GWSkyNet

for multi-messenger astronomy

Miriam Cabero Müller

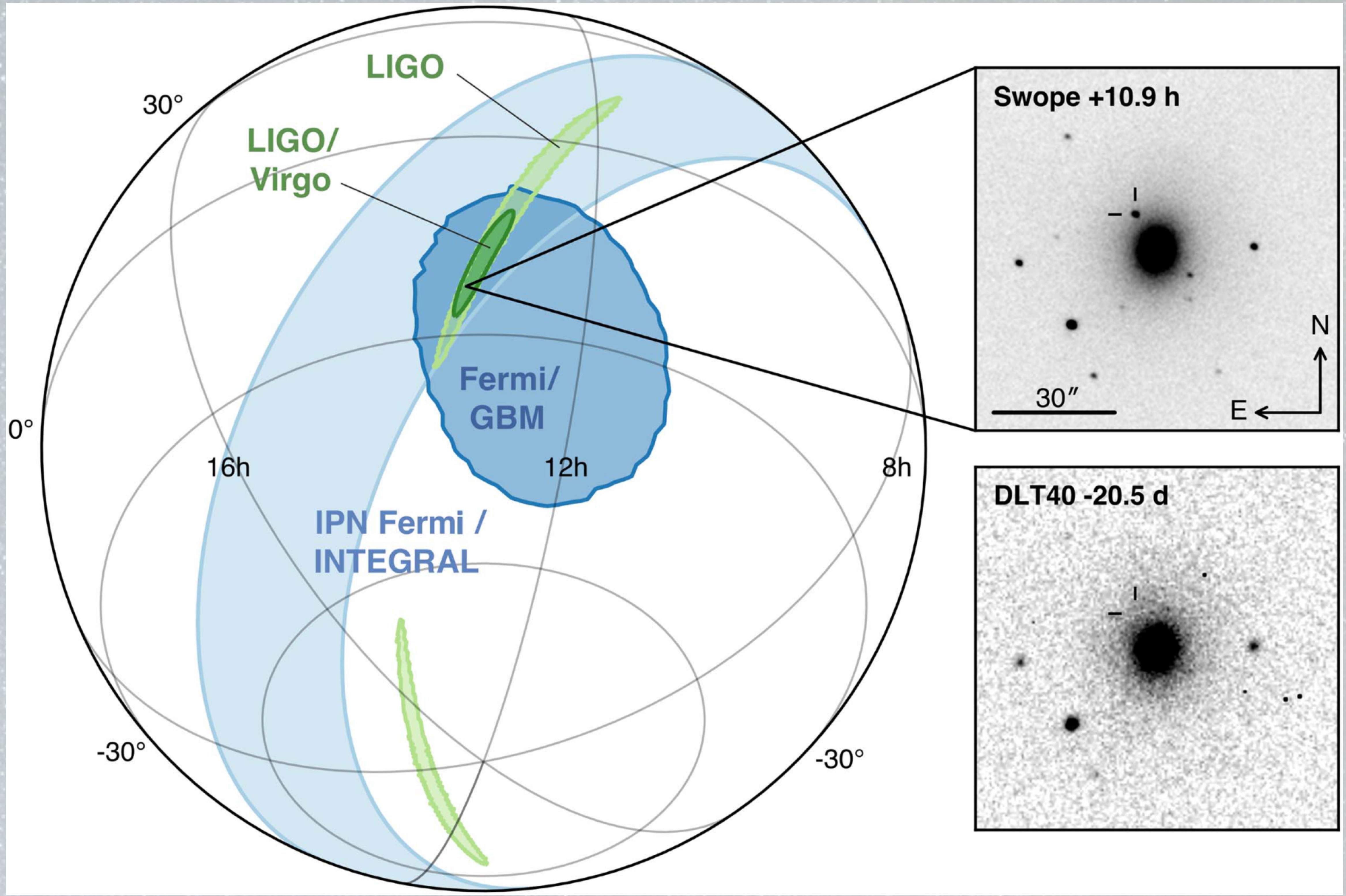
University of British Columbia

LISA Canada Workshop

27-29 April 2021

Multi-messenger astronomy

LIGO / Virgo example: GW170817



LIGO Scientific and Virgo Collaborations,
Astroph. J. Lett. 848:L12 (2017)

Host galaxy:
NGC 4993

Two main ingredients for a successful followup campaign

- Accurate sky localization
- Release of candidate information

More precise sky localization expected for some LISA sources.

