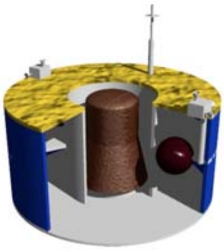
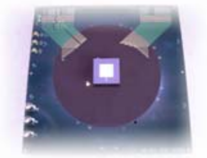
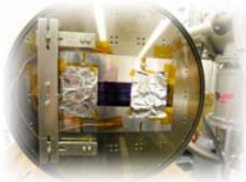
International Planetary Probe Workshop 6(2008)

IPPW-6

Research Activities on Venus Atmosphere Balloon Observation Mission







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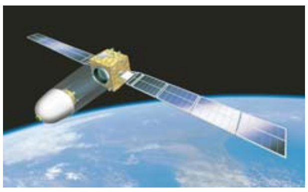
Japan Aerospace Exploration Agency

1) Institute of Space and Astronautical Science

2) Institute of Aerospace Technology

Be a Dawn of Japanese Planetary Entry !

Reentry Researchers in ISAS have been engaged in...



What's Next ?

we would answer

Planetary Entry !

Begin with Venus !!

USERS/REV

dedicated to μG Experiment

ISAS cooperate with USEF on Research Activities

Launched Sept/2002

Recovered May/2003

HAYABUSA

Asteroid Sample Return

Launched April/2003

Arrive at Asteroid Aug/2005

Return June/2007

DASH

Launched Mar/2002

-Hyperbolic Velocity

-Precursor for M-C

EXPRESS

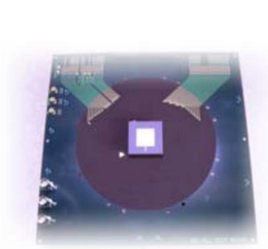
Launched Jan/1995

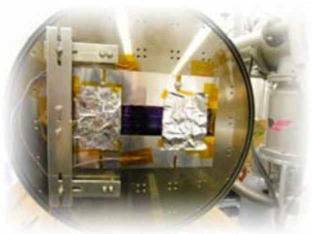
Reentry Tech. Acquisition

Contents of the Presentation

Research Activities on Venus Atmosphere Balloon Observation Mission

- Brief Introduction of Target Mission Concept
- Recent Status including External Relations
- Brief Outline of the Subsystems
  with Recent R&D Activities for Critical Issues
- Future Work and Schedule addressed





Planet Venus and Probe Explorations

Venus : Twins of Earth
but Mysterious Planet in the Solar System

- 0.72 AU from the Sun
- R=6052 km (95% earth), 0.815 Earth Mass
- Rot. Period = 243 days (reverse)
- T=460°C, P=90 atm (Surface)
- T=200°C (@H=35km)
- Strong Equatorial Wind
- Sulfuric acid Cloud (H47-70km)

※Observations under clouds is Significant from Scientific Point of View

Venus **Great Historical Probe Missions**

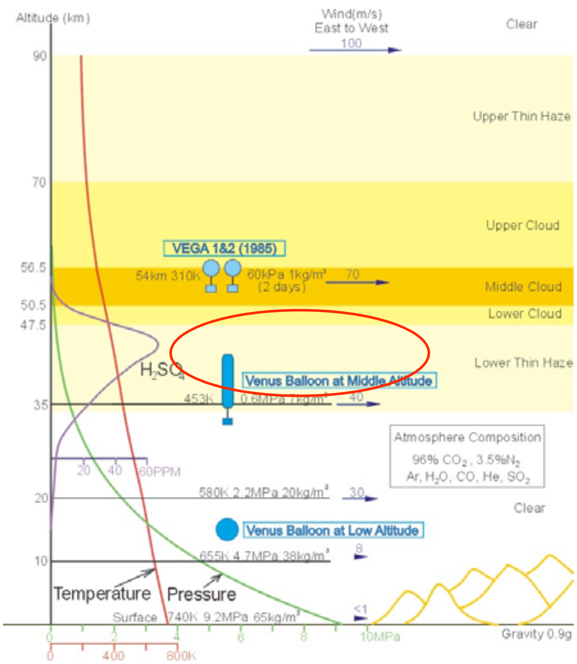
Venera 4-16 (USA,1967-84)

Mariner 2-10 (USA, 1962-78)

Pioneer-Venus, (USA,1978)

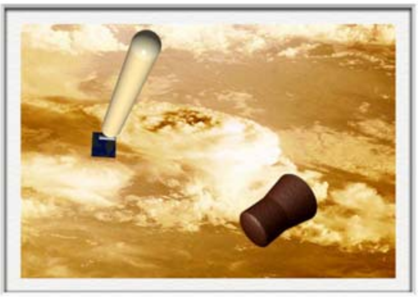
VEGA (USSR/FR 1984)

historically, lots of probes in USA, USSR



VENUS ENVIRONMENT AND BALLOONS

Long-term Observation under the Clouds



Long-term Observation of
Low-Altitude Venus Atmosphere
by Tracking of water-vapor Balloon

- Target Altitude : H=35km (under the Clouds)
- Mission Period : beyond 2 weeks' observation

1) Scientific Significance

Long Term Observation under the Cloud(H70-47km) will reveal....

