Testing the fragmentation limit in the Upper Sco association

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Outline & objectives

Outline of the talk

- ➔ The Upper Sco association (USco)
- ➔ Main results from the UKIDSS Galactic Clusters Survey (GCS)
- ➔ The deep imaging: UKIRT, CFHT, INT
- ➔ The selection of M, L, and T cluster members
- ➔ The spectroscopic follow-up with VLT X-shooter
- ➔ Discussion on the theory of the fragmentation limit

Main scientific objectives

- ➔ Finding T-type members in clusters and star-forming regions
- ➔ Constrain the shape of the IMF below 10 Jupiter masses
- ➔ Testing the fragmentation limit: what is the lowest mass that SF can form?

All results are published in Lodieu et al. (2011, A&A, arXiv1108.4783)

The Upper Sco association

USco is part of the nearest OB association to the Sun, Scorpius Centaurus

1) Main characteristics of USco:

- ✓ Large area on the sky
- ✓ Age = 5±2 Myr
- ✓ Distance = 145±2 pc
- ✓ Region relatively free of extinction, except in some parts

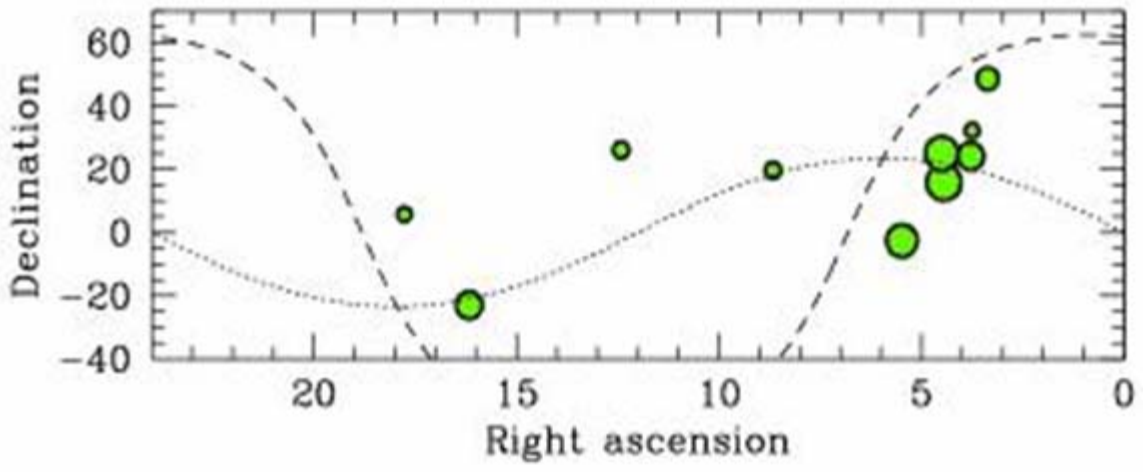
2) Previous surveys:

- ✓ X-rays *(Walter et al. 1994)*
- ✓ Hipparcos astrometry *(de Bruijne et al. 1997; de Zeeuw et al. 1999)*
- ✓ Deep optical surveys *(Ardila et al. 2000)*
- ✓ Optical + infrared *(Martin et al. 2004; Slesnick et al. 2006)*
- ✓ Deep near-infrared surveys *(Lodieu et al. 2006, 2007, 2011; Dawson et al. 2011)*
- ✓ Spectroscopy *(Martin et al. 2004; Slesnick et al. 2008; Lodieu et al. 2006, 2008, 2011)*

