"Crewed Missions to Venus: a New Frontier for QUAD Cooperation"

Guillermo Sohnlein [1]
Founder & Chairman, Humans2Venus Foundation [2]
6595 Roswell Road, Suite G2269, Atlanta, GA 30328
+1 (703) 346-3041 (mobile/WhatsApp)
guillermo@humans2venus.org

Keywords:
Venus, human spaceflight, planetary science, technology innovation, QUAD cooperation

INTRODUCTION

As colleagues gather for the India Space Congress in June 2024, they stand on the verge of a potentially historic time in space history, both for humanity in general and also for India in particular. There are several meta-trends at play that could provide India the unique opportunity to forge an ambitious path for humanity into the cosmos, specifically by leading a collaborative effort to Venus.

Generally, the global space science community has recently regained interest in Earth's nearest planetary neighbor, with several robotic missions announced and currently under development. [3] Simultaneously, two consortia of national partners led by Russia-China and the United States are pushing human spaceflight beyond Earth's orbit and onto the surface of the

[1] Guillermo Sohnlein is a serial entrepreneur, helping to launch over a dozen for-profit ventures and nonprofit organizations during a 25-year career that started during the Internet Boom in Silicon Valley. In 2006, he founded Space Angels Network to connect accredited individual investors with entrepreneurs creating new space ventures. He is currently an advisor to several space startups and two space-focused venture capital funds. He earned his AB in Economics from the University of California at Berkeley and his JD from the University of California San Francisco College of the Law.

[2] The Humans2Venus Foundation (www.humans2venus.org) is an international nonprofit organization that promotes Venus-focused science and education programs. It also curates a global community of Venus-focused space professionals and leads the Venus Roadmap Initiative (www.venusroadmap.org).

[3] Sanjay S. Limaye and James B. Garvin, "Exploring Venus: next generation missions beyond those currently planned," Frontiers in Astronomy and Space Sciences, 18 May 2023.
https://www.frontiersin.org/articles/10.3389/fspas.2023.1188096/full

Moon. [4] Meanwhile, India is poised to advance its robust space program onto the same top tier as Russia, China, and the United States by growing its human spaceflight program and pushing to become only the fourth nation to successfully fly humans into space and return them safely to Earth. [5]

Despite the decades-old fixation on getting humans back to the Moon and eventually going further out to Mars, there is a growing global community of scientists that believes perhaps humanity might be better served heading to Venus instead. [6] While its surface is completely inhospitable to human life, there is data to support the notion that 50km-60km into the atmosphere may exist the most Earth-like conditions in the solar system. At that altitude, the pressure is roughly 1 ATM and the temperature ranges between 25C and 50C. [7] More importantly, Venus has 0.98G of gravity, which could be critical for a permanent multi-generational human presence, since the medical community currently does not know if *homo sapiens* can reproduce in less than 1G of gravity, as humans would experience on the Moon (0.16G) and Mars (0.38G). [8] Additionally, Venus is closer to Earth than Mars and has a similar circular orbit, making interplanetary trips safer and less expensive, presumably with more available launch windows. [9] Of course, there would be at least two major challenges to overcome, namely, the primarily CO2 atmosphere and the sulfuric acid clouds. However, engineers currently have technologies here on Earth that can provide adequate solutions to both. [10] [11]

[4] Mustafa Bilal, "The advent of astropolitical alliances," Space News, 8 January 2024. https://spacenews.com/advent-astropolitical-alliances/

[5] "India announces crew for first manned space mission," BBC, 27 February 2024. https://www.bbc.co.uk/newsround/68411897

[6] Noam Izenberg, Mallory Lefland, Alexander MacDonald, "Meeting with the Goddess: Notes from the First Symposium on Venus Science Enabled by Human Proximity", Keck Institute for Space Studies, September 2022. https://kiss.caltech.edu/final_reports/Venus-Science-Final-Report.pdf

[7] "Venus Facts," NASA, retrieved 20 May 2024. https://science.nasa.gov/venus/venus-facts/

[8] Noa Leach, "Earth's first space gynaecologist explains how humans will reproduce in future," BBC Science Focus, 13 December 2023. https://www.sciencefocus.com/space/babies-in-space-gynaecology

[9] David Sky Brody, "Don't ignore Venus — Earth's twin hides surprising opportunities (op-ed)," Space.com, 4 September 2020. https://www.space.com/dont-ignore-venus-op-ed.html

