Carbon for extraterrestrial habitability

From Earth to other habitable worlds

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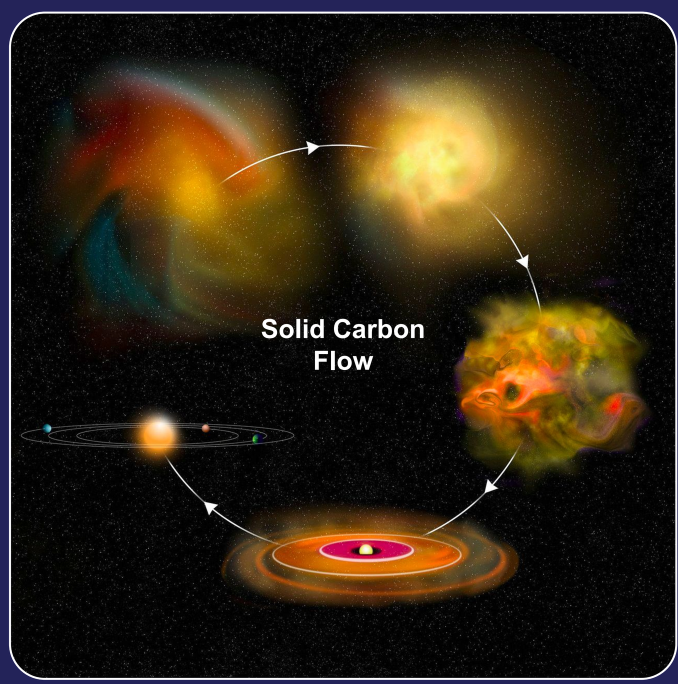
A. Context

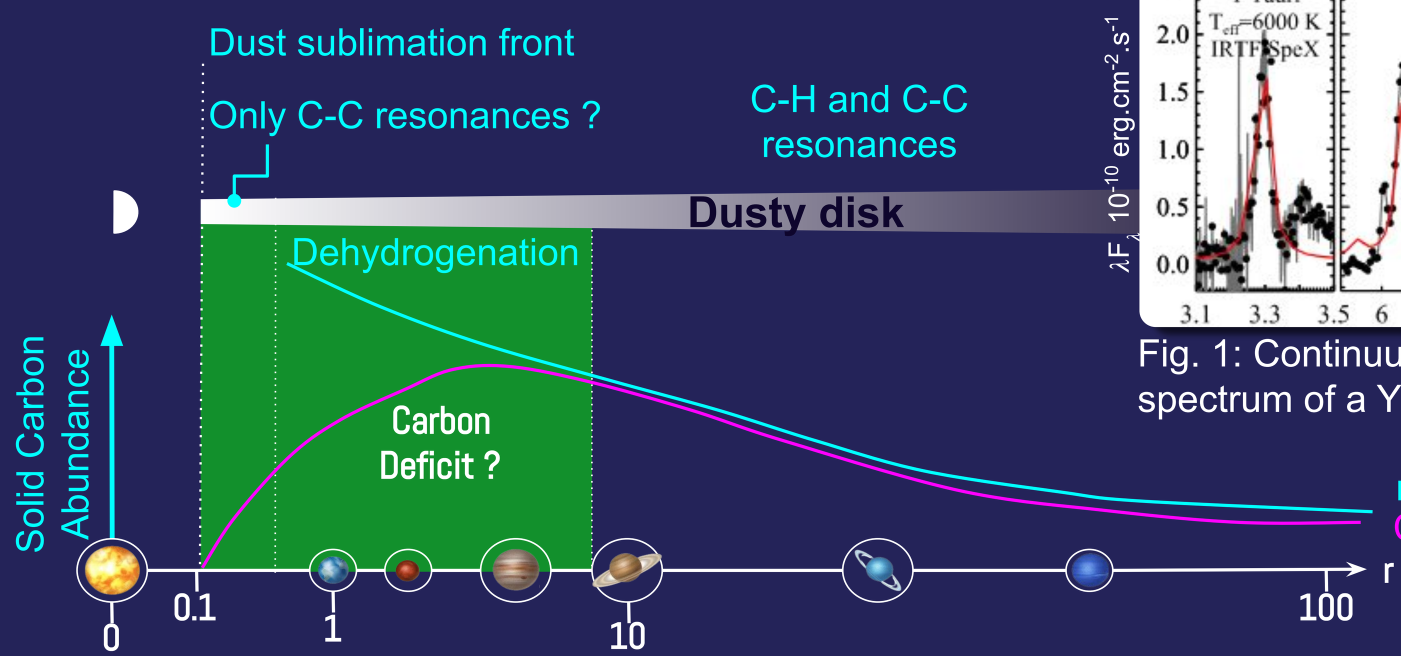
- Carbon is the 4th most abundant element in the interstellar medium (ISM), with ~50% in solid form.
- **Earth is carbon depleted by factor ~10 000** compared to outer solar system and ISM [1].
- Carbon depletion on Earth was essential for habitability setting (plate tectonics, climate stabilization, …)
- Inner 10 astronomical unit (au) region of protoplanetary disks (PPDs) → expected formation site of terrestrial planets



