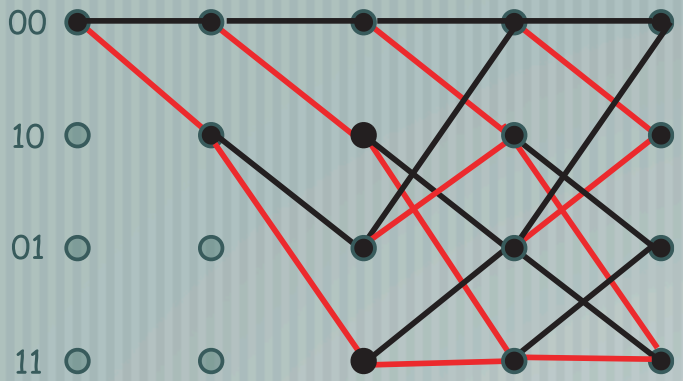
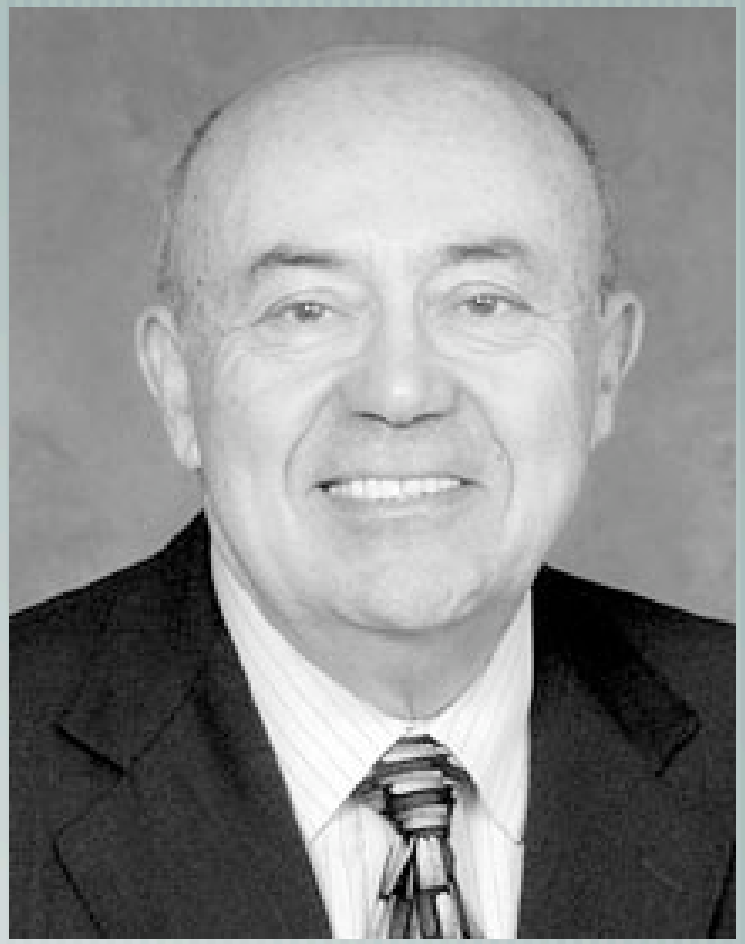
Viterbi's Impact on the Exploration of the Solar System





FOR INTERNAL USE ONLY

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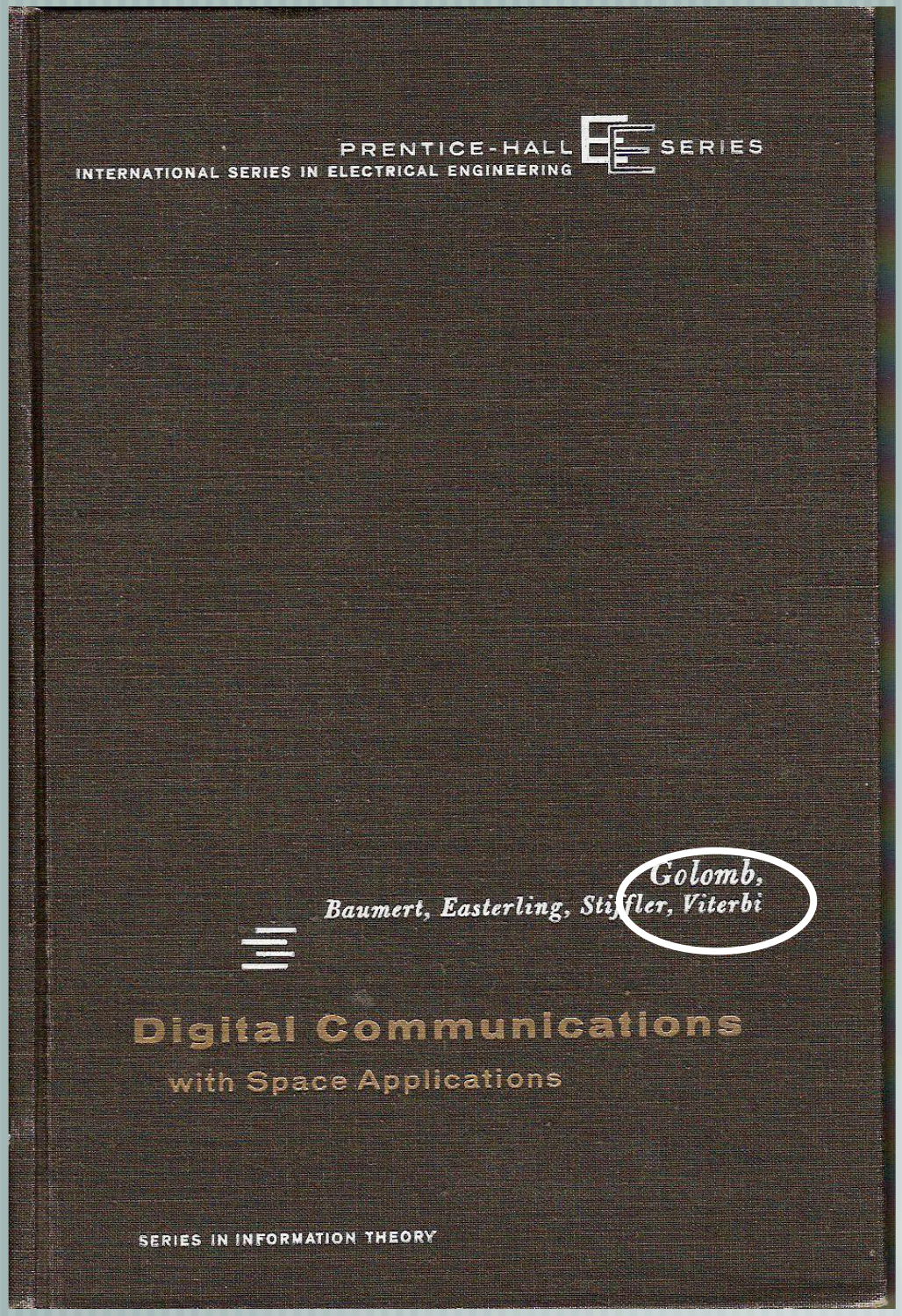
K. L. Price

1. Starting on 10-7-63
2. Starting on 10-21-63

October 25, 1963



Proof of Optimality of Orthogonal Codes

First Appearance of

$$\frac{E_b}{N_0} > \ln 2$$

Error Bounds for Convolutional Codes and an Asymptotically Optimum Decoding Algorithm

ANDREW J. VITERBI, SENIOR MEMBER, IEEE

IV. A Probabilistic Nonsequential Decoding Algorithm

We now describe a new probabilistic nonsequential decoding algorithm which, as we shall show in the next section, is asymptotically optimum for rates $R > R_0 = E_0(1)$. The algorithm decodes an L-branch tree by performing L repetitions of one basic step. We adopt the convention of denoting each branch of a given path by its data symbol a_i, an element of $GF(q)$. Also, although $GF(q)$ is isomorphic to the integers modulo q only when q is a prime, for the sake of compact notation, we shall use the integer r to denote the rth element of the field.

