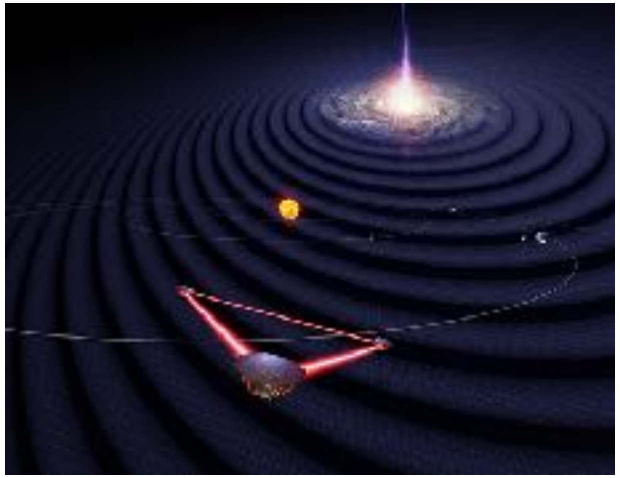
GW astronomy at UBC/TRIUMF

Jess McIver for the UBC/TRIUMF team

June 25, 2024

GWANW 2024

Across the GW spectrum: UBC and TRIUMF

Ground based interferometers
- UBC LIGO group
- Cosmic Explorer/future GW detectors

Space based interferometers
- UBC-TRIUMF LISA group

Pulsar Timing Arrays
- UBC CHIME team

B-mode polarization
- Search for B-mode polarization at UBC

Not pictured: Katja Nell, Franz Herbst, Harshini Paranjape

The UBC LIGO team: astrophysics

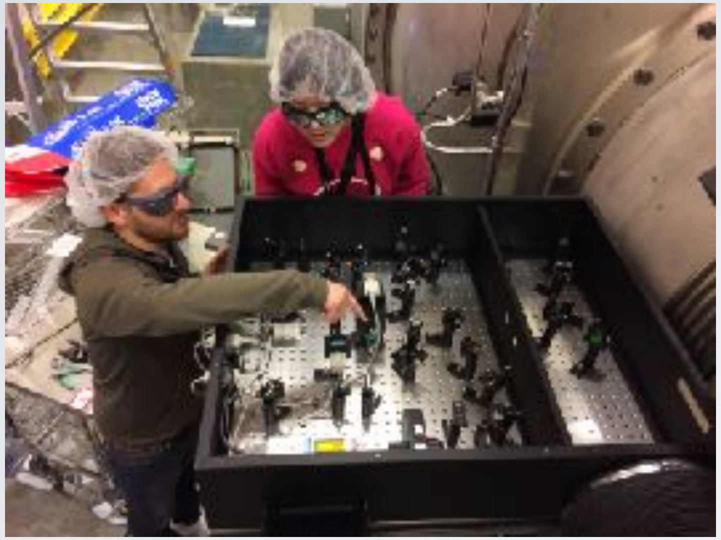
In collaboration with:

The LIGO DetChar, CW, CBC, and calibration groups,
Beverly Berger (Stanford LIGO), Raymond Ng (UBC DSI), Scott Oser (UBC/TRIUMF),
Smadar Naoz and Bao Minh Hoang (UCLA), Isobel Romero-Shaw (Cambridge),
Xiaoxaio Li and Ruichen Yao (UBC ECE),
Ky Potter and David Stenning (SFU Stats)
And others!

EVAN GOETZ

evan.goetz@ligo.org

Research Associate
UBC Physics and Astronomy

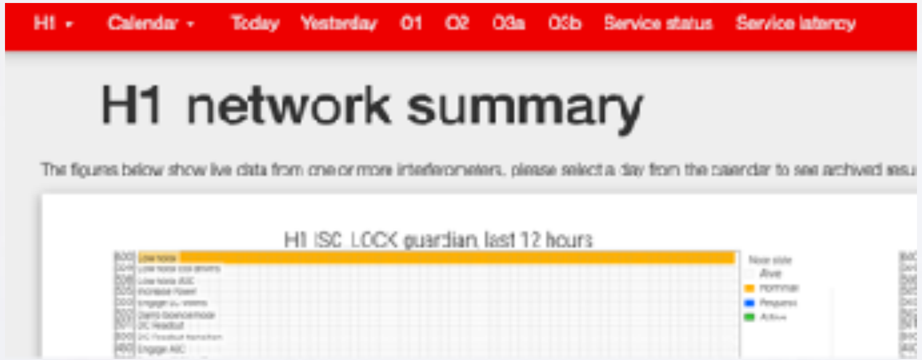


Calibration, metrology

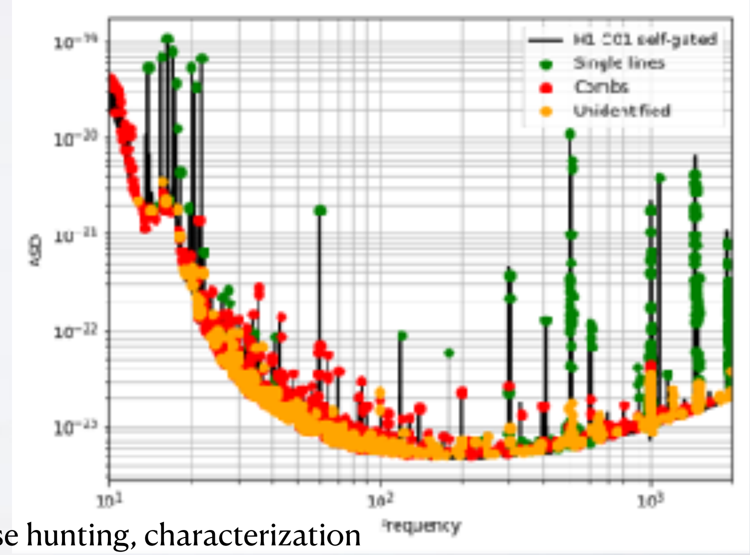
Main research topics:

- Astrophysics with gravitational waves
- particularly neutron stars
- Gravitational wave detector calibration and characterization
- Precision metrology
- Developing enabling software to enhance
- scientific output from GW detectors

CW NS astrophysics



Summary pages, DetChar tools



Noise hunting, characterization

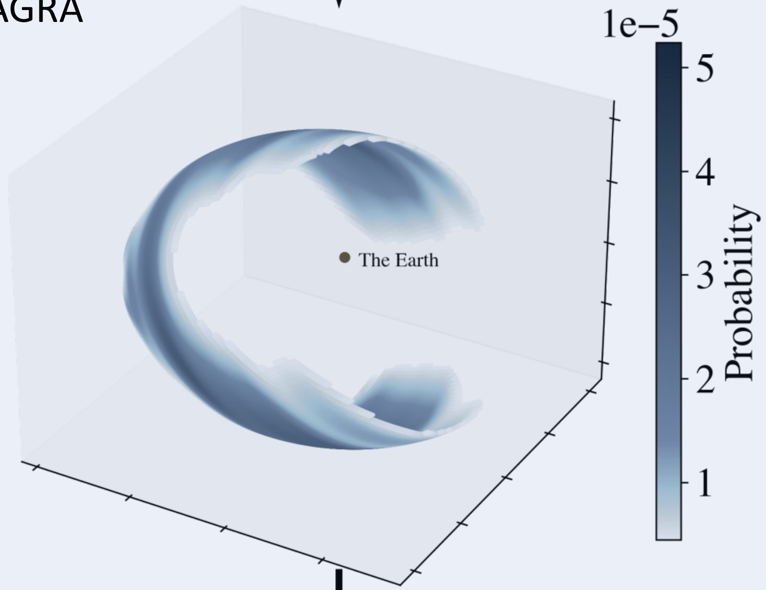
Machine Learning algorithms for real time GW candidate evaluation and noise transient localization

Man Leong Chan, Jess McIver and et al

GWSkyNet real-time evaluation (within minutes)

LVK GW real-time search pipelines → Potential GW events → Rapid sky localization and meta data by BAYESTAR*

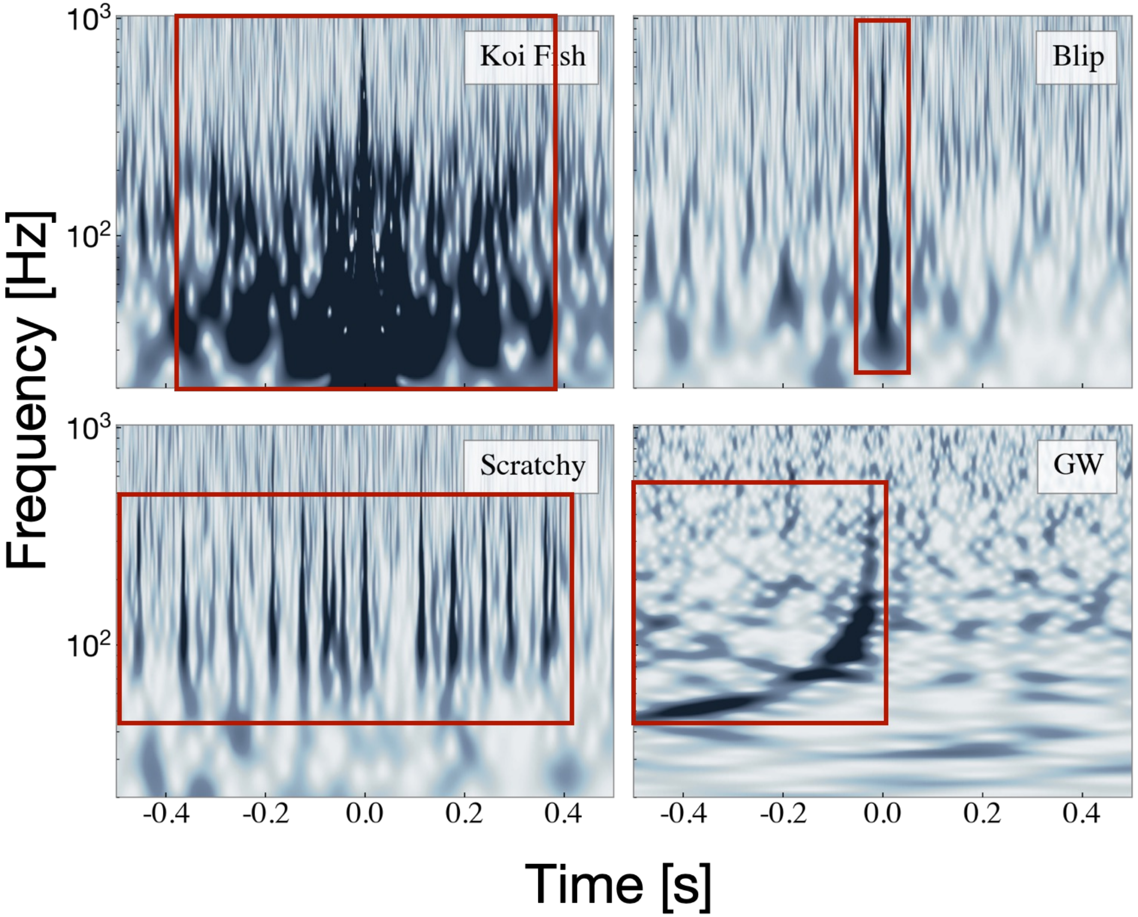
LIGO-Virgo-KAGRA Low-latency infrastructure



Astronomer Community

A GWSkyNet score ranging from 0 to 1: how likely the events are astrophysical?

