Meteorite spectrometry in Vis-NIR with classification and radiative-transfer modeling

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Outline

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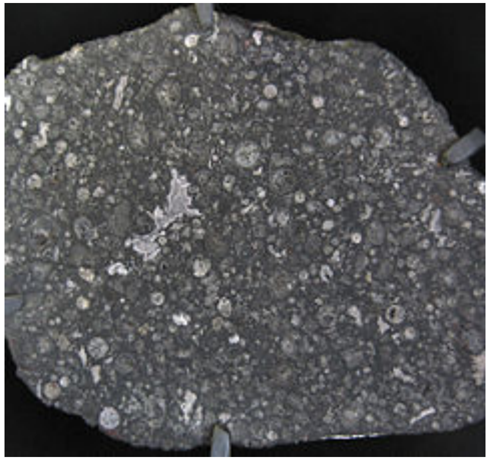
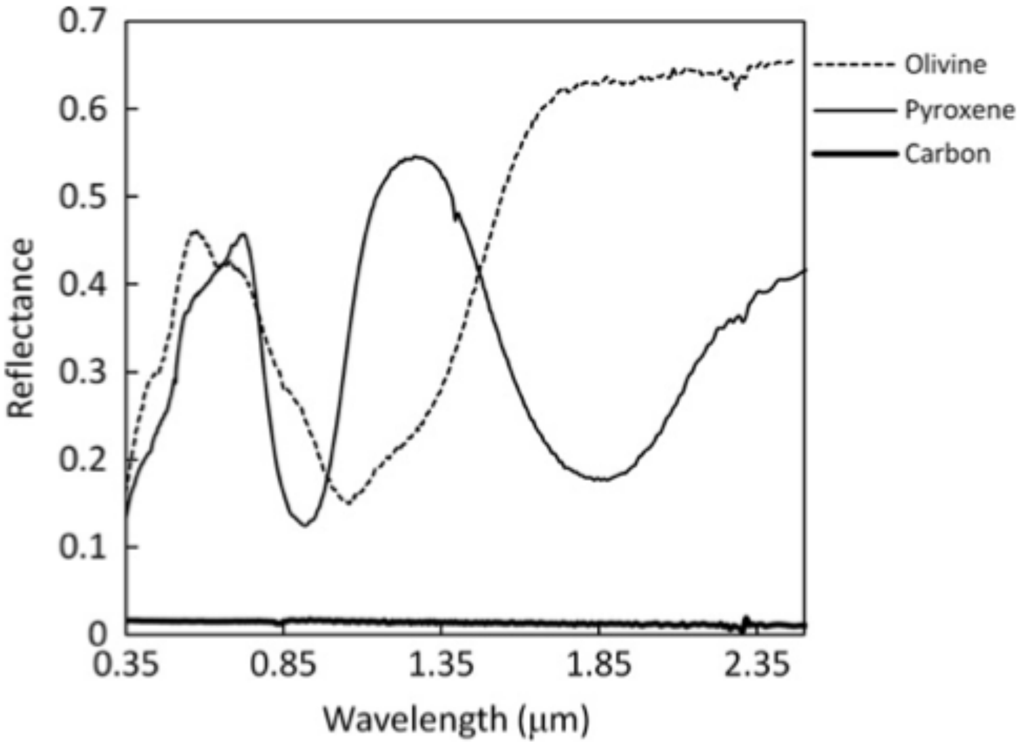
  - Meteorites in general
  - Meteorite spectrometry
- Measurements
  - FIGIFIGO measurements
  - Meteorite samples
  - Data processing
  - Spectra results
- PCA
- Radiative-transfer model

Meteorites

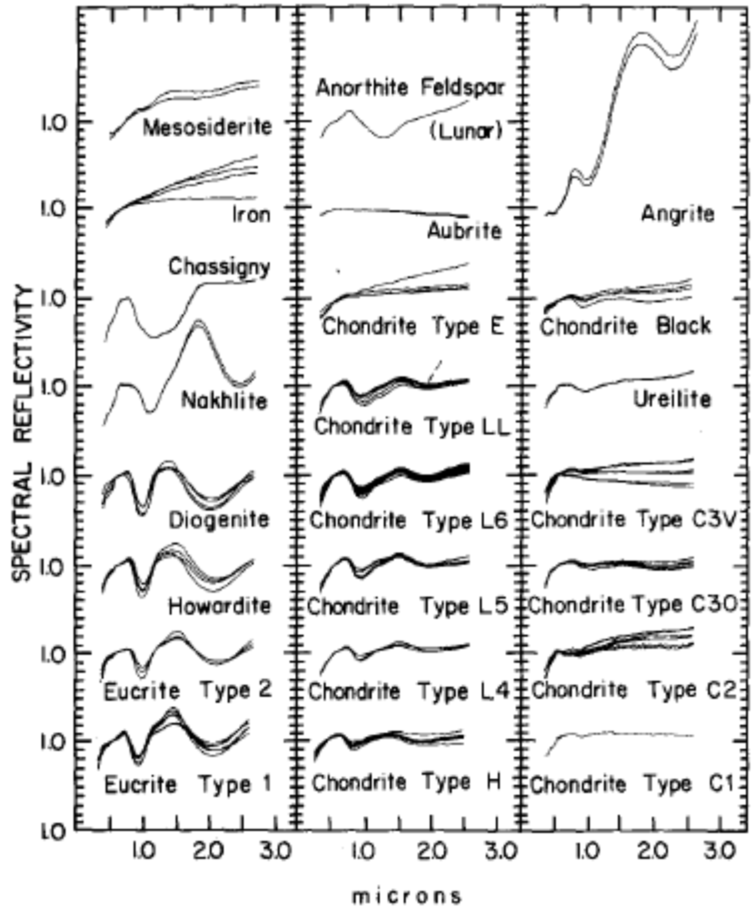
- Free samples of asteroids
- Achondrites (1), chondrites (2), primitive chondrites (3)
  - (1) Differentiated
  - (2) Undifferentiated, protoplanetary consistencies (CAIs)
  - (3) Inbetween (1) & (2): closer to (2), some melting
- Achondrites:
  - Howardite-Eucrite-Diogenite (HED)
  - + stony-irons, Martian and Lunar meteorites
- Chondrites:
  - Carbonaceous
  - Ordinary (H, L, & LL)
  - Enstatite



