Getting the most out of planetary entry probes

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Planetary Science Seminar, Earth and Atmospheric Sciences, Georgia Tech

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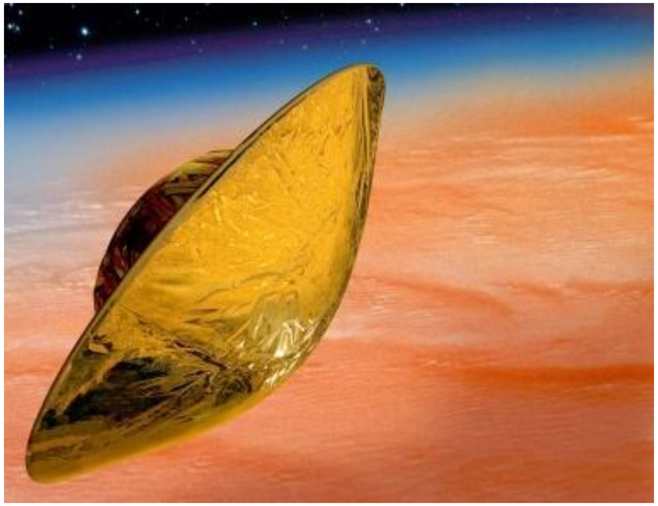
What is an entry probe?



Science issues **Engineering issues**

Related aerospace activities

The plan for today

- Typical trajectory and atmospheric structure reconstruction

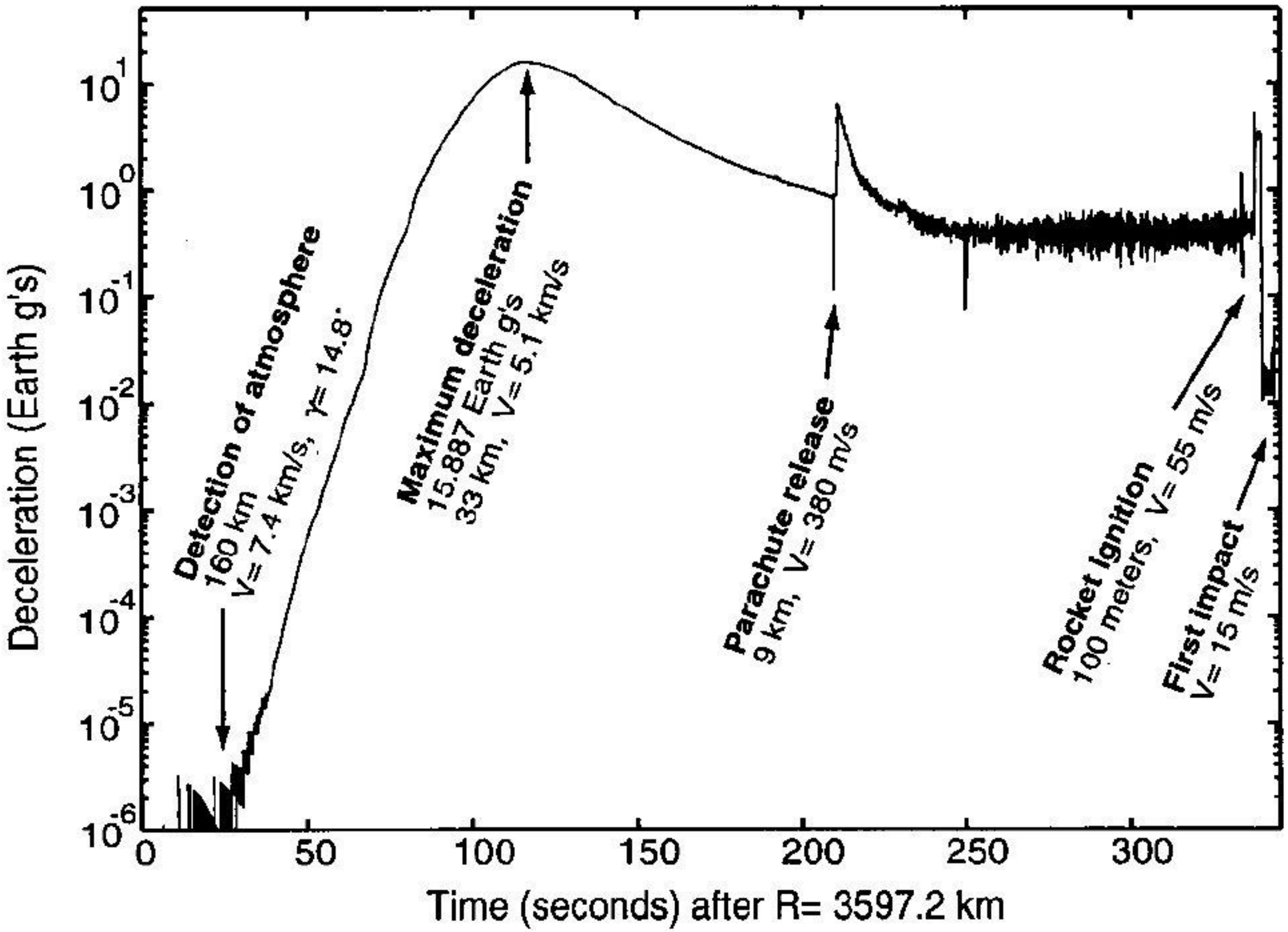
- Creative smoothing of data
- Creative use of no data
- Creative use of additional data

Where are we?

