# АСТРОФИЗИКА И ЗВЕЗДНАЯ АСТРОНОМИЯ

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## ТЕОРЕТИЧЕСКОЕ И ЭКСПЕРИМЕНТАЛЬНОЕ ИССЛЕДОВАНИЕ СУПЕРРОТАЦИИ АТМОСФЕРЫ ПЛАНЕТЫ ВЕНЕРА

Экономов А. П.[a,1], Готлиб В. М.[a,2], Кержанович В. В.[a,3], Линкин В. М.[a,4], Липатов А. Н.[a,5], Макаров В. С.[a,6], Манукин А. Б.[a,7]

[a] Российская академия наук, г. Москва, 117997, Россия.

Атмосфера Венеры была отдаленно изучена в течение приблизительно 100 лет и с космическими кораблями почти половины столетия. В результате была драматическая модернизация представлений. Главное открытие — обнаружение уникального явления — суперротация атмосферы. Впервые это обнаружено с орбиты в 1974 с космического корабля Mariner, и это — главный элемент атмосферной динамики. Исследование супервращения проводилось в УЛЬТРАФИОЛЕТОВОМ диапазоне в высотах 65-69 км и в диапазоне IR 51-59 км, и также в ходе эксперимента с баллоном ВЕГИ на 53-55 км. В промежуточных высотах не были выполнены систематические измерения. Предложено ввести легкие зонды–баллоны в атмосферу в различных высотах, но с увеличенной длительностью полета. Оболочки сделаны из металлизированной PET фольги. Масса полезного груза на каждом зонде составляет 1 кг. Диаметр оболочки зависит от высоты, и в высотном диапазоне 50-70 км находятся в диапазоне 1-3 метров. Экспедиция должна продлиться приблизительно 30 земных дней. Также предложено продвинутое объяснение физического механизма суперротации.

*Ключевые слова*: пространство, процесс, информация, структура, развитие.

## VENUS THEORETICAL AND EXPERIMENTAL ATMOSPHERE SUPERROTATION STUDY

Ekonomov A. P.[a,1], Struct P. V.[a,2], Kerzhanovich V. V.[a,3], Linkin V. M.[a,4], Lipatov A. N.[a,5], Makarov V. S.[a,6], Manukin A. B.[a,7]

[a] Russian Academy of Sciences, Moscow, 117997, Russia.

Advanced explanation of the physical mechanism of superrotation is proposed. The reason is solar light pressure. The atmosphere of Venus was remotely studied for approximately 100 years and with spacecrafts for nearly half a century. As a result, there was a dramatic modernization in terms of views. The main finding is the detection of a unique phenomenon: the superrotation of the atmosphere. For the first time, this was detected from orbit in 1974 via the spacecraft Mariner, and this is the main element of atmospheric dynamics. The superrotation

[1] E-mail: alekonomo@yandex.ru
[2] E-mail: gotlib@iki.rssi.ru
[3] E-mail: kerzanov1@yahoo.com
[4] E-mail: slavalinkin1@yandex.ru
[5] E-mail: slip@iki.rssi.ru
[6] E-mail: vmakarov@mx.iki.rssi.ru
[7] E-mail: amanukin@yandex.ru

study was conducted in the UV range at altitudes of 65-69 km and in the IR range of 51-59 km, and also, during the course of the experiment, using a VEGA balloon at 53-55 km. At intermediate altitudes, systematic measurements were not carried out. It is proposed to introduce light weight balloon probes into the atmosphere at different altitudes, but with increased durability. Envelopes are made of metalized PET foil. The payload mass on each probe is 1kg. The diameter of the envelope depends on the altitude and at an altitude range 50-70 km is within the range of 1-3 meters. The expedition should last approximately 30 Earth days.

*Keywords*: Venus, atmosphere superrotation, balloon.

## Introduction

The results of two balloons which flew in the cloud layer of the atmosphere of Venus during the Vega experiments were analyzed as to the nature of the superrotation and local dynamic and thermodynamic characteristics of the atmosphere. These measurements via balloon, along with measurements of temperature profiles from Venera 15 Fourier spectrometer measurements, allow us to propose a mechanism that accelerates the atmosphere to high zonal velocities and maintains these speeds, i.e. the superrotation of the atmosphere in general. Spectral measurements with balloons confirm the possibility of imaging the planet's surface from a height of not more than 55 km. Future experiments with balloons in the atmosphere of Venus are being considered.

In particular, we discuss the possibility of measuring the geopotential height, because Venus has no seas and oceans for vertical positioning of the temperature profiles. As an innovative research platform within the atmosphere, an overpressure balloon with a lifetime greater than 14 Earth days, as well as vertical microprobes, are being considered.

