

**ESPTR**

**(English)**

**Signal Processing in Telecommunications and Radar**

**Channel properties**

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## Communications channel

Channel → (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
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## Channel model: noise

Model: linear system + added noise; AWGN model

- Thermal noise (mainly receiver) with white PSD

$$\bar{u}_n^2 = 4k_B T R \quad [\text{V}^2/\text{Hz}]$$

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

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

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

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

(radar only) clutter

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## Channel model: linear

### Transmission properties

- Physical parts characteristics

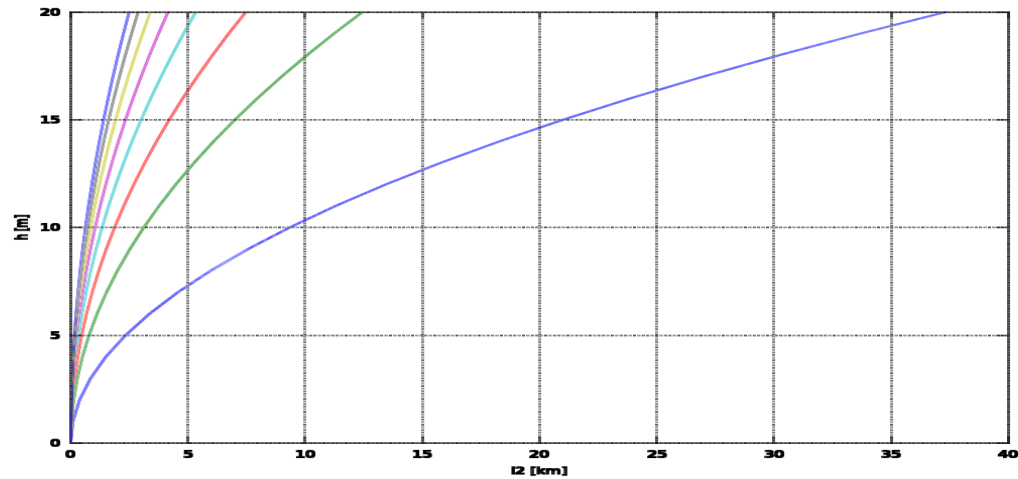
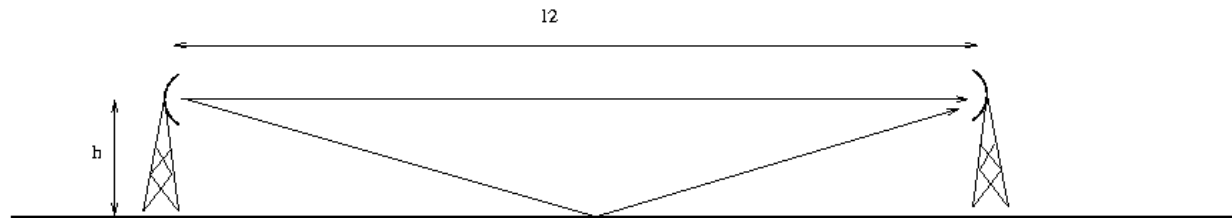
Cable (etc) losses and reflections (standing wave effect)

Directional antenna gain  $G$  and effective aperture  $S_{eff}$ :

$$S_{eff} = \frac{G\lambda^2}{4\pi} \text{ or } G = \frac{S_{eff}4\pi}{\lambda^2}$$

- Propagation characteristics, including propagation losses  $P \sim \frac{1}{4\pi R^2}$  (one way)  
→ note that this is POWER – voltage (or field strength) drops as  $1/R$
  - Multipath propagation → self-interference  
Multipath description:
    - Time domain: impulse response
    - Frequency domain: transfer function (phase is important!)
  - Non-LTI effects:
    - Doppler effect
    - Impulse noise saturating the receiver
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## Multipath



( $l_2$ =distance vs.  $h$ =tower height), 7GHz, curves for  $[1\ 3\ 5\ ..\ 15]*\lambda/2$ , flat earth geometry

