

Optical spectroscopy of the coolest known brown dwarfs, the Y dwarfs

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Collaborators: V. J. S. Béjar, R. Rebolo, and F. Allard

Talk @ GTC V Science meeting, Puebla

Wednesday 2 December 2015

Outline

- **Spectral classification**
- **New spectral classes: L, T, and Y dwarfs**
- **GTC OSIRIS photometry** of Y dwarfs
- **GTC OSIRIS spectroscopy** of Y dwarfs
- **Comparison** observations vs models

Part 1

Spectral classification

Harvard Spectral Classification

Class	Surface temperature ^[8] (kelvin)	Conventional color description	Actual apparent color ^{[9][10][11]}	Mass ^[8] (solar masses)	Radius ^[8] (solar radii)	Luminosity ^[8] (bolometric)	Hydrogen lines	Fraction of all main-sequence stars ^[12]
O	≥ 33,000 K	blue	blue	≥ 16 M _⊙	≥ 6.6 R _⊙	≥ 30,000 L _⊙	Weak	~0.00003%
B	10,000–33,000 K	blue white	deep blue white	2.1–16 M _⊙	1.8–6.6 R _⊙	25–30,000 L _⊙	Medium	0.13%
A	7,500–10,000 K	white	blue white	1.4–2.1 M _⊙	1.4–1.8 R _⊙	5–25 L _⊙	Strong	0.6%
F	6,000–7,500 K	yellow white	white	1.04–1.4 M _⊙	1.15–1.4 R _⊙	1.5–5 L _⊙	Medium	3%
G	5,200–6,000 K	yellow	yellowish white	0.8–1.04 M _⊙	0.96–1.15 R _⊙	0.6–1.5 L _⊙	Weak	7.6%
K	3,700–5,200 K	orange	pale yellow orange	0.45–0.8 M _⊙	0.7–0.96 R _⊙	0.08–0.6 L _⊙	Very weak	12.1%
M	2,000–3,700 K	red	light orange red	≤ 0.45 M _⊙	≤ 0.7 R _⊙	≤ 0.08 L _⊙	Very weak	76.45%

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L	1,300–2,000 K	red brown ^[citation needed]	scarlet ^[citation needed]	Unknown	Unknown	Unknown	Extremely weak	

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T	700–1,300 K	brown ^[citation needed]	magenta ^{[13][14][15]}	Unknown	Unknown	Unknown	Extremely weak	

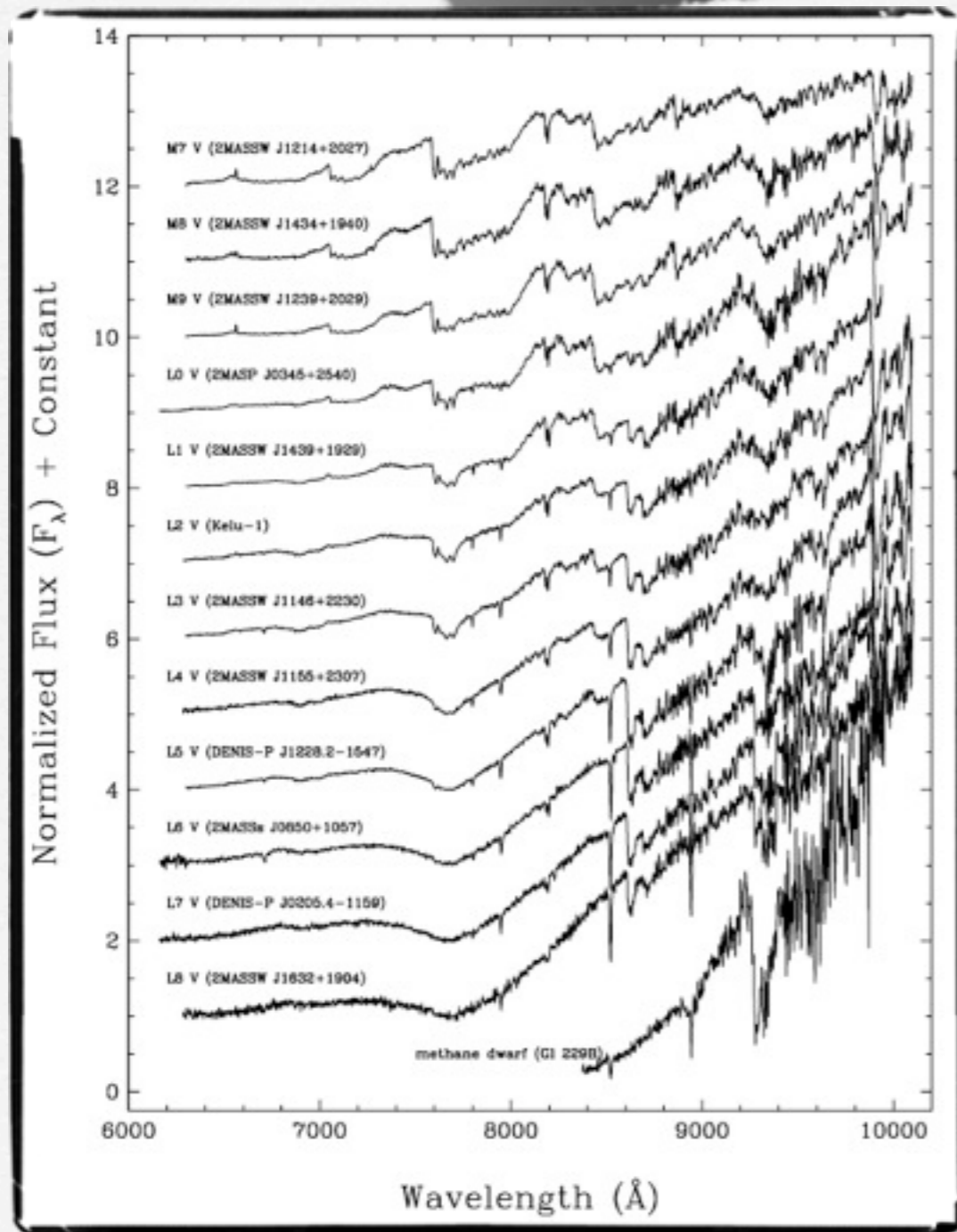
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T	700–1,300 K	brown ^[citation needed]	magenta ^{[13][14][15]}	Unknown	Unknown	Unknown	Extremely weak	
Y	≤ 700 K	dark brown ^[citation needed]	dark purple ^[citation needed]	Unknown	Unknown	Unknown	Extremely weak	

