Transition-Metal Oxides in Warm Circumstellar Environments

M.R. Schmidt[1], T. Kamiński[2], R. Tylenda[1]
[1]N. Copernicus Astronomical Center, Dep. of Astrophysics, Toruń
[2]Max Planck Institut fur Radioastronomie, Bonn

In collaboration with:
M. Konacki, NCAC Torun
M. Gromadzki, , Dep. De Fisica y Astronomia, Universidad de Valparaiso, Chile
R. Kurtev, Dep. De Fisica y Astronomia, Universidad de Valparaiso, Chile
T. Tomov, Center for Astrophysics of Nicolaus Copernicus University, Torun

Scientific Colloquium to mark the formal retirement of Prof. Dr hab. R. Tylenda, 9 July, 2013

V838 Mon

- erupted in January 2002 as apparent nova

- subsequent evolution towards later spectral type is in contradiction to classical novae

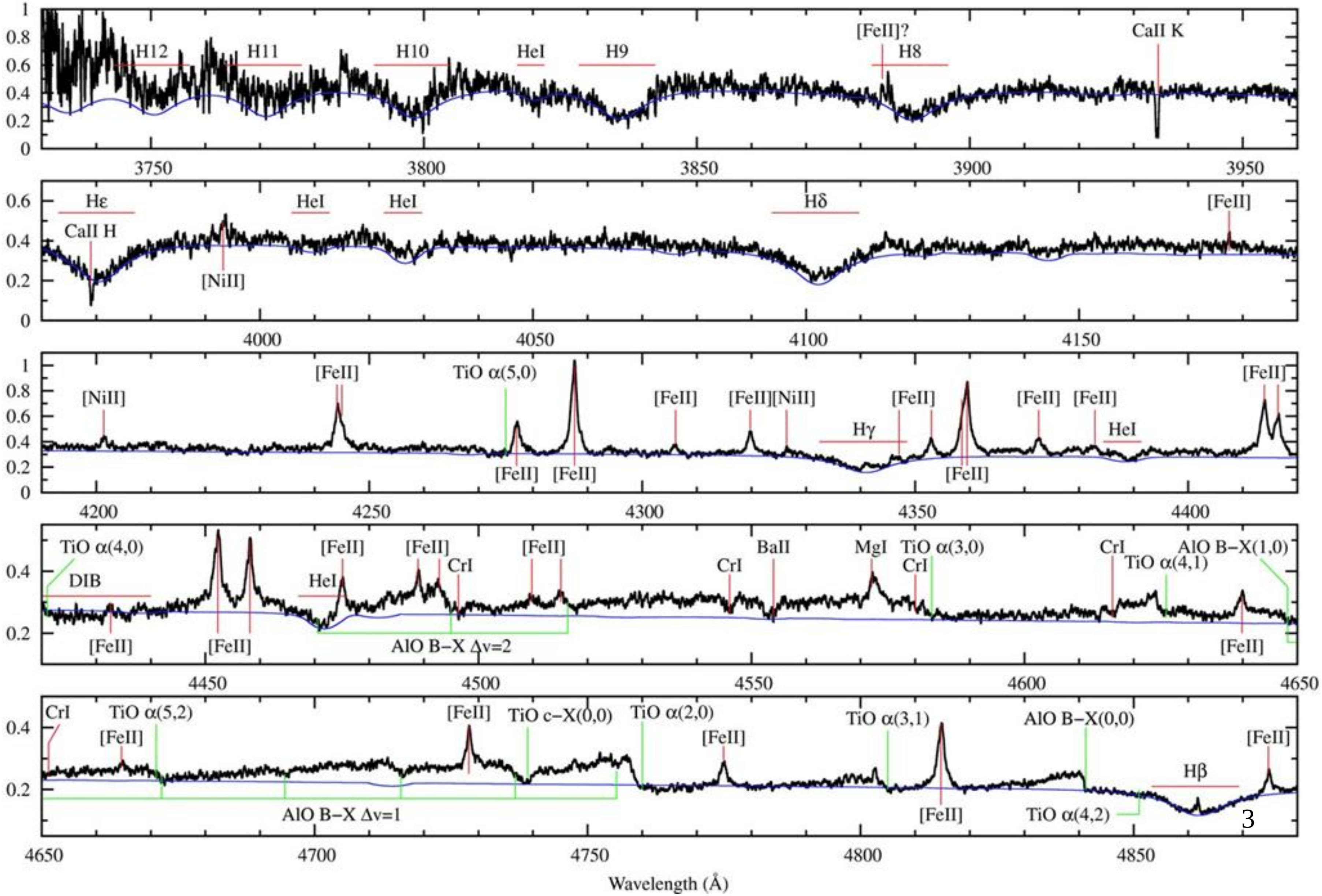
- progenitor of F V type

- brightening in three phases (in monthly intervals) up to 10^6 solar luminosities

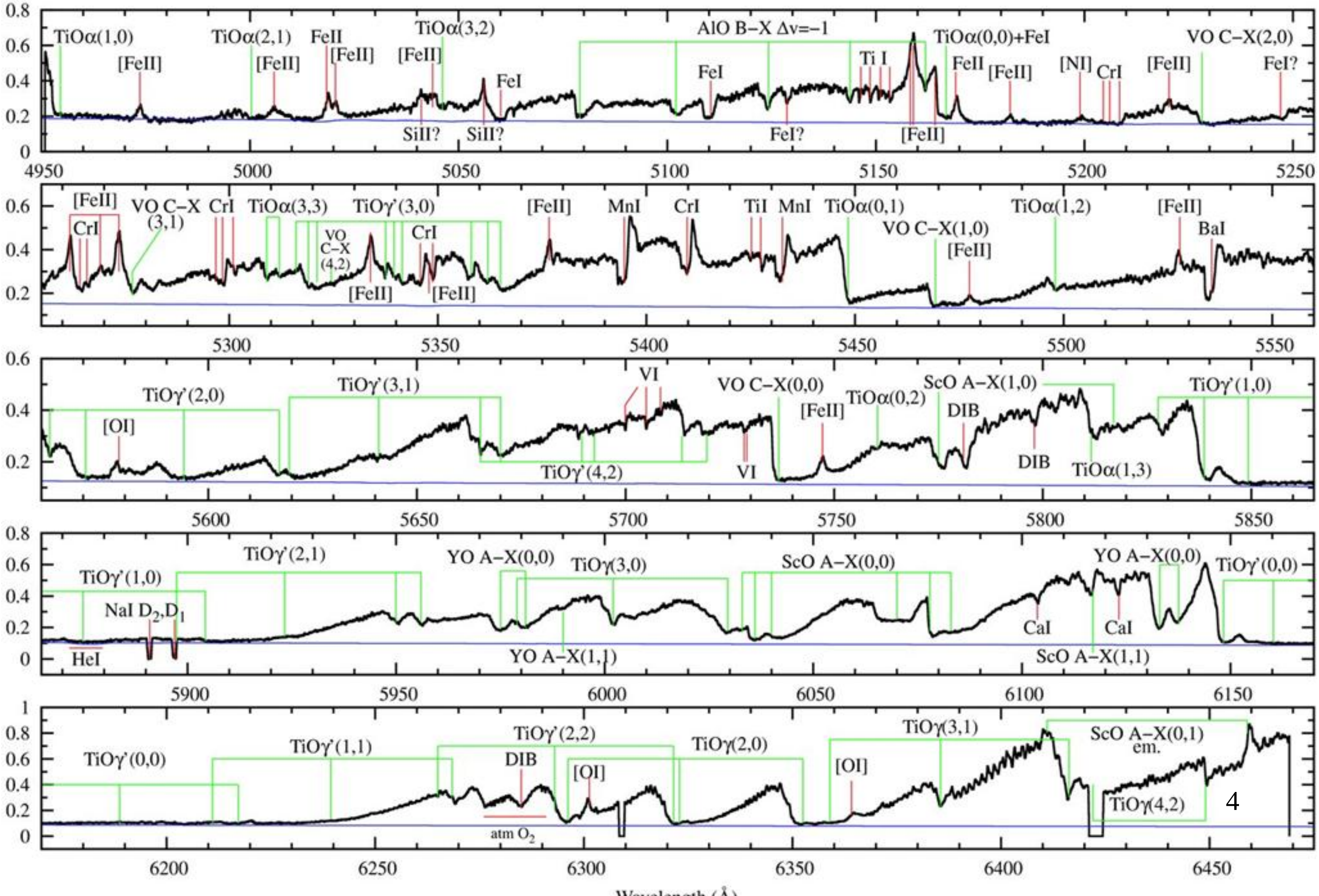
- qfter eruption A-type and later F-type with P-Cygni profiles

- after one year molecular lines appeared (Lynch et al. 2003)

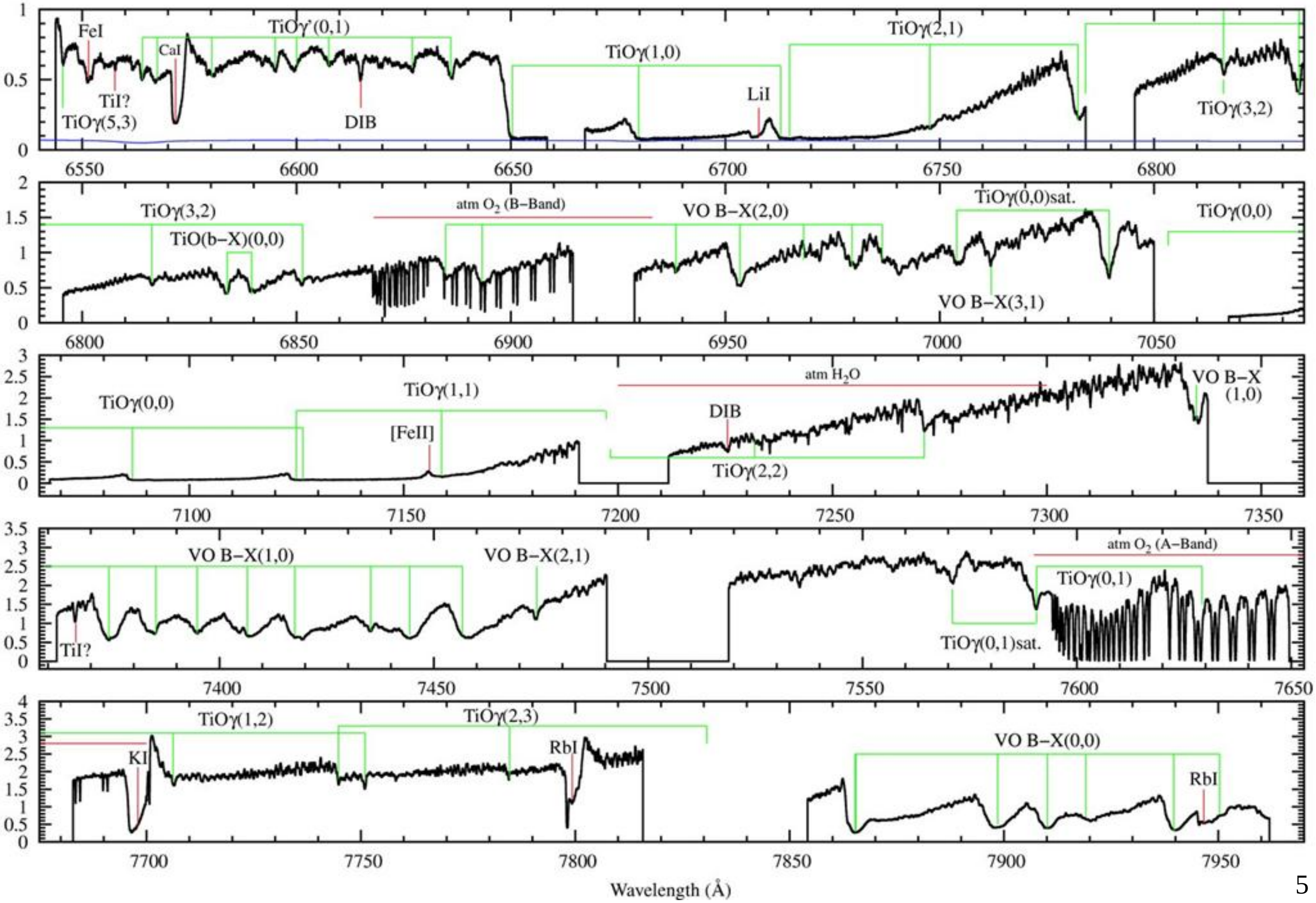
Visual spectrum of V838 Mon in October 2005 – Keck/HIRES

