Synergies between E-ELT and space instrumentation for extrasolar planet science

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Main topics in exo-planetary science for the next 15 years – my view

- **Planets formation**
  - How planets form?
  - Why planets have different masses and separation from the stars? What is the impact of disk-planet interactions?
  - What is the impact of the environment?
- **Early evolution**
  - What is the evolution of young planets?
  - How are their atmospheres made and what are their chemical composition?
  - What is the impact of planet-planet interactions?
- **Search for habitable planets**
  - How common are rocky planets in the habitable zone?
  - What is the structure of small mass planets?
  - What is the composition of their atmospheres?
  - Are we able to detect bio-signatures?

Schematic of methods goals

	Hot planets (P~days)	< snow-line (P~a few years)	> snow-line (P~several years)
Discovery: detection and statistics	Radial Velocities Transits	Radial velocities Space Astrometry (GAIA) Microlenses ELT imaging	8m imaging
Dynamical characterization & Structure	Radial Velocities + Transits	Radial velocities Space Astrometry (GAIA) ELT imaging	Coupling 8m imaging and GAIA?
Atmospheric characterization & search for biosignatures	Transits - Duration - Transmission spectroscopy - Secondary transit	ELT imaging	8m imaging (and) JWST ELT MIR

However, situation may differ for specific target groups (M-stars)!

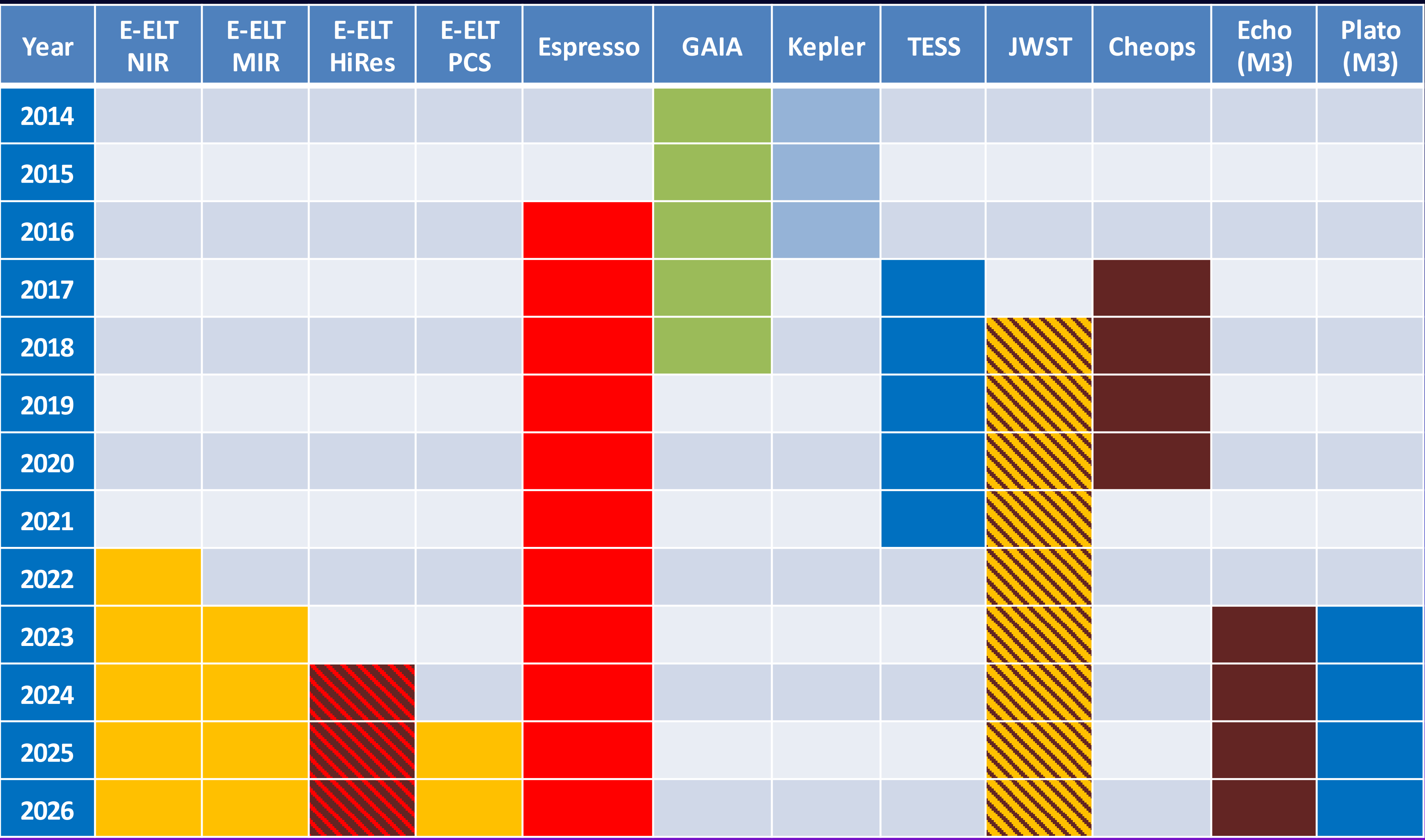
- Competition
- Complementarity
- Synergy

