Refining the Search for Sub-threshold Lensed Gravitational Waves

LIGO SURF 2021

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Key Points

I. Where were we? Lensing, Sky location, Ranking

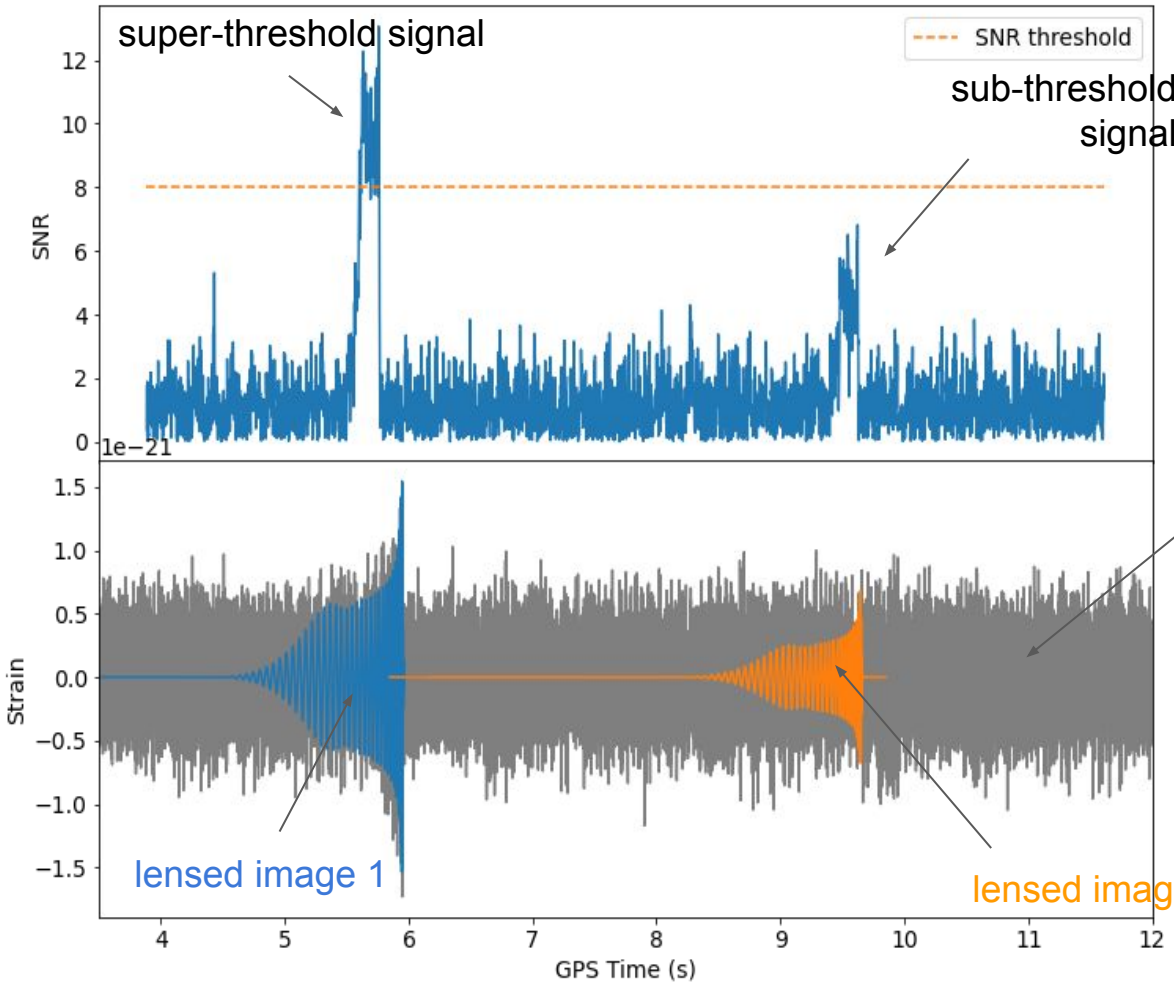
II. Aims: Boosting ranking of lensed images

III. Solution + Results so far

IV. What next

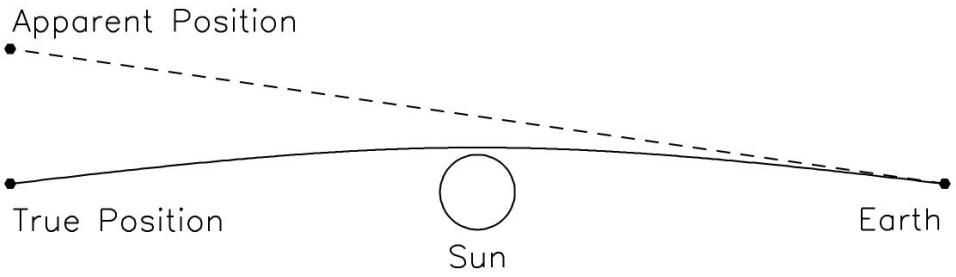
Refresher: Finding sub-threshold Gravitationally Lensed GWs

STRONG LENSING!

