Hunting exoplanets around ultracool dwarfs with RV NIR-spectrographs

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Case of study - The M-dwarfs are the most frequent and have the longest lifespan of all main-sequence stars. A sub-group are the so called **ultracool dwarfs** (or UCDs), stars with spectral type M6.0 V or later. They are expected to form **multi-planetary systems,** but only few have been confirmed: SPECULOOS-2 and 3, TRAPPIST-1 and Teegarden's star. There are several reasons for this:

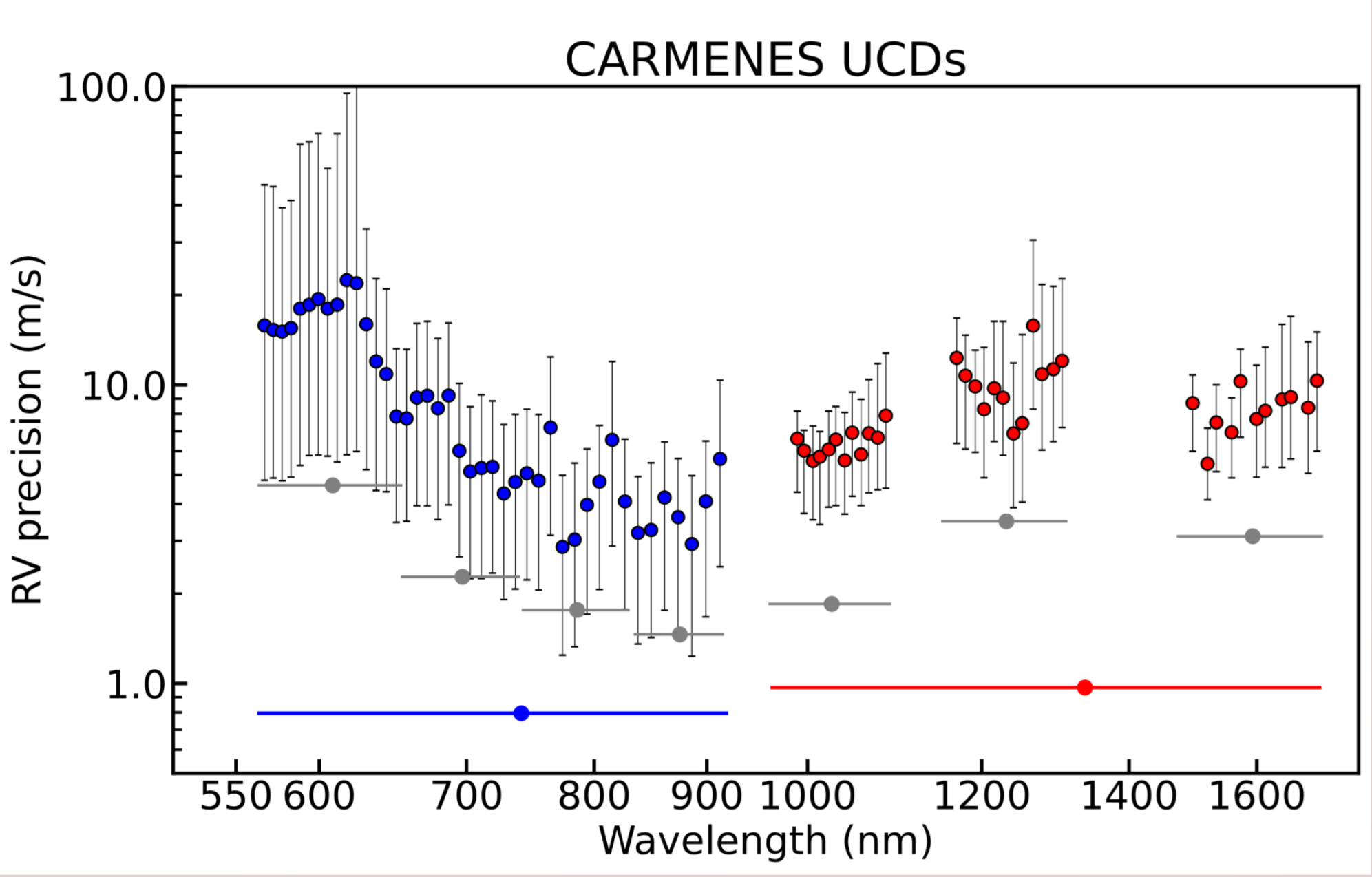
(i) **Faint** stars: low signal to noise ratio