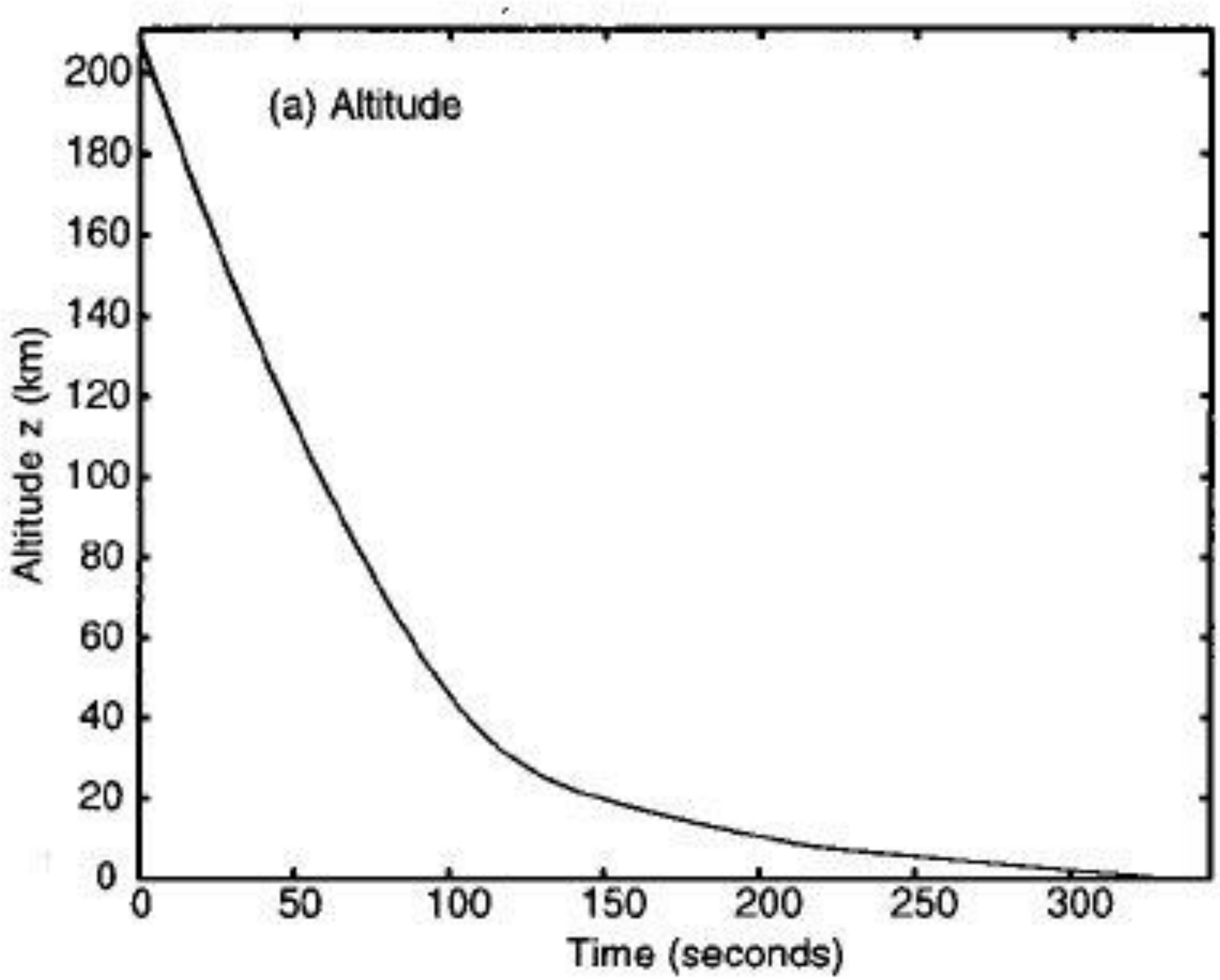
- $d\underline{r}/dt = \underline{v}$
- $d\underline{v}/dt = \underline{a\text{-}aero} + \underline{g}(\underline{r})$
- $\underline{r}0$, $\underline{v}0$ known

- Aerodynamic accelerations measured with respect to spacecraft structure
- Which way is spacecraft pointing?
- Which way is up?

