A simple method for supporting future landers by predicting surface pressure on Mars

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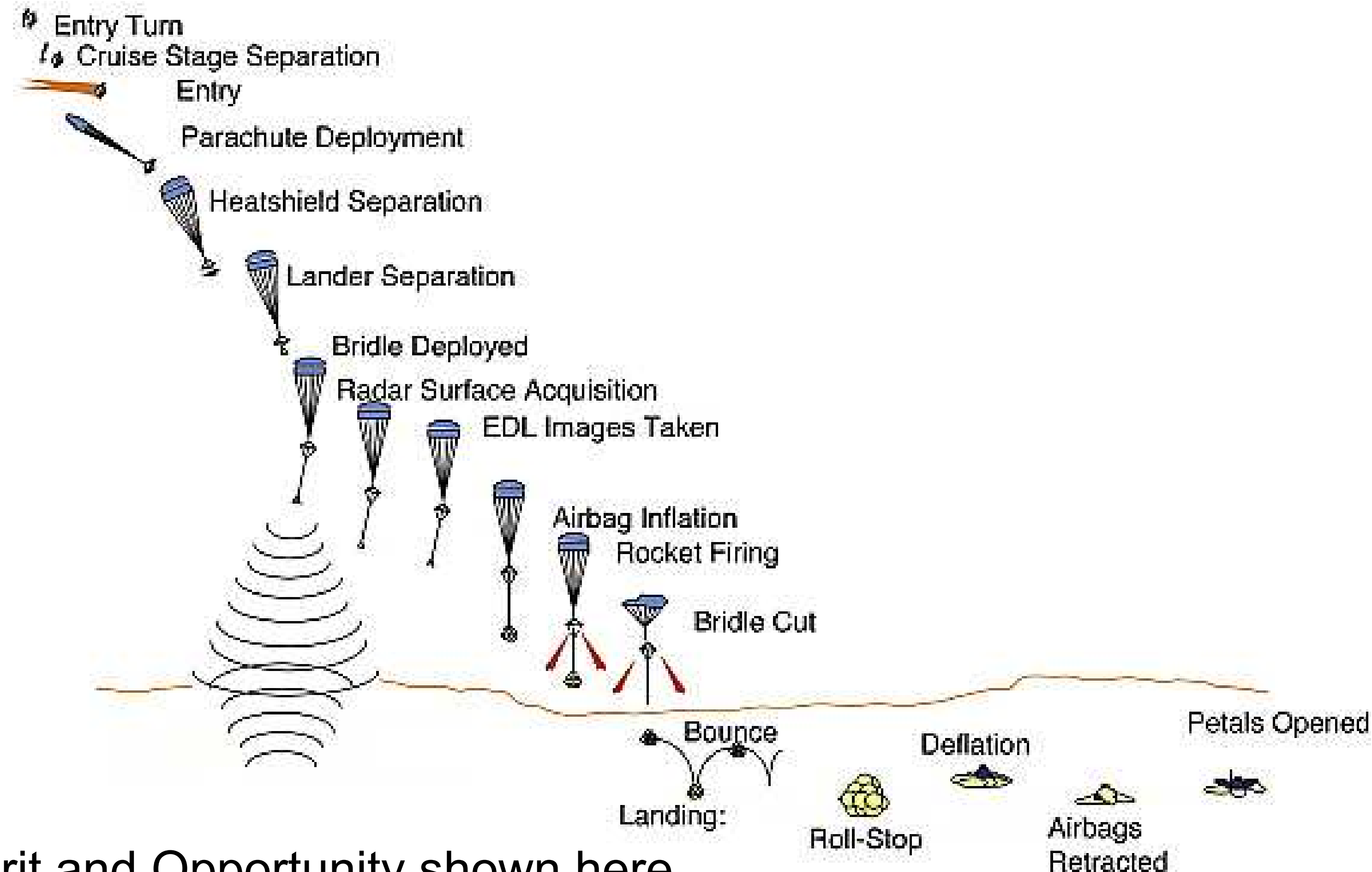
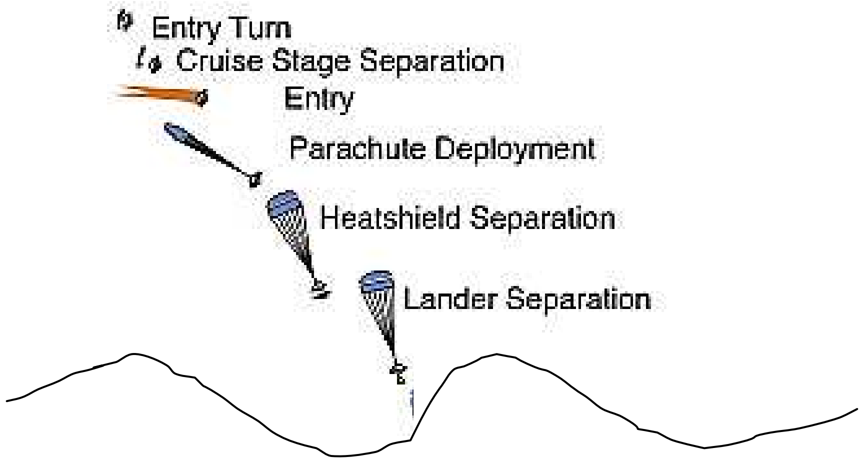
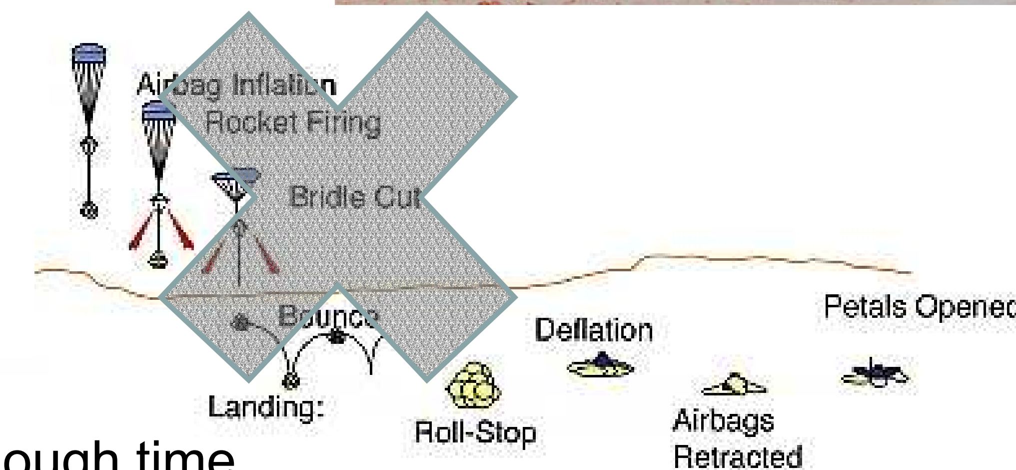
How to land on Mars



