Extra-solar planet imaging: ground vs. space based coronagraphs

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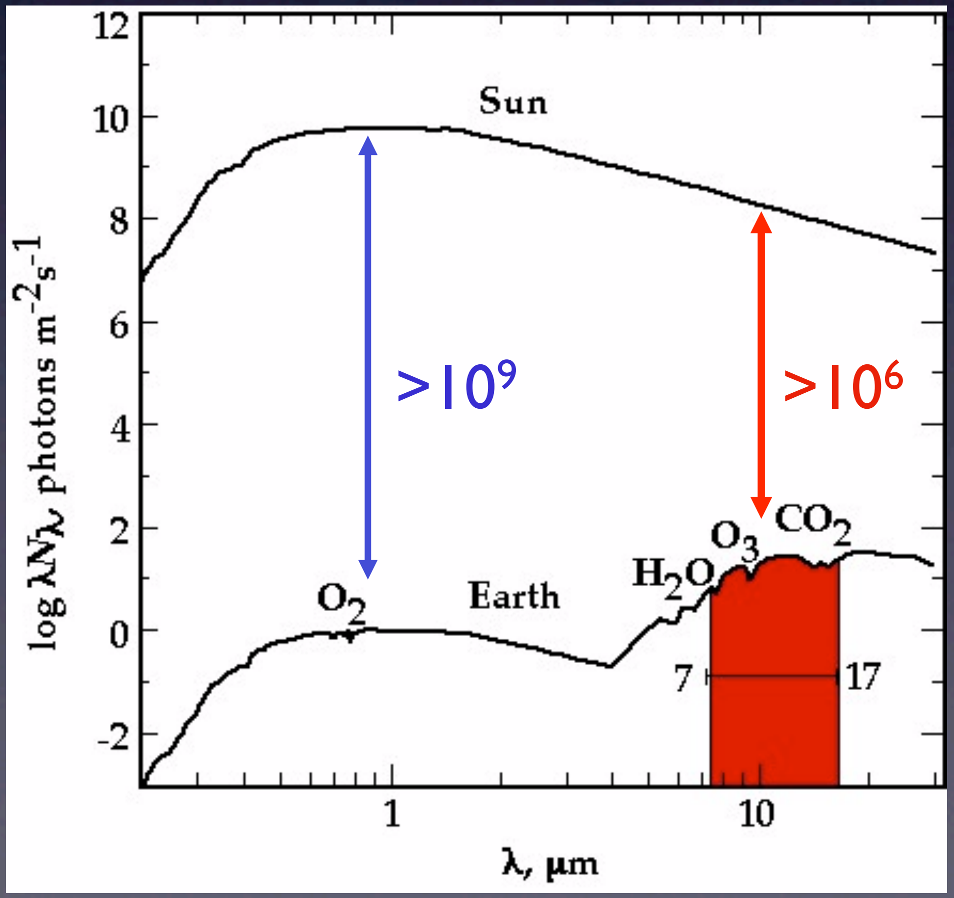
In the spirit of Lyot, October 28 2010

Ground vs. space, not a fair comparison?

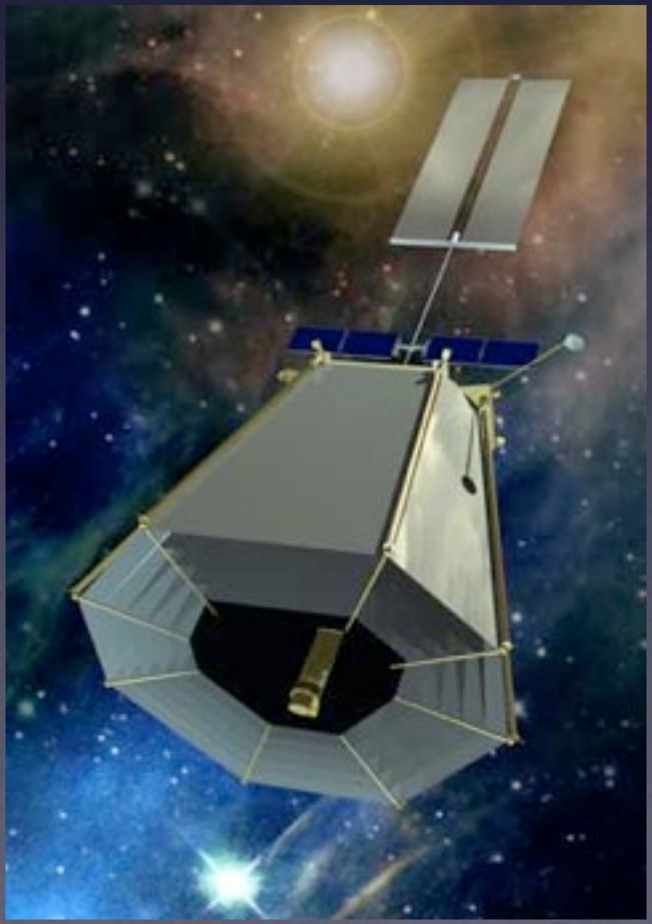
- Direct imaging of high contrast objects:
  - Huge contrast ratio:
    - ➡Earth-like exoplanet: 10^7 (10μm) & 10^{10} (vis.)
  - High angular resolution
  - Small inner working angle
  - High dynamic range
  - Wavefront quality



Ground vs. space, not a fair comparison?

Before

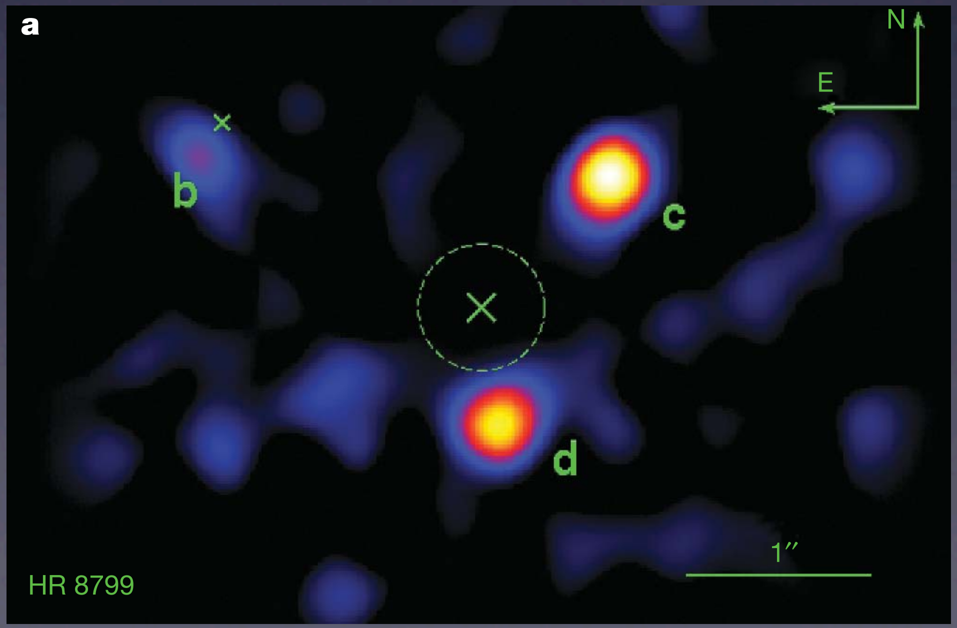
- Direct imaging of high contrast objects:
  - Huge contrast ratio: ⟶ SPACE
    - ➡Earth-like exoplanet: 10^7 (10µm) & 10^{10} (vis.)
  - High angular resolution → OK
  - Small inner working angle → OK
  - High dynamic range ⟶ SPACE
  - Wavefront quality ⟶ SPACE



Ground vs. space, not a fair comparison?

Today

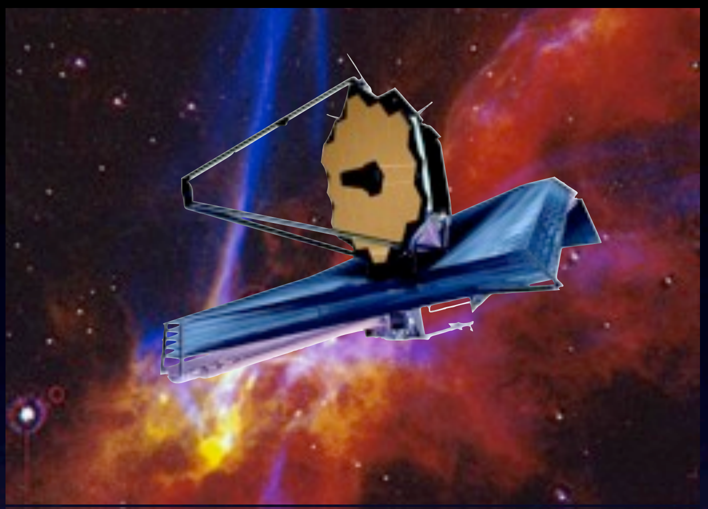
- Direct imaging of high contrast objects:
  - Huge contrast ratio: → OK
    - ➡Earth-like exoplanet: 10^7 (10μm) & 10^{10} (vis.)
  - High angular resolution → OK
  - Small inner working angle → OK
  - High dynamic range → OK
  - Wavefront quality → OK