Credit:Bill Saxton/NRAO/AUI/NSF

B. Science case

- Question: Are all close-in planets depleted in solid carbon ?
- Solution: The spectral signatures of solid carbon allow us to probe its abundance in the rocky planet formation zones of young stellar object (YSO).



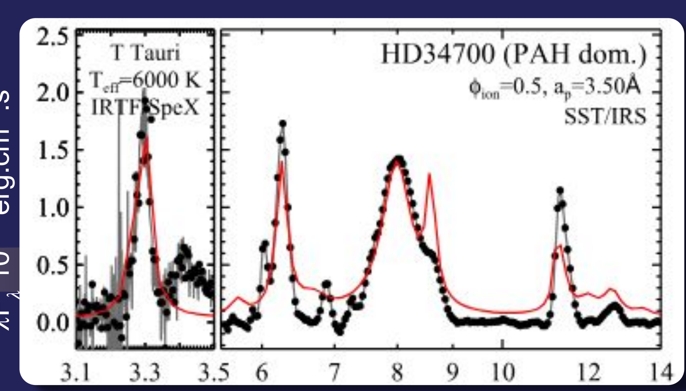
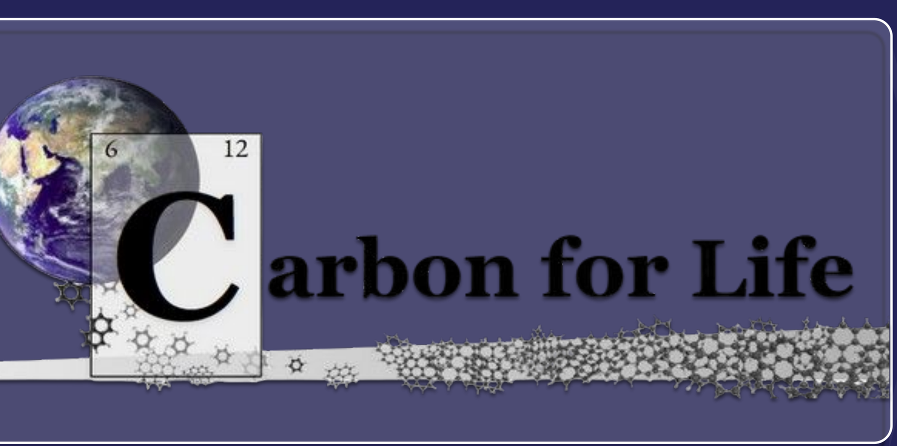


Fig. 1: Continuum-subtracted MIR spectrum of a YSO. [2]

C. The C4Life project



An ESA space mission applicant

Objective:

Statistical view of solid carbon depletion in the planet-forming region of PPDs

- 2-telescope **space interferometer**
- to observe **solid carbon features**
- between **3 and 9 µm**
- in the **inner 10au of PPDs**

D. Feasibility study: the PPD model

- 10 inner au around YSO
- Solid carbon spectral profil
- Solid carbon deficit hypothesis
  - resonance C-C (& C-H)
  - accessible **only from space**
- **Variation in correlated flux**

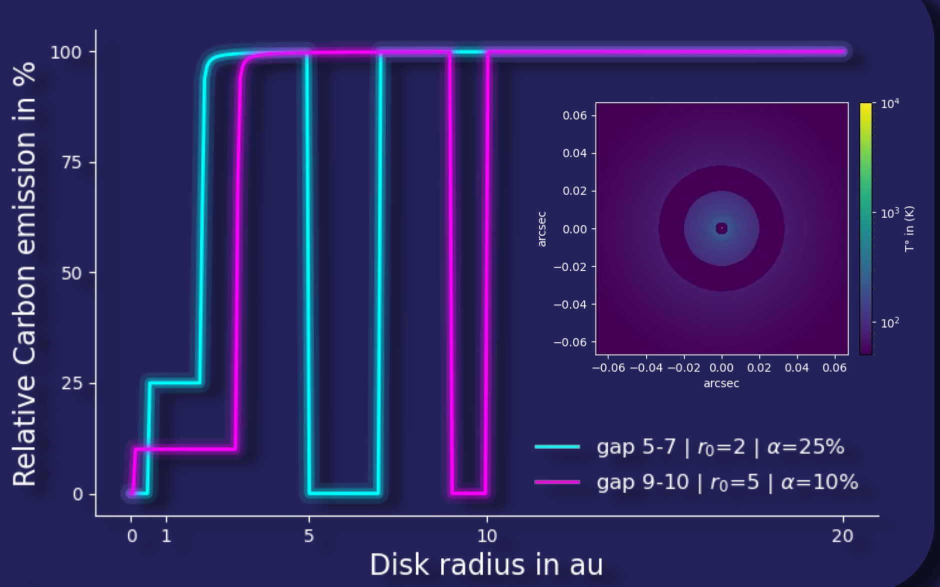


Fig. 2: Example of a solid carbon deficit hypothesis with a PPD model based on temperature gradient

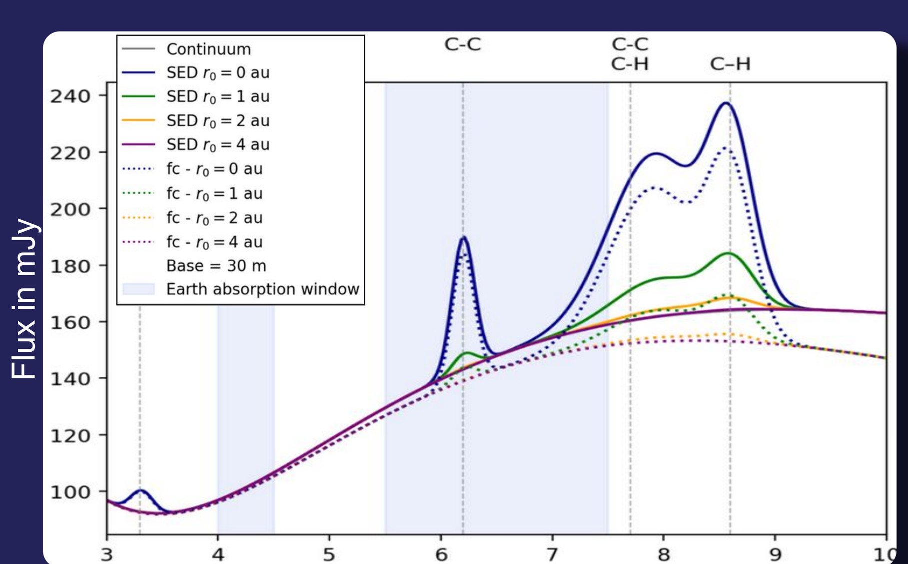


Fig. 3: Total & correlated flux under differents carbon emission deficit hypothesis

Correlated flux = fringes amplitude

He allows to associate the **amount of flux** emitted by a chemical species with its **emitting area** whose **spatial resolution depends on the base** length.