Machine learning with sky maps

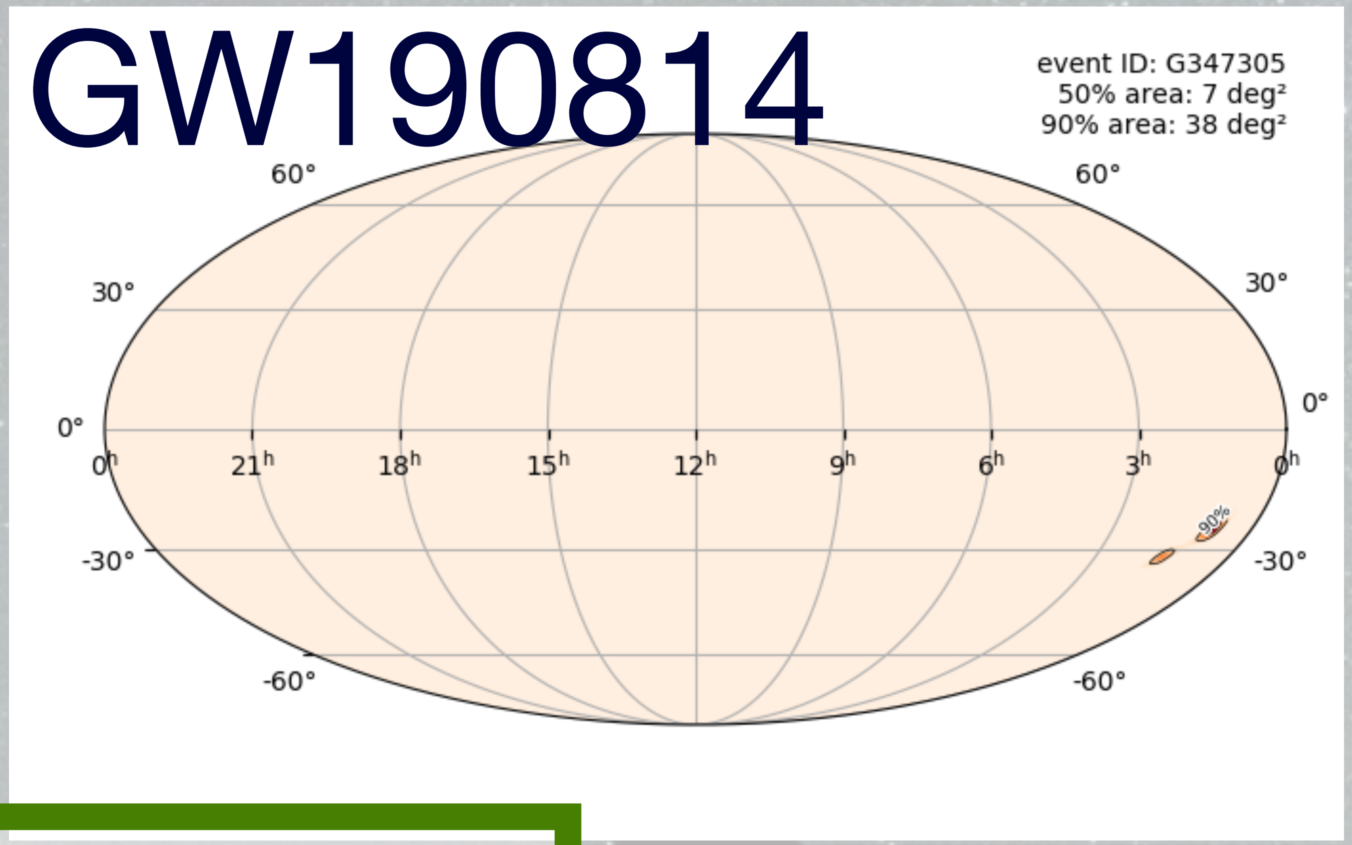
GWSkyNet

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

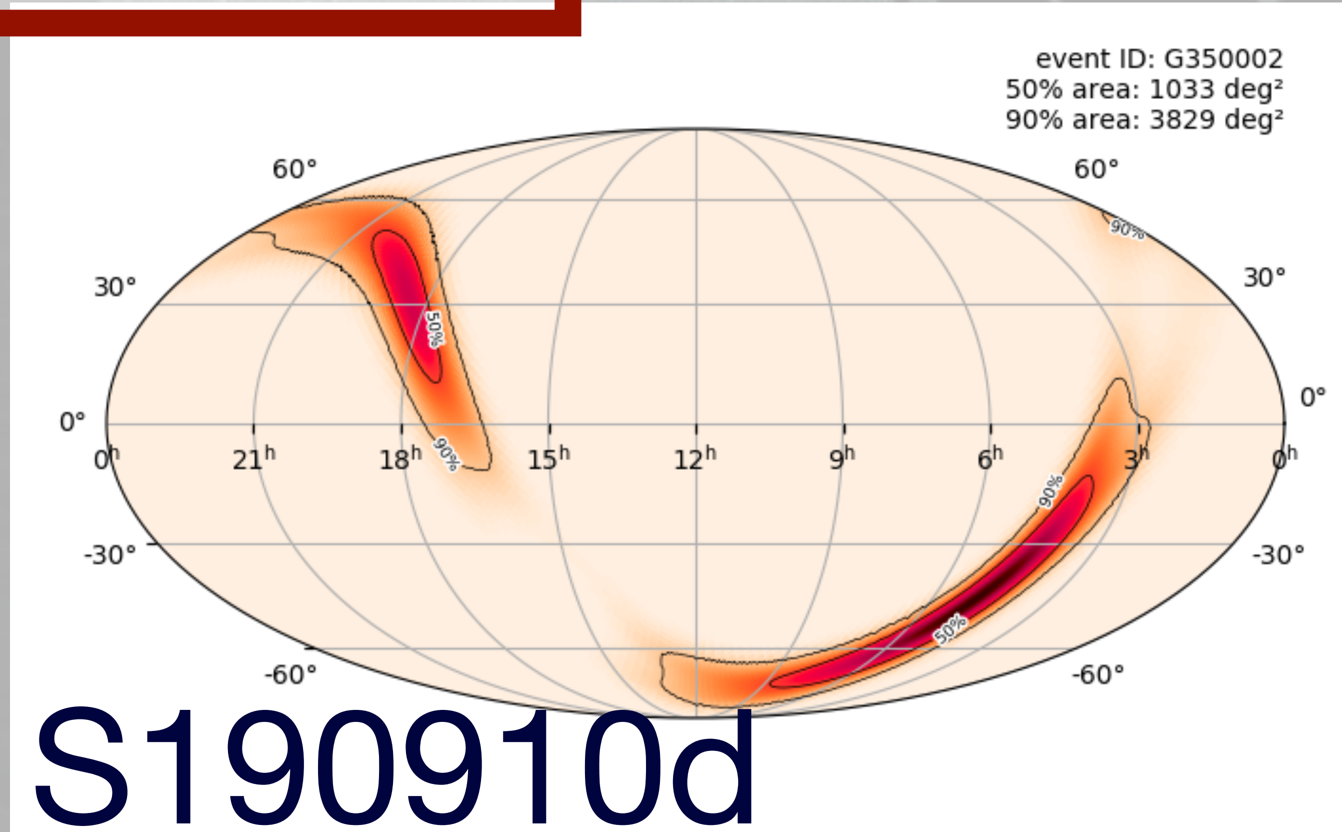
→ Astrophysical

→ Not astrophysical

GW190814



GraceDB



S190910d

M. Cabero et al.,
Astroph. J. Lett. 904:L9 (2020)

LIGO Scientific and Virgo Collaborations,
arXiv:2010.14527 (2020)

Performance on GWTC-2

GWTC-2: GW discoveries between
1 April and 1 October 2019

→

29 non-retracted & unpublished
candidates in this period

	Astrophysical	Not astrophysical
Results (GWTC-2)	22	7
Prediction (GWSkyNet)	23	6

Correctly rejected most
non-astrophysical events
(except S190923y)

Accuracy: How often is the model correct?

$$A = \frac{\text{Correct predictions}}{\text{All predictions}} = 96.5\,\%$$

Recall: How many astrophysical events are predicted correctly?

