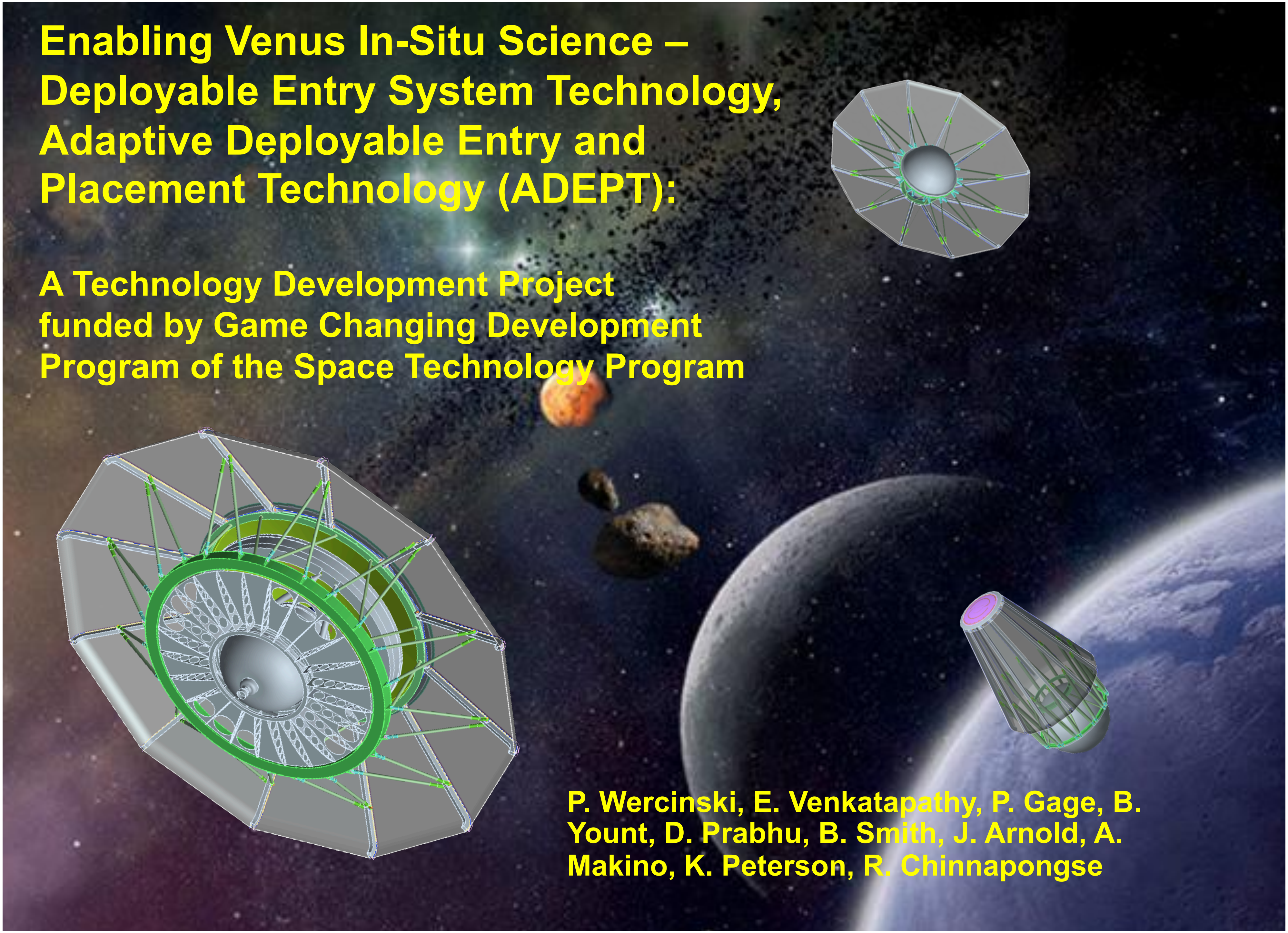
Enabling Venus In-Situ Science – Deployable Entry System Technology, Adaptive Deployable Entry and Placement Technology (ADEPT):

A Technology Development Project funded by Game Changing Development Program of the Space Technology Program



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What is this talk about?

- **Venus is one of the important planetary destinations for scientific exploration, but…**
  - The combination of extreme entry environment coupled with extreme surface conditions have made mission planning and proposal efforts very challenging
- **We present an alternate, game-changing approach (ADEPT) where a novel entry system architecture enables more benign entry conditions and this allows for greater flexibility and lower risk in mission design**

Outline

- **Background: The challenge of entry at Venus**
- **Venus Mission**
  - VITaL: Example Venus Lander mission to meet NRC Decadal Survey Science Recommendations
- **ADEPT – Mechanically Deployable Aeroshell Integrated Approach and Results of application to VITaL mission design**
- **Concluding Remarks**

ADEPT

ACKNOWLEDGEMENT

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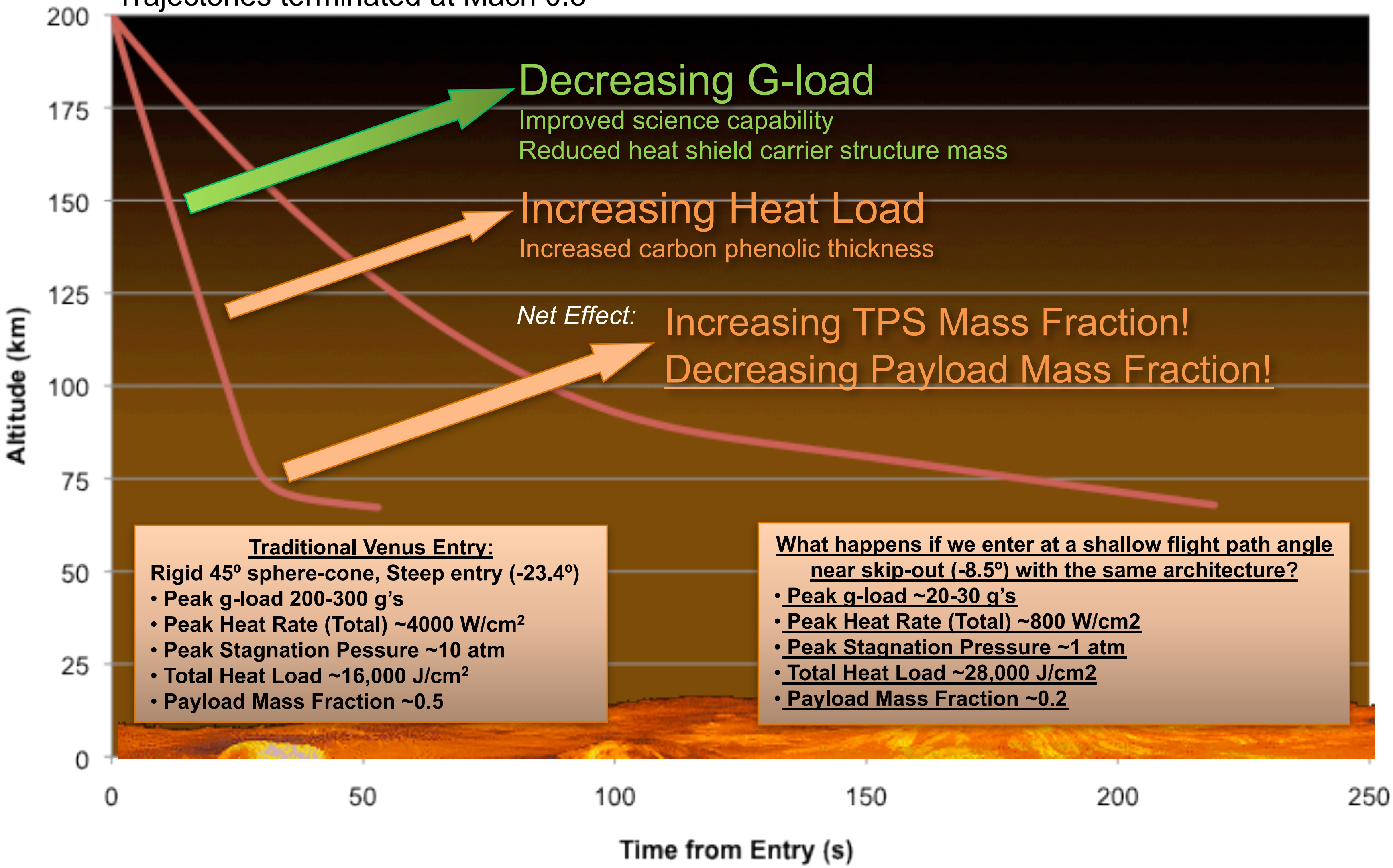
– NASA Ames Research Center is leading this effort and is supported by NASA Langley Research Center, NASA Johnson Flight Center, NASA Goddard Flight Center and Jet Propulsion Laboratory.
– Content of this presentation was previously given at the IPPW-9 (June 2012) in two presentations by (Venkatapathy, Glaze et al)