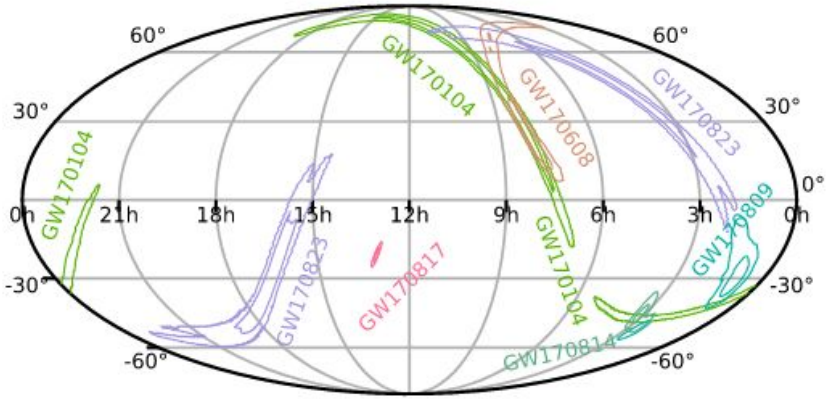


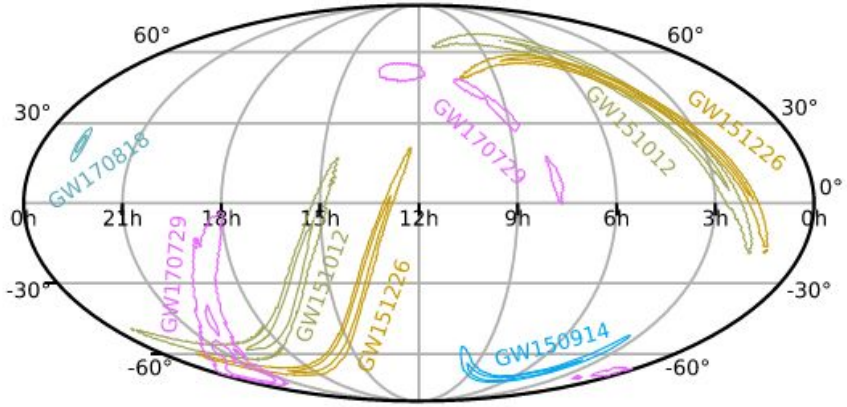
Refresher: Sky Localisation of GWs >> Lensed Image Separation

STRONG LENSING!



SKYMAPS!





Refresher: Ranking Candidates in GstLAL Pipeline

STRONG LENSING!

SKYMAPS!

RANKING!

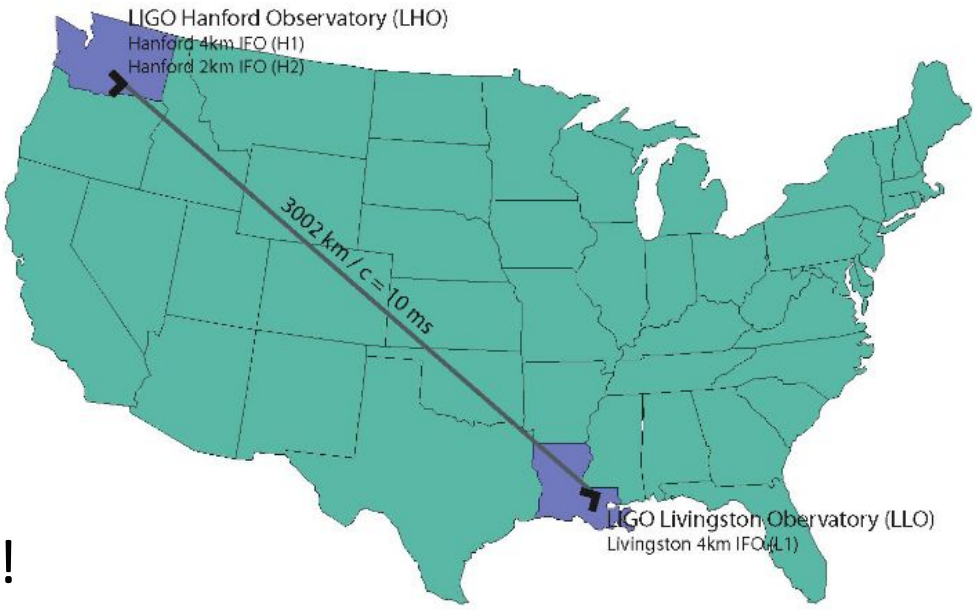
$$\mathcal{L} = \frac{P(\{D_1, D_2\}\{d_1, d_2\}, \rho_1, \rho_2, \xi_1^2, \xi_2^2, \Delta\phi, \Delta t | signal)}{P(\{D_1, D_2\}\{d_1, d_2\}, \rho_1, \rho_2, \xi_1^2, \xi_2^2, \Delta\phi, \Delta t | noise)}$$

Refresher: Tying it all together...

STRONG LENSING!

SKYMAPS!

RANKING!