In *Step 1* the decoder considers all q^K paths for the first K branches (where K is the branch constraint length of the code) and computes all q^K likelihood functions $\prod_{i=1}^{K} p(\mathbf{y}_i \mid a_i)$. The decoder then compares the likelihood function for the q paths:

$$(0, a_2, a_3, \cdots a_K),$$

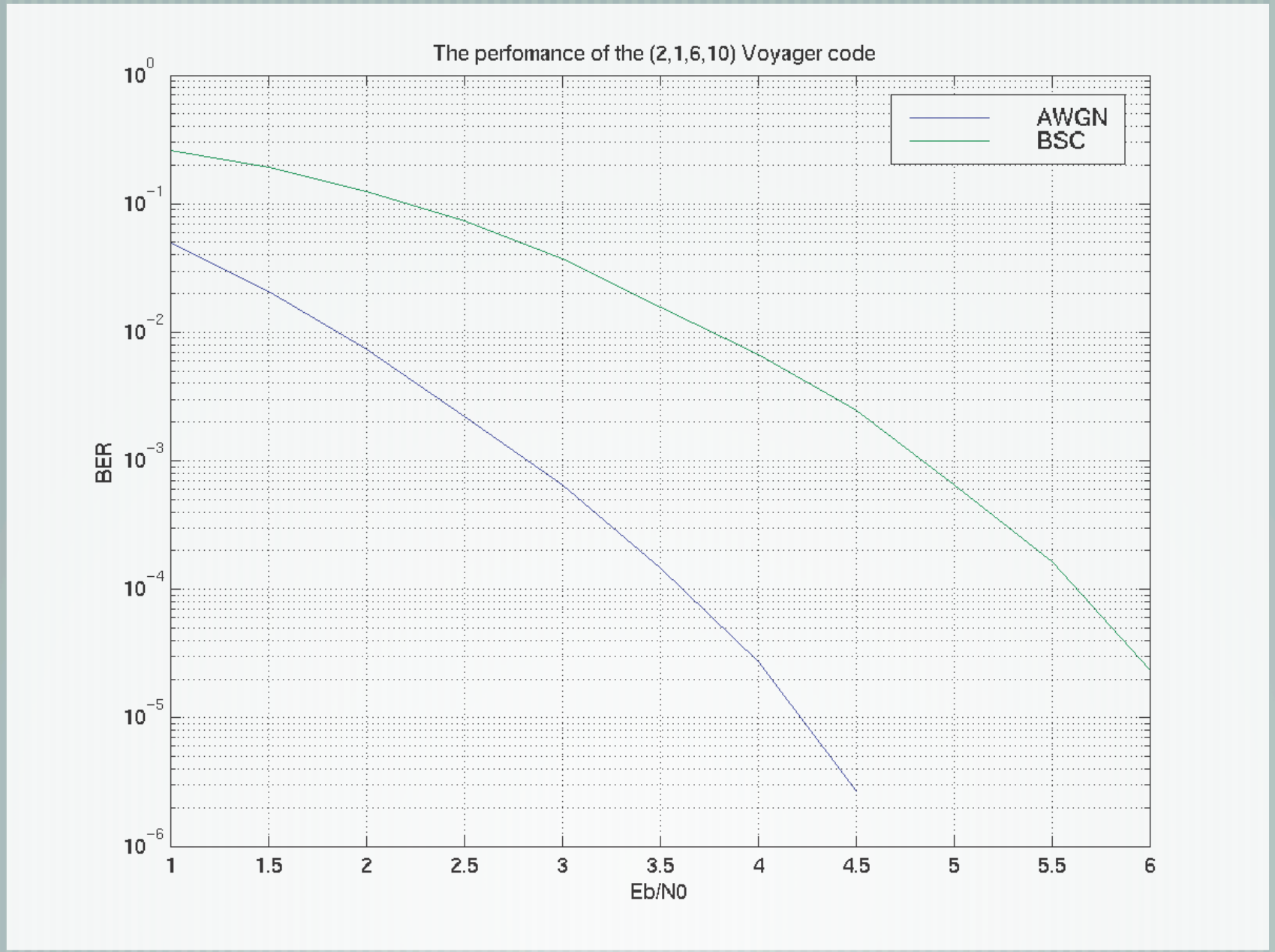
$$(1, a_2, a_3, \cdots a_K),$$

$$\cdots\cdots\cdots\cdots\cdots$$

$$(q-1, a_2, a_3, \cdots a_K)$$

for each of the q^{K-1} possible vectors $(a_2, a_3 \cdots a_K)$. It thus performs q^{K-1} comparisons each among q path likelihood functions. Let the path corresponding to the greatest likelihood function in each comparison be denoted the *survivor*. Only the q^{K-1} survivors of as many comparisons are preserved for further consideration; the remaining paths are discarded. Among the q^{K-1} survivors

EE/Ma 127b, Class Project 2



Jet Propulsion Laboratory
Interplanetary Error-Control Codes

- No Coding (Pre 1969)
-  (32,6) Biorthogonal Block Code (1969 - 1975)
-  K =7, R = 1/2 Conv. Code + Viterbi Decoding (1977 – 1986)
  - Plus Reed-Solomon if Data Compression is Used
-  K= 15, R = 1/6 CC/VD + RS (1986 – 2004)
- Turbo Codes (2004 – ?)
- LDPC Codes (2006 – ?)

No Coding: The Early Mariners

- Mariner 2, 1962
  - Venus Flyby
- Mariner 4, 1965
  - Mars Flyby
  - First close-up photographs of another planet.
- Mariner 5, 1967
  - Venus Flyby

(32,6) Biorthogonal Code + "Green Machine" Decoding

- Mariners 6, 7 (1969)
  - Mars Flyby
- Mariner 9 (1971)
  - Mars Orbit

+	+	+	+	+	+	+	+
+	−	+	−	+	−	+	−
+	+	−	−	+	+	−	−
+	−	−	+	+	−	−	+
+	+	+	+	−	−	−	−
+	−	+	−	−	+	−	+
+	+	−	−	−	−	+	+
+	−	−	+	−	+	+	−
−	−	−	−	−	−	−	−
−	+	−	+	−	+	−	+
−	−	+	+	−	−	+	+
−	+	+	−	−	+	+	−
−	−	−	−	+	+	+	+
−	+	−	+	+	−	+	−
−	−	+	+	+	+	−	−
−	+	+	−	+	−	−	+

The (8,4) biorthogonal code

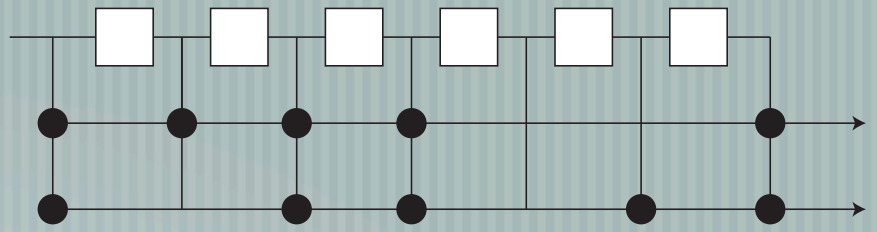
(32,6) Biorthogonal Code/ "Green Machine" Decoding

- Mariner 10, 1973-1974
  - Mercury and Venus
- Viking Mars Landers, 1976
  - Mars' Surface

+	+	+	+	+	+	+	+
+	−	+	−	+	−	+	−
+	+	−	−	+	+	−	−
+	−	−	+	+	−	−	+
+	+	+	+	−	−	−	−
+	−	+	−	−	+	−	+
+	+	−	−	−	−	+	+
+	−	−	+	−	+	+	−
−	−	−	−	−	−	−	−
−	+	−	+	−	+	−	+
−	−	+	+	−	−	+	+
−	+	+	−	−	+	+	−
−	−	−	−	+	+	+	+
−	+	−	+	+	−	+	−
−	−	+	+	+	+	−	−
−	+	+	−	+	−	−	+

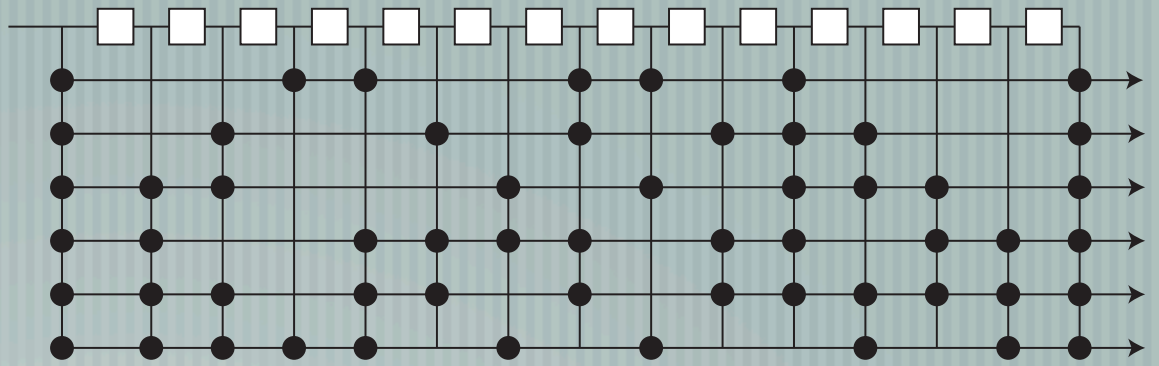
The (8,4) biorthogonal code

K= 7, R = 1/2 Convolutional Code with Viterbi Decoding



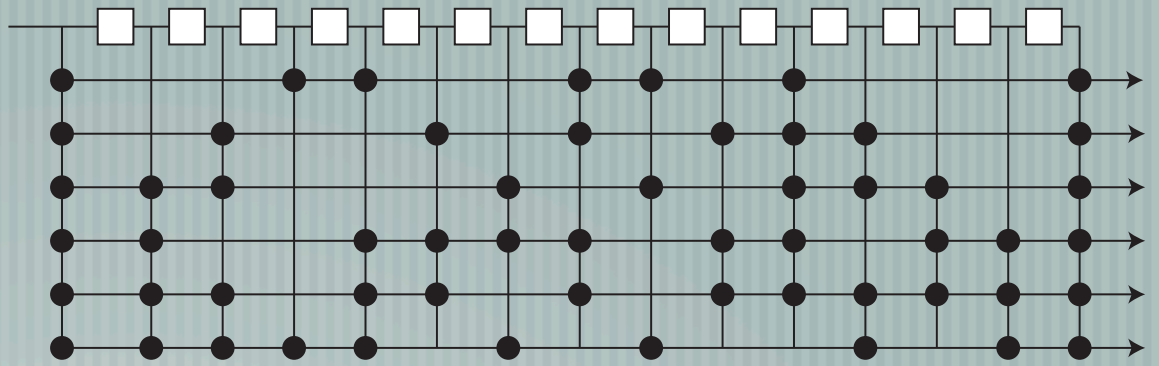
- Voyagers 1&2 (1977–)
  - "Grand Tour"
- Magellan Venus Radar Mapper (1989-1993)
- Mars Global Surveyor (1997-)