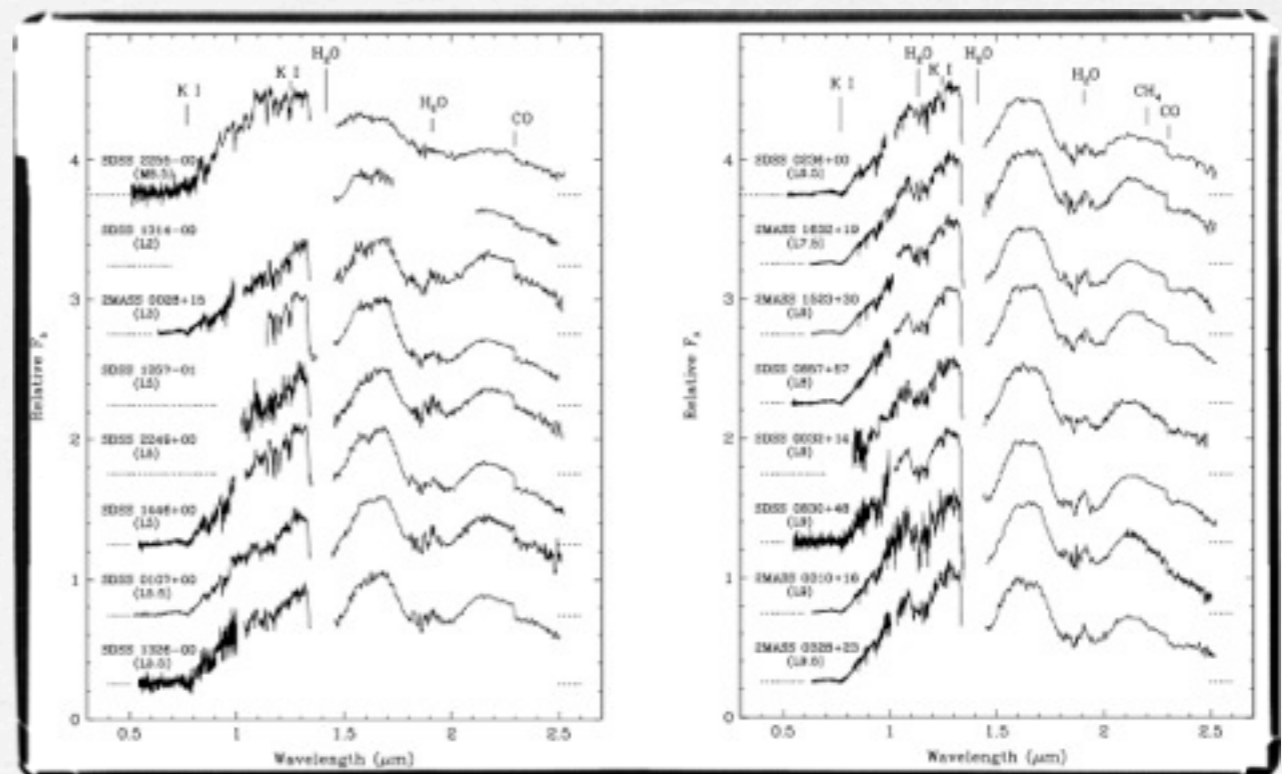
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L dwarfs

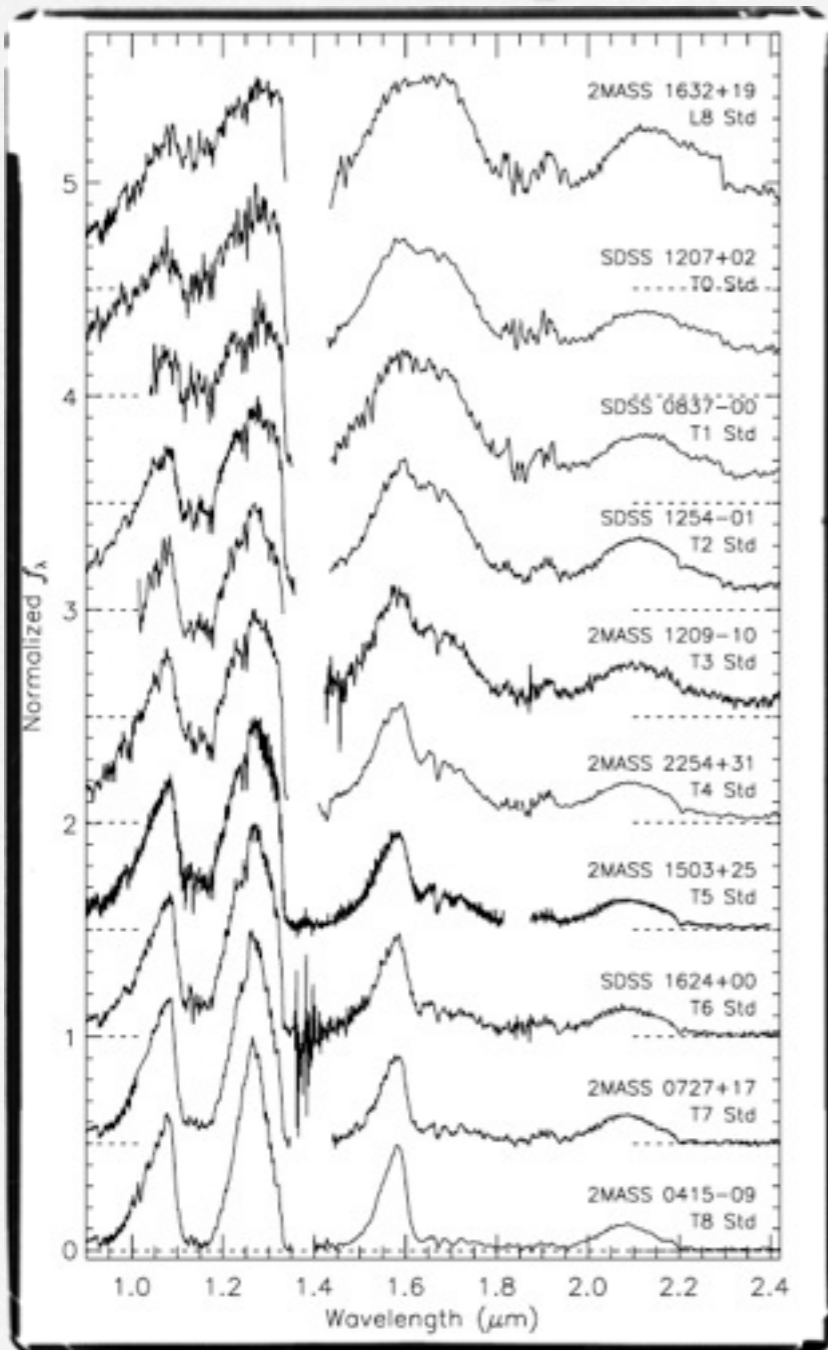


*Kirkpatrick et al. 1999; Martin et al. 1999;
Geballe et al. 2001*

- ~920 known Ls
- Red optical and NIR colours
- Cloudy and dusty objects
- $T_{\text{eff}} = 2200\text{-}1300\text{ K}$
- Optical spectra marked by metal hydrides and neutral alkalis
- NIR spectra marked by molecular and water absorption bands + CO band-head

