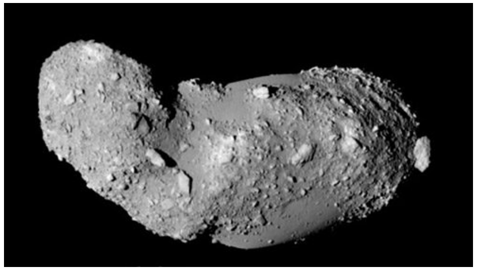
INGMAR

IrradiatioN de Glaces et Météorites Analysées par Réflectance VIS-IR

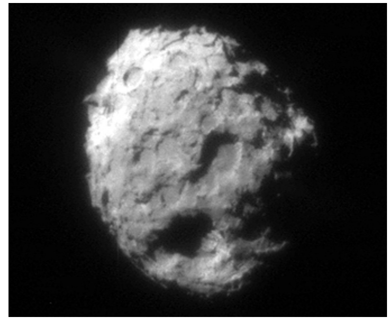
Rosario BRUNETTO
Institut d'Astrophysique Spatiale
Bât 121
91405 Orsay, France
rosario.brunetto@ias.u-psud.fr

Marie GODARD
Centre de Sciences Nucléaires et de Sciences de la Matière, Bât 104,
91405 Orsay, France
marie.godard@csnsm.in2p3.fr

