Toward an international Venus Exploration Program

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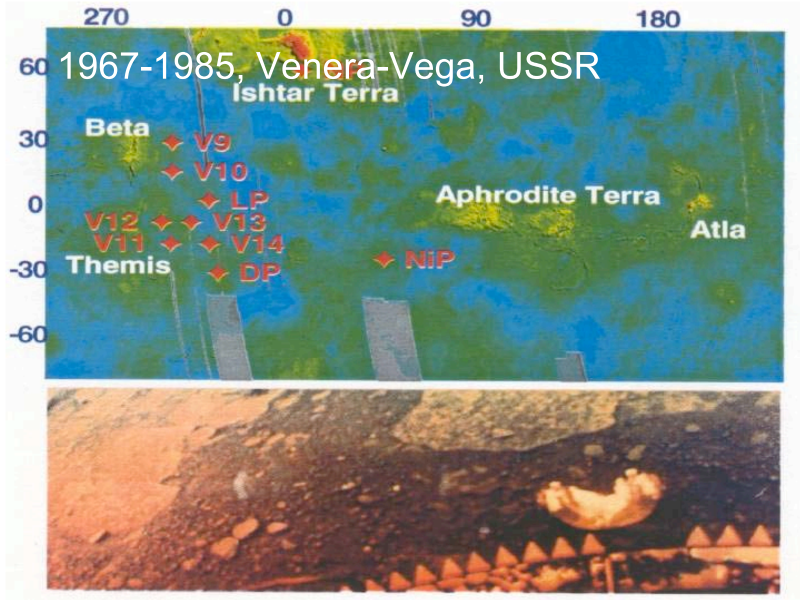
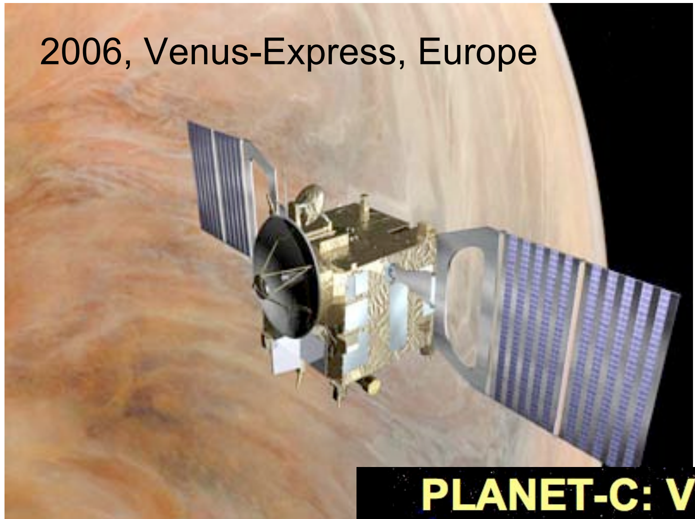
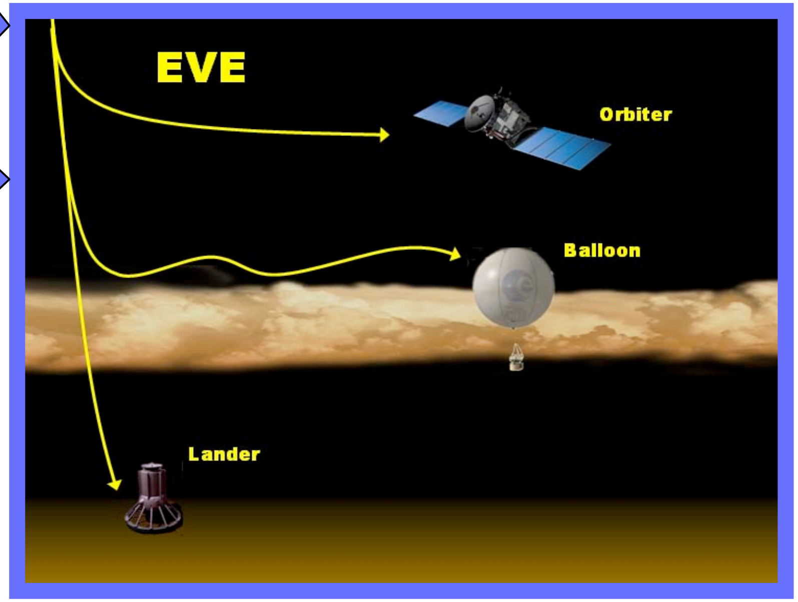
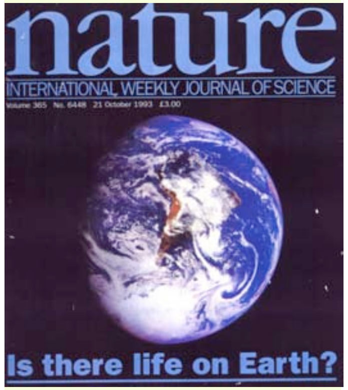
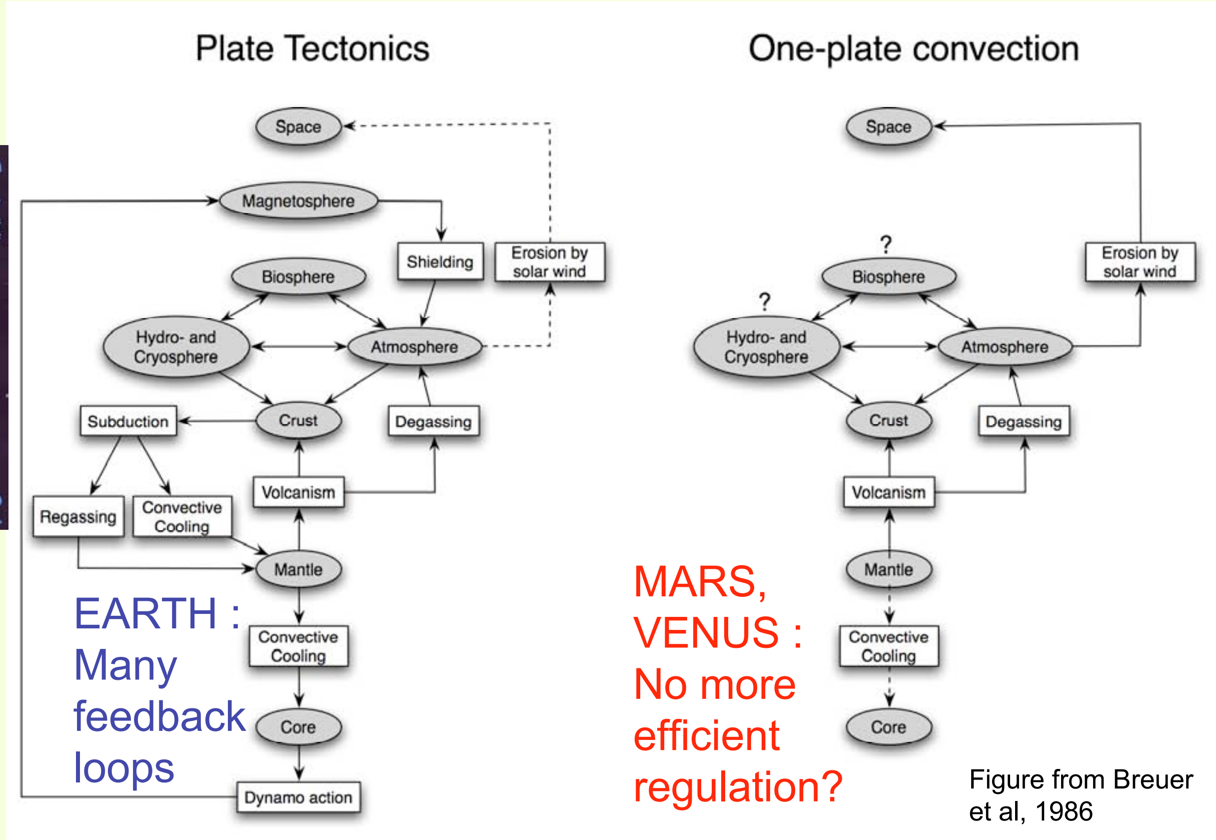






