SPECTROSCOPIC EVIDENCES FOR A LOW-MASS BLACK HOLE IN SWIFT J1753.5-0127

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Collaborators

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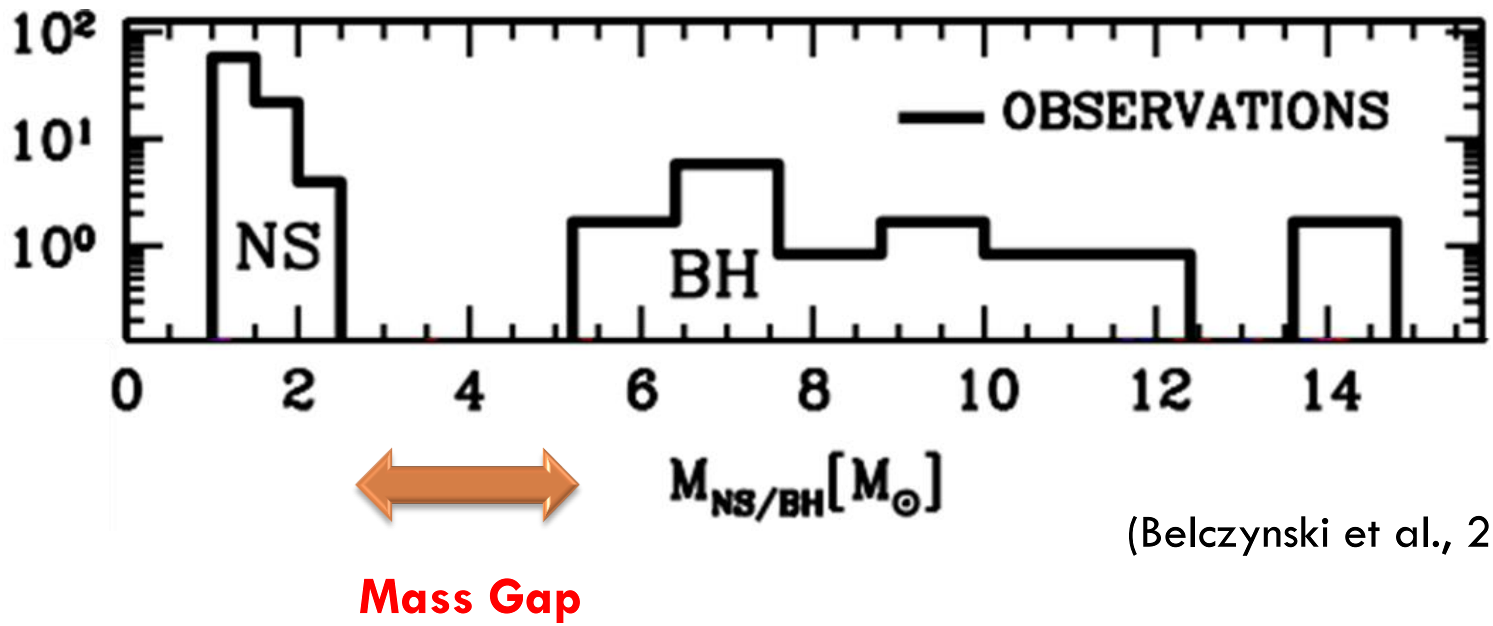
- AAVSO:
  - George Sjoberg

→ University of Turku

→ ESA/ESAC

Black Holes and mass distribution of compact objects

According to the current convention, the black holes are compact objects, whose measured masses exceed the limit of $3M_{\odot}$.



(Belczynski et al., 2012)

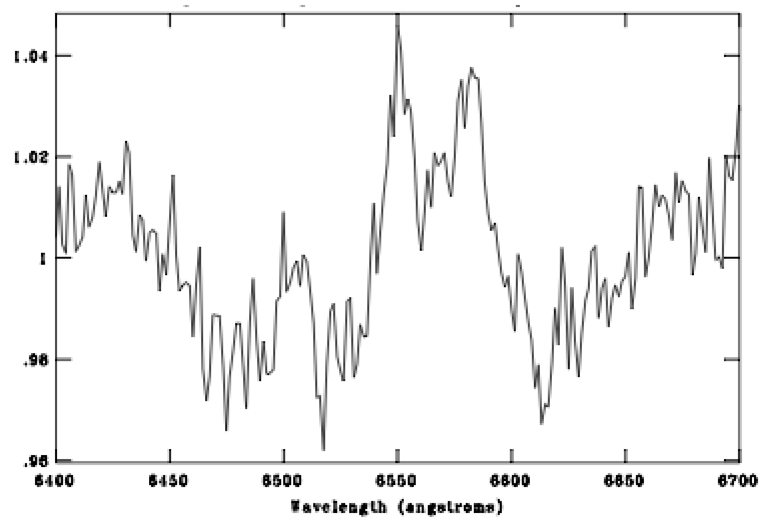
SWIFT J1753.5−0127

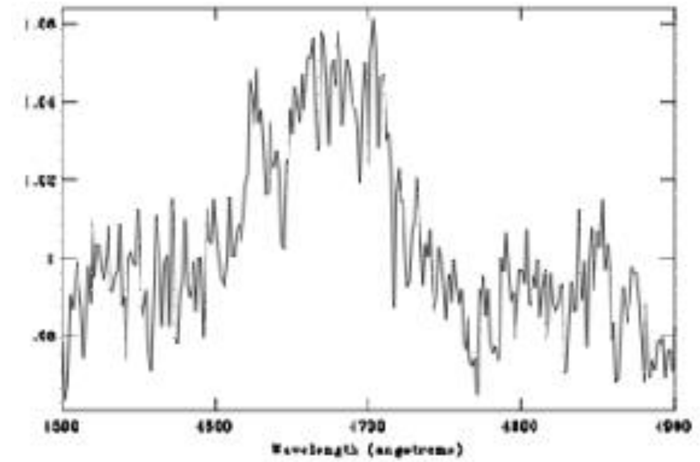
- An atypical X-ray transient system: the outburst was reported on 2005 May 30 and is still on-going (**already 9 years!**).
- SWIFT J1753.5−0127 shows, in an optical light curve, relatively strong modulations with a period of **3.24** h. They were attributed to a superhump period (Zurita et al. 2008).
- Observational properties evidence that the binary hosts a black hole. However, the mass of the primary **was not dynamically measured**.

Optical spectra

Double-peaked Hα and He II 4686 lines were observed immediately after the initial outburst

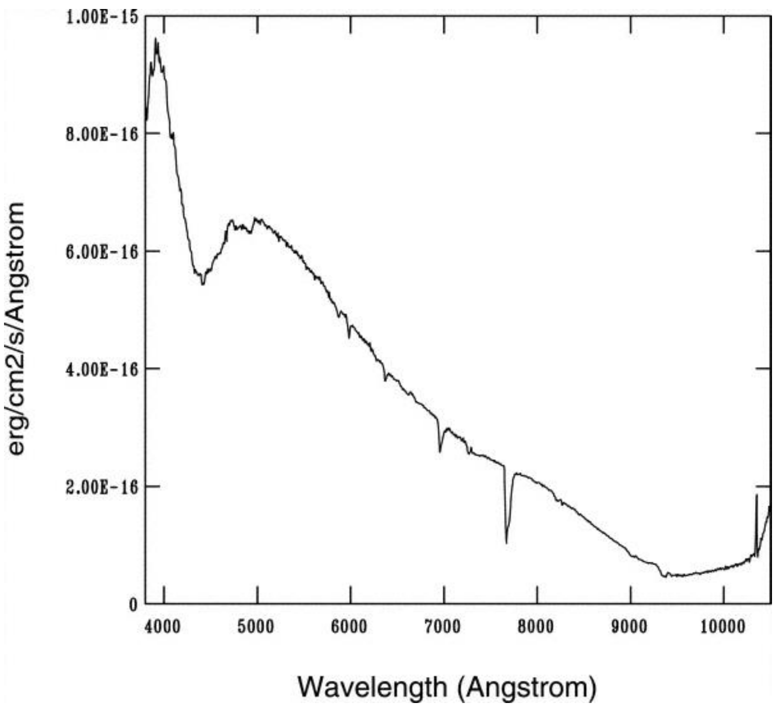
(Torres et al. 2005a, 2005b).



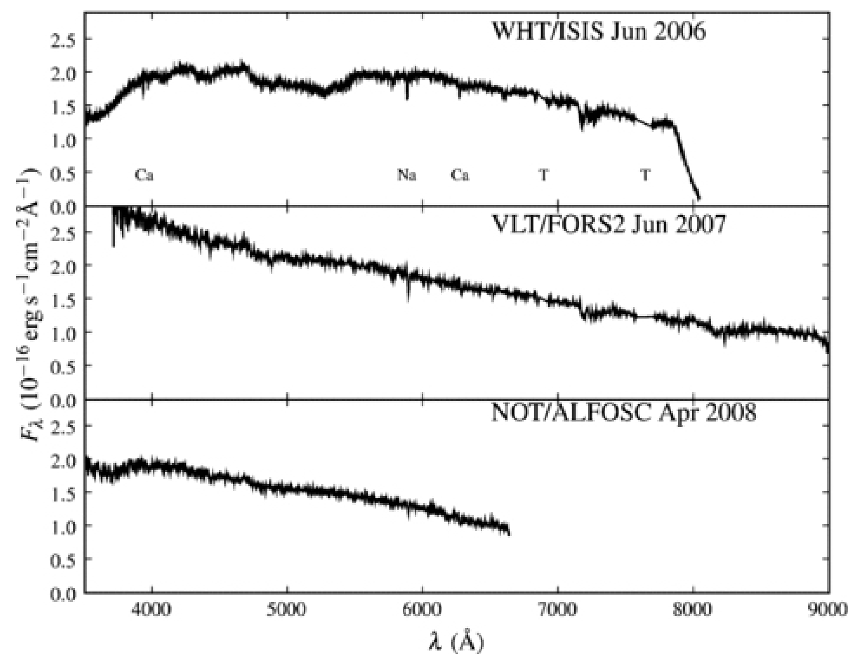


Optical spectra: no features

Cadolle Bel et al. (2007):
2005 August 11



Durant et al. (2009):
2006, 2007 and 2008.



