One of a kind: A radio pulsing white dwarf binary star

Dr. F.-J. (Josch) Hambsch

VVS, BAV, AAVSO, GEOS

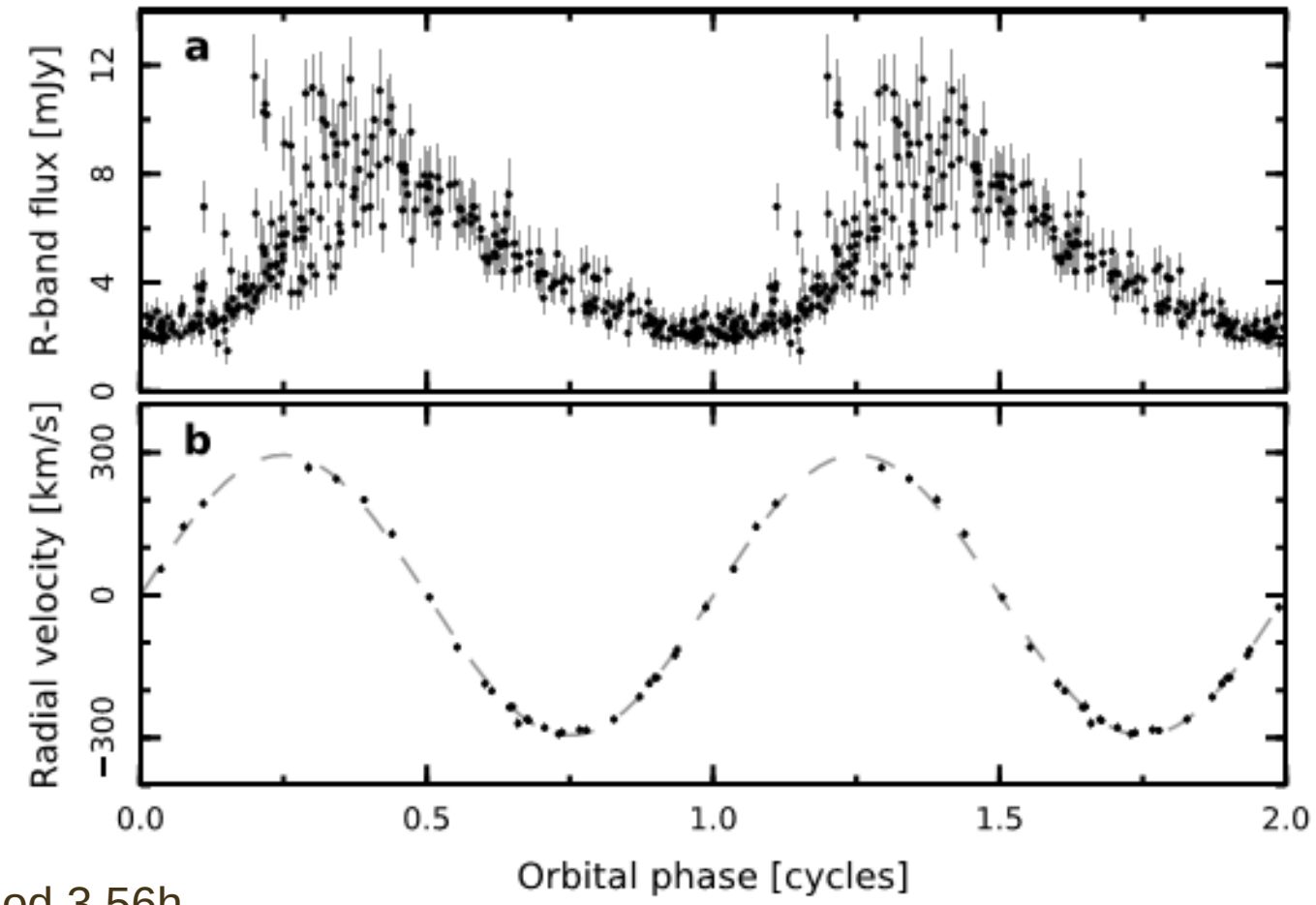
Introduction

- White dwarfs are compact stars, similar in size to Earth but 200000 times more massive
- Isolated white dwarfs emit most of their power from ultraviolet to near-infrared wavelengths,
- but when in close orbits with less dense stars, white dwarfs can strip material from their companions,
- the resulting mass transfer can cause X-ray emission, as well as mid-infrared radiation if the white dwarf is magnetic
- However, even in binaries, white dwarfs are rarely detected at far-infrared or radio
- We have discovered a white dwarf / cool star binary that emits across the electromagnetic spectrum from X-ray to radio wavelengths
- It is the first white dwarf system observed to pulse periodically at radio frequencies

How we found this star

- Datamining by amateurs S. Hümmerich and K. Bernhard
- Comparison of ROSAT X-ray sources with photometrical data of the Catalina Sky Survey
- Star is close to the Rho Ophiuchi nebula complex between Sco and Oph.
- Star is correlated with the X-ray source 1RXS J162147.0-225306
- Stable lightcurve with P = 0.1485354(4) d = 3.56 h (Catalina data and own observations)
- Same value already known since 1971
- Amplitude change in V ~ 2 mag

AR Sco photometric variation and radial velocity curve from CSS



Period 3.56h

ROAD: Remote Observatory Atacama Desert

- San Pedro de Atacama
- 2450 m above sealevel
- 5000 inhabitants
- Electricity, Water, Lodging, Food, Shops
- High speed (10MB and more) internet
- + 300 clear nights / year
- Southern Hemisphere (23 deg south)
- Competent people for service
- Dark sky 22.00 mag/sq arcsec

ROAD Equipment

- 40cm f/6.8 Optimized Dall Kirkham (ODK)
- ASA DDM85 Direct Drive Mount
- FLI Atlas focuser
- FLI CFW 5-7 filter wheel
- FLI ML 16803 CCD camera (4k x 4k x 9μm)
- Win 7 PC with MAXIM, The Sky, CCDCommander, RADMIN, Teamviewer

ROAD in action

Mad Telescope.mp4

Courtesy Y. Beletsky

Weather in San Pedro (May 24, 2014)

