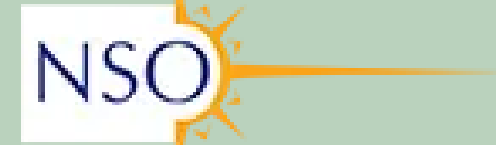




# Full-disk H $\alpha$ Spectroheliograph development for GONG: Preliminary results



Sanjay Gosain, Alexei Pevtsov, Greg Card, Timothy Purdy and Christoph Keller  
National Solar Observatory, 3665 Discovery Drive, Boulder, CO 80303, USA

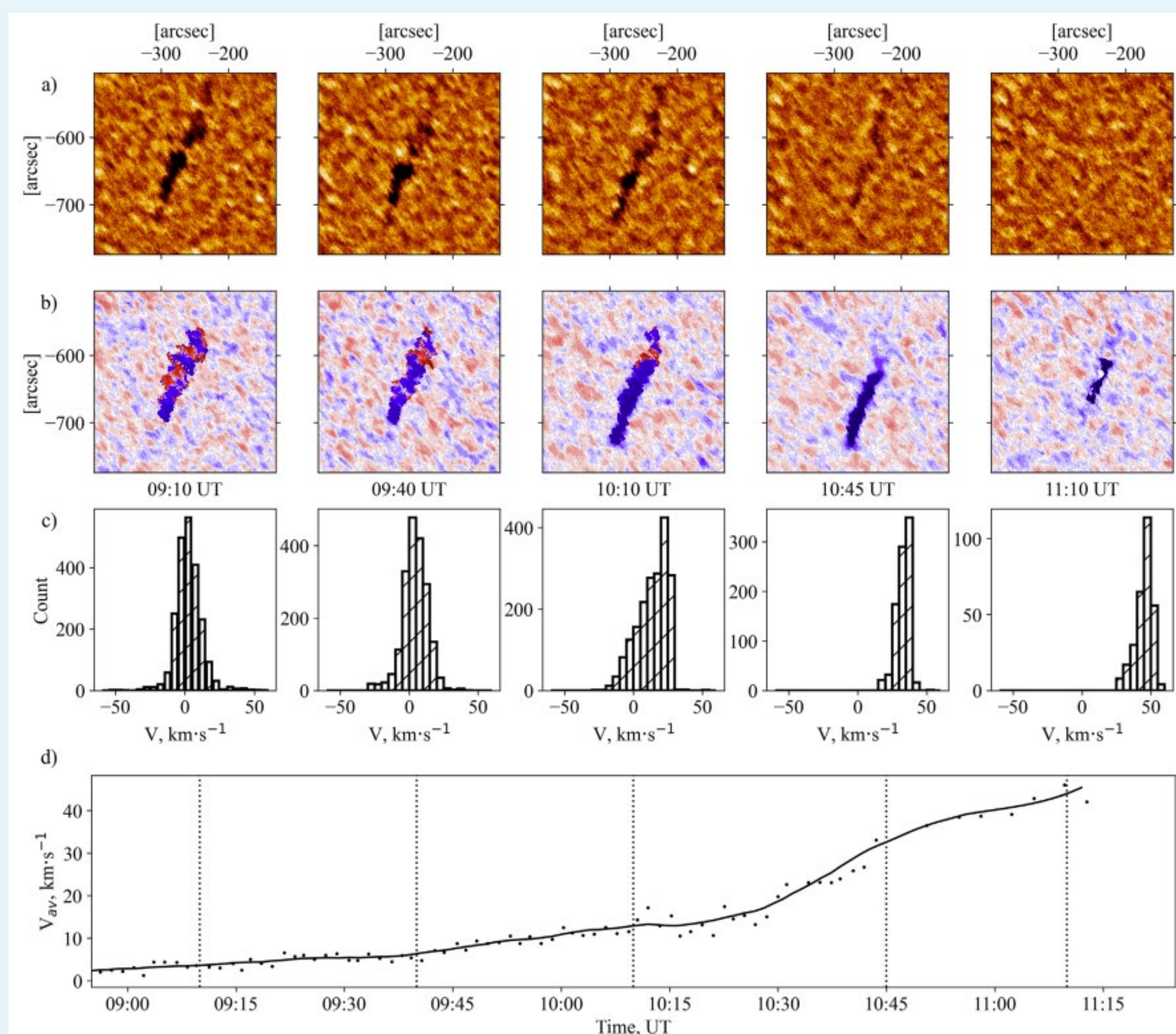


## Abstract

We present the design and preliminary test results of a full-disk spectroheliograph instrument under development as a potential upgrade to the GONG system. This instrument aims to enhance the current GONG H $\alpha$  system by enabling full-disk Dopplergram observations, thereby facilitating the study of filament dynamics in relation to eruptive events.

## Motivation

- The pre-eruptive dynamics of a solar filament such as its slow rise phase, oscillations and early acceleration phase are important precursors which can be used to predict an impending filament eruption and the associated coronal mass ejection (CME).
- The physical mechanism behind the flux rope (filament) eruption requires careful study of the early acceleration profile of the filament (Torok et al 2005; Gosain et al, 2012, 2016).
- Such studies require continuous full-disk H $\alpha$  spectral observations with high Doppler sensitivity and dynamic range, such as shown below for a well observed filament eruption by Berezin et al (2023).



**Figure 1:** 2021 February 20 filament eruption at about 30 minute cadence from 09:10 UT (left column) to 11:10 UT (right column): (a) filament H $\alpha$  line core, (b) line-of-sight (LOS) velocities (blue/redshifts), (c) histograms of velocities in filament body, and (d) average velocity derived from these histograms (dots). Vertical dotted lines in the bottom (d) panel correspond to UT time shown in (a)-(c). The solid black line is the running average.