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## 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)
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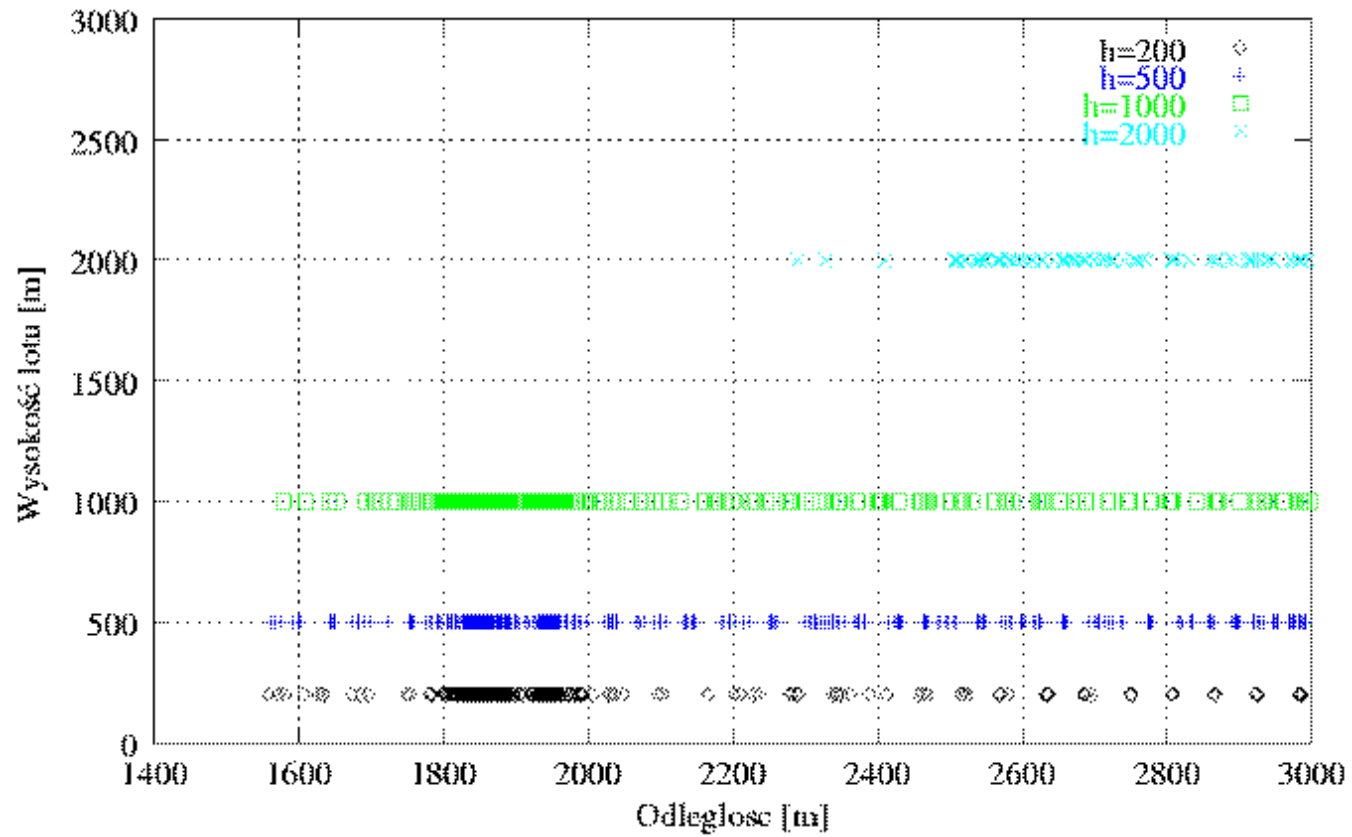
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## Frequency dependence of multipath

See the blackboard example:

- different  $\lambda$ , different interference
  - the same expressed as frequency characteristics of channel
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## Radar fading



Plot points = detections. Note lighter and darker regions.



