Venus Atmosphere Platform Options Reconsidered

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Author background

Flights over tropical rain forest canopy

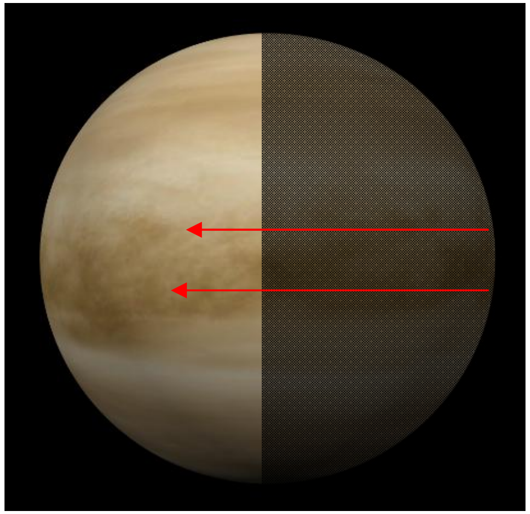
Content

- VEGA Super-Pressure Balloons (SPBs)
- VEGA derived vertical wind velocity
- EVE SPB (some concerns)
- Alternative platform options
  - Phase Change (Oscillating) Balloons
  - Other concepts

VEGA 1 and 2, June 1985

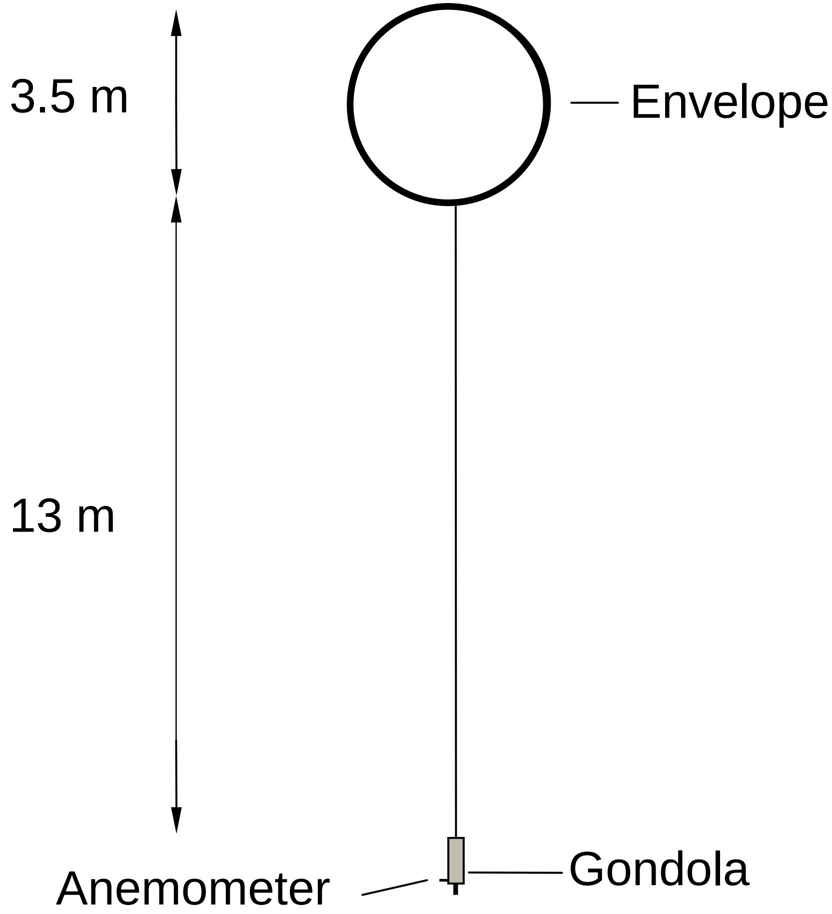
53.5 km altitude westward drift

46 hr limited by battery capacity



Blamont: “Demonstration or feasibility study” (1985)

Helium-filled spherical Super-Pressure Balloon (SPB)