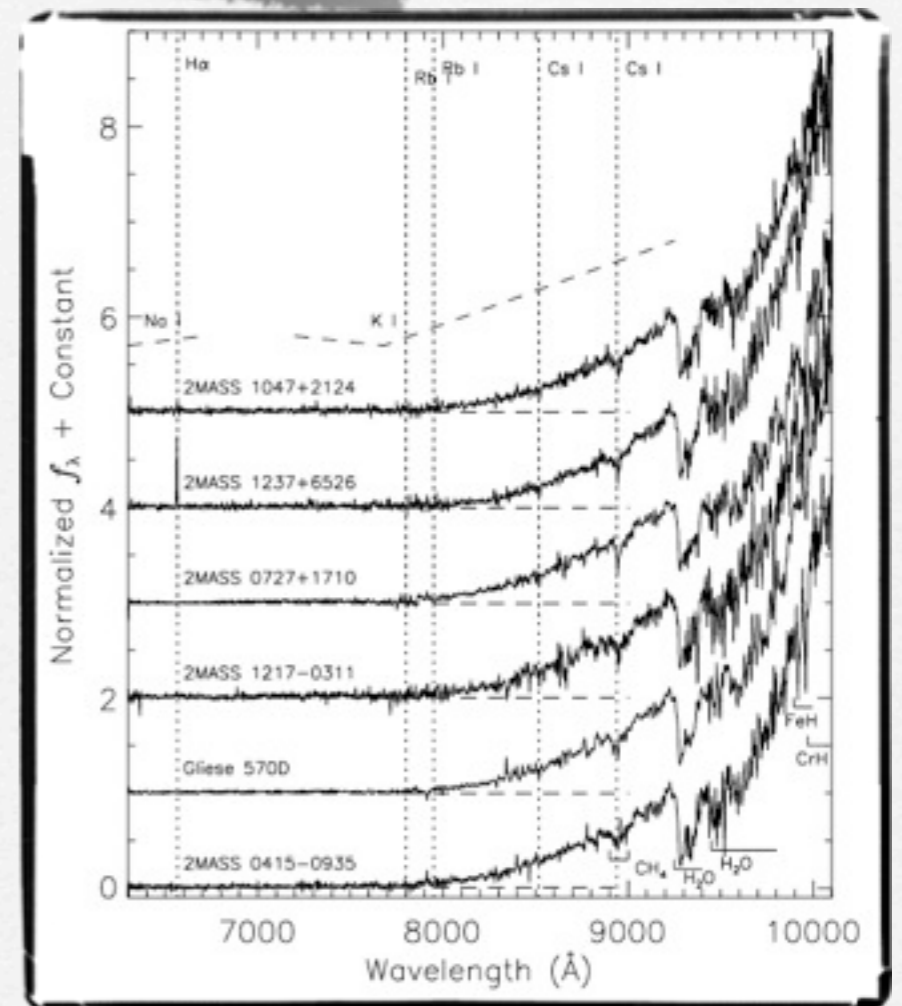


T dwarfs



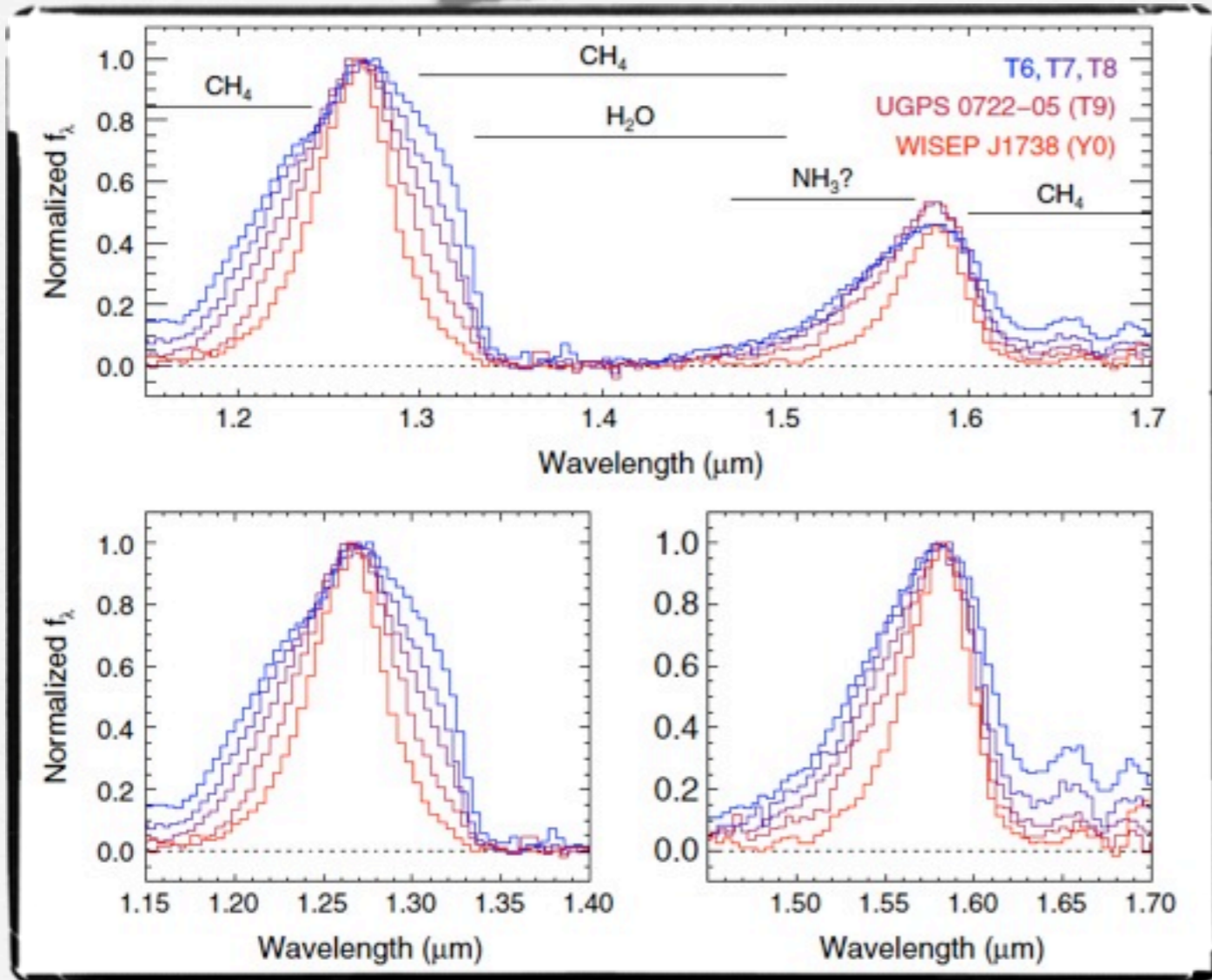
Burgasser et al. 2003, 2006

- ~350 known Ts
- Red optical colours
- Blue NIR colours
- $T_{\text{eff}} = 1300\text{-}700\text{ K}$



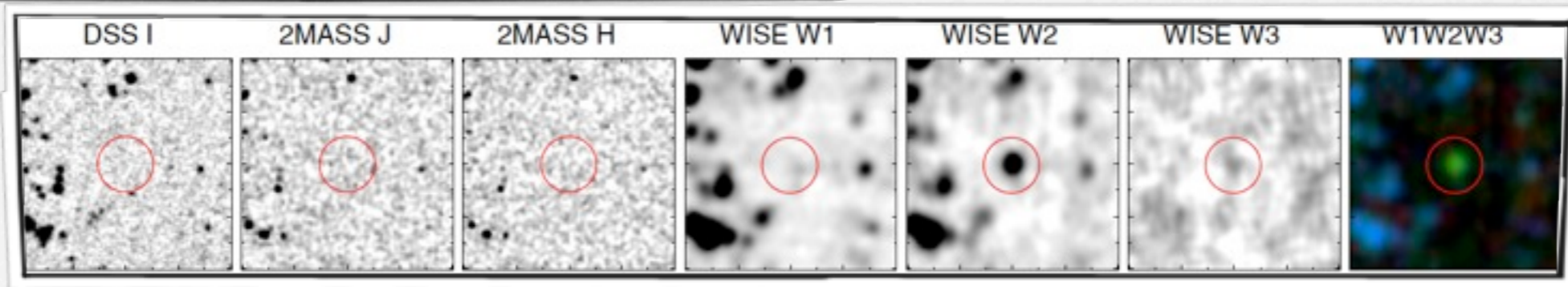
- Optical spectra marked by broadened potassium doublet and Cesium lines
- NIR spectra shaped by strong methane and water absorption bands
- Dust settled at the bottom of the atmosphere

