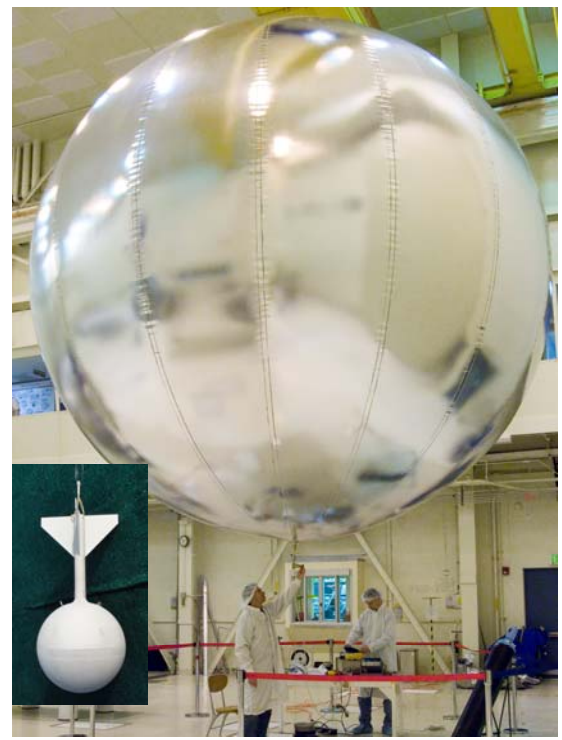
EXPLORING VENUS WITH BALLOONS: SCIENCE OBJECTIVES AND MISSION ARCHITECTURES FOR SMALL AND MEDIUM-CLASS MISSIONS

Kevin H. Baines, Jeffery L. Hall, Tibor Balint, Viktor Kerzhanovich, Gary Hunter, Sushil K. Atreya, Sanjay S. Limaye, and Kevin Zahnle

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.



6TH International Planetary Probe Workhop
Atlanta, Georgia June 23-27, 2008

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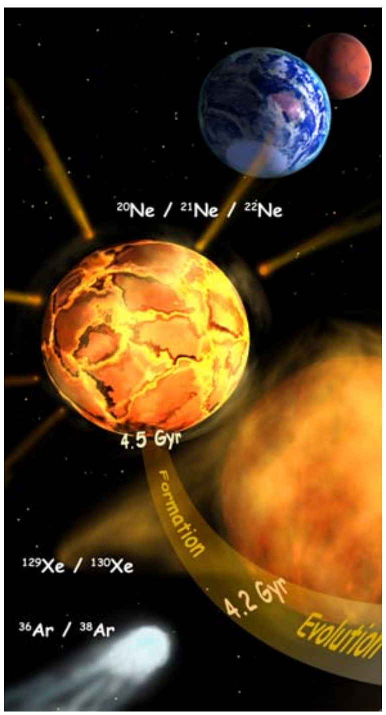


Outline

-Why Explore Venus?

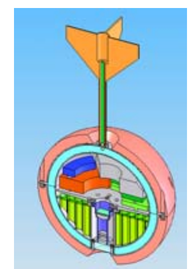
-Venus Exploration Today

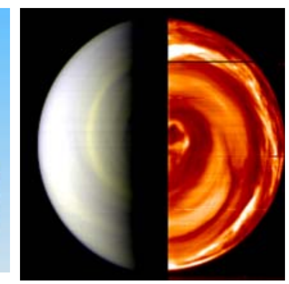
- Science Objectives for Middle-Atmosphere Balloons

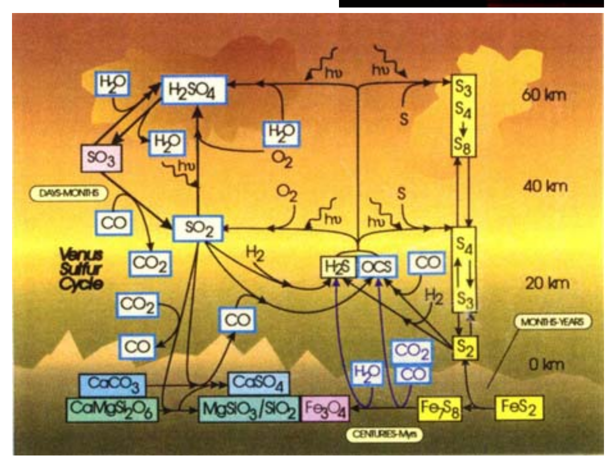
-Status of Case Studies:

<u>Discovery</u>: VALOR and Nuclear Polar VALOR

<u>New Frontiers</u> : VALOR +



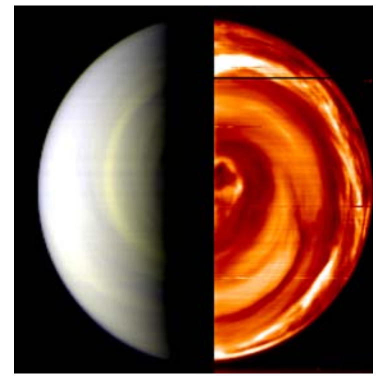




Why Explore Venus?

Earth's Twin Sister Planet…..

- Common size, in both volume and mass
- Common bulk composition and gravity
- Common position from the Sun
- Common effective temperature at cloud level, with common pressure/temperature structure there



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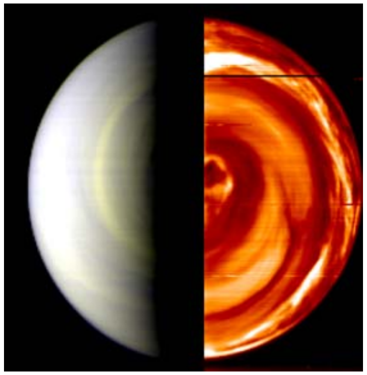

…Gone awry….

- Dry (~ 30 ppm vs ~300,000 ppm for Earth's atmosphere)
- Sulfuric acid clouds, not water
- 740 K (470 C) at surface, not predicted 300K as predicted pre Mariner flyby (1962)
- Slow, retrograde spin (118 Earth days is a solar day)
- Yet - Hurricane-force winds virtually everywhere, from the ground to over 120 km altitude

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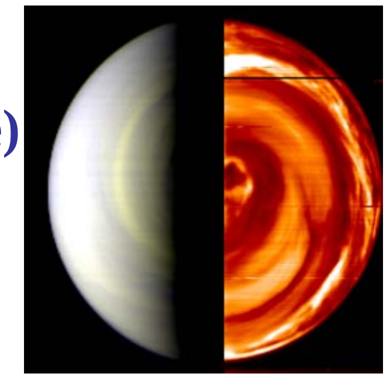

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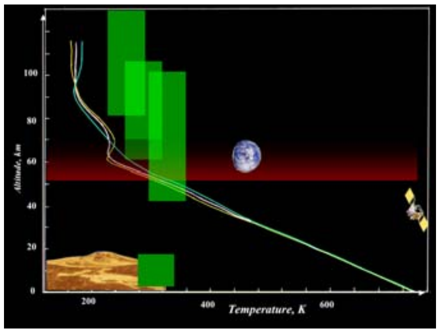
**Alien Chemistry, Dynamics, Structure, and Geology Today,
Due to both Cataclysmic and Subtle Events in the Past,
With Key Lessons for Earth's Future.**

VENUS EXPLORATION TODAY

On-Going Orbital Reconnaissance by ESA's Venus Express

- Since April 2006
- Studies of Sun/Venus interactions, global atmospheric dynamics, cloud chemistry and physics, surface properties
- Well over 1 Tbits of data returned
- From the ground up: Images, spectra, movies, occultations, plasma and magnetometer measurements



