DEVELOPMENT OF SCINTILLATION GAMMA RAY SPECTROMETERS FOR PLANETARY MISSIONS AND METHODOLOGICAL INVESTIGATIONS OF INFRARED STIMULATED LUMINESCENCE SIGNALS FROM FELDSPARS

A thesis submitted to

Sardar Patel University, Vallabh Vidyanagar,

For the award of the degree of

Doctor of Philosophy

In

Physics

DIPAK KUMAR PANDA

(Reg. No. 556/10-10-2012)

Under the supervision of

Dr. KULJEET KAUR MARHAS
(Guide)

Planetary Science Division
Physical Research Laboratory
Navrangpura
Ahmedabad-38009

Prof. K.D. PATEL
(Co-Guide)

Department of Physics
Sardar Patel University
Vallabh Vidhyanagar
Anand-388120

March 2018

DEVELOPMENT OF SCINTILLATION GAMMA RAY SPECTROMETERS FOR PLANETARY MISSIONS AND METHODOLOGICAL INVESTIGATIONS OF INFRARED STIMULATED LUMINESCENCE SIGNALS FROM FELDSPARS

A Thesis Submitted to Sardar Patel University, Vallabh Vidyanagar

For

THE DEGREE OF DOCTOR OF PHILOSOPHY

IN

PHYSICS

by

Dipak Kumar Panda

Physical Research Laboratory
Ahmedabad 380009
India

CERTIFICATE

I hereby declare that the work presented in this thesis titled "Development of Scintillation Gamma Ray Spectrometers for Planetary Missions and Methodological Investigations of Infrared Stimulated Luminescence Signals from Feldspars" is original and has not formed the basis for the award of any degree or diploma by any University or Institute. The material obtained from other sources and used in the thesis have been acknowledged appropriately.

(DIPAK KUMAR PANDA)

Certified by:

Dr. Kuljeet Kaur Marhas
Planetary Science Divison
Physical Research Laboratory
Navrangpura
Ahmedabad-380009

Prof. K.D. Patel
Department of Physics
Sardar Patel University
Vallabh Vidhyanagar,
Anand-388120

Prof. P.C. Vinodkumar
Head, Department of Physics
Sardar Patel University
Vallabh Vidhyanagar, Anand-388120

HEAD
DEPARTMENT OF PHYSICS
SARDAR PATEL UNIVERSITY
VALLABH VIDYANAGAR

Abstract

Chemical composition of various solar system objects such as planets, satellites and asteroids provides important clues towards understanding of their origin and evolution. The elemental abundances of such objects are established very early in the history of the solar system during the accretion of solar system material leading to their formation. Some of these objects also experienced subsequent thermal differentiation leading to formation of core, mantle and crust as in the case of the Earth. The chemical composition of a planetary surface allows us to infer whether accretionary process itself led to partial melting and caused large-scale redistribution of elements. Partial or complete melting will lead to a planetary surface that will be relatively depleted in Fe and Mg and enriched in O, Si, Al, and also in Na, K, Th and U. Partial losses of volatile elements such as C, N and S may also be inferred from surface composition.

Atmosphereless Planets or those with thin atmospheres (e.g. Mars, where surface pressure is ~7 millibars) are continuously irradiated with galactic cosmic rays (GCR), mainly protons and alpha particles with energies typically ~GeV/nucleon. These GCR particles enter the planetary surface and produce a cascade of secondary particles, including ~7 neutrons (for the case of Moon) with energies of ~0.1-20 MeV, per primary particle. Many of these secondary neutrons can produce gamma rays in inelastic scattering (n, xγ) reactions, where x is usually a neutron. Neutrons with energies below the first excited level of target nuclei in planetary surface can be elastically scattered by nuclei, escape from the surface (about one third of neutrons), or be captured by nuclei in the (n,γ) reaction when the neutron energy is of the order of ~0.025 eV. Both the inelastic and the neutron capture gamma ray lines are those classically used in planetary applications. Gamma rays can also be produced by the decay of naturally available radioactive elements such as K, U, Th. In comparison to X-ray fluorescence spectrometry, compositional data from gamma spectrometry is more representative of the planetary sub-surface as gamma rays come from

depths of a few centimeters to tens of centimeters whereas characteristic X-rays have a maximum interaction depth of the order of tens of microns.

Three types of detector systems are suitable for 0.1 to 10 MeV energy range. The scintillation detectors such as NaI(Tl), CsI(Tl) and Bismuth Germanate (BGO) have been used in many space missions for gamma ray spectroscopy. Their advantages include heritage, easy availability, high detection efficiency, and easily realizable large area detectors. The main disadvantage of these detectors is their poor energy resolution, and are not considered for the present experiment. High Purity Germanium (HPGe) detectors have been used in the 2001 Mars Odyssey Mission, Selene (Kaguya) moon mission and Messenger Mercury mission. These detectors have significantly better spectral resolution than the scintillation detectors used on previous missions. The GRS instrument on Odyssey used a passively cooled (~85 K) high-purity n-type germanium crystal that detects gamma rays in the energy range of 0.1 to 10 MeV. However, the HPGe detectors need to be cooled to liquid nitrogen temperatures (77 K) to achieve high energy resolution levels, implying the use of a Stirling cycle cooler or a passive cooling system, require high power (~50W) and a long time for development.

The newly developed cerium doped lanthanum bromide ($LaBr_3$:Ce) crystal is the latest among the family of the scintillation counters, and has an advantage over conventional room temperature detectors. It has a high effective atomic number, high light yield, and therefore, the energy resolution and detection efficiency of $LaBr_3$:Ce detector is superior to NaI(Tl). The energy resolution of this detector is 2.8% at 662 keV (^{137}Cs) and ~1.6% at 2615 keV (^{208}Tl). The light output of this scintillator is 7 times higher in comparison to BGO, and 1.6 times higher compared to NaI(Tl). Furthermore, this detector does not require active or passive cooling systems as required for HPGe detectors, and can be operated at room temperature.

In this thesis, a $LaBr_3$:Ce gamma ray spectrometer has been developed for a future planetary orbiter mission with the primary objective of determining the abundance and distribution of Th, U, K, and other major elements on the entire planetary surface by measuring gamma ray signals produced by radioactive decay, neutron inelastic scattering and neutron capture reactions in the energy region 0.03 to 8 MeV. Based on weight, power, and operating temperature considerations for the spacecraft payloads, a $LaBr_3$:Ce gamma detector would appear be the best choice for the gamma spectrometer and was our original choice for the proposed gamma ray spectrometer. However, the intrinsic activity count-rate for a 3″× 3″ $LaBr_3$:Ce gamma ray spectrometer observed to be ~61 counts s^{-1} (i.e. ~0.18 counts s^{-1} cm^{-3}) for the ^{40}K energy window (1400-1520 keV) and ~3.4 counts s^{-1} for the ^{232}Th (2550-2700 keV) energy window (Panda et. al. 2016). Thus, the gamma ray background arising from intrinsic activity of ^{138}La and due to the contamination of ^{227}Ac are significantly large and makes it difficult to make abundance measurements of Th, U and K in the 0.05-3 MeV energy region.

