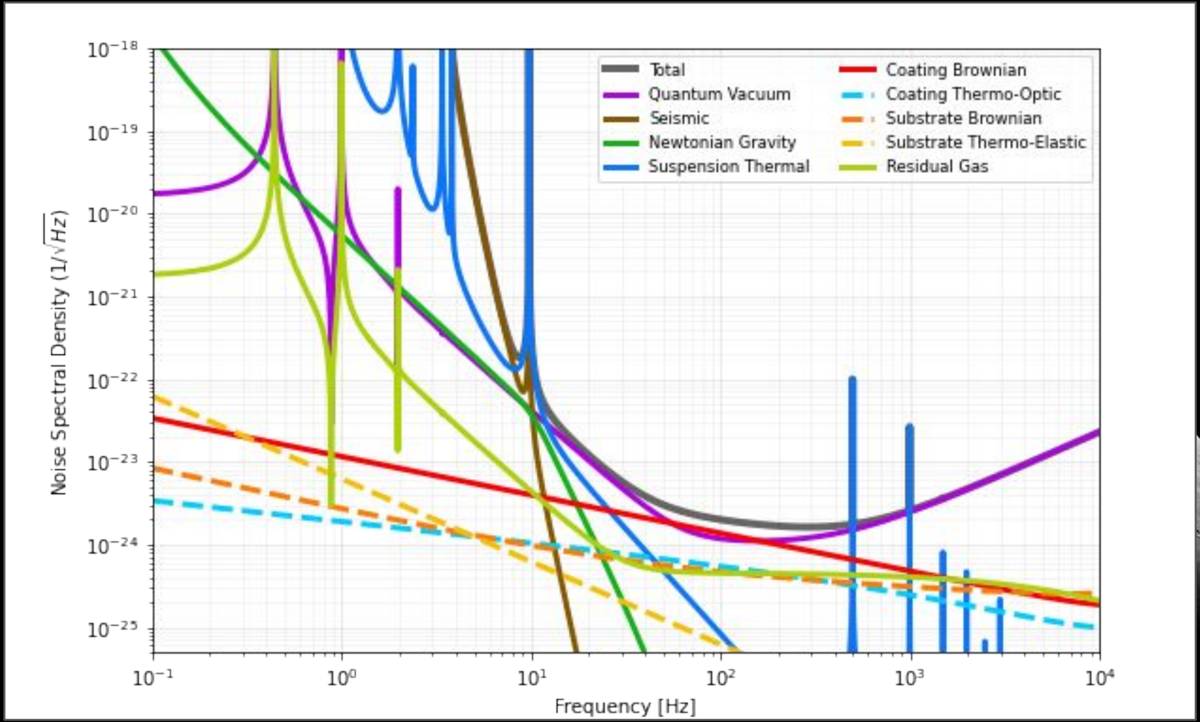
Introduction to the LILA project

Laser Interferometer Lunar Antenna

Main limitations of terrestrial interferometers

Many noises



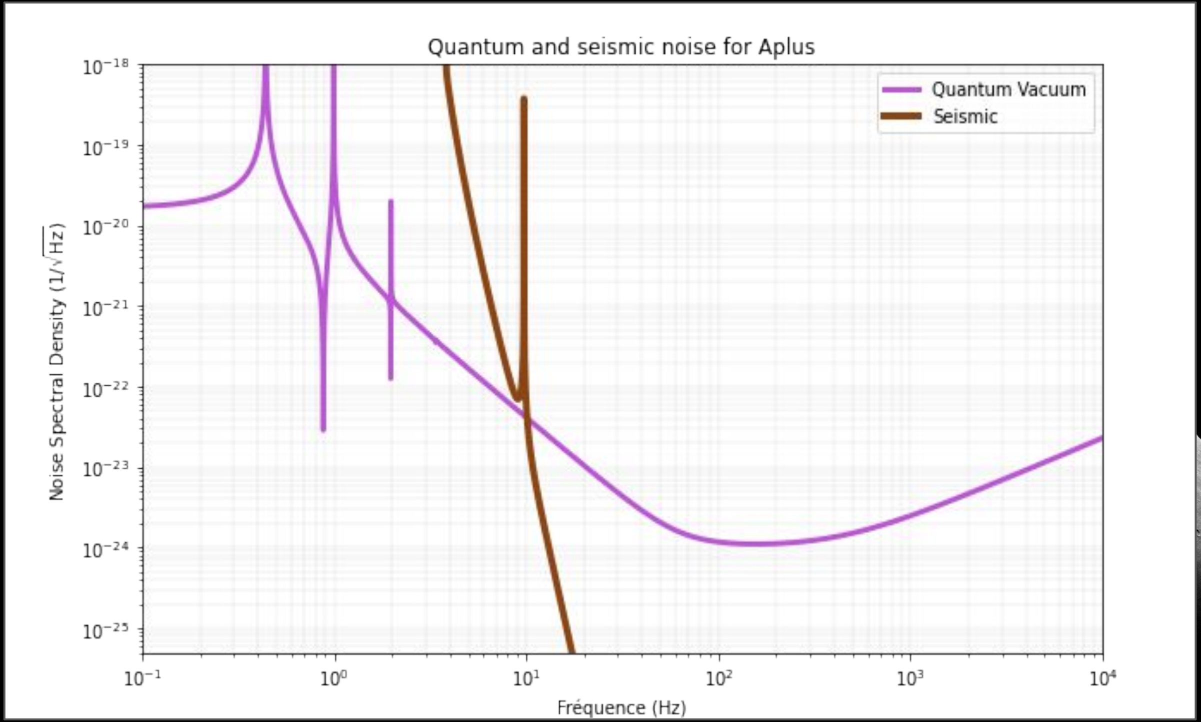
Main limitations of terrestrial interferometers

At low frequency :

- Seismic noise

At high frequency :

- Quantum noise
- IFO response



Gravitational wave spectrum

Multitude of different sources :

