Science cases for SHARK-NIR

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On behalf of the SHARK-NIR science team

…What we are dealing with here is a perfect engine […]
(Jaws, 1975)

Exoplanets: detection and characterisation

Discs around young stars and their jets

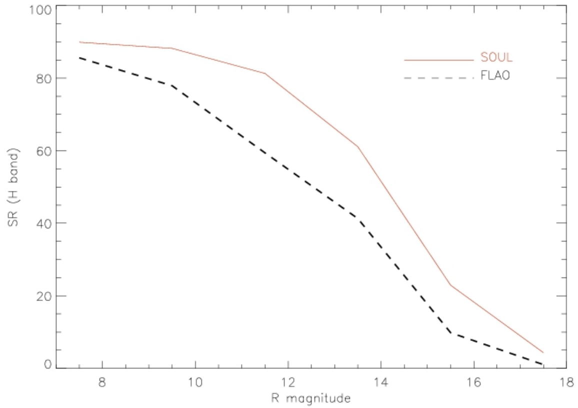
(F. Bacciotti –INAF Arcetri)

Extragalactic science: AGN and QSO

(A. Bongiorno –INAF Roma)

Giant planets in wide orbits of low-mass stars

A special niche for SHARK is offered by the LBT AO at faint mag, especially with AO upgrade →



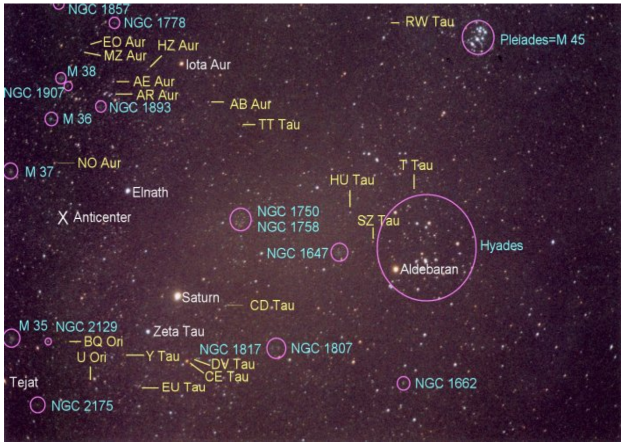
1. Giant planets around low-mass stars (K/M dwarfs) in Star forming regions

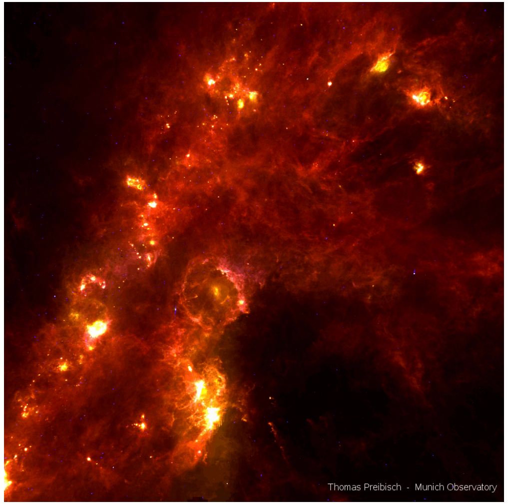
Taurus-Auriga:

Age of ≈1-2 Myr
Distance of 140 pc.

About 350 members identified →

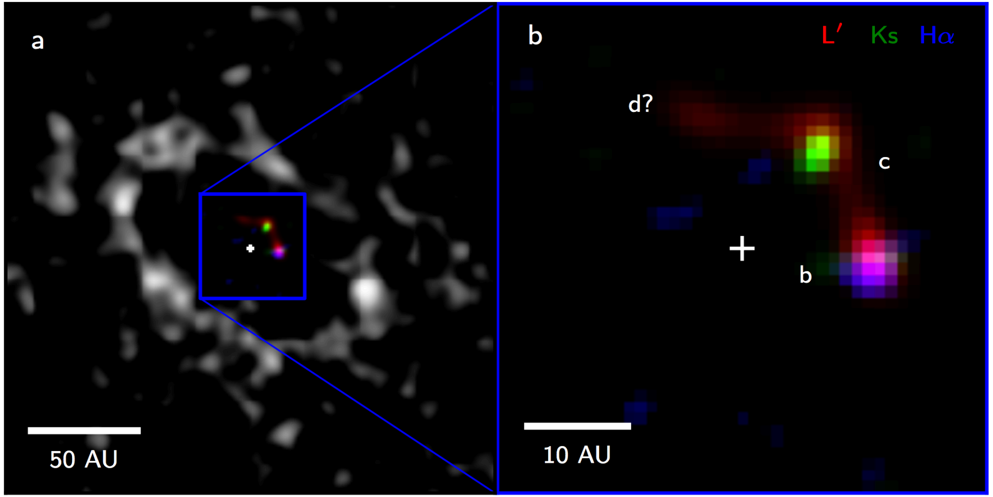
130 brighter than R=15.





The identification and the physical properties of planets in their very early stages will allow to obtain crucial information on the formation mechanisms (core accretion, disk instability), together with studying the interactions between planets and disks.

