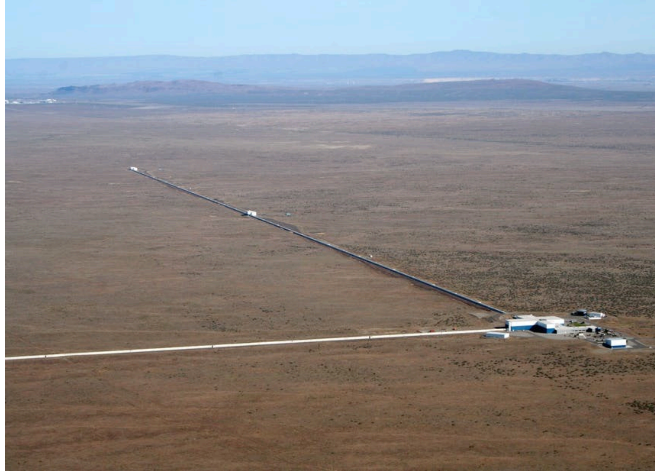
GW astronomy at UBC/TRIUMF

Jess McIver for the UBC team
June 29, 2021
GWANW 2021

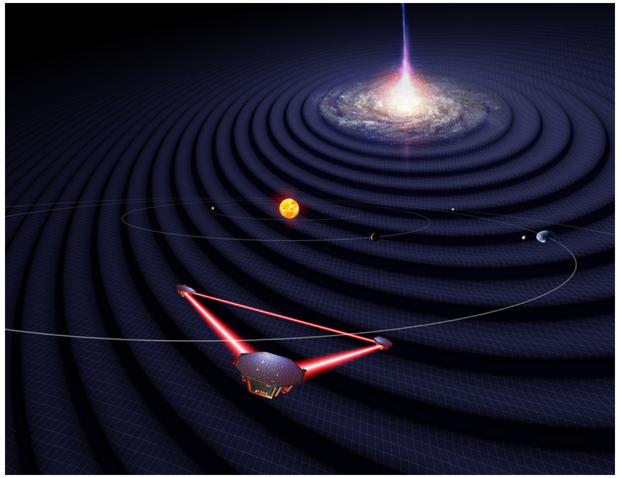
LIGO DCC G2101374

Across the GW spectrum: UBC and TRIUMF



Ground based interferometers

- UBC LIGO group
- UBC GW astrophysics group

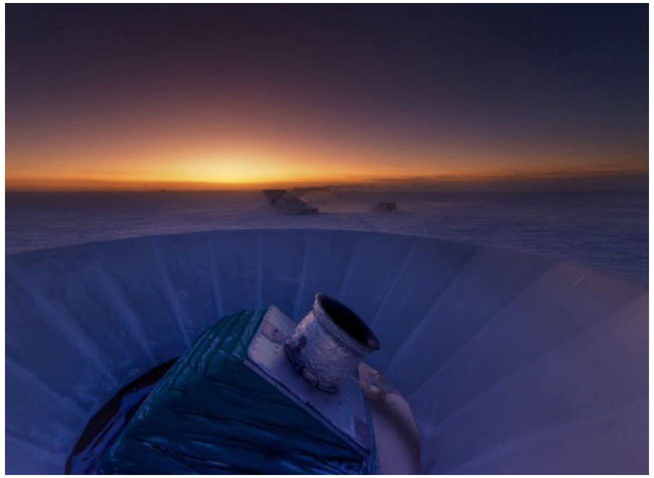


Space based interferometers

- UBC-TRIUMF LISA group

Pulsar Timing Arrays/FRBs

- UBC CHIME team



B-mode polarization

- Search for B-mode polarization at UBC

Multi-messenger astronomy and tests of GR with ground-based GW detectors at UBC

Dr. Miriam
Cabero

GWSkyNet

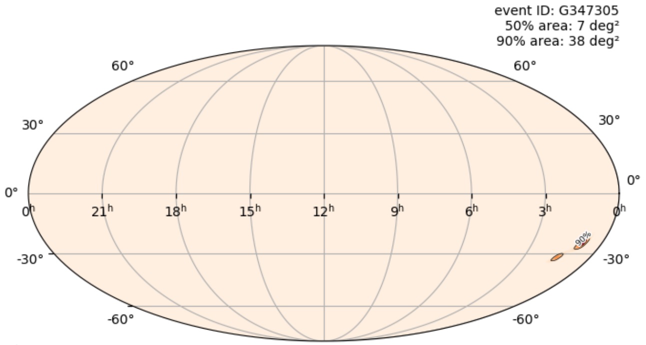
Convolutional neural network

- 2D sky map image
- 3D volume image
- Detector network
- Estimated distance

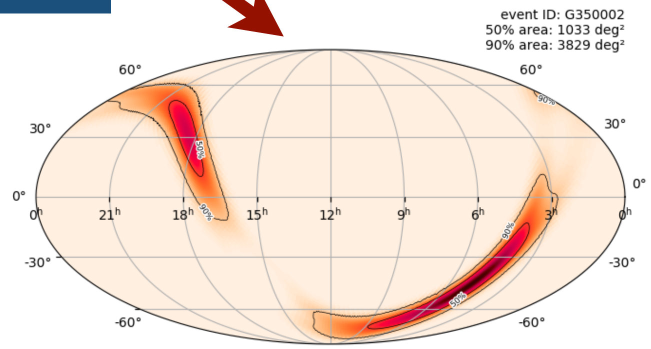
Astrophysical

GraceDB

Not astrophysical



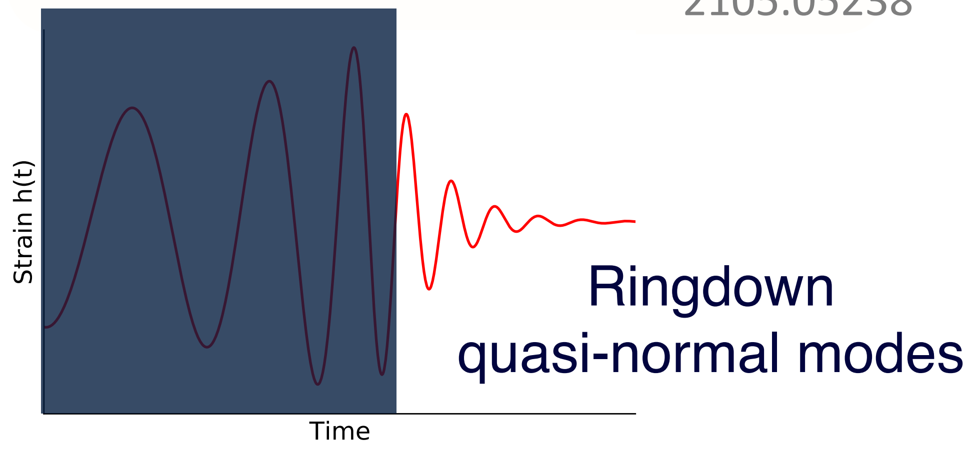
GW190814



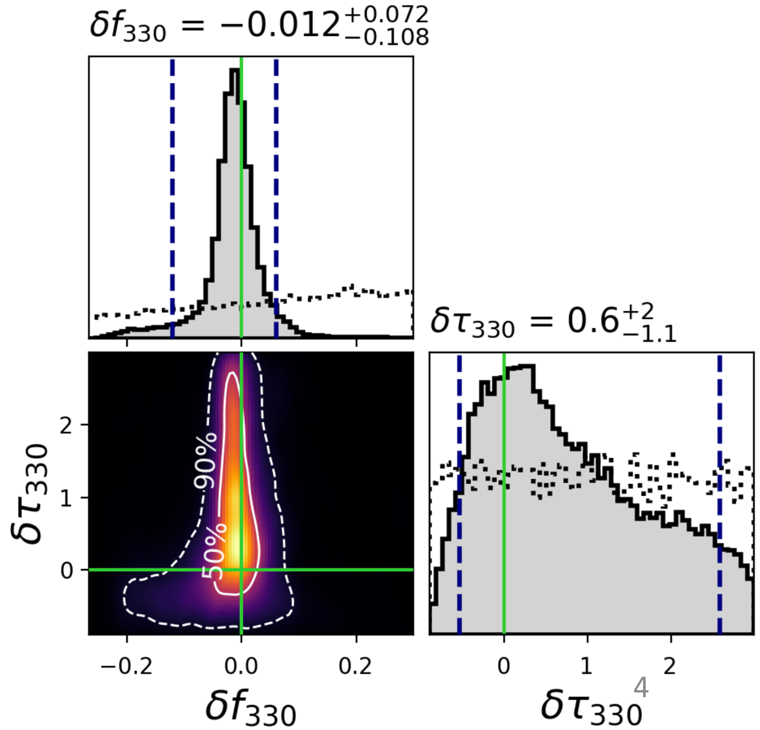
S190910d

Testing GR

arXiv
2105.05238



Ringdown
quasi-normal modes



$\delta f_{330} = -0.012^{+0.072}_{-0.108}$

$\delta \tau_{330} = 0.6^{+2}_{-1.1}$

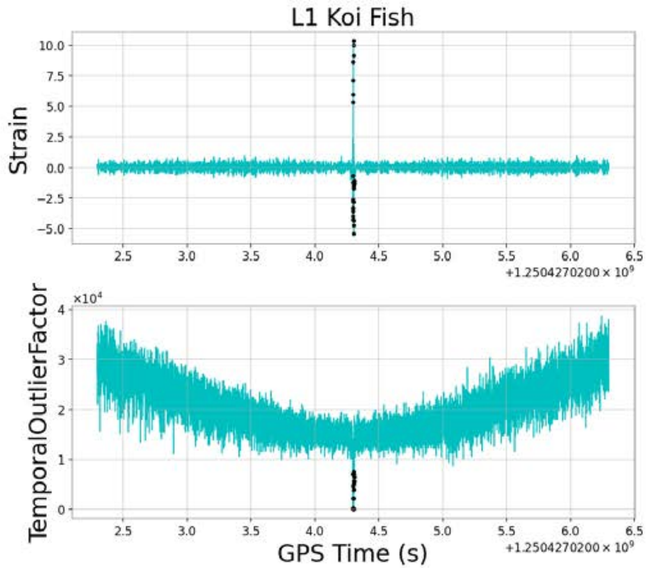
The UBC LIGO team: astrophysics

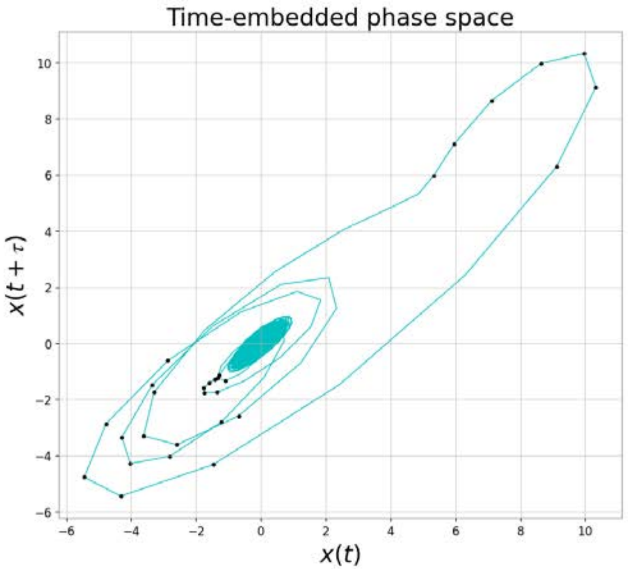
In collaboration with Beverly Berger (Stanford), Priti Ragnekar (Stanford) and Raymond Ng (UBC)

Julian Ding