Cytherean Triple Cloud Layer

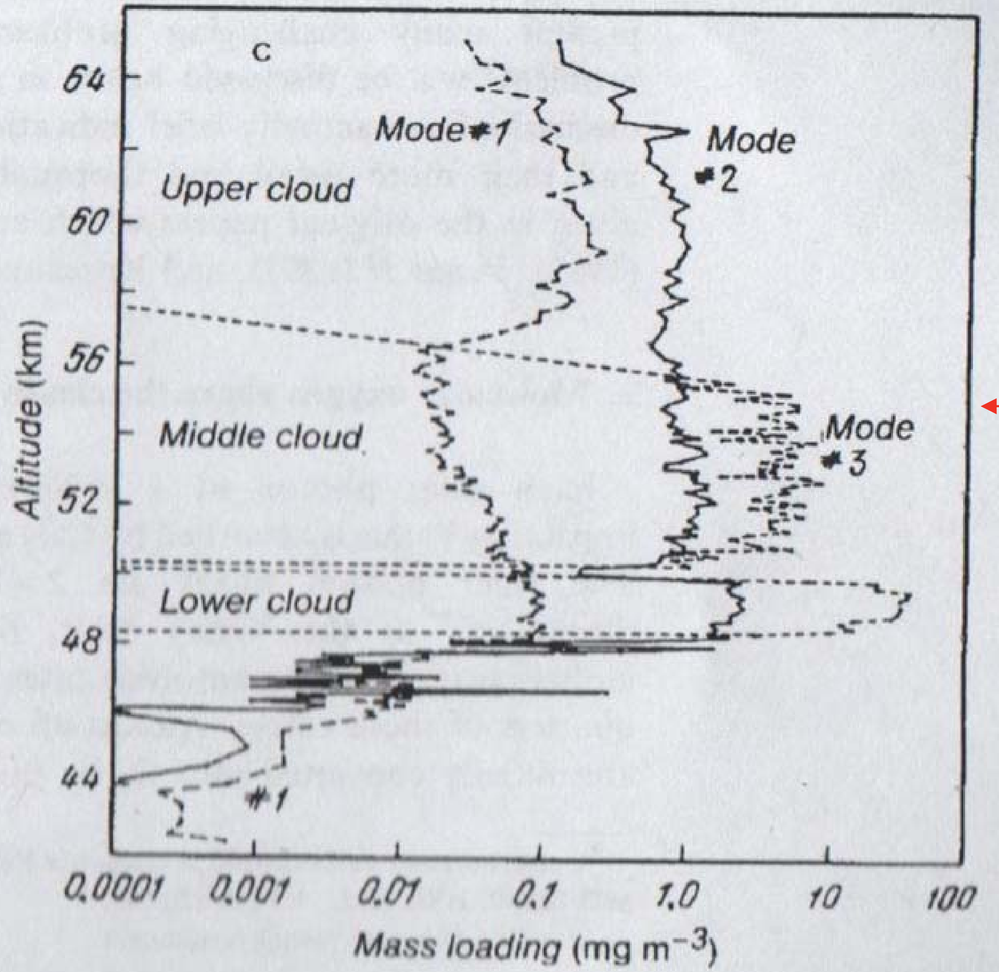


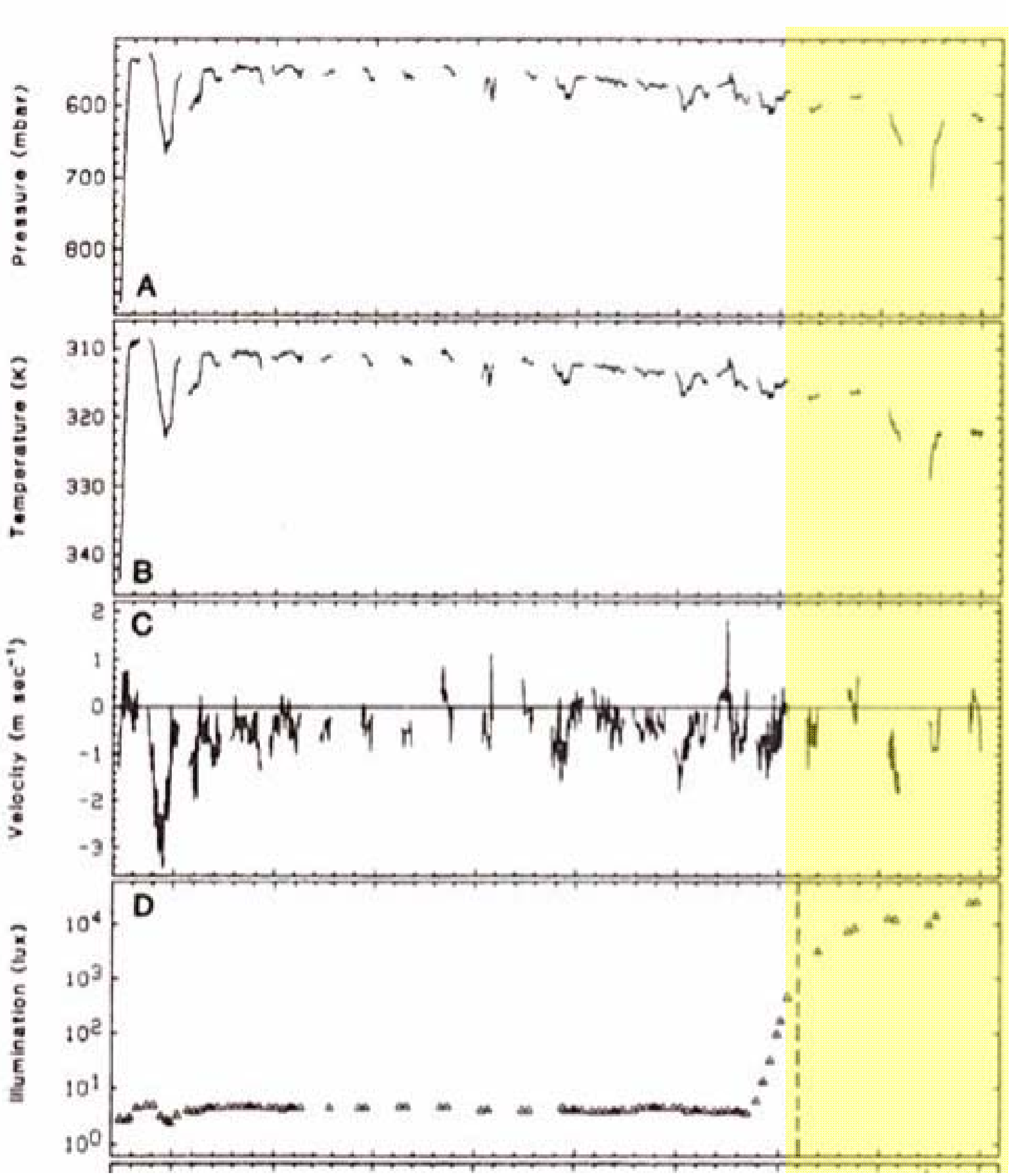
Fig. 4. Mass loading in the clouds of Venus as measured by the PV particle size spectrometer (Knollenberg and Hunten, 1980).

EVE & Vega SPBs

Krasnopolsky (2006)

VEGA 1

- Pressure (mBar)
- Temperature (K)
- Derived vertical wind velocity (m/s)
- Illumination (lux)



Sagdeev et al. Science (1985)