- Mechanism of the Strong Equatorial Wind, N-S circulation
  (Internal Gravity Wave, Turbulence, Structure of Vertical Wind)
- Concentration of Aerosol (unknown particle) : optional
- Precise Mapping of the Venus Surface(λ~1μm) : opational

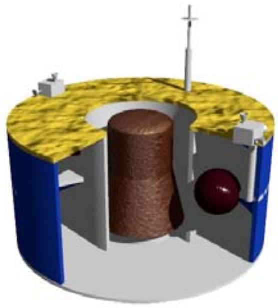
2) Engineering Significance leading to future Planetary Exploration

The mission is meant to be ....

- Dawn in Aerothermodynamic Technology on Atmospheric Entry for Future Outer Planets' Exploration in JAPAN.
- Demonstration of the High Temperature Electronics in the Hot Venusian Atmosphere.
- Planetary Long Term Observation by Balloon itself is of significance

Recent Status including External Relations

Long-term Observation of
Low-Altitude Venus Atmosphere
by Tracking of water-vapor Balloon



1) ISAS / JAXA

Authorized as a pre-phase-A WG for "Future Small Scientific Sat"

- Not Selected to Proceed to Phase-A in 2007FY

2) International Collaboration

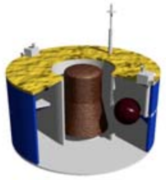
Applied to COSMIC Vision 2018 of European Science Academy

- "JAXA low-altitude balloon" : one option of EVE(European Venus Explorer)
- Passed First Selection but not selected as Final 8 Candidates.

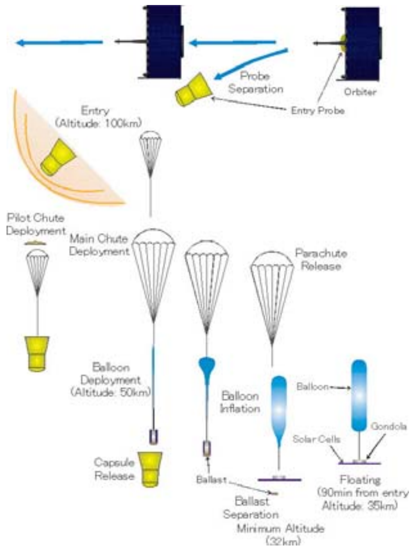
Never Give up and
Apply again !!
Improving Technical Readiness Levels.

Technical Issues associated with the Mission

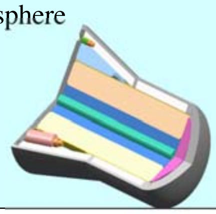
W : 160 kg
Size : φ1.4 x H0.7 m
Cap (BALN,PI) : 35kg



Direct Entry
V0=11.5 km/s, γ ~ 15 deg



1) Venus Entry Capsules
- High Speed Entry to CO2 Atmosphere
  - Flight Environment Prediction
  - Thermal Protection Design
- TPS Development and Facility
  - High Enthalpy CO2 Generation
- Descent System



2) Water-vapor Balloon
- Long-term Observation (2weeks)
- Multi-Layered Balloon Film
  (Gas-Barrier, Lightweight, High Strength)
- Efficient Heat-exchange and Inflation

3) Tracking of the Probe
- narrow-band VLBI under Hight Temperature

4) High-Temperature Electronics
- High Temperature Electronics over 180°C
  (Solar Battery Cells, Oscillator/Transmitter,
  Other SOI devices)

Water-vapor Pressure Balloon

Water-Vapor Balloon System makes 2kg Bus+PI float at H=35km .

For Successful Inflation,

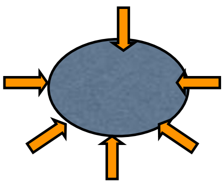
Efficient Heat-convection from the atmosphere is Important !

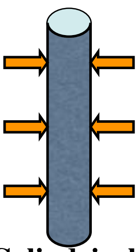
Water-Mass / Surface Ratio is a Key Parameter

