# Free-floating planets and the E-ELT

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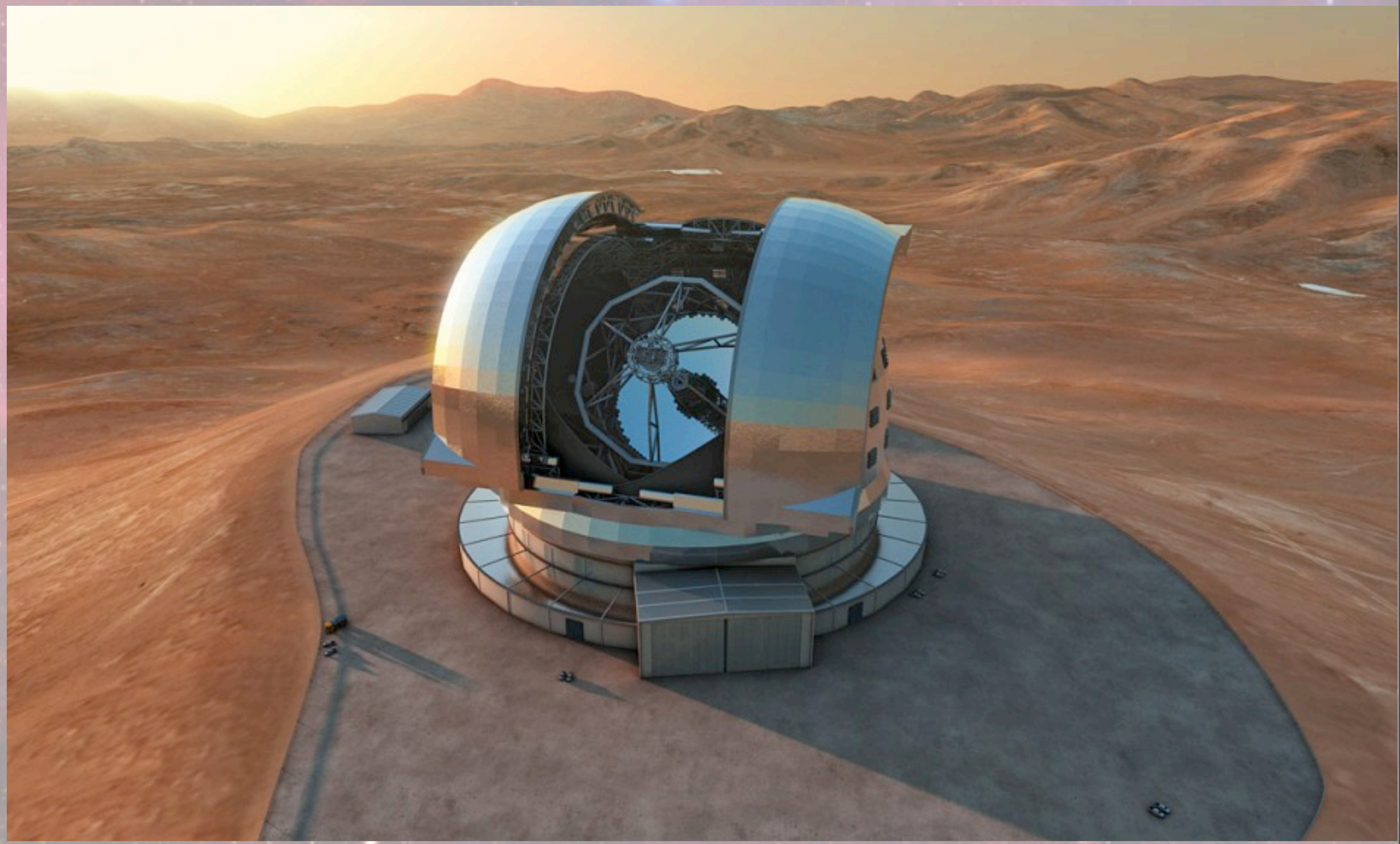
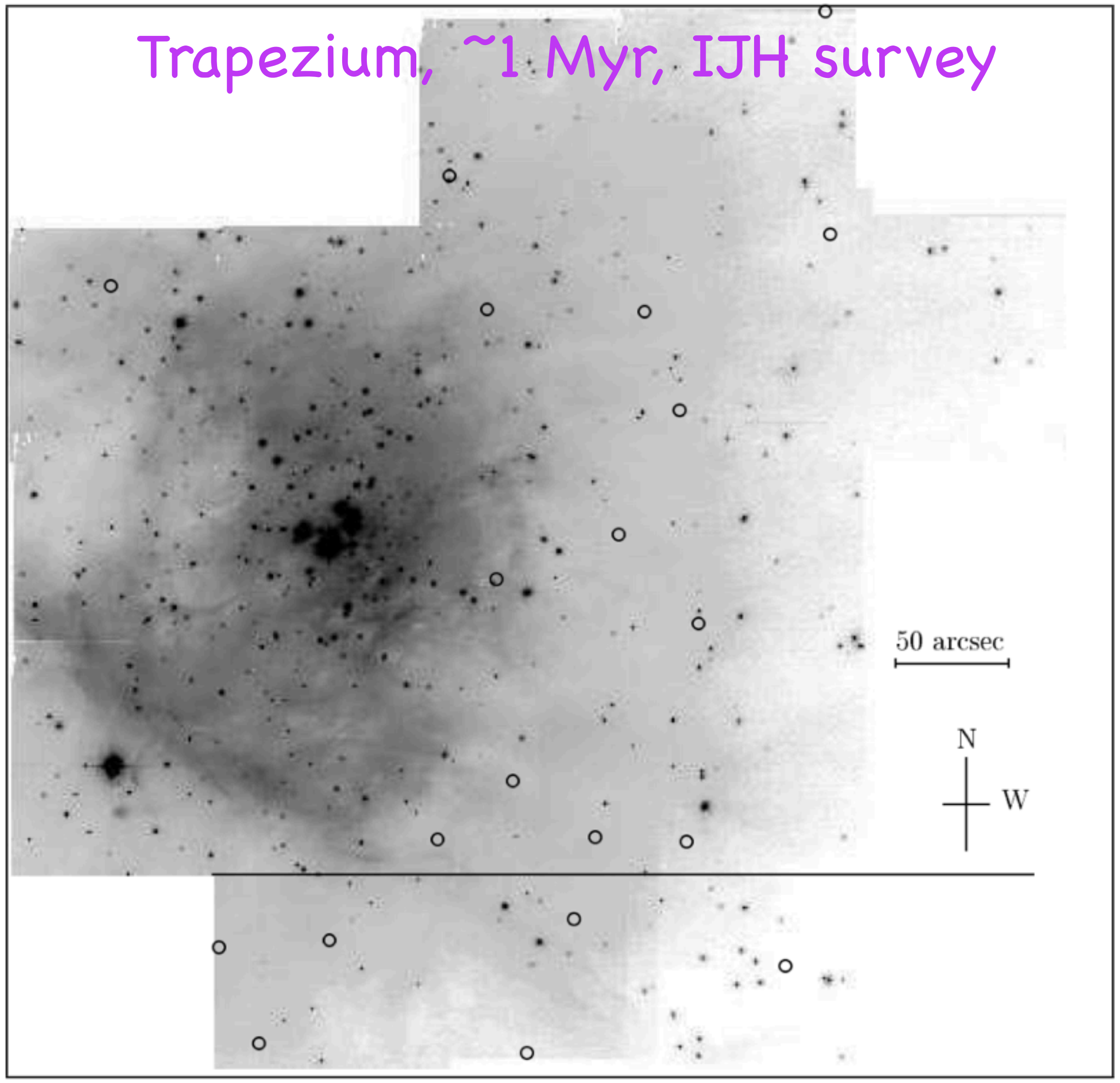
Guideline

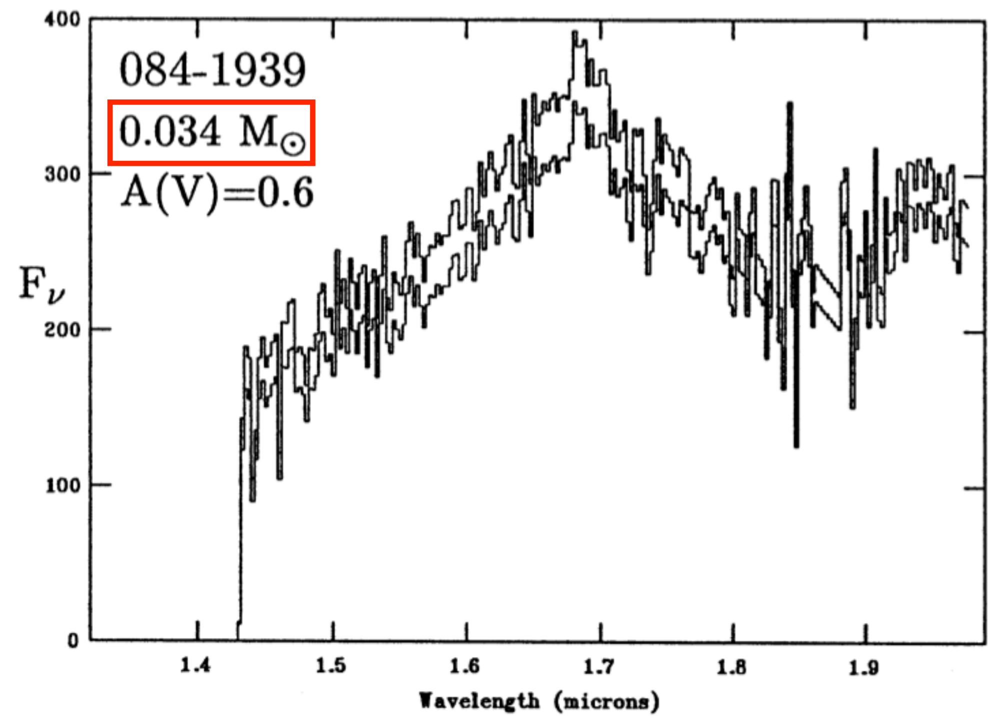
- Introduction
- Recent results
- Science objectives and
  a few possible observing programs

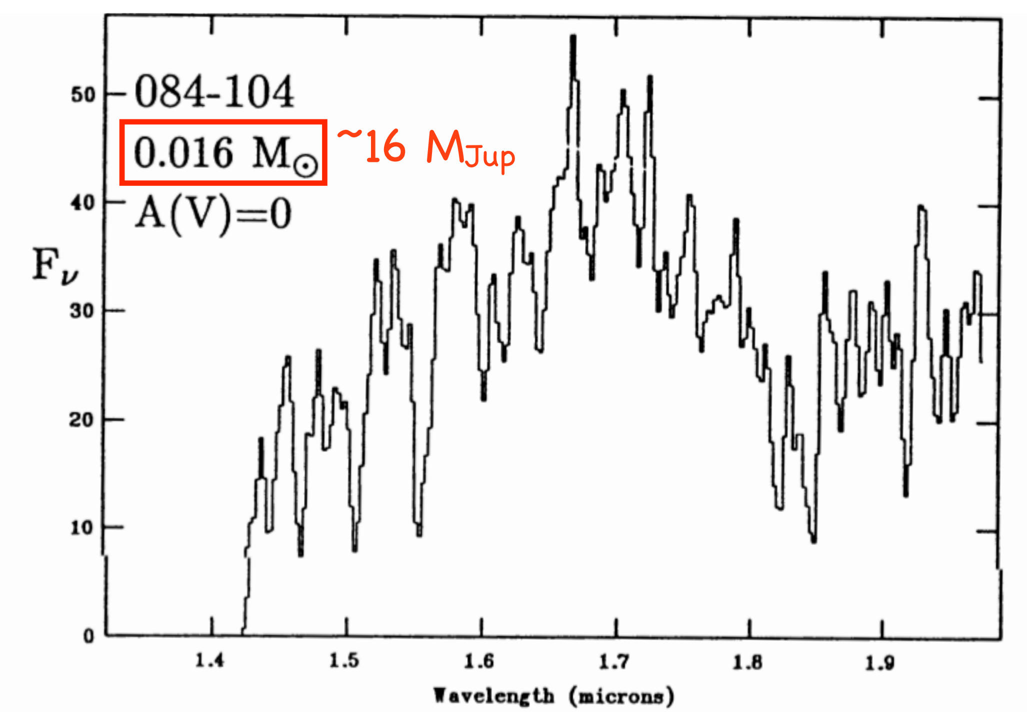


# First detections of free-floating planetary mass objects




Lucas & Roche (2000); Lucas et al. (2001)