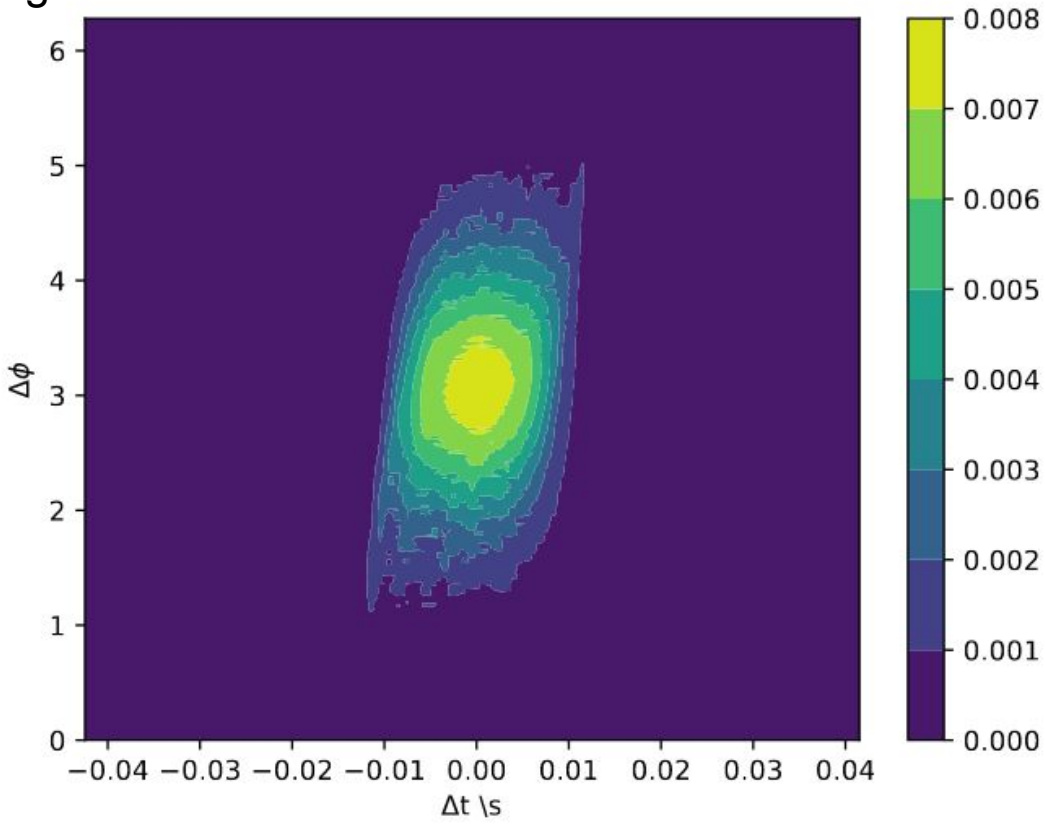
Credit: Duncan Brown

WOO!

$$\mathcal{L} = \frac{P(\{D_1, D_2\}\{d_1, d_2\}, \rho_1, \rho_2, \xi_1^2, \xi_2^2, \Delta\phi, \Delta t | signal)}{P(\{D_1, D_2\}\{d_1, d_2\}, \rho_1, \rho_2, \xi_1^2, \xi_2^2, \Delta\phi, \Delta t | noise)}$$

Aims: Looking for ΔΦ Δt PDF

2D Probability distribution for ΔΦ and Δt considering signals **across the whole sky** for Hanford and Livingston:



But what if we constrain the sky location…..?

Aims: Looking for ΔΦ Δt PDF

Working on….

- Figuring out how the **PDF of ΔΦ and Δt changes** when considering a **smaller sky location**

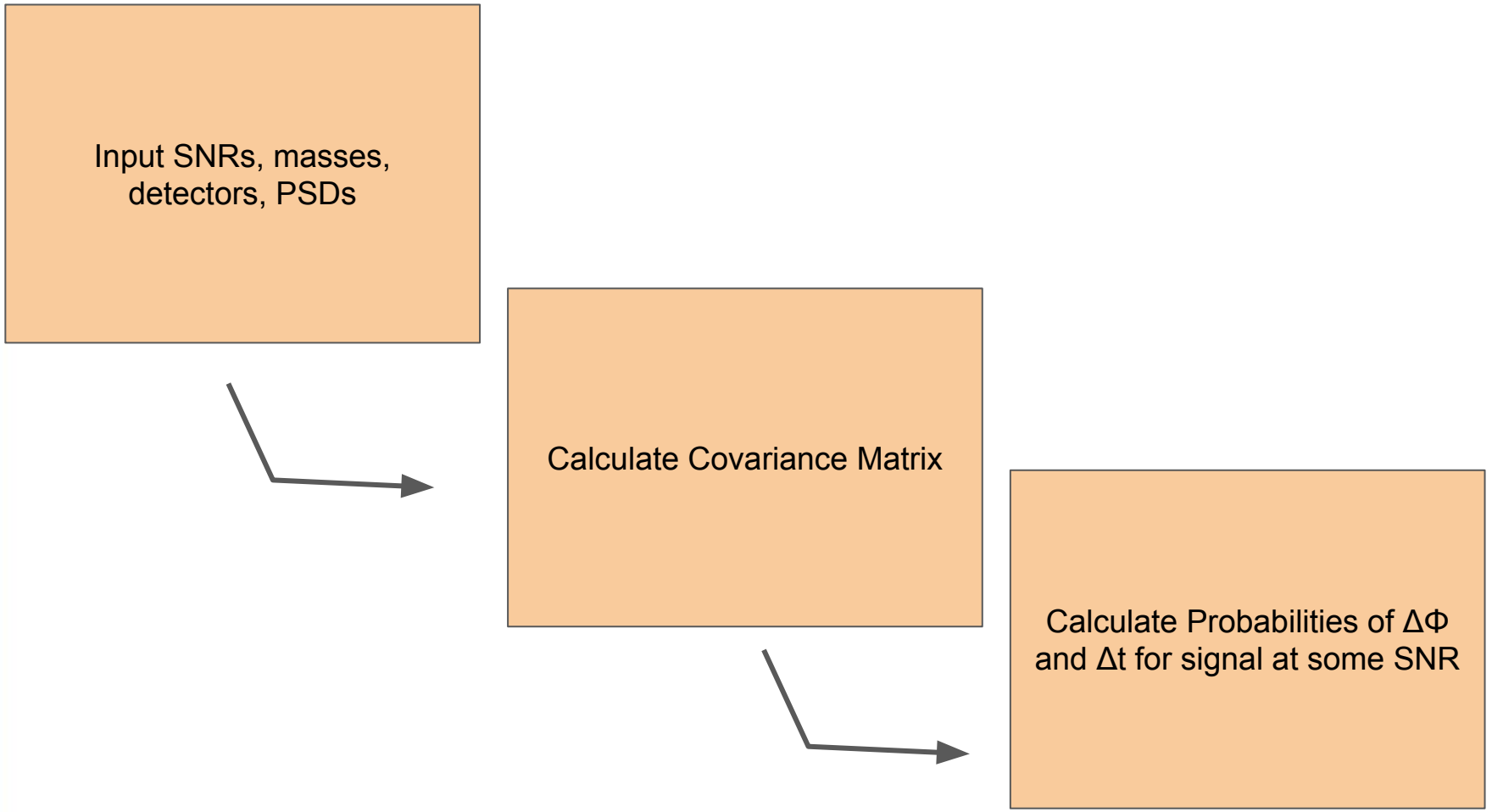
To eventually implement….

