Tentative searches for parent bodies of meteorites from polarimetric properties of regolithic surfaces
The case of 21 Lutetia

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Outline
Motivation
Background: Polarimetric observations and experimental simulations
Lutetia: Observations and measurements on relevant meteoritic samples

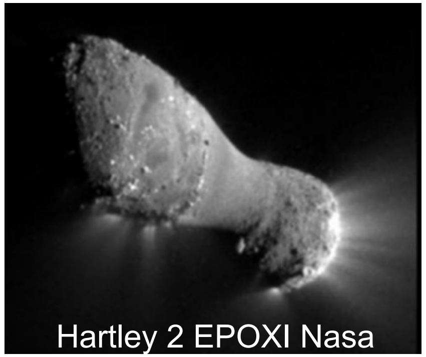
Motivation, 1

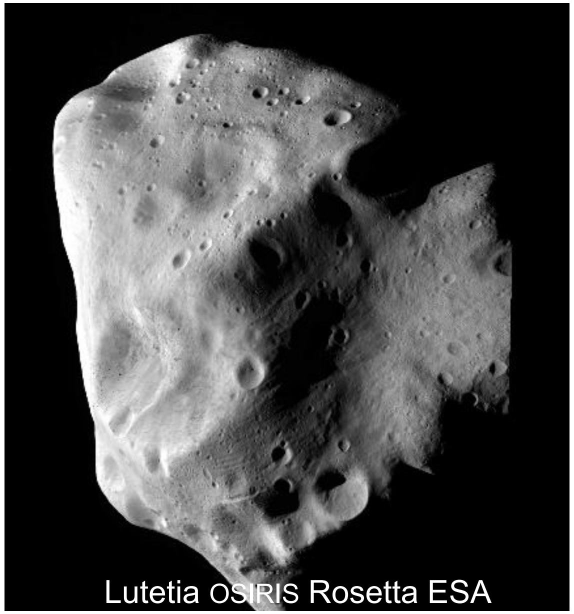
Getting clues about the parent bodies of some meteorites

Numerous meteorites collected and classified
Surface properties of quite a few asteroids extensively checked
However
Parent bodies of meteorites
of a given class hardly known

Studies triggered by Rosetta mission

2008 flyby of 2867 Steins
2010 flyby of 21 Lutetia
2014 rendezvous with
Churyumov-Gerasimenko





Motivation, 2

Approach

Comparing the properties of meteorites,

e.g. reflectance spectrum, dielectric constant,

polarization of scattered light,

to those of their potential asteroidal progenitors

Constraints

Only the surfaces of asteroids are studied,

with layers of debris (rocks, regolith)

⇨ Measurements of the properties of powders of meteorites,

with various size distributions

All meteorites are not coming from asteroids

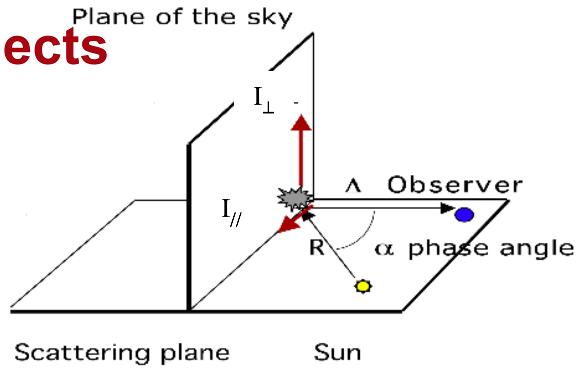
Lunar meteorites

SNC from Mars

Meteorites from comets?

Background

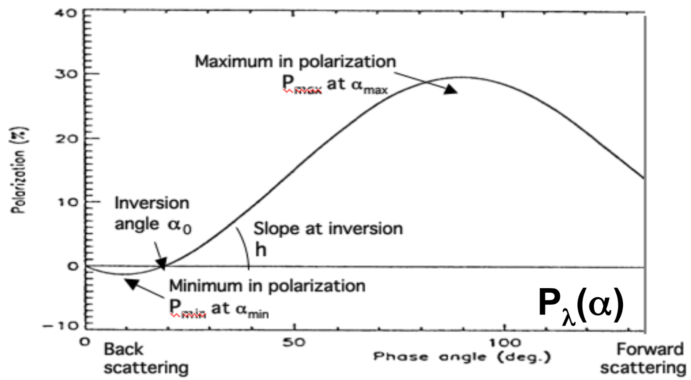
Polarimetry of solar system objects



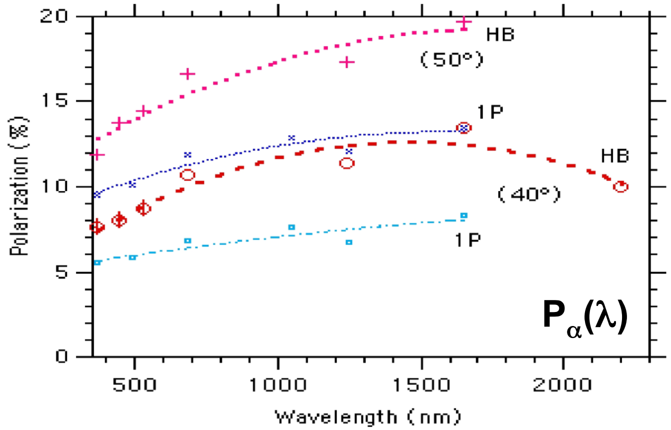
Linear polarization P, dimensionless ratio, allowing comparison of data obtained on various epochs, for one or for different objects

$$P = (I_\perp - I_{//})/(I_\perp + I_{//})$$

P varying only with phase angle α, wavelength λ and properties of the dust (e.g. albedo, structure, size distribution)