E. Model analysis

By exploring this parameter space, we investigate the evolution of :

- the **sensitivity** to measure bands on top of the continuum,
- the **accuracy** to distinguish between models.

The observational scenarios provide the top level requirements for the design of the space interferometer.

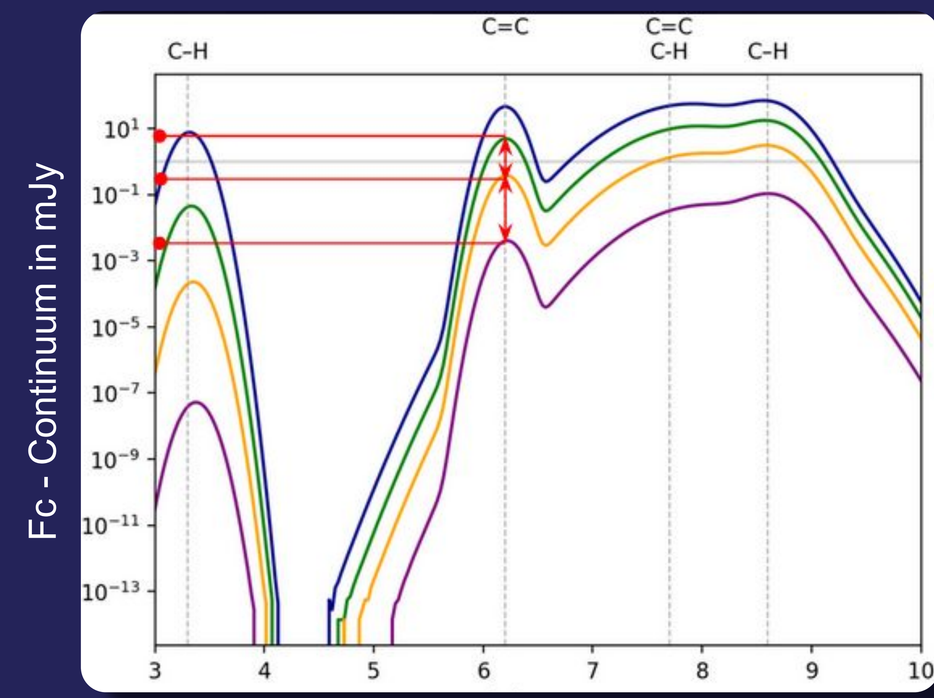
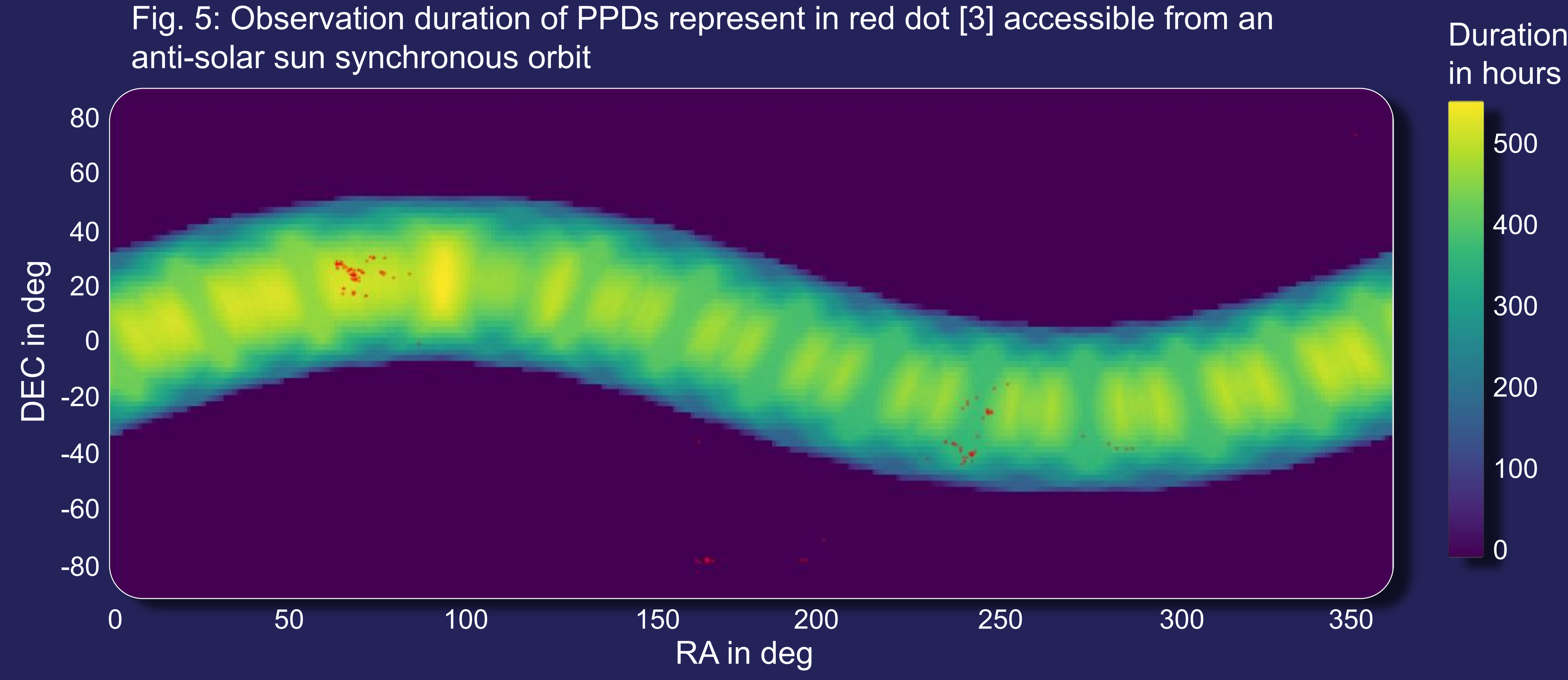


