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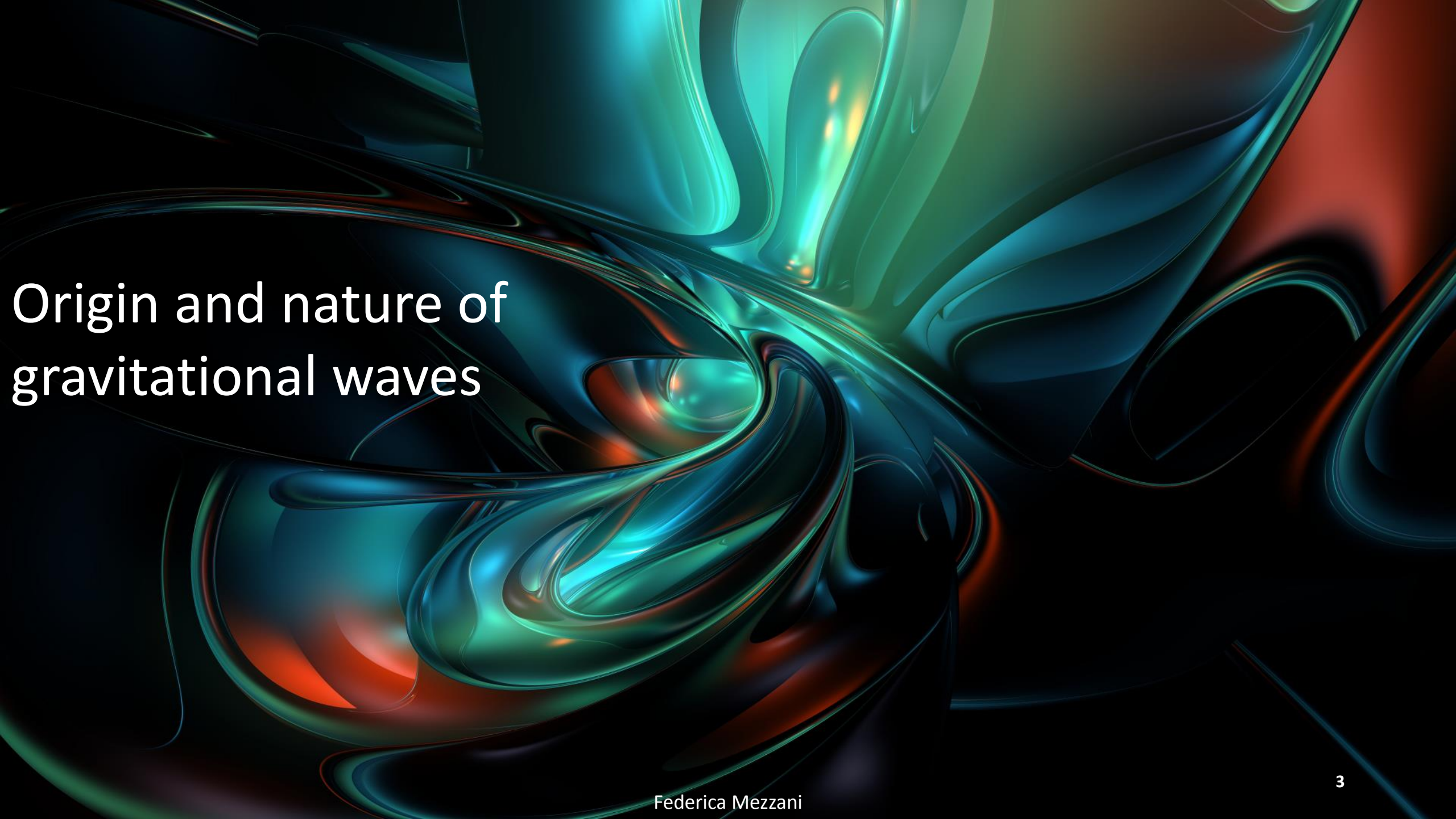
On behalf of the Virgo collaboration

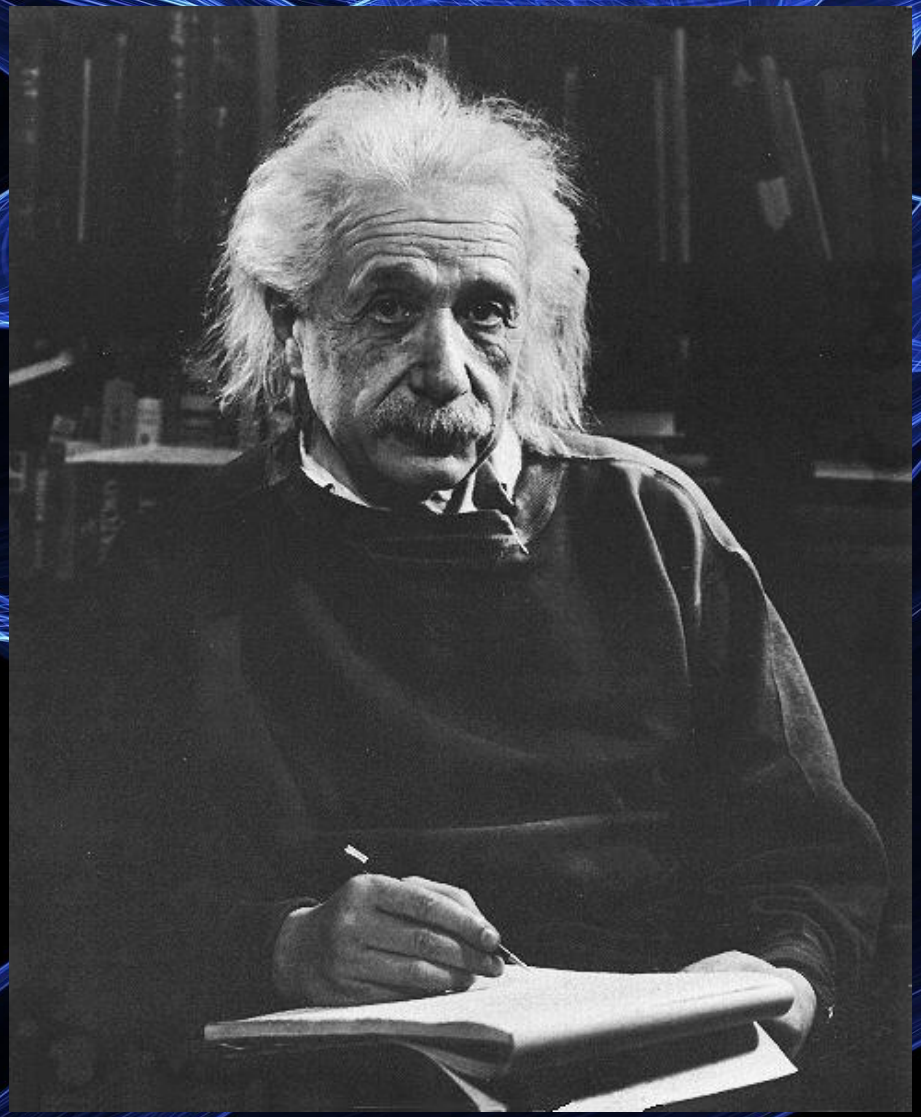
Vibration analysis of the Advanced Virgo payloads

International Conference on
Advances in Vibrations
FEUP, 31 March 2015

Talk outline

- Gravitational waves: nature and sources
- Gravitational waves detector: interferometer
- Structure and function of payloads
- Test sessions on payload
- Conclusions and proposals


