Physical parameters of T dwarfs derived from high-resolution near-infrared spectra

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Based on results in

del Burgo, Martín, Zapatero-Osorio, Hauschildt, 2008, A&A, submitted

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Motivation: NAHUAL

Observations: NIRSPEC spectra of nine T dwarfs

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Observations

High-resolution NIRSPEC/Keck II spectra in the J-band of 9 T dwarfs

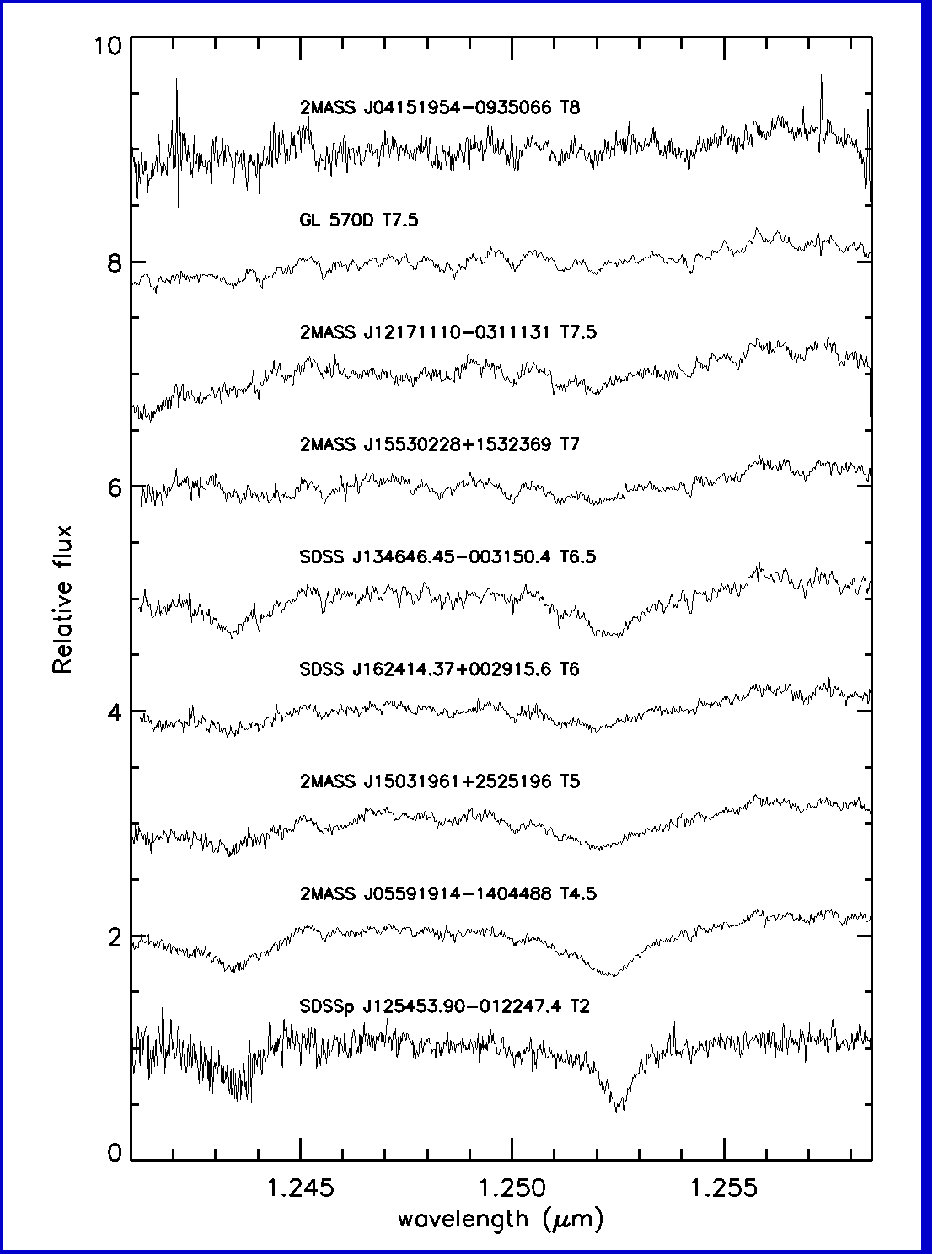
Range: 1.148-1.346 μm

Nominal dispersion: 0.164-0.191 Å pix^{-1} (from blue to red wavelengths)

Resolution: 0.55-0.70 Å at 1.2485 μm (R=17,800-22,700)

Details about the instrument set-up in McLean et al. 2007

Details about data reduction in Zapatero-Osorio et al. 2006



Variation of the strong KI doublet at 1.2436 and 1.2525 μm along STp

Models

Stellar atmosphere modelling package: PHOENIX code (Hauschildt & Baron 1999)

At the low temperatures of brown dwarfs, a rich chemistry in the atmospheres of these objects is present, with hundreds of gas-phase species, liquids and crystals, and the formation of tens of different types of dust grains

There are four scenarios for the dust formation considered in PHOENIX, among them the *AMES-COND* cloudless models (Allard et al. 2001), where the dust falls into deep atmosphere layers, without contributing to the opacity

Data preparation

Models, grid: T_{eff}: 700 – 3,000 K (steps of 100 K)
log g: 3.0 - 5.5 (steps of 0.5), g in cm s^{-2}
rotv sini: 0-50 km/s

Synthetic

+ transformation to take into account the rotational broadening (rotv) of the objects (Gray's formalism)

⊗ Gaussian (PSF)

+ rebinning to the same resolution of the NIRSPEC observations

+ normalization: order 59 is normalized to unity and the rest according to its flux relative to that order

+ cross-correlation of the spectra with alike modelled spectra to correct from any velocity shift

Analysis

Constrain the # possible solutions: RMS between observations and models

… for each order, with different S/N, sky contamination, etc

Table 10. Weights of echelle orders.

Order	Weight	Remark
66	0.3	for all objects
65	0.4	for all objects
64	0.6	for all objects
63	1.0	for all objects
62	1.0	for all objects
61	1.0	for all objects
60	0.2	for 2MASS J12171110-0311131
	0.6	for 2MASS J04151954-0935066
	1.0	for the rest
59	1.3	for all objects
58	1.1	for all objects
57	0.8	for all objects

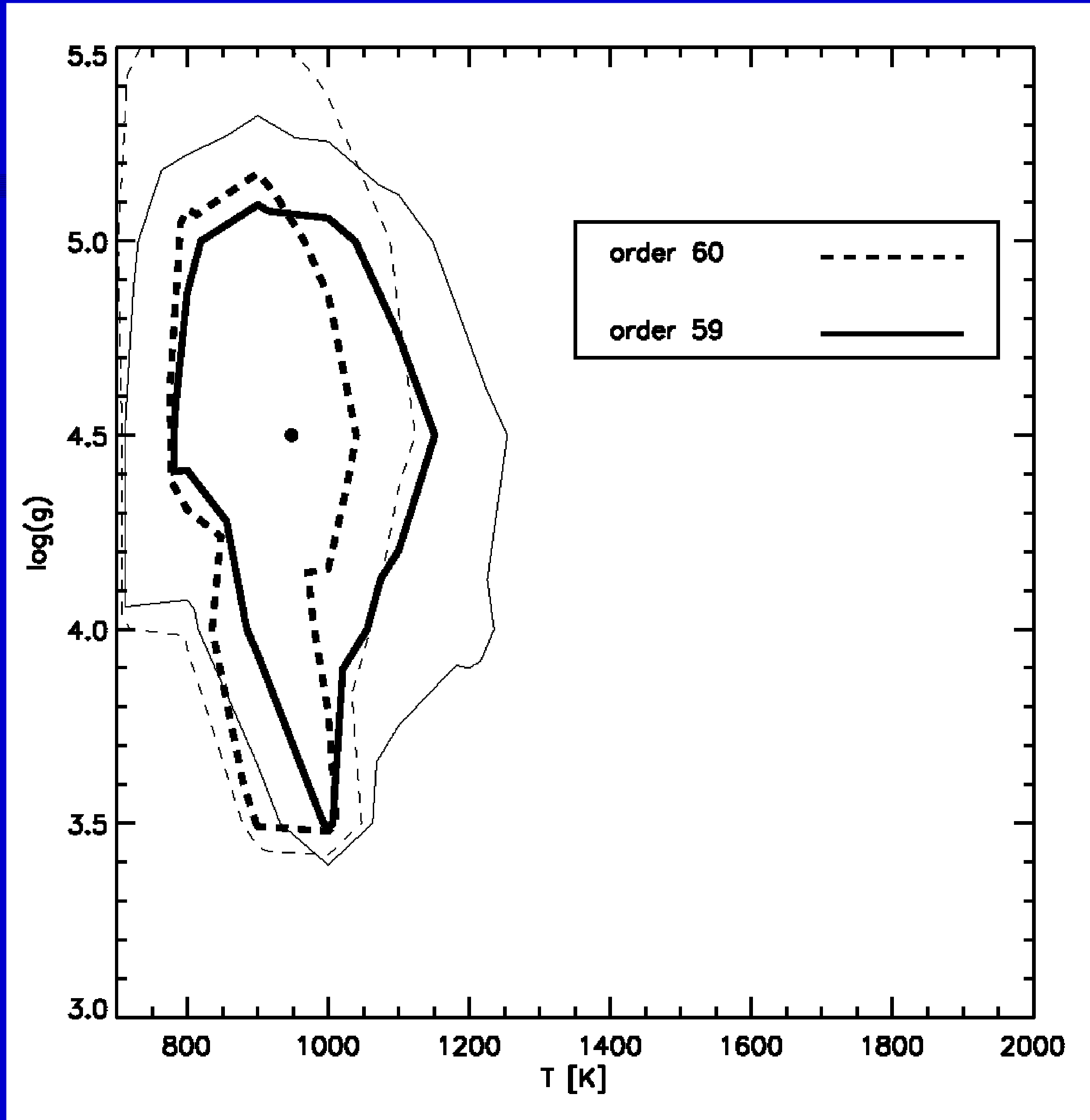
Minimum RMS ⇒ T_{eff}, log g, v_{rot}sini

