What do we know about VENUS SURFACE ELEMENTAL AND MINERALOGICAL COMPOSITION

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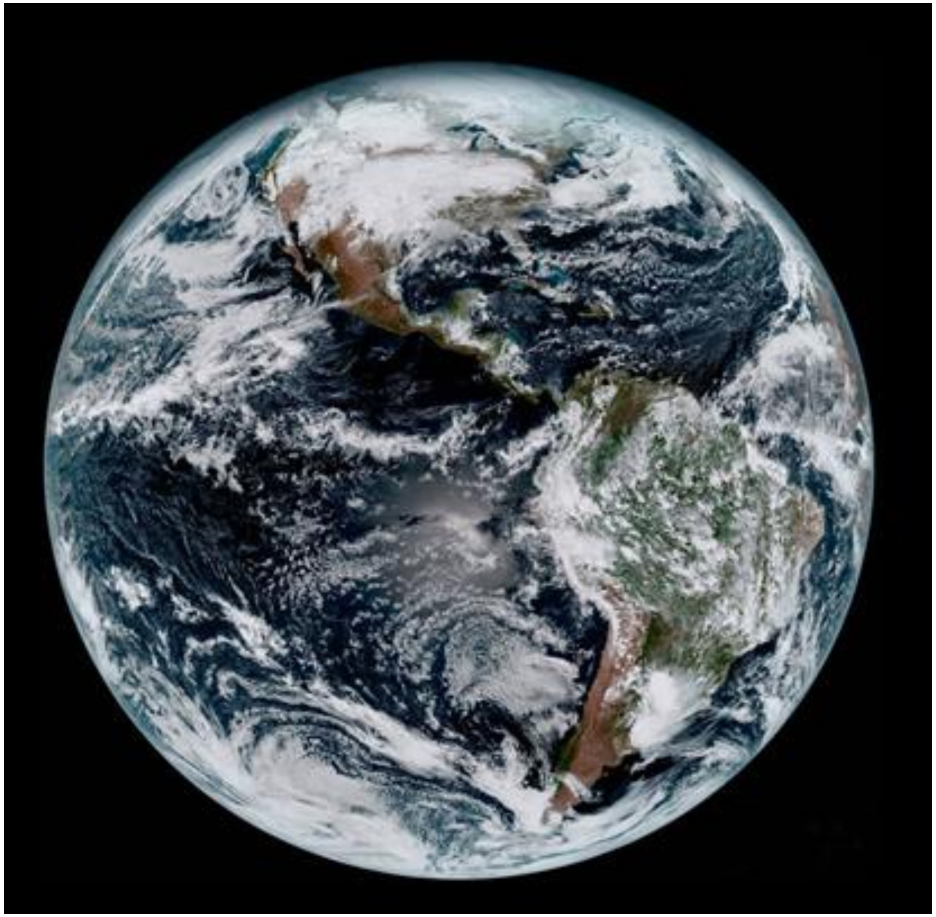
Venera-D Landing Sites Selection/Cloud Layer Habitability Workshop, Space Research Institute (IKI), 2-5 October 2019

Venus vs. Earth



VENUS

Although Venus is a rocky planet similar to the Earth in size and mass, its surface and atmosphere differ from our planet.
Shrouded by a thick atmosphere, the rocky surface lies beneath the thick layers of clouds and remained hidden until it was probed by Pioneer Venus Orbiter radar in 1978 that showed that, unlike Mars and Mercury which are both scarred by craters, Venus has a relatively smooth surface.

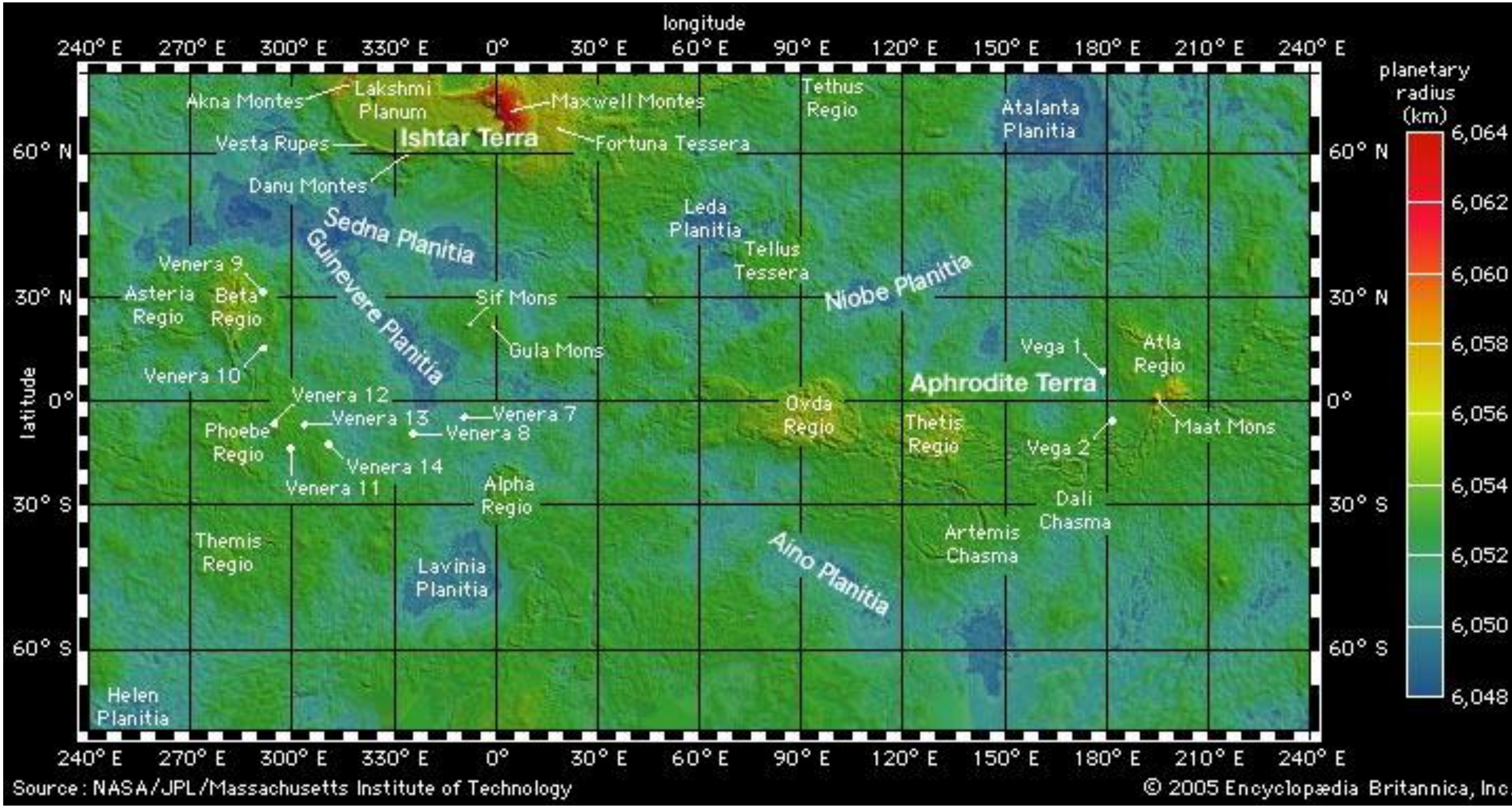
Venus likely also has a **mantle and a core**. The mantle is probably rocky and the core is somewhat liquid. Venus has a much weaker magnetic field than Earth, supposedly because of its slow rotation -243 Earth's days — and the core may not spin fast enough to create a magnetic field the way the core of Earth and other planets do. The core may also be completely solid, or may not even exist at all.

How well do we know the surface of Venus? Not very well.

The purpose of my talk is to summarize briefly the present status of surface elemental and mineralogical composition and show how we obtained it and look ahead what could be done on VENERA-D and how to achieve it.

Whatever we know about Venus surface chemistry, it comes from the Soviet Venera and Vega space missions in 1970's and 1980's.

VENERA & VEGA LANDING SITES



Venera 8 Atm/surface probe Landed on 22 Jul 1972 on the day side near the terminator at 10 S, 335 E. Measured the abundance of naturally occurring radiogenic elements **K–U–Th** . Operated for 50 min on the surface.