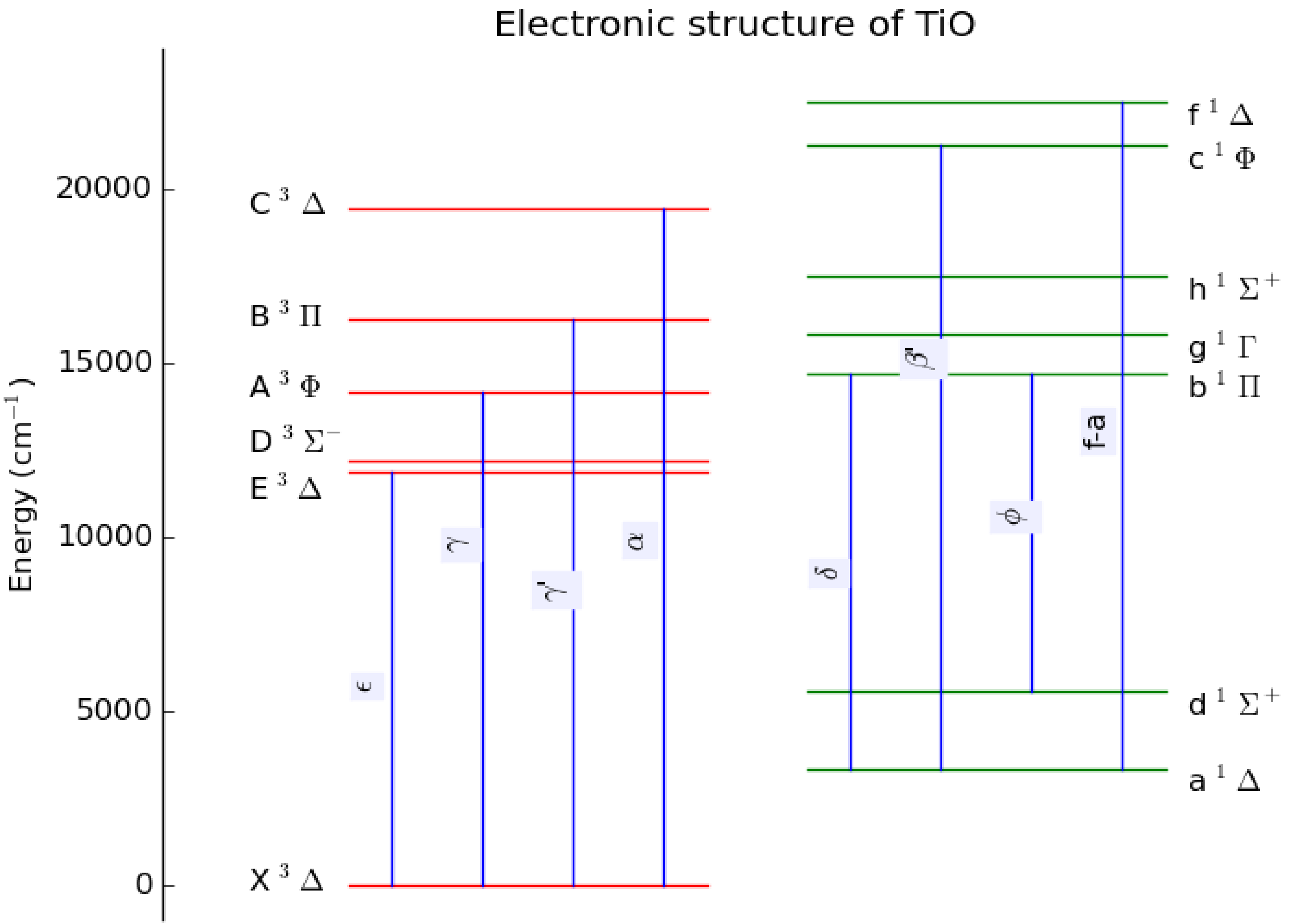


Visual spectrum of V838 Mon in October 2005



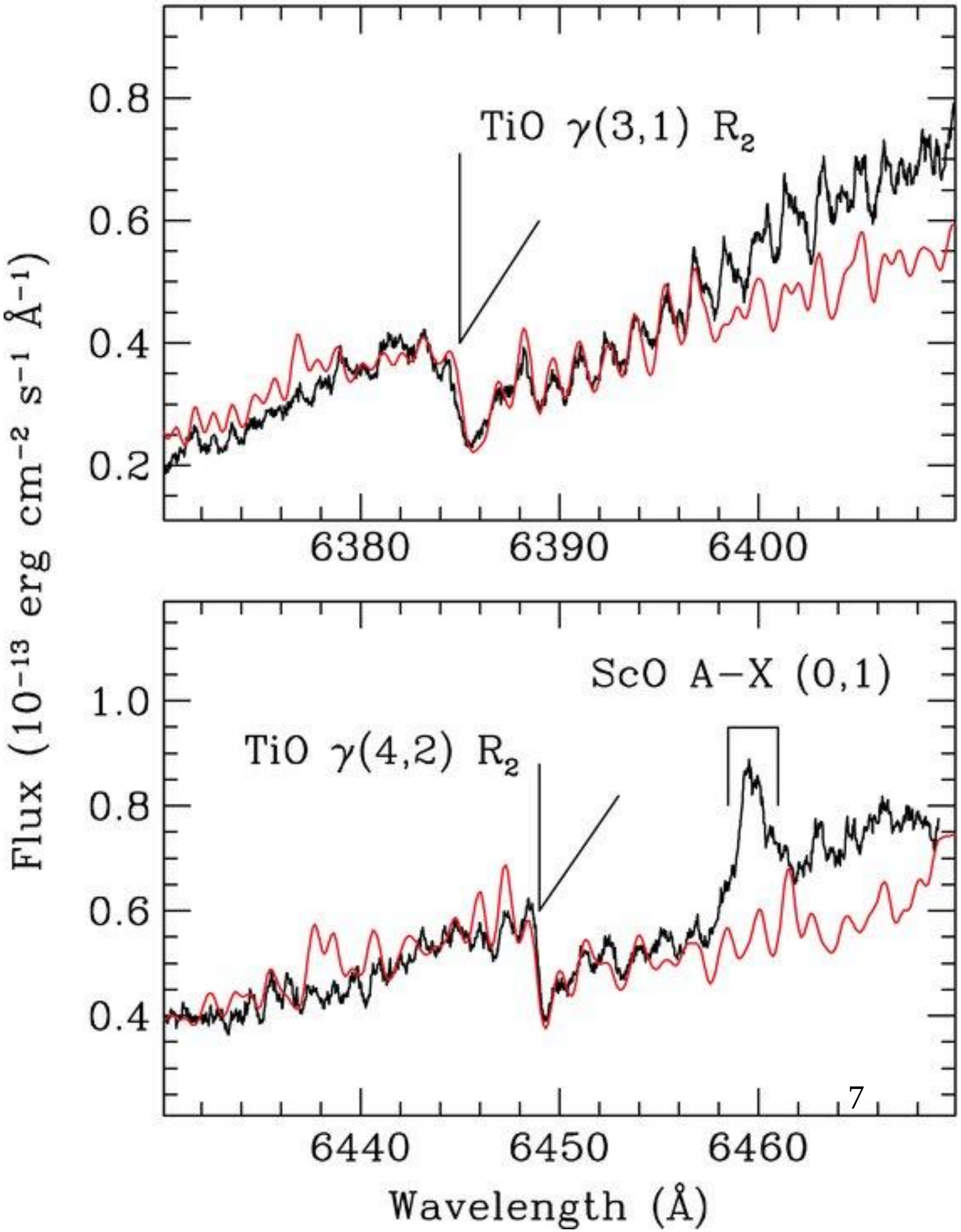
Visual spectrum of V838 Mon in October -2005

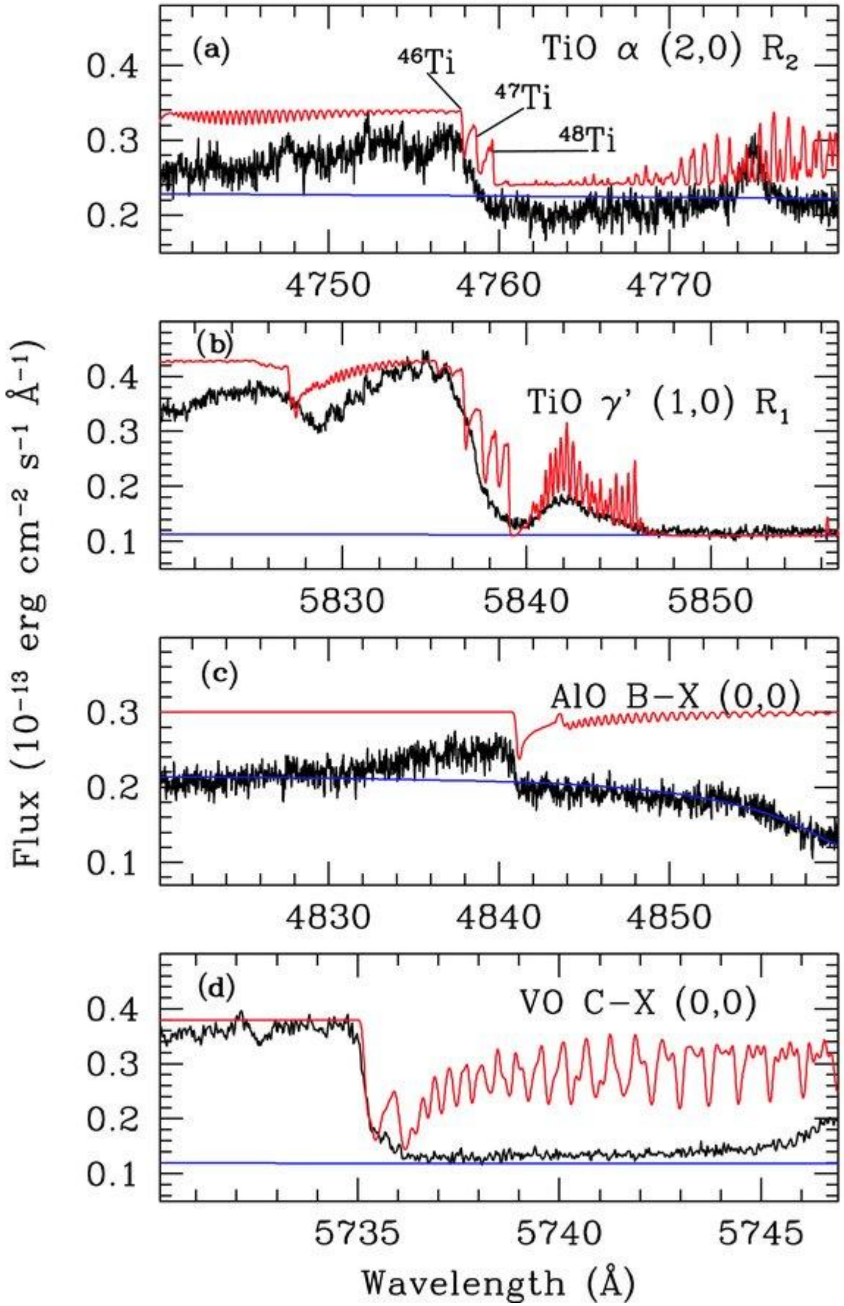



Electronic structure of TiO
Energy (cm⁻¹)
20000
15000
10000
5000
0
C ³Δ
B ³Π
A ³Φ
D ³Σ⁻
E ³Δ
X ³Δ
ε
γ
γ'
α
f ¹Δ
c ¹Φ
h ¹Σ⁺
g ¹Γ
b ¹Π
d ¹Σ⁺
a ¹Δ
δ
β'
φ
f-a

Rotational structure of highly excited levels of two gamma bands of TiO. The observed spectrum (black line) is compared with simulations (red line).

In order to fit the simulated rotational features to those in the observed spectrum, the simulated spectra have been shifted to a velocity of V = 58 km s−1 and smoothed with a Gaussian with FWHM = 34 km s−1. An emission feature of ScO can easily be seen in the bottom panel (ScO was not included in the simulations shown here).





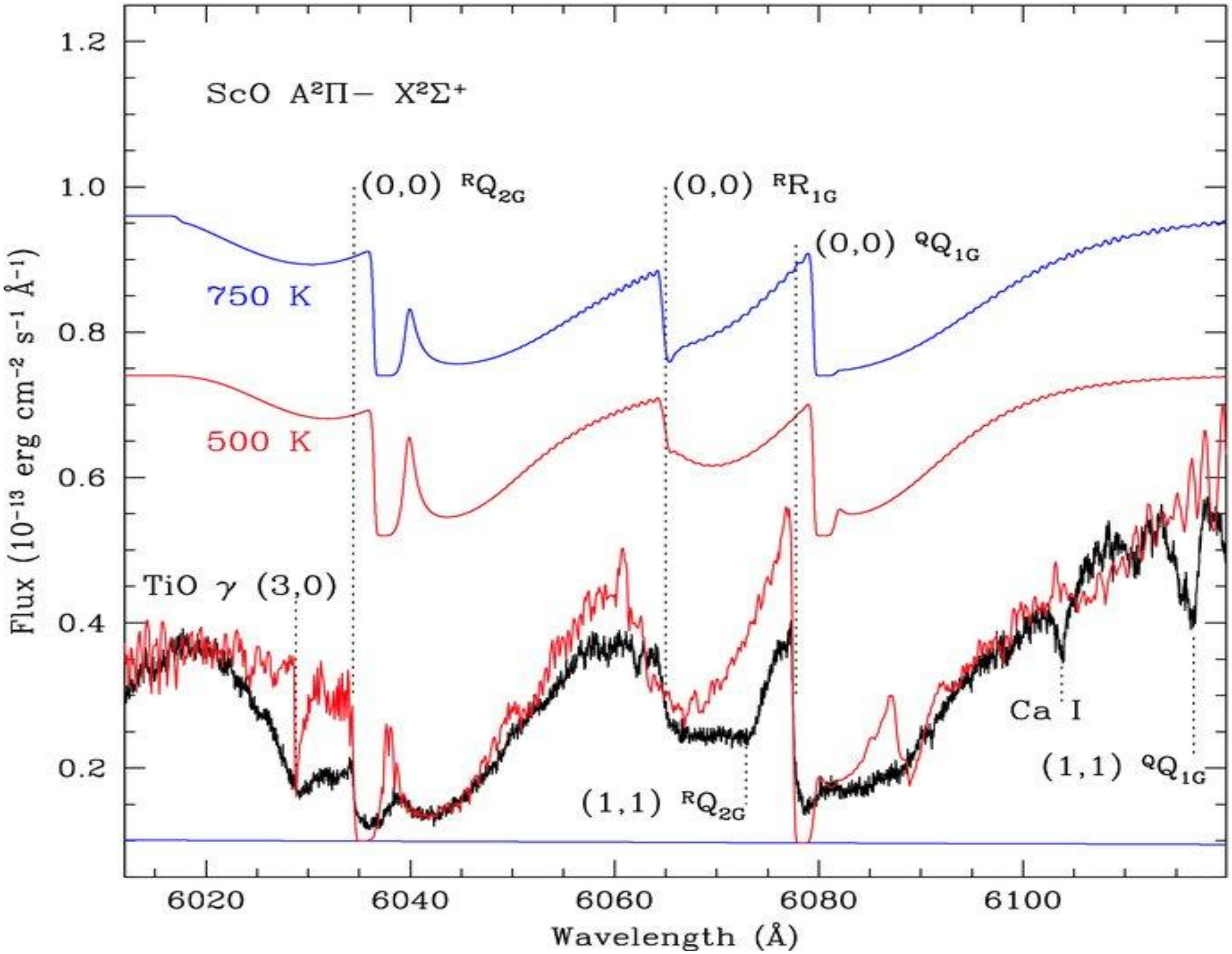
(a) The α (2, 0) band head of TiO. The three heads clearly distinct in the simulated profile correspond to 46TiO, 47TiO, and 48TiO isotopes.

