A search for gravitational waves from Cassiopeia A using LIGO S5 data

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Cassiopeia A

Youngest known
neutron star
(ca. 300 years)

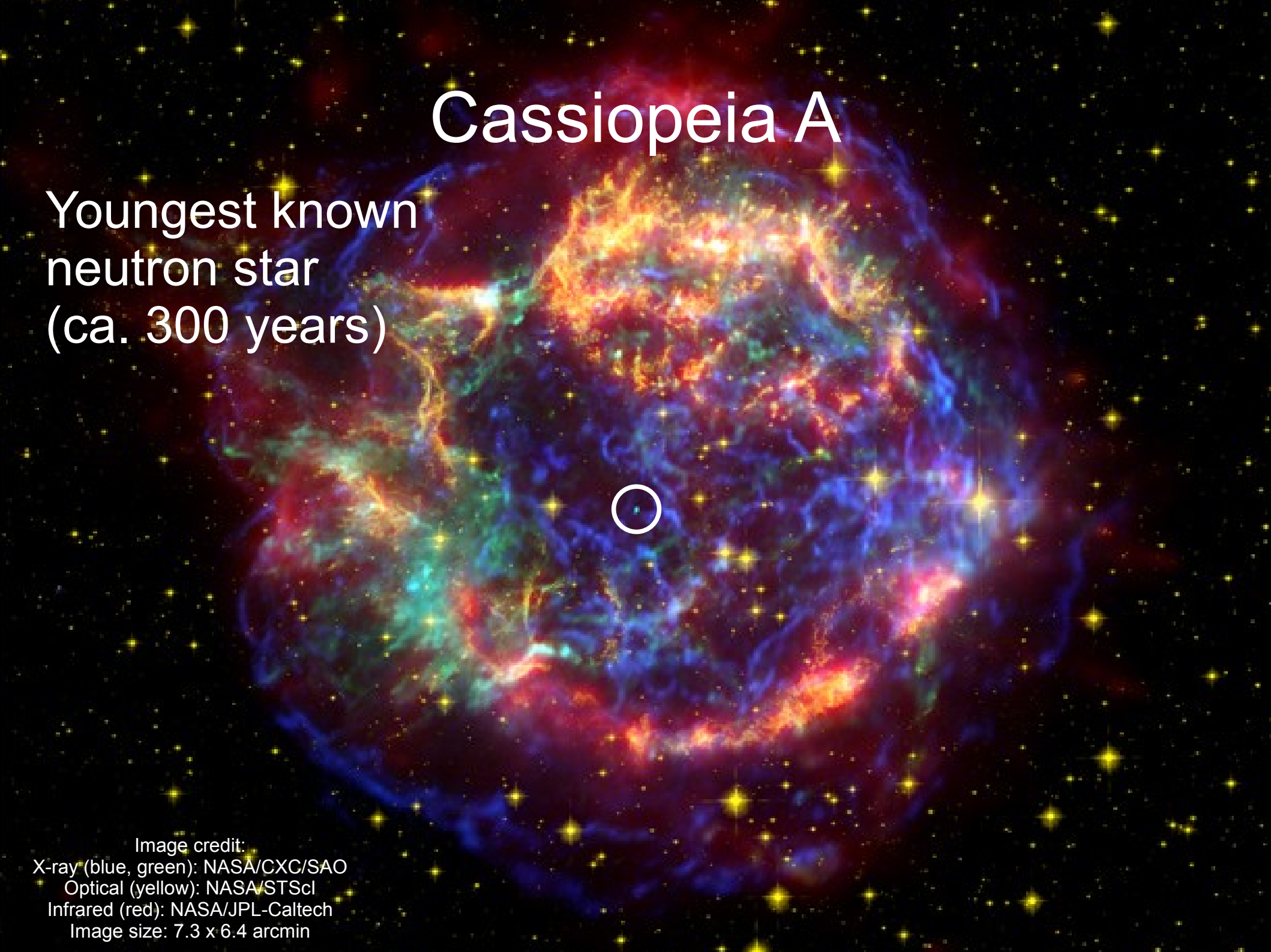
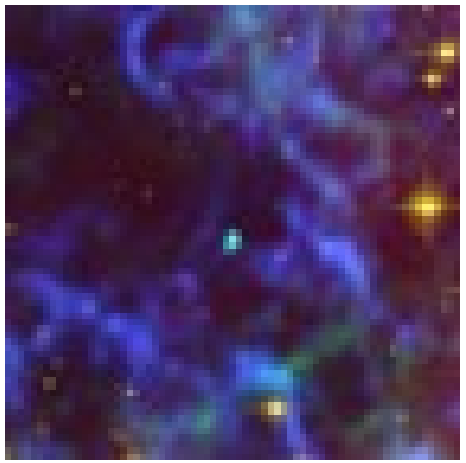