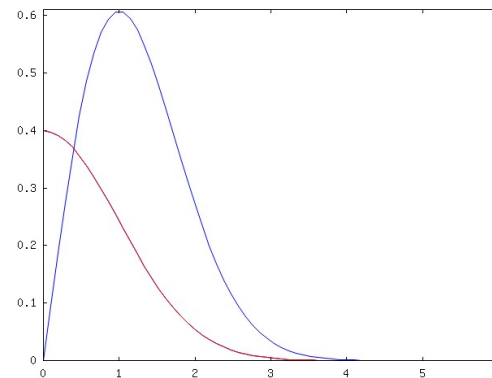
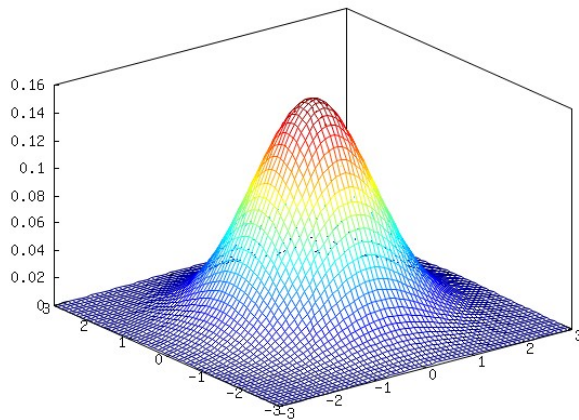
## Rayleigh fading

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.



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## 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  $f$ ,  $df$ )

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## 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  $t_d = \frac{r_0 + vt}{c}$

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

Doppler frequency  $\longrightarrow F_c \frac{v}{c}$ ;

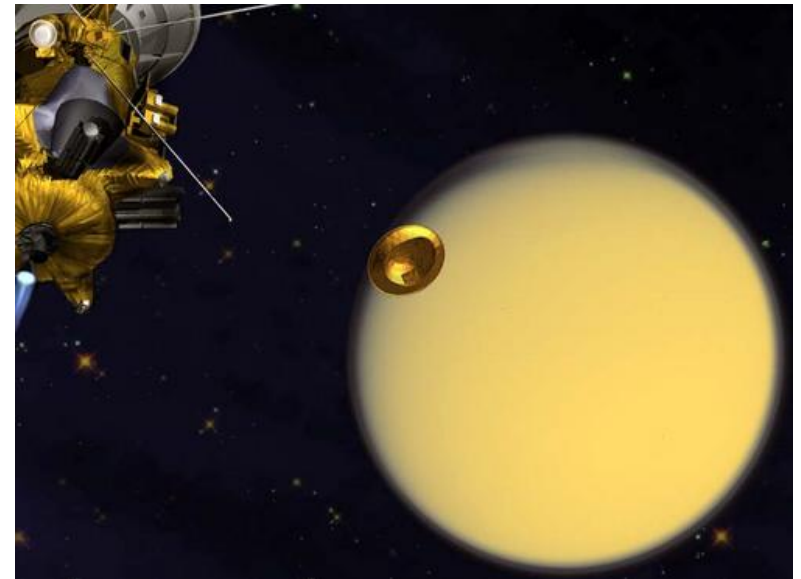
stretch factor  $\longrightarrow 1 - \frac{v}{c}$