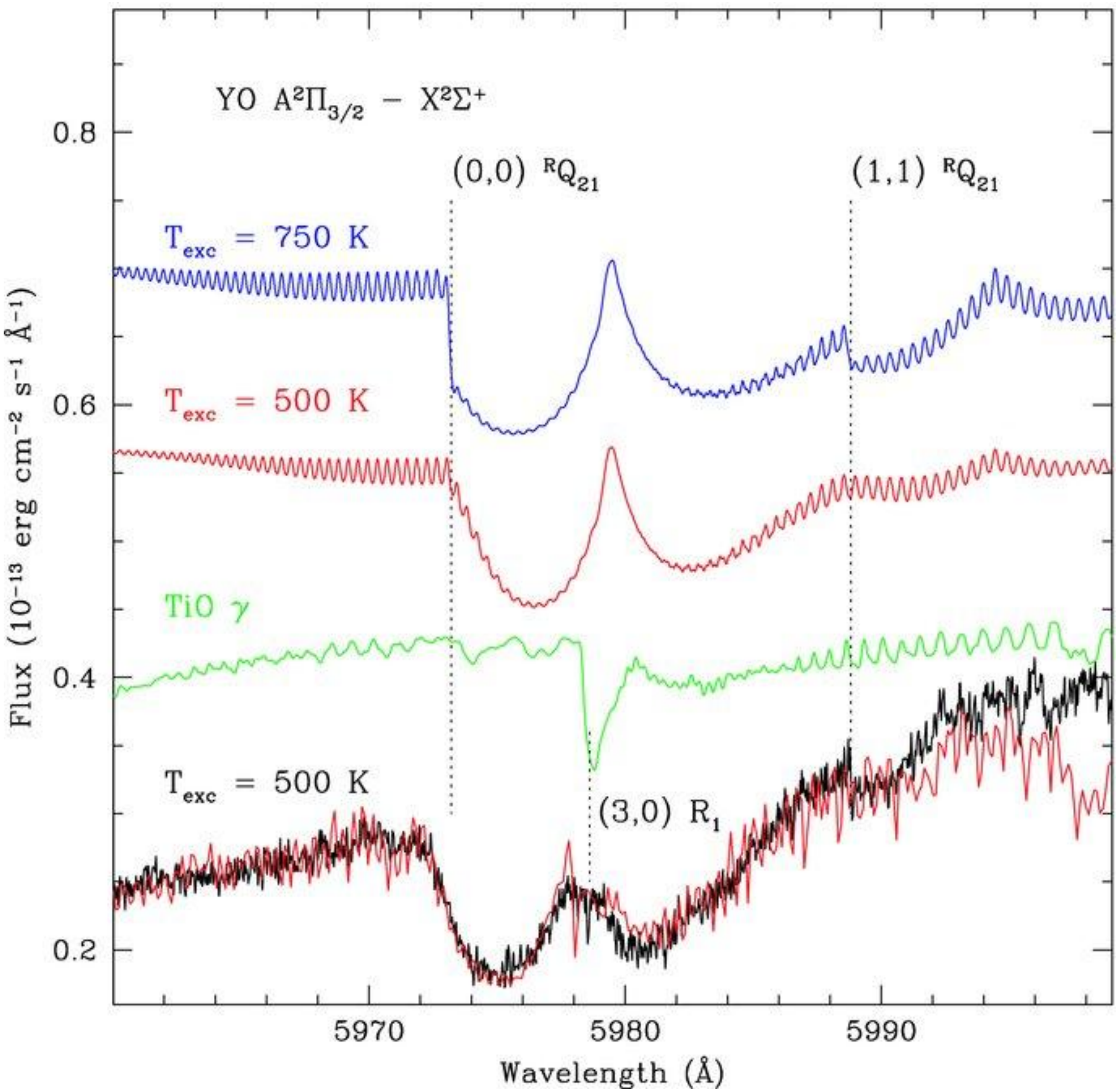
(b) The gamma' (1, 0) band head of TiO. This head is formed by multiple strong satellite branches and defining a reference laboratory position of the blue edge of the absorption feature is problematic.

(c) The sharp B −X (1, 0) band head of AlO. In this case, the reference laboratory position is well defined.

(d) The C −X (0, 0) band head of VO. As seen in the computed profile, this head has a double structure when the band is not very saturated.

The observed (black) and simulated spectrum of the ScO $A^2\Pi – X^2\Sigma^+$ A2Pi (0, 0).





Observed spectrum (black) around subband of YO $A^2\Pi_{3/2}$–$X^2\Sigma^+$ and simulated spectra.

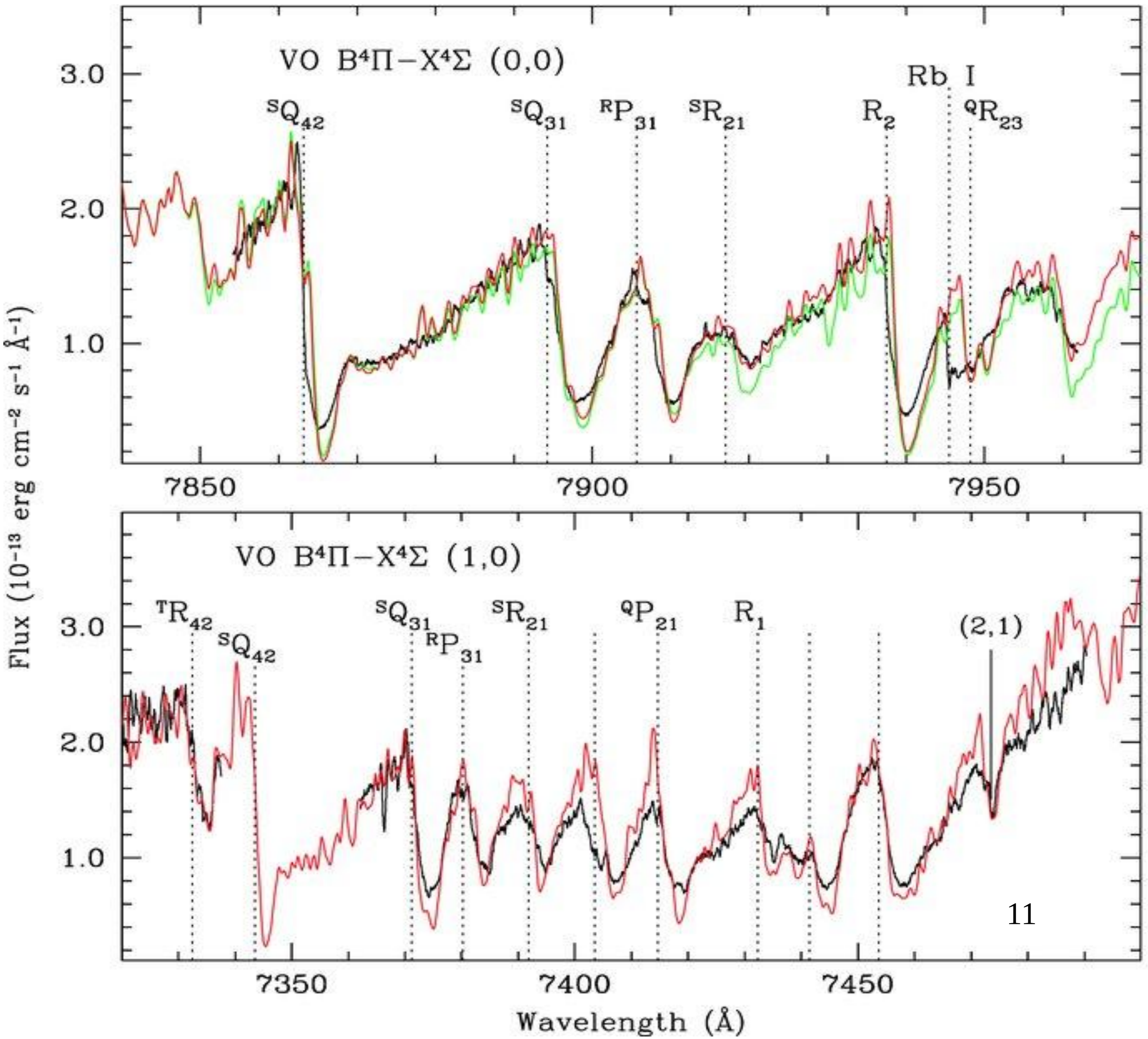
The final simulation (bottom) includes an extra absorption of TiO, which is shown with a green line.

Remark.
Both ScO and YO have blue-green systems below 5000 A – not found.

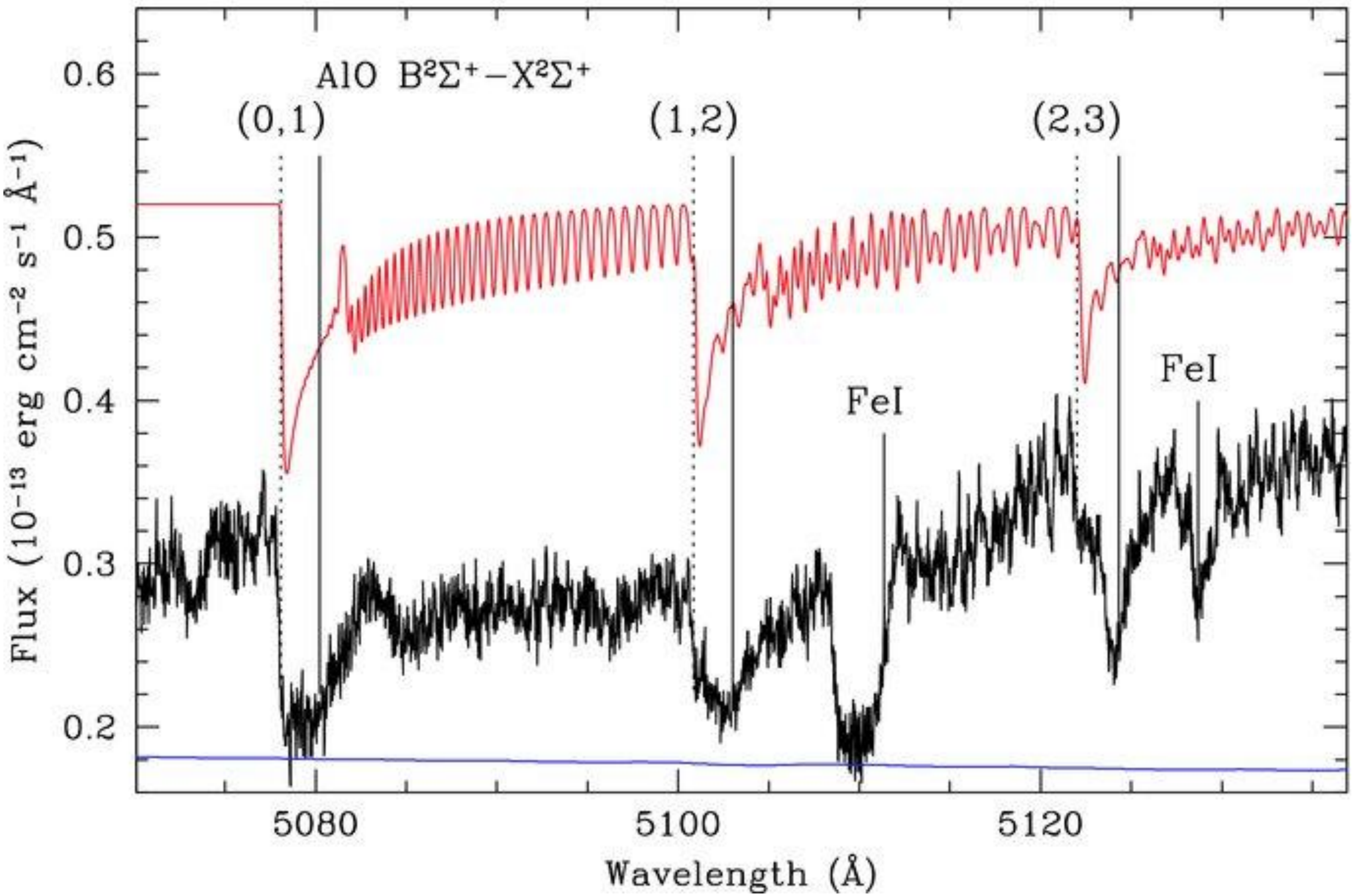
Observed (black) and simulated (red,green) spectra of the $B^4\Pi$–$X^4\Sigma$ bands of VO.