Low M/S is desirable

Slow Descent
by Parachute
until Full-Inflation

Φ0.35m x 18m
@Full-expansion





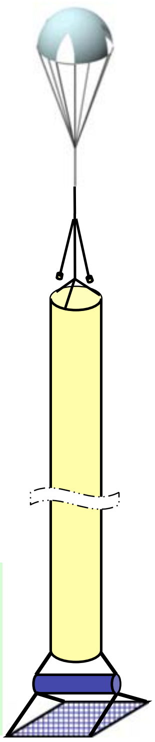
Safety & Accommodation

18 m Long Balloon

Pumpkin-type
- Hi Buoyancy
- light Weight

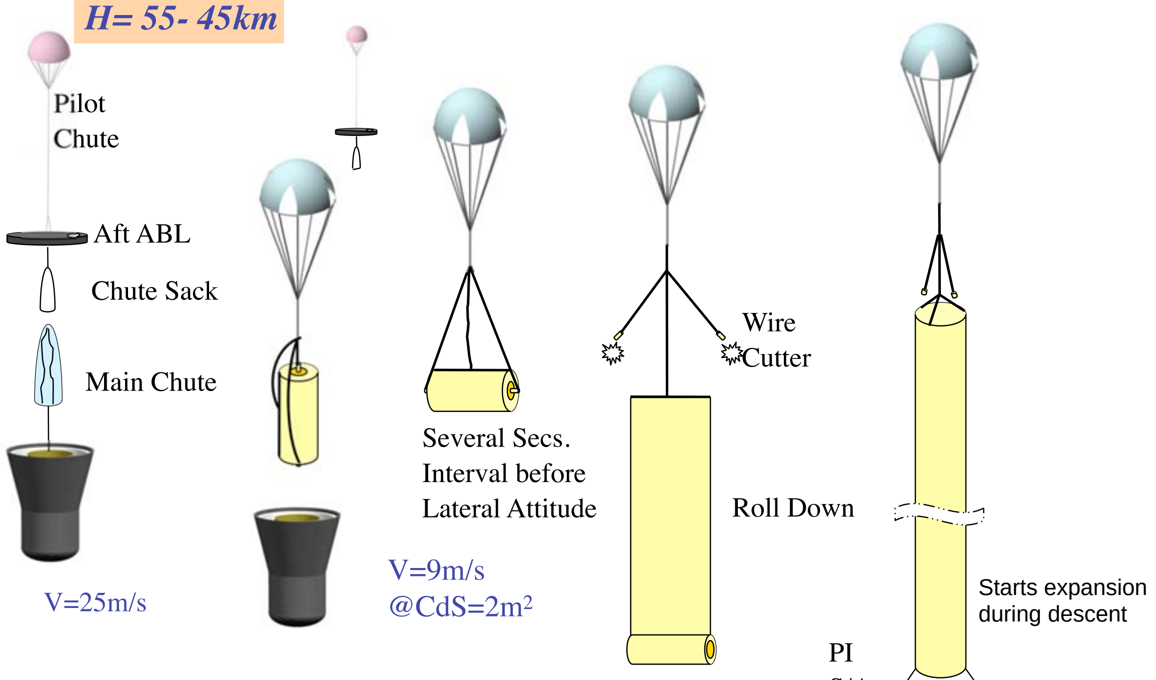
Cylindrical-type
- large heated surface
- needs large film
  => weight penalty

Weight Allocation
Bus+ PI = 2 kg
Balloon = 3.2 kg
Water = 4.8 kg



Balloon Deployment Sequence

H= 55- 45km



$$V = \sqrt{\frac{2 \cdot M \cdot g}{\rho \cdot Cd \cdot S}}$$

H [km]	ρ [kg/m3]	CdS=1	CdS=2
55	1	12.9	9.1
35	7.5	4.7	3.3

Balloon Release Altitude from 55 to 45 km

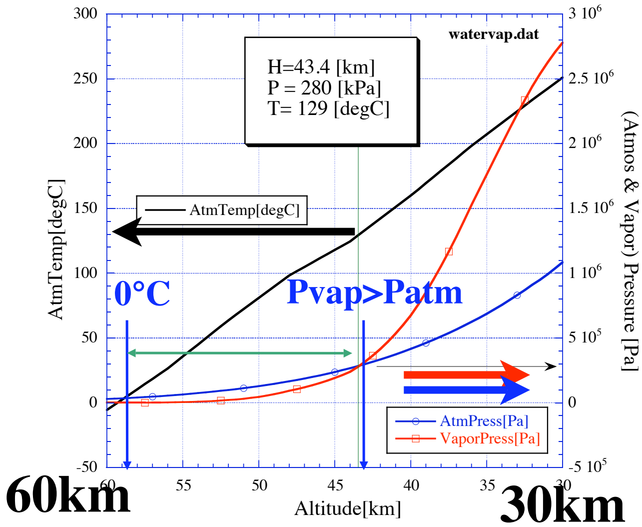
Constraints for Release Altitude
- Liquid Water must not be freezed
- avoid Inflation inside Capsule

・BALN is Never Released
@H > 55 km (T~ 0°C)
so as not to Freeze the BALN Water

・BALN can Inflate (@H=43 km)
Vapor Press > Atmos Press
→ BALN released @H=45km

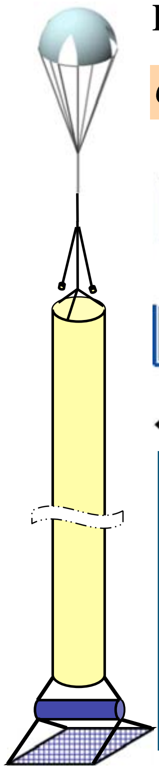
Venus Atmosphere				
Z [km]	T [degC]	ρ [kg/m3]	P [Pa]	As [m/s]
59.3	0	0.62	4289	260.2
47.7	100	2.4	4091	299.6
37.9	180	5.97	4073	327.8
35.0	207	7.5	4074	336.7

Balloon Release Altitude
55km ~ 45km



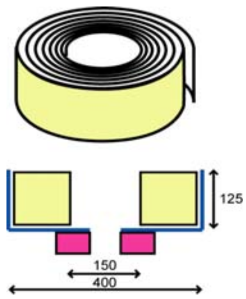
T_atmos, Water Vapor Press Profiles

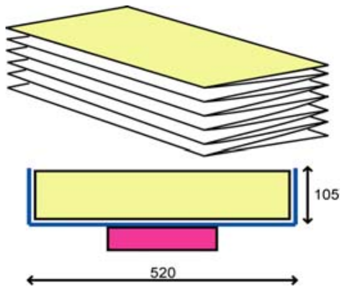
Trade-off Studies on Balloon Accommodation

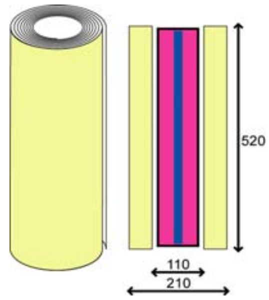


How to accommodate 20m-long Balloon

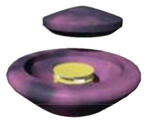
Configuration minimizing the number of Folding Lines