$$R = \frac{\text{Predicted astro}}{\text{Actual astro}} = 100\,\%$$

M. Cabero et al.,
Astroph. J. Lett. 904:L9 (2020)

GWSkyNet

for multi-messenger astronomy

UBC DEPARTMENT OF PHYSICS ASTRONOMY

UBC

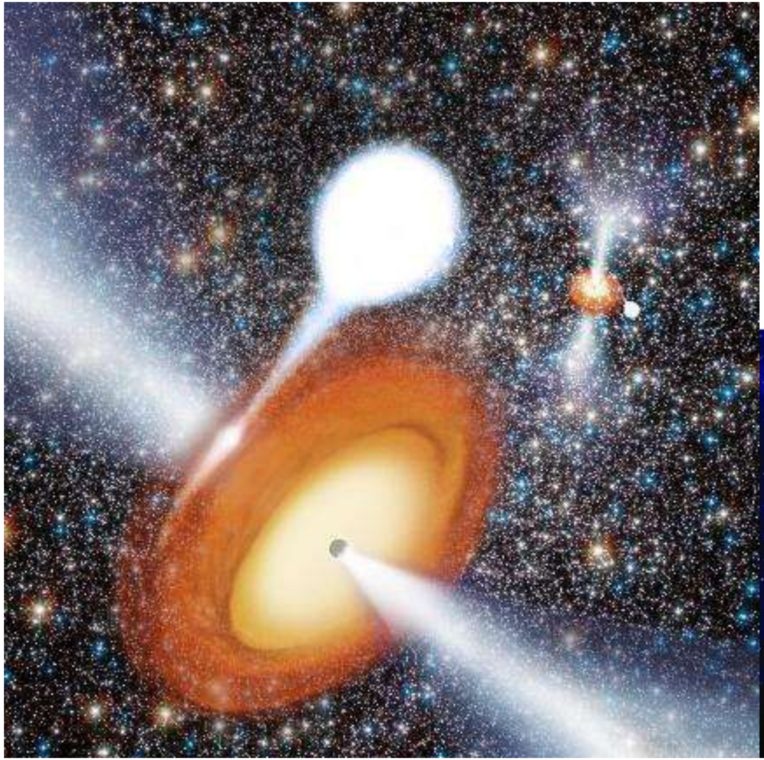
GWSkyNet is a classifier that uses GW sky maps to identify non-astrophysical events

Results look promising: GWSkyNet can help astronomers decide which candidates to follow up

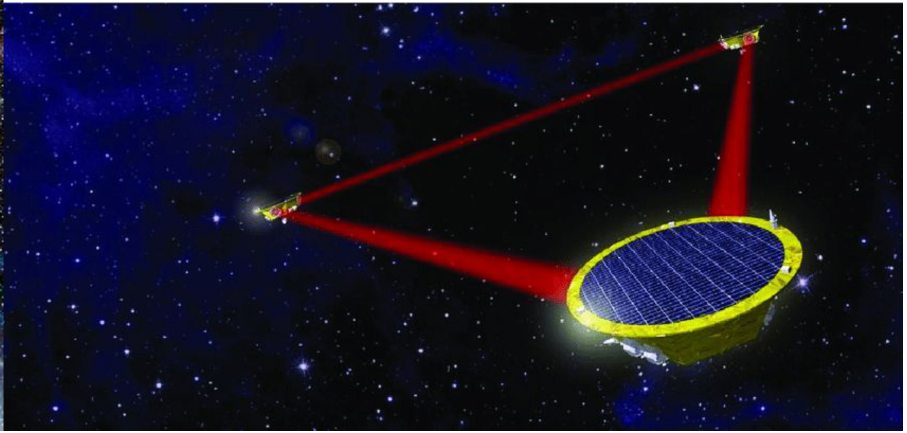
Can be applied to LISA sources once a training set with LISA data has been constructed

Thank you

The hunt for ultra-compact X-ray binaries in extragalactic globular clusters: lessons for LISA

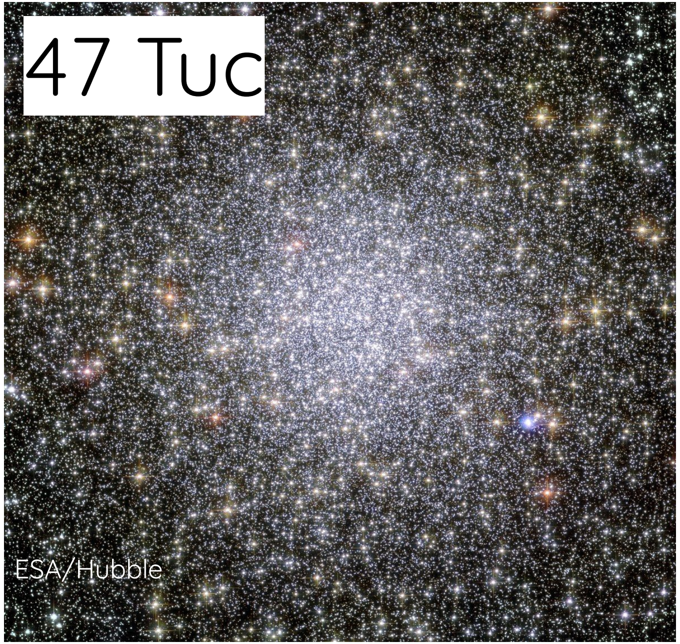


Kristen Dage
McGill University
April 28, 2021



Ultra-compact X-ray binaries in globular clusters?

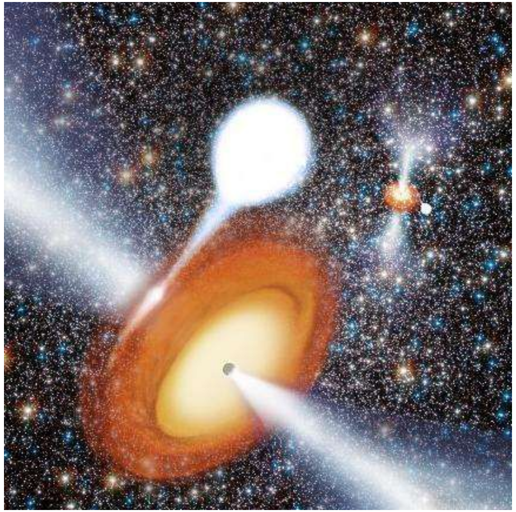
The globular cluster environment is dynamic and crowded, and because of this, all kinds of exotic X-ray binaries form...including ultra-compact X-ray binaries (UCXBs)

