
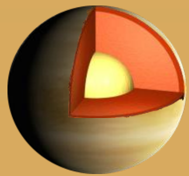

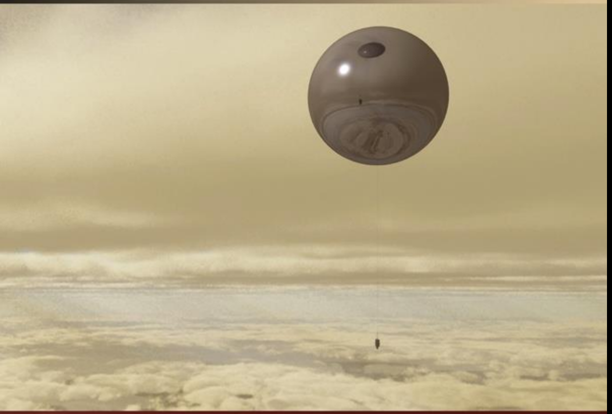
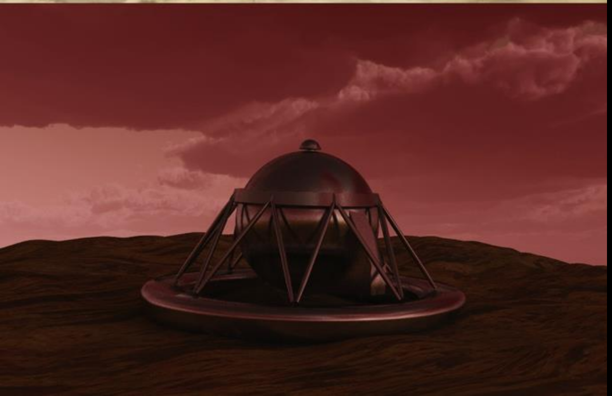

Venus Bridge: Orbiter and atmospheric element

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Members of the Venus Bridge Focus Group

Members of the NASA ARC and LaRC aeroentry team

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Nov 15, 2017

Topics

- Objectives
- Venus Orbiter and Atmospheric Element Concepts
- Background
- Approach
- Study Participants
- Getting to Venus
- Team X Study Focus
- Venus Orbiter concepts studied
- Atmospheric Element Concepts – Feasibility
- Telecom – Orbiter to earth and balloon relay
- Summary