Meteorite spectrometry



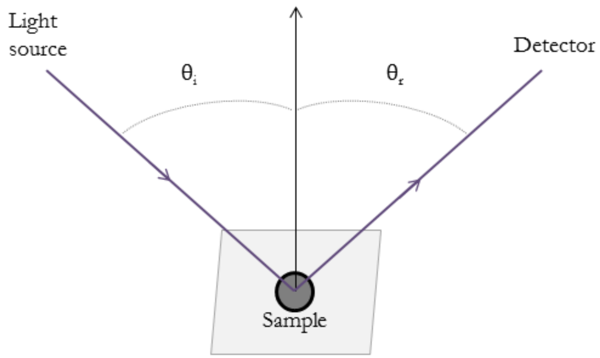
Paton et al. 2011



Gaffey and McCord, 1978

FIGIFIGO measurements

- Finnish Geodetic Institute Field Goniospectrometer
- Spectral range 350-2500 nm, 1 nm steps
- Zenith angle of incidence $\theta_i \approx 30°$
- Zenith angle of reflection $-60° < \theta_r < +60°$
- Lambertian reference panel: Spectralon
- Measurements on Spectralon and a black canvas
  - 3 geometrical orientations of the meteorite
- The results in this presentation
  - Spectrum with $\theta_r = 0°$
  - Black canvas background



Meteorite samples

13 ordinary chondrites, 3 HEDs, one enstatite and one carbonaceous chondrite, all "falls"

No.	Meteorite	Type	No.	Meteorite	Type
1	Abee	E4	10	Juvinas	Eucrite
2	Allende	CV3	11	Menow	H4
3	Buschnof	L6	12	Nyirabrany	LL5
4	Chitado	H6	13	Sevrukovo	L5
5	Collescipoli	H5	14	Souslovo	L4
6	Dhurmsala	LL6	15	Stannern	Eucrite
7	Ergheo	L5	16	St Germain du Pinel	H6
8	Jilin	H5	17	St Michel	L6
9	Johnstown	Diogenite	18	Vernon County	H6

Meteorite samples

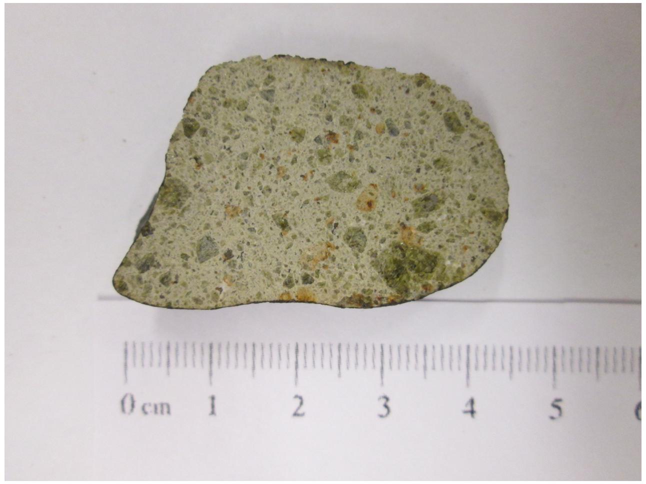
Abee (Enstatite chondrite, E4)

Allende (Carbonaceous chondrite, CV3)

Meteorite samples

Dhurmsala (Ordinary chondrite, LL6)

Chitado (Ordinary chondrite, H6)

