Computing Model for ET

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Einstein gravitational wave Telescope
Conceptual Design Study
ET
EINSTEIN
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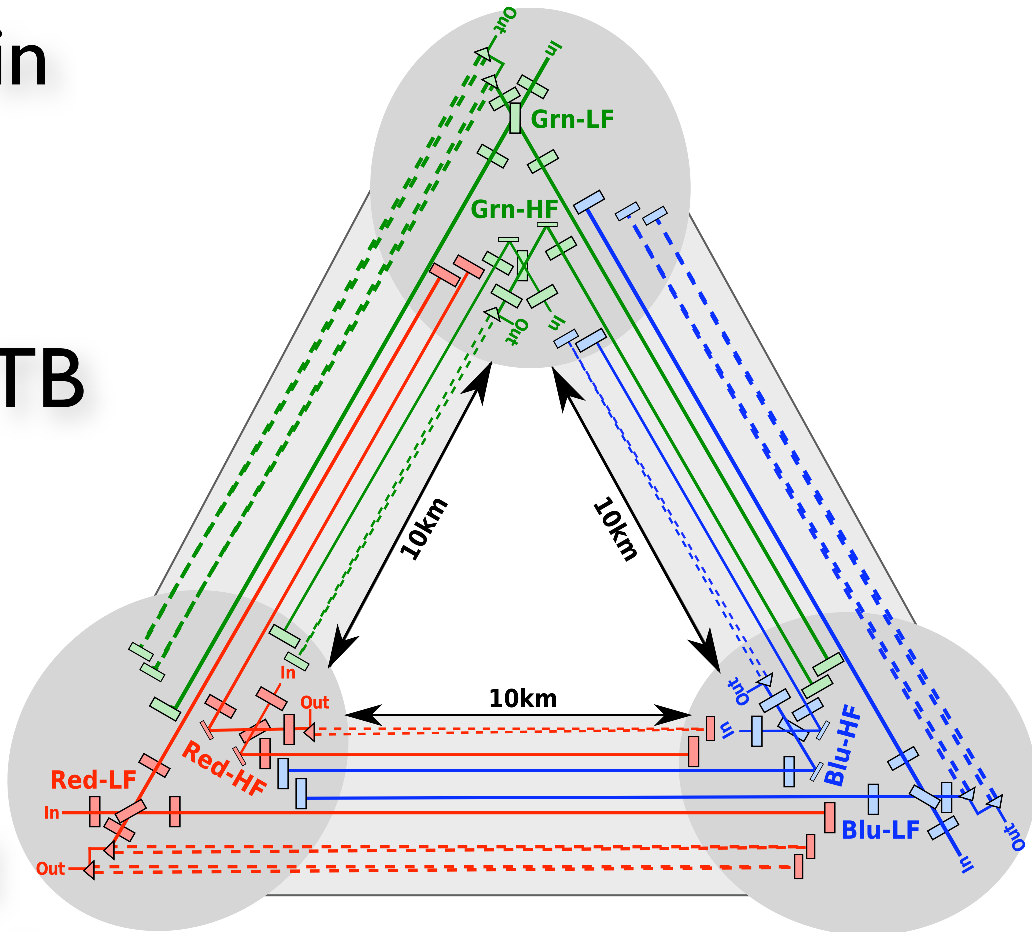
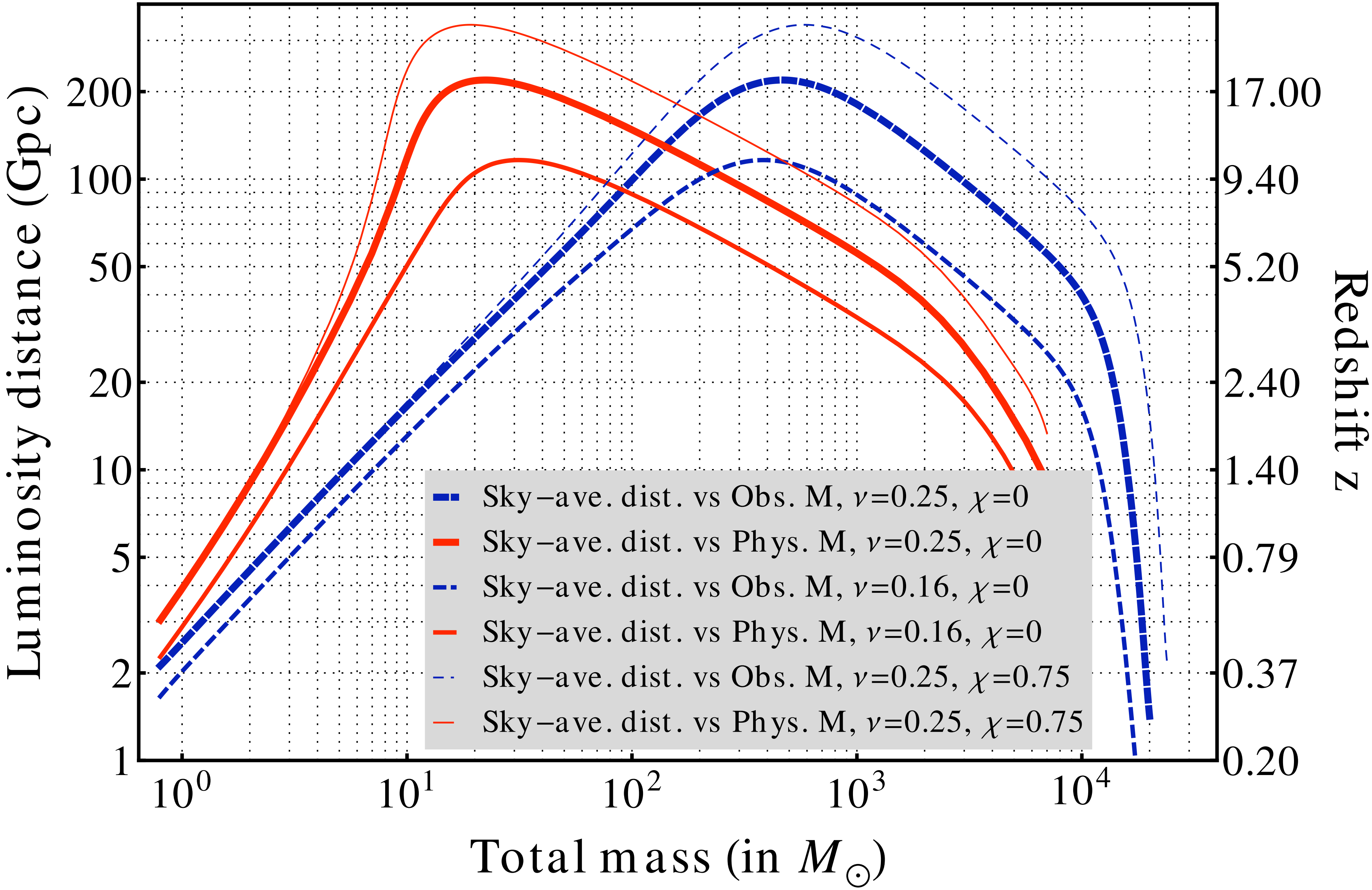
Einstein Telescope: An Observatory

