ESPTR
(English)
Signal Processing in Telecommunications and Radar

Channel properties

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Communications channel

Channel $\longrightarrow$ (usually) everything between modulator and demodulator:

- (mainly) the transmission medium (space between antennas, or the connecting cable)
- (plus:) antennas, amplifiers, cables, waveguides, couplers, optics....

Channel properties:

- Channel bandwidth
- Channel noise
- Channel capacity
- Bandpass channel & equivalent baseband channel

Channel model: noise

Model: linear system + added noise; AWGN model

- Thermal noise (mainly receiver) with white PSD

$$\bar{u}_n^2 = 4k_B T R \ \left[\mathrm{V}^2/\mathrm{Hz}\right]$$

e.g. for room temp. and 10 kHz channel

$$P = k_B T \Delta f = 1.38 \cdot 10^{-23} \ \mathrm{J/K} \cdot 300 \ \mathrm{K} \cdot 10^4 \mathrm{Hz} = 4.1 \cdot 10^{-17} \mathrm{W} = -134 \mathrm{dBm}$$

rule: $P = -174 + 10 \ \log(\Delta f) [\mathrm{dBm}]$

- Interfering signals (know nothing, assume white (??) $\longrightarrow$ not always true!)
  - Outer space
  - Atmospheric (“static”)
  - Man-made (EMC problems $\longrightarrow$ computer, broken shaver motor...) impulse noise
  - Other transmissions (unintentional and ECM)

(radar only) clutter

Channel model: linear

Transmission properties

- Physical parts characteristics
- Propagation characteristics, including propagation losses $P \sim \frac{1}{4\pi R^2}$ (one way)
- Multipath propagation $\longrightarrow$ self-interference

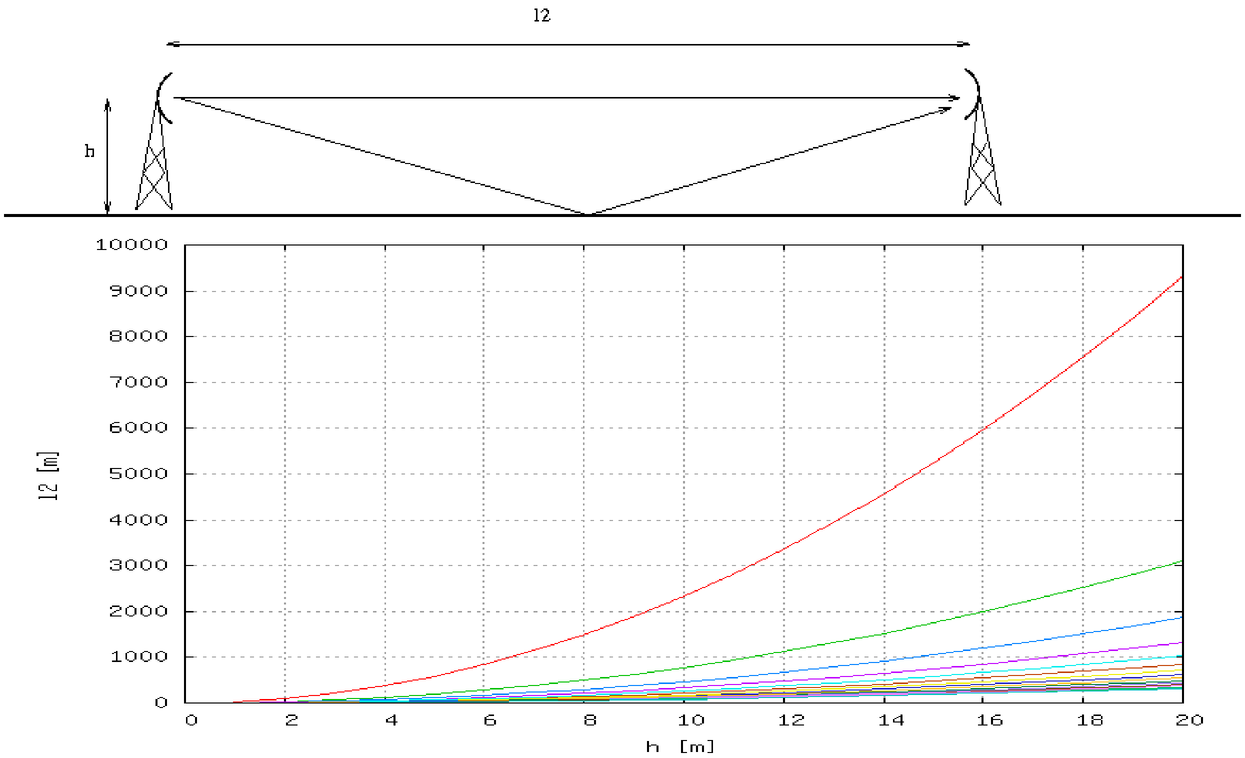
Description:

