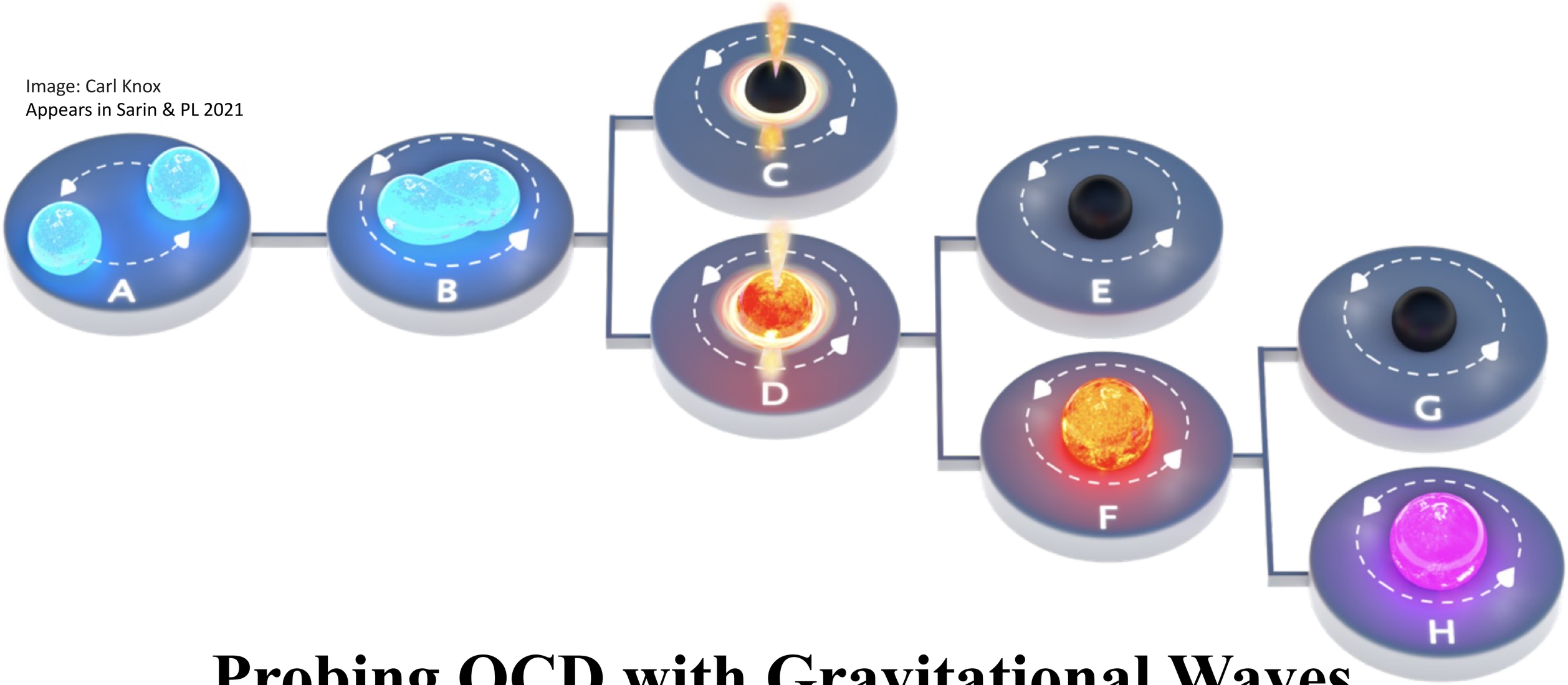


Image: Carl Knox
Appears in Sarin & PL 2021

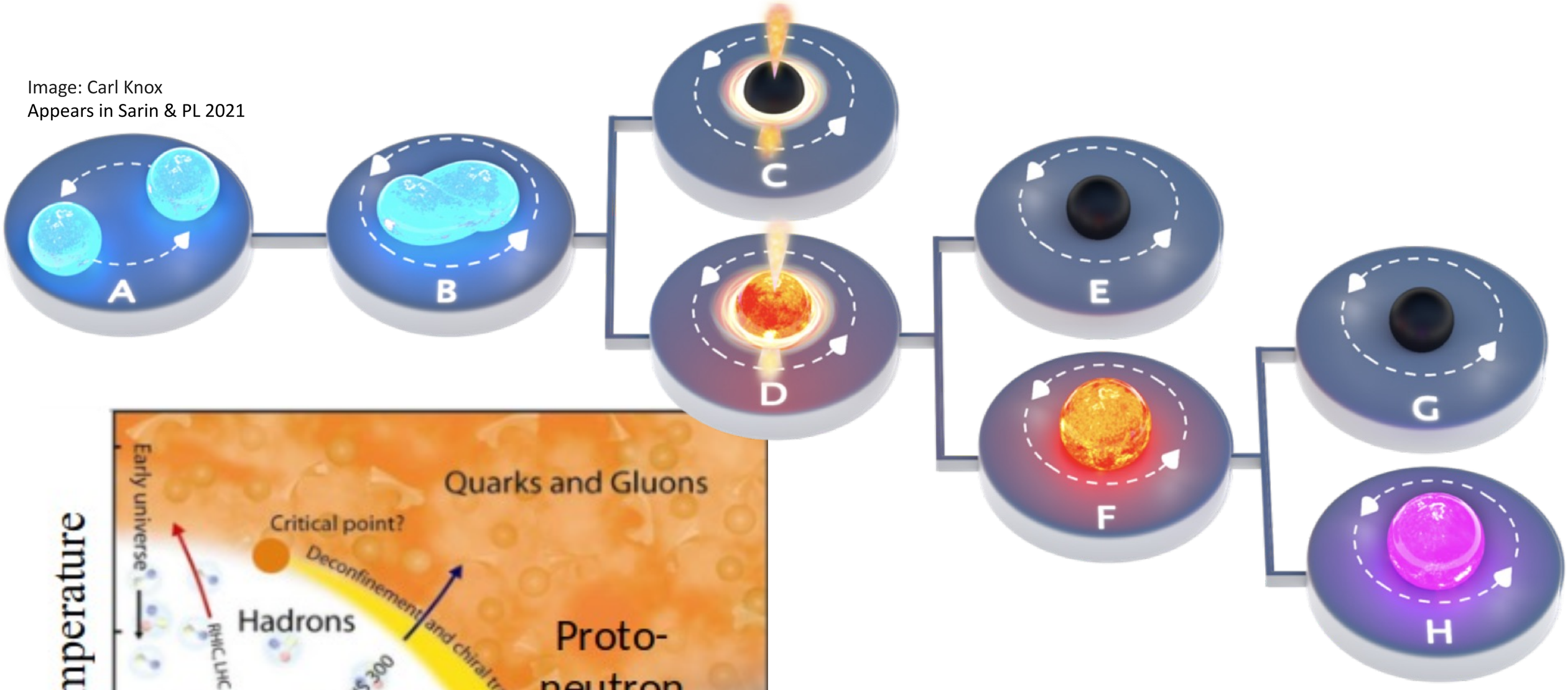
Probing QCD with Gravitational Waves

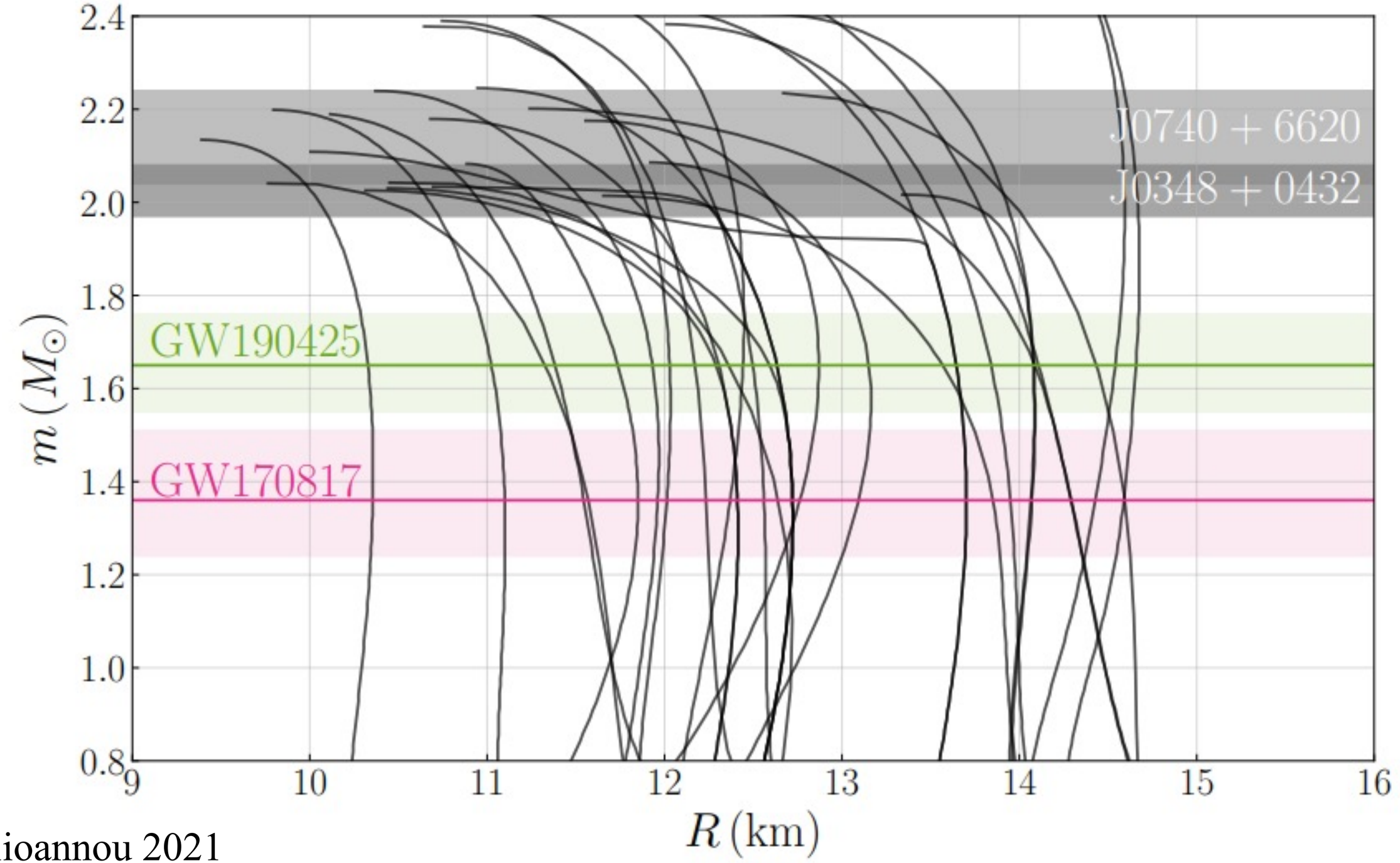
Paul Lasky

MONASH University

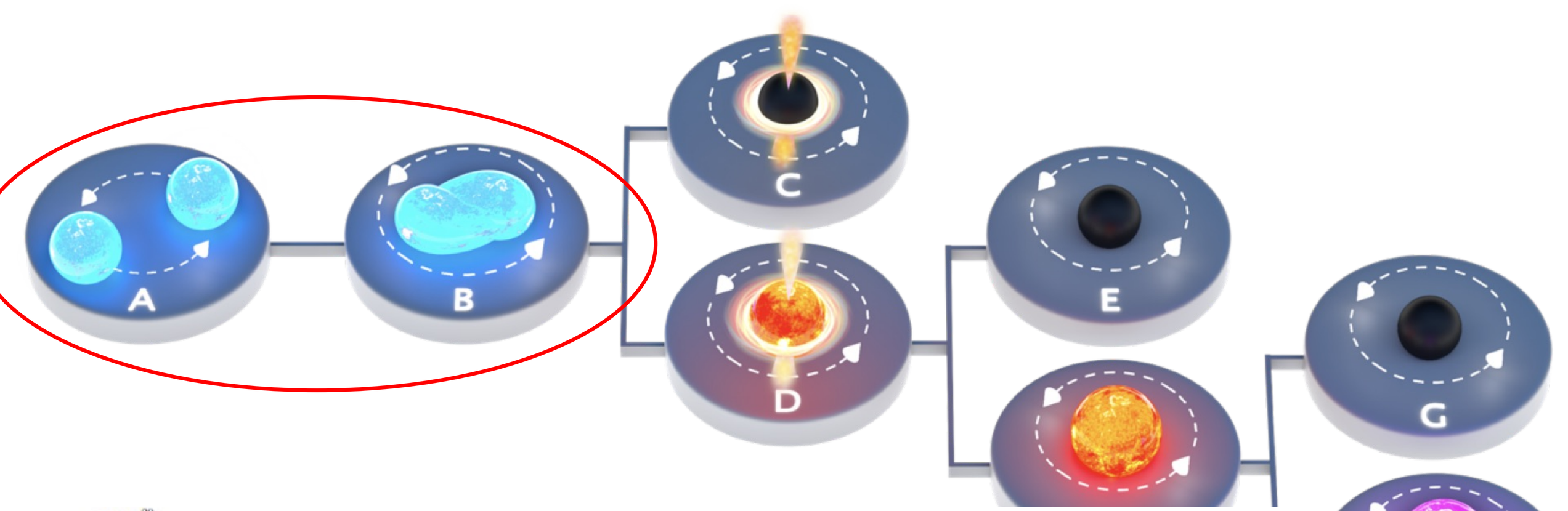
OzGrav

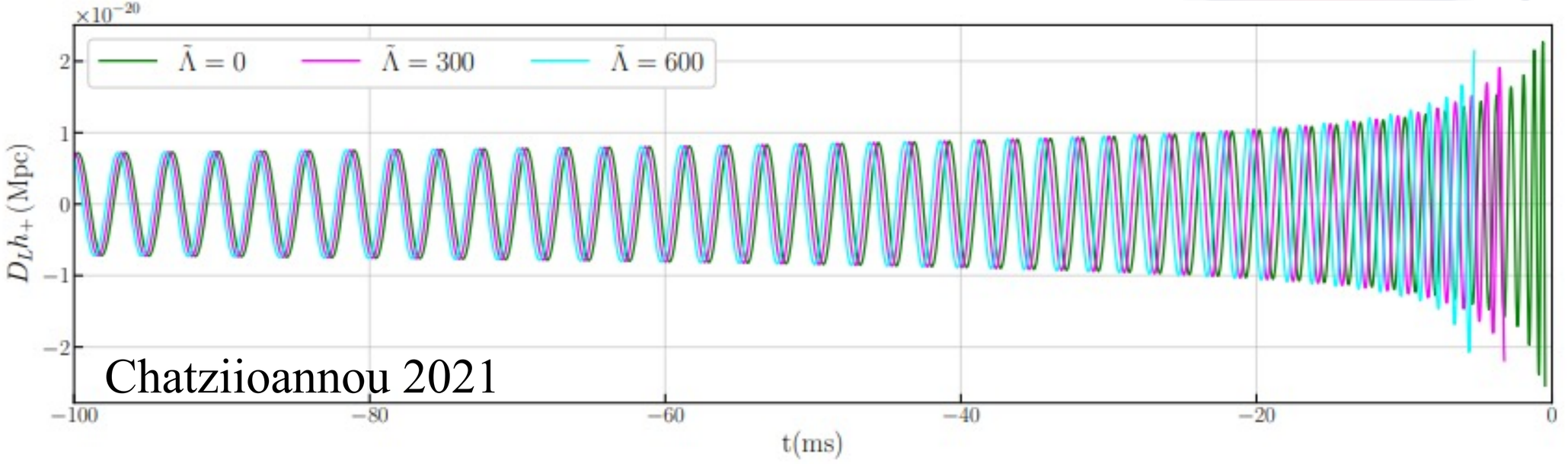
Image: Carl Knox
Appears in Sarin & PL 2021