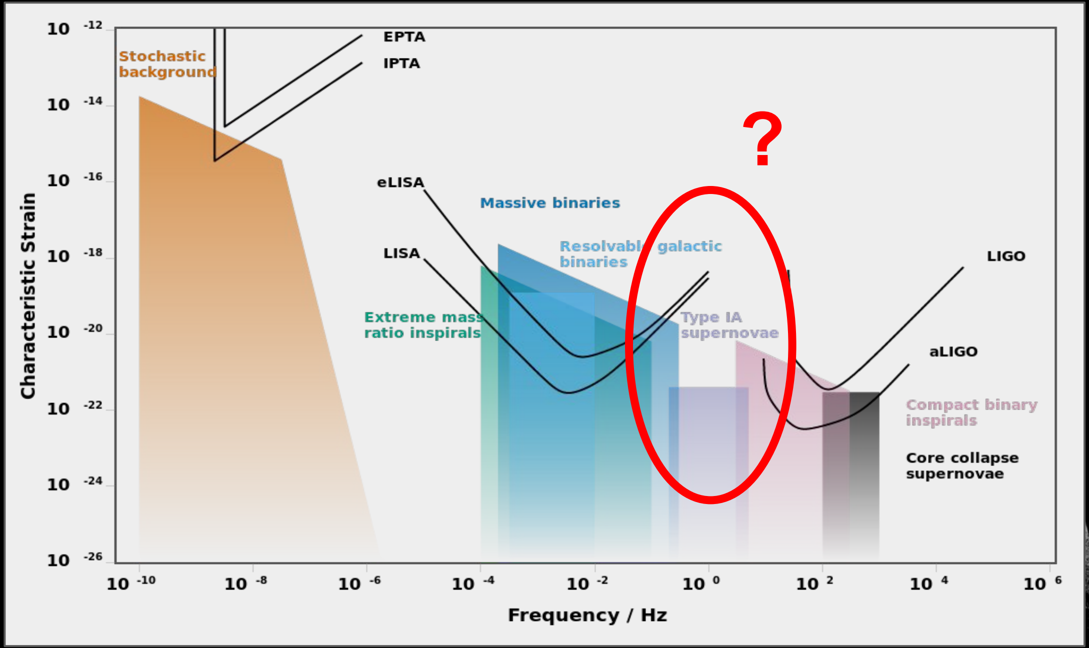
- LIGO/Virgo : (10 Hz ~ 1000 Hz)

  Merger of binary compact system

- LISA : (0.1mHz ~ 0.1 Hz)

  Merger of supermassive black holes
  Inspiral of LIGO/Virgo sources
  Extreme mass ratio inspiral
  Galactic binaries

- PTA : (1 nHz ~ 1 μHz)



Gravitational wave spectrum

Multitude of different sources :

- aLIGO/Virgo : (10 Hz ~ 1000 Hz)

  Merger of binary compact system

- LILA (0.1Hz ~ 10 Hz)
- LISA : (0.1mHz ~ 0.1 Hz)

  Merger of supermassive black holes
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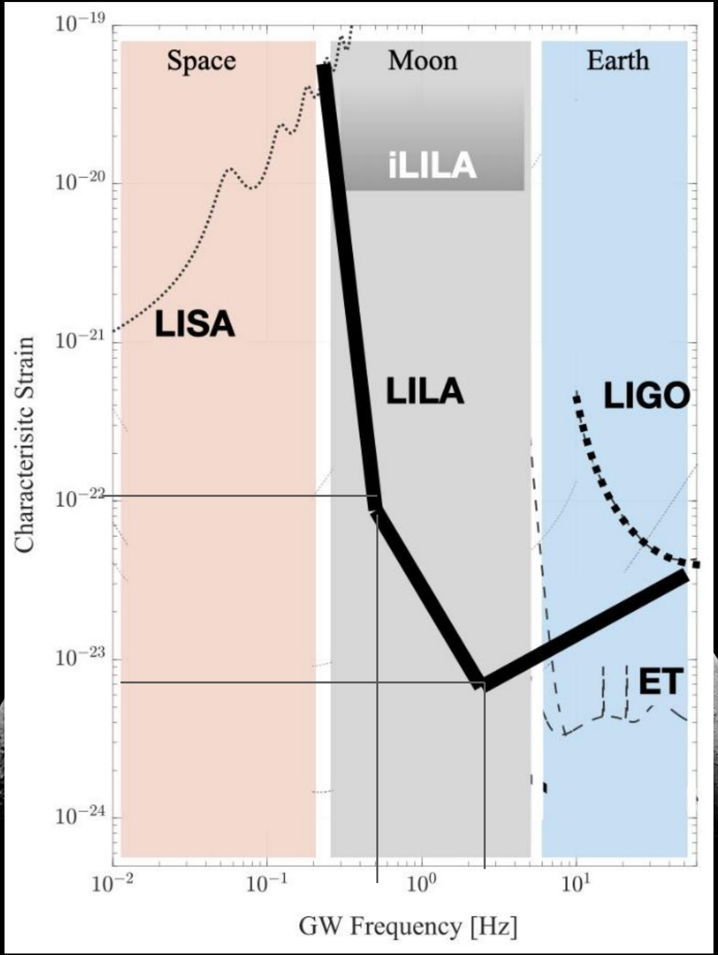
- PTA : (1 nHz ~ 1 μHz)



The Moon

<u>Positive points</u> :

- Lower seismic noise at 1 Hz
  - ≈ 10e6 quieter than on Earth
  - rare Moonquakes (max. 5 on Richter magnitude scale)

  Could observe at lower frequency than LIGO/Virgo

- Lunar Vacuum
  - Pressure ≈ 0,3 nPa

  No need to maintain vacuum on kilometric arms

- Etc...

The Moon

Negative points :

- No atmosphere
  - Extreme temperatures !

