Direct Aerial Robot Explorers (DARE) For Planetary Exploration

Presentation to NIAC Fellows Meeting

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NIAC
NASA Institute for Advanced Concepts

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TOPICS

- Concept Description
- Analysis and Applications:
  - Study of Venus' general atmospheric circulation
  - Applications for Titan, Jupiter and Mars
- Summary

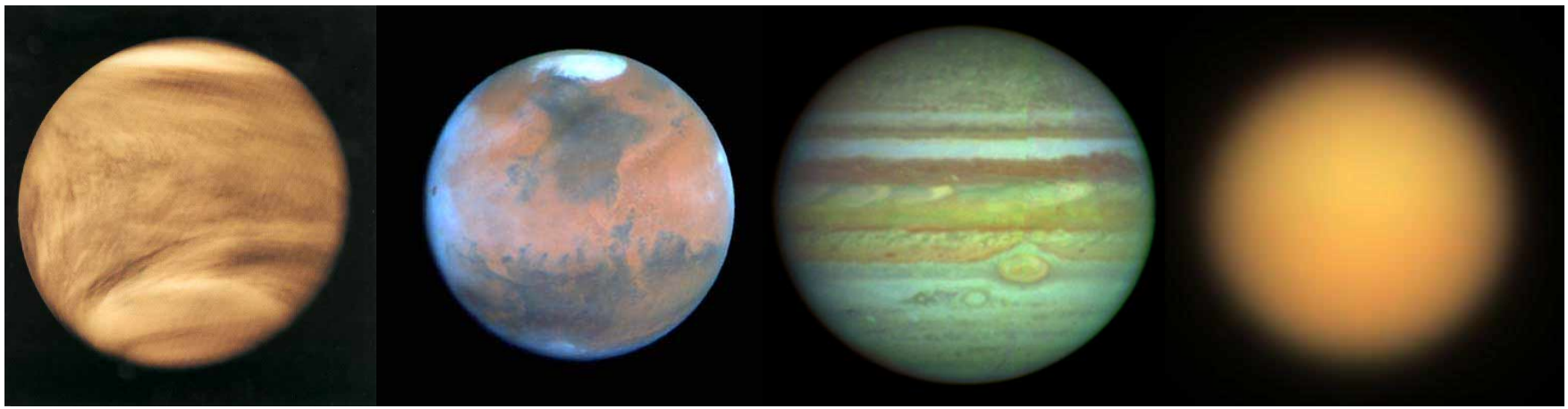


Photo of Venus taken by the Pioneer Venus Orbiter (NASA)

Mars image (NASA)

Hubble Space Telescope image of Jupiter

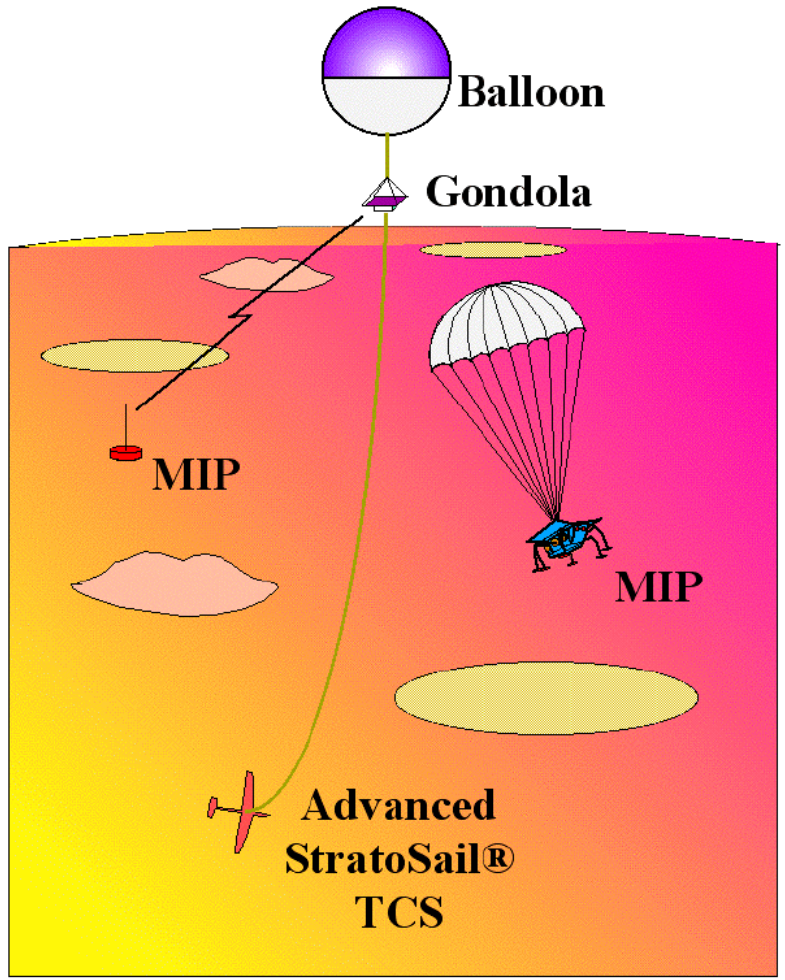
Hubble Space Telescope image of Titan

DARE CONCEPT OVERVIEW

- **Phase I NIAC conceptual study of new system architecture for planetary exploration**

- **Key elements:**
  - Long-duration planetary balloon
  - Balloon trajectory control
  - Lightweight and efficient power generation and energy storage
  - Deployable micro probes (MIPs)
  - Communications relay orbiter

- **Loosely based on previous planetary balloon concepts**



ADVANTAGES OF DARE

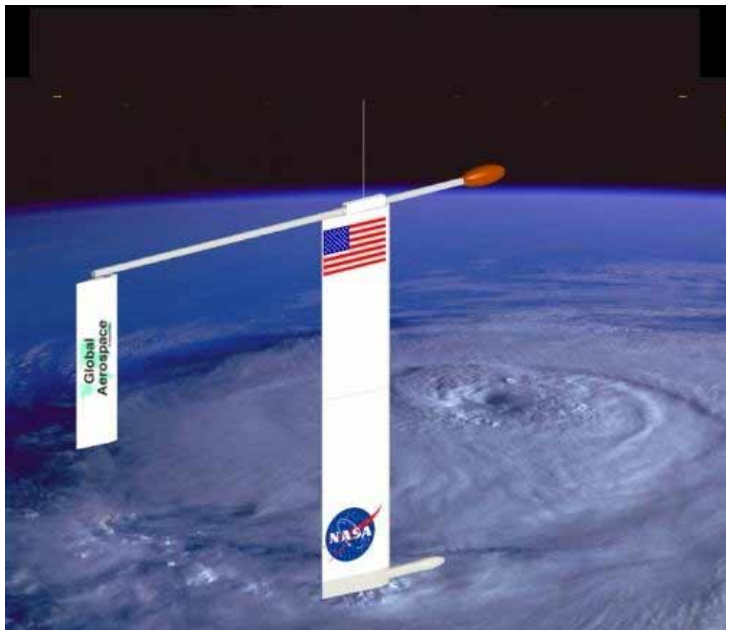
- **Bridge the gap between orbital and surface observations**
- **Combine advantages of orbital and in situ platforms:**
- **Nearly global spatial coverage**
- **Long duration**
- **Targeted observations on global scale**
- **In situ atmospheric profiling on global scale**
- **Diurnal coverage**