Average values:

$$< T_{\rm eff} >= \frac{\sum_j \left(T_{eff,j} \frac{W_j}{\sigma_j} \right)}{\sum_j \frac{W_j}{\sigma_j}},$$

$$< log\, g >= \frac{\sum_j \left(log\, g_j \frac{W_j}{\sigma_j} \right)}{\sum_j \frac{W_j}{\sigma_j}},$$

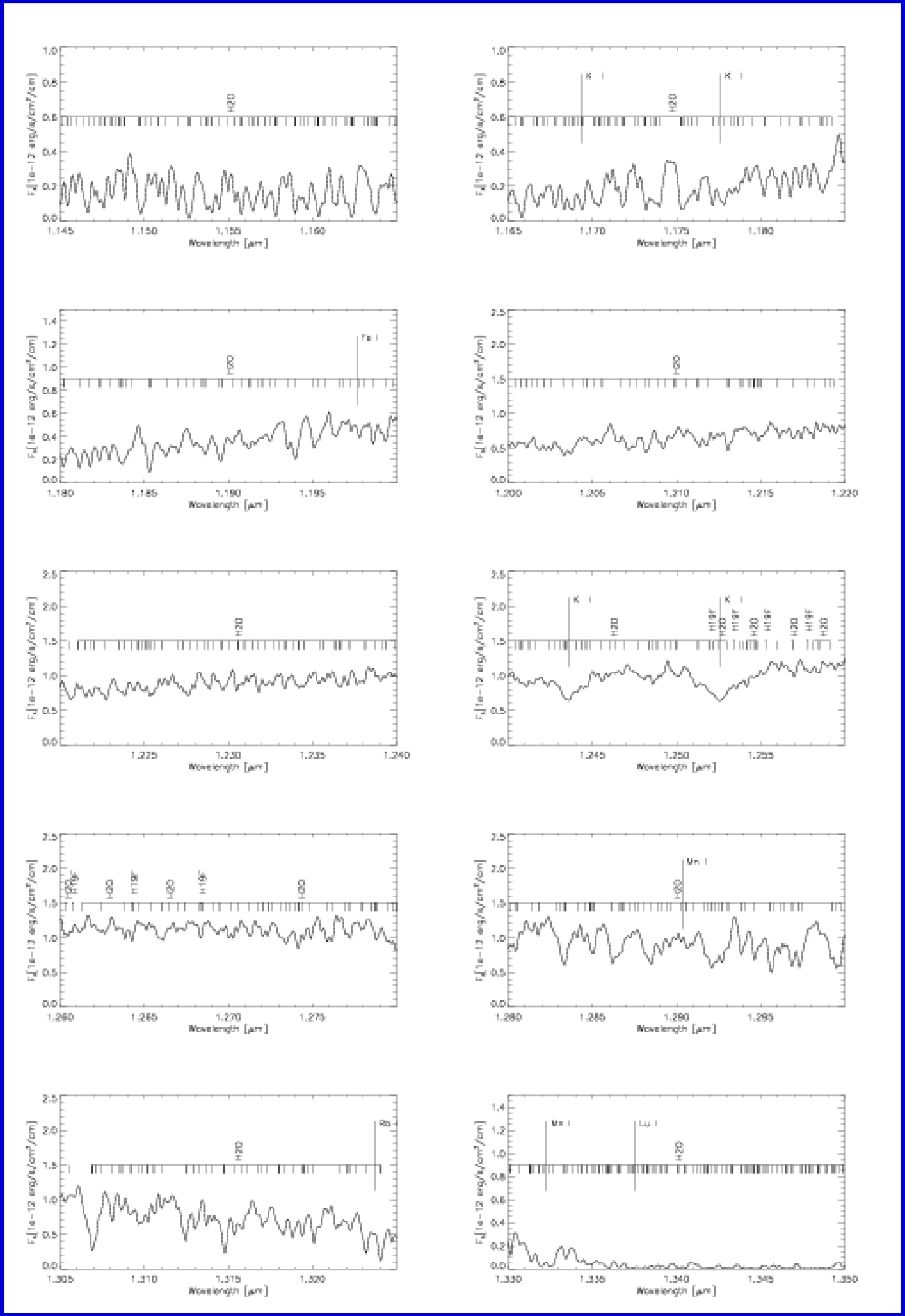
$$< v_{\rm rot} {\rm sin} i >= \frac{\sum_j \left(v_{\rm rot} {\rm sin} i_j \frac{W_j}{\sigma_j} \right)}{\sum_j \frac{W_j}{\sigma_j}},$$


order 60
order 59
log(g)
T [K]
5.5
5.0
4.5
4.0
3.5
3.0
800
1000
1200
1400
1600
1800
2000

Analisis:
J-band features

Identifications of some features of a synthetic spectrum with
T_{eff}=1,000 K
log g = 4.5 (g cm^{-2})
Vrot = 0 km/s

Most of the lines are due to water vapour



SDSSpJ125453.90-012247.4

T2

T_{eff} = 2,007 K

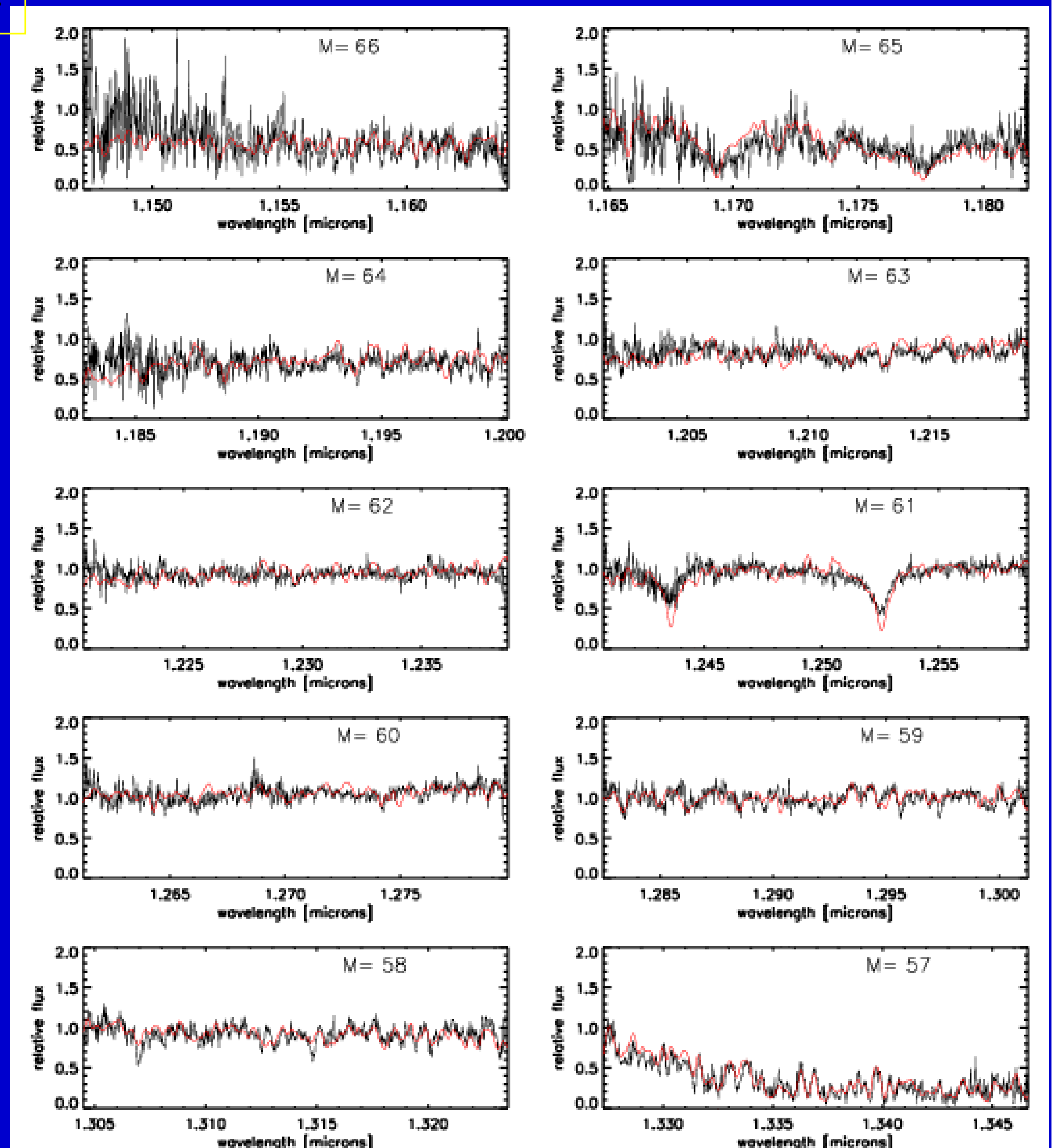
log g = 4.3 (cm/s^{-2})