A candidate in the gap of the circumstellar disk around LkCa15 has been proposed by Krause & Ireland (2012) as a possible planet caught in the formation phase ($M < 6\ M_{jup}$, assuming 1 Myr hot-start models)

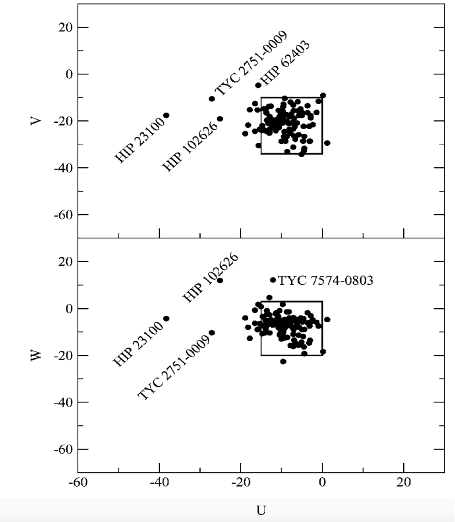


Sallum+ (2015)

LkCa 19	04:55:36.85	+30:17:53.7	10.490
RY Tau	04:21:57.40	+28:26:35.5	9.620
SU Aur	04:55:59.27	+30:34:00.2	8.830
GI Tau	04:33:34.05	+24:21:17.0	9.610
GK Tau	04:33:34.56	+24:21:05.8	9.610
NTTS042417+1744	04:27:10.57	+17:50:42.6	9.700
DG Tau	04:27:04.69	+26:06:16.3	8.970
DETau	04:21:55.57	+27:55:07.0	8.560
RXJ0405.1+2632	04:05:12.40	+26:32:44.6	10.010
RXJ0408.2+1956	04:08:12.60	+19:56:51.5	9.510
RXJ0409.2+1716	04:09:17.05	+17:16:08.3	9.260
RXJ0433.7+1823	04:33:41.99	+18:24:27.4	10.450
RXJ0457.0+3142	04:57:06.50	+31:42:50.5	8.710
NTTS035120+3154SW	03:54:29.40	+32:03:02.0	10.090
DD Tau A+B	04:18:31.12	+28:16:29.0	9.970
GV Tau A+B	04:29:23.73	+24:33:00.2	9.190
V927 Tau A+B	04:31:23.82	+24:10:52.9	10.300
ZZ Tau IRS	04:30:51.71	+24:41:47.5	10.060
HD285281	04:00:31.07	+19:35:20.9	9.880
RXJ0409.1+2901	04:09:09.74	+29:01:30.3	9.680
RXJ0412.8+1937	04:12:50.71	+19:36:58.1	9.020
RXJ0415.3+2044	04:15:22.92	+20:44:16.9	10.190
RXJ0422.1+1934	04:22:04.96	+19:34:48.2	10.080
RXJ0431.3+1800	04:31:24.00	+18:00:22.0	8.520
RXJ0435.9+2352	04:35:56.82	+23:52:14.5	10.010
RXJ0437.2+3108	04:37:16.87	+31:08:19.7	10.320
RXJ0444.3+2017	04:44:23.57	+20:17:17.8	10.270
RXJ0444.9+2717	04:44:55.00	+27:17:45.5	9.140
RXJ0450.0+2230	04:50:00.15	+22:29:57.4	9.250
RXJ0451.8+1758	04:51:54.26	+17:58:27.9	8.900
RXJ0458.7+2046	04:58:39.75	+20:46:44.4	10.020
J04224786+2645530	04:22:47.86	+26:45:53.0	10.000
CFHT-Tau 6	04:39:03.96	+25:44:26.4	10.060

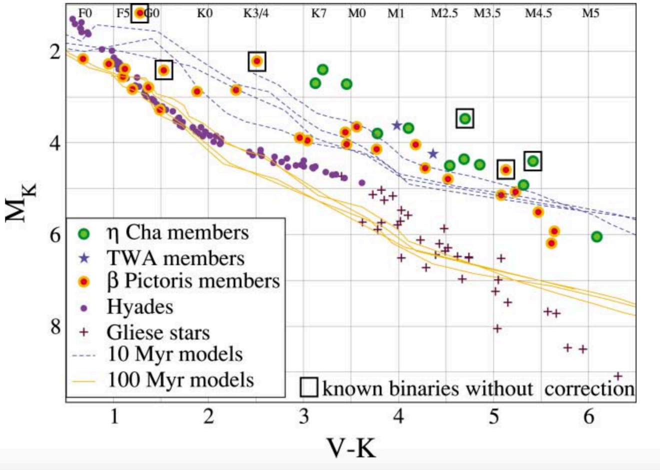
2. Planets around K/M type stars in young (loose) associations

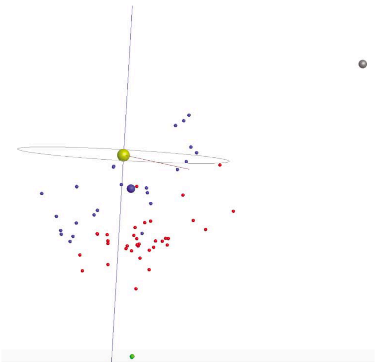
Several members of young moving groups (age~10-100 Myr) were recently identified, with special effort for low-mass stars.
→ stream of stars with common age and motion through the Milky Way and with no overdensity of stars discernable in any region (e.g., the Ursa Maior, AB Dor, Beta Pic)