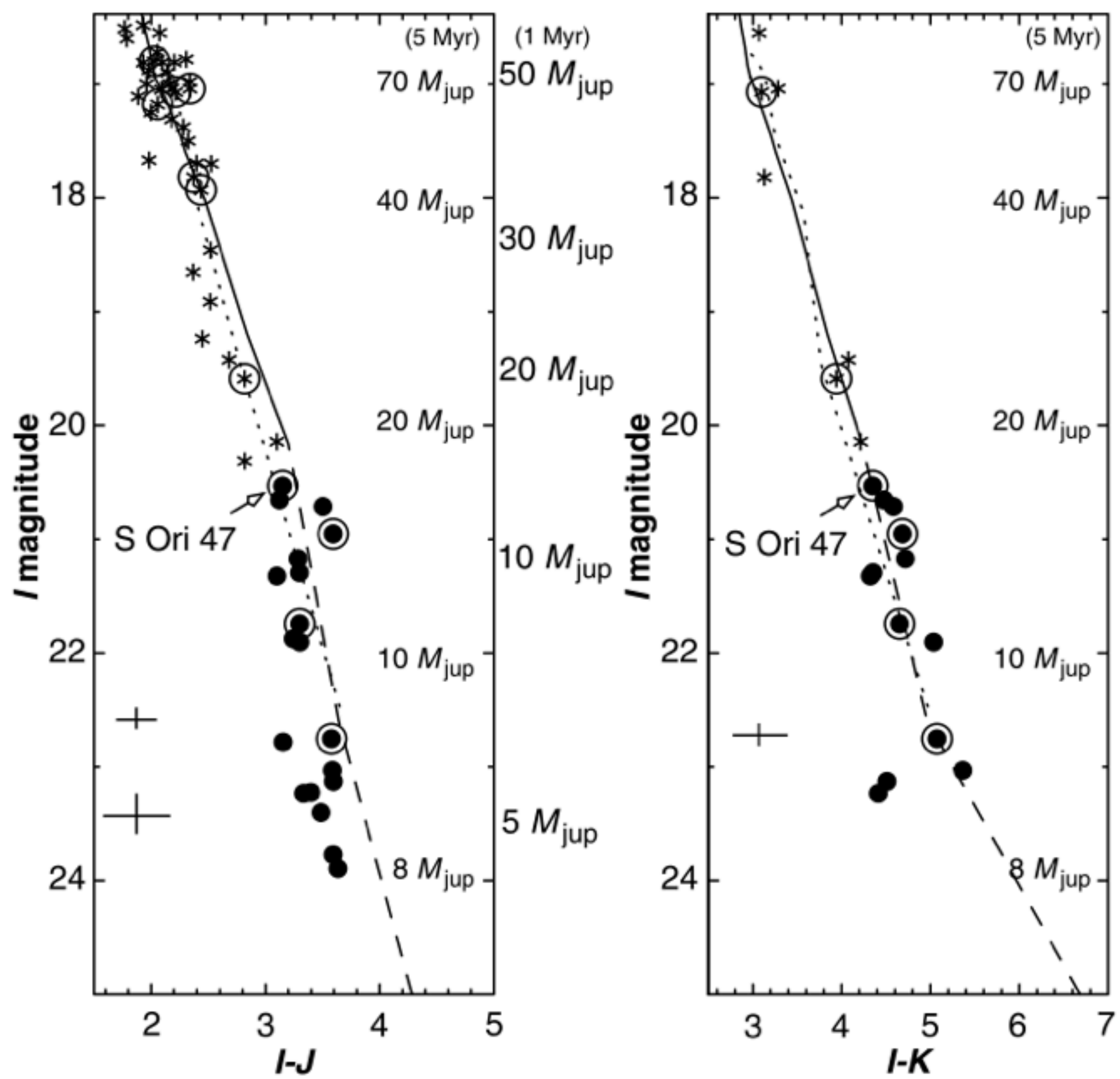


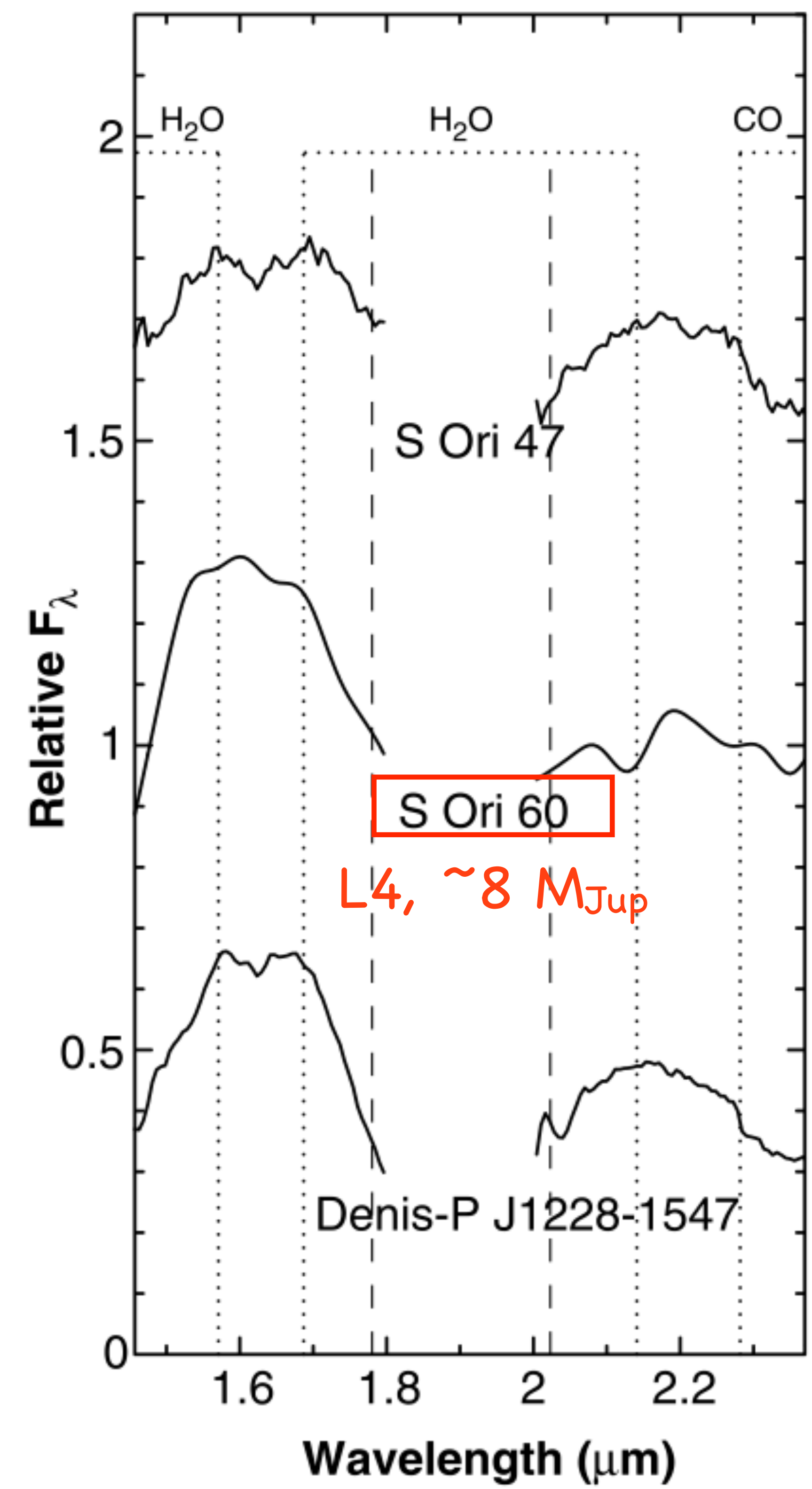

The authors detected a significant population of "free-floating objects with masses below the deuterium-burning (planetary) threshold at 0.013 $M_{sol}$, which are detectable because of their extreme youth". Their H-band spectra show a triangular shape due to low-gravity atmospheres.

# First detections of free-floating planetary mass objects

σ Orionis, ~3 Myr, IJK survey

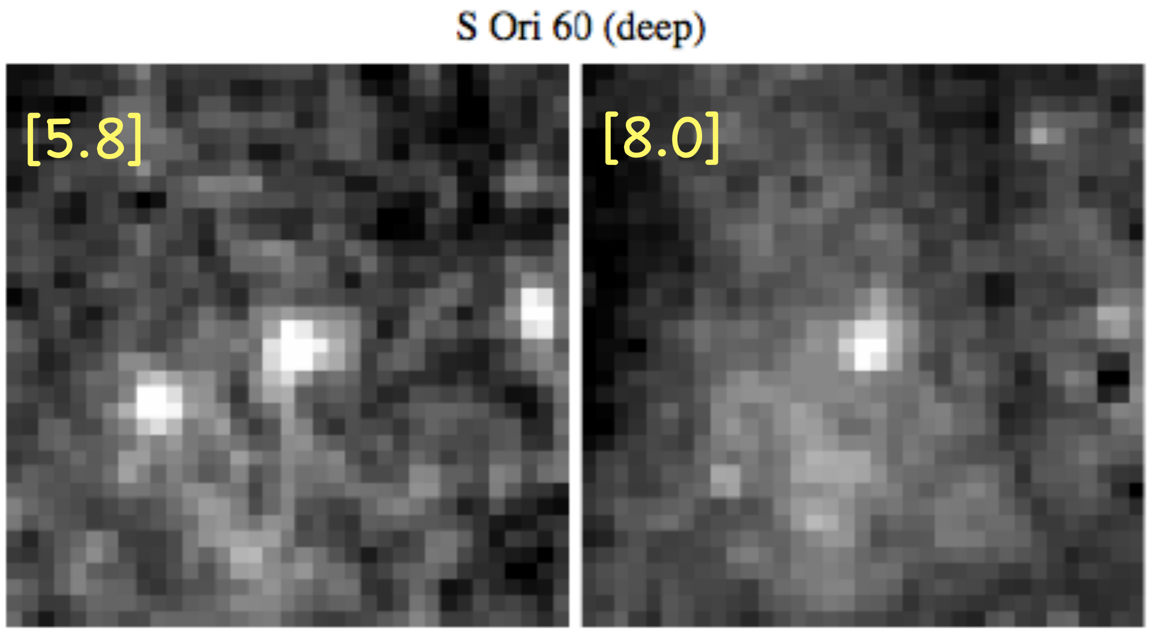



Zapatero Osorio et al. (2000)



