Planets 2020, ALMA, March 2nd-6th, 2020

Direct Imaging of Disks & Exoplanets with the E-ELT

Gaël Chauvin *(French – Chilean Laboratory for Astronomy, Chile)*

ESO - ELT Project Science Team
MICADO-MAORY, HARMONI, METIS consortia
https://www.eso.org/public/teles-instr/elt/

FCLA French-Chilean Laboratory for Astronomy

cnrs advancing the frontiers

ESO

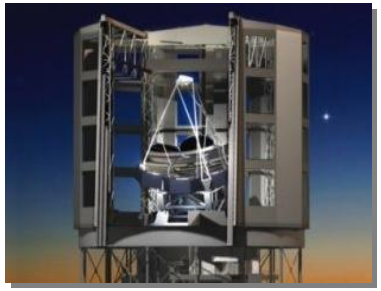
ELT(s) Project

Discoveries by opening a new parameter space

- Unique spatial resolution (10 mas scale at K band),
- Increased sensitivity,
- Instrumentation versatility,
  over at least 30 years of operation...

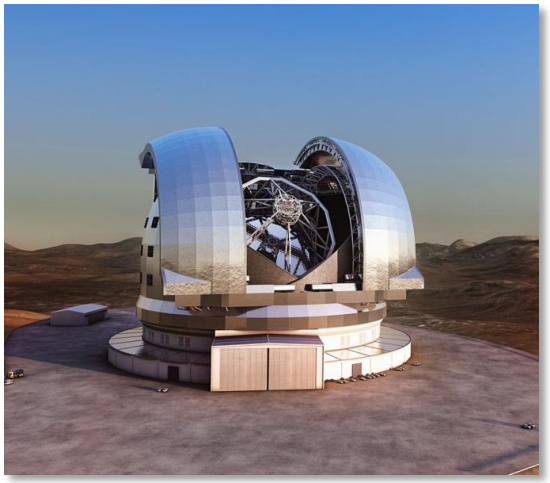
VLT

GMT



TMT

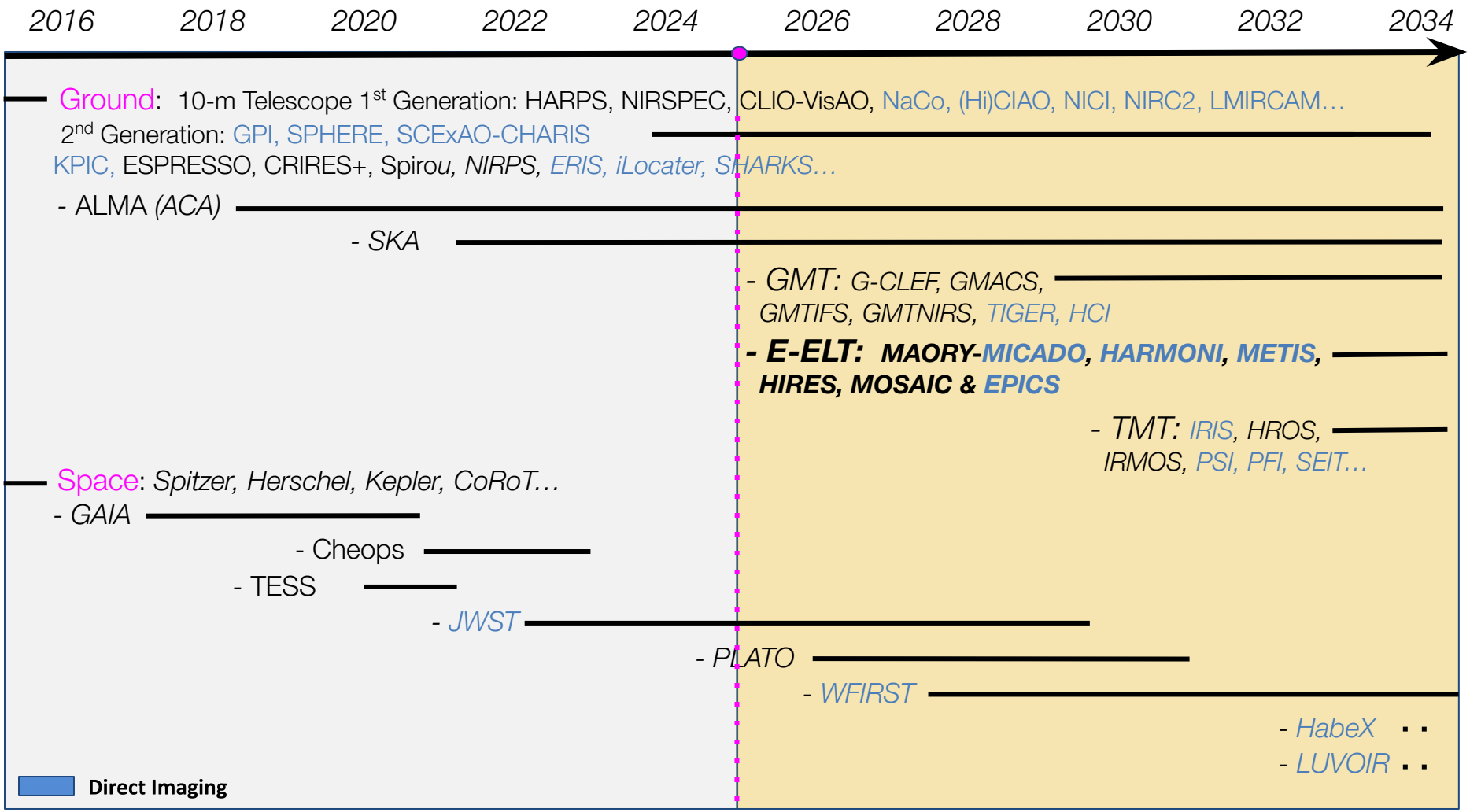
E-ELT



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

The Golden Age

Timeline of current & future missions/instruments



ELT: Instrumentation roadmap

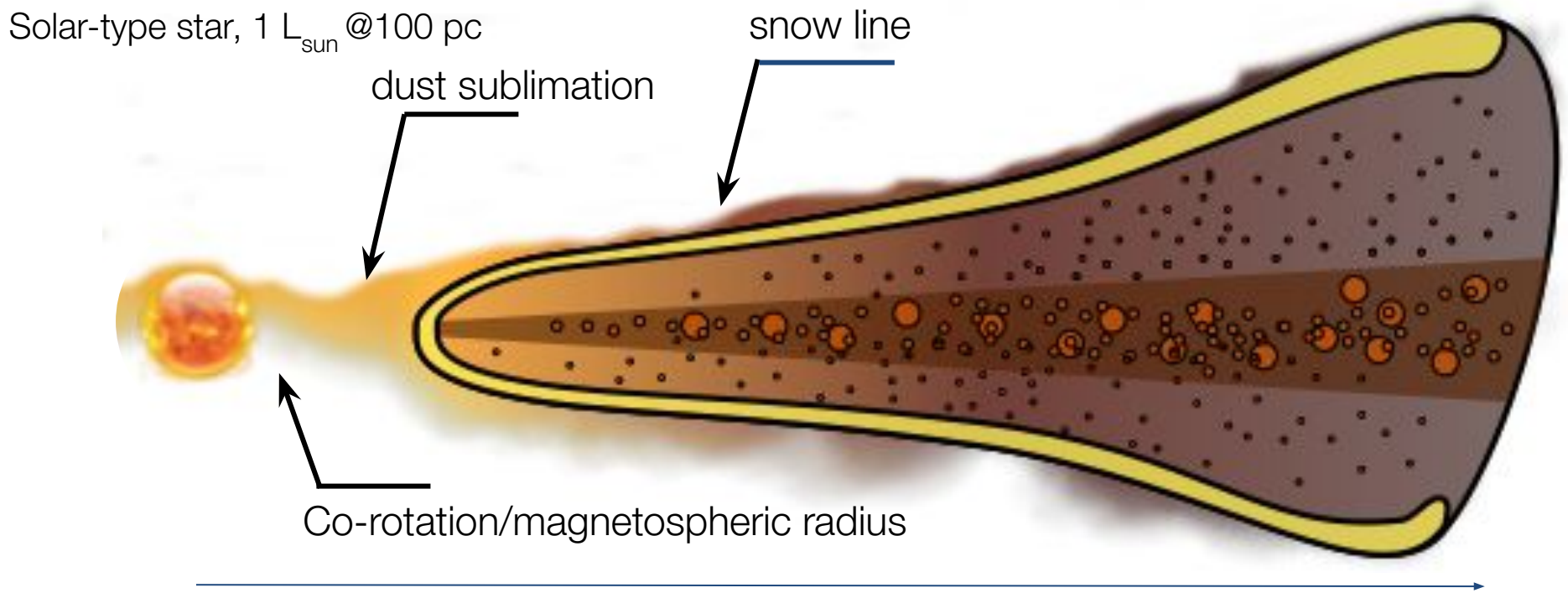
Phasing

1st Generation 2nd Generation

Instruments - First Light	Description	AO	λ (μm)	Resolution	FoV	Add. Mode
MAORY/MICADO (PdR completed*) (2026-2028)	Spectro-imager	SCAO, MCAO	0.8 – 2.4	3000 - 18 000	53.0” 19.0” 6.0”	Astrometry 40μas Coronography Long-Slit Spectro
