# Detection Sensitivity for the Gemini Planet Imager (GPI) to Potential Europa Plumes

[1]Jamie McCullough, [2]Bruce Macintosh, [3]Max Millar-Blanchaer, [4]Laura Schaefer, [5]Dustin Schroeder, [6]Rob De Rosa

Kavli Institute for Particle Astrophysics and Cosmology, Stanford University, Contact: jmccull@stanford.edu

## Summary

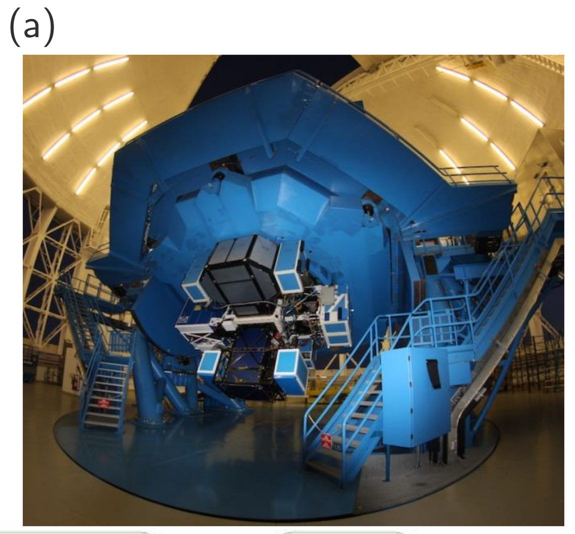
There has been possible evidence from ground based telescopes for plumes of water emanating from Europa's ice shell. Because of their potential connection to the subsurface ocean these plumes are of significant interest as targets for the in-situ instruments on upcoming NASA and ESA missions to the Jovian system. Their potential similarity to tidally-modulated plumes observed at Enceladus have led to speculation that the occurrence of these plumes could be predicted accurately enough to plan in-situ sampling. However, the plumes could be the result of stochastic processes releasing near surface water from the ice shell and may not occur during the missions at all. Better observational constraints on plume distribution, predictability, and character would provide critical information for planning operations and measurements on the upcoming missions to Europa. The aim of this study is to demonstrate capability of the Gemini Planet Imager (GPI) for this task, modeling the detectability of Enceladus-like plumes on the surface of Europa using polarimetry. The polarized signal from an Enceladus sized plume is approximated by Mie scattering from micron-scale ice particulates at 1.5 - 1.8 μm. Ground-based observations with a nearly automated facility such as GPI could allow daily searches for plumes and enable dramatically more informed mission planning, increasing the potential for habitability characterization and even potentially life detection.