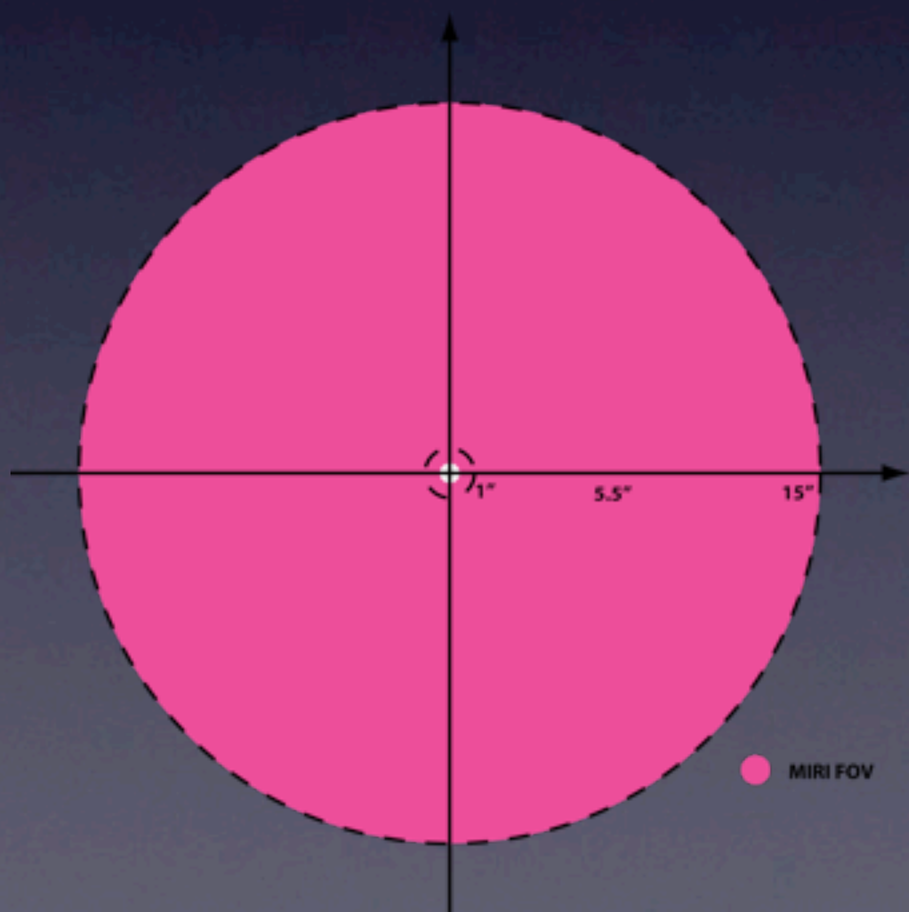


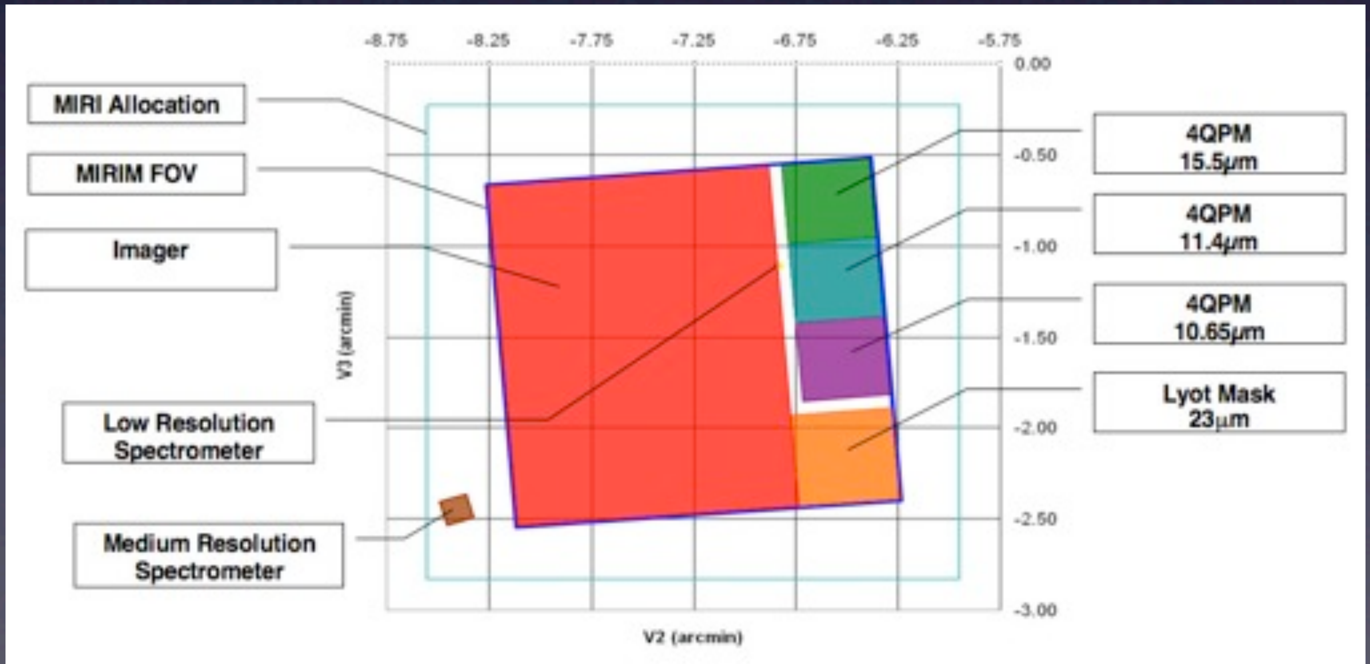
Serabyn 2010

JWST/ MIRI

- Mid-InfraRed Instrument (5-27μm)
- FQPM Coronagraph. @ 11.4μm
- λ/D ≈ 0.36”
- FOV ≈ 15”

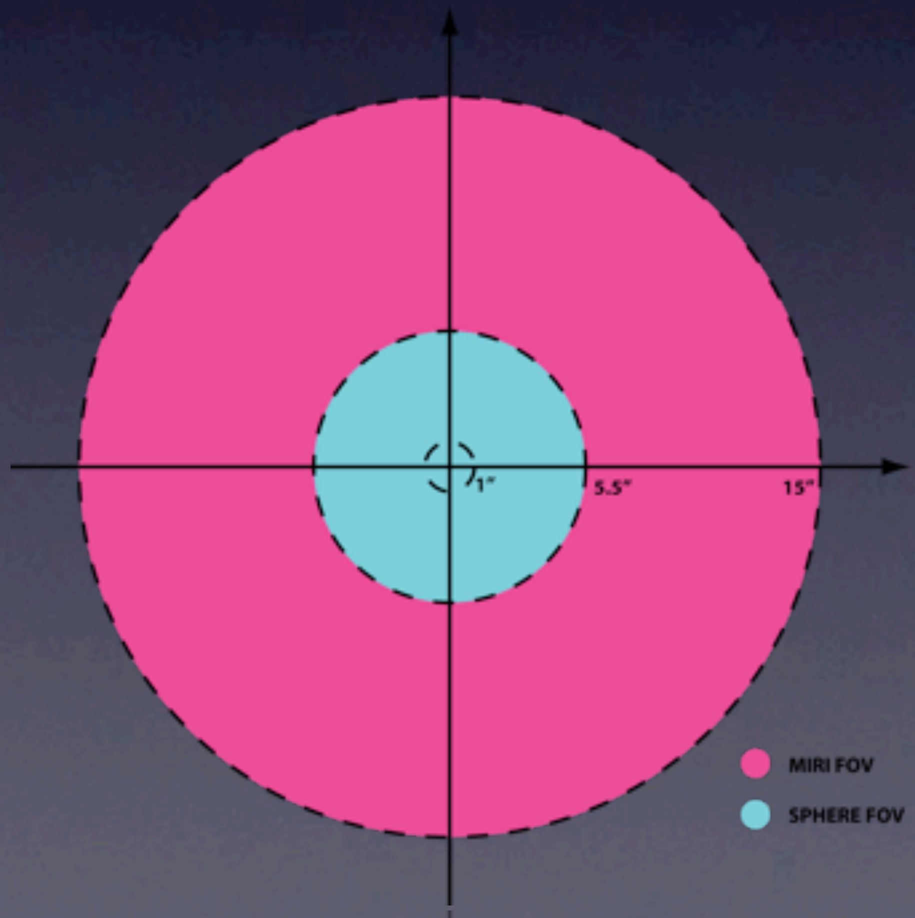




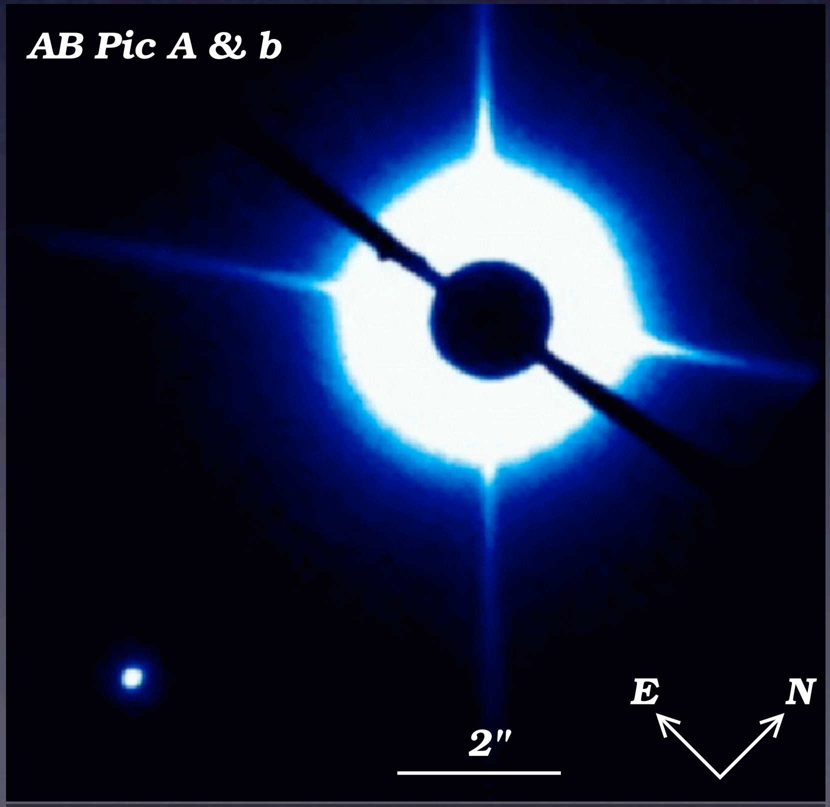


VLT/SPHERE

- Extreme adaptive optics (XAO)
- FQPM Coronagraphs @ 1.6µm
- $\lambda/D \approx 40$ mas
- FOV ≈ 5.5”

