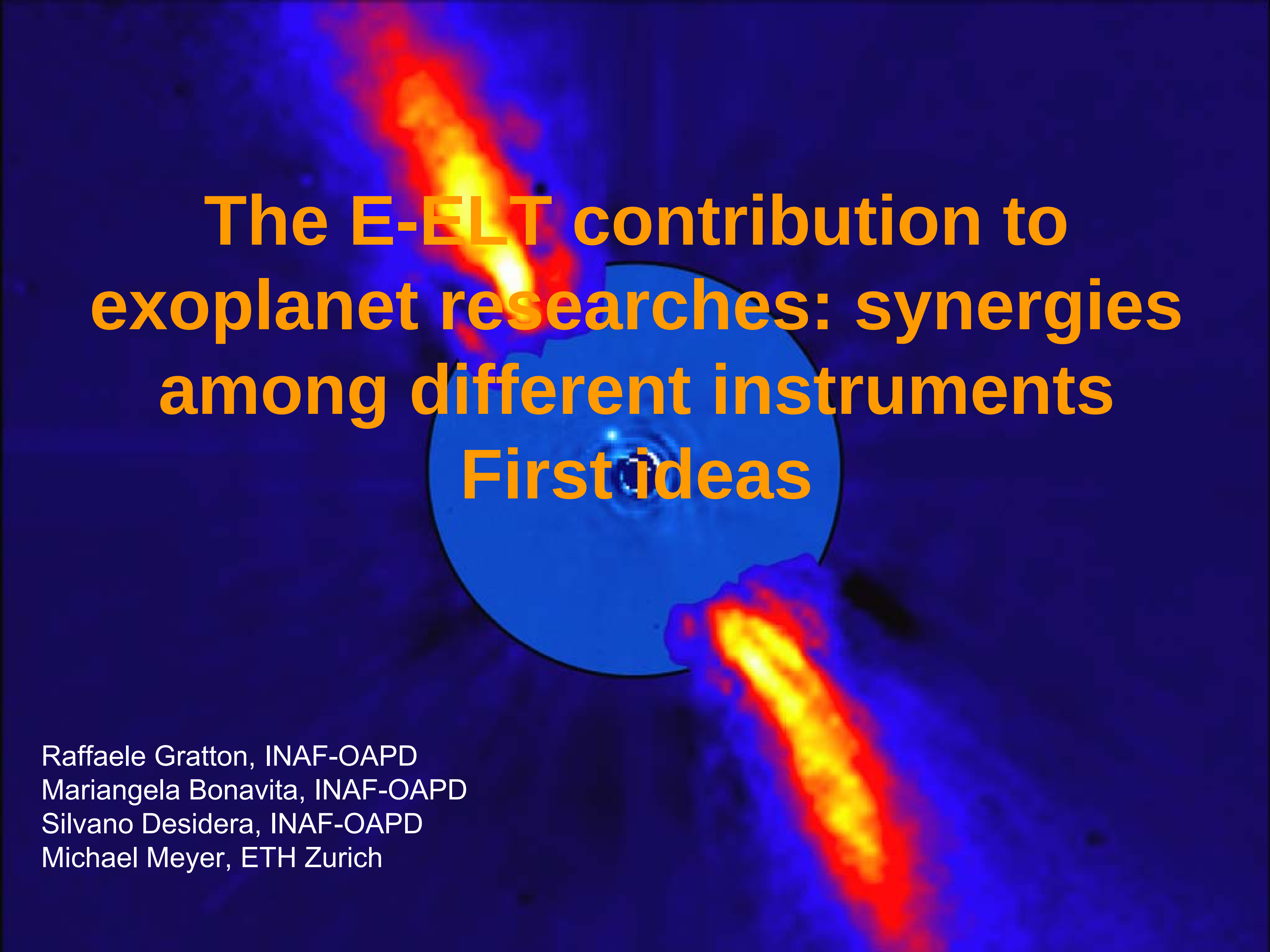

The E-ELT contribution to exoplanet researches: synergies among different instruments First ideas

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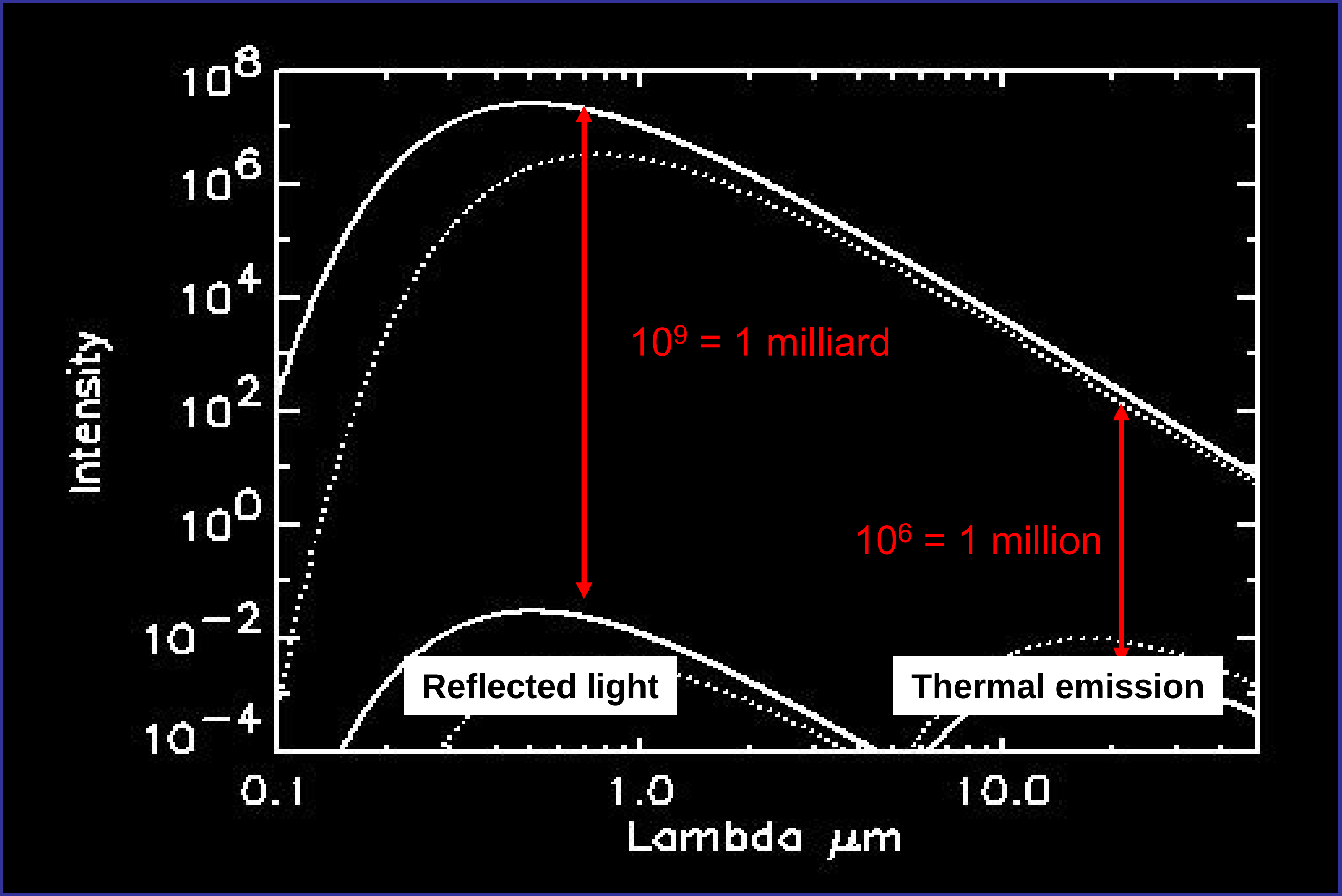
E-ELT Instruments & exo-planets

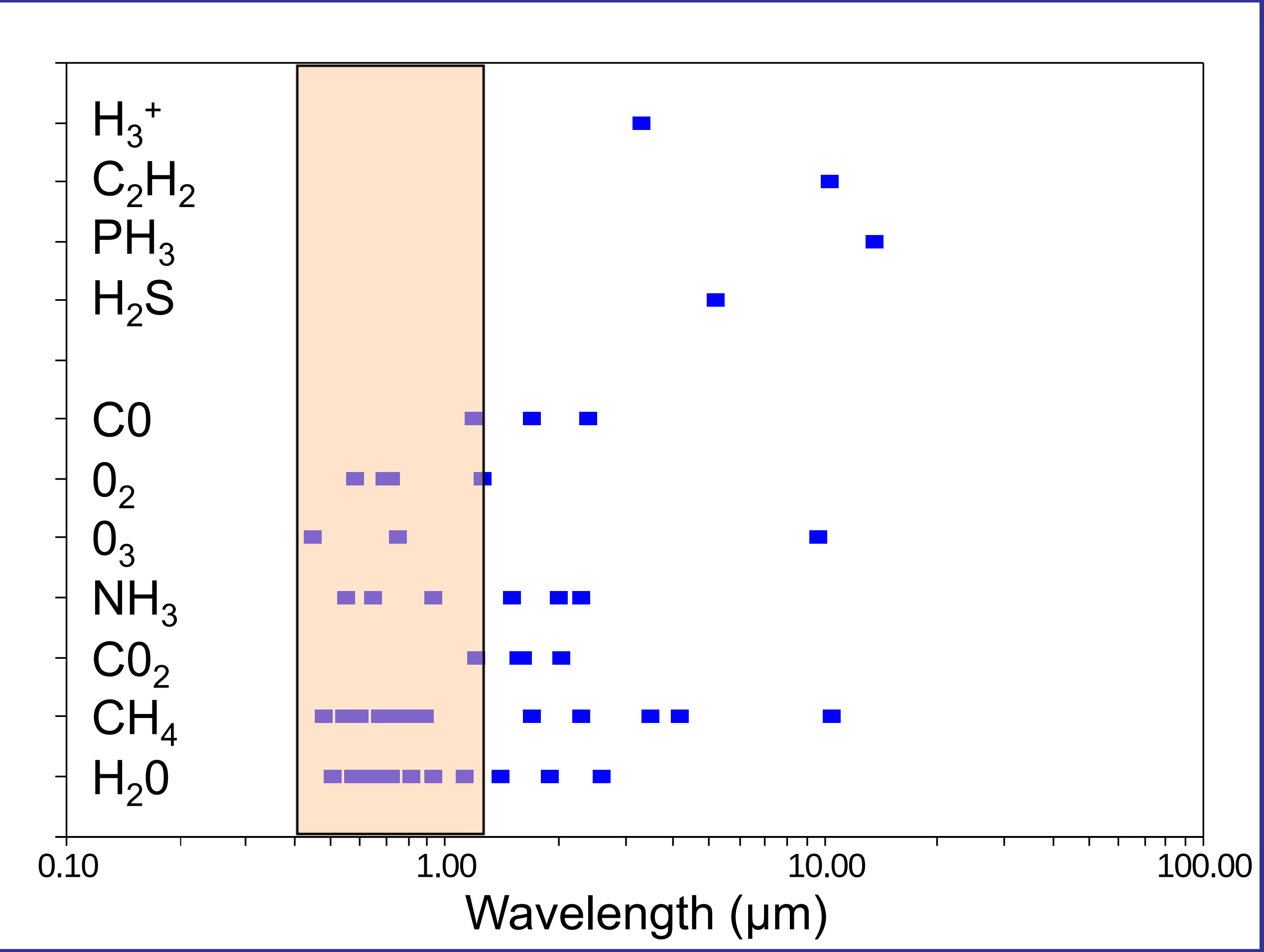
Technique	Instrument	Short Description	Exo-planet science
Imaging, spectroscopy and polarimetry	EPICS	NIR high contrast imager	Survey for detections System architecture Planet atmosphere characterization (Temperature, composition)
	METIS	MIR imager and spectrometer	Planet atmosphere characterization (Temperature, composition)
	HARMONY	NIR imager and spectrometer	Planet atmosphere characterization (Temperature, composition)
Very high precision radial velocities (<M2)	CODEX	Very stable HR spectrograph in visible	Survey for detection (<M2) System architecture Dynamical masses
	SIMPLE	Stable HR spectrograph in NIR	Survey for detection (>M2) System architecture Dynamical masses
	OPTIMOS Eve	Fiber fed Multiobject Spectrograph	Survey for detection System architecture Dynamical Masses