The (0, 0) band was simulated with the excitation temperatures of 350 K (red line) and 500 K (green line). , smoothed with a Gaussian with FWHM = 65 km s−1.

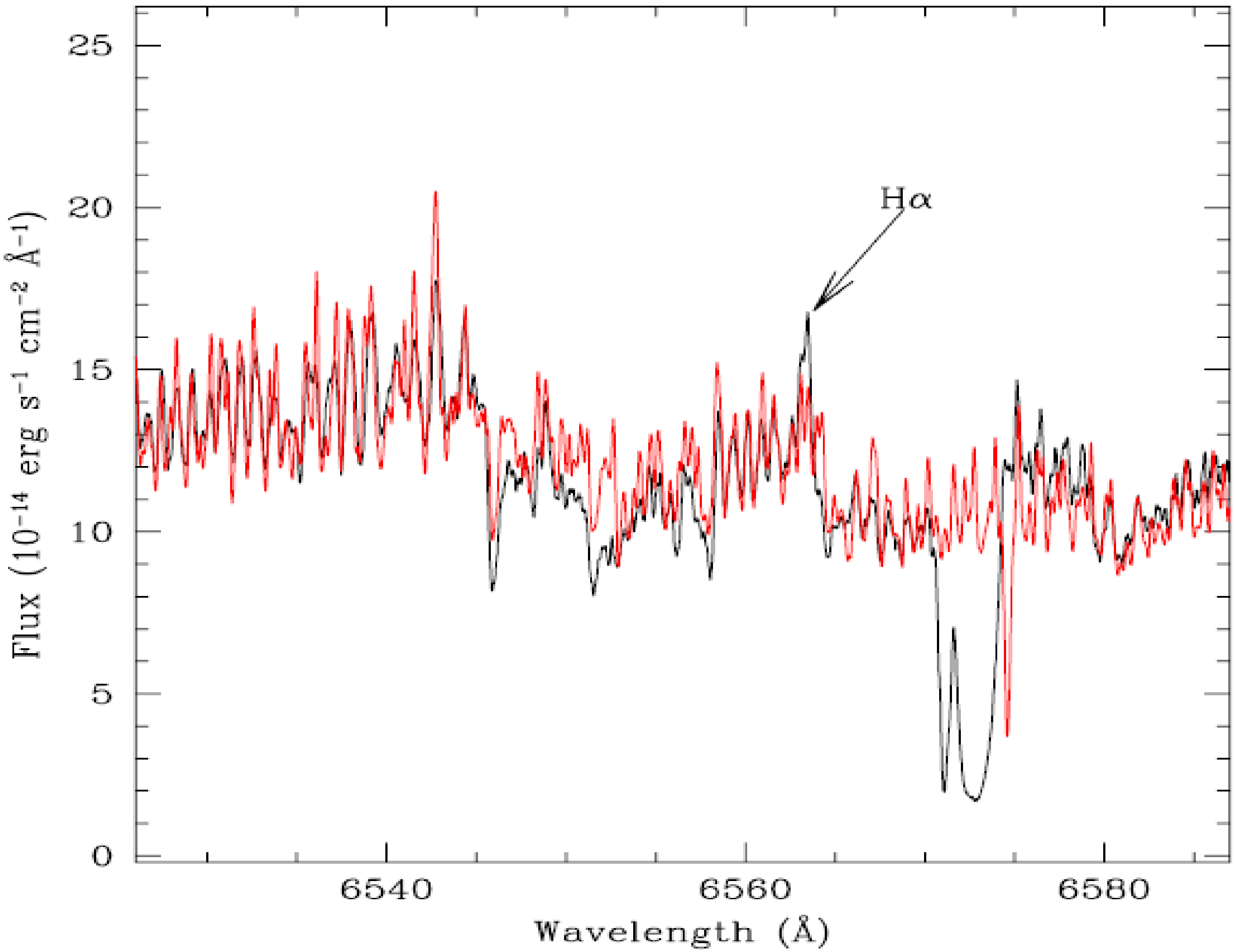
The simulation of the (1, 0) band obtained with two layers of the absorbing molecular gas with different temperatures, i.e., 500 K and 1500 K. .



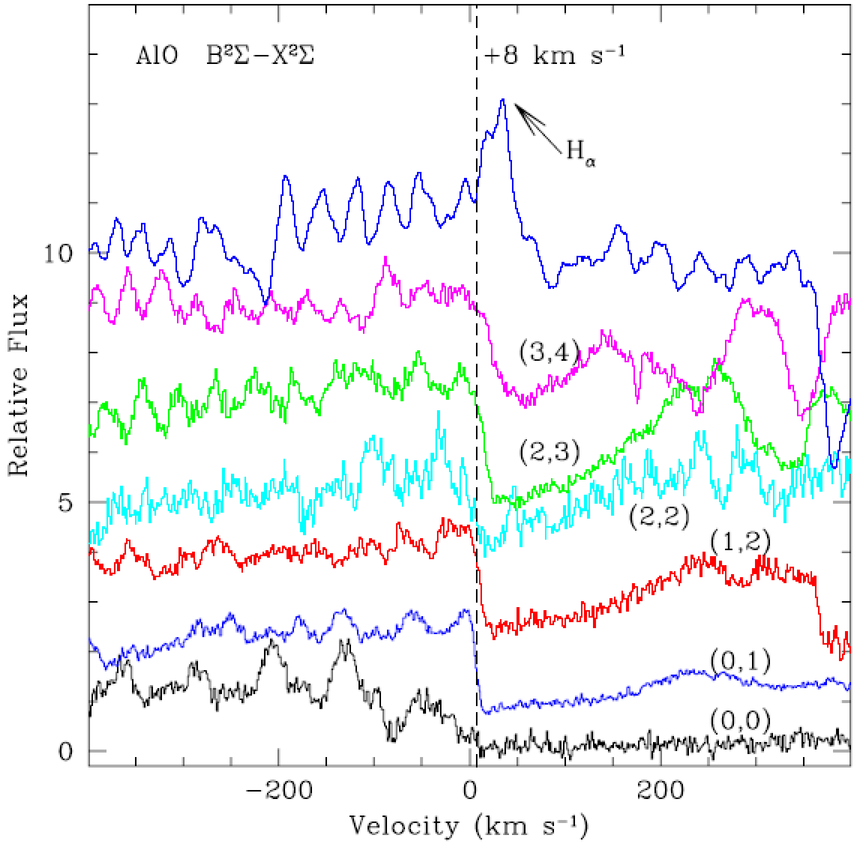
Observed spectrum (black line), simulated (red) computed for an excitation temperature of 1500 K (red). The profile was shifted in velocity by −82 km −1. The solid vertical lines are drawn for Vhel = 58 km s−1, photospheric velocity.

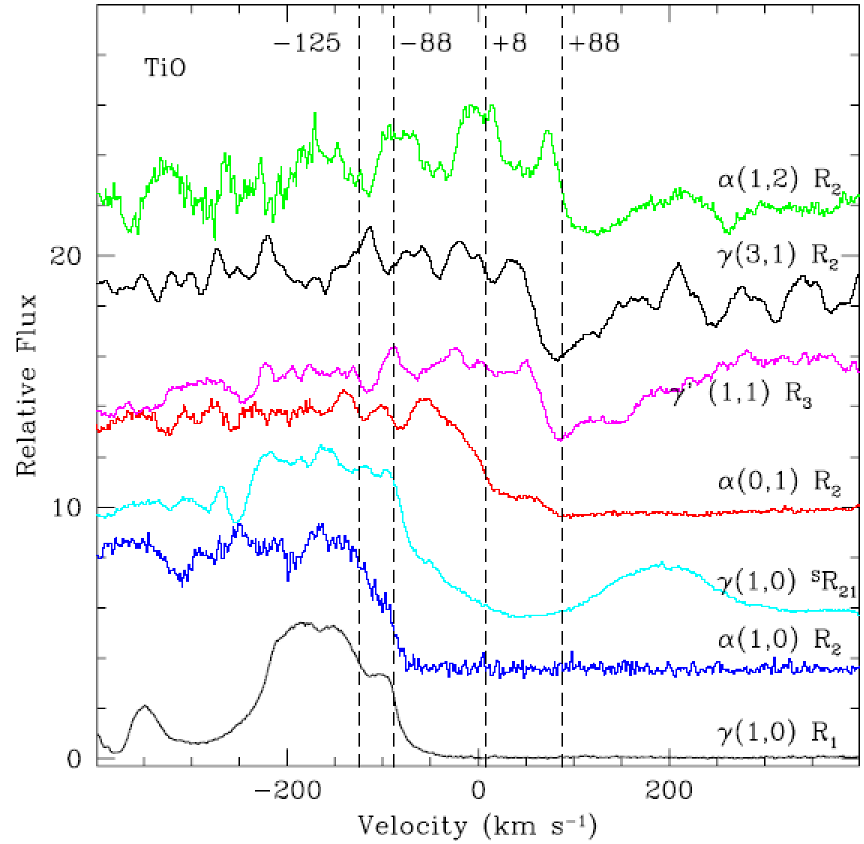


H alpha line in emission in V838 Mon
(black line - UVES@VLT from 2009, red M5 III)

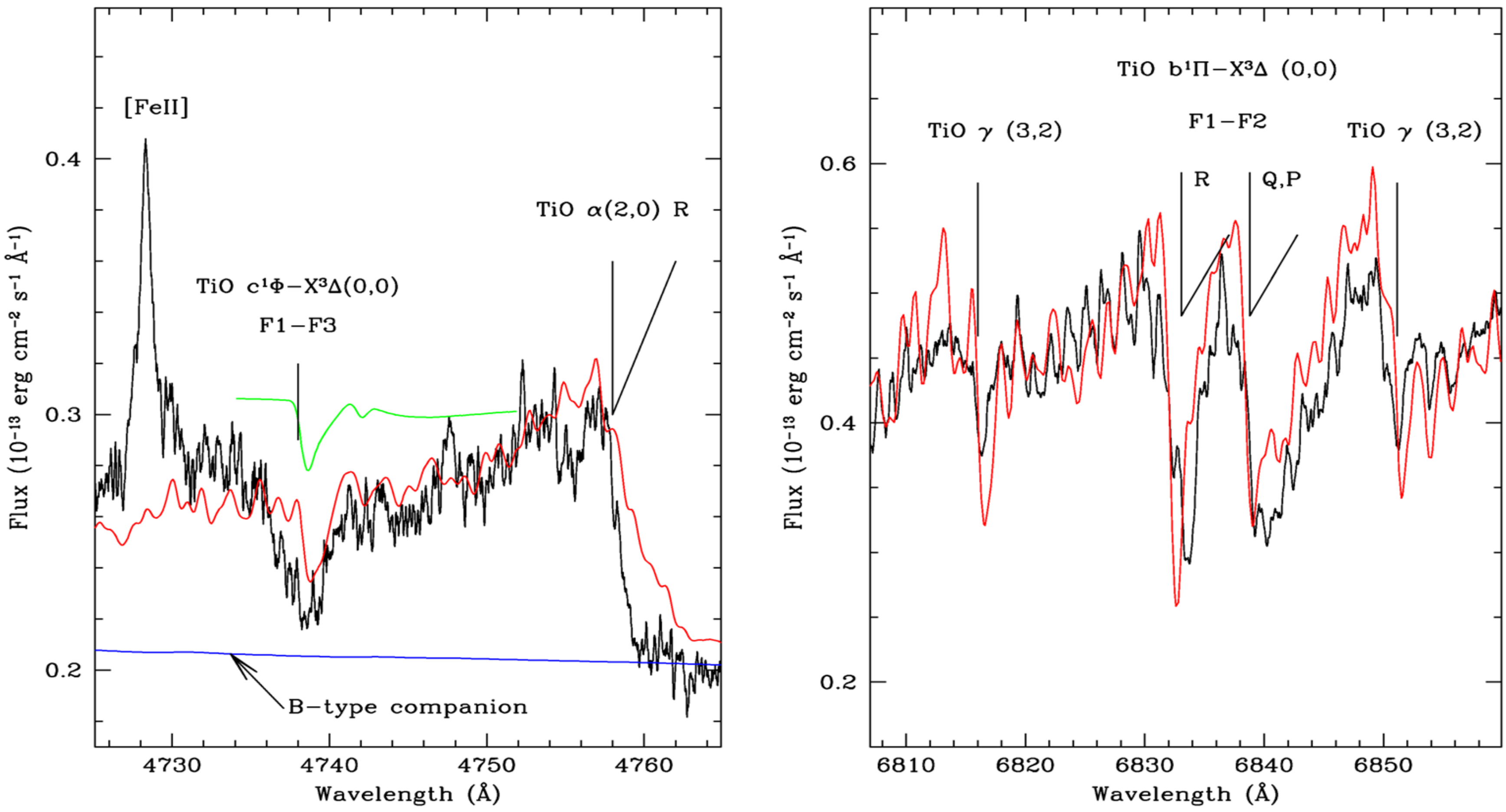


Band-heads positions of AlO and TiO in velocity scale (heliocentric system).