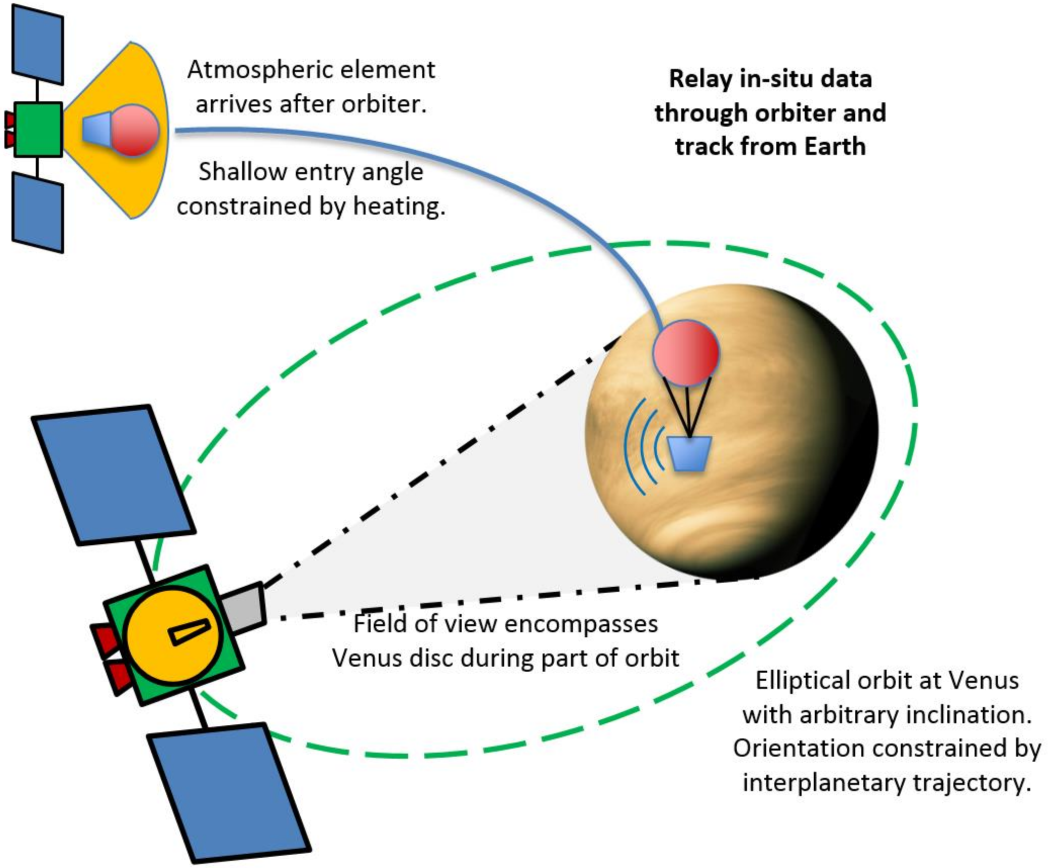
Objectives

- NASA is conducting parallel and complementary studies of two linked-mission concepts.
  - Surface Element (lander) + Orbiter Relay study performed by the COMPASS team at Glenn Research Center
  - Atmospheric Element (Probe or Aerial Platform) + Orbiter Relay study led by JPL with support from ARC, LaRC and JPL's Team X
- This is a progress report on the JPL study which began in late September. A full report will be completed in the February time frame

Venus Orbiter and Atmospheric Elements

Concept of Operations

- Probe 20–60 minutes, Balloon 1–12 days
- In-Situ Data Volume: 30–300+ Mb



Venus Bridge - Background

- Meeting of VEXAG Leadership with Green and Zurbuchen in Feb 2017
- VEXAG Planetary Newsletter request for concepts March 2017
- Venus Bridge Focus Group formed - March 2017
- JPL A-Team study conducted - May 2017
- Team X – COMPASS study plan formulated – Aug 2017
  - JPL led study focused on orbiter and atmospheric element
  - GRC-led study focused on orbiter and long-lived lander
- Science value of atmospheric elements initiated – August 2017
- Atmospheric entry studies initiated – Sept 2017
- Team X study conducted Oct 31 to Nov 2, 2017
- Findings from Team X study compiled Nov 8, 2017

Approach

- Explore different ways of getting to Venus.
  - Leverage work done on PSDS3 studies
- Assess feasibility of atmospheric elements
  - Atmospheric entry at Venus with small entry systems
  - Small probes feasibility
  - Feasibility of small balloons systems
- Telecom relay from atmospheric elements
- Orbiter design - Leverage MarCO mission
- Conduct a 3 day Team X study which focused primarily on the orbiter, relay telecommunications and getting to Venus

Study Participants

Venus Bridge Focus Group

- Jim Cutts (JPL)
- Kandis Lea-Jessup (SWRI)
- Bob Grimm (SWRI)
- Noam Izenberg (JHUAPL)
- Robbie Herrick (U of Alaska, Fairbanks)
- Rob Lillis (U.C. Berkeley)

Orbiter Science

- Attila Komjathy (JPL)
- Valeria Cottini (U of Maryland)

Atmospheric Element Science

- Dave Atkinson (JPL) - Probe
- Kevin Baines (JPL) -Balloon
- Christophe Sotin (JPL) – Skimmer

Venus Bridge System Engineering

- Damon Landau (JPL)

Orbiter System Engineering

- Alan Didion (JPL)
- Nicolas Gorius (Catholic University)

Atmospheric Entry

- Ron Merski (LaRC)
- Jamshid Samareh (LaRC)
- Alicia Dwyer Cianciolo (LaRC)
- Paul Wercinski (ARC)
- Raj Venkatapathy (ARC)
- Robin Beck (ARC)
- Gary Allen (ARC)

Atmospheric Elements – Technology

- Jeff Hall(JPL) – Balloon
- Jacob Izraelevitz(JPL) – Descent Probe

JPL Team X

- Alfred Nash (JPL) lead

Getting to Venus

- A dedicated launch vehicle for Venus bridge is not affordable within the constraints based on current and projected launch vehicle costs
  - Price per kilogram scales adversely at small sizes

