REFLECTANCE SPECTRUM OF (1154) ASTRONOMIA

MIREL BIRLAN[1,2], DAN ALIN NEDELCU[2,1]

[1]*Institut de Mécanique Céleste et des Calculs des Éphémérides, CNRS UMR8028, Observatoire de Paris, PSL Research University*
77 av Denfert-Rochereau, 75014 Paris Cedex, France
Email: Mirel.Birlan@imcce.fr
[2]*Astronomical Institute, Romanian Academy*
5-Cuţitul de Argint, 040557 Bucharest, Romania

Abstract. First reflectance spectrum in the near-infrared region between 0.9 and 2.5 μm of asteroid (11154) Astronomia is presented. Taxonomic and comparative planetology studies show similarities with carbonaceous and enstatitic chondrite meteorites. Spectral data together with thermal albedo conclude to a surface rich in CM, CM-like regolith. Numerical integration of clones for this object shows no marked chaoticity.

Key words: Solar System – asteroid – spectroscopy – comparative planetology .

1. INTRODUCTION

Asteroid (1154) *Astronomia* is a large asteroid located in the outer part of the Main Belt of Asteroids (Figure 1). It as discovered by K. Reinmuth en 1927 (Klare, 2003).

This asteroid was observed by ECAS survey of color index (Zellner, Tholen, and Tedesco, 1985), and its thermal albedo was also derived from IRAS data (Tedesco and Veeder, 1992). Taxonomic studies concludes to a C_0 taxon in Barucci's taxonomy (Barucci *et al.*, 1987). This taxon is confirmed also with recalibrate IRAS albedo (Birlan, Fulchignoni, and Barucci, 1996). Based on ECAS data only, Tholen (1989) classify this object within FXU: taxonomic classes.

Spectral data in the visible region were obtained by the S^3OS^2 survey (Lazzaro *et al.*, 2004) and their taxonomic analysis placed the asteroid into the X-taxon.

The NEOWISE survey (Mainzer *et al.*, 2011) data analysis derived a fairly low value of the geometric albedo of 0.034$\pm$0.006. In the assumption of Standard Thermal Model, the diameter of (1154) *Astronomia* was computed for a value of 57.235$\pm$0.339 km.

Photometry of (1154) *Astronomia* was published recently; the asteroid spins with a period of 18.1154$\pm$0.0139 hours, and the composite lightcurve has an amplitude of 0.39$\pm$0.05 mag (Brincat, 2017).

In the article we present first spectrum of this asteroid in the 0.8-2.5 μm spectral range. Section 3 presents the spectral analysis which was done using the composite

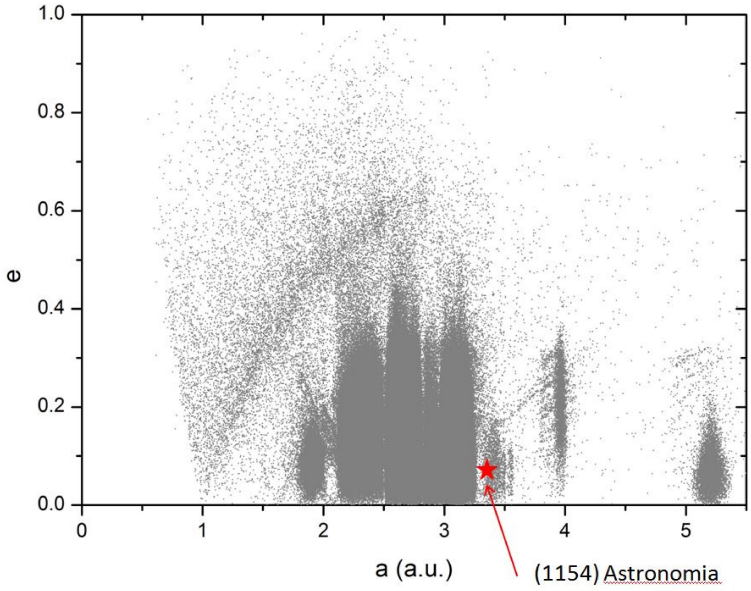

Fig. 1 – Location of (1154) *Astronomia* in a diagram eccentricity *vs* semimajor axis.

visible plus near-infrared (NIR) data. Results concerning its dynamics and conclusions are also presented.