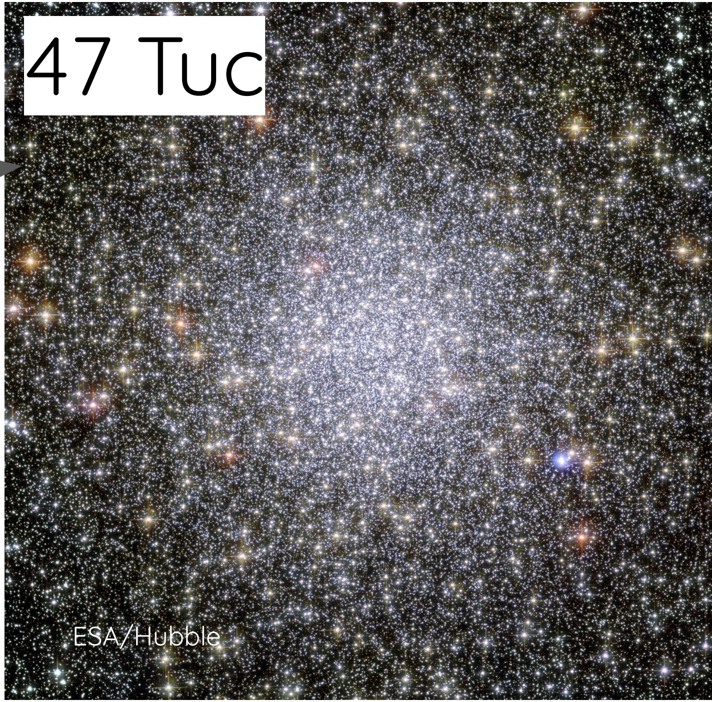


Ultra-compact X-ray binaries in globular clusters?

Some Galactic globular clusters are home to UCXBs, but unfortunately, our Galaxy is home to only ~150 globular clusters making it difficult to find observational evidence to test against theoretical predictions of GC UCXB formation rates for LISA.

Luckily, there are tens of thousands of clusters outside our Galaxy!





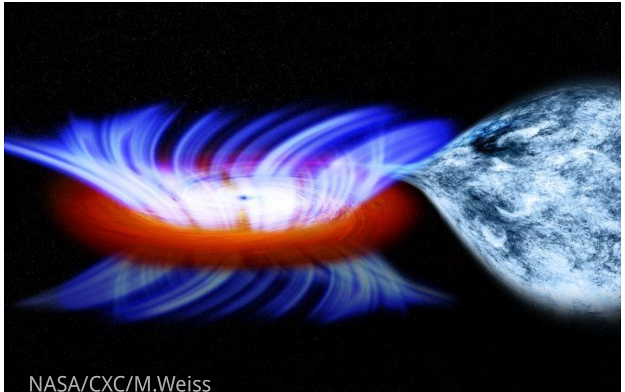
47 Tuc X-9 & extragalactic friend RZ2109

47 Tuc X-9

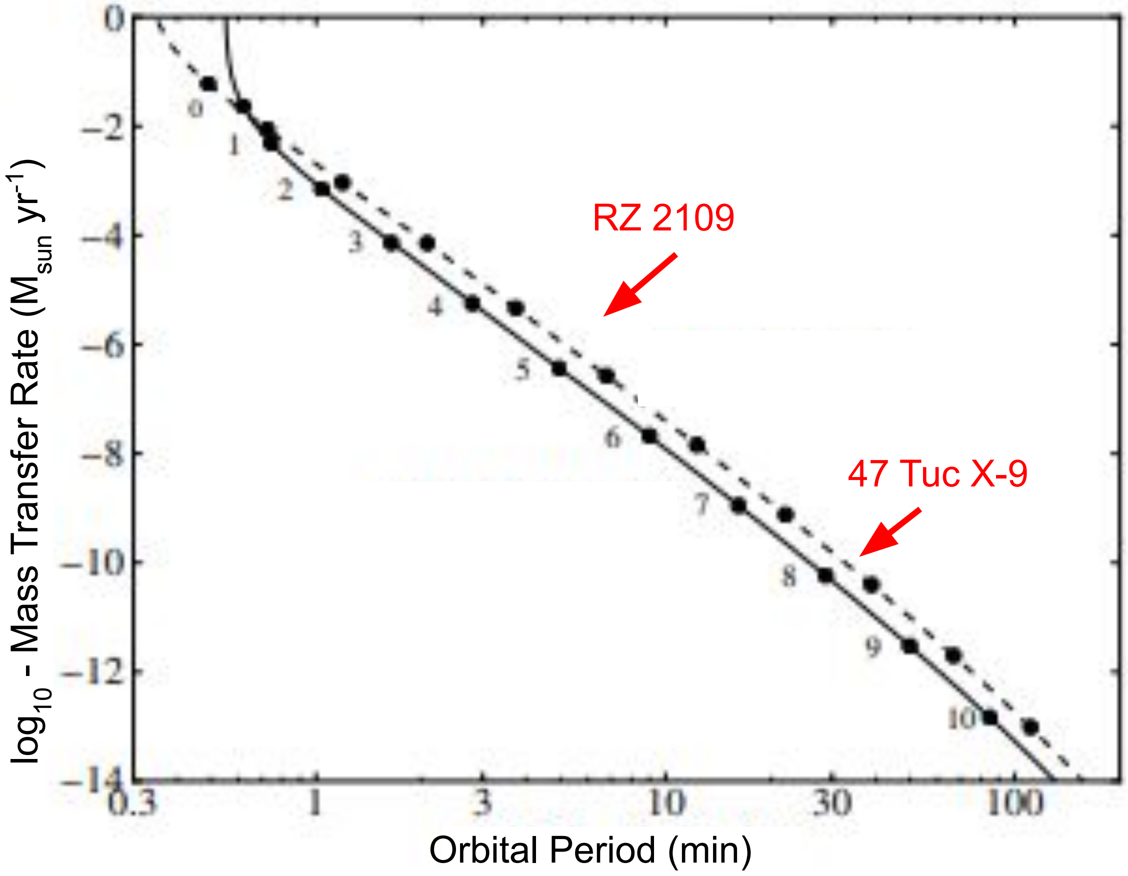
- BH? (*Miller-Jones+2015*)
- O_{VII} and O_{VIII} emission (*Bahramian+2017*)
- No H emission (*Tudor+2018*)
- Variability on ~days (Bahramian+2017)
- Unusually FUV bright (*Knigge +2007*)
- $L_X \sim 10^{33}$erg/s (*Grindlay+2001*)

RZ2109

- BH? (*Maccarone+2007*)
- O[III] emission (*Zepf+2007*)
- No H emission (*Steele+2011*)
- Variability on ~days (in prep)
- Unusually NUV bright (in prep)
- $L_X \sim 10^{39}$erg/s (*Maccarone+2007*)