K = 15 Convolutional Codes with Big  Decoding



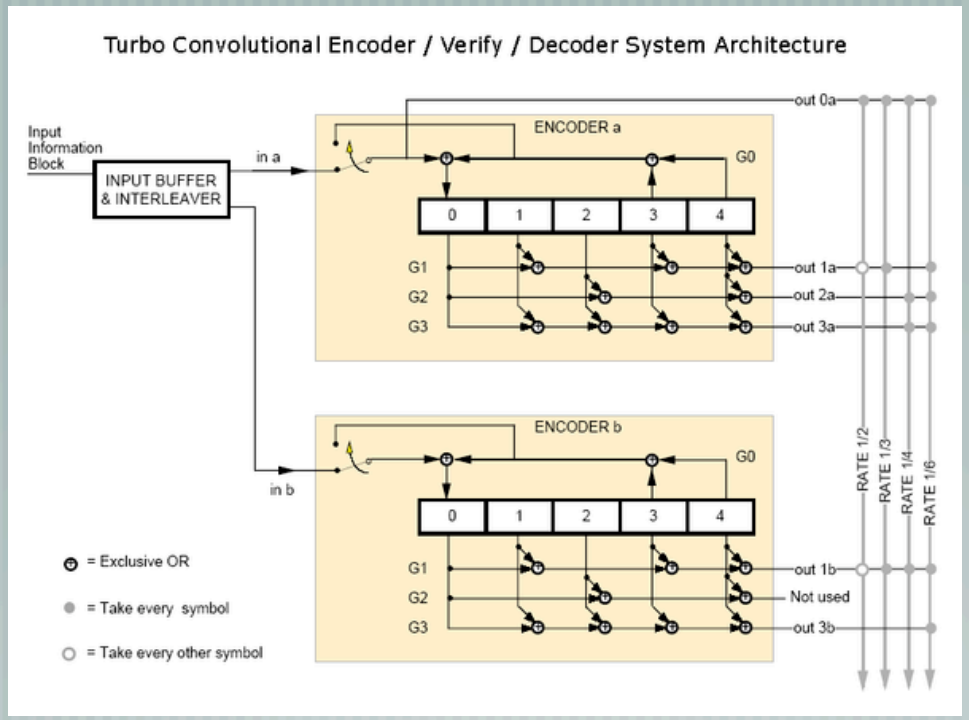
- Galileo (1989 – 2003)
  - A Sea of Troubles
- Mars Pathfinder (1996- 1997)
  - Sojourner

K = 15 Convolutional Codes with Big  Decoding



- Cassini (1997 —)
  - Huygens Titan Probe, 2005
- Mars Exploration Rover (2003–2004)
  - Spirit and Opportunity

A Brave New World :Turbo Codes

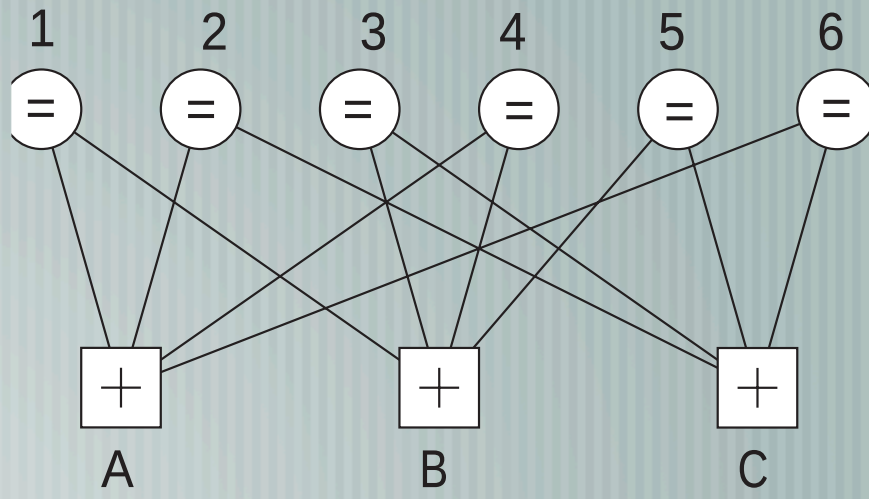


- Messenger to Mercury (APL Mission: 2004–2011)
- Mars Reconnaissace Orbiter (Aug 2005 Launch)
  - Both use (8920, 1/6) CCSDS turbo code

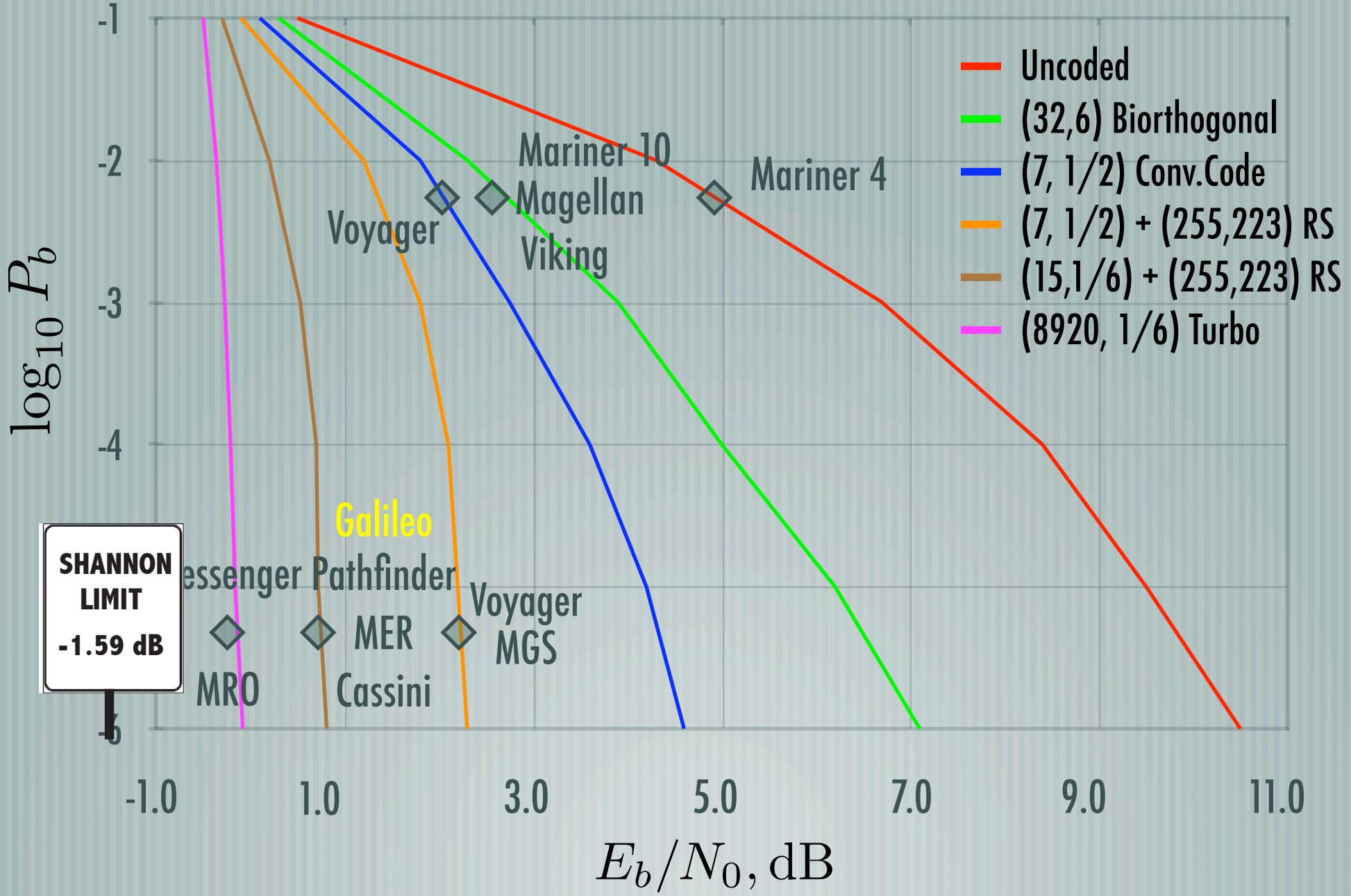
Back to the Future: LDPC Codes

- Mars Telecomm Orbiter 2010
- And Beyond ?

