High-contrast imaging for E-ELT and other telescopes

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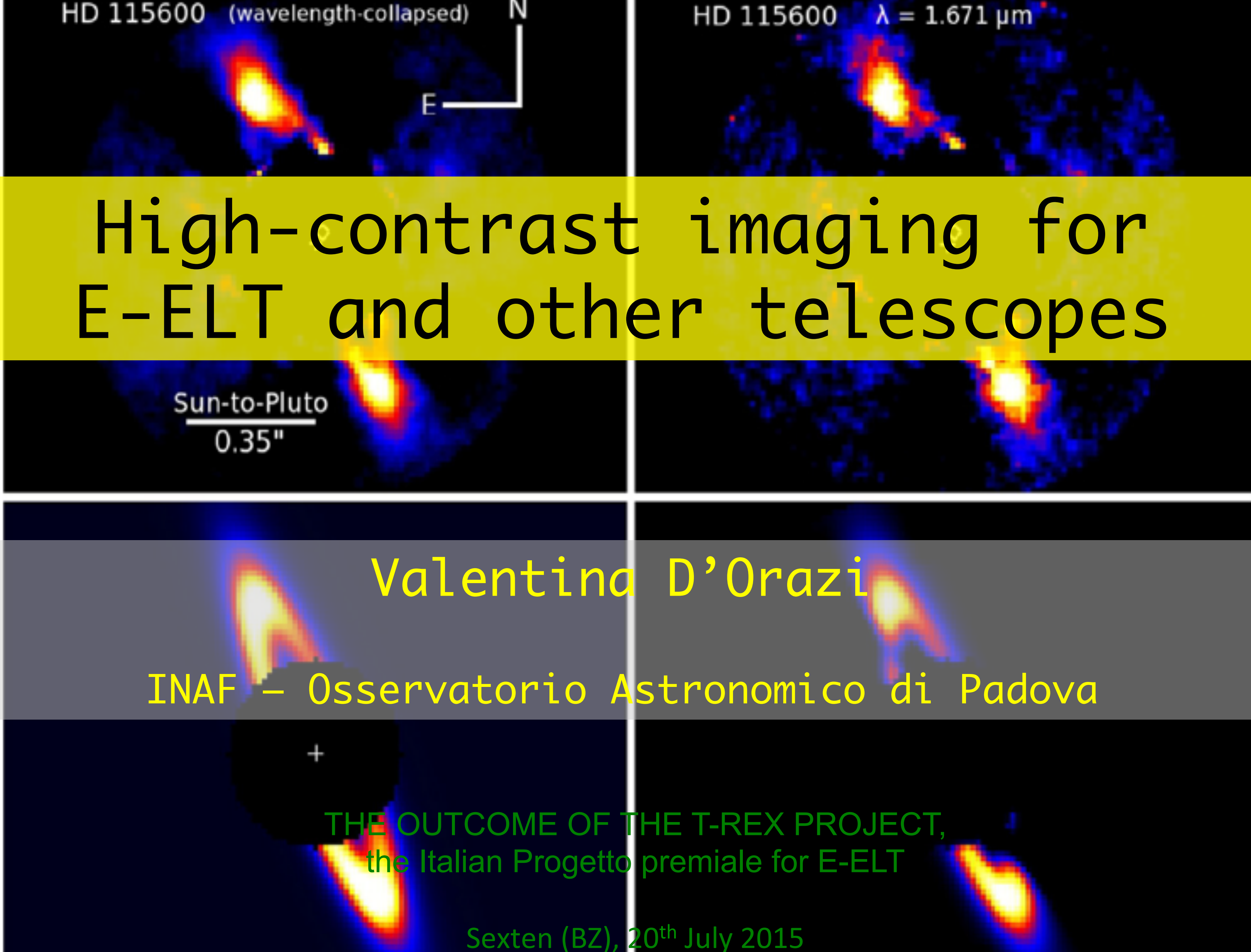
THE OUTCOME OF THE T-REX PROJECT,
the Italian Progetto premiale for E-ELT

Sexten (BZ), 20th July 2015



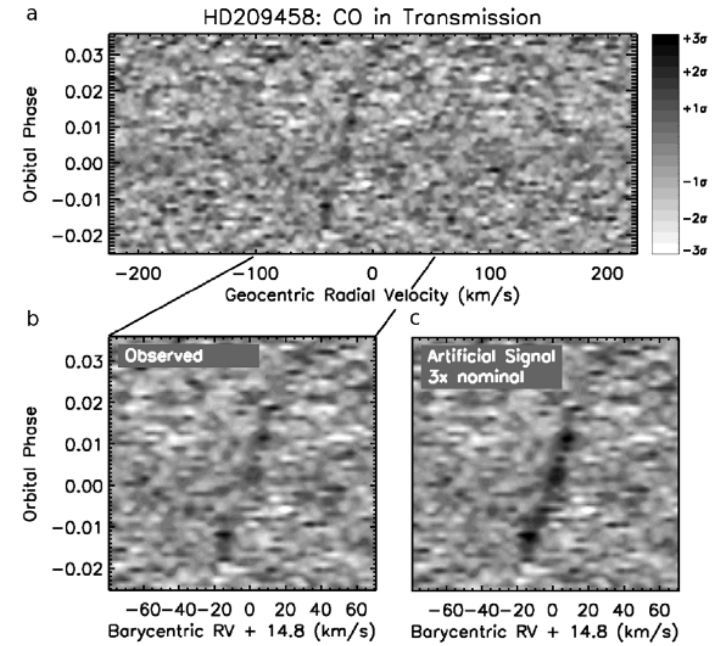
1. Combining high-dispersion spectroscopy with high-contrast imaging

Raffaele's talk

People: Ignas Snellen, Christoph Keller (Leiden University)
Raffaele Gratton (INAF – Padova)

High-dispersion spectroscopy as a very powerful tool to characterise exoplanet atmospheres (and NOT only!) →

- Molecular Bands are resolved in tens of individual lines
- Strong Doppler effects due to orbital motion of the planet (up to >150 km/sec) so that moving planet lines can be distinguished from stationary telluric & stellar lines