In light of the above, we focused on the development of a $CeBr_3$ gamma ray spectrometer with in-house developed electronics and software. The energy resolution of the $CeBr_3$ gamma ray spectrometer using front-end and processing electronics developed in-house has been measured at 662 and 1274 keV to be 4.0% and 2.8% respectively. The intrinsic activity count-rate for the 1″× 1″$CeBr_3$ gamma ray spectrometer is ~0.03 counts s^{-1} for the ^{40}K energy window (1400-1520 keV), and ~0.001 counts s^{-1} for the ^{232}Th (2550-2700 keV) energy window. The U concentration of a sample (3A) from a granite rock was estimated to be ~2.1 ppm and agrees with the 2.04 ppm value determined using a HPGe gamma ray spectrometer. The K concentration of sample 3A was estimated to be 3.7%, and is consistent with the 3.8% value determined independently using a HPGe gamma ray spectrometer.

The third section of the thesis is focused on the determination of luminescence ages of feldspar grains since the luminescence signal from feldspar has potential for measuring large doses (~kGy). Luminescence technique is used to evaluate the time that has elapsed since the mineral grains crystalized, were exposed to daylight or heated beyond 400^0C. These methods use optically and thermally sensitive light signal from minerals such as quartz and feldspar. We investigate the source of the IRSL signal in two feldspars obtained from NIST, viz., Standard Reference Material (SRM) 99b (soda feldspar) and K-feldspar SRM 607. For SRM 607, the TL glow curve consists of a several peaks at ~95^{o}C, 160^{o}C, 260^{o}C and 340^{o}C. In the soda feldspar SRM 99b, a broad TL peak is observed at temperatures between 140^{o}-190^{o}C; this TL signal is absent in the preheated SRM 99b aliquot, and a TL peak at ~300^{o}C is observed in the glow curve. Although IRSL signals from the soda-feldspar SRM 99b indicate no significant depletion at temperatures below 200^{o}C, the pulse anneal data for the K-feldspar sample SRM 607 does show a 30% loss in IRSL while heating upto 200^{o}C. For the natural feldspar extracts considered here (SUN-1-GR and SHRD-1), the equivalent dose value remains constant for preheat temperatures between 80^{o}C - 320^{o}C. It has been previously argued that a single trap (around 410^{o}C) may be primarily responsible for the IRSL signal (Murray et al. 2009). The preheat plateaus from natural feldspar extracts presented here support the conclusion that low temperature TL peaks do not make a significant contribution to IRSL in several feldspar samples.

DECLARATION

I hereby declare that the work incorporated in the present thesis entitled, "Development of Scintillation Gamma Ray Spectrometers for Planetary Missions and Methodological Investigations of Infrared Stimulated Luminescence Signals from Feldspars" is my own work and is original. This work (in part or in full) has not been submitted to any University for the award of a Degree or a Diploma.

Dipak Kumar Panda

Acknowledgements

There are many people to whom I am deeply grateful and would like to thank for making this possible. Firstly, for his encouragement, support, and enthusiasm for the nuclear science, I would like to thank my supervisor Prof. D. Banerjee for guiding me to complete my thesis. I sincerely thank him for his advice for developing my presentable skill. He was a 'friend' disguised as thesis supervisor and the informal relationship gave me space to argue freely on several scientific issues. This, in a way, concretized many of the ideas that are recorded in this work.

I also would like to thank Dr. K.K Marhas, who took interest in my thesis and allow me to register with her. I sincerely regard Dr. Marhas for her time to time discussion and suggestion related to thesis work and other scientific areas. I thank Prof. K.D. Patel, who was kind enough to be my co-guide. His valuable suggestions and concise comments helped me improve thesis work.

Prof. J.N. Goswami, whose questioner & discussion helped me to shape my way of thinking to any scientific problem. I sincerely thank Prof. Goswami and to all the members of Ion MicroProbe Laboratory where I started my research carrier at PRL. I thank our chairman Prof. Haider for his support and encouragement to carried this work. I thank Prof. G. Srinivasan with whom I started my research carrier at PRL. I thank Prof. S.V.S Murty and Dr. Y.B. Acharya for their kind suggestion & encouragement. I thank to Prof. P Janardan, Prof Ramachandra and Dr. Bhushit for their generous support.

Dr. A.D. Shukla who not only helped in the thesis work but also support like an elder brother during the odd times. I must thank Dr. Navin Jual, who is always an inspirable person. He taught me geology during my early research carrier at PRL. Dr. Jual has shared a lot of his expertise during field work. I also thank Dr. S. Ghosh from GSI, who also has shared his field experience during the fieldwork.

I acknowledge S.K Goyal, Arpit Patel, Tinkal Ladia and Neeraj Tiwari for their kind support to complete this work. I am lucky to have Prof. Varun Sheel, Dr. Vinay Rai Dr. D. Ray, Dr. A. Basu, Dr. Vijayan, Rishitosh, Dr. N Srivastav, R. Mahajan, Dr. J Pabari, Durga Prasad, Dr. M. Shanmugam, Rajiv, Chandan, Sanjeev, Vikram, Garima as my colleague who are always their when I needed any help. I thank Nambiarji for his support in office administrative work. I thank Prof J.K Pati, from Allahabad University for his valuable discussion. Prof. R. Ramesh, Prof. J.S. Ray, and Prof. Sunil Singh for their discussion in different scientific areas. I thank, Dr. Ravi Bhusan, Sudheer, Dr. N Rastogi, Dr. D Chakraborty, Dr. Deshpande, Pranab Bhai, Manan, Lakhan , Dr. Sanjeev, and other colleagues who are the well-wisher, good friends.

No research is possible without the Library, I take this time to express my gratitude Nishta madam and all the library staff for their support whenever I required any help. I thank Jigar bhai and all the members of computer center for their technical support. I must thank Mr. G.P Ubale, Hitesh Bhai and all the people in the workshop, and the members of CMD for their help. I thank all members of purchase & administration for their support during this tenure.

A special thanks to Rajesh TA, a colleague and family friend, who has always supported me whenever I needed his advice both in professional and personal life. I thank his wife Seena and son Rishav who are always like a family member. I thank Venkat bhai for his kind support both in my personal and professional life.