Comparative study of terrestrial planets

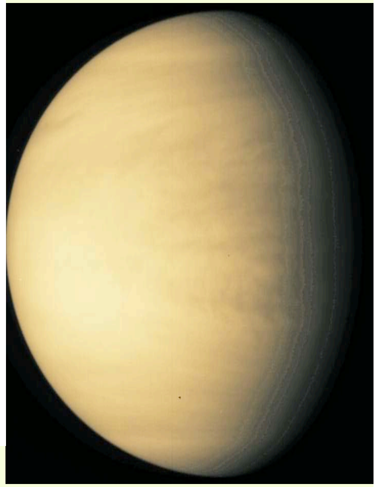


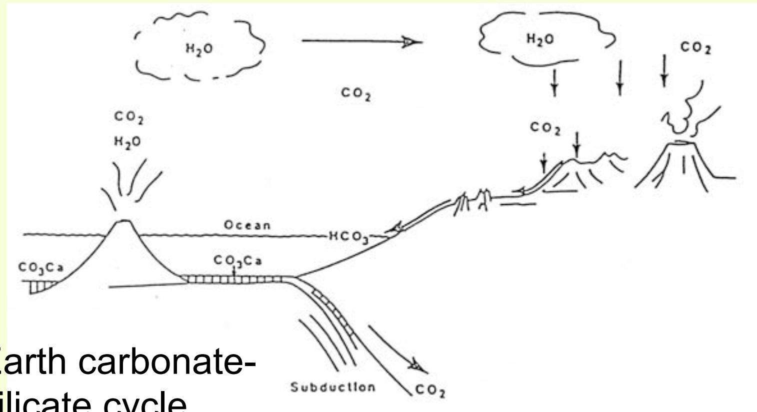


EARTH : Many feedback loops

MARS, VENUS : No more efficient regulation?

Figure from Breuer et al, 1986





Earth carbonate-silicate cycle

- Earth : greenhouse effect stabilized by interacting processes in the biosphere, atmosphere, hydrosphere, crust and mantle.
- Life can be seen as a geology-related process
- NOTION OF LIFE-GEOLOGY COEVOLUTION

Examples of important questions

- Is there a feedback between life and tectonic style, atmosphere evolution, and – possibly– magnetic field generation?
- Is there a link between the failure to sustain plate tectonics and the loss of habitability? Is surface recycling on Venus similar to plate tectonics?
- What is the climate history of Mars and Venus?
- If there was once water on the surface of Venus, how fast was it lost? If Venus was dry how much atmosphere could have been lost over the planets history and under which conditions?
- Can massive abiotic oxygen amospheres be generated by runaway greenhouse on extrasolar planets?

Context for a come back to Venus?

➢ Why did Venus evolved differently of Earth?

➢ An urgent need for a unified scenario of terrestrial planet formation and evolution

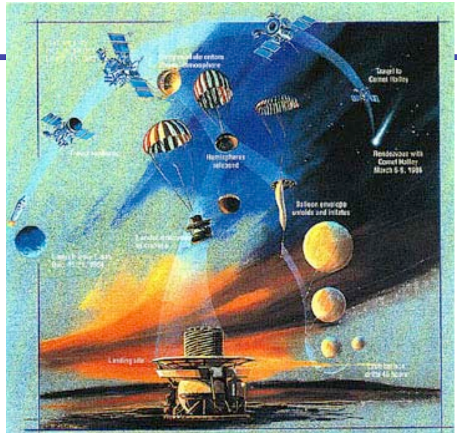
➢ A necessary step toward extrasolar terrestrial planet observation and modelling

➢ A wide interested international science community

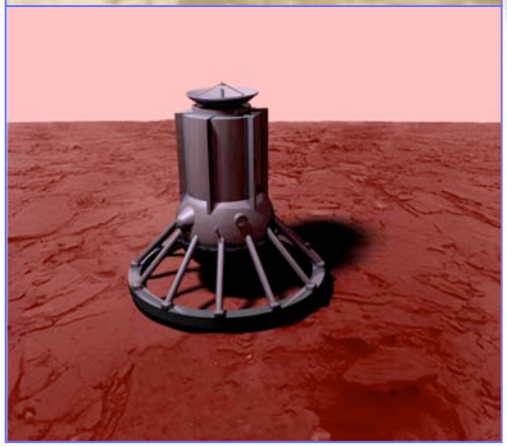
➢ An ongoing program with the European VeX and the Japanese VCO orbiters

➢ A technically and scientifically high return-on-investment planetary mission relying on ESA, Roscosmos, NASA and JAXA experiences

Need for an in situ mission to understand the evolution of Venus and its climate





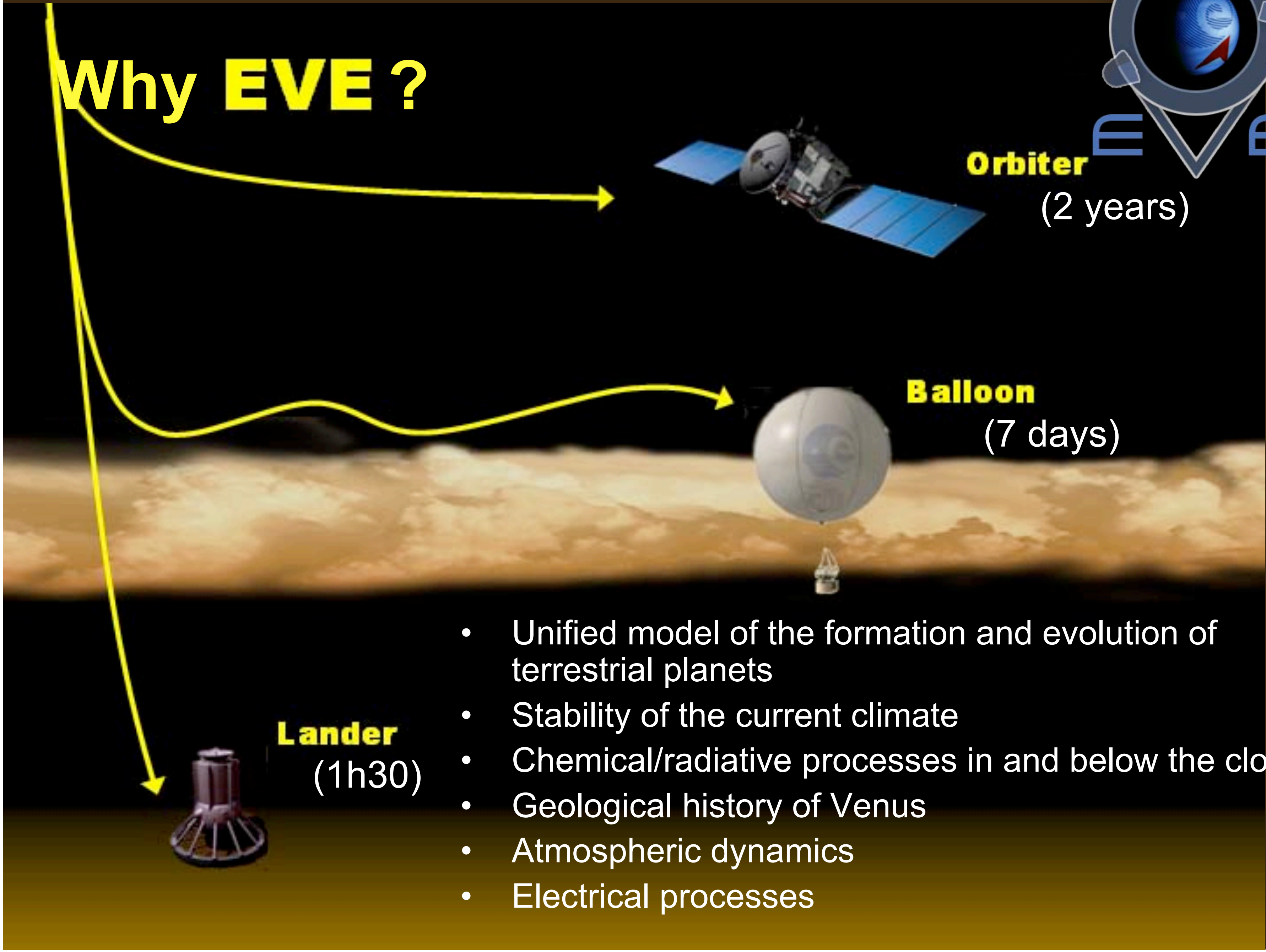


European Venus Explorer

A proposed mission for ESA's Cosmic Vision 2015-2025

E. Chassefière, O. Korablev, T. Imamura, K. Baines, C. Wilson (Co-PI), K. Aplin, T. Balint, J. Blamont, C. Cochrane, Cs Ferencz, F. Ferri, M. Gerasimov, J. Leitner, Lopez-Moreno, B. Marty, M. Martynov, S. Pogrebenko, A. Rodin, D. Titov, J. Whiteway, L. Zasova and the EVE team.