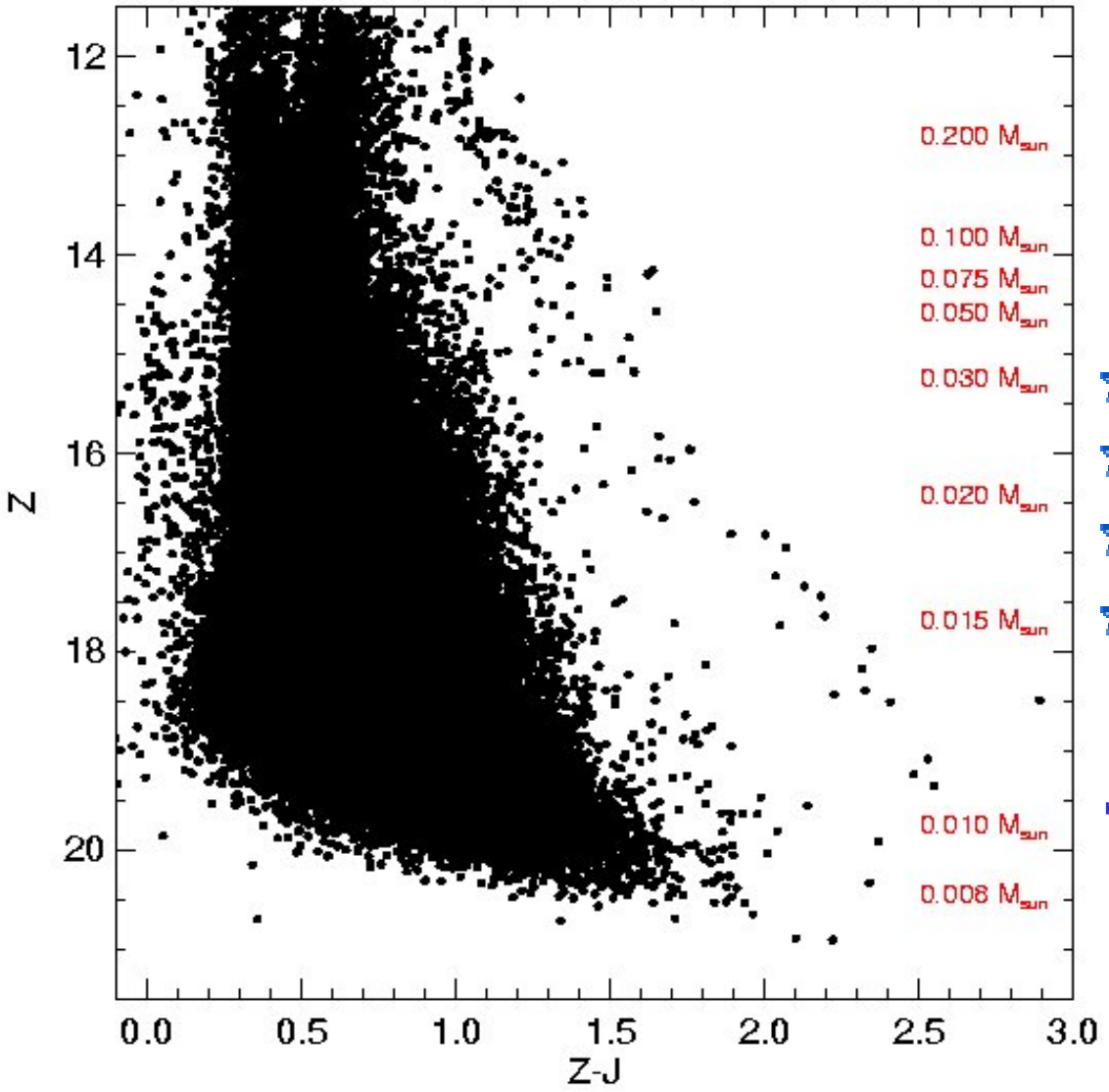
The UKIDSS Galactic Clusters Survey

- ➔ *ZYJHK* observations
- ➔ 1000 square degrees
- ➔ 10 star-forming regions and open clusters
- ➔ Scientific Goal: Universality of the stellar and substellar IMF
- ➔ 2 epochs in the *K*-band for proper motions
- ➔ 5 sigma completeness limits: *Z*=20.4, *J* = 19.6, *K* = 18.2 mag

Priority	Name	Type	RA	Dec	Area sq. degs
			J2000		
1	Pleiades	open cluster	03 47	+24 07	79
2	Alpha Per	open cluster	03 22	+48 37	50
3	Praesepe	open cluster	08 40	+19 40	28
4	IC 4665	open cluster	17 46	+05 43	0.8
5	Taurus-Auriga	SF assoc.	04 30	+25 00	386
6	Orion	SF assoc.	05 29	-02 36	314.2
7	Sco	SF assoc.	16 10	-23 00	154
8	Per-OB2	SF assoc.	03 45	+32 17	12.6
9	Hyades	open cluster	04 27	+15 52	292
10	Coma-Ber	open cluster	12 25	+26 06	78.5



Upper Sco seen by the GCS



Observations:

- GCS Science Verification
- Survey depth *J* ~ 18.7 mag
- 6.5 sq. deg. imaged in *ZYJHK*
- Proper motions from 2MASS/GCS

➔ Cluster sequence well defined

Main GCS results in Upper Sco

- First deep near-infrared survey of the full USco association
- Extraction of tenths of BDs yielding significant increase in the substellar census
- Discovery of 18 new BDs below 20 Jupiter masses
- Discovery of the first L dwarfs in the association
- Photometry and proper motions for members with M ≥ 15 Mjup
- Extension of the mass function down to 10 Mjup
- Derivation of the photometric & spectroscopic mass function

Deep imaging surveys in Upper Sco

Goals:

Going deeper than the GCS to find young T-type brown dwarfs in USco, investigate the shape of the IMF below 10 Jupiter masses, and test the theory of the fragmentation limit

- ✓ **Deep *YJ* survey with UKIRT WFCAM**
- ✓ **Deep methane survey with CFHT WIRCam**
- ✓ **INT WFC z-band imaging over 6.5 sq. deg.**

Deep UKIRT WFCAM YJ survey

1) UKIRT WFCAM:
- ❖ 2048x2048 camera
- ❖ 0.4”/pix scale; FOV=50’ aside
- ❖ 1 tile = 0.75 sq. deg.

2) Observations:
- ❖ 2 deep *Y*+*J* WFCAM tiles
- ❖ 20s and 10s in Y,*J*, respectively
- ❖ 2x*Y*, 3x*J* repeated patterns
- ❖ 1 shallow field in *Z*

3) Depths:
- ❖ *Y* ~ 22.0-22.3 mag @ 5σ
- ❖ *J* ~ 21.5-21.7 mag @ 5σ

4) Data Reduction:
- ❖ Automatic pipeline @ CASU
- ❖ Stacking @ WFAU, Edinburgh

Deep CFHT/WIRCam methane survey

1) CFHT WIRCam:
- ❖ 2048x2048 camera
- ❖ 0.3”/pix scale; FOV=20’ aside

2) Observations:
- ❖ 9 WIRCam pointings = 1 sq. deg.
- ❖ 5 point dither patterns repeated
- ❖ 38 sec integrations, total exposure of 72 min
- ❖ 92918 sources with err(CH4off) ≤ 0.3 mag

