Gravitational Wave Astrophysics at the NBIA

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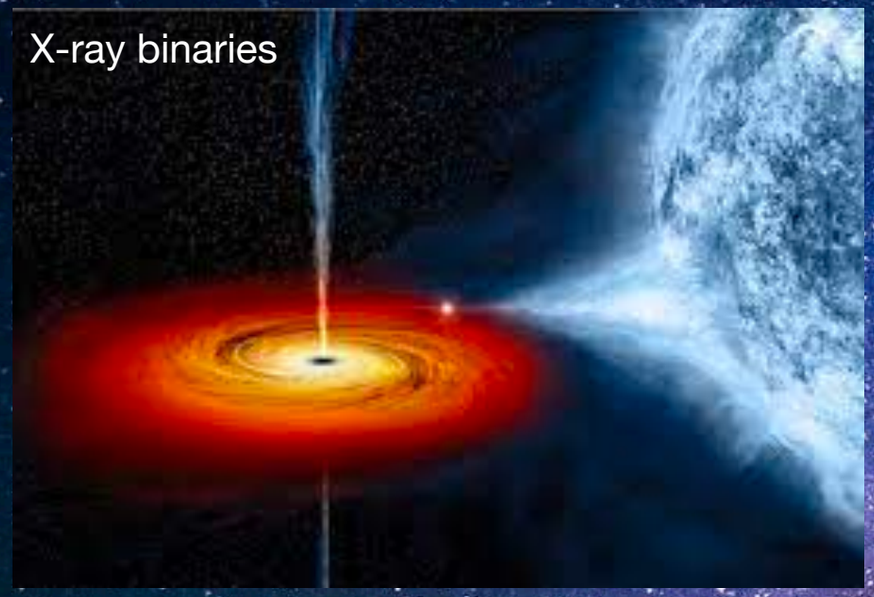
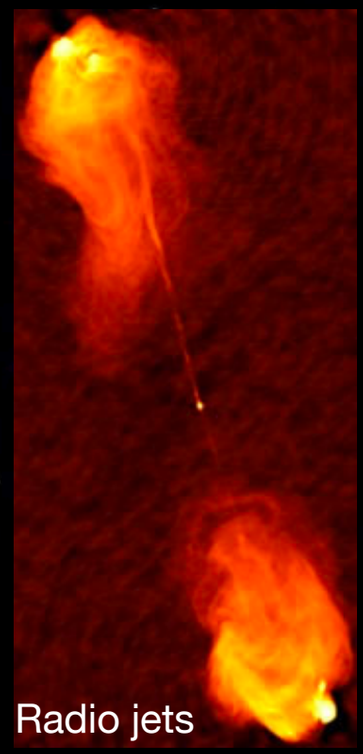
The Electromagnetic Sky: Conventional Astrophysics



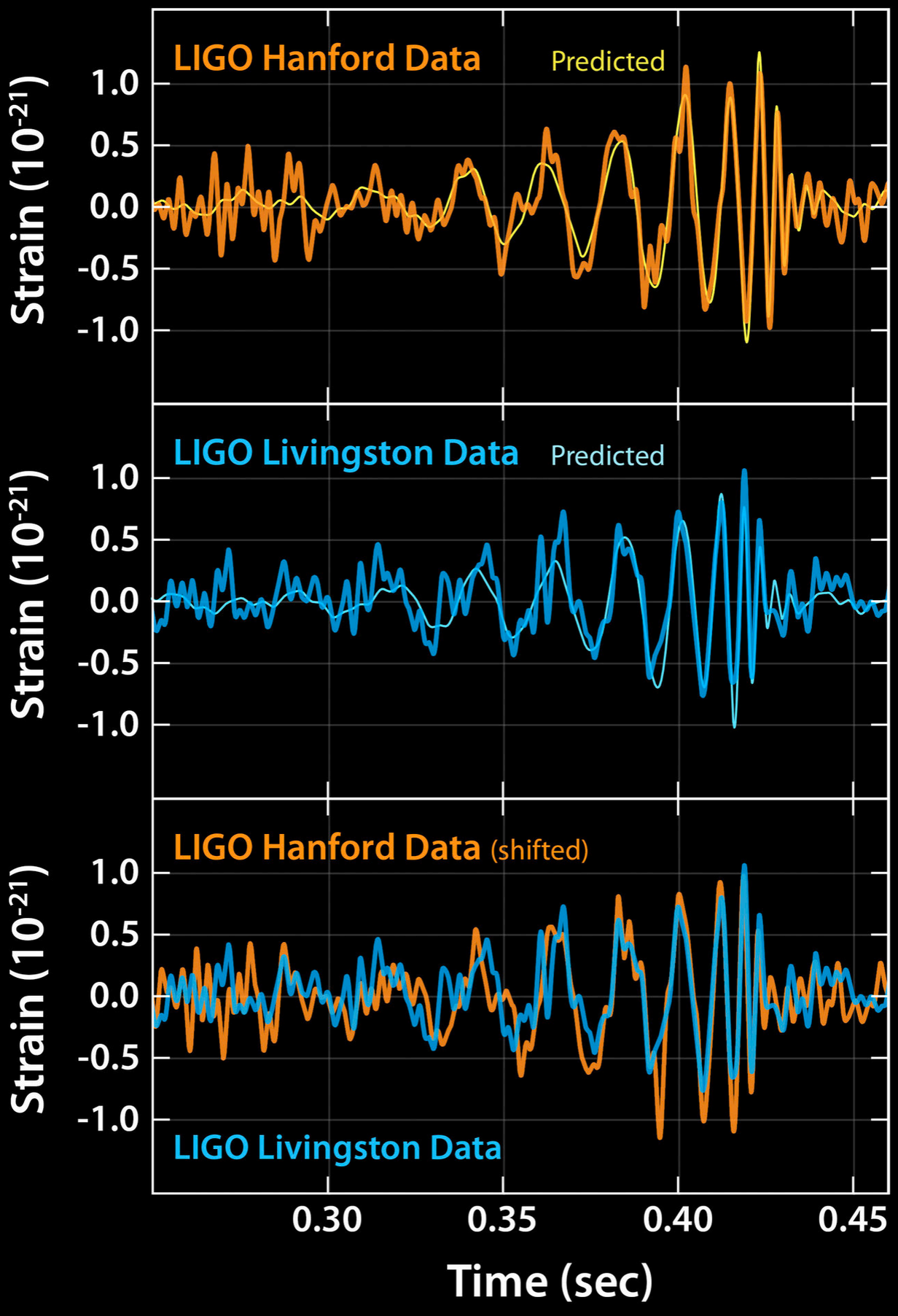
gamma ray X-ray ultraviolet visible infrared microwave radio