[10] "NASA's Perseverance Mars Rover Extracts First Oxygen from Red Planet," NASA, retrieved 20 May 2024. https://www.nasa.gov/news-release/nasas-perseverance-mars-rover-extracts-first-oxygen-from-red-planet/

[11] "6 Acid Resistant Materials That Can Be Used Effectively in a Lab," iPolymer, 3 October 2017. https://ipolymer.com/blog/6-acid-resistant-materials-that-can-be-used-effectively-in-a-lab/

India currently finds itself in the enviable position of potentially taking an historic leadership role in humanity's expansion beyond Planet Earth. This could be the dawn of a new era in space exploration for the QUAD member states: India is pushing forward with its human spaceflight program; the United States is transitioning its LEO program to the private sector [12] in order to focus on its lunar program, in which Japan will be an active partner; [13] and Australia is ramping up its relatively new space agency. [14] All four benefit from strong government space programs, as well as vibrant private space sectors.

Taking all of these meta-trends into consideration, this paper presents an argument in favor of India taking a global leadership role in pushing humanity toward the Venusian atmosphere over the coming decades.

PART I. ARGUMENT FOR "VENUS IN PARALLEL"

A. Venus Science Missions

From the earliest days of the Space Age and the Cold War Space Race, Venus was a frequent objective for Soviet and American missions. [15] The first attempt to learn more about Venus was launched by the Soviets in 1961, but the first successful flyby was the American *Mariner 2* in 1962. Several failed missions later, the Soviet *Venera 4* made the first successful atmospheric entry in 1967 and the *Venera 8* made the first fully successful soft landing in 1972. All told, humanity launched 38 missions to Venus during the 20th century, including impactors, orbiters, landers, and flybys, as well as missions that used Venus for a gravity assist en route to other destinations. Only 23 of them were rated as "partially successful", "mostly successful", or "successful" (~60% success rate). The Soviets led the charge with 29 total missions (over ¾ of

[12] "The International Space Station Transition Plan," NASA, retrieved 20 May 2024. https://www.nasa.gov/faqs-the-international-space-station-transition-plan/
[13] "NASA, Japan Advance Space Cooperation, Sign Agreement for Lunar Rover," NASA, retrieved 20 May 2024. https://www.nasa.gov/news-release/nasa-japan-advance-space-cooperation-sign-agreement-for-lunar-rover/
[14] Ching Wei Sooi, "Australia's Growing Space Agency Amid a Renewed Push to the Stars," Australian Institute of International Affairs, 24 April 2024. https://www.internationalaffairs.org.au/australianoutlook/australias-growing-space-agency-amid-a-renewed-push-to-the-stars/
[15] Elizabeth Howell, "Here's every successful Venus mission humanity has ever launched," Space.com, 18 September 2020. https://www.space.com/venus-mission-success-history

all missions), and they were the only ones to successfully soft land a spacecraft on the surface and collect data.

In the 21st century, interest in Venus waned as interest in the Moon and Mars gained momentum. The only missions launched thus far have been ESA's *Venus Express* in 2005 (successful), the Japanese joint *Akatsuki* orbiter (still operational) and *IKAROS* solar sail flyby spacecraft (successful) in 2010, and the Japanese *Shin-en* flyby spacecraft also in 2010 (failure). There have also been three gravity assist missions, including two that are still operational but have not observed Venus (the American *Parker Solar Probe* in 2018 and ESA's *Solar Orbiter* in 2020) and one that successfully captured images of Venus (ESA's *BepiColombo* in 2018).

However, this landscape is poised to change dramatically in the next decade. [16] For numerous reasons, Venus has regained the attention of the global scientific community, and several new missions have been announced and are currently under development. These include:

- 2025 - *Morning Star 1* - a privately funded atmospheric probe from Rocket Lab and MIT
- 2026 - *VOICE* - a Chinese orbiter
- 2028 - *DAVINCI* - an American atmospheric probe
- 2028 - *Shukrayaan* - India's orbiter and atmospheric probe
- 2029 - *Venera-D* - Russia's orbiter and lander
- 2030 - *VERITAS* - an American orbiter
- 2032 - *EnVision* - ESA's orbiter

There are also several more Venus missions that have been proposed at NASA, ESA, and the UAE's Space Agency. If most of these missions actually launch, the next decade could emerge as a renaissance of sorts for Venus science. This is a much-needed turn of events, since scientists have much more detailed data, analysis, and knowledge about the Moon and Mars than they do about Earth's closest planetary neighbor.

[16] Limaye and Garvin (2023).