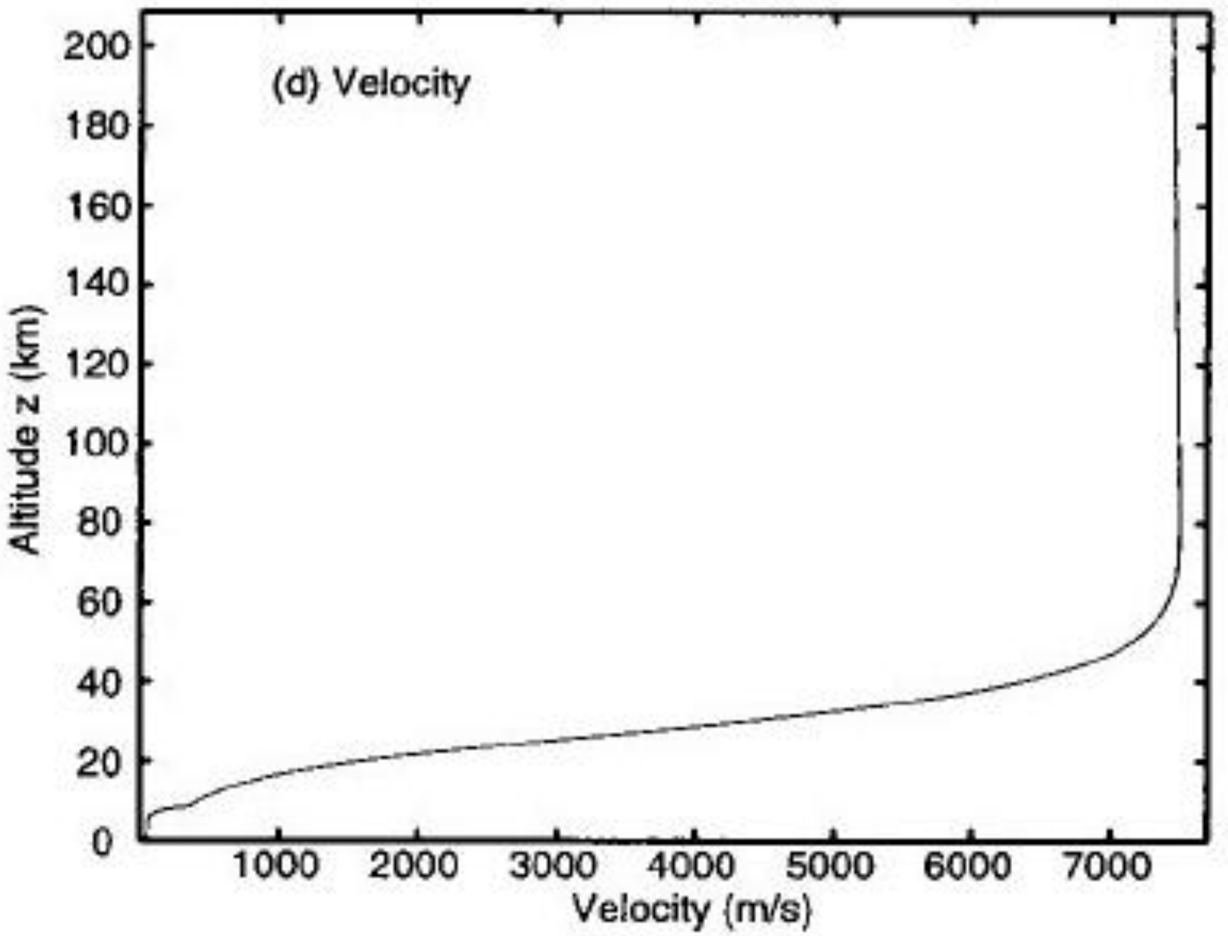
Pathfinder - Acceleration



Pathfinder altitude profile

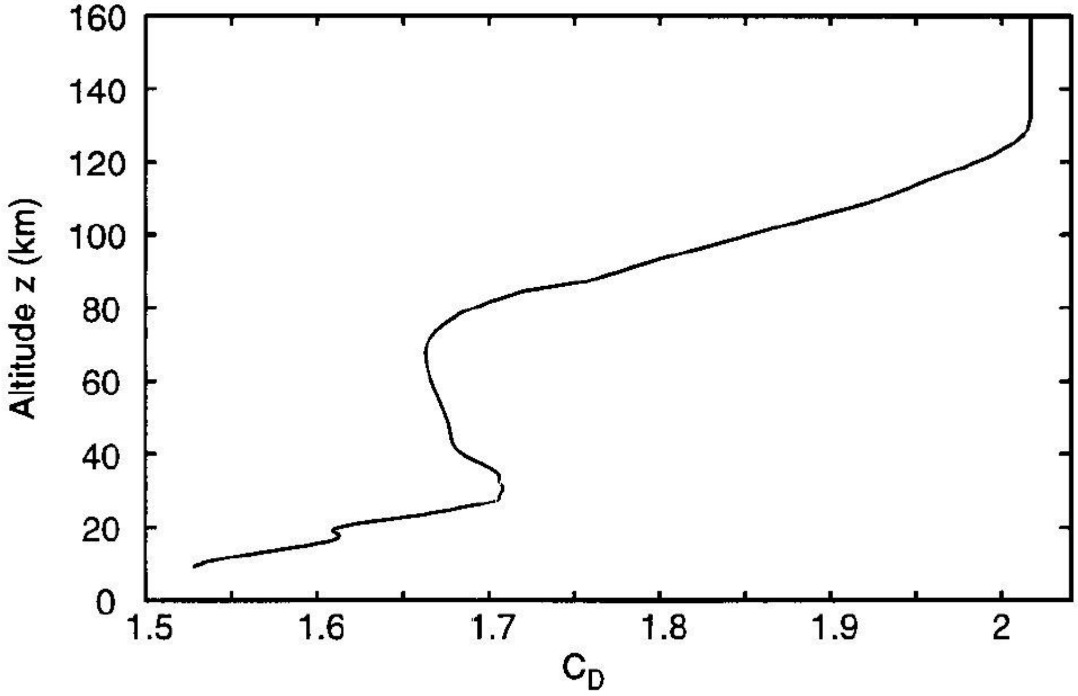


Pathfinder speed profile



Density from deceleration

- Force = m a
- rho A v^2 = m a

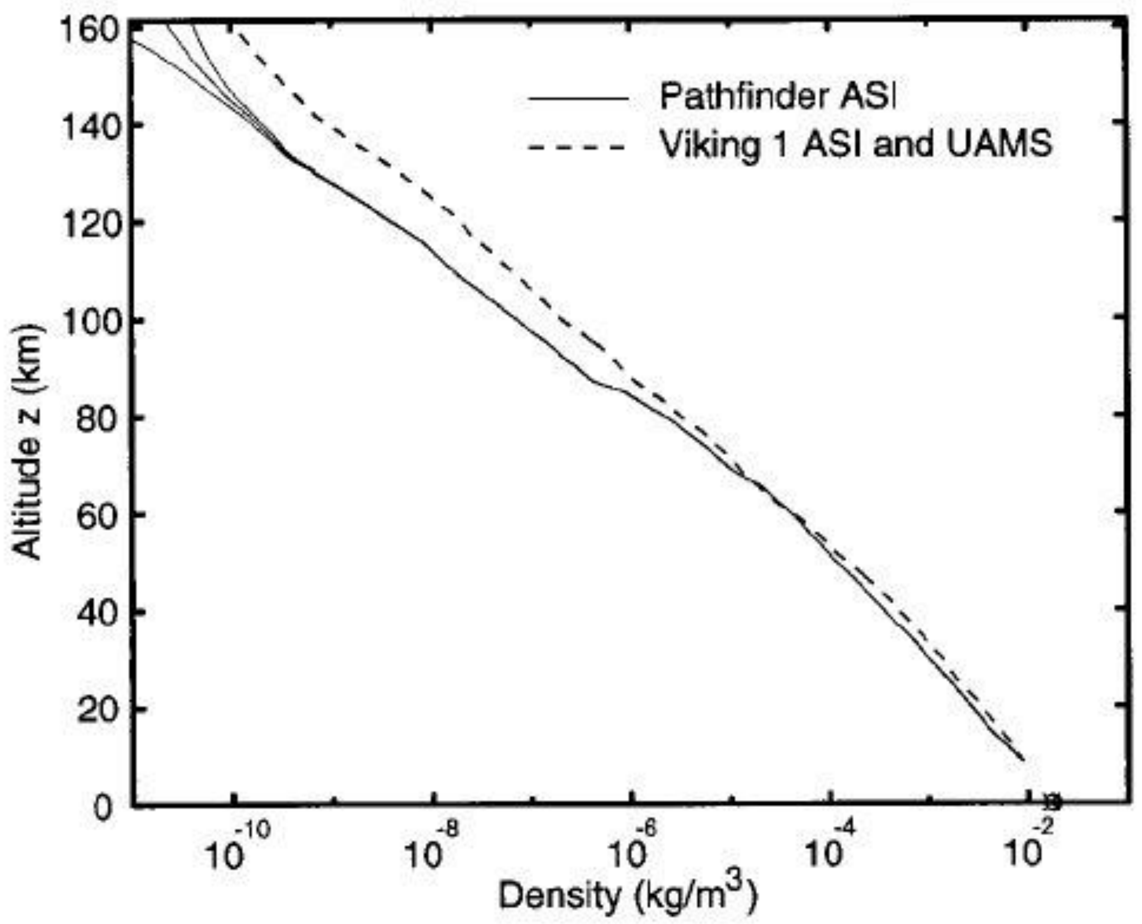


- Define “C” by rho A v^2 (C/2) = m a

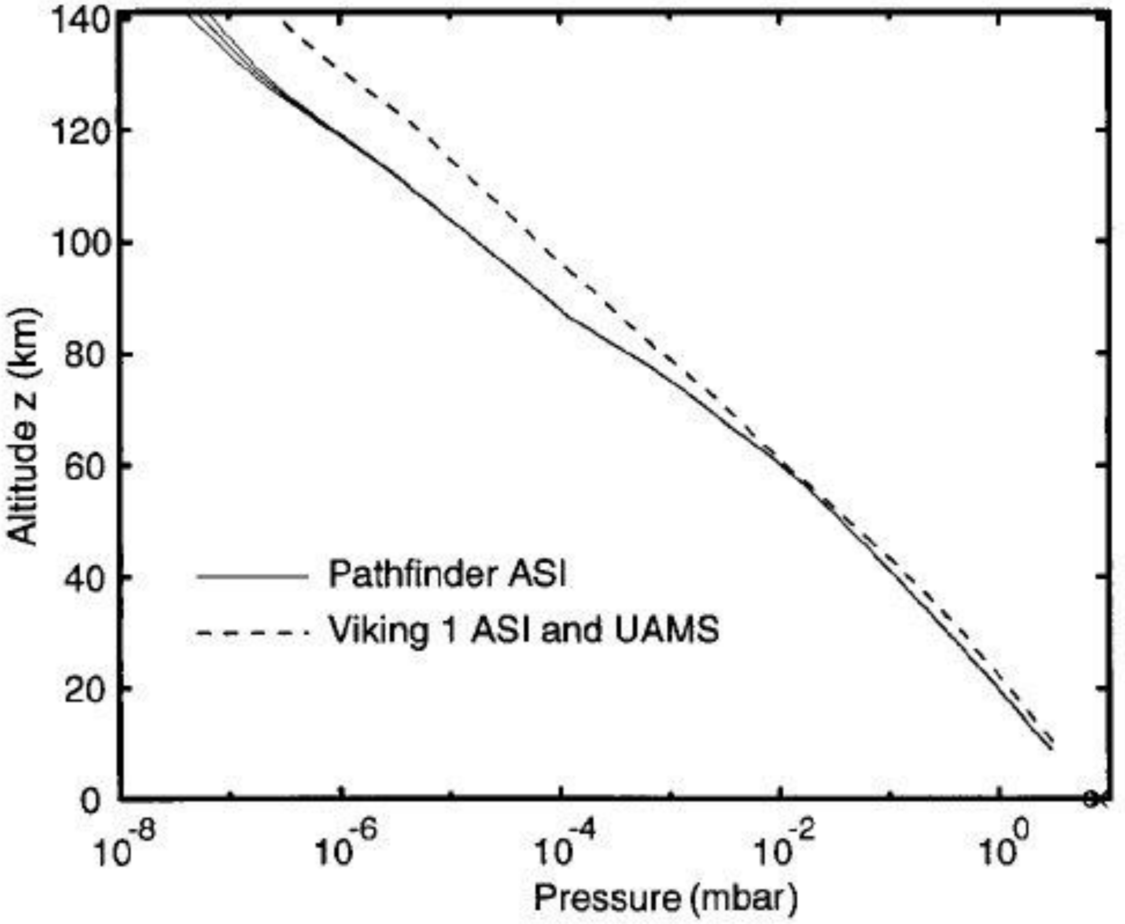
Atmospheric conditions

- dp/dz = rho g
  - Find p(z) from rho(z) and an upper boundary
- p = rho k-Boltzmann T / (molecular mass)
  - Find T(z) from rho(z) and p(z) and assumed molecular mass
- How important is precise C for drag?