Zuckerman & Song (2004)

Quite hard to identify because these groups are sparse and spread over large regions of the sky, usually there is no clustering, whereby a stellar over-density can be picked out against the background stars



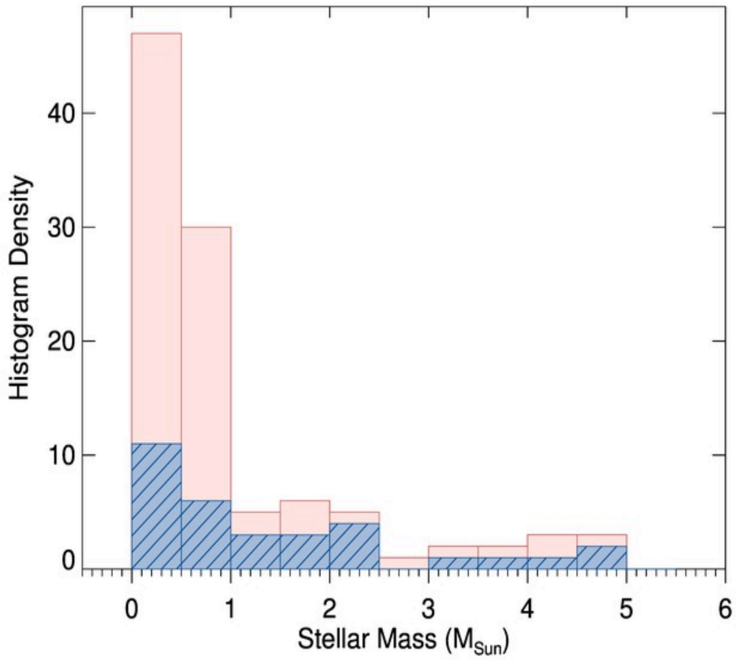


Observational investigations of planetary system and theoretical studies indicate that giant planets form in < 10 Myrs and Earth-like terrestrial planets in ~30 Myrs.
→ Thus, local, post T Tauri stars **promise** to reveal the story of the formation and early evolution of planetary systems.

There are several tens of potential targets, depending on exact magnitude limit of the instrument, accessible for a deep search for planets in wide orbits

With the current limit at R<10.5 our sample comprises **33 targets** (basically FGK-type stars)

Adopting R=12.5 as a magnitude limit we would gain more than a factor of three in sample size (that is **108 objects)**



What do we want?

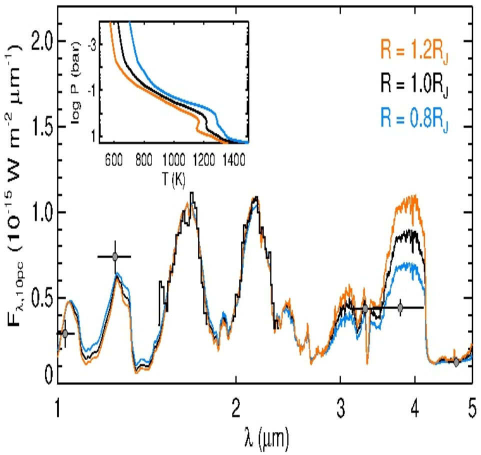
Coro IWA required: minimum 4 λ/D (128 mas in J band) → goal 2-3 λ/D

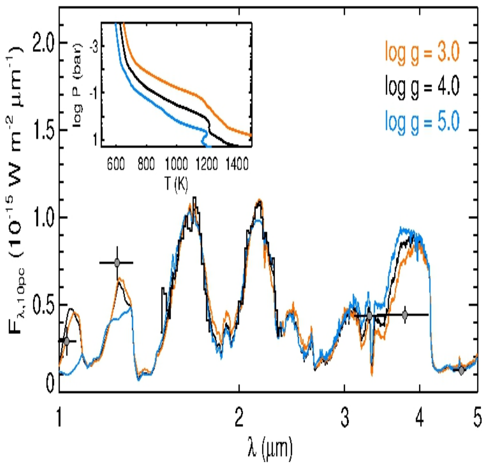
Contrast : $\sim 2 \times 10^{-6}$ in the range IWA=300-500 mas
10^{-5} for IWA<300 mas

→ A contrast of 10^{-6} ($\Delta M=15$), assuming a distance for the system of 140 pc and ages of 10 Myr and 100 Myr, would correspond to mass limits of $M=4.24\ M_{jup}$ and $M=5.29\ M_{jup}$, respectively (employing models by Allard and collaborators).