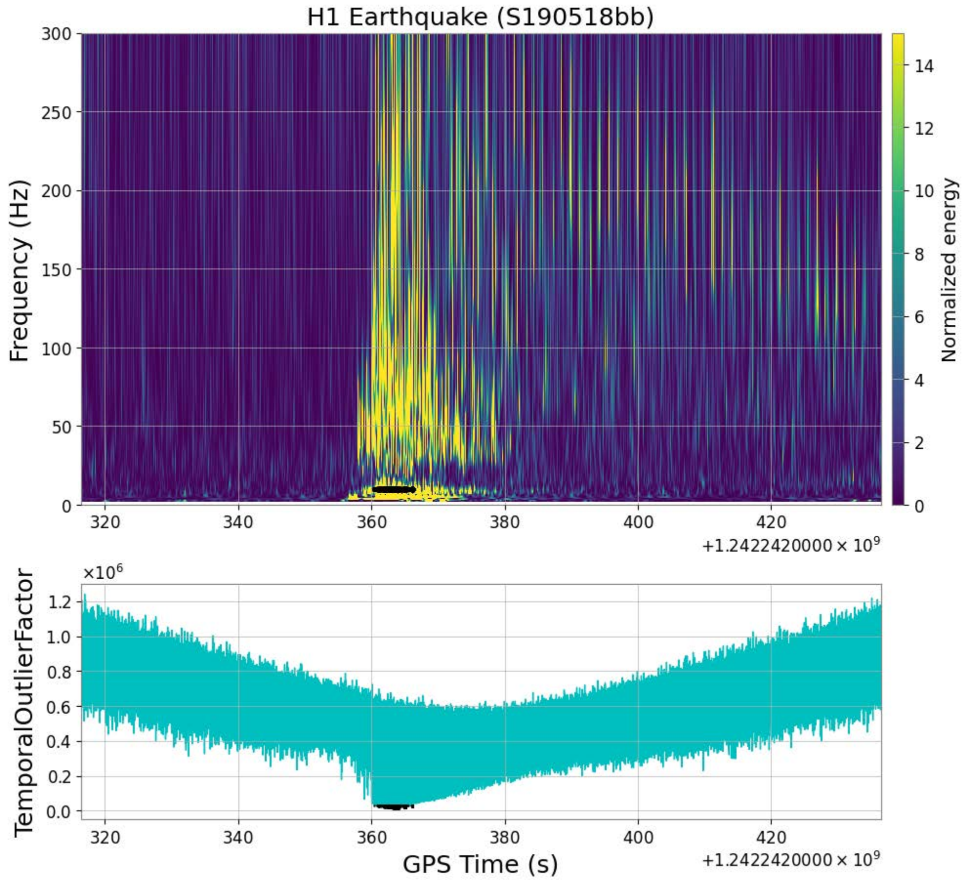
Time Series Anomaly Detection

using Temporal Outlier Factor





$$\mathbf{X}(t) = \underbrace{[x(t),\ x(t+\tau),\ \ldots,\ x(t+(n-1)\tau)]}_{n}$$

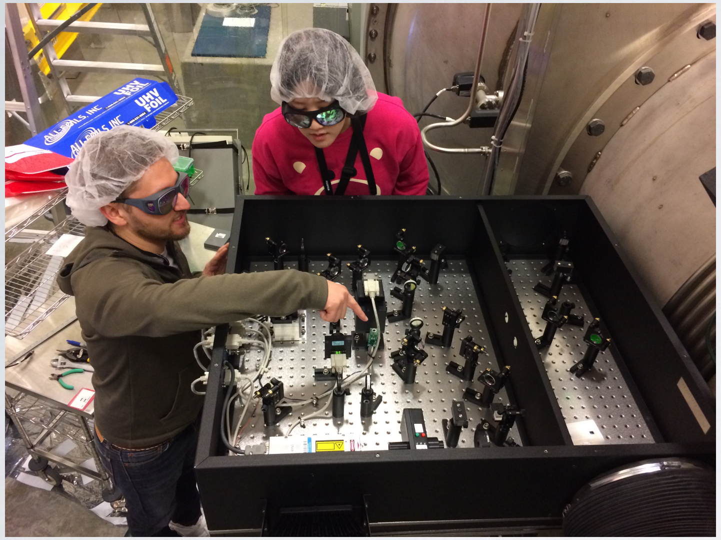


- Time series can be “embedded” into a higher-dimensional space that approximates the dynamics of the system (Takens’s Embedding Theorem)

- Define “unicorns” as points that **cluster in phase space** and also **cluster in time**
- Unicorns correspond to unique events in the time series; can be used to detect loud glitches

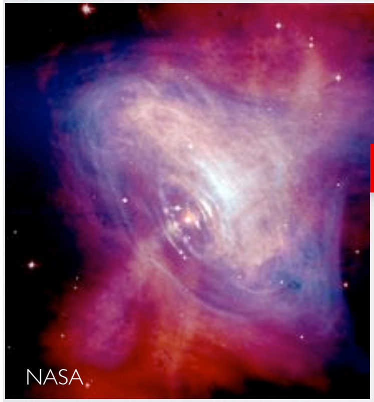
EVAN GOETZ

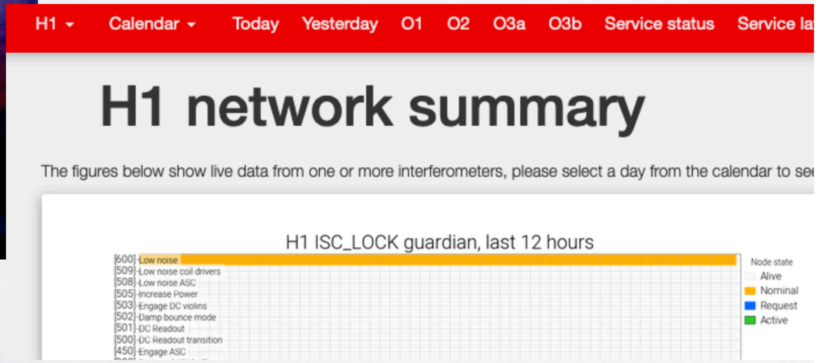
Research associate
UBC Physics and Astronomy



Main research topics:

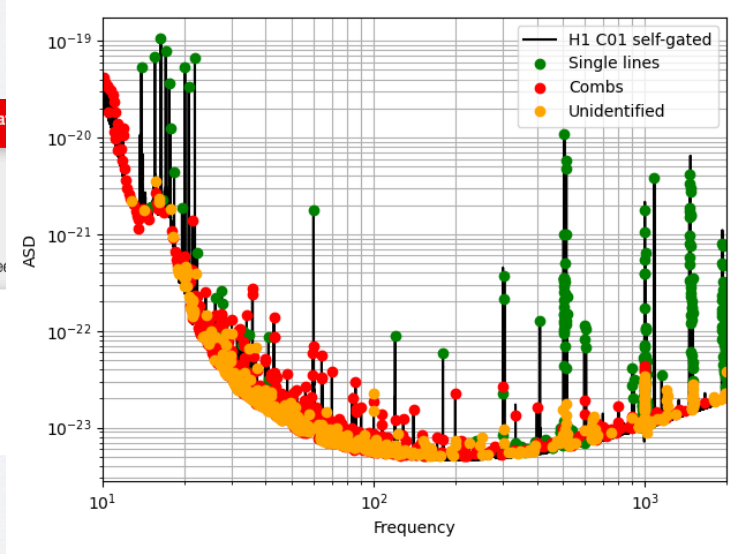
- Astrophysics with gravitational waves particularly neutron stars
- Gravitational wave detector calibration and characterization
- Precision metrology
- Developing enabling software





H1 network summary

The figures below show live data from one or more interferometers, please select a day from the calendar to see

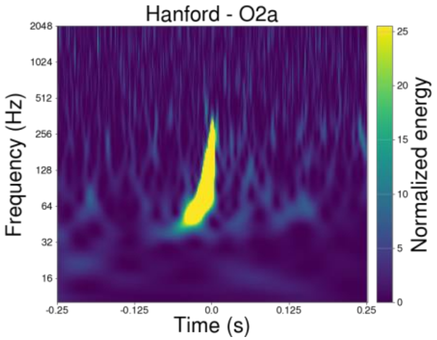


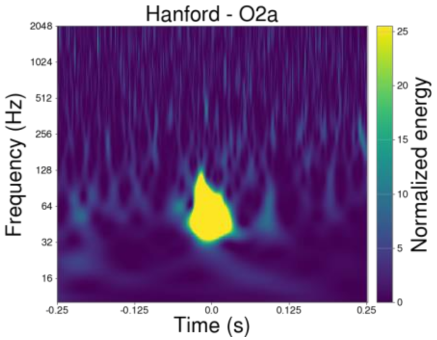
Improving Gravity Spy’s Classification Safety

Seraphim Jarov

- Gravity Spy has trouble distinguishing between high mass chirps and low frequency blip glitches.