ADEPT

High-Speed Atmospheric Entry at Venus : The Challenge

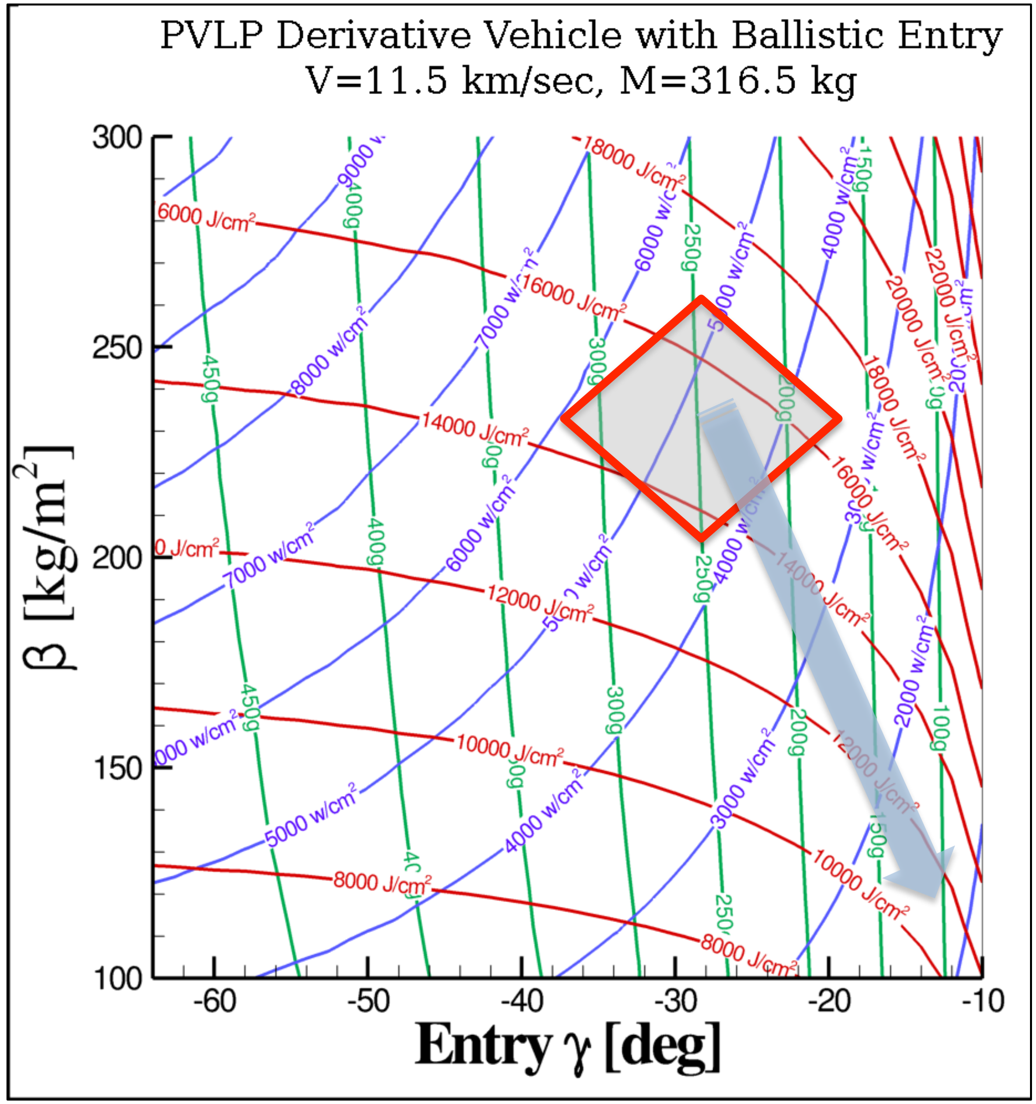
m/CdA(β) = 208 kg/m^2 (3.5m diam, 45º sphere-cone, 2100 kg entry mass)
V_{entry} = 11.25 km/s
Trajectories terminated at Mach 0.8



High-Speed Atmospheric Entry at Venus : The Challenge

ADEPT

- **For rigid aeroshell entry:**
  - Ballistic coefficient 200-250 kg/m^2
  - Size constrained by launch shroud
  - Entry mass constrained by launch vehicle throw capability
- **For Carbon-Phenolic TPS:**
  - Balance between TPS and Payload mass fraction leads to extreme heatflux, pressure and G'load
- **Alternate option:**
  - Design entry architecture that can operate at shallower entry flight path angle (lower g-loads) and a lower ballistic coefficient (lower heat load)