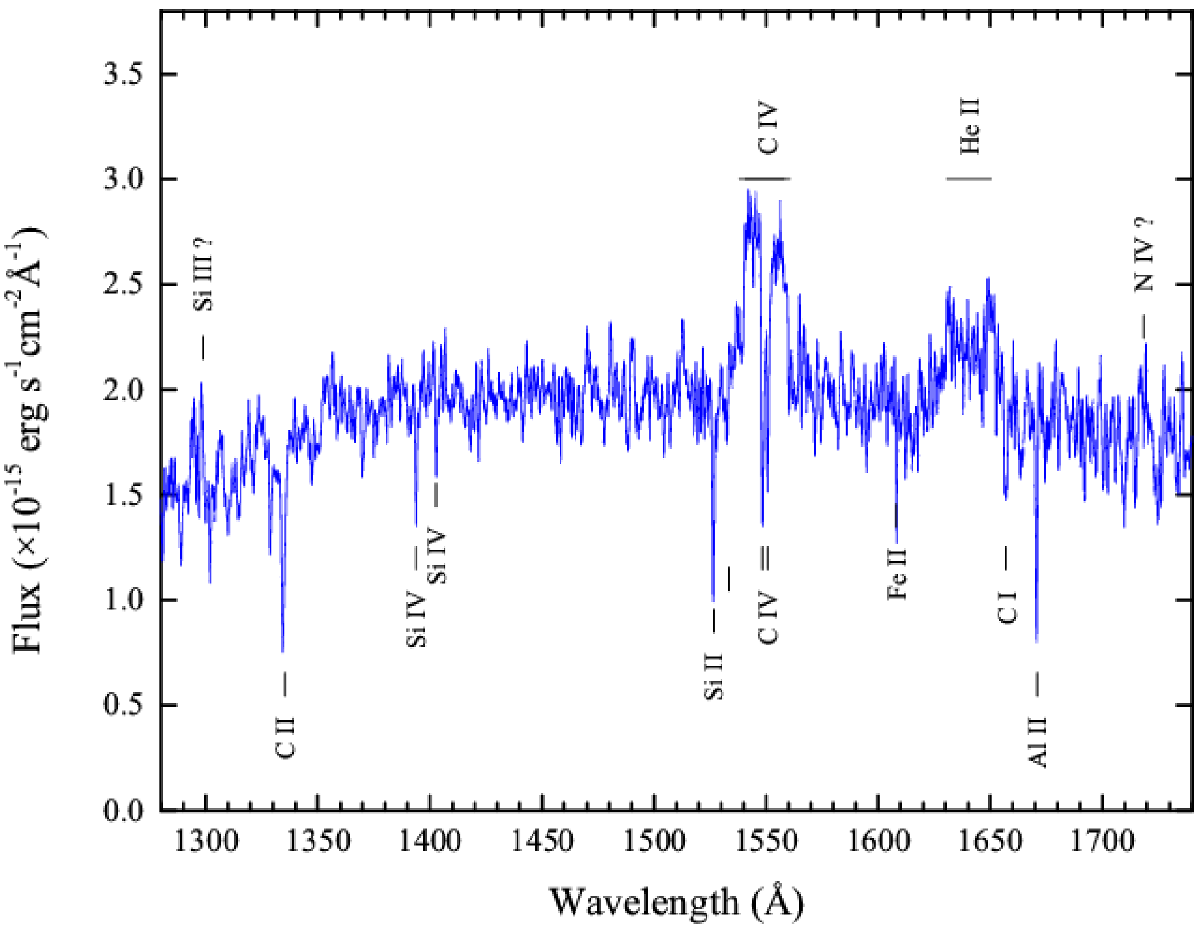
New Observations

- Far-UV HST/COS spectroscopy:
  - October 8, 2012: 2 orbits (~4000 sec)
    - The Far-UV G140L grating (spec. resolution ~0.5Å)
  - October 2, 2012 (Froning et al. 2013)
    - The Near-UV G230L grating
- OAN SPM optical spectroscopy:
  - August 2013: 54×15 min spectra (~4000–7000Å)
- Johnson- Cousins BVRI photometry
  - Several sets (2012-2013)

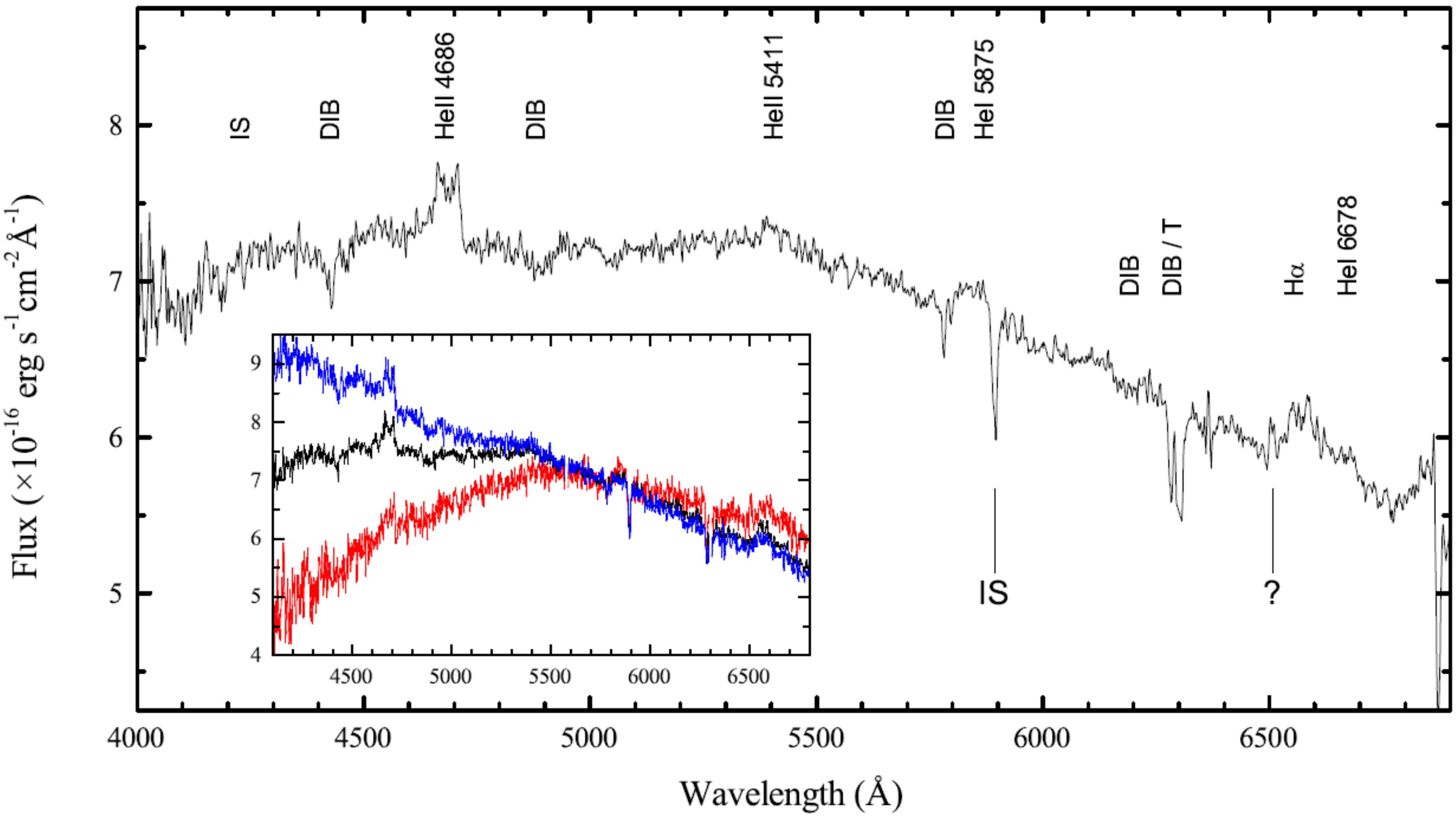
Far-UV HST/COS spectrum

The spectrum is dominated by broad and double-peaked emission lines of C IV and He II.

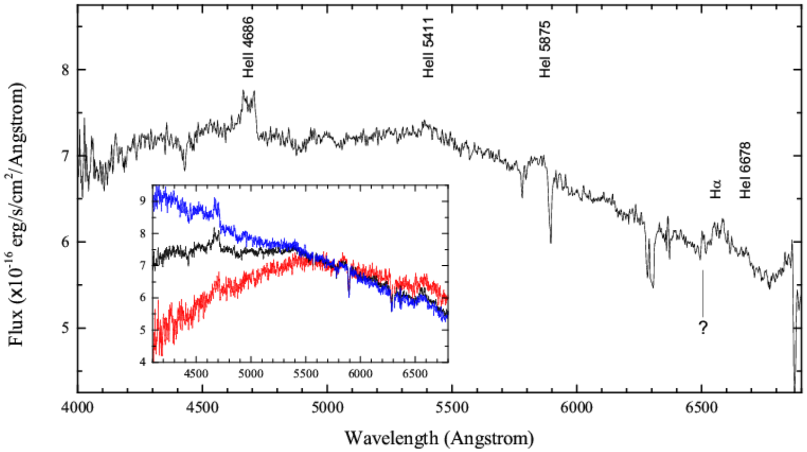
All absorption lines are of interstellar origin.