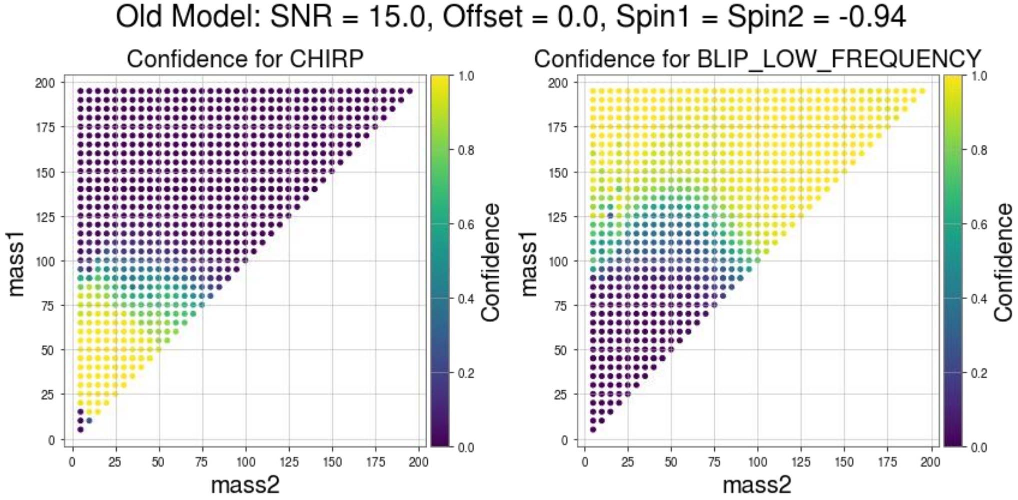
Simulated chirp:
m1=m2=30 $M_{\odot}$
Gravity Spy classification:
Chirp = 0.992

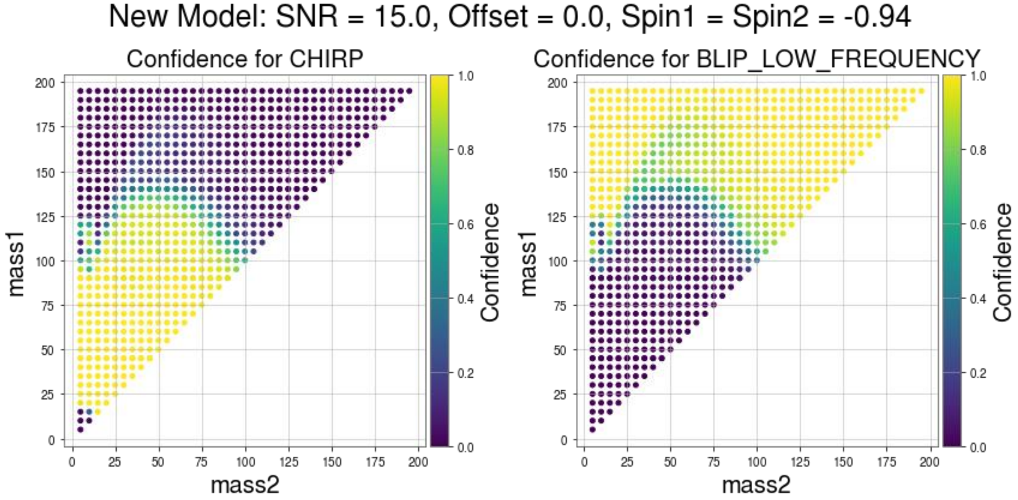




Simulated chirp:
m1=m2=135 $M_{\odot}$
Gravity Spy classification:
Blip_Low_Frequency = 0.996

- We have introduced 1000 high mass chirp signals to Gravity Spy’s CNN to improve on its classification performance.





Percentage of our simulated chirps classified with >0.95 confidence:

Old Model	New Model
~11%	~31%

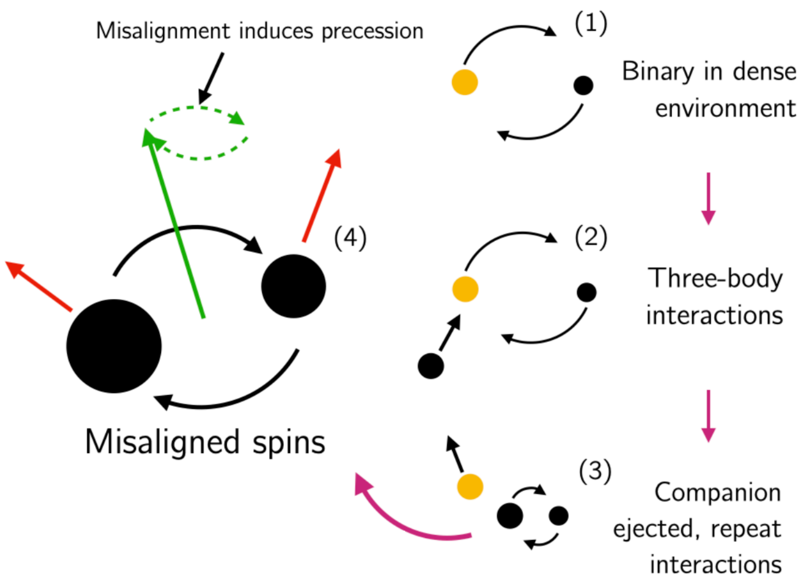
Prospects for measuring off-axis spins of binary black hole sources with A+/AdV+

Alan M. Knee, Jess McIver, and Miriam Cabero

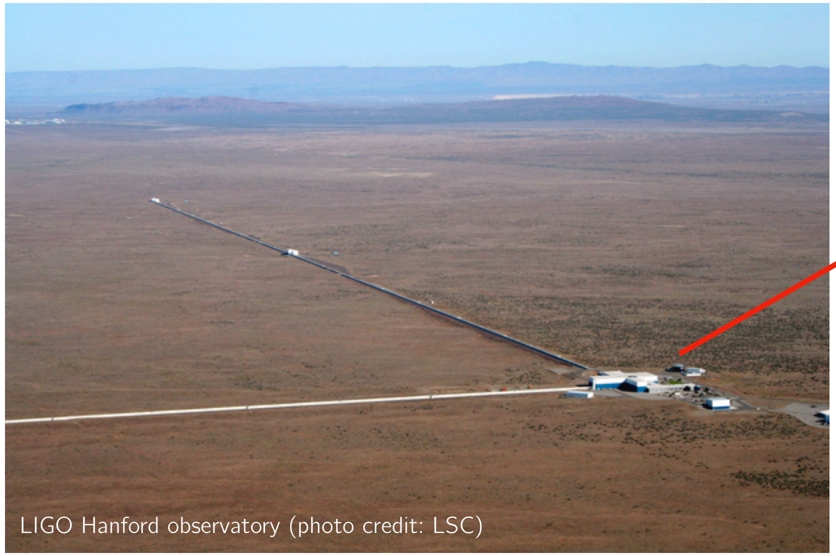
Department of Physics & Astronomy, University of British Columbia, Vancouver, BC

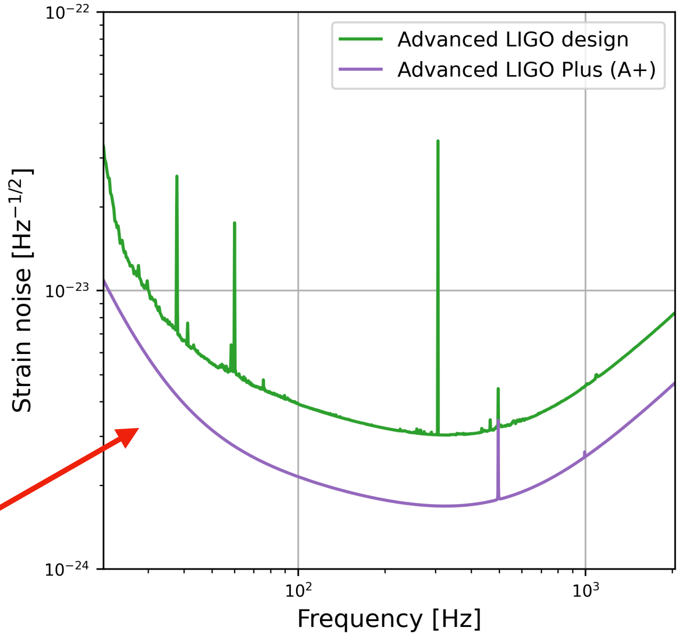
GWANW 2021

1. Spin properties of binary black holes reveal clues about how they formed, and can be recovered from their gravitational-wave (GW) emissions

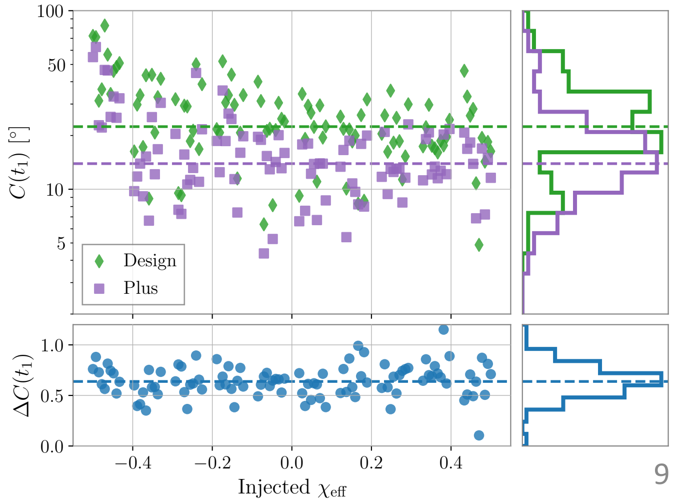


2. Planned upgrades to existing GW detectors will improve sensitivity and allow the spins to be measured with greater precision