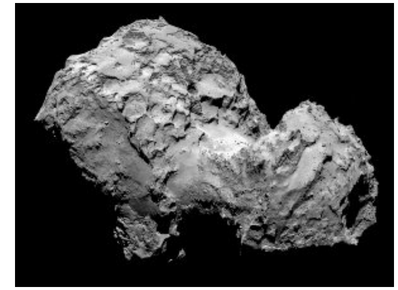
Small Solar System Bodies



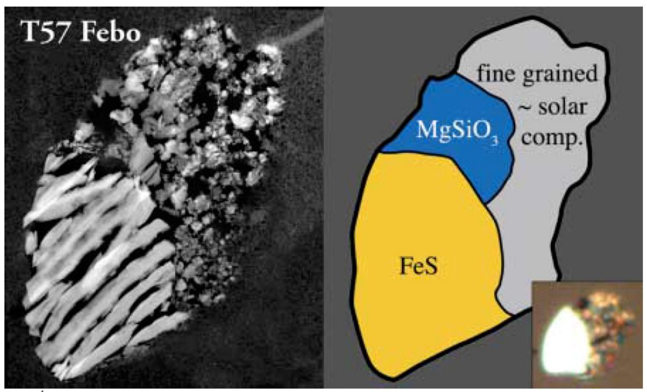
Itokawa, JAXA



Wild 2, NASA

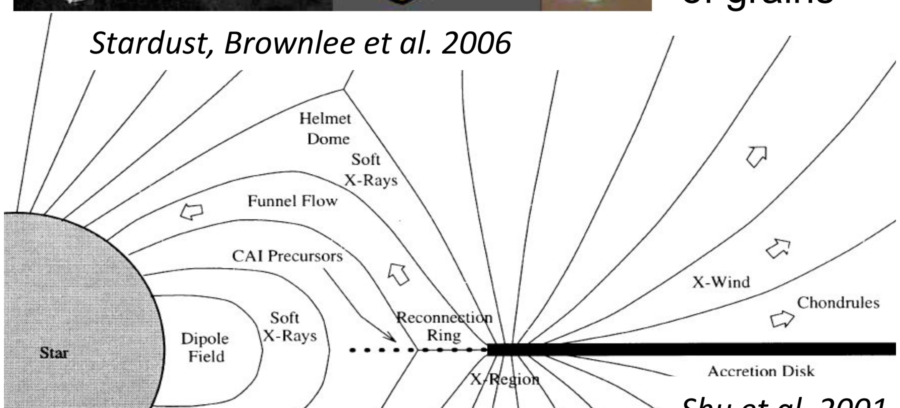


67P/C-G, ESA

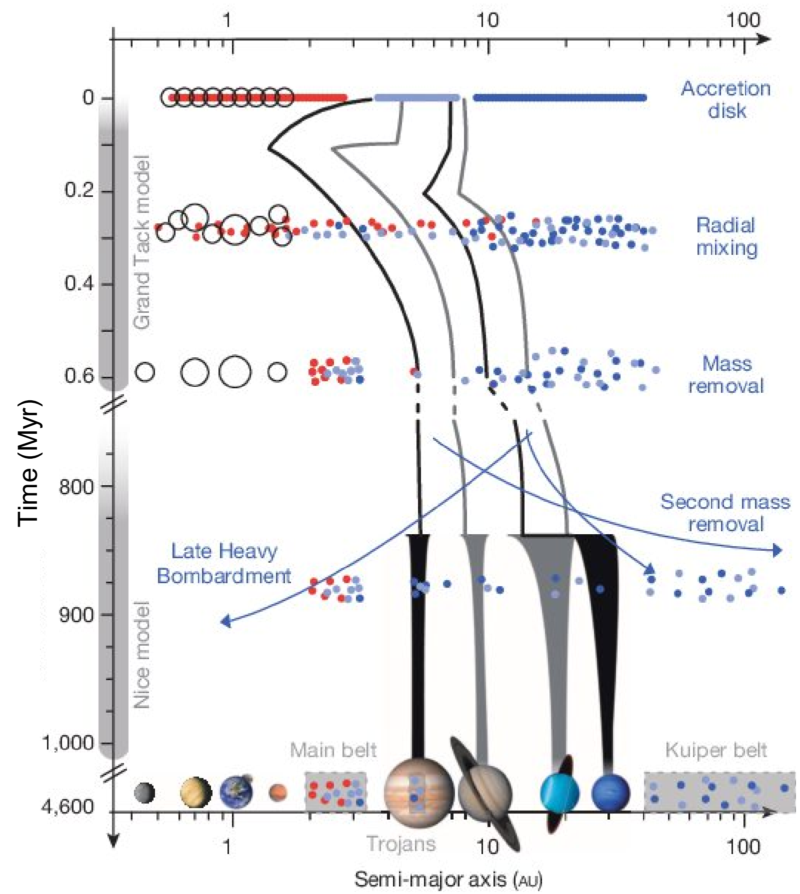


Radial mixing of grains

Stardust, Brownlee et al. 2006

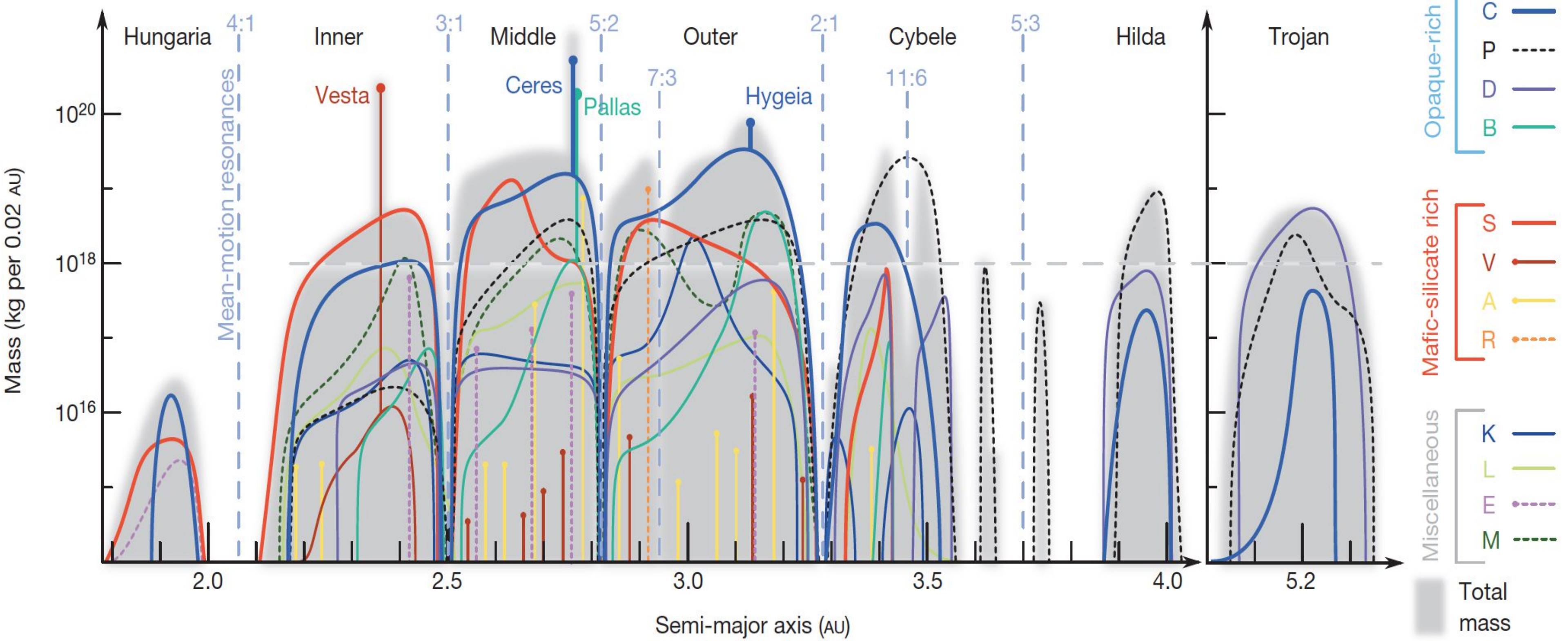


Shu et al. 2001



Walsh et al. 2011 ; Morbidelli, Levison, Gomes, Bottke, et al.

The distribution of asteroids: a new view of the Main Asteroid Belt

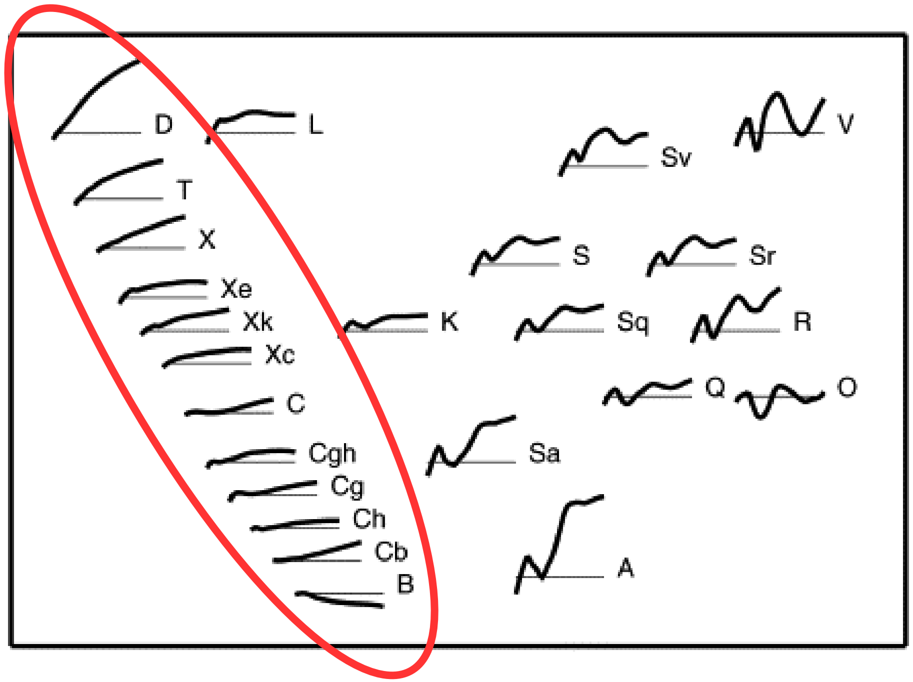


DeMeo & Carry 2014

“Excluding the four most massive asteroids, primitive material (C-, P-types) account for more than half main-belt and Trojan asteroids by mass”

→ huge biases in the meteorite collections

Compositional information obtained though
VIS-NIR reflectance observations → taxonomy



DeMeo et al. 2009
Asteroid Taxonomy

Microscopy – reflectance – ion irradiation

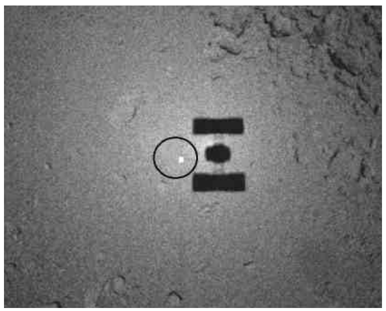
- Largely studied for the Moon and S-type Asteroids. **Open questions for primitive bodies**.