Spirit and Opportunity shown here,
similar systems used by other landers

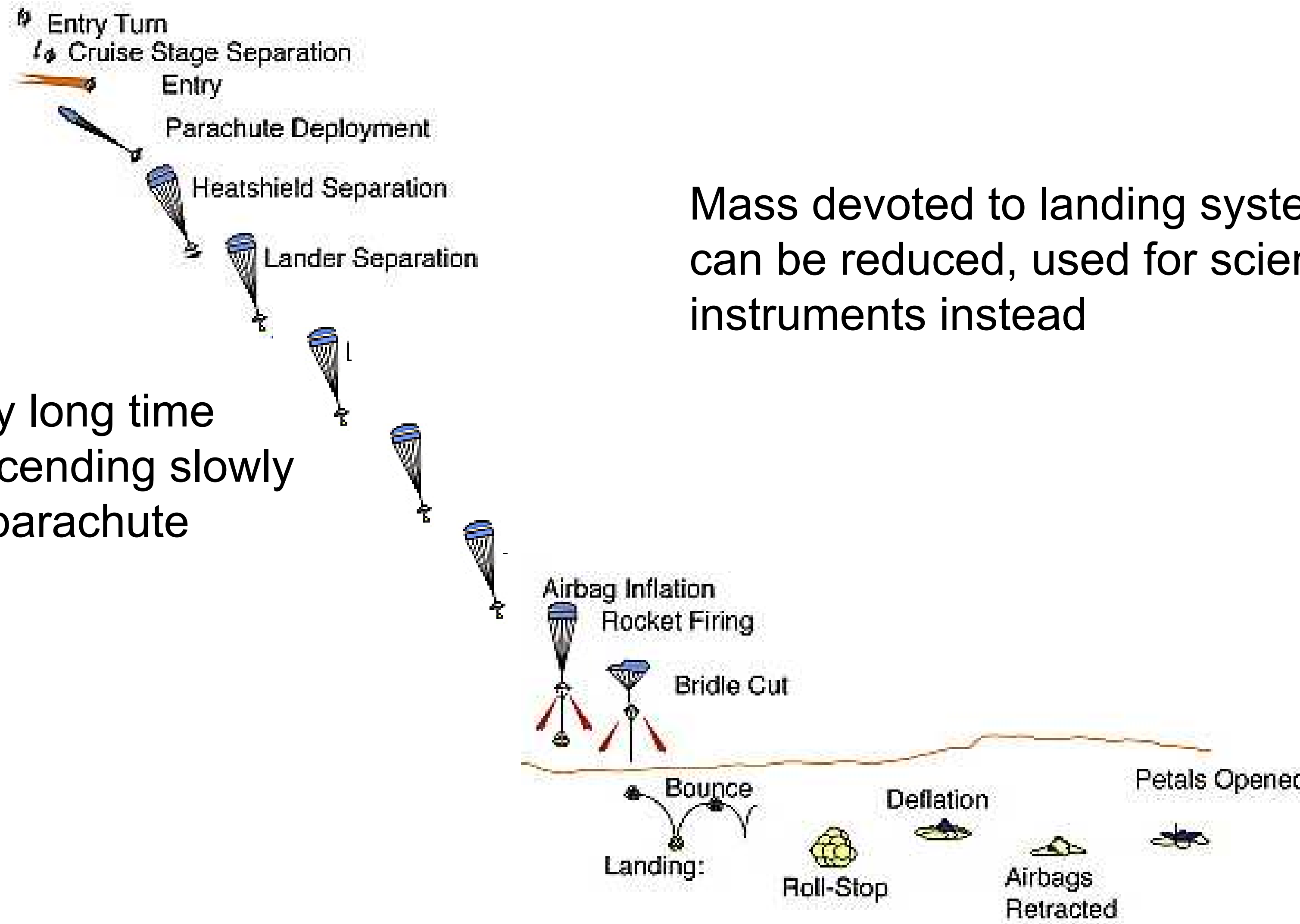
If actual surface pressure is much smaller than estimated