- Six interferometers in a triangular array
- Timeline: 2025+
- Data rates of ~ 100 TB per year from the observatory
  - data handling is not a great challenge
- Data processing and science exploitation is the challenge



ET Distance Reach for Compact Binary Mergers



ET Challenge for Data Analysts

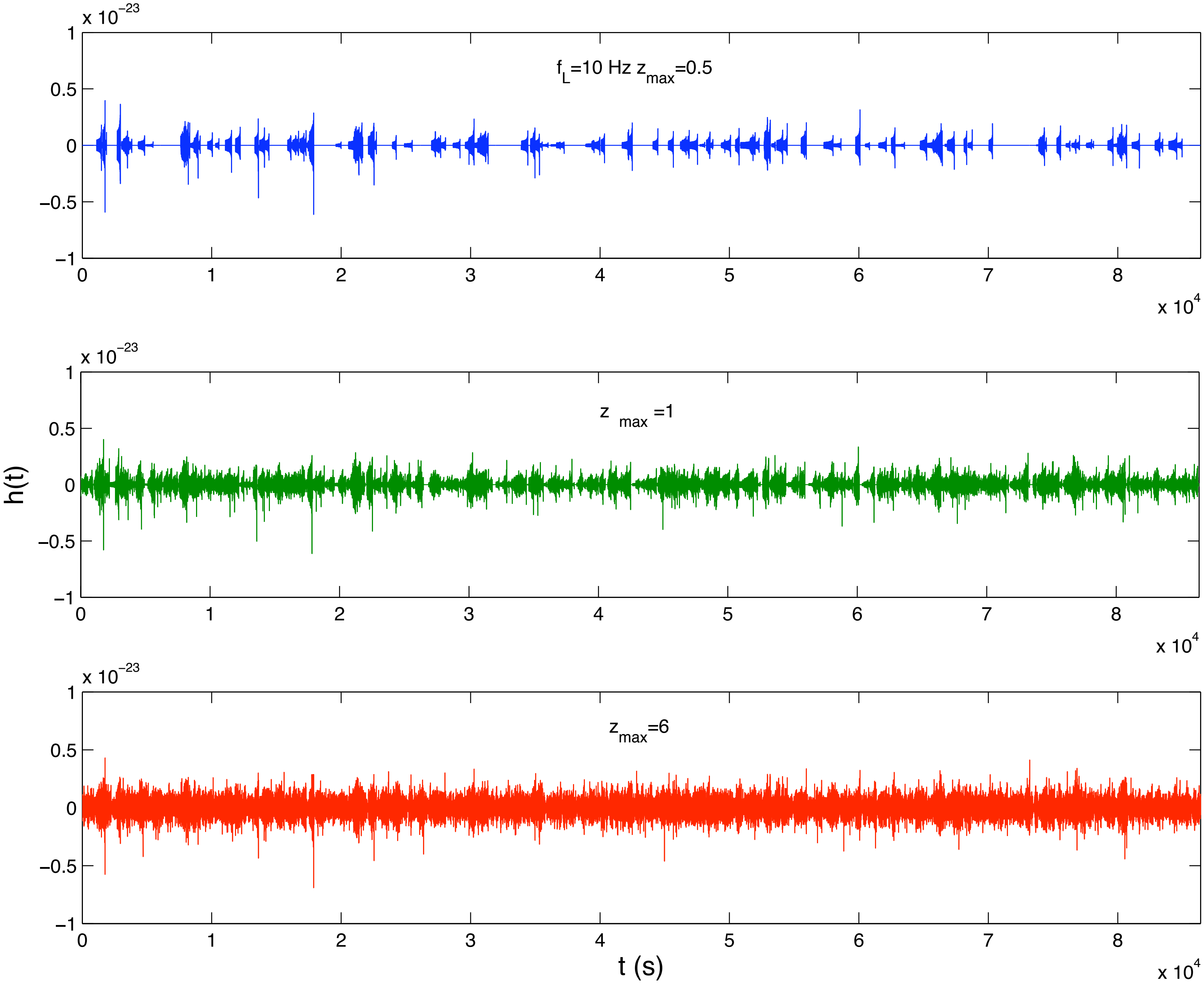
- Signal durations ranging over seven orders of magnitude
  - 10's of milliseconds for intermediate-mass black hole binaries, supernovae, neutron star glitches, etc.
  - Up to a week in the case of binary neutron stars
  - Continuous wave sources that last for weeks to years
- There could be many overlapping sources
  - Possible stochastic background but likely below detector noise
- Detecting rare transients from SN, pulsar glitches, etc.
  - Hidden amidst millions of sources observed each year might be a transient that lasts for 10's of milliseconds to a second

