



Annual report

Name and surname: Dhiraj Hiralal Gupta

Cycle and a.a.: 39° cycle 2023/2024

Supervisor: Dr. Andrea Bianco

- Research activity carried out during the year

Research Topic: **Innovative Holographic Optical Elements for Modern Optical Instrumentation**
Focus this year: Holographic Diffusers for astronomy/spectroscopy and adaptive optics (PWFS)

During my second year of PhD, I developed and characterized **holographic diffusers** within the framework of **Volume Holographic Optical Elements (VHOEs)** for modern optical instrumentation. In collaboration with **INAF Bologna**, diffuser requirements for the **Pyramid Wavefront Sensor (PWFS)** were defined as **angular diffusion $\approx 0.023^\circ$** over the **0.9–1.1 μm** band, with **target optical efficiency $\lesssim 90\%$** . To guide design before fabrication, I developed a **Mie-inspired speckle model** that treats the speckle grain as an effective scatterer. Because coherent (laser) light on a rough or diffusing surface produces a **granular interference pattern (speckle)**, controlling the grain size provides a direct handle on the diffuser's angular spread; both the model and measurements confirm the expected inverse trend—**larger speckle grains yield smaller diffusion angles**. The speckle size at the recording plane and comparison with Mie theory were set and tuned using the average speckle size formula

$$\sigma = \frac{2.44 \cdot f \cdot \lambda}{a}$$

which gives choices of wavelength, focal length, and aperture. The resulting speckle size was verified experimentally.

Fabrication and Recording

Building on last year's **VPHG** work (used primarily to acquire holography/fabrication experience), I configured the **green-laser holography bench** to record diffusers **directly in photopolymer** at the image plane by forming a controlled speckle field from the aperture–lens geometry above. The **two-beam VPHG bench** was repurposed in-line: one arm was reconfigured to generate the diffuser's speckle field at the photopolymer plane, while the second arm was blocked. I explored **multiple apertures, materials, irradiance levels, and exposure** times to map the recording window. Speckle size was checked by (i) direct imaging at the recording plane (pre-recording) and (ii) phase microscopy of the recorded structure (post-recording).

Characterization

Path A - Collimated-Beam Angle Extraction

A collimated beam passed through the diffuser to a camera (**diffuser–sensor distance $L=43\text{mm}$**). Using **ImageJ**, I extracted a **rectangular line average** and, in **Origin**, fitted **two Gaussians**: a narrow **zero-order** and a broader **diffused** component. From the diffused component's **FWHM**, compared against the collimated baseline and converted from pixels to angle, yielded minimum **diffusion angles ranging from $\approx 1.03^\circ$ to 1.43°** across **0.625–0.95 μm** under the current bench geometry and recording recipe



**PhD course of National Interest in Technologies for
Fundamental Research in Physics and Astrophysics**

Path B - Lens Placement Study (ongoing)

A lens was inserted between the collimated beam and the sensor, and the diffuser was placed before and after the lens to assess diffuse intensity and throughput. Data acquisition is complete; throughput has been measured, which shows that at the shorter wavelength (625 nm), configurations that generate larger speckle grains (i.e., smaller apertures, larger diffusion angle) exhibit reduced throughput. At longer wavelengths (850 nm and 950 nm), the After-lens and Before-lens throughputs become higher and comparable. Analysis of diffuse intensity is ongoing.

Parallel project Denisjuk (object) Hologram for INAF Padua.

I produced a **Denisjuk reflection (object) hologram** for **INAF Padua** on the other arm of the repurposed bench. The requested hologram was of a **cylindrical object image** (for a laser-guiding system in telescope), having a **length of 24.3 mm**, a **diameter of 1.0 mm**, and a **projection at 83.7°**. Some tests were carried out optimizing the (diffused) reflectivity of the stick object. A **bright, well-defined hologram**, visible in **green light** from multiple angles was obtained. Upon confirmation by INAF Padua, a second Denisjuk hologram will be produced, incorporating the requested adjustments.

Challenges and Mitigations

Fabrication: addressed via alignment routines, exposure bracketing, and iterative optimization.

Model–experiment alignment for diffusers: adopting a speckle-based (Mie-inspired) approach matched holographic recording physics and guided parameter selection.

Image processing after fabrication: standardized the workflow

Planned third-year work.

Complete the lens-placement study with full diffused intensity and consolidated throughput results.

Optimize diffuser fabrication against targets (core angle, diffused pattern, throughput/efficiency) and lock parameter recipes.

AO bench integration: implement the optimized diffuser on the adaptive-optics bench; verify PWFS modulation and stability.

On-sky demonstration (exoplanet photometry): deploy the optimized diffuser for a controlled on-sky test and collect performance data.

Consolidate methodology and results into a manuscript/technical report, image-driven quantification of holographic diffuser performance for adaptive optics.

• **List of attended courses and passed exams**

1. Radio and Optical Interferometry (8/10/2024, 2 credits)
2. Laser Physics and Applications (19/12/2024, 2 credits)
3. Advanced scientific programming in Matlab (09/05/2025, 6 credits)
4. Management of Scientific Projects (03/04/2025, 2 credits)

• **List of attended conferences, workshops, and schools, with mention of the presented talks**



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- Participation in ICSO conference on space optics in Antibes Juan-les-pins, France from 21/10/2024-25/10/24
- Summer school on "Scientific Communication in Astronomy Summer School" in Bertinoro, Italy from 12/10/2025 to 17/10/2025

- **List of published papers/proceedings**
- **Thesis title**

"Innovative holographic optical elements for modern optical instrumentation"

Date, 12/09/2025

Signature

Seen, the supervisor