Origin and nature of gravitational waves



GENERAL RELATIVITY THEORY

Gravity is a property of the space-time

$$G_{\mu\nu} = 8\pi(G/c^4)T_{\mu\nu}$$

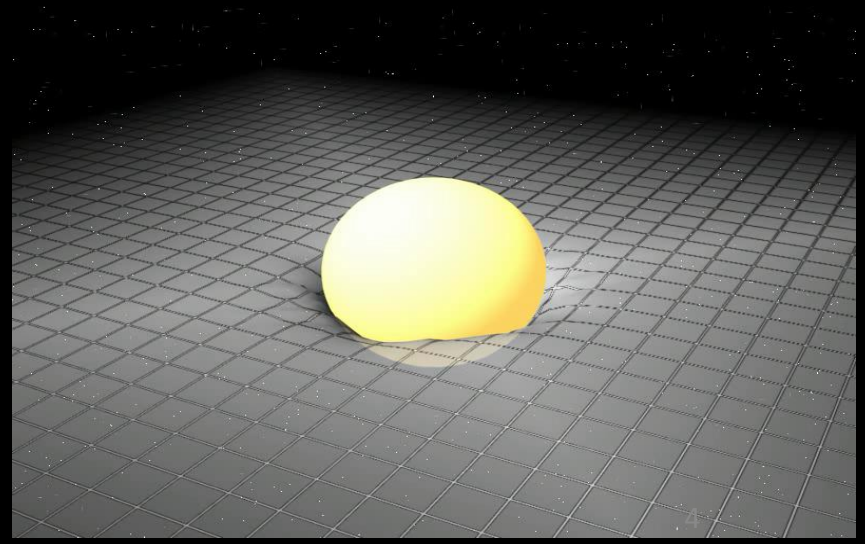
$G_{\mu\nu}$: Einstein's tensor

$T_{\mu\nu}$: energy-momentum tensor

G: gravitational constant

C: speed of light

Phenomenon: big concentration of mass or energy deform the space-time



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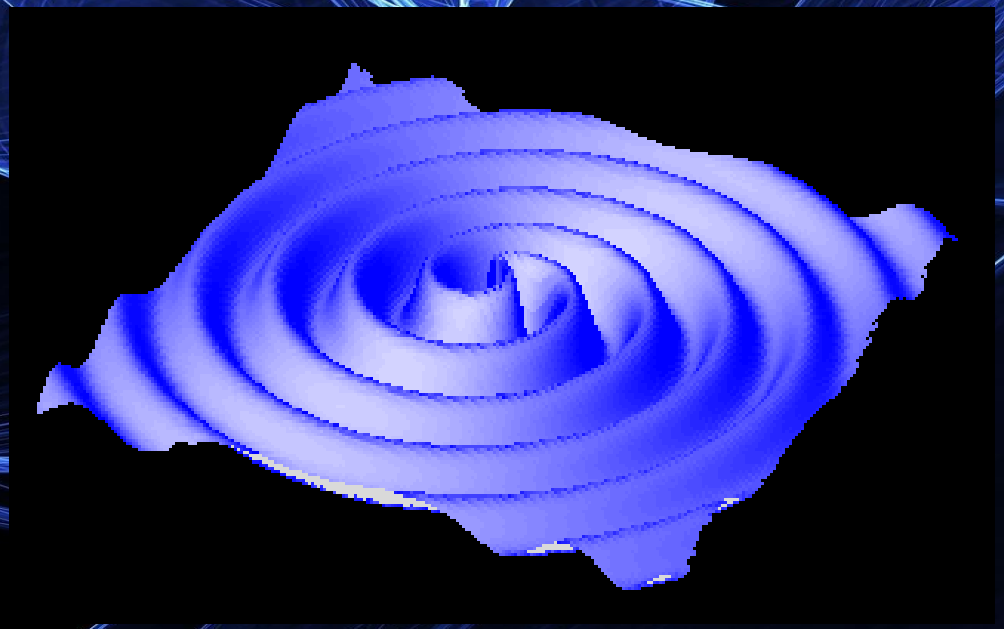
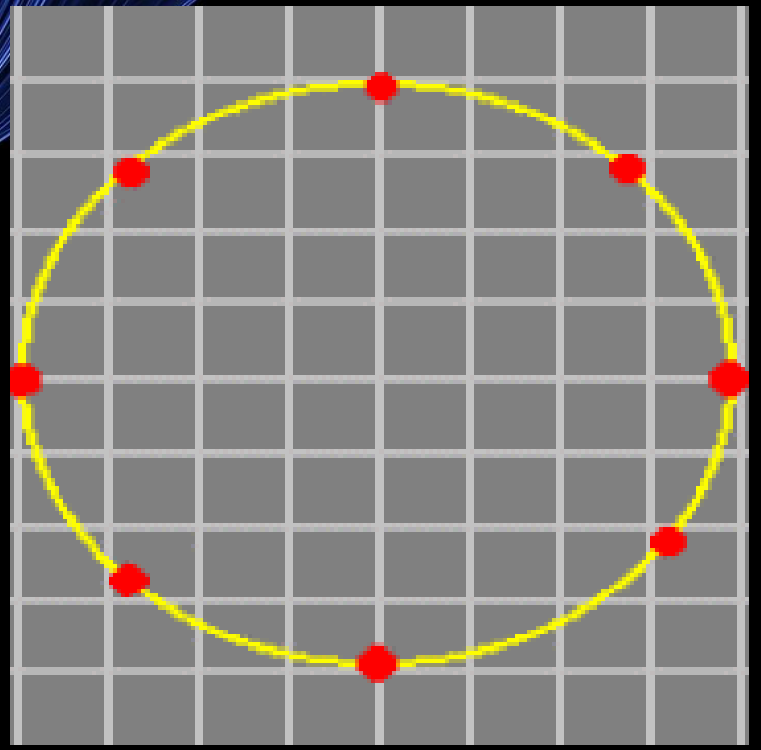
Gravitational waves are ripples in the curvature of the space-time propagating at the speed of light



Effect: GW produce tidal forces in such a way that the distance between two free masses will alternatively decrease and increase

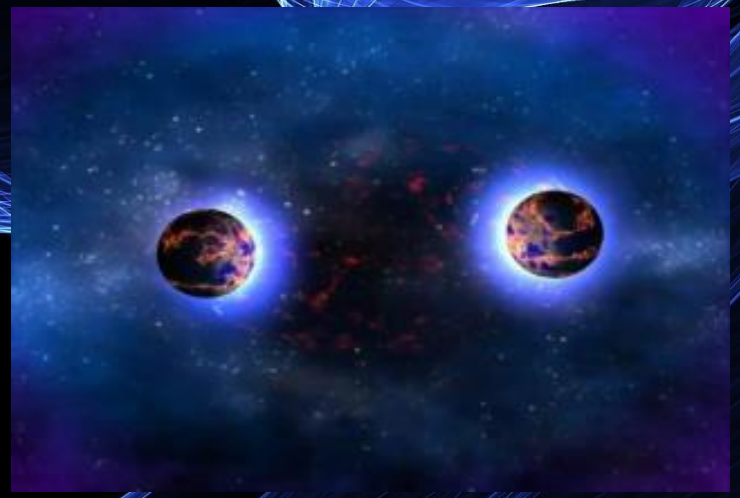


NEW WINDOW ON THE UNIVERSE

Sources of gravitational waves

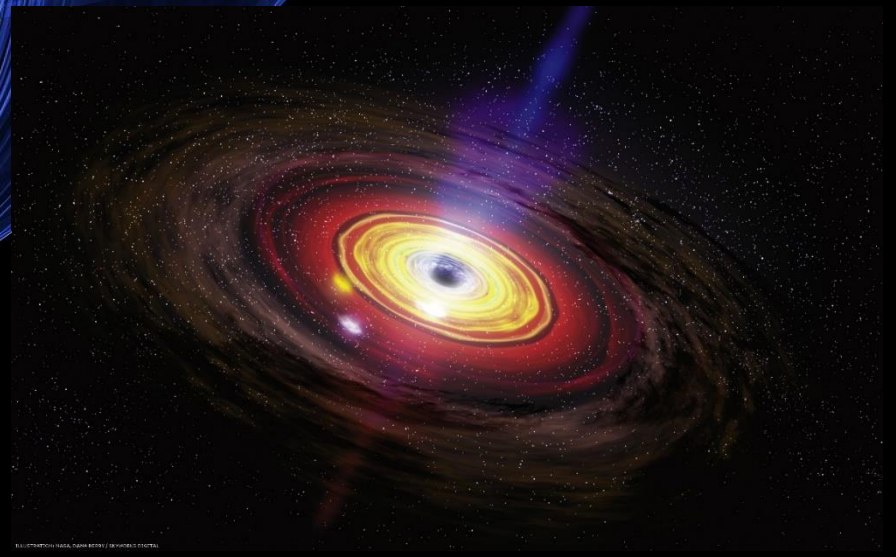
Gravitational waves are produced by quadrupolar asymmetric accelerating bodies:

- Big masses involved
- High speeds

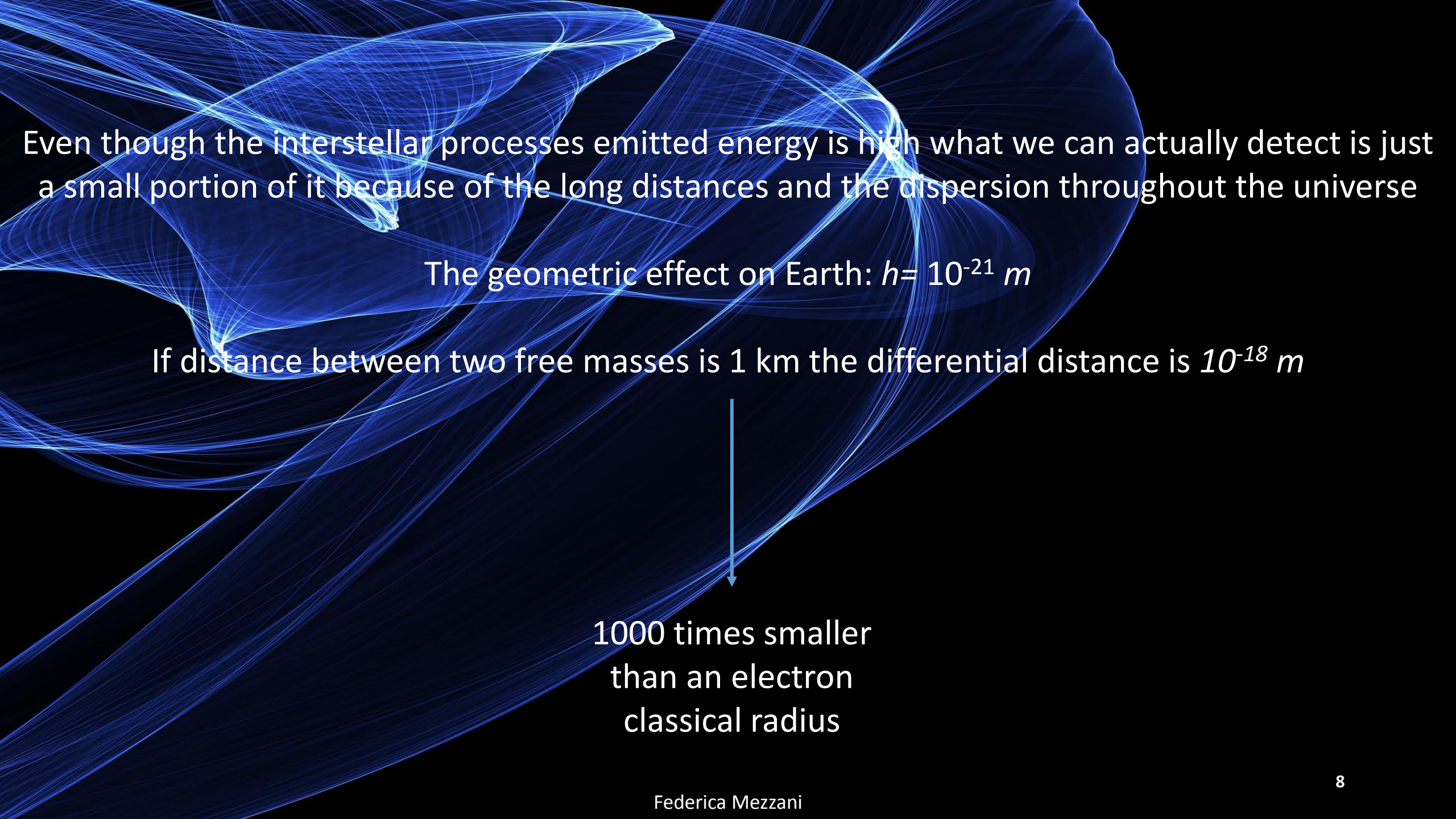


Binary system

Neutron stars



Black holes

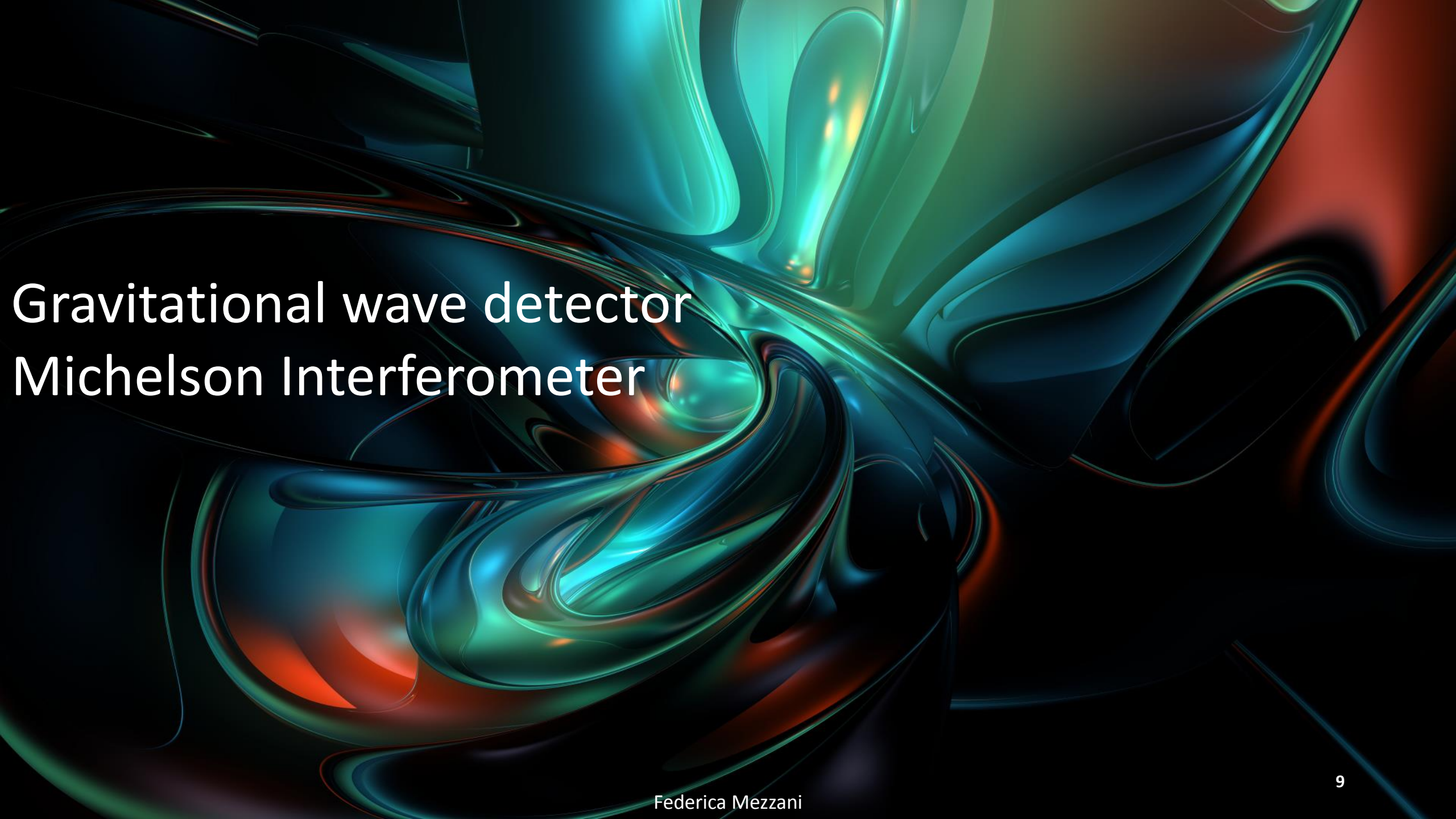


Even though the interstellar processes emitted energy is high what we can actually detect is just a small portion of it because of the long distances and the dispersion throughout the universe