3) Depths:
- ❖ Methane: 20.2-20.3 mag
- ❖ Similar depth in CH4on and CH4off

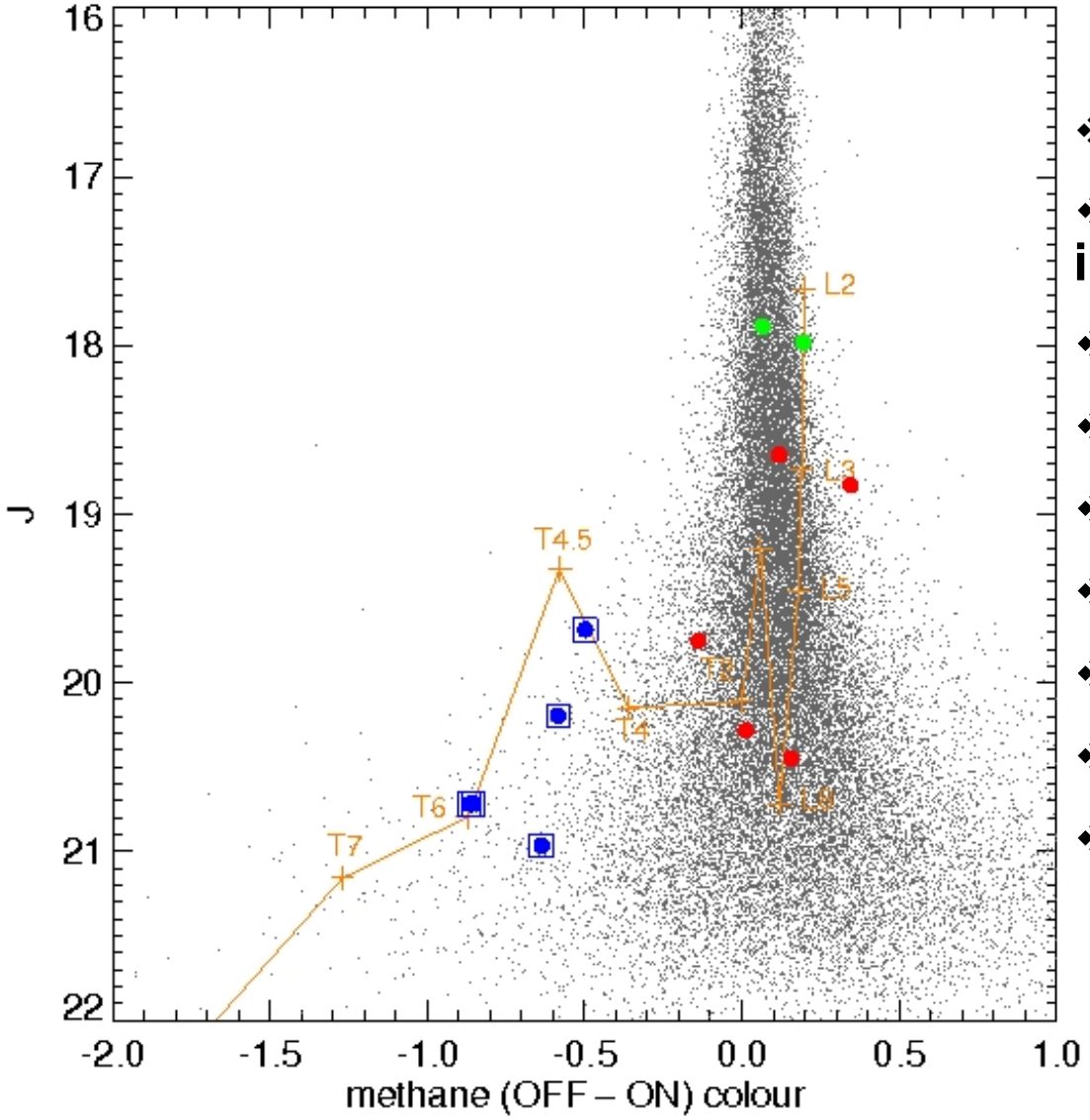
4) Data Reduction:
- ❖ CFHT pipeline: Terapix
- ❖ CFHT data reduction: I’iwi

The INT/WFC *z*-band survey

- Isaac Newton 2.54-m telescope on La Palma, Canary Islands
- 4 thin EEV 2048x4096 CCDs
- Pixel scale: 0.33 arcsec/pixel
- Field-of-view of 34 arcmin aside
- Observations carried out on 19-26 April 2006
- 6.5 square degrees common to the GCS SV area
- *z*-band depth variable between 20 and 21 mag