Day ≈ 127 °C / Night ≈ - 230 °C

Huge fluctuation of Thermal noise and temperature-dependent noises

- Space environment
  - Radiation and micro-meteorits exposure
  - Solar winds

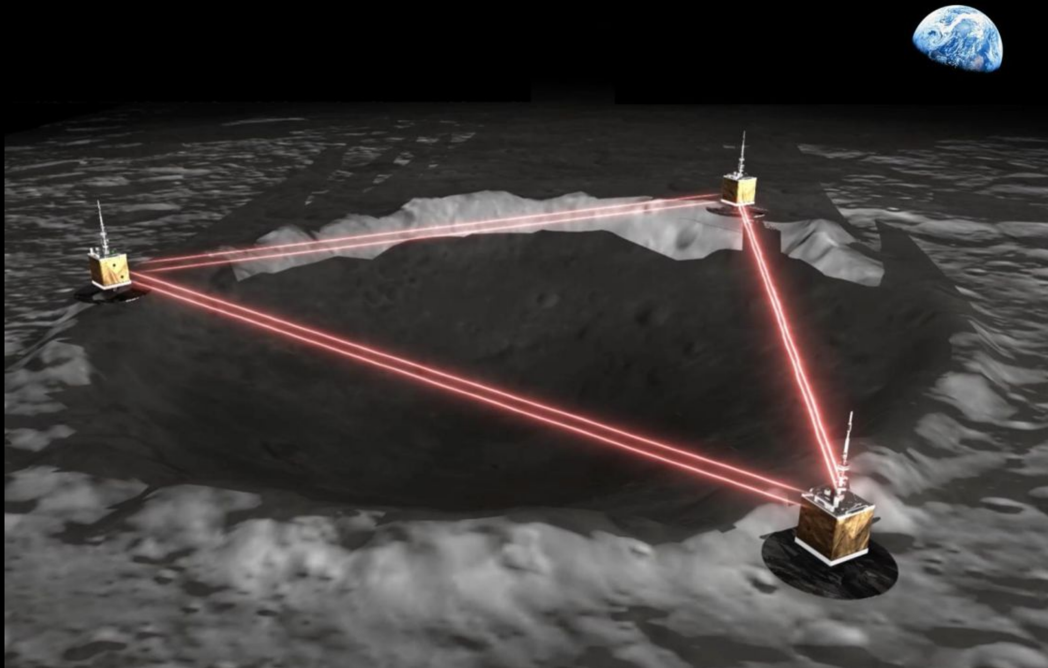
- Lunar Dust
  - Floating particles with different sizes and fluctuating densities

Scattering of the laser beams

- To be investigated !!

LILA mission concept

- 3 arms Laser IFO
  - Arm length ≈ 10 km
  - λ = 1064nm
  - Cavities (?)
- GW Sources
  - inspiral of stellar black holes and neutron stars **weeks before** Virgo
  - intermediate-mass black holes of over 1000 solar masses
- Coupling Seismic and interferometric data



Lunar Dust

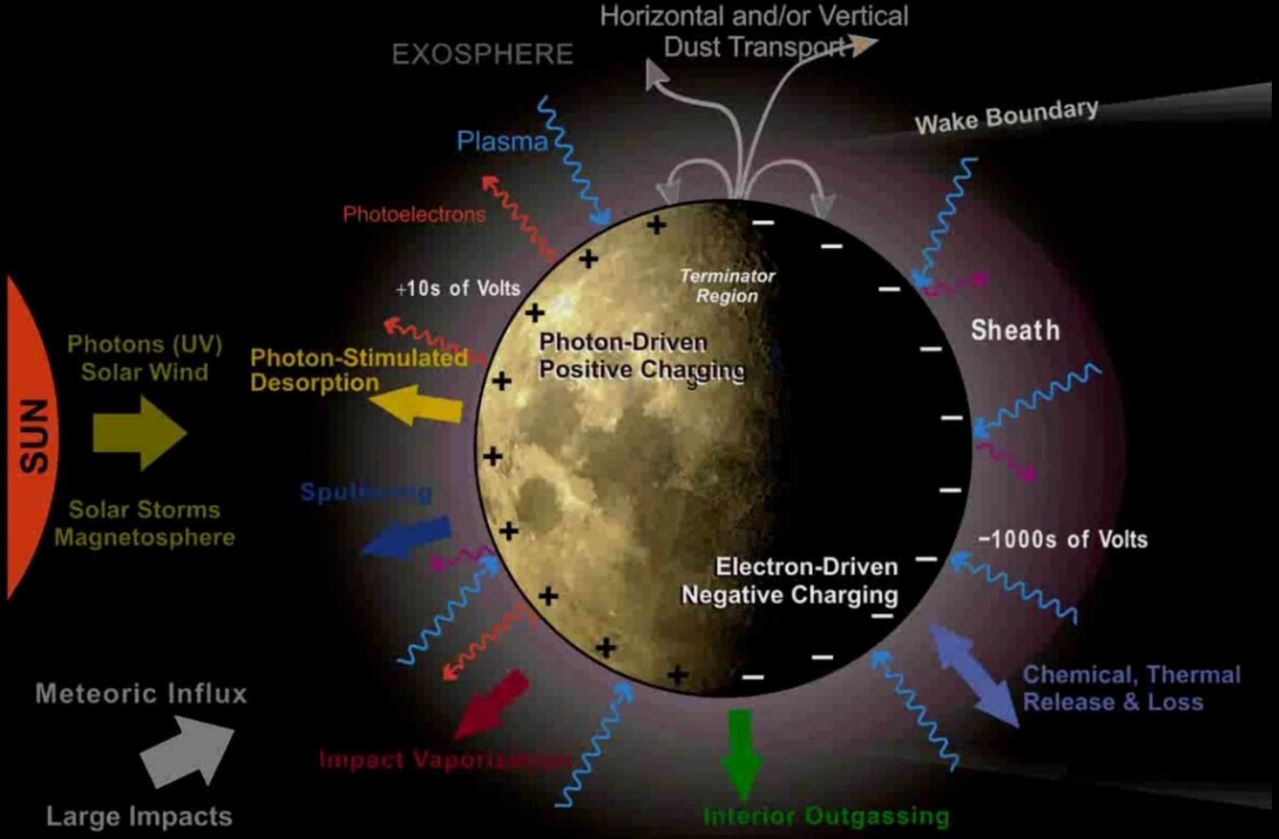
- First observations
  - Astronautes coming back from the moon

