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Brown Dwarfs and Planetary-Mass Members in the Upper Scorpius association

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Outline of the talk

Part 1: **The Upper Scorpius association**

Part 2: **Photometric selection of members**

Part 3: **Near-infrared spectroscopy**

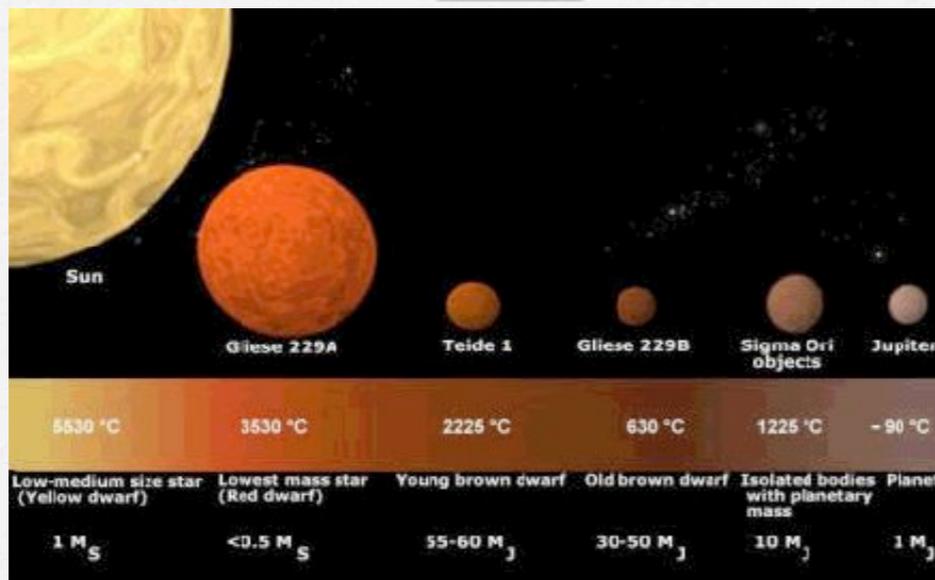
Conclusions and future work

Brown Dwarfs and exoplanets

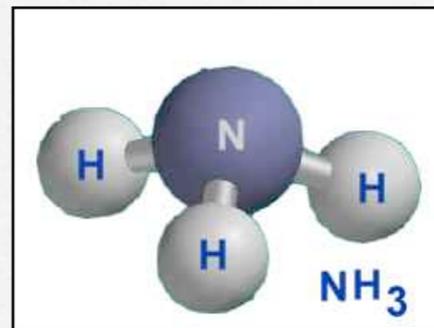
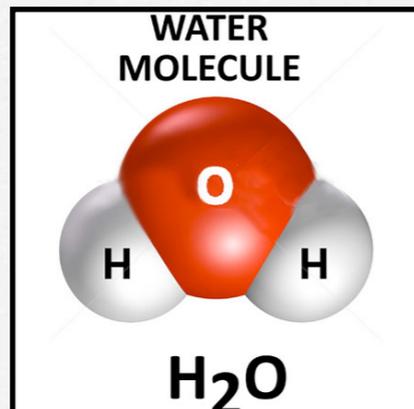
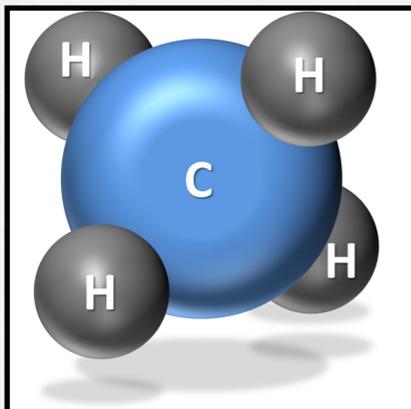
1) Temperatures