Donuts - Type	Plate-Type	Cylinder-Type
Suitable for Flat&Large (Low-β) CPSL Many Folding Lines Distortion at Deployment	Easy Extraction Off-centered PI Crossing (double) Folding	Suitable for Long (Hi-β) CPSL **A Few Folding Lines** Distortion at Deployment

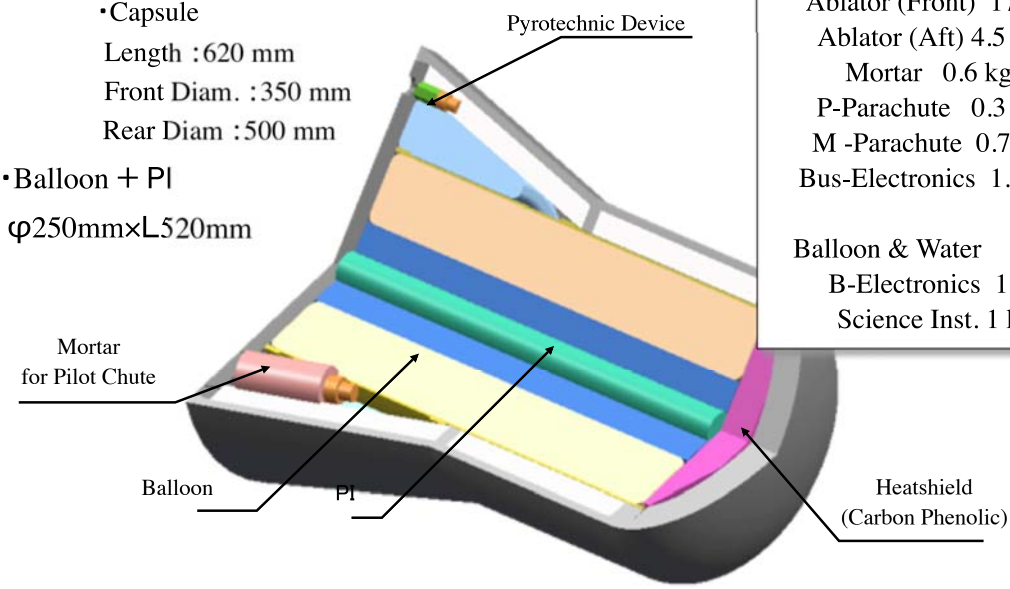


Venus Entry Probe (Hi-Ballistic Coeff-type)

For Satisfying Fast Descending Reqirement from Internal Temperature
Balloon accommodation => Hi-Ballistic Coeff. Capsule

・Capsule
Length :620 mm
Front Diam. :350 mm
Rear Diam :500 mm

・Balloon + PI
φ250mm×L520mm



Total Weight 35 kg

Ablator (Front) 17 kg
Ablator (Aft) 4.5 kg
Mortar 0.6 kg
P-Parachute 0.3 kg
M -Parachute 0.7 kg
Bus-Electronics 1.9 kg

Balloon & Water 8 kg
B-Electronics 1 kg
Science Inst. 1 kg

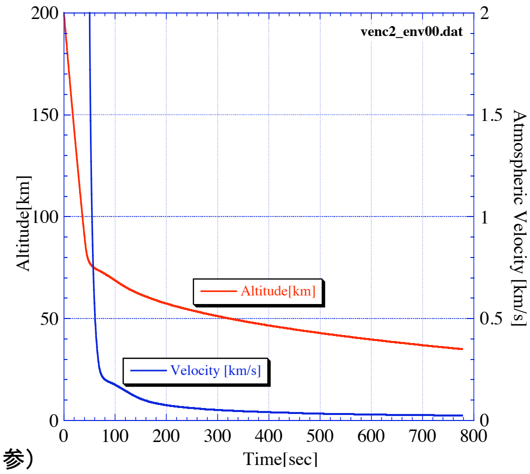
Flight Environment of the Capsule

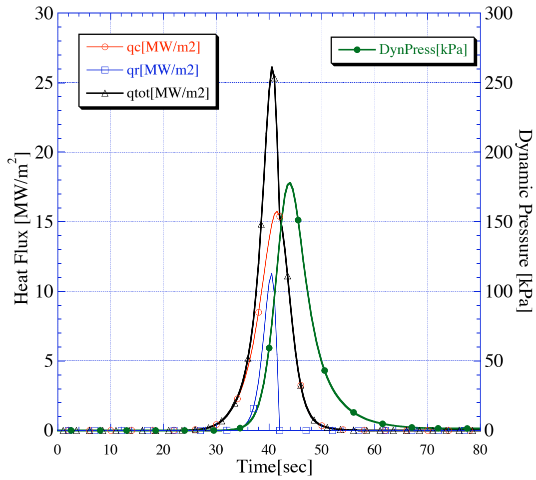
Max. Heat Flux expected

Z : 89.4 km
V : 10.62 km/s

Atmos. Pressure : 45.2 Pa
Atmos. Temperature : 173.8 K

max. qr = 12 MW/m²
max. qc = 16 MW/m²
max. dyn. Press = 180kPa





参)
dyn.P @100km/h
=500Pa=5/1000気圧

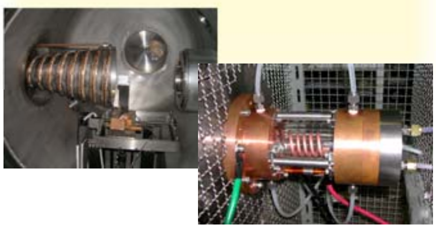
Venus Entry and TPS Development

TPS Development Scenario

Ablator Material Requirements
- Protect Capsule against High Heatflux
- Lightweight