LIGO Hanford observatory (photo credit: LSC)



3. Approach: simulate hundreds of GW signals with different masses and spins, and investigate how well we can recover the spins with the A+/AdV+ LIGO/Virgo network



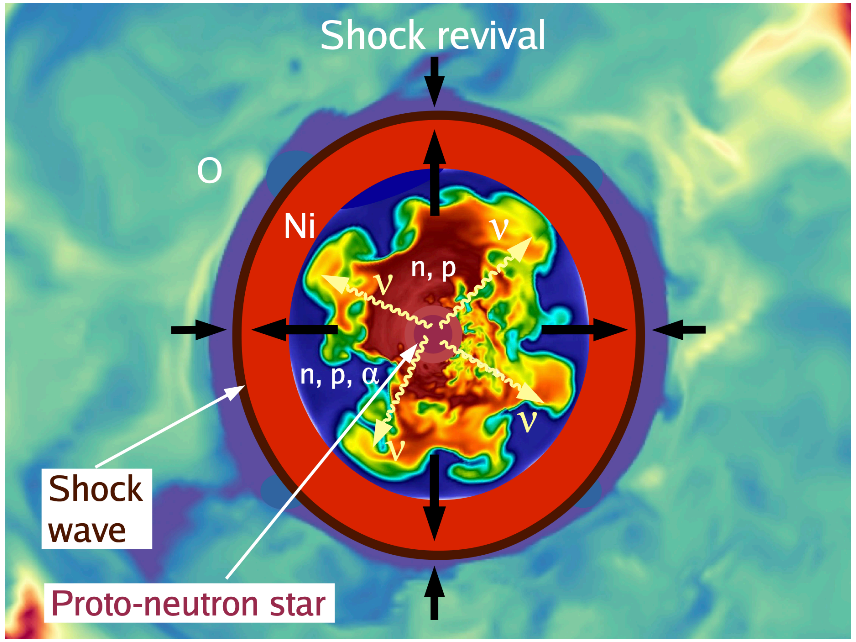
$C(t_1)$ represents the quality of the constraint, measuring the variance in the posterior and any offset of the peak from the true value

THE UNIVERSITY OF BRITISH COLUMBIA

This material is based upon work supported by NSF's LIGO Laboratory which is a major facility fully funded by the National Science Foundation. We also gratefully acknowledge the support of the NSF for provision of computational resources.

Reconstructing gravitational waves from core-collapse supernovae

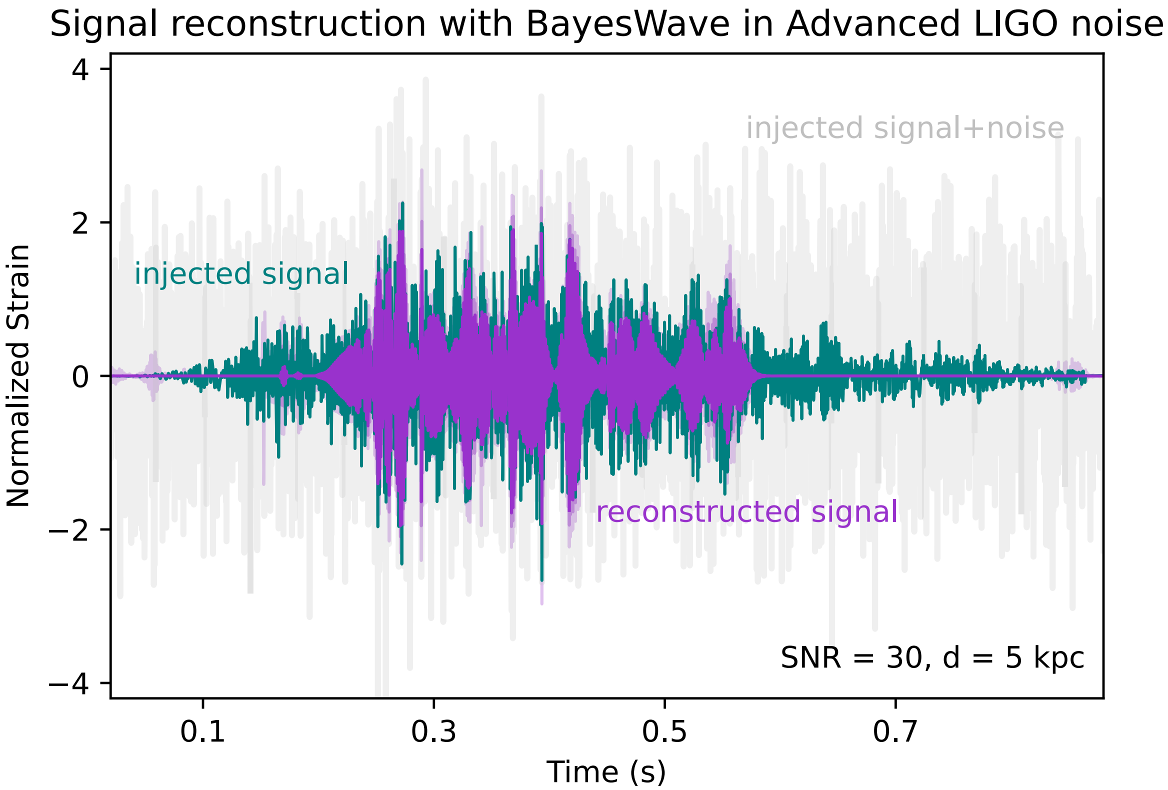
Nayyer Raza **Jess McIver**



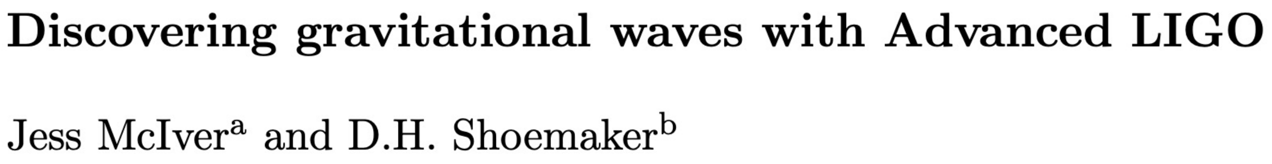
H. T. Janka (2017)

- Non-spherical mass motions in the dense supernova core emit gravitational waves
- How well can we hope to detect and reconstruct these signals with Advanced LIGO-Virgo?

- Use BayesWave to study recovery of simulated supernova signals

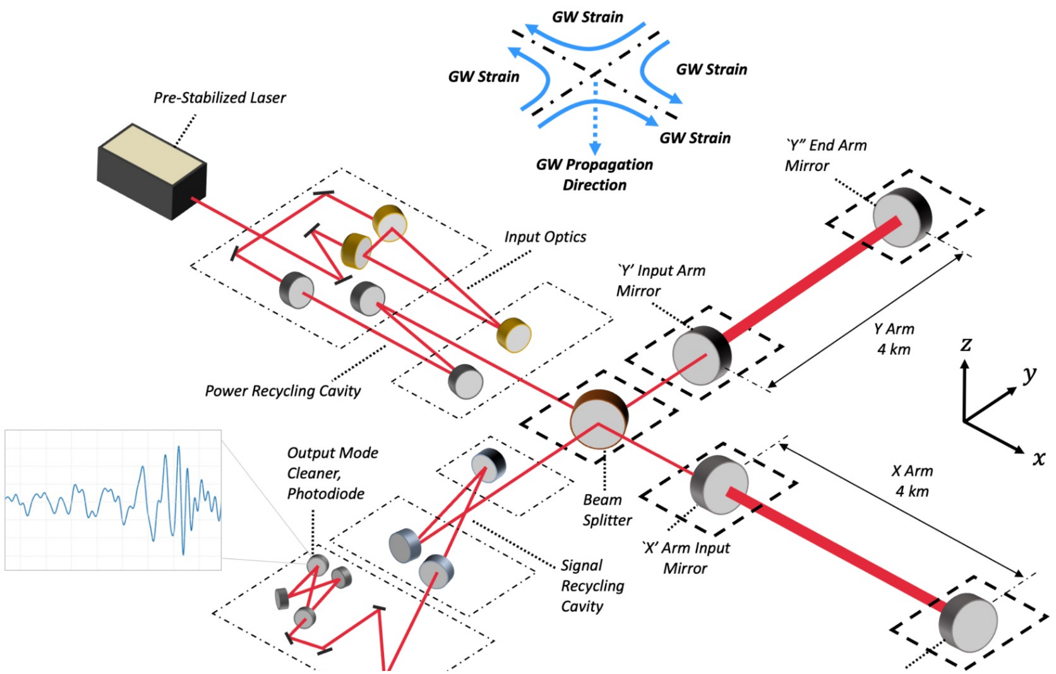


New review paper in part by the UBC team:



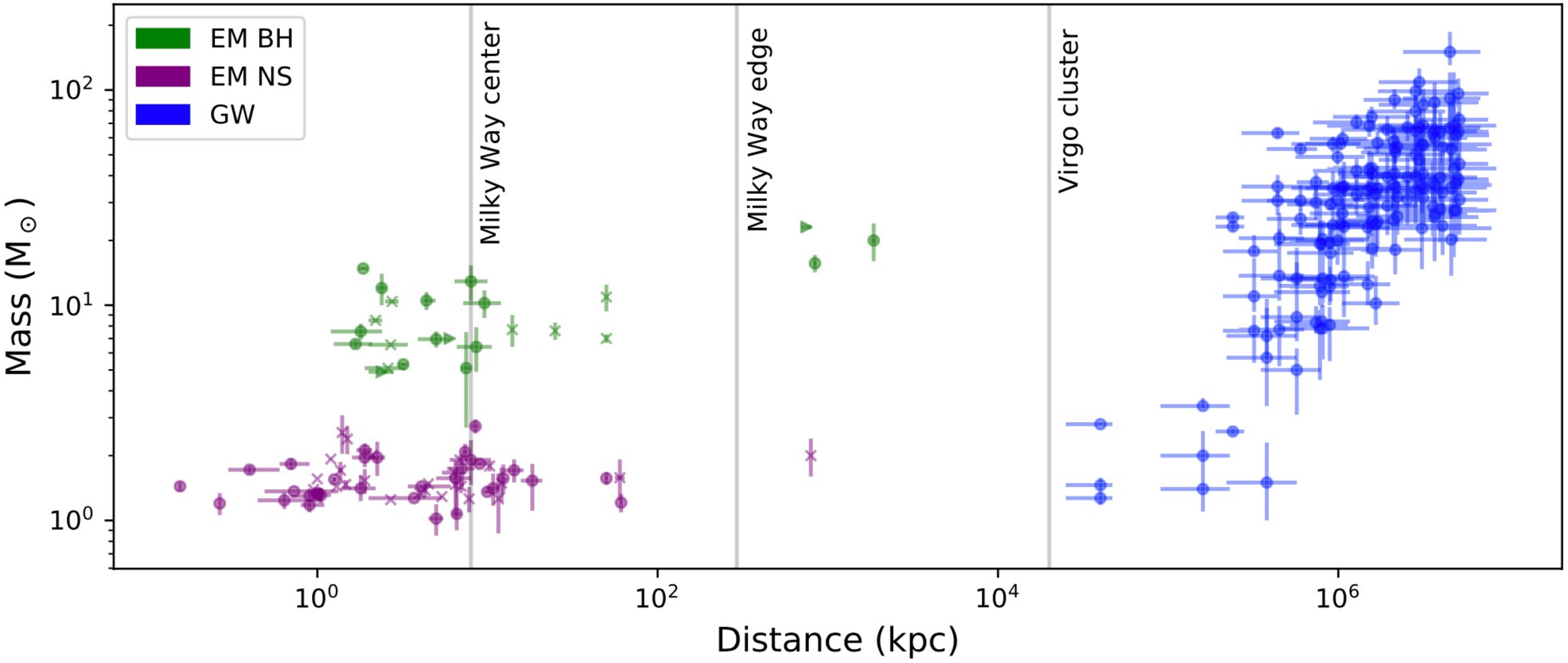
Discovering gravitational waves with Advanced LIGO

Jess McIver[a] and D.H. Shoemaker[b]



Introduction to GW sources and the Advanced LIGO detectors at the undergraduate level.

Coming soon to Contemporary Physics (and hopefully also the arXiv)



The UBC LIGO team: GW detector coatings

Coating thermal noise: a breakthrough is needed for next gen ground-based detectors

Harry et al. 2002

Temperature

Coating thickness

$$S_x(f) = \frac{4k_BT}{\pi^2 f}\frac{d}{Y_s\omega^2}\phi \leftarrow$$

Mechanical loss (much higher for current materials at lower temp)

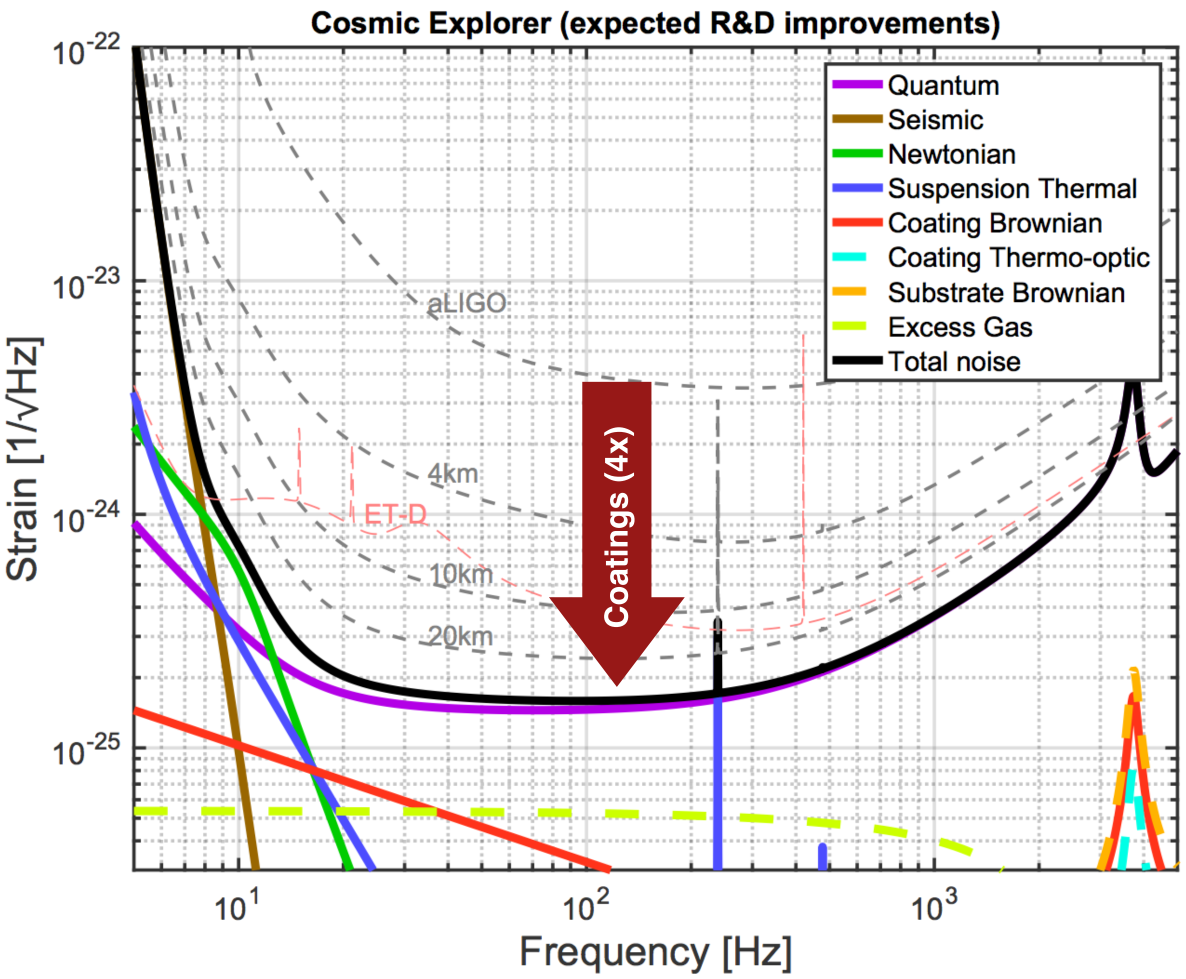
Substrate Young's modulus

Beam radius

Still need (for target laser wavelength):

- High reflectivity
- Low absorption
- Low scattering

Up to 60 cm diameter mirrors.

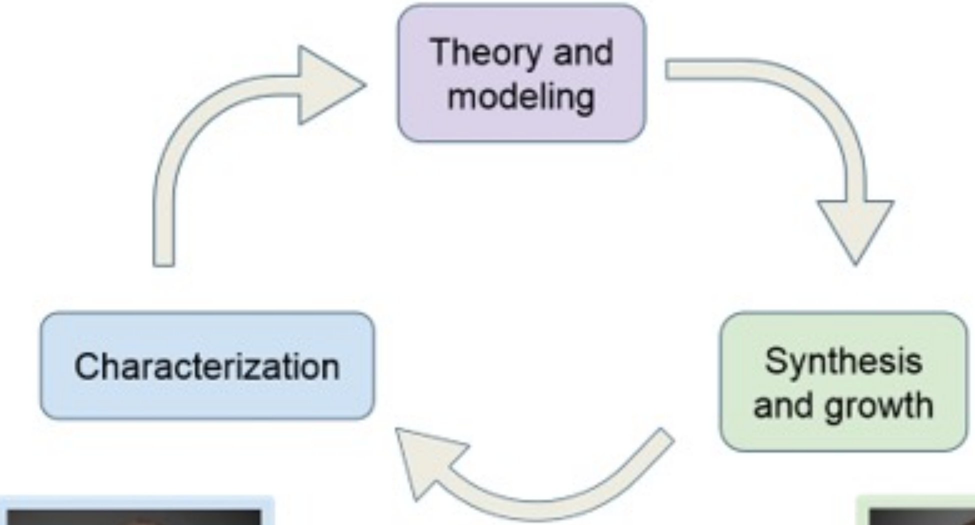


Dawn IV workshop report (McIver et al, 2019); Cosmic Explorer Astro 2020 decadal submission (Reitze et al 2020); Einstein Telescope Conceptual Design Study (Punturo et al 2020)

AMORPHOUS MATERIALS COATING FOR GRAVITATIONAL WAVE DETECTORS

Amorphous coatings for gravitational-wave detector optics

Jess McIver, leader of the LIGO detector characterization effort, will co-liaise with the LIGO collaboration and GW community.



Theory and modeling

Synthesis and growth

Characterization

Joerg Rottler's group will perform **atomistic simulations** to predict the internal friction and mechanical loss of oxide glasses of interest for GW detector coatings.

Jeff Young's group will build a **high-throughput optical cryostat** to perform direct measurements of mechanical loss of synthesized materials.

Curtis Berlinguette's group will synthesize state-of-the-art **amorphous metal oxide films** and explore a wide range of metal oxide layered structures.

Ke Zou's group will use **molecular beam epitaxy (MBE)** to synthesize amorphous and crystalline oxide candidate materials.

Microdisk measurements with laser doppler vibrometer

Kirsty Gardner, Matthew Mitchell, Chang Ge

In collaboration with David Dvorak, Jeff Young, Ke Zou, Andree Coschizza, Joerg Rottler, Daniel Wong, Curtis Berlinguette.