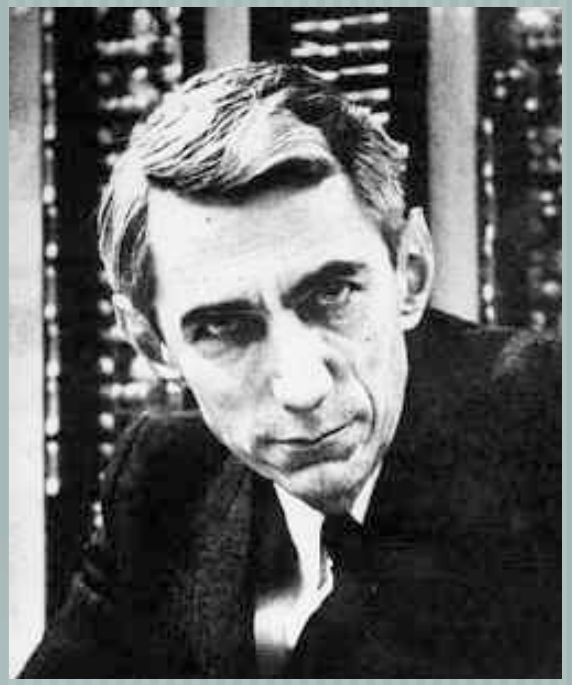
$$\begin{array}{c} \\ A \\ B \\ C \end{array} \begin{array}{c} \begin{array}{cccccc} 1 & 2 & 3 & 4 & 5 & 6 \end{array} \\ \begin{pmatrix} 1 & 1 & 0 & 1 & 0 & 1 \\ 1 & 0 & 1 & 1 & 1 & 0 \\ 0 & 1 & 1 & 0 & 1 & 1 \end{pmatrix} \end{array}.$$



SUMMARY


-1
-2
-3
-4
-5
$\log_{10} P_b$
-1.0
1.0
3.0
5.0
7.0
9.0
11.0
E_b/N_0, dB
Uncoded
(32,6) Biorthogonal
(7, 1/2) Conv.Code
(7, 1/2) + (255,223) RS
(15,1/6) + (255,223) RS
(8920, 1/6) Turbo
Mariner 10
Magellan
Viking
Mariner 4
Voyager
Galileo
Messenger
Pathfinder
MER
Voyager
MGS
MRO
Cassini
SHANNON LIMIT
-1.59 dB

Claude Shannon:



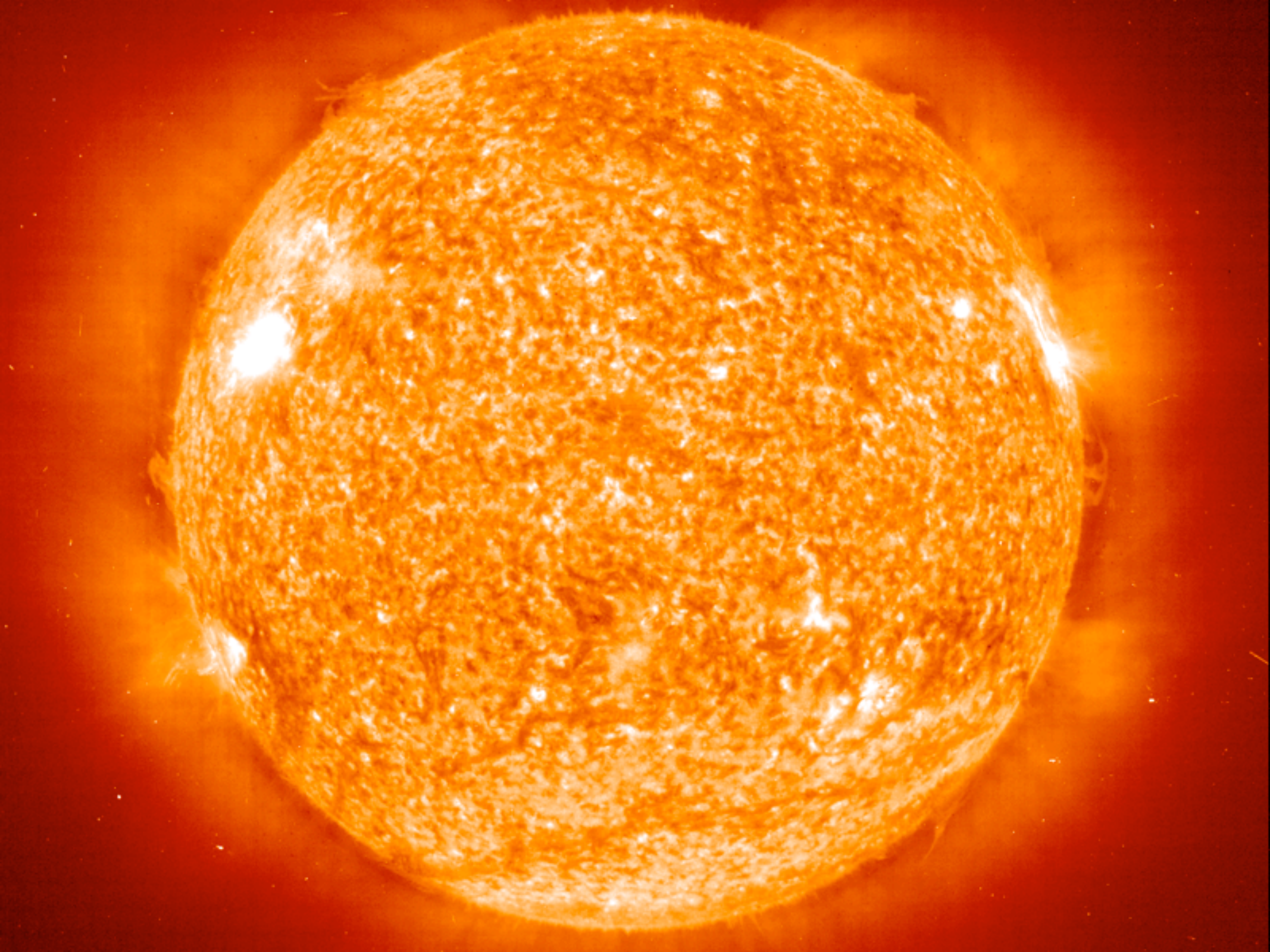
"The fundamental problem of communication is that of reproducing at one point either exactly or approximately a message selected at another point."

"Frequently the messages have *meaning*"

A Tour of the Solar System

On the Occasion of Andrew Viterbi's 70th Birthday.

