Venus Exploration
VEXAG
Analysis Group

Decadal Survey and the VEXAG Goals, Objectives and Investigations

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Outline

- Themes from Decadal and overlap w/ VEXAG
- Make explicit references to those connections in the GOI documents
- Consider the ensemble of missions

Aligning VEXAG Goals, Objectives and Investigations with Visions and Voyages 2013-2022

- Venus is mentioned in all three strands of the Decadal Survey:
  - – Building New Worlds
  - – Planetary Habitats
  - – Workings of Solar Systems

Visions and Voyages Recommended Program of Small, Large and Flagship Missions: Priorities

EXECUTIVE SUMMARY:

- First and most important was science return per dollar
- Second was programmatic balance—striving to achieve an appropriate balance among mission targets across the solar system and an appropriate mix of small, medium, and large missions
- The other two were technological readiness and availability of trajectory opportunities within the 2013-2022

Visions and Voyages: International Collaboration

From the EXECUTIVE SUMMARY

- Space exploration has become a worldwide venture, and international collaboration has the potential to enrich the program in ways that benefit all participants
- The program therefore relies more strongly than ever before on international participation, presenting many opportunities for collaboration with other nations

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Venus in the Decadal Survey

Current State of Knowledge and Important Scientific Questions

What governed the accretion, **supply of water, chemistry, and internal differentiation of the inner planets and the evolution of their atmospheres**, and what roles did bombardment by large projectiles play?	***Building New Worlds***
Did Mars or Venus host ancient aqueous environments conducive to early life, and is there evidence that life emerged?	***Planetary habitats*** *Important objects for study: Mars and Venus*
Can understanding the roles of physics, chemistry, geology, and dynamics in driving planetary atmospheres and climates lead to a better understanding of climate change on Earth?	**Workings of solar systems** *Important objects for study: Mars, Jupiter, Neptune, Saturn, Titan, Uranus, and Venus.*
How have the myriad chemical and physical processes that shaped the solar system operated, interacted, and evolved over time?	*Important objects for study:* ***all*** *planetary* bodies

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Decadal Survey vs. VEXAG G&O

1. ***Building New Worlds*** 1-3What governed the accretion, **supply of water, chemistry, and internal differentiation of the inner planets and the evolution of their atmospheres**, and what roles did bombardment by large projectiles play?	***1. Origin and Evolution*** How did Venus originate and evolve, and what are the implications for the characteristic lifetimes and conditions of habitable environments on Venus and similar extrasolar systems?
2. Planetary habitats **2-2 Did Mars or Venus host ancient aqueous environments conducive to early life, and is there evidence that life emerged?.**	***2. Venus as a Terrestrial Planet*** What are the processes that have shaped and still shape the planet?
3. Workings of solar systems **3-3 Can understanding the roles of physics, chemistry, geology, and dynamics in driving planetary atmospheres and climates lead to a better understanding of climate change on Earth?** **3-4 How have the myriad chemical and physical processes that shaped the solar system operated, interacted, and evolved over time?**	***3. Climate Change and the Future of Earth*** What does Venus tell us about the fate of Earth's environment?

Decadal Survey……

5. The Inner Planets: The Key to Understanding Earth-Like Worlds

SCIENCE GOALS FOR THE STUDY OF MERCURY, VENUS, AND THE MOON

The goals for research concerning the inner planets for the next decade are threefold:

- Understand the origin and diversity of terrestrial planets. How are Earth and its sister terrestrial planets unique in the solar system and how common are Earth-like planets around other stars? *Addressing this goal will require constraining the range of terrestrial planet characteristics, from their compositions to their internal structure to their atmospheres, to refine ideas of planet origin and evolution.*
- Understand how the evolution of terrestrial planets enables and limits the origin and evolution of life. What conditions enabled life to evolve and thrive on the early Earth? The Moon and Mercury preserve early solar system history that is a prelude to life. Venus is a planet that was probably much like Earth but is now not habitable. *Together, the inner planets frame the question of why Earth is habitable, and what is required of a habitable planet.*
- Understand the processes that control climate on Earth-like planets. What determines the climate balance and climate change on Earth-like planets? Earth's climate system is extraordinarily complex, with many inter-related feedback loops. *To refine concepts of climate and its change, it is important to study other climate systems, like Venus, Mars and Titan, which permit us to isolate some climate processes and quantify their importance*

