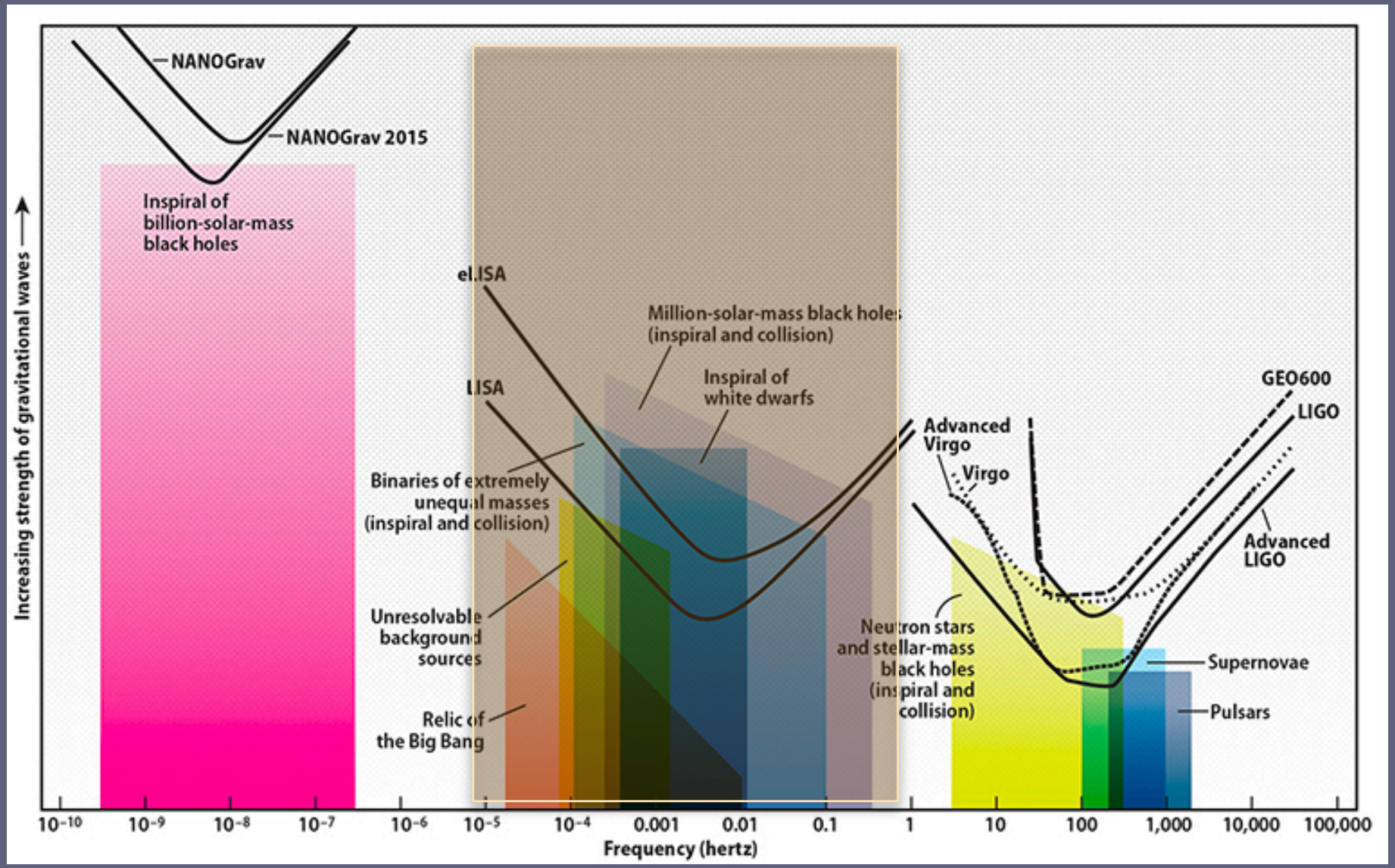
# Synergies between LISA and the Rubin Observatory Legacy Survey of Space and Time (LSST)

Maria R. Drout
University of Toronto
Carnegie Observatories

# LISA

## *A New Window on Gravitational Waves*

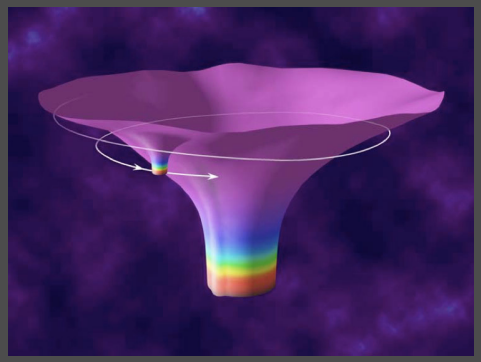



Credit: Roen Kelly, after C. Moore, R. Cole, and C. Berry (Institute of Astronomy, Univ. of Cambridge

# LISA

## *A New Window on Gravitational Waves*

Inspiral and Merger of
Million Msun Black Holes



Extreme Mass Ratio
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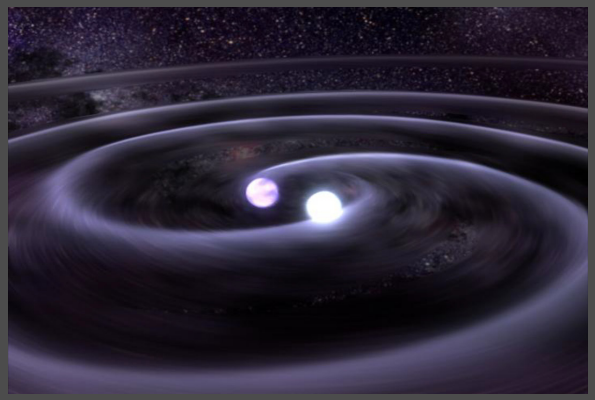

Galactic Compact
Object Binaries

# LISA

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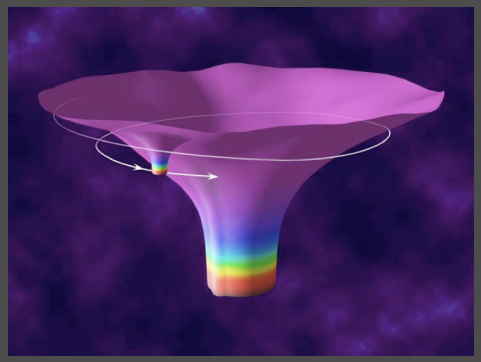
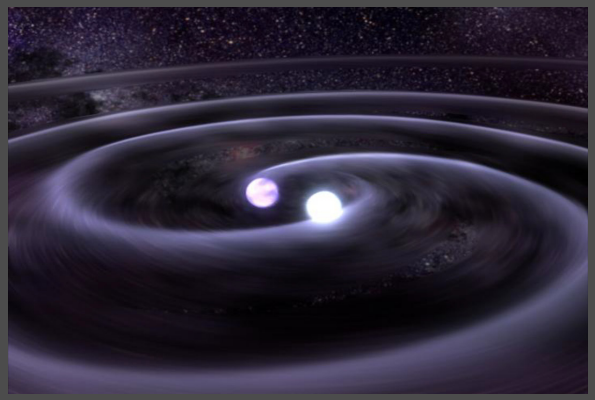