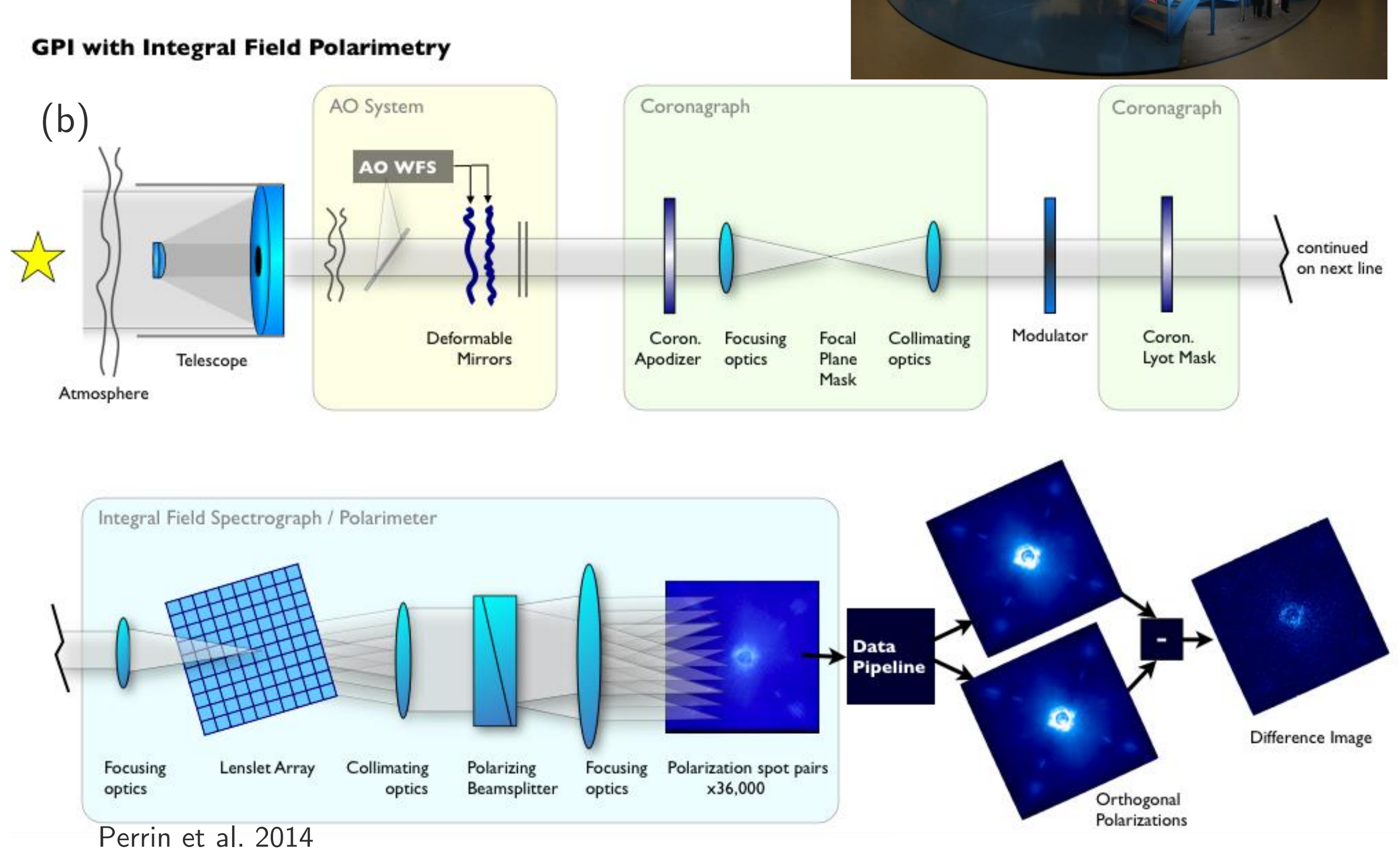
## The Gemini Planet Imager

The primary task of the Gemini Planet Imager (seen in fig. (a)) is to directly image and spectroscopically characterize exoplanets (Macintosh et al 2014). GPI's adaptive optics system produces images with a spatial resolution at Europa of ~150 km. The integral field spectrograph can provide either low-resolution (dλ/λ≈ 40) spectroscopy or broadband polarimetry from 1 – 2.5 μm. A broad schematic can be seen in (fig. (b)). Optically dividing the light via a lenslet array prior to dispersion helps crosstalk between spectral or polarization channels.

GPI is currently located at the Gemini South telescope in Chile, but will be moving to Gemini North in 2022. As part of a GPI 2.0 upgrade, we will enhance its capability for *rapid cadence monitoring* in the Gemini queue-scheduled framework, allowing brief, efficient nightly observations.

(a)






