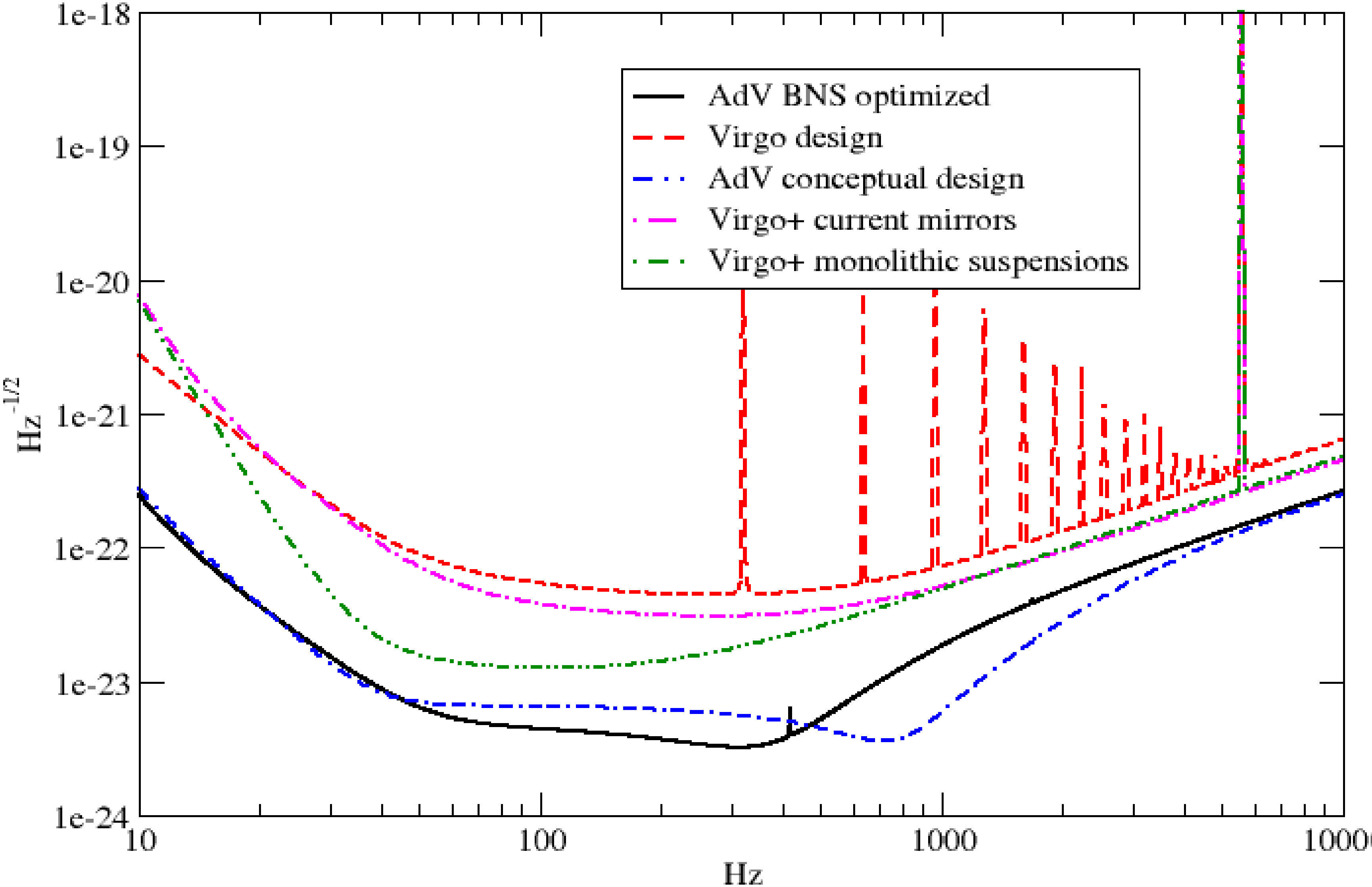
Science case for AdV

1st project review
November 1st, 2008

A.Viceré for the AdV Team

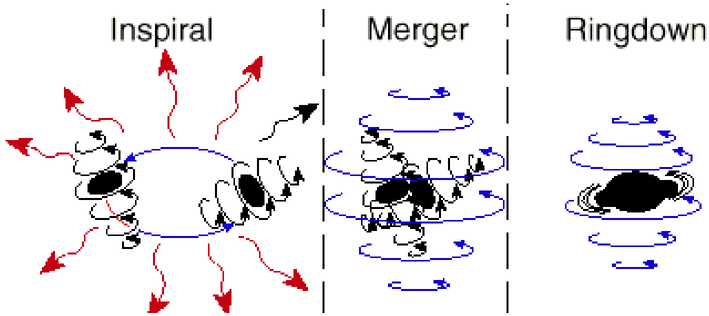
Sensitivities



- AdV sensitivity, BNS tuned, about 10x better at all frequencies
- Compared to Virgo design and Virgo+ alternatives

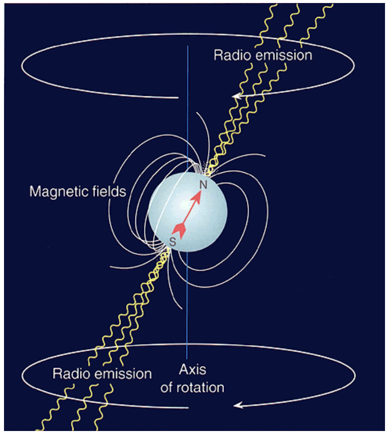
A partial list of sources...

- Binary coalescences
  - *"Bread and butter"* of the field

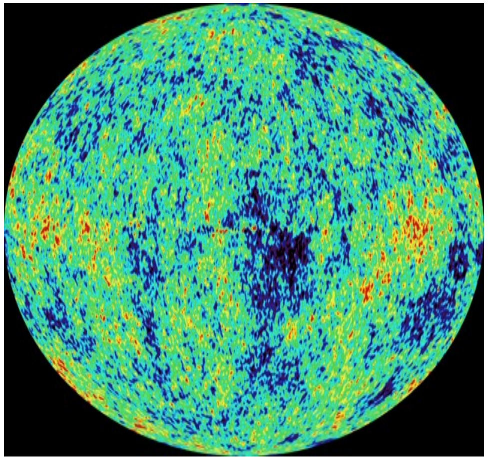


- Supernovae
  - Can GW be a third way to look at them?

- Rotating neutron stars
  - Possibly the cleanest signal of all



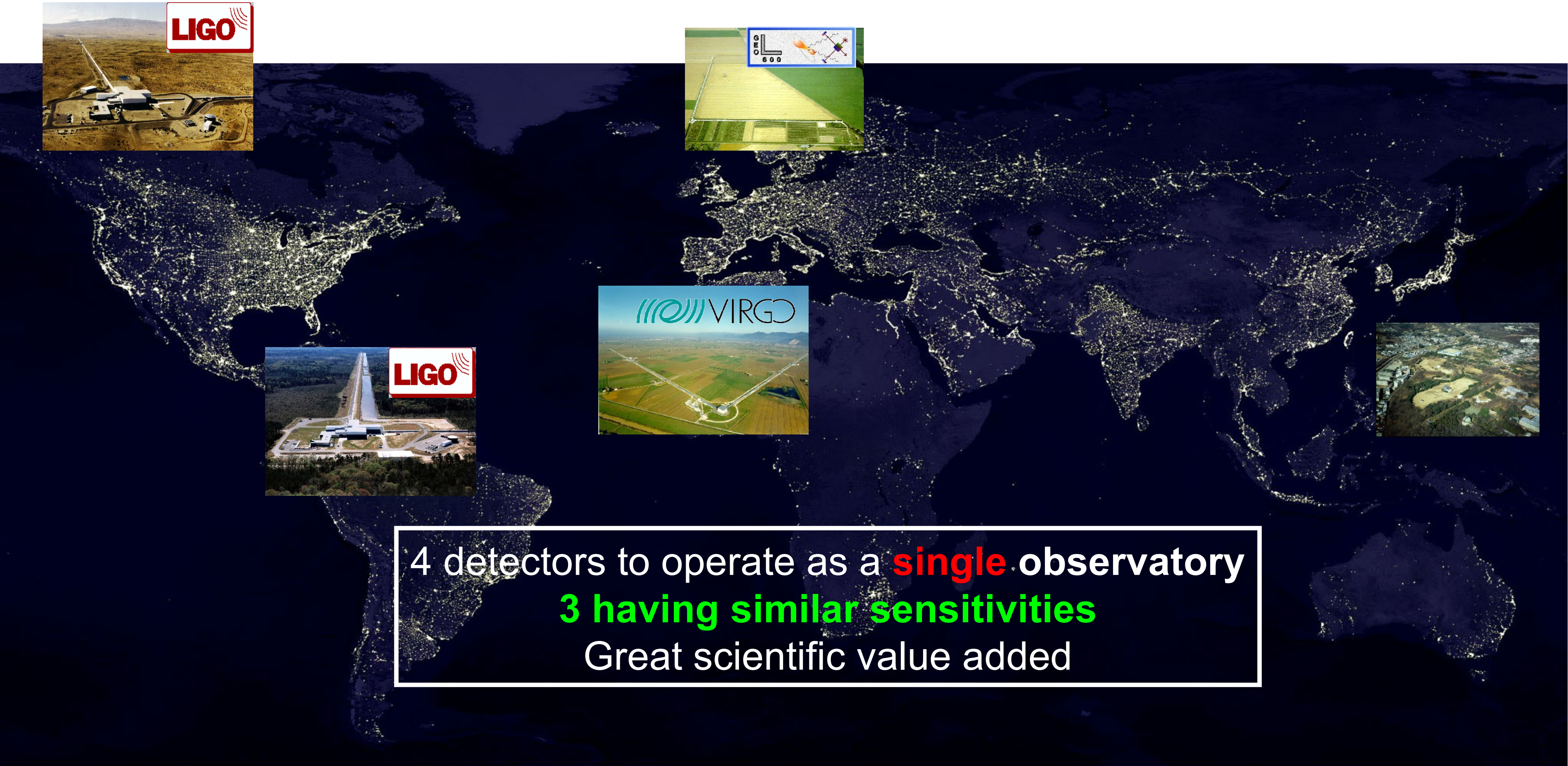
- Stochastic background
  - Key to first instants of the universe