HARMONI (PdR completed) (2026-2028)	IFU Spectrograph	SCAO, LTAO	0.5 – 2.4	3500 7000 17 000	1.0” 10.0”	Coronography
METIS (PdR completed) (2026-2028)	IFU & Spectro-Imager	SCAO LTAO	3 – 20 3 - 5	5000 100 000	18” 0.4”×1.5”	Coronography Long-Slit Spectro
HIRES (Phase A completed) (2030+)	Optical and NIR High-Resolution Spectrograph	SCAO	0.37 – 0.71 0.84 – 2.50	200 000 120 000	0.82” 0.5”	Polarimetry IFU mode
MOSAIC (Phase A completed) (2030+)	Optical and NIR Wide/Narrow field Multi Object Spectrograph	- - MOAO	0.37 – 1.4 0.37 – 1.4 0.8 – 2.45	300- 2500 5000 – 30 000 4000 – 10 000	6.8” 420’ 2”	Multiplex ~ 400 Multiplex ~100 Multiplex ~10 Imaging?
EPICS (2030+)	Optical and NIR High Contrast IFU Spectrograph & imager	XAO	0.6 – 0.9 0.95 – 1.65	125 – 20 000 100 000?	2.0” 0.8“	Coronography Polarimetry

Key science drivers

1. Initial conditions for planetary formation



Distance	[au]	0.1	1.0	10.0	100.0
Temperature	[K]	1000	300	100	30
Time		2 weeks	1 yrs	30 yrs	1000 yrs

ALMA, SPHERE, GPI, SCExAO...

VLTI, CHARA, LBTI, *CRIRES*

MICADO, HARMONI, METIS

ELT :
10 mas x 100pc = 1 au

spectro-astrometry

Key science drivers

1. Initial conditions for planetary formation

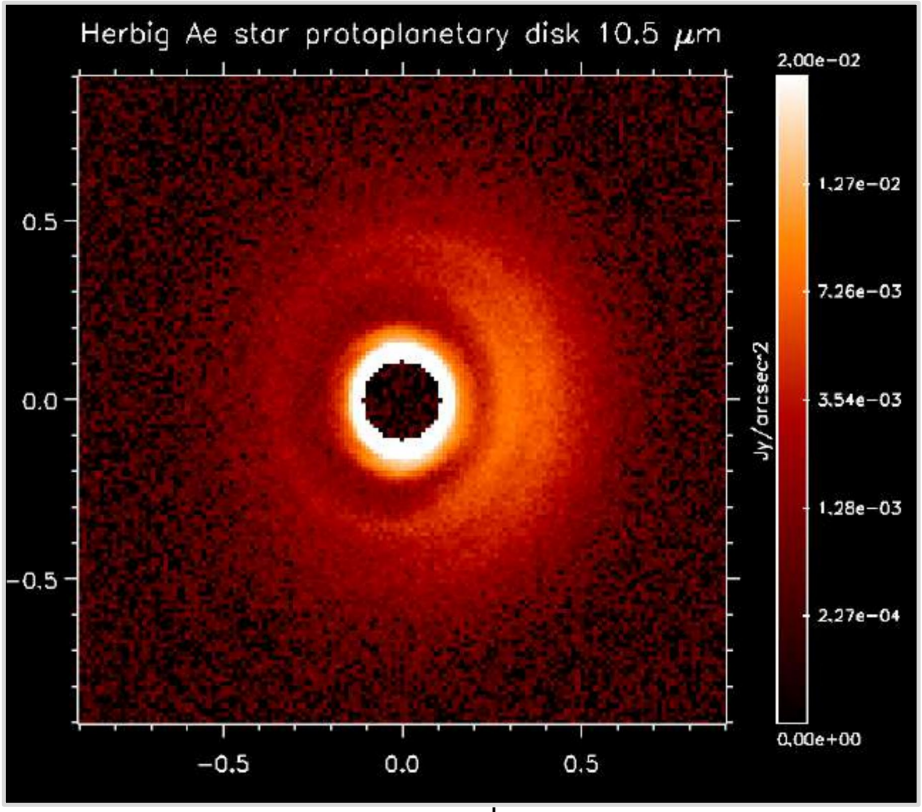
Dust structures & properties in planet-forming regions

