SPECTRAL ENERGY DISTRIBUTION FOR GJ406

Yu. Lyubchik[1], **Ya. V. Pavlenko**[1], **H. R. A. Jones**[2], **J. Tennyson**[3], **D. Pinfield**[2]

[1] *Main Astronomical Observatory, NAS of Ukraine*
27 Akademika Zabolotnoho Str., 03680 Kyiv, Ukraine
e-mails: lyu@mao.kiev.ua, yp@mao.kiev.ua

[2] *Centre for Astrophysics Research, Science and Technology Research Centre, University of Hertfordshire*
College Lane, Hatfield, Hertfordshire AL10 9AB, UK
e-mail: hraj@star.herts.ac.uk

[3] *Department of Physics and Astronomy, University College London*
Gower Street, London WC1E 6BT, UK

We present results of modelling the bulk of the spectral energy distribution (0.45–5 μm) for GJ406 (M6V). Synthetic spectra were calculated using the NextGen model atmospheres of Hauschildt *et al.* [6] and the incorporate line lists for H_2O, TiO, CrH, FeH, CO, MgH molecules as well as the VALD line list of atomic lines. The computed water partition function is in a good agreement with the one obtained by Vidler & Tennyson [14]. A comparison of synthetic and observed spectra gives $T_{\rm eff} = 2900 \pm 100$ K for this late M-dwarf.

INTRODUCTION

The spectral energy distributions for several model atmospheres with effective temperatures around 3000 K were computed and compared with the observed fluxes of GJ406. Using this procedure we pursue several goals. First, we test the quality of the existing molecular and atomic line lists. Second, we investigate the possibility for the use of the NextGen model atmospheres to compute the spectral energy distribution of late type dwarfs.

OBSERVATIONS

Table 1 lists the information on observational spectra used for our investigations. The observed fluxes are shown in Fig. 1.

Table 1. Observational data

Waverange, μm	Instrument (configuration)	Telescope	Date
0.35 – 0.56	ISIS (blue arm)	WHT	2001 Jan 29
0.55 – 0.80	ISIS (red arm)	WHT	2001 Jan 29
0.79 – 1.20	NICMOS (G096)	HST	1998 June 19
1.05 – 1.95	NICMOS (G141)	HST	1998 June 19
1.3 – 2.59	NICMOS (G206)	HST	1998 June 19
2.48 – 2.60	SWS (06 1A)	ISO	1996 June 26
2.60 – 2.75	SWS (06 1A)	ISO	1996 June 26
2.74 – 2.90	SWS (06 1A)	ISO	1996 June 26
2.88 – 3.02	SWS (06 1B)	ISO	1996 June 26
3.03 – 3.23	CGS4 (150 l/mm)	UKIRT	1993 April 20
3.21 – 3.40	CGS4 (150 l/mm)	UKIRT	1993 April 20
3.36 – 3.75	CGS4 (75 l/mm)	UKIRT	1992 May 7
3.76 – 4.15	CGS4 (75 l/mm)	UKIRT	1992 May 7
4.51 – 4.90	CGS4 (75 l/mm)	UKIRT	1992 October 26