Part of the SB Quantum Matter Institute's 'Disorder and entropy as design principles' Grand Challenge

Laser Doppler Vibrometer (LDV)

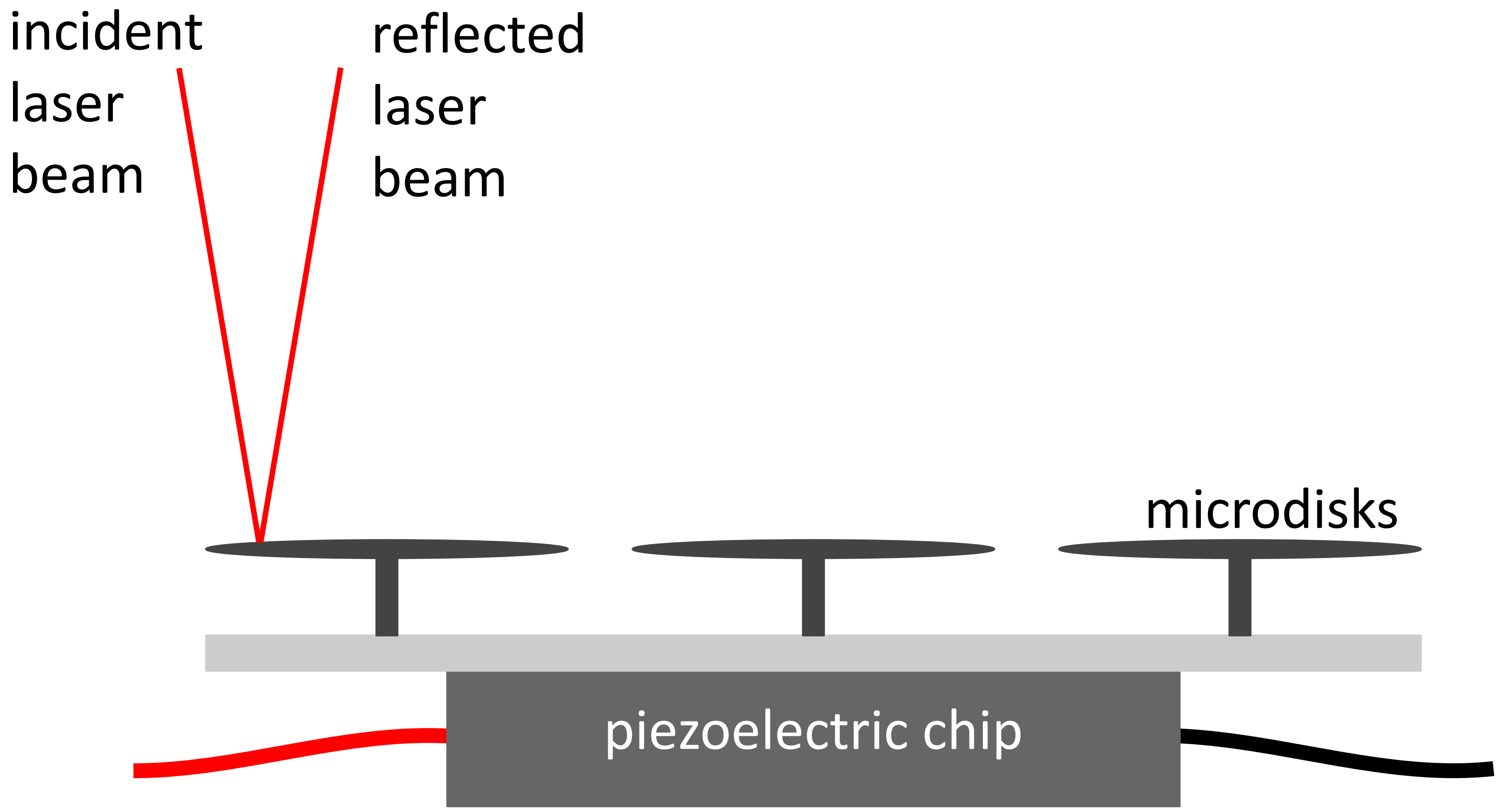
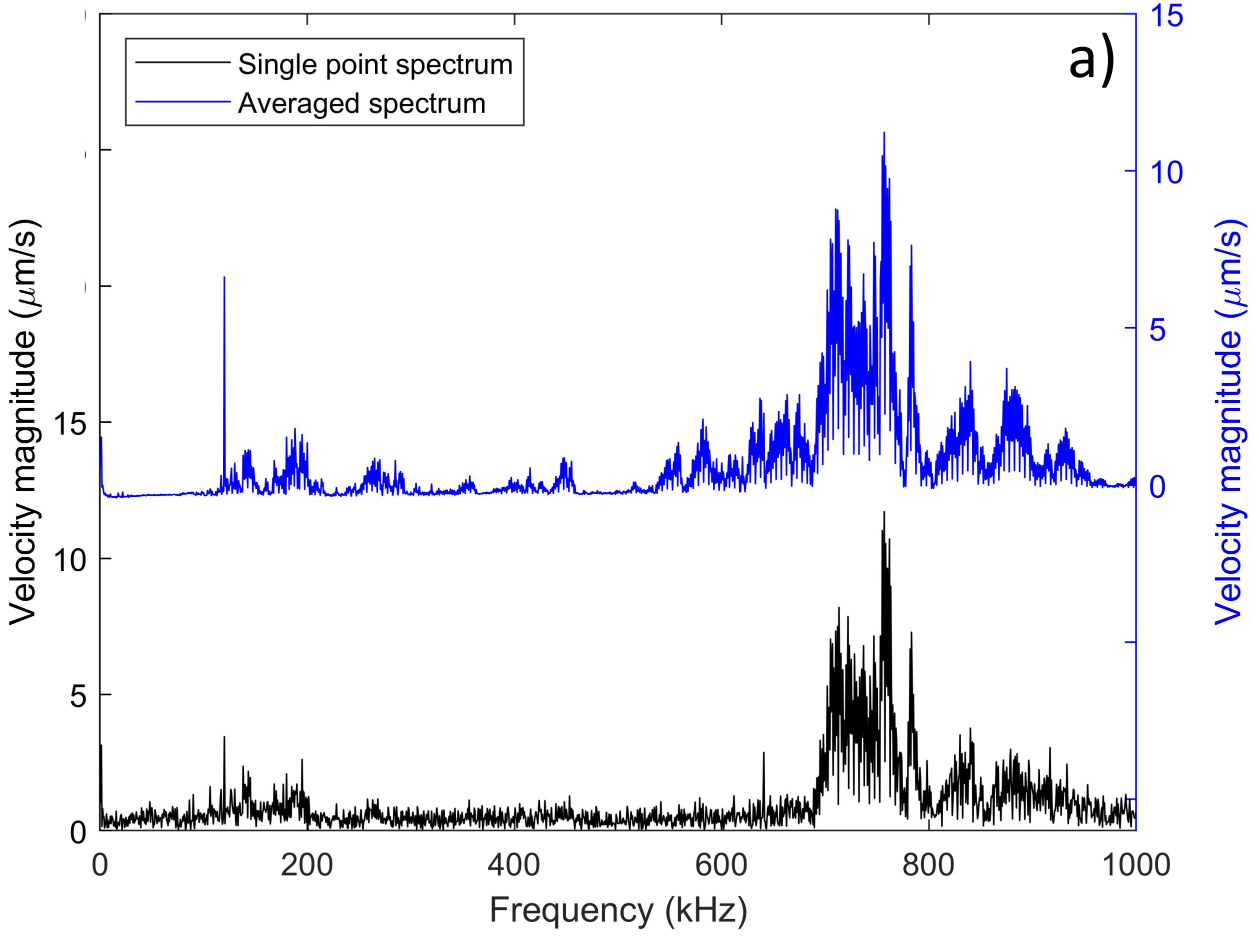


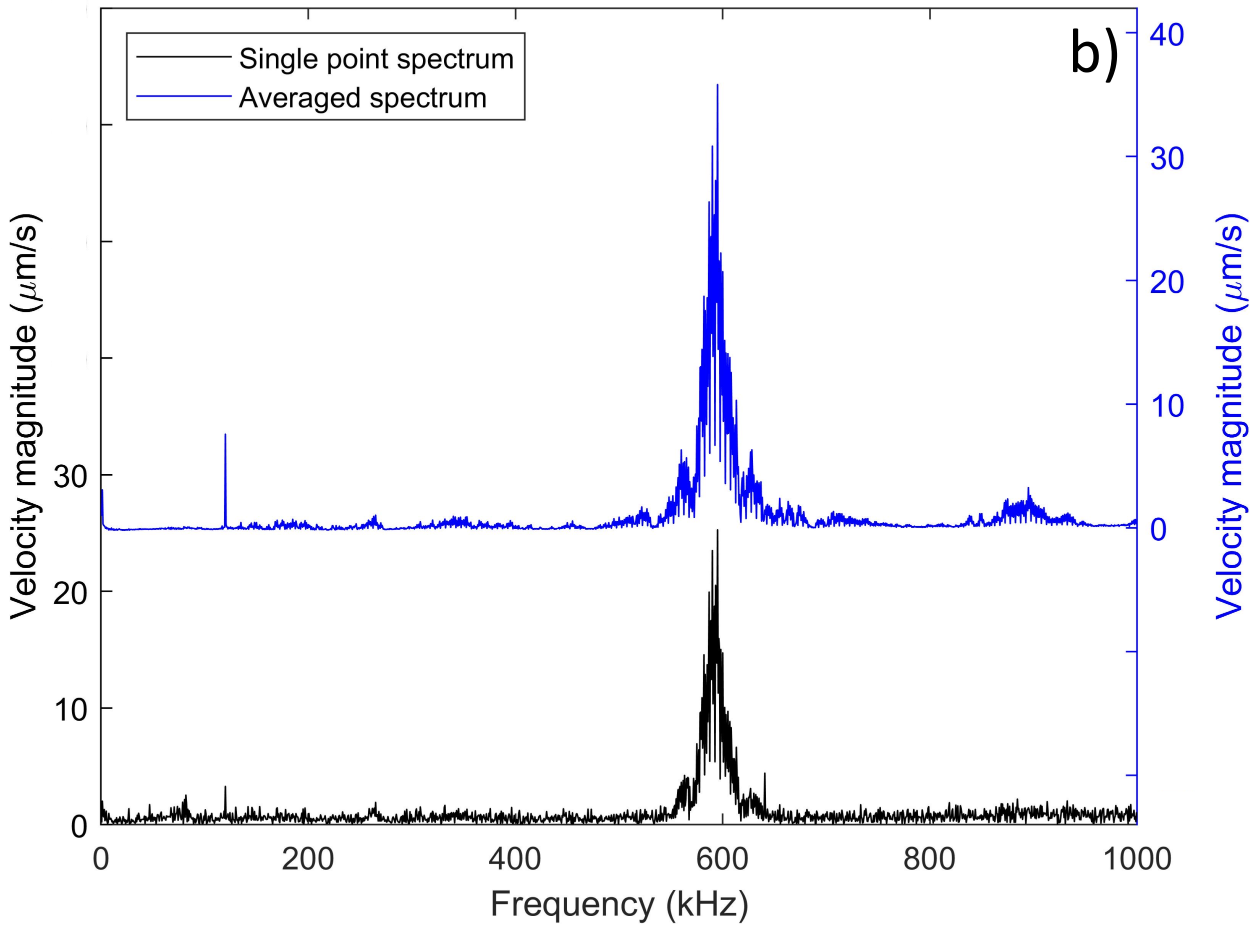
Diagram of experimental setup for LDV measurements of microdisks using a piezoelectric chip actuator.

