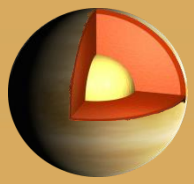

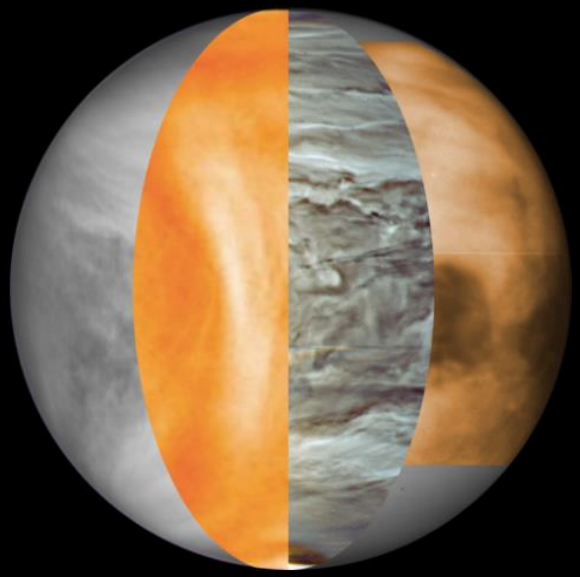

Exploration of Venus with Aerial Platforms

James A. Cutts[1], Jeffery L. Hall[1], Larry H. Matthies[1] & Thomas W. Thompson [1] and Members of the Venus Aerial Platform Study Team

International Venus Conference 2018

Niseko, Hokkaido, Japan

September 11-14, 2018

1. Jet Propulsion Laboratory, California Institute of Technology

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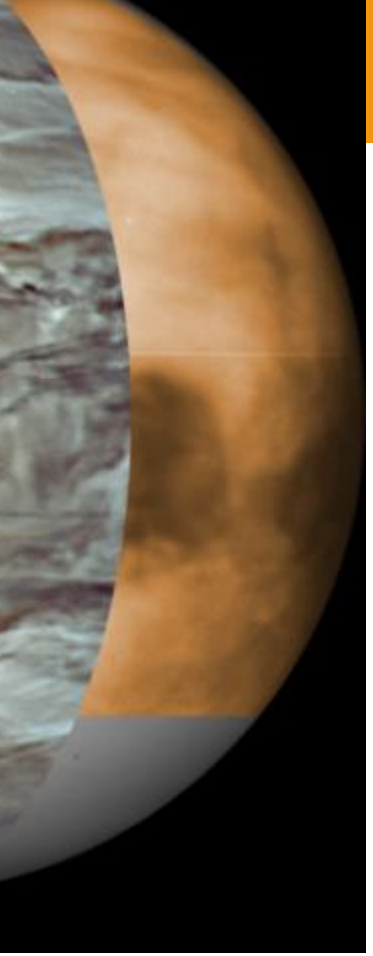


Topics

- Motivation
- Venus Aerial Platforms Study Overview
- Types of Aerial Platforms Considered
- Trade Study
- Trajectory Models
- Venus Entry Option Space
- Venus Aerial Platforms – Design Sweet Spot
- Science Instruments Trade Study
- Aerial Platform Trajectories – Earth and Venus
- Technology Needs
- Summary

Pre-Decisional Information -- For Planning and Discussion Purposes Only

Motivation

- In situ exploration of Venus has been seriously hampered by the severe environment (T =460C and P=90 bars) of the Venus surface.