- Three general “ridealong“ approaches have been explored
  - Venus mission or a mission using Venus gravity assist
  - Earth departure mission (e.g. lunar flyby)
  - Secondary payload on launch to Geosynchronous Transfer Orbit (GTO)

- The GTO option is particularly attractive:
  - High frequency of commercial and DoD launches
  - ESPA ring deployment standard provides flexible accommodation
  - Options exist for transfer from GTO to an earth escape trajectory

Desired Venus orbit affects propulsion preference

- PSDS3 Venus mission concept have different orbital preferences driven by the science
  - VAMOS - circular, near equatorial, period ~ 24 hours
  - CUVE - elliptical, near polar, period ~ 12 hours

- Telecom relay orbital preferences
  - Shorter period (down to a few hours) preferred over long
  - Circular milder preference over elliptical
  - Inclination will depend on balloon insertion latitude (see later chart)

- Chosen orbit will dictate the propulsion choice
  - Elliptical orbit (12 hours) - Chemical propulsion
  - Circular orbit (24 hours) – Solar Electric Propulsion

Chemical vs Solar Electric Propulsion

Chemical Propulsion wet mass for a 100 kg dry mass spacecraft

Final Orbit> **Initial Orbit**	Lunar intercept	Venus intercept	Venus Orbit Elliptical 12 hours	Venus Orbit Circular 24 hours
GTO	150 kg	200 kg	360 kg	600 kg
Lunar intercept		140 kg	230 kg	360 kg
Venus intercept			170 kg	260 kg

Hybrid Chemical-Solar Electric Propulsion
for a 100 kg dry mass spacecraft (w/o SEP stage)

Final Orbit > **Initial Orbit**	Venus Orbit Circular 24 hours		
	Chemical Stage	SEP Stage	Total Wet Mass
GTO	70 kg	50 kg	220 kg
Lunar intercept	NA	50 kg	150 kg

SEP Option is most amenable to a 24 hour circular orbit
24-hour elliptical orbits are also achievable for any orientation

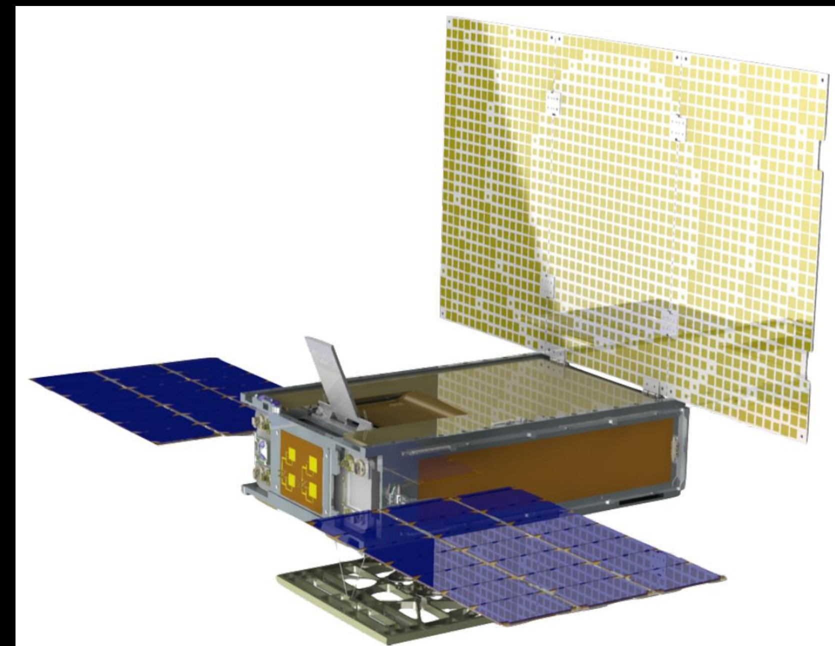
Team X Study Focus

- No interplanetary smallsats with a significant propulsion capability exist and so we were breaking entirely new ground with this Team X study at JPL
- Our original plan for the orbiter was to leverage the VAMOS study conducted in mid October and conduct a separate Team X study on the atmospheric element
- The VAMOS study did not make the expected progress towards a $100M mission and so we decided to focus the Venus Bridge study on this target for the orbiter
- Two spacecraft approaches appeared promising
  - JPL MarCO Mars Relay CubeSat adaptation
  - Commercial GTO smallsat adaptation
- The MarCO cubesat approach was selected only because of the ready availability of information at JPL's Team X.