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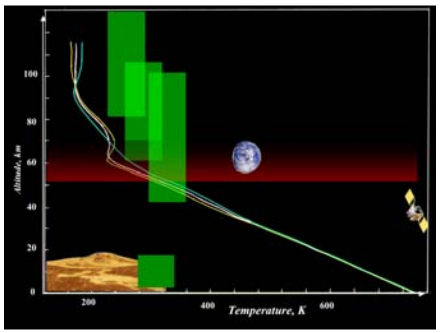
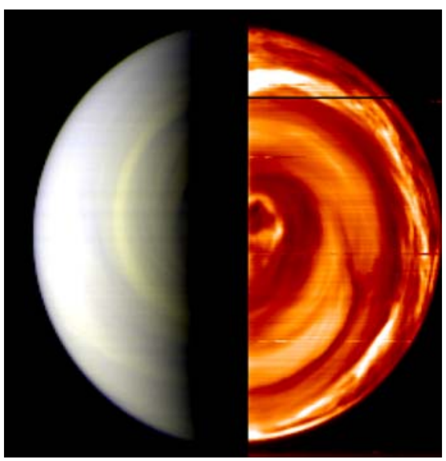


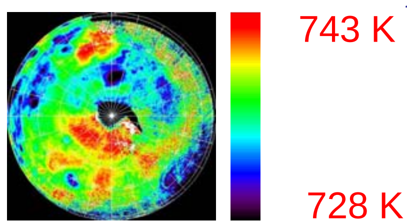
Selected Highlights:

- Atmospheric escape quantified. Loss of ocean.
- O_2, NO airglows: Sun-Anti-sun Circulation.
- Lightning Detection and Characterization (with MAG)
- Winds: Discovery of Strong Longitudinal and Tempora Variability; Local and Planetary Waves; Progress in GCM's explaining super-rotation
- Trace chemicals in upper atmosphere via occultations and emissons: OH discovery, NO, CO, SO_2 variability
- Ground mapping.



Day
Upper-cloud reflectivity

Night
Deep-Cloud Transparency

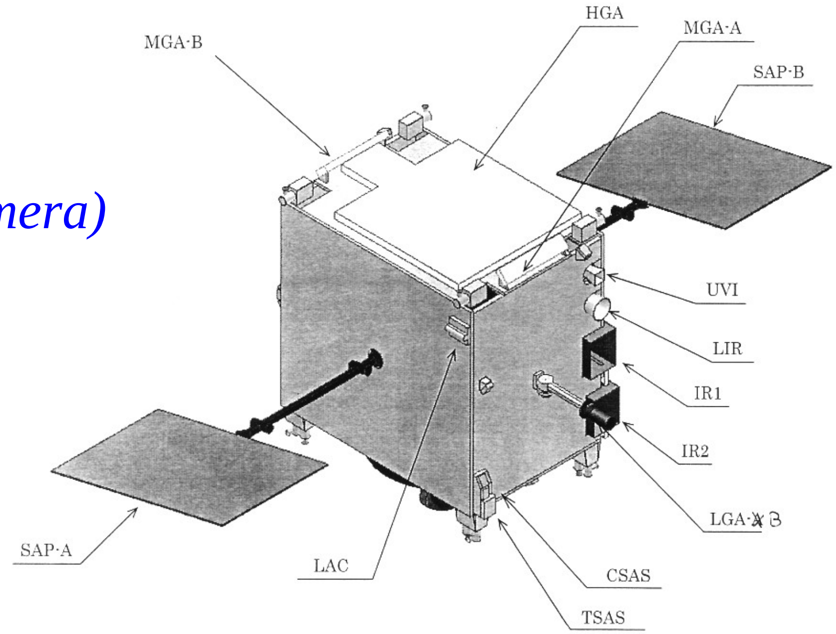


Surface Temps/Elevation
Southern Hemisphere

- Ongoing volcano search and Surface emissivity mapping
- Evidence for felsic materials in Venusian highlands
  => Ancient ocean

Reconnaissance By Japan's Venus Climate Orbiter (VCO)

- Launch in 2010, Arrival in 2011
- Equatorial orbit, goes with the flows of atmospheric winds
- Multiple cameras for imaging global dynamics and surface
- Radio Science with USO

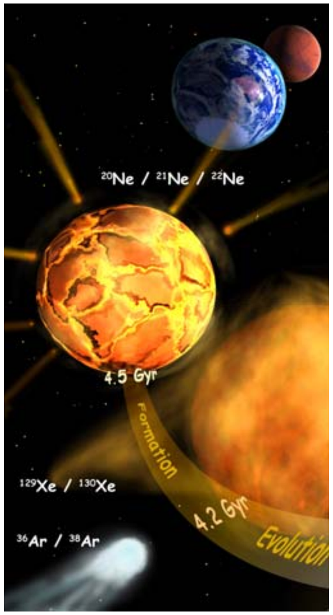


- ***UVI*** *(Ultraviolet Imager)*
  Shigeto Watanabe (Hokkaido Univ.)
- ***LAC*** *(Lightning and Airglow Camera)*
  Yukihiro Takahashi (Tohoku Univ.)
- ***IR1*** *(1-μm Infrared Camera)*
  Naomoto Iwagami (Tokyo Univ.)
- ***IR2*** *(2-μm Infrared Camera)*
  Takehiko Satoh (ISAS/JAXA)
- ***LIR*** *(Long-wave IR Camera)*
  Makoto Taguchi (Nat'l Institute for Polar Res.)
- ***USO*** *(Ultra-Stable Oscillator)*
  Takeshi Imamura (ISAS/JAXA)

The Next Step: *In-Situ* Exploration
Experiencing Venus

Salient Science Measurements Unachievable From Orbit

- **Noble Gases and Their Isotopes:** **Formation/Evolution**
- **Isotopes of Light Gases:** **Formation/Evolution**



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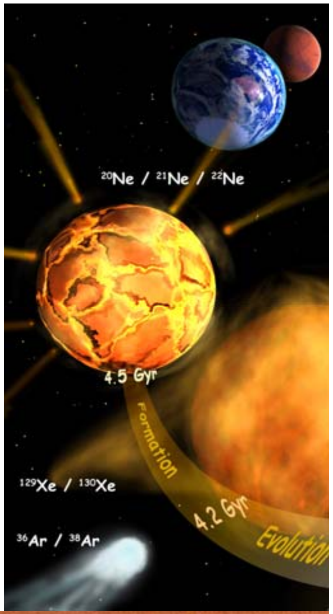