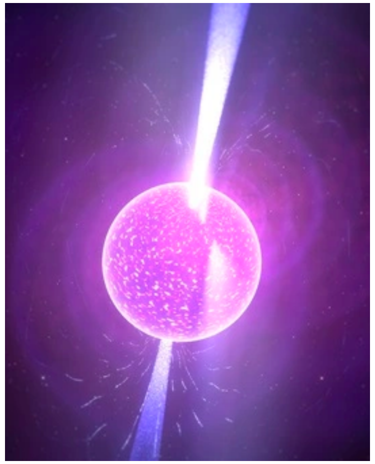
Automatic identification of noise transients' frequency range and time window

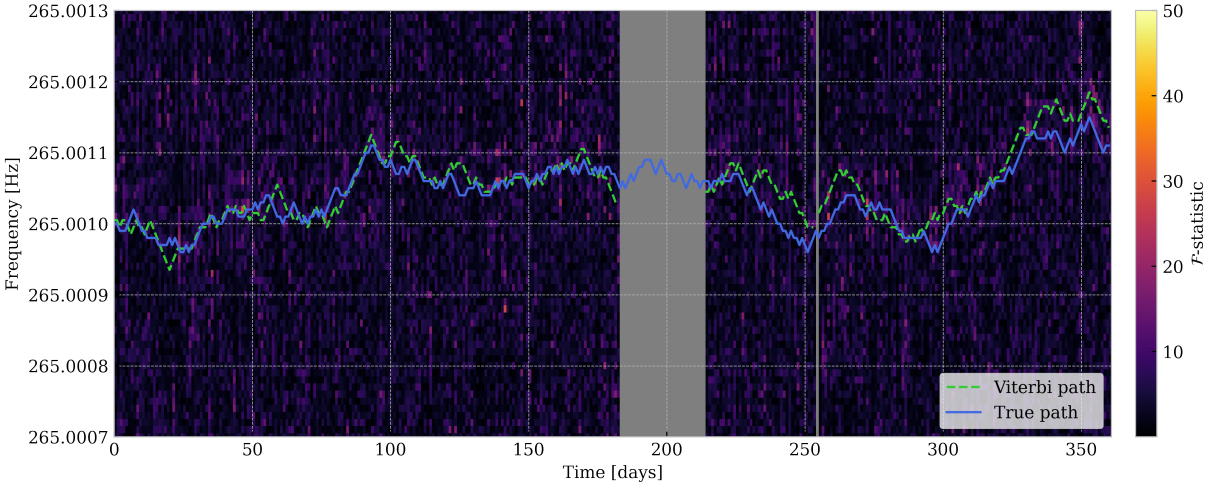


Alan Knee

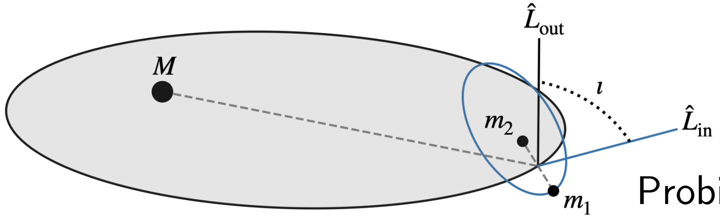
PhD candidate, UBC

GW data analysis with LIGO and LISA

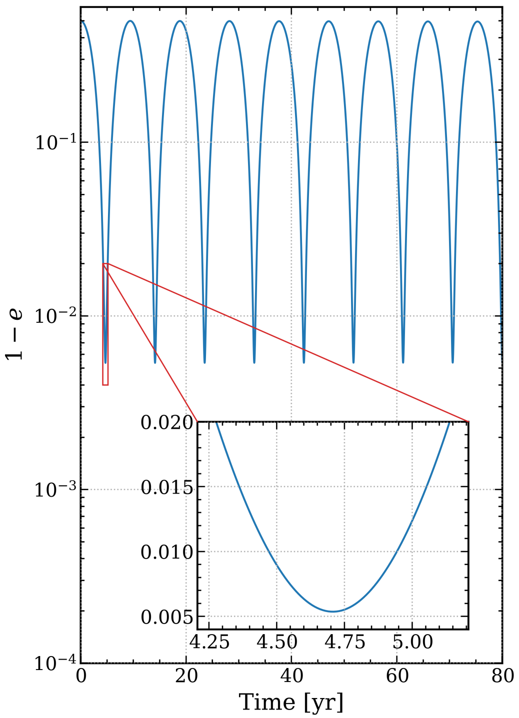


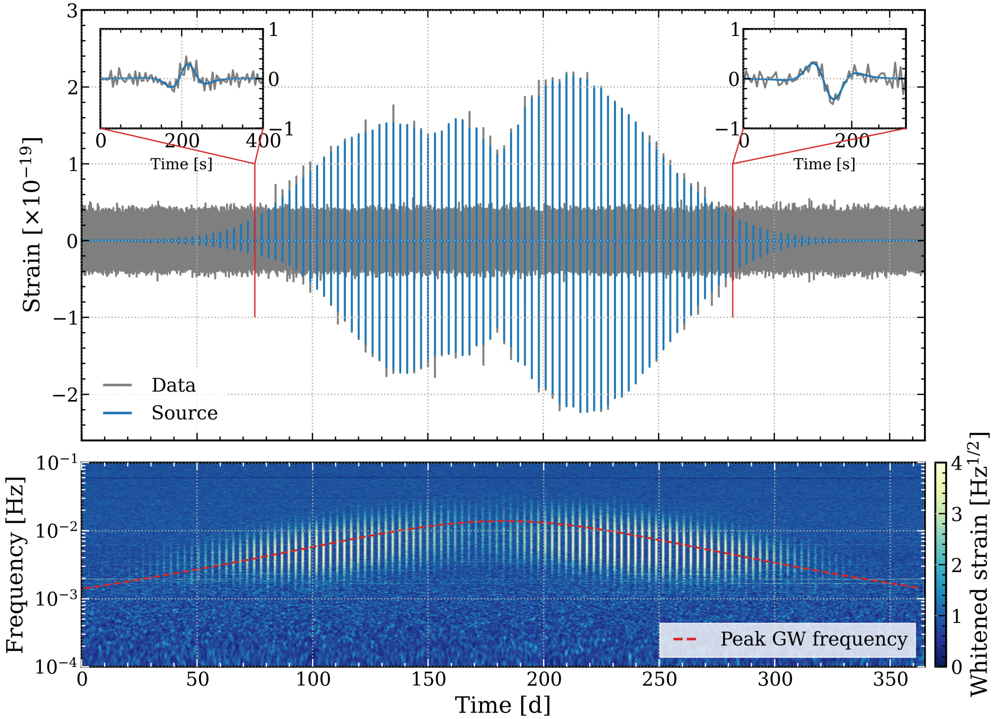


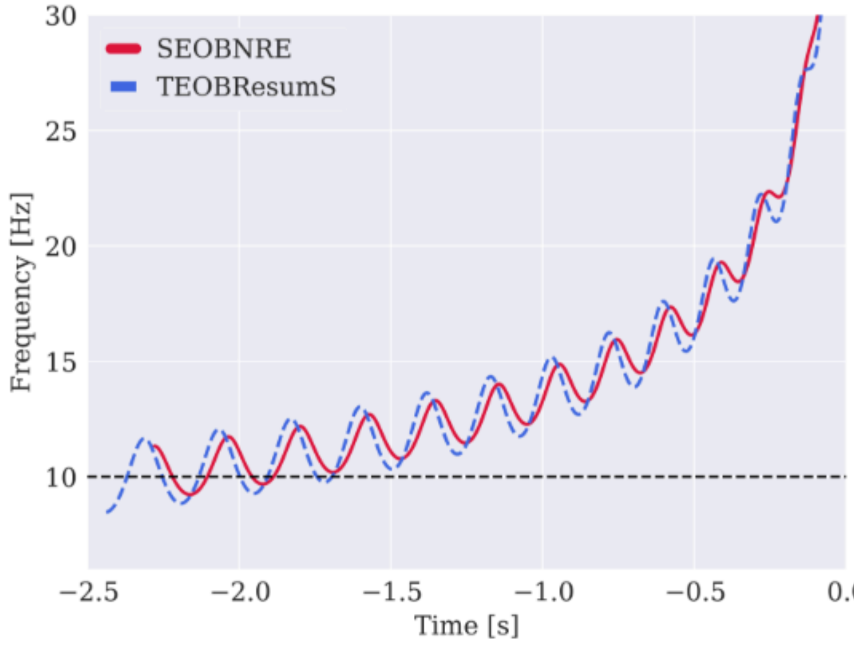
Continuous gravitational-wave searches with Viterbi



Probing black hole dynamics with LISA



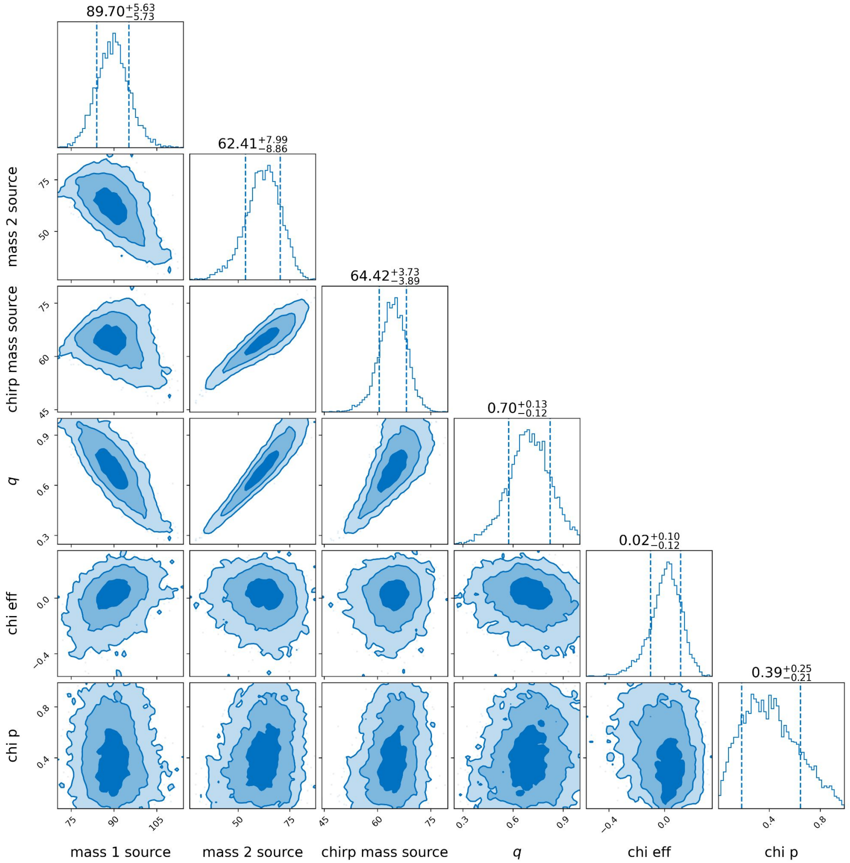




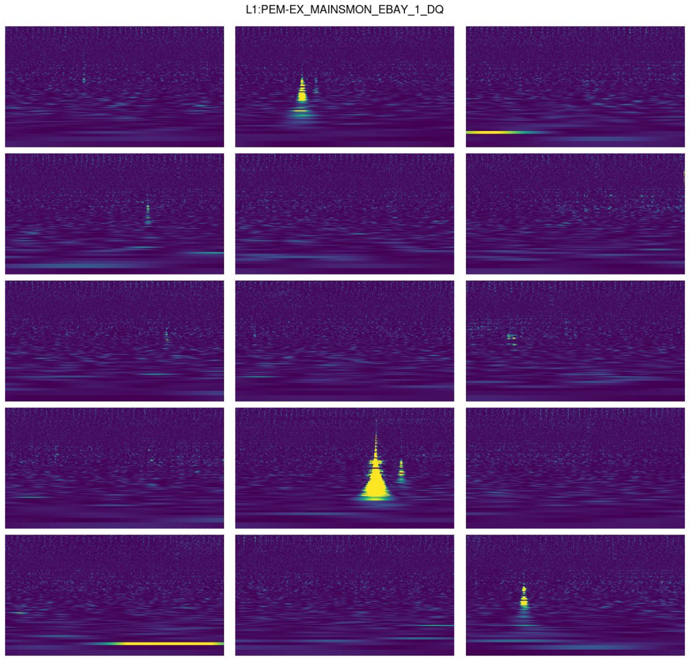
Eccentric black hole binaries

Niko Lecoeuche - PhD student, UBC Physics and Astronomy

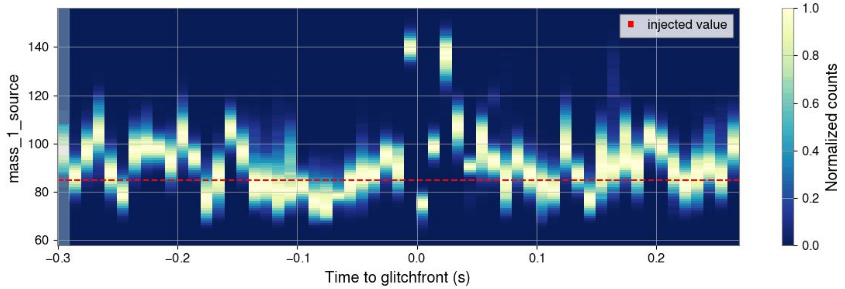
Investigating glitch subtraction biases on parameter estimation