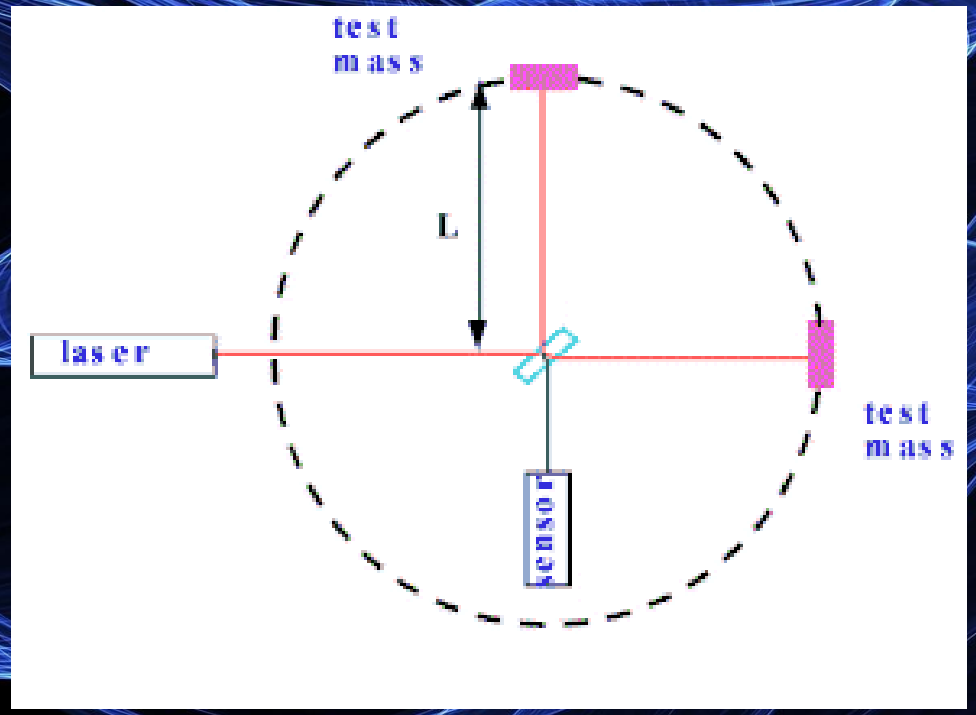
The geometric effect on Earth: $h = 10^{-21}\ m$

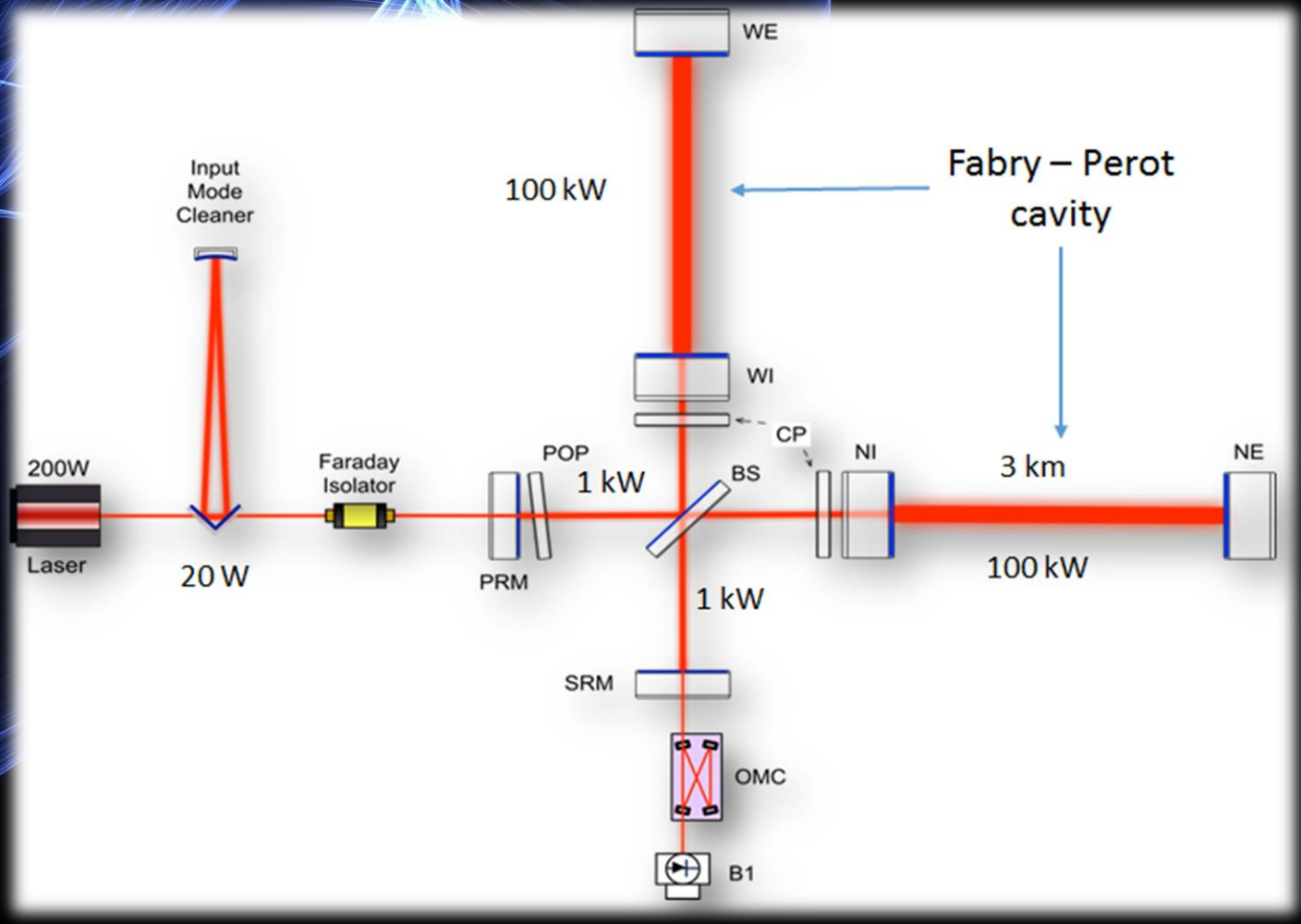
If distance between two free masses is 1 km the differential distance is $10^{-18}\ m$

1000 times smaller
than an electron
classical radius


Gravitational wave detector
Michelson Interferometer

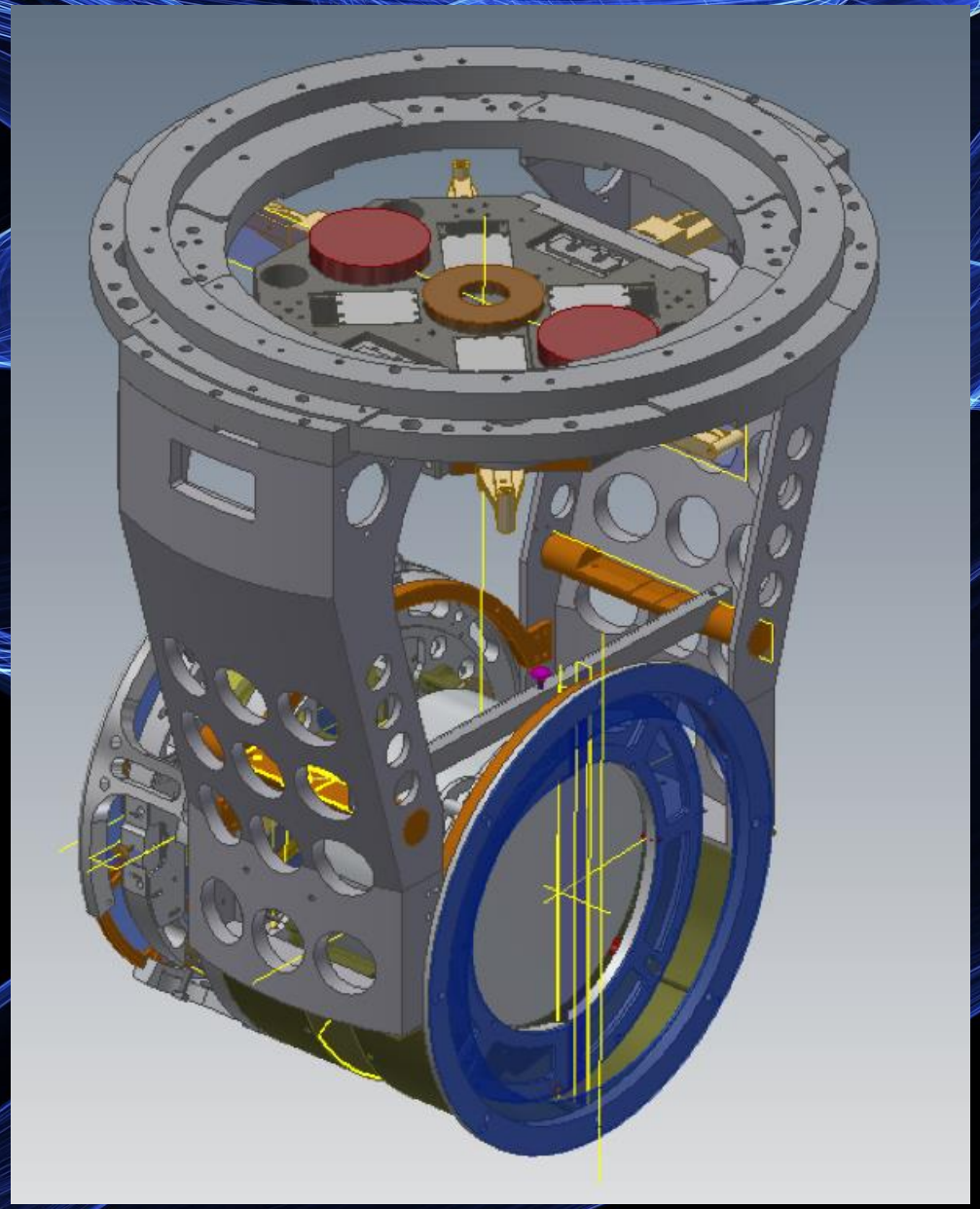
Michelson Interferometer's functional scheme





