# Exoplanet Imaging Using a Lenslet Array to Suppress Starlight

Gabriel Grell[1], Michael McElwain[2,4], Qian Gong[2], Maxime Rizzo[2,3], Tyler Groff[2], Neil Zimmerman[2], William Fanning[5]

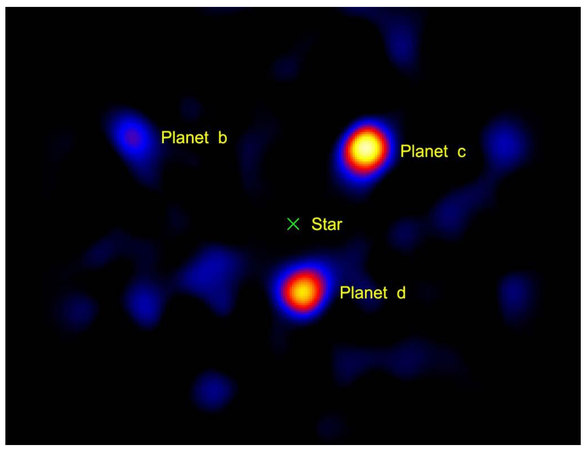
[1]Harvard University, [2]NASA Goddard, [3]USRA, [4]NASA Roman Technology Fellow, [5]Embry-Riddle Aeronautical University

## Abstract

We present an experiment that used relay optics to test the hypothesis posed by *Gong, McElwain & Shiri 2016*, which theorized that a lenslet array and pinhole mask may be implemented into a coronagraph to further suppress uncorrected starlight that leaks through the occulting mask in order to directly detect nearby exoplanets. An optical system consisting of 1) a non-telecentric relay that introduces differential phase curvature between the wavefronts of the star and the off-axis planet in the image plane, and 2) a microlens array at the image plane that focuses the planet light and star light in different directions, was constructed in order to investigate whether the diffraction ring of an on-axis point source has the phase curvature predicted by the chief ray of the source, or the phase curvature corresponding to the chief ray of an off-axis source at the separation of the diffraction ring. This phase curvature would indicate whether or not the microlens-pinhole technique is viable for future use in coronagraphs such as WFIRST, LUVOIR, and HabEx.

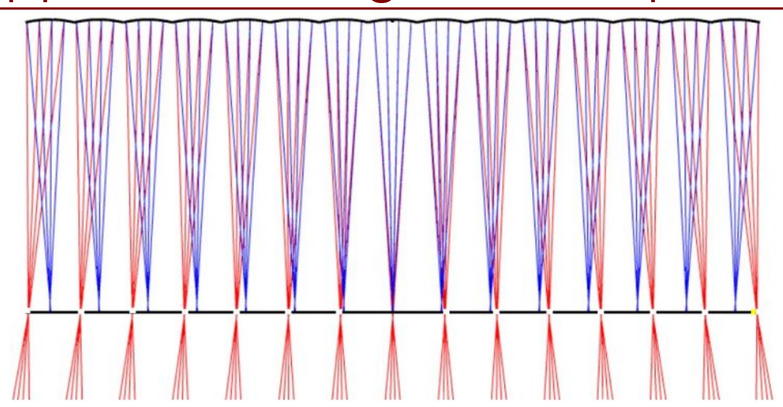
## Exoplanet Direct Imaging

**Right:** Direct image of planets orbiting HR 8799 (*Image Source: NASA/JPL-Caltech/Palomar Observatory*). Direct imaging of exoplanets provides a powerful approach to studying planetary properties. Spectra from these planets are used to extract many parameters and characteristics, including planet mass, radius, temperature, orbital velocity, and atmospheric conditions (*Spergel et al. 2015*).

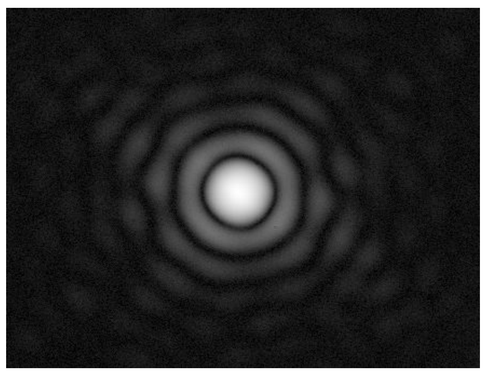


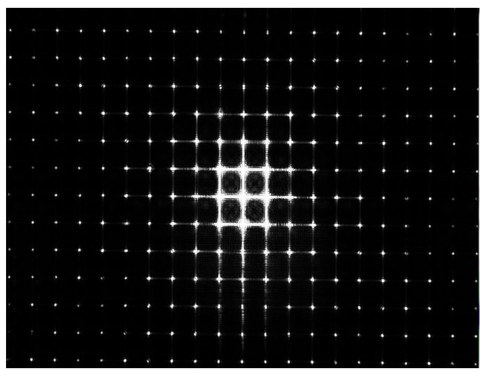

- Most directly imaged exoplanets have been young, self-luminous planets
- The challenge with direct imaging stems from the small angular separation and the high luminosity contrast between the planet and its host star (*Marois et al. 2008*)
- Coronagraphs have been implemented on telescopes to block the light from stars in attempts to observe orbiting exoplanets
  - Ground-based telescopes such as GPI and Subaru CHARIS combine coronagraphs with adaptive optics to observe exoplanets in the solar neighborhood
  - The goal of future missions such as WFIRST is to use high contrast coronagraphs to optimally suppress starlight and enable the direct imaging of Earth-like exoplanets within the habitable zones of their host stars
    - Reflected light from Earth-like exoplanets require a higher contrast than one can currently achieve with ground-based telescopes