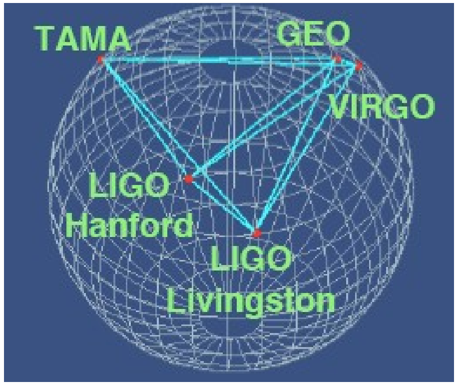
AdV as part of a network

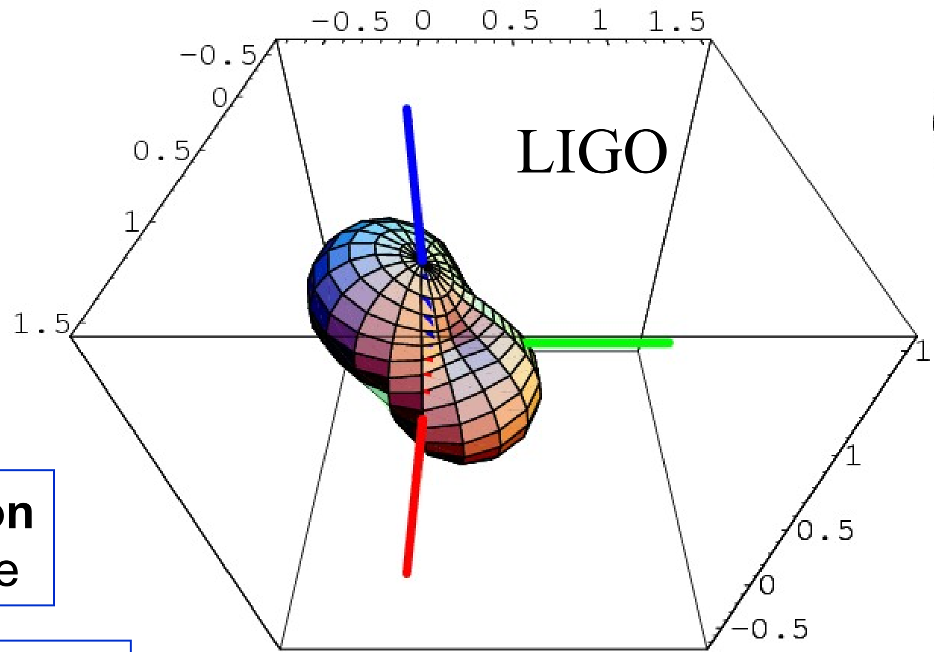
Joint Advanced LIGO – AdV observations

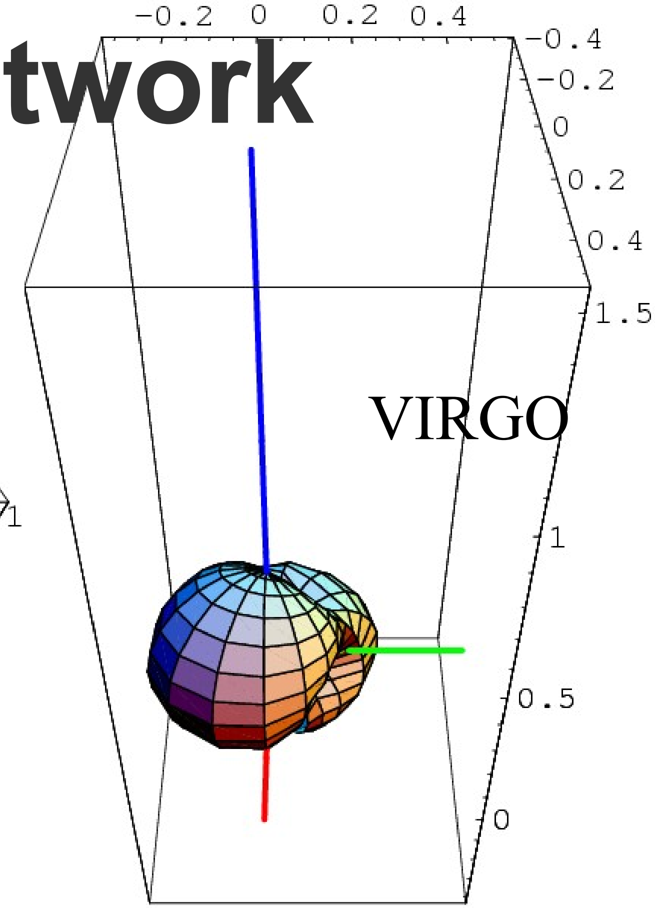
- Full exchange of data, joint analysis
- Joint science