In situ studies of the atmosphere of Venus are necessary because the dense atmosphere blocks remote observations from orbit. Below cloud level is a large percentage of the atmosphere, the surface of Venus and numerous processes that determine the heat balance of the planet, the mechanism of interaction of the atmosphere with the surface (inducing wave buoyancy), and geological processes on the surface. Data from previous missions are insufficient to answer the questions regarding the generation of the superrotation of the atmosphere of the planet, buoyancy waves penetrating to great heights, what is the full range of turbulence in the cloud layer, and many other tasks of significance, so it is necessary to continue studying the atmosphere of Venus with balloon probes and descent probes. Important parameters for balloon probes is the duration of their flight in the atmosphere of Venus. Project Vega showed that it is possible to solve the problem of increasing the flight duration of balloons in the atmosphere using well-verified manufacturing technology. This can be achieved by using a reserve gas which can be utilized to compensate for gas losses during flight, which will increase flight duration from 2 to 20 days. To study the atmosphere of Venus on the lander and balloon probes, a meteorological complex should be used for measuring the main atmospheric parameters P, T, dT, W, W', E (pressure, temperature, temperature gradient, wind speed, acceleration, infrared flux).

Tables 1-3 shows the main parameters of balloons, respectively, for altitudes of 55 km and 48-50 km.

## 1. Download advancement — deep dive

From a comfortable trajectory of 50 km, we can advance the balloon down to the surface. The problem is the hot environment for electronics. To overcome the 100°C limit for Si electronics, we must exchange Si for GaAs. In this case, we will be able to produce a long flight of 37 km. There the lifting power of a balloon is 10 times greater compared to 50 km. After several revolutions around

Venus at a constant altitude in superpression mode, the aerobot starts a slow dive into the atmosphere along a sloping spiral. Vertical section of the atmosphere will lead to electronics overheating failure at approximately 11 km.

## 2. The reason for the abnormal rotation of the atmosphere of the planet Venus

It is known that the atmosphere of Venus rotates in the same direction as the planet itself, but the period of rotation of the planet is about 240 Earth days, and the period of rotation of the upper atmosphere is approximately 4 days.

Thus, the entire atmosphere rotates faster than the surface of the planet, therefore, the external constant torque should act on the atmosphere.

At the base of the model of external torque formation, there is an experimentally confirmed effect of rotational pondermotive instability. Any spherical or cylindrically symmetric body with an initial angular momentum will be rotationally unstable after uniform luminous flux dropping perpendicular to the axis of symmetry. The reason for this is that symmetric surface points as to a flow will have different temperatures: the point emerging from a shadow has a lower temperature in comparison with another which was heated by the flow. As the tangential component of light pressure is proportional to the absorption coefficient growing with a rise in temperature, there is the torque accelerating initial rotation of the body.

The gear of formation of the difference in absorption coefficient symmetric concerning the direction towards the Sun for the portions of the atmosphere of Venus is more difficult, but the idea of using light pressure seems fruitful. Cloud layer altitudes also differ for morning and evening terminators, which also increases the torque of light pressure.

Even in a case when the difference in an albedo is less than one percent, and the area where there is an albedo difference is no more than 10% from all areas of the planetary disc, and cloud layer altitudes differ by no more than 5 km, the difference of light pressure over several million years can untwist the atmosphere till observable speeds.

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In drawing change of altitude of a cloud layer for morning and evening terminator is schematically shown.

**Table 1.** Scientific payloads for 48-55 km

| Scientific payload | АЗ-55 | АЗ-48 |
|---|---|---|
| т, p, w, w', dт, e, $\omega$, нkg | 0.4 | 0.6 |
| camera ( 1 mkm) kg | 0.5 | 0.5 |
| Acoustics kg | 0.3 | 0.3 |
| Nephelometer kg | 0.5 | 0.5 |
| TDLAS | 0.5 | 0.5 |
| seismology | 0.4 | 0.4 |
| GS-MS | | 2.5 |
| LIDAR | | 0.5 |
| dropzonds | | 2*2 |

**Table 2.** Balloon parameters for 48-55 km

| Parameters | АЗ-55 | АЗ-48 |
|---|---|---|
| Envelope volume m3 | 20 | 20 |
| Total floating mass kg | 21 | 38 |
| Altitude of operation km | 53-55 | 48-50 |
| Photovoltaic cell power W | 1-2 | 2-3 |
| Velocity of flight m/s | 70 | 70 |
| Transmission rate to orbiter bit/s | 10 | 10 |
| Mass of gondola kg | 6.7 | 21.5 |