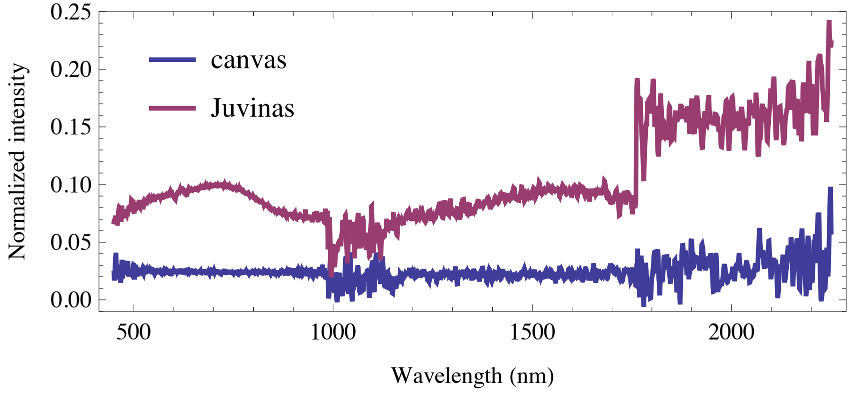


Johnstown (HED, Diogenite)

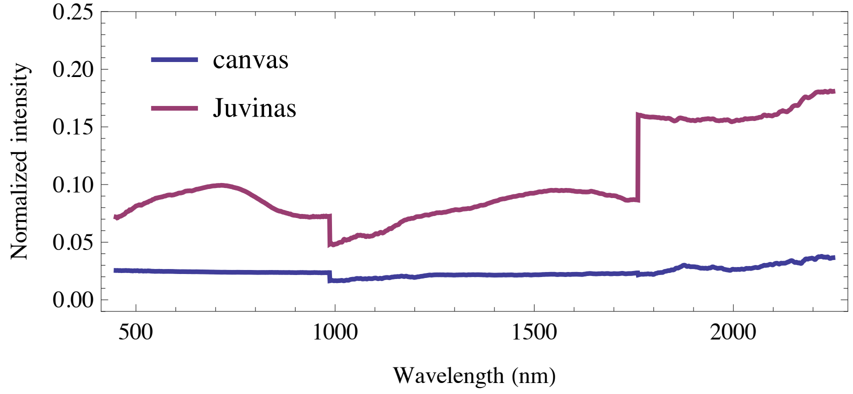
Data processing

- Raw data smoothed with moving average filter
- Background is extracted

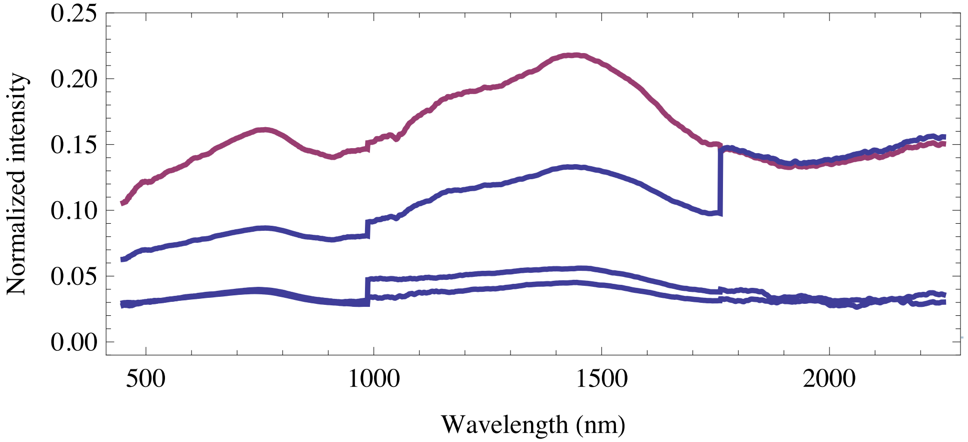
Raw data from black canvas and Juvinas HED



