Monitoring Void Fraction and Bubble Formation in Flowing Liquid Nitrogen

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Background

- The Laser Interferometer Gravitational-Wave Observatory (LIGO) is a large-scale physics experiment and observatory that detects gravitational waves from some of the most violent and energetic processes in the Universe.

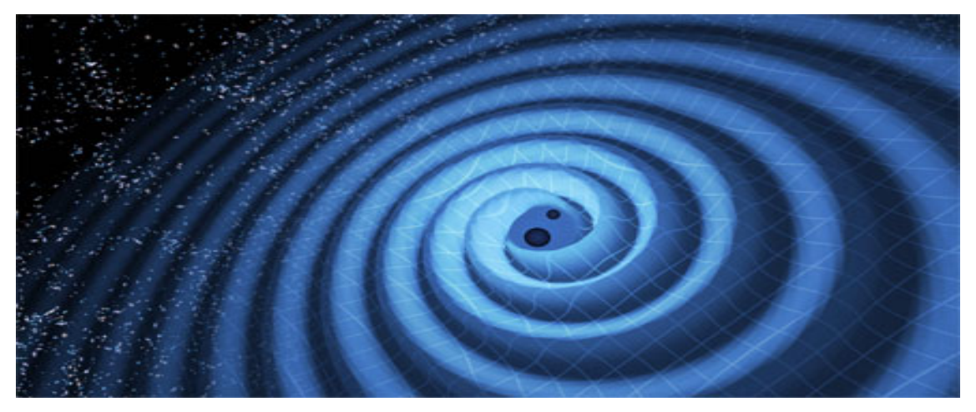

Figure 1. Merger of two black holes and the gravitational waves that ripple outward

- The new generation of observatories hopes to improve the sensitivity, opening a new era in our exploration of the universe. In particular, research is being done on how to reduce thermal noise by cooling the test mass to 124 K with the use of liquid nitrogen, to contribute in achieving this goal.
- However, the cryogenic systems for future LIGO detectors can potentially introduce other sources of noise that would undo the progress and impact the sensitivity levels.

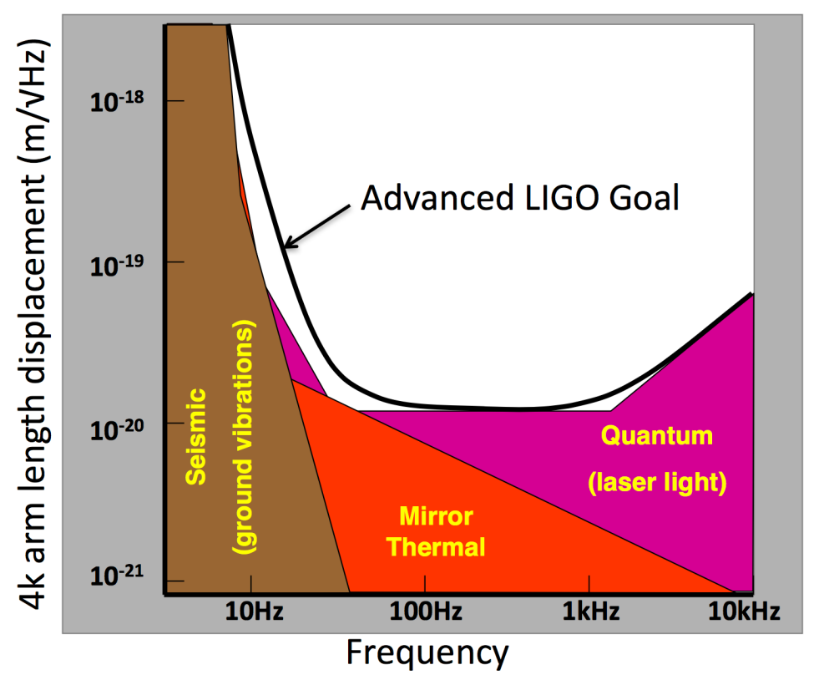

Figure 2. Advanced LIGO's dominant noise contributions
LIGO-G1701418

- As liquid nitrogen absorbs enough heat from the test mass and the scattered light from the laser, it warms up and might boil.

Density changes in the liquid nitrogen near the mirror result in changing gravitational forces, better known as Newtonian Noise. If the forces on the test mass are too large, they could limit LIGO's performance.