- Implement this new constraint on ΔΦ and Δt into the search pipeline to **target the search based on the sky location** of the super-threshold event

- Thus **boost ranking of lensed counterparts with similar sky location** to the target

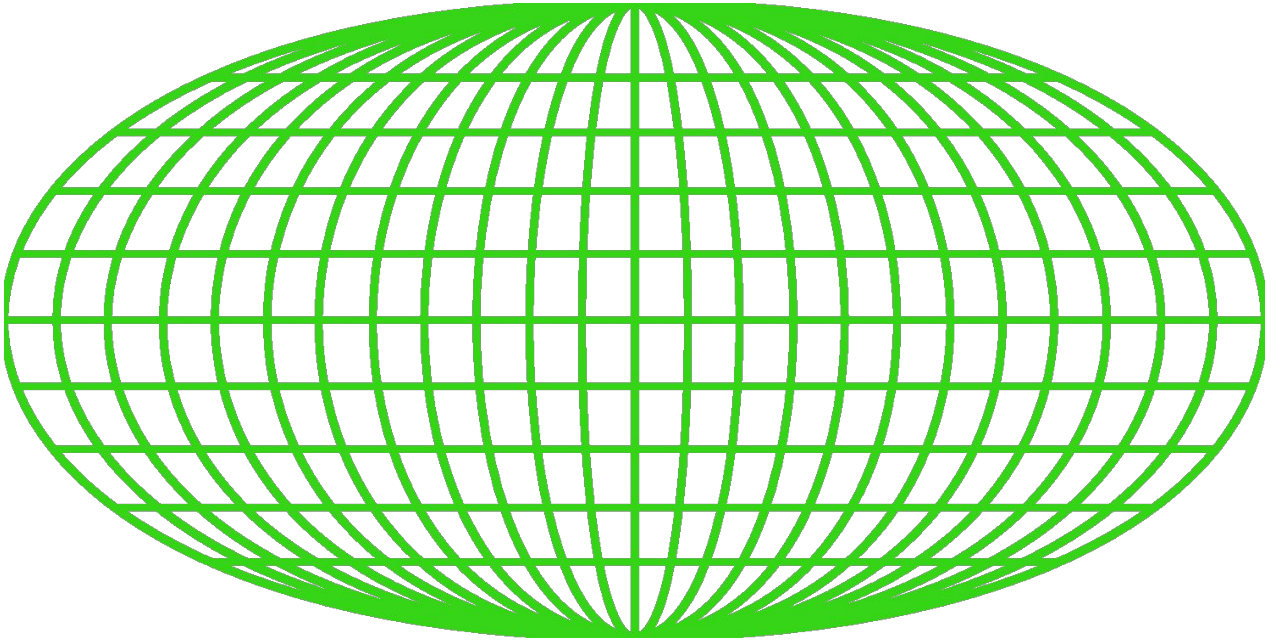
How?????????

Inside the GstLAL Pipeline:



Inside the Probability Calculation:

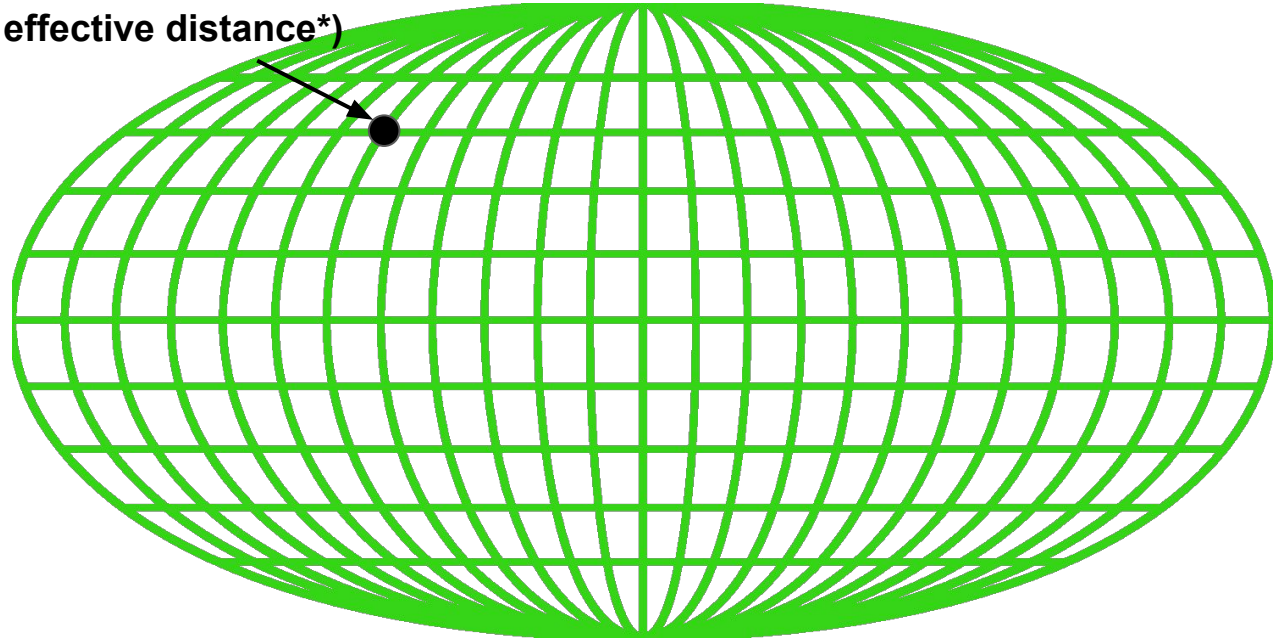
- GstLAL finds the PDF of ΔΦ and Δt with a tiling function: tiles **the whole sky** with even probability of event from each direction



Inside the Probability Calculation:

- GstLAL finds the PDF of ΔΦ and Δt with a tiling function: tiles **the whole sky** with even probability of event from each direction

Calculates for each detector:
(time, phase, effective distance*)



***equivalent to SNR**

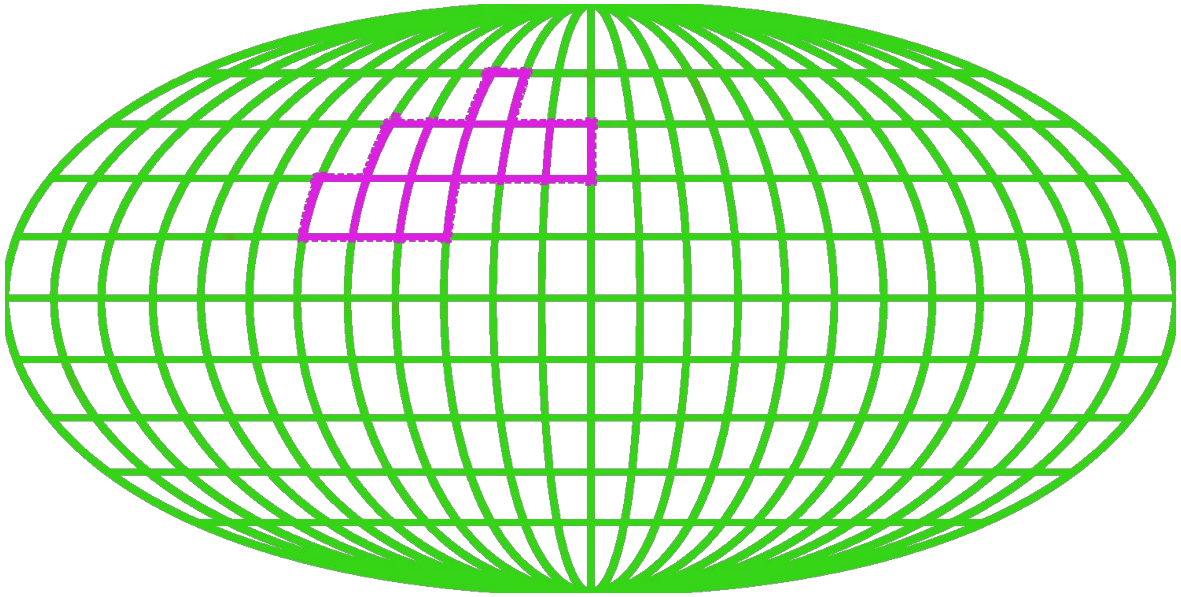
Inside the Probability Calculation:

- Obtain **Δt, ΔΦ, ΔD_{eff}** between **each of the detectors** for **each point**

- **Use this to calculate the PDF** using the covariance matrix, with lots more maths [Chad Hanna, 2019] https://arxiv.org/pdf/1901.02227.pdf

