Implications of a possible low value of η_{earth}

Alain Léger, Blue Dot meeting 5 April 2013

Present estimate of η_{earth} (Kepler data)

- Kepler release Feb 2011: Catanzarite & Shao (ApJ. 738, 2011)
  ==> **1 – 3% Earth analogues**

- Jan. 2013, at EXOPAG (San Diego),

  1. $\boldsymbol{\eta_{earth}}$**~ 7%**; F,G,K; R_{pl} = 1 - 2 R_{earth}; a = 0.8 - 1.8 AU

  2. **M stars,** $\boldsymbol{\eta_{earth}}$**~ 5%** (AAS meeting)

How many habitable planets in spectro? visible / thermal IR

- A simple model to estimate this number, for different parameters

- Hypotheses:
  - Shot noise only, systematics under control…
  - Means values for: R_{pl}, a_{HZ},…
  - 2 cases: with / without prior detection of habitable pl.

Signal / noise

$$S_i = a\,\Phi^2\,(\Delta\lambda/\lambda)\,R_{pl}^2\,D_i^{-2}\,t_i$$ (Photo-e$^-$ #)

$$N_{i,corono} = \left[b\,\Phi^2\,(\Delta\lambda/\lambda)\,L_i\,\rho(i,D_i)\,D_i^{-2}\,t_i\right]^{1/2}$$ (Photo-e$^-$ #)$^{1/2}$

$$N_{i,\mathrm{int}} = \left[\left(b_1 + b_2\,\Phi^2\,L_i\,\rho\,D_i^{-2}\right)(\Delta\lambda/\lambda)\,t_i\right]^{1/2}$$

To obtain a given S/N, e.g. 10, ==> integration times $\boldsymbol{t_i}$:

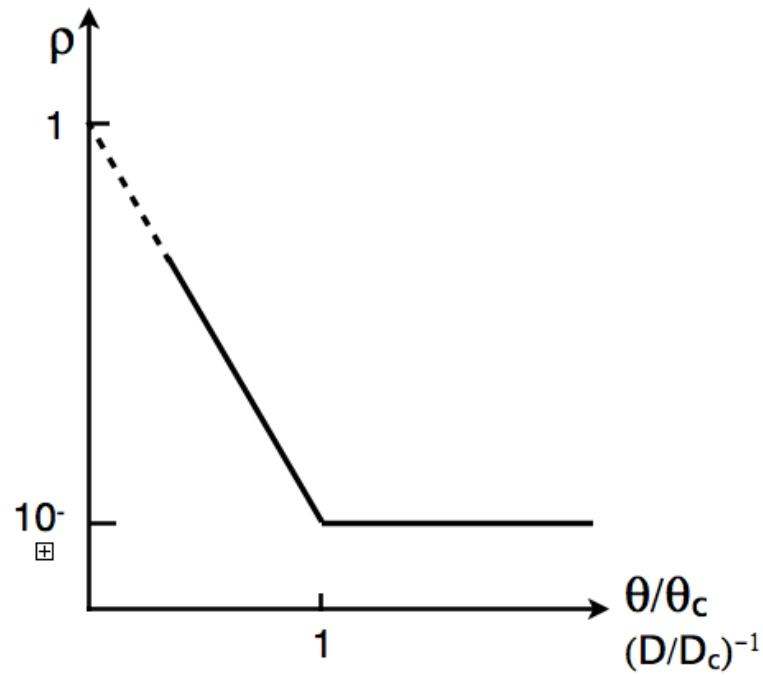
$$t_{i,corono} = c\,\Phi^{-2}\,(\Delta\lambda/\lambda)^{-1}\,R_{pl}^{-4}\,L_i\,\rho(i,D_i)\,D_i^2$$

$$t_{i,\mathrm{int}} = d\left[1 + 11.3\,L_i\,\Phi^2\,D_i^{-2}\right]^{1/2}\Phi^{-4}\,(\Delta\lambda/\lambda)^{-1}\,R_{pl}^{-4}\,D_i^4$$

$$\sum_{i=1}^{N_{last}} t_i = t_mission$$ ==> N_{last}

Coronograph: instrument model (1)