  - Glow above the lunar surface

Ref : KUZNETSOV et al. Lunar Dust: Properties and Investigation Techniques

Lunar Dust

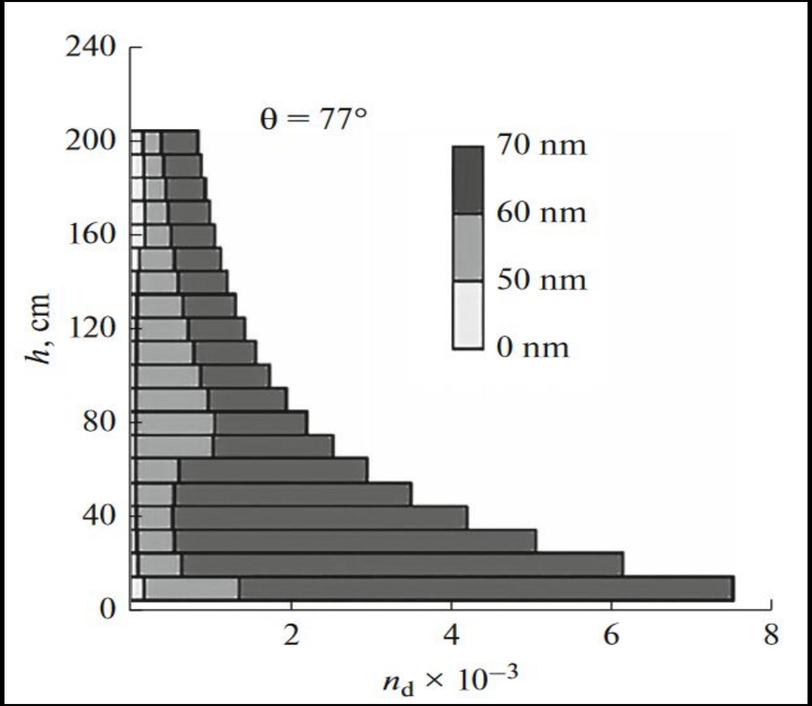
- Origin
  - 400 meteorites per year
  - Surface potential



Ref : KUZNETSOV et al. Lunar Dust: Properties and Investigation Techniques

Lunar Dust

- Principal characteristics
  - Dimension:
    - from tenth of nanometers
      up to hundreds of micrometers
    - random shapes and sharp features
  - Density: decreases steeply with particles size and altitude



Lunar Dust : Scattering noise

- LISA Article on Interplanetary dust
  - Mie Theory

$$h(f) = \left| \frac{2\pi N}{k^3} \mathrm{Im}[(S(0)] \right| \sqrt{\frac{1}{L b w_0 \bar{v} N}} \exp(-\sqrt{2\pi\lambda L} f/\bar{v})$$

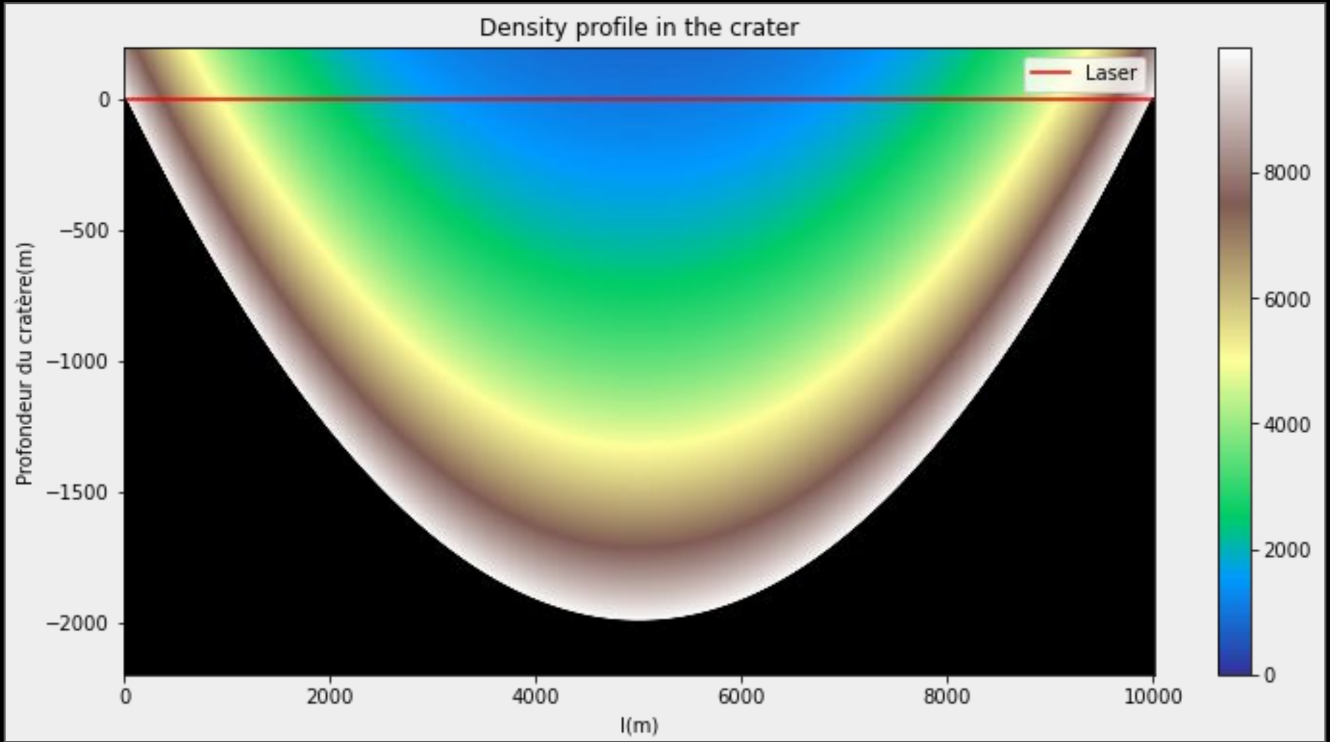
- Compute Im{S(0)}
  - Still Mie Theory

$$S_1(\Theta) = \sum_{n=1}^{\infty} \frac{2n+1}{n(n+1)} \left[a_n \pi_n(\Theta) + b_n \tau_n(\Theta)\right]$$

Ref : F Rubanu et al. Interplanetary dust: a source of noise for LISA?