Lander does not have enough time
to perform steps necessary for safe landing

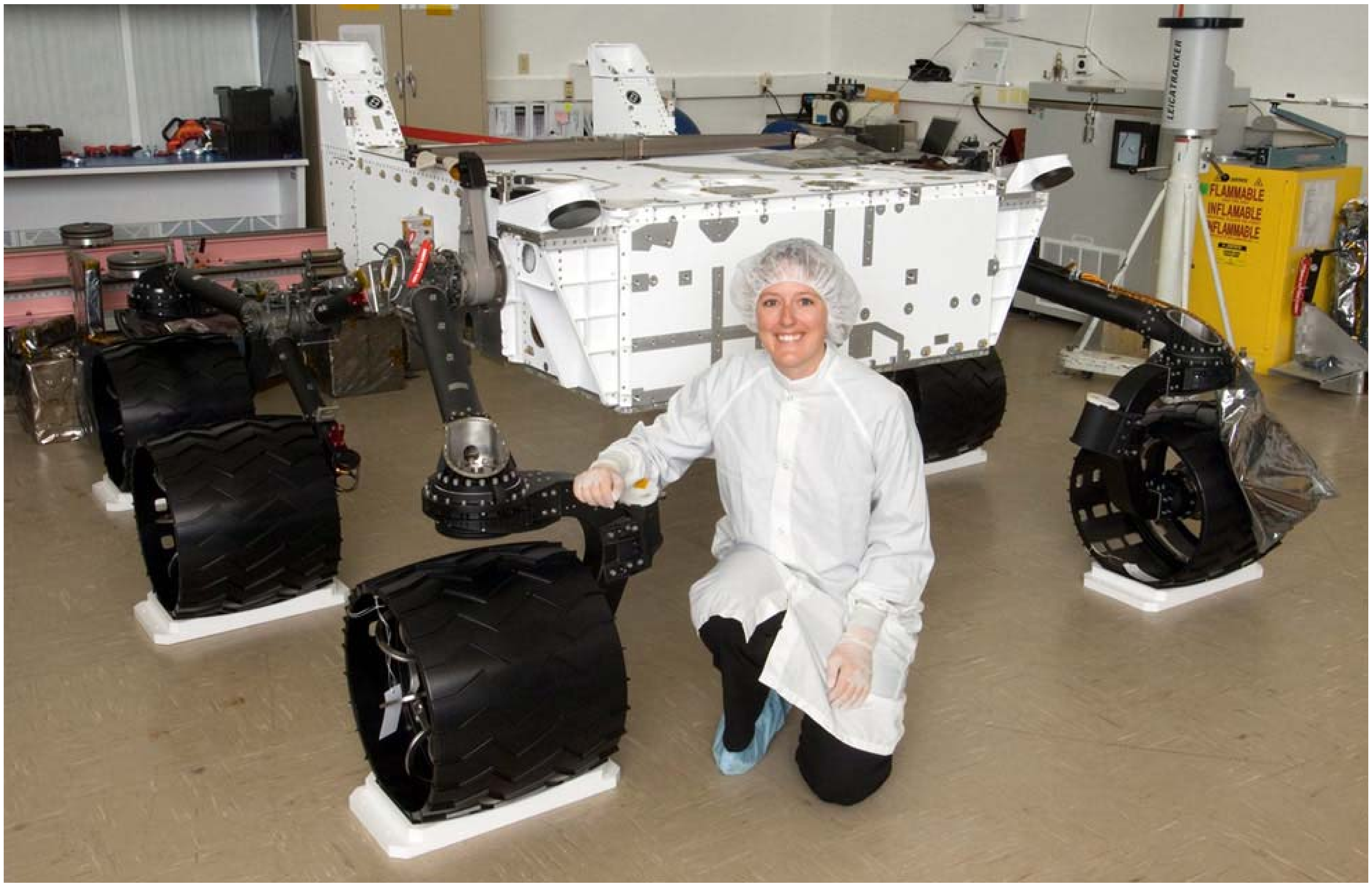
If actual surface pressure is much larger than estimated



