IPPW-11 Short Course

"Discovery and Surprise : Science from Planetary Probes"

Introduction

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The *justification given* for planetary missions is usually to make scientific discoveries and answer scientific questions (agencies' other reasons may in practice be more important…..)

This course aims to review how some of these questions have been formulated and answered (or not), and to note how scientific progress is often a mix between answering well-structured questions, and discovering things that no-one had even thought of before.

Elements of the course

- Formulation of Scientific Mission priorities (Sotin, Coradini)
- History of Mars, Venus, Titan, Giant Planets exploration, with questions and discoveries (Golombek, Baines, Lorenz, Spilker)
- Proposing, implementing and operating an experiment/mission (Oudrhiri, Mimoun, Lorenz)
- Making discoveries in data, including simple engineering data (Lorenz, Sorgenfrei) Data analysis exercise.

ESA Huygens Project Team 1990-1991

University of Kent (SSP) 1991-1994

University of Arizona 1994-2006

JHU Applied Physics Lab 2006-

Engineers are dogs, Scientists are cats.

Engineers

- usually work in packs. They are loyal to the pack.
- want to make their “master” happy. Like “buy-in”.
- like well-posed questions, to which there is a single right answer (and that you know that it is the right answer when you get it)
- like clarity (black and white)
- just want the d*** number to design to

Scientists

- often work alone
- are not strongly driven by others’ happiness
- enjoy finding new questions
- are comfortable with uncertainty. Indeed they are often only happy if wide uncertainty is acknowledged
- just want some shiny data to play with

Some ruminations on scientific value – how to measure it ?

1. Coverage (= spatial coverage, temporal coverage, etc.)

This is a relatively straightforward thing to measure. But value is non-linear. E.g. mapping a planet – do you really need to see every single sand dune, every single crater? But finding rare things is important..

Value goes logarithmically ? First 1% tells you as much as the next 9%, as much as the next 80%... You start to see more and more of the same things over again, but you also can see patterns, correlations…

Some intrinsic scales exist in temporal coverage (e.g. see diurnal cycle, seasonal cycle, etc.)

Somewhat linear probabilties for stochastic rare events (e.g. earthquakes ; gamma-ray bursts) but need confidence in model to anticipate !

Some ruminations on scientific value – how to measure it ?

2. Information-theoretic *

Can measure number of bits easily. Information content per bit can be measured by Shannon entropy (qv data compression, crosswords, etc.) but most information-rich signal looks like white noise…

Other measures like minimum description length (Kolmogorov complexity ~ the length of the instruction sequence of a Turing machine that can reproduce the data). Information value might be the incremental Kolmogorov complexity ?