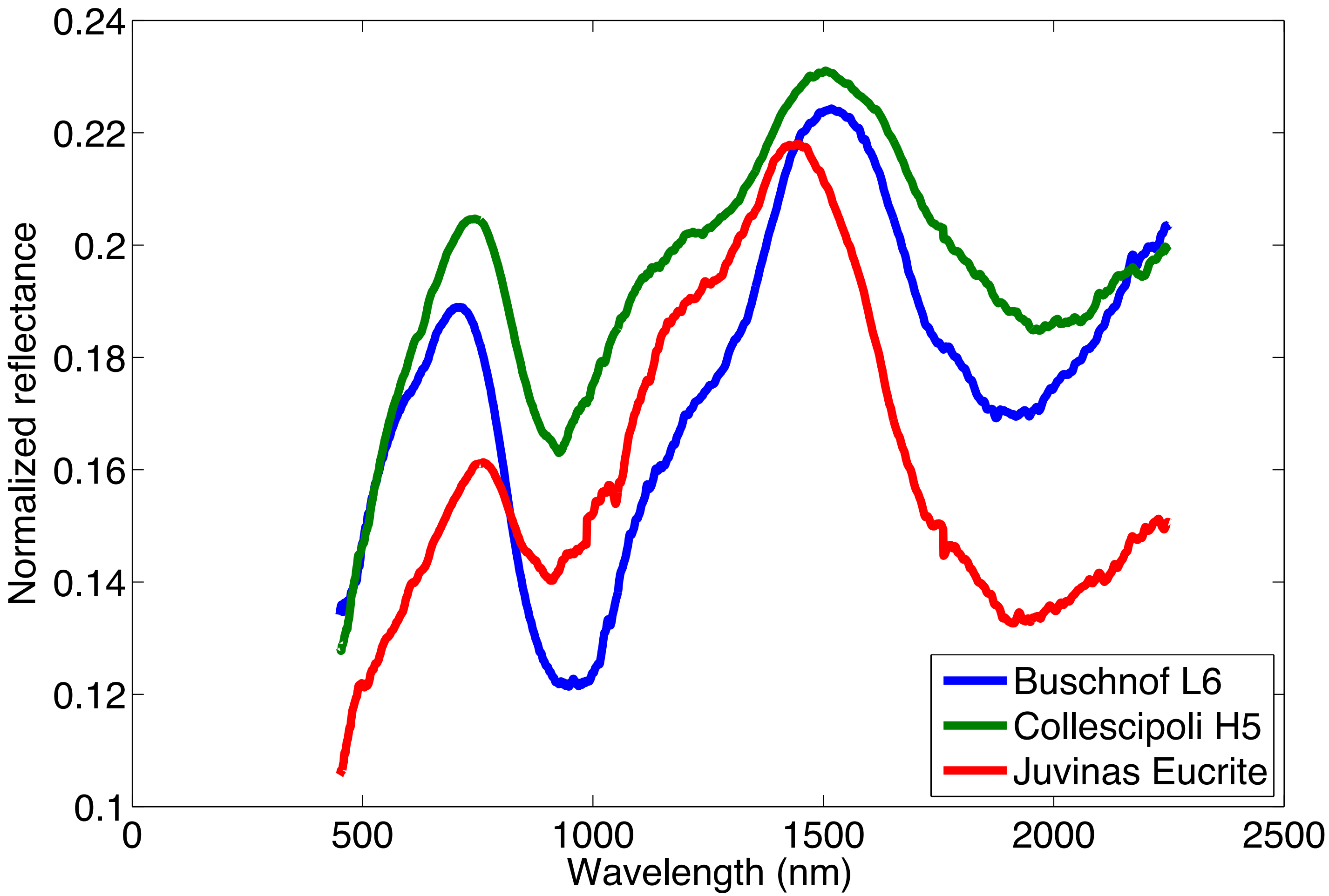
Smoothed data from black canvas and Juvinas HED



Three measured signals from Juvinas HED and background (blue), and fitted true signal (red)

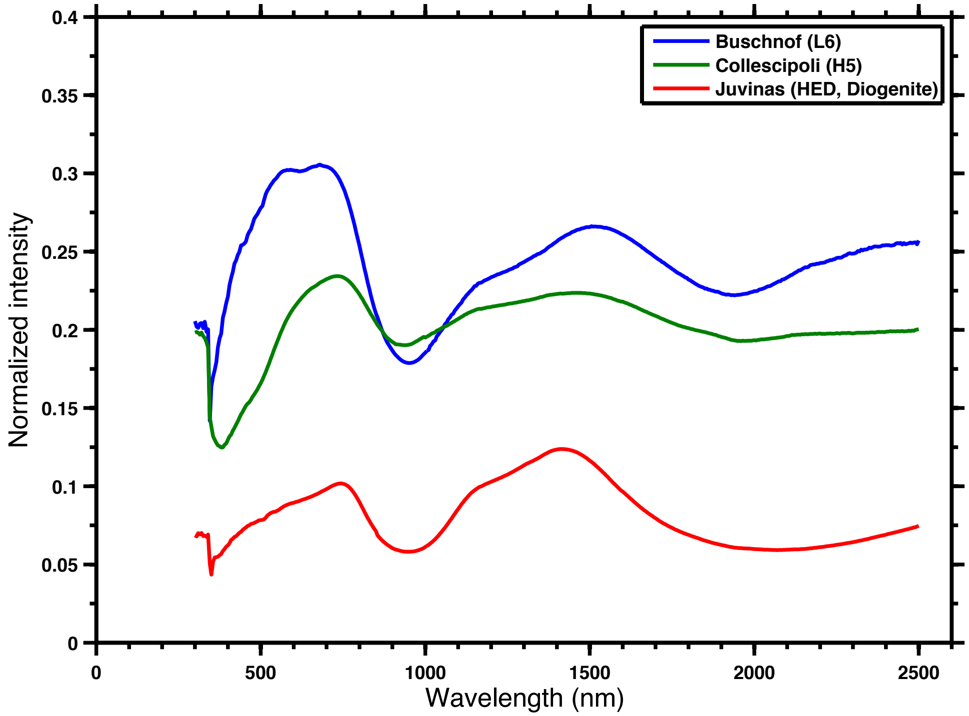


Spectra results



Spectra results

Buschnof, Collescipoli and Juvinas meteorites, from 300 to 2500 nm with 5 nm steps