observed

modelled

Table 1. SDSSp J125453.90-012247.4. Synthetic and observed spectra comparison for all orders: RMS, N, $T_{\rm eff}$, *log g* and $v_{\rm rot}$ sin*i*.

order	N	RMS	$T_{\rm eff}$	*log g*	$v_{\rm rot}$ sin*i*
66	996	0.2797	1600	5.5	38
65	995	0.1740	1300	5.5	46
64	1001	0.1336	2400	3.5	36
63	1002	0.0931	2500	3.5	26
62	1002	0.0839	2700	3.5	27
61	1002	0.0960	2700	5.5	46
60	890	0.0914	700	5.5	28
59	1002	0.0811	2000	3.0	36
58	1002	0.0932	1500	5.5	36
57	994	0.0862	2000	4.0	31



Models are not adequate!

2MASSJ05591914-1404488

T4.5

T_{eff} = 1,000 K

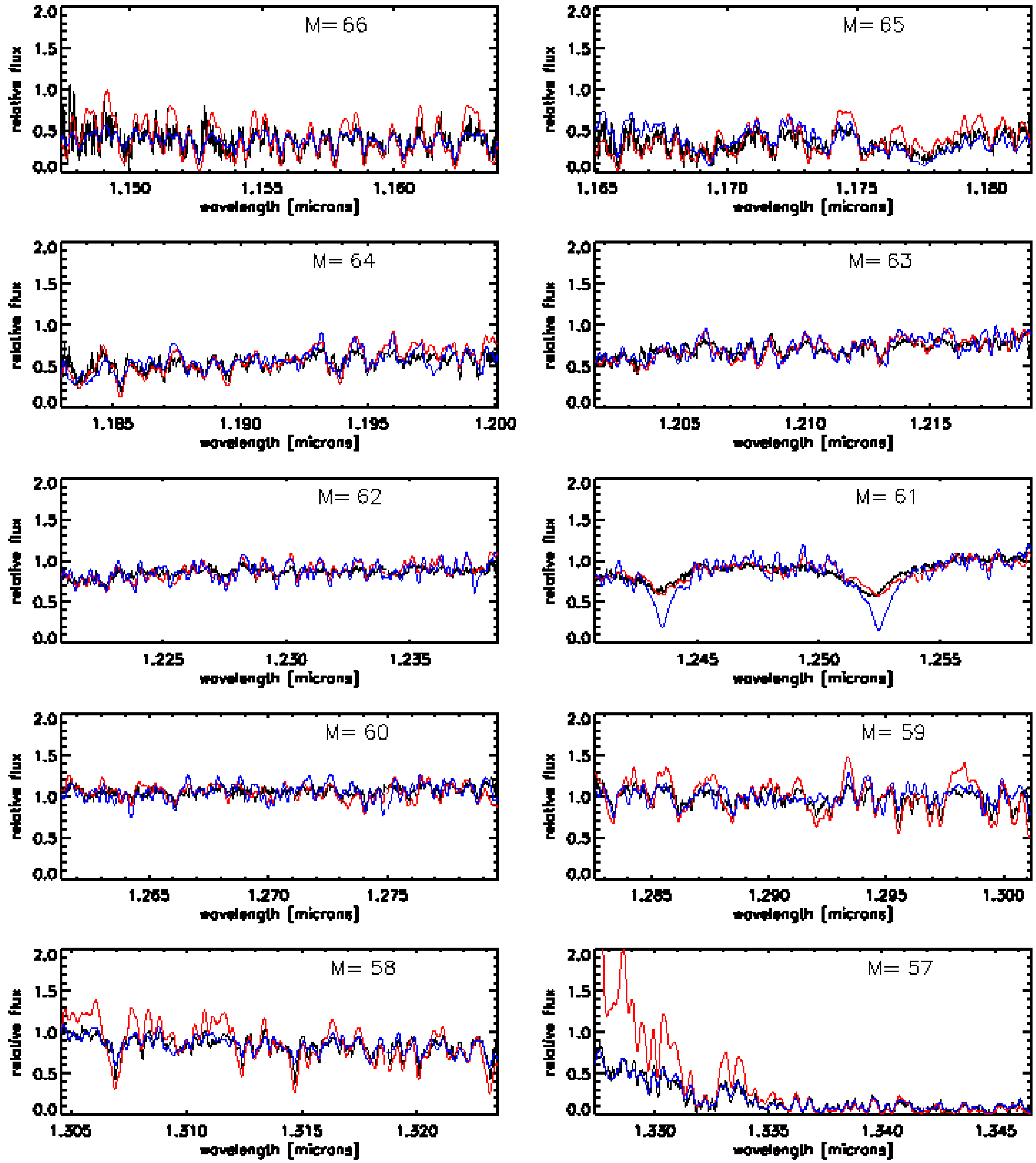
T_{eff} = 1,700 K

log g = 4.9 (cm/s^{-2})

Table 2. 2MASS J05591914-1404488. Synthetic and observed spectra comparison for all orders: RMS, N, $T_{\rm eff}$, *log g* and $v_{\rm rot}$ sin*i*.

order	N	RMS	$T_{\rm eff}$	*log g*	$v_{\rm rot}$ sini
66	987	0.1079	1500	5.0	21
65	989	0.0796	1200	5.5	25
64	991	0.0575	1000	3.5	33
63	991	0.0512	800	5.5	24
62	991	0.0416	800	5.5	27
61	991	0.0612	1000	5.0	33
60	882	0.0434	800	5.5	25
59	991	0.0724	900	3.5	33
58	991	0.0682	1300	5.5	33
57	957	0.0491	1500	4.0	33

Models are not adequate!