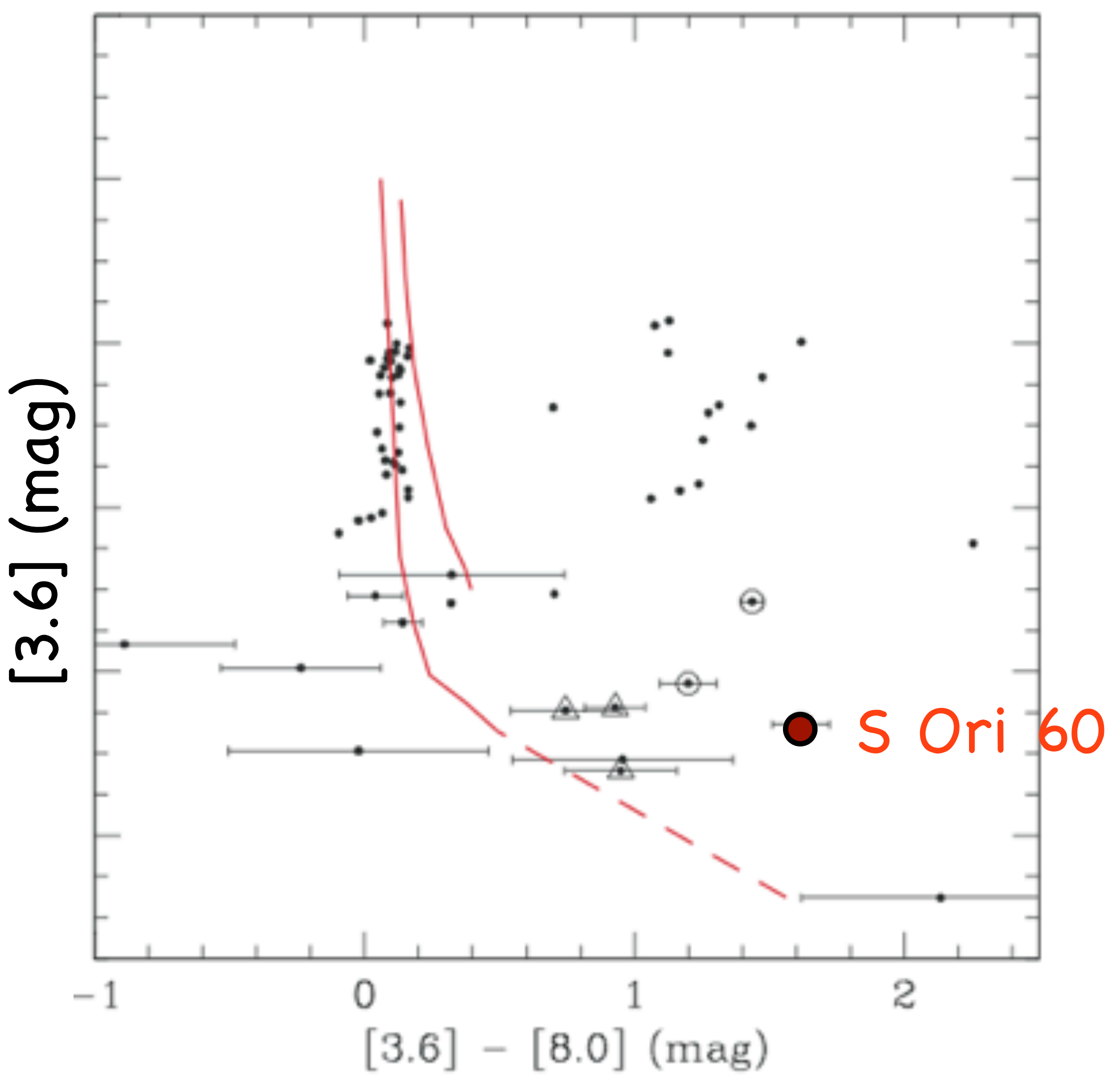

The authors detected objects with a mass between 5 and 15 $M_{Jup}$. Some are classified as L-type sources.

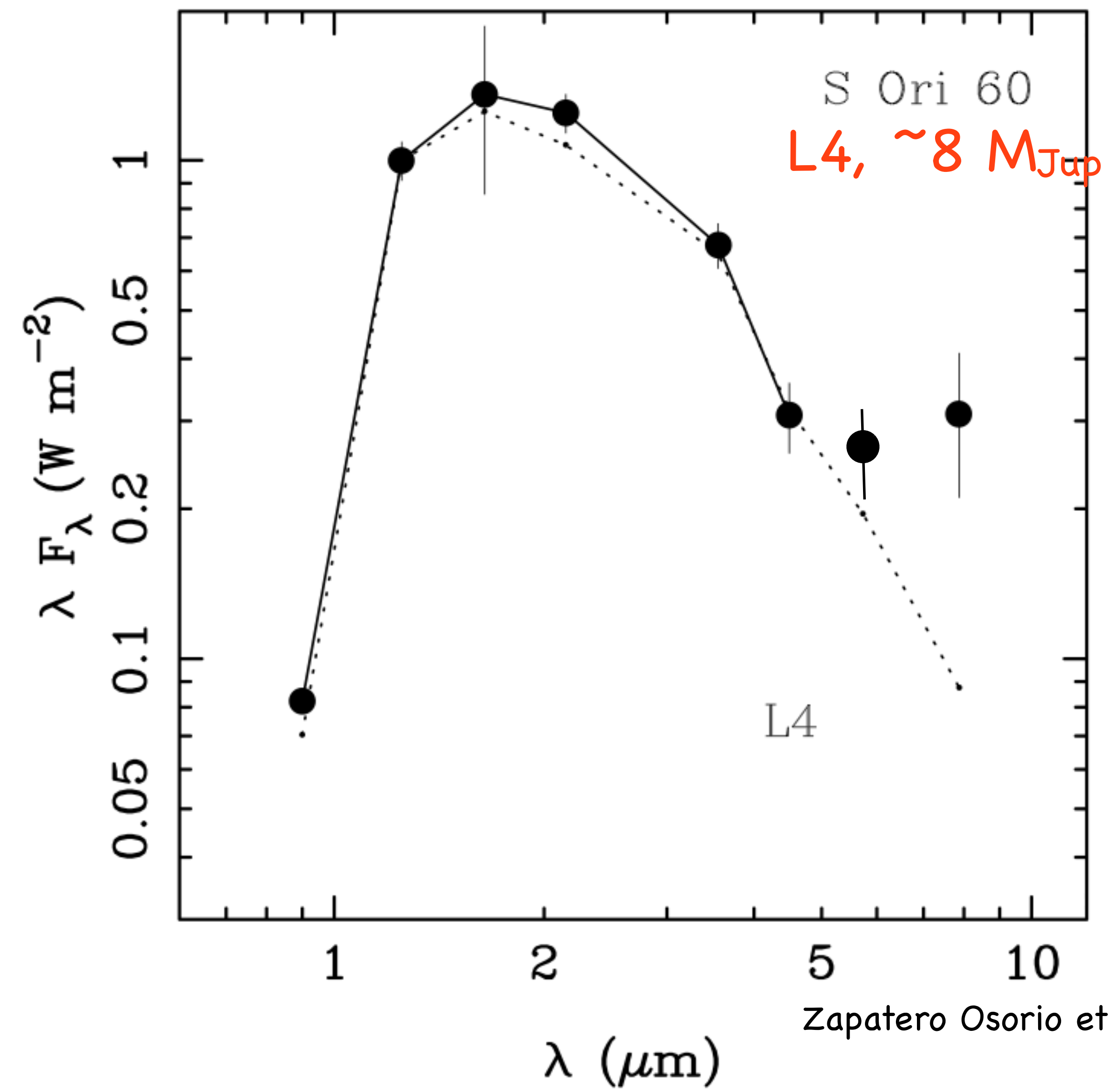
# Disks of free-floating planets




In the σ Orionis planetary regime, 40-60% of free-floating planets have Spitzer/IRAC mid-infrared flux excesses indicative of the presence of disks or circumsubstellar envelopes. S Ori 60 is the smallest object known with a disk.

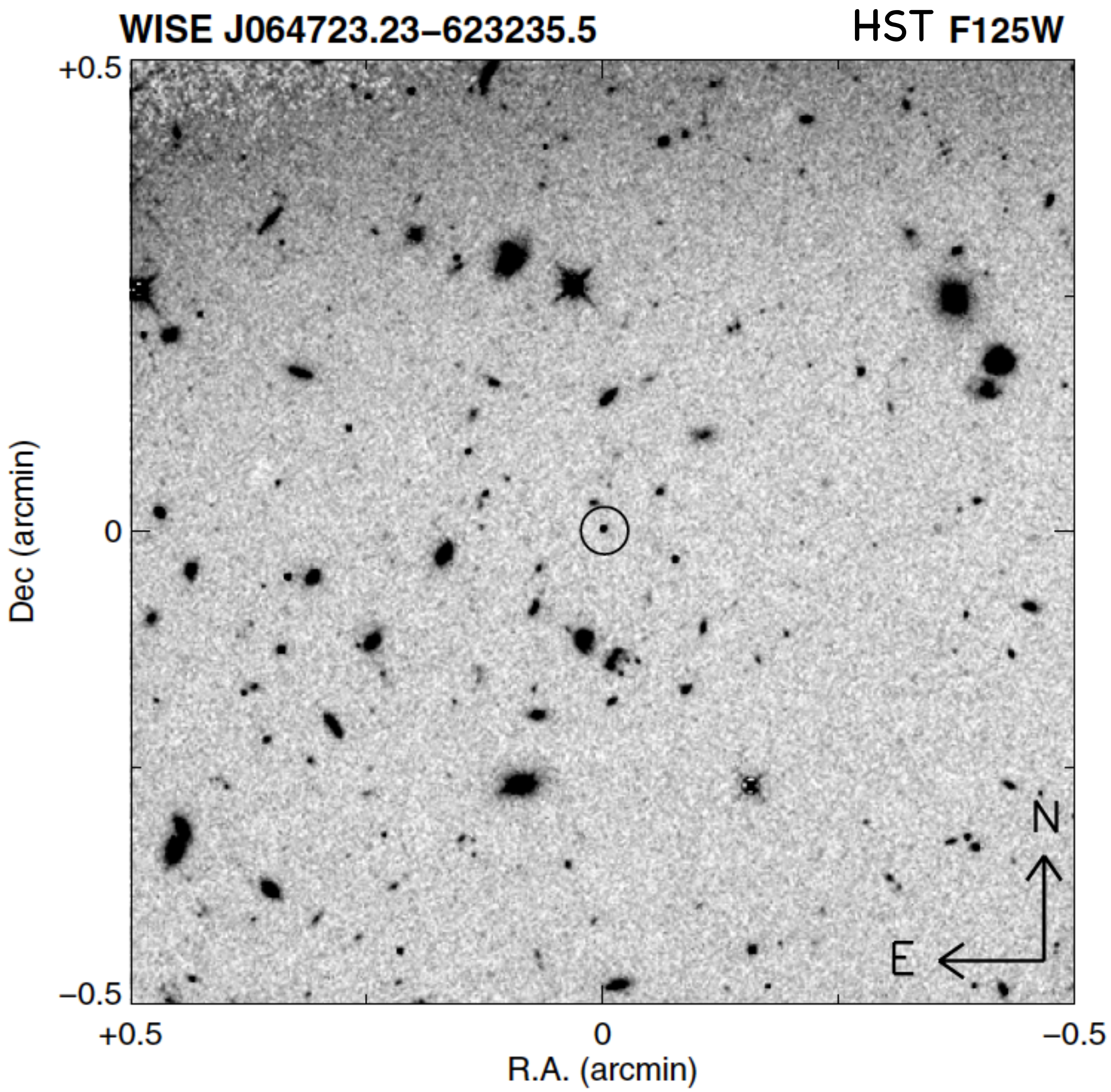
Luhman et al. (2008)