- Some examples

- **Competition** **Detection and statistics**
- **Complementarity**
- Synergy

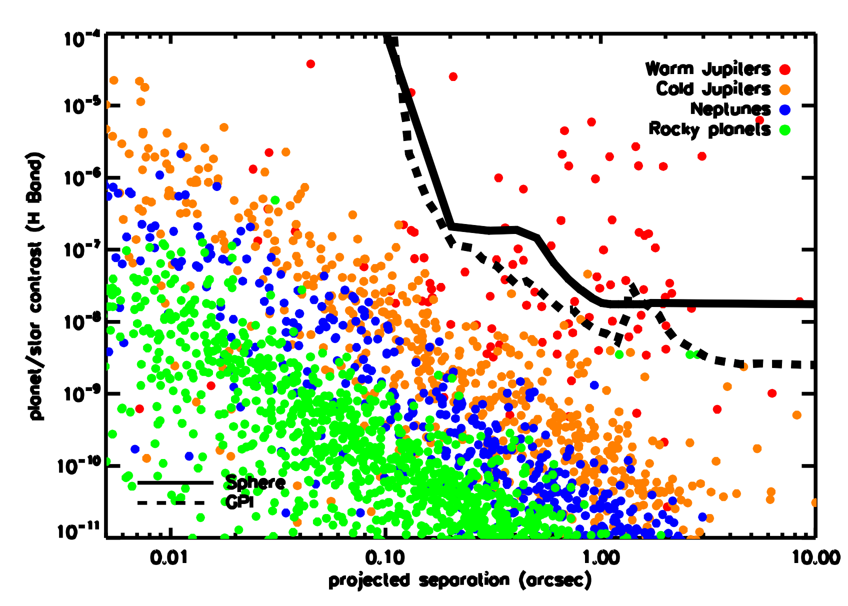
- Some examples

Timeline

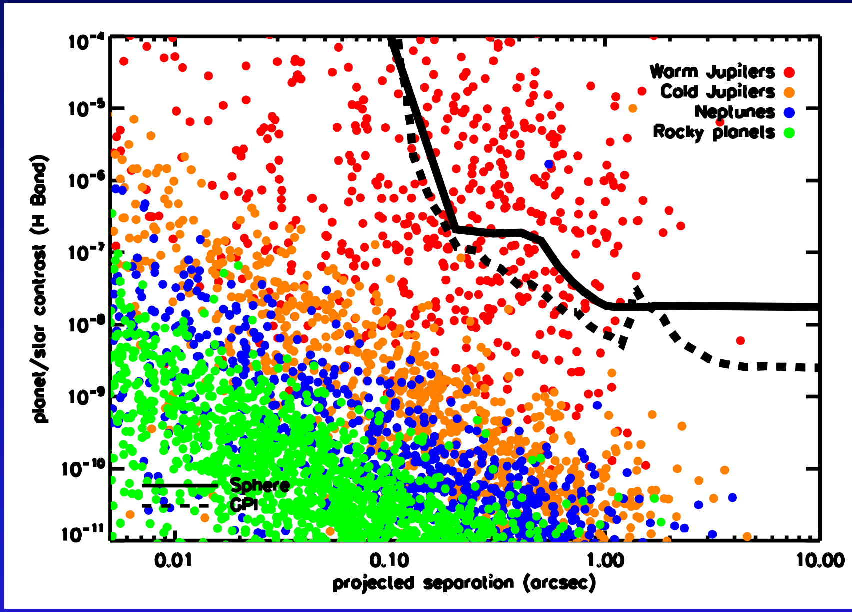

Year
E-ELT NIR
E-ELT MIR
E-ELT HiRes
E-ELT PCS
Espresso
GAIA
Kepler
TESS
JWST
Cheops
Echo (M3)
Plato (M3)
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026

Planets observable with Sphere and GPI (2013-)

Monte Carlo simulations using MESS (Bonavita et al. 2012)



Nearby stars (<20 pc)

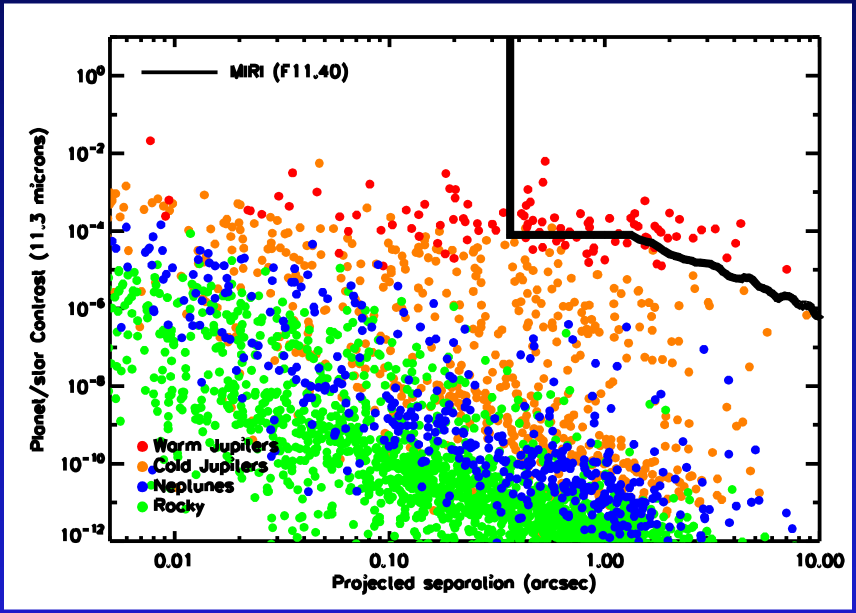


Young stars (<5 10^8 yrs)

