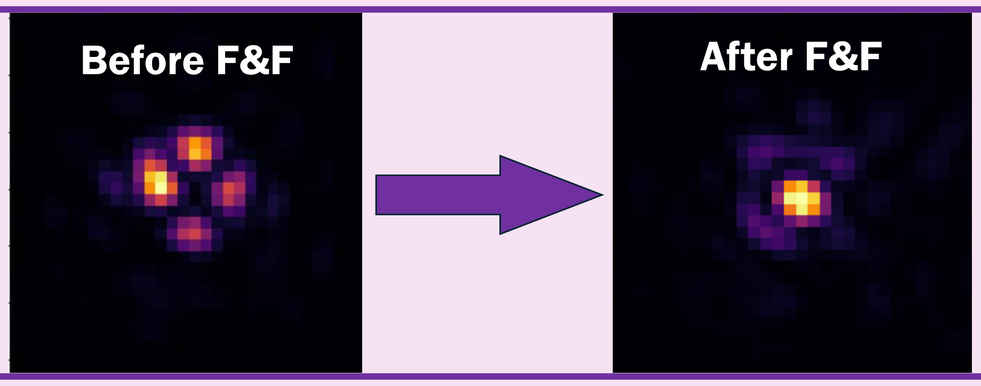
2 Fast 2 Furious: Focal-plane wavefront sensing with a coronagraph at Subaru/SCExAO

Authors: Sam Walker, Mike Bottom, Sebastien Vievard

Focal-plane wavefront sensing and control can help achieve the high contrasts at small angular separations required to image exoplanets from ground-based telescopes by using the light on the science detector to minimise wavefront errors that traditional AO cannot detect.

The Fast and Furious algorithm (F&F; Keller et al., 2012; Korkiakoski et al., 2014; Bos et al., 2020, 2021) uses the previous deformable mirror correction to break the degeneracies inherent to focal-plane wavefront sensing. F&F can be run in the loop while taking science data, making it **highly efficient compared to other algorithms**.

F&F does not work with coronagraphs. We investigate novel solutions for **focal-plane wavefront control with a coronagraph** in the optical path.



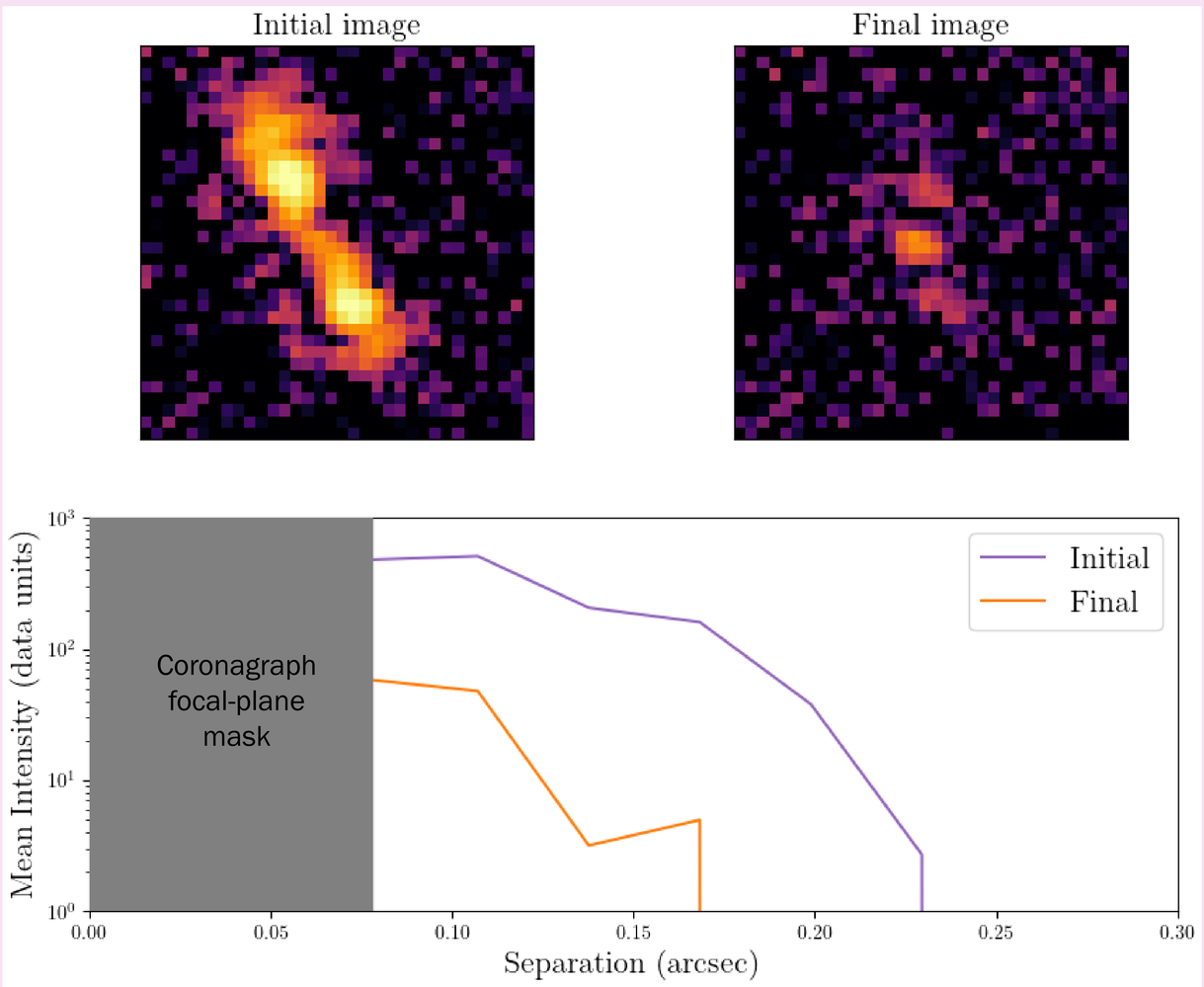
SCExAO data are often subject to the low wind effect (LWE), which significantly degrades image quality.