Y dwarfs

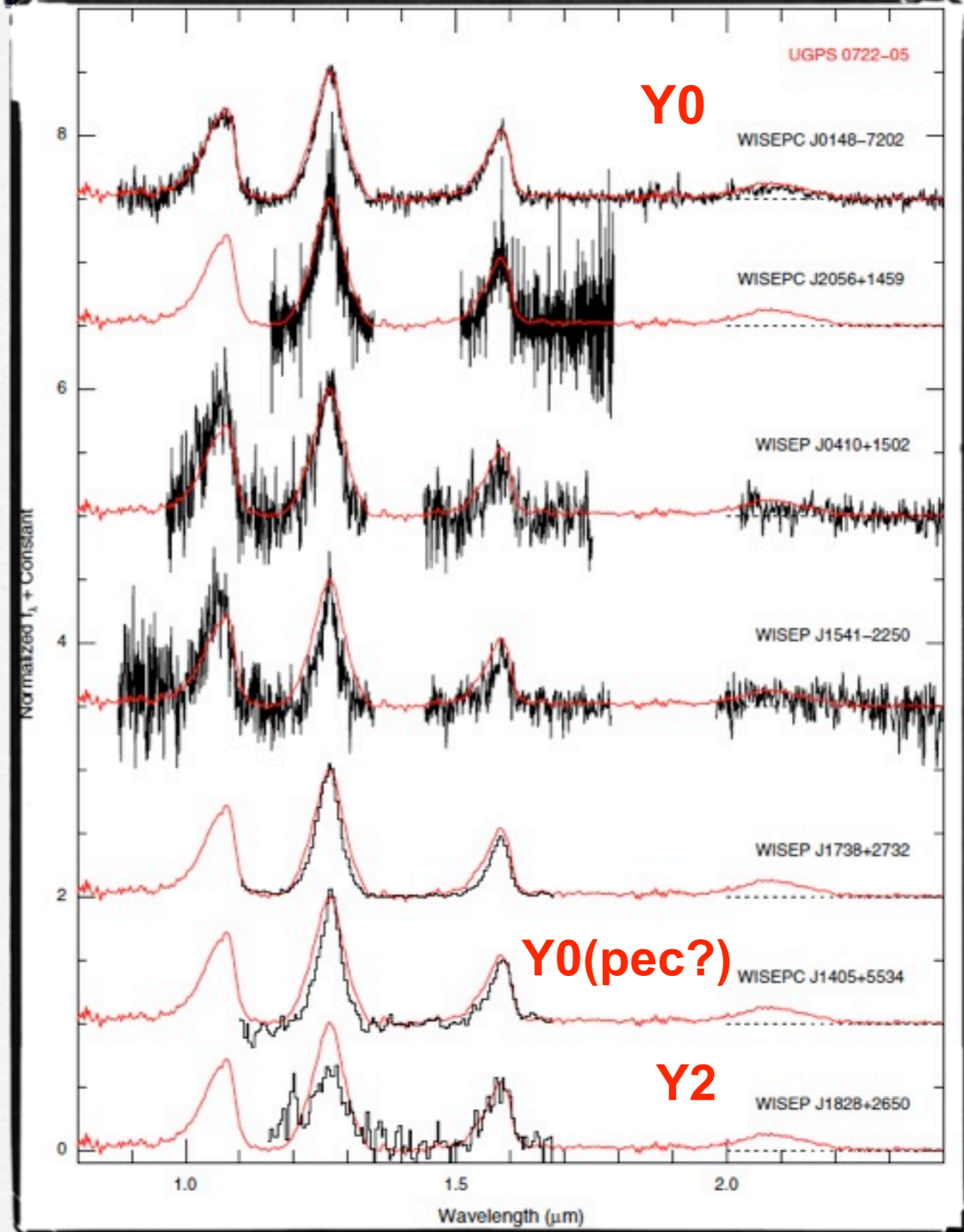


- 18 known Ys
- Red mid-IR colours
- NIR colours turn red again?
- Faint in the optical and NIR
- Nearby and fast moving
- $T_{\text{eff}} = 500\text{-}300\text{ K}$
- NIR spectra marked by narrower peak in the H-band

Cushing et al. 2011; Kirkpatrick et al. 2011, 2012



Y dwarf sequence



Cushing et al. 2011

Part 2

GTC OSIRIS optical imaging

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&
Astrophysics**

LETTER TO THE EDITOR

GTC OSIRIS z-band imaging of Y dwarfs

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ABSTRACT

Aims. The aim of the project is to contribute to the characterisation of the spectral energy distribution of the coolest brown dwarfs.

Observing logs

1) Red optical imaging:

- **z-band imaging** with GTC OSIRIS in service mode
- Observations in June, August, September, and December 2012
- **6 of 7 Y dwarfs** in the Northern Hemisphere (*Cushing et al. 2011*)
- **30 to 50 integrations of 50 sec** combined
- **i-band imaging for 1 object** attempted: lower limit derived

2) Goals of the observations:

- Derive **optical-to-infrared colours**
- Measure **proper motions** using WISE as first epoch

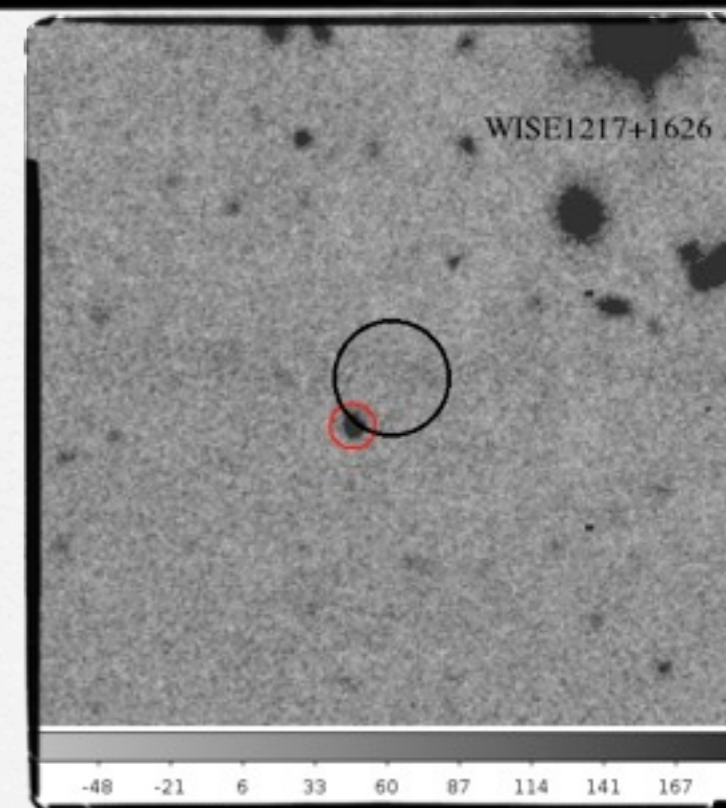
First optical z-band imaging of γ O dwarfs

Photometry and astrometry

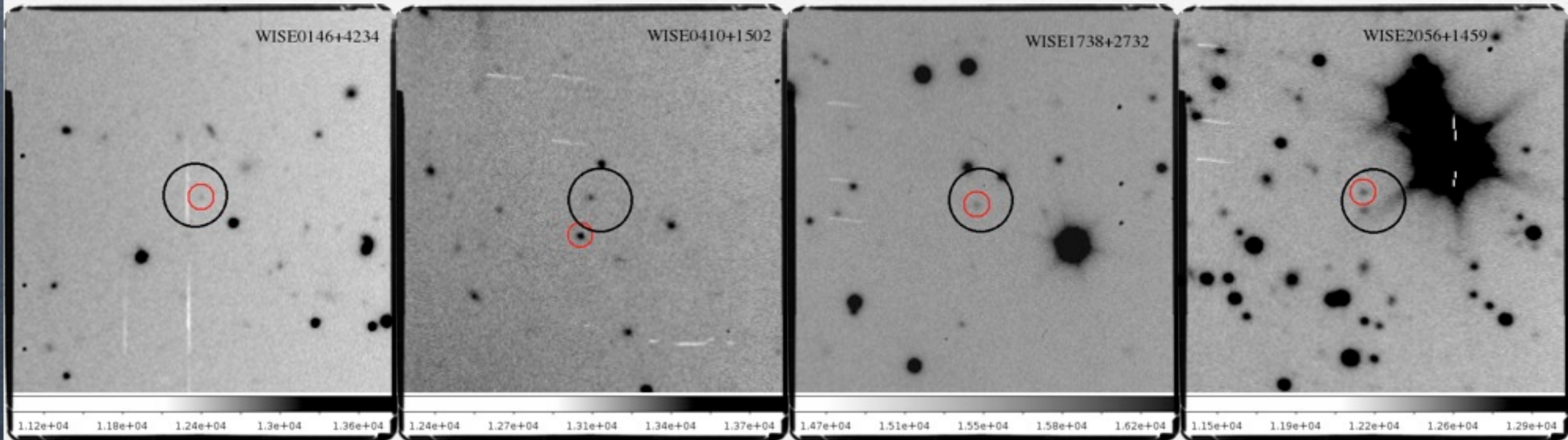
Table 1. GTC/OSIRIS astrometry, photometry (or 3σ lower limits), observing information, and photometry for six Y dwarfs and a T9+Y0 binary.