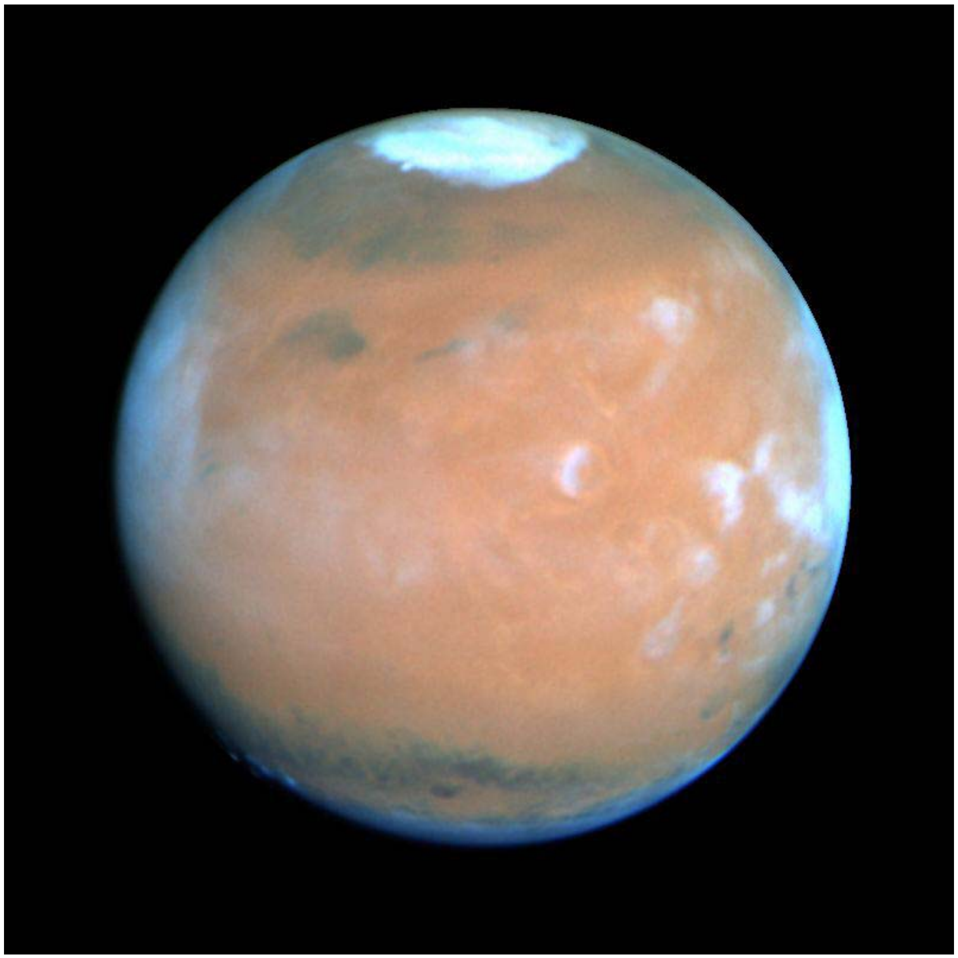
Mass devoted to landing system can be reduced, used for scientific instruments instead