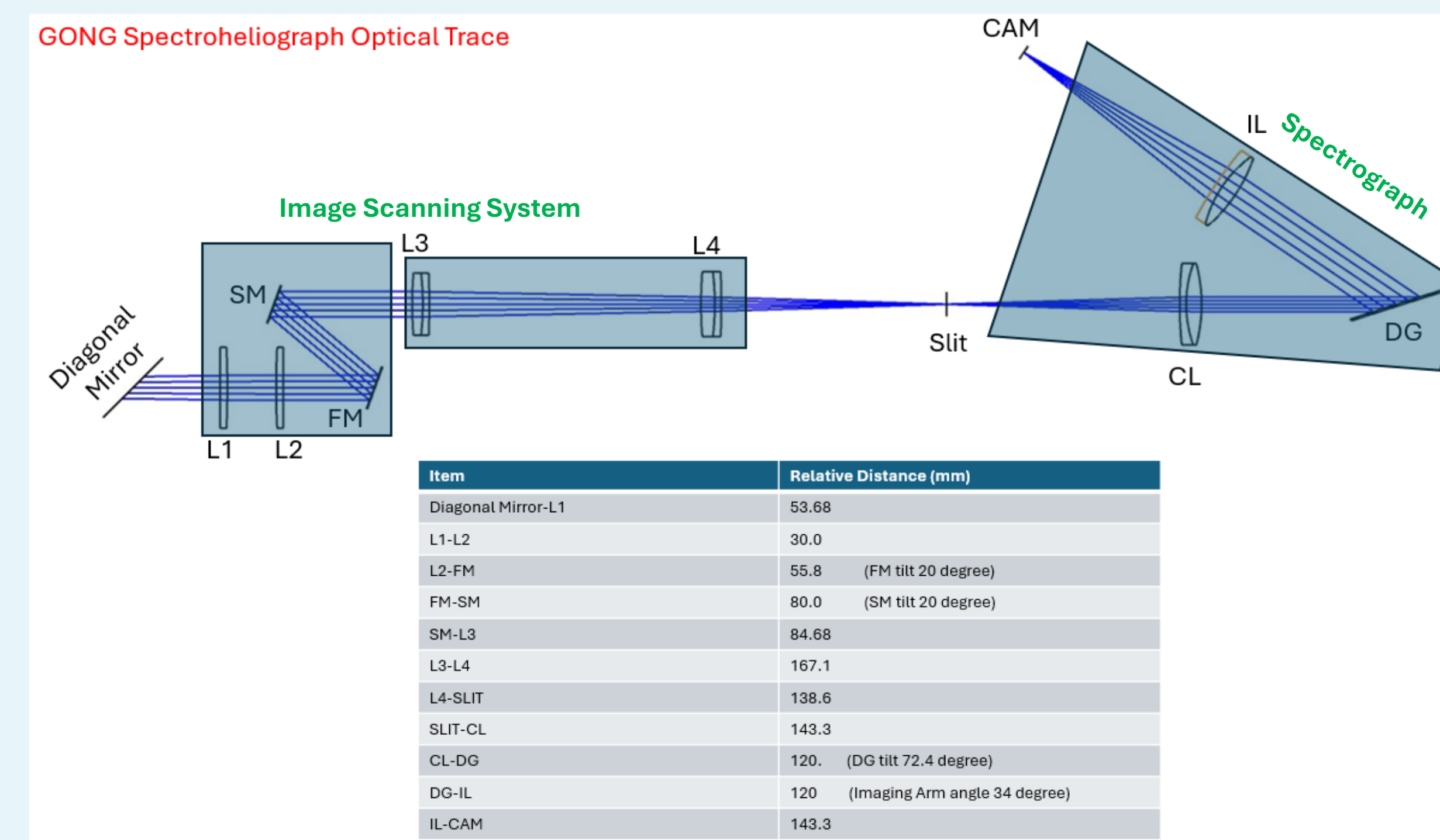
## Design Requirements

Observation Parameter	Value
Angular Resolution	1"/pixel sampling (*seeing limited)
Field-of-view	1.1 R $_{\text{sun}}$
Temporal Cadence	A Dopplergram & filtergram per minute
Doppler sensitivity	<1 km/s
Doppler Dynamic range	+/- 100 km/s
Size/Dimensions	~ current system's length & width