- Contemporary concepts for lander missions to Venus have more sophisticated instruments but do not survive on the surface of Venus for very much longer than Soviet- era Venera landers

- There are two plausible pathways to long-duration Venus *in-situ* missions
  - Aerial Platforms operating in the temperate regions of the upper atmosphere
  - Surface Platforms utilizing high temperature electronics

- NASA's Planetary Science Division (PSD) is currently studying both pathways for Venus exploration and is considering both concepts as U.S. provided contributions to a joint mission with Russia (Venera D)

Venus Aerial Platforms Study Overview

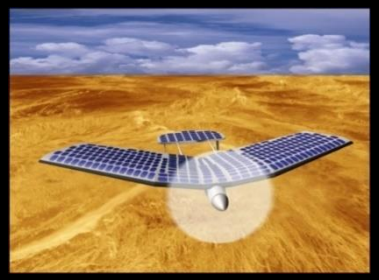
- NASA PSD formed a study team in April 2017 to assess the state of science and technology for aerial platforms and develop a technology plan
- Two face-to-face study meetings were held in June and December 2017 covering the science implementation concept and technical maturity
  - Scientific objectives and aerial platform options space (June 2017)
  - Technical feasibility and technology roadmap (Dec 2017)
- Since the second meeting the study team has been working on completing a report with the key findings of the study
- Today's presentation provides an overview of the principal accomplishments of the study
- The presentation by Jeff Hall that follows provides a detailed description of the principal trade study that will appear in our report

Types of Aerial Platform Considered

Superpressure Balloon (JPL Venus prototype)

Mechanical Compression Balloon (Thin Red Line Aerospace)

Pumped Helium Balloon (Paul Voss CMET)



Solar Aircraft
Geoff Landis (NASA-GRC)

Air Ballast Balloon (Google Loon)

Phase Change Fluid Balloon (JPL)

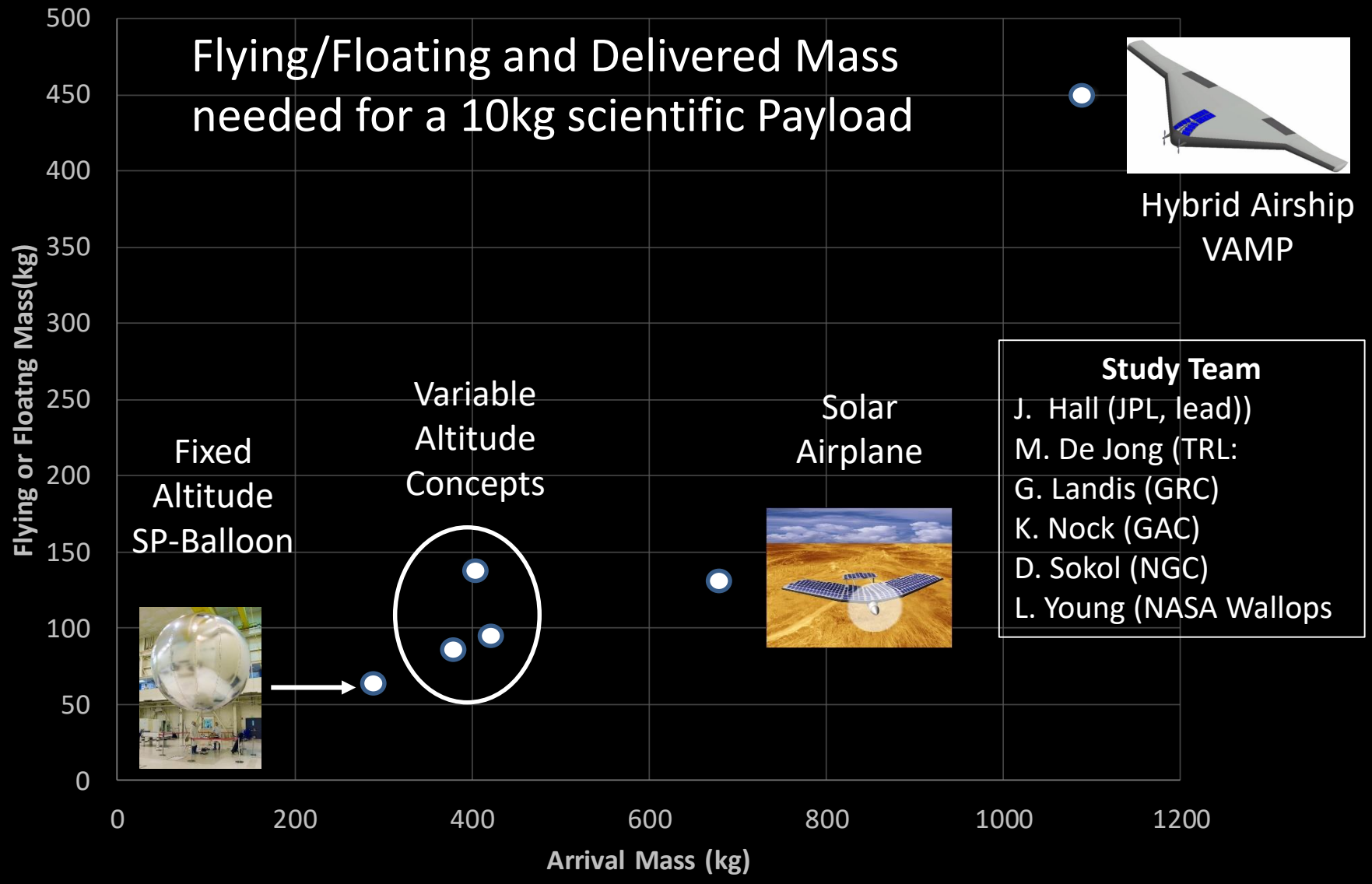
Hybrid Airship (Northrup Venus Atmospheric Maneuverable Platform (VAMP)
Northrop Grumman