Induction-coupled Plasma Generator (ICPG) 10 kW

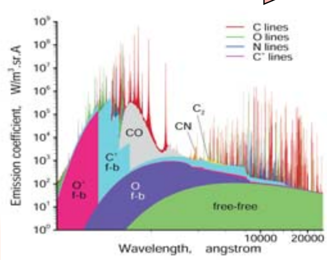
※High enthalpy CO2 heated by 13.56MHz RF
- Acquisition of Thermochemical Aspect of High Enthalpy CO2



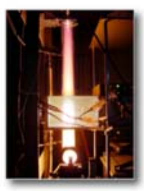
Thermochemical Basic Data

- Reaction Rate Measurement in Hi-Enthalpy CO_2
- Numerical Simulation
- **CFD Analysis**

utilizes the Ground Simulation Result to predict Flight Environment and Thermal behavor of the Ablator



Exampl : Radiative Heat Flux Analysis



触媒性計測装置

Arc windtunnel : 1 MW

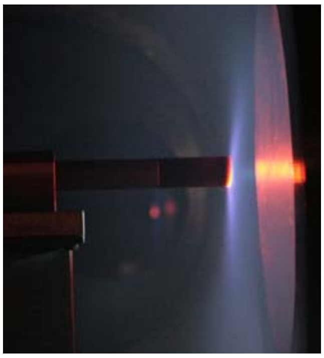
=> useful in Hi-Enthalpy Air but in CO2 due to C deposit to the Electrodes
- Material Thermal Strength Test in High Heat Flux upto 12MW/m²
- Temperature Profile Data

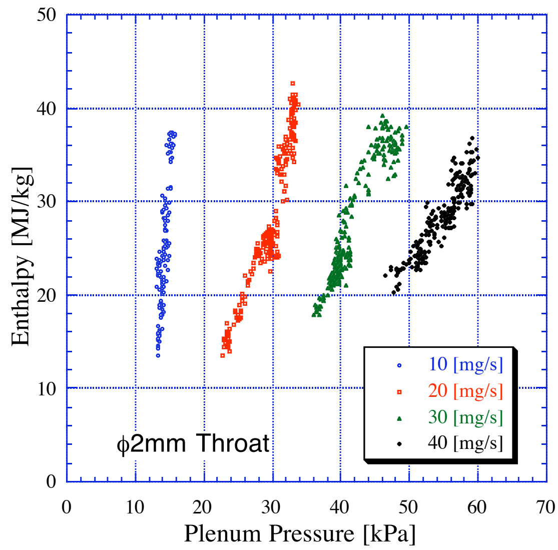
Venus Entry and TPS Development (1/2)

Characterization of ICPG and Material Heating Test are now carried out ...

- Preliminary Heating Test Started in CO2
- 40 MJ/kg Enthalpy Accomplished

  => useful for Thermochemical Data of Marial/CO2 Reactions
- Higher Impact Pressure predicted.

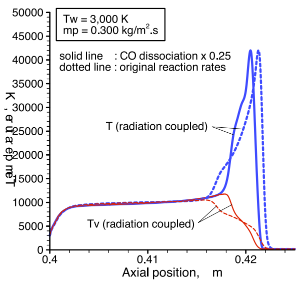




Thermochemical Aspect of Venus Entry

Improvement in Flight Environments Assessment

CO thermal relaxation & dissociation has great effect on both q_c & q_r

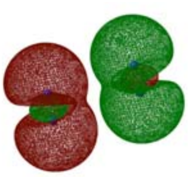


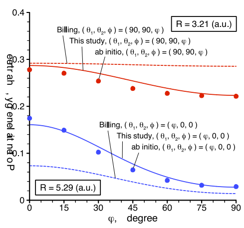
Modification	$\dot{m}_p = 0.3$ kg/m²·s[a]			
	Uncoupled		Coupled	
	q_c	q_r	q_c	q_r
CO dissociation rate ×0.25	4.6	17.5	6.0	12.0
rate of reaction 23) from Ref. 12	4.6	11.3	5.3	8.2
rate of reactions 22) and 23) from Ref. 12	4.6	11.3	5.3	8.2
Nominal	4.6	11.2	5.4	8.0

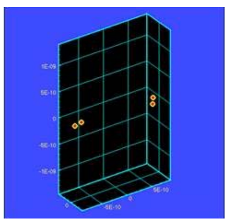
[a] $T_W = 3,000$ K. [b] $T_W = 300$ K.