- Spirals, Rings, Gaps, Shadows, vortices… (SPHERE+, ALMA, SKA synergy)

- Rich perspectives:
  - Grain properties,
  - Dust filtration,
  - Pressure bump & dust trap,
  - Hot spots & proto-planets

METIS high-contrast imaging
- N-band 10 μm, Herbig-star (100 pc)
- Jupiter footprint at 20 au,
- Gap detection at a few mJy/as2 @0.1-0.2” (10 – 20 au)
- very competitive with JWST

Rough simulations: background limited beyond a radius of 2λ/D



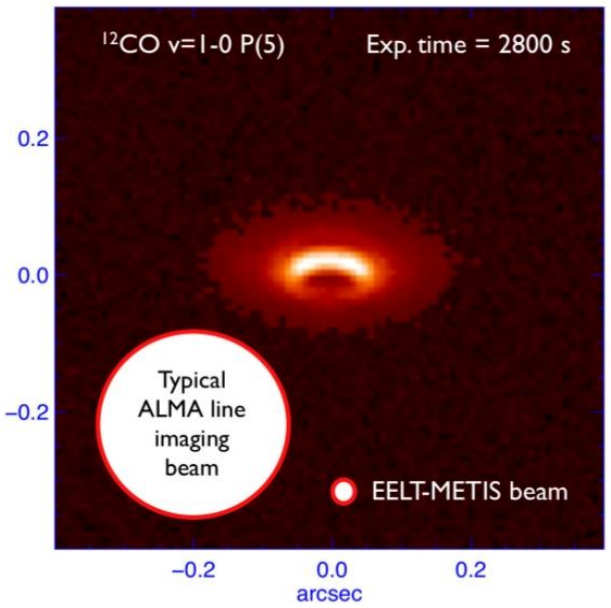
Key science drivers

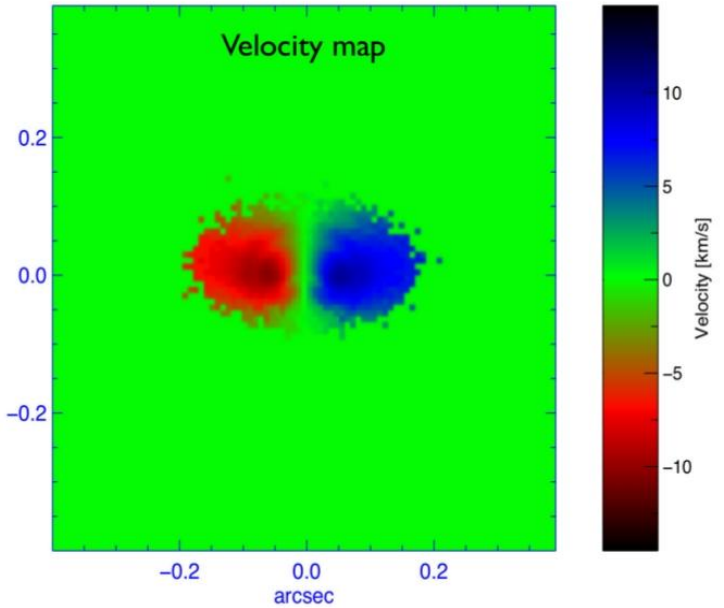
1. Initial conditions for planetary formation

Gas properties, spatial distributions & dynamics,

- New window @ midIR with METIS:
  - Wide range of gas-phase molecules: CO, OH, CH4, NH3, HCN, C2H2...
  - Organic/Prebiotic chemistry, snowlines, disk cooling, planetesimals formation
  - Isotopic Fractionation of CO > Water Transfer to Terrestrial Planets
  - Dynamics: turbulence, deviation from Keplerian velocities (planetary kink),

METIS (R_λ = 100 000, 3 km/s) IFU simulations, ^{12}CO line emission at 4.7µm
Proto-planetary disk of SR21 (Ophiuchus, 160pc, 1 Myr), gap at 18 au (Pinilla et al. 2015)



