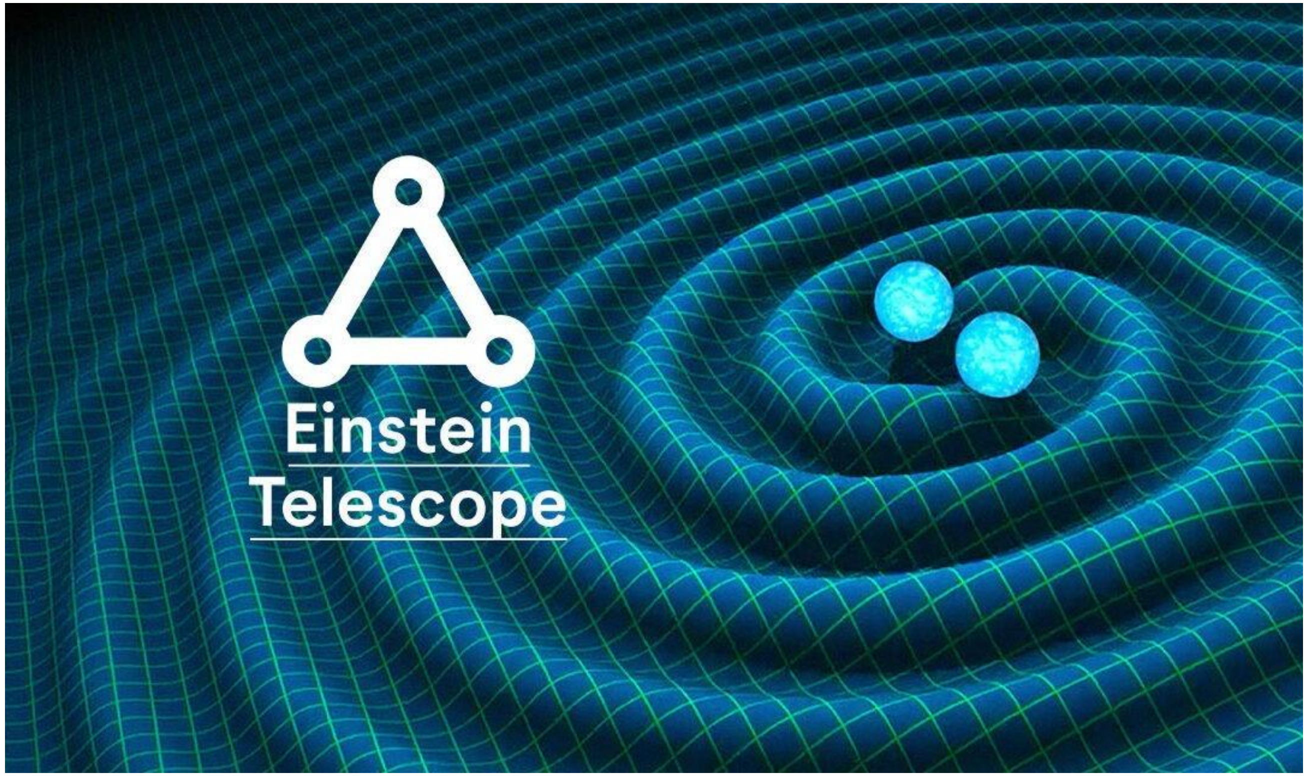
Data Analysis Challenges for the Einstein Telescope



Praveen Kumar and Thomas Dent

IGFAE, University of Santiago de Compostela

14th Iberian GW meeting, CIEMAT, Madrid

Motivation and Key Data Challenges in ET

- Higher sensitivity → many more CBC detections per unit time (expected to detect hundreds of BNS/BBH per day)
- Long-duration (minutes–hours) signals due to low-frequency (~1–3 Hz) sensitivity
- Overlapping signals become common, complicating event separation
- Increased glitch impact with long-duration templates
- High event rates make background estimation more difficult
- Calls for new techniques: better noise modeling, background estimation, null stream use