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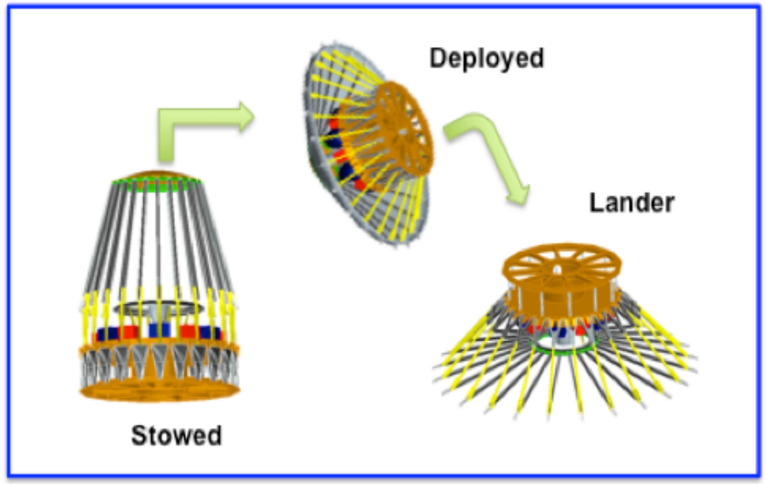
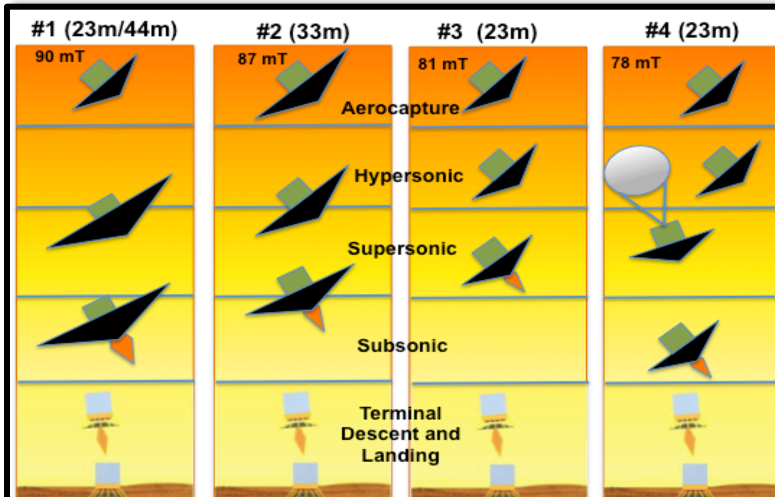
Adaptive Deployable Entry and Placement Technology (ADEPT) for Human Mars Missions

- **A Mechanically deployable, low ballistic coefficient concept developed and demonstrated to be viable (2010-2011) for Human and Heavy Mass Mars Missions**

- Designed like an umbrella with flexible carbon fabric to generates drag and withstand entry heating. Ribs, struts and and mechanisms allow deployment and gimballing of the frontal surface for lift vectoring during aerocapture, entry and descent.
- Analysis, design, testing as well as mission design performed to prove viability of the mass competitive concept.
- Mechanically deployed systems achieve low ballistic coefficients resulting in:
  - Load path that is predictable via skin/ribs/struts and behaves more like rigid aeroshell system
  - OCT requested risk mitigation strategy for alternate low ballistic coefficient entry systems
  - Allows for extensive ground tests to achieve many system certification requirements
  - Lower cost than extensive flight test program
- OCT funded a Technology Maturation Project (2012)





Mars 40 MT Landed Payload for all architectures

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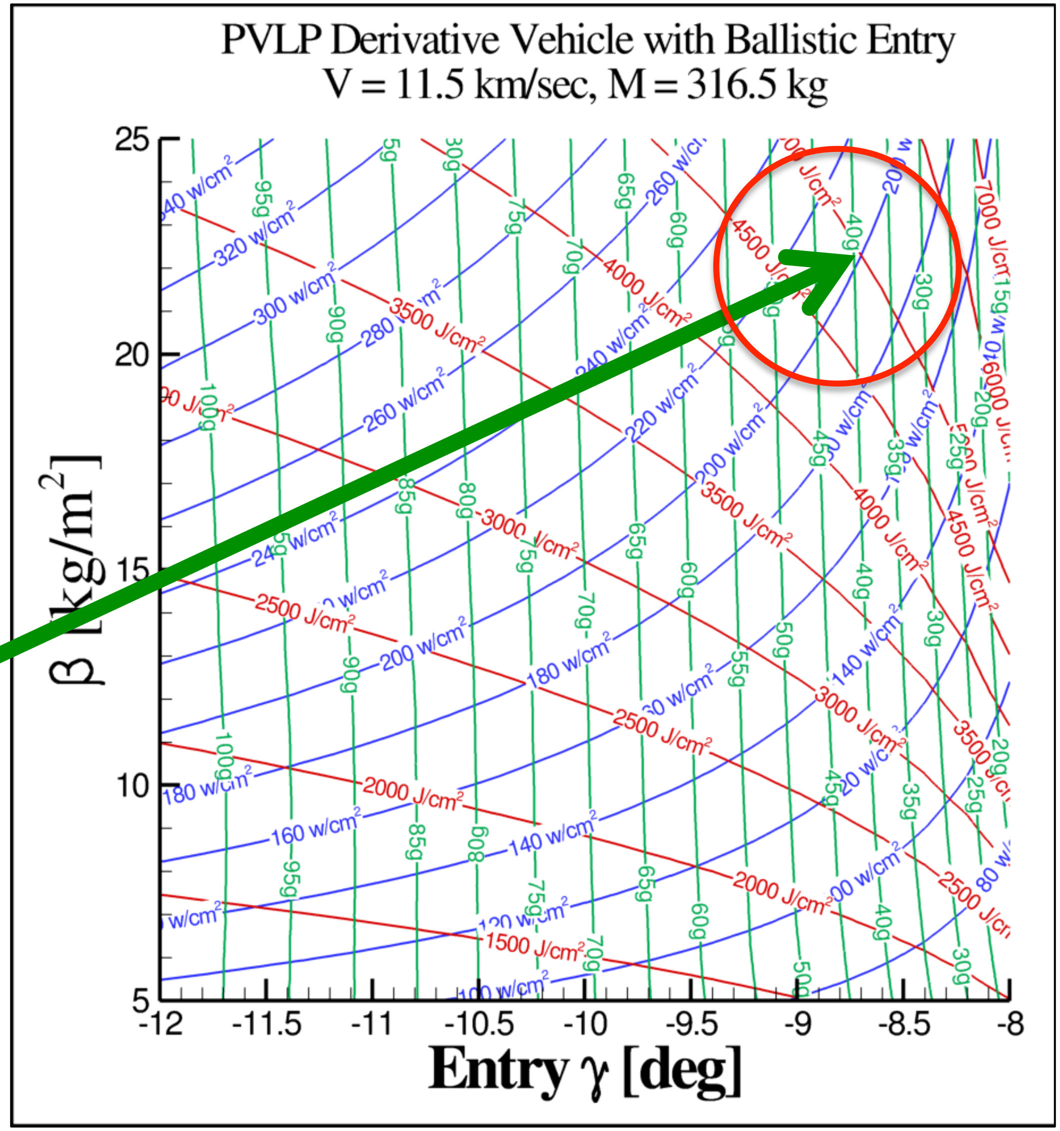
Game Changing Approach to Venus Direct Entry with a Low Ballistic Aeroshell Concept

