

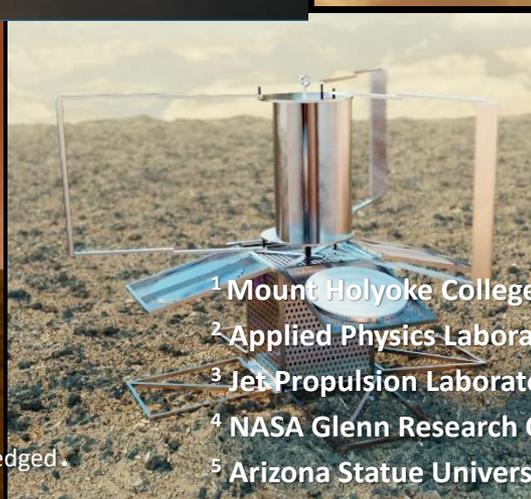
# The Decade of Venus Revitalizing Exploration of our Sister Planet

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Presentation to  
International Planetary Probe Workshop 2019

Oxford, England

July 10, 2019



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# Topics



- Overview
- Decade of Venus
- VEXAG Roadmap Focus Group - Members
- Roadmap Development Process
- Roadmap Development – Topics Assessed
- Venus Goals Objectives and Investigations
- Venus Roadmap 2018
  - Near and Mid Term – 2019 to 2032
  - Far Term – 2033 to 2042
- Roadmap Interdependencies – Science & Technology Feedforward (NEW)
- Mapping New GOI to the Venus Roadmap
  - New and Mid Term – 2019 to 2032 (NEW)
  - Far Term – 2033 to 2042 (PENDING)
- Roadmap Technology Matrix (PENDING)
- Summary

- The three guiding documents for Venus Exploration were written in 2014. Only the Goals Objectives and Investigations has been updated since then
- VEXAG initiated a revision to the three documents in the spring of 2018 with the goal of completing the revision by the end of the calendar year.
- The Roadmap Team was formed in April and had its kickoff meeting in May. Fifteen additional telecons have been held since then leading up to the VEXAG annual meeting
- This is a status report on the Venus Exploration Roadmap

# Decade of Venus!



- Venus exploration, particularly in the U.S., has lagged seriously in recent decades with no missions since Magellan (1989 launch) and no mission selections despite many highly competitive proposals.
- Venus science is now poised for a renaissance in exploration driven by
  - Increasing importance of understanding the evolution of Venus with respect to its sister planet Earth and the multitude of Earth & Venus-sized exoplanets
  - Need to bring the study of Venus into the 21<sup>st</sup> century to enable meaningful comparative planetology for the terrestrial planets
  - Growing interest from early career scientists and engineers in exploring Venus
  - Extensive advances in technologies and experimental techniques for unveiling Venus's scientific secrets
  - Potential of international partnerships for exploring the most accessible of the planets
- The Decade of Venus (2023 to 2032) beckons!

# VEXAG Roadmap Focus Group - Members



- James A. Cutts, JPL, Lead
- Michael Amato, GSFC
- Candace Gray, NMSU
- Scott Hensley, JPL
- Gary Hunter, GRC, (Lead, Technology Focus Group)
- Noam Izenberg, JHUAPL, (Member, Technology Focus Group)
- Walter Kiefer, LPI
- Tibor Kremic, GRC
- Kevin McGouldrick, U. Col. , (Member, GOI Focus Group)
- Joseph O'Rourke, ASU
- Sue Smrekar, JPL

