Why ET?

Fifth ET Symposium

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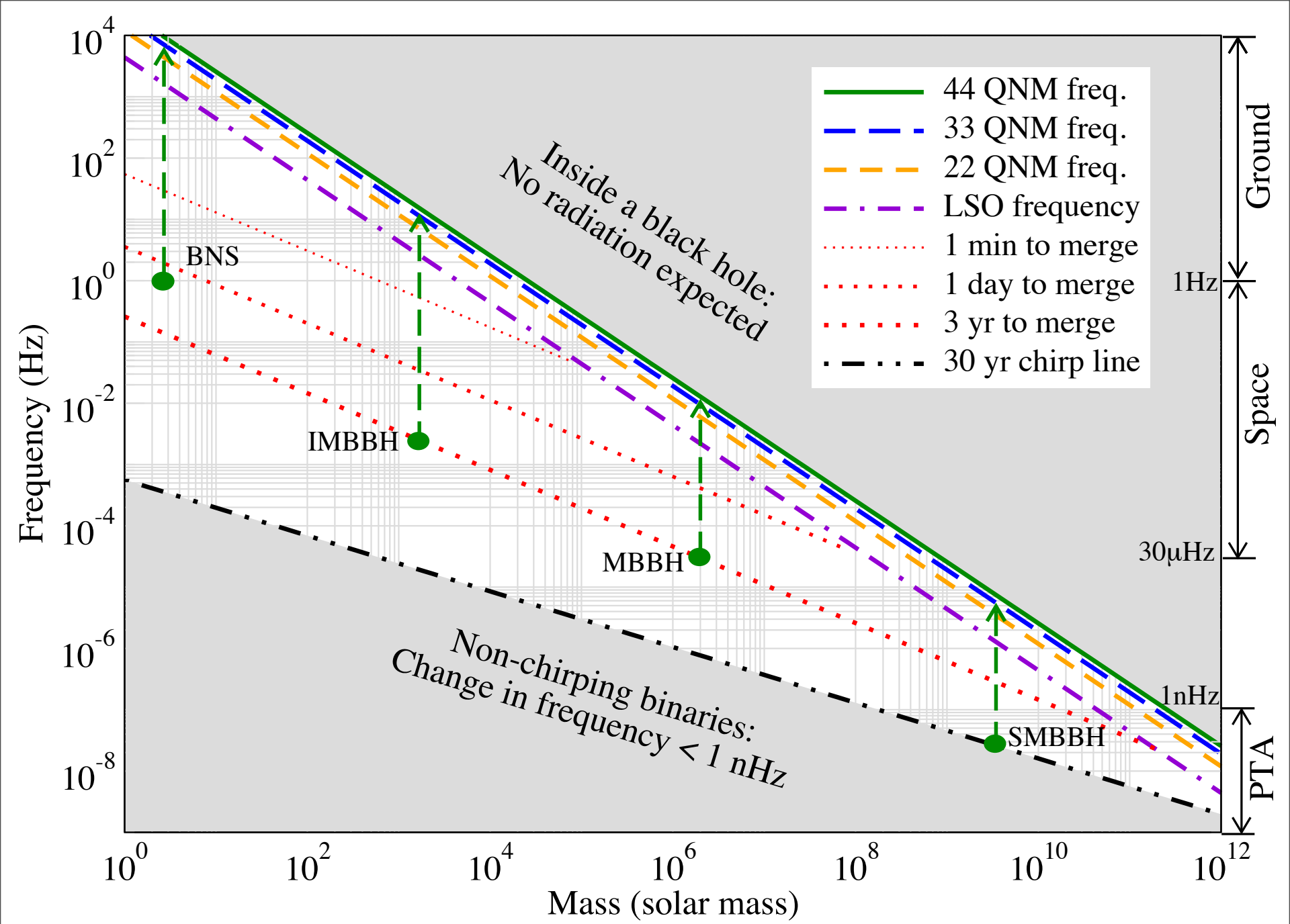
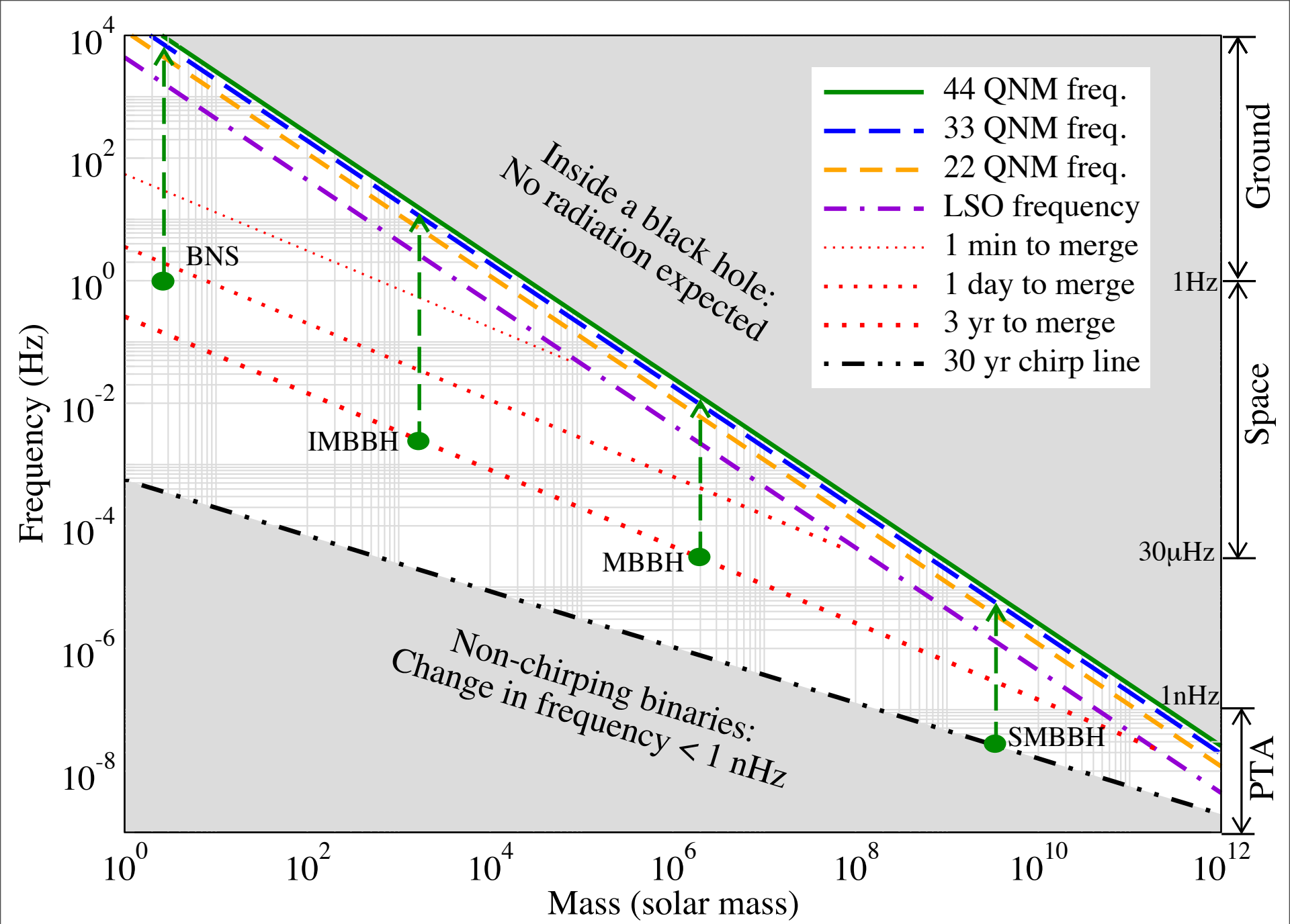
B.S. Sathyaprakash