- Time domain: impulse response
- Frequency domain: transfer function (phase is important!)

Non-linear:

- Doppler effect
- Impulse noise saturating the receiver

Multipath



(l2=distance vs. h=tower height), 7GHz, curves for [1 3 5 .. 15]*lambda/2, flat earth geometry

Effects in baseband

- Echo (ghosts on TV)
- Nonuniform frequency characteristics
- Fading in subchannels
- Fading at some locations (e.g. when you drive and listen to FM)
- Fading in some regions with radar (a plane undetected at some range/height combinations)

Echo interpretation in telecommunications:

- inter-symbol interference (ISI): energy from a symbol leaks to the next one

Fought with:

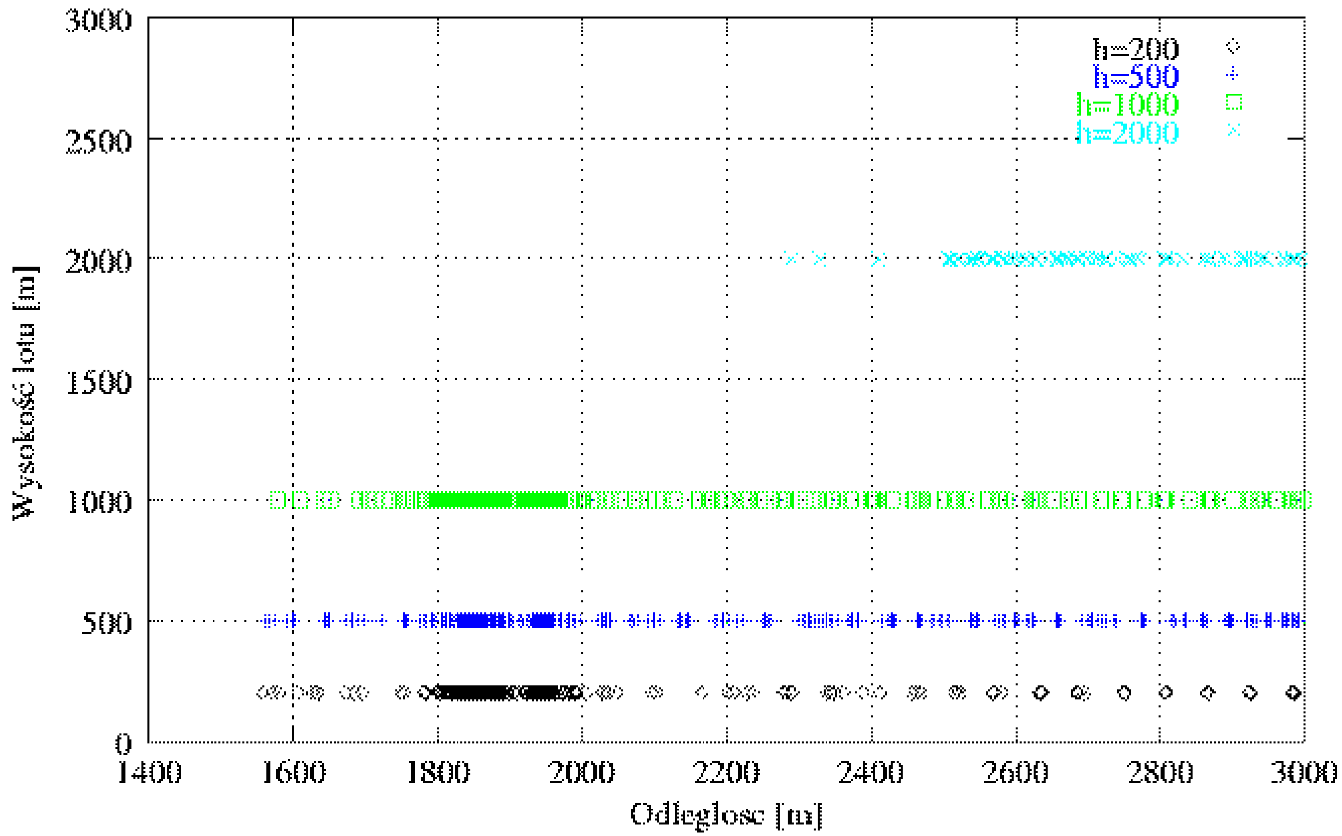
- guard interval $\longrightarrow$ waste of time!
- equalization of channel (note: workload, stability, dynamics...)
- advanced detectors (ML sequence detector)