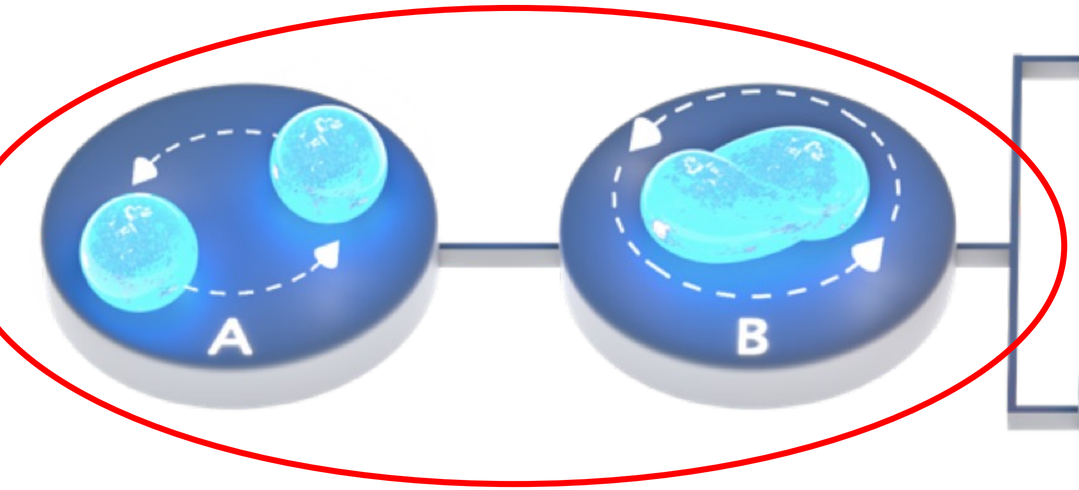


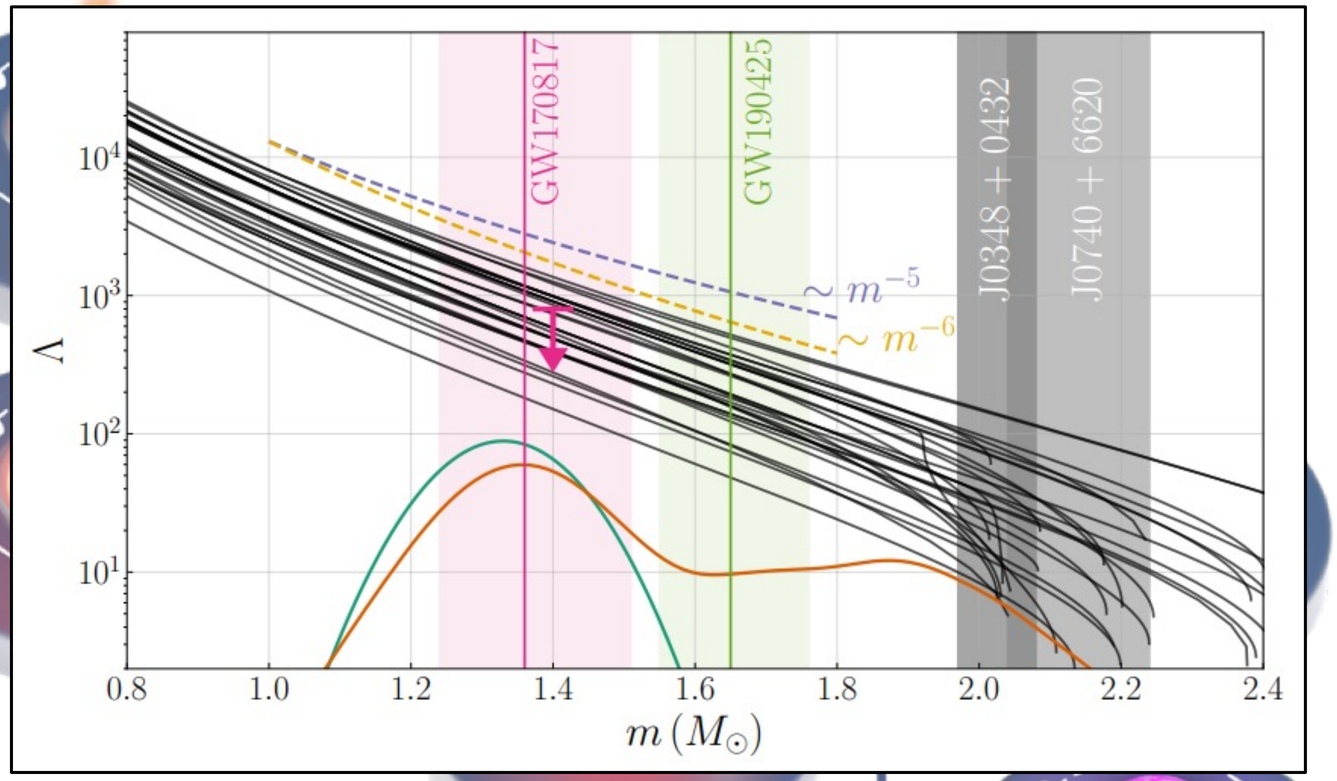
Chatziioannou 2021

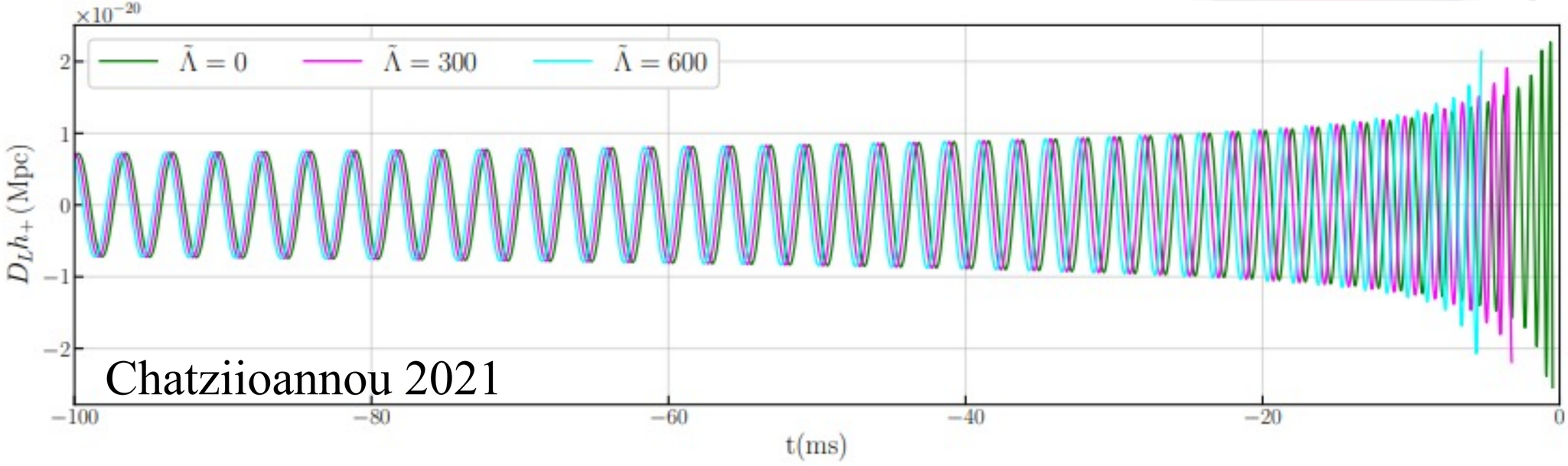




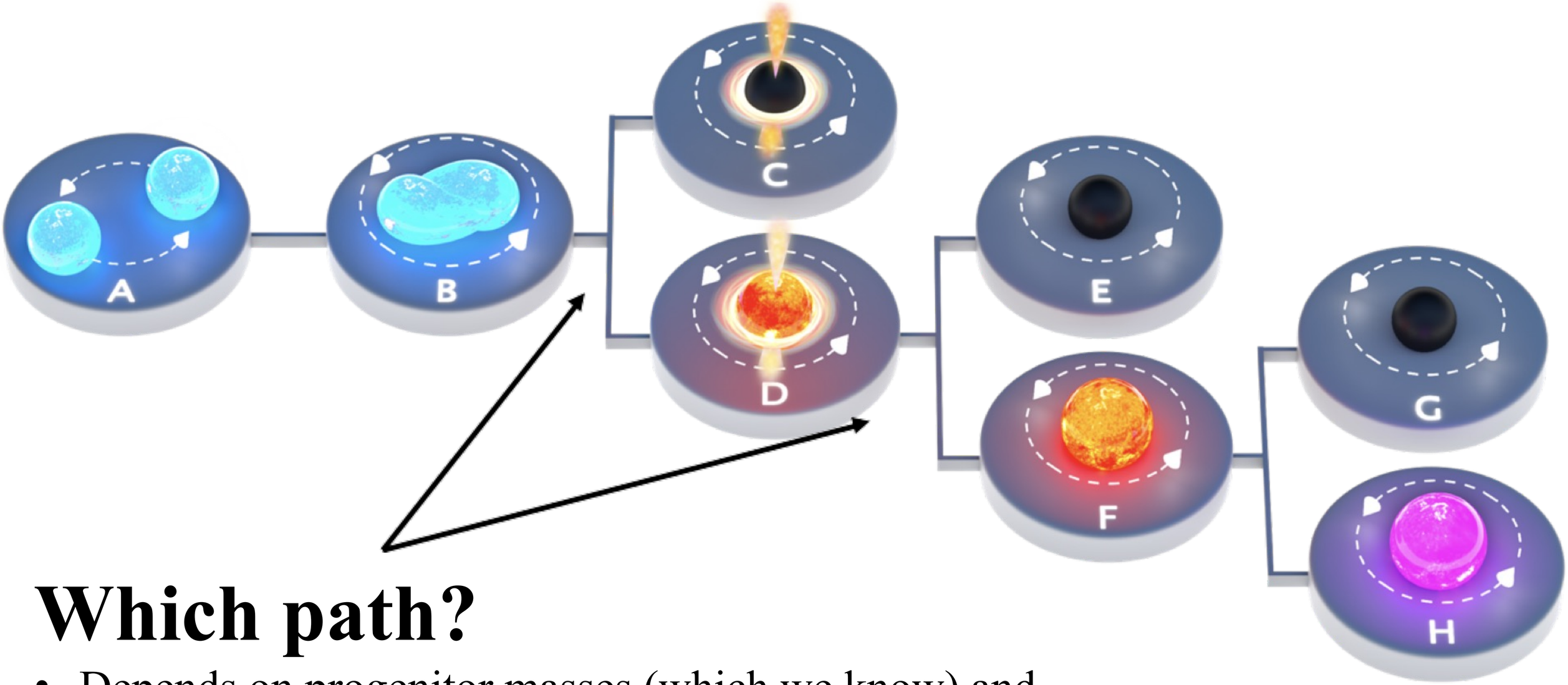
Chatziioannou 2021





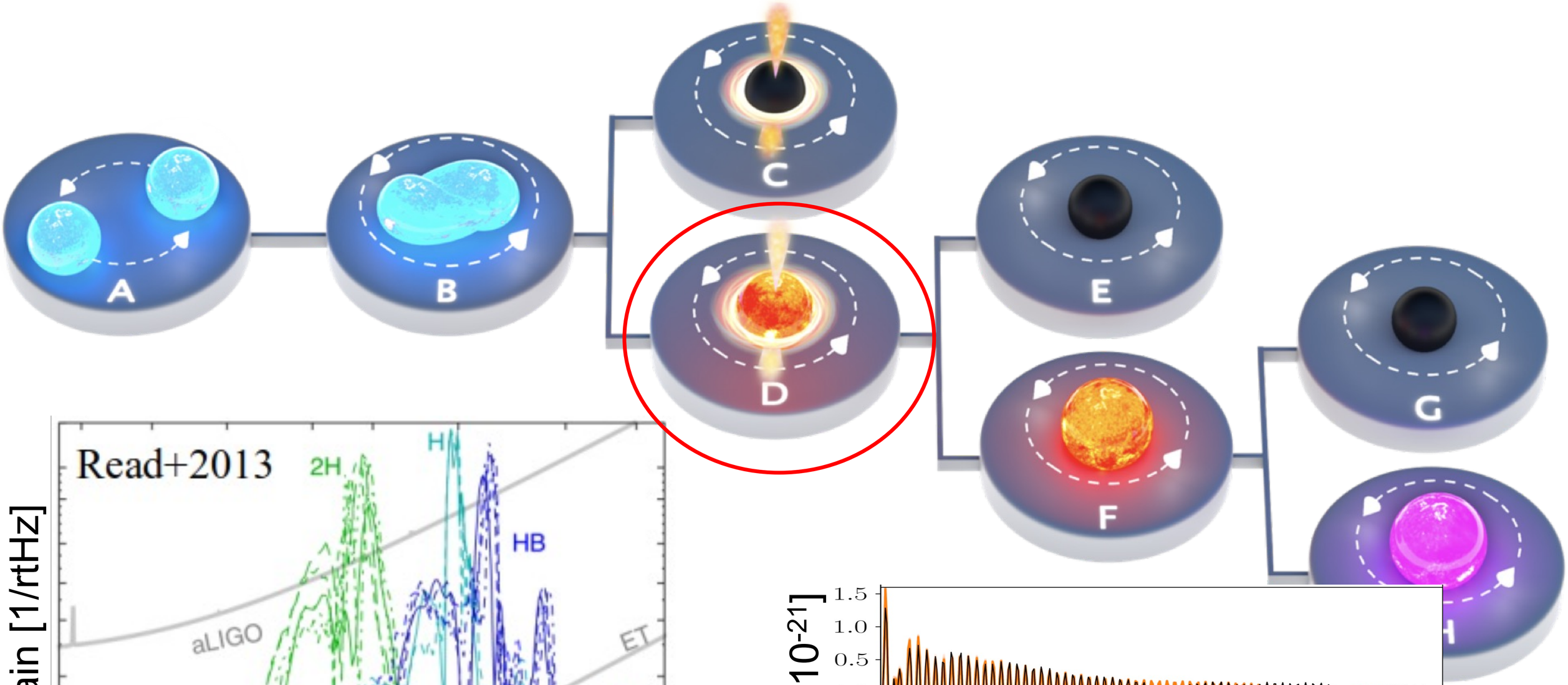


Chatziioannou 2021

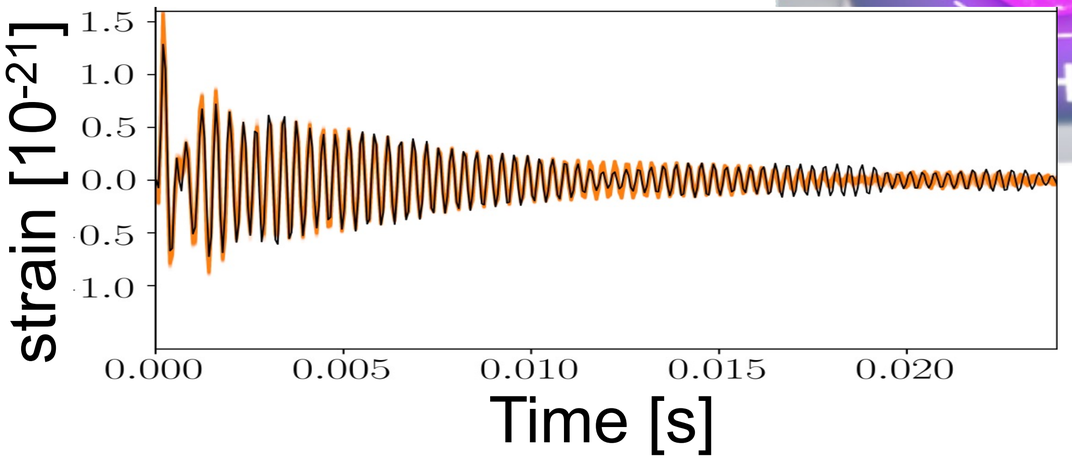


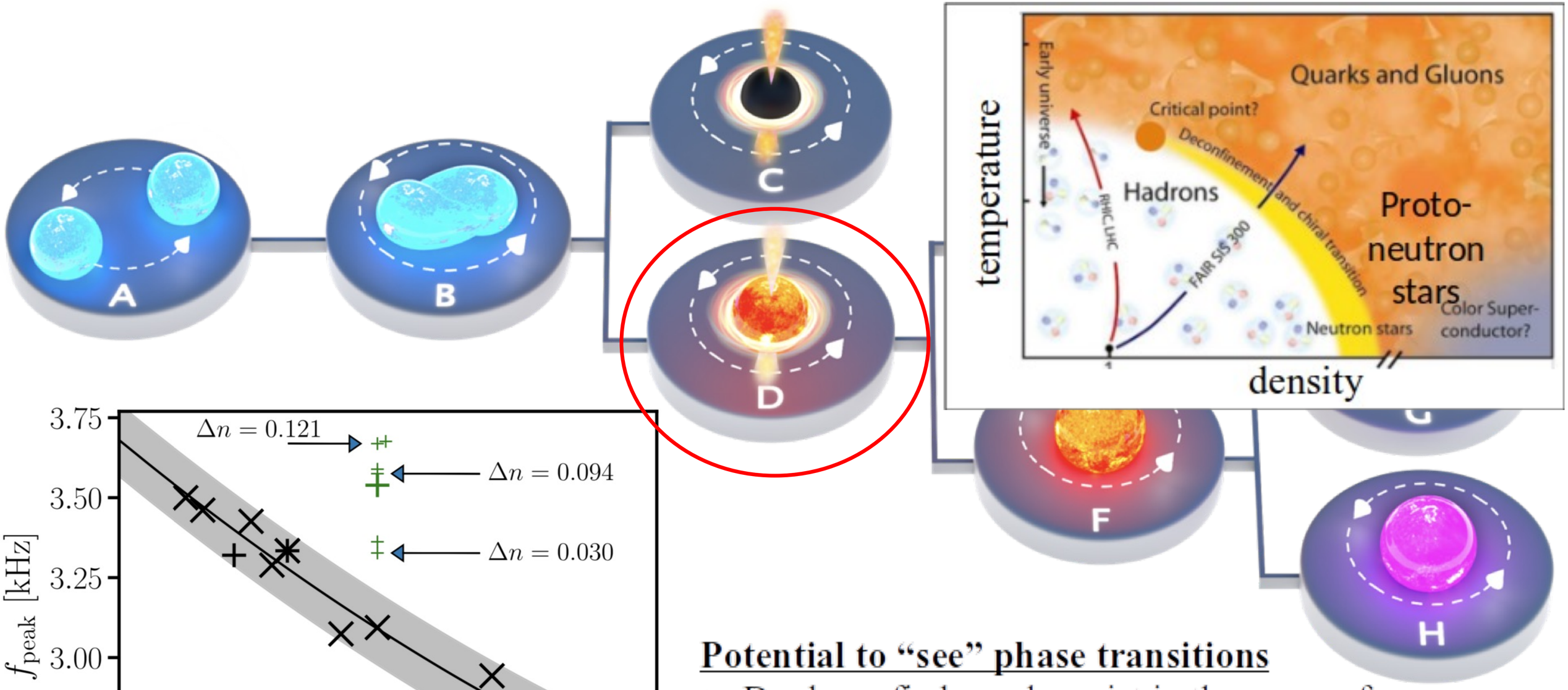
Which path?

- Depends on progenitor masses (which we know) and
- Maximum non-rotating mass of neutron stars (which we don't know)
  - Measure M_{TOV}
- Measure path with gravitational waves and/or electromagnetically


A
B
C
D
E
F
G
H

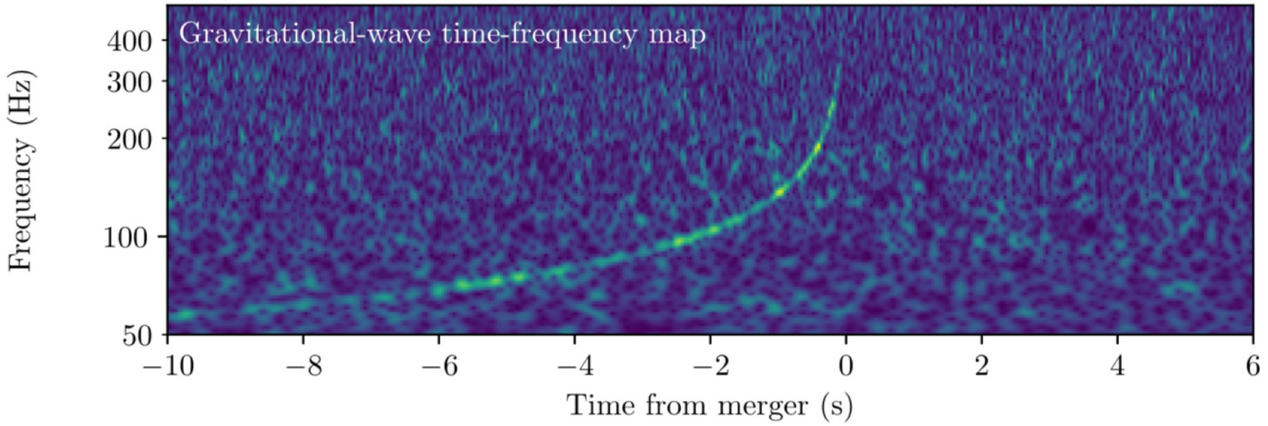
Read+2013
2H
H
HB
aLIGO
ET
B
500
700
1000
1500
2000
3000
5000
7000
Strain [1/rtHz]
GW frequency [Hz]

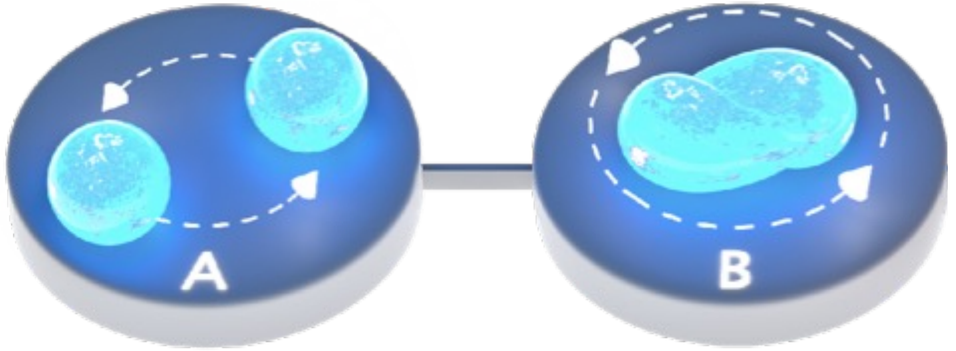

1.5
1.0
0.5
0.0
0.5
1.0
strain [10-21]
0.000
0.005
0.010
0.015
0.020
Time [s]



Potential to "see" phase transitions

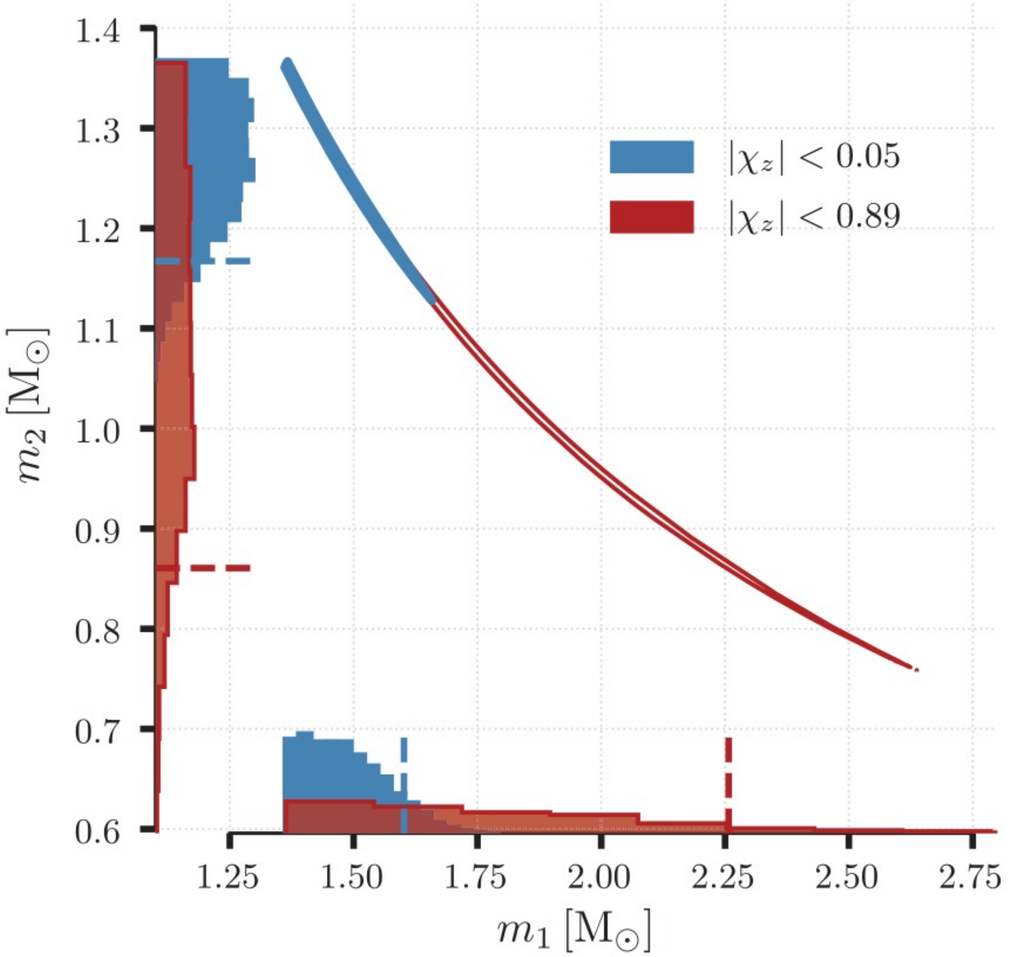
- Do deconfied quarks exist in the cores of neutron stars?
- Hyperons, ….
- See Bauswein+2019