Problematic

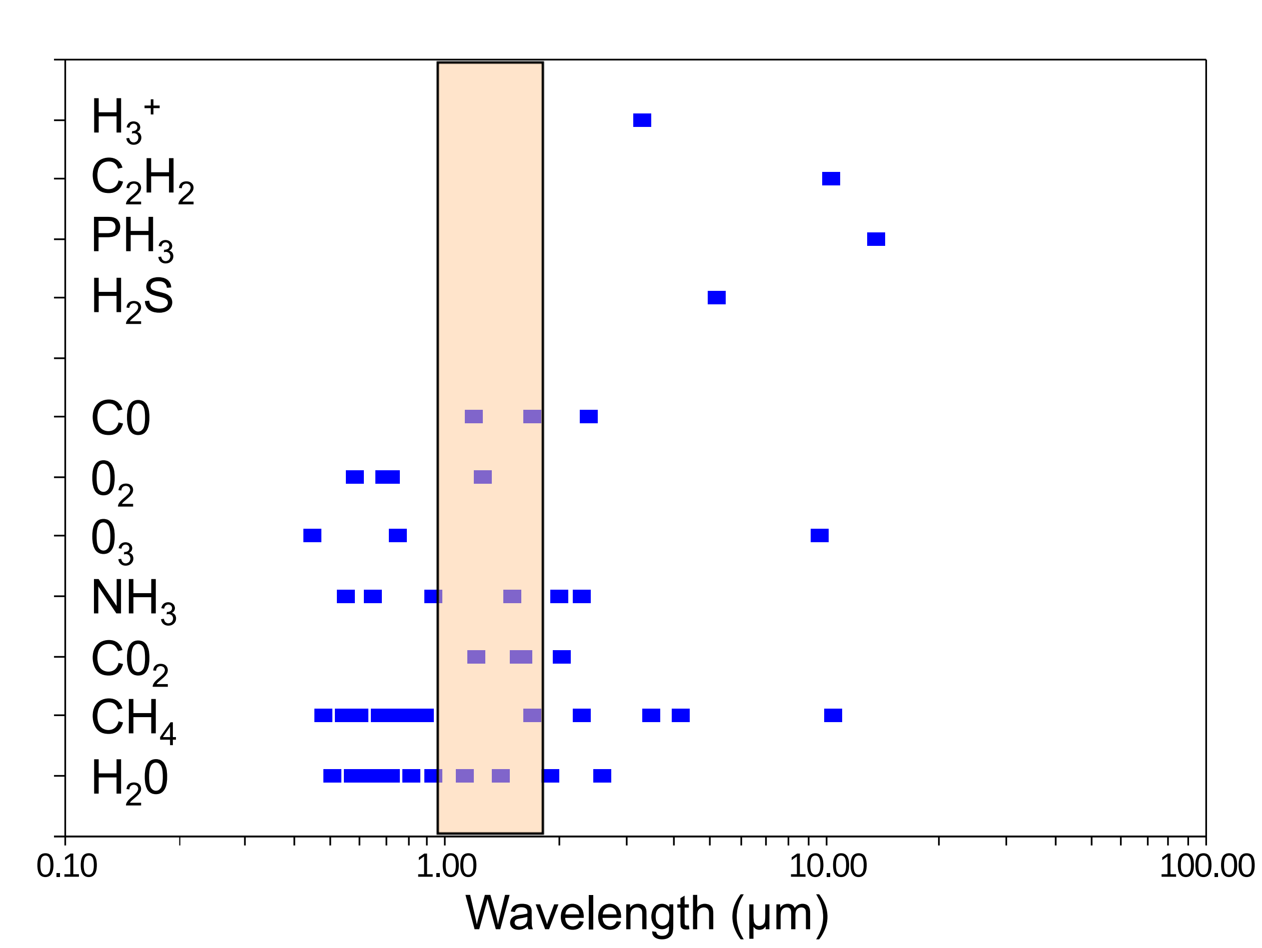
Planets are faint and close ….