PLANETARY SCIENCE WITH BALLOONS

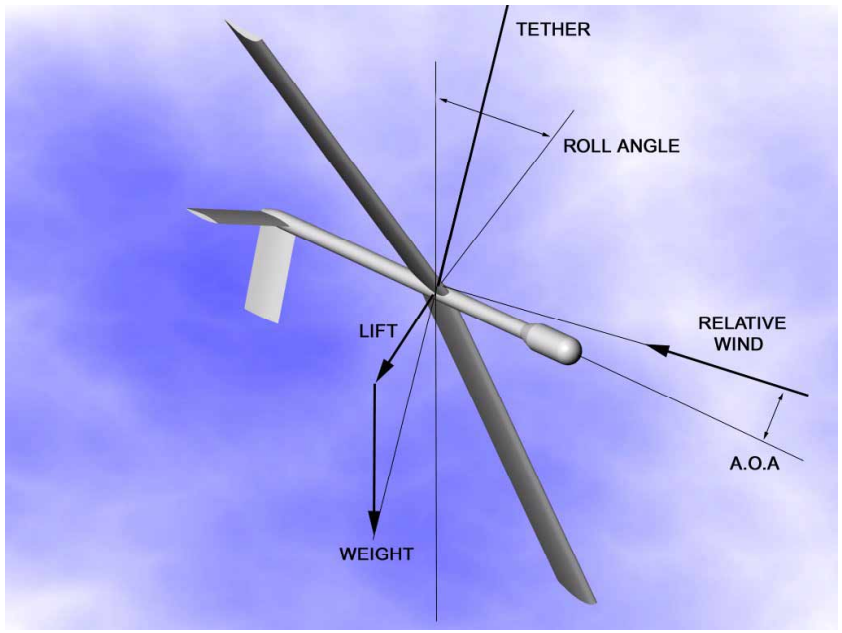
Venera/VEGA balloon

- Venera-VEGA (USSR, France, USA, 1984) – 2 floating stations successfully operated in atmosphere of Venus for 2 days
- Mars-94 balloon (USSR, France) – designed, tested, cancelled
- Numerous concepts for Venus, Mars, Titan and Gas Giants
- Balloon technology is there
- No trajectory control

STRATOSAIL® TRAJECTORY CONTROL SYSTEM (TCS)



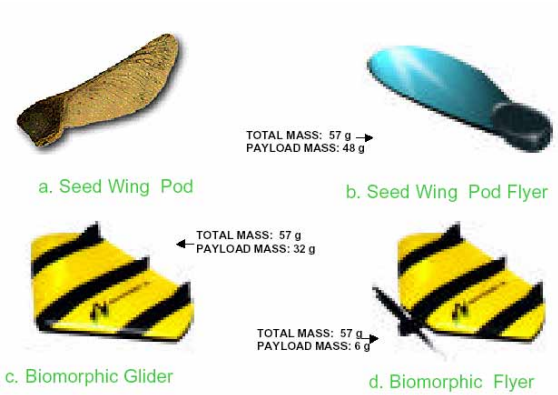
First Generation TCS



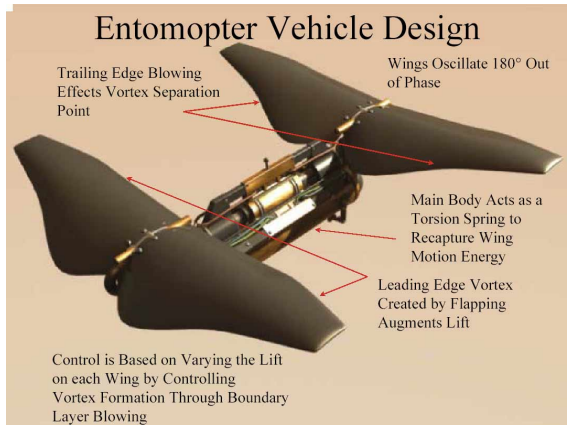
Advanced TCS

- **Wing on a tether several km below the balloon**
- **Variation of wind and density with altitude result in lateral lifting force**
- **Rudder controls angle of attack**
- **Corresponding control velocity 1-2 m/s**

MICROPROBES



Biomorphic flight system examples (JPL NASA)



Entomopter for flight on Mars (A. Colozza, Ohio Aerospace Institute)

Mars Hexabot (JPL NASA)

- **Single DARE platform can carry hundreds of small probes or several large probes**
- **DARE platform can serve as a launching and refueling floating station**

PLANETS TO DEPLOY DARE

TITAN

- high degree of trajectory control
- no balloon technology (cold atmosphere)
- too far away

MARS

- high scientific priority
- low density atmosphere requires large balloons
- balloon flight altitude dangerously close to surface topography
- strong chaotic winds make targeting difficult

JUPITER

- hydrogen atmosphere makes balloons difficult to deploy
- requires large and heavy TCS

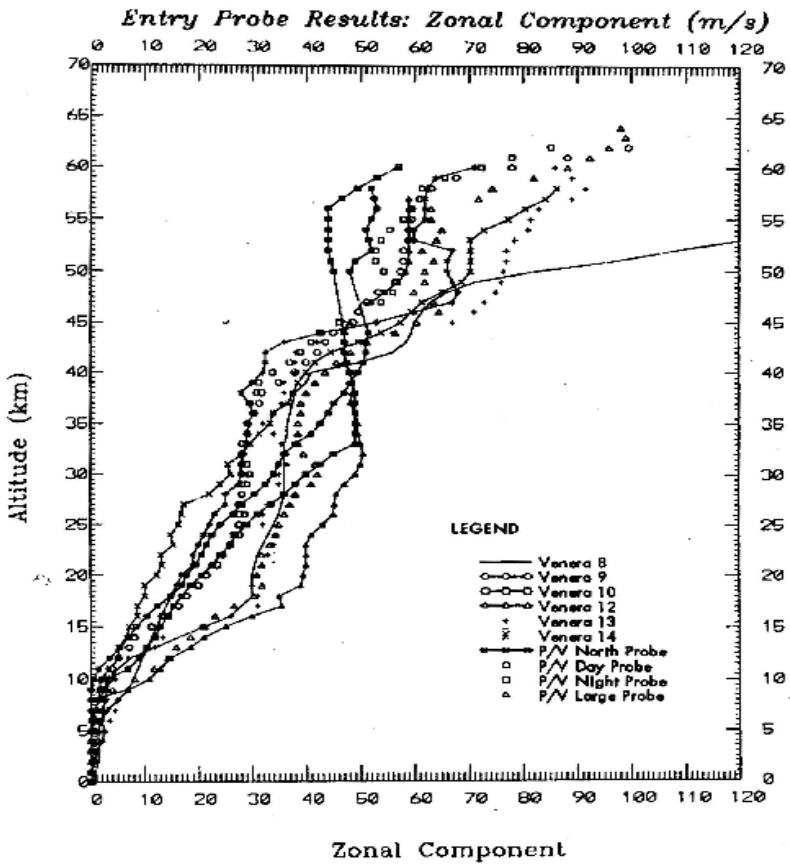
VENUS

- high scientific priority
- tested balloon technology
- high degree of trajectory control