**Table 3.** Mass distribution for 48-55 km

| Mass distribution kg | АЗ-55 | АЗ-48 |
|---|---|---|
| Photovoltaic cell | 0.3 | 0.6 |
| Rechargeable battery | 0.4 | 0.8 |
| Control system | 0.3 | 0.3 |
| Communication subsystem | 0.9 | 0.9 |
| structure | 1.2 | 2.5 |
| Helium pressure vessel | 1 | 4.5 |
| reserve | | 3.5 |
| TOTAL | 6.7 | 20 |

**Table 4.** Comparisons for missions

| | Vega balloon | Undercloud orbit | Undercloud finish | Deep dive |
|---|---|---|---|---|
| H km | 53-54 | 37 | 54-37 | 54 ÷ 11 |
| T K (T °C) | 300 (27) | 430 (166) | 300 ÷ 430 (27 ÷ 166) | 625 (400) |
| P bar | 1.03 | 4.8 | 1.03 ÷ 4.8 | 1.03 ÷ 35 |
| Time h | 46 | 100 | 200 | 100(?) |
| Density kg/m3 | 0.6 | 5.8 | 0.5 ÷ 5.8 | 0.5 ÷ 30 |
| Frequency MHz | 1668 | 1668 | 1668 | 1668 |
| Electronics | Si | GaAs | GaAs+Si | GaAs |

**Table 5.** Comparisons for HTE materials

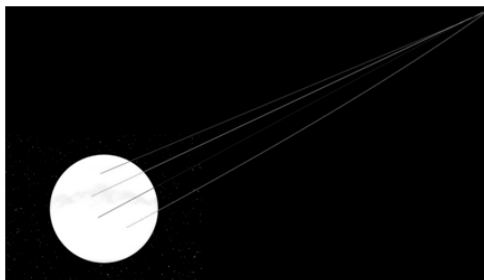| Material | Tech maturity | Temp tolerance (°C) |
|---|---|---|
| Silicon (Si) | Very high | 125 ÷ 250 |
| Silicon-on-Insulator (SOI) | Medium | 250 ÷ 300 |
| Gallium Arsenide (GaAs) | High | 350 |
| Gallium Nitride (GaN) | Very low | >500 |
| Silicon Carbide (SiC) | Low | >750 |
| Diamond | Very low | >800 |

**Fig. 1.** Entry vehicles aimed at different Venus latitude zones in turn consist of several vehicles intended for different heights assembled using a tandem principle. After entering into the atmosphere, these vehicles disintegrated, releasing balloons
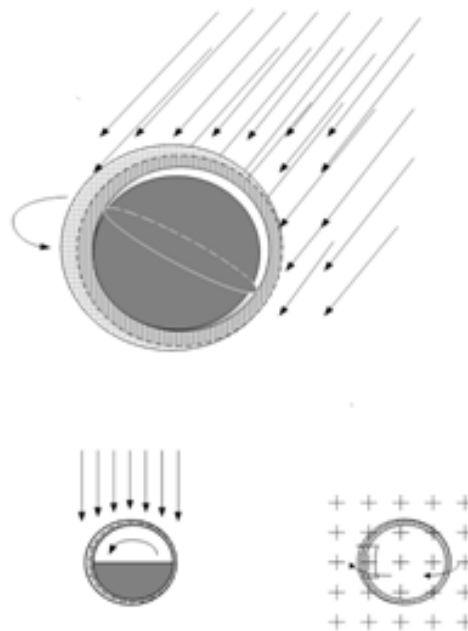


**Fig. 2.** In the illustration, the change of altitude of a cloud layer for morning and evening terminators is shown schematically
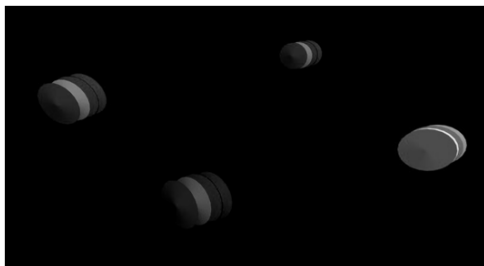


