Towards Other Earths II: The Star – Planet Connection, Porto, September 15-19th, 2014

Exoplanets at the E-ELT era

Gaël Chauvin

- IPAG/CNRS -
Institute of Planetology
& Astrophysics of Grenoble/France

ESO-Project Science Team,
and E-ELT CAM, IFU, MIDIR, MOS, HIRES & PCS consortia

Outline

Exoplanets at the E-ELT era

I- The E-ELT project

- Telescope & context
- Instrumentation road map

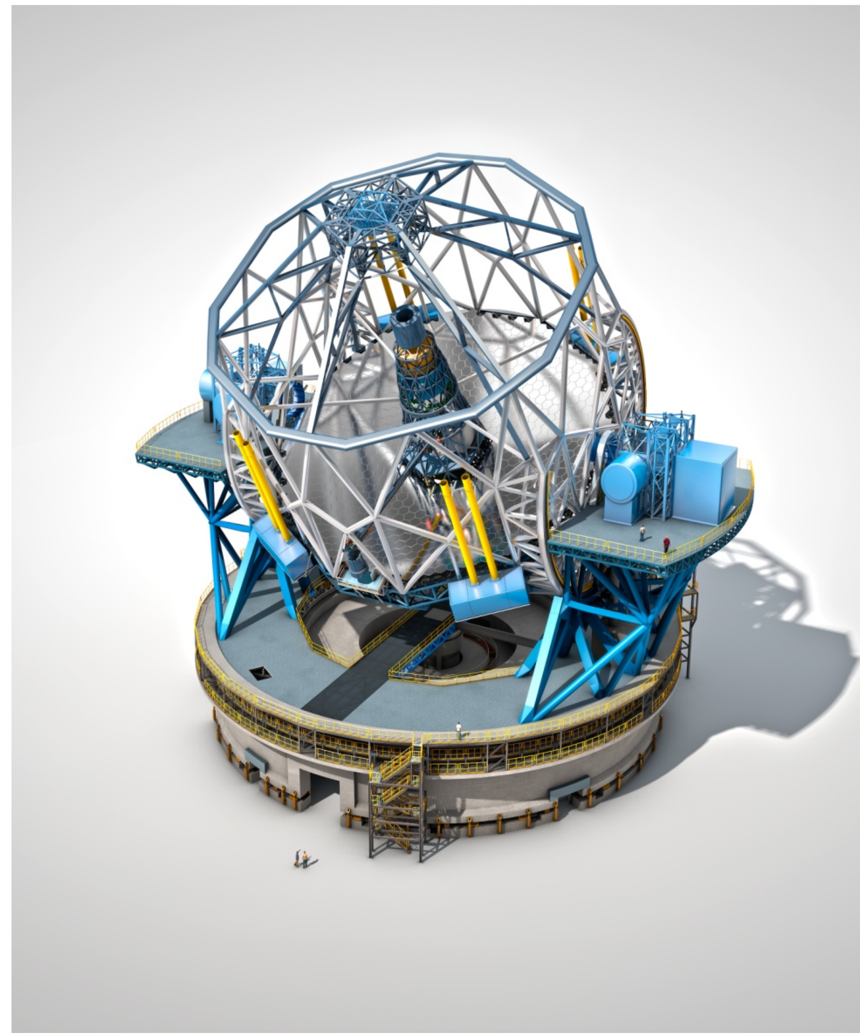
II- Exoplanetary science

- 2.1 Study of planet-forming regions
- 2.2 Exoplanetary system characterization
  (Architecture, Formation, Atmosphere)

The E-ELT Project

The Telescope

- **39-m class telescope**: largest **optical-infrared** telescope in the world.
  (GMT = 25m; TMT = 30m)
- **Novel 5 mirrors design**
- **Segmented-primary (M1)**
  800 segments, 1.4m size
- **Adaptive assisted** telescope
  M4 adaptive mirror, 5000 actuators
- Diffraction limited performance:
  12mas@K-band; 7 arcmin patrol FoV
- Mid-latitude site (**Amazones**/Chile).
  Fast instrument changes.

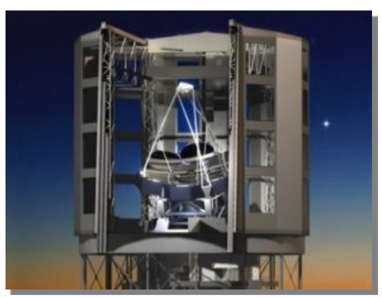


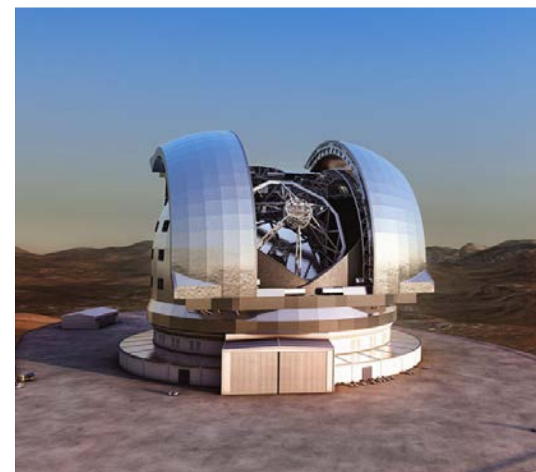
The E-ELT Project

E-ELT & other competitive projects

Discoveries by opening a new parameter space

- **Increased Sensitivity**
- **Spatial resolution (10 mas scale)**

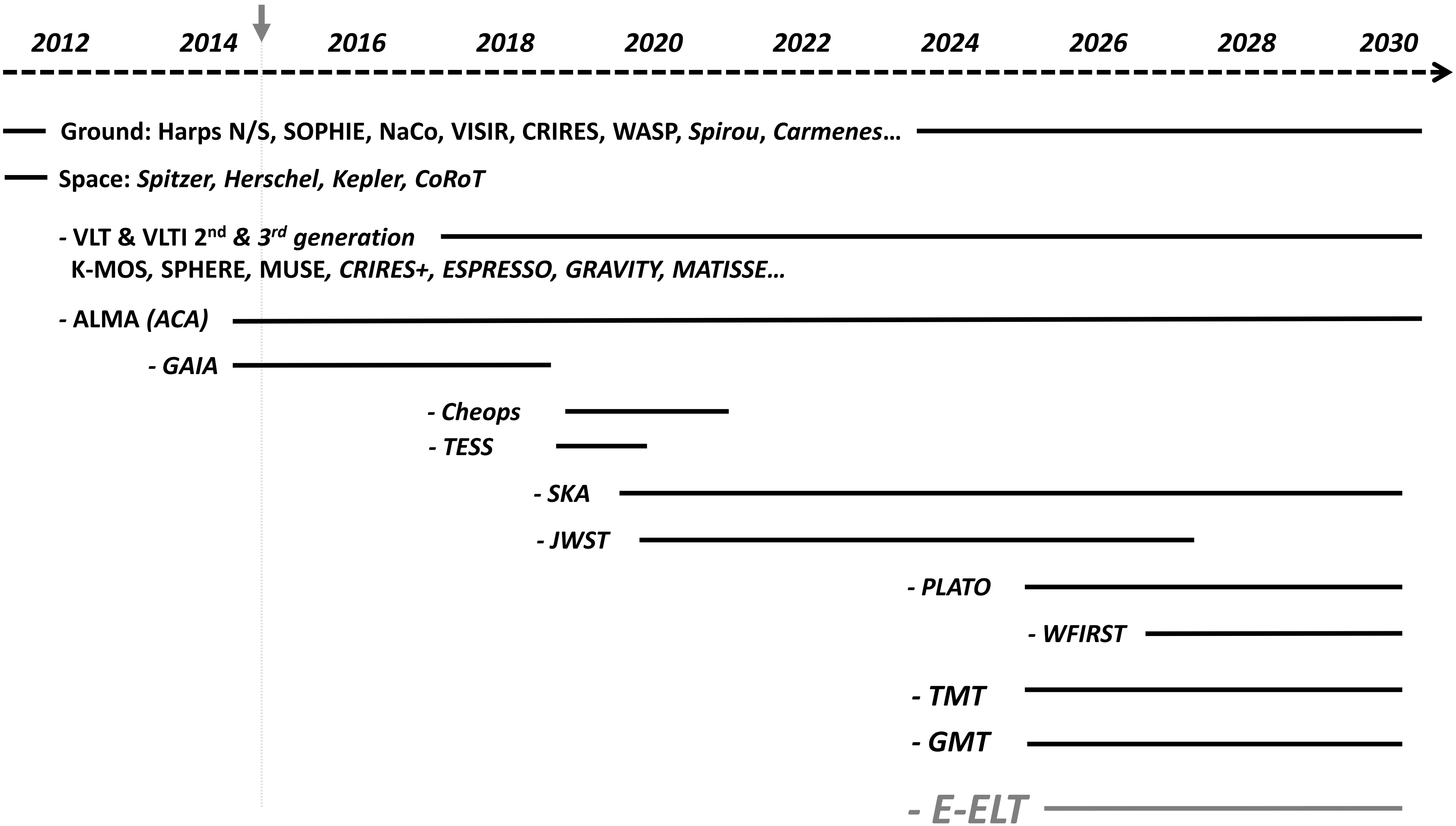





	50m2	**400m2**	**600m2**	**1200m2**	**(JWST: 25m2)**
2 µm	**50mas**	**18mas**	**14mas**	**10mas**	**(JWST: 68mas)**

The E-ELT Project

Timeline: current/future missions



The E-ELT Project

Instrument Roadmap

Instruments - First Light	AO	Mode	λ (µm)	Resolution	FoV / Sampling	Add. Mode
E-CAM **– 2024**	SCAO, MCAO	- IMG - MRS	0.8 – 2.4	BB, NB 3000	53.0" / 3 mas	Astrometry 40µas Coronography
E-IFU **– 2024**	SCAO, LTAO	- IFU	0.5 – 2.4	4000 10 000 20 000	0.5×1.0" / 4mas 5.0×10.0" / 40mas	Coronography
E-MIDIR – **2025**	SCAO LTAO	- IMG - MRS - IFU	3 – 13 3 - 13 3 - 5	BB, NB 5000 100 000	18" / 12 mas 0.4"×1.5" / 4 mas	Coronography Polarimetry
E-HIRES - **2026/2028**	SCAO	- HRS	0.37 – 0.71 0.84 – 2.50	200 000 120 000	0.82" 0.027"×0.5"	Polarimetry
E-MOS **- 2026/2028**	 MOAO	Slits IFUs IFUs	0.37 – 1.4 0.37 – 1.4 0.8 – 2.45	300- 2500 5000 – 30 000 4000 – 10 000	6.8' / 0.1" 420' / 0.3" 2" / 40mas	Multiplex ~ 400 Multiplex ~100 Multiplex ~10 Imaging?
E-PCS **- 2030/2032**	XAO	EPOL IFS	0.6 – 0.9 0.95 – 1.65	 125 – 20 000	2.0" / 2.3 mas 0.8" / 1.5 mas	Coronography Polarimetry

The E-ELT Project

Instrument Roadmap

- 1st Light Instruments

Instruments - First Light	AO	Mode	λ (µm)	Resolution	FoV / Sampling	Add. Mode
E-CAM – 2024	**SCAO, MCAO**	**- IMG - MRS**	**0.8 – 2.4**	**BB, NB 3000**	**53.0” / 3 mas**	**Astrometry 40µas Coronography**
E-IFU – 2024	**SCAO, LTAO**	**- IFU**	**0.5 – 2.4**	**4000 10 000 20 000**	**0.5×1.0” / 4mas 5.0×10.0” / 40mas**	**Coronography**
E-MIDIR – **2025**	SCAO LTAO	- IMG - MRS - IFU	3 – 13 3 - 13 3 - 5	BB, NB 5000 100 000	18” / 12 mas 0.4”×1.5” / 4 mas	Coronography Polarimetry
E-HIRES - **2026/2028**	SCAO	- HRS	0.37 – 0.71 0.84 – 2.50	200 000 120 000	0.82” 0.027”×0.5”	Polarimetry
E-MOS **- 2026/2028**	 MOAO	Slits IFUs IFUs	0.37 – 1.4 0.37 – 1.4 0.8 – 2.45	300- 2500 5000 – 30 000 4000 – 10 000	6.8” / 0.1” 420’ / 0.3” 2” / 40mas	Multiplex ~ 400 Multiplex ~100 Multiplex ~10 Imaging?
E-PCS **- 2030/2032**	XAO	EPOL IFS	0.6 – 0.9 0.95 – 1.65	 125 – 20 000	2.0” / 2.3 mas 0.8“ / 1.5 mas	Coronography Polarimetry