Frequency dependence of multipath

See the blackboard example:

- different λ, different interference
- the same expressed as frequency characteristics of channel

Radar fading



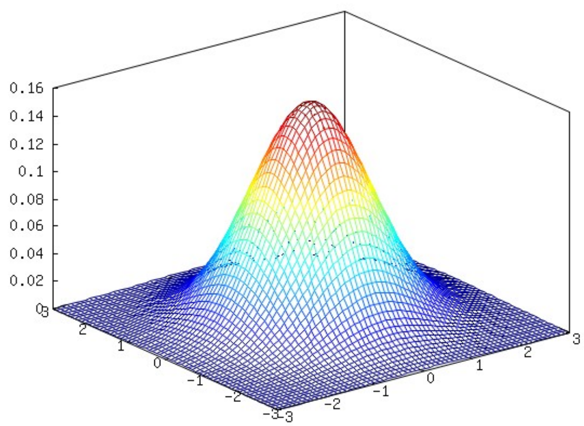
Plot points = detections. Note lighter and darker regions.

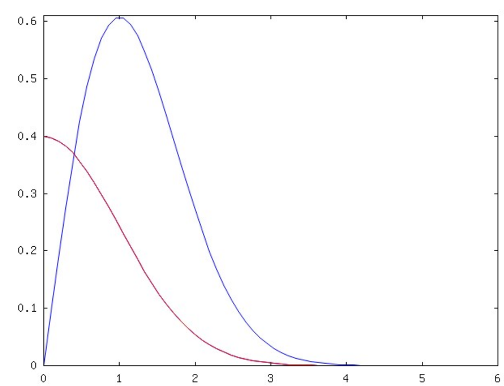
Rayleigh fading

Many paths to a moving receiver (or from a moving transmitter) $\longrightarrow$ destructive and constructive interference.

Model: multitude of paths, with random amplitude and phase (uniform @ 360deg) $\longrightarrow$ summing to complex gaussian distribution.

Effect: Rayleigh distribution of received amplitude
When moving: Rayleigh distributed changes in amplitude.





Channel capacity

With AWGN

$$C = B\log_2\left(1+\frac{S}{N}\right)$$

(otherwise: integrate over whole B, with S/N as a function of f, df)

Doppler effect

Transmitted signal: a band-limited envelope $x_T(t)$ · carrier of frequency F_c

$$X_T(t) = x_T(t) \cdot cos(2\pi j F_c t)$$

The received signal at $r_0 + vt$ distance is delayed by $t_d = \frac{r}{c} = \frac{r_0+vt}{c}$.

factor	Received carrier	Received envelope
(r_0)	phase change	delay
(v)	Doppler shift	stretch (dilation)

$$X_R(t) = A_0 \cdot X_T(t - t_d) = A_0 \cdot x_T(t - t_d) \cdot cos(2\pi j F_c(t - t_d)) + \xi(t)$$