B. Moon, Mars, and Beyond

The Soviet-American Cold War-era "Space Race" culminated with the last human leaving the lunar surface in 1972. After that, both countries focused their human spaceflight efforts on operations in LEO, relying instead on robotic missions to conduct science missions across the solar system and beyond. Over the ensuing decades, several hundred people from various nations have flown beyond the Karman Line, primarily into LEO for missions aboard an ongoing line of orbiting space stations, currently consisting only of the Chinese Tiangong and the International Space Station led by Russia, the United States, Japan, ESA, and Canada. [17] While the Chinese continue to build up Tiangong, over the next decade the ISS is scheduled to be deorbited in favor of new privately owned space stations from several different companies.

In 2004, American President George W. Bush published his "Vision for Space Exploration" ("VSE") in the aftermath of the 2003 tragedy that destroyed NASA's Space Shuttle *Columbia* and killed its crew of seven astronauts. [18] Even though it was subsequently replaced by the official space policies of his three successors, the VSE laid the foundation for a long-term plan commonly referred to by NASA as "Moon, Mars, and Beyond". [19] The basic premise is to expand humanity's presence in the cosmos by returning to the Moon as a prelude to more ambitious plans to explore Mars. The rationale is that engineers can test technologies and build operational expertise in the relative near-Earth safety of the Moon before venturing to the much further, dangerous, and expensive Martian surface.

For the past two decades, the United States Congress has continued to approve funding for different versions of the same long-term plan. This has allowed NASA to forge international partnerships sharing similar goals for human space exploration. Its Artemis Program of lunar missions has been supplemented by a series of bilateral agreements–called the "Artemis

[17] Michael G. Smith, Michelle Kelley, and Mathias Basner, "A brief history of spaceflight from 1961 to 2020: An analysis of missions and astronaut demographics," Acta Astronaut, 3 June 2020. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7422727/

[18] "Vision for Space Exploration", NASA, retrieved 20 May 2024. https://www.nasa.gov/history/vision-for-space-exploration/

[19] "Moon to Mars Overview," NASA, retrieved 20 May 2024. https://web.archive.org/web/20201112020742/https://www.nasa.gov/topics/moon-to-mars/overview

Accords"–by which countries agree to certain norms for operating on the Moon. [20] In 2022, NASA conducted the mostly successful *Artemis 1* uncrewed lunar flyby mission, setting up the *Artemis 2* crewed flyby mission for potential launch in late-2025. [21] The *Artemis 3* mission is currently planned for late-2026 and will be the first human lunar landing since 1972. After that, NASA has plans for several other crewed missions to further develop the orbiting Lunar Gateway and the surface facilities. [22]

In the meantime, Russia and China have partnered to create the International Lunar Research Station ("ILRS"), a planned permanent facility on the Moon. The pair of founding partners has already signed agreements with a growing list of "member" countries that will provide different supporting technologies and operational capabilities. [23] There has been a recent flurry of robotic missions to the Moon, including China with the successful *Chang'e 4* and the still-operational *Chang'e 6* and Russia with a failed *Luna 25*. China is also planning to launch *Chang'e 7* in 2026 and *Chang'e 8* in 2028, and Russia is developing *Luna 26*, *Luna 27*, and *Luna 28* for launches in 2027, 2028, and 2030, respectively. The current plan is for China to land humans on the Moon by 2030. [24]

To the extent that China also has ambitions for human exploration of Mars, it has stated a goal of landing there by 2033. [25] However, there has been relatively little public progress toward this specific long-term plan, with the primary focus being the ILRS.

[20] Jeff Foust, "Lithuania 40th nation to sign Artemis Accords," Space News, 16 May 2024. https://spacenews.com/lithuania-40th-nation-to-sign-artemis-accords/
[21] Jeff Foust, "NASA compiling lessons learned from Artemis 1," Space News, 5 February 2024. https://spacenews.com/nasa-compiling-lessons-learned-from-artemis-1/
[22] "Artemis", NASA, retrieved 20 May 2024. https://www.nasa.gov/humans-in-space/artemis/
[23] Andrew Jones, "Serbia becomes latest country to join China's ILRS moon base project," Space News, 10 May 2024. https://spacenews.com/serbia-becomes-latest-country-to-join-chinas-ilrs-moon-base-project/
[24] Andrew Jones, "China on track for crewed moon landing by 2030, space official says," Space News, 24 April 2024. https://spacenews.com/china-on-track-for-crewed-moon-landing-by-2030-space-official-says/
[25] "China plans for first manned mission to Mars in 2033," Al Jazeera, 24 June 2021. https://www.aljazeera.com/news/2021/6/24/china-plans-for-first-manned-mission-to-mars-in-2033

C. "Venus Direct"

The rationale for sending humans back to the Moon before heading to Mars is that it will offer a relatively safe environment to develop technologies and gain operational capabilities that will be needed for Mars. However, almost none of those will help prepare for Venus' atmosphere, so there is no need to go to the Moon first. A "Venus Direct" approach can easily be implemented.