Ludwig van Beethoven, Moonlight Sonata
Daniel Barenboim, pianist



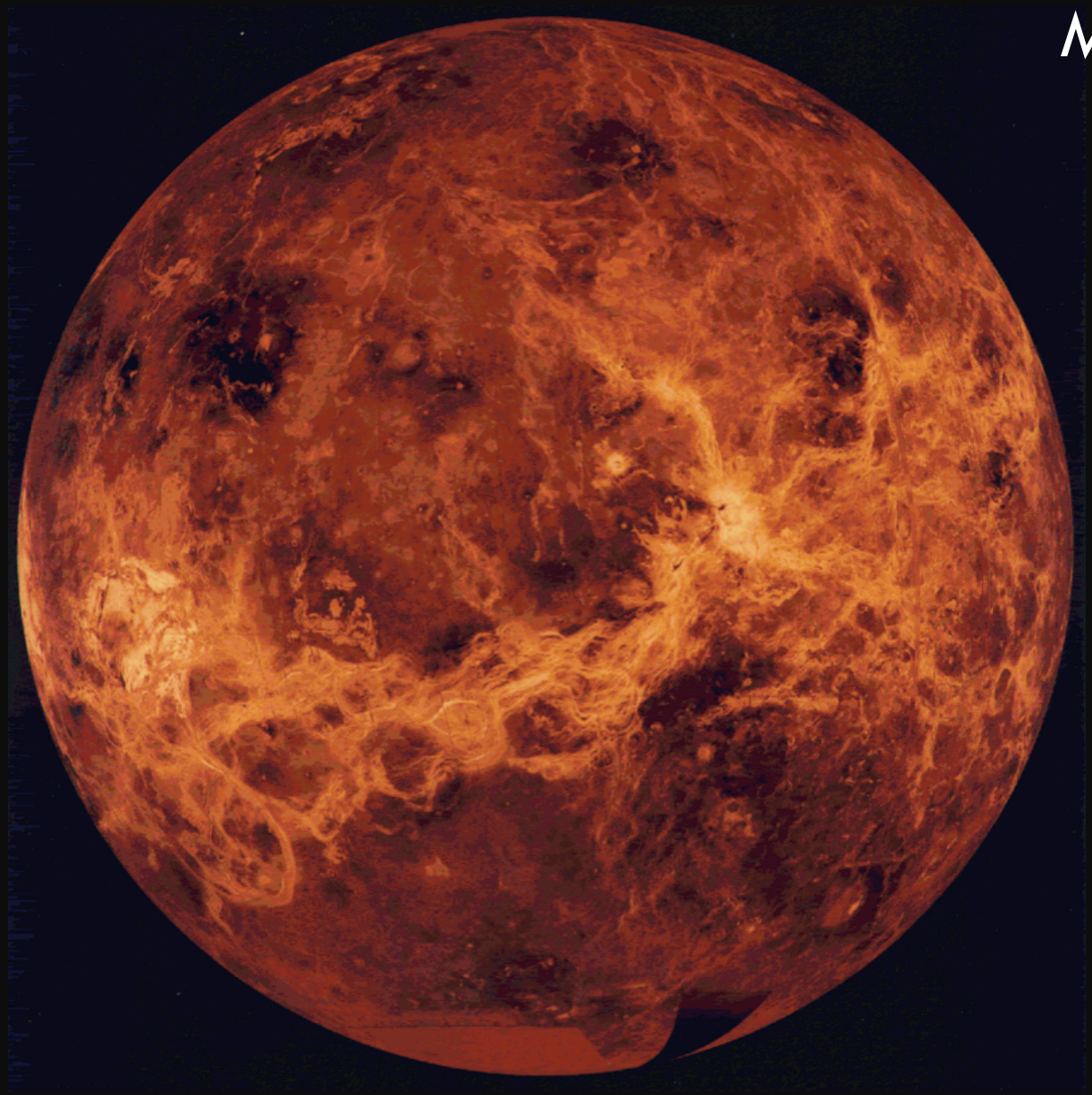
Mercury

Mariner 10

1974

Venus

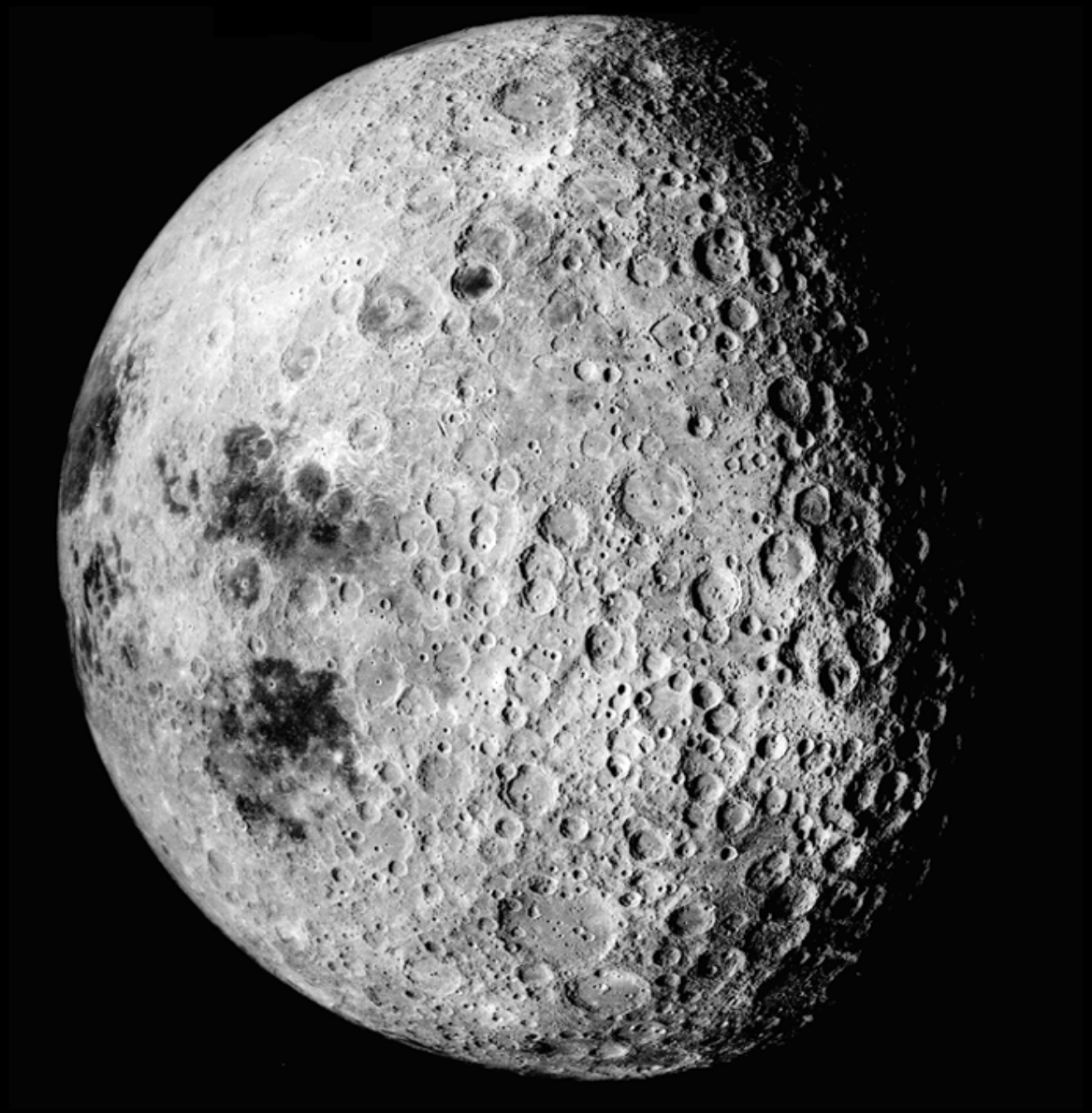
Magellan
1990



The Far Side of the Moon

Apollo 16

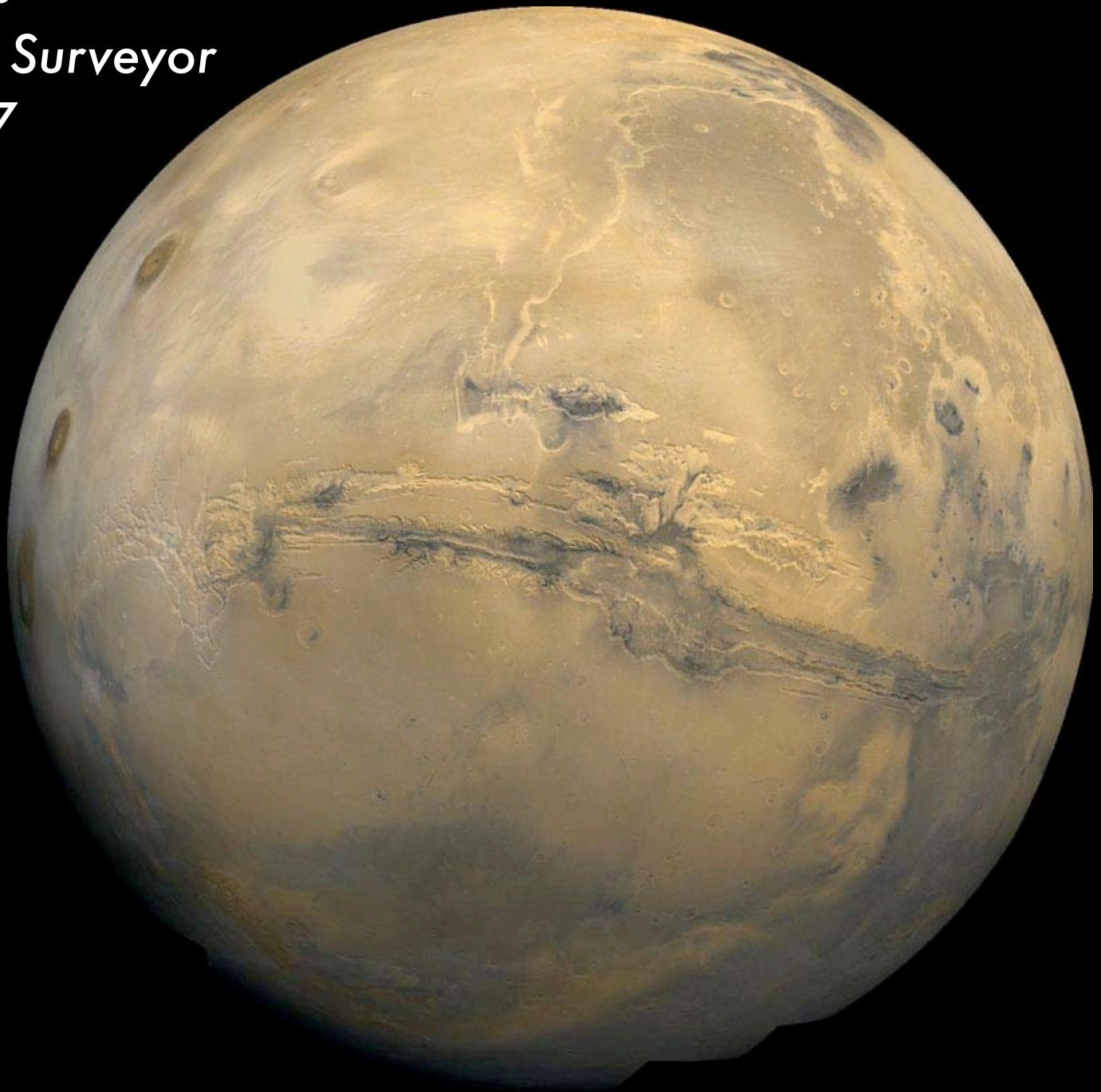
1972



Mars

Mars Global Surveyor

