Modelling the recurrent nova U Scorpii in quiescence

Michael Maxwell

Stewart Eyres
Mark Rushton

University of Central Lancashire

Intro to U Sco

- Semi-detached binary: P = 1.23 days
- High mass WD: ≈1.4 $M_{\odot}$
- sub-giant(?) companion: 0.88$M_{\odot}$, 2.1$R_{\odot}$ (Thoroughgood 2001)
- Eclipsing system: i ≈83°

Outburst history

- Most prolific recurrent nova
- 10 recorded outbursts 1863-2010
- Latest outburst predicted as 2009.3 ± 1 (Schaefer 2005)
- Next outburst due ≈2020

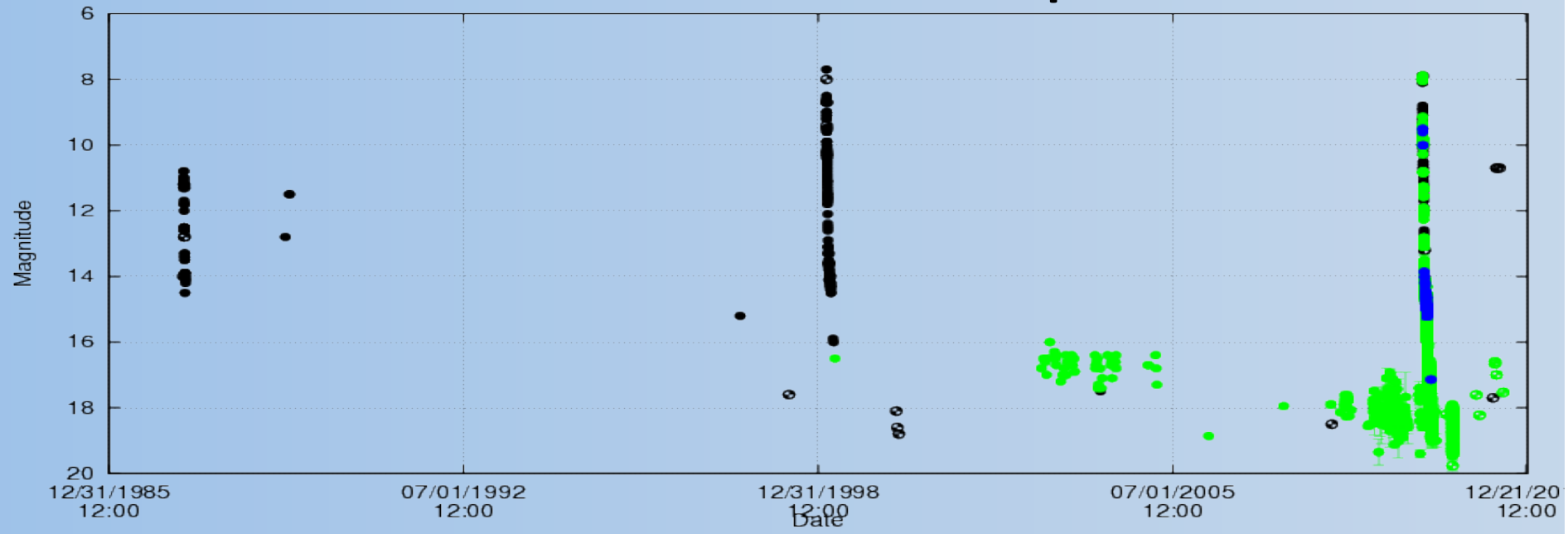
The 2010 outburst

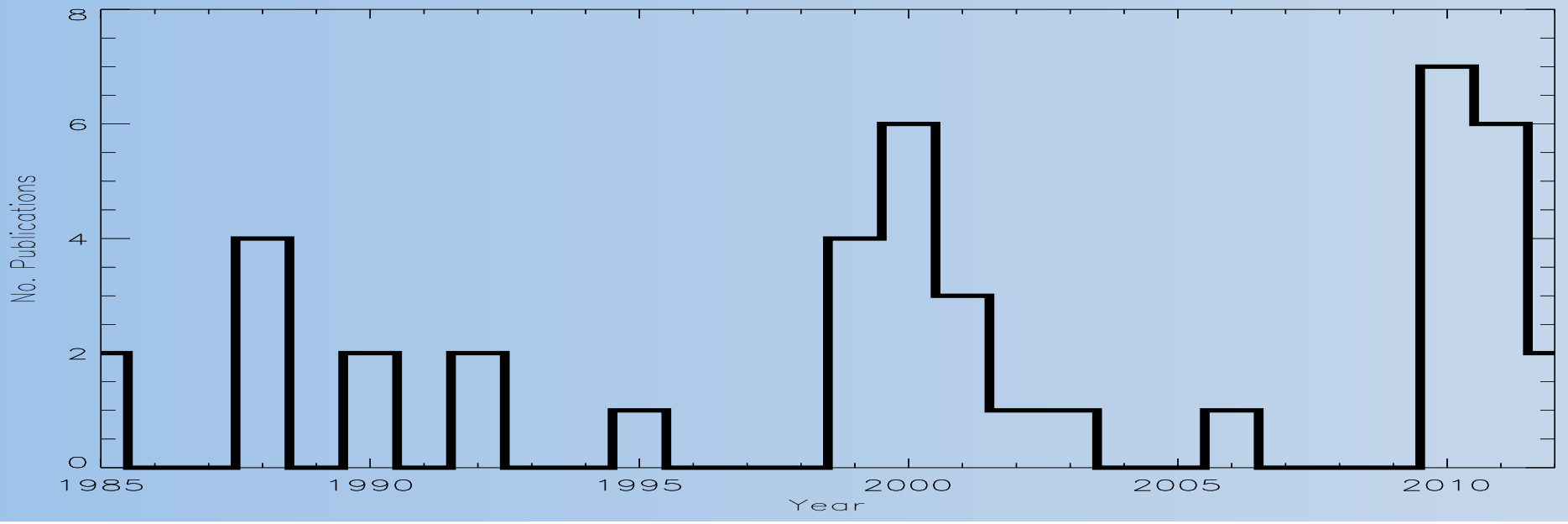
- Optical maximum at 28.19 January 2010
- High velocity outflows: ≈10,000 km/s (Banerjee et al. 2010)
- Solar helium abundance in ejecta: 0.073±0.031 (Maxwell et al. 2012)

The 2010 outburst

- Ejected mass $10^{-6} – 10^{-7}$ $M_{\odot}$ (Diaz et al. 2012, Schaefer 2011)
- Dips, eclipses and flares in lightcurves (Pagnotta et al. 2011, Schaefer et al. 2011, Ness et al. 2012)
- Evidence of ONeMg white dwarf (Mason 2011)

