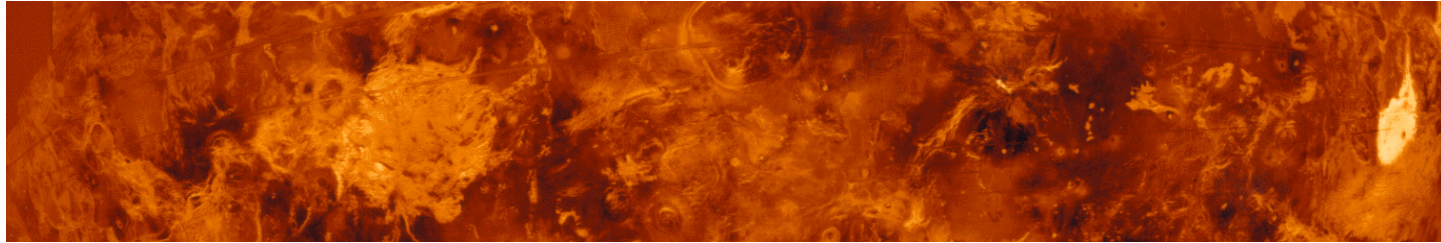
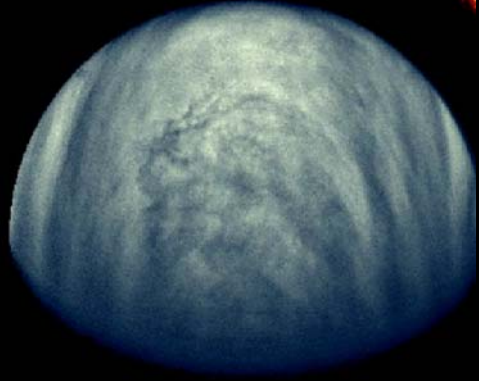


Neutral Mass Spectrometry for Venus Atmosphere and Surface

Paul Mahaffy
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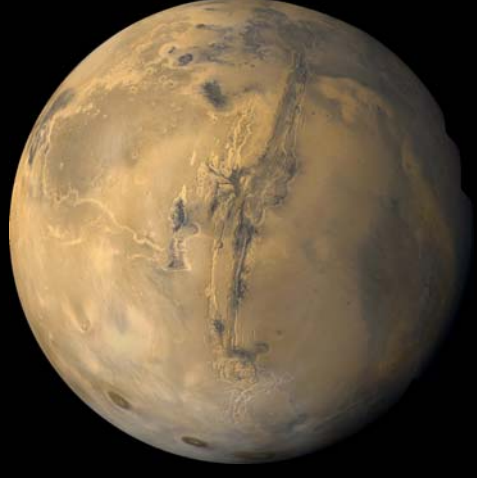
Why such divergent evolution in terrestrial planets?



90 bar CO₂
730 K
H₂SO₄ clouds
100,000 x drier
than Earth
D/H 160 x Earth
(Venus once wet?)
Thermochemistry
below clouds

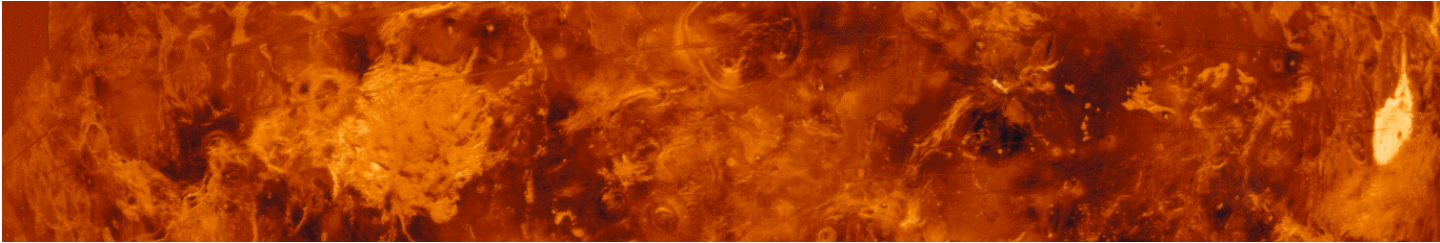


1 bar N₂, O₂
300 K in San Francisco
Receives ½ the solar
radiation of Venus
H₂O clouds
Oceans, Life



7 mbar CO₂
~210 K
H₂O and CO₂
ice clouds
D/H 5 x Earth
Photochemistry
at surface

How unique is our solar system?



Motivation for improved mass spectrometer measurements at Venus

- to address fundamental issues of terrestrial planetary formation and evolution

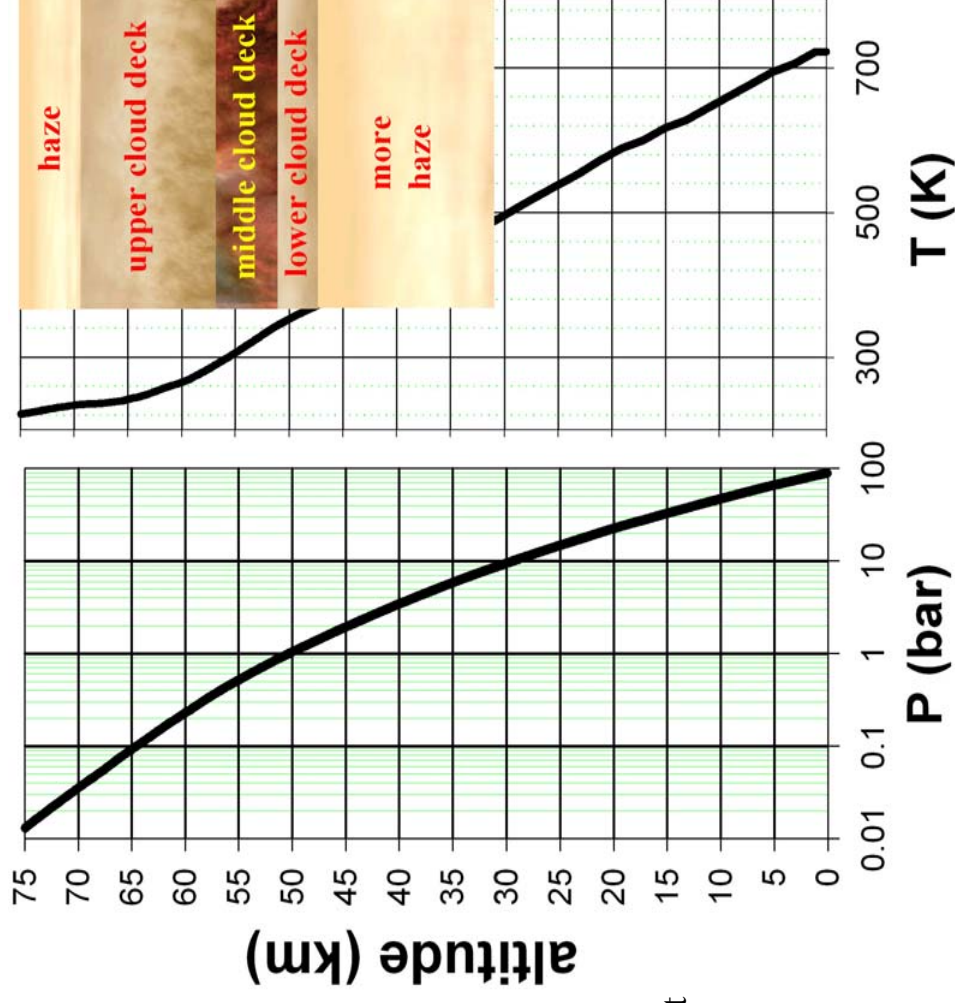
The assignment

- to make precise (better than 1 %) measurements of isotope ratios and accurate (5-10%) measurements of abundances of noble gas
- to obtain vertical profiles of trace chemically active gases from above the clouds all the way down to the surface

The challenge for Venus

probe mass spectrometry

- 4 orders of magnitude pressure differential on track from above clouds to surface
- trace species measured to parts per billion
- 9 orders of magnitude difference between atmospheric pressure at surface and ion source pressure in mass spectrometer
- 500 degree temperature gradient from atmosphere above clouds to surface
- cloud droplets and aerosols that can clog mass spectrometer inlet systems and mask real vertical variations due to their condensation on surfaces
- a fast ride to the surface with an entry probe



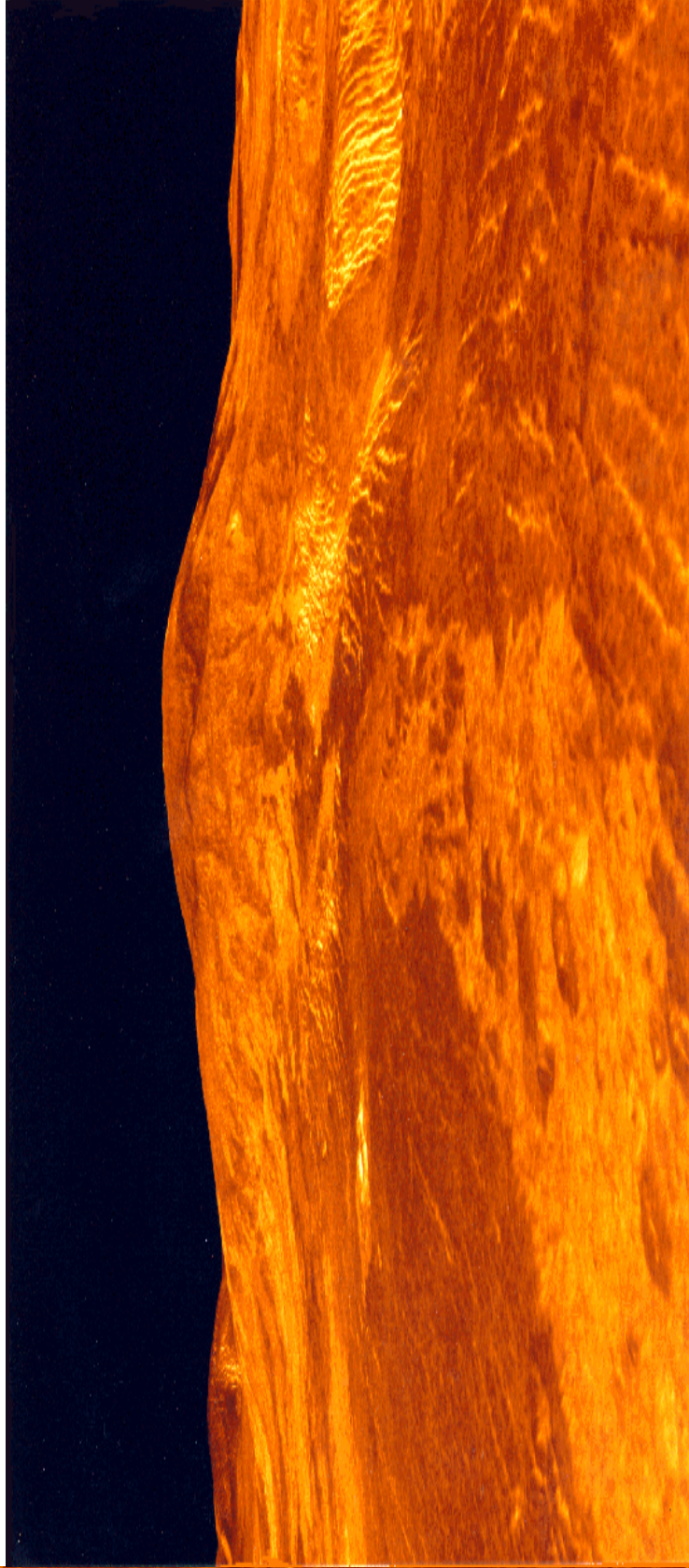
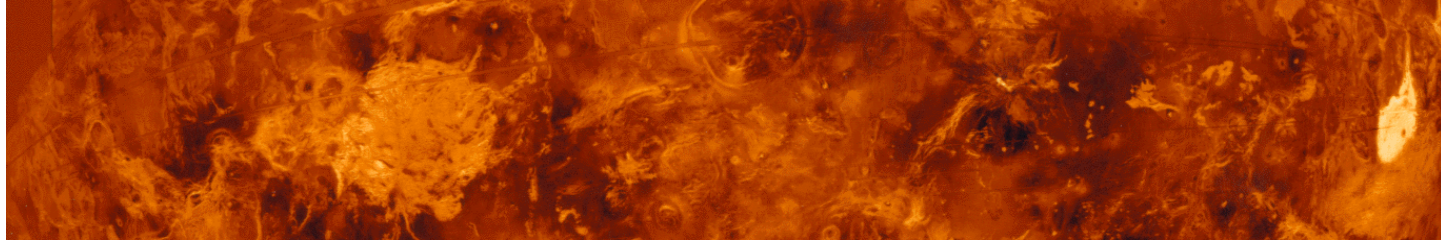
Topics