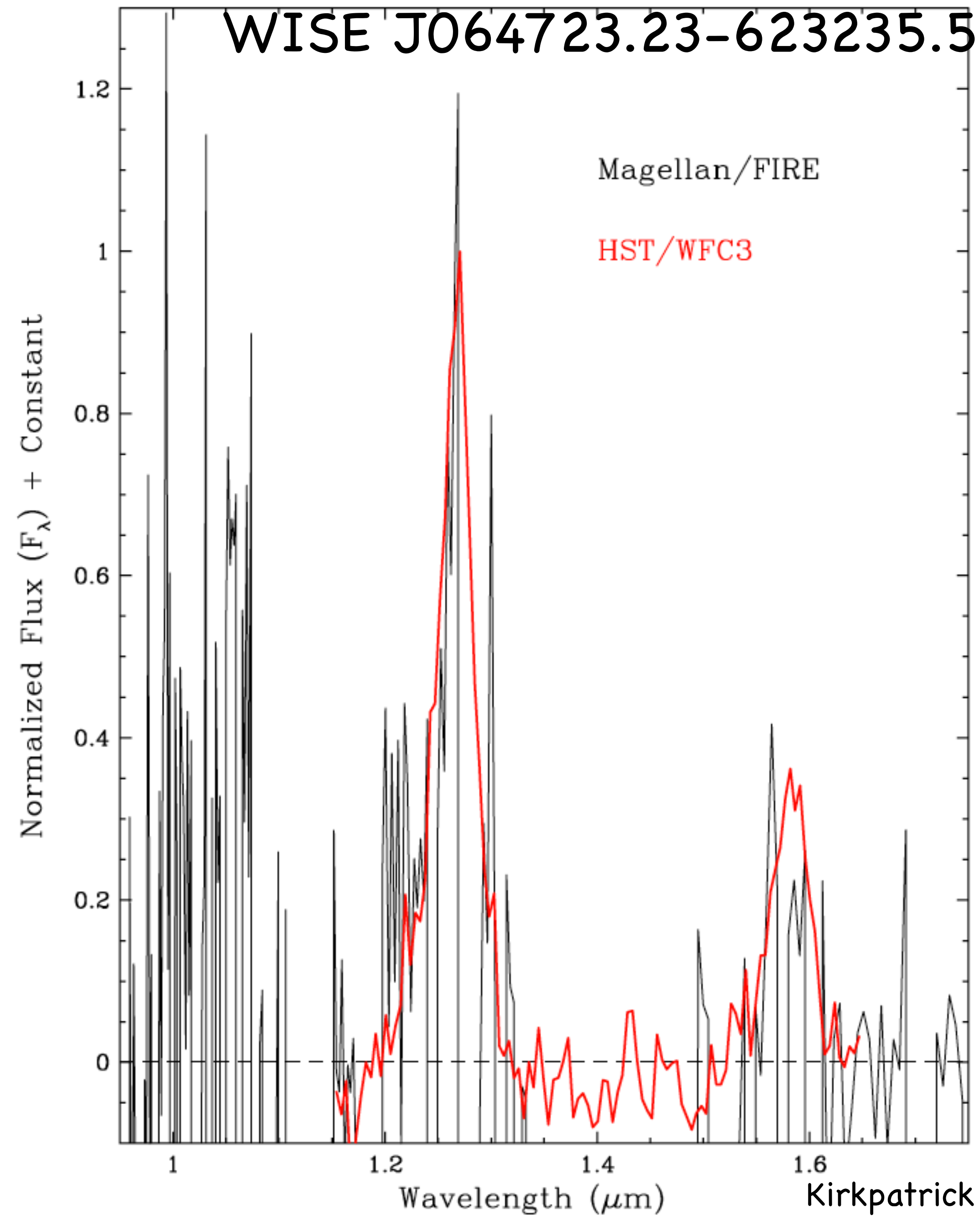



Zapatero Osorio et al. (2007)

# First discoveries of Y dwarfs in the field (unknown age)




Kirkpatrick et al. (2013)

To date there are 17 Y dwarf discoveries (mostly due to WISE). They have very red near- to mid-infrared colors, while their J-H color ranges from blue to red.

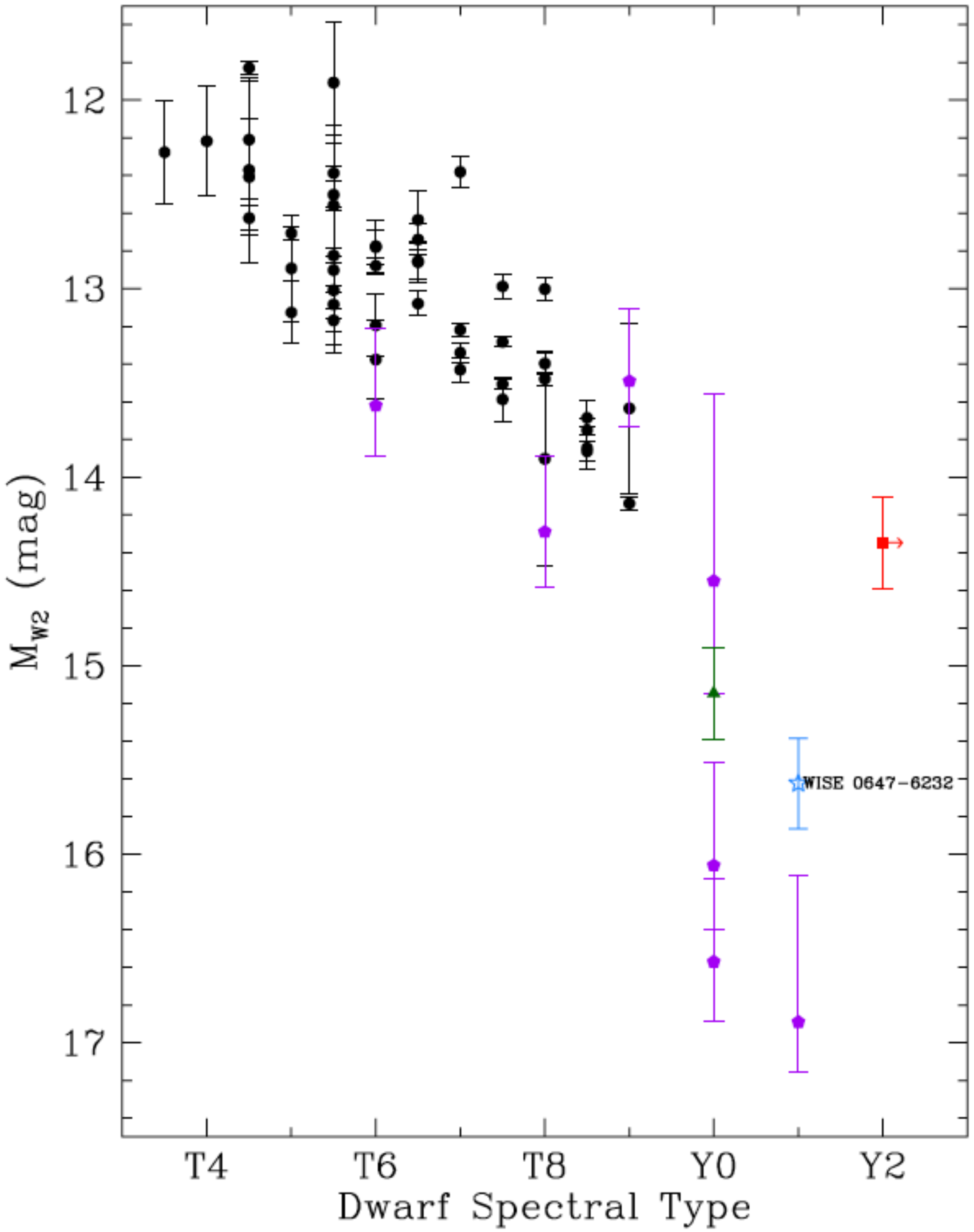
J-[4.5] = 7.58 mag (J0647-6232)

J = 22.7 mag !!!

5-30 $M_{Jup}$, even <2 $M_{Jup}$ (30 Myr)

E-ELT is crucial for the characterization of Y (and cooler) dwarfs. They fall beyond of the capabilities of most ground-based instruments available today.

# First discoveries of Y dwarfs in the field (unknown age)




Dupuy & Liu (2012); Tinney et al. (2012); Beichman et al. (2013); Marsh et al. (2013); Kirkpatrick et al. (2013)

Y dwarfs likely represent the “old” image of the giant free-floating planets seen in Orion.

The majority of the detected Y dwarfs are located within 10 pc from the Sun. According to evolutionary models, they have surface temperatures below 600-700 K.

The E-ELT will contribute to characterize this pretty faint population in the nearest solar vicinity by providing optical to mid-infrared colors, radial velocities, accurate proper motions, parallaxes, and spectroscopic studies.

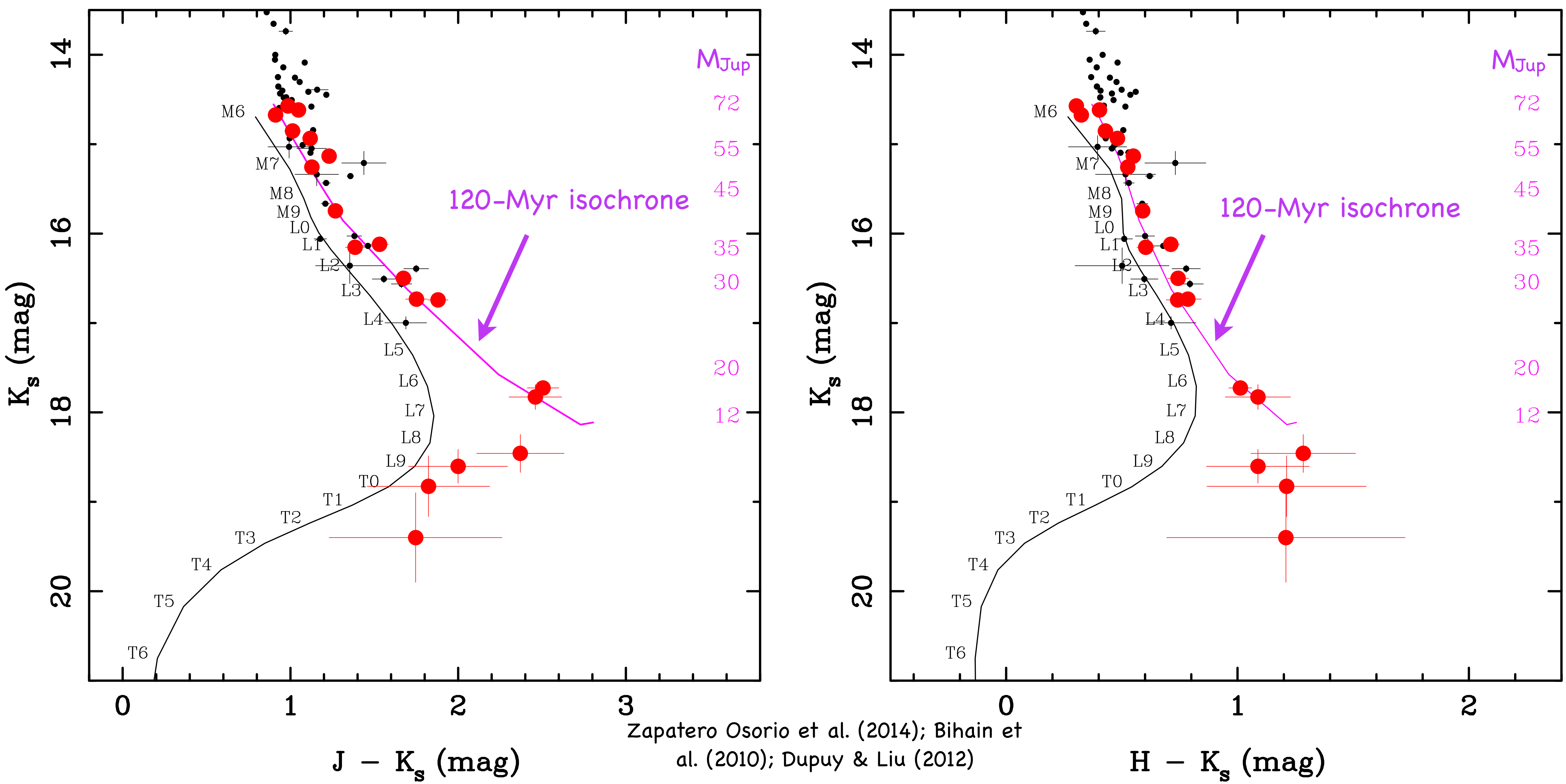
Additionally, E-ELT can search for Y dwarfs as companions to nearby stars and brown dwarfs.

