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A search for temporal changes on Pluto and Charon

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A R T I C L E I N F O

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A B S T R A C T

A search for temporal changes on Pluto and Charon was motivated by (1) the discovery of young surfaces in the Pluto system that imply ongoing or recent geologic activity, (2) the detection of active plumes on Triton during the Voyager 2 flyby, and (3) the abundant and detailed information that observing geologic processes *in action* provides about the processes. A thorough search for temporal changes using New Horizons images was completed. Images that covered the same region were blinked and manually inspected for any differences in appearance. The search included full-disk images such that all illuminated regions of both bodies were investigated and higher resolution images such that parts of the encounter hemispheres were investigated at finer spatial scales. Changes of appearance between different images were observed but in all cases were attributed to variability of the imaging parameters (especially geometry) or artifacts. No differences of appearance that are strongly indicative of a temporal change were found on the surface or in the atmosphere of either Pluto or Charon. Limits on temporal changes as a function of spatial scale and temporal interval during the New Horizons encounter are determined. The longest time interval constraint is one Pluto/Charon rotation period (~6.4 Earth days). Contrast reversal and high-phase bright features that change in appearance with solar phase angle are identified. The change of appearance of these features is most likely due to the change in phase angle rather than a temporal change. Had active plumes analogous to the plumes discovered on Triton been present on the encounter hemispheres of either Pluto or Charon, they would have been detected. The absence of active plumes may be due to temporal variability (i.e., plumes do occur but none were active on the encounter hemispheres during the epoch of the New Horizons encounter) or because plumes do not occur. Several dark streak features that may be deposits from past plumes are identified.

1. Introduction

The New Horizons spacecraft flew through the Pluto-Charon system in July of 2015. Its exploration of the system included imaging with two complementary cameras: the wide angle Multispectral Visible Imaging Camera (MVIC, Reuter et al., 2008) and the narrow angle LOng Range Reconnaissance Imager (LORRI, Cheng et al., 2008). Both imaged Pluto and Charon at orders of magnitude better spatial resolution than any previous observations, resulting in many astounding discoveries (Stern et al., 2015; Moore et al., 2016; Grundy et al., 2016a; Gladstone et al., 2016) and enabling a myriad of new scientific investigations. One of the enabled investigations is a search for temporal changes on the surfaces and in the atmospheres from presently active geologic processes at spatial scales that were not previously detectable. In this manuscript, *temporal changes* means any observable changes of appearance over time; this generic terminology is used because the phase space of possible changes of appearance is broad.

Observation of a geologic or atmospheric process *in action* provides abundant and detailed information about the process and this information is sometimes difficult or impossible to derive

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from observation of the outcome alone. Thus detection of temporal changes on Pluto and Charon is expected to lead to important insights into the geologic or atmospheric processes that are presently operating on these bodies. In fact, characterizing the time variability of Pluto's surface and atmosphere was a secondary objective of the New Horizons mission (Stern, 2008). Geologic processes in the solar system, however, are not typically caught in the act and temporal changes are generally more likely to be observed between images with longer time intervals. Due to the flyby architecture of the New Horizons mission, the period of geologically resolved imaging was relatively short, a consideration that decreases the probability that temporal changes were detected.

Nonetheless, there were three reasons for conducting a search for temporal changes:

1. Pluto and Charon have young surfaces and features that imply ongoing or recent geologic activity (Stern et al., 2015),
2. Temporal changes of plumes on Triton were observed in images with similar temporal intervals and spatial resolutions (Soderblom et al., 1990),
3. The significant scientific rewards from detection of temporal changes outweighed the concern of lower return on investment in the event that no temporal changes were detected.

Of the many discoveries from the New Horizons mission, two of the most astounding are the youthfulness of some surfaces and features in the Pluto system and the extent of ongoing and recent geologic activity (Stern et al., 2015). Pluto's Sputnik Planitia[1] has a crater retention age of <30 million years and resurfacing from convective overturning likely continues to the present (McKinnon et al., 2016; Singer et al., 2017). Directly to its east, eastern Tombaugh Regio also has a young surface that is probably being renewed by actively flowing glaciers (Moore et al., 2016). South of Sputnik Planitia, Wright and Piccard Mons and their surrounding terrain are lightly cratered, possibly because of geologically recent cryovolcanism (Moore et al., 2016). In addition, condensation and sublimation of volatiles is also expected to occur on Pluto and was possibly observed with Earth-based telescopes (e.g., Buie et al., 2010a, b; Buratti et al., 2015).