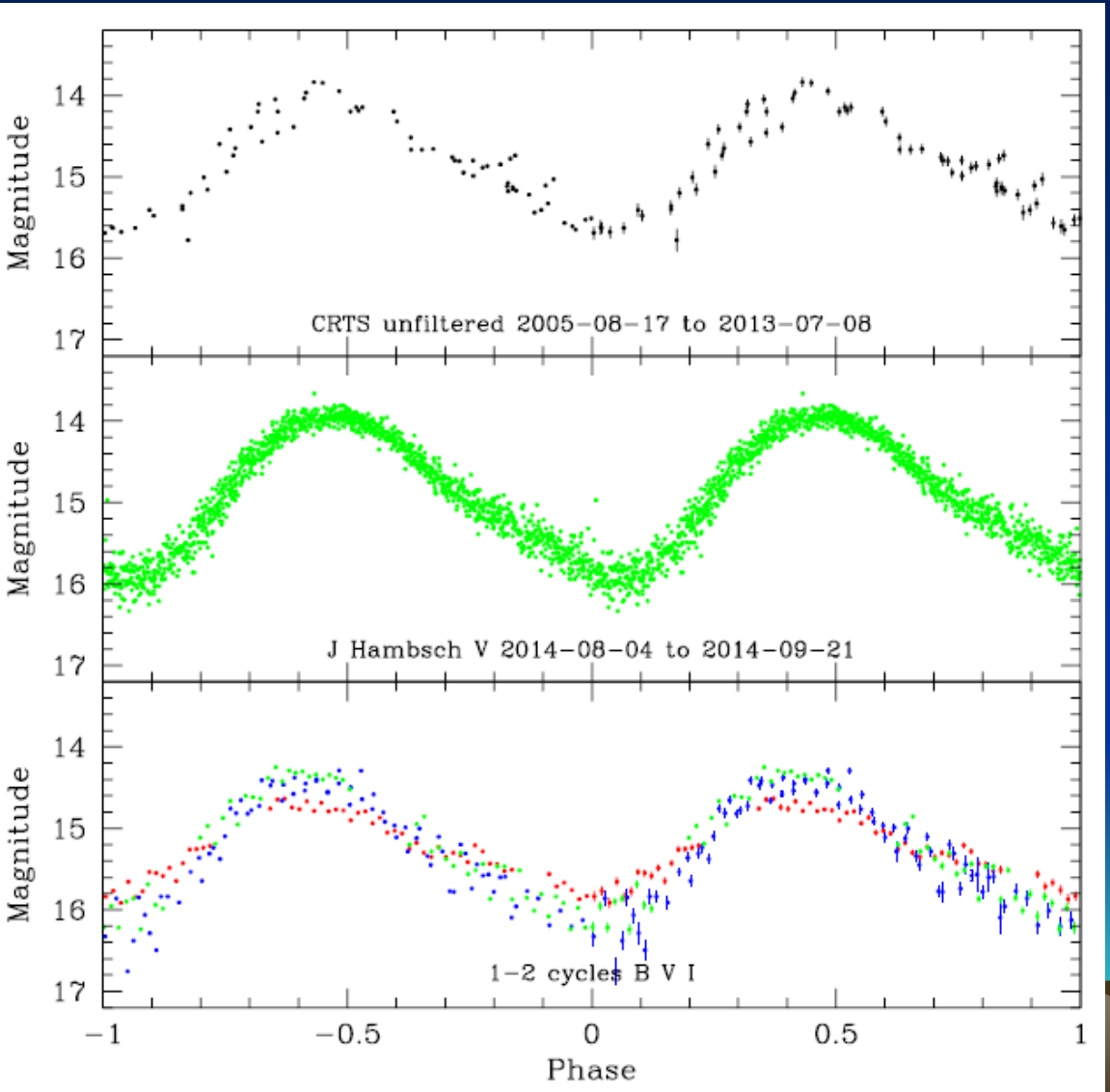
ROAD statistics

- Setup of observatory and testing (2 weeks July 2011)
- Start routine observations: Aug. 1, 2011
- Clear nights
  - 01.08.11-31.07.12 321 nights
  - 01.08.12-31.07.13 320 nights
  - 01.08.13-31.07.14 335 nights
  - 01.08.14-31.07.15 312 nights
  - 01.08.15-31.07.16 312 nights

Observations at ROAD

- *Observations during 42 nights of AR Sco*
- *Analysis incl. Catalina Surveys data confirmed the period of P = 0.1485354(4) d and an amplitude of ~2 mag (V)*
- *DSCT-type can therefore be rejected*
- *Other classification scenarios for AR Sco:*
  - *a young stellar object (YSO) based on T-Tauri type spectrum*
  - *or a (pre-)cataclysmic variable based on period and amplitude*

