Perspectives on detector networks, and noise

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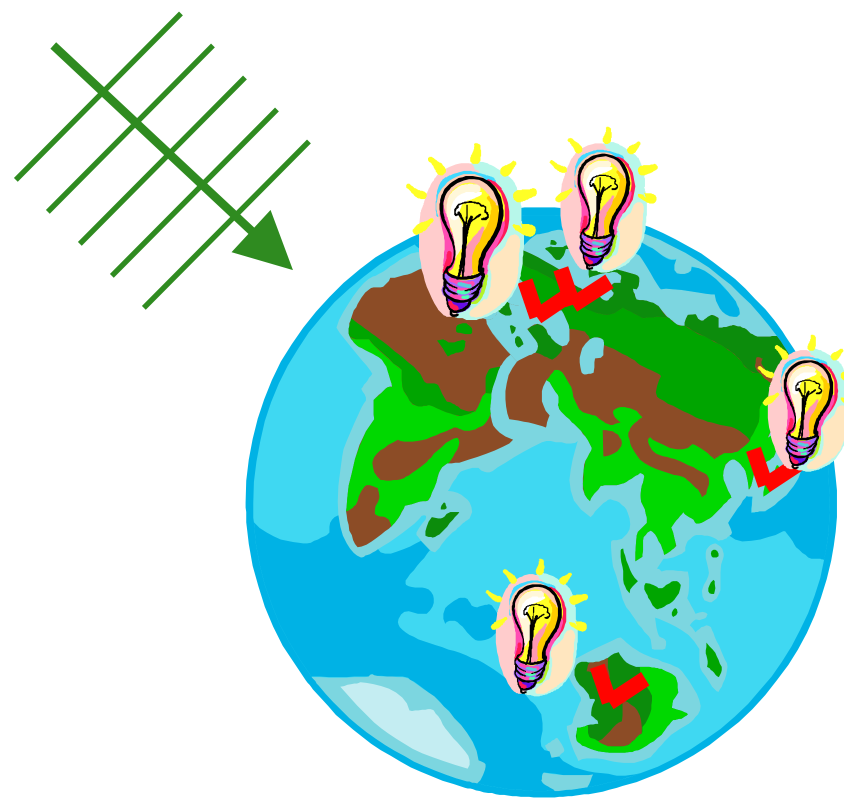
Overview

- Coincidence, Correlation and the Effective Detector
  - Is the whole less or greater than the sum of the parts?
- In the presence of non-Gaussian noise
  - The effectiveness of the Normal distribution, and going beyond

- Cf. Finn, "Aperture synthesis for grav. wave data analysis…", PRD **63**, 102001 (2001)

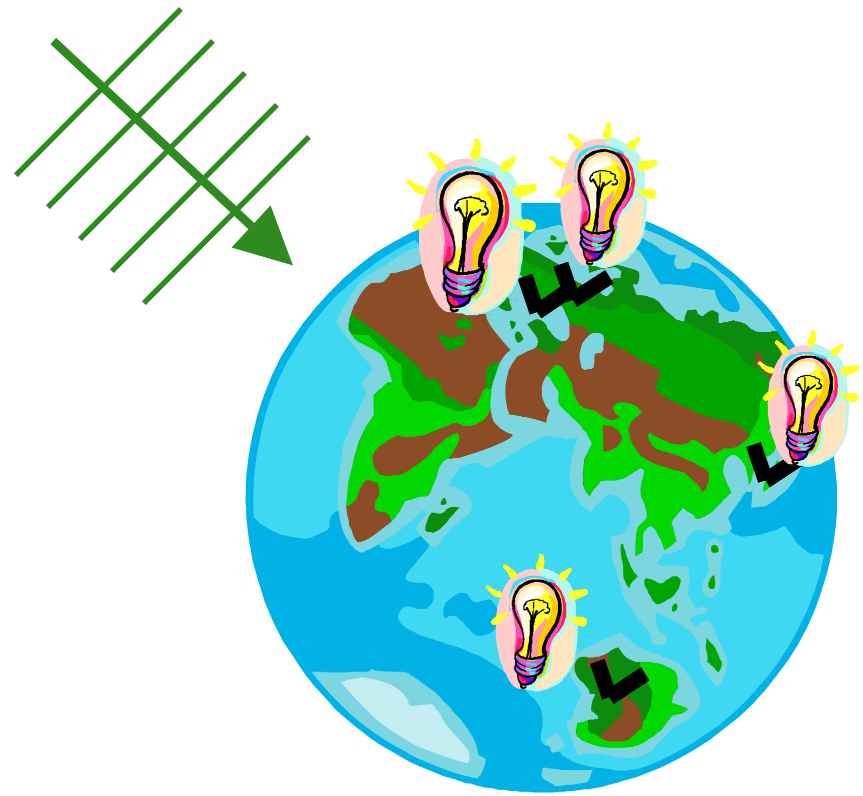
Coincidence …

- Incident plane wave interacts with an array of detectors
- Coincidence
  - Detection if each detector registers wave's passage
- Sensitivity limited by weakest link …
  - No detection, no coincidence
- … or gain nothing by including weaker detectors
  - Too high false rate leaves statistics unimproved