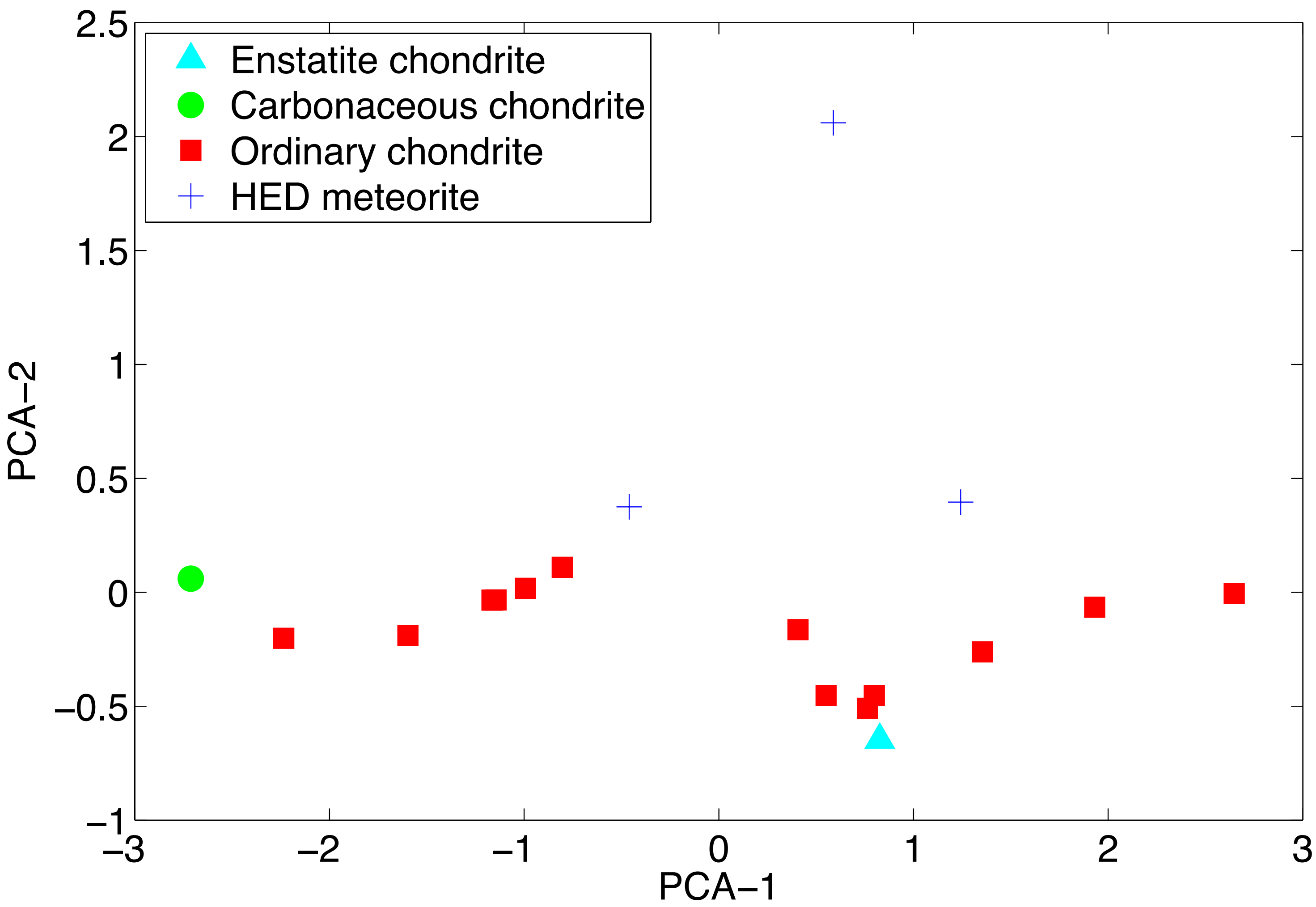


University of Helsinki scattering laboratory spectrometer

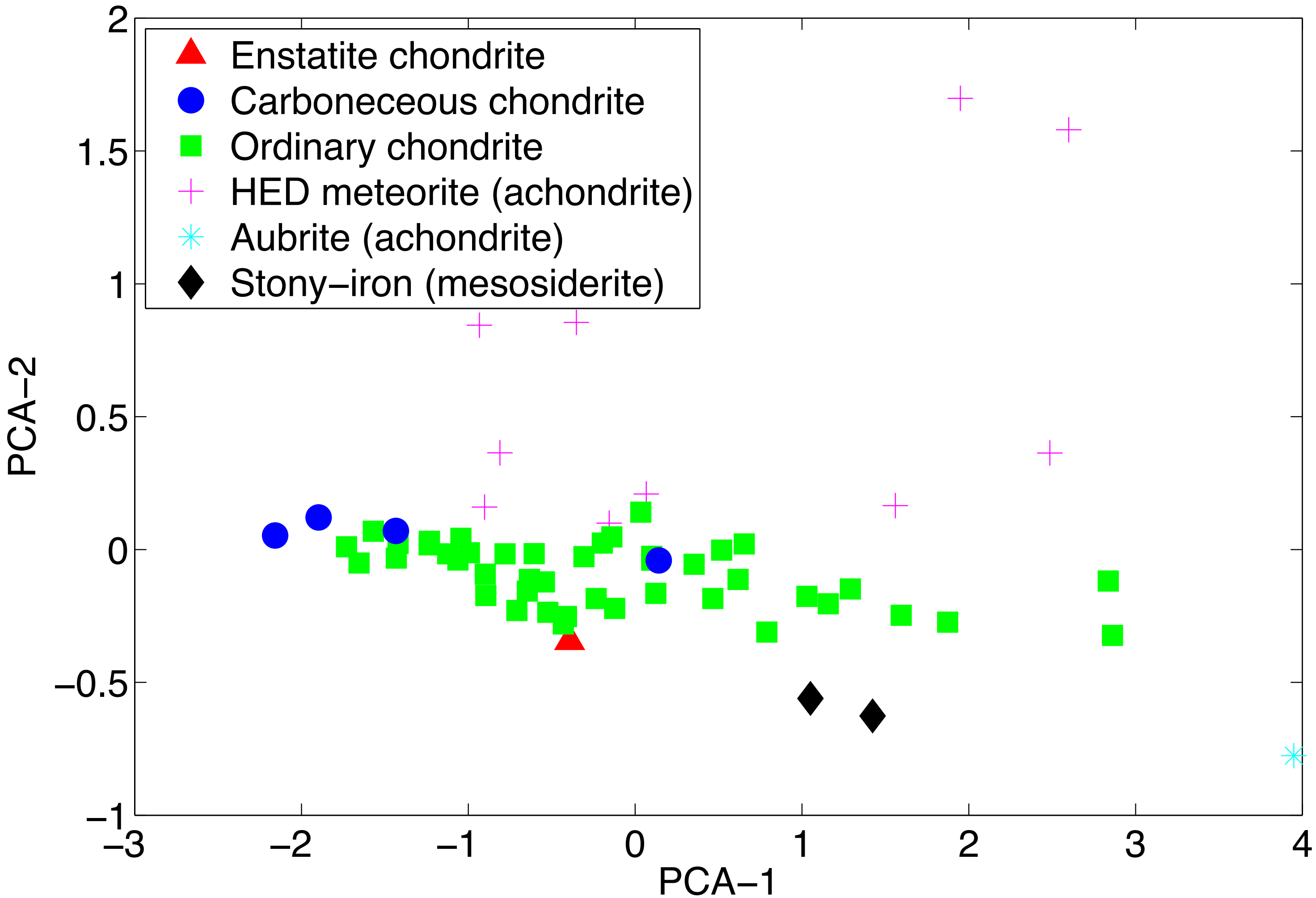
PCA

- Principal Component Analysis
- Technique for statistically analyzing large, unclear data sets
- Removes the correlations between n-dimensional vector elements