- Measurements done at room temperature and in ambient atmosphere
- Piezo chip actuates microdisks
- Doppler shift of reflected laser beam used to measure motion of single disk
- Software generates spectra of microdisks, as well as animation of microdisk motion

Spectra of Uncoated Microdisks

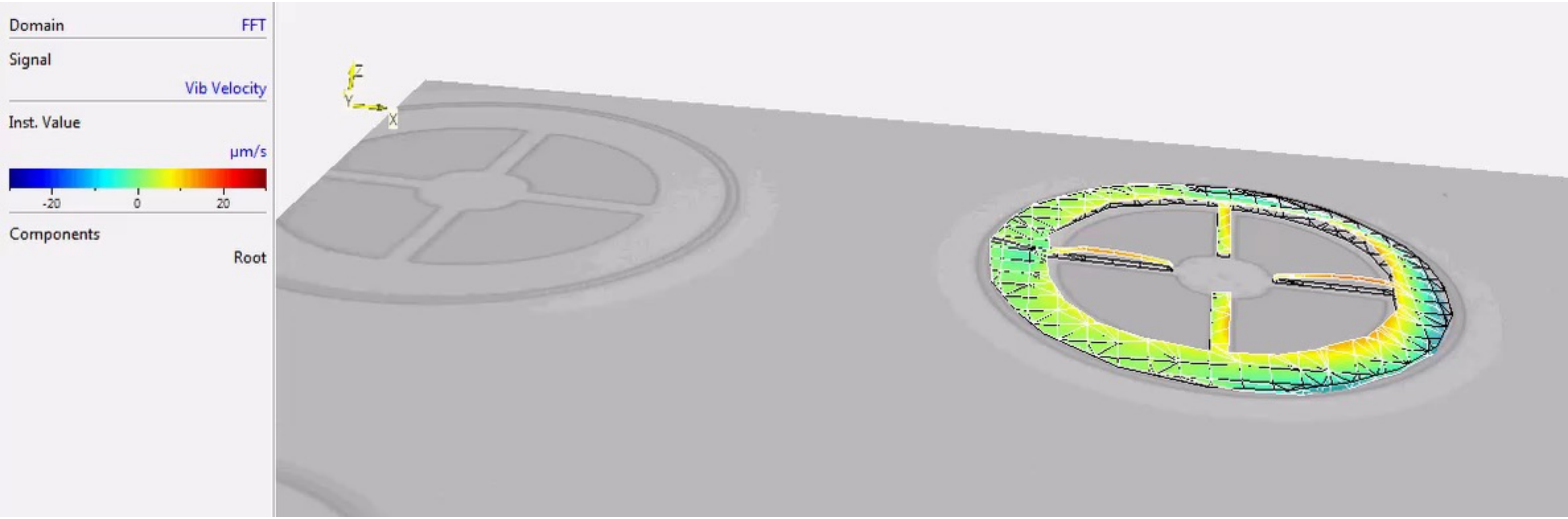


a) Spectra from a disk of radius 71.5 µm, showing a resonance at approximately 750 kHz.



b) Spectra from a disk of radius 80.0 µm, showing a resonance at approximately 600 kHz.

Animation of vibrational mode



Domain FFT

Signal Vib Velocity

Inst. Value µm/s

Components Root

Figure 3. Video of the mode shape of the smallest disk (radius 71.5 µm) at 760 kHz, showing the motion of the microdisk.

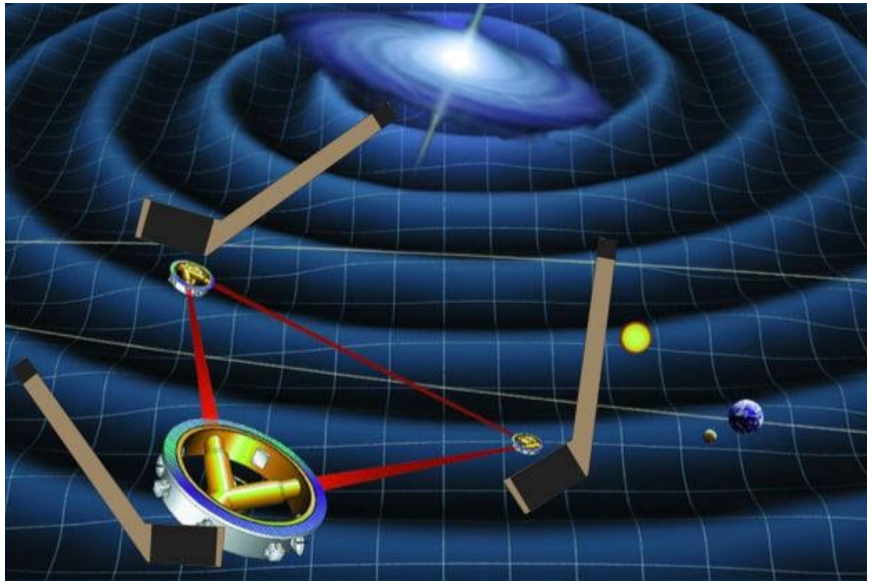
The UBC-TRIUMF LISA team

Djuna Croon (PI), Evan Goetz, Jess McIver, David Morrissey, Scott Oser

The LISA Canada 2021 workshop

Well attended

- >300 registrants (100+ Canadian)
- Over 150 participants on Zoom on Day 1



Featured:

- Overview of LISA science and the LISA experiment
- Introduction to each working group in the LISA Consortium and how to plug into ongoing research
- Discussion of Canadian contributions to LISA
- Most talks are available on YouTube (please ask for the links)

Coming soon: white paper summarizing the outcomes of the workshop.

The UBC CHIME team

What is CHIME/Pulsar?

Deborah Good for the UBC CHIME team

Image: Richard Shaw

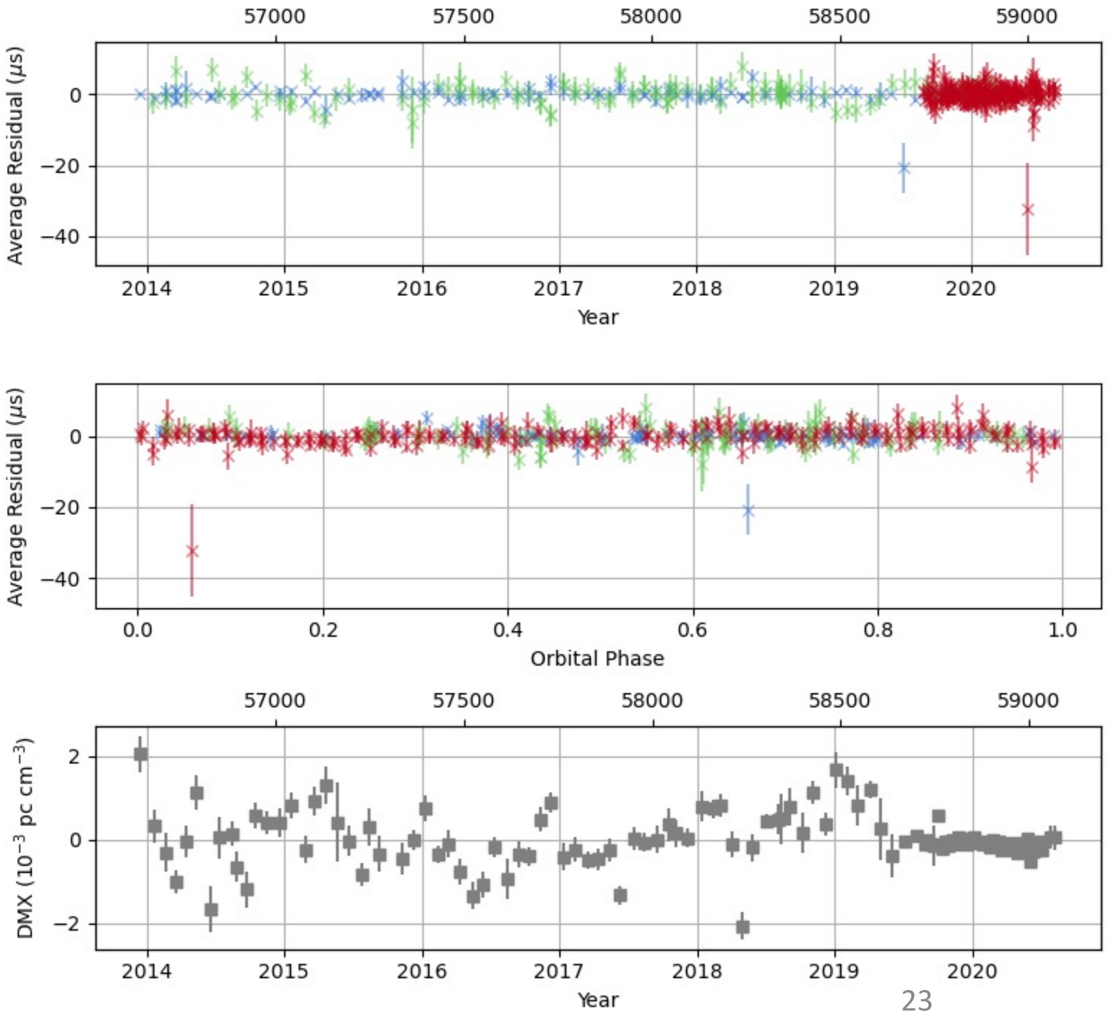
- The Canadian Hydrogen Intensity Mapping Experiment
  - Radio transit telescope, observes the whole sky each day
  - No moving parts: as the Earth rotates, we see different parts of the sky.
  - Frequency range: 400-800 MHz
- CHIME/Pulsar system
  - Creates 10 tied-array tracking beams, which let us digitally ”point” at pulsars and track them across the sky.
  - We can observe up to 10 pulsars at a time, 24/7. We observe each pulsar for about 15 minutes.
  - An automated scheduling software ensures pulsars are observed equitably, based on pre-assigned priorities.