## Key Features

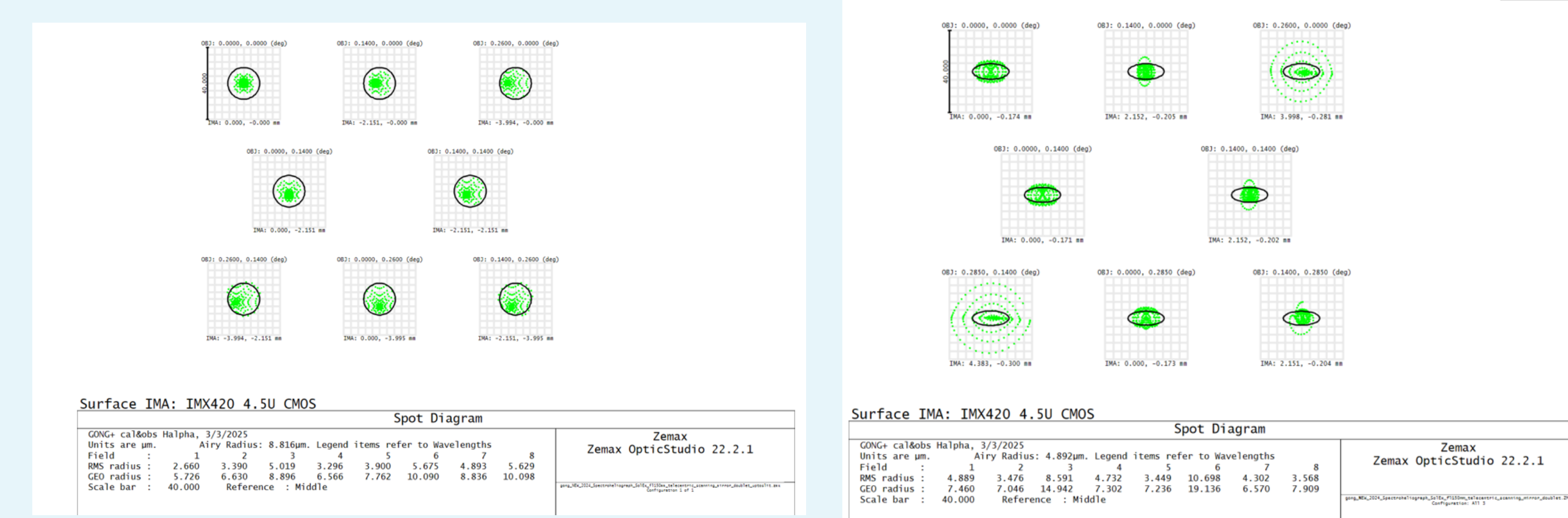
- Ray trace below shows the layout of image scanning system followed by spectrograph.
- The spot diagrams below show uniform image quality from disk center to limb.
- Design balances throughput and resolving power for H $\alpha$  LOS velocity sensitivity <1 km s $^{-1}$ .
- Bench tests will validate LSF, throughput, and stray-light level.