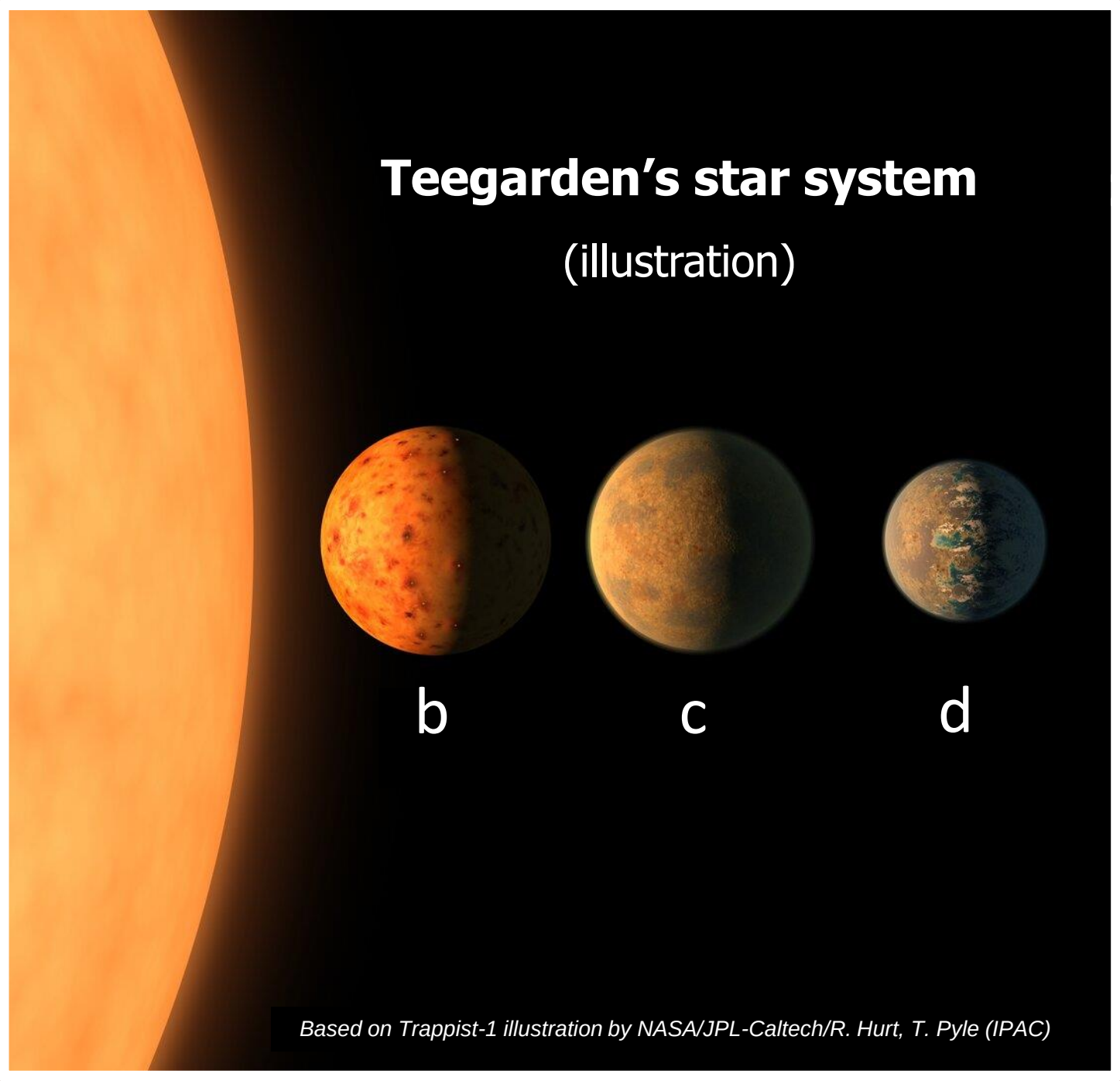
(ii) The spectral energy distribution peaks in the **near-infrared** (NIR)