Establishing a permanent human presence in Venus' atmosphere will not be a trivial undertaking, by any stretch of the imagination. There will be myriad challenges, including science, engineering, technology innovation, materials, medicine, socio-politics, and of course economics. However, almost all of the major areas of opportunity are unique to Venus, as shown in Table 1 below.

Venus Science	Despite the historic slate of successful missions by the Soviet space program, relatively little is known about Venus, from a scientific perspective. Fortunately, there are several new missions announced and under development, but it will be years before those reach the planet and even longer before scientists can analyze the data collected from those missions. This will be a critical step before sending humans into its atmosphere, and this cannot be achieved by heading to the Moon or Mars first.
CO2 Atmosphere	The Venusian atmosphere is composed primarily of carbon dioxide, and techniques for converting this into breathable air will need to be developed. This is theoretically possible, but it is a capability that will not be needed for the Moon or Mars, only Venus.
Sulfuric Acid Clouds	At an altitude of 50km to 60km, Venus appears to have a permanent layer of clouds across the entire planet, and these clouds seem to be composed of sulfuric acid. Materials and manufacturing processes to withstand these toxic clouds will need to be developed. This is theoretically possible, but it is a capability that will not be needed for the Moon or Mars, only Venus.
Atmospheric Operations	Venus' atmosphere is much thicker than Earth's, and techniques for operating in such an environment will need to be developed. This includes floating habitats, transportation between them and orbiting stations, and atmospheric transportation among several floating habitats. Launching and landing rockets from floating "pads" is not only

	something that has not really been done before, but also something that will not be needed on the Moon or Mars, only Venus.
Atmospheric ISRU	At a minimum, techniques for extracting drinkable water from the CO2 atmosphere and the sulfuric acid clouds will need to be developed. Ideally, new materials will also need to be created from those same elements. This is a form of "in-situ resource utilization" that is unique to Venus, since surface materials will perform the same functions on the Moon and Mars.

Table 1. Challenges Unique to Venus

There is one more challenge facing humanity on Venus that is actually shared with plans for Mars: **interplanetary human spaceflight**. After all, no human has ever flown beyond the relative safety of the Earth-Moon system, so no one is exactly sure what to expect. Of course, by definition this will not be alleviated by any precursor missions to the Moon. More importantly, an argument could be made that sending humans to Venus BEFORE sending them to Mars might actually be a safer, less expensive, and more efficient way to develop interplanetary capabilities, since it is closer to Earth and its orbit is more similar.

The bottom line is that the "Moon then Mars" approach makes sense for sending humans to Mars, but a "Venus Direct" approach may work better for sending humans to Venus.

D. "Venus in Parallel"

If the "Venus Direct" approach works best for establishing a permanent human presence in the Venusian atmosphere, then should the "Moon then Mars" approach be reconsidered? The answer is an emphatic, "No." There are many different reasons for humanity expanding into the cosmos–with both crewed and robotic space missions–and there is already global public support and momentum established for humanity's return to the Moon and for a subsequent exploration of Mars. If anything, it could be argued that those plans deserve even more support and commitment in order to make significant progress in a timely manner.

However, Venus is also a feasible and enticing potential destination for humanity, so the more important question is, "Why not do it all … the Moon, Mars, AND Venus?"