Smooth polarimetric phase curves $P_\lambda(\alpha)$, typical of scattering by irregular dust particles with a size greater than the observational wavelength (< 1μm)

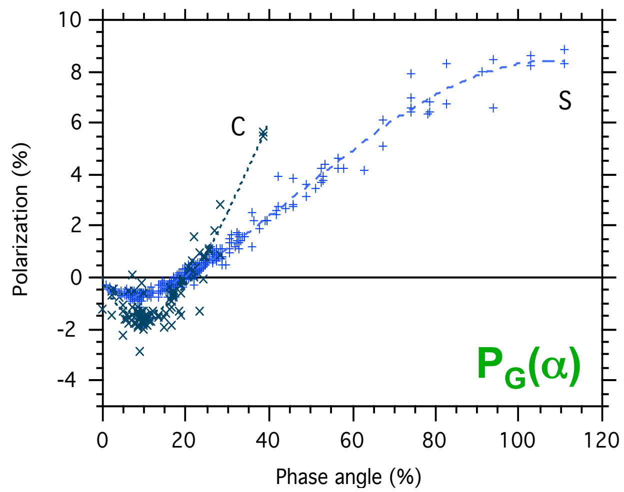


$P_\alpha(\lambda)$ curves likely to vary linearly with λ

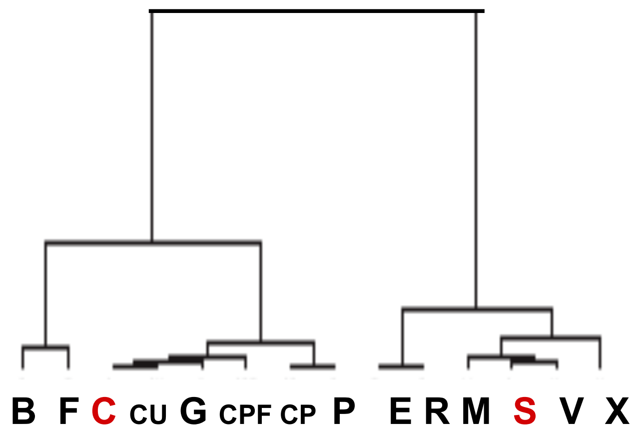
Background
Specificity of asteroidal polarimetry

Light scattered by irregular surfaces, often covered by regolithic layers

Polarimetric phase curves $P_{\lambda}(\alpha)$
- well documented for numerous S- & C- types and rather small phase angles (MBA)
- providing information that fairly agrees with taxonomic super-classes



Phase angle at inversion α_0 drastically varying, from ≈ 18° for Steins to 25° for Lutetia (Fornasier et al., 2006; Belskaya et al., 2010) and more for Barbarians (Masiero & Cellino, 2010)



Pentillä et al., 2005

Slope at inversion h and absolute value of P_{min} increasing with decreasing albedo, as defined with empirical laws (from e.g. Dollfus and Zellner, 1979 to Cellino et al., 2005), probably not valid for all types of asteroids

Background
Laboratory simulations

Available polarimetric observations needing to be interpreted in terms of properties of the scattering medium dust
(refractive indices / albedo, size distribution, structure, porosity)

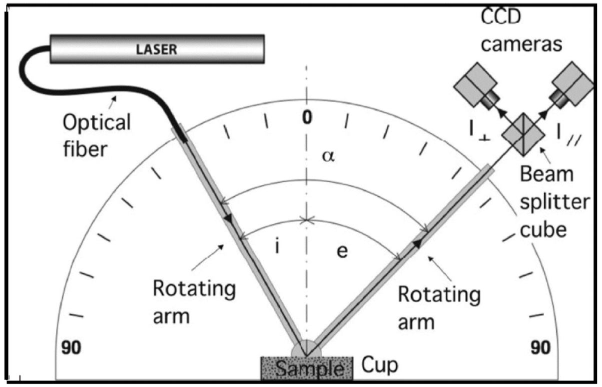
Both laboratory and numerical simulations of importance to provide clues, through complementary assumptions
(as already done for cometary dust… with clues to the presence of aggregates and compact irregular particles, consisting of both silicates and organic compounds; Lasue et al., 2006; Hadamcik et al., 2007)

Laboratory simulations of major importance
- to estimate the properties of asteroidal surfaces
(most complex numerical simulations with multiple scattering)
- to compare them to those of meteorites and provide a link