- **Assume ballistic coefficient can be lowered 10 x**

- **A material that can sustain 250 W/cm^2 is now feasible**
- **Corresponding heatload and pressure are considerably lower as well**
- **Peak deceleration can be reduced by an order of magnitude**

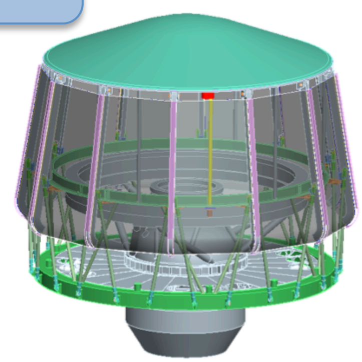
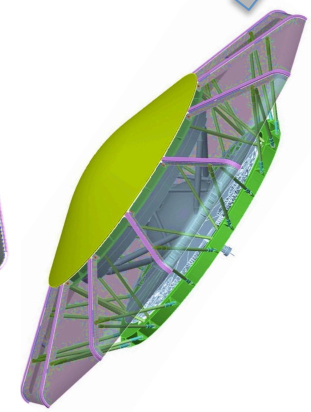
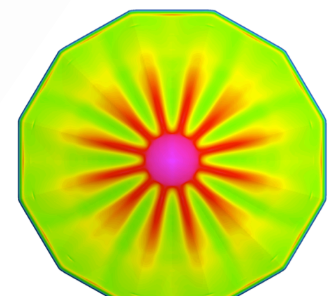


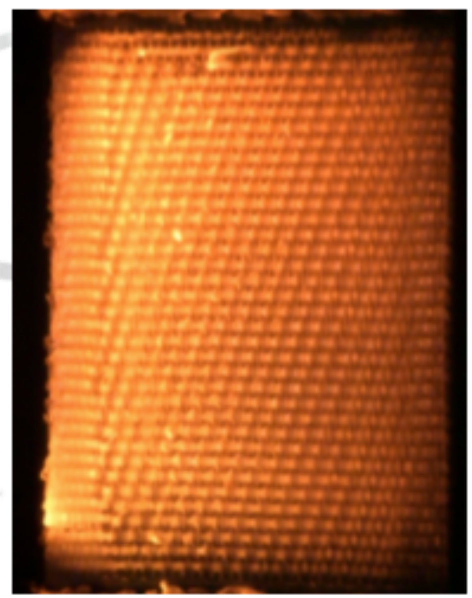
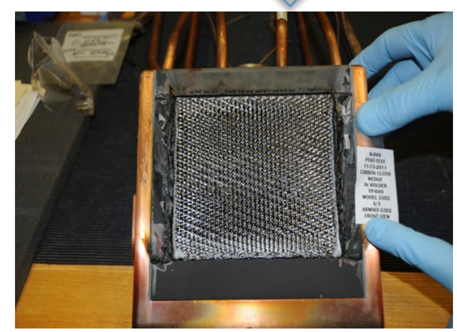
ADEPT

***ADEPT (Adaptable, Deployable, Entry and Placement Technology)** is a low ballistic coefficient entry architecture (m/CdA < 50 kg/m²) that consists of a series of deployable ribs and struts, connected with flexible 3D woven carbon fabric skin, which when deployed, functions as a semi-rigid aeroshell system to perform entry descent landing (EDL) functions.*

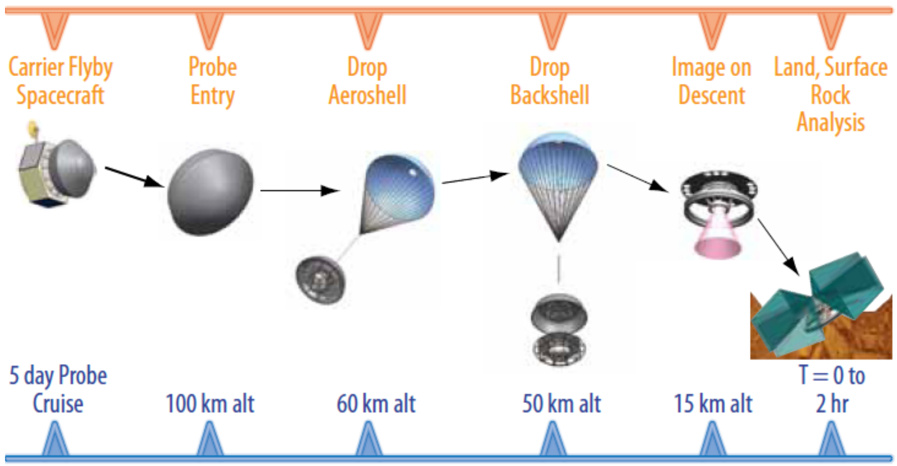
ADEPT: STP GCD Project (2yr) started in FY12
=> Achieve TRL 5 at end of FY13

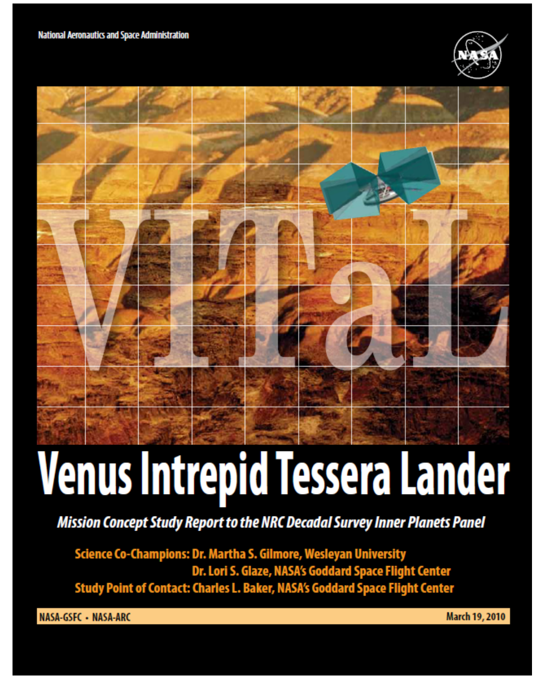
- **ADEPT Year 1 – Budget ($3.3 M)**
  - Characterize thermal and mechanical performance of 3D woven carbon fiber fabric
  - Develop ADEPT flight system requirements/capabilities
  - Start design process for Sub-scale demonstration ground test article
- **ADEPT Year 2 – Budget ($3.5M**
  - Continue 3D woven material of Thermal and Mechanical characteristics development
  - Design, Fabricate and Test sub-scale ground test article (~2m diameter)
  - Initiate Potential Flight Test and/or Focused Ground Test and Development Planning