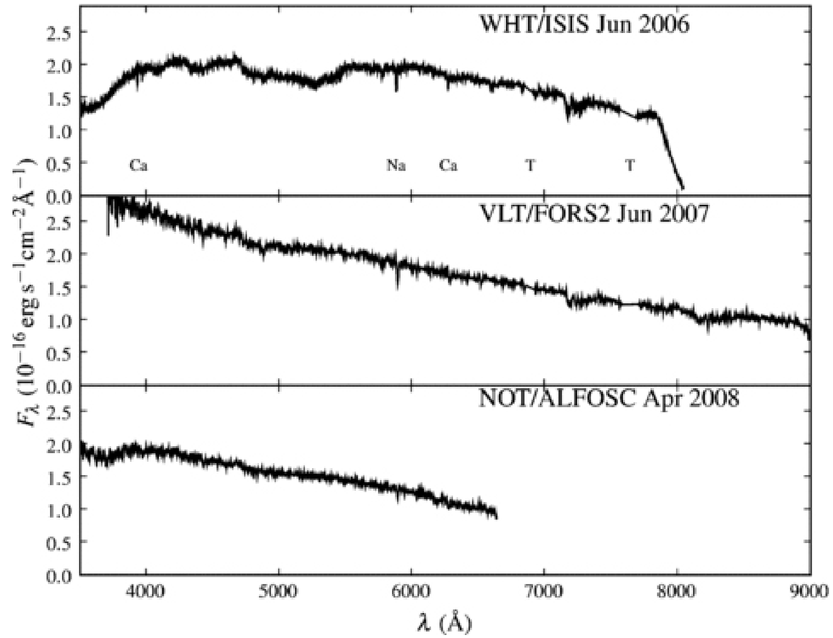


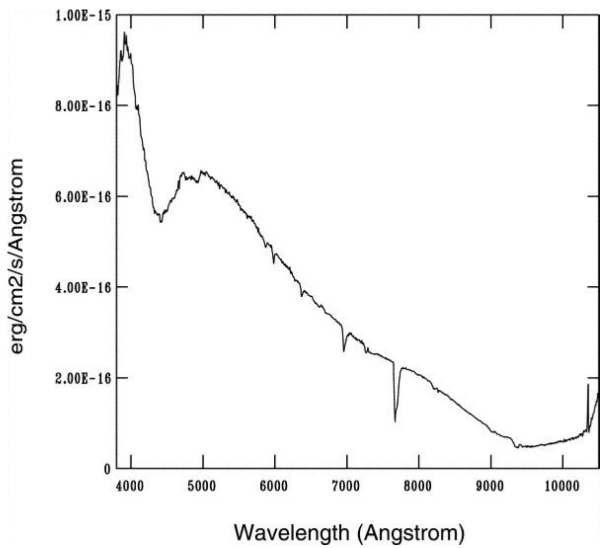
Optical spectrum



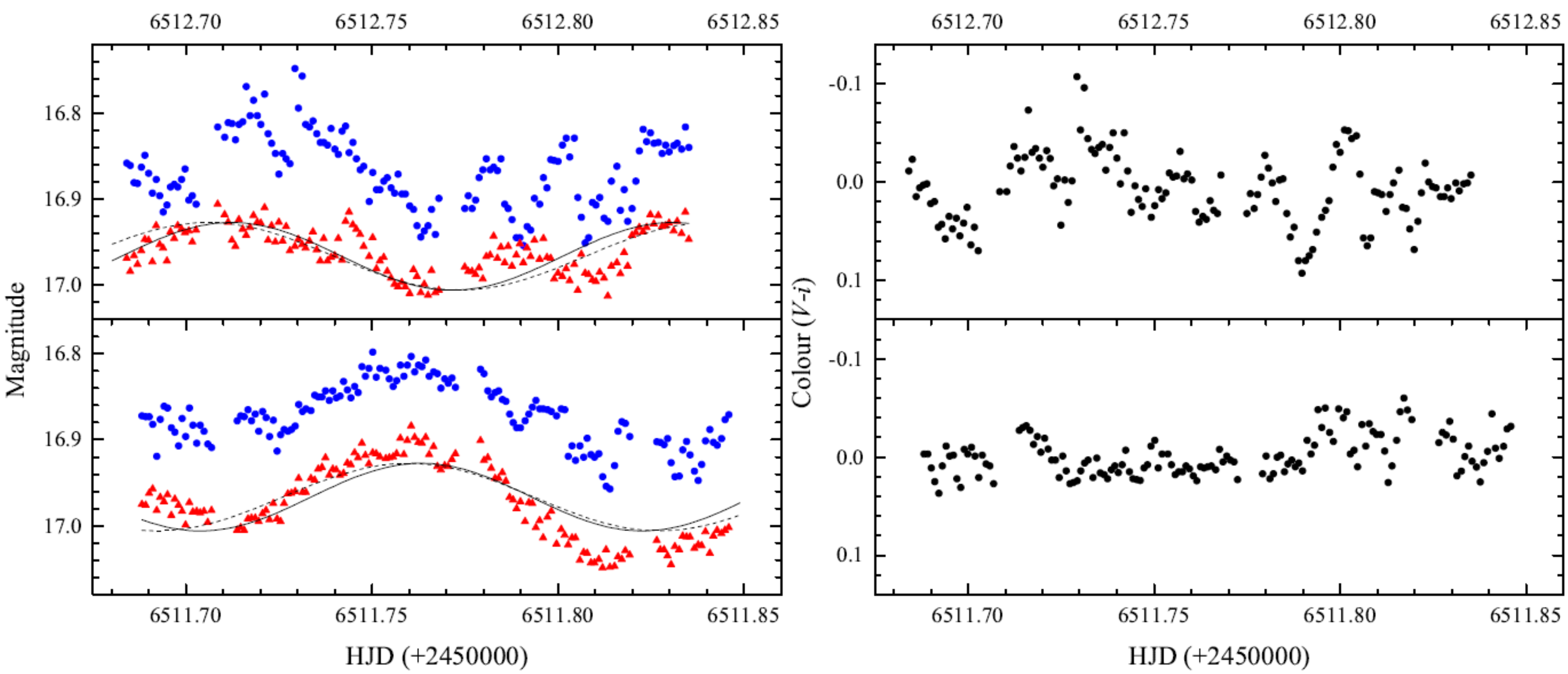
Optical spectrum





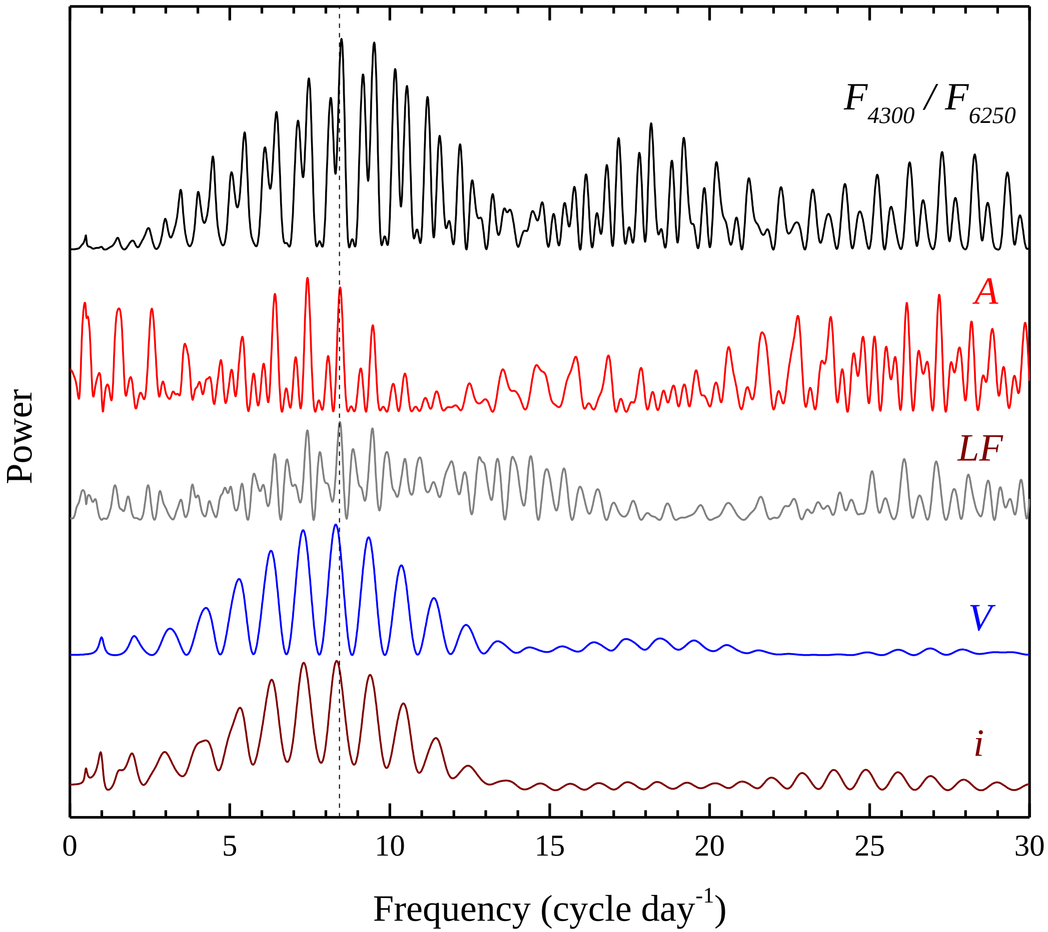


Optical photometry (*V* and *i* filters)