synergy with LMIRCAM : extension to thermal infrared for SED determination and broad spectral coverage to remove degeneracies affecting NIR photometry

synergy with VIS channel: Hα and accretion mechanisms





Spectroscopic characterisation of (known) planets/BDs

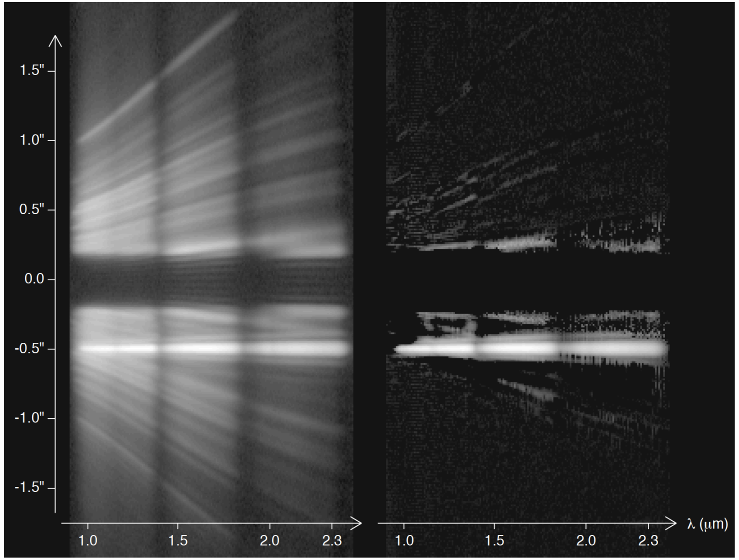
The implementation of a long-slit coronagraphic mode will furnish spectral classification if R≳30 and molecular band + atomic feature identification if R≳100.

Vigan+ 2008

SHARK-NIR will have two LSS modes: a low-resolution (R~100) and a high-resolution (R~700), depending on target magnitudes and properties, as needed.

LRS data obtained on PZ Tel (H=6.5) →

The spectrum of the companion PZ Tel B is visible as a straight line at an angular separation of ~0.5".



Why would we do that ?

Photometry suffers degeneracy

High-quality (SNR) spectra are FUNDAMENTAL as to determine physical properties

→ Cool atmospheres of young objects are not fully understood

Limited number of sub-stellar objects with accurate spectra because of:

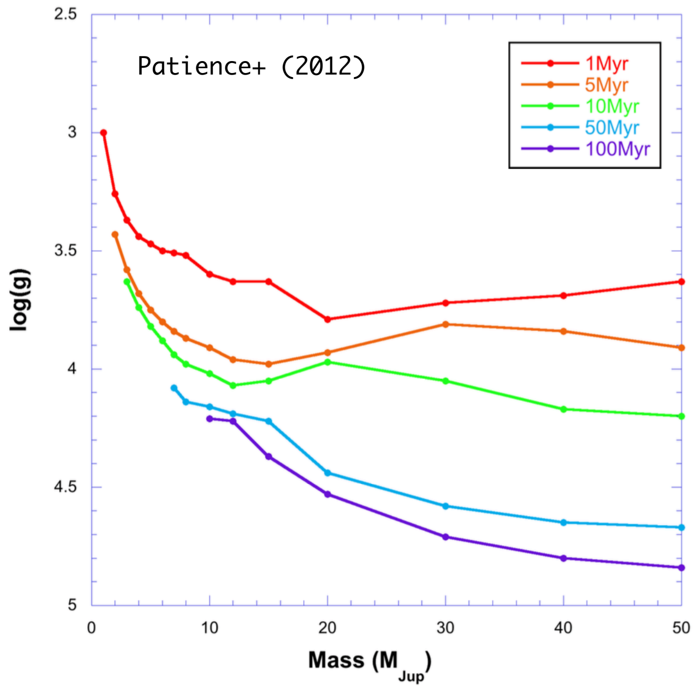
- very few imaged planets
- high-contrast
- small angular separation

Key diagnostics for gravity estimates

One way to distinguish between young and old brown dwarfs is to look for gravity-sensitive spectral features.

The radius of field brown dwarfs varies only slightly with mass and age, and therefore the surface gravity ($g \sim GM/R^2$) is determined by the mass ($\log g \sim 5$).
The radius of the young objects can be as m
their eventual equilibrium state (Burrows e

→ As a result, young objects can exhibit s
gravities (10–100 times) than the more mass
same spectral type.



Gorlova et al. (2003) showed that the neutral potassium (K I) lines in the J band are very **sensitive** to surface gravity.
Other sensitive line:
NaI at 1.14 um (Allers+2007) and FeH at 0.99 um (McGovern+ 2004)

HIP 19176

Bonavita+ (2014) survey of 74 targets in the Taurus star forming region with ALTAIR/NIR
→ Discovery of 18–50 M_{Jup} companion at a projected separation of ~400 AU from the F8 star HIP 19176.