2. SPECTROSCOPIC DATA OF (1154) *ASTRONOMIA*

Observations of (1154) *Astronomia* was observed in March 2, 2010 using the 3m telescope IRTF equipped with SpeX instrument (Rayner *et al.*, 2003). The telescope was operated remotely from Paris Observatory (Birlan *et al.*, 2004). Six cycles of A-B pairs of spectra were obtained for a total exposure time of 24 min. The object was observed almost at the zenith (an airmass around 1.02). HD73708 star was used as solar analog for data reducing; indeed, this star is located at almost the same airmass as the asteroid. Data reduction was performed using Spextool pipeline (Cushing, Vacca, and Rayner, 2004).

The obtained NIR spectrum has a S/N around 80.

For data analysis, the NIR spectrum was composed with the visible counterpart obtained the S_3OS_2 survey. The composite spectrum is presented in Figure 2. Overall, the NIR data are relatively good; a small depression in spectrum, around 1.45μm and 2.0μm are the markers that the influence of telluric absorptions were not completely removed during the data reduction process.

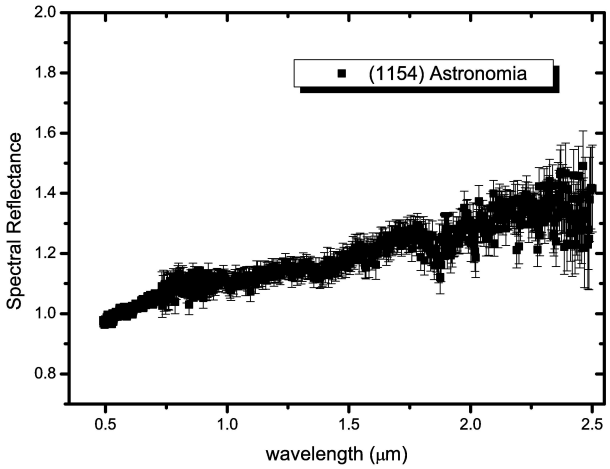

Fig. 2 – Composite spectrum of (1154) *Astronomia*.

3. SPECTRAL ANALYSIS AND DYNAMICS

The composite spectrum shows a flat featureless spectrum with a positive slope. The visible spectrum seems to have a slope slightly larger than the NIR one. The composite spectrum has a slope of (0.181 ± 0.001) μm^{-1}.

A taxonomic analysis as well as the comparative mineralogic studies of (1154) *Astronomia* were performed using the M4AST online service (Popescu, Birlan, and Nedelcu, 2012; Birlan *et al.*, 2016).

We used the comparison with Bus-DeMeo taxonomy. (1154) *Astronomia* is classified as C_b, C, C_g, X_k, X asteroid (Table 3).

The comparison with meteorites spectra from Relab database was also performed using M4AST using χ^2 method.

The comparative analysis shows a good match between the composite spectrum

Table 1

(1154) *Astronomia* taxonomic classes
from Bus-DeMeo taxonomy

Taxon	Score
C_b	0.0003
C	0.0005
C_g	0.0006
X_k	0.0006
X	0.0009

Table 2

Spectral match between the composite spectrum of (1154) *Astronomia* and Relab meteoritic samples

Meteorite	Type	Relab file	Sample
ALH-77307	CO3	bkr1mp102	≤ 125 μm
MAC88100,30	CM2	c1mp22	rock pressed powder
Y-86029,61	C1	bkr2mp111	≤ 125 μm
EET96135,20	EH4/5	bkr1mt120b	≤ 25 μm
A-881632,95	CO3	bkr1mp104	≤ 125 mum

and the carbonaceous chondrite meteorites (Table 3). Most of the best fit samples are from meteorites collected in the polar regions of Earth. However, the spectral fit contains also meteoritic samples which are coming from enstatitic meteorites. This imply that the degeneracy between chonditic and enstatitic regolith cannot be solved just using reflectance spectrum data. An investigation of the 3µm spectral region could help into determining the presence of aqueous alteration on the asteroid surface.