Structure of a payload

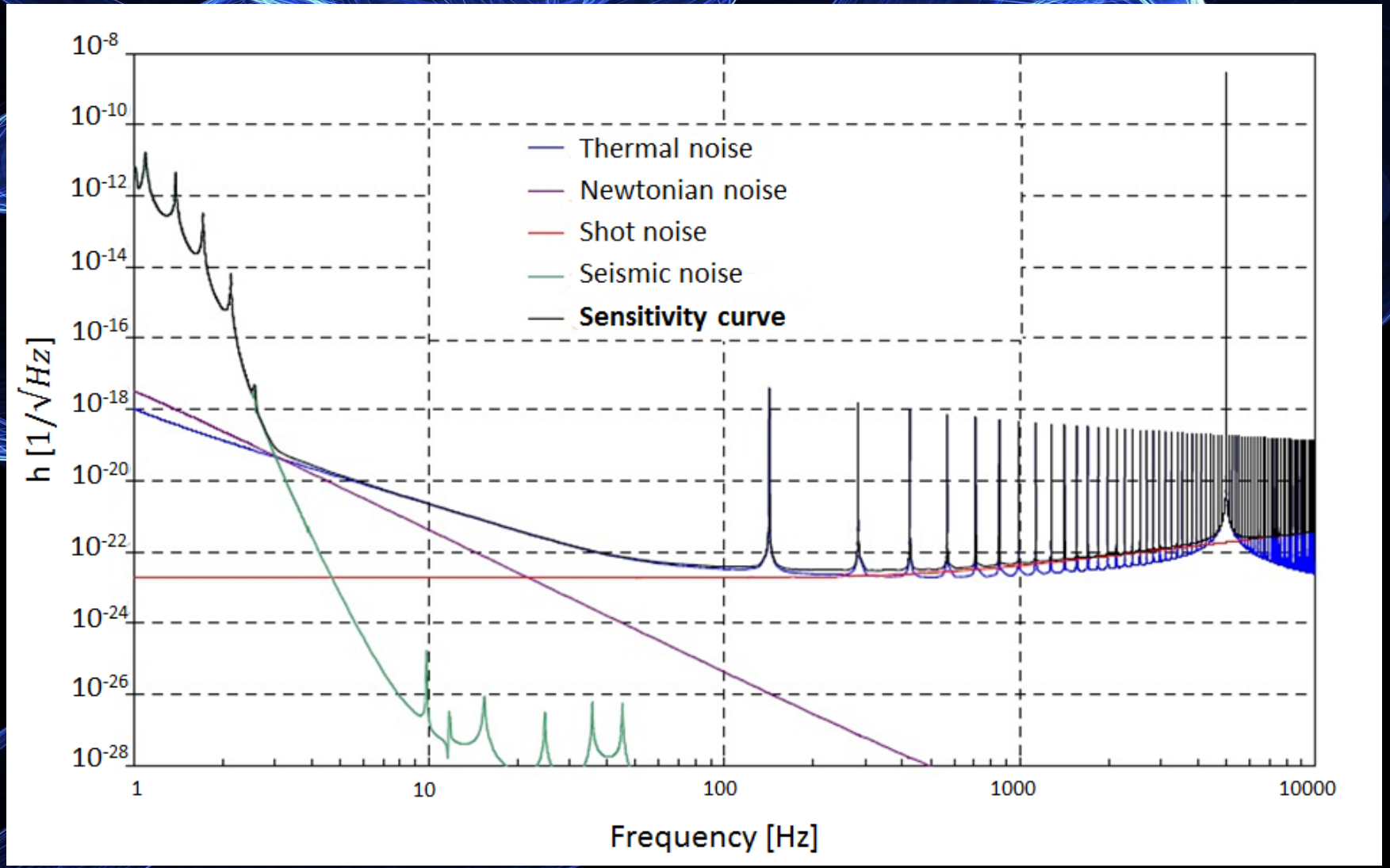
HEART OF THE INTERFEROMETER



- **Location**: lower part of the tower in a Ultra-High Vacuum (UHV) chamber
- **Configuration**: double stage system with the so called marionette as first pendulum and the mirror suspended from it
- **Role**: steering the optical components maintaining the relative position of the interferometer mirrors, suspend all the additional components
- **Issues**: limiting the overall weight, avoiding transversal modes in the control loop bandwidth


Test session on the Power Recycling payload

Virgo+ sensitivity curve
Minimum detectable signal



An accurate frequency analysis in order to:

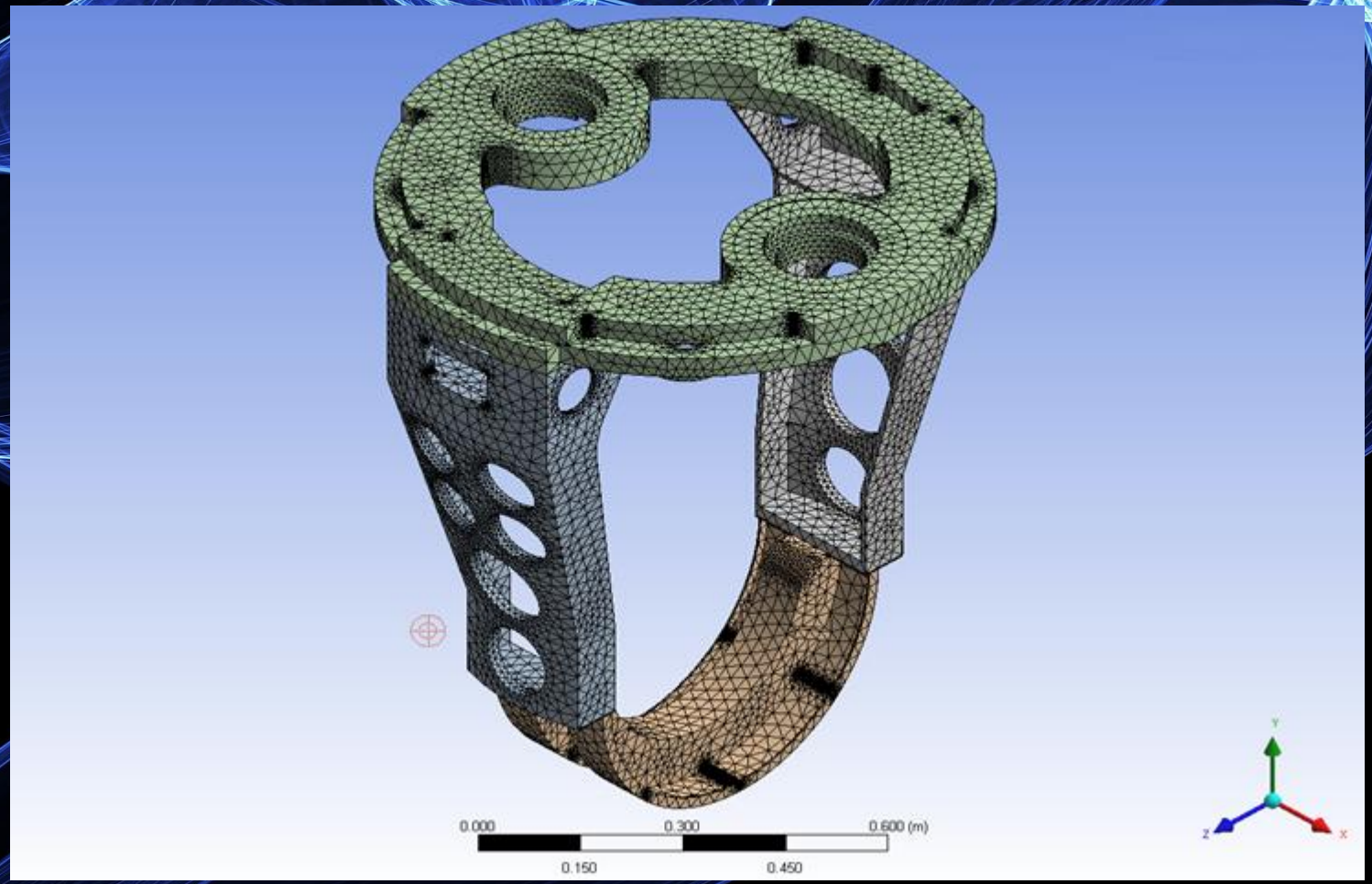
- Properly tell the effect of a gravitational wave
- Avoid resonances in the control loop bandwidth

COMPLETE ANALYSIS PROCEDURE

- Numerical analysis to evaluate modal behaviour
- Experimental test to validate the model
- Effective mass evaluation in order to identify, among all, critical modes

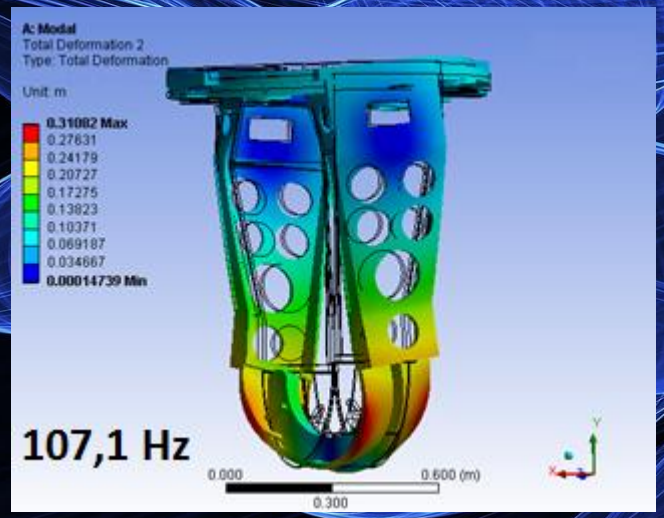
Numerical analysis

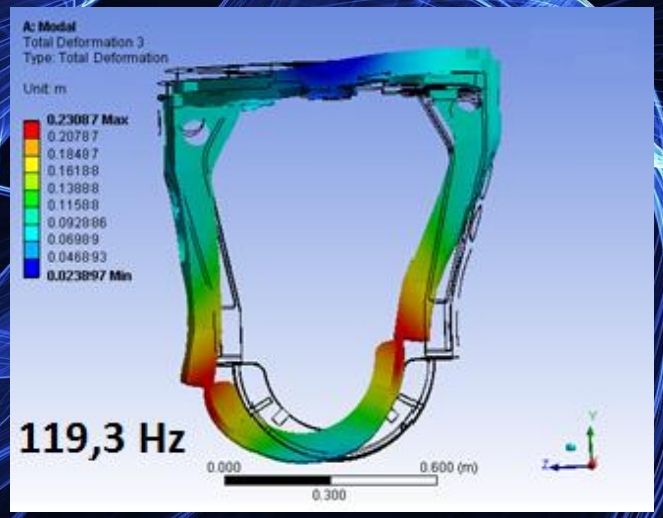
Ansys workbench – Mesh
Cage of the payload
Modal analysis