SCAO: single-conjugated AO **MCAO:** Multi-Conjugated-AO **LTAO**: Laser-Tomographic AO

MOAO: Multi-Object AO **XAO**: Extreme-AO

The E-ELT Project

Instrument Roadmap

- 2^{nd} Pool Instruments

Instruments - First Light	AO	Mode	λ (µm)	Resolution	FoV / Sampling	Add. Mode
E-CAM **– 2024**	SCAO, MCAO	- IMG - MRS	0.8 – 2.4	BB, NB 3000	53.0" / 3 mas	Astrometry 40µas Coronography
E-IFU **– 2024**	SCAO, LTAO	- IFU	0.5 – 2.4	4000 10 000 20 000	0.5×1.0" / 4mas 5.0×10.0" / 40mas	Coronography
E-MIDIR – **2025**	**SCAO** LTAO	**- IMG** **- MRS** **- IFU**	**3 – 13** **3 - 13** **3 - 5**	**BB, NB** **5000** **100 000**	**18" / 12 mas** **0.4"×1.5" / 4 mas**	**Coronography** **Polarimetry**
E-HIRES - **2026/2028**	**SCAO**	**- HRS**	**0.37 – 0.71** **0.84 – 2.50**	**200 000** **120 000**	**0.82"** **0.027"×0.5"**	**Polarimetry?**
E-MOS **- 2026/2028**	 **MOAO**	**Slits** **IFUs** **IFUs**	**0.37 – 1.4** **0.37 – 1.4** **0.8 – 2.45**	**300- 2500** **5000 – 30 000** **4000 – 10 000**	**6.8" / 0.1"** **420' / 0.3"** **2" / 40mas**	**Multiplex ~ 400** **Multiplex ~100** **Multiplex ~10** **Imaging?**
E-PCS **- 2030/2032**	XAO	EPOL IFS	0.6 – 0.9 0.95 – 1.65	 125 – 20 000	2.0" / 2.3 mas 0.8" / 1.5 mas	Coronography Polarimetry

SCAO: single-conjugated AO **MCAO:** Multi-Conjugated-AO **LTAO**: Laser-Tomographic AO

MOAO: Multi-Object AO **XAO**: Extreme-AO

The E-ELT Project

Instrument Roadmap

- XAO Instrument

Instruments - First Light	**AO**	**Mode**	**λ (μm)**	**Resolution**	**FoV / Sampling**	**Add. Mode**
E-CAM – 2024	SCAO, MCAO	- IMG - MRS	0.8 – 2.4	BB, NB 3000	53.0” / 3 mas	Astrometry 40μas Coronography
E-IFU – 2024	SCAO, LTAO	- IFU	0.5 – 2.4	4000 10 000 20 000	0.5×1.0” / 4mas 5.0×10.0” / 40mas	Coronography
E-MIDIR – 2025	SCAO LTAO	- IMG - MRS - IFU	3 – 13 3 - 13 3 - 5	BB, NB 5000 100 000	18” / 12 mas 0.4”×1.5” / 4 mas	Coronography Polarimetry
E-HIRES - 2026/2028	SCAO	- HRS	0.37 – 0.71 0.84 – 2.50	200 000 120 000	0.82” 0.027”×0.5”	Polarimetry
E-MOS - 2026/2028	 MOAO	Slits IFUs IFUs	0.37 – 1.4 0.37 – 1.4 0.8 – 2.45	300- 2500 5000 – 30 000 4000 – 10 000	6.8” / 0.1” 420’ / 0.3” 2” / 40mas	Multiplex ~ 400 Multiplex ~100 Multiplex ~10 Imaging?
E-PCS - 2030/2032	**XAO**	**EPOL** **IFS**	**0.6 – 0.9** **0.95 – 1.65**	**125 – 20 000**	**2.0” / 2.3 mas** **0.8“ / 1.5 mas**	**Coronography** **Polarimetry**

SCAO: single-conjugated AO **MCAO:** Multi-Conjugated-AO **LTAO**: Laser-Tomographic AO

MOAO: Multi-Object AO **XAO**: Extreme-AO

The E-ELT Project

Instrument Roadmap

- Various AO Flavors

Instruments - First Light	AO	Mode	λ (μm)	Resolution	FoV / Sampling	Add. Mode
E-CAM **– 2024**	**SCAO,** **MCAO**	- IMG - MRS	0.8 – 2.4	BB, NB 3000	53.0" / 3 mas	Astrometry 40μas Coronography
E-IFU **– 2024**	**SCAO,** **LTAO**	- IFU	0.5 – 2.4	4000 10 000 20 000	0.5×1.0" / 4mas 5.0×10.0" / 40mas	Coronography
E-MIDIR – **2025**	**SCAO** **LTAO**	- IMG - MRS - IFU	3 – 13 3 - 13 3 - 5	BB, NB 5000 100 000	18" / 12 mas 0.4"×1.5" / 4 mas	Coronography Polarimetry
E-HIRES - **2025/2028**	**SCAO**	- HRS	0.37 – 0.71 0.84 – 2.50	200 000 120 000	0.82" 0.027"×0.5"	Polarimetry
E-MOS **- 2025/2028**	**MOAO**	Slits IFUs IFUs	0.37 – 1.4 0.37 – 1.4 0.8 – 2.45	300- 2500 5000 – 30 000 4000 – 10 000	6.8' / 0.1" 420' / 0.3" 2" / 40mas	Multiplex ~ 400 Multiplex ~100 Multiplex ~10 Imaging?
E-PCS **- 2030/2032**	**XAO**	EPOL IFS	0.6 – 0.9 0.95 – 1.65	 125 – 20 000	2.0" / 2.3 mas 0.8" / 1.5 mas	Coronography Polarimetry

SCAO: single-conjugated AO **MCAO:** Multi-Conjugated-AO **LTAO**: Laser-Tomographic AO

MOAO: Multi-Object AO **XAO**: Extreme-AO

The E-ELT Project

Instrument Roadmap

- Science Priority / Exoplanets

Instruments - First Light	AO	Mode	λ (µm)	Resolution	FoV / Sampling	Add. Mode
E-CAM **– 2024**	SCAO, MCAO	- IMG - MRS	0.8 – 2.4	BB, NB 3000	53.0" / 3 mas	Astrometry 40µas Coronography
E-IFU **– 2024**	SCAO, LTAO	- IFU	0.5 – 2.4	4000 10 000 20 000	0.5×1.0" / 4mas 5.0×10.0" / 40mas	Coronography
E-MIDIR **– 2025**	SCAO LTAO	- IMG - MRS - IFU	3 – 13 3 - 13 3 - 5	BB, NB 5000 100 000	18" / 12 mas 0.4"×1.5" / 4 mas	Coronography Polarimetry
E-HIRES **- 2026/2028**	SCAO	- HRS	0.37 – 0.71 0.84 – 2.50	200 000 120 000	0.82" 0.027"×0.5"	Polarimetry
E-MOS **- 2026/2028**	 MOAO	Slits IFUs IFUs	0.37 – 1.4 0.37 – 1.4 0.8 – 2.45	300- 2500 5000 – 30 000 4000 – 10 000	6.8" / 0.1" 420' / 0.3" 2" / 40mas	Multiplex ~ 400 Multiplex ~100 Multiplex ~10 Imaging?
E-PCS **- 2030/2032**	XAO	EPOL IFS	0.6 – 0.9 0.95 – 1.65	 125 – 20 000	2.0" / 2.3 mas 0.8" / 1.5 mas	Coronography Polarimetry

Low Medium High

Outline

Exoplanets at the E-ELT era

I- The E-ELT project

- Telescope & context
- Instrumentation road map

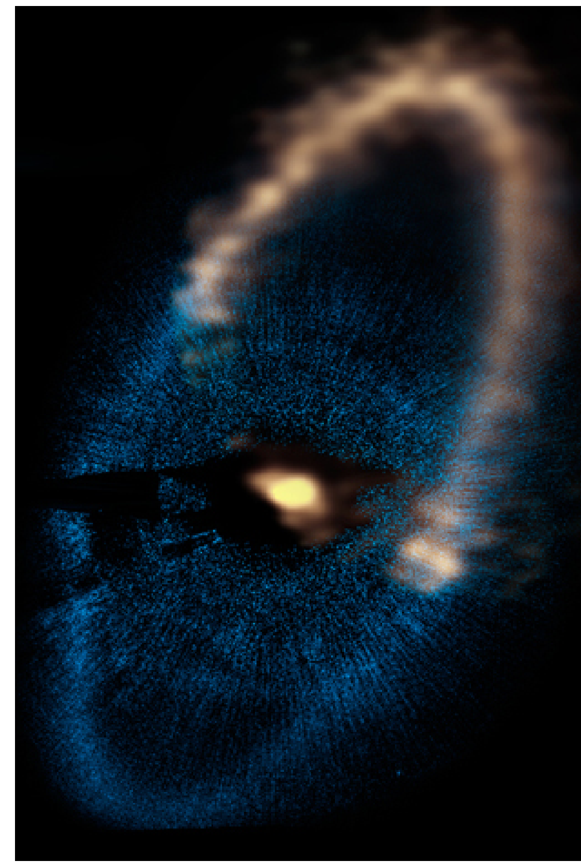
II- Exoplanetary science

- 2.1 Study of planet-forming regions
- 2.2 Exoplanetary system characterization
  (Architecture, Formation, Atmosphere)

2.1 Planet-forming regions

Key Scientific Questions

- **Star/disk Evolution**
  - Accretion, Mass loss & Magnetic fields
- **Disk Structure & Dynamics**
  - Gas & Dust components
- **Composition & Chemistry:**
  - Water & Organics
- **Planetary Formation & Observation**
  - Initial conditions
- **Planets/Disk interactions**