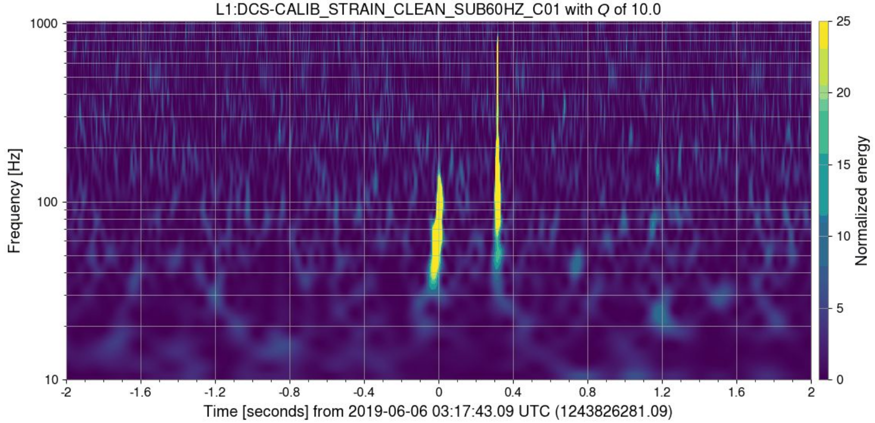


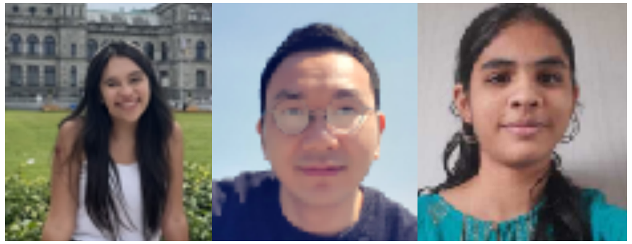
Machine learning tool for flagging noisy auxiliary channels



Parameter Estimation of GW in the Presence of Detector Glitches



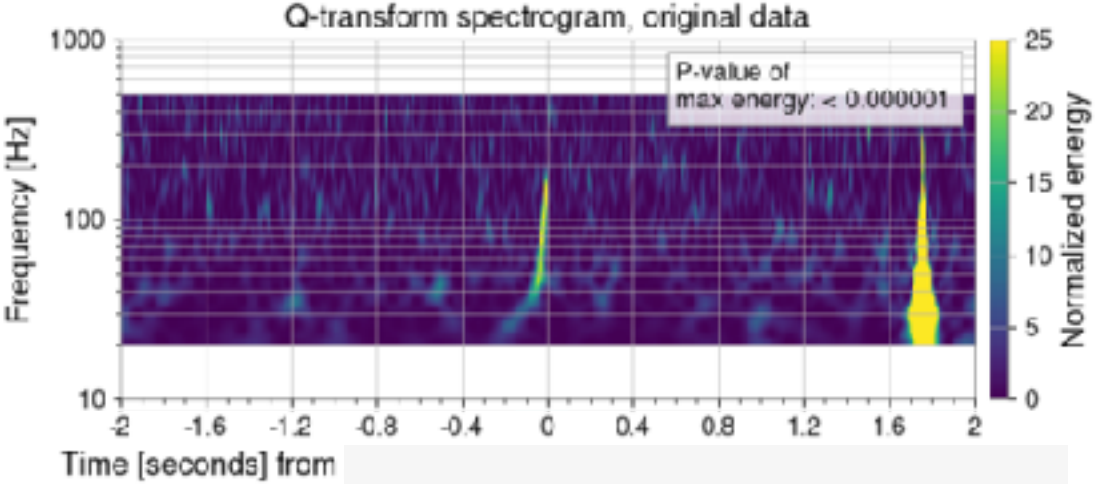




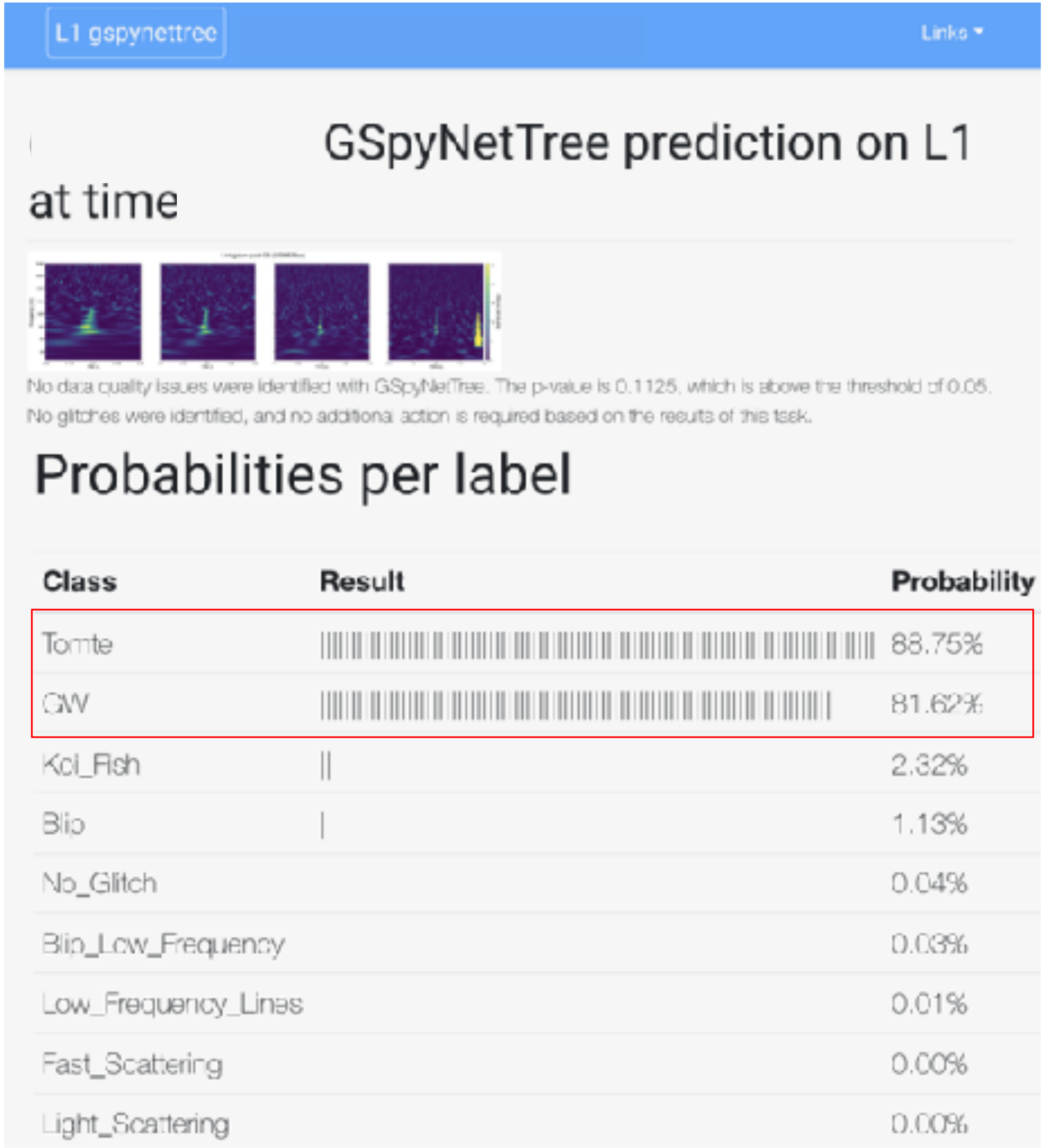
Sofía Álvarez-López
Mervyn Chan
Dhatri Raghunathan
Franz Herbst

GSpyNetTree example

- One of the significant events of ER15.
- A glitch occurred in close proximity of the GW.
- Shows the potential of GSpyNetTree on identifying glitches in the proximity of GWs.



Spectrogram adapted from the GlitchFind task.



Class	Result	Probability
Tomte		88.75%
GW		81.62%
Koi_Fish		2.32%
Blip		1.13%
No_Glitch		0.04%
Blip_Low_Frequency		0.03%
Low_Frequency_Lines		0.01%
Fast_Scattering		0.00%
Light_Scattering		0.00%

Testing/training GSpyNetTree on Virgo glitches; metastudy of DQR tasks (+ DQ shift, glitch characterization, and event validation)

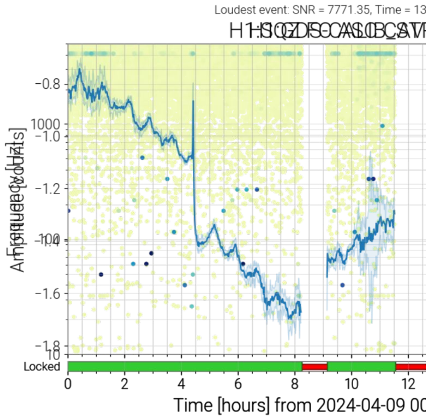
UBC
Physics & Astronomy

Erich Vogt First Year Summer Research Experience award

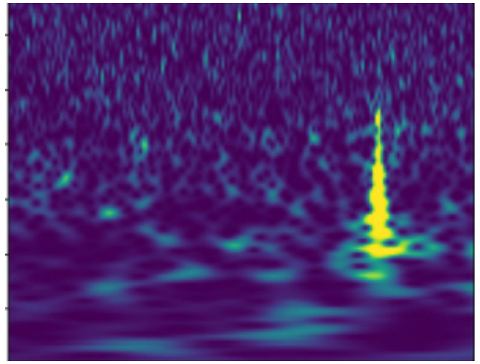
Airene Ahuja

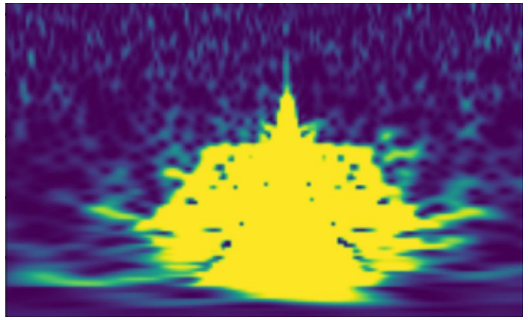
4kHz glitch characterization spreadsheet and correlation to SQZ channel:

	A	B	C	D	E	F	G	H	I
1		Glitches present?	Strength?	00:00 - 3:59	4:00 - 7:59	8:00 - 11:59	12:00 - 15:59	16:00 - 19:59	20:00 - 23:59
2	4/8/2024	Yes	4						
3	4/9/2024	Yes	5						
4	4/10/2024	Yes	2						
5	4/11/2024	No	0						
6	4/12/2024	Yes	3						
7	4/13/2024	No	0						
8	4/14/2024	No	0						
9	4/15/2024	No	0						
10	4/16/2024	No	0						
11	4/17/2024	No	0						
12	4/18/2024	Yes	1						
13	4/19/2024	Yes	4						
14	4/20/2024	Yes	3						
15	4/21/2024	Yes	5						
16	4/22/2024	Yes	3						
17	4/23/2024	Yes	1						
18	4/24/2024	No	0						
19	4/25/2024	Yes	5						
20	4/26/2024	Yes	5						
21	4/27/2024	Yes	4						
22	4/28/2024	Yes	3						
23	4/29/2024	Yes	4						
24	4/30/2024	Yes	3						



Example Virgo glitches:





Metastudy of DQR tasks for GraceDB superevents:

	A	B	C	D	E	F	G	H	I	J	K
1			H1	L1	V1	DQR status	Date	Candidate	GPS start	GPS end	GraceDB logged?
2	Colour code:		low freq noise	low freq noise	faint line	Not significant	240501	k	1398559886.95	1398559886.98	Y
3	0	All fine				Not significant		v	1398563478.58	1398563478.63	Y
4	1	Minor error				Not significant		af	1398567316.44	1398567318.44	Y
5	2	DQ tasks diff	signal	signal		Done		an	1398569751.92	1398569753.93	Y
6				faint glitch	No V1	Not significant		ap	1398570616.38	1398570616.40	Y
7	Count:		plus V1. L1, V1	faint lines	Plus, faint line	Not significant		dc	1398600209.92	1398600211.96	Y
8	0	0	Omegascans f	Omegascans f	Omegascans f	Not significant		dr	1398611457.30	1398611457.30	Y
9	1	0	Fixed	fixed	small glitch, fi	Not significant	240502	bb	1398687696.83	1398687698.85	Y
10	2	0		low freq noise	glitch	Not significant		bf	1398689001.83	1398689001.73	Y
11			glitches + low	glitches	faint lines	Not significant		ck	1398714141.61	1398714143.63	Y
12	Significant det	14	big koi		low freq glitch	Not significant	240503	j	1398732756.49	1398732757.57	Y
13	Retracted sign	0	low freq noise	low freq noise	faint low freq	Not significant		bk	1398766834.97	1398766834.98	Y
14	Total detectio	184	Omegascans f	Omegascans f	Omegascans f	Not significant		bp	1398772061.44	1398772063.46	Y
15	f significant to	8%	Fixed	glitch, fixed	Fixed	Not significant		cx	1398781536.56	1398781538.56	Y
16				glitches	glitches	Not significant		cz	1398781513.07	1398781513.12	Y
17	Percentages:				low freq glitch	Not significant		ff	1398815005.67	1398815007.68	Y
18	0	0%				Not significant	240504	bt	1398772880.68	1398772882.68	Y
19	1	0%				Not significant		bv	1398772968.22	1398772970.22	Y
20	2	0%	small lines, low freq noise			Not significant		by	1398774184.24	1398774186.24	Y
21						Not significant		ca	1398774886.83	1398774888.83	Y
22		means inj	line		small line	Not significant		cu	1398779619.42	1398779619.44	Y
23		means OBS	small glitch	small lines		Not significant		dd	1398783061.32	1398783063.33	Y
24	NO	mean not OBS				Not significant		dm	1398789487.06	1398789499.06	Y

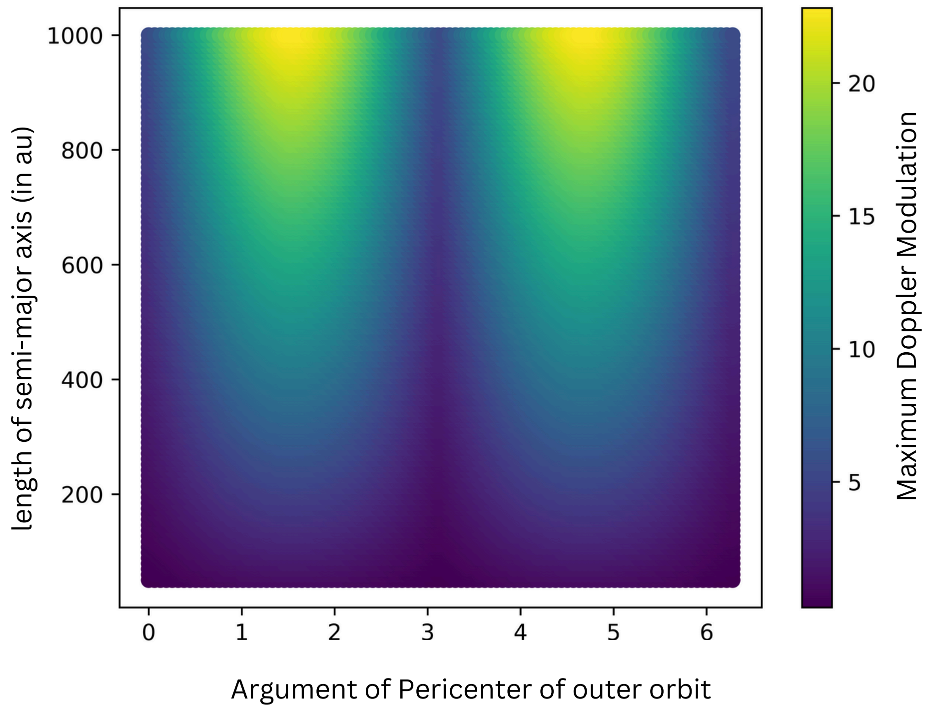
GSpyNetTree results on Virgo glitches:

	A	B	C	D	E	F	G	H	I	J	K	L
1	filename	Manual Prediction	GSpyNetTree Prediction:	Blip	Blip_Low_Frequency	Fast_Scattering	GW	Koi_Fish	Light_Scattering	Low_Frequency_Lines	No_Glitch	Tomte
2	0_Blip_0_trn_set.pkl	Low_Frequency_Lines		0.23%	0.14%	1.12%	12.90%	0.22%	0.40%	10.79%	70.53%	0.31%
3	0_Blip_10_trn_set.pkl	Blip_Low_Frequency		0.03%	0.25%	4.28%	7.71%	0.09%	0.13%	1.23%	85.66%	0.20%
4	0_Blip_100_trn_set.pkl	Tomte		99.82%	0.10%	0.02%	99.93%	0.10%	0.06%	0.01%	0.02%	0.13%
5	0_Blip_1002_trn_set.pkl	Light_Scattering		0.07%	0.04%	0.03%	78.12%	0.06%	6.25%	1.50%	23.21%	0.15%
6	0_Blip_1013_trn_set.pkl	Blip		0.59%	0.62%	2.32%	94.89%	0.05%	0.83%	1.34%	2.24%	0.12%
7	0_Blip_1017_trn_set.pkl	Koi_Fish		0.03%	0.14%	0.17%	3.18%	99.06%	0.04%	0.02%	0.03%	0.25%
8	0_Blip_1051_trn_set.pkl	Low_Frequency_Lines		0.81%	0.02%	0.03%	2.34%	0.02%	0.05%	98.27%	0.76%	0.02%
9	0_Blip_1071_trn_set.pkl	Fast_Scattering		0.20%	0.05%	0.15%	5.09%	0.09%	0.28%	11.11%	61.25%	0.16%
10	0_Blip_1074_trn_set.pkl	Fast_Scattering		0.11%	0.11%	0.72%	50.00%	0.12%	1.80%	1.01%	41.32%	0.13%
11	0_Blip_1102_trn_set.pkl	Low_Frequency_Lines		0.90%	0.02%	4.11%	34.36%	0.03%	70.98%	1.16%	0.31%	0.03%
12	0_Blip_1127_trn_set.pkl	Blip		0.37%	0.03%	0.33%	54.16%	0.08%	7.12%	1.42%	19.50%	0.12%
13	0_Blip_1234_trn_set.pkl	Blip		2.82%	0.05%	0.66%	1.02%	0.05%	45.39%	5.46%	0.32%	0.02%
14	0_Blip_1293_trn_set.pkl	Koi_Fish		0.05%	0.03%	96.30%	98.73%	6.08%	0.25%	0.00%	0.01%	0.06%
15	0_Blip_1305_trn_set.pkl	Koi_Fish		0.27%	0.11%	1.15%	58.17%	66.80%	3.09%	0.06%	0.09%	17.54%
16	0_Blip_131_trn_set.pkl	Koi_Fish		0.01%	0.01%	2.72%	80.57%	24.79%	0.01%	0.00%	0.01%	67.06%
17	0_Blip_1314_trn_set.pkl	Tomte		0.34%	0.05%	4.64%	60.59%	0.07%	0.76%	1.57%	7.21%	0.25%
18	0_Blip_1338_trn_set.pkl	Tomte		0.16%	0.13%	0.97%	99.97%	2.10%	54.86%	0.03%	0.49%	1.11%
19	0_Blip_1339_trn_set.pkl	Koi_Fish		0.00%	0.02%	2.44%	84.50%	37.05%	71.18%	0.01%	0.02%	0.07%
20	0_Blip_1350_trn_set.pkl	Low_Frequency_Lines		0.47%	0.03%	0.04%	12.63%	0.06%	0.06%	65.64%	19.36%	0.09%
21	0_Blip_1360_trn_set.pkl	Fast_Scattering		0.45%	2.12%	0.06%	81.31%	0.12%	0.07%	0.36%	26.47%	0.11%

Incorporating Roemer delay in the GWs bursts by hierarchical triple system

Rishav Agrawal Alan Knee Jess McIver

- Simulate gravitational wave bursts from a binary system in orbit around a tertiary supermassive black hole, including Roemer delay.
- Analyze time intervals between GW bursts in LISA data to infer orbital parameters for these systems.



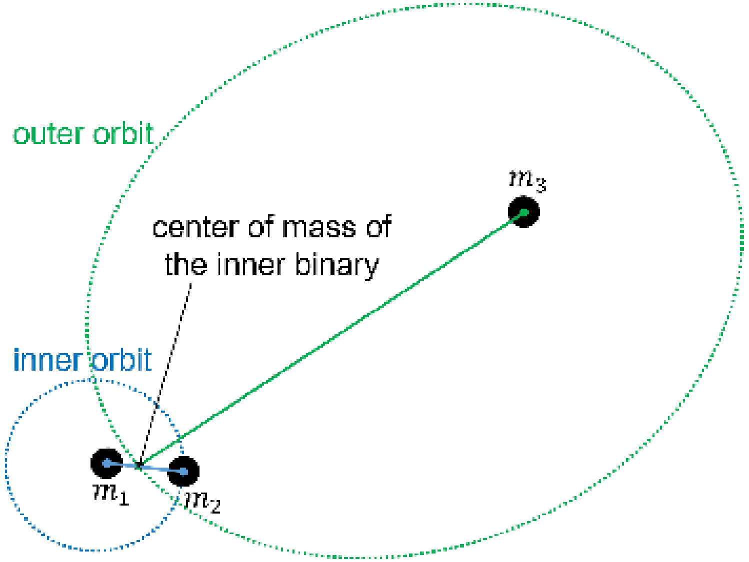


Image credits: Gupta, P., Suzuki, (2019)

- Incorporate relativistic effects in the analysis for future work.

Implement a Bayesian machine learning model for GSpyNetTree

Shreeja Bandyopadhyay–Mitacs GRI @ UBC

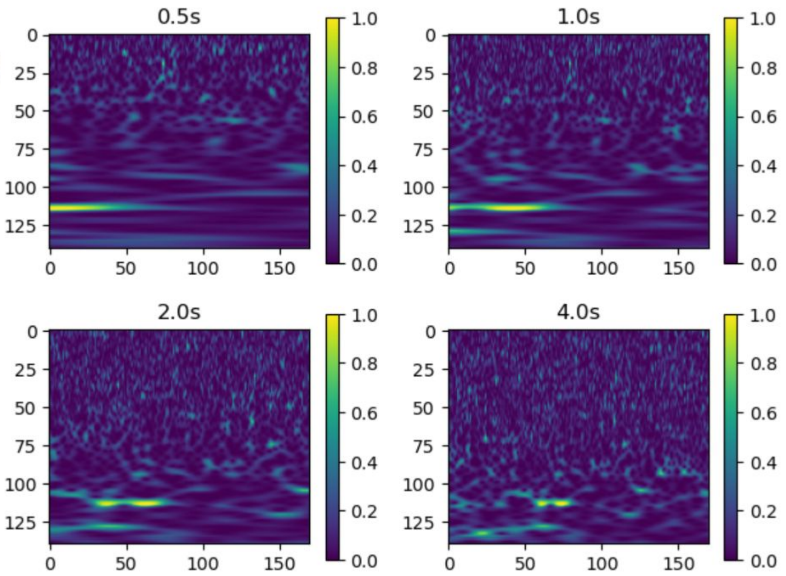
$$p(w|D) = \frac{p(D|w)p(w)}{p(D)} = \frac{p(D|w)p(w)}{\int_{w'} p(D|w')p(w')dw'}.$$