Selected for more focused study

DARE AT VENUS

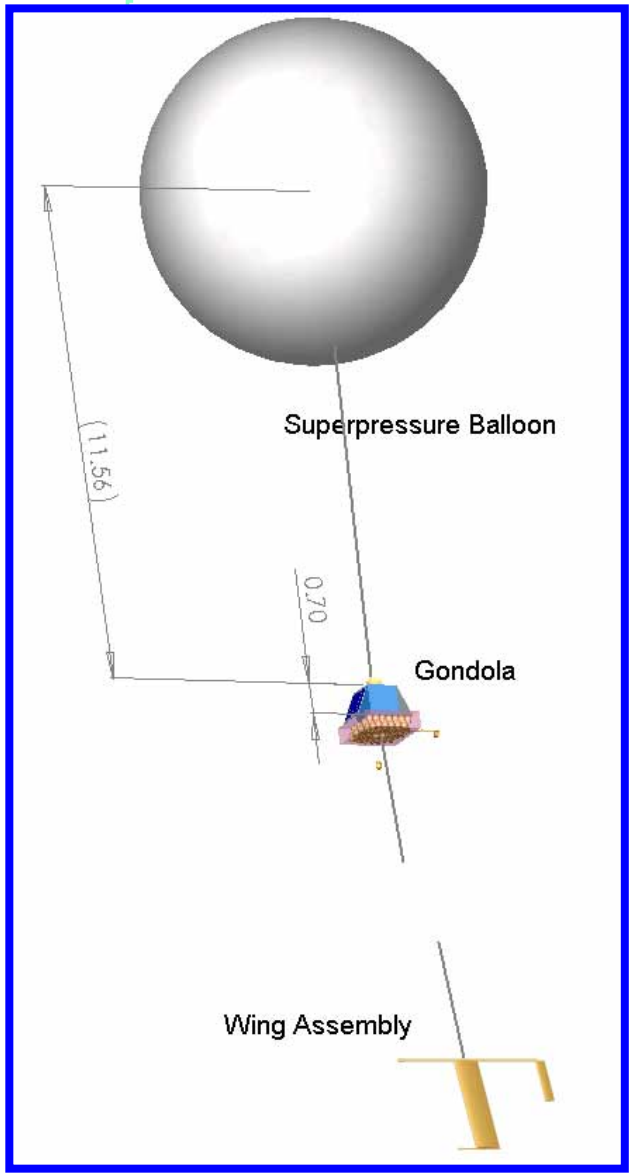
VENUS ENVIRONMENT



Venus zonal winds from Venera probes measurements

- Hot and dense CO_2 atmosphere
  $T_{surface}$=733 K, $P_{surface}$=92 bar
  T_{55km}=300 K, $P_{surface}$=0.5 bar
- Main H_2SO_4 cloud deck from 40 to 75 km
- Strong zonal winds (superrotation)
- Nature of the meridional circulation is debated (Hadley or solar tides dominated)

GUIDED VENUS BALLOON SYSTEM

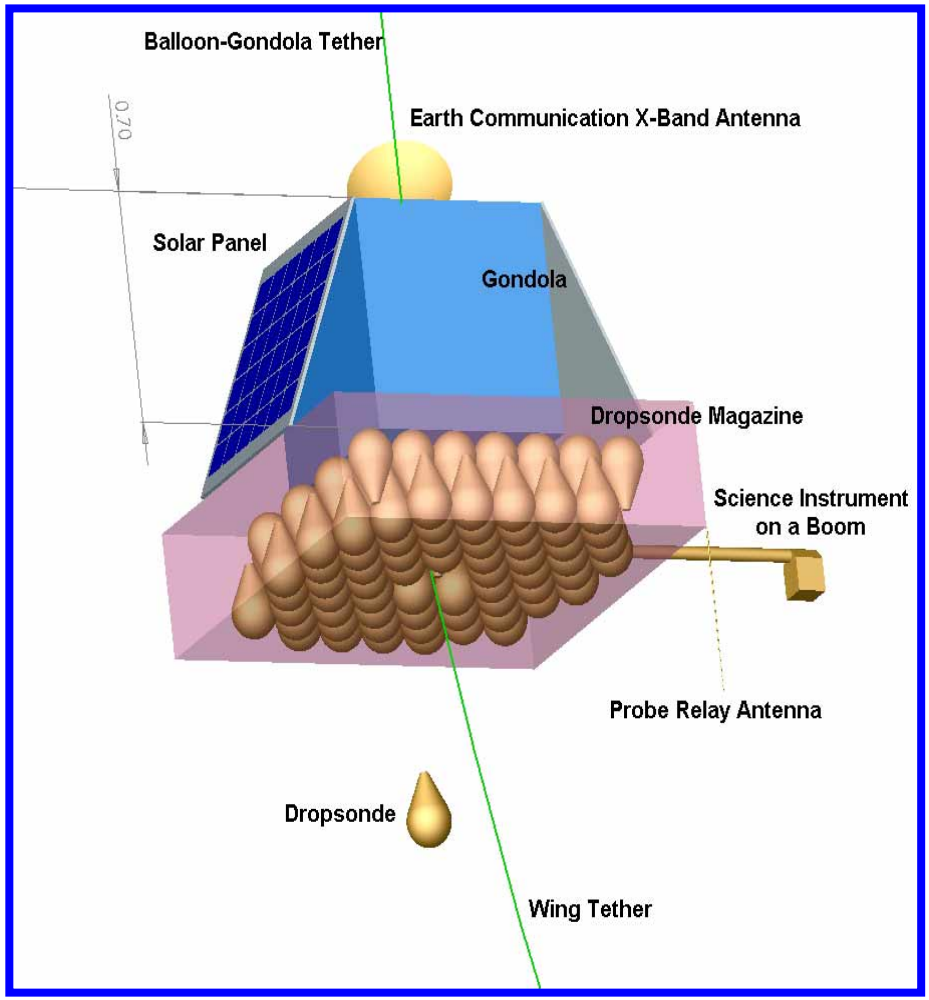


- Balloon and gondola designs based on Venus Balloon Discovery design (NASA JPL, 1997)
- General circulation study mission:

  - What maintains the superrotation of the atmosphere?

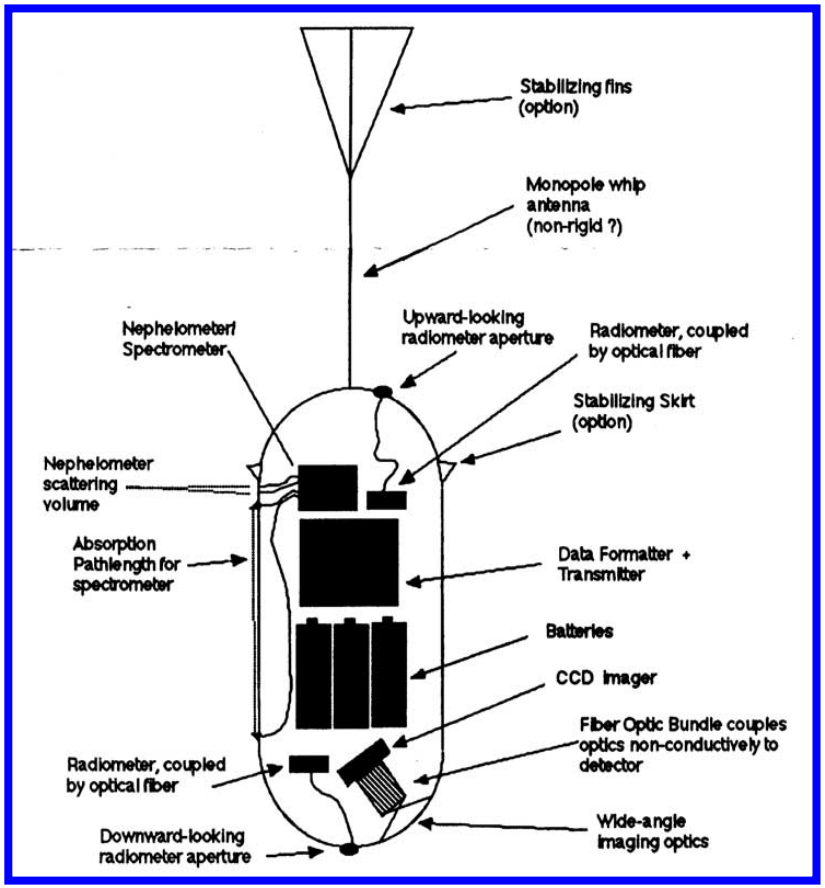
  - What is the nature of the meridional circulation?
- Soundings of the lower atmosphere (0-15 km) at multiple locations
- 100 day flight at 55 km
- 100 light (<1 kg) dropsondes
- Floating mass ~208 kg
- Superpressure Teflon balloon, D=7.6 m