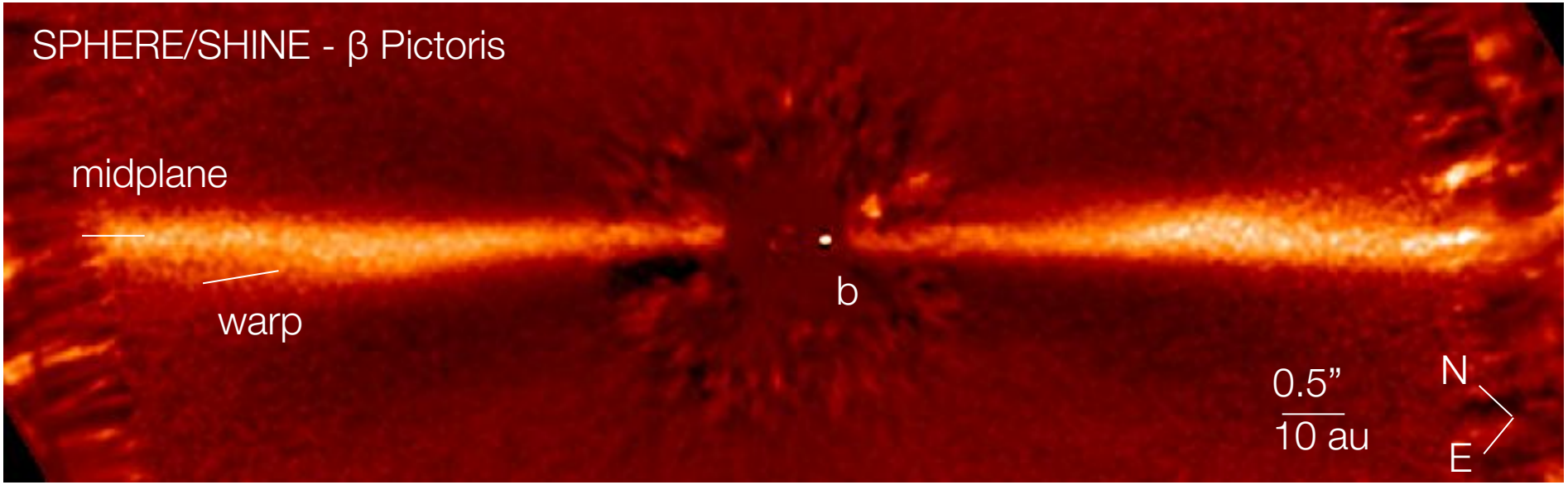


Key science drivers

2. Architecture of planetary systems

Investigating the planet(s) - disk connection

- Connecting Planet(s) physical properties (orbit, mass),
  & Structures of debris disks (eccentricity, edges, multiple belts),
  exocometary activity, presence of exo-zodiacal dust,
- Global dynamical stability & evolution,
- Telluric planets in stable HZ (our solar system into context)?



MICADO, METIS

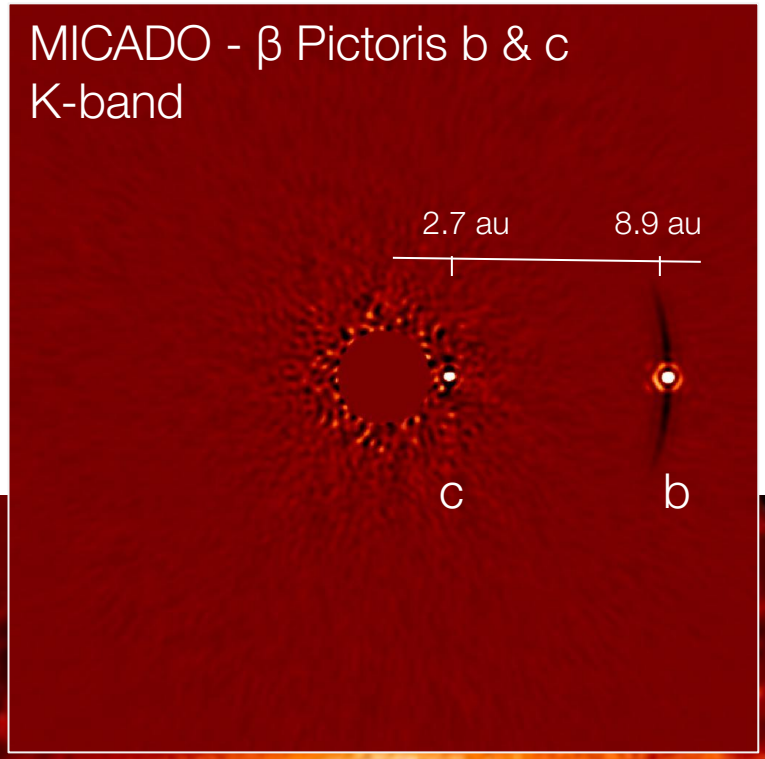
Key science drivers

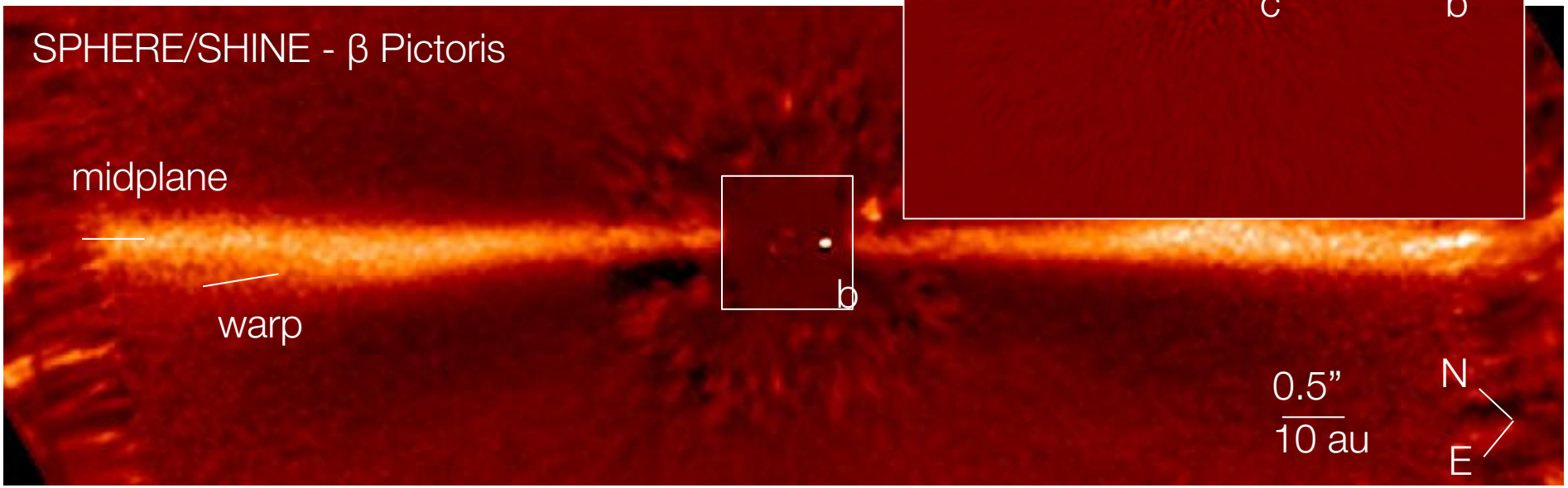
2. Architecture of planetary systems

Searching for inner planet(s)

COMPASS/MISTHIC (Baudoz/Huby):

- β Pic c (Lagrange et al. 2019),
  9 M_{Jup} planet at 2.7au (e = 0.24)
- MICADO ADI sequence (1hr-meridian),
  Telescope, SCAO, NCPA, Corono...