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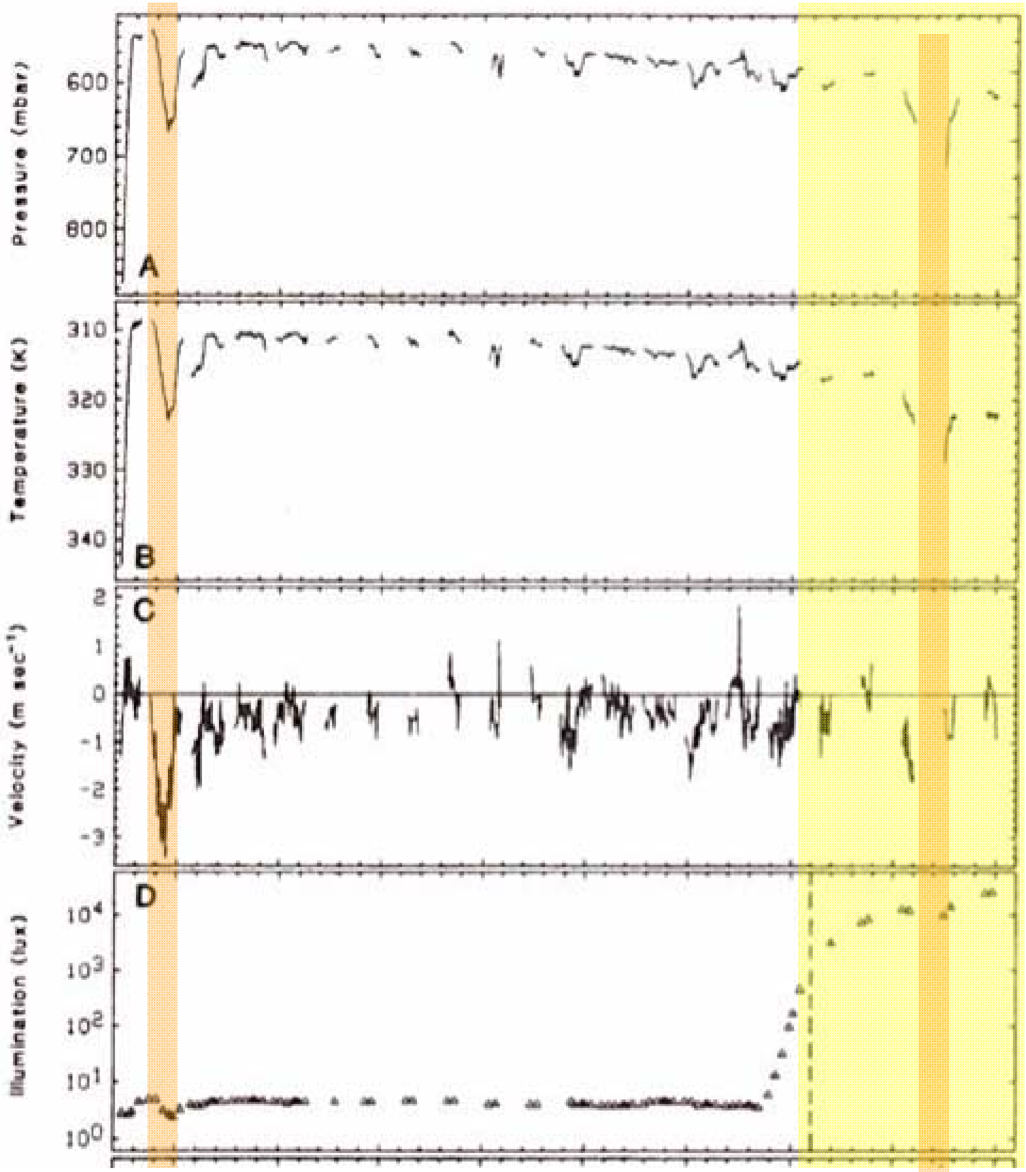
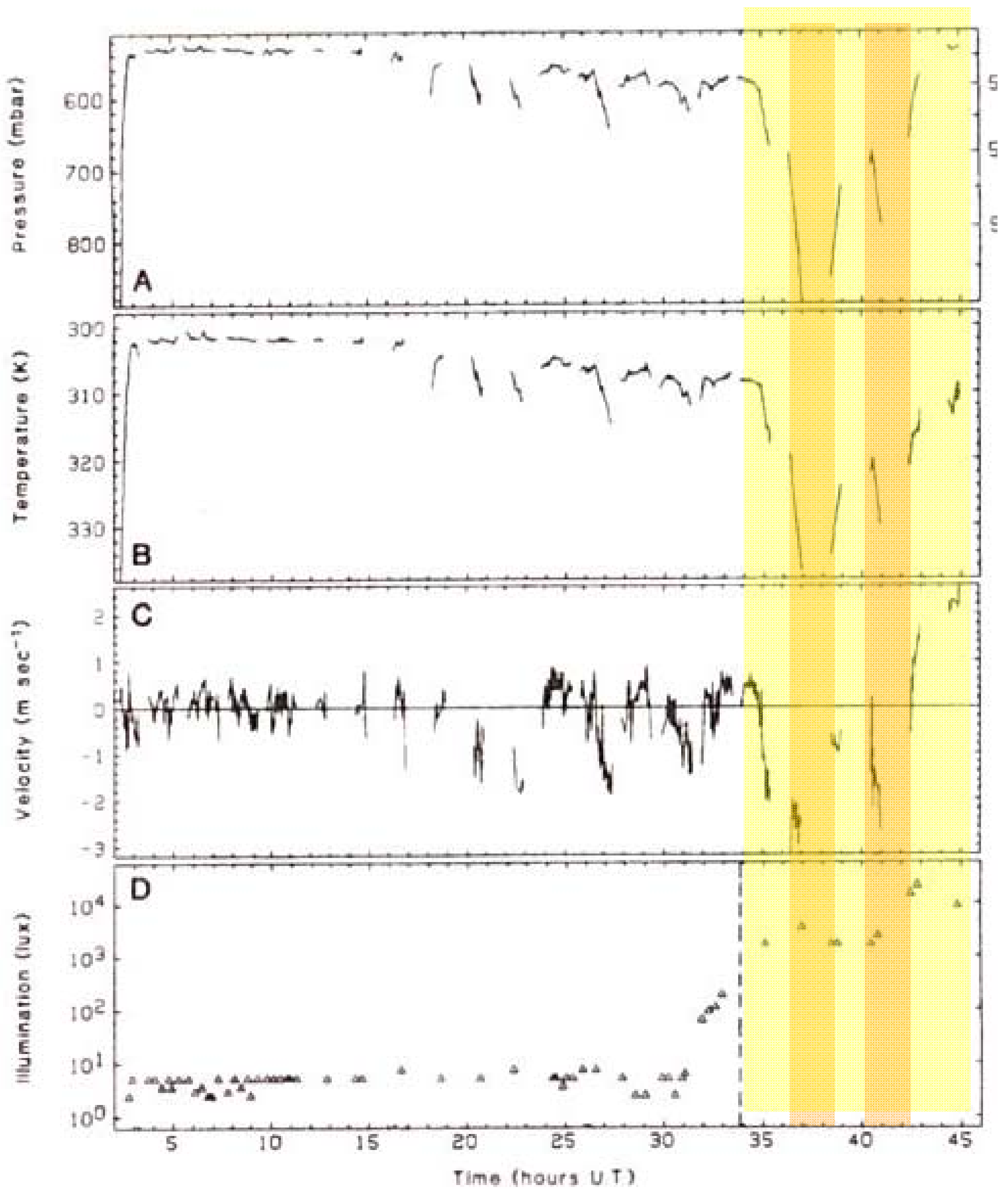


Sagdeev et al. Science (1985)

VEGA 2

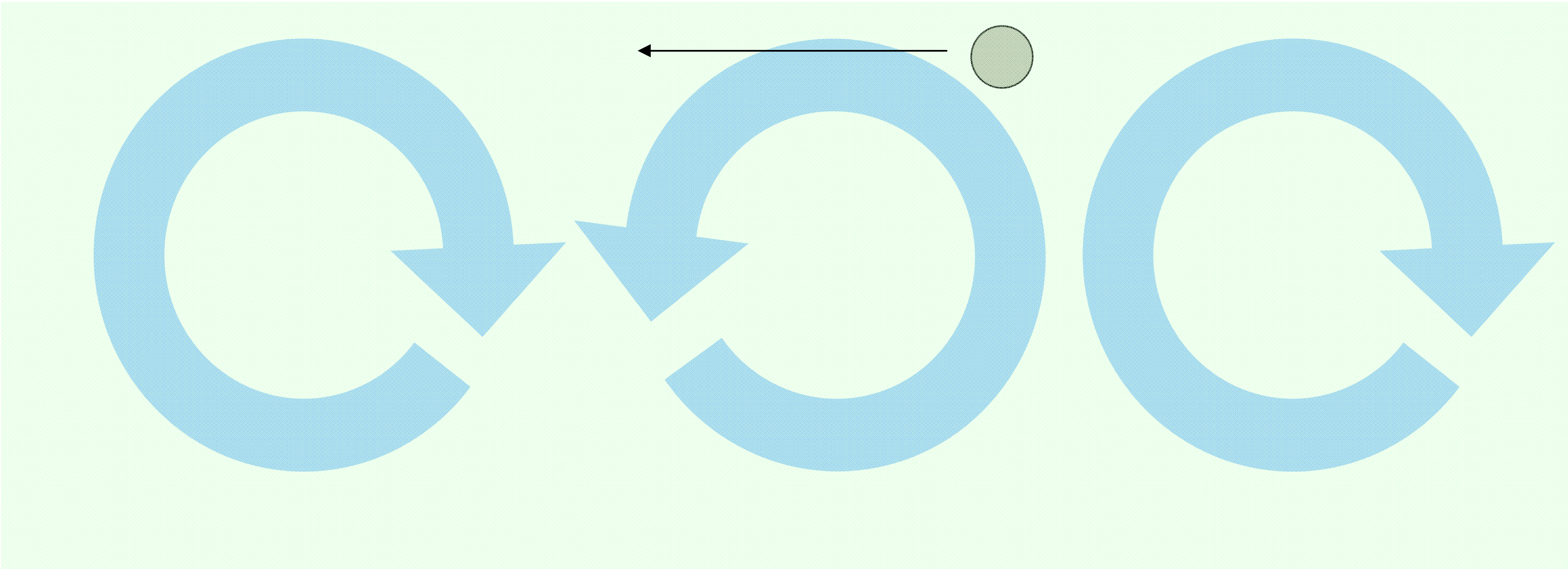
- Pressure (mBar)
- Temperature (K)
- Derived vertical wind velocity (m/s)
- Illumination (lux)