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Decadal Survey Inner Planets Questions vs. VEXAG G&O

1. Understand the **origin and diversity** of terrestrial planets. How are Earth and its sister terrestrial planets unique in the solar system and how common are Earth-like planets around other stars? *Addressing this goal will require constraining the range of terrestrial planet characteristics, from their compositions to their internal structure to their atmospheres, to refine ideas of planet origin and evolution*	***1.Origin and Evolution*** How did Venus originate and evolve, and what are the implications for the characteristic lifetimes and conditions of habitable environments on Venus and similar extrasolar systems?
Understand how the evolution of **terrestrial planets** enables and limits the origin and evolution of life. What conditions enabled life to evolve and thrive on the early Earth? The Moon and Mercury preserve early solar system history that is a prelude to life. Venus is a planet that was probably much like Earth but is now not habitable. *Together, the inner planets frame the question of why Earth is habitable, and what is required of a habitable planet.*	***2. Venus as a Terrestrial Planet*** What are the processes that have shaped and still shape the planet?
Understand the processes that control **climate** on Earth-like planets. What determines the climate balance and climate change on Earth-like planets? Earth's climate system is extraordinarily complex, with many inter-related feedback loops. *To refine concepts of climate and its change, it is important to study other climate systems, like Venus, Mars and Titan, which permit us to isolate some climate processes and quantify their importance*	***3. Climate Change and the Future of Earth*** What does Venus tell us about the fate of Earth's environment?

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Venus in the Decadal Survey Recommended Program

• *Venus Climate Mission*—This mission is designed to address science objectives concerning the Venus atmosphere, including carbon dioxide greenhouse effects, dynamics and variability, surface/atmosphere exchange, and origin. The mission architecture includes a carrier spacecraft, a gondola/balloon system, a mini-probe, and two drop-sondes. $2.4 billion – lowest cost flagship mission.	**The fourth and fifth highest priority Flagship missions are, in alphabetical order, the Enceladus Orbiter and the Venus Climate Mission.** In order to maintain an appropriate balance among small, medium, and large missions, **these missions should be considered for the decade 2013-2022 only if higher priority missions above cannot be flown for unanticipated reasons, or if additional funding makes them possible.** No relative priority is assigned to these two missions; rather, any choice between them should be made on the basis of competitive peer review.
Following the priorities and decision rules outlined above, two example programs of solar system exploration can be described for the decade 2013-2022. Both assume continued support of all ongoing flight projects, a research and analysis grant program with a 5 percent increase and further growth at 1.5 percent per year above inflation, and $100 million FY2015 annually for technology development.	

Mission Prospects 2013-2022 from the Decadal Survey

The *Cost Constrained Program* can be conducted assuming the currently projected NASA planetary budget. It includes the following elements (in no particular order):

- Discovery program funded at the current level adjusted for inflation;
- Mars Trace Gas Orbiter conducted jointly with ESA;
- New Frontiers Mission 4 and 5;
- MAX-C (descoped to $2.5 billion);
- Uranus Orbiter and Probe (*if affordable at 2.5 B$)*

Plausible circumstances could improve the budget picture presented above. If this happened, the additions to the recommended plan should be, in priority order:

1. An increase in funding for the Discovery program,
2. Another New Frontiers mission, and
3. Either the Enceladus Orbiter mission or the Venus Climate Mission.

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Mission Prospects….contd.

It is also possible that the budget picture could be less favorable than the committee has assumed. If cuts to the program are necessary, the first approach should be descoping or delaying Flagship missions. Changes to the New Frontiers or Discovery programs should be considered only if adjustments to Flagship missions cannot solve the problem.

And high priority should be placed on preserving funding for research and analysis programs and for technology development.