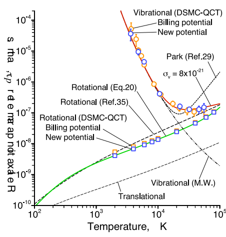
Development of improved models for CO relaxation & dissociation

MO analysis → High accuracy PES → QCT collision analysis → CFD model

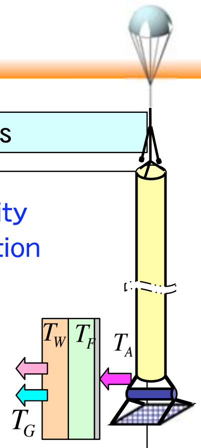








Inflation Analysis of Balloon Film

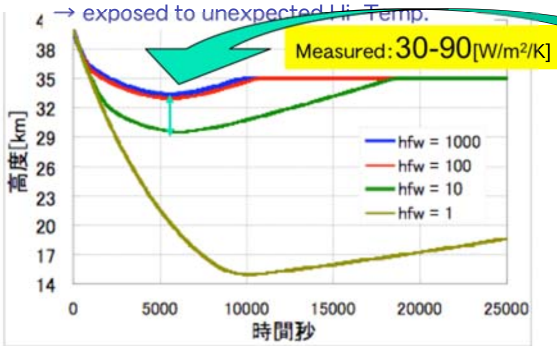


Analysis of Heat-exchange Process	Heat-Convection Measurements

Heat Transfer Rate between
Film – "Water sheet" is important

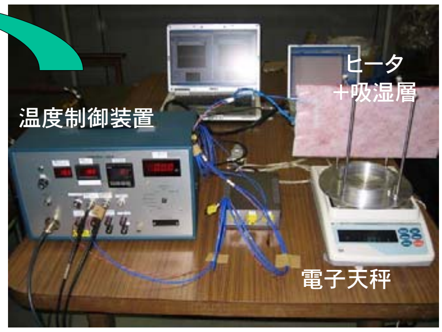
Hight Heat Transfer Rate
→ Fully-expanded at higher altitude
→ Burst out due to insufficient film strength

Low Heat Transfer Rate
→ Late Inflation, and Overshoot to low Z.
→ exposed to unexpected Hi-Temp.



Measurement of Gas Permeability
and Heat Convection

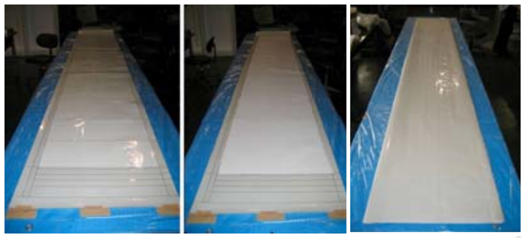
フィルム-吸湿層の熱伝達率計測

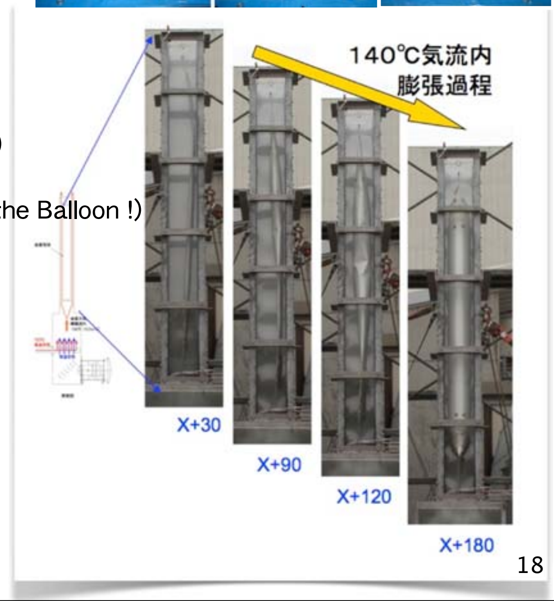


Balloon Expansion Simulation

【Lessons learned until 2006FY】
– Fabrication of Subscale Model(D=0.159m, L=1.88m)
– Expansion Simulation in Hot-Airflow (140℃) Cavity

=> Successful Expansion in 180 sec.
within dispersion of prediction
→inflexibility problem of the film
was revealed during the experiment !





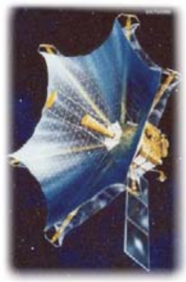
【Research Activities in 2007FY】

Balloon Film made of Liquid-crystal Polymer(LCP)
・Good Performance in Gas-Barrier Characteristics
・Manufacutured in Cylindrical-shape Inflation (desirable for the Balloon !)
・Drawback : Film has hard/ poor-flexibility,
hard to be accomodated

Change of Resin
make the film more flexible, easy to treat.
: from PolyPlasitc→ Sumitomo Chemicals

・Strength in High-Temperature (now 103% of Pa)
・Flexibility
・Corrosion due to High-Temperature Water

Tracking of Balloon by delta-VLBI



VLBI・Radio-Telescope
HALCA (M-B) / Astro-G

normal VLBI（Cont. Wave like QUASAR）

Sensitivity ∝ (Band Width)^0.5

Wide Band Detection => Emission Power

Narrow-band VLBI

（for spacecraft and probes）

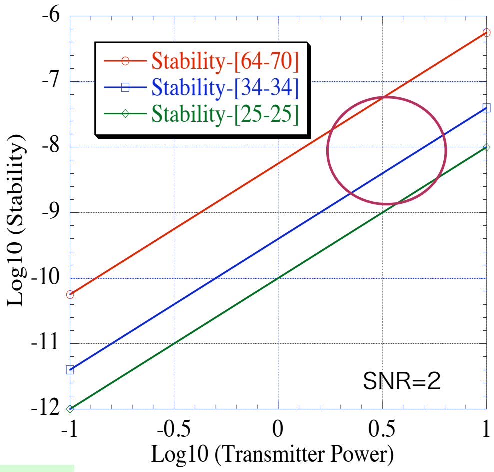
Sensitivity ∝ (Band Width) ^(–0.5)

because of transmitter power limitation

Integration Time 〜100sec

（Wind Speed @H35km =30m/s

=> Spatial Resolution ~ several km



Scientific Positioning Request (~2,30km)
depends on Transmitter Frequency Stability