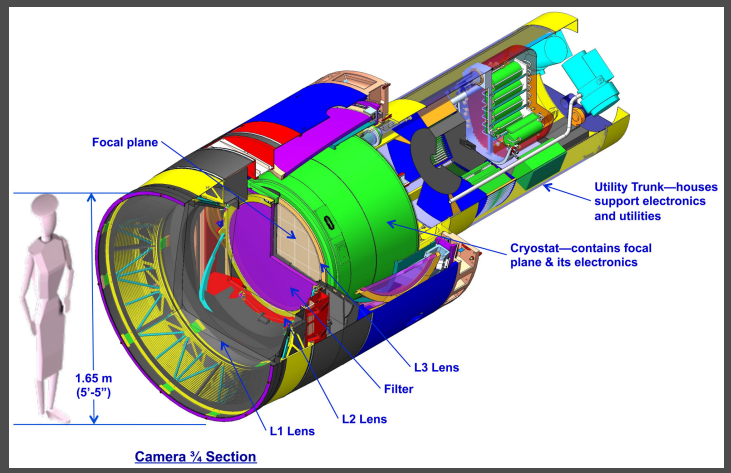
Gravitational Waves Give Us:

- Combined (chirp) mass
- Period/Period derivative
- Distance
- Spin
- Sky localization (few arcmin to 10 $deg^2$)
- Eccentricity

# The Rubin Observatory

## *What is It?*

8.4 m Telescope located
Cerro Pachón, Chile

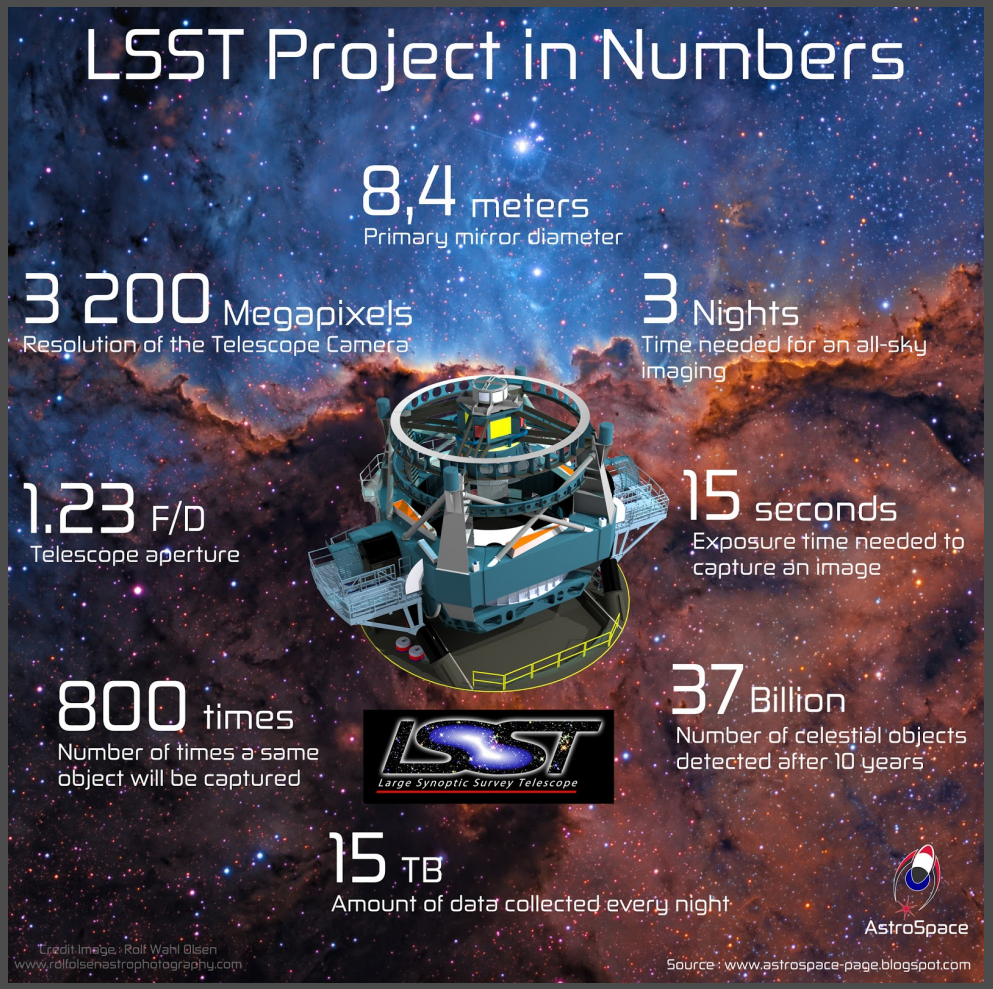



3.2 giga-pixel camera
providing 0.2"/pixel
imaging over a 9.6 deg$^2$
field of view

Dedicated to Survey Observations

# The Legacy Survey of Space and Time

## *What Type of Data Are We Talking?*




Main Survey (Wide, Fast, Deep):

- 10-year baseline survey
- Coverage of the entire southern sky every three nights*
- Six filters: ugrizy
- Single image depths: 25 mag (g)
- 10-year image depth: 27.4 mag (g)

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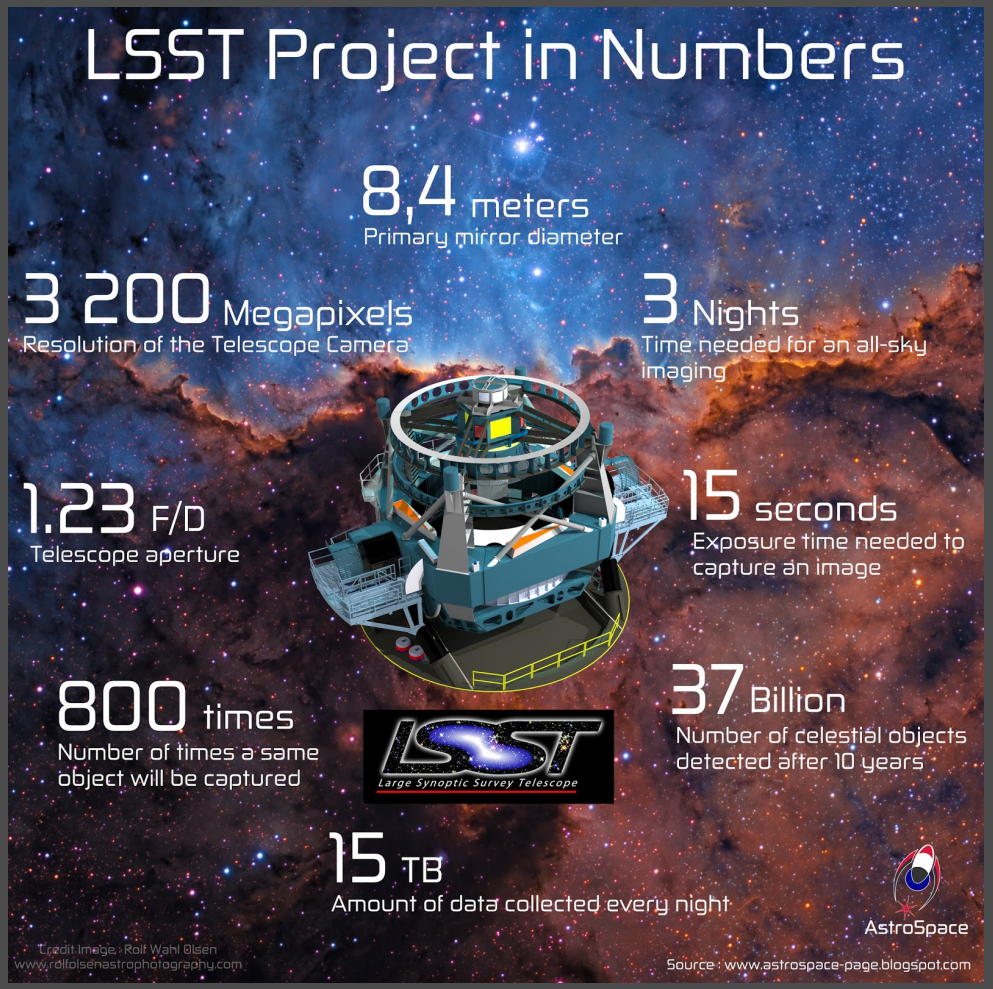


