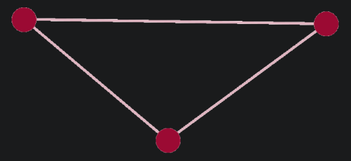


MAX PLANCK INSTITUTE
FOR GRAVITATIONAL PHYSICS
(ALBERT EINSTEIN INSTITUTE)

Don’t reinvent the wheel

Including EMRIs in the global fit

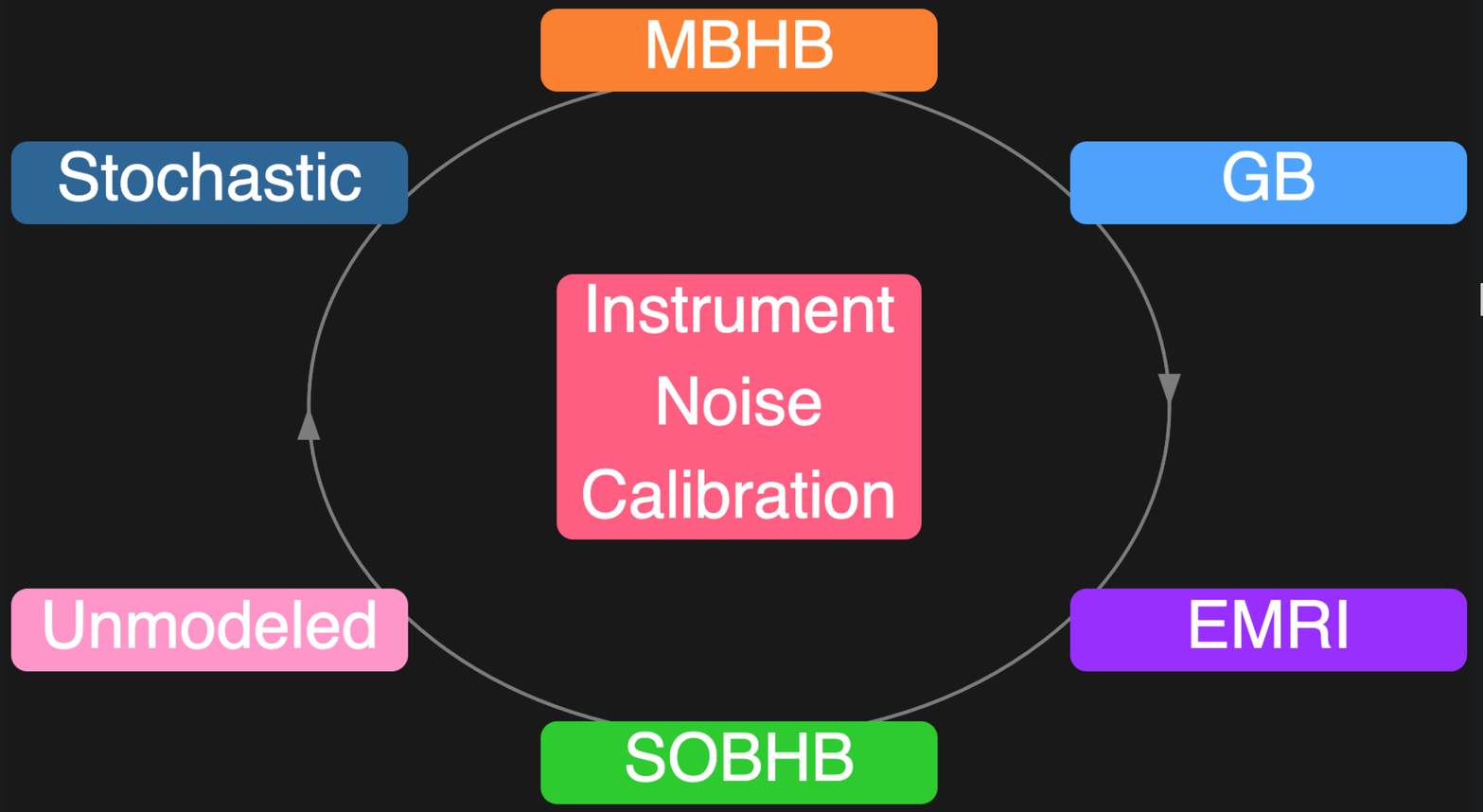
Alessandro Santini

& Michael Katz, Natalia Korsakova,
Nikos Karnesis, Jonathan Gair

EMRI Search and Inference within the LISA Global Fit
25/06/25

Global Fit framework: the wheel

Simultaneous analysis of all the sources



Littenberg:2023xpl

Strub:2024kbe

Katz:2024oqg

Deng:2025wgk

Fancy a drink?

cocktail

menu

RADLER	4.90
YORSH Stellar origin BHs / EMRIs	5.45
SANGRIA + higher modes: + 2 Euros	6.90
SPRITZ	6.45

cocktail

menu

COMING SOON

MOJITO (light)	6.50
MOJITO (Heavy)	8.50

COMING LATE

LONG ISLAND ICED TEA	9.50
AUNT ROBERTA	10.50

the LDC2A: Sangria

Sangria:

- Red wine (+ Brandy)
- Fruit (Oranges, apples…)
- Cinnamon
- Combined in a jar

Instrumental Noise

Galactic Binaries

MBHBs (`PhenomD`)

1-year-long dataset

From Sangria to Mojito (light)

Throw 8 EMRIs in the mix

[+ better models for the other sources]