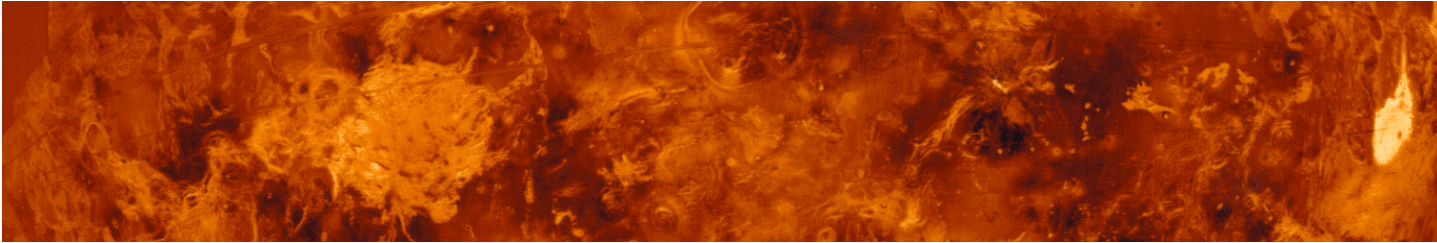
Near term Venus science goals for chemical and isotopic measurements

Where have the Venus missions, to date, left us with respect to these goals?

- noble gas elemental and isotopic composition
- cloud chemistry
- surface science

The challenge of Venus mass spectrometry and future directions





Science goals - atmosphere & surface chemical & isotope measurements

Space Studies Board SSE Strategy – July 2002

• The first billion years of solar system history

1. What processes marked the initial stages of planet and satellite formation?
2. How long did it take Jupiter to form and how did the formation of the gas and ice giants differ?
3. What was the rate of decrease of impacts by comets, asteroids, and other objects and how did it affect the emergence of life?

• Volatiles and organics: the stuff of life

1. What is the history of volatile material, especially water, in our solar system?
2. What is the nature and history of organic material in our solar system?
3. What planetary processes affect the evolution of volatile on planets?

• The origin and evolution of habitable worlds

1. Where are zones in our solar system where life can exist and what are the processes for producing and sustaining habitable planets?
2. Does (or did) life exist beyond the Earth?
3. Why did Mercury, Venus, Earth, and Mars diverge so much in their evolution?
4. What hazards do solar system objects present to Earth?

• How planets work

1. How do the processes that shape planets today operate and interact?
2. What does our solar system tell us about other solar systems?

Decadal Study Recommendations for Venus

Profile

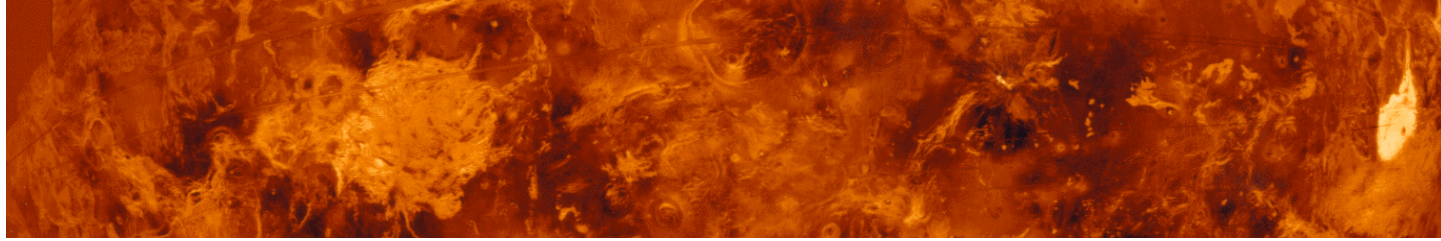
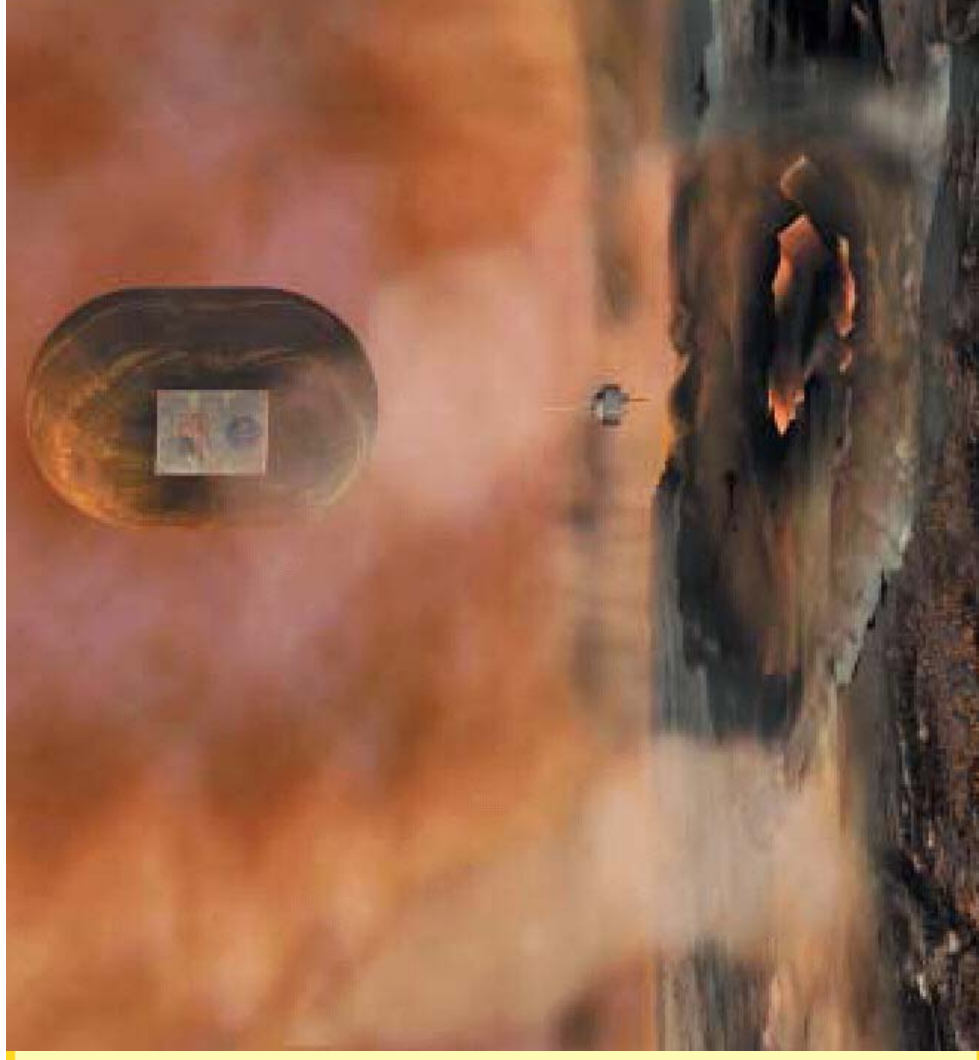
Venus In Situ Explorer

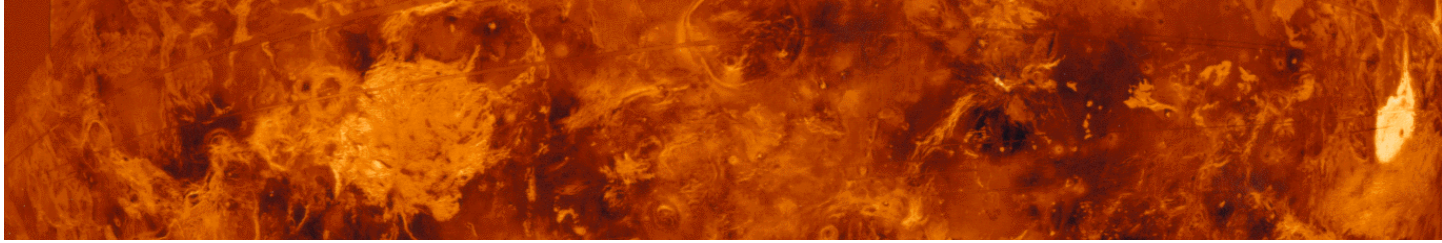
Mission Type: Lander

Cost Class: Medium

Priority Measurements:

- Determine elemental and mineralogical surface compositions.
- Measure the composition of the atmospheres, especially trace gases and their isotopes.
- Undertake high-precision measurements of noble gases and light stable isotopes.
- Assess processes and rates of atmosphere-surface interaction.
- Search for evidence of volcanic gases in inner-planet atmospheres.