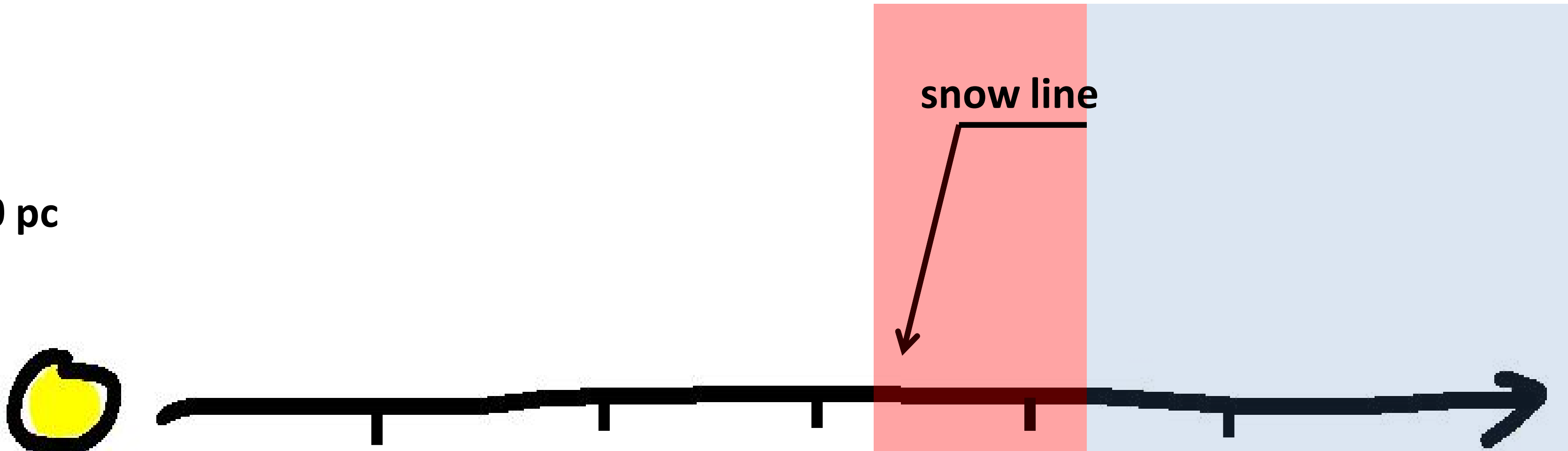


Fomalhaut ALMA/HST
Bowler et al. 12

2.1 Planet-forming regions

Accessing the AU to the sub-AU scale

1 L_{sun}
@100 pc



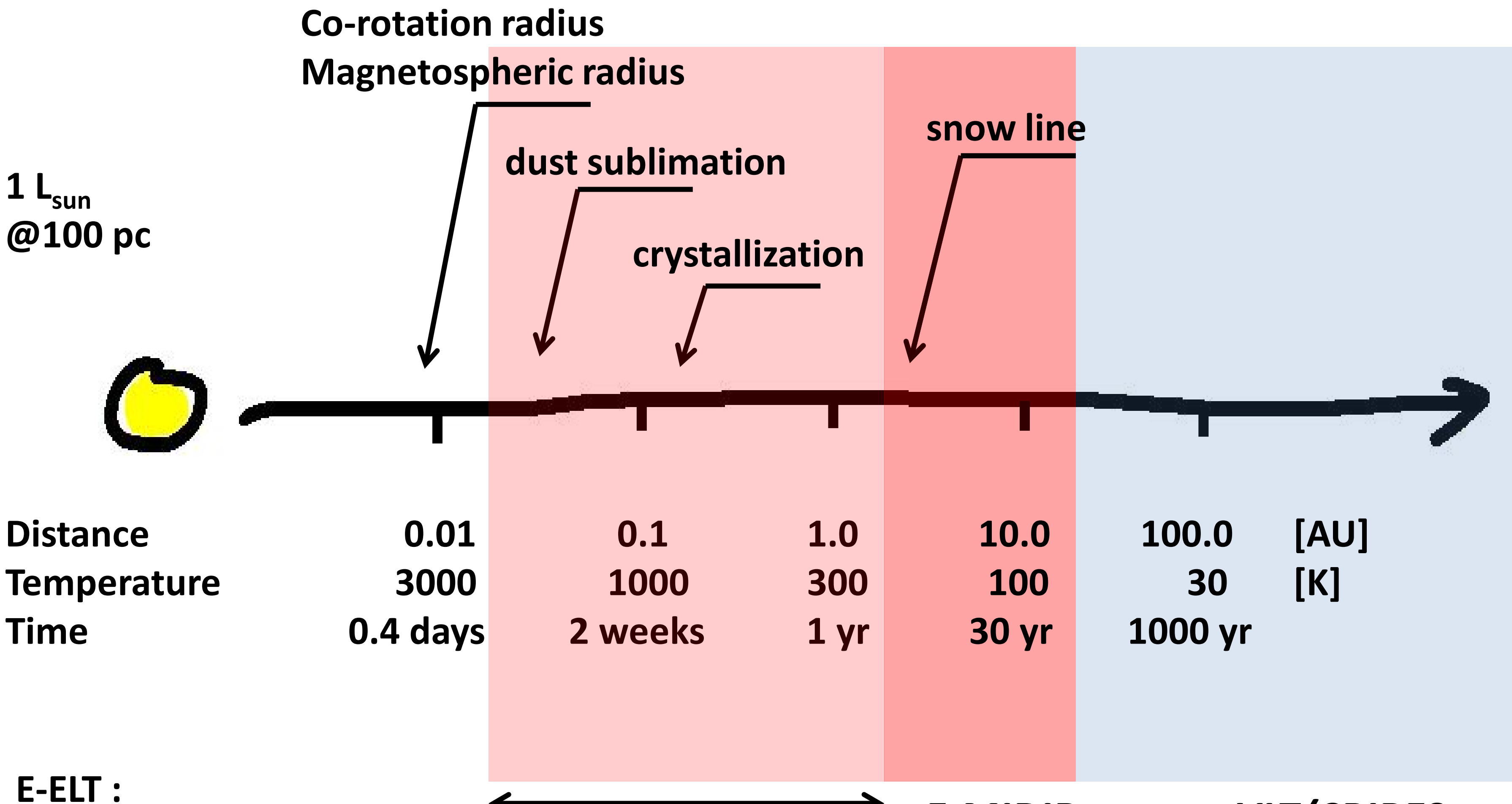
Distance	**0.01**	**0.1**	**1.0**	**10.0**	**100.0**	**[AU]**
Temperature	**3000**	**1000**	**300**	**100**	**30**	**[K]**
Time	**0.4 days**	**2 weeks**	**1 yr**	**30 yr**	**1000 yr**	

E-ELT :
10 mas x 100pc = 1 AU

E-MIDIR ***VLT/CRIRES***
E-IFU, E-HIRES ***ALMA***

2.1 Planet-forming regions

Accessing the AU to the sub-AU scale



E-ELT :
10 mas x 0.01 x 100pc
= 0.01 AU

Spectro-astrometry

E-MIDIR
E-IFU, E-HIRES

VLT/CRIRES
ALMA

2.1 Planet-forming regions

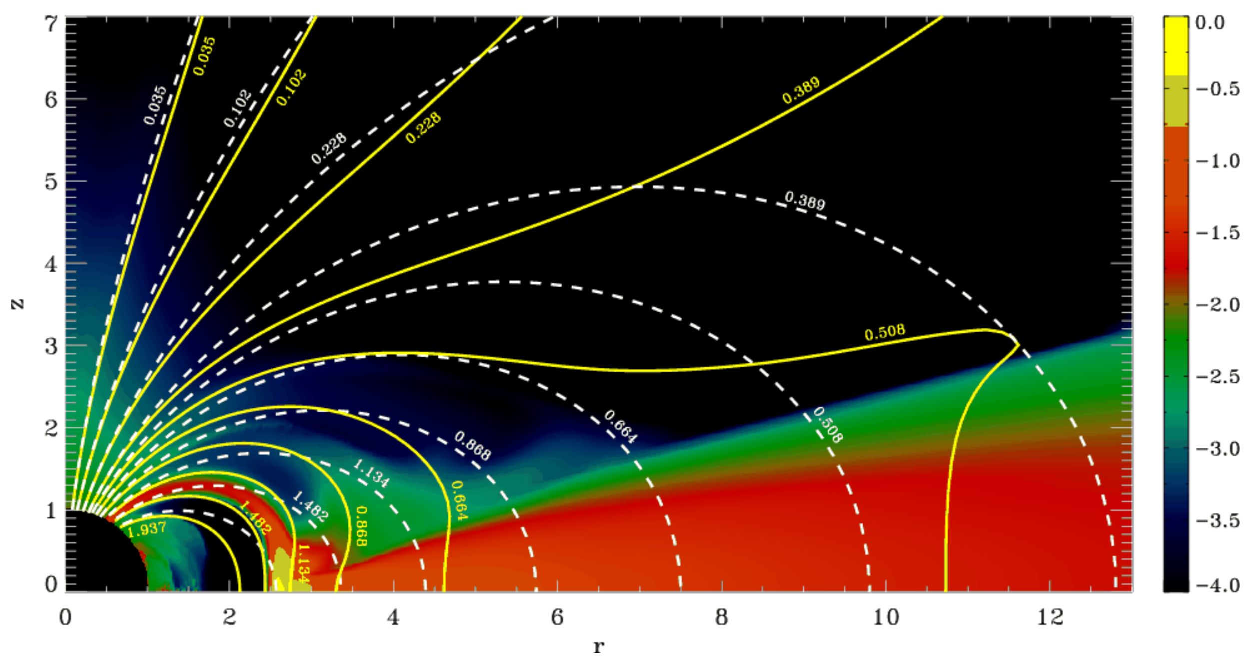
Star/Disk interactions

- Geometry of Accretion Channels
- Inner Disk Properties (Warp, asymmetries…)
- Role of Magnetic Fields (Config., Reconnection)
- Jet Launching Zone,
  Stellar & Disk Winds

Spectro-astrometry

E-ELT : 10 mas x 0.01 x 100pc
= 0.01 AU
= 2 Ro

MHD star – disk simulations



(0.01 AU)

R/Ro

Zanni & Ferreira 09

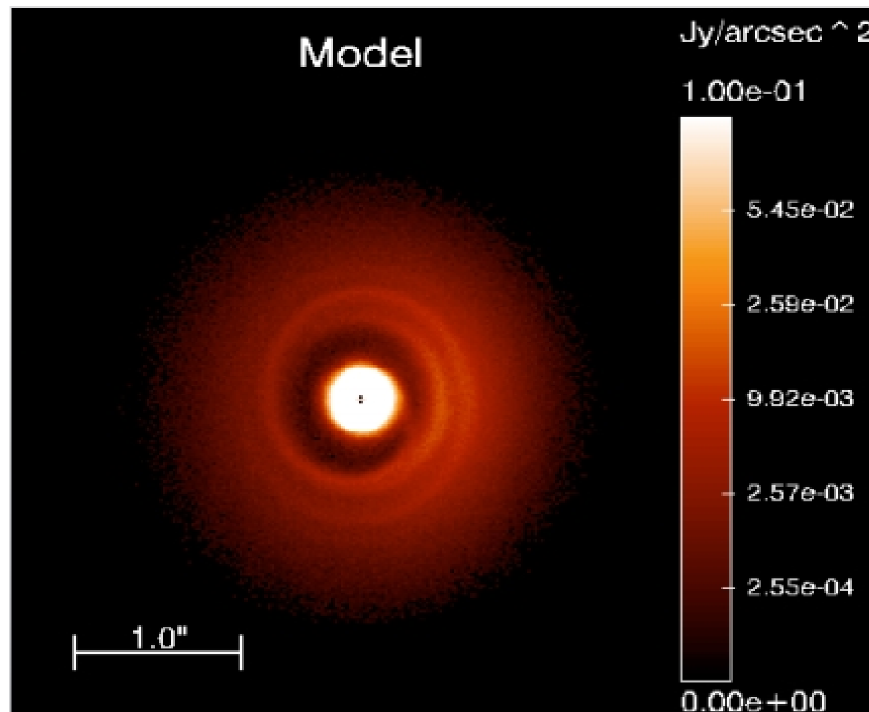
2.1 Planet-forming regions

Dusty Disk Structures

Asymmetries/Spirals in proto-planetary disks

- E-MIDIR ***simulations*** of high-contrast imaging at **10 µm**.
- Jupiter footprint at 20 AU (@100pc) from G-star,
- Gap detection at a few mJy/as2 at 0.1-0.2” (10 – 20 AU)
- ELT-MIR very competitive with JWST

Grain differentiation with size
Pressure Bump and dust trap
Hot spot/Proto-planets



E-CAM, MIDIR

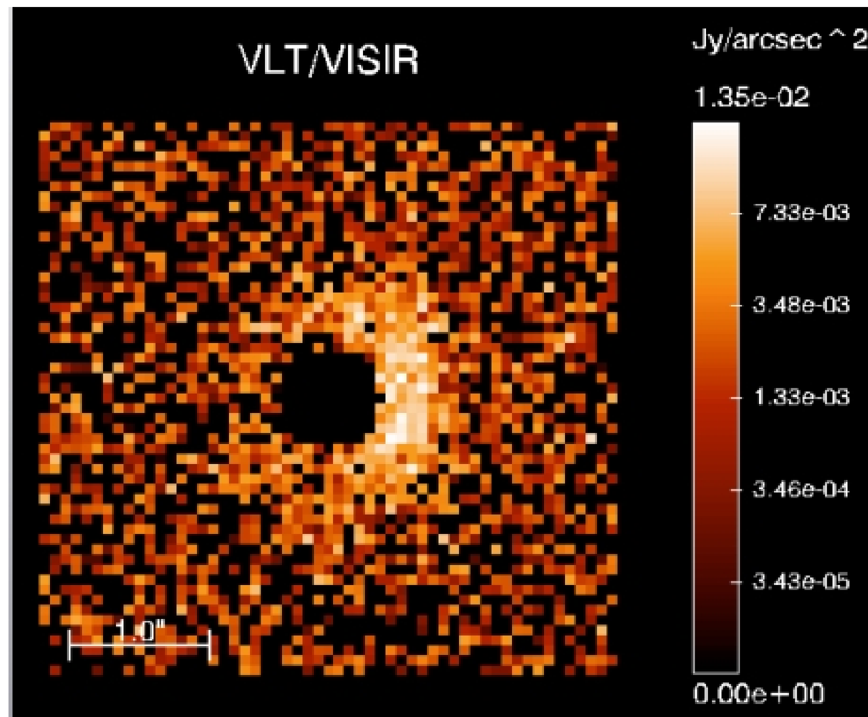
2.1 Planet-forming regions

Dusty Disk Structures

Asymmetries/Spirals in proto-planetary disks

- E-MIDIR ***simulations*** of high-contrast imaging at 10 µm.
- Jupiter footprint at 20 AU (@100pc) from G-star,
- Gap detection at a few mJy/as2 at 0.1-0.2" (10 – 20 AU)
- ELT-MIR very competitive with JWST

