Blinking the fringes, development and results of the Ultra-Low Speed Optical Chopper for the Self-Coherent Camera

Adam B. Johnson[1,2], Colin Bradley[1], Christian Marois[1,2], Olivier Lardière[2], William Thompson[1,2], Garima Singh[2], Darryl Gamroth[2], Joeleff Fitzsimmons[2]
[1] University of Victoria, [2] National Research Council of Canada

Summary and Requirements

- The Self-Coherent Camera detects interference fringes between the science and reference beam, requiring synchronized chopping of the reference beam
- Optical chopping generates the fringed and unfringed images using a pinhole adjacent to the Lyot stop
- Chopping frequency must be adjustable to accommodate different magnitude stars and observations through variable cloud cover
- An integral component of the system, the chopper must be able to synchronize with the rest of the system and have accurate operation throughout all speeds in high altitude observatory environment (~-5° C at 4500m above sea level)
- Noise-free, continuous, and slow operation between 0.05Hz and 100Hz with:
  - the ability to stop in the 'on' or 'off' position
  - the ability to phase lock with an external trigger

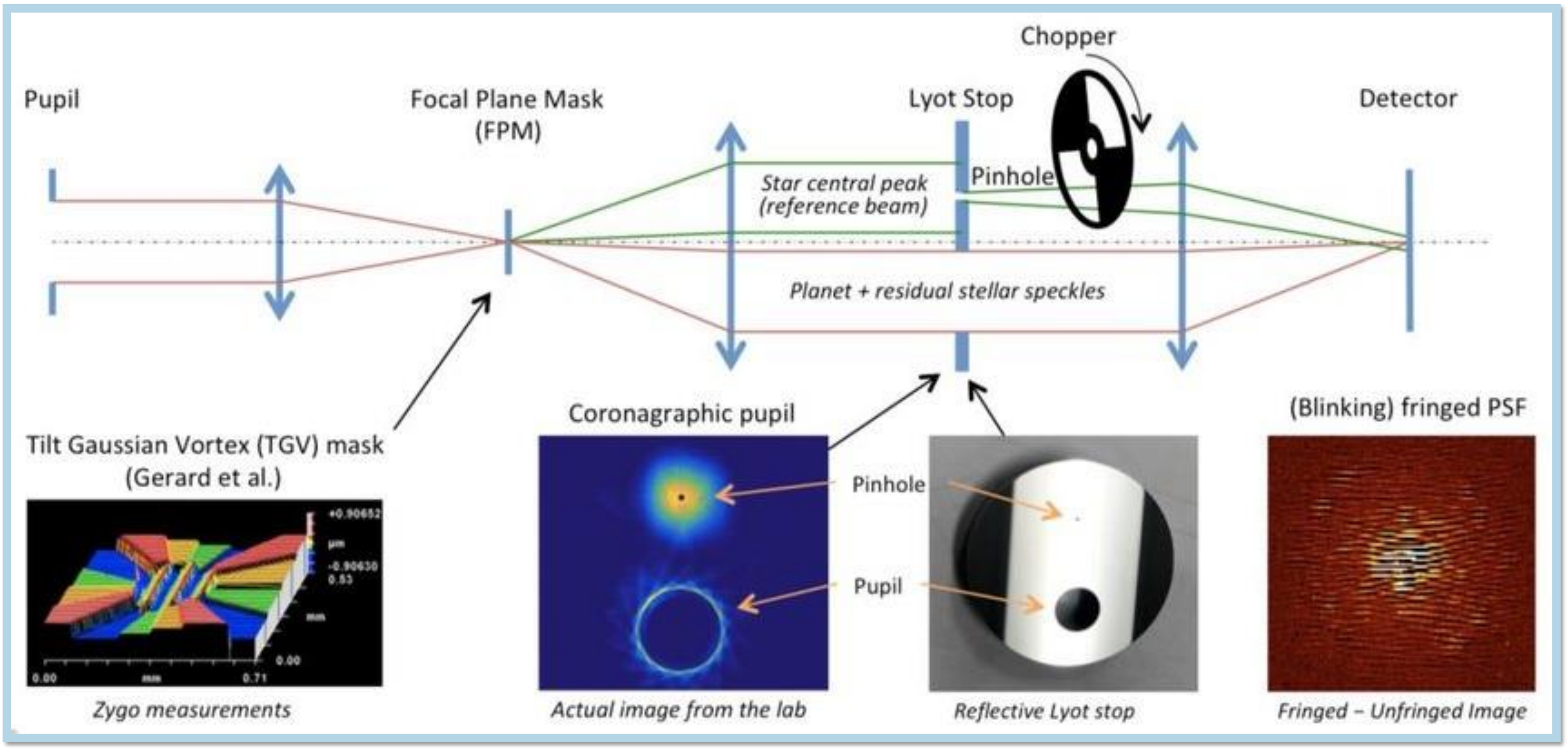


Figure 2 – A portion of the proposed optical path and concept of FAST implemented in the NEW EARTH Lab at NRC HAA. The chopper blinks the reference beam coming through the pinhole on the Lyot stop which is recombined with the planet and residual stellar speckles image at the self-coherent camera (labeled detector above). The resulting blink of fringed and unfringed images are used with a deformable mirror to produce a dark background (dark hole) around the star and keep any non-coherent planet light in the image.
Figure from Olivier Lardière et al, NEW EARTH Lab, December 2020

