HORIZON 2061

Planetary Exploration 2061

STEP 3 : Synthesis Workshop

11-13 September 2019 - Toulouse, France

Critical scientific space missions to Venus in the Horizon 2061 perspective - the role and feasibility of a sample return mission

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irap
astrophysique & planétologie

11 September 2019

LATMOS

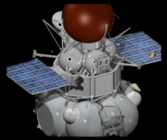
A few keywords

- Potential next target of in-situ robotic exploration
- Poor orbital data (clouds and dense atmosphere)
- No meteorites (Sun gravity)
- 1st rank scientific questions:
    - Life potential in the clouds
    - Why so different from Earth

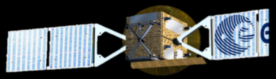
VENUS exploration

incoming missions

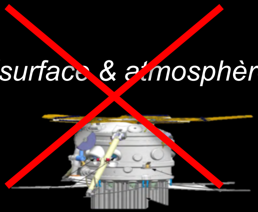
Russia's Venera-D Mission



EnVision: radar & spectrométrie

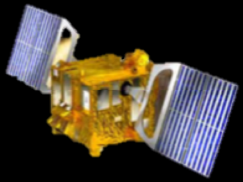


SAGE (surface & atmosphère)

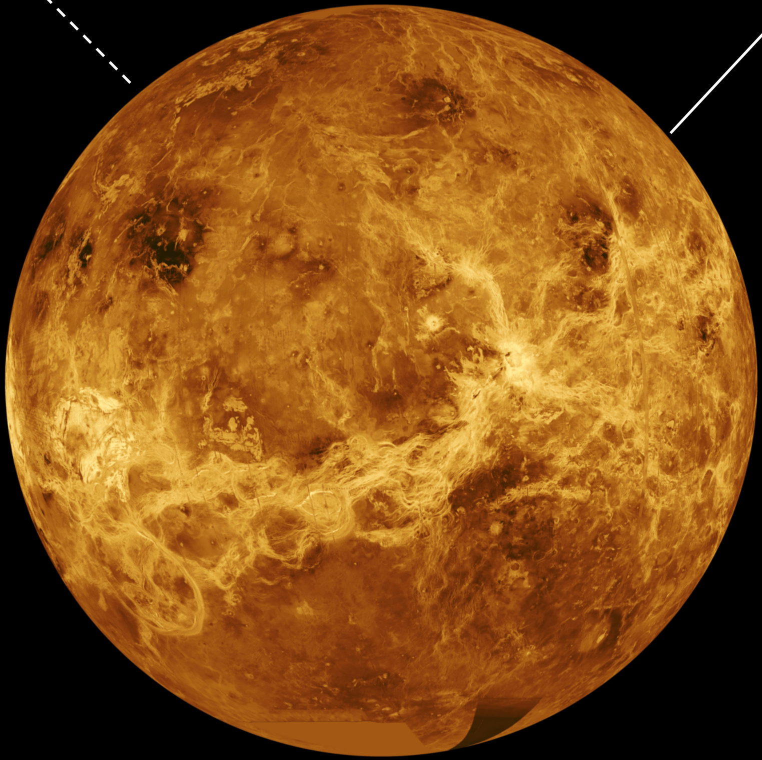


VERITAS (topographie surface) &
DAVINCI (chimie atmosphérique)

Akatsuki



Venus Express since 2006



flyby

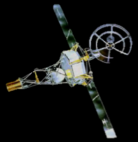
Messenger (to Mercury, 2004)

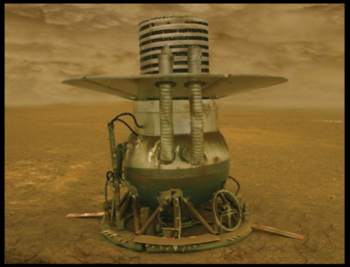
Galileo (to Jupiter, 1990)

Vega (to Comet Halley, 1985)

past missions

Mariner 2-10,
(1962-1975)



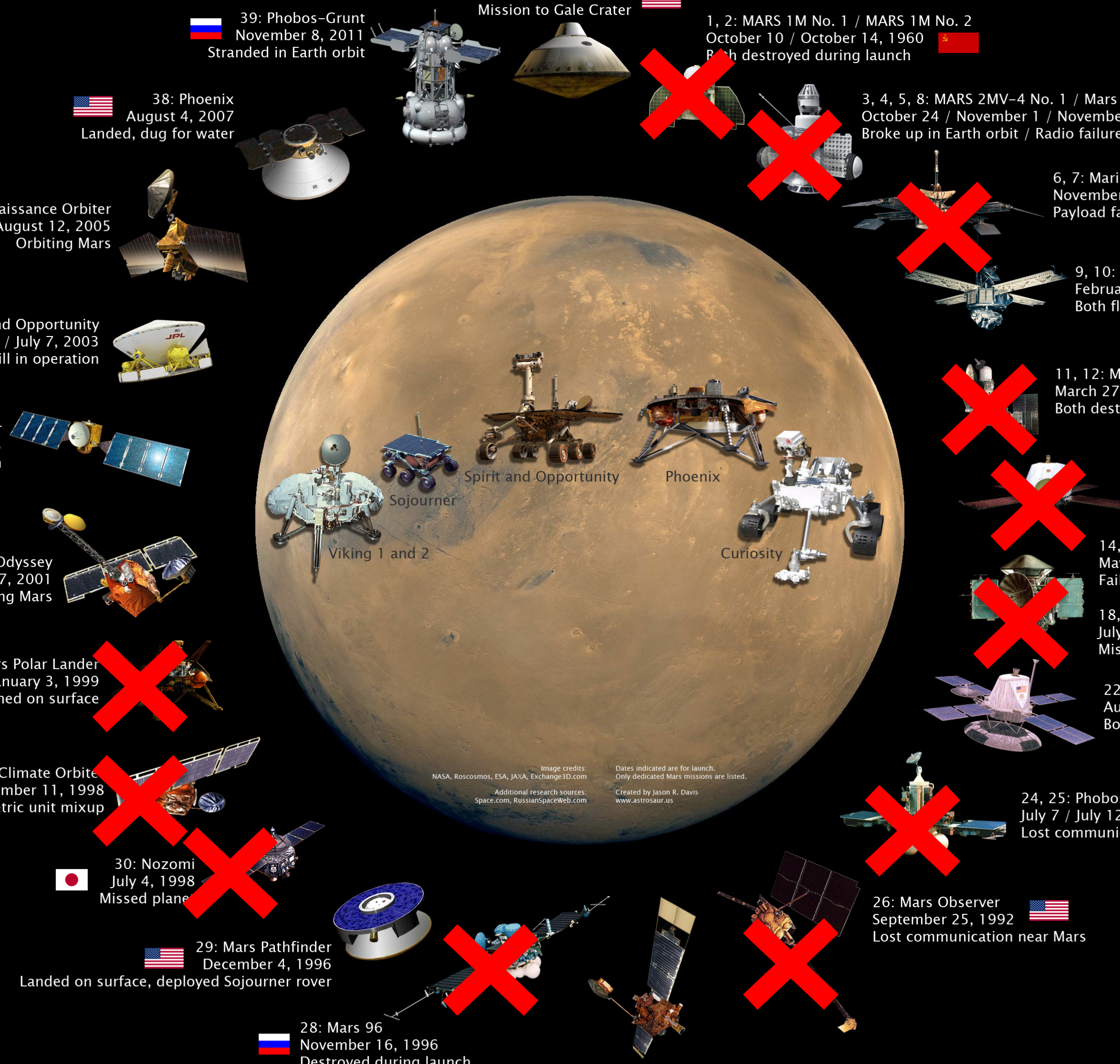


Venera soviet missions (1961-1983)

Pioneer Venus Orbiter
(1978–1992)

Magellan (1990–1994)

Mars Exploration Family Portrait



1, 2: MARS 1M No. 1 / MARS 1M No. 2
October 10 / October 14, 1960
Both destroyed during launch

3, 4, 5, 8: MARS 2MV-4 No. 1 / Mars 1 / Mars 2MV-3 No. 1 / Zond 2
October 24 / November 1 / November 4, 1962 / November 30, 1964
Broke up in Earth orbit / Radio failure en route / Stranded in Earth orbit / Radio failure en route

6, 7: Mariner 3 / Mariner 4
November 5 / November 28, 1964
Payload fairing failed to open / First flyby and picture return

9, 10: Mariner 6 / Mariner 7
February 25 / March 27, 1969
Both flew by, returned pictures

11, 12: Mars 1969 A / Mars 1969 B
March 27 / April 2, 1969
Both destroyed during launch

13, 17: Mariner 8 / Mariner 9
May 8 / May 30, 1971
Destroyed during launch / First probe to orbit Mars

14, 15, 16: Cosmos 419 / Mars 2 / Mars 3
May 10 / May 19 / May 28, 1971
Failed in Earth orbit / Lander crashed / Lander failed

18, 19, 20, 21: Mars 4 / Mars 5 / Mars 6 / Mars 7
July 21 / July 25 / August 5 / August 9, 1973
Missed planet / Orbited planet / Lander failed (6 and 7)

22, 23: Viking 1 / Viking 2
August 20 / September 9, 1975
Both landed on surface, returned data

24, 25: Phobos 1 / Phobos 2
July 7 / July 12, 1988
Lost communication en route / Lost communication near Phobos

26: Mars Observer
September 25, 1992
Lost communication near Mars

27: Mars Global Surveyor
November 7, 1996
Orbited and returned data

28: Mars 96
November 16, 1996
Destroyed during launch

29: Mars Pathfinder
December 4, 1996
Landed on surface, deployed Sojourner rover

30: Nozomi
July 4, 1998
Missed plane

31: Mars Climate Orbite
December 11, 1998
Crashed due to imperial/metric unit mixup

32: Mars Polar Lander
January 3, 1999
Crashed on surface

33: Mars Odyssey
March 7, 2001
Orbiting Mars

34: Mars Express / Beagle 2 lander
June 2, 2003
Orbiting Mars, Beagle lost after separation