Perrin et al. 2014

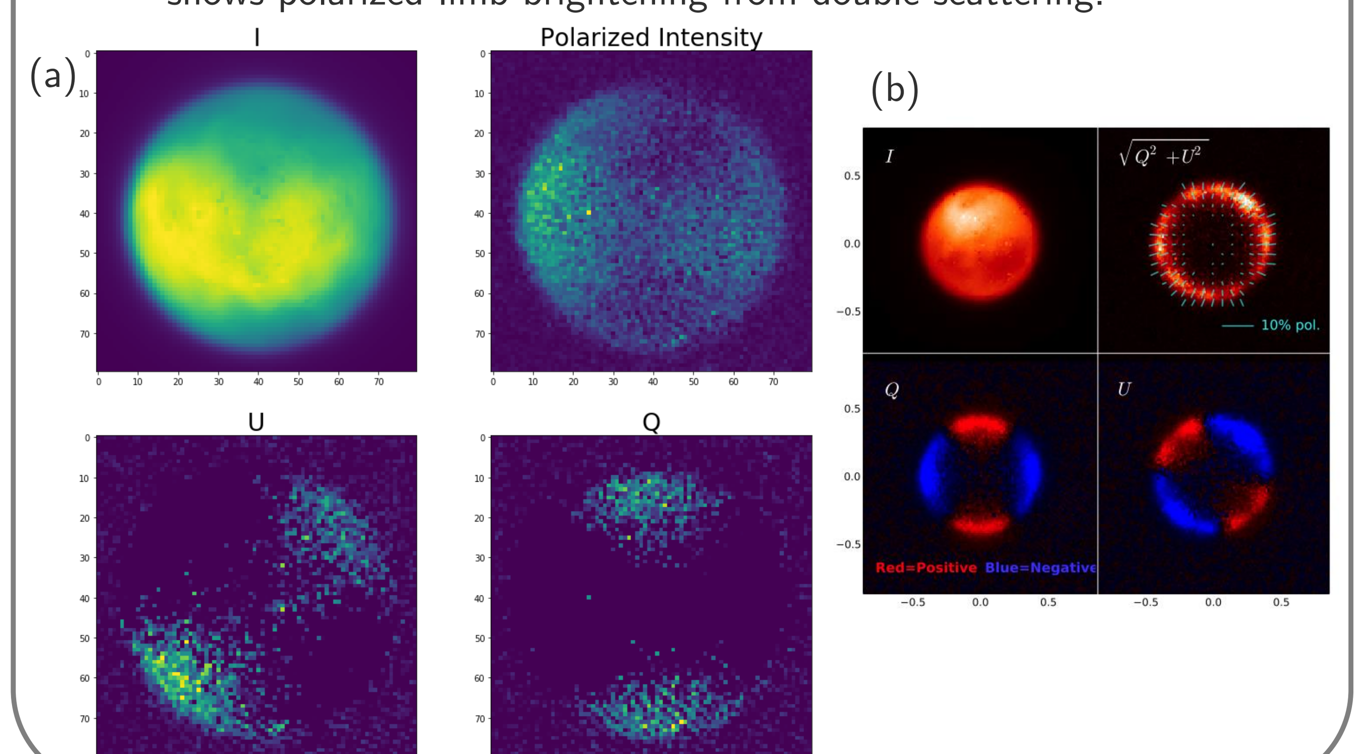
## Preliminary Data

The resulting detection capability begins from GPI initial observations of Europa's disk, in the H-band (1.5 - 1.8 μm) polarimetry mode on 04/2019. The data pipeline converts raw images into a calibrated Stokes parameter cube. Observations of reference star HIP 80628 measure the instrument point spread function and sensitivity.

**Note:** Stokes parameters are measures of polarization, with four components: $\boldsymbol{I}$ – total intensity, $\boldsymbol{Q}$ – + polarization, $\boldsymbol{U}$ – x polarization, and $\boldsymbol{V}$ – circular polarized. Circularly polarized light would be an unexpected signal, so we do not measure it, and total polarized signal for our purposes consists of the two other parameter combined in quadrature, $S_{pol} = \sqrt{Q^2 + U^2}$.

(a) The polarization data for Europa taken from GPI with a half hour of instrument time.

(b) GPI K-band data for Titan, which has a significant atmosphere that shows polarized limb brightening from double scattering.

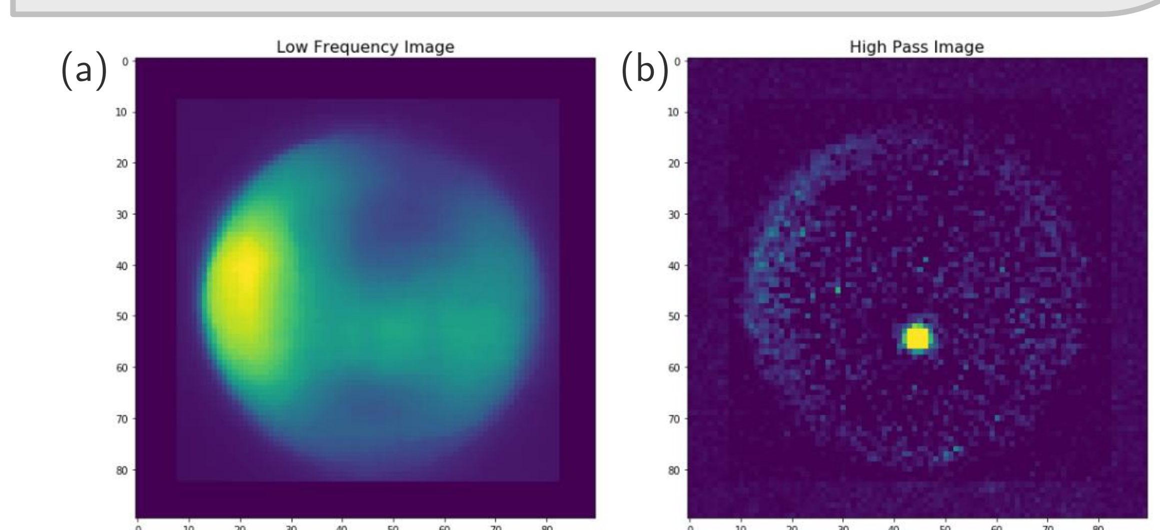



## Detection Criteria

After plume injection, the procedure for characterizing detection is a simple one, though more sophisticated methods could be developed beyond this order of magnitude study.