Design Specifications

- TSM11 Stepper-servo provides smooth 1/256 micro-stepping operation with closed-loop position and velocity space vector current control
- Speed operation between 0Hz and 120Hz with noise-free driving
- Stepper motor can count steps and stop in 'on' or 'off' position, communicated serially as needed
- Self-calibrating with 10-30 blade chopping wheels and homing on power-up
- Long operational periods over a lifetime of at least 10 years
- Stepper-servo control and blade position feedback guarantees accurate and repeatable operation
- Operational down to -30° C and up to 5000m above sea level

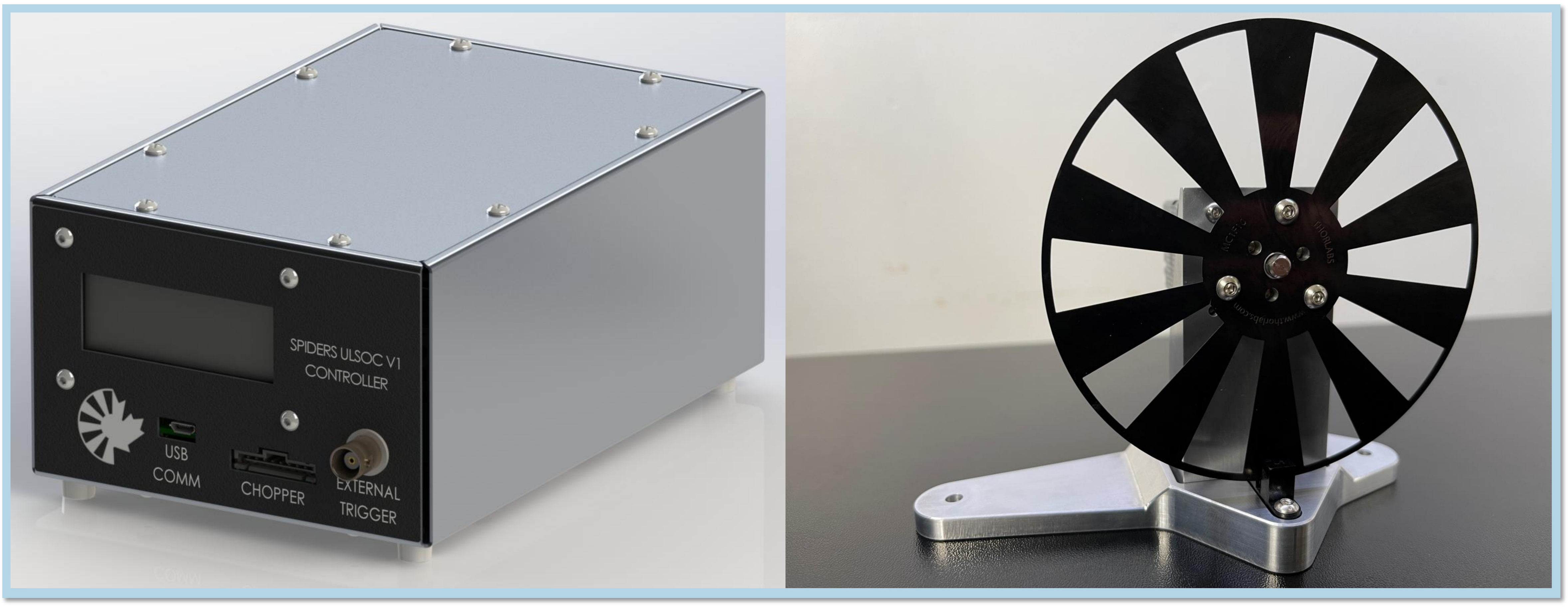


Figure 3 – An initial concept rendering of the SPIDERS Ultra-Low Speed Optical Chopper control box (left) and the assembled chopper mechanism (right). A 9-conduit cable connects the control box to the chopper mechanism to provide power and communications over a 2.5m cable. The control box accepts an external trigger in which the chopping of the beam can be phase locked with. The beam is chopped 180° from the optical sensor that determines the chopper blade position and tracks it through step counting of the motor. The stepper-servo has an additional high-resolution encoder which provides closed-loop position and velocity control. Speed changes including the phase locking and stopping/starting is communicated serially over a Modbus RTU protocol. The control box can run stand-alone with an external trigger, or in tandem with an external trigger and a computer through the USB COMM port. The LCD screen will show status and frequency information.