Transmit Power ~Several W → 10^–8 Stability

VEGAは1.7GHz,6.5MHz離れた2波長,送信パワ 5W,発生電力20W

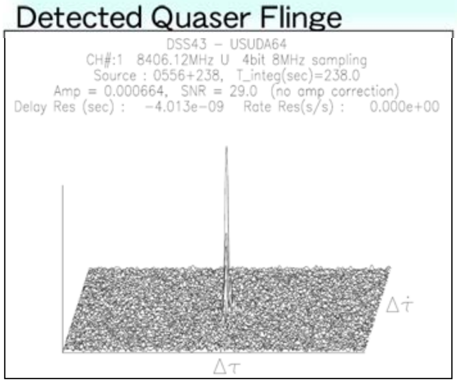
金星–地球間距離（**最大**:1.7AU）
1AU=1.495e11 [m]
参）月・地球 38**万**km = 3.8e8 [m]
金星上距離 100km = 7e-7 rad

delta-VLBI Lesson by Hayabusa S/C

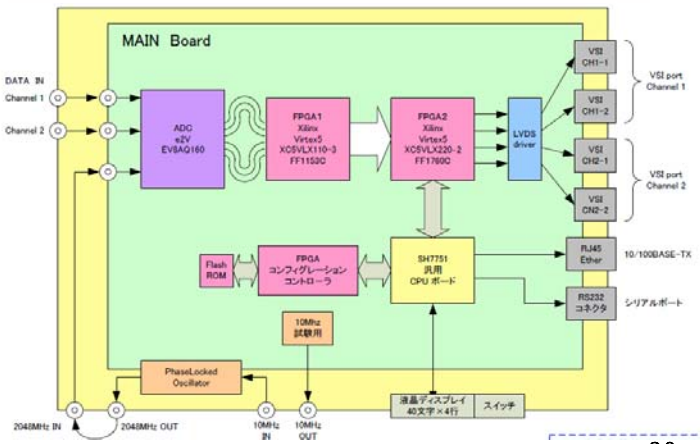
- ΔDOR Signal sent from Goldstone (JPL) (±1 MHz)、Return at Hayabusa
- Received at Goldston(JPL),Canberra (JPL)、Usuda,Kashima.

Canberra 70m —Usuda 64m

Detected Quaser Flinge



VLBI Data Acquisition System (ADS-3000)
for narrow band detection



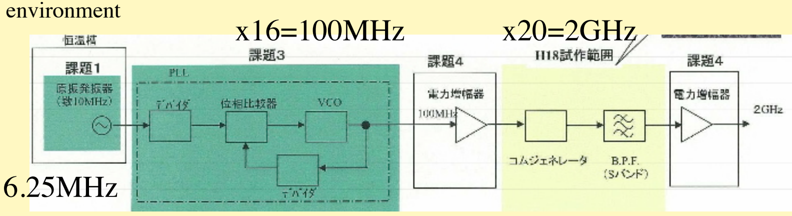
High-Temperature Electronics

High-Temperature Electronics are Key Technology for Tracking Low-altitude Venus Balloon.

・Quartz Oscilator ：Stability beyond 10^-8 by means of Appropriate Crystal-Cutting and Temperature Control.

・Solar Cells operable in 200 degC environment

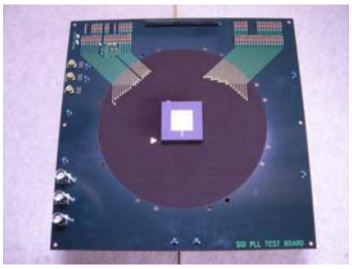
(Though 200 degC in operation)

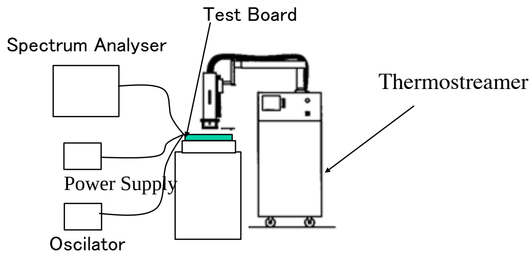


【Objectives】 in Pre-Phase-A (Concept and Feasibility Demonstration Phase) Study

・PLL Functional Demonstration and Characterization in 200°C environment for 3 hours

・First Step Lessons for Stabilization of PLL



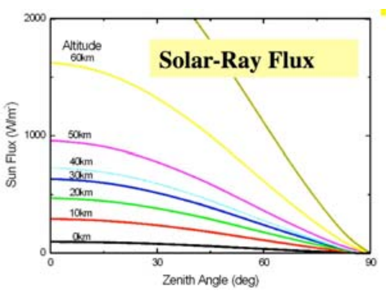


Test Board (IC is centered)

Experimental Setup

Thin-Film Solar Cells in High-Temp (1)

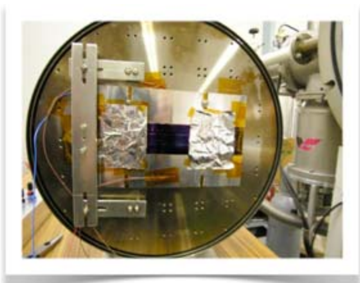
Temperature Characteristics of Thin-film Solar Battery Cell were obtained;
- Tandem-type Amorphous-Silicon Solar Battery Cells on Polyimide Film.