## Optical Design Raytrace



**Figure 2:** The diagonal mirror diverts the beam towards the image scanning system, which has two parts, first is a tip-tilt scanning mirror, and the second is an imaging telescope that makes a full disk image of the sun on to the slit. The slit is reflective and slightly tilted. The compact spectrograph is shown on the right. The spectroheliograms are accomplished by scanning the image of the sun across the slit while recording the spectrum near the H-alpha line.

## Optical Design Expected Performance



**Figure 3:** The spot diagram on the left shows the optical performance of the image scanning system. The spot diagram shows that the point spread function is within the diffraction limit. The lenses L1 and L2 are custom made while the rest of the lenses are stock lenses. The spot diagram on the right shows the optical performance of the spectrograph camera. The horizontal axis is spatial while the vertical axis is spectral.

## Image Scanning System

**S-335 Piezo Tip/Tilt Platform**

Beam Steering with Very Large Deflection Angles for Mirrors and Optics

- Tip/tilt angle to 35 mrad, high optical deflection angle to 70 mrad (1°)
- Resonant frequencies to 0.7 kHz (1°/min) for dynamic motion and fast step-and-settle
- Parallel kinematic design: Two orthogonal tip/tilt axes with one common pivot point
- Stroke sensors for high linearity
- Different versions available: Without mirror, "Y" mirror, "T" mirror

**Performance Test Protocol**  
S-335-2SH - Linearity

Order Info

Customer: PI  
Customer Ref No.:  
PI Order No.:

System Setup

Stage: S-335-2SH  
Controlled Axis: 1  
Feedback Sensor: QED  
Sensor Bandwidth: Standard  
Design: Standard  
Nominal Open Voltage: 05 +100V  
Nominal Extension: 30 mm  
Controller: E-277-380A (SN: 11702005)  
Calibration Type: Resonant, via algebra interface

Measurement Setup

Measurement Device: Edmund 2000  
Block Choice Type: 25.0 C  
Temperature: 20.0 C  
Air Pressure: 1013.0 mbar  
Humidity: 47.5 %  
Measurement Date: 08/17/2023 20:17:00-02  
Block Program: PTC500 5.0.1  
Equation: 07  
Min. Control Input: 0.0 mrad  
Max. Control Input: 35.0 mrad  
Min. Step: 1.75 mrad  
Time Delay: 0.5 s