Benefits of a network





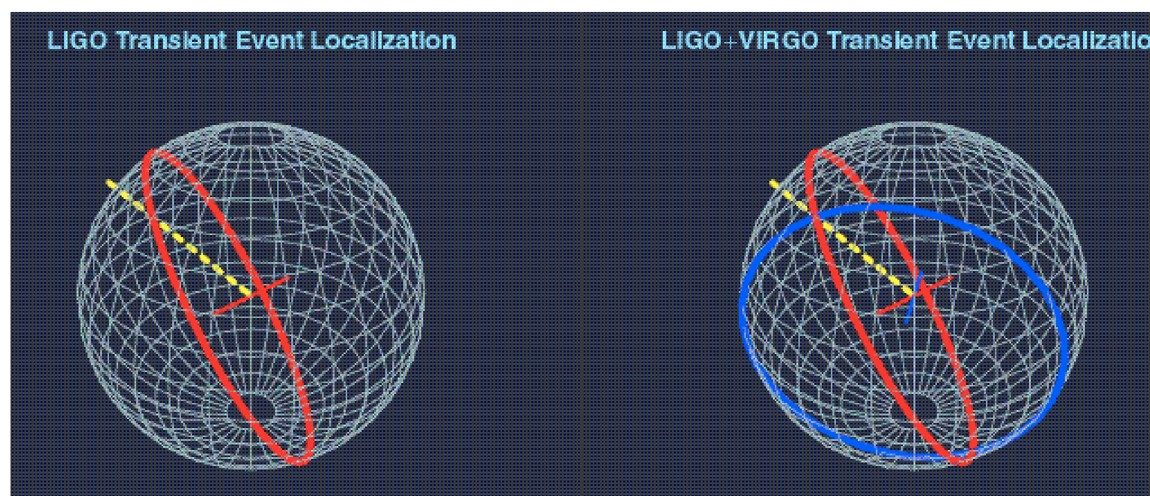


False alarm rejection
thanks to coincidence

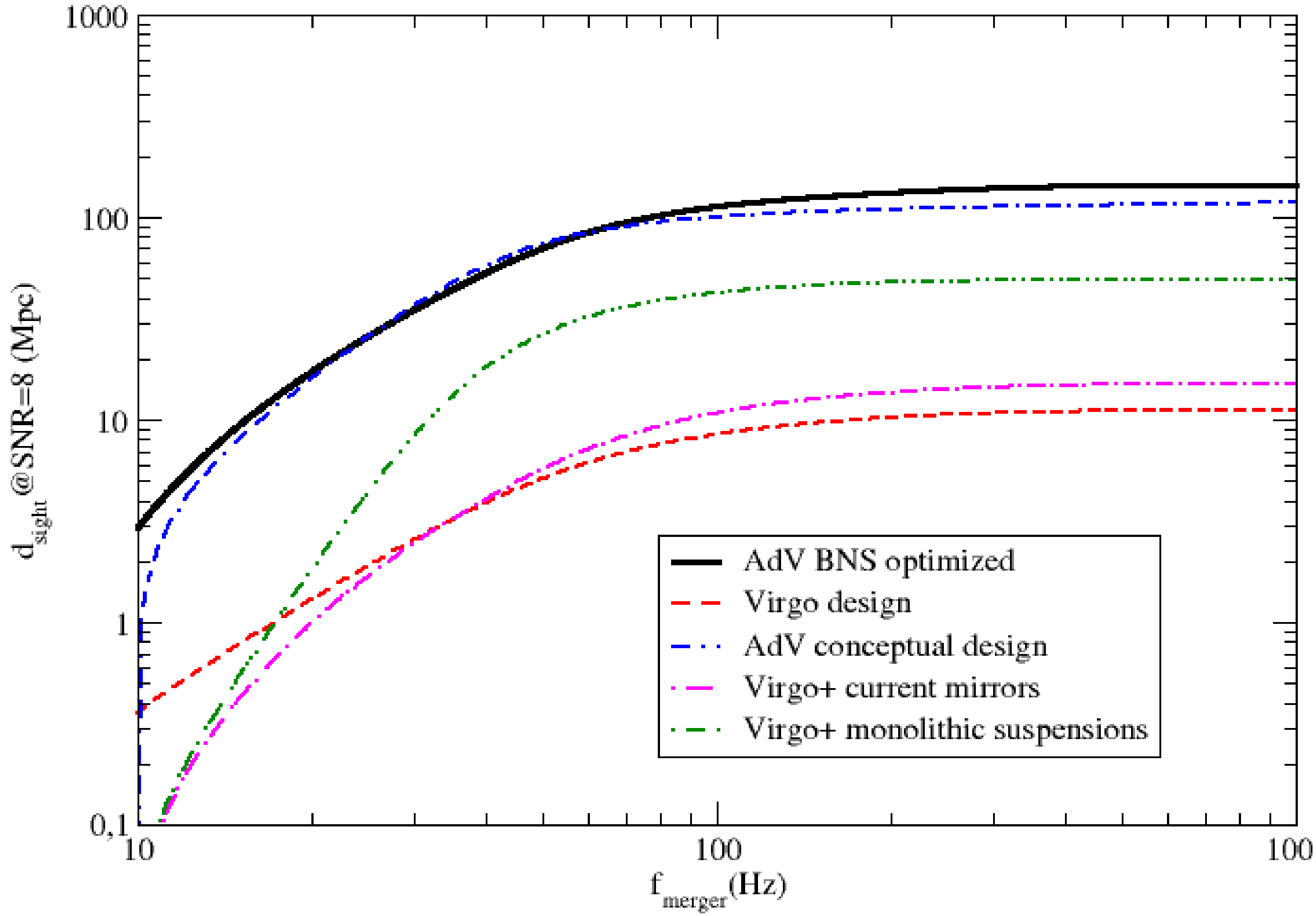
Triangulation allowing to
pinpoint the source

A network allows to deconvolve
detector response and regress
signal waveform -->
measure signal parameters

Joint operation yields a longer
observation time, and a better
sky coverage



Binary NS sight distance



$$\frac{d_{sight}}{1Mpc} = \frac{2}{5} \times 1.95 \times 10^{-20} \left[\frac{\mathcal{M}}{M_\odot}\right]^{5/6} \sqrt{\int_0^{f_{ISCO}} \frac{f^{-\frac{7}{3}}}{S_n(f)} df},$$

- AdV: ~150 Mpc
- Advanced LIGO: ~170 Mpc each detector

BNS events: how frequent?

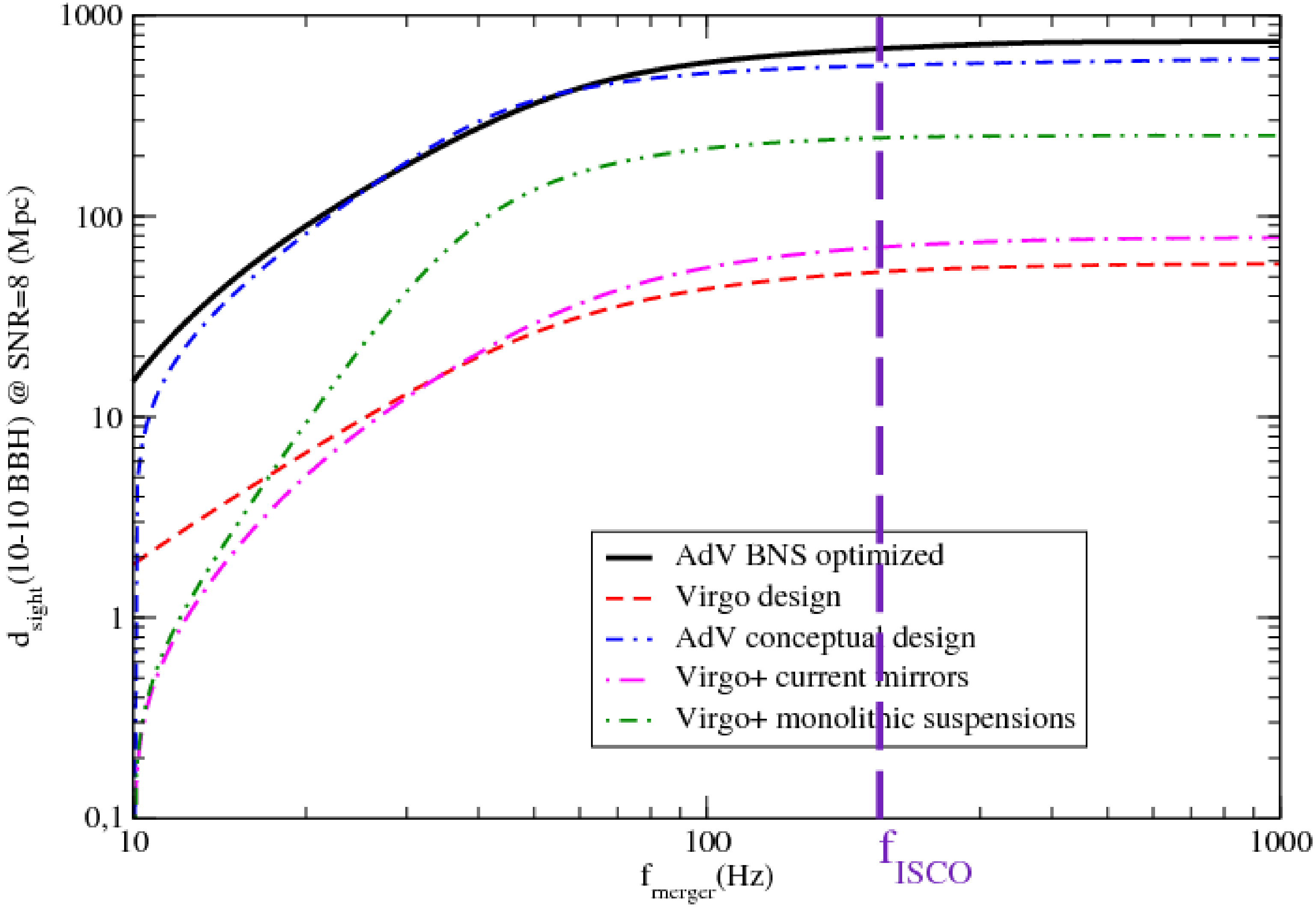
- **Empirical models**
  - Use observed (4) galactic binary systems coalescing on timescales comparable to Universe age
  - Infer # of events/Milky Way Equivalent Galaxy
  - Assume galactic density 0.01 Mpc^{-3}
- **Population synthesis models**
  - Use galactic luminosity to deduce star formation rate
  - Alternatively, use supernova events to calibrate the number of massive stars
  - Model binary formation and evolution to deduce # of systems coalescing in less than Hubble time

BNS: AdV predictions

model	merger rate ($Myr^{-1}MWEG^{-1}$)	detection rate (yr^{-1})	comments
empirical	3 - 190	0.4 - 26	empirical model
A	12 - 19	1.6 - 2.6	reference model
B	7.6 - 12	1 - 1.6	full CE accretion
C	68 - 101	9.2 - 14	CE for HG stars

- **Empirical model rather uncertain**
  - Small number of systems observed, little statistic
- **Population synthesis still unclonclusive**
  - Strong dependence on models
  - AdV alone sees from O(1) to O(10) events/year
- **AdV will operate together with LIGO!**
  - Combined sight distance may exceed 300 Mpc, if coherent analysis works as well as hoped
  - Network will see from O(10) to O(100) events/year

BBH sight distance



- AdV: ~ 700 Mpc

$$f_{ISCO} \simeq \frac{4\text{kHz}}{(M/M_{\odot})}$$

BBH: pop. synth. predictions

Model	$\mathcal{M}/M\_\odot$ range	$d_{eff-sight}$Mpc	merger rates Myr^{-1}	AdV detection rate yr^{-1}
A	$5-8$	613	$0.02-0.03$	$0.2-0.3$
C	$2.5-8.5$	545	$7.7-11$	$52-75$

- **Notes**
  - Sight distance is *effective*: takes into account the distribution of masses in the population synthesis
  - Only masses < 10 M are simulated
- **BBH population synthesis *very* uncertain**
  - Merger rates vary by factors of hundreds
  - **If model A is true, prospects of detection are dim!**
  - *However ...*

BBH: empirical prediction

- **IC10 X-1**
  - Binary system in local group (~ 700 kpc)
  - Includes a BH, m~24 M_o,
    and a massive Wolf-Rayet star, m~ 35 M_o

