Building the next Einstein@Home search code for continuous gravitational waves

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GR21, New York City, July 10-15, 2016

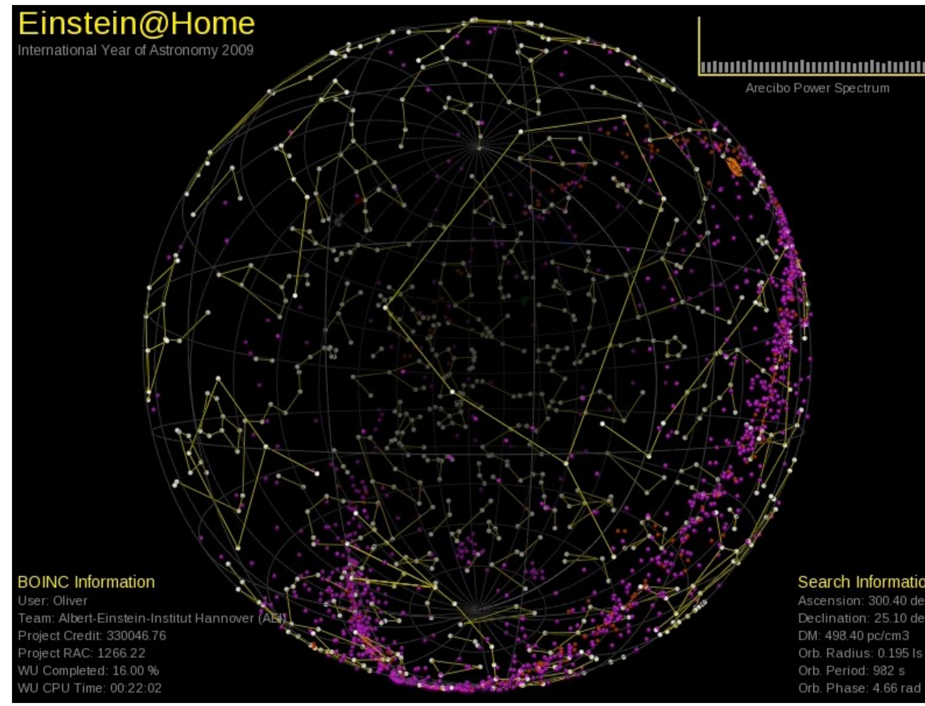
LIGO DCC: G1600977-v2

Continuous gravitational waves (CW)

- Rapidly-rotating (~50-1000 Hz) deformed neutron stars
- Generate quasi-sinusoidal narrow-band signals
  - Parameterised by pulsar sky position and frequency evolution
- Non-axisymmetric deformation, possibly due to e.g.:
  - Magnetic field-induced deformation
  - Unstable fluid oscillation modes, e.g. *r*-modes
  - Accretion from a binary companion ☞ mountain
- *Ellipticity* of neutron star characterises fractional deformation
  - *Maximum* ellipticity uncertain, may be ~ $[10^{-11}, 10^{-4}]$
  - *Typical* ellipticity even more uncertain

Einstein@Home

- Volunteer distributed computing project
  - ~45k users, ~70k hosts
  - ~2 petaflops performance
- Latest searches for CWs:
  - O1 all-sky search (Sinéad Walsh, Thursday 2-4)
  - S6 Cassiopeia A (Sylvia Zhu, ditto)
- Also very successful at finding radio and gamma-ray pulsars (50+ so far)



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Continuous wave (CW) searches

- (Generally) computationally limited
- Trade off sensitivity vs computational cost
- Fully coherent matched filtering too expensive
- *Semicoherent*: more sensitive per compute cost
- Optimise e.g. number of coherent segments [1]

Fully Coherent Search

Coherent + Coherent + Coherent + Coherent + Coherent

Sum = Semicoherent Search

[1] Shaltev & Prix, PRD 87, 084057 (2013)