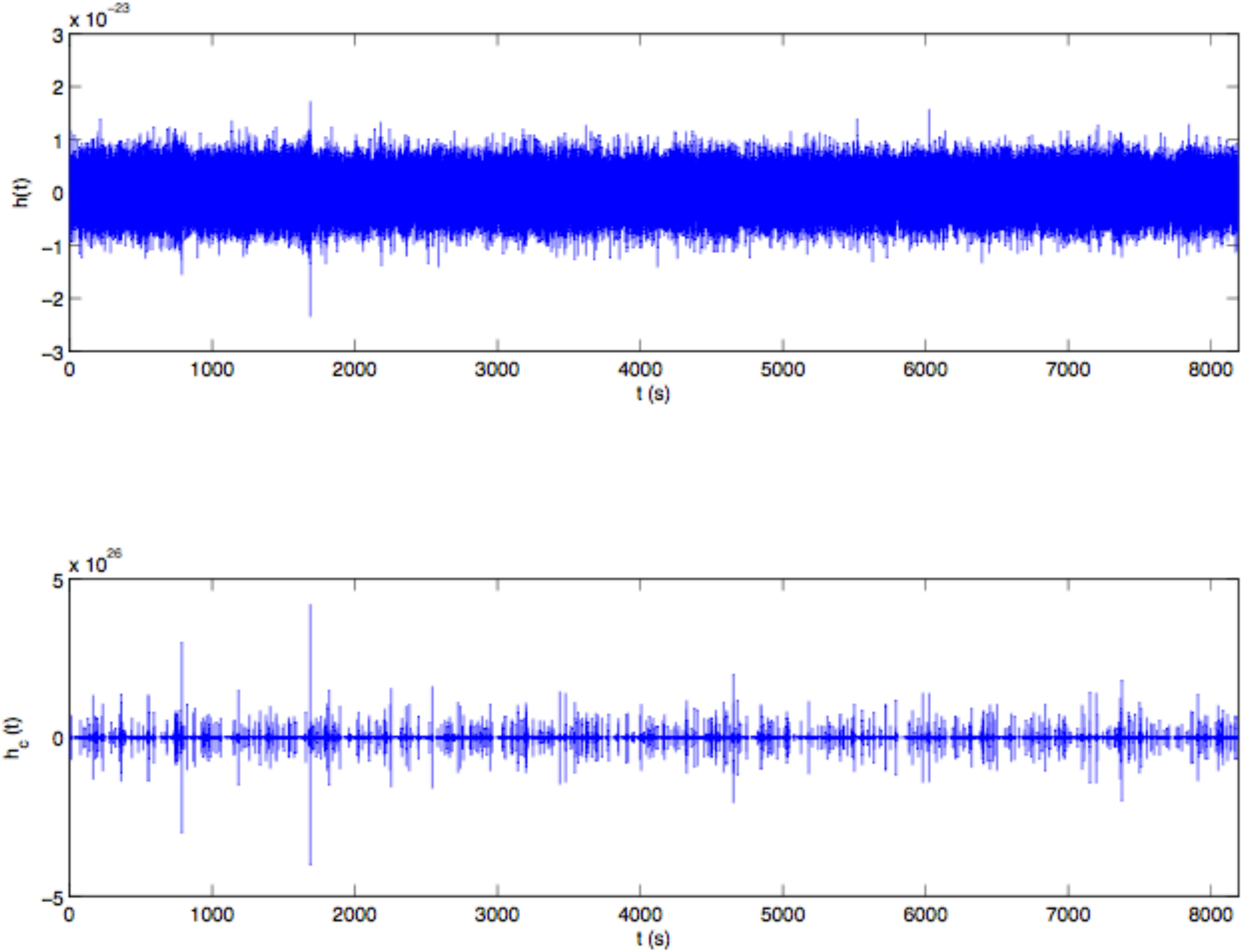
Duration of Inspiral Signals in ET

f_L (Hz)	NS-NS (1.4+1.4)	NS-BH (1.4+10)
40 (initial)	25 s	5.8 s
10 (Ad LIGO)	16.7 m	3.9 m
5 (Ad Virgo)	1.8 h	24.6 m
3 (possible ET)	6.9 h	1.6 h
1 (planned ET)	5.4 d	1.2 d