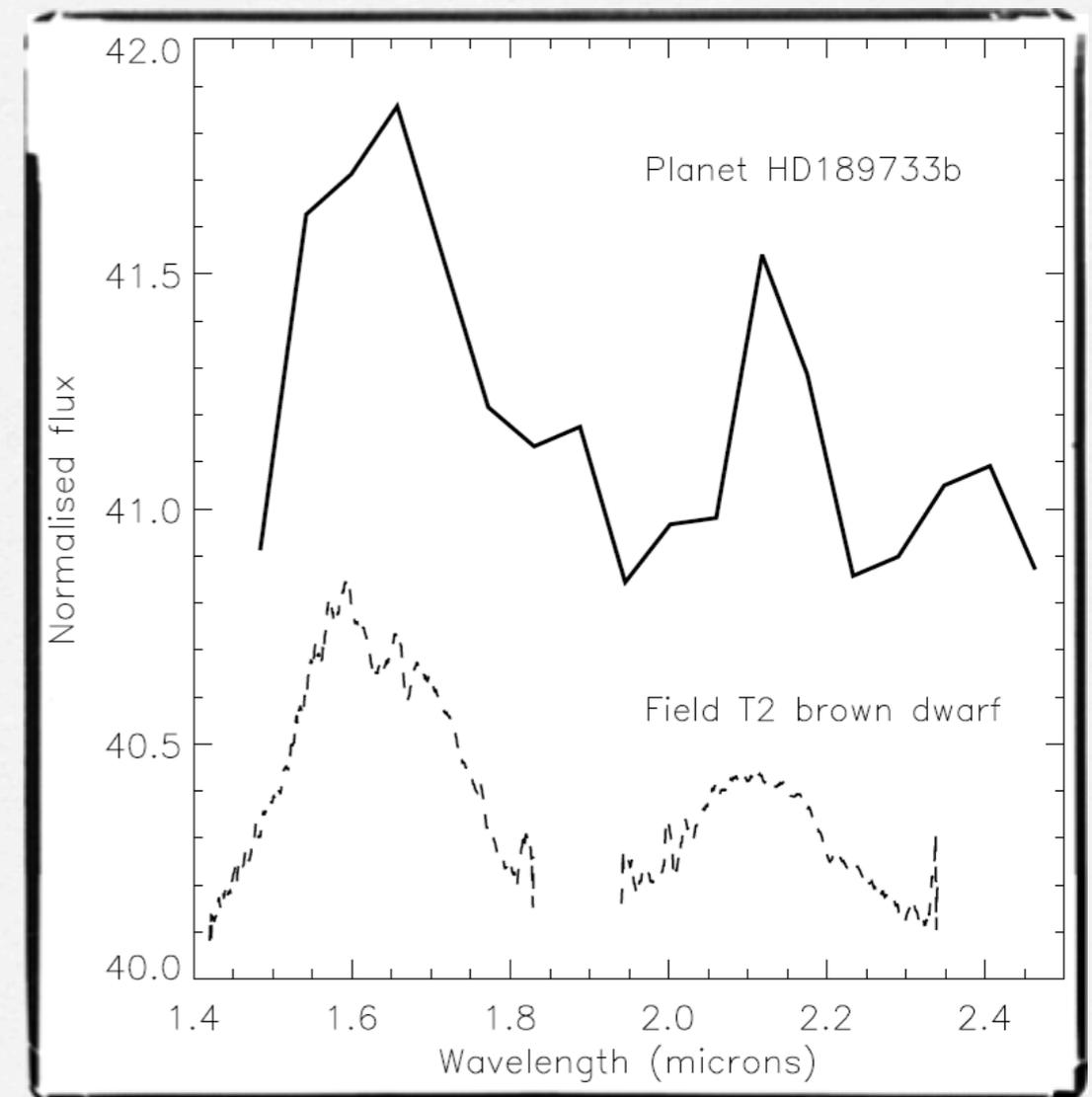
2) Radii



3) Composition



4) SEDs



Part 1

The Upper Scorpius association



Upper Sco in the literature

- ★ Part of the nearest OB association to the Sun, **Scorpius-Centaurus**
- ★ **Distance = 145 pc** (*de Bruijne et al. 1997*)
- ★ Mean **proper motion** = (-11, -25) mas/yr (*de Bruijne et al. 1997; de Zeeuw et al. 1999*)
- ★ **Age = 5-10 Myr** (*Preibish & Zinnecker 2002; Pecaute et al. 2012; Song et al. 2012*)
- ★ **X-rays surveys** (*Walter et al. 1994; Kunkel 1999; Preibish et al. 1998*)
- ★ **Astrometric surveys** (*de Bruijne et al. 1997; de Zeeuw et al. 1999*)
- ★ **Optical and near-infrared photometry** (*Ardila et al. 2000; Slesnick et al. 2006; Lodieu et al. 2006, 2007, 2013; Dawson et al. 2011, 2013*)
- ★ **Spectroscopic surveys** (*Preibish & Zinnecker 2002; Martin et al. 2004; Slesnick et al. 2008; Lodieu et al. 2008, 2011*)
- ★ **Binary searches** (*Kraus et al. 2008; Bejar et al. 2008; Lafreniere et al. 2008, 2011, 2014*)
- ★ **Mass function determination** (*Preibish & Zinnecker 2002; Slesnick et al. 2008; Lodieu et al. 2007*)