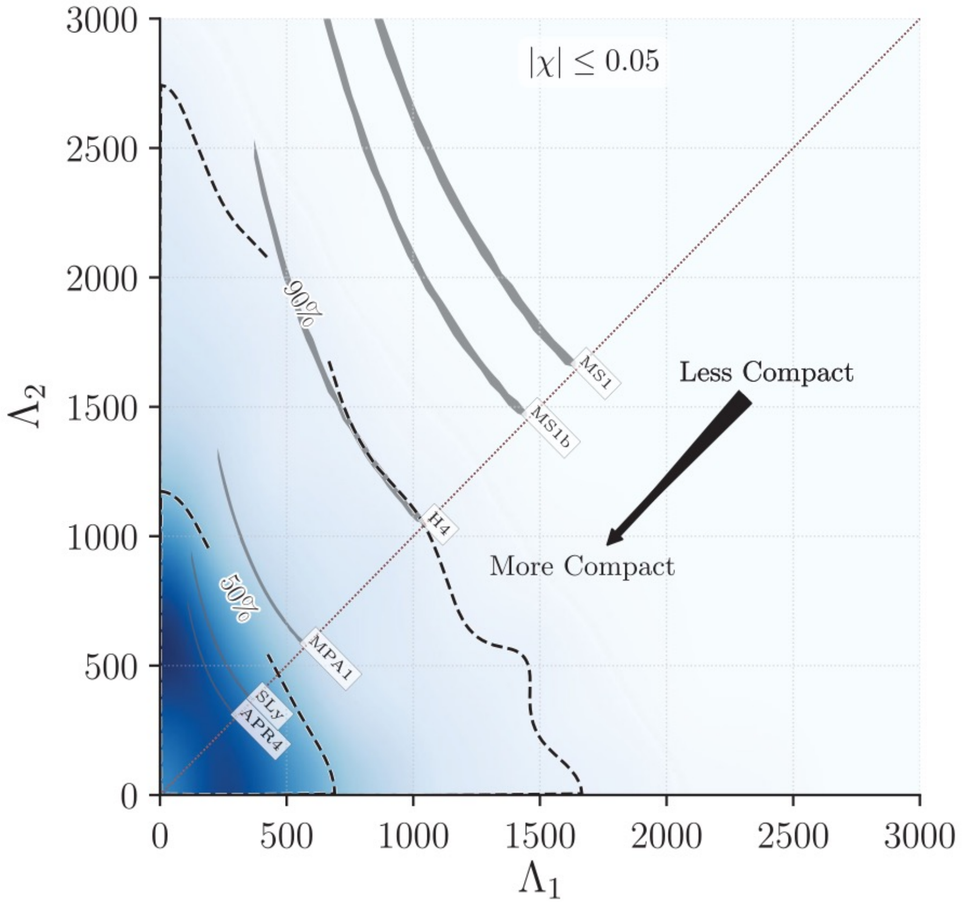




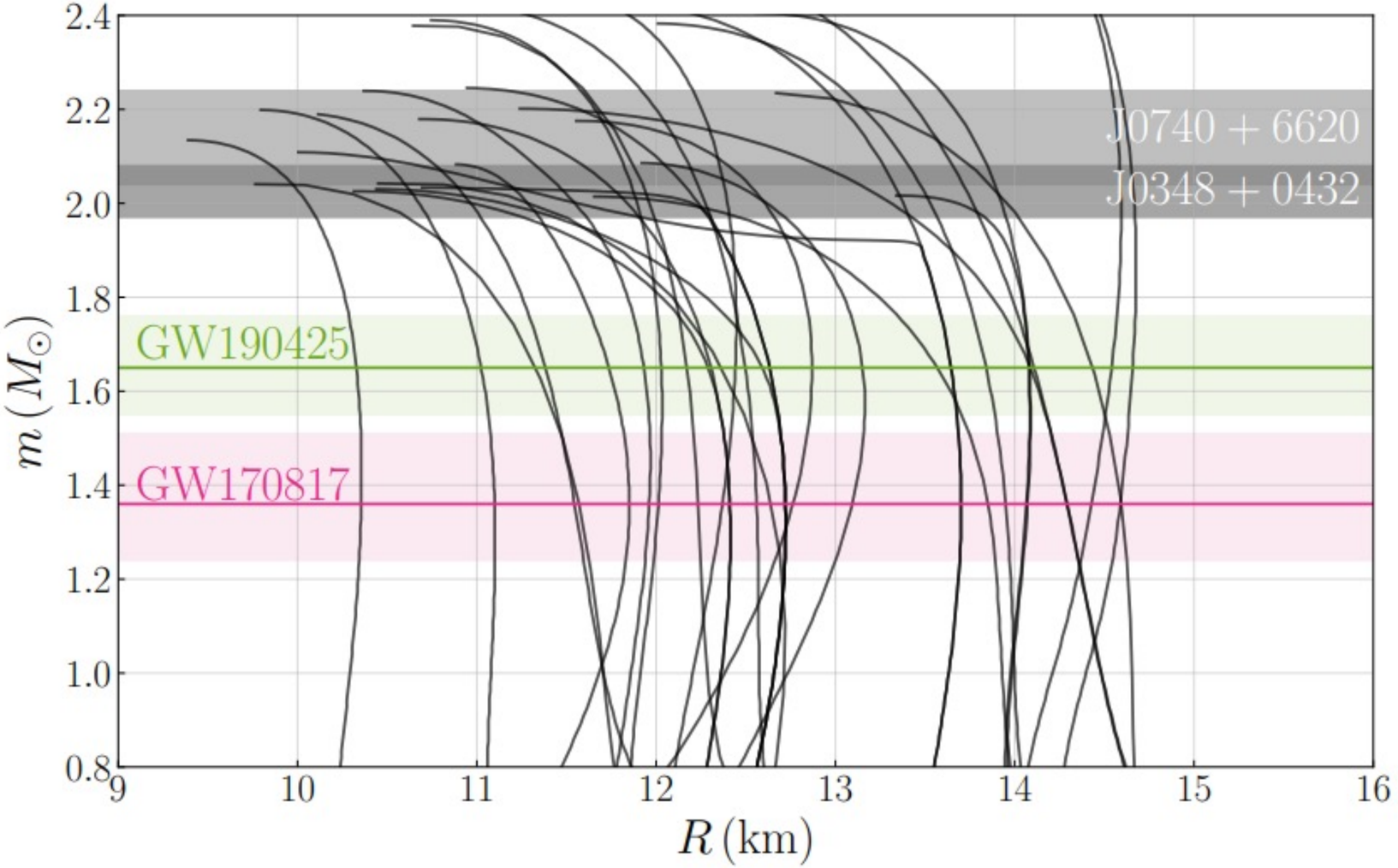
GW170817

Abbott+17



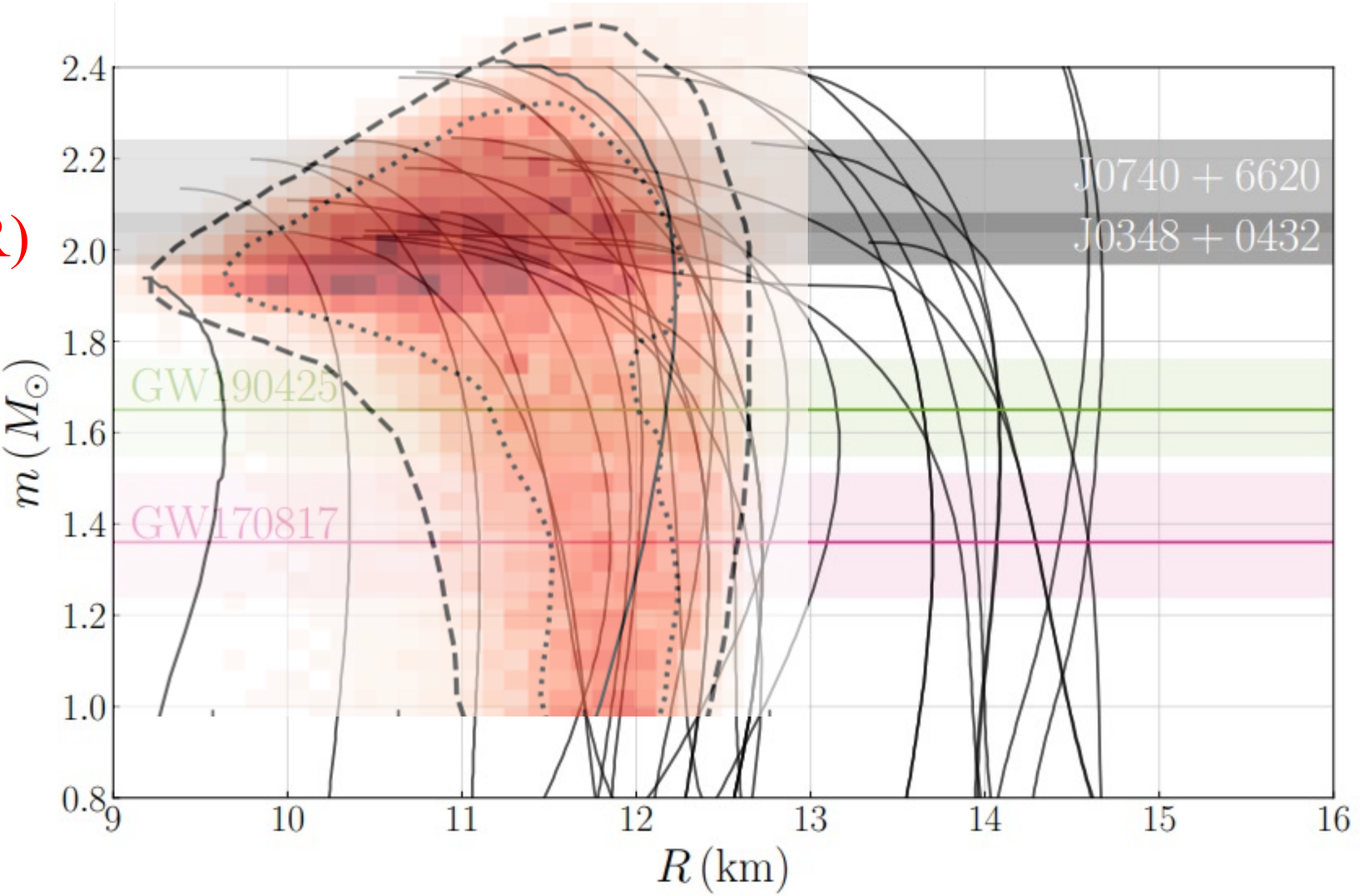


GW170817 + ….


2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
$m\,(M_\odot)$
9
10
11
12
13
14
15
16
$R\,(\mathrm{km})$
J0740 + 6620
J0348 + 0432
GW190425
GW170817

GW170817 + ….

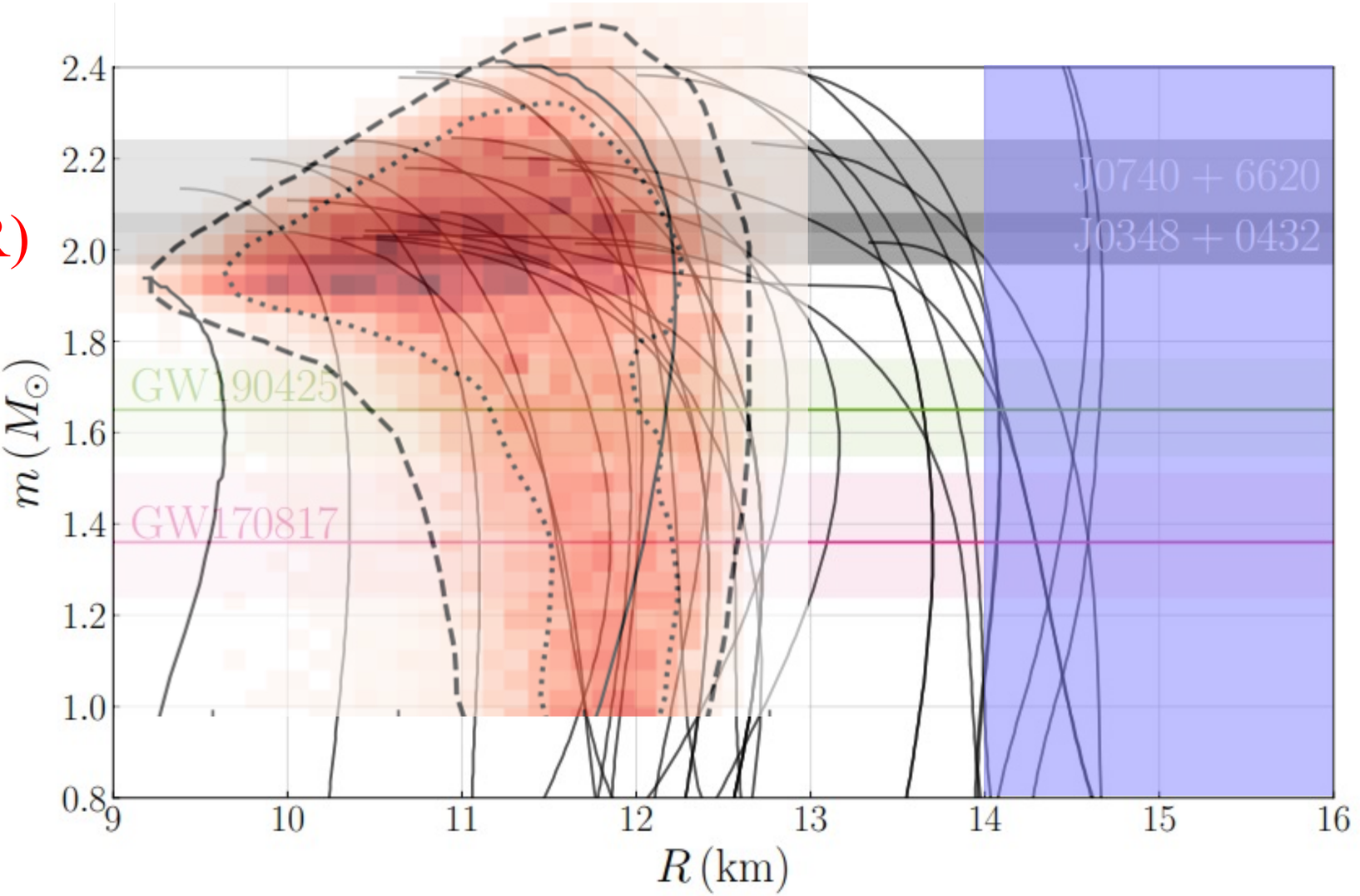
J0030+0451
(Raaijmakers+2020; NICER)



GW170817 + ….

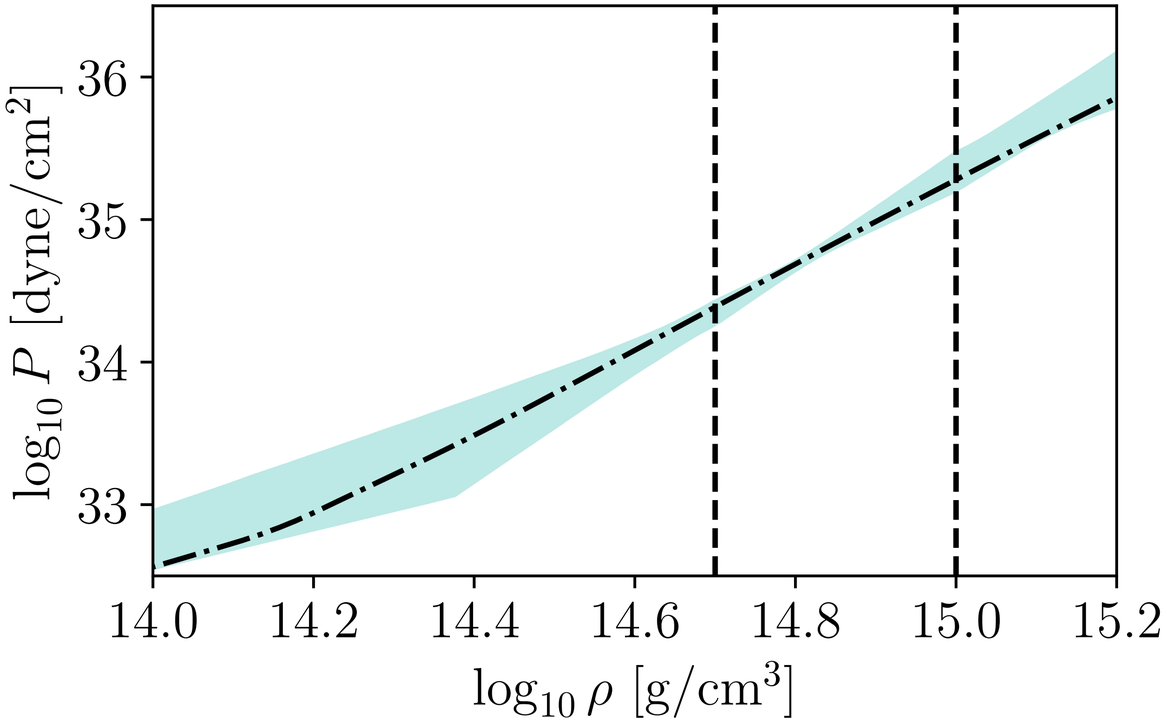
J0030+0451
(Raaijmakers+2020; NICER)

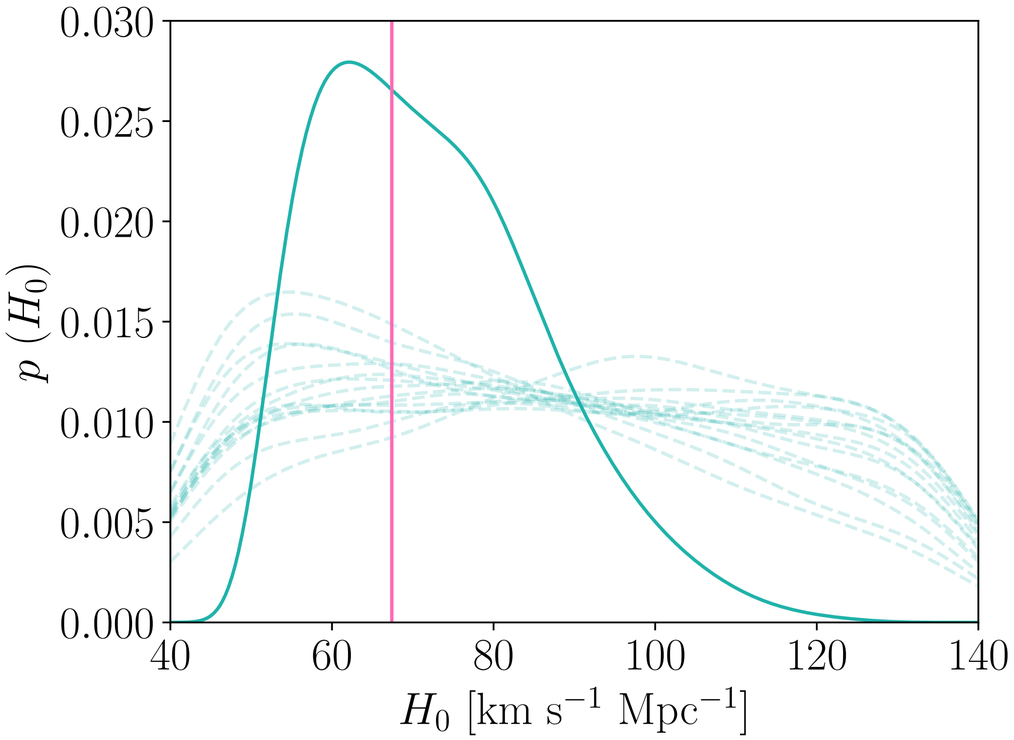
GW170817 tides
(conservative...)



A+/Virgo+ - one year

Abbott+17, 19



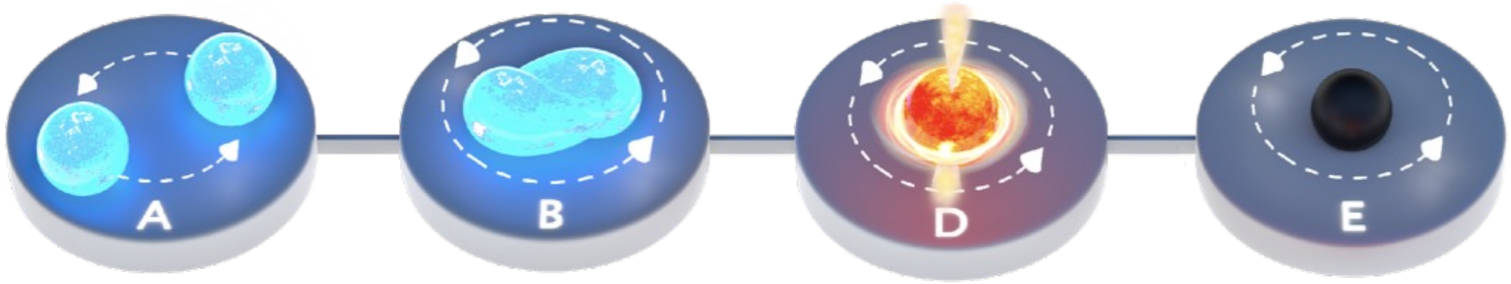


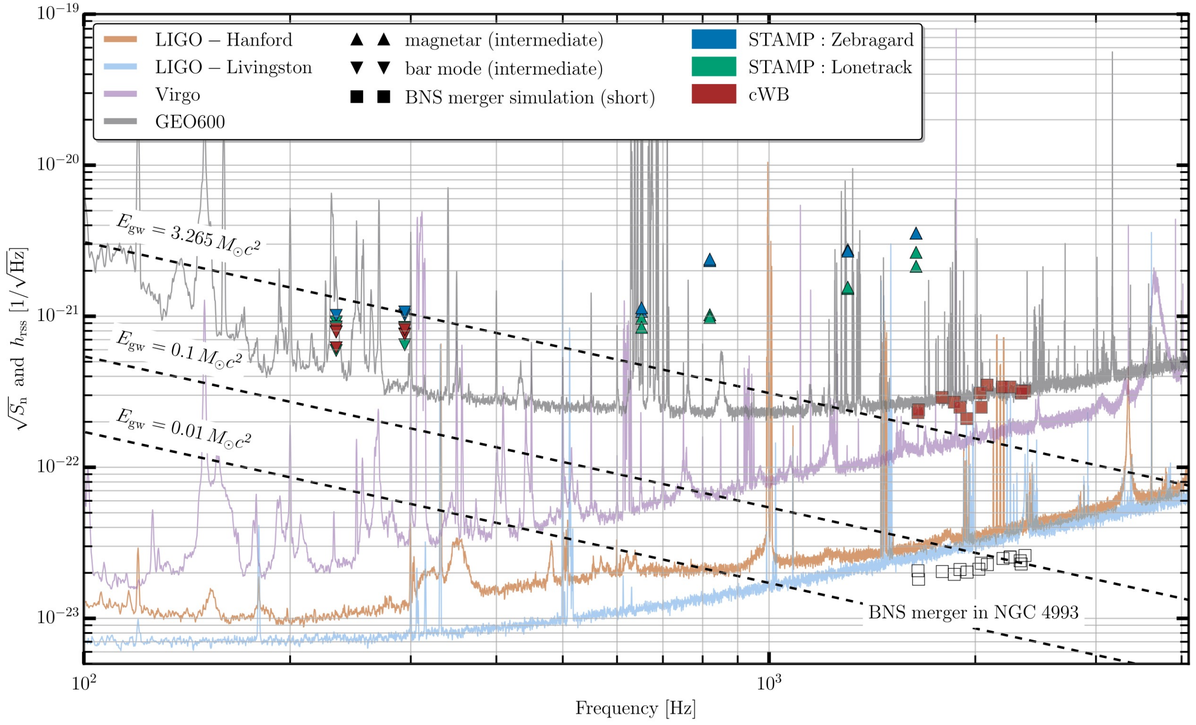
Magnall, Goode, Sarin, PL (in prep.)

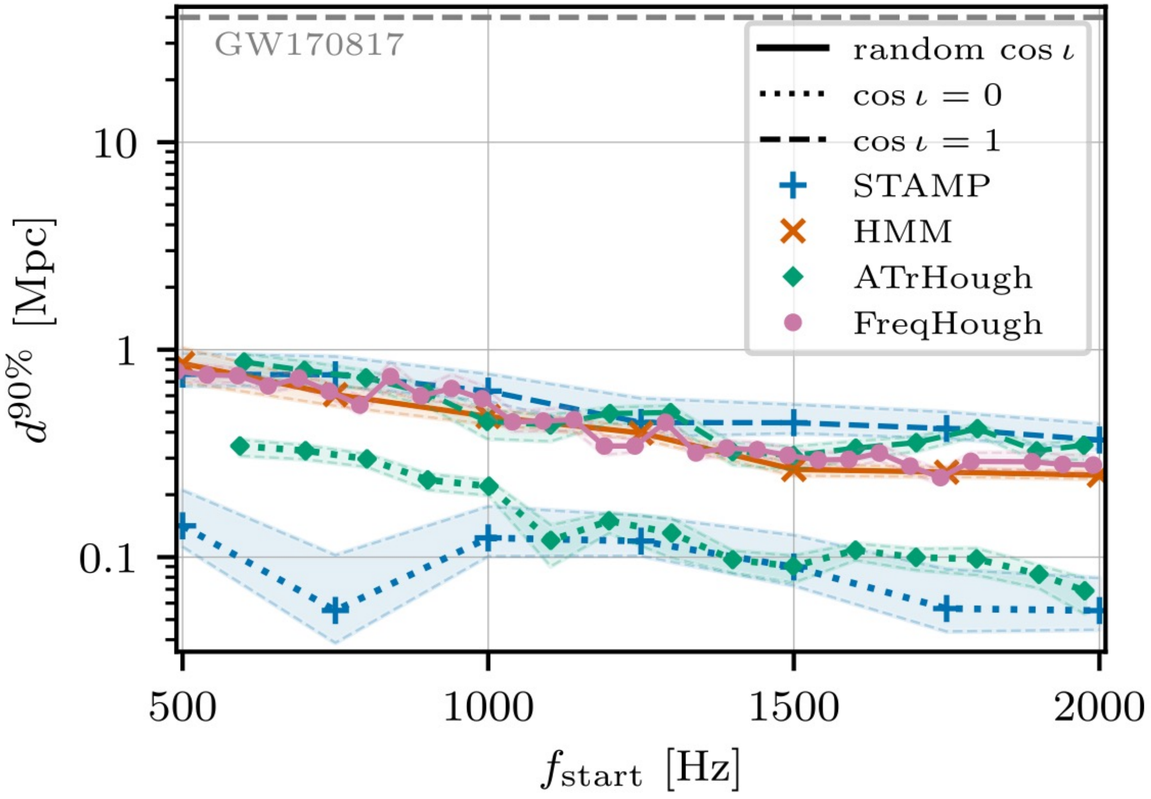
- Full parameter estimation for a ~year of GW observations at A+ and A# sensitivity
- MLA model (uTOV) for solving TOV equations
- Simultaneous EOS and Hubble constant constraints