Looking ahead to possible missions in the decade beyond 2022, it is important to make significant near-term technology investments in the Mars Sample Return Lander, Mars Sample Return Orbiter, Titan Saturn System Mission, and Neptune System Orbiter and Probe. → No explicit mention of Venus needs!

Venus in the Decadal Survey Recommended Program

Building New Worlds 3. What governed the accretion, supply of water, chemistry, and internal differentiation of the inner planets and the evolution of their atmospheres, and what roles did bombardment by large projectiles play?	TABLE S.1 Crosscutting Themes, Key Questions and the Missions in the Recommended Plan That Address Them Mars Sample Return, Venus In Situ Explorer, Lunar Geophysical Network, Lunar South Pole-Aitken Basin Sample Return, Trojan Tour and Rendezvous, CSSR, Venus Climate Mission, Discovery missions
Planetary Habitats 5. Did Mars or Venus host ancient aqueous environments conducive to early life, and is there evidence that life emerged?	Mars Sample Return, Venus In Situ Explorer, Venus Climate Mission, Discovery missions
Workings of Solar Systems 9. Can understanding the roles of physics, chemistry, geology, and dynamics in driving planetary atmospheres and climates lead to a better understanding of climate change on Earth?	Mars Sample Return, JEO, Uranus Orbiter and Probe, Venus In Situ Explorer, Saturn Probe, Venus Climate Mission, Discovery missions
10. How have the myriad chemical and physical processes that shaped the solar system operated, interacted, and evolved over time?	All recommended missions

Decadal Survey: Venus and Earth Climates

Can Understanding the Roles of Physics, Chemistry, Geology, and Dynamics in Driving Planetary Atmospheres and Climate Lead to a Better Understanding of Climate Change on Earth? (p-3-13)

The interactions of Earth's atmosphere, biosphere, lithosphere, and hydrosphere present extremely complex, even chaotic, problems that defy our ability to reliably predict their future or derive their past, either on short or long timescales. Venus, Mars, and Titan provide atmospheric laboratories that exhibit many Earth-like characteristics but operate across the spectrum of temperature, pressure, and chemistry.

Decadal Survey: Planetary Climates

- Consideration of the full suite of planetary atmospheres immensely broadens the scope of atmospheric science. The goal to understand the full spectrum of planetary atmospheres—the physics, chemistry, dynamics, meteorology, photochemistry, solar wind and magnetospheric interactions, response to solar cycles, and particularly greenhouse processes—drives a richer and more comprehensive perspective in which Earth becomes one example.
- Venus and Earth are nearly identical in size and bulk density, but Venus's massive atmosphere presents an extremely different system when compared with Earth's. The upper reaches of its hot, dense carbon dioxide atmosphere, laden with sulfuric acid clouds, circle the planet every 4 days. Venus Express discovered that lightning, aurora, and nightglows light up the planet's sky. Evidence of active volcanism is also suggested, supporting the idea that ongoing volcanic emission of sulfur dioxide feeds the thick sulfuric acid clouds.