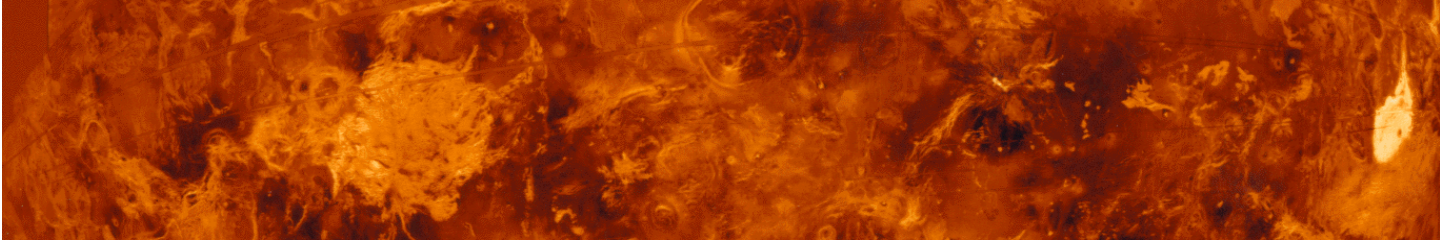


Decadal Study Themes and Science Questions for Terrestrial Planets

Guiding Themes Addressed	Important Planetary Science Questions Addressed
Volatiles and Organics The Stuff of Life	<i>What global mechanisms affect the evolution of volatiles on planetary bodies?</i> <i>What is the history of water on the inner planets?</i> <i>How did the atmospheres of the inner planets evolve?</i>
The Origin and Evolution of Habitable Worlds	<i>Why have the terrestrial planets differed so dramatically in their evolution?</i> <i>What kinds of minerals are the inner planets made of, and does this vary depending on a planet's distance from the Sun?</i>
Processes How Planetary Systems Work	<i>How do the processes that shape the contemporary character of planetary bodies operate and interact?</i> <i>What processes stabilize climate?</i> <i>How do planets' varied geological histories enable predictions of volcanic and tectonic activity?</i>

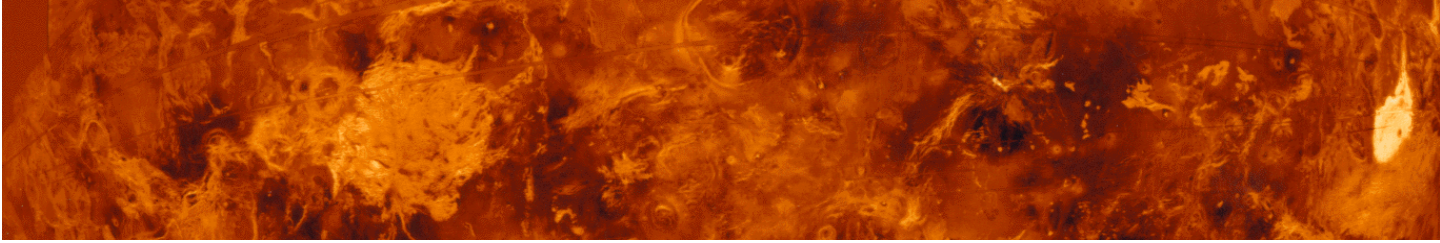
Science measurement objectives of VISE are as follows:

- Determine the composition of Venus' atmosphere, including trace gas species and light stable isotopes
- Accurately measure noble-gas isotopic abundance in the atmosphere
- Provide descent, surface, and ascent meteorological data
- Measure zonal cloud-level winds over several Earth days
- Obtain near-IR descent images of the surface from 10-km altitude to the surface
- Accurately measure elemental abundances & mineralogy of a core from the surface
- Evaluate the texture of surface materials to constrain weathering environment.



Motivation for noble gas measurements at Venus

**Noble gas elemental ratios and isotopic fractionation
constrain models of atmospheric formation and evolution**

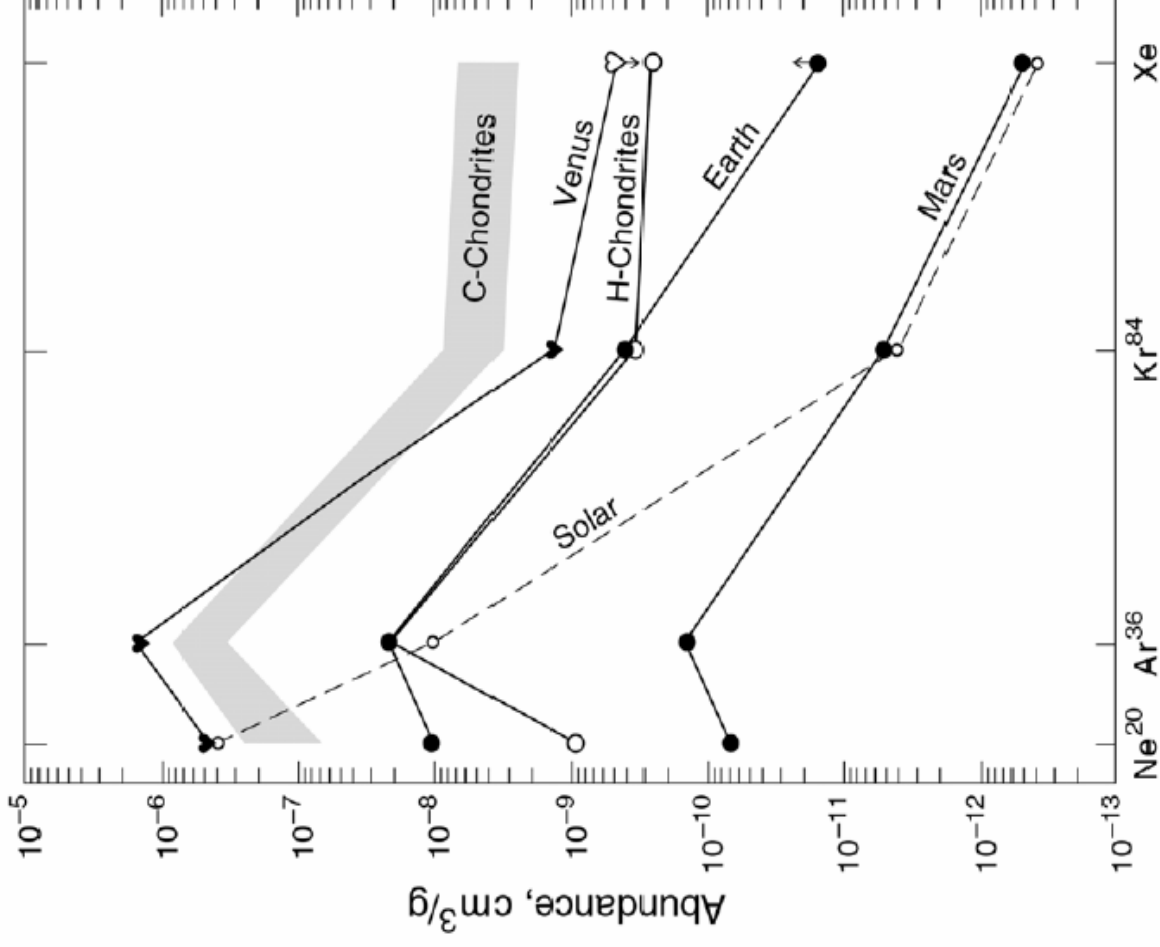


Noble gas elemental ratios

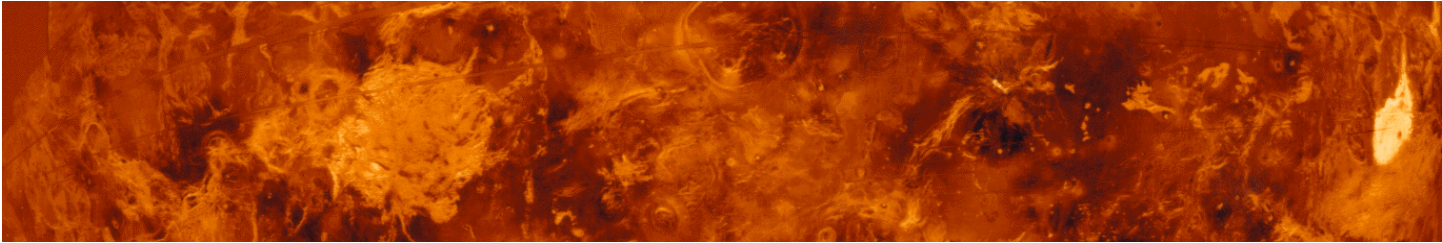
Inner planet noble gas elemental abundances do not match those of the sun or various types of chondrites.

The $^{36}\text{Ar}/^{84}\text{Kr}$ ratio at Venus may be much more solar like than Earth or Mars.

However - great uncertainty in Kr and Xe elemental abundances



From Owen and Bar-Num, Orig. of Life and the Evolution of the Biosphere, 31, 435, 2001.



Xenon Isotopic Composition

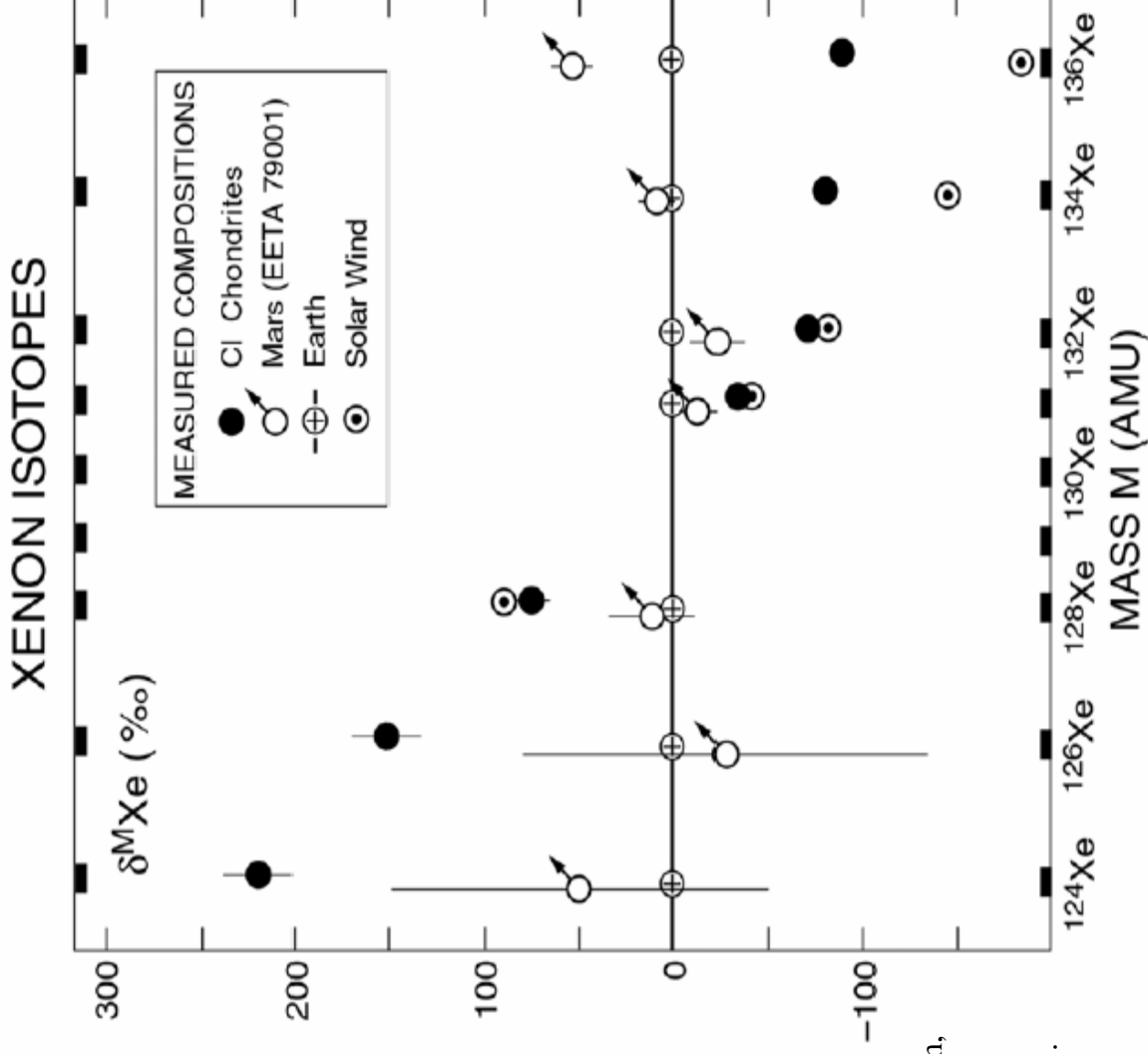
Mars and Venus vs. the Sun and chondrites.