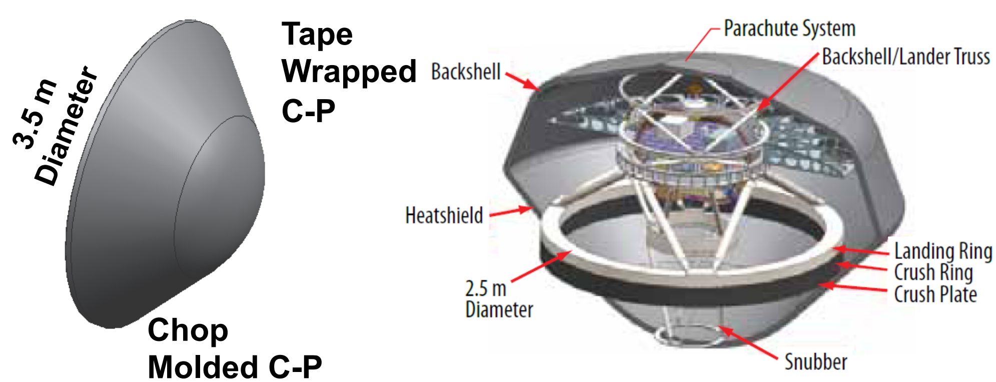



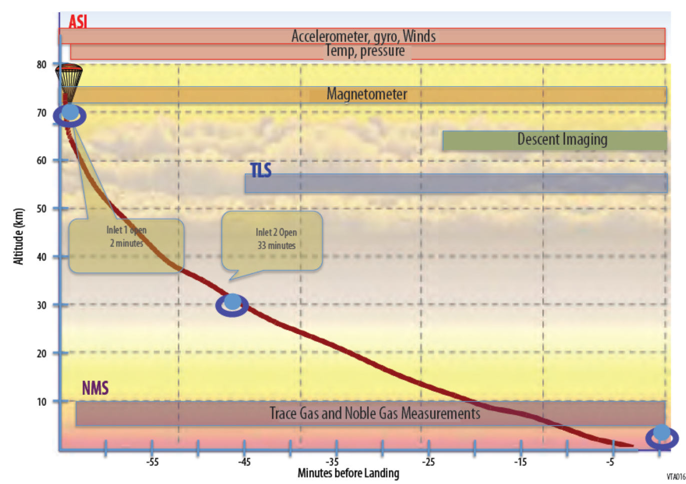
Applying ADEPT to a VISE-like Surface Mission: Venus Intrepid Tessera Lander (VITaL)





- **1 hour descent science**
  - Evolution of the atmosphere
  - Interaction of surface and atmosphere
  - Atmospheric dynamics
- **2 hours of surface and near-surface science**
  - Physics and chemistry of the crust





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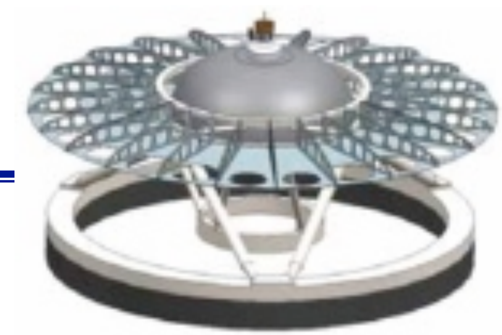
VITaL Strawman Science Instrument Complement

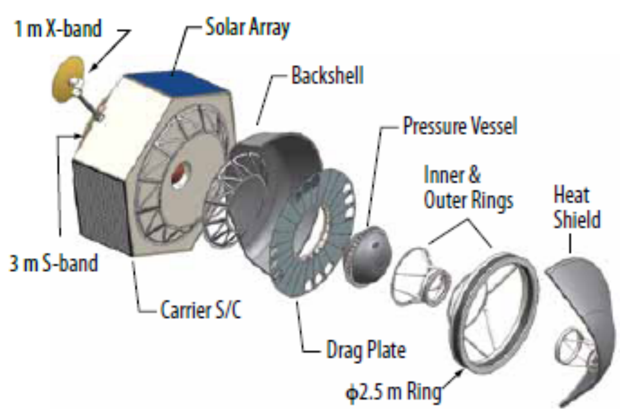


Optimistic with conventional aeroshell: steep entry angle = high g-loads

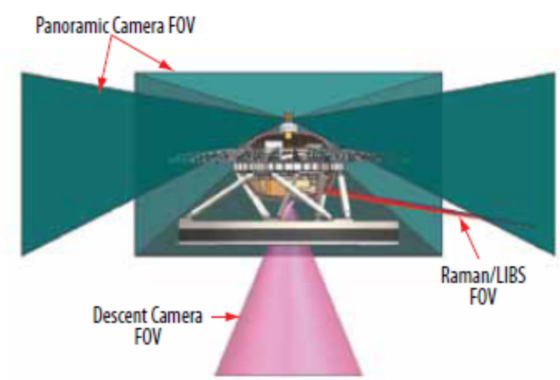
	Mass (kg)	Power (W)	Volume (meters)	Data Rate/ Volume	TRL / Heritage	Comment
Neutral Mass Spectrometer (NMS)	11	50	0.26 x 0.16 x 0.19	2 kbps	High/MSL/SAM	Data rate during descent; reduced to 33 bps on surface
Tunable Laser Spectrometer (TLS)	4.5	17	0.25 x 0.10 x 0.10	3.4 kbps	High/MSL/SAM	Data rate during descent; reduced to 300 bps on surface
Raman/Laser Induced Breakdown Spectroscopy (LIBS)	13	50	Per Optical Design	5.2 Mb per sample	Medium	12 bit, 3 measurements per sample - one Raman and 2 LIBS
Descent Imager	2	12	Per Optical Design	6.3 Mbits per image	High	12 bit, 1024 x 1024
Magnetometer	1	1	0.20 x 0.10 x 0.10	0.064 kbps	High/Various	Data rate during descent; reduced to 6.4 bps on surface
Atmosphere Structure Investigation (ASI)	2	3.2	0.10 x 0.10 x 0.10	2.5 kbps (descent) 0.25 kbps (surface	High/Flagship	
Panoramic Imager	3	12	Per Optical Design	16.4 Mbits per band	High	12 bit, 2048 x 2048 detector
Context Imager	2	12	Per Optical Design	25.2 Mbits	High	12 bit, 2048 x 2048 detector