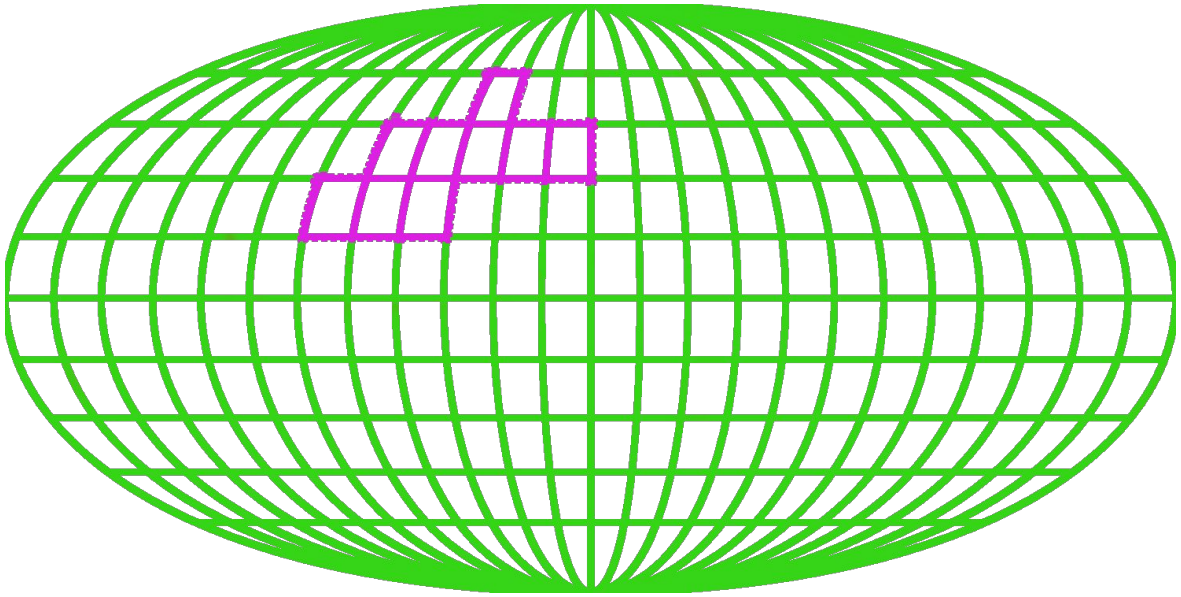
Inside the New Improved Probability Calculation:

- We modify GstLAL to find the PDF of ΔΦ and Δt with a tiling function: tiles the **90% credible region** of a real target event with even probability



Inside the New Improved Probability Calculation:

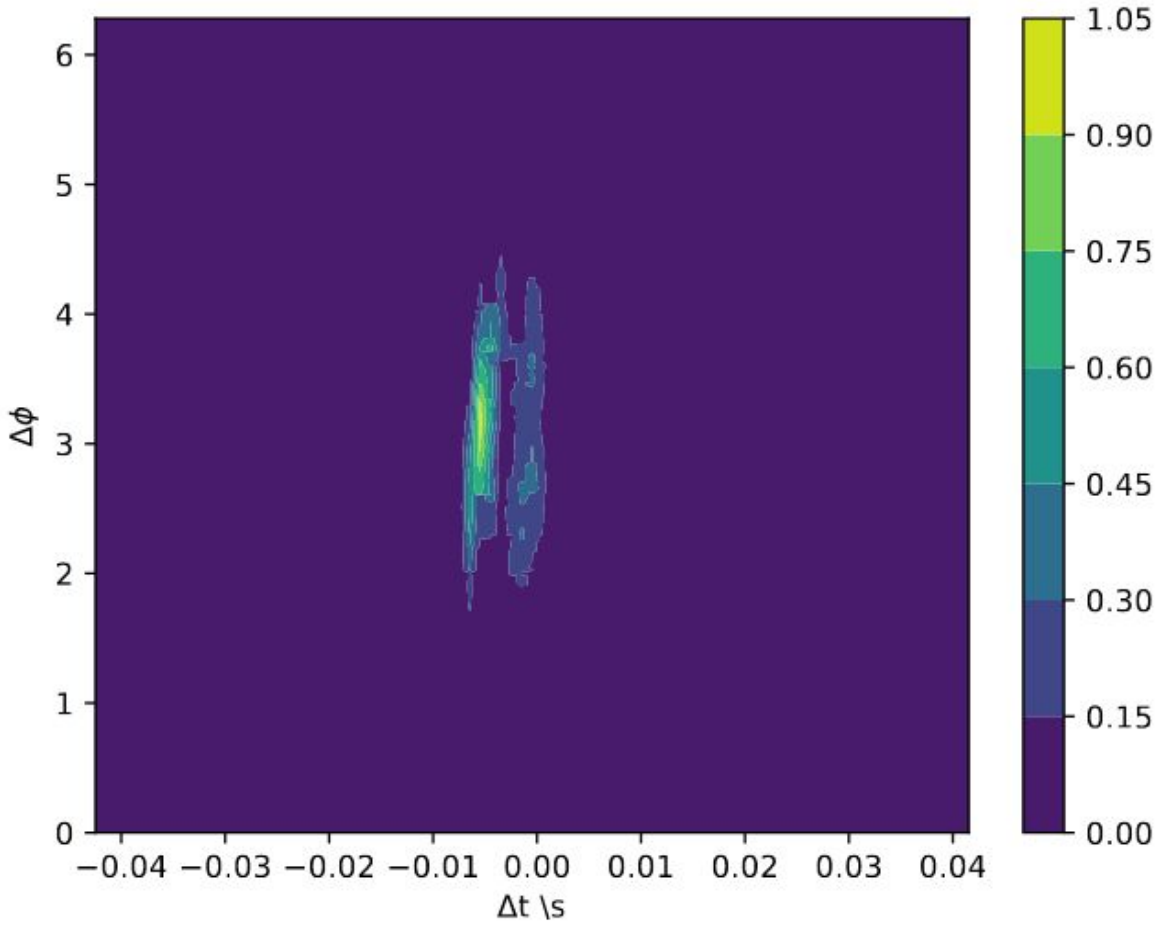
- We modify GstLAL to find the PDF of ΔΦ and Δt with a tiling function: tiles the **90% credible region** of a real target event with even probability
- PDF then found as before…..