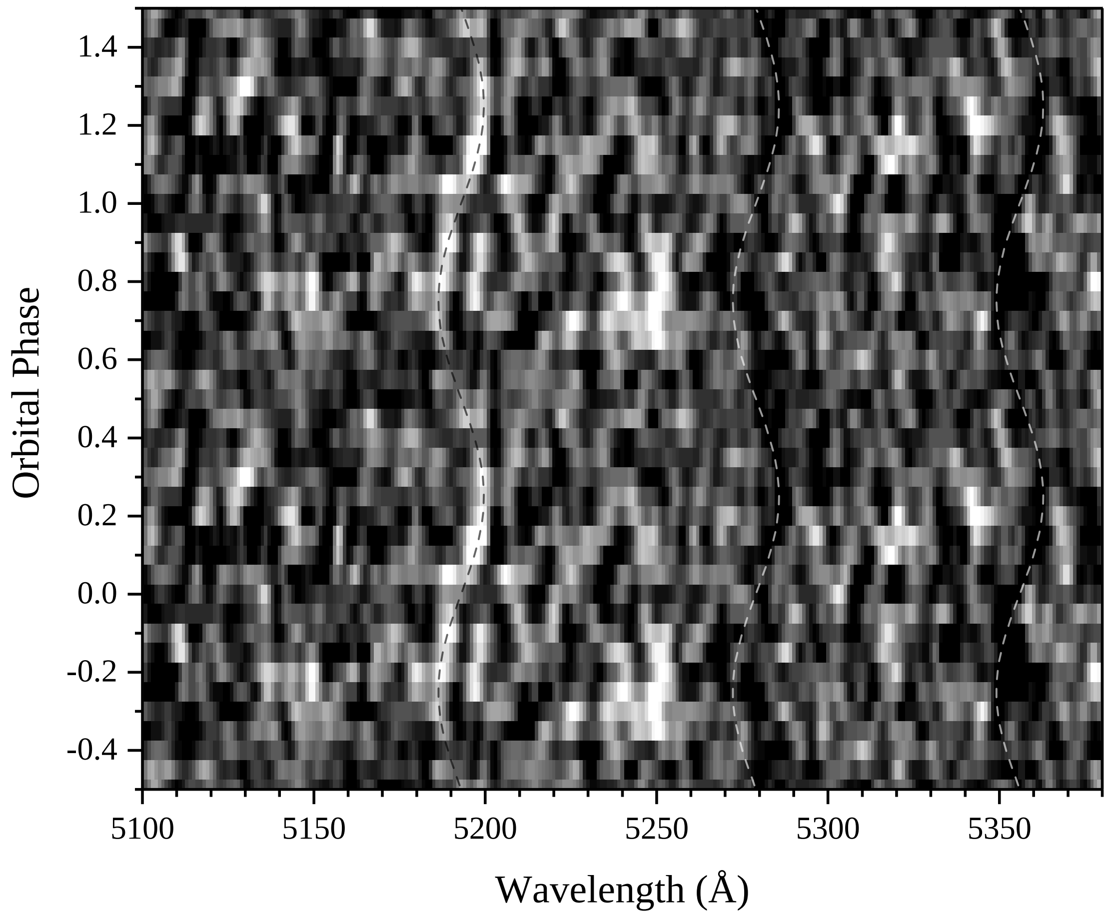
Orbital Period

The power spectra are dominated by a peak at **2.85 hr**, that is close to the one-day alias of Zurita et al.'s period.