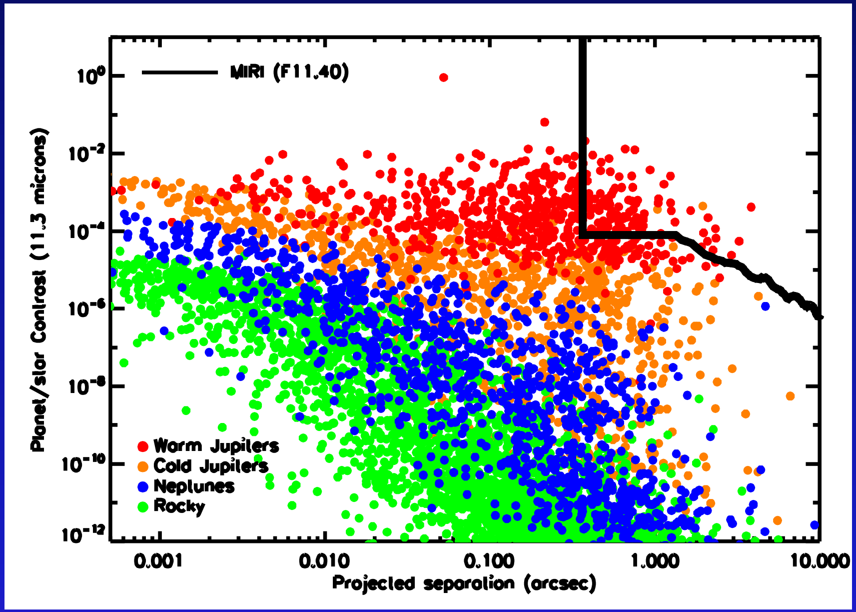
➔Tens of young giant planets at rather large separations

Planets observable with JWST-MIRI (2018-)

Monte Carlo simulations using MESS (Bonavita et al. 2012)



Nearby stars (<20 pc)



Young stars ($<5\ 10^8$ yrs)

➔Tens of young giant planets at large separations

JWST vs ground

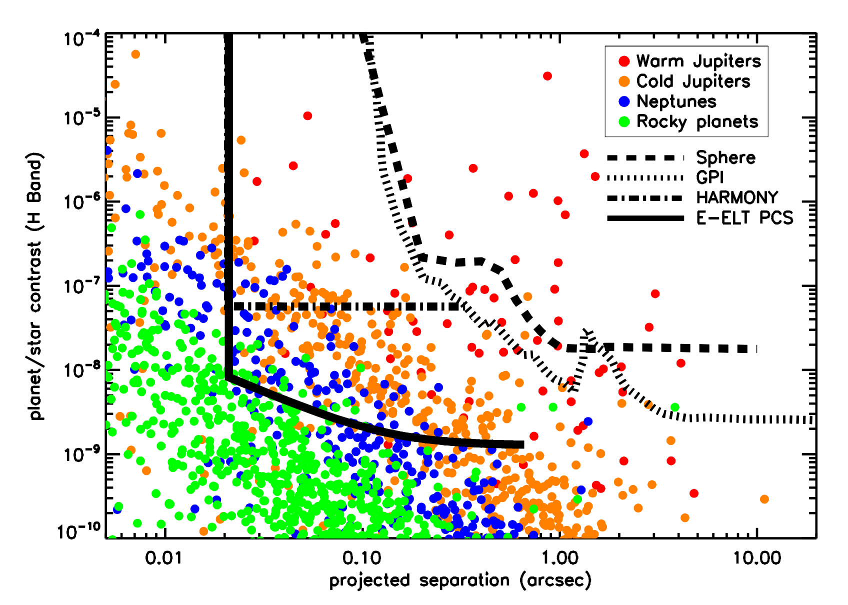
JWST will have limiting contrasts similar to GPI, SPHERE and worse IWA, BUT:

- JWST will not be limited by target luminosity
  - Planets around faint targets
    - Small mass nearby stars and BDs
    - Solar type and fainter stars in star forming regions
- JWST will allow access to spectral regions not visible from ground (especially in the MIR)
  - Important for breaking degeneracies in stellar atmospheres (temperature vs dust layers)
  - Access to more molecular bands

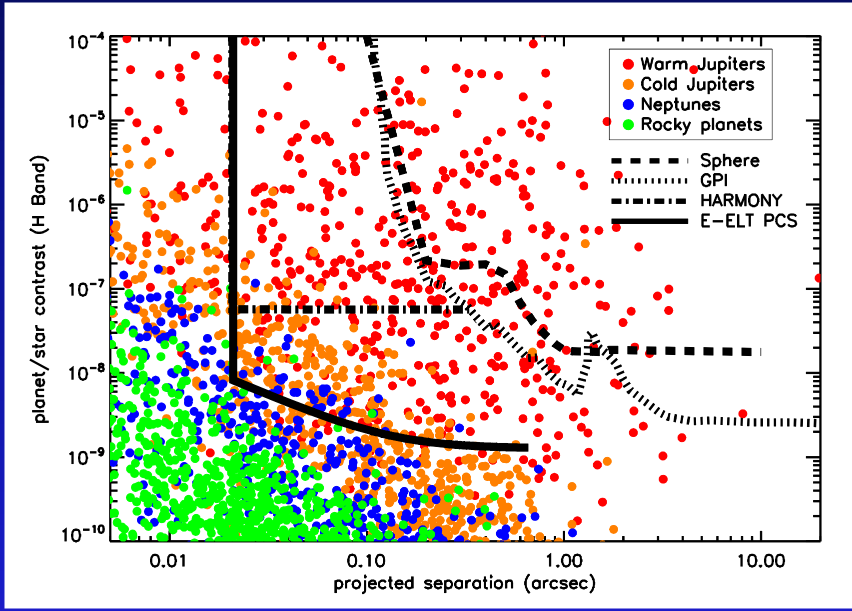
Problem: strong time competition ➔ likely more characterization than discovery

Planets observable with E-ELT (2023-)

Monte Carlo simulations using MESS (Bonavita et al. 2012)



Nearby stars (<20 pc)



Young stars (<5 10^8 yrs)

- → Many giant planets (both young and old)
- → Tens of Neptune-like planets
- → A few rocky planets