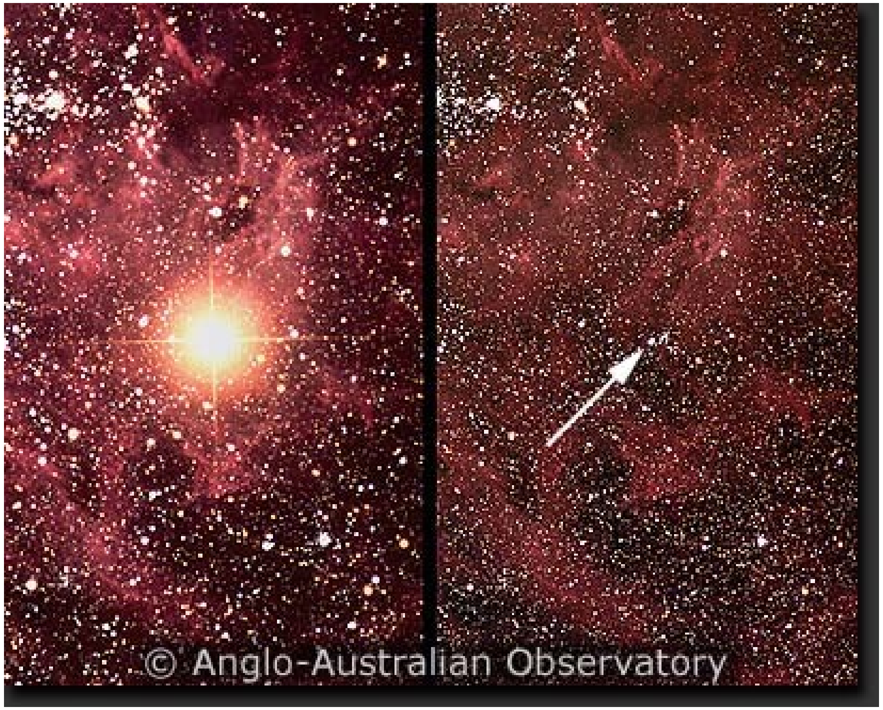
- **Allows to predict a rate (Bulik et al.)**
  - The WR will evolve in BH, without disrupting the binary system
  - The resulting system should have M_{chirp}~14M_o
  - Such systems are detectable by AdV up to 1.1 Gpc ...
  - Rate for AdV should be ~ 250 /year

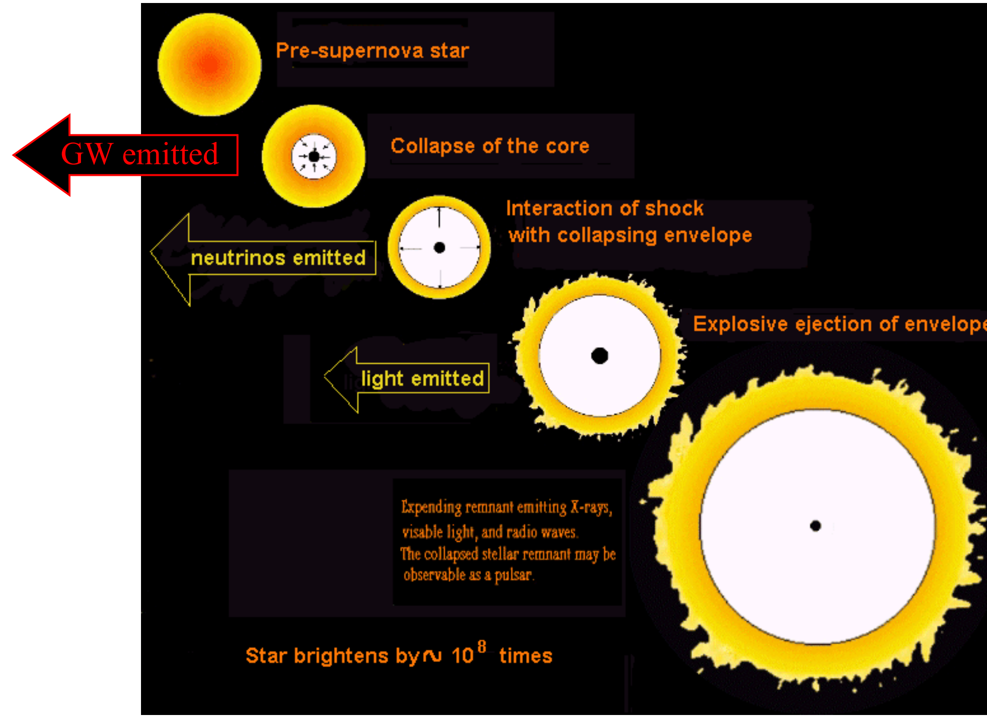
Rate for combined Advanced LIGO – AdV ~ 2500/year

Binaries: network advantages

- **Detection probability increase**
  - Advanced LIGO will have 300 Mpc coherent sight distance for BNS; corresponds to three detectors having d~170Mpc in coherent mode
  - AdV will boost sight distance by 10% -> rate by 30%
- **More importantly, detection confidence**
  - Allow checks based on coincidencing and on requiring amplitude consistency (NULL streams techniques)
- **Event reconstruction**
  - Location of the source in the sky
  - Reconstruction of the polarization components
  - Reconstruction of the amplitude @ source, hence
  - **Determination of the source distance**

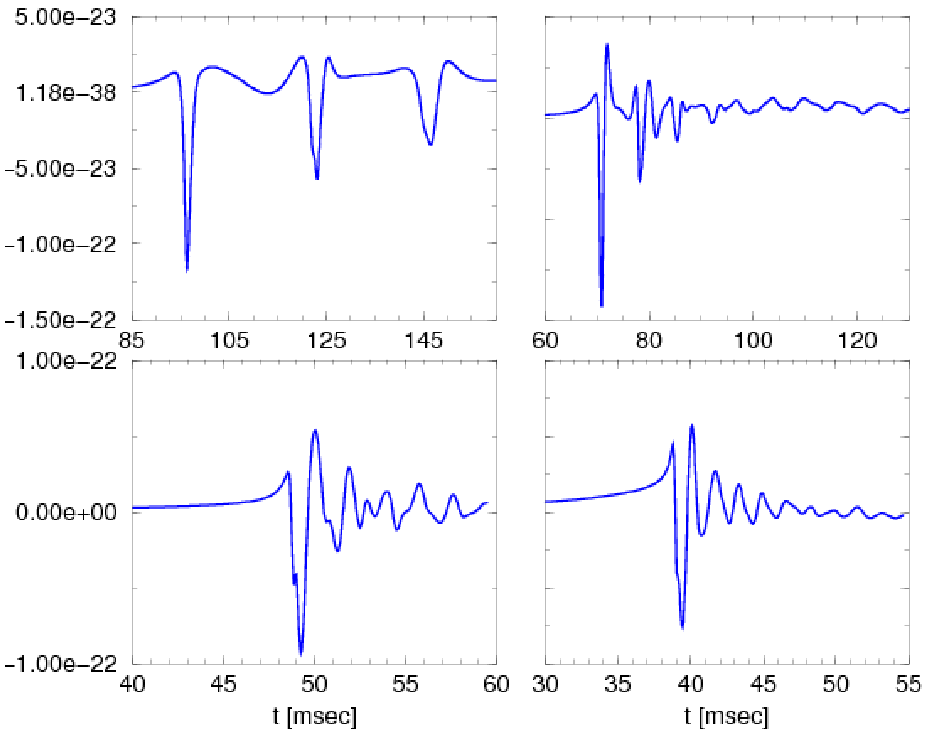
Core-collapse supernovae ...

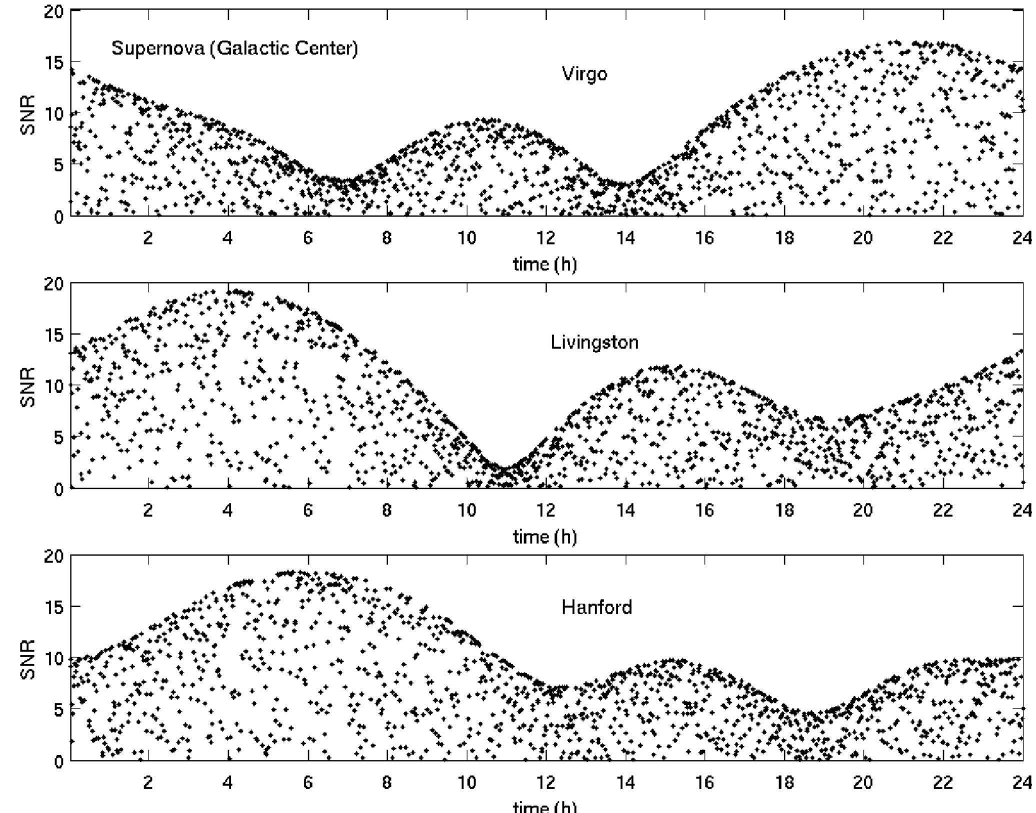




- **A possible mechanism for short bursts of GW energy**
  - Not the only one! But uncontroversial about its existence
  - Clear correlation between ν and GW emission
- **Events relatively rare in our Galaxy**
  - Less than 1 event/20 yrs in the local group
  - Sanduleak, or 1987a, was the latest in the Milky Way