Role of the Null Stream

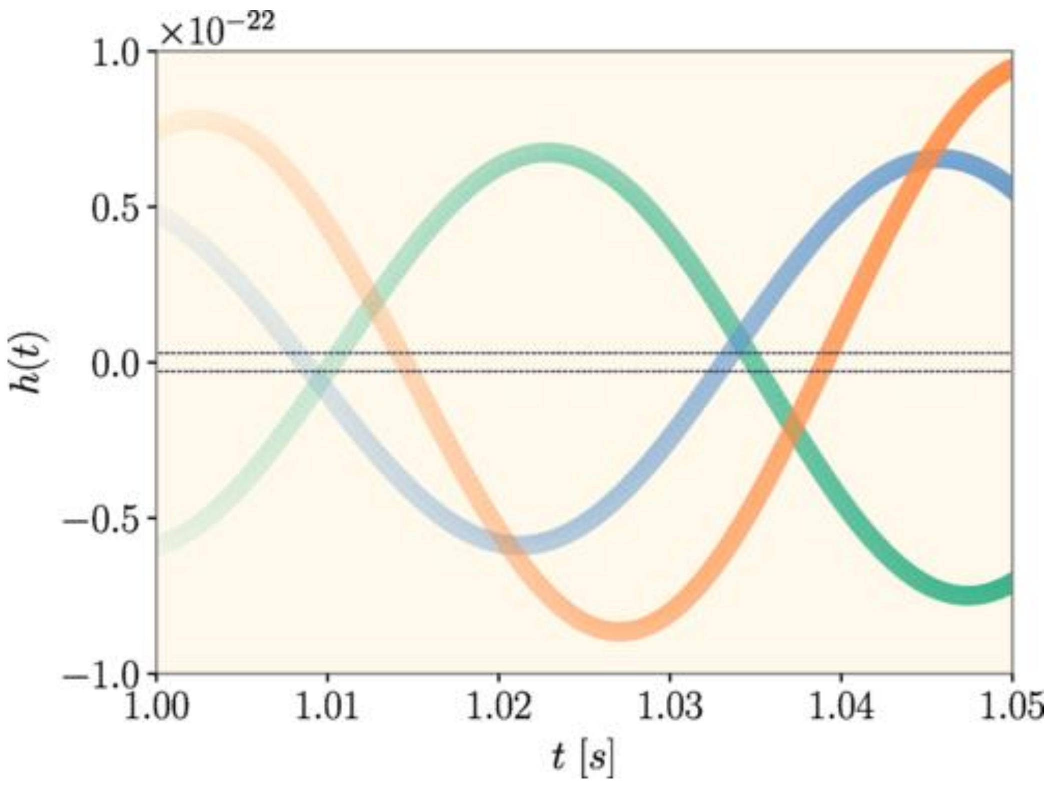
- What is the null stream?

$$E_0 = \sum_{i=E_1}^{E_3} \left(h_i + n_i \right), \qquad E_0 = \sum_{i=E_1}^{E_3} n_i.$$

- Triangular design of ET enables a null stream

- Signal cancels; noise remains

- Identify non-GW noise (glitches)



Goncharov et al. (2022)