# Free-floating planets in the Pleiades (120 Myr, 133.5 pc)

Co-authors: M. C. Gálvez-Ortiz, G. Bihain, C. A. L. Bailer-Jones, R. Rebolo, Th. Henning, S. Boudreault, V. J. S. Béjar, B. Goldman, R. Mundt, and J. A. Caballero

# Free-floating planets in the Pleiades (120 Myr, 133.5 pc)

Proper motion and ZJHK photometric selection of Pleiades candidates.
Surveyed area = 0.8 deg$^2$




Zapatero Osorio et al. (2014); Bihain et al. (2010); Dupuy & Liu (2012)

Pleiades very low-mass brown dwarfs and free-floating planets are much redder at NIR wavelengths than field objects of similar spectral classification.

# Free-floating planets in the Pleiades (120 Myr, 133.5 pc)

Proper motion and ZJHK photometric selection of Pleiades candidates.
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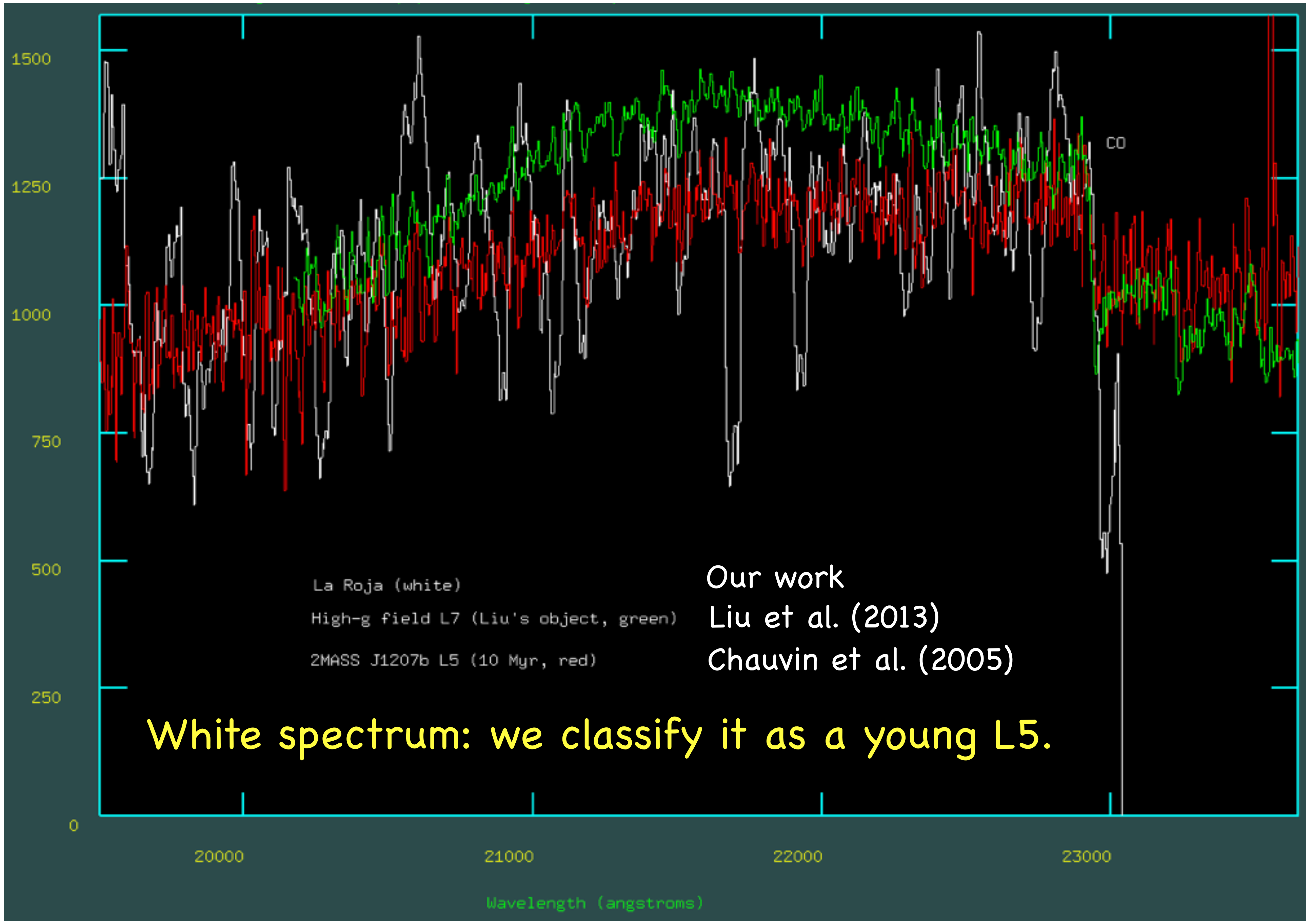
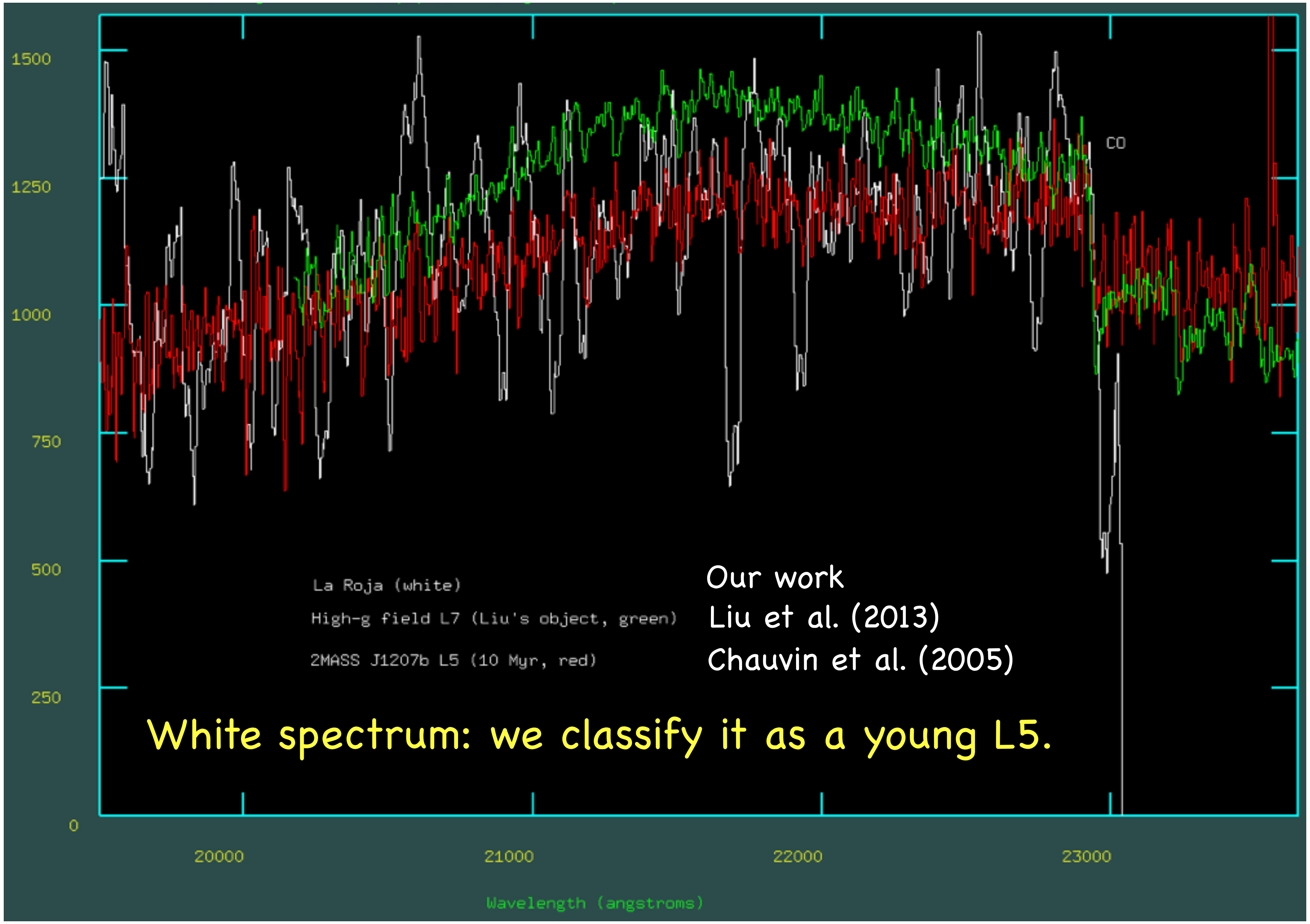



Keck/NIRSPEC spectrum of a J=20.2, K = 17.8 source in the Pleiades (one of the brightest Pleiades candidates close to the D burning-mass threshold).

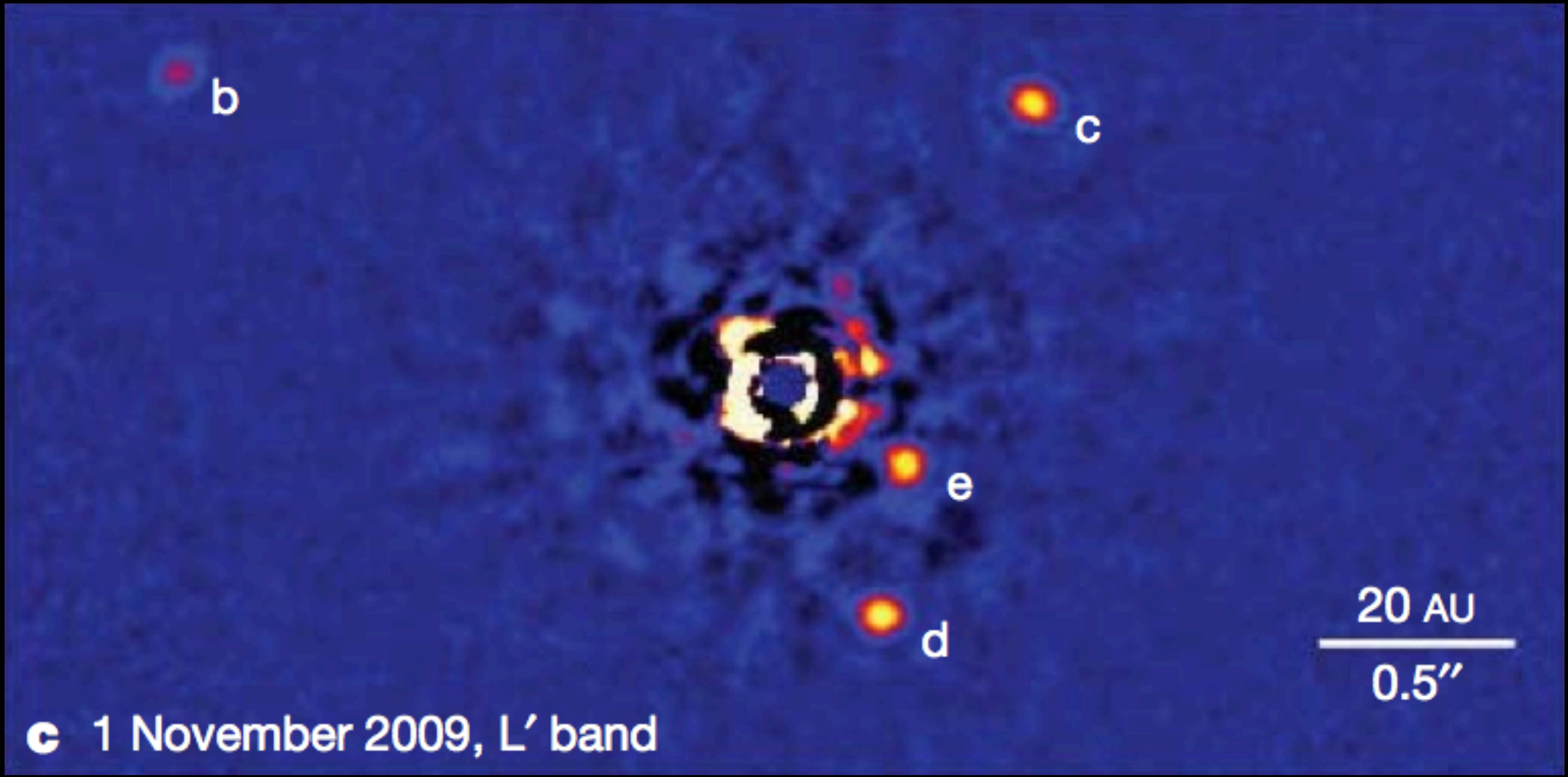
# Free-floating planets in the Pleiades (120 Myr, 133.5 pc)

Proper motion and ZJHK photometric selection of Pleiades candidates.
Surveyed area = 0.8 deg$^2$




Pleiades free-floating planets are cooler than L5-L7 spectral type and fainter than J~20.5 and $K_s$~18 mag. For their proper spectroscopic follow-up, we need telescopes like the E-ELT.