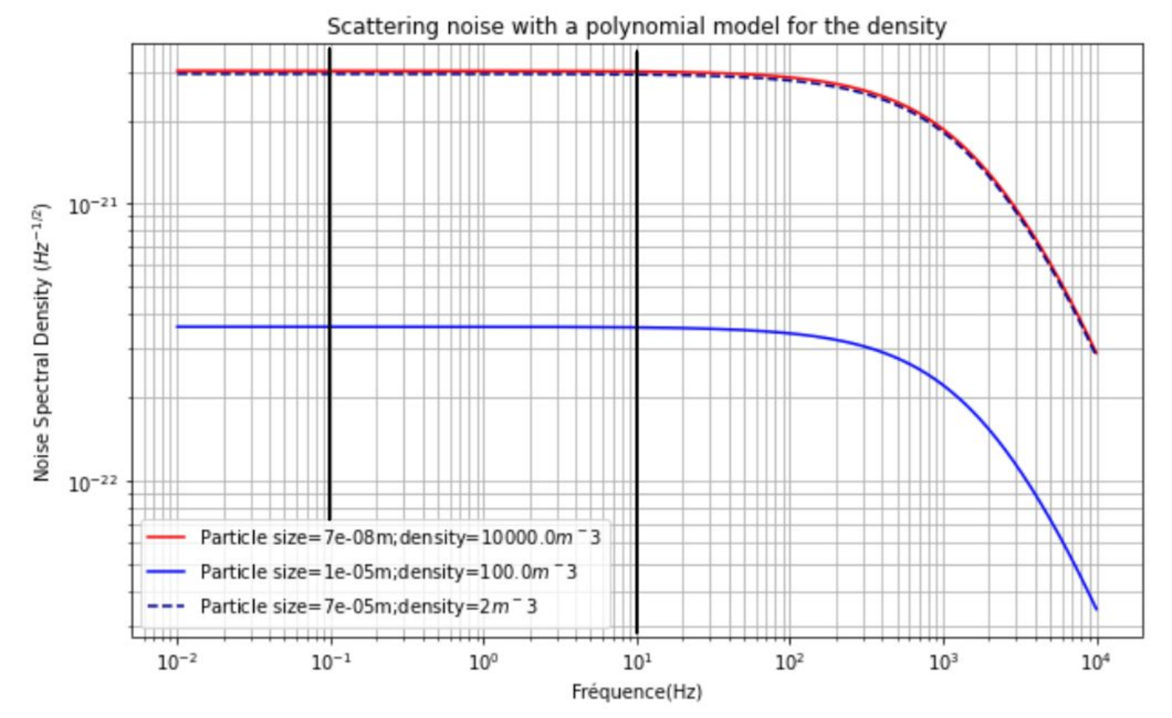
Lunar Dust : Preliminary results

- Crater for a polynomial evolution of density



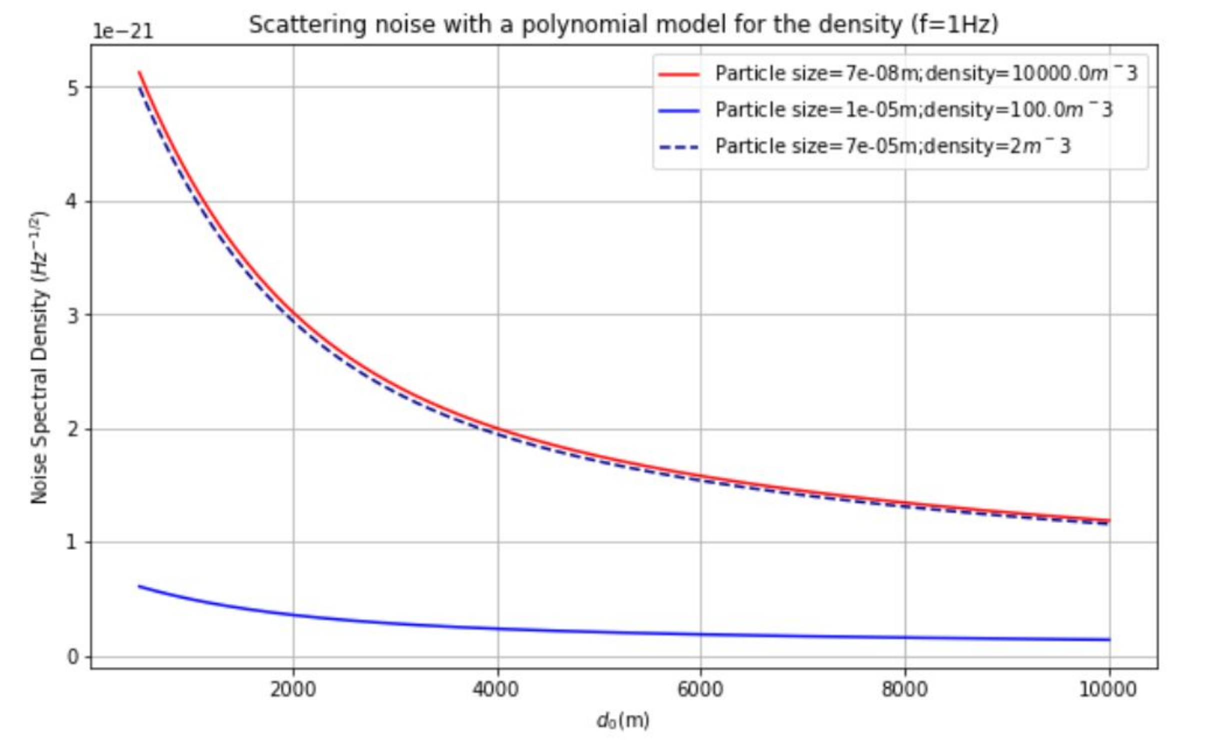
Lunar Dust : Preliminary results

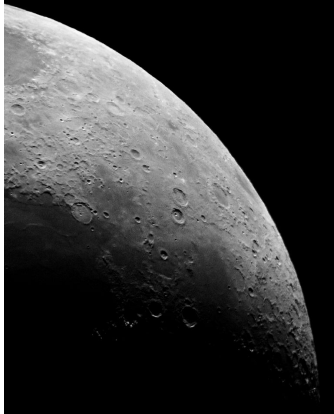
- Dust noise variation with respect to frequency