Space weathering

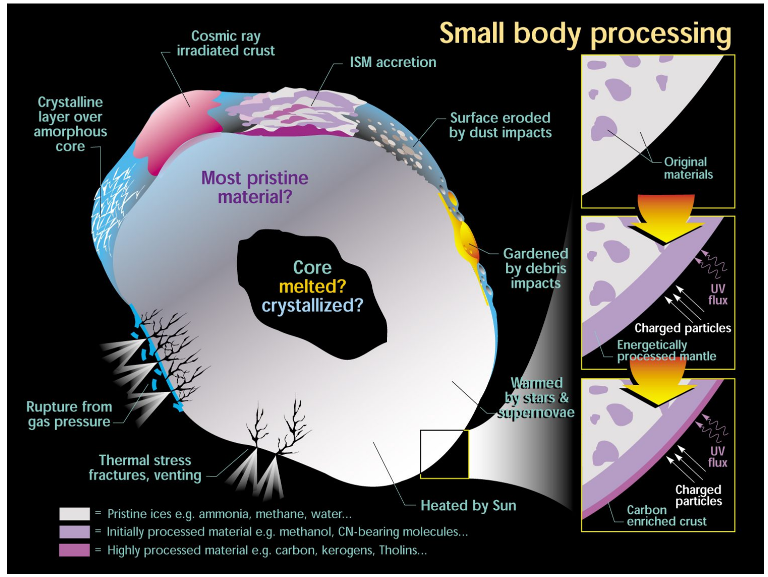
The majority of small solar system bodies is affected by weathering processes induced by solar wind and cosmic ions.

Interpreting observed reflectance spectra requires the comprehension of mechanisms determining surface evolution.

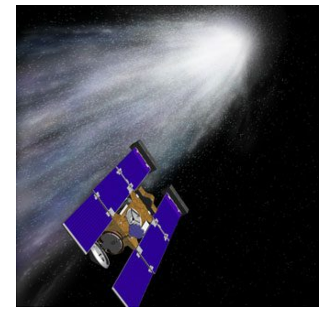
Asteroids



JAXA



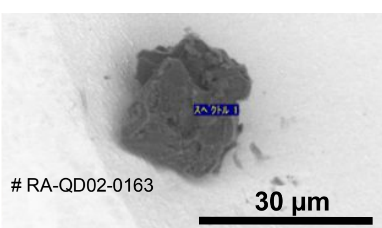
Comets



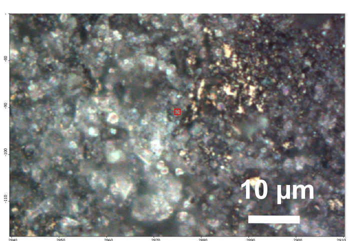
NASA

Extraterrestrial materials

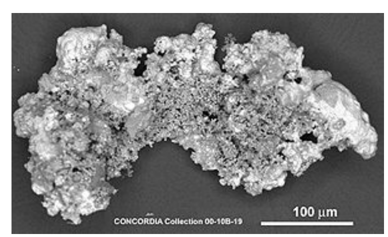
Particles from asteroid Itokawa
collected by Hayabusa



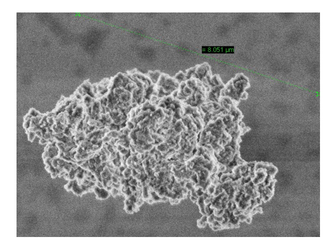
Primitive meteorites



IDPs & Micrometeorites from Antarctica



Comet Wild 2 particles
collected by Stardust



Ion irradiation experiments

Bibring 1978, Langevin 1978, Borg et al. 1983, 1998, Benit et al. 1987, Strazzulla et al. 1983, etc.

Laboratory experiments can help understanding surface weathering and spectral variations of small bodies.
The majority of VIS-NIR studies has been performed on high albedo objects.
Few studies have been dedicated to low albedo (primitive) objects.

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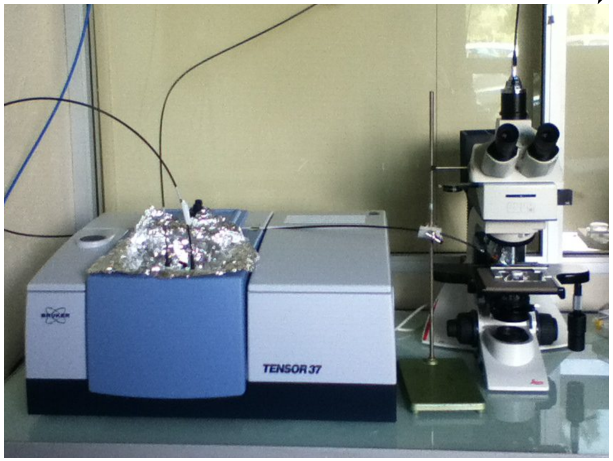
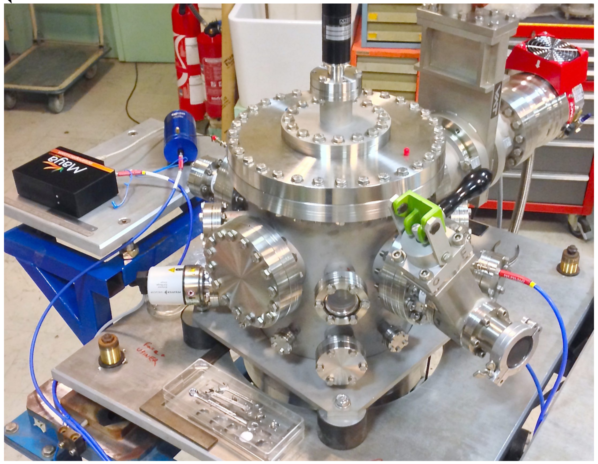




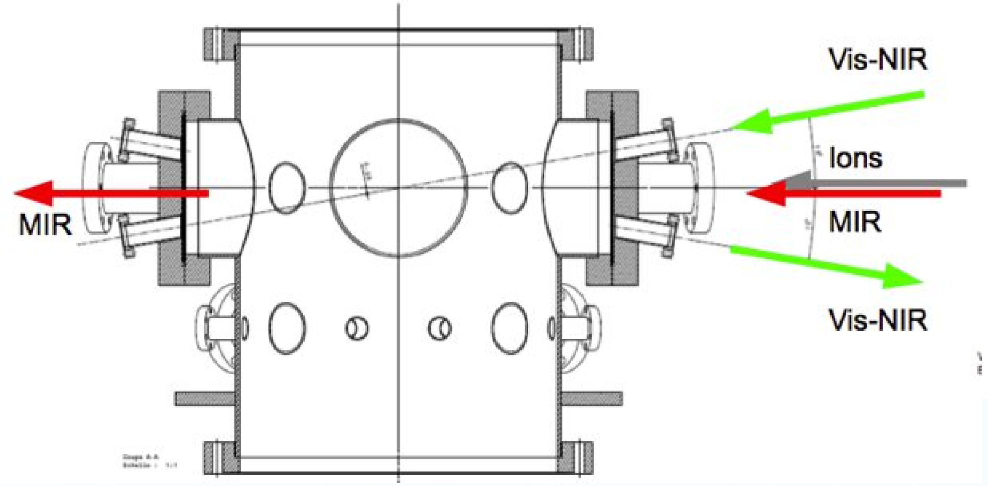
Micro-spectroscopic reflectance measurements on cometary and asteroid particles, and their analogs