## Other Contributors

- Bob Grimm, SWRI, VEXAG Chair
- Marty Gilmore, Wesleyan U., VEXAG Co-Chair



# VEXAG Venus Exploration Roadmap – Process



Venus Goals, Objectives and Investigations (GOI) Focus Group

Venus Technology Focus Group

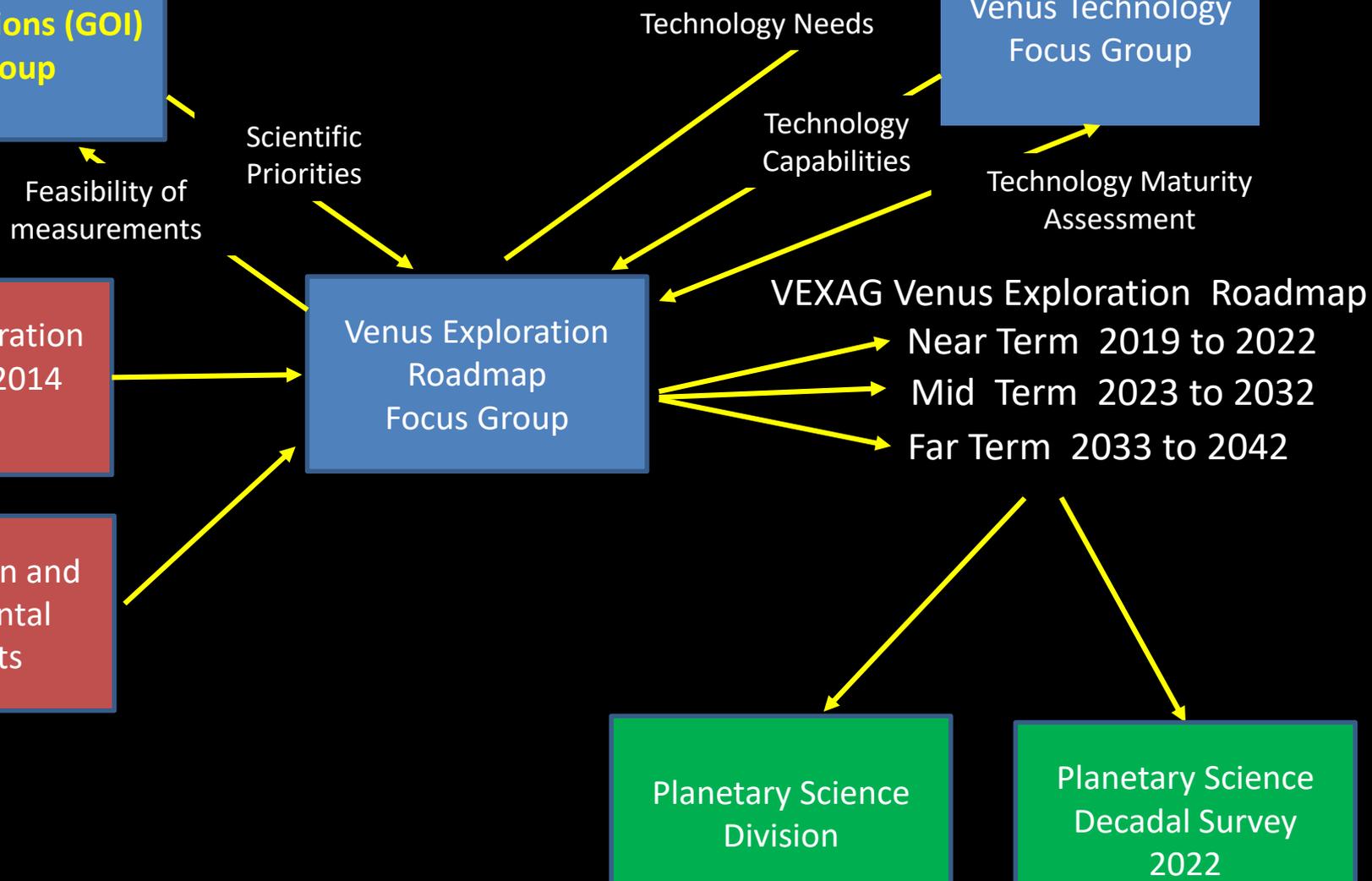
Venus Exploration Roadmap Focus Group

Venus Exploration Roadmap 2014

New Mission and Experimental Concepts

Planetary Science Division

Planetary Science Decadal Survey 2022



# VEXAG Roadmap Focus Group – Topics Assessed



WEEK	DATE	TOPIC	Lead Presenter
1	29-May	Kick Off Meeting	Cutts
2	5-Jun	Discussion of current roadmap	Smrekar
5	26-Jun	Venus Bridge - Implications for Roadmap	Izenberg
7	10-Jul	International Missions - Venera D	Kremic
10	1-Aug	International Collaboration/GOI and Tech update	Cutts, McGouldrick, Hunter
11	8-Aug	Venus Flagship Mission Studies	Amato/Gilmore
12	15-Aug	GOI Team update	Treiman/McGouldrick
13	22-Aug	International Missions/ 2014 Roadmap Revisited	Hensley/Cutts
14	29-Aug	Orbiters and Landers for Surface and Interior Science	Smrekar/Kiefer
15	5-Sep	Orbiters for Atmospheric Science	McGouldrick/Gray
17	19-Sep	Aerial Platforms - Technology and Science Capabilities	McGouldrick/Hall
18	26-Sep	Long Lived Surface Platform - Technology and Science Capabilities	Hunter/Izenberg
20	10-Oct	Review Powerpoint Presentation of Roadmap for VEXAG	Cutts/Smrekar
21	17-Oct	Review alignment of GOI with Roadmap	Treiman/Smrekar
22	24-Oct	Review Alignment of Technology Plan with Roadmap	Hunter/Cutts
23	31-Oct	Review PowerPoint Presentation for VEXAG	Cutts
24	6-Nov	Presentation at VEXAG	Cutts

