AO4ELT meets the Solar System: The coming interplay between adaptive optics on ELT, space telescopes, and spacecraft missions.

Al Conrad, Christian Veillet, Antonin Bouchez,
Warren Skidmore, Carmelo Arcidiacono, Fraser Clarke

October 31, 2017

Contents

1 Introduction

Why should large telescopes be designed to observe solar system objects? The relative impact of planetary science to the other fields in astronomy can be debated, but here we look at this question in the light of a more pragmatic consideration: the issue of funding large facilities for astronomical research.

Firstly, the education and public outreach (EPO) efforts of ground-based telescopes benefit signficantly from programs to support spacecraft missions, and from planetary science in general. Strong EPO leads to increased funding. Consider the now iconic image of Uranus shown in figure 1, which was produced with an early AO system on one of today's large telescopes.

Secondly, space agencies (NASA, ESA, etc) often fund high angular resolution at large observatories to vet mssion targets (Defrère, et al., 2008), to probe a target's surroundings for spacecraft hazards (Merline, et al., 2012), and/or to characterize an object's shape, size, density, and spin pole for missioning planning (Drummond, et al., 2010; Carry, et al., 2012).

It is this second potential funding benefit that we address in this paper. We discuss here the expanding role of ground-based telescopes for remotely supporting spacecraft missions and, in particular, the role of high angular resolution.

In section 2 we give examples of past and current spacecraft visits that have benefited from ground-based imaging and spectroscopy prior to their encounter. In section 3 we look at plans for the future, with emphasis on the role of the 23-to-39 meter telescopes, so-called extremely large telescopes (ELT), which are just now coming on line.

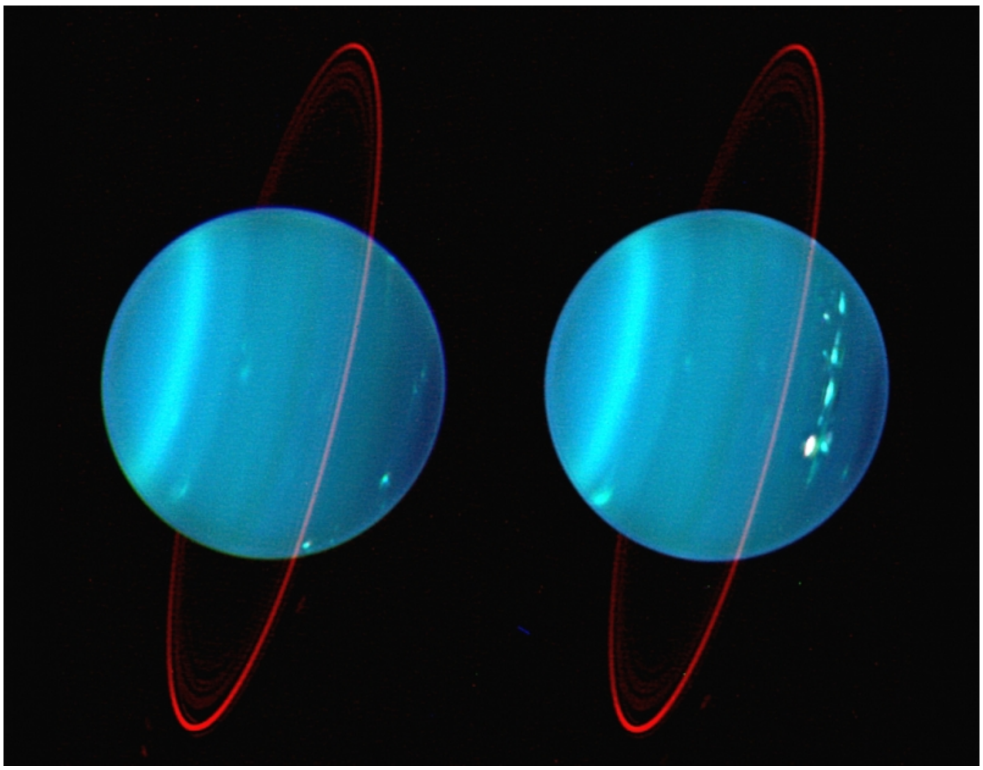

Figure 1: Adaptive optics images of Solar System objects are often used for early press releases when new systems are first commissioned. Credit: Lawrence Sromovsky, University of Wisconsin-Madison/W.W. Keck Observatory