Full USco census presented in *Luhman & Mamajek (2012)*

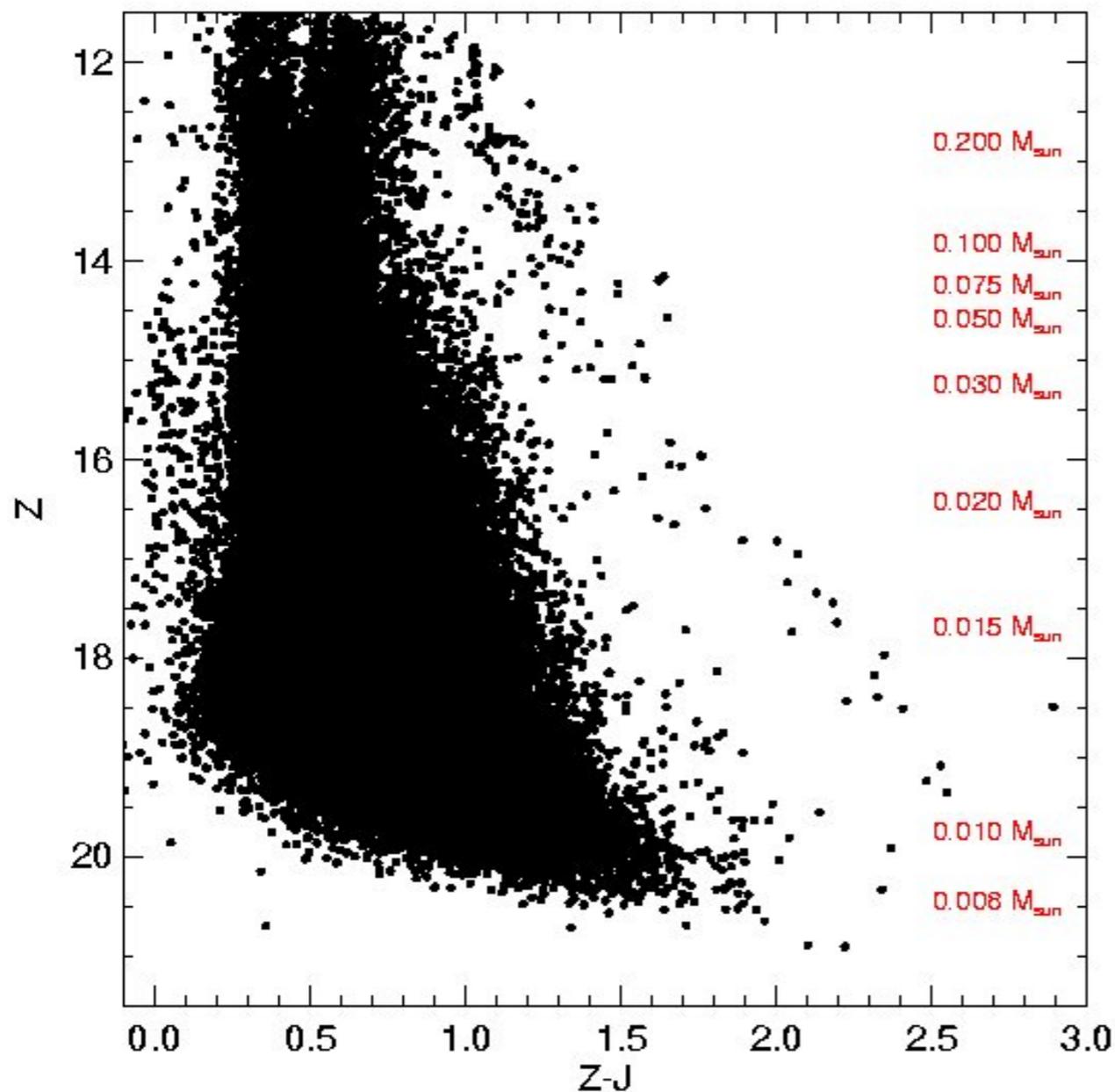
Part 2

Photometric selection of members



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Upper Sco seen by UKIDSS



1) Observations:

- ★ GCS Science Verification
- ★ Survey depth $J \sim 18.7$ mag
- ★ 6.5 sq. deg. Imaged in ZYJHK
- ★ 30% coverage in USco in DR8

2) Selection procedure:

- ★ Cluster sequence well defined
- ★ Various colour cuts applied
- ★ Proper motion selection
- ★ Optical and NIR spectroscopy for 94+20 sources: 105 members
- ★ Spectral types: M4-L2
- ★ $T_{\text{eff}} = 3350-1800$ Kelvins
- ★ Mass = 0.4-0.005 M_{sun}



The VISTA telescope



- **VISTA** = Visible and Infrared Survey Telescope for Astronomy
- **4-m class** telescope equipped with the world largest NIR camera
- VIRCAM offers a **FOV of 1.65 sq. deg.** with a pixel scale of 0.34"
- VISTA started operations on **15 October 2009**
- **ZYJHKs** filters + 2 narrow-band filters
- 75% of VISTA dedicated to ESO public surveys