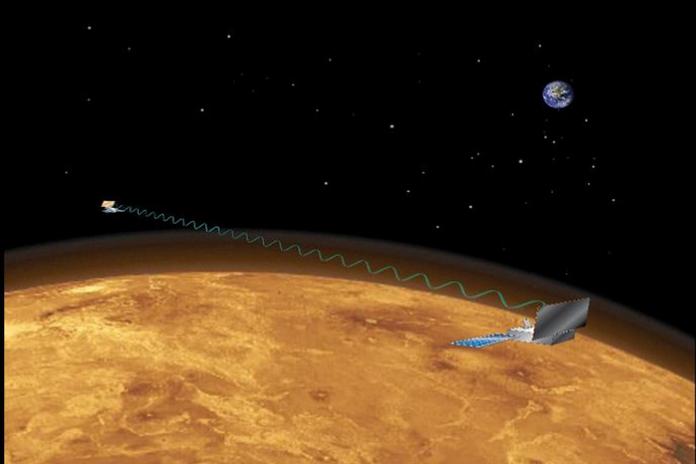


- The initial planning of the Venus Roadmap 2018 relied on the scientific guidance in the 2016 GOI.
- When the GOI focus group developed a consensus around the new GOI, they briefed the Roadmap focus group on the changes and the Roadmap Focus group responded
- The Roadmap Focus Group emphasized the importance of **Actionable Investigations** in the GOI:
  - Prefers investigations with an explicit or implied platform and experimental approach
  - Recognizes exceptions -high priority science questions with no obvious solution but where identification as an investigation may stimulate creative solutions

# VEXAG Roadmap – Emerging Capabilities



- Since the 2014 Venus Exploration Roadmap significant developments have occurred in three exploration modes and their associated technologies



**SmallSats and CubeSats  
Venus Bridge**

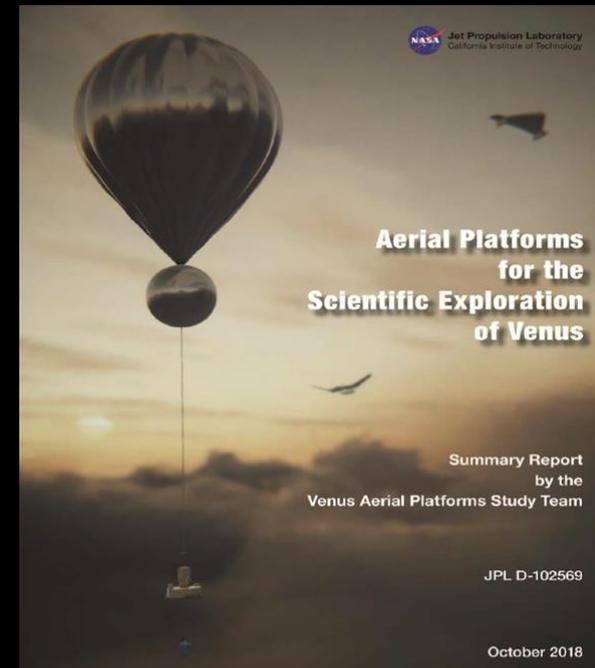


LLISSE



SAEVE

**Long-Lived Surface  
Platforms**



**Aerial Platforms**



# Venus Roadmap – Near Term 2019 to 2022



- This time frame includes the announcement of opportunities for competitive programs including
  - Discovery
  - New Frontiers (NF 5)
  - Venus Bridge (were it to be approved)
- Two types of missions have been rated Category 1 and/or advanced to step 2 in the last several Discovery and New Frontiers opportunities
  - Atmospheric composition probe with surface composition/mineralogy and descent imaging
  - Orbiters conducting radar (topo/imaging/deformation) and infrared surface observations, one with an atmospheric skimmer
- Other concepts have been developed which are slightly less mature scientifically or technically
  - Venus landers of the VISE class
  - Four SmallSat or CubeSat concepts selected for study under the PSDS3 program