School of Physics and Astronomy, Cardiff University, UK

What Will ET Observe?
Illustrated by Frequency–Mass Diagram


44 QNM freq.
33 QNM freq.
22 QNM freq.
LSO frequency
1 min to merge
1 day to merge
3 yr to merge
30 yr chirp line
Inside a black hole:
No radiation expected
Non-chirping binaries:
Change in frequency < 1 nHz
BNS
IMBBH
MBBH
SMBBH
Ground
Space
PTA
1Hz
30μHz
1nHz
Frequency (Hz)
Mass (solar mass)
10^{4}
10^{2}
10^{0}
10^{-2}
10^{-4}
10^{-6}
10^{-8}
10^{0}
10^{2}
10^{4}
10^{6}
10^{8}
10^{10}
10^{12}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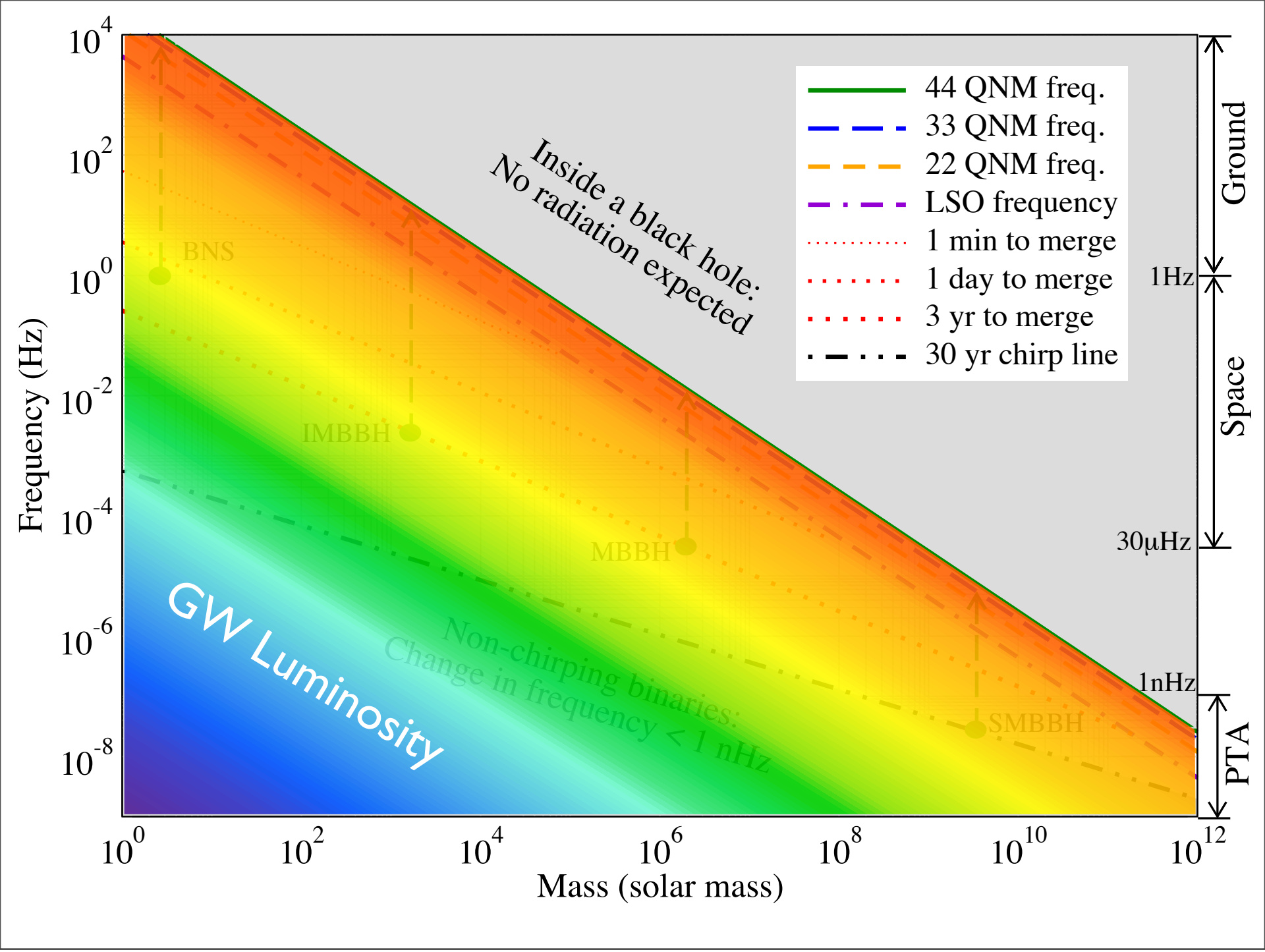