2MASSJ15031961+2525196

T5

T_{eff} = 982 K

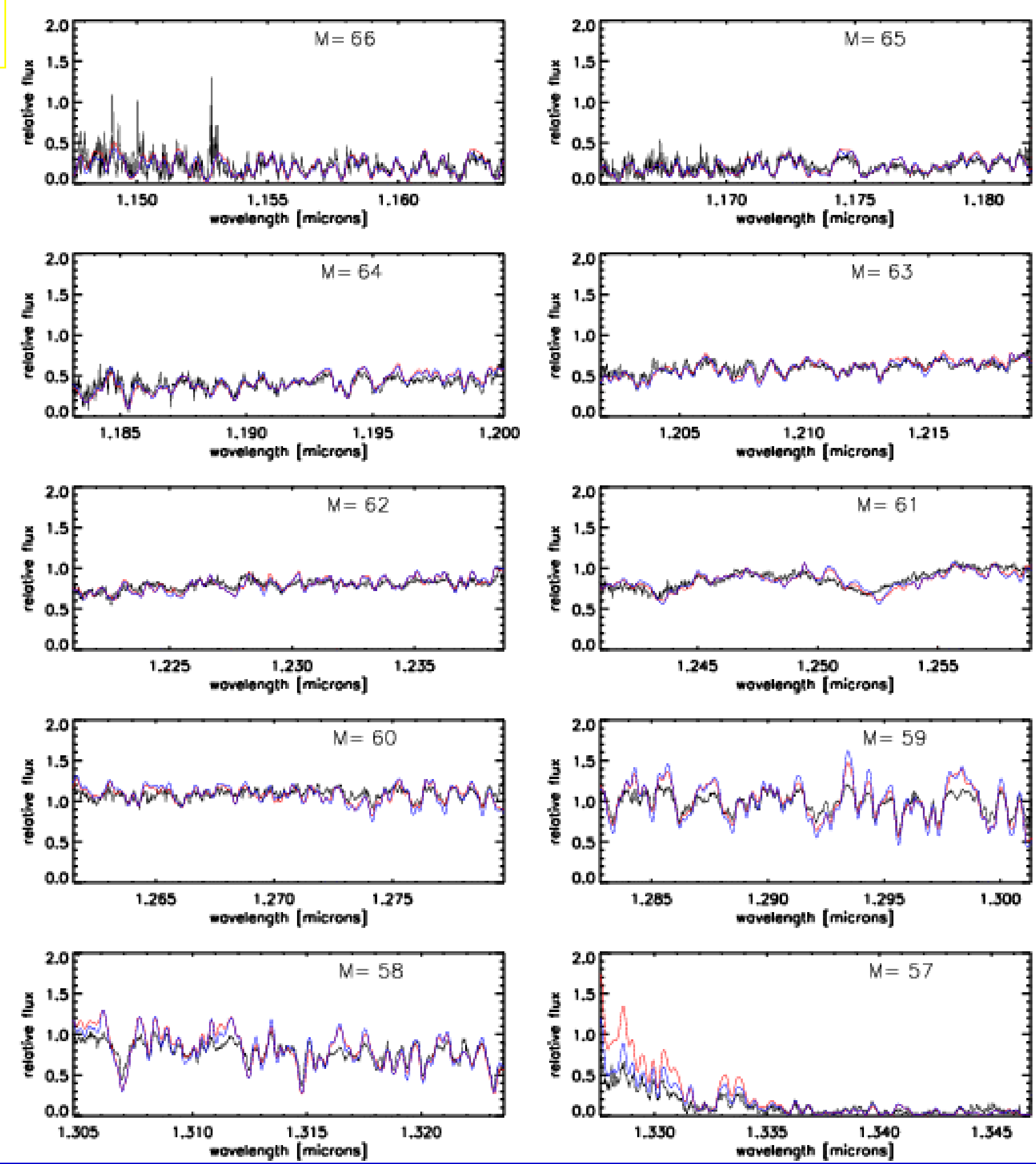
log g = 5 (cm/s^{-2})

T_{eff} = 1,009 K

log g = 4.6 (cm/s^{-2})

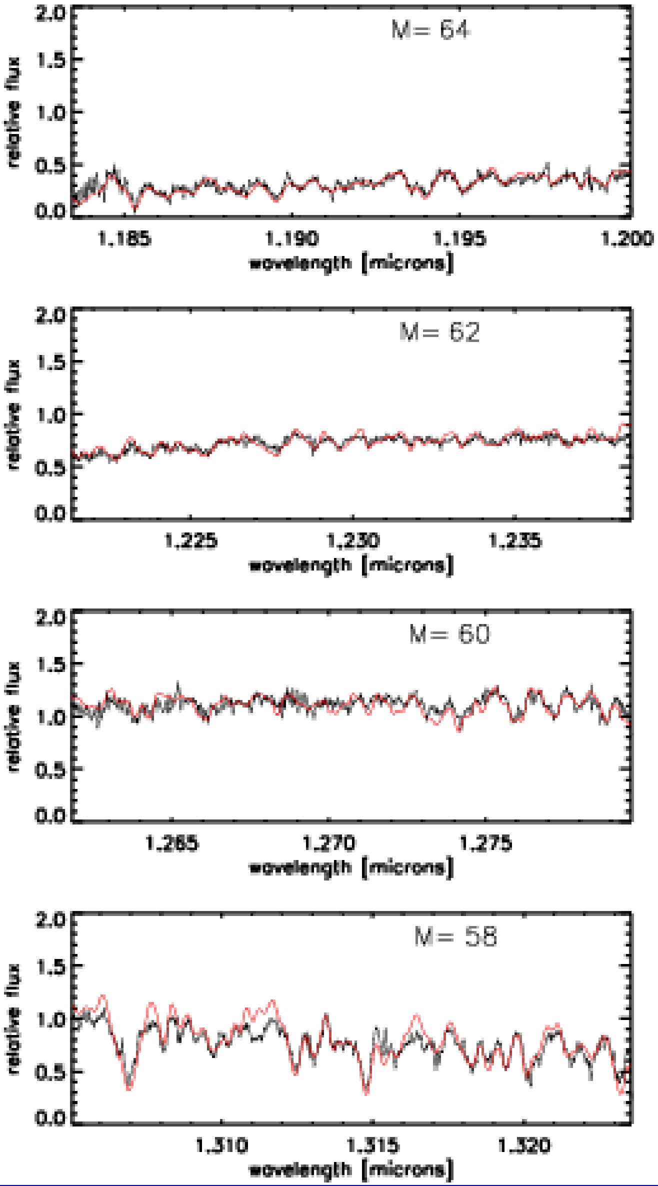
Table 3. 2MASS J15031961+2525196. Synthetic and observed spectra comparison for all orders: RMS, N, $T_{\rm eff}$, *log g* and $v_{\rm rot}$ sin*i*.

order	N	RMS	$T_{\rm eff}$	*log g*	$v_{\rm rot}$ sin*i*
66	969	0.1112	1300	5.0	34
65	978	0.0627	1100	4.0	42
64	987	0.0542	900	4.0	30
63	987	0.0445	1000	3.5	42
62	987	0.0413	800	5.5	37
61	987	0.0576	1000	5.5	42
60	873	0.0461	800	5.5	31
59	987	0.0619	900	3.5	37
58	987	0.0633	1300	5.0	33
57	911	0.0448	1400	4.5	33



Models are much better!

SDSSJ162414.37+002915.6



T6

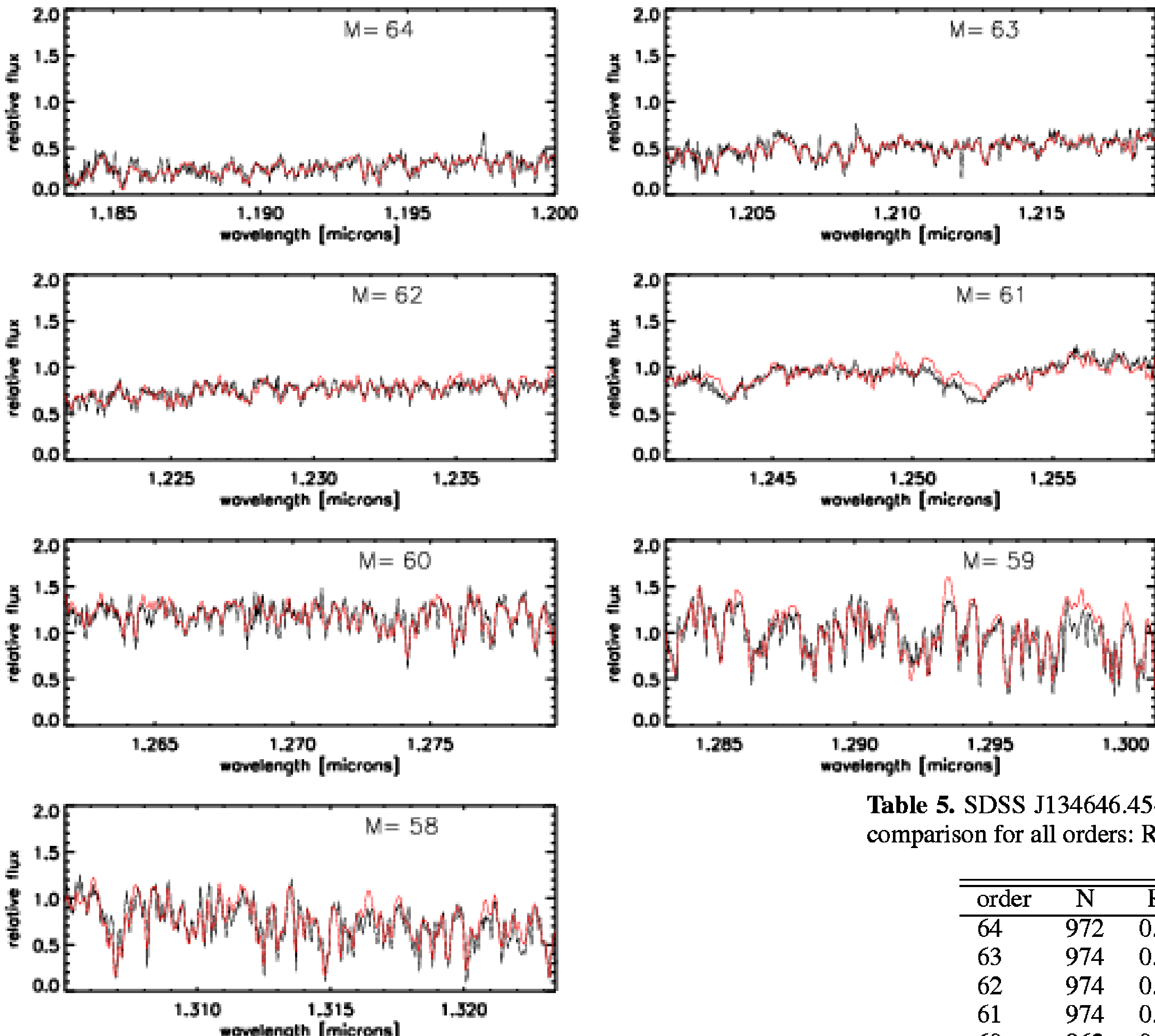
T_{eff} = 980 K
log g = 4.8 (cm/s^{-2})

Models are much better now!

