Synthetic Aperture Radar instrument concept for subsurface geological observations of Io. J. M. Christoph[1] and D. A. Williams[2], [1,2]School of Earth and Space Exploration, Arizona State University [1](jmchri17@asu.edu) [2](david.williams@asu.edu).

Introduction

Io is the most volcanically active object in the Solar System, with hundreds of active volcanoes (hot spots) scattered across its surface. The extreme volcanism on Io is driven by tidal interactions with Jupiter and the other Galilean satellites Europa and Ganymede, which cause tidal flexing of approximately 100 meters in Io's crust every orbit [1]. A majority of Io's volcanoes erupt mafic silicates, and possibly also ultramafic silicates analogous to terrestrial komatiites [2], although sulfur volcanism is also widespread. More than two thirds of Io's surface is covered by bright plains material [3], with three compositional variants: white-gray SO_2 frost recrystallized from volcanic plume fallout, yellow cyclo-S_8 from sulfur volcanism, and red S_3-S_4 which decompose from cyclo-S8 in response to high charged particle flux near the poles [3]. We do not know precisely how deep these bright plains deposits extend beneath the surface, or the nature of the material they overlie; however, the silicate lava flow units associated with contemporary eruptions are typically emplaced on top of the bright plains material and we assume that the bright plains materials began forming at the start of active volcanism on Io [4].

Bright plains materials present an obstacle to certain geologic studies of Io because they overlie, and thus hide from spacecraft instruments, much of the bedrock of Io's crust. Observations of impact craters, structural, volcanic, and other geologic features of the bedrock are only possible where they are not obscured by overlying deposits. Although a great wealth of information on Io's crustal and interior processes has been gleaned from studies of regional-scale tectonic structures such as Hi'iaka Patera [5] and concentrated volcanic features such as the Chaac-Camaxtli [6] and Zamama-Thor regions [7], we still lack a global perspective on crustal deformation and heat flow processes on Io. For the purposes of further developing our models of the impact of tidal interactions with Jupiter and the Galilean satellites on Io's crust and interior, it would be beneficial to be able to observe the two thirds of Io's surface obscured by bright plains deposits.

Synthetic Aperture Radar

A remote sensing technology particularly well-suited to examining planetary subsurfaces is Synthetic Aperture Radar (SAR). The general principle of radar has been well-established for decades: a radio signal is transmitted towards a target and reflected back to a receiver, and information about the target can be obtained by comparing the outgoing and incoming signals. SAR takes advantage of the motion of an airborne or spaceborne platform to artificially recreate the effect of having a larger antenna size – higher spatial and reflectance resolution of the target – which is only possible due to the wavelength scale of light in the radio spectrum.

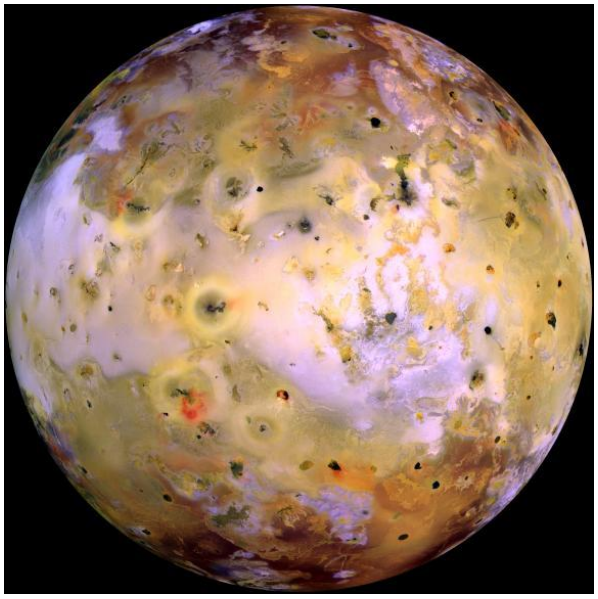

Fig. 1: Galileo false-color mosaic of Io, showing the grey-white, yellow, and red-brown bright plains materials. NASA PIA02309

A unique property of SAR is its ability to perform ground penetration detection. The Shuttle Imaging Radar instrument flew four times on the Space Shuttle in Earth orbit: SIR-A on STS-2 in 1981; SIR-B on STS-41G in 1984; and SIR-C (combined with the German-built X-SAR) on STS-59 and again on STS-68, both in 1994. On each of these missions radar images taken of the Sahara desert were able to see through meters of surface sand and directly image the underlying bedrock, revealing river channels that indicated significant climate change in North Africa in the Pleistocene and Holocene [8], [9], [10], [11], [12].