(iii) **Less spectral information** in the NIR than in the visible range

(iv) **Small planets**, inducing small RV amplitudes

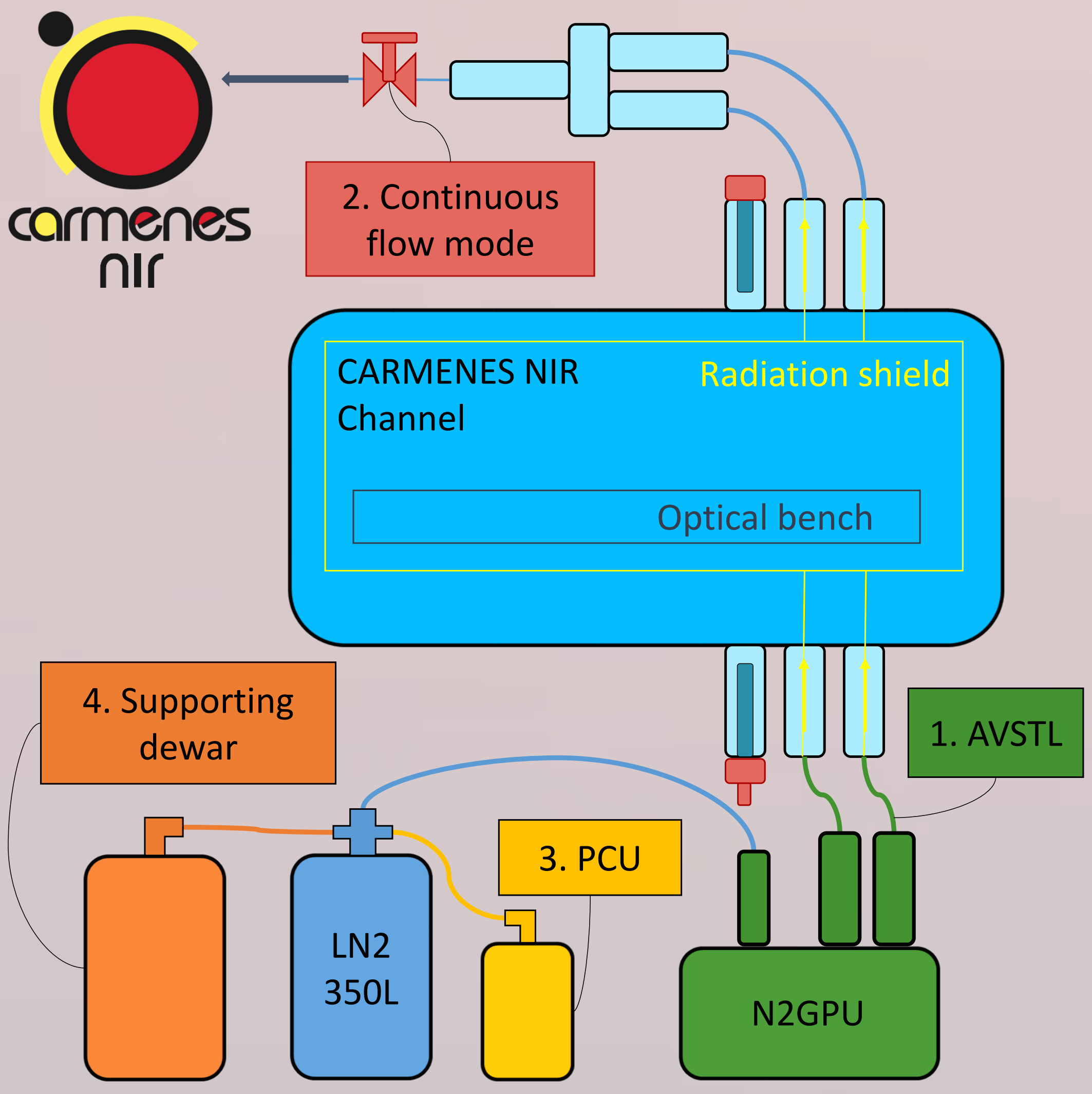
(v) **Fast rotators:** widening of the spectral lines





Based on Trappist-1 illustration by NASA/JPL-Caltech/R. Hurt, T. Pyle (IPAC)