Fixed Altitude

Variable Altitude

Variable Altitude and Lateral Control

Venus Aerial Platform – Trade Study



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Venus Entry System Trade Study

Mission Design
Direct Entry
Orbit from Entry

Entry State

Science Objectives
Measurement
Requirements

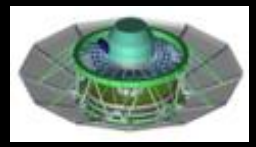
Payload and Measurement Details

Entry System Constraints

Entry Velocity
Entry Flight Path Angle Options

Payload Mass and Volume
Payload Environment Limits
Payload Deployment Conditions
Trajectory Timeline (Transitions)

Study Team
J. Corliss (LaRC, lead))
N. Cheatwood (LaRC)
R. Venkatapathy (ARC)
P. Wercinski (ARC)



Ballistic Coefficient Trades
Controlled Entry
Ballistic Entry

Entry System Design Space

- Entry of most aerial platform concepts feasible with rigid body aeroshell technology
- Deployables (ADEPT and HIAD) may provide packaging and deployment advantages but they are still under development
- Dual-function VAMP requires a protracted multistage development/test program

Scientific Assessment of Aerial Platforms

VEXAG Goals, Objectives and Investigations				Venus Aerial Platform and Sonde Types with Altitude Range (km)							
Goals	Objectives	Investigations	GOI Code	Constant Altitude	Variable Altitude Aerobot		3D control		Probes/Sondes		
				SP Balloon	Nominal Range	Enhanced Range	Solar Airplane	Airship VAMP	Large Probe	Targeted Sonde	Shallow Sond (mult)
				55	50 to 60	40 to 60	66 to 75	50 to 60	65 to 0	55 to 0	60 to 40
Atmosphere	Atmospheric Evolution	Solar Nebula/noble gases	I.A.1	Necessary and sufficient	Necessary and sufficient	Necessary and sufficient	Necessary and sufficient	Necessary and sufficient	Necessary but not sufficient		
		Atmospheric Escape	I.A.2	Necessary but not sufficient	Necessary but not sufficient	Necessary but not sufficient	Necessary but not sufficient	Necessary but not sufficient	Necessary but not sufficient		
	Radiative balance, climate and superotation	Global circulation	I.B.1	Complementary	Necessary but not sufficient	Necessary but not sufficient	Complementary	Necessary and sufficient	Complementary	Complementary	Complementary
		Radiative Balance	I.B.2	Complementary	Necessary but not sufficient	Necessary but not sufficient	Complementary	Necessary and sufficient	Necessary but not sufficient	Necessary but not sufficient	Necessary but not sufficient
		Vertical motions	I.B.3	Complementary	Necessary but not sufficient	Necessary but not sufficient	Complementary	Necessary and sufficient	Complementary	Complementary	Complementary
	Clouds and Haze characterization	Cloud chemistry	I.C.1	Necessary but not sufficient	Necessary and sufficient	Necessary and sufficient	Complementary	Necessary and sufficient	Complementary	Complementary	
		Greenhouse /Cloud physics	I.C.2	Necessary but not sufficient	Necessary and sufficient	Necessary and sufficient	Complementary	Necessary and sufficient	Complementary	Complementary	Complementary