DARE VENUS GONDOLA



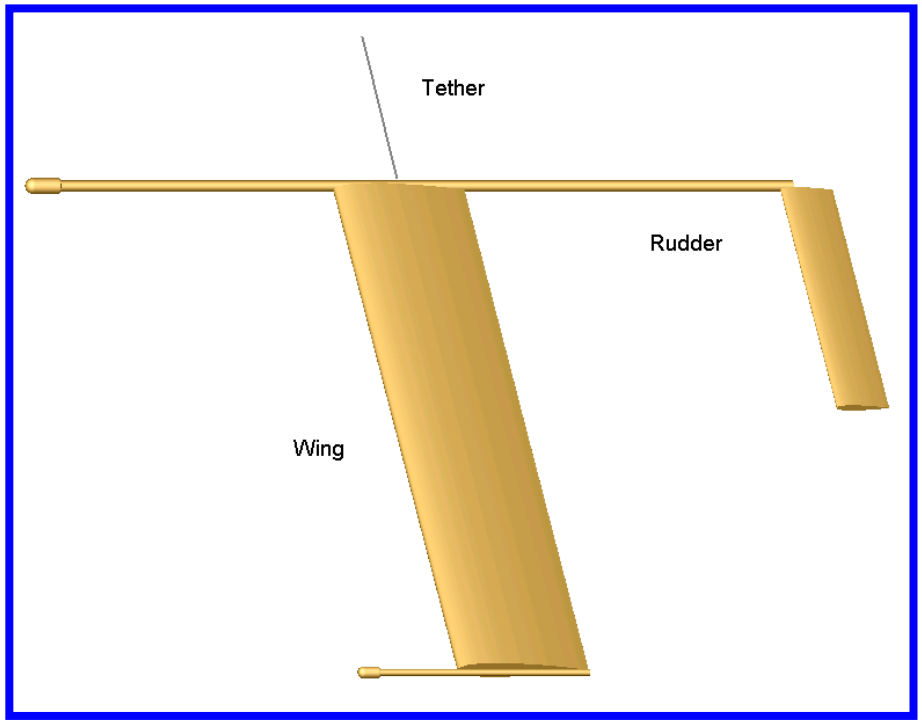
- Design based on Venus Balloon Discovery design
- 2 solar panels (0.5 m^2) + batteries
- Earth com X-Band and dropsonde relay S-band antennas
- 100 dropsonde magazine
- Gondola science suite
- TCS deployment mechanism

EXAMPLE VENUS DROPSONDE DESIGN



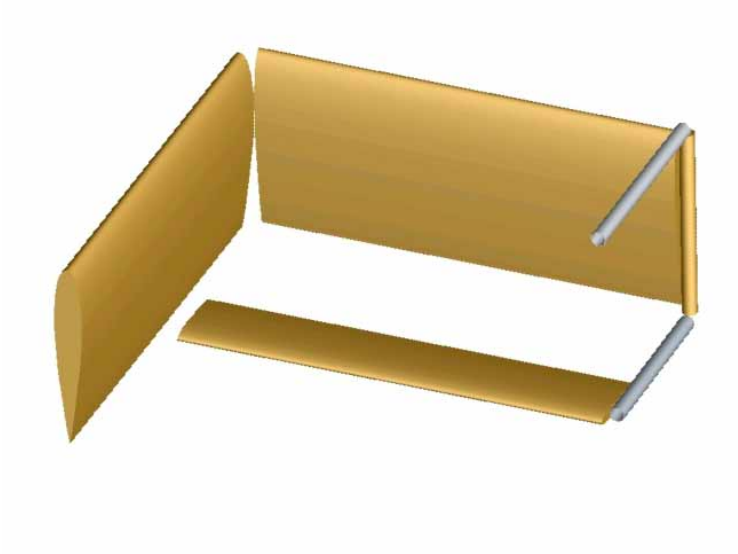
- Must survive the descent through hot atmosphere
- Advanced Dewar insulation (Lorenz, 1997)
- Descent time about 1 hour
- Internal temperature at impact ~360 K
- Mass=0.7 kg, D=12.4 cm
- P, T, V, imaging, radiometry, spectrometry

DARE VENUS TCS



- 10 kg 1 m^2 wing
- 10 km 10 kg PBO tether (d=1 mm)
- Control velocity 1–2 m/s limited by wing weight
- Advanced TCS would provide higher control velocity