# HR 8799 planets




Marois et al. (2008, 2010)

# Free-floating planets in the Pleiades (120 Myr, 133.5 pc)

Proper motion and ZJHK photometric selection of Pleiades candidates.

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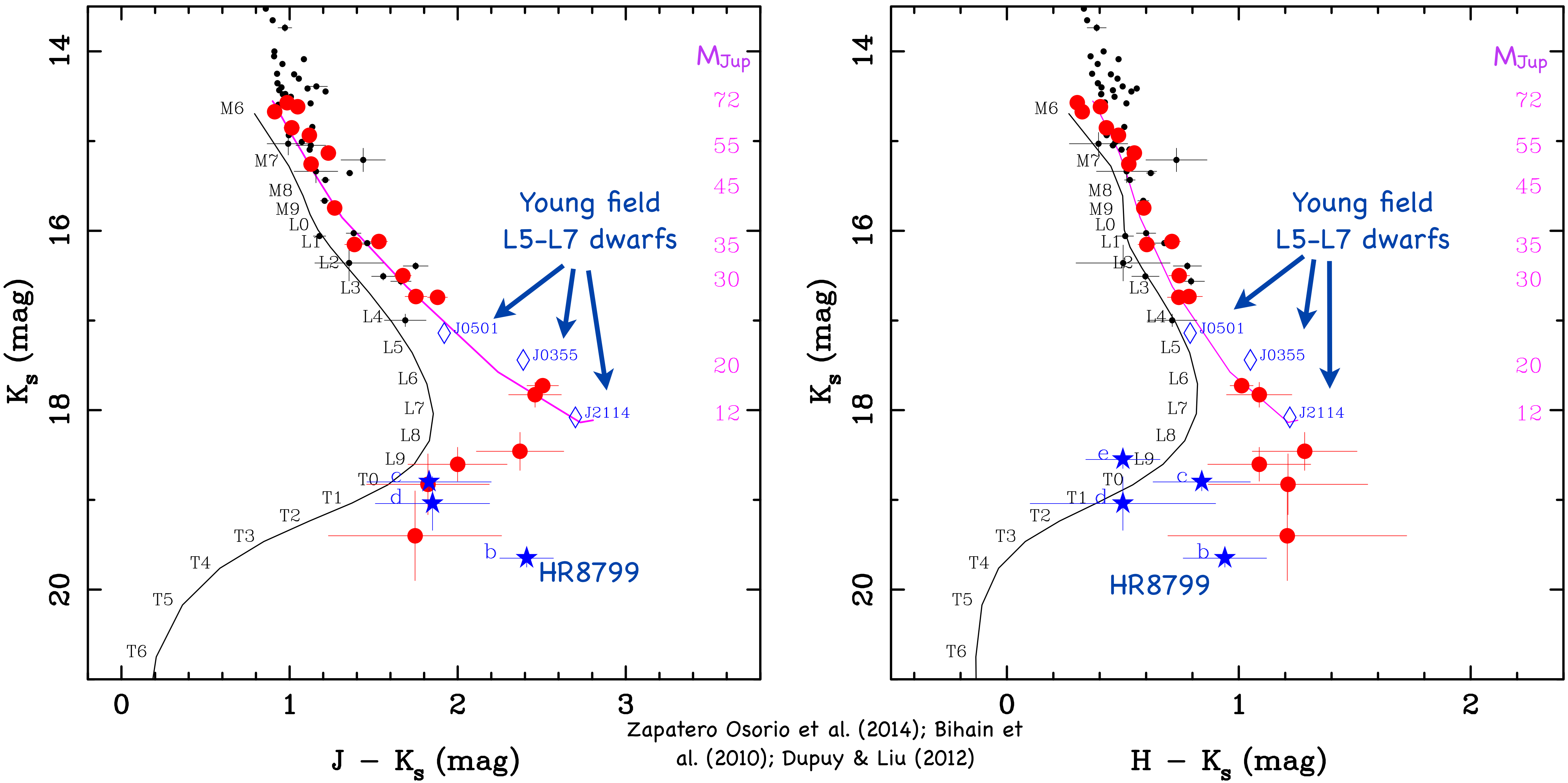
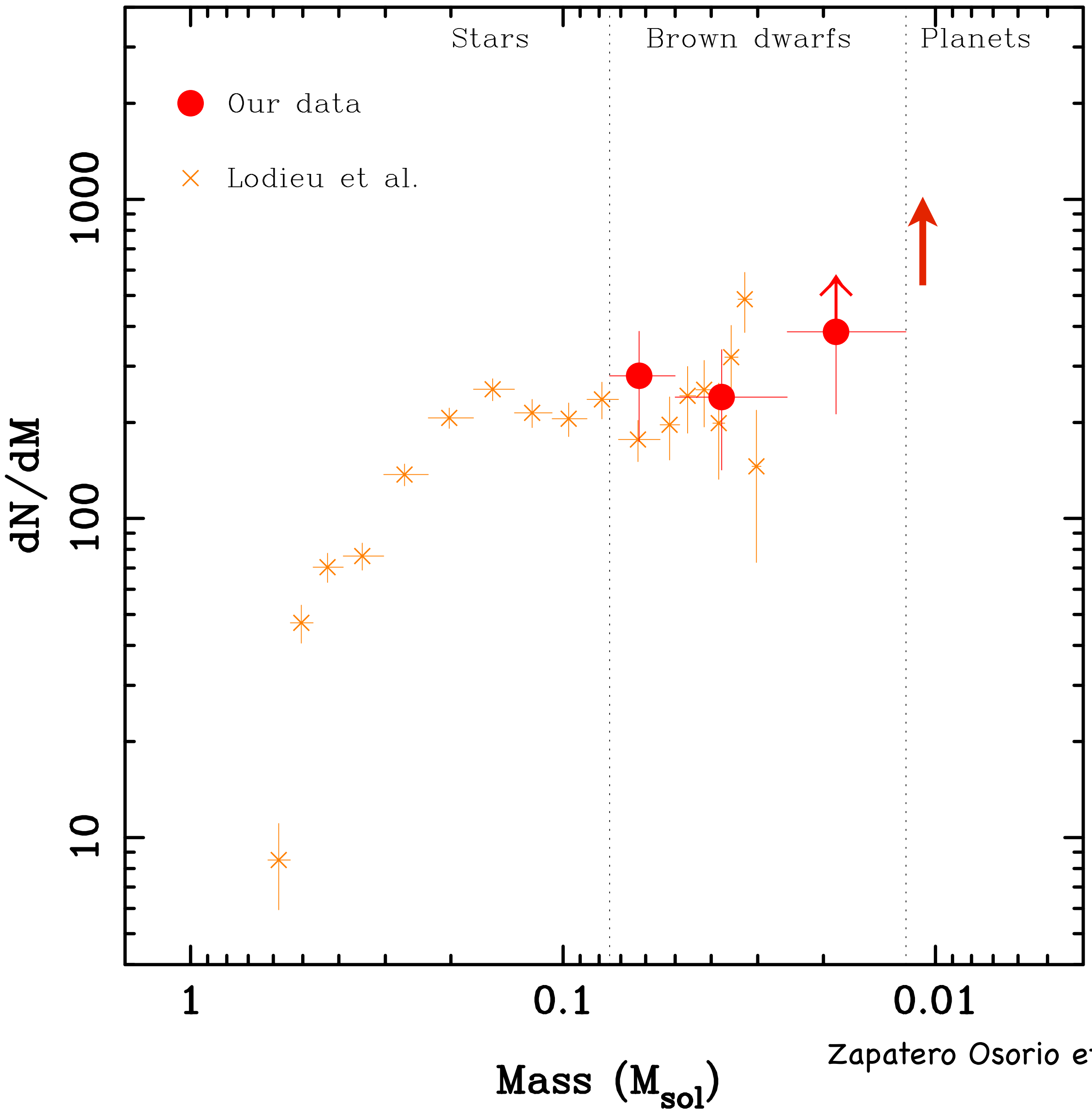



Zapatero Osorio et al. (2014); Bihain et al. (2010); Dupuy & Liu (2012)

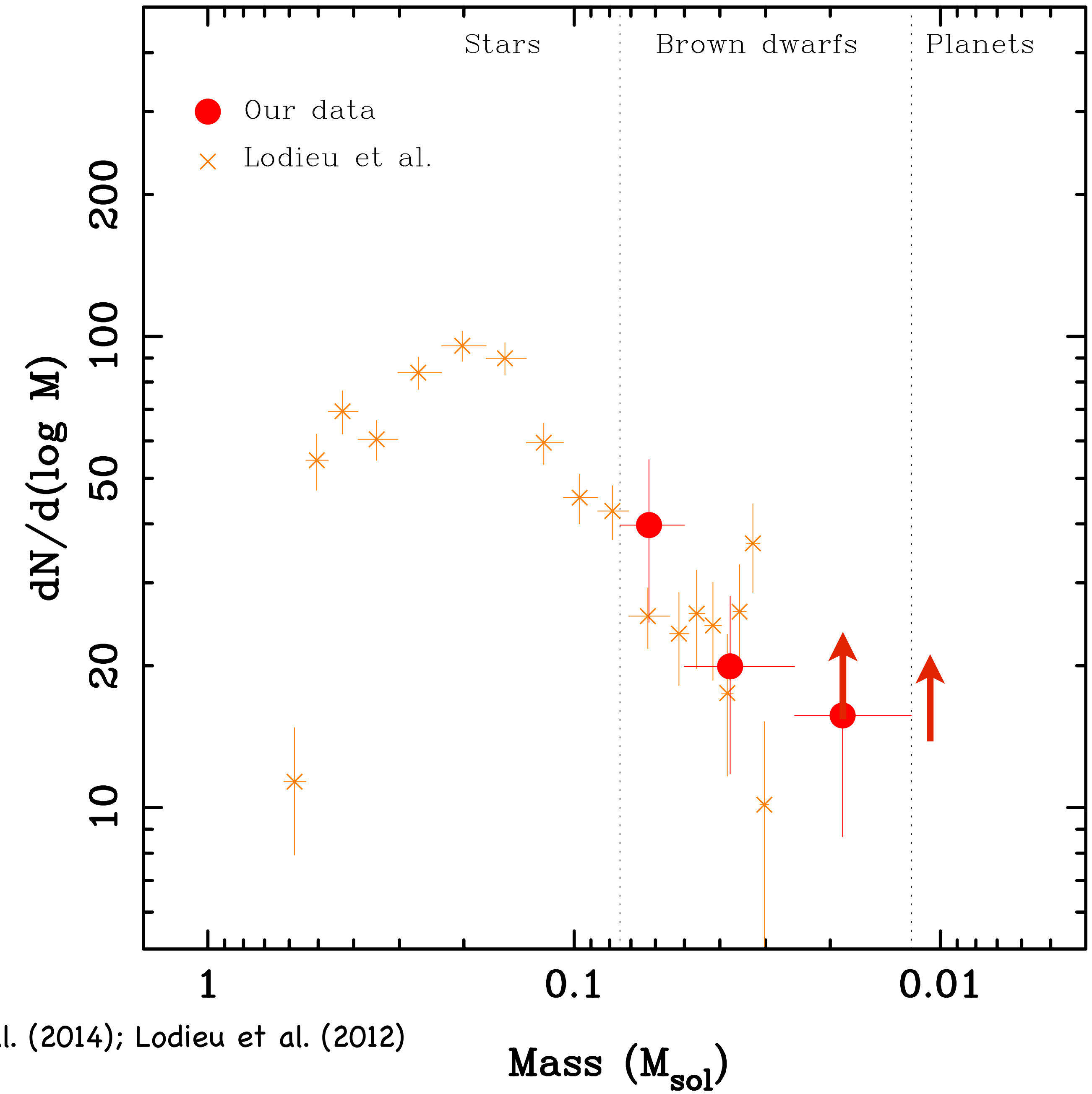
Very low-mass, free-floating Pleiades members can become benchmark objects to understand giant planets orbiting stars and young field dwarfs.