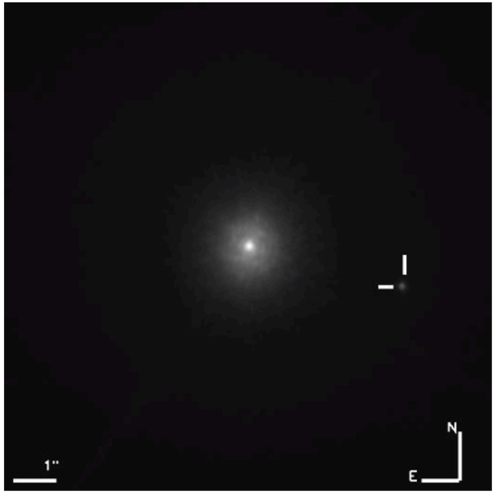
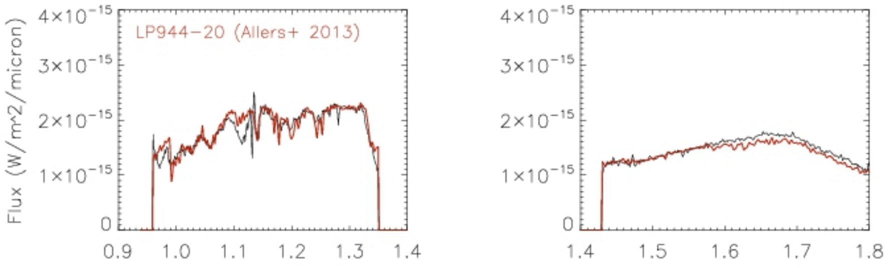


Table 1
Summary of Properties of Both HD 284149 and Its Companion

Parameter	Host Star	Companion	Ref.
V (mag)	9.653 ± 0.060		2
$B - V$	0.58		3
$V{-}I$	0.675 ± 0.088		4
J (mag)	8.479 ± 0.043	15.516 ± 0.043	5, 1
H (mag)	8.208 ± 0.021	14.715 ± 0.047	5, 1
K (mag)	8.100 ± 0.029	14.332 ± 0.040	5, 1
Parallax (mas)	9.24 ± 1.58		6
$E(B{-}V)$	0.05 ± 0.05		1
RV (km s^{-1})	14.0 ± 2.0		7, 8
Ew Li m(Å)	208		7
Prot (days)	1.079		9
$\log L_x/L_{bol}$	−3.3 ± 0.1		1
$v \sin i$ (km s^{-1})	27.0 ± 1.9		8
Age (Myr)	25^{+25}_{-10}		1
Sp. Type	G1-F8	M8-L1	7, 8, 1
T_{Eff} (K)	5970–6100	2537^{+95}_{-182}	1
Mass	$1.14 \pm 0.05\ M_\odot$	$32^{+18}_{-14}\ M_{Jup}$	1

Star: G1-F8 spectral classification: T_{eff}=5970–6100 K and an estimated age of 25 Myr (??)

With an adopted age of 25 Myr, the K_s brightness of the companion suggests a mass of 32 M_{Jup}, according to the DUSTY models by Chabrier et al. (2000) Teff=2337 K: together with the color measurements (J–H ~ 0.8, H–K ~ 0.4) this suggests a spectral type between M8 and L1



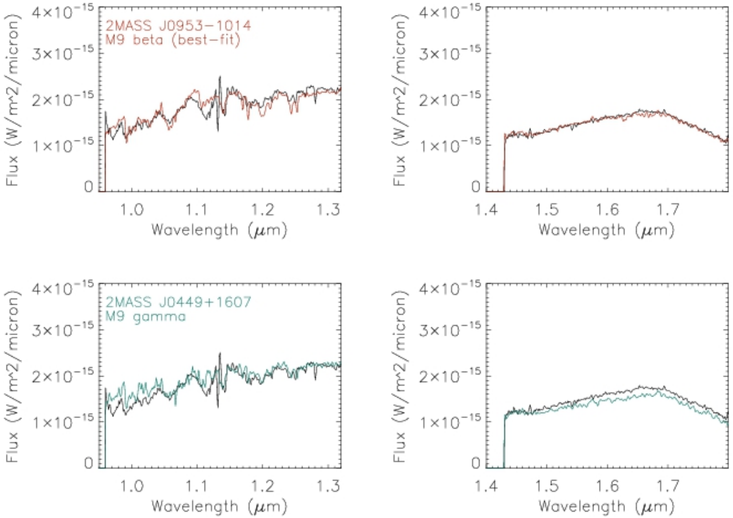
the M9 gamma template provides a very good fit of the spectral lines

The best match is given by star LP944-20, classified as M9.

whereas the global shape of the pseudo-continuum is well represented by this kind of spectral type, the gravity sensitive features (e.g., Na I, K I) are significantly weaker in our target→ reduced gravity (younger age)

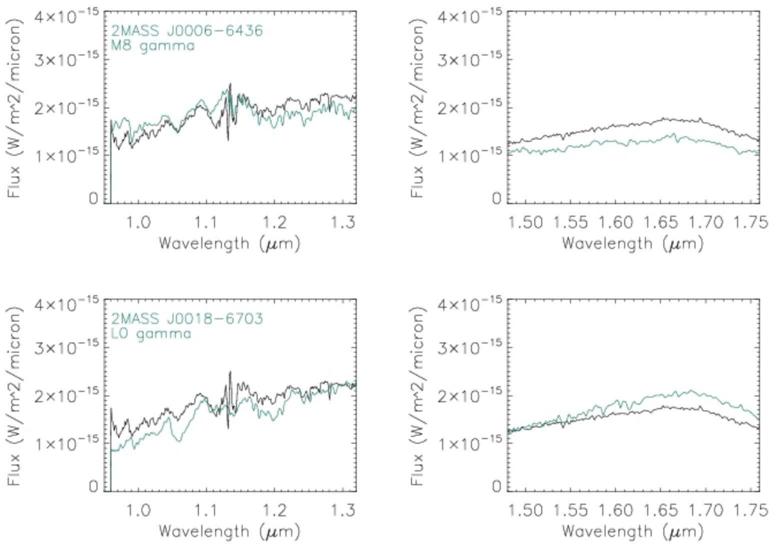
We measure EW(K I)1:169= 2.70 Å and EW(K I)1:177= 4.72 Å , which provide a very strong indication of reduced gravity, confirmed by the position of HD 284149b on diagnostic plots by Allers & Liu (2013)