Finally, I acknowledge the people who mean a lot to me, my parents, Bapa and Maa, for showing faith in me and giving me the liberty to choose what I desired. I salute you all for the selfless love, care, pain and sacrifice you did to shape my life. I deeply miss my mother (Maa), who is not with me to share this joy. The affection and support provided by my sisters, brother-in-laws, elder brother, bhauja, nieces (Isha & Illa) and nephew (Gudlu) deserve special mention. My sincere regards to my father-in-law, mother in law for their love and moral support.

I owe thanks to a very special person, my wife, Pranati for her continued and unfailing love, support and understanding made the completion of thesis possible. You were always around at times I thought that it is impossible to continue, you helped me to keep things in perspective. I greatly value her contribution and deeply appreciate her belief in me. I appreciate my son Priyanshu for abiding my ignorance and the patience he showed during my thesis writing. Words would never say how grateful I am to both of you. I consider myself the luckiest in the world to have such a lovely and caring family, standing beside me with their love and unconditional support.

I would like to thank God Almighty for giving me the strength, knowledge, ability and opportunity to undertake this research study and to persevere and complete it satisfactorily. Without his blessings, this achievement would not have been possible.

Dipak Kumar Panda

Table of Contents

List of Tables

Chapter 2

Chapter 3

Chapter 4

Chapter 5

List of Figures

Chapter 1

Chapter 2

Chapter 3

Chapter 4

Chapter 5

List of Publications:

1. Panda, D. K., Banerjee, D., Goyal, S. K., Patel, A. R. and Shukla, A. D., "Development of a Cerium bromide gamma ray spectrometer for space applications." Advances in Space Research, 2017, 60, 1307-1314, doi.org/10.1016/j.asr.2017.06.016.

2. Panda, D. K., Banerjee D., Goyal S. K., Patel A. R., Shukla, A. D., "Development of a Cerium-doped Lanthanum Bromide gamma-ray spectrometer for planetary missions and feasibility studies for determination of elemental abundances of radioactive elements (Th, K and U).", Current Science, 2016, 110, 2135-2138.

Conference Proceedings:

1. Development of $LaBr_3$:Ce and $CeBr_3$ gamma ray spectrometers for space applications.
   Dipak K. Panda, D. Banerjee, S.K. Goyal, A.R Patel, and A.D. Shukla, SSD-18, 4th -8th July-2016.

2. On the application of visible - NIR reflectance spectroscopy for distinguishing feldspar and quartz OSL signals
   Debabrata Banerjee, Dipak Kumar Panda, SSD-18, 4th -8th July-2016.

3. New Results from laboratory model of a $LaBr_3$:Ce based gamma ray spectrometer.
   D. K. Panda, D. Banerjee, S.K. Goyal, A. R. Patel and Tinkal Ladiya, NSSS, 9-12th Feb-2016.

4. A $LaBr_3$:Ce Gamma Ray Spectrometer for Future Planetary Mission.
   D. K. Panda, D. Banerjee, S.K. Goyal, A. R. Patel and Tinkal Ladiya, NSSS, 29th Jan- 1st Feb 2014.

Bibliography

1. Agostinelli S. et. al., "Geant4—A Simulation Toolkit" Nuclear Instruments and Methods in Physics Research A, 2003, 506, 250–303.
2. Aitken M.J., Reid J., Tite M.S. "Thermoluminescence dating of ancient ceramics.", Nature, 1964, 202: 1032.
3. Aitken M.J., Xie J.," Optical dating using infrared diodes: young samples", Quaternary Science Reviews, 1992, 11, 147-152.
4. Aitken M.J., "Optical dating: A review for non-specialists" Quaternary Science Reviews, 1994, 13, 503-508.
5. Aitken, M.J., "Thermoluminescence Dating.", 1985, Academic press, London.
6. Arnold J. R., Metzger A. E., Anderson E. C., Marvin A. Dilla V., "Gamma rays in Space, Ranger 3.", JGR, 1962, 67, 4878-4880.
7. Arnold L.J., Duval M., Falguères C., Bahain J.J., Demuro M., "Portable gamma spectrometry with cerium-doped lanthanum bromide scintillators: Suitability assessments for luminescence and electron spin resonance dating applications", Radiation Measurements, 2012, 47, 6-18.
8. Auclair M., Lamothe, M., Huot, S. "Measurement of anomalous fading for feldspar IRSL using SAR." Radiation Measurements, 2003, 37, 487-492.
9. Beck A.W., Lawrence D. J., Peplowski P. N., Viviano-Beck Christina E., Prettyman T. H., McCoy T. J., McSween Jr H. Y., Yamashita N., "Igneous lithologies on asteroid (4) Vesta mapped using gamma-ray and neutron data.", Icarus, 2017, 286, 35-45.
10. Berger A. "Milankovitch theory and climate" Reviews in Geology, 1988, 26, 624-657.
11. Bhattacharya A. B. and Litchman J.M., "Solar Planetary System" CRC press, 2017,
12. Bielefeld M. J., Reedy R. C., Metzger A.E., "Chemistry of the Lunar Equatorial zone.", Proceedings 7th Lunar Science Conference, 1976, 2661-2676.
13. Billnert R., Oberstedt S., Andreotti E., Hult M., Marissens G., Oberstedt A., "New information on the characteristics of 1 in x 1 in. cerium bromide

scintillation detectors.", Nuclear Instruments and Methods in Physics Research A, 2011, 647, 94 - 99.

14. Bizarri G, de Haas J, Dorenbos P, van Eijk C.W.E, "Scintillation properties of ø 1x 1 inch $LaBr_3$:% 5 percent Ce^{3+} crystal.", IEEE Transaction on Nuclear Science, 2006, 53, 615–9.10.1109/TNS.2006.870090.

15. Bøtter-Jensen L., Andersen C.E., Duller G.A.T., Murray A.S., "Developments in radiation, stimulation and observation facilities in luminescence measurements.", Radiation Measurements, 2003, 37, 535–541.

16. Bøtter-Jensen L., Jungner H., Mejdahl V., "Recent Developments of OSL Techniques for Dating Quartz and Feldspars", Radiation Protection Dosimetry, 1993, 47,643-648, https://doi.org/10.1093/oxfordjournals.rpd.a081824

17. Boynton W.V. , Trombka J.I. , W.C. Feldman, Arnold J.R. , Englert P.A.J., Metzger A.E. , Reedy R.C. , Squyres S.W, Wänke H. , Bailey, S.H. Brückner J., Callas J.L. , Drake D.M. , Duke P. , Evans L.G. , Haines E.L. , McCloskey F.C., Mills H. , Shinohara C. , Starr R. , "Science applications of the Mars Observer Gamma Ray Spectrometer", Journal of Geophysical. Research, 1992, 97, 7681-7698.