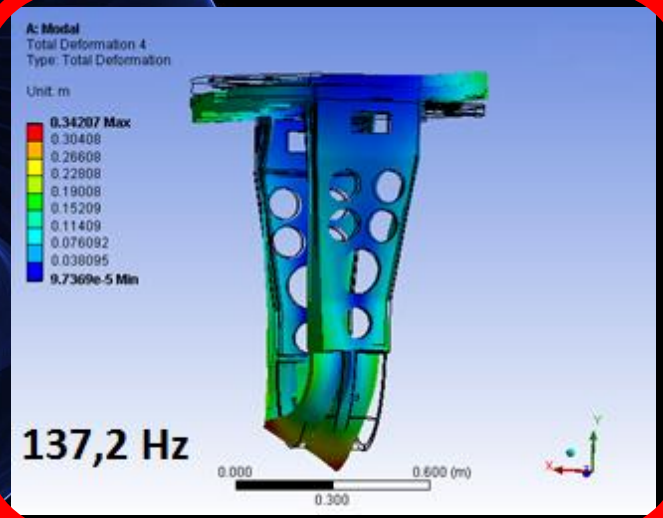


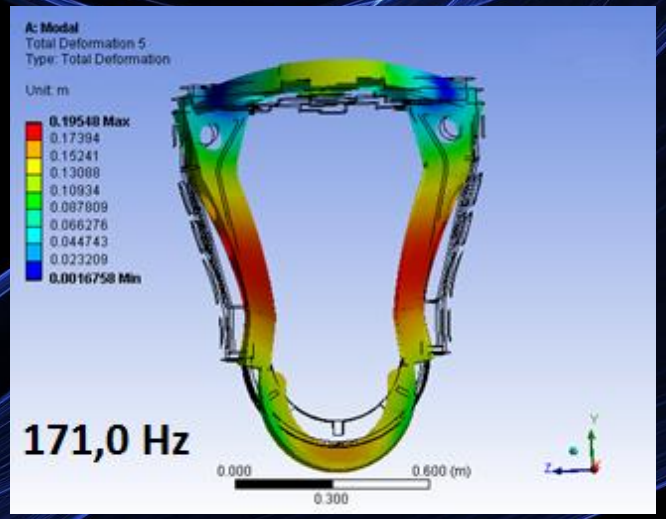
- Free boundary conditions (no constrains)
- N° of elements: 497057
- Materials: Anticorodal 6082, Aisi 316L steel
- Overall weight: 109 kg

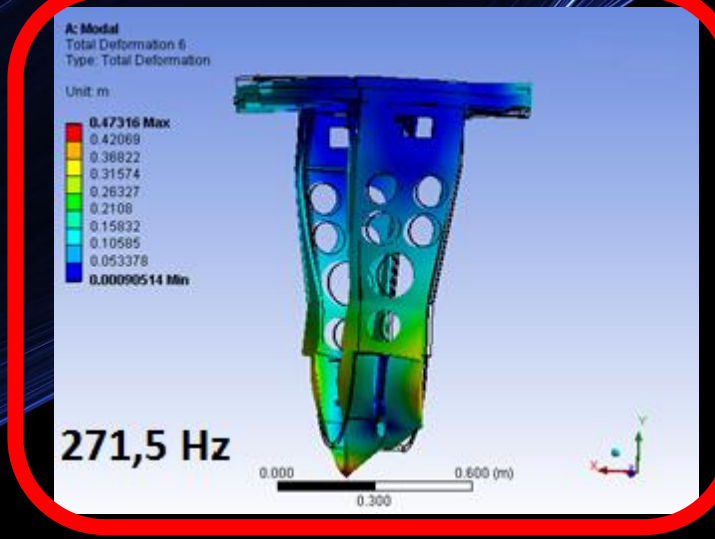
Ansys workbench - Modes

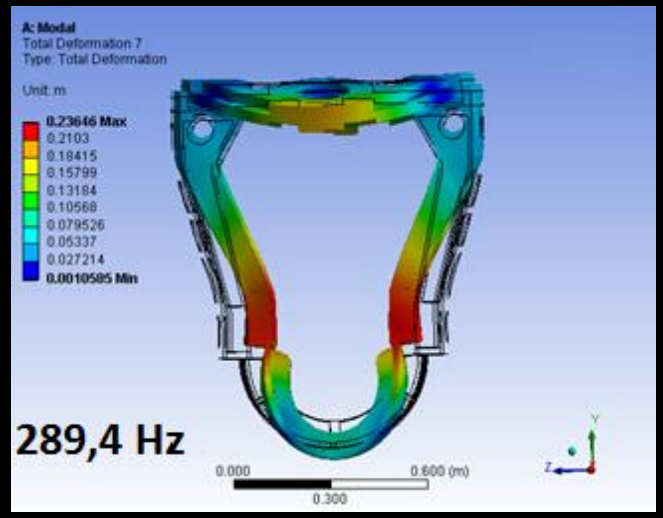




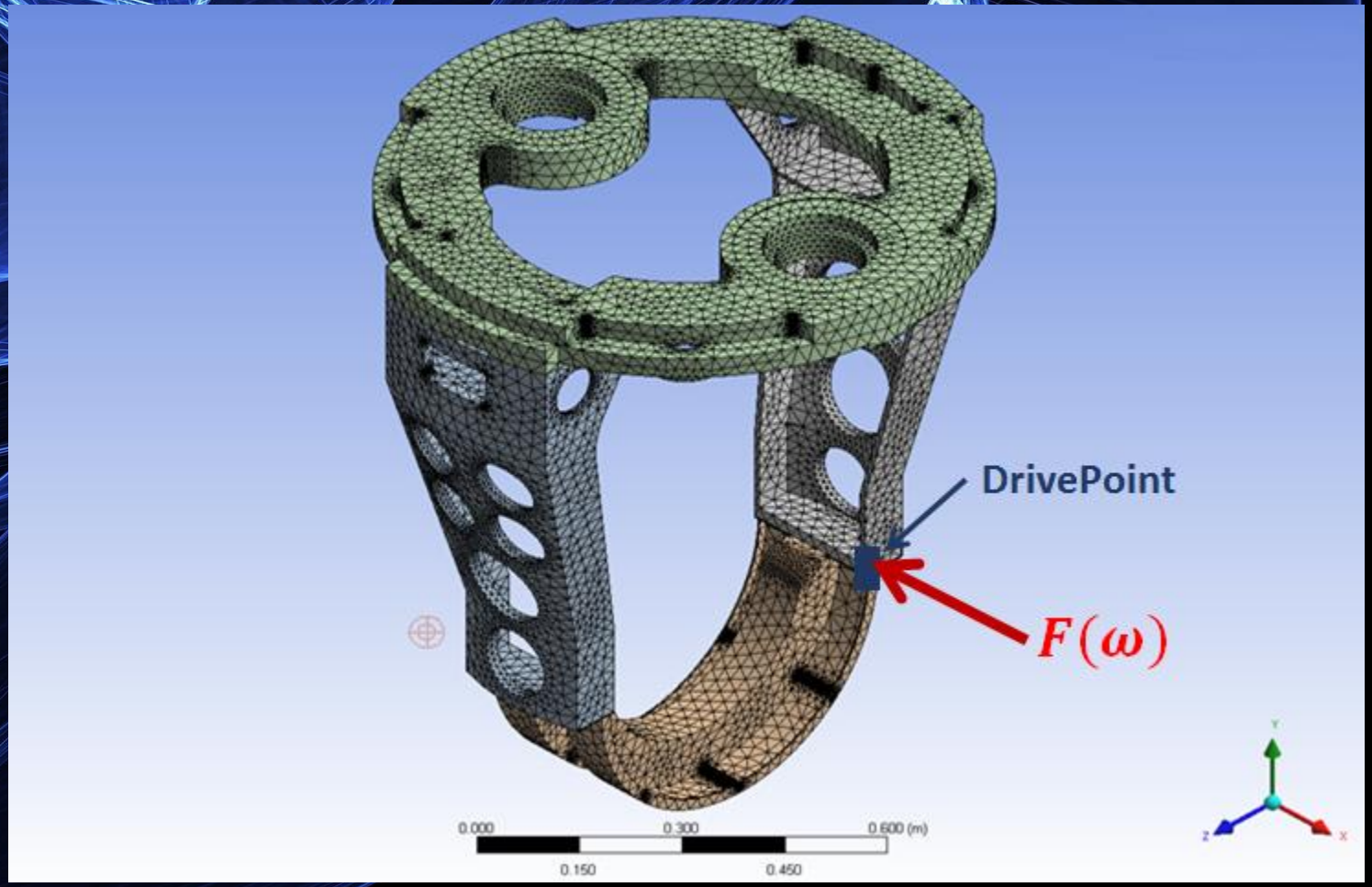








Ansys workbench – Mesh
Cage of the payload
Harmonic analysis



Ansys workbench – Mesh
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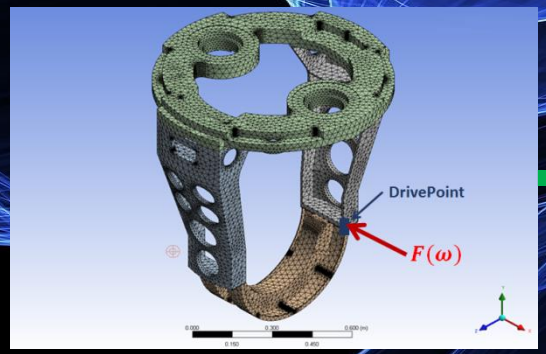
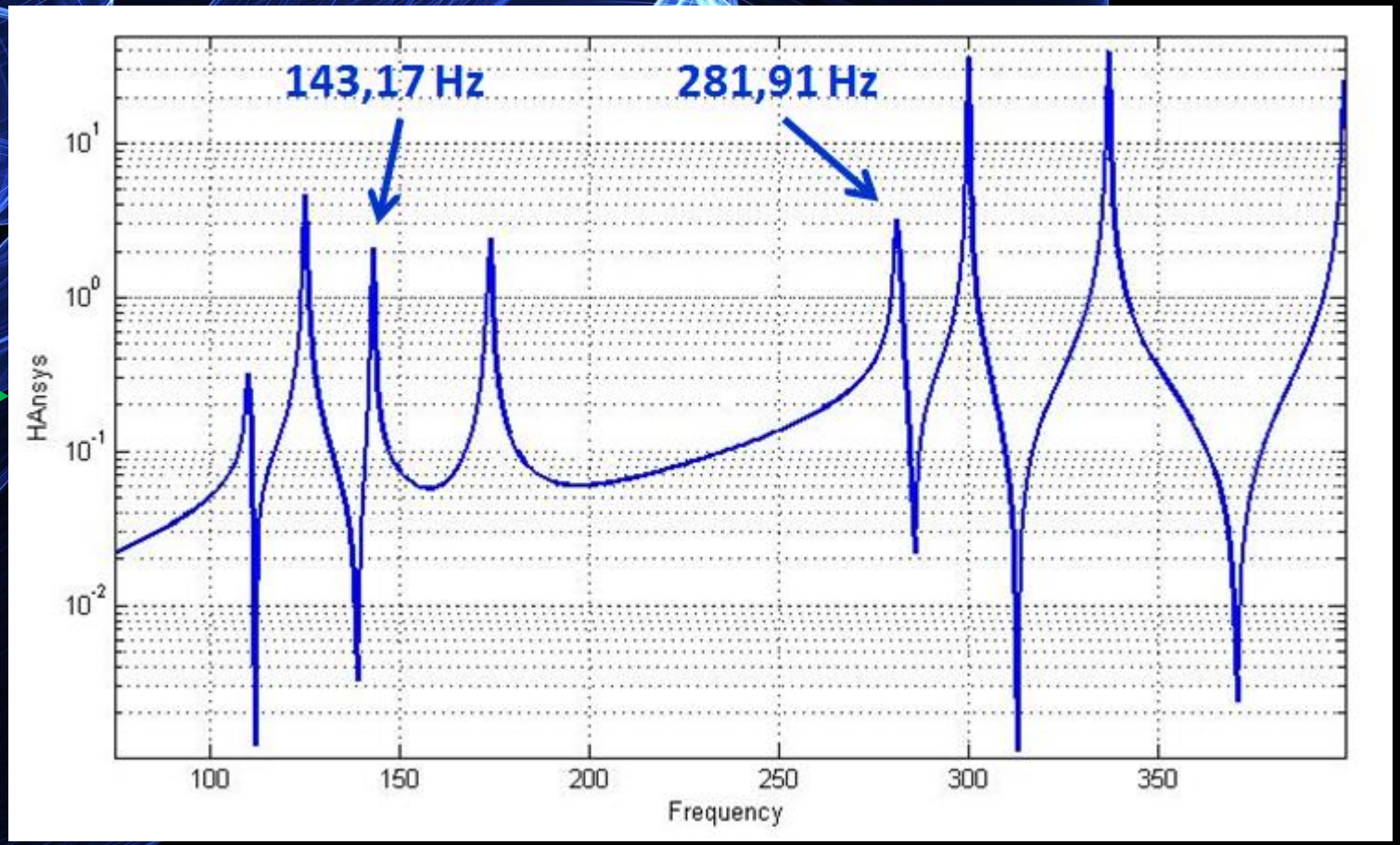