Note also that the very low-gravity allows an independent assessment of the system's age with gravity suffix of gamma have typically ages of the order of log(age yr)~7 (e.g., Allers & Liu 2013).



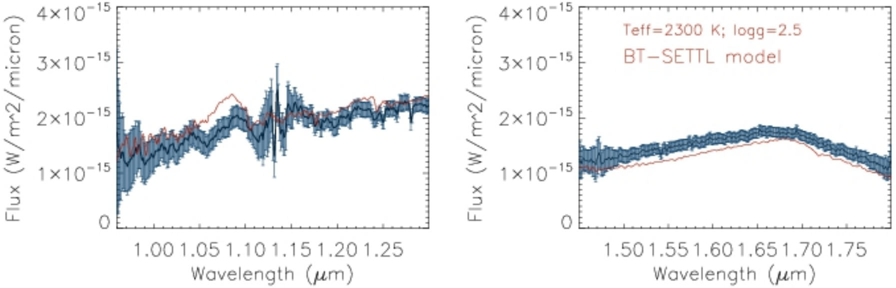
Bonavita, D'Orazi, Mesa+ 2017

The brown dwarf companion has a spectral type of M9 gamma → a young age



thanks to the very high quality of our spectra much stronger constraints on the spectral type range, which in the literature is reported to be between M8 and L1.

However, it is clear that neither M8 nor L0/L1 spectra provide a good match of our spectrum Thus, our final value is **M9±0.5** for the brown dwarf companion of HD 284149.

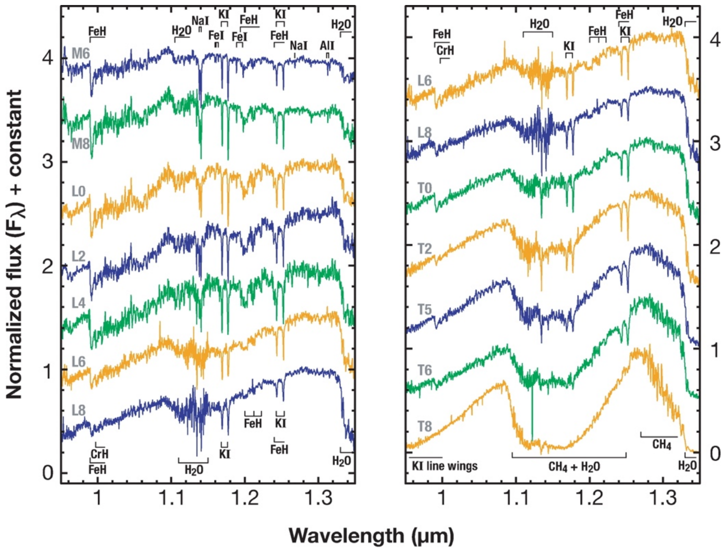


Comparison with theoretical Models
←

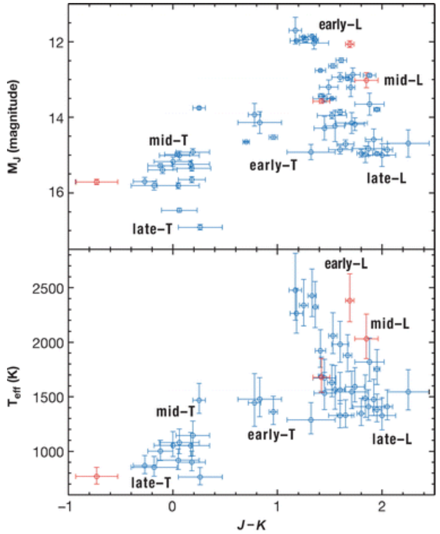
The L-T transition

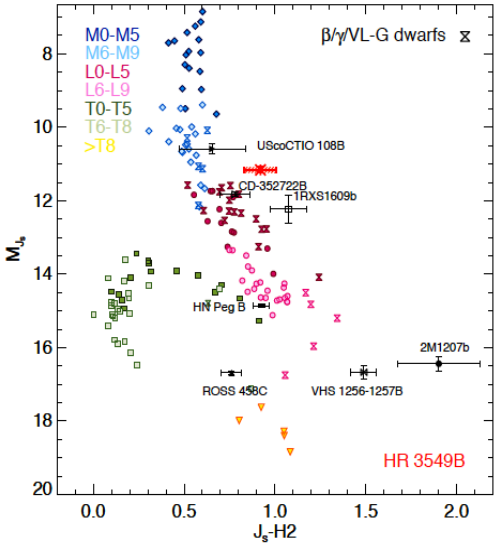
Shed light on L-T transition and on the characteristics of brown dwarfs and giant planets, which are expected to somewhat overlap but also significantly differ in terms of chemistry of the atmospheres and mechanisms of clouds formation (Mandushev et al. 2014).