Grain differentiation with size
Pressure Bump and dust trap
Hot spot/Proto-planets



E-CAM, MIDIR

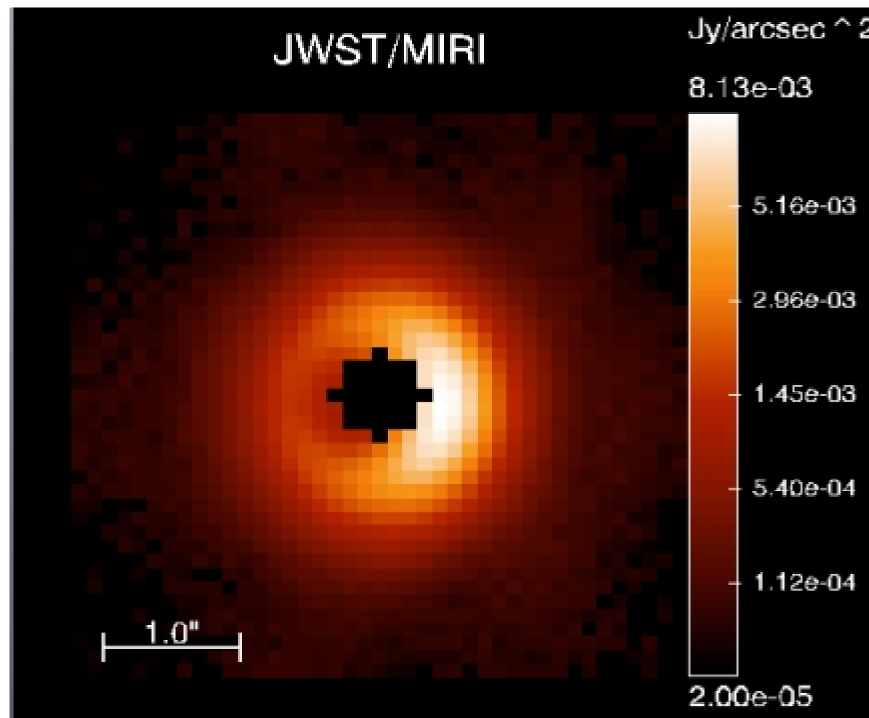
2.1 Planet-forming regions

Dusty Disk Structures

Asymmetries/Spirals in proto-planetary disks

- E-MIDIR ***simulations*** of high-contrast imaging at 10 μm.
- Jupiter footprint at 20 AU (@100pc) from G-star,
- Gap detection at a few mJy/as2 at 0.1-0.2” (10 – 20 AU)
- ELT-MIR very competitive with JWST

Grain differentiation with size
Pressure Bump and dust trap
Hot spot/Proto-planets



E-CAM, MIDIR

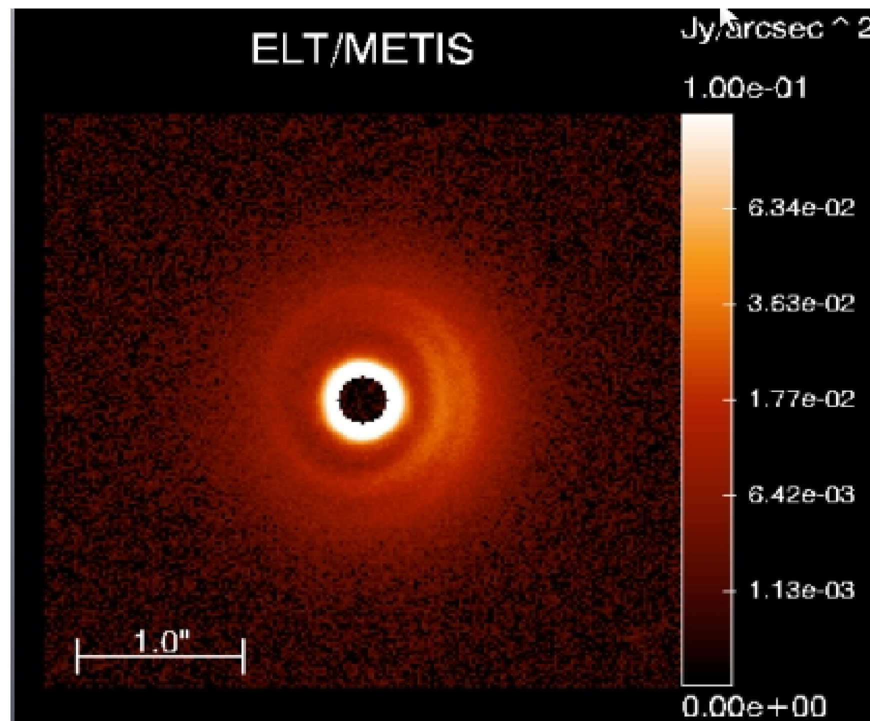
2.1 Planet-forming regions

Dusty Disk Structures

Asymmetries/Spirals in proto-planetary disks

- E-MIDIR ***simulations*** of high-contrast imaging at 10 µm.
- Jupiter footprint at 20 AU (@100pc) from G-star,
- Gap detection at a few mJy/as2
  at 0.1-0.2" (10 – 20 AU)
- ELT-MIR very competitive with
  JWST

Grain differentiation with size
Pressure Bump and dust trap
Hot spot/Proto-planets



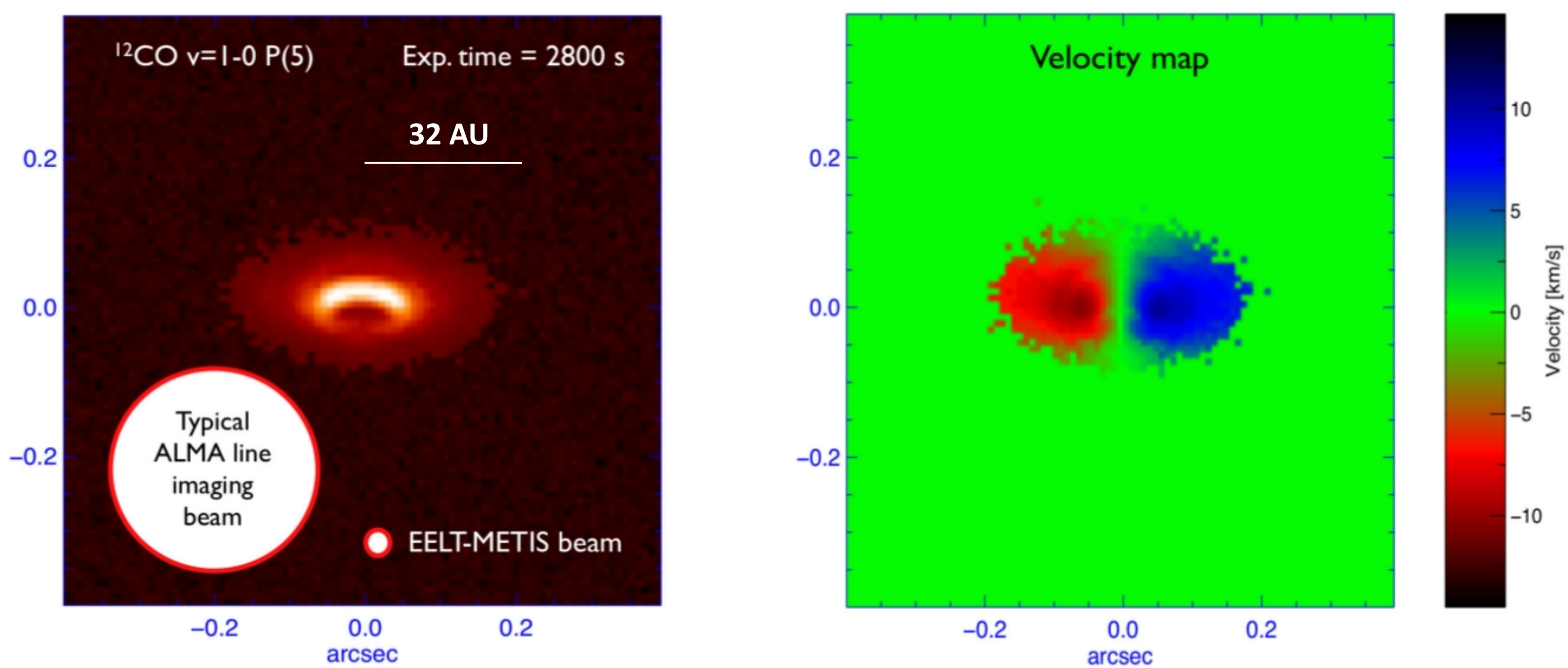
E-CAM, MIDIR

2.1 Planet-forming regions

Gas Distribution & Dynamics

Proto-planetary disk of SR21 (Ophiucus, 160pc, 1 Myr)
Gap at 18 AU (sub-mm continuum emission Brown e al. 07)

- E-ELT-MIDIR ***simulations*** of ^{12}CO line emission at 4.7µm of SR21.
  - o **Left**: Continuum subtracted and velocity channel co-added
  - o **Right**: Velocity map with a resolving power of 100 000 (**3 km/s**)



E-MIDIR

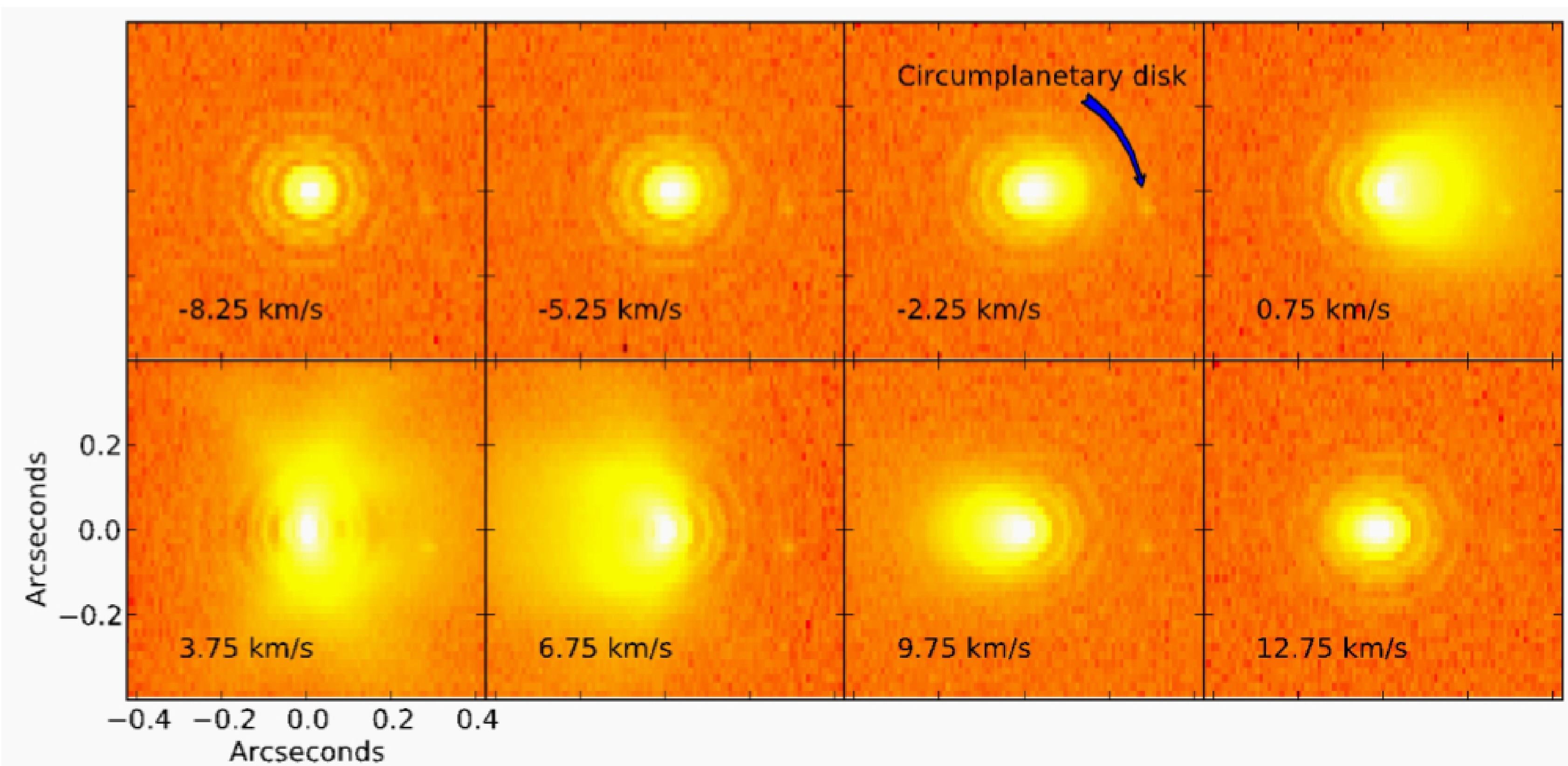
2.1 Planet-forming regions

Proto-planet direct detection

Proto-planetary disk in young SFRs (solar-type star, 150pc)