Null Stream

Benefits

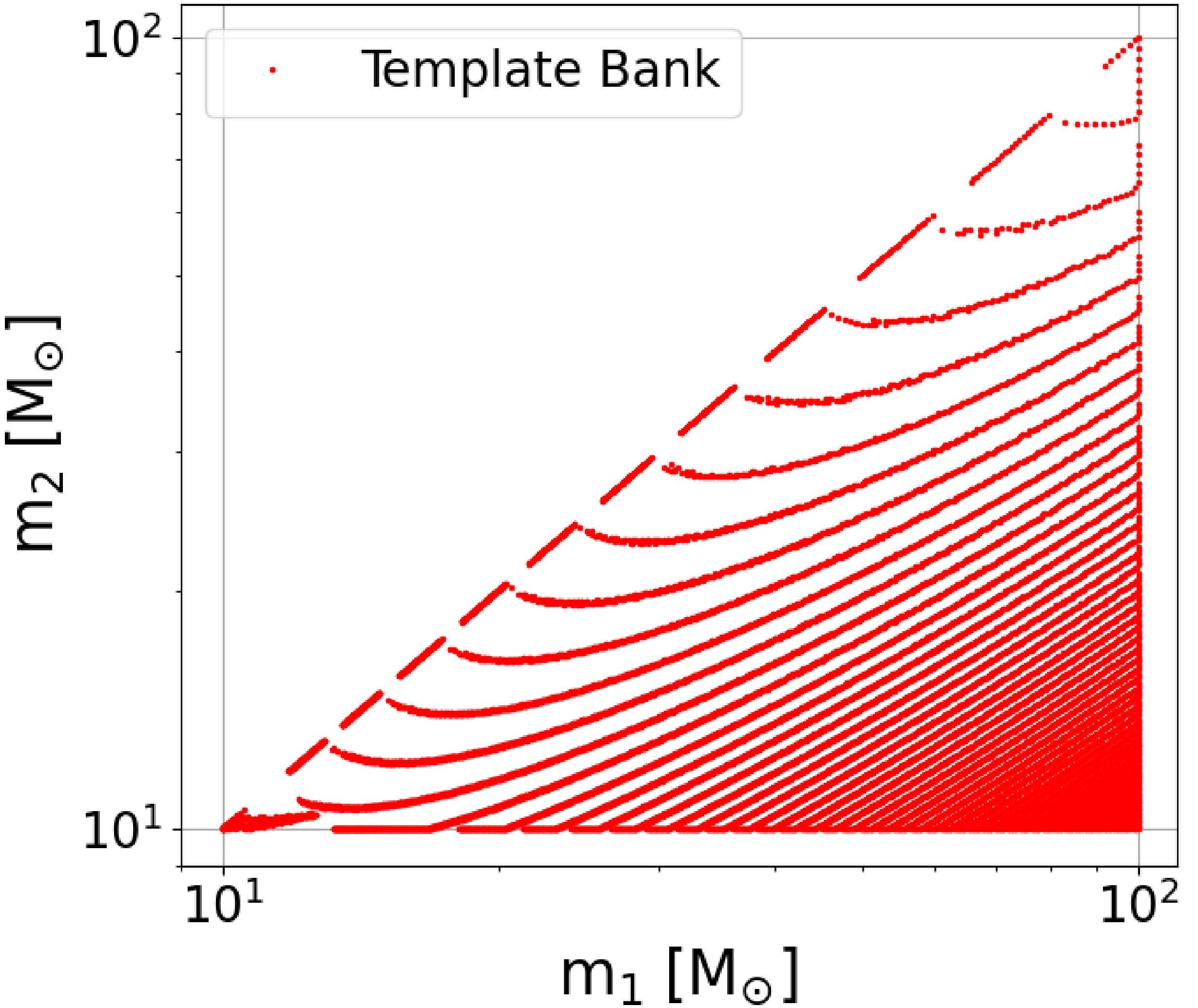
- Unbiased noise PSD estimation
- Glitch identification
- Calibration error control
- Aids in signal-vs-noise separation for overlapping events

Limitations

- Requires all detectors online
- Sensitive to correlated noise
- Adds computational load (low latency searches)
- Still being explored for real-time use

Our Search Setup

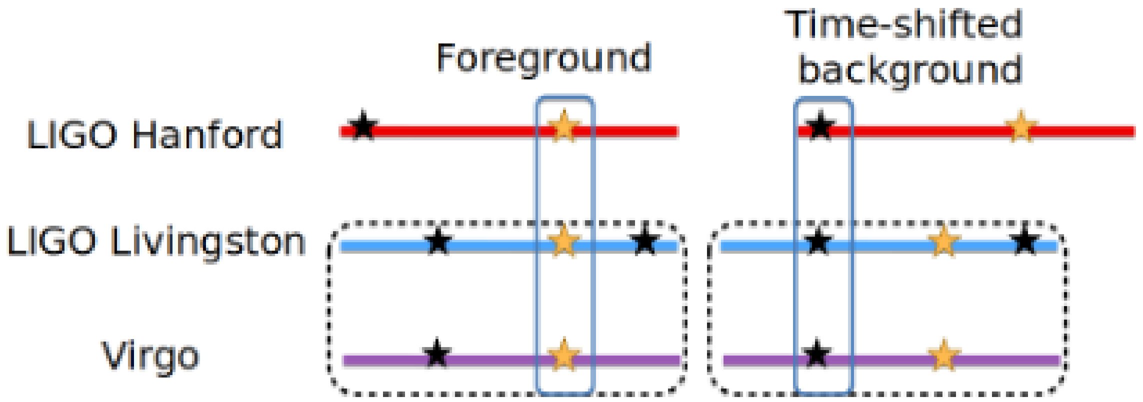
- 31-day ET-MDC dataset (continuous data for all 3 detectors, 1-600 Msun)
- Template bank: BBH, non-spinning (18,854 templates), geometric (MM = 0.95)
- PyCBC search with matched filtering



Search Strategy

- Test whether the null stream can improve background estimation in the presence of loud signals which might contaminate the background