1. Inject the plume into the polarized data, $\sqrt{Q^2 + U^2}$, at some pixel position, $(x, y)$
2. The simulated image, is sent through a high pass filter (resulting in fig (b) below) to remove low frequency behavior (fig. (a)).
3. A weighted sum for each pixel is computed using the PSF shape (Note: this relies an a point source assumption for the plume).
4. SNR measurement is computed by comparing weight at true simulated plume position to the standard deviation of the neighboring pixels.
5. Repeat SNR measurement with plume injection at every pixel on Europa's disk.

Therefore, for the modelled Enceladus like plumes, we create a SNR map for detection capability via GPI for the observing conditions seen in spring, 2019.

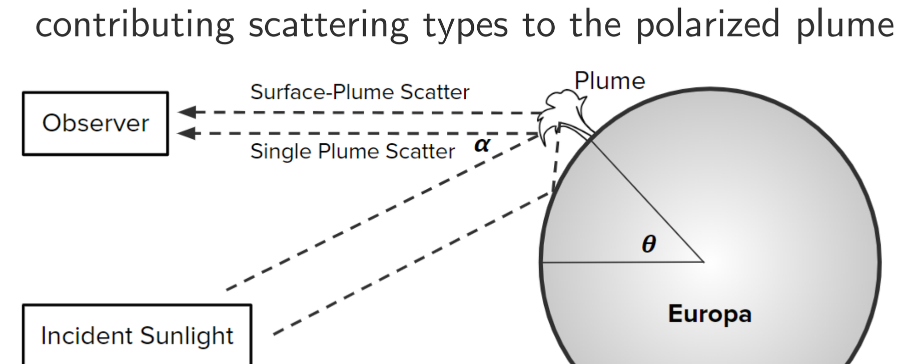



## Injecting Plumes

Using a fluid and particle simulation model courtesy of Keat Yeoh et al. 2010 for the Enceladus plume system as a reference particle distribution allows us to create a simple Mie scattering model of polarization as a function of scattering angle. If we parametrize plume position on Europa's surface, we can generate expected polarized flux for a hypothetical plume and place that into the data.

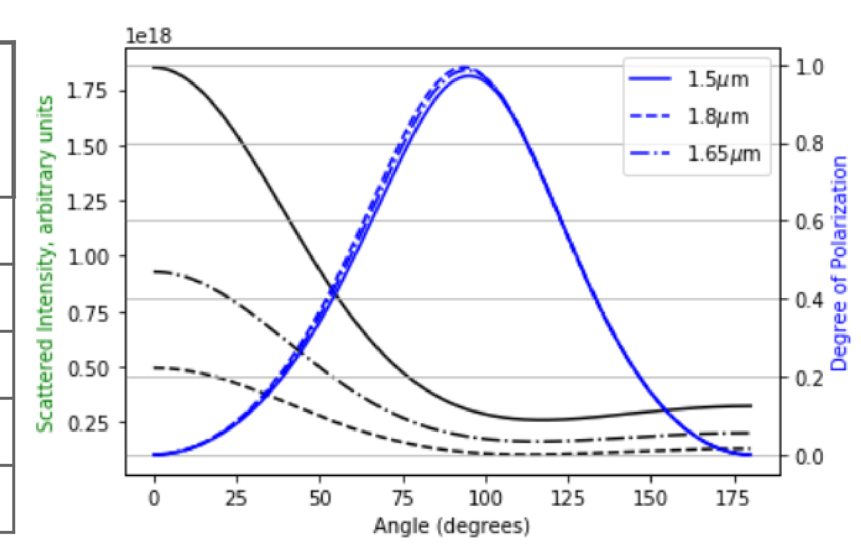
In fig. (b), we see the effect of wavelength, and scattering angle on the polarization fraction and scattered intensity of light for the Enceladus like ice particles, whose distribution is seen to the left. In fig. (c) we integrate over all wavelengths and parametrize the total polarized signal as a function of position, $\theta$ for a simulated plume. In fig. (d) we inject plumes into real data.