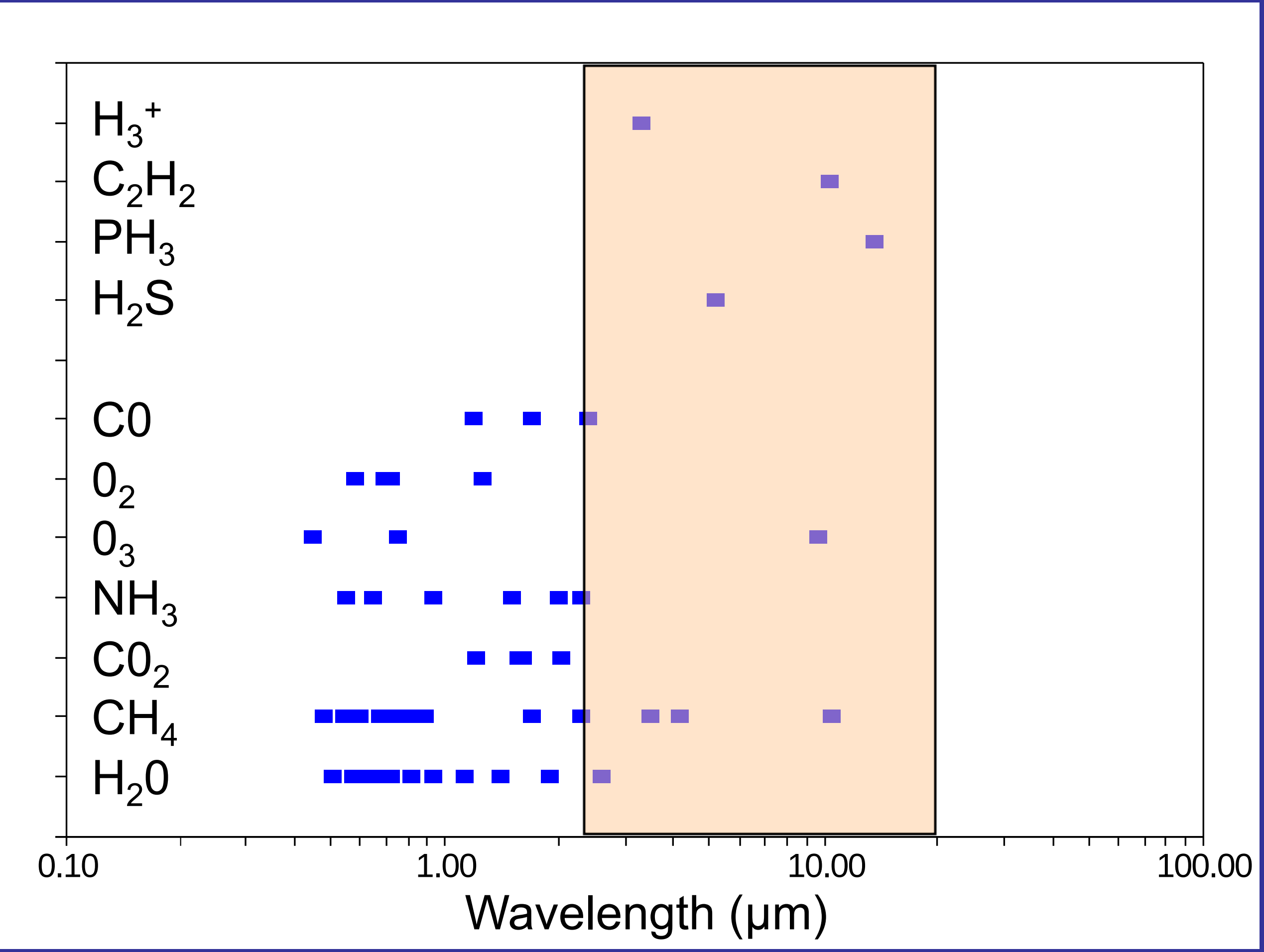
Visible: Space Coronagraphs

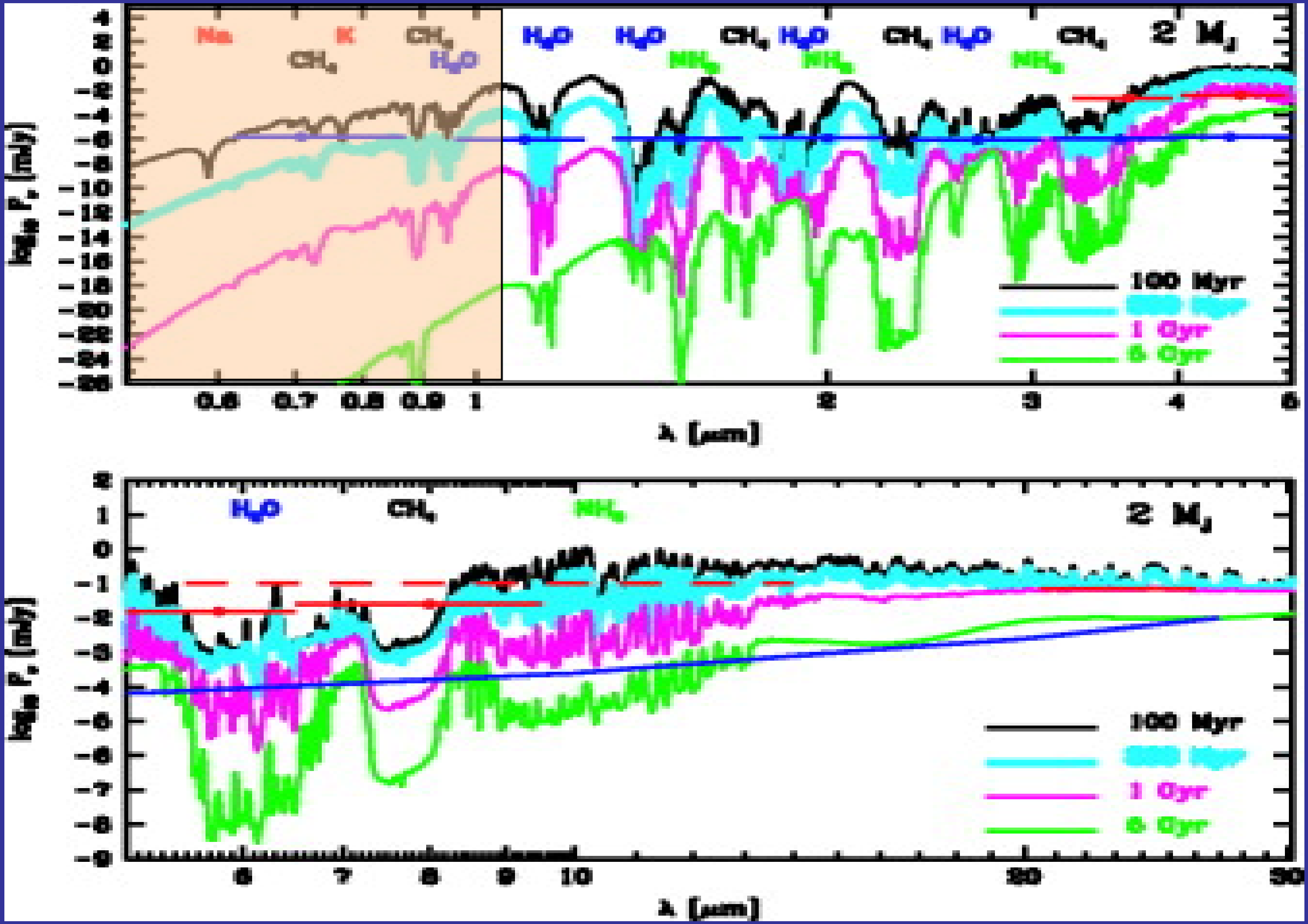


NIR: Sphere, GPI, NIRCAM, EPICS

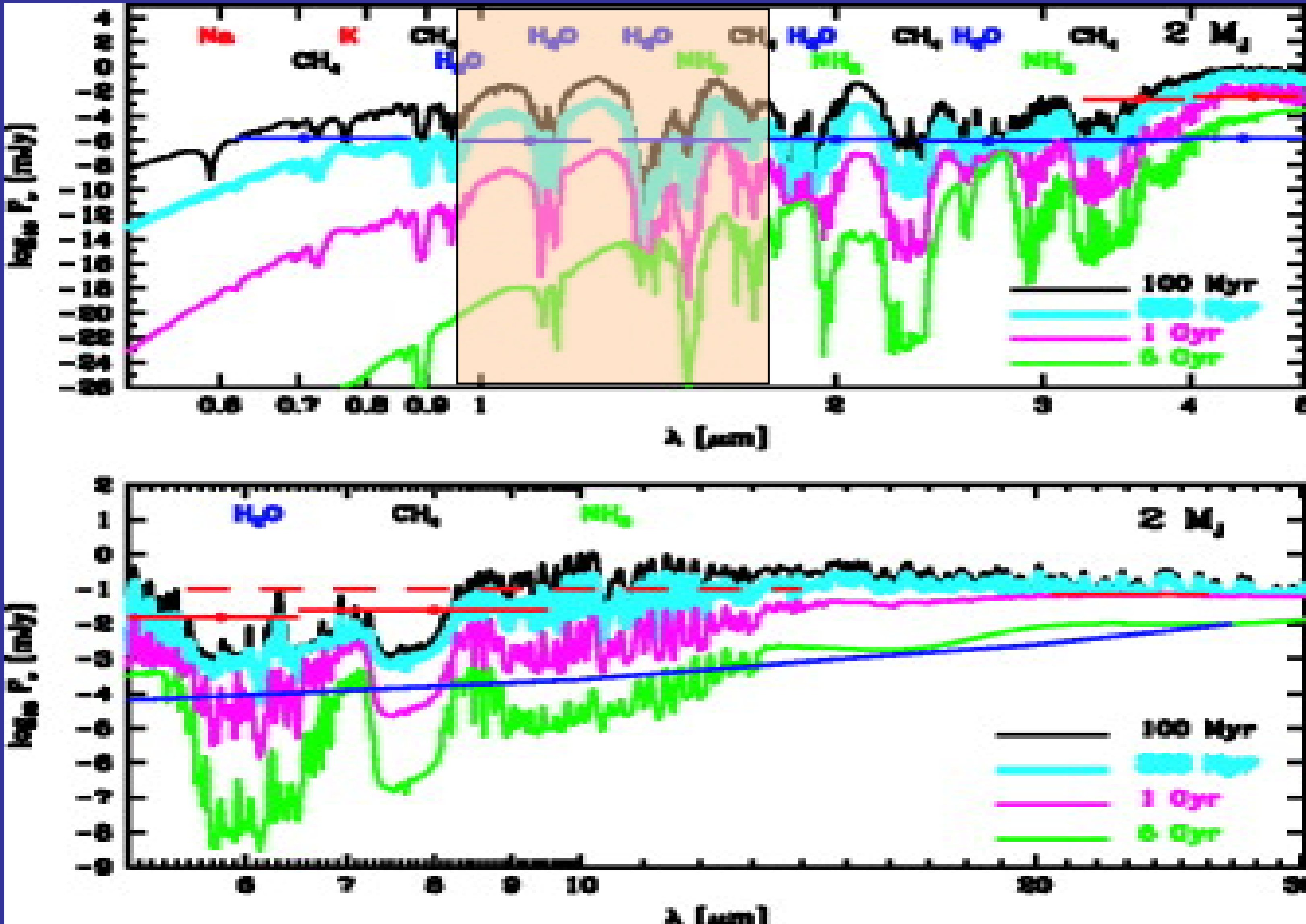


MIR: MIRI, METIS

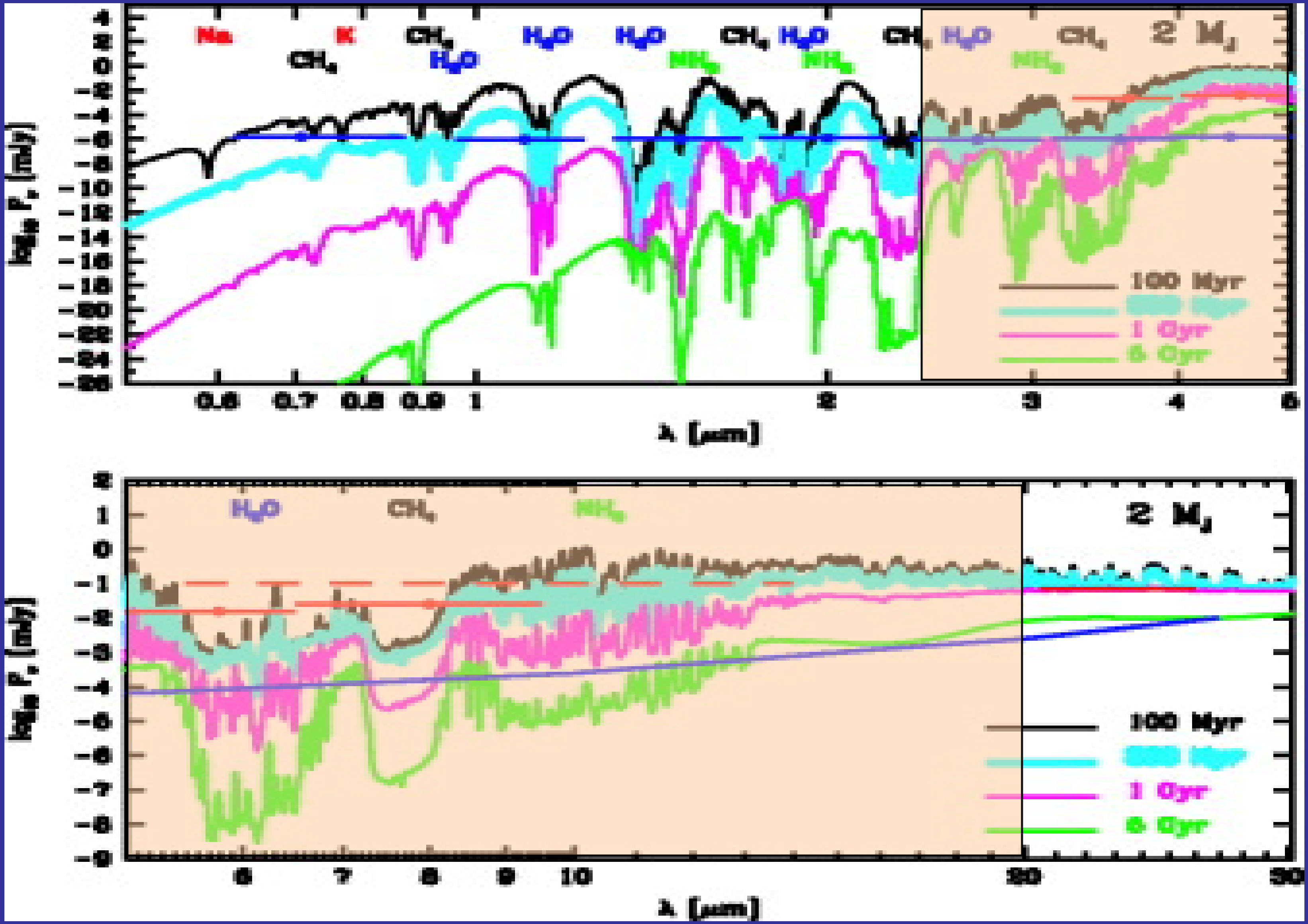




0.5-30 μm spectrum of an isolated 2 M_J planet (Burrows et al.2003, ApJ 596, 587) vs Visible (Space Coronagraphs)



0.5-30 μm spectrum of an isolated 2 M_J planet (Burrows et al.2003, ApJ 596, 587) vs NIR (Sphere, GPI, NIRCAM, EPICS)



0.5-30 μm spectrum of an isolated 2 M_J planet (Burrows et al.2003, ApJ 596, 587) vs MIR (MIRI, METIS)

Spectroscopic characterization

- Wide spectra coverage veri desiderable. Complementarity between information provided by Vis, NIR and MIR
- Spectra at higher resolution than in standard set-up for planet detection will allow a more detailed characterization (for planets detected with high enough S/N)
- Some science goals: identification of spectral features, determination of physical parameters (temperature, gravity, chemical composition), cloud process and their variation with time (e.g. for planets in eccentric orbits)
- R=3000, R=20000 considered

Observable planets: methodology - inputs

STELLAR PARAMETERS (M_{Star} (M_{sun}), d (pc), Age (Myr), etc.) from two samples of real stars:

- Young sample (Age < 500 Myrs, d<100 pc), ~1200 stars
- Nearby sample (d < 20 pc) ~600 stars

PLANET PARAMETERS:

- $M_p \sin i$ (M_J) and P (days) randomly generated using the distributions from Cumming et al. 2008, extrapolated up to periods corresponding to a = 40 AU (for M_{Star} = 1 M_{sun}) and scaled with the stellar mass
- 0.0 < e < 0.6 generated following the observed RV distribution
- All the orbital elements (including inclination), randomly generated using uniform distributions

MONTE-CARLO SIMULATION TOOL:

- **MESS (**Multi-purpose Exo-planet Simulation System) see Bonavita et al.(2009) in prep.

DETECTION LIMIT CURVES:

- Direct Imaging (SPHERE, GPI, EPICS, METIS, JWST, Space Coronagraphs)
- Radial velocity (HARPS, EXPRESSO, CODEX)
- Astrometry (GAIA)

Observable planets: methodology - outputs

DERIVED PLANET PARAMETERS:

• Semi-major axis (AU) and projected separation (arcsec) evaluated assuming Distance and Mass of each star

• Radius (R_J) estimated following the approach of Fortney et al. (2007)

• T_{eff} (K) estimated using the models by Sudarsky et al. (2001)

• Intrinsic luminosity obtained using the models by Baraffe et al. (2003)

• Reflected luminosity in visible and NEAR-IR (V, H, K, L Band) obtained scaling the Jupiter luminosity with planet semi-major axis and radius

• Reflected luminosity in MID-IR (λ_C = 11.4 μm) obtained assuming a black body emission at $T = T_{eff}$ and $\lambda = \lambda_C$

• Radial Velocity Semi-amplitude (m/s)