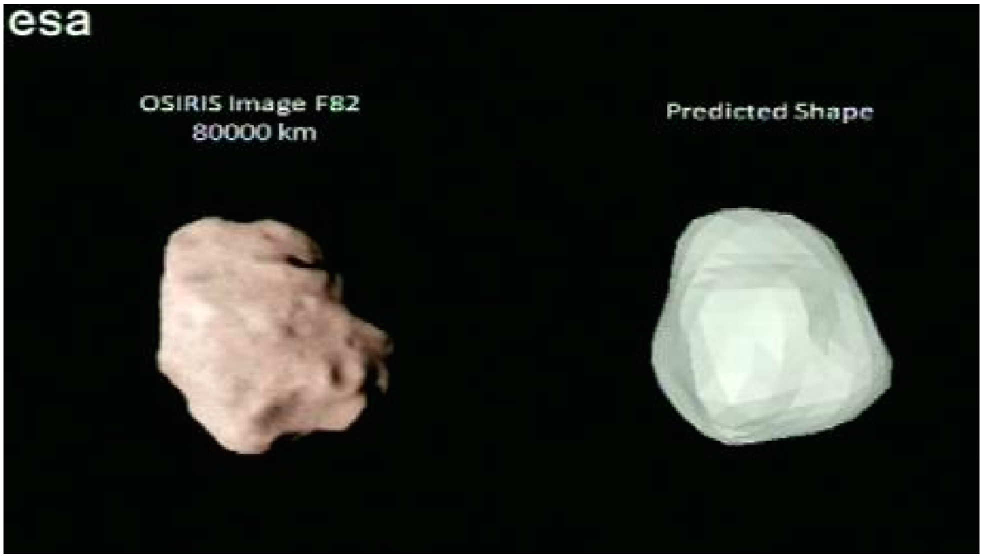

Figure 2: Shape model derived from ground-based high angular resolution compared to the fly-by image captured by the Rosetta spacecraft. Credit: ESA.

2 Past and Current - 8 to 10m apertures

2.1 Rosetta: (21) Lutetia

Prior to its July 10, 2010, fly-by of asteroid (21) Lutetia, a shape model that was largely based on AO data collected by ground-based observatories was provided to the mission team (Drummond, et al., 2010). The shape model and spin solution, together with the spacecraft trajectory (obtained from JPL spice kernels) were used to derive the relative position and orientation of Rosetta and Lutetia. In particular, the coordinates (longitude λ, latitude β) of the sub-Rosetta point as a function of time during the fly-by were provided (Carry, et al., 2010). The accuracy of the shape predicted from the AO data was later validated after the flyby (Carry, et al., 2012).

2.2 Journey to a Metal World: (16) Psyche

The mission to Psyche is scheduled to launch in 2022 to begin its four year journey to encounter in 2026. Once in orbit around the asteroid, the spacecraft will begin its study of the body with the primary goal of understanding its unusually metallic nature (Matter, et al., 2013). In particular, is Psyche the core of a larger body who's mantle was somehow stripped off. The spacecraft will remain in orbit for 21 months.

How can high angular resolution from the ground support and enhance the Psyche mission? Two recent publication based on both radar (Arecibo and Goldstone) and AO (Gemini and Keck) data have already provided the team with a refined mass and volume (and hence density), as well as an improved spin pole, to assist with mission planning. (Shepard, et al., 2017; Drummond, et al., 2017)

This information has been vetted by the IAU Working Group for Cartographic Coordinates and Rotational Elements and appears in their recently submitted triennial report. (Archinal, et al., 2017, 2011)

Between now and the launch date the only ELT equipped the high angular resolution facilities available to improve on this characterization is the Large Binocular Telescope on Mount Graham in Arizona. That facilty, with both a 23m aperture and planned visible light AO system, should be able to improve by approximately a factor of 3 the current estimates for size, shape, and pole.

3 Future - 23 to 39m apertures

3.1 Lucy: 5 Trojans

The number of NASA small-body missions grew substantially in the last year (see table 1). These missions are particularly well-suited for ground-based support.