Very long time descending slowly on parachute

Mars Science Laboratory (MSL, 2011 launch)

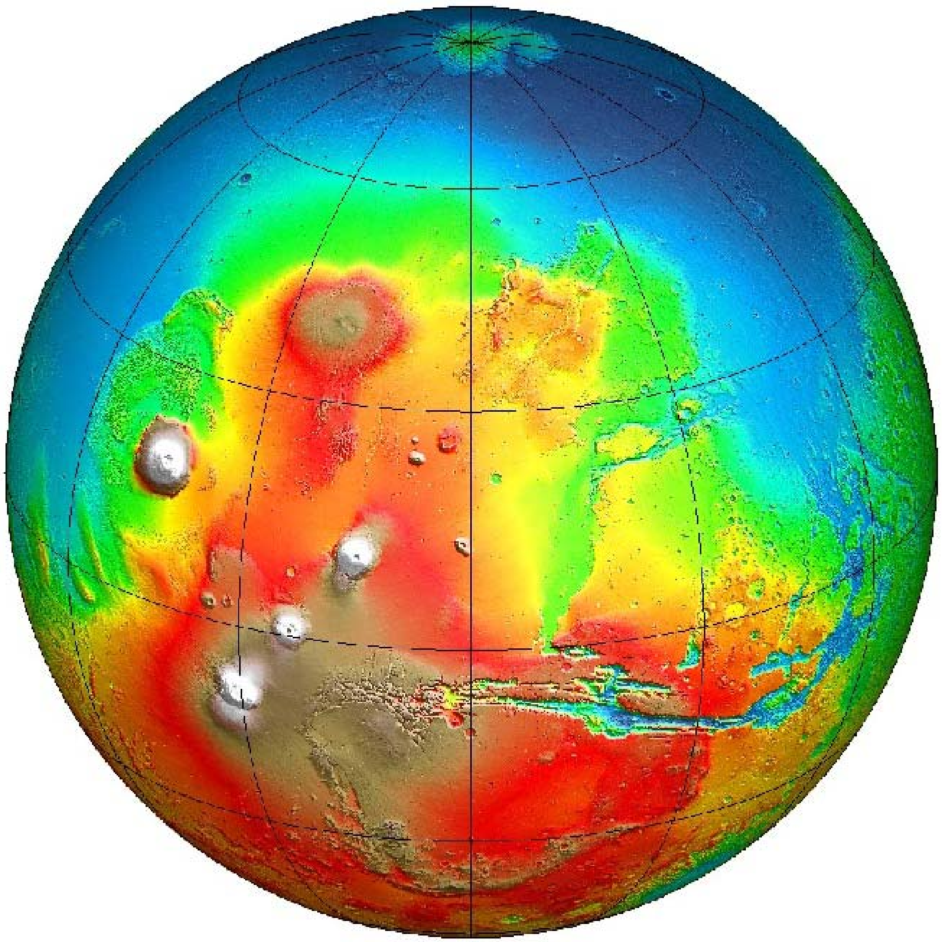


Surface pressure varies with season



Atmosphere of CO_2 freezes onto polar cap in winter hemisphere

Surface pressure varies with position

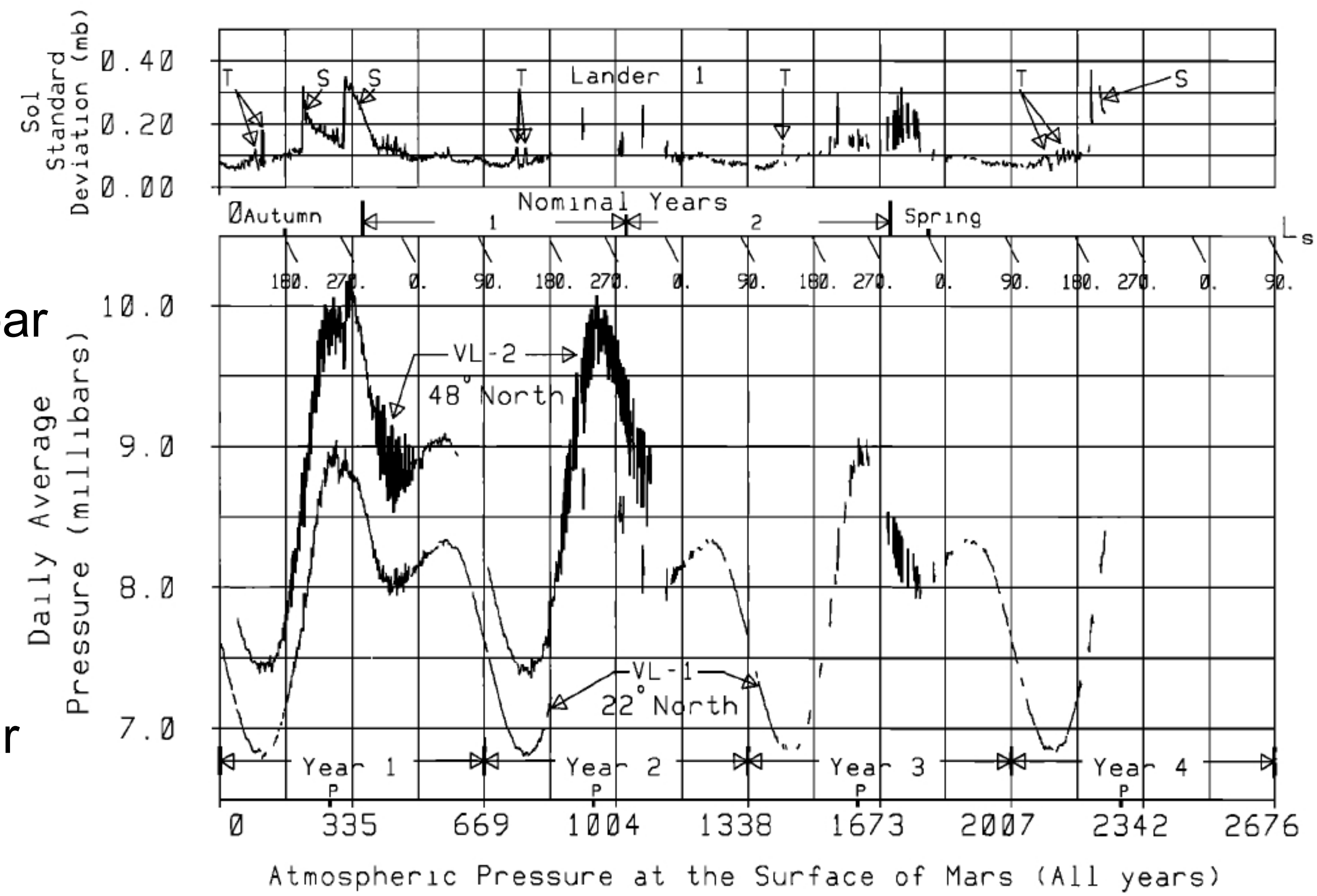


Altitude of surface varies by three atmospheric scale heights or >30 km

Viking surface pressure data

10 mbar

7 mbar



Ls=0 Ls=0 Ls=0 Ls=0

Estimating surface pressure for MSL's landing

- Other scientists are developing very sophisticated climate models
- I focus on a simple expression for Ps derived from data
  - Transparent
  - Easy to use
  - Quantify accuracy easily
  - Reality-check for more complex predictions
- Ls=120-180, z<+1 km, 45S-45N