Why EVE ?

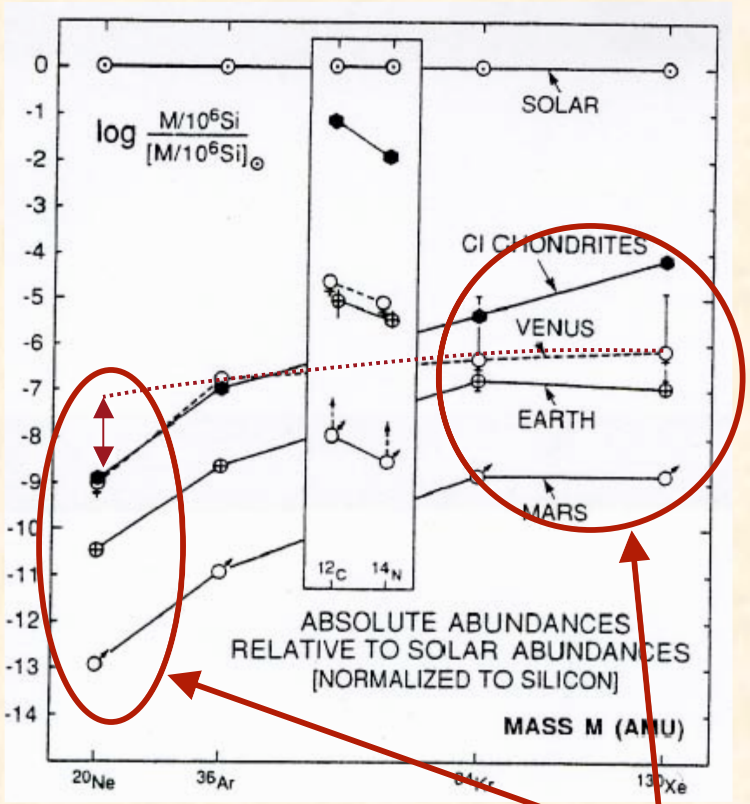


- Unified model of the formation and evolution of terrestrial planets
- Stability of the current climate
- Chemical/radiative processes in and below the clouds
- Geological history of Venus
- Atmospheric dynamics
- Electrical processes

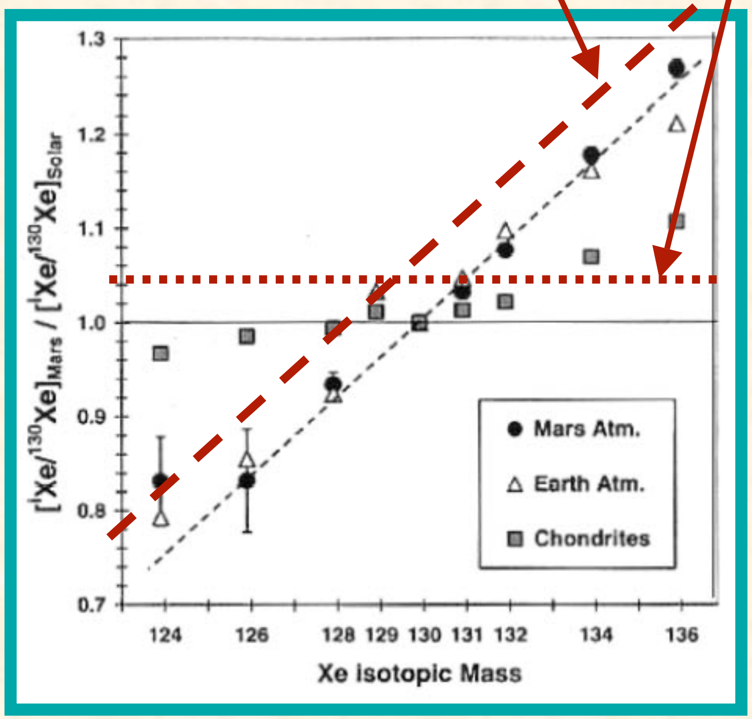
Main science return : isotopes

➢ In situ measurement from the balloon of noble gas abundances and stable isotope ratios from the balloon, to study the record of the evolution of Venus.

Venus isotopic ratios : Earth/Mars-like or solar-like?