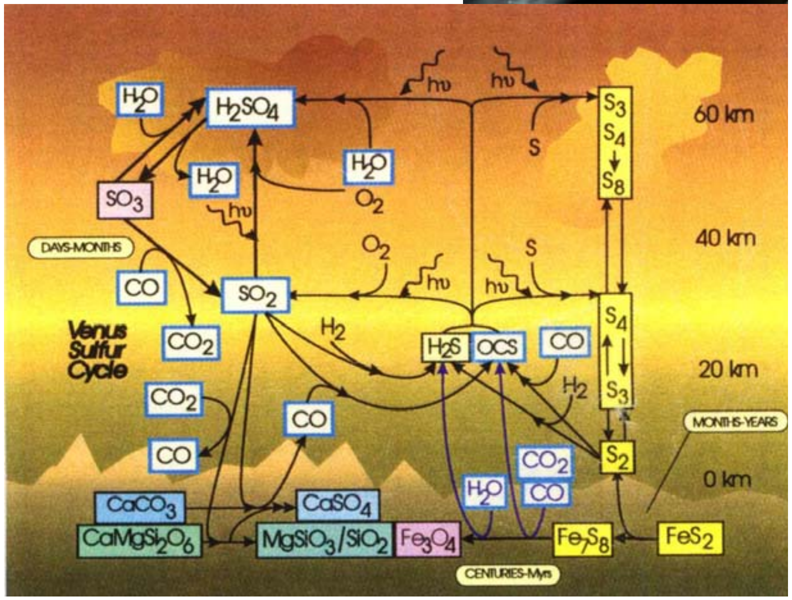

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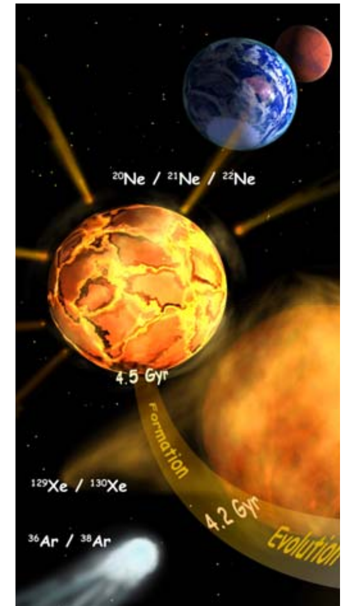
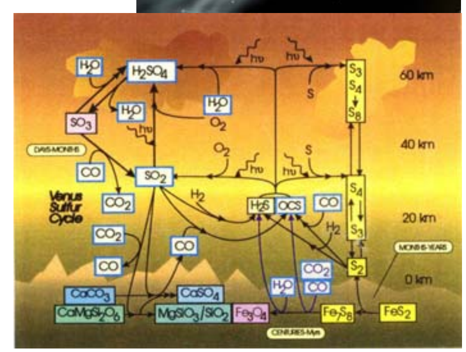
  - Convection, Turbulence
  - Hadley Cell : Latitudinal boundaries
- Meridional Character of 3-D Circulation/Meteorology
  (Momentum and Heat Transfer; Hadley Cell)





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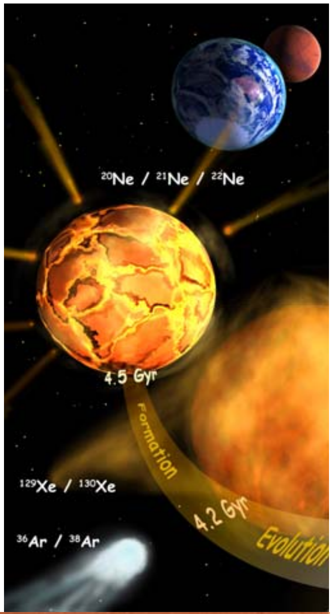
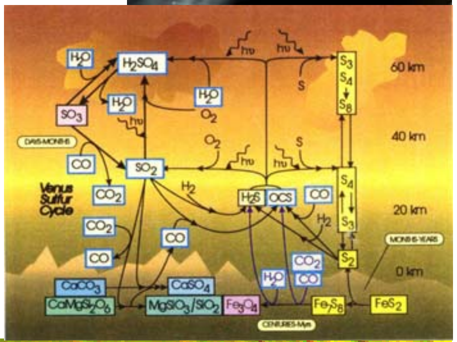
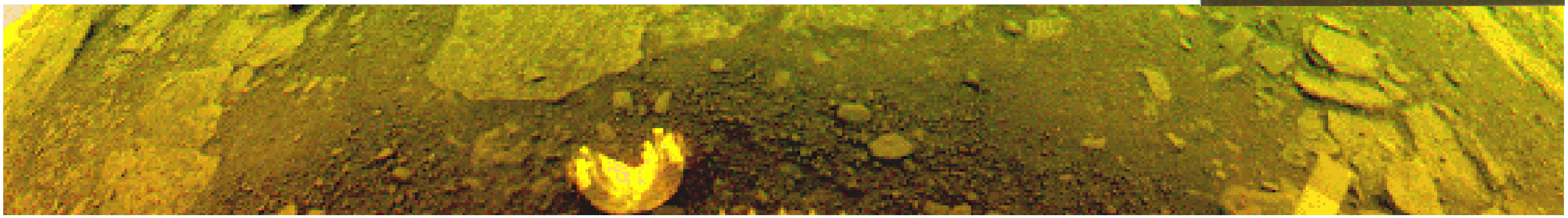
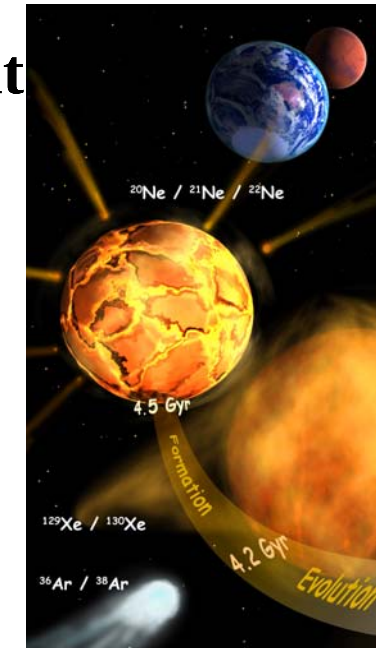
  - Seismic Measurements: Geology







The Next Step: *In-Situ* Exploration
Experiencing Venus by Mid-Level Balloons



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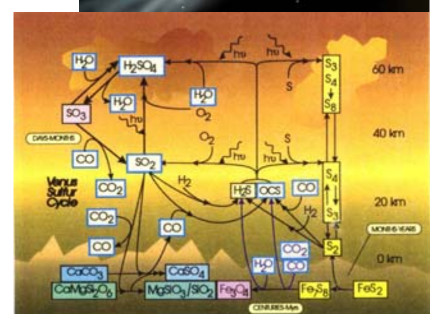

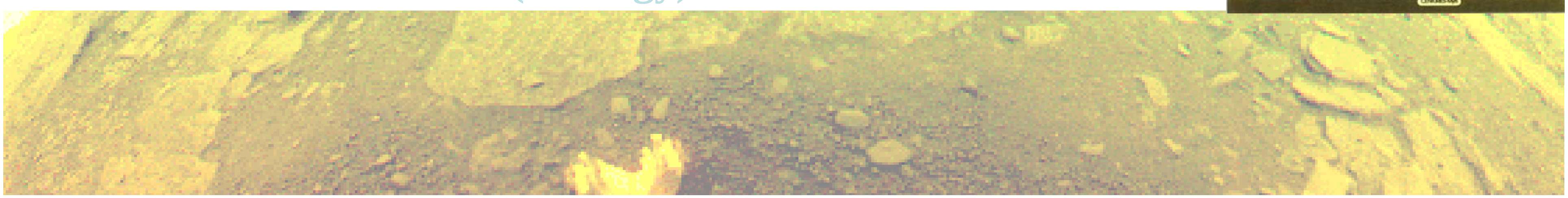

VEXAG
Salient Science Objectives
Vs Mission Class

Table IV-1. Traceability Matrix of Objectives Met with Discovery, New Frontiers, and Flagship Missions.