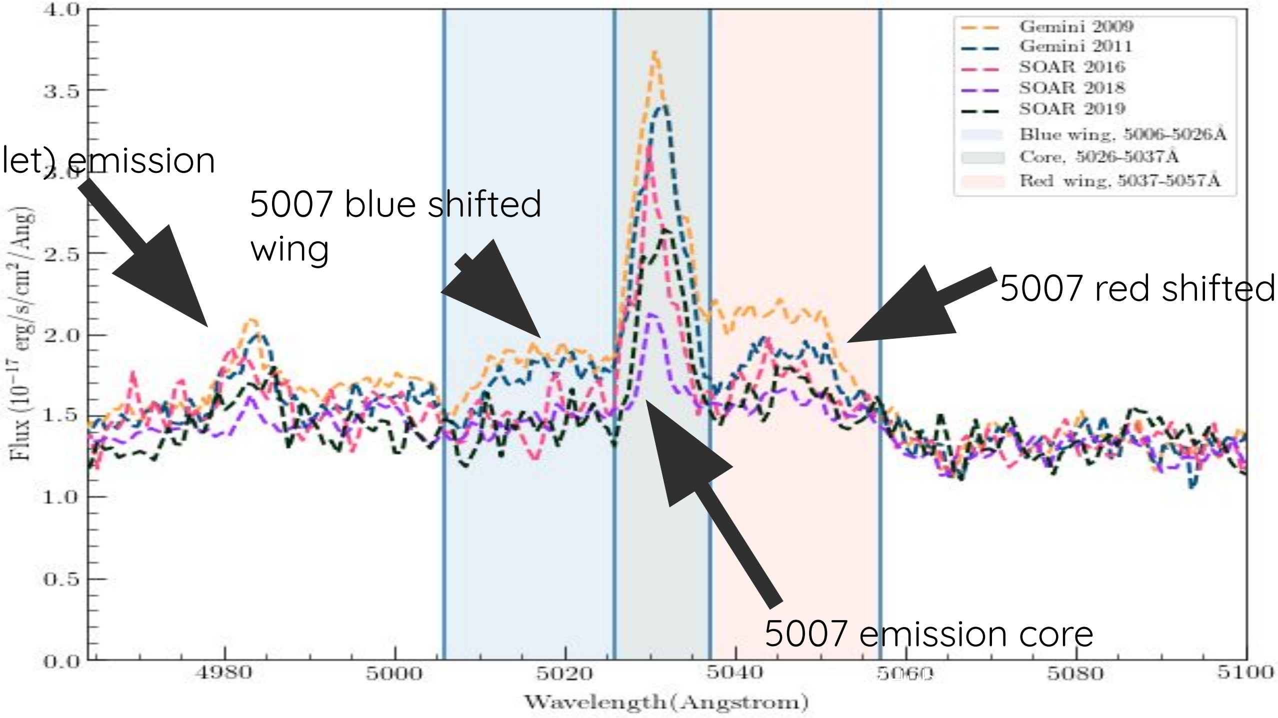


Higher mass transfer rate sources (visible in X-ray) produce optical emission lines which we can search for with optical telescopes.



Adapted from van Haaften+ 2012

super Eddington outflows

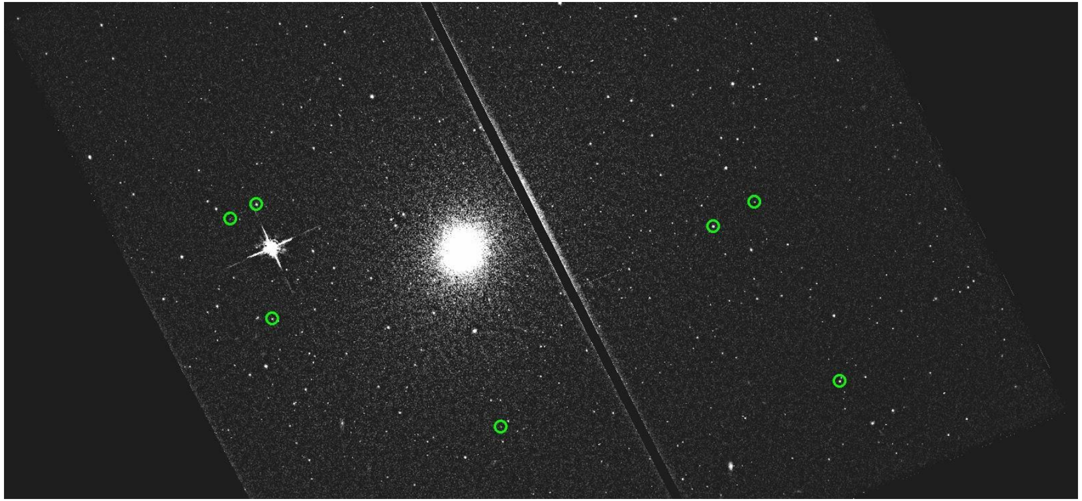


(Dage et al, 2019b)

How can we find more?

We can find GC ULX sources by matching optically known GCs to sources with high X-ray luminosity.

Follow-up optical spectroscopy will reveal emission lines caused by super-Eddington outflows.



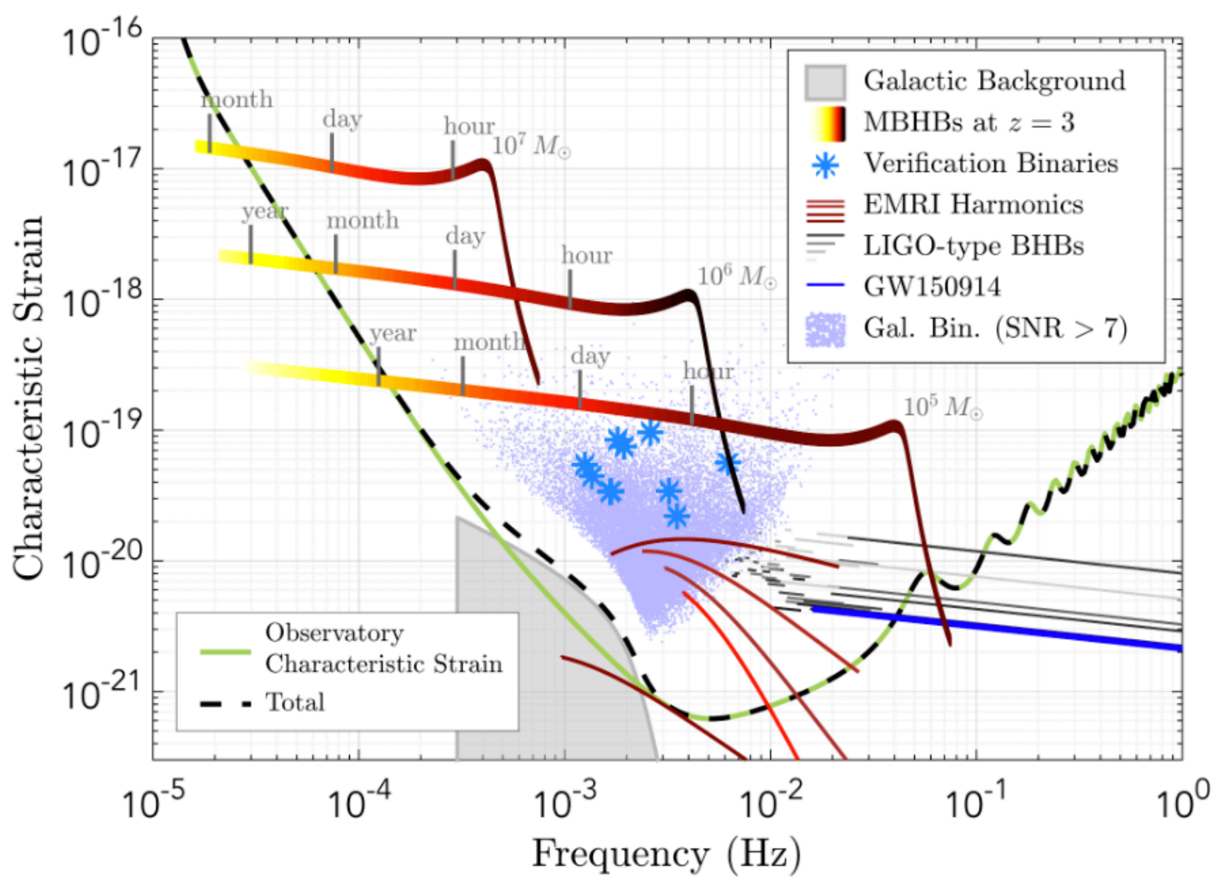
Applying LIGO-Virgo continuous gravitational wave analysis methods to LISA data