18. Boynton W.V., Feldman W.C., Mitrofanov I.G., Evans L.G., Reedy R.C., Squyres S.W., Starr R., Trombka J.I., d'Uston C., Arnold J.R., Englert P.A.J., Metzger A.E., Wänke H., Brückner J., Drake D.M., Shinohara C., Fellows C., Hamara D.K., Harshman K., Kerry K., Turner C., Ward M., Barthe H., Fuller K.R., Storms S.A., Thornton G.W., Longmire J.L., Litvak M.L., Ton'chev A.K., "The Mars Odyssey Gamma-Ray Spectrometer Instrument suite" Space Science Reviews, 2004, 110, 40-83.

19. Boynton W.V., Taylor G.J., Evans L. G., Reedy R. C., Starr R., Janes D. M., Kerry K. E., Drake D. M., Kim K. J., Williams R. M. S., Crombie M. K., Dohm J. M., Baker V. Metzger, A. E., Karunatillake S., Keller J. M., Newsom H. E., Arnold J. R., Bru¨ckner J., Englert P. A. J., Gasnault O., Sprague A. L., Mitrofanov I., Squyres S. W., Trombka J. I., d'Uston L., Wa¨nke H., and Hamara D. K. , "Concentration of H, Si, Cl, K, Fe, and Th in the low- and mid-latitude regions of Mars", JGR, 2007, 112, E12S99, doi:10.1029/2007JE002887.

20. Buylaert, J.P, Murray A.S., Thomsen K.J & Jain M., "Testing the potential of an elevated temperature IRSL signal from K-feldspar" Radiation Measurements, 2009, 44, 560-565. DOI: 10.1016/j.radmeas.2009.02.007.
21. Daniels F., Boyd C.A. & Saunders, D.F. "Thermoluminescence as a research tool", Science, 1593, 117: 343-349.
22. Debenham N.C., Walton A.J. "TL properties of some wind-blown sediments", Council of Europe, J. PACT, 1983, 9, 531-538.
23. Drozdowski W. , Dorenbos P. , Bos A. J. J. , Bizarri G. , Owens A. , Quarati F. G. A., "$CeBr_3$ Scintillator Development for Possible Use in Space Missions.", IEEE Transactions on Nuclear Science, 2008, 55, 1391.
24. Duller, G.A.T., "A new method for the analysis of infrared stimulated luminescence from potassium feldspars.", Radiation Measurements, 1994. 23, 281–285.
25. Duller, G.A.T., Bøtter-Jensen, L., "Luminescence from potassium feldspars stimulated by infrared and green light.", Radiation. Prot. Dosimetry, 1993, 47, 683–688.
26. Duller, G.A.T., Infrared bleaching of the thermoluminescence of four feldspars. J. Physics. D. Applied Physics, 1995, 28, 1244-1258.
27. Etchegaray-Ramirez M I., Metzger A.E., Haines E.L., Hawke B.R, "Thorium Concentrations in the Lunar Surface, 4, Deconvolution of the Mare Imbrium, Aristarchus and adjacent regions JGR, 1983, 88, A529 –A543".
28. Evans L G., Peplowski P.N., Rhodes E. A., Lawrence D. J., McCoy T. J., Nittler L.R., Solomon S.C., Sprague A.L., Stockstill-Cahill K. R., Starr R.D., Weider S. Z., Boynton W. V., Hamara D.K., and Goldsten J. O. "Major-element abundances on the surface of Mercury: Results from the MESSENGER Gamma-Ray Spectrometer" JGR, 2012, 117, E00L07, doi:10.1029/2012JE004178.
29. Evans L. G., Peplowski P. N., McCubbin F. M., McCoy T. J., Nittler L. R., Zolotov M. Yu., Ebel D. S., Lawrence D. J., Starr R. D., Weider S. Z., Solomon S. C., "Chlorine on the surface of Mercury: MESSENGER gamma-ray measurements and implications for the planet's formation and evolution", Icarus, 2015, 257, 417-427.

30. Evans L. G., Peplowski P. N., Rhodes E. A., Lawrence D. J., McCoy T.J., Nittler L. R., Solomon S. C., Sprague A. L., Stockstill-Cahill K. R., Starr R. D., Weider S. Z., Boynton W. V., David K., and Goldsten J. O. "Major-element abundances on the surface of Mercury: Results from the MESSENGER Gamma-Ray Spectrometer" JGR, 2012, 117, E00L07, doi:10.1029/2012JE004178.

31. Feldman W. C., Lawrence D. J., Elphic R. C., Barraclough B. L., Maurice S., Genetay I., Binder A. B., "Polar hydrogen deposits on the Moon", JGR, 2000, 105, 4175-4195.

32. Feldman W.C., Barraclough B.L., Fuller K.R. , Lawrence D.J., Maurice S., Miller M.C., PrettymanaT.H, Binder A.B. ,"The Lunar Prospector gamma-ray and neutron spectrometers.", Nuclear Instruments and Methods in Physics Research A, 1999, 422, 562-566.

33. Feldman W.C., Binder A.B., Hubbard G.S., McMurray R.E., Miller Jr. M.C., and Prettyman T.H., "The Lunar Prospector gamma-ray spectrometer", LPSC, 1996, XXVII, 355.

34. Fields B.D, Olive K.A "Big bang nucleosynthesis", Nucl Phys A, 2006,777,208–225

35. Fireman E. L., Spannagel G. "Radial gradient of cosmic rays from the Lost City meteorite", JGR, 1971, 76, 4127-4134, DOI: 10.1029/JB076i017p04127.

36. Forman D.S, McEwen B.S. and Grafstein B, "Rapid transport of transport of radioactivity in goldfish optic nerve following injections of labeled glucosamine", Brain Research,1971, 28, 119-130.

37. Forni O., Gasnault O., Yamashita N., d'Uston C., Hasebe N., Reedy R. C., Karouji Y., Kobayashi S., Hareyama M., Kobayashi M. N., and Kim K. J., "Potassium-Thorium ratio on the moon: new results from Kaguya-GRS", European Planetary Science Congress, 2010, 5, 556,

38. Fraile L.M., Mach H., Vedia V., Olaizola B., Paziy V., Picado E., Udı´as J.M., "Fast timing study of a $CeBr_3$ crystal: Time resolution below 120 ps at ^{60}Co energies" Nuclear Instruments and Methods in Physics Research A, 2013, 701, 235–242.