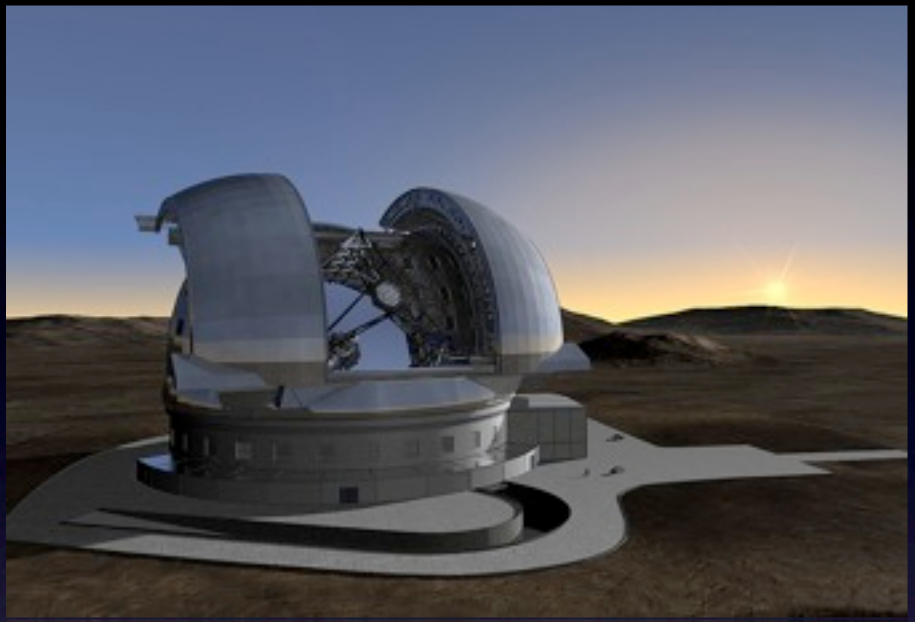


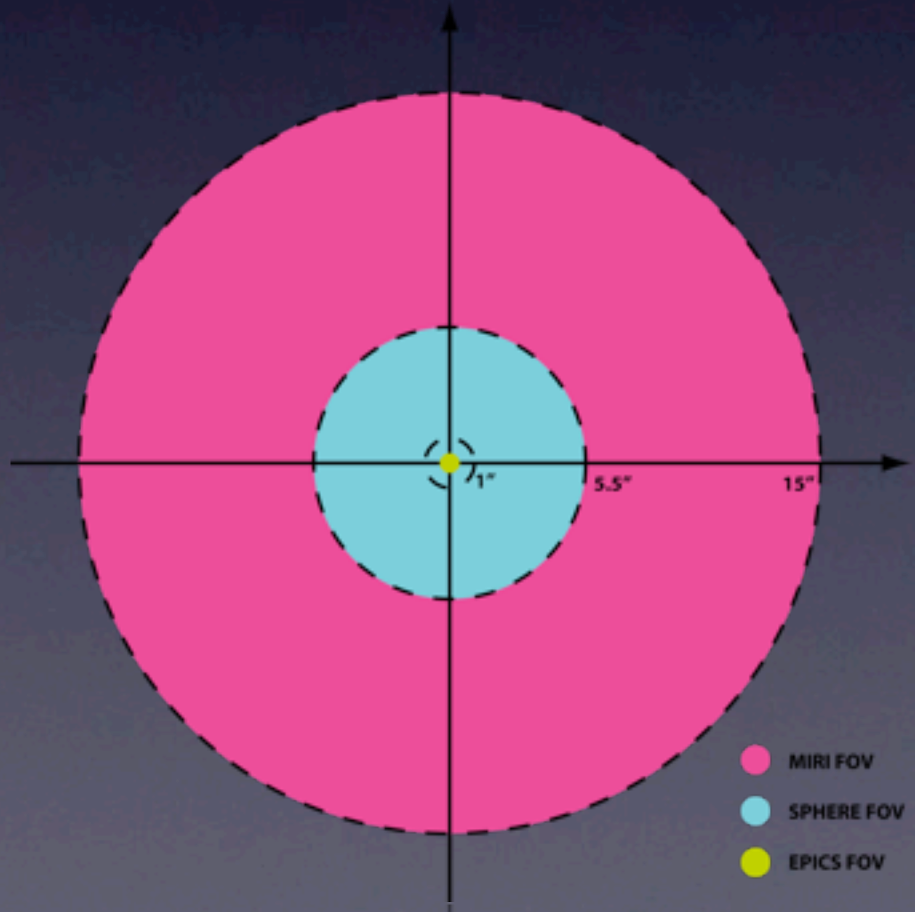
Chauvin et al. 2005

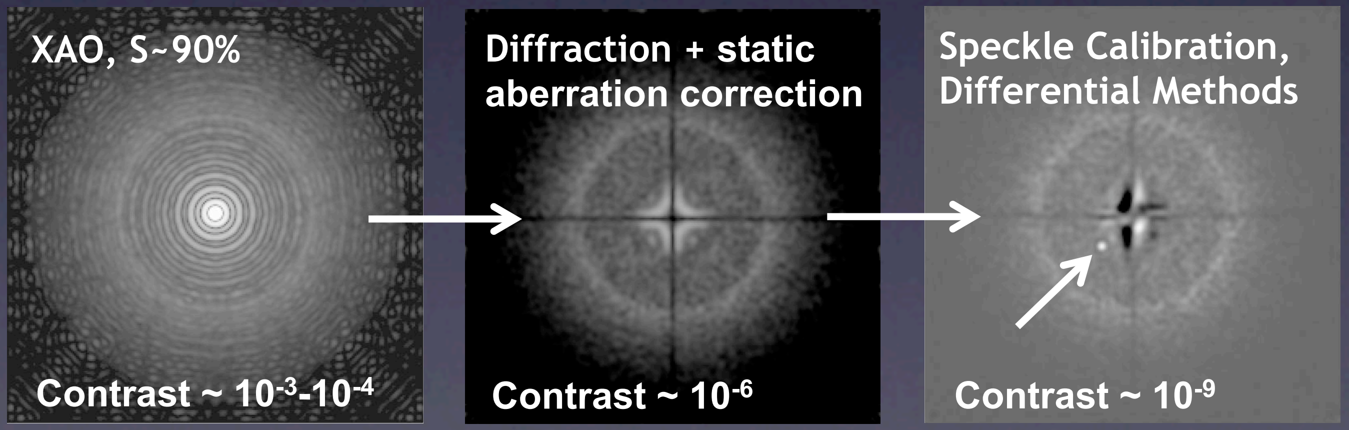


E-ELT/EPICS

- Vis-NIR imager and spectrograph
- Extreme adaptive optics (XAO)
- Coronagraphs (0.95-1.65µm)
- λ/D ≈ 8 mas
- FOV ≈ 0.4”







Kasper 09

Performance comparison around young MS K-M stars

Most abundant stellar type

Planetary systems not well known

- Planet formation/migration similar to Sun-like stars?

Currently a hot topic

- RV and transit surveys starting
- Prospects for super-Earths in habitable zones

Low luminosity

- For a given contrast, fainter planets can be imaged

Why young main sequence stars?