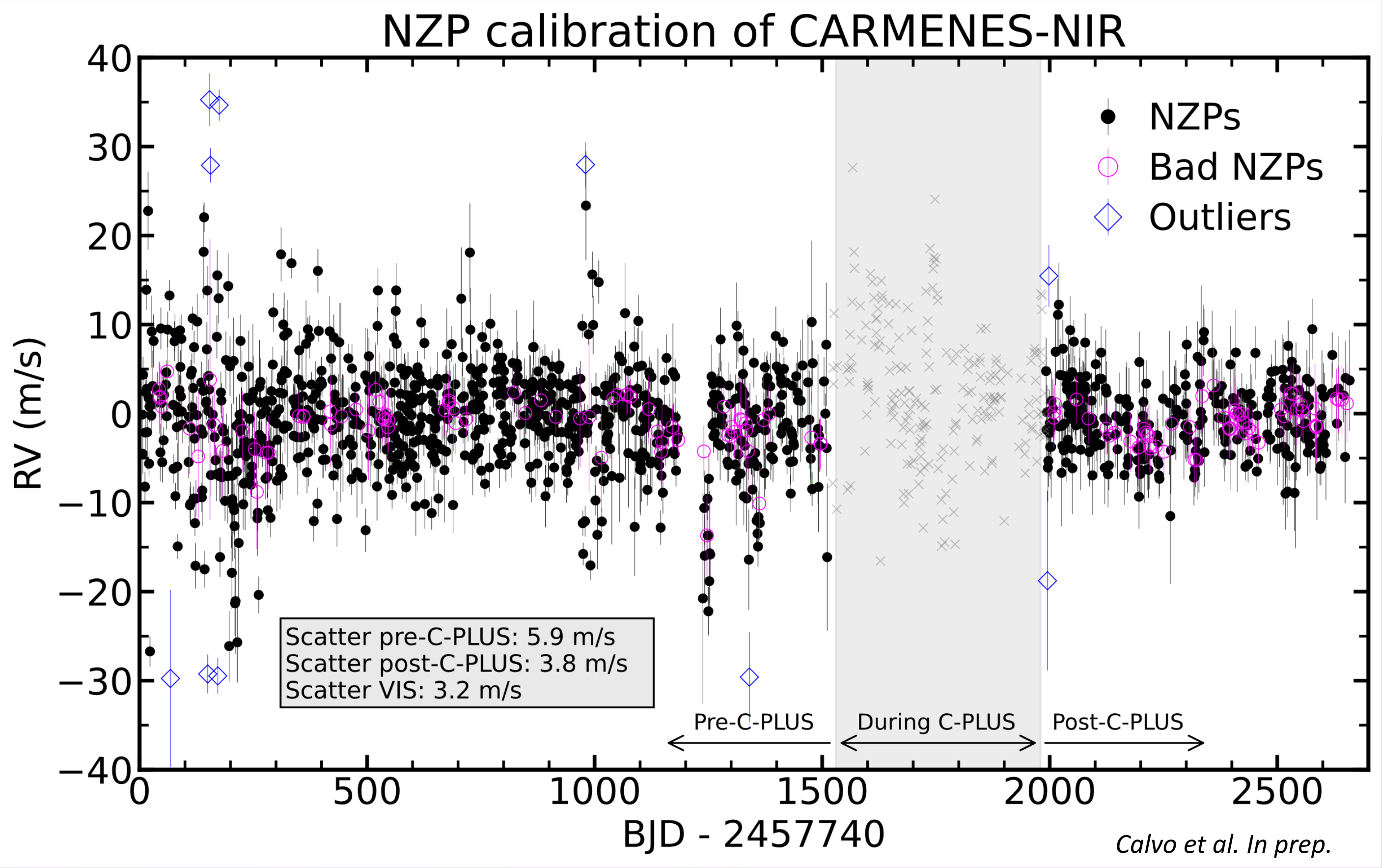
Methods - Given the challenges of these objects, we need to (i) use **large aperture telescopes** with (ii) spectrographs simultaneously in the near-infrared and (iii) optical (iv) that have RV **stability below 1 m/s**. (v) To address the line broadening, we can select the slowest rotators and optimize the pipelines accordingly.



An upgrade of the near-infrared spectrograph cooling system (*Calvo et al. In prep.*)

Results: 1 m/s stability in the NIR - Astronomical instruments in the NIR need to be cooled down to prevent thermal contamination. In order to go below the 1 m/s precision, thermal stability in the **mK range** is mandatory. Thanks to **CARMENES-PLUS,** CARMENES-NIR spectrograph has achieved an **intrinsic precision of 0.7 m/s**, entering the sub-m/s range together with CARMENES-VIS.