10 M_{Jup} protoplanet at 30 AU surrounded by a circumplanetary disk

- E--MIDIR ***simulations*** of ^{12}CO line emission at 4.7μm, continuum subtracted



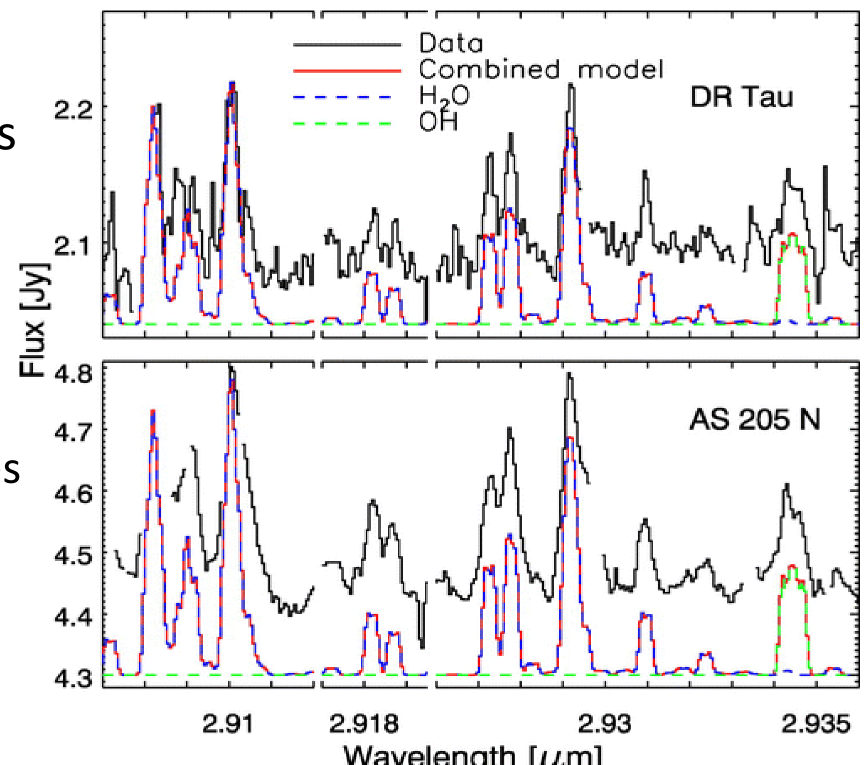
E-MIDIR

2.1 Planet-forming regions

Gas Composition & Chemistry

Water & Organics

- Distribution and Dynamics
- Disk cooling & Planetesimals formation
- Organic/Prebiotic chemistry (CH4, C2H2, HCN…)
- Isotopic Fractionation
- Water Transfer to Terrestrial Planets

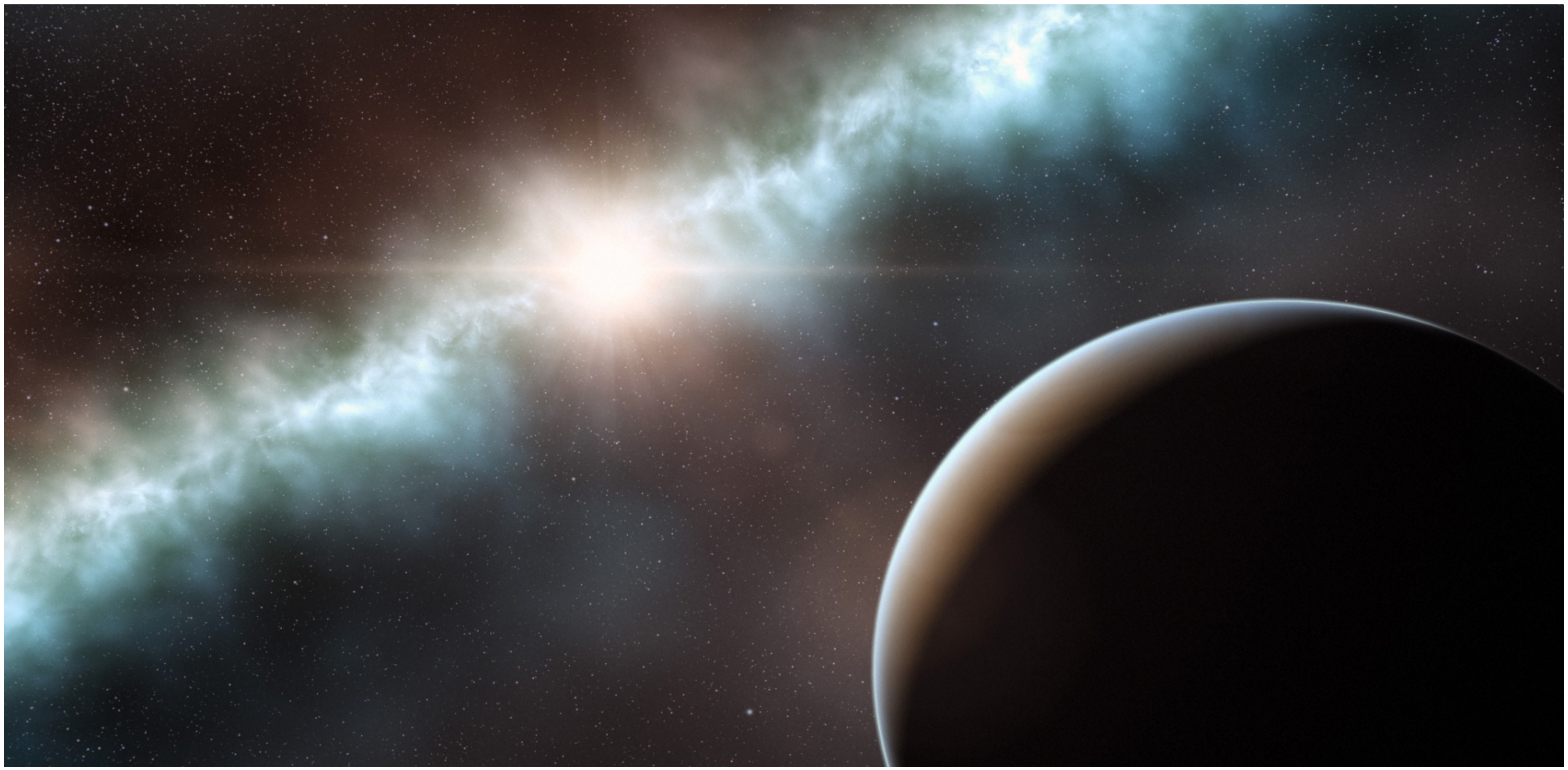


. Keck-NIRSPEC
. high HRS (R = 25 000) in L-band.
. Detection of H20 and OH radicals MIR lines
. Hot (800K) water from the inner AUs

DR Tau, AS 205 N; Salyk et al. 08

E-MIDIR

2.2 Exoplanets Characterization



Artist's View ESO-PR-1106

2.2 Exoplanets Characterization

Key Scientific Questions

. **Architecture of Planetary Systems**

- o Frequent of GP/Telluric planets
- o Dynamical evolution/stability

. **Formation/Internal Evolution of Young Planets**

- o Accretion history/Cooling

. **Physics of Planetary Atmospheres**

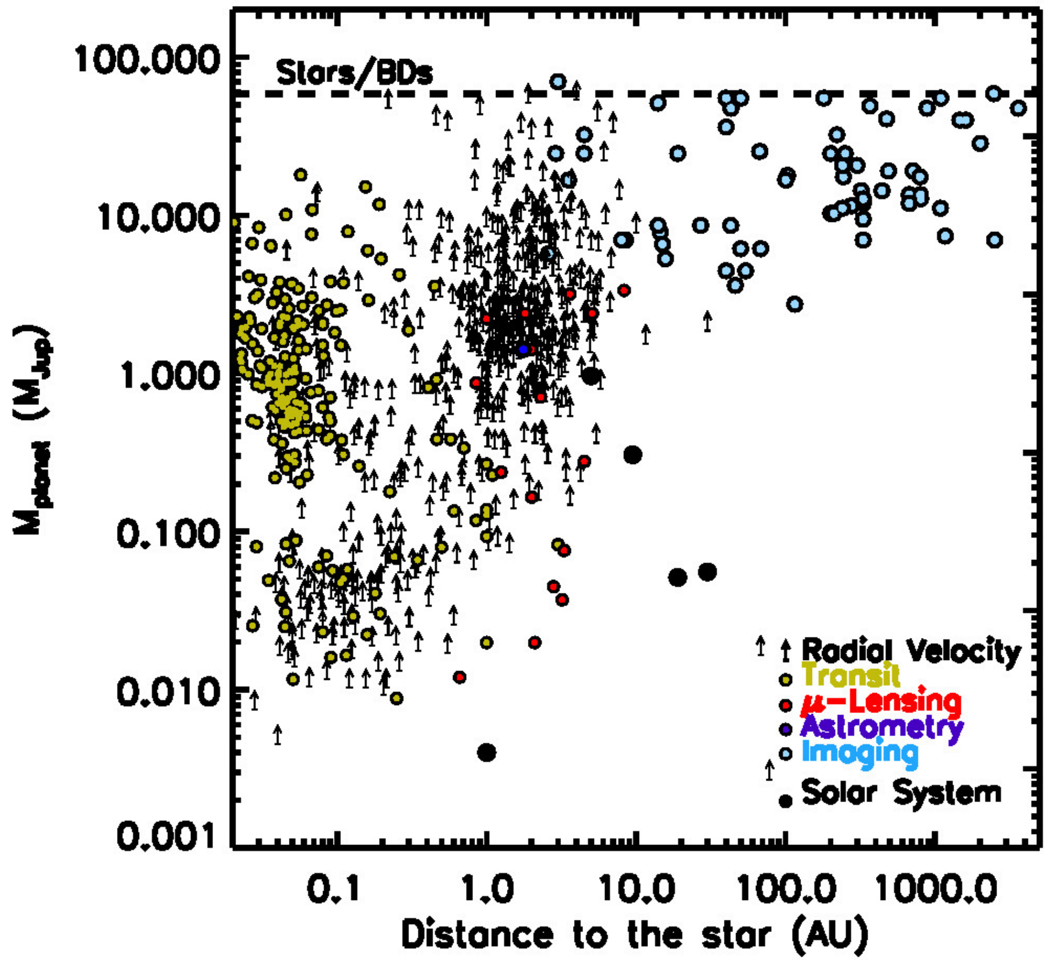
- o Composition/Chemistry
- o Bio-Signatures Discovery

2.2 Exoplanets Characterization

Architecture & Formation/Evolution

E-CAM, IFU, MIDIR, PCS

Exoplanets, current view (2014)