Sagdeev et al. Science (1985)

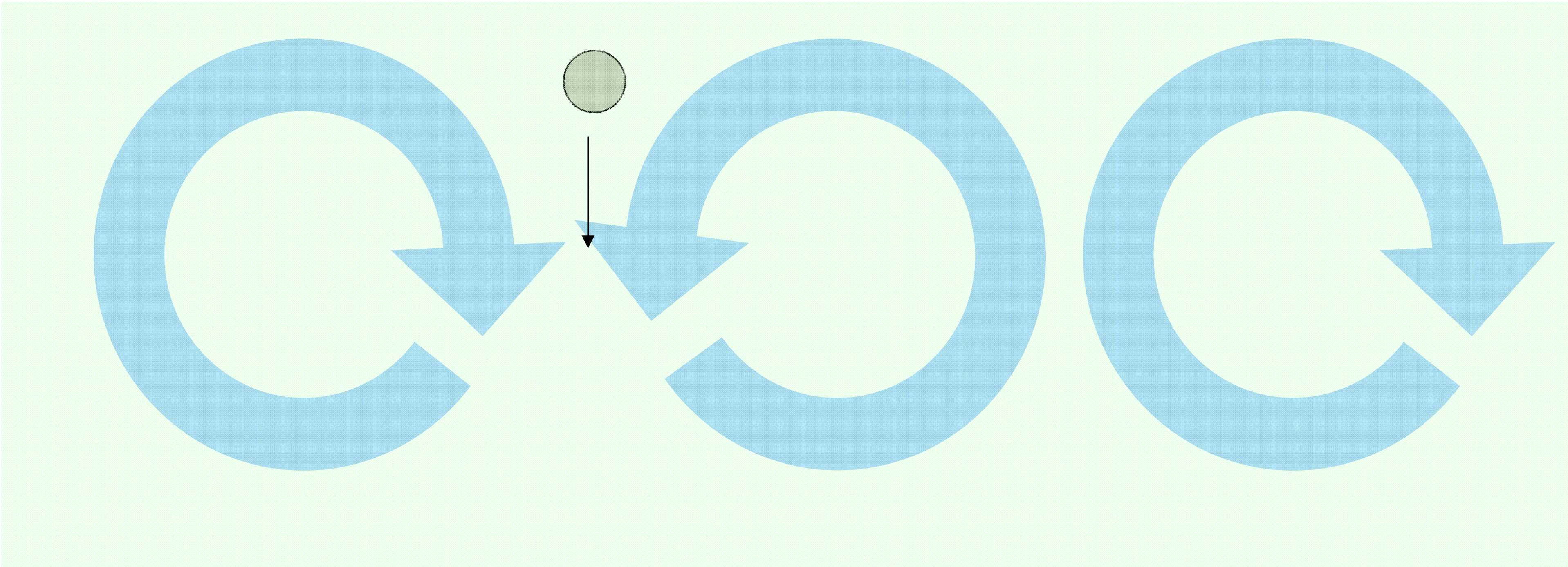
Drift towards downward wind velocity zones

SPB above convection region drifts laterally towards convergent zones



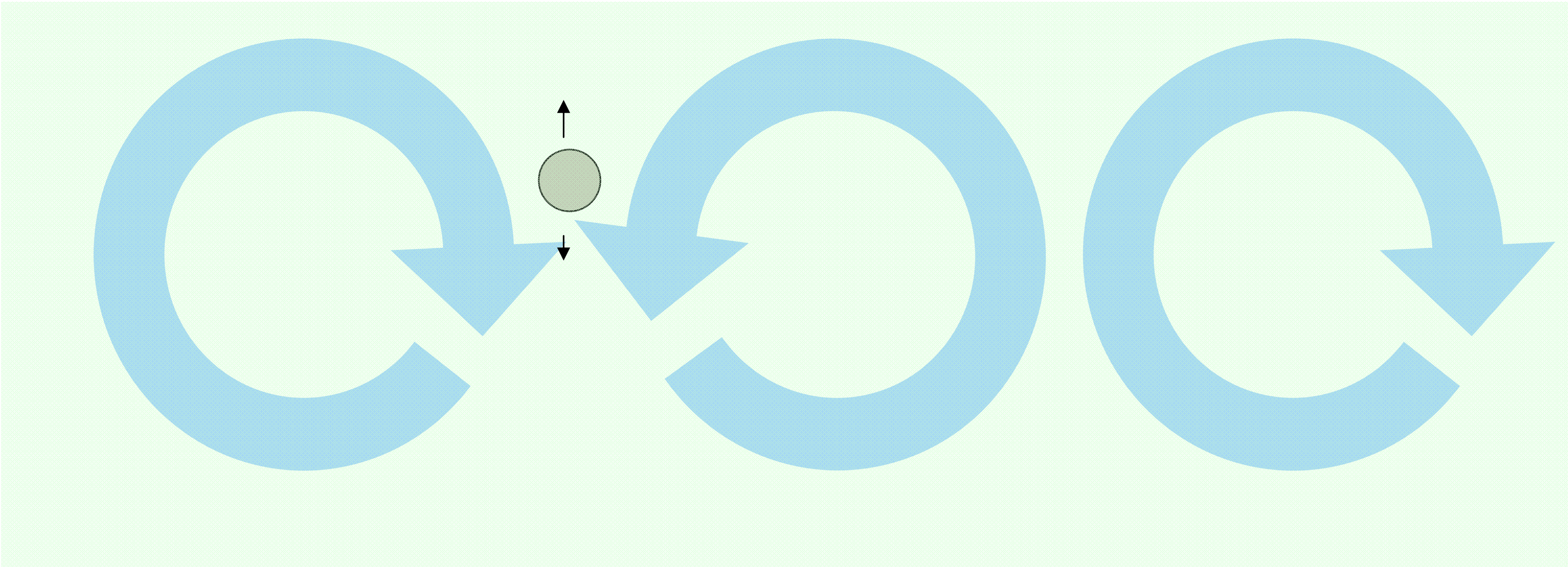
Drift towards downward wind velocity zones