Venus Bridge Orbiter - Exploiting MarCO Heritage

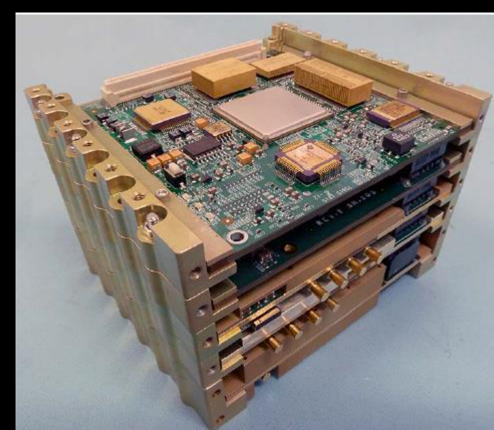
What is MarCO?

- MarCO is the first interplanetary CubeSat – will support telecom relay from the INSIGHT missions entry descent and landing system
- Mounted on the aft bulkhead of the Centaur upper stage, two MarCOs are released after launch and travel to Mars independent of the INSIGHT spacecraft



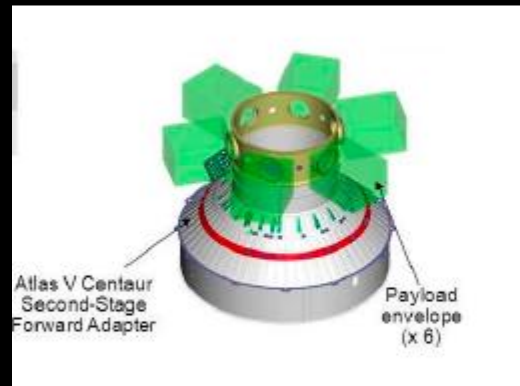
Relevance to Venus Bridge

- Several subsystem technologies – telecom, C&DH and attitude control are relevant to a Venus small satellite mission.
- Venus Bridge SmallSat concepts must build on the MarCO heritage to keep costs in the target range.

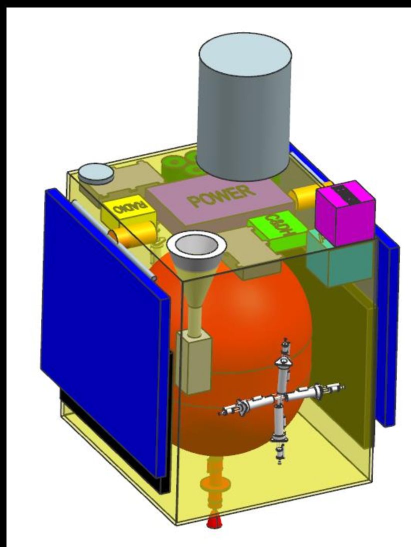


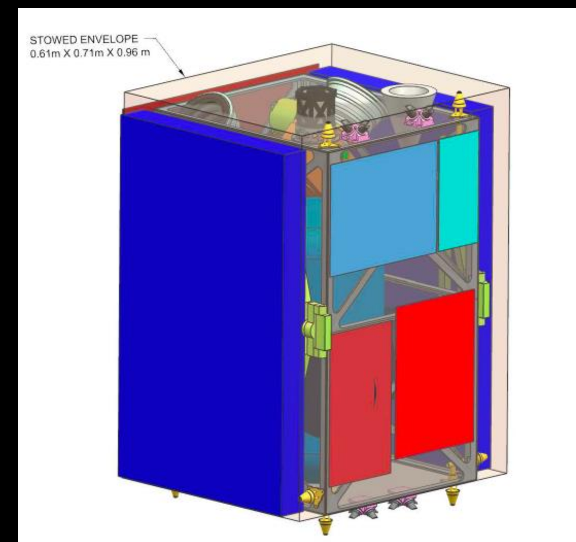
IRIS V2
CubeSat
SmallSat
Deep Space
Transponder