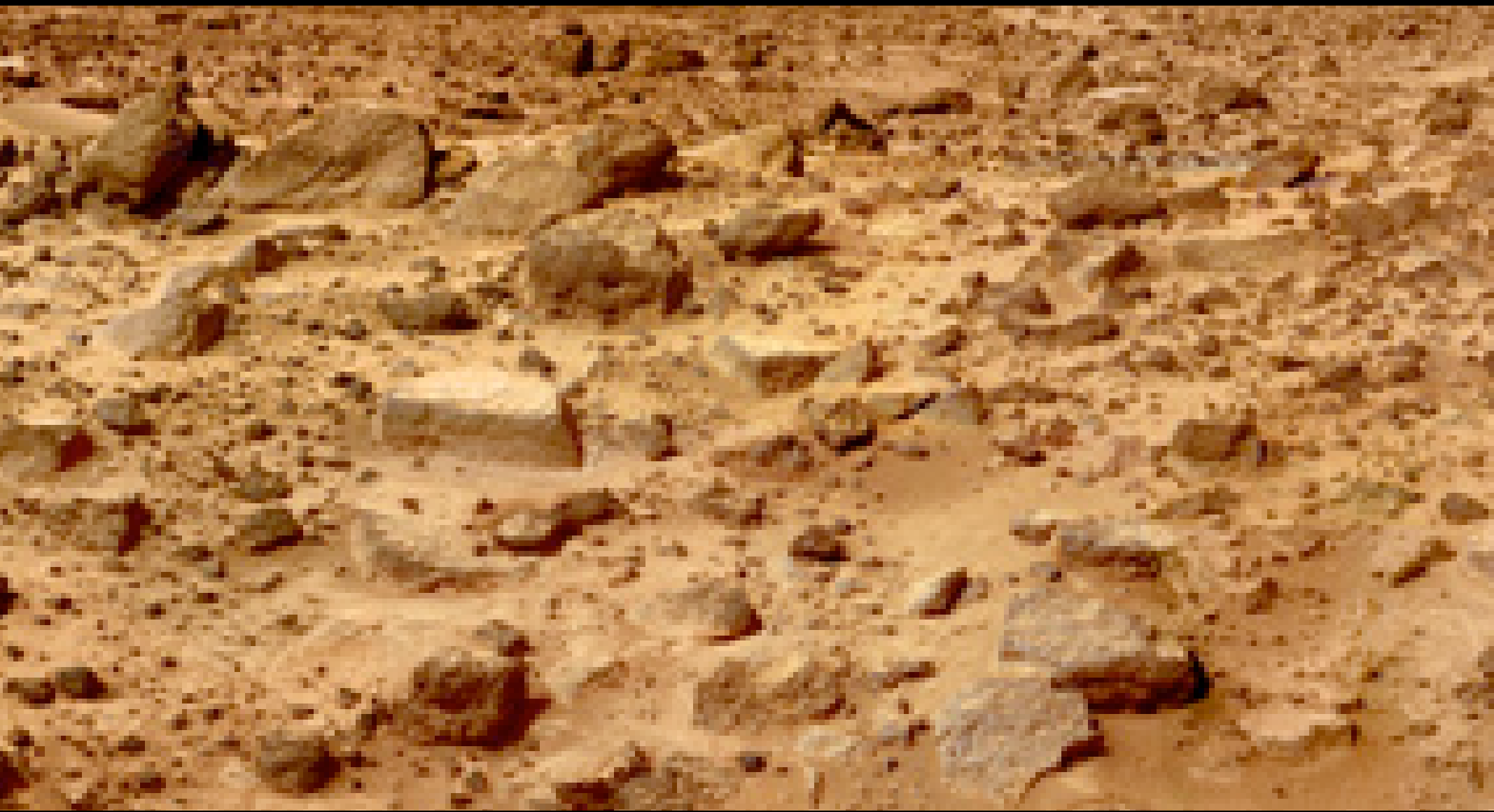
1997



The Surface of Mars

Mars Pathfinder

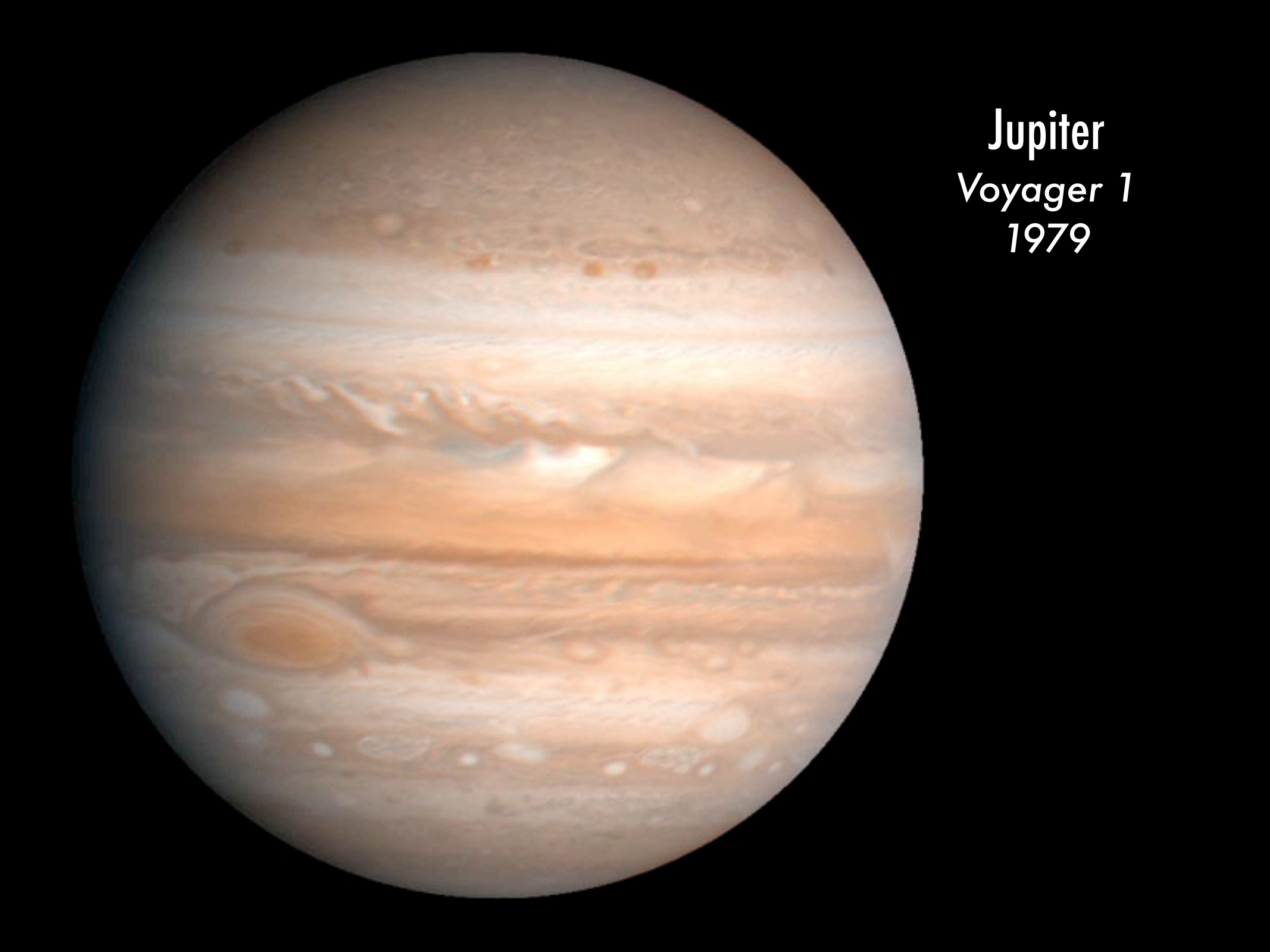
1998



The Asteroid Gaspra

Galileo

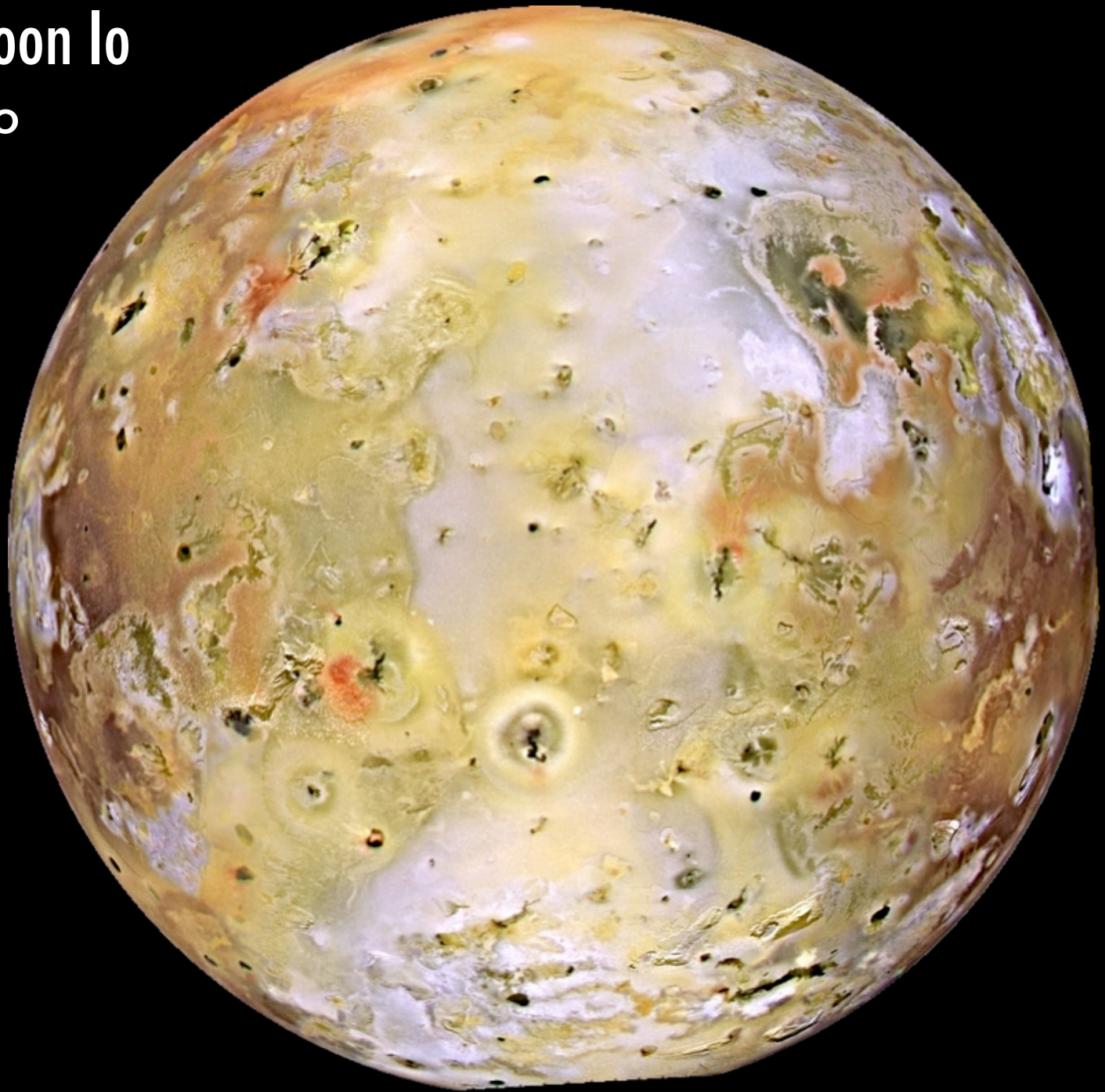
1991


Jupiter
Voyager 1
1979

Jupiter's moon Io

Galileo

1996



Io above Jupiter

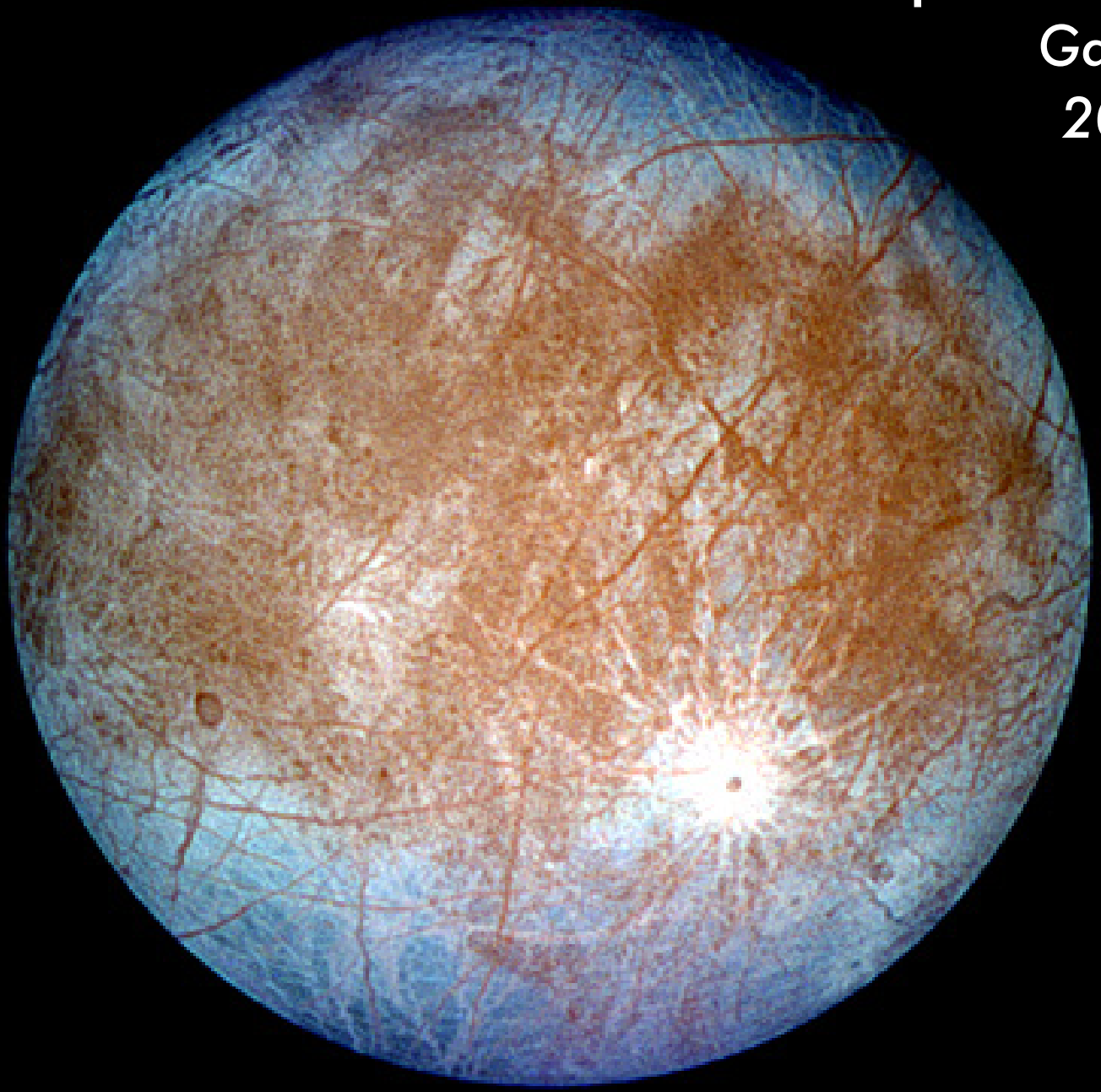
Cassini

2004