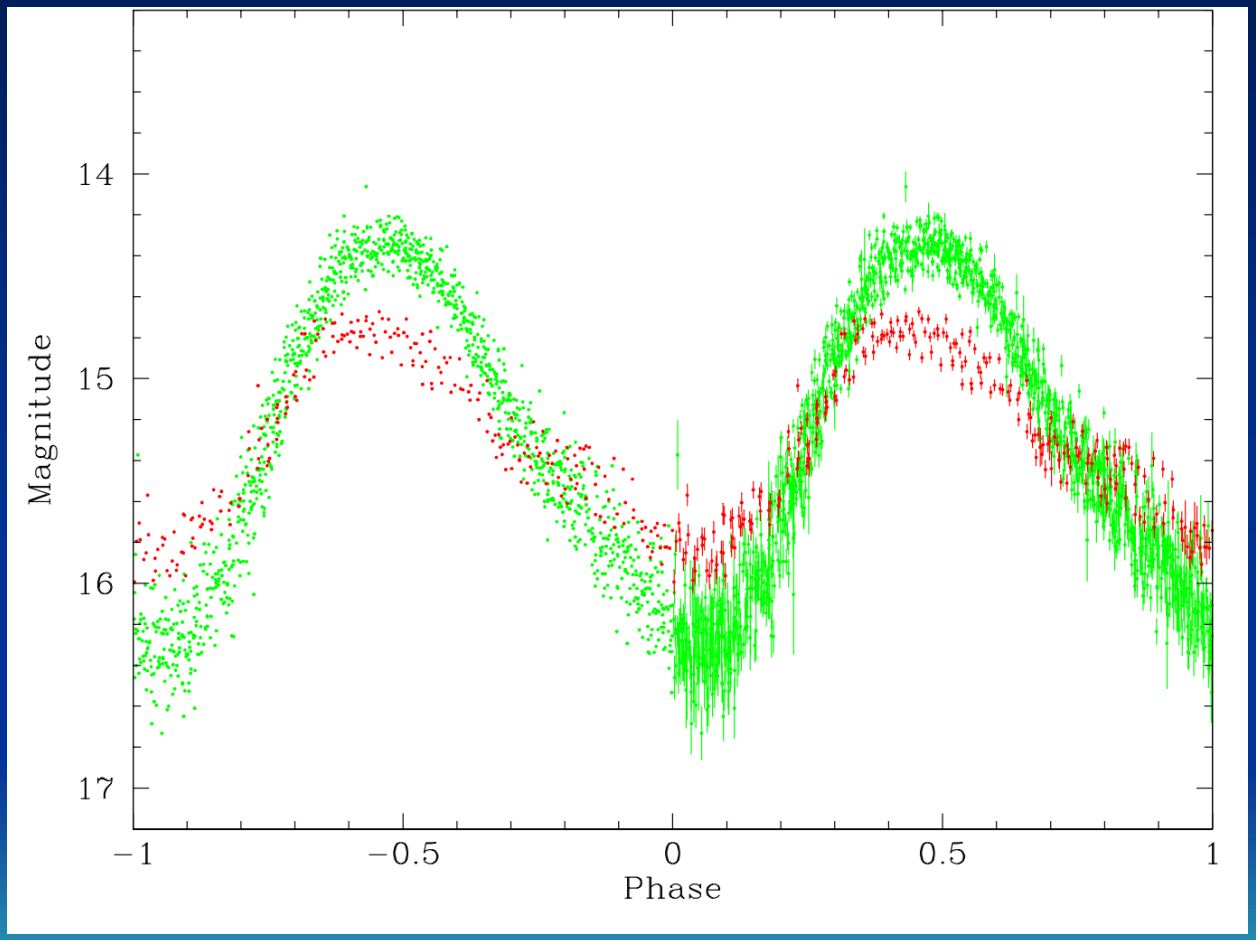
AR Sco phase diagram all data



P = 0.1485354(4) d
= 213.891 min
= 3.56 h

Modulation reduces towards the red
(2 mag in V, 1.3 mag in I),

AR Sco phase diagram all data



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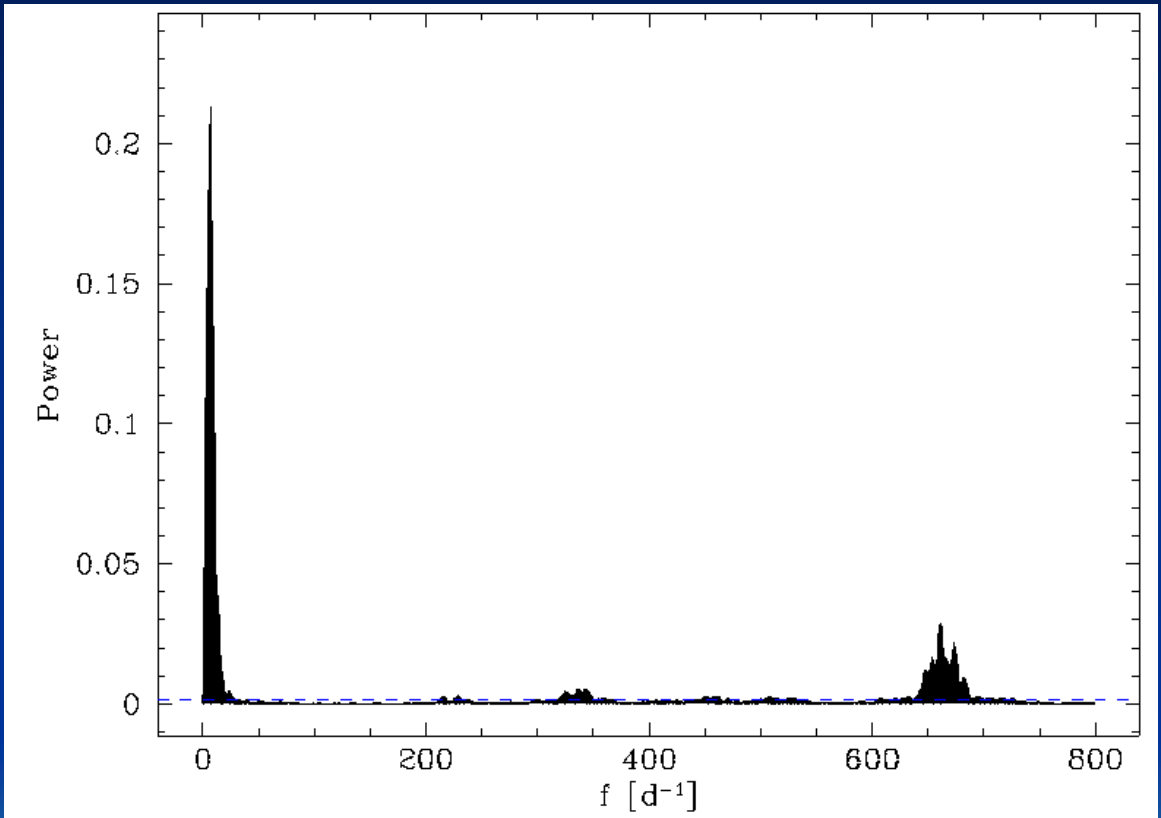
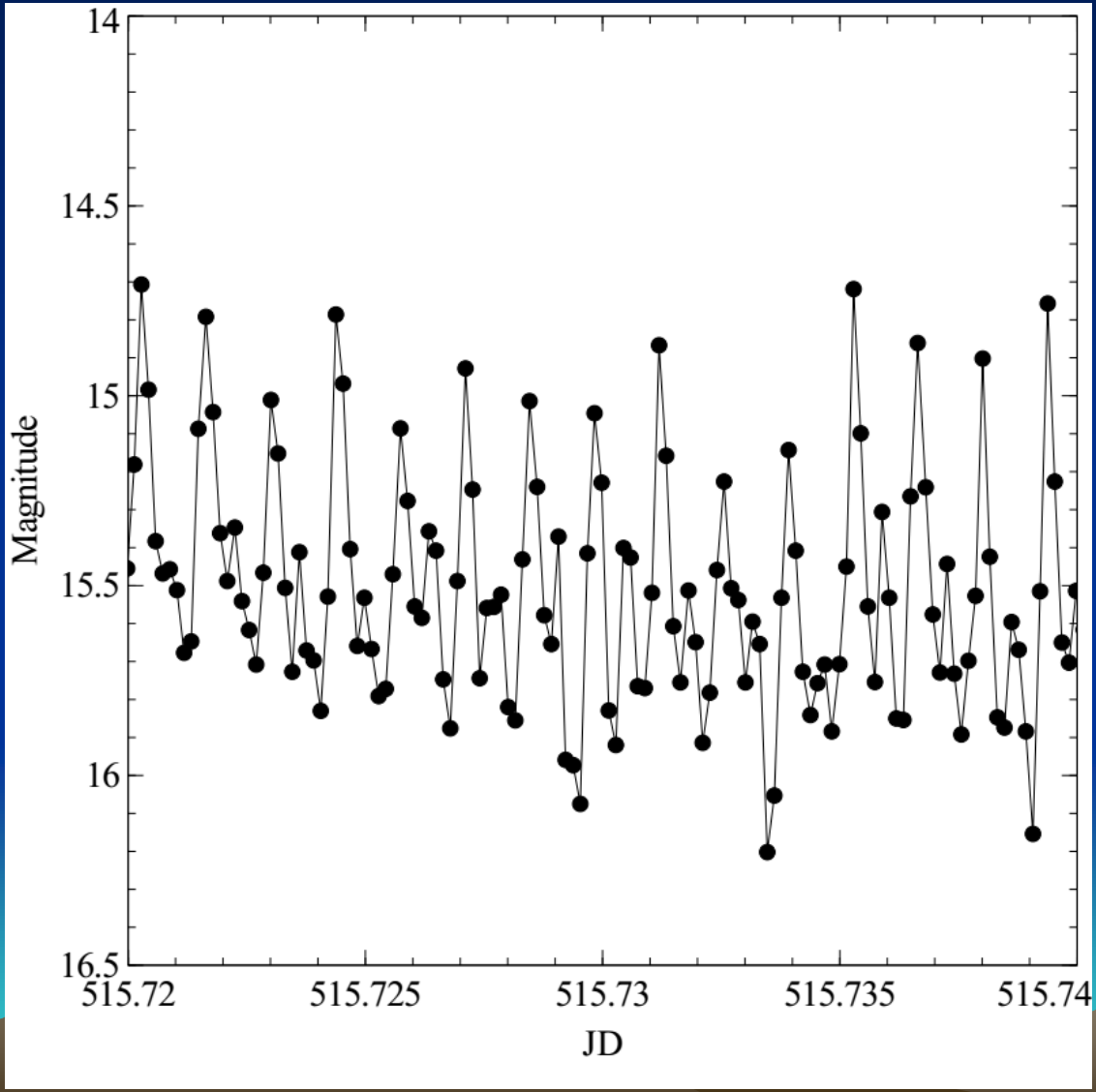
AR Sco Fourier transform V data



Signal at about
~2min (661 cycles/day).