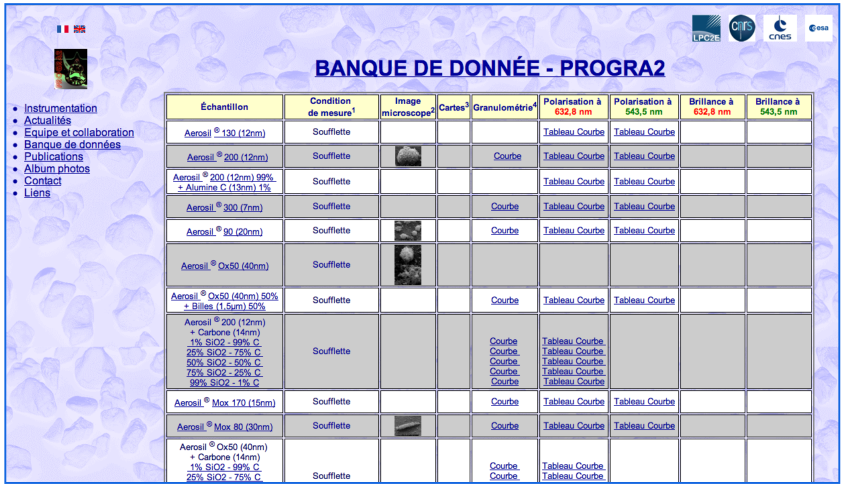
Background
PROGRA² experiments

Developed / upgraded for ≈ 15 years
Results and data bases on www.icare.univ-lille1.fr/progra2/

Analysis of light (lasers at λ = 543.5 nm & 632.8 nm) scattered (α ≈ 10° to 150°)
by a sample, providing P (for a given α and λ),
and size of the particles (and formed aggregates)



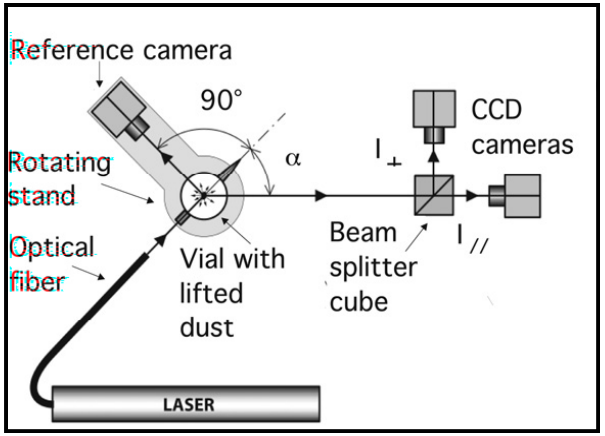
Dust sample
- Deposited on a surface, PROGRA²-surf
- Lifted in a vial, PROGRA²-vis



BANQUE DE DONNÉE - PROGRA2

- Instrumentation
- Actualités
- Equipe et collaboration
- Banque de données
- Publications
- Album photos
- Contact
- Liens

Échantillon	Condition de mesure[1]	Image microscope[2]	Cartes[3]	Granulométrie[4]	Polarisation à 632,8 nm	Polarisation à 543,5 nm	Brillance à 632,8 nm	Brillance à 543,5 nm
Aerosil ® 130 (12nm)	Soufflette				Tableau Courbe	Tableau Courbe		
Aerosil ® 200 (12nm)	Soufflette			Courbe	Tableau Courbe	Tableau Courbe		
Aerosil ® 200 (12nm) 99% + Alumine C (13nm) 1%	Soufflette				Tableau Courbe	Tableau Courbe		
Aerosil ® 300 (7nm)	Soufflette			Courbe	Tableau Courbe	Tableau Courbe		
Aerosil ® 90 (20nm)	Soufflette			Courbe	Tableau Courbe	Tableau Courbe		
Aerosil ® Ox50 (40nm)	Soufflette							
Aerosil ® Ox50 (40nm) 50% + Billes (1,5µm) 50%	Soufflette			Courbe	Tableau Courbe	Tableau Courbe		
Aerosil ® 200 (12nm) + Carbone (14nm) 1% SiO2 - 99% C 25% SiO2 - 75% C 50% SiO2 - 50% C 75% SiO2 - 25% C 99% SiO2 - 1% C	Soufflette			Courbe Courbe Courbe Courbe Courbe	Tableau Courbe Tableau Courbe Tableau Courbe Tableau Courbe Tableau Courbe			
Aerosil ® Mox 170 (15nm)	Soufflette			Courbe	Tableau Courbe	Tableau Courbe		
Aerosil ® Mox 80 (30nm)	Soufflette			Courbe	Tableau Courbe	Tableau Courbe		
Aerosil ® Ox50 (40nm) + Carbone (14nm) 1% SiO2 - 99% C 25% SiO2 - 75% C	Soufflette			Courbe Courbe	Tableau Courbe Tableau Courbe			



Background

Relevance of measurements under Earth gravity and microgravity

Particles lifted in an air draught (if small enough) or under microgravity on board the ZeroG (CNES & ESA) dedicated aircraft

Microgravity
- avoiding dust sedimentation and segregation
- comparable to that on the surface of asteroids
  ≈ 4 10^{-3} *g* for Lutetia and ≈ 2 10^{-4} *g* for Steins
- with however pull-up and pull-down

Approach of the samples properties through comparison of measurements under Earth gravity and microgravity