Jupiter's moon Europa

Galileo

2000



Jupiter's moon Callisto

Galileo

2001

Saturn

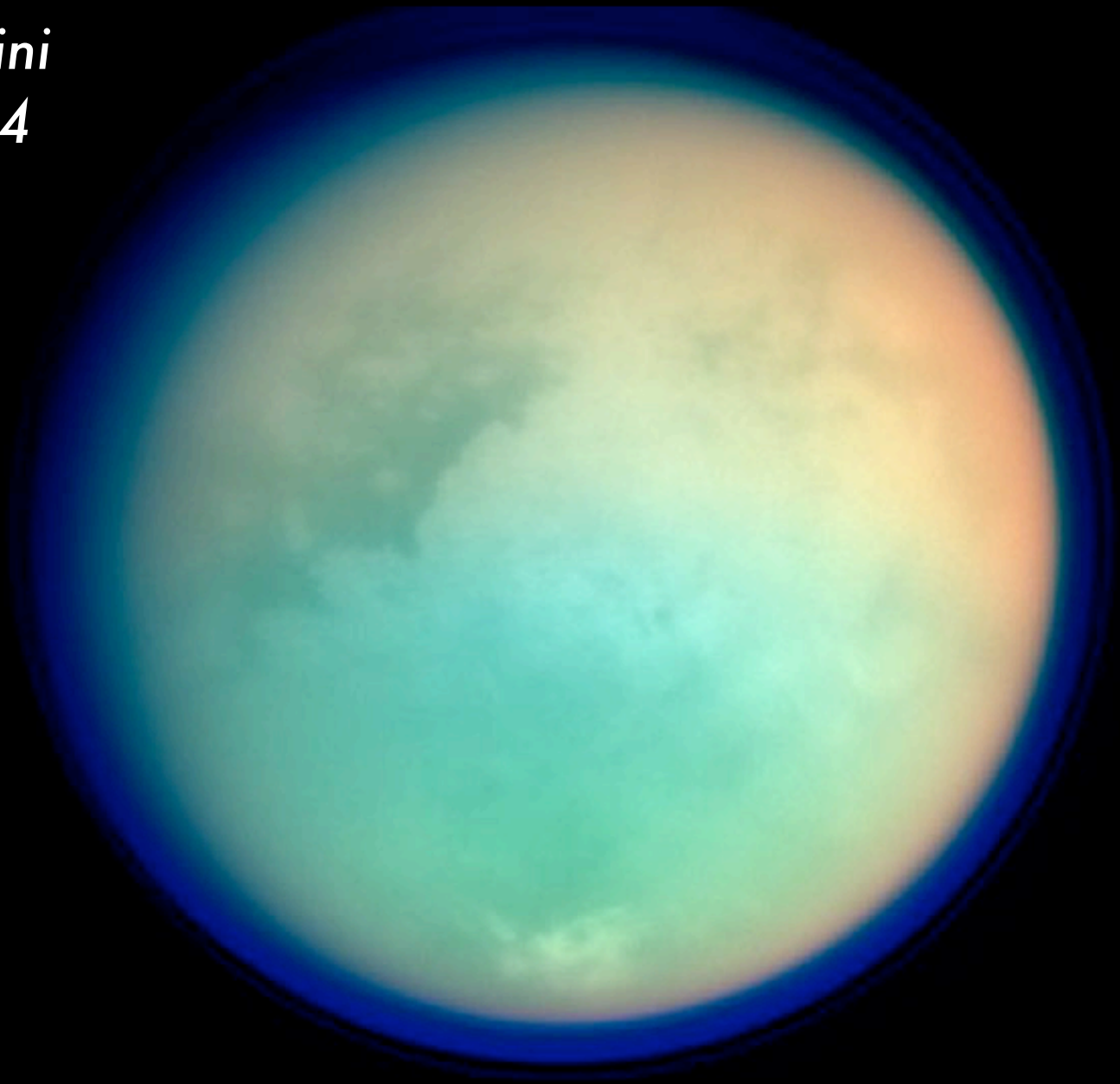
Cassini

2004

Saturn's moon Titan

Cassini

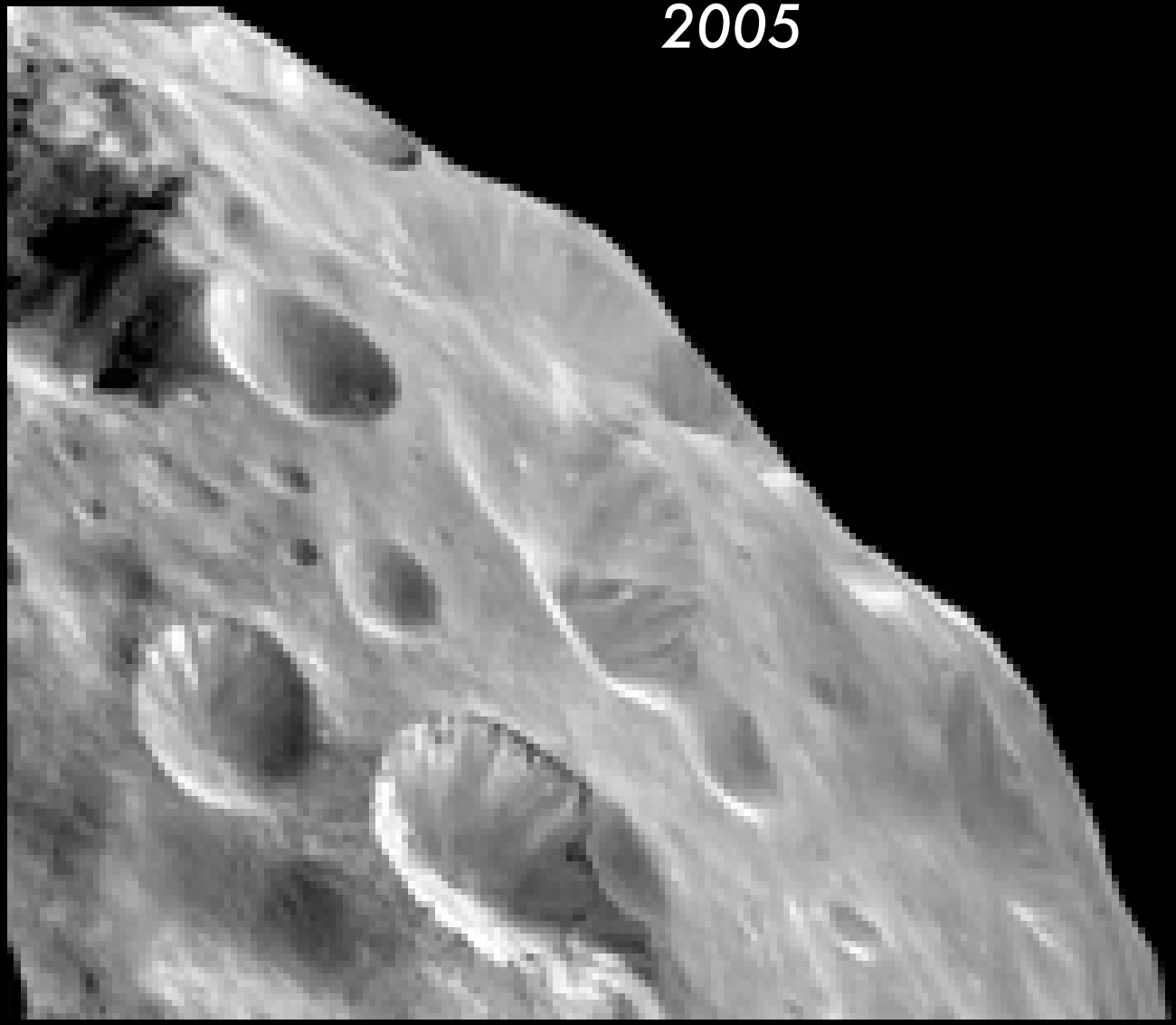
2004



Saturn's moon Phoebe

Cassini

2005



Uranus

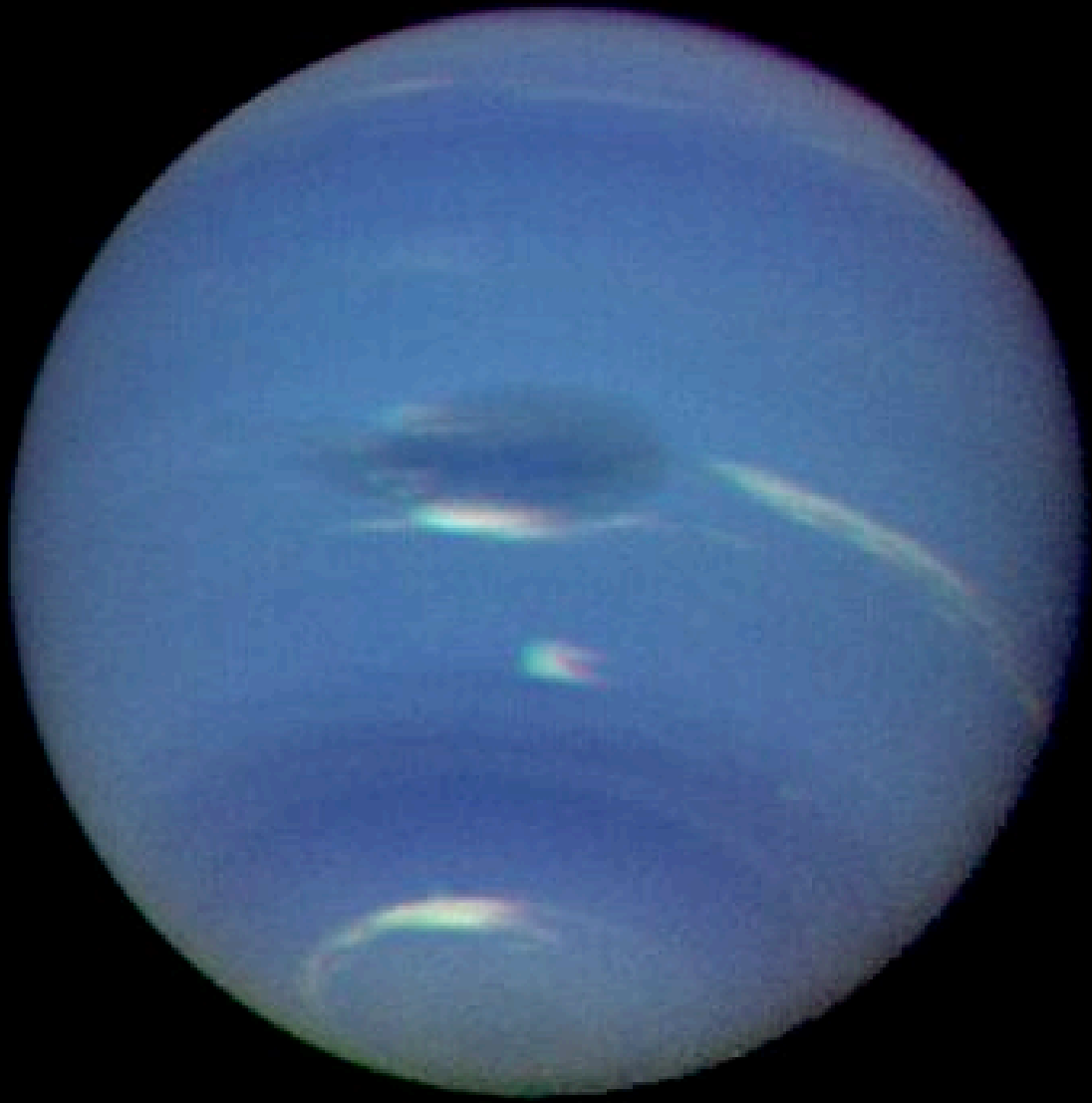
Voyager 2

1986