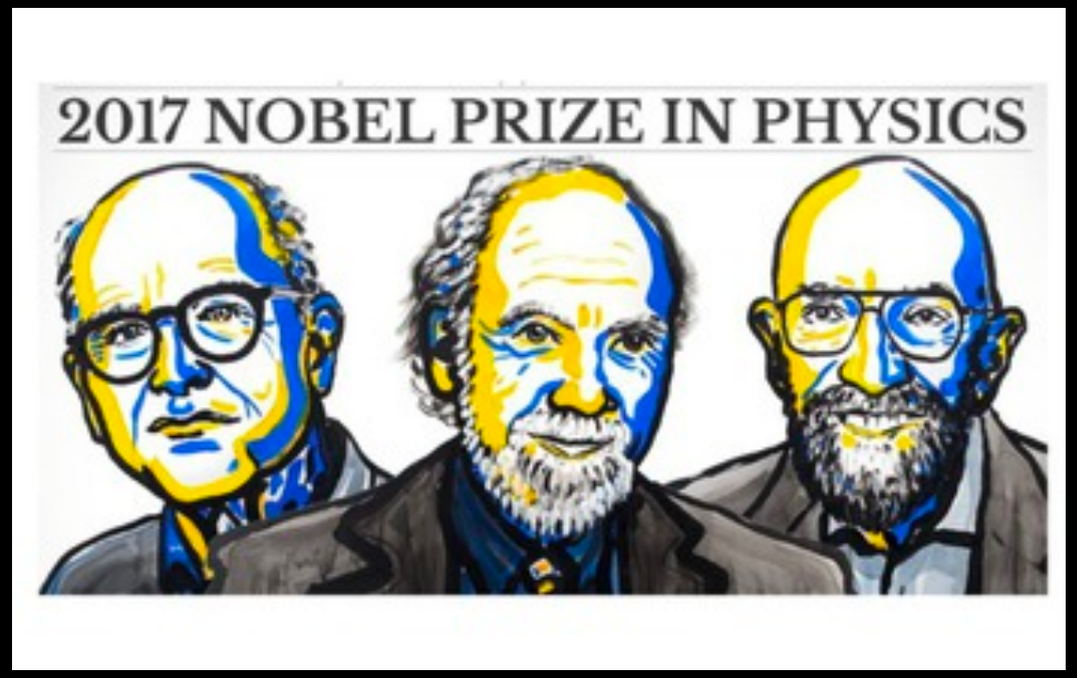
The Gravitational Wave Sky?

Gravitational Wave:
Messenger of the gravitational field

Generated by ~accelerated mass distributions
Most extreme example: Black Hole Binaries