Evan Goetz
University of British Columbia

LISA Canada 2021 Workshop, April 2021

Analyses for GW signals in LIGO-Virgo and LISA

- LIGO-Virgo data is noise dominated
- LIGO-Virgo compact binary coalescence analyses
  ==> matched filtering for transient signal
- Continuous wave analyses of signals from rapidly rotating neutron stars
  ==> matched filtering* for quasi-monochromatic signal
- Certain classes of LISA sources are quasi-monochromatic on timescale of months to years



LISA mission proposal for ESA L3 mission

* CW searches are often more complicated than matched-filtering

CW analysis parameter estimation

- Parameters for an isolated neutron star emitting monochromatic gravitational wave signal

$$\vec{\lambda}_{\mathrm{NS}} = \{\alpha,\ \delta,\ f,\ \dot{f},\ h_0,\ \cos\iota,\ \psi,\ \phi_0\}$$

- Long integration times required (expected signal is noise-dominated)
- Matched-filter analysis only practical for pulsars with timing solution
- MCMC techniques to perform parameter estimation
- With less knowledge, unknown parameters have to be searched over, often with suboptimal methods due to computing constraints

Application to LISA sources

- Certain qualitative overlap LIGO-Virgo CW signal/analyses and LISA signal/analyses
- Natural extension of LIGO-Virgo CW parameter estimation techniques

$$\vec{\lambda}_{\rm CB} = \{\alpha,\, \delta,\, h_0,\, m_1,\, m_2,\, \cos\iota,\, \psi,\, \phi_0,\, \vec{s}_1,\, \vec{s}_2,\, e,\, \ldots\}$$

- CW Search techniques potentially useful for low-SNR or "obscured" signals
- Useful to search the "confusion limited" regime...?

Next steps

- Investigate utility of LIGO-Virgo continuous wave search methods
- Extending CW parameter estimation method/software to LISA sources
- Understanding under what conditions these are most beneficial/useful (e.g., CW searches the low-SNR LISA regime?)

- Thanks for your attention!

Extra slides

Possible sources of interest

- CW methods most useful for slow phase evolution, e.g., compact binary well-before merger
- Compact binaries; NS-NS, NS-BH, BH-BH
- Extreme mass ratio (before the merger)
- BH binaries + SMBH (triple system)
- Other exotic systems?