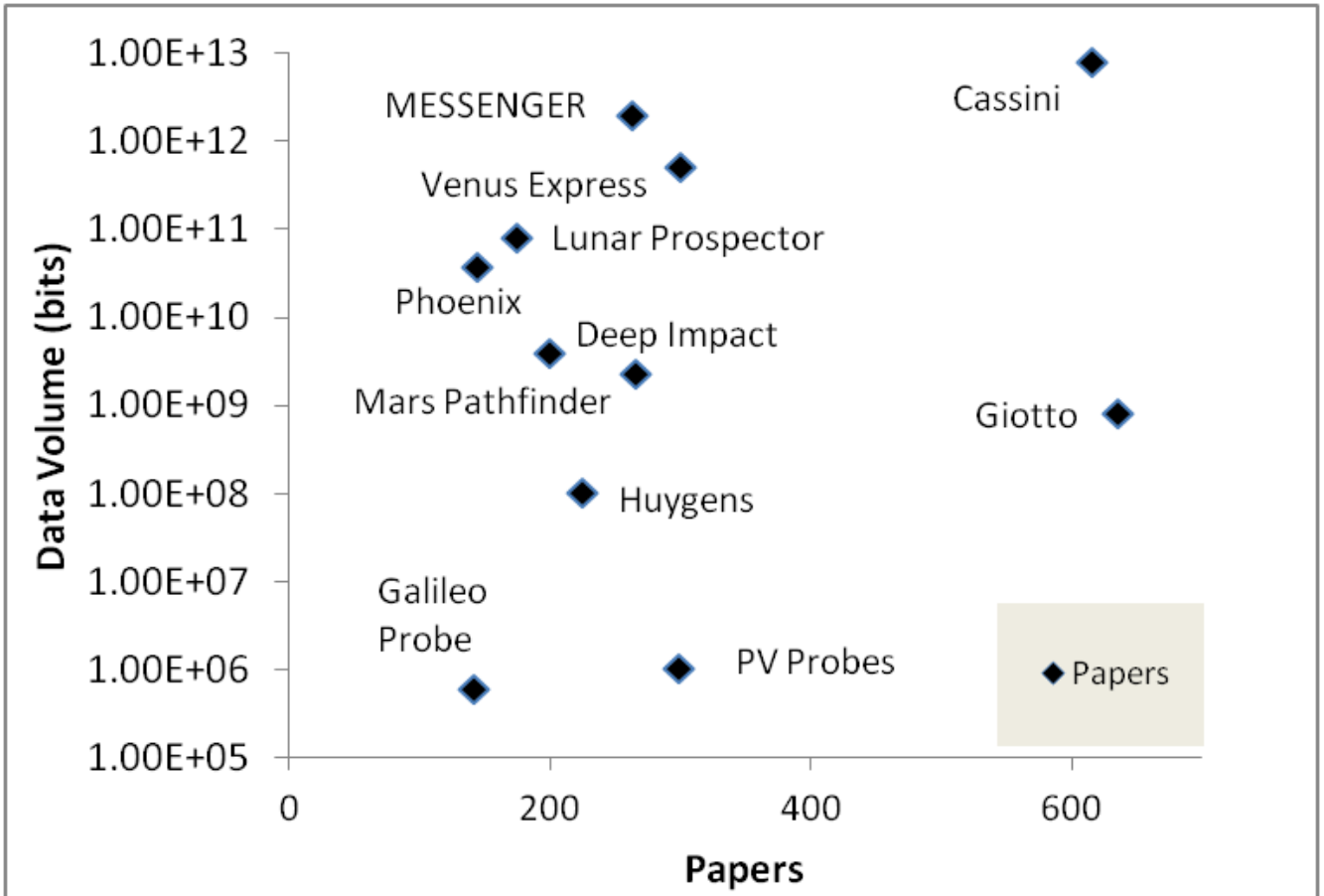
Extreme example : Gravity Probe B - $750 million experiment to measure 2 numbers (essentially answering a 1-bit question : is the prediction of general relativity correct ?

(Answer, yes. geodetic drift rate of −6,601.8±18.3 milliarcsecond/year (mas/yr) and a frame-dragging drift rate of −37.2±7.2 mas/yr, to be compared with the general relativity predictions of −6,606.1 mas/yr and −39.2 mas/yr. Am I surprised? No.)