- NZP scatter: The instrument's nightly zero-points (NZPs) of the RVs are computed using RV-quiet stars (RV standard deviation below 10 m/s) and are used to correct the RVs each night. The CARMENES-NIR **NZP scatter is now 3.8 m/s,** diminishing 2.1 m/s after the upgrades of CARMENES-PLUS, demonstrating the improvement with on-sky data.



Calvo et al. In prep.

Results: large aperture telescopes - MARCOT (Multi-Array of Combined Telescopes) is a modular astronomical infrastructure facility for high resolution spectroscopy. The following phases are planned:

1) MARCOT-**pathfinder** (since 2022 in CAHA)
2) **5-m module**
3) **15-m equivalent** infrastructure (9 x 5 m modules)

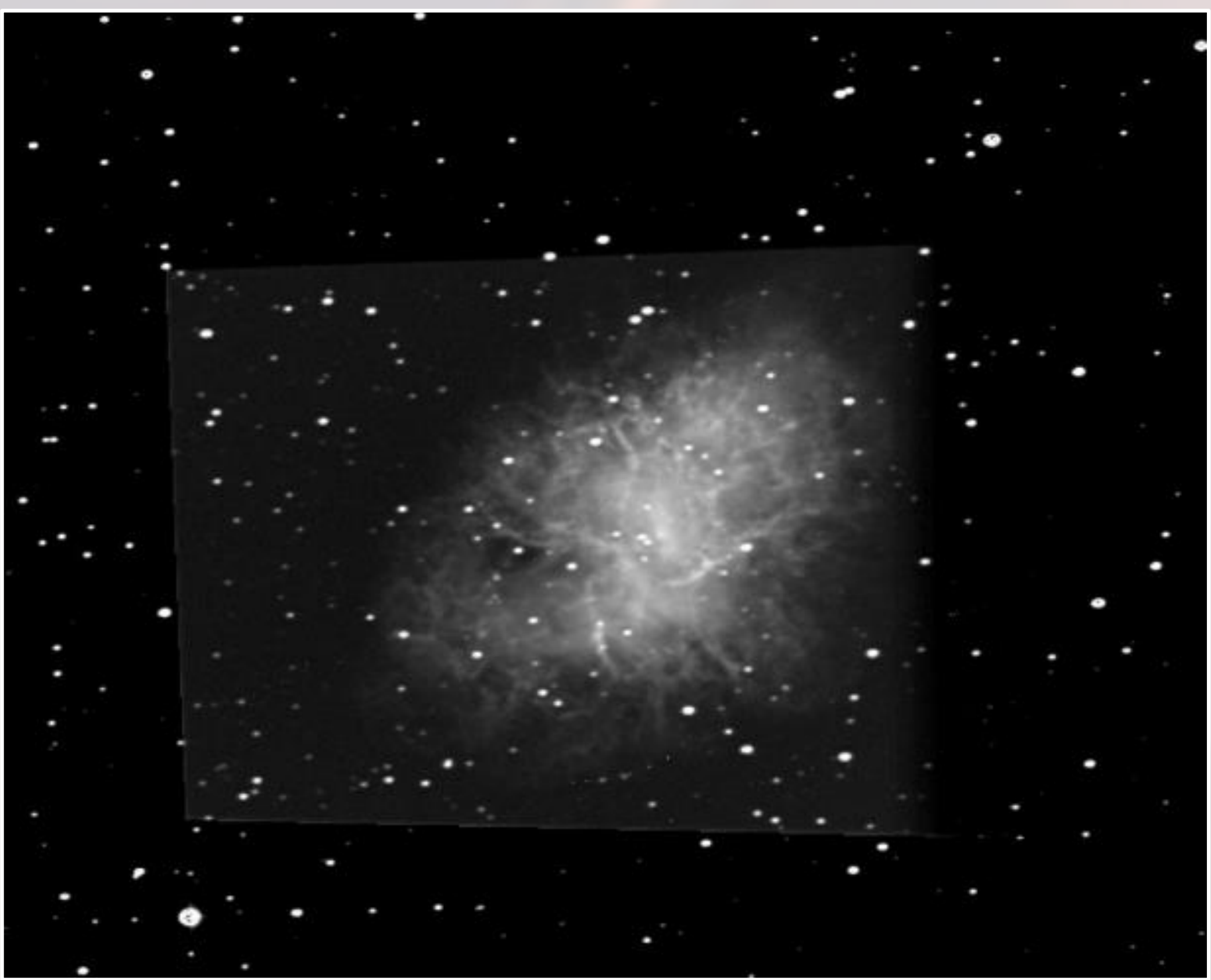
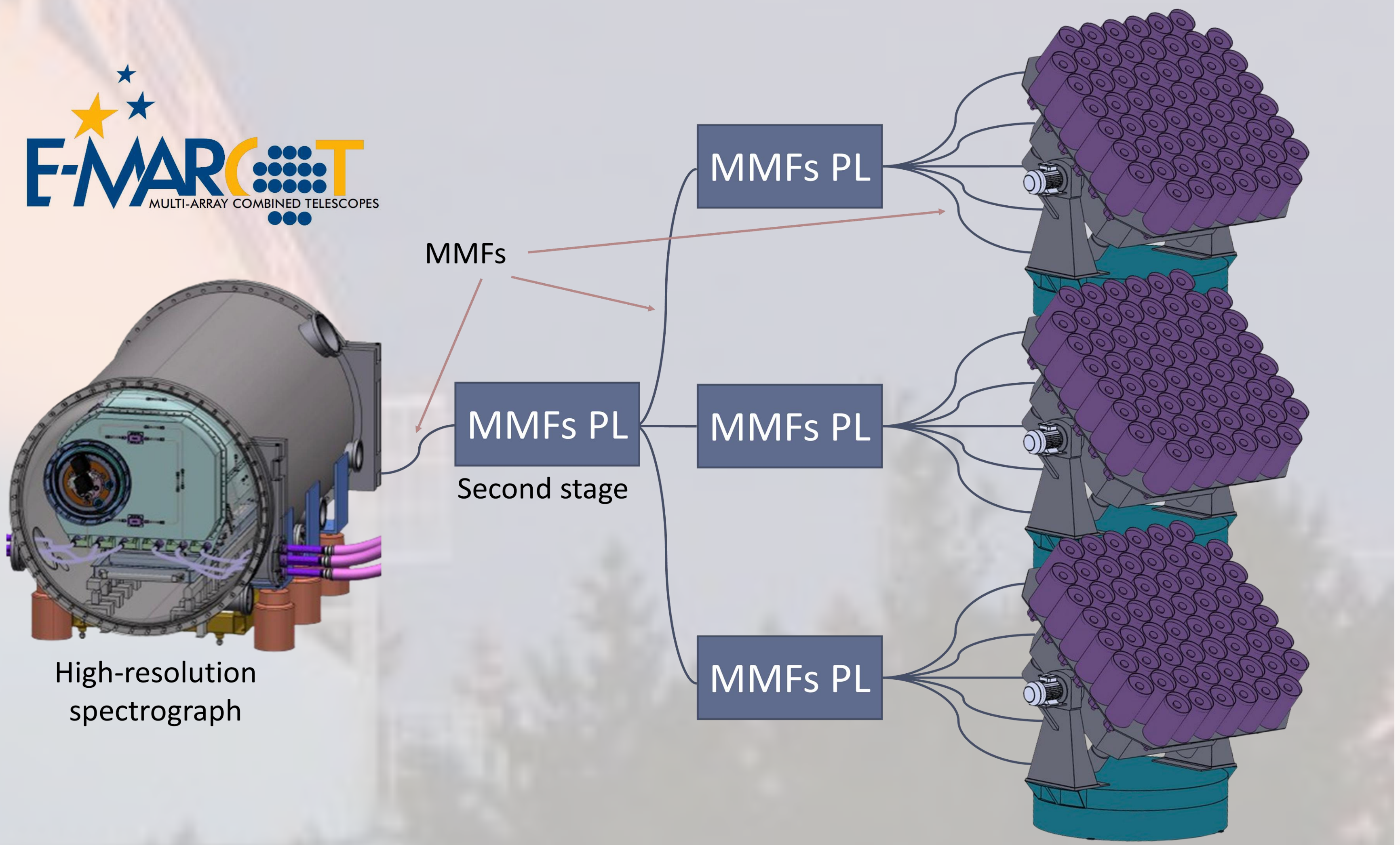


Image of M1 using MARCOT-pathfinder

- The novel **photonic lantern** (MMFs PL) will be able to adiabatically fuse multi-mode fiber optics into a **multi-mode** exit fiber, resulting in a high efficiency light merging.



- The main advantage is that its **cost will decrease an order of magnitude** compared to a similar aperture (traditional) telescope. This is thanks to the use of commercial telescopes and its **scalability** (made of modules).

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