IDENTIFICATION OF PREVIOUSLY UNRECOGNIZED IMPACT STRUCTURES ON TITANIA ENABLED BY IMAGE REPROCESSING.
E. Nathan[1], C. Huber[1], and J. W. Head[1], [1]Department of Earth, Environmental and Planetary Sciences, Brown University, Providence, RI 02912, USA, (erica_nathan@brown.edu)

Introduction: Voyager 2's encounter with the Uranian system provides us with a legacy not only of rich datasets, but also a wide range of questions about the Uranian satellites, Uranian system dynamics, and the history of the Outer Solar System. Titania is a particularly enigmatic moon in the Uranian system. Like Oberon and Umbriel, it is heavily cratered, yet it also has large chasmata and rupes more similar to Ariel and Miranda [1]. We focus on three overarching and longstanding questions to guide our investigation into the cratering record and geologic history of Titania:

- What is the orbital-thermal history of Titania [1-2]?
- Why does the cratering record on Titania appear to be missing large craters [1-4]?
- Does Titania preserve a record of the impactor population during giant planet migration and/or the event that tilted Uranus' rotational axis [e.g., 5]?

Background: Approximately 35-45% of Titania's surface was imaged by Voyager 2 with >3 km/pixel resolution [1-2, 6]. The lower resolution of the images limits the extent to which geologic inferences can be drawn [e.g., 6], but image quality, specifically the blurriness of these images due to Voyager 2's high relative velocity during imaging, is another important limitation in this dataset. The existing maps of Titania [1, 7] recognize three geologic units and several feature classes: cratered terrain, smooth material, bright material, craters, chasmata, and rupes.

Compared to other Outer Solar System satellites, Titania's surface is lacking in large (50 to >150 km diameter) craters [1-3]. Three explanations for this dearth of large craters have been proposed: (i) Titania experiences a significantly different impactor population than similar worlds in the Saturnian system [1-2], (ii) Titania experienced one or more extensive resurfacing events that have destroyed the record of early large craters [3-4], and (iii) the crater population on Titania is dominated by secondaries from large primary crater(s) yet to be observed [1].

Understanding the cratering record of Titania is crucial to probing past dynamics of the Uranian system (possibly including the event that led to Uranus' highly tilted rotation axis) [e.g., 1, 6] as well as past Outer Solar System impactor populations, particularly important for constraining proposed giant planet migration in Solar System evolution [e.g., 5].

Methods: Though improving image resolution remains a challenging problem, efforts to remove camera motion blur from an image have advanced significantly since the Voyager 2 flyby of Titania with the advent of techniques [e.g., 8-10] to improve recovered image sharpness while reducing noise and artifacts. We apply a non-uniform blind deconvolution [e.g., 10] to Voyager frames of Titania to remove the spacecraft motion blur. We test this procedure by comparing reprocessed Voyager images of Jovian and Saturnian satellites to images from more recent missions (e.g., Fig. 1).
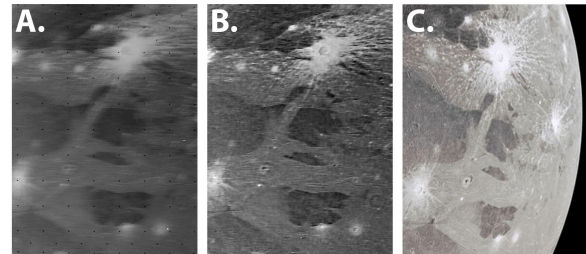

Fig. 1 (A) Voyager frame (OPUS ID: vg-iss-1-j-c1640354) of Shu Crater on Ganymede cropped and contrast adjusted. **(B)** Same as (A), but reprocessed to reduce camera motion blur. **(C)** Juno image of a similar region. Image sourced from NASA/SwRI/Kevin Gill.

We use the reprocessed Titania images (e.g., Fig. 2B) as a tool to enable an updated mapping of surface features on Titania (Fig. 2C).

Preliminary Results: An example reprocessed Voyager frame is shown in Fig. 2B. We have created a preliminary sketch map of geologic features on Titania. A major previously unidentified feature we map is a series of quasi-concentric lineaments (QCLs) with a morphology similar to large multi-ring basins found on other icy bodies (e.g., Valhalla and Asgard on Callisto [11]). We are also working to identify other potential palimpsests and smaller craters in this image.

Discussion: The collection of QCLs we map on Titania are visually and morphologically similar to lower resolution Voyager images of the Valhalla multi-ring basin on Callisto and is characterized by a smoother irregular central zone surrounded by a zone of closely spaced QCLs resembling discontinuous rings; this putative basin can provide an additional point of comparison for known multi-ring basins in the Solar System and would be the first Valhalla-class basin identified in the Uranian system [3, 12-13]. In addition, ring spacing can be used to estimate a first constraint on the past thermal and rheological structure of Titania [11-12]. This would also provide a constraint for proposed models of resonances among the Uranian satellites involving Titania, including those hypothesized to be responsible for geologic activity on Miranda and Ariel [e.g., 14-15]. It could additionally provide insight into the debate on the nature and origin of Gertrude (Fig. 2C), a potential impact structure on Titania [1-2]. Multi-ring basins are also valuable as stratigraphic markers [3, 12].

A.