39. Gilmore, G., Hemingway, J.D., Practical gamma-ray spectrometry. Wiley & Sons, Chichester, 1995.

40. Glodo J., Shah K. S., Klugerman M., Wong P., and Higgins B., "Thermolumineseence of $LaBr_3$: Ce and $LaCl_3$:Ce crystals," Nuclear Instruments and Methods in Physics Research A, 2005, 537, 93–96.

41. Goldreich P., Ward W. R., " The formation of planetesimals ", Astrophysical Journal,1973, 183, 1051-1061.

42. Goldsten J.O., Rhodes E. A., Boynton W. V., Feldman W. C., Lawrence D. J., Trombka J. I., Smith D. M., Evans L. G., White J., Madden N. W., Berg P. C., Murphy G. A., Gurnee R. S., Strohbehn K., Williams B. D., Schaefer E. D., Monaco C. A., Cork C.P., Del Eckels J., Miller W. O., Burks M. T., Hagler L. B., DeTeresa S. J., Witte M. C. "The MESSENGER Gamma-Ray and Neutron Spectrometer" Space Science Review, 2007, 131, 339–391.

43. Guillot-Noël O., de Haas J. T. M., Dorenbos P., van Eijk C. W. E., Krämer K., and Güdel H. U. "Optical and scintillation properties of cerium-doped $LaCl_3$, $LuBr_3$ and $LuCl_3$" Journal of Luminescence. 1999, 85, 21-35.

44. Guss P, Reed M, Yuan D, Reed A, Mukhopadhyay S, "$CeBr_3$ as a room-temperature, high-resolution gamma-ray detector." Nuclear Instruments and Methods in Physics Research A, 2009, 608, 297-304.

45. Harrington T.M., Marshall J H, Arnold J., Peterson L. E., Trombka J. I., Metzger A.E., "The Apollo gamma-ray spectrometer" Nuclear Instruments and Methods in Physics Research A, 1974, 118, 401-411.

46. Hasebe N., Shibamura E., Atarashiya T., Doke T., d'Uston C., Grande M., Kashiwagi T., Kikuchi J.', Kobayashi'M., Kubo K., Mitani S., Mori K., Narasak K., Nomi K., Takashima T., Tanibata R. and Reedy R.C., "Gamma Ray Spectrometer for Japanese Lunar Polar Orbiter". Advance. Space Research., 1999, 23, 1837-1840.

47. Hasebe N., Yamashita N., Okudaira O., Kobayashi S., Yamamoto H., Ishizaki T., Hirano K., Sakurai K., Miyachi T., Miyajima M., Fujii M., Kobayashi M.N., Takashima T., Shibamura E., Gasnault O., Maurice S., d'Uston C., Reedy R., Grande M. "The high precision gamma-ray spectrometer for lunar polar orbiter SELENE", Advances in Space Research, 2008, 42, 323–330,

48. Hastings A S, Jr., and Lucas M., "Gamma Ray Detectors from Passive Non-destructive Assay of Nuclear Material.".

49. Hiesinger H., Head III J. W., "The Syrtis Major volcanic province, Mars: Synthesis from Mars Global Surveyor data", JGR, 109, E01004DOI: 10.1029/2003JE002143
50. Higgins W., Churilov A., Loef E. van, Glodo J., Squillante M., Shah K., "Crystal growth of large diameter $LaBr_3$:Ce and $CeBr_3$" J. Crystal Growth, 2008, 310, 2085-2089.
51. Huntley D.J. Lamothe M., "Ubiquity of anomalous fading in K-feldspars and the measurement and correction for it in optical dating." Canadian Journal of Earth Sciences, 2001, 38, 1093- 1106.
52. Huntley D.J., Godfrey-Smith, D.I. & Thewalt M.L.W. "Optical dating of sediments." Nature, 1985, 313, 105-107.
53. Hurtado S., García-León M., García-Tenorio R., "GEANT4 code for simulation of a germanium gamma-ray detector and its application to efficiency calibration.", Nuclear Instruments and Methods in Physics Research A, 2004, 518, 764–774.
54. Hutt G., Jaek I., Tchonka J., Optical dating: K-feldspars optical response stimulation spectrum Quaternary Science Reviews, 1988, 7, 381-386.
55. Hutton J.T. , Bowman J.R. , Dunham M.N.E., Crone A.J., Machette M.N., Twidale C.R., "Thermoluminescence dating of Australian palaeo-earthquakes", Quaternary Science Reviews, 1994, 13, 143-147.
56. Jian Chen Jian Chen, Zongcheng Ling, Bo Li, Jiang Zhang, Lingzhi Sun, Changqing Liu, Lunar Global Aluminum Results from Chang'E- 2 Results from Chang'E-2 Gamma Ray Spectrometer 2016, 47th LPSC-3022.
57. Jolliff B. L., Gillis J. J., Haskin L. A., Korotev R.L., and Wieczorek M.A., "Major lunar crustal terranes: Surface expressions and crust-mantle origins, JGR, 2005, 105, 4197-4216.
58. Keller J. M., Boynton W. V., Karunatillake S., Baker,V. R., Dohm J. M., Evans L. G., Finch M. J., Hahn B. C., Hamara D. K., anesD. M. J, Kerry K. E., Newsom H. E., Reedy R. C., Sprague A. L., Squyres S. W., Starr R. D., Taylor G. J., and Williams R. M. S." Equatorial and mid-latitude distribution of chlorine measured by Mars Odyssey GRS" JGR, 2006, 111, E03S08, doi:10.1029/2006JE002679.