Image credit:
X-ray (blue, green): NASA/CXC/SAO
Optical (yellow): NASA/STScI
Infrared (red): NASA/JPL-Caltech
Image size: 7.3 x 6.4 arcmin

The neutron star in Cas A



- Isolated system
- No radio/x-ray pulsations
  - No known rotation frequency
  - So not a pulsar
- Possible neutron star models:
  - Highly magnetized, slow rotation, not good for GW detection
  - Weakly magnetized, higher rotation, potential for GW detection

Why is Cas A interesting?

- Can derive an indirect limit on gravitational wave strain h_0 or neutron star ellipticity ε
- Method is similar to known pulsars
  - Assume all rotational energy goes into GWs
  - Spindown is not known, assume ∝ 1 / age
- Limits are:

$$h_0 < 1.2 \times 10^{-24} \left(\frac{3.4 \text{ kpc}}{D} \right) \sqrt{\frac{300 \text{ yr}}{\tau} \frac{I_{zz}}{10^{45} \text{ g cm}^2}}$$

$$\epsilon < 3.9 \times 10^{-4} \left(\frac{100 \text{ Hz}}{f} \right)^2 \sqrt{\frac{300 \text{ yr}}{\tau} \frac{10^{45} \text{ g cm}^2}{I_{zz}}}$$

[Wette et al, CQG 25 235011]

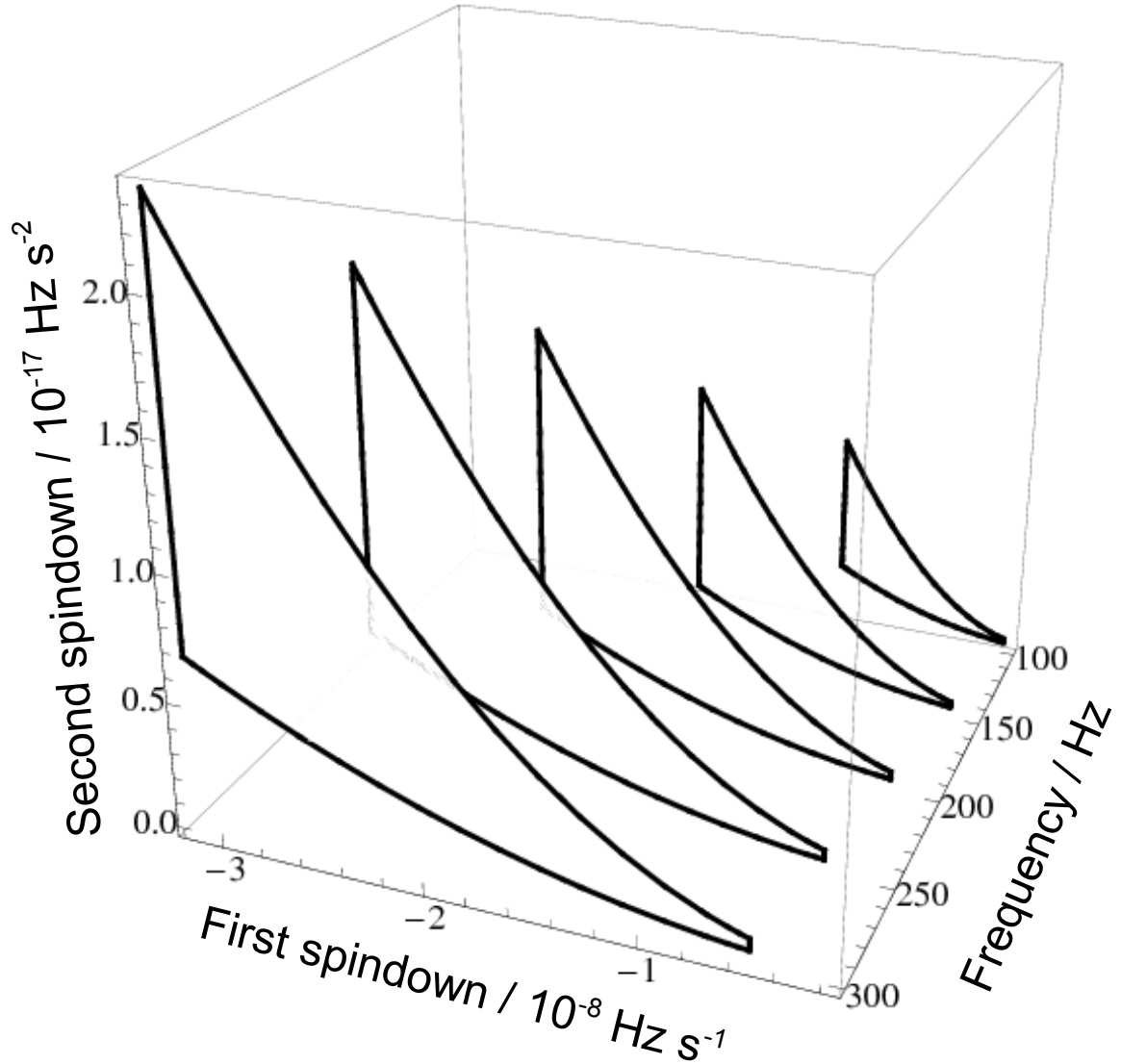
Why is Cas A interesting?