"Main sequence"

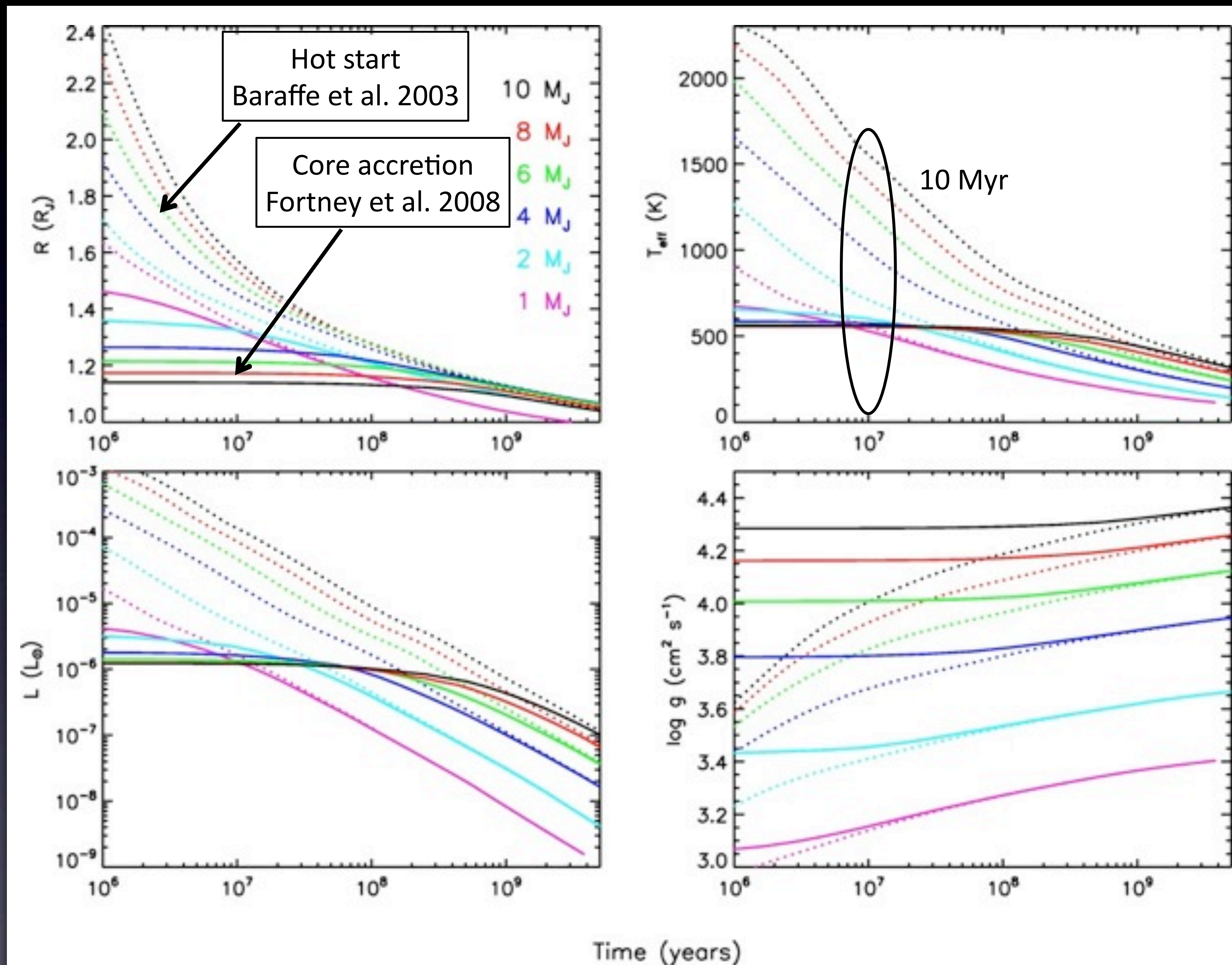
- Thick disks have disappeared
- Planetary systems mostly formed

"Young"

- Planets are still warm and luminous → easier
  - Cooling models poorly constrained
- Moving groups and associations
  - Nearby (typically 20 – 50 pc)
  - Ages relatively well defined