Measure density fluctuations in liquid nitrogen flowing through a pipe

Materials and Methods

Visually detect bubbles and their characteristics: count, size and rate of appearance.

- Liquid flows through a ½" wide stainless steel tube, with a 6" long Pyrex window.
- The tube is illuminated by two flashlights, pointed diagonally from below, which strobe at 30 Hz to match the camera's frame rate of 30 fps.
- A webcam is placed directly above the tube since bubbles will naturally rise and center in the tube due to buoyancy.

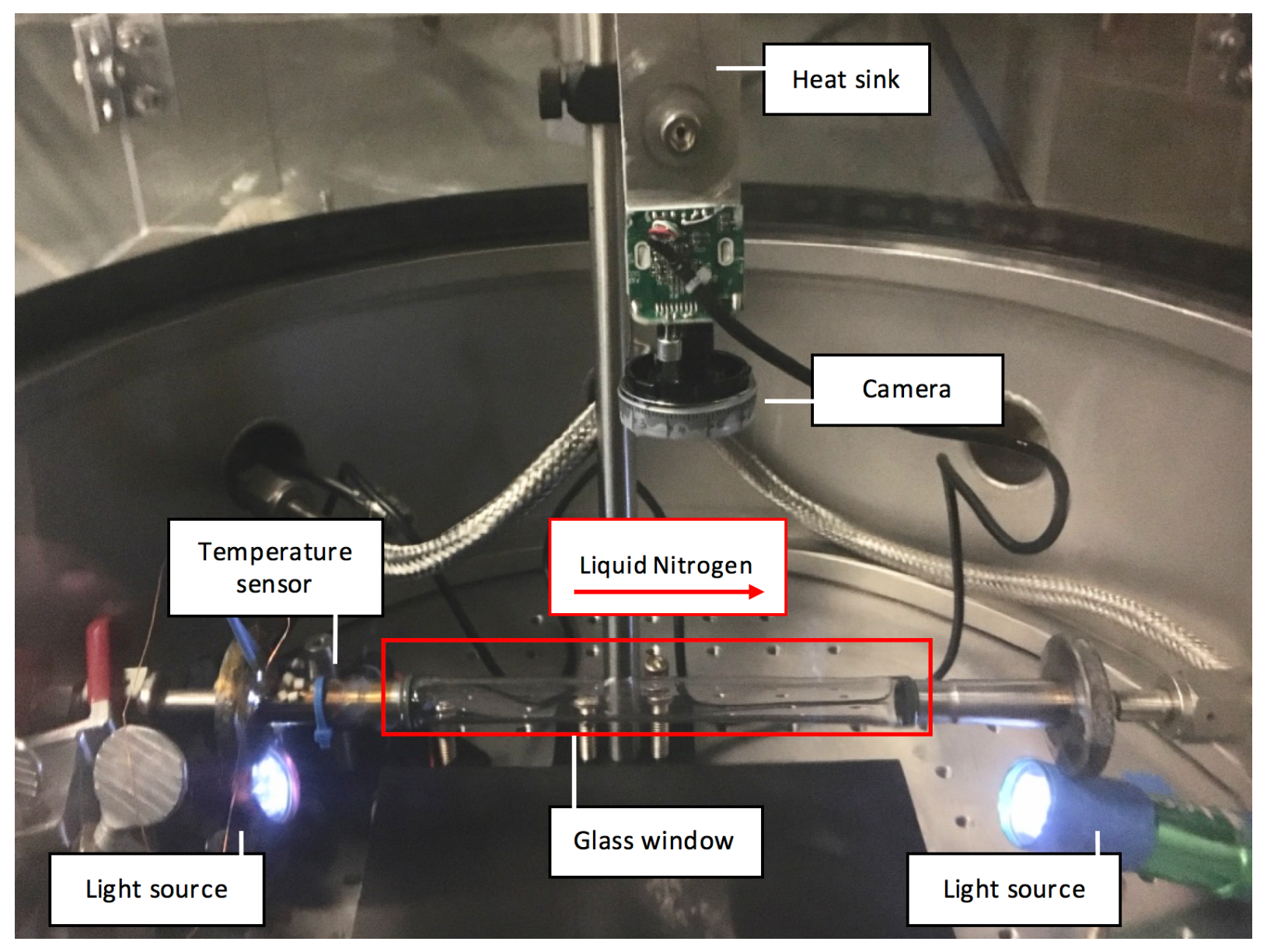

Figure 3. Experimental set up

This set up is placed inside a vacuum chamber that reaches high vacuum (10^{-5} torr). Liquid nitrogen subcooled to nearly 63.15 K is sitting in a closed tank, and it is pressurized by introducing nitrogen gas from a secondary tank.