		Role of lightning	I.C.3	Necessary but not sufficient	Necessary and sufficient	Necessary and sufficient	Necessary but not sufficient	Necessary and sufficient	Complementary		
		Biologically relevant chemistry	I.C.4	Necessary but not sufficient	Necessary and sufficient	Necessary and sufficient	Complementary	Necessary and sufficient	Complementary	Complementary	
Surface and Interior	Geodynamics	Stratigraphy/deformation	II.A.1						Complementary	Necessary and sufficient	
		Radiogenic He_4 Ar_{40} in atmos	II.A.2	Necessary and sufficient	Necessary and sufficient	Necessary and sufficient	Necessary and sufficient	Necessary and sufficient	Necessary but not sufficient		
		Geophysical studies	II.A.3	Necessary but not sufficient	Necessary but not sufficient	Necessary but not sufficient	Complementary	Necessary and sufficient			
		Active volcanism and tectonism	II.A.4	Necessary but not sufficient	Necessary but not sufficient	Necessary but not sufficient		Necessary but not sufficient			
		Absolute rock ages	II.A.5								
	Differentiation	Elemental composition	II.B.1.								
		Large scale composition variations	II.B.2			Necessary and sufficient			Necessary and sufficient	Necessary and sufficient	
		Structure of crust	II.B.3	Necessary but not sufficient	Necessary but not sufficient	Necessary but not sufficient		Necessary but not sufficient			
		Core and mantle structure	II.B.4	Complementary	Complementary	Complementary		Complementary			
		Radiogenic crustal elements	II.B.5								
		Subsurface layering	II.B.6	Necessary but not sufficient	Necessary but not sufficient	Necessary but not sufficient					
Interior Surface Atmosphere	Liquid water and the greenhouse effect	History of water from Isotopes	III.A.1	Necessary and sufficient	Necessary and sufficient	Necessary and sufficient	Necessary and sufficient	Necessary and sufficient	Necessary but not sufficient		
		Role of water in tessera	III.A.2			Necessary but not sufficient			Necessary but not sufficient	Necessary and sufficient	
		Hydrous minerals and sediments	III.A.3								
	Interactions of interior-surface and atmosphere over time	Elemental composition-noble gas	III.B.1	Necessary but not sufficient	Necessary but not sufficient	Necessary but not sufficient	Necessary but not sufficient	Necessary but not sufficient	Necessary but not sufficient		
		Rock weathering investigations	III.B.2			Necessary but not sufficient			Necessary but not sufficient		
		Altitude profiles of reactive species	III.B.3	Complementary	Necessary but not sufficient	Necessary and sufficient		Necessary but not sufficient	Necessary and sufficient	Necessary but not sufficient	
		Sulfur outgassing from surface	III.B.4	Complementary	Necessary but not sufficient	Necessary and sufficient	Necessary but not sufficient	Necessary but not sufficient	Necessary but not sufficient	Necessary but not sufficient	
	Other	Solid Body Atmosphere Ang Mom	NA								