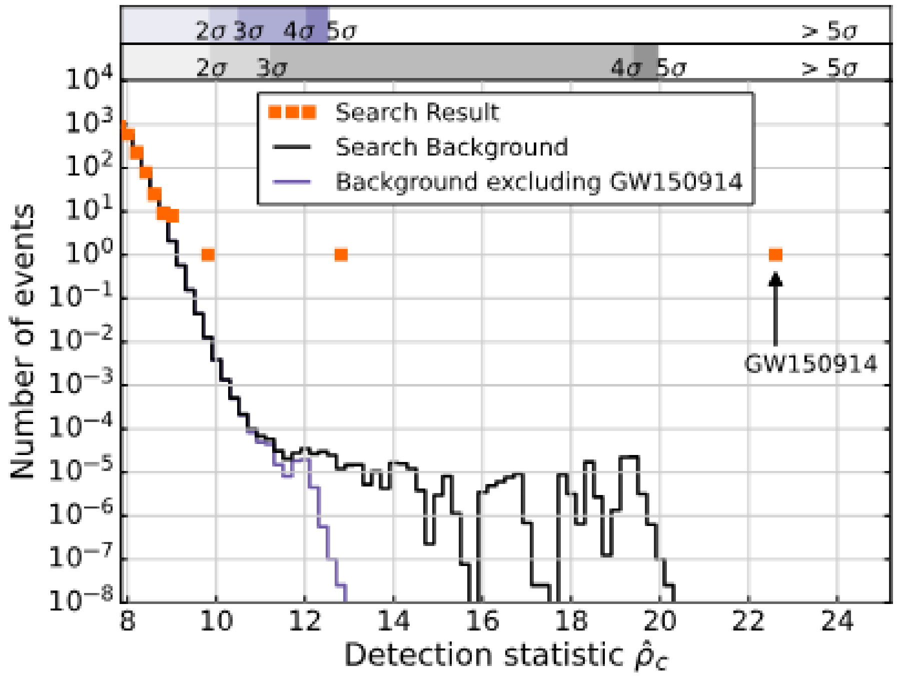
- Two ranking methods: SNR vs. reweighted SNR



- Different background estimates:
  - Standard: Based on time-shifting detector data streams, e.g., shifting E1 relative to E2
  - Null-stream-informed: Use alternative detector pairs (E0E1, E0E2) for background, while keeping E1E2 as foreground (produced by time-shifting E0 against E1 or E2)