Experimental test

Cage of the payload
Experimental analysis
SETUP

Simulated free conditions

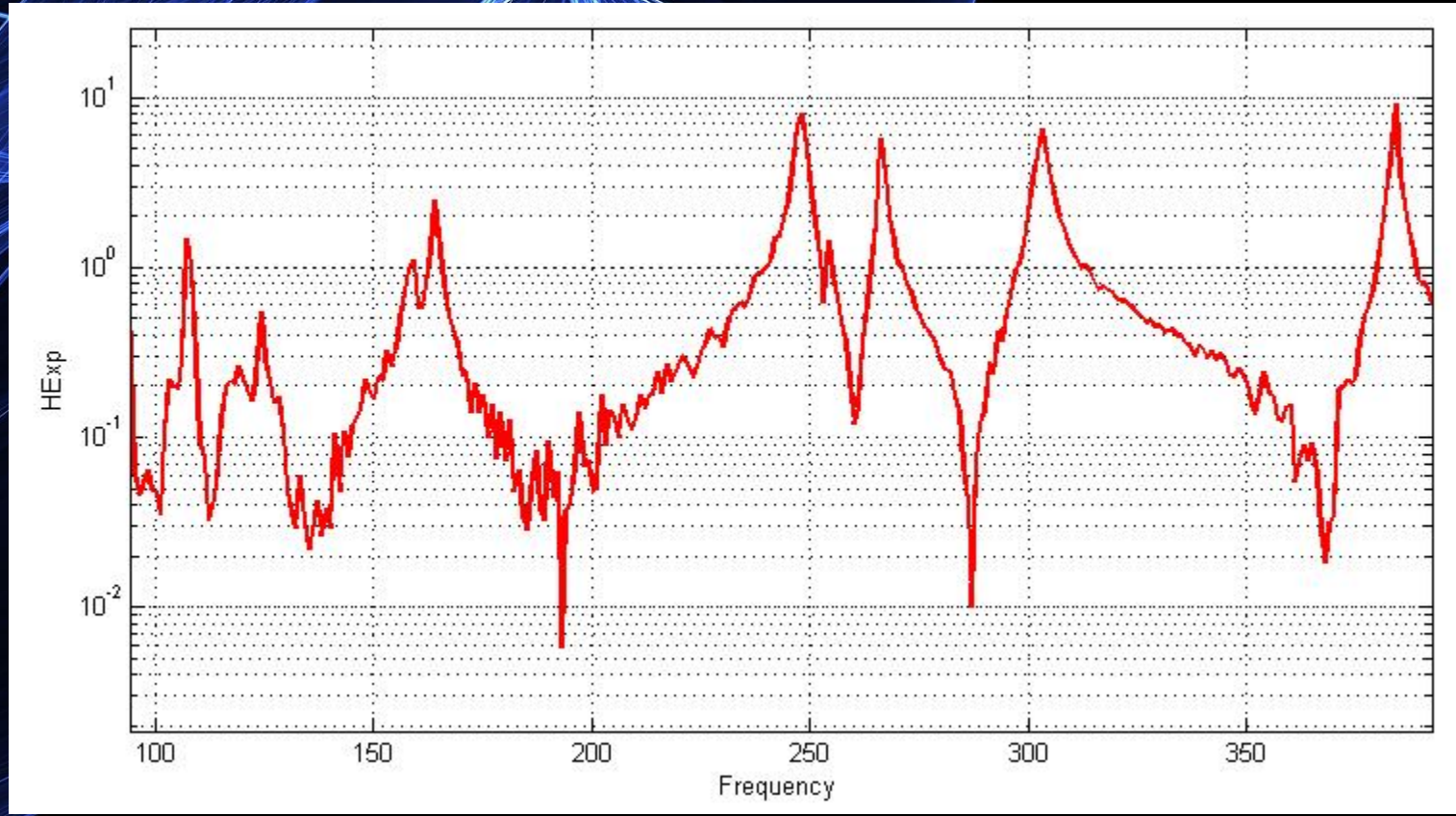
- Excitation: multiple impact hammer

- Acquisition system: prosig

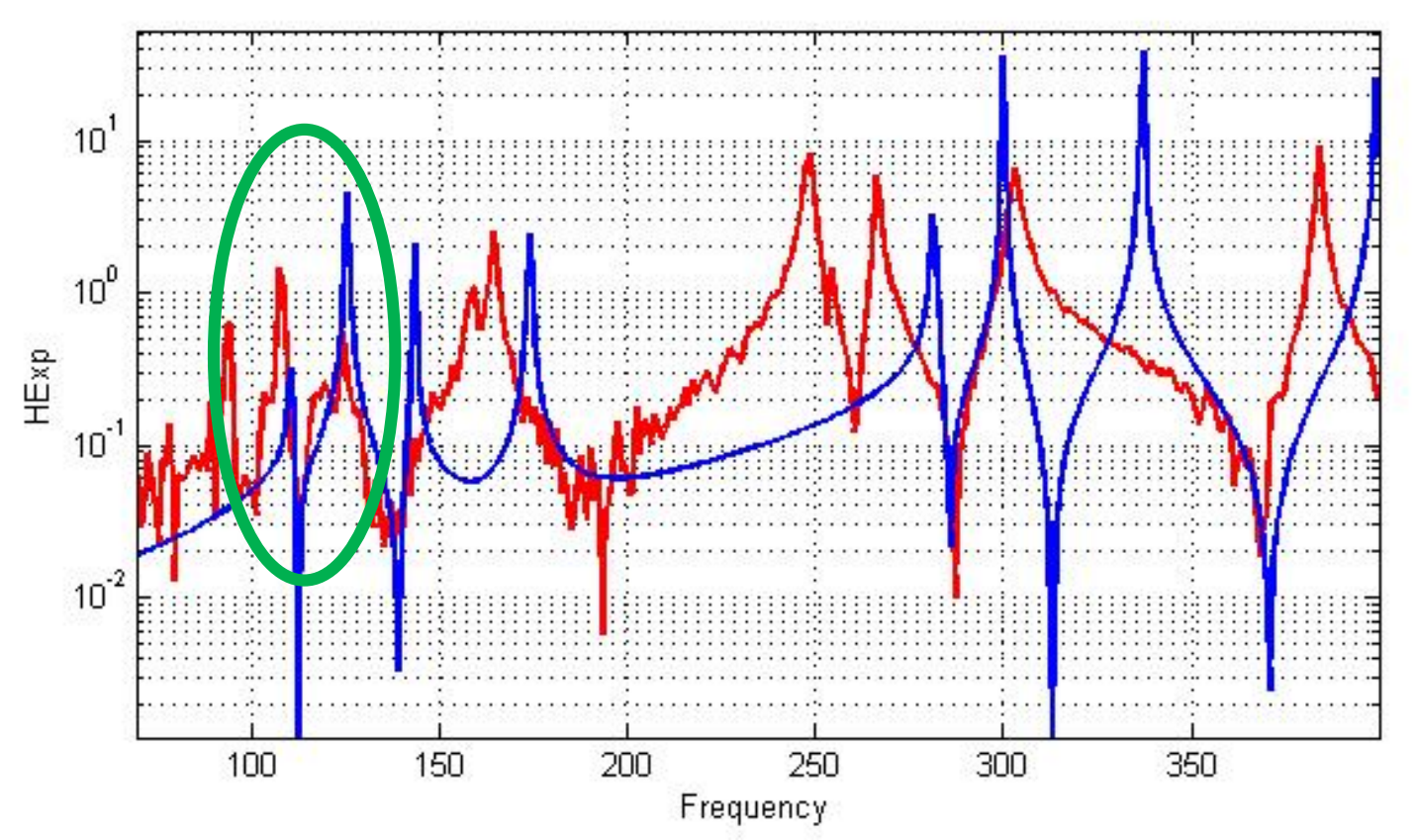
- 3D accelerometer

Cage of the payload
Experimental analysis

Simulated free conditions



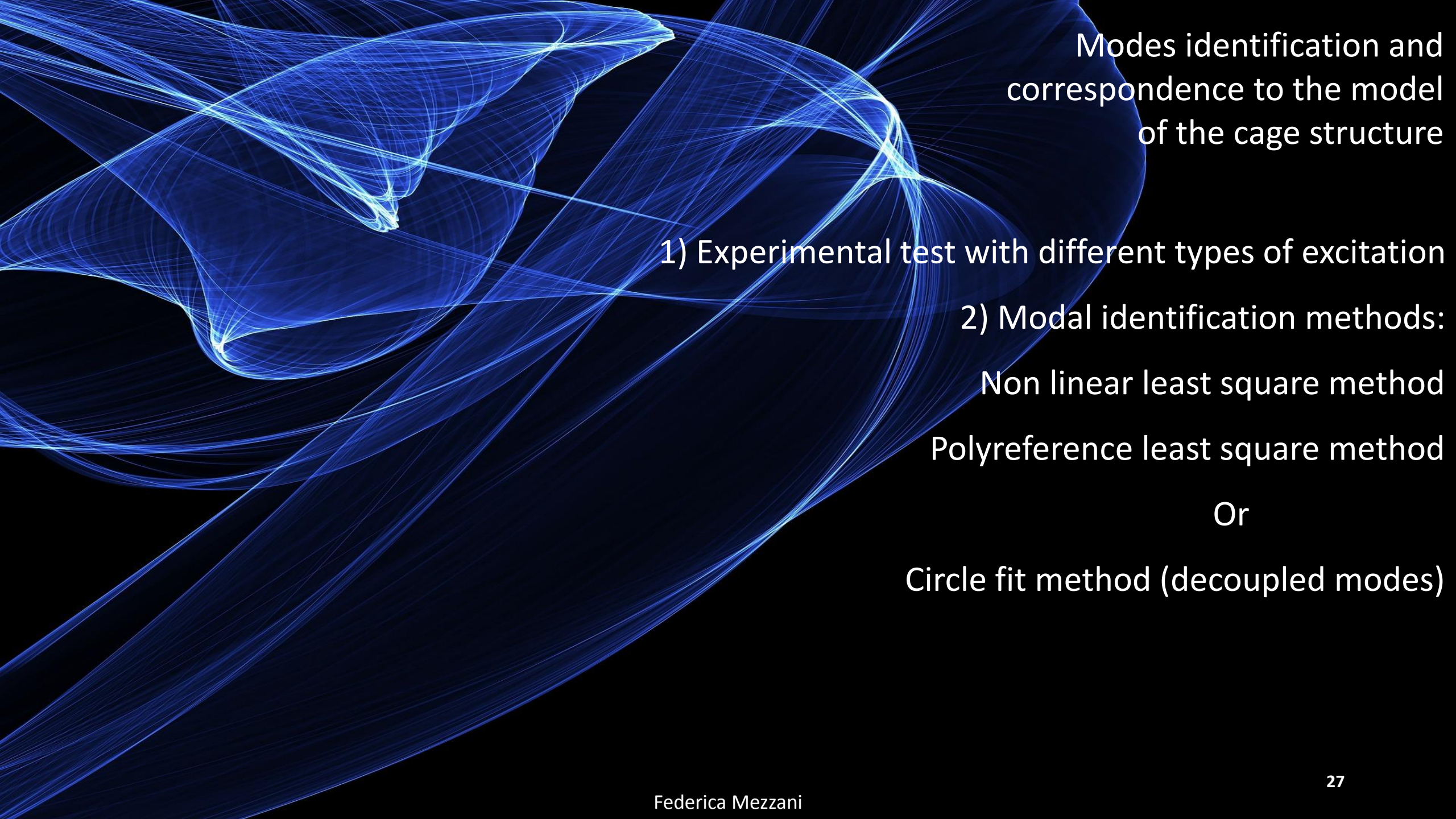
Results comparison
Preliminary analysis



Blue curve: **Numerical** results

Red curve: **Experimental** results

Proposals



Modes identification and correspondence to the model of the cage structure

1) Experimental test with different types of excitation

2) Modal identification methods:

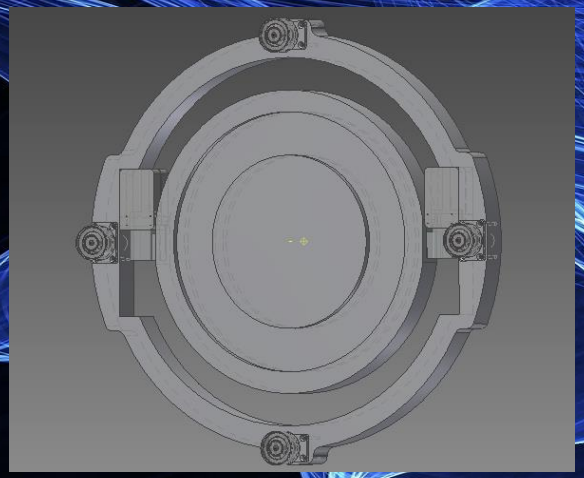
Non linear least square method

Polyreference least square method

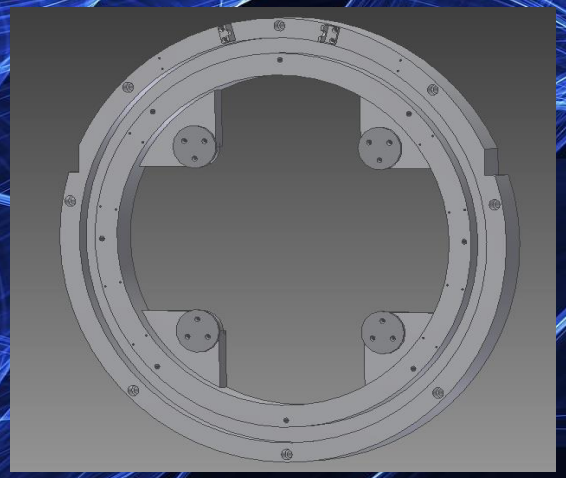
Or

Circle fit method (decoupled modes)

Implementation of further components in the model

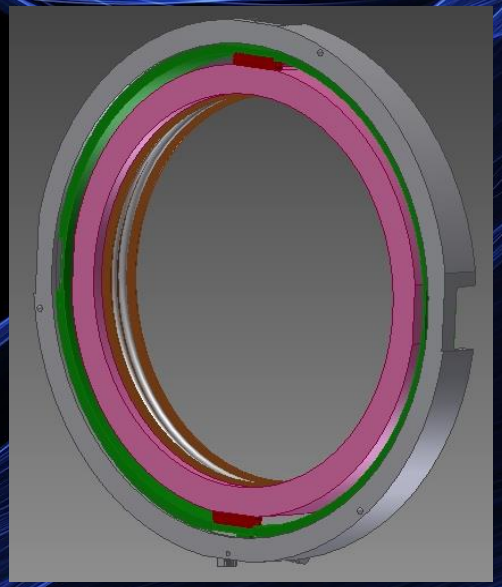


Pick Off Plate (POP)