Forbidden bands of TiO in V838 Mon

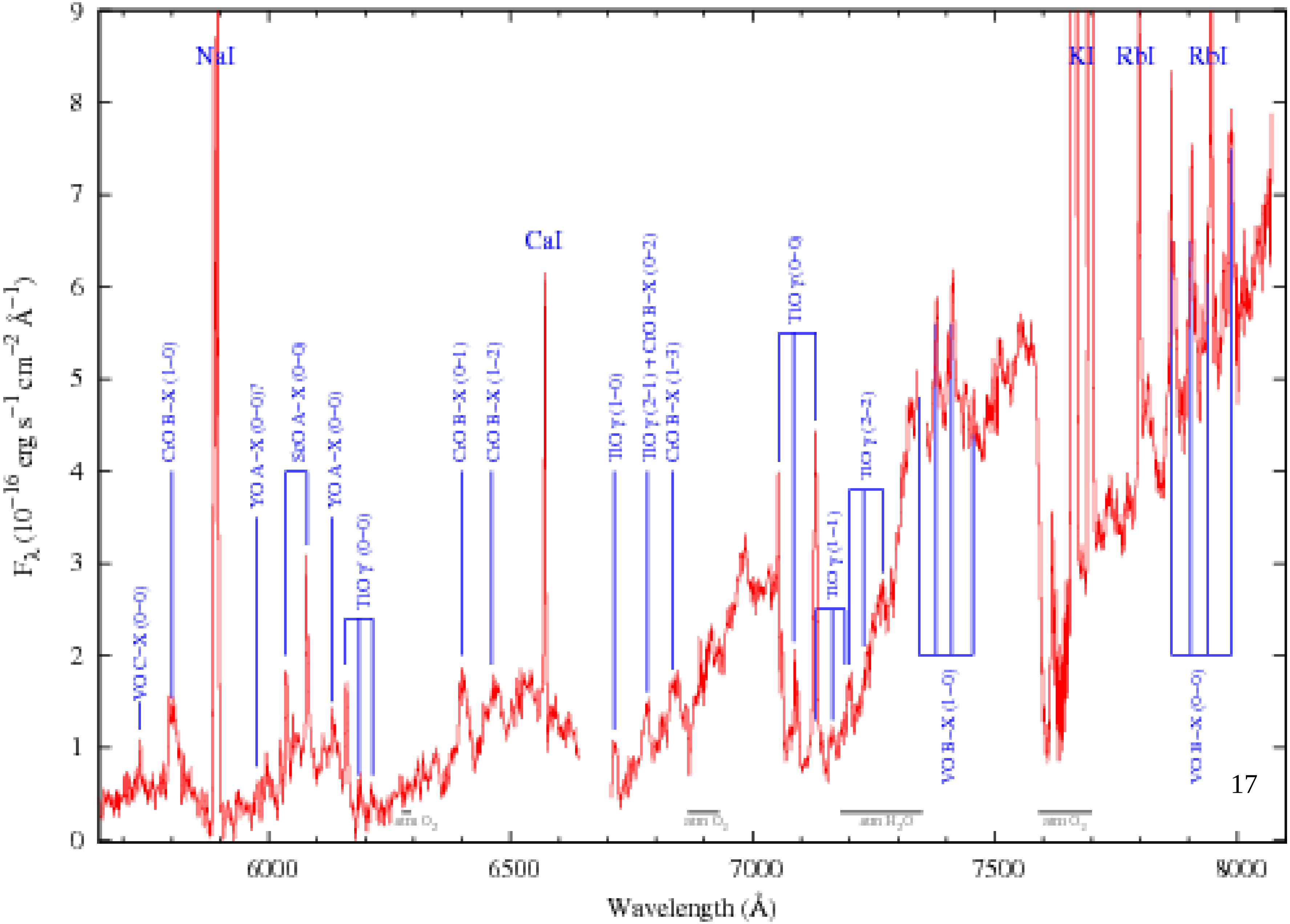


Schwenke 1998 (data from CD ROM by R. Kurucz)

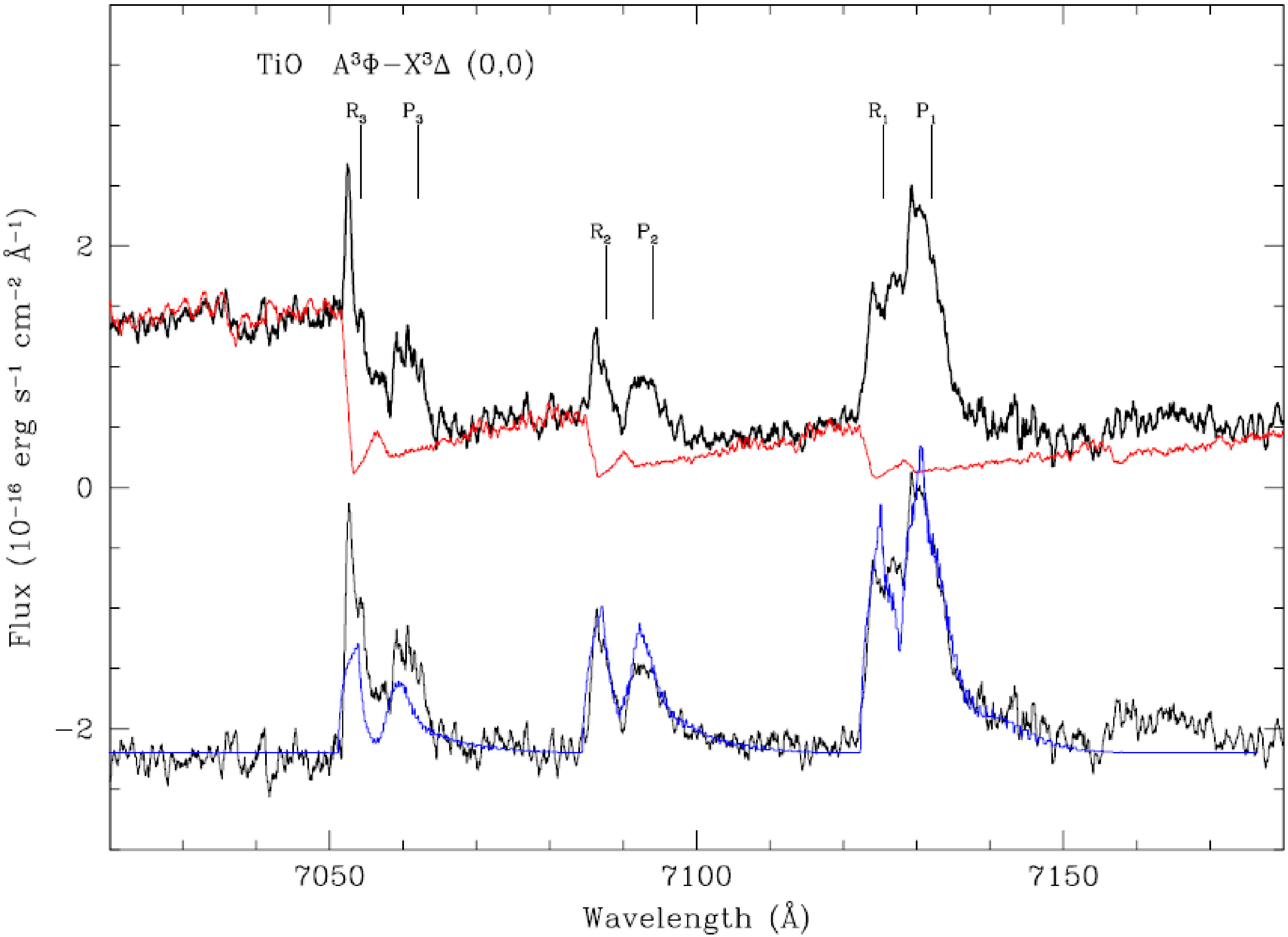
V4332 Sgr

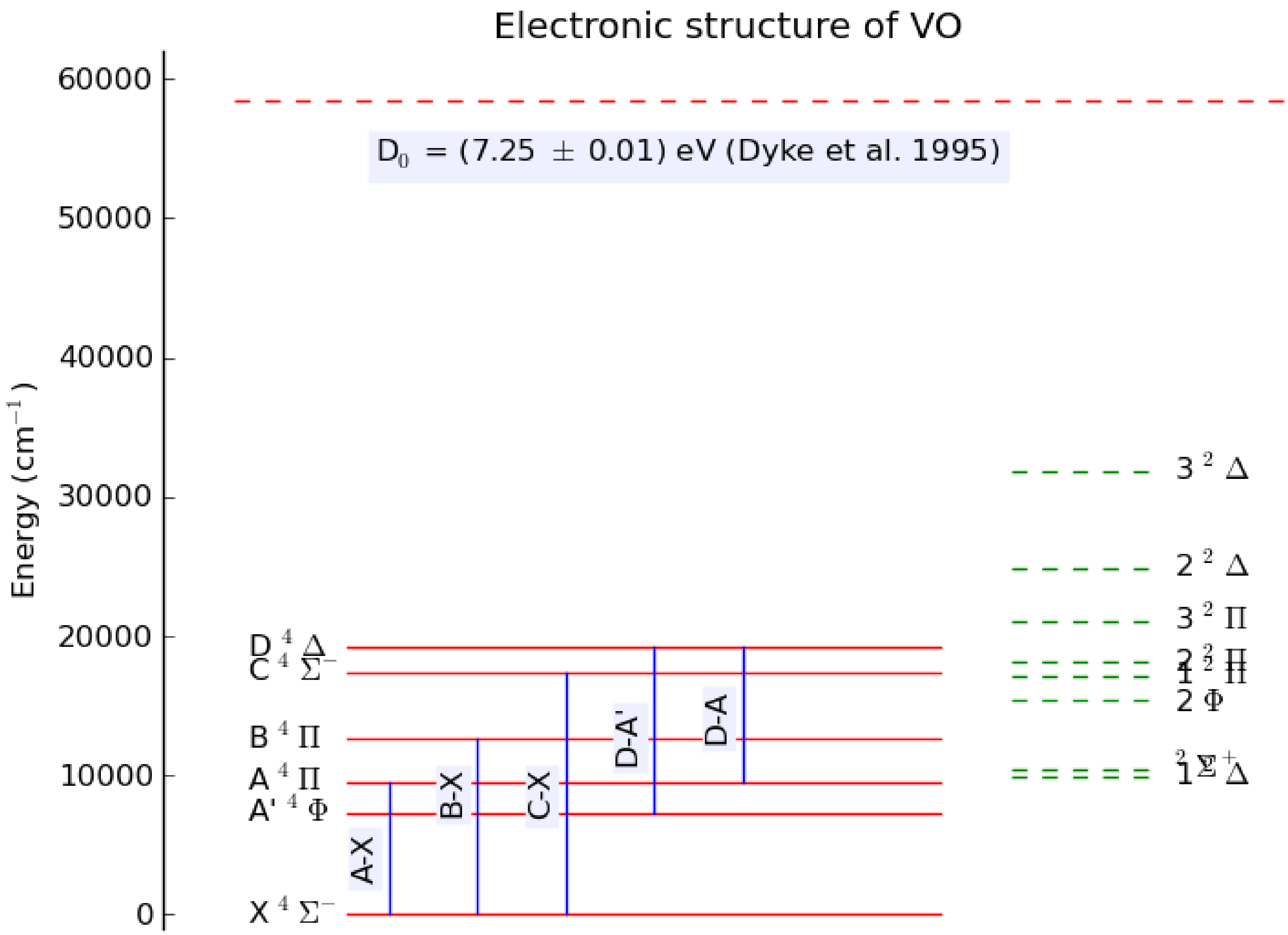
- discovered in end of february 1994 as apparent nova
- similar change of spectral type like V838 Mon
- distance not well determined, 1.8 – 10 kpc
- E(B-V) =0.32 (so 1.8 kpc fits better)
- after 1998 is seen excess of energy in far-infrared
- progenitor K0 V – G5 V
- maximum luminosity in eruption 2,000-10,000 solar luminosities

Spectrum of V4332 Sgr (Subaru telescope June 2009, spectral resolution 22,000)