More details at www.vista.ac.uk

Photometric observations

(1) Deep VISTA ZYJ imaging survey of 13.5 deg² in USco:

- ★ Observations between 28 April and 17 May 2012 with VISTA
- ★ Conditions: clear sky, seeing < 1.2", airmass < 1.5
- ★ Total ExpTimes in Z, Y, J of 100min, 30 min, and 10 min, respectively
- ★ 100% completeness limits of 22.0, 21.2, and 20.5 mag in Z, Y, and J, respectively



(2) Complementary dataset from the UKIDSS:

- ★ Observations part of the UKIDSS Galactic Clusters Survey
- ★ 5 sigma completeness limits of $H = 18.4$ mag and $K = 18.1$ mag
- ★ Proper motion information with precisions of 5-10 mas/yr

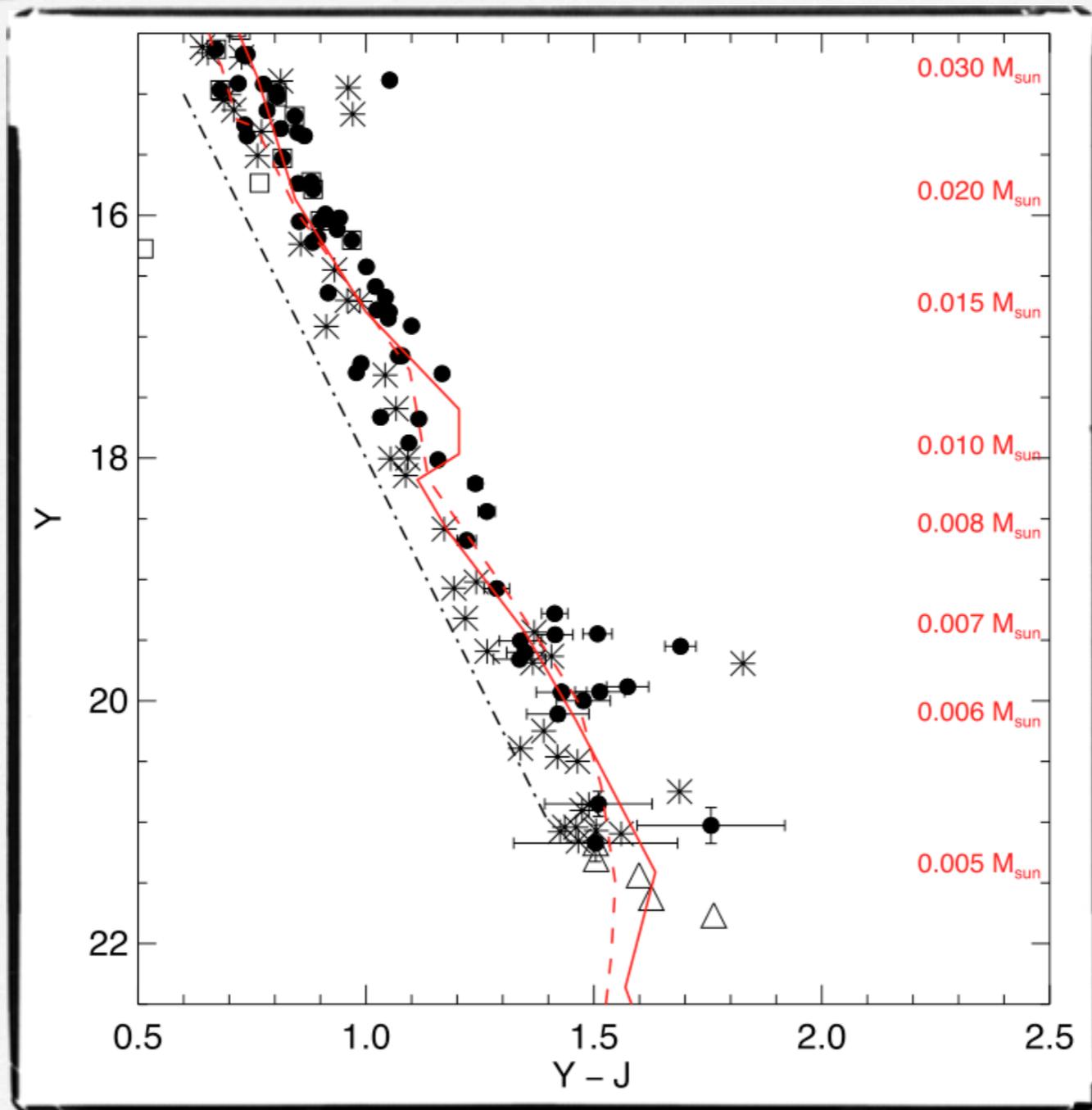


(3) Complementary optical photometry from Magellan/IMACS:

- ★ Observations conducted in May 2009 in the Sloan Z-band filter
- ★ Total ExpTimes of 900 sec with seeing of 0.6-0.7 arcsec

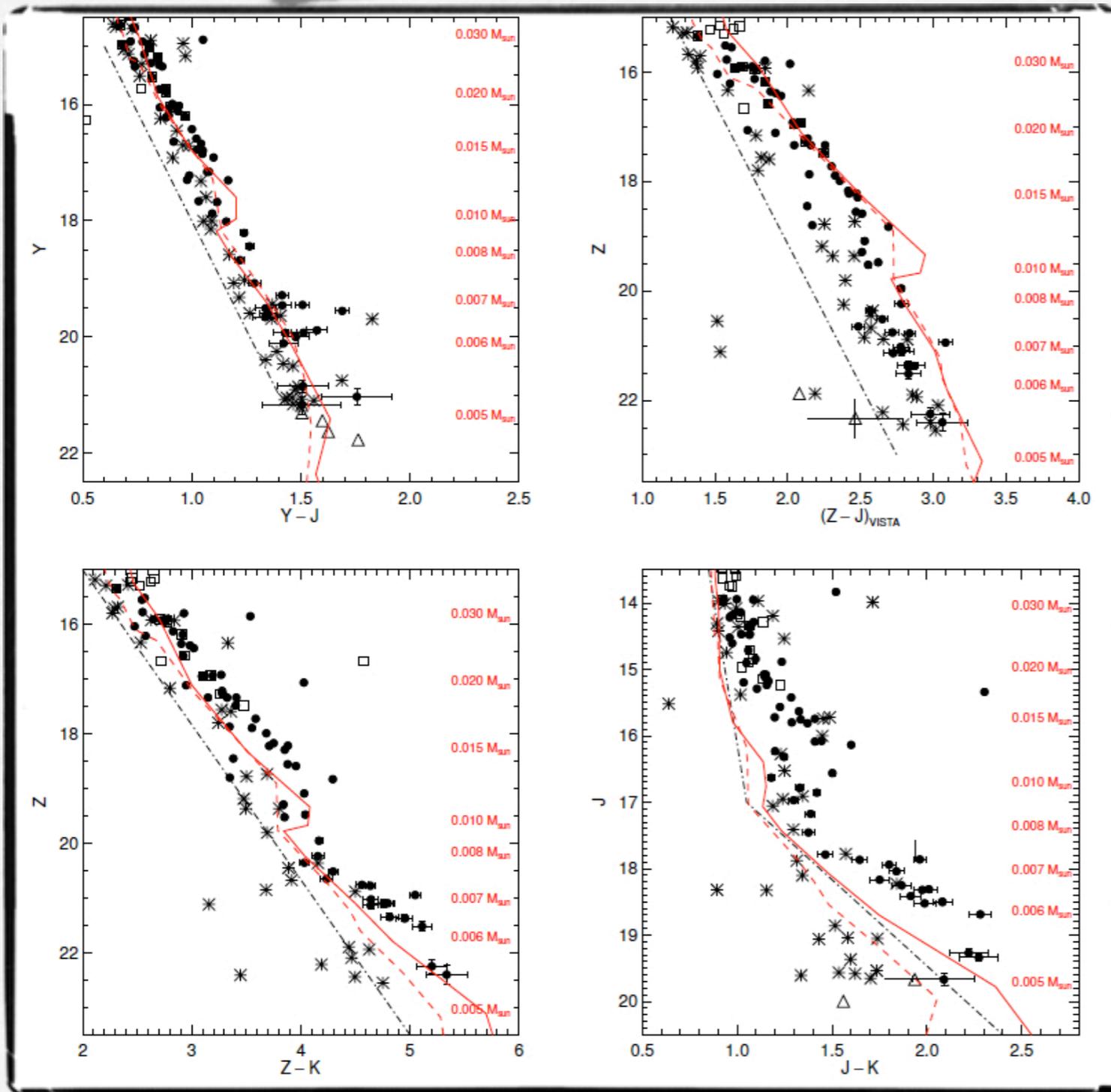


Photometric selection (I)



~100 ZYJ candidates selected photometrically with $M=30-5 M_{\text{Jup}}$

Photometric selection (II)



Deep VISTA ZYJ imaging
survey of 13.5 deg² in USco:

67 bona-fide ZYJ candidates
kept after additional proper
motion and photometric criteria

5 additional YJ-only candidates

Conclusions: USco MF seems to
decrease in the planetary-mass
regime although a flat MF
cannot be discarded