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;
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VEXAG
Salient Science Objectives Vs Mission Class

High-Altitude Balloons Address and Satisfy Numerous High-Priority Science Issues

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Case Study: VALOR Discovery Mission
VALOR: Venus Aerostatic-Lift Observatories for *in-situ* Research

***In-situ*, Long-Duration, Wide-Ranging Exploration of our Sister World**

- **By Successfully Flying the Skies of Venus**
- **On a Multi-day Mission Spanning a Large Range of Longitudes/Latitudes**
- **Including Plans for Circumnavigation of the Globe**

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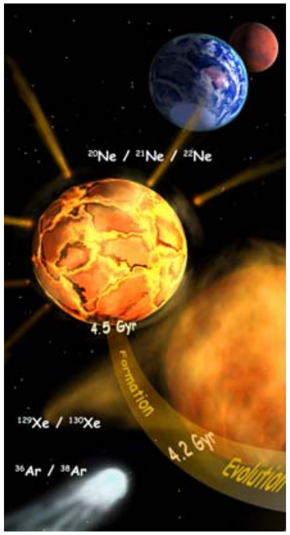

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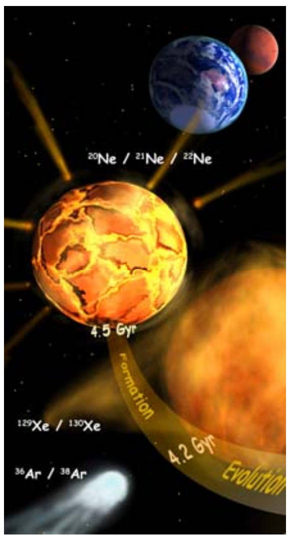

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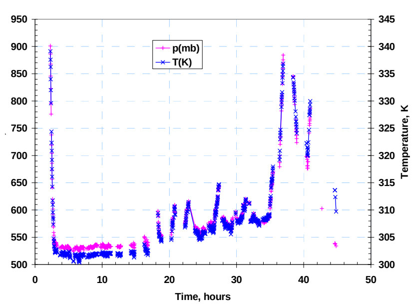

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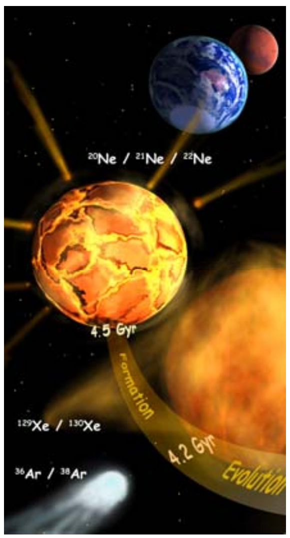

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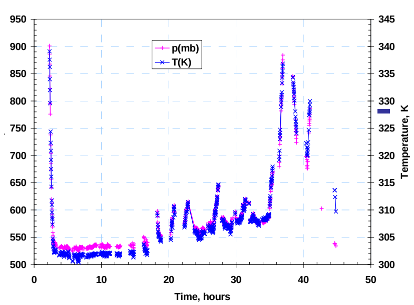
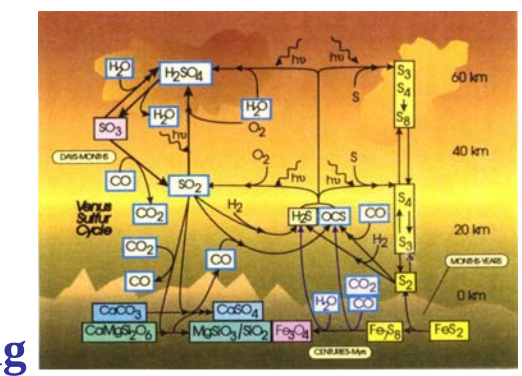


- Investigate Sulfur-Based Meteorology

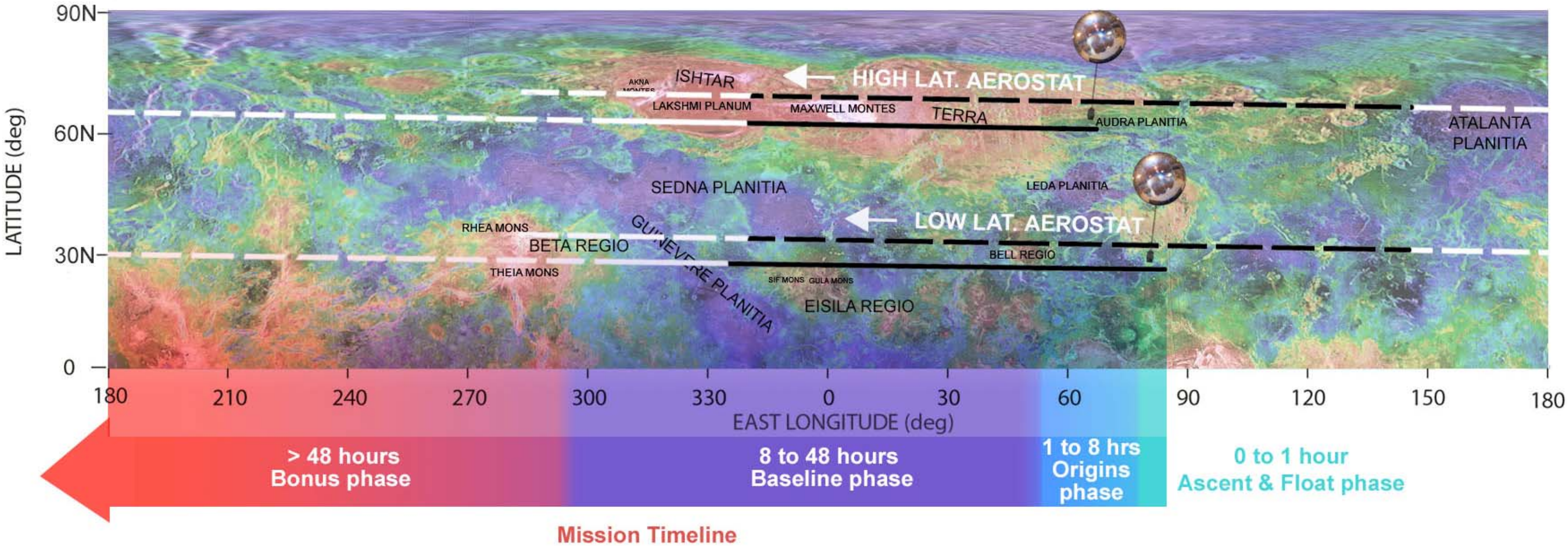
- H_2SO_4 aerosols and their parent gases

- Convection and Lightning

- Diurnal, Vertical, NS Latitudinal Sampling



VALOR Flight Paths
Dual Balloons Circumnavigate Venus
During Planned 8-Day Mission



Mean Float Altitude: 55.5 km
Mean Ambient Pressure: 500 mbars
Mean Ambient Temperature: 24 C

Begin on Nightside, East limb (relative to Earth)
Drift westward at ~ 300 km/hr (180 knots)

Riding the Waves of Venus

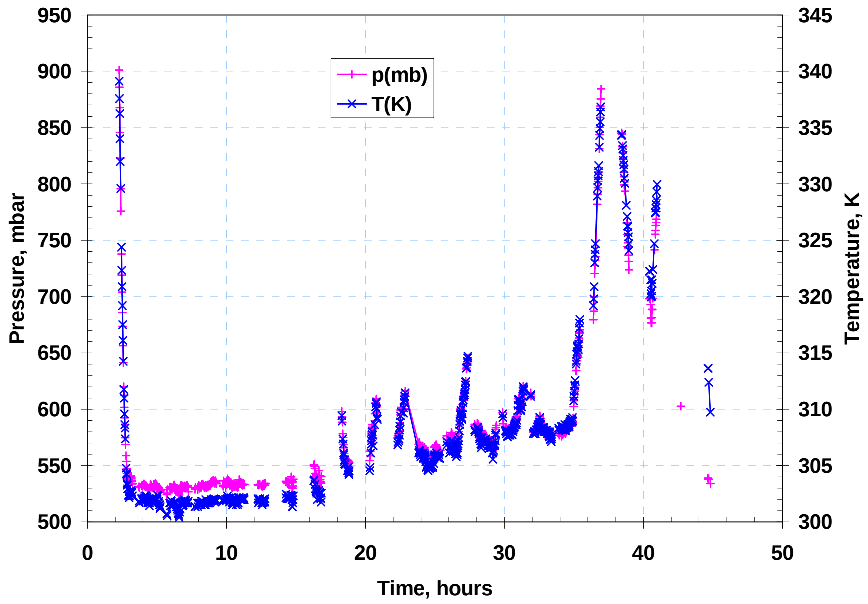
VEGA regularly "bobbed" vertically ~ 3 km riding gravity waves