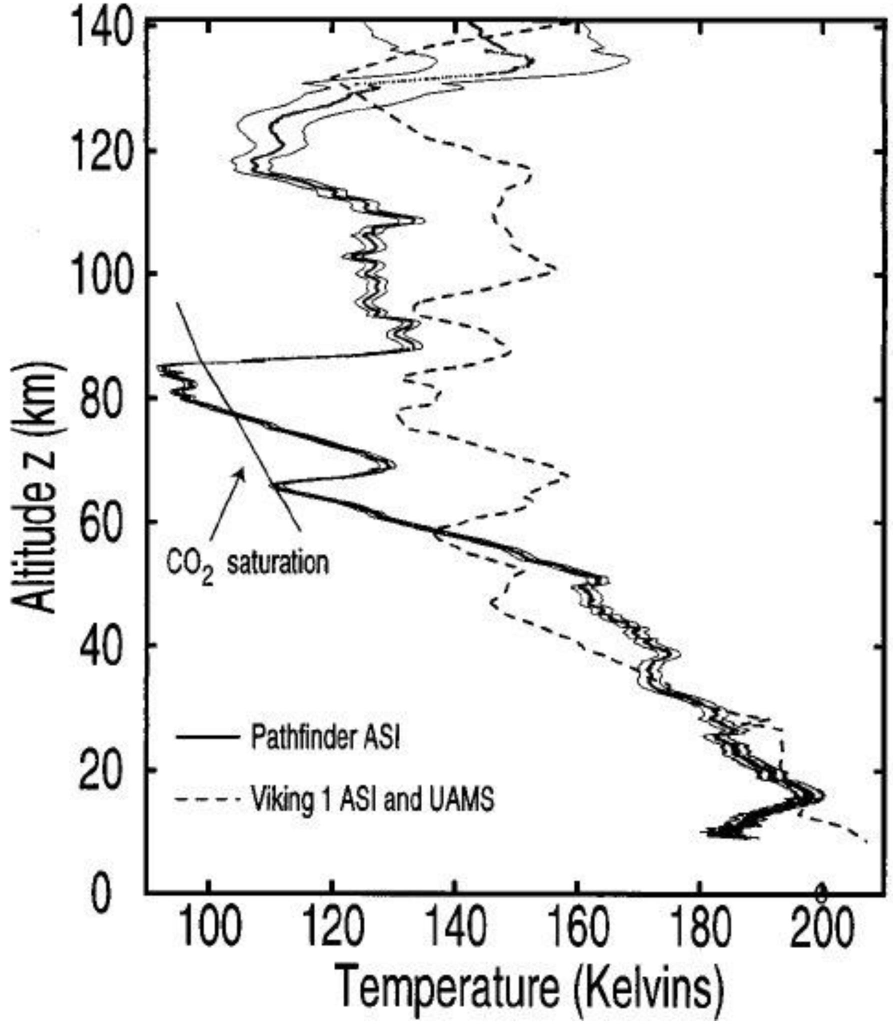
Pathfinder density



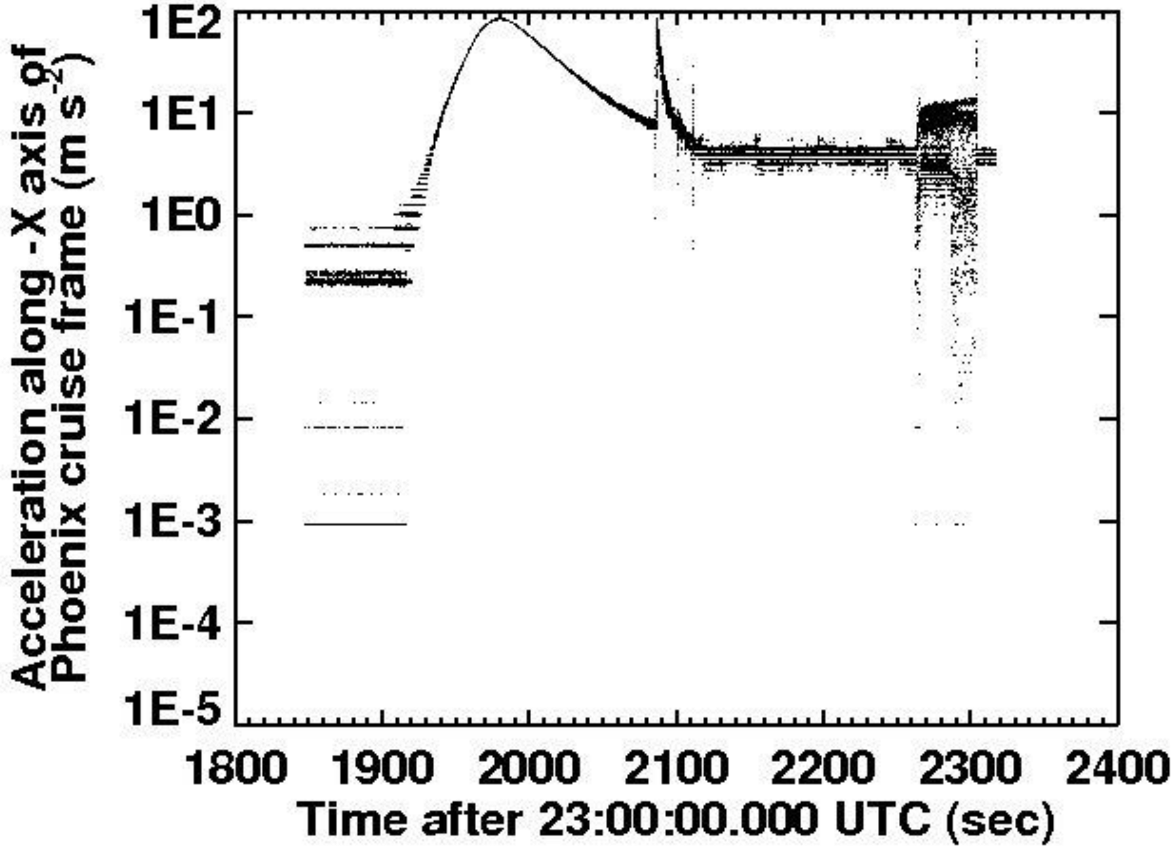
Pathfinder pressure



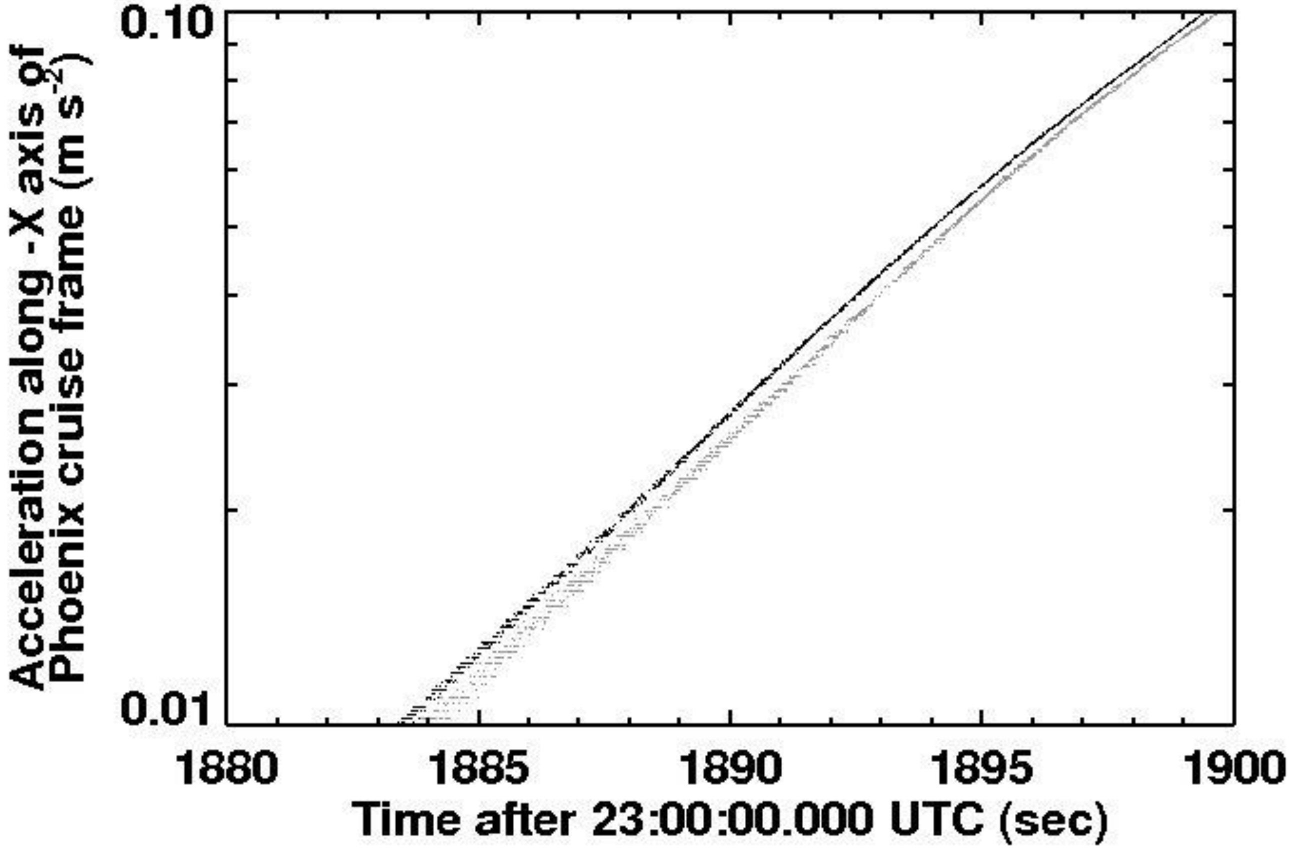
Pathfinder temperature



Unsmoothed Phoenix data