Selection of T-type members

3 Jupiter mass T-type @ 5 Myr & 145 pc: T_{eff}=900K, M_J=14.66 mag, J=20.47 mag

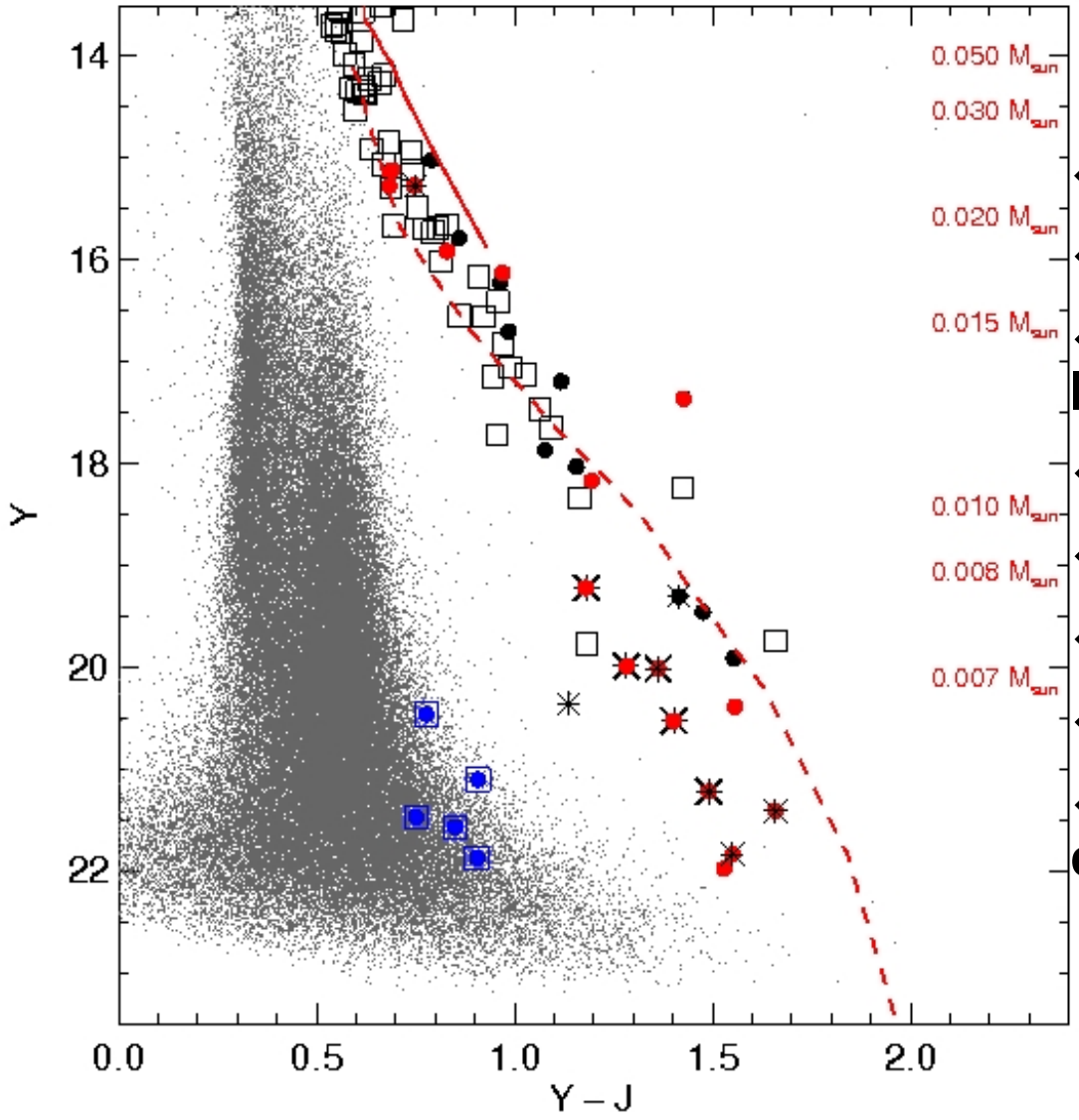


Selection procedure:

- ❖ **Errors (CH4off) ≤ 0.3 mag**
- ❖ **Median CH4 colours per 0.5 mag intervals from 17.5 to 21 mag**
- ❖ **3σ selection above 1.48*MAD**
- ❖ **Cross-match with INT catalogue**
- ❖ **1750/2608 candidates with *YJ* mags**
- ❖ **Kept only (*J*-CH4off) ≤ 0.5 mag**
- ❖ **Kept only (*Y*-*J*) ≥ 0.7 mag**
- ❖ **Removed false positives & artefacts**
- ❖ **Removed candidates detected in *Z***

➔ 5 T-type candidates left

Selection of M/L members



Selection procedure:

- **Selection in (*Y*-*J*,*Y*) diagram**
- ***Y*=15-22.2 mag ≡ M ≤ 30 M_{Jup}**
- **Candidates selected to the right of a line defined by spectroscopic members**
- **26 candidates with *YJ* photometry**
- **10/26 already in the GCS SV survey**
- **16/26 new candidates**
- **13/16 new with *HK* from GCS DR8**
- **Proper motions measured from the different surveys: deep *YJ*, SV, DR8**