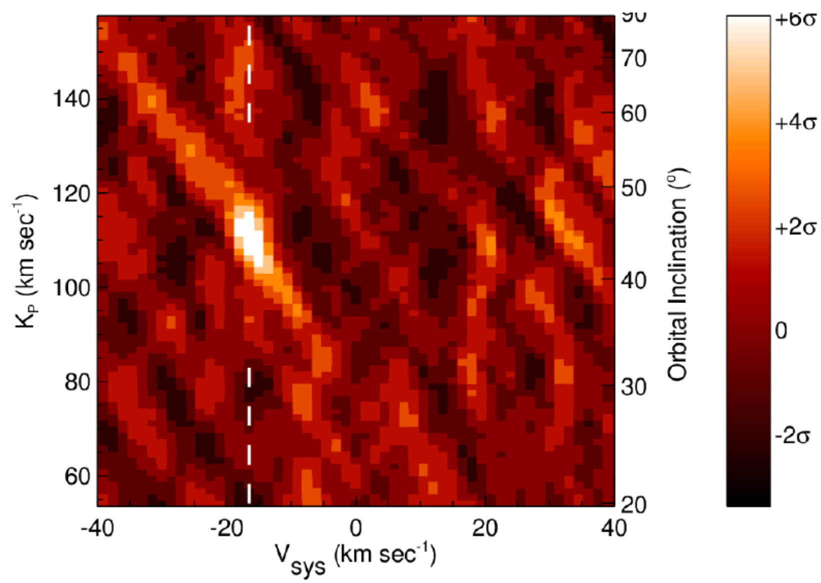


CRIRES @VLT (NIR domain, R~100,000)

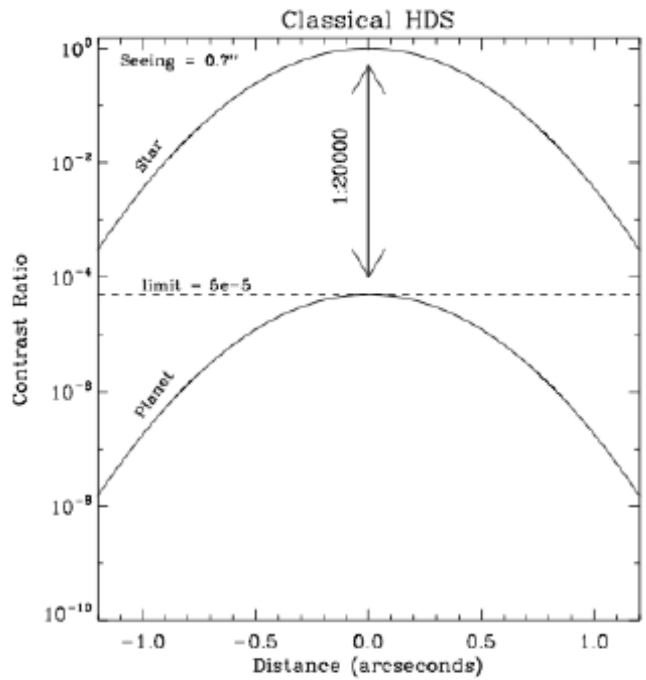
Snellen et al. (2010) carbon monoxide at 2.3 micron in the transmission spectrum of HD209458b

Brogi et al. (2012) CO at 2.3 micron in the thermal spectrum of the non-transiting planet tau Bootis (mass and orbital inclination determined)

Birkby et al. (2013) Water absorption in the thermal spectrum of HD189733b



Classical HDS

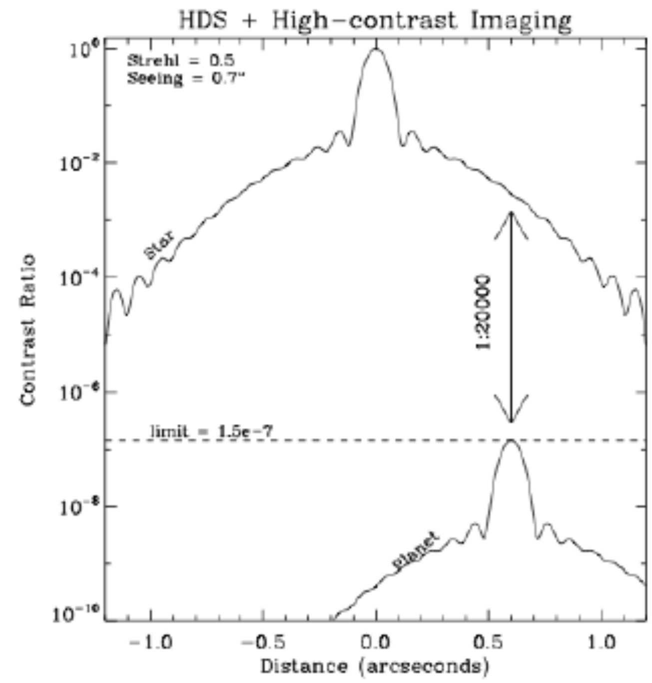


$$\mathrm{SNR} = \frac{S_{\mathrm{planet}}}{\sqrt{S_{\mathrm{star}} + \sigma_{\mathrm{bg}}^2 + \sigma_{\mathrm{RN}}^2}}$$

Limits: 10^{-5} with VLT

$\times \sqrt{N_{\mathrm{lines}}}$

HDS + HCI



$$\mathrm{SNR} = \frac{S_{\mathrm{planet}}}{\sqrt{S_{\mathrm{star}}/K + \sigma_{\mathrm{bg}}^2 + \sigma_{\mathrm{RN}}^2}}$$

$\times \sqrt{N_{\mathrm{lines}}}$

Limits: $10^{-5}/\sqrt{K}$ with VLT

Snellen et al. (2015)

How far can we push this with the ELTs?

High-resolution IFU (R=100,000) in the optical domain (0.6 – 0.9 micron) -possible implementation for PCS?