Fig. 4: Fc minus continuum under different carbon emission deficit hypothesis.

F. Sources

Fig. 5: Observation duration of PPDs represent in red dot [3] accessible from an anti-solar sun synchronous orbit



200 PPDs

456 h Mean observation period

145 pc Mean distance

Mean tot. flux computed from WISE space mission :

0.67 Jy @3.4µm

0.37 Jy @4.2µm

0.08 Jy @12µm

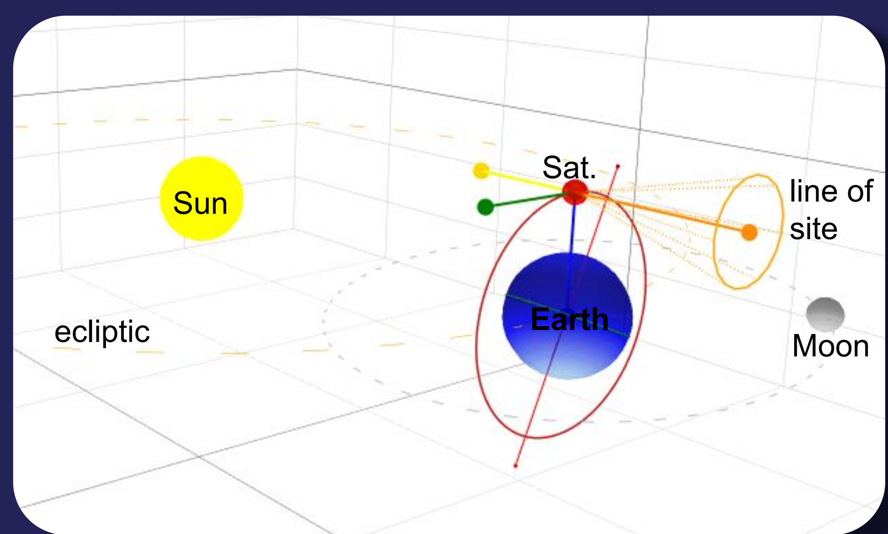
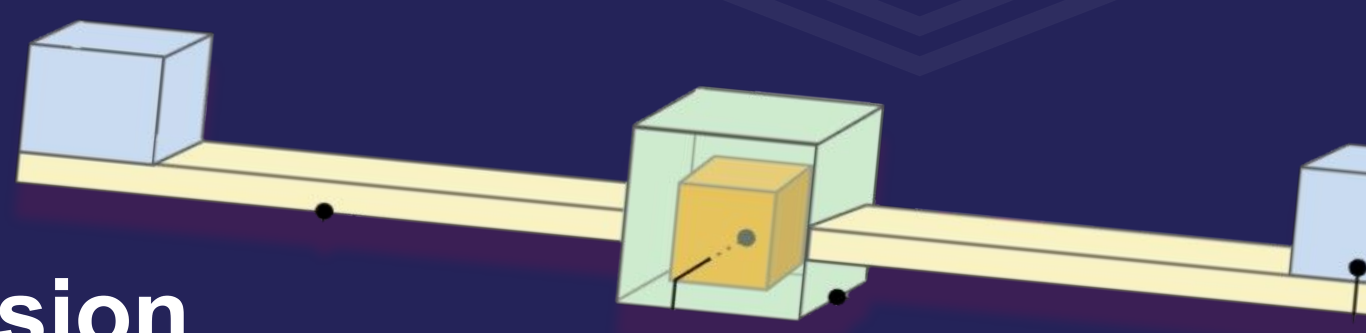


Fig. 6: Anti-solar sun synchronous orbit scheme



Artistic view of C4Life satellite

G. Conclusion

Table 1: Preliminary C4Life specification table

Main science case		
Main science objective	Determine a statistical view on solid carbon spatial distribution in a set of more than 200 PPDs around stellar mass ranging from 0.1 to 2.5 Msolar	
Physical parameters	Amplitude of the spectral features of carbon as function of distance to the star. ⇒ radial solid carbon abundance profile versus silicate down to the au	
Observables	Spatially unresolved spectra and correlated flux probing disk region < 1 au	
Target number	~ 200	
Payload		
Primary telescope	Number	2
	Diameter - Field of view	30 to 50 cm - 2-4” (restricted to PSF telescope)
	Deployable arm n° - length	2 - 15 m (baseline = 30m)
Core instrument	Scientific wavelength range	3-9 µm
	Alignment, fringe search and tracking wavelength	2 µm
	Operating temperature	~ 180K
	Spatial resolution	2-5 au @ 150pc
	Spectral resolution	70 - 300
Detector	Operating temperature	$T_{cold\ stop}$ < 100 K - $T_{detector}$ < 60 K
	Cut off wavelength	15µm
	Sensitivity	SNR 20-50 on 1mJy source (TBC)

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(*) 6.2µm - 1.λF_λ 10^{-10} erg.cm^{-2}.s^{-1} - 207mJy

[1] Dartois, E., et al. "Dome C ultracarbonaceous Antarctic micrometeorites: Infrared and Raman fingerprints." Astronomy & Astrophysics, vol. 609, A65, 2018.
[2] Seaok, Li. “Polycyclic Aromatic Hydrocarbons in Protoplanetary Disks around Herbig Ae/Be and T Tauri Stars.” Year, vol. X, no. Y, 2017.
[3] Chen, P. S., J. Y. Liu, and H. G. Shan. "A new photometric study of T Tauri stars in the infrared." New Astronomy, vol. 74, 2020, 101286. Elsevier.