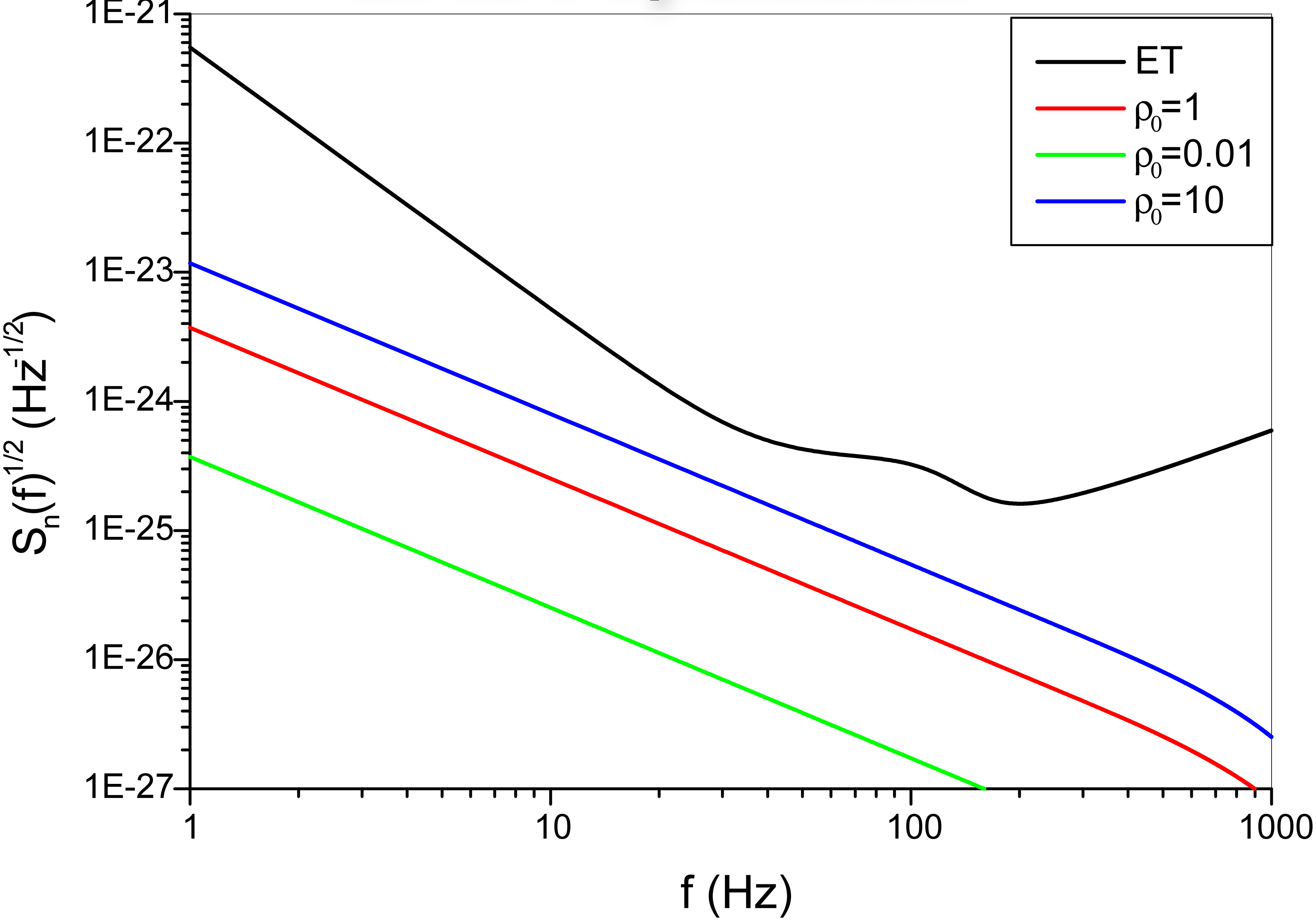
Searching for binary inspirals in ET

- Inspirals are traditionally searched using matched filtering
- Whitened data is filtered through a bank of templates that are copies of the expected signal
  - The search space and algorithm is already limited due computational requirements
  - The full parameter space is 17-dimensional
  - A coincidence search is carried out instead of a coherent search although the latter has a great potential to strengthen the searches


x 10^−23
f_L=10 Hz z_max=0.5
z max =1
z_max=6
h(t)
t (s)
x 10^4
1
0.5
0
−0.5
−1
0 1 2 3 4 5 6 7 8


x 10^-23
h(t)
3
2
1
0
−1
−2
−3
0
1000
2000
3000
4000
5000
6000
7000
8000
t (s)
x 10^26
h_c (t)
5
0
−5
0
1000
2000
3000
4000
5000
6000
7000
8000
t (s)