The list of best fit meteorites contains also samples from Kaidun meteorite. This meteorite is unique while it contains both carbonaceous and enstatitic lithologies (Nedelcu *et al.*, 2007). Thus, we can speculate that (1154) *Astronomia* could be an asteroid which contains both lithologies.

The ambiguity between enstatitic and chodritic composition of this asteroid is however solved by the measurements of its thermal albedo. Indeed, the low value of this parameter (less than 5%) is a strong argument to place it between objects with carbonaceous composition.

Extensive spectroscopic survey as performed recently by Vernazza *et al.* (2016) for more than C_h/C_{gh} asteroids from both families and background asteroids. This study conclude to a strong similarity between the asteroids and unheated CM chondritic meteorites. Our findings for (1154) *Astronomia* could be placed in the same context by several reasons: i) the asteroid is belonging to the C-complex; ii) the location of the asteroid in the outer part of Main Belt of Asteroids is in favor of the unheated and unaltered surface; iii) its diameter is smaller than 100 km thus in agreement with the conclusion of Vernazza *et al.* (2016).

We followed the orbital evolution of (1154) *Astronomia* by integrating 10 orbital clones for a 10 000 years period in the past. The past evolution shows no marked chaotic behavior, with the 10 clones following similar trajectories in the phase space (Figures 3 and 4). For a realistic determination of chaos in the evolution of (1154) *Astronomia* we numerically integrated the variational equations of motion for 1My in the past using the Bulirsch Stoer method (Nedelcu *et al.*, 2010).

The Lyapunov time thus determined is T_L = 9 650 $\pm$ 40 y. The most important high order mean motion resonances in the vicinity of (1154) *Astronomia* location

are the 19:10 and 17:9 with Jupiter, located at 3.3905 A.U. and 3.404 A.U. respectively,with the later 1.75 times stronger than the former (Gallardo, 2006). Both resonances appear to be crossed multiple times in the last 10 000 years and their locations explain well the (a, e) phase space trajectory. The Lyapunov time of *Astronomia* is typical of objects of moderate eccentricities located in the outer main belt at $\sim$ 3.4 A.U. (Holman and Murray, 1996).

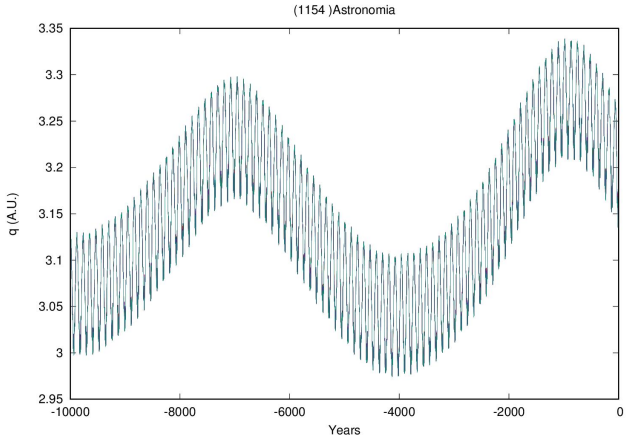

Fig. 3 – The evolution of distance of periapsis for 10 clones of asteroid (1154) *Astronomia*. The numerical integration was done backward in time for 10 000 years.