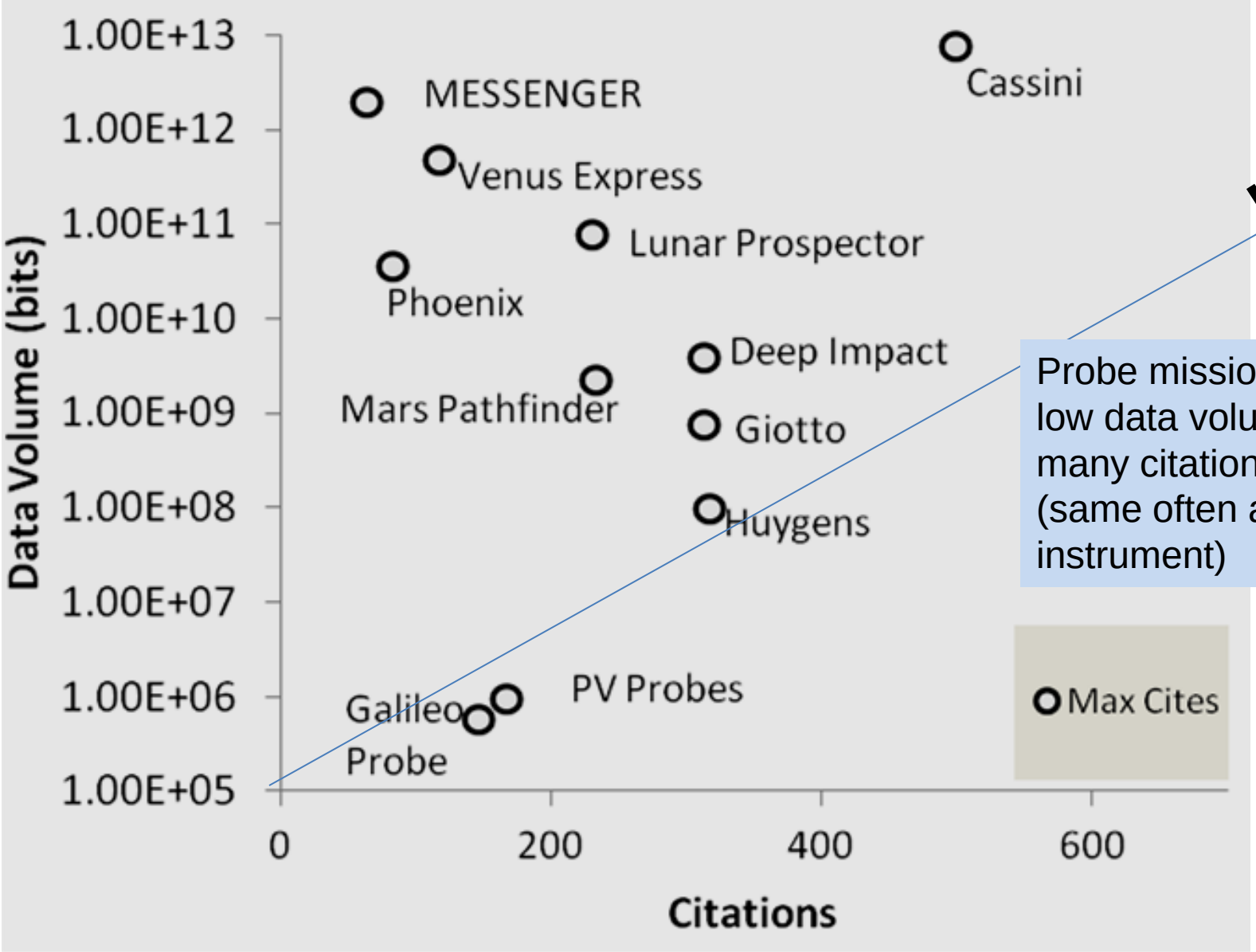
*An excellent text (free pdf) on this stuff and machine learning is “Information Theory, Inference, and Learning Algorithms” by David J.C. MacKay

Some ruminations on scientific value – how to measure it ?

3. Bibliometric – number of papers written. Number of citations. Or hybrid measures like H-index (often used in scientific recruiting)
But, only possible to measure after the fact ! Also, difficult to disentangle funding from value of data (scientists are machines for turning data and $$ into papers) and age of data (longer time to be cited, also follow-on missions)



ADS Refereed paper search by title, May 2012



Probe missions have low data volumes but many citations/bit (same often applies per instrument)

ADS Refereed paper search by title, May 2012

Evaluation of scientific importance generally developed by crude consensus. Some sort of committee making pseudoqualitative judgements on what is important – usually eventually coming down to a low-fidelity scoring. Suffers the usual problems of committees.

Relative Science Value of Enceladus Mission Candidates
Referenced to Cassini-Huygens

	Mission									
	Flagship Class Total Mission Cost (TMC)>$2B							Small Flagship Class $2B>TMC>$1B		NF Class TMC<$1 B
Science Objectives	Enceladus Orbiter + Lander	Enceladus Orbiter	Enceladus Lander	Saturn Orbiter + Enceladus SR	Saturn Orbiter; Titan/Enc Cycler	Fly-By S/C + Enc Inst Impactor	Fly-By S/C + Enc Hard Lander	Enceladus Sample Return	Saturn Orbiter w/Multiple Enc Fly-By	Single Enceladus Fly-By
Tidal Heating	3	3	2	2	1	1	2	1	2	1
Interior Structure	3	3	3	2	2	1	2	1	2	1
Bulk Composition	3	3	2	3	2	1	2	3	2	1
Tectonics	3	3	1	2	1	1	1	1	2	1
Cryovolcanism	3	3	2	3	2	3	2	2	3	2
Surface Processes	3	2	3	1	1	1	2	1	1	1
Biological Potential	2	2	2	3	2	2	2	3	2	2
Sum	20	19	15	16	11	10	13	12	14	9
Relative Science Value Value = sum/total possible * 10	**10**	**9**	**7**	**8**	**5**	**5**	**6**	**6**	**7**	**4**