59. Kim et al., Significance of Kaguya GRS-Detected Si Abundance and Distribution SELENE", SELENE Symposium 2013.
60. Kim K.J, Dohm J. M., Williams J.P., Ruiz J., Hare T.M., Hasebe N., Karouji Y., Kobayashi S., Hareyama M., Shibamura E., Kobayashi M, d'Uston C., Gasnault O., Forni O., Maurice S., "South Pole-Aitken basin region, Moon: GIS-based geologic investigation using Kaguya elemental information", ASR, 2012, 50, 1629-1637.
61. Knoll G.F. "Radiation Detection and Measurement", 1999.
62. Kramer G.Y, Jolliff B. L., and Neal C. R., "Distinguishing high-alumina mare basalts using Clementine UVVIS and Lunar Prospector GRS data: Mare Moscoviense and Mare Nectaris" JGR, 2008, 113, E01002, doi:10.1029/2006JE002860.
63. Lawrence, D. J., Feldman W. C., Barraclough B. L., Binder A. B., Elphic R. C., Maurice S., Thomsen D. R., "Global elemental maps of the Moon: The Lunar Prospector Gamma-Ray Spectrometer.", Science, 1998,284, 1484.
64. Ling, Z., Zhang, J., Liu, J., et al., "Preliminary results of FeO mapping using Imaging Interferometer data from Chang'E-1," China Science Bulletin, 2011, 56, 376–379.
65. Liu, F., Shi, J., Le, Q., Rong, Y., "Lunar titanium characterization based on Chang'E (CE-1) interference imaging spectrometer (IIM) imagery and RELAB spectra.", Lunar and Planetary Science Conference XXXXI, 2010, 1642.
66. Lucey, P.G., Taylor G.J., and Malaret E., "Abundance and distribution of iron on the Moon.", Science, 1995,268, 1150-1153.
67. Ma T., Chang J., Zhang N., Cai M.S., Gong Y.Z., Tang H.S., Zhang R.J., Wang N.S., Yu M., Mao J.P., Su S.B., Fang Z., Xu R., Y.M. Hu, Gu Q., Zhou Y.L., Xu A.A., Liu L.G., "Gamma-ray detector on board lunar mission Chang'E-1", Advances in Space Research, 2008, 42, 347-349.
68. Ma T., Chang J., Zhang N., Jian W., Cai M.S., Gong Y.Z., Tang H.S., Zhang R.J., Wang N.S., Yu M., Mao J.P., Hu Y.M., Xu A.A., Zhu M.H., "Gamma-ray spectrometer onboard Chang'E-2". Nuclear Instruments and Methods in Physics Research A, 2013, 726, 113–115.

69. Martin R.G. and Livio M., "On the evolution of the snow line in protoplanetary discs", Earth and Planetary Astrophysics, 2012, DOI: 10.1111/j.1745-3933.2012.01290.x.

70. McCord T. B., Adam J. B., and Johnson T. V., "Asteroid Vesta: Spectral reflectivity and compositional implications." Science, 1970, 168, 1445–1447.

71. Metzger A. E. and Arnold J. R. "Gamma Ray Spectroscopic Measurements of Mars" Applied Optics, 1970, 9, 1289-1303.

72. Mitrofanov I.G., Kozyrev A.S., Konovalov A., Litvak M.L., Malakhov A.A. Mokrousov, M.I., Sanin A.B., Tret'ykov V.I., Vostrukhin A.V., Bobrovnitskij Yu.I., Tomilina T.M., Gurvits L., Owens A., "The Mercury Gamma and Neutron Spectrometer (MGNS) on board the Planetary Orbiter of the BepiColombo mission.", Planetary and Space Science, 2010, 58, 116–124.

73. Montmerle T., Augereau J.C., Chaussidon M., Gounelle M., Marty B. and Morbidelli A., "Solar system formation and early evolution: the first 100 Million Years", Earth, Moon, and Planets, 2006, 98, 39-95.

74. Moses W. W., "Current Trends in Scintillator Detectors and Materials", Nuclear Instruments and Methods in Physics Research A, 2002,487, 123–128.

75. Moszyński M., Nassalski A., Syntfeld-Każuch A., Szczęśniak T., Czarnacki W., Wolski D., Pausch G., Stein J. "Temperature dependences of $LaBr_3$(Ce), $LaCl_3$(Ce) and NaI(Tl) scintillators" Nuclear Instruments and Methods in Physics Research A, 2006, 568, 739–751.

76. Murray A.S., Wintle A.G., "Luminescence dating of quartz using an improved single-aliquot regenerative-dose protocol", Radiation Measurements, 2000, 32, 57-73.

77. Murray A.S., Buylaert J.P., Thmosen K.J., Jain M., "The effect of preheating on the IRSL signal from feldspar", Radiation Measurements, 2009, 44, 554-559.

78. Nicolini R., Camera F., Blasi N., Brambilla S., Bassini R., Boiano C., Bracco A., Crespi F.C.L., Wieland O., Benzoni G., Leoni S., Million B., Montanari D., Zalite A. "Investigation of the properties of a 1″ x 1″ $LaBr_3$:Ce scintillator", Nuclear Instruments and Methods in Physics Research A, 2007, 582, 554-561.

79. Nobuyuki Hasebe, Eido Shibamura, Takashi Miyachi, Takeshi Takashima, Masanori Kobayashi, Osamu Okudaira, Naoyuki Yamashita, Shingo Kobayashi, Takeshi Ishizaki, Kunitomo Sakurai, Mitsuhiro Miyajima, Masayuki Fujii, Keisuke Narasaki, Shigeki Takai, Katsuhiro Tsurumi, Hiroshi Kaneko, Michio Nakazawa, Kunishiro Mori, Olivier Gasnault, Sylvestre Maurice, Claude d'Uston, Robert C. Reedy, and Manuel Grande, "Gamma-ray spectrometer (GRS) for lunar polar orbiter SELENE", Earth Planets Space, 2008, 60, 299–312.
80. Ouyang, Z., Li, C., Zhou, Y., et al, "Chang'E-1 lunar mission: An overview and primary science results.", Chinese Journal of Space Science, 2010, 30, 392–403.
81. Panda, D. K., Banerjee D., Goyal S. K., Patel A. R., Shukla, A. D., "Development of a Cerium-doped Lanthanum Bromide gamma-ray spectrometer for planetary missions and feasibility studies for determination of elemental abundances of radioactive elements (Th, K and U).", Current Science, 2016, 110, 2135-2138.
82. Panda, D. K., Banerjee, D., Goyal, S. K., Patel, A. R. and Shukla, A. D., "Development of a Cerium bromide gamma ray spectrometer for space applications." Advances in Space Research, 2017, 60, 1307-1314, doi.org/10.1016/j.asr.2017.06.016.
83. Peplowski P. N., Evans L.G., Hauck II S. A., McCoy T. J., Boynton W. V., Gillis-Davis J. J., Ebel D. S., Goldsten J.O., Hamara D. K., Lawrence D.J., McNutt Jr R. L.., Nittler L. R., Solomon S. C., Rhodes E. A., Sprague A. L., Starr R. D., Stockstill-Cahil K. R., "Radioactive Elements on Mercury's Surface from MESSENGER: Implications for the Planet's Formation and Evolution", Science, 2011, 333, 1850-1852.
84. Peplowski P. N., Lawrence D. J., Rhodes E. A., Sprague A. L., McCoy T. J., Denevi Brett W., Evans L.G., Head J. W., Nittler L.R., Solomon S. C., Stockstill-Cahill K. R., and Weider S. Z., "Variations in the abundances of potassium and thorium on the surface of Mercury: Results from the MESSENGER Gamma-Ray Spectrometer", JGR, 2012, 117, E00L04, doi:10.1029/2012JE004141.