Continuous wave (CW) searches

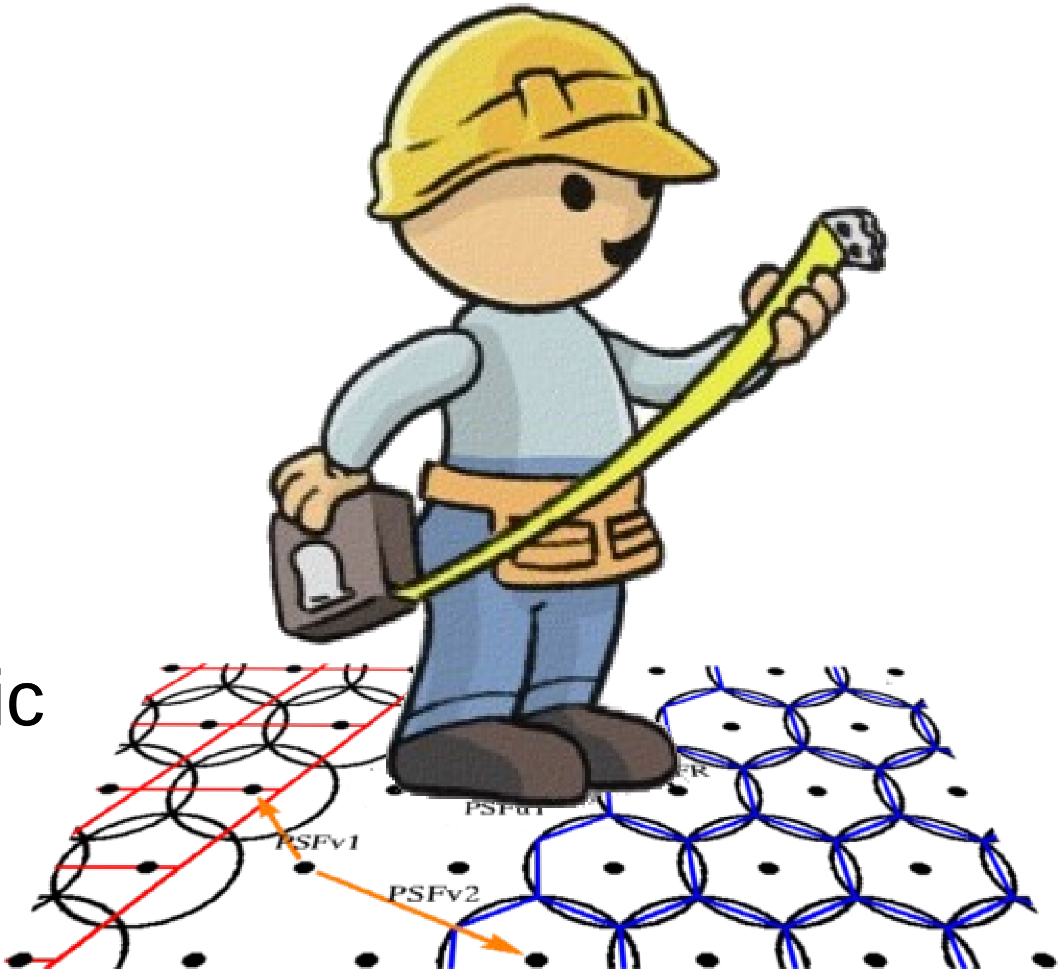
- Current E@H search uses *global correlation transform (GCT) method* [2] to combine segments
- Main limitation: method starts to lose SNR if data time span > 20 days
- Implementation (*LALSuite*) difficult to maintain / add new features
- Future searches will use new code based on *supersky parameter-space metric* [3]

[2] Pletsch, PRD 82, 042002 (2010)
[3] Wette & Prix, PRD 88, 123005 (2013); Wette, PRD 92, 082003 (2015)