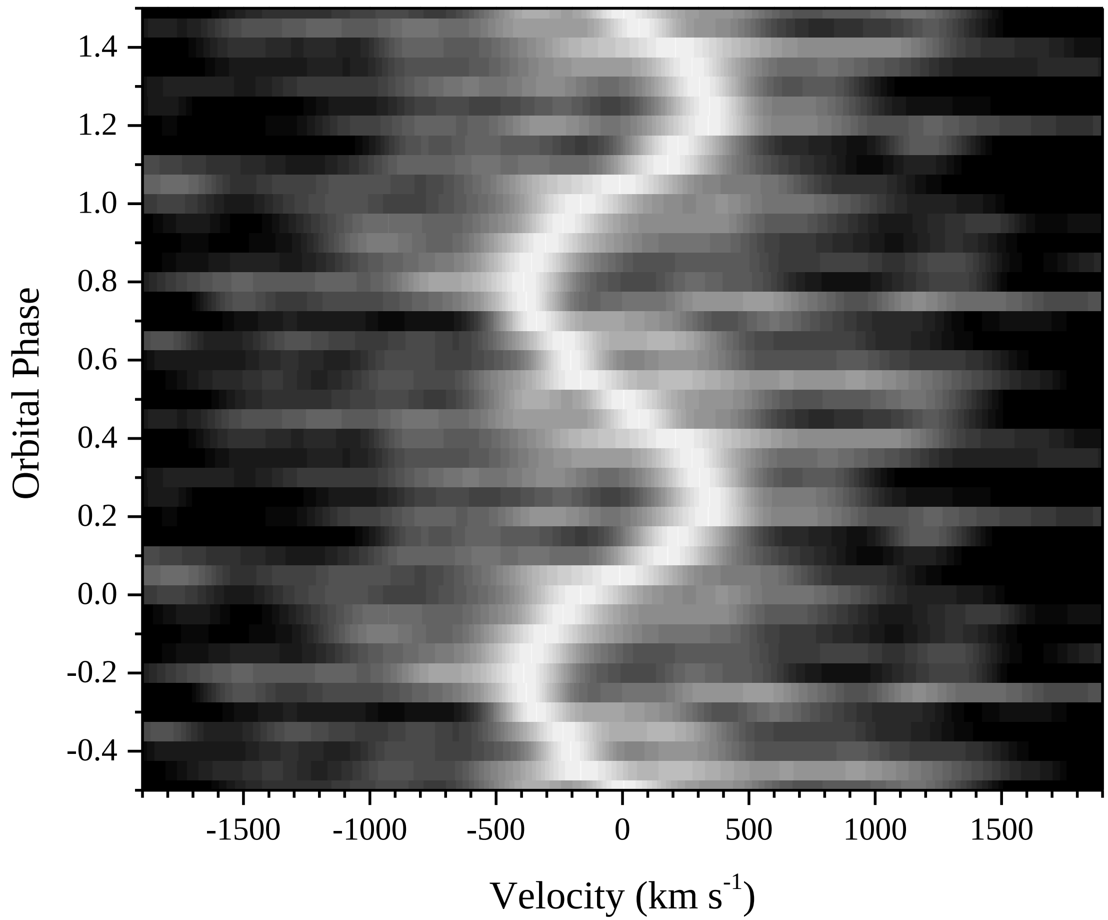
Radial Velocity of the Donor star

Trailed spectrum shows sinusoidal trails of absorption and emission features



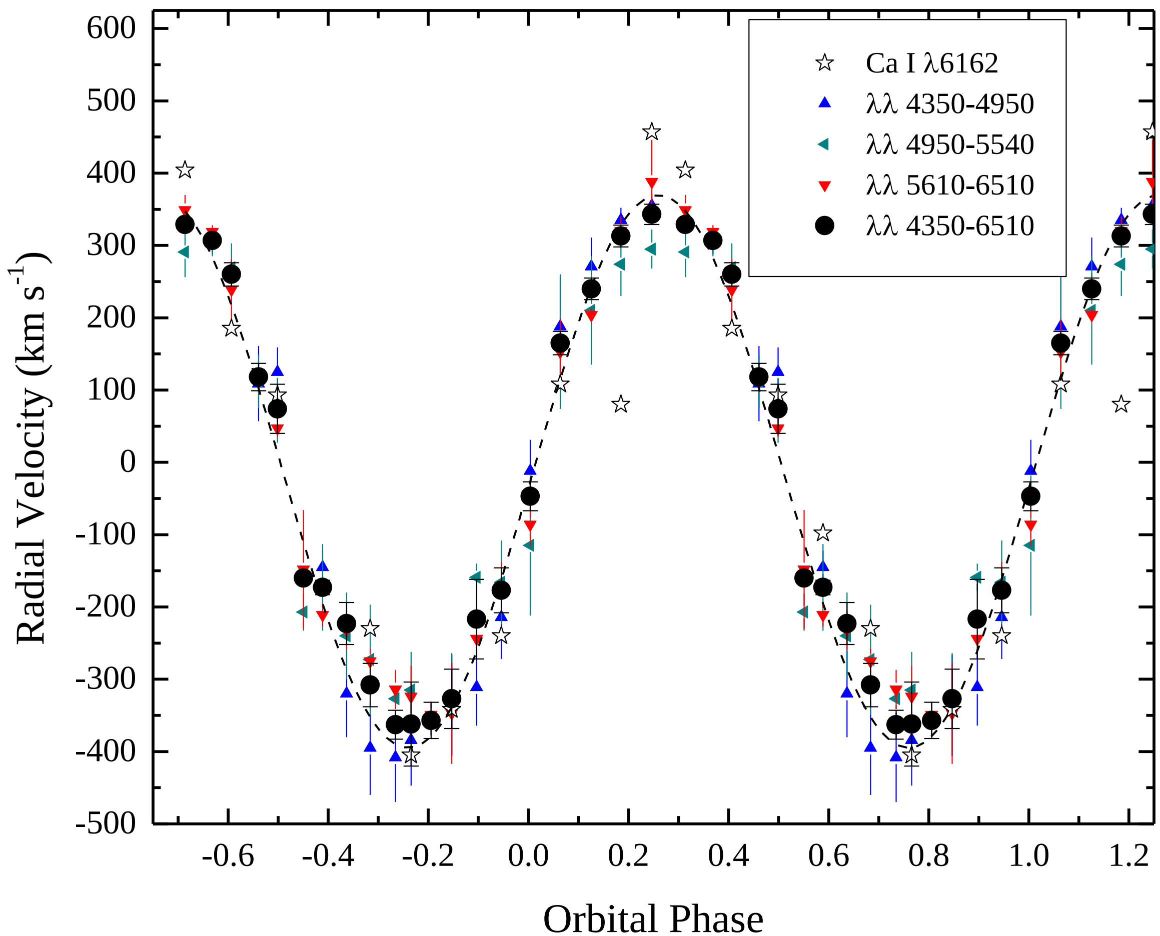
Cross-correlation

CCFs show very strong and distinct peak



Radial Velocity of the Donor star

$K_{2,o}$=382±8 km/s



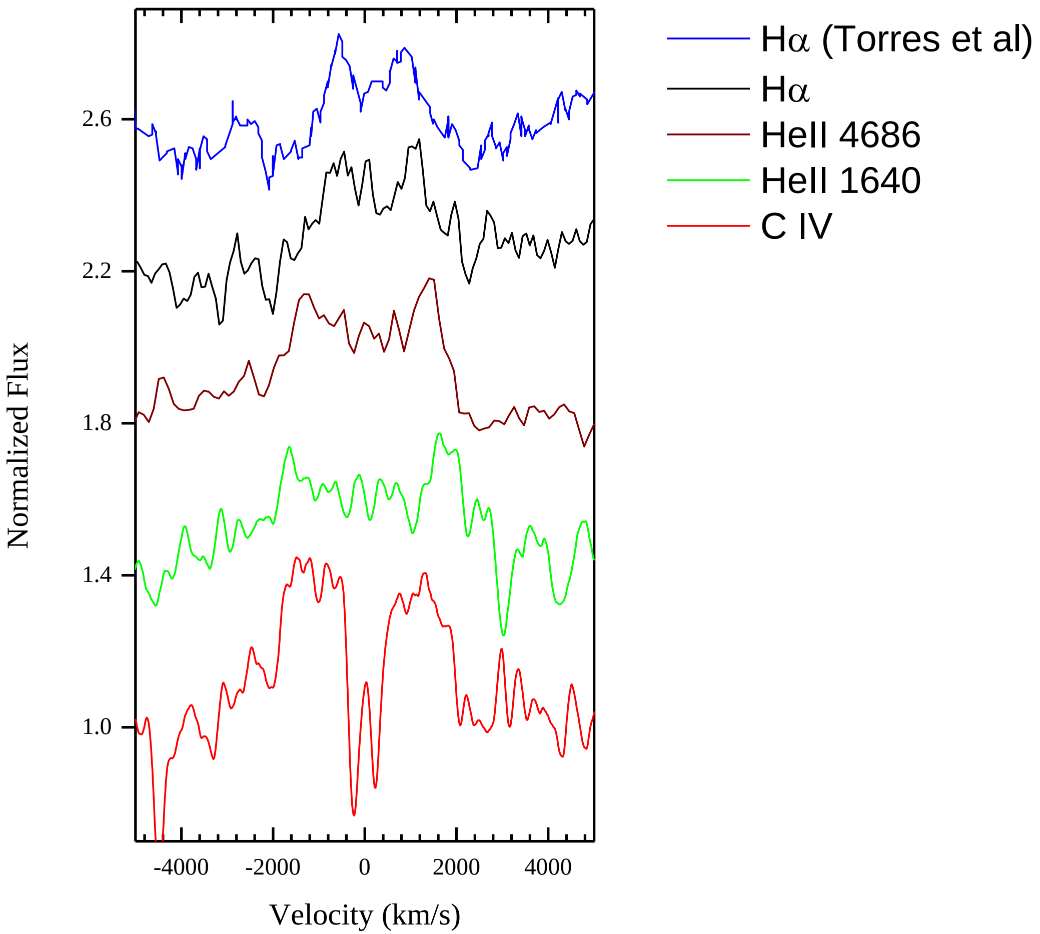
Emission line profiles

Emission lines are now much wider than during Torres et al.'s observations.

The lines are **VERY** wide.

Peak-to-Peak separation:

Hα (Torres) -> 1200km/s
Hα -> 1650km/s
He II 4686 -> 2660 km/s
He II 1640 -> 3200 km/s



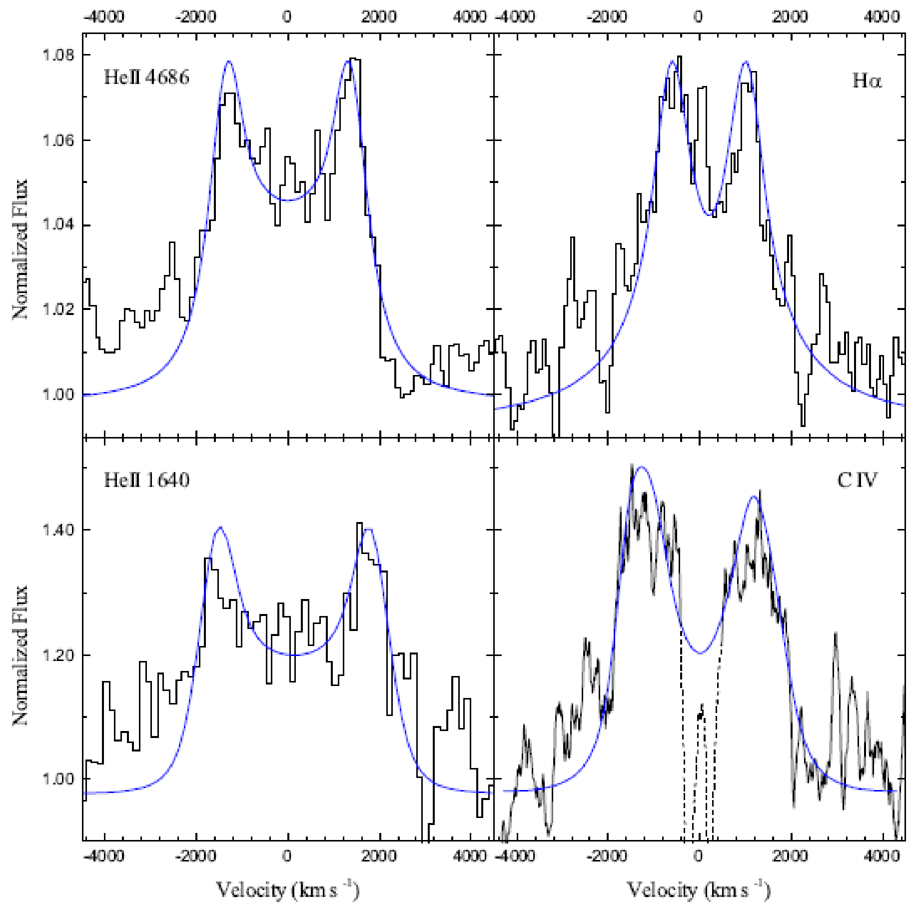
Emission line profiles

The lines have very steep wings.

The shape of the double-peaked profile wings is controlled by the density distribution of the emitting atoms:

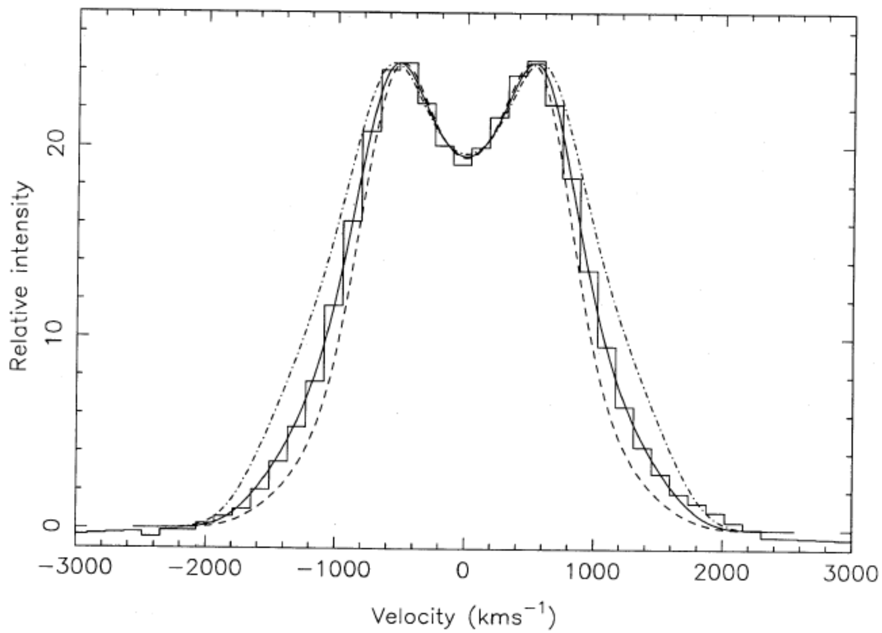
$$f(r) \propto r^{-b}$$

b is usually in range of 1—2, rarely being less than 1.5



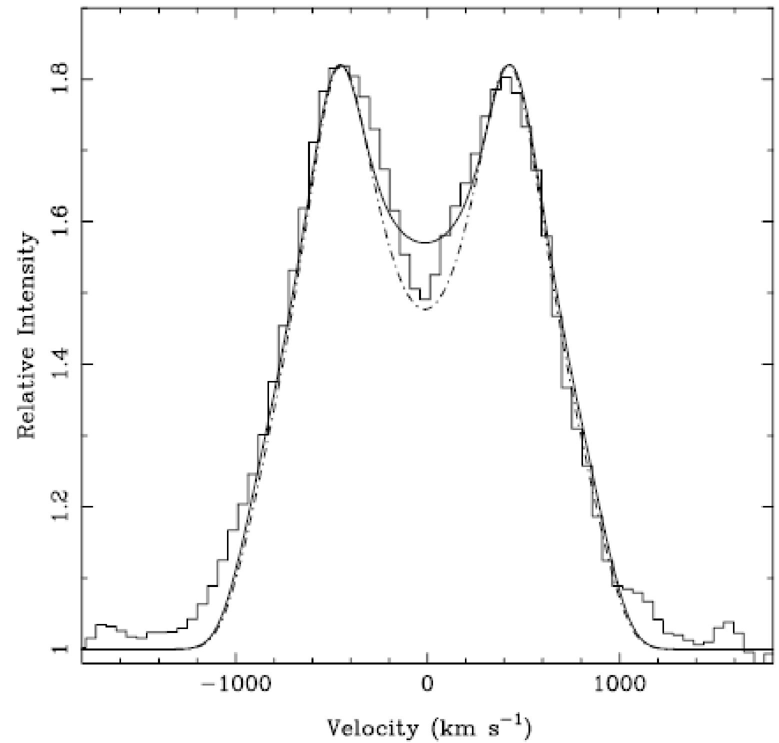
Emission line profiles

A0620 – 00: ***b*≈1.5**



Johnston et al. 1989

XTE J1550 – 564: ***b*≈2.0**



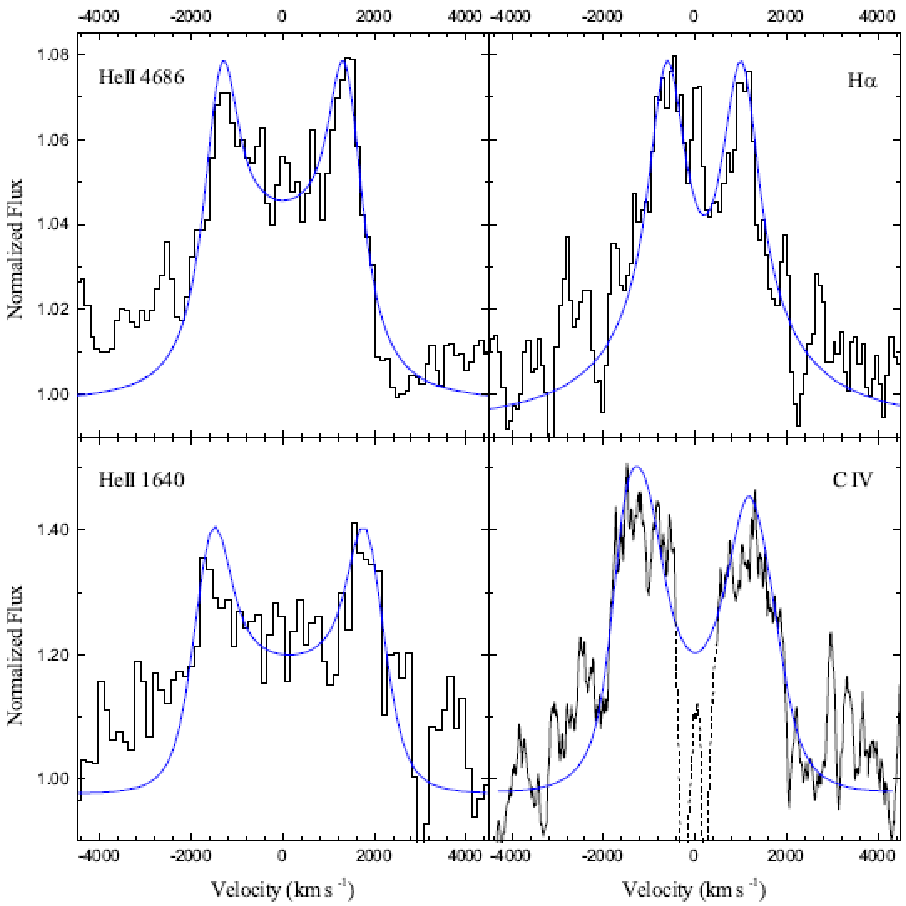
Orosz et al. 2002

Emission line profiles

$$f(r) \propto r^{-b}$$

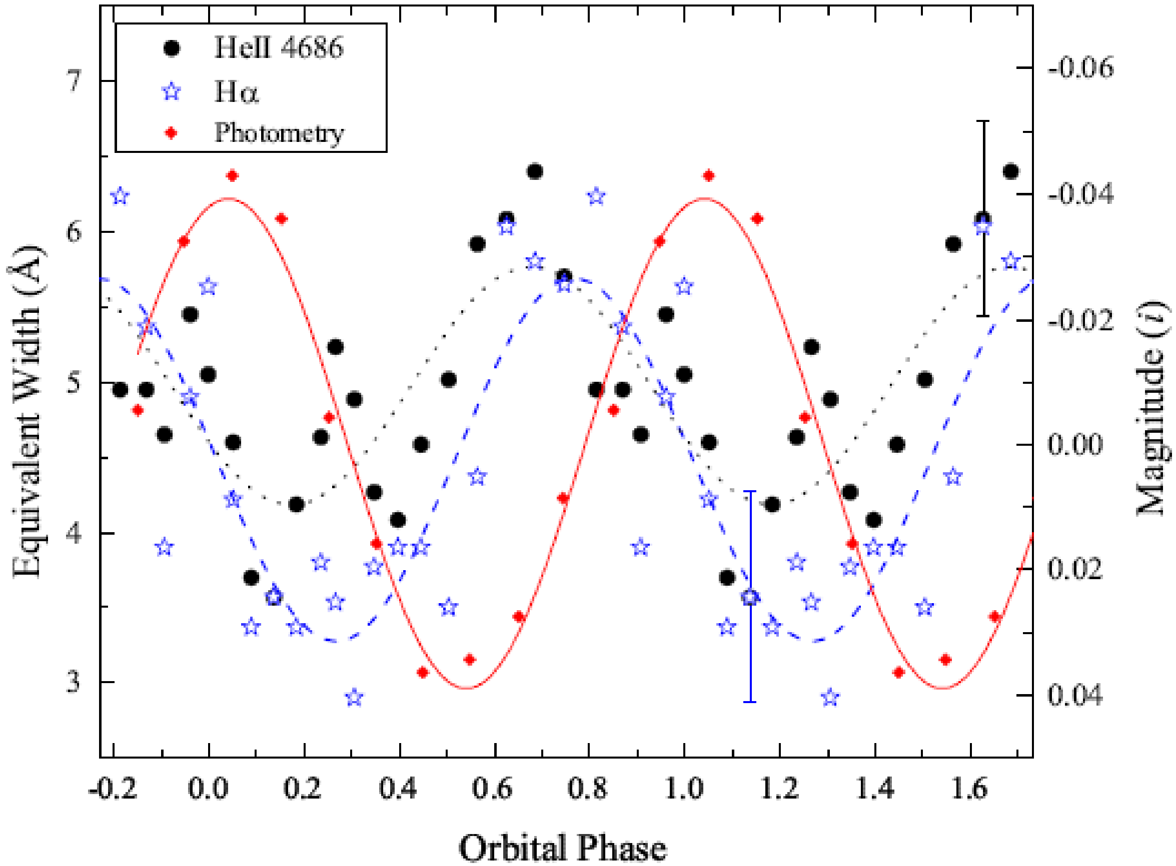
b is usually in range of 1−2, rarely being less than 1.5

In Swift J1753 ***b*≈0.5**



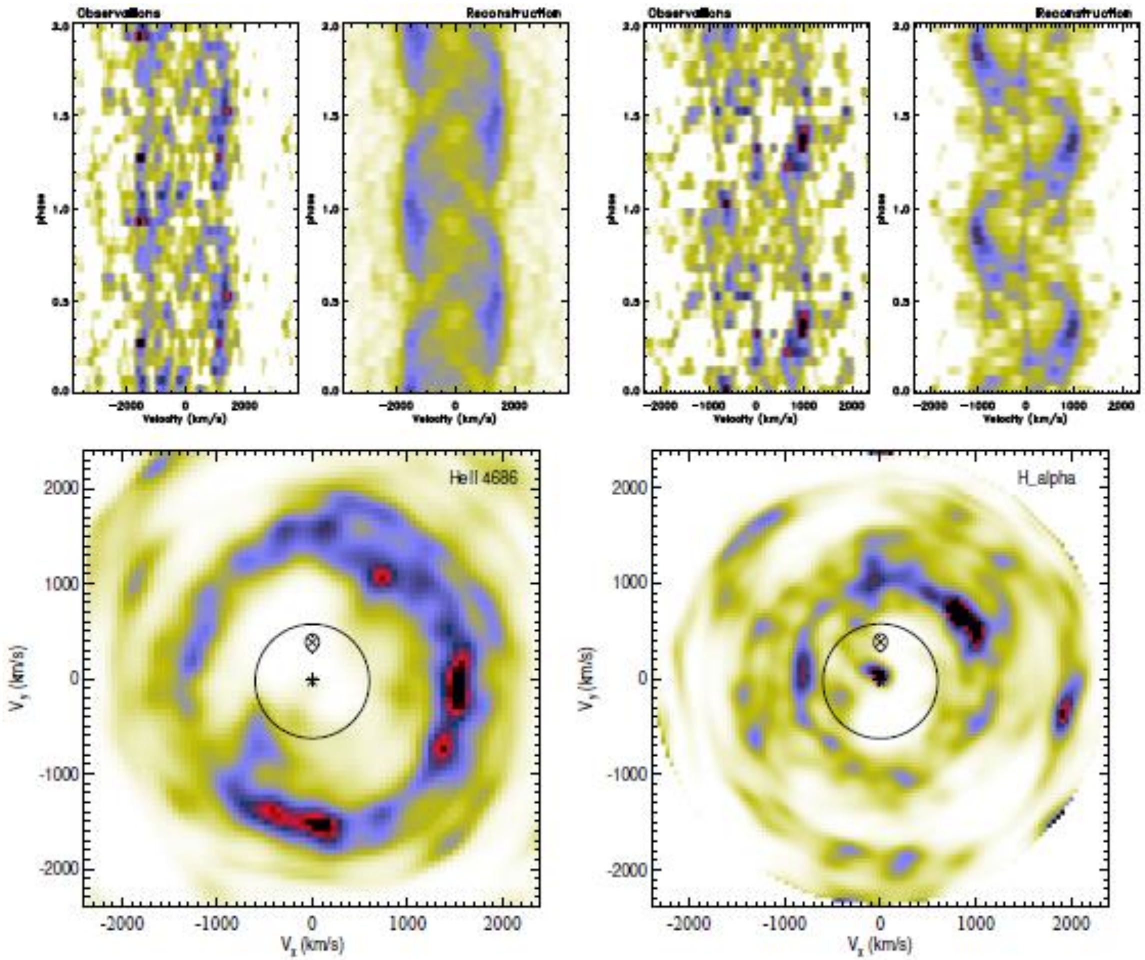
Orbital variability of emission lines

Equivalent Widths



Doppler Tomography

Asymmetric structure

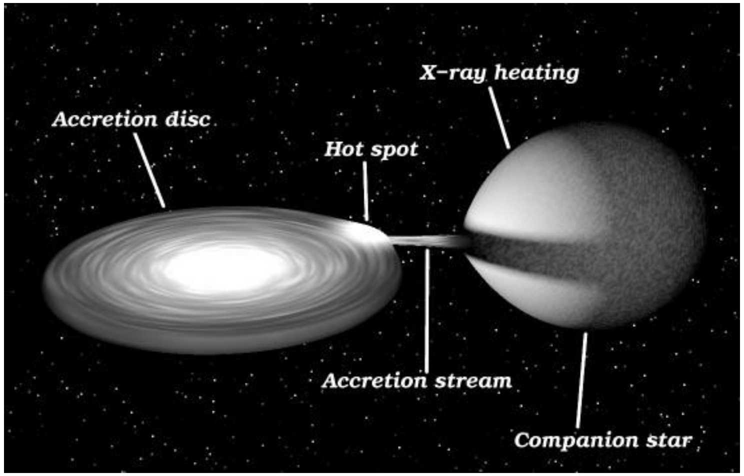


System Parameters

- Mass Function:

$$f(M) = \frac{K_2^3 P_{\rm orb}}{2\pi G} = \frac{M_1^3 \sin^3 i}{(M_1 + M_2)^2}$$

- The secondary star is likely irradiated by the X-ray source



- K_2 must be corrected!
  $K_{2,o} / K_2 \approx 0.9$

- $f_o(M) = 0.69 \pm 0.04\ \mathrm{M}_\odot$
  $f(M) \lesssim \quad 0.95\ \mathrm{M}_\odot$

One of the lowest measured mass function for a BH in a LMXB !

