TITLE: Super-resolution mapping for Jupiter and Saturn icy moons: applications to future observations of JUICE and Dragonfly missions

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Cassini-Huygens was the first mission specifically dedicated to studying Saturn and its satellites. Launched in 1997, Cassini-Huygens was inserted into Saturn's orbit in 2004. Initially scheduled to last 4 years, the mission has been extended until 2017. The Cassini-Huygens mission was designed to explore the Saturn system, including its rings, magnetosphere and icy moons. Saturn's icy moons have been mapped at optical wavelengths by the Imaging Science Subsystem (ISS) and hyperspectral Visual and Infrared Mapping Spectrometer (VIMS) instruments during numerous flybys. Because of the highly variable flyby geometries, these data were acquired at very different spatial resolutions and under changing observation conditions. When the acquisition geometry is too extreme, for example for very high angles of incidence and/or emergence, the data are difficult to reconcile to form homogeneous mosaics, mainly because of the photometric properties of the surface and the strong atmospheric contributions in the particular case of Titan. This makes the complete fusion of all the images acquired, and the analysis of the resulting mosaics, very difficult.

In a similar way to Cassini, the payload of the JUICE mission, dedicated to the study of the Jupiter system (with particular emphasis on its icy Galilean moons thought to harbour underground oceans of liquid water), will include both a high-resolution camera (JANUS) and a hyperspectral imaging spectrometer (MAJIS). The combined acquisition of high-resolution images by JANUS and hyperspectral cubes by MAJIS will enable a detailed geological and compositional study of these moons, as can be done on Titan by combining information from ISS and VIMS (e.g. Seignovert et al., LPSC 2018). Launched in April 2023, with insertion into Jovian orbit scheduled for 2031, the probe will carry out several flybys of three of Jupiter's largest moons, namely Callisto (20 targeted flybys), Europa (2) and Ganymede (12). It will then orbit Ganymede for more in-depth studies, which will be completed in 2035. Once again, these different observation and spatial resolution conditions represent a major challenge when it comes to reconciling all the data for a specific instrument in the first instance (JANUS or MAJIS), and for several instruments in the second instance (JANUS and MAJIS).

Our research team has developed a new methodology for combining a large number of overlapping observations to increase the spatial resolution of icy satellite surface maps. This super-resolution method aims to merge highly variable data sets, which may come from different optical remote sensing instruments, and restore a higher resolution mosaic from several lower resolution images. This requires the implementation of a reliable map reprojection procedure and a precise and reliable correction algorithm for (1) the photometry of icy surfaces and (2) atmospheric scattering and absorption in the case of Titan. For Titan, we have also developed a radiative transfer algorithm that simulates the infrared spectra of Titan's atmosphere and surface. This algorithm uses inversion to extract physical information about the optical properties of Titan's atmospheric and surface components from infrared observations, in particular the surface albedo. This algorithm is very costly in terms of computing time, and has only been used very locally for a limited number of observations. More recently, we have developed a specific algorithm for the massive inversion of observations. This algorithm is still in the testing and validation phase.

In this context, this thesis proposal can be broken down into two main, complementary areas:

(1) **Super-resolution and composition of Titan's surface at regional and global scales with Cassini and the JWST; preparation of the Dragonfly mission.** The aim of this work will be to use the radiative transfer and super-resolution mapping algorithms developed by our team (in Fortran90, C, IDL and Python languages) to produce a global super-resolved reflectance map of Titan's surface, corrected for atmospheric contributions (absorption and scattering by gases and aerosols), based on all the infrared hyperspectral images of Titan acquired by Cassini in the 0.8-5 µm spectral range (VIMS instrument) between 2004 and 2017. This represents several hundred million spectra to be processed and analysed. This reflectance map can then be used to identify candidate materials for surface composition. Combined with the high spatial resolution Cassini/RADAR observations of dunes, mountains, rivers and seas, knowledge of the materials present on the surface will help us to better constrain the geological and climatic history that led to the formation of these landscapes (by mechanical and/or chemical erosion by wind and/or methane rain?). Observations from the JWST's NIRSPEC instrument, in the same wavelength range as VIMS but with much higher spectral resolution, will make it possible to check, and correct if necessary, the atmospheric inputs to the radiative transfer model and help identify the composition of Titan's surface. It will also be possible to help prepare for future observations of Titan's lower atmosphere and surface by the cameras that will equip the Dragonfly drone, particularly of its landing site (Selk crater) and its immediate surroundings.

(2) **Preparation of the future MAJIS and JANUS observations of the JUICE mission.** Validated on Enceladus (before this thesis) and Titan (objective (1) of this thesis), the super-resolution mapping approach will finally be applied to the satellites of Jupiter (Europa, Ganymede and Callisto) using synthetic tests and all the available observations acquired by the Voyager and Galileo probes, as well as JUNO and New Horizons during their Jupiter and icy moon flybys. This will help to prepare the JUICE mission, by increasing the scientific feedback from previous missions and helping to optimise the programming of future JANUS and MAJIS observations for JUICE.