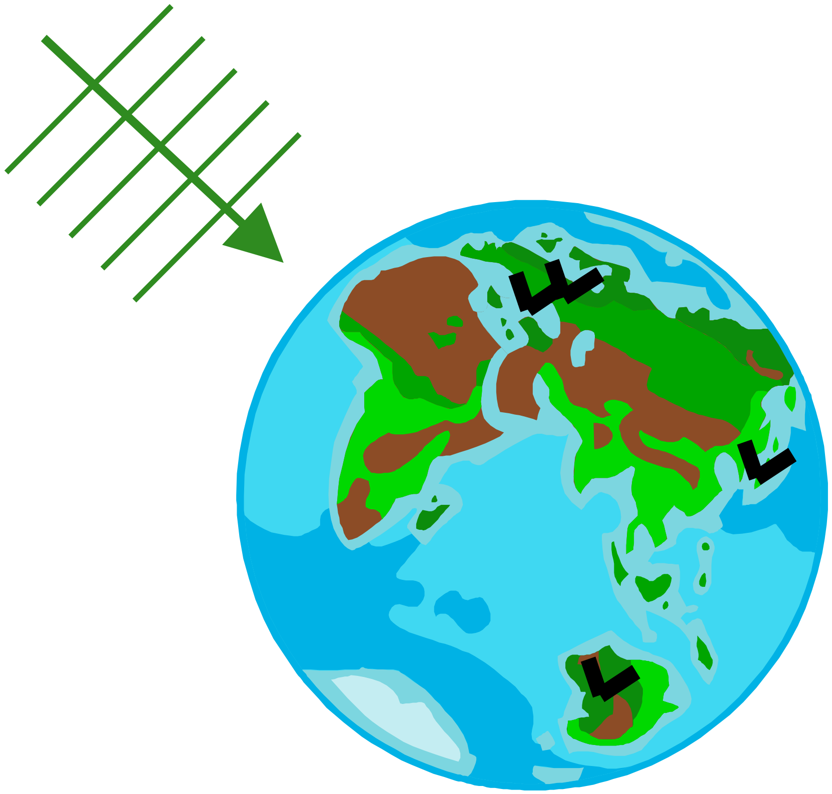
Coincidence …

- Incident plane wave interacts with an array of detectors
- Coincidence
- Sensitivity limited by weakest link …
- … or gain nothing by including weaker detectors
- But what if we shouldn't have seen anything in a given detector?
  - Polarization, amplitude, signal bandwidth, *etc.*



… and Correlation

- Incident plane wave interacts with array of detectors
- Detector array responds *coherently*
  - I.e., relative timing, polarizations, amplitudes
- Treat network response via likelihood techniques
  - I.e., optimal filter when signal known
- Sensitivity?



Correlation

- Recall optimal filter for single detector:

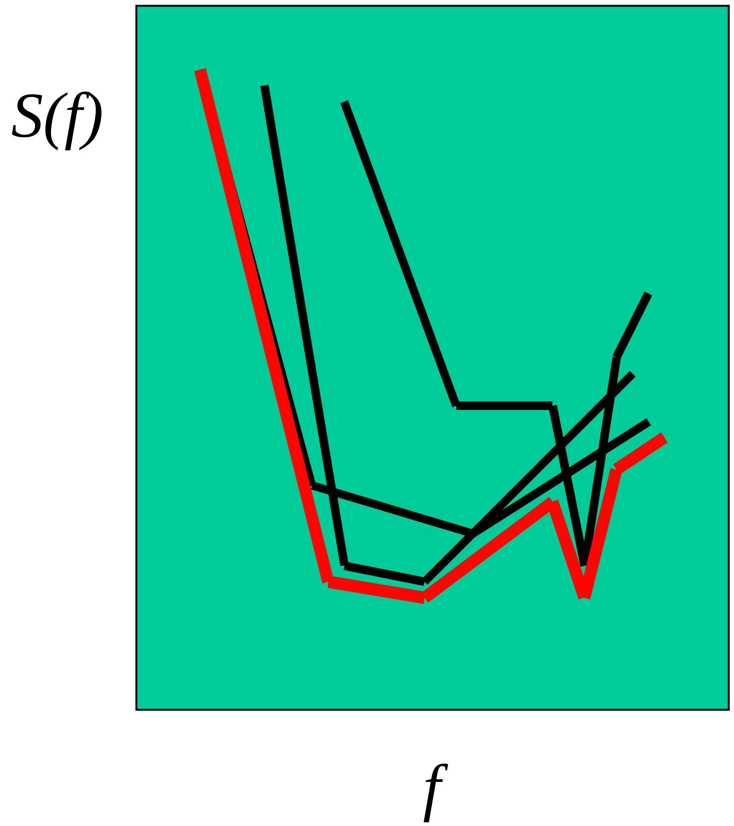
$$\langle h, m \rangle_k = \int df \, \frac{\tilde{h}(f)\tilde{m}^*(f)}{S_k(f)}$$