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- Approximately 10% of time will be devoted to special projects (mini-surveys, deep drilling fields)

# The Legacy Survey of Space and Time

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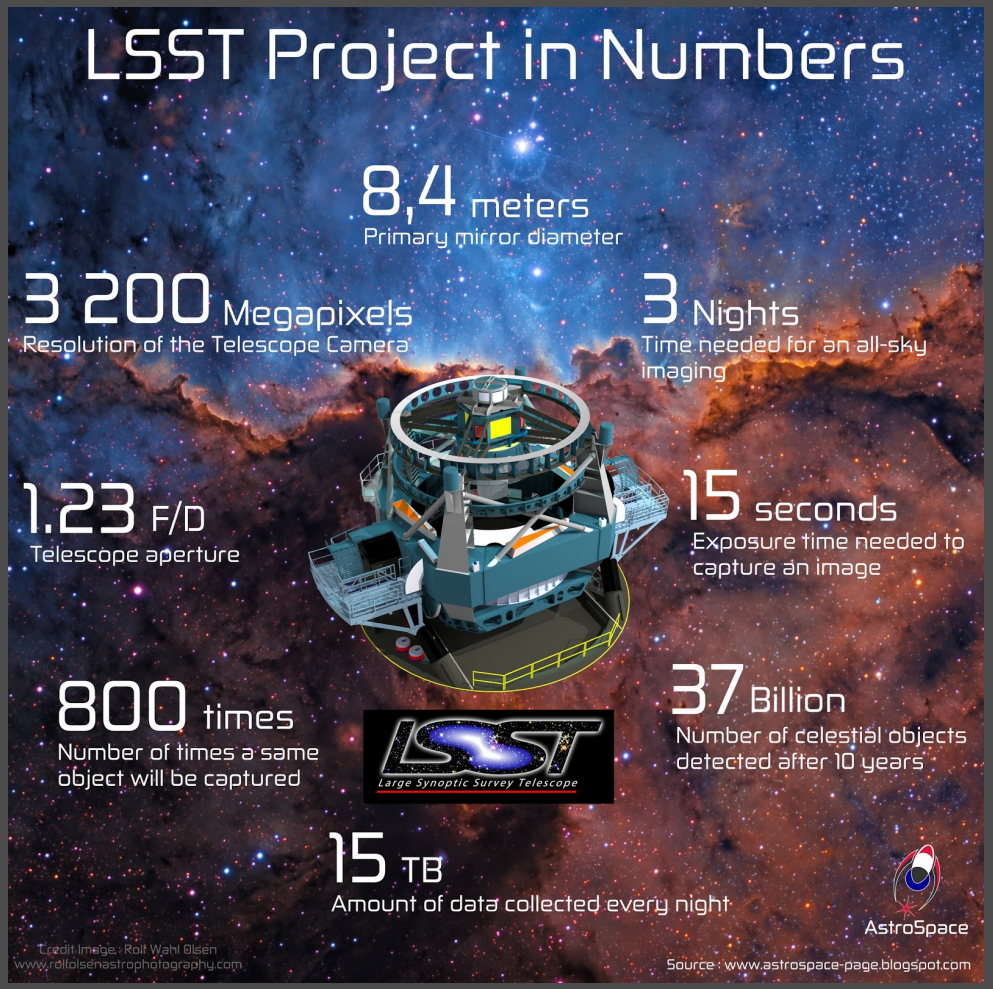
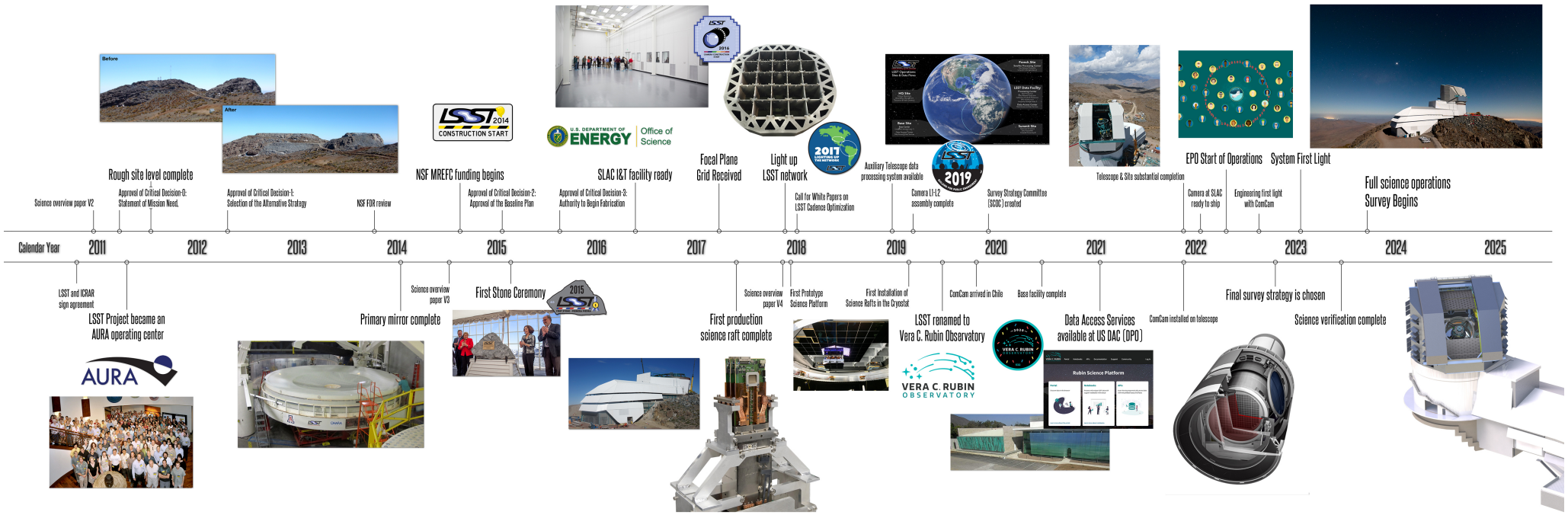



Data Products:

- Real-time alerts on objects that change brightness (60s)
- Nightly images and updated catalogs (24 hours)
- Yearly data releases

# The Legacy Survey of Space and Time

## *What is the Timeline?*




## Science Observations Expected in 2024

# The Legacy Survey of Space and Time

## *What is Canada's Involvement?*

The Rubin In-Kind Program Provides Data Access to International Partners

CAN-CAN Contributions:

- Directable Efforts for 7 Canadian-Rubin Fellows
- Canadian pubic data archive

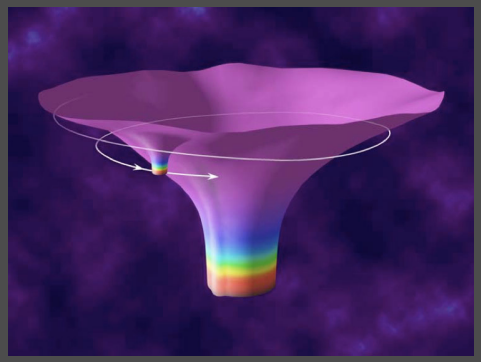
# Multi-messenger Synergies

*What Science will we get by combining LISA & LSST?*

# Multi-messenger Synergies

## *What Science will we get by combining LISA & LSST?*

Inspiral and Merger of
Million Msun Black Holes



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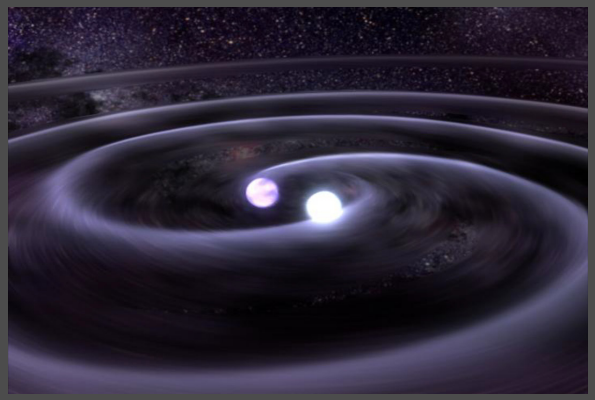

Galactic Compact
Object Binaries

# Multi-messenger Synergies

## *What Science will we get by combining LISA & LSST?*

Inspiral and Merger of

## Other Resources:

White Paper on Multimessenger Opportunities with mHz GWs:
https://lisa.nasa.gov/downloads/forScientists/whitePapers/Multimessenger_Science.pdf

LISA Science Proposal:
https://arxiv.org/abs/1702.00786

Rubin Observatory LSST Transients and Variable Stars RoadMap:
https://arxiv.org/abs/2208.04499

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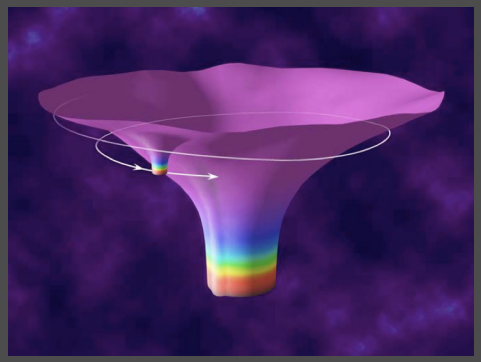

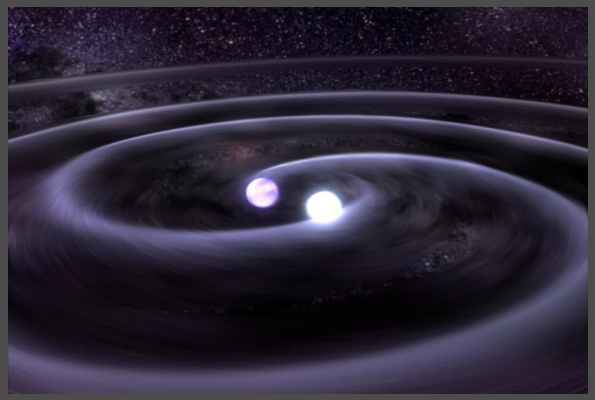

Electromagnetic Light Probes Matter:

- Stellar/Galactic Light
- Accretion
- Outflows
- Local Environment
- Redshift

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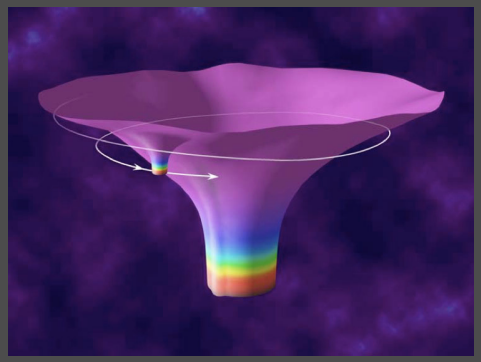

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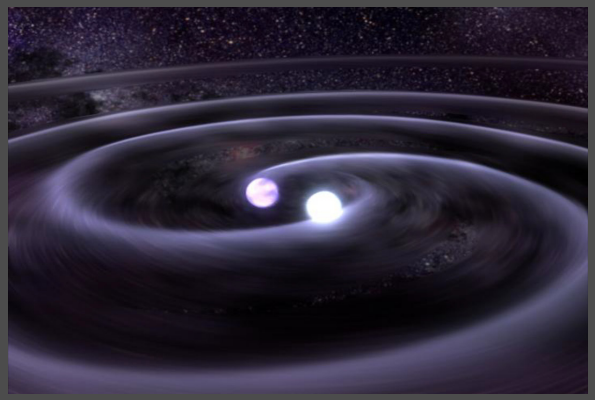

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# Multi-messenger Synergies

## *Massive Black Hole Binary Science Themes*

Tests of LCMD Cosmology

Co-evolution of SMBHs and Galaxies

Growth of the Earliest BH Seeds

# Multi-messenger Synergies

## *Massive Black Hole Binary Science Themes*

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LISA will provide luminosity distances to MBHBs out to z~3.
EM observations of a host are needed to get redshifts.

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### Growth of the Earliest BH Seeds

LISA can probe assembly of $10^6$ Msun BHs via mergers out to z~20
EM observations can probe growth of those BHs via accretion

# Multi-messenger Synergies

## *Massive Black Hole Binaries: Potential LSST Data*

Identification/Localization of LISA Mergers

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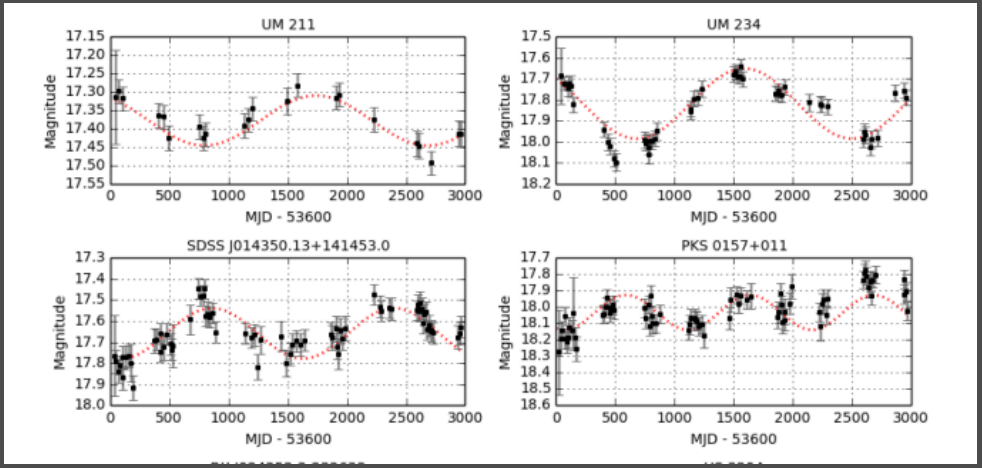


Graham et al. (2015)

<u>Prior to LISA operations:</u>

Long-baseline record of AGN variability

- Search for periodic/evolving signals
- Frame of reference for after LISA commences