35, 36: Mars Exploration Rovers Spirit and Opportunity
June 10 / July 7, 2003
Both landed on surface, Opportunity still in operation

37: Mars Reconnaissance Orbiter
August 12, 2005
Orbiting Mars

38: Phoenix
August 4, 2007
Landed, dug for water

39: Phobos-Grunt
November 8, 2011
Stranded in Earth orbit

40: Mars Science Laboratory Curiosity
November 26, 2011
Mission to Gale Crater

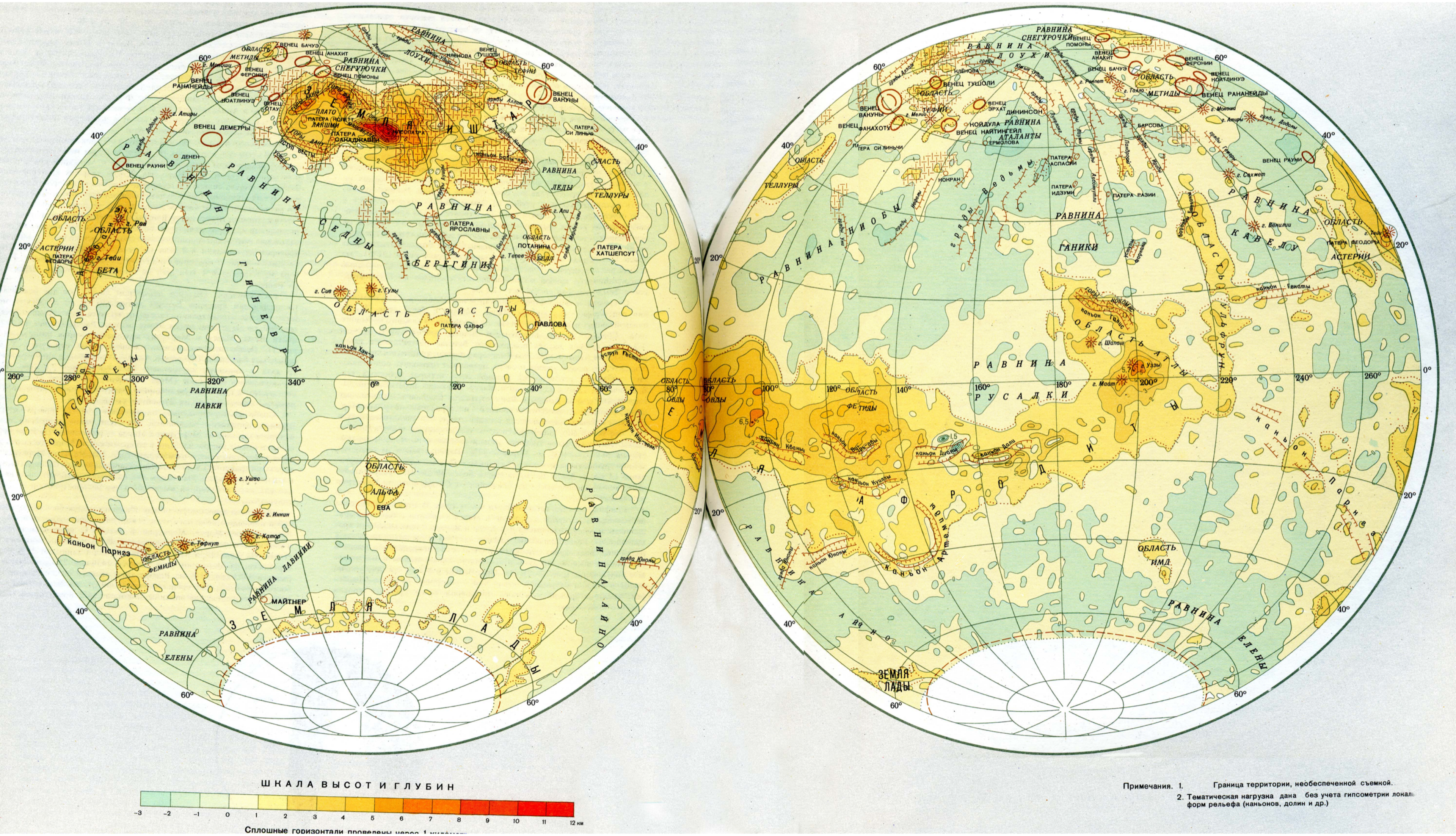
Image credits:
NASA, Roscosmos, ESA, JAXA, Exchange3D.com

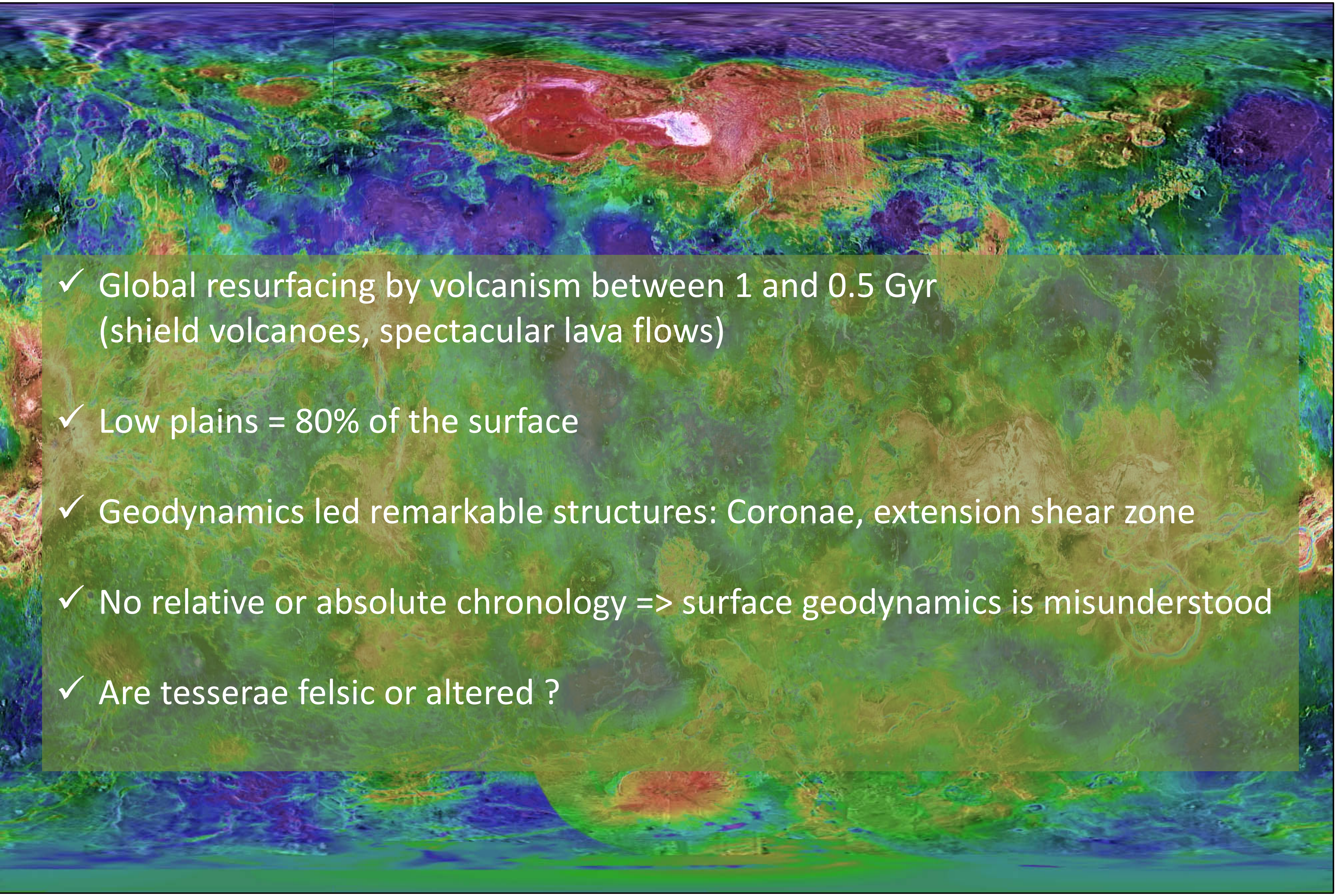
Additional research sources:
Space.com, RussianSpaceWeb.com

Dates indicated are for launch.
Only dedicated Mars missions are listed.

Created by Jason R. Davis
www.astrosaur.us

radar mapping by Venera





- ✓ Global resurfacing by volcanism between 1 and 0.5 Gyr (shield volcanoes, spectacular lava flows)
- ✓ Low plains = 80% of the surface
- ✓ Geodynamics led remarkable structures: Coronae, extension shear zone
- ✓ No relative or absolute chronology => surface geodynamics is misunderstood
- ✓ Are tesserae felsic or altered ?

Ground observations

granite ?