Table 4. SDSS J162414.37+002915.6. Synthetic and observed spectra comparison for all orders: RMS, N, $T_{\rm eff}$, $log\ g$ and $v_{\rm rot}$ sin$i$.

order	N	RMS	$T_{\rm eff}$	$log\ g$	$v_{\rm rot}$ sin$i$
64	977	0.0396	1000	4.0	43
63	977	0.0437	1000	4.5	47
62	977	0.0386	800	5.0	41
61	976	0.0550	900	5.5	47
60	858	0.0533	900	3.5	37
59	977	0.0582	1100	5.0	40
58	977	0.0671	1300	5.0	35

SDSSJ134646.45+003150.4



T6.5

T_{eff} = 990 K
log g = 4.1 (cm/s^{-2})

Models can reproduce the features very well!

Table 5. SDSS J134646.45-003150.4. Synthetic and observed spectra comparison for all orders: RMS, N, $T_{\rm eff}$, *log g* and $v_{\rm rot}$ sin*i*.

order	N	RMS	$T_{\rm eff}$	*log g*	$v_{\rm rot}$ sin*i*
64	972	0.0544	1000	4.0	19
63	974	0.0554	1000	4.0	20
62	974	0.0500	900	4.5	17
61	974	0.0644	1000	5.0	25
60	862	0.0801	900	4.0	12
59	974	0.1185	900	4.0	13
58	973	0.1139	1200	4.5	13

2MASSJ15530228+1532369

T7

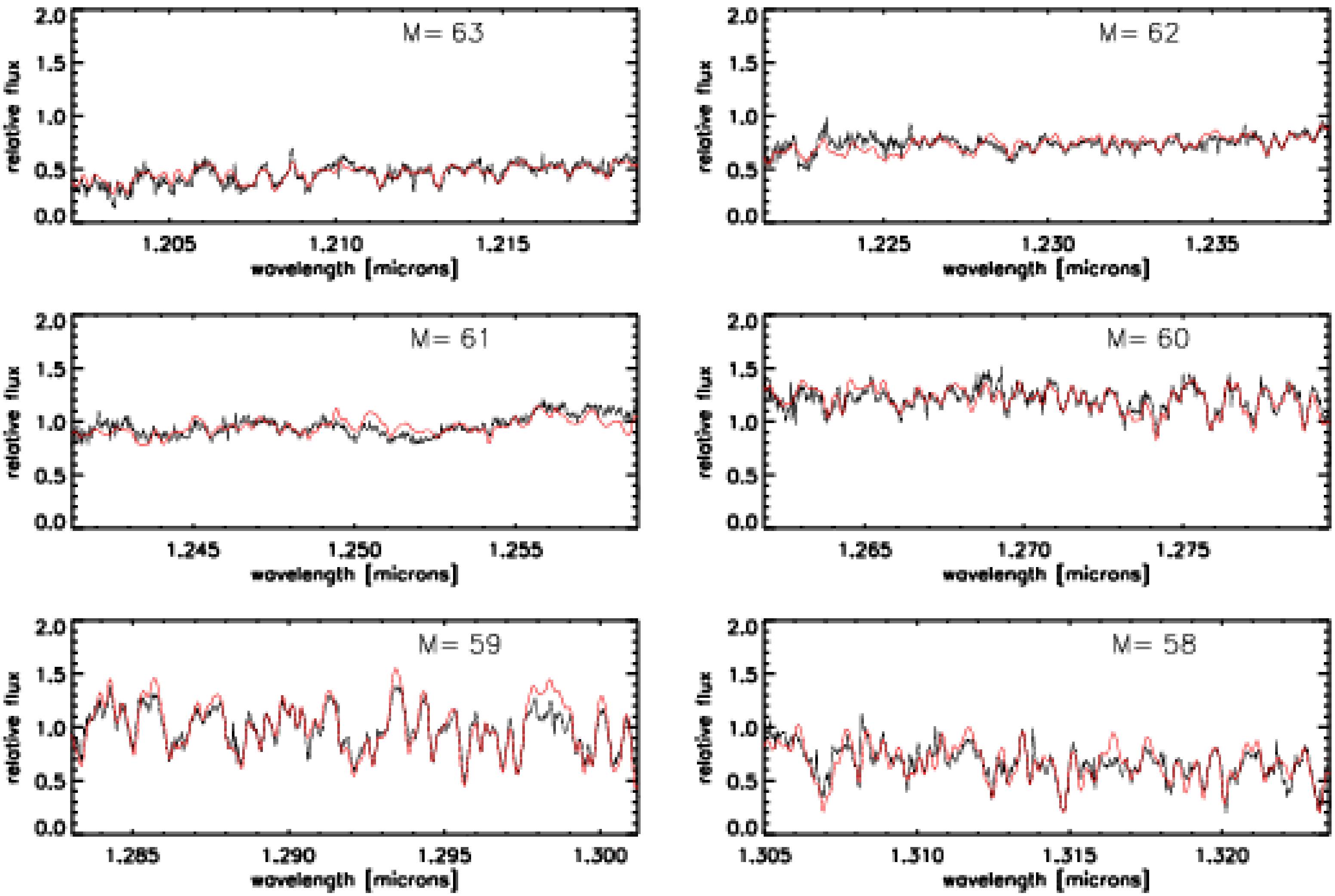
T_{eff} = 941 K

log g = 4.6 (cm/s^{-2})

Models can reproduce all the features very well!

Table 6. 2MASS J15530228+1532369. Synthetic and observed spectra comparison for all orders: RMS, N, T_{eff}, *log g* and v_{rot} sin*i*.

order	N	RMS	T_{eff}	*log g*	v_{rot} sin*i*
63	976	0.0507	1000	4.5	37
62	976	0.0582	800	5.0	21
61	976	0.0659	900	5.5	39
60	857	0.0563	900	4.0	27
59	976	0.0733	900	4.0	30
58	979	0.0863	1100	5.0	23