Key science drivers

2. Architecture of planetary systems

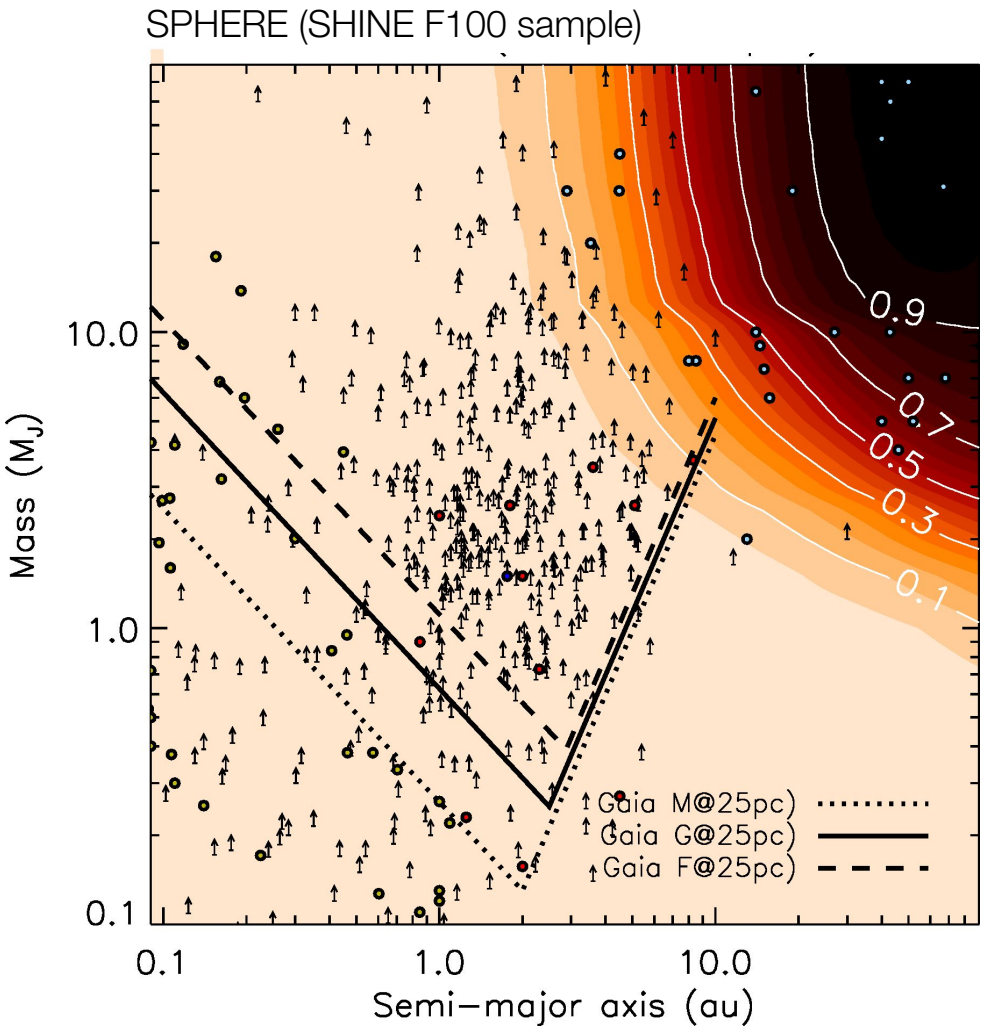
Global content of giant population

At ELT 1st Lights (2026):

. End of large-scaled surveys?
(RV, Astro., Transit & DI)

. Complete census of
nearby planetary systems?

SPHERE - SHINE completeness
F100 - 152 stars (50 pc, 100 Myr)



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2. Architecture of planetary systems

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MICADO - SHINE completeness
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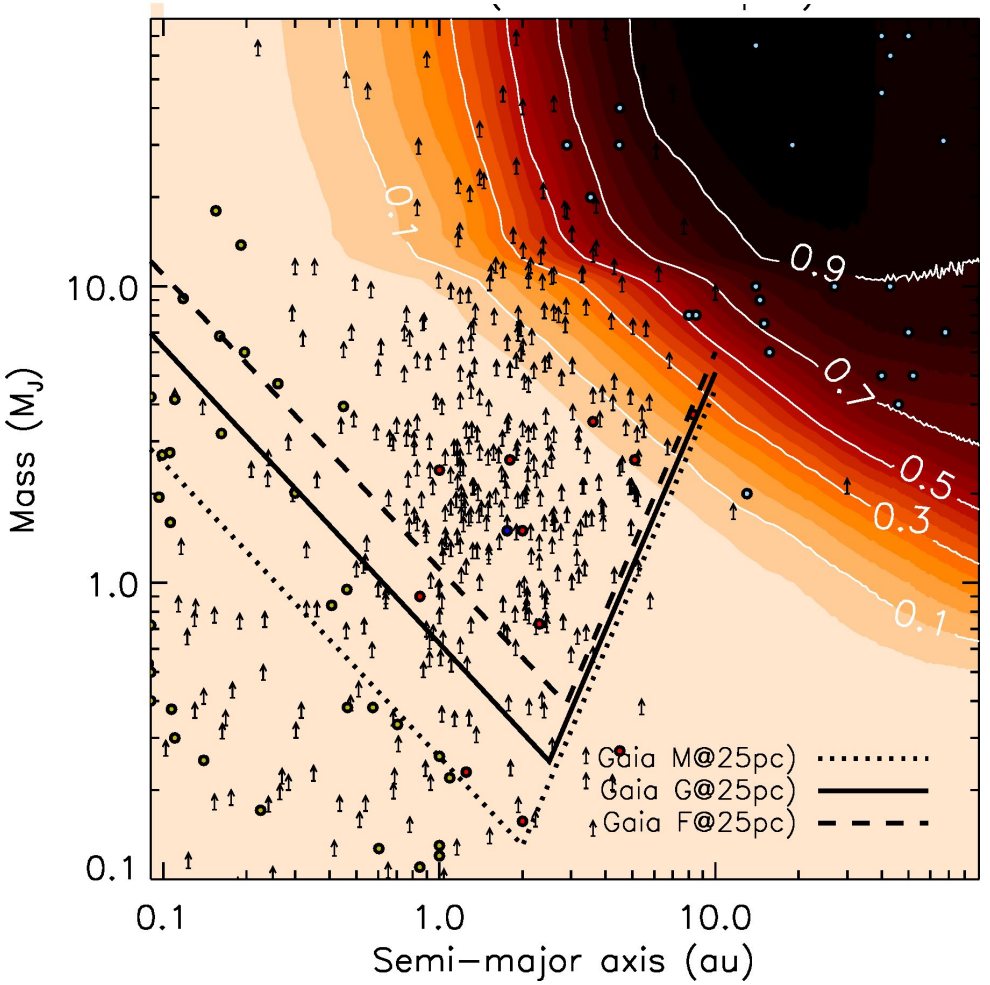
COMPASS/MISTHIC (Baudoz/Huby)