AR Sco light curve during one night



Higher resolution observations
at ROAD
(10 s exposure)

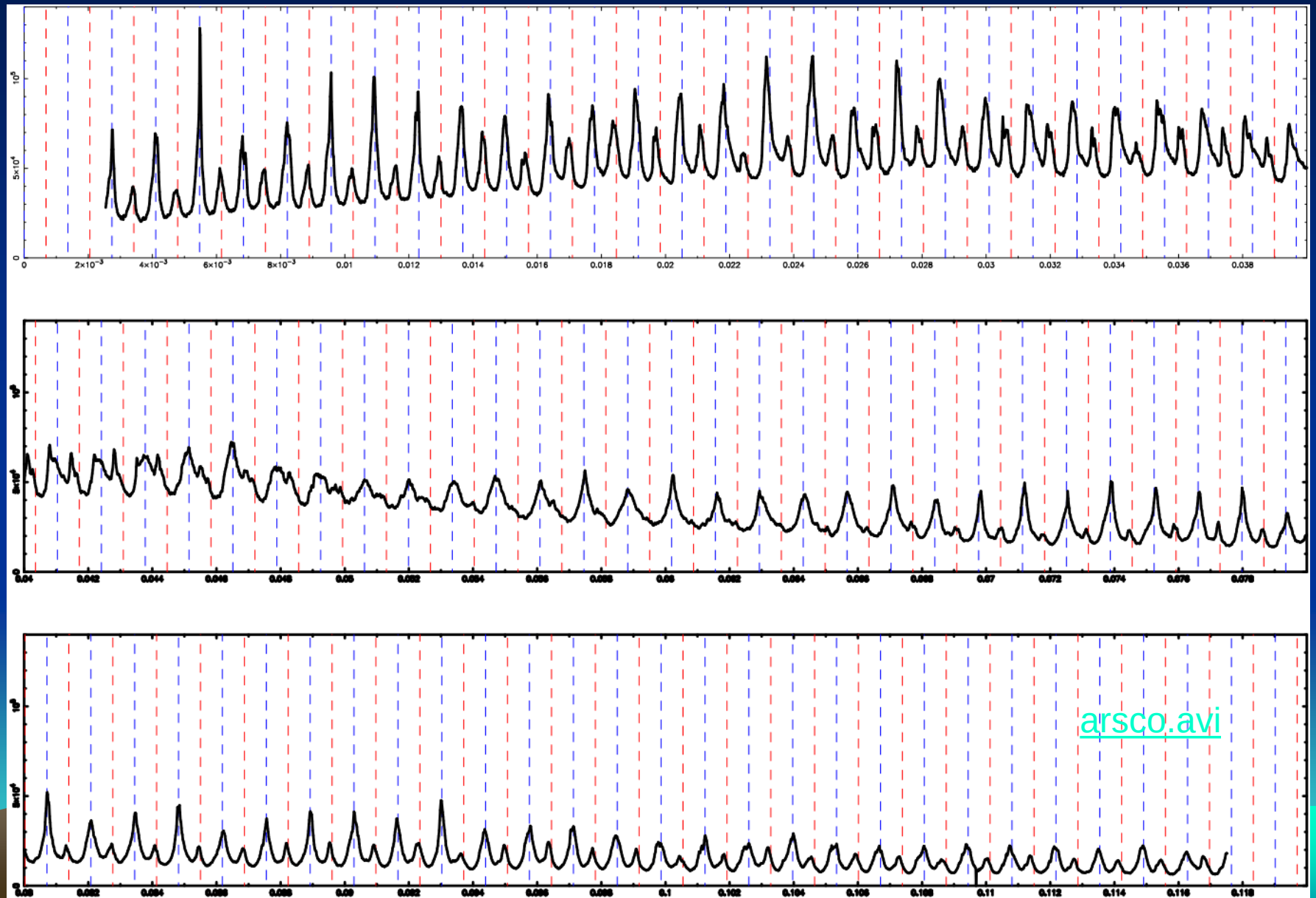
Shows actually
two frequencies

Changes of about
1 mag in about 1 minute

Involvement of professional astronomers

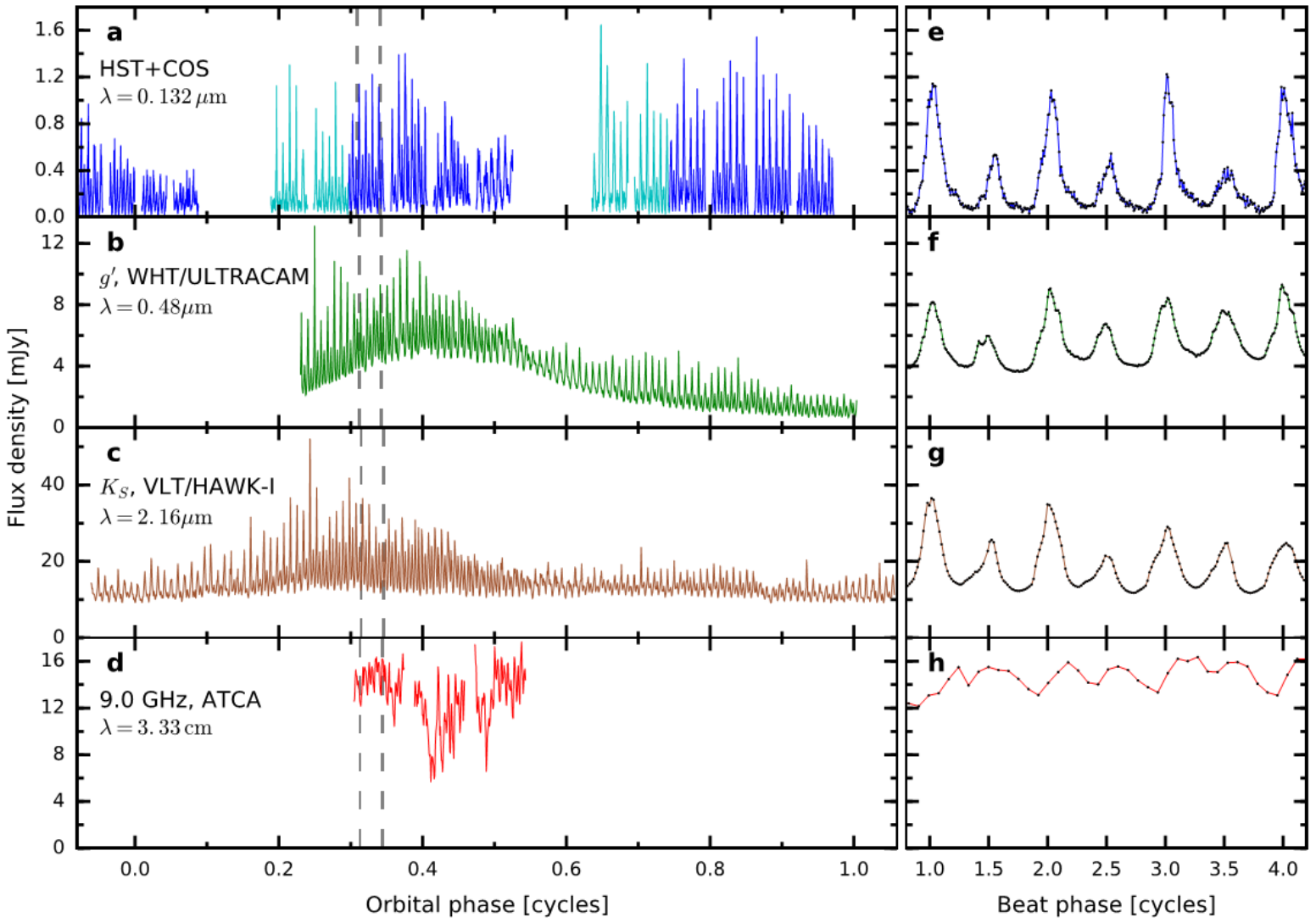
- Contact: 27.05.2015
- First spectrum with VLT 08.06.2015
- Request for B and I filter data from ROAD
- Request for VLT X-shooter observations 19.06.2015
- ULTRACAM, SWIFT X-ray observations
- New season (Jan. 2016): VLA (radio), XMM (X-rays), HST (ultraviolet), ULTRACAM (high-speed photometry), and VLT spectroscopy observations
- Nature paper accepted April 26