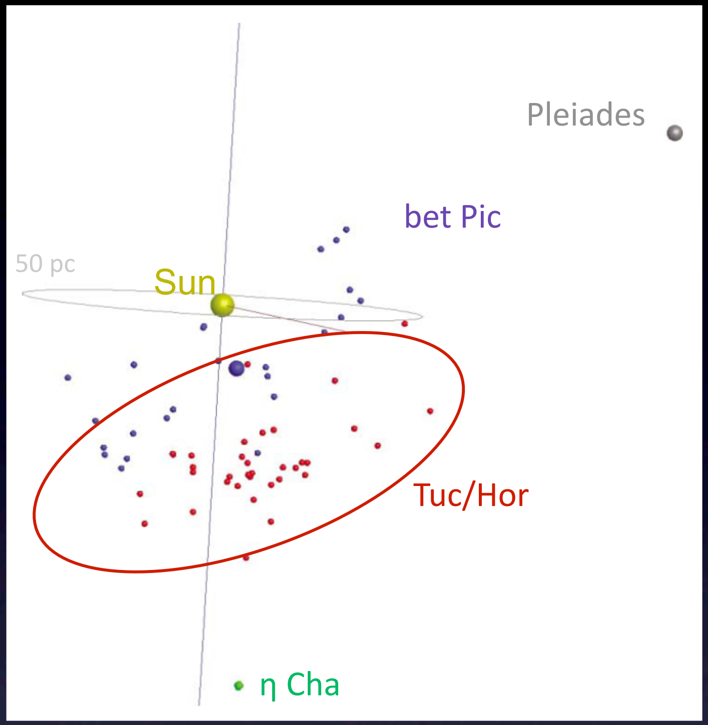
Evolutionary models

Fortney et al. 2008



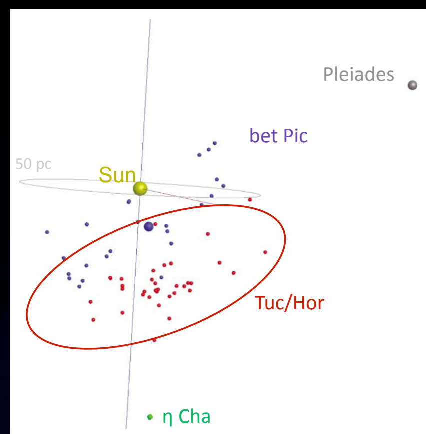
Simulations

Simulations



1. Age, distance and magnitude

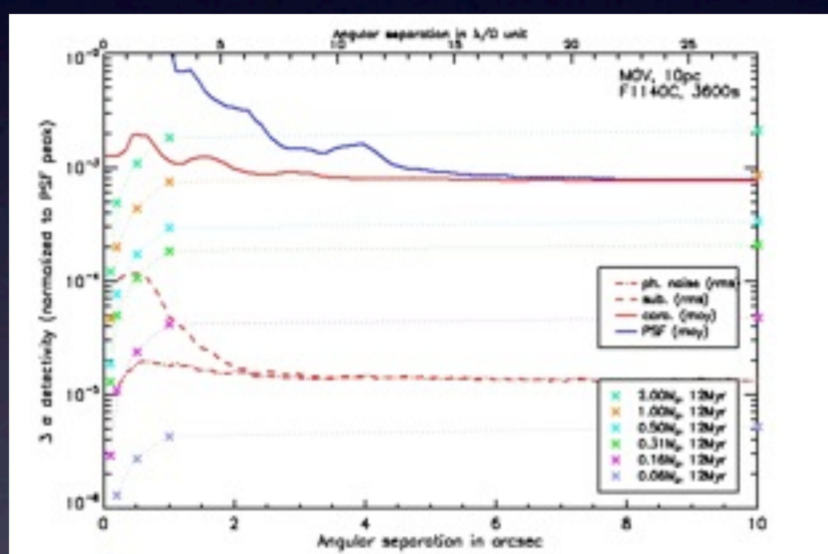
Simulations



1. Age, distance and magnitude

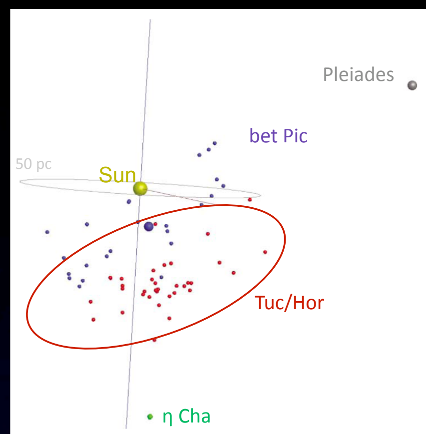
MIRI

M0V,10pc, 12 Myr, 1h



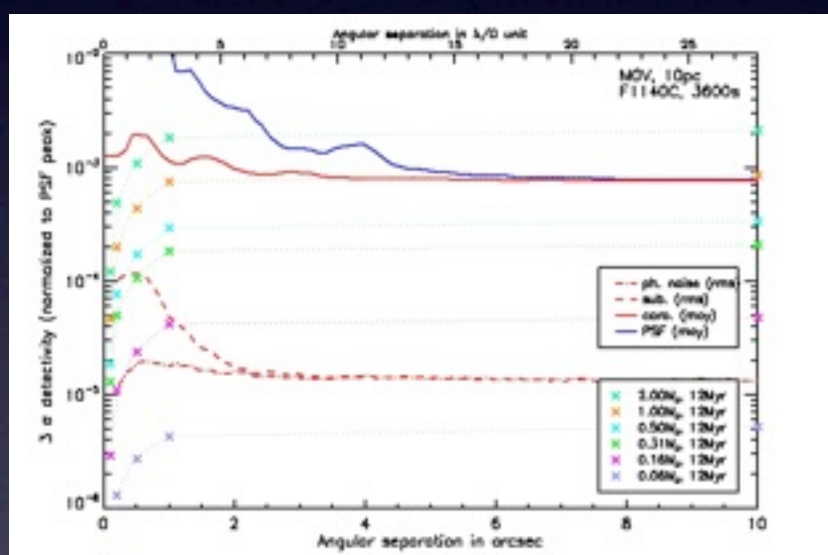
2. Coro. profile ⇒ contrast

Simulations



MIRI

M0V,10pc, 12 Myr, 1h

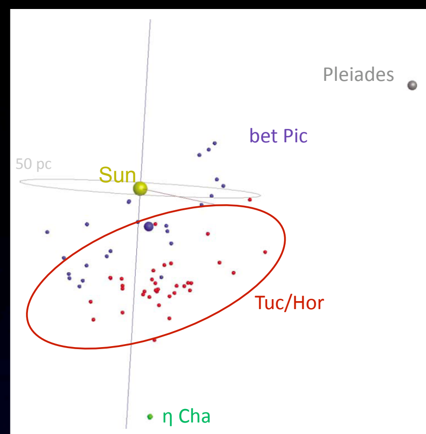


1. Age, distance and magnitude

2. Coro. profile ⇒ contrast

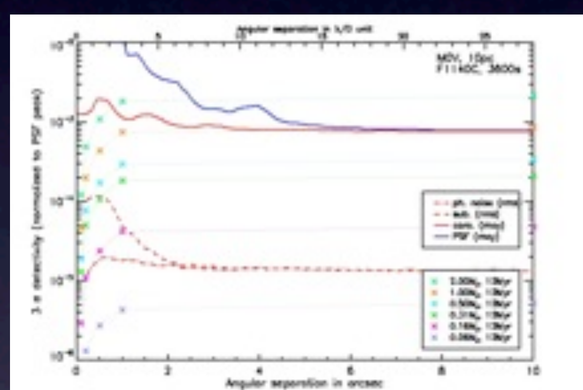
3. ⇒ Companion magnitude

Simulations



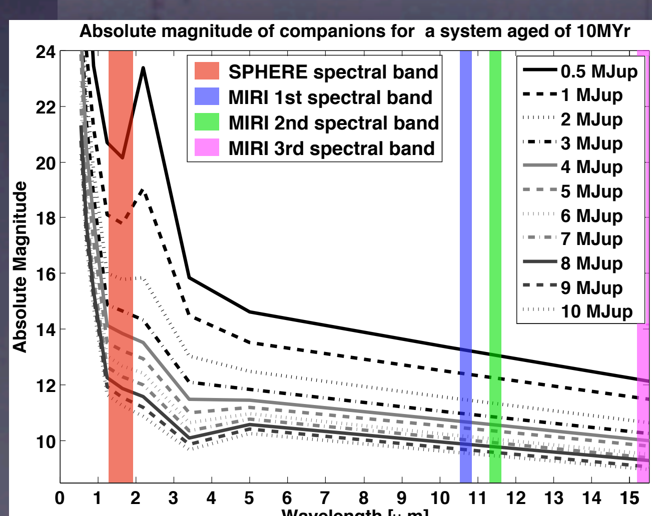
1. Age, distance and magnitude

MIRI M0V,10pc, 12 Myr, 1h



2. Coro. profile ⇒ contrast

3. ⇒ Companion magnitude



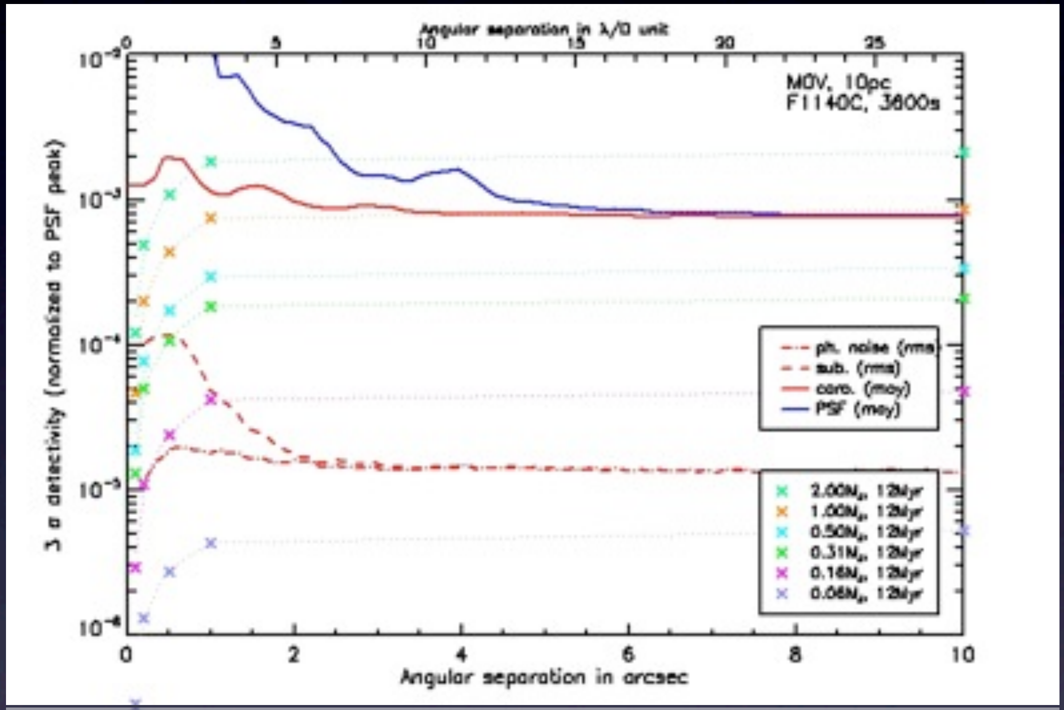
4. Evol. model ⇒ mass

Simulations & assumptions

MIRI

- Reference subtraction

MIRI M0V,10pc, 12 Myr, 1h



Courtesy A. Boccaletti

Simulations & assumptions

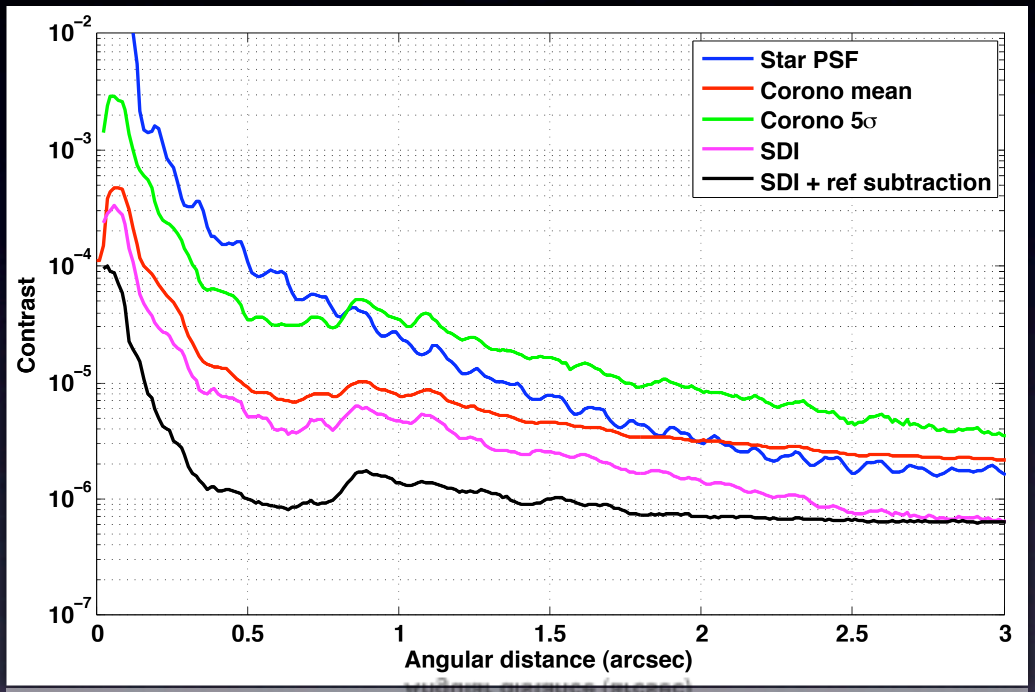
MIRI

- Reference subtraction

SPHERE

- Reference subtraction
- Ref subtraction + SDI

SPHERE G0V, 24pc, 12 Myr, 1h



Courtesy A. Boccaletti

Simulations & assumptions

MIRI

- Reference subtraction

SPHERE

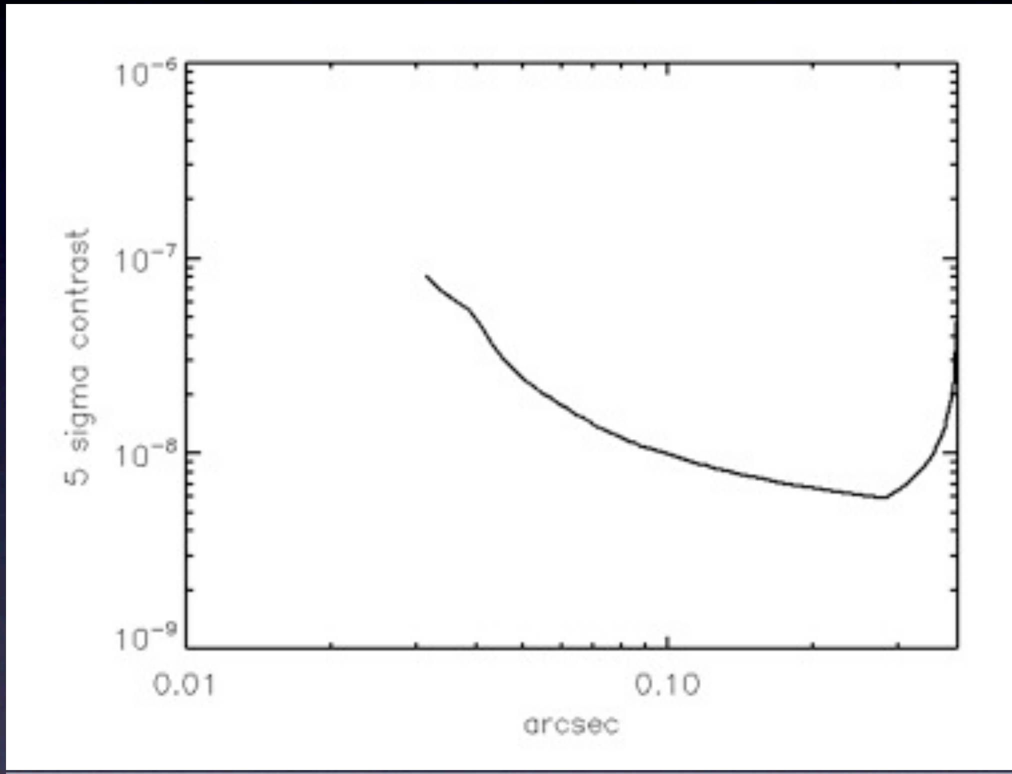
- Reference subtraction
- Ref subtraction + SDI

EPICS

- Ref subtraction + SDI + Pol.