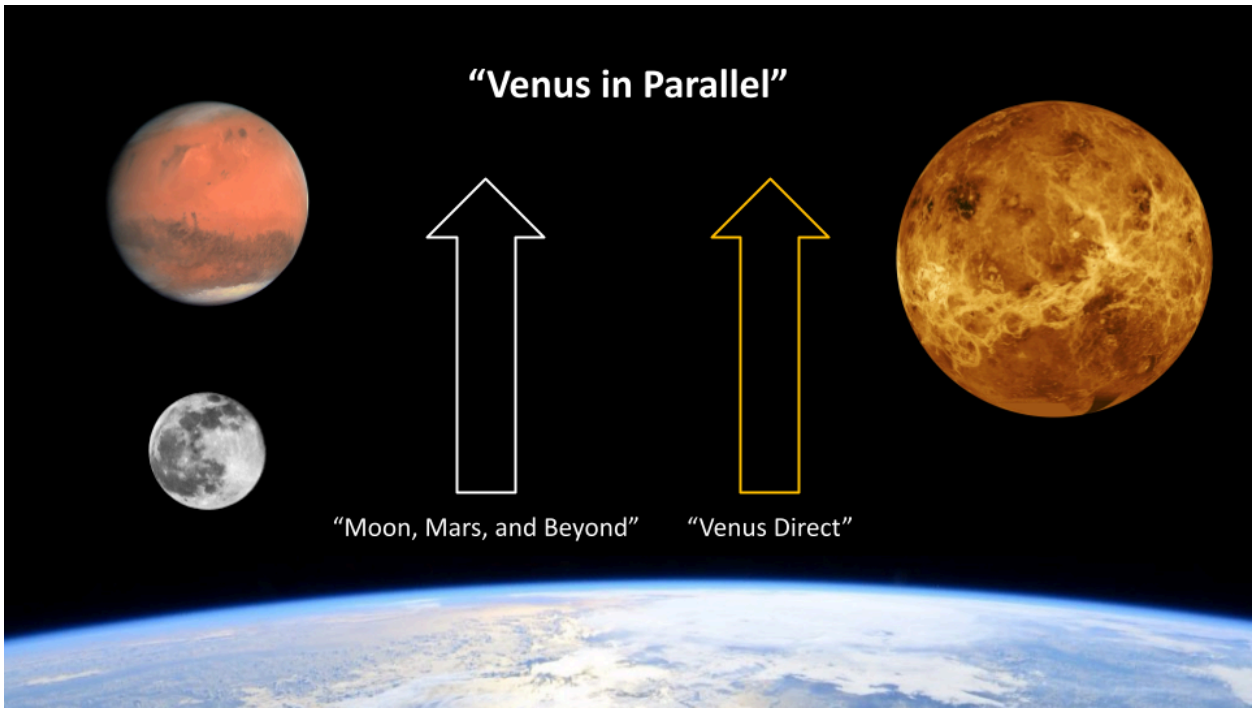

Figure 1. Venus in Parallel (© Humans2Venus Foundation)

Given the current trajectory of humanity's plans for the Moon and Mars, and given that plans for Venus can be almost completely independent of those for the Moon and Mars, then it is possible to run both programs **IN PARALLEL** (see Figure 1 above). While the US-led Artemis team and the Russia-/China-led ILRS team develop a permanent human presence on the Moon and then expand those capabilities on Mars, there is no reason why a similar international collaborative effort could not concurrently develop different capabilities for Venus. In fact, the two timelines could potentially synchronize in such a way that a race might develop for which planet will be the first to receive human visitors.

The only missing puzzle piece for the proposed Venus program is a global leader to build the consortium necessary to turn this long-term vision into a reality. This leader could quickly emerge from either the private sector (i.e., a company or a wealthy individual) or another spacefaring nation (i.e., a country's space agency), or both.

PART II. INDIA'S CURRENT LONG-TERM PLANS

A. Venus

India already has a long history of successful space missions, starting from the launch of *Aryabhata* in 1975 and stretching across 120 missions and almost 100 rocket launches. [26] It has a strong slate of science missions planned, including destinations like the Moon, Mars, and, of course, Venus. [27] Specifically, the *Shukrayaan* mission is envisioned to send an orbiter to study Venus' atmosphere. [28]

B. Human Spaceflight

Despite a long track record as one of the most well-respected spacefaring nations for rocket launches and uncrewed missions, India has lagged behind China, Russia, and the United States when it comes to human spaceflight. Indian Air Force pilot Rakesh Sharma spent almost 8 days aboard the Soviet Salyut 7 in 1984 and space tourist Gopi Thotakura flew on a Blue Origin suborbital flight in 2024, but they remain the only two Indians to fly to space. [29] Four other astronauts of Indian descent (all American citizens) have venture into space, including Kalpana Chawla (first Indian-American in space), Sunita Williams (second female ISS commander), Raja Chari (flew on SpaceX Crew-3), and Sirisha Bandla (flew on Virgin Galactic suborbital flight). All of these Indian astronauts flew on either Russian or American spacecraft and launch systems, since India has not yet developed its own crewed launch capabilities. [30]