The on-sky data opposite show how detrimental the LWE is for non-coronagraphic observations (left) and **how effective and necessary F&F is for correcting the low wind effect** on-sky (right).

In 24B, **50% of coronagraphic data had to be discarded because of the low wind effect.** If we can run Fast and Furious with a coronagraph in the optical path, we can prevent this in the future!

2 Fast 2 Furious

- 2 Fast 2 Furious (2F2F) is an adaptation of the formalism of F&F to work with symmetric coronagraphic systems (e.g. Lyot coronagraphs).
- 2F2F has been tested and characterised extensively in simulation. We find that it **works well for coronagraphs with small inner working angles** (≤2λ/D) **with aberrations ≤1 radian**.
- 2F2F has been **successfully tested on the SCExAO bench** (see below).
- Despite its successes 2F2F still has some inherent disadvantages. Firstly, 2F2F is slower than original Fast & Furious, typically running at speeds of 1-2Hz. Secondly, 2F2F is restricted to small coronagraphs, which are not the ones most regularly used for SCExAO science.

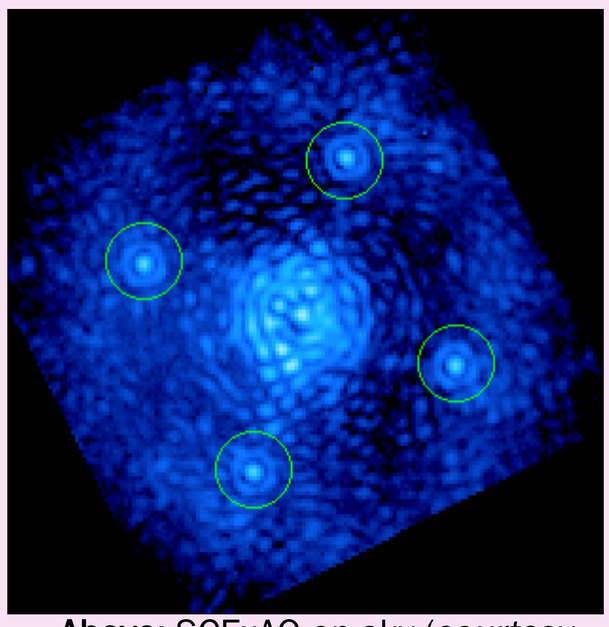


Above: data from bench testing showing 2 Fast 2 Furious correcting 160nm of defocus and astigmatism. The intensity from the occulted source at 0.1” is decreased by an order of magnitude by 2F2F’s corrective power.