γ-spectrometry (Venera 8-10)

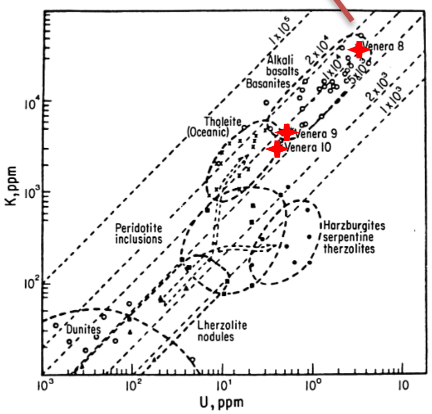
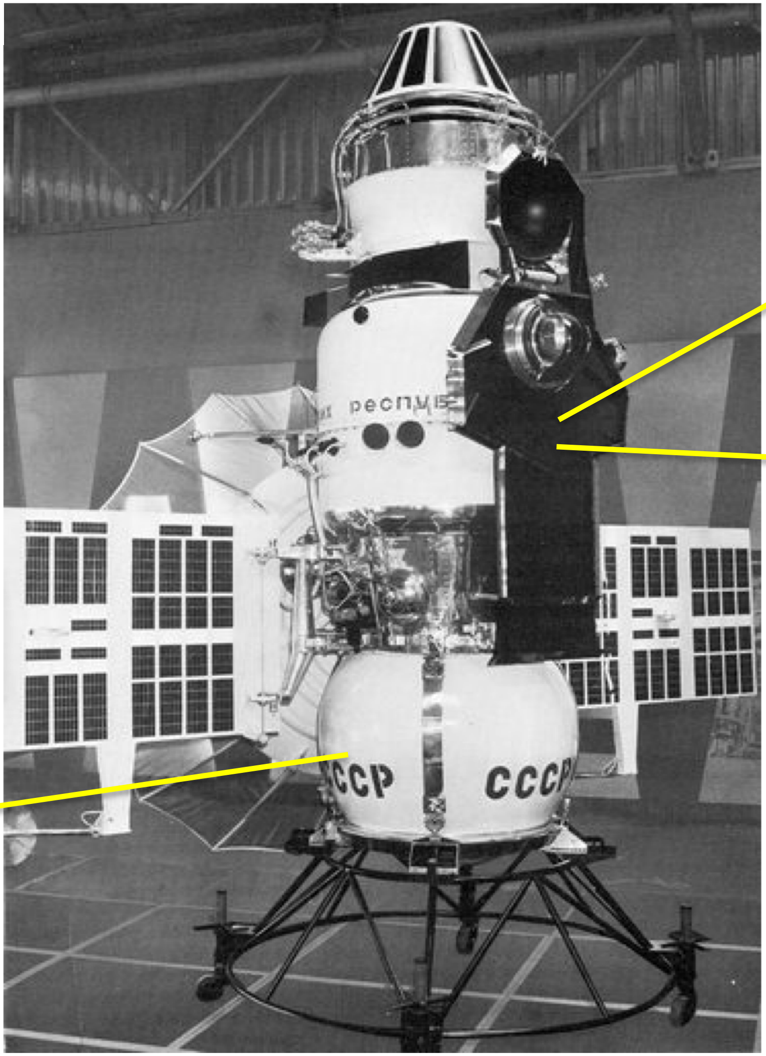
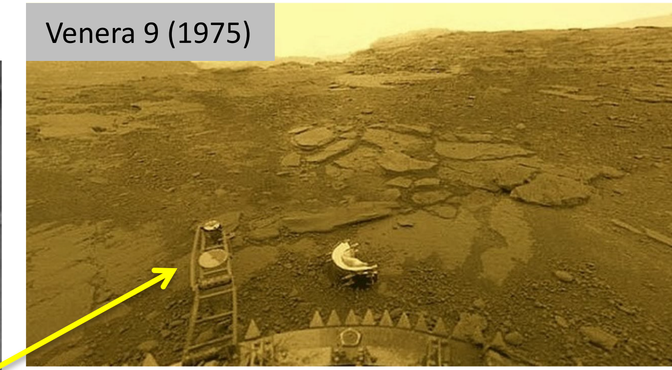
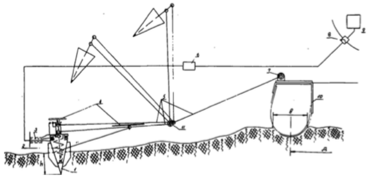


Fig. 2. K/U diagram for the content of potassium and uranium in the major types of Earth and Venus rock.





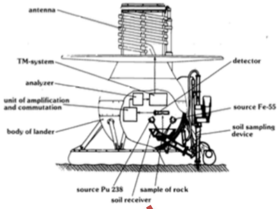
Venera 9 (1975)



Dynamic penetrometer
(physical properties,
electric resistivity)

altered basalt

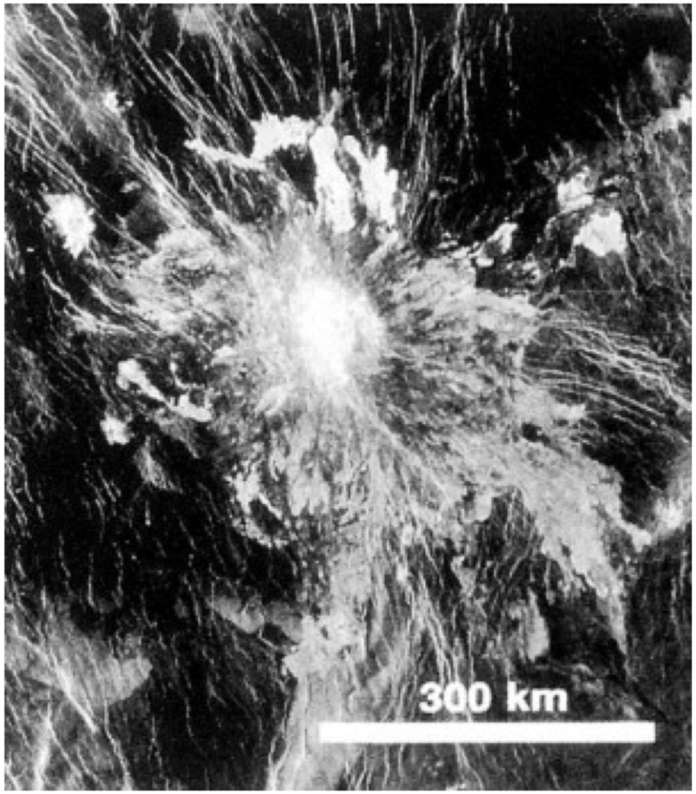
XR-fluorescence
(Venera 13-14)



basalt

=> old, scarce, incomplete data

Radar emissivity anomaly, another interesting feature



A variety of radar-bright lava flows radiate from the summit area down the flanks of a shield volcano on Venus. (NASA *Magellan* image.)

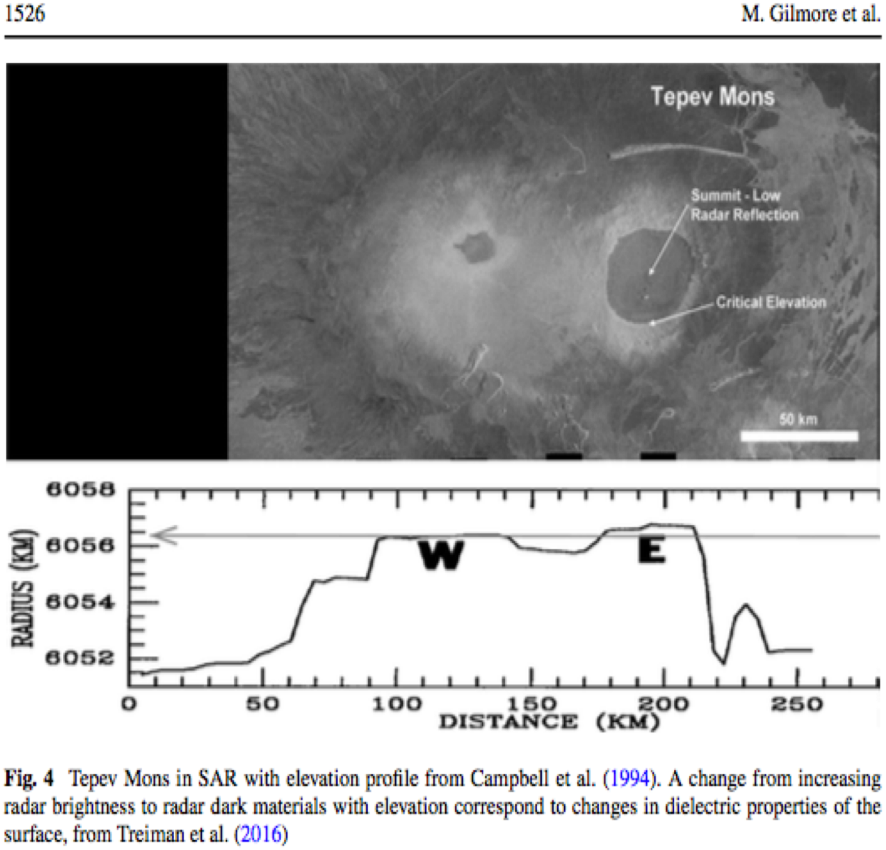
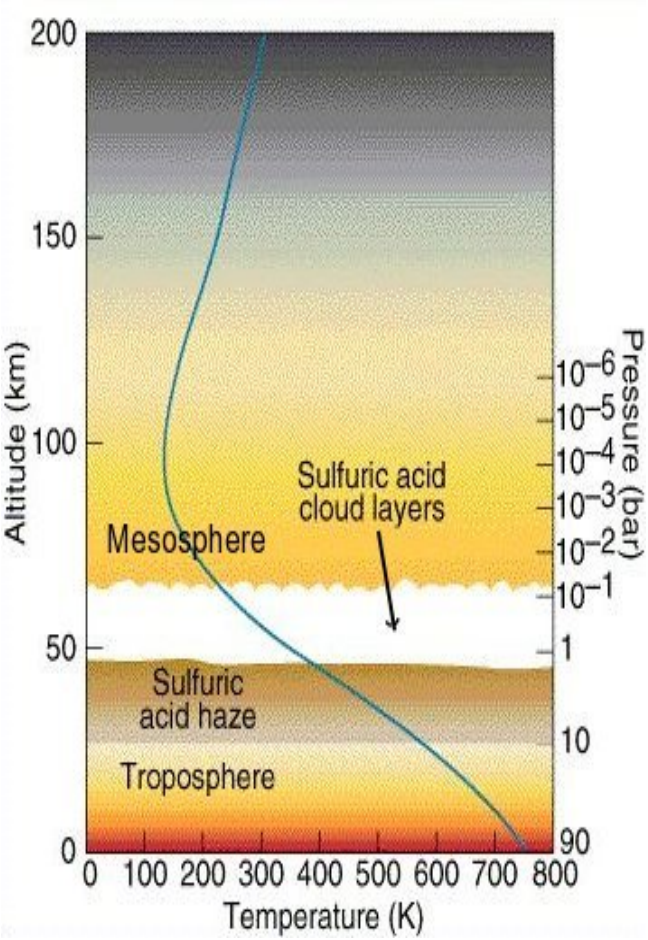
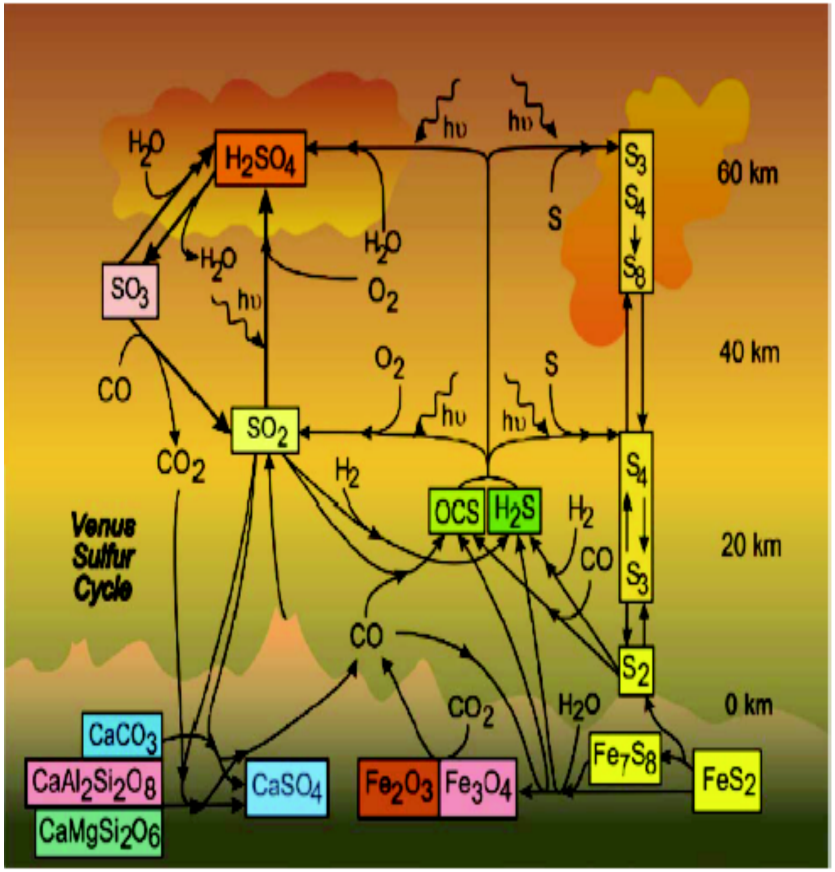