# Venus Roadmap – Mid Term 2023 to 2032



- This is the planning time frame for the next Planetary Science Decadal Survey
- Concepts considered for this time frame include candidates for Discovery and New Frontiers missions
- This is also an opportunity for a Venus Flagship class mission
  - Studies will begin in the fall of 2018
  - Can draw on past work on Flagship mission studies including the Venus Climate Mission, the Venus Flagship Design Reference Mission, and Venera D
  - These are multiplatform missions including an orbiter, short duration lander, long-lived lander, aerial platforms, probes, sondes and subsatellites.
  - Can incorporate some level of new technology



# Venus Roadmap – Near to Mid Term to 2032



## Orbiter Surface and Interior

- Radar
- IR Spectroscopy
- Gravity

## Orbiter Atmosphere

## SmallSat orbiter

- Telecom relay navigation
- Synergistic with in situ science

## Atmospheric Skimmer

- Noble Gas composition

## Aerial Platform

- Fixed altitude
- May include Sondes

Aerial Platform  
(50 to 60 km altitude)  
Mid cloud exploration

## Entry Probes

- Composition, structure
- Descent imaging

## Short Lived Lander

- Stand off sample analysis (LIBS)
- Sample acquisition and analysis

Long Lived In Situ  
Exploration (LLISSE)

## Technology Maturity



These platforms are candidates for Discovery and New Frontiers missions: they may be combined into synergistic combinations as Flagship Missions



# Venus Roadmap – Far Term 2033 to 2042



Advanced Orbiters for Surface and Interior

Smallsats for Targeted Atmospheric Investigations

Aerial Platform  
(40 to 60 km altitude) Access below clouds

Enhanced-Capability Landers

- Lifetime up to 24 hours?
- Precision Landing?
- ?

Long Lived Landers (SAEVE)