Table 1: For each of the 9 targets to be visited by spacecraft, the visual magnitude and subtended angle on the sky are given. In the last column the single letter ID for which observing mode is most optimal for our goals is given. The definition for each observing mode identifier is given in table 2.

Mission	Number	Target	Vmag	Size (mas)
LUCY	3548	Eurybates	16.8 to 17.7	13 to 20
	15094	Polymele	18.9 to 19.8	5 to 7
	11351	Leucus	17.8 to 18.8	7 to 11
	21900	Orus	16.9 to 17.9	11 to 16
	617	Patroclus	15.9 to 16.5	33 to 39
	52246	Donaldjohanson	18.3 to 20.1	2 to 4
DAWN	145	Adeona	11.0 to 13.6	56 to 133
DESTINY	3200	Phaethon	10.2 to 19.1	4 to 101
Psyche	16	Psyche	10.9 to 12.2	85 to 156
TBC	469219	HO3 2016	21.5 to 26+	0.5
Osiris-Rex	101955	Bennu	21 to 23	2 to 3

Consider the Lucy mission designed to study the 6 objects listed in table 1. The Lucy science goals are to learn the source of Trojan differences which would then provide clues to the history of the Solar System. The size and brightness range of the LUCY targets puts them out of reach for todays AO systems on 8-10m telescopes with NGS.

With visible AO on GMT, TMT, and E-ELT we will measure shape and pole of the larger (10 to 20 mas) bodies and search for satellites around all 6. This will be starting 2023.

What might be done in the meantime? 23m Fizeau Imaging on the Large Binocular Telescope could fill the 2018 to 2023 gap for observing the LUCY mission targets. With queue observing and selected observations (10 to 20 per semester), snapshots could be taken, while using only approx. 5 to 10 hours total observing time.

Our preliminary estimates show that the probability that one of these is observable via appulse on a given night is approx. 20%, i.e.; one object per week. Three particularly good mutual events for (11351) Leucus are given in table 2.

3.2 Io Volcano Observer: Io

The launch date for NASA's potential mission to Io called Io Volcano Observer (IVO) is not known, likely mid 20's at the earliest and the journey will take approximately six years.[1]

[1] One of the largest challenges for IVO has been the need to contend with the extreme radiation environment near Io, however, very recent mearurements from Juno have shown that radiation levels at the location are not as great as previously believed.

Table 2: Three close appulse events for (11351) Leucus in the coming year. Sep is the seperation in arcseconds. Dia is angular diameter in milliarcseconds. oMag is the magnitude of Leucus.

Appulse Star	Sep	Date	RA Dec	Mag	Dia	oMag
TYC25201-01009-1	2.1	2018 Jun 16.3	21 08 30 -04 39 35	10.4	10.1	18.3
UC4-427-118933	0.8	2018 Aug 5.4	20 49 06 -04 39 14	12.2	10.9	17.8
UC4-423-132916	1.4	2018 Sep 1.2	20 37 00 -05 32 31	11.9	10.1	18.0

So for this object there is plenty of time for observation with the 30-39 meter ELT, should those facilities provide the necessary instrumentation, telescope tracking and acquisition software, and wave front sensors, to observe Io.

Being the only object in the solar system with built in wave front sensing beacons that are both bright and point-like, Io provides the best opportunity to show off high angular resolution, should ELT have the right instumentation.

For both IVO, and the Europa Clipper discussed in the next section, we note that ground based facilities will be able to respond to detections of suspected activity or changes in activity in ways that fly-by spacecraft cannot do and where orbiting spacecraft may also be limited.

3.3 Europa Clipper: Europa

Eruopa is a mysterious object. For example, it is not well known which species are present on the surface, nor whether these were deposited externally (e.g. transported from Io), or arrived via upwelling through the ice shell from the subsurface ocean. In the latter case, the composition of the minerals tells us something about the composition of the ocean, and therefore whether it is capable of supporting life.

Europa Clipper will launch around 2025 and arrive at Europa 5 years later.