## 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).

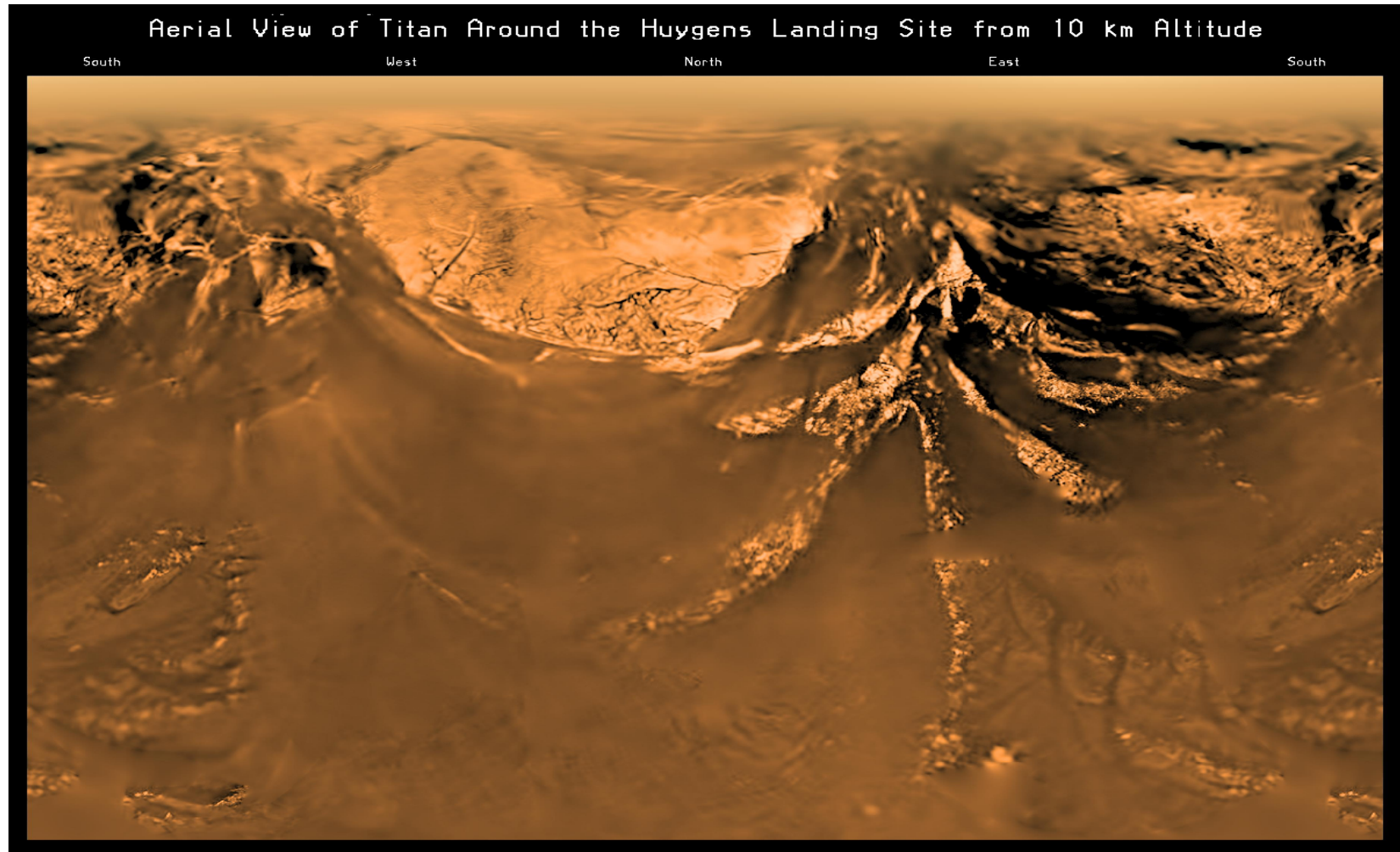
- Huyghens - lander
- Cassini - orbiter, retransmitting data to Earth
- Doppler effect on carrier frequency
- Doppler effect on data rate & sync (usually neglected, but not for spacecraft....)