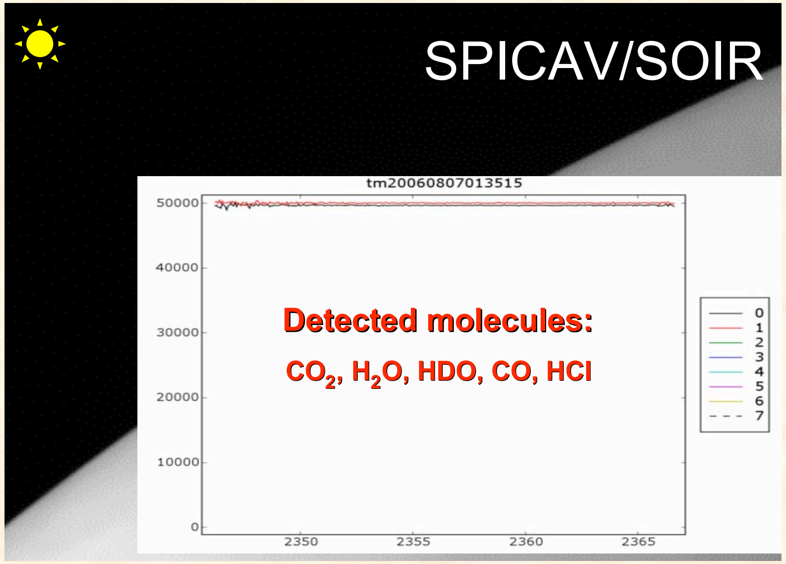
From Pepin and Porcelli, 2002

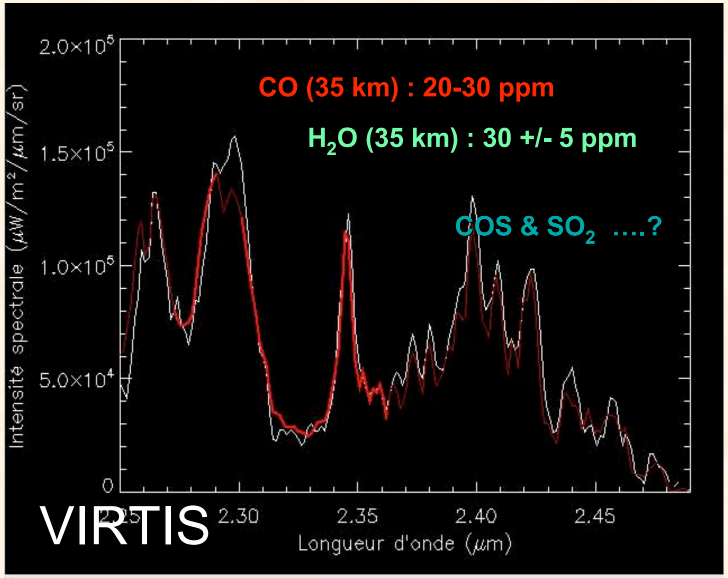


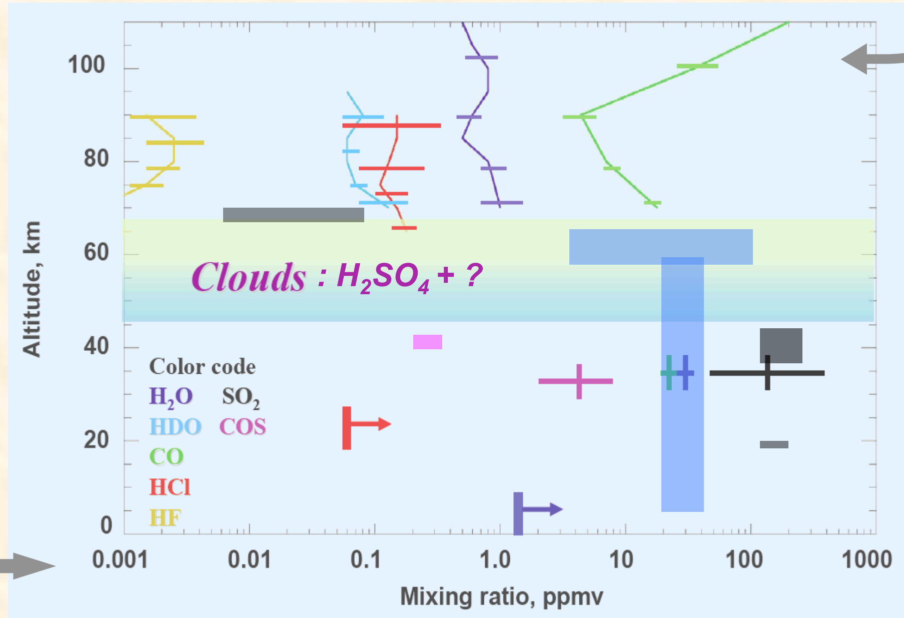
Elemental ratios : Kr, Xe Earth/Mars-like, solar-like or chondritic-like? Why is Ne depleted?

Main science return: composition

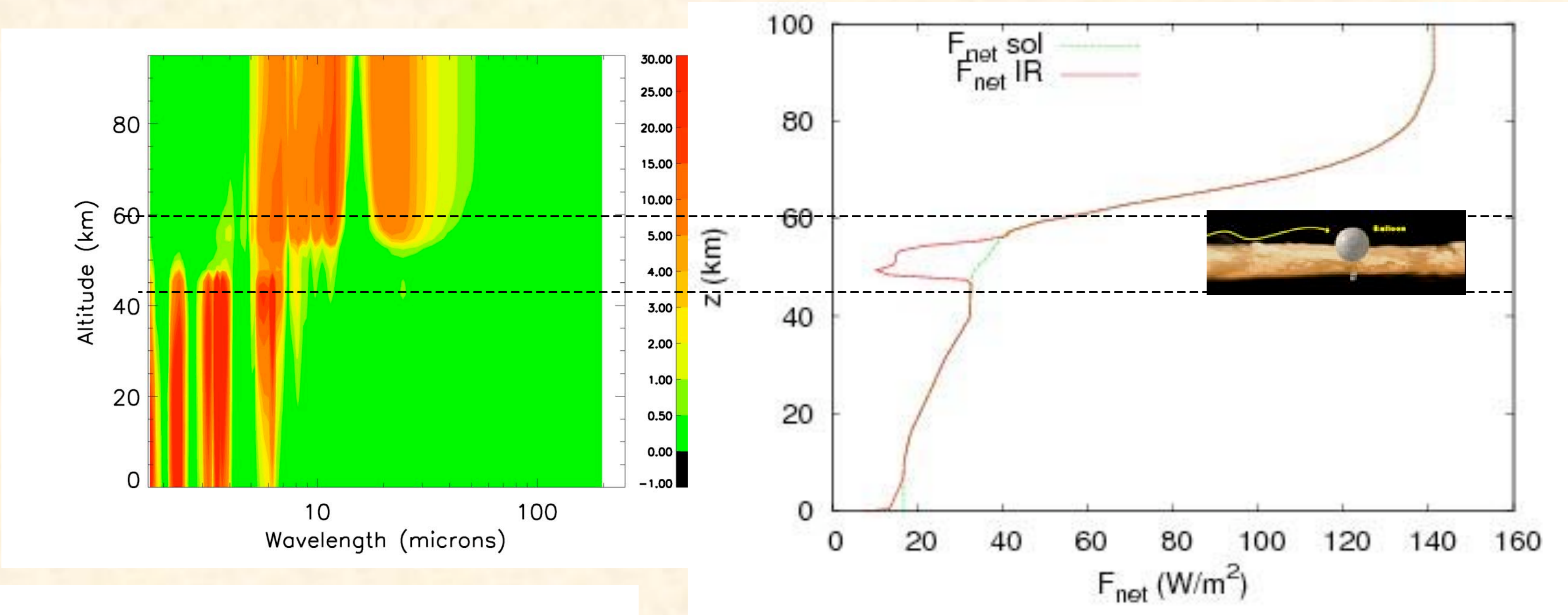
- In situ balloon-borne measurement of cloud particle and gas composition, and their spatial variation, to understand the complex cloud-level chemistry.