Which smoothing interval?



Exponential acceleration helps

$$a = a_0 \exp \frac{t}{\tau}$$

We know the acceleration varies like this

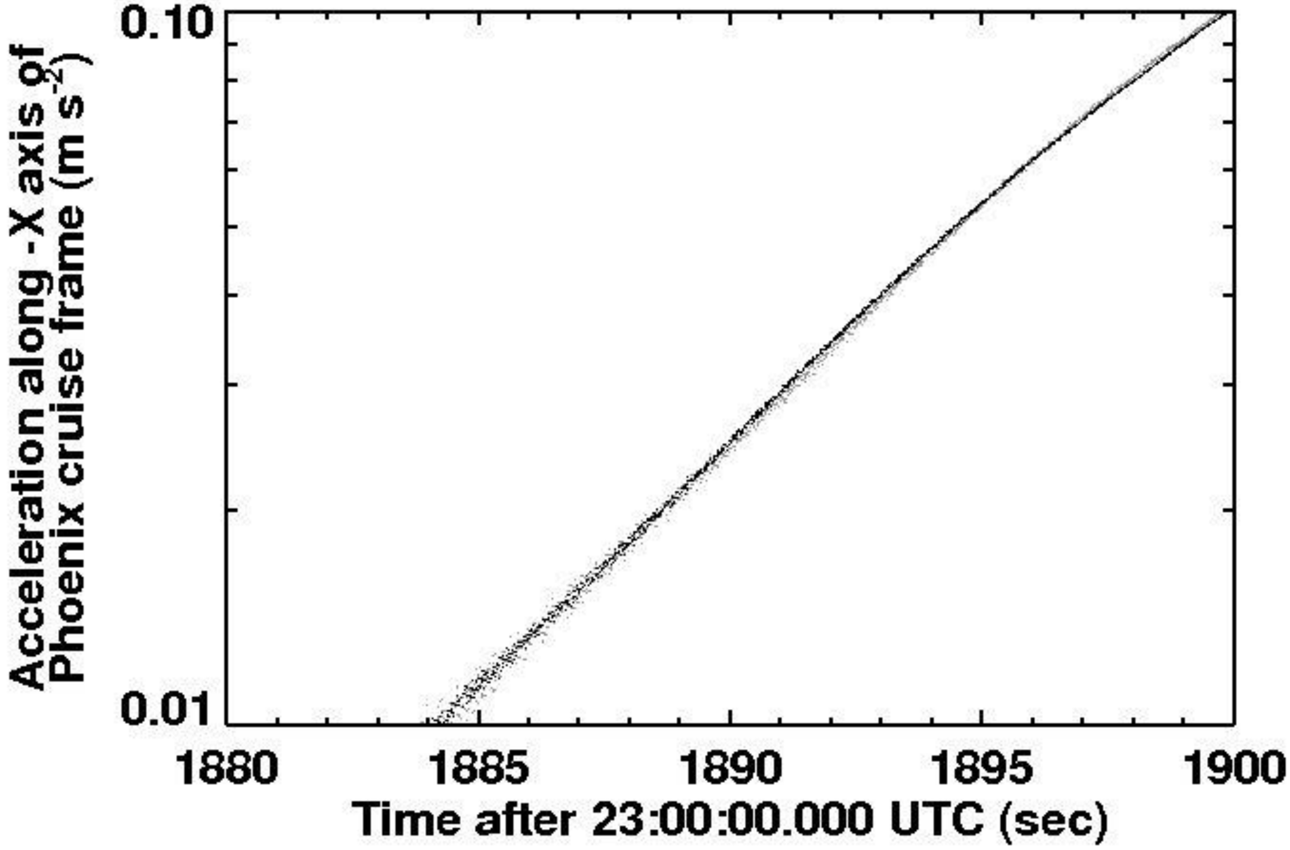
$$a_{mean} = a_0 \frac{\tau}{t_X} \sinh\left(\frac{t_X}{\tau}\right)$$