EPICS

M0V, 10pc, 12 MYr, 1h



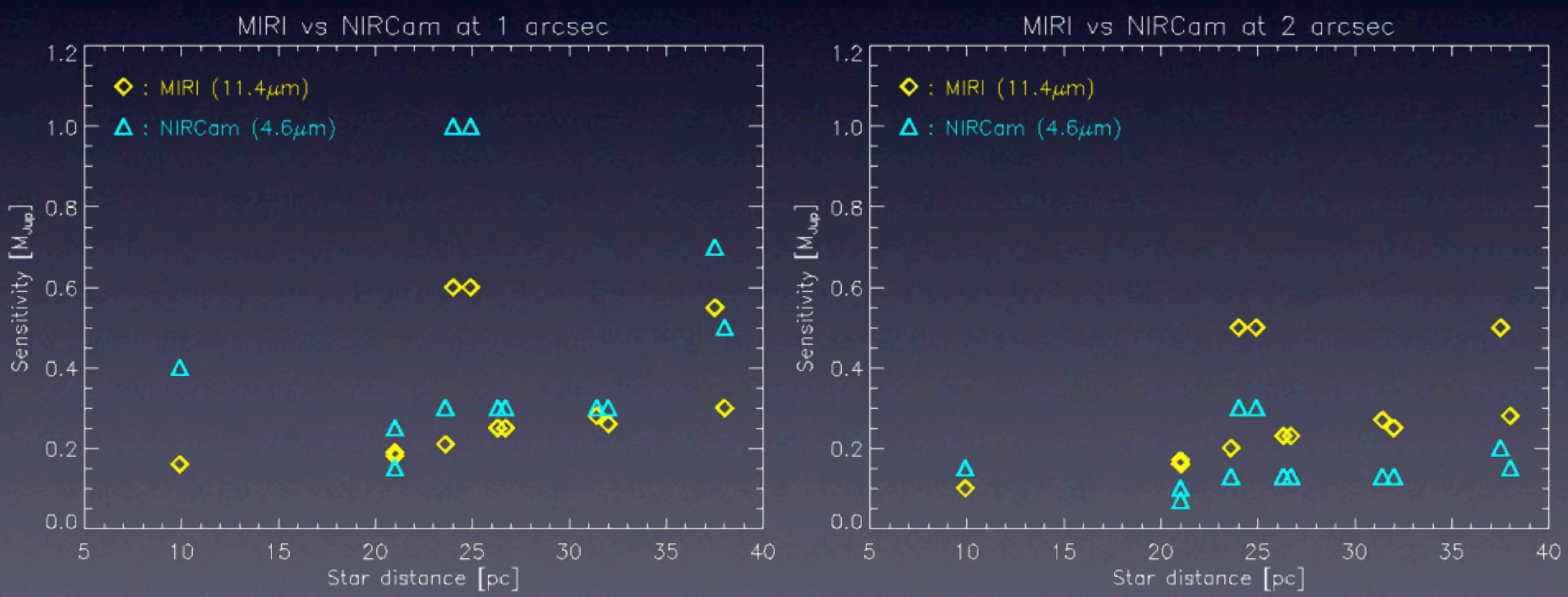
Courtesy C. Verinaud

Sample and sensitivity for MIRI

Name	Dist (pc)	Age (Myr)	Sp type	V	0.2" a AU	0.2" M Mjup	0.5" a AU	0.5" M Mjup	1.0" a AU	1.0" M Mjup	2.0" a AU	2.0" M Mjup
AU Mic	9.9	12	M1Ve	8.8	2	**0.50**	5	**0.30**	10	**0.16**	25	**0.10**
TWA 8A	21.0	8	M3Ve	12.2	4	**0.40**	11	**0.25**	21	**0.19**	53	**0.16**
TWA 8B	21.0	8	M5	15.2	4	**0.33**	11	**0.23**	21	**0.18**	53	**0.17**
WW PsA	23.6	12	M4	12.2	5	**0.50**	12	**0.30**	24	**0.21**	59	**0.20**
CD-57 1054	26.3	12	M0/1	10.0	5	**0.80**	13	**0.50**	26	**0.25**	66	**0.23**
V1005 Ori	26.7	12	M0.5V	10.1	5	**0.80**	13	**0.50**	27	**0.25**	67	**0.23**
TWA 12	32.0	8	M1Ve	12.9	6	**0.80**	16	**0.45**	32	**0.26**	80	**0.25**
CPD-66 3080B	31.4	12	M3Ve	12.7	6	**0.80**	16	**0.42**	31	**0.28**	79	**0.27**
TWA 7	38.0	8	M2Ve	11.7	8	**0.90**	19	**0.52**	38	**0.30**	95	**0.28**
GJ 4020 A	24.0	50	M0	10.2	5	**2.00**	12	**1.10**	24	**0.60**	60	**0.50**
GJ 9809	24.9	50	M0	10.9	5	**2.00**	12	**1.10**	25	**0.60**	62	**0.50**
CT Tuc	37.5	30	M0Ve	11.5	7	**1.70**	19	**0.95**	37	**0.55**	94	**0.50**

Comparison with NIRCam

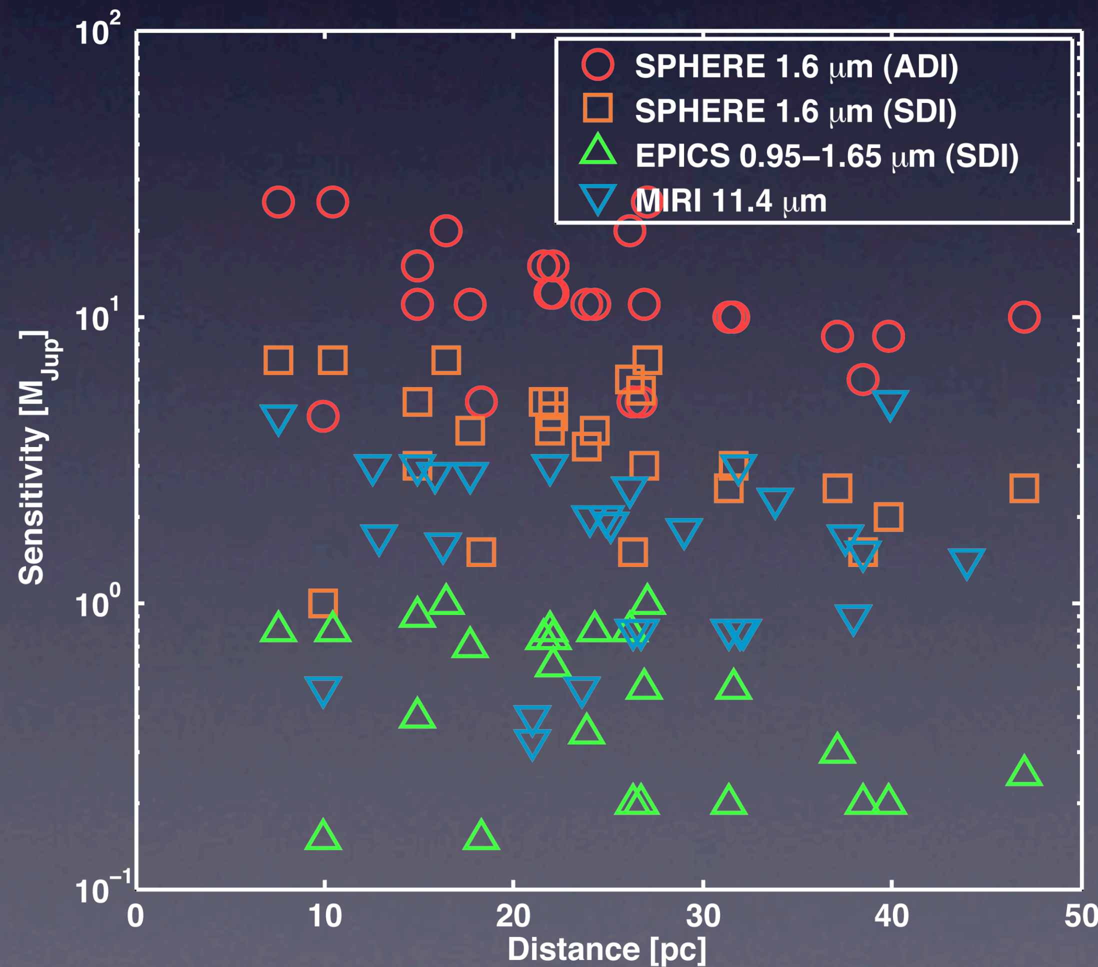
MIRI better than NIRCam for planets <1.5” (~40AU)
Only MIRI can access planets <0.8” (~20AU)