(a) The geometry of the system reveals the two first order contributing scattering types to the polarized plume signal.

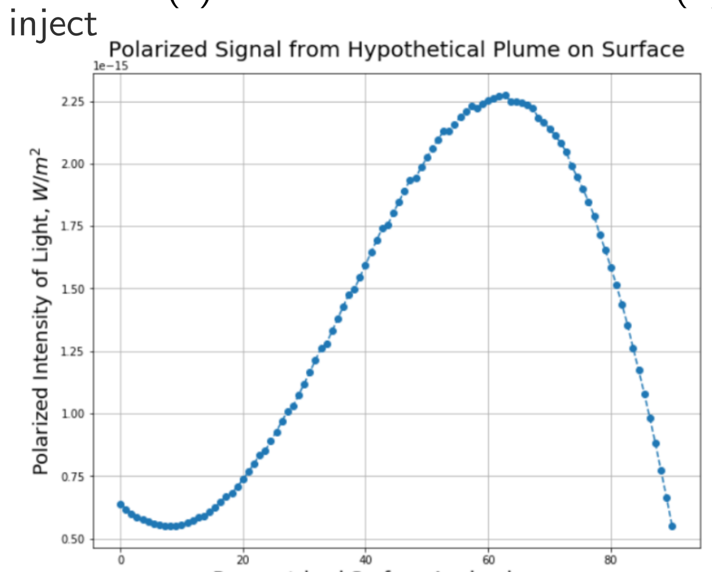



(b)

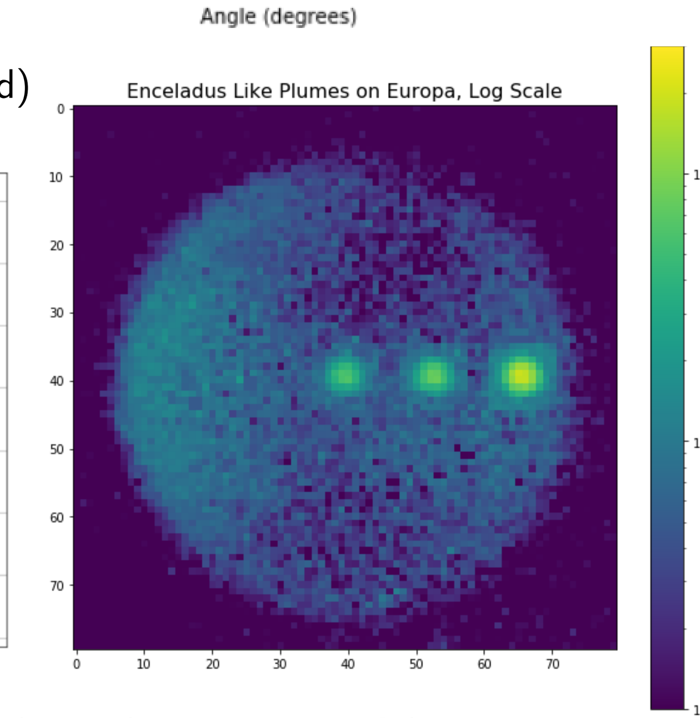
| Particle Diameter (nm) | Line of Sight Number |
|---|---|
| 10 | 6e14 |
| 50 | 5e12 |
| 100 | 6e11 |
| 500 | 6.0e9 |
| 1000 | 6.5e8 |




(c)