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[26] "Spacecraft Missions," ISRO, retrieved 20 May 2024. https://www.isro.gov.in/SpacecraftMissions.html
[27] "ISRO SYNERGISES NATIONAL EFFORTS TO STUDY PLANET VENUS," ISRO, retrieved 20 May 2024. https://www.isro.gov.in/PLANETVENUS.html
[28] D V L S Pranathi, "From Mangalyaan-2 to Shukrayaan-1, here's what Isro is planning in 2024," Business Standard, 20 February 2024. https://www.business-standard.com/industry/news/from-mangalyaan-2-to-shukrayaan-1-here-s-what-isro-is-planning-in-2024-124022000403_1.html
[29] "Andhra-Born Gopi Thotakura Makes History, Becomes First Indian Space Tourist," DD News, 20 May 2024. https://ddnews.gov.in/en/andhra-born-gopi-thotakura-makes-history-becomes-first-indian-space-tourist/
[30] "From Sunita Williams to Kalpana Chawla: Here's a list of people of Indian origin who have been to space to date," Financial Express Lifestyle, 3 September 2023. https://www.financialexpress.com/lifestyle/from-sunita-williams-to-kalpana-chalwa-heres-a-list-of-people-from-indian-origin-who-have-been-to-space-till-date/3228802/

However, all of this is about to change. In 2019, ISRO created the Human Spaceflight Center ("HSFC") in Bangalore to implement the nation's vision for its Human Spaceflight Programme. [31] Specifically, HSFC is focused on the *Gaganyaan* program, which targets launching a crew of three astronauts into LEO for a 3-day mission. Several critical milestones have already been completed successfully, and the country continues to push forward with its slate of development missions. In fact, in early 2024 Prime Minister Narendra Modi announced India's first four astronauts, all former test pilots and proven leaders in the Indian Air Force. [32]

PART III. ARGUMENT FOR INDIA'S LEADERSHIP ROLE TO VENUS

A. Crewed Missions to Venus

Although the global space community is still developing a viable roadmap toward a future permanent human presence in the Venusian atmosphere, [33] it is clear that the initial missions will need to be focused on science and technology demonstrations. However, as with any other space exploration, the first crewed missions following robotic missions will likely consist of flyby and orbital missions before any attempt is made to descend into the atmosphere. As stated in prior sections above, these missions will not be dependent on the ongoing success of human missions to the Moon or Mars, so they could progress at their own pace, perhaps even ahead of the slate of Venus science and technology demonstration missions.

Given orbital mechanics, a crewed flyby mission would likely last 12 months, [34] which is already well within the bounds of human spaceflight experience in LEO. [35] In fact, depending on the size of the crew, such a mission could feasibly be conducted with existing launch systems

[31] "Inauguration of Human Space Flight Centre (HSFC)," ISRO, retrieved 20 May 2024. https://www.isro.gov.in/HSFC.html
[32] "India announces crew for first manned space mission," BBC, 27 February 2024. https://www.bbc.co.uk/newsround/68411897
[33] See, e.g., www.venusroadmap.org
[34] Noam R. Izenberg, Ralph L. McNutt Jr., Kirby D. Runyon, Paul K. Byrne, and Alexander MacDonald, "Venus Exploration in the New Human Spaceflight Age," ScienceDirect, Volume 180, March 2021. https://www.sciencedirect.com/science/article/pii/S0094576520307554
[35] Ayana Archie, "A NASA astronaut is back on Earth after a year in space, the longest for an American," NPR, 28 September 2023. https://www.npr.org/2023/09/20/1200374445/nasa-frank-rubio-record-yearlong-flight

and spacecraft. Of course, such a long-duration flight would be better served by a specially designed spacecraft, so some development time would likely be required. Regardless, it is not inconceivable that a crewed flyby of Venus could potentially be undertaken within the decade, which would align it almost exactly with other stated goals for sending humans to Mars. Indeed, a novel "space race" could emerge between crewed missions bound for Mars and Venus.

B. Potential for India Leadership Role

The United States' experience with the Apollo program and its aftermath offers many key lessons to be learned by other spacefaring nations. Arguably the most critical of these is the power of a single unifying vision and "call to action". In the 1960s, Americans rallied behind President Kennedy's bold plan to send humans to the Moon and return them safely within less than a decade, and in July 1969 NASA succeeded in fulfilling his vision. Unfortunately, there was no clear direction beyond that achievement, and so many critics feel that NASA "lost its way" after the lunar landings. In his 2004 "Vision for Space Exploration", President George W. Bush tried to reinstate that driving force through what has over time evolved into NASA's "Moon, Mars, and Beyond" program.