85. Peplowski Patrick N., Rhodes Edgar A., Hamara David K., Lawrence David J., Evans Larry G., Nittler Larry R., and Solomon Sean C., "Aluminum abundance on the surface of Mercury: Application of a new background-reduction technique for the analysis of gamma-ray spectroscopy data", JGR, 2012, 117, E00L10, doi:10.1029/2012JE004181.
86. Pil Soo Lee, Chun Sik Lee, Ju Hahn Lee "Development of FPGA-based digital signal processing system for radiation spectroscopy" Radiation Measurements, 2013, 48, 12-17.
87. Prescott J.R. and Stephan L.G. "The contribution of Cosmic Radiation to the environmental dose for Thermoluminiscent dating, Latitude, altitude, and depth dependences", PACT Journal (Coulcile of Europe), 1982, 6, 17-25.
88. Prescott J.R., Hutton J.T. "Environmental dose rates and radioactive disequilibrium from some Australian luminescence dating sites", Quaternary Science Reviews, 1995, 14, 439-448.
89. Prettyman T. H. · Feldman W. C., McSween Jr H. Y., Dingler R. D., Enemark D. C. · Patrick D. E., Storms S. A., Hendricks J. S., Morgenthaler J. P., · Pitman K. M., · Reedy R. C., "Dawn's Gamma Ray and Neutron Detector" Space Science Review, 2011, 163, 371–459, doi:10.1007/s11214-011-9862-0.
90. Prettyman T. H. Yamashita N. Castillo-Rogez J. C. Feldman W. C. Lawrence D. J., McSween H. Y., Schorghofer N., Toplis M. J., Forni O., Joy S. P., Marchi S., Platz T., Polanskey C. A., Sanctis M. C. de, Rayman M. D., Raymond C. A., Russell C. T., "Elemental Composition of Ceres by Dawn's Gamma Ray and Neutron Detector Elemental mapping of Ceres by Dawn's Gamma Ray and Neutron Detector reveals a hydrogen-rich regolith and evidence for near-surface water ice at high latitudes." , LPSC XXXXVII, 2016, 2228.
91. Prettyman T. H., Mittlefehldt D. W., Yamashita N., Beck A. W., Feldman W. C., Hendricks J. S., Lawrence D. J., McCoy T. J., McSween H. Y., Peplowski P. N., Reedy R.C., Toplis M. J., Le Corre L., Mizzon H., Reddy V., Titus T. N., Raymond C. A., and Russell C. T. "Neutron absorption constraints on the composition of 4 Vesta.", Meteoritics & Planetary Science, 2013, 48, 2211–2236, doi:10.1111/ maps.12244.
92. Prettyman T. H., Mittlefehldt D. W., Yamashita N., Lawrence D. J., Beck A. W., Feldman W. C., McCoy T. J., McSween H. Y., Toplis M. J., Titus T. N., Tricarico

P., Reedy R. C., Hendricks J. S., Forni O., Le Corre L., Li J.-Y., Mizzon H., Reddy V., Raymond C. A., and Russell C. T. "Elemental mapping by Dawn reveals exogenic H in Vesta's regolith." Science, 2012, 338, 242–246, doi:10.1126/ science.1225354.

93. Prettyman T.H., Yamashita N., Reedy R.C., McSween Jr H.Y., Mittlefehldt D.W., Hendricks J.S., Toplis M.J., "Concentrations of potassium and thorium within Vesta's regolith", Icarus, 2015, 259, 39–52.

94. Proszynska H., "TL dating of dome sub-aerial sediments from Poland", PACT, 1983, 9, 539-546.

95. Prószyńska-Bordas Hanna "TL dating of loess and fossil soils from the last interglacial-glacial cycle.", Nuclear Tracks and Radiation Measurements, 1982, 10, 737-742.

96. Quarati F.G.A., Dorenbos P., van der Biezen J., Owens A., Selle M., Parthier L., Schotanus P., "Scintillation and detection characteristics of high-sensitivity $CeBr_3$ gamma-ray spectrometers", Nuclear Instruments and Methods in Physics Research A, 2013, 729, 596–604

97. Quarati, F., Bos A.J.J., Brandenburg S., Dathy C., Dorenbos P., Kraft S., Ostendorf R.W., Ouspenski V., Owens A. ., X-ray and gamma-ray response of a 2″ × 2″ $LaBr_3$:Ce scintillation detector, Nuclear Instruments and Methods in Physics Research A, 2007, 574, 115–120.

98. Rao, M. N., D. D. Bogard, L. E. Nyquist, D. S. McKay, and J. Masarik, "Neutron capture isotopes in the Martian regolith and implications for Martian atmospheric noble gases.", Icarus, 2002, 156, 352–372.

99. Reedy R. C. and Arnold J. R. "Expected γ ray emission spectra from the Lunar surface as a function of chemical composition.", JGR, 1973, 78, 5847-5866

100. Reedy R. C. and Arnold J. R., "Interaction of Solara and Galactic Cosmic-Ray Particles with the Moon" JGR, 1972, 77, 537-555.

101. Russell C. T. and Raymond C. A. "The Dawn mission to Vesta and Ceres.", Space Science Reviews, 2011, 163:3–23, doi:10. 1007/s11214-011-9836-2.

102. Sasaki S., Iijima Y., Tanaka K., Kato M., Hashimoto M., Mizutani H., Takizawa Y., "The SELENE mission: Goals and status.", 2003, 31, 2335-2340.

103. Schotanus P., Stam G., Gerritse E., Utts B., Briaux B., "Scintillation detectors, Crismatec Catalogue", Saint-Gobain, 1992.

104. Shah K.S., Glodo J., Klugerman M., Cirignano L., Moses W.W., Derenzo S.E., Weber M.J., "$LaCl_3$:Ce scintillator for γ-ray detection", Nuclear Instruments and Methods in Physics Research A, 2003, 505, 76–81.

105. Shah K.S., Glodo Jaroslaw, Higgins W., van Loef E. V. D, Moses W. W., "$CeBr_3$ Scintillators for Gamma-Ray Spectroscopy", IEEE Transaction of Nuclear Science, 2005, 52, 3157.

106. Shannon R.D. "Revised effective ionic radii and systematic studies of interatomic distances in halides and chalcogenides", Acta Cryst. (1976). A32, 751-767. https://doi.org/10.1107/S0567739476001551

107. Sharma S, Bartarya SK, Marh BS, "The role of pre-existing topography in the evolution of post-glacial fluvial landforms in the middle Satluj valley, north-western Himalaya, India." Quaternary International, 2016, 425, 399-415

108. Singhvi A.K., Sharma J.P., Agrawal D.P., "Thermoluminescence dating of sand dunes in Rajasthan, India" Nature,1982, 295, 313-315.