- Finds the rotation in vector space, which allows the new rotated coordinates to have the largest possible variances
- Data set can be represented by these principal components
- The number of dimensions can be reduced by leaving out the components with the smallest variances

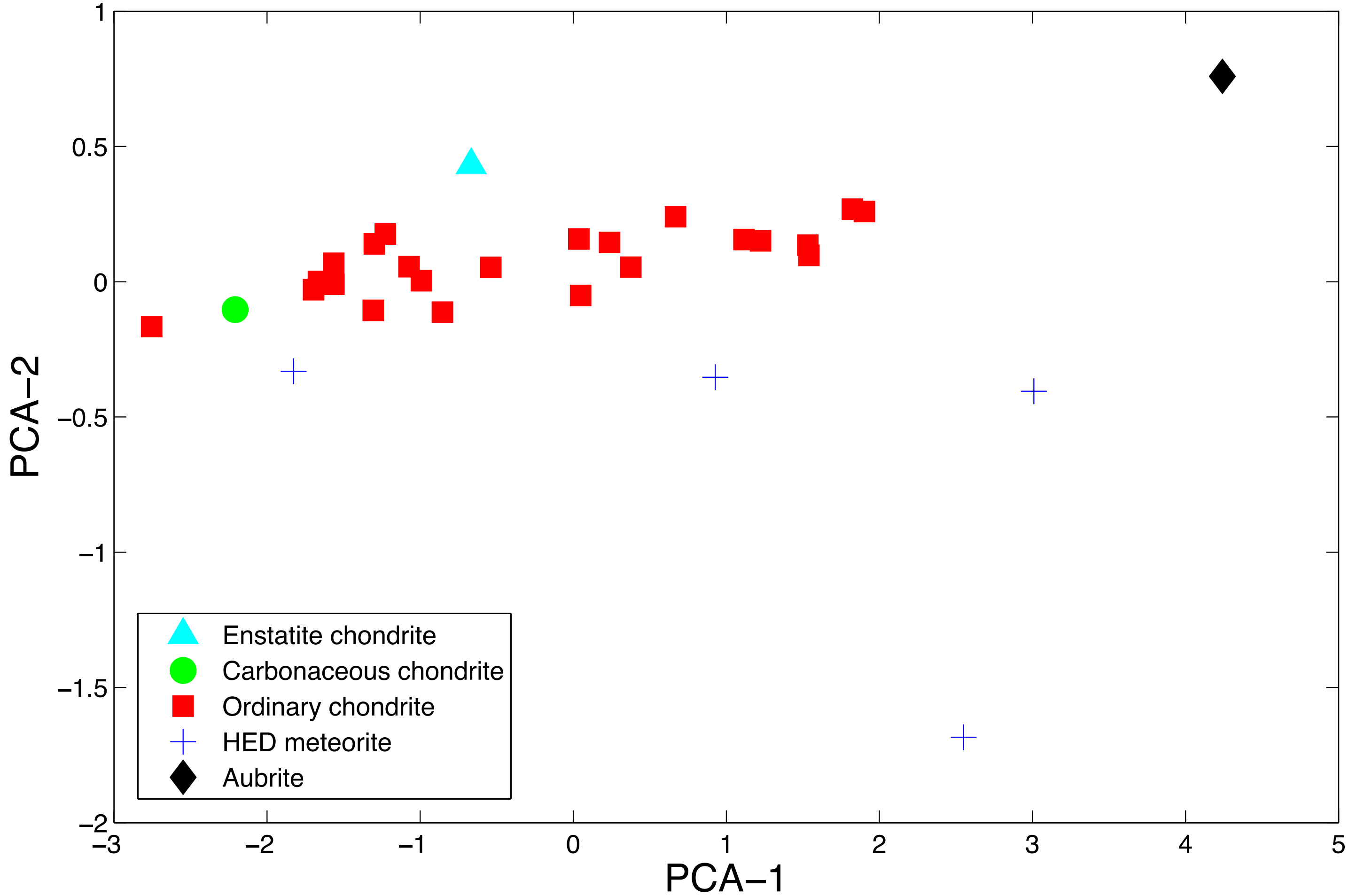
PCA (FIGIFIGO)