0.4 – 17 µm
Reflectance & Transmittance

Ion irradiation of meteorites (and ices) rich in carbon and in-situ analysis by reflectance & transmittance

Spectra to be compared with telescopic and in-situ observations => towards a complete scenario for the irradiation-induced evolution of carbon-rich surfaces

ASTRO line @ SIDONIE (IAS-CSNSM)



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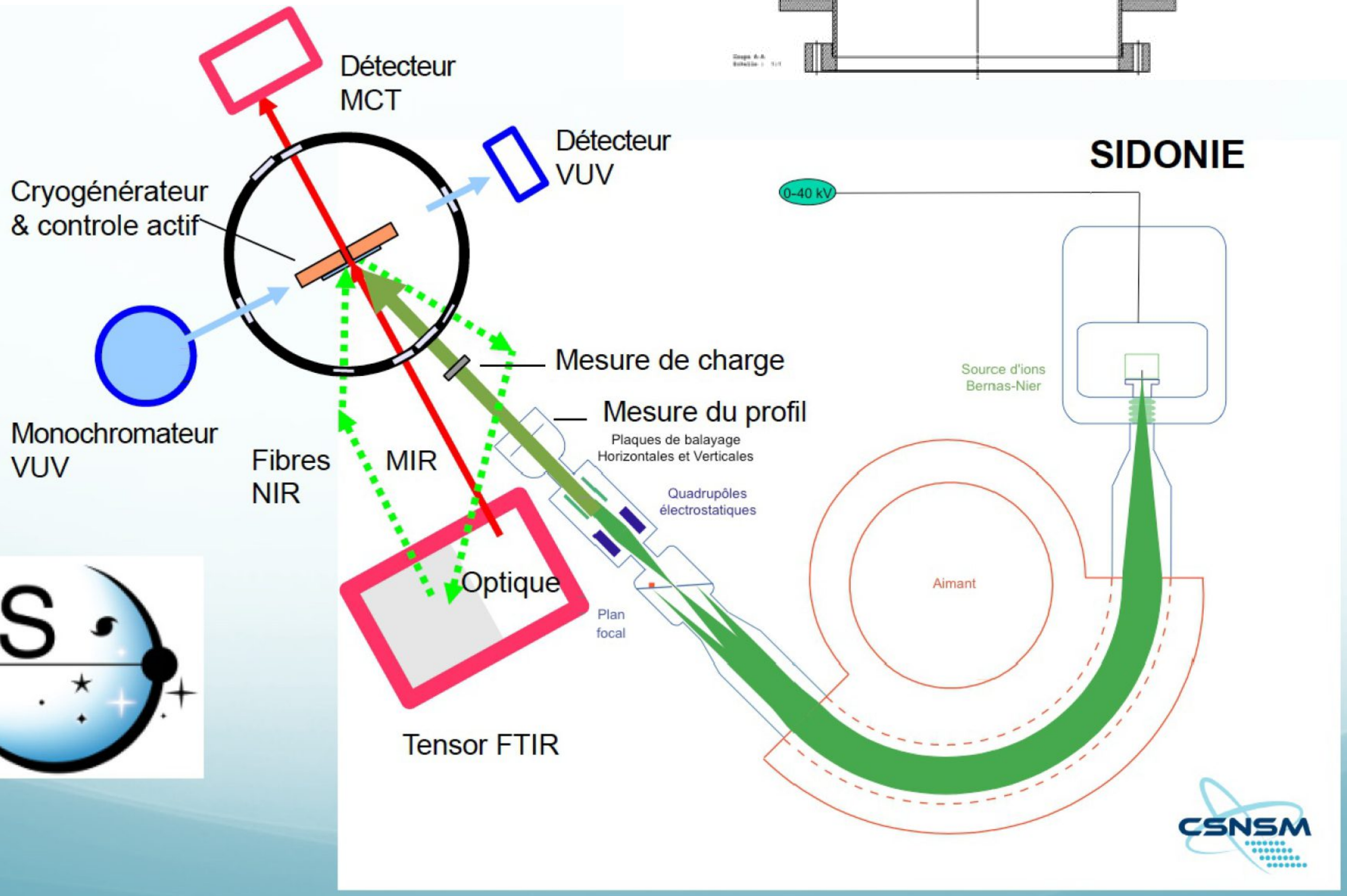
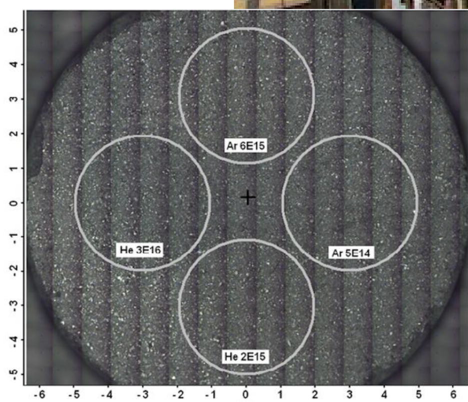


Personnels participant au projet

Nom	Grade	Fonction	Laboratoire/organisme
Rosario Brunetto	CR2	Coordinateur du projet Irradiation et réflectance	IAS, Orsay
Philippe Duret	AI-CNRS	Technicien Montage et adaptations	IAS, Orsay
Obadias Mivumbi	AI-BIATOS	Technicien Montage et adaptations	IAS, Orsay
Emmanuel Dartois	DR2	Expérimentateur Spectroscopie IR	IAS, Orsay
Donia Baklouti	MdC	Expérimentatrice Préparation et analyse	IAS, Orsay
Jean Duprat	DR2	Responsable collection micrométéorites	CSNSM, Orsay
Cécile Engrand	DR2	Préparation et analyse d'échantillons	CSNSM, Orsay
Marie Godard	MdC	Irradiation, transmission, modélisation	CSNSM, Orsay
Dominique Ledu	IE	Implantation ionique (responsable du service)	CSNSM, Orsay
Lucie Delauche	T	Préparation et microscopie	CSNSM, Orsay
Frank Fortuna	IR	Implantation ionique et microscopie électronique	CSNSM, Orsay
Cateline Lantz	Doctorante	Préparation, irradiation, analyse, application astro	LESIA, Obs Paris-Meudon
Maria Antonietta Barucci	Prof	Comparaison observations	LESIA, Obs Paris-Meudon
Eric Quirico	Prof	Préparation et analyse d'analogues	IPAG, Grenoble
Mathilde Faure	Doctorante	Préparation et analyse d'analogues	IPAG, Grenoble