Among the features that might be observed from the ground to prepare for the arrival of the Clipper are the water plumes. From a NASA press release we see what might be possible: "Out of 10 observations, Hubble saw what may be water vapor plumes on three of the images. This adds another piece of supporting evidence to the existence of water vapor plumes on Europa; Hubble also detected spectroscopic signatures of water vapor in 2012"

Could plumes, like the one imaged with New Horizons on Io in the visible (see figure 4), be observed on Europa with visible wavelength AO systems on future ELT? We are investigating this intriguing possibility as a science case for future visible AO systems.(Antoniucci, et al., 2017) Moreover, using SCAO mode and Europa itself as the reference we may achieve about 10% Strehl in the R band using MAORY/MICADO on the EELT with intriguing performance in terms of FWHM in the range 0.5-0.7 um.

4 Conclusion

The role role of ground-based telescopes for remotely supporting spacecraft missions is expanding. In particlar, the role of high angular resolution, has become a game-changer in this area. Past missions, like the Rosetta fly-by of Lutetia, have demonstrated the value of ground based observations in supporting the mission and increasing scientific return. Future missions like the Journey to Psyche, Io Volcanic Observer, and the Europa Clipper will benefit from observations from ELT, should those facilities be properly instrumented for solar system observations. Ground based facilities will also be able to "visit" many of the millions of small bodies not planned for spacecraft exploration, and will also respond to detections of suspected activity or

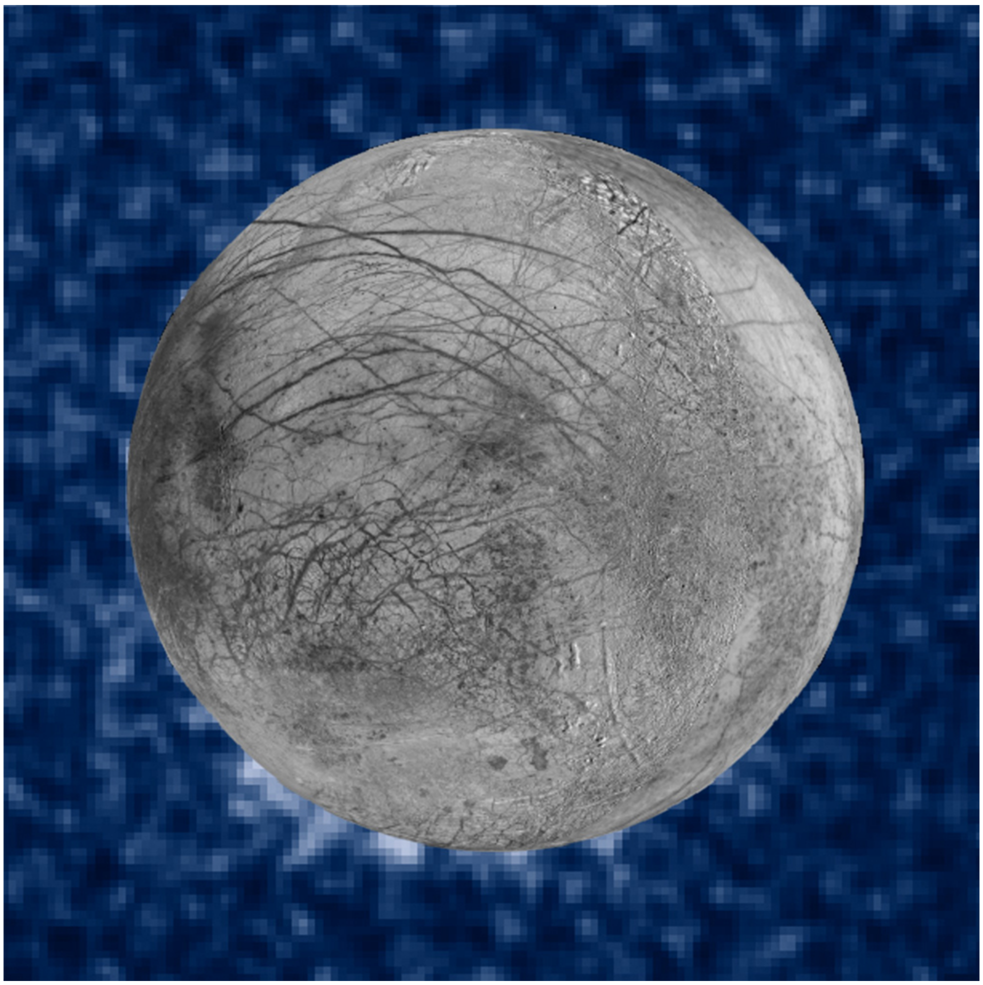

Figure 3: Suspected water plumes seen by HST on Jupiter's icey moon Europa. Credit: NASA.