Available Datasets

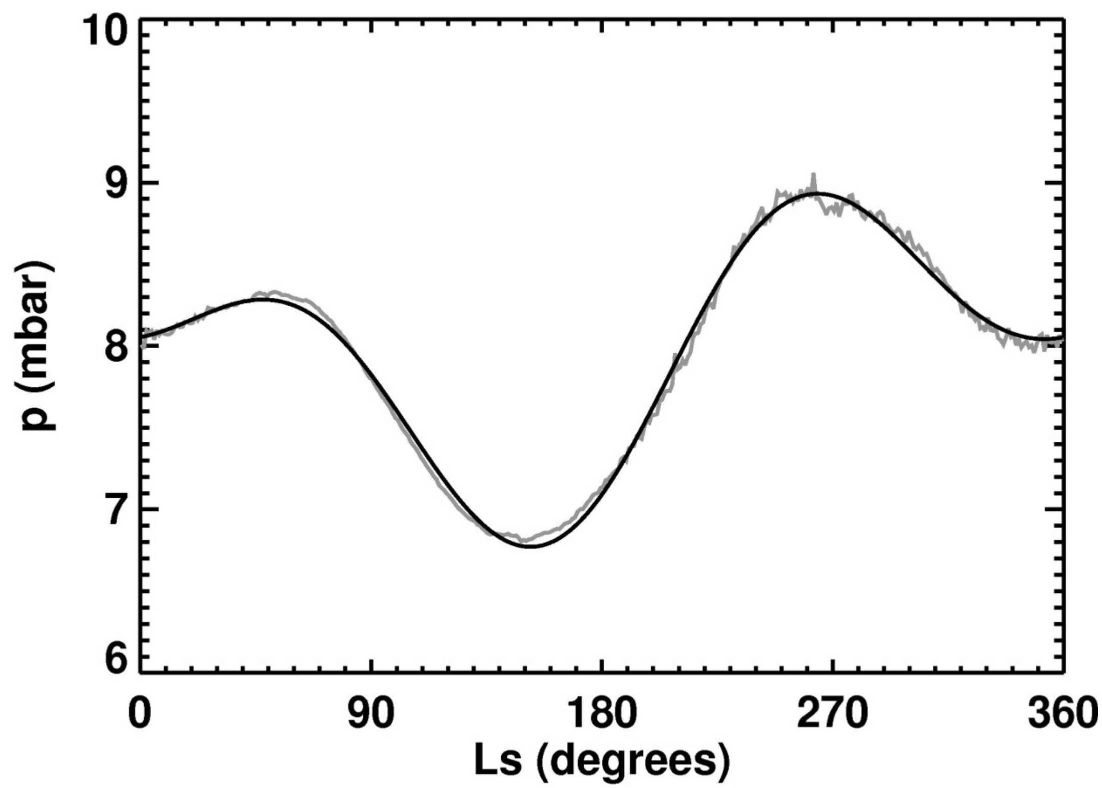
- <u>LANDERS</u>
- Viking Lander 1 (VL1)
  - Multiple years, coarse digitization, 22N
- Viking Lander 2 (VL2)
  - Almost one year, coarse digitization, 48N
- Mars Pathfinder (MPF)
  - Ls=142-188, same elevation as VL1, systematic error of about 0.1 mbar, 19N
- Phoenix (PHX)
  - Ls=76-151, 68N, large and precise dataset
  - Data from Ls=120 to 151 not yet incorporated into analysis

- <u>RADIO OCCULTATIONS</u>
- Mariner 9
  - Apparent inconsistencies of 10%
- Viking Orbiters 1/2 (VO1/2)
  - Barely 20 pressures reported
- Mars Global Surveyor (MGS)
  - 21243 profiles, including 297 at Ls=120-180, z<+1 km, latitude=45S to 45N
  - Extrapolate p(r) to MOLA surface and assign MOLA altitude
- Mars Express (MEX)
  - 484 profiles, only 5 at Ls=120-180, z<+1 km, latitude=45S to 45N

Most useful datasets are: VL1 for seasonal cycle, MGS for validation and testing,

Goal is: Simple expression for DIURNAL MEAN Ps as function of season and altitude.

Approach



Grey line is 360 diurnal mean surface pressure from VL1

Black line is wave-2 fit

Parameter	VL1
p_0 (mbar)	7.9723740
s_1	-0.068622849
c_1	0.060390972
s_2	0.044663631
c_2	-0.050183946

Use expression below to predict surface pressure, Ps
zVL1 = -3.63 km
Constant and uniform H0 needed (found on next slide)

$$p_s = p_{0,VL1} \exp\left(-\left(z - z_{VL1}\right)/H_0\right) \times$$

Eqn 1

$$\left(1 + s_{1,VL1}\sin\left(1L_s\right) + c_{1,VL1}\cos\left(1L_s\right) + s_{2,VL1}\sin\left(2L_s\right) + c_{2,VL1}\cos\left(2L_s\right)\right)$$