VALOR will "bob" ~ 1 km

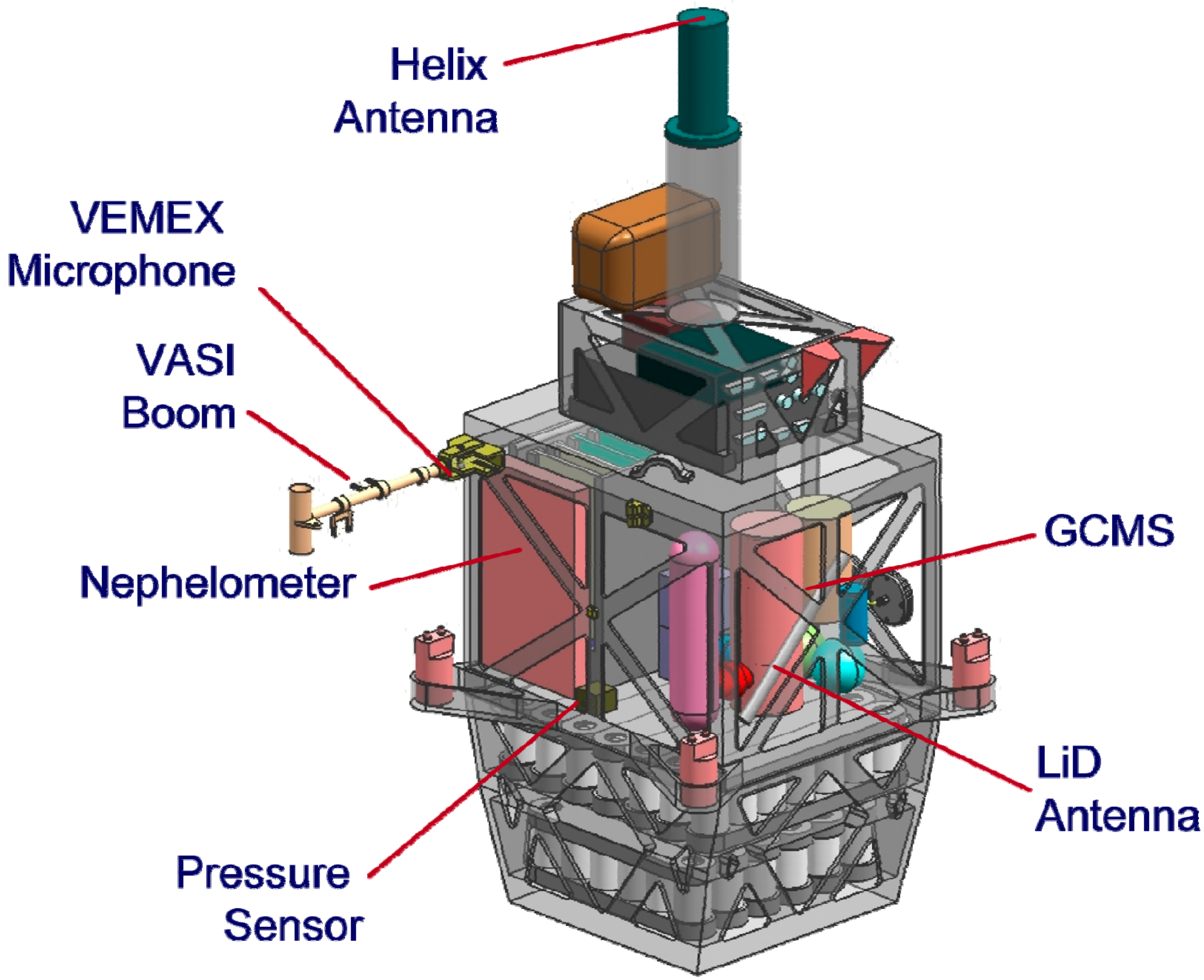
- **Will measure, directly, 3-D winds at high temporal and spatial resolution**
- **Will measure vertical motion and wave characteristic**
- **Will obtain direct measurements of zonal and meridional winds**
- **Uses radio tracking, pressure, and temperature sensors together with aerobot aerodynamic modelling for precise measurements of 3-D winds**

