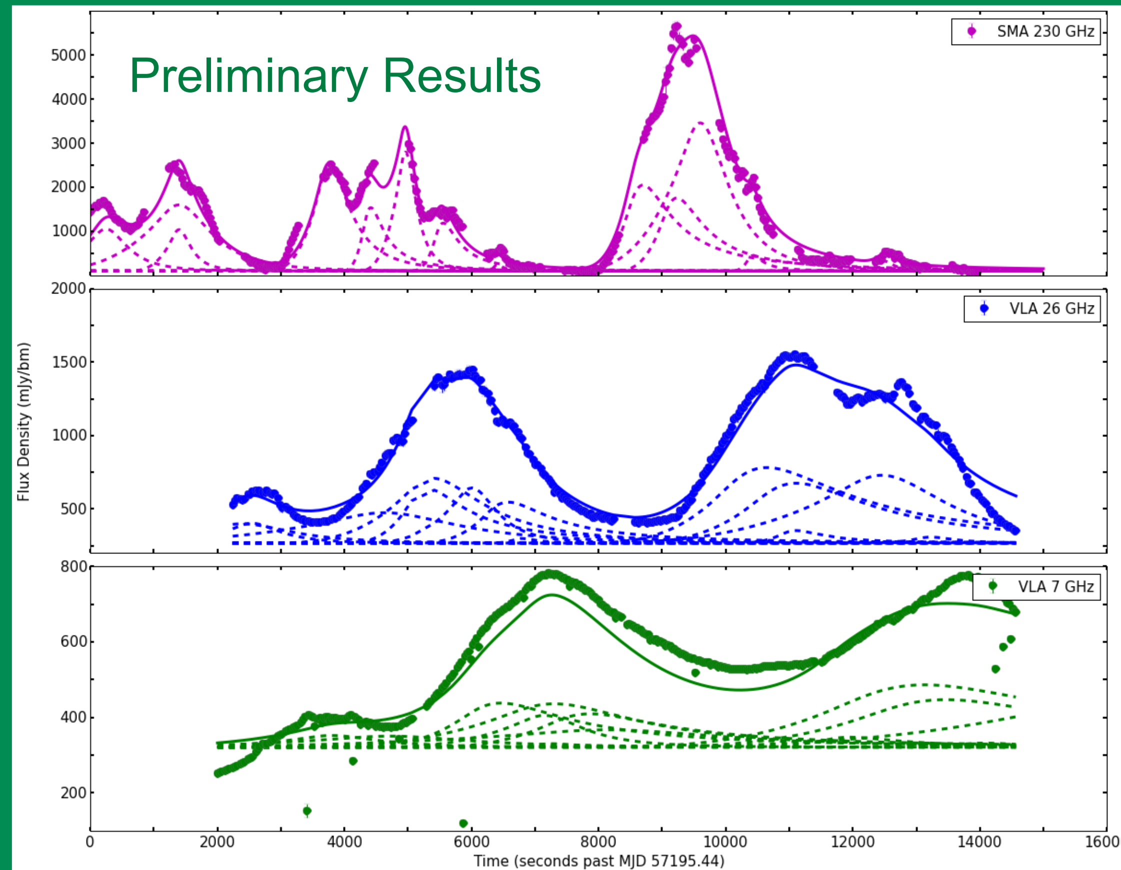
Modeling the Compact Jet

- Could the jet spectral break occur between C and K band?



Importance of the mm/sub-mm

- Substructure in mm/sub-mm light curves critical in modeling
- Why not include JCMT data?
- Evolution in C band?