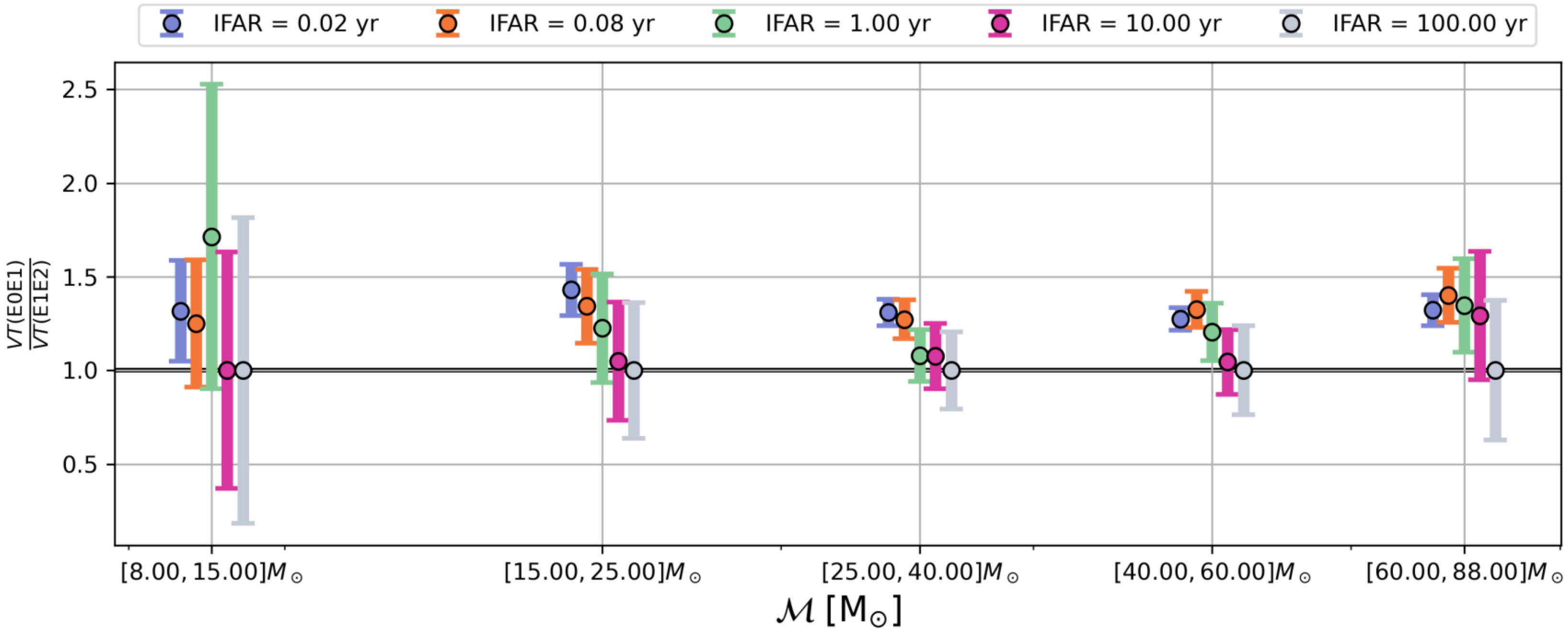
Hierarchical Foreground Removal

- It is a iterative procedure to avoid background contamination by real signals
- Start with a first-pass background including all triggers (signals + noise)
- Identify foreground triggers louder than any background event
- Remove loudest trigger, recalculate background without it
- Repeat until no foreground trigger exceeds background in new iteration



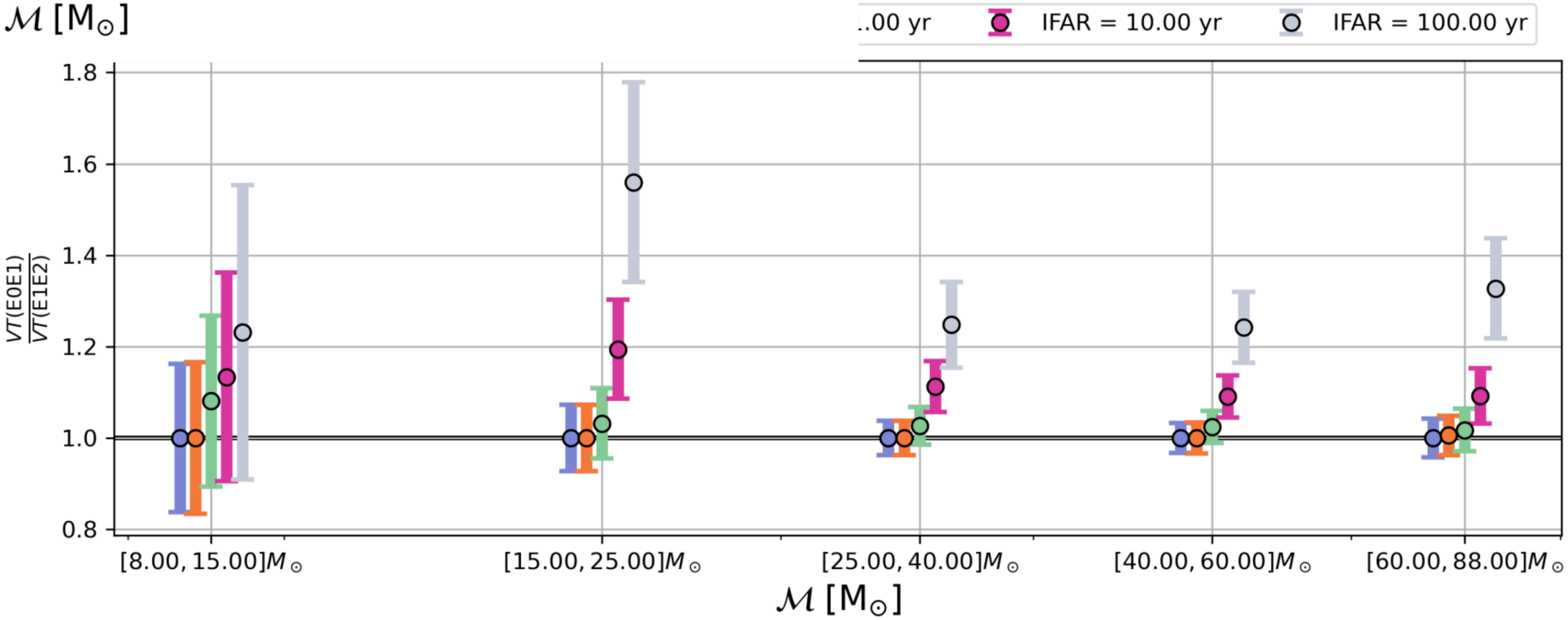
- Used to get realistic FAR for lower-ranked candidates
- Helps ensure that background is unbiased by strong signals