After the demodulation (baseband received signal):

$$x_R(t) = A_0 \cdot x_T(t - t_d) \cdot e^{-2\pi j F_c t_d}$$

or, putting $t_d = \frac{r_0+vt}{c}$

$$A_0 \cdot x_T\left((1 - \frac{v}{c})t - \frac{r_0}{c}\right) \cdot e^{-2\pi j F_c \frac{r_0}{c}} \cdot e^{-2\pi j F_c \frac{vt}{c}}$$

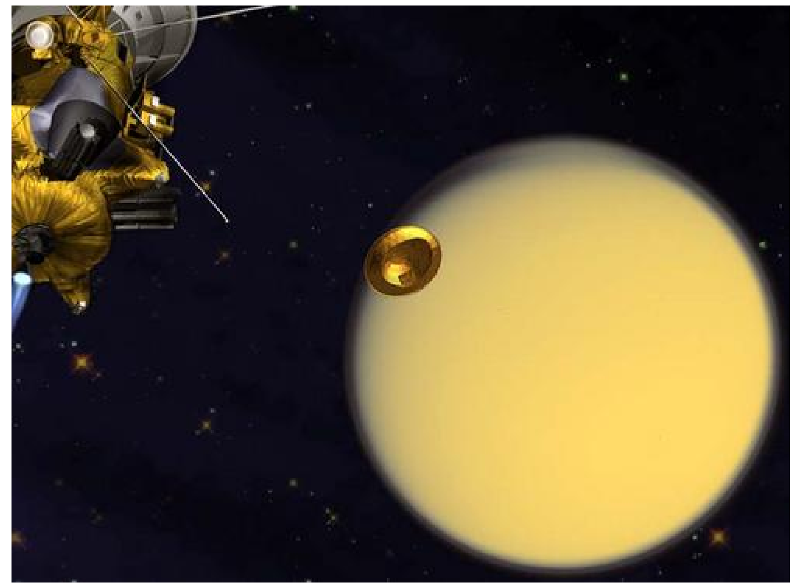
Doppler frequency $\longrightarrow F_c \frac{v}{c}$; stretch factor $\longrightarrow 1 - \frac{v}{c}$

Titan calling (Doppler)

(whole story ⟶ IEEE Spectrum, October 2004 `http://www.spectrum.ieee.org/oct04/4339/7`)

Huyghens-Cassini mission to Titan (moon of Saturn).