**Fig. 3.** Each vehicle aimed at different Venus latitude zones in turn consists of several vehicles intended for different heights
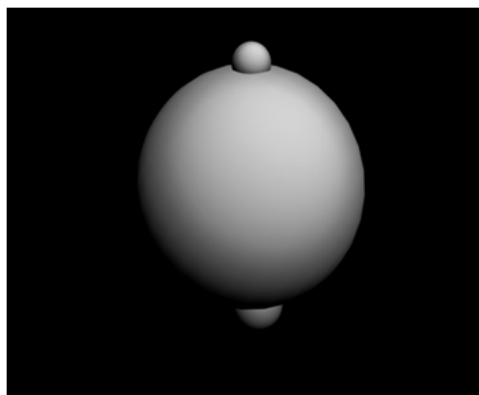


**Fig. 4.** Envelopes are made of metalized PET foil. The payload mass on each probe is 1 kg. The diameter of the envelope depends on the altitude, and at an altitude range of 50-70 km, is in the range of 1-3 meters. At the upper pole is a transmitter antenna, and at the lower pole is the payload

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## Авторы

**Экономов Алексей Павлович**, кандидат технических наук, старший научный сотрудник, Институт космических исследований РАН, Российская академия наук, ул. Профсоюзная, д. 84/32, г. Москва, 117997, Россия.
E-mail: alekonomo@yandex.ru

**Готлиб Владимир Михайлович**, к.ф.-м.н., ведущий научный сотрудник, Институт космических исследований РАН, Российская академия наук, ул. Профсоюзная, д. 84/32, г. Москва, 117997, Россия.
E-mail: gotlib@iki.rssi.ru

**Кержанович Виктор Валентинович**, д.ф.-м.н., ведущий научный сотрудник, Институт космических исследований РАН, Российская академия наук, ул. Профсоюзная, д. 84/32, г. Москва, 117997, Россия.
E-mail: kerzanov1@yahoo.com

**Линкин Вячеслав Михайлович**, д.ф.-м.н., профессор, заведующий лабораторией, Институт космических исследований РАН, Российская академия наук, ул. Профсоюзная, д. 84/32, г. Москва, 117997, Россия.
E-mail: slavalinkin1@yandex.ru

**Липатов Александр Николаевич**, к.ф.-м.н., старший научный сотрудник, Институт космических исследований РАН, Российская академия наук, ул. Профсоюзная, д. 84/32, г. Москва, 117997, Россия.
E-mail: slip@iki.rssi.ru

**Макаров Владислав Сергеевич**, инженер, Институт космических исследований РАН, Российская академия наук, ул. Профсоюзная, д. 84/32, г. Москва, 117997, Россия.
E-mail: vmakarov@mx.iki.rssi.ru

**Манукин Анатолий Борисович**, к.ф.-м.н., старший научный сотрудник, Институт космических исследований РАН, Российская академия наук, ул. Профсоюзная, д. 84/32, г. Москва, 117997, Россия.
E-mail: amanukin@yandex.ru

## Authors

**Ekonomov Alexey Pavlovich**, candidate of technical Sciences, senior researcher, Institute of Space Research, Russian Academy of Sciences, Profsoyuznaya str., 84/32, Moscow, 117997, Russia.
E-mail: alekonomo@yandex.ru

**Gotlib Vladimir Mikhailovich**, candidate of physical and mathematical Sciences, leading researcher, Institute of Space Research, Russian Academy of Sciences, Profsoyuznaya str., 84/32, Moscow, 117997, Russia.
E-mail: gotlib@iki.rssi.ru

**Kerzhanovich Viktor Valentinovich**, doctor of physics and mathematics, leading researcher, Institute of Space Research, Russian Academy of Sciences, Profsoyuznaya str., 84/32, Moscow, 117997, Russia.
E-mail: kerzanov1@yahoo.com

**Linkin Vyacheslav Mikhailovich**, doctor of physics and mathematics, professor, head of laboratory, Institute of Space Research, Russian Academy of Sciences, Profsoyuznaya str., 84/32, Moscow, 117997, Russia.
E-mail: slavalinkin1@yandex.ru

**Lipatov Alexander Nikolaevich**, candidate of physical and mathematical Sciences, senior researcher, Institute of Space Research, Russian Academy of Sciences, Profsoyuznaya str., 84/32, Moscow, 117997, Russia.
E-mail: slip@iki.rssi.ru

**Makarov Vladislav Sergeevich**, engineer, Institute of Space Research, Russian Academy of Sciences, Profsoyuznaya str., 84/32, Moscow, 117997, Russia.
E-mail: vmakarov@mx.iki.rssi.ru

**Manukin Anatoly Borisovich**, candidate of physical and mathematical Sciences, senior researcher, Institute of Space Research, Russian Academy of Sciences, Profsoyuznaya str., 84/32, Moscow, 117997, Russia.
E-mail: amanukin@yandex.ru