Erebor: Sangria tools

Katz:2024oqg

Eryn
https://github.com/mikekatz04/Eryn

BBHx
https://github.com/mikekatz04/BBHx

MBHB

GBGPU
https://github.com/mikekatz04/GBGPU

GB

Stochastic

LISAanalysistools
https://github.com/mikekatz04/LISAanalysistools

Instrument Noise Calibration

Erebor: Mojito tools

Katz:2024oqg

Eryn
https://github.com/mikekatz04/Eryn

BBHx
https://github.com/mikekatz04/BBHx

MBHB

GBGPU
https://github.com/mikekatz04/GBGPU

GB

Stochastic

LISAanalysistools
https://github.com/mikekatz04/LISAanalysistools

Instrument
Noise
Calibration

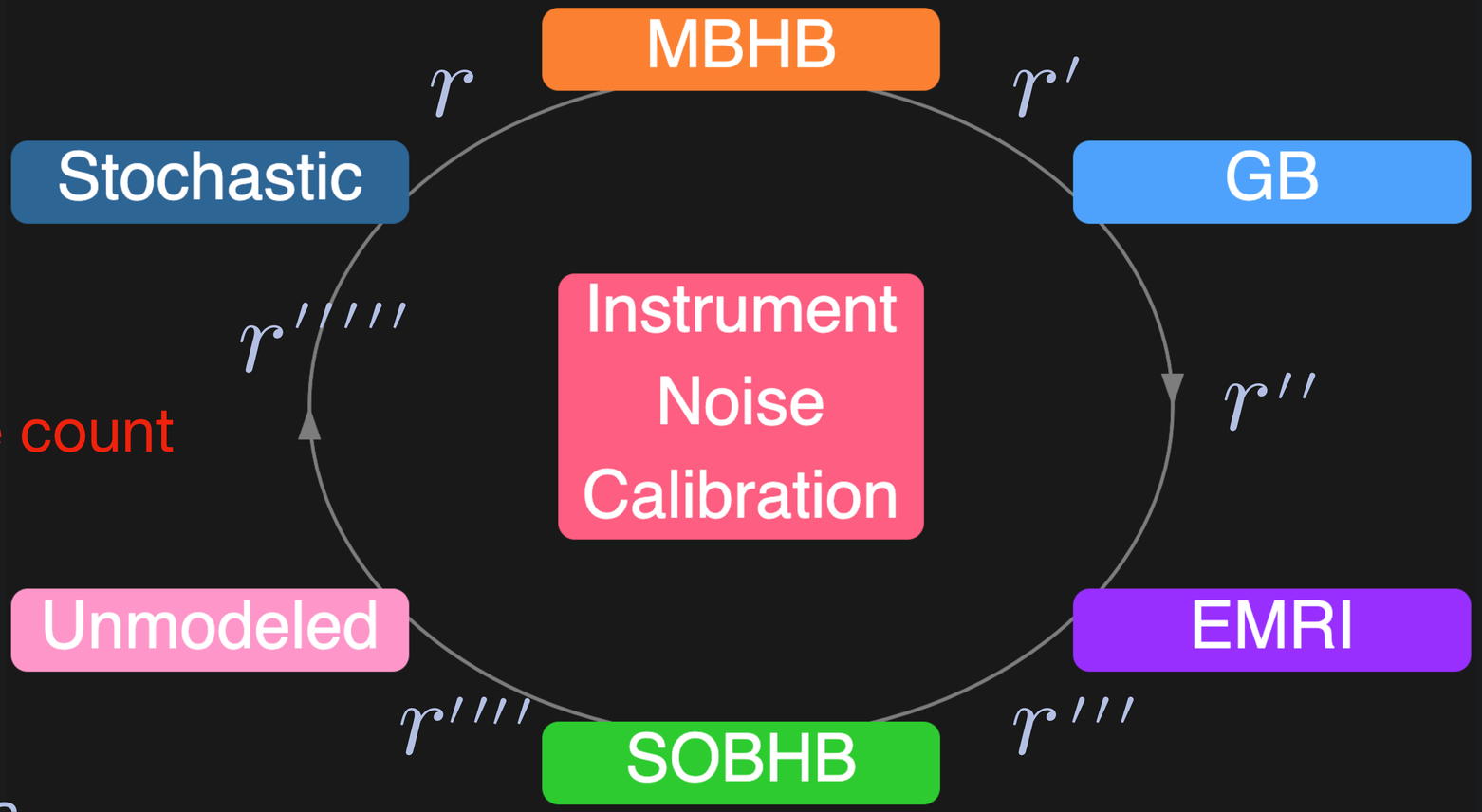
FEW, Fastlisaresponse
https://github.com/BlackHolePerturbationToolkit/FastEMRIWaveforms
https://github.com/mikekatz04//lisa-on-gpu

EMRI

Erebor's core: data residuals

$$r = d - \sum_{i,j} h_{i,j}$$

Source type i,j Source count



Serial update of the residuals

Residual-based Global Fit

@ sampler iteration n

Source type k

r → $k-1$

Fix all the parameters $\theta^{n}_{i\neq k,\,j}$

Take $\theta^{n-1}_{k,\,j}$ and produce $H^{n-1}_{k} = \sum_{j} h(\theta^{n-1}_{k,\,j})$

Take the “pseudo-residuals” $\tilde{r} = r + H^{n-1}_{k}$

Propose new points $\theta^{n}_{k,\,j} \rightarrow$ accept/reject

Compute $r' = \tilde{r} - H^{n}_{k} = \tilde{r} - \sum_{j} h(\theta^{n}_{k,\,j})$

$\times\, n_{\text{repeat}}$

r' → $k+1$

Add one, Remove one

All of this is source-independent (ish), and ultimately propose = compute a $\log \mathscr{L}$

Base propo
of residu

Move, Move):

“““Easy”””” to add a new source type

Encode source-specific
operations in child proposals

You, 1 second ago | 2 authors (Michael Katz and one other)
class MBHSpecialMove(ResidualAddOneRemoveOneMove, GlobalFitMove, RedBlueMove):

[e.g. Heterodyning for MBHs]