‘Subduction’ of SPB into downward convergence zone



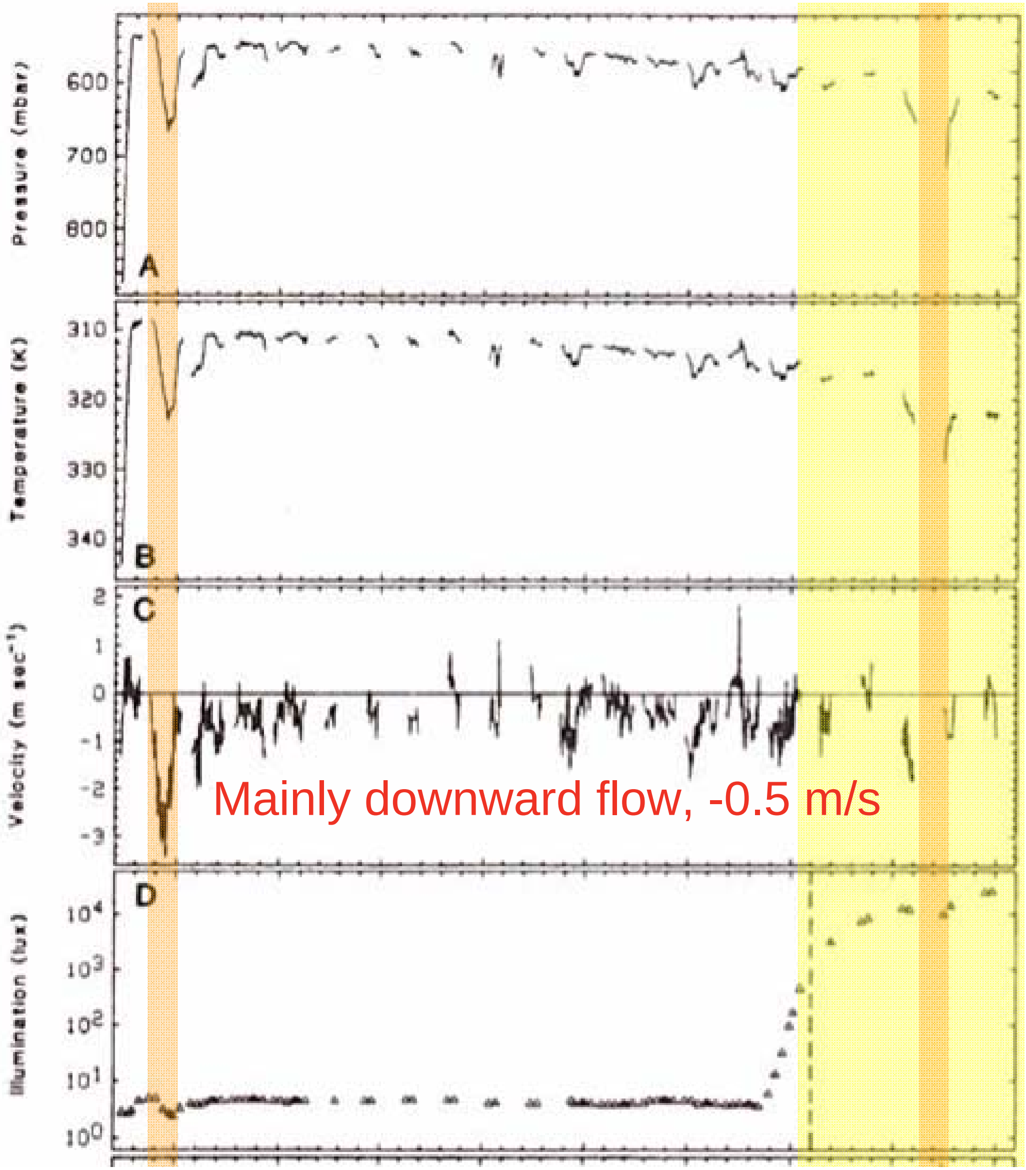
Drift towards downward wind velocity zones