Acceleration at t=0 is a0
Mean acceleration from –tx to tx is <u>not</u> a0

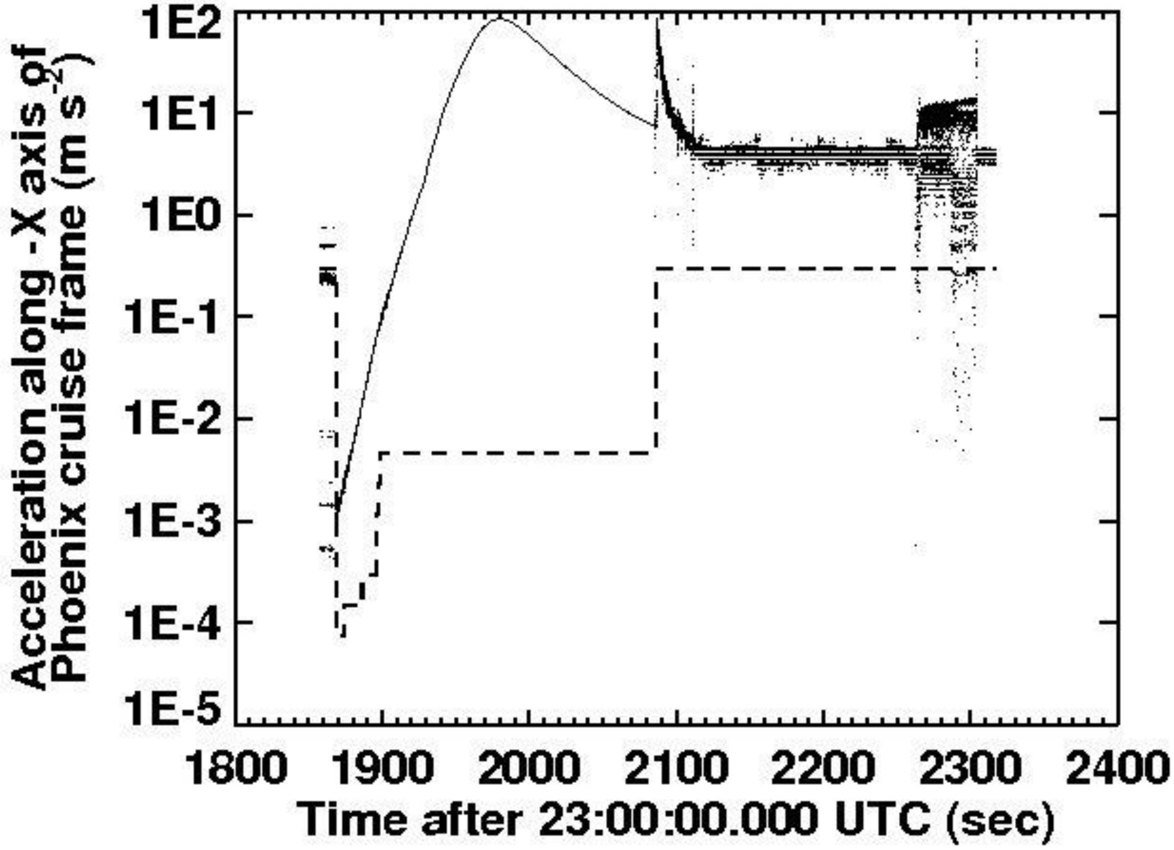
$$\frac{a_L}{a_S} = \cosh\left(\frac{t_S}{\tau}\right)$$

Mean accelerations over two related time intervals are related - tL = 2 tS
We know aL, aS, tS – Find tau!

Vary smoothing interval OK!