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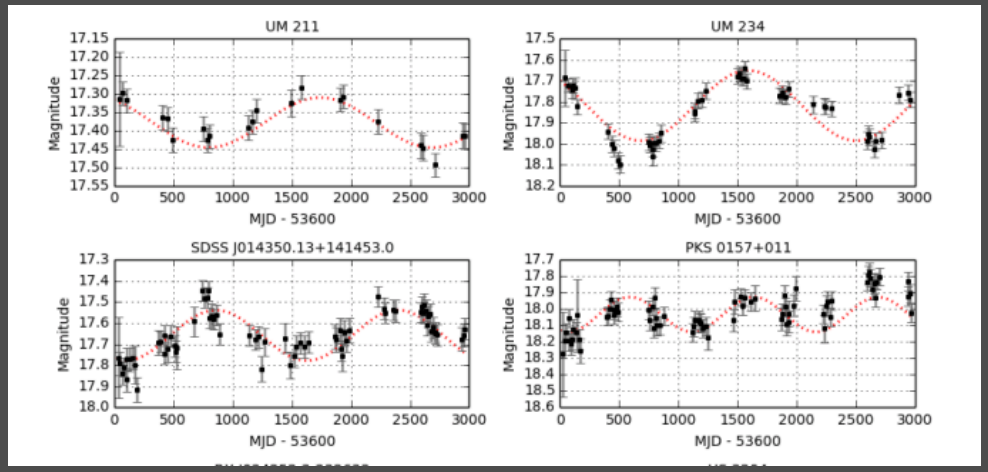


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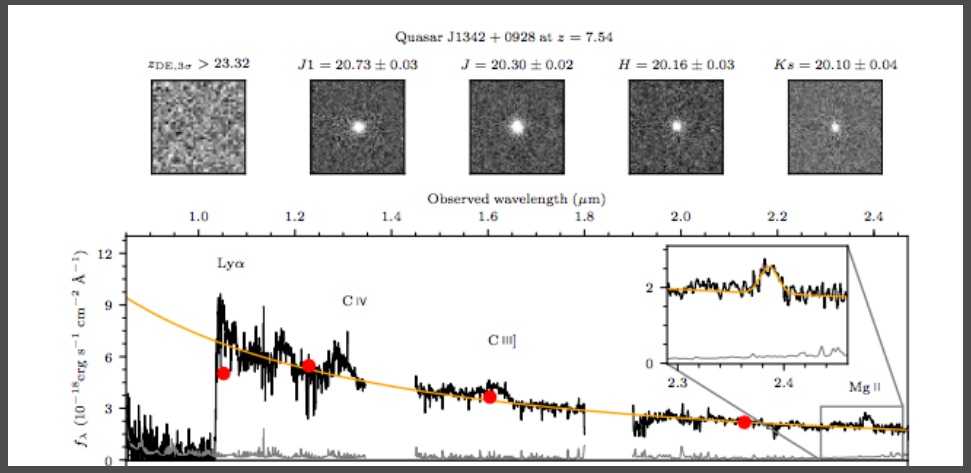


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Deep Galaxy Catalogs

High-z AGN Searches

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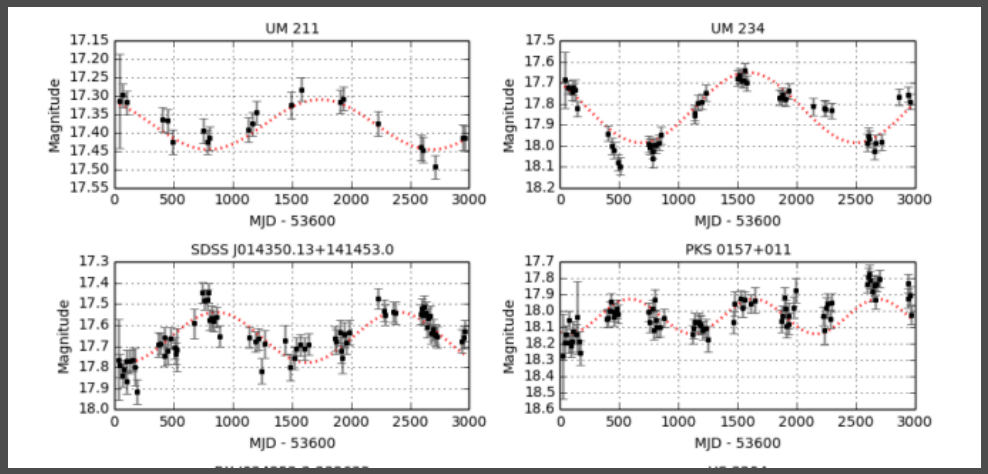


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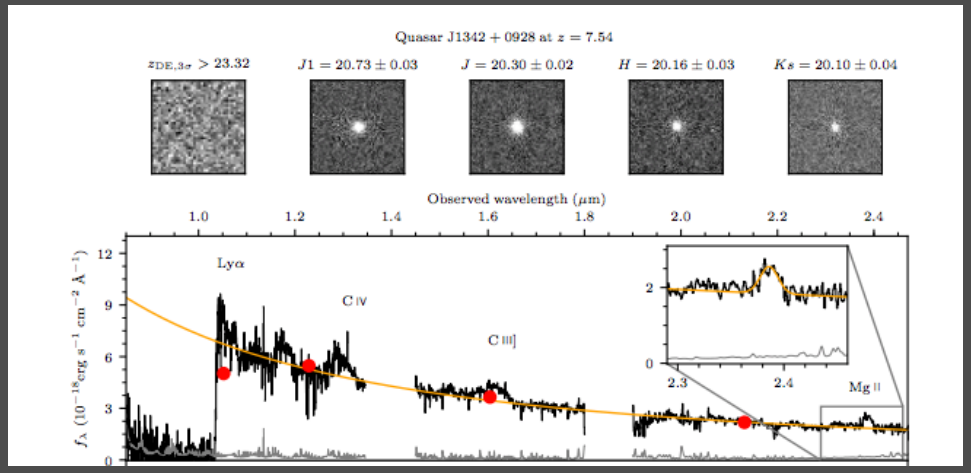


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Prior to LISA operations:

Long-baseline record of AGN variability

- Search for periodic/evolving signals
- Frame of reference for after LISA commences

Deep Galaxy Catalogs

High-z AGN Searches

Commensurate with LISA:

Targeted searches for precursor signals, prompt emission, and afterglows

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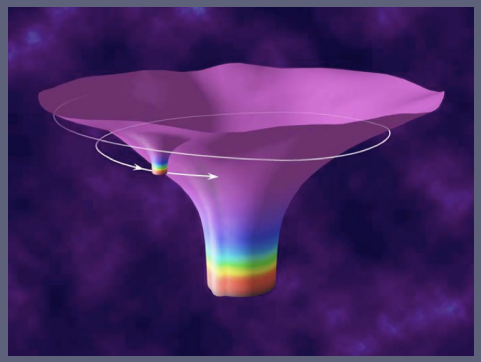

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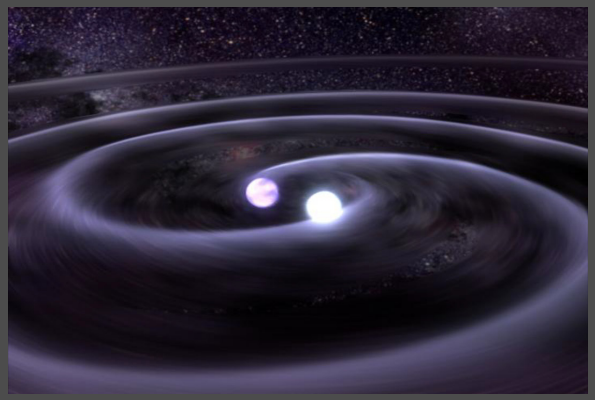