Previous observations in quiescence

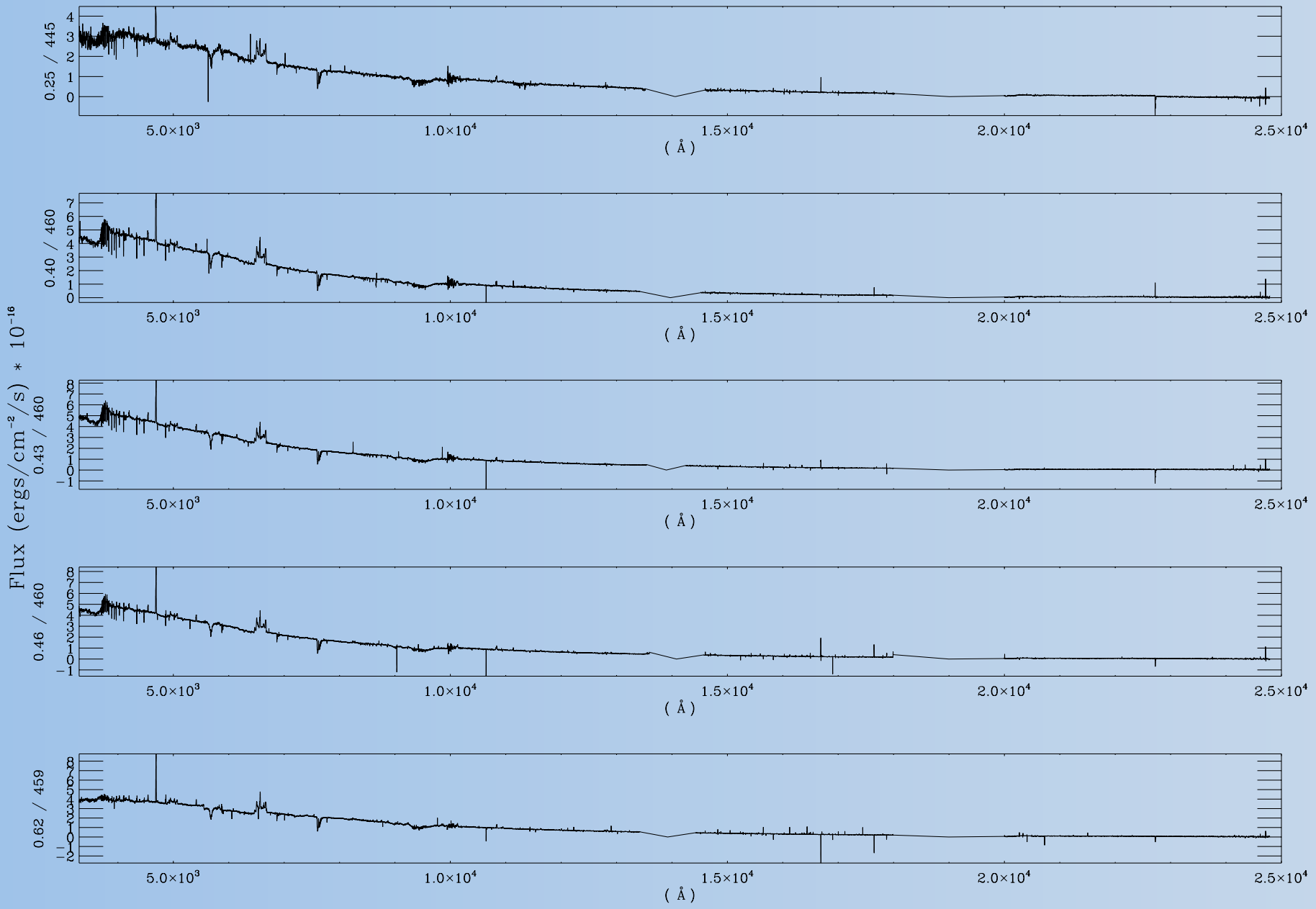




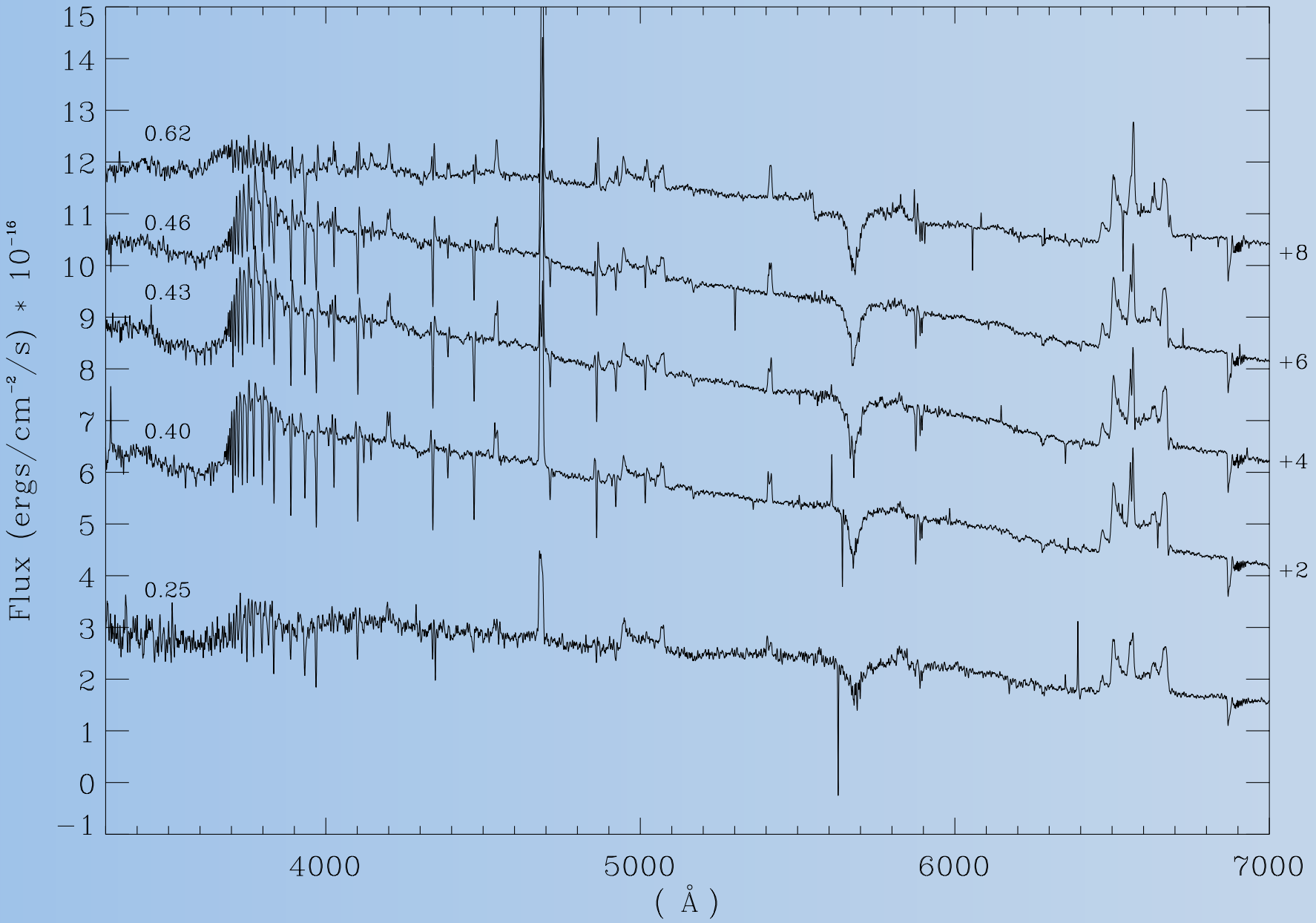
Previous observations in quiescence

- Johnston & Kulkarni (1992) obtained 18 spectra 3-4 years after outburst – no flux cal, poor resolution
- Hanes (1985) obtained one spectrum 3 years after outburst
- Strong He II 4686, some other He lines, not much else