First tests @ SIDONIE (CSNSM)



Ion irradiation of Allende meteorite probed by visible, IR, and Raman spectroscopies

R. Brunetto [a,*], C. Lantz [b], D. Ledu [c], D. Baklouti [a], M.A. Barucci [b], P. Beck [d], L. Delauche [c], Z. Dionnet [a], P. Dumas [e], J. Duprat [c], C. Engrand [c], F. Jamme [e], P. Oudayer [a], E. Quirico [d], C. Sandt [e], E. Dartois [a]

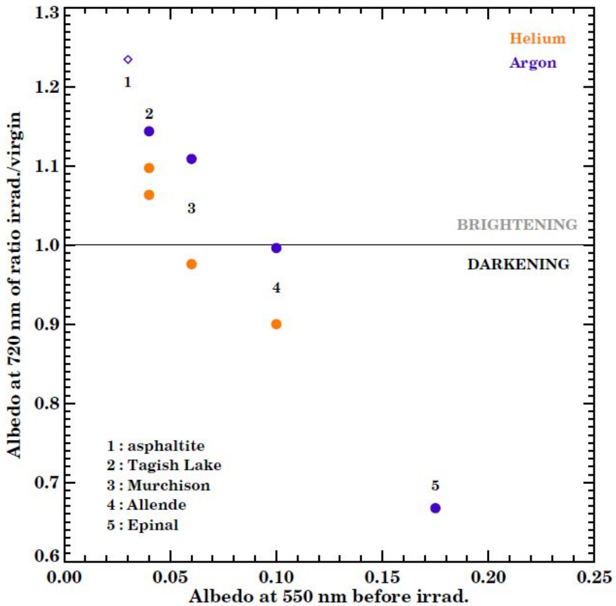
→ Icarus, 2014

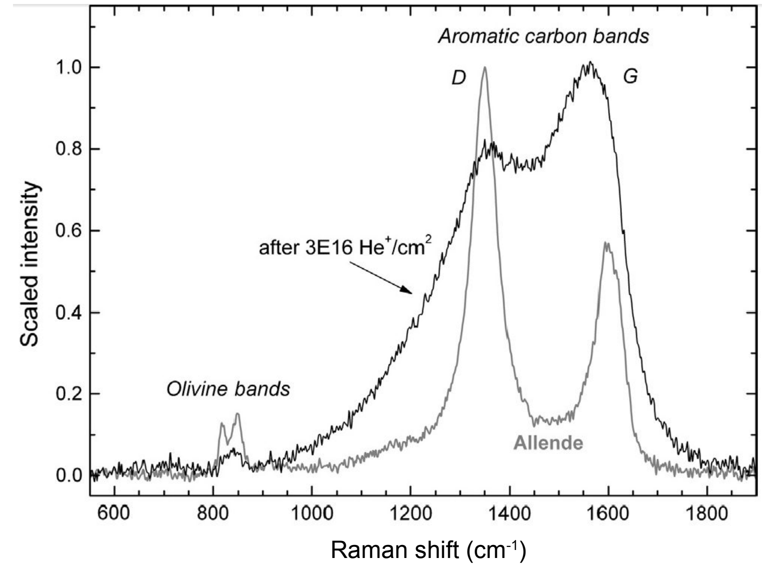
Ion irradiation of the Murchison meteorite: VIS - MIR spectroscopic results

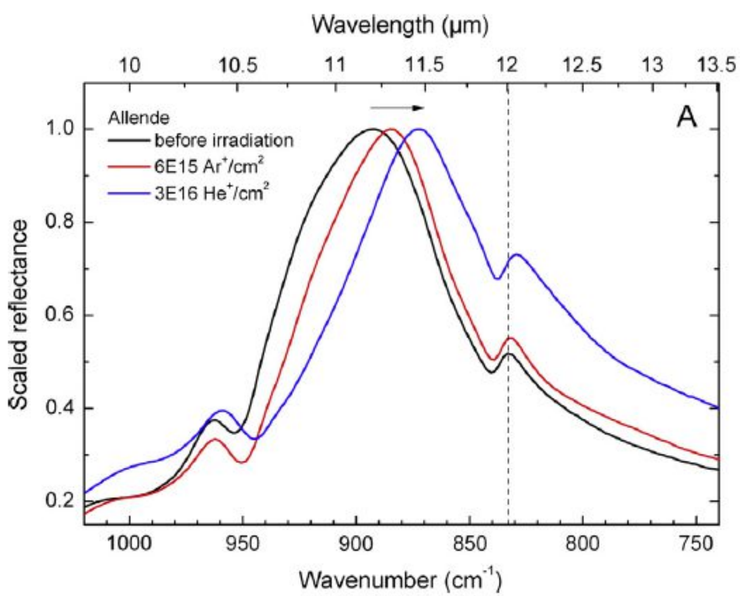
C. Lantz[1,2], R. Brunetto[3], M. A. Barucci[1], E. Dartois[3], J. Duprat[4], C. Engrand[4], M. Godard[4], D. Ledu[4], and E. Quirico[5]