Probing the habitable zone of nearby M-dwarfs
→ we can target stars like e.g., Proxima Centauri

V=11.05 mag
Stellar radius 0.141 R_sun
Distance 1.30 pc
Planet radius 1.5 Earth
Orbital radius 0.032 AU
Angular distance from star 25 mas

Back-of-the envelope calculations demonstrate that the planet can be detected with a contrast of almost 10^{-8} at 25 mas separation with a SNR ~8/10 (in agreement with preliminary simulations by Snellen et al.)

Although being more challenging (lower Strehl ratios than NIR/MIR), the optical regime has the obvious advantage that sky background is significantly smaller + we can cover the O_2 band (biomarker!) at 770 nm

Testing with current instrumentation: LEXI -Leiden EXoplanet Instrument

A pathfinder towards E-ELT instruments that will characterise the atmospheres of Earth-like exoplanets and search for biological activity by combining HDS and HCI

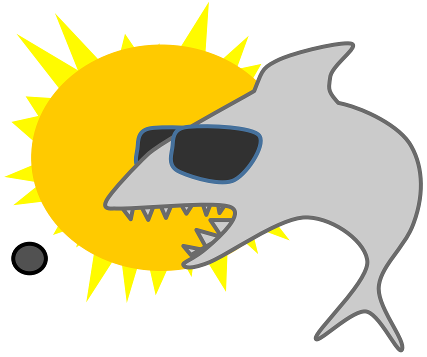
LEXI will be the first instrument specifically designed for this observing method and will work at optical wavelengths – ultimately the regime where biomarker gases in Earth-like atmospheres will need to be probed.

Reaching optical planet/star contrasts of ~10-7, it will be used for the optical characterisation of young hot gas giants and brown dwarfs, and uniquely map velocity fields of proto-planetary dust around young stars.

LEXI is a fiber-fed, bench-mounted, high-dispersion spectrograph that will record spectra of a small area around a star with high spatial resolution and high dynamic range. The fiber-feed reformats the square image area into a single, long slit that feeds a spectrograph with a Volume Phase Hologram (VPH) grating to record spectra with a dispersion of ($\lambda/\Delta\lambda$~100,000) for hundreds of locations simultaneously in the image area over a spectral range of 5-10 nm where interesting spectral features are expected.

An exciting perspective: testing LEXI on LBT SHARK-VIS

2. SHAR(K)



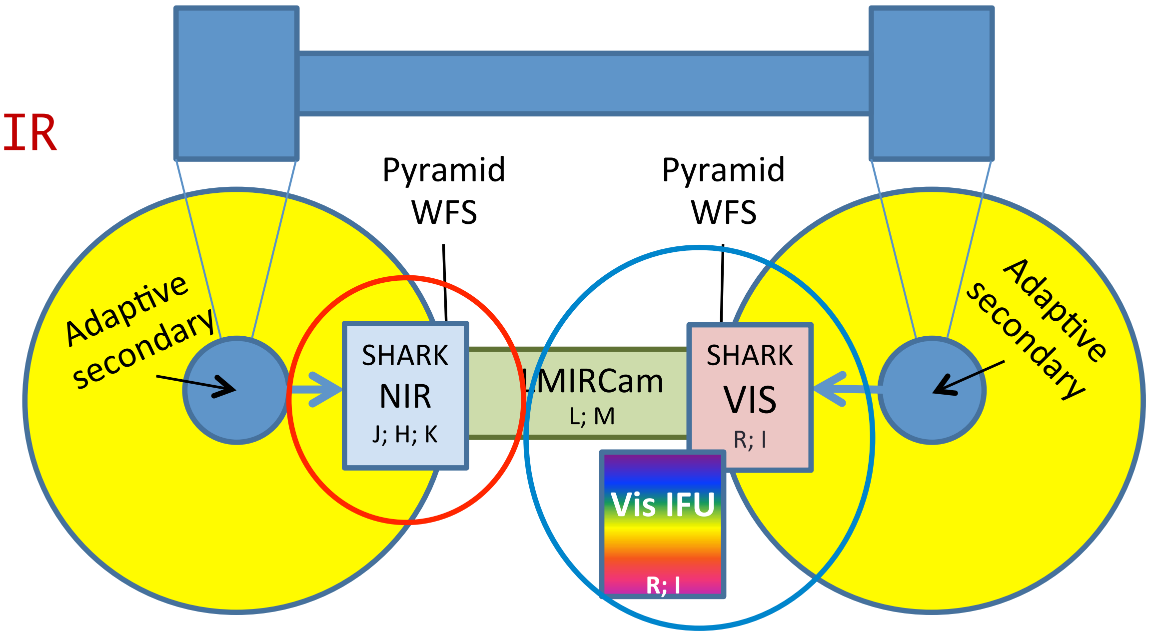
System for coronagraphy with High-order Adaptive Optics from R to (K) band

The SHARK Team J.Farinato[1], F.Pedichini[2], E.Pinna[3], S.Antoniucci[2], F.Bacciotti[3], C.Baffa[3], A.Baruffolo[1], S.Benatti[1], M.Bergomi[1], M.Bonavita[1], M. Bonnefoy[4], A.Bongiorno[2], L.Borsato[7], E.Brocato[2], P.Bruno[4], E.Cappellaro[1], L.Carbonaro[3], A.Carlotti[4], E.Carolo[1], M.Centrone[2], G. Chauvin[4], R.Claudi[1], L Close[6], J.Codona[6], I.Crossfield[5], P. Delorme[4],S.Desidera[1], M.Dima[1], V.D'Orazi[1], S.Esposito[3], D.Fantinel[1], G.Farisato[1], F.Fiore[2], A.Fontana[2], W.Gaessler[6], E.Giallongo[2], T.Giannini[2], V.Granata[7], R.Gratton[1], D.Greggio[1], J.C.Guerra[5], O.Guyon[5],T.Henning[6], P.Hinz[5],M.Kasper[13], D.Kopon[8], F.Leone[9], F.Lisi[3], D.Magrin[1], A.-L.Maire[1], L.Malavolta[7],J.Males[6], L.Marafatto[1,7], F.Massi[3], D.Mesa[1], G.Micela[11], M.Munari[4], V.Nascimbeni[7],B.Nisini[2], I.Pagano[4], G.Piotto[7], L.Podio[3], A.Puglisi[3], R.Ragazzoni[1], M.Rieke[6],B.Salasnich[1], E.Sani[3], G.Scandariato[9], S.Scuderi[9], E.Sissa[1], A.Sozzetti[10],M.Stangalini[2], M.Turatto[1], D.Vassallo[1,7], C.Verinaud[4], V.Viotto[1], S.Zibetti[3], A.Zurlo[1,12]