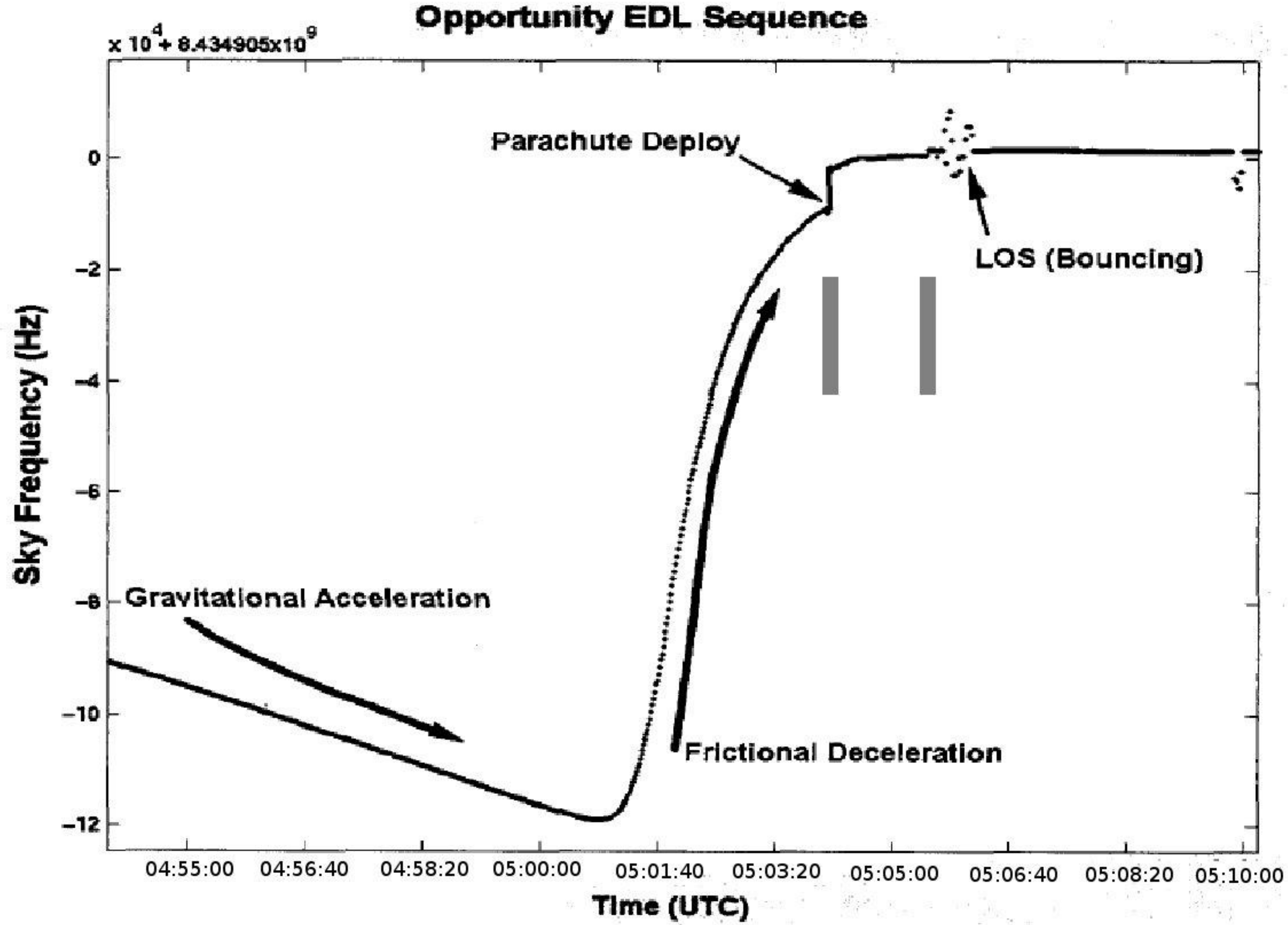


Smoothed Phoenix data



What if…

Radio link is helpful

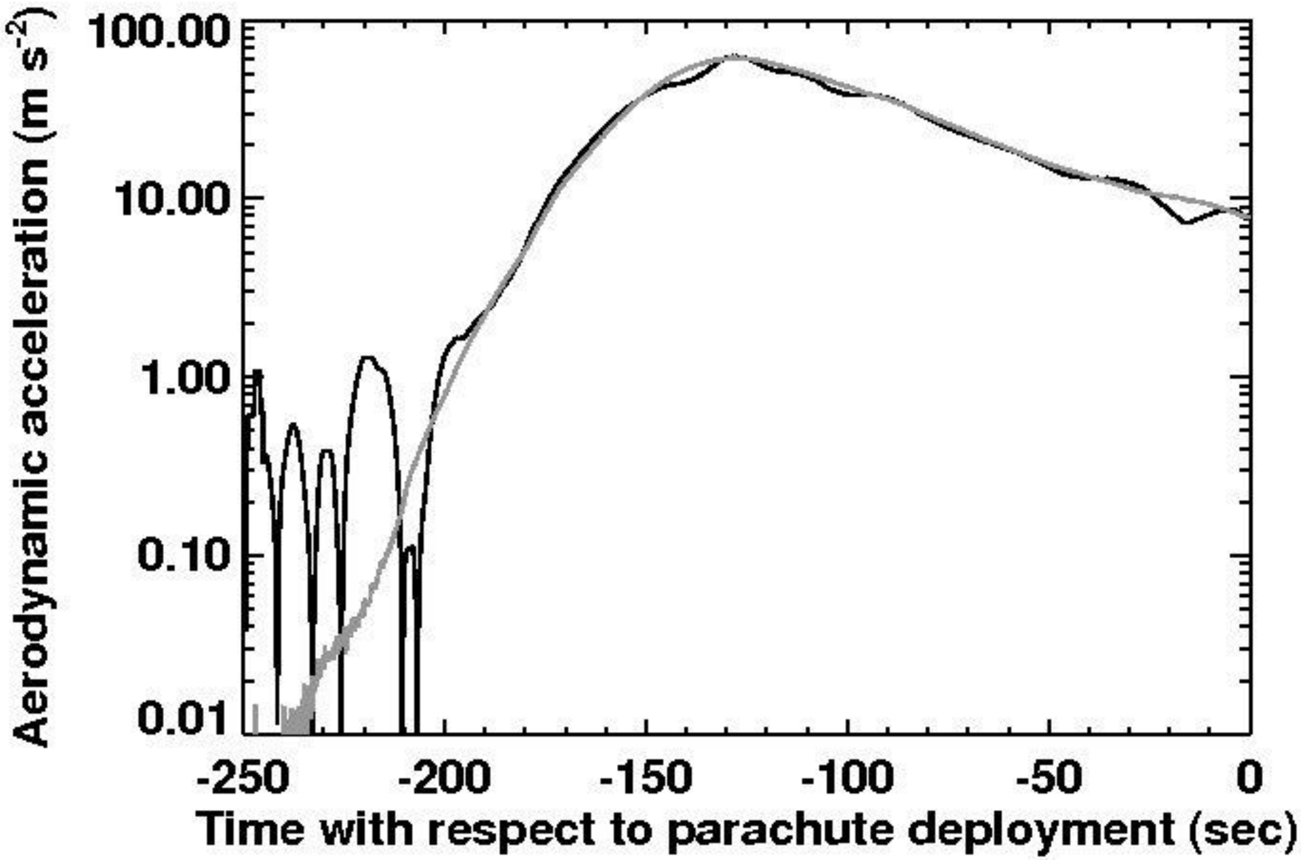


How is it helpful?

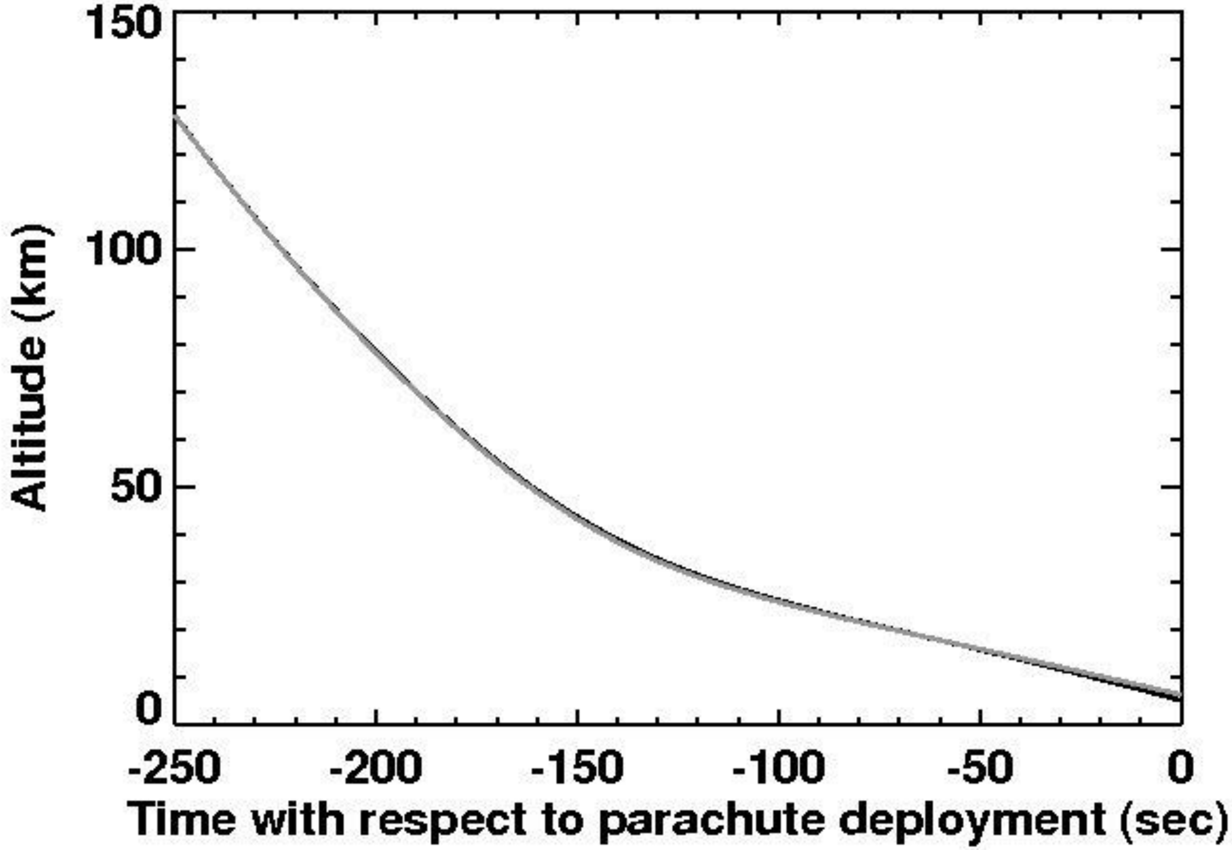
- Doppler shift provides line of sight speed
- One dimensional only!