Tetarenko et al., 2016, in prep

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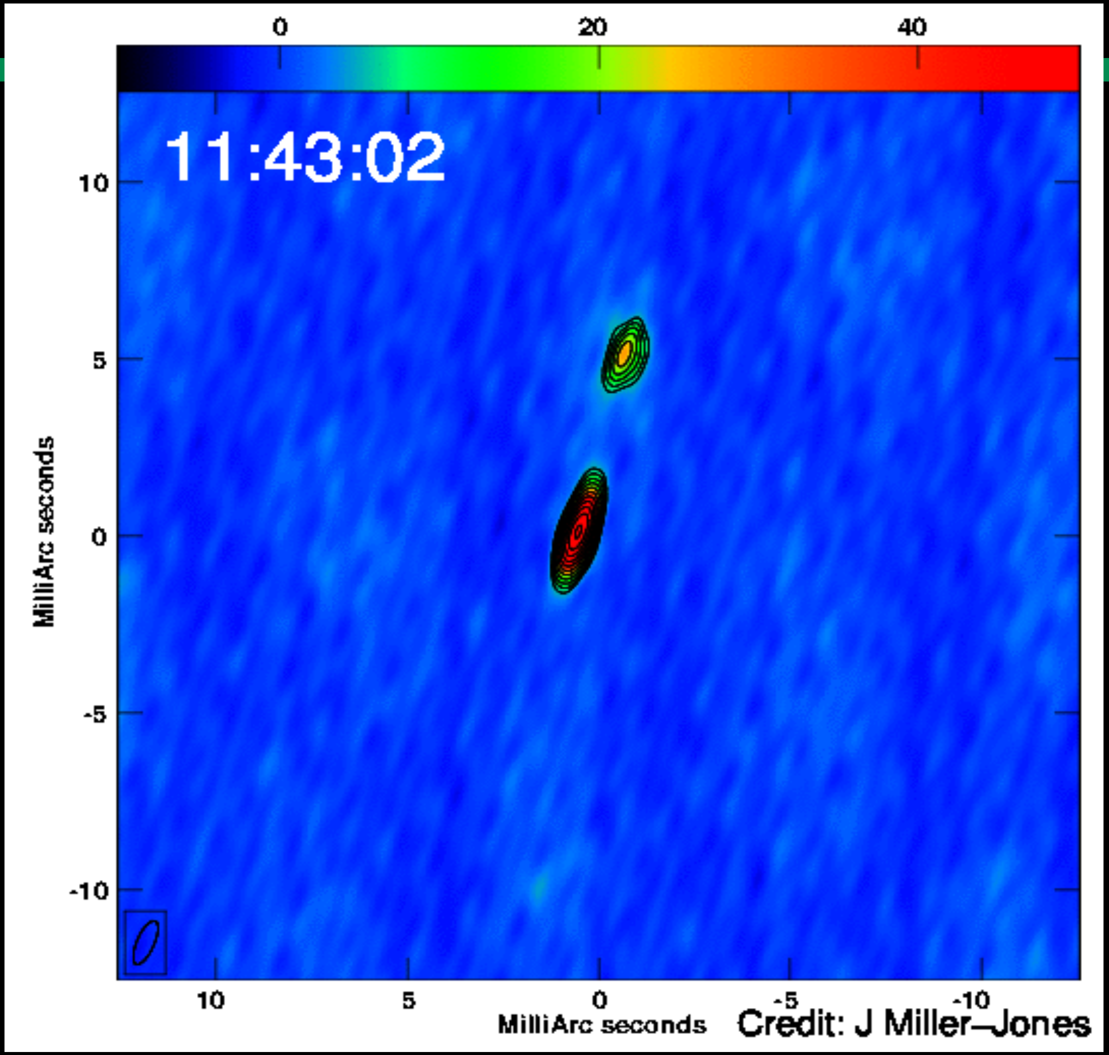
“Golden Data Set” Part 2

