Planet-D mission to Venus in the future

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Example images taken by Akatsuki cameras (IR1, IR2, UVI, LIR)

A synthesized false color image

(283 nm : blue; 365 nm : green; 0.90 µm : red.)

IR1, UVI

Y shape structure clearly appears

IR2

Venus nightside clouds at the deep cloud layer.

(brightness inverted)

1.735 µm (blue) and 2.26 µm (red)

Images

IR1: 1,643
IR2: 3,201
UVI: 17,306
LIR: 31,444

by Jan. 2, 2020

cloud top temperature taken by LIR. A huge bow shape structure is seen.
Mission to Lagrange points

Lyapunov orbit
or
Lissajous orbit
or
Halo orbit

around Lagrange points
We will be able to watch both dayside and nightside simultaneously.

- We need much more IR2 images at nightside (1643 images << 31,444 LIR images from Akatsuki).
The orbits around Venus L1 and L2

To make angle to the Venus 25deg, the semimajor axis must be under 0.5M km.

Because Halo orbit has minimum length for z direction in theory, Lissajous orbit is preferable.

(The graph above is for Sun-Earth L-point)
It’s difficult to make linkage two probes simultaneously because of that distance.

Plan A1: to use 2 ground stations
Plan A2: to use 1 ground station and share by time
Plan B: to make linkage between probes
   i.e.
   L1 probe has 2 HGA-T (for L2 probe & the ground station)
   L2 probe has 1 HGA-T (for L1 probe)
Sequence to orbital insertion

1. Insertion to **elliptical orbit** by Epsilon S (*1) + Kick Stage (*2)

2. Transfer to **Earth-Venus interplanetary trajectory**

3. Transfer to **Venus L1 Lissajous orbit**

4. Planet-D2 separation from Planet-D1

5. Planet-D2 Transfer to **Venus L2 Lissajous orbit**

6. Station keeping of Planet-D1 around Venus L1 and Planet-D2 around Venus L2

*1 Epsilon S: Improvement of the current Epsilon Launch Vehicle
   Development started in 2020

*2 Kick Stage: Under development for Destiny+
Launch period

The launch opportunity comes every 584 days, the period of Venus’ meeting with Earth. However, since the orbital planes of Venus and Earth are tilted, the optimal timing comes every 8 years (about 2920 days $\div 5$ times the meeting period).

If sufficient development time is kept, the optimal period is autumn 2032. However, considering the risk of development delays, the provisional target is spring 2031. Since this is a point-to-point analysis, it is necessary to examine detailed elements such as Right Ascension of Ascending Node.
PLANET-D Configuration (without mission devices)

**PLANET-D1**: 430kg

**PLANET-D2**: 50kg

- **OMS** (for D1&D2 Orbit Maneuver)
- **RCS** (for D1 Attitude Control)
- **RCS** (for D2 Attitude Control)
- **Probes Separation System**
- **Rocket I/F**
**Delta V Estimation**

- Results of the analysis

Earth

- orbit: alt. 230 x 37000 km

  ΔVe (1460m/s) by OMC

Earth-Venus transfer orbit

- ΔVs (200m/s) by OMC

Venus flyby at 400km altitude

- ΔVL (520m/s) by OMC

Venus L1 Lissajous orbit

  ΔVbL (1-6 m/s) by RCS

Venus L2 Lissajous orbit

Station keeping in L1/L2 Lissajous orbit by RCS

  ΔVsk (1-10 m/s/year)

⇒ probe total mass = 480kg

  ΔV = 2500~2800 m/s

  (ΔV by OMS = 2200~2600 m/s)
Propellant Selection for OMS

NTO/N2H4 is preferable for OMS Propellant in the range of ΔV 2200〜2600m/s. (see right figures)

<table>
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<tr>
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<th>N2H4</th>
<th>NTO/N2H4</th>
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<tbody>
<tr>
<td>ΔV [m/s]</td>
<td>2200</td>
<td>2600</td>
</tr>
<tr>
<td></td>
<td>2200</td>
<td>2600</td>
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<tr>
<td>Propellant Mass [kg]</td>
<td>320</td>
<td>355</td>
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<tr>
<td>Dry Mass [kg]</td>
<td>160</td>
<td>125</td>
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<tr>
<td>Sum [kg]</td>
<td>480</td>
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</table>

*Dry mass in this page means the mass except OMS propellant*
Mass Distribution

Mass distribution based on NTO/N2H4 OMS system is as below.

<table>
<thead>
<tr>
<th>Contents</th>
<th>Mass [kg]</th>
<th>notes</th>
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<tbody>
<tr>
<td></td>
<td>for OMC ΔV =2200 m/s</td>
<td>for OMC ΔV =2600 m/s</td>
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<tr>
<td>D1 Mission devices</td>
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<td>16</td>
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<tr>
<td>Bus Structure/devices</td>
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<td>30*</td>
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<tr>
<td>Propulsion devices</td>
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<td>99</td>
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<tr>
<td>Propellant</td>
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<tr>
<td><strong>D1 Sum</strong></td>
<td><strong>430</strong></td>
<td><strong>469</strong>*</td>
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<tr>
<td>D2 Mission devices</td>
<td>26</td>
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<tr>
<td>Bus Structure/devices</td>
<td>15*</td>
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<td>Probes Separation System</td>
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<td>1</td>
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<td>Rocket I/F</td>
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<tr>
<td>Propulsion devices</td>
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<tr>
<td>Propellant</td>
<td>2</td>
<td>2</td>
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<tr>
<td><strong>D2 Sum</strong></td>
<td><strong>50</strong></td>
<td><strong>50</strong></td>
</tr>
<tr>
<td><strong>D1 + D2 Sum</strong></td>
<td><strong>480</strong></td>
<td><strong>519</strong>*</td>
</tr>
</tbody>
</table>

*necessary to improve*
Current Issues

1. ΔV optimization
   - Acceleration timing
   - Swing-by
   - Tolerance to Z-direction amplitude in Lissajous orbit

2. Mass distribution
   - Refinement of bus structure/devices
   - Updating of devices information
   - Redistribution of D1/D2 function

Image by the paper: Optimization for Lissajous Orbit
Optional Instruments for ion escape

- Solar EUV monitor
- Fluxgate magnetometer

Observation can be done during L1 to L2 transfer

4 weeks

O$^+$ ion tail

EUV imager

O$^+$ distribution observed by PVO
[Luhmann, 1986]
Summary

- We need to plan a new generation Venus mission after Akatsuki.

- Russia is planning Venera-D in 2029 and Lagrange point mission (India plans something)

- ISAS has a heritage of Akatsuki 5 cameras and easy to put them to the new mission, Planet-D.

- Planet-D consists of two spacecraft inserted into Lagrange points, L1 and L2 and look at the dayside and nightside hemisphere. UVI, LIR and IR2 are the candidate cameras onboard the spacecraft.

- Launch by Epsilon launch vehicle is assumed.

- Ion escape may be imaged during one spacecraft’s moving from L1 to L2.