HIGH CONTRAST IMAGER MAIN PROPERTIES

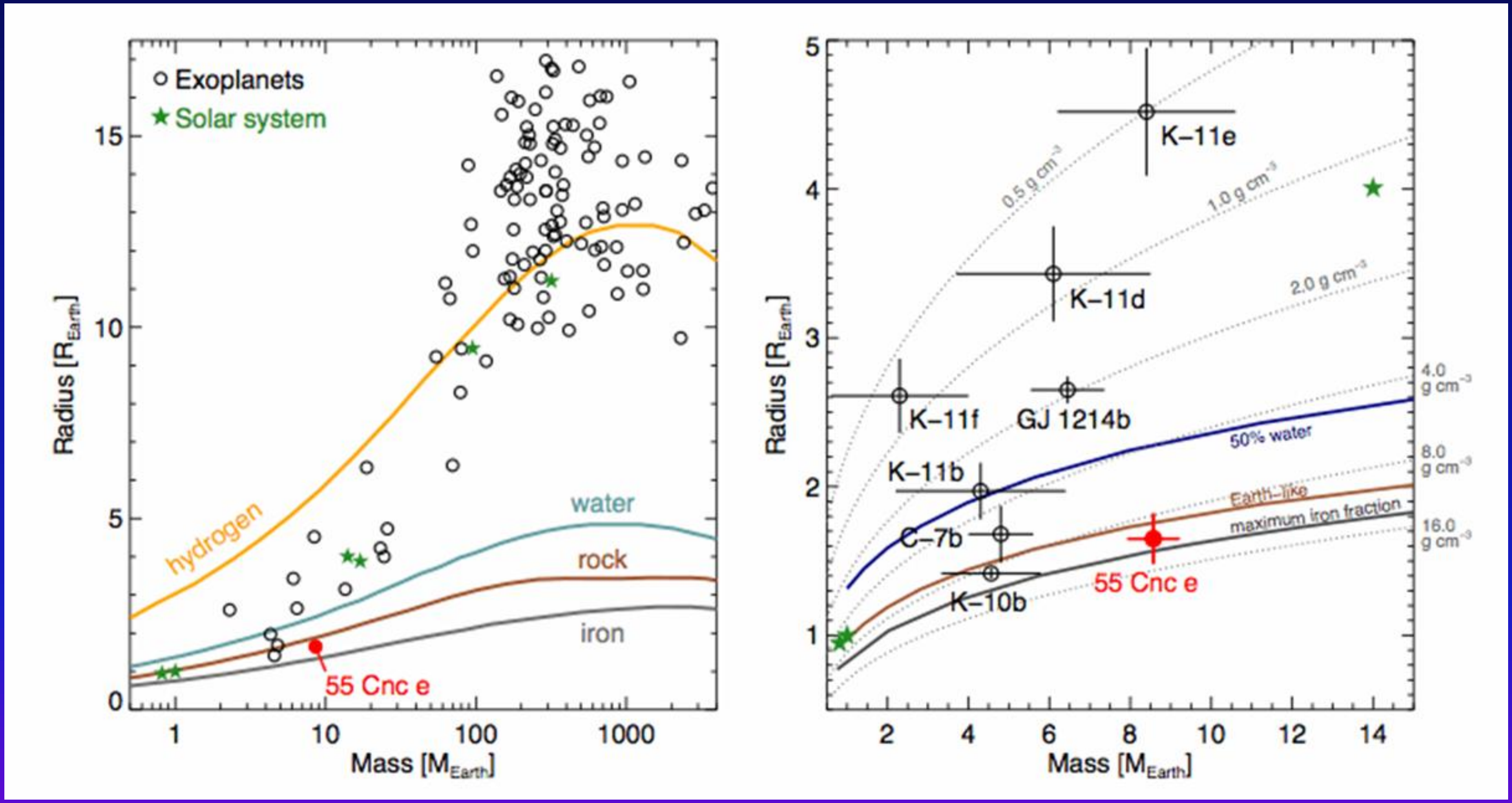
		GPI/SPHERE	E-ELT (IFU)	E-ELT (PCS)	JWST
NIR Ground: 0.6-2.5 μm JWST (NIRCam): 0.6-2.5 μm	Contrast	10^{-6}-10^{-7}	10^{-6}-10^{-7}	10^{-8}-10^{-9}	10^{-6}
	IWA (mas)	100	20	20	270
	Spectral Res.	50	4000	100	-
	Star mag	I<10		I<10	
	Targets	Young giants	Young giants Reflecting giants	Young Giants and Neptunes Reflecting giants, Neptunes, super-Earths?	Young giants Nearby stars
MIR Ground: 2.9-14 μm JWST (MIRI): 5-28.3 μm FGS: M-band	Contrast		10^{-4}		10^{-4}
	IWA (mas)		80		350 MIRI 100 FGS
	Spectral Res.		5000 (slit)		-slit
	Targets		Young giants Nearby stars		Young giants Nearby stars

- Competition
- Complementarity
- **Synergy**

- Competition
- Complementarity
- **Synergy: planetary structure → density:**
  - **Masses from dynamics**
  - **Radii from photometry**