VLBA Movie

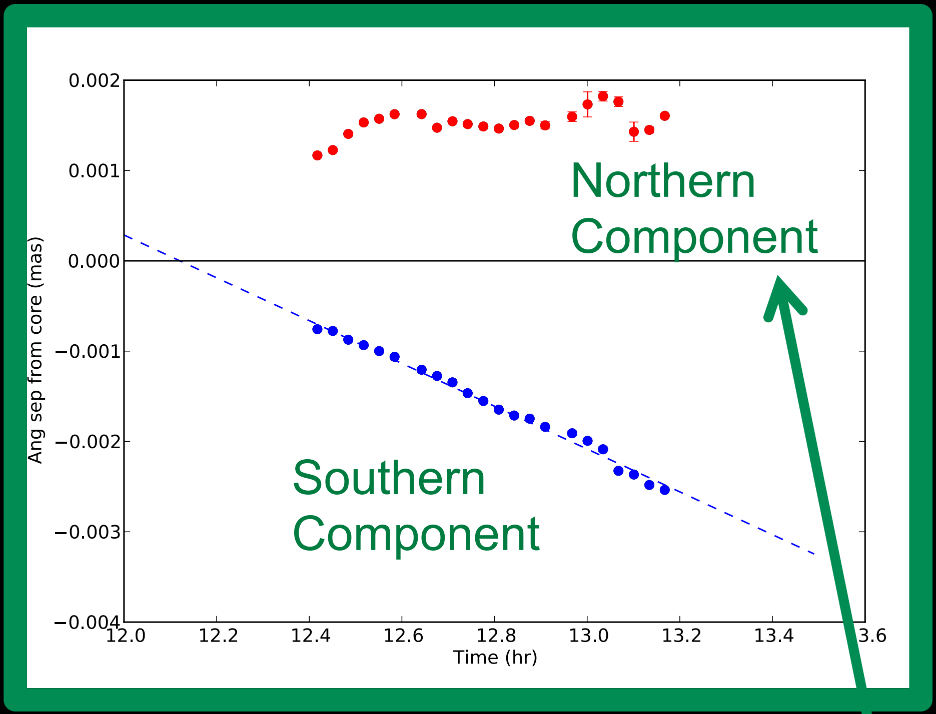


Preliminary Results

Tetarenko et al., 2016, in prep

VLBA Imaging

- Imaging and self-calibration procedure of > 100 individual frames
- Astrometric Measurments:
  - Proper Motion
  - Bulk Jet Speed
  - Ejection Times
- VLBA ejection times coincide with those inferred from our modeling!



Tetarenko et al., 2016, in prep

Preliminary measurements suggest atypical behavior of some ejecta

Combining the Two

- Unique probes of jet speed, structure and size scale
- This is the first time expansion speeds and proper motions of ejecta have been simultaneously measured!