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No radiation expected
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LSO frequency
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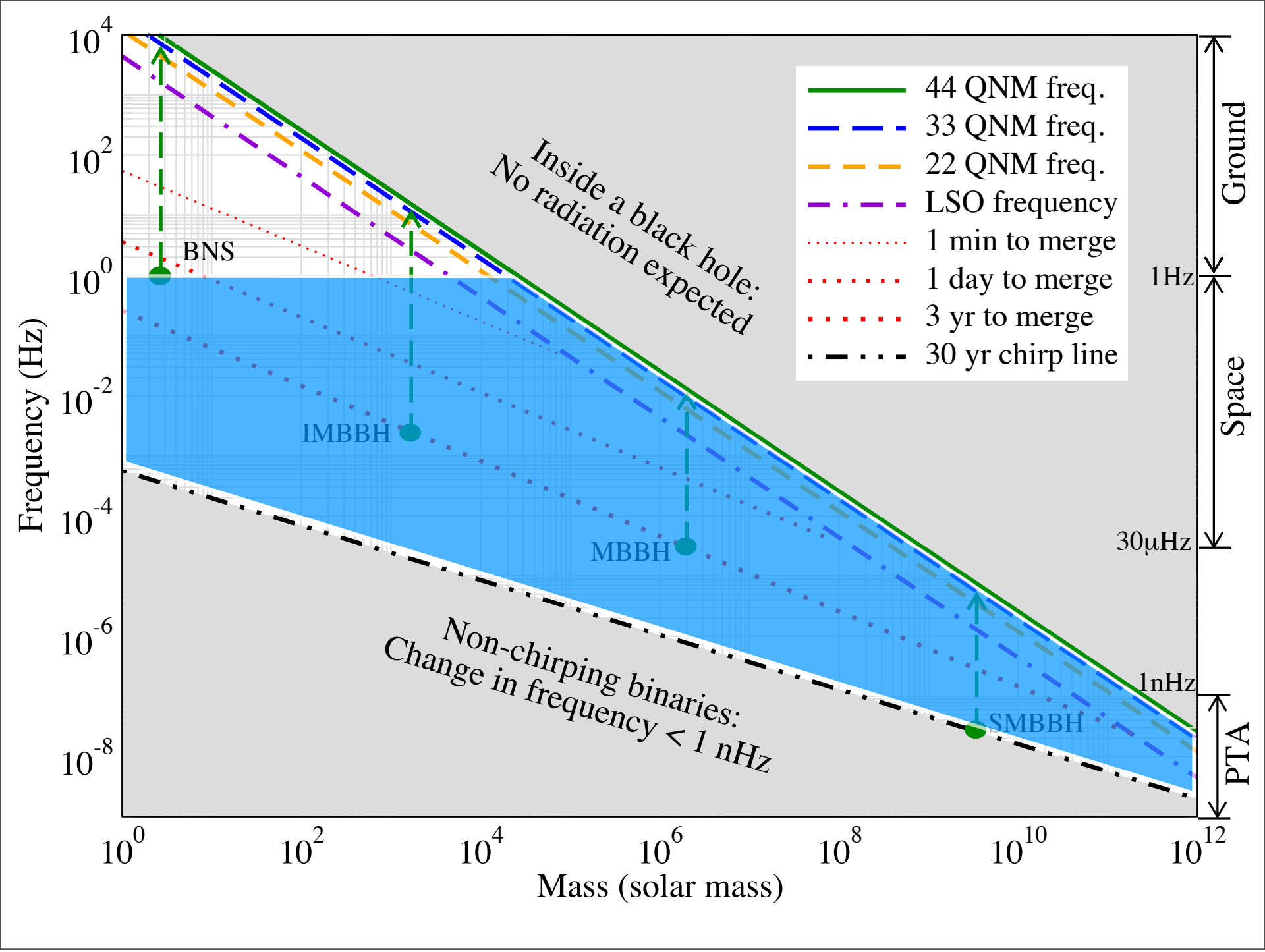
1 day to merge
3 yr to merge
30 yr chirp line
BNS
IMBBH
MBBH
SMBBH
GW Luminosity
Non-chirping binaries:
Change in frequency < 1 nHz
Ground
1Hz
Space
30μHz
1nHz
PTA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30μHz
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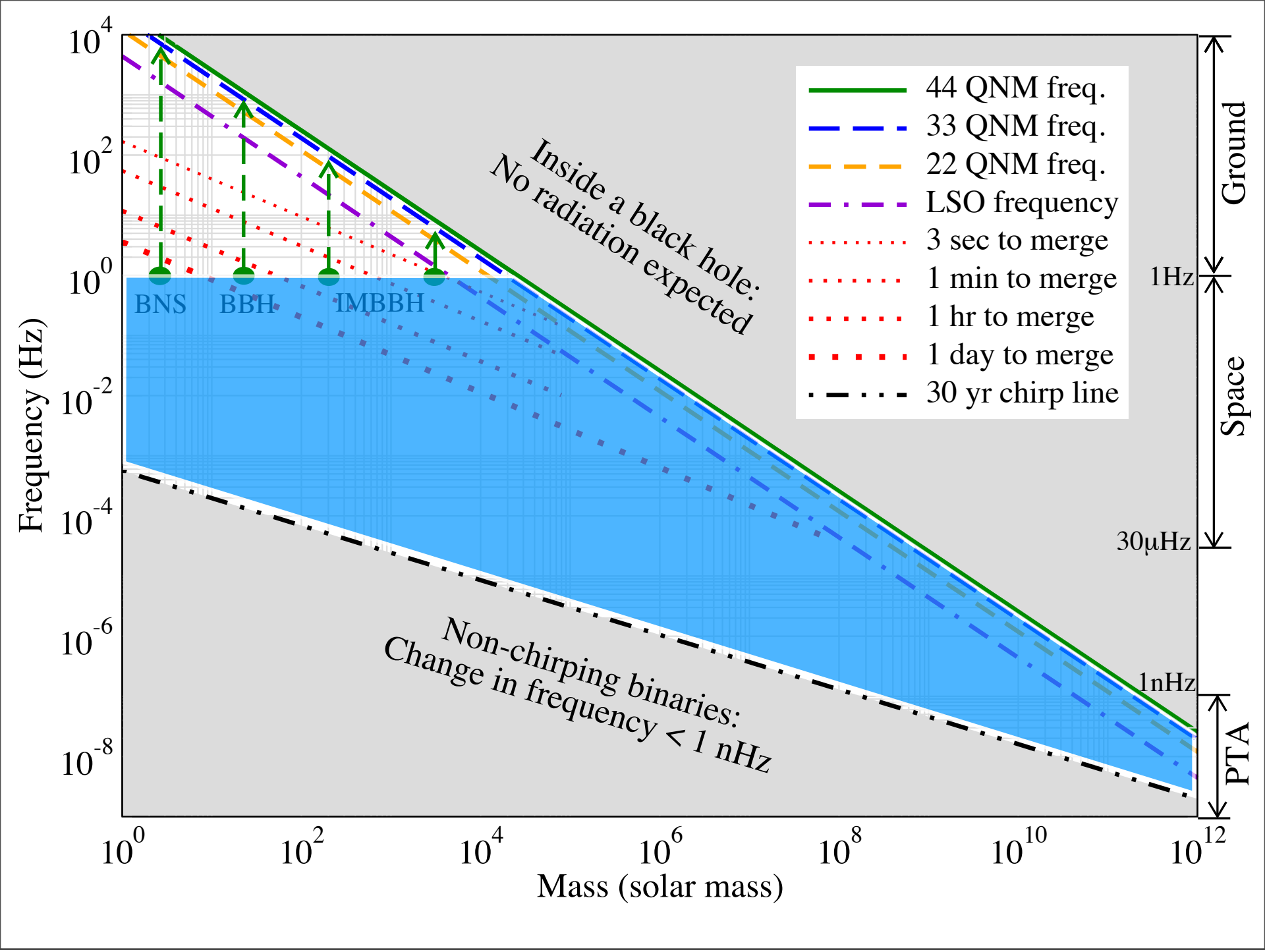
10^{4}
10^{6}
10^{8}
10^{10}
10^{12}