VALOR Balloon

VEGA Balloon



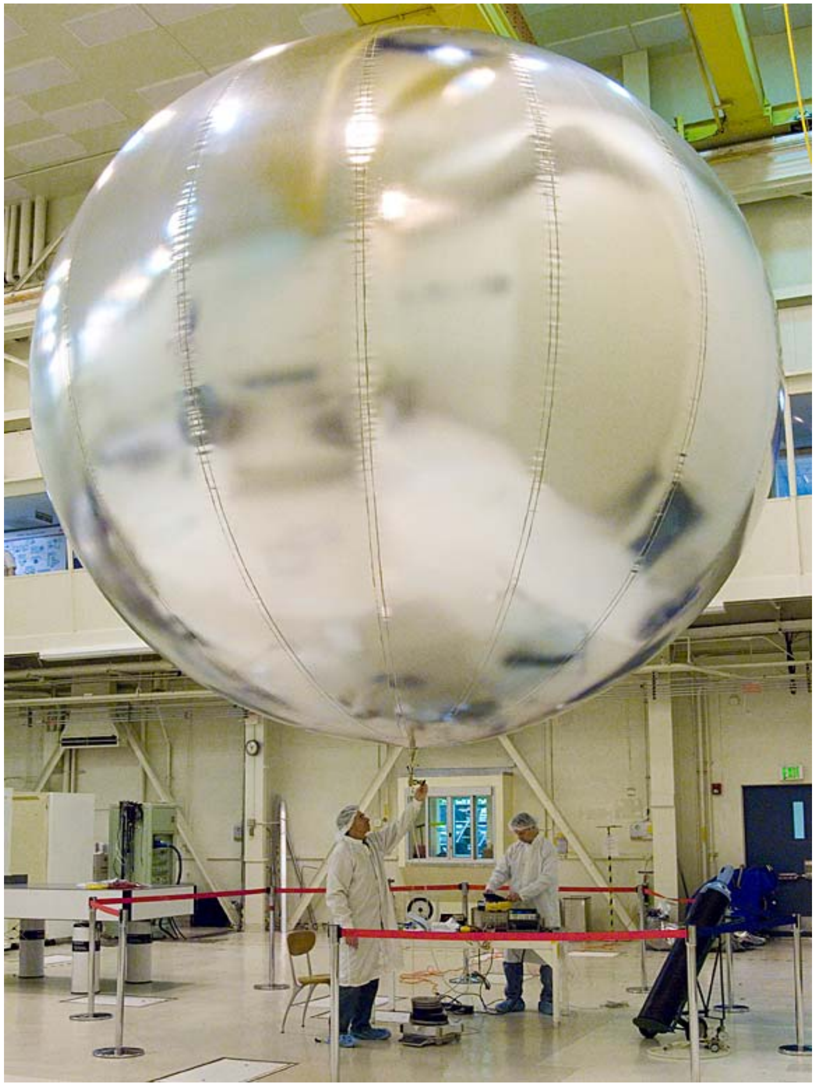
VALOR Instrument Complement



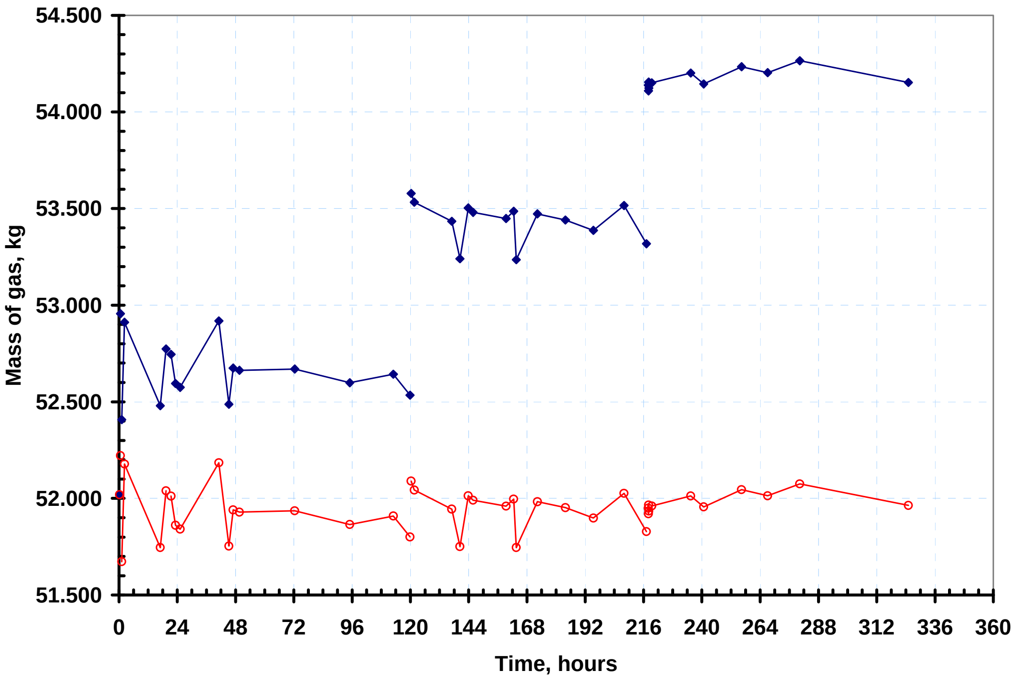
VALOR
Balloon Design Approach

- **Benign thermal environment: altitude 54-56 km**
- **Capable for long duration: superpressure (constant volume) balloon**
- **Sphere: most mass efficient**
- **Robust: safety factor (ratio of burst load to actual load) >2.5 in the most adverse combination**
- **Low gas permeability: metallized film**
- **Minimum day/night temperature variations: minimum optical absorptivity/infrared emissivity ratio (α/ε)**
- **Tolerate sulfuric acid of Venus clouds: fluoropolymer outside layer**

VALOR Prototype Balloon Tests
No Helium Leak In 2-week Test



- Balloon inflated with ~50/50% helium-nitrogen in JPL SAF clean room
- Known amounts of nitrogen added two times to vary superpressure level
- Monitored buoyancy, superpressure, ambient pressure, temperature and humidity to calculate mass of gas
- No noticeable leak measured



Polar VALOR

POLAR VENUS ATMOSPHERIC LONG-DURATION OBSERVATORIES for *in-situ* RESEARCH

Mission to Intensively Study Middle and High-Latitudes:

- **Single, larger, balloon begins at mid-latitudes and drifts to pole, over one month**
- **Larger balloon (~7 m diameter) accomodates ASRG plus some backup batteries, plus additional instrument (TLS)**
- **Investigates meteorology and dynamics in both convective mid-latitude and in relatively stable high-latitude regimes**
- **Polar End of Hadley Cell**
- **Winds in unchartered cloudy polar atmosphere**
- **Effect of Maxwell Montes on circulation: gravity waves?**

ASRG provides continuous power

- **More than an order of magnitude greater data return over 30-day mission compared to battery-powered version**
- **Continuous dynamics and chemistry measurements possible**

New Frontiers VALOR +

Expand VALOR Discovery Missions to Perform High-Priority Surface Science and

Enhanced Atmospheric Science

While Preserving a Strong Risk Posture

Under the Cost Constraints of New Frontiers (~ $800 M)

New Frontiers VALOR +
Required Measurements

Science Goal	Measurement Requirements	Spatial/Temporal/Coverage	Instruments
Venus' Past:	Noble Gas isotopic abundances	~ 50 measurements for S/N	GCMS
	Light isotope abundances		TLS
	Surface morphology for geologic history	Near-global coverage	Orbiter RADAR
Venus' Present			
Circulation/Dynamics			
- Tides	Zonal velocities at known altitude	Over all longitudes and several distinct latitudes	Balloon Radio Tracking (BRT)
- Waves, eddies	Vertical and meridional velocities	Over large latitude/longitude/ temporal range	BRT and Drop Sonde (DS) Radio Tracking (DSRT)
		Over significant range of known	Balloon and DS P/T
	Cloud Wave-train characteristics	Near-global coverage	Orbiter N-IR camera
- Hadley Cells	Vertical and meridional velocities	Over large range of latitudes	BRT, DSRT
		Over significant range of altitudes	BRT,DSRT, Orbiter N-IR camera
	Trace gas abundances	Over large range of latitudes	GCMS (or TLS)
- Vertical transport	Vertical velocities and P/T profiles	Over many lats, lons, and times	Balloon and DS P/T sensors
Chemistry/Meteorology			
- Cloud-level Sulfur Cycle	Trace gas abundances in clouds	Over many lats, lons, times	GCMS
	Cloud particle sizes, density	Over many lats, lons, times	Nephelometer
- Sub-cloud Sulfur Cycle	Sub-cloud trace gas abundances	Several profiles to near the ground	Drop Sonde sniffers and P/T sensors
- Lightning characterization	Lightning power, frequency	Over many lats, lons,and times	Lightning detector
- Surface/Atmo Interactions	Trace gas abundances to ground	Several profiles to near surface	Drop sonde sniffers
	Surface slopes on km scales	Near-global coverage	Orbiter RADAR

New Frontiers VALOR +
Required Measurements (2)

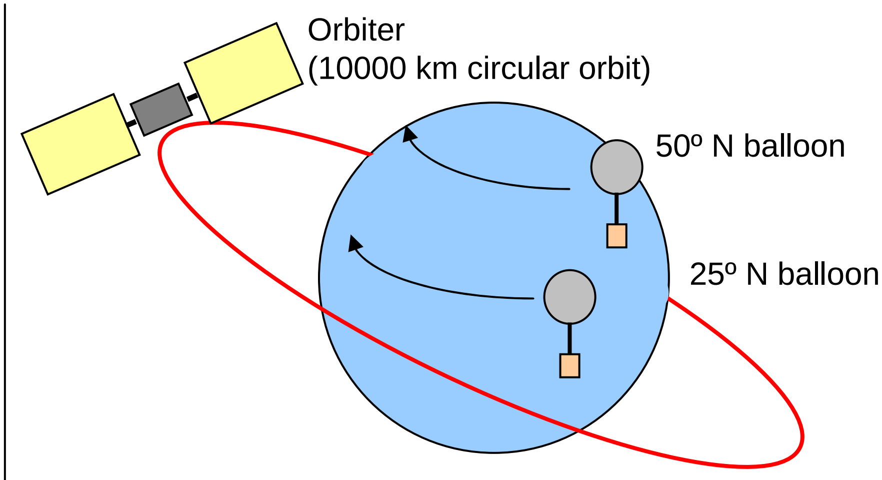
Science Goal	Measurement Requirements	Spatial/Temporal/Coverage	Instruments
Geology			
- Roles of volcanism, fluvial flows	Km-scale topography Meter-scale imaging	Near-global coverage Several key featiures	Orbiter RADAR DS Surface Imager
Venus' and Earth's Future			
- Greenhouse Effect	Trace gas abundances, cloud properties at cloud levels	Over large range of lats, lons, and times	GCMS Nephelometer
- Water's role in geology	HDO/H_2O abundance	Several measurements for S/N	GCMS (or TLS)
	H_2O abundance profiles	Over several lats, lons	Drop sonde sniffer
- Resurfacing events	Surface topography at km scales Meter-scale imaging	Near-global Several key features	Orbiter RADAR DS Surface Imager