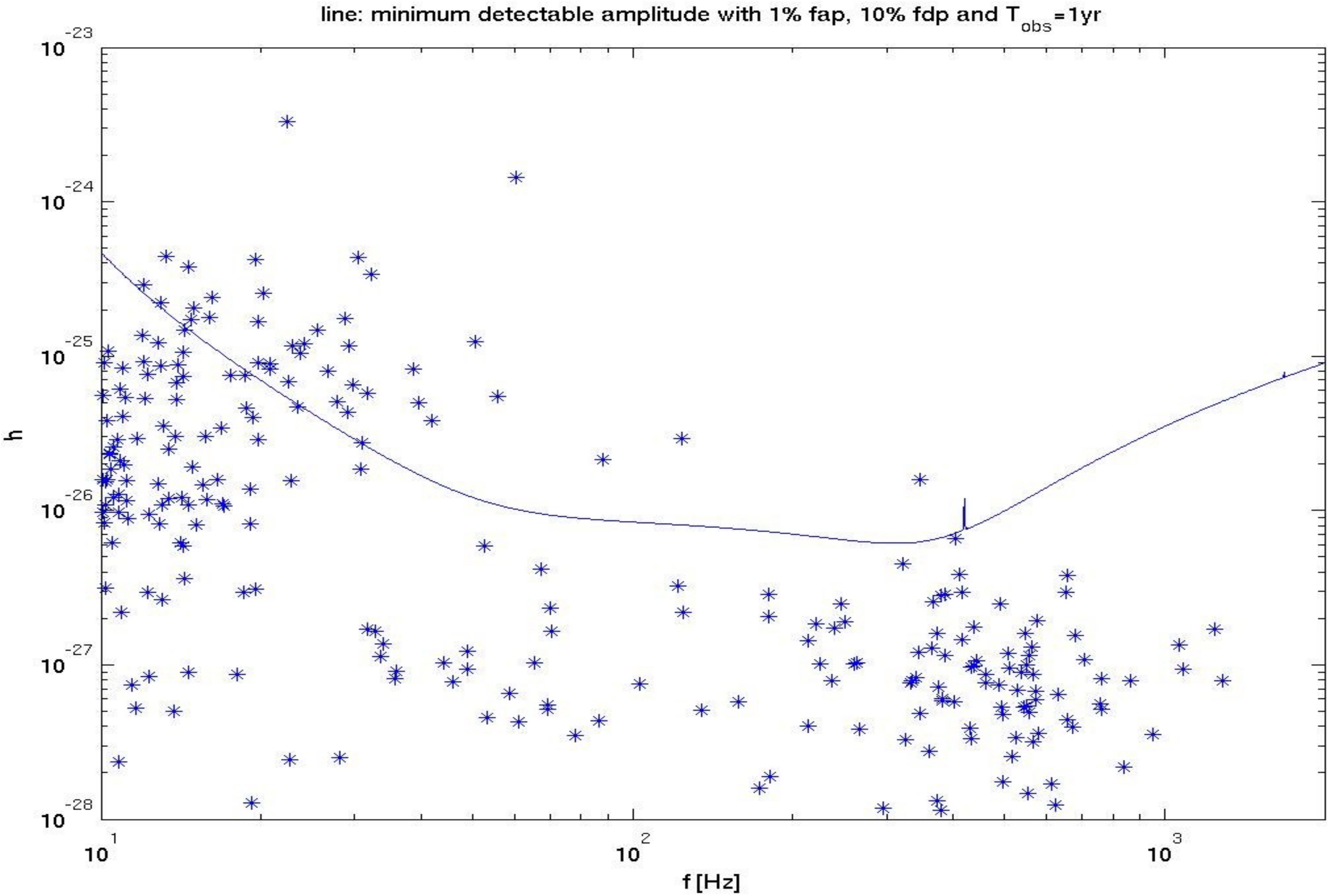
.. and the advanced network





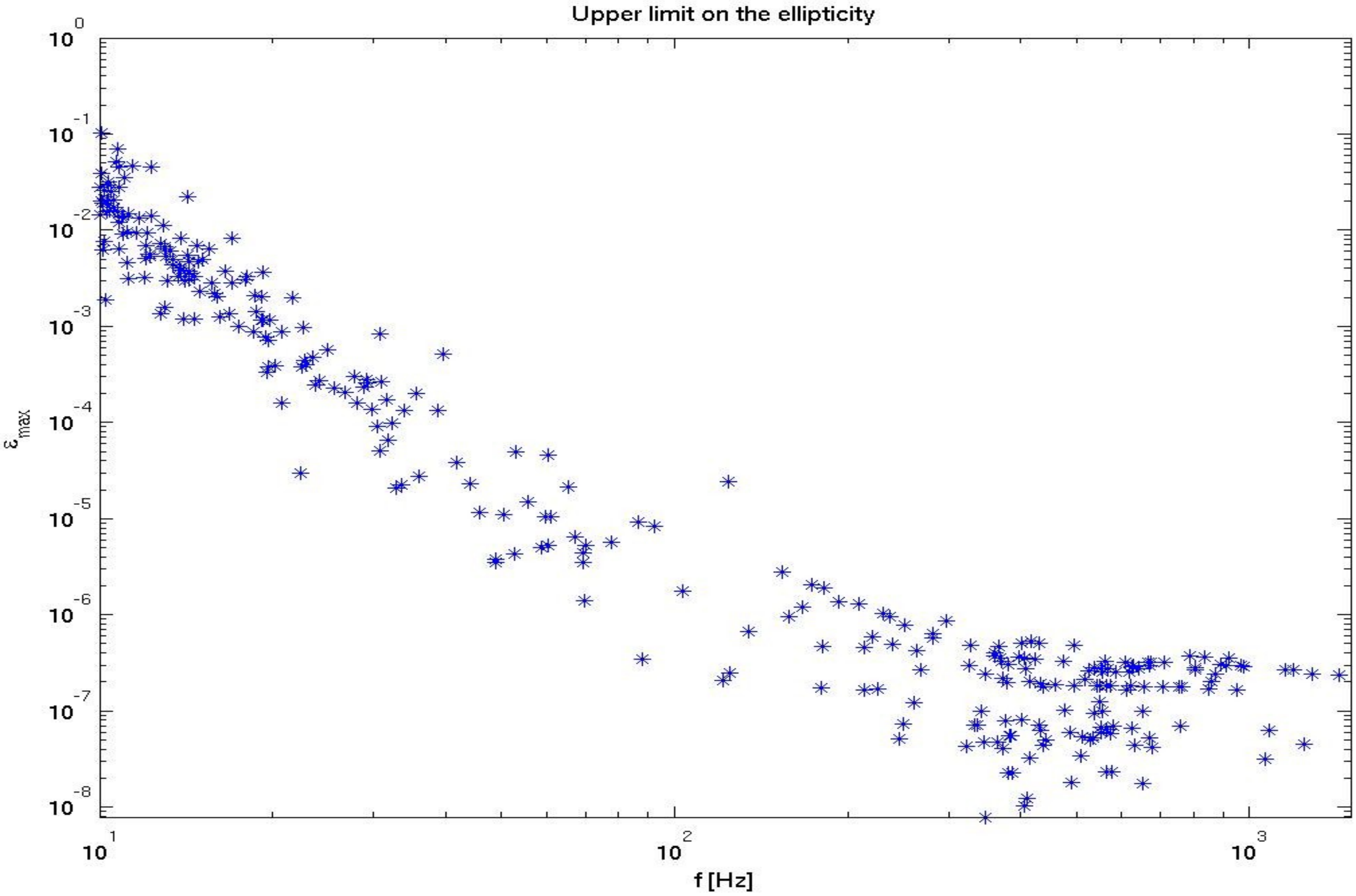
- Waveforms poorly known, and signal weaker than BNS
- AdV + AdLIGO will guarantee the galactic coverage
- As for BNS, source parameters will be accessible
- A very good timing, in conjunction with ν detection, could constrain ν mass strongly