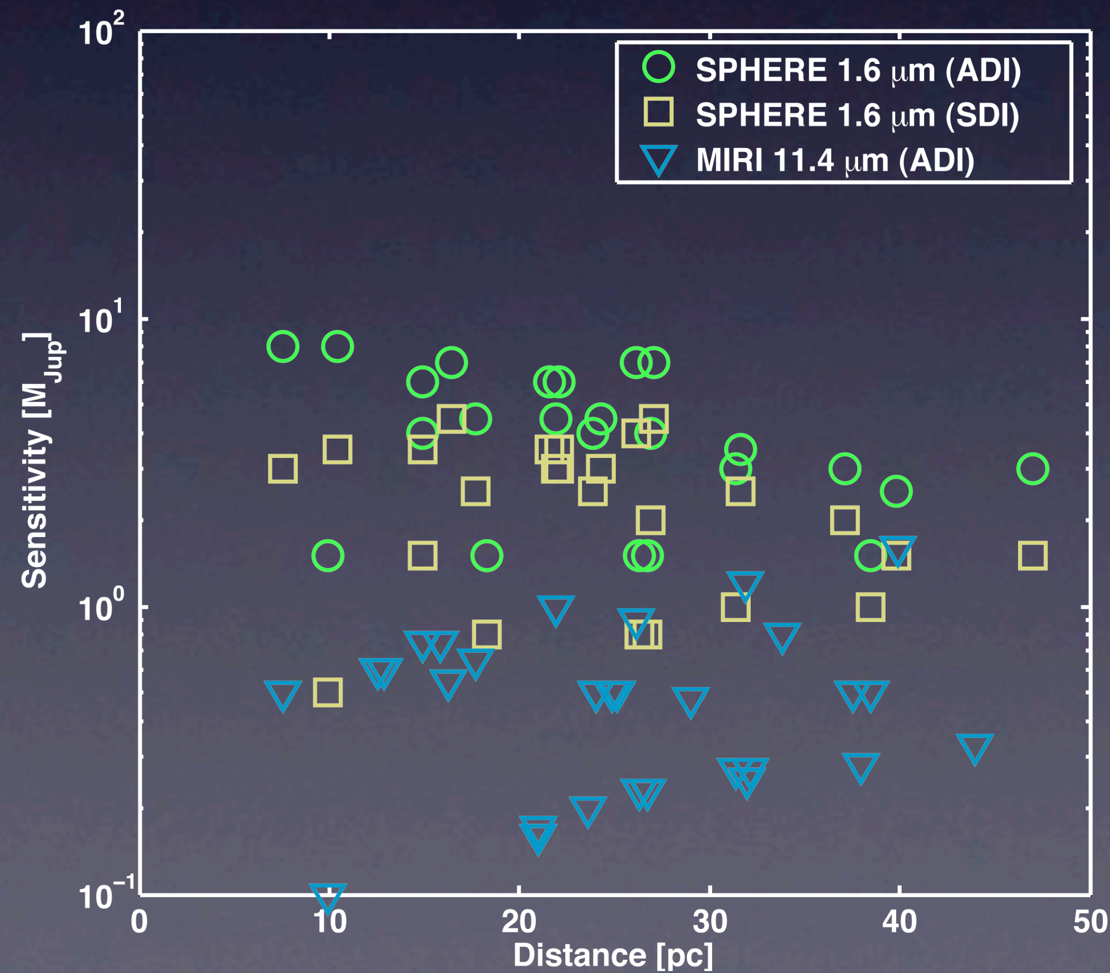
MIRI vs SPHERE

Most M stars too faint for SPHERE's AO
SPHERE competitive with MIRI <0.5"

0.2"



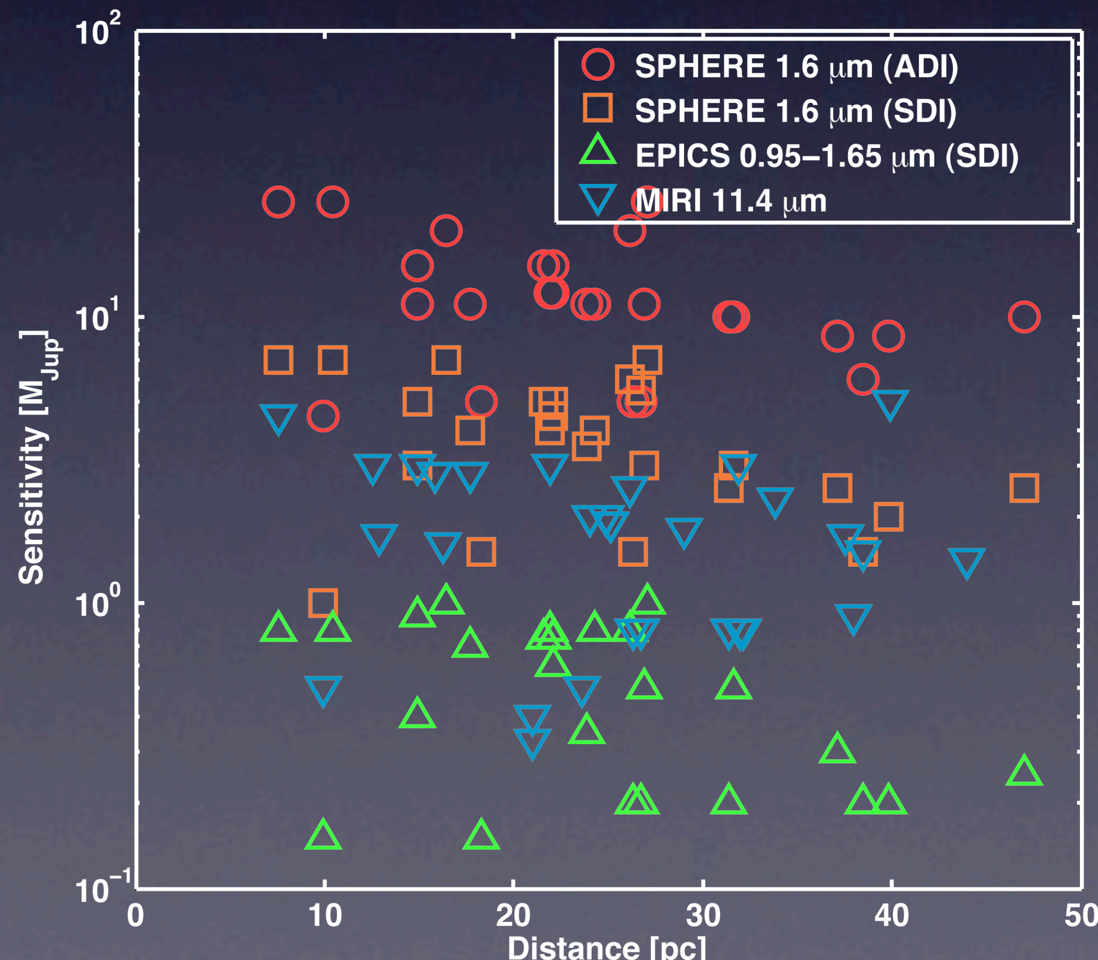
2"