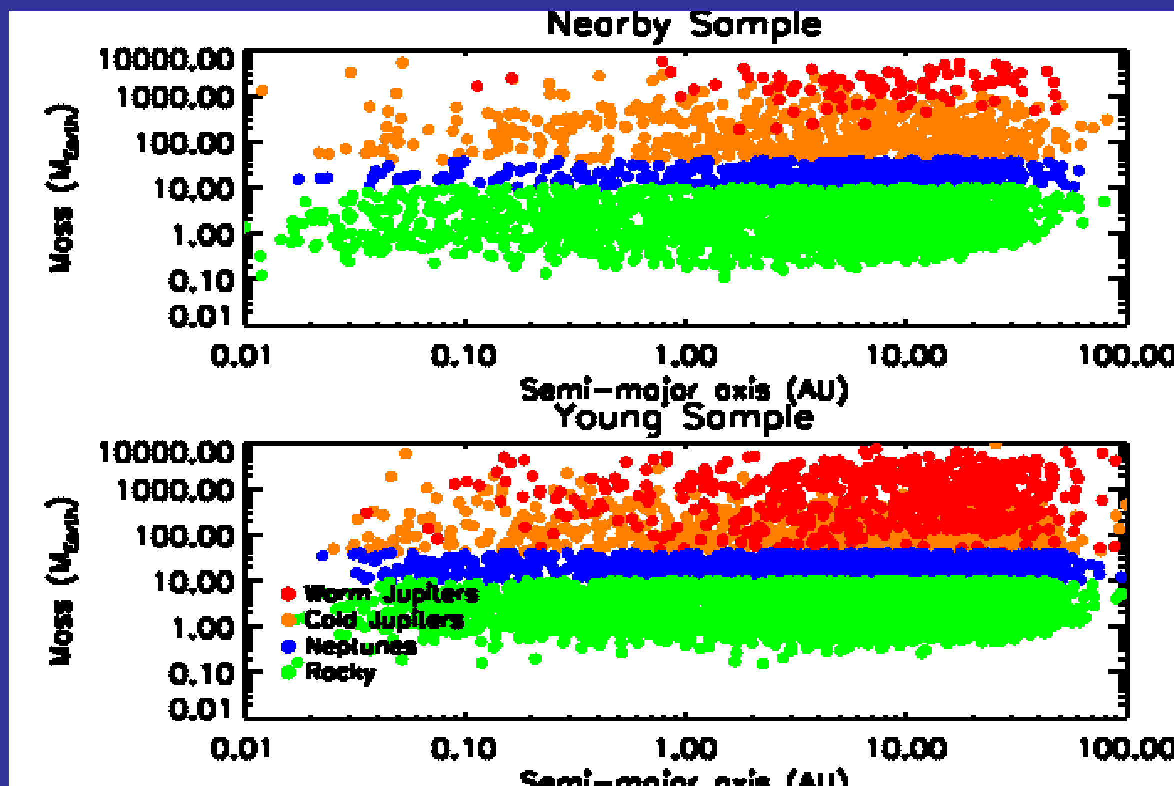
• Astrometric Signature (mas)

SYNTHETIC PLANET POPULATION:

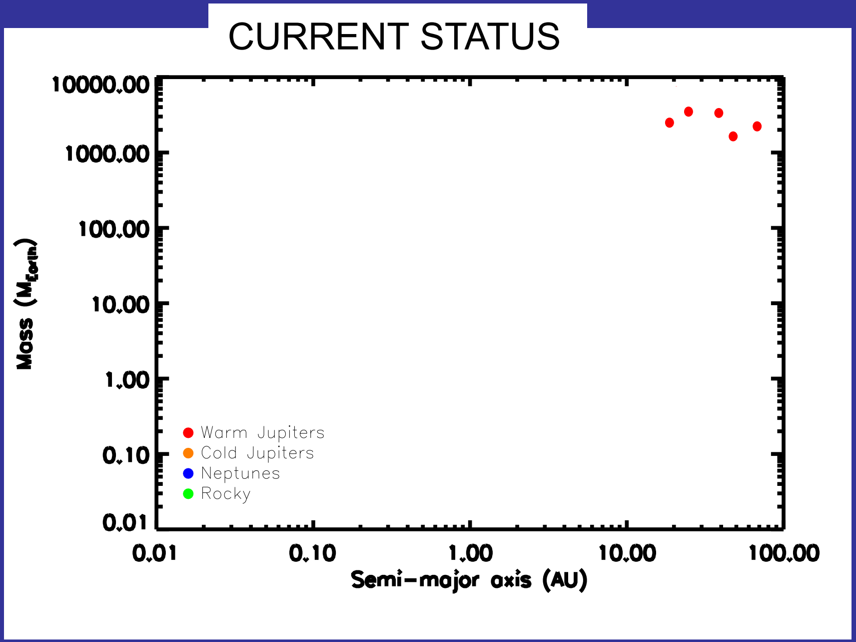
- 5 planets per star (mass>0.7 M_{Earth}), randomly extracted from a set of 10.000 combinations of planet parameters

CHARACTERISTICS OF DETECTABLE PLANETS

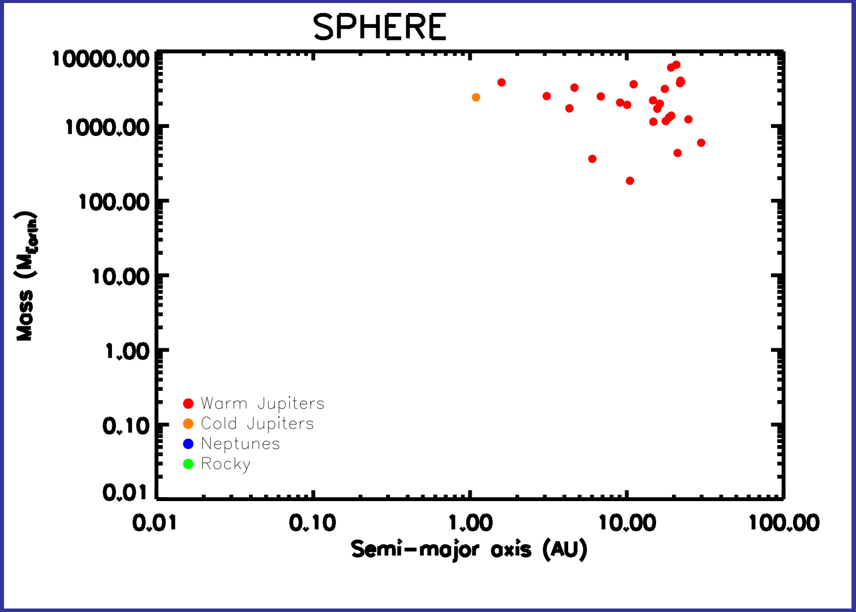
- Contrast vs projected separation
- Mass vs Semi-major Axis
- Radial velocity signal (K(RV)) vs Period
- Astrometric Signature vs Period



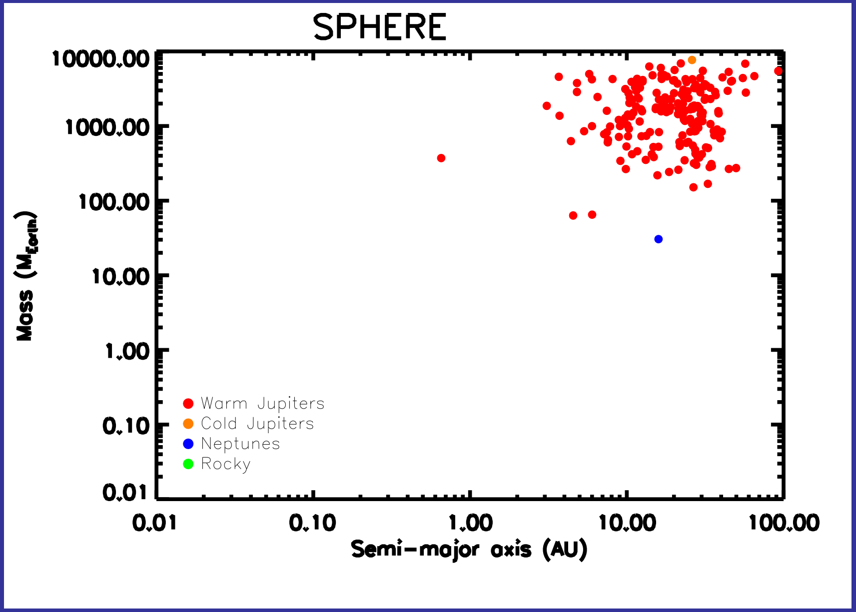
Mass/semimajor axis distribution of detectable planets: Present



Mass/semimajor axis distribution of detectable planets: 2011-

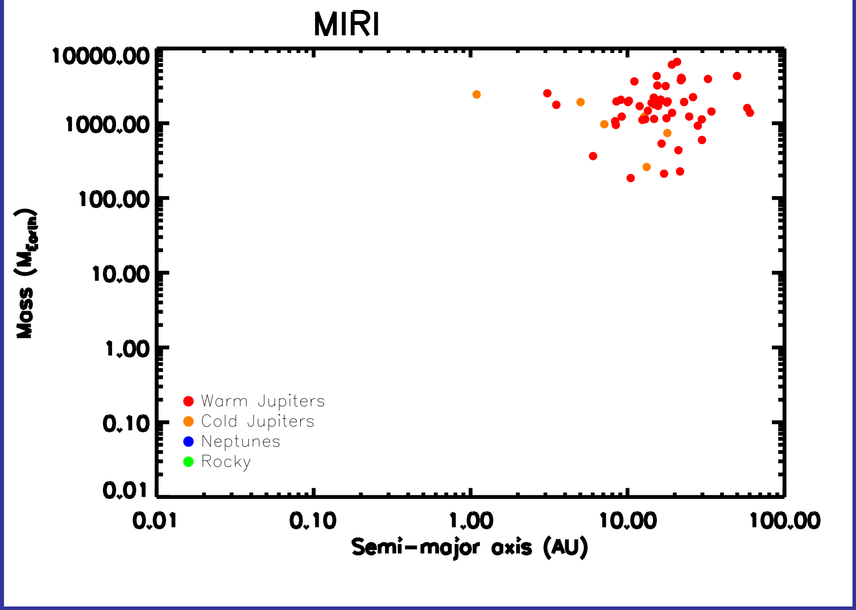


Nearby stars (<20 pc)

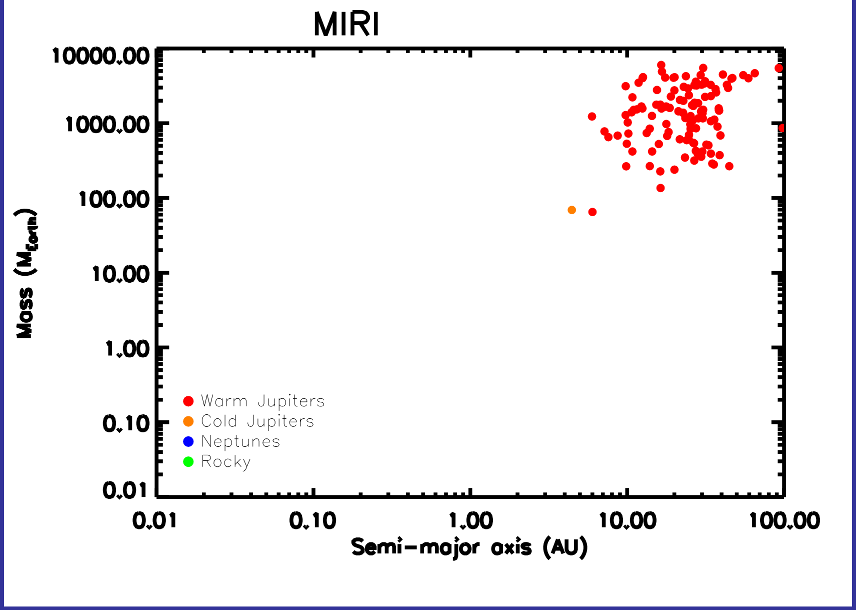


Young stars (<5 10^8 yrs)

Mass/semimajor axis distribution of detectable planets: 2014-

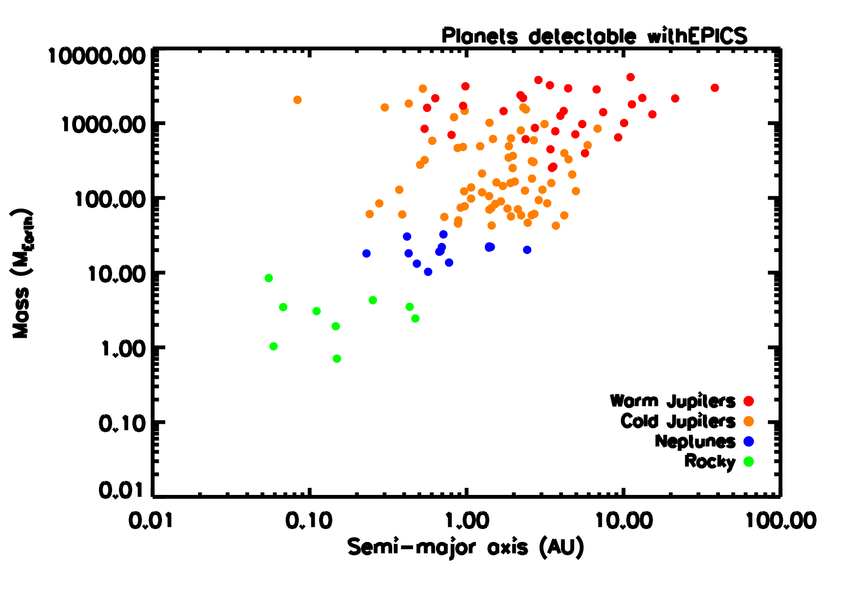


Nearby stars (<20 pc)

