High-precision differential astrometry for discovering exoplanets

Differential astrometry is the branch of astronomy dedicated to measuring the position, distance, and motion of celestial objects relative to the stars within a given field of view. Space missions such as Hipparcos and Gaia have pushed astrometric precision to the level of tens of microarcseconds. The next frontier is sub-microarcsecond astrometry. NASA’s upcoming flagship mission, HWO, and ESA’s proposed M-class mission, Theia, are expected to reach this regime. Achieving sub-microarcsecond precision opens unique opportunities to probe the nature of dark matter in the Milky Way and to detect nearby exoplanets up to 10 parsecs down to Earth-mass.

Reaching these ambitious goals requires major advances in detector technology, optical metrology, spacecraft stability, and data analysis. This contribution will present the key elements of an astrometric instrument, along with the underlying concepts and simulations of the calibrations needed to attain sub-microarcsecond accuracy.

This contribution introduces the method of searching for exoplanets using astrometry, potential targets for observations, and how an astrometric instrument works. I will also briefly present the characterization of the 46-megapixel Gigapyx CMOS detector from Pyxalis, demonstrating its strong potential for future astrometric focal planes. Coupling this characterization with the study of the typical field of view allowed us to simulate observations and estimate measurement accuracy.

Relative astrometric measurements must reach sub-microarcsecond angular precision, corresponding to 10^{-5} (HWO) to 10^{-6} (Theia) pixels on the detector. Achieving this level of accuracy requires micro-pixel mapping of gigapixel-scale detectors. This contribution will present the testbed developed at IPAG (Grenoble, France) that enables the interferometric calibration of the barycenter of a pixel's detection.

Reaching sub-microarcsecond accuracy also requires precise calibration of the relationship between measurements and sky coordinates, including telescope distortion. This presentation will introduce the methods developed to reach this goal and the use of high-order polynomial models in this context.