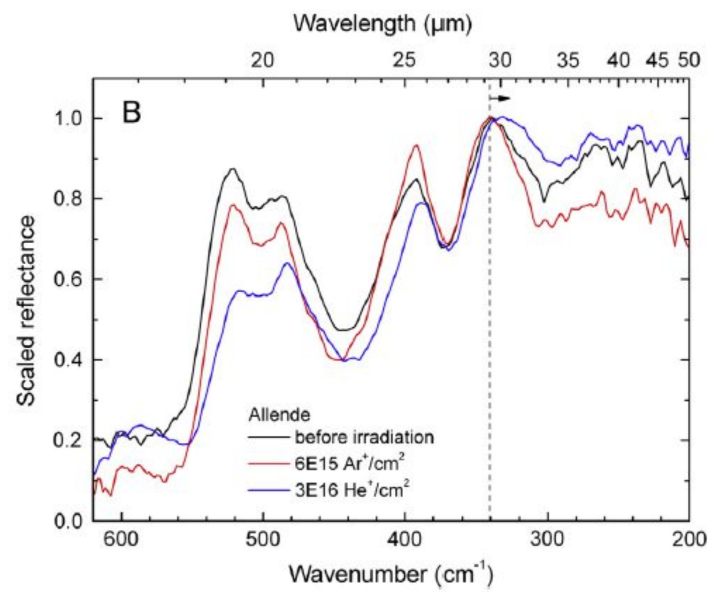
→ A&A, 2015

VIS-IR and Raman spectra: modification of silicates and of the aromatic carbon component



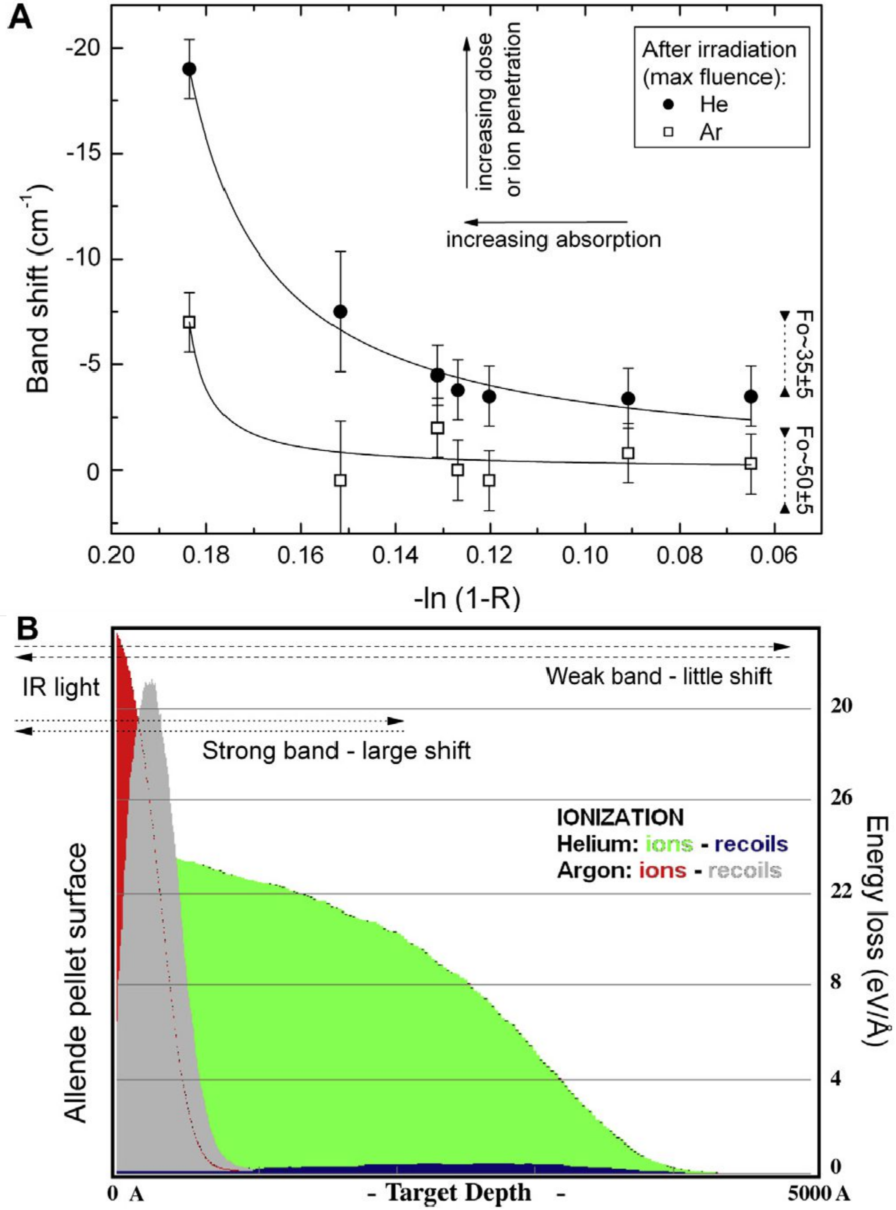






Effects on Mg/ Fe ratio

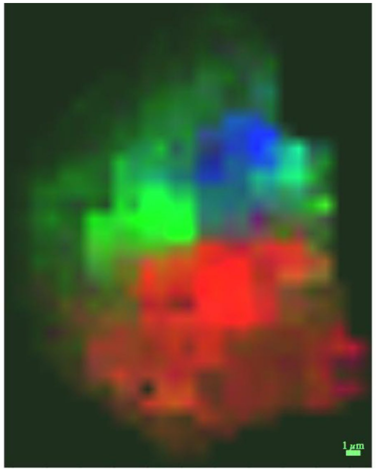
Ion	He^+		Ar^+	
Energy (keV)	40		40	
Max fluence (ions cm^{-2})	3E16		6E15	
Penetration range (nm)	300 ± 80		40 ± 15	
Initial S_e (MeV/(mg/cm^2))	0.48		0.80	
Initial S_n (MeV/(mg/cm^2))	0.021		2.5	
Energy loss (%)	Ions	Recoils	Ions	Recoils
Ionizations	85.4	2.5	18.5	22.9
Vacancies	0.2	0.5	0.3	3.5
Phonons	1.8	9.6	1.4	53.4



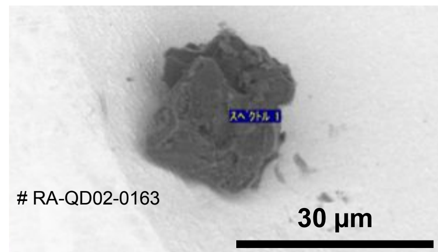
Irradiation timescales of **10^3–10^4 yrs**
in the main asteroid belt
=> very efficient rejuvenating processes

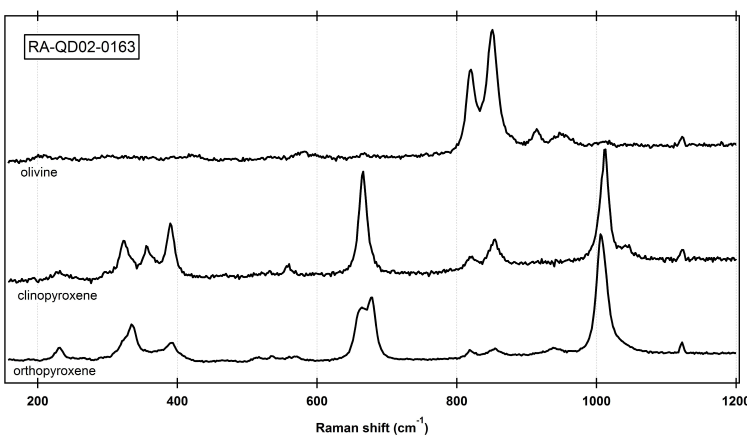
Visible-IR and Raman micro-spectroscopic investigation of three Itokawa particles collected by Hayabusa: mineralogy and degree of space weathering based on non-destructive analyses.