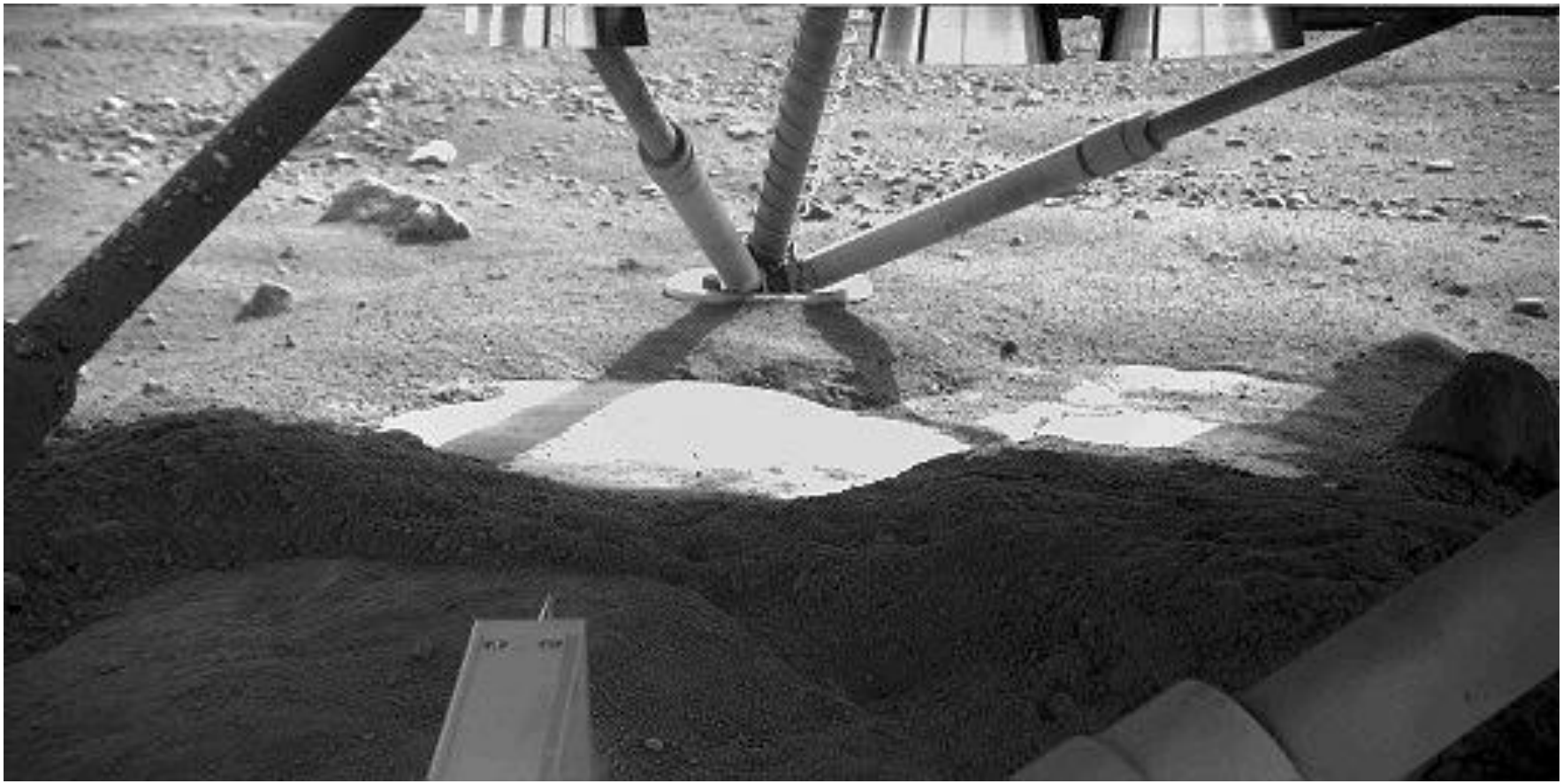
Coding	Value
X	1
XX	2
XXX	3

Maximum Total possible = 21 (7 objectives X possible highest rating of 3)

Missions Selected for Feasibility Assessment

- missions meet science criteria but fail cost by small amount
- missions that meet the cost criteria but fall well short of science

Considerable effort devoted to designing sampling arm for Phoenix to dig possibly frozen ground. Would it be able to get ice-bearing samples from beneath a dessicated layer of regolith?