- Assumption – All aerodynamic forces are parallel to velocity vector
- Drag only, no lift
- Just enough information to solve trajectory

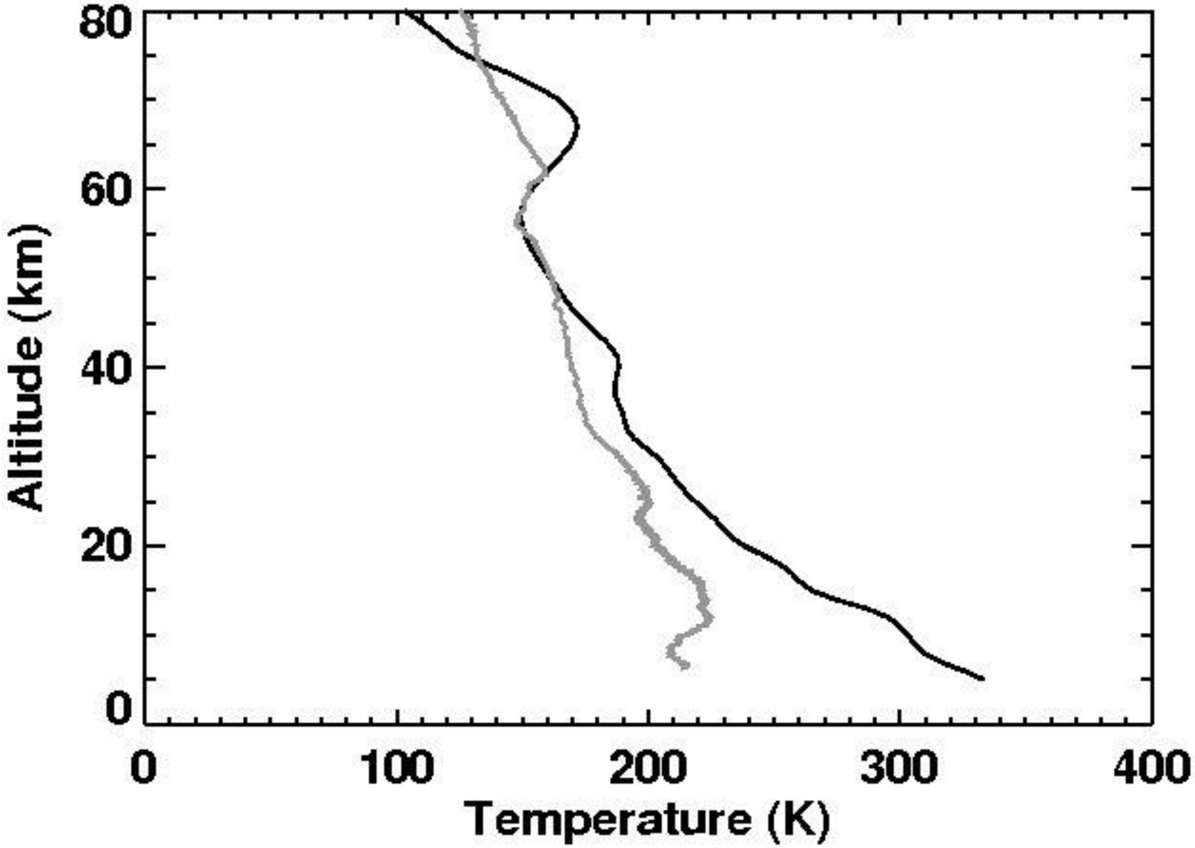
Opportunity accelerations



Opportunity altitudes

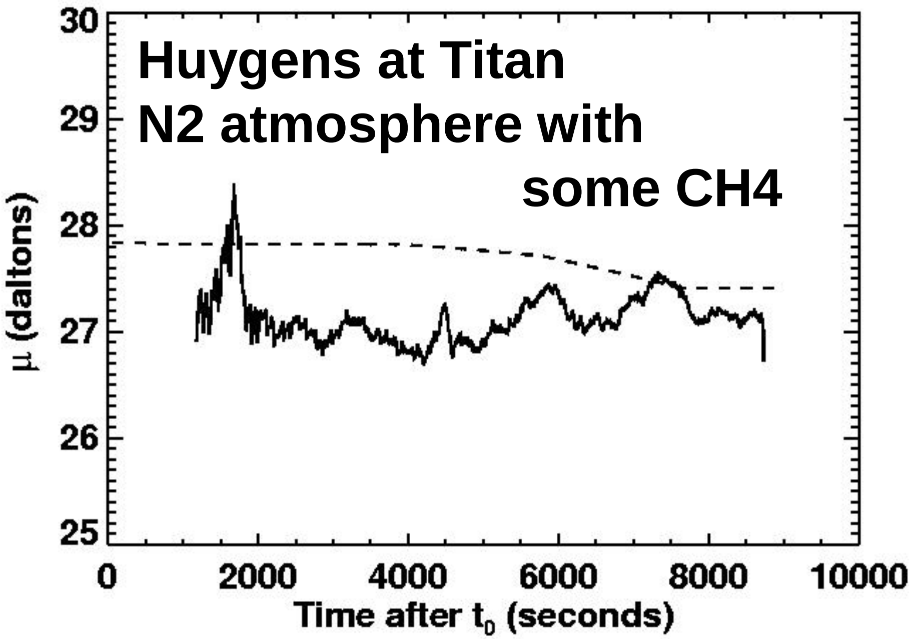


Opportunity temperatures



Atmospheric composition

- molecular mass = dp/dz k T / (rho g)
- molecular mass = dp/dt k T / (rho g v)



Easy to measure p, T directly at subsonic speeds on parachute

Combine with trajectory information to find atmospheric molecular mass

This means composition!
Who <u>needs</u> a mass spectrometer?

Conclusions

- Entry probes are not simply engineering making science possible
- Engineering analysis produces science

- Imagination is helpful
  - Situation-specific smoothing approach
  - Doppler data survives crash landings
  - Composition can usually be found as well