Momentary Pause while we get lost in GstLAL bugs

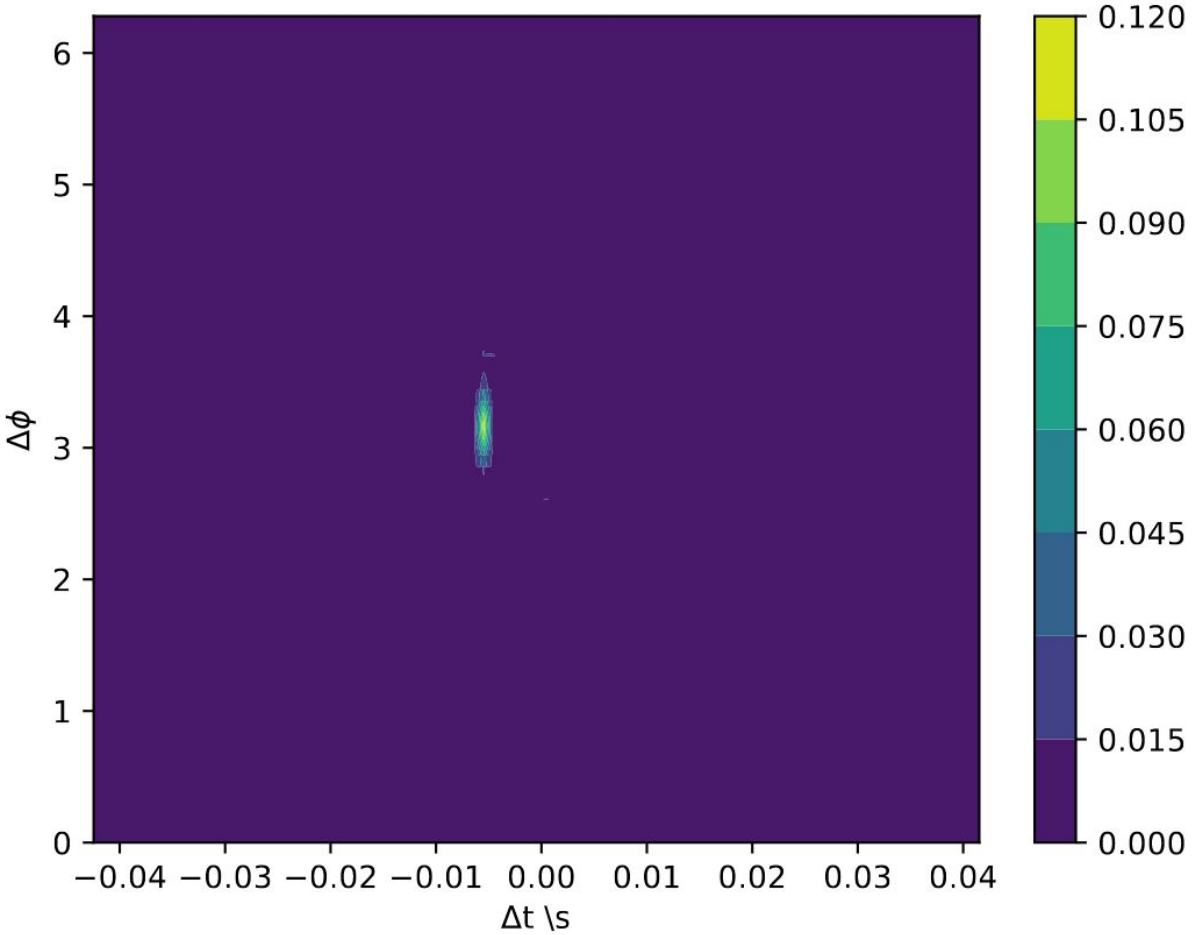
Results…. !