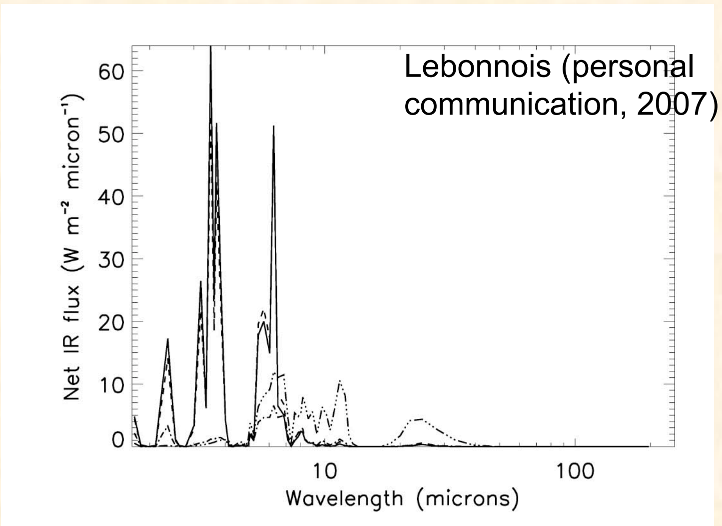




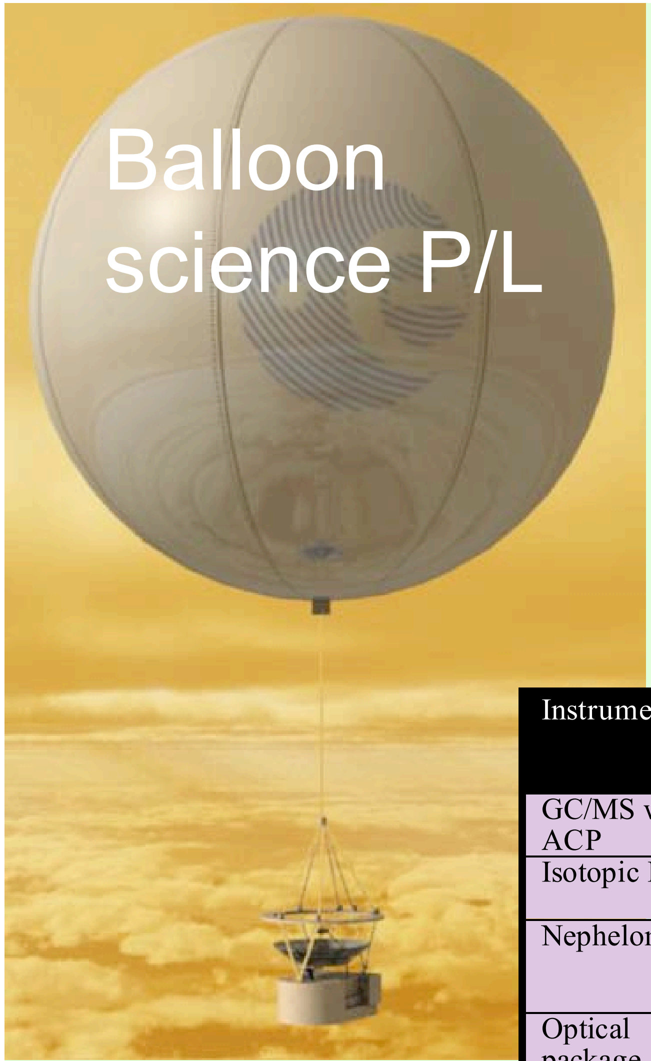


Main science return: dynamics





- ➢ In situ measurements of environmental parameters and winds (from tracking of the balloon) for one rotation around the planet (7 days), to understand atmospheric dynamics and radiative balance in this crucial region.

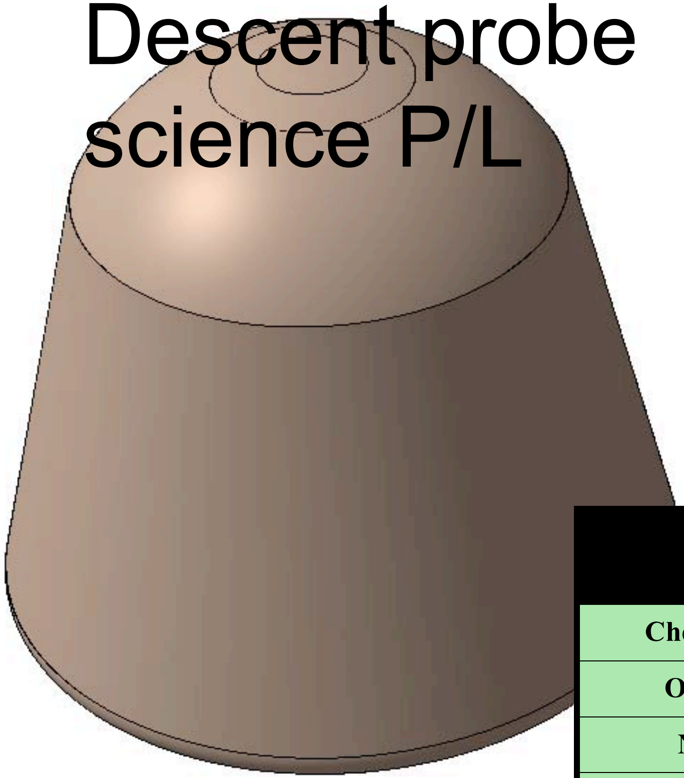


- Composition of atmosphere and aerosol particles
- Microphysical properties of aerosol particles
- Isotopic ratios of noble gases, and of light elements
- Determination of local wind velocity, from tracking the balloon’s position
- Upwards and downwards fluxes of radiation
- Electrical properties of atmosphere and clouds
- Cloud particles for exobiological potential
- Vertical profiles of radiative fluxes, pressure, temperature, and chemical abundances.

Instrument	Mass (kg)	Power (W)	Data rate (bps)	TRL Level/ heritage	Potential provider (laboratory, consortium)
GC/MS with ACP	3.6	15W (peak)	30	4/5, Huygens, MSL, ExoMars, Phobos	IPSL (France), Open University (UK), IKI (Russia), others.
Isotopic MS	4.0	15W (peak)	11.6	4/5, Beagle2, Rosetta	Open Univ (UK) / IPSL (Fr) / U. Berne (CH)
Nephelometer	1.0	2 W	1.4	3-4	NASA-led (Cornell/Ball Aerospace) with TU Delft. Other possibility: IKI
Optical package	0.5	1.2 W	1.6	4	Univ. Oxford (UK)
Atmospheric package (p, T, acc, sound)	0.4	2 W	0.4	5 Huygens, Beagle 2, ExoMars	FMI (Finland) / Oxford U & Open U (UK) / Padova (Italy) / IAA (Spain) / IWF (Austria)
VLBI beacon / USO	0.5	5 W	0.8	8	CNES (France) / TBD
Electrical / EM package	0.4	2.5 W (peak)	10.0	6 Compass-2, ISS	Eötvös Univ (Hungary) & RAL (UK)
ATR spectrometer	2	5 W (peak)	5	4	IKI (with IFSI participation)
TOTAL	12.4 kg w/o margin; or **15 kg including 21% margin**				

Heritages : Huygens, Exomars…

Descent probe science P/L

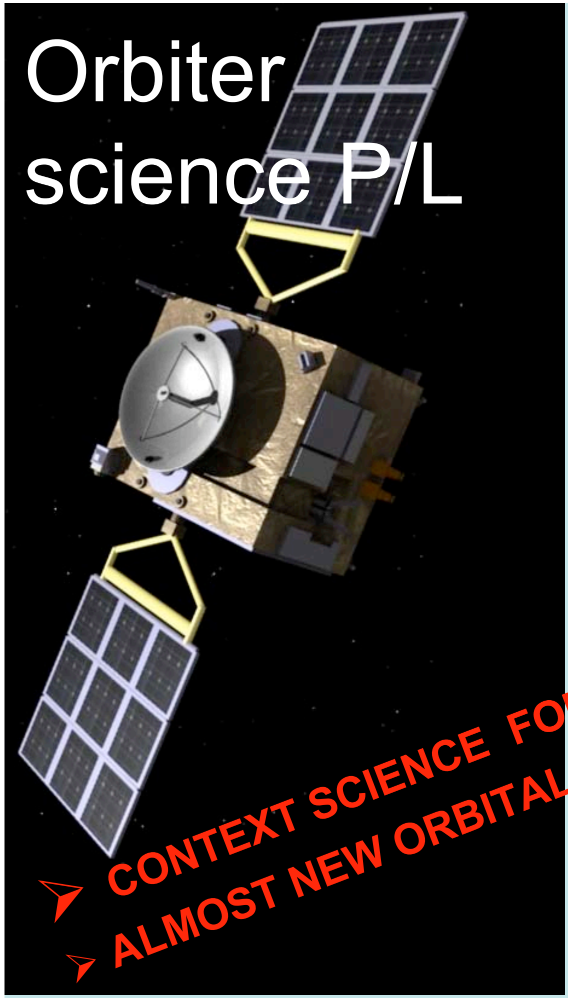


- Atmospheric chemistry.
- Cloud chemistry and optical properties.
- Atmospheric structure, dynamics, and radiative balance.
- Surface composition.
- Atmospheric electrical properties and EM wave phenomena.