VT Sensitivity: E0E1 vs. E1E2

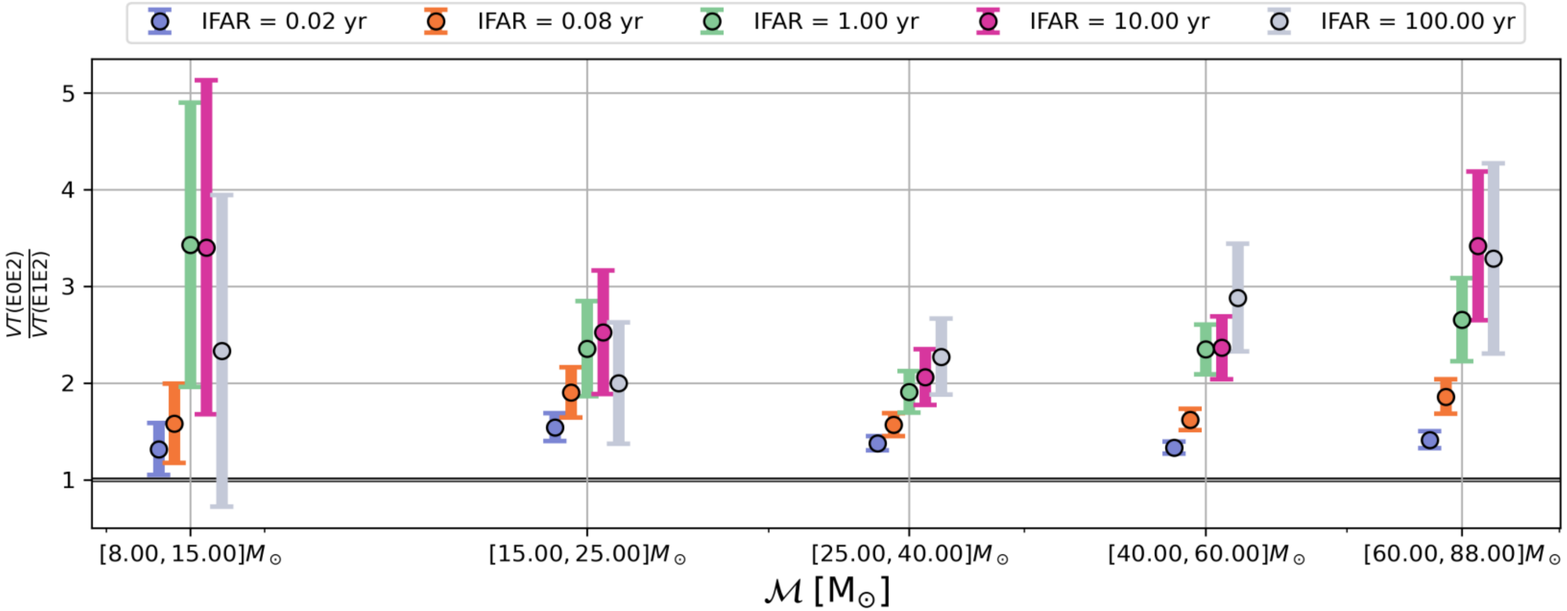


- SNR vs reweighted SNR

Highlight: Null stream background improves sensitivity