Previous measurements on meteorites (Worms et al., 2000) with powders of Orgueil (CI1 carbonaceous chondrite) and Allegan (H5 chondrite)
⇨ In microgravity, P_{max} usually higher (reduced multiple scattering)

Now with aubrite samples for Steins and tentative analogues for Lutetia

The case of 21 Lutetia
New polarimetric observations

Observations in Feb. 2006, May 2007 & March 2009 from OHP, France
Also in Dec. 2008 and April 2009 from IUCAA, India

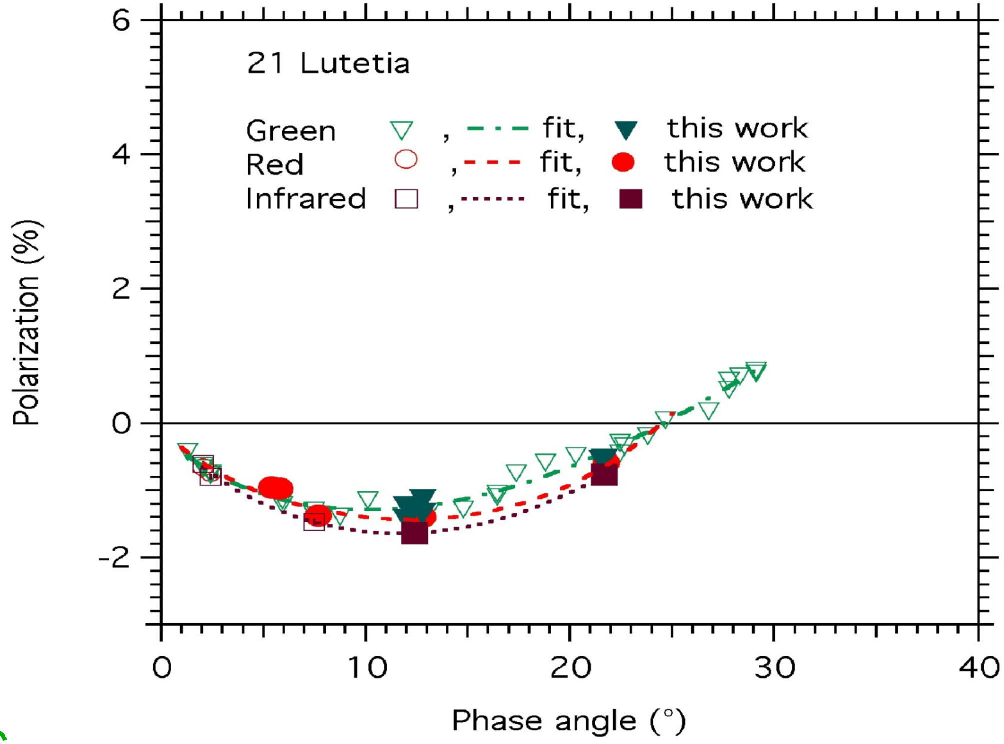
Deep negative branch

$\alpha_{min} \approx 11°$

P_{min} = (-1.31 ± 0.04)% in G
(-1.43 ± 0.06)% in R
(-1.64 ± 0.08)% in I

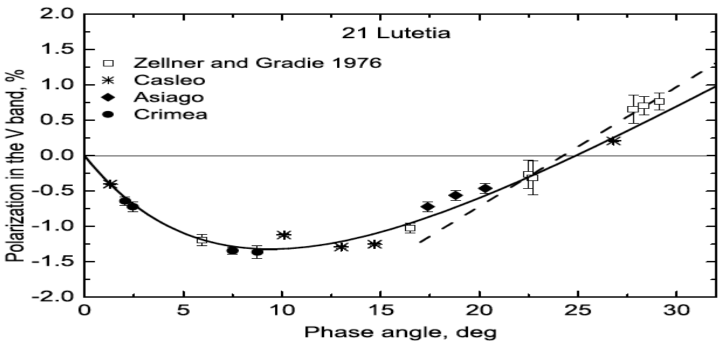
P slightly more negative
for longer wavelengths

High inversion angle, $\alpha_0 \approx 25°$
with a slope at inversion
h = (0.15 ± 0.01) percent per deg in G
⇨ Bulk geometric albedo ≈ 0.13 (?)