2MASSJ12171110-0311131

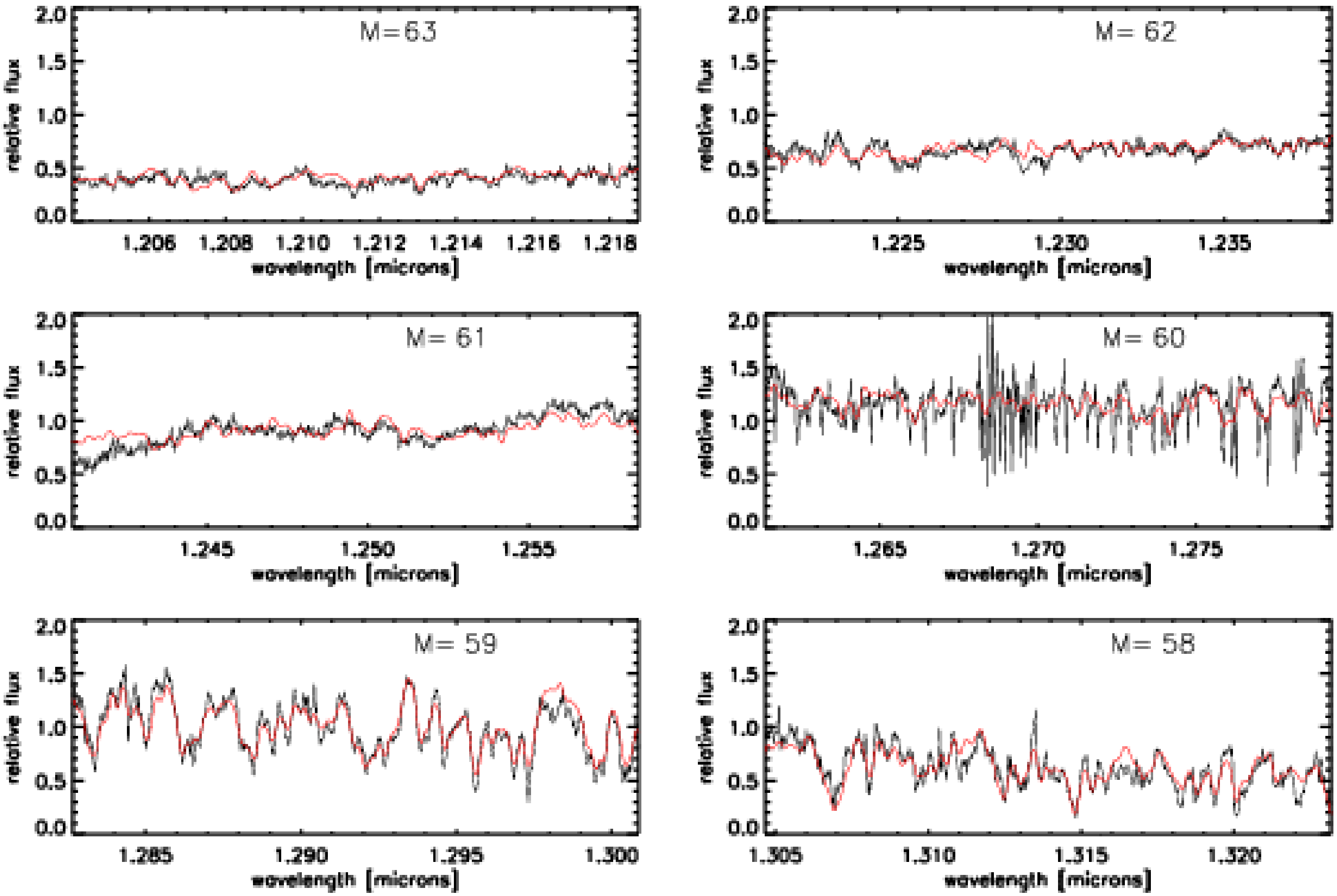
T7.5

T_{eff} = 922 K

log g = 4.8 (cm/s^{-2})

Table 7. 2MASS J12171110-0311131. Synthetic and observed spectra comparison for all orders: RMS, N, $T_{\rm eff}$, *log g* and $v_{\rm rot}$ sin*i*

order	N	RMS	$T_{\rm eff}$	*log g*	$v_{\rm rot}$ sin*i*
63	843	0.0467	800	5.5	21
62	972	0.0581	900	4.0	32
61	972	0.0947	900	5.5	41
60	882	0.1777	900	4.0	21
59	972	0.0894	1000	4.5	27
58	972	0.0918	1100	4.5	29

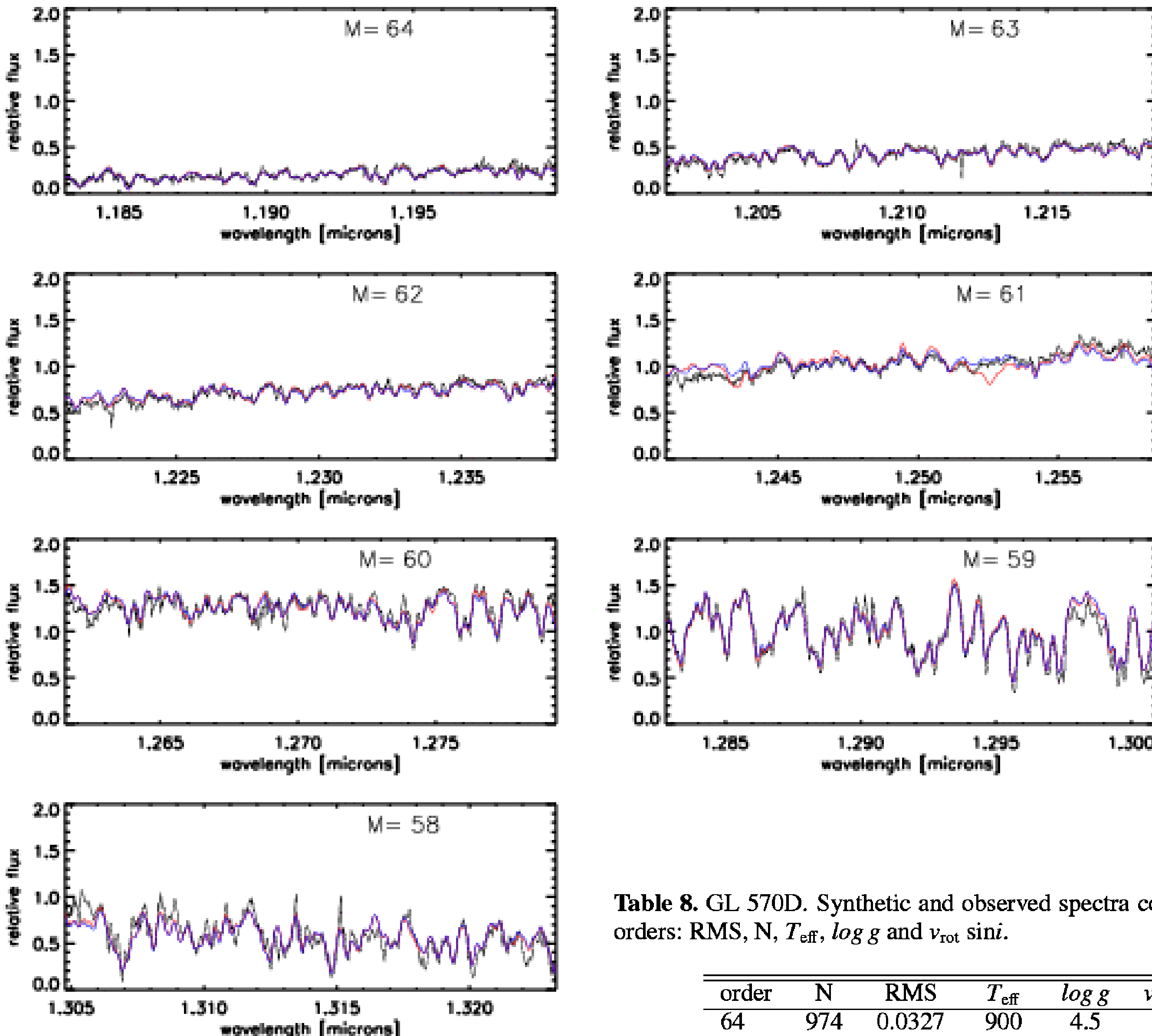


Models are good

Note problems of telluric line subtraction and flat-fielding

GL570 D

T7.5



T_{eff} = 948 K

T_{eff} = 900 K

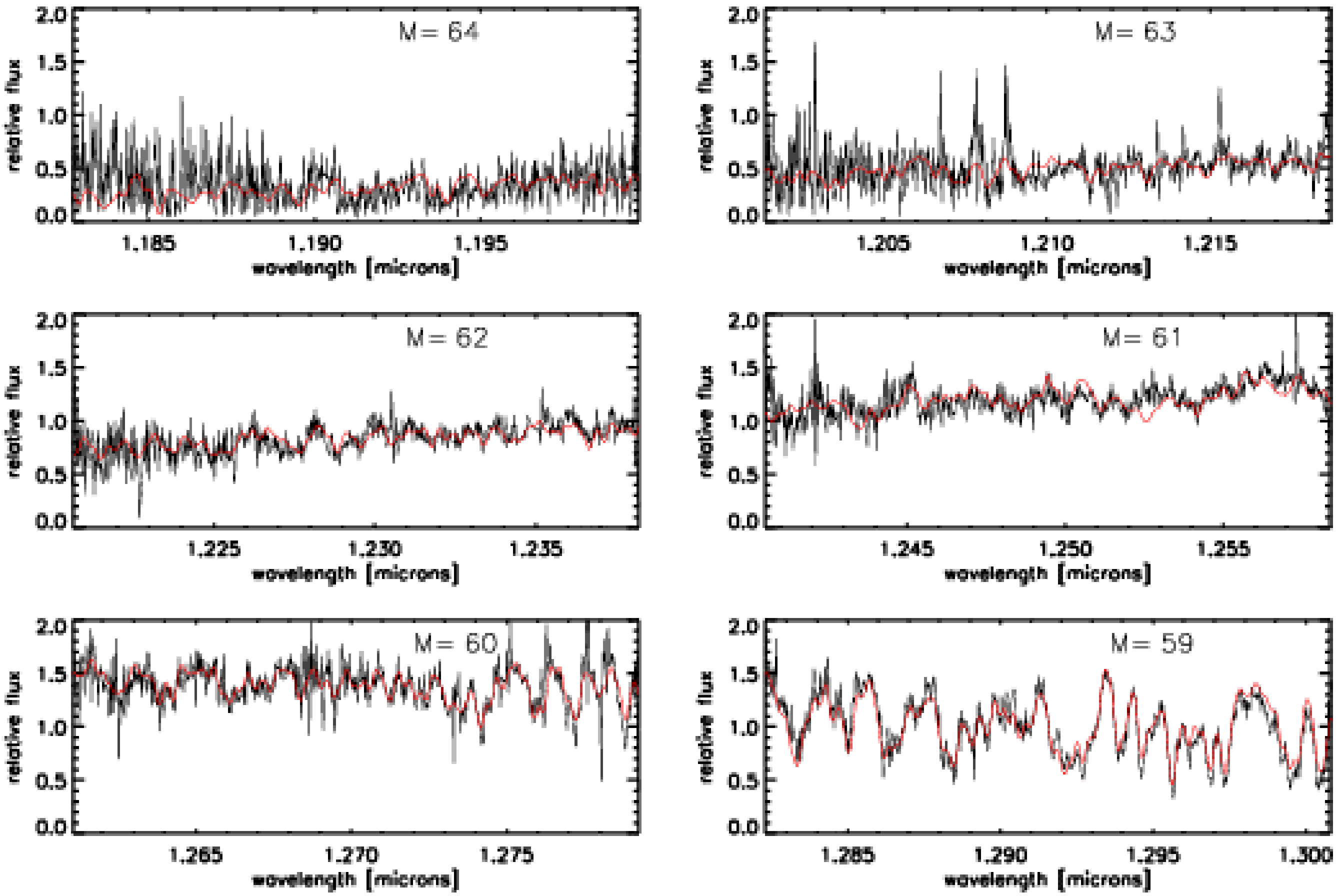
log g = 4.5 (cm/s^{-2})