WISE J... (SpT)	RA hh:mm:ss.sss	Dec °:′:″	z mag	Date dd/mm/yy	ExpT s	J mag	H mag	$z - J$	$\mu_\alpha \cos \delta$	μ_δ
0146+4234 (Y0)	01:46:56.576	+42:34:09.80	24.10 ± 0.13	03/09/12	50 × 50	19.40 ± 0.25	18.71 ± 0.24	5.39 ± 0.27	-0.52 ± 0.08	-0.11 ± 0.08
0410+1502 (Y0)	04:10:22.933	+15:02:42.91	22.66 ± 0.09	15/09/12	40 × 50	19.44 ± 0.03	20.02 ± 0.05	3.22 ± 0.09	$+1.20 \pm 0.08$	-2.17 ± 0.08
1405+5534 (Y0p)			>23.85	06/08/12	45 × 50	21.06 ± 0.06	21.41 ± 0.08	>2.79	–	–
1738+2732 (Y0) ^a	17:38:35.585	+27:32:58.28	22.80 ± 0.09	17/06/12	30 × 50	20.05 ± 0.09	20.45 ± 0.09	2.75 ± 0.13	$+0.32 \pm 0.10$	-0.39 ± 0.10
1828+2650 ($\geq Y2$)			>24.46	09/09/12	40 × 50	23.48 ± 0.23	22.85 ± 0.24	>0.98	–	–
2056+1459 (Y0)	20:56:29.028	+14:59:54.64	23.09 ± 0.08	15/06/12	40 × 50	19.94 ± 0.04	19.96 ± 0.04	3.66 ± 0.09	$+0.89 \pm 0.10$	$+0.61 \pm 0.10$
1217+1626 (T9+Y0)	12:17:57.144	+16:26:35.99	21.60 ± 0.03	15/12/12	15 × 60	17.83 ± 0.02	18.18 ± 0.05	3.77 ± 0.04	$+1.41 \pm 0.10$	-1.96 ± 0.10

- **4 Y0 detected out 5**
- **2 non detections** => lower limits
- **Proper motions** accurate to 0.1 arcsec/yr
- **Calibrator: T9+Y0 binary** (Liu et al. 2012)