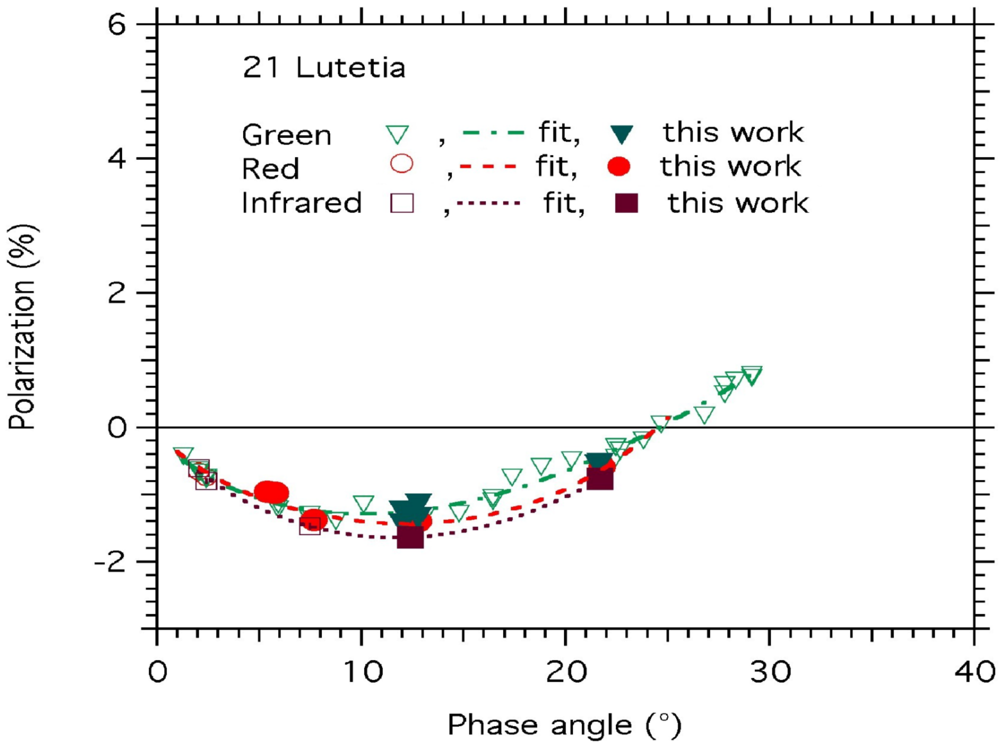


The case of 21 Lutetia
Comparison with other observations, α-dependence

Agreement with observations recently performed in Italy, Argentina and Ukraine
(Fornasier et al., 2006; Gil-Hutton, 2007; Belskaya et al., 2009 & 2010)