44 QNM freq.
33 QNM freq.
22 QNM freq.
LSO frequency
3 sec to merge
1 min to merge
1 hr to merge
1 day to merge
30 yr chirp line
Inside a black hole:
No radiation expected
Non-chirping binaries:
Change in frequency < 1 nHz
BNS
BBH
IMBBH
Ground
Space
PTA
1Hz
30μHz
1nHz
Frequency (Hz)
Mass (solar mass)
10^{4}
10^{2}
10^{0}
10^{-2}
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10^{10}
10^{12}

Sources last at most few hours starting at 5 Hz

Modulation of the signal due to Earth's rotation is not good enough to resolve the source on the sky

Scientific Questions only ET can Answer

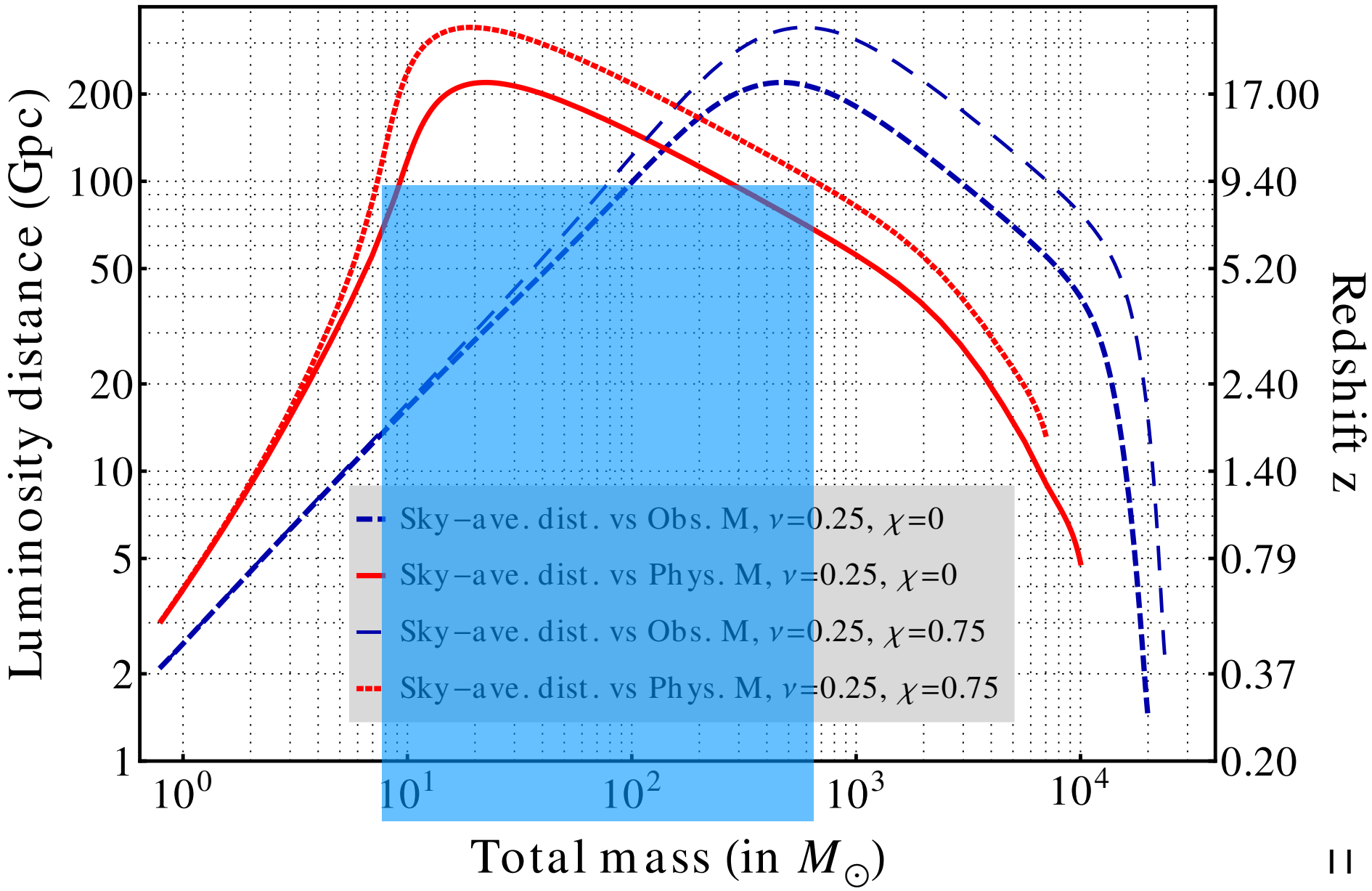
ET Design Study Document

- Lists 18 questions that ET would address
  - 5 in Fundamental Physics
  - 5 in Cosmology
  - 8 in Astronomy
- Which of these are uniquely addressed by ET?
- Which critically require ET?
- Which are complementary to EM and other observations?

The problem of origins

- Where did black holes at galactic nuclei come from?
- An unsolved problem in cosmology
  - When did they first form? What were their masses? How did they grow to be so big, so fast?
- There is no known mechanism to form massive black holes from primordial gas; certainly not the supermassive BHs in giant ellipticals
  - If initial black hole masses were small then astrophysicists think they have not had enough time to grow so big
- If seed black holes are in the 10–100 solar mass range, ET will detect these systems at epochs before galaxy formation is believed to have occurred