- **Subcooling:** Liquid nitrogen cooled to a temperature below its normal boiling point (77.36 K).

Results

- Bubble flow in the liquid nitrogen can be measured by the camera and software. However, if the nitrogen flow is around 77 K, the bubbles are big enough that two bright spots appear from the light sources. In contrast, the bubbles of a subcooled flow are greater in quantity and exceedingly smaller in size.
- It must be noted that for the subcooled trial, the flow had to be slow enough (~ 0.2 m/s) for the bubbles to start forming.

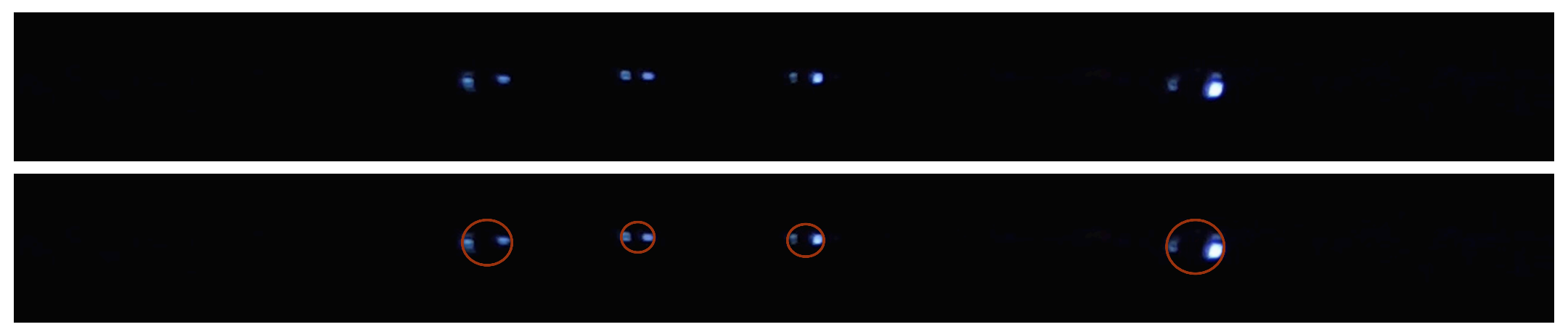

Figure 4. Bubble formation of a flow at boiling temperature

Figure 5. Bubble formation of subcooled flow

- A MATLAB script detects the bubble centroids and collects information, including the area of each bubble. This information can be statistically analyzed later.