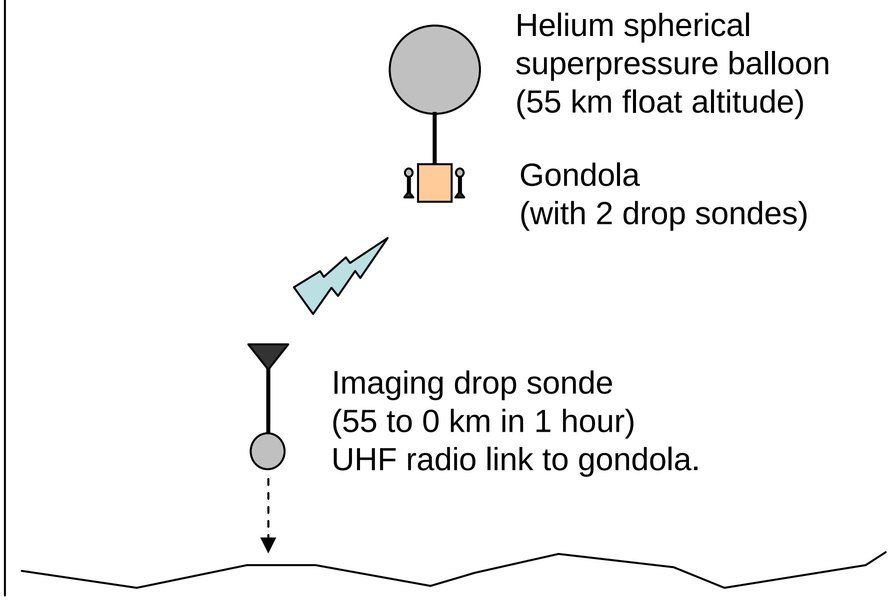
New Frontiers VALOR +
Instruments

Instrument	**Major Measurement Objectives**
Balloon Platform:	
GCMS	Abundances of Noble gas isotopes and trace species
TLS	Abundances of light isotopes and trace species
VASI	Pressure/Temperature, cloud particle sizes and number densities, vertical velocity)
Radio Tracking	Wind velocity profiles, circulation pattern
Lightning Detector	Lightning frequency and power
Drop Sondes:	
Environmental Package (Electronic "Sniffer" and P/T sensors)	Vertical profiles of (1) trace species abundances and (2) pressure/temperature
Surface Imager	Surface texture, compositional constraints, morphology
Orbiter	
Near-IR Imager	Global cloud-tracked winds and opacities
Topographic RADAR	Km-scale global topography at km-scales

New Frontiers VALOR +
Mission Architecture Overview

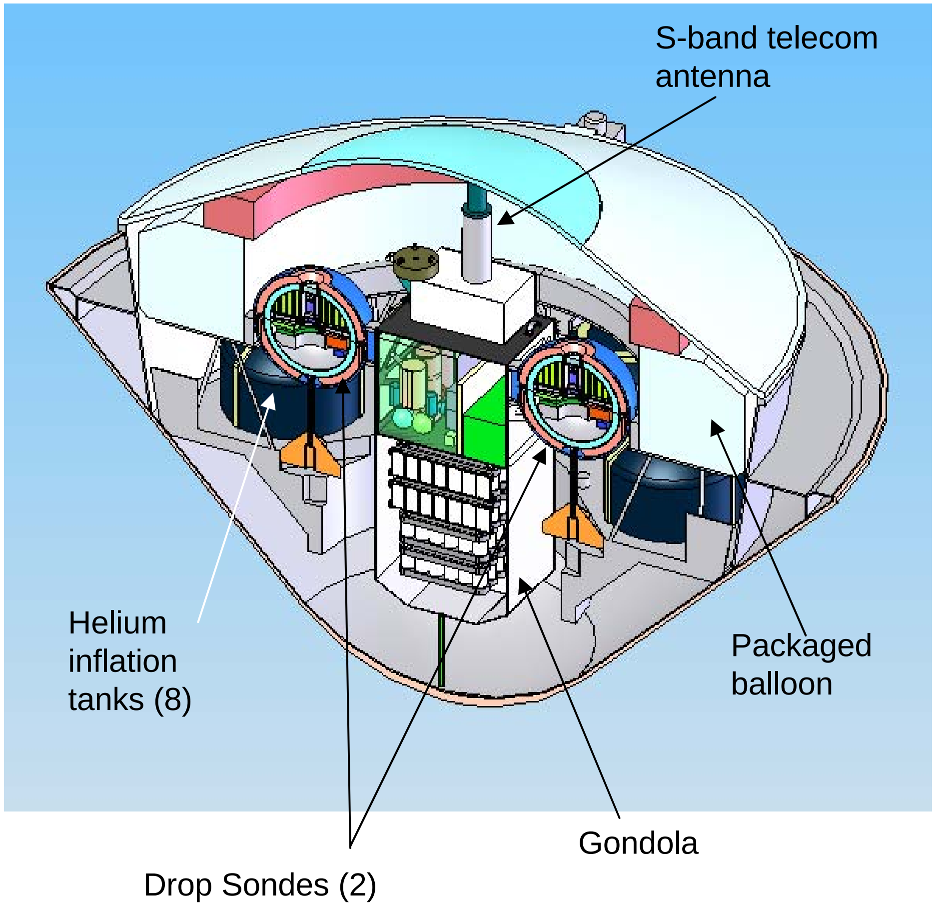
- The **VALOR+** instruments require a three element architecture that spans the near surface to orbit regions:
  - The GCMS, TLS VASI and LiD are carried by a pair of balloons at 55 km altitude that will move longitudinally and latitudinally over a 30 day mission
    - Doppler tracking of the balloons will give wind velocities
  - The radar altimeter and IR cloud motion imager are carried on an orbiter at low altitude and high inclination
    - The orbiter also serves as a telecom relay for the balloons
  - The descent imager and chemical species detector are carried on four drop sondes, instrumented probes that detach from the balloons (2 each) and fall to the surface
    - Data are relayed to the overhead balloon





New Frontiers VALOR +
Flight System: Entry Vehicle

- 2 m diameter, 700 kg entry vehicle contains the balloon, gondola, drop sondes and helium inflation system
- Geometrically identical to Pioneer-Venus aeroshell, but 2 m instead of 1.5 m diameter
- Entry deceleration limited to 400 G's (PV limit was 450)
- Use drogue chute and large subsonic parachute to provide low descent rate for aerial deployment and inflation of balloon