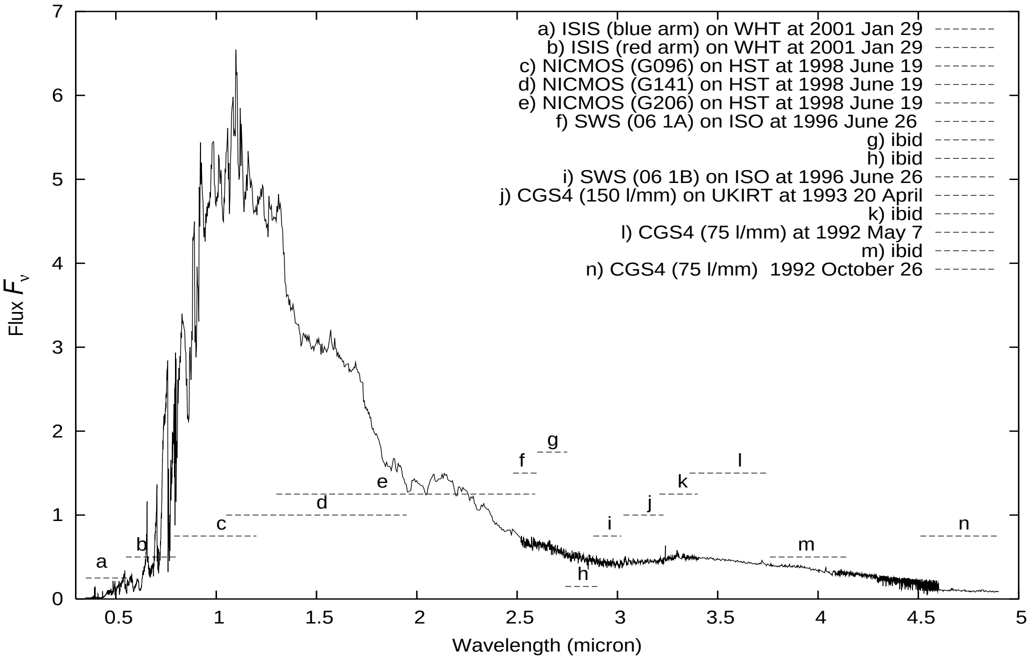

Figure 1. Observational data used for our analysis. The wavelength coverage of various instruments is shown

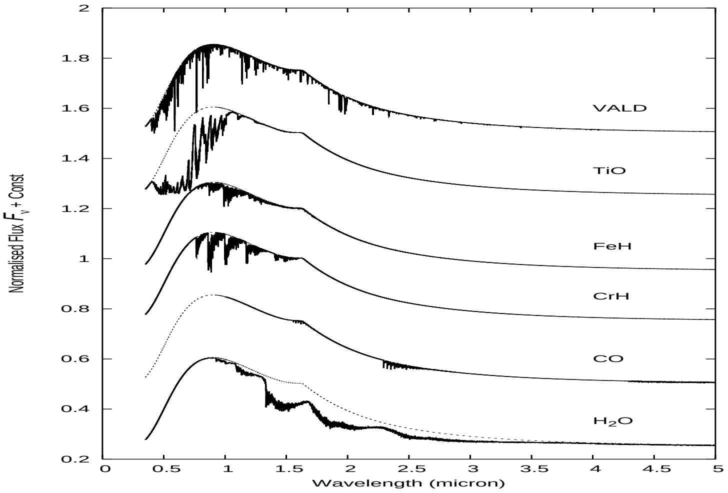

Figure 2. Contribution of different molecules to the formation of spectrum of GJ406

PROCEDURE

Synthetic spectra were computed for the NextGen model atmospheres [6] with the following parameters: effective temperatures $T_{\rm eff}$ = 2600–3600 K, log g = 5.0, solar metallicity [1] and microturbulent velocity v_t = 2 km/s. Calculations of synthetic spectra were carried out by using the program WITA6 [10] assuming LTE, hydrostatic equilibrium for an one-dimensional model atmosphere and absence of sources and sinks of energy. The equations of the ionization-dissociation equilibrium were solved for media consisting of atoms, ions, and molecules. We took into account about 100 components [10]. The constants for equations of the chemical balance were taken from [13].

Molecular line data were taken from various sources. The $^1H_2^{16}O$ lines were calculated using the AMES database [9]. The partition functions of H_2O were also calculated from these data (see [11]). The $^{12}C^{16}O$ and $^{13}C^{16}O$ line lists were calculated by Goorvitch [4]. The CO partition functions were taken from [5], a TiO line list – from [12]. CN lines were taken from CDROM 18 by Kurucz [8], CrH and FeH lines – from [2] and [3], respectively. An atomic line list was taken from VALD [7].