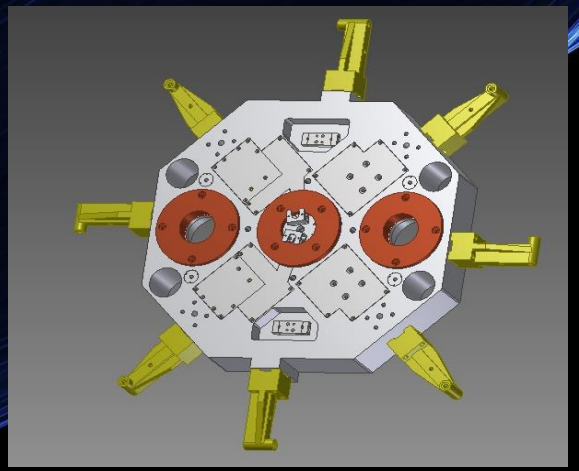


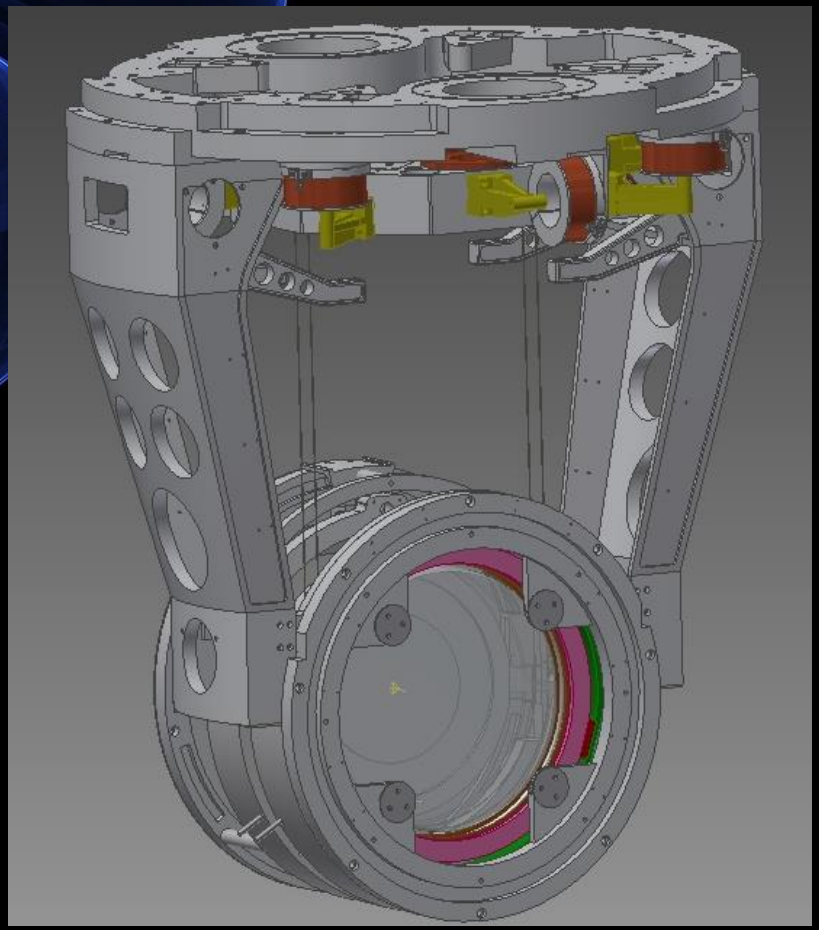
Actuators plate

Ring Heater

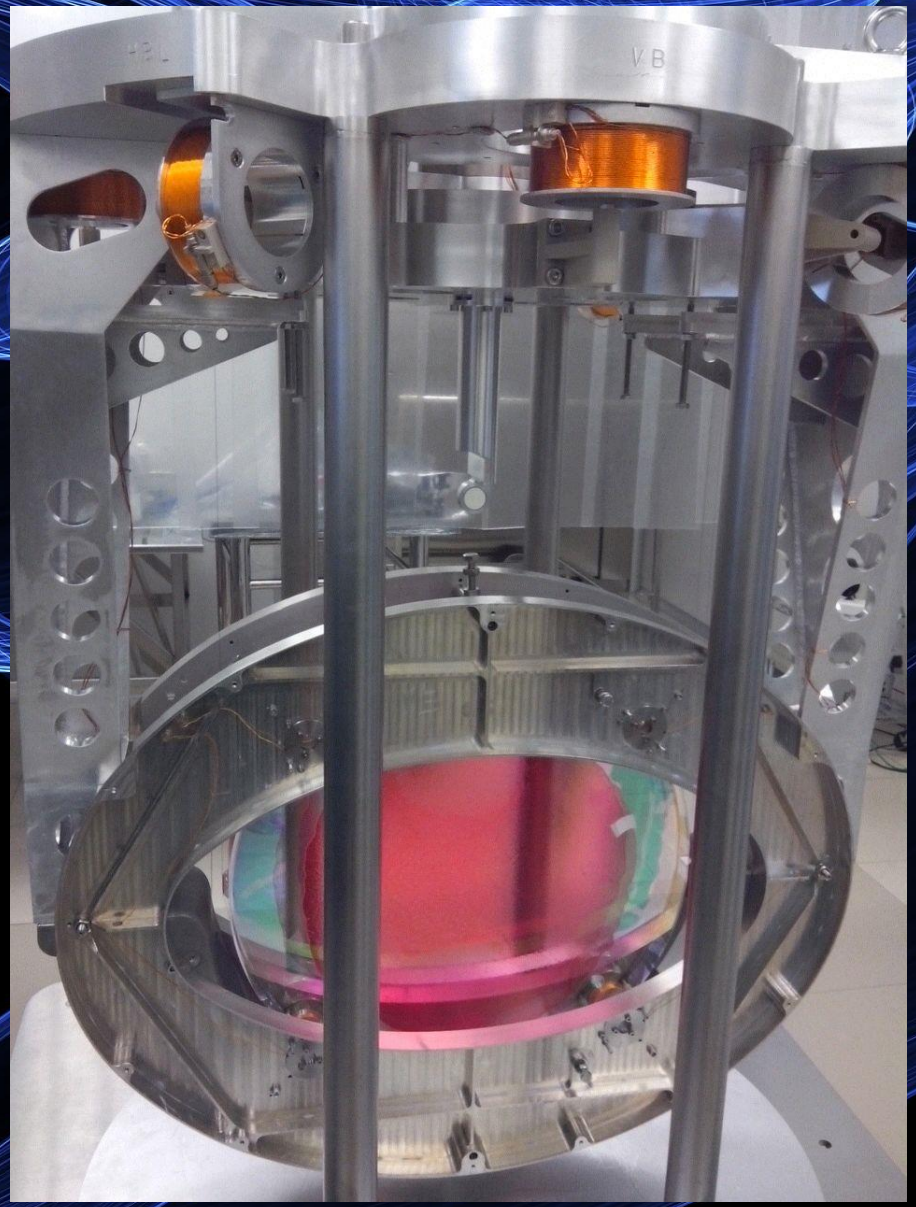


Marionette



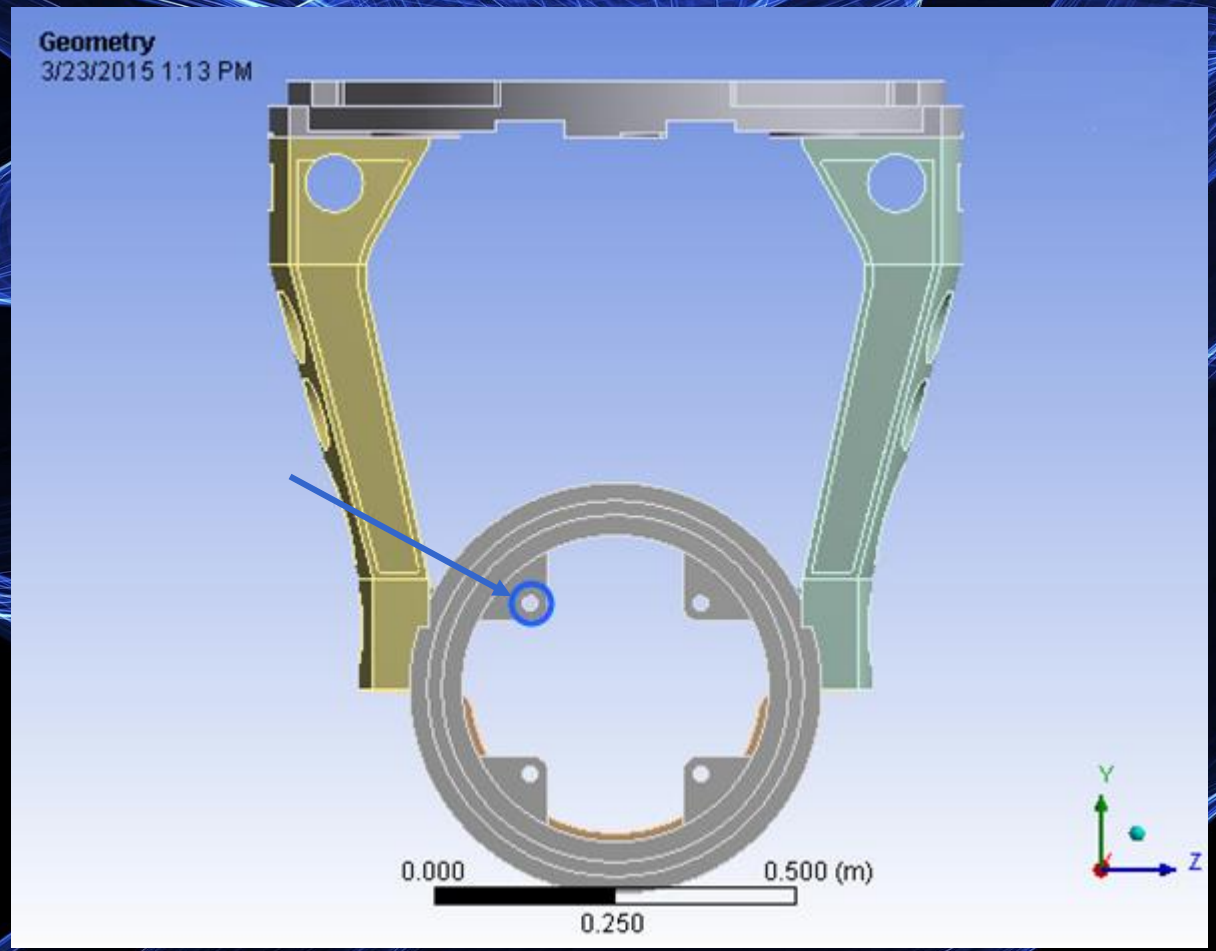


Test session on the complete structure



- Numerical analysis to evaluate modes
- Geometry review
- Experimental analysis
- Effective mass evaluation

Effective mass evaluation



Cage + actuators plate

Effective mass defines the percentage of the total mass that contributes to a specific mode

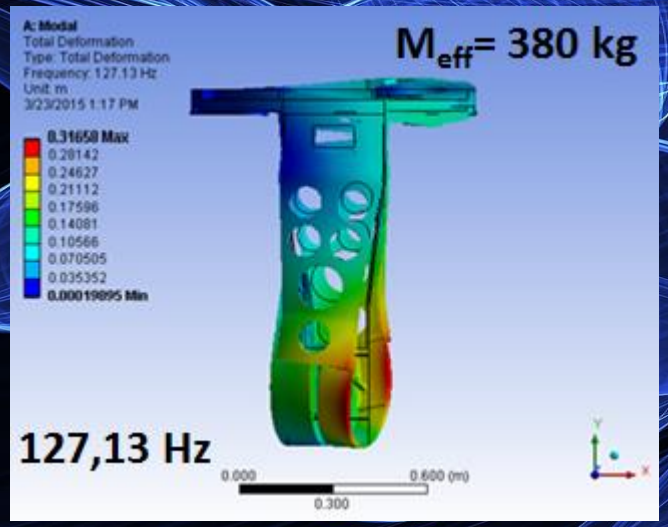
It provides an estimation of the coupling between modes