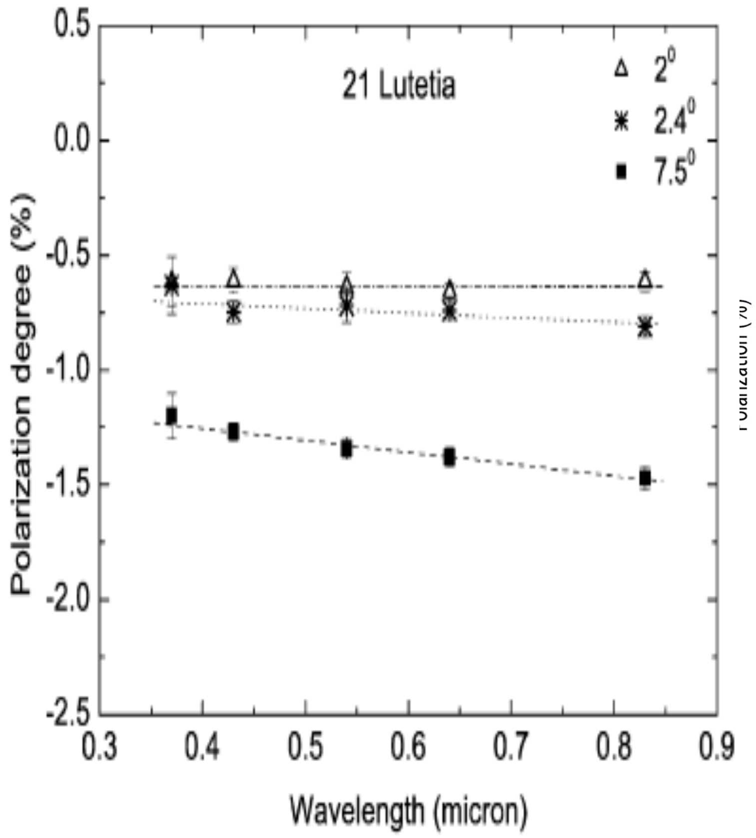


Belskaya et al., 2010

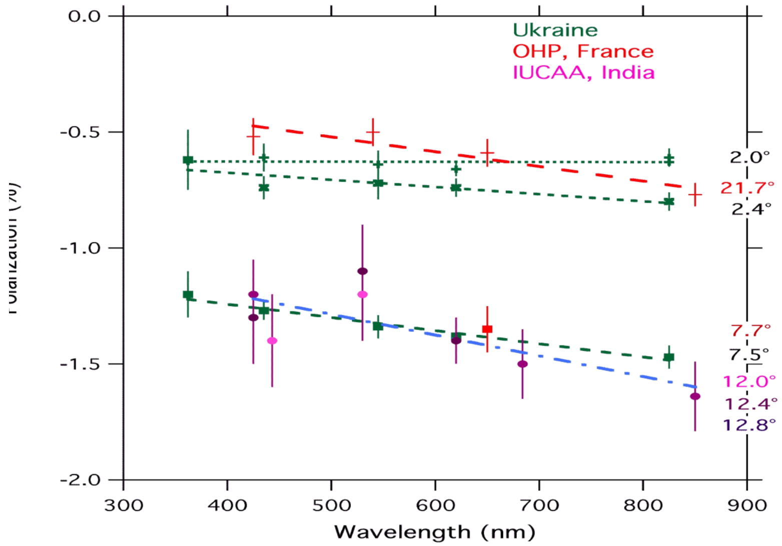


The case of 21 Lutetia
Comparison with other observations, λ-dependence

Fairly linear λ-dependence now monitored on a large set of phase angles



Belskaya et al., 2009



The case of 21 Lutetia
Comparison with observations of M- and C-type asteroids

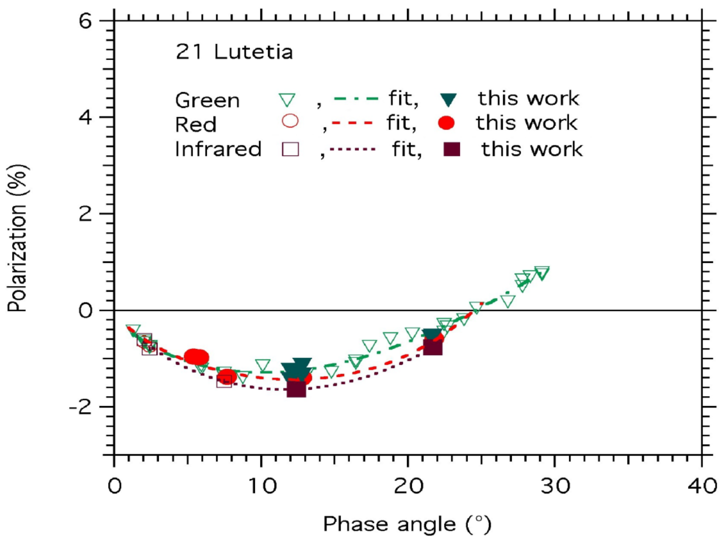
C-type

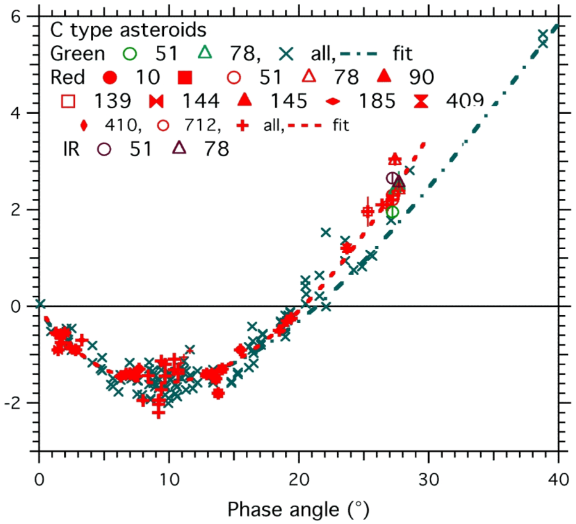
Negative branch deeper, α_0 smaller by 5°, slope at inversion ≈ twice higher