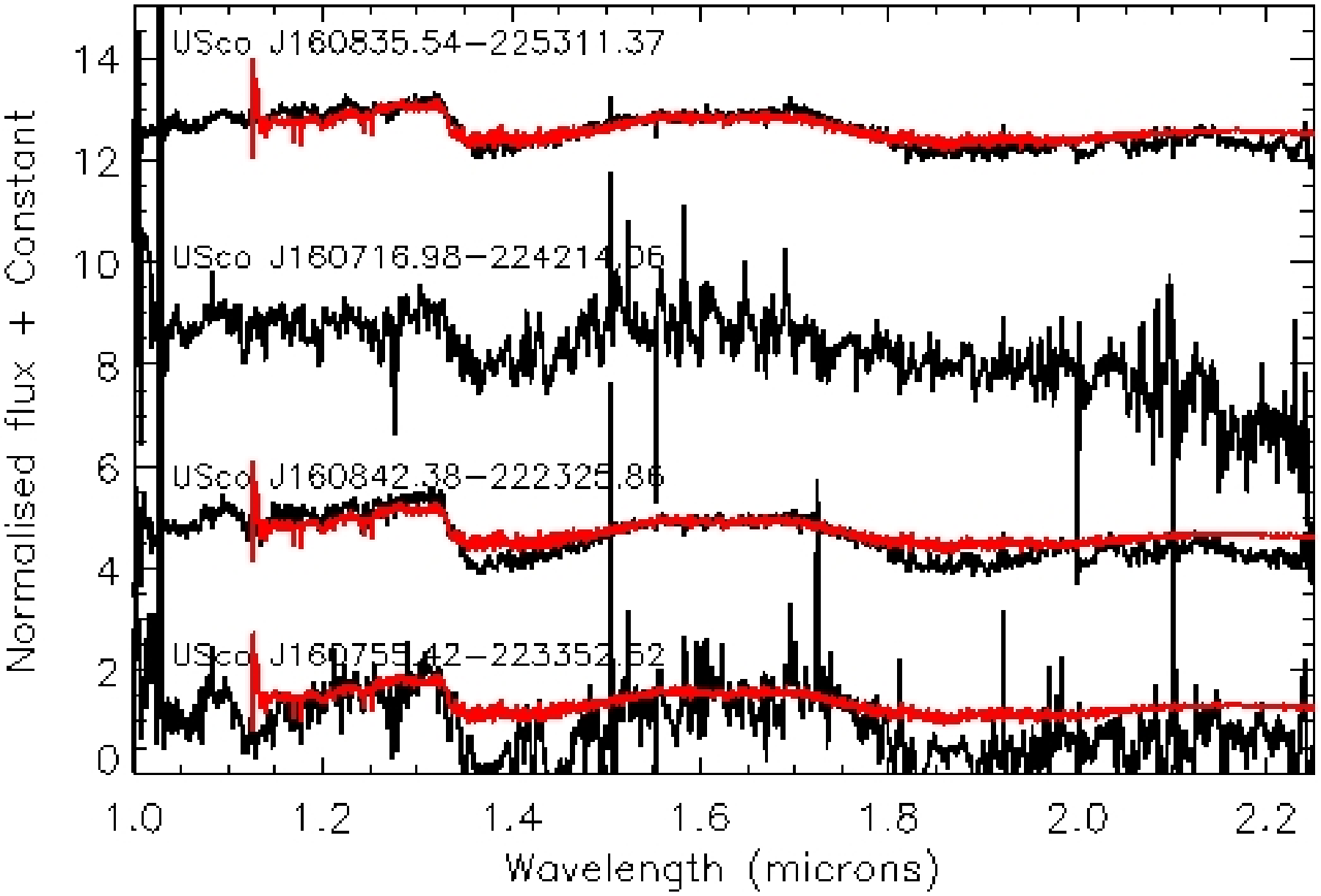
➔ 1 photometric+PM candidate

➔ 1 faint photometric candidate

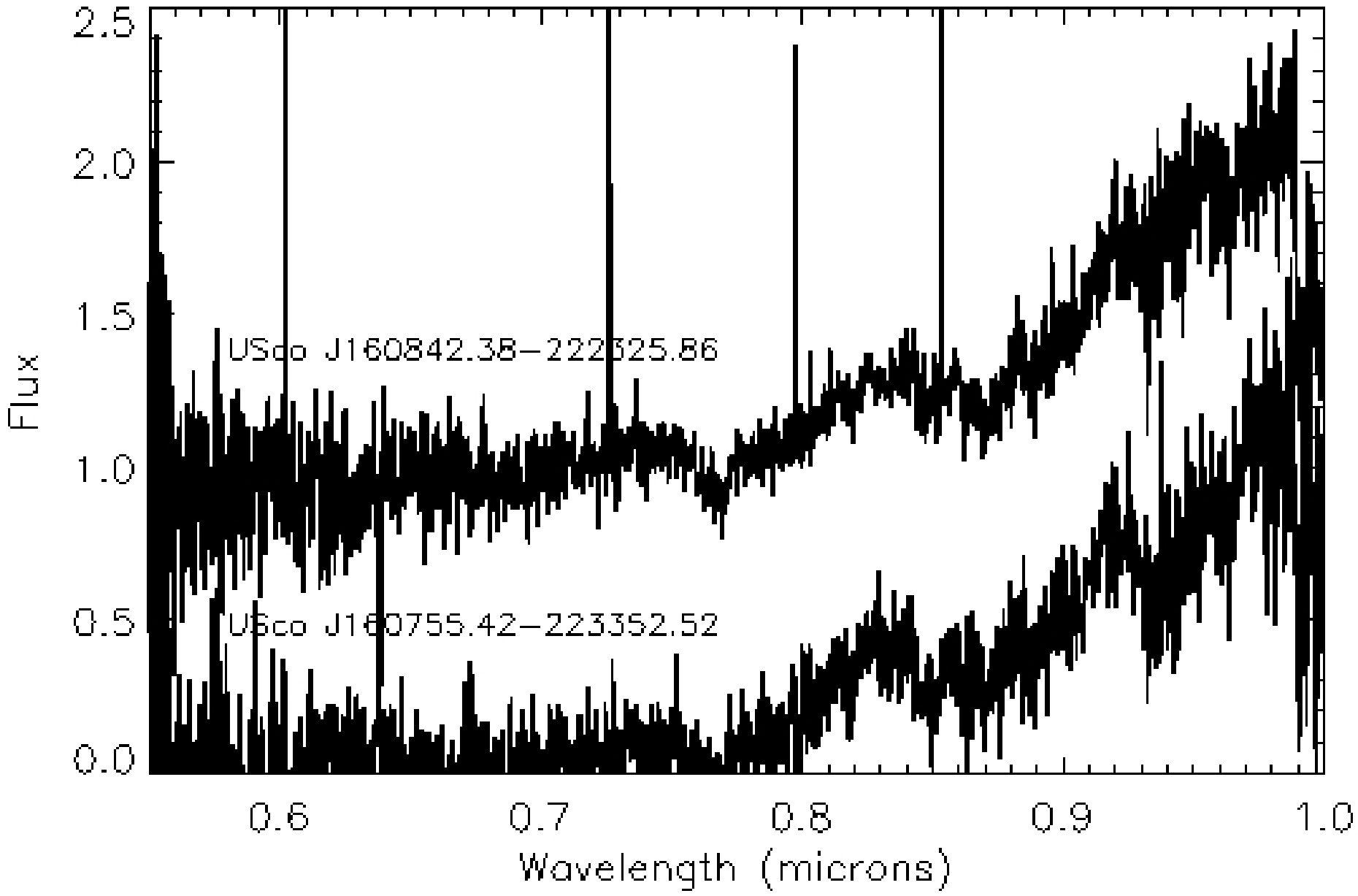
Spectroscopic follow-up

- VLT X-shooter (UV+VIS+NIR) during Period 85 in service mode
- Coverage VIS (0.56-1.02μm) + NIR (1.02-2.48 μm) @ R~3500
- Data reduction with the X-shooter v1.3 pipeline
- 5 photometric M/L candidates observed
- Results: 4 field L dwarfs + 1 quasar @ z=0.88

Spectroscopic follow-up: NIR



Spectroscopic follow-up: VIS



The fragmentation limit: discussion

1) Results of the surveys:

- ❖ 1 photometric+PM candidate in 1.7 deg^2 *YJ* survey
- ❖ 1 faint photometric candidate in 1.7 deg^2 *YJ* survey
- ❖ 5 T-type candidates in deep methane imaging survey

➔ 1 candidate in the *Y* = 20-22 mag interval

➔ Sensitive to 2 M_{Jup} members according to COND models

➔ Puzzling result because we found 4 spectroscopic contaminants

2) Extrapolations:

- ❖ GCS Mass Function: 3.7 members in 1.7 deg^2
- ❖ Field Mass Function: 1.2 member in 1.7 deg^2
- ❖ LAS nearby T dwarfs: 1-2 field T dwarfs in 1 deg^2

3) Conclusions: We may see a turn down in the USco mass function but we cannot yet argue that we have reached the fragmentation limit

4) Solution: Deeper & wider (15 deg^2) survey for 3σ statistics to put a stringent constrain on the lower mass fragment that SF can form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