Stochastic Background from BNS Population



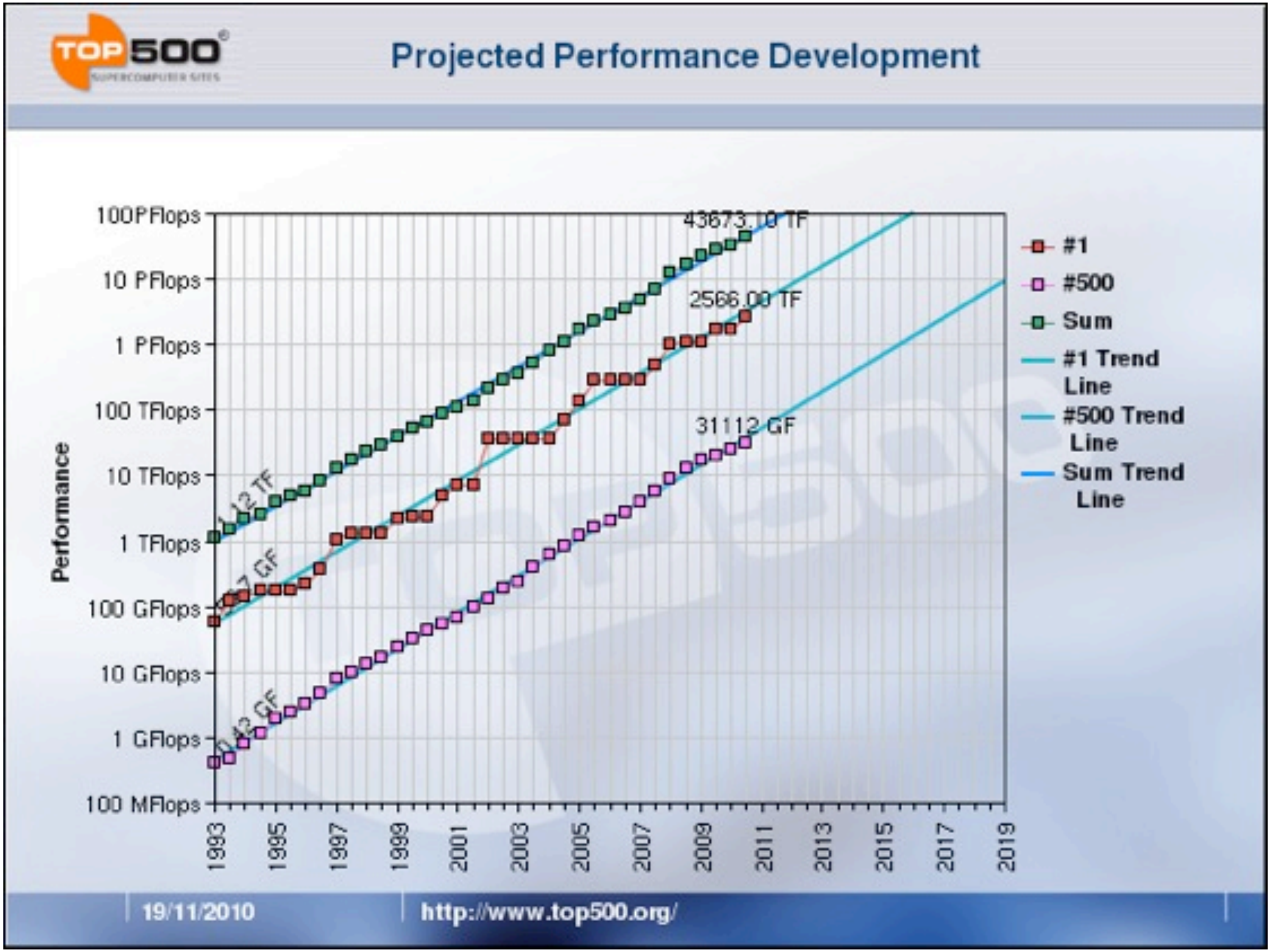
Cost of Matched Filtering

To search for one day's worth of data

		GPU C2050	WLCG	Tianhe-1A	Low-cost
Power (TFlops)		0.25	2000	2567	100
# of Params	# of Templates	Computational Time			
2	10^{9}	128 d	24 m	18 m	7 h
4	10^{13}	> 1 y	182 d	128 d	9 y
6	10^{18}	> 1 y	> 1 y	> 1 y	> 1 y

Projected Performance of Top 500

Computing power available in the ET era (even assuming Moore's law) is not sufficient, need other ways of analysis



New Computing Paradigms

- Conventional computing paradigms for detecting binary inspirals simply won't work
  - Signal lengths are far too long - need to break up the data set as in CW case
  - Number of overlapping signals means focus should be on those that are brightest
- At several events every minute the signal rate is far too high for post-processing pipelines
  - Current follow-up analyses take ~ days per event
  - E.g., posterior distribution of parameters is essential for delivering the science but takes too much time

Multi-messenger Astronomy

- A subset of events (50%) might be followed up in radio, X-ray, gamma-ray, etc
  - Processing power is required for not just GW data
  - Need to process EM observations
- Current set up and that envisaged for advanced detectors still work with semi-automated set ups for EM follow-ups
  - Must have fully automated data pipelines
  - Automated alerts, observation and analysis

A new model for data processing

- Current data analysis of most GW data is centrally controlled
  - A software library that is contributed and maintained by the collaboration as a whole
- This is not a good model in the ET era
  - It might be impossible to centrally process all the data and keep up also with progress in algorithms, theory, models, etc.
- Computation and analysis should perhaps be decentralized
  - End users apply for "observatory time" and they get a week's worth of data or a month's worth
  - They could have the ownership for a set period (say six months), after which the data will be made public
- The decentralized models might help distribute the load

Summary

- Raw data rates in ET are not expected to be too different from advanced detectors
  - Each site might host a number (~10) interferometers but even so the data rate might not be a big issue
- ET will be a signal-dominated detector
  - 1 event per week in advanced detectors translates to millions per year in ET
  - Data products could overwhelm the raw data rate
- A new model for data products might be needed
  - ET could see a variety of different signals and we need a way to store all the information associated with them
  - Need to develop a new formats/structures/databases, to store data products