Analysis of the mineralogy of S-type asteroids from reflectance spectra

R. Albuquerque[1], T. Seixas[1,2] and M. Silva[1,2]

[1] Department of Physics and Astronomy, Faculty of Sciences, University of Porto, Portugal.
[2] Centre for Geophysics, University of Coimbra, Portugal.

XXIII ENAA, 18-19 July 2013, Lisbon, Portugal

Raquel Albuquerque
raquelmgalbuquerque@gmail.com

U.PORTO

FACULDADE DE CIÊNCIAS
UNIVERSIDADE DO PORTO

Supervisors: Prof. Teresa Seixas
Prof. Manuel Silva

18th July 2013

Introduction

- Asteroids are composed by a dusty regolith layer:
  - Minerals
  - Impact products

  →
  - Mineralogic variety
  - Optical properties
  - Grain size

- Processes of asteroids surface alteration must be considered when analyzing their spectra:
  - Micrometeorite impacts
  - Solar wind sputtering

  →
  - Spectral reddening
  - Subdued absorption bands
  - Lower albedo

Complex spectra of mineral mixtures!

How can we determine the mineralogy of an asteroid ?

How can we model an asteroid spectrum?

Hapke radiative transfer model

- According to Hapke(2001), the reflectance coefficient, r_c, can be calculated from the following expression:

$$r_c(i,e,g) = \frac{w}{4}\frac{1}{\mu_0+\mu}\{[1+B(g)]P(g)+H(\mu_0)H(\mu)-1\}$$

w – Single scattering albedo
μ – Cosine of the emission angle, *e*
μ_0 – Cosine of the incidence angle, *i*
g – Phase angle
B(*g*) – Backscatter function
P(*g*) – Single particle phase function
H(μ)– Chandrasekhar's isotropic *H* function

- *B*(*g*) can be set to zero for phase angles greater than 15º;
- *P(g)* is given by the 2nd order Legendre polynomial:

Mustard and Pieters (1989)

$$P(g) = 1 + b\cos(g) + c(1.5\cos^2(g) - 0.5)$$

***b* = -0.4 and *c* = 0.25 for silicate minerals**

- Chandrasekhar's function *H*(μ) is given by:

$$H(\mu) = \left[1-\left(1-\sqrt{1-w}\right)\mu\left\{r_0+\left(1-\frac{r_0}{2}-r_0\mu\right)\ln\frac{1+\mu}{\mu}\right\}\right]$$

$$\boldsymbol{r_0 = \frac{2}{1+\sqrt{1-w}} - 1}$$

Mixing Model

- Developed by M.A.Salgueiro da Silva and T.M.Seixas;

- The calculation of $w(\lambda)$ from $r(\lambda)$ can be performed recursively, by knowing *i*, *e*, b and c values and an initial estimate for $w(\lambda)$:

$$w^{(n)}(\lambda) = \frac{4(\mu_0 + \mu)}{p(g) + H(\mu_0, w^{(n-1)})H(\mu, w^{(n-1)}) - 1} r(\lambda)$$

- But first, we need to normalize asteroids reflectance spectra at $\lambda = 0.55\ \mu m$ and calibrate it with the respective geometric albedo w_{geom}:

$$r_{mix}^{calib}(\lambda) = \frac{r_{mix}(\lambda)}{r_{mix}(0.55)} w_{geom} \equiv f_{calib}\, r_{mix}(\lambda)$$

Angles *i* and *e* ???