Galactic Compact
Object Binaries

# Multi-messenger Synergies

## *EMRI Science Themes*

The Existence and Formation of IMBH

Stellar Populations and Dynamics in Galactic Nuclei

# Multi-messenger Synergies

## *EMRI Science Themes*

### The Existence and Formation of IMBH

LISA can prove the existence of IMBHs
EM observations of a counterpart are likely required to localize precise environment
Tidal disruption of white dwarfs around IMBHs are predicted to produce a transient

### Stellar Populations and Dynamics in Galactic Nuclei

# Multi-messenger Synergies

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LISA can prove the existence of IMBHs

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Tidal disruption of white dwarfs around IMBHs are predicted to produce a transient

### Stellar Populations and Dynamics in Galactic Nuclei

LISA can probe (stellar mass) compact objects around SMBHs via EMRIs

EM observations can probe stellar objects via tidal disruption events

# Multi-messenger Synergies

## *EMRIs: Potential LSST Data*

Identification of Tidal Disruption Events

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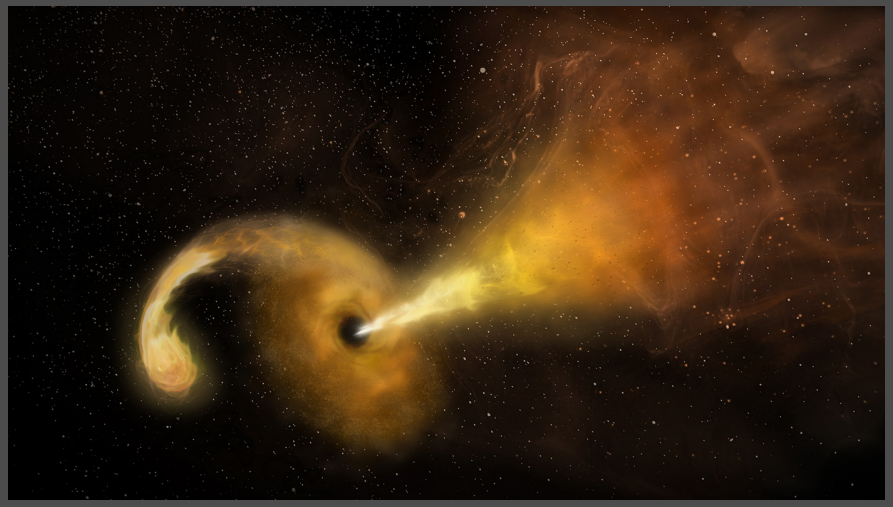
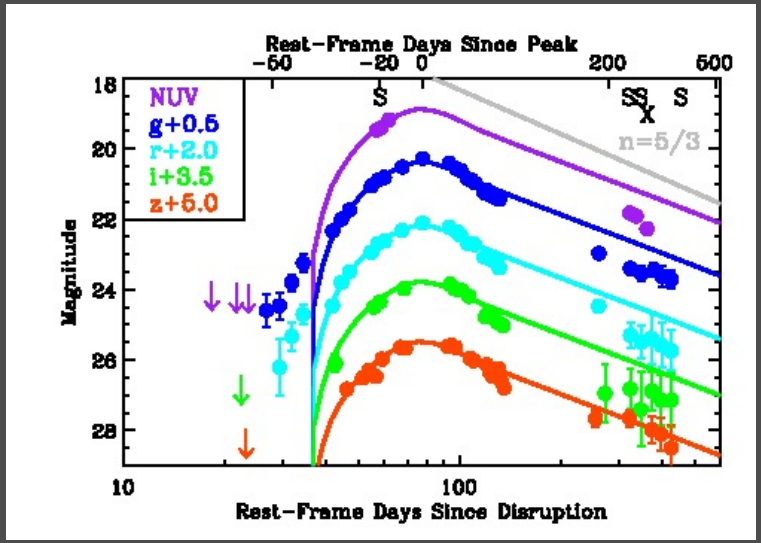
### Identification of Tidal Disruption Events






Gezari et al. (2012)

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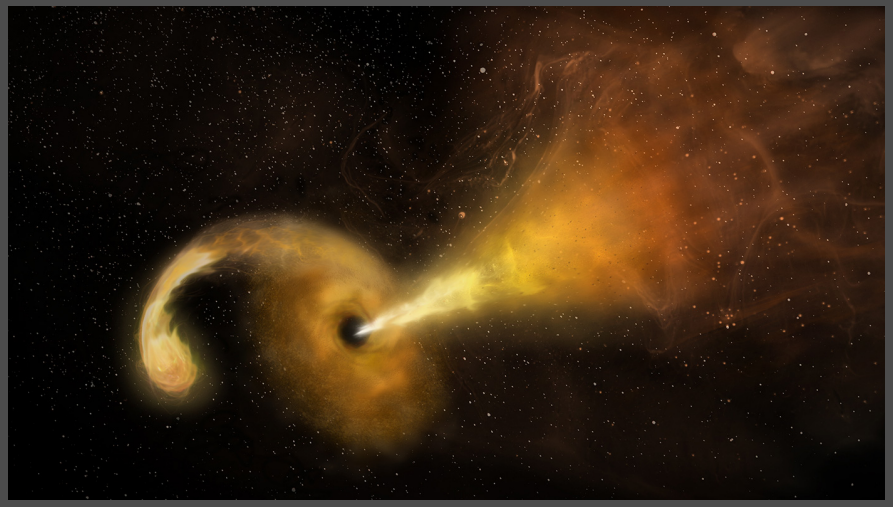
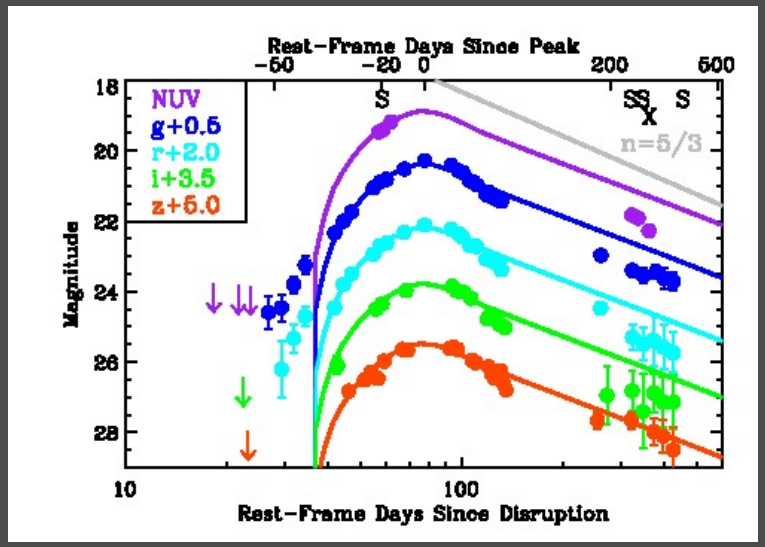
### Identification of Tidal Disruption Events



LSST should discover 1000s of TDEs *per year* (van Gelzen et al. 2011, Brieman & Comboc 2020)