Instrument	Mass (kg)	Power (W)	Data rate (bit/s)	TRL (2007)	Origin
Chemistry package	3.7	<20 W	3	4-8	IKI, IPSL, MPS, UK
Optical package	1.5	6 W	1.6	4	IKI, IPSL
Nephelometer	1	2 W	1.4	4	IKI, Inst Appl. Math.
Imaging system	0.7	3W	3+	6	IKI
ATR spectrometer	2	5 W	5	4	IKI, IFSI
Accelerometer	0.2	1 W	0.3	8	IKI, TSNIIMASH
Meteorological package	0.3	2 W	0.4	5-7	IKI/ FMI
Gamma-spectrometer	8	17W	2	6-8	IKI
Lightning detector	0.8	2.3W	0.5	6	IKI, Eötvös Univ
OBDH	1.7	5W	-	7	IKI
20% Margin	4				
Budget:	**23.9 kg**				Russia, EU

Heritages : Vega, Phobos, BepiColombo…

Orbiter science P/L



➢ CONTEXT SCIENCE FOR PROBES

➢ ALMOST NEW ORBITAL PAYLOAD

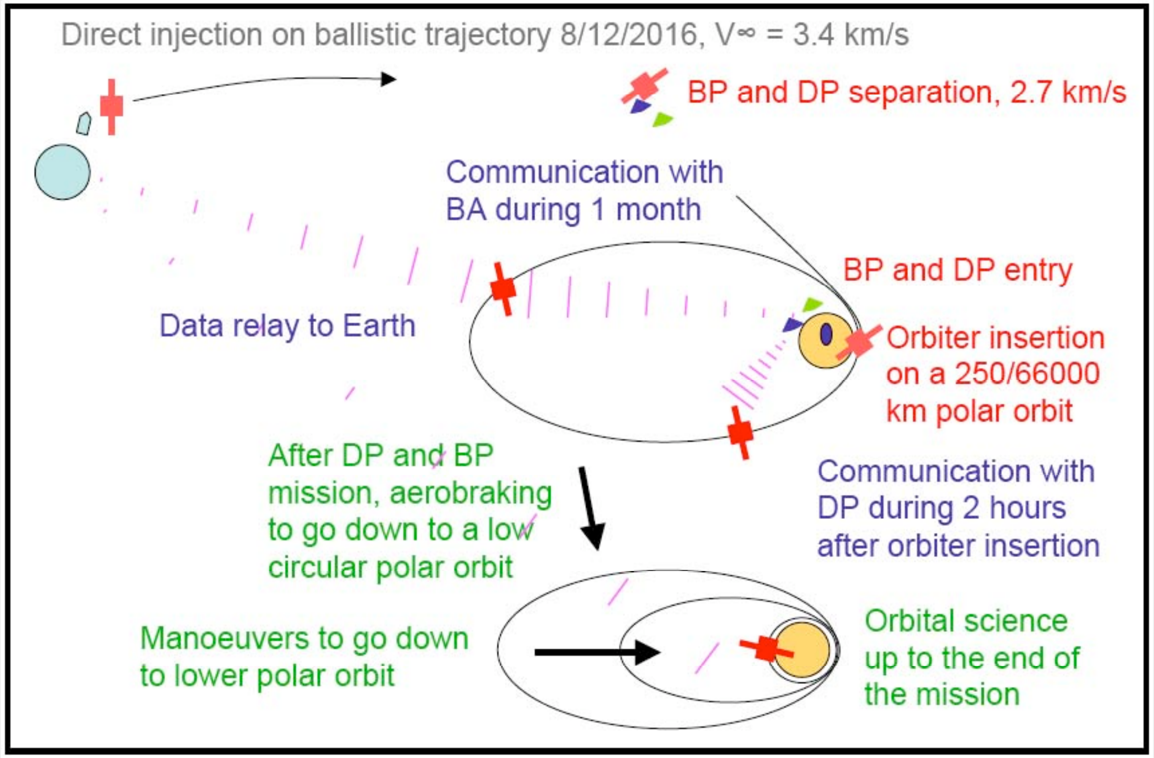
- Escape fluxes (mass spectrometers, magnetometer)
- Auroras (UV imager)
- Meso-thermospheric wind field (submm spectro + camera)
- Atmospheric composition (IR-submm spectro)
- Temperature profiles (radio science, in-situ, IR-submm spectro)

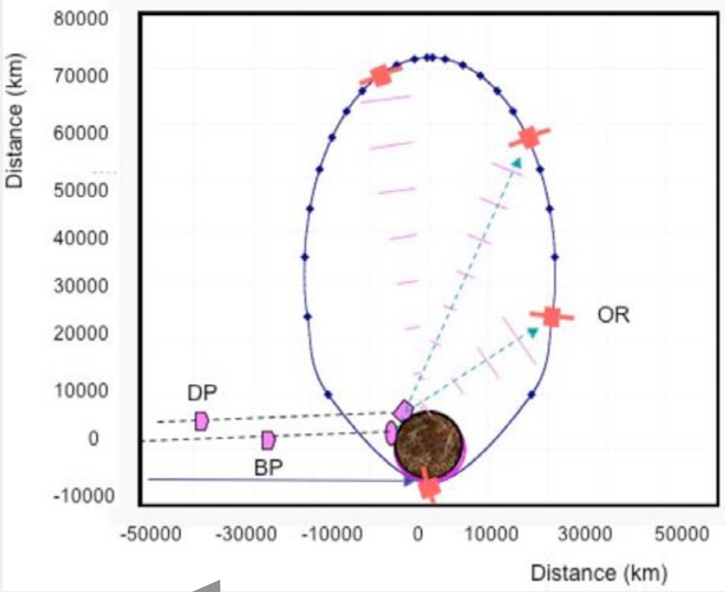
Instrument	Mass (kg)	Power (W)	Data rate (kbps)	TRL Level/ heritage	Potential provider (laboratory, consortium)
Neutral mass spec.	3	4	~ 1	4, Giotto, Cassini, BepiColombo	IPSL (France)
Ion mass spec.	1.5	3-7	~ 2 (≥0.02)	4, BepiColombo	Consortium: IKI (Russia), Mullard (UK)
UV plasma imager	2.3	5	6	6, Nozomi, BepiColombo	Tohoku Univ. (Japan)
Sub-mm sounder	9.2	40	~ 9.2	8/9, Rosetta, Herschel	Max Planck Institute (Germany)
UV mapping spectrometer	1.5	5	40	9, MEX	Consortium: INAF (Italy), IKI (Russia)
Lidar (TBC)	7.4	70	4.8	4/9, Phoenix Mars	York Univ., MDA, CSA (Canada)
Infrared Spectrometer	2.4	7	4.4	5, Mars Express, Venus Express	Consortium: IKI (Russia), INAF (Italy)
High-speed / context camera	3.5	10	< 10	6, ground based	German Aerospace Center (Germany)
USO for radio science	1	1	0	9, in most of missions	e.g General Dynamics (UK)
EM Wave analyser	0.7	4-4.5	~ 4	7/5, Compass-2, ISS,… sw. BepiColombo	Consortium: Eötvös Univ., BL Electronics (Hungary)
Subsurface Radar	7.2	9	≤ 80	7/8, MEX, MRO and ExoMars	Consortium: IPG, Obs. Midi-Pyrénées & de Bordeaux (France), GSFC, JPL and UTA (USA)
Magneto-meter	≤ 1.2	1.2	1.5	9, Oersted, Champ, Proba-2, Swarm …	Dan. Nat. Space Center (Danemark), Imperial College London (UK)
Gamma Flash Detector	2.3	3	10	7/5, Coronas-F	Consortium: IKI, SINP MSU (Russia)
20% margin	8.6				
Total :	**51.8**	**≤ 170**	**210**	-	**ESA (& ECS), Russia, USA, Japan, *Canada***

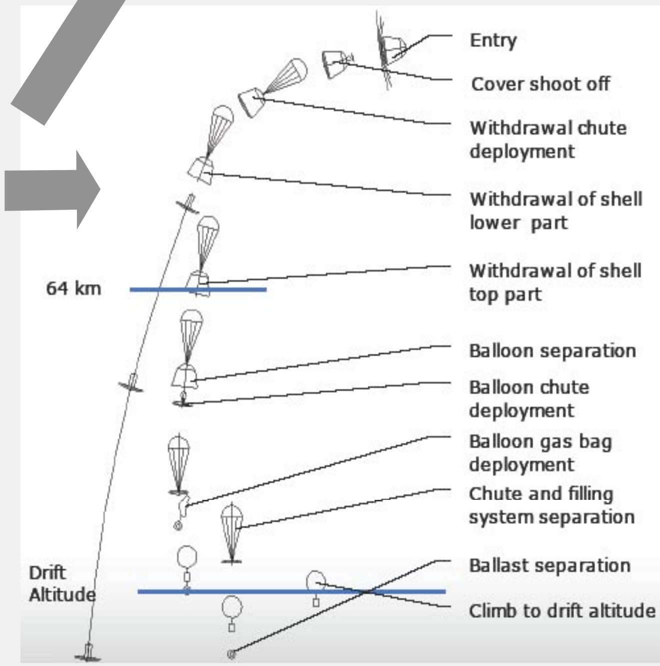
- Electric activity (gamma, visible, radio emissions, in-situ)
- Cloud structure (lidar, camera, IR spectro, in-situ)
- Subsurface structure (radar)