1) INAF PADOVA 2) INAF ROMA 3) INAF-ARCETRI 4) IPAG 5) STEWARD OBSERVATORY – ARIZONA (USA) 6) MPIA 7) UNIVERSITY OF PADOVA 9) INAF CATANIA 10) INAF TORINO 11) INAF PALERMO 12) LAM – MARSEILLE 13) ESO

Call for LBT instruments (Feb 2014)

SHARK-NIR
PI Jacopo Farinato



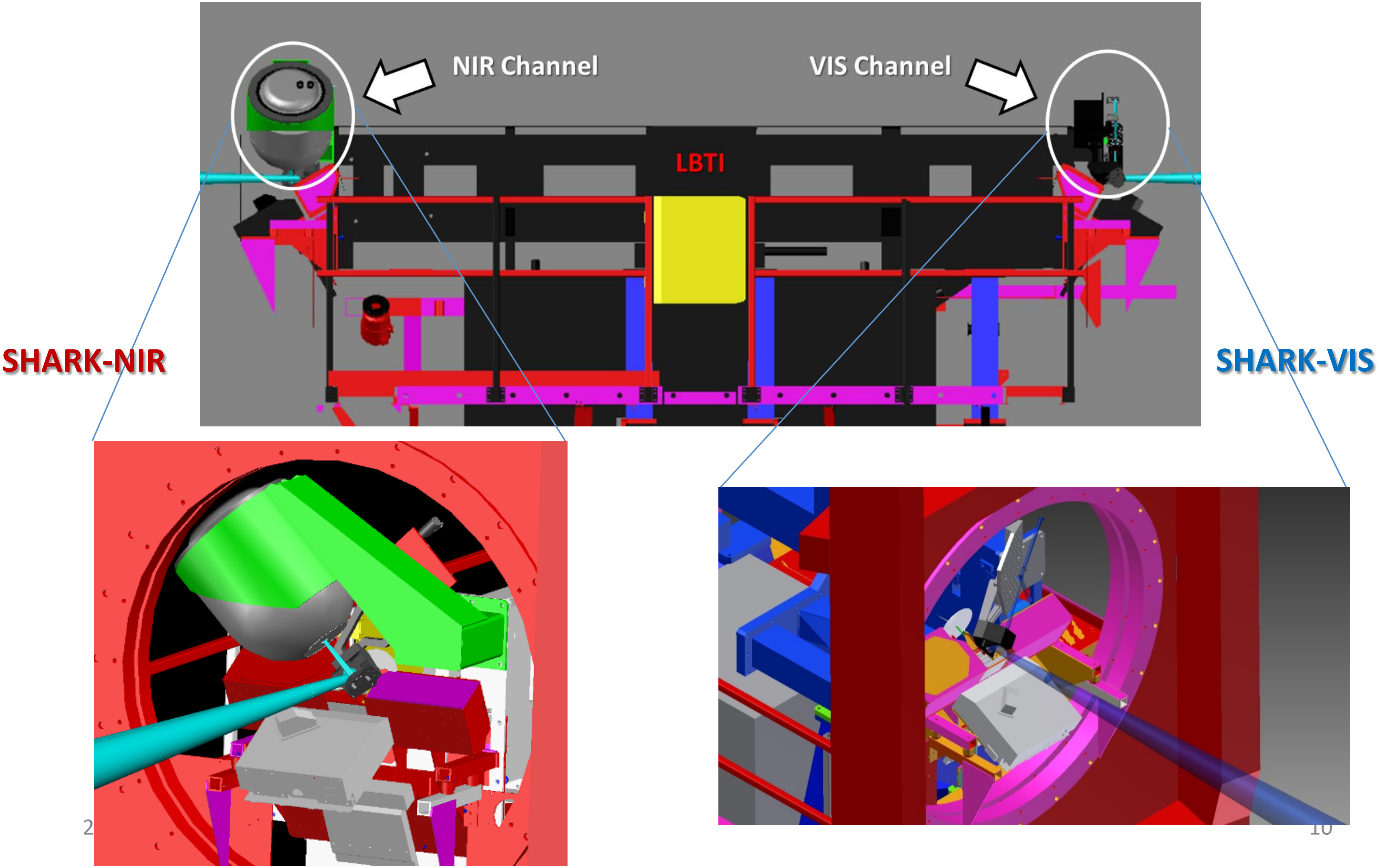
SHARK-VIS
PI Fernando Pedichini

Even if it is a 2nd generation instrument, it can coexist with the 1st generation, with an impact as soft as possible (simplicity, small dimension, only partially overlapping wavelength range).