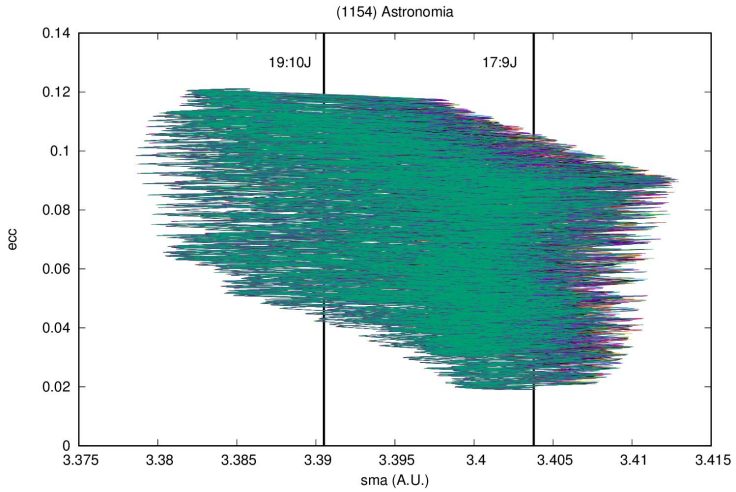

Fig. 4 – The evolution of eccentricity *versus* semimajor axis for (1154) *Astronomia*. Vertical lines show the closest mean motion resonances with Jupiter.

4. CONCLUSION

The asteroid (1154) *Astronomia* seems more akin to C–complex taxonomy. Its mineralogy is close to that carbonaceous meteorites. This mineralogy is confirmed also by its low albedo. Numerical integrations of 10 clones backward in time for 10 000 years show no marked chaoticity of this object.The Lyapunov time was estimated to the value $T_L = 9\,650 \pm 40$ y.

Acknowledgements. This article uses observations obtained with IRTF/Spex instrument, and CODAM facilities of Paris Observatory. The work of D.A.N. was supported by a grant of the Romanian National Authority for Scientific Research, Ministry of Research and Innovation, project number 11PS/2017

REFERENCES

Barucci, M.A., Capria, M.T., Coradini, A., Fulchignoni, M.: 1987, Classification of asteroids using G-mode analysis. *Icarus* **72**, 304 – 324. doi:10.1016/0019-1035(87)90177-1.

Birlan, M., Fulchignoni, M., Barucci, M.A.: 1996, NOTE: Effects of IRAS Albedo Correction on the G-Mode Asteroid Taxonomy. *Icarus* **124**, 352 – 354. doi:10.1006/icar.1996.0210.

Birlan, M., Barucci, M.A., Vernazza, P., Fulchignoni, M., Binzel, R.P., Bus, S.J., Belskaya, I., Fornasier, S.: 2004, Near-IR spectroscopy of asteroids 21 Lutetia, 89 Julia, 140 Siwa, 2181 Fogelin and 5480 (1989YK8), potential targets for the Rosetta mission; remote observations campaign on IRTF. *New Astron.* **9**, 343 – 351. doi:10.1016/j.newast.2003.12.005.

Birlan, M., Popescu, M., Irimiea, L., Binzel, R.: 2016, M4AST - A Tool for Asteroid Modelling. In: *AAS/Division for Planetary Sciences Meeting Abstracts*, *AAS/Division for Planetary Sciences Meeting Abstracts* **48**, 325 – 17.

Brincat, S.M.: 2017, Lightcurve Analysis for Three Main-belt Asteroids. *Minor Planet Bulletin* **44**, 1 – 2.

Cushing, M.C., Vacca, W.D., Rayner, J.T.: 2004, Spextool: A Spectral Extraction Package for SpeX, a 0.8-5.5 Micron Cross-Dispersed Spectrograph. *Pub. Astron. Soc. Pac.* **116**, 362 – 376. doi:10.1086/382907.

Gallardo, T.: 2006, Atlas of the mean motion resonances in the Solar System. *Icarus* **184**, 29 – 38. doi:10.1016/j.icarus.2006.04.001.