- The calibration factor (f_{calib}) is insufficient and a smooth function $U(\lambda)$ is introduced:

$$U(\lambda) = \sum_{n=0}^{3} A_n \lambda^n$$

Mixing Model

- Mineral mixtures can be mathematically seen as a linear combination of the albedos of *N* minerals and the respective mineral parameter estimated x_k:

$$w_{mix}(\lambda) = \sum_{k=1}^{N} x_k w_k(\lambda)$$

$$\sum_{k=1}^{N} x_k = 1$$

- Taking all into account, the calibrated reflectance of a mixture of minerals can be given by:

$$r_{mix}^{calib}(\lambda) = f_{calib} w_{mix}(\lambda) U(\lambda) = \left[\frac{w_{geom}}{w_{mix}(0.55) U(0.55)}\right] w_{mix}(\lambda) U(\lambda)$$

- Now we are able to determine the mineral mass fractions (M_k), of *k* minerals, by knowing grain sizes (d_k) and mineral densities (ρ_k).

$$M_k = \frac{\rho_k d_k x_k}{\sum_{l=1}^{N} \rho_l d_l}$$

Procedure

- Sample selection of minerals

RELAB (Keck/NASA Reflectance Experiment Laboratory at Brown University)

Fig.2 and 3 – Asteroids 7 Ida and 433 Eros. *Source*: NASA/JPL

- Selection of asteroid spectral data;

S-type

  - 433 Eros and ~~4179 Toutatis~~; → **NEO's (Near Earth Objects)**
  - 5 Astraea, 6 Hebe, 7 Iris, 18 ~~Melpomene~~, 243 Ida and 532 Herculina. → **Main asteroid belt**

MIT-UH-IRTF Joint Campaign for NEO Reconnaissance

- Compute the calibrated reflectance spectra through the mixing model:

Input data

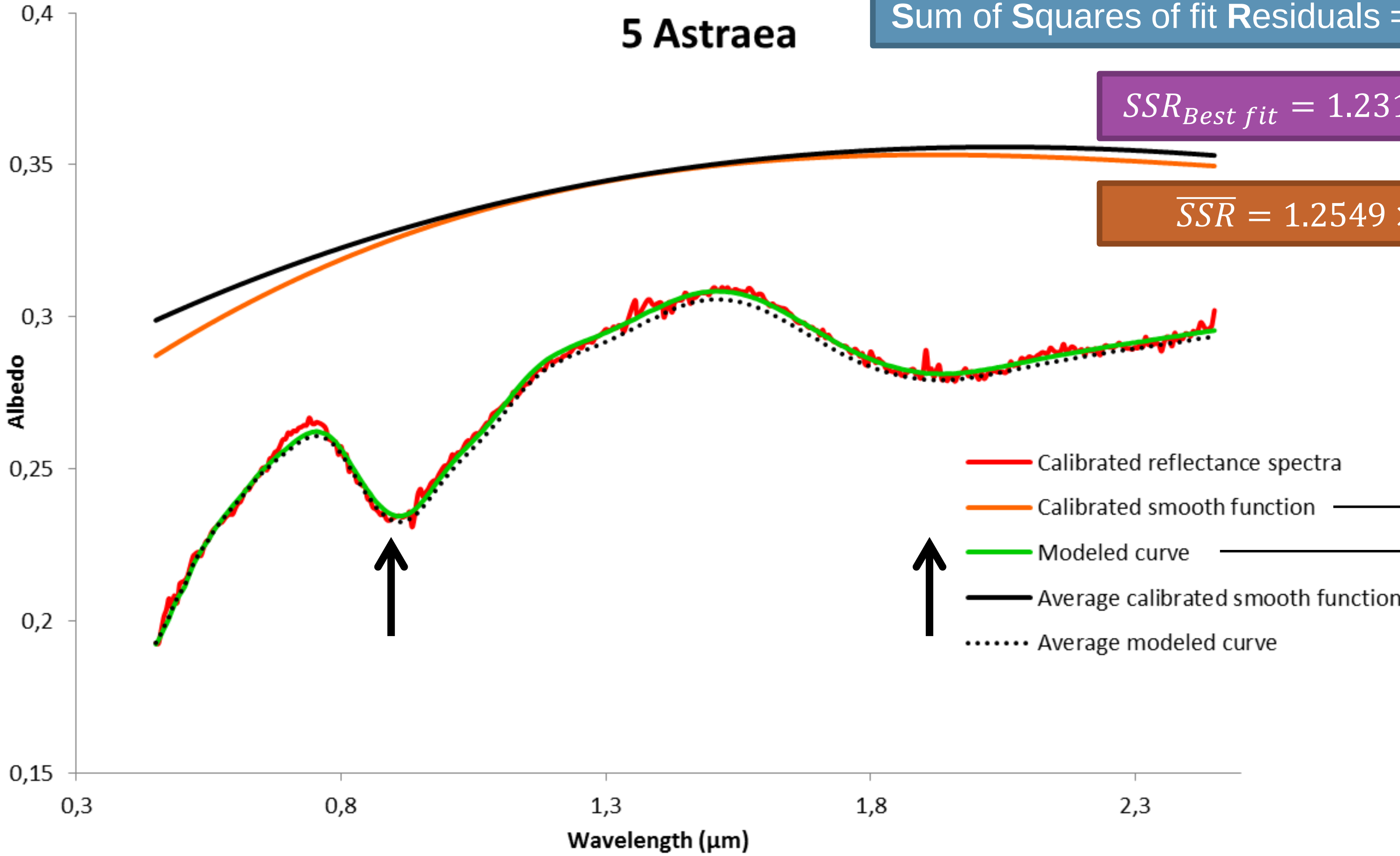
  - Geometric albedo;
  - Normalized asteroids reflectance spectra at $\lambda = 0.55\ \mu m$;
  - Initial values for the polynomial coefficients of $U(\lambda)$ smooth function (A_0, A_1,A_2 and A_3) and
  - Mineral parameters (plagioclase, endiopside, anorthite, …).