GW170817: Post Merger

Abbott+17, 19

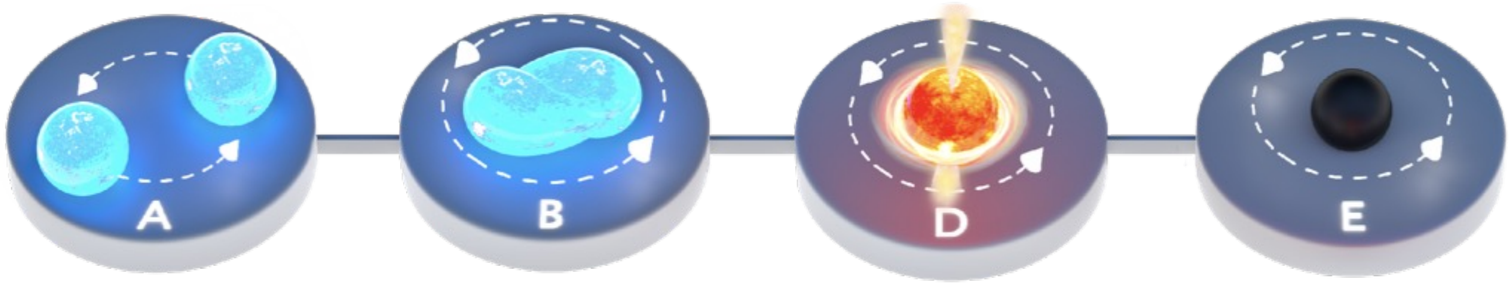


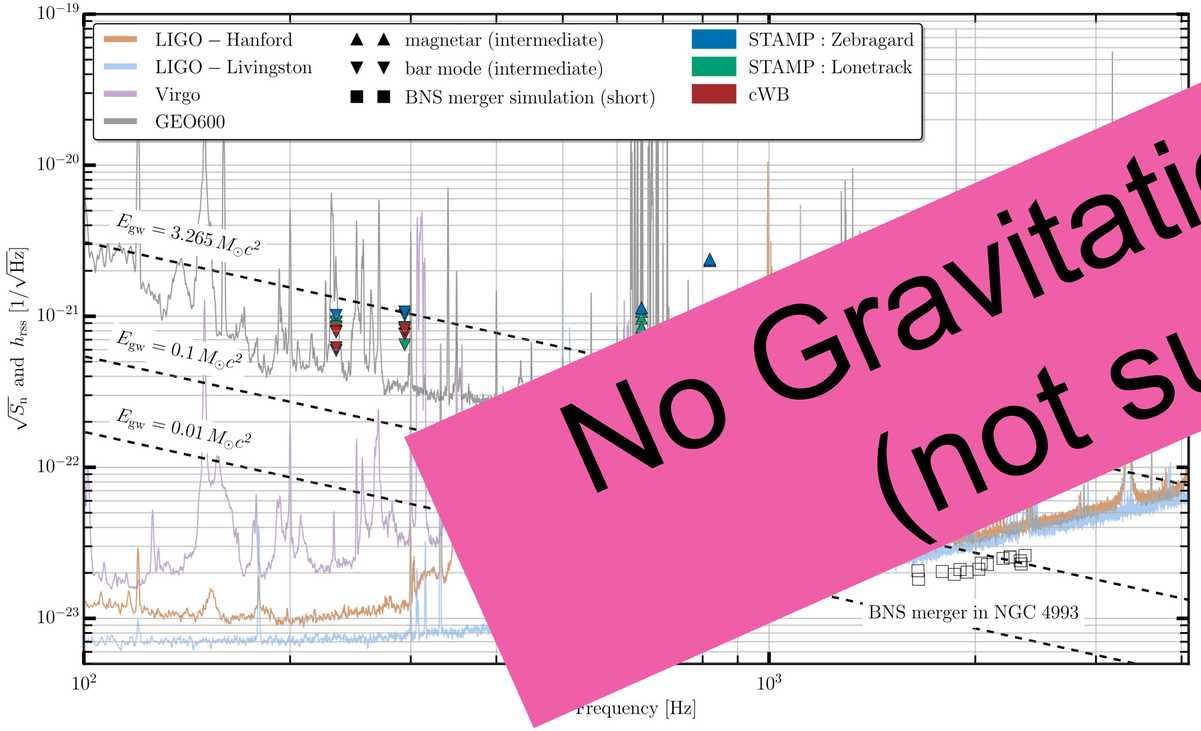




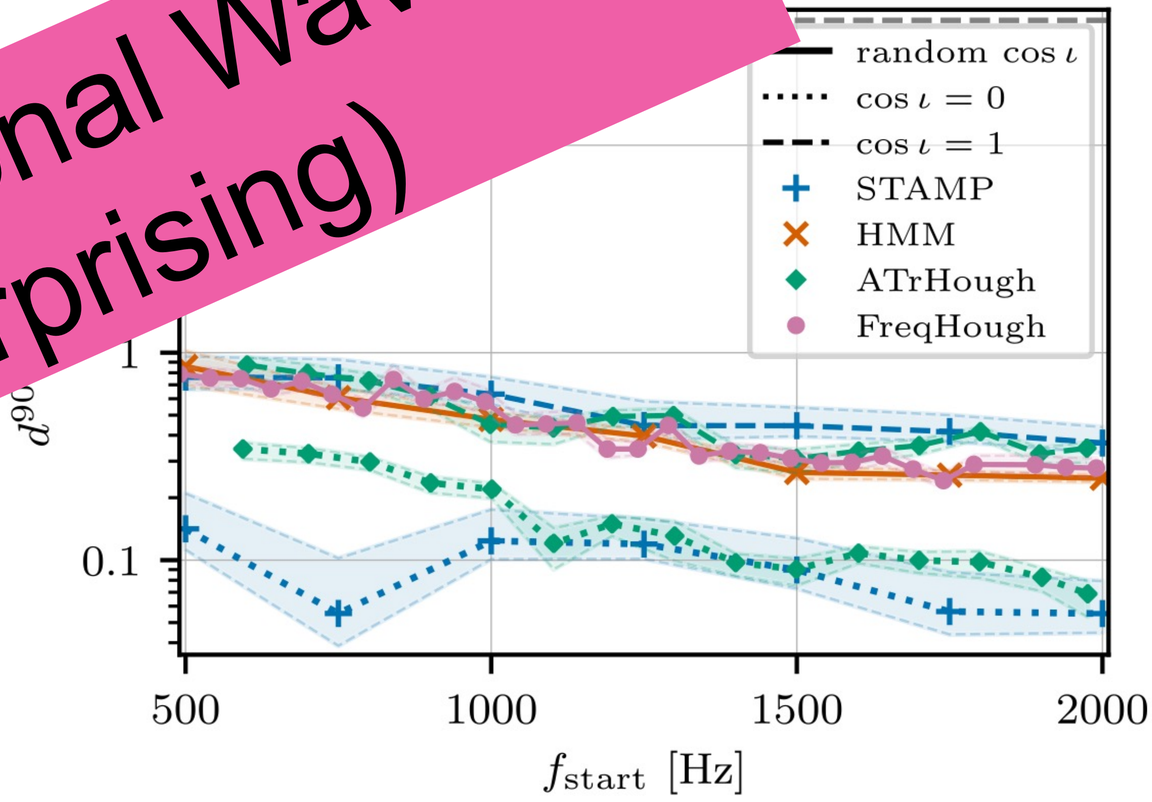
GW170817: Post Merger

Abbott+17, 19

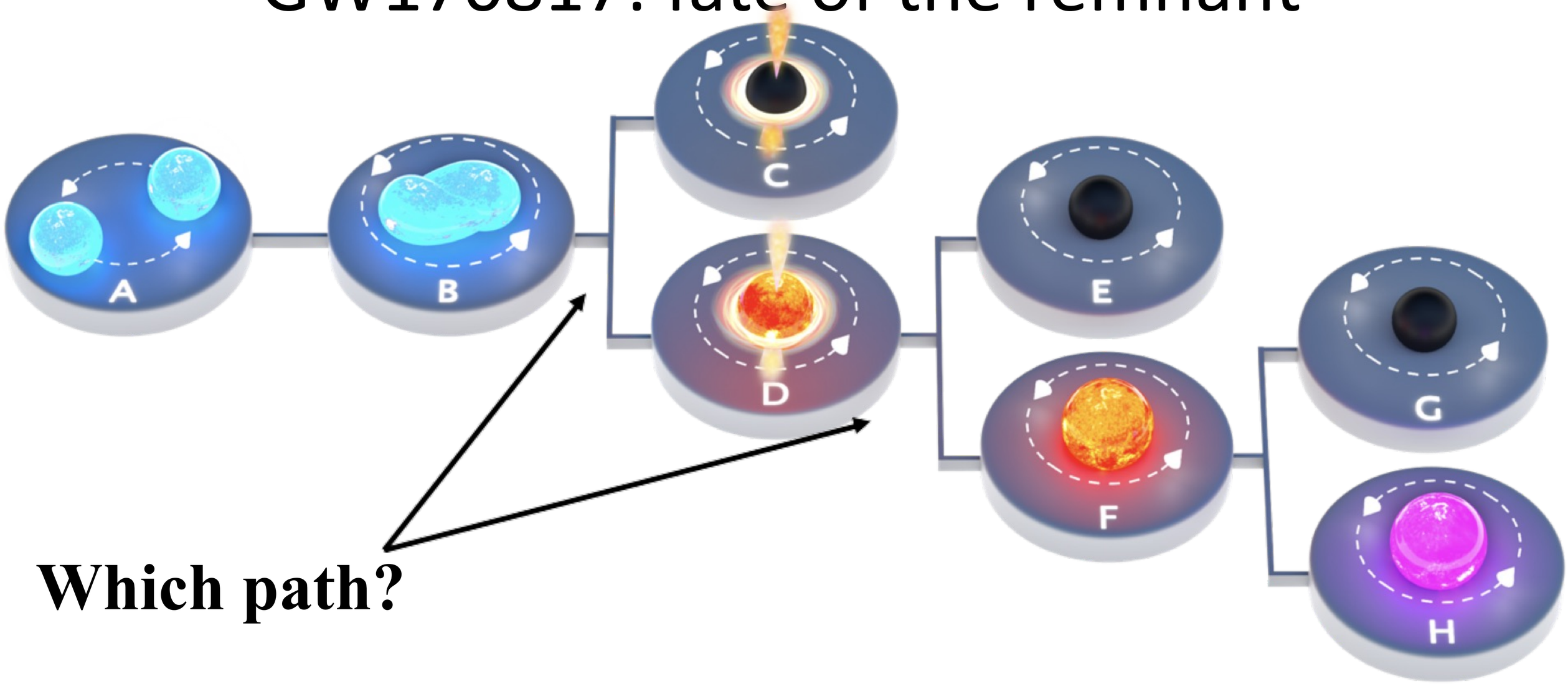




No Gravitational Waves
(not surprising)

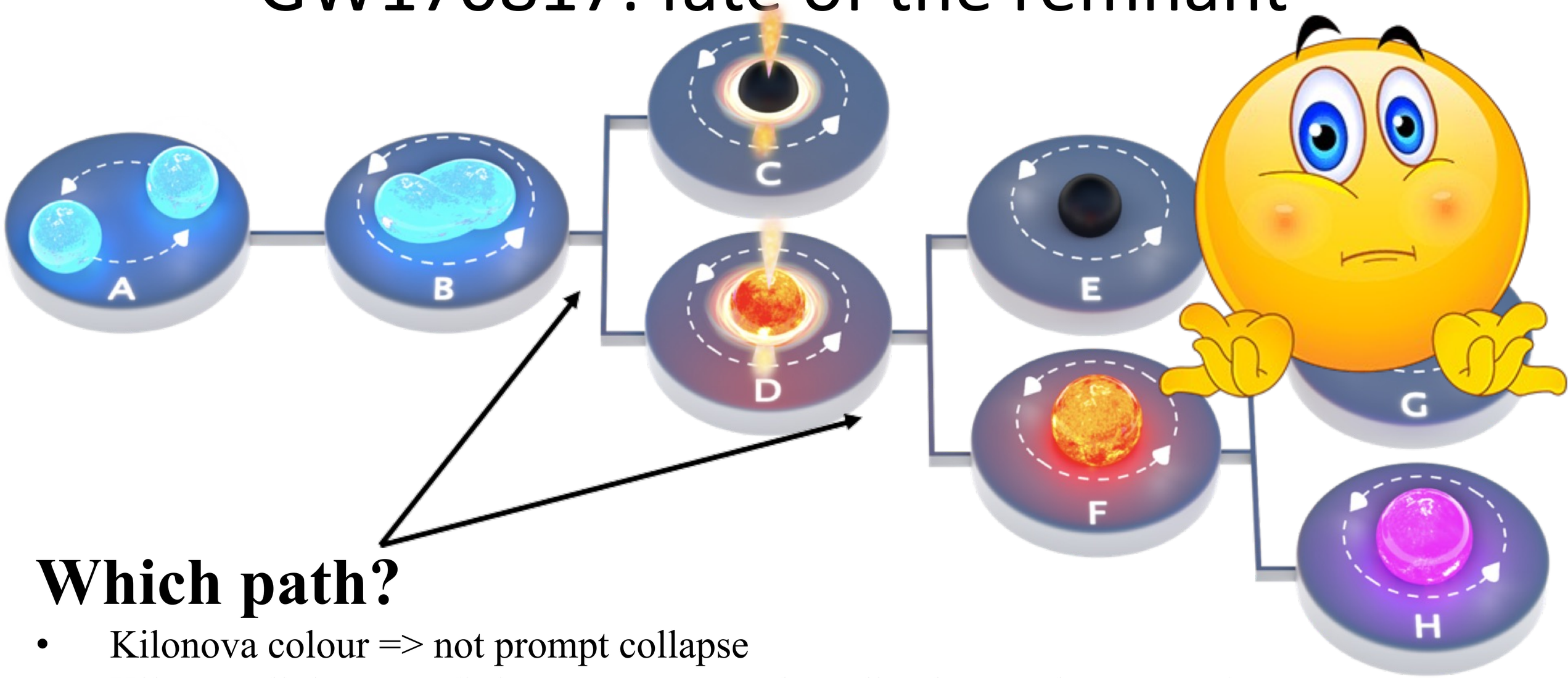


GW170817: fate of the remnant



Which path?

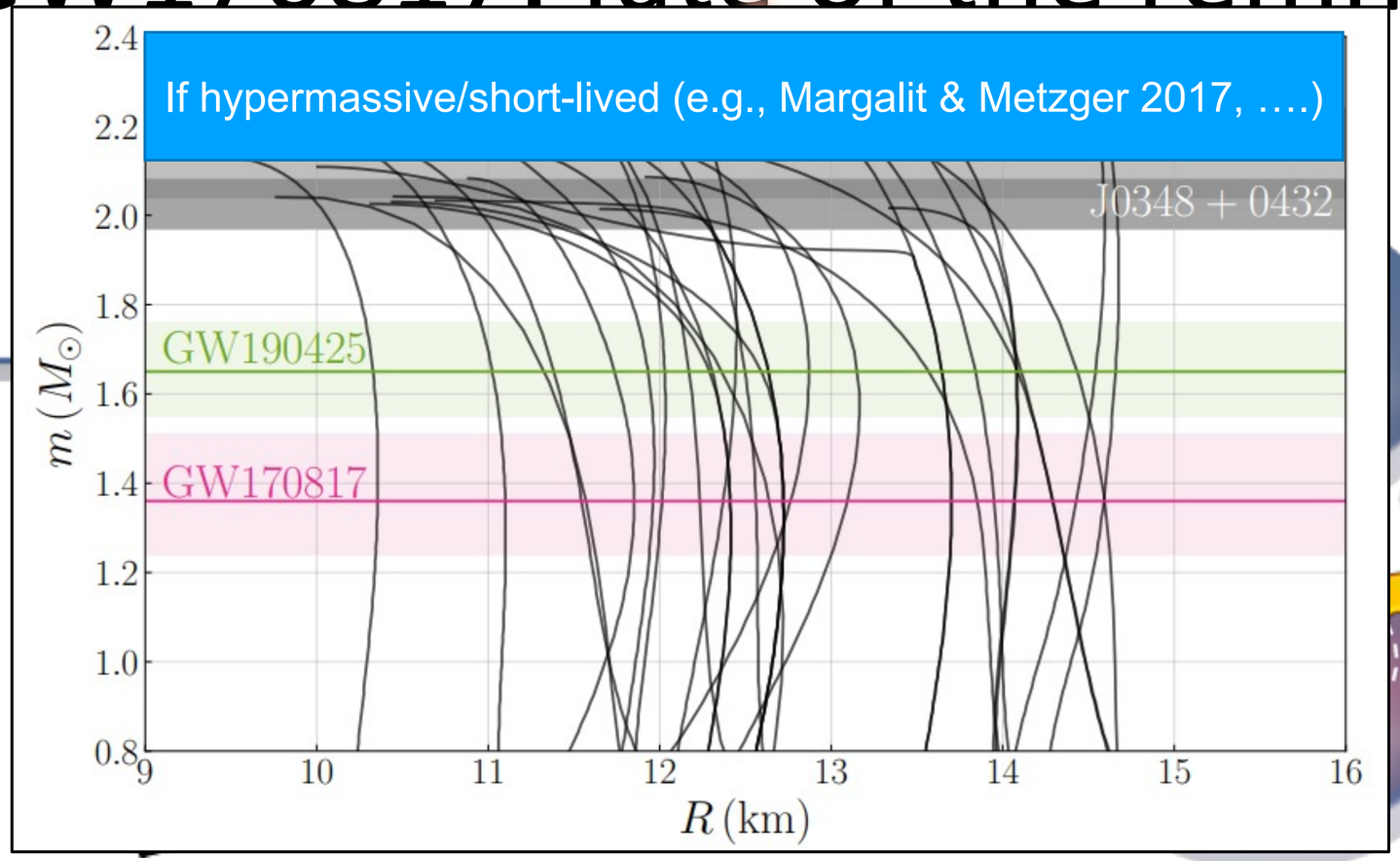
GW170817: fate of the remnant

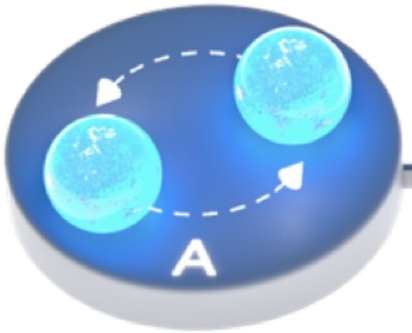


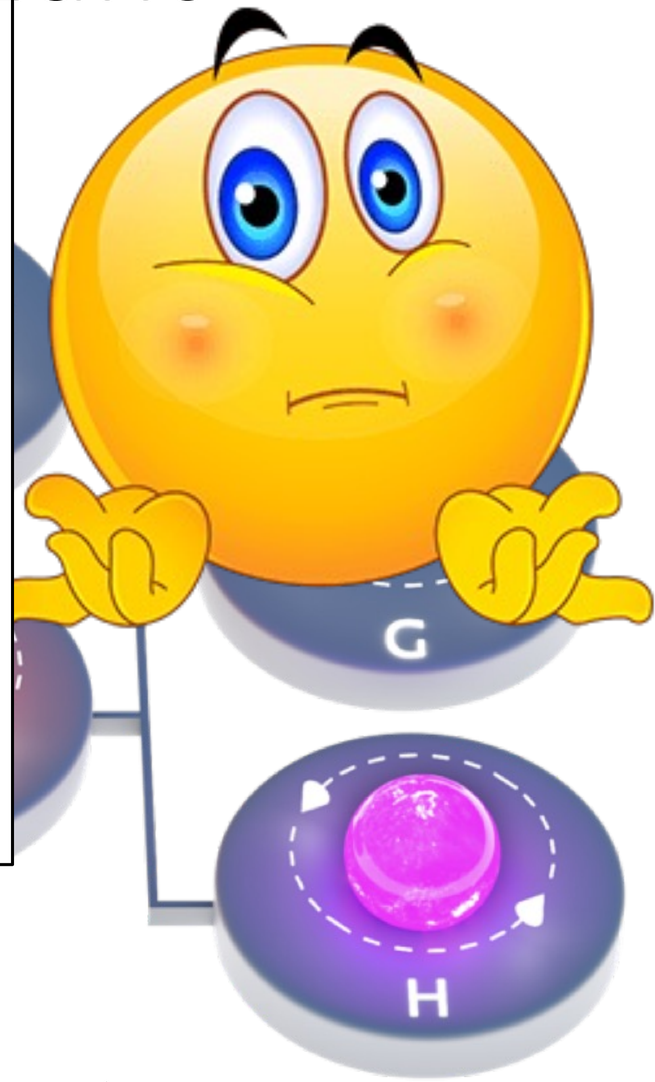
Which path?

- Kilonova colour => not prompt collapse
- Kilonova light curve fitting: some groups long-lived, some hypermassive
- Low x-ray luminosity => hypermassive (??)
- X-ray bump at 160 days => long-lived (??)

GW170817: fate of the remnant





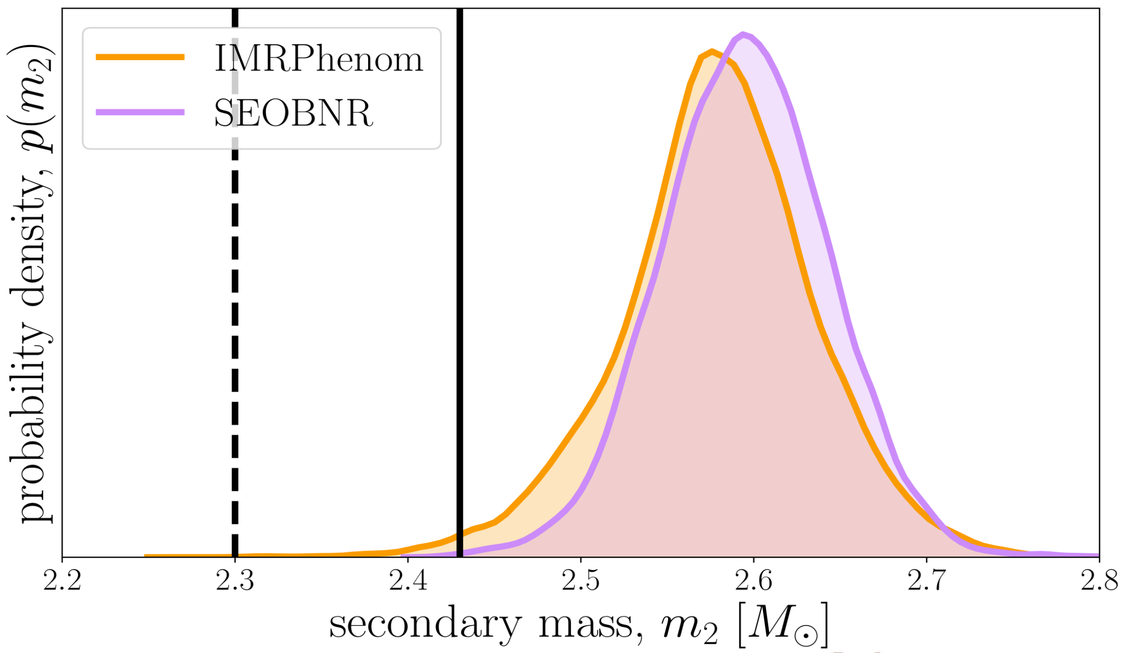


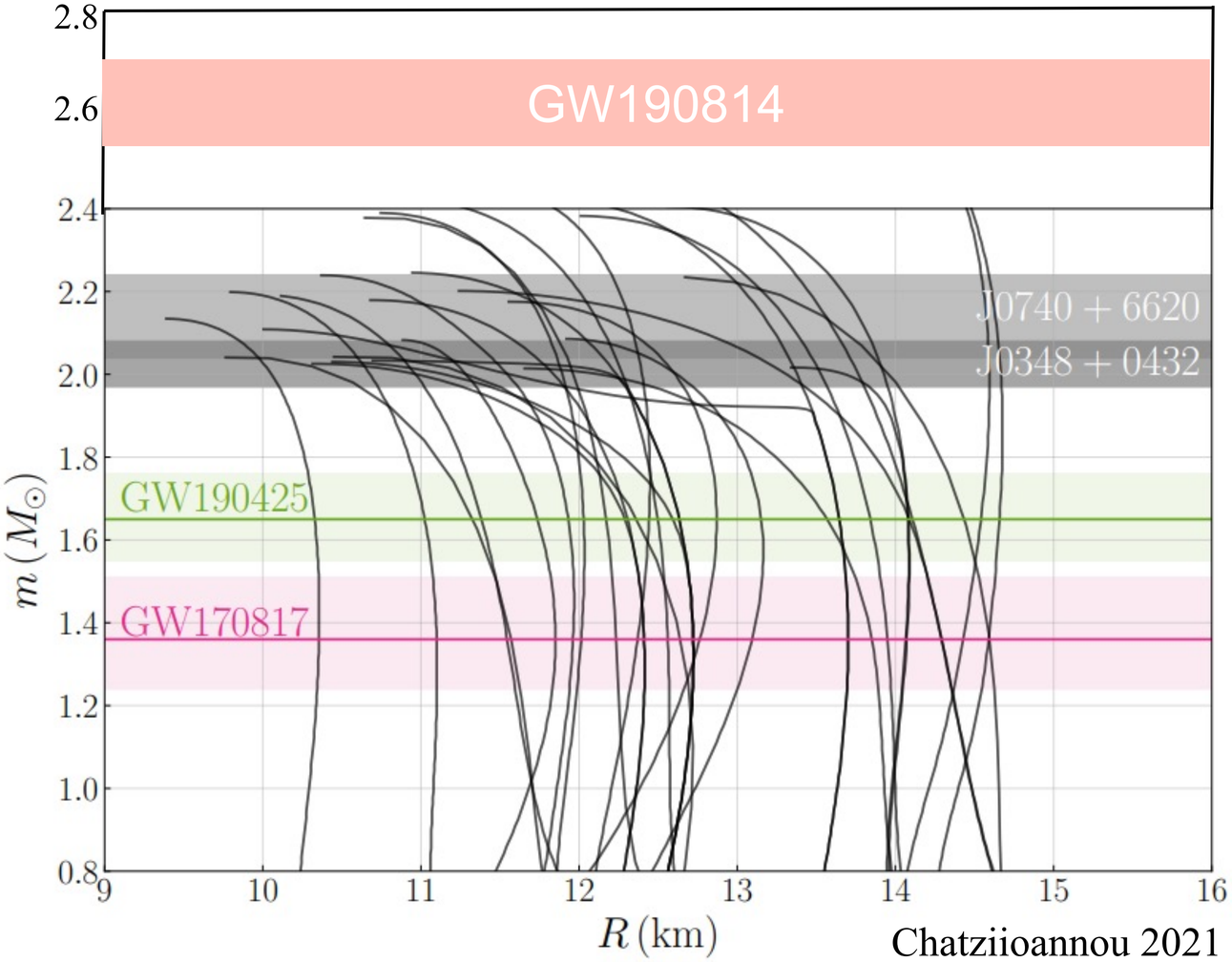
Which path?