Data volumes include 2:1 compression

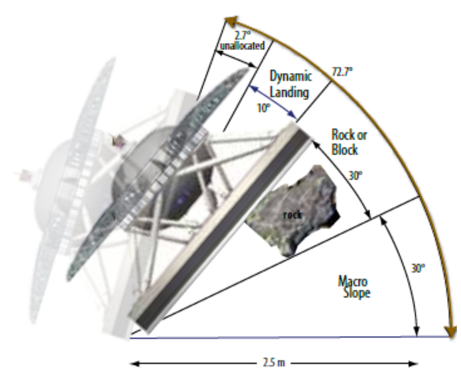
Entry flight System



Camera/Raman/LIBS Fields of View



Stable Landing



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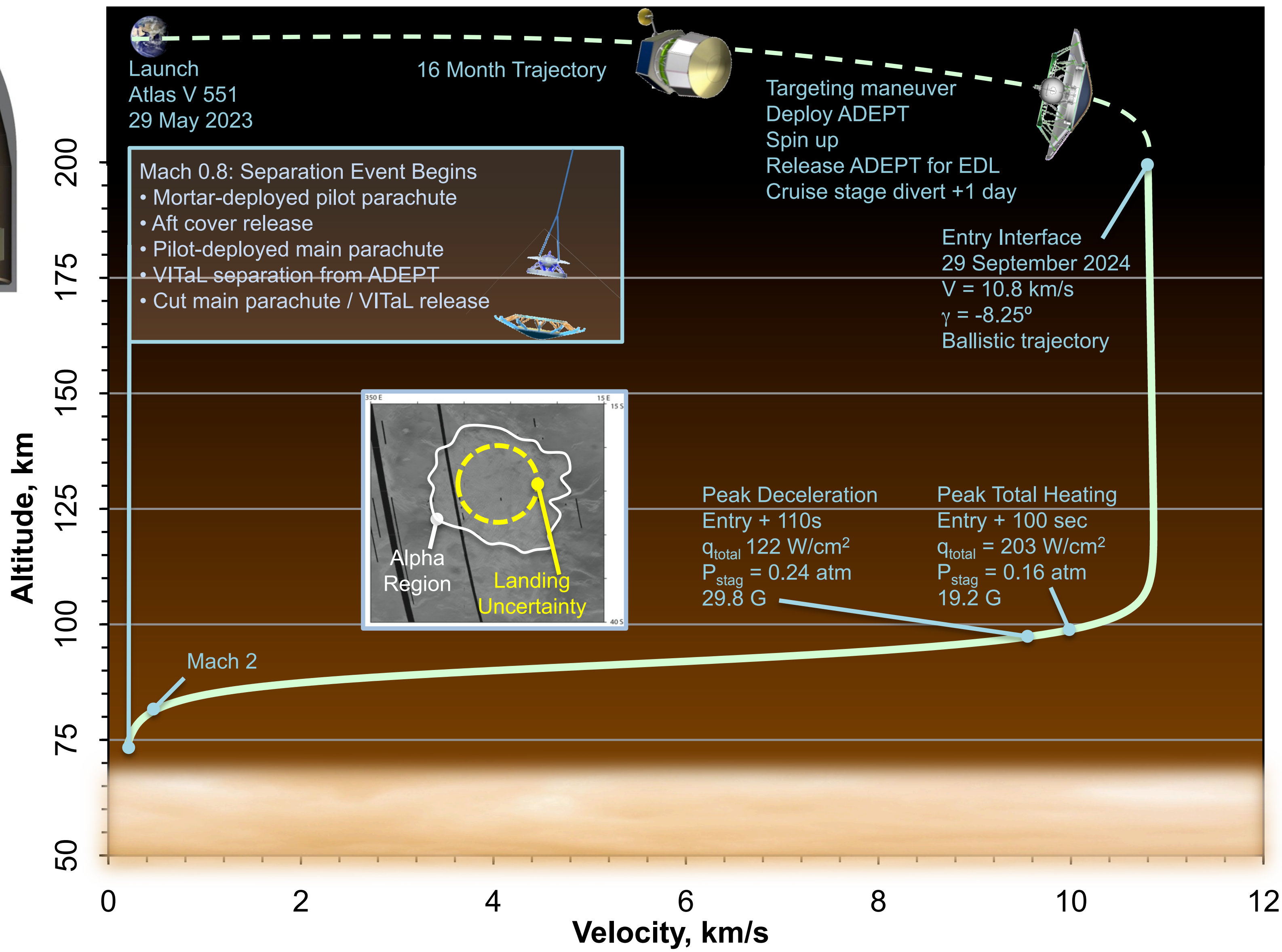
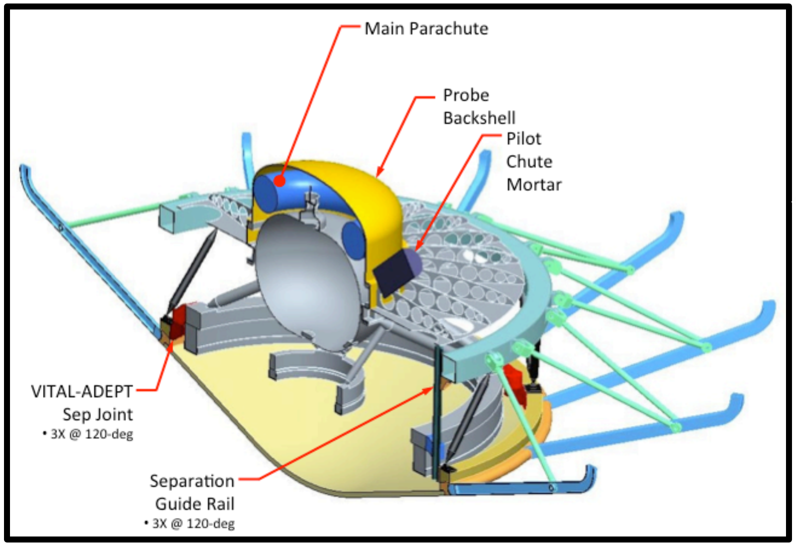
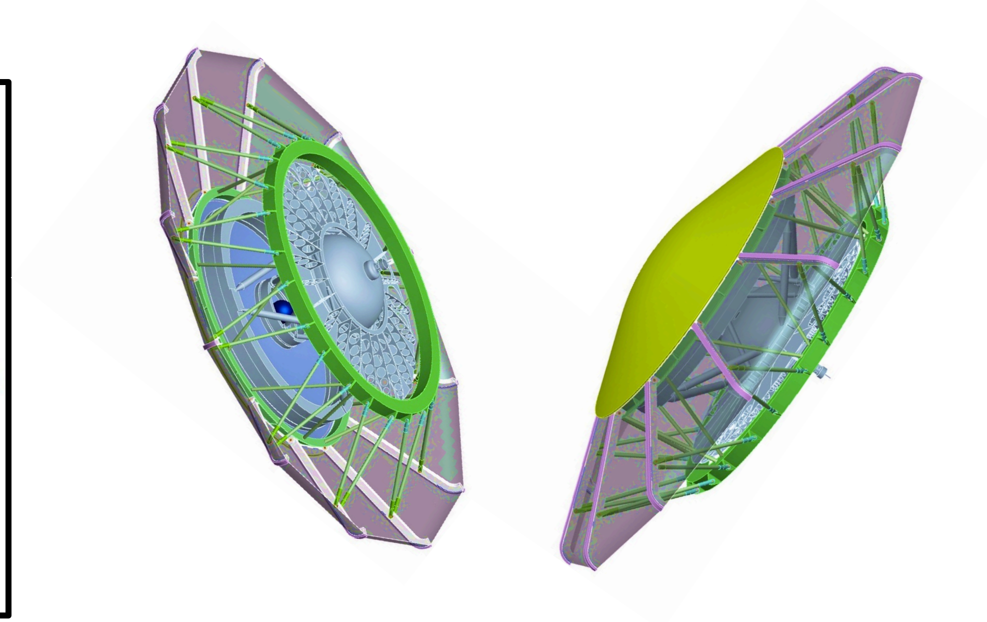
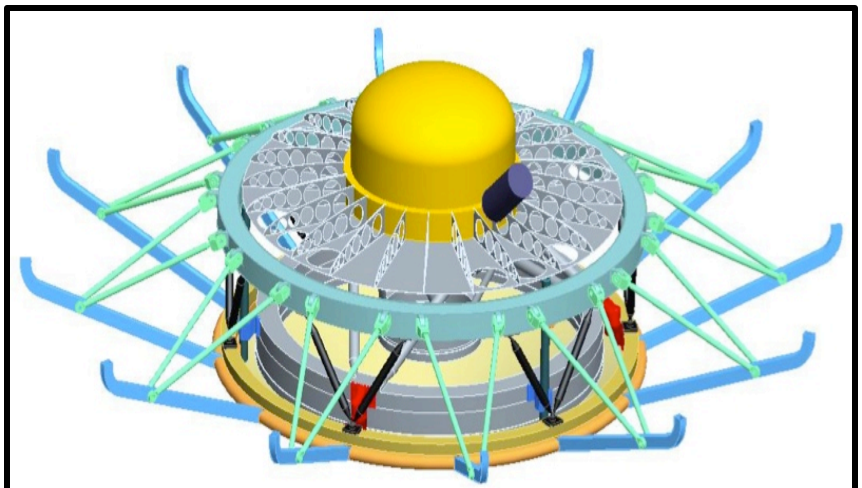
ADEPT-VITaL Mission Quick-Look