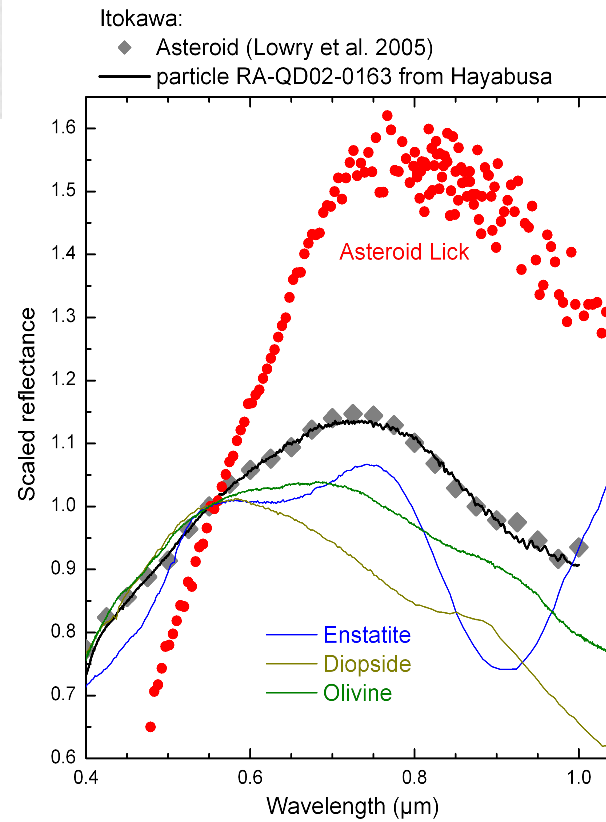
Bonal L.[1], Brunetto R.[2], Beck P.[1], Dartois E.[2], Dionnet Z.[2], Djouadi Z.[2], Duprat J.[3], Füri E.[4], Kakazu Y.[3], Montagnac G.[5], Oudayer P.[2], Quirico E.[1], and Engrand C.[3]



Enstatite Diopside Olivine



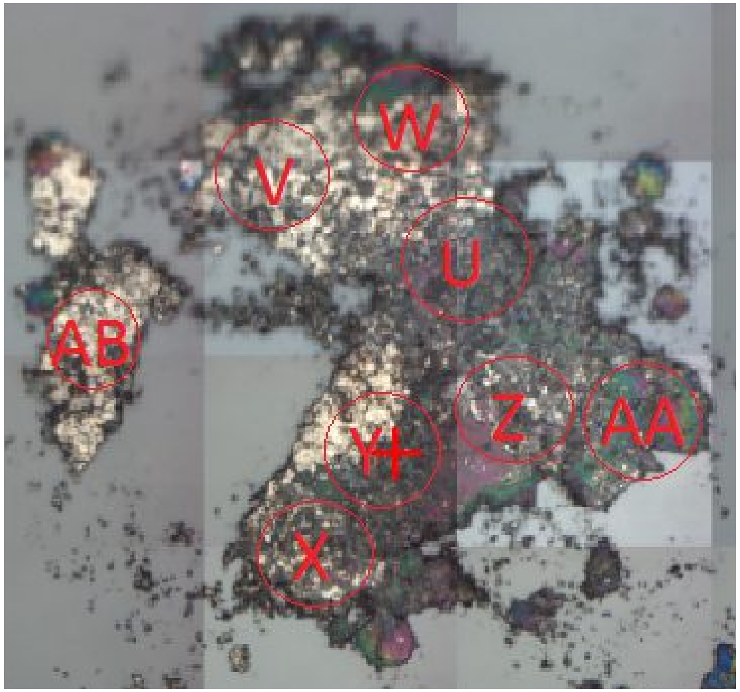




We estimate a 0.11% volume fraction of metallic iron particle inclusions in the host silicate matrix and upper limit timescales of 2 Myr for this particle

Primitive Antarctic Micrometeorites (CSNSM)

(Duprat et al. 2010, Engrand et al. 2011, Dartois et al. 2013)



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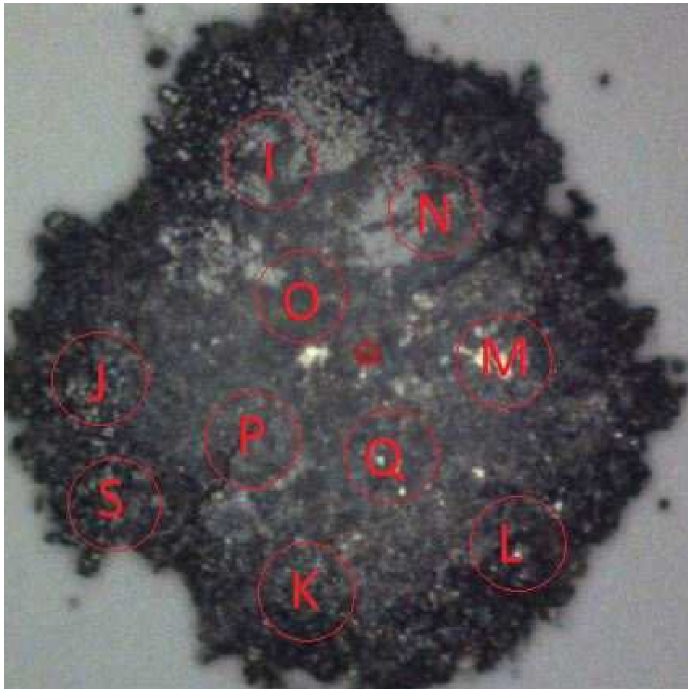
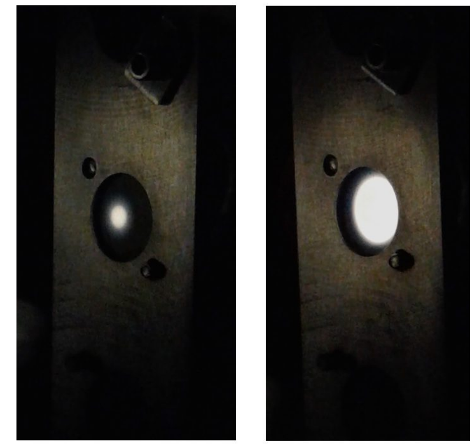