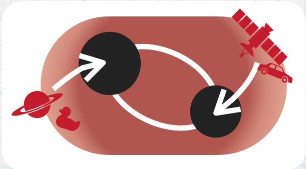
Laura Sberna

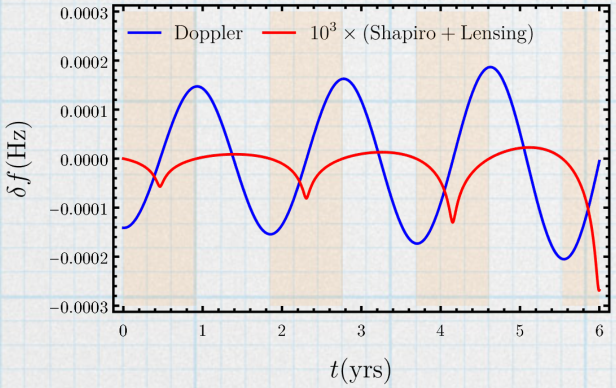
BSc/MSc
Sapienza U. Rome
2016

2021
PhD
Perimeter Institute/ U. Waterloo

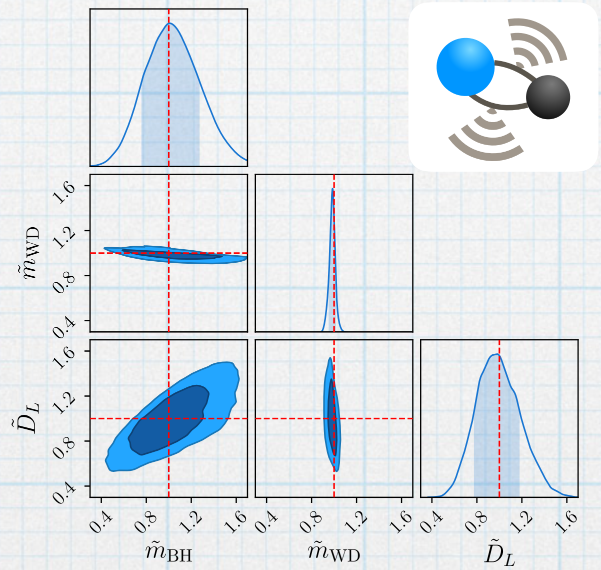
Postdoc
AEI Potsdam
2021

LISA





1. Black hole binaries & EMRIs in accretion disks



2. Black hole-white dwarfs

3. Massive binaries (population modelling and inference)

Other

Black hole ringdown

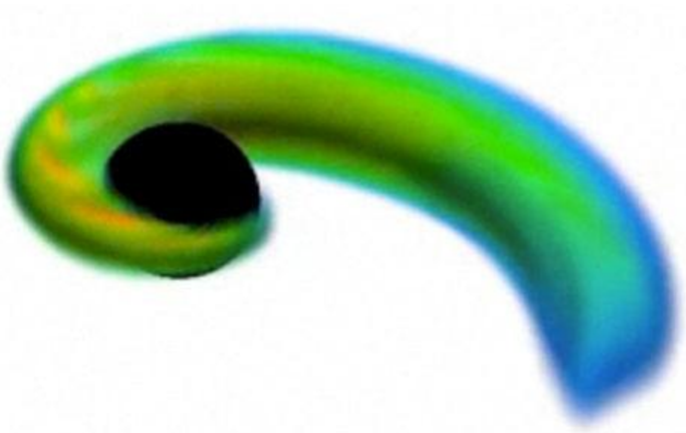
Electromagnetic superradiance

Canadian Multi-messenger Astronomy: a CFHT + GW190814 Case Study

Nicholas Vieira
McGill Space Institute
Supervisors: Daryl Haggard & John Ruan

MEGA
McGill Extreme Gravity & Accretion

Institut Spatial de McGill
McGill Space Institute



CFH

Fonds de recherche sur la nature et les technologies
Québec

NSERC
CRSNG

GW190814

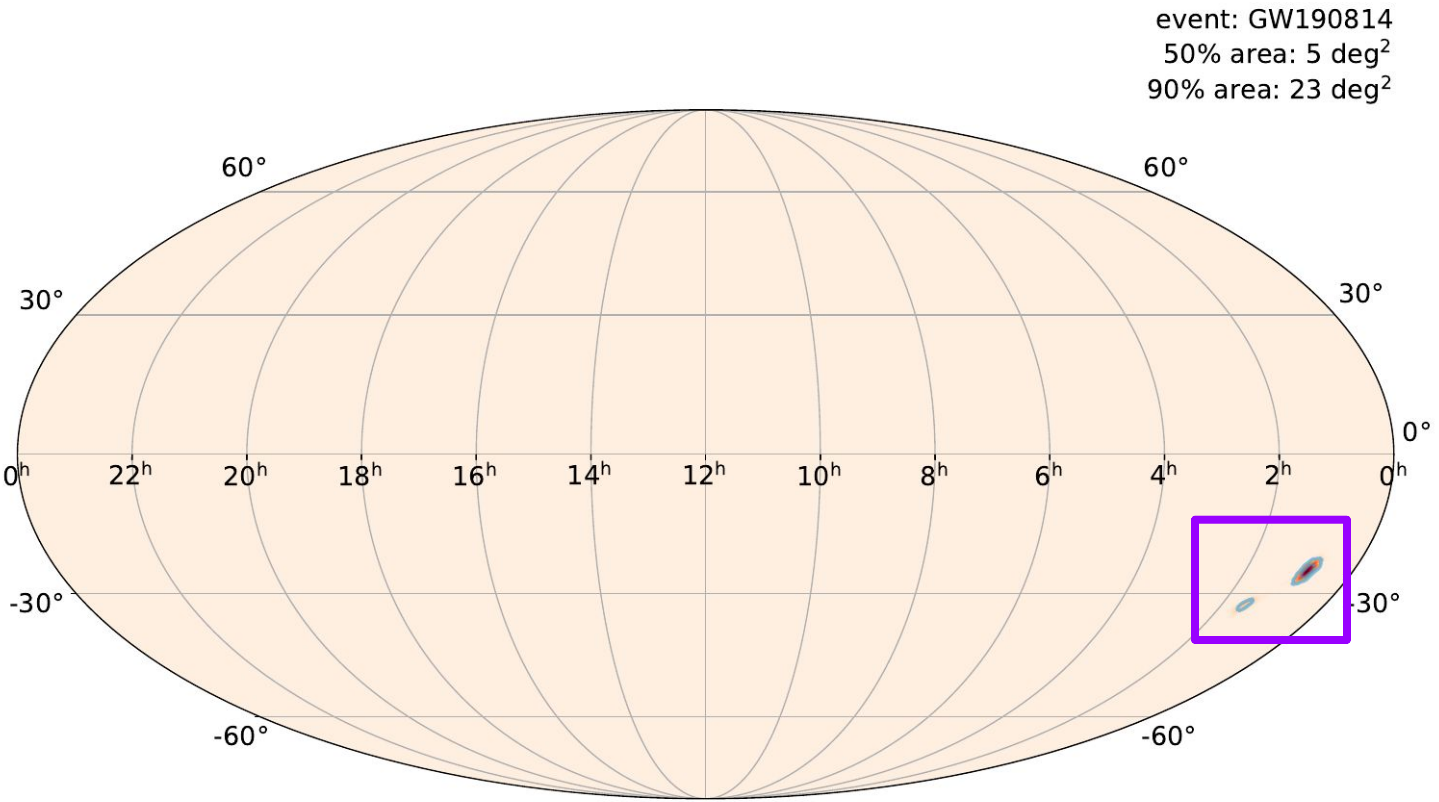
- GW190814: the first strong candidate **neutron star + black hole** (NSBH) merger with **excellent** sky localization
- Are NSBH kilonovae (UV/optical/IR transient) “redder” than binary NS?
- Implications for *r*-process synthesis of heavy elements?
- NS equation of state

A Deep CFHT Optical Search for a Counterpart to the Possible Neutron Star–Black Hole Merger GW190814

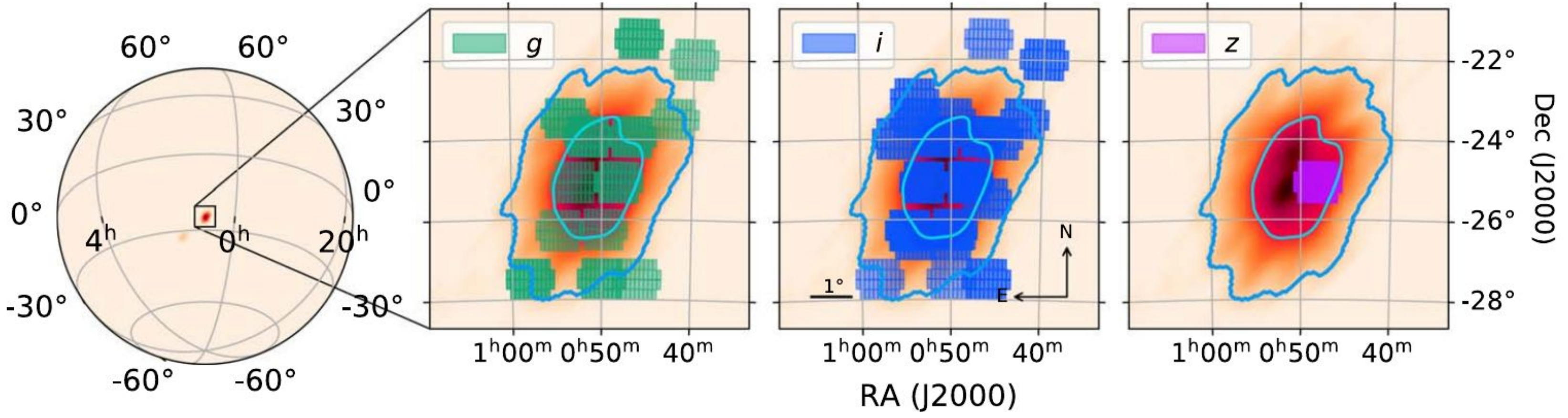
Nicholas Vieira[1], John J. Ruan[1], Daryl Haggard[1,2], Maria R. Drout[3], Melania C. Nynka[4], Hope Boyce[1], Kristine Spekkens[5], Samar Safi-Harb[6], Raymond G. Carlberg[3], Rodrigo Fernández[7], Anthony L. Piro[8], Niloufar Afsariardchi[3], and Dae-Sik Moon[3]