Lodieu et al. (2013, MNRAS, 435, 2474)

Part 3

Near-infrared spectroscopy

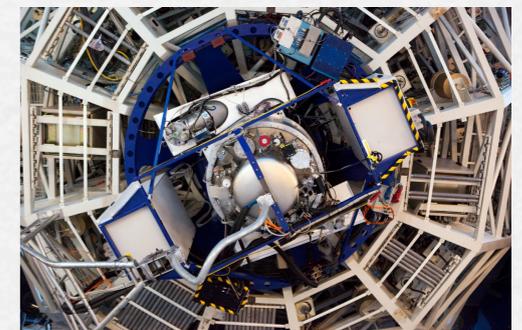
preliminary



Spectroscopic observations

(1) VLT Xshooter spectroscopy:

- ★ Visitor-mode observations on 10-14 April 2015 (4 half nights)
- ★ Variable conditions: 1 half night lost, 1 cloudy half night, 2 good half nights
- ★ 15 candidates observed with $J = 17.0-19.5$ mag
- ★ Total exposure times typically of 1 hour: 6 AB cycles of 300 sec
- ★ 2D flux-calibrated generated with the Xshooter pipeline
- ★ Extracted of 1D spectra with IRAF

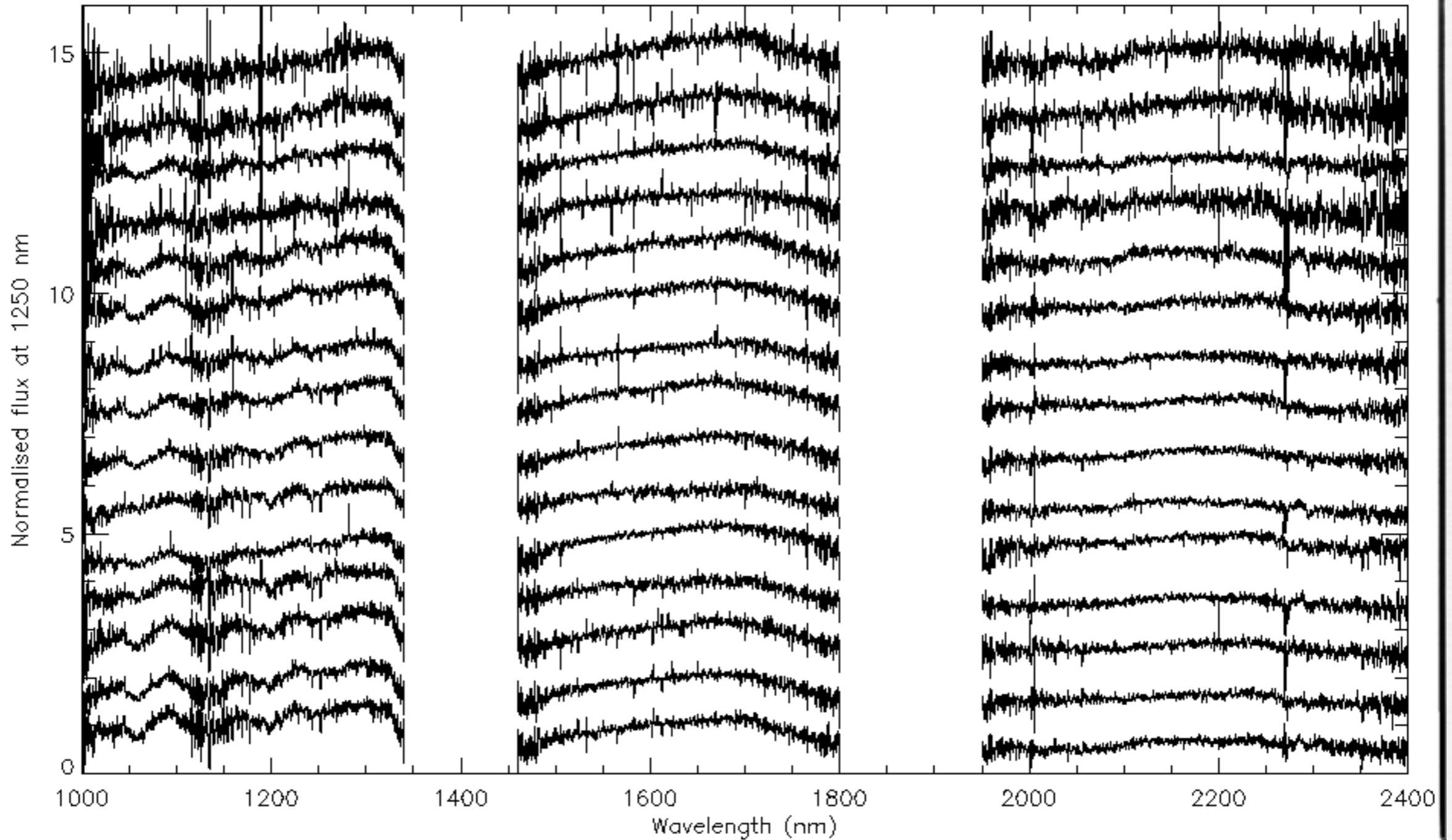


(2) ESO spectroscopic archival data:

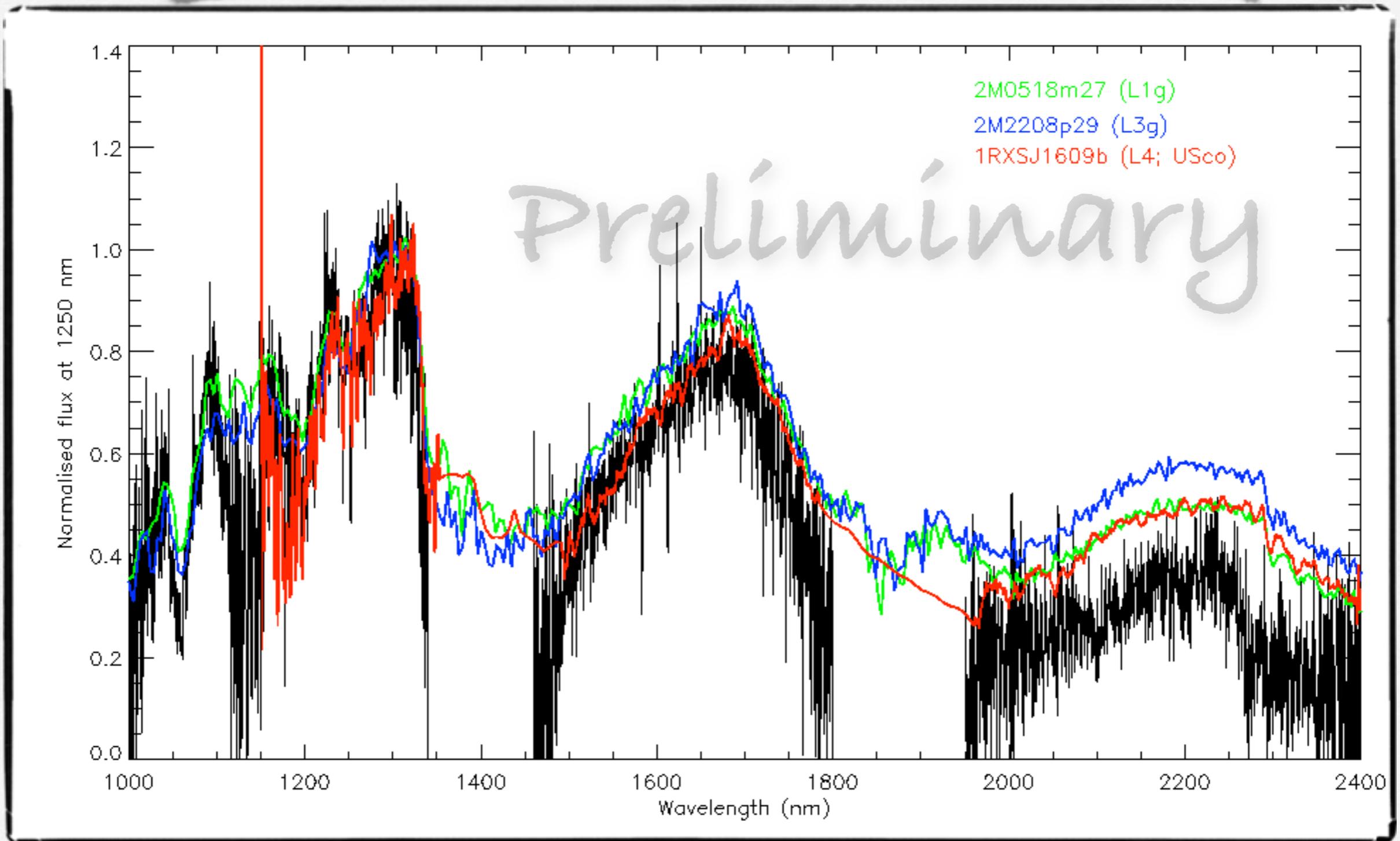
- ★ Additional VLT Xshooter spectra available in [ESO archive](#)
- ★ 3+3 member candidates with $J = 15-15.5$ mag and $J = 16.0-16.8$ mag
- ★ Spectral types in the $M8.5-M9.25$ range
- ★ Variable total exposure times
- ★ Spectra not yet reduced and analysed