# Free-floating planets in the Pleiades (120 Myr, 133.5 pc)

## Pleiades mass spectrum




## Pleiades mass function

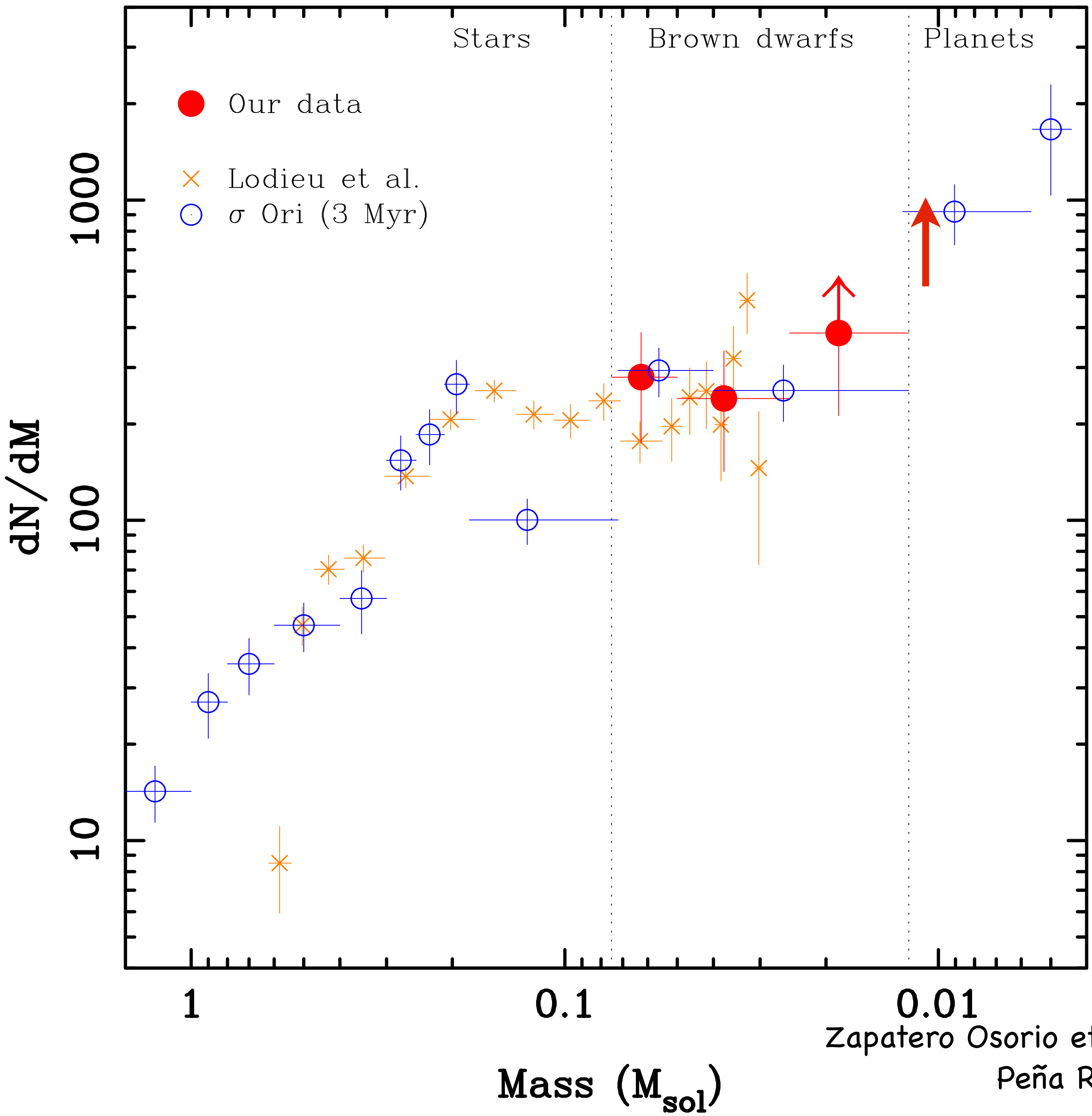



Zapatero Osorio et al. (2014); Lodieu et al. (2012)

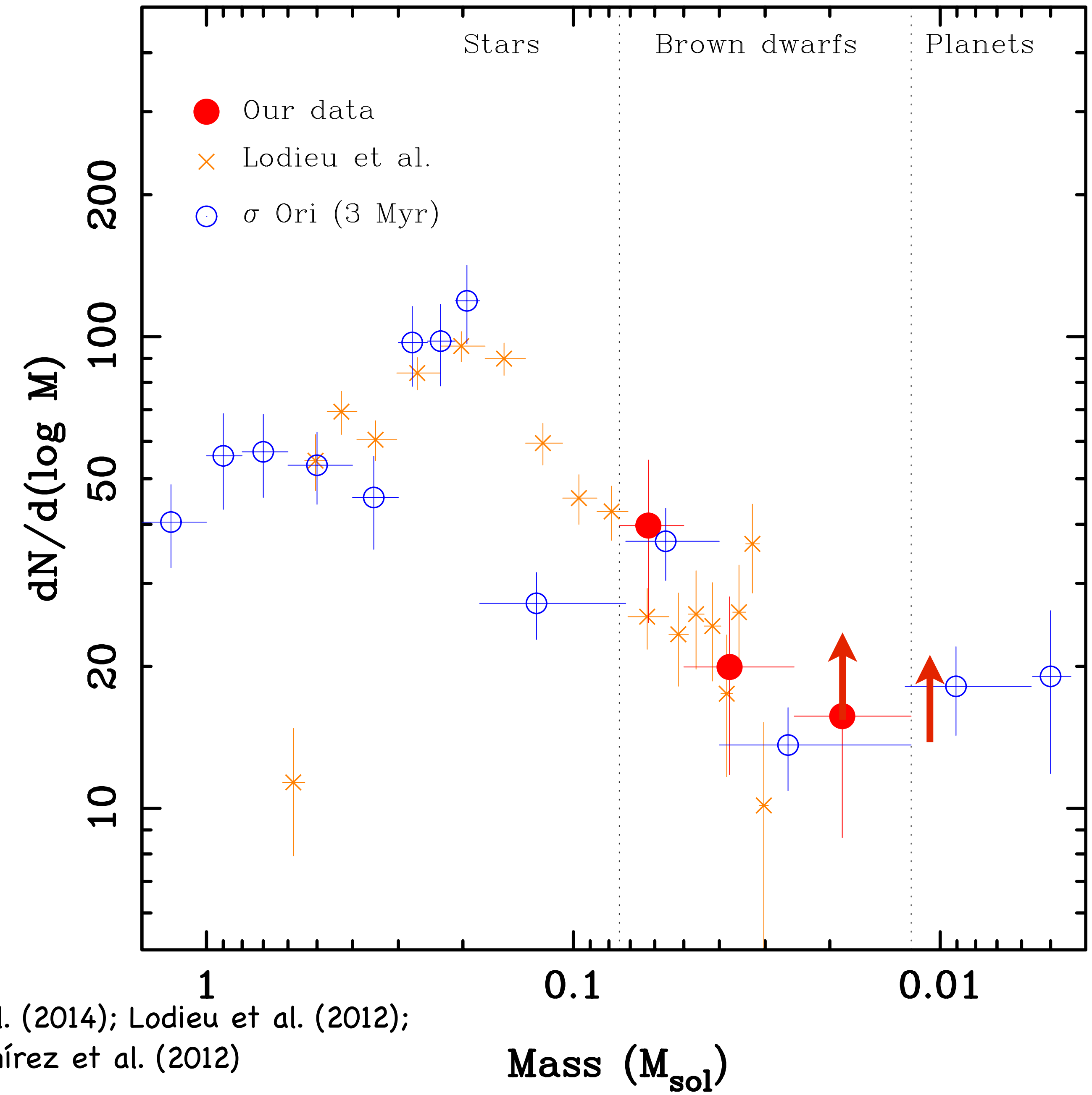
The number of low-mass brown dwarfs and free-floating planets appears to increase toward smaller masses. The planetary regime may deviate from Chabrier's mass function (see Peña Ramírez et al. 2012).

# Free-floating planets in the Pleiades (120 Myr, 133.5 pc)

## Pleiades mass spectrum




## Pleiades mass function




Zapatero Osorio et al. (2014); Lodieu et al. (2012); Peña Ramírez et al. (2012)

Universality of the mass function.

We estimate that there may be 150-850 giant planets (1-12 $M_{Jup}$) free-floating in the Pleiades cluster.

# Some scientific goals that the E-ELT can tackle regarding free-floating planets

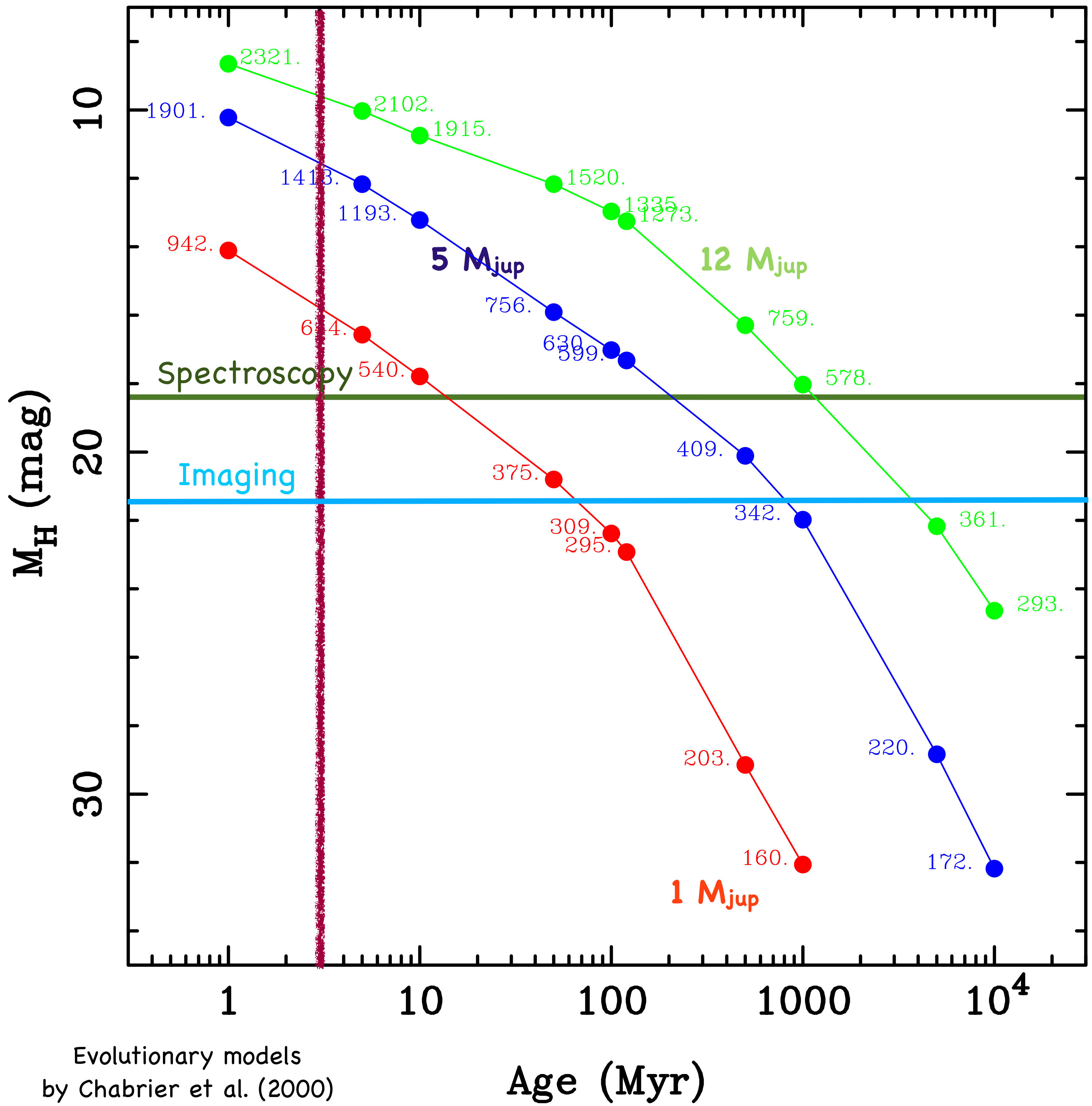
- Origin and evolution of brown dwarfs and free-floating giant planets.
- Substellar mass function at different ages.
- Presence of disks/rings around free-floating planets and disk/ring properties.
- Dynamics of substellar members in star forming regions and stellar clusters.
- Physical and chemical properties of planetary atmospheres of different $T_{eff}$ and surface gravities.
- Multiplicity of free-floating planets ("planets or moons" around planets).
- Characterization of the planetary mass borderline: deuterium studies.