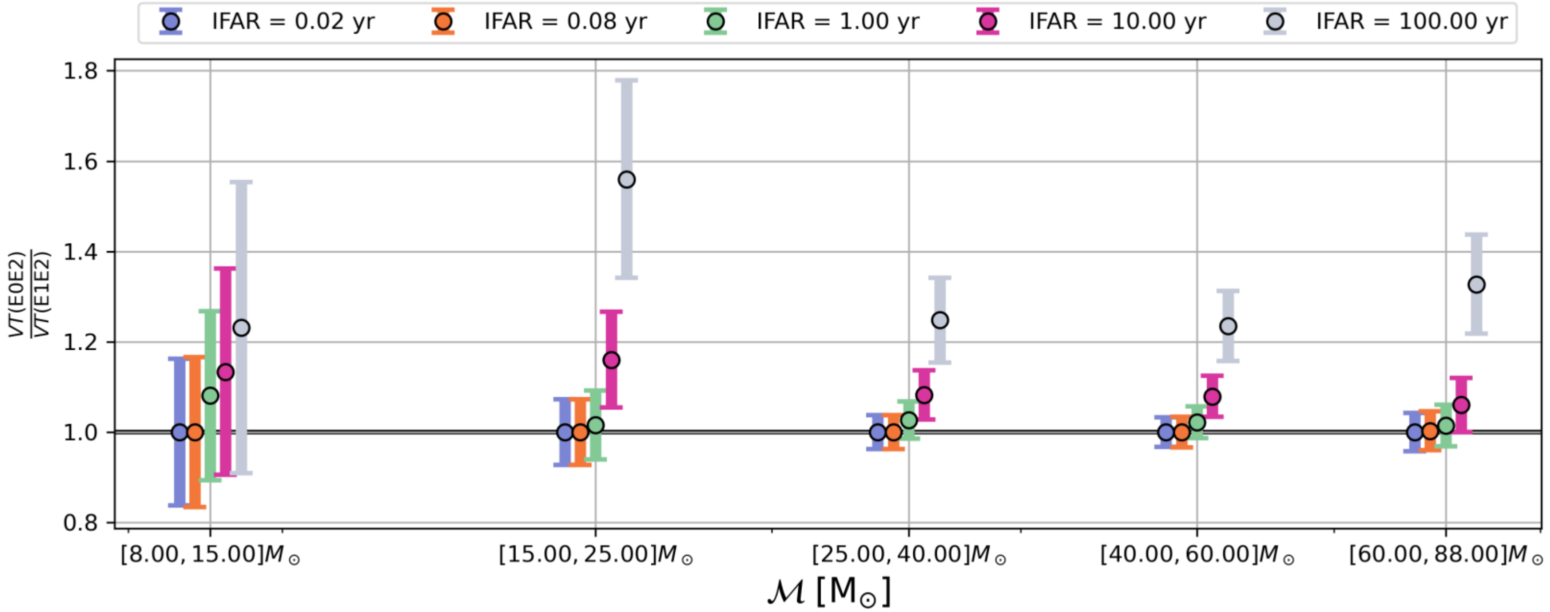
VT Sensitivity: E0E2 vs. E1E2



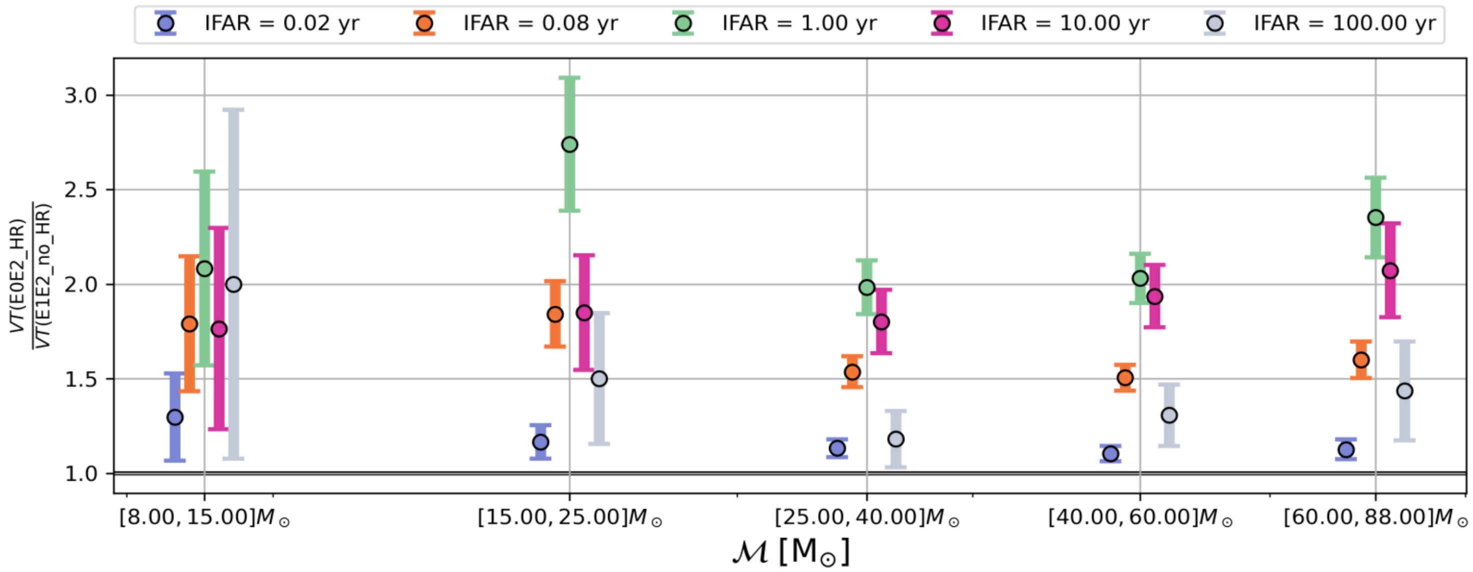
- Consistent improvement with null stream