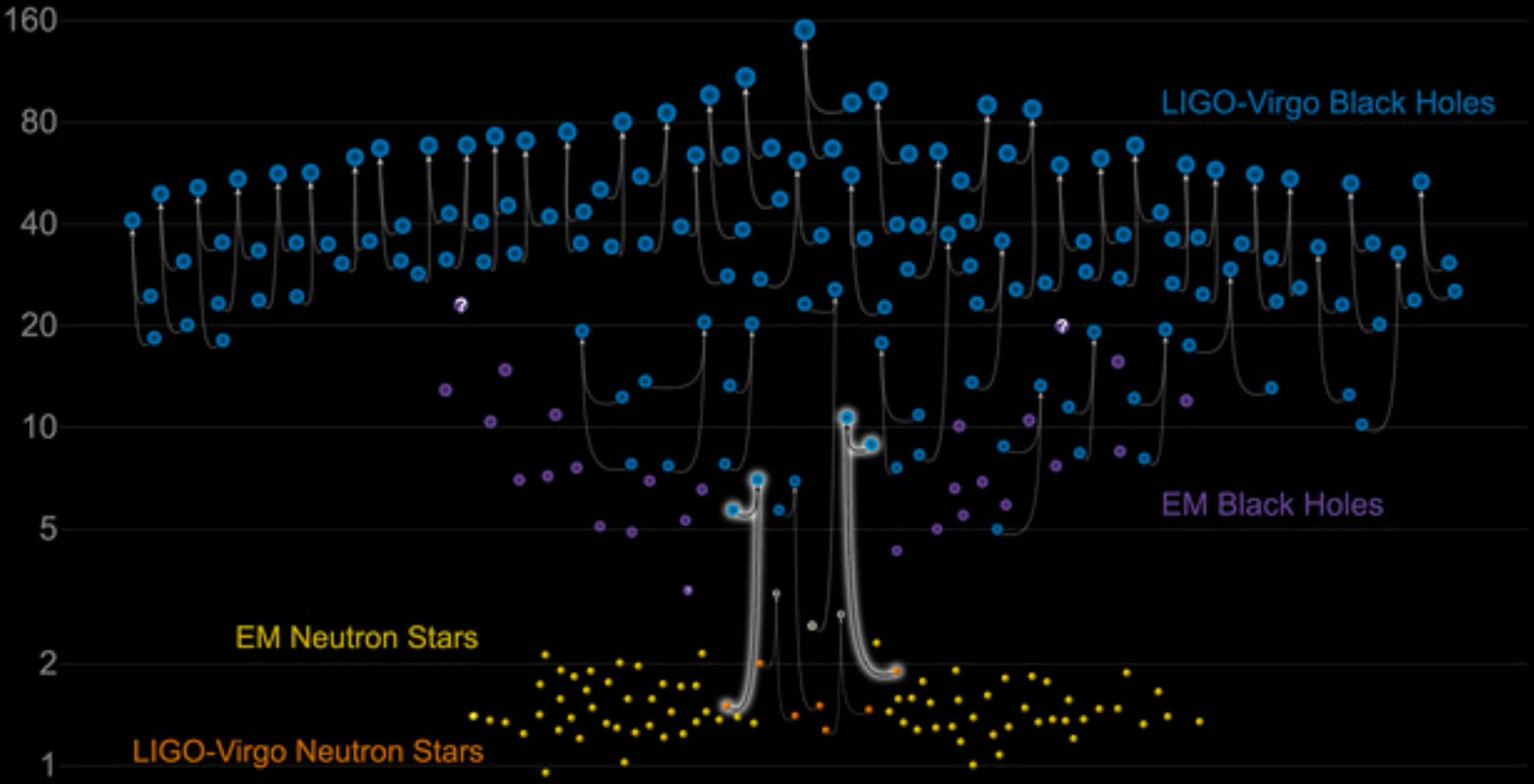
2015 Discovery of Gravitational Waves



Laser **I**nterferometer **G**ravitational **W**ave **O**bservatory

Masses in the Stellar Graveyard

in Solar Masses



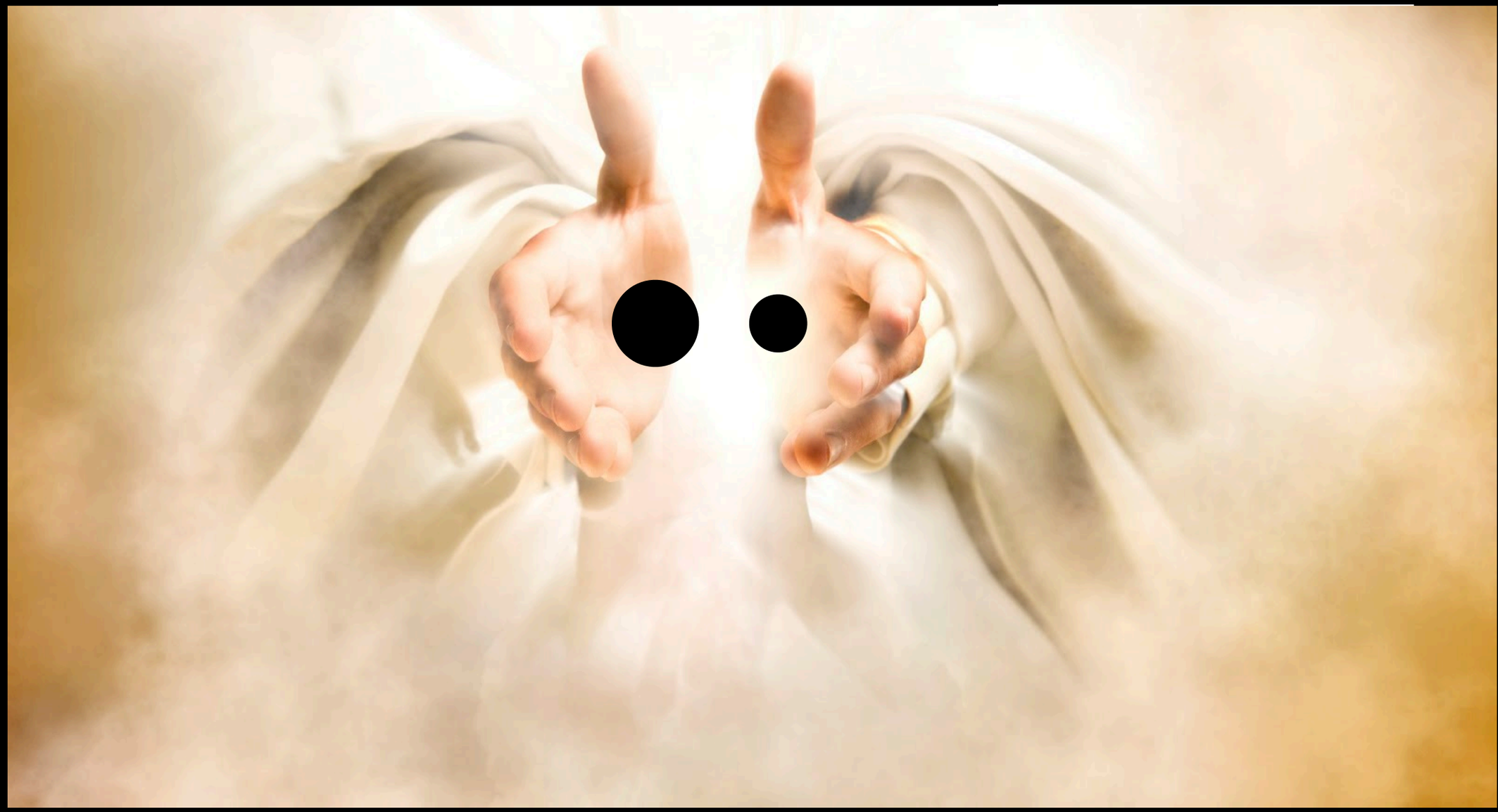
The LIGO Orrery

GWTC-2 plot v1.0

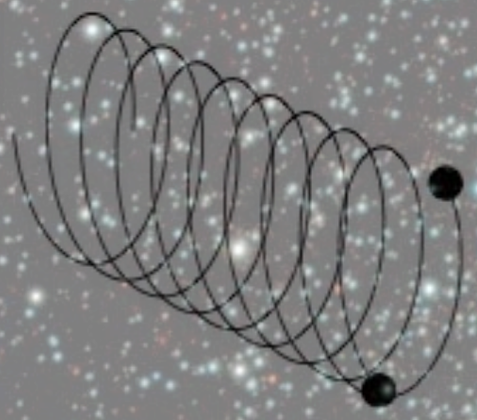
LIGO-Virgo | Frank Elavsky, Aaron Geller | Northwestern

Open Question: How did these form!?