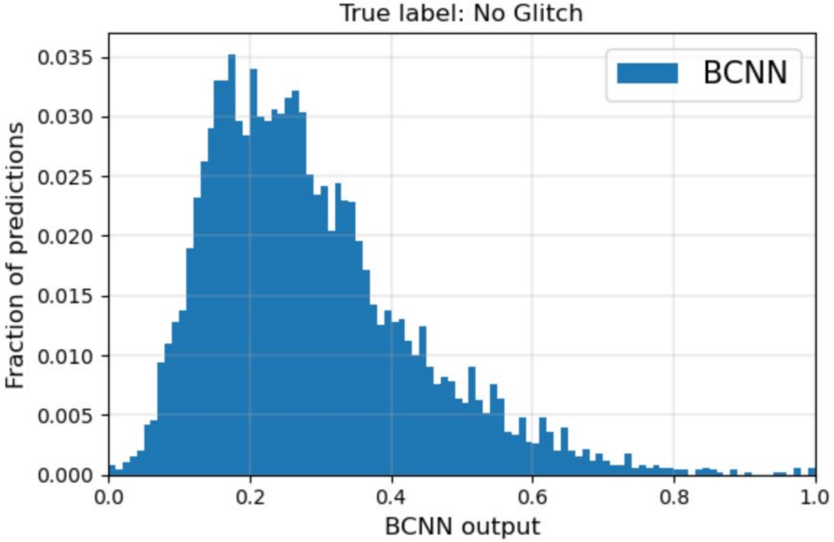
$$p(\hat{y}(x)|D) = \int_w p(\hat{y}(x)|w)p(w|D)dw$$

$p(w)$=Prior $p(D|w)$=Likelihood

$p(w|D)$=Posterior

$p(\hat{y}(x)|D)$ =predictive distribution





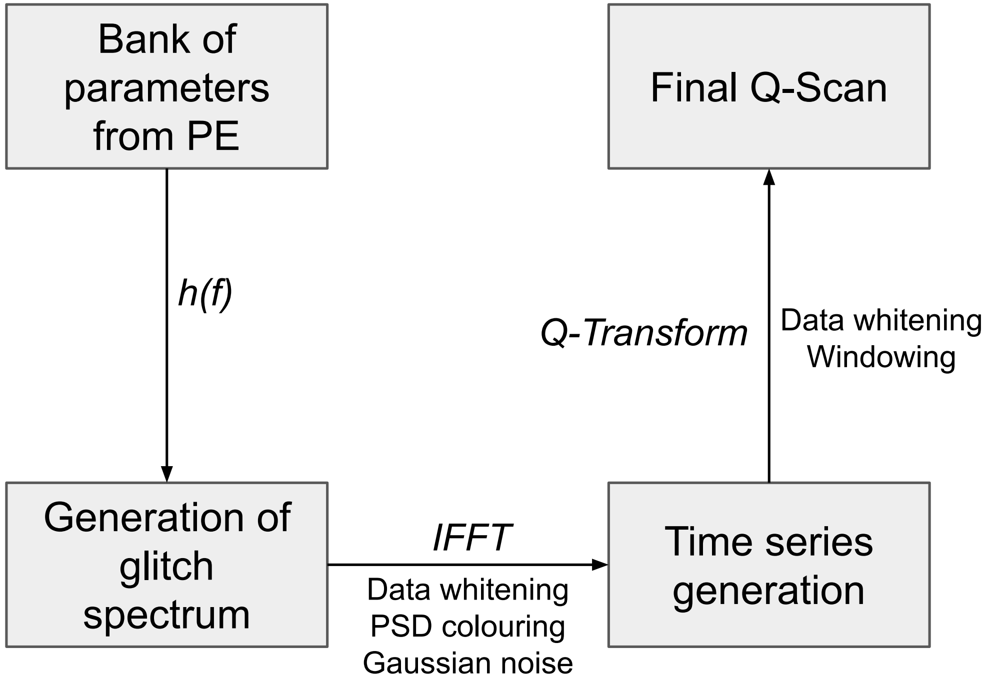
0=No Glitch, 1=Glitch

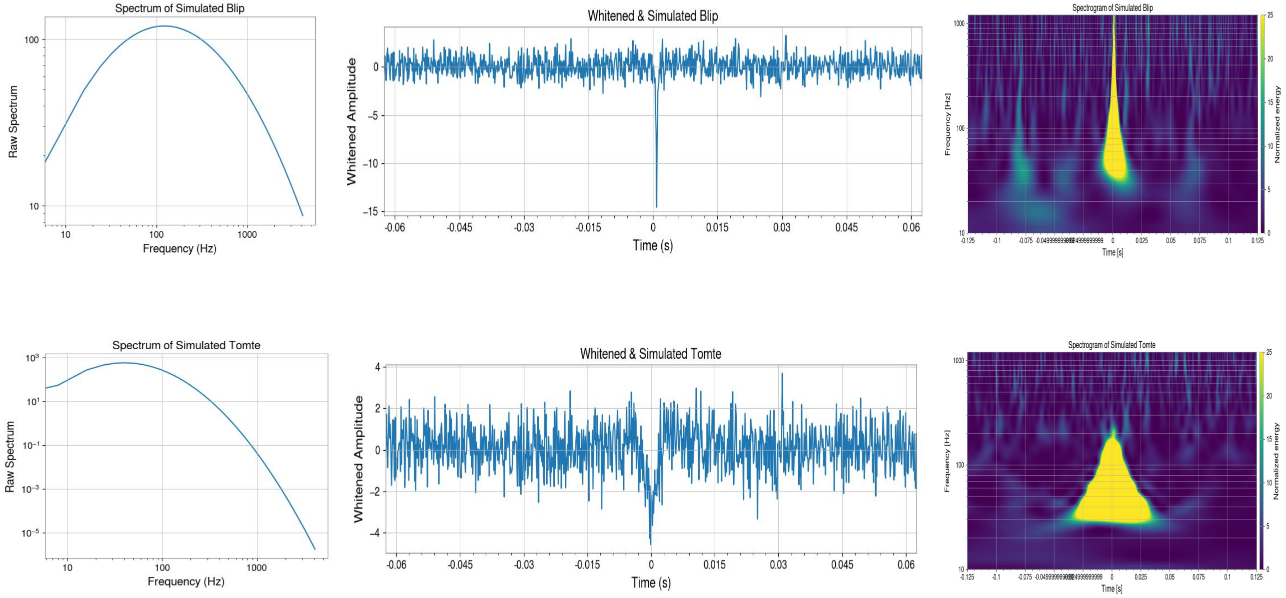
Build Bayesian CNN classification models for glitches/signals that output a probability distribution for each class rather than a single value —Not only reduces overfitting but also provides a measure of uncertainty in the predictions.

Simulation of Short Transient Glitches with Quasi-Physical Model

Sean Collins - NSERC USRA Awardee

- ⇨ Five parameter model* defined in frequency domain
- ⇨ Simulates 4 types of glitches in calibrated strain channel
- ⇨ Options to model different detectors and various sensitivities
- ⇨ Applications in machine learning and glitch identification/subtraction

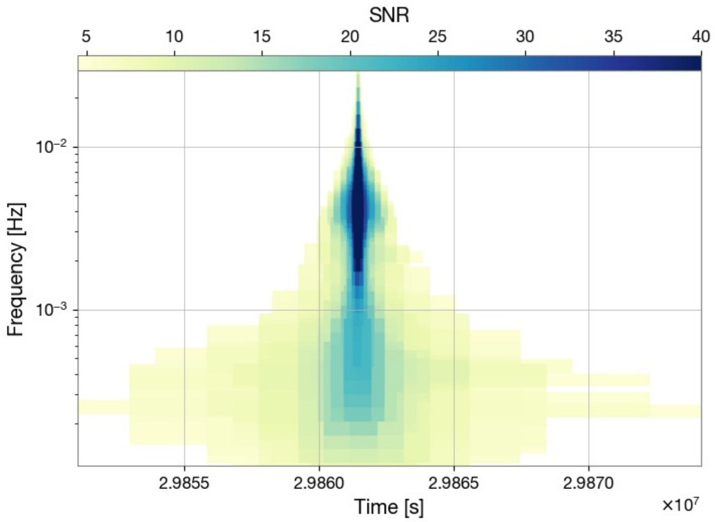


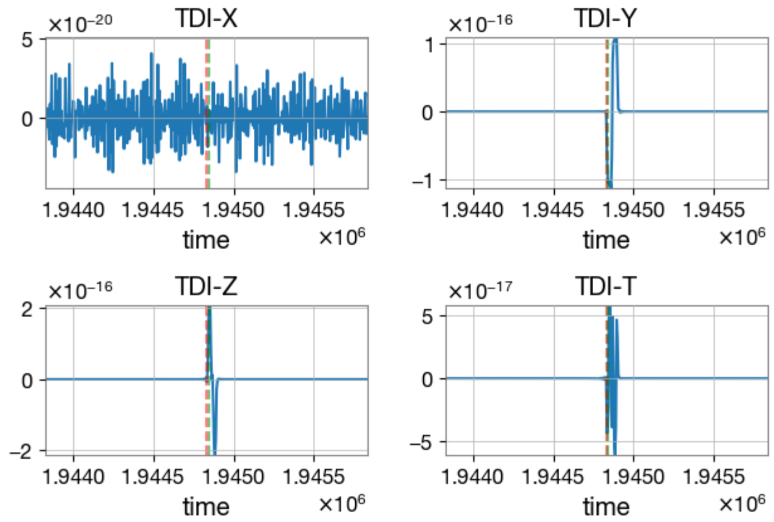


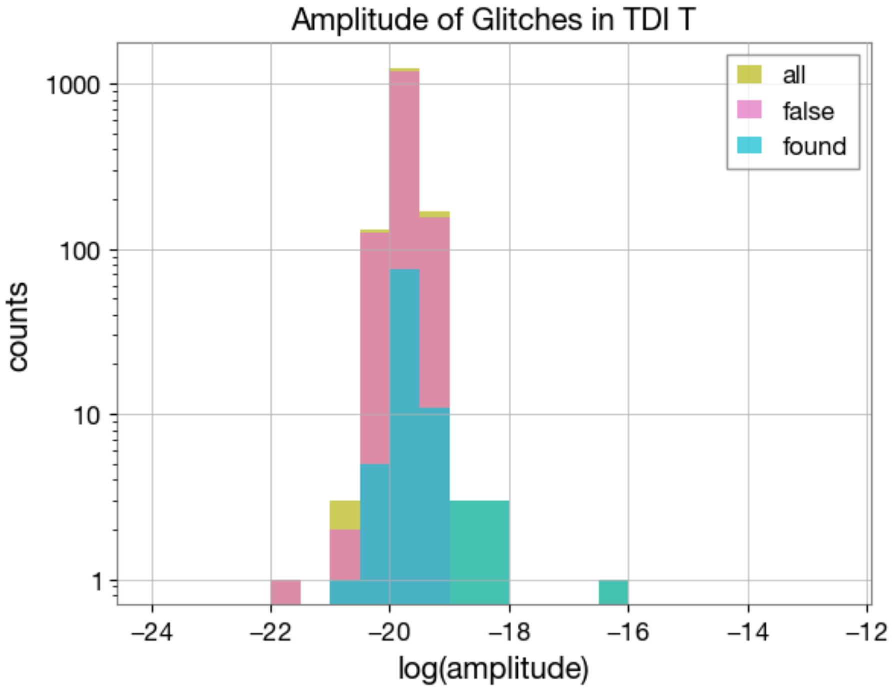
*Model from Bondarescu et al. 2023 (arXiv 2309.06594)

LISA Glitch Detection with Q-transform

Beth Flanagan







- Implementation of Q-transform on Spritz Data from LISA data challenge (LDC) 2b
- Does well at identifying glitches with amplitude around 10^{-19} and above at an SNR threshold of 5
- Creating a new data set of LISA glitches to further test the Q-transform method

Data Segmentation Algorithm Development & Noise Source Investigation in LIGO's O4b using Hveto

Ananya J Nawale — Mitacs GRI @ UBC Summer 2024

Data Segmentation:

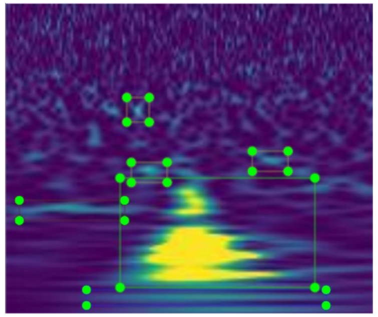
Producing a segmented data set with examples of detector glitches and simulated gravitational wave (GW) signals

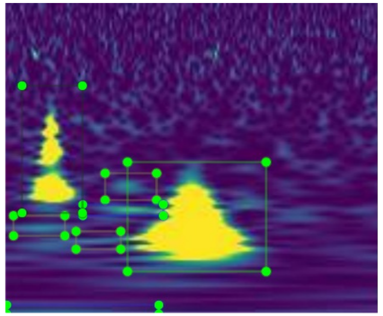
Contributing to the development of a data segmentation algorithm, investigating classifier performance, and retraining the model with augmented data.