Known pulsars: limits on *h*



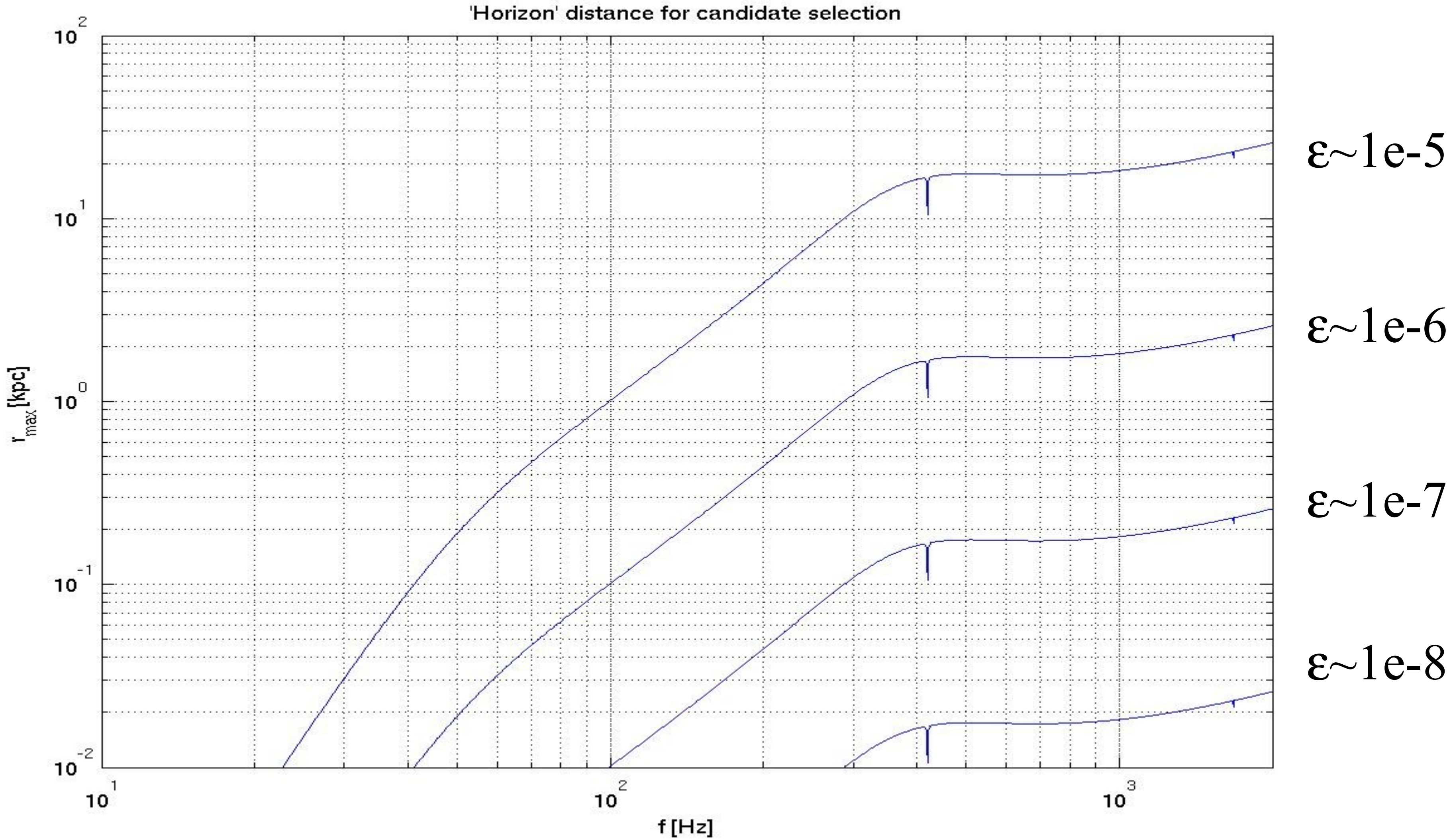
- Dots: spin down limits.
- Beaten by AdV for about 40 known objects

Known pulsars: limits on ε



- Dots; minimal ε in the hypothesis of reaching h_{min}
- More interesting at higher frequencies (smaller ε values)

What about unknown NS?



- Distance at which the blind search would select a candidate
- **AdV covering a fraction of the Milky Way**

AdV – AdLIGO network & pulsars

- **Coherent analysis sensitivity grows as #detectors$^{1/2}$.**
  - Gain a factor 2
  - Well motivated for **known** sources.
- **Blind search sensitivity grows as #detectors$^{1/4}$**
  - Coherent analysis boost at best by a factor 40%
  - Use coincidences of candidates to cut the false alarm rate.
- **Further benefits of AdV in the network**
  - Good sensitivity at low frequencies
  - Stronger limits on objects like Vela and Crab

Cosmological stochastic background

Frequency distribution of SNR

The upper limit for a power law model

$$\Omega_{GW}(f) = \Omega_{f_0}\left(\frac{f}{f_0}\right)^n$$

can be written as

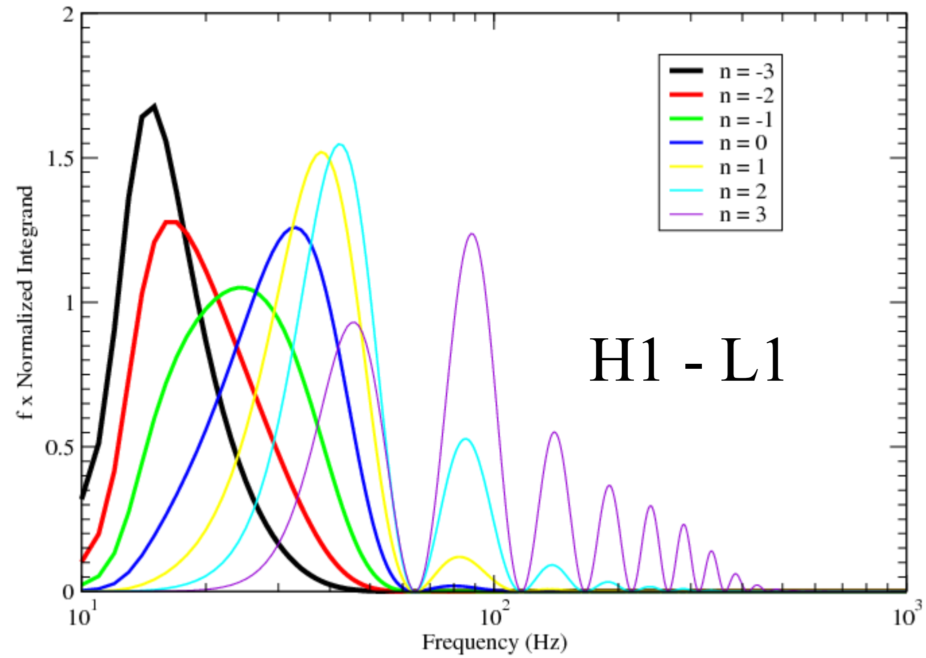
$$h_{100}^2\Omega_{f_0} > \beta\frac{10\pi^2}{3H_0^2}\frac{1}{\sqrt{T}}\left(\int df\, I(f)\right)^{-1/2}$$