Clouds, are the product of condensation and sedimentation, and their presence has the effect of both veiling features in the spectra and reddening the NIR colors



Kirkpatrick+ (2004)





Mesa+ 2016

Brown dwarfs in open clusters

Brown dwarfs –intermediate objects between stars and planets- are still poorly understood, especially in terms of formation mechanisms (star-like or planetary-like formation??)

It is now undeniable that the stellar and planetary formation mechanisms overlap in the substellar regime. They can both lead to the formation of planetary mass objects, including companions to stars and BDs.
(see e.g., Chauvin+ 2015a,b)

Fossil traces of the formation processes should be revealed by different physical features (presence of core, composition of the atmosphere, system architecture...)

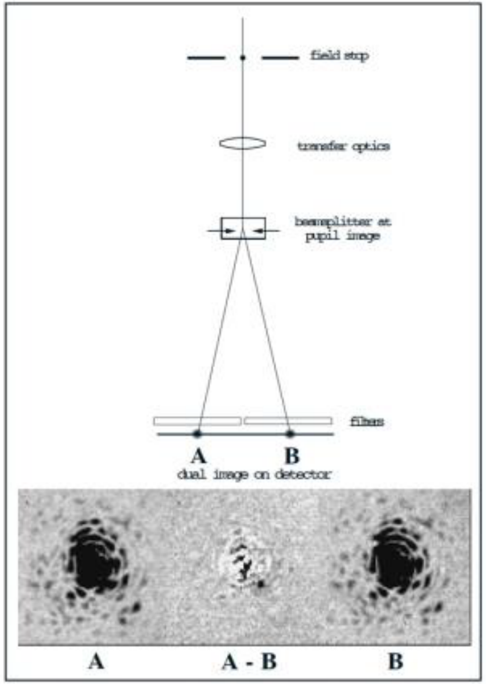
→ statistical properties -occurrence, the mass, and the main orbital parameters- should help to identify the dominant mechanism to forming substellar companions.

Objects belonging to moving groups, local associations, very young Open clusters are preferred objects: they are nearby (20-100pc) and young (several to several hundred Myr), so their substellar objects (planets and BDs) are relatively bright → PLEIADES (known age, distance, metallicity)

Detecting T-Type substellar objects via Dual band imaging observations

This technique relies on the fact that planetary objects have strong molecular features in their spectrum, whereas the host star has a relatively flat spectrum. By simultaneously acquiring two images of a system at two close wavelengths located around one of these sharp features and subtracting them, the star contribution can be partially eliminated, and the planet signal revealed

SDI is most effective when used for detecting cool companions that show deep molecular absorption bands caused by e.g., H_2O, CH_4 and NH_3 at low *Teff*

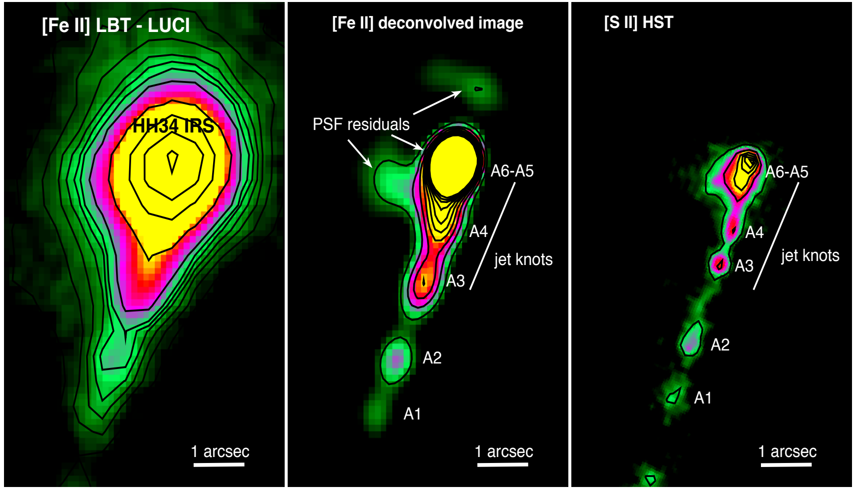


The implementation in SHARK-NIR of a dual band imager with purposely designed filter pairs (e.g., H2 and H3 at 1589 and 1667 nm, respectively) will provide us a very powerful tool to reveal very cool targets, such as e.g., T type substellar objects that are characterised by strong absorption in the CH4 band.