Of course, the obvious difference between President Kennedy's vision and the NASA current directive is a clear objective and timeline, or lack thereof. Currently neither the US-led Artemis program nor the Russia-/China-led ILRS program has any clearly articulated success metrics or timelines, just estimated goals and schedules. As a counter-example (whether it is feasible or not), Elon Musk founded SpaceX with a clear objective of having "a million people living on the Martian surface by 2050." [36] Likewise, Jeff Bezos founded Blue Origin with a clear objective of having "millions of people living and working in space to benefit Earth", which admittedly suffers from the lack of a clear timeline. [37] Whether achievable or not, the benefit of long-term visions like Kennedy's, Musk's, and Bezos' is that they help align strategic planning

[36] Morgan McFall-Johnsen and Dave Mosher, "Elon Musk says he plans to send 1 million people to Mars by 2050 by launching 3 Starship rockets every day and creating 'a lot of jobs' on the red planet," Business Insider, 17 January 2020. https://www.businessinsider.com/elon-musk-plans-1-million-people-to-mars-by-2050-2020-1

[37] Corey S. Powell, "Jeff Bezos foresees a trillion people living in millions of space colonies. Here's what he's doing to get the ball rolling.," NBC News, 15 May 2019. https://www.nbcnews.com/mach/science/jeff-bezos-foresees-trillion-people-living-millions-space-colonies-here-ncna1006036

and near-term tactics. They also help inspire current and future generations engineers, scientists, entrepreneurs, technologists, investors, and many many others.

The implication is that today there is a huge leadership vacuum when it comes to Venus, so a credible individual or nation could play an historic role by stepping onto the world stage with a bold and clear vision for establishing a permanent human presence in the Venusian atmosphere. India is by far the most plausible candidate to take advantage of this situation.

India has vast resources in terms of economics, human talent, and natural resources, such that it could undertake this kind of bold long-term endeavor. It also has the political clout and diplomatic relationships to broker the many bilateral and multilateral agreements–as well as public-private partnerships–necessary to succeed on Venus. Most importantly, it has a track record of success with space missions that is rivaled only by China, Russia, and the United States, all of whom will be focused on the Moon and Mars for the next decade or more.

India's *Gaganyaan* program is a solid first foray into making the country a true spacefaring nation, but history teaches that HSFC will benefit greatly from a much more ambitious long-term vision and aggressive timeline. Setting its sights on the Venusian atmosphere may be precisely the kind of incentive that will drive India into the global leadership role it richly deserves based on its past successes. While the Soviet Union and the United States pushed humanity into space during the last part of the 20th century, it could very well be that India leads humanity beyond the Earth-Moon system through the rest of the 21st century.

C. Potential for QUAD Cooperation

Establishing a permanent human presence in the Venusian atmosphere will be a huge undertaking, so it will likely require multiple strategic partners brought together by a strong leader to succeed in achieving this long-term vision. If India takes on this leadership role, then the most likely core of its international consortium will be the QUAD countries. After all, the United States is already one of the leading spacefaring nations, Japan has a strong and growing space program, and Australia recently demonstrated its commitment to space by creating its own

space agency. There are many ways for the four countries to cooperate toward a common goal on Venus.

Obviously, NASA has the most human spaceflight experience and would be critically important to the long-term Venus effort. However, it is also focused on the Artemis program on the Moon and on forging onward to Mars soon thereafter, so it does not have many resources to allocate for a human Venus effort. However, it can contribute several key elements, including general knowledge of human spaceflight, scientific data from its two planned Venus missions (DAVINCI and VERITAS), and detailed research from its HAVOC program ("High-Altitude Venus Operational Concept") that studied the feasibility of floating research stations in the Venusian Atmosphere. [38]

For many reasons, JAXA may be the optimal QUAD partner for an ambitious Venus program. It has a proven track record of successful space missions, it has had over a dozen astronauts fly in space, [39] it is an active participant in the Artemis lunar program, and it has a robust private space ecosystem, including large corporations, startup ventures, and equity investors. [40] There are multiple connection points where Japan could contribute significantly to an India-led Venus consortium.