HARMONI performances
HSIM2 (Carlotti) + astrophysical injection

MICADO (SHINE F100 sample)



Key science drivers

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Global content of giant population

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nearby planetary systems?

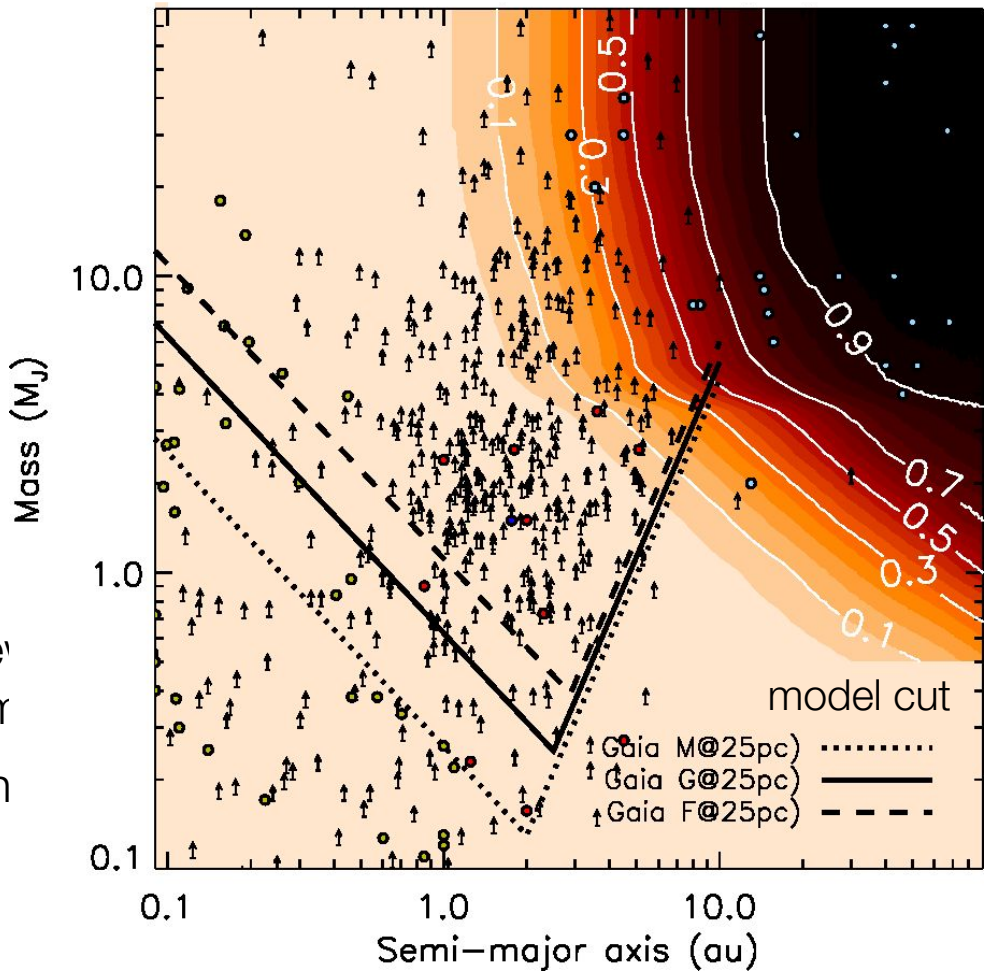
METIS - SHINE completeness
F100 - 152 stars (50 pc, 100 Myr)
PdR extrapolation

Already with 1st Gen. instruments:

i/ overlap btw techniques, global vie
of giant (> 2-3 M_{Jup}) planets at all sm

ii/ Testing Luminosity - Mass relation
of evolutionary models calibration

METIS (SHINE F100 sample)



Key science drivers

3. Physics of Exoplanets

Atmospheres of imaged exoplanets

- Contrast: 10^{-6} (50mas) to 10^{-9} (20mas)
- Emitted (1st Gen) & Refl. (2nd Gen) light
- From Giant planets to super-Earths?
- around Young stars & Nearby stars