Mission baseline

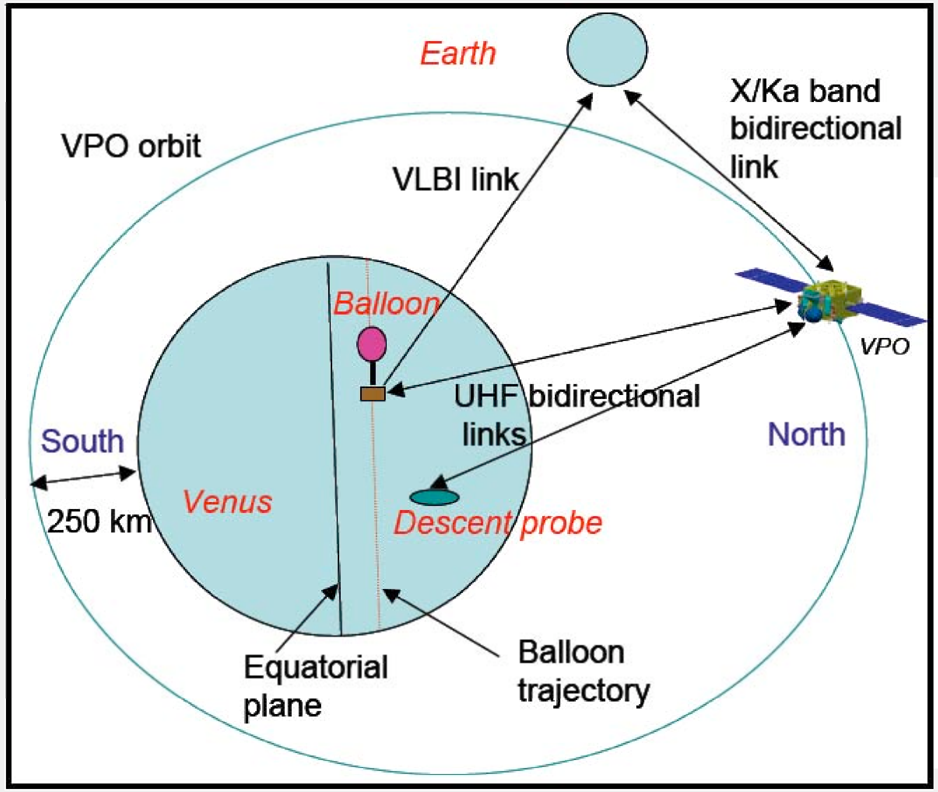
	2016 (nominal)	2018 (backup)
Departure date	8.12.2016	10.06.2018
Departure conditions	v_∞ = 3.38km/s δ_∞ = 32deg	v_∞ = 3.93km/s δ_∞ = -39deg
Arrival date	18.05.2017	11.12.2018
Arrival relative velocity	2.68 km/s	2.99 km/s
Cruise duration	161 days	184 days

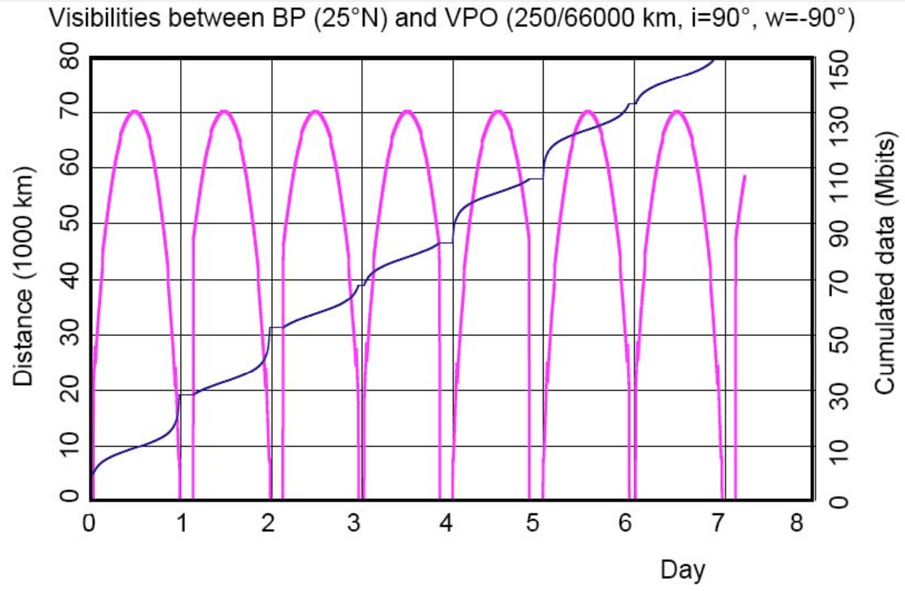






Telecommunication strategy





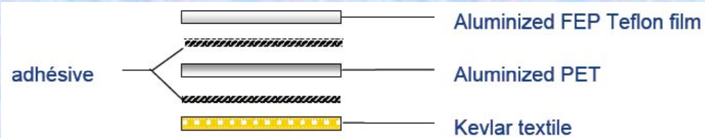
Back-up option : direct Balloon-to-Earth downlink

	Westbrock	*Effelsberg*	*Green Bank*	*Medicina*	*Arecibo*	*SKA=30%*
Aperture	14 x 25m	100 m	100 m	30,000 m^2	300 m	300,000 m^2
Frequency range (MHz)	300-450	350-450	300-500	406-410	425-435	300-500
Aperture efficiency	0.35	0.6	0.6	0.4	0.4	0.4
SNR (in 1Hz)	35	110	270	230	1100	3500
Max. data rate (bps)	20	6	150	130	600	2000
Aver. Data rate (bps)	≈2	≈7	≈20	≈15	<≈30	≈200
TRL (2007)	8	8	8	8	8	3

Data rate achievable by UHF transmission from balloon (or descent probe) direct to Earth

Balloon probe

Option 1 : Superpressure balloon

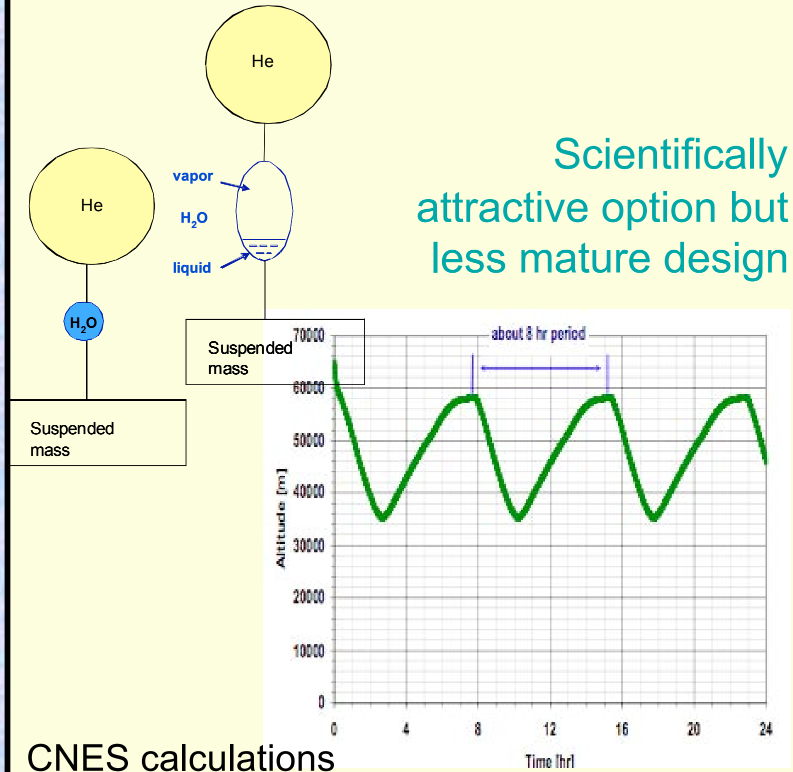


CNES Venera super pressure balloon (1970 – 1980)