Probing black hole mergers at z ~ 5–20



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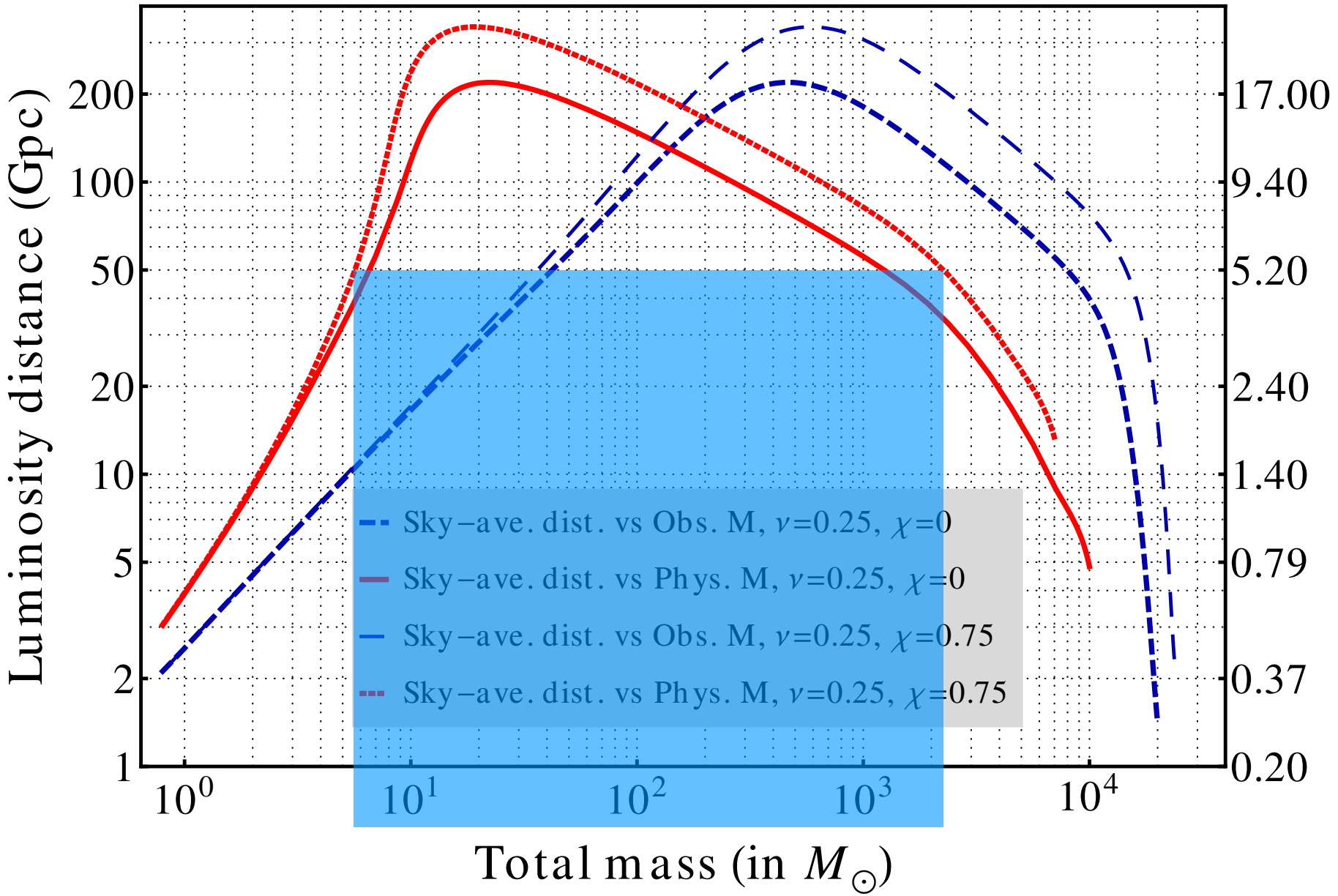
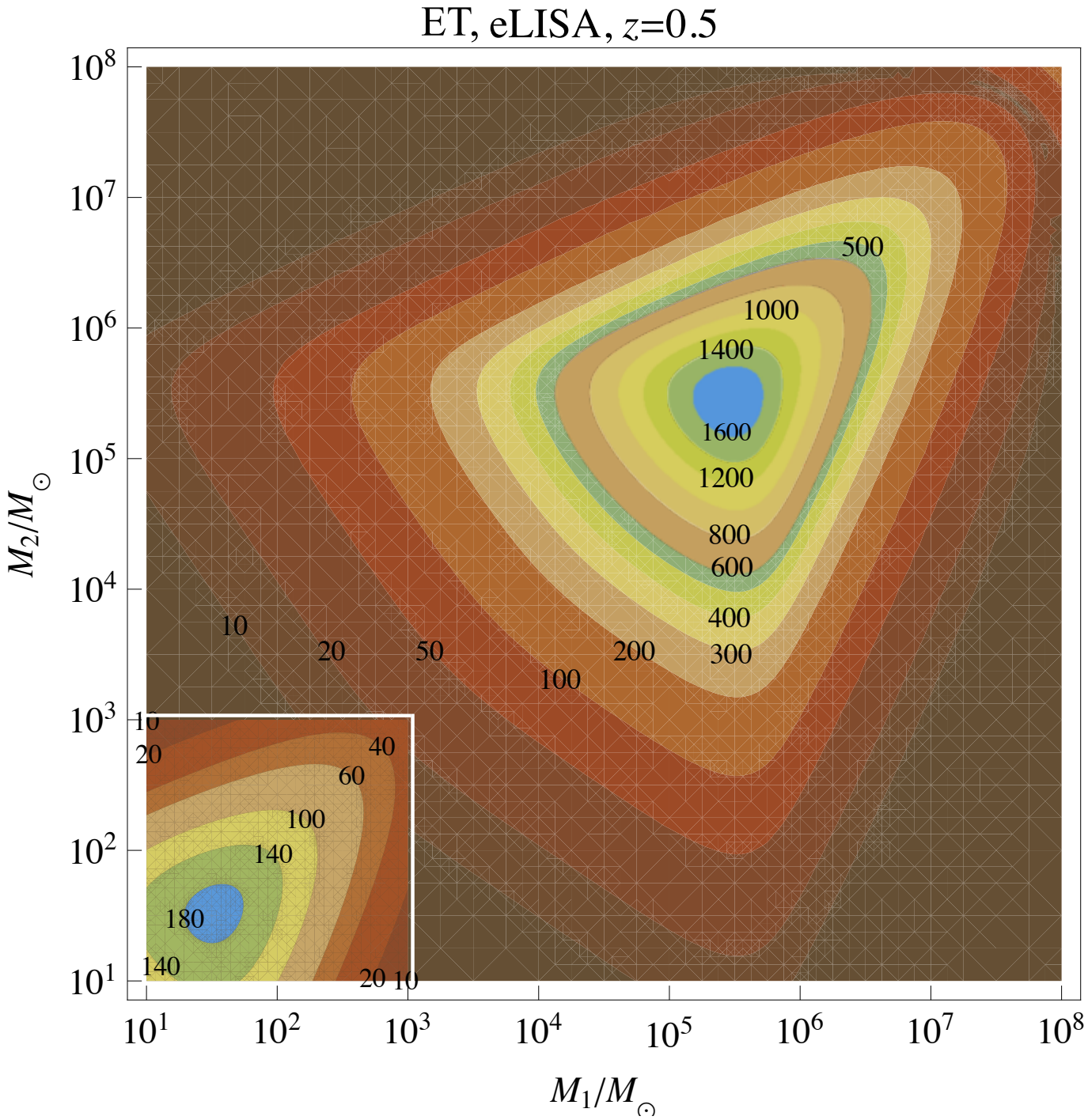
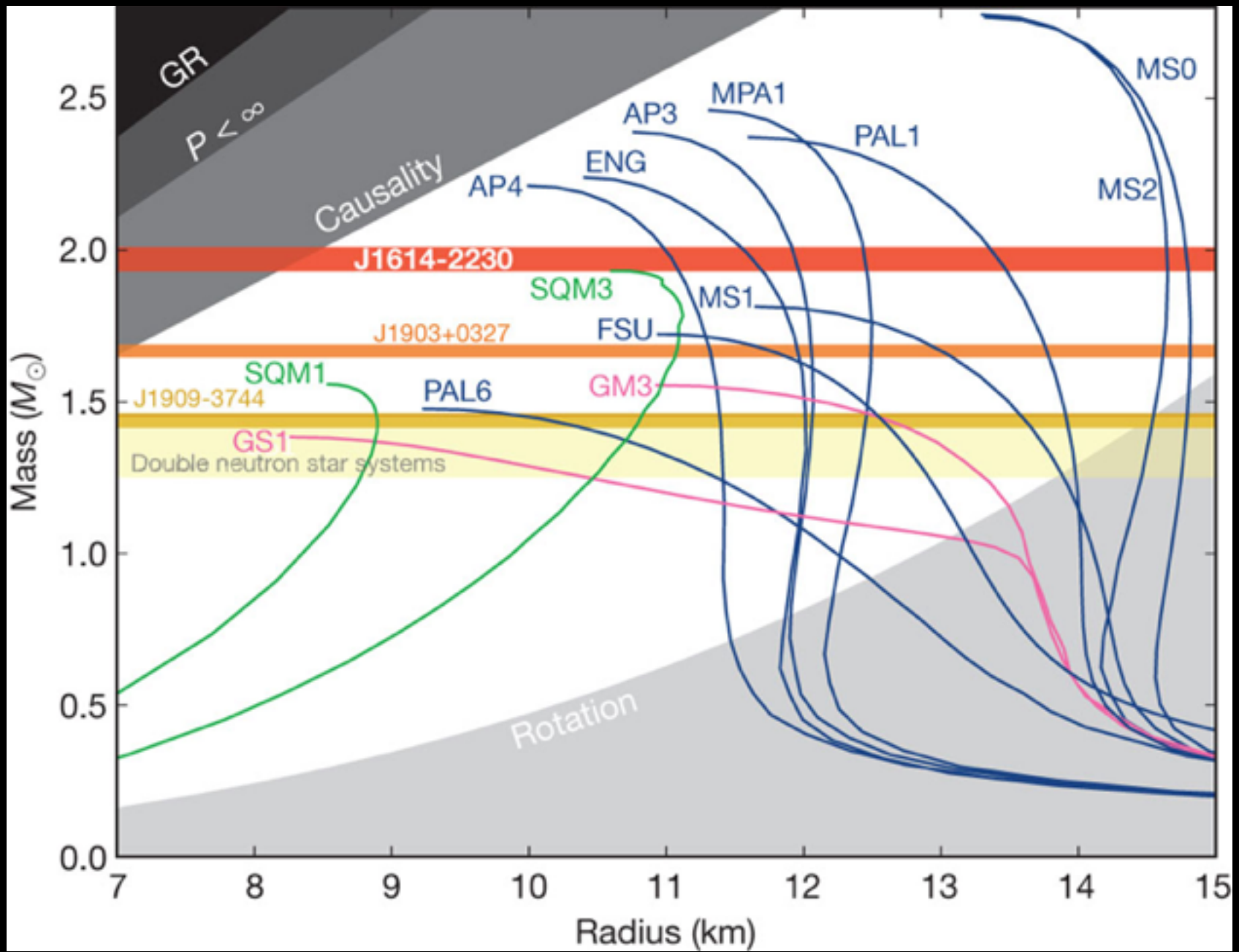