Venera 9 Orbiter/lander. Landed on 22 Oct 1975 on the day side at 32°N ,291°E, First image from the surface, **K–U–Th gamma ray analysis on the surface**. Operated for 53 min on the surface. Maybe lost contact with the orbiter out of range.

Venera 10 Orbiter/lander. Same design and science as Venera 9. Landed on 25 Oct. 1975 at 16°N 291°E. Measured **K–U–Th gamma ray surface composition**.

Venera 13 Orbiter/lander. Landed on the day side at 7.5°S, 303.0°E on 1 Mar 1982. **Conducted XRF analysis of the surface material.**

Venera 14 Orbiter/lander. Same design and science as Venera 13. Landed on the day side at 13.4°S 310.2°E on 5 Mar 1982. **Conducted XRF analysis of the surface material**.

Vega 1 flyby/lander. Lander on the night side of the planet at 8.1°N 176.7°E. The lander **conducted K–U–Th gamma ray surface composition** with a GRS (XRF analysis failed) on the surface.

Vega 2 flyby/lander. Same design and science as Vega-1. Landed at 7.2°S 179.4°E on 15 Jun 1985 and conducted successfully **XRF analysis &** Measured **K–U–Th gamma ray surface composition.**

Instruments used on Venera & VEGA missions:

A. ***XRF spectrometer***

To obtain the chemical composition of the Venusian surface.

Used successfully on Venera 13 14 & VEGA 2.

Instrument specifications:

- Uses radioactive Fe-55 and Pu-238 sources for x-ray excitation, proportional counters as a sensor and electronic box – all inside the lander – no need of deployment.
- Energy range: 1.5keV-8.0 keV
- Energy resolution: 20-25% (FWHM) at 5.9 keV
- Weight: 7.5- 8.0 kg
- Power: 12.5 Watt

Needs ~grams of surface material delivered inside lander
Needs low pressure inside the lander (< 0.05 atm)

VEGA2 XRF Characteristics

Габариты анализатора	2I6xI42xI28 мм
Число каналов анализатора	384 (3xI28)
Емкость канала	2^{16} – Iимп
Диапазон измеряемых энергий	I,25 – 8 кэВ
Энергетическое разрешение	20–25% по линии 5,9 кэВ
Масса	8 кг

Прибор разрабатывался специалистами СССР.

Power 9W

40cm x φ10.7 cm

Venera & VEGA XRF Sensor

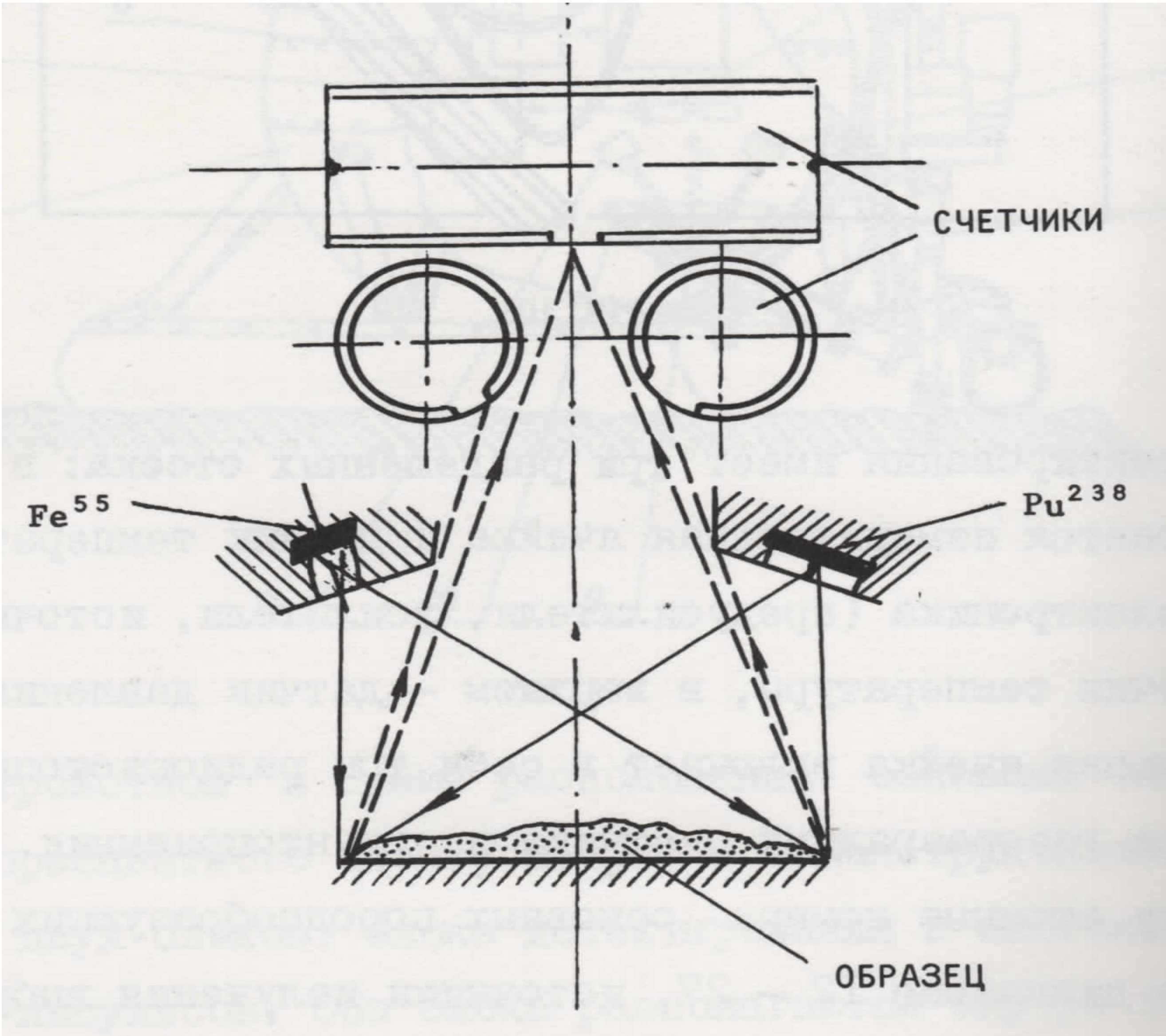


РИС. 106.

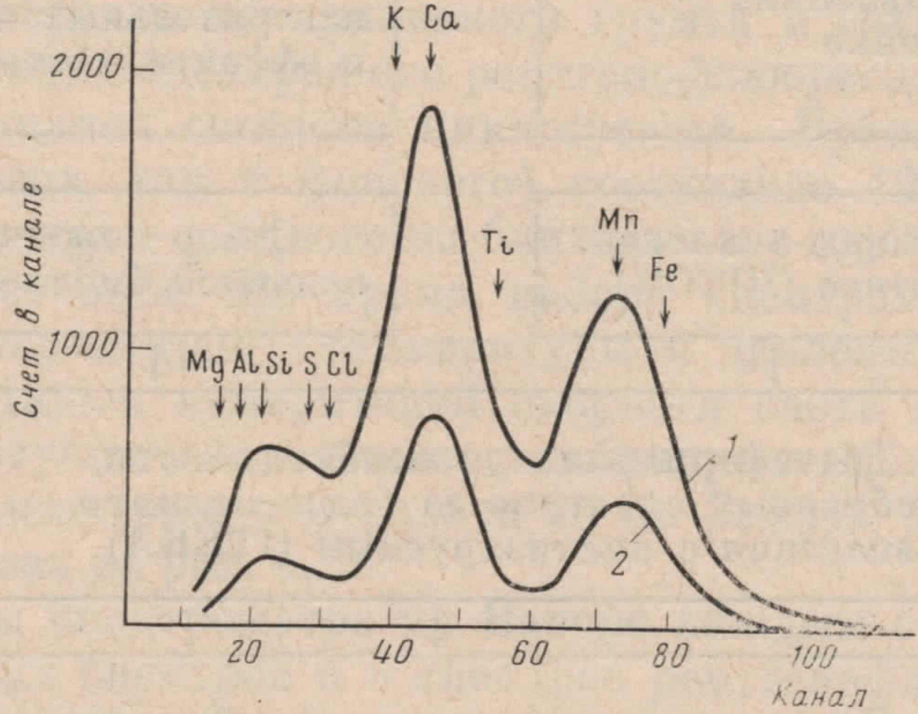


Рис. 5. Спектры рентгенофлюоресцентного излучения венерианской породы, измеренные на посадочном аппарате станции «Вега-2»