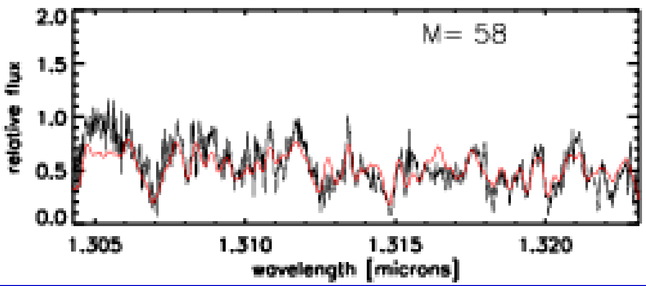
Very good fit!

Table 8. GL 570D. Synthetic and observed spectra comparison for all orders: RMS, N, $T_{\rm eff}$, $log\ g$ and $v_{\rm rot}$ sin$i$.

order	N	RMS	$T_{\rm eff}$	$log\ g$	$v_{\rm rot}$ sin$i$
64	974	0.0327	900	4.5	27
63	974	0.0411	1000	4.5	34
62	974	0.0428	1000	4.0	41
61	974	0.0649	900	5.5	41
60	861	0.0675	900	4.0	26
59	974	0.0919	1000	4.5	26
58	974	0.0986	1000	5.0	21

2MASSJ04151954-0935066





T8

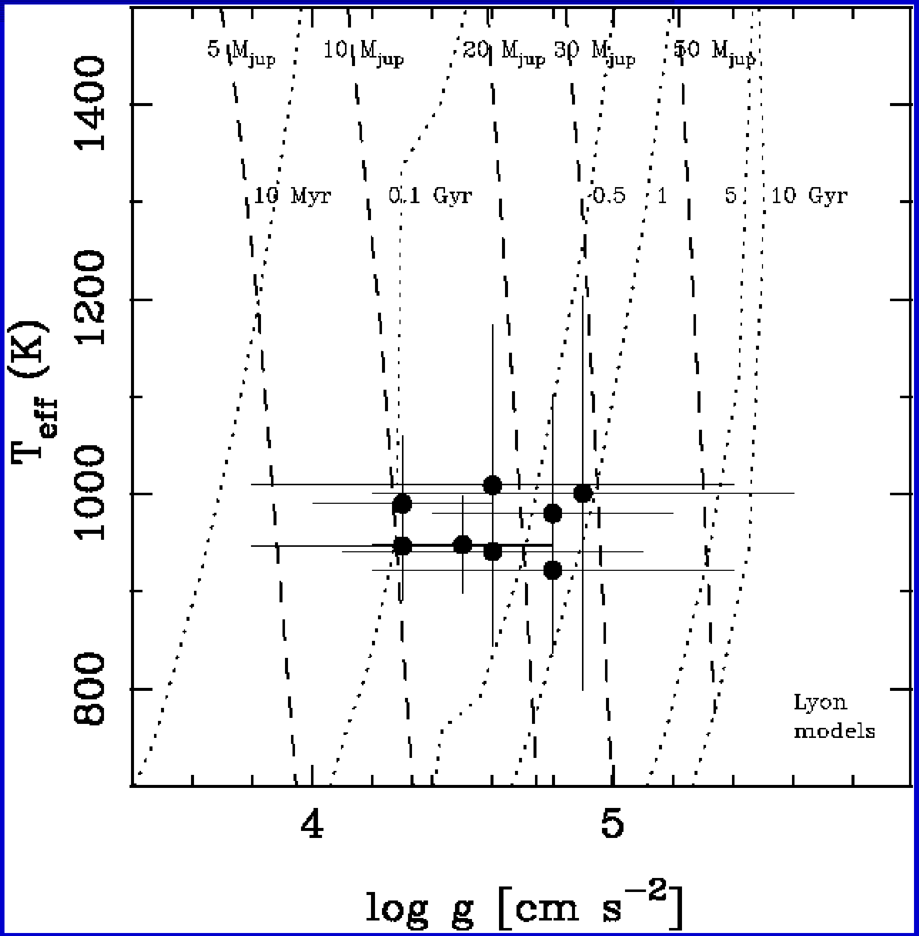
T_{eff} = 947 K
log g = 4.3 (cm/s^{-2})

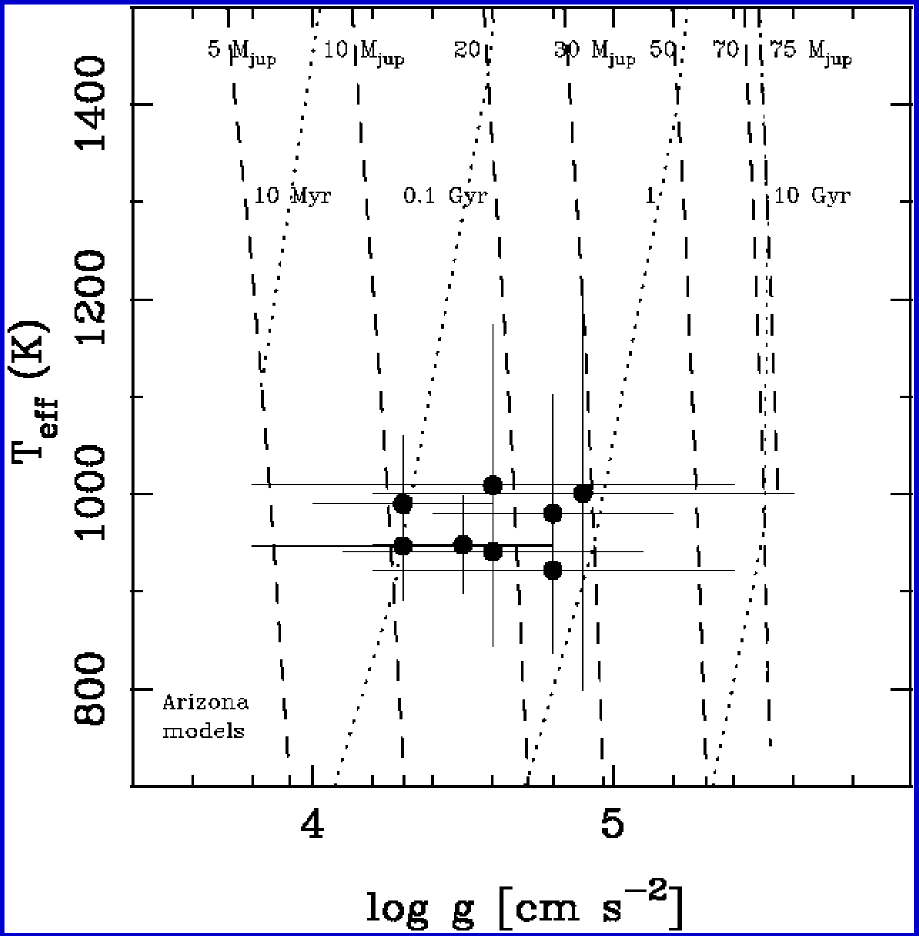
Good fit!