Neptune

Voyager 2

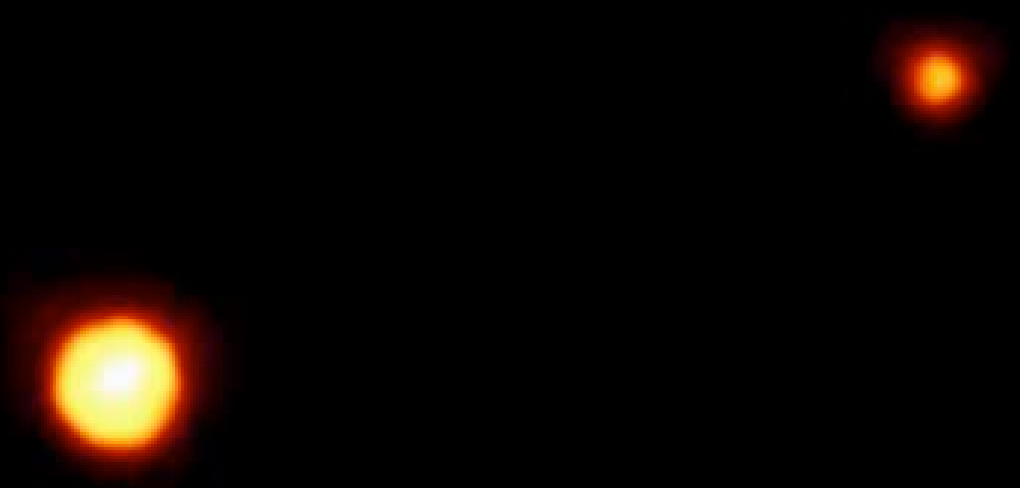
1989



Pluto and its moon Charon

Hubble Space Telescope

1994



Earthrise
Apollo 8
1968

We shall not cease from exploration
And the end of all our exploring
Will be to arrive where we started
And know the place for the first time.

-T. S. Eliot

Happy Birthday Andy!