1526 M. Gilmore et al.

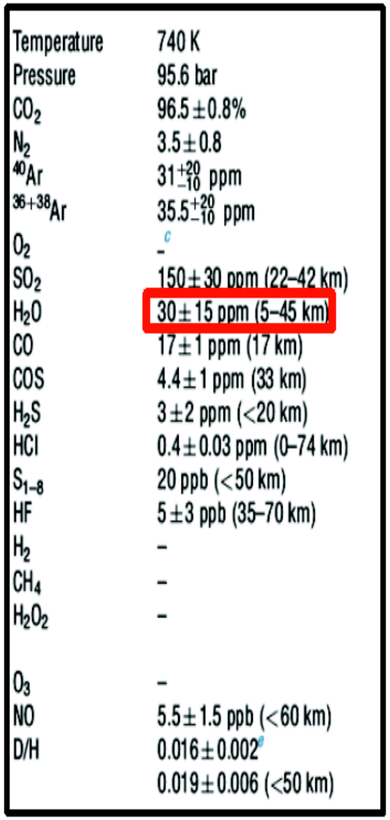
Fig. 4 Tepev Mons in SAR with elevation profile from Campbell et al. (1994). A change from increasing radar brightness to radar dark materials with elevation correspond to changes in dielectric properties of the surface, from Treiman et al. (2016)

FeS_2 Bi_2Te_3 $(Ca,Na)PO_4$ PbS ?

The atmosphere of Venus:
a complex and stratified medium





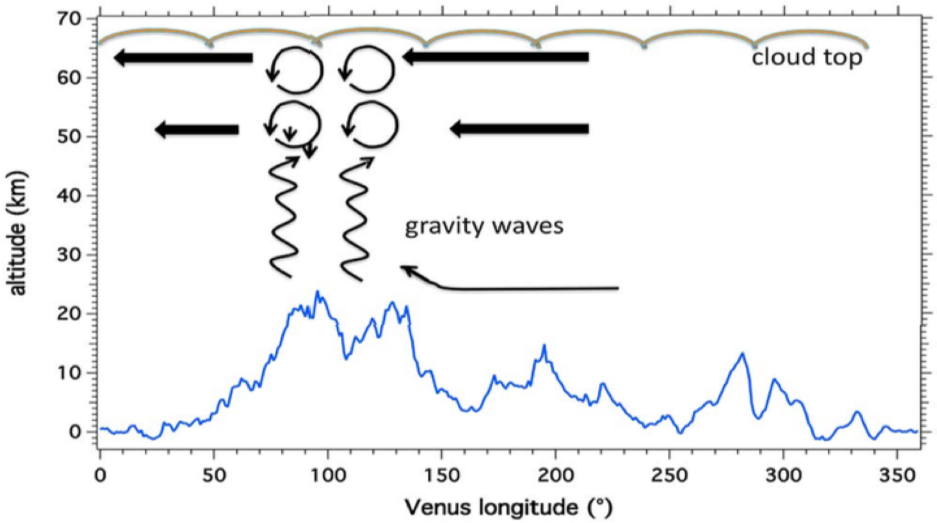


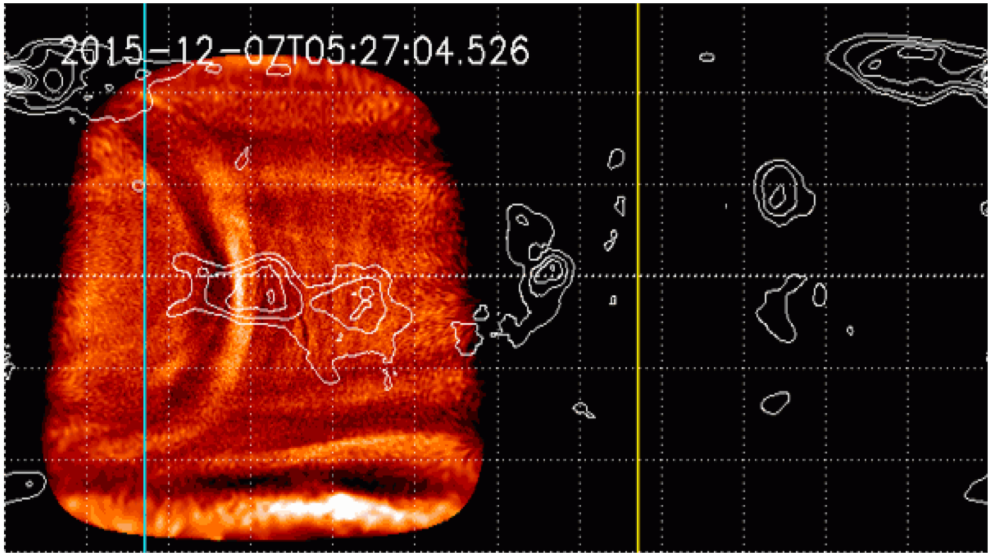
Temperature	740 K
Pressure	95.6 bar
CO_2	96.5 ± 0.8%
N_2	3.5 ± 0.8
^{40}Ar	31^{+20}_{-10} ppm
$^{36+38}Ar$	35.5^{+20}_{-10} ppm
O_2	–[c]
SO_2	150 ± 30 ppm (22–42 km)
H_2O	30 ± 15 ppm (5–45 km)
CO	17 ± 1 ppm (17 km)
COS	4.4 ± 1 ppm (33 km)
H_2S	3 ± 2 ppm (<20 km)
HCl	0.4 ± 0.03 ppm (0–74 km)
S_{1-8}	20 ppb (<50 km)
HF	5 ± 3 ppb (35–70 km)
H_2	–
CH_4	–
H_2O_2	–
O_3	–
NO	5.5 ± 1.5 ppb (<60 km)
D/H	0.016 ± 0.002[e] 0.019 ± 0.006 (<50 km)

Zolotov et al., 2015

Open questions

- ✓ Gravity waves
- ✓ Planetary scale structures
- ✓ UV absorber
- ✓ Life in the clouds





Thermal signature of wave breaking above Aphrodite Terra as observed by Akatsuki

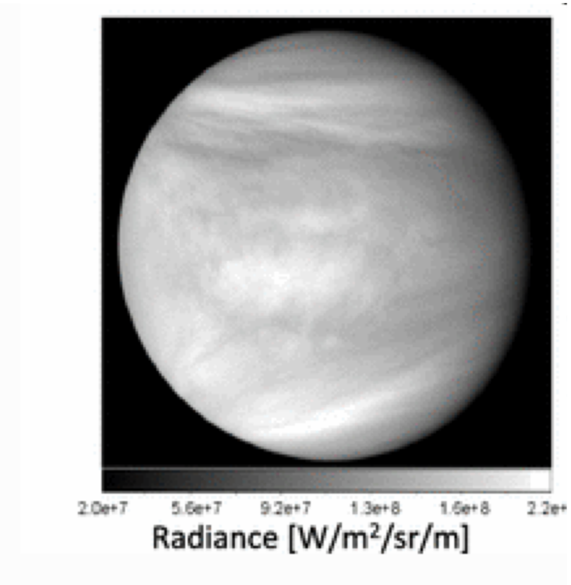
Open questions

- ✓ Gravity waves
- ✓ Planetary scale structures
- ✓ UV absorber
- ✓ Life in the clouds

Night side thermal imaging of lower clouds, showing unexpected sharp boundaries extending over thousands of km.

