MITIGATION of PARAMETRIC INSTABILITY

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Rencontres de Moriond 2019
Parametric Instability: 3 mode interaction

- Where? In cavities (optomechanical systems)
- Predicted by Braginsky, Strigin, Vyatchanin (2001) in GW detectors

\[ \omega_0 - \omega_m \]
\[ \omega_1 = \omega_0 - \omega_m \]

if
- \( \omega_0 \) and \( \omega_1 \) resonant in the cavity
- Matching between mechanical and optical mode shapes

\( \Rightarrow \) Growing amplitude of \( \omega_m \) and \( \omega_1 \)
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  \( \rightarrow \) Growing amplitude of \( \omega_m \) and \( \omega_1 \)
Outline

• Experimental observations
• PI mitigation strategies
• PI Damping system based on radiation pressure
• First developments
• Conclusions and next steps
Experimental observations

- Gravitational Waves detectors: Observation of Parametric Instability in Advanced LIGO [Evans et al. PRL 114,161102 (2015)]


- Micromechanical resonators: Observation of three-mode parametric instability in a micromechanical resonator [Ganesan APPLIED PHYSICS LETTERS 109, 193501 (2016)]
Mitigation strategies

Thermal tuning with RH

Thermal tuning with the RH changes the Mirror radius of curvature and shifts the beating note far from the most critical mode (E)
Mitigation strategies

Active damping by Electrostatic driver (ESD)

\[ \tau_{\text{PI}} = 182 \text{ sec} \]
\[ \tau_{\text{eff}} = -23 \text{ sec} \]

PRL 118, 151102 (2017)

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Mitigation strategies

Acoustic Mode Dampers (ESD)

Piezo+ reaction mass

25% loss factor

Low loss in GW band

[S. Biscans PhD Thesis 2018]
Mitigation strategies

Acoustic Mode Dampers (ESD)

Piezo+ reaction mass

Confidence level 95%, $P_{\text{arm}} = 750\text{kW,} \ MC = 250\text{k}$

[S. Biscans PhD Thesis 2018]
Mitigation Activities for Virgo

- Rome group activity
  - AMD study at Rome labs

- Activity on Virgo site
  - Use of Thermal compensation to shift the beat note (Roma Tor Vergata)
  - Use the coil for damping (Roma)

- Active damp by radiation pressure.
  - T. Harder PhD thesis started in November 2018
    R. Soulard, W. Chaibi, G. Bogaert, M. Merzougui, M. Pichot
Principle of the damping system based of radiation pressure

PI mitigation with an auxiliary Laser outside the cavity

Super attenuators

Stabilized laser

\[ dz \]

Time
Principle of the damping system based of radiation pressure

PI mitigation with an auxiliary Laser outside the cavity

Concept:
- Modulate the beam amplitude to damp mirror modes at correct times.

Super attenuators

Stabilized laser

RF mod

AOM

Damping by radiation pressure

Time

dz

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Principle of the damping system based on radiation pressure

PI mitigation with an auxiliary Laser outside the cavity

Concept:
- Modulate the beam amplitude to damp mirror modes at correct times.
- Use two acousto-optic modulators: vertical and horizontal displacement
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AOM Deflector

Damping by radiation pressure

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Research and development plan in ARTEMIS

1. Design of a table-top cavity for studying PI

Challenges:
• Match all criteria: high $Q_m$, resonance $\omega_1 = \omega_0 - \omega_m$
  spatial mode overlap of $\omega_1$ and $\omega_m$, cavity stability

→ Develop new tools for simulation, a dynamical approach
Research and development plan in ARTEMIS

2. Design and implementation of active mitigation device

Challenges:
• Sensing, RF frequency control, synchronization

Mach-Zehnder interferometer to monitor mirror displacement

λ = 1064 nm or 1030 nm, P

1. Suspended Test Mass

2. Laser

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Research and development plan in ARTEMIS

- Objectives 1. and 2. will be developed in parallel
- Optical and mechanical simulations, PI simulations → cavity design
- Development of dynamical simulations for including the auxiliary laser damping force
- Experimental development and characterization
Choosing the Acousto-Optic Modulators

- RF frequency modulation $\rightarrow$ spatial scan
- Acousto-optic modulator: deflectors / frequency shifters

\[ \alpha P_0, \nu_L + \nu_{RF} \]
\[ (1 - \alpha)P_0, \nu_L \]
Deflector vs. Frequency shifter

- Frequency shifter
  - higher rise time $\rightarrow$ smaller scan angle

- Deflector
  - Smaller rise time $\rightarrow$ higher scan angle

\[
\Delta \theta = \frac{\lambda v_{RF}}{v_{acoust}}
\]
\[
T_{rise} \propto \frac{\theta_{beam}}{v_{acoust}}
\]

The chose AOM
- Scan Angle: 50 mrad for $\theta_{beam} = 210 \mu m$
- $T_{rise} = 33$ ns
- 10 W input power
RF frequency control

1. Mach-Zehnder interferometer with phase modulation + frequency shift

2. Software defined radio reconfigurable device from National Instruments

→ Frequency change in range 1MHz - 6GHz in 5ns
Experimental results of the MT110-A1.5-1064 Frequency shifter

- Sinusoidal deflection
- Good description of the deflection for sinusoidal modulation frequencies up to 3 MHz
Next steps

- Power stabilisation
- RF control by programmable card
- Simulations/calculation for the cavity design
Conclusions

• Parametric instability is a multimode (three) optomechanical interaction → interesting from a fundamental point of view.

• PI is bad for GW detectors. PI must be mitigated in order to allow improvement of sensitivity by increasing the laser power.

• We have started an experimental research program to develop a flexible device for PI mitigation based on radiation pressure.
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- Parametric instability is a multimode (three) optomechanical interaction → interesting from a fundamental point of view.

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Thank you!