Speed Accuracy Results

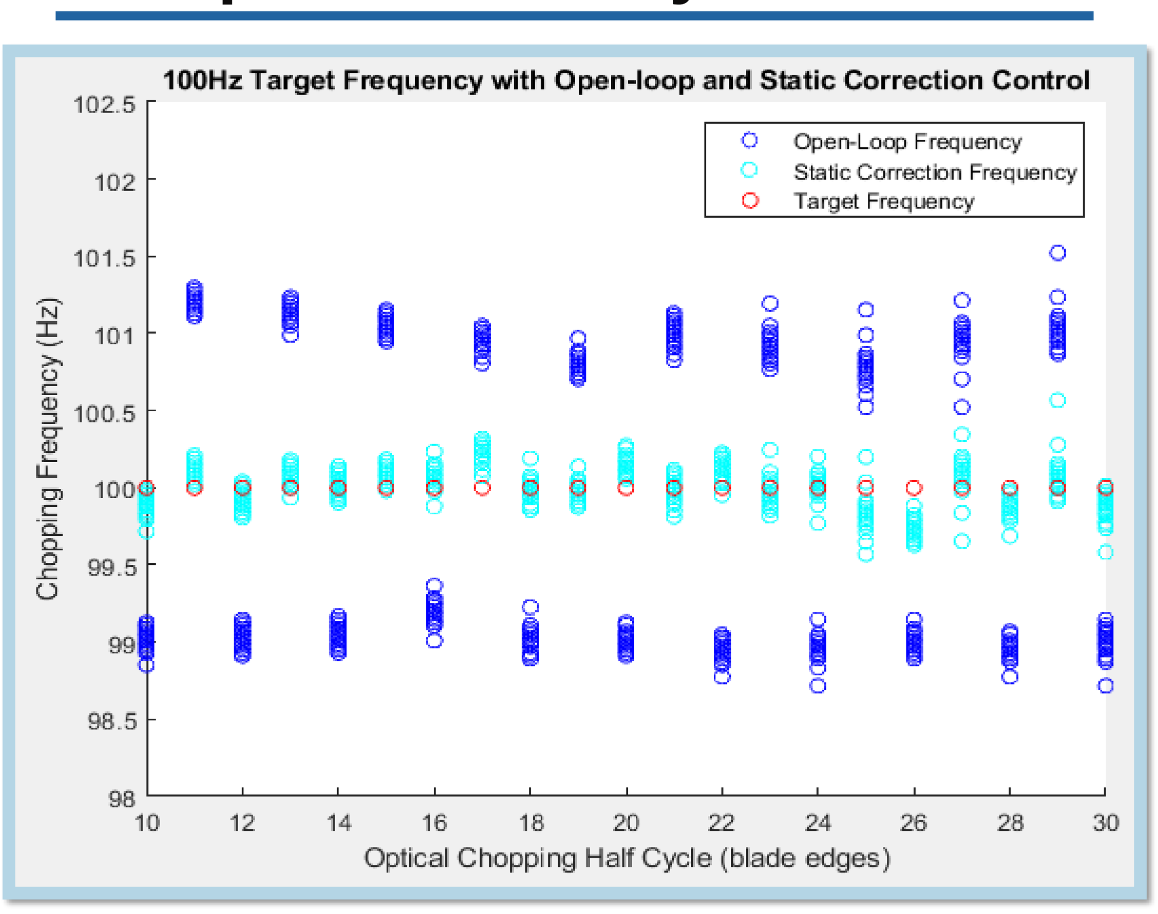
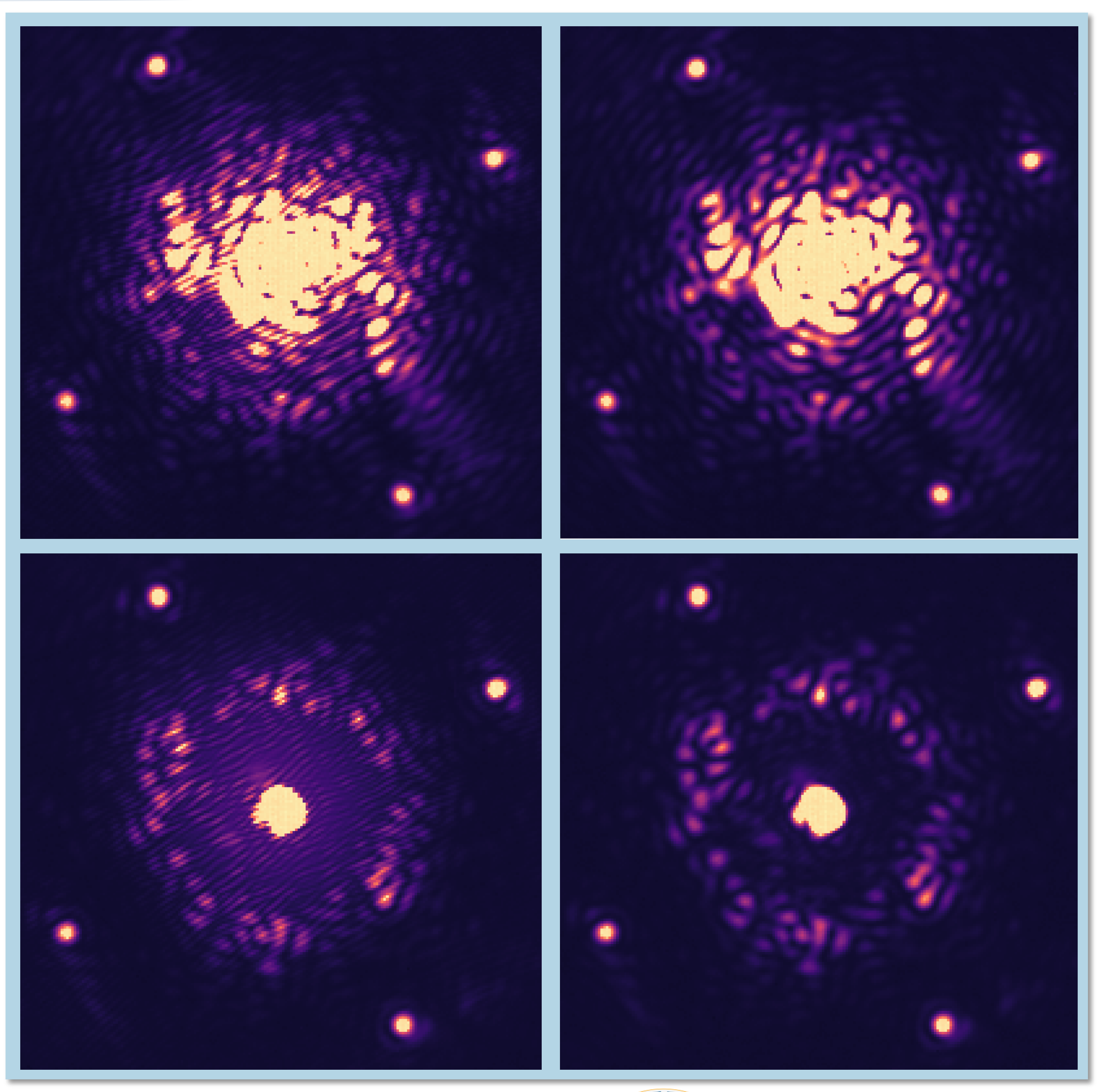