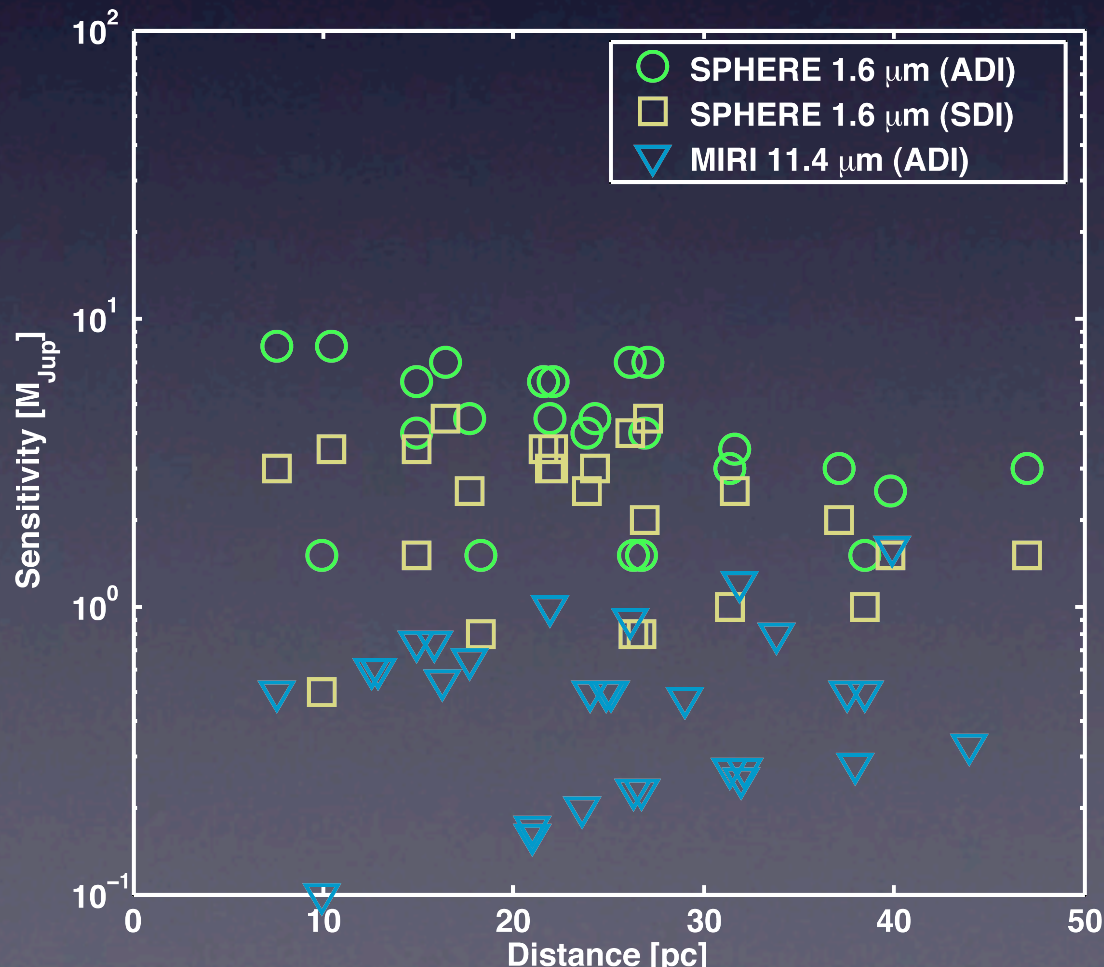
MIRI vs SPHERE vs EPICS

Most M stars too faint for EPICS's AO too
EPICS always more sensitive
EPICS FOV ≈ MIRI IWA

0.2"



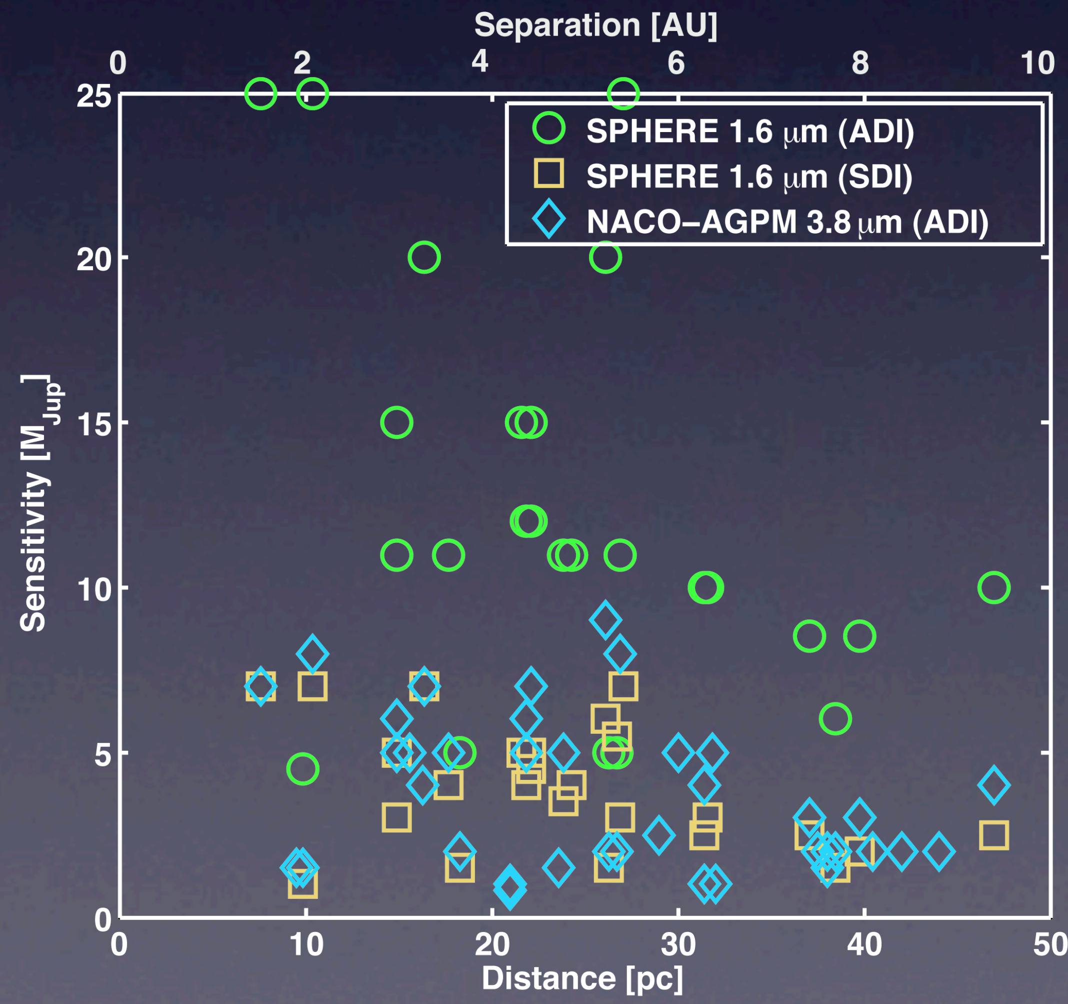
2"



Ground-based L band coronagraphy?

Why?

- Strehl much better
- Background still OK
- IWFS => Fainter stars
- Loss of angular resolution → phase mask coro.



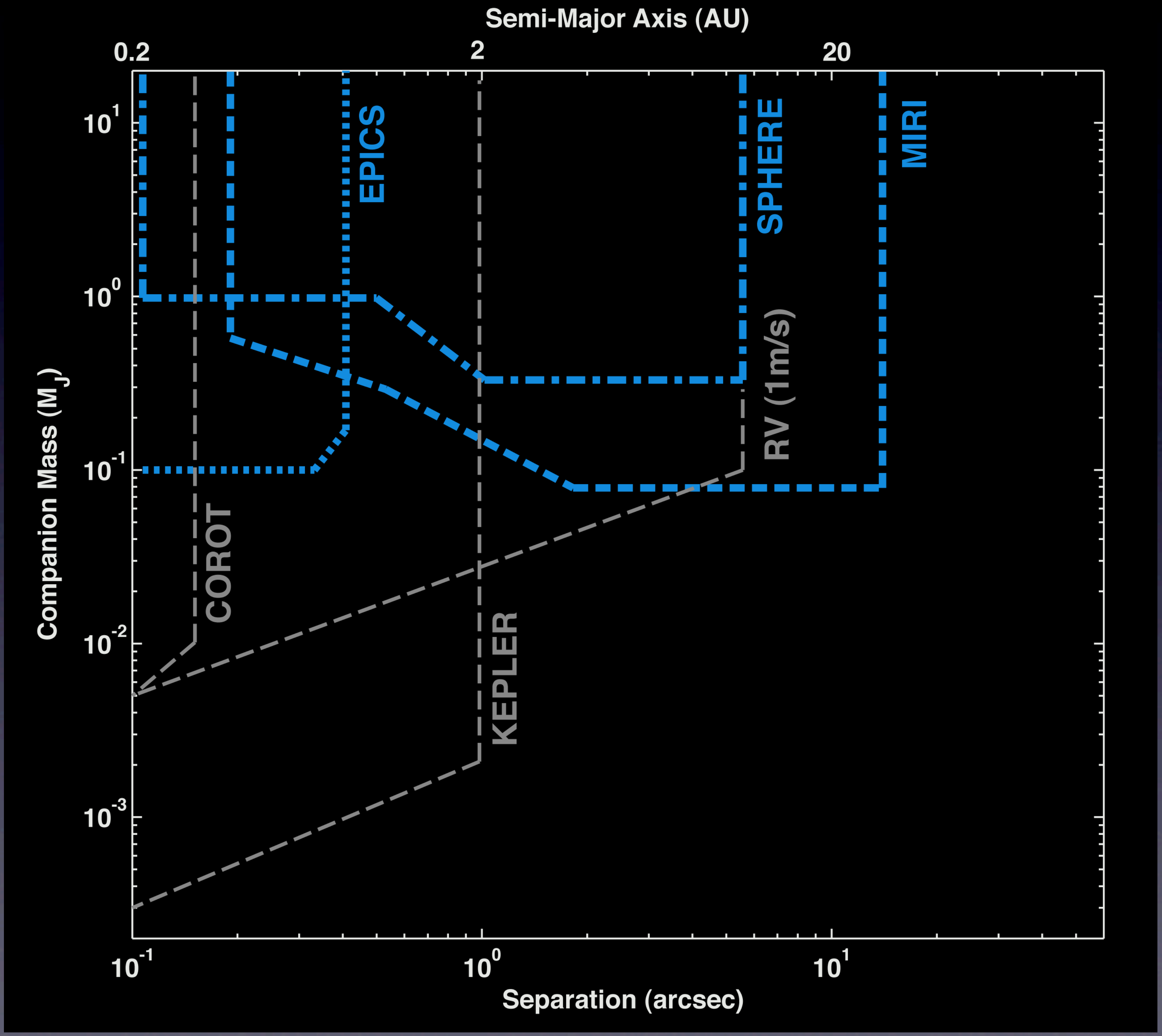
Poster:

- O. Absil (NACO L + VVC)

Talks:

- C. Delacroix (VVC)
- M. Kasper (NACO L)
- S. Quanz (NACO)

Conclusions



Conclusions

- Today, ground-based facilities are competitive
- Dedicated space-based coronagraphs must focus on aspects that cannot be done from ground
    - Spectroscopy across the full IR
    - low-mass planets around faint M dwarfs
- Optimizing current facilities make sense (cf. L band)
- Exploiting advanced reduction methods !