Open questions

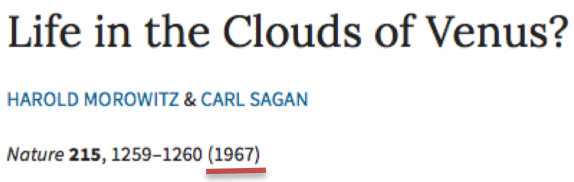
- ✓ Gravity waves
- ✓ Planetary scale
- ✓ **Unknown UV absorber**
- ✓ Life in the clouds



365-nm image: the contrast is originated from the unknown absorber

More generally, the missing reservoirs in atmospheric cycles is a challenge for sulfur

Open questions



Life in the Clouds of Venus?

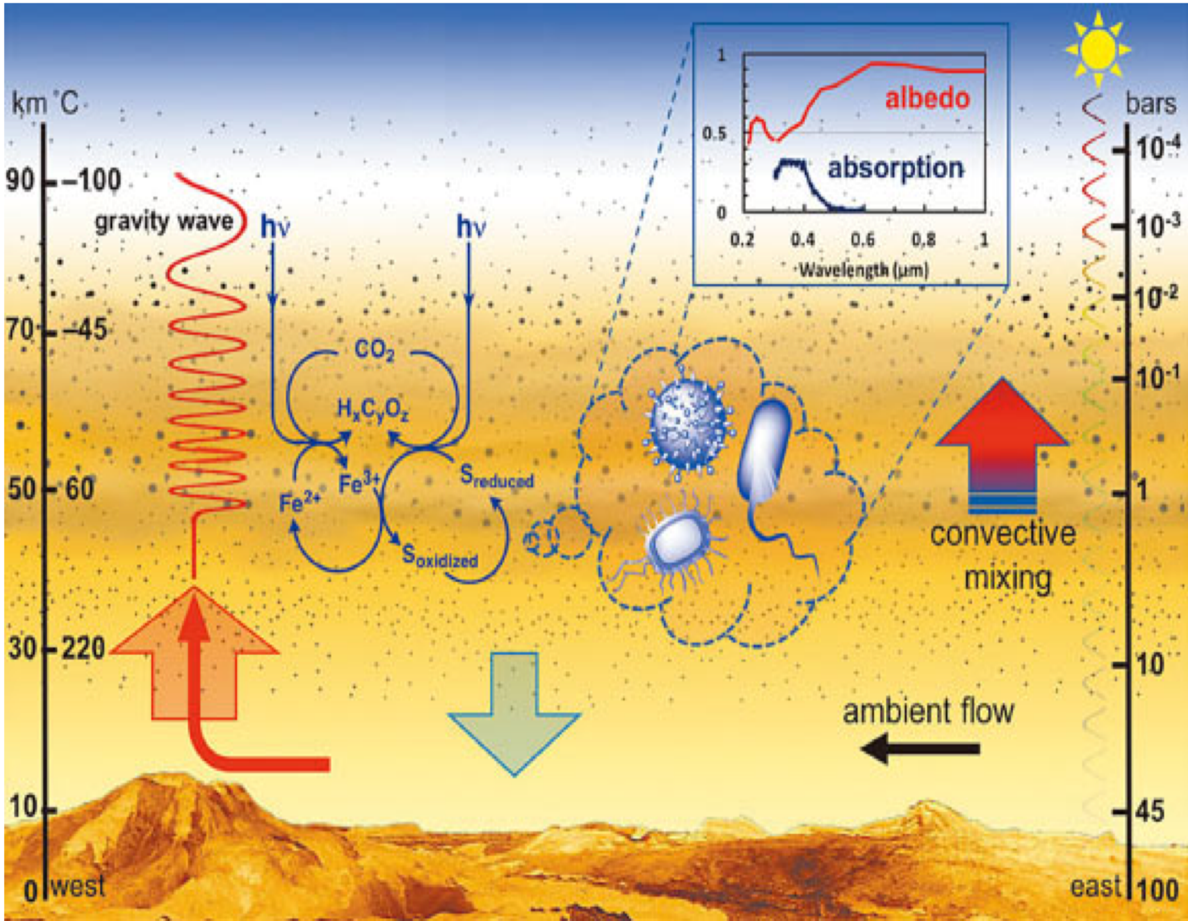
HAROLD MOROWITZ & CARL SAGAN

Nature **215**, 1259–1260 (1967)

an old but still relevant story

- ✓ Gravity waves
- ✓ Giant structures
- ✓ UV absorber
- ✓ **Life in the clouds**

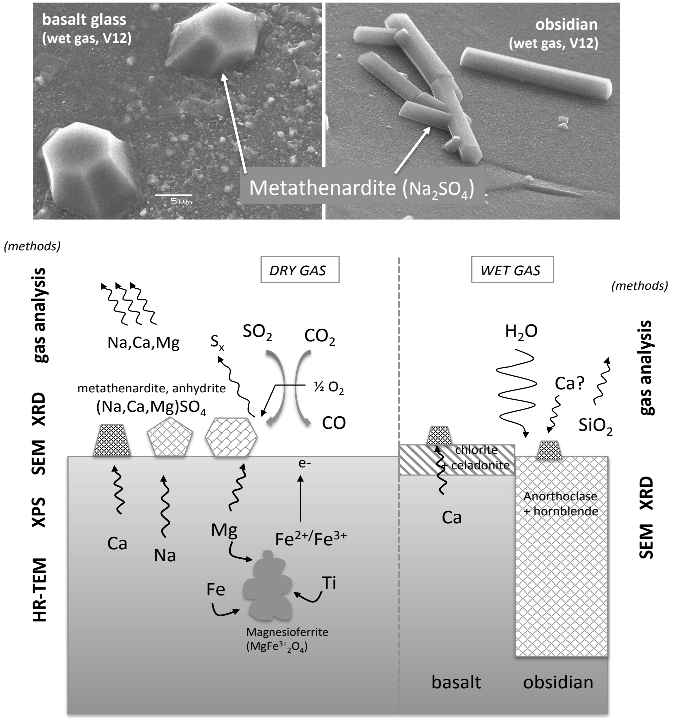
- *50 km conditions favorable to acidophilic life forms*
- *Might account for issues in chemical cycles ?*
- *Could the 365-nm UV absorber be a photosynthetic pigment?*



Experimental

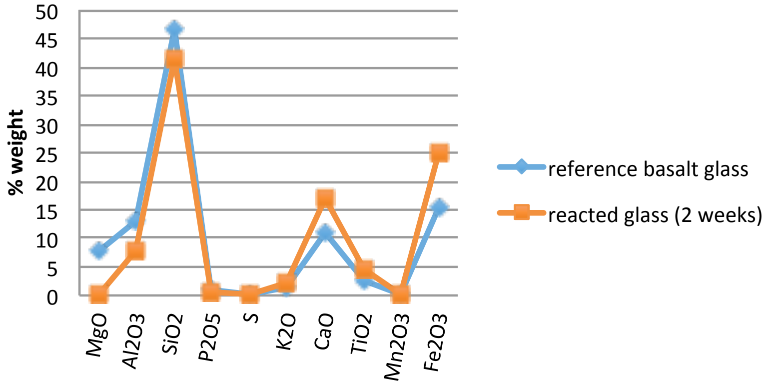
Key lesson

- ✓ Even in the dry modern atmosphere, some rock constituents (olivine and glass) are chemically modified in the first µm of the surface
- ✓ Deposition of iron oxide and sulfate coating
- ✓ Consequence for the remote sensing ?



Berger et al., Icarus 2019

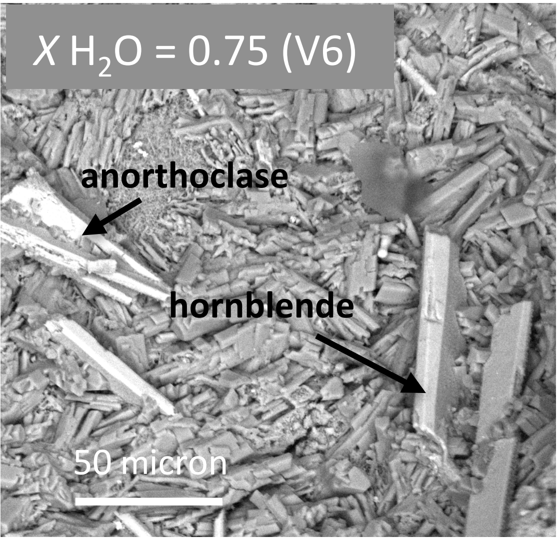
XRF spectra

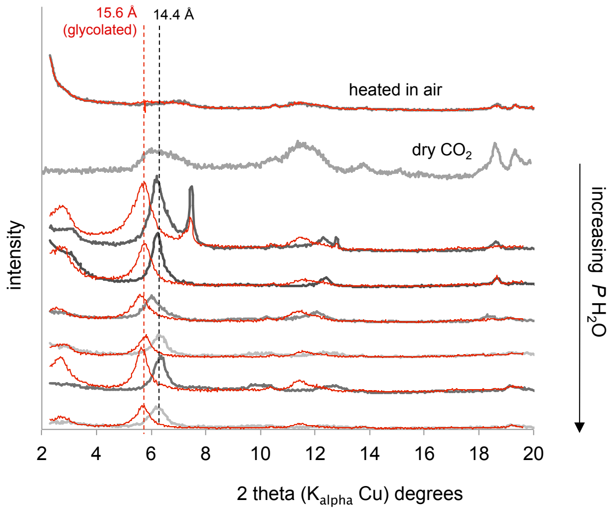


unpublished data

What measure remote sensing ?

- ✓ In wet atmosphere (early Venus or beginning of resurfacing) water may have accompanied degassing
- ✓ Hydrated secondary phases is a possible sink of water, in addition to atmosphere erosion
- ✓ Once formed, hydrated phases may persist in the modern dry atmosphere





➢ Consequences for the water cycle ?