References

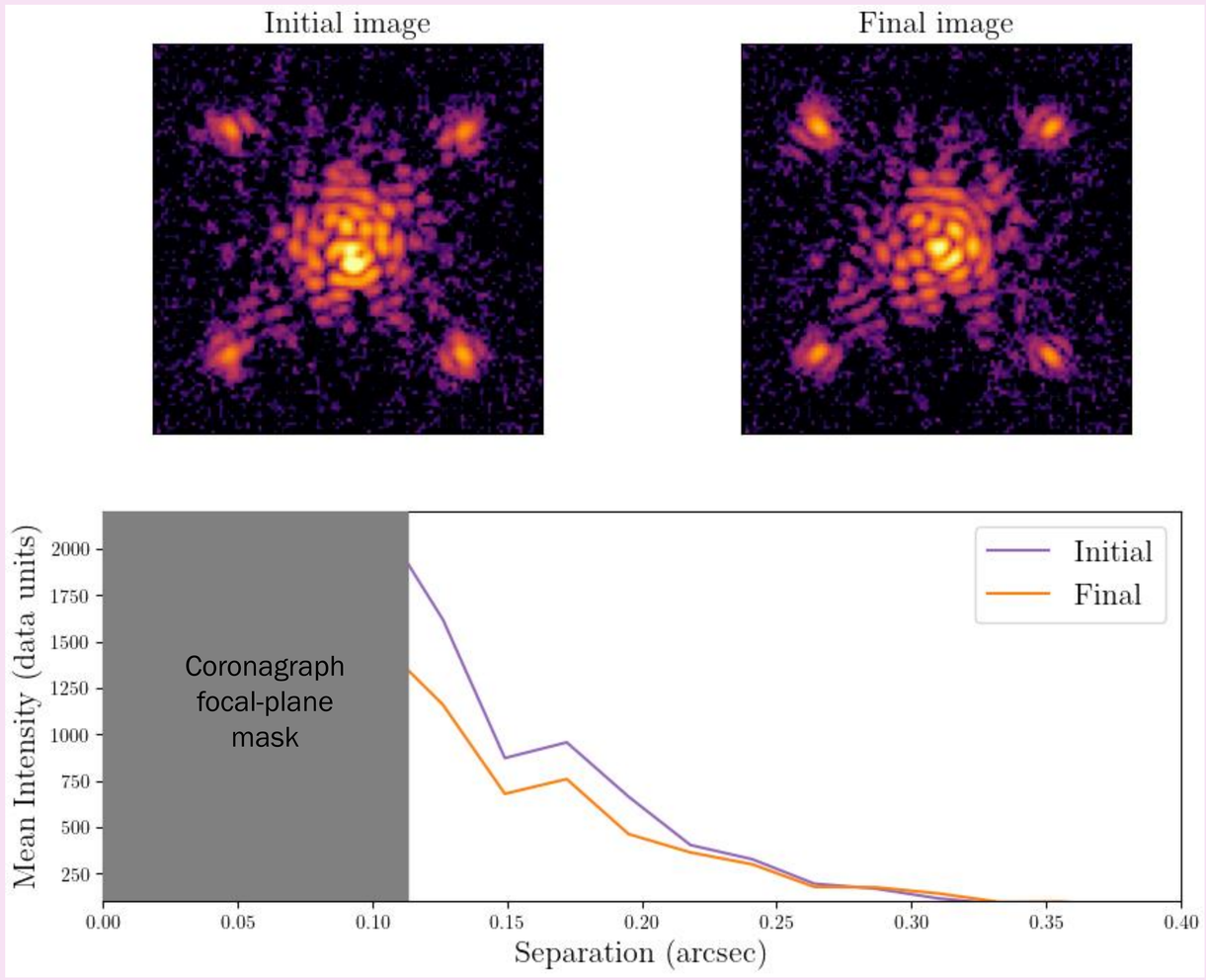
Bos et al., 2020, A&A, 639, A52
Bos et al., 2021, Proc. SPIE, 11823, 118231E
Keller at al., 2012, Proc. SPIE, 8447, 844721
Korkiakoski et al., 2014, Appl. Opt., 53, 4565

F&F with the astrogrid



Above: SCExAO on-sky (*courtesy Thayne Currie*). Astrogrid spots circled.

- An alternative to 2F2F involves SCExAO’s astrogrid, a pattern of speckles induced by the DM and used for calibration (left).
- The astrogrid speckles mimic the central PSF without the occulting focal-plane mask (FPM), so **we can use F&F as usual** without needing to account for the FPM.
- This is less generalizable than 2F2F but will run faster and is independent of coronagraph size, making it a **more robust solution for SCExAO**.



Above: bench data showing a correction of 80nm of defocus + astigmatism using the astrogrid spots. Intensity at close separations is reduced by 25%.