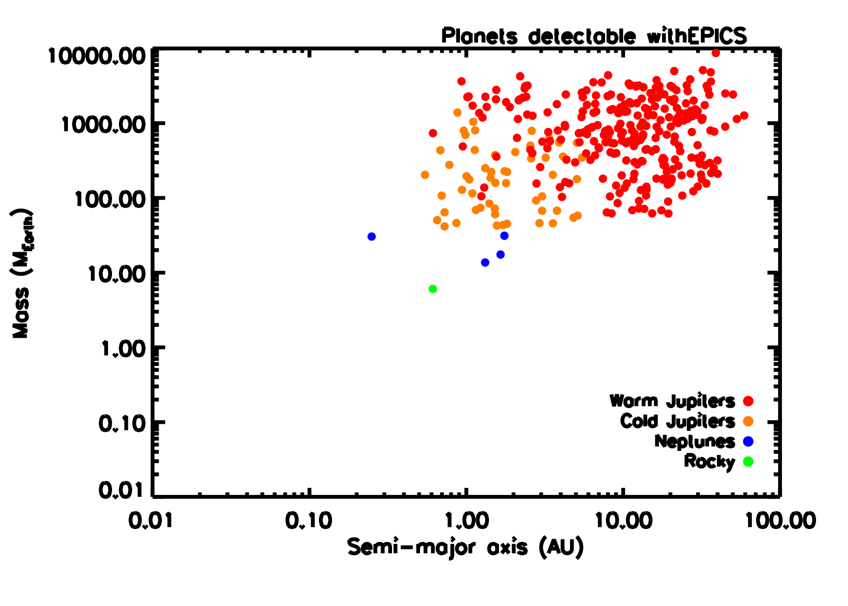


Young stars (<10^8 yrs)

Mass/semimajor axis distribution of detectable planets: EPICS

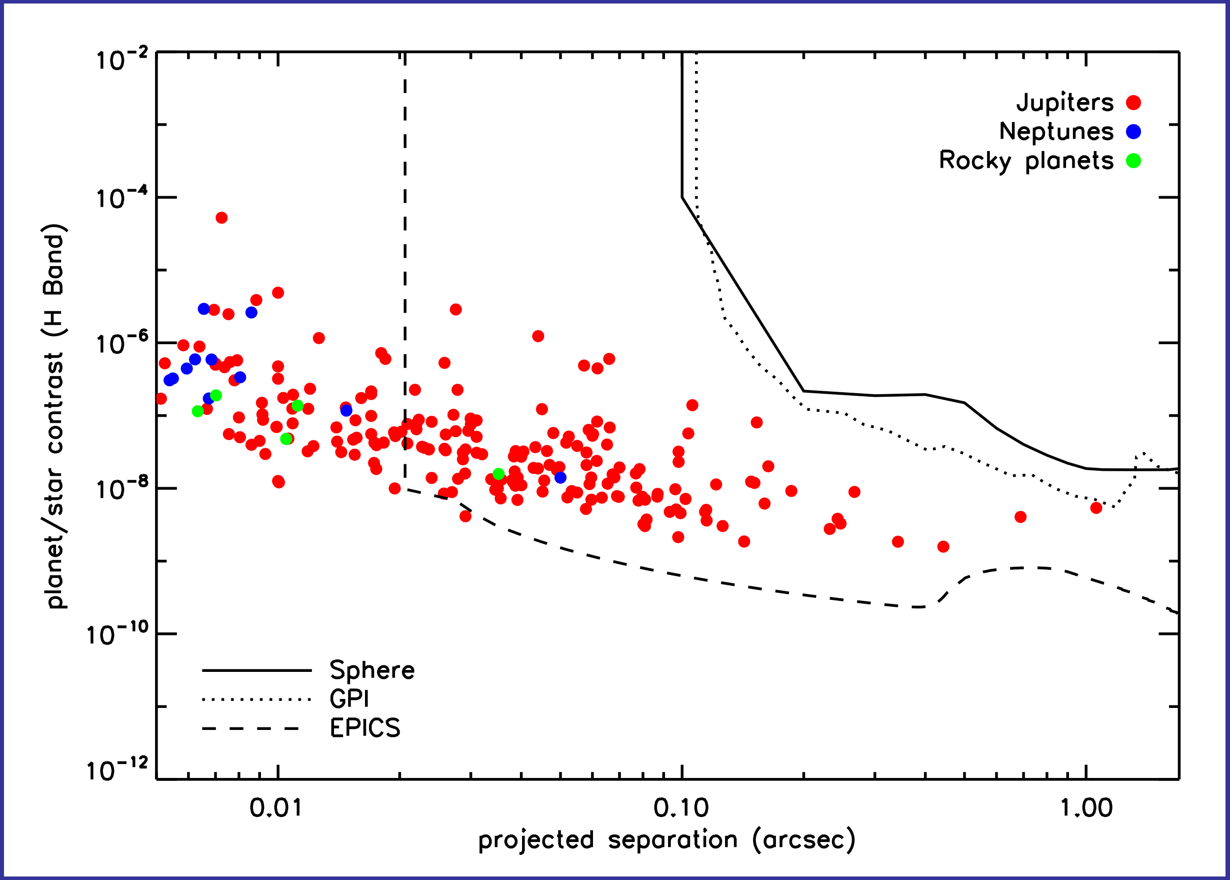


Nearby stars (<20 pc)



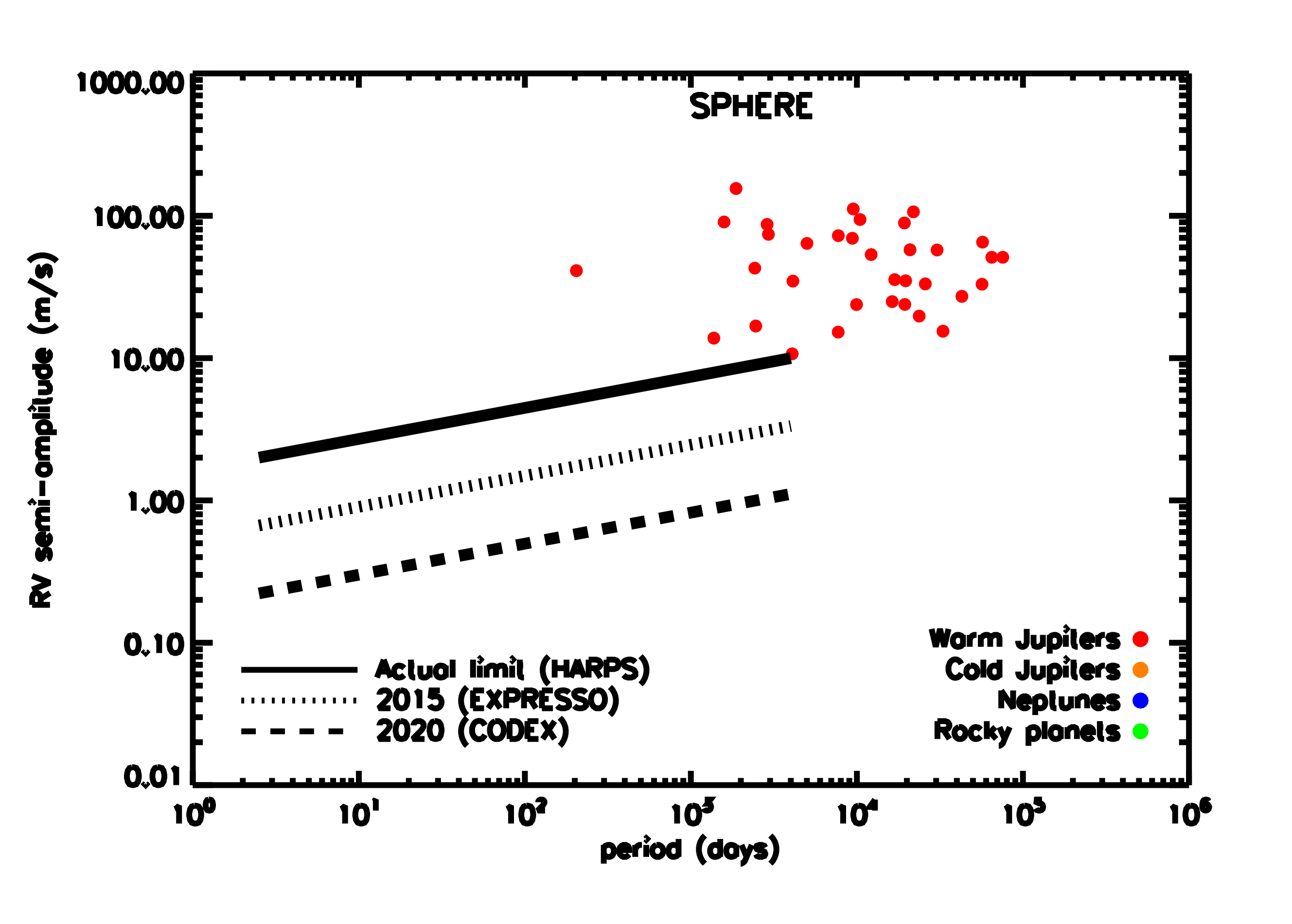
Young stars (<5 10^8 yrs)

Synergies with radial velocities
Planets already discovered from RVs

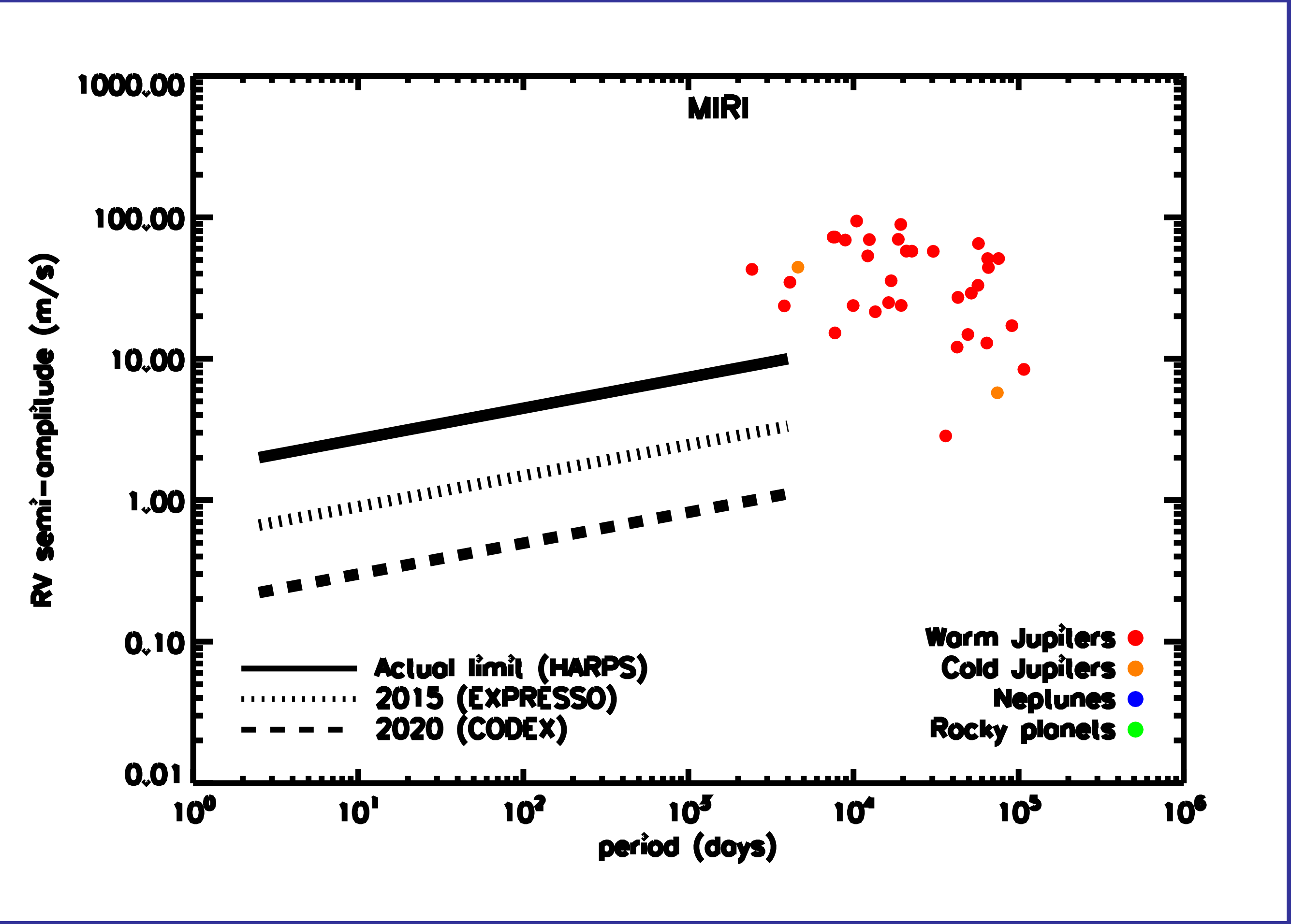


Very important: planet mass independent of model assumptions!