Noise Investigation:

Identifying sources of LIGO detector noise in O4b using Hveto.

Investigating identified outliers by correlating triggers with environmental trends, visualizing changes in noise behavior, and comparing morphology and amplitude in possible witness sensors.





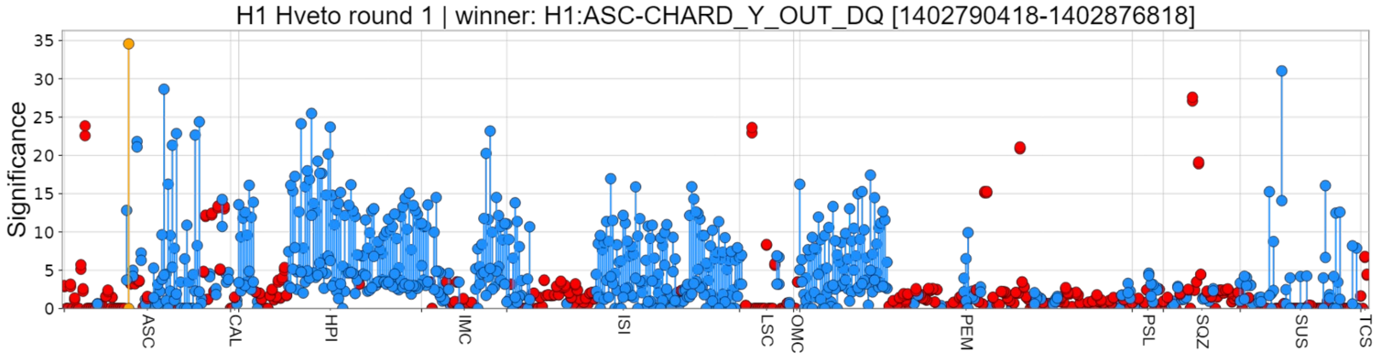
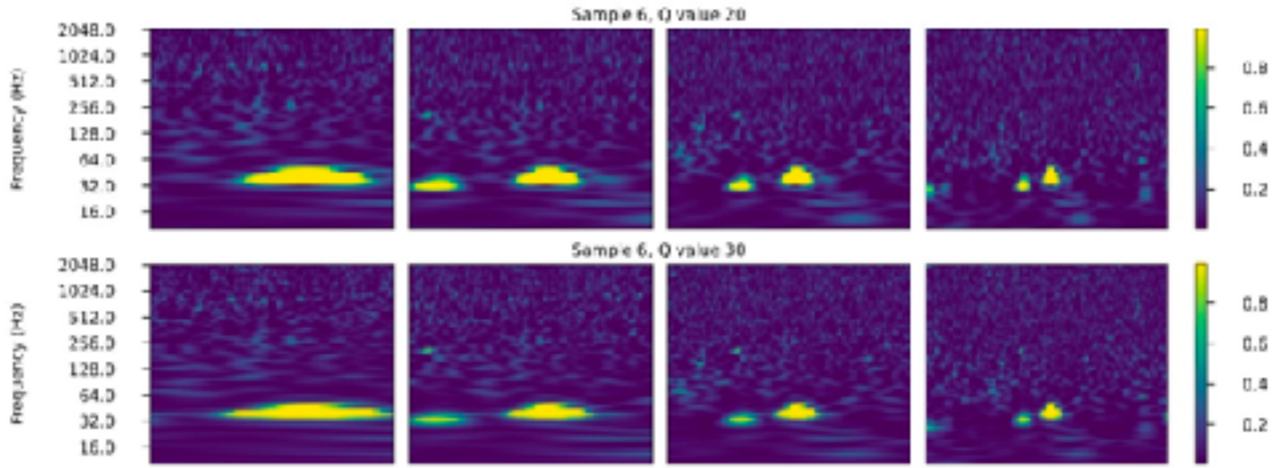
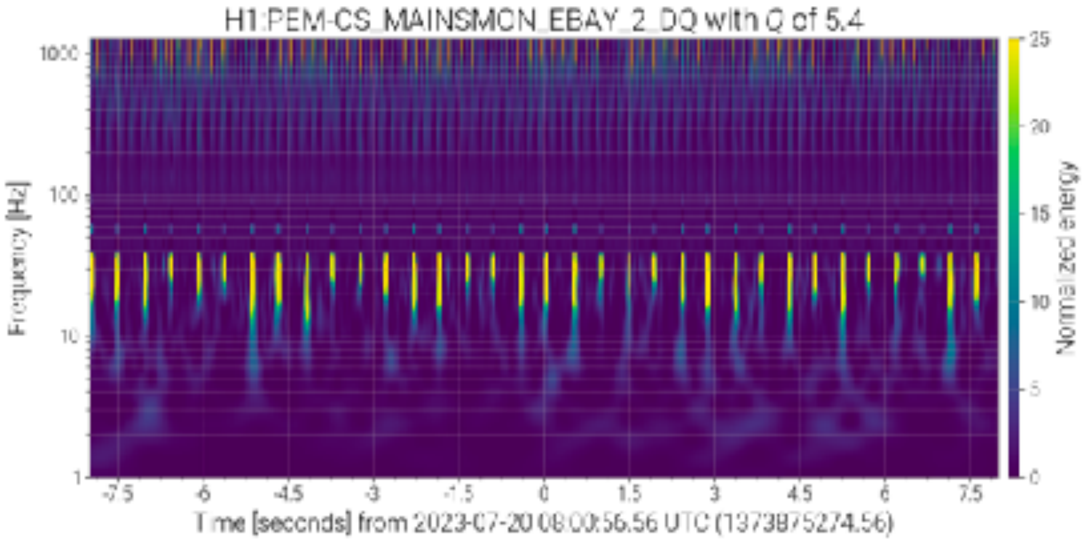


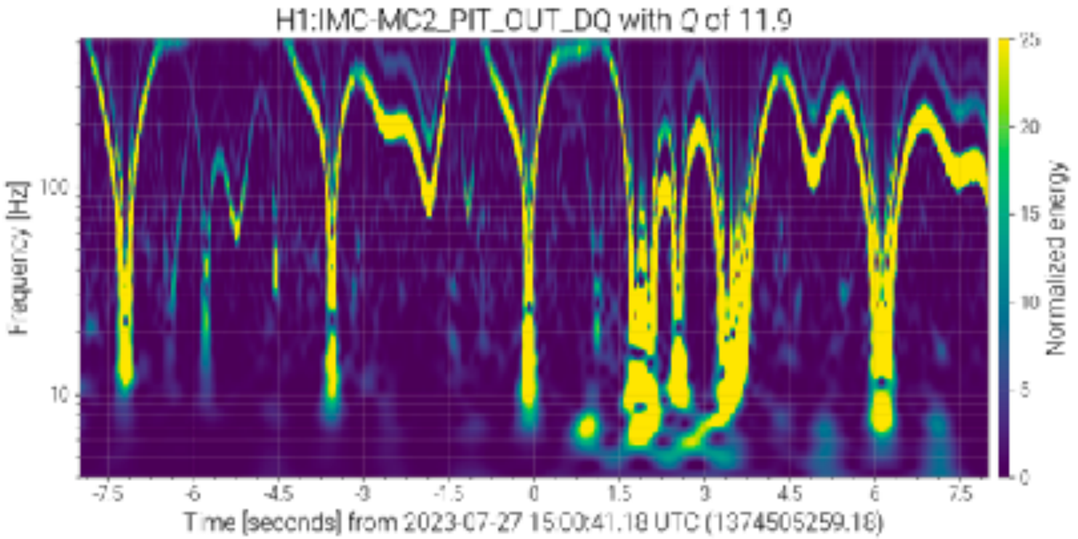
Fig: Significance Drop Plot

Honours Theses 2024

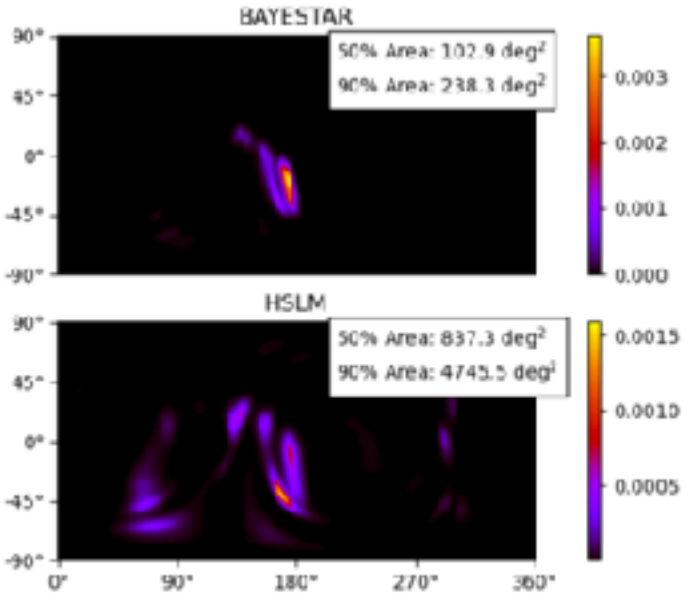


Dhatri Raghunathan - IIT Karagpur/UBC
GSpyNetTree feature set optimization





Eli Cohen - UBC
GWSkyNet-Lite



Harshini Paranjape - IIT Roorkee/UBC
ML to identify noisy auxiliary channels

Highlighted short-authorlist papers from the past year

Preprints:

1. *Detecting gravitational-wave bursts from black hole binaries in the Galactic Center with LISA*. **A.M. Knee, J. McIver,** S. Naoz, I.M. Romero-Shaw, B.M. Hong. Submitted to ApJL April 2024. Preprint: https://arxiv.org/abs/2404.12571
2. *GWSkyNet II : a refined machine learning pipeline for real-time classification of public gravitational wave alerts*. **M.L. Chan, J. McIver**, A. Mahabal, C. Messick, D. Haggard, N. Raza, **Y. Lecoeuche,** R. Ewing, F. DiRenzo, **M. Cabero**, M. Coughlin, S. Ghosh, P. Godwin. Accepted by ApJ. (Preprint embargoed.)
3. *Explaining the GWSkyNet-Multi machine learning classifier predictions for gravitational-wave events*. N. Raza, **M. Chan**, D. Haggard, A. Mahabal, **J. McIver**, T. Abbott, E. Buffaz, N. Viera. Accepted to ApJ. Preprint: arXiv 2308.12357
4. *A new method to distinguish gravitational-wave signals from detector noise transients with Gravity Spy*. **S. Jarov, S. Thiele,** S. Soni, **J. Ding**, **J. McIver**, R. Ng, R. Hatoya, D. Davis. Submitted to Phys Rev D. Preprint: arXiv 2307.15867

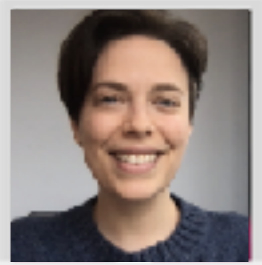
Published:

1. Search for continuous gravitational waves directed at subthreshold radiometer candidates in O3 LIGO data. **A. M. Knee, H. Du, E. Goetz, J. McIver**, et al. Phys. Rev. D 109, 062008 (2024)
2. *Waves in a Forest: A Random Forest Classifier to Distinguish between Gravitational Waves and Detector Glitches*. **N. Shah, A. Knee, J. McIver**, D. Stenning. CQG 40, 23500 (2023)
3. *Multimode Quasinormal Spectrum from a Perturbed Black Hole*. Collin D. Capano, **Miriam Cabero** et. al. Phys. Rev. Lett. 131, 221402 (2023)
4. GSpyNetTree: A signal-vs-glitch classifier for gravitational-wave event candidates. **S.Alvarez, A. Liyanage, J. Ding**, R. Ng, **J. McIver**. Class. Quant. Grav. 41, 085007 (2024)

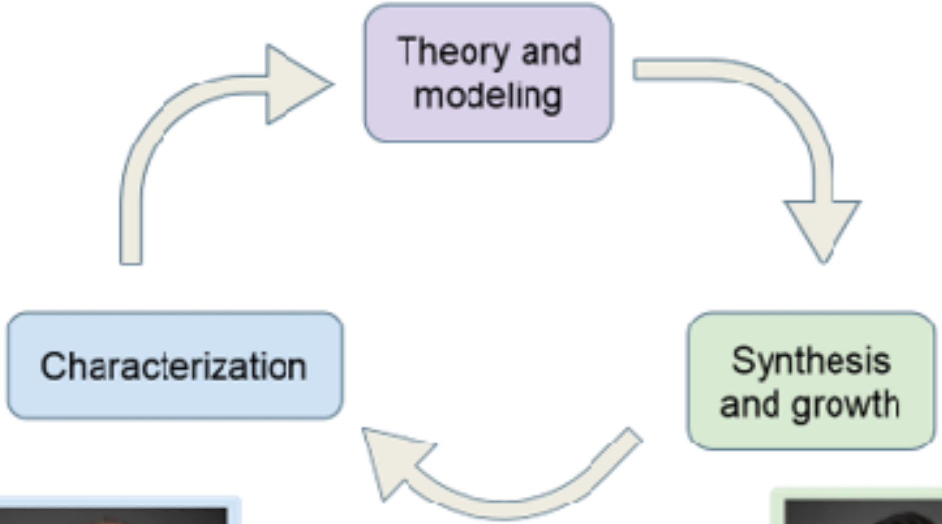
New LSC roles and updates

- New CW-DetChar co-liaison: Alan Knee
- New UBC Research Associate and member of the LSC Identity and Authentication Management team: Heather Fong
  - *(Soon: role will also include IGWN gitlab support and information security)*
- Possibly coming soon: public GWSkyNet annotations on GraceDB

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.



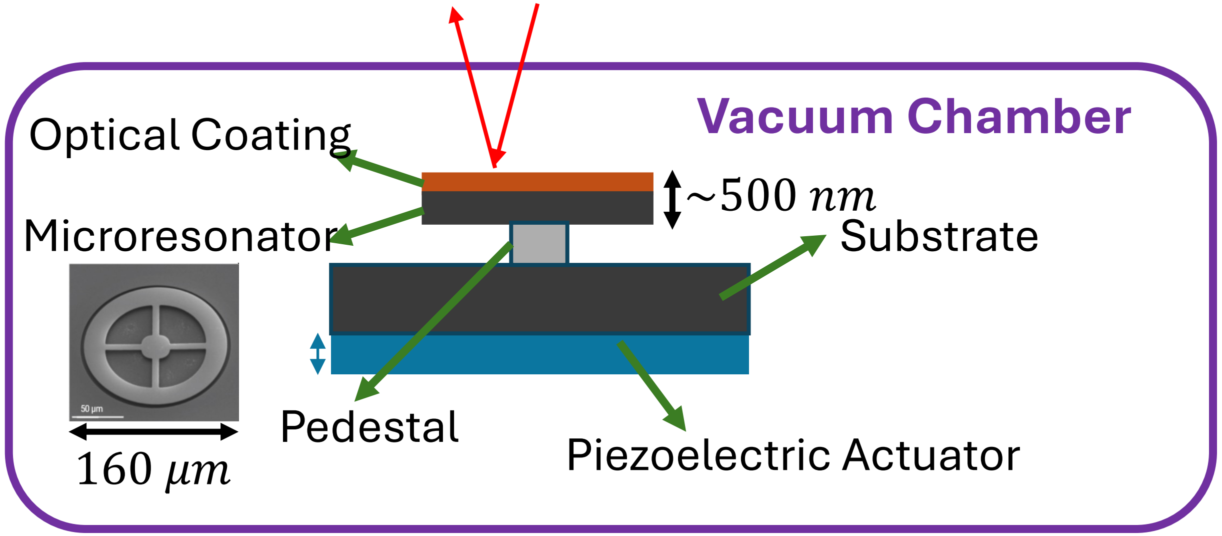
Joerg Rottler's group will perform **atomistic simulations** to predict the internal friction and mechanical loss of oxide glasses of interest for GW detector coatings.

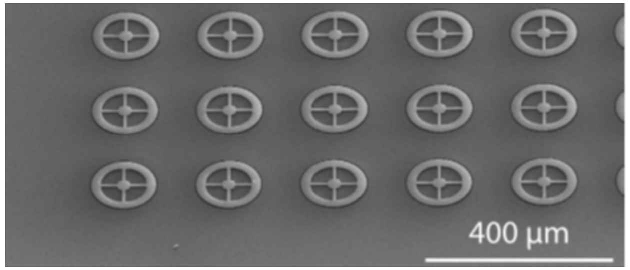
Jeff Young's group will build a **high-throughput optical cryostat** to perform direct measurements of mechanical loss of synthesized materials.

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

MBE-grown thin film oxides on silicon micro resonators

Slide by Jeff Young





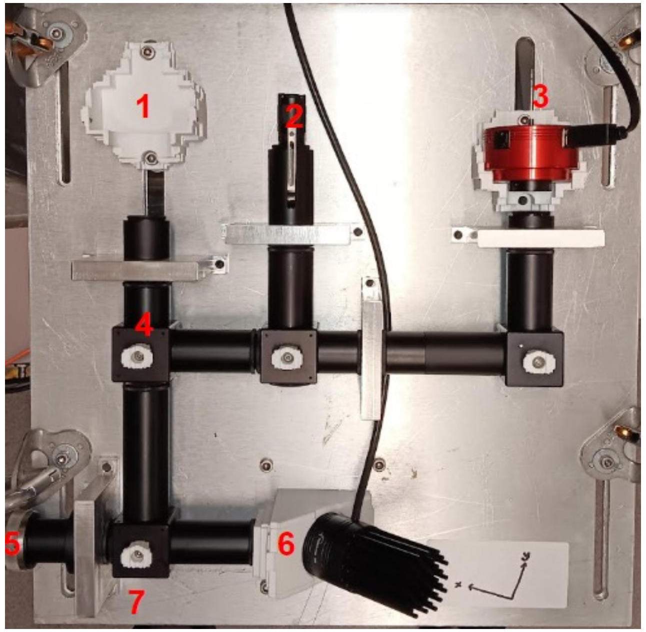
Kirsty Gardner
Ruixin Qiu
Henry Mullock
Philip Macau

MBE-grown, 10 nm thick films: Preliminary Analysis

Fengmiao Li
Ke Zou

Material	Loss Angle (This work)	Loss Angle (Literature)
Titanium dioxide	2.0×10^{-3}	$0.8\times10^{-3}\sim6.0\times10^{-3}$ [4] [5]
20% Strontium-doped titanium dioxide	5.0×10^{-3}	N/A
50% Strontium-doped titanium dioxide	0.8×10^{-3}	N/A

Towards Automated Scanning



Mirror Coating

Philip Macau
UBC QMI

Extracting Q Factors from thin optical films.

Q Factor is a measure of how rapidly a resonator/oscillator loses energy.

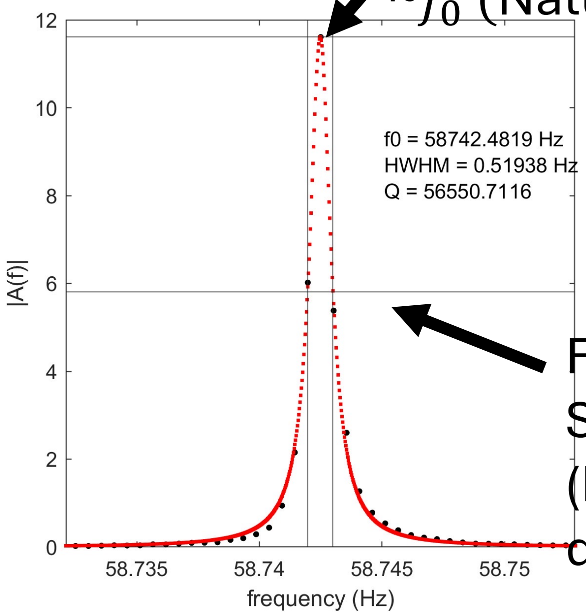
Relationship of Q *to the* loss angle ϕ

$$\phi = \frac{1}{Q} = \left\{\frac{\Delta E}{E}\right\}_{cycle}$$

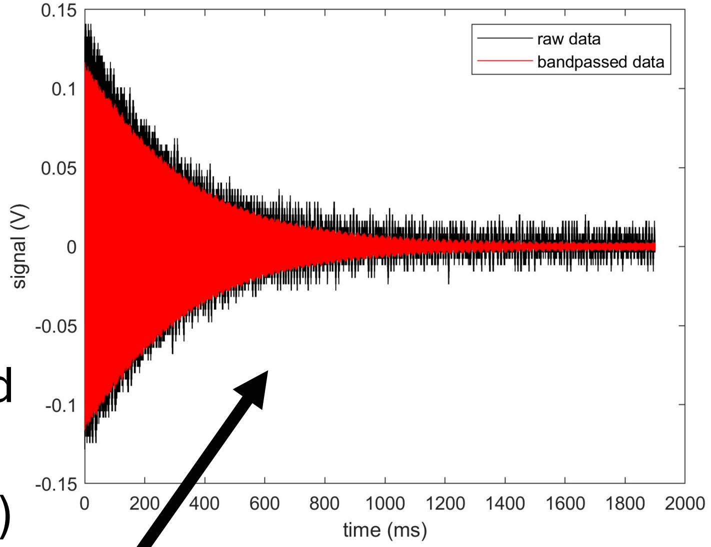
Finding ϕ, quantifies thermal fluctuation in a material through **fluctuation-dissipation theorem**.

Helping find coatings that can reduce noise in mirror coatings.

$\sim f_0$ (Natural Frequency)

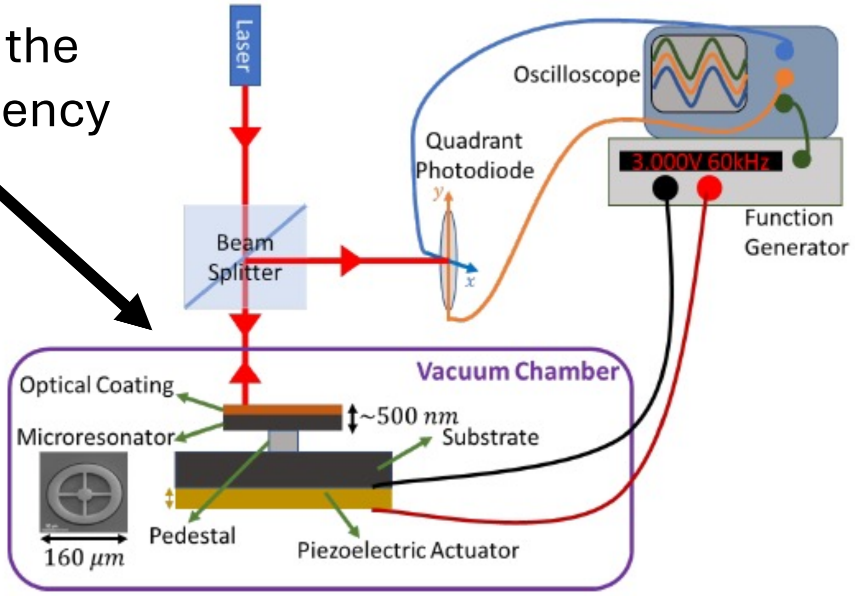


FFT Data of Signal Fitted (how Q is determined)



Ringdown pattern (obtained by Oscilloscope)

Driving a sinusoidal signal close to the resonant frequency of a disk.