Lunar Dust : Preliminary results

- Dust noise variation with respect to the crater dimension





Quantum Noises

- Shot noise

$$h_{\text{shot}} = \frac{\lambda}{2\pi L}\sqrt{\frac{\hbar\omega}{\eta P_{\text{in}}}}$$

- Radiation Pressure noise

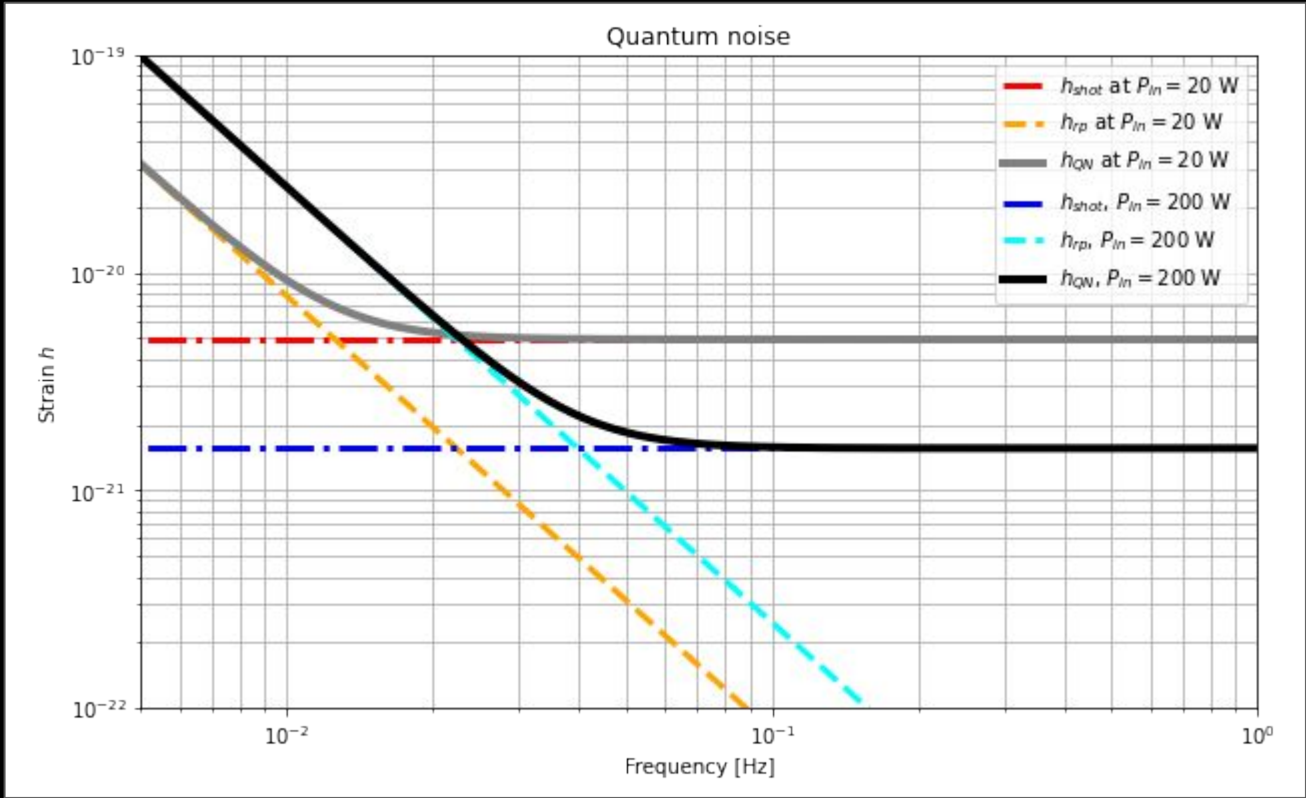
$$h_{\text{rp}} = \frac{2}{LMw_{GW}^2}\sqrt{\frac{2\pi\hbar P}{c\lambda}}$$

- Quantum Noise

$$h_{\text{qn}} = \sqrt{h_{shot}^2 + h_{rp}^2}$$

Quantum Noises

- Arm length :
  - 10 km
- No cavity



Quantum Noises

With Fabry-Perot and Power Recycling cavities

$$S^h(\Omega) = \left[\frac{1}{\mathcal{K}} + \mathcal{K}\right] \frac{h_{\mathrm{SQL}}^2}{2}$$