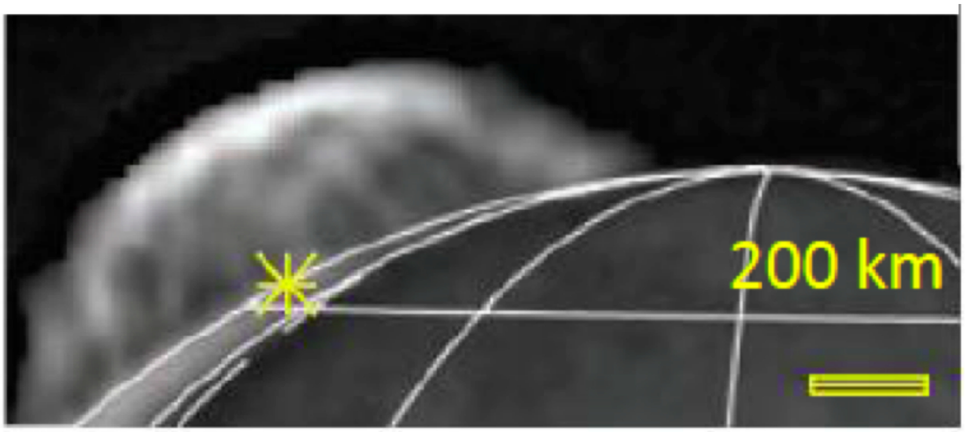

Figure 4: Voyager image of volcanic plume on Io with scale bar showing that the structure is within the resolving capability of ground-base visible AO systems. Credit: Antoniucci, S.

changes in activity in ways that fly-by spacecraft cannot do and where orbiting spacecraft may also be limited.

5 Acknowledgements

The authors thank Cathy Olkin and the LUCY team for providing the appulse information that appears in table 2, Katherine de Kleer for information on Europa science potential, and Simone Antoniucci for re-use of figure 4.

References

Antoniucci, S. et al 2017 Science with SHARK-VIS *Presentation given at the SHARK-VIS FDR, Sep. 21, 2017, Tucson, AZ*

Archinal, B. et al 2011 Report of the IAU Working Group on Cartographic Coordinates and Rotational Elements: 2009 *CM*, **109**

Archinal, B. et al 2017 Report of the IAU Working Group on Cartographic Coordinates and Rotational Elements: 2015 *CM*, **in press**

Carry, B. et al 2012 Shape modeling technique KOALA validated by ESA Rosetta at (21) Lutetia *P&SS*, **66**

Defrère, D. et al 2008 Nulling interferometry: performance comparison between space and ground-based sites for exozodiacal disc detection *A&A*, **490**

Carry, B. et al 2010 Physical properties of the ESA Rosetta target asteroid (21) Lutetia. II. Shape and flyby geometry Shape modeling technique KOALA validated by ESA Rosetta at (21) Lutetia *A&A*, **523**

Drummond, J. et al 2010 Physical properties of the ESA Rosetta target asteroid (21) Lutetia. I. The triaxial ellipsoid dimensions, rotational pole, and bulk density Shape modeling technique KOALA validated by ESA Rosetta at (21) Lutetia *A&A*, **523**

Drummond, J. et al 2017 The triazial ellipsoid size, density, and rotational pole of asteroid (16) Psyche and Gemini AO Observations 2004-2015 *Icarus*, *in press*

Matter, A. et al 2013 Evidence of a metal-rich surface for the Asteroid (16) Psyche from interferometric observations in the thermal infrared *Icarus*, *226*

Merline, W. J. et al 2010 A Keck Search for Faint Satellites of Pluto in Support of New Horizons *AAS/DPS*, **44**

Shepard, M. et al 2017 Radar observations and shape model of asteroid 16 Psyche *Icarus*, *281*