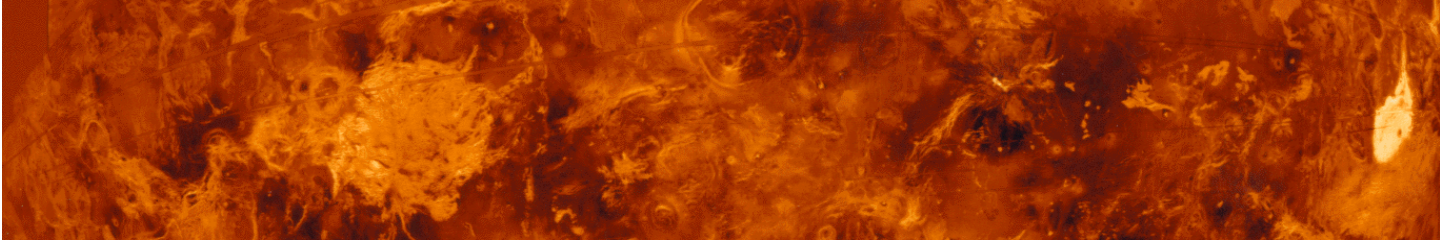
The Martian values are established from SNC meteorite analysis.

The fractionation in Venus is unknown.

If fractionation on Venus was found to be similar to Earth and Mars, then fractionation could have occurred in planetesimals prior to their incorporation in planets

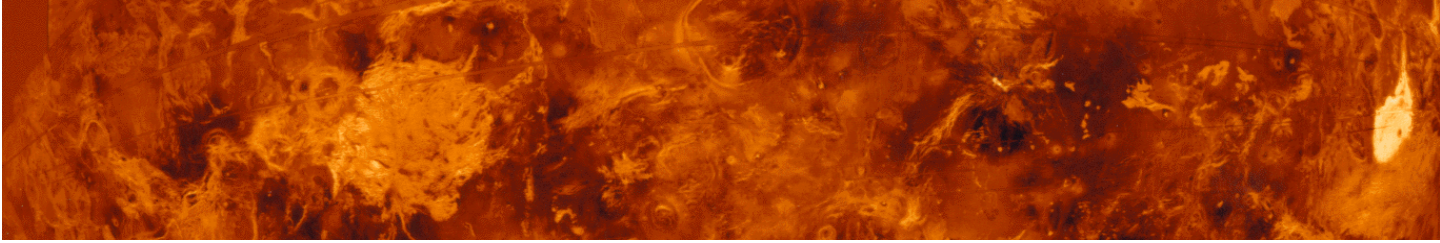
from Owen and Bar-Num, Orig. of Life and the Evolution of the Biosphere, 31, 435, 2001.





Current status of noble gas measurements at Venus

- Xe – no isotope information, upper limit on abundance**
- Kr – no isotope information, great uncertainty in abundance**



Present state of the art in Venus noble gas measurements

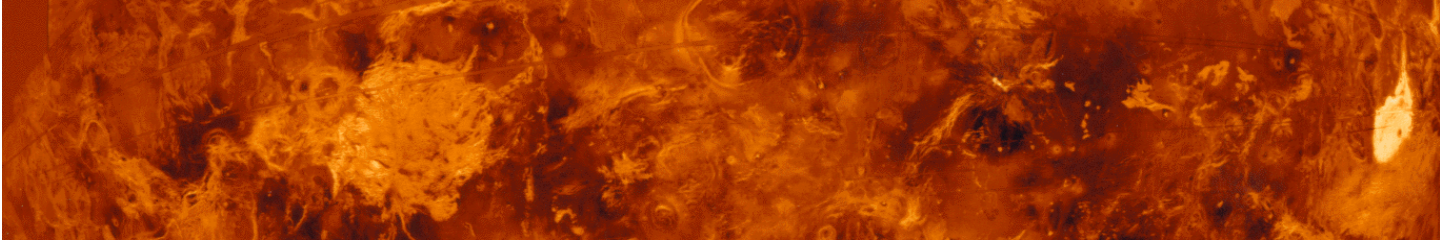
Noble gas abundance	Previous measurements	notes
He	12 (+24,-8) ppm	extrapolated from meas. > 130 km
Ne	7 ± 3 ppm	4 MS measurements
Ar	70 ± 25 ppm	3 MS and 2 GC measurements
Kr	0.4 ± 0.14	Venera 11 and 12 reproduced measurements
	0.2	PV Probe Hoffman analysis
	0.025	PV Probe Donahue analysis
Xe	0.12 upper limit	PV Probe Donahue analysis

Target accuracy <5-10%

Noble gas isotope ratio	Previous measurement	notes
³ He/ ⁴ He	---	³ He predicted at low ppb level – methane or H ₂ could give H ₃ ⁺ interference with HD
²⁰ Ne/ ²² Ne	11.8 ± 0.7	Potential interference from ⁴⁰ Ar ⁺⁺ at 20 Da and CO ₂ ⁺⁺ at 22 Da
²⁰ Ne/ ²¹ Ne	---	
³⁶ Ar/ ³⁸ Ar	5.56 ± 0.62	PV Probe Donahue analysis
	5.08 ± 0.05	Venera 11/12 MS
⁴⁰ Ar/ ³⁶ Ar	1.03 ± 0.04	PV Probe Donahue analysis
	1.19 ± 0.07	Venera 11/12 MS
Kr isotopes	---	
Xe isotopes	---	