MASS BUDGET

Overall balloon mass (kg)	57.0
Suspended mass (kg)	40.0
Balloon envelop mass (kg)	10.0
Balloon radius (m)	2.5
Over-pressure (hPa)	100

Option 2 : Phase change oscillating balloon



Scientifically attractive option but less mature design

CNES calculations

Sub system	Mass (kg)	Comments
Gondola	40	Includes 15 kg of scientific instruments
Balloon	17	Includes 10 kg of envelop and 7 kg of He
Gas storage system	23	Based on He gas tank.
Russian Entry System	90	Parachute, inner structure, back cover
Total	170	

EVE international cooperative scheme

- EUROPE
  - The spacecraft,
  - the balloon platform and
  - the Kourou element of the launch costs.
- RUSSIA
  - The dry Soyuz launcher,
  - the descent probe,
  - the entry/descent systems for both balloon and descent probe and
  - A contribution to the science payload and data analysis.
- JAPAN
  - A small balloon for low altitude studies (option).
- USA & CANADA
  - Comprehensive science and instrument hardware involvements and
  - possibility of using NASA/JPL developed Venus balloon technology through international collaboration, under NASA's Mission of Opportunity (MoO) program.

A step-by-step international program to Venus

- Step 1 (2000-2010) : Orbiter missions (VEx and VCO) ➔ atmospheric and cloud dynamics

Venus Express (Europe)

Venus Climate Orbiter (Japan)

- Step 2 (2010-2020) : Balloon/descent probe mission (EVE?) ➔ evolution, chemistry and general dynamics

EVE (Europe/Russia)

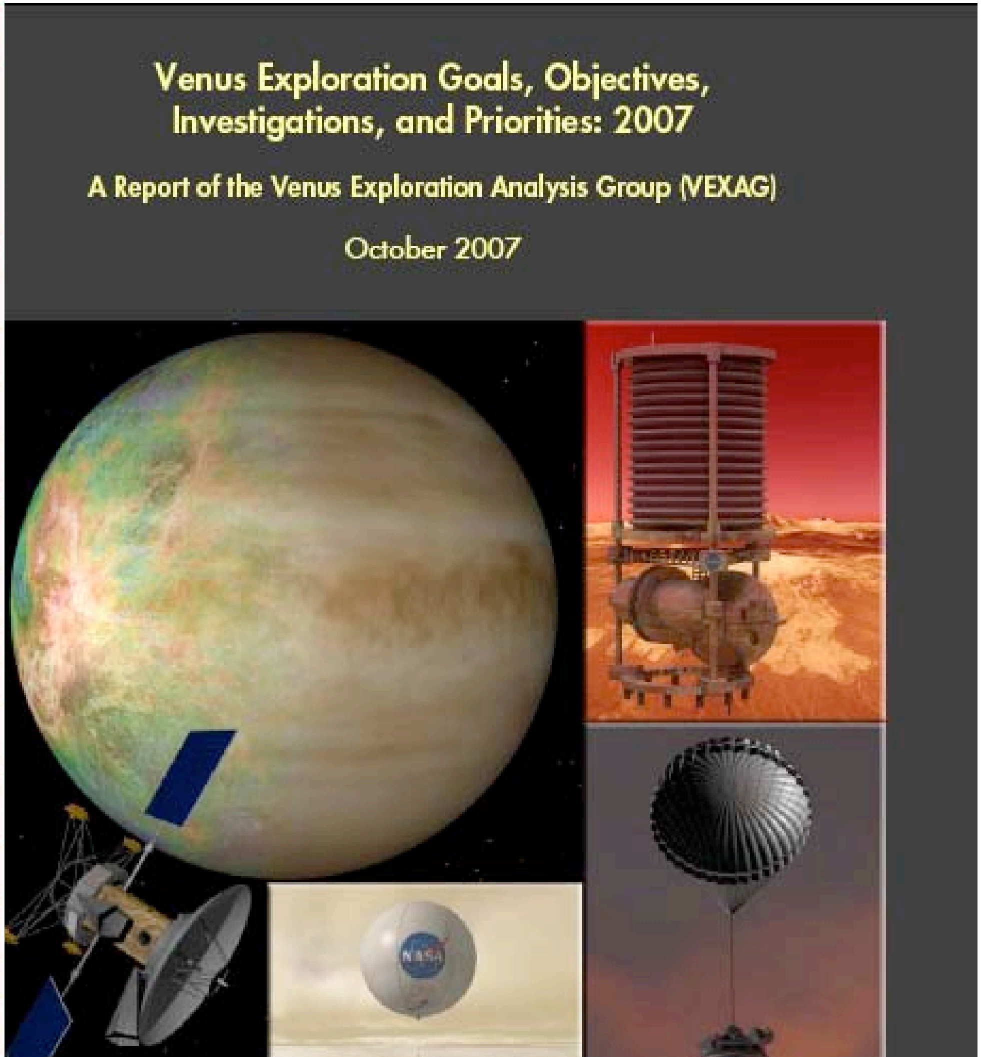
Low H_2O balloon (Japan)

- Step 3 (2020-2030) : Long-living landers/low atmosphere platforms ➔ interior structure/dynamics and coupling to the climatic system

VENERA-D (Russia + others)

Flagship mission (NASA + others)

Mission Class	Discovery		New Frontiers	Flagship		
Objectives	Venus Orbiter	High / Mid. Alt. Balloon	VISE	VME	VNET	VSSR
Goal I. Origin and Early Evolution of Venus: How did Venus originate and evolve, including the lifetime and conditions of habitable environments in solar systems?						
Determine isotopic composition of the atmosphere		●	●	●		●
Map the mineralogy and composition of the surface on a planetary scale	▲	▲	▲	●		●
Characterize the history of volatiles in the interior, surface, and atmosphere	▲	▲	●	●		●
Characterize the surface stratigraphy of lowland regions and evidence for climate change	●	▲	●	●		▲
Determine the ages of various rock units on Venus			▲	▲		●
Goal II. Venus as a terrestrial planet: What are the processes that have and still shape the planet?						
Characterize and understand the radiative balance of the Venus atmosphere	●	●	▲	▲	▲	
Investigate the resurfacing history and the role of tectonism, volcanism, impact, erosion and weathering.	▲	▲	▲	●	▲	▲
Determine the chronology of volcanic activity and outgassing	▲		▲	●	▲	●
Determine the chronology of tectonic activity	▲			▲		
Investigate meteorological phenomena including waves, tides, clouds, lightning and precipitation.	●	●	▲	●	▲	▲
Goal III. What does Venus tell us about the fate of Earth's environment?						
Search for fossil evidence of past-climate change in the surface and atmospheric composition.		●	●	●		●
Search for evidence of changes in interior dynamics and its impact on climate	▲		▲	▲	●	▲
Characterize the Venus Greenhouse effect and its similarities to those on Earth and other planets	●	●	▲	▲	▲	
Convention: ● *Major Contribution* ▲ *Supporting Contributions*						
VISE – Venus In-Situ Explorer; VME – Venus Mobile Explorer; VNET – Venus Network Explorer; VSSR – Venus Surface Sample Return						



A Venus In-Situ Explorer (VISE) was listed as a possible mission among those solicited in the last announcement of opportunity (AO) for New Frontiers (NF) missions, and is still under consideration for the next New Frontiers AO, subject to the current National Research Council (NRC) review of the process for identifying NF mission candidates. The science goals for a VISE mission were described in the last NRC Solar System Exploration Decadal Survey* as well as in the recent (2006) NASA Solar System Exploration Roadmap**. The goals for VISE were