2.2 Exoplanets Characterization

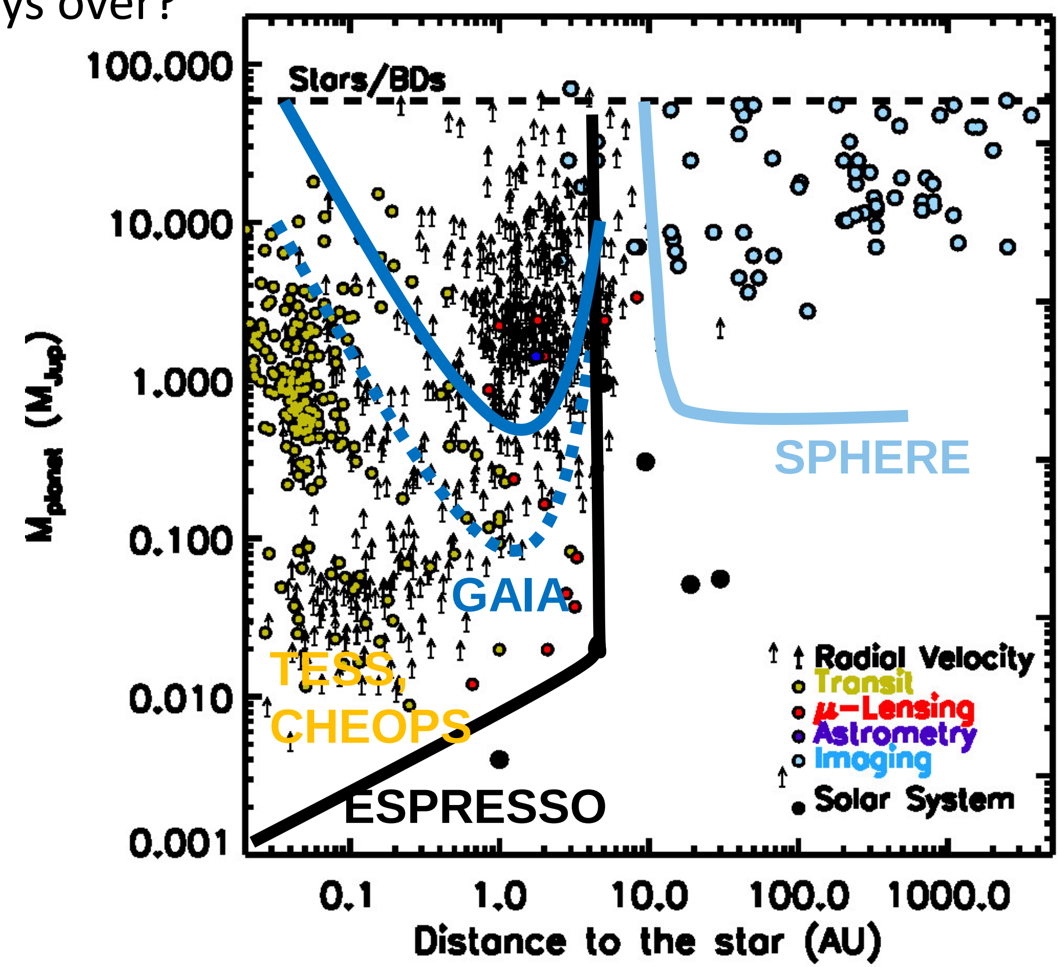
Architecture & Formation/Evolution

E-CAM, IFU, MIDIR, PCS

At E-ELT 1st Lights (2024):

. RV, Astro., Transit & DI surveys over?

. Complete census of nearby planetary systems?



2.2 Exoplanets Characterization

Architecture & Formation/Evolution

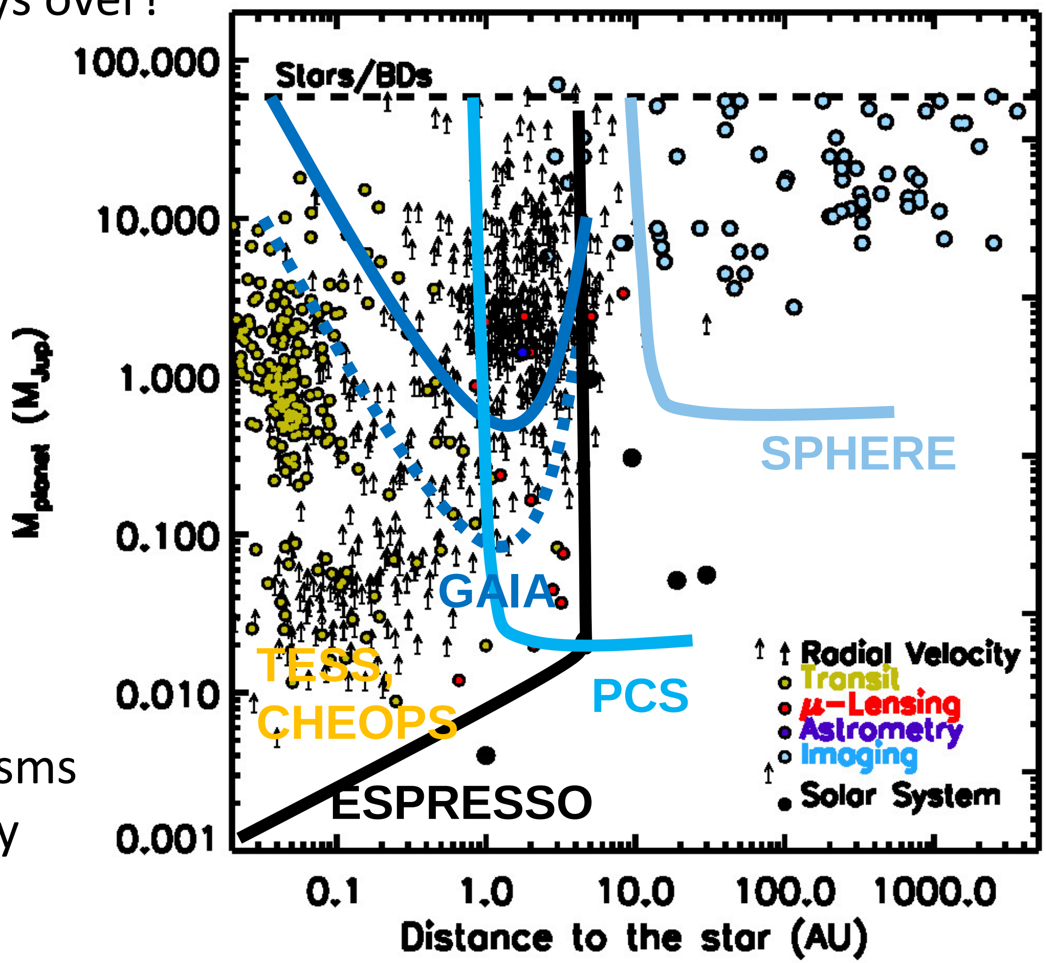
E-CAM, IFU, MIDIR, PCS

At E-ELT 1st Lights (2024):
. RV, Astro., Transit & DI surveys over?
. Complete census of nearby planetary systems?

E-ELT High-contrast Imaging
(CAM, IFU, MIDIR, **PCS**)
Overlap btw techniques

Planetary freq. at all Periods
Global view of planetary systems **architecture**

Dominant formation mechanisms
Dynamical evolution & stability



2.2 Exoplanets Characterization

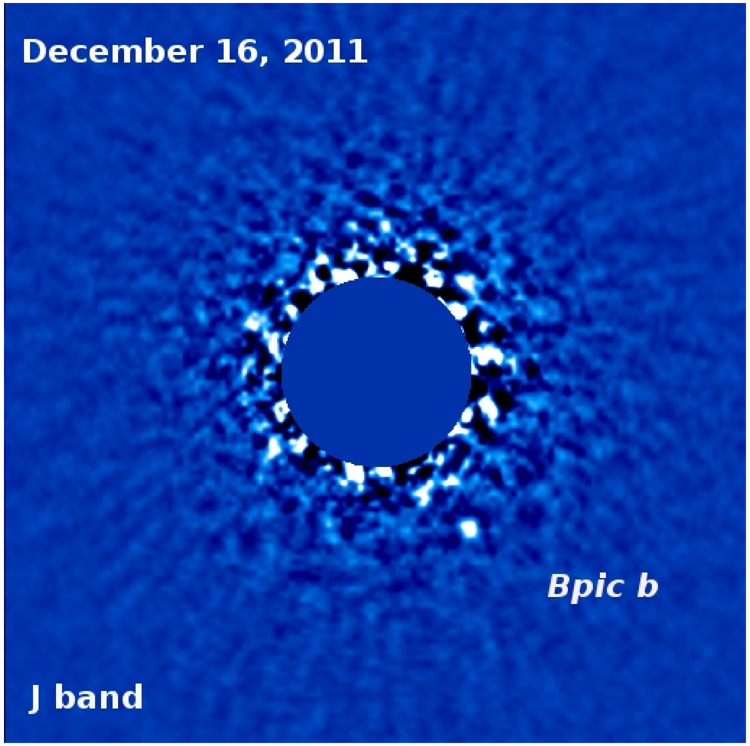
Young Jupiters Properties/History

E-CAM, IFU, MIDIR, PCS

Physics of Giant Planets

- Observables: **Luminosity**
- **Orbital** properties: a, e, i,
- **Complementarity** RV, Astr…
  > Access **Dynamical Mass**

Bpic; Lagrange et al. 09, 10, Chauvin et al. 12
Bonnefoy et al. 14



2.2 Exoplanets Characterization

Young Jupiters Properties/History

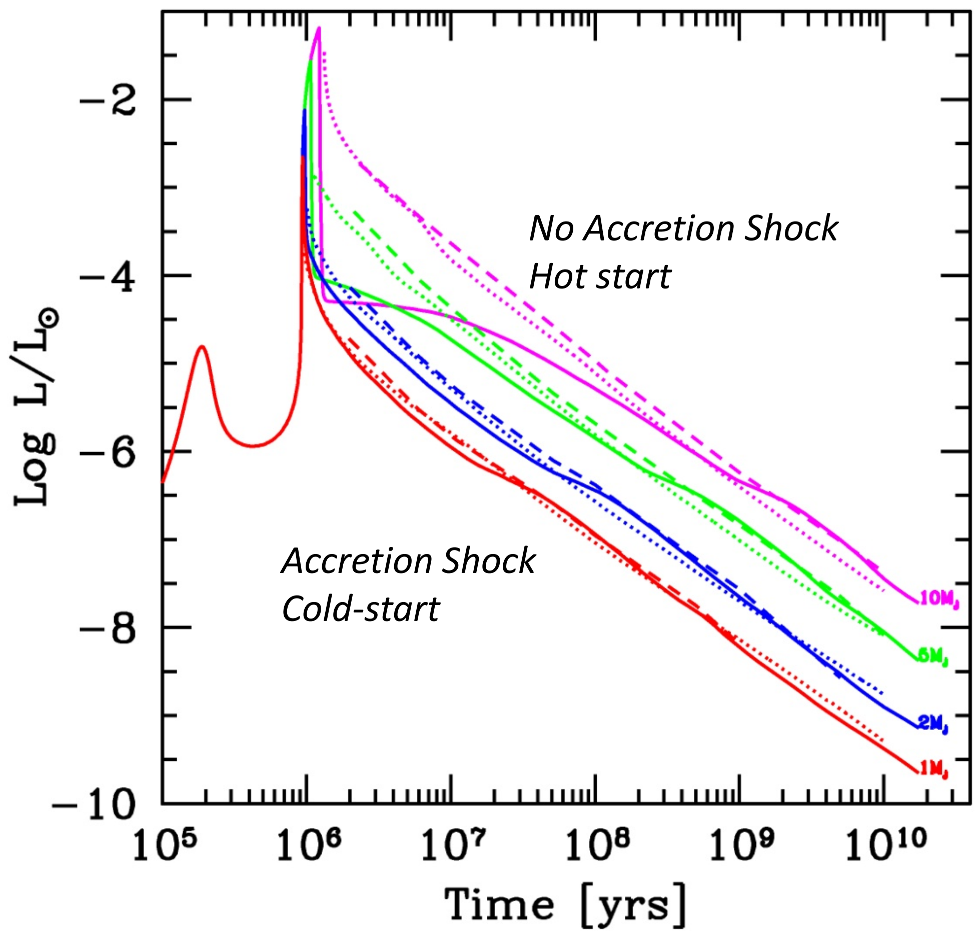
Physics of Giant Planets

- Observables: **Luminosity**
- **Orbital** properties: a, e, i,
- **Complementarity** RV, Astr…
  > Access **Dynamical Mass**

Formation/Cooling Evolution

- Lum. – Mass parameter space
- Calibrate model predictions
- Gas Accretion History
  Presence of a core