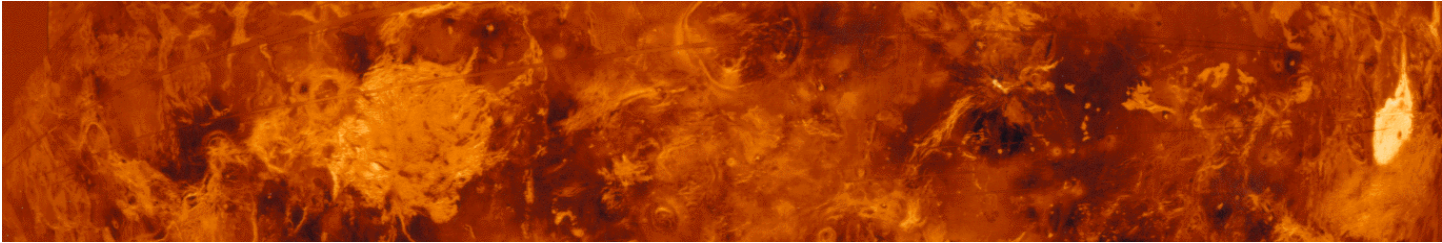
Target precision <1-2%

Key future measurements → Kr and Xe abundance and isotopic distribution

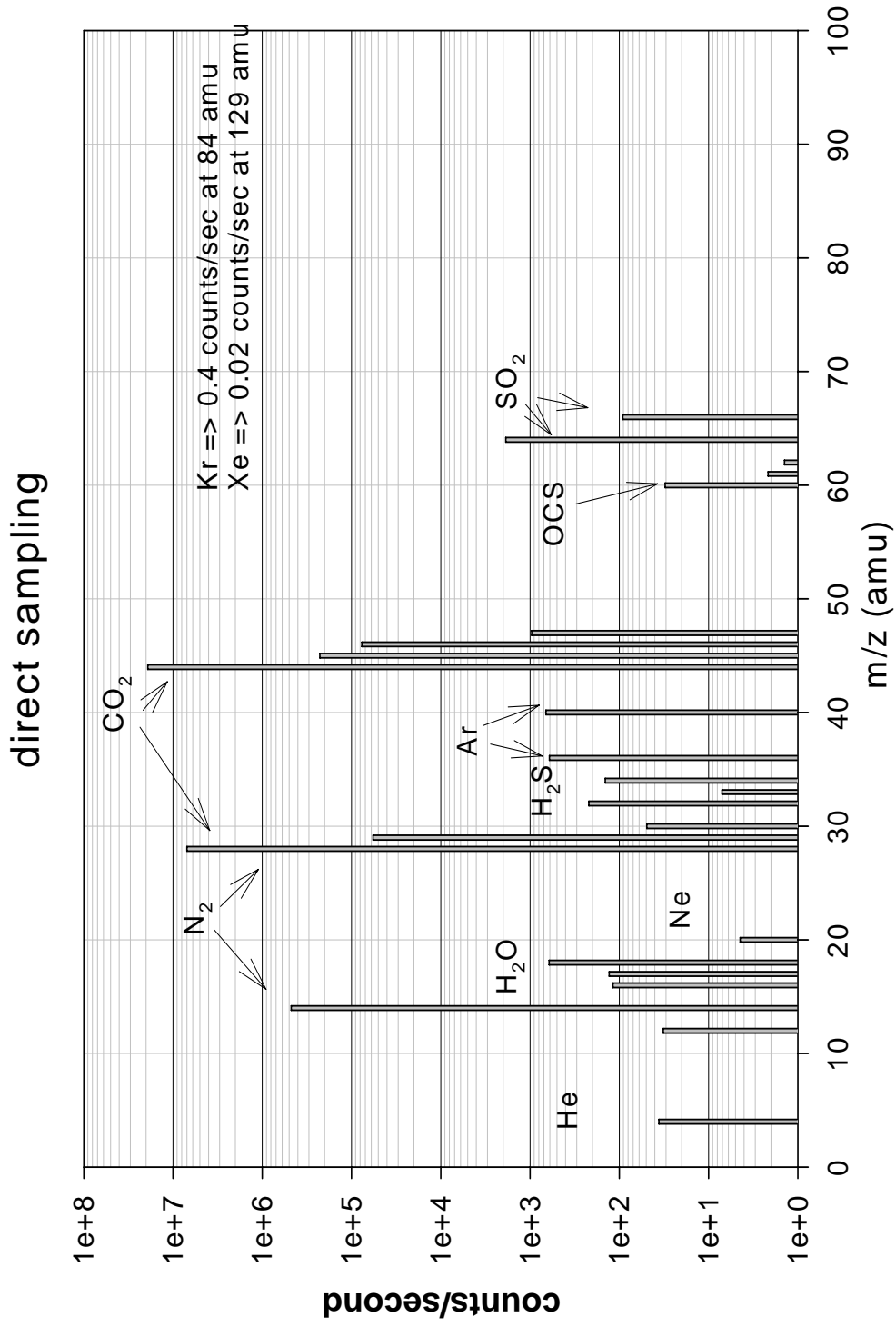


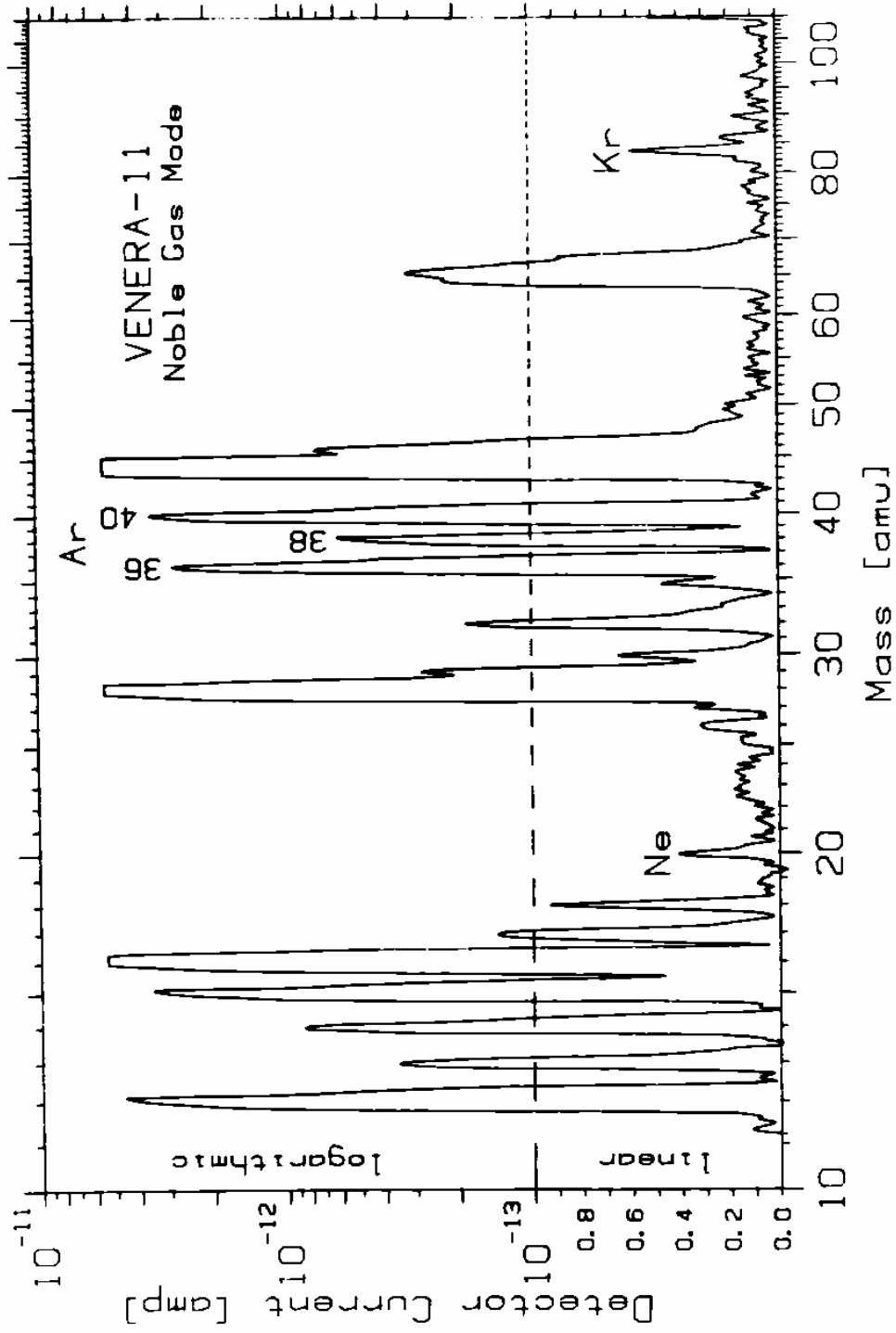
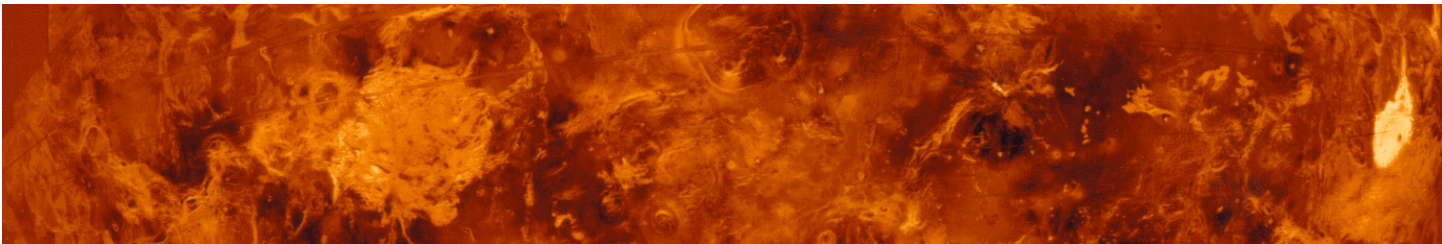
Approach for future noble gas measurements at Venus

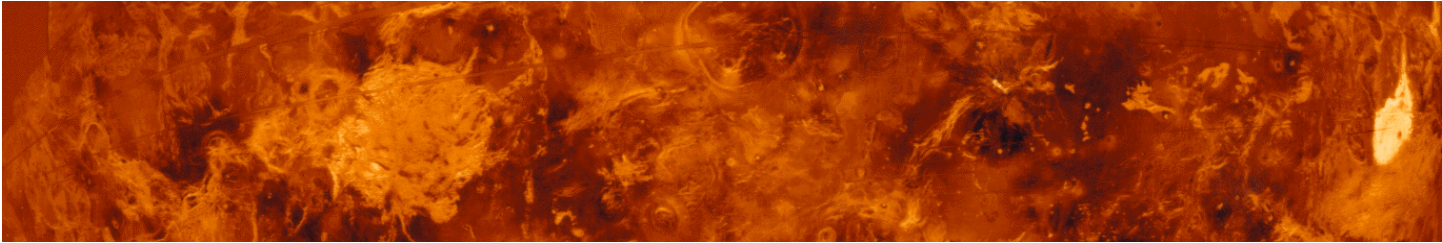
**Wide dynamic range mass spectrometer
Dedicated noble gas processing unit to optimize all noble gas
measurements including Xe and Kr**



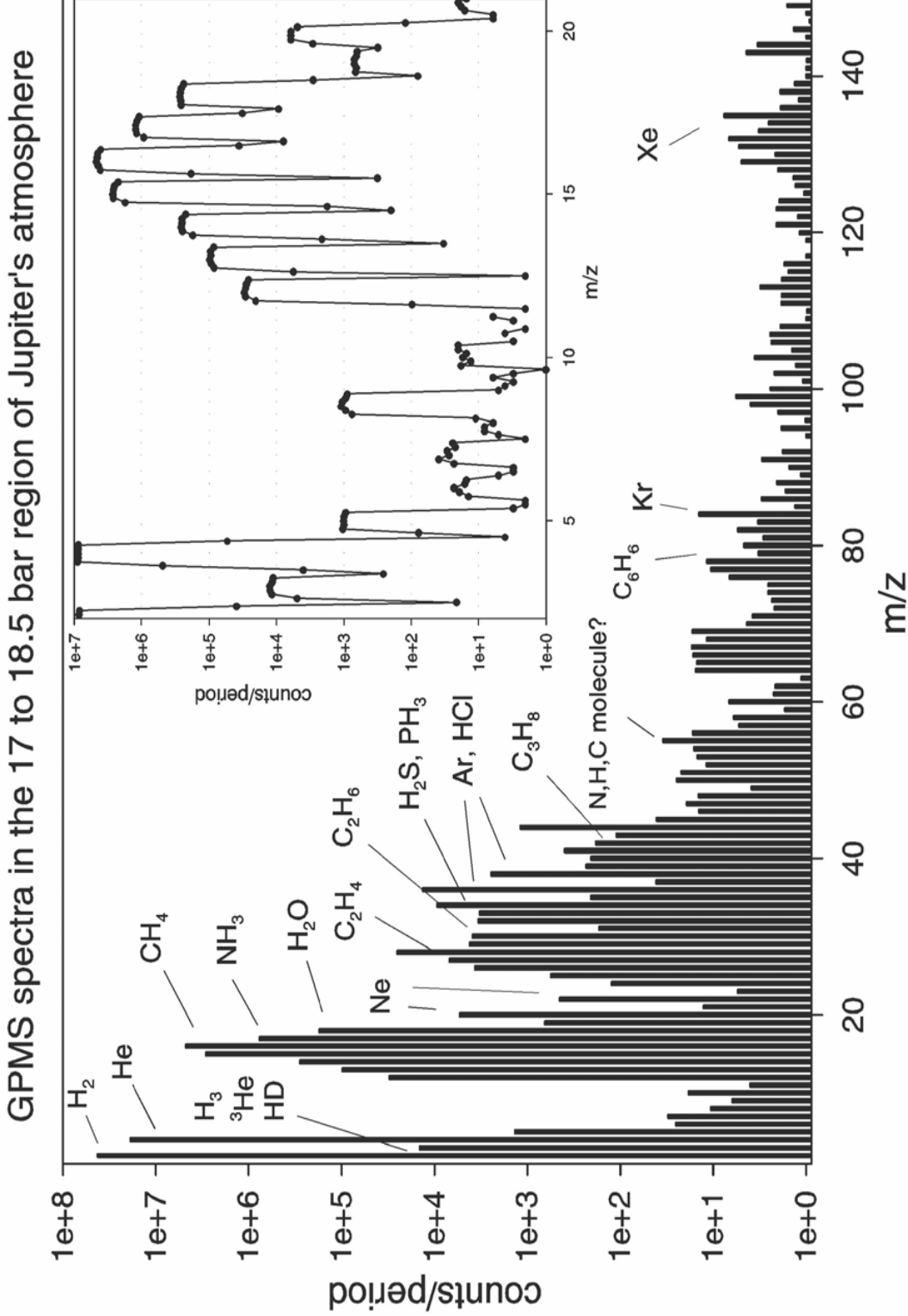
Predicted signal with direct sampling at Venus with no enrichment or saturation of CO₂