Parameter-space metric

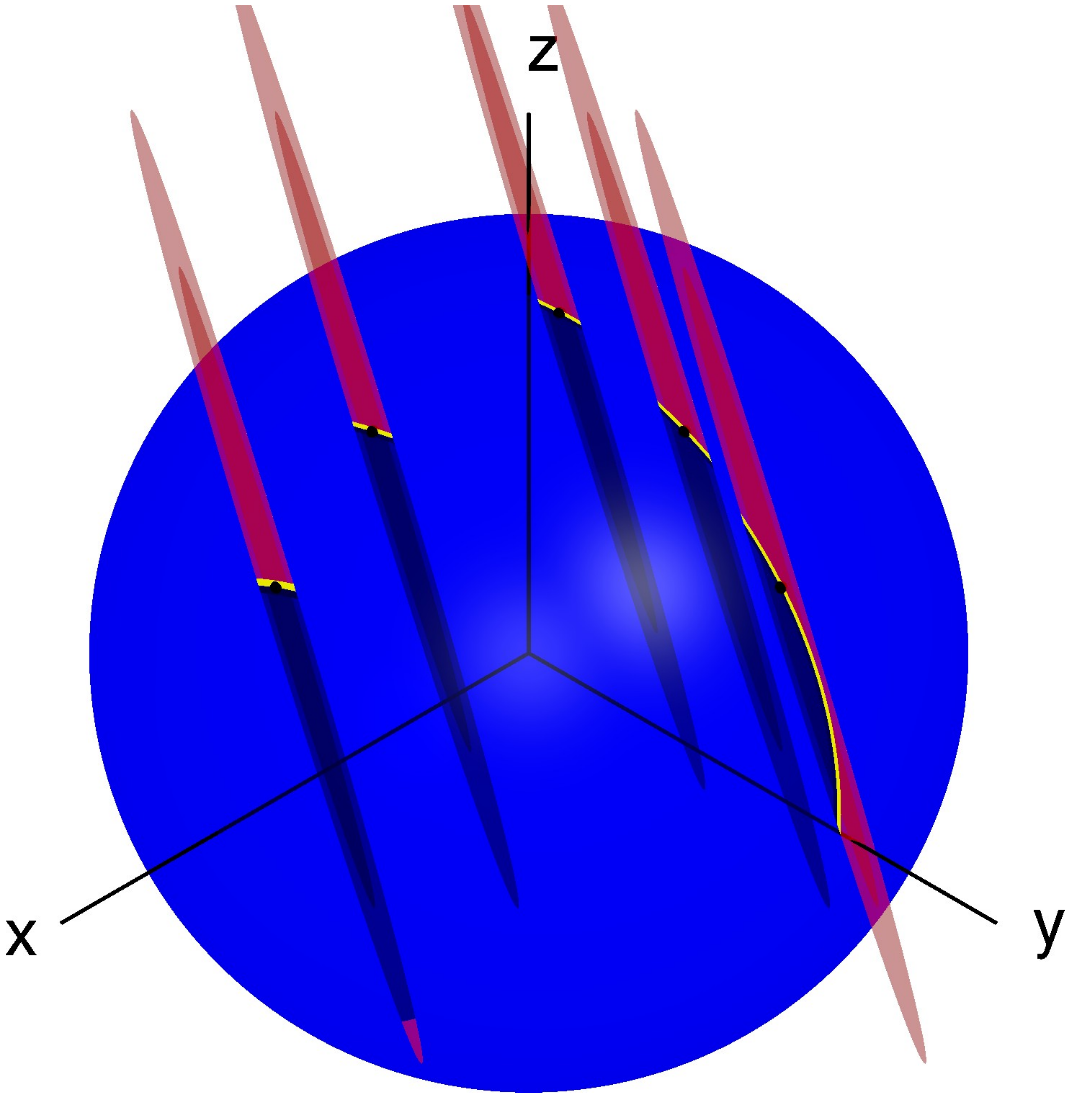
- Used to measure loss of signal-to-noise ratio (*mismatch*) between signal and nearest search template

- Easy to generate template banks if metric tensor is **constant** [4]