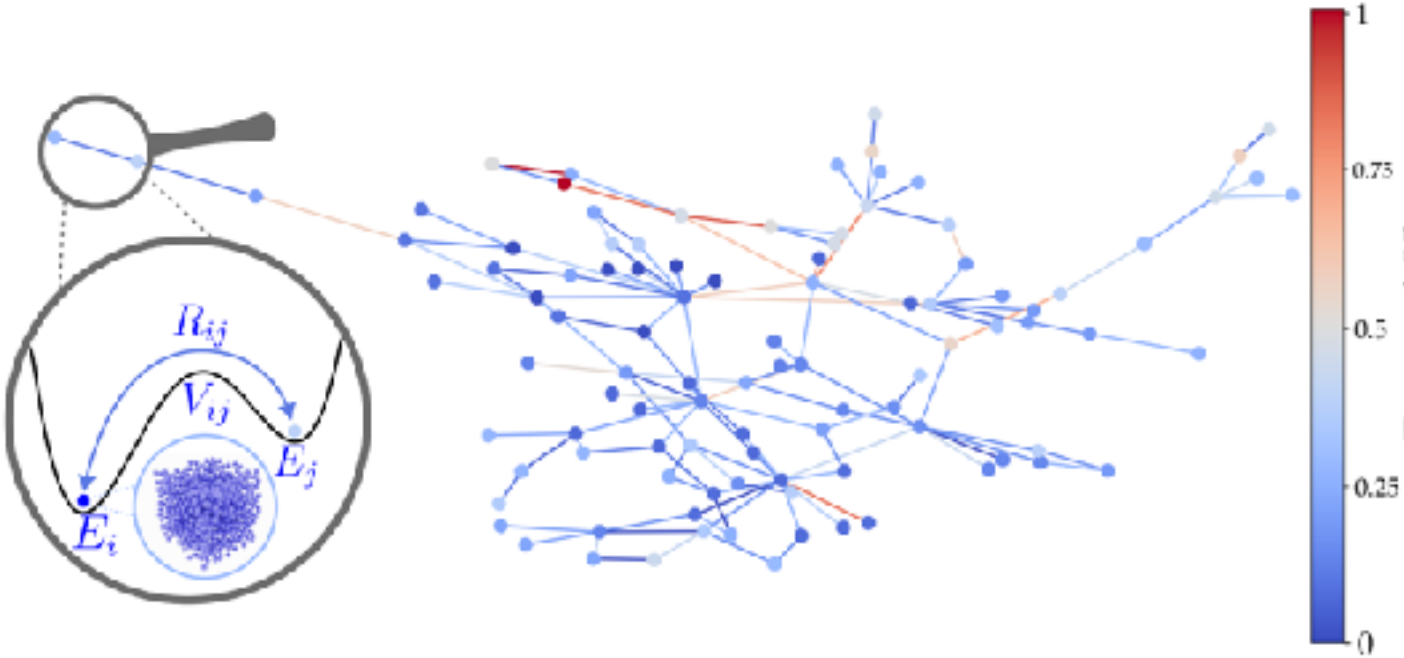


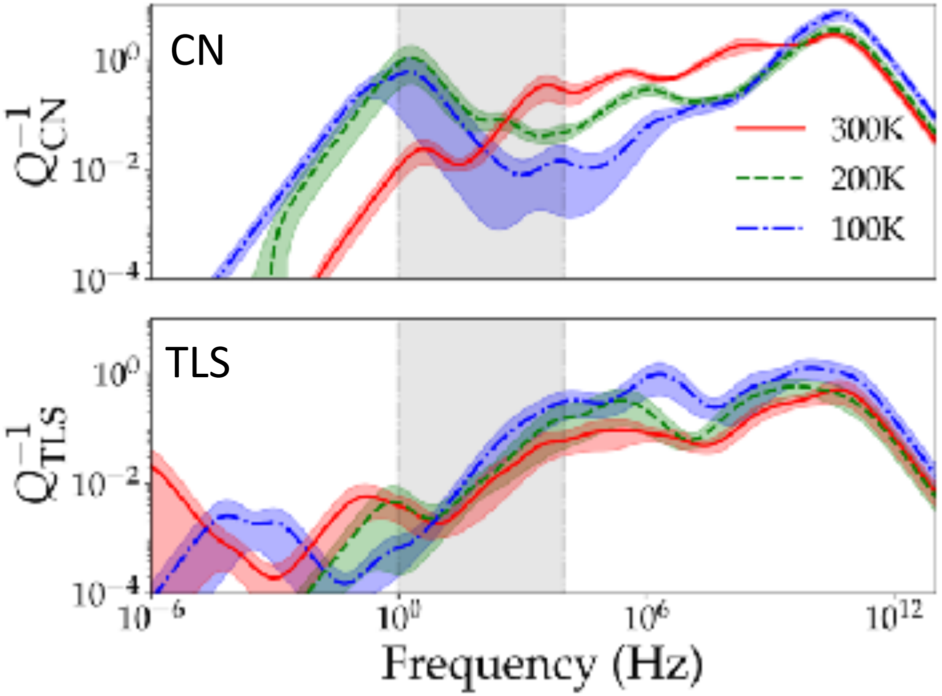
Connected Network Model for the Mechanical Loss of Amorphous Materials

Steven Blaber, Daniel Bruns, and Jorg Rottler

New approach to modelling the thermal noise properties of amorphous silicon.

LIGO DCC: P2400246





UBC-TRIUMF LISA group

Alan Knee, Evan Goetz,
Jess McIver, David Morrissey, Scott Oser

Canadian involvement in LISA

- The Canadian Space Agency has awarded its first funding in support if the LISA mission (CSA Flights and Fieldwork for the Advancement of Science: FAST) to UBC (PI: McIver, co-I: Oser)
  - Soon we hope to hire a new postdoc into a role supported by these funds to target LISA glitch mitigation and developing analysis methods for expected 'burst'-like LISA sources (see Alan's recent paper).
- The CSA is initiating discussions to formalize a possible Canadian contribution to the LISA Distributed Data Processing Centre (DDPC)
  - Researchers across Canada (UBC, McGill, UdeMontreal, Manitoba, Lethbridge, Bishop's) are collaborating on an infrastructure proposal (through the Canadian Foundation for Innovation) that would supply a bonder for A# coatings (housed at LMA in France) as well as computing infrastructure for a LISA DDPC contribution and LIGO infrastructure (calibration software, detector monitoring, and identity/authentication management)

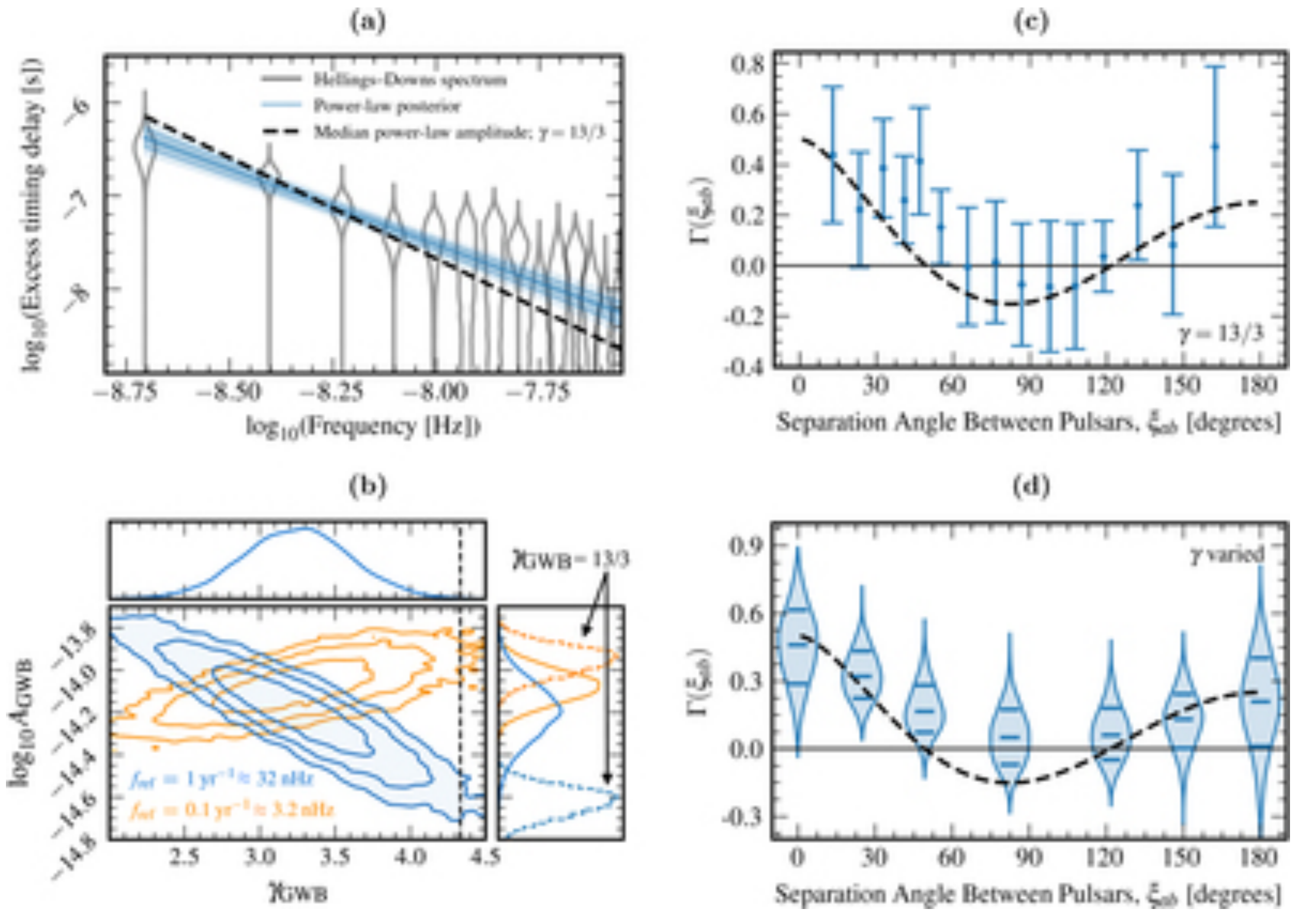
Gravitational Waves with LISA and Big Science Questions

David Morrissey,
TRIUMF

- LISA will address some of the major science drivers of the Canadian Astronomy (CASCA) and Subatomic Physics (SAP) Long Range Plans:
  - How did the Universe begin and what is it made of? (CASCA LRP)
  - What are the extreme conditions of the Universe? (CASCA LRP)
  - How have stars and galaxies changed over cosmic time? (CASCA LRP)
  - What are the fundamental building blocks of matter and what is the fundamental nature of space and time? (SAP LRP)

- These questions connect to theoretical research at UBC and TRIUMF:
  - Nature, cosmological formation, and signals of dark matter
  - GW emission from new physics such as cosmological phase transitions and cosmic strings
  - Testing the history and evolution of the pre-CMB cosmos with GW standard candles.
  - Multimessenger astronomy for determining to origins of the elements and the nature of stars.
  - See for example https://arxiv.org/abs/1912.08832 and https://arxiv.org/abs/1808.08968 for TRIUMF theory contributions.

The UBC CHIME team: pulsar timing



Agazie et al. ApJL (2023)

Major contributions to the NANOGrav 15 year dataset release, including evidence for a GW background.
Pursuing a wide array of pulsar studies with CHIME.

Image: Andre Recnik

The search for B-modes at UBC

CGEM:
the Canadian Galactic Emission Mapper

The ground screen for CGEM at the Dominion Radio Astrophysical Observatory. The pointing system, reflector and this ground screen are all at the DRAO and the radiometer is under construction at UBC.

The system measures polarized foregrounds at 9 GHz to help clean contamination by Galactic synchrotron from direct B-mode searches made at 150 GHz.

-Mark Halpern

Photo by Mark Halpern
DRAO, BC

June 2024: UBC hosted Dawn VII

Keep an eye out for the Dawn VII report!