- Kilonova colour => not prompt collapse
- Kilonova light curve fitting: some groups long-lived, some hypermassive
- Low x-ray luminosity => hypermassive (??)
- X-ray bump at 160 days => long-lived (??)

GW190814

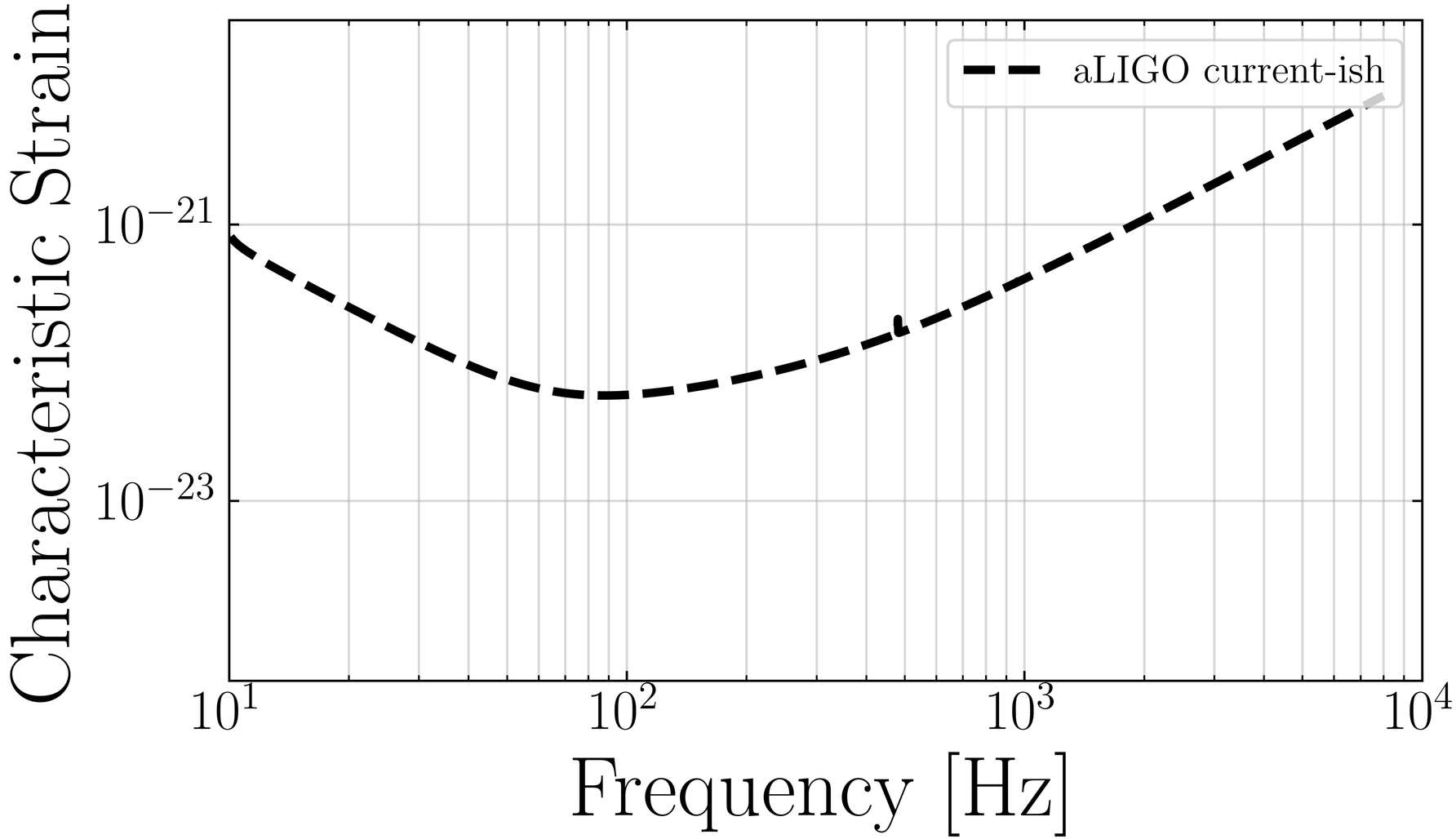
Abbott+20



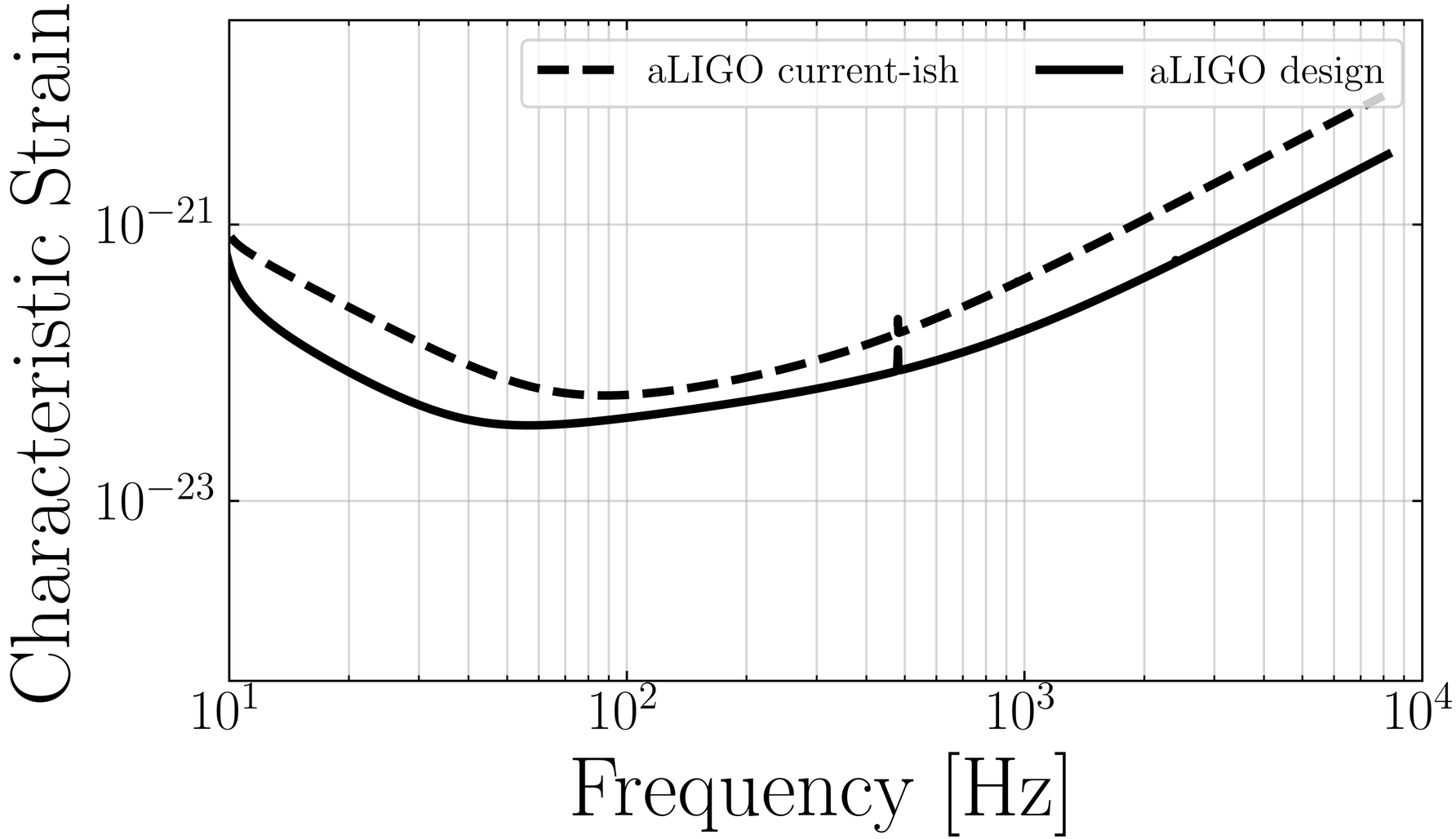


Chatziioannou 2021

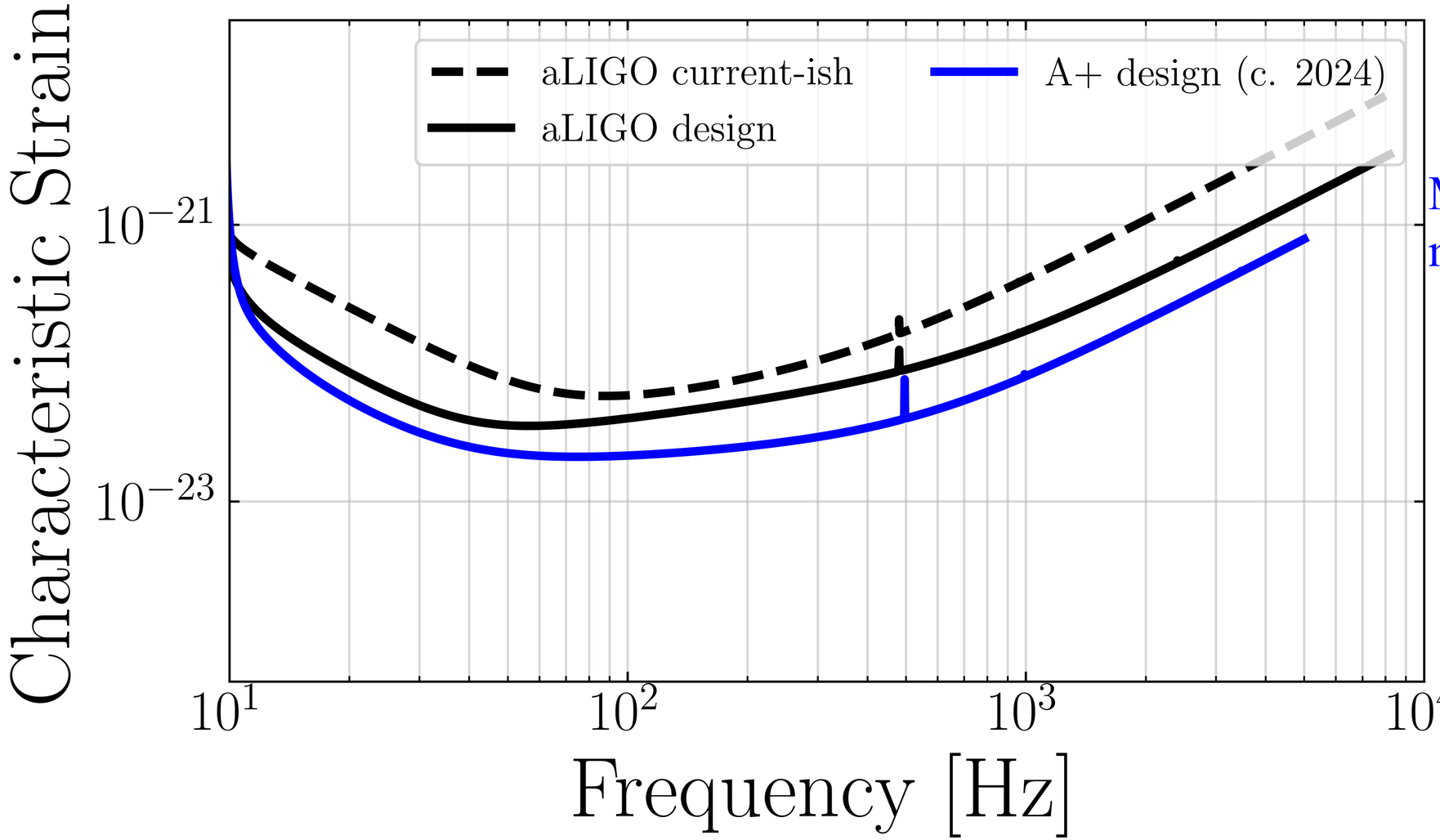
What's next in gravitational-wave astronomy?



What's next in gravitational-wave astronomy?

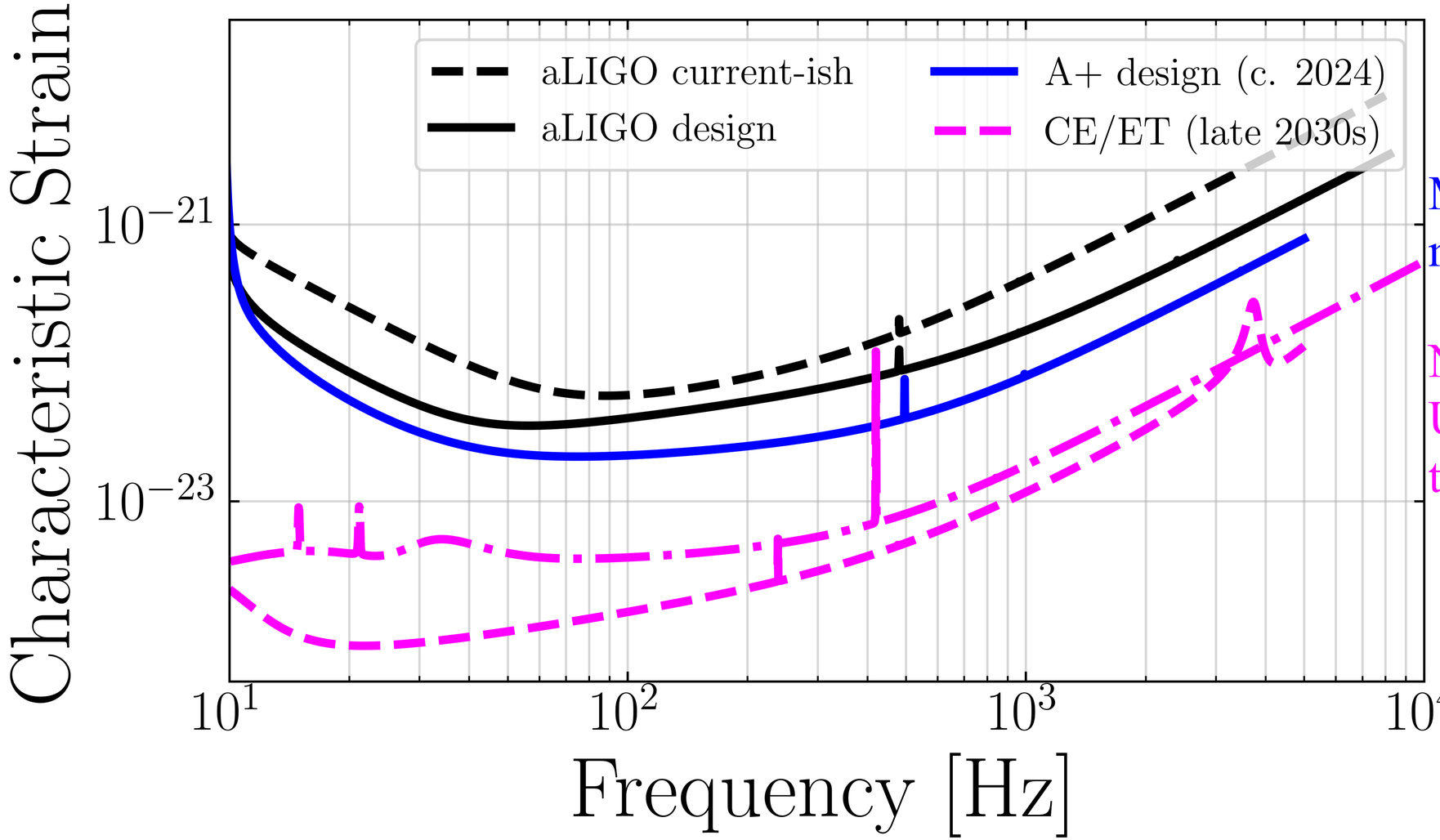


What's next in gravitational-wave astronomy?



Mostly funded,
minimal technology risk

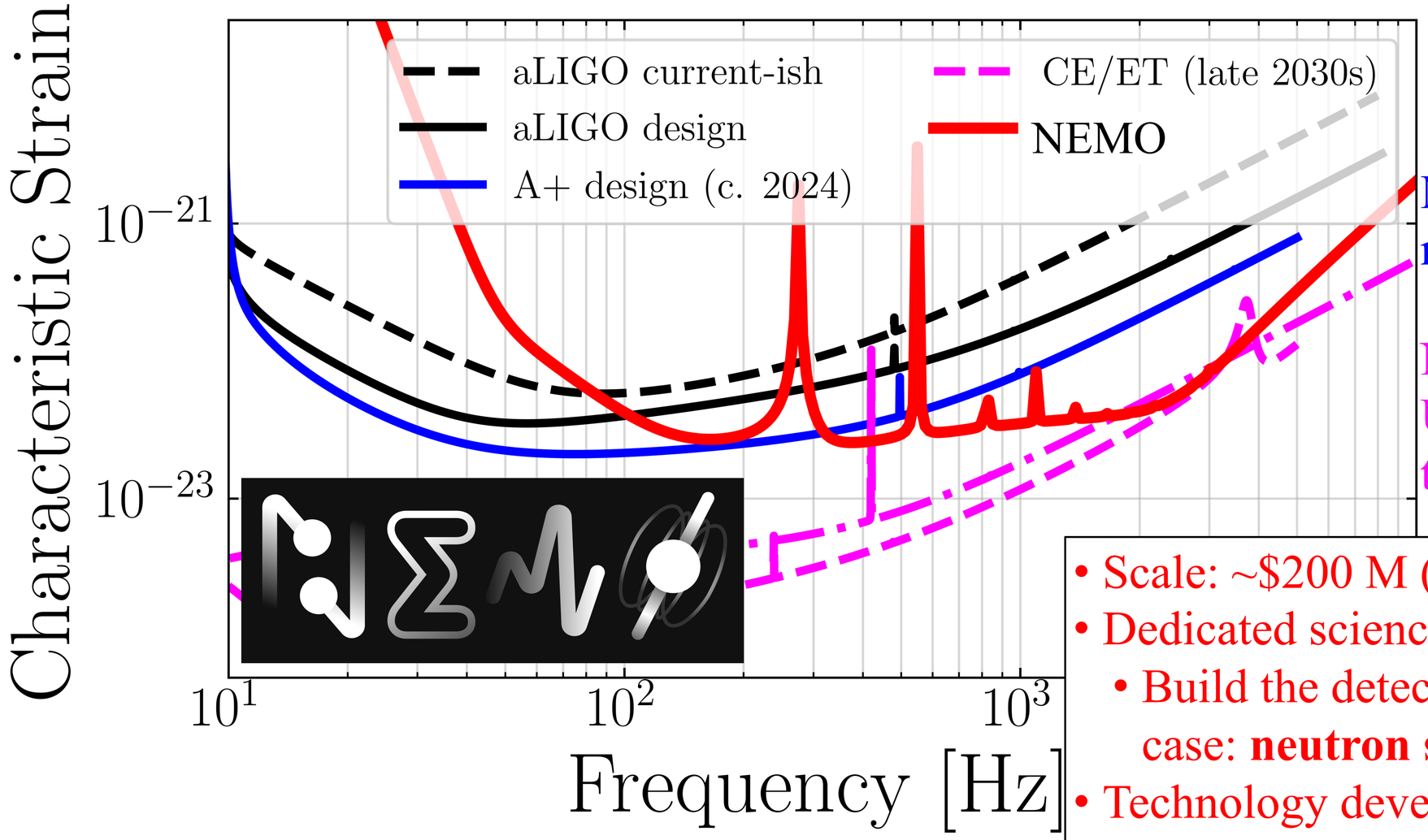
What's next in gravitational-wave astronomy?



Mostly funded, minimal technology risk

Not funded, Unchartered territory in terms of technology

What's next in gravitational-wave astronomy?