EMRIs as fancy MBHBs

Modular proposal blocks

EMRIs single source PE

} Straightforward to add the EMRIs block

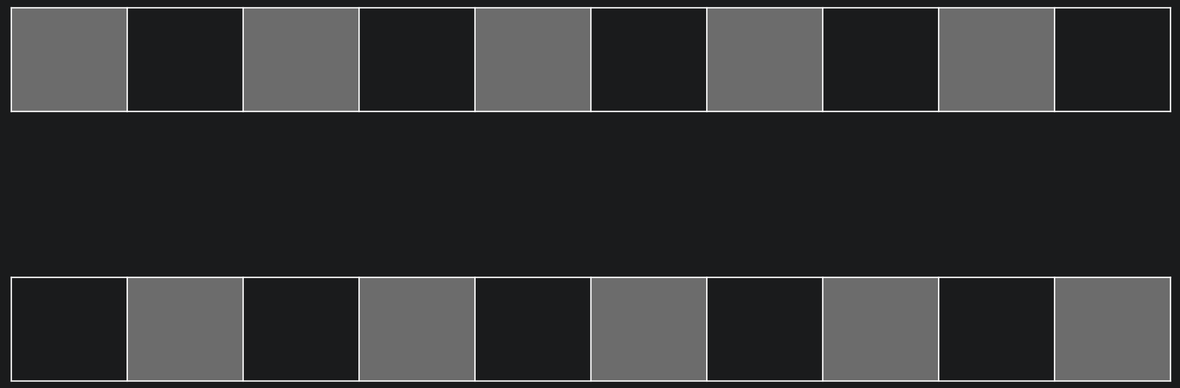
```
gf_branch_information = (
    GFBranchInfo("mbh", 11, 15, 15, branch_state=MBHState, branch_backend=MBHHDFBackend)
    + GFBranchInfo("gb", 8, 15000, 0, branch_state=GBState, branch_backend=GBHDFBackend)
    + GFBranchInfo("emri", 12, 1, 1, branch_state=EMRIState, branch_backend=EMRIHDFBackend)
    + GFBranchInfo("galfor", 5, 1, 1)
    + GFBranchInfo("psd", 4, 1, 1)
)
```

Galactic Binaries are tricky

~10000 resolvable over one year, but very compact in frequency

Update the odd/even frequency sub-bands in turn

$$\tilde{r}_{\text{odd}} = r + H^{n-1}_{k,\,\text{odd}}$$



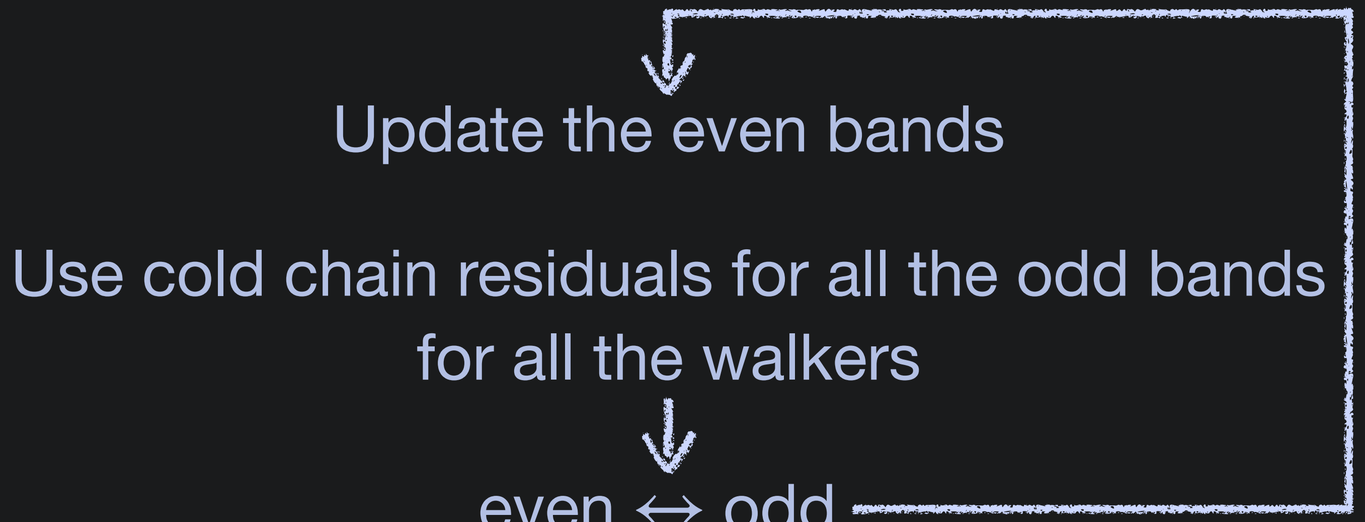
For each walker w, temperature t:

$$\tilde{r}_{\text{even}} = r + H^{n-1}_{k,\,\text{even}}$$

Galactic Binaries are tricky

Must consider global memory storage: save **only** cold chain residual and parameters

For each sub-band, load a buffer



(w, t_1)	(w, t_1)	(w, t_1)
(w, t_1)	(w, t_2)	(w, t_1)
• • •	• • •	• • •
(w, t_1)	(w, t_{k-1})	(w, t_1)
(w, t_1)	(w, t_k)	(w, t_1)

Back to EMRIs

We do have a working proposal for EMRIs, FEW 2.0

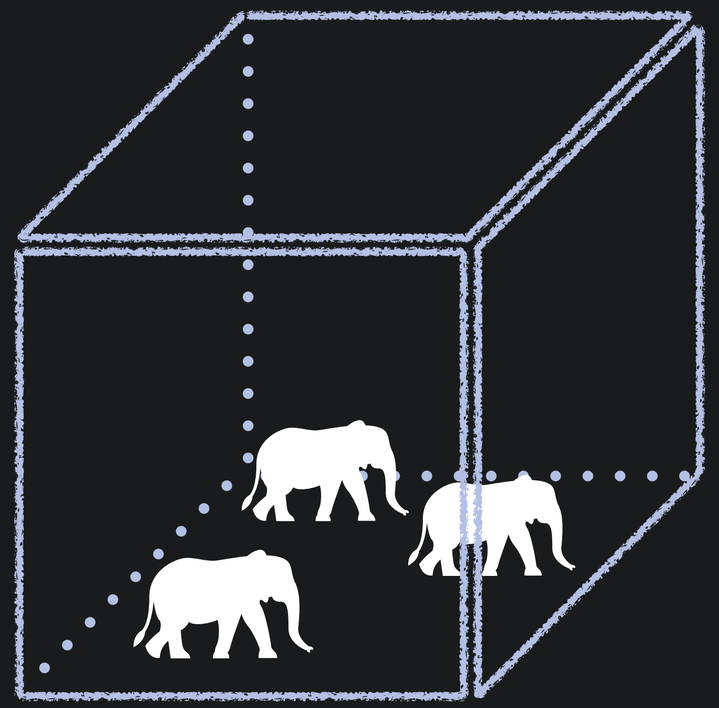
Current roadmap:

- Take the Sangria training data
- Take the Erebor catalogs **https://zenodo.org/records/11130700**
- Subtract MBHBs and GBs
- Add an EMRI to the residuals
- Take the last PSD + foreground state
- Run on EMRI, PSD, foreground

The elephants in the room

- No search is done here, just looking at the PE stage
- Not looking at correlations between source types
- Building a global fit has never been about building a global fit

- Ensure compatibility with external search pipelines (priors, starting point)
- Repeat the entire Sangria(HM) analysis with (at least) one EMRI(s)
- Investigate if we can be more efficient in the EMRI proposal / back to MPI



Conclusions

- With all the base residual operations already in place, it’s easy to add a new block
- EMRIs make no difference
- We can now sample in EMRIs together with the rest, but still in a ‘naive’ way
- Start to run on signals injected in our residuals
- Increase the complexity from there [include MBHBs, multiple EMRIs…]

TODOs

- Start to think about a time-iterative pipeline
- Address the elephants