Detections



WISE0146+4234

$z = 24.10 \pm 0.13$

$\mu = 0.53''/\text{yr}$

WISE0410+1502

$z = 22.66 \pm 0.09$

$\mu = 2.48''/\text{yr}$

WISE1738+2732

$z = 22.80 \pm 0.09$

$\mu = 0.50''/\text{yr}$

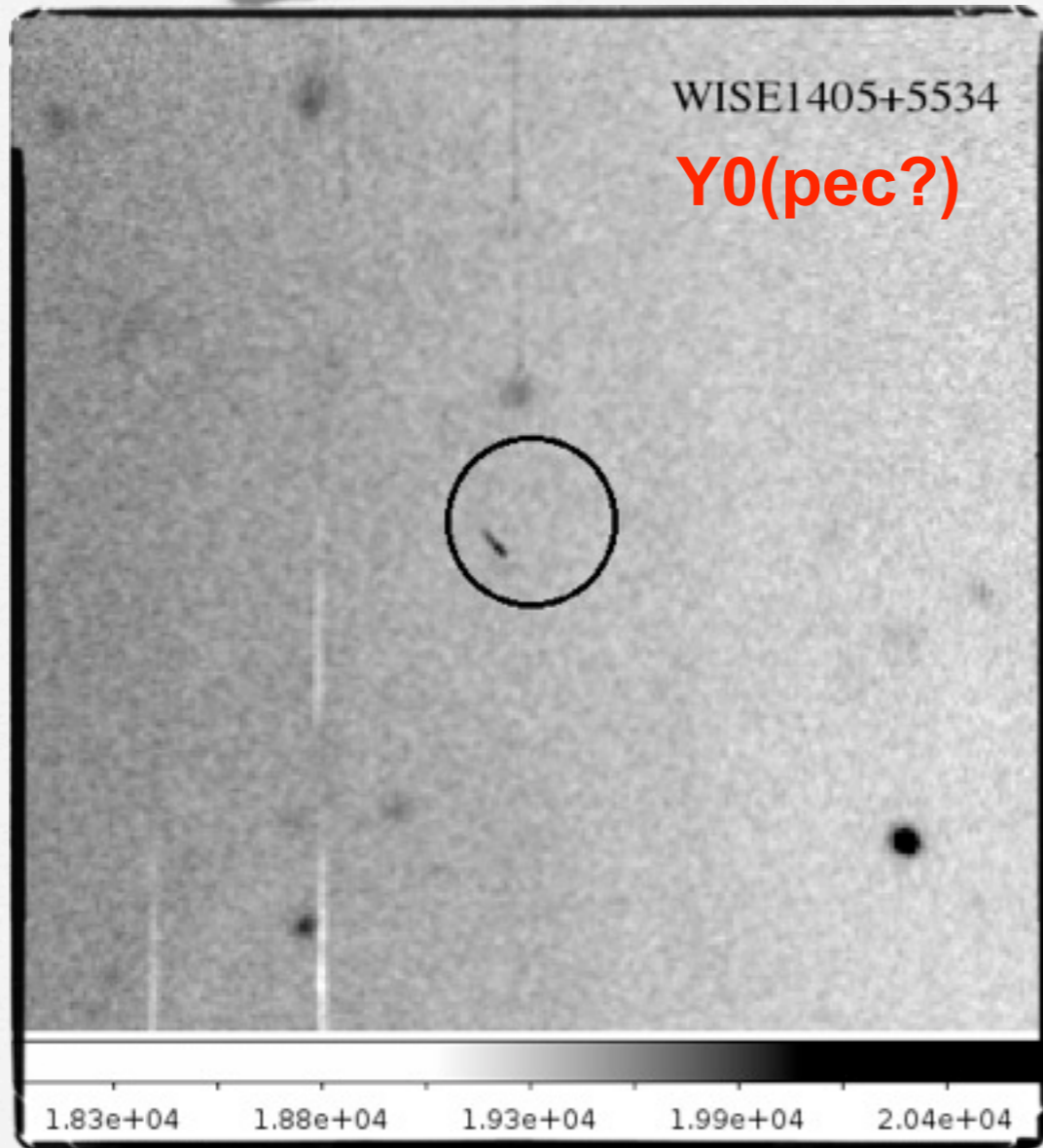
WISE2056+1459

$z = 23.09 \pm 0.08$

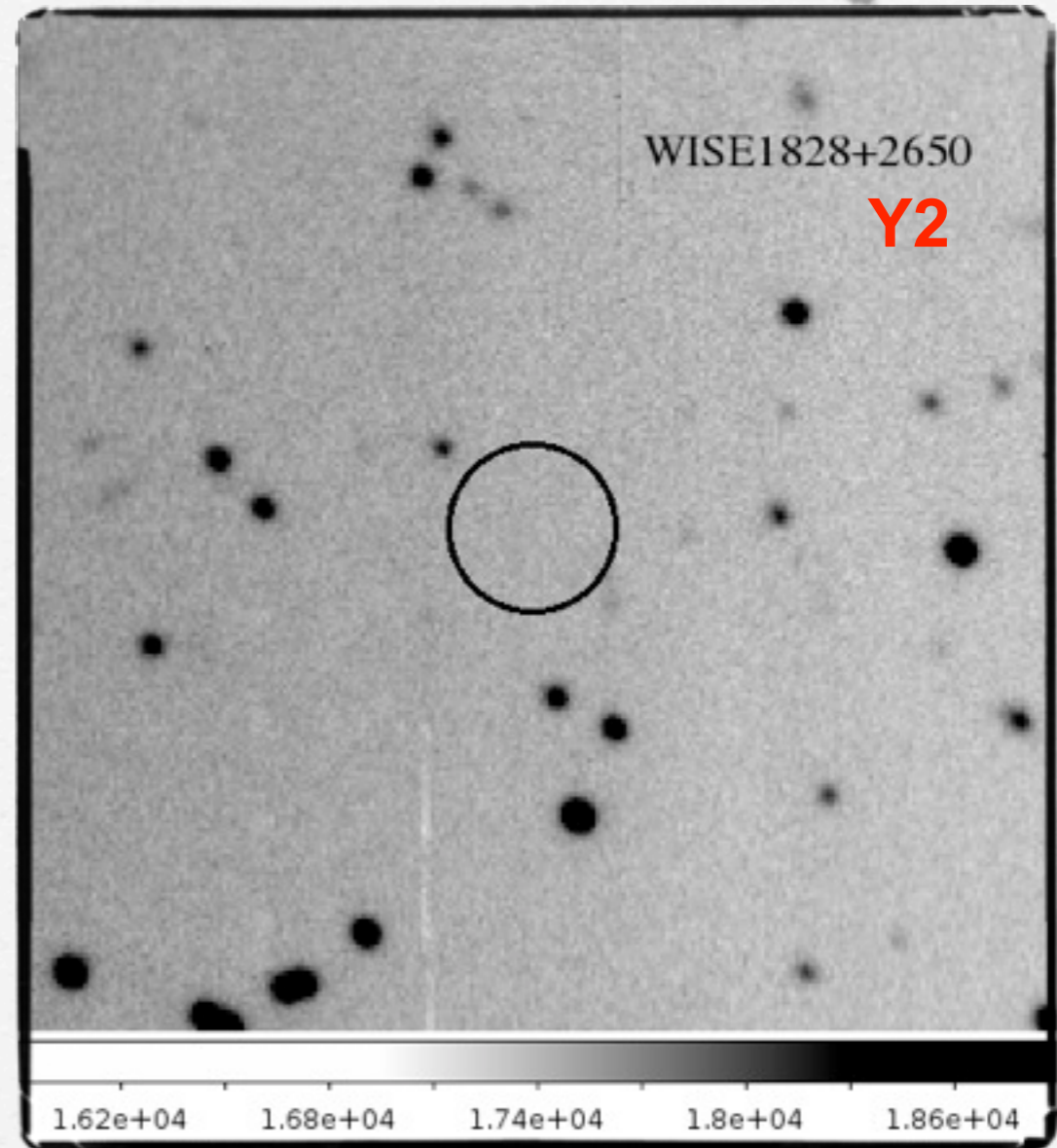
$\mu = 1.08''/\text{yr}$

All Y0 dwarfs are detected in the z-band

Non detections

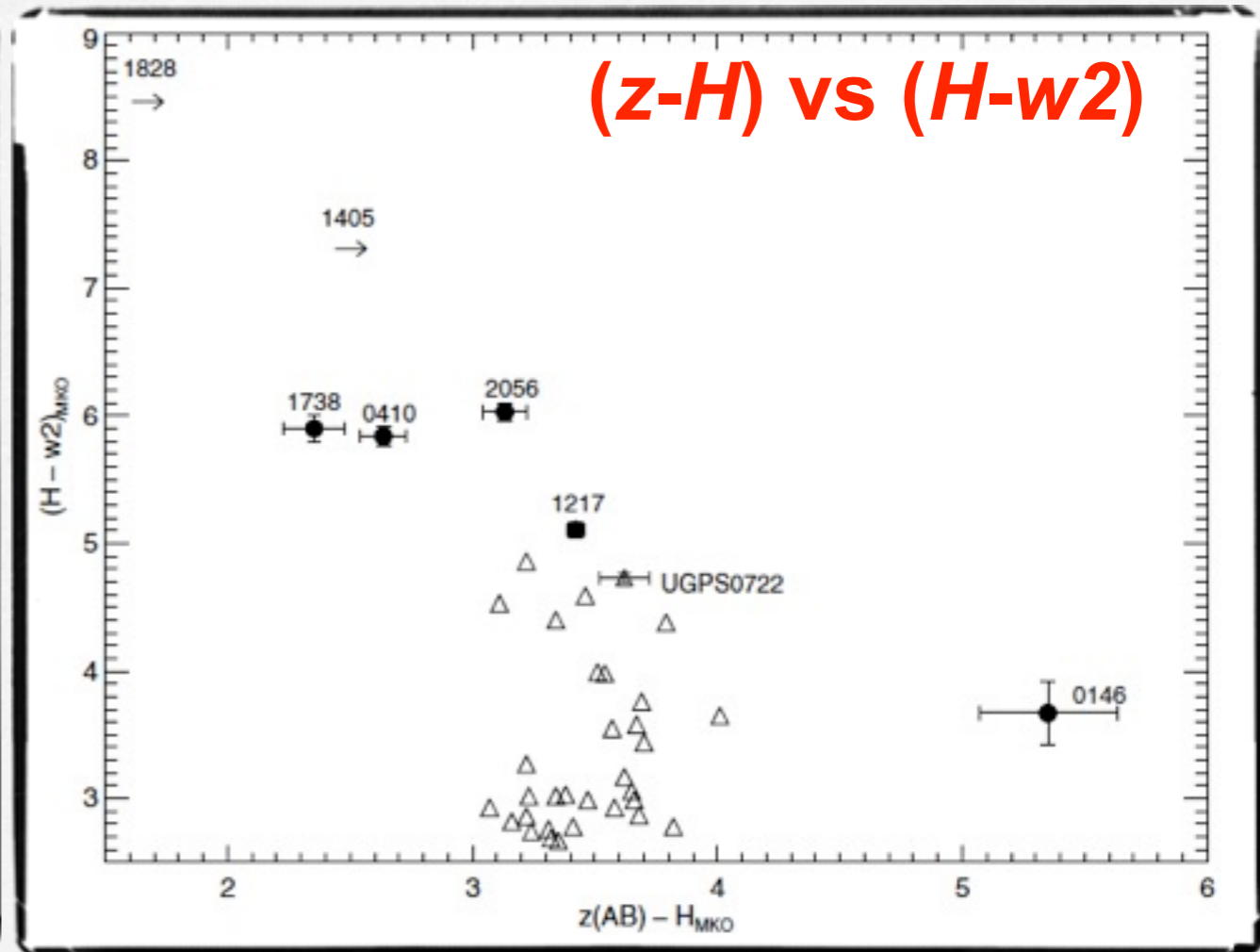
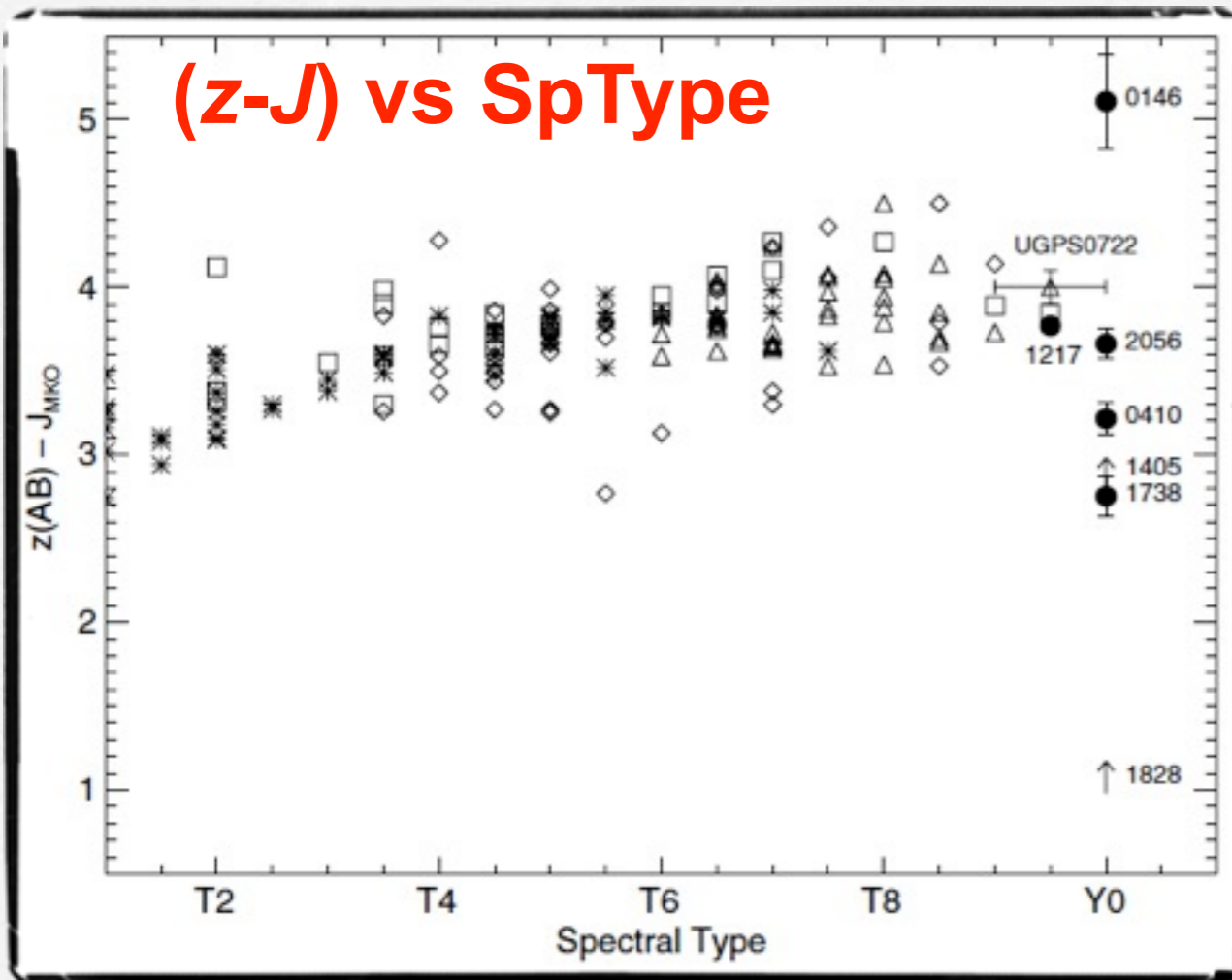