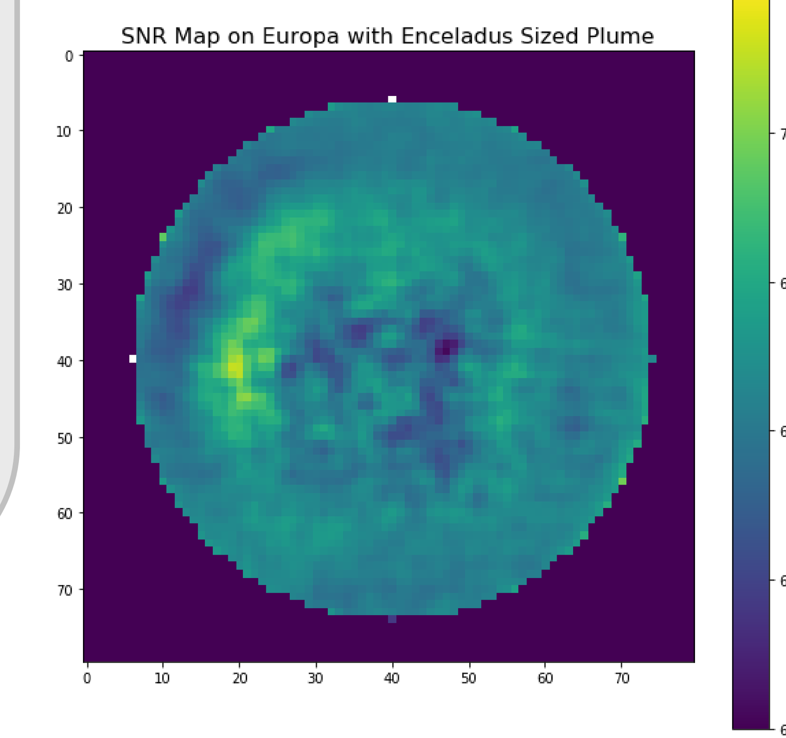

(d)




The nonzero signal at $\theta = 0$ is due to the solar phase angle, $\alpha \approx 8^{\circ}$ at time of observation.

## Results

The order of magnitude estimate for Enceladus-type plume visibility is favorable as seen in the SNR map below, with a mean signal across the disk of about $7\sigma$. It is a reasonable approximation to scale the polarized signal from a given plume with the mass flow rate – meaning sub Enceladus sizes would also be detectable.




A more rigorous study might explore this with better plume modelling prior to injection, but it is clear from these calculations that large plumes would be visible to this earth based observatory and GPI fills a desirable niche for further cryovolcanic studies on Europa via more frequent monitoring than space-based observatories allow.

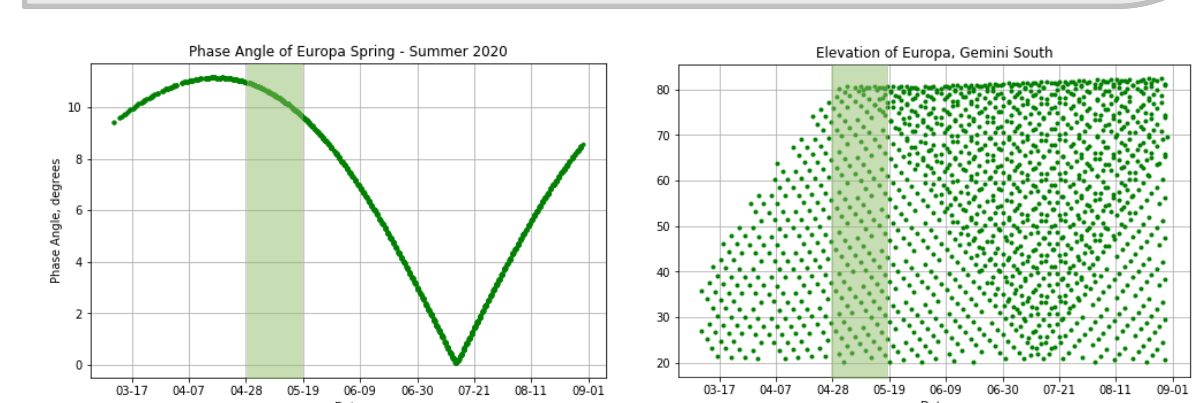
## Observing Implications

This study suggests that plumes comparable in scale to Enceladus would have an unmistakable signal in GPI polarization data. The lack of visibility and overall detection for plumes on Europa would be consistent with transient, potentially irregular ejecta. The existence and frequency of these events are of great interest, and a ground based observing program is uniquely positioned to examine the system repeatedly with brief exposures. GPI is particularly well suited for rapid cadence monitoring, which would be optimal for these, thus far, unpredictable events.

For maximum polarized signal for a detection case, best observing conditions would require:

- A large solar phase angle, α
- Angular separation of Europa and Jupiter
- High elevation at Gemini South (low airmass)
- Europa nearer to apojove if plumes are tidally modulated

An proposal given these constraints was submitted for observing time in early May, 2020.




## Acknowledgements

Many thanks to Laura Schaefer and Dustin Schroeder, who provided advice and insight as well as Max Millar-Blanchaer, who reduced the polarimetry data coming off the instrument and Rob De Rosa who assisted in the resulting observing proposal. Additional thanks go to the entire GPI team for their invaluable help throughout.