High-speed measurements with ULTRACAM at the 4.2 m William Herschel



arsco.avi

High-speed measurements in different wavelengths



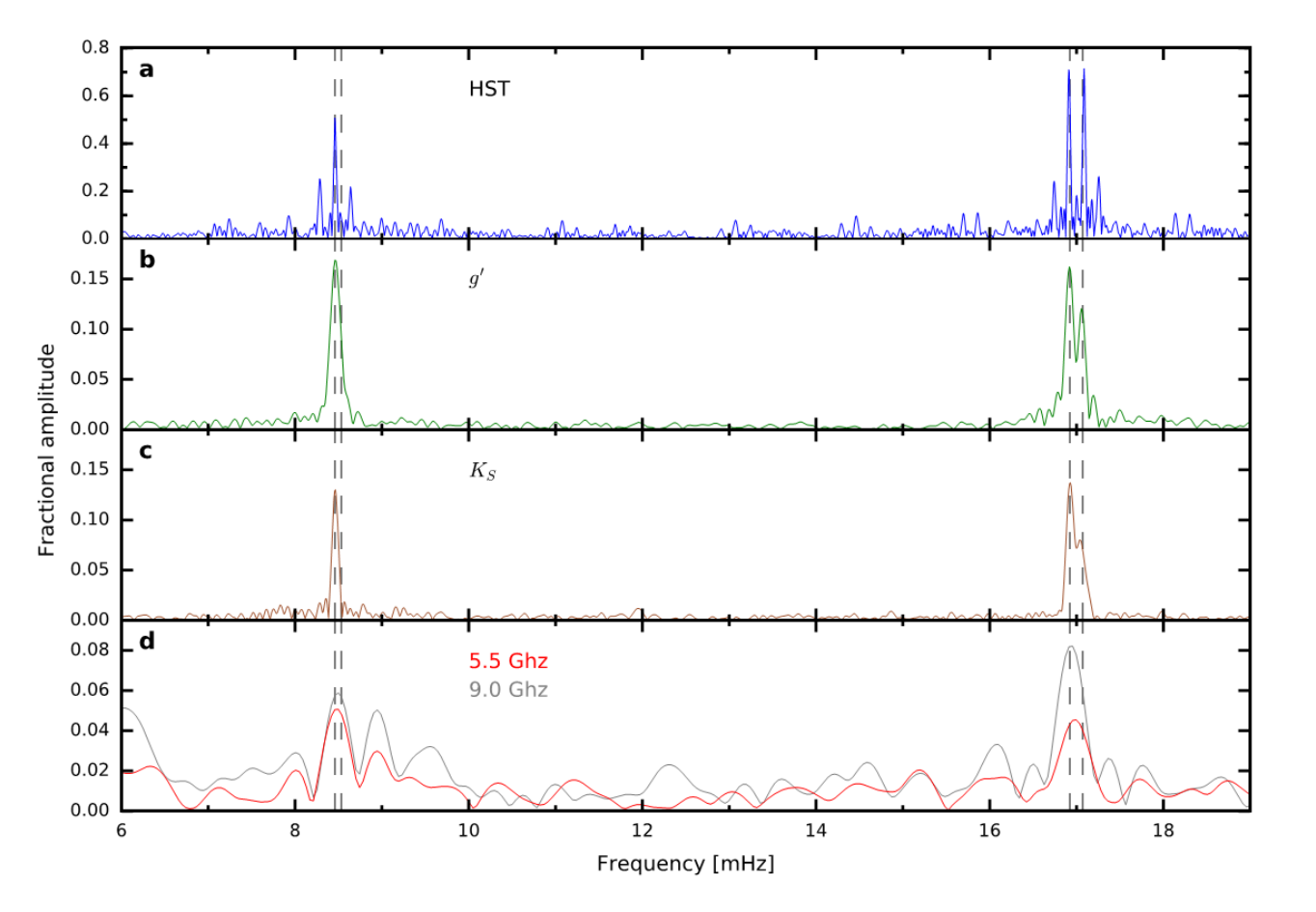
UV

g‘

K

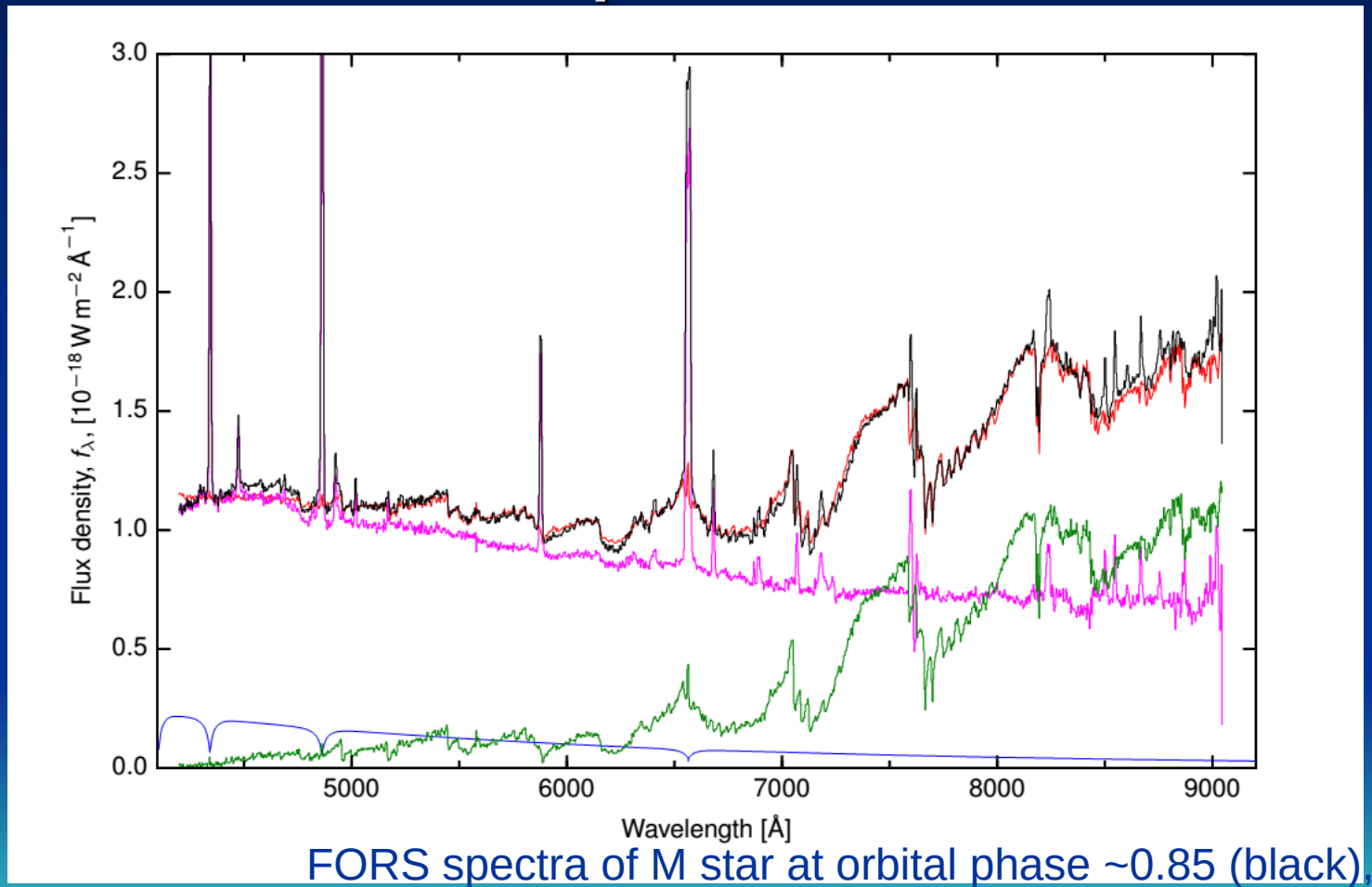
Radio

Frequency plot of photometry measurements



Fundamental (beat) period ~ 1.97 min (8.46 mHz), spin frequency ν_S and "beat" frequency $\nu_B = \nu_S - \nu_O$, where ν_O is the orbital frequency. Spin period is 1.95 min, orbital period 3.56h

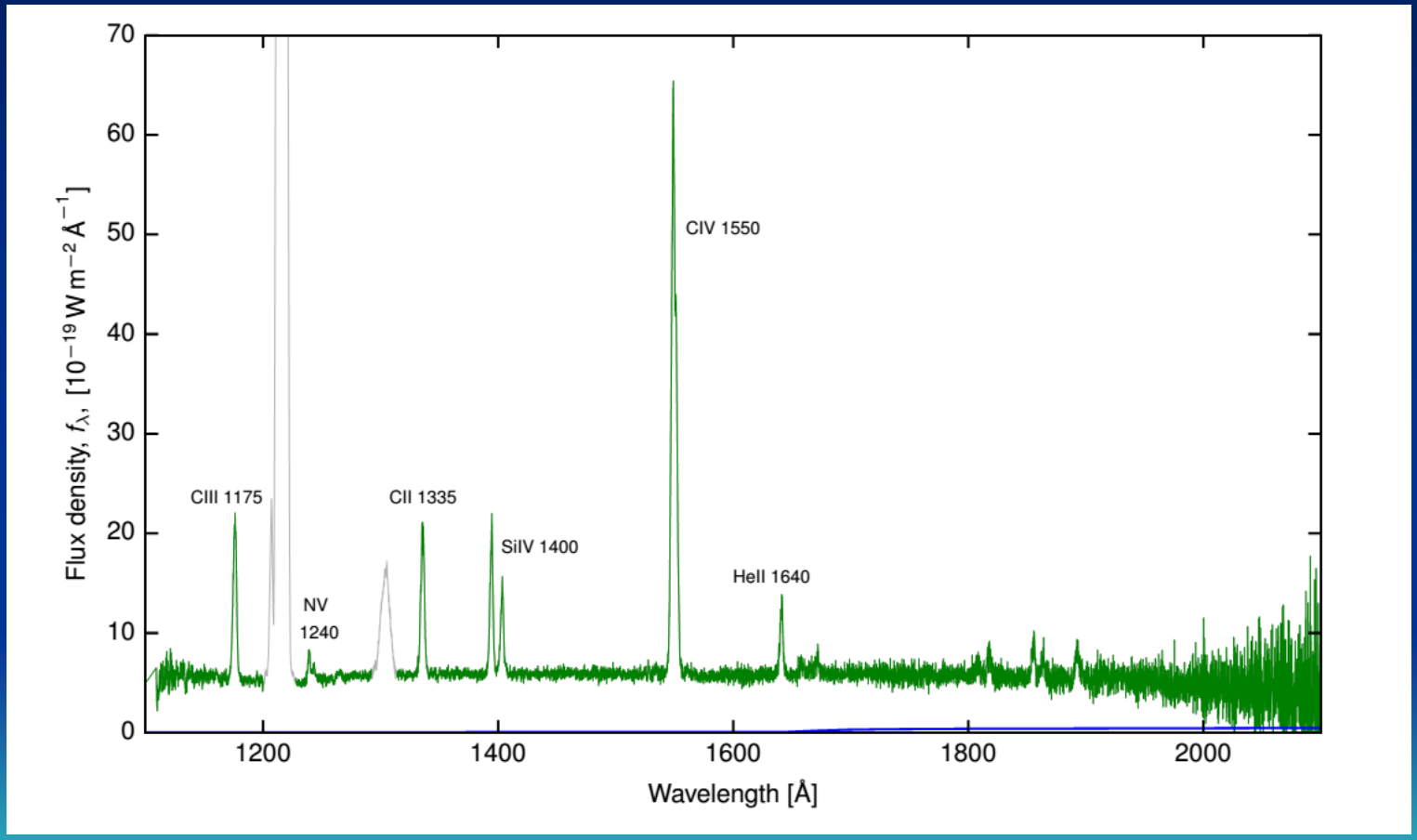
Spectrum with FORS* at VLT of M companion star



FORS spectra of M star at orbital phase ~0.85 (black),
model spectra of M5 star (green)
Sum of M5 model and smooth spectrum (red)
AR Sco minus M5 model (magenta)