Venus Orbiter Concepts Studied



ESPA Ring for Atlas Centaur Second Stage showing payload envelope





Initial Orbit: Venus Intercept
Propulsion: Chemical - Hydrazine

Initial Orbit: Lunar Intercept
Propulsion: Solar Electric

- **Reaching Venus orbit directly from GTO with an ESPA compatible vehicle is a stretch.**
- **However, boost from GTO to lunar intercept or beyond should be possible with either a relight of the Centaur upper stage or a SHERPA space tug**

Potential Atmospheric Elements - Assessment

- Atmospheric Entry with Small Entry Systems
  - Both rigid and deployable entry systems can be designed to handle the Venus entry environment
  - Only the rigid aeroshells are compatible with the ESPA ring dimensional constraints
  - The ESPA compatible 0.54m aeroshell is compatible with delivery of deep probes but balloon systems will require a level of miniaturization that has not been explored

- Deep Probe – Miniaturization Feasibility
  - Probes can be as small as 3 kg and still reach the surface in operational condition
  - Streamlining is desirable to optimize lifetime
  - Speed of descent may impact science

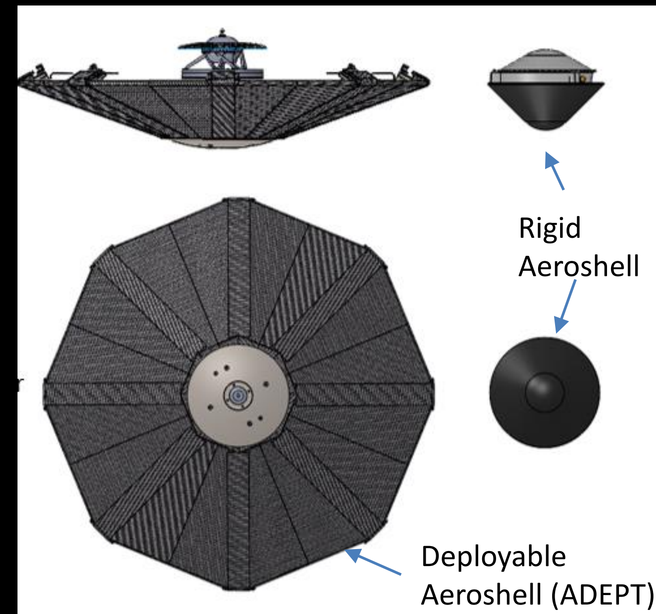
- Balloon – Miniaturization Feasibility
  - Balloon systems are feasible with entry systems of 120 kg or smaller
  - Packaging consideration means that they are not compatible with a 0.54m aeroshell
  - Further balloon miniaturization may be possible but has not been explored

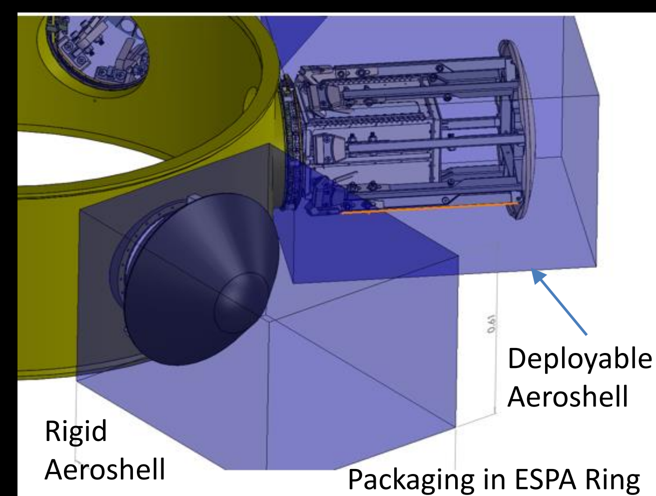
Atmospheric Entry with Small Entry Systems

- Two approaches with similar entry mass examined for feasibility
  - Conventional rigid aeroshell/advanced thermal protection system (HEEET) – 0.54m diam
  - Deployable entry system (ADEPT) – 2 m diam

- Both approaches can be designed to accommodate entry conditions for Venus approach at shallow entry angles
  - Rigid aeroshell tolerates higher heat loads
  - Deployable offers lower deceleration