System Parameters

- Assumptions:
  - The secondary star fills its Roche lobe.

    $$M_2 = 0.1\text{-}0.3\ M_\odot$$
  - The double-peaked emission lines originate in an accretion disc.
  - The Keplerian velocity in the disc:

    $$V = \sqrt{\frac{GM}{R}}$$
  - The outer parts of a large accretion disc are under the gravitational influence of the secondary star, which prevents the disc from growing larger than R_{max}:

    $$\frac{R_{max}}{a} = \frac{0.6}{1+q}$$

System Parameters

- Combine with Kepler's third law and get:

$$(M_1 + M_2)\sin^3 i = \frac{0.074 P V_{out}}{G}$$

- Adopting Torres et al.'s V_{out}=600 km/s, we obtain:

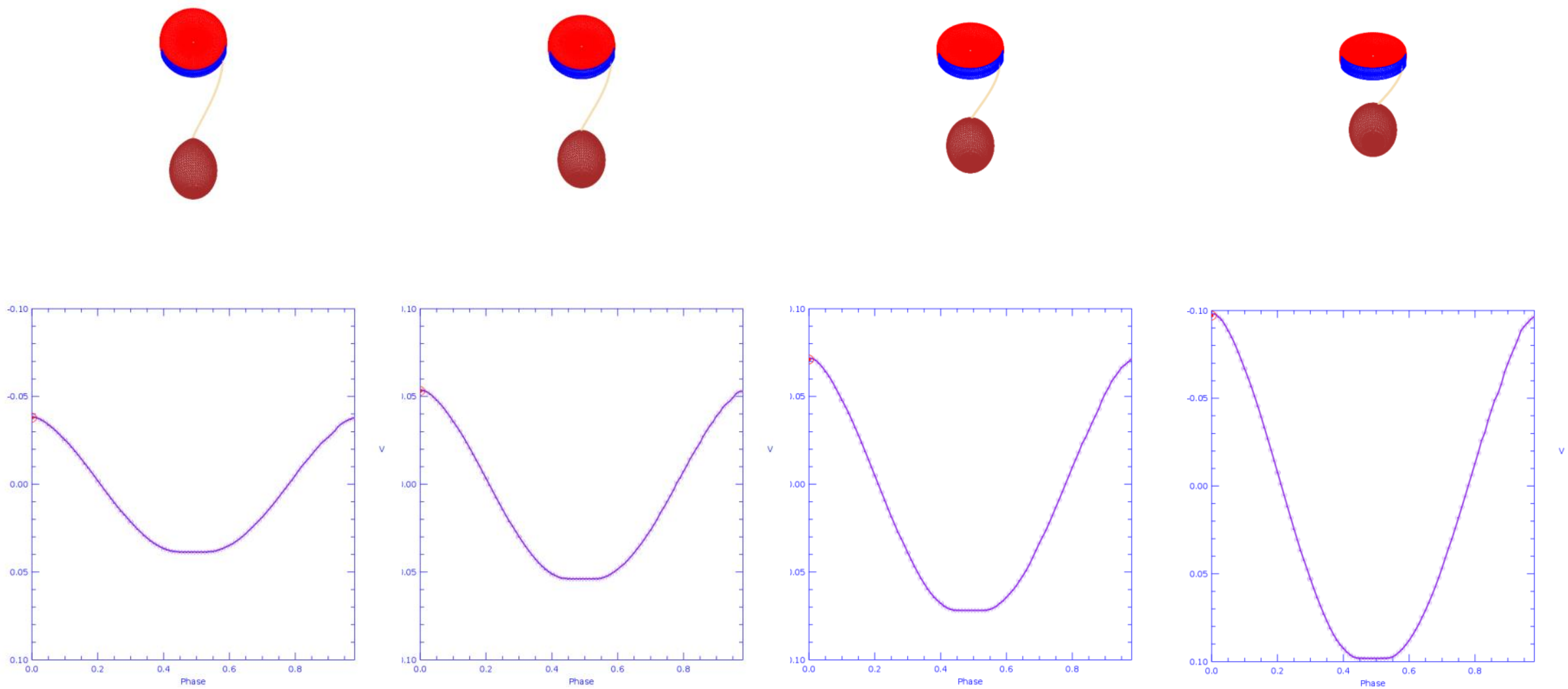
$$(M_1 + M_2)\sin^3 i = 1.2 M_{\odot}$$

Constraints on the inclination

- The emission line are strongly dependent on orbital inclination:
  - low inclination systems show spectra mainly in absorption (La Dous, 1991).
  - Intermediate-to-low inclination systems show P Cyg profiles and/or blueshifted deep absorptions.
- Strong photometric and spectroscopic orbital variability.

Constraints on the inclination

i=30° i=40° i=50° i=60°



Constraints on the inclination

- The emission line are strongly dependent on orbital inclination:
  - low inclination systems show spectra mainly in absorption (La Dous, 1991).
  - Intermediate-to-low inclination systems show P Cyg profiles and/or blueshifted deep absorptions.
- Strong photometric and spectroscopic orbital variability.

- **SWIFT J1753.5-0127 should be a relatively high inclination system (>40^{o})**

System Parameters

Measurements and Assumptions:

- Orbital period: 2.85 h
- The secondary star fills its Roche lobe:

  $M_2 = 0.1\text{-}0.3\ M_\odot$
- Inclination i >40^{o}
- M_1>2.5 $M_\odot$

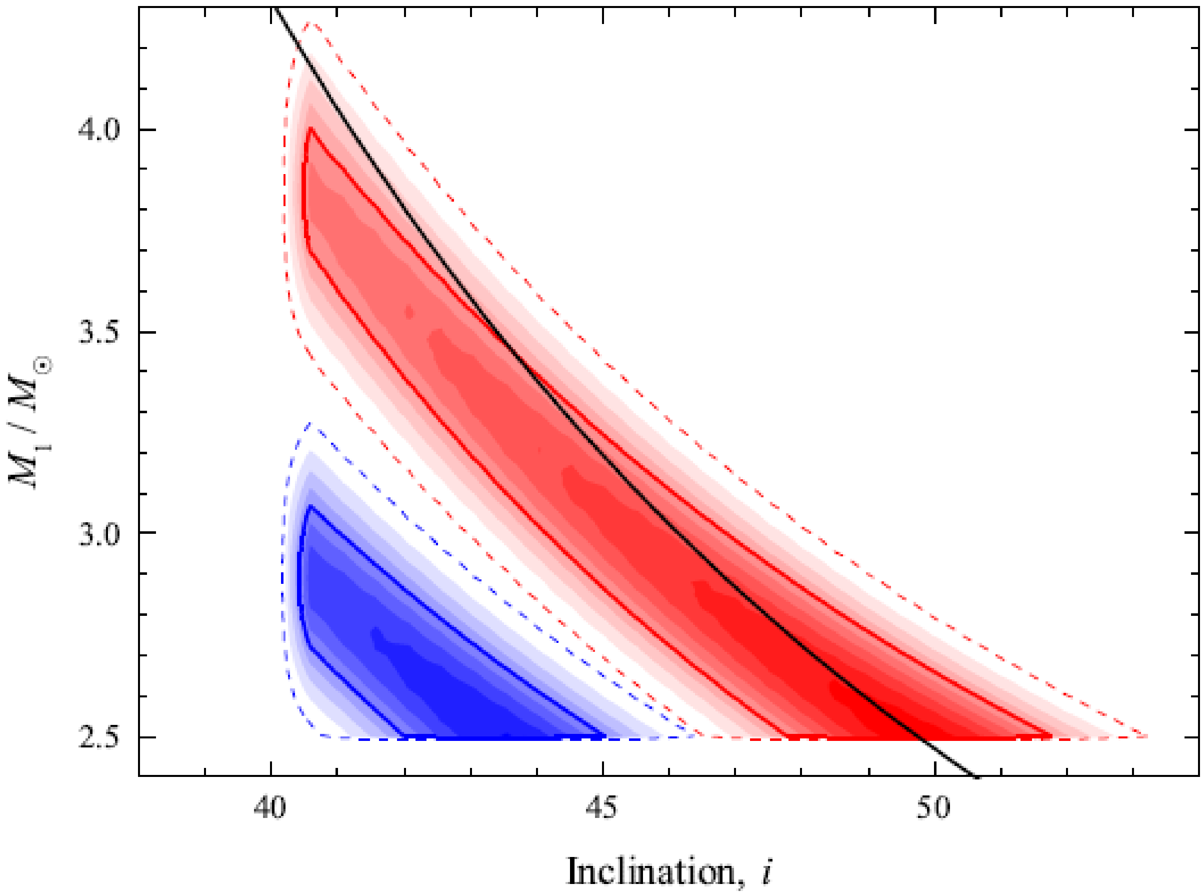
Constrained system parameters

- i=40^{o}–45^{o} (51^{o})
- $M_1/M_\odot$=2.5–3.1 (4.1)
- q= 0.04 (0.03) – 0.12
- $a/R_\odot$=1.4–1.53 (1.67)