Key science drivers

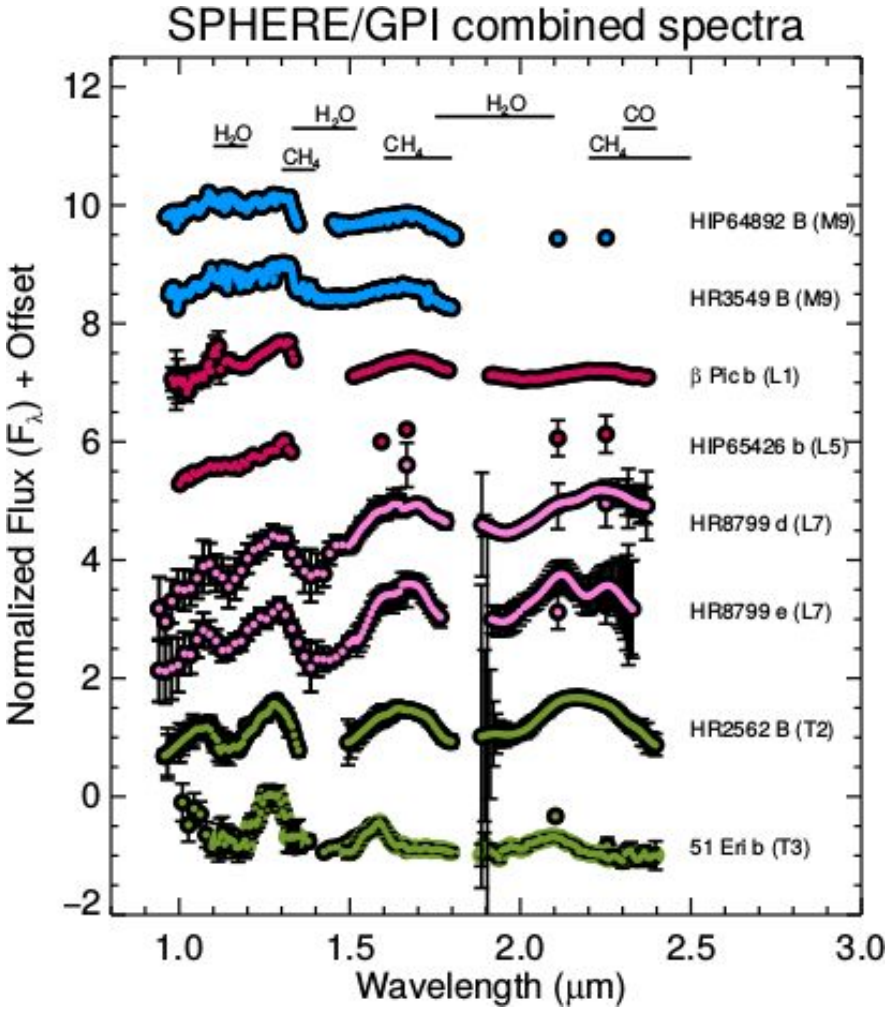
3. Physics of Exoplanets

Atmospheres of imaged exoplanets: Low spectral resolution

- Contrast: 10^{-6} (50mas) to 10^{-9} (20mas)
- Emitted (1st Gen) & Refl. (2nd Gen) light
- From Giant planets to super-Earths?
- around Young stars & Nearby stars

Exploring atmospheric diversity

- Sequence: Lighter & Cooler planets
- Broad molecular absorptions:
  H2O, CO, CH4, NH3, CO2…
- Composition & chemical processes,
- Cloud formation & evolution,



MICADO/HARMONI: R_λ = 20 000, [1.1 - 2.45] μm
METIS : IFU, R_λ = 100 000, [3 - 5] μm
LSS, R_λ = 5 000, [3 - 20] μm

Key science drivers

3. Physics of Exoplanets

Atmospheres of imaged exoplanets: Medium spectral resolution

- Contrast: 10^{-6} (50mas) to 10^{-9} (20mas)
- Emitted (1st Gen) & Refl. (2nd Gen) light
- From Giant planets to super-Earths?
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Exploring atmospheric diversity

- Sequence: Lighter & Cooler planets
- Broad molecular absorptions:
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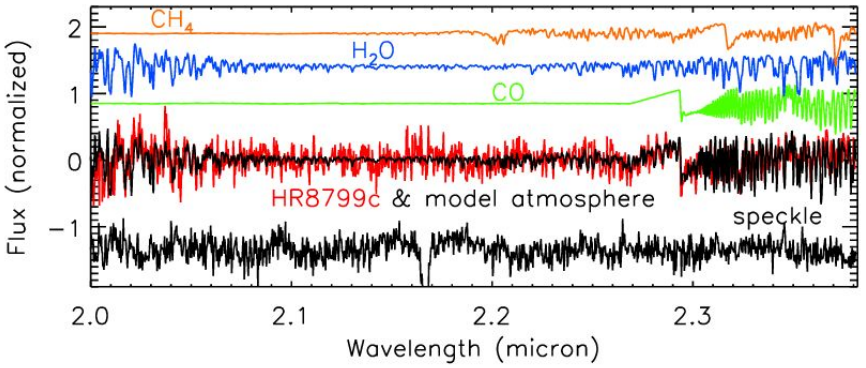
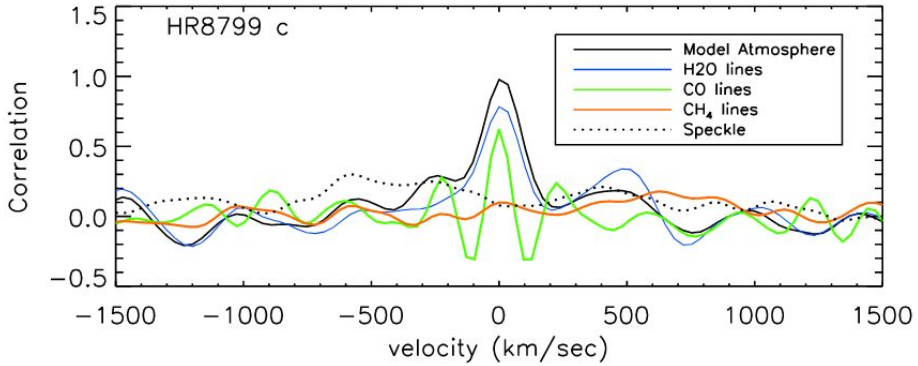
- Composition & chemical processes,
- Cloud formation & evolution,
- Molecular abundances & mapping
  C/O ratio, T/P profile, RV, accretion





Keck/OSIRIS (R_λ = 4000) observation of HR8799 c
CO & H2O detection; Konopacky et al. (2013)

MICADO/HARMONI: R_λ = 20 000, [1.1 - 2.45] μm
METIS : IFU, R_λ = 100 000, [3 - 5] μm
LSS, R_λ = 5 000, [3 - 20] μm

Key science drivers

3. Physics of Exoplanets

Atmospheres of imaged exoplanets: High spectral resolution

- Contrast: 10^{-6} (50mas) to 10^{-9} (20mas)
- Emitted (1st Gen) & Refl. (2nd Gen) light
- From Giant planets to super-Earths?
- around Young stars & Nearby stars