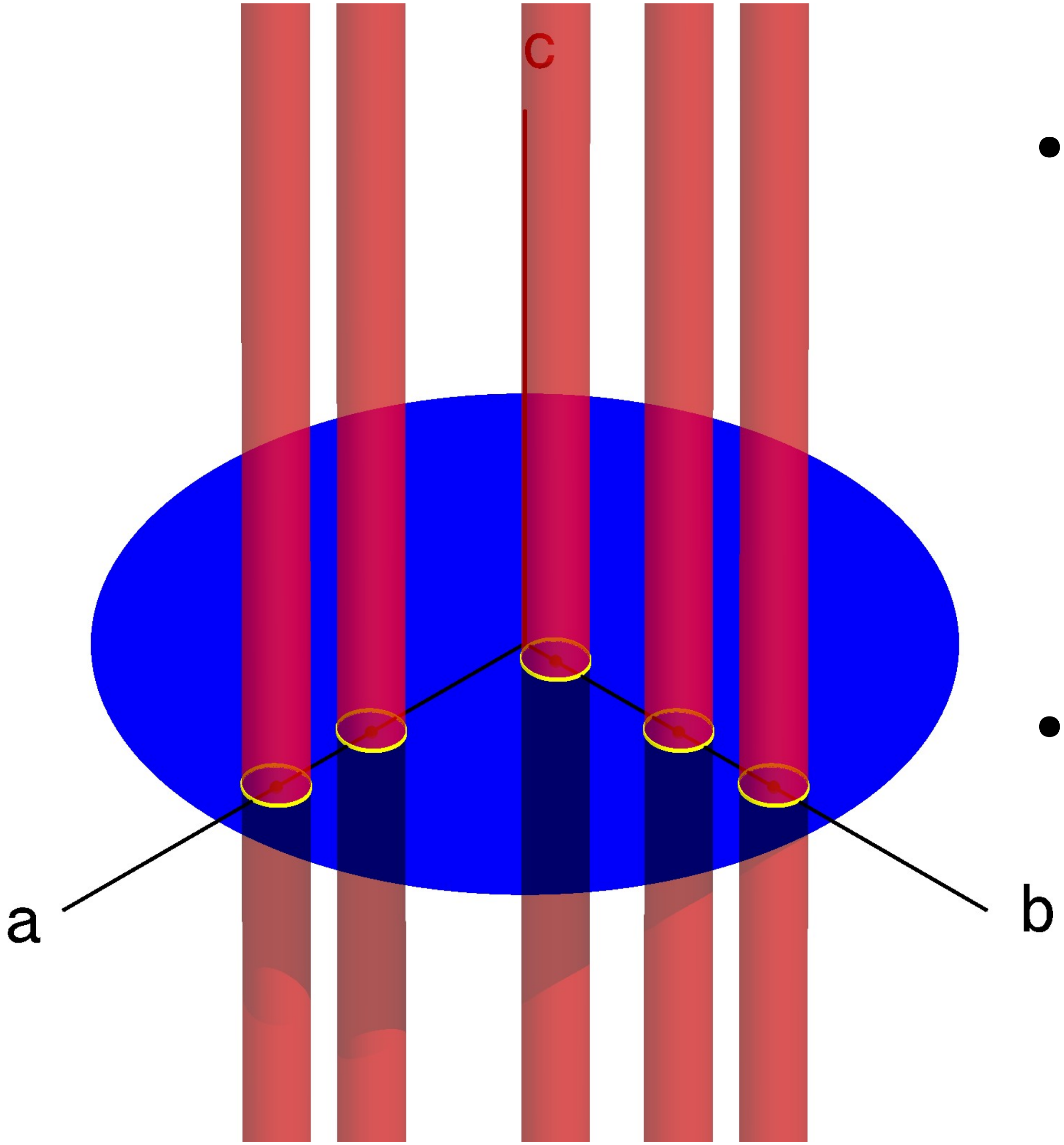
[4] Wette, PRD 90, 122010 (2014)

Sky metric: embedding in 3D



- Yellow: metric on surface of 2D sky sphere (blue), **not constant**
- Red: metric in 3D *supersky* space, **constant**, but not easy to place templates in 2D subspace of 3D