- Temperature：180℃
- Input Irradiance：200W/m²

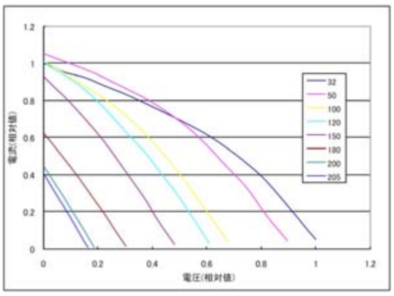
Test Cells：
by Fuji Electric Systems co.
（富士電機システムズ）

Results：
Temperature Characterics：
Voc：-0.46%/℃
Pmax：-0.56%/℃

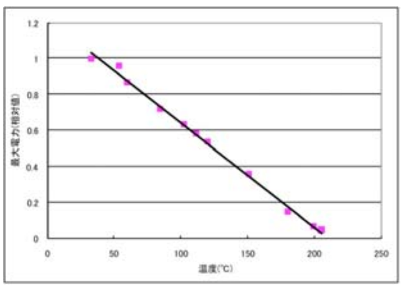


Experimental Configuration

Experimenal Apparatus



Temperature Profiles of V-I Characteristics



Time Profile : Max Output Power

Thin-Film Solar Cells in High-Temp (2)

Spec of a Module (12Cells Series)

- Max Output Power：2W
- Max Voltage：13V
- Dimension：170×240mm
- Conversion Eff. ：about 7%
- 1μm Solar Cells on 50μm Polyimide Film

Perforamance on the Venus

- Operable Tempeature：180°C
- Input Irradiance：200W/m^2
- Generated Power ：about 2W/m^2

Research Issues

- Surface Protection Film with Anti-Acid Characteristics
- Adhesive bonding

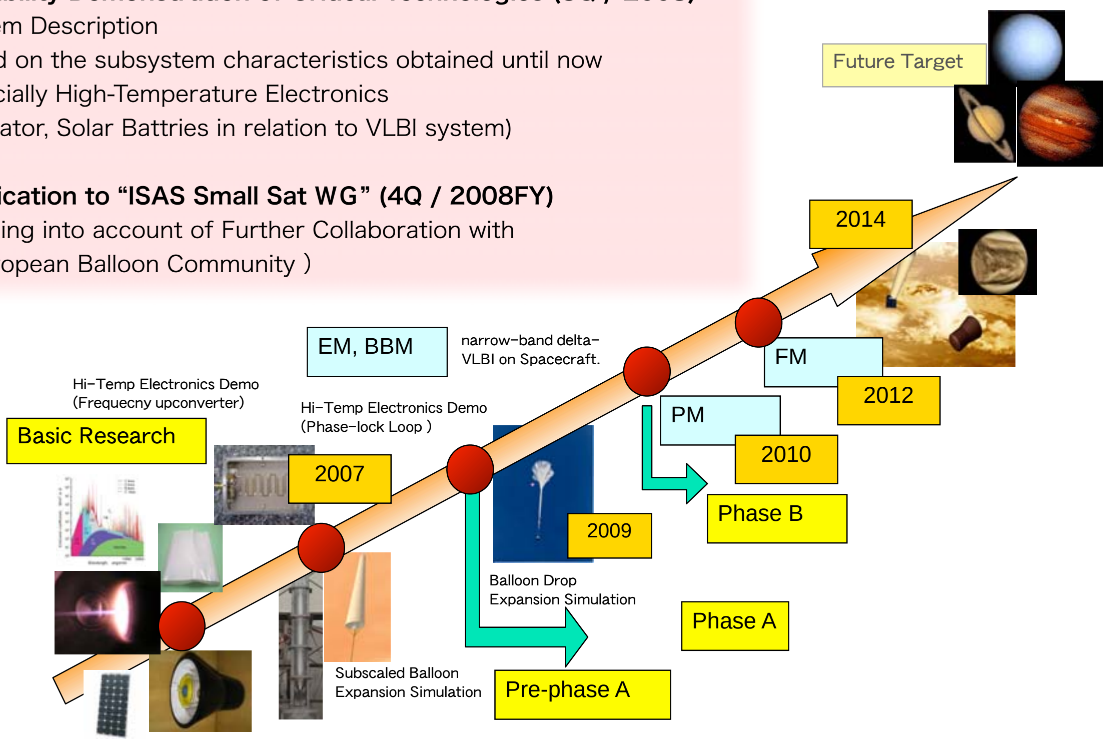
a-Si薄膜太陽電池：富士電位システムズ[FWAVE]

Research and Development Schedule

Schedule

- **Feasibility Demonstration of Critical Technologies (3Q / 2008)**
  System Description
  based on the subsystem characteristics obtained until now
  especially High-Temperature Electronics
  (Oscillator, Solar Battries in relation to VLBI system)

- **Application to “ISAS Small Sat WG” (4Q / 2008FY)**
  (Taking into account of Further Collaboration with
  European Balloon Community)



Summary

Research Activities on Venus Atmosphere Balloon Observation Mission

- Introduction of Target Mission Concept
- Research Status and External Relations
- Brief Outline of the Subsystems
- Recent R&D Activities for Critical Issues
- Future Work and Schedule