1 – спектр, измеренный ближним счетчиком; *2* – спектр, измеренный дальним счетчиком

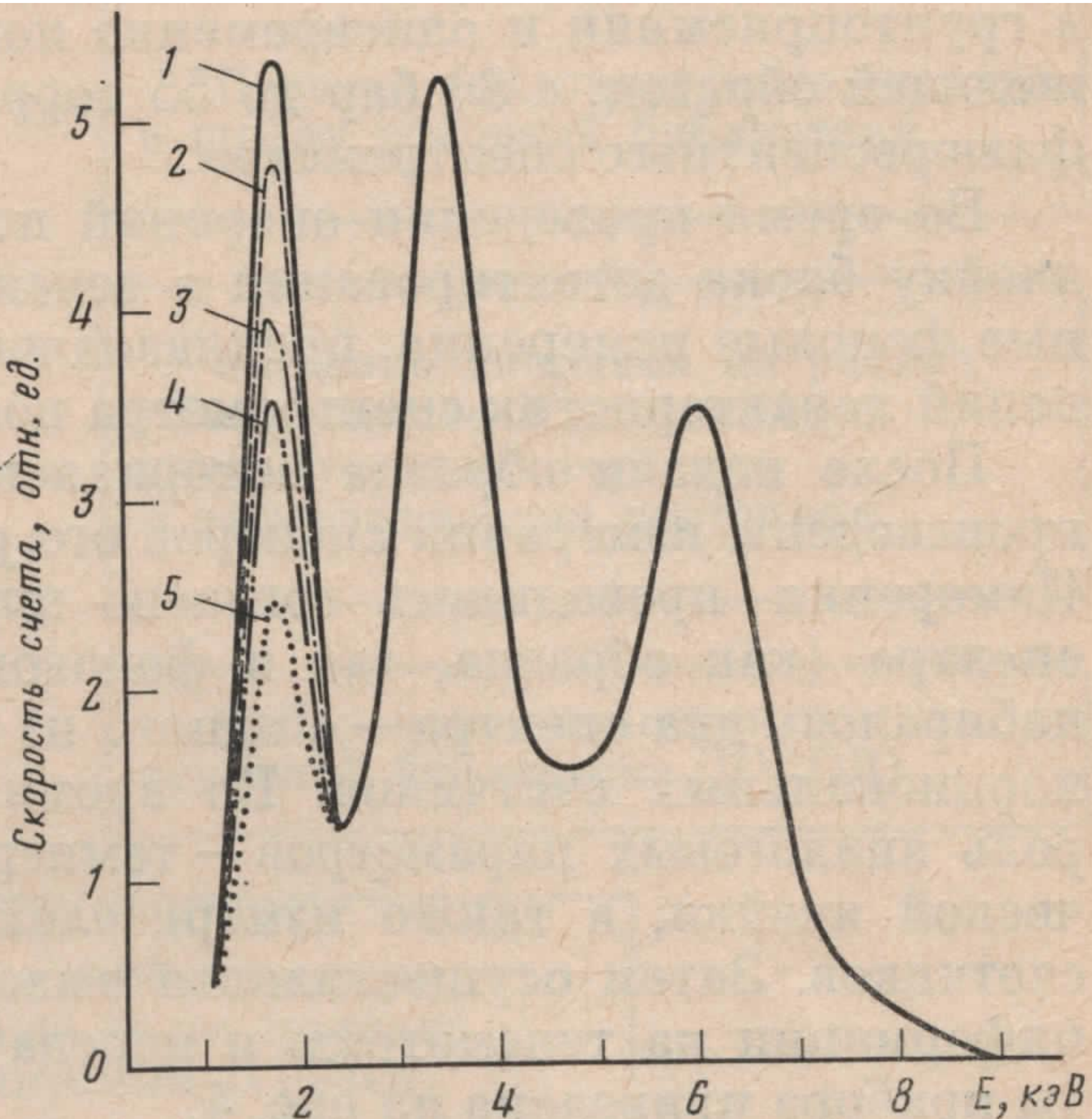


Рис. 3. Рентгенофлюоресцентные спектры породы, измеренные при различных давлениях в аналитической ячейке в мм рт. ст. *1* – 40; *2* – 50; *3* – 80; *4* – 100; *5* – 150

Yu. Surkov's paper of VEGA-2 elemental composition

КОСМИЧЕСКИЕ ИССЛЕДОВАНИЯ

Т. XXV 1987 Вып. 5

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Ю. А. Сурков, Л. П. Москалева, В. П. Харюкова, А. Д. Дудин, Г. Г. Смирнов, С. Е. Зайцева, А. Н. Тихомиров, О. С. Манвелян

ЭЛЕМЕНТНЫЙ СОСТАВ ПОРОД ВЕНЕРЫ В СЕВЕРО-ВОСТОЧНОЙ ЧАСТИ ЗЕМЛИ АФРОДИТЫ (ПО ДАННЫМ СА «ВЕГА-2»)

петрохимического сопоставления $A-S$ диаграмм, где $A=Al_2O_3+CaO+$ $+Na_2O+K_2O$, а $S=SiO_2-(FeO+MgO+MnO+TiO_2)$ [5]; для «Венеры-13 и -14» из петрохимического сопоставления зависимостей $[K_2O/(K_2O+$ $+Na_2O)]-[(\sum FeO/(\sum FeO+MgO)]$ для земных пород [2].

Определение концентрации S в исследуемом образце потребовало проведения дополнительных методических работ. Были измерены образцы (содержащие окислы основных породообразующих элементов в концентрациях, определенных в результате рассмотренного выше анализа), в кото-

Элемент (окисел)	«Венера-13»	«Венера-14»	«Вега-2»	АНТ «Луна-20»
MgO	11,4±6,2	8,1±3,3	11,5±3,7	13,4
Al_2O_3	15,8±3,0	17,9±2,6	16±1,8	19,1
SiO_2	45,1±3,0	48,7±3,6	45,6±3,2	44,2
K_2O	4,0±0,63	0,2±0,07	0,1±0,08	0,47
CaO	7,1±0,96	10,3±1,2	7,5±0,7	13,3
TiO_2	1,59±0,45	1,25±0,41	0,2±0,1	0,52
MnO	0,2±0,1	0,16±0,08	0,14±0,12	0,12
FeO	9,3±2,2	8,8±1,8	7,74±1,08	6,91
SO_3	1,62±1,0	0,88±0,77	4,7±1,5	0,08
Cl	<0,3	<0,4	<0,3	
Na_2O *	2,0±0,5	2,5±0,4	2,0	0,55
	98,1	98,7	95,8	

* Оценено теоретически.