## Star Suppression Integral Field Spectroscopy



**Above:** A diagram illustrating the function of the lenslet-pinhole mask combination in a non-telecentric IFS (*Image Source: Gong, McElwain, & Shiri 2016*). The IFS obtains a spectrum at each spatial location of the coronagraph's focal plane, sampling the image with a lenslet array. The lenslet array is used to resolve images by breaking it up into elements and steering light to a focus in different directions. At the focus, a pinhole mask is placed to reject the blue on-axis source (starlight), while transmitting the red off-axis source (planet light). Using a lenslet array and pinhole mask in an IFS will enable the extraction of the spectral content of exoplanet atmospheres.





**(Above) Left**: Fiber source diffraction pattern without lenslet array in imaging system. **Right:** Fiber source diffraction pattern with lenslet array in imaging system. The goal of this experiment is to observe any change in diffraction angle when offsetting the fiber source.

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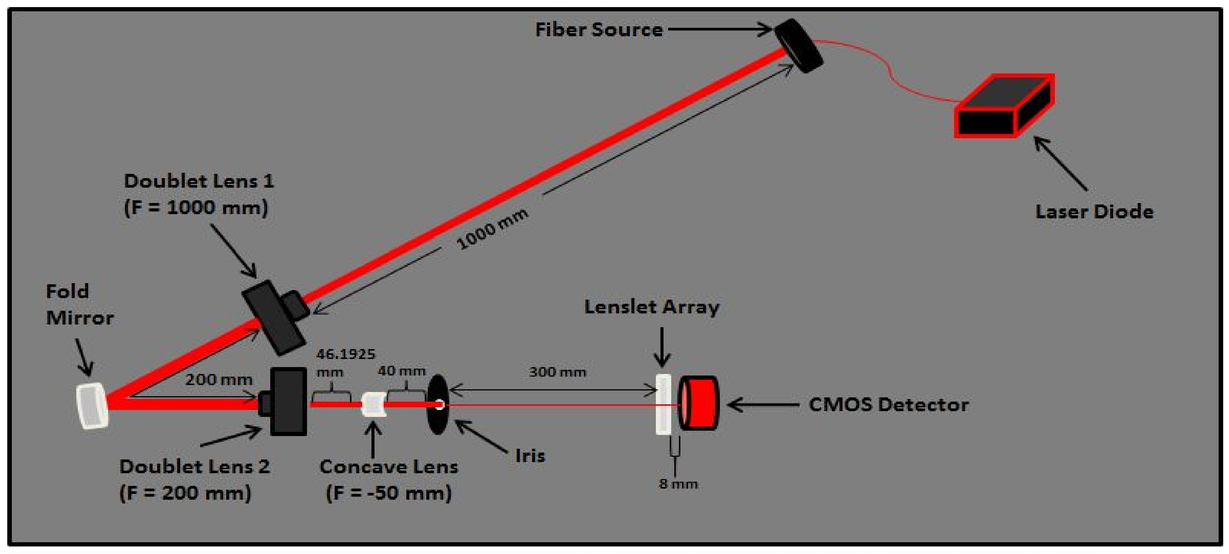
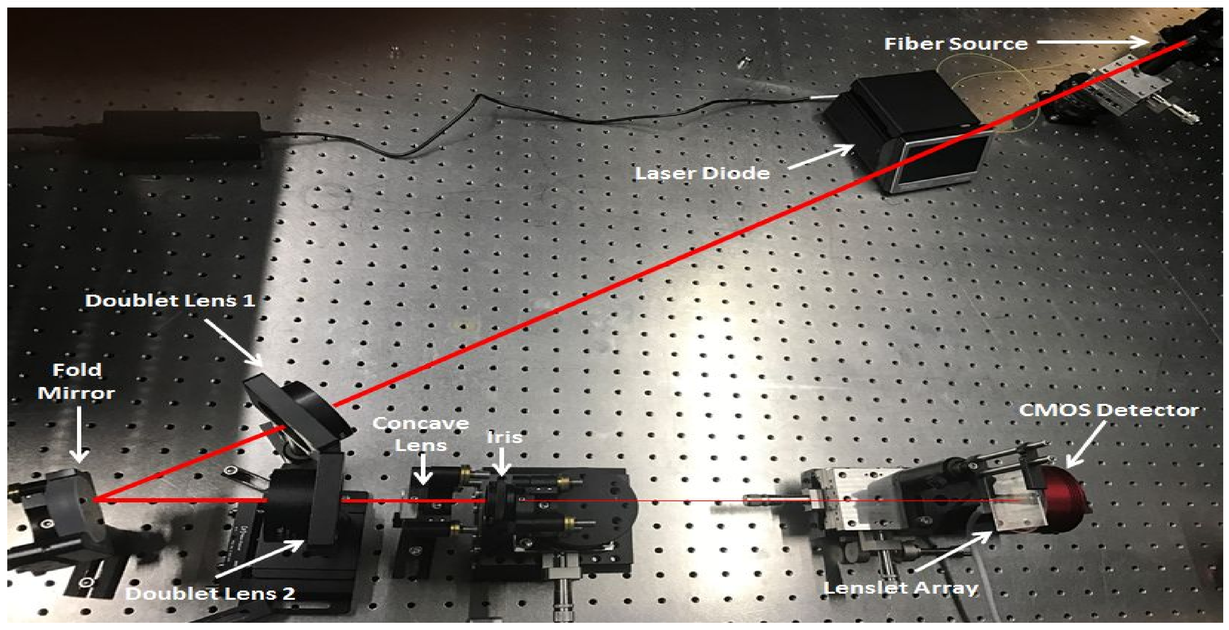
## Non-Telecentric Imaging Experiment



