Continuous gravitational wave atlas.

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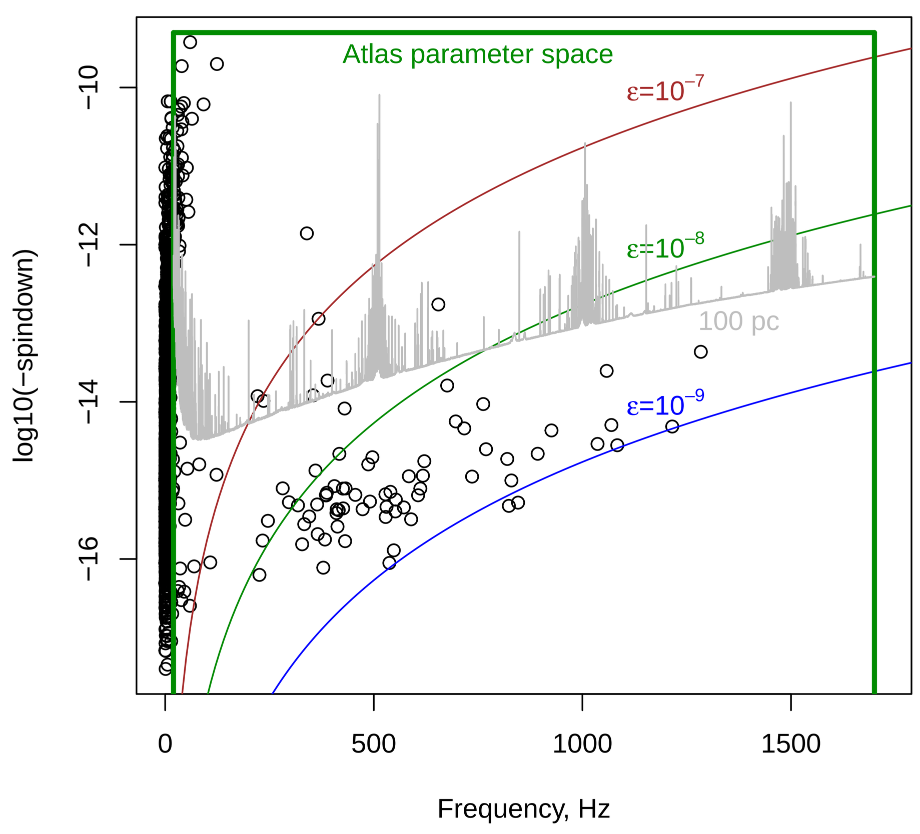
Introduction

Continuous gravitational waves emitted by non-axisymmetric neutron stars are significantly weaker — by orders of magnitude — compared to transient signals generated by collisions involving black holes or neutron stars.

However, once discovered, a continuous wave source allows repeated observations. Ideally, we want to find a source that can be studied in gravitational and electromagnetic channels simultaneously.

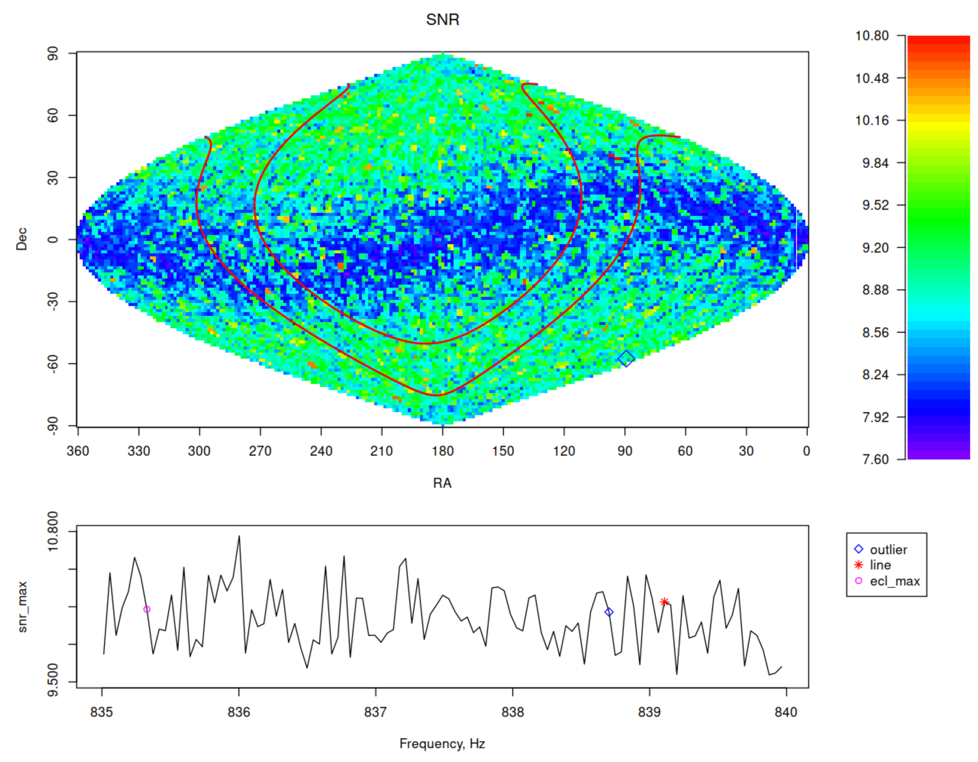
All-sky search



Only a small fraction of our galactic neutron stars have been discovered through electromagnetic and particle observations. The plot above depicts the parameters (black circles) of these known neutron stars in relation to their *equatorial ellipticity* ϵ — a key metric of the degree of deformation required for a neutron star to generate gravitational wave signals.