- High temp electronics
- (200 day life)
- Seismology

Move beyond 2042



Venus Surface Sample Return

Surface or near surface platform with regional mobility

Concepts from VEXAG 2014 Roadmap

Technology Maturity

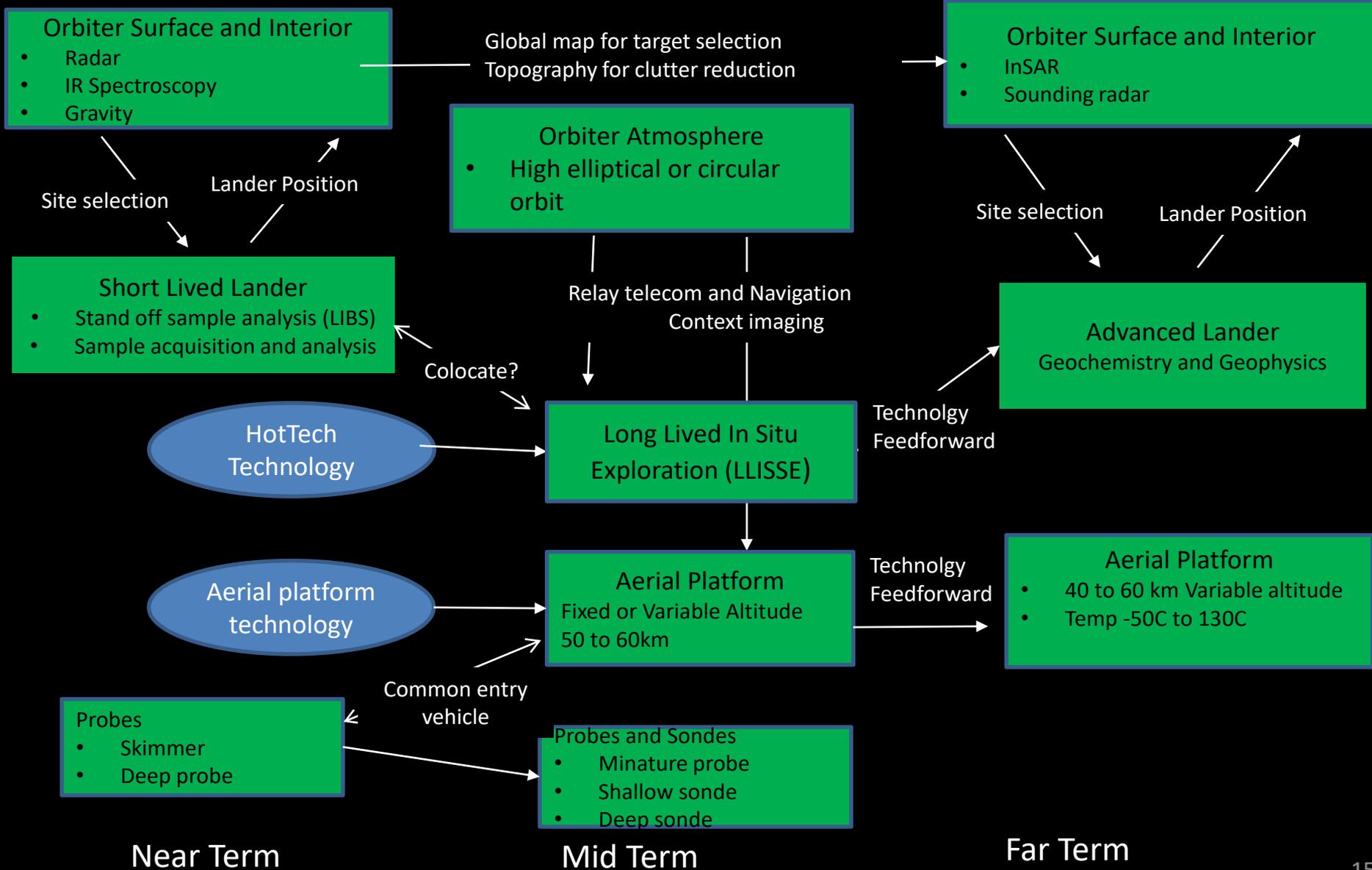


Concepts for this time frame can consider a greater level of new technology than for the prior period but the size and complexity and hence cost should still be commensurate with current ground rules.



- Interdependencies considered here include
  - Orbiter data used for landing site selection
  - Locate landers in orbital imagery
  - Orbital relay and navigation data for aerial and long duration missions
  - Orbital context imaging and other data for aerial and long duration images
  - Development of enabling technologies =- long lived landers –aerial platforms
  - Common launch and common entry system providing cost saving
  - Global map and topo data to enable advanced radar mission
- The option space is large and so not all the possible interdependencies have been identified
- In the following chart, the coding of technology maturity has been removed and some platform concepts have been consolidated into a single box
  - Atmospheric skimmer and entry probe
  - Enhanced capability lander and long lived lander.

# Roadmap Interdependencies- Science-Technology Feedforward





- Rankings for aerial platforms and long-lived landers assume an orbiter which can be a smallsat which provides
  - Communications relay
  - Context imaging
- Not sure how to assess science contribution of smallsats in the tables In general, smallsats will be less capable:
  - Some instruments will be too large for the SmallSat'
  - Instruments complement will be limited for the SmallSat
  - Synergy provides by multiple instruments lacking
- The tables that follow are very preliminary
  - Based on latest version of GOI but there may be changes
  - First draft for Near and Mid Term missions - Need Roadmap Focus group inputs to complete
  - Far Term missions pending. Will try to integrate them into the Near and Mid Term table.



## **Venus Roadmap – Near to Mid Term to 2032**

- Goal 1: Evolution, Habitability and Exoplanets
- Goal 2: Atmospheric Dynamics and Composition
- Goal 3: Surface and Interior

## **Venus Roadmap – Far term 2033-2042**

- Goal 1: Evolution, Habitability and Exoplanets
- Goal 2: Atmospheric Dynamics and Composition
- Goal 3: Surface and Interior

# Goal 1: Evolution, Habitability and Exoplanets



Goals	Objectives	Investigations	GOI Code	GOI Rating	Decadal 2019 to 2032									
					Orbiter Radar IR Gravity	Atmospheric Prober		Lander		Aerial Platform		Orbiter - Elliptical or High Alt Circular		
						Skimmer	Deep probe	Short	Long Lived	Fixed Alt	50 to 60 km	65 to 0	SmallSat	
Evolution, Habitability and Exoplanets	Why did Venus evolve as it did?	Isotopic ratios of noble gases	I.A.1	E		Necessary and sufficient to address the investigation in the GOI								
		Evidence for water derived rocks	I.A.2	E							Necessary but not sufficient			
		Evolution of Venus atmosphere	I.A.3	I								Necessary but not sufficient		
		Structure of mantle and core	I.A.4	I	Necessary but not sufficient						Necessary but not sufficient		Necessary and sufficient to address the investigation in the GOI	
		Remanent magnetism	I.A.5	E						Necessary and sufficient to address the investigation in the GOI		Complementary to a primary measurement		
	Implications of Venus evolution for exoplanets	Unique volcano-tectonic features	I.B.1	E						Necessary but not sufficient				
		Crust and upper mantle	I.B.2	E						Necessary and sufficient to address the investigation in the GOI				
		Plate tectonics vs mobile lid	I.B.3	E										
		Heat producing elements distribution	I.B.4	I				Necessary but not sufficient						
		Exoplanet observables vs Venus	I.B.5	I										