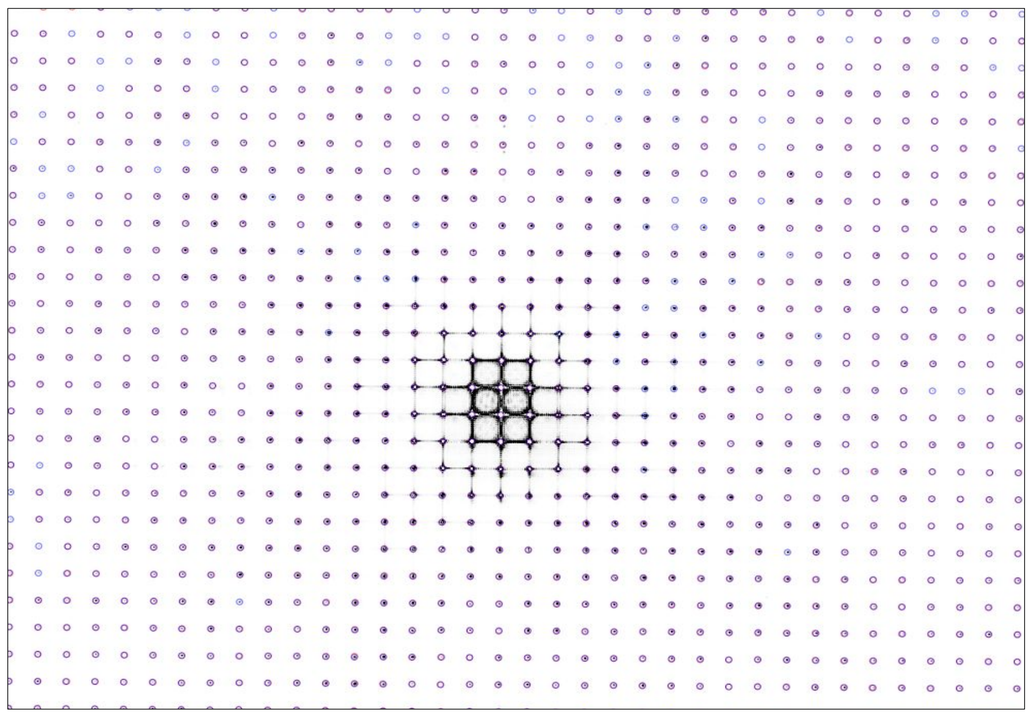



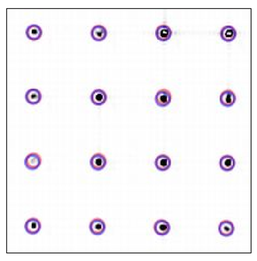

**Above: Schematic Diagram and Photograph of Non-Telecentric Imaging System**

Optical Elements:

- Fiber source acting as star forming diffraction pattern
- Non-telecentric relay consisting of doublet lenses, fold mirror, concave lens, iris
- Lenslet (microlens) array

## Diffraction Pattern Centroid Fits





**Above:** Overlay of fiber source diffraction pattern and fitted centroids at two different positions on the detector (8 mm offset). Red circles represent centroid fits at the original position, and blue circles represent fits at the offset position.

**Left:** Close-up view of centroid fits with some deviation, but not significant enough to definitively separate.

## Conclusions

We found that the diffraction ring of the fiber point source did not change significantly when moving the source off-axis. Therefore, we have not yet shown whether the microlens-pinhole starlight suppression technique is viable. Further alignment tests and analysis are necessary to conclusively prove or disprove the theory.

**References**

[1] Gong, Q., McElwain, M., & Shiri, R. 2016. "Lenslet array to further suppress starlight for direct exoplanet detection." SPIE 9904
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