ΔΦ and Δt PDF for S190408an, with detector H1 and L1, SNRs = 4



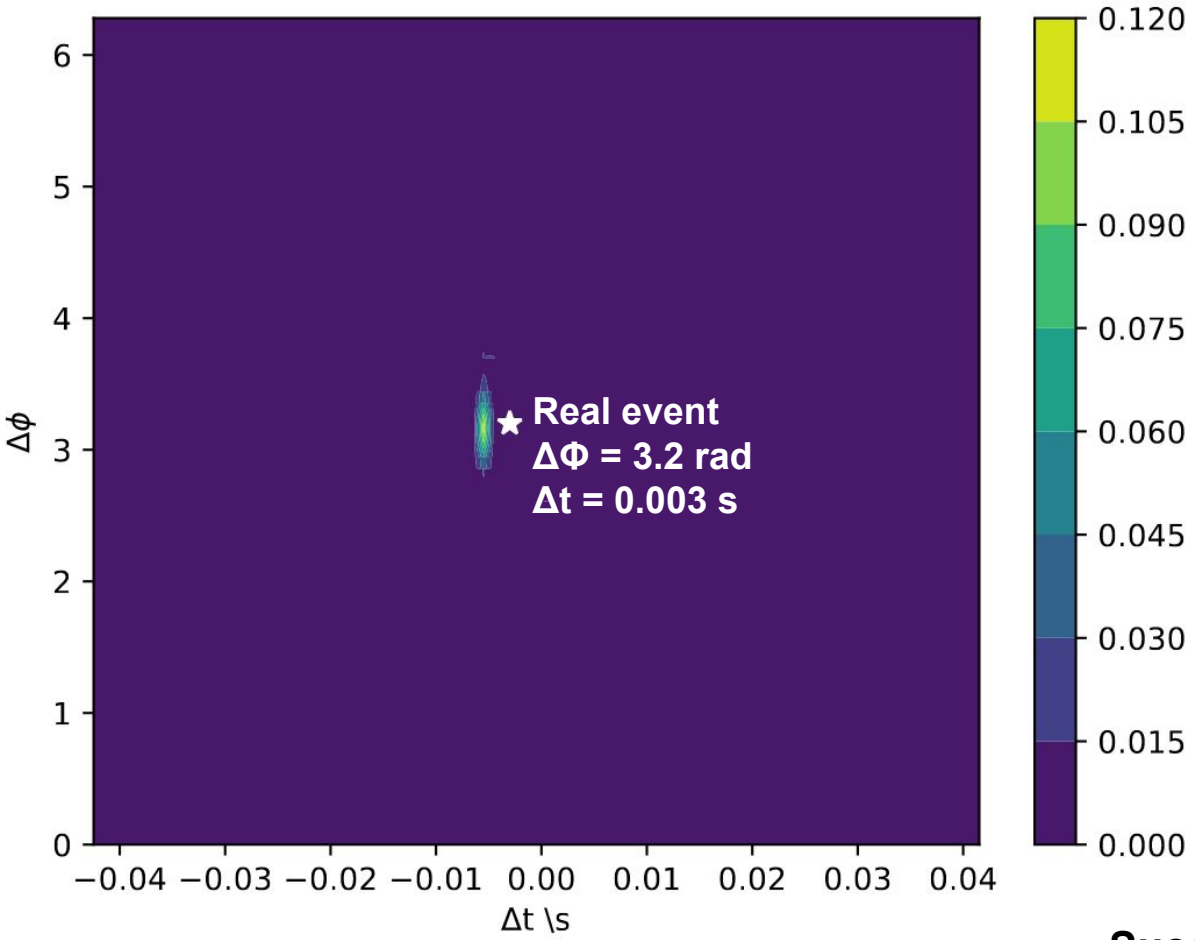
Results…. With Real SNRs!

ΔΦ and Δt PDF for S190408an for H1L1 with detector SNRs equal to event values



Results…. With Real SNRs!

ΔΦ and Δt PDF for S190408an for H1L1 with detector SNRs equal to event values



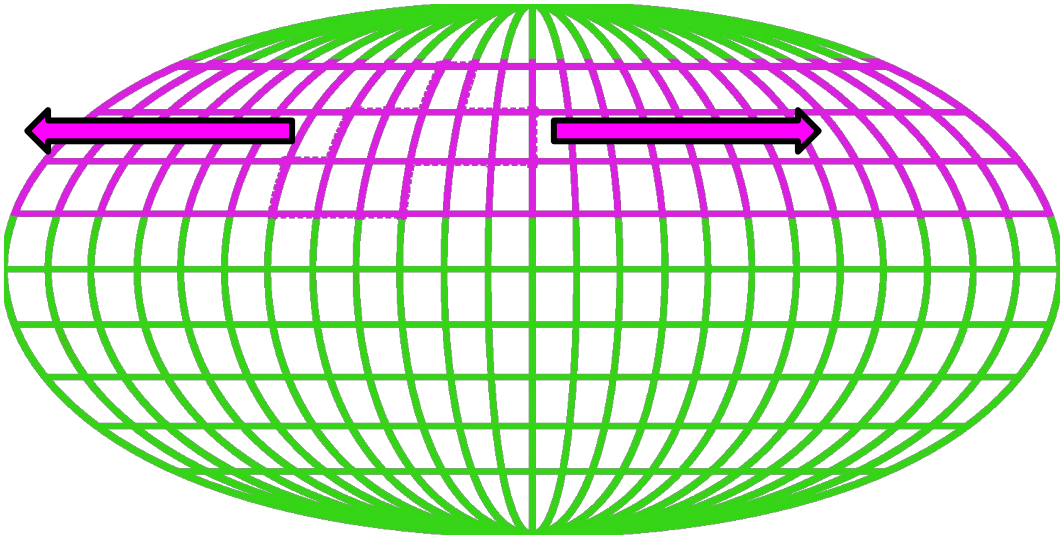
Success!!

What about Rotation of the Earth?

- Lensed **images separated** by **minutes up to weeks or months**

  Earth will have rotated between images

- Need to account for different detector response functions
- Image will effectively come from any RA within target's DEC range



What next?

- Implement the skymap rotation into GstLAL to **tile 90% band of the sky**
- Run modified search pipeline and **compare to previous candidates** with known target event overlap between sky localisations and **see if events are boosted appropriately**

Summary

- Aiming to **boost rankings of lensed images with similar sky localisations**

Done:

- Changed tiling method to only account for **90% credible interval** of a target event

To do:

- Need to further modify this to **account for the rotation of the Earth**, and tile a band around the sky
- Test in sub-threshold search pipeline against previously found candidates to **see if likelihood boosting works as expected**