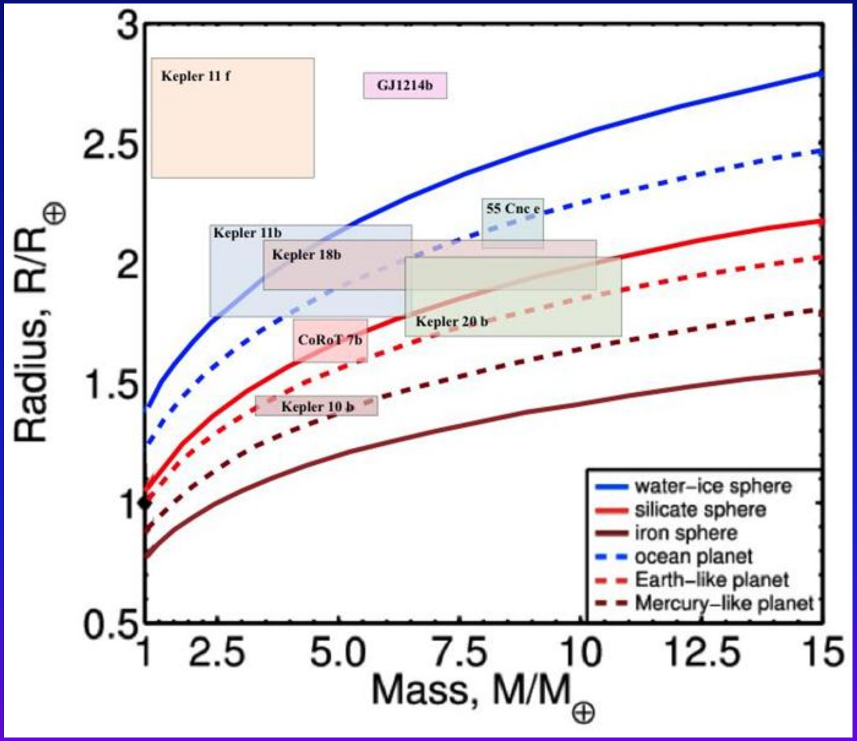
- Some examples

Mass-radius relation and planet structure – small mass planets

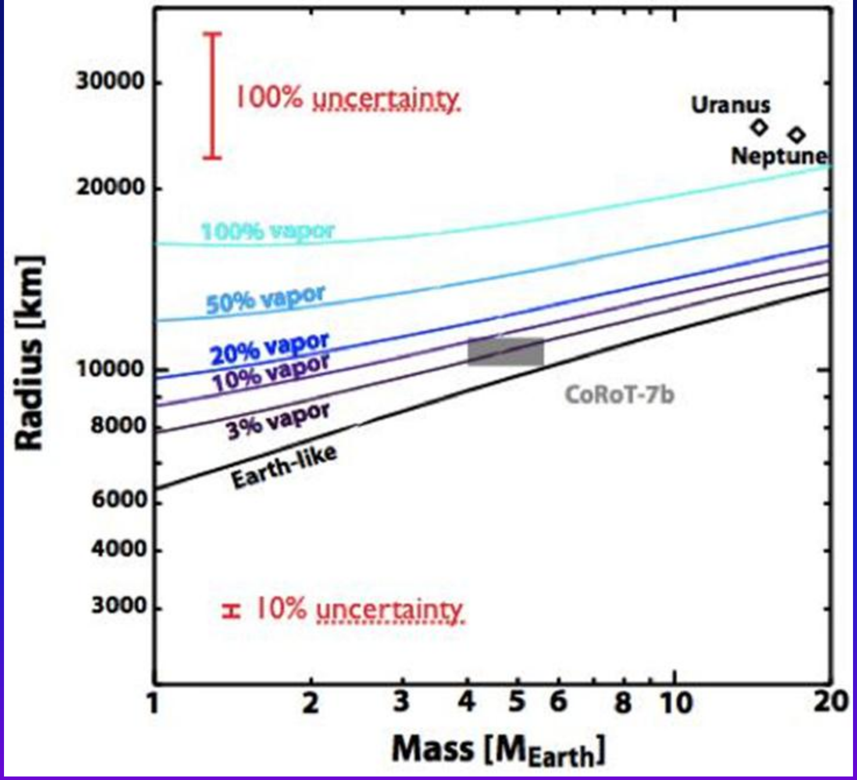


Structure of warm Earth-like planets

Current status



CHEOPS, TESS and PLATO



Young giant planets

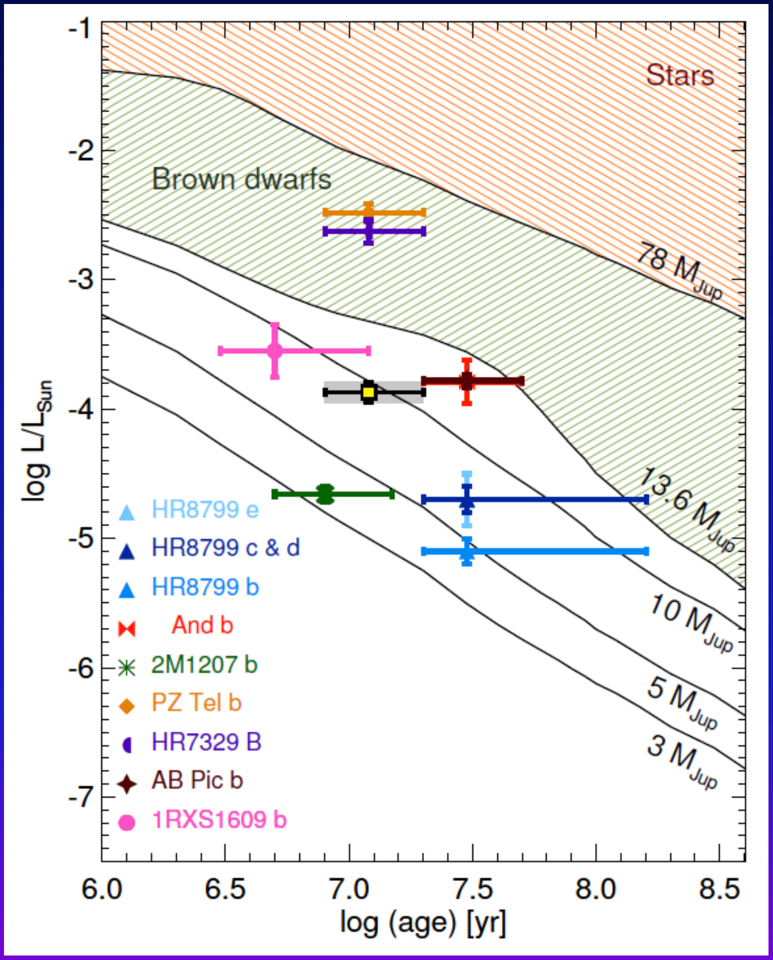
Direct imaging allows extensive characterization of planets BUT it does not provide their masses