Mostly funded, minimal technology risk

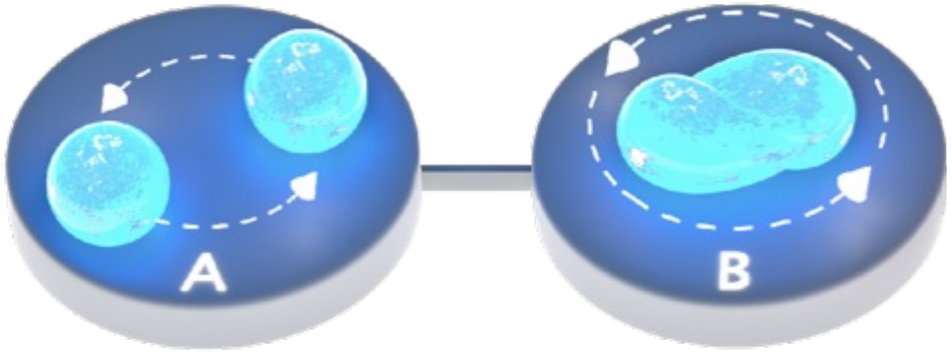
Not funded, Unchartered territory in terms of technology

- Scale: ~$200 M (cf. >>$1B for CE)
- Dedicated science goals:
  - Build the detector around the science case: **neutron stars**
- Technology development for full 3G detectors

Ackley et al. (2020)

NEMO: tidal deformability

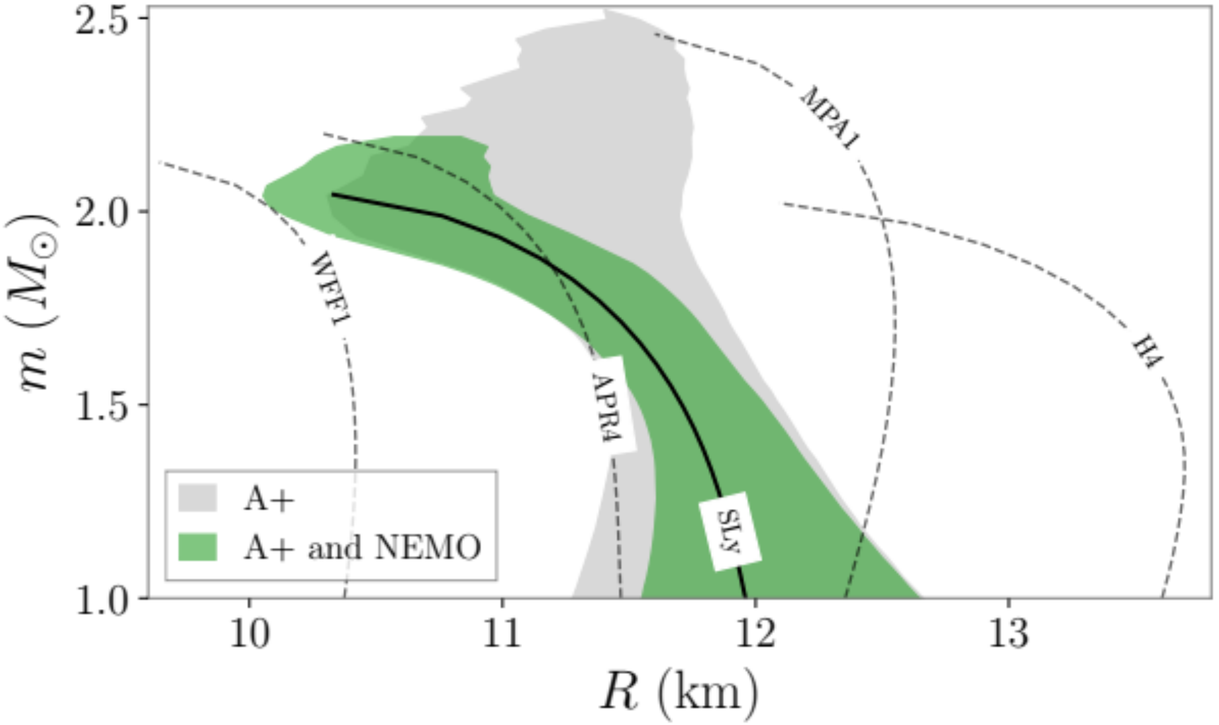
Ackley+20



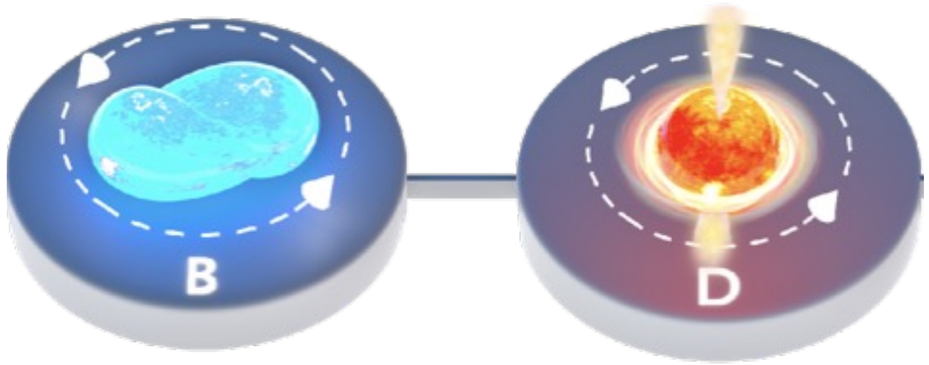
BNS rates

- 2 x A+: 44 BNS with SNR > 20
- 2 x A+ + NEMO: 61 BNS with SNR > 20

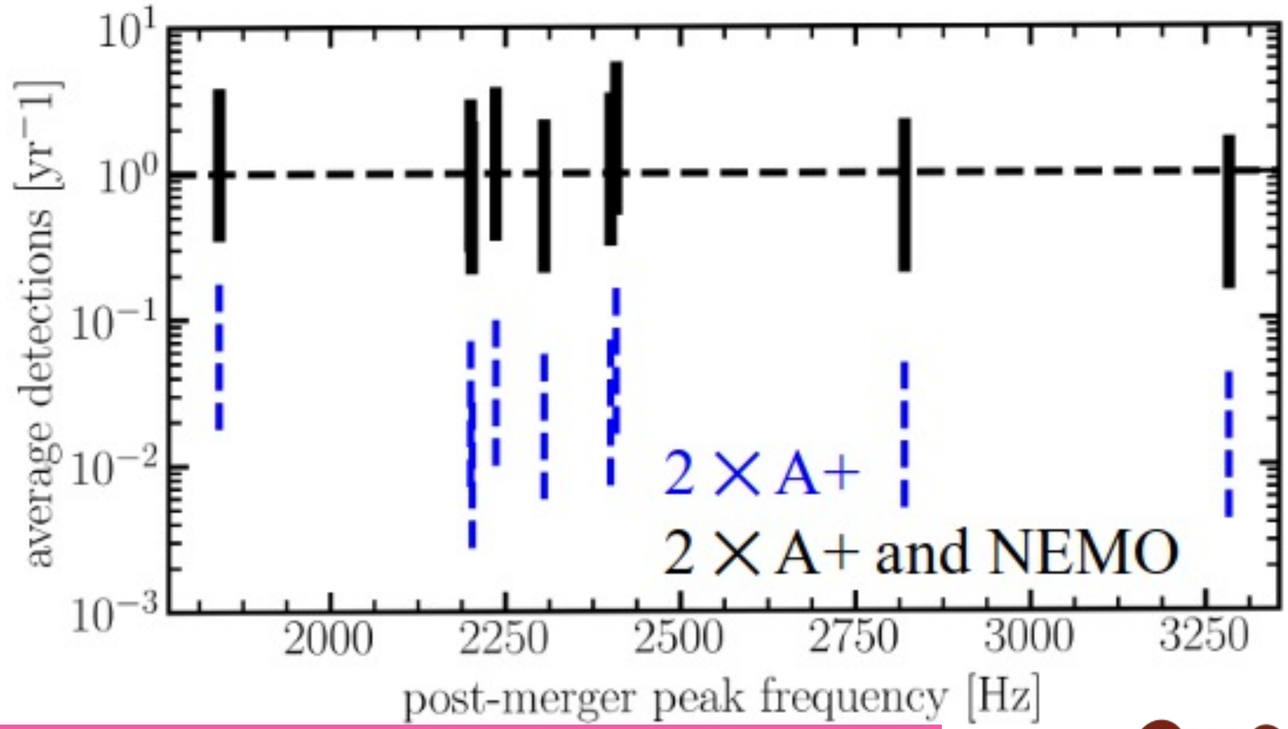
Marginal improvement on EOS

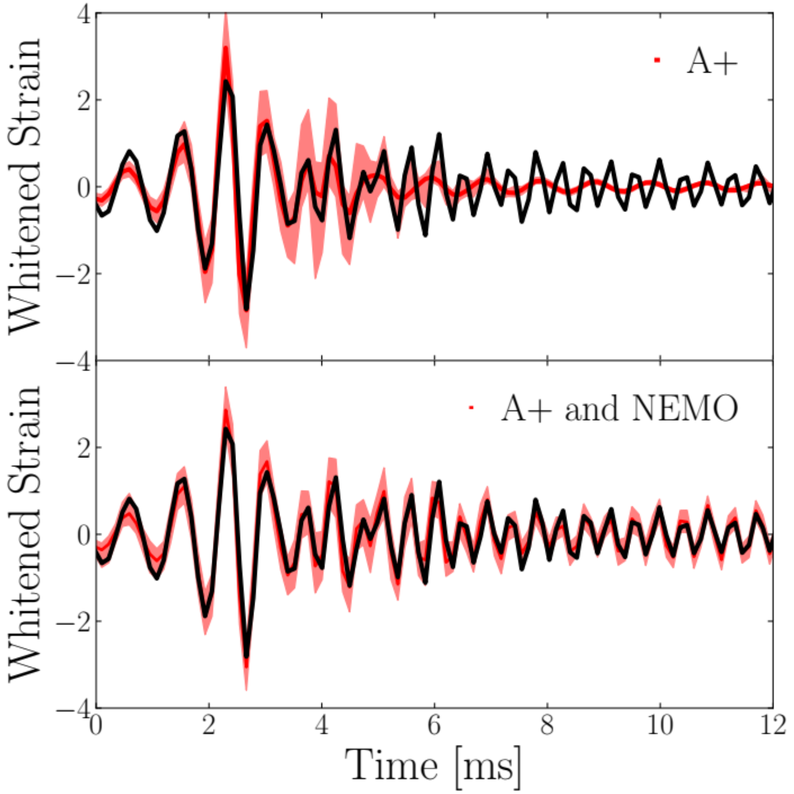


: post-merger

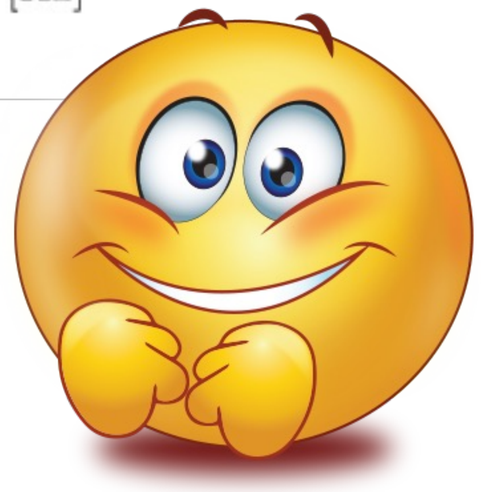


Ackley+20

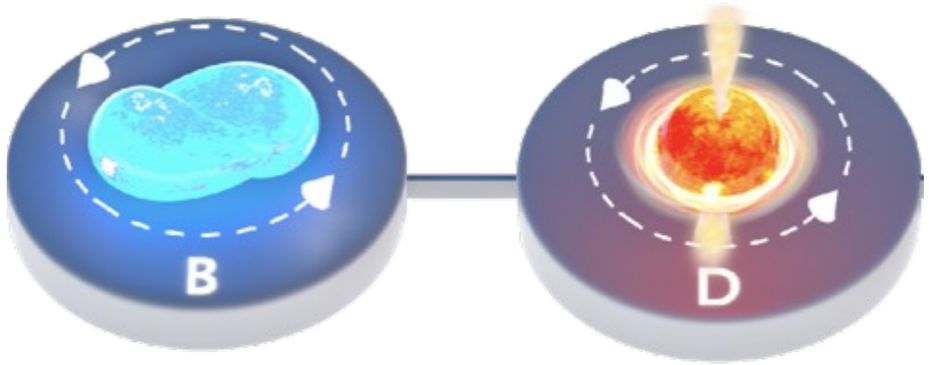




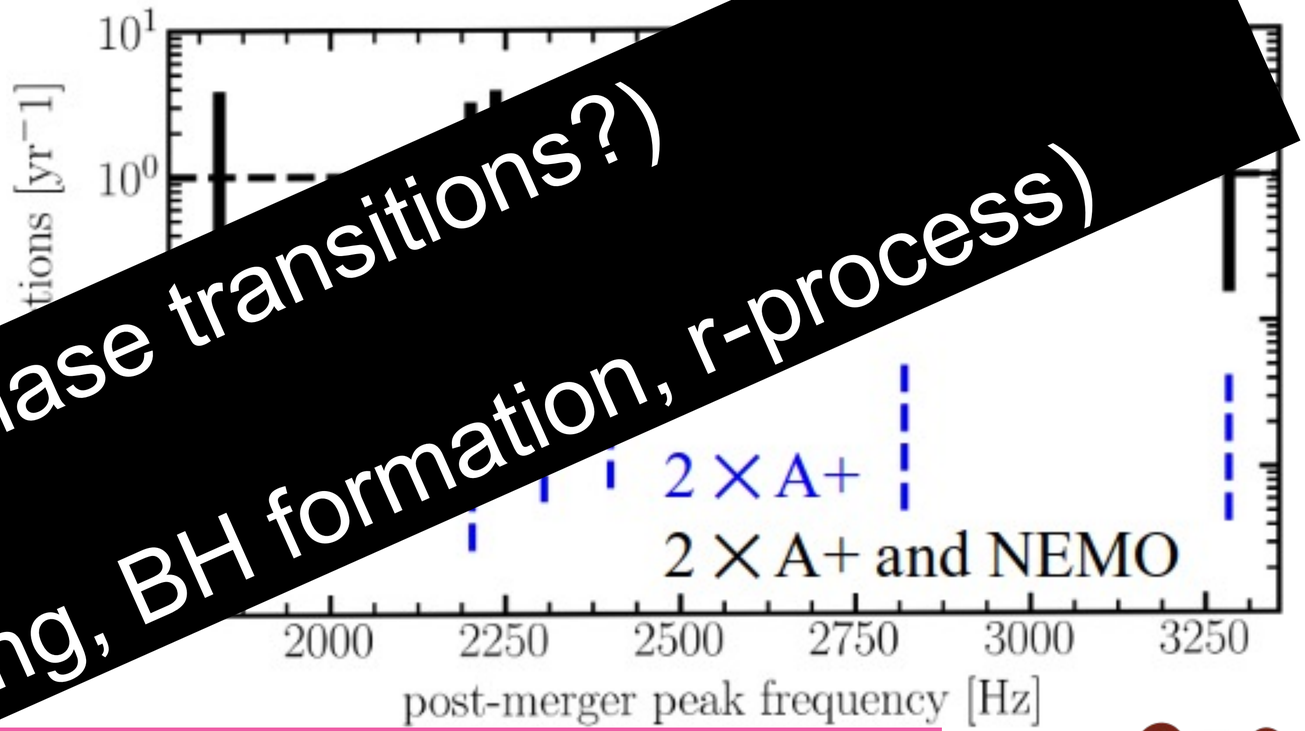
Potential first post-merger! First hot EOS measurement!

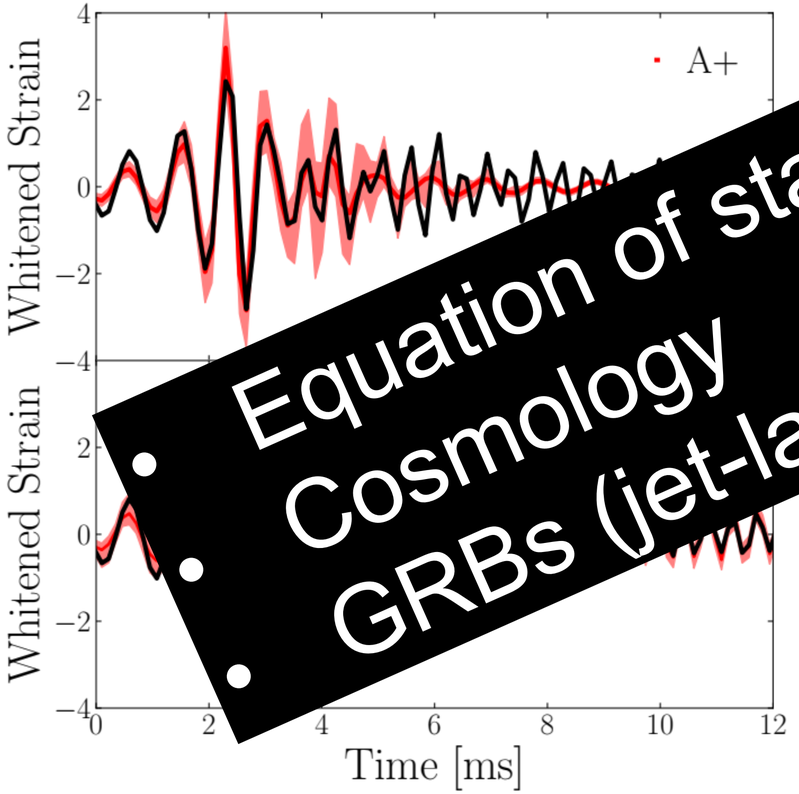


: post-merger



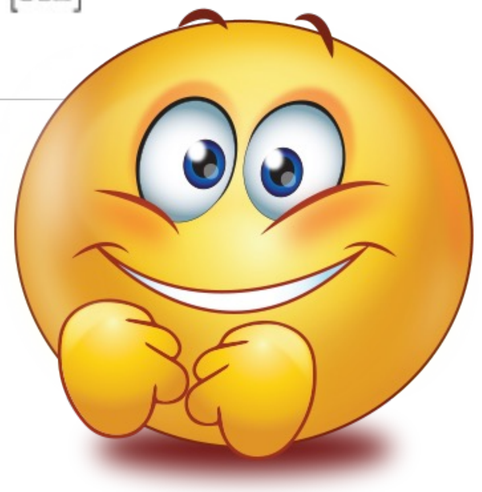
Ackley+20





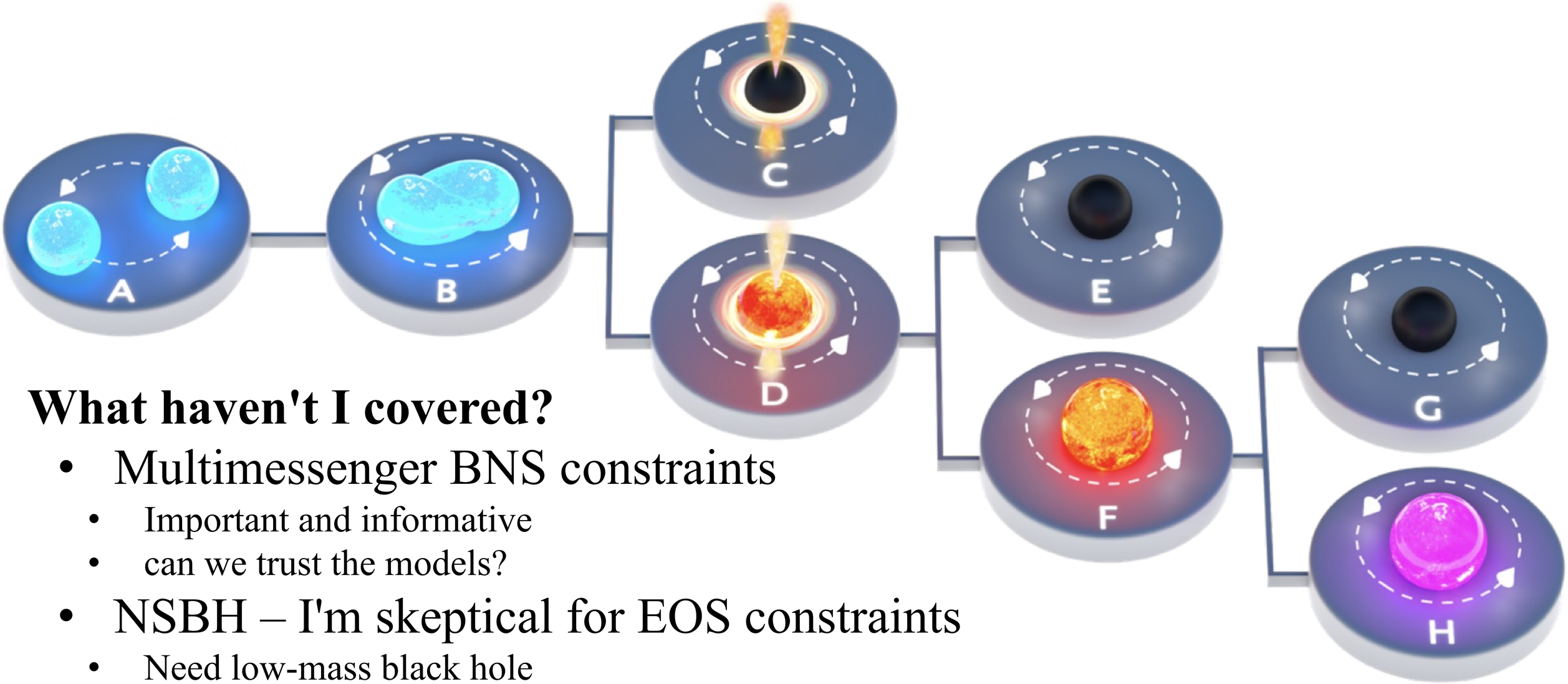
- Equation of state (phase transitions?)
- Cosmology
- GRBs (jet-launching, BH formation, r-process)

Potential first post-merger! First hot EOS measurement!



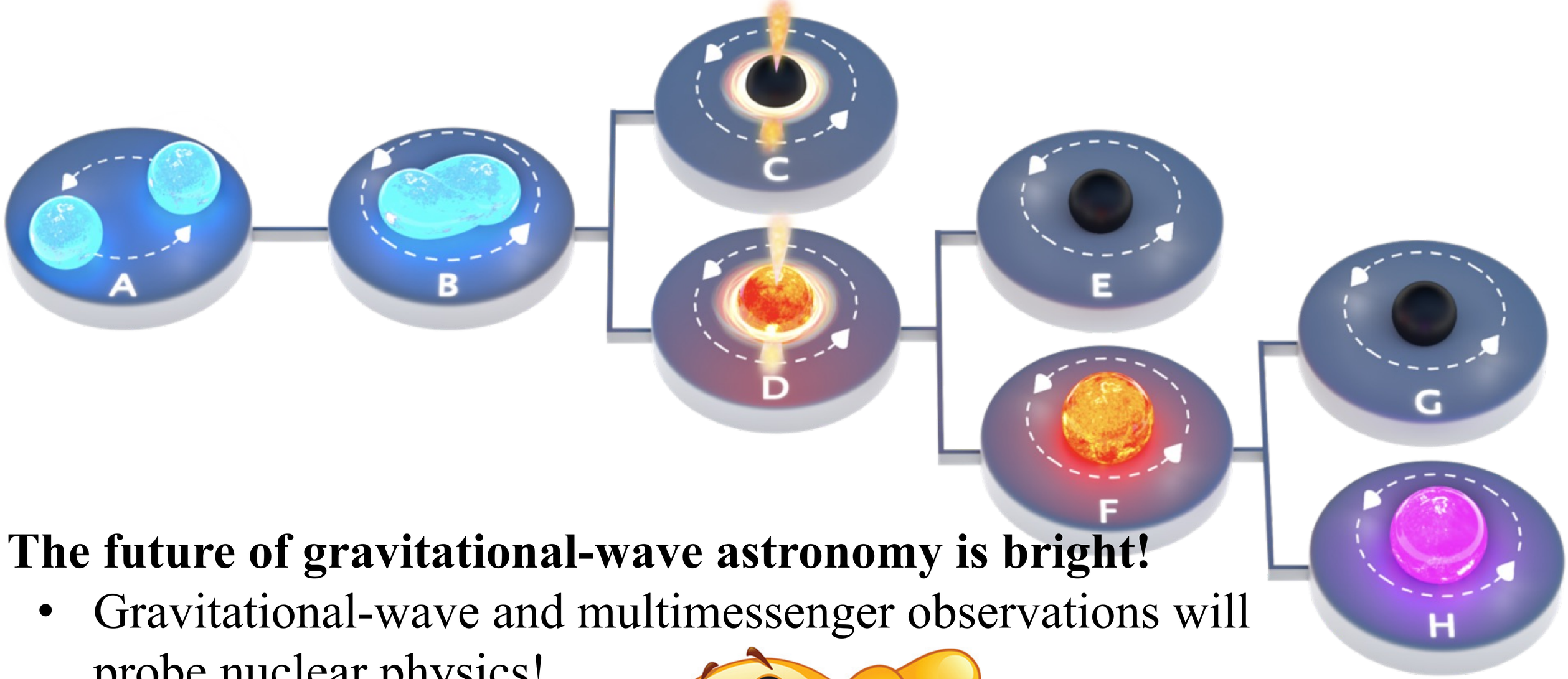
Science Case

- Binary neutron star mergers
- Supernovae
- Continuous Waves
- Burst sources
- Exotica



What haven't I covered?