Optimize with Delta metric, where Delta = (p-pred – p-meas) / p-meas

Finding H0 from MGS

- Quickly find that H0<10 km and H0>12 km have problems at low and high altitudes
- MGS measurements at z<+1 km and 45S to 45N divide neatly into seven Ls blocks

L_s range	N	$\overline{z}$ (km)	H_0 (km)	$\overline{\Delta}$	S. D. of Δ
340°–20°	293	-1.3	10.0	-2.1E-02	3.2E-02
			10.5	-9.9E-03	2.5E-02
			11.0	1.5E-04	2.3E-02
			11.5	9.5E-03	2.6E-02
			12.0	1.8E-02	3.2E-02
20°–65°	824	-2.9	10.0	-4.1E-03	1.5E-02
			10.5	-8.5E-04	1.0E-02
			11.0	2.2E-03	1.0E-02
			11.5	5.1E-03	1.4E-02
			12.0	7.7E-03	1.9E-02
65°–120°	740	-2.2	10.0	-1.4E-02	1.9E-02
			10.5	-7.2E-03	1.5E-02
			11.0	-1.1E-03	1.4E-02
			11.5	4.6E-03	1.6E-02
			12.0	9.9E-03	1.9E-02
120°–175°	297	-1.7	10.0	-3.4E-02	2.6E-02
			10.5	-2.5E-02	2.1E-02
			11.0	-1.7E-02	1.8E-02
			11.5	-9.7E-03	1.7E-02
			12.0	-2.9E-03	1.8E-02

L_s range	N	$\overline{z}$ (km)	H_0 (km)	$\overline{\Delta}$	S. D. of Δ
175°–200°	127	-2.8	10.0	-2.2E-04	1.9E-02
			10.5	3.7E-03	1.6E-02
			11.0	7.3E-03	1.6E-02
			11.5	1.1E-02	1.8E-02
			12.0	1.4E-02	2.1E-02
255°–300°	306	-1.0	10.0	4.8E-02	4.4E-02
			10.5	6.1E-02	3.7E-02
			11.0	7.3E-02	3.2E-02
			11.5	8.3E-02	2.9E-02
			12.0	9.4E-02	2.7E-02
300°–340°	479	-1.3	10.0	2.6E-02	2.9E-02
			10.5	3.8E-02	2.3E-02
			11.0	4.8E-02	2.0E-02
			11.5	5.8E-02	2.0E-02
			12.0	6.7E-02	2.3E-02

Optimal scale height is:

H0 = 11 km
Equivalent to T=215 K, which is reasonable

Accuracy of Predictions

Mission	$\overline{\Delta}$ (all L_s)	S. D. of Δ (all L_s)	$\overline{\Delta}$ ($L_s = 120°$–$180°$)	S. D. of Δ ($L_s = 120°$–$180°$)
VL1	2.5E-3%	0.6%	-0.4%	0.6%
VL2	6.7E-3%	1.1%	-0.4%	0.6%
MPF	2.2%	0.2%	2.2%	0.2%
PHX	-0.2%	3.0%	—	—
MGS	1.4%	3.2%	-1.7%	1.8%
MEX	0.2%	3.3%	-7.1%	7.0%

<u>Expect 3% accuracy for MSL landing with 1-sigma confidence level</u>

Overbar = Mean
S. D. = Standard deviation
Only data from z<+1 km and 45S to 45N used for orbital datasets

Potential Applications

- First-order surface pressure estimates for landing site selection
- Reality-check on predictions from more complex, physics-based models
- Total atmospheric mass from Eqn 1 is about 10 p_0R^2 f(Ls) / g. Annual mean value is 2.4E16 kg and difference between maximum and minimum values is 6.6E15 kg, consistent with previous results.
- Correct orbital gamma ray and neutron spectrometer for atmospheric absorption effects
- Absolute altitude scales for T(p) profiles measured from orbit, such as MGS TES or Mariner 9 IRIS profiles
- Theoretical simulations of dust lifting and aeolian modification of surface features, the thermodynamic stability of near-surface liquids, and the surface radiation environment

Conclusions

- A simple expression with 7 free parameters provides surprisingly accurate predictions for surface pressure
- Expected accuracy of prediction for MSL landing is 3% (1-sigma confidence level)
- Predictions are least accurate at Ls=240 to 360 when interannual variability (large dust storms) is greatest
- There are many potential applications for accurate surface pressure predictions