- We can beat the indirect limit with LIGO
  - Using ~10 days of data from S5 science run
  - Computationally feasible search
- Cas A is a young star
  - More likely to still have any non-zero ellipticity acquired at birth
  - Might still be emitting in r-modes
- First LIGO search for an isolated non-pulsing neutron star
  - Trail blazer for future LIGO “directed” searches

Search pipeline basics

- Coherent / matched filter “F-statistic” search
  - Known signal template for spinning neutron stars
- Template parameters:
  - Sky position: known from photon astronomy
  - Frequency: search 100 Hz to 300 Hz
    - Most sensitive LIGO band, computationally limited
    - Can make no statement about gravitational waves from Cas A outside of this band
  - First and second spindown (df/dt, d^2f/dt^2)

Search parameter space

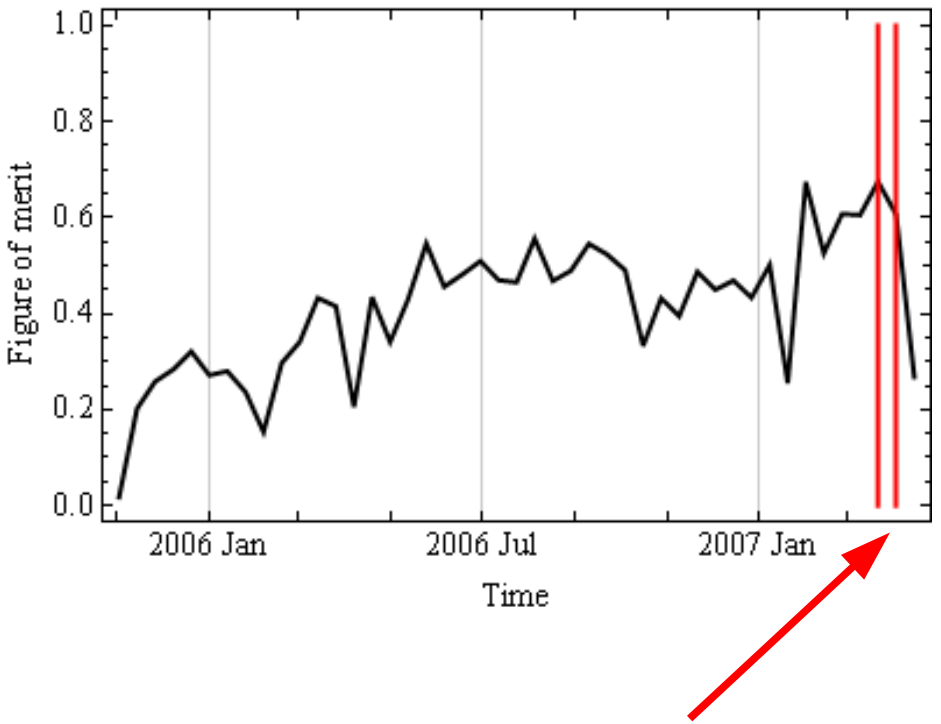


Limits on spindowns chosen based on:

- Spindown age
- Range of braking indices 2 - 7
- Allows for spindown from other physics besides GWs, e.g. photons, r-modes

BCC lattice for optimal template placement

Data selection and compute cost

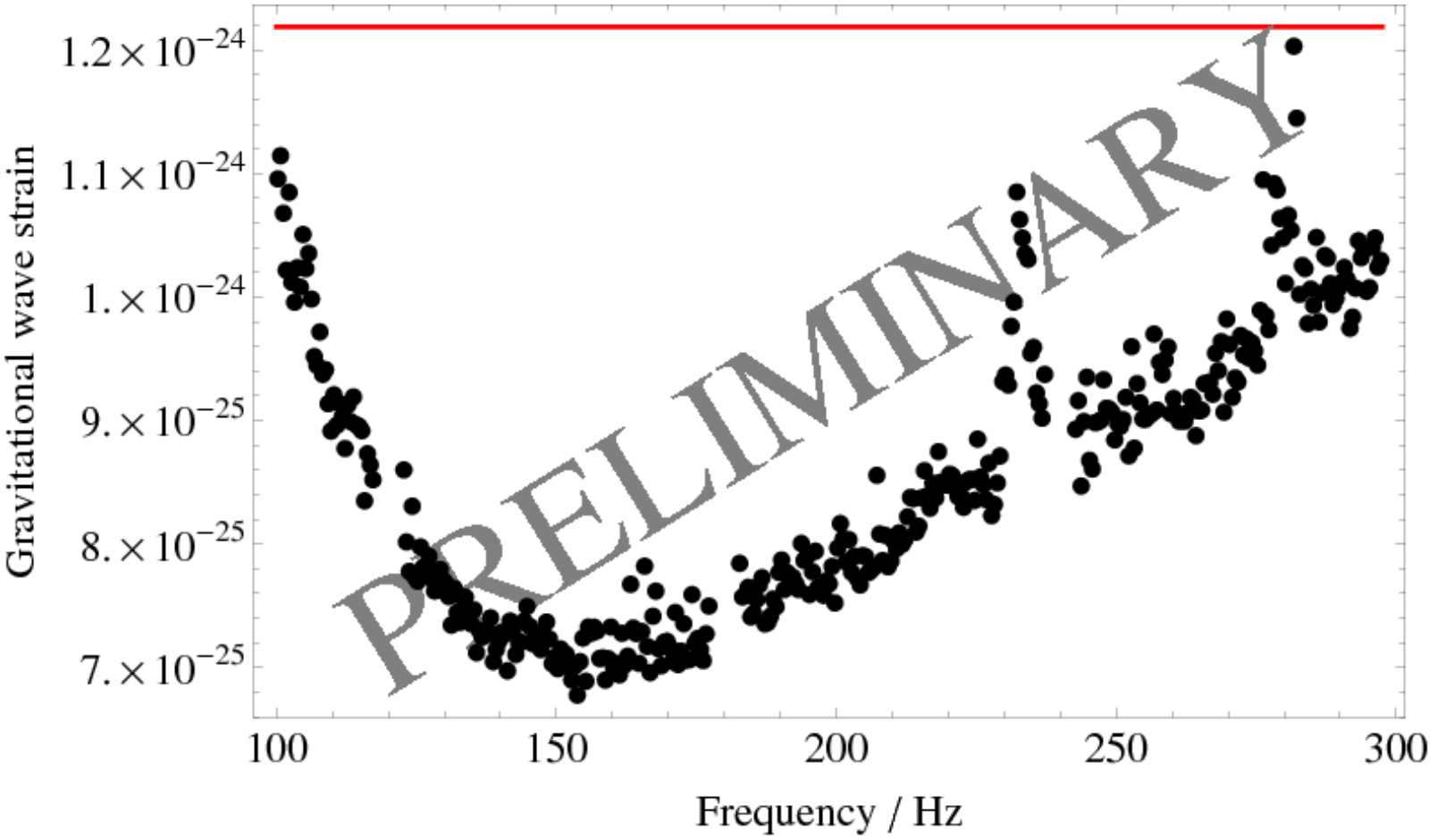


- Data from the two LIGO 4-km interferometers
- 9.7 days of data within a 12-day window
- ATLAS cluster @ AEI
  - 3.5 days
  - ~5000 nodes
  - ~7 x 10^{12} templates