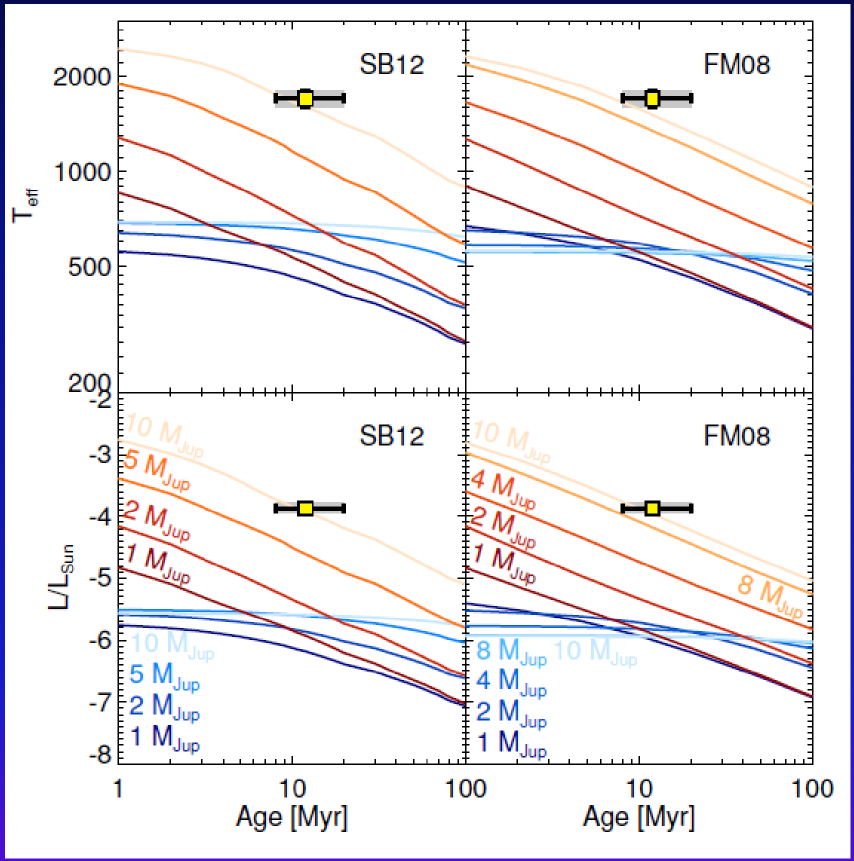
Masses may be obtained:

- through modelling
  - Requires determination of temperatures

  ➔ uncertainties in the models, especially at very young ages (hot vs. cold start)
- Through dynamical observations
  - Radial velocities (but young very active stars)
  - Astrometry (GAIA!)
  - Proto-planetary accretion disks or satellites (only resolved by ELTs)
- Problem: the planets discovered by RV and (in the future) by astrometry are not those easily discovered by imaging