Supersky metric: project back to 2D

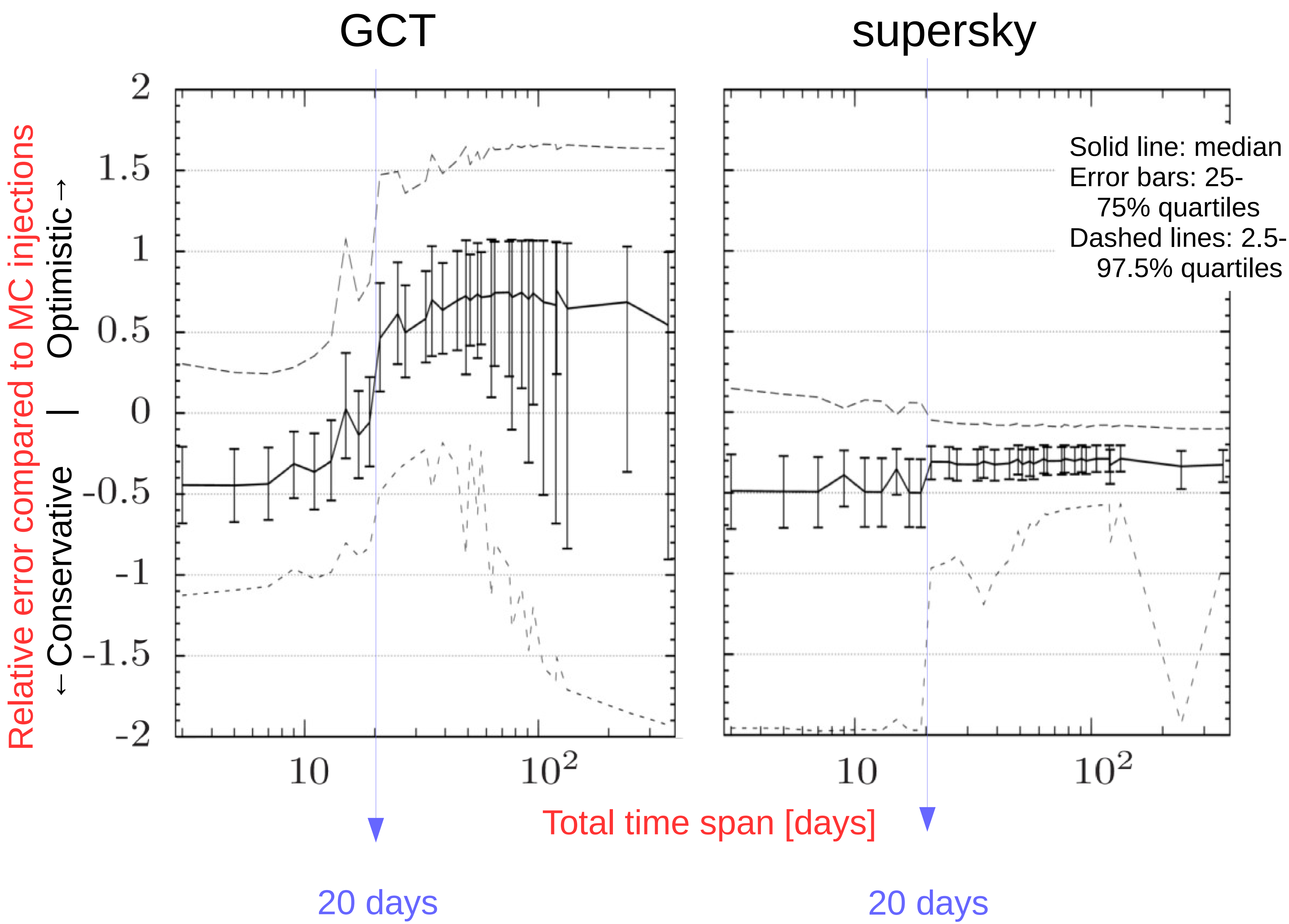


- Perform linear transformation which aligns coordinates with metric principal axes [3]

- Project metric back onto 2D disk, **constant**, can now easily place templates

[5] Wette & Prix, PRD 88, 123005 (2013)

GCT vs supersky method



Status and future plans

- Strain sensitivity of new supersky code *estimated* to be $\geq$ 30% than GCT → $\geq$ 2x sensitive volume
  - Need to confirm with large-scale MC injections
- Some work to integrate code with BOINC framework used by Einstein@Home
- Plan to analyse new LIGO data with new code
- In future, add ability to search for CW sources with a binary companion, e.g. Sco X-1 [6]

[6] Leaci & Prix, PRD 91, 102003 (2015)