Necessary and sufficient to address the investigation in the GOI  
 Necessary but not sufficient  
 Complementary to a primary measurement

Preliminary only. Focus group members will be asked to complete

# Goal 2: Atmospheric Dynamics and Composition



VEXAG Goals, Objectives and Investigations					Mission Concepts									
Goals	Objectives	Investigations	GOI Code	GOI Rating	Decadal 2019 to 2032									
					Orbiter Radar IR Gravity	Atmospheric Prober		Lander		Aerial Platform		Orbiter - Elliptical or High Alt Circular		
						Skimmer	Deep probe	Short	Long Lived	Fixed Alt	50 to 60 km	65 to 0	SmallSat	
Atmospheric Dynamics Composition	Global Atmospheric Dynamics	Lower Atmosphere below 75km	II.A.1	E										
		Upper Atmosphere Thermosphere	II.A.2	E										
		Mesoscale dynamics	II.A.3	I										
	Atmospheric Compositions and Radiative Balance	Atmospheric radiative balance	II.B.1a	E										
		Physical, chemical biology	II.B.1b	E										
		Volcanic outgassing	II.B.2	E										
		Ultraviolet absorber investigation	II.B.3	E										
		Surface atmosphere chemical inter.	II.B.4	I										
		Nature and origin of aerosols	II.B.5	I										

Necessary and sufficient to address the investigation in the GOI

Necessary but not sufficient

Complementary to a primary measurement

Preliminary only. Focus group members will be asked to complete

# Goal 3: Surface and Atmosphere Surface Interaction

VEXAG Goals, Objectives and Investigations					Mission Concepts								
Goals	Objectives	Investigations	GOI Code	GOI Rating	Decadal 2019 to 2032								
					Orbiter Radar IR Gravity	Atmospheric Prober		Lander		Aerial Platform		Orbiter - Elliptical or High Alt Circular	
						Skimmer	Deep probe	Short	Long Lived	Fixed Alt	50 to 60 km	65 to 0	SmallSat
Surface and Interior	Current Geologic Processes	Volcanic Tectonic Activity	II.A.1	E									
		Mineral Composition-Oxidation State	II.A.2	I									
		Interior - Mantle and Core	II.A.3	I									
		Structure of crust	II.A.4	I									
		Crustal recycling	II.A.5	I									
		Current sedimental processes	II.A.6	I									
	Age of surface	Crater populations- morphology	II.B.1										
		Age Dating on rocks	II.B.2										
	Atmosphere Surface Interaction	Mineralogy Oxidation State In Situ	III.C.1										
		Weathering causes and extent	III.C.2										
		Coupling Mantle-Crust-Atmosphere	III.C.3										

 Necessary and sufficient to address the investigation in the GOI

 Necessary but not sufficient

 Complementary to a primary measurement

Preliminary only. Focus group members will be asked to complete



- Mapping GOI to capabilities of the roadmap platforms.
  - Preliminary versions in this presentation for Near/Mid Term 2019 to 2032
  - Requires review and completion by the Roadmap Focus Group
  - Version for Far Term 2033 to 2042 pending
- Technology maturity of the roadmap platforms
  - [Technology Focus update table with current missions](#)
- Roadmap Interdependencies -Scientific and technology feedforward
  - Highlights included in chart in this version
  - Will be addressed in more detail the narrative report



- The Roadmap Focus group has been evaluating the candidate missions to enable a renaissance in Venus exploration - the Decade of Venus
- Our approach has been to look critically at concepts in terms of their technical realism and their ability to address priority Venus science
- We are working closely with the GOI Focus Group and the Technology Focus group to bring our assessments into alignment
- Following VEXAG our attention will turn to completing the narrative report which is in early draft form and requires major revision from the 2014 report