With advancements in algorithms, it is now possible to search the entire sky for unknown neutron stars. Since continuous gravitational waves persist over time, sensitivity is enhanced by integrating data over months of observation, albeit at a significant computational cost. The plot above shows results from our "Expanded Atlas of the Sky in Continuous Gravitational Waves".

Gravitational wave atlas



In the past, searches for continuous wave sources yielded frequency-dependent upper limits and a few outliers that stood out in the data, while the majority of intermediate computational results were lost.

Our Falcon searches release all-sky data as an *atlas* [1]. For each frequency band, the atlas provides images of the entire sky using upper limit and signal-to-noise ratio (SNRs) data. While some of these results have been followed up, the majority are unexplored. New searches can be built upon the computationally intensive first-stage results of the Falcon search.

The atlas data is presented in a novel MVL file format, designed for ease of analysis on small computers, such as your notebook. The included spatial index speeds up queries by sky position.

The atlas comes with practical examples that demonstrate how to

- Retrieve upper limits and SNRs for specific sky locations and frequencies
- Produce upper limits and SNRs over entire frequency band for a specific sky location
- Find all points above a fixed SNR threshold
- Generate a skymap and a spectrum plot for any frequency range (example above)

Several atlas releases are available [1].

Introduction to MVL

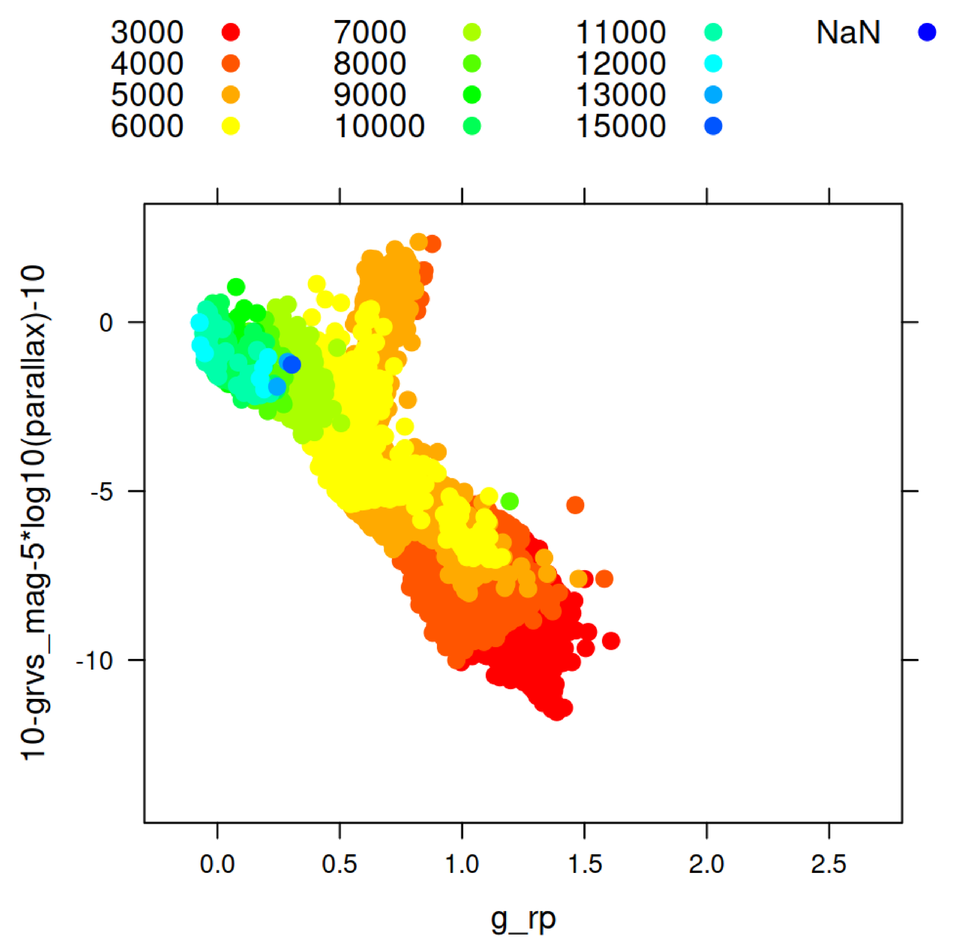
Mappable Vector Library (MVL) is a file format optimized for memory mapping, enabling efficient and direct data access. With MVL files, you can:

- Analyze datasets as large as the capacity of your solid state storage.
- Seamlessly exchange bulk binary-level data between C [2] and R [3] programs.
- Share large datasets between multiple processes.

Beyond providing seamless array-style access, MVL libraries offer database-like functionality, including the ability to sort data and create hash-based value and spatial indices for faster queries.

To ensure optimal performance, the library functions have been carefully optimized to minimize the number of write operations to solid-state drives, enhancing both speed and longevity.

Gaia data in MVL format



Gaia mission collected a wealth of data on nearby stars. While online databases allow to search for a given object, it would be nice to explore Gaia data as a whole. To make this possible, Gaia data has been converted to MVL format [1], which is available for download using HTTP and Torrent.

Besides raw data, we provide indices allowing to search and scan in order of distance from Earth, or by sky position.

Gaia example

```
library("RMVL")
M<-mvl_open("gaia_dr3.mvl")
Mpi<-mvl_open("parallax_index.mvl")
# Find closest one million stars
idx<-Mpi$parallax_index[1:1000000]
plot(M$gaia[idx, "parallax"], log="xy")
```

References

[1] Gravitational Wave Atlas and Gaia DR3 Releases
https://www.atlas.aei.uni-hannover.de/work/volodya/releases.html

[2] https://github.com/volodya31415/libMVL

[3] https://cran.r-project.org/package=RMVL

[4] https://github.com/volodya31415/gaia_mvl

CONTINUOUS GRAVITATIONAL WAVES