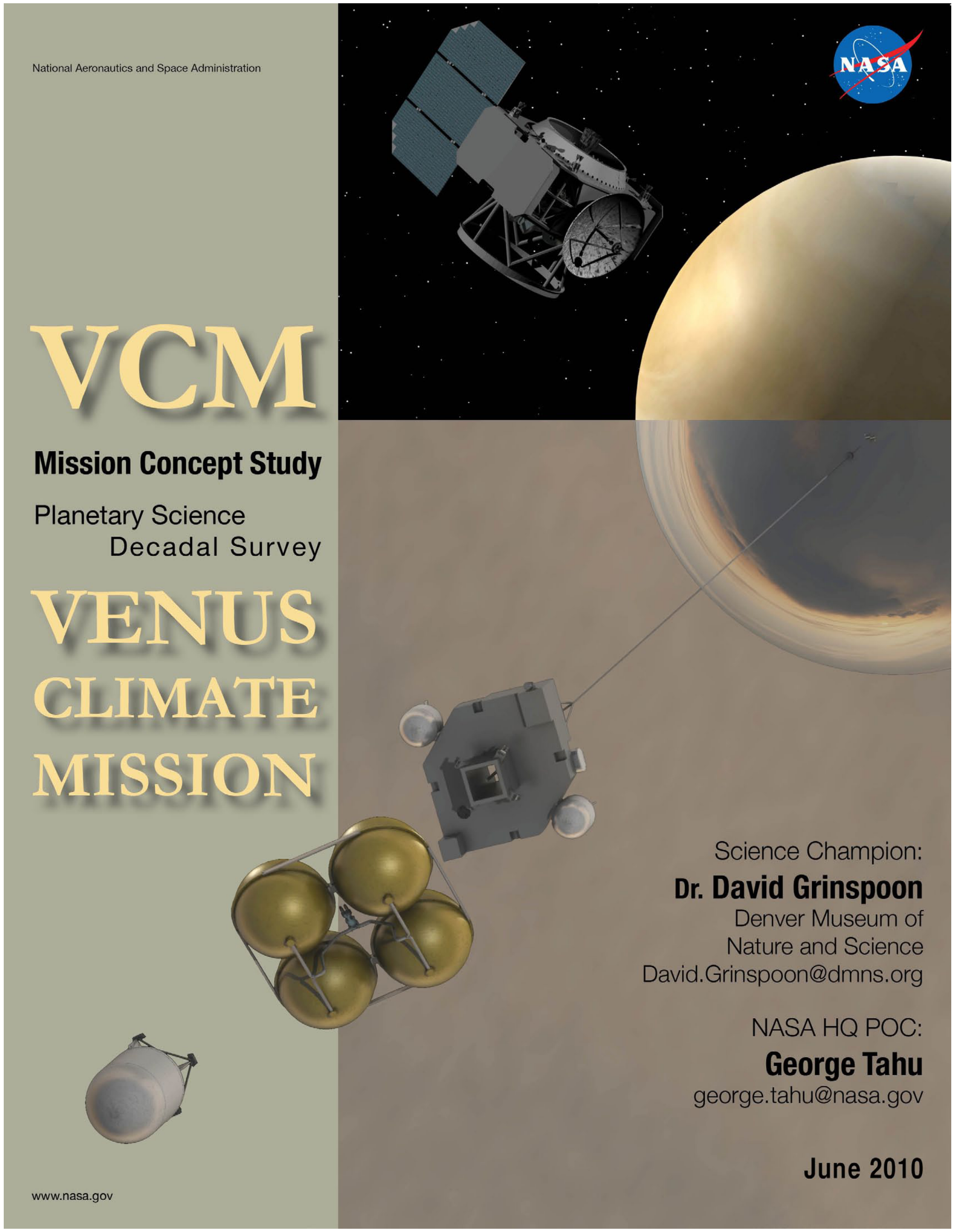
Venus and Terrestrial Climates

What mechanisms triggered Venus's runaway greenhouse and on what timescale remain open questions. Addressing them can help us better understand the principles of greenhouse atmospheres in general, placing Earth's in a broader context. For Venus, addressing these questions requires measurements of atmospheric chemistry, notably of the isotopic and noble gas chemistry of the lower atmosphere. Establishing the initial climate conditions and modern states of Venus and Mars can help us to understand how their environments diverged so dramatically from Earth's.

New lessons from the inner solar system over the last few decades show it, too, is far more complex and active than previously known—discoveries here are equally exciting. Venus may harbor active volcanic eruptions issuing sulfurous compounds and water vapor to feed the sulfuric acid clouds.