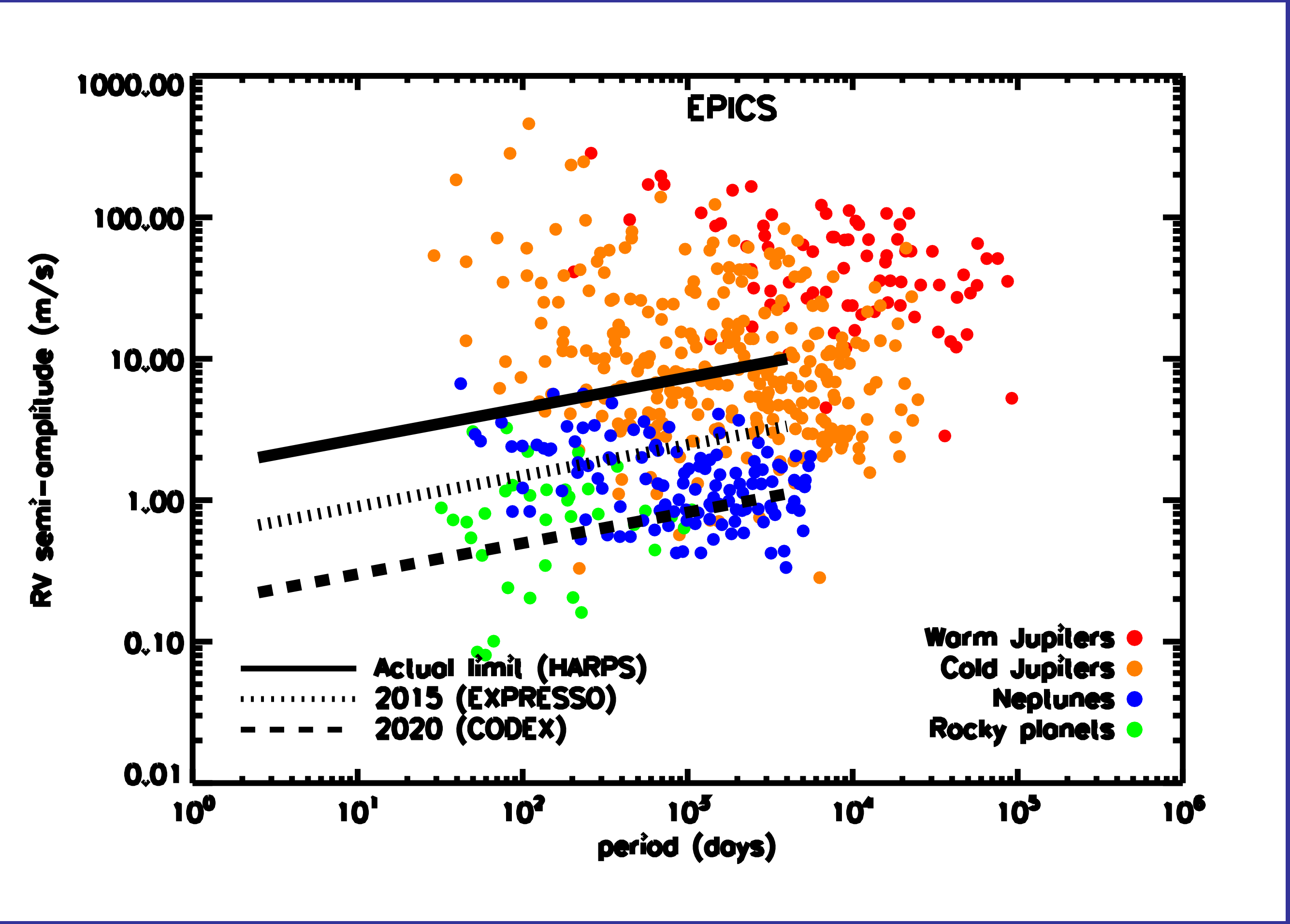
RV signal of detectable planets



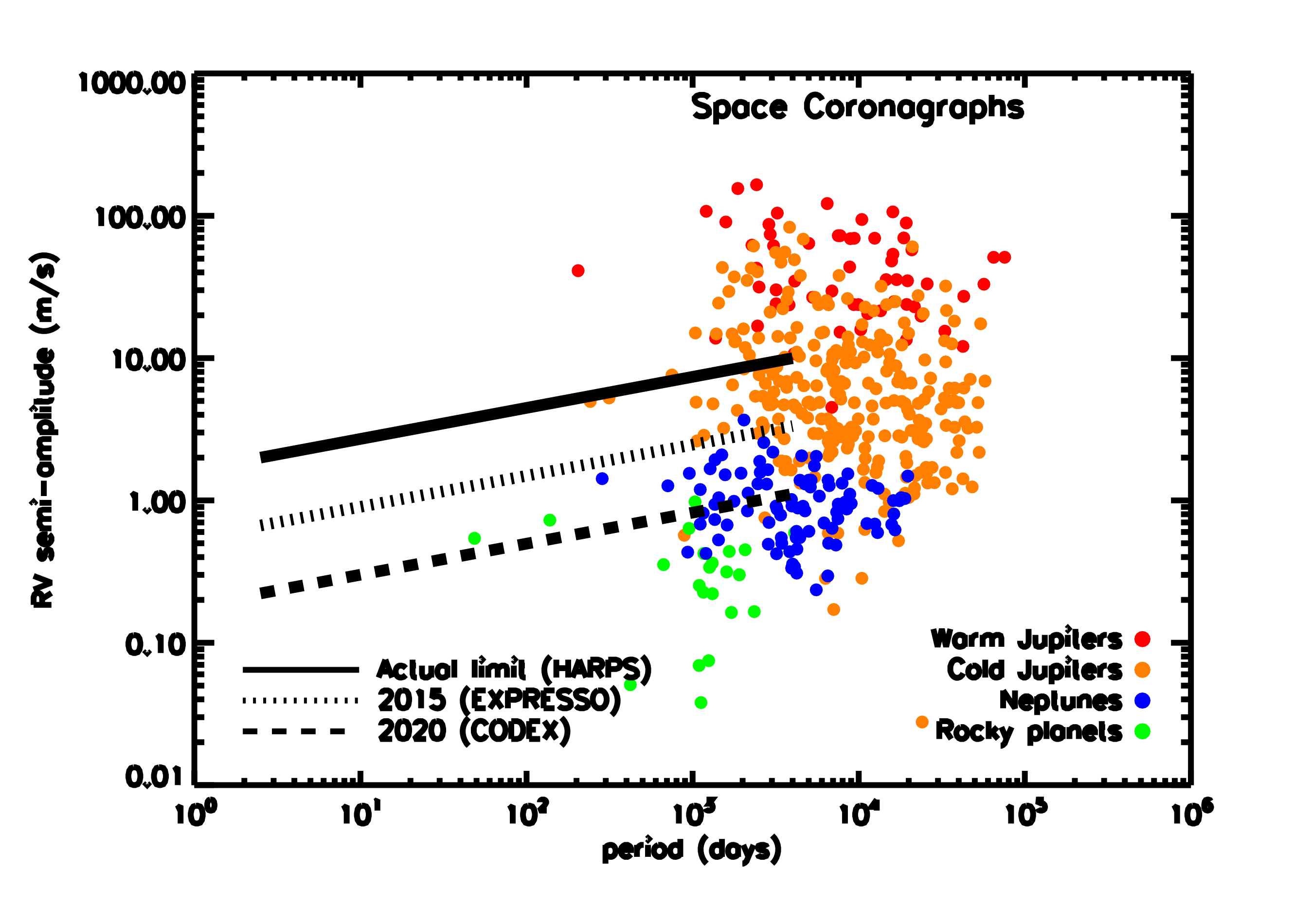
RV signal of detectable planets



RV signal of detectable planets

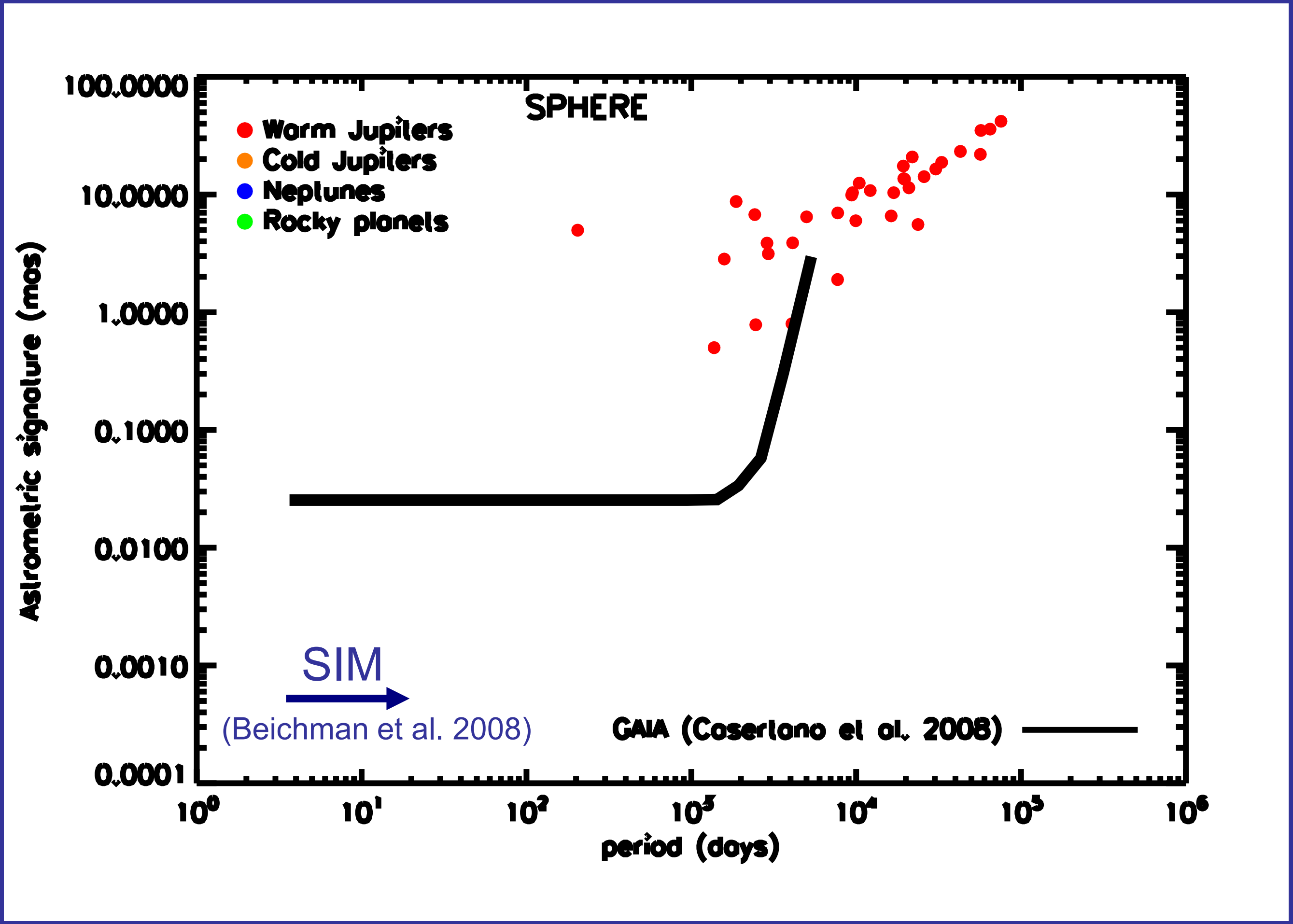


RV signal of detectable planets