Measurement Results

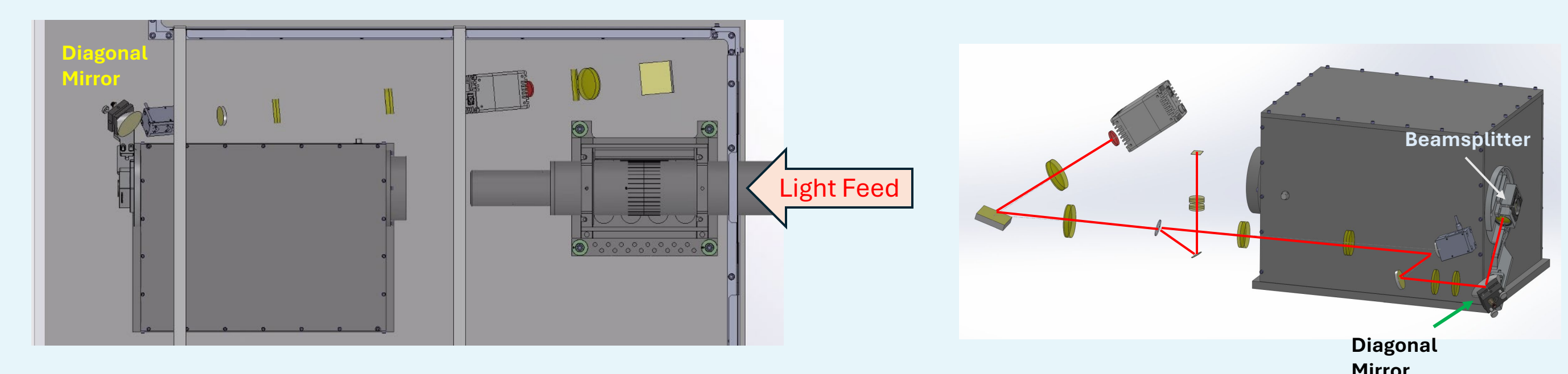
Control Input (mrad)	Measured Output (mrad)	Residual (%)
0.0000	0.0000	0.0000
0.1000	0.1000	0.0000
0.2000	0.2000	0.0000
0.3000	0.3000	0.0000
0.4000	0.4000	0.0000
0.5000	0.5000	0.0000
0.6000	0.6000	0.0000
0.7000	0.7000	0.0000
0.8000	0.8000	0.0000
0.9000	0.9000	0.0000
1.0000	1.0000	0.0000
1.1000	1.1000	0.0000
1.2000	1.2000	0.0000
1.3000	1.3000	0.0000
1.4000	1.4000	0.0000
1.5000	1.5000	0.0000
1.6000	1.6000	0.0000
1.7000	1.7000	0.0000
1.8000	1.8000	0.0000
1.9000	1.9000	0.0000
2.0000	2.0000	0.0000
2.1000	2.1000	0.0000
2.2000	2.2000	0.0000
2.3000	2.3000	0.0000
2.4000	2.4000	0.0000
2.5000	2.5000	0.0000
2.6000	2.6000	0.0000
2.7000	2.7000	0.0000
2.8000	2.8000	0.0000
2.9000	2.9000	0.0000
3.0000	3.0000	0.0000

Displacement Curves

Linearity

- The image scanning system is based upon a precise piezo scanning system from PI-USA. More specifically the model used is S-335 (shown above) which has a maximum tilt range of 2 degrees, more than required for full disk scan.
- The linearity performance test data-sheet is shown on the right. Excellent linearity over full scan range can be seen. The residual errors are less than 0.05%.
- The minimal incremental motion is 0.2 arcsec while the bidirectional repeatability is also of the same order in the closed loop.

## Optical Bench Layout



**Figure 4:** The CAD model on the left shows the optical components positioning relative to the optical bench of GONG, as seen from the top. The light feed from the turret system is shown as labeled. The side view is shown on the right. A part of the beam is diverted to the GONG H-alpha system using a beamsplitter and a diagonal mirror. This beam then gets collimated on the tip-tilt mirror which scans the final image on the slit. A slit jaw imager optics is also shown.

## Proof-of-concept prototyping



**Figure 5:** An early prototype of the spectroheliograph concept is shown on the left. The 3D printed Sol'Ex spectroheliograph (Buil 2021), popular among amateur astronomers was realized and tested for performance. The Sol'Ex has smaller optics (smaller grating and slit length) compared to our design, which is geared for higher resolution and employs larger optical components. The observations obtained from Sol'Ex are shown in the middle panel and a GONG H-alpha image is shown on the right panel for comparison.

## References:

- Berezin, I. A. et al. 2023, ApJ, 950, 100, 10.3847/1538-4357
- Gosain, S. et al 2012, ApJ, 761, 25, DOI 10.1088/0004-637X/761/1/25
- Gosain, S. et al 2016, ApJ, 821, 85, DOI 10.3847/0004-637X/821/2/85
- Torok, T. & Kliem, B. 2005, ApJ, 630, L97
- C. Buil (2021): [https://buil.astrosurf.com/solex/education/2021-ProAm-SF2A-G-Le-projet-SolEx\\_StarEx.pdf](https://buil.astrosurf.com/solex/education/2021-ProAm-SF2A-G-Le-projet-SolEx_StarEx.pdf)