**SURFACE CHANGES ON IO.** P. Geissler[1], A. McEwen[1], L. Keszthelyi[1], C. Phillips[2] and J. Spencer[3], [1]Lunar and Planetary Laboratory, University of Arizona, Tucson AZ 88721, [2]SETI Institute, Mountain View, CA, [3]Lowell Observatory, Flagstaff AZ

**Introduction:** Io's appearance continually changes due to the deposition of new lava flows and plume deposits around active volcanic centers. These changes provide a partial record of the times, locations and vigor of volcanic eruptions across the satellite. We have begun a program to systematically search for surface changes on Io, both from Voyager-to-Galileo and from one Galileo orbit to the next. Here we report preliminary results from this global survey along with a discussion of the most recent surface changes.

**Background:** The manner and mechanisms of Io's resurfacing are of interest for several reasons. Io is a major polluter of the jovian system, spewing volcanic ash and gas that can be monitored by Galileo dust and charged particle detectors. These instruments have detected variability in the concentrations of dust and plasma from one spacecraft orbit to the next that are believed to be linked to volcanic episodes on the satellite [e.g., 1-3]. Io's prodigious resurfacing is highlighted by the lack of impact craters on its surface, even in the highest resolution images obtained by Galileo. At least a millimeter per year of globally averaged deposition is needed to account for the erasure of craters, according to recent estimates of the flux of large cometary impactors [4]. An even greater constraint is placed by Io's heat flow, estimated at 2.5 W $m^{-2}$ [5]. If this heat is carried by melts with the heat capacity of silicate lavas, then the amount of magma erupted each year could cover the satellite with a layer ~1 cm thick [6,7]. The resurfacing is very nonuniform, however. About 90% of the surface remained apparently unchanged between the Voyager and Galileo eras [8]. Over the short term, Io's resurfacing is concentrated around its active volcanoes.

Many unanswered questions remain about the nature of Io's resurfacing. It is presently unknown whether the surface changes are due primarily to the deposition of new lava flows that are tens of meters thick, or to plumes that mantle the surface with deposits that are only microns deep. The disappearing act performed by Masubi's plume deposit between Galileo's orbit 10 and orbit 15 [9] (along with those of Surt and Aten, which vanished between the flyby of Voyager 2 and Galileo's arrival [10]) suggests that erosion or alteration competes with deposition to modify the appearance of the surface. Some of the large scale changes could be tricks of photometry, while many smaller sites may have gone unnoticed. A detailed inventory of the distribution and chronology of Io's resurfacing is needed.

**Approach:** Photometric variations caused by differences in illumination and viewing geometry greatly complicate the identification of genuine surface changes. Io's surface materials vary markedly in their light scattering behavior, producing sharp color differences and contrast reversals that alter the appearance of the surface depending on whether it is illuminated obliquely or viewed with the Sun more directly behind the observer [11,12]. For example, $SO_2$ frosts that are nearly invisible under normal illumination become quite conspicuous at high phase angles, because they scatter light more isotropically than Io's average surface.

A general solution to this problem is to devise a photometric model to predict the appearance of the surface as a function of incidence, emission and phase angle (e.g. [11]) and use it to correct images for different illumination and viewing geometries. As a first step, however, we have concentrated on images taken under similar conditions by calculating the mismatch in phase angle and subsolar longitude (time of day) for each image pair, sorting the results and focusing attention on the best-matched images. In these cases, no assumptions need be made about the scattering behavior of the surface.

**Voyager-to-Galileo Changes:** Figure 1A shows that only a small subset of Io's active hotspots were responsible for noticeable surface changes over the 17 year interval between the Voyager encounters and the arrival of Galileo. Of these, several were changes that took place between the two Voyager flybys. Most of the major changes are found at low to mid-latitudes on Io, within 40 degrees of the equator. Together with evidence that the most persistent plumes and hotspots are located near the equator [13], the dearth of surface changes at high latitudes suggests that Io's poles are relatively quiet in terms of volcanic activity.

**Changes during the Galileo Era:** A smaller list of volcanic centers have caused major surface changes during the past 5 years (Figure 1B). Most of these are in areas known to have altered prior to Galileo's arrival, signaling continued activity at these sites. There are a few surprises, however, including Tvashtar (63N, 123W) and a previously unknown volcano at 41N, 134W, caught erupting during orbit 31. The plume from this latter eruption reached a record-setting 500 km in height and left a broad ring of bright SO2 deposits.

Much activity during the recent close flybys of Io by Galileo took place at high northern latitudes. Along with Tvashtar and the new volcanic center just mentioned, eruptions occurred at Surt (46N, 338W) and Dazhbog (54N, 302W). The eruption of Tvashtar late in 2000 provides an opportunity to study the evolution of a conspicuous plume deposit near Io's north pole. Tvashtar's enormous red ring rivals that of Pele and is presumed to be similar in composition. It was imaged both by Galileo (during orbit 29) and by Cassini as it flew through the Jupiter system, and is large enough to be resolved by Earth-based telescopes. Galileo reimaged the Tvashtar region during orbits 31 and 32 and found that the red material so far persists unchanged except where buried by new deposits from the un-named volcano at 41N, 134W.

Elsewhere, Pele's red ring continues to be replenished and has nearly buried the dark deposits from Pillan. Nearby Reiden Patera, on the other hand, has darkened noticeably since orbit 24 and sprouted bright red pyroclastic deposits of its own. Another caldera that has darkened is located at 24S, 148W, to the east of Culann. This un-named volcano was formerly covered with greenish materials during orbit 14. Dark diffuse deposits have appeared along the eastern edge of Amirani since orbit 21. New white and red deposits were also noted near the perennially active plume Prometheus.

**Next Steps:** We are still in the process of identifying surface changes on Io and placing limits on the possible dates of activity, including significant non-detections. Soon we will begin the more difficult task of comparing images taken under very different photometric conditions. We look forward to integrating these data with observations of plumes, auroral emissions and thermal outbursts recorded by Galileo, Cassini and groundbased observers to derive a detailed chronology of volcanic eruptions on Io.

**References:** [1] Graps, A. L., et al., Nature, 4 May 2000. [2] Wang, Y. L., et al., 2000, DPS meeting #32, #35.07. [3] Russell, C. T., Kivelson, M. G. 2000. Science, 287, pp. 1998-1999. 4] Zahnle, K., Dones, L. and Levison, H. F., Icarus, 136, 202, 1998. [5] Veeder, G. J., et al., Journ. Geophys. Res., 99, 17095-17162, 1994. [6] Blaney, D. L., et al., Icarus, 113, 220, 1995 . [7] Spencer, J. R. and Schneider, N. M., Ann. Rev. Earth Plan. Sci.,24, 125, 1996. [8] Geissler, P. E., et al., Icarus, 140, 265, 1999. [9] Phillips, C., Ph.D. Dissertation, Univ. of Arizona, 2000. [10] McEwen, A. S., et al., Icarus, 135, 181, 1998. [11] Geissler, P.E., et al., Journ. Geophys. Res., in press 2001. [12] Simonelli, D. P., Veverka, J. and McEwen, A. S., Geophys. Res. Lett., 24, 2475, 1997. [13] Lopes-Gautier, R., et al., Icarus, 140, 243, 1999.