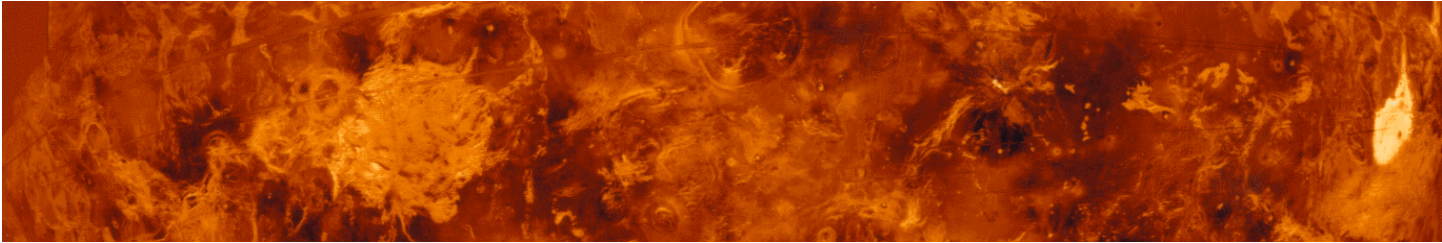




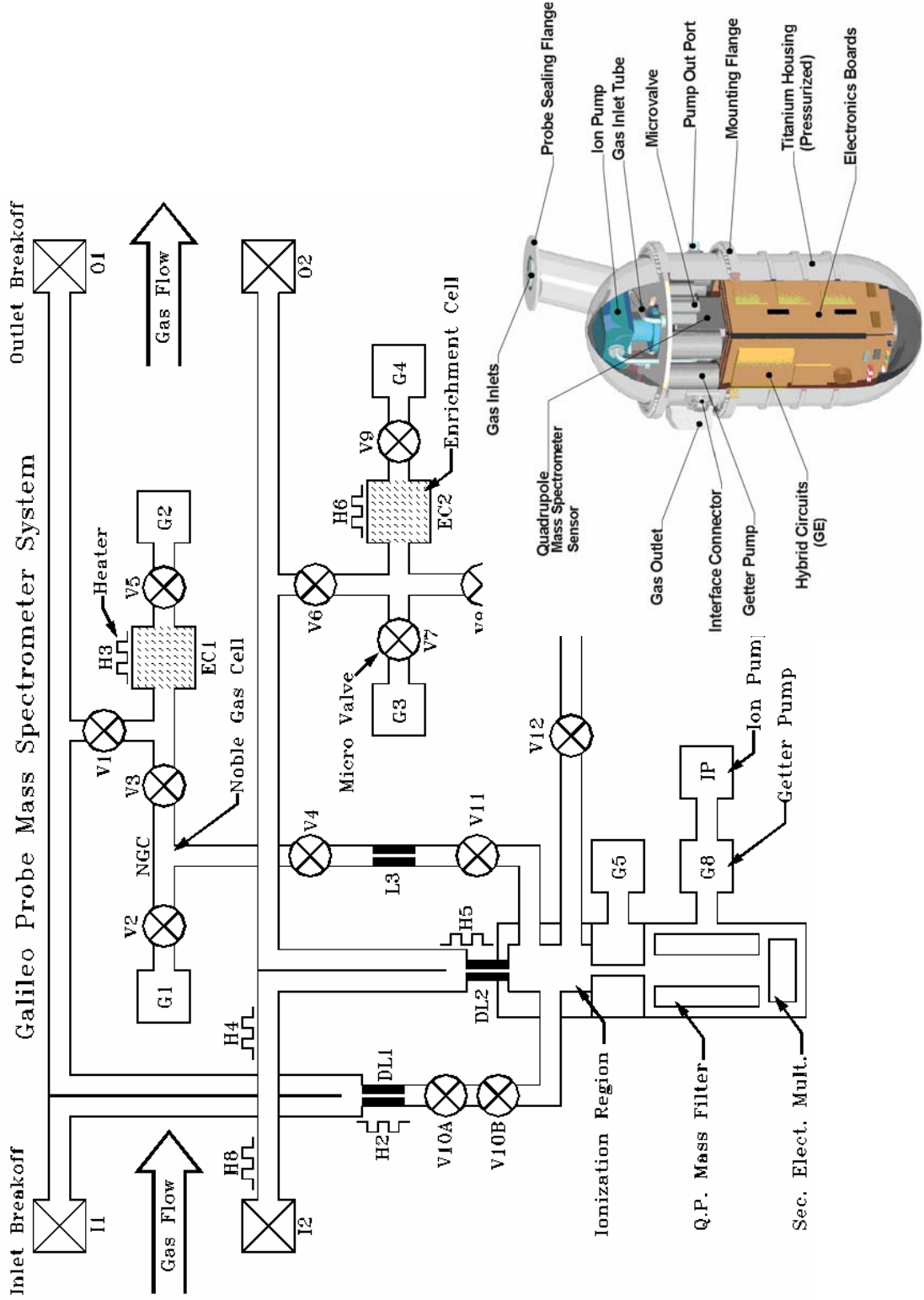


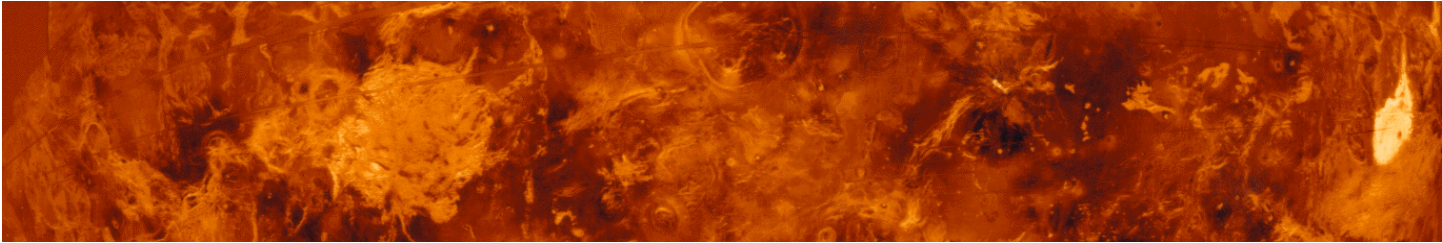
Dynamic range possible with small quadrupole mass spectrometer



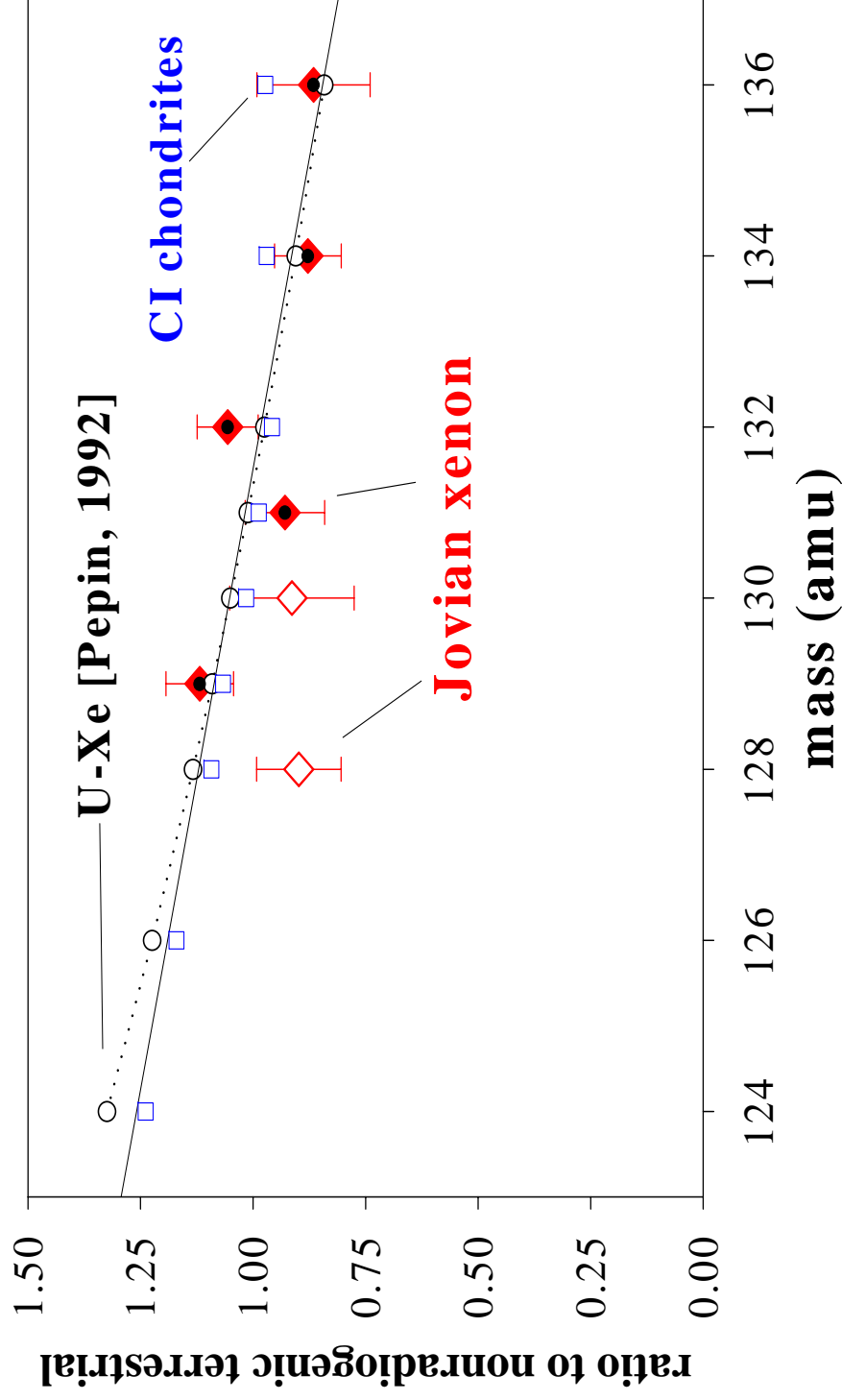


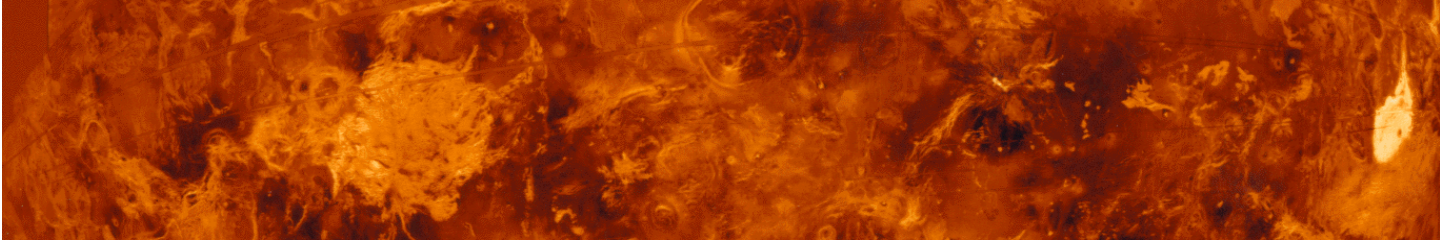
Enrichment techniques – the Galileo Probe Neutral Mass Spectrometer approach