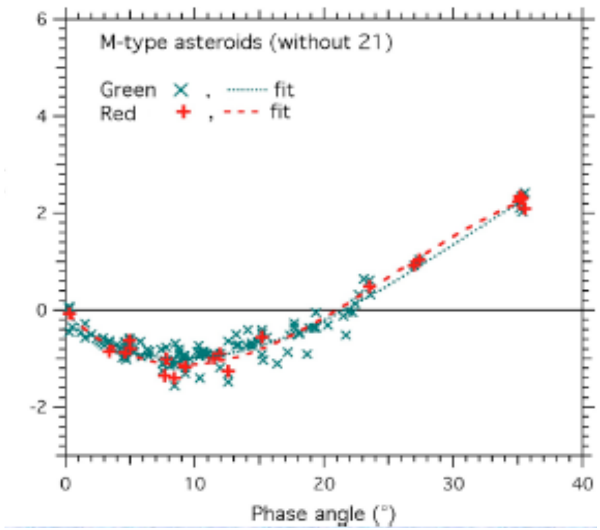
M type

Negative branch less deep, α_0 less high by 3°

⇨ Lutetia definitively different in terms of polarimetric properties

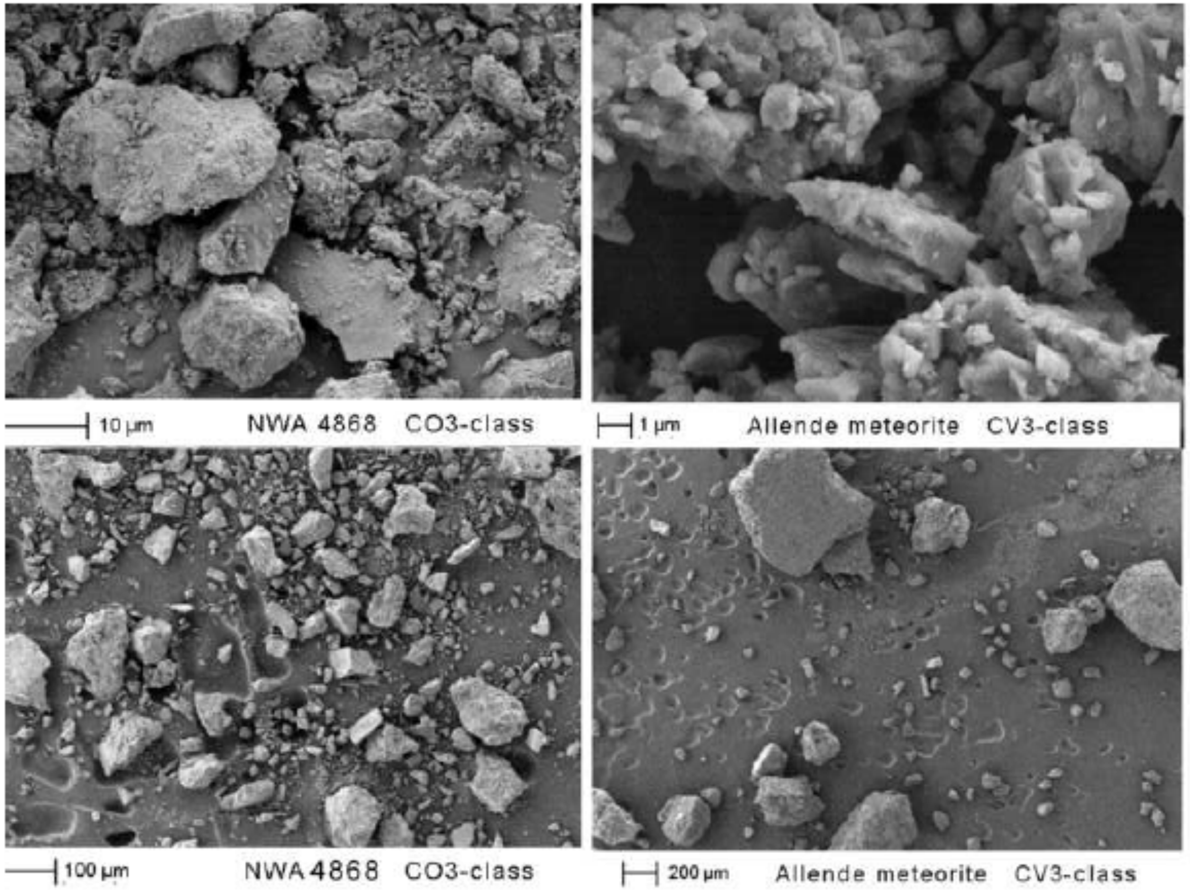






The case of 21 Lutetia
Choice of meteoritic samples

Carbonaceous chondrite samples (Barucci et al., 2008)
  CO3 (NWA 4858) and CV3 (Allende)
Cleaning, removal of oxidized fragments, grinding, sieving
   Sizes ranges below 500, 200, 50 or 20 µm



The case of 21 Lutetia
Polarimetric measurements on samples, 1

As expected: Smooth phase curves

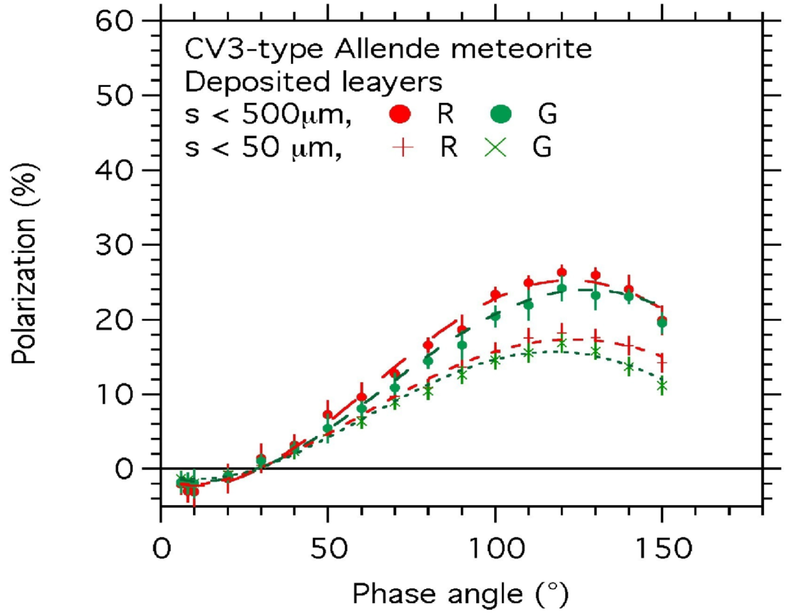
Polarization smaller for deposited layers (and for smaller sizes)

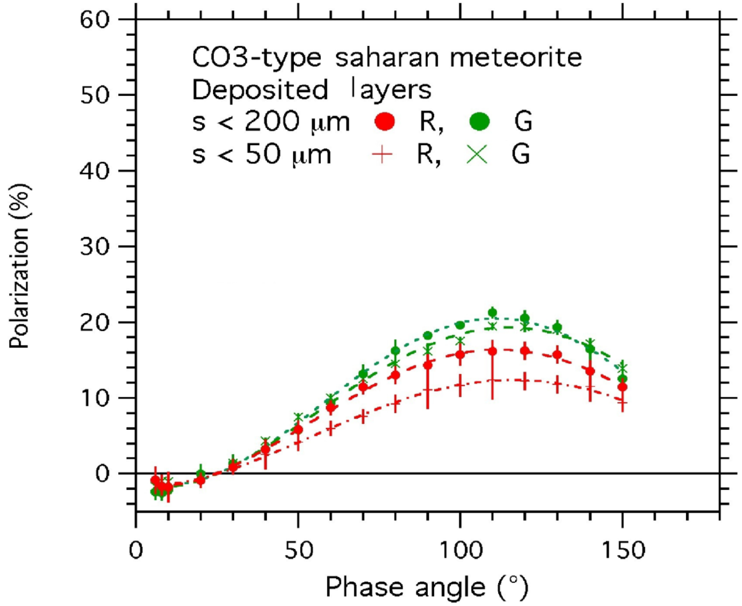
In agreement with Lutetia polarimetric observations