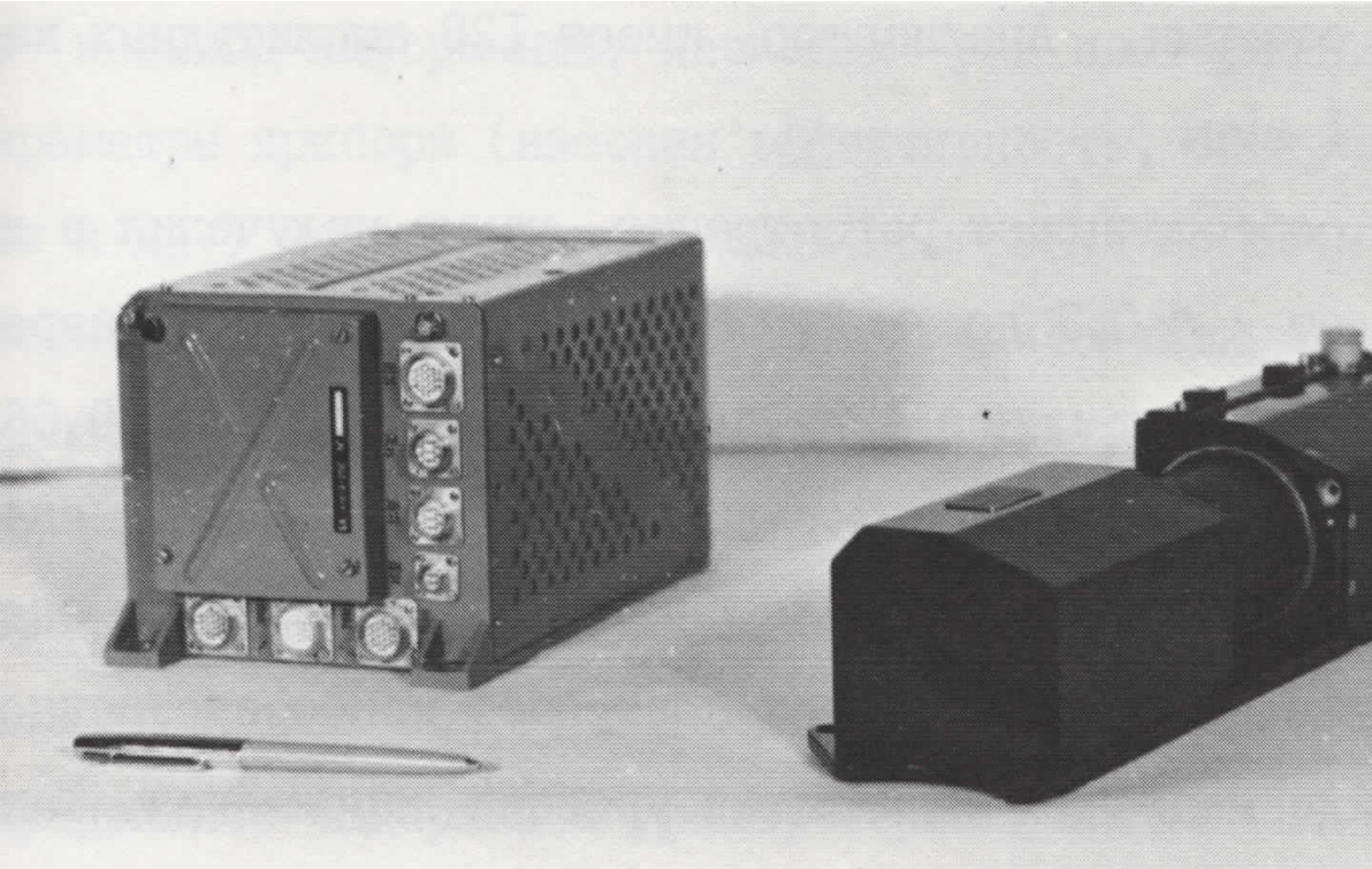
B: *Multichannel Gamma-Ray Spectrometer*

To detect the presence of naturally existing radioactive elements in Venusian soil (K, U, Th). From the level of these elements, it is possible to deduce the general character of the rocks (basalt, granite, etc.) and the approximate chemical composition

Used successfully on Venera 8, 9,10 & VEGA1&2.

Instrument specifications:

- Used CsI (ø 6.3x100cm)sensor and electronic box – all inside the lander – no need of deployment or bring sample inside the lander.
- Energy range: 0.3-3.0 MeV
- Energy resolution: 12% at CsI line
- Weight: 7.5 kg
- Power: 12.5 Watt
- Spectral size: 128 channel



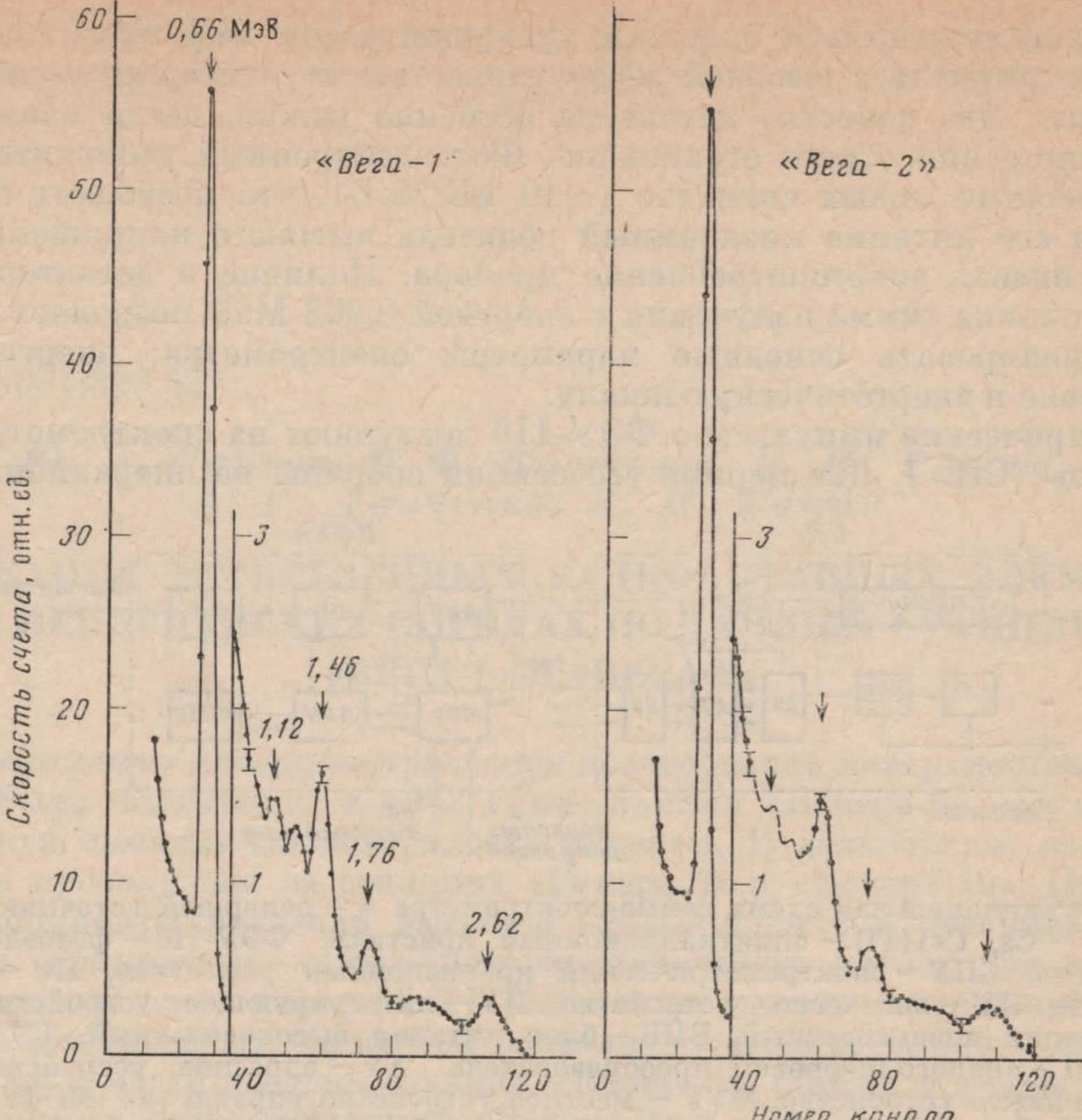


Рис. 2. Гамма-спектры, зарегистрированные на поверхности Венеры

Natural Radiogenic elements on Venus obtained by Venera & Vega Missions in 1970's and 1980's

Содержание урана, тория и калия в породах Венеры

Станция	Содержание, %		
	калий	уран, 10^{-4}	торий, 10^{-4}
«Вега-1» (1984)	0,45±0,22	0,64±0,47	1,5±1,2
«Вега-2» (1984)	0,40±0,20	0,68±0,38	2,0±1,0
«Венера-8» (1972)	4,0±1,2	2,2±0,7	6,5±0,2
«Венера-9» (1975)	0,47±0,08	0,60±0,16	3,65±0,42
«Венера-10» (1975)	0,30±0,16	0,46±0,26	0,70±0,34

Conclusions

XRF and GRS analyses indicate that surface composition at the Venera 9, 10, 14 and VEGA1,2 sites is chemically close to tholeiitic basalts, while at the Venera 8 and 13 sites it is close to alcaline basalts.

No mineral composition has been determined.