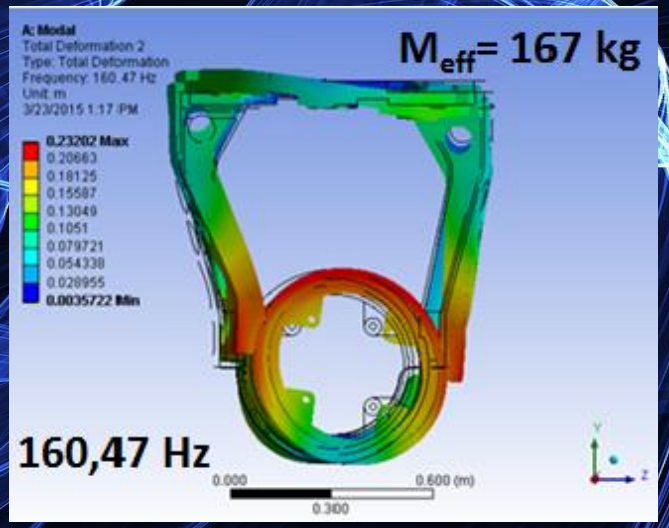
Around a resonance frequency the behaviour of a structure is equivalent to the one of a 1D harmonic oscillator of M_{eff}

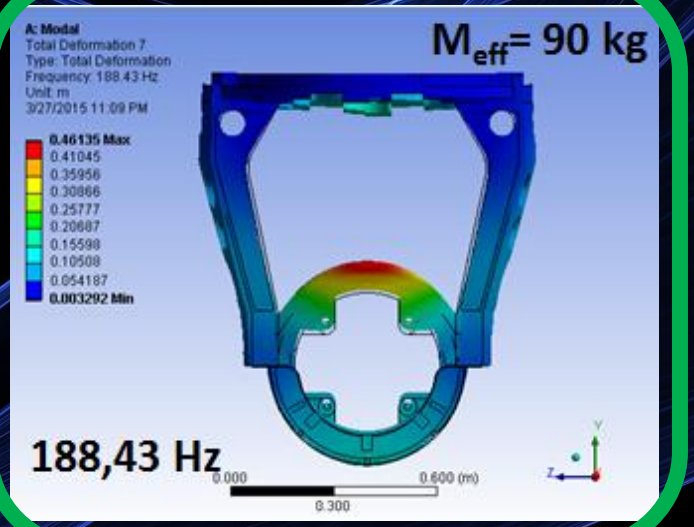
$$E_{strain} = \frac{1}{2} M_{eff} \omega_0^2 x_{eff}^2$$

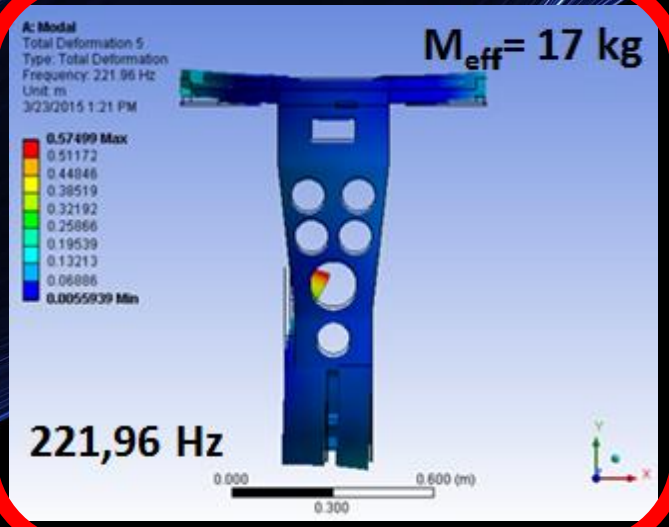
Hyp: small dissipations

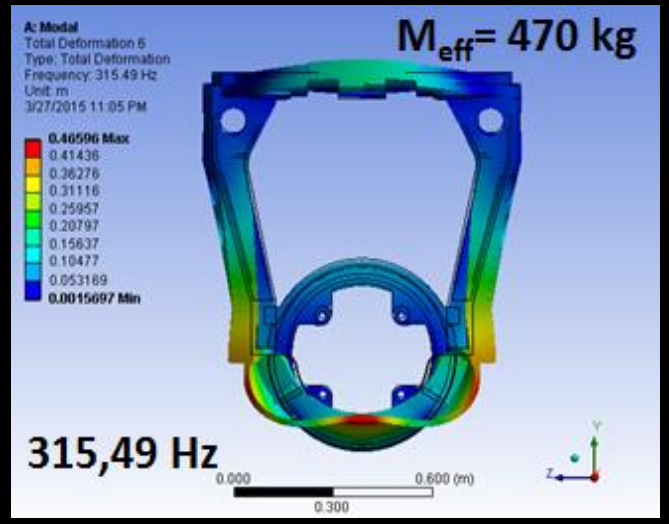
Ansys workbench - Modes











Conclusions

- Design in accompliance with the target
- Towards a standardisation of the approach in order to extend the application for all the payloads

Thank you for your attention!!