The relative importance of the different opacities contributing to our synthetic spectra is shown in Fig. 2.

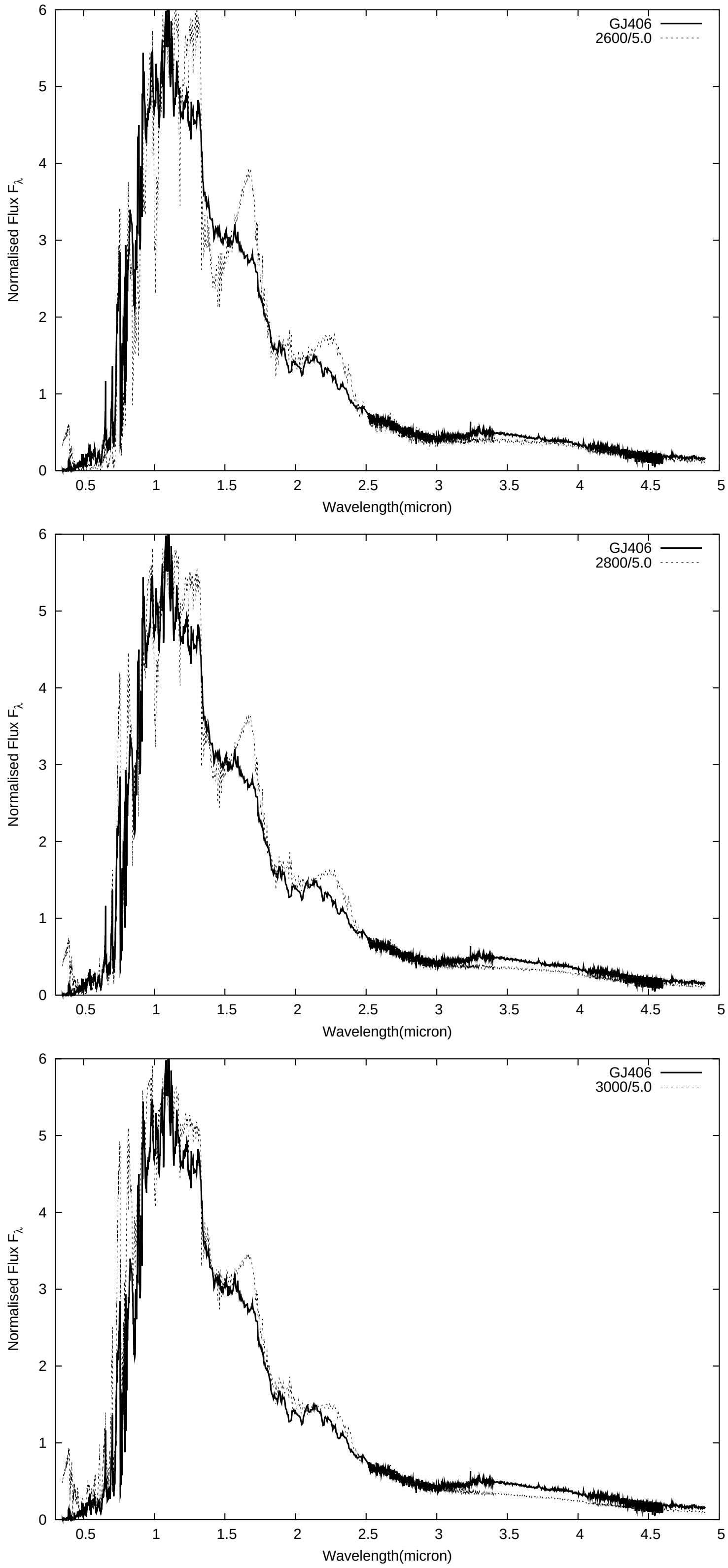

Figure 3. Fits of the GJ406 spectra to the theoretical spectra computed for the NextGen model atmospheres

RESULTS

Dependence of fits on input parameters

We computed synthetic spectra using various input parameters such as effective temperatures, gravities, metallicities, microturbulent velocities. And we found that temperature has a relatively greater effect on the spectra than metallicity and gravity. A temperature change of 200 K is roughly equivalent to a change in metallicity of 0.5 dex or a gravity of log $g = 1$.