Measurement requirements and mission type:

Analyzes for significant advances in previous scientific issues

- Bulk mineralogy of different geologic units

- Surface analyses to evaluate possible bias in remote analyzes due to surface modifications

- Volatile content of volcanic lavas

- Mineralogy of the minerals surface versus elevation

➢ Venus geodynamics parameters, the surface mineralogy

- Detailed elementary and isotopic composition of atmosphere and clouds

➢ Biologic or mineral reactions affecting the halogen, carbon, water and sulfur cycle

- Elementary and isotopic composition of noble gases

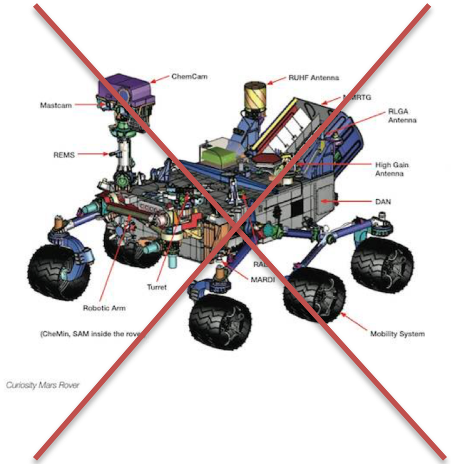
➢ Escape and endogenous processes affecting the atmosphere

Measurement requirements and mission type:

What is realist ?

- 2 projects in the running for the next future, EnVision (ESA), Venera-D (IKI), perhaps VERITAS (NASA)
- But current limitation of instruments on the ground
- analytic bias due to surface modifications
- No possibility to run a rover like Discovery on Mars

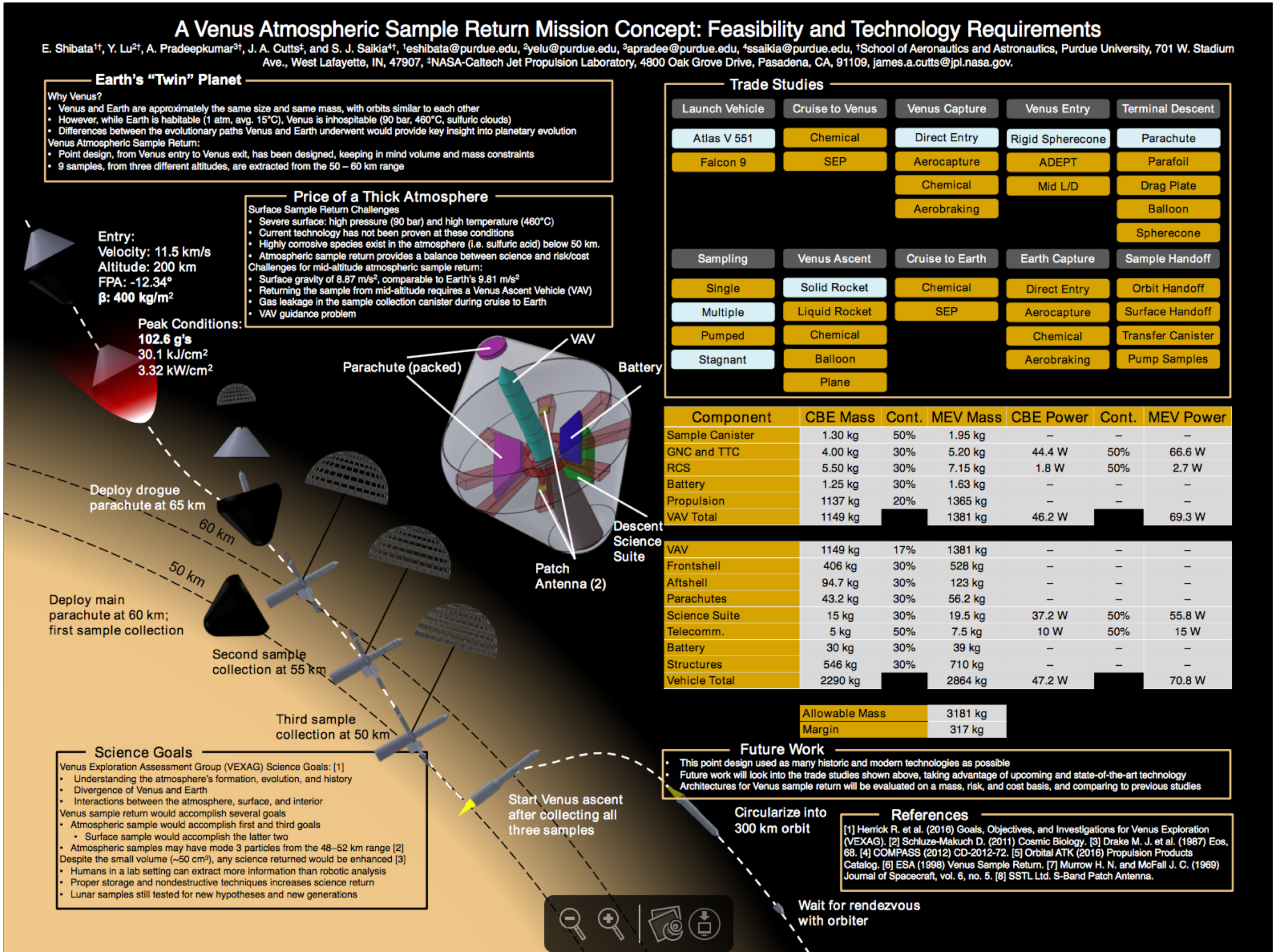
➢ **Pertinence of a return sample mission in the far future**



Curiosity Mars Rover

The concept has already been evaluated by NASA, mainly for the atmosphere sampling

LPI Conference 2017 (atmosphere sampling)



A Venus Atmospheric Sample Return Mission Concept: Feasibility and Technology Requirements

E. Shibata[1†], Y. Lu[2†], A. Pradeepkumar[3†], J. A. Cutts[‡], and S. J. Saikia[4†], [1]eshibata@purdue.edu, [2]yelu@purdue.edu, [3]apradee@purdue.edu, [4]ssaikia@purdue.edu, [†]School of Aeronautics and Astronautics, Purdue University, 701 W. Stadium Ave., West Lafayette, IN, 47907, [‡]NASA-Caltech Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA, 91109, james.a.cutts@jpl.nasa.gov.

Earth's "Twin" Planet

Why Venus?
- Venus and Earth are approximately the same size and same mass, with orbits similar to each other
- However, while Earth is habitable (1 atm, avg. 15°C), Venus is inhospitable (90 bar, 460°C, sulfuric clouds)
- Differences between the evolutionary paths Venus and Earth underwent would provide key insight into planetary evolution

Venus Atmospheric Sample Return:
- Point design, from Venus entry to Venus exit, has been designed, keeping in mind volume and mass constraints
- 9 samples, from three different altitudes, are extracted from the 50 – 60 km range

Price of a Thick Atmosphere

Surface Sample Return Challenges
- Severe surface: high pressure (90 bar) and high temperature (460°C)
- Current technology has not been proven at these conditions
- Highly corrosive species exist in the atmosphere (i.e. sulfuric acid) below 50 km.
- Atmospheric sample return provides a balance between science and risk/cost

Challenges for mid-altitude atmospheric sample return:
- Surface gravity of 8.87 m/s², comparable to Earth's 9.81 m/s²
- Returning the sample from mid-altitude requires a Venus Ascent Vehicle (VAV)
- Gas leakage in the sample collection canister during cruise to Earth
- VAV guidance problem

Trade Studies

Launch Vehicle	Cruise to Venus	Venus Capture	Venus Entry	Terminal Descent
Atlas V 551	Chemical	Direct Entry	Rigid Spherecone	Parachute
Falcon 9	SEP	Aerocapture	ADEPT	Parafoil
		Chemical	Mid L/D	Drag Plate
		Aerobraking		Balloon
				Spherecone

Sampling	Venus Ascent	Cruise to Earth	Earth Capture	Sample Handoff
Single	Solid Rocket	Chemical	Direct Entry	Orbit Handoff
Multiple	Liquid Rocket	SEP	Aerocapture	Surface Handoff
Pumped	Chemical		Chemical	Transfer Canister
Stagnant	Balloon		Aerobraking	Pump Samples
	Plane			

Component	CBE Mass	Cont.	MEV Mass	CBE Power	Cont.	MEV Power
Sample Canister	1.30 kg	50%	1.95 kg	–	–	–
GNC and TTC	4.00 kg	30%	5.20 kg	44.4 W	50%	66.6 W
RCS	5.50 kg	30%	7.15 kg	1.8 W	50%	2.7 W
Battery	1.25 kg	30%	1.63 kg	–	–	–
Propulsion	1137 kg	20%	1365 kg	–	–	–
VAV Total	1149 kg		1381 kg	46.2 W		69.3 W
VAV	1149 kg	17%	1381 kg	–	–	–
Frontshell	406 kg	30%	528 kg	–	–	–
Aftshell	94.7 kg	30%	123 kg	–	–	–
Parachutes	43.2 kg	30%	56.2 kg	–	–	–
Science Suite	15 kg	30%	19.5 kg	37.2 W	50%	55.8 W
Telecomm.	5 kg	50%	7.5 kg	10 W	50%	15 W
Battery	30 kg	30%	39 kg	–	–	–
Structures	546 kg	30%	710 kg	–	–	–
Vehicle Total	2290 kg		2864 kg	47.2 W		70.8 W

Allowable Mass	3181 kg
Margin	317 kg

Science Goals

Venus Exploration Assessment Group (VEXAG) Science Goals: [1]
- Understanding the atmosphere's formation, evolution, and history
- Divergence of Venus and Earth
- Interactions between the atmosphere, surface, and interior

Venus sample return would accomplish several goals
- Atmospheric sample would accomplish first and third goals
  - Surface sample would accomplish the latter two
- Atmospheric samples may have mode 3 particles from the 48–52 km range [2]

Despite the small volume (~50 cm³), any science returned would be enhanced [3]
- Humans in a lab setting can extract more information than robotic analysis
- Proper storage and nondestructive techniques increases science return
- Lunar samples still tested for new hypotheses and new generations

Future Work

- This point design used as many historic and modern technologies as possible
- Future work will look into the trade studies shown above, taking advantage of upcoming and state-of-the-art technology
- Architectures for Venus sample return will be evaluated on a mass, risk, and cost basis, and comparing to previous studies

References

[1] Herrick R. et al. (2016) Goals, Objectives, and Investigations for Venus Exploration (VEXAG). [2] Schluze-Makuch D. (2011) Cosmic Biology. [3] Drake M. J. et al. (1987) Eos, 68. [4] COMPASS (2012) CD-2012-72. [5] Orbital ATK (2016) Propulsion Products Catalog. [6] ESA (1998) Venus Sample Return. [7] Murrow H. N. and McFall J. C. (1969) Journal of Spacecraft, vol. 6, no. 5. [8] SSTL Ltd. S-Band Patch Antenna.