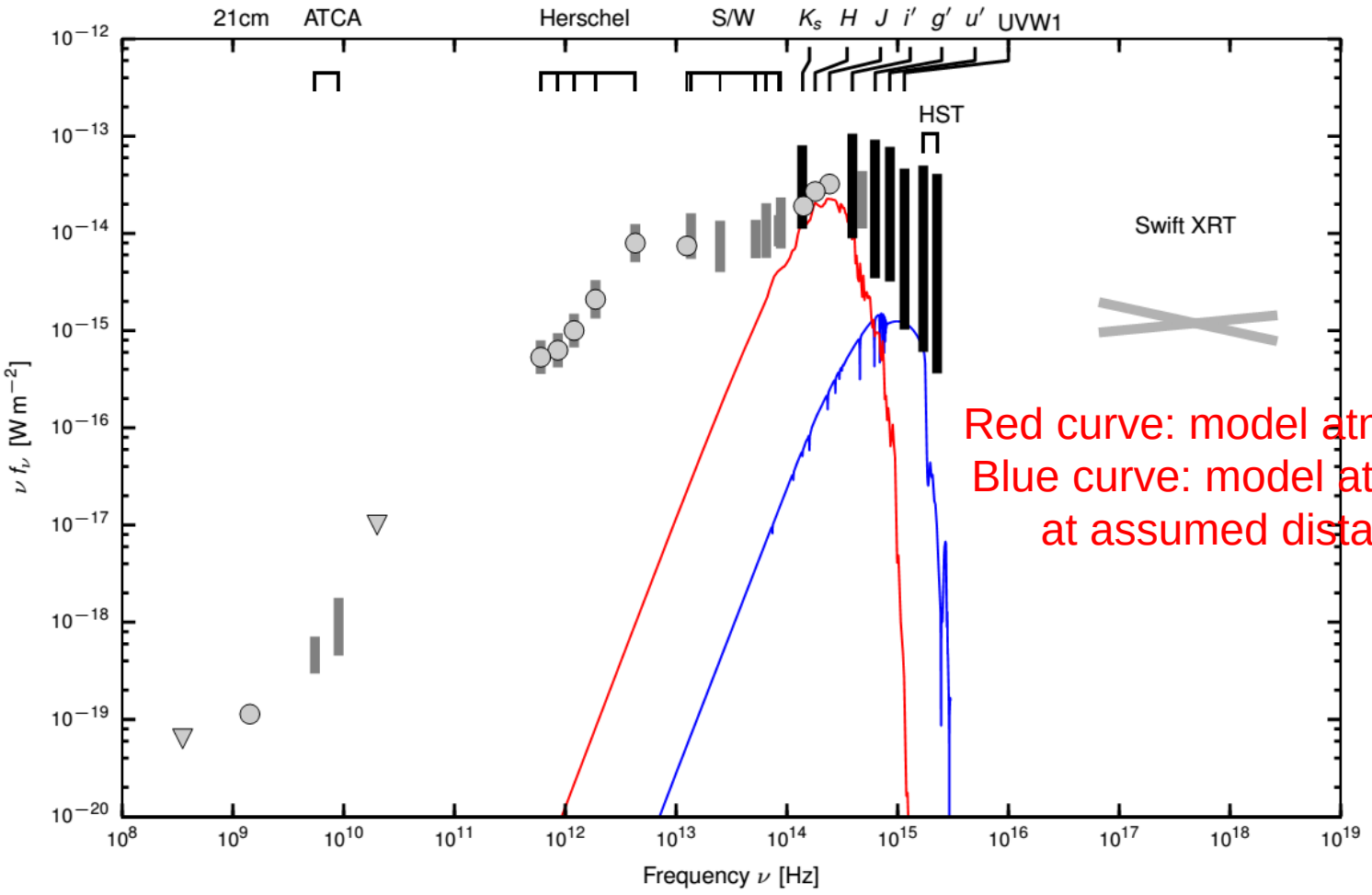
* Focal Reducer and Low Dispersion Spectrograph

HST UV spectrum of AR Sco



ultraviolet lines
mainly come from the irradiated face of the M star

The wide band Spectral Energy Distribution (SED) of AR Sco



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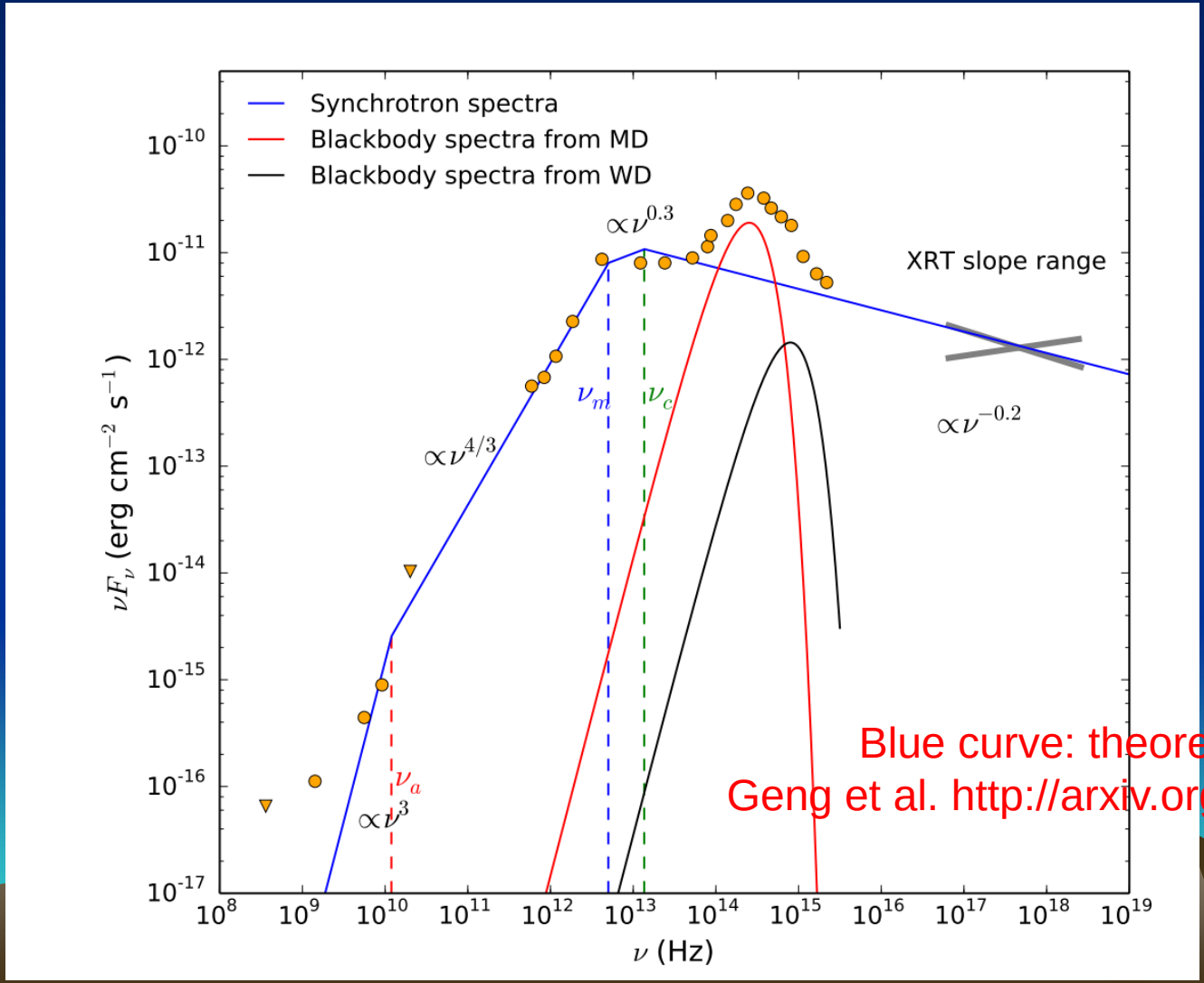


Blue curve: theoretical assumption
Geng et al. http://arxiv.org/pdf/1609.02508v1.pdf