TCS FOLDING OPTIONS

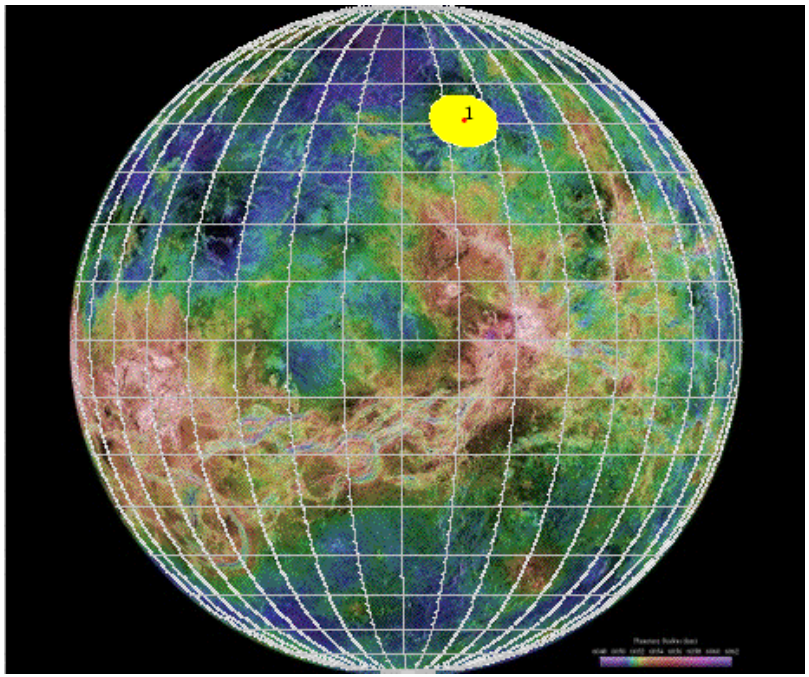


- **Frame style – "wraps around" the gondola**

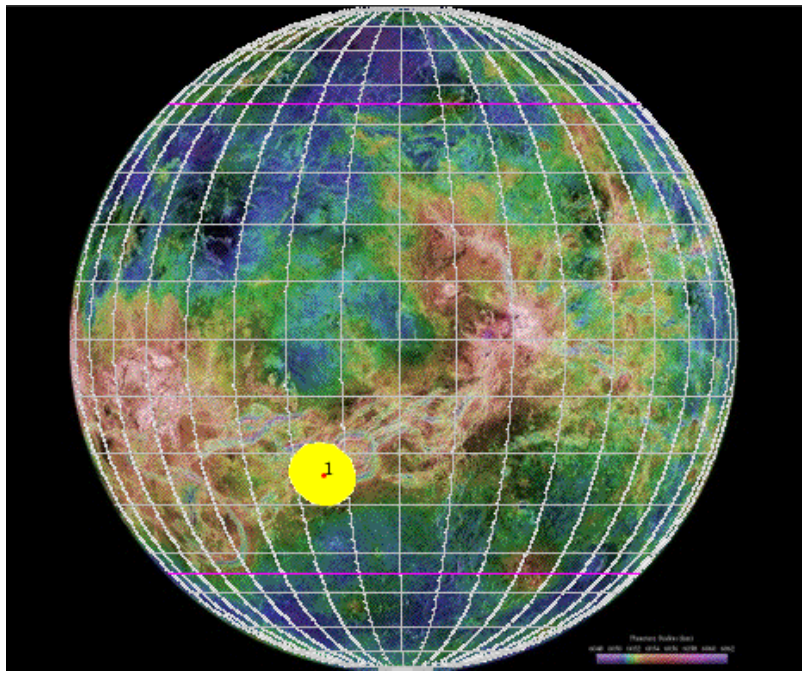
- **Box style – stored below the gondola**

DARE MOBILITY AT VENUS

Venus balloons at the end of 100 day flight at 55 km



Uncontrolled balloon



Controlled balloon, 1 m/s control velocity

- Start at 55ºN latitude
- Atmospheric model assumes that meridional winds are dominated by solar tides

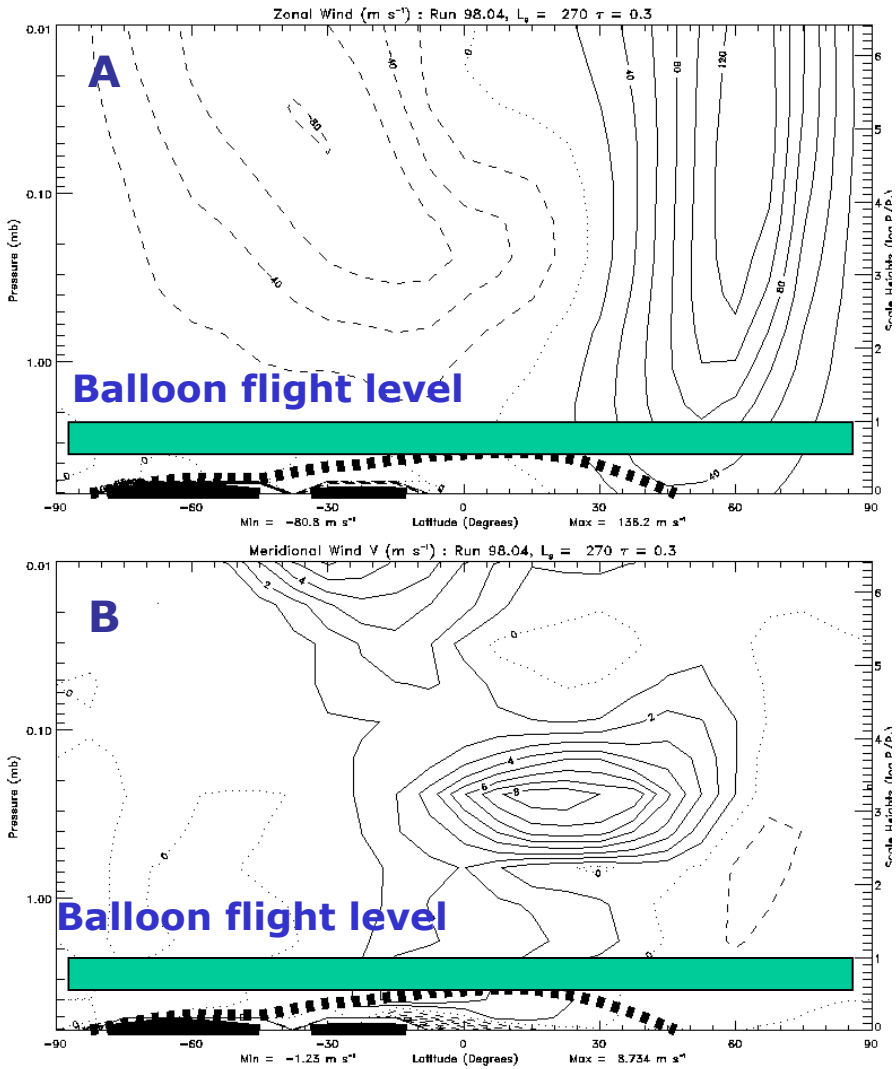
A VENUS DARE CAN:

- Capitalize on past Venus balloon mission
- Enable global coverage
- Enable targeted observations
- Provide opportunities for in situ atmospheric profiling
- Enable surface imaging (VIS/IR)
- Resolve questions about the nature of meridional circulation and atmospheric superrotation