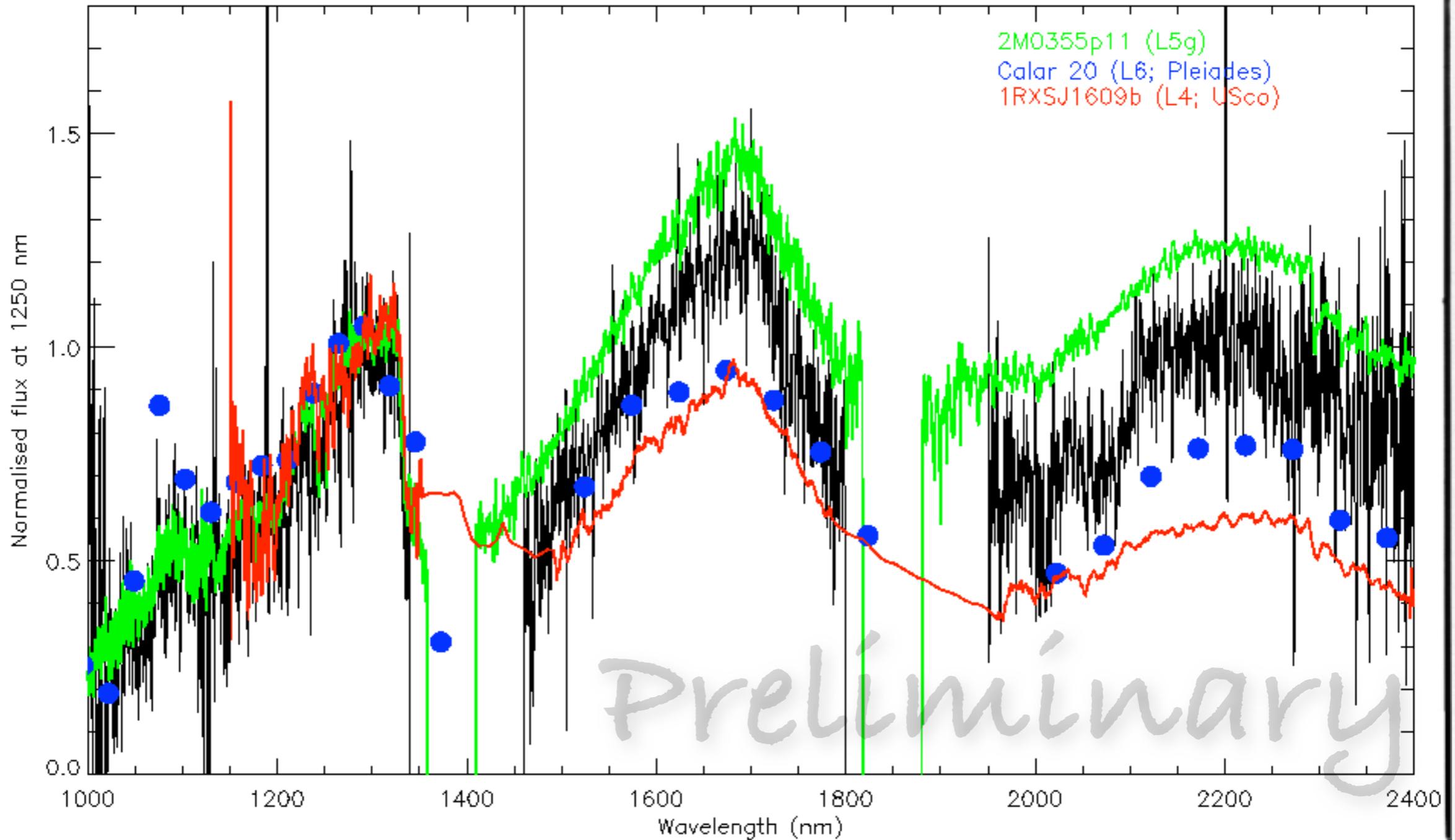
Near-infrared spectra (I)



Near-infrared spectra (II)



Near-infrared spectra (III)



Preliminary



Conclusions

- **67 new candidates** in USco with $M=30-5 M_{\text{Jup}}$ ($J\sim 15-19.5$ mag)
- **Extending cluster sequence** to L dwarfs and possibly T dwarfs
- **Medium-resolution spectroscopy of mid-L members** with VLT/Xshooter
- **Spectroscopic benchmarks at 5-10 Myr**

Future work

- **Near-infrared spectroscopy** with Magellan/FIRE of the 3 coolest candidates
- **Compute spectral indices** for young sources (*Allers & Liu 2013*)
- **Derive spectral types** for confirmed members
- **Compare** observed spectra with the latest **BT-Settl models**