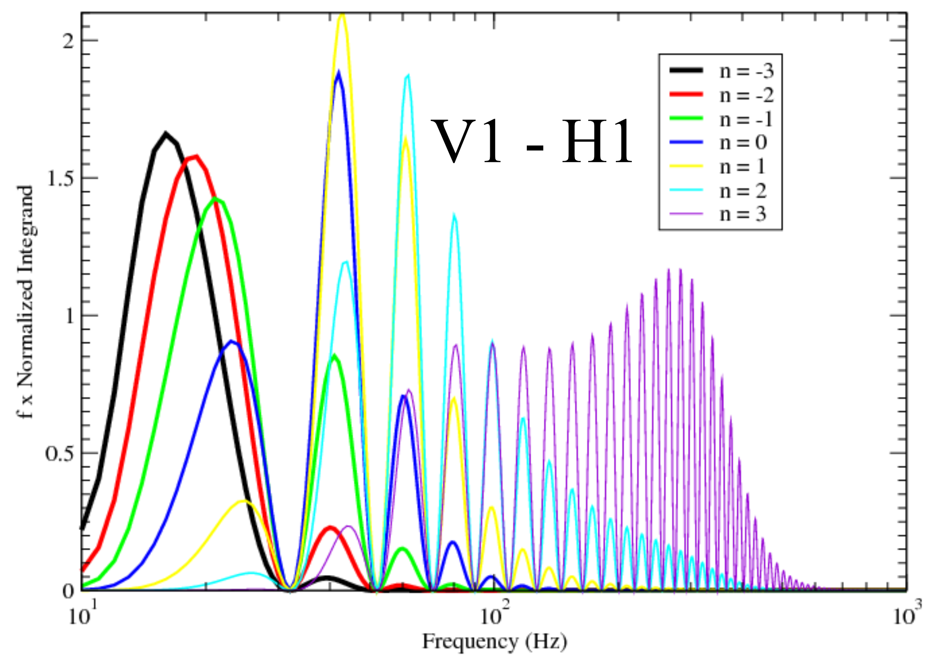
here

$$I(f) = \frac{\gamma^2(f)}{f^6 S_1(f) S_2(f)}\left(\frac{f}{f_0}\right)^{2n}$$

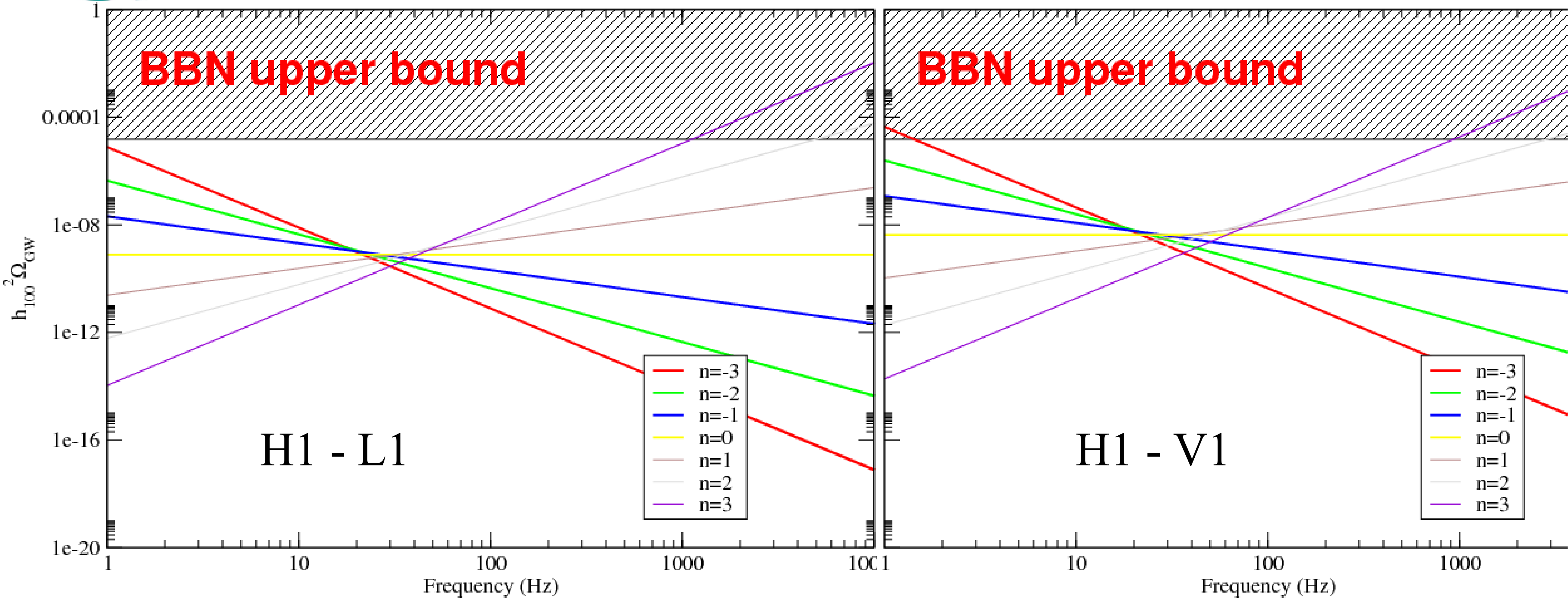
- β : statistical factor related to false dismissal and false alarm probability
- γ(f) : overlap reduction function
- S_i(f): spectrum of detector noise

Correlation signal is differently distributed in frequency for LIGO pair and for LIGO-Virgo



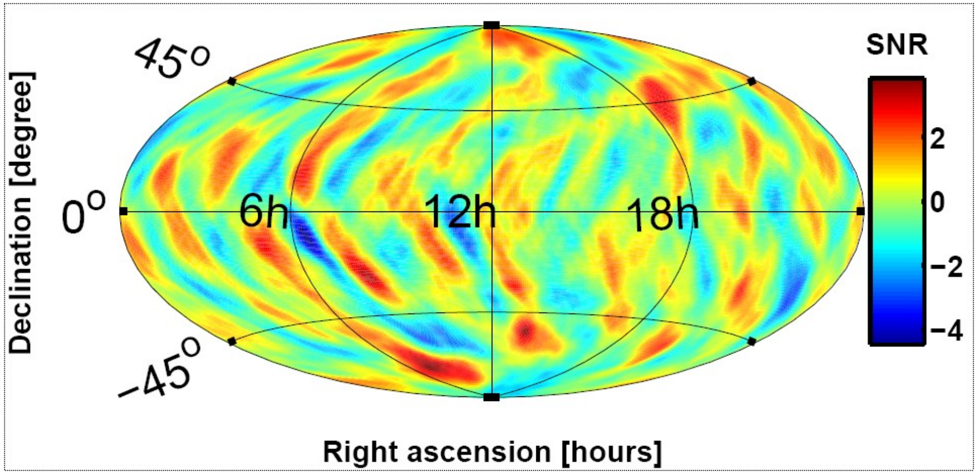


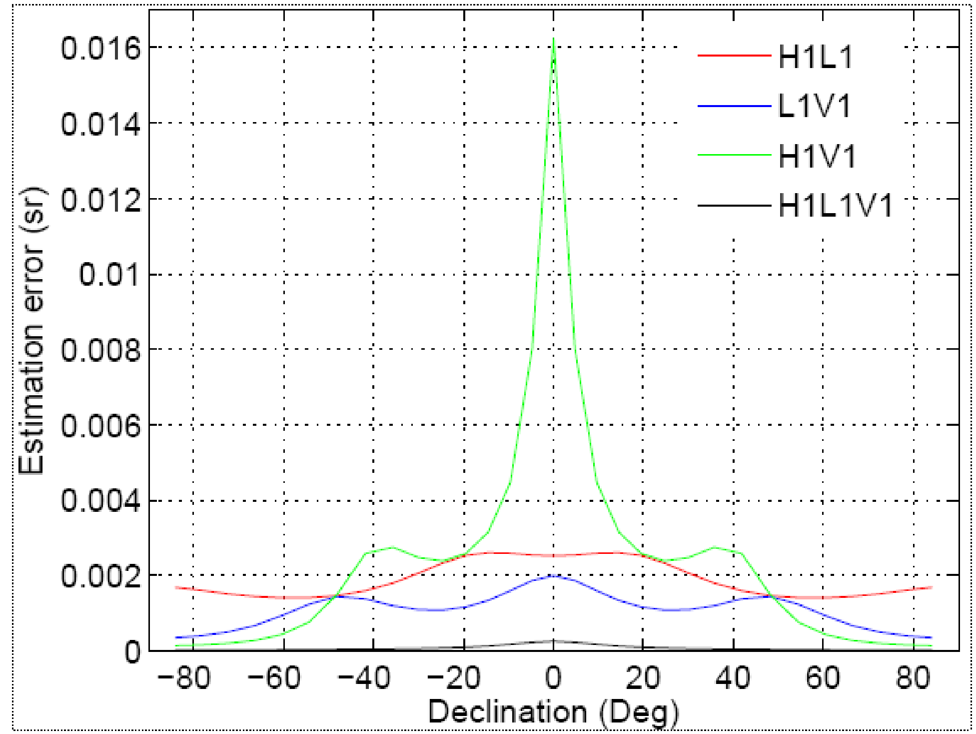
Limits for power law models



- **One year of operation of AdV – AdLIGO**
  - Will improve over nucleosynthesis bounds by several orders
  - For comparison, LIGO S5 results should be just below BBN limit
  - AdV contribution depends on the exponent n of the stochastic background model, and is more relevant for larger n

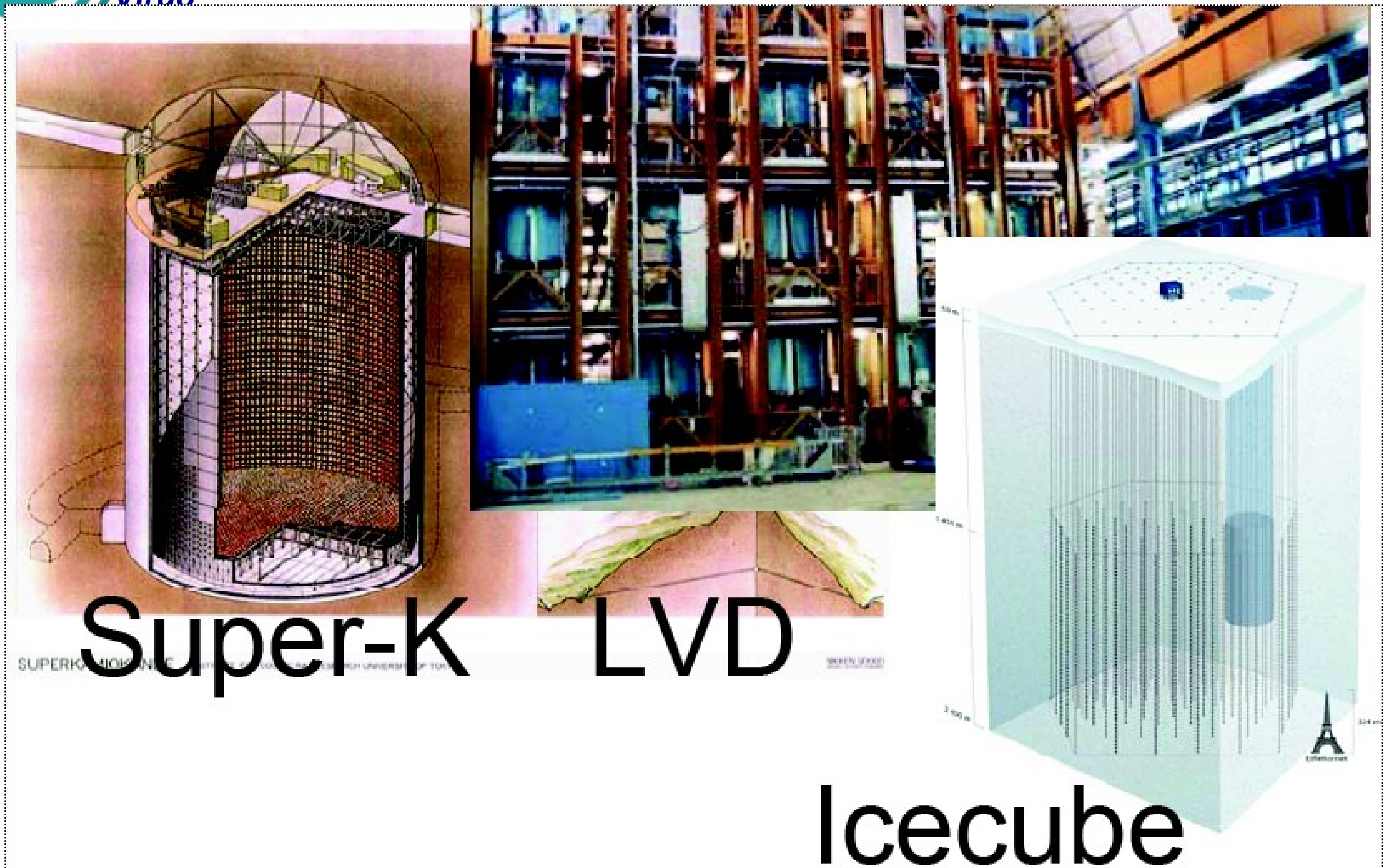
Astrophysical backgrounds





- **A network can locate point sources of random GW signals**
  - Such could be objects of astrophysical interests, for instance very large black holes in active galaxies
  - LIGO – Virgo network, with multiple baselines, improves sensitivity by 25% at equator and by 42% at poles, over LIGO only
  - Source localization is improved by a factor O(10)