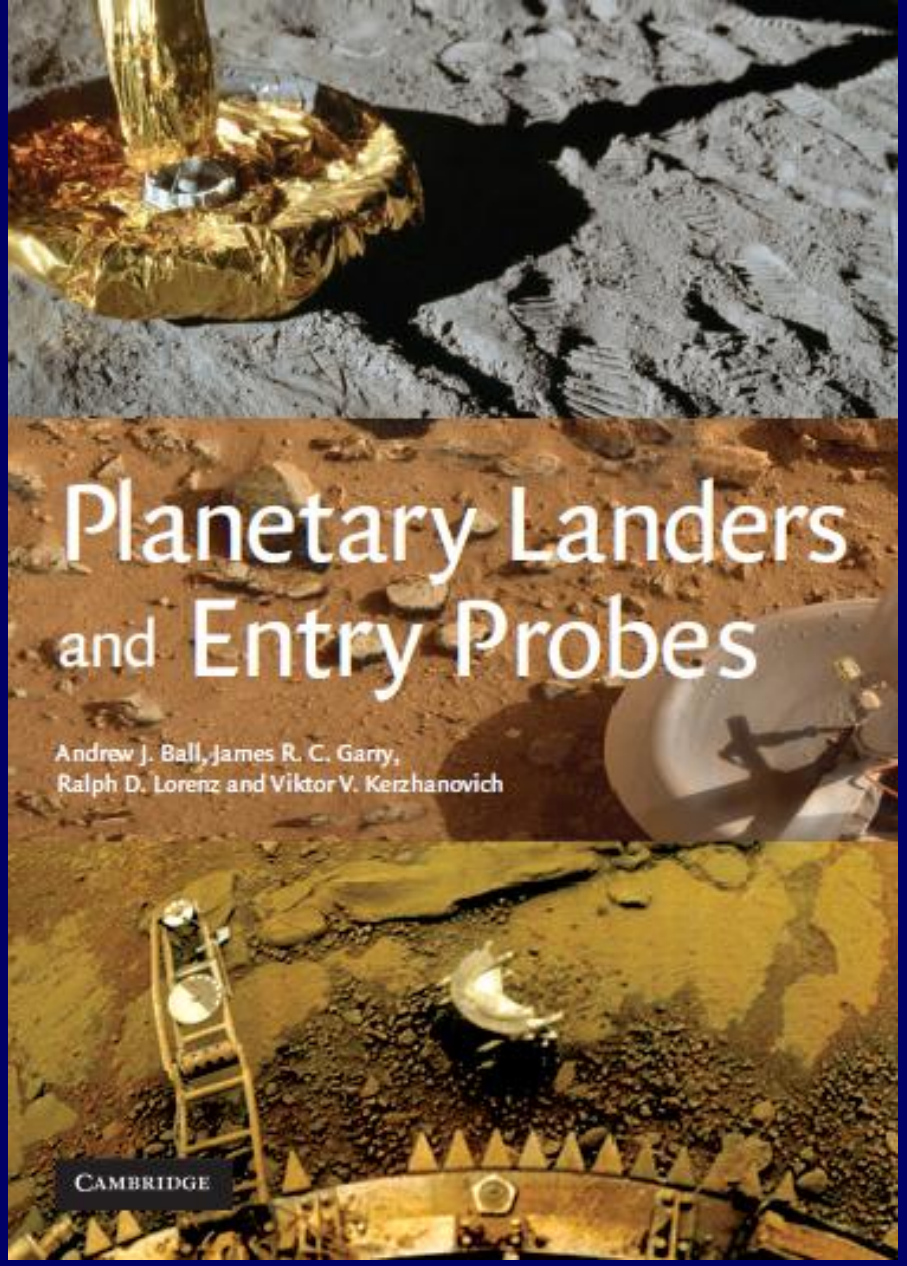
Landing thruster plume exposed buried ice !

Voyager 1 image of Io at high phase, 4.5 million km distance.

Active volcanism on a moon of Jupiter !!!!

This was in fact a long-range optical navigation image. Contrast stretch to bring out background stars showed plume (due to volcano Pele)

How to design for this !!!???


Planetary Landers
and Entry Probes
Andrew J. Ball, James R. C. Garry,
Ralph D. Lorenz and Viktor V. Kerzhanovich
CAMBRIDGE

CUP 2007

DUNE WORLDS
How Windblown Sand
Shapes Planetary Landscapes
Ralph Lorenz
James Zimbelman
Springer
PRAXIS

Springer, 2014