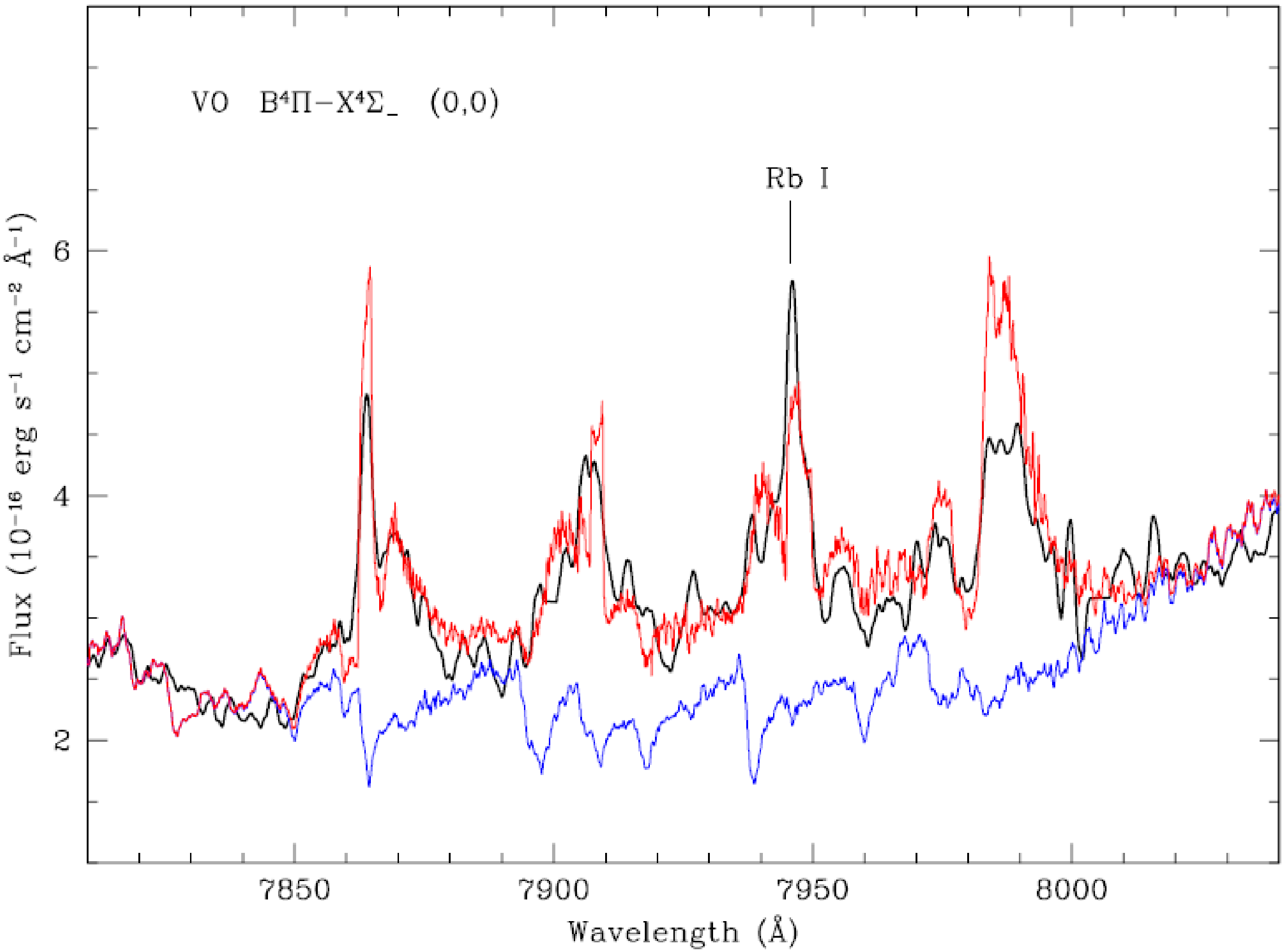


Emission in main branches of TiO in V4332 Sgr

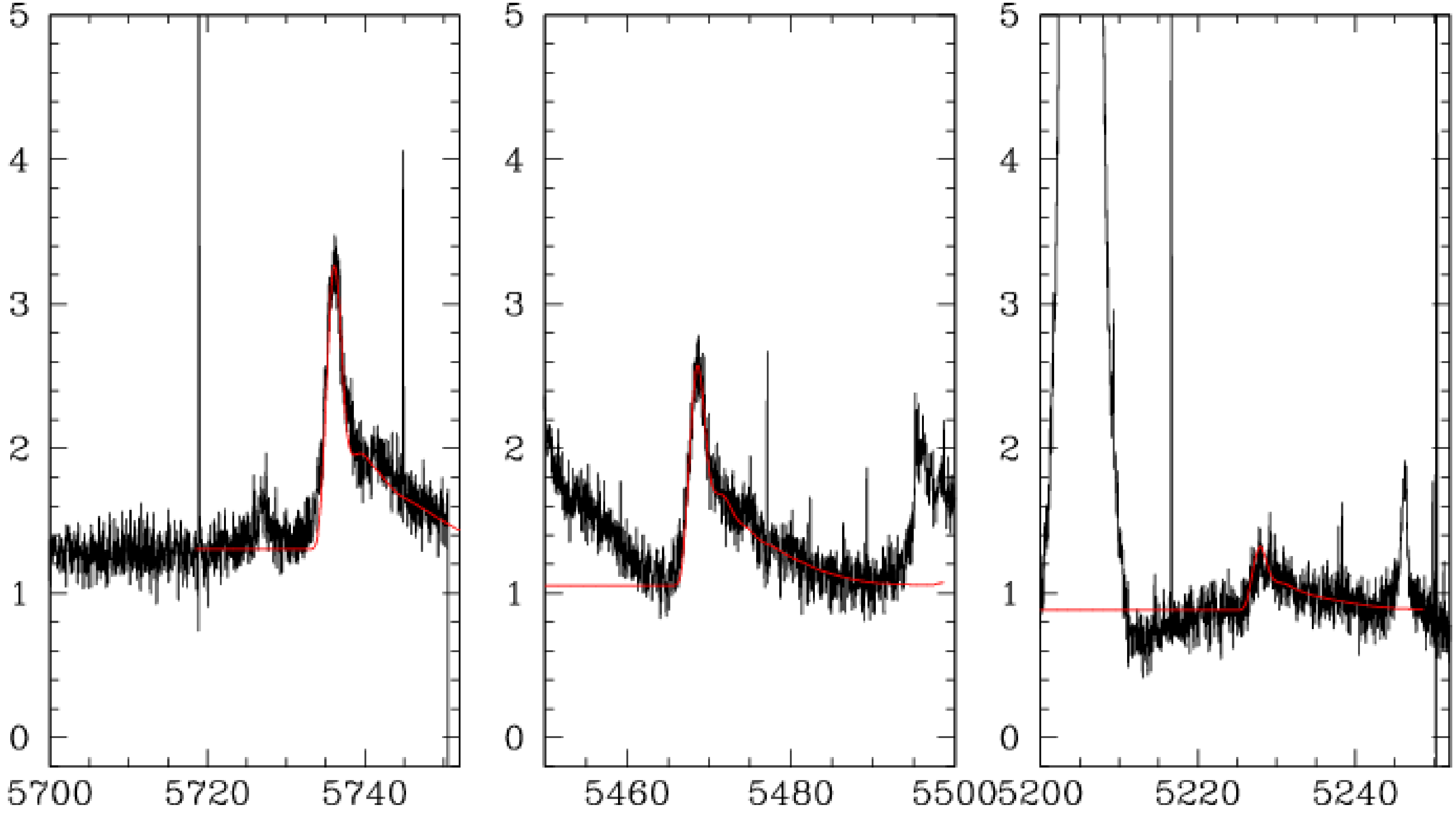



Electronic structure of VO
Energy (cm^{-1})
60000
50000
40000
30000
20000
10000
0
D$_0$ = (7.25 ± 0.01) eV (Dyke et al. 1995)
D $^4\Delta$
C $^4\Sigma^-$
B $^4\Pi$
A $^4\Pi$
A' $^4\Phi$
X $^4\Sigma^-$
A-X
B-X
C-X
D-A'
D-A
3 $^2\Delta$
2 $^2\Delta$
3 $^2\Pi$
2 $^2\Pi$
1 $^2\Pi$
2 Φ
$^2\Sigma^+$
1 Δ

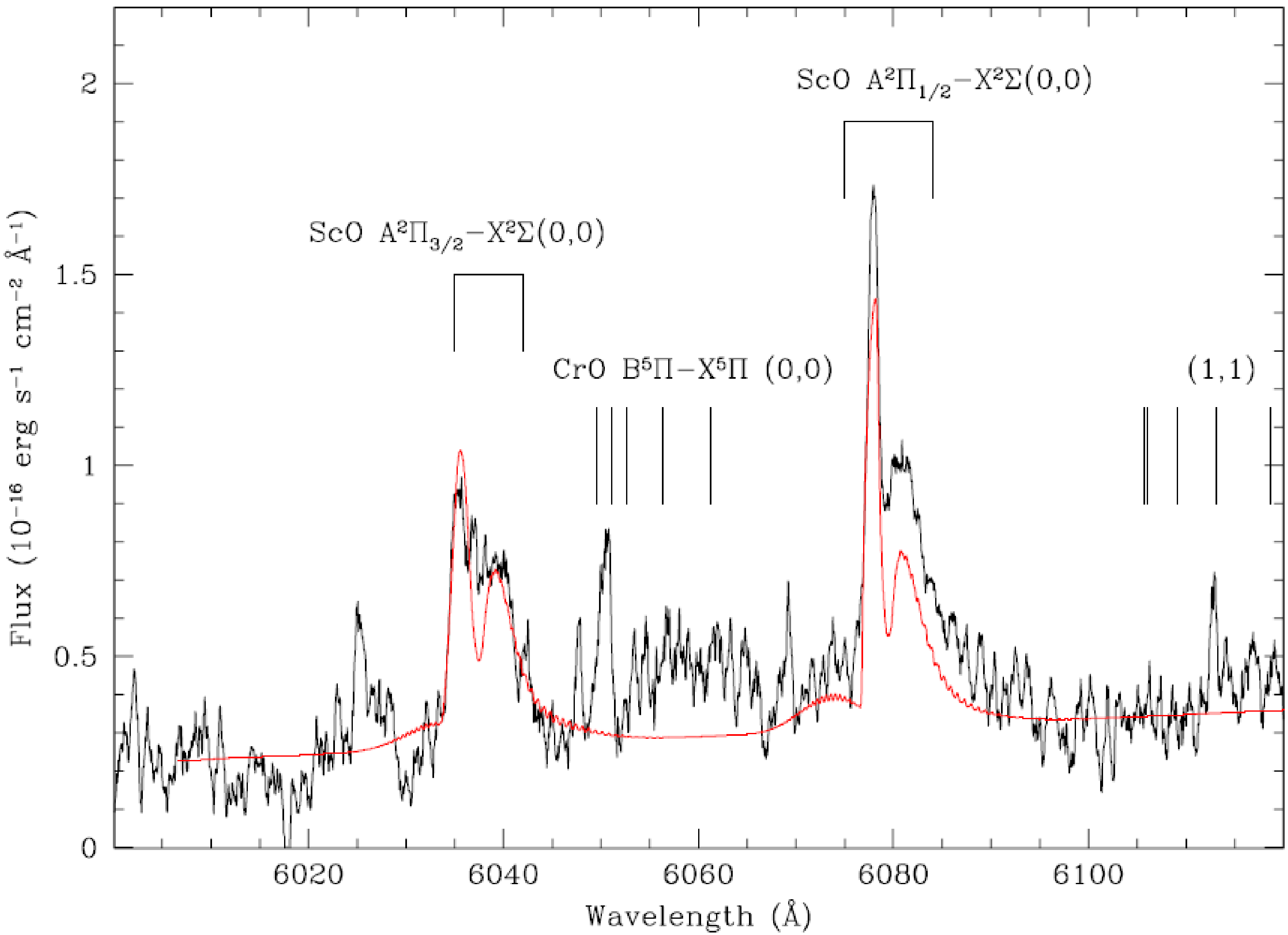
Vanadium monoxide VO $B^4\Sigma$-$X^4\Sigma$ (0,0) band in emission in spectrum of V4332 Sgr. Theoretical spectrum in red for the rotational excitation temperature =120 K.



Vanadium monoxide VO $C^4\Sigma$-$X^4\Sigma$ (0,0) (1,0) and (2,0) bands in emission in spectrum of V4332 Sgr.
Theoretical spectrum in red for the rotational excitation temperature =120 K.