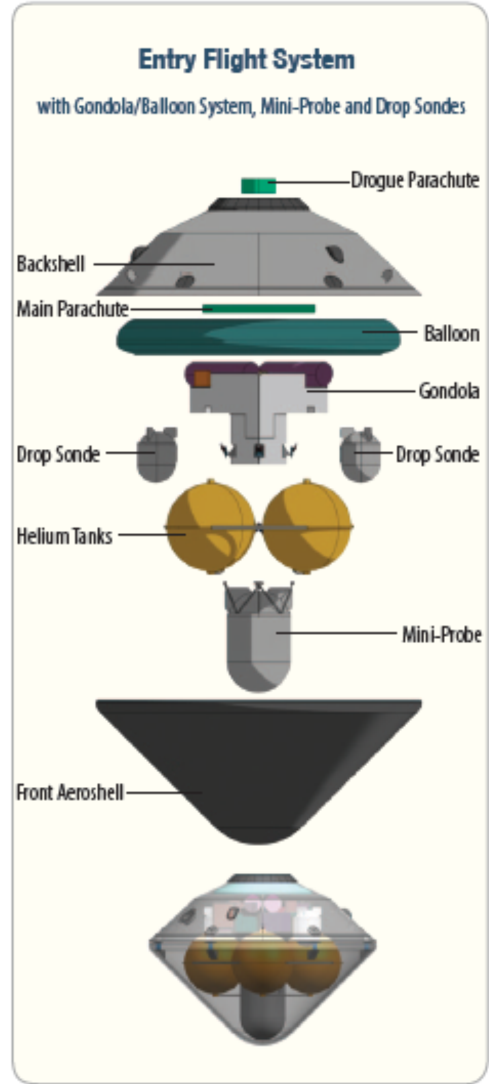
Decadal Survey Recommendation: Venus Climate Mission

- Scaled down version of the Design Reference Mission studied by the STDT
- One orbiter, one balloon, one lander
- Also studied two other missions – ViTAL and Venus Mobile Explorer, but did not consider them mature enough for further study



www.lpi.usra.edu/vexag

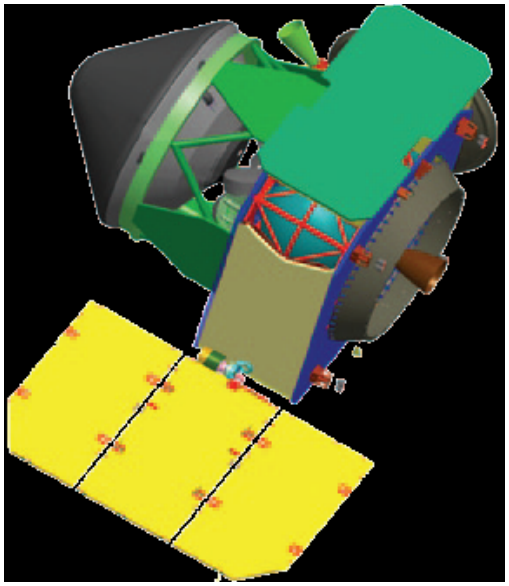
A scaled down version of the Venus Design Reference Mission (VSTDT)



Mini-Probe
Function: 45 minute descent from 55.5 km to surface
Power: Distributed rechargeable Polymer Lithium-ion batteries
Telecom: 1 way S-band to gondola
Science Data Return: 5 Mb
Design: 44 cm dia., 66 cm tall titanium pressure vessel, passive thermal control

Drop Sondes (2)
Function: 45 minute descent from 55.5 km to surface
Power: Distributed rechargeable Polymer Lithium-ion batteries
Telecom: One-way S-band to gondola
Science Data Return: 1 Mb (each probe)
Design: 29 cm dia., 35 cm tall titanium pressure vessel, passive thermal control

Entry Flight System
Function: Deliver in situ elements through the atmosphere; carries the Gondola/Balloon System, Inflation System, Mini-Probe and two Drop Sondes
Power: Lithium-thionyl chloride (Li-$SOCl_2$) primary battery
Design: Carbon-Phenolic front shell, Phenolic Impregnated Carbon Ablator back shell, 45 deg cone angle (Pioneer-Venus heritage), 2 m diameter



Gondola/Balloon System

Function: 21 day science campaign at 55.5 km float altitude
Power: Lithium-thionyl chloride (Li-$SOCl_2$) primary battery
Telecom: Two way S-band (plus Doppler) to Carrier Spacecraft; one way S-band from Mini-Probe and Drop Sondes
Science Data Return: 135 Mb from Gondola science + 7 Mb from Probe & Sondes science
Balloon Design: 8.1 m diameter helium filled balloon; teflon coated for sulfuric acid resistance; Vectran fabric plus Mylar film construction; metalized for low solar heating
Inflation System Design: 4 x 0.5 m dia. titanium tanks; pipes; valves