Model uncertainties



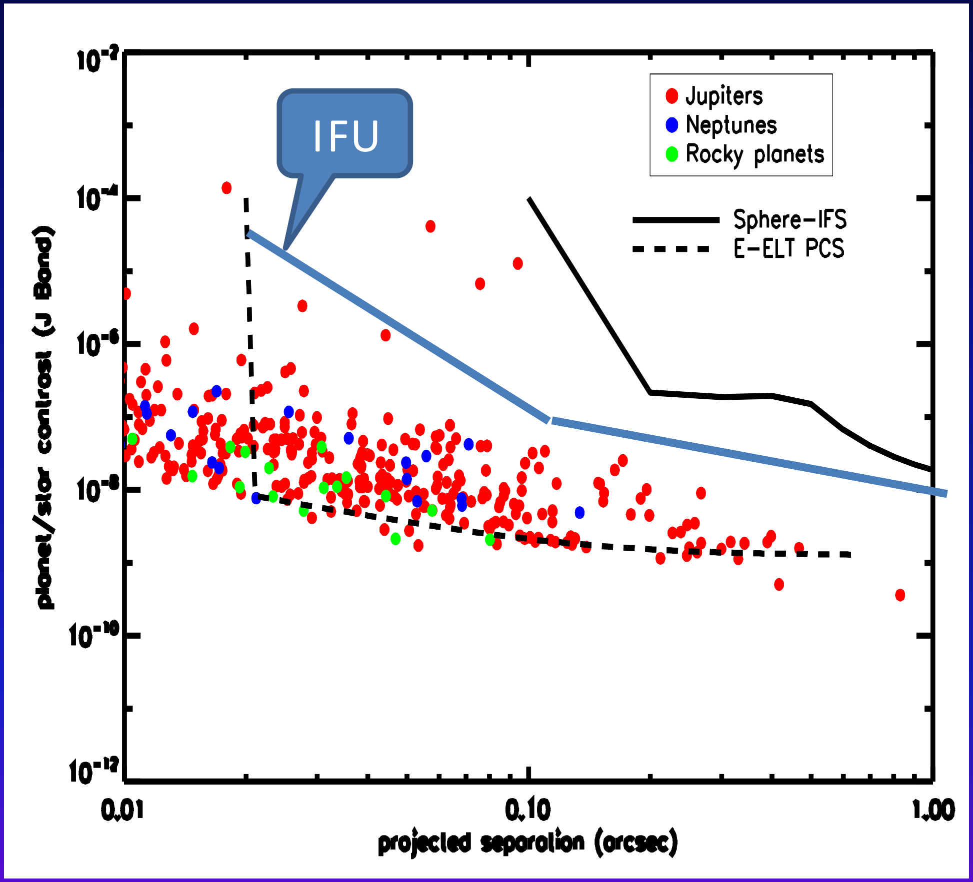


From Bonnefoy et al. 2013, A&A, 555, A107

Current situation and very near future

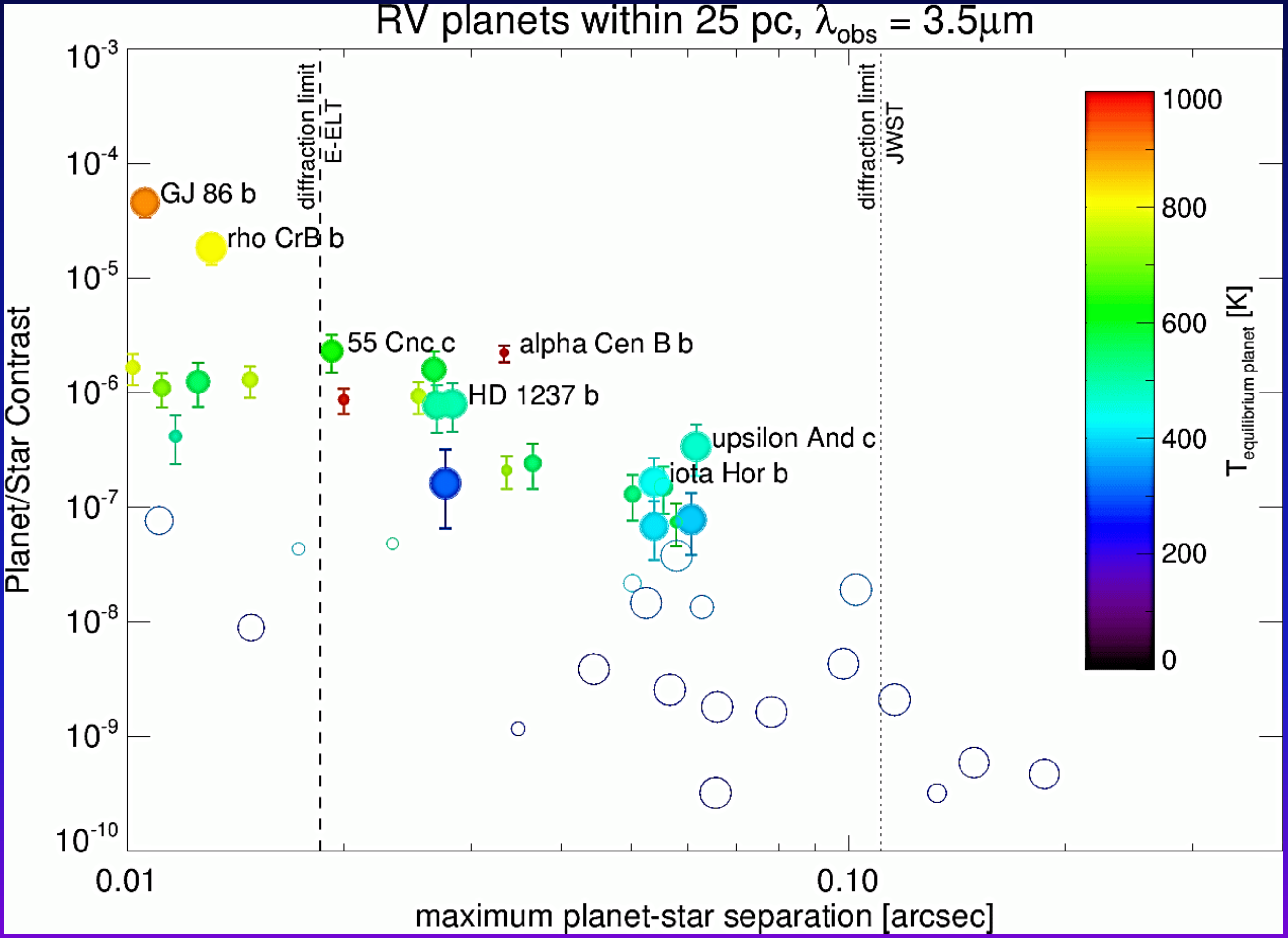
- Currently, only an upper limit for β Pic from RVs (<15.5 M_{Jup} if a<10 AU, <12 M_{Jup} if a<9 AU: Lagrange et al. 2012)
- Within 2-3 years, combination of ground-based (SPHERE/GPI) and space astrometry (Hipparcos + GAIA)
  - Masses with 10-20% error for β Pic
  - Masses within 30% for ~10 additional young planets (most of them still to be discovered by ground based imaging)