Mordasini et al. 12



E-CAM, IFU, MIDIR, PCS

2.2 Exoplanets Characterization

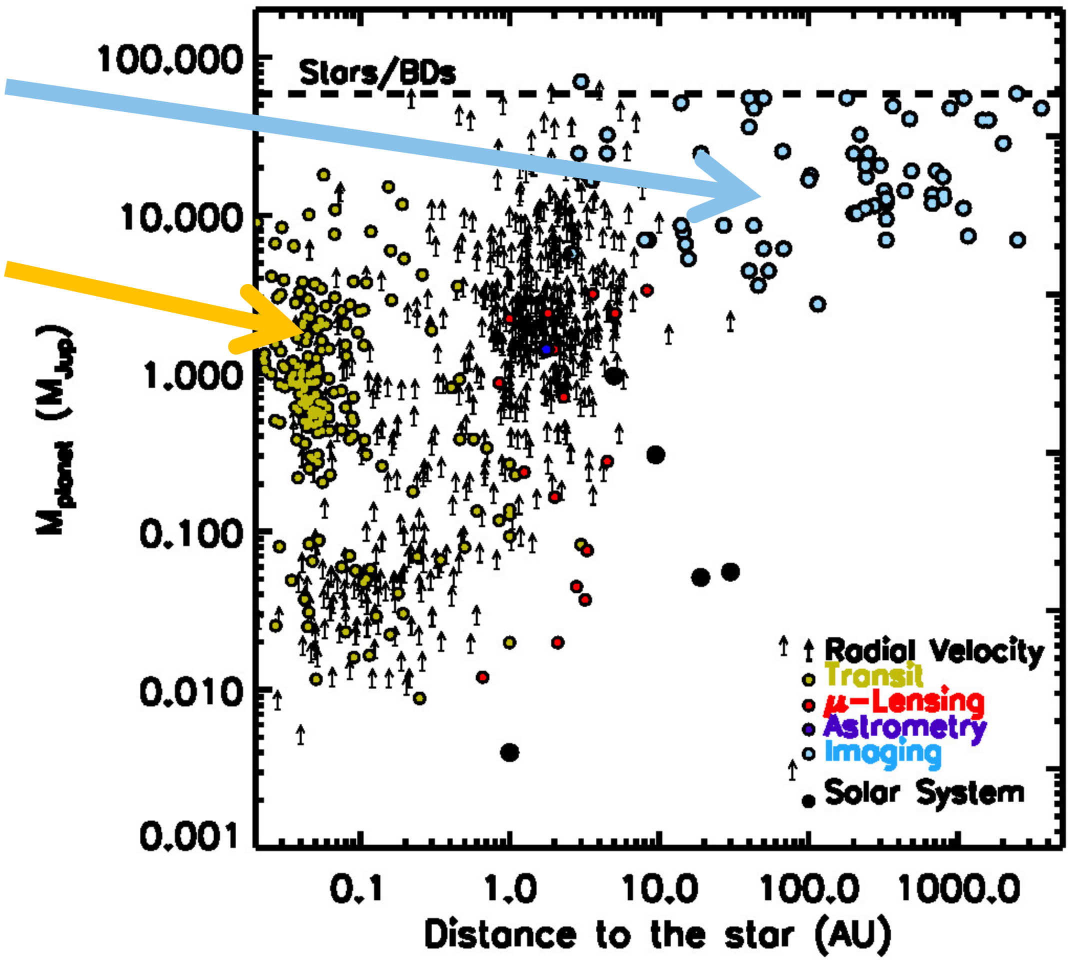
Physics of the Planetary Atmosphere

Wide orbit self-lum. planets

- High-contrast LRS
- High-contrast + HDS

Close-in Irradiated planets

- Transmission/Eclipse LRS
- HDS



2.2 Exoplanets Characterization

Physics of the Atmosphere

i/ High-Contrast Low-Resolution Spectroscopy

- Contrast Goal: **10^{-6}** (50mas) to **10^{-9}** (20mas) - Targets: **M-dwarfs, young stars**
- Emitted (E-IFU, MIDIR) and Reflected (E-PCS) light of giant icy planets (Super-Earths?)
- Broad molecular absorptions: H_2O, CO, CH_4, NH_3, CO_2…

E-IFU, MIDIR, PCS

2.2 Exoplanets Characterization

Physics of the Atmosphere

E-IFU, MIDIR, PCS

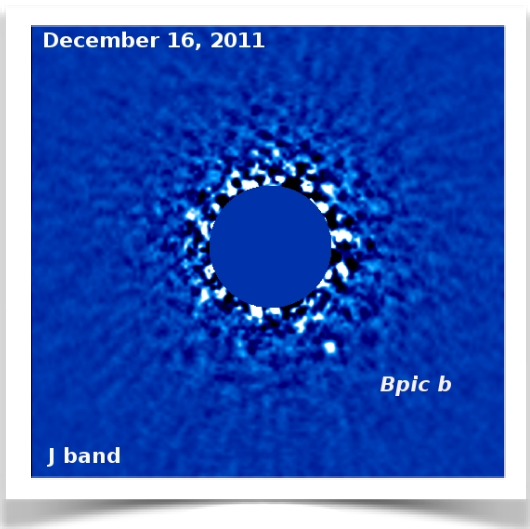
i/ High-Contrast Low-Resolution Spectroscopy

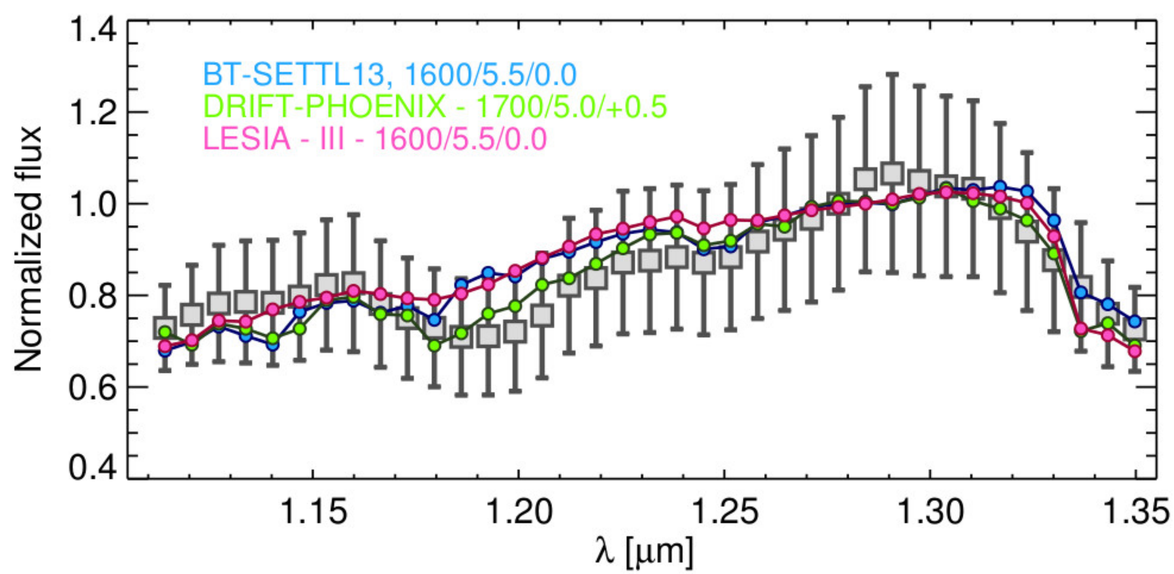
- Contrast Goal: **10^{-6}** (50mas) to **10^{-9}** (20mas) - Targets: **M-dwarfs, young stars**
- Emitted (E-IFU, MIDIR) and Reflected (E-PCS) light of giant icy planets (Super-Earths?)
- Broad molecular absorptions: H_2O, CO, CH_4, NH_3, CO_2…

Beta Pic b – GPI and SPHERE Observations in J-band (Res = 50)

8 – 13 M_{Jup} planet, 9 AU; T_{eff} = 1650 +- 150K, *log*(g) = 4.0±0.5 and R = 1.3+-0.2 R_{jup}

H_2O, FeH absorptions (Bonnefoy et al. 14)





2.2 Exoplanets Characterization

Physics of the Atmosphere

ii/ MOS Transit Medium-Resolution Spectroscopy

- Photometric accuracy Goal: **10-6**
- Targets: **M dwarfs**
- Search for bio-signatures to telluric planets
- Complementarity to JWST in visible: **Presence of Haze**

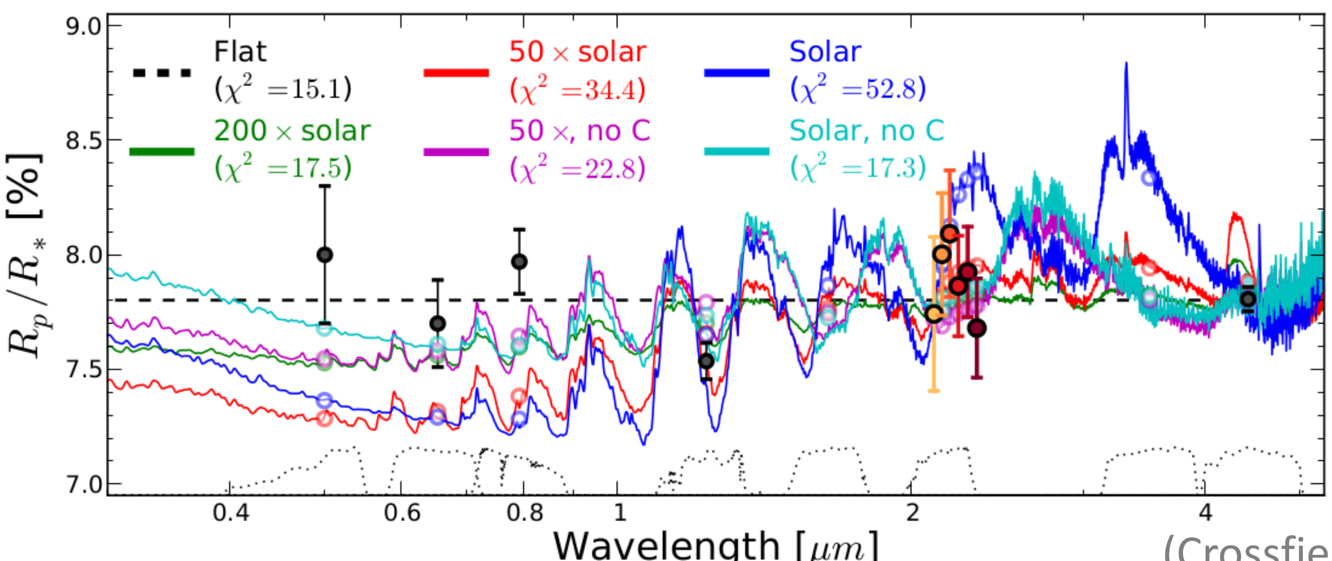
2.2 Exoplanets Characterization

Physics of the Atmosphere

ii/ MOS Transit Medium-Resolution Spectroscopy

- Photometric accuracy Goal: **10-6**
- Targets: **M dwarfs**
- Search for bio-signatures to telluric planets
- Complementarity to JWST in visible: **Presence of Haze**

GJ3470 b – Keck/MOSFIRE; FoV = 6' x 6'; Reference stars; Spectral range= 2.0 – 2.4 µm; Resolution = 3500 (OH lines); 10^{-4} photometric precision; Hot Neptune Transmission spectrum looks flat! Suggests hazes and/or disequilibrium chemistry



(Crossfield et al. 13)

