Optical lock-in camera for gravitational wave detectors

M.G. Schiworski[a,b], D.D. Brown[a,b,c], H.T. Cao[a,b], P.J. Veitch[a,b,c] and D.J. Ottaway[a,b,c]

[a]*Department of Physics, The University of Adelaide, Adelaide, South Australia 5005, Australia.*

[b]*OzGrav, Australian Research Council Centre of Excellence for Gravitational Wave Discovery*

[c]*The Insitute for Photonics and Advanced Sensing (IPAS), Australia*

Phase cameras measure the transverse amplitude and phase of specific frequency components of optical fields. Their invention came from the need to sense the spatial profile of weak Radio Frequency (RF) sideband fields used to control interferometric gravitational wave detectors [1, 2]. Those sensors use heterodyne detection, where the laser beam is scanned across a small-aperture photo-diode and the resulting signal demodulated to baseband, yielding a map of the complex amplitude profile.

The optical lock-in camera uses an all-optical parallel approach, in which a Pockels Cell is used to intensity modulate the laser beam and images of the resulting beam are recorded using a high bit-depth sCMOS camera [3]. This technique has been demonstrated to produce shot-noise-limited measurements of the transverse amplitude and phase of RF optical sideband fields at frame-rates and spatial resolutions limited by the camera.

In this presentation, we give an overview of the design and working principle of the optical lock-in camera. We describe its use within gravitational wave detectors, the first-ever images of optical modes due to three mode parametric instability [4], sensing and control of the mode matching of a laser beam incident on an optical cavity [5], and machine-learning-based fast modal decomposition [6].

[1] K. Goda, D. Ottaway, B. Connelly, R. Adhikari, N. Mavalvala and A. Gretarsson, *Opt. Lett.* **29**, 1452 (2004).

[2] K. Agatsuma, L. van der Schaaf, M. van Beuzekom, D. Rabeling and J. van den Brand, *Opt. Express* **27**, 18533 (2019).

[3] H. T. Cao, D. D. Brown, P. J. Veitch and D. J. Ottaway, *Opt. Express* **28**, 14405 (2020).

[4] M. Schiworski, V. Bossilkov, C. Blair, D. D. Brown, A. Jones, D. J. Ottaway and C. Zhao, *Opt. Lett.* **47**, 1685 (2022).

[5] D. D. Brown, H. T. Cao, A. Ciobanu, P. J. Veitch and D. J. Ottaway, *Opt. Express* **29**, 15995 (2021).

[6] M. Schiworski, D. D. Brown and D. J. Ottaway, *J. Opt. Soc. Am. A* **38**, 1603 (2021).