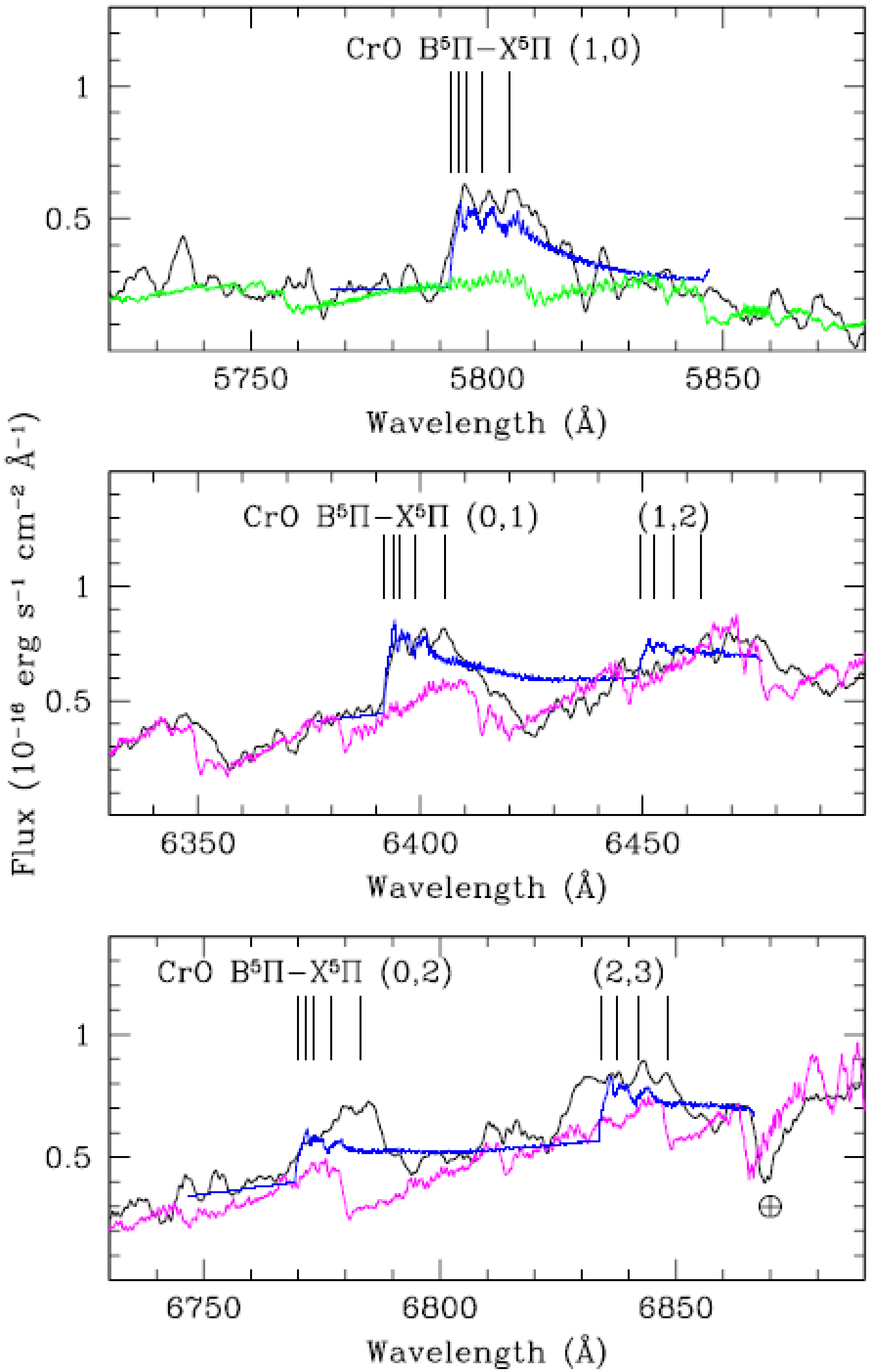
ScO emission band in V4332 Sgr

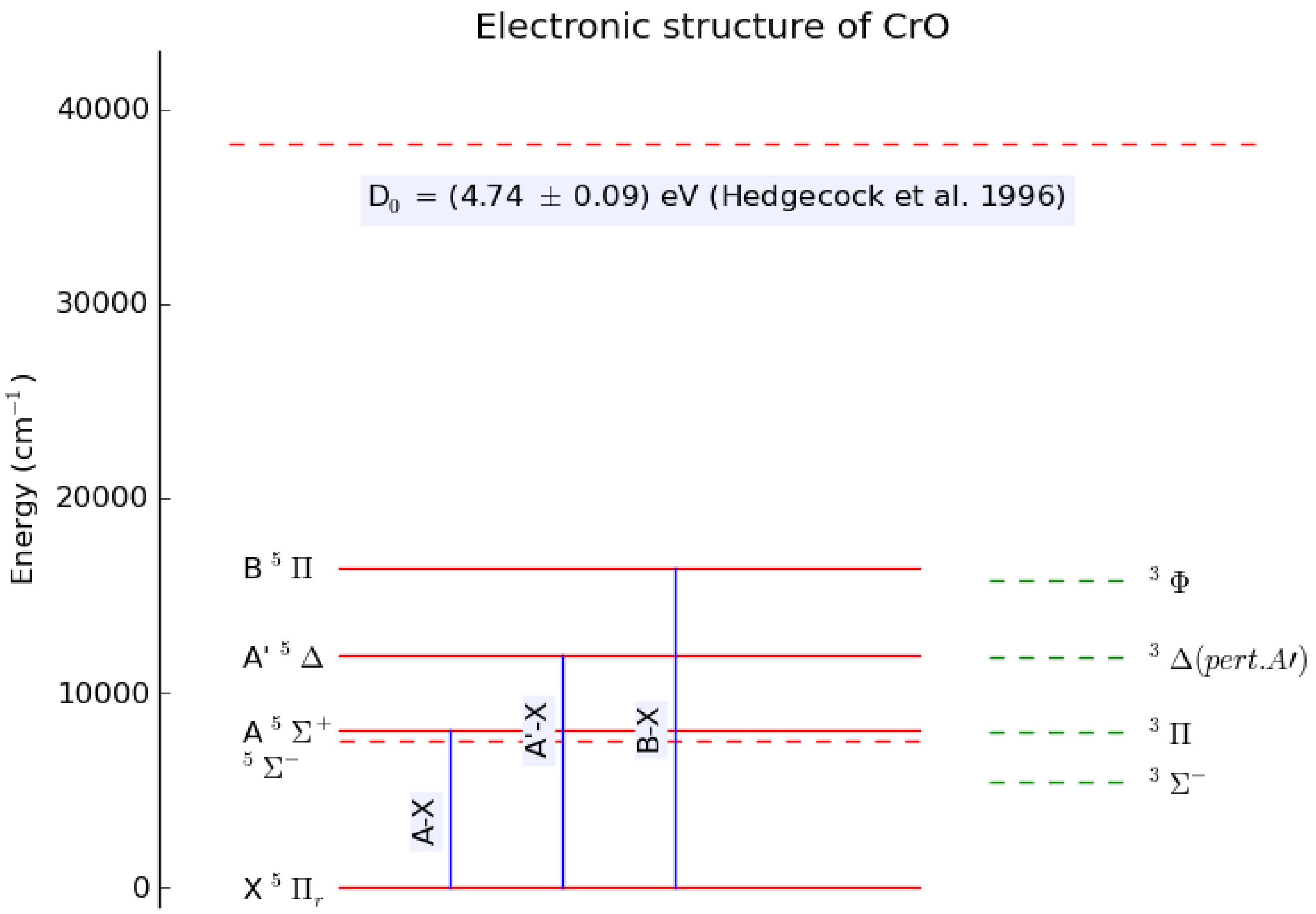


Detection of CrO bands in V4332 Sgr

Bands of CrO of electronic system of B-X detected in emission.

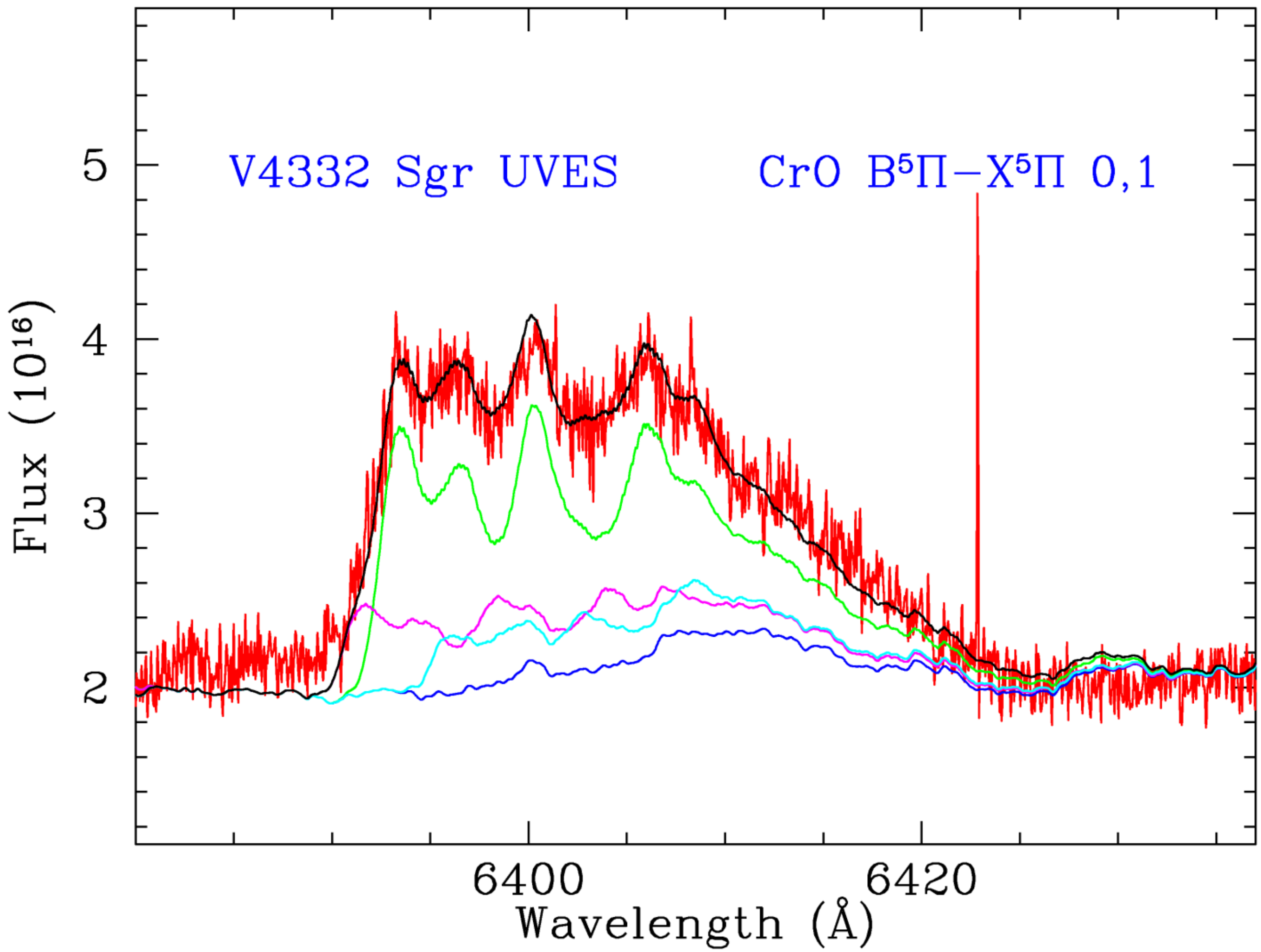
CrO reported earlier in beta Peg (Davis 1947).



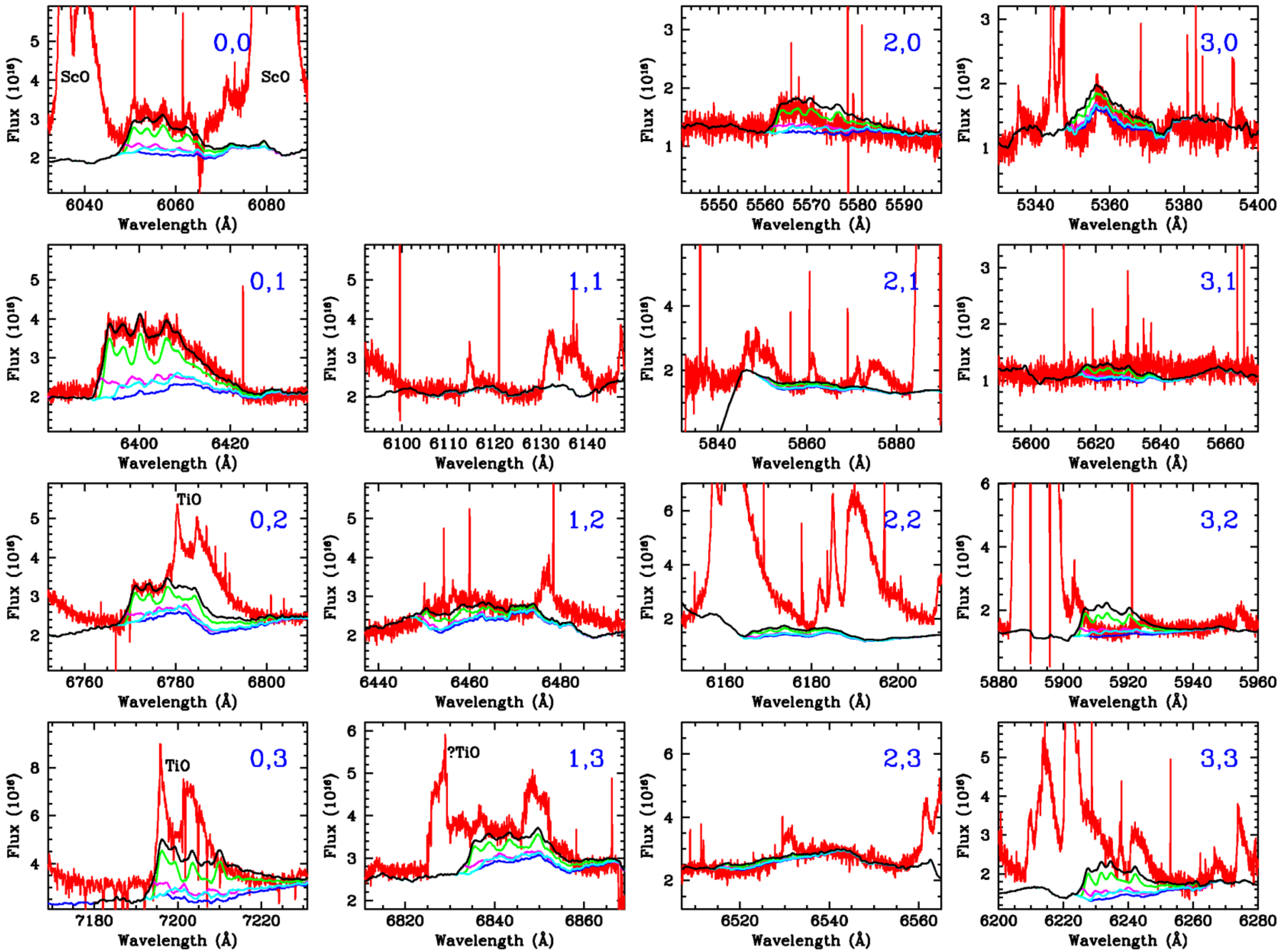


Electronic structure of CrO
Energy (cm^{-1})
40000
30000
20000
10000
0
D$_0$ = (4.74 ± 0.09) eV (Hedgecock et al. 1996)
B $^5\Pi$
A' $^5\Delta$
A $^5\Sigma^+$
$^5\Sigma^-$
X $^5\Pi_r$
A-X
A'-X
B-X
$^3\Phi$
$^3\Delta(pert.A')$
$^3\Pi$
$^3\Sigma^-$

CrO $B^5\Pi$-$X^5\Pi$ (0,1) band in UVES spectrum of V4332 Sgr (in red). Simulation of optically thin emission for spin and vibrational excitation temperature =1800 K
and for rotational temperature=120 K in black.