Venus Climate Mission

VCM

Planetary Science Decadal Survey
Mission Concept Study

VCM Science Objectives

- Characterize the strong CO_2 greenhouse atmosphere of Venus, including variability.
- Characterize the dynamics and variability of Venus's superrotating atmosphere.
- Characterize surface/atmosphere chemical exchange in the lower atmosphere.
- Search for atmospheric evidence of climate change on Venus.
- Determine the origin of Venus's atmosphere and the sources and sinks driving evolution of the atmosphere.
- Understand implications of Venus's climate evolution for the long-term fate of Earth.

Mission Concept Study Report to the NRC Decadal Survey Inner Planets Panel

June, 2010

Concept Maturity Level: 4

Cost Range: Low End Flagship

Launch Date: November 2, 2021

Science Campaign:

April 7, 2022 - April 28, 2022

Launch Mass: 3,948 kg

Launch Vehicle: Atlas V 551

VCM Science Payload

- Carrier Spacecraft
  - Venus Monitoring Camera Vis-IR
- Gondola/Balloon System
  - Neutral Mass Spectrometer (NMS)
  - Tunable Laser Spectrometer (TLS)
  - Atmospheric Structure Instrumentation (ASI)
  - Nephelometer
  - Net Flux Radiometer (NFR)
- Mini-Probe
  - NMS; NFR; ASI
- Drop Sondes,
  - ASI; NFR

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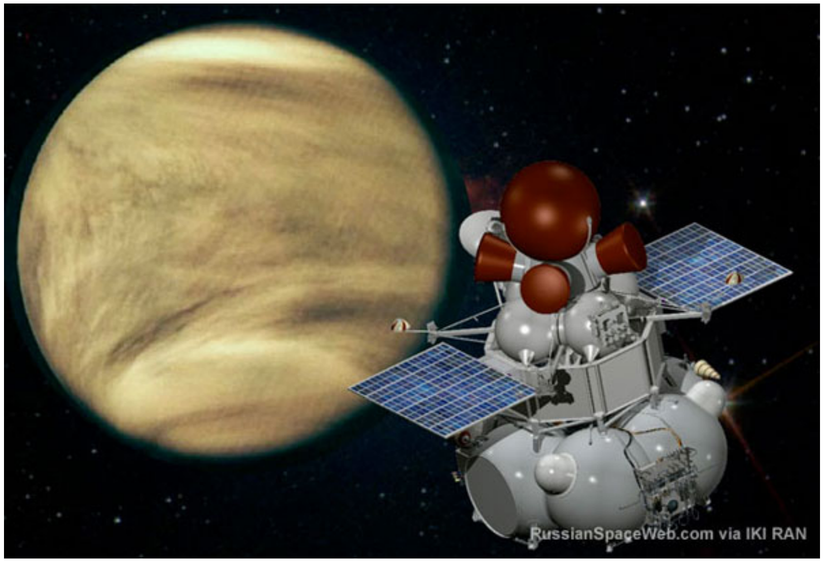
Future Opportunities for Venus Exploration Missions

- NASA
  - Discovery Program (500 M$, AO *NET 2015, launch NET 2020 ?*)
  - New Frontiers (1 B$, NF-4, AO *NET* 2016, *launch NET 2022* ?)
  - Flagship: Venus Climate Mission, (Decadal Survey Recommendation, 2013-2022)
- ESA
  - Cosmic Vision (L and M Class) call expected in 2013-2014 for launch ~ 2024
- Russia
  - Venera D (*NET 2022*)
- ISRO
  - ??
- China
  - ??



VEXAG: Updating Goals, Objectives and Investigations

- Next Announcements of Opportunity for Competed Missions Discovery-12 (~ 2015) and NF-4 (~ 2016) – it is quite possible that the AOs may explicitly refer to the VEXAG documents during the selection process
- Other international agencies are also expected to embark on studies of future missions to Venus in the near future
- What new questions have been raised by Venus Express and which ones have been answered partially or fully?