ADEPT-VITaL Design Details







- **ADEPT- VITaL Design Results:**
  - Margined mass estimates for ADEPT-VITaL entry configuration are lower than baseline VITaL

ADEPT-VITaL Mission Feasibility Report

- **Study Objective:** ***assess the feasibility of the ADEPT concept by quantifying potential benefits for the NRC Decadal Survey's Venus In-Situ Explorer (VISE) Mission and checking for potential adverse interactions with other mission elements, such as launch and cruise.***

- **The ADEPT project chose to study the Venus Intrepid Tessera Lander (VITaL) design, a VISE lander developed by NASA GSFC for the Decadal Survey's Inner Planets Panel. Results are documented in the *ADEPT-VITaL Mission Feasibility Report*, dated 13 July 2012.**

The ADEPT-VITaL Study Addresses:

- **Mission Design Elements:**
  - **Launch vehicle**
  - **Interplanetary trajectory design / launch date**
  - **Cruise CONOPS / time of ADEPT deployment**
  - **Carrier spacecraft mods. / mass and power impacts**
  - **VITaL lander modifications and mass savings**
- **ADEPT-VITaL Vehicle Subcomponent Design:**
  - **Structures**
  - **Mechanisms**
  - **Materials**
- **Payload Separation Event**
- **Key Trade Studies:**
  - **Entry shape / trajectory**
  - **Structures and mechanisms trades**
- **Operating environments: stowed configuration**
  - **Launch vibro-acoustic**
  - **Cruise cold soak**
- **Operating environments: deployed configuration**
  - **Aerothermodynamic loads**
  - **Structural and aeroelastic loads**
  - **Aerodynamic stability and flight dynamics**

The ADEPT Team used Venus robotic as most challenging class for low ballistic coefficient decelerator applications

- Fully addressed mission feasibility
- Technology development risks identified
- Close collaboration with Venus Mission Stakeholder (GSFC: Glaze)

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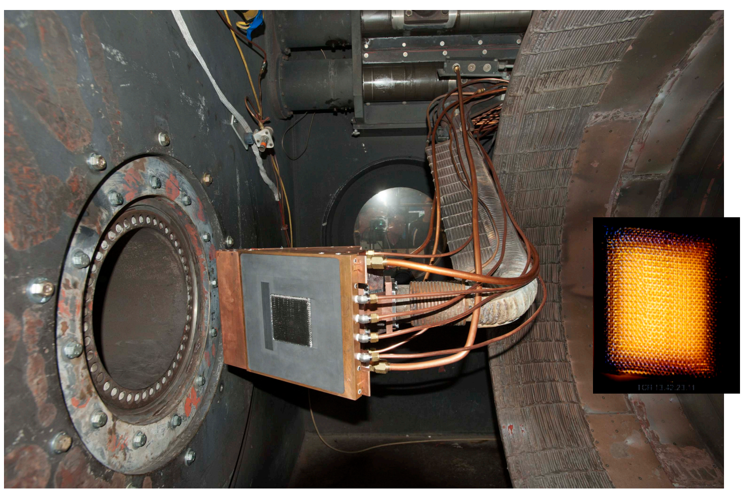
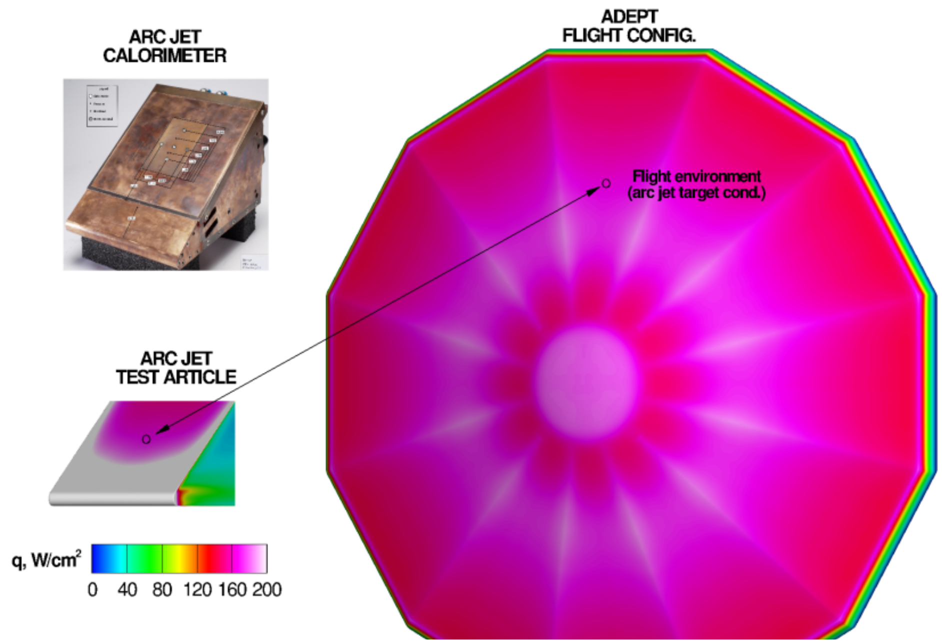
ADEPT Year-1 Major Accomplishment: Carbon Fabric Capability Demonstration

- **Bi-axial Loaded Aerothermal Mechanical (BLAM) Test Objectives:**
  - Evaluate the carbon fabric's structural integrity under combined aerothermal and biaxial loading. Intended to be a unit test for the acreage of the ADEPT vehicle (far away from the ribs)
  - Evaluate the rate of layer loss as a function of different combined loads.
- **Test Results:**
  - Data shows that the carbon fabric is able to maintain load at temperature.
  - Biaxial load in the cloth from 188 lbs/in to 750 lbs/in has little to no impact on the rate of layer loss of the carbon fabric.
  - Flipping the warp/weft direction had little effect on the rate of layer loss of the carbon fabric.
  - Fabric tested easily withstood a heat load of 15.7 k above the 11 kJ/cm^2 expected for a Venus mission