Bobbing in downward winds – dependent on super-pressure stabilisation



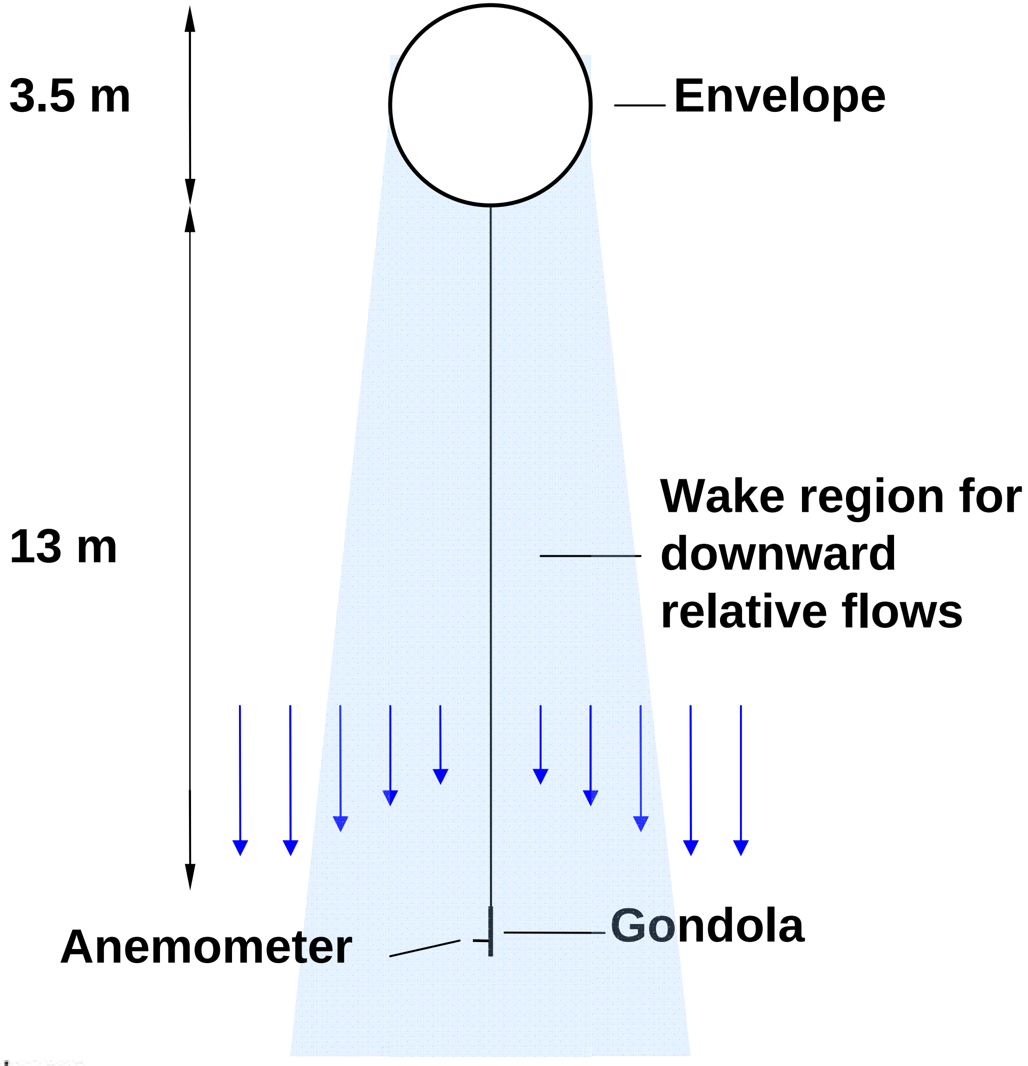
Vega 1

- Pressure (mBar)
- Temperature (K)
- Derived vertical wind velocity (m/s)
- Illumination (lux)



Sagdeev et al. Science (1985)

Vega 1 & 2 wake effects



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Wake measurements behind 0.5 m sphere

Test using RMIT Industrial Wind Tunnel Facility

Vega 1

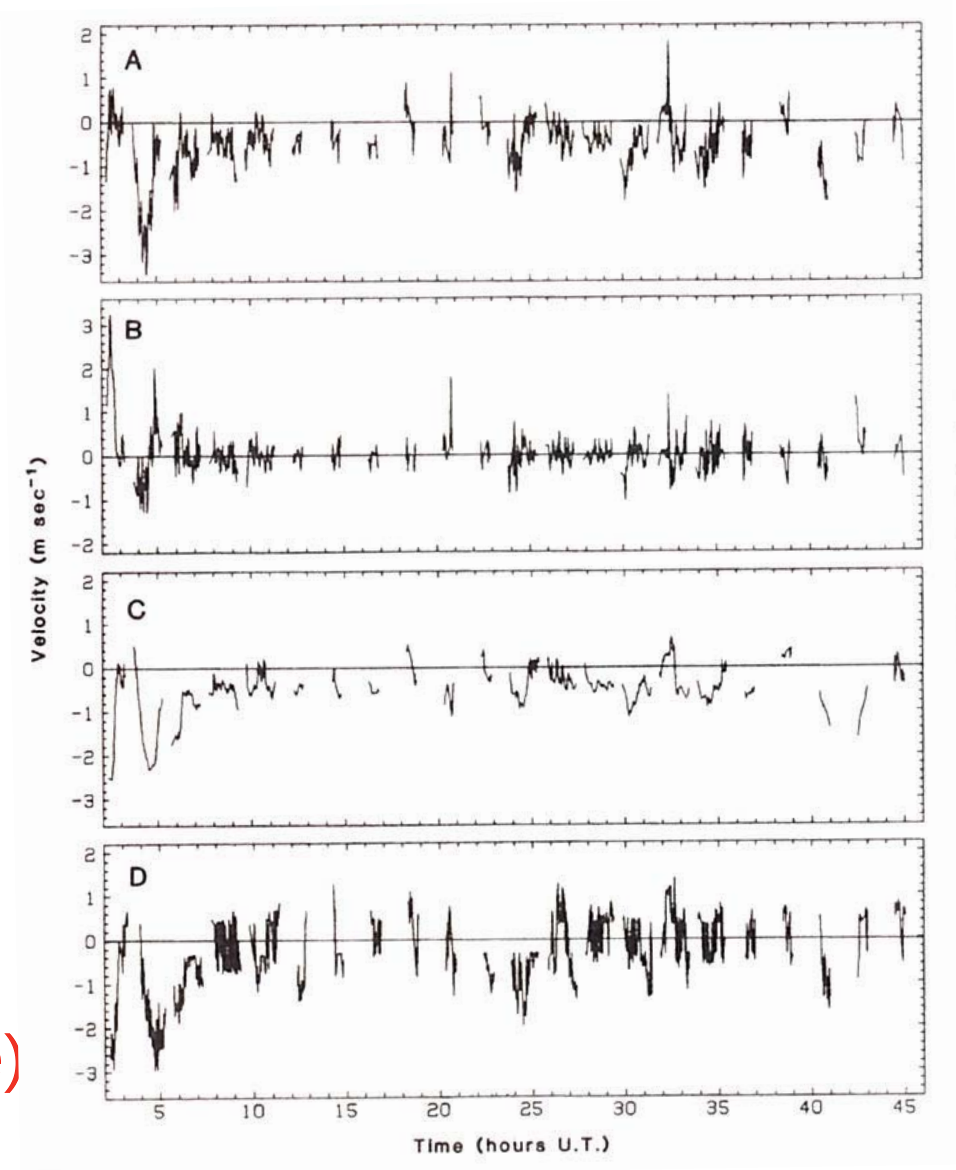
A. Derived vertical wind velocity w

B. Balloon vertical velocity

C. Relative velocity w_{rel}

D. Anemometer velocity

(extra noise caused by wake)