Figure 1 – Using a NEMA 11 hybrid stepper motor with 1/256 micro-stepping and the optical sensor for blade position and frequency feedback, a speed study was conducted. Without correction, a frequency error up to ±1.3% was observed over 20 measurements (1 revolution of a '10-blade' chopper wheel), sampled 2,000 times. A smooth-spline static correction of the motor speed was implemented over every step in 1 revolution. The observed static correction produced a chopping frequency within ±0.25% of the target. The high resolution and dynamic correction of the TSM11 stepper is expected to produce even more accurate operation over time, with its 4096ppr built in encoder and high resolution closed-loop control.

Figure 4 – A fringe pattern is produced when the light coming through the pinhole and the Lyot stop aperture are coherent, indicating AO residuals and quasi-static speckles exist in the system – light coming from a planet will not produce fringes. Blinking the fringes on and off, a differential imaging technique is used to correct these speckles and close the loop with the deformable mirror. Fast blinking is ideal to freeze aberrations and avoid speckle evolution between images. Images in the top row show before any correction is done. The lower row of images show after the loop has closed and the corrections are actively being applied. Both rows have the fringed image on the left and unfringed on the right. Images were captured with a commercial chopper as a bench test and proof of concept.



Future Work

- Implementation of the TSM11Stepper-Servo system
- Implementation of magnetic sensor to replace optical sensor
- Manufacturing and assembly of chopper controller
- Performance testing of velocity response and phase locking
- Testing with external triggering for frequency input
- Bench testing to confirm accurate operation at low and high frequencies
- Implementation in SPIDERS for the Subaru telescope and CAL2 for the Gemini Planet Imager