But, thermodynamic calculations indicate that the basaltic material should react with atmospheric gases forming magnetite, quartz, magnesite, anhydrite, pyrite, enstatite and albite.

The same conclusion can be derived from densitometers on some of Veneras , that determined density to be between 2.7-2.9 g/cm^3 –similar to Earth's basalts.

Payload considered for VENERA-D lander for surface elemental & mineralogical composition

- XRD/XRF - for mineralogical composition
- Mössbauer Spectrometer (with XRF/APXS mode) – for iron bearing minerals ans a detailed elemental composition
- Camera System (many imaging cameras, including an IR spectrometer
- Chemical analyses package – (CAP) – with a GCMS for atmospheric isotopic composition
- Gamma and Neutron spectrometer (ADRON) – for radiogenic and many other elements
- Raman Spectrometer (with synergistic LIDAR)
- METEO Package – for temperature, pressure and wind direction
- Multichannel diode laser spectrometer with gas sampling system
- infrared radiometer & UV-Vis spectrometer

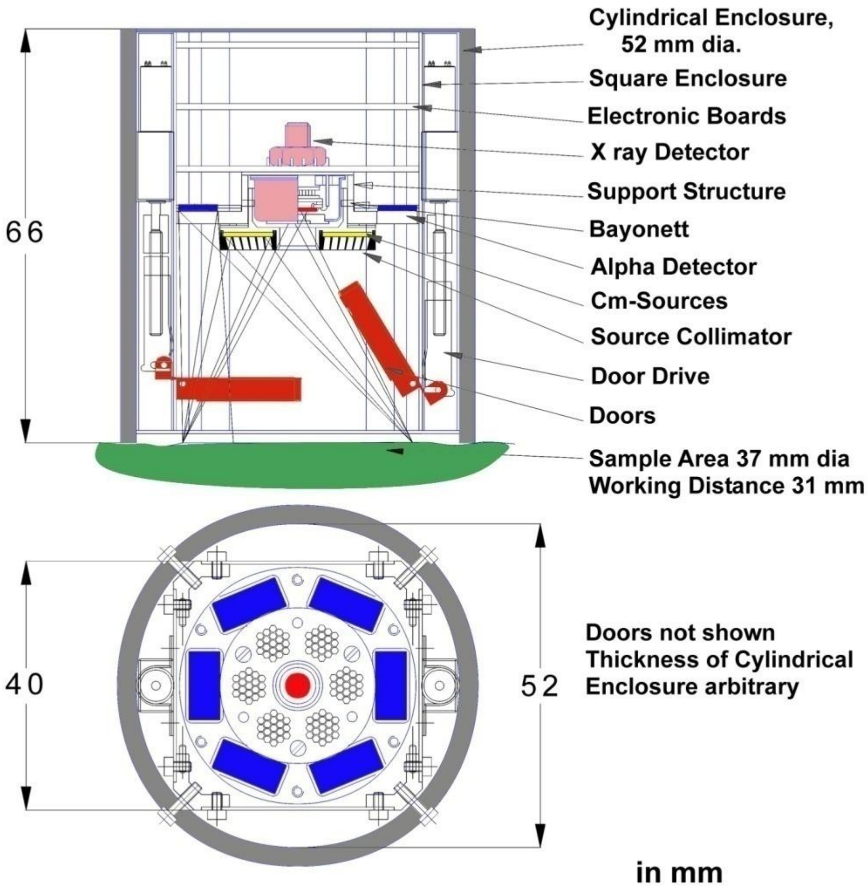
3. XRF/APXS

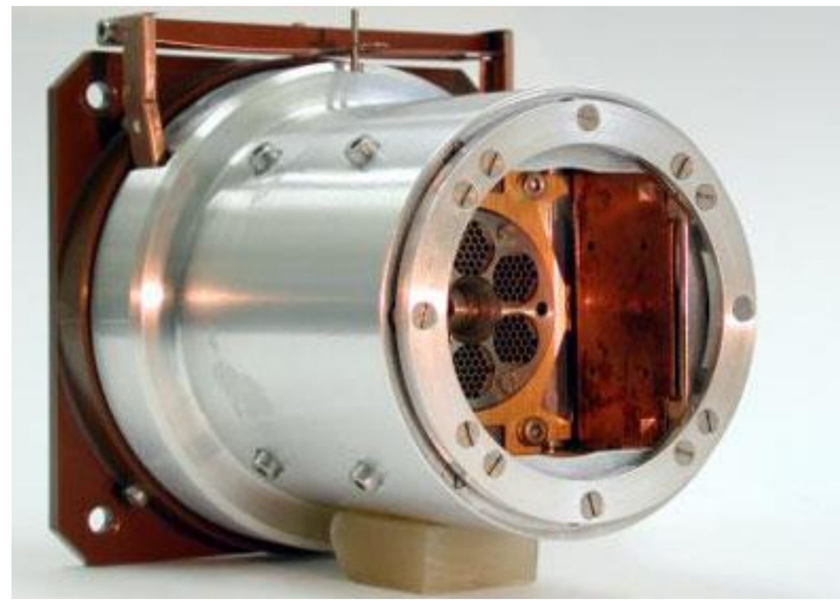
The XRF was used in the past on the Moon, Mars, Venus.
The APXS which is PIXE/XRF type instrument is now the choice instrument for the elemental chemical composition.
It has quite a lot of space heritage: A first version was developed in Chicago in 1960's for the Surveyor lunar mission.
An improved version then was used on the Soviet Phobos 1&2 in 1988, Mars-96 & Pathfinder in 1996, Rosetta mission in 2002, MER missions (Spirit & Opportunity) in 2003 and Curiosity in 2012 with excellent performance and complete success on every missions.

Specifications:

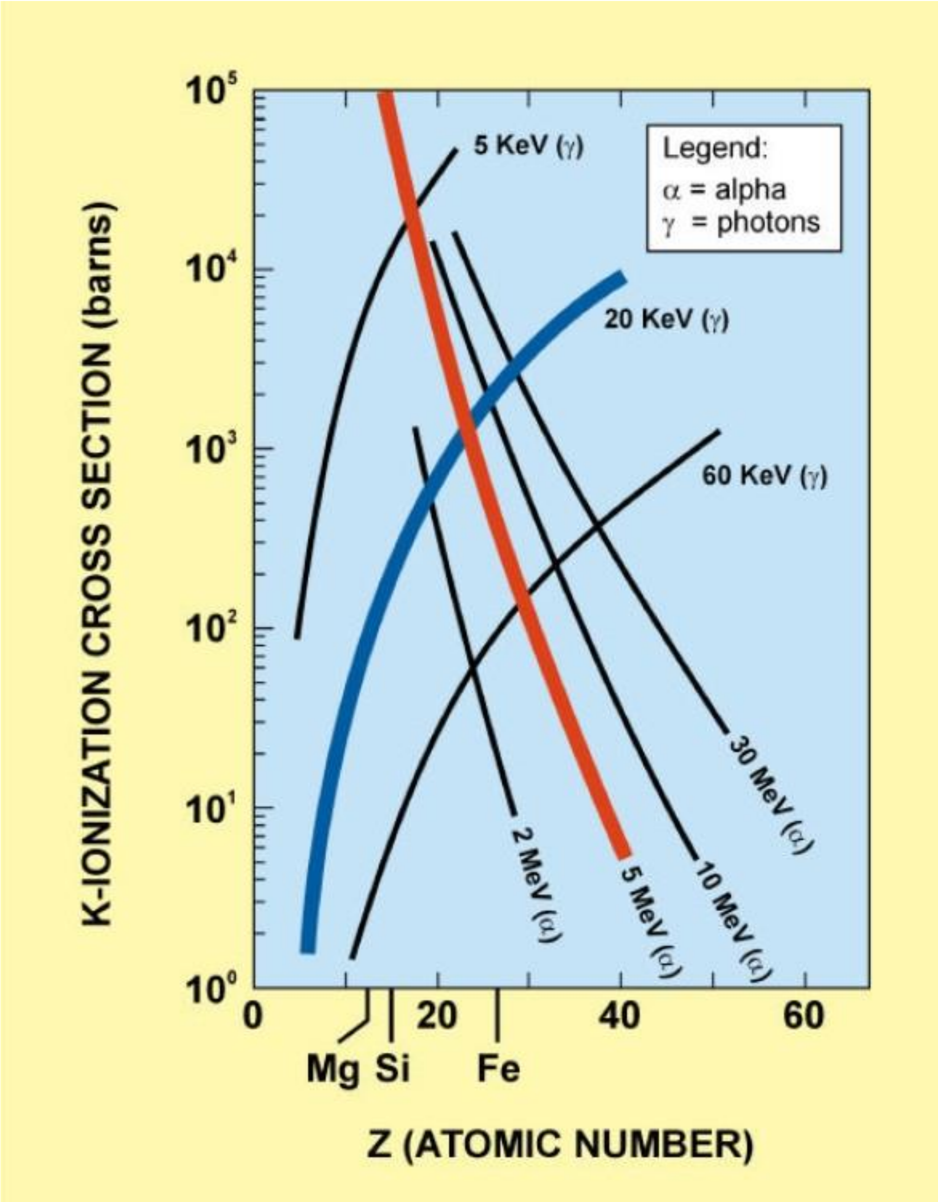
Uses ~ 50mCi of Cm-244 for excitation
X-ray Sensor: Si PIN or Si drift detectors
Weight : ~500g
Power: ~500 mW
Energy resolution: 140 eV (FWHM) at 5.9 keV
Detects all elements above Na, down to 10 ppm for some trace elements