- Toy model for rejection



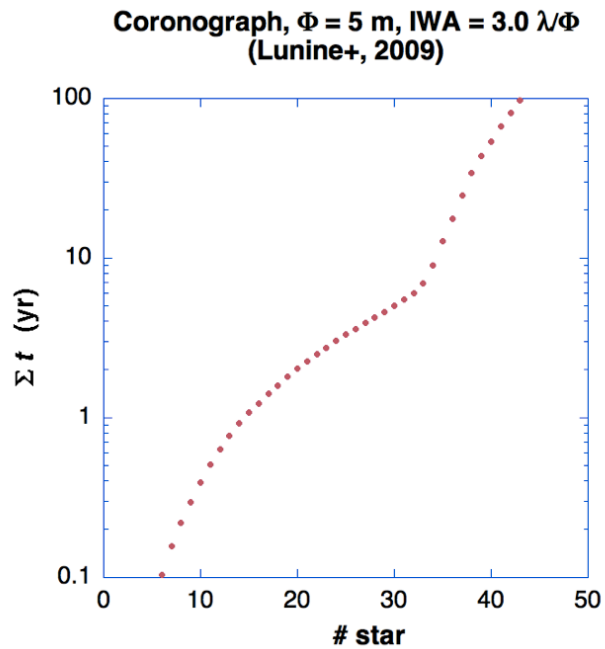
- **Case (1)** (Lunine+, 2009)

  Φ = 5 m, $IWA = 3.0\ \lambda/\Phi$, R_{pl} = 1.0, $a_{HZ} = 1.0\ L^{1/2}$ (AU)

  ==> can *study* ***30 stars*** --> fit parameter "c"

Case (1) Lunine+ 2009

Star_identif	D (pc)	Sp type	log(L/Lo)	Dc (pc)	D/Dc	rho	ti/c	# st	S_(ti/c)	S_(ti) (yr)
HIP71681	1.25	K1V	-3.30e-01	6.91e+00	5.29e-01	1.00e-10	1.02e-11	1	1.02e-11	1.38e-04
HIP71683	1.32	G2V	2.00e-01	1.27e+01	1.65e-01	1.00e-10	3.86e-11	2	4.88e-11	4.75e-04
HIP99240	6.11	G5IV-Vvar	1.10e-01	1.15e+01	9.39e-01	1.00e-10	6.73e-10	3	3.80e-10	5.39e-03
HIP22449	8.07	F6V	4.40e-01	1.68e+01	5.80e-01	1.00e-10	2.51e-09	4	1.97e-09	2.74e-02
HIP27072	8.93	F7V	3.60e-01	1.53e+01	7.72e-01	1.00e-10	2.56e-09	5	4.50e-09	6.23e-02
HIP12777	11.13	F7V	3.60e-01	1.53e+01	9.62e-01	1.00e-10	3.97e-09	7	1.10e-08	1.55e-01
HIP78072	11.25	F6V	4.60e-01	1.72e+01	7.72e-01	1.00e-10	5.11e-09	8	1.56e-08	2.18e-01
HIP57757	10.93	F8V	5.50e-01	1.90e+01	6.10e-01	1.00e-10	5.93e-09	9	2.11e-08	2.94e-01
HIP16852	13.96	F9V	4.90e-01	1.78e+01	8.95e-01	1.00e-10	8.42e-09	10	2.83e-08	3.93e-01
(...)										
HIP17651	17.63	F3/F5V	7.00e-01	2.26e+01	6.97e-01	1.00e-10	2.18e-08	26	2.61e-07	3.60e+00
HIP61174	18.28	F2V	6.90e-01	2.24e+01	7.39e-01	1.00e-10	2.29e-08	27	2.83e-07	3.91e+00
HIP36366	18.05	F0V...	7.30e-01	2.34e+01	6.66e-01	1.00e-10	2.45e-08	28	3.07e-07	4.24e+00
HIP77760	15.89	F9V	4.80e-01	1.76e+01	1.04e+00	2.53e-10	2.69e-08	29	3.32e-07	4.59e+00
HIP92043	19.21	F6V	7.90e-01	2.51e+01	6.17e-01	1.00e-10	3.18e-08	30	3.62e-07	5.00e+00
HIP76829	17.44	F5IV-V	5.20e-01	1.84e+01	1.04e+00	2.58e-10	3.63e-08	31	3.96e-07	5.47e+00
HIP71908	16.57	F1Vp	1.05e+00	3.38e+01	2.92e-01	1.00e-10	4.31e-08	32	4.35e-07	6.02e+00
HIP77257	12.12	G0Vvar	3.20e-01	1.46e+01	1.15e+00	1.97e-09	8.46e-08	33	4.99e-07	6.90e+00
(...)										