Results

Sum of **Squares** of fit **Residuals** = SSR

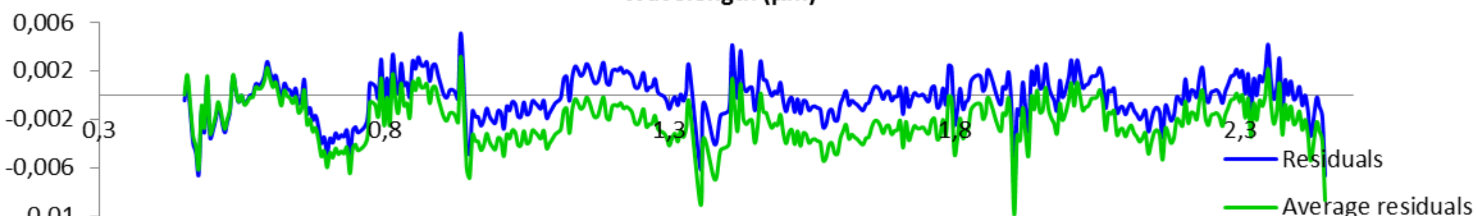
$SSR_{Best\ fit} = 1.2313 \times 10^{-3}$

$\overline{SSR} = 1.2549 \times 10^{-3}$

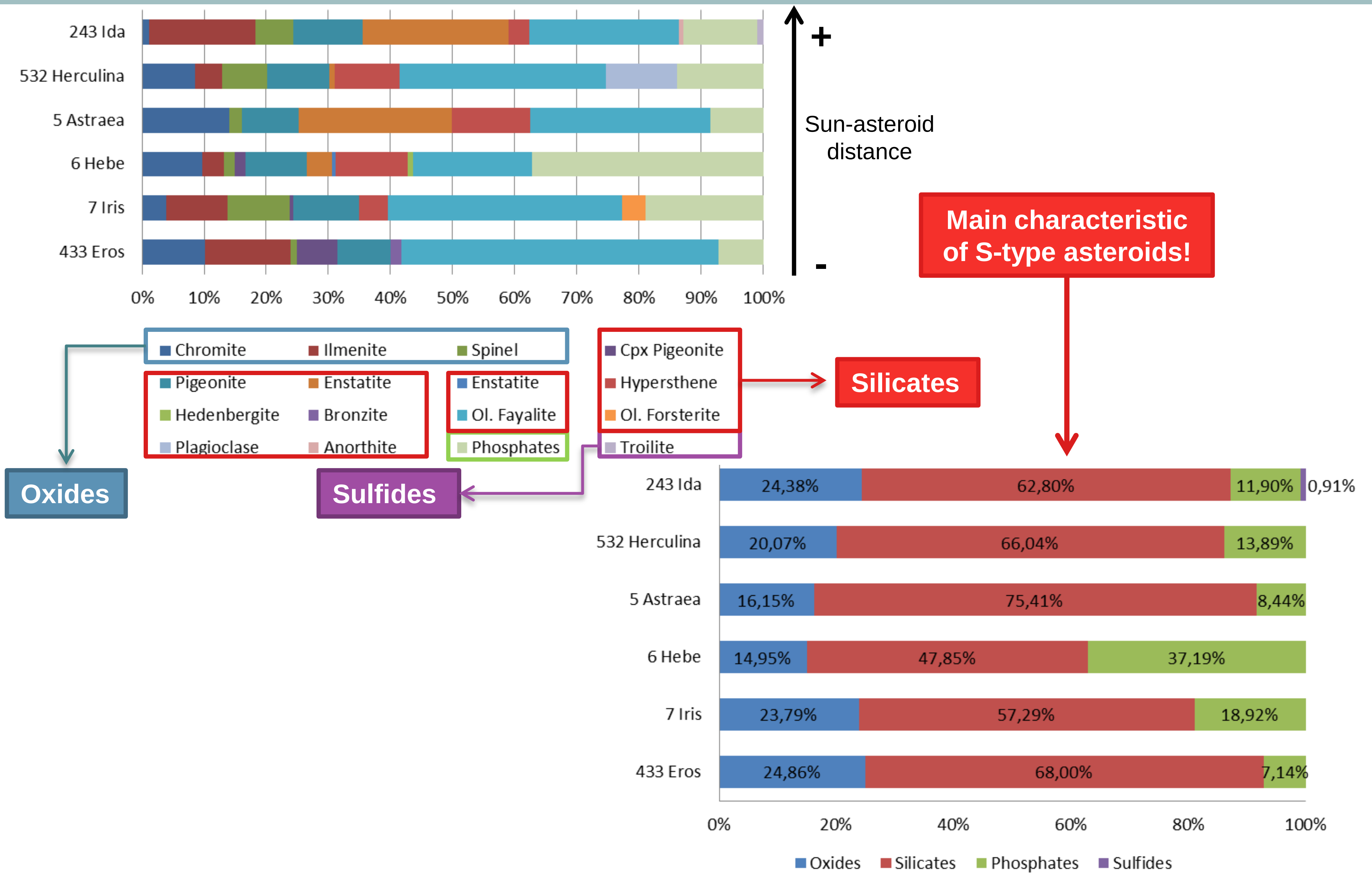


Calibrated smooth function → $U(\lambda)$

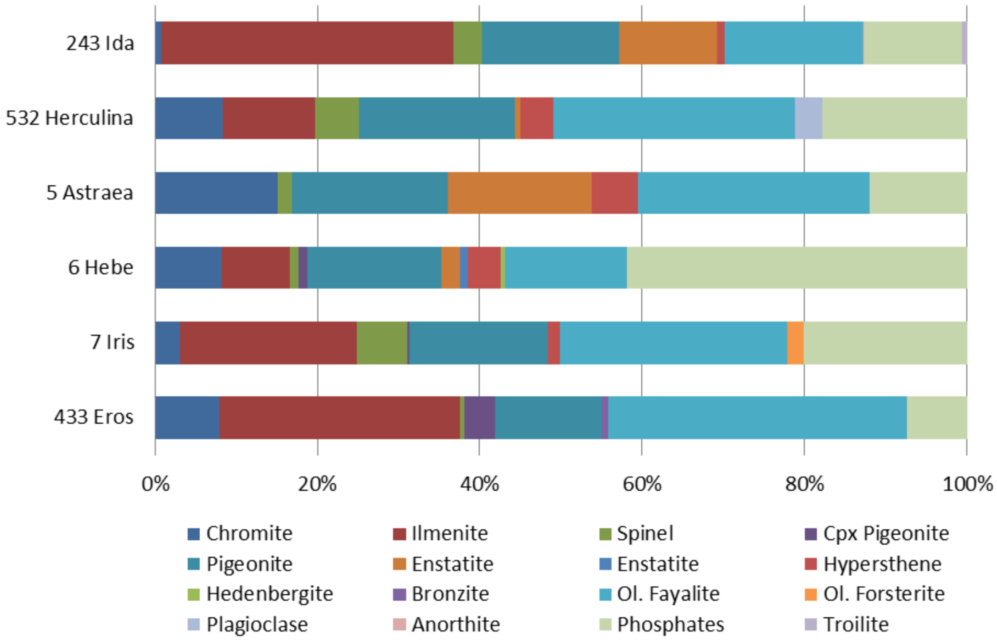
Modeled curve → $r_{mix}^{calib}(\lambda)$