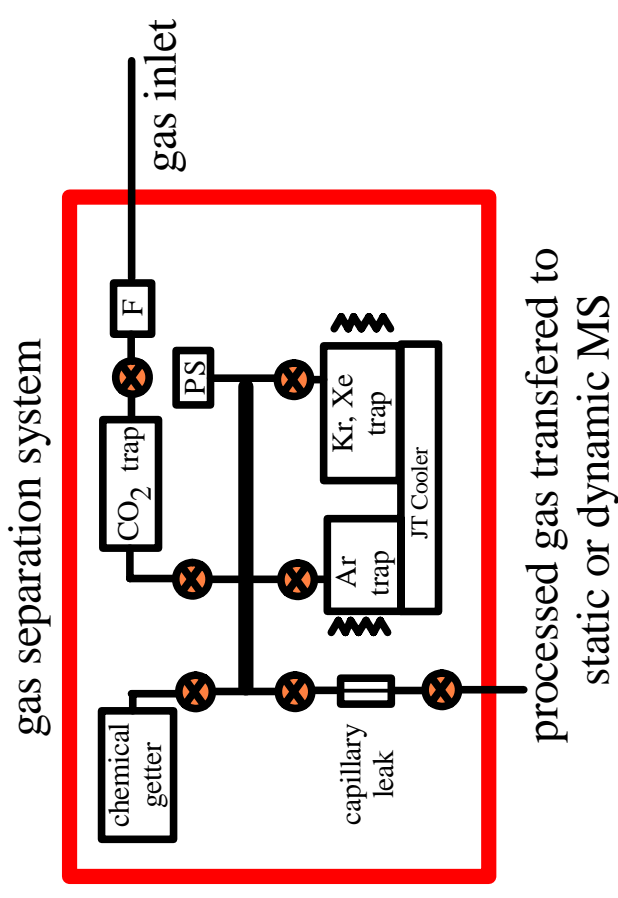
Xenon Isotopic Fractionation at Jupiter from the Galileo Probe Mass Spectrometer

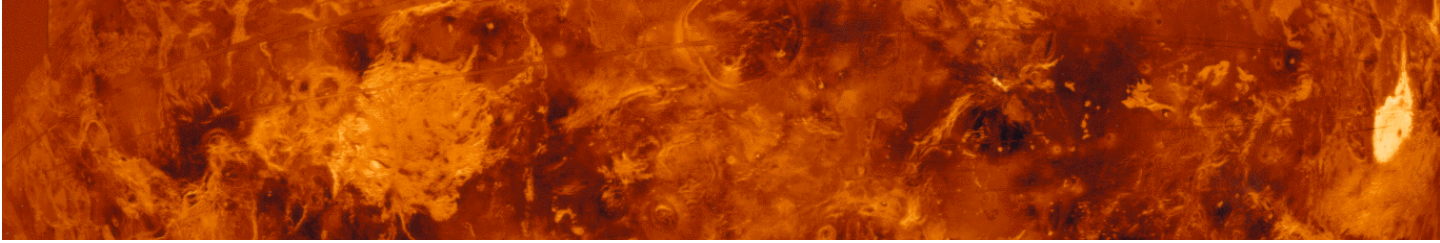




A proposed measurement protocol for Venus noble gas and $^{15}\text{N}/^{14}\text{N}$ measurement

- sample a volume of Venus atmospheric gas
- chemically remove CO_2 as gas is sampled
(for example, $\text{CaO (s)} + \text{CO}_2(\text{g}) \rightarrow \text{CaCO}_3(\text{s})$)
($^{15}\text{N}/^{14}\text{N}$)/ $^{14}\text{N}_2$ with dynamic MS to obtain $^{15}\text{N}/^{14}\text{N}$)
- chemically remove N_2 and other active gases with a getter
- cryogenically remove Kr and Xe (on high surface area trap)
- $^{38}\text{Ar}/^{36}\text{Ar}$ and $^{36}\text{Ar}/^{40}\text{Ar}$ with static MS
- cryogenically remove Ar
- residual $^{20}\text{Ne}/^{22}\text{Ne}$ and $^{21}\text{Ne}/^{22}\text{Ne}$ and $^3\text{He}/^4\text{He}$ with static MS
- release Kr and Xe
- all Kr and Xe isotopes with static MS

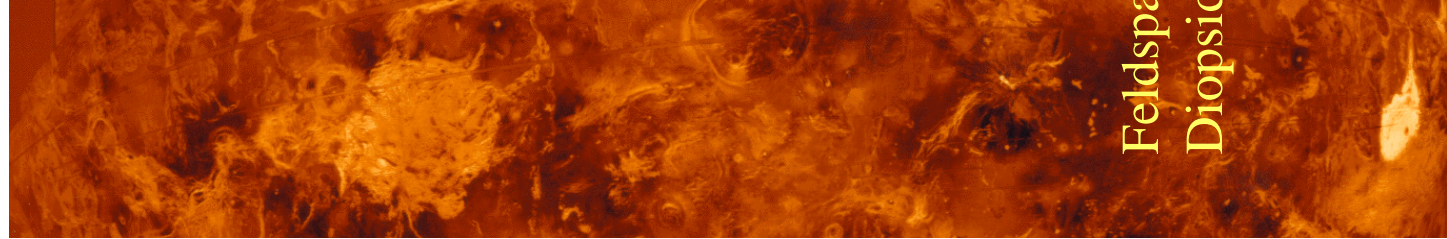
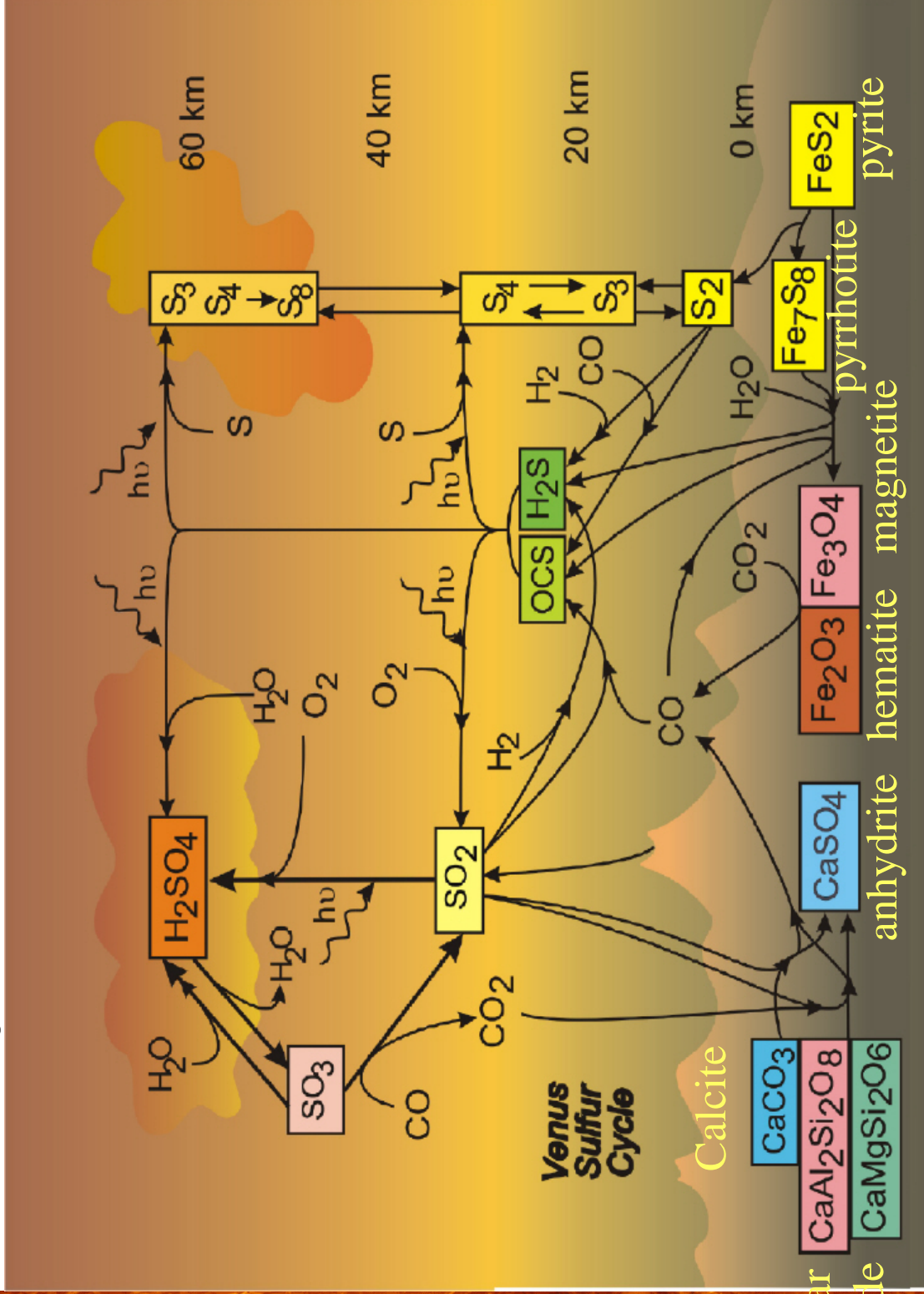


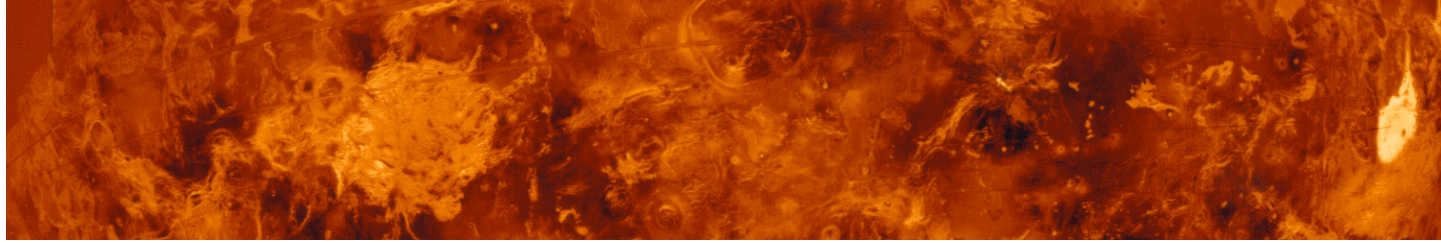


Motivation for trace gas measurements at Venus

Vertical profiles through the clouds and down to the surface enable cloud chemistry and atmosphere/surface interactions to be studied

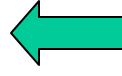
S cycle - B. Fegley et al., in Venus II, U. AZ Press, 618 (1997)
 (following van Zahn & Prinn).