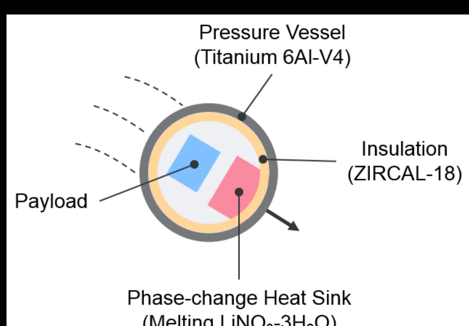
- Packaging volumn in the ESPA rings is the key discriminator
  - Rigid aeroshell- leaves space for carrier
  - Deployable aeroshell – requires all the available space. Nothing for carrier or propulsion

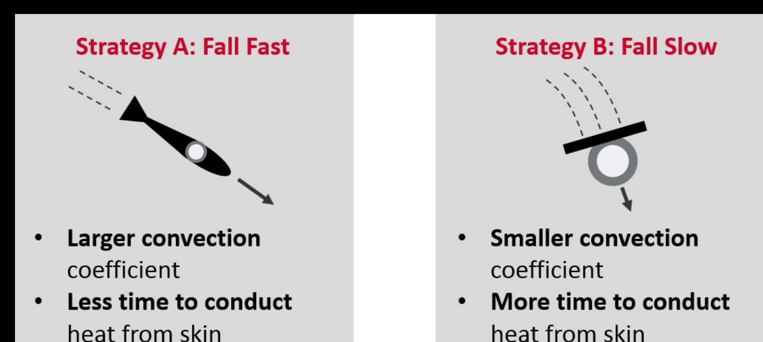




Deep Probe Concept – Miniaturization Feasibility

- **Size is important** for a descent probe to reach the Venus surface
  - Smaller probes have a smaller ballistic coefficient and descend more slowly
  - Smaller probes heat more rapidly because of limited thermal mass
- Pioneer Venus small probe (63 kg) did survive to the Venus surface
- A new analysis of probe scaling indicates that probes can be made as small as 3 kg
  - Would require a streamlined probe to enhance the descent rate
  - Speed of descent may impact ability to do science
  - Trades exist between size science payload and data return for probes in size range 3 to 50 kg



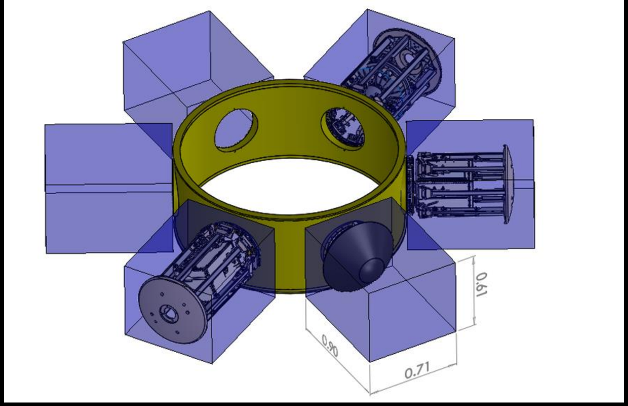


Balloon -Miniaturization Feasibility

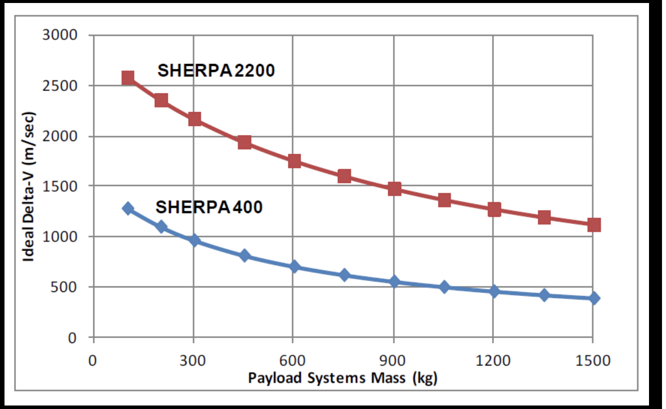
- Balloon and inflation system and science package would be packaged inside the aeroshell
  - Parachute required to enable heat shield separation and balloon inflation
  - Parachute is released after balloon inflation is complete
- Deliver a gondola/instrument module tabout twice the size of the Soviet era VEGA balloon of 1985 and could carry out a signficiant science mission
- Requires an aeroshell with a diameter of at least 1 meter and would only be compatible with a ridealong option
- **Much smaller balloon concepts with entry mass less than 50 kg may be feasible but feasibility has not been assessed**