Results – Mineral parameters *Solver*



Results – Mineral mass fractions



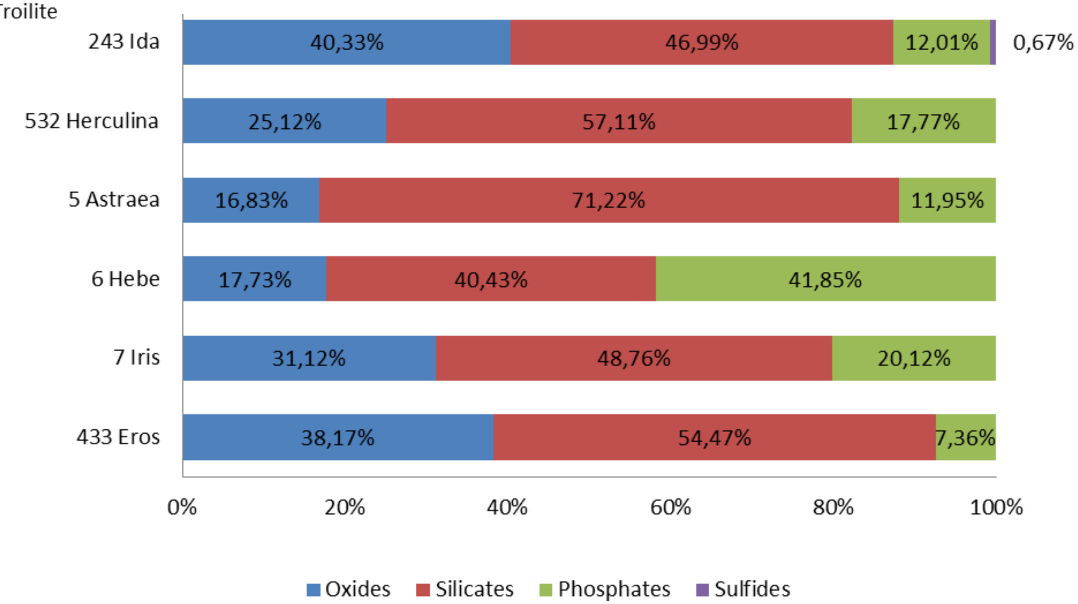
$$M_k = \frac{\rho_k d_k x_k}{\sum_{l=1}^{N} \rho_l d_l}$$

x_k - estimated mineral parameter

M_k - mineral mass fraction

d_k - grain size

ρ_k - mineral densities



Conclusions

- The mixing model returned very satisfactory results;
- Practically, all the asteroids showed overlapping modeled functions with the respective calibrated spectra;
- $U(\lambda)$ fitted functions are third degree polynomials;
- The final fitted mineral abundances confirmed the silicates predominance, characteristic of S-type asteroids;
- The mixing model reveals to be a promising tool regarding asteroid mineral composition studies.

Questions?