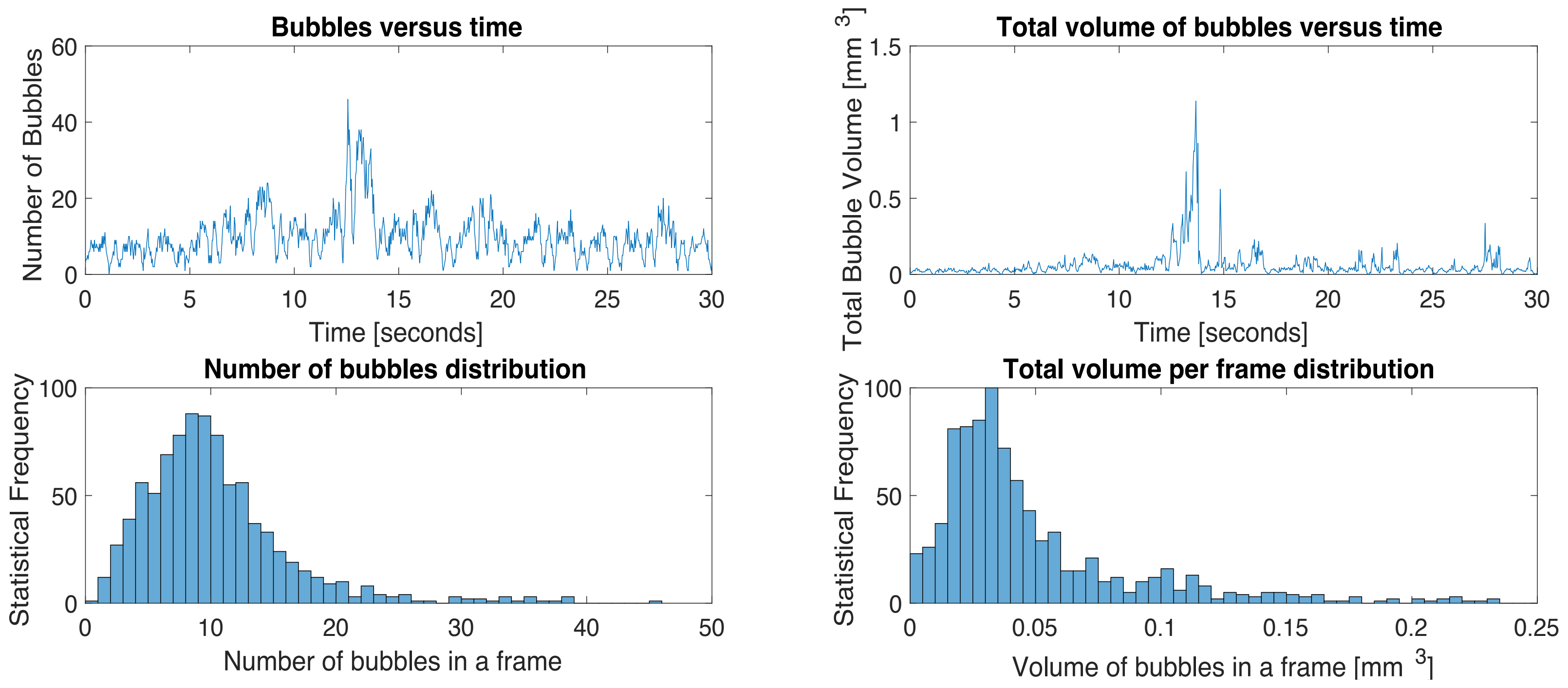

Figure 6. Bubble distribution in time and statistical distribution of subcooled flow

Conclusions

- The technique developed is suitable to measure bubbles greater than 160 microns in diameter, to make observations about the flow, and to calculate the Newtonian Noise. However, it is not suitable for the liquid nitrogen at boiling temperature.
- Subcooling is shown to be effective for the reduction of bubbles in the system.
- The velocity of the flow is inversely proportional to the amount of bubbles. At flows faster than 0.2 m/s, no bubbles were observed because the nitrogen does not reach its boiling temperature with the heat absorbed.

Future Work

- Determine the required conditions for the flow to have Newtonian Noise compliant with the desired sensitivity levels of LIGO Voyager.
- Connect the experimental set up to the end of the cryogenics shield and verify that the density fluctuations will not be a concern.
- Automate the software used to process the data.

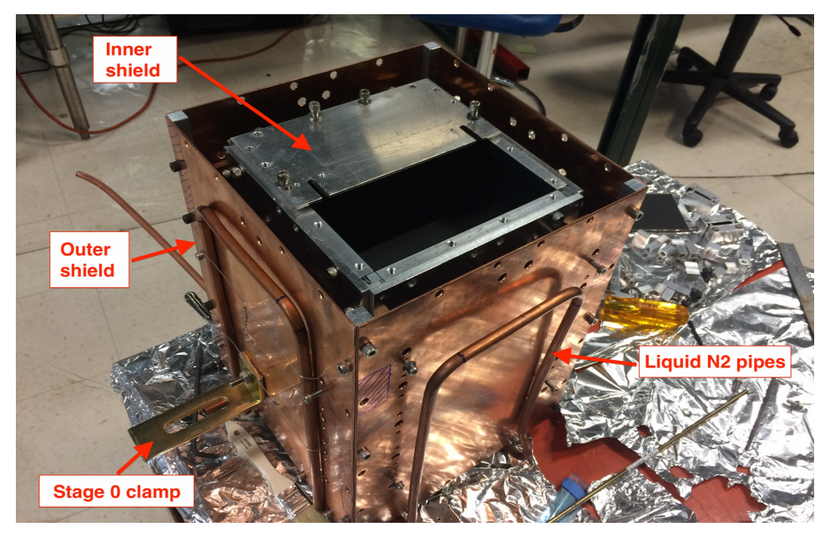

Figure 7. Test mass heat shield
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