Discs around Young Stars and their Jets

- High-contrast imaging of circumstellar discs with NIR coronagraphy.
- Coronagraphic or classical imaging of stellar jets
- 2D kinematical maps of Jets

Narrow-band images of jets reveal the generation mechanism and its feedback on the star/disc



Antoniucci+ (2014)

Goals:

understand dynamic role of jets in shaping the disc structure

Probe the innermost regions of discs and jets in T Tauri stars (Binocular observations VIS+NIR)

H_2 as key tracer:
SYNERGY with LMIRCAM

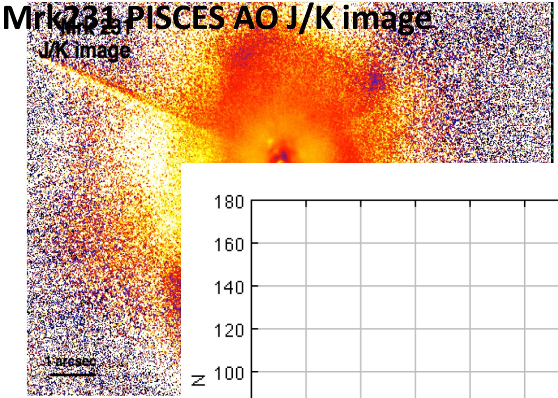
Requirements: **Classical Imaging** + CORO IWA<3λ/D (~100 mas);
Contrasts 10^{-4} for discs and 10^{-3} for jets

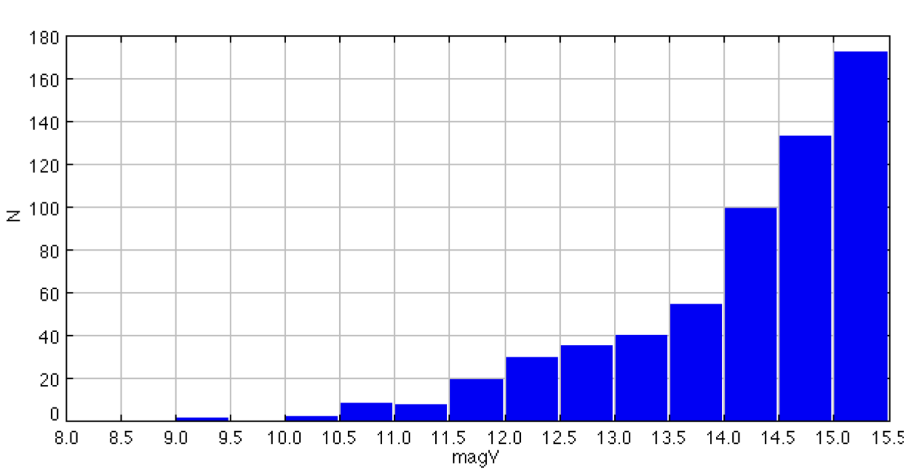
AGNs and QSOs

(1) Discover and fully characterise the AGN close pairs;
(2) Constrain the Black Hole feeding mechanism (e.g., SN driven winds *vs* gravitational asymmetries) in local Seyfert galaxies
(3) Trace, in bright quasars, molecular outflows powerful enough to clean the inner kpc and quench the star formation

- Dust lane maps on scales down to hundreds pc to investigate whether outflows are dusty or rather the AGN driven feedback has already swept the ISM;

- Color maps of SF regions in the galaxy nucleus and disk to constrain the SF rate, the age, and the metallicity.





Requirements:
Binocular VIS and NIR both imaging and coro modes. + Synergy with LMIRCAM for H2

What we have and others do not: Multi-wavelength observations

The confirmation of planetary companions with the direct imaging technique requires two observations spaced of few months/few years to ensure that the faint object close to the target star is bound rather than a background star.

On a typical planet-search survey background objects largely outnumber bound companions: significant lost of time!!

Sub-stellar objects are characterised by peculiar colors in various bands depending on their effective temperature, gravity, and dust content in their atmospheres:

The colors are then largely different with respect to those expected for far background stellar objects

Multi-wavelength photometry of each detected candidate (or even non-detection upper limits), then represents precious information for the classification of the nature of the candidates independently on the common-proper motion astrometric evaluation.

The possibility of getting simultaneous imaging in the visible using V-SHARK, in the near-infrared using SHARK-NIR and in L' or M bands using LMIRCam will be a unique feature of LBT:

1. significant saving of observing time, as in several cases the observed colors of the candidate should be not compatible with a sub-stellar object, then without need of second epoch observation

2. Early identification of the most promising candidates, that could trigger additional follow-up observations (e.g. LSS spectroscopy) in order to secure the detection on rapid timescale.

Most of the direct imaging surveys are young stars, as planets and brown dwarfs are brighter at young ages. Young stars of spectral type from mid-F are usually photometrically variable on various timescales.

Younger, accreting objects show even larger photometric variability.

Simultaneous observations allow to mitigate the issue of photometric variability, then reducing the error on the observed colors of detected sub-stellar objects with respect to independent observations.

Specific cases e.g.: ACCRETING PLANETS

SHARK-VIS → H_α narrow band filter, searching for accretion signatures, as observed in very young brown dwarfs like GQ Lup b.

SHARK-NIR → can observe in Paschen Beta, again to look for accretion, or in broad band, looking for thermal emission.

LMIRcam → imaging with better sensitivity to the thermal emission of young protoplanets (L' and M obs. especially in case they are still embedded in their nascent disks and significantly affected by reddening or in case of very dusty atmospheres, such as e.g., the planet candidate around HD 100546)