Prompt identification will be vital to obtain follow-up observations

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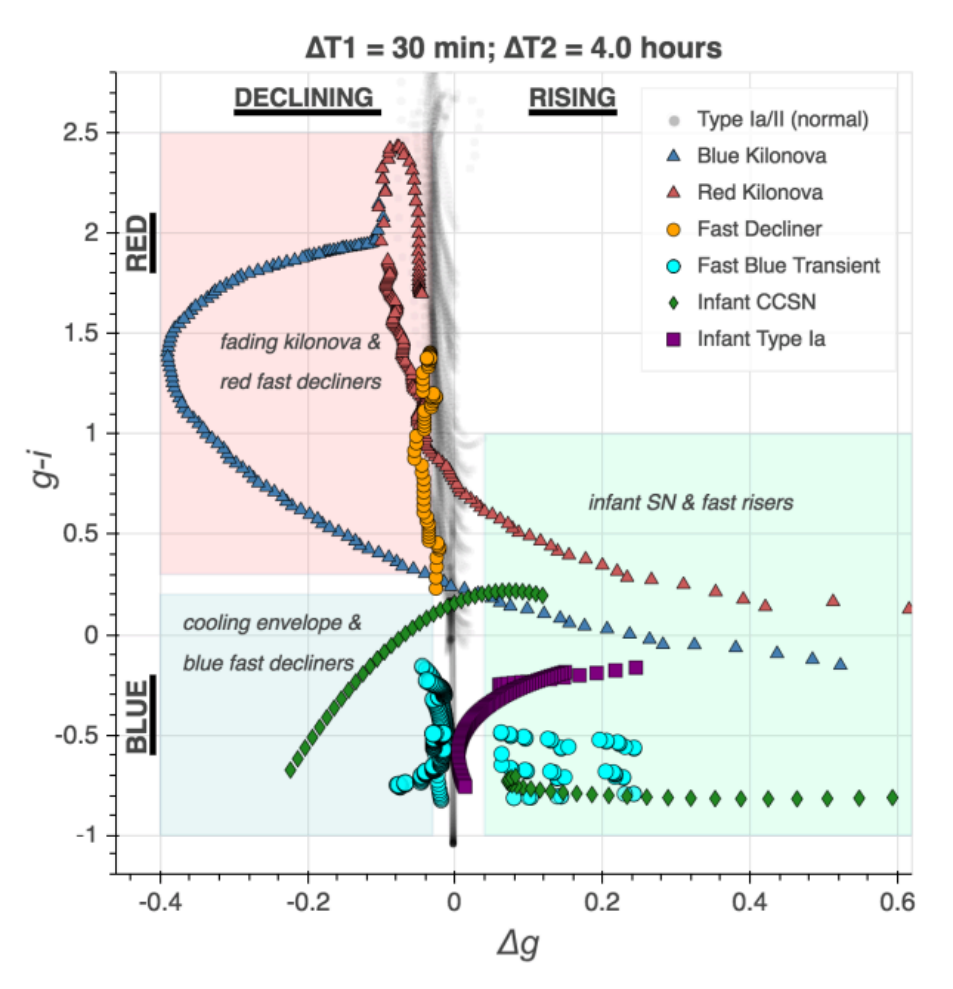


Bianco, Drout et al. (2019)

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Prompt identification will be vital to obtain follow-up observations

For the potential discovery of the disruption of WDs around IMBHs, decisions about exact survey strategy will be critical.

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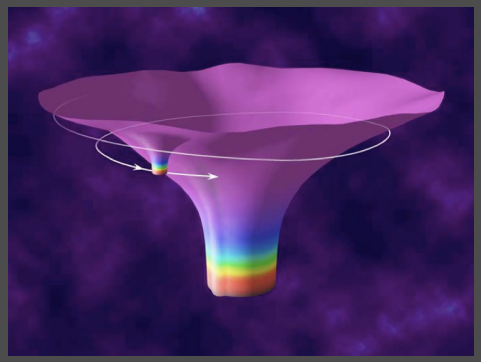

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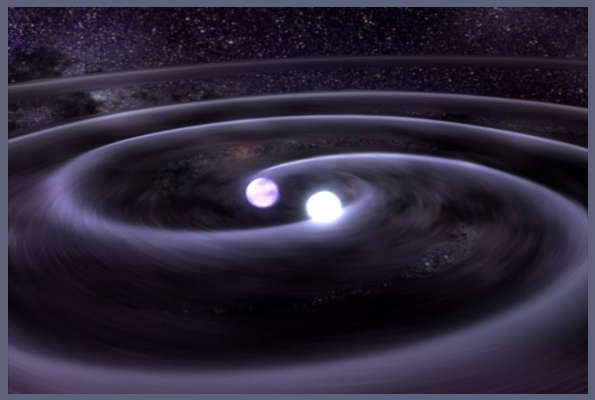

Galactic Compact
Object Binaries

# Multi-messenger Synergies

## *Galactic Compact Binary Science Themes*

The Fate of Stellar Binary Systems

The Physics of WD Binary Mass Transfer

# Multi-messenger Synergies

## *Galactic Compact Binary Science Themes*

### The Fate of Stellar Binary Systems

LISA will provide periods, period derivatives, & chirp masses for thousands of tight compact object binaries (WD-WD, WD-NS, stripped star-WD, stripped star-NS) which are the progenitors of transient events.

EM observations are critical for determining evolutionary state and can aid in determining individual masses