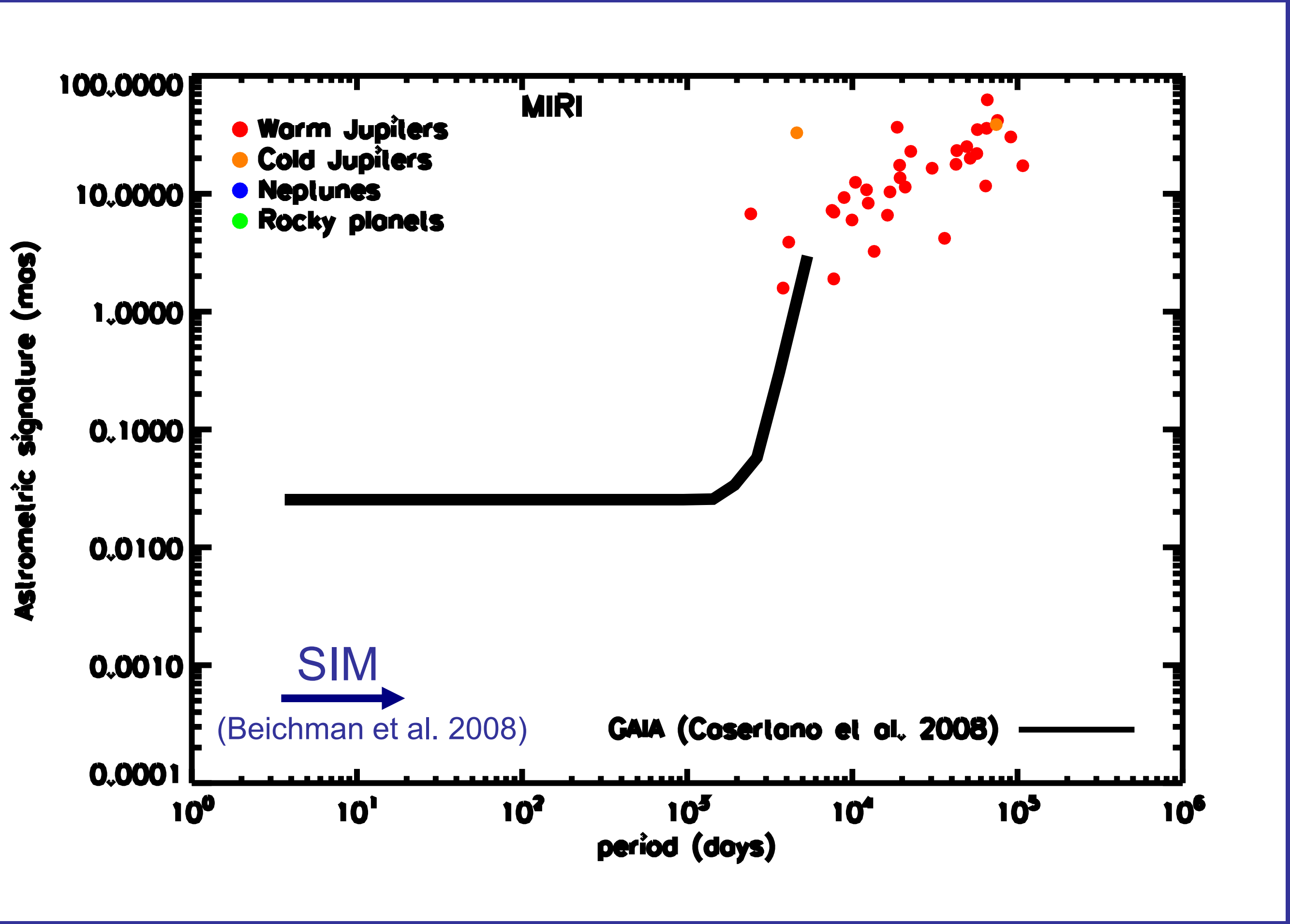


E-ELT SWG Science Meeting,
Garching, October 5/6, 2009

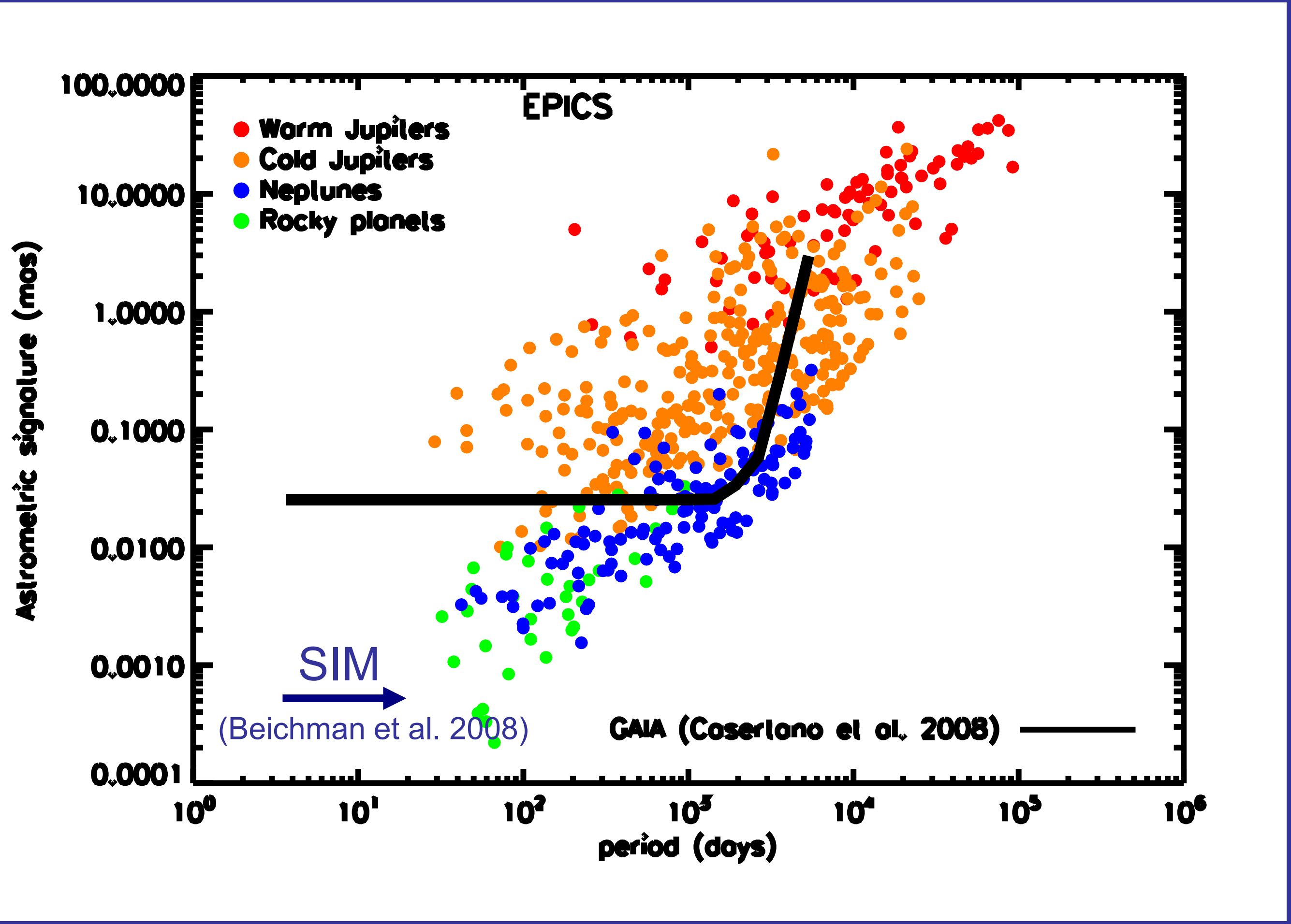
Astrometric signal of detectable planets



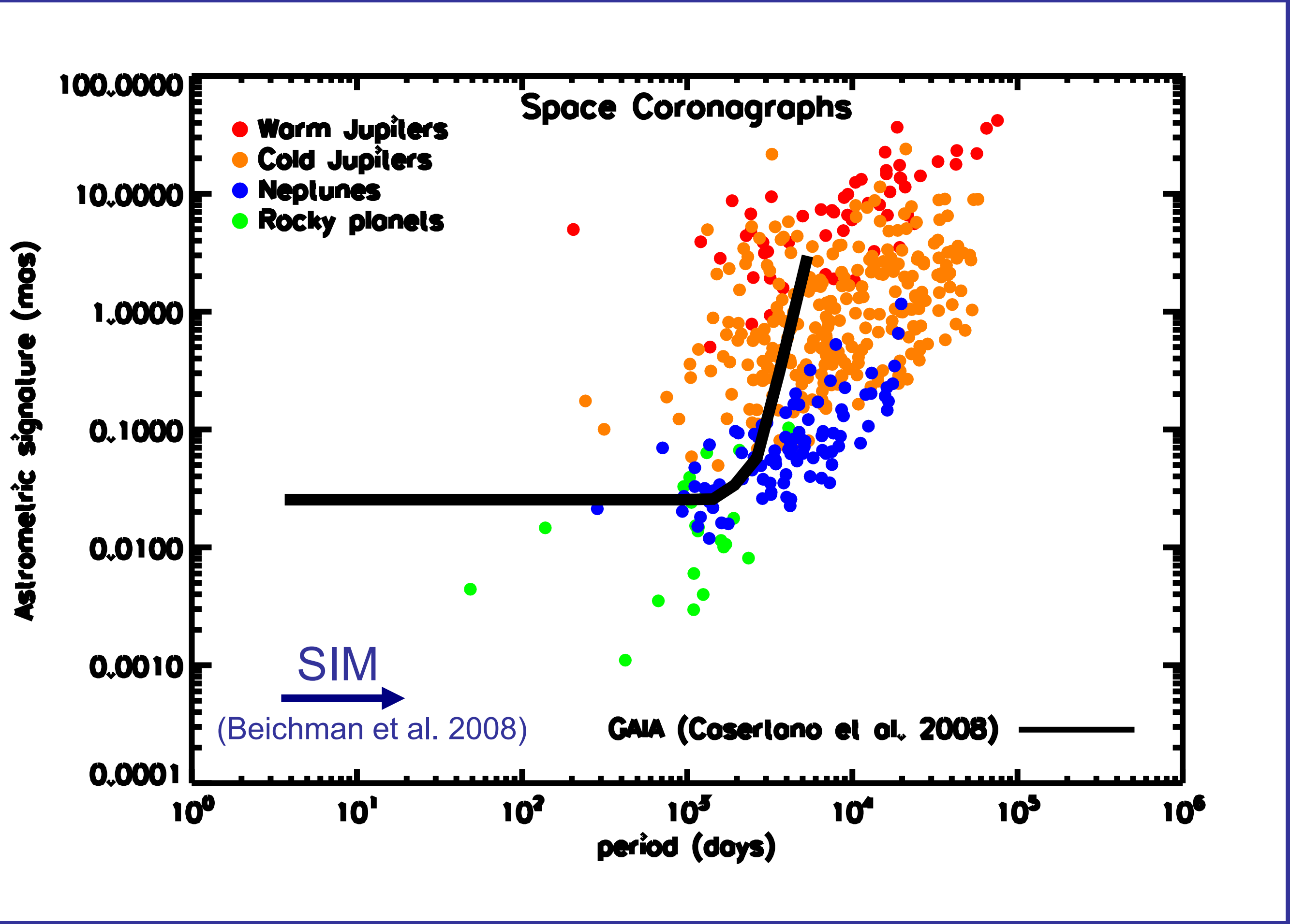
Astrometric signal of detectable planets