‘Field’? **‘Dynamically’?** **‘Other’?**

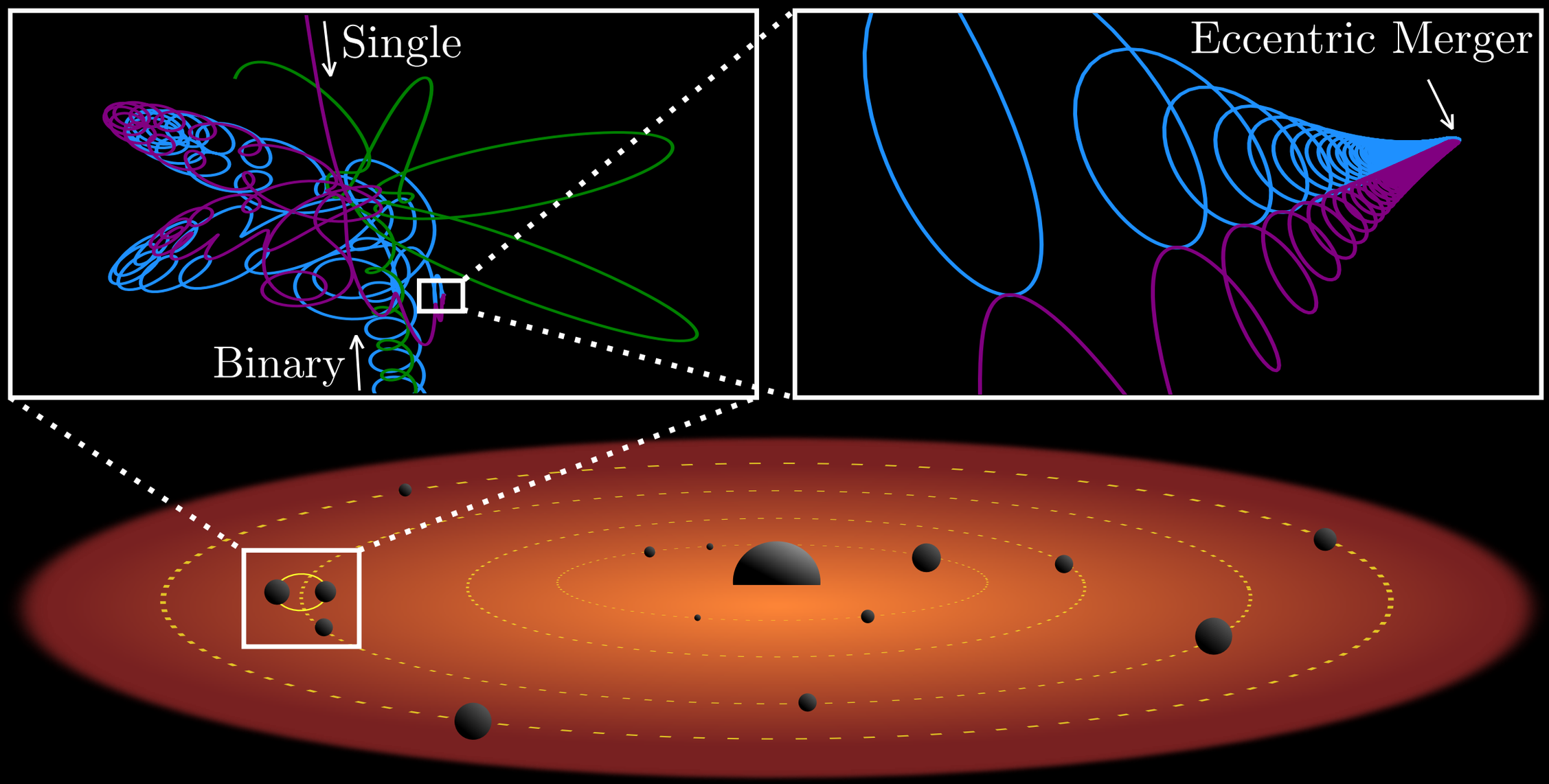


Work being carried out at the NBIA by:
D. D’Orazio, J. Samsing, B. Liu, A. Vigna-Gomez, A. Trani, +

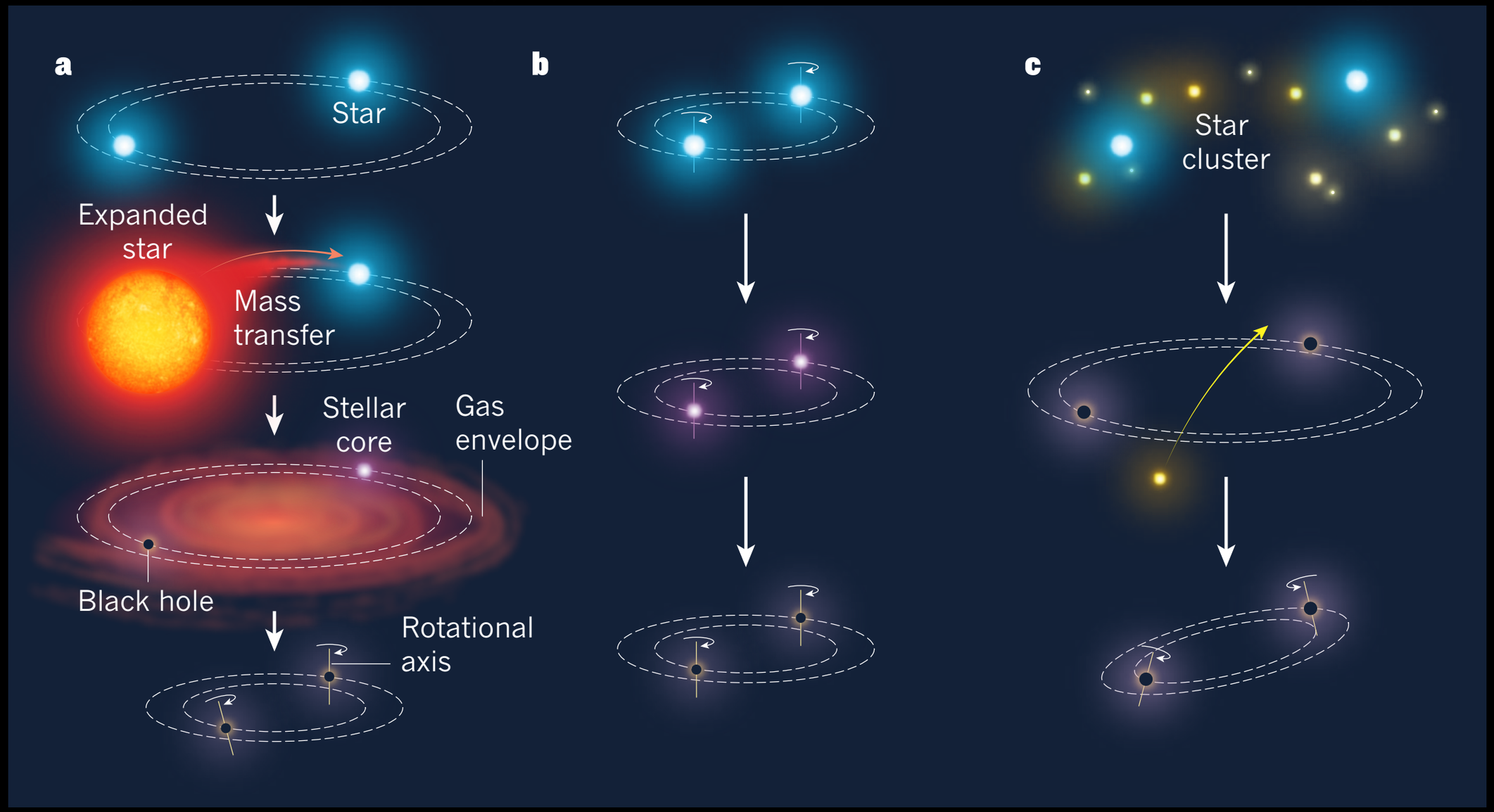


Movie from Johan Samsing

Dynamical Formation in Gas Disk (AGN channel)



Project on (Field) Formation of Black Hole Mergers



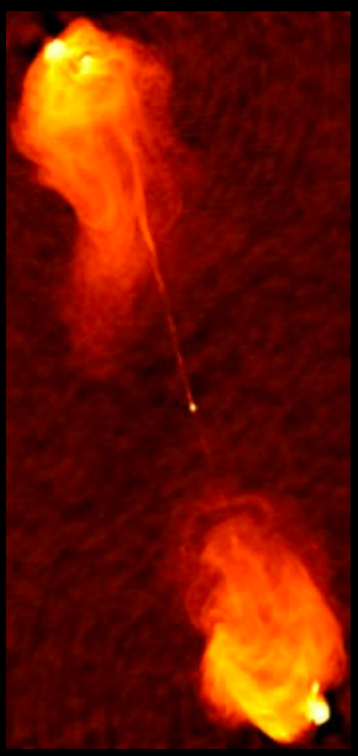
*__Background:__ Internal “Mixing” during stellar evolution is still uncertain and can be parameterised by theoretical models. How does this affect the outcome of binary star evolution and so BBH formation?