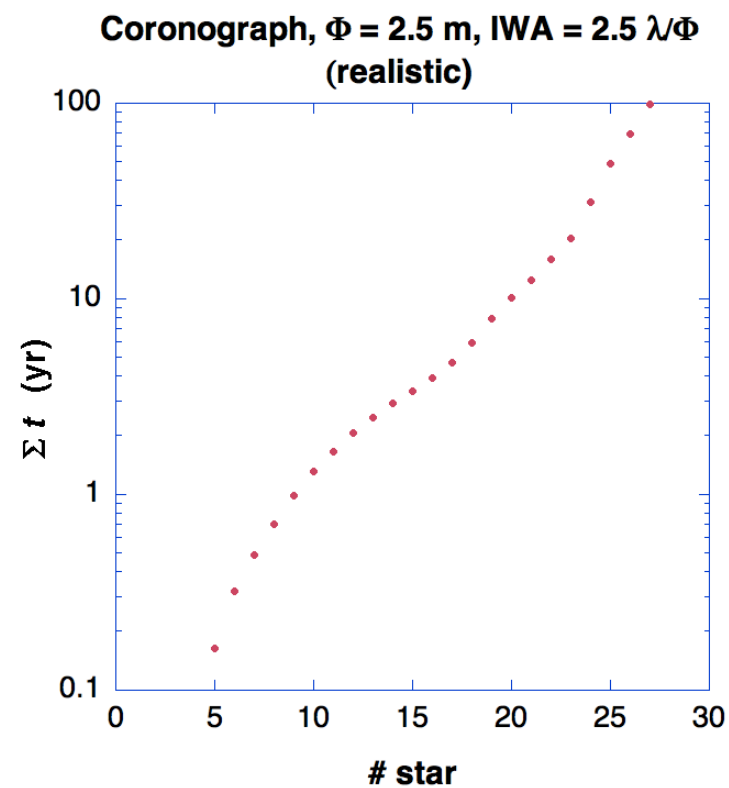
Coronograph: case (2)

Case (2) (possibly ***realistic*** in 2030)

Φ = 2.5 m, $\rho = 10^{-10}$, $IWA = 2.5\ \lambda/\Phi$, + prior detection

==> How many stars, how many planets in spectro ?

Star_identif	Det: t (yr)	Spect: t (yr)	# st	Det : S_(t) (yr)	Spect: n=7%, S_(t) (yr)
HIP71681	1.06e-04	2.23e-03	1	1.00e-04	1.47e-04
HIP71683	4.01e-04	8.42e-03	2	3.54e-04	5.20e-04
HIP16537	5.11e-04	1.07e-02	3	8.10e-04	1.19e-03
HIP8102	9.27e-04	1.95e-02	4	1.53e-03	2.25e-03
HIP99240	6.99e-03	1.47e-01	5	5.49e-03	8.07e-03
HIP108870	8.93e-03	1.87e-01	6	1.34e-02	1.98e-02
HIP19849	2.44e-02	5.13e-01	7	3.01e-02	4.43e-02
HIP22449	2.61e-02	5.48e-01	8	5.54e-02	8.14e-02
HIP15510	2.64e-02	5.55e-01	9	8.16e-02	1.20e-01
HIP27072	2.66e-02	5.58e-01	10	1.08e-01	1.59e-01
(...)					
HIP72659	3.89e-01	8.17e+00	23	2.71e+00	3.98e+00
HIP7513	4.03e-01	8.46e+00	24	3.10e+00	4.56e+00
HIP96100	4.08e-01	8.56e+00	25	3.51e+00	5.16e+00
HIP71908	4.48e-01	9.41e+00	26	3.94e+00	5.79e+00
HIP59199	5.89e-01	1.24e+01	27	4.46e+00	6.55e+00
HIP116771	7.32e-01	1.54e+01	28	5.12e+00	7.52e+00
HIP102485	1.18e+00	2.48e+01	29	6.07e+00	8.93e+00
(...)					