WISE1405+5534
 $z > 23.85 (3\sigma)$



WISE1828+2650
 $z > 24.46 (3\sigma)$

Colours vs spectral types



Y0 dwarfs are marked as **black filled dots**, lower limits as **arrows**. Overplotted as triangles are **known T dwarfs** (Leggett et al. 2013) along with the **T9 dwarf UGPS J0722-0540** (Lucas et al. 2010)

Part 3

GTC OSIRIS optical spectroscopy

Lodieu, Allard, Béjar, and Rebolo, in prep

Observing logs: spectroscopy

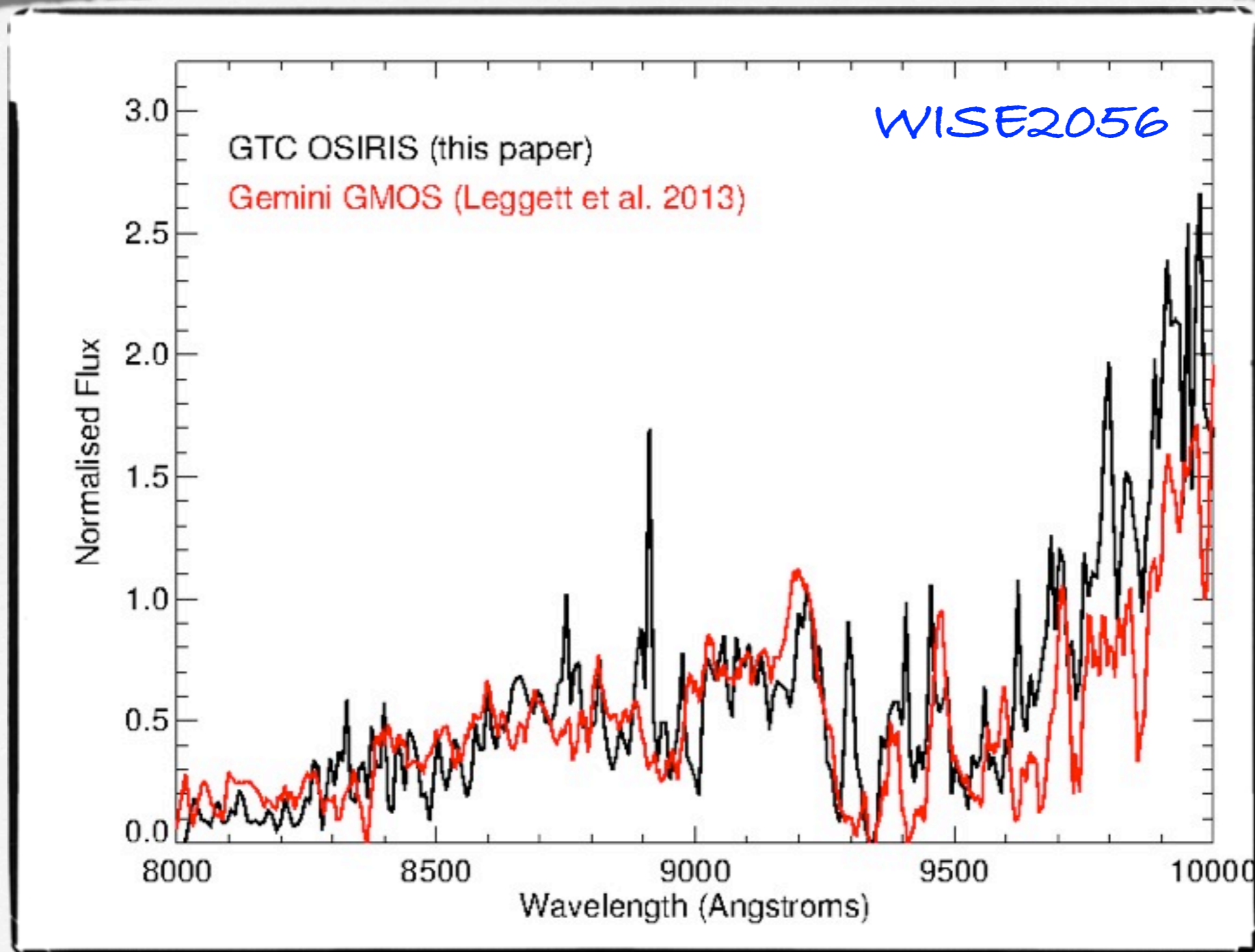
1) Red optical spectroscopy:

- Spectroscopy with R300R and 1.5" slit with GTC OSIRIS
- Observations in service mode (programme GTC49-14B)
- 3 Y0 dwarfs in the Northern Hemisphere (*Cushing et al. 2011*)
- 8 to 12 exposures of 30 min combined