Table 9. 2MASS J04151954-0935066. Synthetic and observed spectra comparison for all orders: RMS, N, $T_{\rm eff}$, *log g* and $v_{\rm rot}$ sin*i*.

order	N	RMS	$T_{\rm eff}$	*log g*	$v_{\rm rot}$ sin*i*
64	926	0.2029	800	3.5	43
63	981	0.1791	1000	3.5	33
62	982	0.1119	1000	4.0	44
61	987	0.1206	900	5.0	43
60	899	0.1539	1000	3.5	38
59	987	0.1081	900	4.5	29
58	984	0.1330	1000	5.0	25

Diagram T_{eff} vs log g for our sample of T dwarfs
and the solar metallicity models by Lyon (left) and Arizona (right)
Isochrones and curves of constant mass



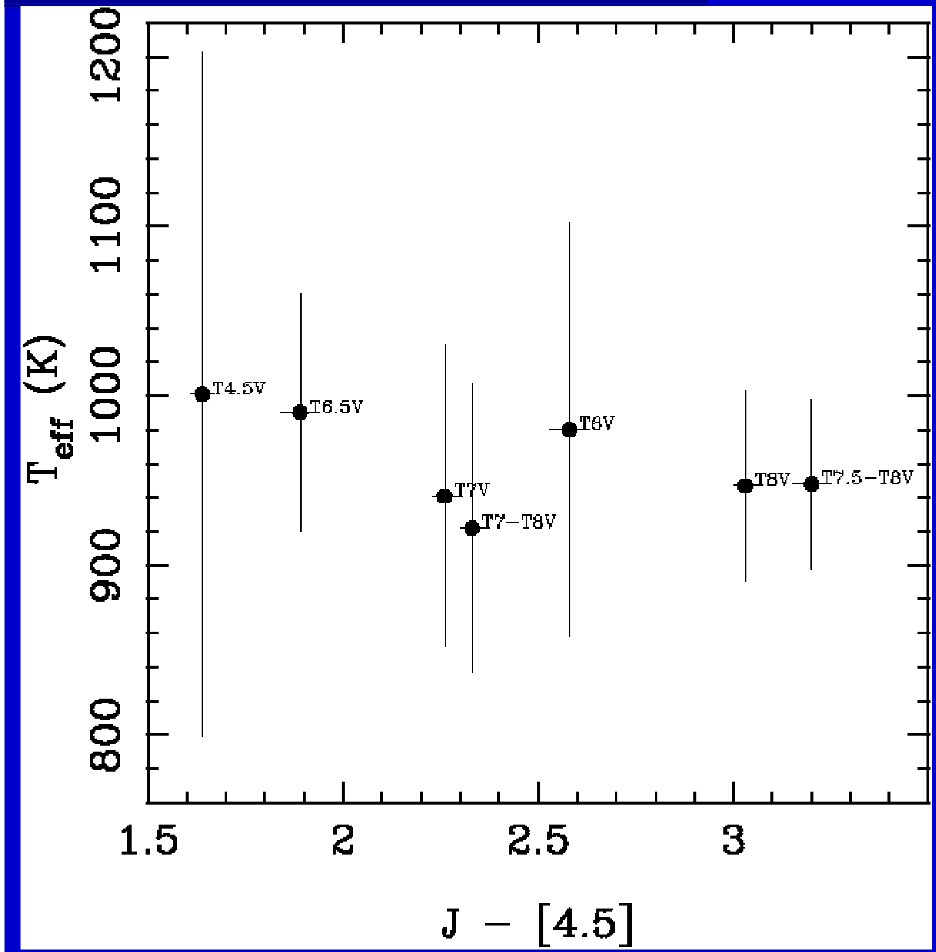


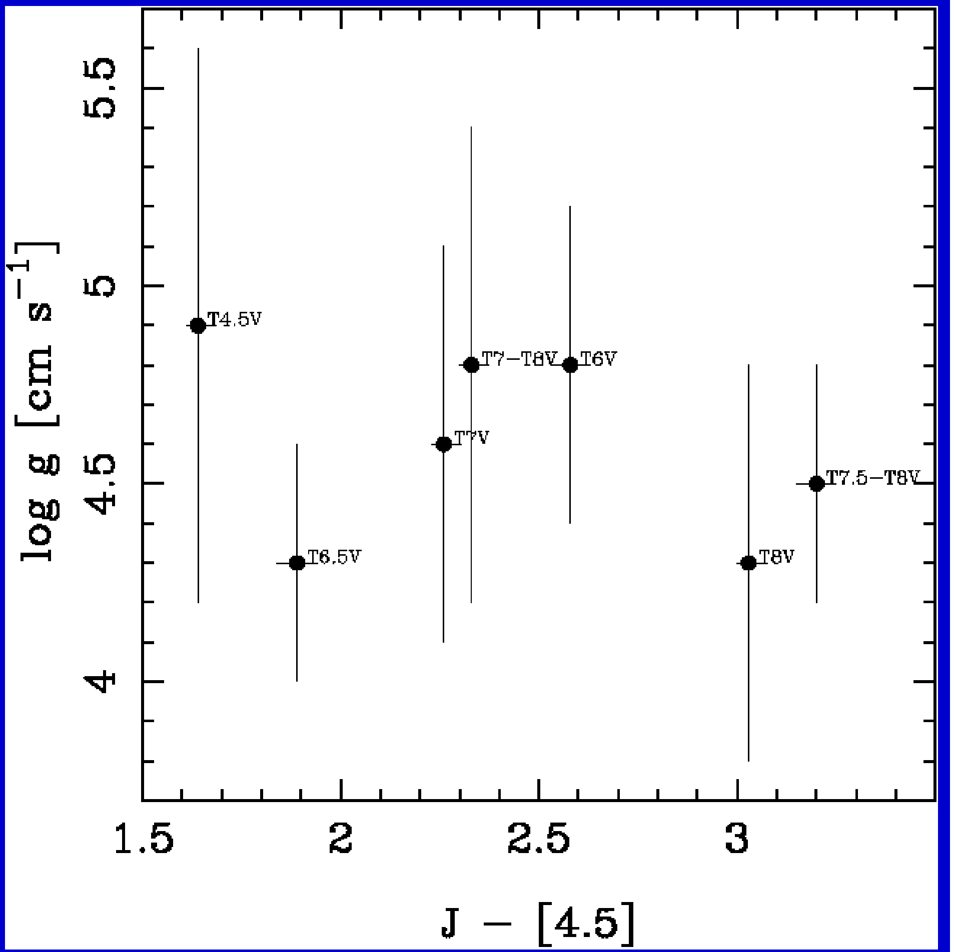
Summary of results

Object	Sp. T.	$V_{rot}\sin i$	Teff	Prev.	Ref.	<logg>	Prev.	Ref.	M	Age
		Km/s	K	K		(cm s^{-2})	(cm s^{-2})		M_J	Gyr
SDSSpJ125453.90-012247.4	T2	34±5	2007±662	1200	1	4.3±1.0	5.0	1	--	--
2MASSJ05591914-1404488	T4.5	23±9	1002±278	1200	1	4.9±0.8	5.5	1	30^{+45}_{-23}	$1.0^{+9}_{-0.9}$
2MASSJ15031961+2525196	T5	33±9	1009±217	~1100	2	4.6±0.8	~5.0	5	18^{+37}_{-13}	$0.4^{+4.6}_{-0.3}$
SDSSJ162414.37+002915.6	T6	37±5	980±163	1002^{+98}_{-86}	3	4.8±0.7	~5.0	5	23^{+52}_{-16}	$0.6^{+9.4}_{-0.5}$
SDSSJ134646.45-003150.4	T6.5	15±4	990±107	960-1020	4	4.1±0.4	5.0-5.2	4	10^{+10}_{-5}	$0.1^{+0.4}_{-0.08}$
2MASSJ15530228+1532369	T7	28±5	941±138	~900	2	4.6±0.6	~5.0	5	18^{+30}_{-11}	$0.4^{+3.6}_{-0.3}$
2MASSJ12171110-0311131	T7.5	30±4	922±103	860-880	4	4.8±0.7	4.7-4.9	4	23^{+52}_{-16}	$0.8^{+9}_{-0.7}$
GL 570D	T7.5	29±1	948±53	780-820	4	4.5±0.5	5.1	4	15^{+15}_{-9}	$0.3^{+1.7}_{-0.2}$
2MASSJ04151954-0935066	T8	35±4	947±79	740-760	4	4.3±0.7	4.9-5.0	4	10^{+20}_{-6}	$0.1^{+1.9}_{-0.09}$

1. Cushing et al. 2008
2. Burgasser 2001
3. Vrba et al. 2004
4. Burgasser et al. 2006
5. Knapp et al. 2004

High resolution NIR spectroscopy vr photometry





Conclusions

- High resolution spectra corresponding to T dwarfs with spectral types later than T5 are well reproduced by the *AMES-COND* models
- The effective temperature values are similar to those found in the literature for intermediate spectral types; the surface gravity values are all similar to those found in the literature
- The estimations of mass, between ~5 and 75 M_J, are consistent with what it is expected
- The estimations of age agree with recent kinematical studies and also with age estimates from brown dwarf binaries, however, it is interesting to find that 3 out of 8 of our targets are younger than 1-2 Gyr (including upper limit errors)
- For earlier type T dwarfs the models do not provide suitable fits, which is likely due to the presence of condensate clouds that are not incorporated in the models