Synergy with eLISA: ET and eLISA Inspiral SNRs for sources at z=0.5



Maximum Mass of a Neutron Star and Mass Gap

- Heaviest known neutron star has a mass of 2 solar masses
  - Although many equations of state are ruled out by this model many more remain
- Finding heavier neutron stars is not likely to fix the problem
  - Many EoS predict heavier neutron stars with exotic cores
- Measuring both NS mass and Radius is the key
  - If radius can be measured to within a few km then EoS will be very tightly constrained
- Advanced detectors would go someway but ET will be critical to resolving the issues


GR
$P < \infty$
Causality
Rotation
MS0
MPA1
AP3
PAL1
ENG
AP4
MS2
J1614-2230
SQM3
MS1
J1903+0327
FSU
SQM1
PAL6
GM3
J1909-3744
GS1
Double neutron star systems
Mass ($M_\odot$)
Radius (km)
2.5
2.0
1.5
1.0
0.5
0.0
7
8
9
10
11
12
13
14
15

Other Important Questions

- Is GR the correct theory of gravity in strong gravitational fields
  - Strong field tests of GR using BNS; will be explored with TIGER infrastructure
- Do relativistic instabilities occur in young neutron stars?
  - Rare, once per 10 year events (possibly supernovae; also LMXBs)

Scientific Questions for which ET is Critical

- Understanding Supernova Core Collapse and Core Bounce
  - rare, one per 10 year events
- What are the progenitors of GRBs?
  - hundreds to thousands of sources
- How do compact binaries evolve?
  - thousands to millions of sources
- What are the mass and spin distributions of neutron sars and black holes?
  - thousands to millions of sources
- What causes pulsar glitches and magnetar flares?
  - rare, one per 10 year events

Working Group 1:
Progress Report

Working Group 1: Tasks

- **Task 1:** *Carry out a series of mock ET data and science challenges of increasing complexity:*
- **Task 2:** *Explore how well astrophysical models of GW sources could be tested with ET*
- **Task 3:** *Investigate possible strong field tests of GR with ET:*
- **Task 4:** *Probe ET's potential for understanding the geometry and dynamics of the Universe:*

Working Group 1 Partners

Work Package Title	Lead Participant	Other Participants involved
ET's scientific potential	Cardiff	Nikhef, Polish ET, Birmingham Consortium, Glasgow, MSU-SAI, Nice

Working Group 1 Tasks: Progress

Work Package Title	Lead Participant	Other Participants involved
ET's scientific potential	Cardiff	Nikhef, Polish ET, Birmingham Consortium, Glasgow, MSU-SAI, Nice

- **Task 1:** *Carry out a series of mock ET data and science challenges of increasing complexity:* Tania Regimbau
  - Nice, Cardiff, NIKHEF, Rome, Amherst, Glasgow, Birmingham, Warsaw
  - 1 year worth of data, 3 data sets (for3 ET detectors)
  - Contains binary neutron stars, binary black holes, GW bursts (supernova, pulsar glitches), stochastic, etc.
  - Some data validation but no detailed analysis yet

Working Group 1 Tasks: Progress

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ET's scientific potential	Cardiff	Nikhef, Polish ET, Birmingham Consortium, Glasgow, MSU-SAI, Nice

- **Task 2:** *Explore how well astrophysical models of GW sources could be tested with ET* Ilya Mandel
  - Warsaw, Birmingham, Nice, Cardiff, NIKHEF
  - Computer models of binary evolution scenarios exist
  - Need to assess how well parameter estimation with ET will help differentiate among different models
  - MDCs are probably not needed

Working Group 1 Tasks: Progress

Work Package Title	Lead Participant	Other Participants involved
ET's scientific potential	Cardiff	Nikhef, Polish ET, Birmingham Consortium, Glasgow, MSU-SAI, Nice

- **Task 3:** *Investigate possible strong field tests of GR with ET:*
  - NIKHEF, Cardiff
  - Test of the no-hair theorem using ringdown signals only
  - Ringdown signals are simple:
    - frequency and time constant depend only on the final mass and spin of the black hole
    - Amplitudes of modes excited depends on progenitor masses and spins
  - Use TIGER infrastructure to test how well ET can test GR

Working Group 1 Tasks: Progress

Work Package Title	Lead Participant	Other Participants involved
ET's scientific potential	Cardiff	Nikhef, Polish ET, Birmingham Consortium, Glasgow, MSU-SAI, Nice

- **Task 4:** *Probe ET's potential for understanding the geometry and dynamics of the Universe:*
  - Cardiff, NIKHEF, Nice Birmingham
  - We know that binary neutron stars with EM counterparts are good for ET cosmology
    - Can measure w and its variation with redshift
  - We also know BBH sources without EM counterparts could be very useful for cosmology (Schutz's method)
  - Now working on realistic mock galaxies catalogues

Some example activities ...

- Maxim Fays (graduate student, Cardiff)
  - Exploring parameter estimation of overlapping signals using Bayesian inference techniques
- Maurycy Frejdlich (undergraduate student, Cardiff)
  - Testing massive graviton theories with ET
- Gemma Hughes (undergraduate student, Cardiff)
  - Assessing parameter estimation (masses and spins, distances, sky position, etc.) of low-mass systems (inspiral signal only)
- Duncan Meacher (graduate student, Nice)
  - Using gst-lal for ET analysis, potentially going down to 5 Hz
- Jeoren Meidam (graduate student, NIKHEF)
  - Testing GR with ringdown signals
- Jonathan Rawlins (undergraduate student, Cardiff)
  - Same as Hughes, focussing on high mass systems for which plunge and ringdown phases are important

Working Group 1: Deliverables in Year 1

WG	Description	Year 1											
		1	2	3	4	5	6	7	8	9	10	11	12
1	Mock ET data challenge: produce data	■	■	■	■	■	■	■	■	■	■	■	■
	Explore and develop algorithms							■	■	■	■	■	■
	Mock ET data challende: analyze data												■
	Assess ET's ability to test strong field gravity	■	■	■	■	■	■	■	■	■	■	■	■
	Assess ET's ability to do precision cosmology												■
	Assess ET's ability to test astrophysical models	■	■	■	■	■	■	■	■	■	■	■	■
	Publications on MDC and science capabilities												■

Plans for the coming months ...

- Organise regular teleconferences amongst various partners
  - Periodic review of work
- Face_to_Face meetings of WG1
- Publication plans
  - Especially deliverables
- Present ET activities at prominent conferences
- Begin outreach activities