E-MOS

2.2 Exoplanets Characterization

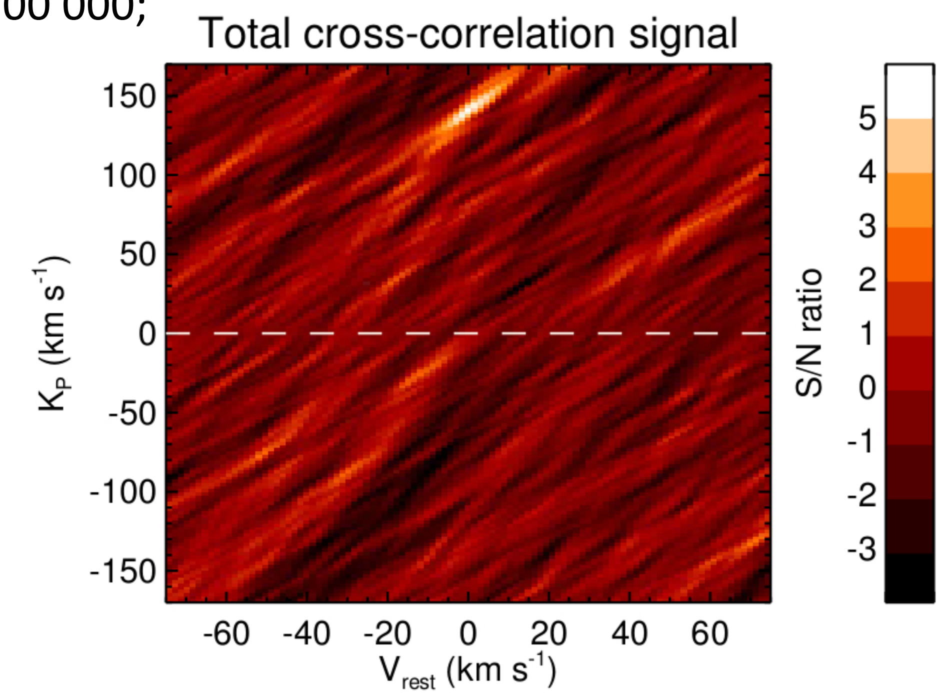
Physics of the Atmosphere

E-HIRES, MIDIR

iii/ High-Dispersed Spectroscopy

- Contrast: **10^{-5}** - Targets: **bright stars with close-in planets (>40)**
- Search for molecular absorptions of CO, H2O, CH4, NH3…
- Mass, inclination , thermal inversion, C/O ratio, atmosphere circulation… rotation

HD179949 b, Non-transiting planets
VLT/CRIRES observations, Resolution = 100 000;
Spectral coverage = 2.29-2.35 µm
Dayside seen in CO, H2O
Kp = 142.8 ± 3.4 km/s
Mass = 0.98 ± 0.04 MJup
Incl = 67.7 ± 4.3 deg



(Brogi et al. 14)

2.2 Exoplanets Characterization

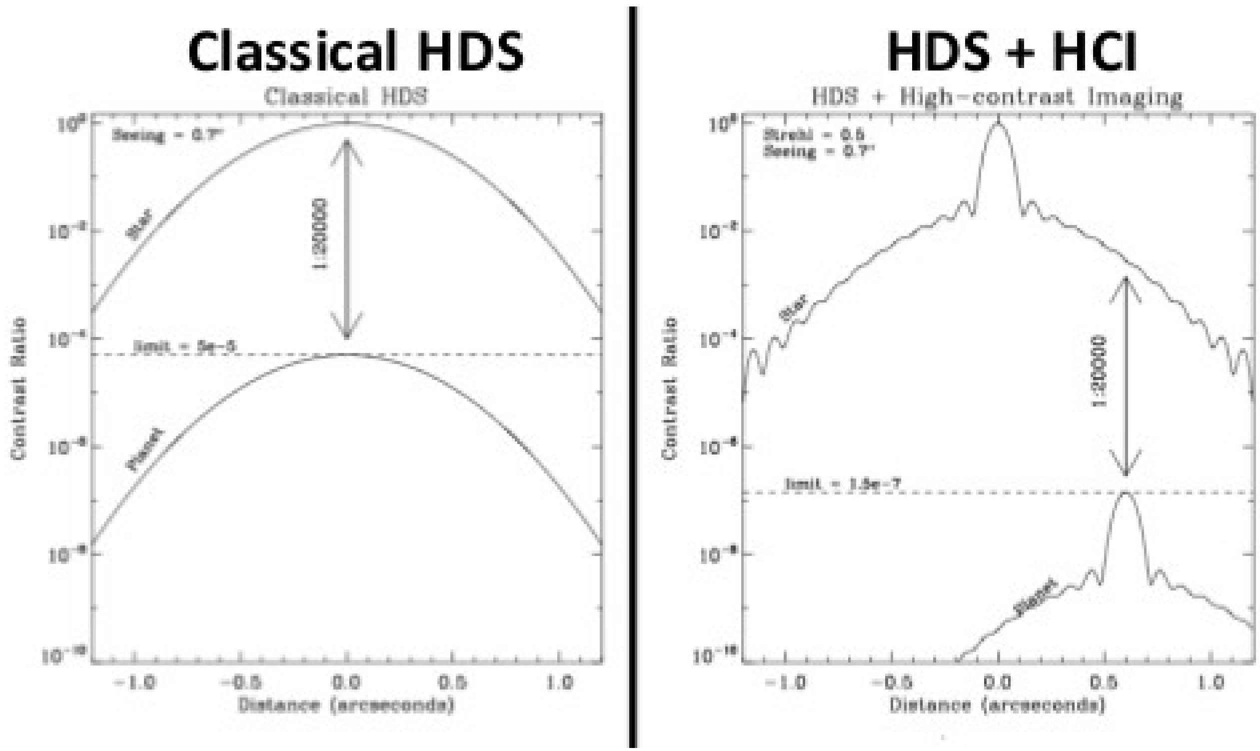
Physics of the Atmosphere

E-MIDIR & new PCS?

iv/ XAO High-Contrast + High-Dispersed Spectroscopy

- Powerful technique, capable to characterize rocky planets in HZ?
- Reflected light (from **10^{-4} to 10^{-9} contrast**); Search for O2 and bio-signatures…

Snellen et al. 13 and Talk



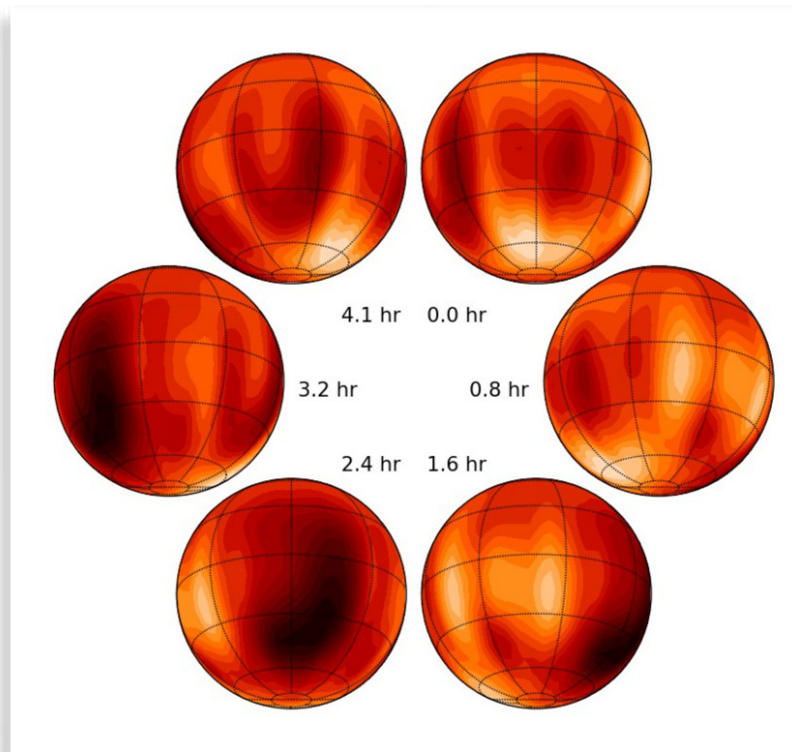
2.2 Exoplanets Characterization

Physics of the Atmosphere

E-MIDIR & new PCS?

iv/ XAO High-Contrast + High-Dispersed Spectroscopy

- Powerful technique, capable to characterize rocky planets in HZ?
- Reflected light (from **10^{-4} to 10^{-9} contrast**); Search for O2 and bio-signatures…
- Doppler imaging mapping of Exoplanets: Cloud/Molecular Coverage



Luhman 16 B, 2 pc, Rotation 4.9hrs
spectroscopic variability

(Crossfield et al. 14)

Conclusions

- **The E-ELT project**
  > **Unique Spatial resolution & sensitivity**
  > Offering a **versatile instrumentation**
  (wavelengths coverage, modes, spatial/spectral resolution…)
  > Will count on new discoveries (ALMA, SPHERE, GPI, GAIA, TESS...)
  > Mostly aimed at **Characterizing** , but not only…

- **Exoplanetary science**
  > Observing **planet-forming regions** (0.01 – 10 AU scale)
  > Initial conditions for planetary formation
  (Disk Structure, Composition & Chemistry)
  > **Overlap** btw observing techniques
  Architecture of planetary systems (**Global view**)
  Physics of Young Jupiters (Formation, Accretion)
  > Atmospheres
  Giant/Icy to Sper-Earths,
  T/P structure, composition, C/O ratio, cloud coverage & variab….
  Path toward characterization of exo-Earths atmospheres

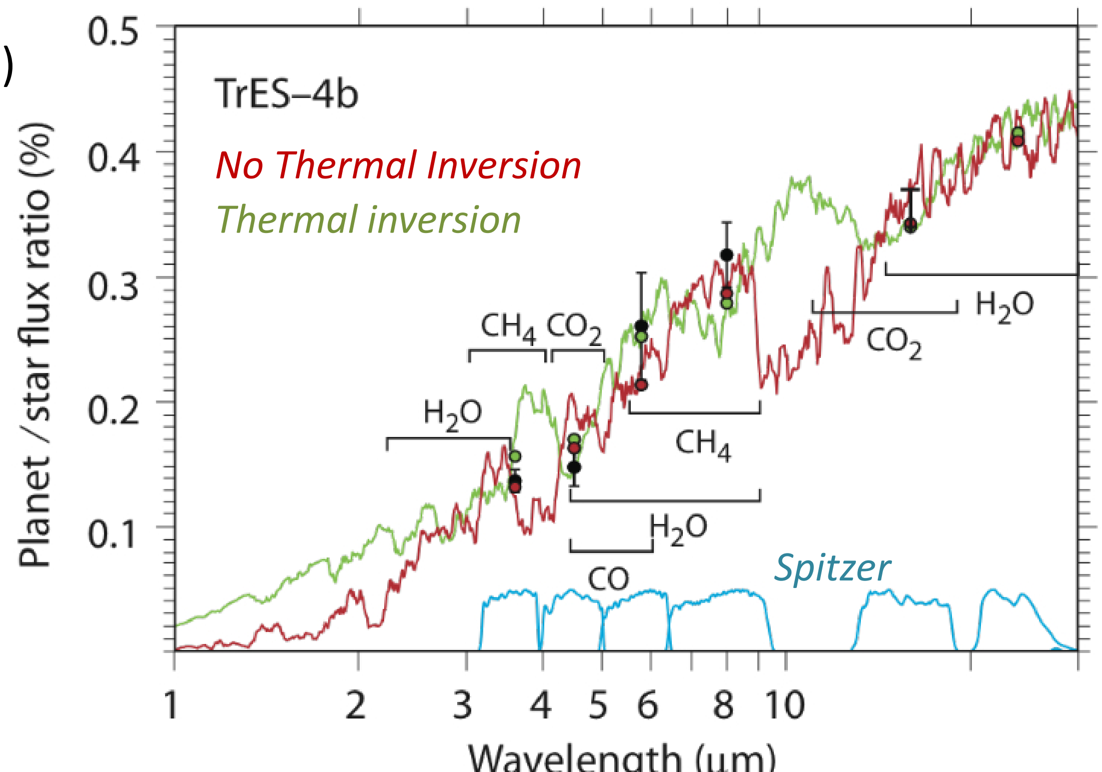

Thank you
Cerro Amazones, Sep 12th, 2014
© Julien Girard 2014

2.2 Exoplanets Characterization

Planetary Atmospheres

- **Reflected**, **Transmitted** or **Emitted** light of Exoplanets
- **Strongly** or **non-strongly irradiated** planets
- **Physics** of Planetary Atmospheres (Giant, Exo-Neptunes to Super-Earths)
  - Geometric Albedos
  - Chemical Composition (H20, CH4, CO, CO2, NH3…)
  - Atmosphere's Dynamics
    . Inversion,
    . Vertical Mixing,
    . Circulation,
    . Evaporation,
- **Imprints of Formation Mechanisms?**

Knutson et al. 09



E-HIRES, E-MIDIR, E-PCS

2.2 Exoplanets Characterization

Physics of the Atmosphere

iii/ High-Dispersed Spectroscopy