ÉCOLE DOCTORALE
SCIENCES DE LA TERRE ET DE L'ENVIRONNEMENT
ET PHYSIQUE DE L'UNIVERS, PARIS

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TITLE: Development of super-resolution mapping and analysis methods for icy moons: applications to Enceladus, Titan, Ganymede and Callisto, and to future observations of JUICE and Dragonfly missions.

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Financing: **Doctoral contract with or without teaching assignment**

Presentation of the subject: (Maximum 2 pages)

Cassini-Huygens was the first dedicated mission to study Saturn and its satellites. Launched in 1997, the spacecraft was inserted in Saturn's orbit in 2004. Planned for an initial duration of 4 years, the mission was finally extended until 2017. The Cassini-Huygens mission was designed to explore the Saturn system, including its rings, magnetosphere and moons, with a special focus on Titan. The latter has been mapped at optical wavelengths by the Imaging Science Subsystem (ISS) and the Visual and Infrared Mapping Spectrometer (VIMS) during 127 targeted flybys. ISS, composed of two multispectral framing cameras, provided information on the surface brightness (Porco et al., Nature, 2005). VIMS acquired hyperspectral images (352 spectral channels ranging from 0.4 to 5.1 µm), providing not only information on the composition of the surface but also the physical state of the surface materials. However, due to highly variable flyby geometries, these data have been acquired at very different spatial resolutions and with changing observation conditions. When the acquisition geometry is too extreme, e.g. very high angles or grazing observation conditions, data are difficult to reconcile with each other into homogeneous surface mosaics, essentially due to Titan's atmosphere contributions and surface photometry. This makes the comprehensive merging of all the acquired images and the analysis of the resulting mosaics quite challenging.

In a similar way to Cassini, the payload of the JUICE mission, dedicated to the study of the Jupiter system with a special focus on its icy Galilean moons thought to harbor subsurface 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 permit a detailed geological study of these moons, as can be done on Titan when combining ISS and VIMS information (e.g. Seignovert et al., LPSC 2018). Scheduled for launch in 2022 and insertion into Jovian orbit at the end of 2029, the probe will perform 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 further study, which will be completed in 2033. These different conditions of observation and achievable spatial resolution present a major challenge when it comes to reconcile the entire dataset for one specific instrument in a first step (JANUS or MAJIS), for several instruments in a second step (JANUS and MAJIS).

Super-resolution methods aim to merge highly varying dataset and restore higher resolution image from multiple lower resolution images taken from different positions or viewing angles. On Titan, the most detailed ISS global map has been produced so far by Karkoschka et al. (LPSC, 2017, Figure 1), by combining different corrections taking into account the surface photometric behavior, the image stacking to decrease the signal to noise ratio, the navigation accuracy and the ISS cameras' point spread function. The method uses ≈25 times as many images per location as used before, improving the signal to noise ratio and the spatial resolution by up to a factor of ≈5, which is the best attempt so far to implement super-resolution on Cassini dataset. Regarding VIMS data, a global map of Titan combining characteristic wavelengths has already been produced by Le Mouélic et al. (Icarus, 2019, Figure 2). Nevertheless, in this approach, only the most resolved cube of a given area is used and included in the mosaic. It does not merge observations at different spatial resolution. Besides, the atmospheric contributions and surface photometric behavior are still to be improved to reach the accuracy required to correctly implement the super-resolution.