Inversion angles ≈ 25°

Slopes at inversion = (0.16 ± 0.03) percent per degree

However, red polarimetric colour only for CV3 (significant for large α)



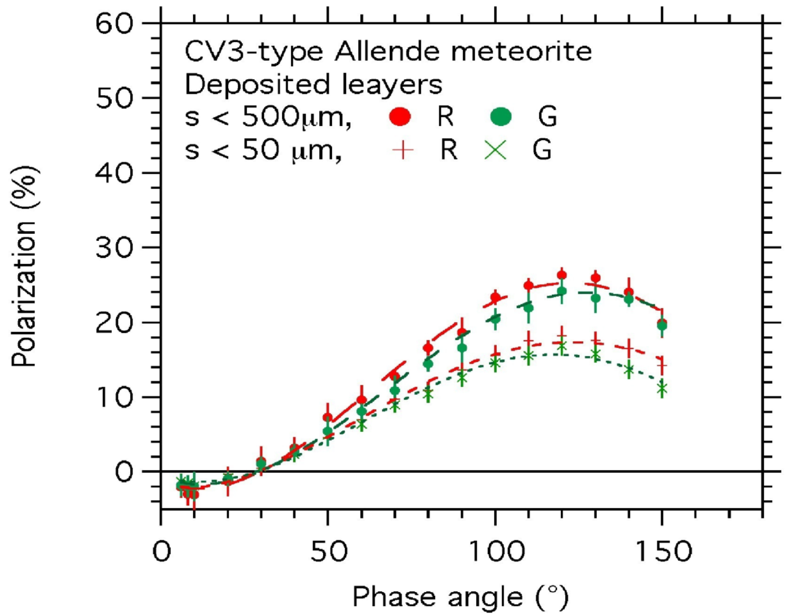


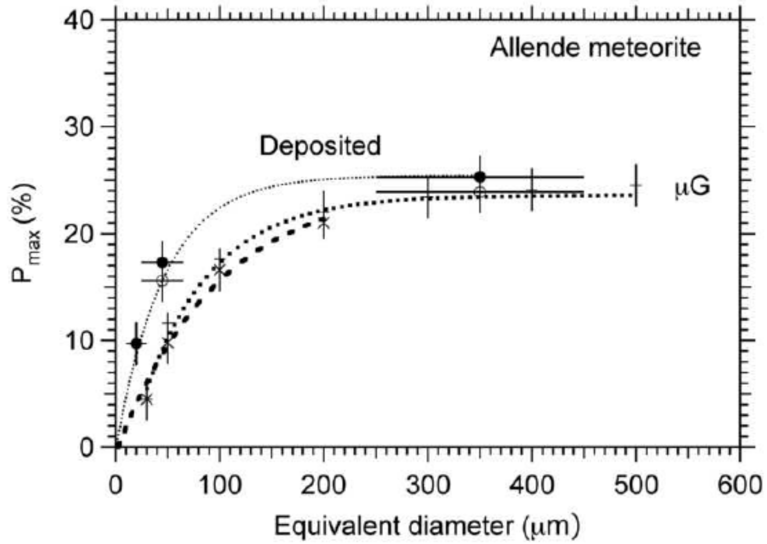
The case of 21 Lutetia
Polarimetric measurements on samples, 2

Polarimetric phases curves and P_{max} for various sizes,
- measured on polarization maps in microgravity (particles and aggregates)
- estimated under Earth gravity

⇨ Assuming Allende is a good analogue,
the average size on Lutetia might be below 50 μm

(in agreement with Belskaya et al., 2010)





Conclusions

Phase angle and wavelength dependences of the linear polarization of 21 Lutetia monitored from 2006 to 2009

Results in agreement with those of other teams
Further analysis showing that:
- surface properties differ from those of M- and C-type asteroids
- polarimetric colour might be red, as for C-type and also cometary dust

Comparison of the polarimetric results to laboratory simulations, with grinded samples of meteorites, indicates that
- CV3 meteorites could represent good analogues
- the average dust size might be below 50 μm

Prospective

Anticipated further laboratory measurements

Measurements of permittivity of meteorites samples, already in progress for aubrites

(in collaboration with Y. Brouet and P. Encrenaz)

Measurements of polarimetric properties of other meteorite samples

(possibly with efforts towards meteorites that could come from comets, e.g. Antarctic micro-meteorites)

Expected theoretical advances

Significance of low/medium/high inversion angle

Significance of red/green polarization colour

(seeming related to low/moderate albedos)

Significance of the linearity of the wavelength dependence…

Thank you for your attention