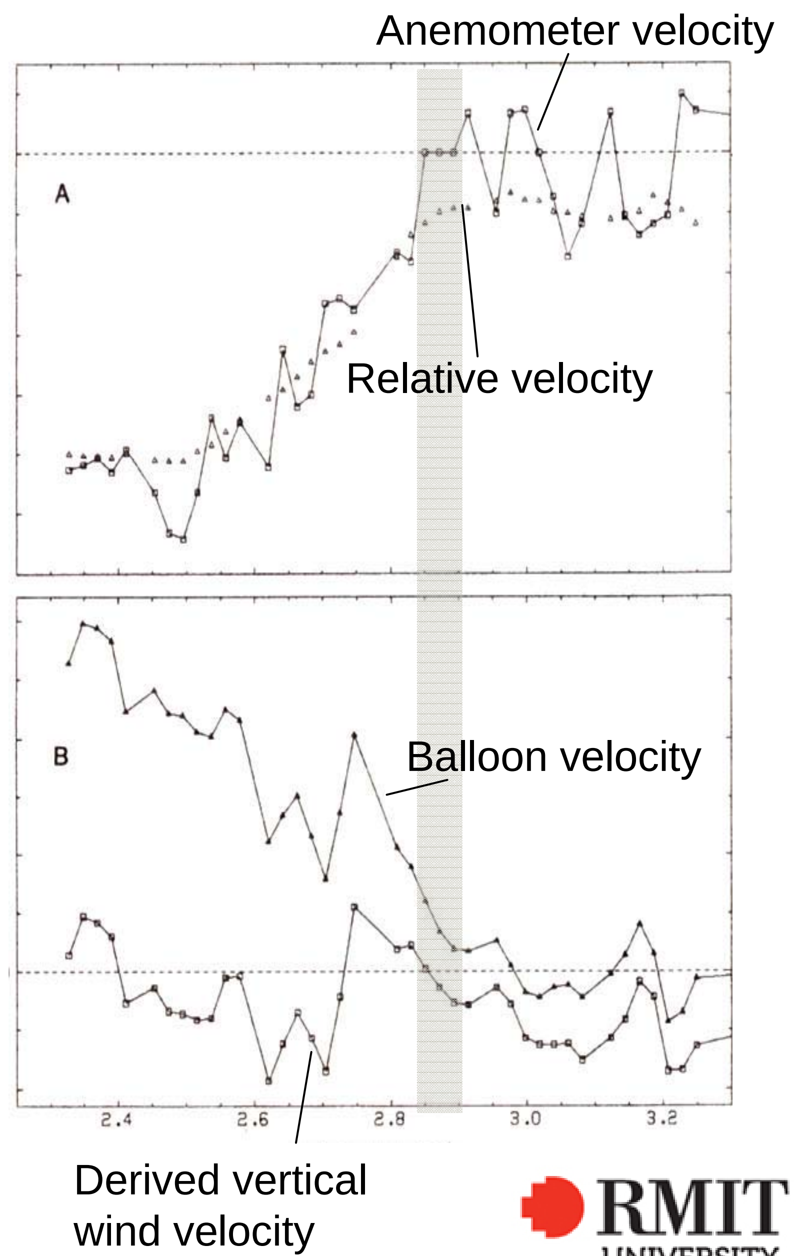


Vega balloon leakage

Linkin et al. (1985) decided to only use anemometer data to establish zero relative flow conditions

Thereby established a leakage rate estimate (5%) over 46 hours (dependent on super-pressure)

Leakage caused by pinholes in folded envelope (subject to high entry g-levels)



Derived vertical wind velocity

Vertical equation of motion:

$$(M + k\rho V)\frac{\partial^2 z}{\partial t^2} = (1+k)\rho V\frac{\partial w}{\partial t} - F_D - Mg + \rho g V$$

Apparent mass term k not properly known for separated flows

$$F_D = \tfrac{1}{2}\rho A\, C_D\left(\frac{\partial z}{\partial t} - w\right)\left|\frac{\partial z}{\partial t} - w\right|$$

Drag coefficient term C_D only known approximately, 20% error?

Derived vertical wind velocity, *w*

Reduction by Linkin et al. (1985):

$$\tfrac{1}{2}\rho A C_D w_{rel}\left|w_{rel}\right| = \rho g V - Mg$$

$$w_{rel} = \frac{1}{\rho g}\frac{\partial P}{\partial t} - w \quad = \frac{RT}{gP}\frac{\partial P}{\partial t} - w$$

Linear envelope volume relation (*e* = elasticity parameter):

$$V = V_0 (P_H - P)/(eP_0) + V_0$$

Linkin et al. (1985) “compute” helium pressure and hence envelope volume in order to derive *w*

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Derived vertical wind velocity

Volume of envelope may actually be derived directly,

$$V/V_0 = \{e - p + \sqrt{(e-p)^2 + 4e\theta\sigma}\}/2e$$

$$p = P/P_0,\ \theta = T_H/T_{H0},\ \sigma = m/m_{H0}$$

But

1) elasticity parameter is dependent on modulus of elasticity of Teflon™ (PTFE) envelope (variable in domain of interest), implies that linear volume relation used is doubtful
2) Linkin et al. assumed helium temperature is same as ambient (after float height attained and before sunrise)
3) Any precipitation (?) on envelope would change mass

VEGA SPB summary

- Vega derived wind velocity may have an error of about +/- 0.4 m/s, but raw flight data is needed to verify this claim
- What happened to Vega 1 & 2 after transmission loss?
  - They may have completed multiple circumnavigations
  - Or they may have suffered super-heating at midday and subsequent helium venting and premature irreversible descent

EVE (2010) Proposal

- Float of 240 hours to “guarantee at least one circumnavigation of Venus” at 55 km
- Science goals include cloud chemistry and measurements of noble gas isotopic ratios, as well as meteorology.
  - Scientific payload (15-20 kg)
  - More power (40 W) and capacity (8600 Wh) than VEGA, solar power augmentation during daytime
  - 5 m diameter envelope for 60 kg float mass (3.5 m VEGA)

Concerns about EVE (2010)

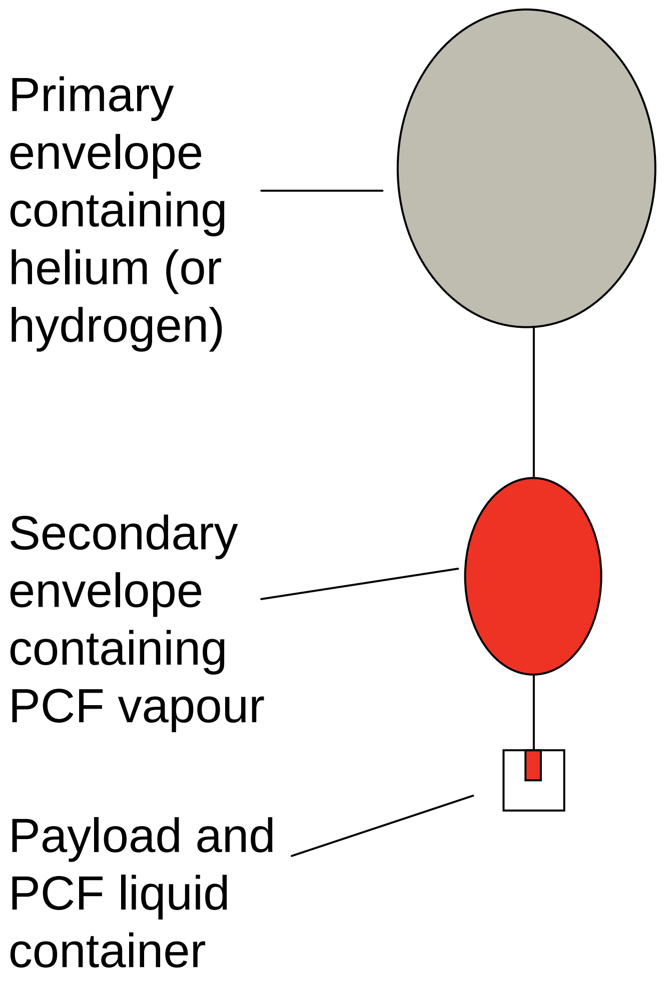
- ESA concerned that choice of 55 km does not permit sampling of other altitudes, e.g., dense lower cloud with large mode 3 particles (49 km) and unknown UV absorber (70 km)
- Anemometer will be in downward flow (repeating VEGA again)
- Smooth sphere is subject to lateral oscillations (could be mitigated by using a JIMSPHERE)
- Super-heating a midday remains a concern (loss of mission). Vertical stability of SPB is improved by using higher strength envelope with higher *e* value, but this is weak effect. Most terrestrial long endurance SPB experience (e.g. "VORCORE") has been with relatively calm stratospheric flight with low vertical wind velocities (cm/s), and mission loss is typically more than 5%.
- Heavy helium/hydrogen storage tank (75+ kg) required