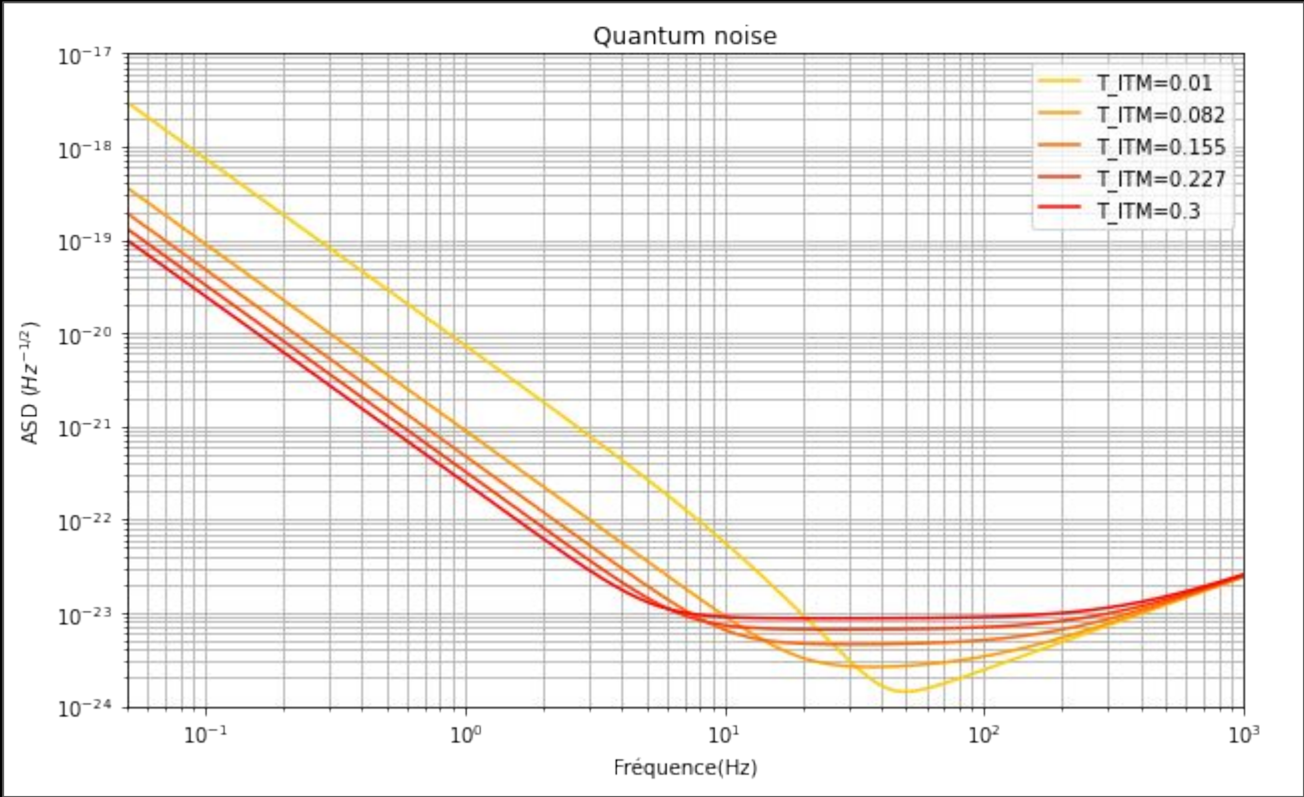
With:

$$\mathcal{K} \equiv \frac{2\gamma\iota_c}{\Omega^2\left(\Omega^2+\gamma^2\right)}, \quad h_{\mathrm{SQL}} = \sqrt{\frac{8\hbar}{m\Omega^2 L^2}}.$$