*__Question:__ Do uncertainties in single star evolution allow yet-unimagined BBH formation channels?

*__Task:__ Implement prescriptions for mixing effects in binary stellar population synthesis code: COMPAS (https://compas.science/; https://github.com/TeamCOMPAS/COMPAS)

The Electromagnetic Sky: Conventional Astronomy

gamma ray X-ray ultraviolet visible infrared microwave radio



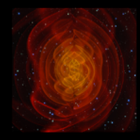
The Gravitational Wave Sky

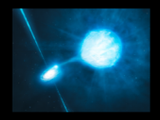
The Gravitational Wave Spectrum

Sources

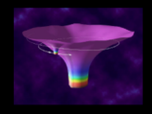
Big Bang

Supermassive Black Hole Binary Merger

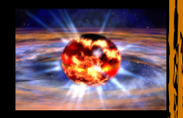




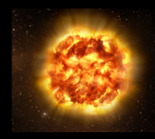
Compact Binary Inspiral & Merger



Extreme Mass-Ratio Inspirals



Pulsars, Supernovae



age of the universe

Wave Period

years

hours

seconds

milliseconds

10^{-16} 10^{-14} 10^{-12} 10^{-10} 10^{-8} 10^{-6} 10^{-4} 10^{-2} 10^{2}

Wave Frequency

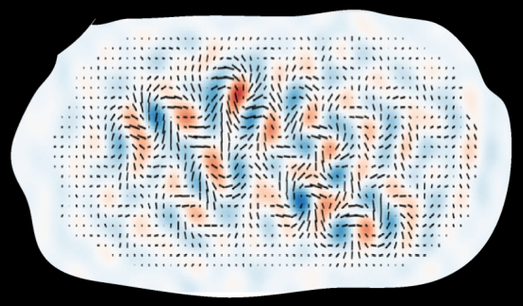
CMB Polarization

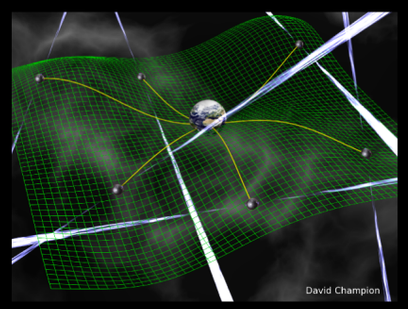
Radio Pulsar Timing Arrays

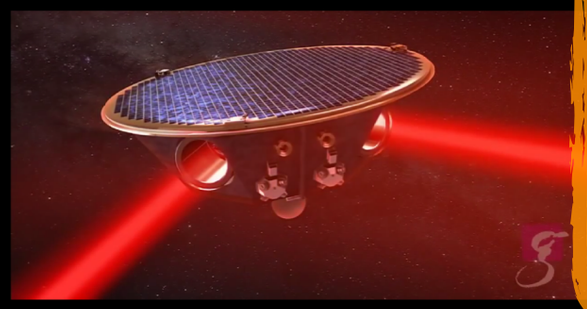
Space-based interferometers

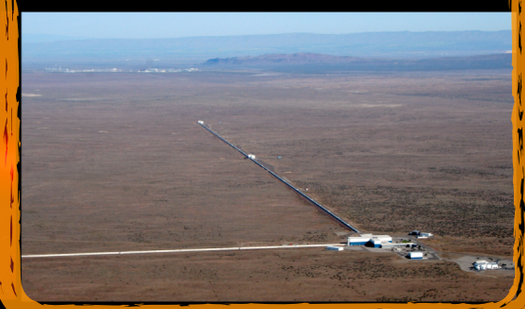
Terrestrial interferometers

Detectors









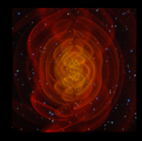
The Low Frequency Gravitational Wave Sky

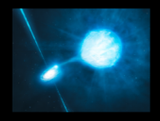
The Gravitational Wave Spectrum

Sources

Big Bang

Supermassive Black Hole Binary Merger





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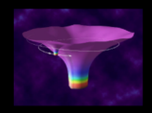

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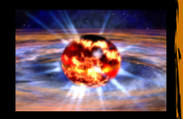

Pulsars, Supernovae

Wave Period

age of the universe

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Wave Frequency

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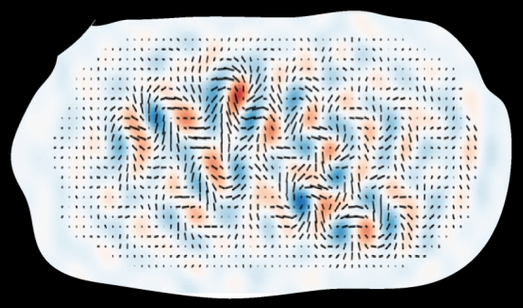
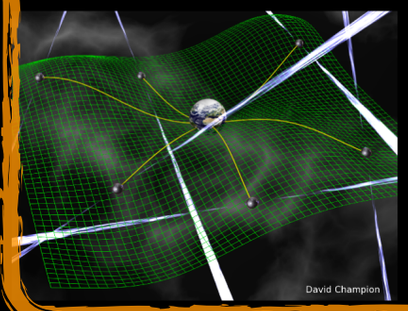
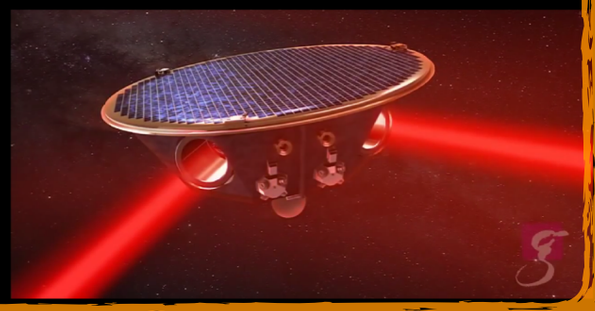