### The Physics of WD Binary Mass Transfer

# Multi-messenger Synergies

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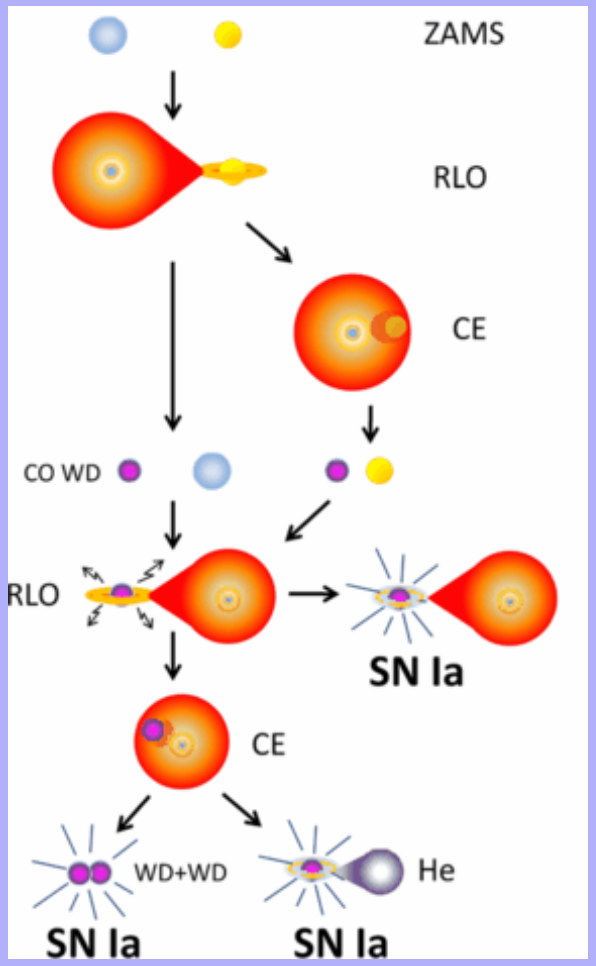
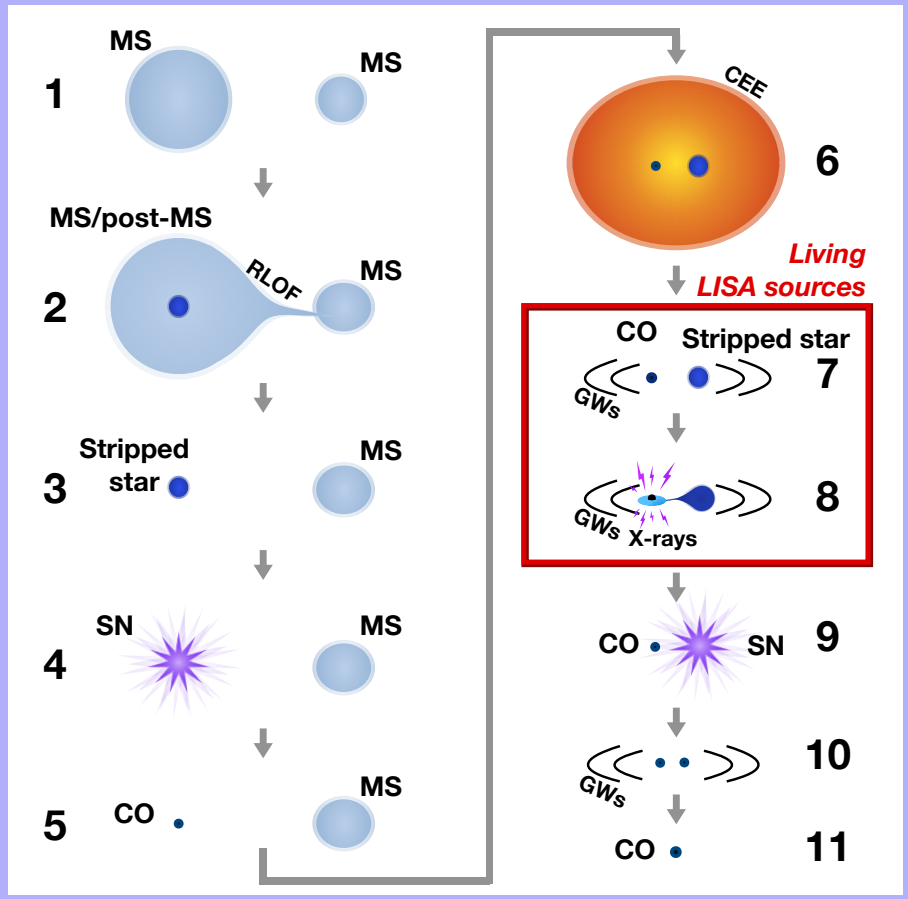



Ivanova et al. (2013)




Y. Götberg et al. (2020)

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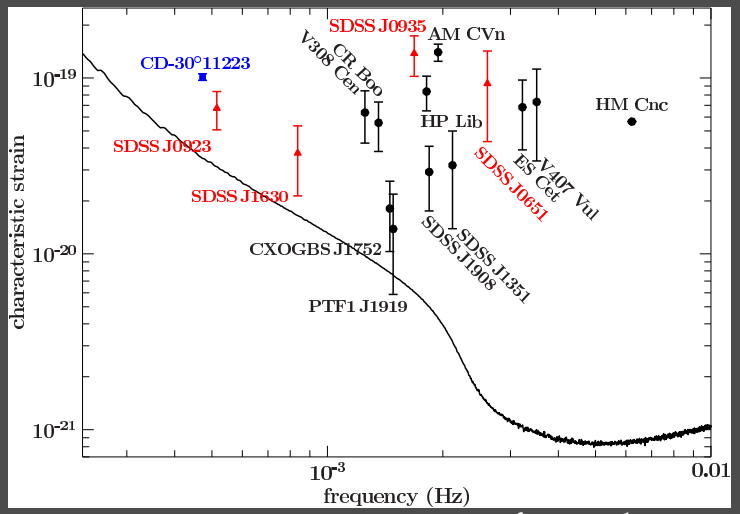
### The Physics of WD Binary Mass Transfer

LISA will provide periods, period derivatives, & chirp masses for stably accreting WDs

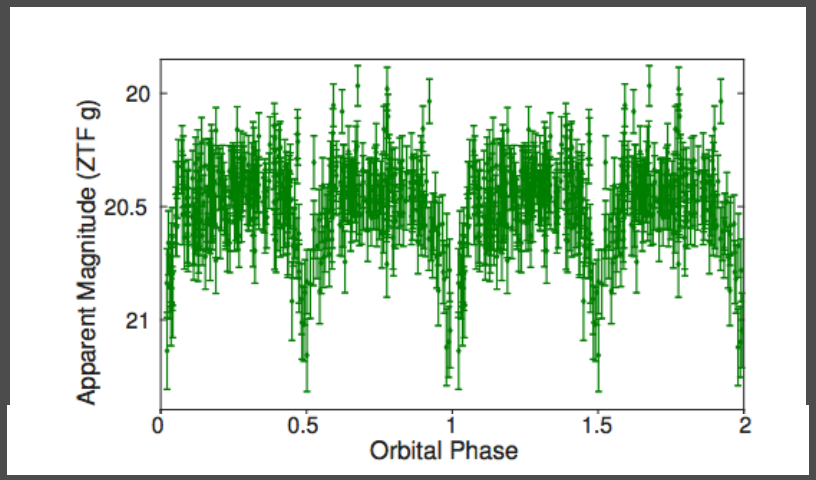
EM observations can probe the accretion luminosity as well as effects like tidal heating for the same population

# Multi-messenger Synergies

## *Galactic Compact Binaries: Potential LSST Data*




Kupfer et al. 2018




Burdge et al. 2020

Prior to LISA operations:

Long-baseline, wide area, high image quality and deep sensitivity limits will allow the identification of many LISA binaries

During LISA operations:

Targeted searches for counterparts to resolved systems

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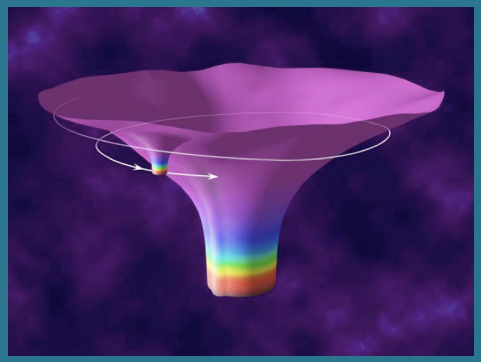

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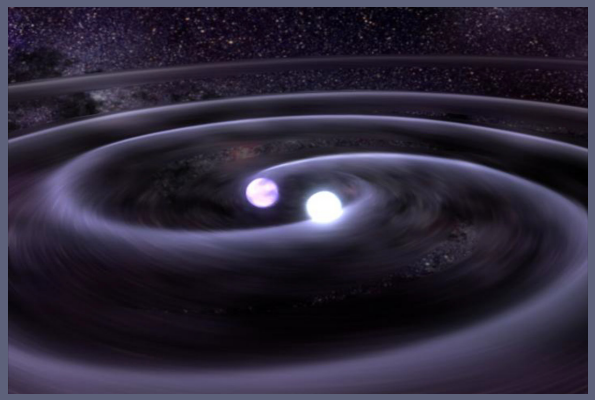

Galactic Compact
Object Binaries

# Canada, LSST (and LISA)

*Now Hiring Data Science Fellows!*

The Rubin In-Kind Program Provides Data Access to International Partners

CAN-CAN Contributions:

- Directable Efforts for 7 Canadian-Rubin Fellows
- Canadian pubic data archive

We are hiring *this year* for fellows to support the TVS and AGN working groups within LSST.

50% software development 50% science