Sc DC06-11-715

Preliminary results show very low albedo (0.01-0.05) compatible to cometary nuclei

Schedule:

2013 -	Validation of INGMAR experimental approach	(Completed)
	First irradiation of meteorites and ex-situ reflectance	(Completed)
	Design and construction of the vacuum chamber	(Completed)
	Acquisition of the pumping system	(Completed)
	First test of micro-reflectance on Itokawa grains	(Completed)
	First applications to observations	(Completed)
2014 -	New irradiation on CM meteorite	(Completed)
	Acquisition of optical and spectroscopic components	(Completed)
	New measurements on two grains from Itokawa	(Completed)
	Tests with grains of the GIADA team (Rosetta)	(Completed)
	First tests with micrometeorites reflectance	(Completed)
	Assembling vacuum chamber and pumping system	(Completed)
	Coupling vacuum chamber - spectroscopy	(Completed)
	Coupling in-situ irradiation - reflectance	(Completed)
	Renewal of the platform SIDONIE	(Ongoing)
2015 -	Irradiation of different classes of meteorites	
	Irradiation of analogue samples	
	Micro-reflectance of micrometeorites	
	Multi-analysis (electron microscopy, etc.)	
	Develop a weathering scenario for low albedo objects	
	Applications to astronomical observations	
2016 …-	Extension of INGMAR to micrometeorites and ices	
	Line open to external collaborations (outside the consortium)	
	Applications for space missions	



Detailed budget plan of the project:

	Financements acquis	**Demandes de financement**			
		2015	**2016**	**2017**	**>2018**
PNP	14.5 k€	17 k€	13 k€	13 k€	-
R&D P2IO	74.5 k€				
TP P2IO	12 k€				
Crédits labo	2 k€				
Autres CNRS					
Ministère					
Régions : DIM-ACAV	10 k€				
CNES					
Contrat					
TOTAL	**113 k€**	17 k€	13 k€	13 k€	

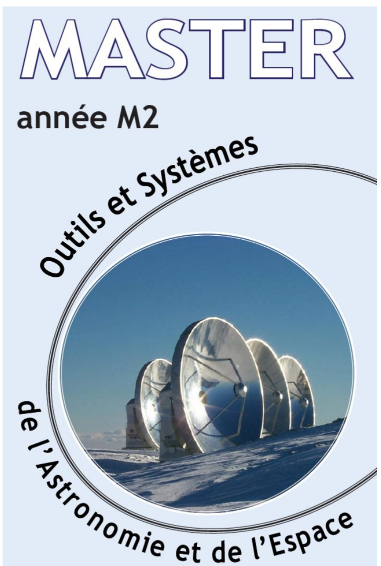
Detailed expenses on P2IO R&D budget:

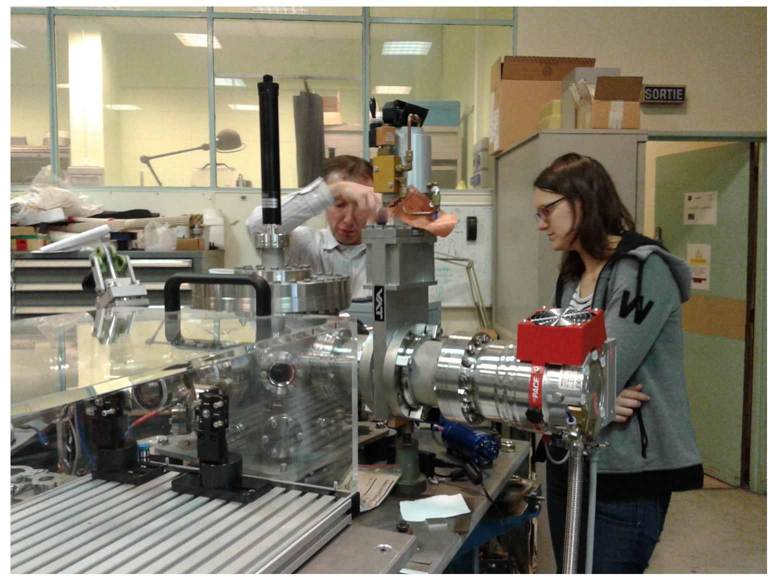
Element	**Expense**	**Year**
Pumping system	11.3 k€	2013
Spectroscopic adaptations and detectors	18.5 k€	2013
Vacuum chamber and mechanics	9.4 k€	2013-2014
Other optical elements	1.5 k€	2014
Computers	2.9 k€	2014
Sample holder and translation system	2.3 k€	2014
TOTAL EXPENDED	**45.9 k€**	
Cryogenic system and ice preparation	30 k€	2015
TOTAL TO BE EXPENDED	**30 k€**	

P2IO context

P2IO
Physique des 2 Infinis et des Origines

Activity based on a close collaboration IAS - CSNSM in Orsay, two laboratories of P2IO.
It will make available an experimental setup to the community working on ion irradiation of solids.
INGMAR can be used to perform **ion irradiation / implantation of any solid in a large range of temperatures, monitored in-situ by visible to IR reflectance and transmittance spectroscopy**.
→ opportunity for other applications (solar cells, thin films, etc.) besides Astrophysics → different communities





The INGMAR setup is already planned to be used also by students attending specific courses.
A series of TP ("Travaux pratiques") within « Environnement spatial, implantations ioniques et spectroscopie » for students of the **M2 OSAE (Outils et Systèmes de l'Astronomie et de l'Espace)** is planned for February 2015.
More activities shall be planned in the future, once the system will be fully operational.

Mission context: Rosetta, New Horizons, Hayabusa 2, OSIRIS-REx, JUICE

It is developed in the frame of a very favorable international context, thanks to upcoming space missions OSIRIS-REx (NASA) and **Hayabusa 2 (JAXA)**, designed to perform **sample returns of primitive asteroids** rich in organic compounds.

In the longer term, the implementation of a dedicated irradiation platform for solids of astrophysical applications may provide a fundamental support to the **JUICE mission (ESA)**.