PCA (FIGIFIGO + Paton et al. + NASA)



PCA (Uni. of Helsinki spectrometer)



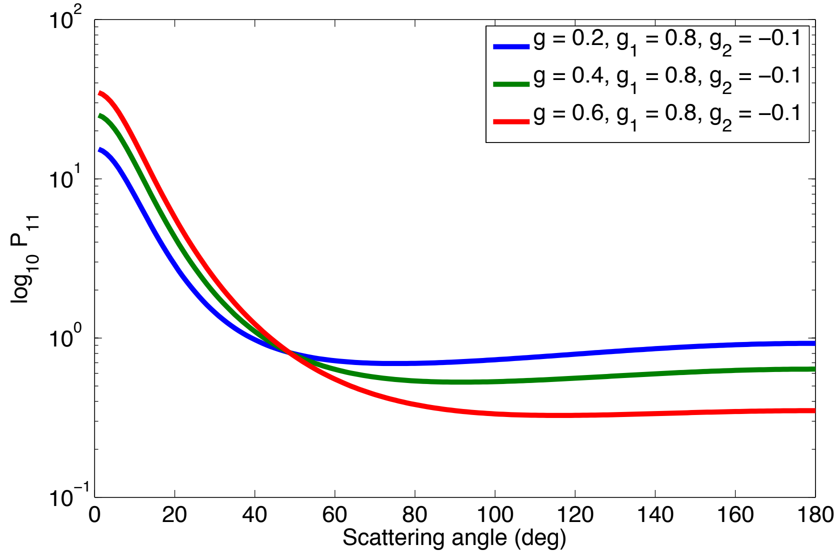
Radiative-transfer model

- Meteorites:
  - semi-infinite planes
  - composed of double Henyey-Greenstein scatterers
- Double Henyey-Greenstein scattering phase function:

$$P_{11}(\theta) = w \frac{1-g_1^2}{(1+g_1^2-2g_1\cos\theta)^{3/2}} + (1-w)\frac{1-g_2^2}{(1+g_2^2-2g_2\cos\theta)^{3/2}},$$