In fact, SHARK basic features are:

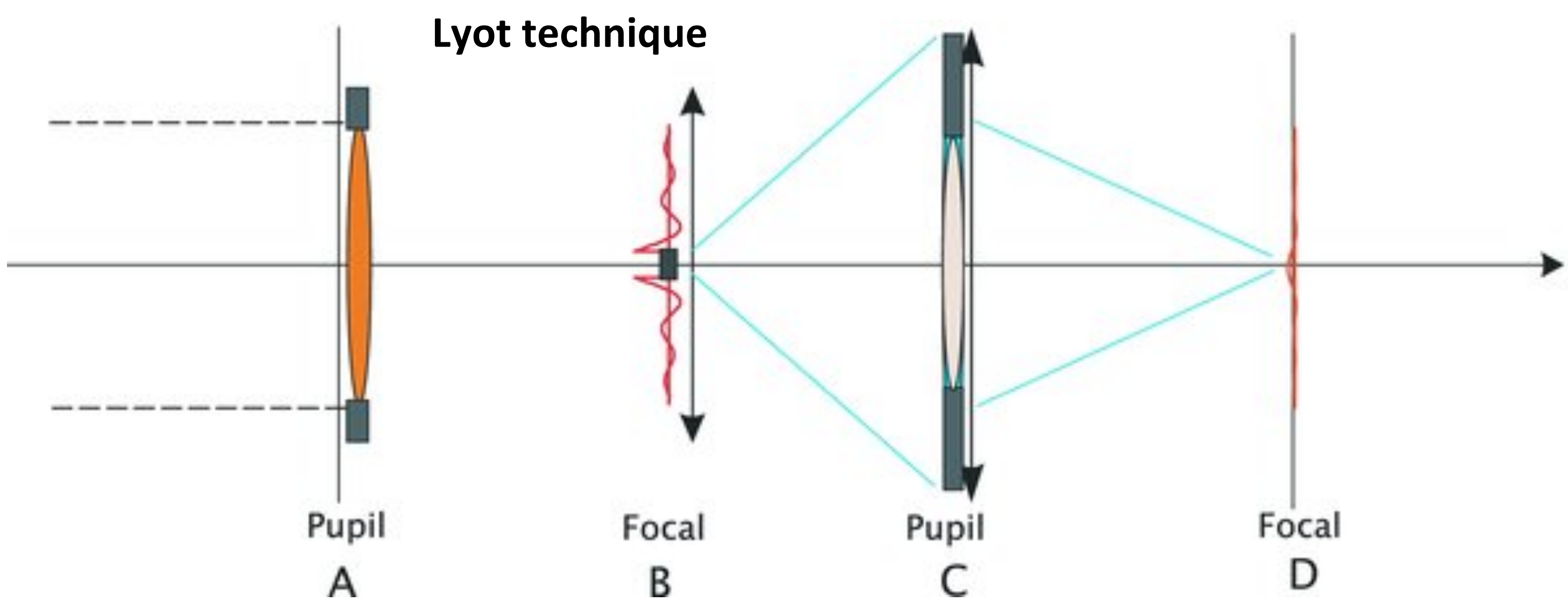
- ✓NIR Coro-Camera : J,H,(K)
- ✓VIS Coro-Camera: R,I
- ✓VIS Spectrograph (→ LEXI ?)

SHARK location: at the entrance of LBTI



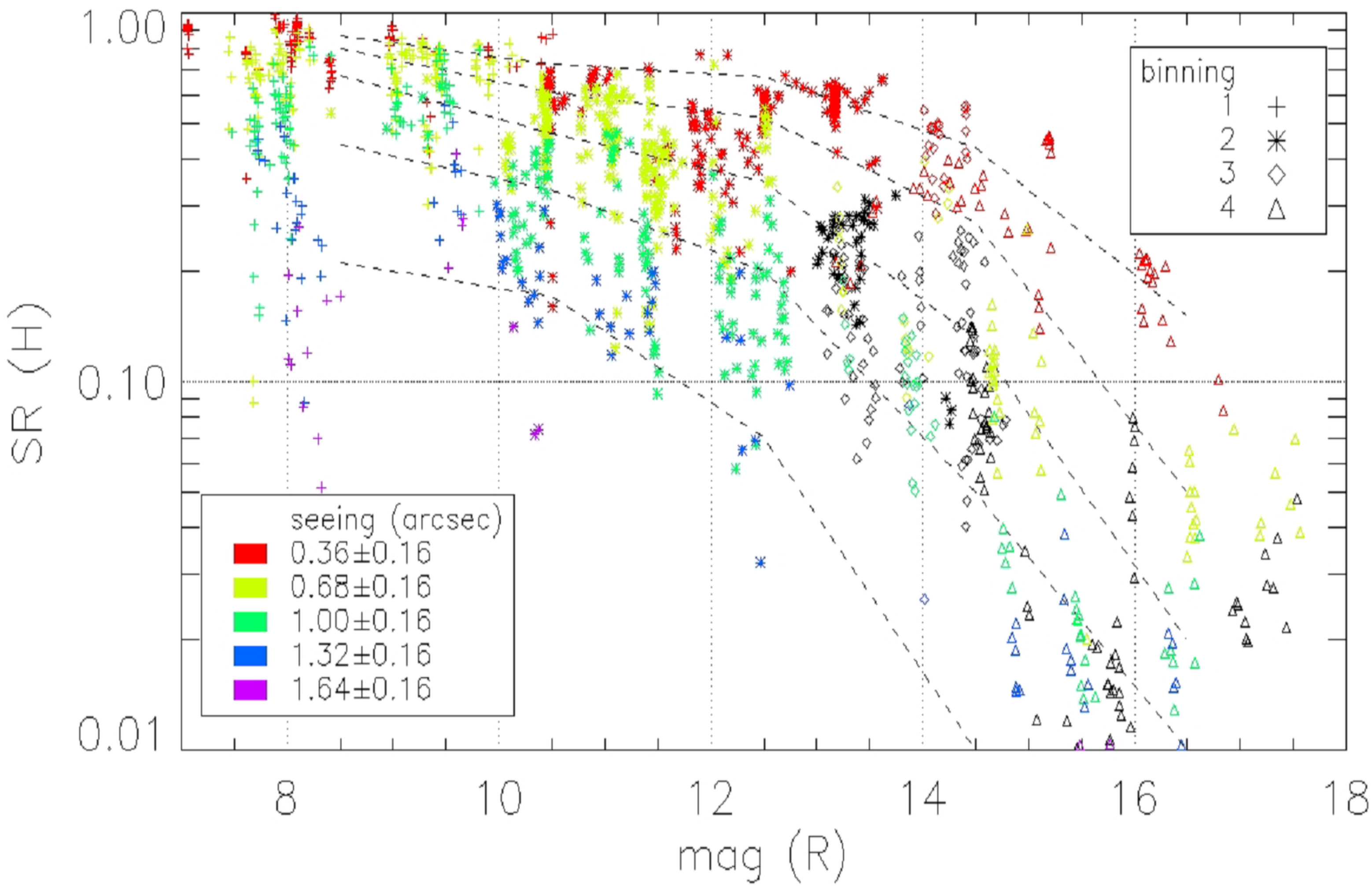
Coronagraphy

There is a baseline design for the coronagraph (Classical Lyot), but we do have a flexible design with filter wheels on both the focal and the pupil planes, where different techniques might be implemented -> (Apodized Lyot Coronagraph + Shaped Pupil)