Necessary and sufficient to address the investigation in the GOI

Necessary but not sufficient

Complementary to a primary measurement

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Scientific Assessment of Aerial Platforms

Platform Type	Concept	Altitude Range	Technology Maturity			
			Entry	Descent Deployment	Aerial Mobility	System
Fixed Altitude	Superpressure balloon	50 to 60 km	Very High	High	High	High
Variable Altitude	All three concepts	50 to 60 km	Very High	High	Moderate	Moderate
Variable Altitude	All three concepts	40 to 60 km	Very High	High	Low to Moderate	Low to Moderate
3D Control	Solar Airplane	50 to 60 km	Very High	High	Moderate	Moderate
3D control	Hybrid Airship (VAMP)	50 to 60 km	Low	Moderate	Moderate	Low

Maturity Color Code

Low | Low to Moderate | Moderate | High | Very High

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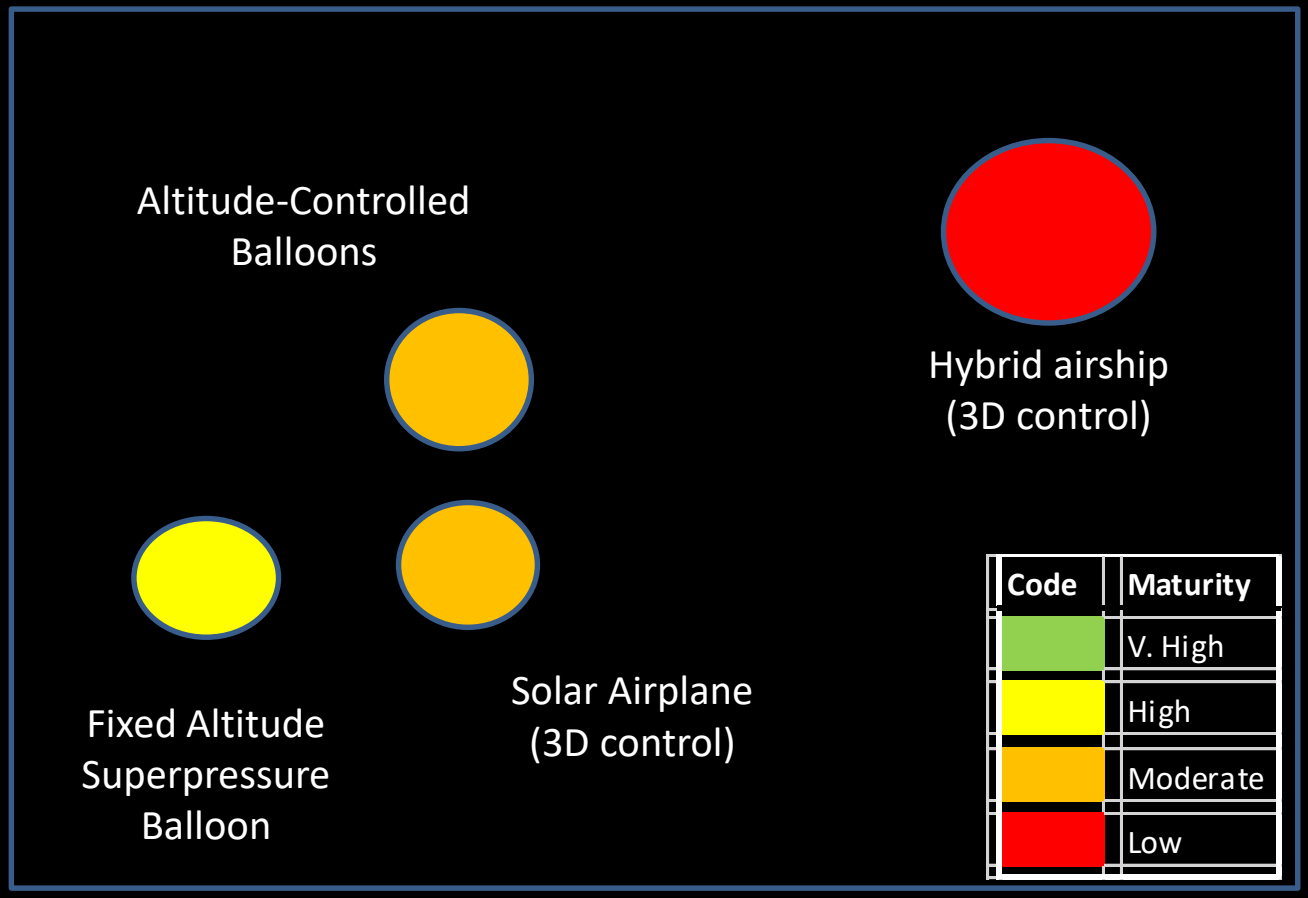
Venus Aerial Platforms – Design Sweet Spot