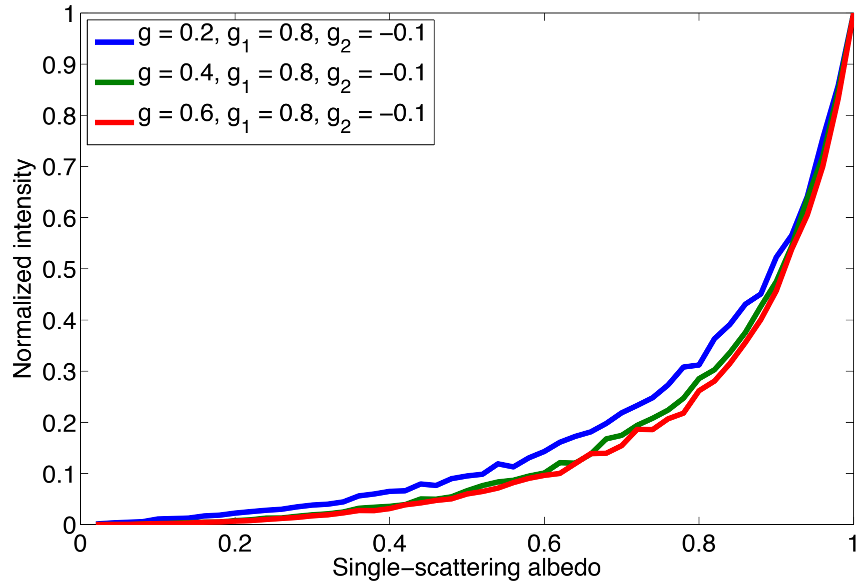
$$g = wg_1 + (1-w)g_2,$$

$g_1 > 0, g_2 < 0$

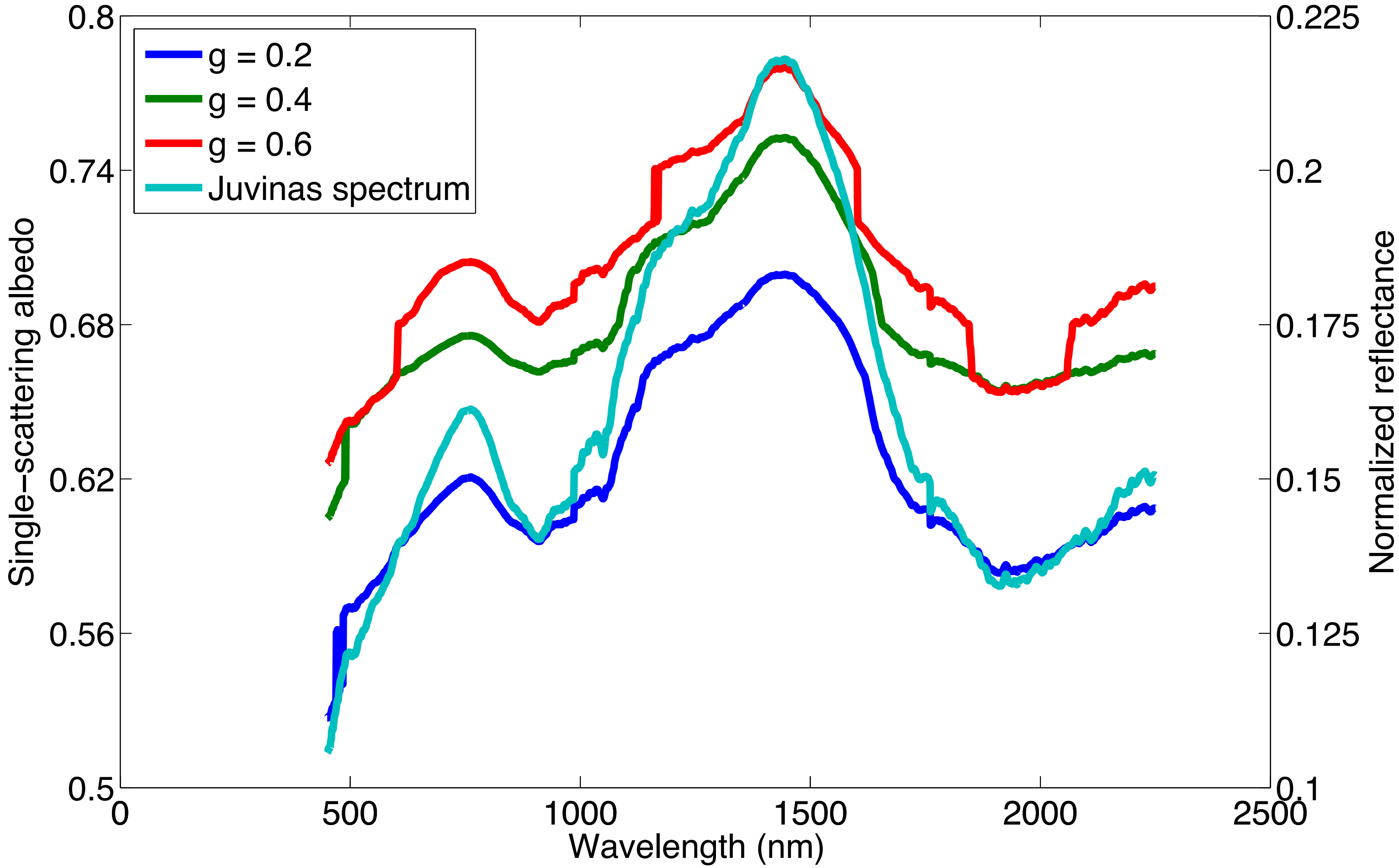


Radiative-transfer model

- Monte Carlo radiative-transfer computer program
- Single-scattering albedo range [0,1]
- 3 different scattering phase functions
  - Fit single-scattering albedos to meteorite spectrum through the whole wavelength range
- Phase angle 30°
- 400 000 rays



Radiative-transfer model



Summary

- Reflectance spectra measurements of 18 meteorite samples expand database of Paton et al. (2011)
- PCA of the spectra may distinguish between ordinary chondrites and HED-meteorites
- Radiative-transfer model of meteorites is under development
- Future prospects
  - New spectrometer
  - More meteorites (e.g. Chelyabinsk meteorite measured by Antti Penttilä)
  - Powders
  - Volcanic ash…

Further reading

- Gaffey, M.J. and McCord, T.B. (1978) Space Science Reviews 21
- Muinonen, K. and Videen, G. (2012) JQSRT 113
- Muinonen et al. (2009) JQSRT 110
- Paton et al. (2011) JQSRT 112
- Suomalainen et al. (2009) Sensors 9