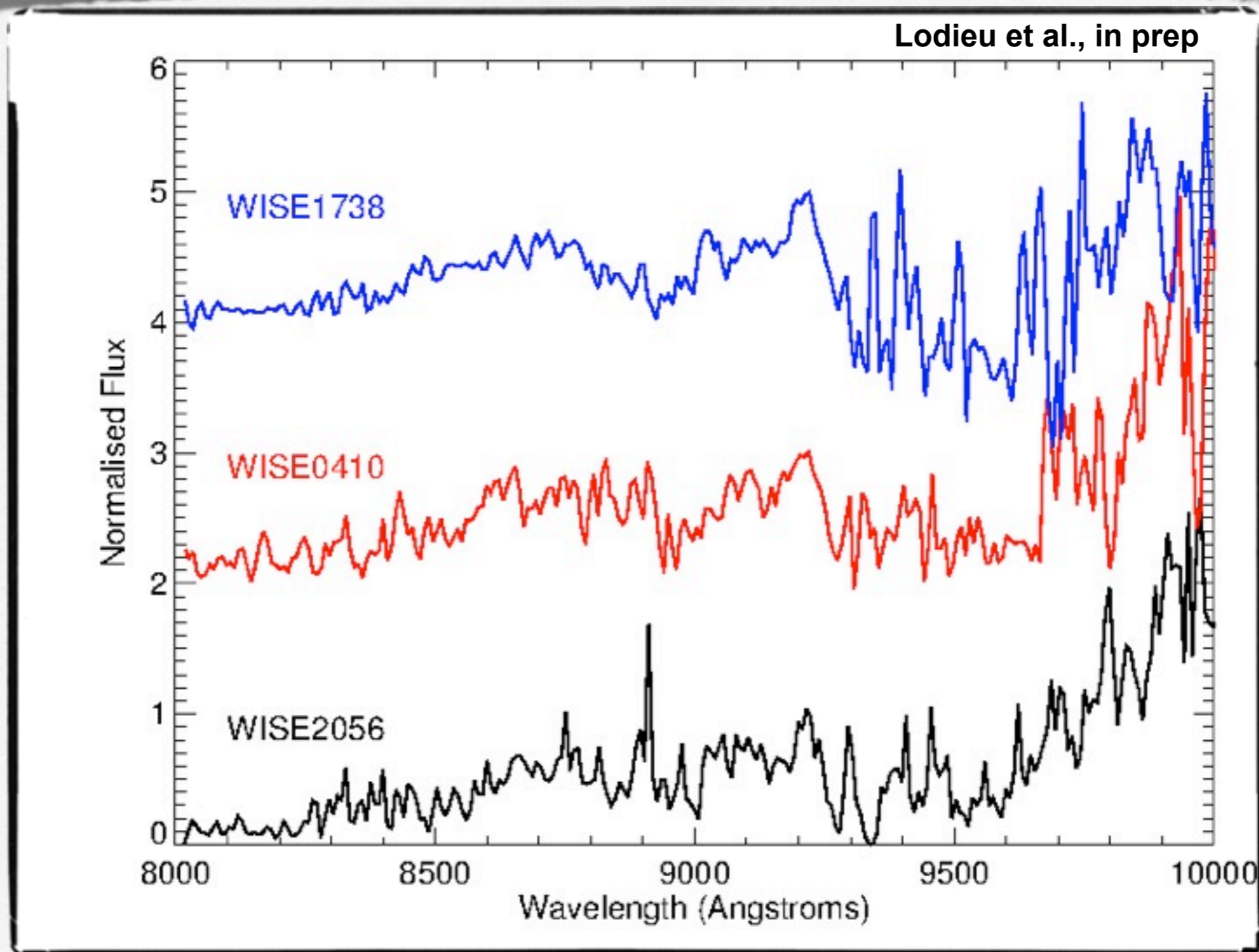
2) Goals of the observations:

- Characterise optical spectra of Y0 dwarfs
- Derive physical parameters by comparison with models

Optical spectroscopy (I)



Optical spectroscopy (II)



Modelling the full SED of Y dwarfs (I)

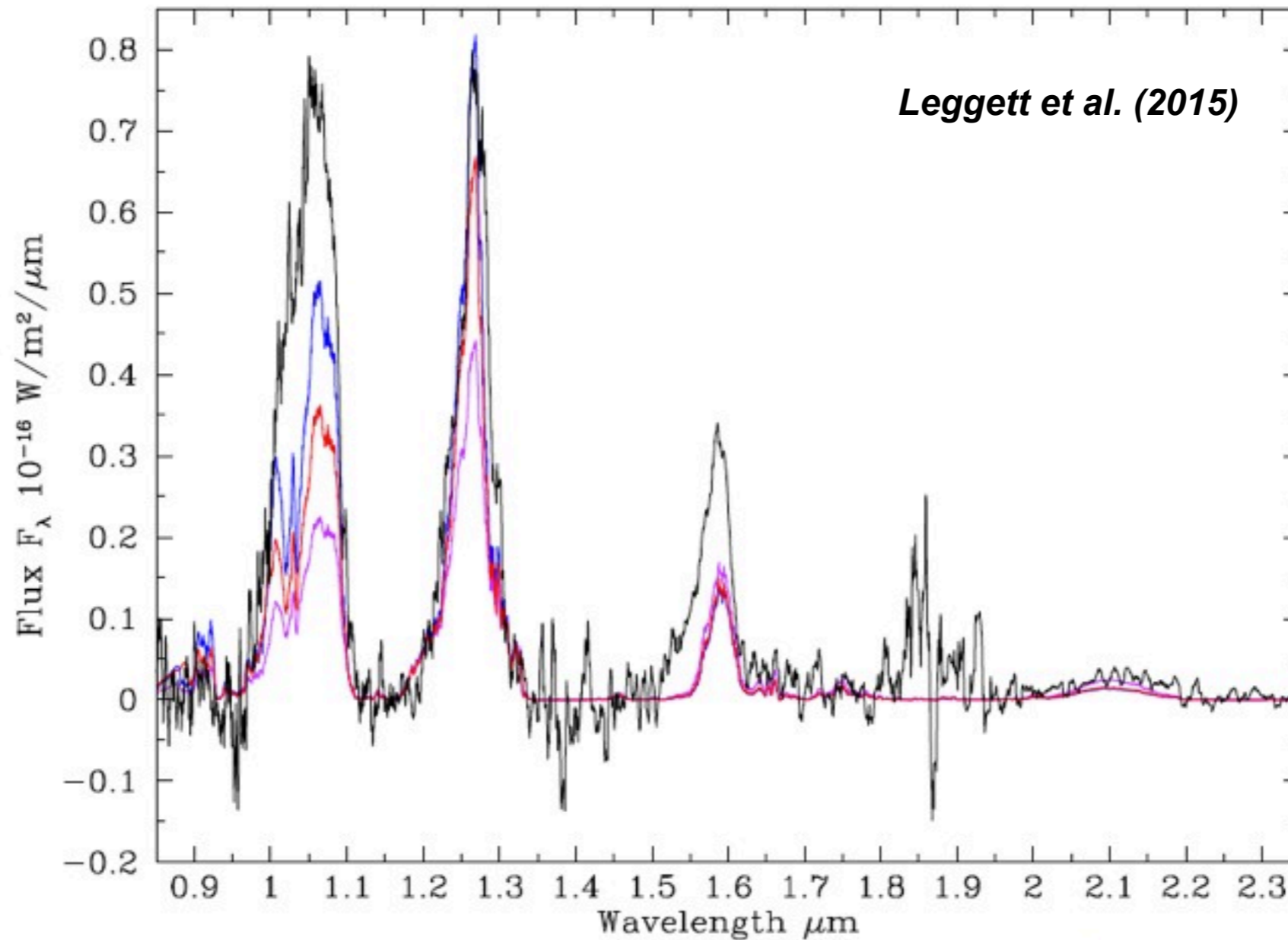


Figure 10. Observed (smoothed) near-infrared spectrum for the Y0 WISEPC J121756.91 + 162640.2B (Leggett et al. 2014) is shown as a black line. The flux has been scaled to what would be observed were the dwarf at a distance of 10 pc. The region of poor atmospheric transmission, 1.80–1.94 μm , is noisy. The blue, red, and violet lines are synthetic spectra for a $T_{\text{eff}} = 400 \text{ K}$, $\log g = 4.48$ brown dwarf at 10 pc, with different cloud cover parameters as in Figure 7.

Modelling the full SED of Y dwarfs (II)