109. Spudis P. "Back to the Moon", Nature Geoscience, 2009, 2, 234–236,

110. Surkov, Y. A., Barsukov V. L., Moskaleva L. P., Kharyukova V. P., Zaitseva S. Y., Stairnov G. G., and Manvelyan G. S., "Determination of the elemental composition of Martian rocks from Phobos 2", Nature, 1989, 341, 595-598.

111. Taylor Jeffrey, Boynton W., Brückner J., Wänke H., Dreibus G., Kerry K., Keller J., Reedy R., Evans L., Starr R., Squyres S., Karunatillake S., Gasnault O., Maurice S., d'Uston C., Englert P., Dohm J., Baker V., Hamara D., Janes D., Sprague A., Kim K., Drake D., "Bulk composition and early differentiation of Mars", 2006b, 111, E03S10, doi:10.1029/2005JE002645.

112. Taylor Jeffrey, Stopar J. D., Boynton W. V., Karunatillake S., Keller J. M., Brückner J., Wänke H., Dreibus G., Kerry K. E., Reedy R. C., Evans L. G., Starr R. D., Martel L. M. V., Squyres S. W., Gasnault O., Maurice S., d'Uston C., Englert P., Dohm J. M., Baker V. R., Hamara D., Janes D., Sprague A. L., Kim K. J., Drake D. M., McLennan S. M., Hahn B. C., "Variations in K/Th on Mars", 2006a, 111, E03S10, doi:10.1029/2005JE002645.

113. Thomsen, K.J., Murray, A.S., Jain, M., Bøtter-Jensen, "Laboratory fading rates of various luminescence signals from feldspar-rich sediment extracts." Radiation Measurements, 2008, 43, 1474–1486.
114. Trombka J. I., Evans L. G., Starr R., Floyd S. R, Squyres S. w., Whelan J. T, Bamford G. J., Coldwell R L., Rester A. c., Surkov Y. A., Moskaleva L. P., Kharyukova V. P., Manvelyan O. S., Zaitseva S. Y. and Smirnov G. G., "Analysis of Phobos Mission Gamma-Ray Spectra from Mars", 1992, Proceeding Lunar Planet. Science. Conference 22, 22-39.
115. van Loef E. V. D., Dorenbos P. and Eijk C. W. E. van, "High-energy-resolution scintillator: Ce3+ activated $LaBr_3$", Applied Physics Letters, 2001, 79, 1573-1575.
116. van Loef E. V. D., Dorenbos P., and C. van Eijk W. E. "High-Energy-Resolution Scintillator: Ce3+ Activated $LaCl_3$," Applied Physics Letters, 2000, 77, 1467-1468.
117. van Loef E. V. D., Dorenbos P., and van Eijk W C. E., Kramer K.W., Güdel H.U., "Scintillation properties of $LaBr_3$:Ce^3+ crystals: fast, efficient and high-energy-resolution scintillators.", Nuclear Instruments and Methods in Physics Research A, 2002, 486, 254–258.
118. Warren P.H., "Lunar Anorthosites and the magma-ocean plagioclase-floatation hypothesis: Importance of FeO enrichment in the parent magma." American Mineralogist, 1990, 75, 46-58.
119. Wehe D. K., "Current trends in ionizing Radiation Detection", Nuclear Engineering and Technology", 2006, 38, 311-318.
120. Weider S. Z., Nittler L. R., Starr R. D., McCoy, T. J., Stockstill-Cahill K. R., Byrne P.K., Denevi B. W., Head J.W., and Solomon S.C., "Chemical heterogeneity on Mercury's surface revealed by the MESSENGER X-Ray Spectrometer", JGR, 2012, 117, E00L05, doi:10.1029/2012JE004153.
121. Williams J. P., Cieza L. A. , "Protoplanetary disks and their evolution" 2011, Annual Review of Astronomy and Astrophysics, 2011, 49, 67-117.
122. Wintle A.G. & Huntley D.J. "Thermoluminescence dating of ocean sediments." Canadian Journal of Earth Sciences, 1980, 17, 348-360.
123. Wintle A.G. & Huntley D.J." Thermoluminescence dating of a deep-sea sediment core." Nature, 1979, 279: 710-712.

124. Wintle A.G. & Huntley D.J.” Thermoluminescence dating of sediments”, Quaternary Science Reviews, 1982, 31-53.

125. Yamashita N., Prettyman T. H., Mittlefehldt D. W., Toplis M. J., McCoy T. J., Beck A. W., Reedy R. C., Feldman W. C., Lawrence D. J., Peplowski P. N., Forni O., Mizzon H., Raymond C. A., Russel C. T. l, “Distribution of iron on Vesta”, MAPS, 2013, 48, 2237-2251.

126. Zheng Y., Ouyang Z., Li C, Liu J., Zou Y. “China’s Lunar Exploration Program: Present and future”, Planetary and Space Science, 2008, 56, 881-886.

127. Zhu M.H., Ma T., Chang J.,” Chang’E-1 gamma ray spectrometer and preliminary radioactive results on the lunar surface”, Planetary and Space Science, 58, 1547-1554.

128. Zhu Meng-Hua, Chang Jin, Ma Tao, Ip Wing-Huen, Fa WenZhe, Wu Jian, Cai MingSheng, Gong YiZhong, Hu YiMing, Xu AoAo & Tang ZeSheng, “Potassium Map from Chang’E-2 Constraints the Impact of Crisium and Orientale Basin on the Moon”, Scientific Reports, 2013, 3, 1611, doi:10.1038/srep01611.

129. Zhu Meng-Hua, Ma Tao, Chang Jin, “Chang’E-1 gamma ray spectrometer and preliminary radioactive results on the lunar surface”, Planetary and Space Science, 2010, 58, 1547-1554.

Web-site & data sheets

1. Canberra Application Note AN2508, 2011.
2. Canberra Application Note AN2508, 2011.
3. Data sheet “http://www.amptek.com/products/a275-pulse-amplifier/”
4. Data sheet “http://www.amptek.com/products/a275-pulse-amplifier/”
5. Data sheet “http://www.amptek.com/products/blr1-baseline-restorer/”
6. Data sheet http://www.analog.com/media/en/technical-documentation/data-sheets/AD829.pdf.
7. Data sheet http://www.analog.com/media/en/technical-documentation/data-
8. Hellma Materials GmbH, http://www.hellma-materials.com.
9. http://www.amptek.com/products/ph300-peak-hold-detector/

10. http://www.analog.com/media/en/technical-documentation/data-sheets/AD7899.pdf.
11. Saint-Gobain Crystals, http://www.detectors.saint-gobain.com.
12. Scionix Holland B.V., http://www.scionix.nl.