Adding CHIME/Pulsar data to NANOGrav

- Why include CHIME/Pulsar data in what is already a good dataset?
    - Low frequency observations are valuable, particularly for better constraining the interstellar medium.
    - CHIME/Pulsar has a wide fractional bandwidth, allowing it to act as a laboratory for wideband timing developments.
    - Daily observation cadence adds unprecedented density to our sampling for timing solutions.
- Is this working? Early results suggest yes!
    - For our test sources, RMS residuals < 5 us; weighted RMS residuals < 3 us.
    - Study of dispersion measure variation is in its infancy, but we already have evidence CHIME/Pulsar will be valuable.

Example: PSR J1125+7819

Green & Blue = epoch-averaged GBT TOAs; Red = epoch-averaged CHIME TOAs



The search for B-modes at UBC

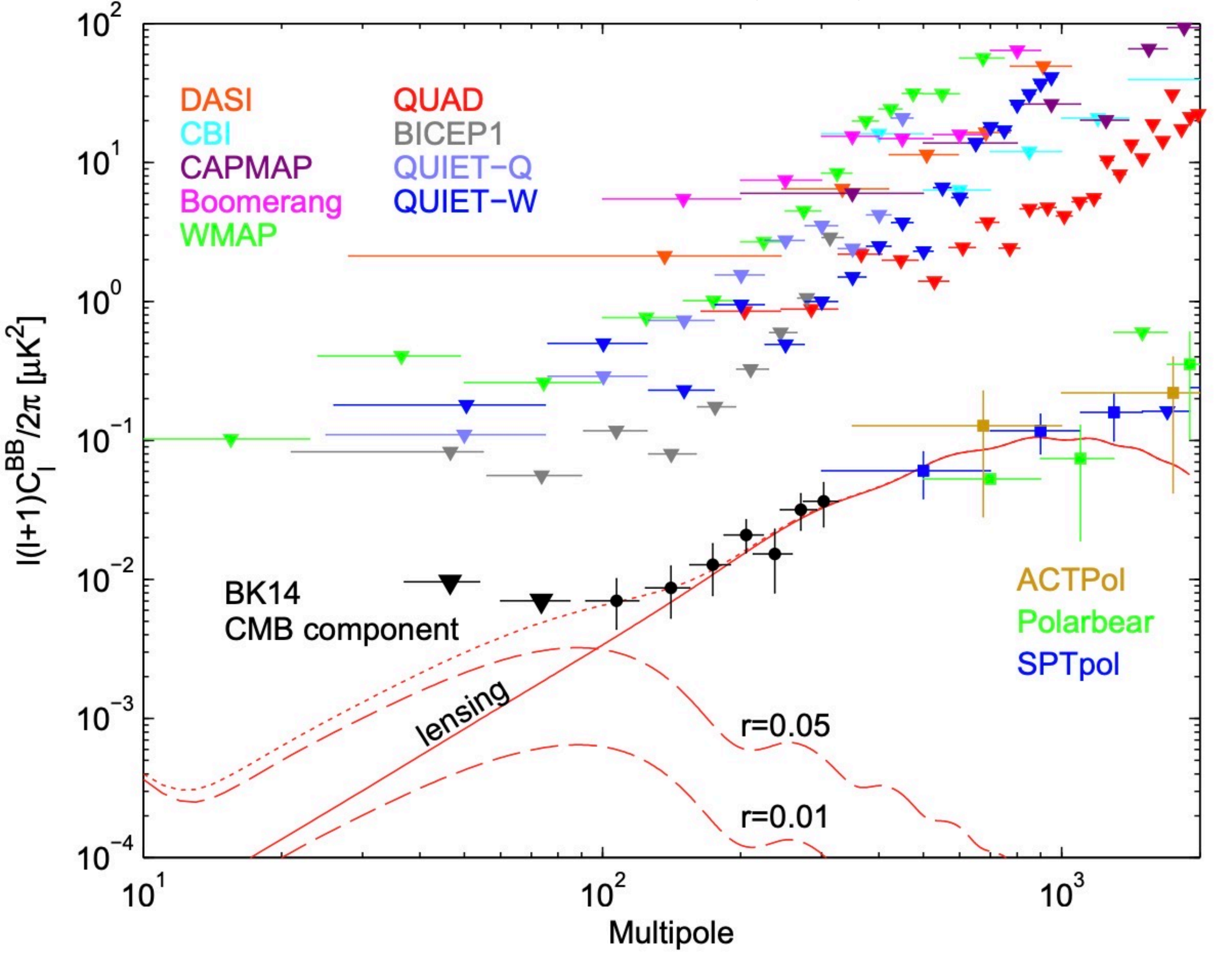
The search for B-modes at UBC   I: Bicep/Keck

Odd parity polarization patterns of the CMB, called B-modes, arise from tensor perturbations of the metric imprinted at the end of inflation. They become gravitational radiation much later, after they pass within the horizon. The anticipated angular power spectrum is shown at left by the dashed red curves labelled with **r**, the tensor fraction of the primordial power spectrum.

Expect better data on a few months time scale as we publish spectra based on 4 or 5 years more data.

Expect substantially better data in a few years with deployment of the Bicep Array , replacement of the SPT telescope with the TMA and coordinated BK / SPT analysis to remove the 'foreground' B-mode spectrum arising from gravitational lensing by z~2 galaxies. (solid red line).

BK PRL (2018)



UBC designed the detector control and readout electronics for CMB experiments ABS, Act, Bicep, CLASS, CMB-S4, … ..Keck, .. Piper, .. Spider, … ZEUS-2

At UBC: Sofia Fatigoni, Mandana Amiri, Don Wiebe, Mark Halpern.

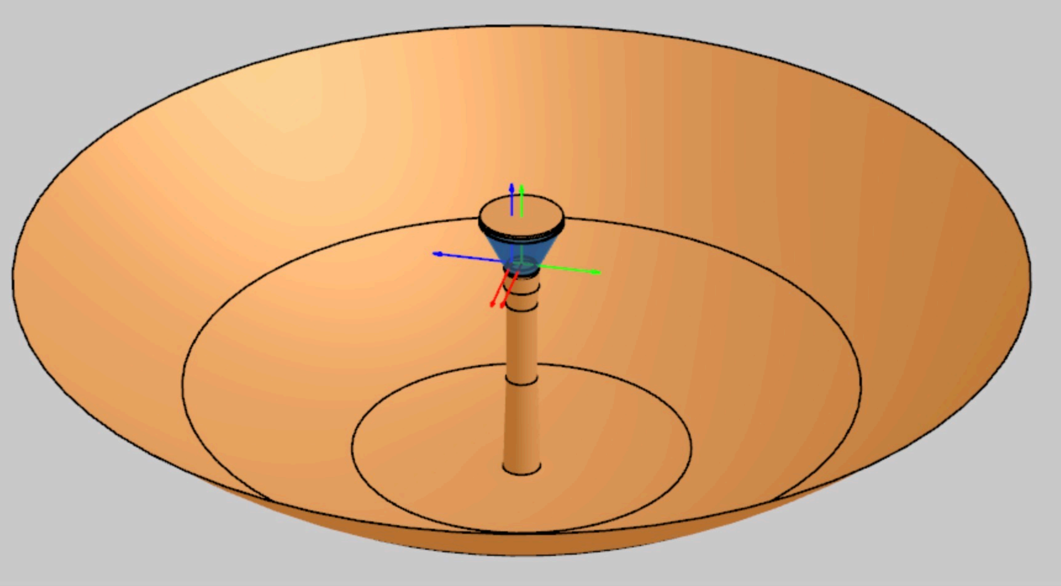
The search for B-modes at UBC II: CGEM

cgem

The **Canadian Galactic Emission Mapper** is a program to map polarized galactic emission at 10 GHz with enough sensitivity and enough control of systematic errors that the data can be used to clean the few nK of residual synchrotron from B-Mode search maps made at CMB frequencies.

The instrument consists of a single 4m aperture dish scanning azimuthally at fixed elevation angle, at 1 rpm. The system scans the full northern sky as the Earth turns, as is illustrated by our logo.

The CGEM team: Gary Hinshaw, Bruce Veidt, Mandana Amiri, Tom Landecker, Madison Allen, Josh MacEachern, Ed Wollack, Mark Halpern, Artem Davidov, Parham Zarei



Daily sky coverage of the Northern hemisphere for the elevation angles 40^{o} and 50^{o}. The green line is $\delta=0$.