- Multimessenger BNS constraints
  - Important and informative
  - can we trust the models?
- NSBH – I'm skeptical for EOS constraints
  - Need low-mass black hole
  - Disruption? Not good for EOS
- Supernovae, continuous waves, ...



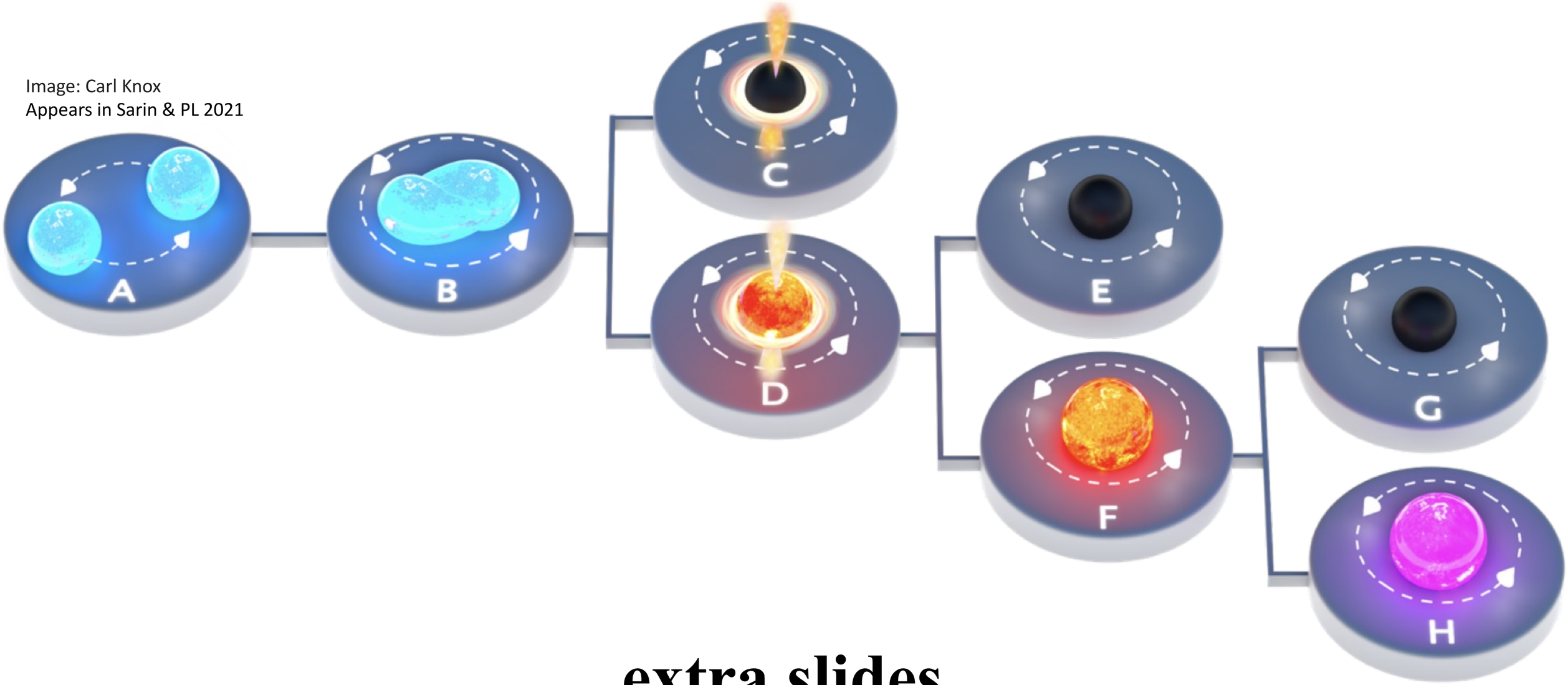
The future of gravitational-wave astronomy is bright!

- Gravitational-wave and multimessenger observations will probe nuclear physics!
- We need support from you

MONASH University

OzGrav

Image: Carl Knox
Appears in Sarin & PL 2021



extra slides

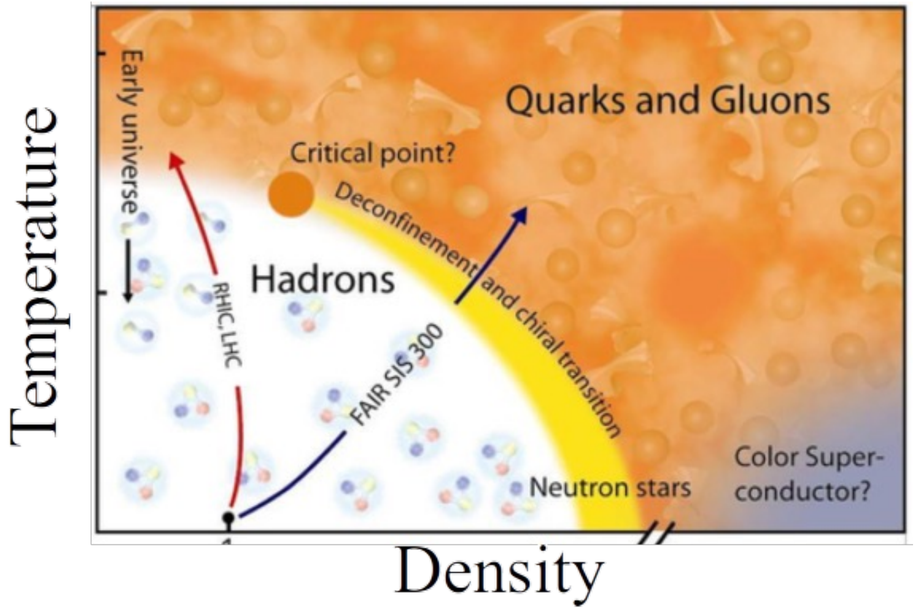
MONASH University

OzGrav

Science Case

Binary neutron star mergers:

- Inspiral (cold equation of state, populations, cosmology, …) -- *easy*
- Post-merger (detectability, hot equation of state, jet-launching, …) -- *harder*
- Multimessenger (don't require network (Sarin & PL 22!) -- *relatively easy*



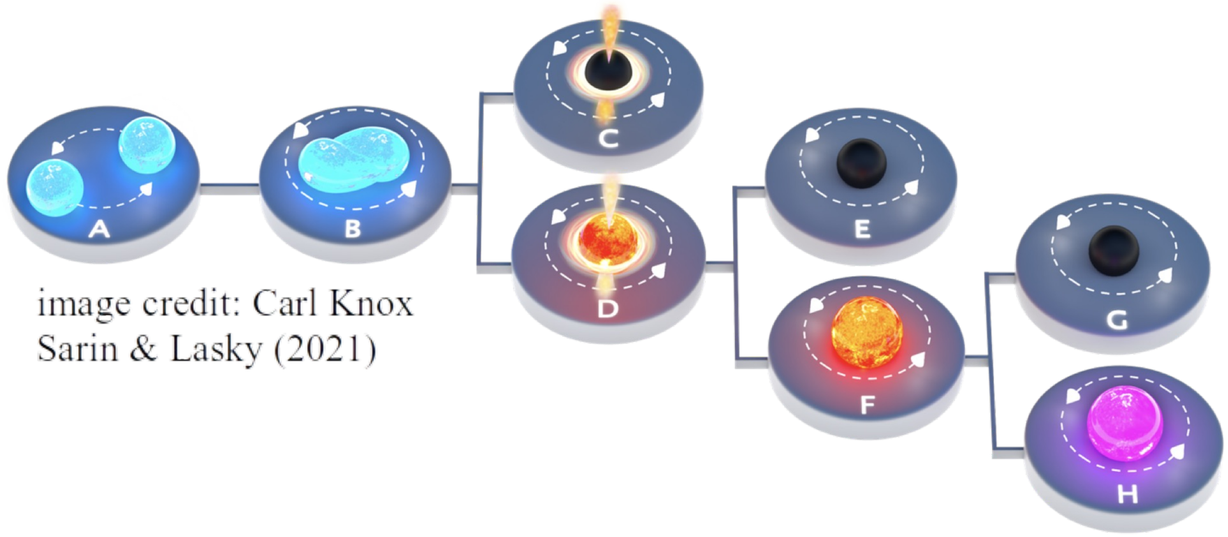
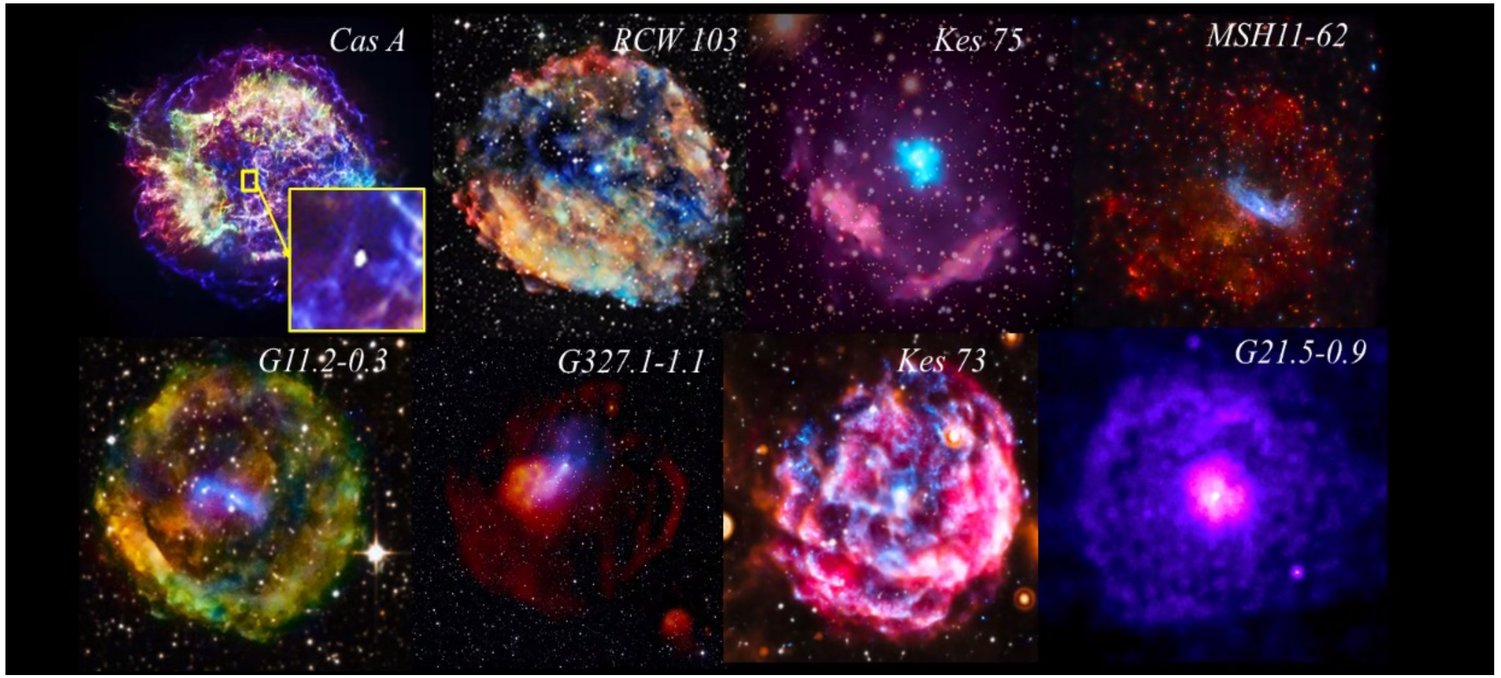


image credit: Carl Knox
Sarin & Lasky (2021)

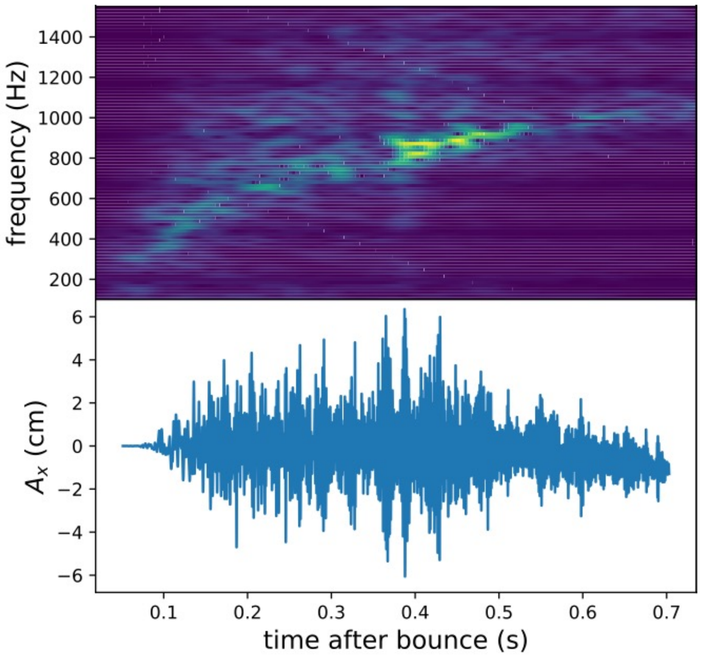
Science Case

Binary neutron star mergers
Supernovae



Stolen from Katie Auchettl!

Powell & Mueller (2019)



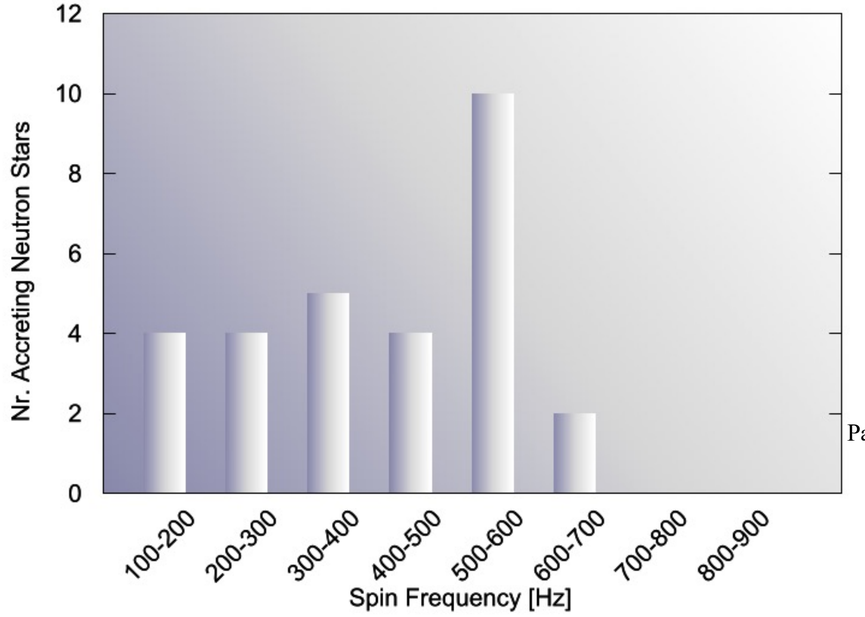
Science Case

Binary neutron star mergers

Supernovae

Continuous Waves

- How elliptical are millisecond pulsars? ¯_(ツ)_/¯
- Is torque balance a thing?
- Etc...



Patruno+2017

Science Case

Binary neutron star mergers

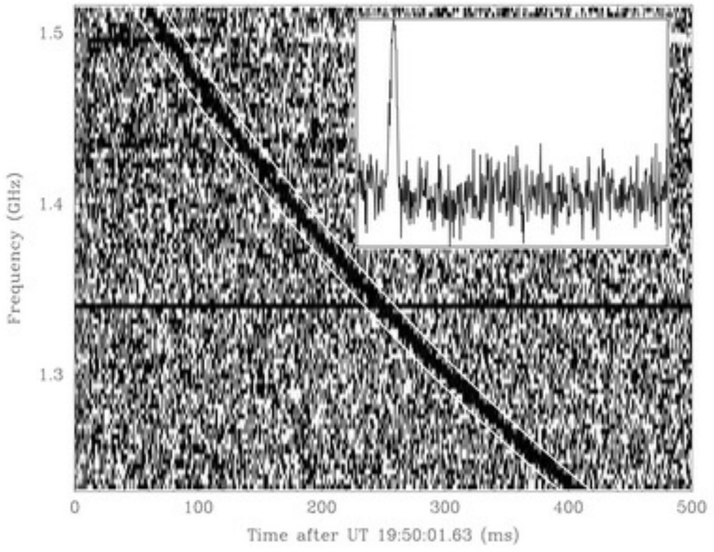
Supernovae

Continuous Waves

Other burst sources

- Magnetar flares (kHz, unknown amplitude)
- Fast radio burst progenitors
- Neutron star glitch recovery
- ….

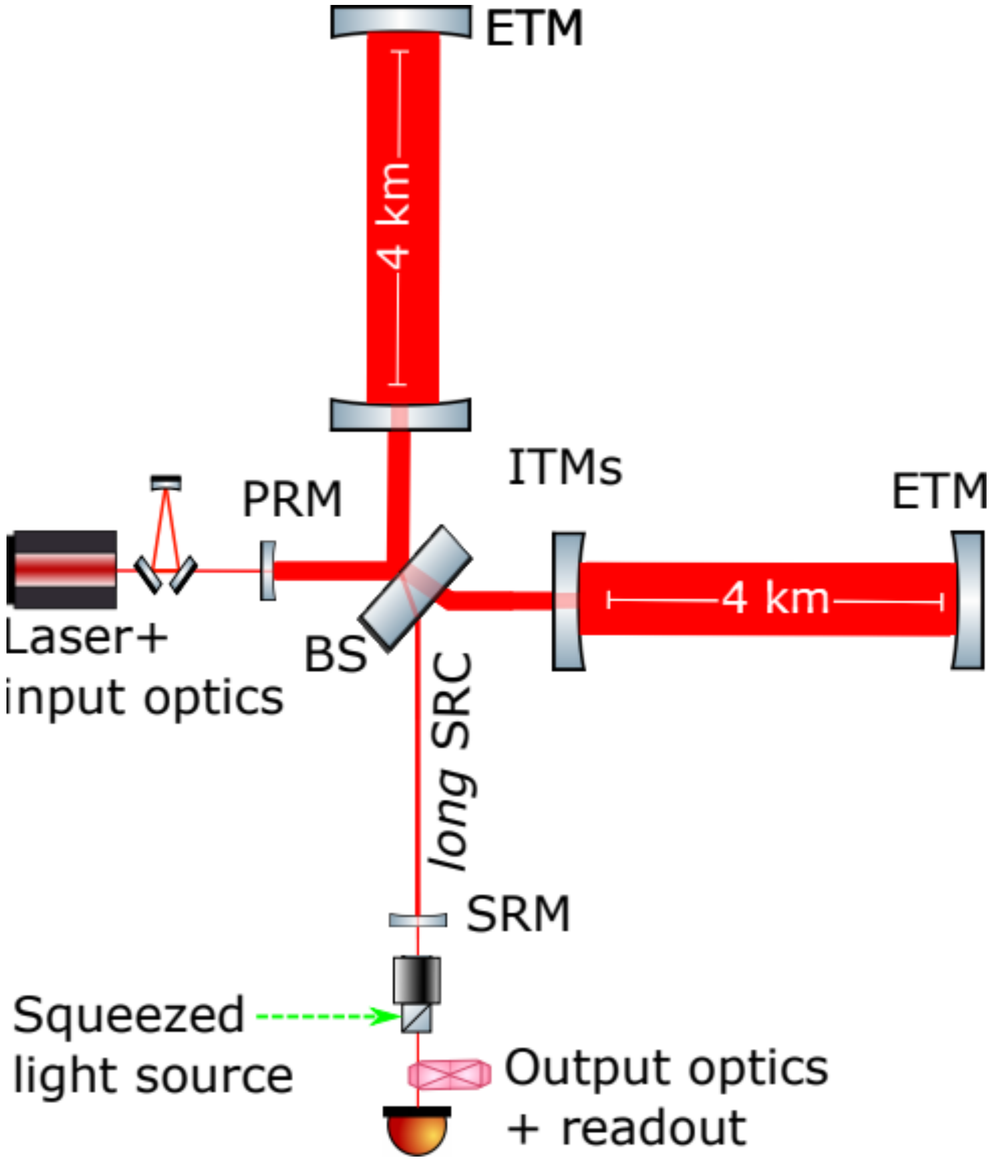
NASA



astronomy.swin.edu.au

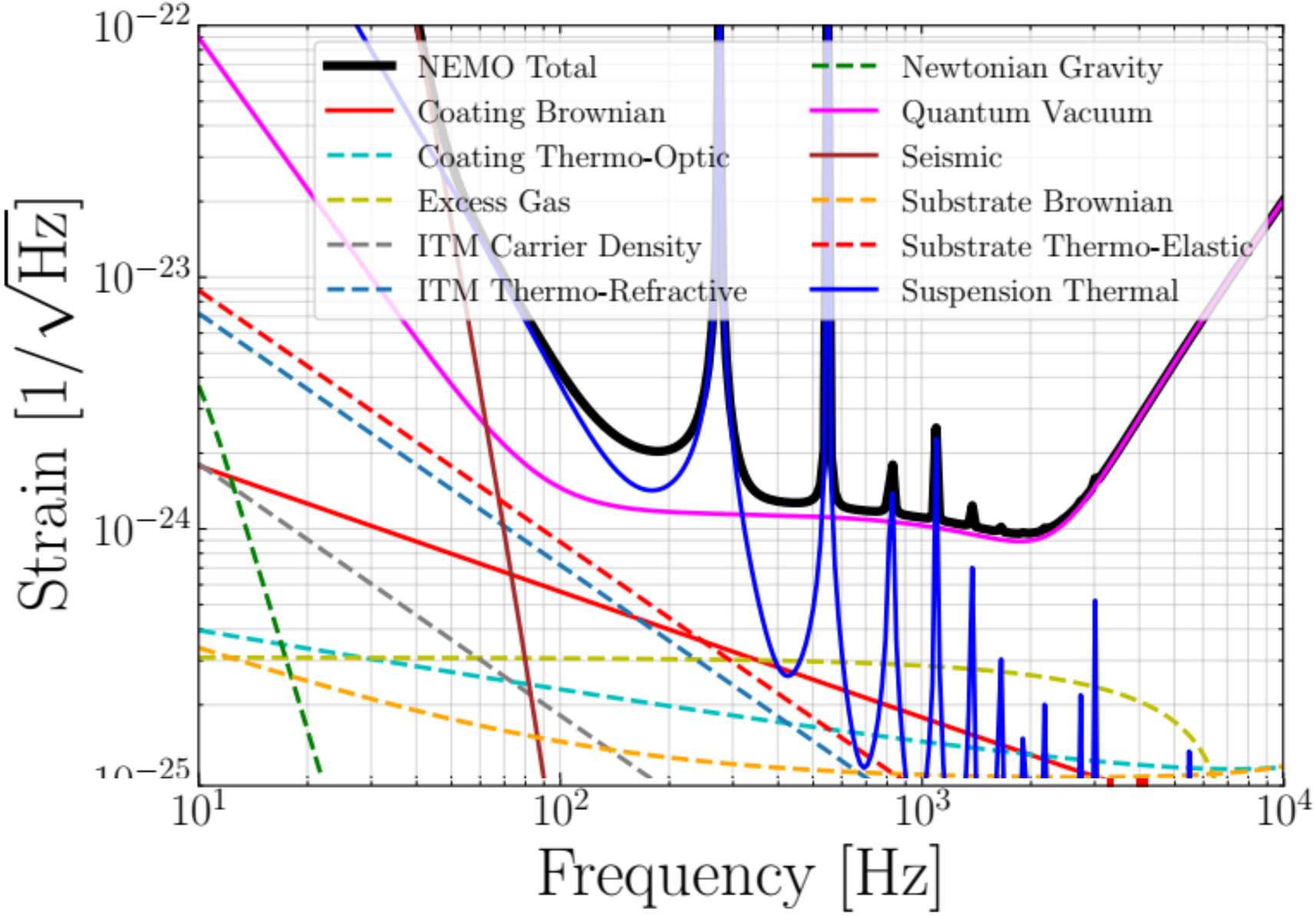
NEMO: preliminary design

- 4km arms
- 74 kg Silicon test masses
- Cooling: 123K
- 2 micron wavelength
- 500 W input power
- 4.5 MW in arms
- 7 dB Squeezing
- Suspension: steel
- **Neglect low frequency isolation**