Getting Atmospheric Elements to Venus

- Options exist for getting the atmospheric elements on an Earth escape trajectory
- Potentially multiple probes could be launched towards Venus still attached to the ESPA ring
- From a lunar intercept trajectory atmospheric elements could be launched towards Venus with a small chemical cruise stage (570m/sec)



Probe concepts on ESPA ring



SHERPA Performance Data

SHERPA In Space Tug

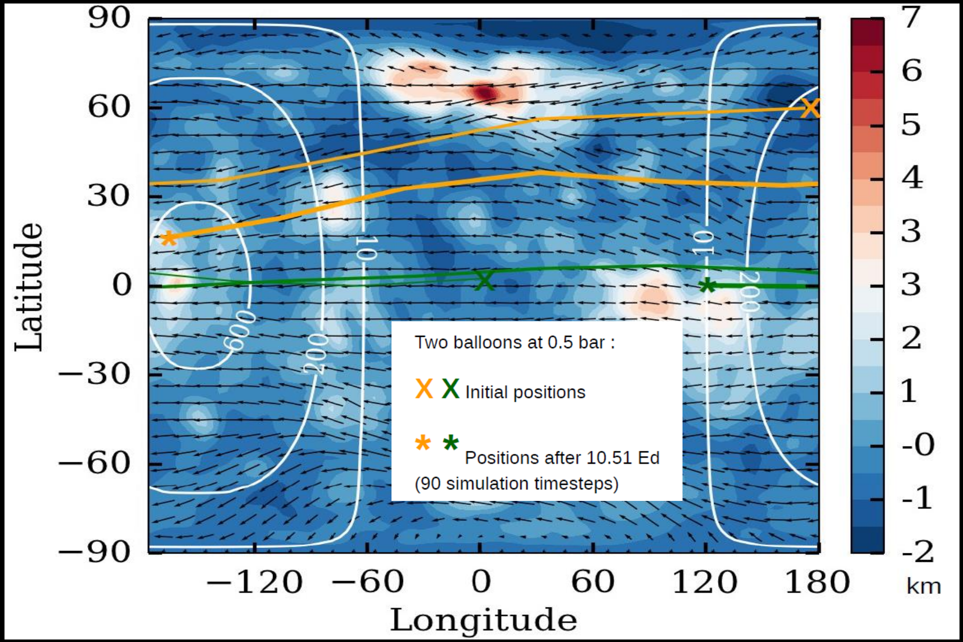
Telecom – Orbiter to Earth and Balloon Relay

- Orbiter to DSN communication is limited by antenna size and transmit power
  - Earth- Venus range variation > large variability in rates
  - On board storage enables optimal transmit time
  - On board processing can reduce telecom needs

- Orbiter to descent probe data rate appear compatible with science needs
  - Probe data return of 30 Mb appears feasible for a one hour probe lifetime with UHF relay

- Orbiter to Balloon relay design needs to consider the path of the balloon
  - Simulations indicate that latitude range of the balloon appears bounded
  - Optimal inclination of the orbiter will depend on latitude where balloon is deployed

Balloon Trajectory Simulations for 10 Earth Days



- *Balloons inserted close to the equator stay close to the equator (green trajectory)*
- *Balloons inserted at mid latitudes show larger excursions in latitude*
- *Balloons do not drift to the pole as initially expected*

Summary

- There are realistic pathways for getting to Venus using secondary payload capabilities that are available to NASA including those using ESPA ring launch adaptors
- Two approaches for developing low cost Venus smallsats with a telecom relay capability have been identified. We do not yet know which will be the most productive direction
- There are no show stoppers for developing entry systems in the size range of 20 to 120 kg also compatible with ESPA ring packaging for delivering probes and balloons to Venus
- Deep probes can be scaled to sub 10 kg sizes and still reach the surface of Venus in operating condition. Miniaturization of balloon deployment still to be addressed
- Propulsion remains a formidable challenge. Both chemical and solar electric approaches may play a role depending on the choice of orbit. Aeroassist technologies should also be considered.
- The study has not reached a definitive conclusion on the feasibility of a Venus Bridge with a $200m cost cap. However, there clearly is a pathway to cost effective science at Venus exploiting advances in smallsats and cubesat technology