Technical Feasibility of SAR at Io

Duplicating the SIR instrument's capability of penetrating surface deposits on a mission to Io could potentially enable studies of the bedrock beneath the bright plains deposits, thus providing a glimpse into both Io's interior and structural processes as well as the history of volcanic activity on Io. There are, however a

Fig. 2: SIR-A L band image of Keraf Suture, a structural feature in northern Sudan obscured from visible imagery by surficial deposits. Reprinted from [10].

number of challenges associated with using a SAR instrument to attempt to duplicate the sediment penetration capabilities of SIR at Io.

The first challenge associated with any radar instrument is wavelength selection. Most ground-penetrating radars operate in the VHF or UHF wavelength bands, from 10 cm to 1000 cm. SIR-C/X-SAR conducted observations at three wavelengths: L-band at 24 cm, C-band at 6 cm, and X-band at 3 cm. Of these three wavelengths, L-band obtained best penetrative resolution of the dry Sahara surficial sand, reaching approximately two meters below the surface [9]. It has been shown that radio waves will penetrate loose, dry surficial deposits to a depth equal to the wavelength times some constant [9]; therefore selecting longer wavelengths should maximize penetration for a SAR instrument.

The second challenge is polarization. The radio waves from a SAR instrument can be polarized in one of two directions: parallel to the azimuth of the antenna's motion (horizontal polarization notated as H) or perpendicular to the azimuth (vertical polarization notated as V). Both the transmitter and the receiver on a SAR instrument can operate with H or V polarization, resulting in three configurations: horizontal plane polarization (HH), vertical plane polarization (VV), or cross polarization (HV). A key observation from SIR-C imaging was that cross polarization delivered increased resolution and penetration in C-band images [12], suggesting that an instrument designed for Io would potentially benefit from being able to manipulate the polarization of both the transmitting and receiving antennas.

The final and arguably most important challenge is the composition of the surficial deposits on Io. Ground-penetrating radar is not compositionally independent; water blocks radar, meaning ground penetration only works on dry sand on Earth [9]. A similar problem impacted the Cassini SAR instrument's observations of hydrocarbon dunes on Titan, which appeared radar opaque [13]; however it is also possible that the great depth of the Titan dune seas and the wavelength Cassini SAR operated on (Ku band) were responsible for the lack of penetration, rather than the chemical makeup of the dunes. It was initially unclear at the start of this research whether the sulfur compounds that make up Io's bright plains deposits would cause similar problems for a SAR instrument and prevent ground penetration. SO_2, cyclo-S_8, and sulfur allotropes S_3-S_4 are all chemically different from both the quartz sand of the Sahara and from liquid water, and they are not abundant enough on Earth's surface or atmosphere to pose much concern to terrestrial radar remote sensing practitioners. Therefore, an investigation of the chemical properties associated with radar reflectance is warranted; however, sulfur compound absorption information relevant to radar remote sensing practitioners is elusive. This ambiguity in observational data potentially merits experimental verification of whether or not these sulfur compounds are, indeed, transparent enough to radar to enable ground penetrating obsevations.

References

[1] Peale, S. J. (1979) *Science 203* 892-894 [2] McEwan A. S. et al. (1998) *GSA Abstracts with Programs 29.6* 190 [3] Lopes R. M. C. and Williams, D. A. (2005) *Rep. Prog. Phys. 68*, 303-340 [4] Williams, D. A. et al. (2011) *Geologic Map of Io* USGS SIM 3168 [5] Bunte M. K. et al. (2010) *Icarus 207* 868-886 [6] Williams D. A. et al. (2002) *JGR 107*. E9, 5068 [7] Williams D. A. et al. (2005) *Icarus 177*. 69-88 [8] Abdel-Rahman M. A. and El-Baz F. (1979) *NASA JSC Apollo-Soyuz Test Project V.2* [9] McCauley J. F. et al. (1982) *Science 218*, 1004-1020 [10] Abdelsalam and Stern (1996) *GSA Abstracts with Programs 28.7* 234 [11] Schaber G. G. et al. (1997) *Remote Sensing of Environment 59.2* 337-363 [12] Abubakr et al. (2013) *Geomorphology 194* 34-45 [13] Radebaugh J. and Bishop, B. (2016) *GSA Abstracts with Programs 48.7* Abstract #140-2