By performing:

- Direct imaging observations: search for free-floating planets and their companions.
- Indirect detection of companions: astrometry and radial velocity studies.
- Accurate astrometric and radial velocity measurements.
- Low-, intermediate-, and high-resolution spectroscopy.

# Detectability of E-ELT first light instruments

## 3 Myr, d = 350 pc, σ Orionis



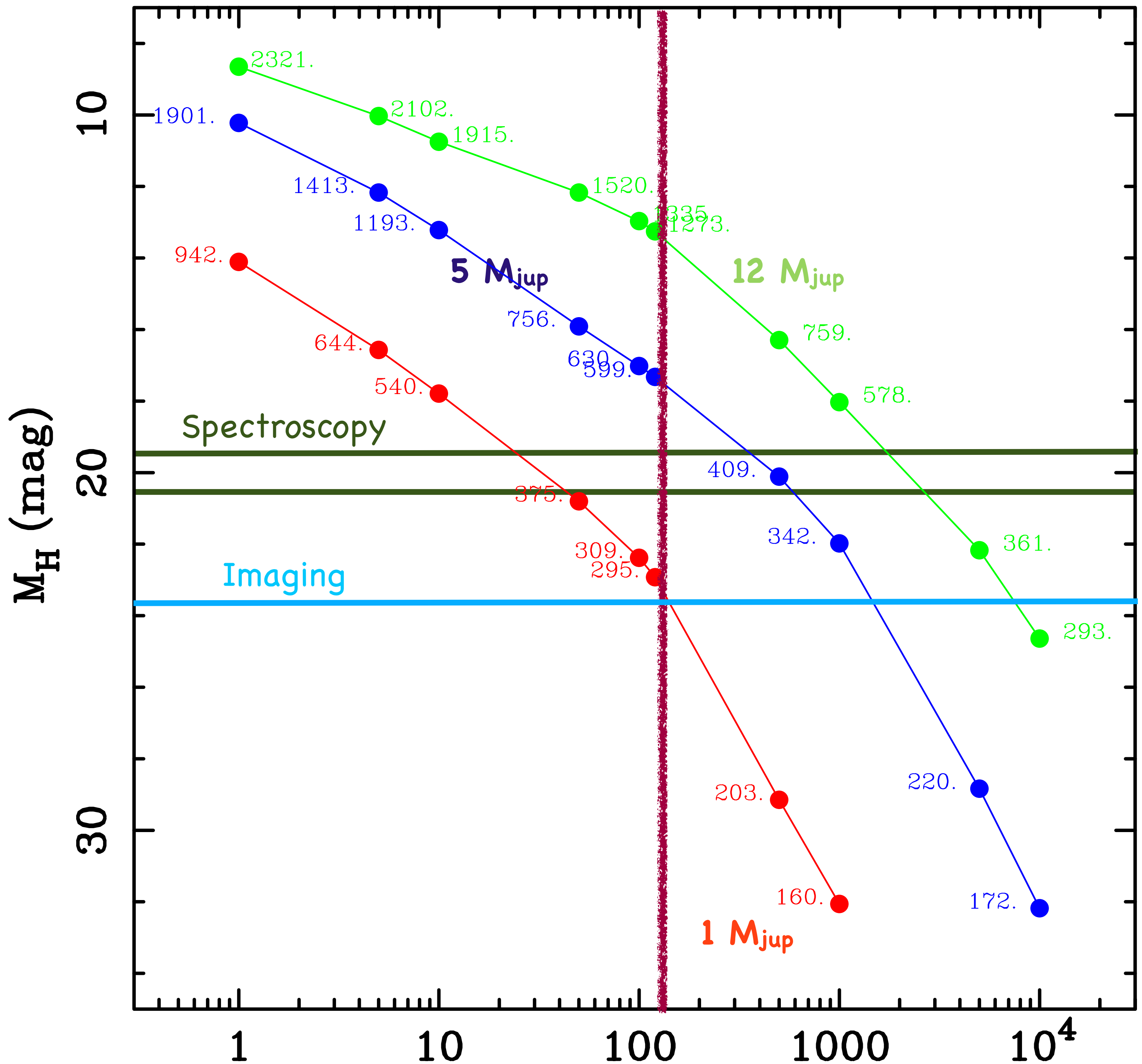

Evolutionary models by Chabrier et al. (2000)

20.3 h (2-3 observing nights) of E-ELT CAM time would suffice to cover the **entire** σ Orionis cluster and discover 20-120 free-floating planets with masses from <0.5 to 12 $M_{Jup}$. Most of them would be followed-up spectroscopically with HARMONI.

New discoveries would have atmospheres with $T_{eff}$ > 500 K and very low gravities. New field for planetary atmospheres.

# Detectability of E-ELT first light instruments

## 120 My, d = 133.5 pc, the Pleiades




Evolutionary models
by Chabrier et al. (2000)

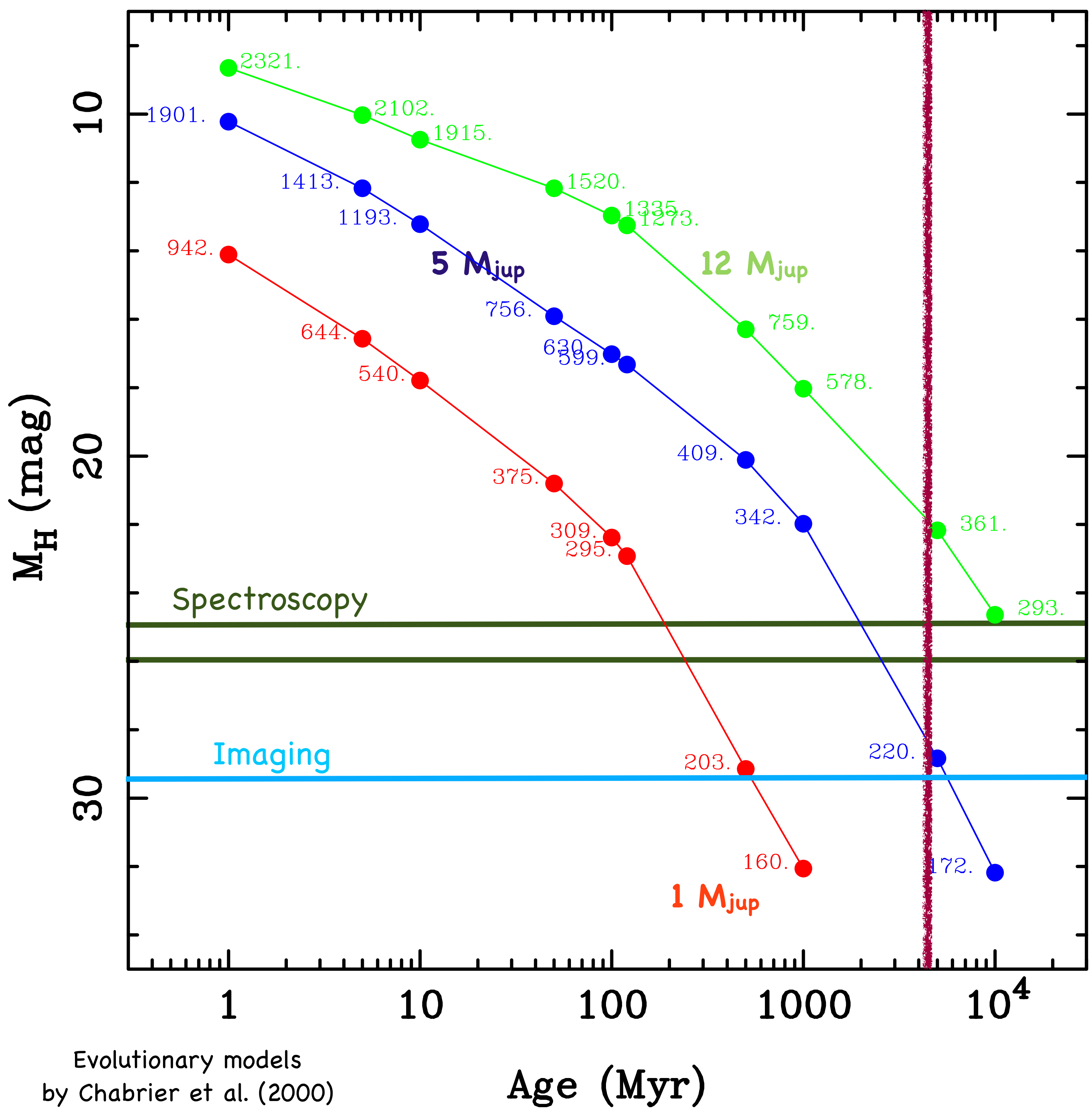
27.4 h (3-4 observing nights) of E-ELT CAM time would suffice to cover 0.8 $deg^2$ in the Pleiades and discover 4-16 free-floating planets with masses from 3 to 12 $M_{Jup}$.

**ALL** would be followed-up spectroscopically with HARMONI.

New discoveries would have atmospheres with $T_{eff}$ > 375 K and intermediate gravities. New field for planetary atmospheres.

# Detectability of E-ELT first light instruments

## d = 10 pc, closest solar vicinity




Evolutionary models by Chabrier et al. (2000)

Up to 10 pc, the E-ELT HARMONY can obtain NIR spectroscopy of free-floating planets down to 1 $M_{Jup}$ and $T_{eff}$ = 250 K at the age of a few hundred Myr, 5 $M_{Jup}$ and 300 K at the age of the solar system.

E-ELT cam has the potential to discover Jupiter-mass bodies of 200 K in wide-orbits around nearly all stars and brown dwarfs within 10 pc.

H~25, HARMONI, 20 mas spaxels, R=20000

H~26, HARMONI, 20 mas spaxels, R=4000

H~29.4, ELT-Cam

# Free-floating planets and the E-ELT

The E-ELT will bring a new era to the field of free-floating planets.

- Origin and evolution of brown dwarfs and free-floating giant planets.
- Substellar mass function at different ages.
- Presence of disks/rings around free-floating planets and disk/ring properties.
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