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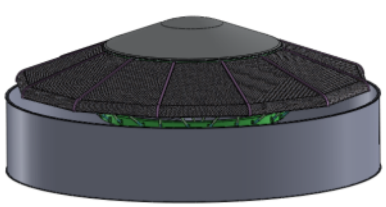
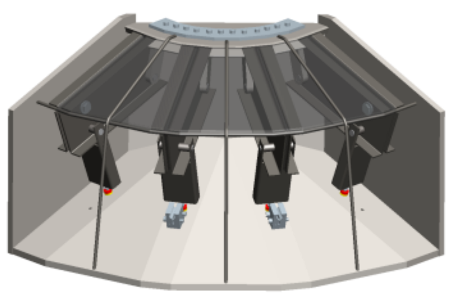
ADEPT Year-2 Technical Plan Highlights

FY 13	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
GTA	SRR		PDR	CDR C-Cloth Procurements	CDR					*Deployment Testing	*Load Testing	
Radiant Testing		PDR			CDR			Radiant Test-1				
Component Testing				C-Cloth Load Tests		PDR BLAM-2	C-Cloth Materials Database	CDR BLAM-2	BLAM-2 Seam Tests			
Flight Test	ADEPT/VITaL Test Plan Kick-off		ADEPT/VITaL		SDR		SRR			ADEPT/VITaL Final Report		MCR

*GTA tests could occur earlier by accelerating procurement of long lead items

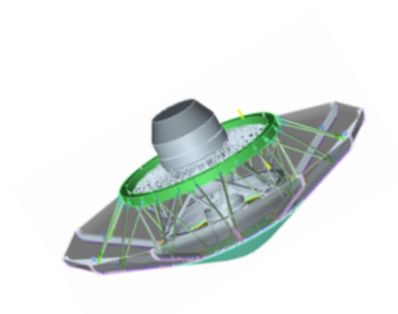


Ground Test Article
Deployment & Load Tests



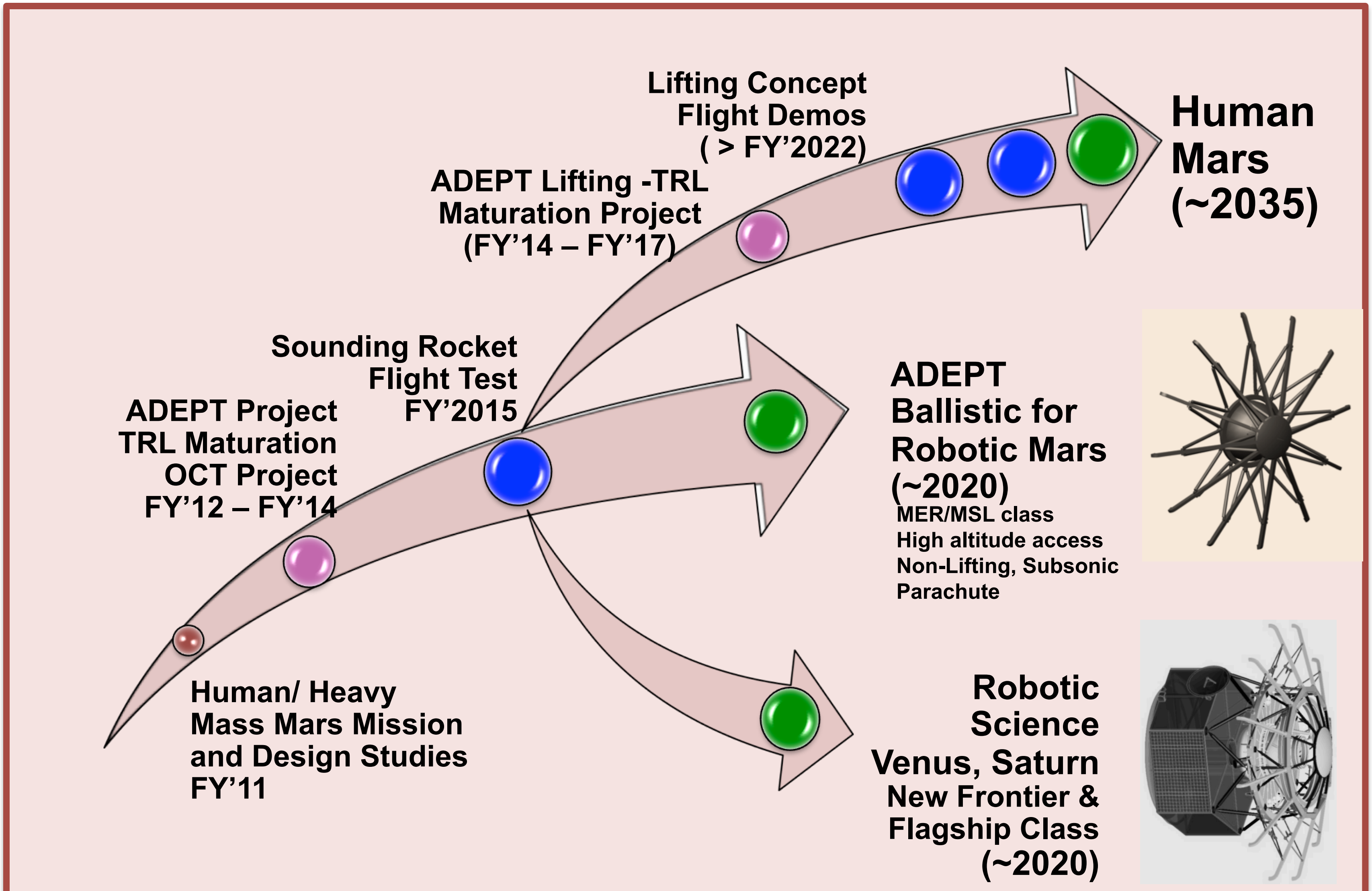
Radiant Testing
Thermal Tests

BLAM-2
C-Fabric Seam Tests



ADEPT/VITaL
Flight Test Planning

ADEPT Technology Maturation and Mission Applications Timeline



Concluding Remarks

- **ADEPT, a Low Ballistic Coefficient, Mechanically Deployable Entry System Architecture is a Game Changer:**
  - Dramatically decreases severity of the entry environment conditions due to high altitude deceleration
  - Enables use of delicate and sensitive instrumentation
  - Use of flight qualified instrumentation for lower g-load at Mars and elsewhere
  - Entry mass and the launch mass are considerably reduced
  - Mission Risk and Cost, once the technology is matured and demonstrated, will be reduced considerably
- **GCD investment in ADEPT, mechanically deployable aeroshell technology, has broad payoff for Solar System Exploration and Science including Venus**
- **Continued Technology Maturation of ADEPT concept by 2015/2016 will**
  - Enable Venus Missions with more comprehensive science to be a top contenders for the next round of New Frontier AO
  - Continue Deployable Entry Concept development for Mars robotic and eventual human exploration missions