Ackley et al. (2020)

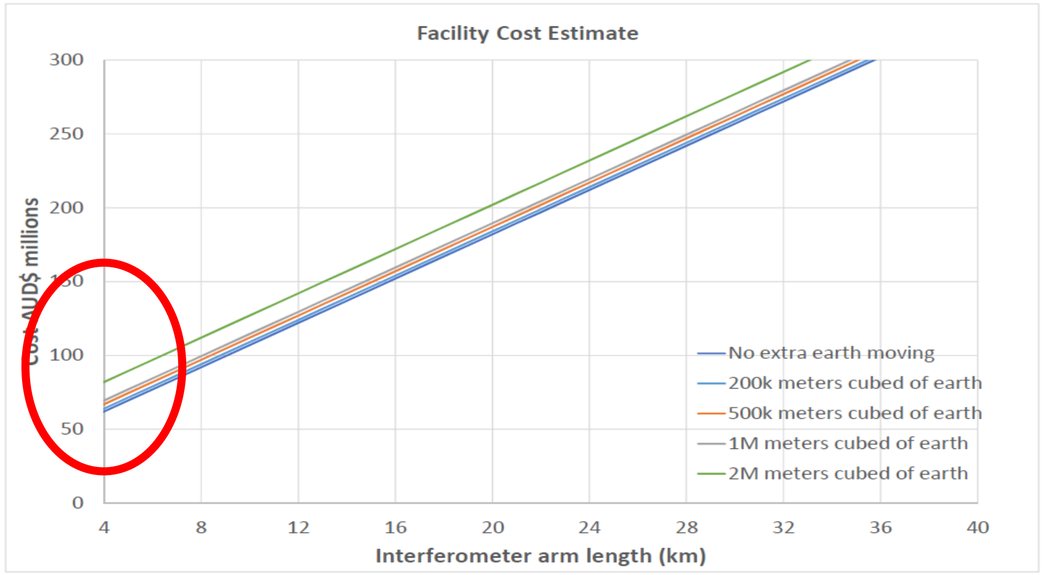
NEMO: preliminary design

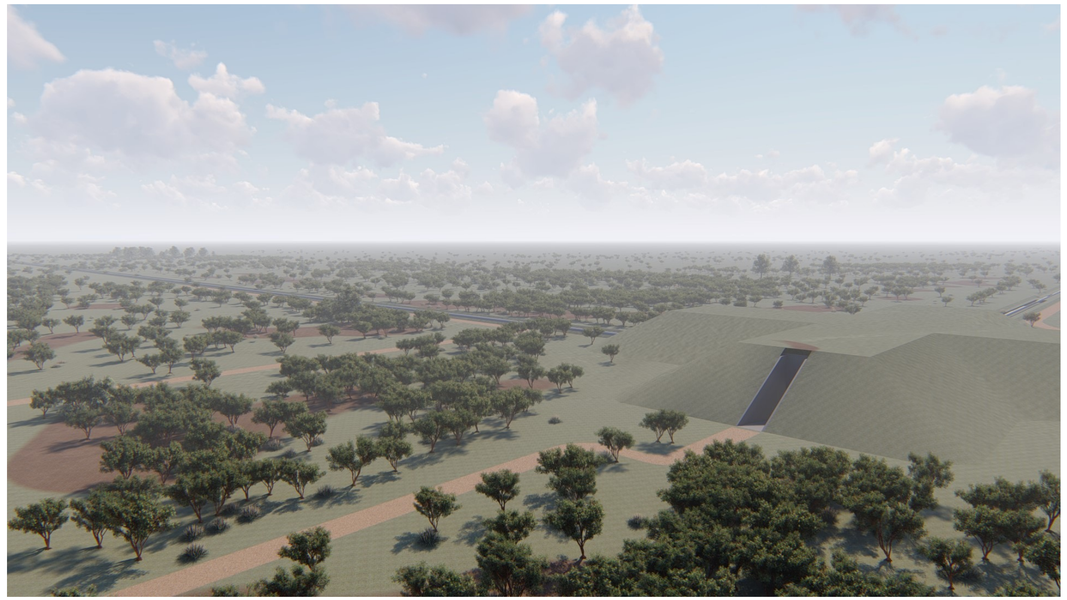


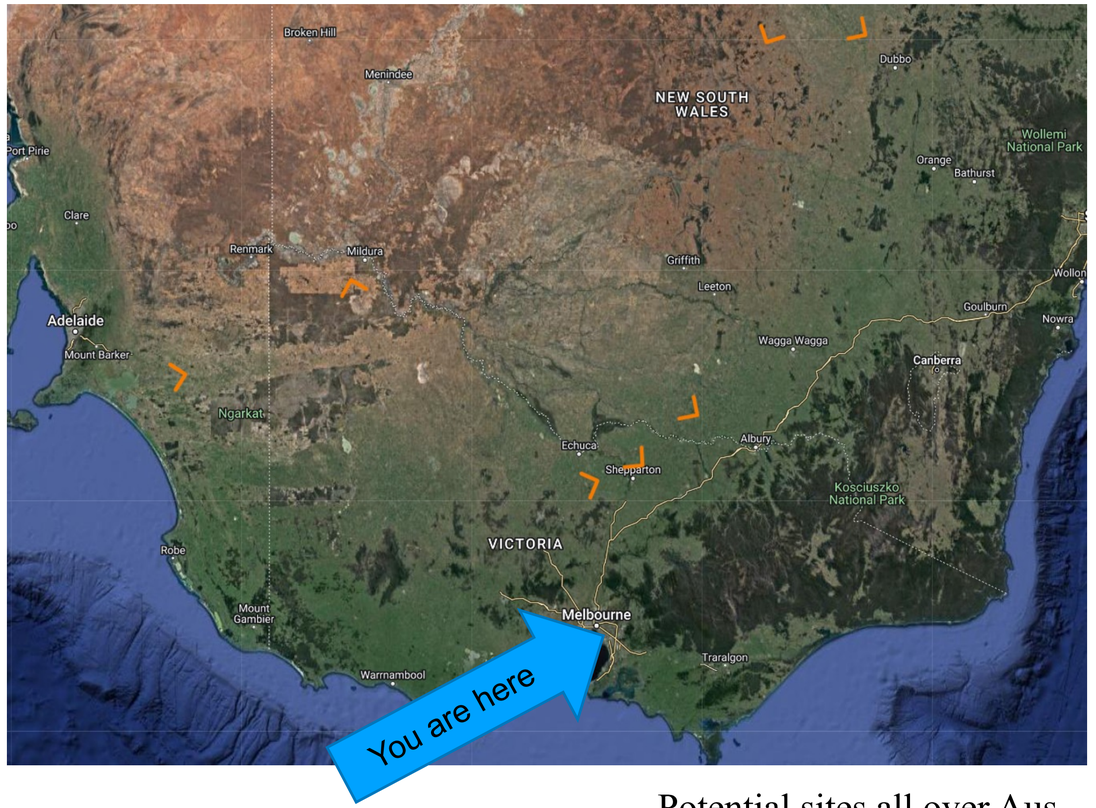
Ackley et al. (2020)

NEMO: scoping study

Carl Blair et al







Potential sites all over Aus, including Gingin near Perth

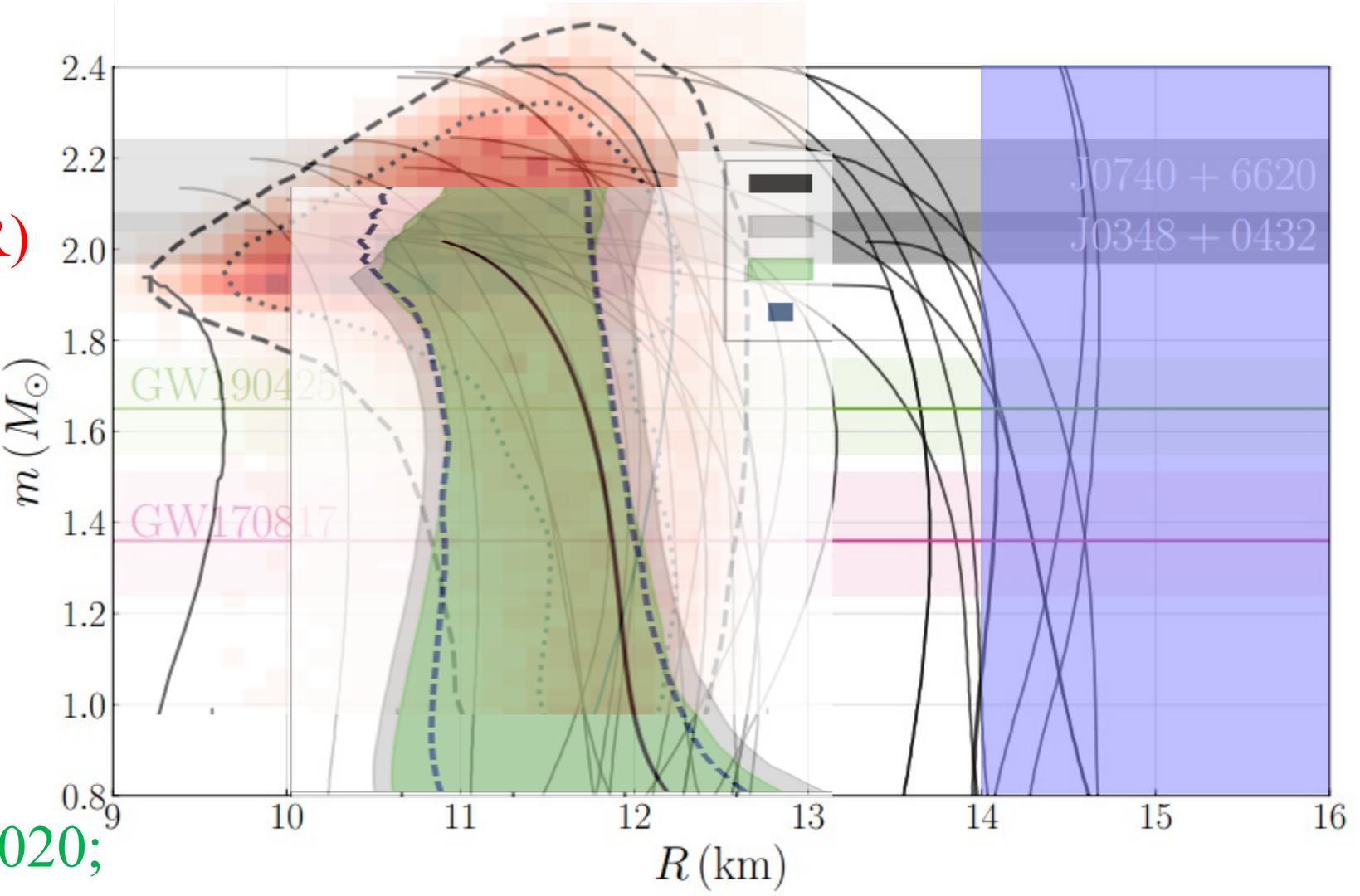
Flythrough

GW170817 + ….

J0030+0451
(Raaijmakers+2020; NICER)

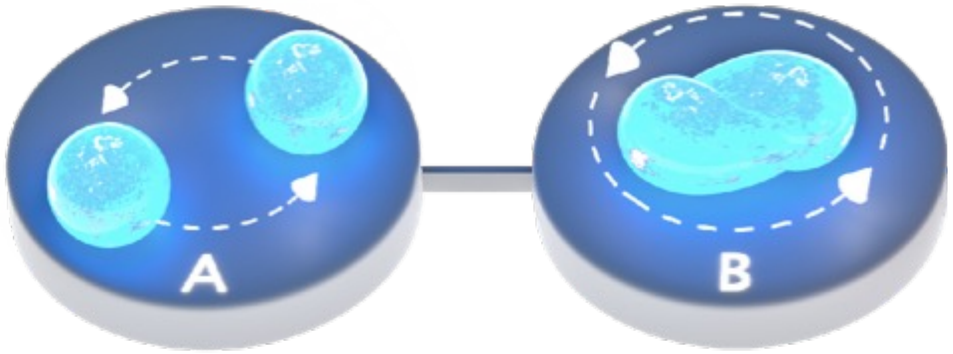
GW170817 tides
(conservative...)

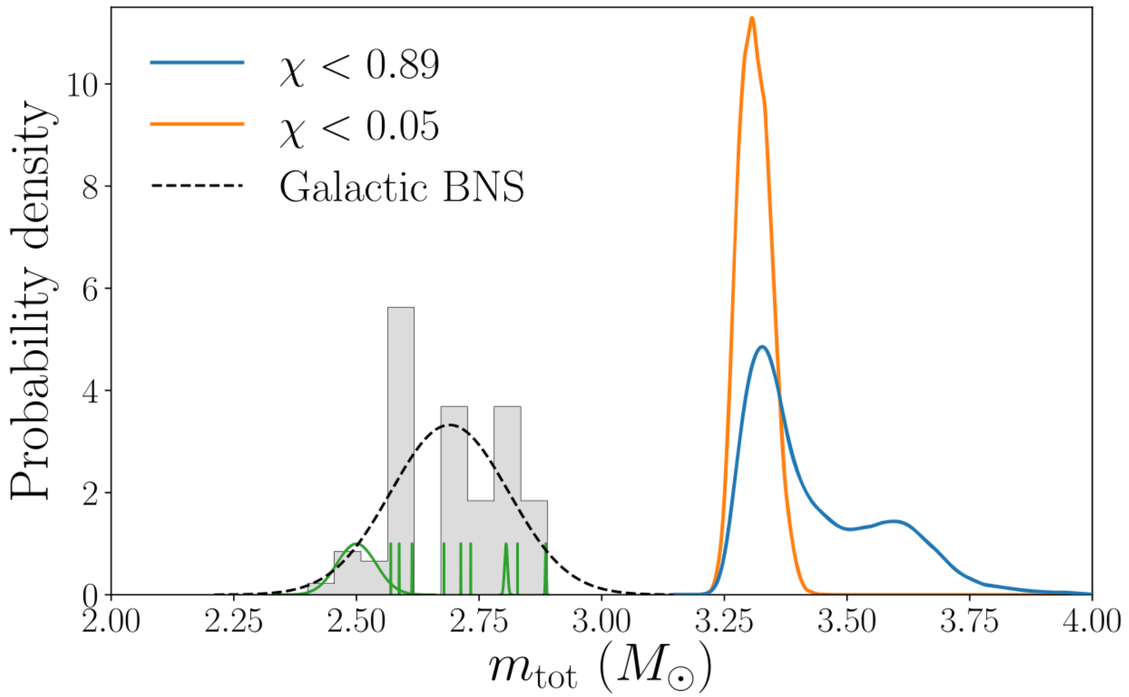
First 40 LVK events
(Hernandez Vivanco, PL+ 2020;
and many other papers!)

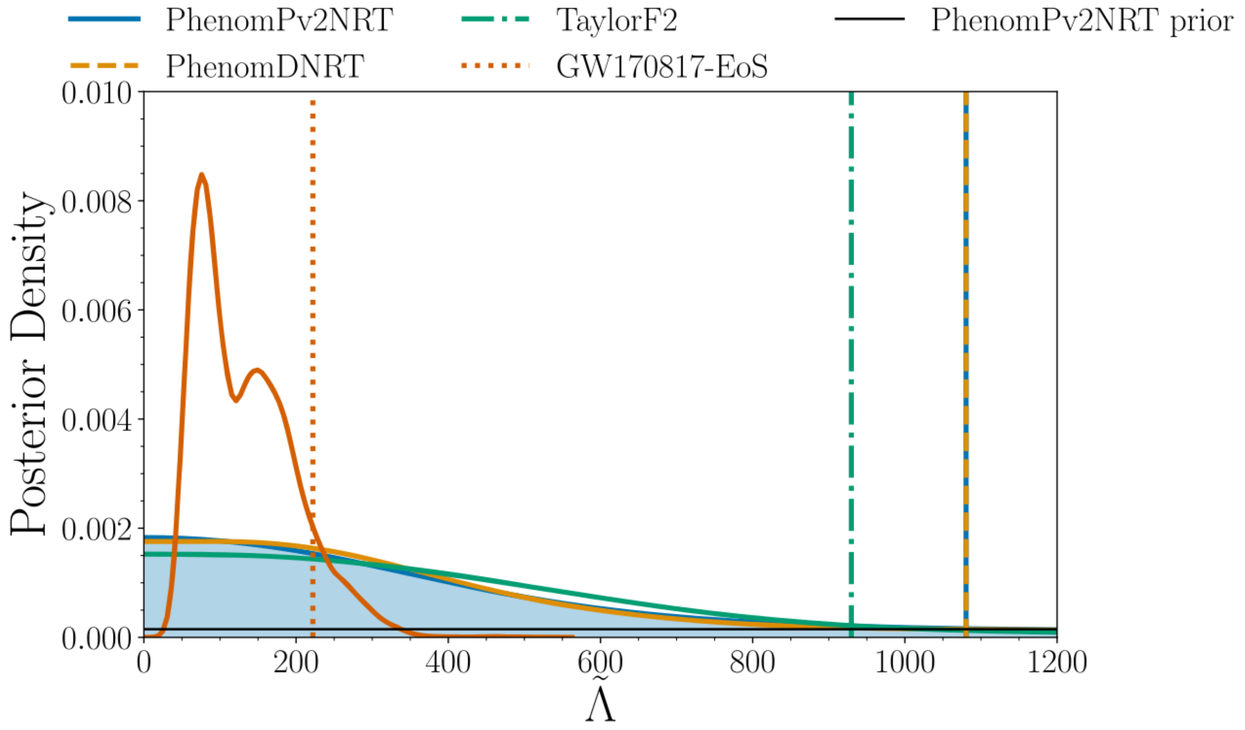


GW190425

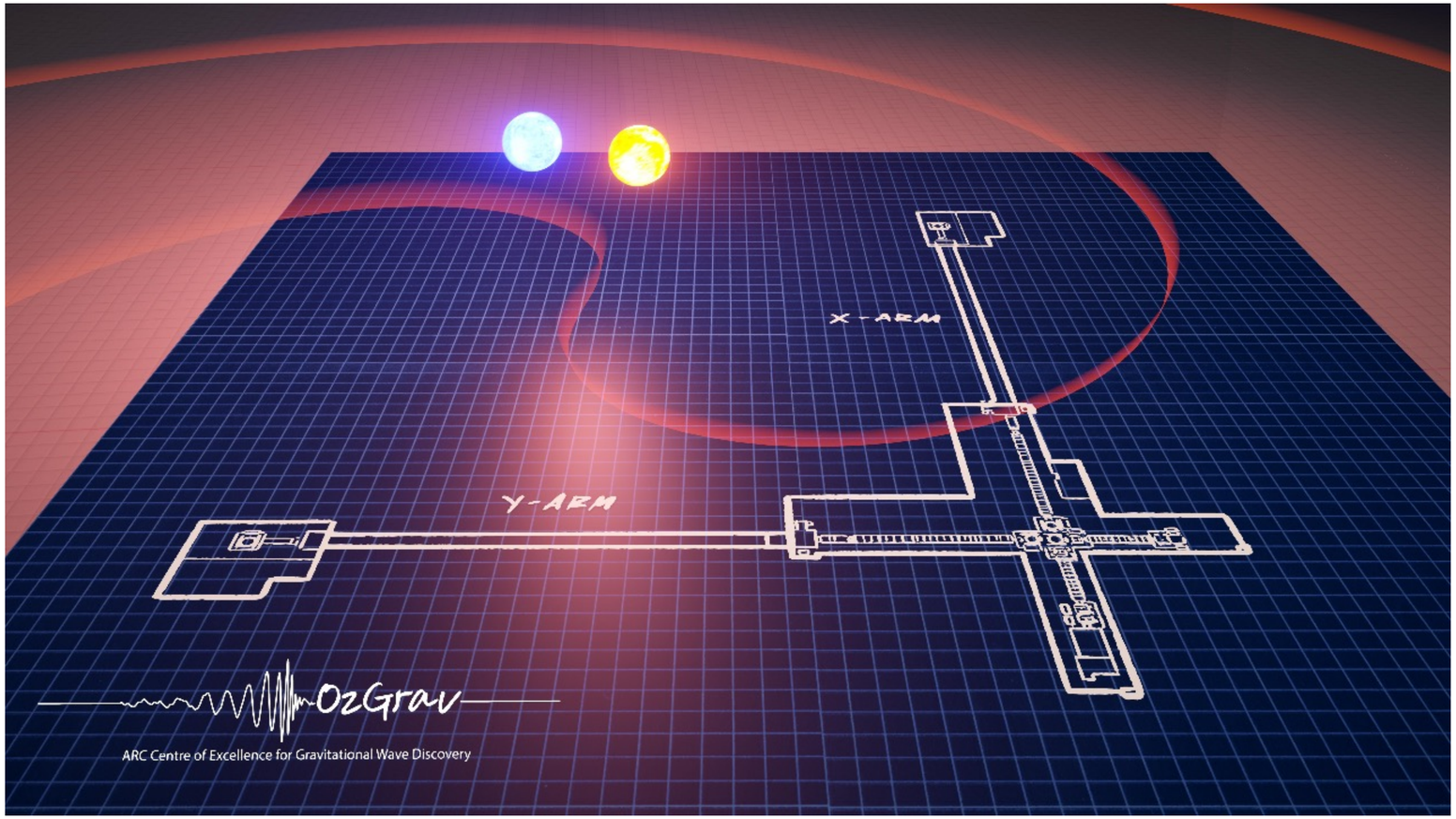
Abbott+20







Rudra Sekhri



Carl Knox

a next-generation gravitational-wave observatory

Paul Lasky

on behalf of the OzGrav NEMO team

MONASH University

OzGrav