New Frontiers VALOR +
Flight System: Balloon

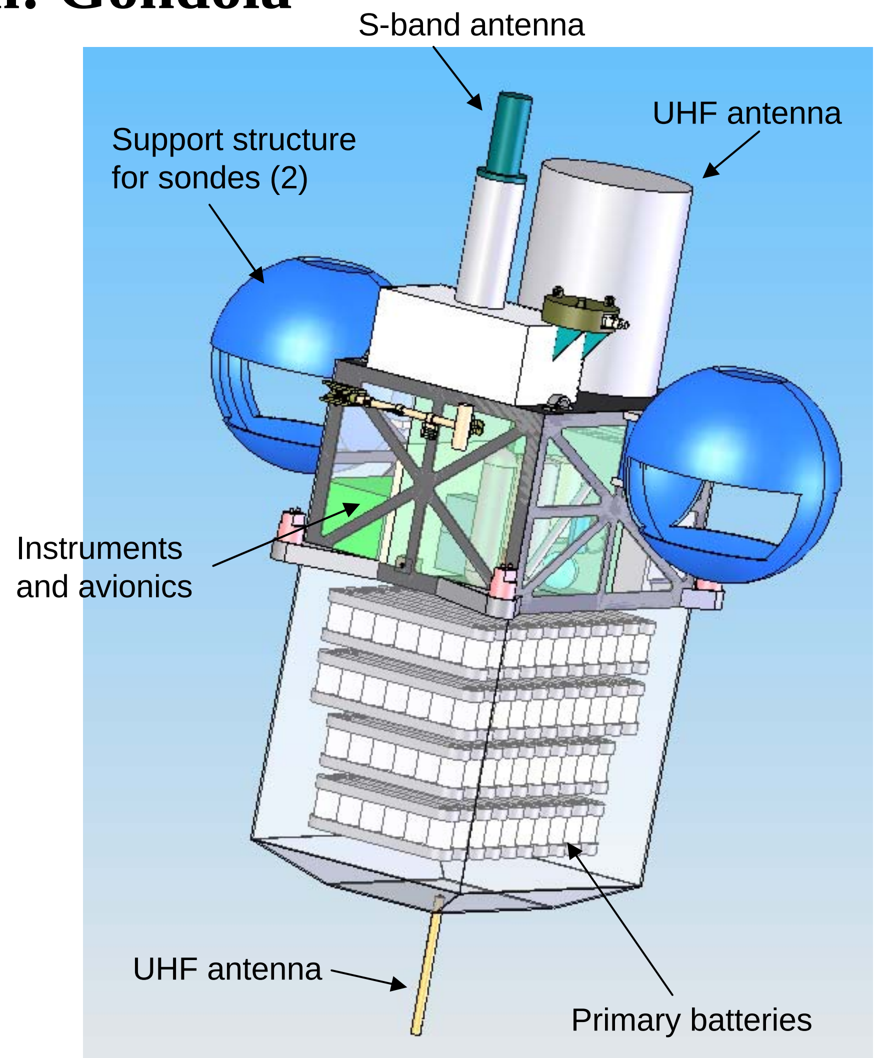
- Helium spherical superpressure balloon, Teflon coated for sulfuric acid resistance
- Vectran fabric plus Mylar film construction, metallized for low solar heating

Metric	Value
Diameter	6.85 m
Surface Area	147 m^2
Volume	167 m^3
Total Balloon Mass	37 kg
Helium Mass	13 kg
Nominal Float Altitude	55 km
Payload Mass	93 kg

5.5 m diameter balloon prototype testing

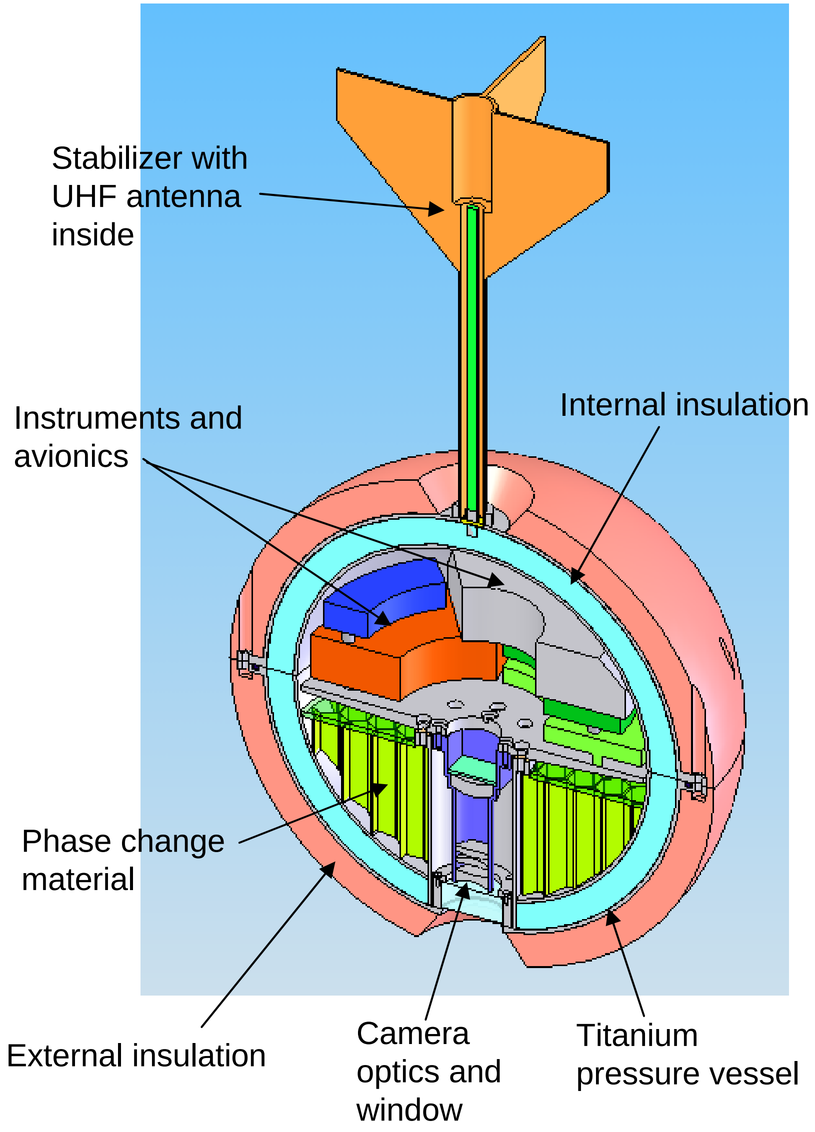
New Frontiers VALOR +
Flight System: Gondola

- Gondola hangs 10 m below balloon and carries GCMS, TLS, VASI and LiD instruments, plus two drop sondes
- Total mass of 90 kg
- Baseline option is all primary batteries; also looking at solar power trades
- Gondola outer surface is Teflon coated for sulfuric acid protection
- Gondola is vented to the atmosphere via sulfuric acid filters
- UHF receiver to obtain sonde data
- UHF transmitter to orbiter relay, also S-band transmitter for direct to Earth data relay



New Frontiers VALOR +
Flight System: Drop Sondes

- Drop sondes are spherical Titanium pressure vessels with a tail for aerodynamic stability
- 6 kg mass each
- 1 hour drop time to the surface
- Thermal insulation and phase change material used to maintain tolerable internal temperature
- Descent imager will take ~ 60 images from 5 km altitude and lower
- Chem species detector will measure all the way from 55 km to 0 km
- Data relayed to balloon via UHF telecom



Summary

Viable Mission Architectures Exist for Scientifically-Compelling Discovery- and New-Frontiers Class Missions to Venus

- **Successful 1985 VEGA Balloons are Proof**
- **VALOR TMC Experience: No Major Weaknesses**

In-Situ Exploration is the Next Step for Understanding the Origin, Evolution, Chemistry, Dynamics, and Meteorology of our Sister World

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.