Vieira+20, ApJ 895, 96

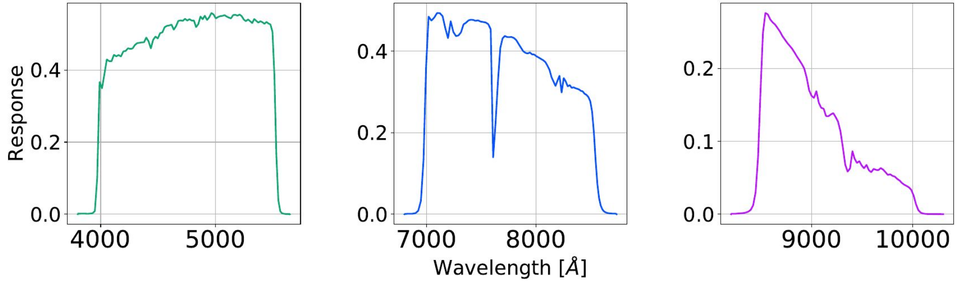
Canada-France-Hawaii Telescope (CFHT) follow-up



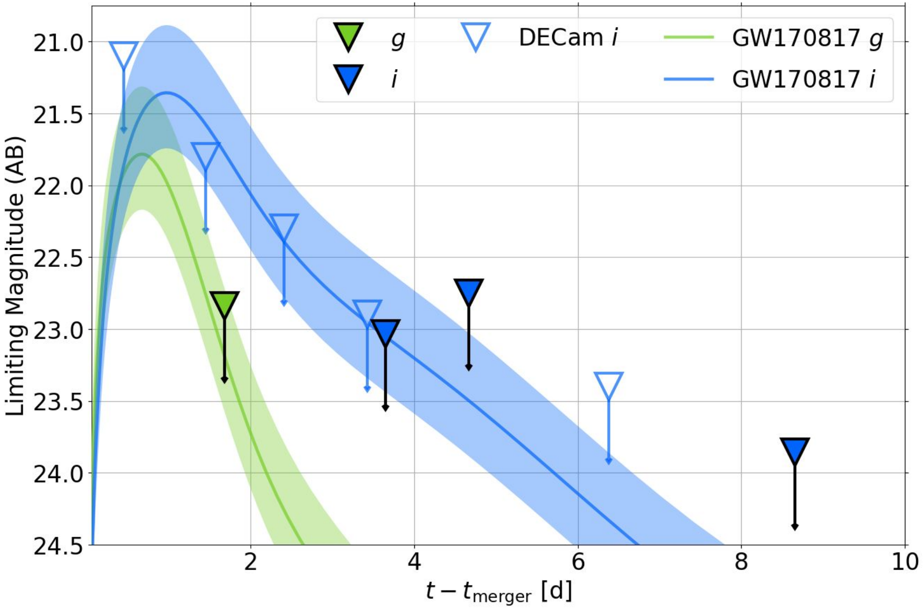
Canada-France-Hawaii Telescope (CFHT) follow-up



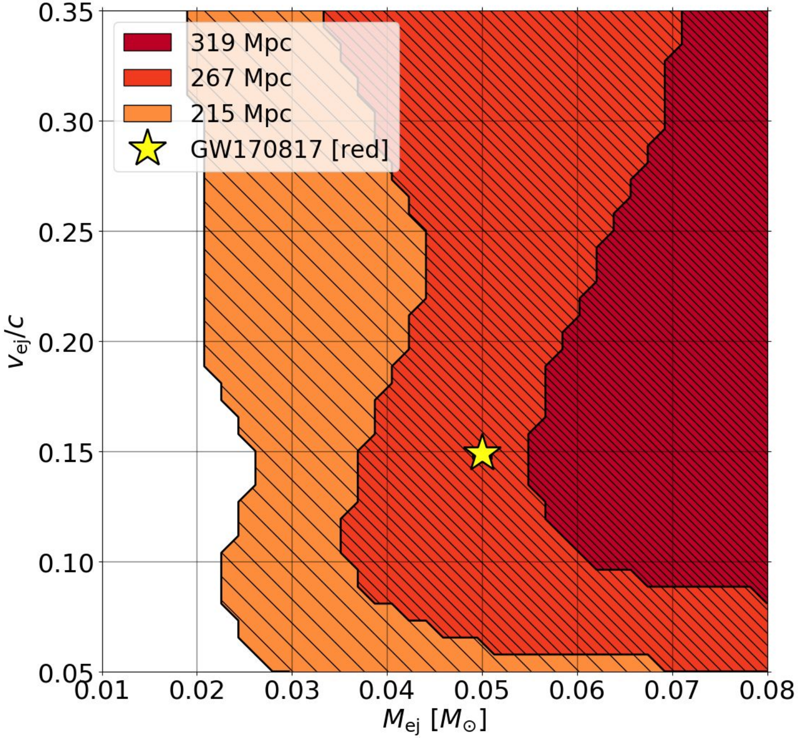
Vieira+20



Constraining the source



Vieira+20



Looking to the future

- GW190814 follow-up with CFHT: example of competitive, constraining multi-messenger astronomy led by Canadians
- Canadian expertise in multi-messenger astronomy is building!
- Excited for LISA!

Looking to the future

What will LISA data products look like?

When will they be released?

How can we ensure that we maximize science returns of LISA + EM observations?

Which existing and upcoming Canadian and Canadian-affiliated EM facilities will be most useful?

Graphic on first slide: Simulating eXtreme Spacetimes