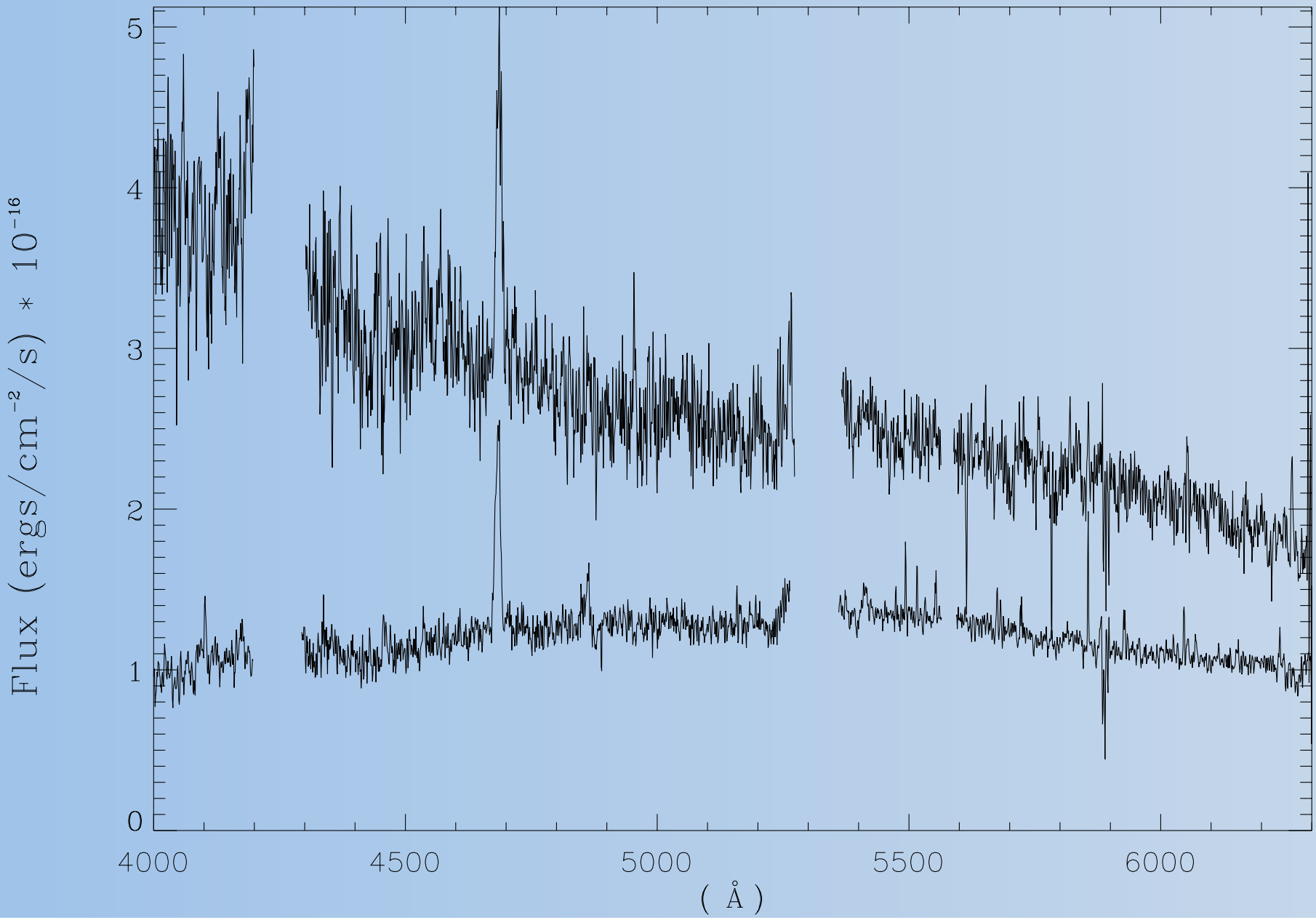
VLT/XShooter



VLT/XShooter



SALT/RSS



Modelling the spectra

- Pair of model atmospheres used: disc + companion
- Temperature range 4000 – 60,000 K
- Solar metallicity
- χ^2 minimisation used to find best fit

Best fits to VLT data

Phase	T_{disc}	$T_{companion}$
0.25	12000^{+250}_{-750}	6000^{+750}_{-250}
0.40	7500^{+250}_{-750}	7000^{+1250}_{-250}
0.43	12500^{+250}_{-750}	7000^{+250}_{-250}
0.46	10500^{+250}_{-3750}	6500^{+1250}_{-250}
0.62	6500^{+250}_{-2500}	7000^{+250}_{-250}

Mass accretion rates - model

Phase	T_{disc}	$L/L_{\odot}$	$\dot{M}(M_{\odot}/yr)$
0.25	12000	$9.15^{+0.63}_{-1.70}$	$1.10^{+0.08}_{-0.24} \times 10^{-9}$
0.40	7500	$6.48^{+0.48}_{-1.38}$	$7.78^{+0.57}_{-1.66} \times 10^{-10}$
0.43	12500	$7.88^{+0.54}_{-1.31}$	$9.46^{+0.65}_{-1.58} \times 10^{-10}$
0.46	10500	$5.21^{+0.45}_{-4.08}$	$6.25^{+0.54}_{-4.90} \times 10^{-10}$
0.62	6500	$2.28^{+0.30}_{-1.88}$	$2.73^{+0.36}_{-2.25} \times 10^{-10}$

Mass accretion rates – He II 4686

Empirical relation from Patterson & Raymond 1985

Phase	L $(\mathrm{ergs\,s^{-1}})$	$\dot{M}(M_{\odot}yr^{-1})$
0.25	$4.40\pm0.09\times10^{31}$	$7.55\pm0.02\times10^{-10}$
0.40	$7.06\pm0.03\times10^{31}$	$1.38\pm0.004\times10^{-9}$
0.43	$6.83\pm0.07\times10^{31}$	$1.33\pm0.01\times10^{-9}$