DARE AT MARS

MARS ENVIRONMENT

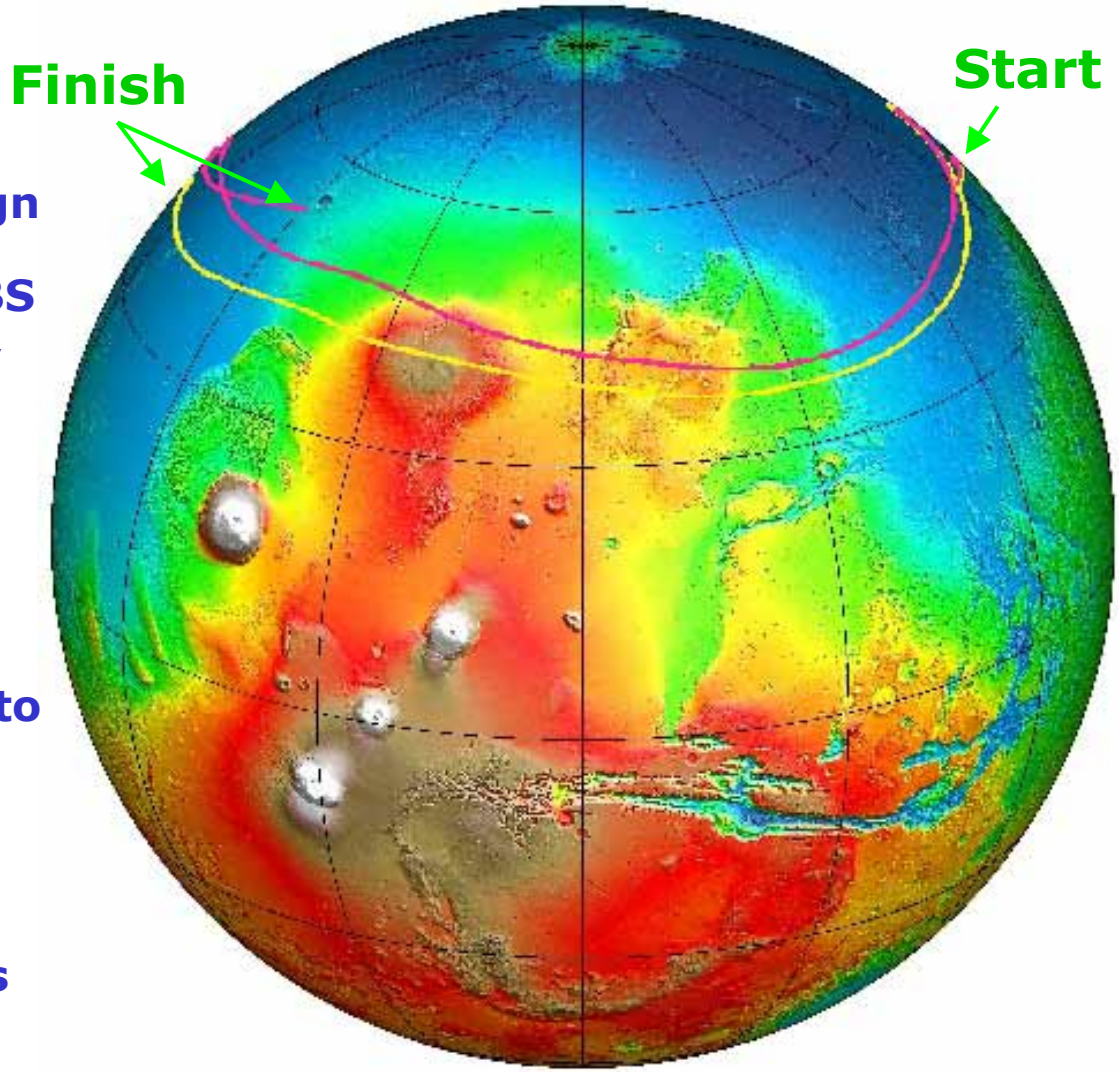
- Low density cold atmosphere (like Earth's stratosphere)
- Southern highlands (2 km above reference level), Northern lowlands (4 km below)
- Tharsis ridge obstacle (8 km above the reference level)
- Ever present atmospheric dust
- Turbulent lower atmosphere (dust devils)
- Strong zonal winds develop during summer and winter seasons



Zonal (A) and meridional (B) winds from Mars GCM for Northern winter season

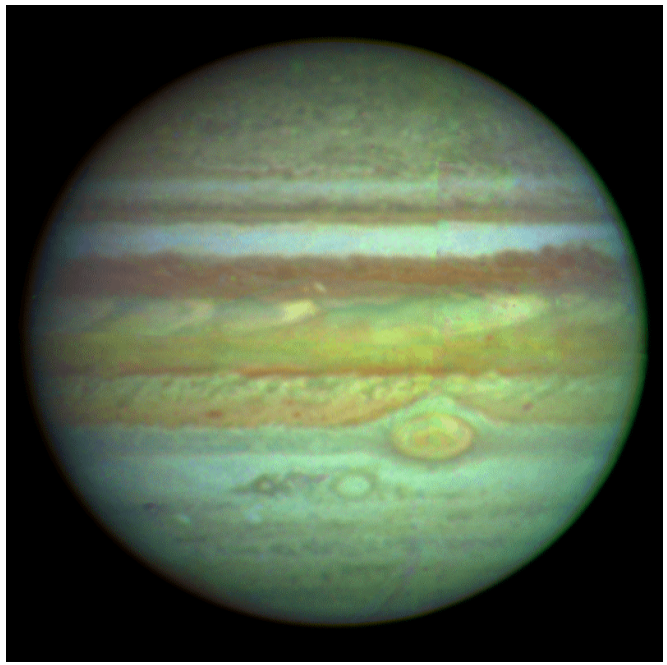
GUIDED BALLOONS AT MARS

- Balloon and gondola design derived from MAP (ASU, NASA JPL, 1994) and MABS designs (JPL&GSFC NASA, 1997)
- Winds, imaging, spectroscopy, surface probes
- Superpressure balloon D=30 m
- TCS – 10 kg 1 m^2 wing, 3 to 6 km tether
- Gondola science payload 5 kg
- Floating mass 111 kg
- Control velocity 0.1-1 m/s



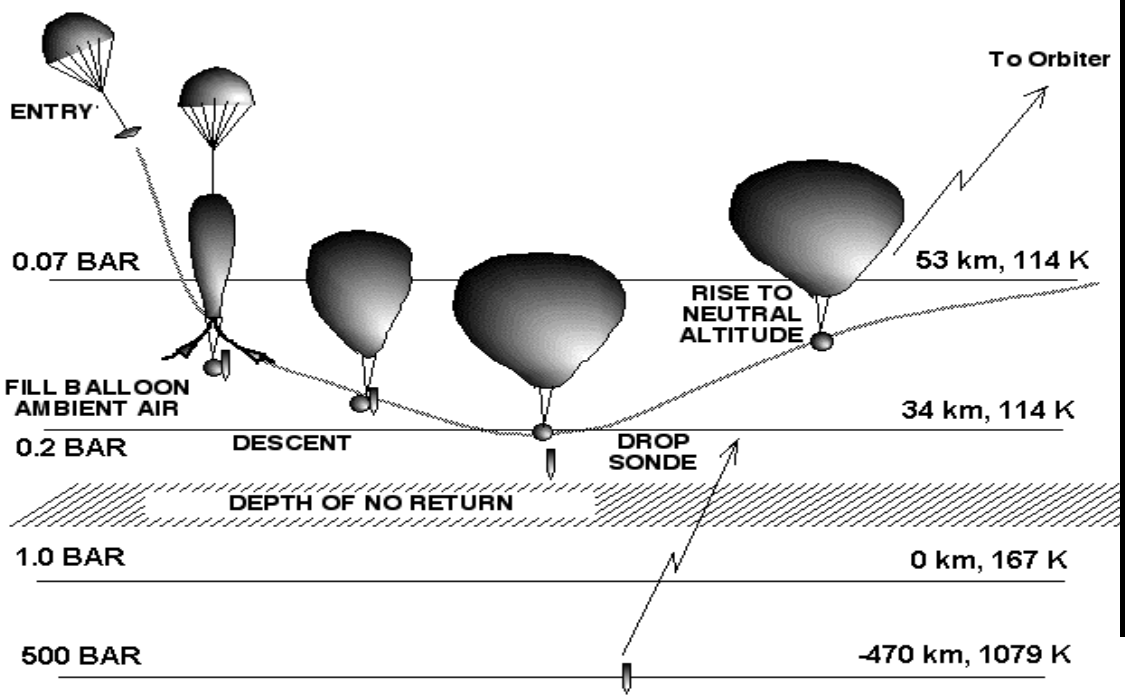
Comparison of 5-day trajectories of uncontrolled (yellow) and controlled (purple) balloons on Mars (MOLA topography image courtesy NASA)