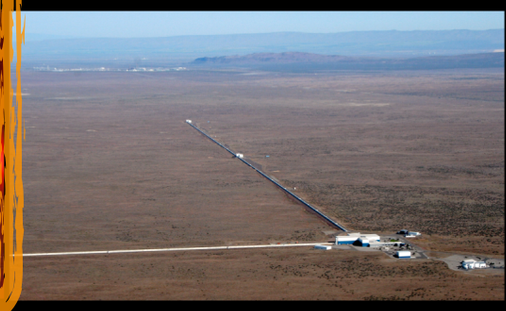
Radio Pulsar Timing Arrays



Space-based interferometers



Terrestrial interferometers



Detectors

LISA

Laser Interferometer Space Antenna

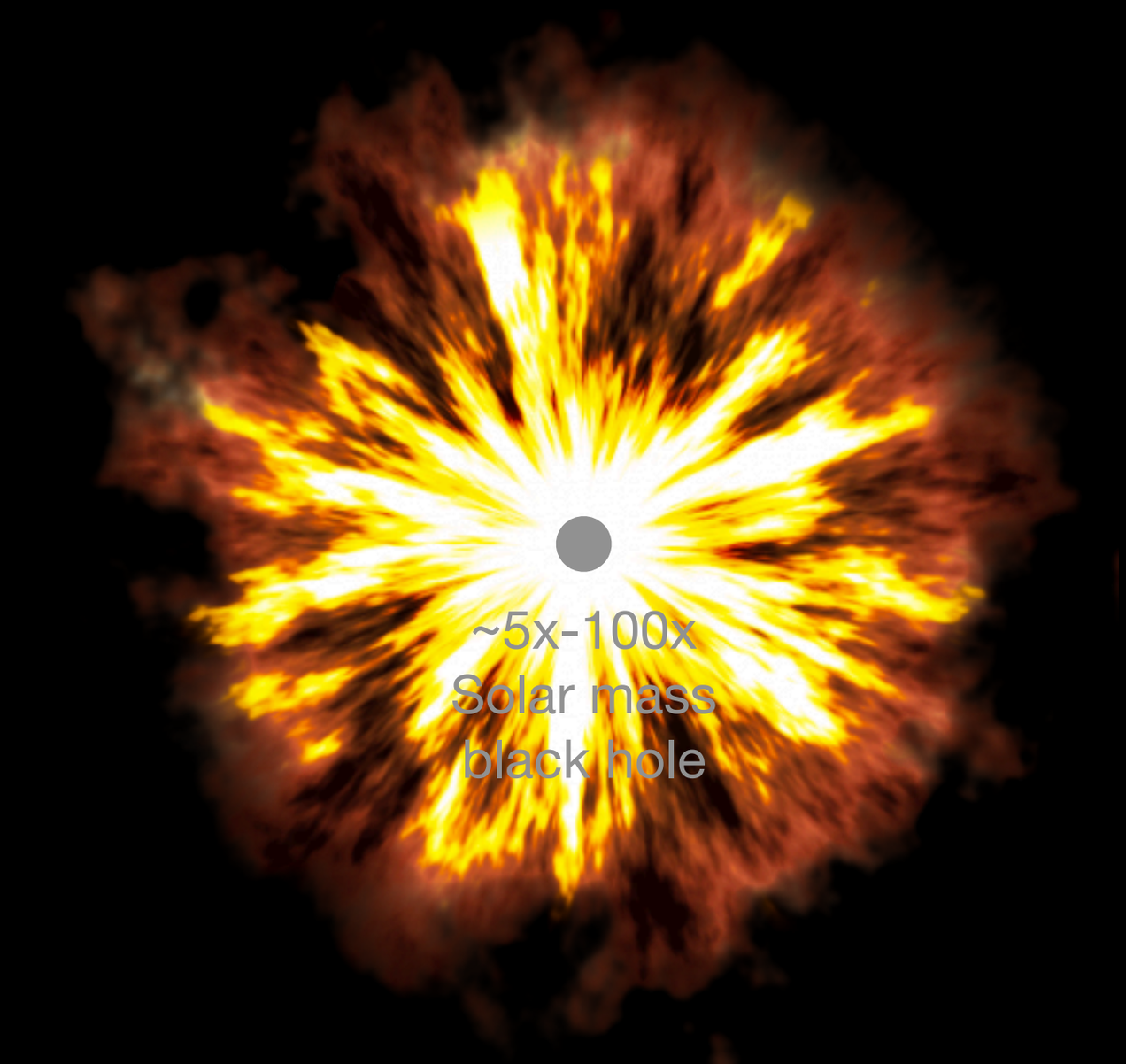
2.5 Million km arms!

Planned Launch: 2034

Pulsar Timing Arrays:

Black Holes in the Universe

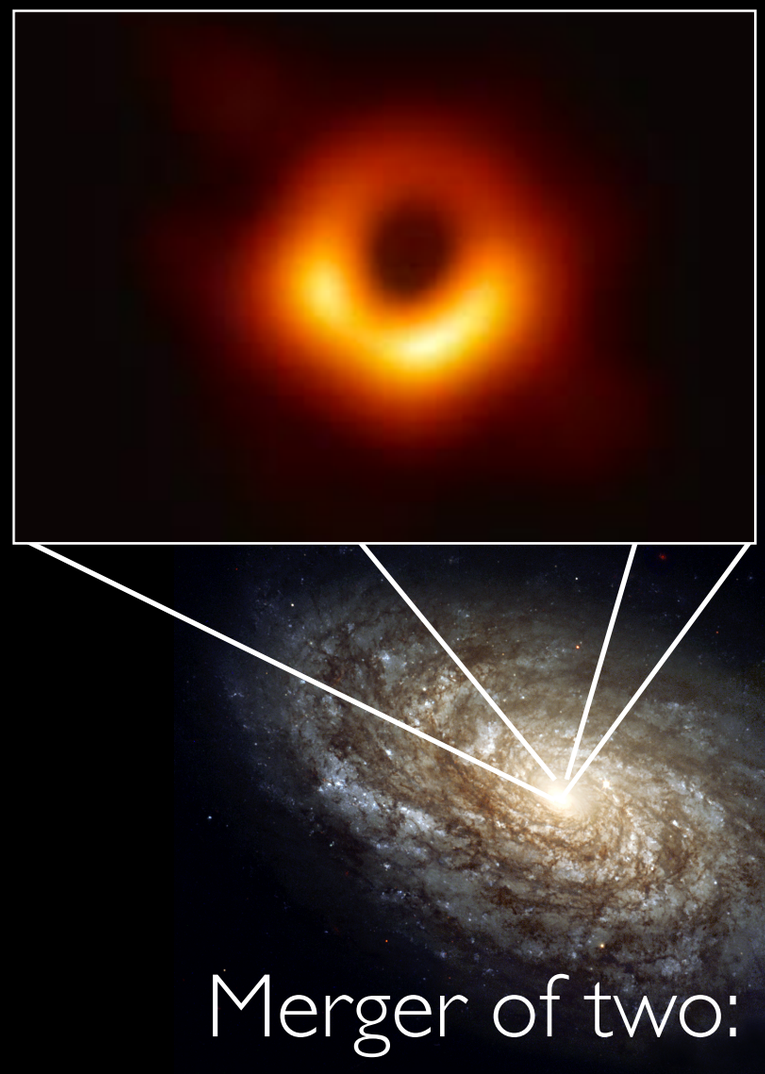
Stellar Mass Black Holes



Merger of two:
High frequency GWs, LIGO

Supermassive Black Holes

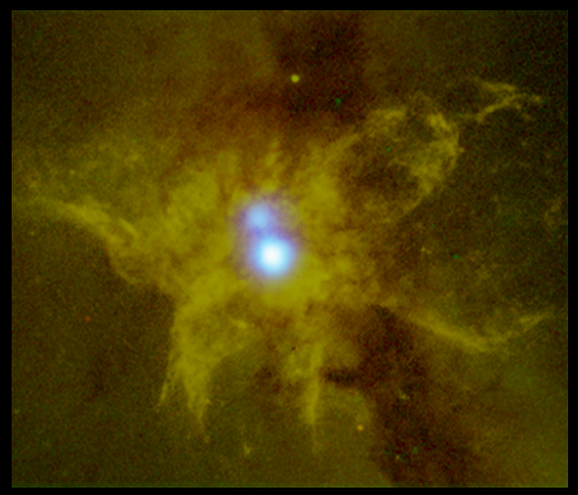
~100 Thousand to 10 Billion
Solar mass black hole



Merger of two:
Low frequency GWs, LISA and PTAs

GALAXIES MERGE, BUT DO THE BLACK HOLES (AND HOW)?

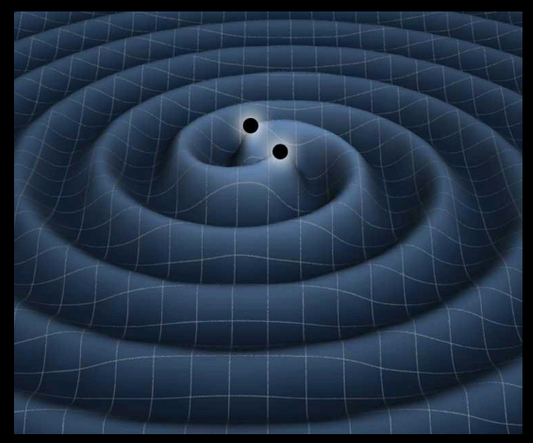
* **Step 1:** *Galaxy merger* forms a supermassive black hole binary



Far apart

Closer together

* **Step 2:** *???*



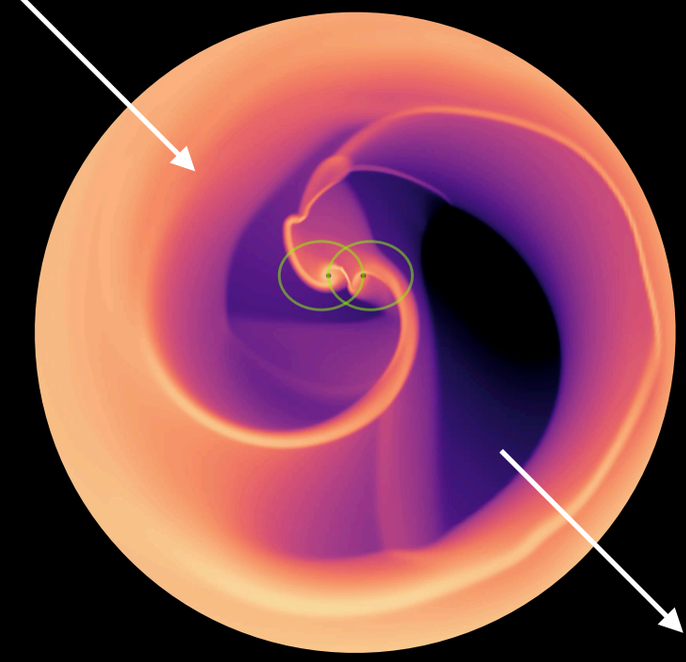
* **Step 3:** *Gravitational Waves* merge the supermassive black holes

Open Question:

How do supermassive black hole binaries get close enough to merger? Do they?

GALAXIES MERGE, BUT DO THE BLACK HOLES (AND HOW)? HOW DO WE FIND OUT?

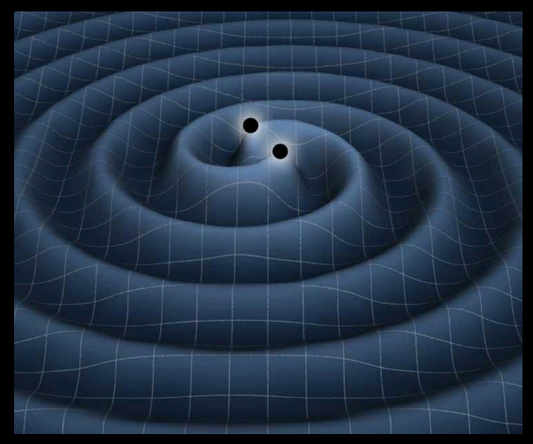
* **Step 1:** *Galaxy merger* forms a supermassive black hole binary



* **Step 2:** *???*

Work at the NBIA:

Understanding binary+gas interactions



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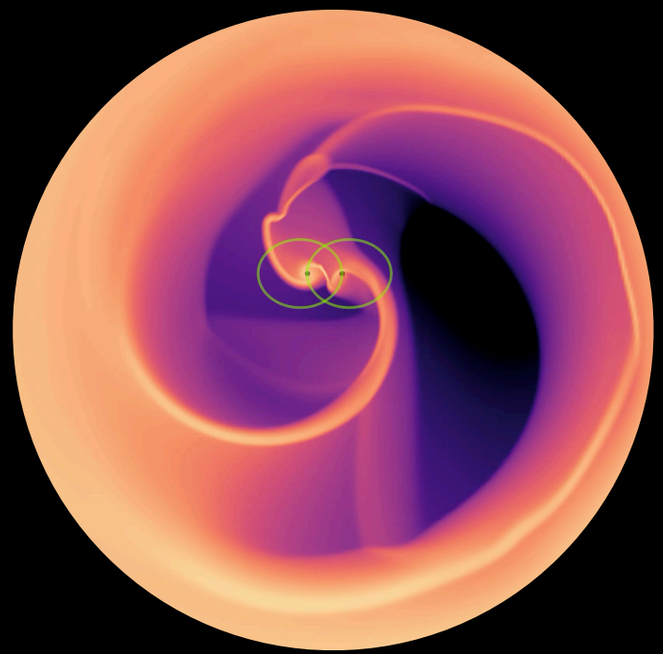
GALAXIES MERGE, BUT DO THE BLACK HOLES (AND HOW)?
HOW DO WE FIND OUT?