Astrometric signal of detectable planets

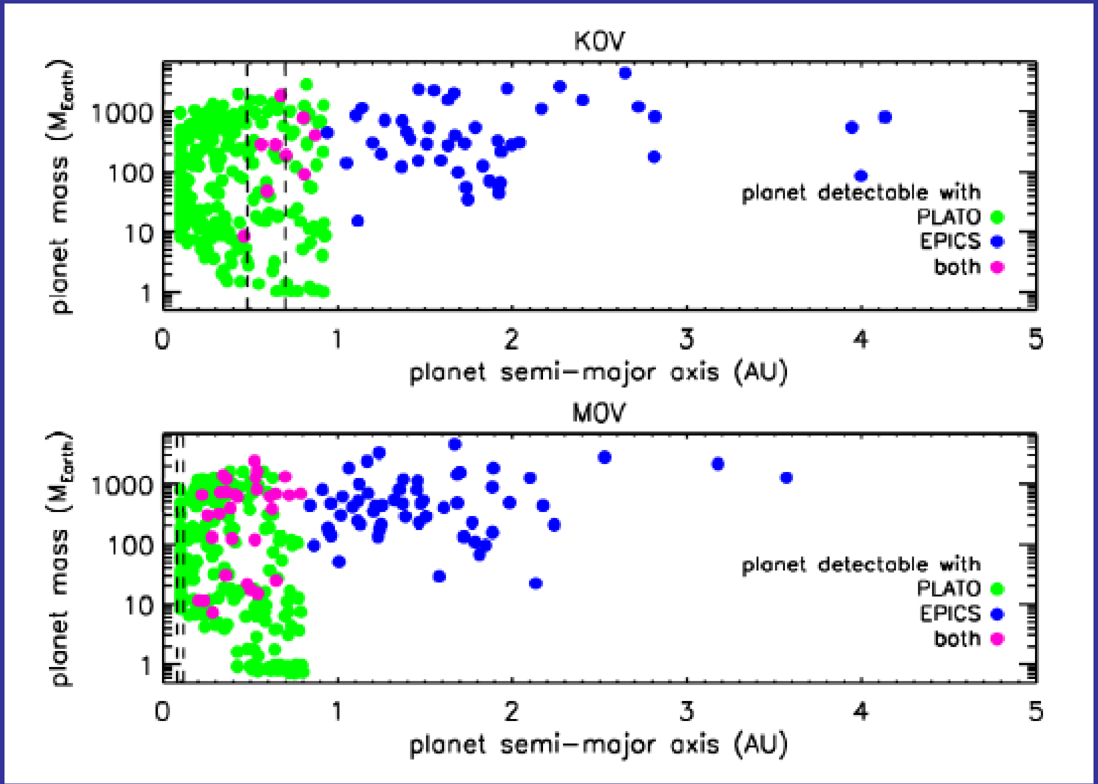


Astrometric signal of detectable planets

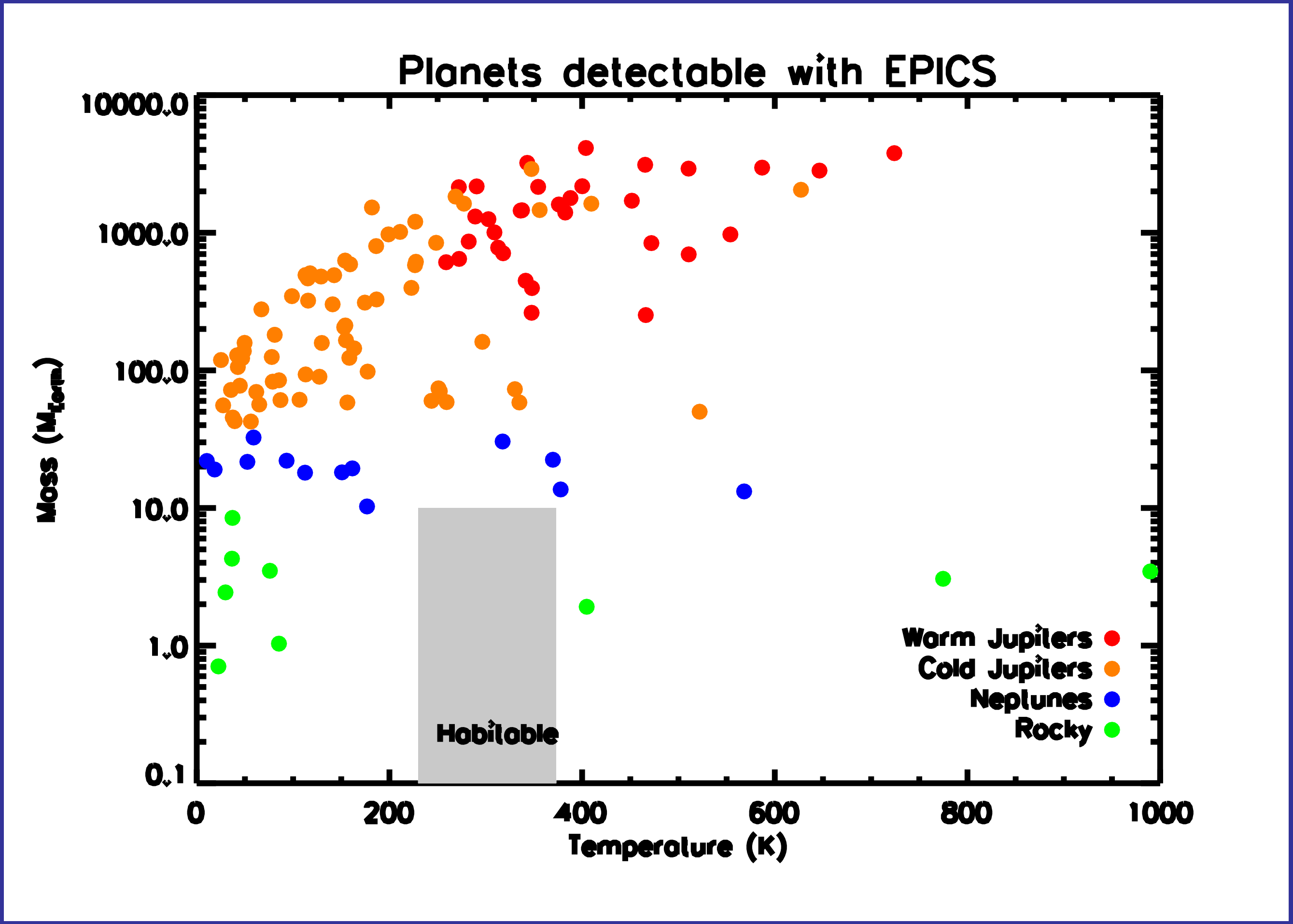


Potential overlap with PLATO

- PLATO: ESA Cosmic Vison proposed mission for the search of transiting planets
- Planets down to about 10 M_{Earth} around K and M dwarfs with V=8.5-10 (bright end of PLATO) can be detected also with EPICS
- For K dwarfs, planets in the habitable zone are detectable
- Availability of planet spectrum from EPICS and planet radius from PLATO will be relevant for the physical study of the planets.
- For G and F stars (and K and M dwarfs as well) planets at separation larger than that accessible to PLATO can be detected, allowing to study the outer planetary system of PLATO targets



Planets in the habitable zone:



E-ELT SWG Science Meeting,
Garching, October 5/6, 2009

Imaging Summary

	Year	Young Giant Planets	Old Giant Planets	Neptunes	Rocky Planets	Habitable Planets
Ground based 8m	2011-	tens	few			
JWST	2014-	tens	few			
1.5m Space Coronagraphs	?	tens	tens	tens	few	??
ELT's	>2018-	hundreds	hundreds	tens	few	??

Summary

- E-ELT will be able to provide a comprehensive approach to exoplanets
- For the first time, masses (from radial velocity) and spectra (from imaging) of planets can be obtained for the same objects over a wide range of masses and separations
- In a few cases even radii can be determined (from transits)
- Very crucial step in the search for habitable extra-solar planets

Document on E-ELT exoplanet science

- Proposed by EPICS team (M. Meyer and R. Gratton)
- For the moment endorsed by METIS team
- HARMONY team contacted
- CODEX and SIMPLE teams still to be involved in the process
- Is this to be supported also by E-ELT SWG?

Summary of EPICS/METIS Synergy:

1. *Complementary in planet searches as a function of target age: EPICS younger stars/METIS older stars.*

2. *EPICS can study accreting gas giants in transition disk systems while METIS (and EPICS?) can search for hot proto-planet collision afterglows.*

3. *EPICS can study proto-planetary/debris disks in scattered light (search for ice-line?) while METIS will observe thermal emission. Extremely useful together. Possibilities to observe orbital motion?*

4. *EPICS/METIS trace warmer/cooler gas in disks through techniques such as spectro-astrometry.*

Draft of Table of Contents (by M. Meyer)

- Formation and Evolution of Planetary Systems: The Transformational Role of the E-ELT. Resolved Studies of Disks and Planets Enabled with the E-ELT
- Gas Giant Planets in the IR
  - Critical scale from > 30 AU to < 5 AU.
    - RV surveys and current imaging null results predict that most planets will be found between 3-30 AU.
    - Increase in resolution from 8 m to 42 m will provide critical breakthroughs in imaging leading to more than order of magnitude increase in samples.
    - Largest discovery space for volume-limited samples of nearby stars dominated by late-type (K/M) primaries.
  - 3-5 microns compared to H/K Band.
    - EPICS best for young stars.
    - METIS best for older stars.
    - HARMONI complementary in K-band.
  - Detect down to Saturn mass for young planets
    - E-ELT will probe planet masses inaccessible with current 6-10 meter telescopes, albeit at large separation around young stars.
  - Complementary to current RV/transit samples.
    - Imagers can detect handful of current RV targets providing luminosity, temperature, surface gravtiy, and composition information for those with MSINI.
    - Will also image dozens of new targets to be discovered with ESPRESSO and CODEX.
    - Imaging determination of orbits will provide estimates of inclination, thus determining unambiguously planet mass from RV signals.
- Planets in Formation
  - Gas giants in formation with EPICS: still accreting gas in T Tauri disks.
  - Hot proto-planet collision afterglows
    - Hot planets are easier to see than big ones!
    - Same star samples/spatial resolution as above.
    - E-ELT should enable detect of dozens of examples.
- Terrestrial and Super-earth Planets Around Mature Stars.
  - the very nearest stars.
    - Can see Earth at 1 AU around nearest few stars.
    - Can see hot super-earths within 1 AU around several nearby stars.
  - Tidally heated planets?
- Structure and Evolution of Circumstellar Disks
  - EPICS can study disks in scattered light while METIS can study them in thermal emission. The combination is powerful to constrain models of their physical parameters resolving ambiguities between particle size and composition thus enabling better constraints on mass. Might be able to see the ice-line in scattered light imagery with EPICS.
  - METIS can study warm gas from 1-10 AU while EPICS can study hot gas at smaller radii both covering the region where terrestrial planets are made inside the ice line.
- Radial Velocity Studies Enabled with the E-ELT
- Synergies with Other Facilities