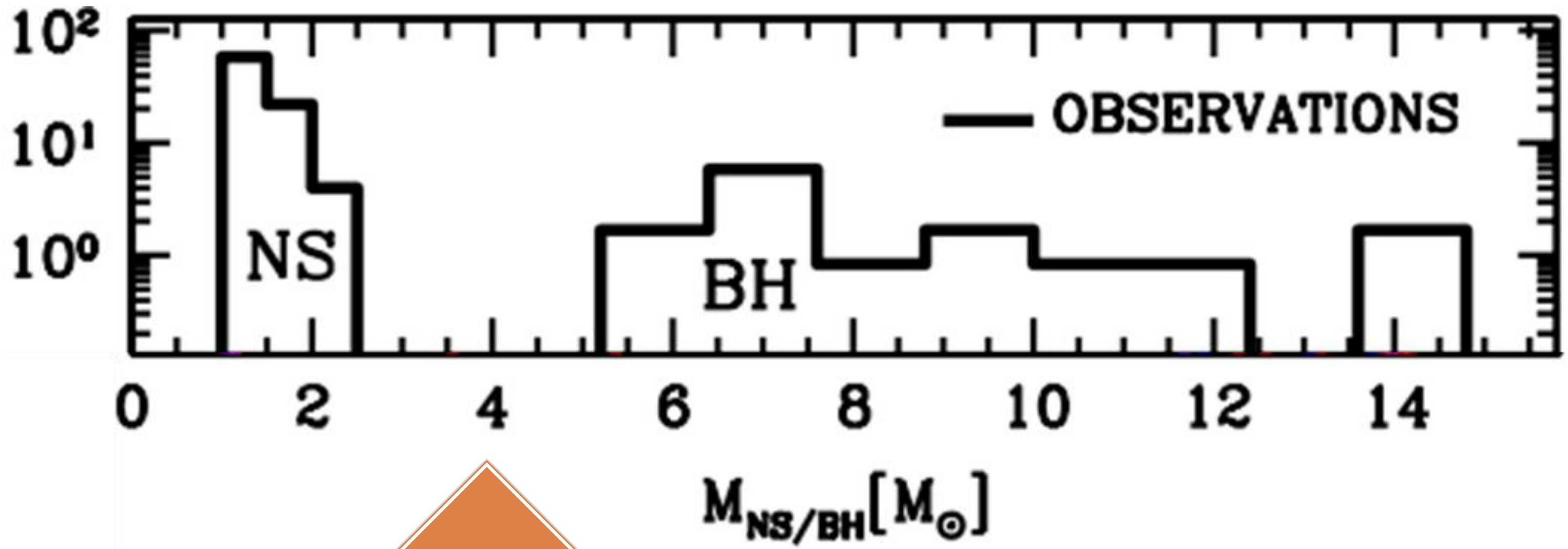
Monte-Carlo

For the observed K_2, upper limit for M_1 is $3.1M_\odot$ at a 68% confidence and $3.3M_\odot$ at 95% confidence.

For the K-correction applied, these limits are $4.0M_\odot$ and $4.3M_\odot$, respectively.



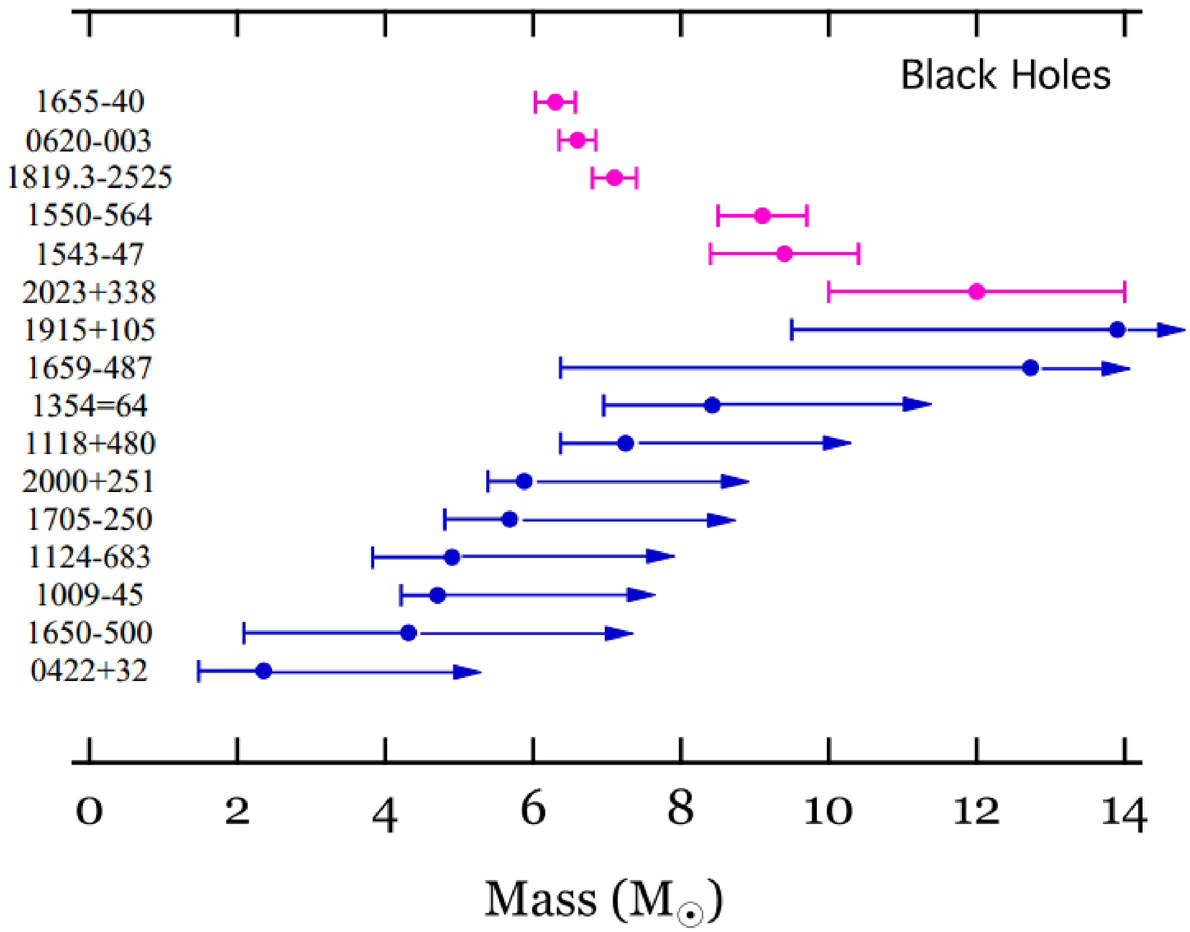
Mass distribution of compact objects



Belczynski et al., 2012

SWIFT J1753.5−0127

Mass distribution of compact objects



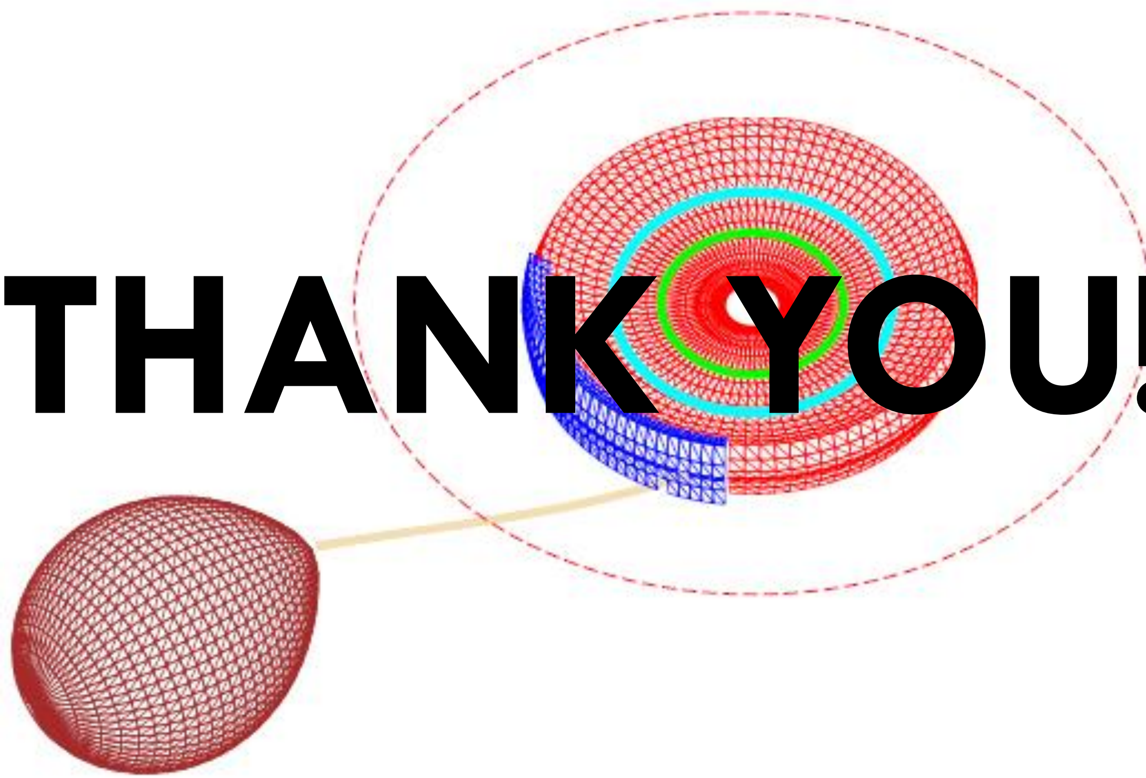
Özel et al., 2010

Summary

- We report the re-appearance of the broad emission lines in the previously featureless optical spectrum.
- We measured a possible orbital periodicity of **2.85 h**, significantly shorter than the reported 3.2 h periodic signal by Zurita et al. (2008).
- We estimated the system parameters of Swift J1753.5-0127. **We constrain the BH mass to be below 4.3$M_\odot$**.
- Thus, SWIFT J1753.5–0127 is a BH binary that has one of the shortest orbital period and hosts probably one of the smallest stellar-mass BH found to date.

SWIFT J1753.5–0127

A schematic representation of the suggested geometry



THANK YOU!