Code	Maturity
	V. High
	High
	Moderate
	Low

Science Team

R. Grimm (SWRI co lead))
L. Glaze (GSFC, co lead)
K. Baines (JPL/UW)
K. Jessup (SWRI)
A. Komjathy (JPL)
S. Lebonnois (LMD)
S. Limaye (UWisc)
K. McGouldrick (UCol)
G. Schubert (UCLA)
D. Senske (JPL)

Altitude controlled balloons represent a “sweet spot” in the aerial platform option space.

Instrument Systems Trade Study – In progress

Atmospheric Gas Composition

Cloud Haze Composition

Atmospheric Structure Investigations

Geophysical Investigations

Surface Imaging

Aerial Platform Instruments

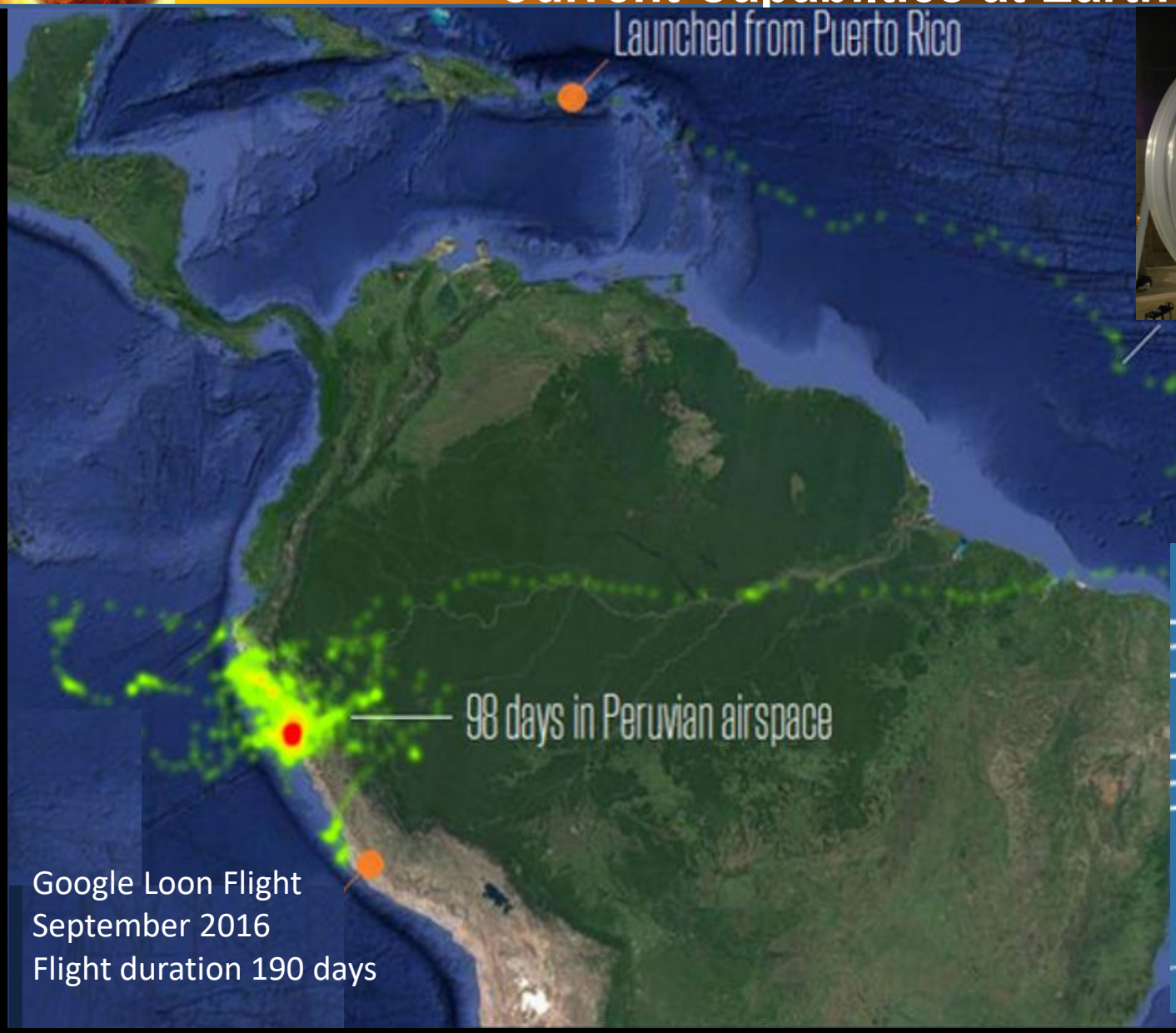
Drop Sondes

Study Team

K. Baines (JPL,)
D. Atkinson (JPL)
S. Krishnamurthy(JPL)
L. Matthies (JPL)
M. Rais-Zadeh (JPL)

- Experimental techniques identified and evaluated
- Instruments with multiple science functions e.g. magnetometers identified
- Prospects of miniaturization assessed