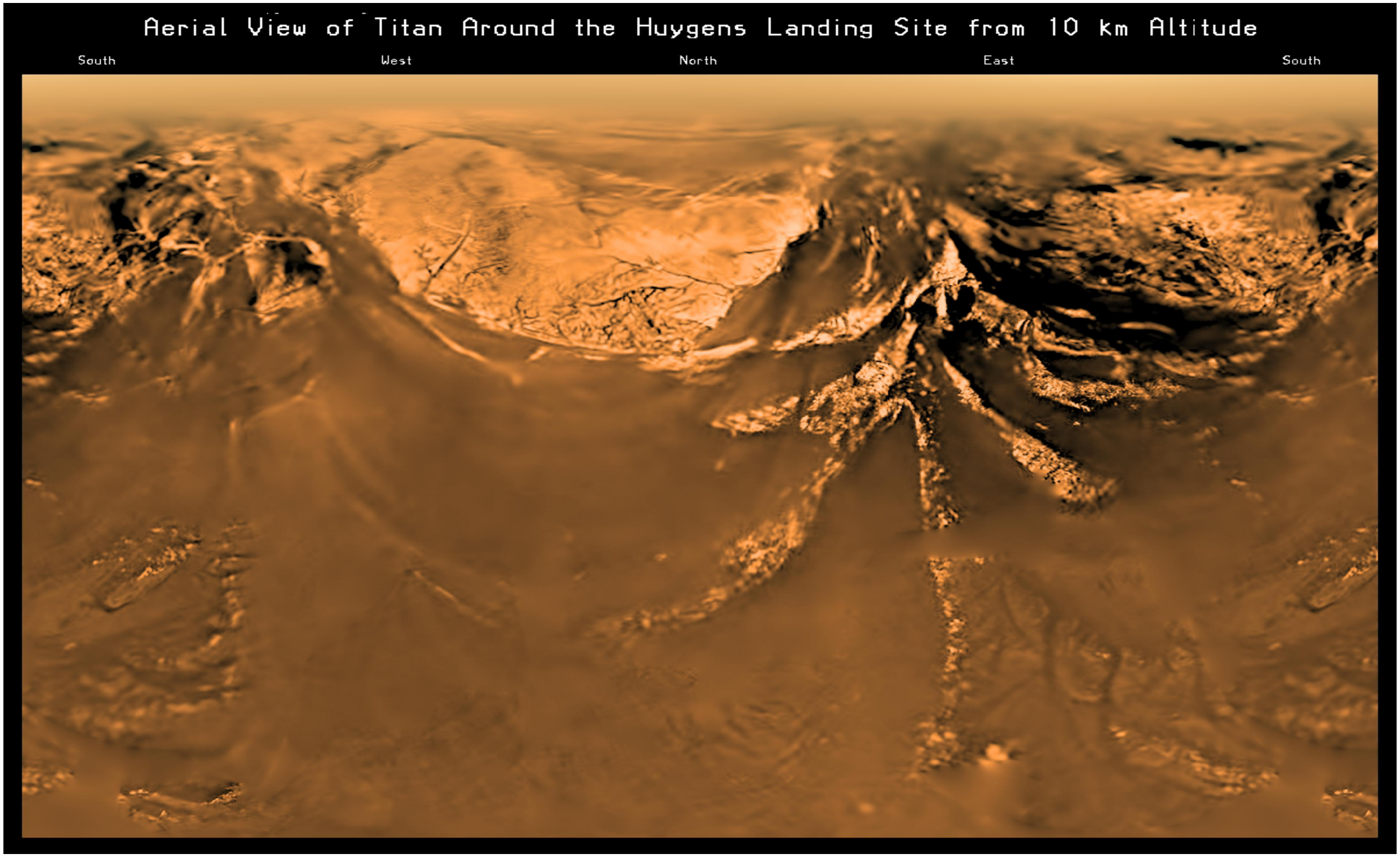
- Huyghens - lander
- Cassini - orbiter, retrasnmitting data to Earth
- Doppler effect on carrier frequency
- Doppler effect on data rate & sync (usually neglected, but not for spacecraft....)



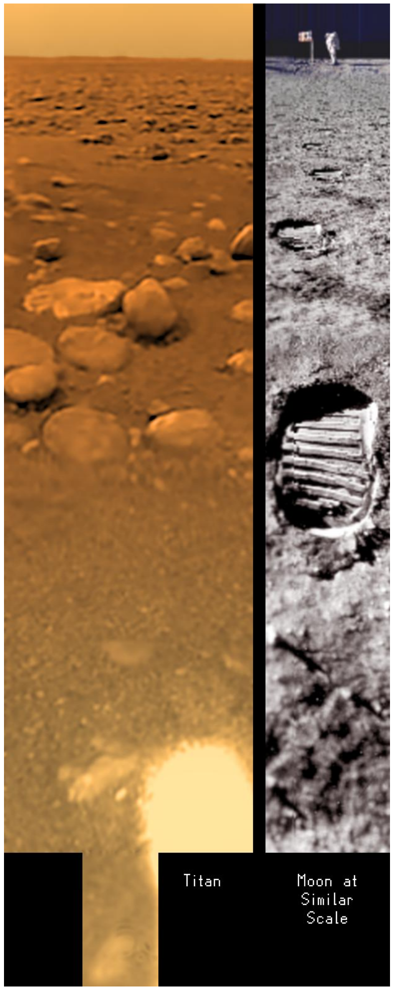
(http://saturn.jpl.nasa.gov/multimedia/images/)