Holman, M.J., Murray, N.W.: 1996, Chaos in High-Order Mean Resonances in the Outer Asteroid Belt. *Astron. J.* **112**, 1278. doi:10.1086/118098.

Klare, G.: 2003, Book Review: Dictionary of minor planet names / Springer, Berlin, 2003 5th ed., XVI+992 pp., ISBN 3-540-00238-3. *Sterne und Weltraum* **42**(10), 96 – 97.

Lazzaro, D., Angeli, C.A., Carvano, J.M., Mothé-Diniz, T., Duffard, R., Florczak, M.: 2004, S^3OS^2: the visible spectroscopic survey of 820 asteroids. *Icarus* **172**, 179 – 220. doi:10.1016/j.icarus.2004.06.006.

Mainzer, A., Grav, T., Masiero, J., Hand, E., Bauer, J., Tholen, D., McMillan, R.S., Spahr, T., Cutri, R.M., Wright, E., Watkins, J., Mo, W., Maleszewski, C.: 2011, NEOWISE Studies of Spectrophotometrically Classified Asteroids: Preliminary Results. *Astrophys. J.* **741**, 90. doi:10.1088/0004-637X/741/2/90.

Nedelcu, D.A., Birlan, M., Vernazza, P., Descamps, P., Binzel, R.P., Colas, F., Kryszczynska, A., Bus, S.J.: 2007, Near infra-red spectroscopy of the asteroid 21 Lutetia. II. Rotationally resolved

spectroscopy of the surface. *Astron. Astrophys.* **470**, 1157 – 1164. doi:10.1051/0004-6361:20066944.

Nedelcu, D.A., Birlan, M., Souchay, J., Assafin, M., Andrei, A.H., Bădescu, O., Popescu, P., Paraschiv, P.: 2010, Apparent close approaches between near-Earth asteroids and quasars . Precise astrometry and frame linking. *Astron. Astrophys.* **509**, A27. doi:10.1051/0004-6361/200913172.

Popescu, M., Birlan, M., Nedelcu, D.A.: 2012, Modeling of asteroid spectra - M4AST. *Astron. Astrophys.* **544**, A130. doi:10.1051/0004-6361/201219584.

Rayner, J.T., Toomey, D.W., Onaka, P.M., Denault, A.J., Stahlberger, W.E., Vacca, W.D., Cushing, M.C., Wang, S.: 2003, SpeX: A Medium-Resolution 0.8-5.5 Micron Spectrograph and Imager for the NASA Infrared Telescope Facility. *Pub. Astron. Soc. Pac.* **115**, 362 – 382.

Tedesco, E.F., Veeder, G.J.: 1992, IMPS albedos and diameter catalog(FP102). *in The IRAS Minor Planet Survey, Tech. Rep.PL-TR-92-2049, Phillips Laboratory, Hanscom AF Base, MA, 1992, Editors: Tedesco E.F., Veeder, G.J., Fowler, J.W., and Chillemi, J.R.* **1**, 313 – 317. doi:10.1051/0004-6361:20041505.

Tholen, D.J.: 1989, Asteroid taxonomic classifications. In: Binzel, R.P., Gehrels, T., Matthews, M.S. (eds.) *Asteroids II*, 1139 – 1150.

Vernazza, P., Marsset, M., Beck, P., Binzel, R.P., Birlan, M., Cloutis, E.A., DeMeo, F.E., Dumas, C., Hiroi, T.: 2016, Compositional Homogeneity of CM Parent Bodies. *Astron. J.* **152**, 54. doi:10.3847/0004-6256/152/3/54.

Zellner, B., Tholen, D.J., Tedesco, E.F.: 1985, The eight-color asteroid survey - Results for 589 minor planets. *Icarus* **61**, 355 – 416. doi:10.1016/0019-1035(85)90133-2.

Received on 21 November 2017