Surface sample return missions would require a surface ascent vehicle (balloon?)

Venus Aerial Platforms Study

By James A. Cutts, JPL

JPL report D-102569 , 2018

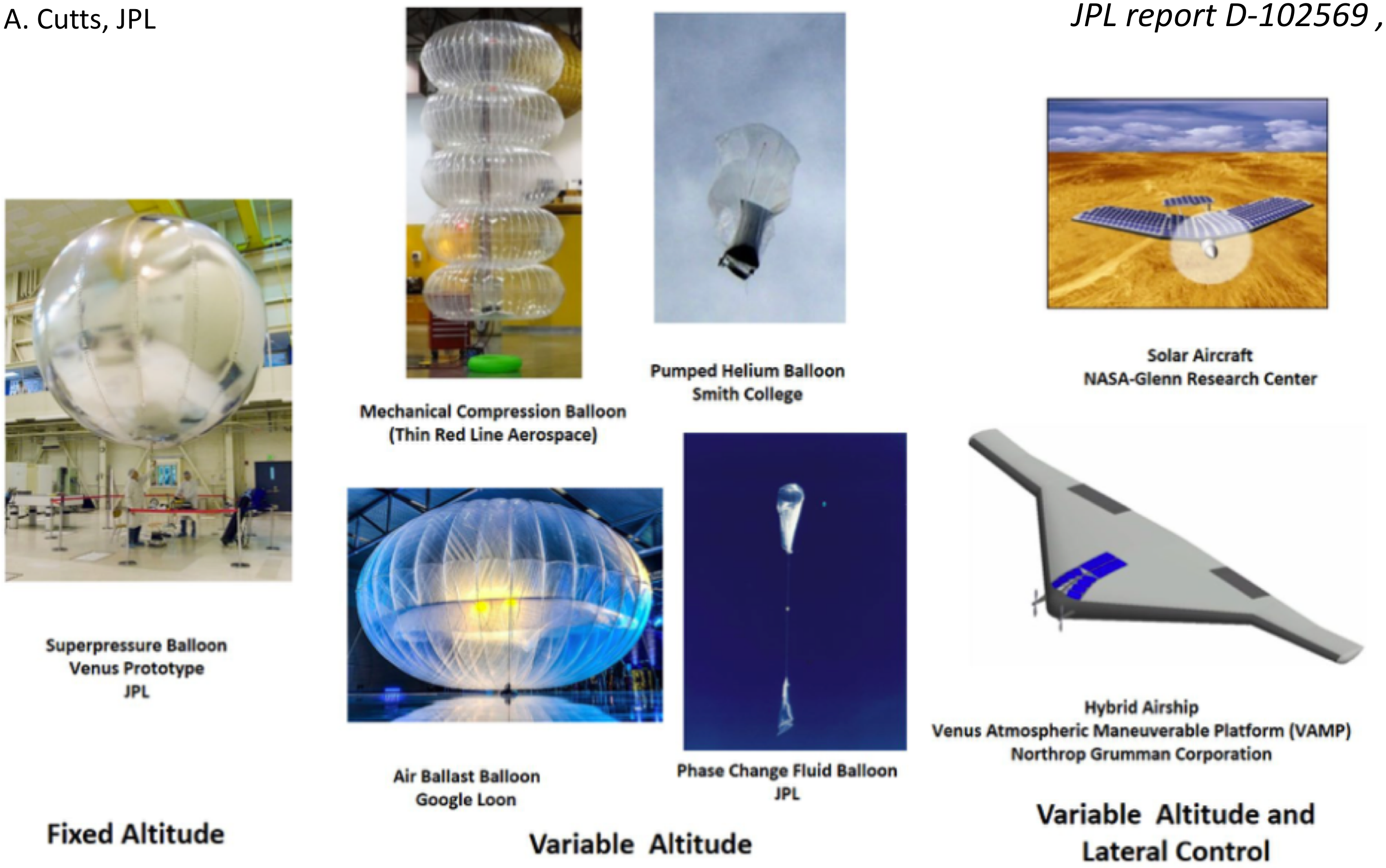


Figure 3-1 Venus Aerial Platform Concepts considered in this study are subdivided into three categories: Fixed Altitude platforms, Variable Altitude platforms as well as Platforms with both Variable Altitude and Lateral Control.

"Not only are Venus Aerial Platforms feasible, but they offer a rich menu of scientific opportunities for studies of the Venus atmosphere, its surface and interior as well as their mutual interaction".

Venus Sample Return Mission Studied (1986)

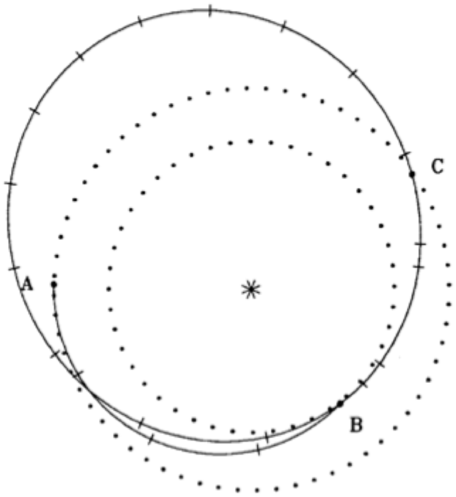
by R.M. Jones & K. T. Nock (JPL) and J. Blamont (CNES)

- ✓ return to Earth at least 1 kilogram
- ✓ small samplers parachuted to the surface
- ✓ then be carried aloft by balloons
- ✓ retrieved by small robotic airplanes
- ✓ transferred to an ascent rocket

- ➢ the return pass and energy source for the return fly ?

A free return trajectory to Venus and back without maneuvers

Venus sample return missions—a range of science, a range of costs
(Sweetser et al. 2003, Acta Astronautica)



- Launch on 2004-03-19
- flies by Venus on 2004-07-10 (11:8km/s altitude:110km)
- Returns to Earth on 2005-10-28

But for rock sample we need a real technological leap

Technology challenges and synergies with existing or planned space missions:

- huge energy required to leave terrestrial planets
- = huge mass launched from the Earth
- the complex trajectory due to the proximity of the Sun

Till today, the only vehicles that return to the Earth were the Apollo CS-Modules and dust collectors under low gravity (Stardust).

- ➢ An alternative in the propulsion concept ?

- Nuclear propulsion has long been considered, note only for space application but also for military rockets and even commercial intercontinental flights.

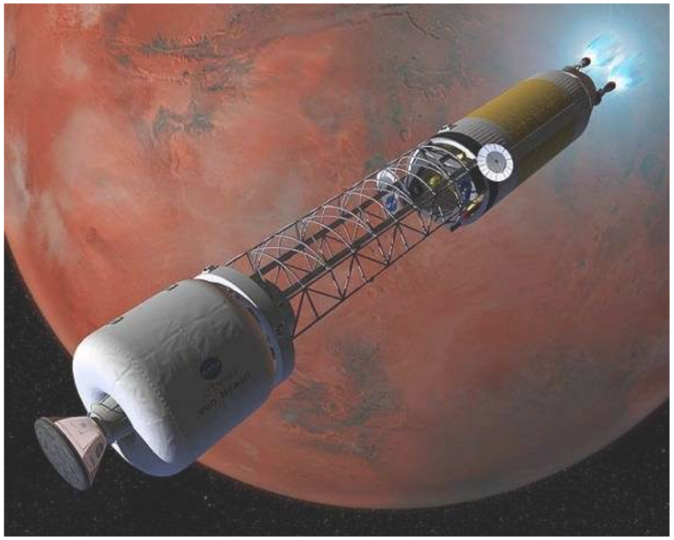
The conversion from the actual chemical reaction to nuclear reactions will provide a significant energy gap.

Nuclear pulse propulsion:

- External pulsed plasma propulsion
- Uses nuclear explosions for thrust
- Past projects: Orion, Daedalus, Medusa, Lonshot, etc…

Nuclear thermal rocket:

- Nuclear reaction replaces the chemical energy of the propellants
- A working fluid, usually liquid hydrogen, is heated to a high temperature
- And then expands through a rocket nozzle to create thrust



Mars return program

Lunar COTS : An Economical and Sustainable Approach to Reaching Mars
A.F. Zuniga et al., NASA, 2017