Dynamical characterization: Radial velocities and E-ELT in the NIR



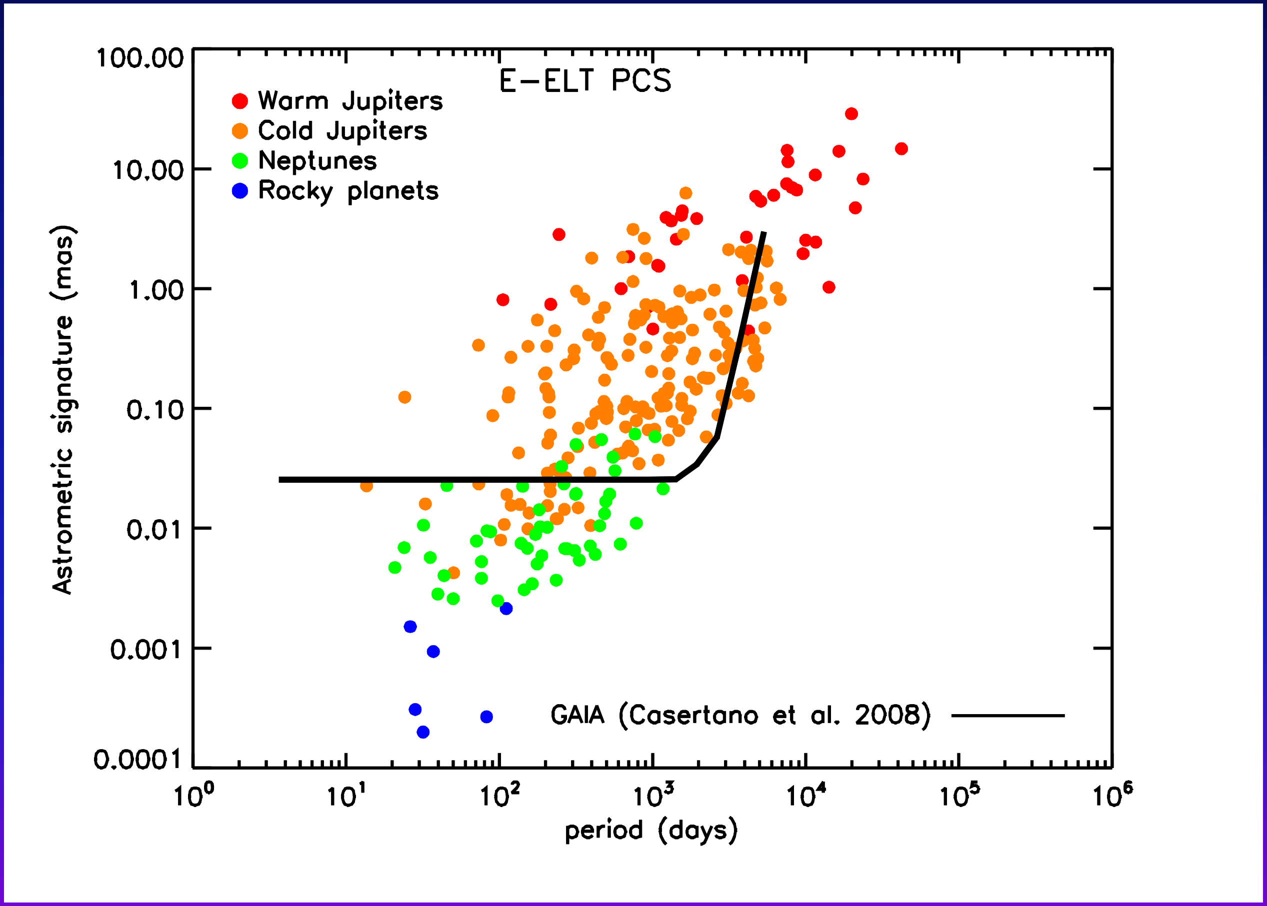
Very important: planet mass independent of model assumptions!

L-band observations (METIS)



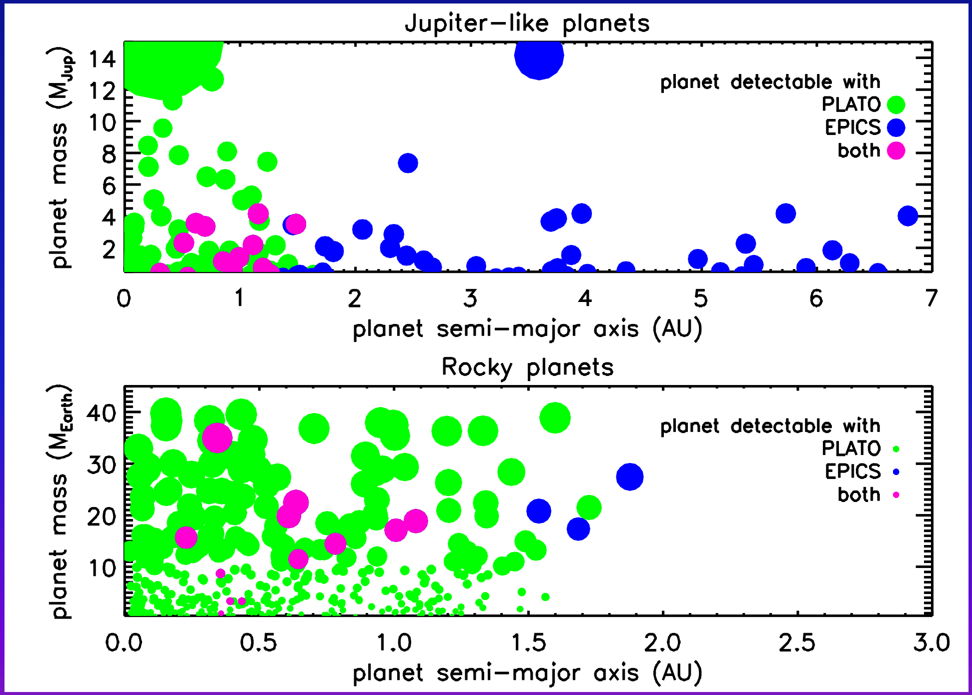
Astrometric signal of detectable planets

Monte Carlo simulations using MESS (Bonavita et al. 2012)



Synergy between PCS and PLATO

- PLATO: ESA M3 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 PCS
- For K dwarfs, planets in the habitable zone are detectable
- Availability of planet spectrum from PCS 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



Transit spectroscopy and characterization

	E-ELT MIR	E-ELT HIRES	JWST MIRI	Cheops	Echo
Telescope Diam. (m)	39	39	6	0.3	1.2-1.5
Sharing				Dedicated	Dedicated
Method	Spectra	Spectra	Spectra	Transit depth	Spectra
Wavelength (µm)	2.5-10	0.5-2.5	5-28		4-16
Resolution			350	-	300-30
Epoch	2023-	2024-	2018-	2017-2020	2023-2028
Pro's					

Transit spectroscopy and characterization

	E-ELT MIR	E-ELT HIRES	JWST MIRI	Cheops	[illegible]
Telescope Diam. (m)	39	39	6	[illegible]	[illegible]-1.5
Sharing			[illegible]	[illegible]ted	Dedicated
Method	Spectra	Spectra	[illegible]	Transit depth	Spectra
Wavelength (µm)	2.5-10	0.5[illegible]	[illegible]-28		4-16
Resolution	[illegible]	[illegible]	350	-	300-30
Epoch	[illegible]	2024-	2018-	2017-2020	2023-2028
Pro's	[illegible]				

BUT NO TIME TO DISCUSS THIS POINT