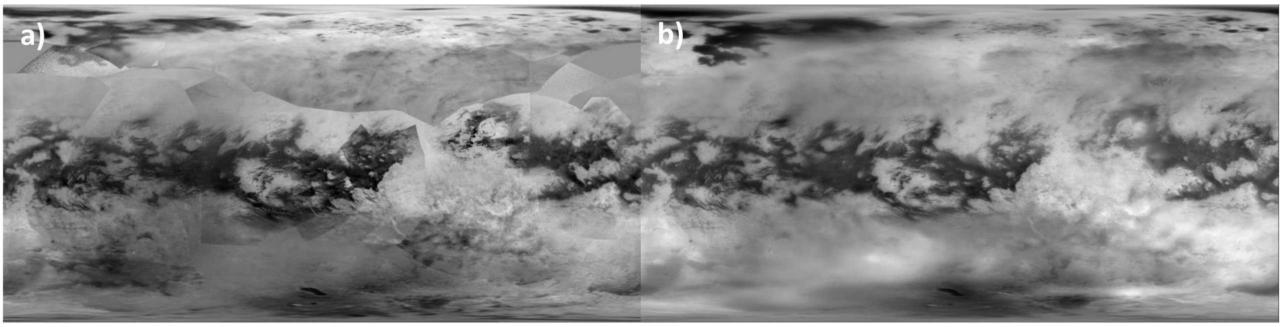

Figure 1: a) Previous Titan mosaic (Cassini image PIA 19658), based on images taken by the Cassini spacecraft's Imaging Science Subsystem (ISS). b) Global mosaic of Titan based on ≈10000 Cassini ISS images taken in the CB3 filter (938 nm). Image seams were eliminated. Apparent spatial resolution was improved by combining many images, reaching ≈1 km.

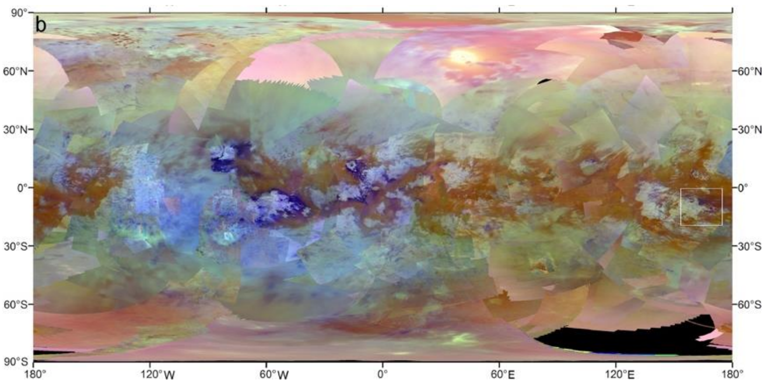

Figure 2: VIMS RGB color map empirically corrected for the airmass dependence (from Le Mouélic et al., Icarus, 2019). The average spatial reolsution is ≈10 km, reaching very locally 500m.The map still presents residual seams and do not take advantage the high number of overlapping VIMS images to increase the overall spatial resolution.

We plan to develop the super-resolution approach specifically for the extensive VIMS dataset. Karkoschka et al. (LPSC, 2017)'s method applied to VIMS dataset will permit to benefit from VIMS multitemporal and overlapping observations in order to improve surface spatial resolution, signal to noise ratio and possibly derived sub-pixel spectral variations. We thus plan to produce new global infrared maps of Titan at the best possible theoretical spatial resolution available, taking advantage of the entire VIMS dataset (60000+ datacubes). This will require the implementation of a reliable procedure for re-projection, i.e. to refine the geometric co-registration of VIMS cubes. Before merging all the spectro-images, this will also require to derive an accurate correction for 1) atmospheric scattering and absorption using both empirical (Le Mouélic et al., Icarus, 2019) and radiative transfer approaches (Cornet et al., LPSC, 2017) and 2) for the surface photometry. In the end, we aim to merge our global super-resolved VIMS map of Titan with the Karksochka et al. (LPSC, 2017)'s ISS map to end up with a the best achievable Titan's global map in the infrared, with a possible application to the preparation of the Dragonfly mission.

Validated on Titan, the developed approach will finally be applied on Ganymede using synthetic tests and available observations acquired by Voyager, Galileo as well as JUNO and New Horizons during Jupiter's flybys, in preparation of the observations of JUICE. The objective is to get the best of the forthcoming available data to improve the spatial resolution at global and local scales.

It should be noted that our team is associated with the VIMS and ISS instrument teams of the Cassini spacecraft and therefore has access to all data and official processing pipelines.