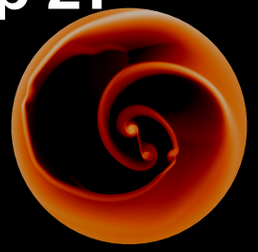


Population Predictions

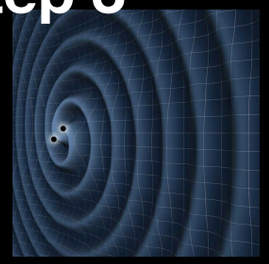
How does gas affect the orbit and drive the black holes to merge?

Step 1

Step 2?

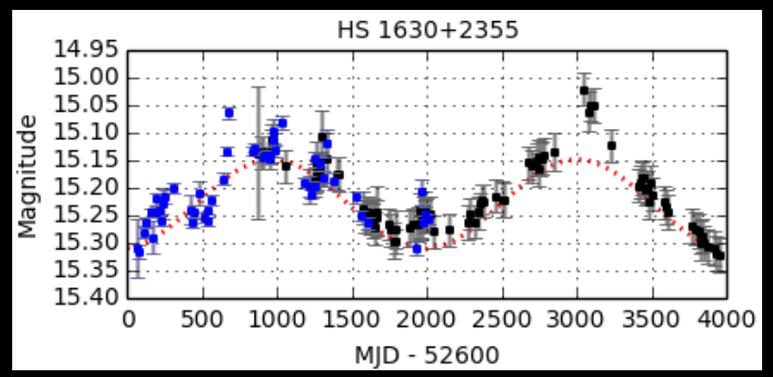


Step 3

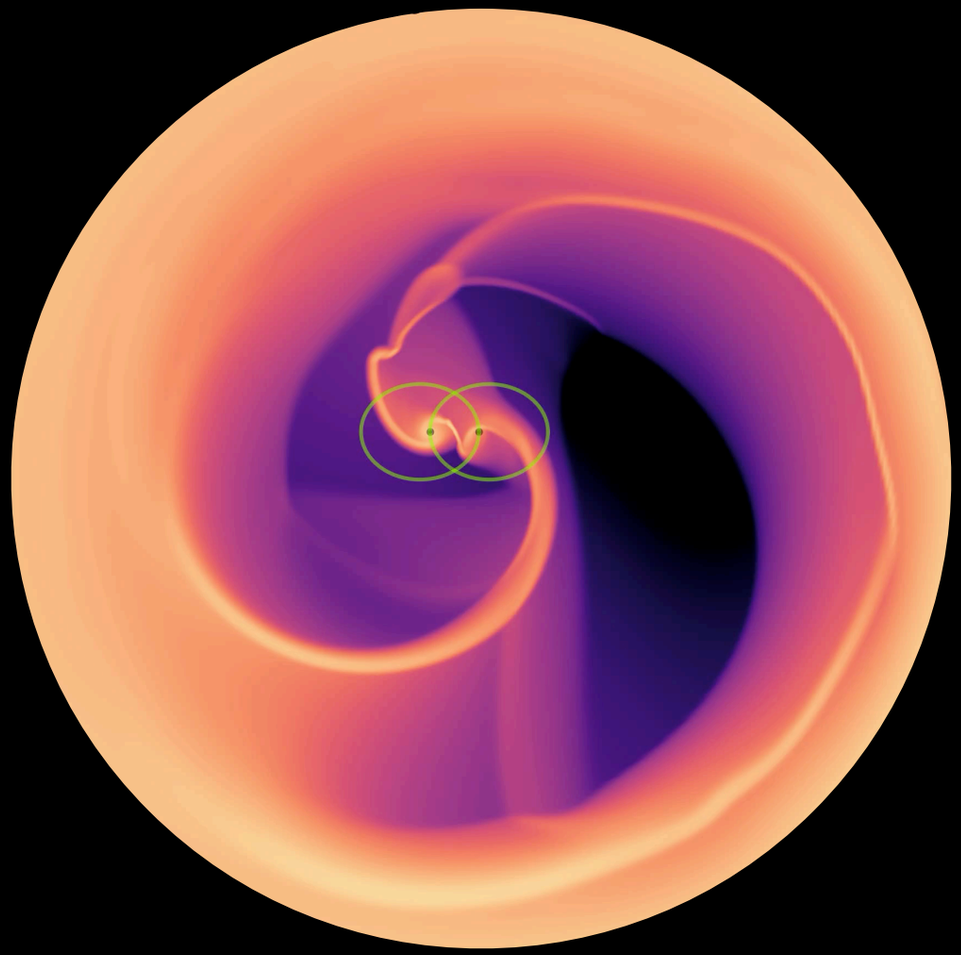


Discovery in EM spectrum

How does the accretion of gas make the binary EM bright?



Project in Numerical Hydrodynamics



*__Background:__ Studies of gas-driven binary orbital evolution fix the binary orbit and calculate how gas forces would change the orbit. For a large enough disk mass this fixed-orbit approximation breaks down. We need a binary that reacts in real time to the gas forces to explore the above question.

*__Question:__ When does back reaction onto the binary orbit affect the problem?

*__Task:__ Implement a “Live Binary” into the DISCO hydrodynamics code.

People

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Research Topics

* Theory at interface with observations: pencil-paper and numerics
* Gravitational Waves and Black Hole Astrophysics
* Many-body (relativistic) gravitational dynamics
* Gas Accretion, Gravitational Lensing

Open Questions

* How do black hole binaries (across the mass scale) form and merge?
  * How do we find evidence for supermassive black hole binaries?
  * Where/How do the stellar mass black hole binaries form/merge?
  * What Electromagnetic and Gravitational Wave observables can we predict and use to find the answers?