0.46	$6.78\pm0.05\times10^{31}$	$1.32\pm0.01\times10^{-9}$
0.55	$2.56\pm0.10\times10^{31}$	$3.77\pm0.04\times10^{-10}$
0.62	$8.08\pm0.05\times10^{31}$	$1.64\pm0.01\times10^{-9}$
0.77	$4.12\pm0.28\times10^{31}$	$6.95\pm0.07\times10^{-10}$

The companion star

Clues to spectral type include:

- Effective temperature from fits to VLT spectra
- Absorption features in VLT spectra
- Comparison with features and continuua of stars in stellar atlases

The companion star

Phase	$T_{companion}$	$L/L_{\odot}$	Spectral class
0.25	6000^{+750}_{-250}	5.62	G0
0.40	7000^{+1250}_{-250}	4.89	F3
0.43	7000^{+250}_{-250}	7.70	F3
0.46	6500^{+1250}_{-250}	7.61	F6
0.62	7000^{+250}_{-250}	9.27	F3

The companion star

- Features such as Ca II H+K, Ca II triplet, Na I and Mg I are present in VLT spectra
- Cool F or hot G star give good fit to continuum in SALT data and features in VLT data
- F6±3 gives the best fit to VLT data

What does it all mean?

- U Sco returns to photometric quiescence before it returns to spectroscopic quiescence
- Rate of 10^{-9} $M_{\odot}$/yr from both model and He II
- Mass accretion rate may be increasing over time

What does it all mean?

- Spectral type is F6±3 from fits to continuum in VLT data
- Spectral type is G0±5 from SALT continuum and features in VLT data
- Observations required further into quiescence in other objects