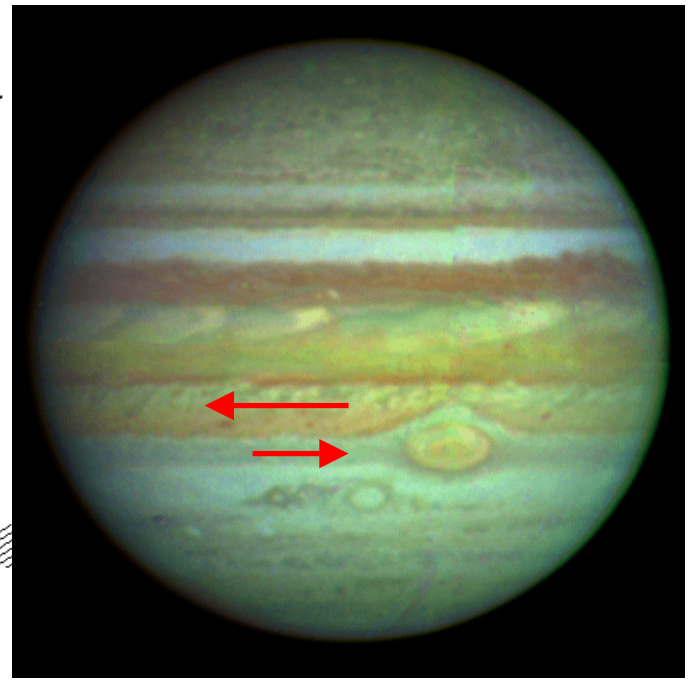
DARE AT JUPITER



JUPITER ENVIRONMENT

- Hydrogen atmosphere makes balloon operation difficult
- Only Solar Infrared Montgolfier (SIRMA) balloons are practical
- Balloon H_2 is heated by the Sun and IR radiation from Jupiter's interior
- Strong "banded" zonal winds + large vortices (Great Red Spot)

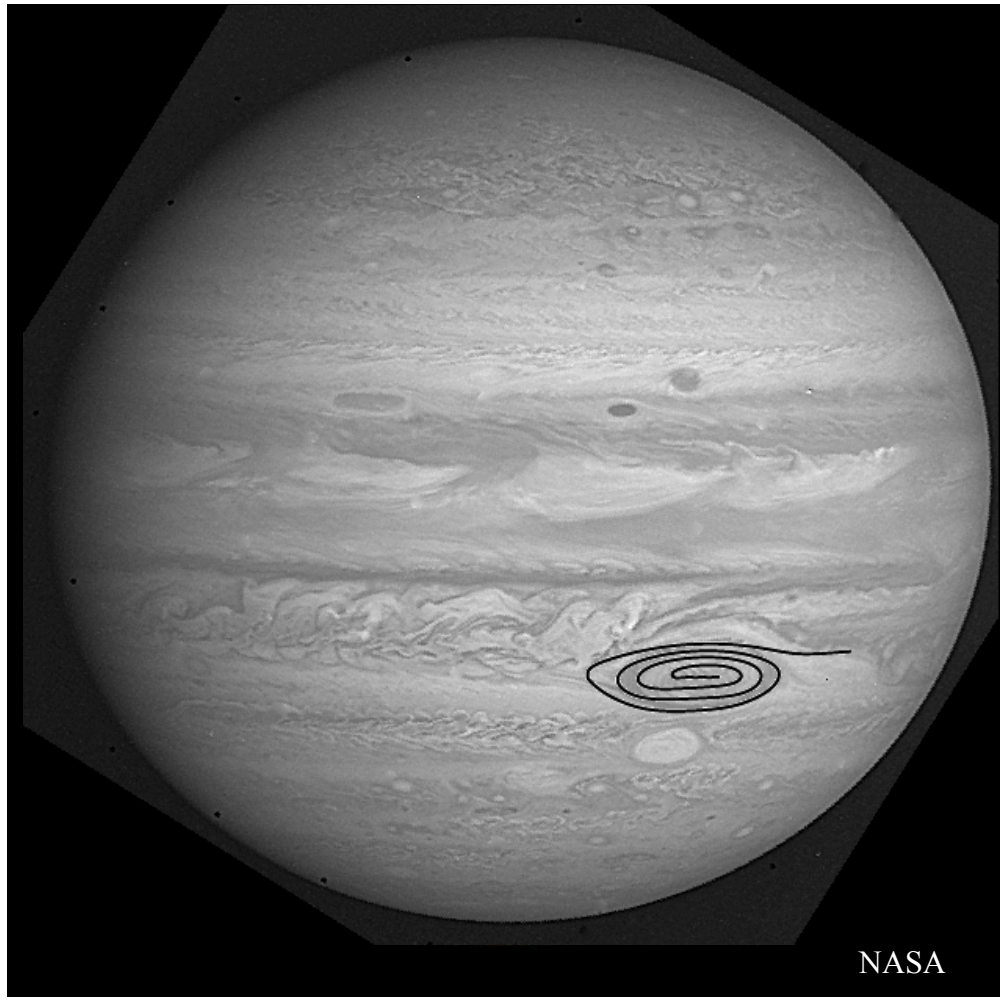




SIRMA Balloon in Jupiter's atmosphere (JPL NASA)

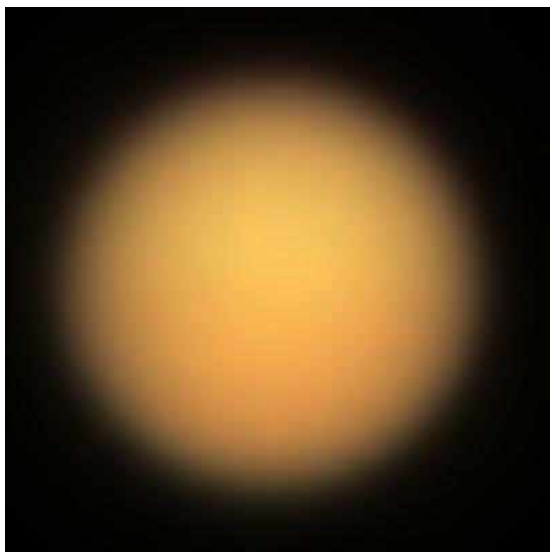
TARGETED SCIENCE AT JUPITER

- D=72 m SIRMA balloon (JPL NASA, 1997) at 0.1-0.2 bar
- Sample with probes distinct regions of the atmosphere (GRS, belt/zone)
- TCS – 50 kg 10 m^2 wing, 10 km tether
- Floating mass 208 kg
- Control velocity 0.9 m/s