Observational record

Tel./Inst.	Type	Wavelength	Date	Exposure
				$T[\mathrm{s}] \times N$
VLT+FORS	Spectra	420 – 900 nm	2015-06-03	600x1
WHT+ULTRACAM	Photometry	u', g', r'	2015-06-23	2.9x768
WHT+ULTRACAM	Photometry	u', g', i'	2015-06-24	1.3x7634
Swift+UVOT/XRT	UV, X-rays	260 nm, 0.2 – 10 keV	2015-06-23 – 2015-08-03	1000x10
VLT+HAWKI	Photometry	K_S	2015-07-06	2.0x7020
WHT+ISIS	Spectra	354 – 539, 617 – 884 nm	2015-07-16	20x94
WHT+ISIS	Spectra	354 – 539, 617 – 884 nm	2015-07-17	300x4
WHT+ISIS	Spectra	356 – 520, 540 – 697 nm	2015-07-19	30x130
ROAD 40 cm	Photometry	White light	2015-07-19 – 2015-07-28	30x1932
WHT+ISIS	Spectra	356 – 520, 540 – 697 nm	2015-07-20	30x210
INT+IDS	Spectra	440 – 685 nm	2015-07-22	27x300
INT+IDS	Spectra	440 – 685 nm	2015-07-23	34x300
ATCA	Radio	5.5, 9.0 GHz	2015-08-13	271x10
WHT+ISIS	Spectra	320 – 535, 738 – 906 nm	2015-08-26	600x8
WHT+ISIS	Spectra	320 – 535, 738 – 906 nm	2015-09-01	600x8
VLT+XSHOOTER	Spectra	302 – 2479 nm	2015-09-23	11x300
HST+COS	Spectra	110 – 220 nm	2016-01-19	5 orbits
TNT+ULTRASPEC	Photometry	g'	2016-01-19	3.8x1061

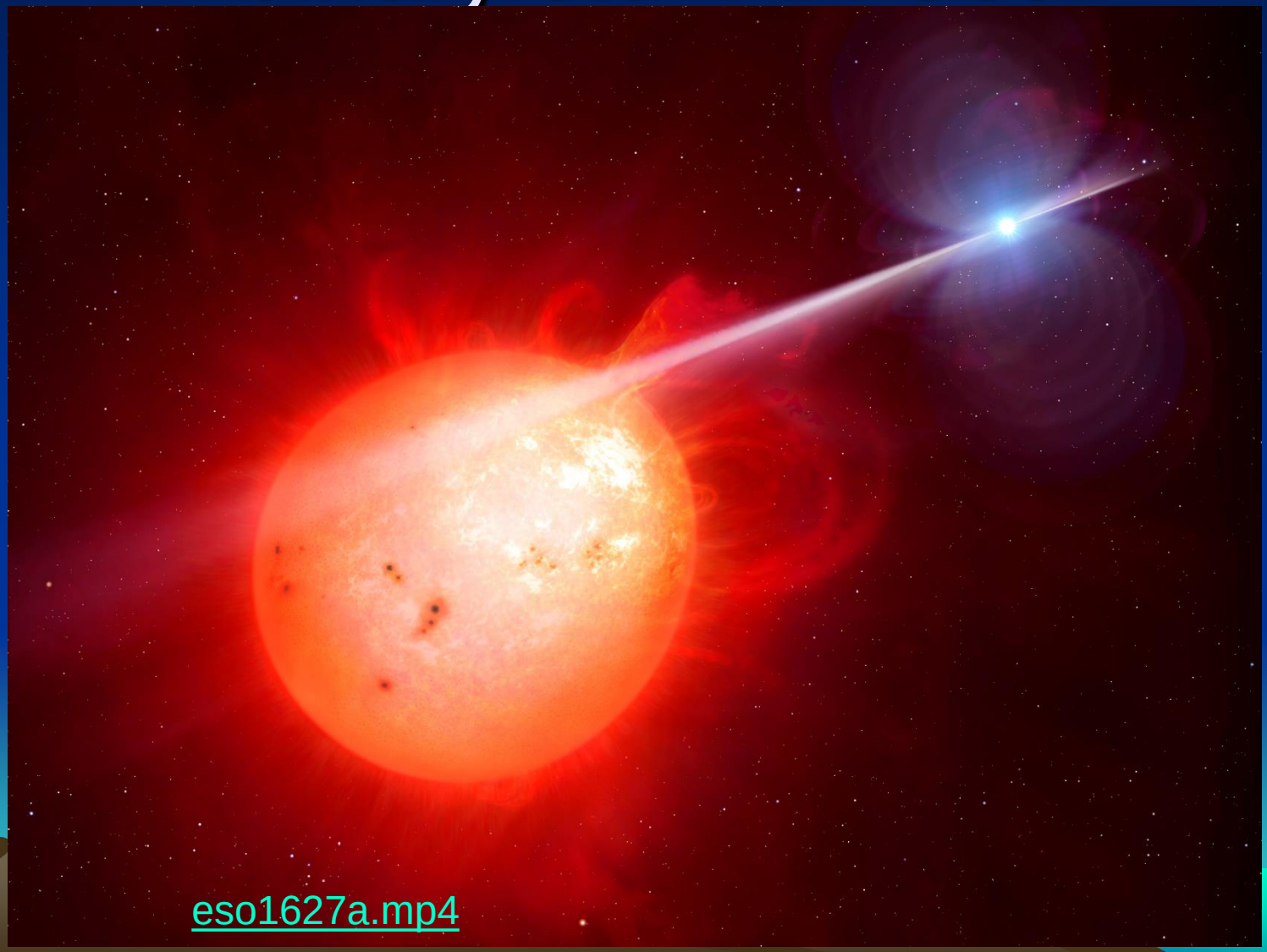
Great to see my humble telescope amongst the big glass (VLT, WHT, HST)

Observed frequencies

Frequency	5 %-ile	95 %-ile	Median	Mean	RMS
	mHz	mHz	mHz	mHz	mHz
ν_O	0.077921311	0.077921449	0.077921380	0.077921380	0.000000042
ν_B	8.4603102	8.4603140	8.4603112	8.4603114	0.0000011
ν_S	8.5382332	8.5382356	8.5382348	8.5382346	0.0000008

ν_O = orbital frequency, Period = 213.891 min
ν_B = beat frequency, Period = 1.97 min
ν_S = spin frequency, Period = 1.95 min

Artist‘s impression of the exotic binary star AR Sco



AR Sco

- AR Scorpii is definitely not a δ-Scuti star.
- The stars X-ray emission is unexpected for a δ-Scuti star.
- High-speed optical observations revealed pulsations so strong that AR Sco can brighten by a factor of four within 30 sec.
- The system pulses on a 1.97 min period,
- Is the first white dwarf system observed to pulse periodically at radio frequencies
- The pulsations reflect the spin of a magnetic white dwarf which we find to be slowing down on a 10^7 yr timescale
- Although the pulsations are driven by the white dwarf's spin, they originate in large part from the cool star.
- AR Sco's broad-band spectrum is characteristic of synchrotron radiation, requiring relativistic electrons.
- These must either originate from near the white dwarf or be generated in situ at the M star through direct interaction with the white dwarf's magnetosphere

Publication

- A radio pulsing white dwarf binary star
- T.R. Marsh, B.T. Gänsicke, S. Hümmerich, F.-J. Hambsch, K. Bernhard, C.Lloyd, E. Breedt, E.R. Stanway, D.T. Steeghs, S.G. Parsons, O. Toloza, M.R. Schreiber, P.G. Jonker, J. van Roestel, T. Kupfer, A.F. Pala, V.S. Dhillon, L.K. Hardy, S.P. Littlefair, A. Aungwerojwit, S. Arjyotha, D. Koester, J.J. Bochinski, C.A. Haswell, P. Frank, P.J. Wheatley,
- Nature 537 (2016) 374–377 (15 September 2016)
- http://www.nature.com/nature/journal/vaop/ncurrent/full/nature18620.html

- It is not yet over, XMM satellite observations performed September 10, 11 2016
- Two theoretical papers already out
- Sure there will be more to come….

Thank you for your attention