We do have an outstanding main science case (exoplanet hunting and characterisation) plus several others very interesting cases that require binocularity + coro mode

We will make use of the XAO LBT capability



SHARK

Cutting the K band:

Time is CRUCIAL (FASTEST TIMESCALE!)
No NEED to be CRYO
Intermediate pupil plane
→ possibility to implement APLC

For non-coro imaging → LUCI
CORO-imaging → LMIRCAM upgrade to NIR (JHK)

↓

Science cases are UNAFFECTED +
Utmost synergy between LBT instrumentations!

Thermal background calculations force us to cut the H-band at 1.7 μm

→

Major contribution: Thermal background due to the window (seen by the dewar) + minor cont. from warm baffle, reflections and cold shield

Adopting as a typical temperature 0 °C (roughly the mean temperature at Mount Graham), and a distance of the detector from the window of 180 mm (NOTE: this is the driving constraint as to the background contribution)

→ Acceptable number is approximately 5 photons/pixel/sec (RON is typically 7-10 e^-/pix/sec)

T=0 °C

lambda	photons
1.70	~5
1.65	~3
1.60	~2

T=-10 °C

lambda	photons
1.70	< 2
1.65	~1
1.60	<1

T=+10 °C

lambda	photons
1.70	~15
1.65	~8
1.60	~5

Less than 10 % of observing time

SHARK-NIR science

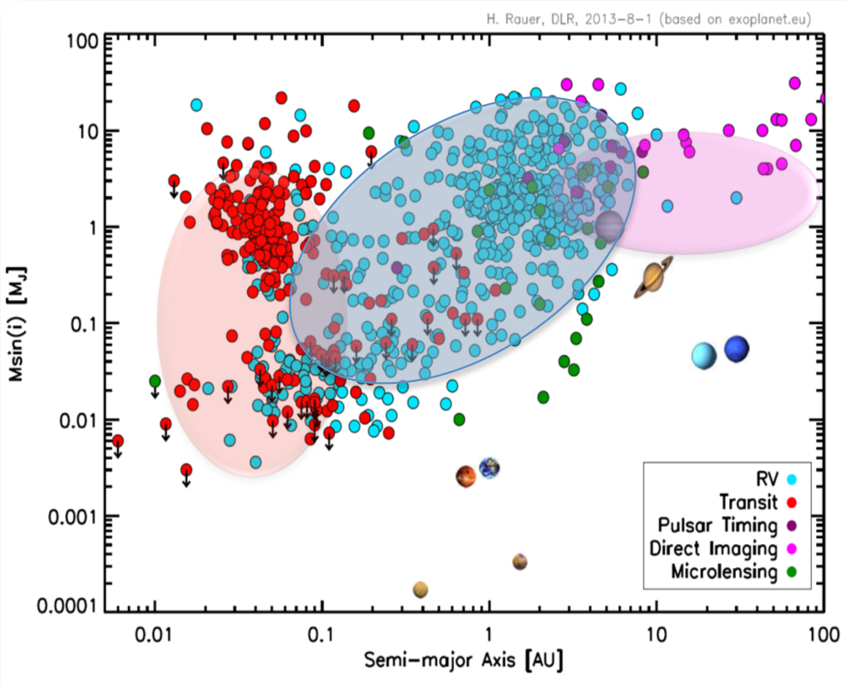
Direct imaging of nearby giant planets (and spectroscopic characterisation)

Disks around Young Stars and their Jets

AGNs and QSOs

Exoplanets: the contest

Direct imaging allows to detect giant planets at larger separations (> 5-10 AU), complementing information from RV and transits.



~3% of known planets discovered by direct imaging

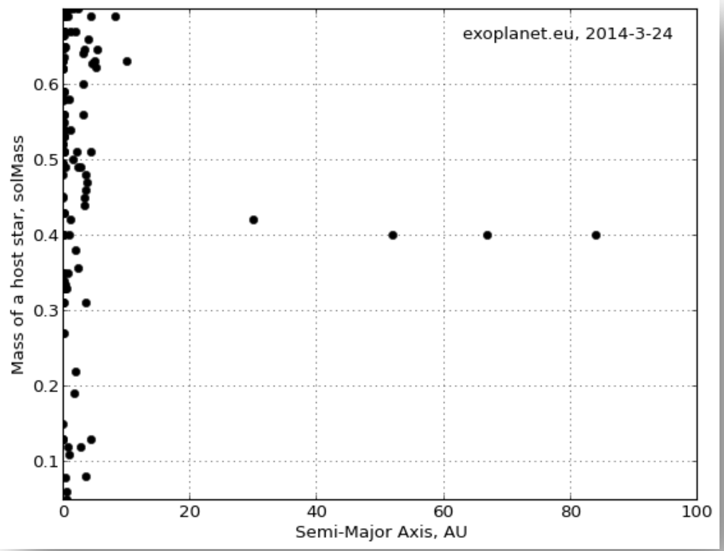
Why do they matter?
→ Diversity

1) Different formation mechanism
2) Different evolution
3) Atmospheric characterisation

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: wide planets orbiting low-mass stars (e.g., K/M dwarfs in young associations and SFRs like Taurus)

SPHERE and GPI will be mostly limited to solar-type and early-type stars (in the Southern hemisphere)



Targets:

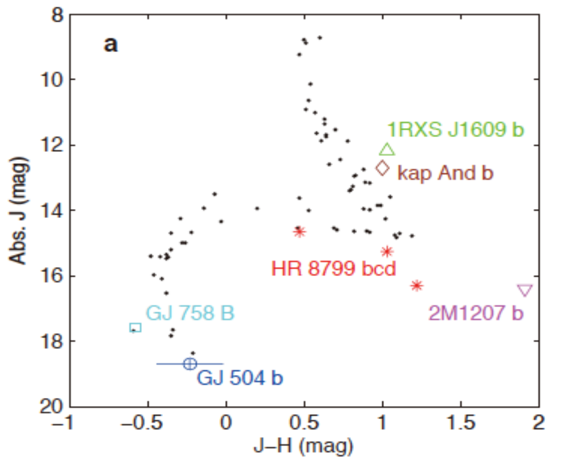
Several members of young moving groups (age 10-100 Myr) were recently identified, with special effort for low-mass stars (see e.g. Schlieder et al. 2012; Gagnè et al. 2013; Riedel et al. 2014).

Requirements
IWA ~ 100 mas; **FoV** ~10x10 arcsec ; **Mode**: imaging + coronagraph;
Filters: Broad band in NIR (JH range 1-1.7 micron)

Photometric and spectroscopic characterisation of known planets

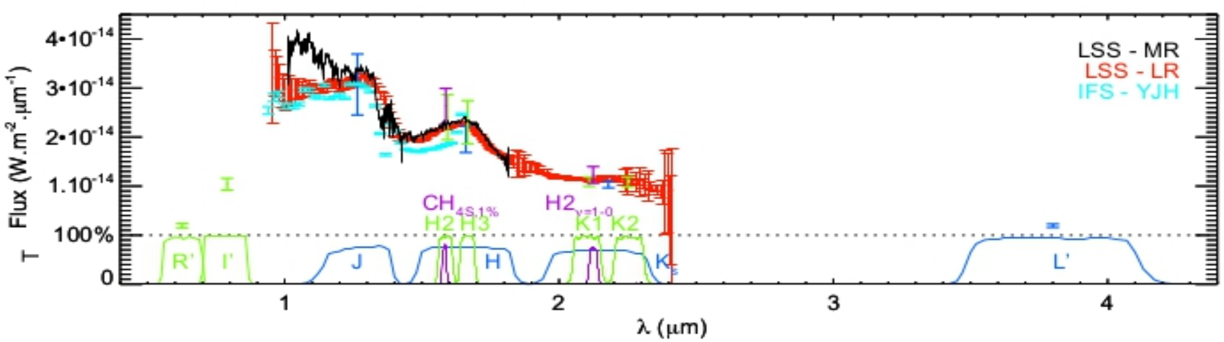
Planet characterization

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).



NIR colour magnitude diagrams for planets and BDs
from Kuzahara et al. (2013)

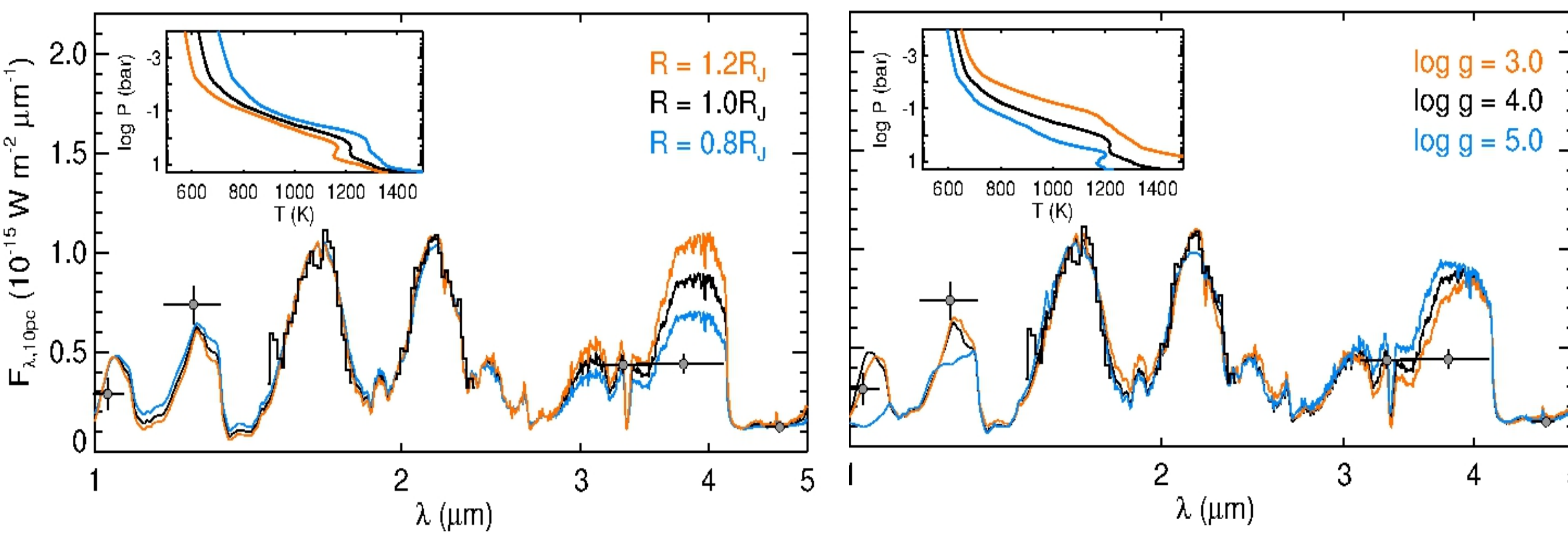
The implementation of a long slit spectroscopic mode will furnish spectral classification (L vs T) if R=30 and molecular band identification if R > 100.