Preliminary results: post-processing

- Removed outliers clearly associated with known instrumental lines
  - e.g. harmonics of 60 Hz U.S. mains power
- Remaining results show no significant outlier
  - F-statistic of loudest template is not statistically significant, given number of templates searched
- So we conclude no detection

Preliminary upper limits: strain



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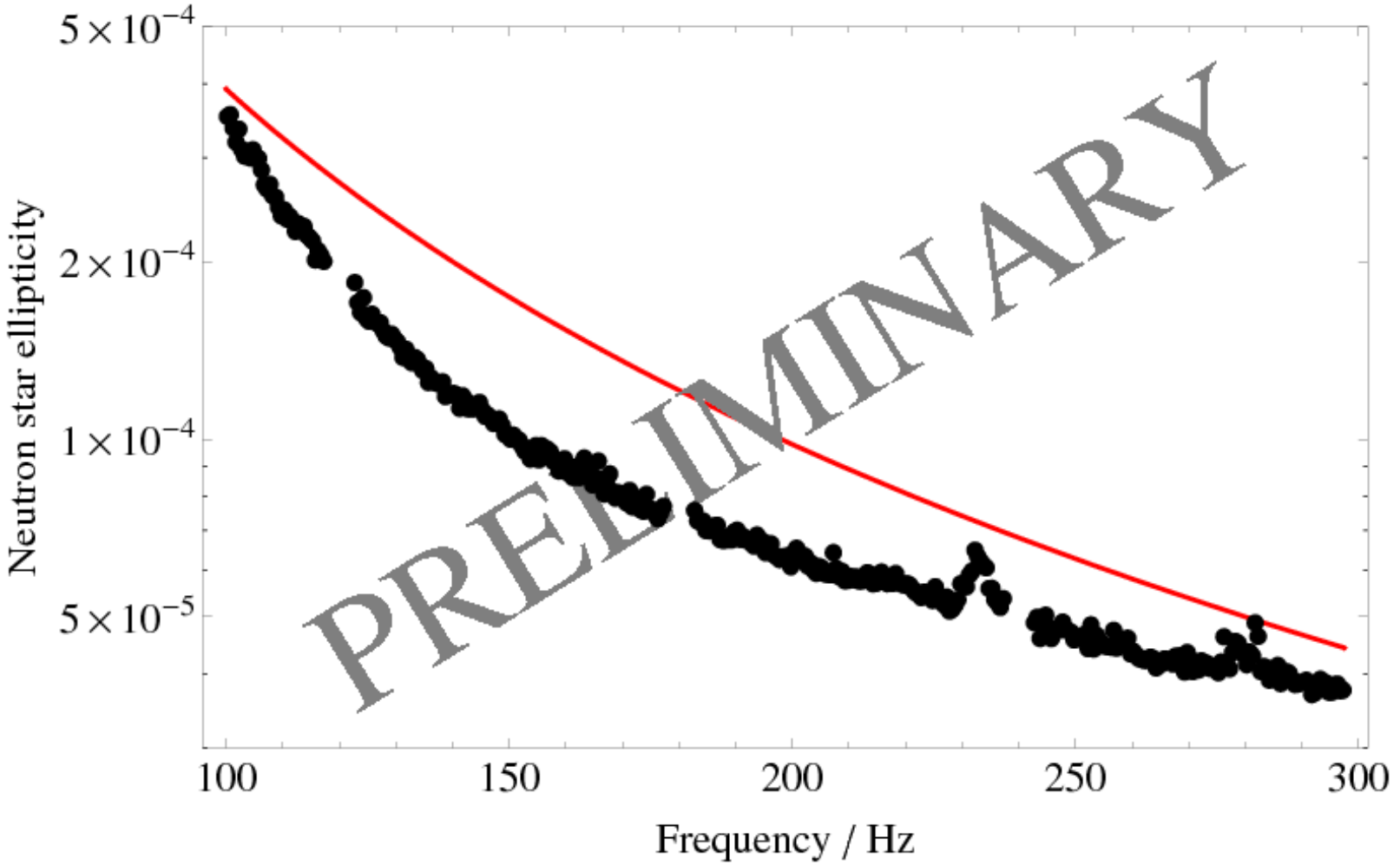
Preliminary upper limits: ellipticity



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Summary of preliminary results

- No detection of gravitational waves from Cas A
  - Only within searched band (100 to 300 Hz)
  - Make no statement about GWs outside this band
- Beat indirect limit on Cas A using LIGO data
  - Only been done a few times before (e.g. Crab)