On Charon, Organa crater has a concentration of ammonia ice that suggests the ice was deposited <10 million years ago (Grundy et al., 2016a). Formation of Charon's red poles from seasonally cold-trapped volatiles originating from Pluto may be ongoing and thus Charon also is a geologically active world, if only exogenously (Grundy et al., 2016b). The plethora of young surfaces and features in the Pluto system from ongoing and recently active geologic processes imply that observation of a temporal change in New Horizons images was plausible.

Neptune's largest moon, Triton, is regarded as a captured Kuiper belt object and thus is one of the best worlds for comparative planetology for Pluto and Charon. Voyager 2 images from its exploration of the Neptune system in 1989 showed at least four active, geyser-like eruptions of dark material on Triton, two of which had wind-blown clouds that were more than 100 km long (Soderblom et al., 1990). Variability in morphology, brightness, and length of one plume cloud was observed in images with resolutions of ∼1 km that were taken less than 45 min apart. These observations were used to infer the wind speed and that the eruption was intermittent on 10 min timescales (Soderblom et al., 1990). New Horizons images of Pluto and Charon at similar spatial resolutions had similar time intervals and thus from the example of Triton, it was plausible that temporal variability was observed.

Temporal changes, including the appearance of dark fans on seasonal ice, that are likely the result of similar geyser-like eruptions have also been observed on Mars (Kieffer et al., 2006; Hansen et al., 2010, 2013). Mars, Triton, and Pluto are the only solar system bodies that have atmospheres (with surface pressures greater than a microbar) where the most abundant atmospheric component is in vapor pressure equilibrium with surface deposits of its solid phase. The observed activity on both Mars and Triton is likely associated with seasonal sublimation of their surface deposits. Since seasonal sublimation is a process that is also expected to occur on Pluto (e.g., Young, 2013) and was possibly observed with Earth-based telescopes, it was predicted that New Horizons would find plume deposits and possibly active plumes (e.g., Buratti et al., 2015). Therefore it was reasonable to search for temporal variability on Pluto that is analogous to that observed on Triton and Mars.

As mentioned previously, the abundant and detailed information that observing a geologic process *in action* provides about that process motivates a search for temporal changes. In the example of Triton's plumes, observation of the active eruptions immediately indicated that the myriad of dark streaks observed on its bright south polar cap were more likely formed by eruptions than saltation, a hypothesis that was given more attention prior to the discovery of the plumes (Sagan and Chyba, 1990). Furthermore, observation of the variability of the plume cloud allowed for detailed measurements such as wind speed and mass flux, which otherwise would not have been uniquely solvable variables. Thus whatever the probability for temporal changes in the brief period of high-resolution New Horizons imaging, the fact that detection of temporal changes was possible and that the scientific rewards for detection of such a change were significant, warranted a search.

2. Data

To search for temporal changes, images with the highest spatial resolution and longest temporal interval are generally the most desirable. Better spatial resolutions permit searches at finer scales and longer time intervals increase the likelihood that changes occurred. In the case of periodic variability, however, it is more optimal to have images at different phases of the period than images separated by many periods but at the same phase. For example, changes driven by diurnal forcing may be more easily detected between two images taken at different times on the same day than two images taken one or more days apart but at the same time of day. For two images with different resolutions, the spatial scale of temporal changes that can be constrained is limited by the lower resolution image.

The New Horizons spacecraft flew through the Pluto system with an approach solar phase angle (Sun-surface-observer angle) asymptote of ∼15° and departure of ∼165°. Since the majority of the visible hemisphere was in nighttime darkness during the departure phase, only the approach and encounter images are useful for searching for temporal changes. Thus the longer the time interval between any two images (from the same camera), the greater the difference of their spatial resolution. Therefore no pair of images optimizes the desire for both high spatial resolution and long temporal interval and every pair of images trades improvement in one parameter at the cost of the other. To be thorough in constraining both the spatial and temporal scales of temporal changes, the highest resolution image should be compared to essentially every other image. Comparison of the highest resolution image to an image taken much earlier provides a long time baseline but only constrains large spatial scales, while comparison to an image taken only slightly earlier significantly improves the constraint of the spatial scale of temporal changes but significantly decreases the time interval.

The problem of selecting the images to compare in the search for temporal changes is further complicated because not all images include the same regions of Pluto/Charon. This is both because of

[1] Some feature names in the Pluto-Charon system are presently informal.