Fits to GJ406 spectra

Fits of our synthetic spectra, which were computed for the NextGen model atmospheres with different $T_{\rm eff}$, to the GJ406 spectrum are shown in Fig. 3. Previous studies have considered GJ406 as a typical M6 dwarf, therefore, log $g = 5.0$ was adopted. From our comparison of computed and observed spectra we assumed $T_{\rm eff} = 2900 \pm 100$ K.

Acknowledgements. The William Herschel Telescope and United Kingdom Infrared Telescope are operated for the Particle Physics and Astronomy Research Council (PPARC). ISO is an ESA project with the participation of ISAS and NASA funded from member states. HST is a NASA project funded in part by ESA. This work was partially supported by a PPARC visitors grants from PPARC and the Royal Society. YP's studies are partially supported by a Small Research Grant from American Astronomical Society. This research has made with the use of the SIMBAD database, operated at CDS, Strasbourg, France.

[1] *Anders E., Grevesse N.* Abundances of the elements - Meteoritic and solar // Geodynamics and Geochemistry Acta.–1989.–**53**.–P. 197–214.

[2] *Burrows A., Ram R. S., Bernath P., et al.* New CrH Opacities for the Study of L and Brown Dwarf Atmospheres // Astrophys. J.–2002.–**577**.–P. 986–992.

[3] *Dulick M., Bauschlicher C. W., Burrows A., et al.* Line Intensities and Molecular Opacities of the FeH $F^4\Delta_i - X^4\Delta_i$ Transition // Astrophys. J.–2003.–**594**.–P. 651–663.

[4] *Goorvitch D.* Infrared CO line for the X 1 Sigma(+) state // Astrophys. J. Suppl. Ser.–1994.–**95**.–P. 535–552.

[5] *Gurvitz L. V., Weitz I. V., Medvedev V. A.* Thermodynamic properties of individual substances.–Moscow: Nauka, 1989. (in Russian).

[6] *Hauschildt P. H., Allard F., Baron E.* The NextGen Model Atmosphere Grid for $3000 \le T_{\rm eff} \le 10{,}000$ K // Astrophys. J.–1999.–**512**.–P. 377–385.

[7] *Kupka F., Piskunov N., Ryabchikova T. A., et al.* VALD-2: Progress of the Vienna Atomic Line Data Base // Asron. and Astrophys. Suppl. Ser.–1999.–**138**.–P. 119–133.

[8] *Kurucz R. L.* CDROMs 1–22, Harvard–Smithsonian Observatory.–1993.

[9] *Partrige H., Schwenke D. J.* The determination of an accurate isotope dependent potential energy surface for water from extensive ab initio calculations and experimental data // Chem. Phys.–1997.–**106**.– P. 4618–4639.

[10] *Pavlenko Ya.* Lithium Lines in the Spectra of M Dwarfs: UX Tau C // Astron. Rep.–2000.–**44**.–P. 219–226.

[11] *Pavlenko Ya.* Modeling the Spectral Energy Distributions of L Dwarfs // Astron. Rep.– 2001.–**45**.–P. 144–156.

[12] *Plez B.* A new TiO line list // Astron. and Astrophys.–1998.–**337**.–P. 495–500.

[13] *Tsuji T.* Molecular abundances in stellar atmospheres. II // Astron and Astrophys.–1973.–**23**.–P. 411–431.

[14] *Vidler M., Tennyson J.* Accurate partition function and thermodynamic data for water // J. Chem. Phys.–2000.–**113**.–P. 9766–9771.