Even Australia, which has a long history in space as a country even though its agency is relatively small and new, can add value to–and benefit greatly from–this effort. Its vast uninhabited territory may be an ideal location for stratospheric test flights of floating habitats and air-launched transportation systems. Also, it can also provide ground segment communications support, as it has for almost the entirety of humanity's journey into space. [41]

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[38] Dale Arney and Chris Jones, "HAVOC: High Altitude Venus Operational Concept - An Exploration Strategy for Venus," NASA, 31 August 2015. https://ntrs.nasa.gov/citations/20160006329

[39] "Japanese Astronauts", JAXA, retrieved 20 May 2024. https://humans-in-space.jaxa.jp/en/astronaut/

[40] Naoko Kutty and Naoko Tochibayashi, "See how Japan's space industry is gaining momentum," World Economic Forum, 5 June 2023. https://www.weforum.org/agenda/2023/06/see-how-japan-s-space-industry-is-gaining-momentum/

[41] Kerrie Dougherty, "Sixty years of Australia in space," Journal & Proceedings of the Royal Society of New South Wales, vol. 153, part 1, 2020, pp. 46–57. https://royalsoc.org.au/images/pdf/journal/153-1-Dougherty.pdf

D. Potential Beyond QUAD

Should India require more resources beyond its QUAD partners in order to achieve its long-term Venus objectives, there is no shortage of potential strategic contributors. The most obvious would be Russia and China, because of their prominent roles as top-tier spacefaring nations with extensive human spaceflight experience. Obviously, this may present a double-edged sword, given geopolitical tensions. Then again, Russia and the United States have proven for years that they could cooperate in space even while clashing here on Earth. [42] Perhaps there is an opportunity for "coopetition" between India and Russia/China?

Beyond those top two candidates, there are many India-friendly countries that might gladly join an ambitious Venus program. If they have demonstrated anything, the ILRS and the Artemis Accords have shown that there is a strong appetite among many countries to develop their own space capabilities while also fostering geopolitical bonds. Given India's global presence and impressive track record in space, countries throughout Europe, Asia, Africa, and Latin America would likely engage with a new "space superpower", even on a long-term project like Venus.

There is one other potential strategic partner that cannot be overlooked: the private sector. The American space program has benefited greatly over the past decade from billions of dollars in private equity investment being poured into thousands of entrepreneurial startups. [43] Even larger companies like SpaceX, Blue Origin, Boeing, United Launch Alliance, Lockheed Martin, Northrop Grumman, and others have supported NASA's various initiatives. In China, the central government opened up its space sector to private investment in 2014, and since then the country's space ecosystem has almost literally taken off like a rocket ship. [44] The technical and operational advances its private and public-private companies have made in such a short period of time are nothing short of breathtaking. Of course, the high-profile involvement of prominent

[42] "Russia, US agree additional US astronaut flight to International Space Station, Interfax reports," Reuters, 25 August 2023. https://www.reuters.com/technology/space/russia-us-agree-additional-us-astronaut-flight-iss-interfax-2023-08-25/
[43] "Space Investment Quarterly," Space Capital, retrieved 20 May 2024. https://www.spacecapital.com/space-iq
[44] Andrew Jones, "China's commercial sector finds funding and direction," Space News, 25 April 2021. https://spacenews.com/chinas-commercial-sector-finds-funding-and-direction/

billionaires is also a phenomenon that cannot be ignored. [45] Like the United States and China, India has an immense private space sector, with a robust mix of established corporations and innovative young startups. [46] In fact, India may find that it will not need to look beyond its own borders to secure the resources and capabilities it needs to successfully establish a permanent human presence in the Venusian atmosphere.

CONCLUSION

India currently finds itself in the enviable position of potentially taking an historic leadership role in humanity's expansion beyond Planet Earth: it could assert itself as the de facto head of an international consortium to establish a permanent human presence in the Venusian atmosphere. This consortium could find its core within the QUAD framework, but it could also extend well beyond. This would give India a bold long-term vision around which to focus its launch, robotic, science, and human spaceflight programs. In the process, embracing such a leadership role would help elevate India into the top tier of Earth's spacefaring nations.

AUTHOR'S DECLARATION

The above article is original and no part of it has been copied or taken from other sources without necessary permission or unless otherwise cited in the footnotes.

[45] Katherine Mangu-Ward, "The Case for Space Billionaires," Reason, 15 November 2022. https://reason.com/2022/11/15/the-case-for-space-billionaires/

[46] AK Bhatt, "Indian private space sector: Navigating growth and challenges in era of reform," ET Satcom, 2 February 2024. https://telecom.economictimes.indiatimes.com/news/portal-in-portal/satcom/blogs/indian-private-space-sector-navigating-growth-and-challenges-in-era-of-reform/107351509