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- Composition & chemical processes,
- Cloud formation & evolution,
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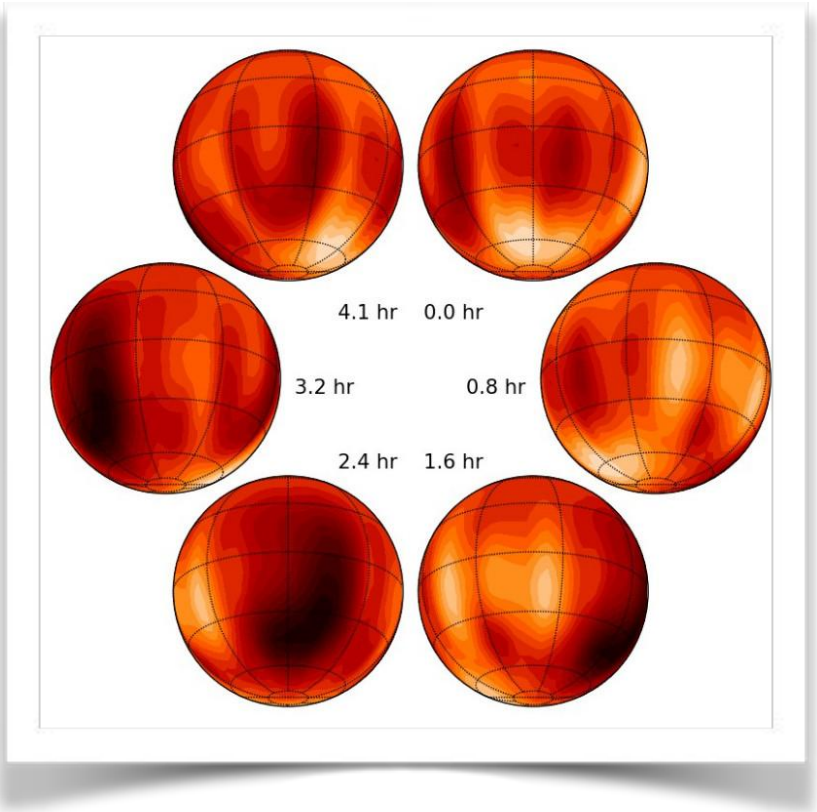
  C/O ratio, T/P profile, RV, accretion
- isotopologues, rotational velocities
  Doppler imaging & atm. circulation

METIS : IFU, R_λ = 100 000, [3 - 5] µm



Luhman 16 B, 2 pc, Rotation 4.9hrs, CRIRES spectroscopic variability (Crossfield et al. 14)

Key science drivers

3. Physics of Exoplanets

Atmospheres of imaged exoplanets: High spectral resolution

- Contrast: 10^{-6} (50mas) to 10^{-9} (20mas)
- Emitted (1st Gen) & Refl. (2nd Gen) light
- From Giant planets to super-Earths?
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Exploring atmospheric diversity

- Sequence: Lighter & Cooler planets
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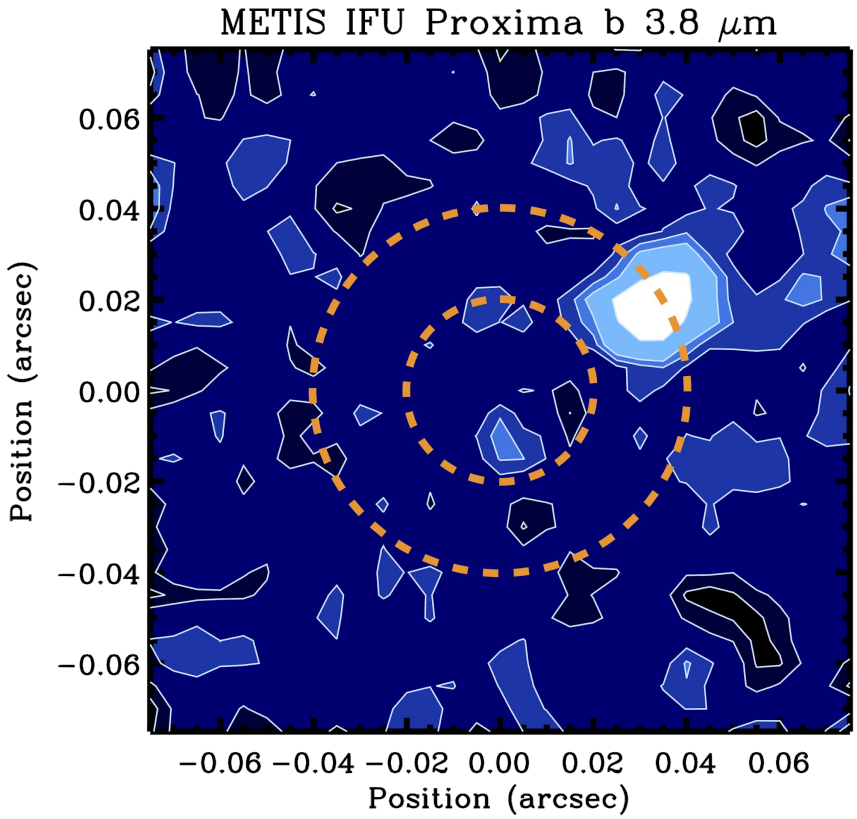
- Composition & chemical processes,
- Cloud formation & evolution,
- Molecular abundances & mapping C/O ratio, T/P profile, RV, accretion
- isotopologues, rotational velocities Doppler imaging & atm. circulation
- HCI+HDS Boost for detection & characterization of bio-markers (O2, O3, H2O, CO, CO2, CH4, …)



Proxima, 1.3 pc, 1.1 R_{Earth} planet radius (albedo 0.3, 50% illumination), CO, CH4 & H2O-rich planet. 10hr obs.

Conclusions

- E-ELT,
  - Unique spatial resolution & sensitivity
  - AND a versatile instrumentation over 30+ years
    (wavelengths coverage, modes, spatial/spectral resolution…)
  - Will count on new discoveries (ALMA, SPHERE, GPI, *GAIA*, *TESS*, *JWST*...)
  - Suited for characterization...

- Drivers for Direct Imaging of Disks & Exoplanets
  - Initial conditions for planetary formation
    - Observing planet-forming regions (0.01 – 10 au scale)
    - Disk Structure, Composition & Chemistry
  - Overlap btw observing techniques
    - Planetary architectures (Solar System in context, Global View)
    - Physics of Young Jupiters (Formation, Accretion, M-L relation)
  - Physics of exoplanets
    - Giant (1^{st} Gen) to Super-Earths (2^{nd} Gen),
    - Composition, cloud, C/O ratio, isotopologues & doppler imaging
    - Path toward characterization of super-Earths & bio-markers

Thank you

Cerro Armazones, July 2019
Construction of the dome foundation starting!