Altitude Controlled Balloons
Current Capabilties at Earth



Google Loon Flight
September 2016
Flight duration 190 days

Variable altitude
air ballast balloon

Using air currents to navigate

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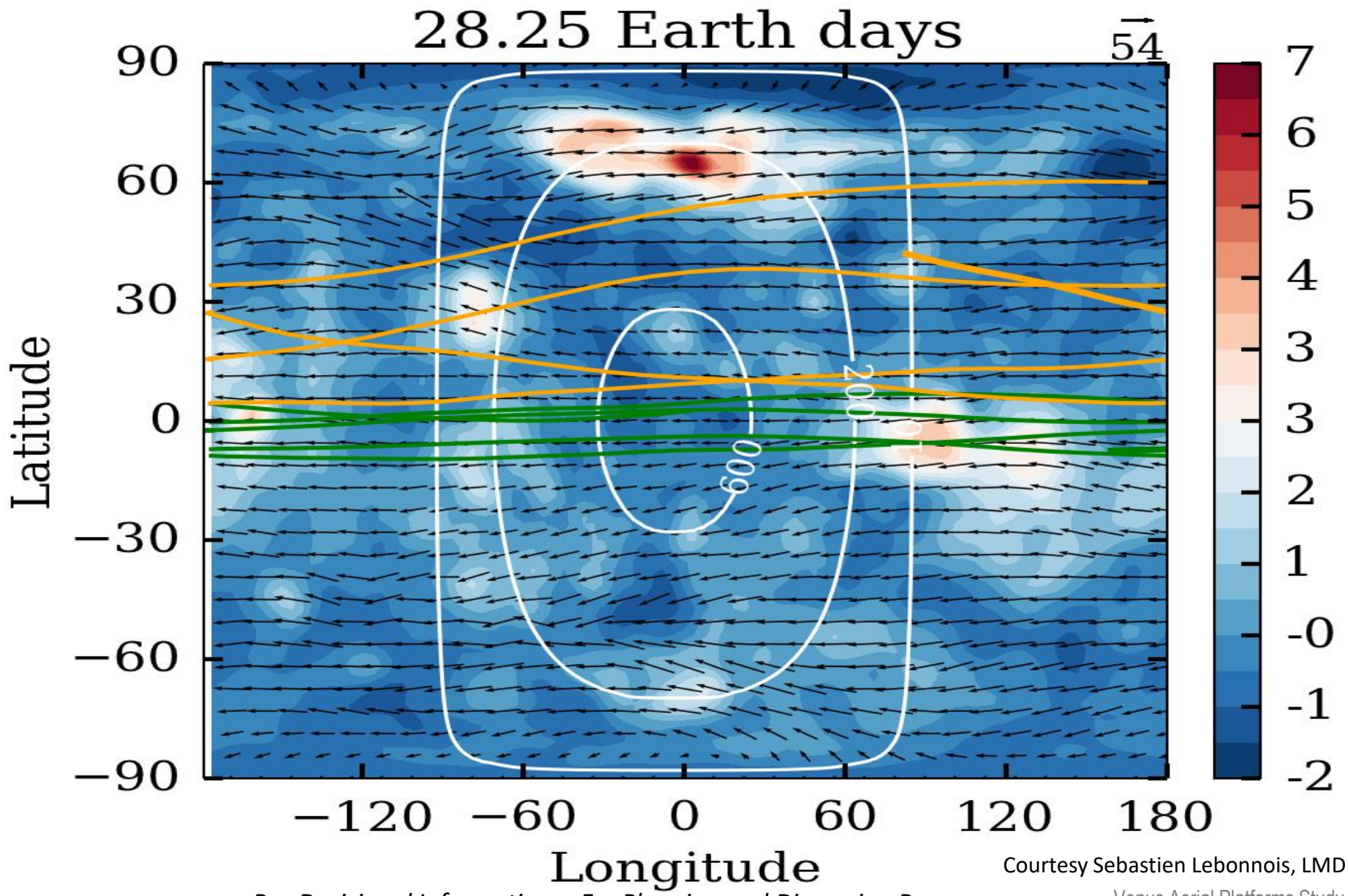
Venus Aerial Platform – Constant Altitude Trajectory Models



Courtesy Sebastien Lebonnois, LMD

Venus Aerial Platform Technology Needs

- Altitude Control Systems Development
  - Design and build subscale models of options.
  - Perform laboratory and atmospheric flight tests
  - Compare performance of options
  - Build full scale model of selected option

- Aerobot Science Module (Gondola) Development
  - Demonstrate GN&C and telecommunications systems
  - Integrate science instruments
  - Incorporate miniaturization (SmallSat and CubeSat technologies)
  - Flight test with full scale model

- Modeling and Simulation Tools
  - Venus environment– atmospheric circulation and solar and thermal fluxes
  - Altitude control systems within the Venus environment
  - Power guidance and telecommunications modesl

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Summary

- Venus Aerial Platforms (VAPs) could offer a credible pathway to long duration in situ missions at Venus. Missions which explore the temperate zone in the Venus clouds are the place to start

- Focusing on the temperate zone enable us to capitalize on the rich heritage of conventional sensors and electronic systems.

- Although the VAP technology for the SP platform is almost ready now, a multi-year investment program focusing on variable altitude capability would enhance the science capability of these platforms

- Among the opportunities for the application of VAP technology are:
  - Joint NASA Russian Venera D Mission Concept– NASA contribution
  - Venus Flagship Mission – currently being studied by NASA
  - Venus Bridge – atmospheric elements
  - Future competitive opportunities – New Frontiers and Discovery