- Gain smaller for reweighted SNR

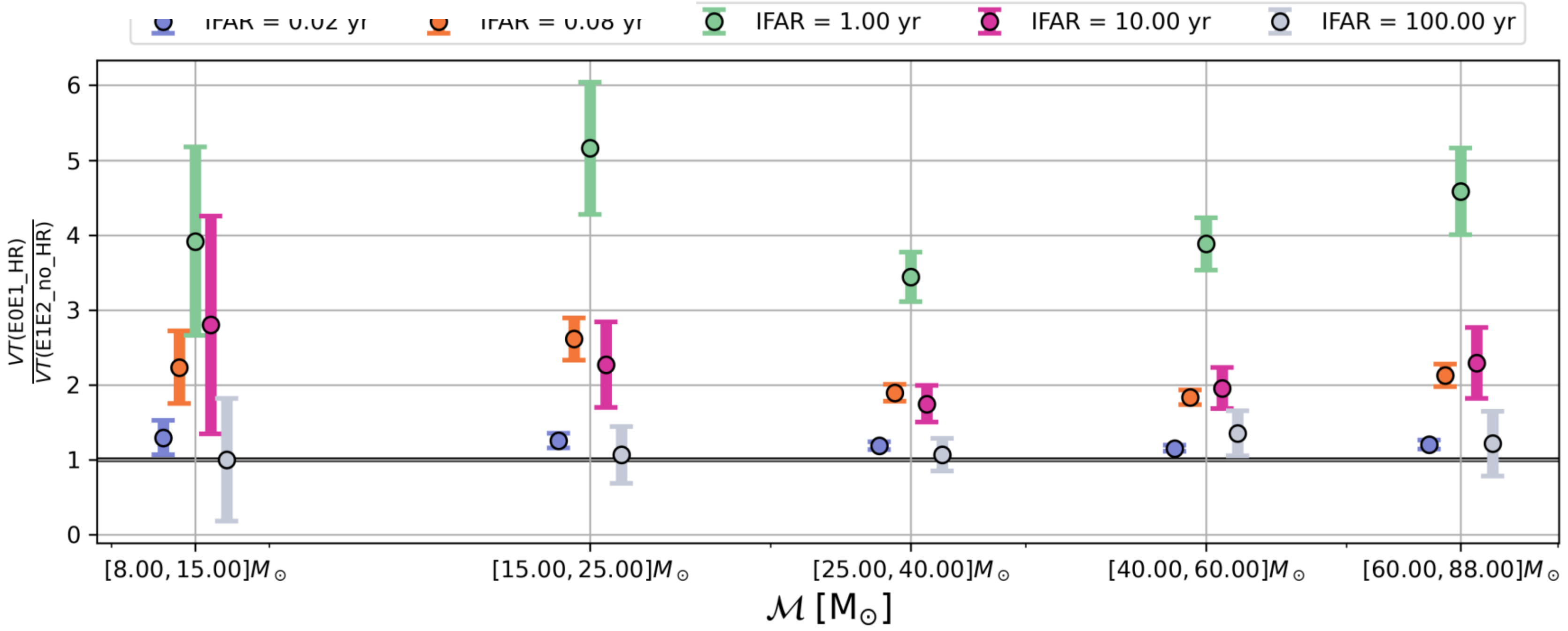
Some loud signals may have smaller stat value due to bad matches with templates



Hierarchical Removal Helps



- Removing loud events from background estimates



- This is useful when many strong signals are present

Summary & Discussion

- Using null stream backgrounds reduces bias in background estimation, especially in the presence of loud signals
- VT sensitivity improves when using alternate backgrounds (e.g., E0E1, E0E2) instead of E1E2 alone
- Hierarchical removal improves FAR estimates by preventing contamination from loud signals — but becomes computationally expensive when many signals are present
- Including null stream backgrounds increases runtime by ~1.5× compared to using E1E2 only
- Future work: Apply null stream techniques to PSD estimation, extend to larger template banks, and test with more signal injections

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