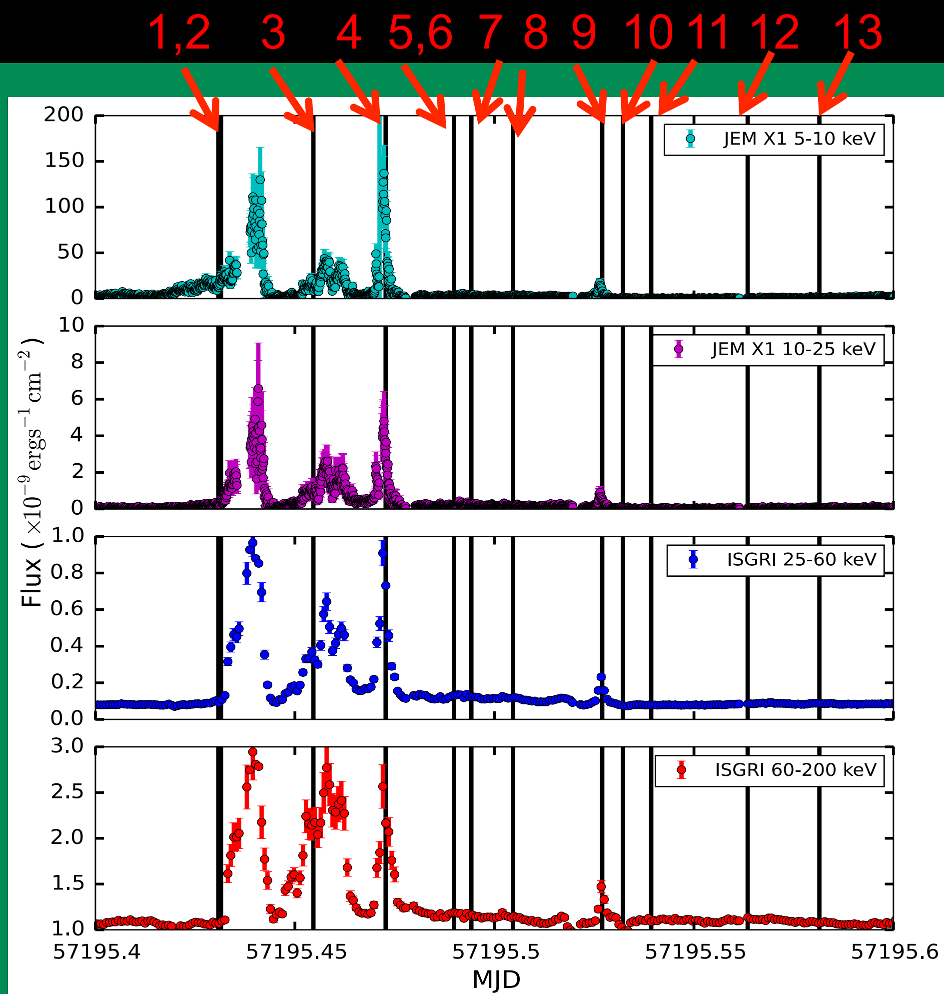
v_{exp}~ 0.01-0.05c

+

μ~ 0.25-0.50c

Opening angle ~ 3-4 degrees

Relationship to X-ray Emission



Data from Rodriguez et al., 2015

- Predicted ejection times do not appear to correlate well with X-ray emission
- Does the X-ray probe synchrotron emission from jet or accretion flow emission?

Preliminary Results
Tetarenko et al., 2016, in prep

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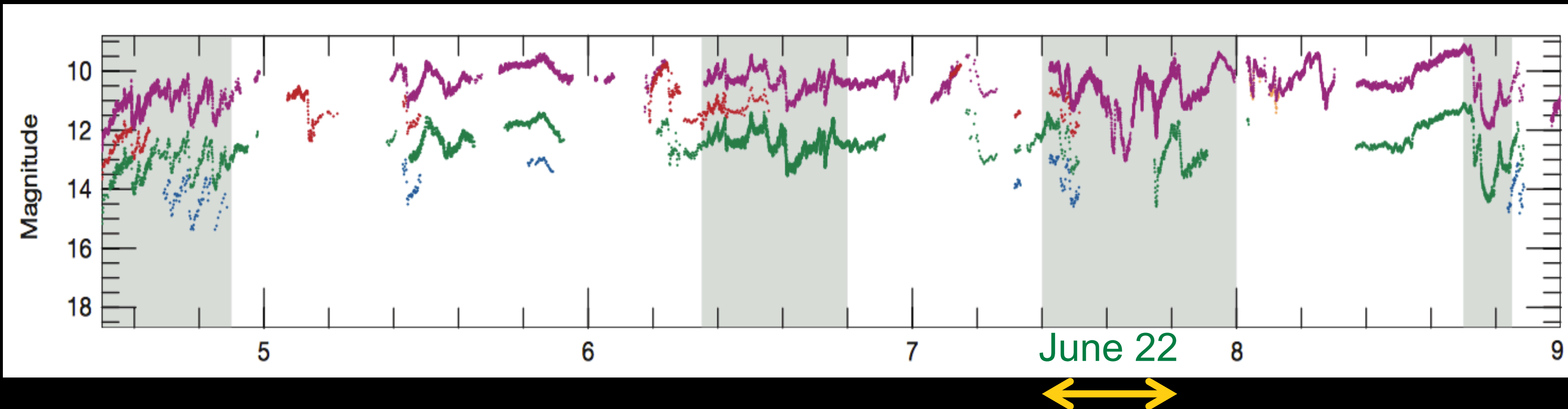
Relationship to Optical Emission

Mariko Kimura, et al. 2015



- Dip-type oscillations are seen at optical wavelengths.
- Same type of oscillations seen in GRS 1915+105, associated with repeated ejection and refilling of inner disk.

Comparing to GRS 1915+105

- Only other source to show repeated multi-wavelength flaring

<u>Similarities</u>

- Enter high luminosity state
- Repeated flaring events
- Low frequencies delayed versions of high frequencies

<u>Differences</u>

- Rise and decay times similar at all frequencies
- No jet ejecta resolved with VLBA
- GRS 1915+105 in outburst state for last 25yrs, V404 transient

High Time Resolution Measurements

- Our team has developed a custom timing script for interferometric data that runs in CASA
- Produces light curves on user specified time bin
- Many customizable options:
  - UV or Image plane
  - Object Detection
  - Fixed Target Position
  - And many more…

SKA/AWS

ASTROCOMPUTE IN THE CLOUD

https://github.com/Astroua/AstroCompute_Scripts

Tetarenko & Koch et al., 2016, in prep

Summary

- Analysis is ongoing
- Simultaneous multi-wavelength coverage essential to unlocking complicated physics.
- Rapid response and specialized observing techniques, like sub-arrays and VLBI, make this possible.
- mm/sub-mm data provides a unique, more detailed view of the jet compared to cm.

Thank you!