Alpha Particle X-Ray Spectrometer



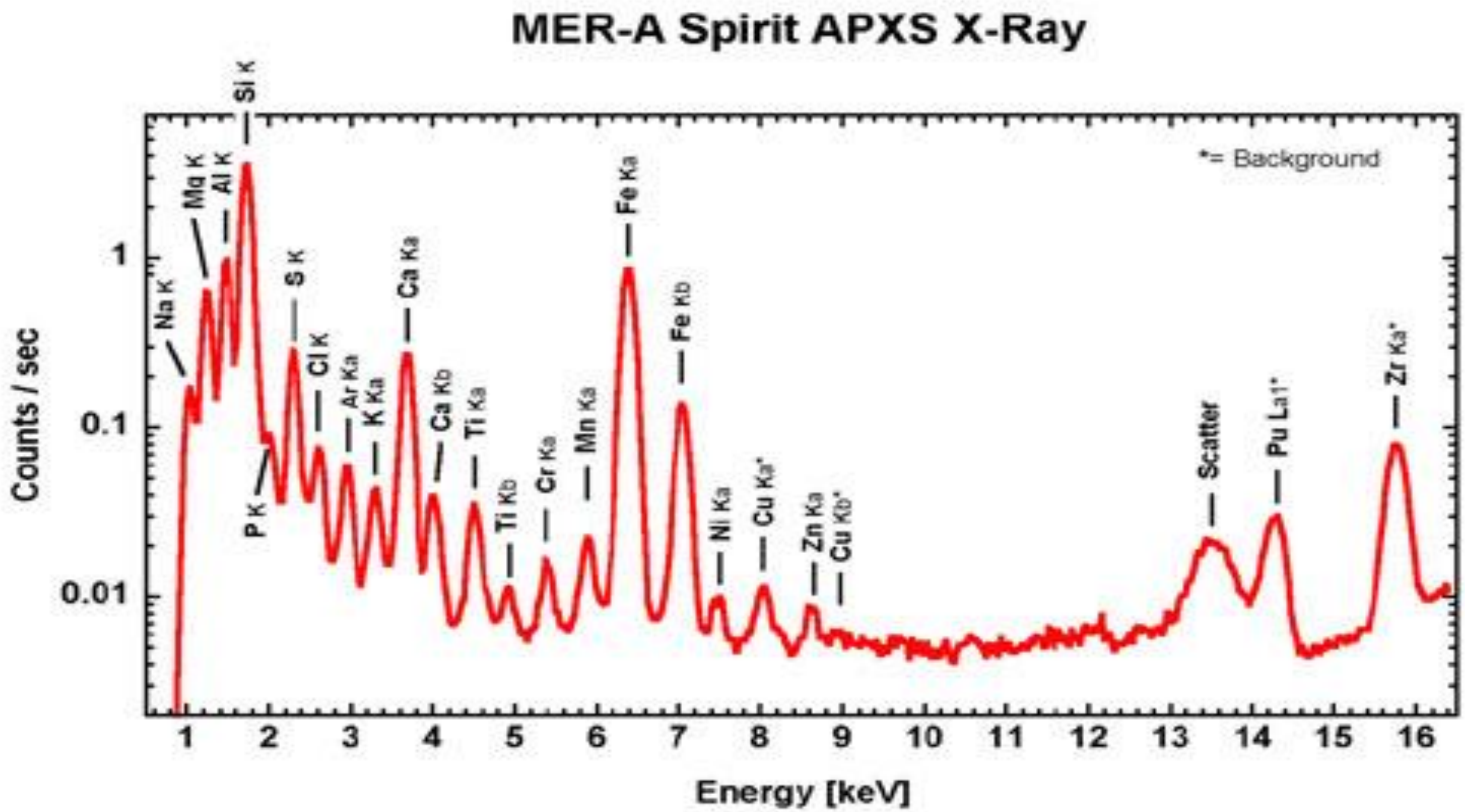


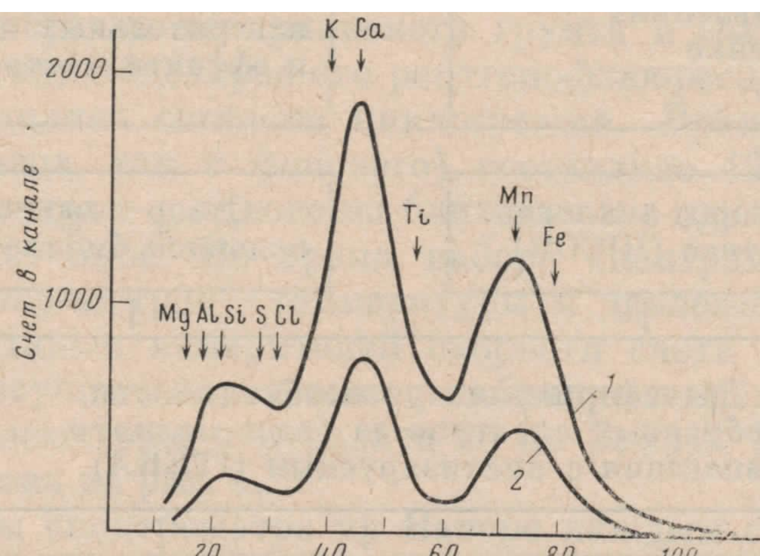
X-Ray Excitation Mechanisms



X-ray emission is stimulated by two different mechanisms:

- X-ray fluorescence: Most effective for high-Z elements
- PIXE (Particle-induced x-ray emission): most efficient for low-Z elements)


MER-A Spirit APXS X-Ray
*= Background
Counts / sec
1
0.1
0.01
Na K
Mg K
Al K
Si K
P K
S K
Cl K
Ar Ka
K Ka
Ca Ka
Ca Kb
Ti Ka
Ti Kb
Cr Ka
Mn Ka
Fe Ka
Fe Kb
Ni Ka
Cu Ka*
Zn Ka
Cu Kb*
Scatter
Pu La1*
Zr Ka*
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Energy [keV]


K Ca
2000
Ti
Mn
Fe
1000
Mg Al Si S Cl
Счет в канале
1
2
20 40 60 80 100

APXS preliminary results

Sample:	Adirondack after brushing		
Elements	wt%	Oxides	wt%
Na	2.3	Na_2O	3.1
Mg	6.5	MgO	10.8
Al	6.2	Al_2O_3	11.7
Si	20.7	SiO_2	44.3
P	0.29	P_2O_5	0.7
S	0.80	SO_3	2.01
Cl	0.28	Cl	0.28
K	0.1	K_2O	0.1
Ca	5.2	CaO	7.2
Ti	0.3	TiO_2	0.4
Cr	0.43	Cr_2O_3	0.62
Mn	0.27	MnO	0.34
Fe	12.7	FeO	16.3
		Fe_2O_3	18.1
Ni	0.01	NiO	0.02
Zn	0.01	ZnO	0.01
Sum Oxides (Fe as Fe_2O_3)			99.7