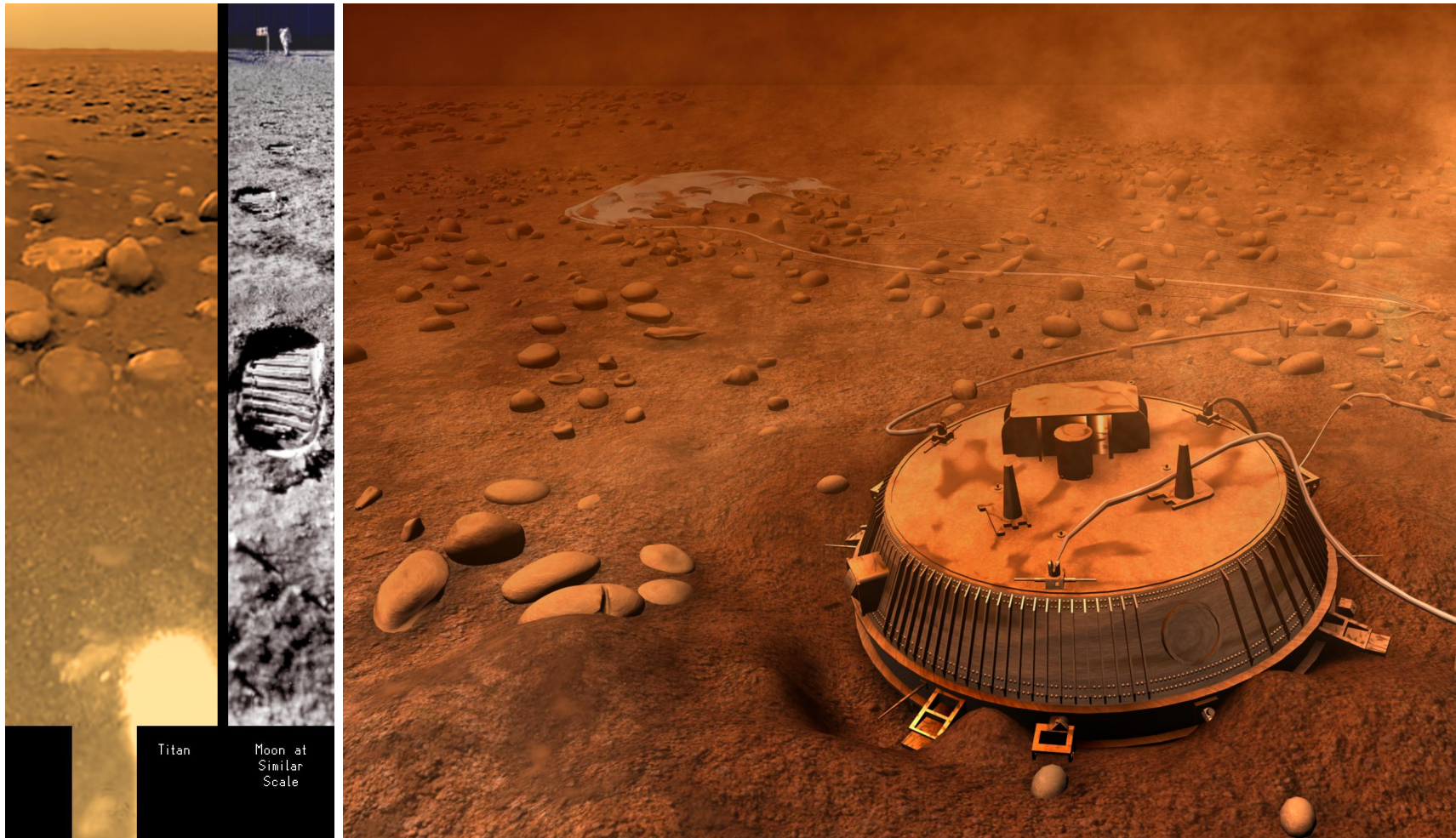
(<http://saturn.jpl.nasa.gov/multimedia/images/>)

→ 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/images/cassini_huygens/posterd_H.jpg))



Titan

Moon at  
Similar  
Scale

<http://esamultimedia.esa.int>