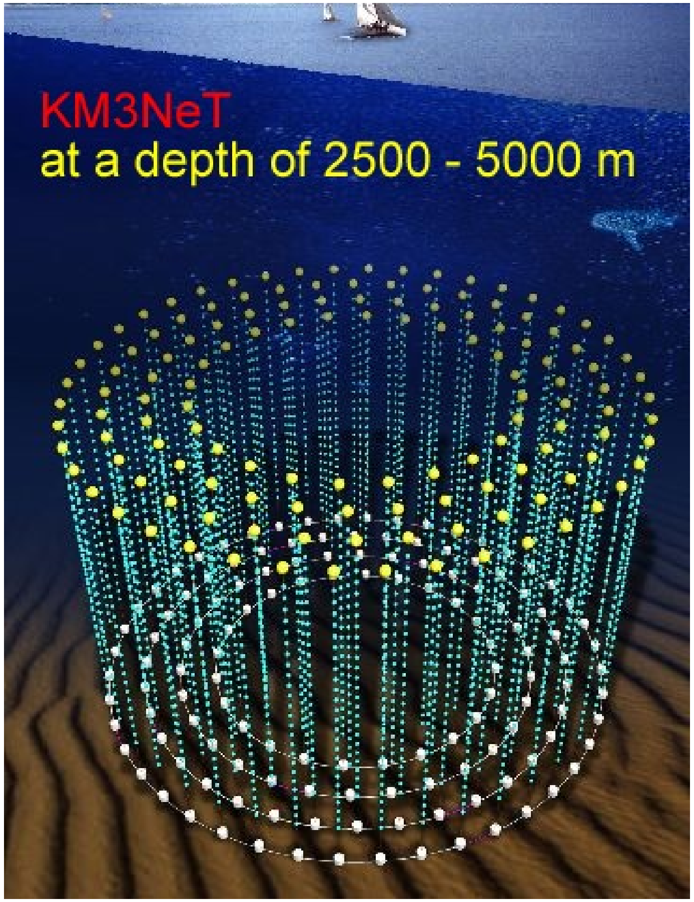
Targeting SNe; low energy ν's ...

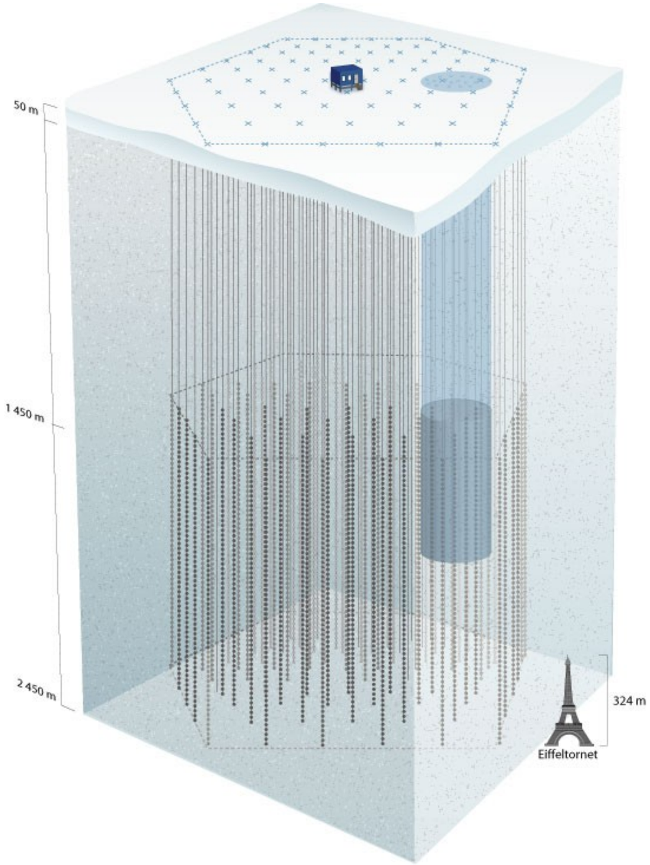


- **Boost detection confidence**
  - Neutrino and GW expected within a few ms delay
  - Very tight coincidence can be required
- **Constrain ν mass strongly**
  - 1ms accuracy: $m_\nu < 1eV$ constrain

$$\delta t_{prop} = 5.2ms \frac{d}{10kpc} \left(\frac{m_\nu}{1eV}\right)^2 \left(\frac{10MeV}{E_\nu}\right)^2$$

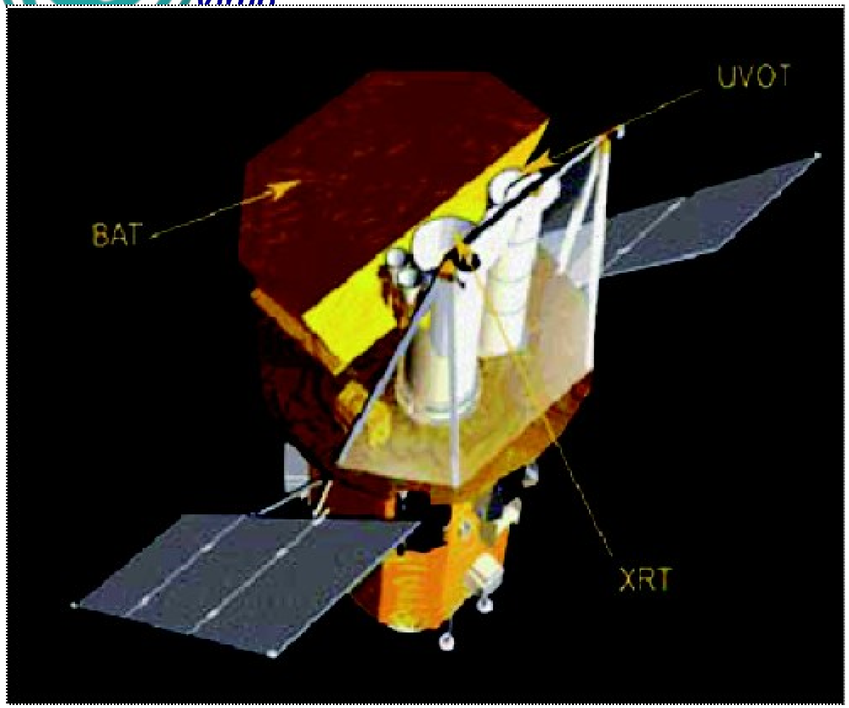
High energy ν's





- **KM3Net and IceCube will see ν with E up to 100's GeV**
  - Coverage of Southern and Northern sky
  - Reconstruction capabilities in the 1° range
  - Common targets: GRB's, SGR giant flares, etc...

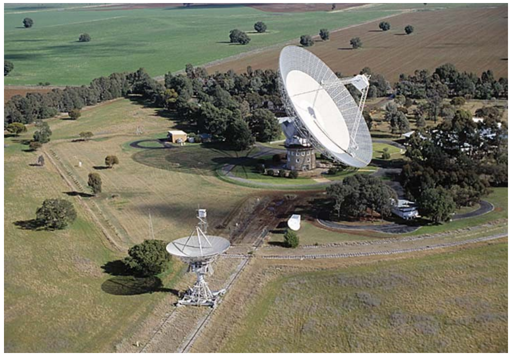
Targeting GRB events



- **Swift now, Fermi (GLAST) keep looking at γ rays from GRB**
- **GRB powered by accretion disks on newly formed objects**
  - Neutrino and GW expected within a few ms delay
- **Short GRB (< 2s) potentially related to BNS, BH-NS**
- **Long GRB (>2s, average 30s) related to (classes of) SNe**
  - Again, boost detection confidence
  - Provide insight in the fireball mechanism

Other messengers ...

- **Radiotelescopes**
  - Crucial, f.i. to “lock” on pulsar signals



- ***(Automated)* Optical telescopes**
  - To alert us of interesting events
  - To be alerted by us of triple coincidences

- **X-ray telescopes**
  - Privileged eyes on the hot material falling into compact objects
  - For instance, in LMXB
  - Another eye at GRB events
  - ..

Conclusions

- **AdV and Advanced LIGO will do great Science!**
  - The models anticipate several sources to be seen or strongly constrained
  - The AdV contribution is **crucial** for characterizing any event and fully extract available physics information
  - Source physics will be accessible: not only to check GR predictions, but to contribute to the understanding of SNe, GRB's, LMXB, NS structure...
- **Lots of multimessenger opportunities**
  - Collaborating with E.M. and ν detectors will increase the search sensitivity, or equivalently detection confidence.
  - Joint studies will shed light on emission mechanisms.