η_{earth} = 7% ==> **1.7 planets in spectro...**

Star shade

- Similar conclusion

Turnbull+ (2012): η_{earth} = 10% ==> **1 – 3 planets in spectro**

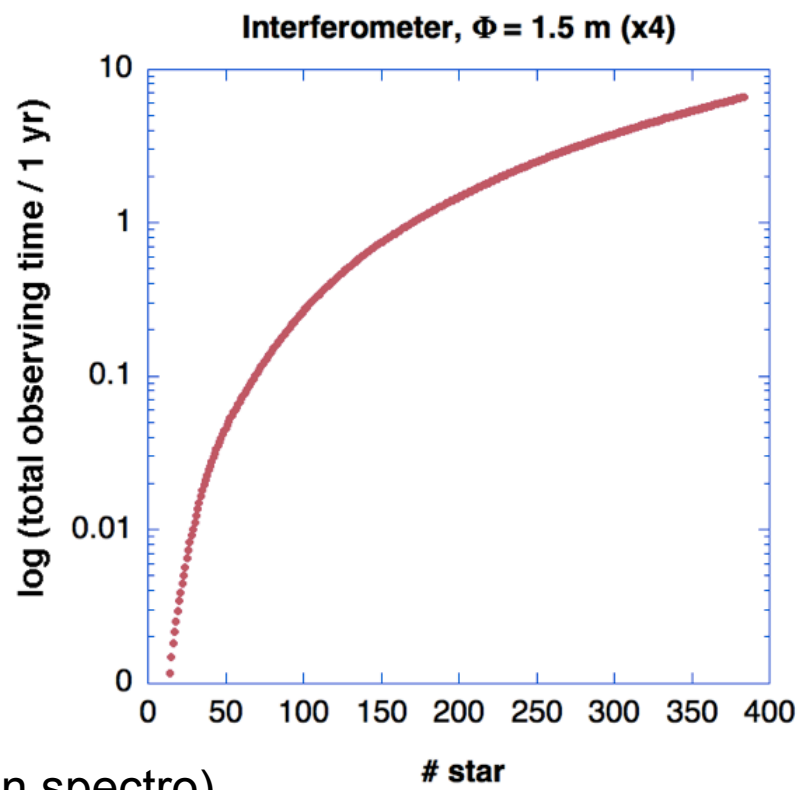
Interferometer

- Fitting results from Defrère+ 2010

N_{last} = 370, R_{pl} = 1.5, $\Delta\lambda/\lambda$ = 1 (detection), Φ = 2 m, t_{tot} = 2 yrs ==> d = 4.6 10^{-6}

- ***Spectro***, *with prior detection,* for R_{pl} = 1.5, $\Delta\lambda/\lambda$ = 1/20, **Φ = 1.5 m** (x4), 5 yrs:

Star_identif	Det: ti (yr)	star #	Det: S_(t) (yr)	Spec, n=7%: S_(t) (yr)
HIP71681	1.29e-06	1	1.29e-06	1.81e-06
HIP71683	2.68e-06	2	3.28e-06	4.59e-06
HIP91772	2.56e-05	3	1.74e-05	2.44e-05
HIP16537	2.62e-05	4	4.33e-05	6.06e-05
HIP104217	2.90e-05	5	7.09e-05	9.92e-05
HIP91768	2.94e-05	6	1.00e-04	1.40e-04
(...)				
HIP96085	1.76e-02	261	1.97e+00	2.75e+00
HIP79248	1.76e-02	262	1.98e+00	2.78e+00
HIP7978	1.76e-02	263	2.00e+00	2.80e+00
HIP36357	1.77e-02	264	2.02e+00	2.83e+00
HIP88694	1.78e-02	265	2.04e+00	2.85e+00
(...)				
HIP61174	2.35e-02	338	3.52e+00	4.93e+00
HIP98677	2.37e-02	339	3.55e+00	4.96e+00
HIP98130	2.38e-02	340	3.57e+00	5.00e+00
HIP66147	2.40e-02	341	3.59e+00	5.03e+00
(...)				



η_{earth} = 7%==> **24 planets** can be studied (in spectro)

Conclusions

1. Almost mandatory we need ***a campaign for detecting habitable pl***. prior to spectroscopy (also => $\boldsymbol{M_{pl}}$)

2. The visible (coronograph) and the thermal IR (interferometer), ***are not equally well-equipped*** to face a low η_{earth} :

   - visible ≈ **1.7** planets in spectroscopy (limitation: IWA)
   - IR ≈ **24** planets - - (limitation: shot noise)

3. This is ***bad news*** because visible and IR are ***complementary*** for identify species (H_2O, O_2, O_3, CO_2) and ***both valuable for qualifying*** a possible detection of biosignature.

If η_{earth} is actually small, facts are tough stuffs…

4. However, such a low value of η_{earth}, ***is not established yet***