Alternative Platform Options

Zero-Pressure Balloon with Phase Change Fluid

Tandem Configuration

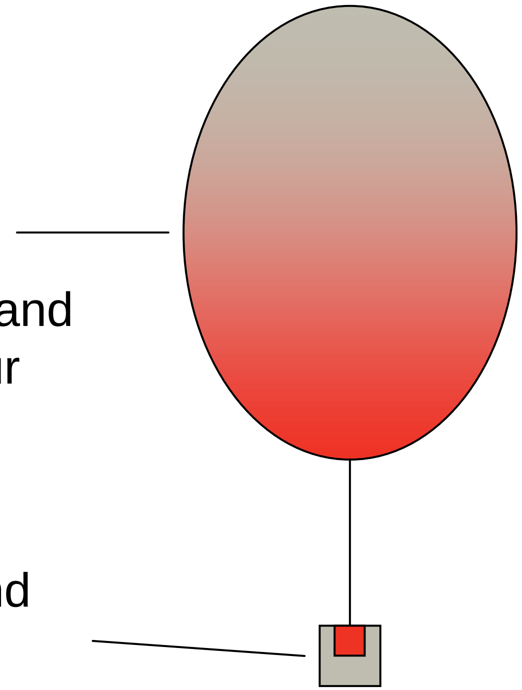
Schematic



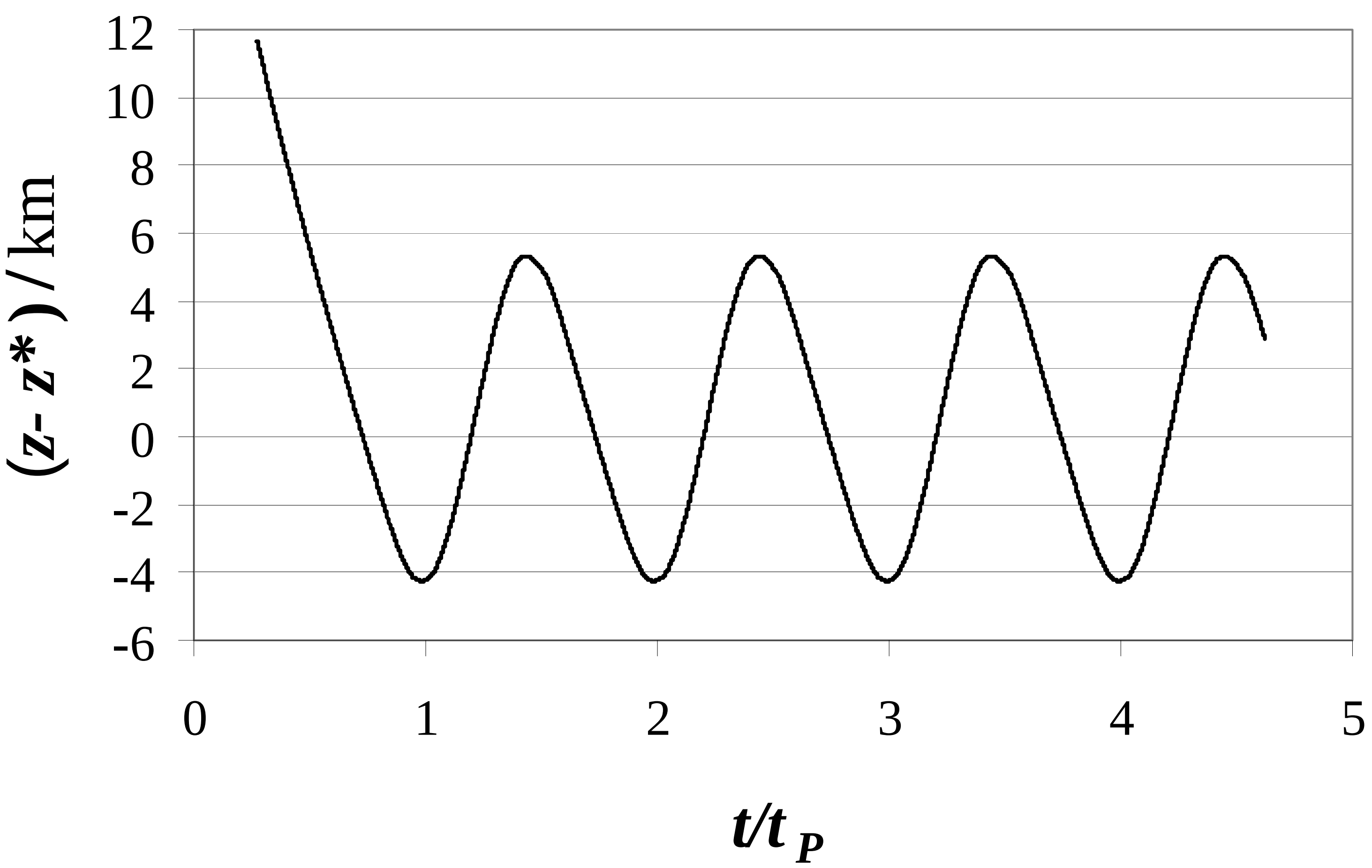
Zero-Pressure Balloon with Phase Change Fluid

Single Envelope Configuration

Schematic



Vertical Oscillation (H_2O plus helium tandem)



Phase Change Fluid (PCF) options

Higher MW PCFs increase oscillation altitude, but reduce payload fraction

PCF	Mol W. / (gram mols)	P *	T*	z*
acetic acid	60	0.71	467	33
water	18	0.28	404	42
ethanol	46	0.11	355	49
methanol	32	0.08	332	52
acetone	58	0.07	316	54
pentane	72	0.04	284	57

Oscillating Phase Change Balloons

- Have been demonstrated in Earth troposphere (ALICE)
- Well known thermodynamics govern predicted oscillation
- High risk deployment and initial helium/hydrogen inflation can be tested at similar Earth-Venus conditions
- PCF evaporation offers low altitude safety “buffer” (reducing mission risk)
- Permits multiple traverses of cloud layers
- MIL specification electronics possible down to 43 km (PCF evaporation cools payload).
- Slightly reduced payload ratio

Other Options Requiring Study

Infra-Red Montgolfière

Fixed-Wing Gliders (6 hours)

Parawings (solar power, 10 hours)

Vetrolets (wind shear dependent)

Etc.

Conclusions

VEGA 1 & 2 SPB flights (1985) rank with major aeronautical historical events, but may not have circumnavigated Venus after power loss

For (multiple) circumnavigation of Venus, Phase Change Balloons offer:

1) lower risk of premature mission loss (e.g., less leakage)

2) multiple traverses of cloud layers

By 2025 there will be a strong demand for Cytherean *in situ* exploration!

End