- For multiple detectors and no inter-detector noise correlations:

$$\langle \vec{h}, \vec{m} \rangle = \sum_k \langle h_k, m_k \rangle_k$$

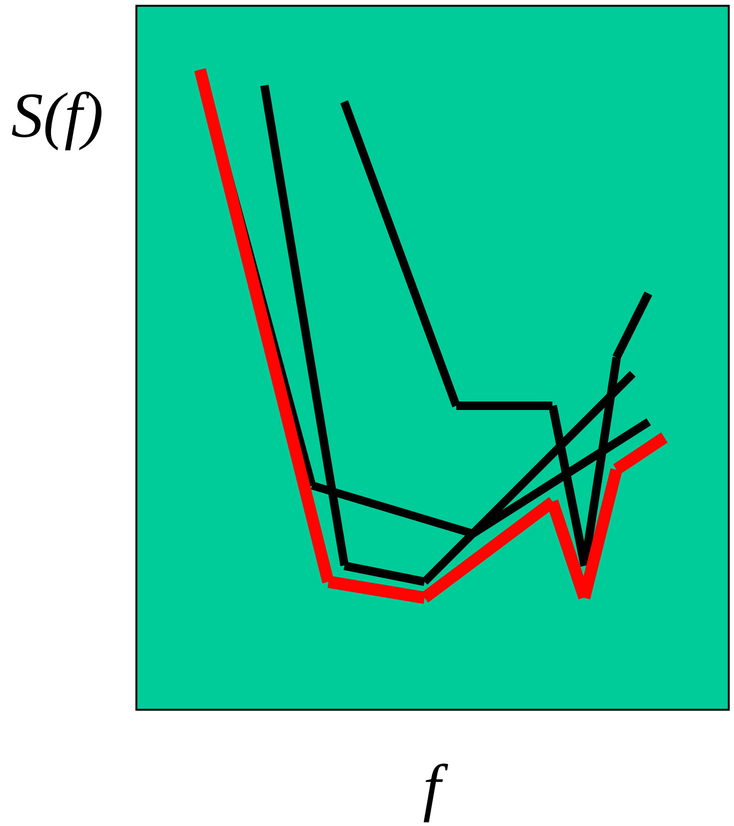
- The *effective detector* noise spectrum:

$$S(f) \approx \left[\sum_k S_k^{-1}(f) \right]^{-1}$$



Correlation

- Additional detectors *always* reduce effective detector noise
  - No more "weakest link" *vis a vis* sensitivity
- Effective detector best envelope of component detectors
  - Get Virgo's low frequency response, LIGO's mid-frequency, GEO's RSE high-frequency, etc.
- Polarization, amplitude, signal bandwidth all accommodated
  - Effective detector noise direction, orientation dependent



What if noise non-Gaussian?

- What *if* noise non-Gaussian!
  - As long as stationary…
- Suppose know only mean, variance (i.e., psd S(*f*))
  - What probability distribution P(x) makes least assumptions about noise character? The *maximum entropy* distribution:

$$0 = \delta \int dx \left[P(x) \log P(x) + \lambda_0 P(x) + \lambda_1 x P(x) + \lambda_2 x^2 P(x) \right]$$

$$P(x) \propto \exp\left[-\frac{(x-\mu)^2}{2\sigma^2} \right]$$

- Extensible to higher-order moments
  - As long as highest order even

Summary

- Coincidence
  - Effective only when working with detectors of comparable sensitivity in comparable bands with comparable polarization …
- Correlation
  - The whole is greater than the sum of the parts
  - Failure to “see” in a given detector is positive information!
- In the presence of non-Gaussian noise
  - The Normal distribution, and “optimal” filtering, is the most robust choice if only noise mean, PSD are known
  - Can do better (with cost!) if additional information available. Critical information is higher-order moments of distribution