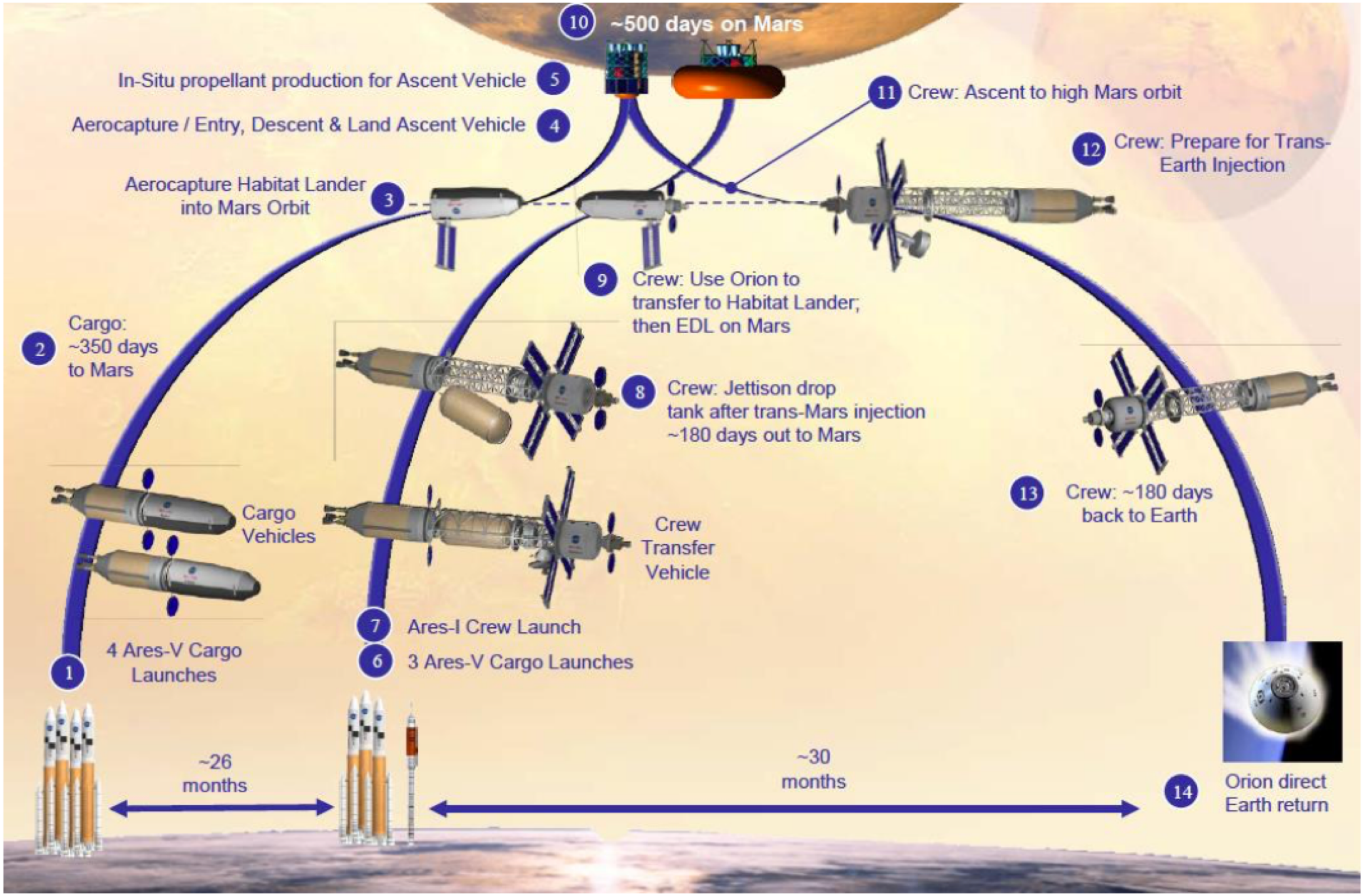
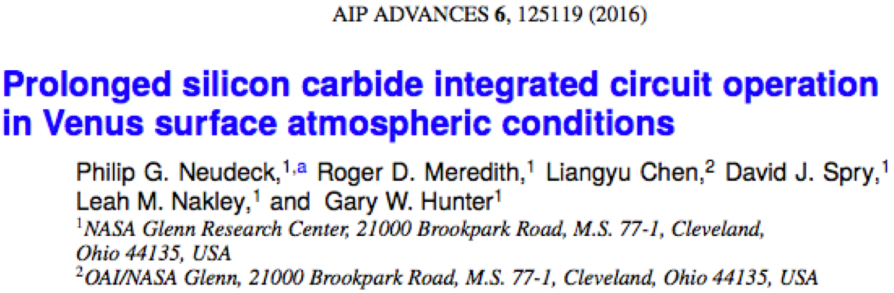


Figure 2. Mars Design Reference Architecture 5.0 from Reference 4, NASA SP-2009-566

High temperature electronics, the second challenge for Venus



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Prolonged silicon carbide integrated circuit operation in Venus surface atmospheric conditions

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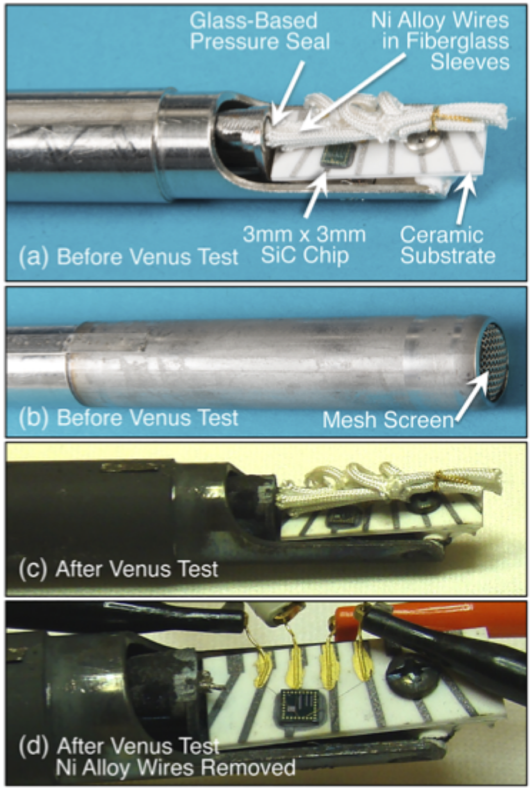
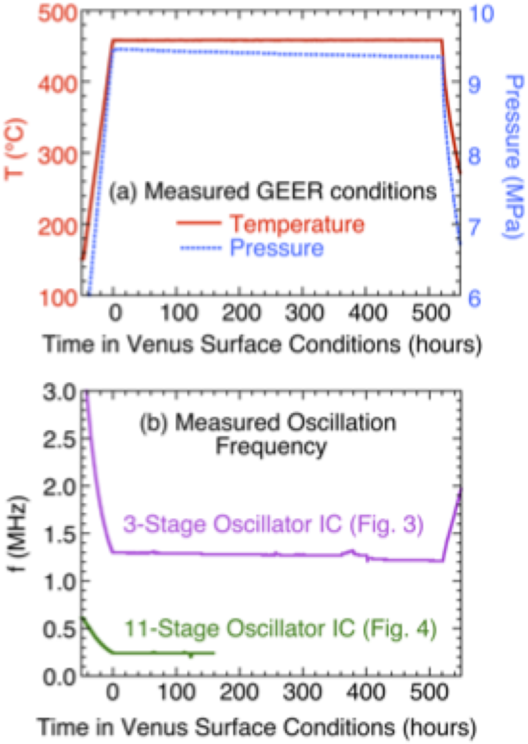
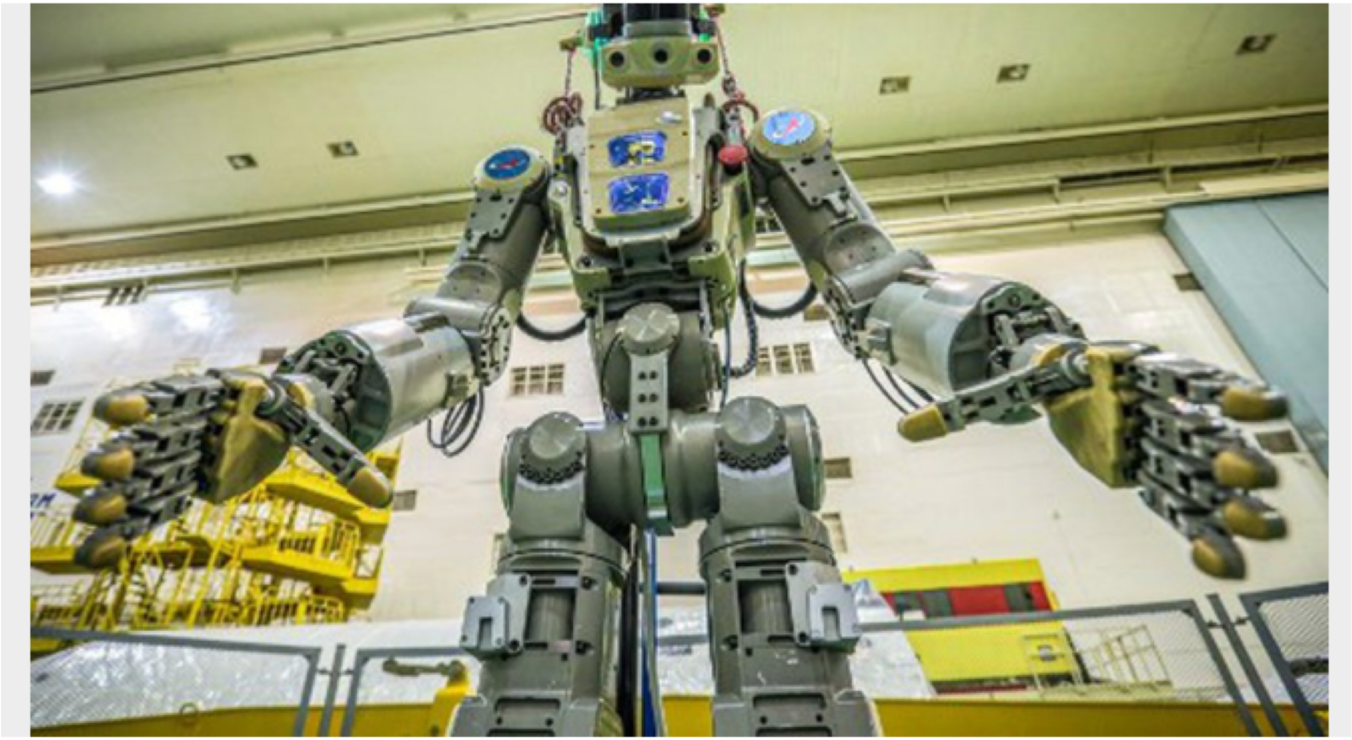




Robotic assistance

FEDOR, a Russian humanoid robot, the last member of the ISS crew (last month) …



… after Robonaut 2 (2011-2018, NASA) and Kirobo (2013, JAXA)