B.
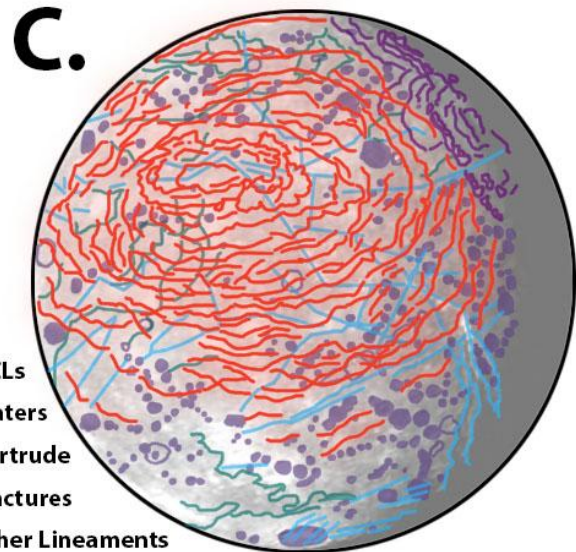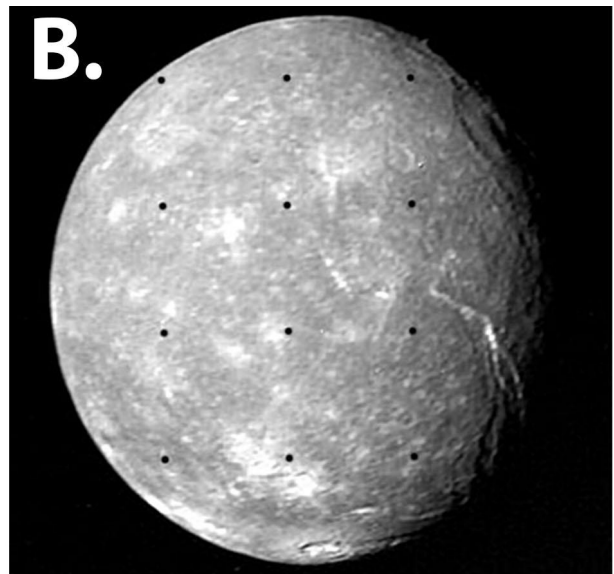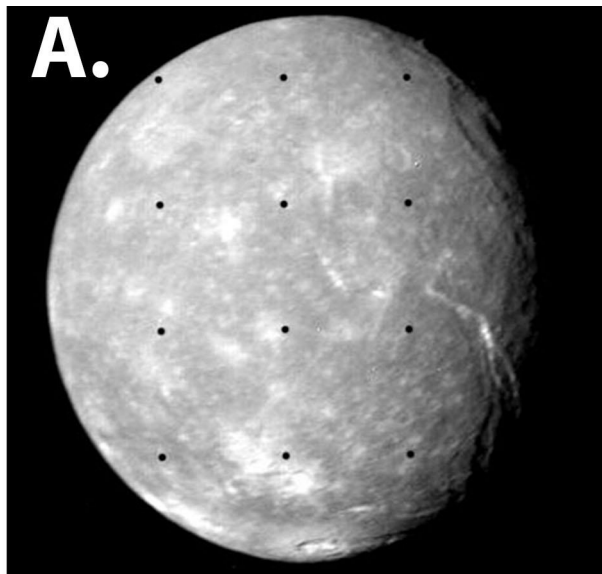
The identification of a large impact basin on Titania could help solve the longstanding problem of its missing large craters [1-4], supporting the idea that the previously-categorized crater population of Titania is dominated by secondary impact craters [1] and eliminating the need to invoke widespread resurfacing in Titania's history [3-4]; this supports an evolution consistent with heavy cratering and some early tectonic modification as a result of the late stages of ocean freezing [1]. If the surface of Titania has not been resurfaced and instead preserves an ancient surface, then better understanding Titania's cratering record has the potential to shed light on early Uranian system dynamics as well as the early migration of giant planets in the Outer Solar System [e.g., 5].

Conclusion: We reprocessed Voyager images with modern image processing techniques to remove blur caused by the high speed of the spacecraft imaging system relative to its target and identified a previously unrecognized multi-ring impact basin on Titania. Multi-ring basins are valuable markers in stratigraphic records [e.g., 12], making this feature an important observational target for future missions visiting Titania. Our result demonstrates the value of using non-uniform blind deconvolution techniques to improve the science return of existing datasets and identify scientific targets for future missions.

The impactor population in the outer solar system may have been dramatically shaped by the migration of the giant planets [e.g., 5] and the dynamics of individual planetary systems, such as debris from the hypothesized impact that caused the high tilt of Uranus' rotational axis. Our findings revise the long-standing dearth of large (>50 km) craters on Titania [1-4] and represent an important step in constructing a diagnostic record of cratering in the Uranian system. This multi-ring impact basin could represent a significant event in Titania's geologic history [e.g., 12]. Our finding is inconsistent with

C.

QCLs
Craters
Gertrude
Fractures
Other Lineaments

Fig. 2 (A) Voyager frame (OPUS ID: vg-iss-2-u-c2683649) cropped and contrast adjusted. **(B)** Same as (A), but reprocessed to reduce camera motion blur. **(C)** Preliminary geologic sketch map from (B).

extensive resurfacing early in Titania's history [3-4] and supports the idea that the previously characterized [1] crater population is dominated by secondary impacts, preserving an ancient surface [1-2].

Future Work: The reprocessed images of Titania enable us to further map Titania's surface and undertake new crater age dating. We have also begun to apply blind deconvolution camera motion blur reduction techniques to other targets, specifically the other Uranian satellites, Io, Charon, and Pluto.

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