Sample:	Adirondack "as is"		
Elements	wt%	Oxides	wt%
Na	1.7	Na2O	2.3
Mg	6.1	MgO	10.2
Al	5.9	Al2O3	11.2
Si	20.7	SiO2	44.2
P	0.35	P2O5	0.8
S	1.30	SO3	3.26
Cl	0.35	Cl	0.35
K	0.1	K2O	0.1
Ca	5.0	CaO	7.0
Ti	0.4	TiO2	0.7
Cr	0.46	Cr2O3	0.67
Mn	0.27	MnO	0.35
Fe	12.9	FeO	16.6
		Fe2O3	18.5
Ni	0.01	NiO	0.01
Zn	0.01	ZnO	0.01
Sum Oxides (Fe as Fe2O3)			99.7

Sample:	Gusev Soil		
Elements	wt%	Oxides	wt%
Na	2.66	Na2O	3.58
Mg	5.93	MgO	9.84
Al	5.83	Al2O3	11.02
Si	20.92	SiO2	44.75
P	0.44	P2O5	1.02
S	2.48	SO3	6.19
Cl	0.62	Cl	0.62
K	0.14	K2O	0.17
Ca	4.04	CaO	5.66
Ti	0.12	TiO2	0.20
Cr	0.19	Cr2O3	0.28
Mn	0.22	MnO	0.28
Fe	11.11	FeO	14.29
		Fe2O3	15.88
Ni	0.05	NiO	0.06
Zn	0.03	ZnO	0.03
Sum Oxides (Fe as Fe2O3)			99.58

Mean Soil (wt% oxide)	
MPF [1]	Viking [2]
1.1	ND
8.7	6.4
8.0	8.0
42.3	47.0
0.98	ND
6.8	7.9
0.55	0.50
0.6	<0.15
6.5	6.4
1.0	0.7
0.3	ND
0.5	ND
22.3	19.7
ND	ND
99.7	96.6

[1] Brückner J. et al., JGR 108, E12, 8094 (2003)
[2] Clark B. C. et al., JGR 87, 10059, (1982)

Note: Relative Yield due to Measurement Geometry was 1.28

КОСМИЧЕСКИЕ ИССЛЕДОВАНИЯ

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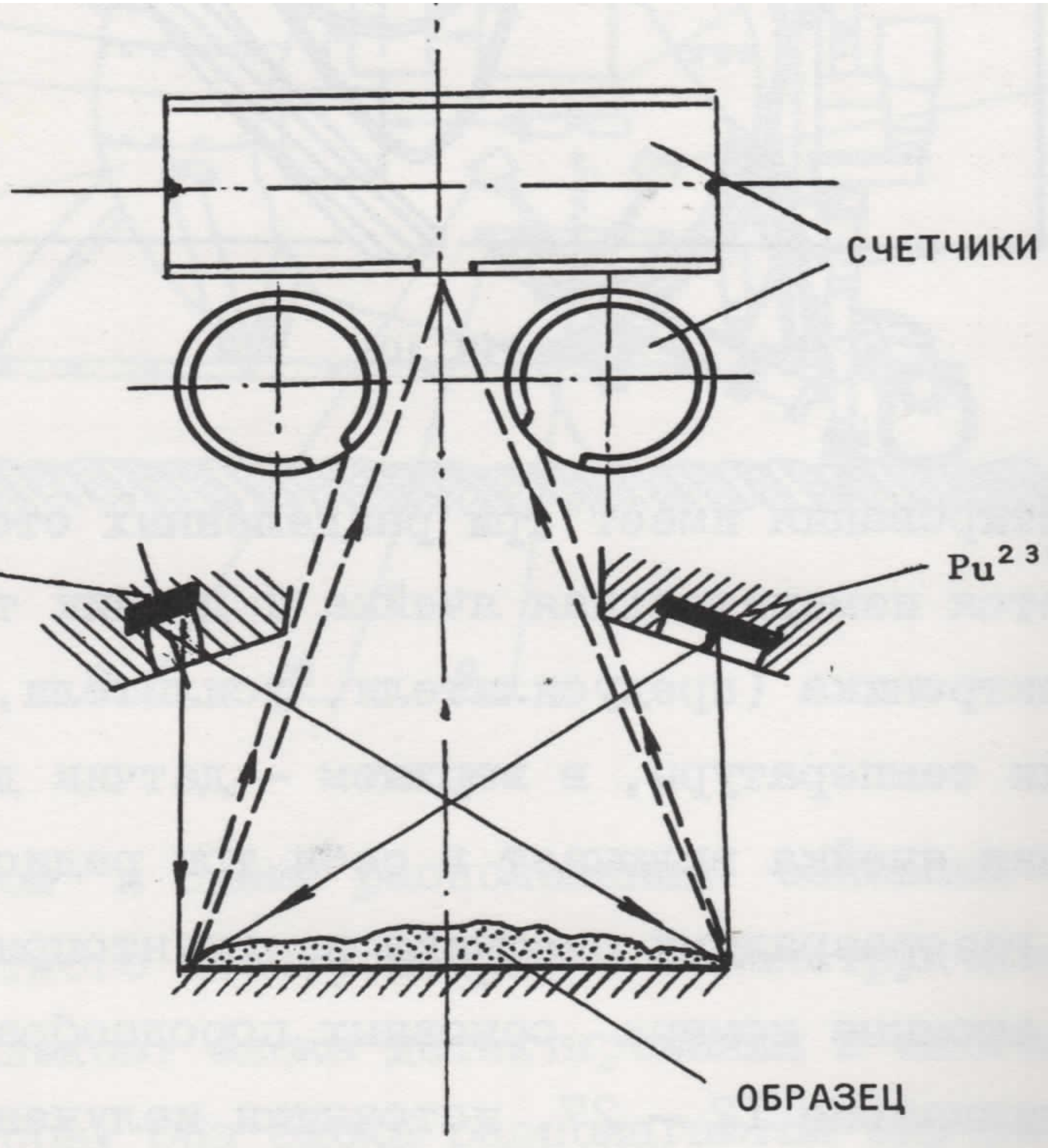
Б. М. Андрейчиков, И. К. Ахметшин, Б. Н. Корчуганов, Л. М. Мухин, Б. И. Огородников, И. В. Петрянов, В. И. Скитович

РЕНТГЕНОРАДИОМЕТРИЧЕСКИЙ АНАЛИЗ АЭРОЗОЛЯ ОБЛАКОВ ВЕНЕРЫ АМС «ВЕГА-1, -2»