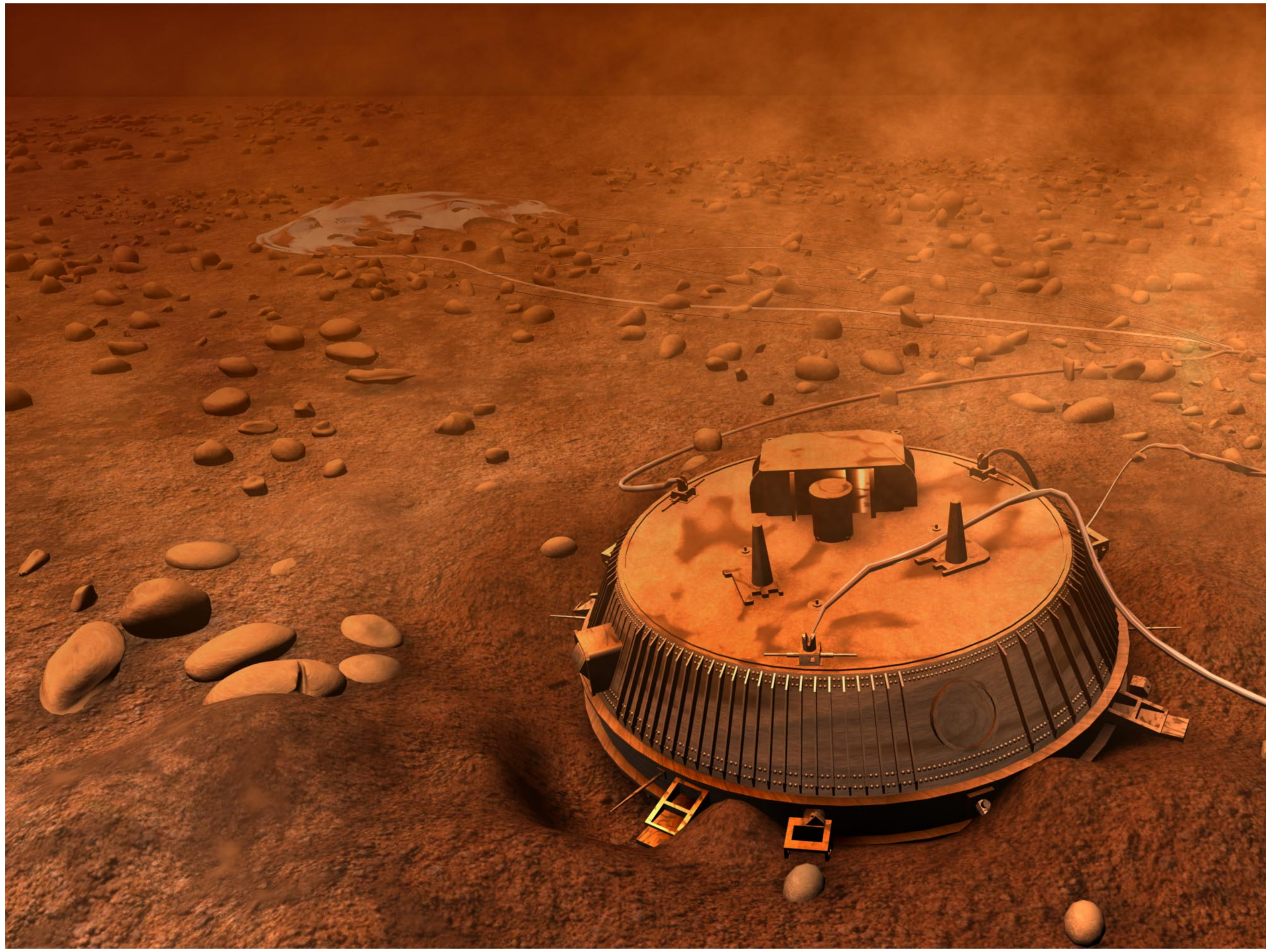
⟶ solution: make Cassini orbit perpendicular to the line-of-sight

Landing: 14 January 2005



(image: `http://esamultimedia.esa.int/images/cassini_huygens/posterd_H.jpg`)





http://esamultimedia.esa.int