Quantum Noises

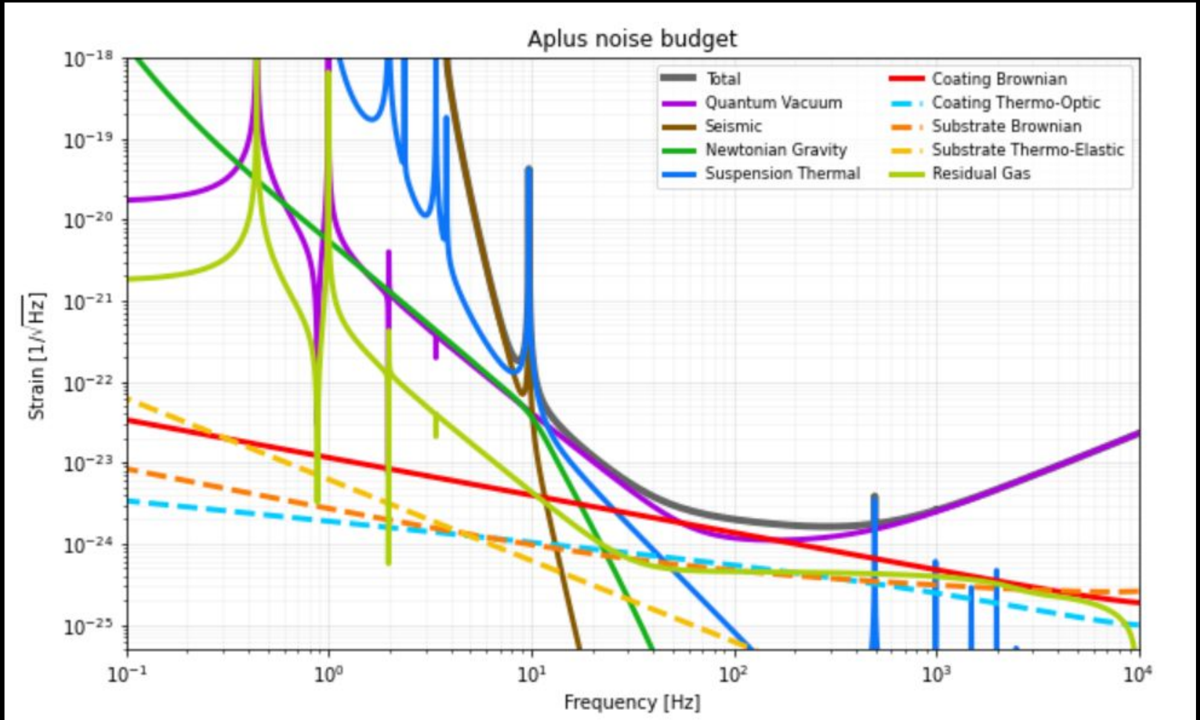
Impact of transmissivity on QN

- Arm length :
  - 10 km
- With cavity
  - Varying input Transmissivity



Design of the lunar interferometer

- Advanced LIGO noise budget



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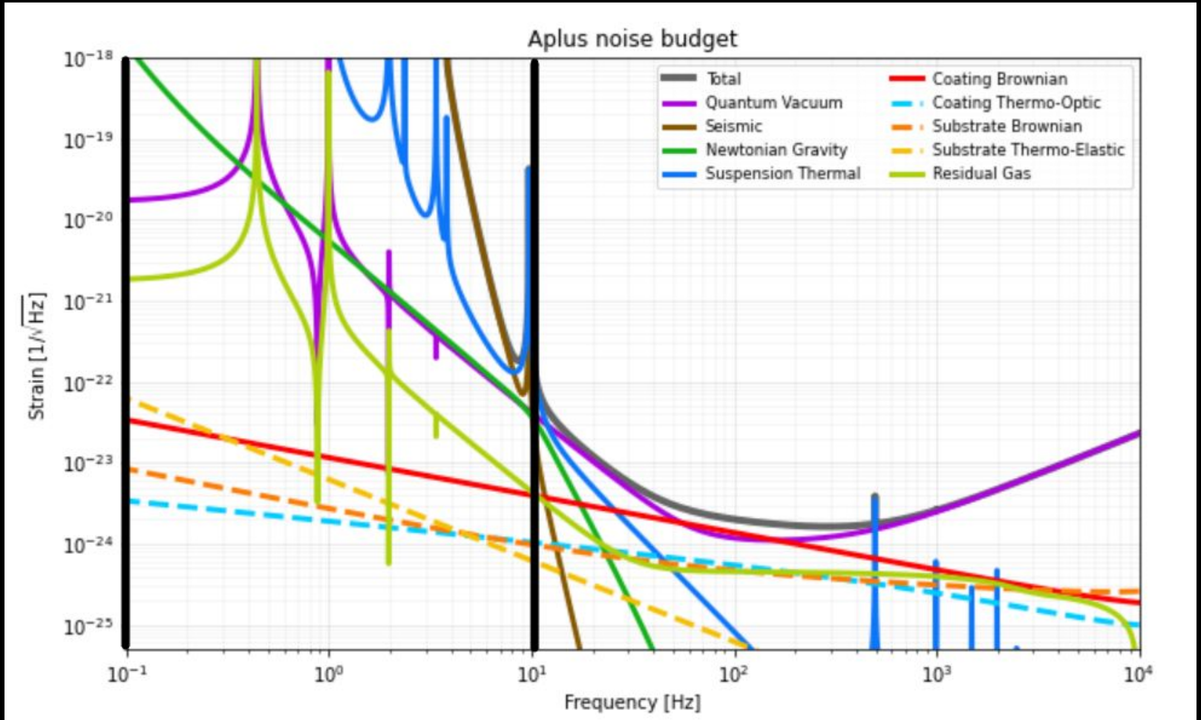
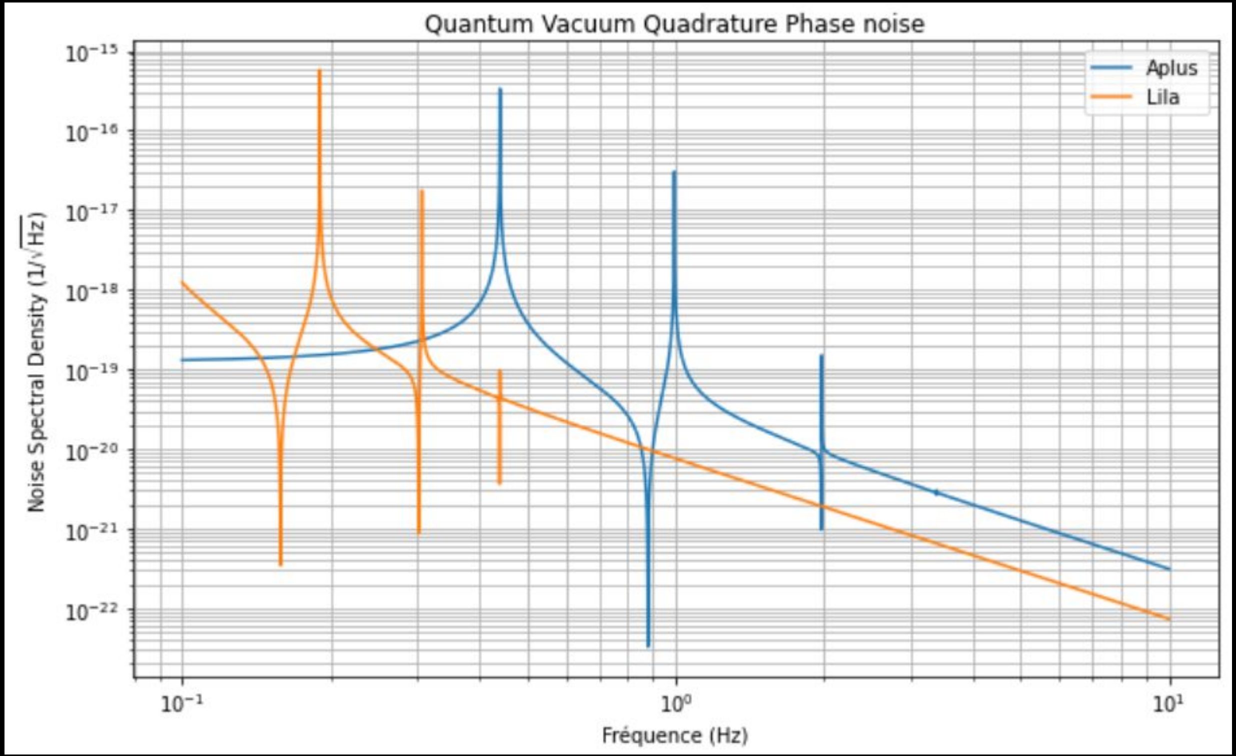


Design of the lunar interferometer

- Quantum Noise in a lunar environment
  - g= 1,622 m/s^2
  - R_lune= 1737 km
  - L= 10000 km
  - l_susp=2 m
  - M_miroir= 50 kg
  - Power= 30 W
  - F= 1000
  - fcut= 0,14



Thank you for your attention