Maire et al. 2015 (subm)

Photometric and spectroscopic characterization of known planets

Synergy with LMIRCAM will provide us with large and critical spectral coverage that is CRUCIAL as to breaking degeneracies affecting NIR-only spectroscopic observations



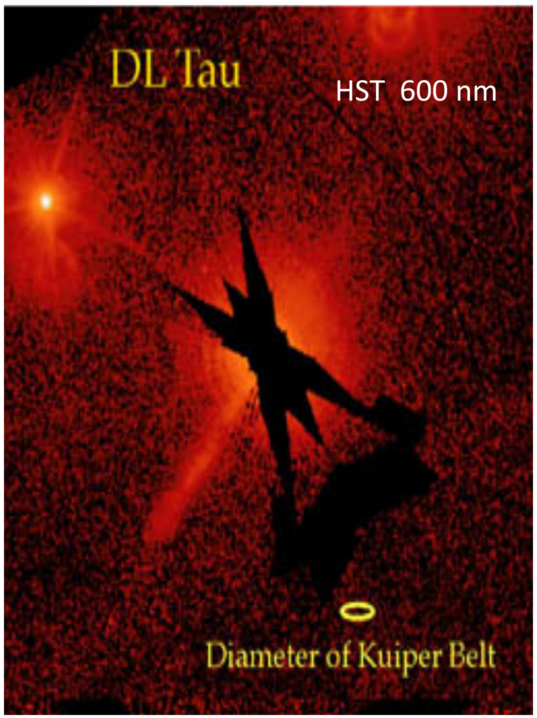
Lee et al. (2013)

Disks around Young Stars and their Jets

- High-contrast imaging of circumstellar disks with NIR coronagraphy.
- Coronagraphic imaging of stellar jets
- 2D maps of Jets

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

Grady et al 2004

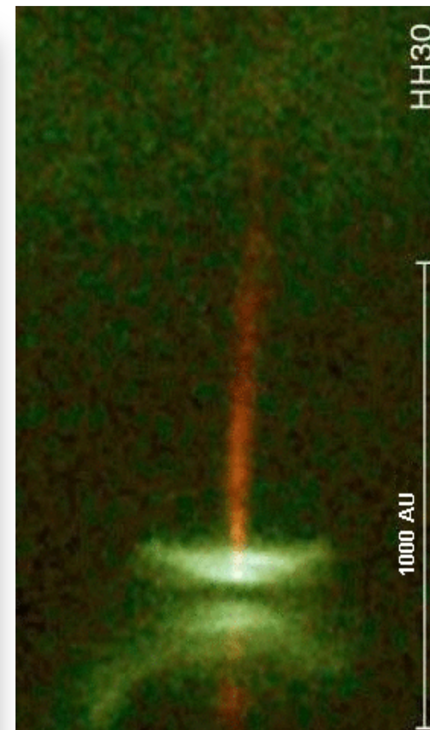


Goals:

understand dynamic role of jets in shaping the disk structure

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

H2 as key tracer: SYNERGY with LMIRCAM

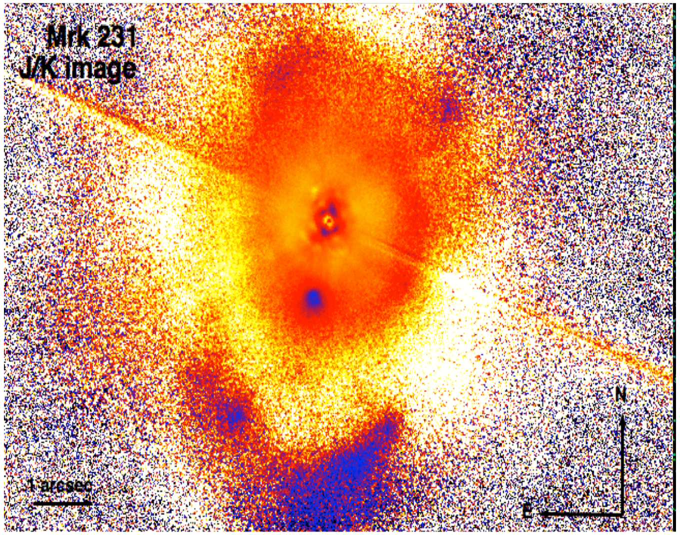


Wood et al. 2001

Requirements

IWA<4λ/D; FoV ~ 10"x10"; SR > 45% Mv=10-13

AGNs and QSOs



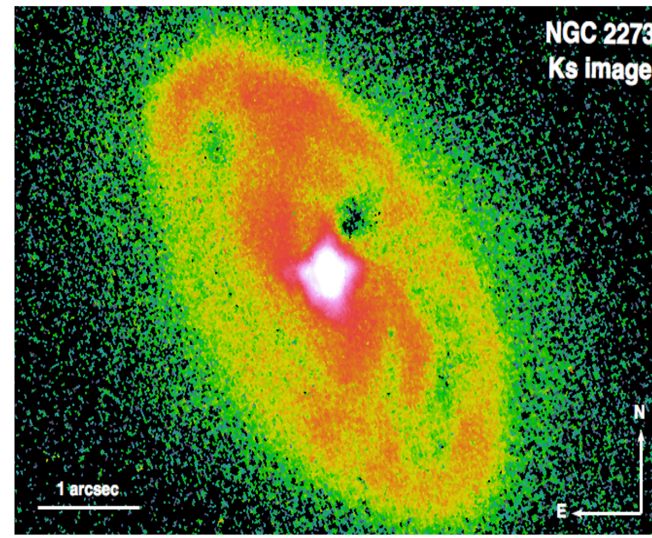
Discover and fully characterize the AGN close pairs;

Constrain the Black Hole feeding mechanism (e.g., SN driven winds *vs* gravitational asymmetries) in local Seyfert galaxies

Trace, in bright quasars, molecular outflows powerful enough to clean the inner kpc and quench the star formation

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

Constrain fundamental physics.



Requirements:
Binocular VIS and NIR both imaging and coro modes. + Synergy with LMIRCAM for H_2
Coronagraphs with $2<\lambda/D<8$; FoV of 5”x5” and ~20”x20” for DLAs and AGN inner morphology.
The achievable SR (H-band, average seeing 0.8”) for AGN with the current FLAO capabilities ranges from 50% for the brightest targets to 30% for I=15 mag.