CrO B-X system in V4332 Sgr



V4332 Sgr – interpretation

- Central star is surrounded by the thick dusty disk – torus; emission components in IR 950 K and 200 K are about 30 and 20 times more luminous than of the central star (Kamiński et al. 2010).

- The spectrum of central star is probably result of scattering on dust grains in the outer edge of the disk

- There is an fast outflow from the central star

- The kinetic temperature of the outflow as concluded from molecular lines is very low – about 120 K

- To preserve molecules in gas phase at so low temperature the outflow must be fast, and/or density very low

- Emission lines are excited by the radiation of the hidden central star

- Absorption lines and the flux are consistent with spectral type M6 III

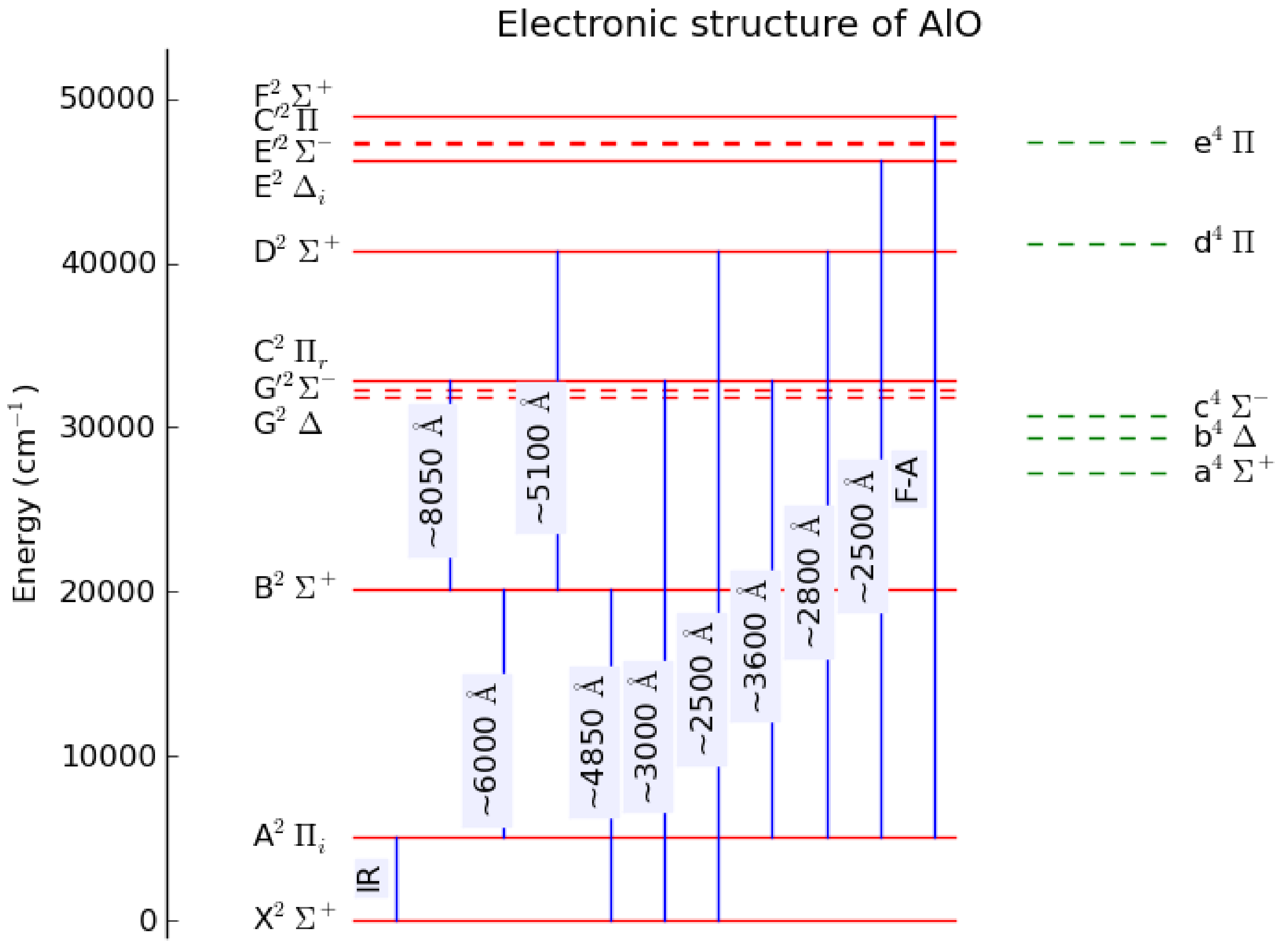
Unobserved oxides

MgO, CaO, FeO were searched for and have NOT been in spectra of V838 Mon and of V4332 Sgr.

As well as SrF.

Observed and unreported oxides

AlO is present in emission both in A-X band (Bannerjee et al.) and in B-X band (Tylenda et al. 2005).
Particularly strong emissions of AlO B-X band are seen in the UVES spectrum and are similar to bands seen in VY CMa (Kaminski, Schmidt, Menten 2013).



Exp. and calculated levels (Zenouda et al. 1999 JMS Theochem 458, 61)

Summary

- red novae provides information on spectra of oxides of transition elements at low excitation temperature, 120-500 K

- high column densities enable observations of otherwise difficult to identify bands, e.g. TiO forbidden,

- new detections of molecules not observed in late type O-rich stars are made, CrO

- there is still deficit of laboratory spectra, e.g higher vibronic bands of A-X system in ScO, TiO gamma'

Thank you !

NCAC, Dep. of Astrophysics, Toruń

The Copernicus Family House, Toruń

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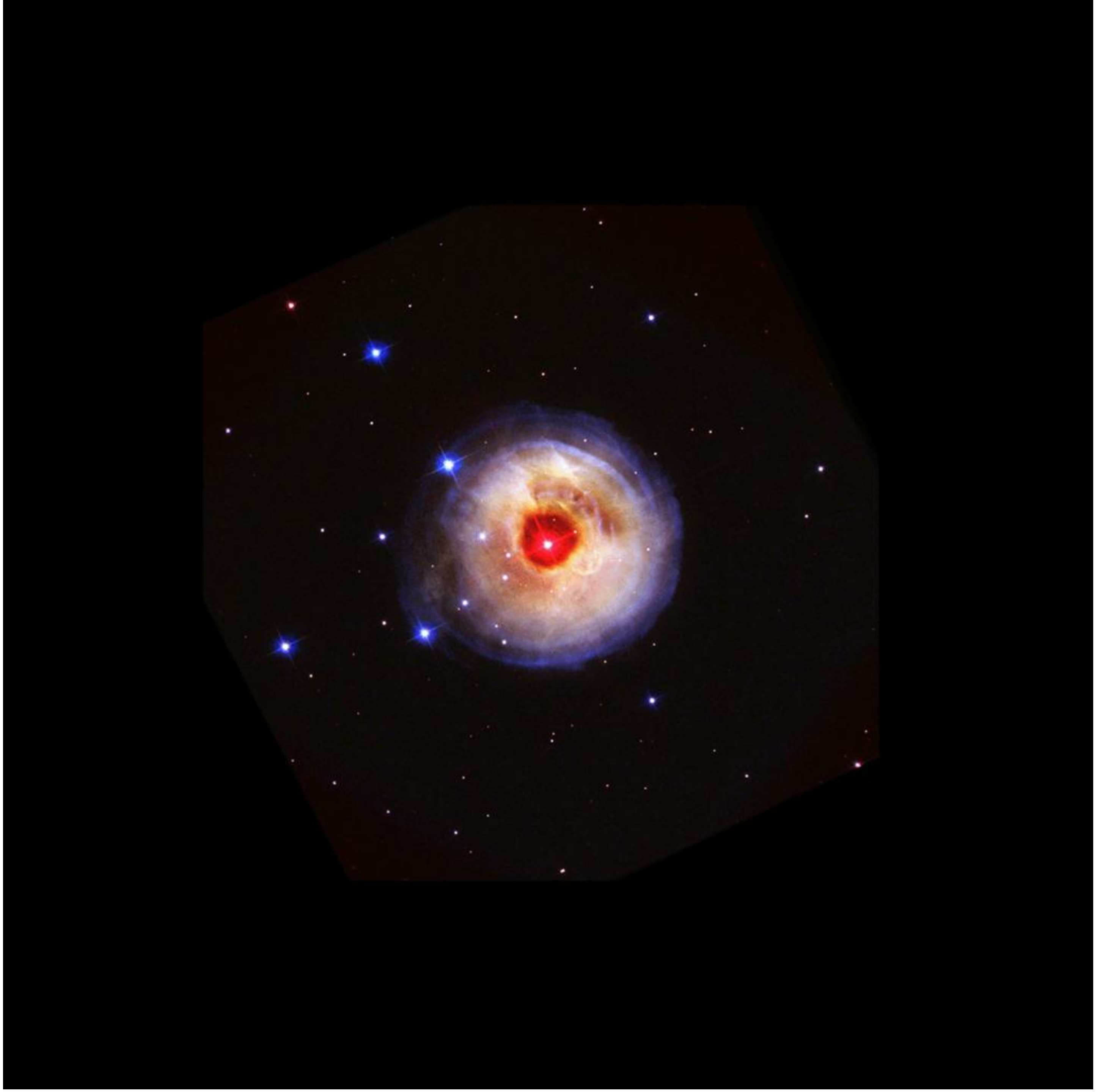
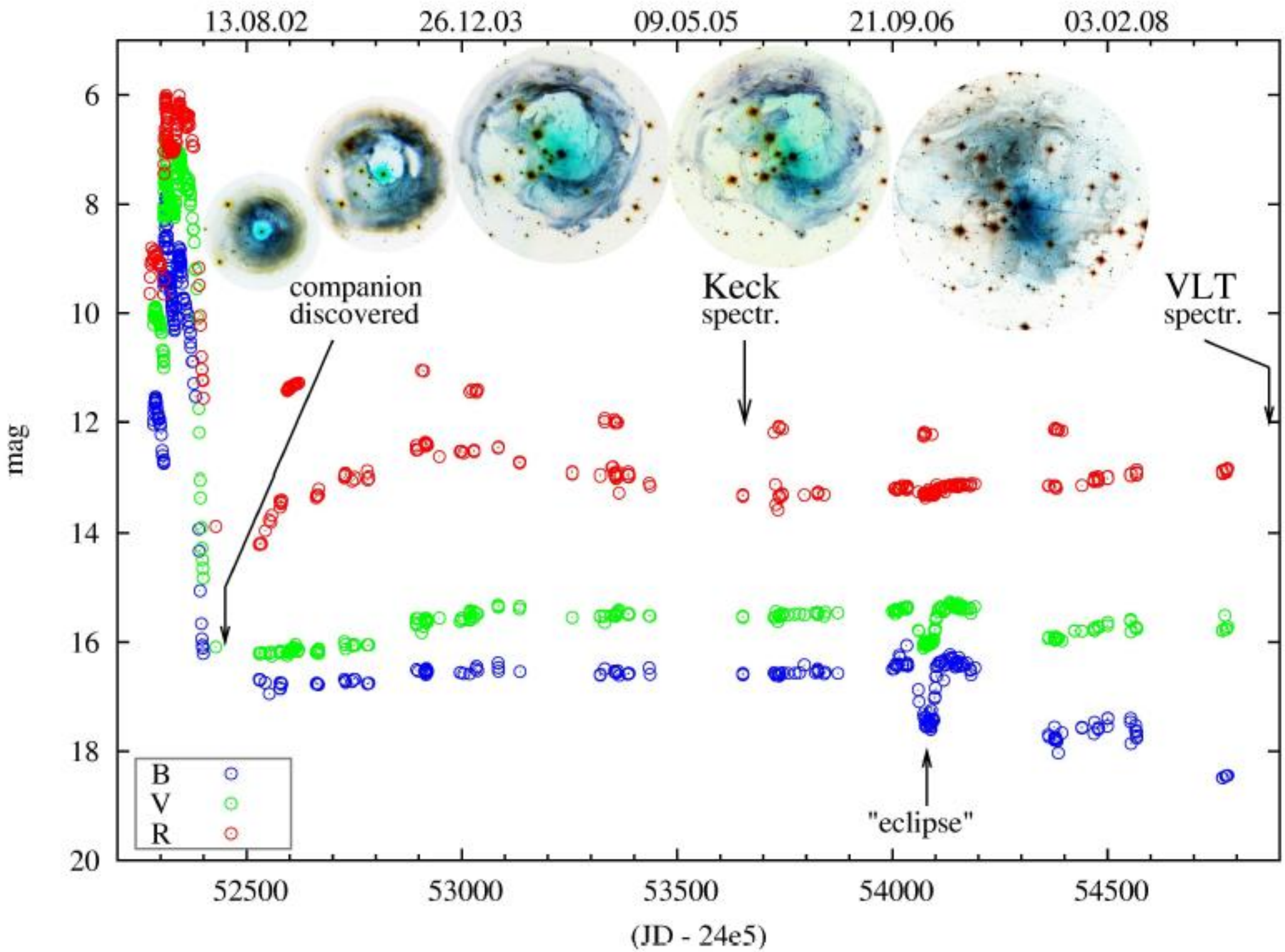
V838 Mon

(Bond et al.)





The light echo images from Bond et al. 2003, 2007. The BVR/Rc light curve of V838 Mon since 2002 collected by Goranskij (http://jet/sao.ru/~goray)

Model of the system V838 Mon+B3V