Venera & VEGA XRF instrment



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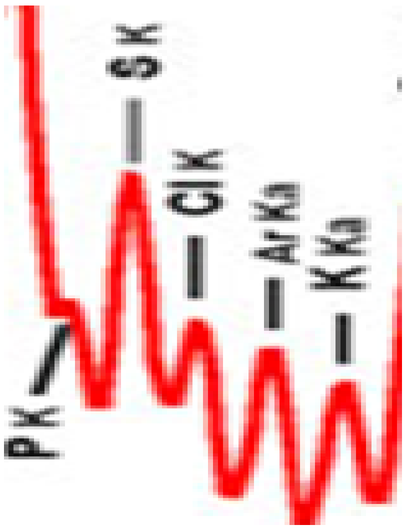
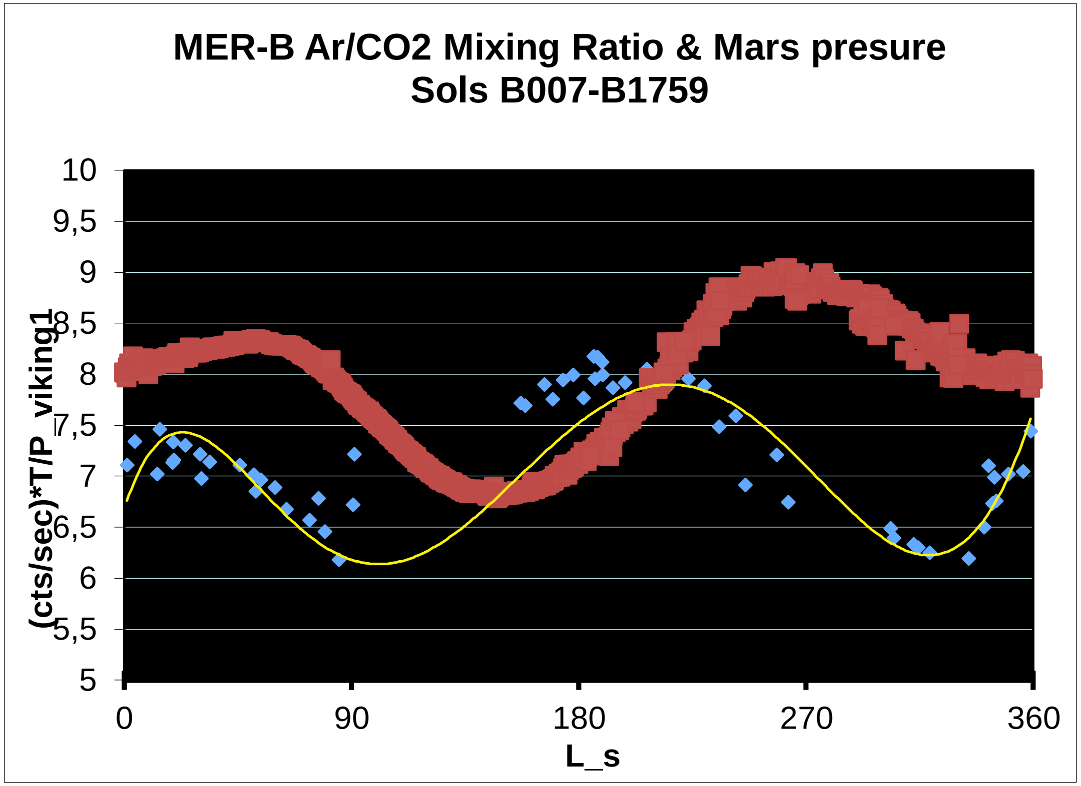
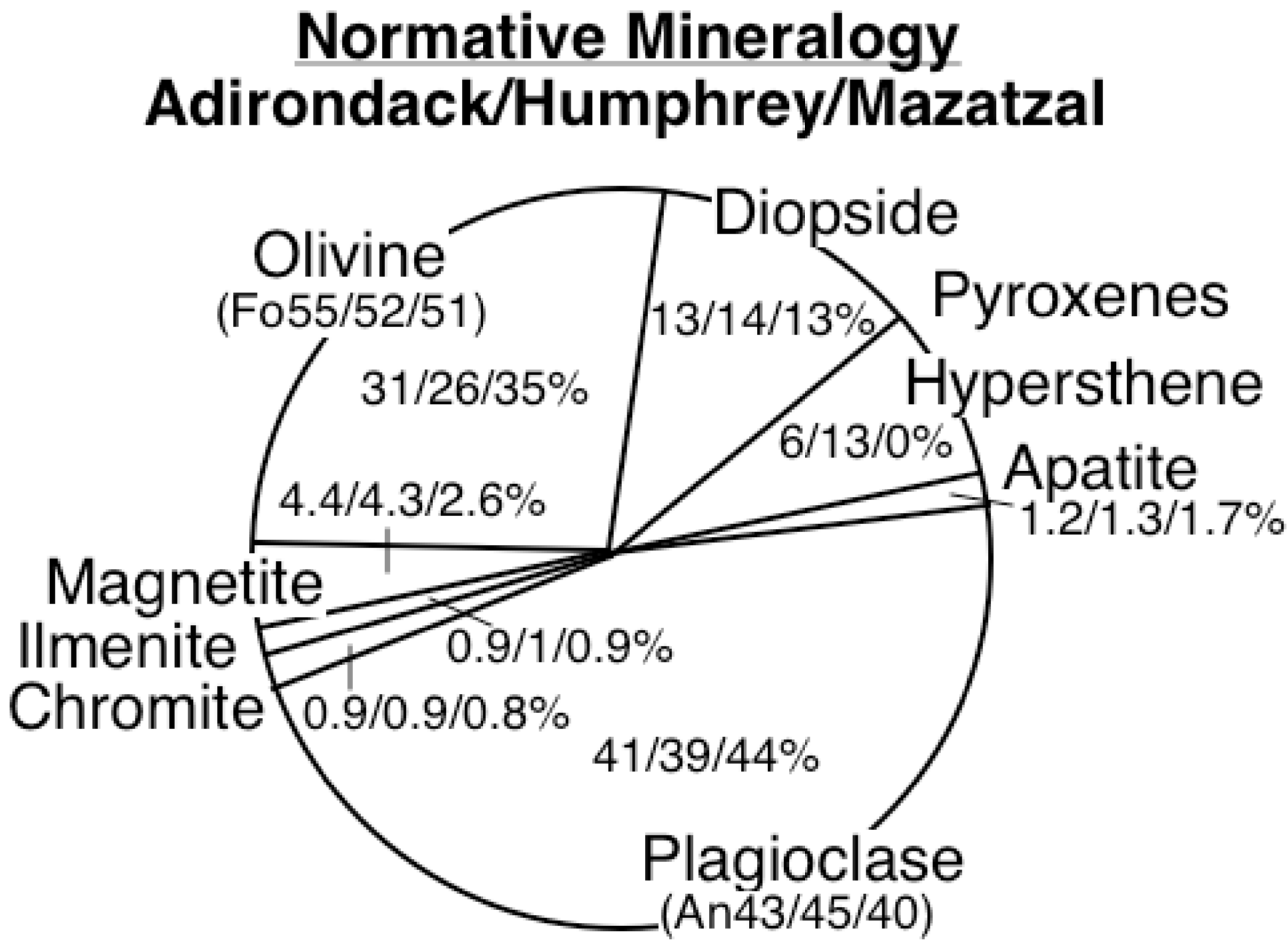


APXS energy region Phosphorus-Potassium (2-4 kev) that can be used to detect P, S, Cl and Ar in Venus clauds during the descent stage



Normative Mineralogy from APXS



Mineralogy Instruments

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- Moessbauer Spectrometer
- Raman Spectrometer
- X-ray Diffractometer.

  - **Moessbauer Spectrometer (MB)**

MB has some space heritage
It was developed in MPI, Germany for MER mission (Spirit & Opportunity) and it was also part of the Phobos Grunt payload that failed in 2011. It determines iron-bearing minerals.
Specifications:
It uses about 400 mCi of Co-57 radioactive source for its operation and Si PIN x-ray detectors that need a slight cooling.
Weight: ~500 g
Power 600 mW
Accumulation time ~several hours.
Can be adapted for VENERA-D or even combined with the APXS in one instrument.

The payload problem for the VENERA-D lander

- None of the old instruments are in existence today
- Even if they could exist , we do not want to use them for a new mission
    - They are too heavy
    - draw too much power
    - it is old technology that do not provide the desired results

The new payload for the VENERA-D lander

- None of the newly proposed VENERA-D mission instruments are ready for a Venus mission:
    - A few (APXS, MB spectrometer, GRS, XRD/XRF) have some space heritage from Mars or other space missions
    - Others (Raman Spectrometer, Pulsed Gamma Ray have none)
    - But none has demonstrated that can operate under expected condition on Venus.

Σας ευχαριστώ

(thank you)

Payload considered for VENERA-D lander for elemental & mineralogical composition

GRS has been used on the Moon, Mars and Mercury orbiters.

Specifications:

- Sensor BGO, or Ge
- Cryogenically cooled to temperature of LN
- Energy resolution: 3.0 keV (FWHM) at 1333 keV
- Energy range 0.2-12.0 MeV
- Weight ~10 kg
- Power: 3-5 Watt

The big problem for a potential VENERA-D GRS is the cooling.

Neutron-induced gamma-ray emission and its detection using a pulsed neutron generator system is an established analytical technique for quantitative multi-element analysis. Traditional gamma-ray spectrometers used for this type of analysis are normally operated either in coincidence mode – for counting prompt gamma-rays following inelastic neutron scattering (INS) events when the neutron generator is ON, or in anti-coincidence mode – for counting prompt gamma-rays from therma

(2) A digital spectrometer approach to obtaining multiple time-resolved gamma-ray spectra for pulsed spectroscopy.