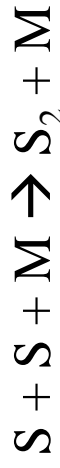
Gases and reactions expected to be important for cloud chemistry

SO₂, H₂O, SO₃, SO, OCS



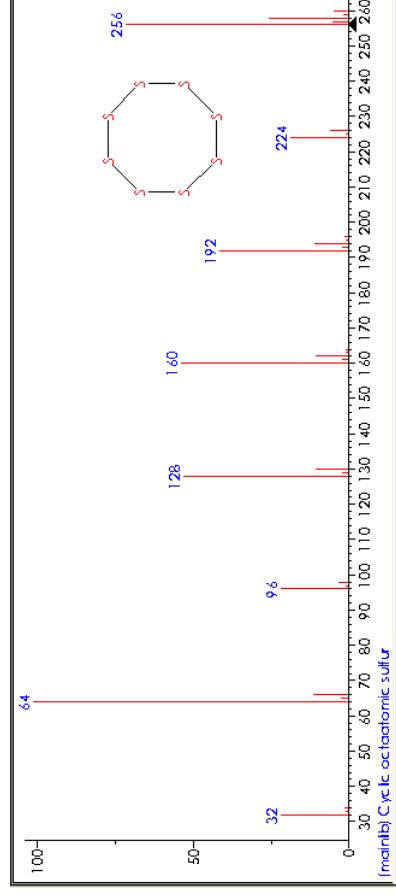
Photolysis of SO₂ → SO + O

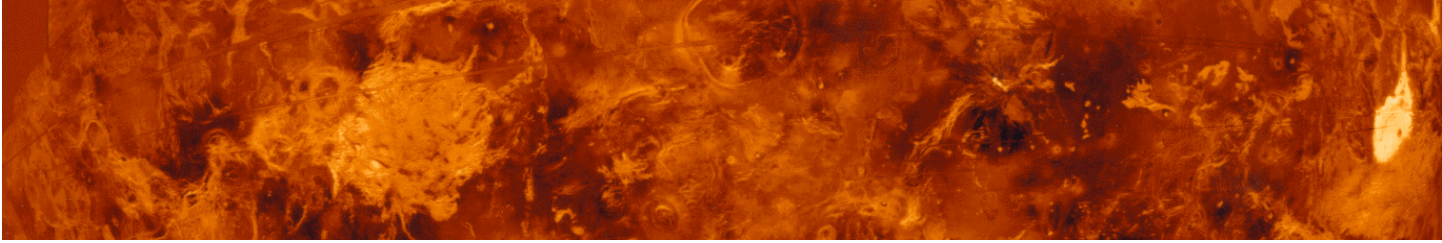
Elemental sulfur



Other possible species

NO, Cl₂, S₂Cl₂ etc





Reactions that may be important for surface/atmosphere interaction

Volcanoes likely source of SO₂

Weathering of surface minerals may buffer atmospheric gases

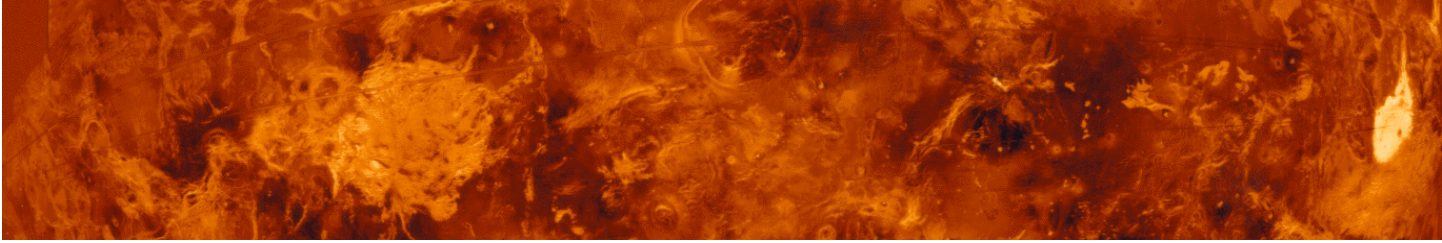


Trace species of interest that reflect the oxidation state near the surface

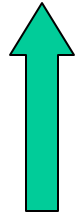


Oxidation state determines Fe mineralogy

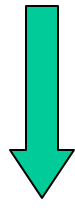


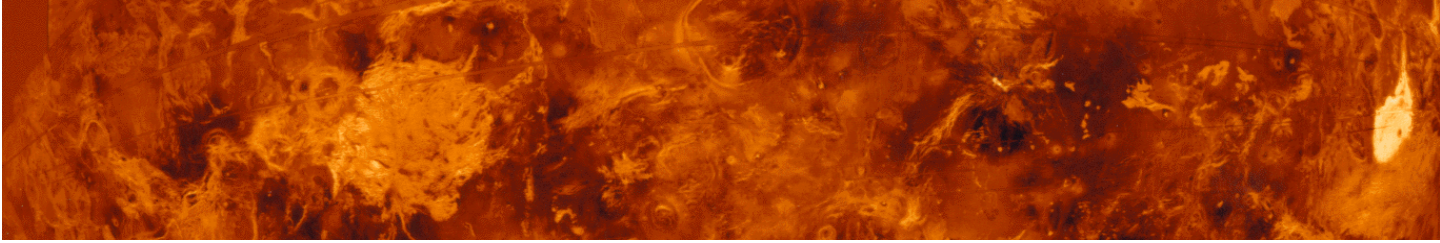


Past and future Venus mass spectrometer experiments



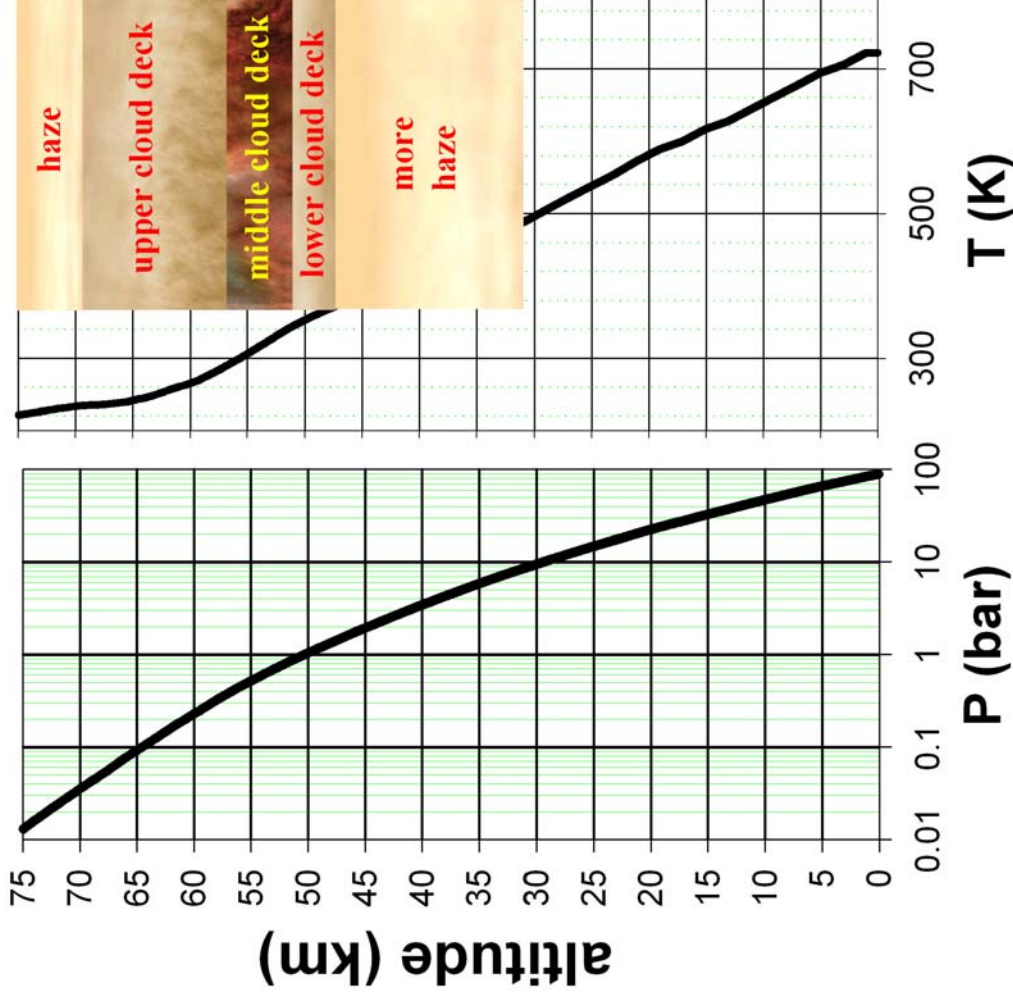
Need to address the difficult sampling issues

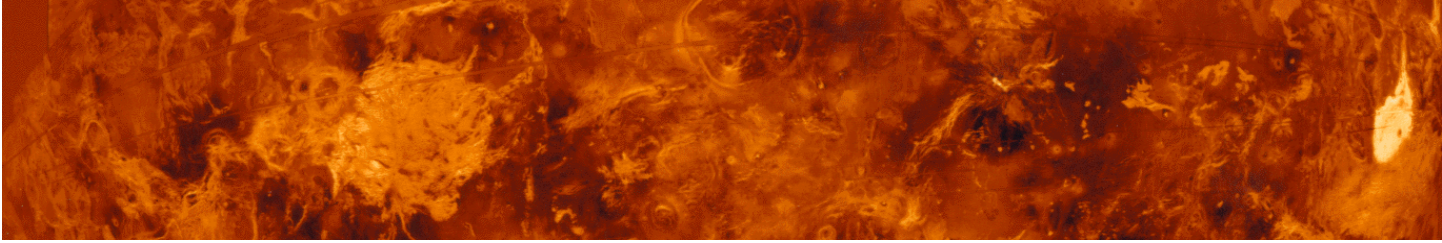




Sampling issues

- 4 orders of magnitude pressure differential on track from above clouds to surface
- trace species measured to parts per billion
- 9 orders of magnitude difference between atmospheric pressure at surface and ion source pressure in mass spectrometer
- 500 degree temperature gradient from atmosphere above clouds to surface
- cloud droplets and aerosols that can clog mass spectrometer inlet systems and mask real vertical variations due to their condensation on surfaces





Example Venus mass spectrometer experiments

Mission (Team, Date)	Mass Spectrometer	Altitude (Pressure)	Inlet type	Outcome
Venera 9 & 10 (Surkov, von Zahn, 1975)	monopole	63-34 km (130 mbar to 6 bar)	3 porous plugs	instrument measured primarily background signal throughout descent
PV-Large Probe (Hoffman, 1978)	magnetic sector	62 km to surface	pinched Ta tube (3 inlets)	50 km to 29 km inlet was blocked and instrument measured outgassing from H ₂ SO ₄ droplets
Venera 11 & 12 Lander (Grechnev, 1978)	Bennett RF	23 km to surface	1 m x 5 mm inlet pipe & pulsed microvalve	possible inlet tube memory effects, Ar isotopes in "static" mode, Kr detected but isotopes NOT resolved
PV-Orbiter (Niemann, Kasprzak, 1978-1992)	Quadrupole MS	orbiter (upper atmosphere)	source open to ambient	14 years of data → neutral scale heights (CO ₂ , CO, N ₂ , O, N, and He) O escape (thermospheric measurements gave no information on heavy noble gas isotopes)
PV-Multiprobe Bus (von Zahn, 1978)	Magnetic Sector	entry to 0.01 mbar	open with differential P	entry measurements (upper limit on ³⁶ Ar and ⁴⁰ Ar), identified He homopause at 137 km

Atmospheric sampling approach

- short inlet lines heated above ambient to vaporize condensates
- chemically inert materials in inlet
- adequate aerosol traps and baffles
- multiple inlet leaks
- redundant inlet lines

TEST

TEST

TEST

TEST

The future of Venus exploration?

- near term objectives from the planetary science community are clearly recommended to NASA in the Decadal Study Report
- the probe/measurement technology is ready for noble gas and trace species measurements
- NASA Discovery & New Frontier Missions may enable some of these recommendations to be realized
- future Venus detailed cloud investigations, long term surface packages and sample return clearly require advanced technology support