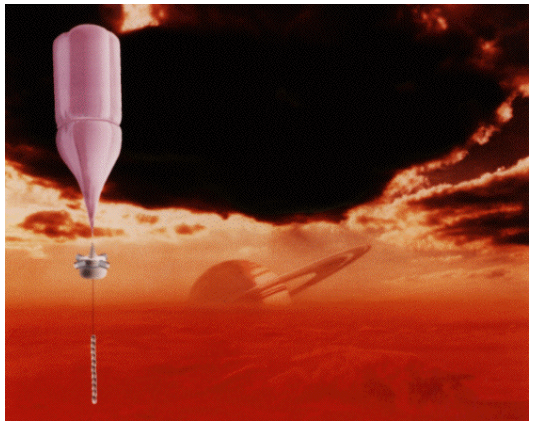


DARE 100 day trajectories at 0.1 bar, control velocity 0.9 m/s

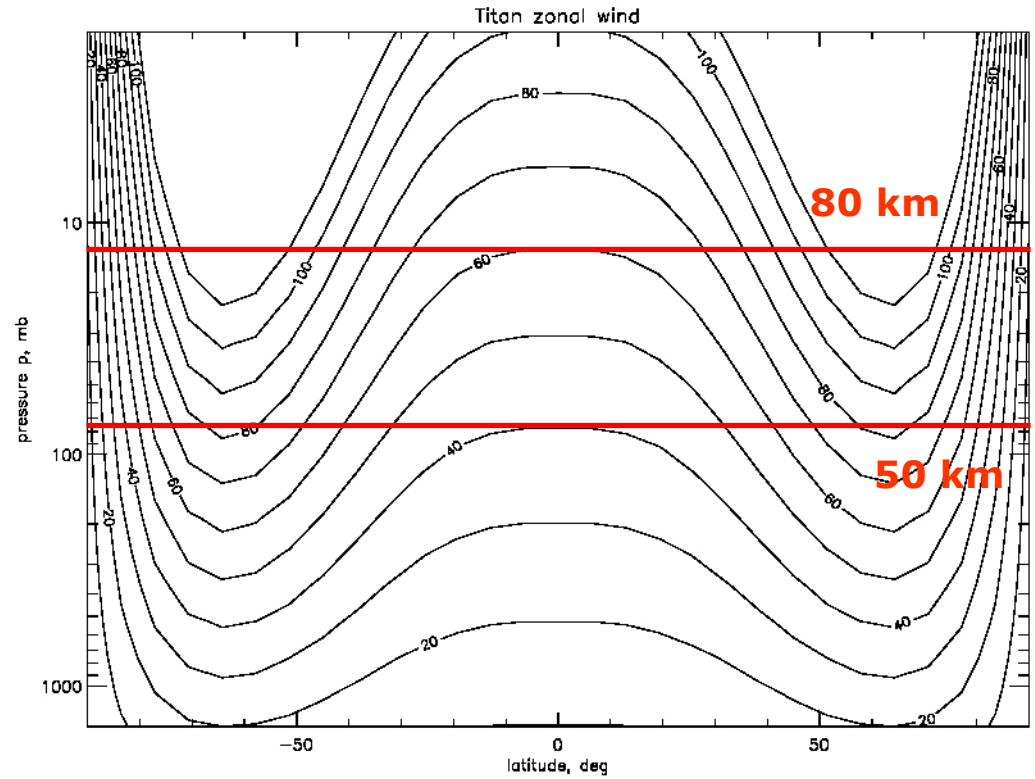
DARE AT TITAN



TITAN ENVIRONMENT



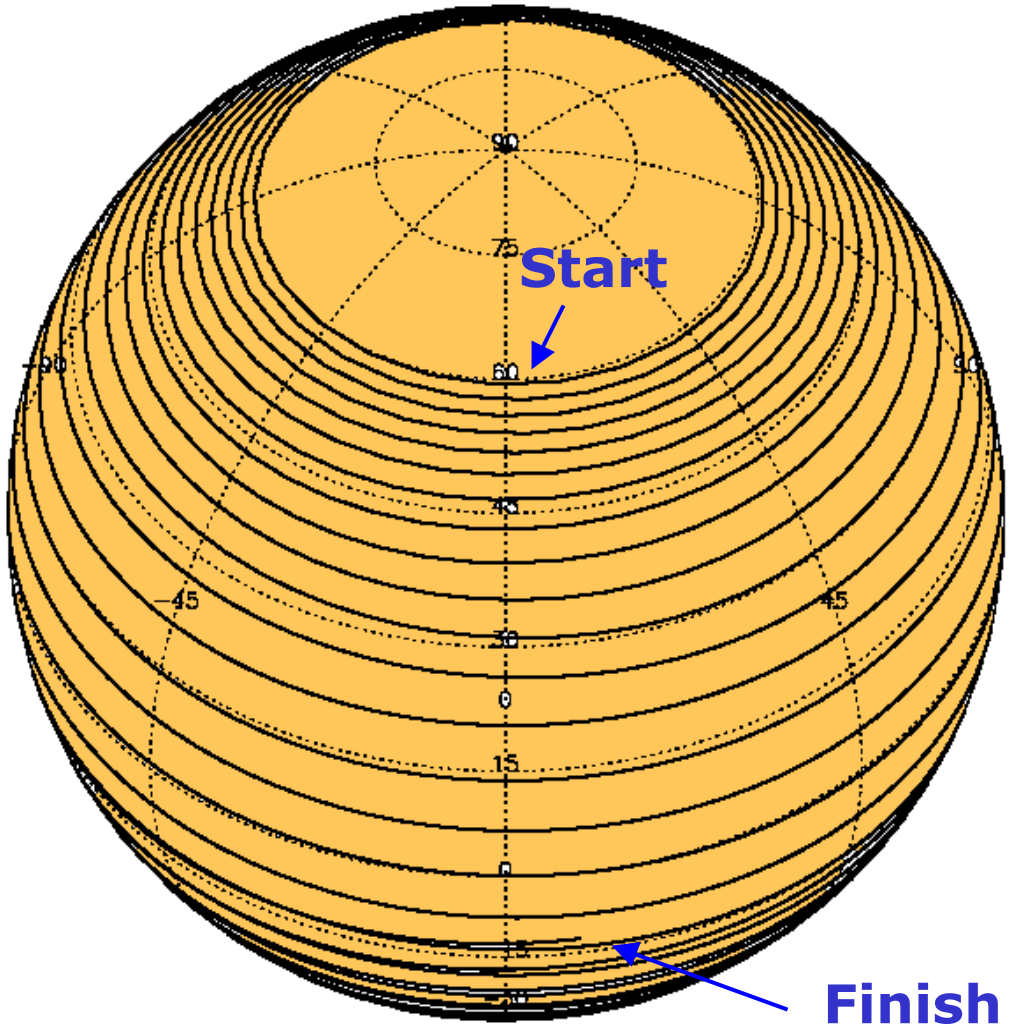
Artist rendition of balloon at Titan (NASA)



- Cold N_2 atmosphere (T_{50km}=72 K)
- Dense haze of organic material above 80 km
- Strong zonal winds
- Weak meridional winds (1 m/s) arising from Saturn tides

GLOBAL COVERAGE OF TITAN

- Superpressure balloon above 50 km, e.g. D=11.2 m at 60 km, 19.8 m at 80 km
- Winds, gas abundances, surface organics/chemistry probes
- TCS – 10 kg 1 m^2 wing, 10 km tether
- Payload mass 100 kg
- Floating mass 136 kg at 60 km,
  195 kg at 80 km
- Control velocity 0.9 m/s at 60 km, 0.5 m/s at 80 km



DARE trajectory for a 100 day mission at 60 km

SUMMARY

- **Relatively small (1 m^2) and light (10 kg) StratoSail® TCS can significantly modify trajectories of planetary balloons on Venus, Titan and Mars**
- **Useful Balloon trajectory control on Jupiter requires larger wing (10 m^2, 50 kg)**
- **A guided Venus balloon can enable global sampling of the surface and atmosphere with microprobes**
- **DARE platforms offer exciting new approach to the in situ atmospheric and surface planetary science**