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Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA

ICSC Centro Nazionale di Ricerca in HPC, Big Data and Quantum Computing

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The Frequency-Hough project: algorithm optimization and HPC for present and future continuous gravitational-wave searches.

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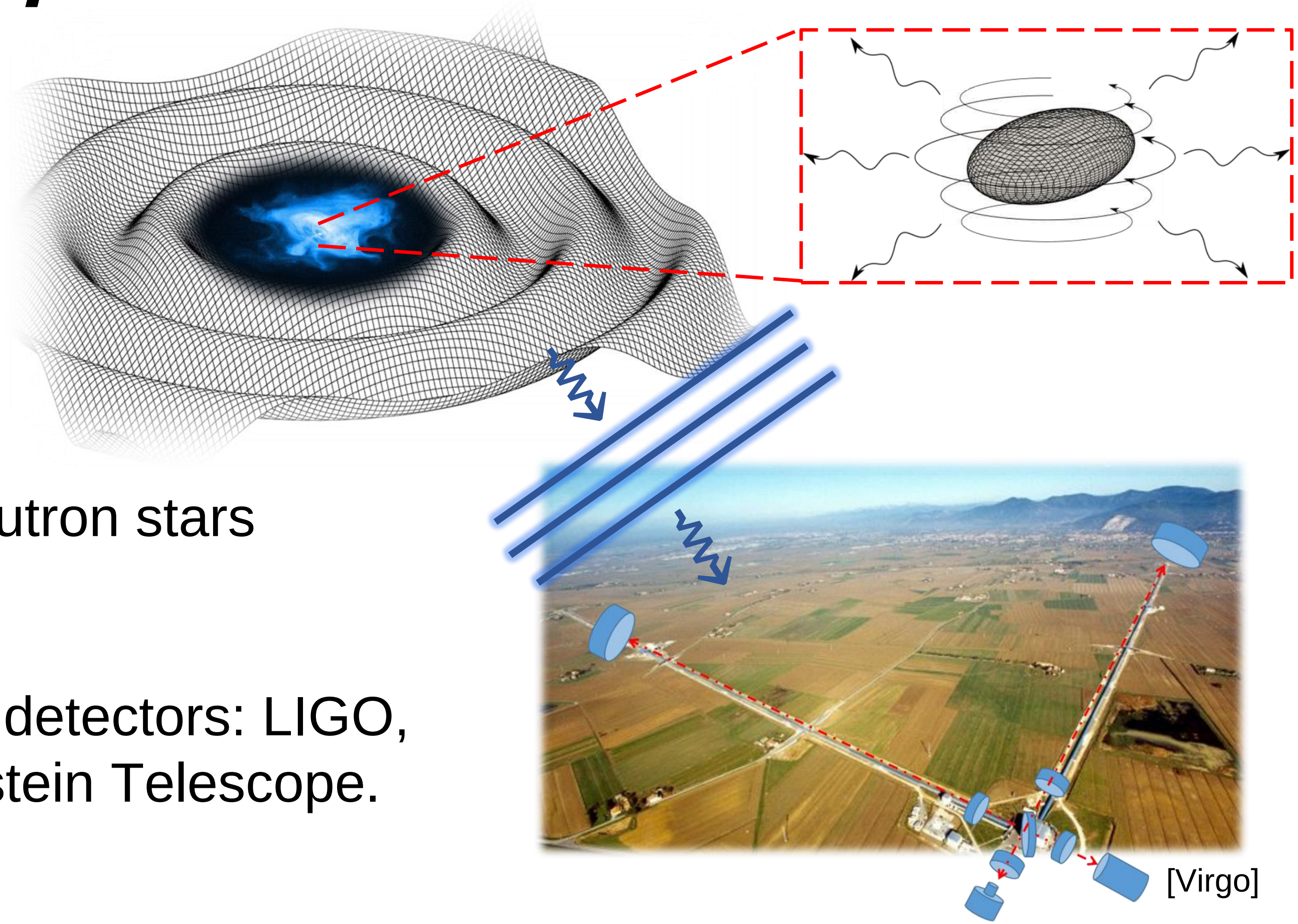
Spoke 2 annual meeting, Catania, 12/12/2024

Frequency Hough analysis for continuous gravitational waves.

Topic: Long-duration gravitational waves, likely present during the whole data taking.

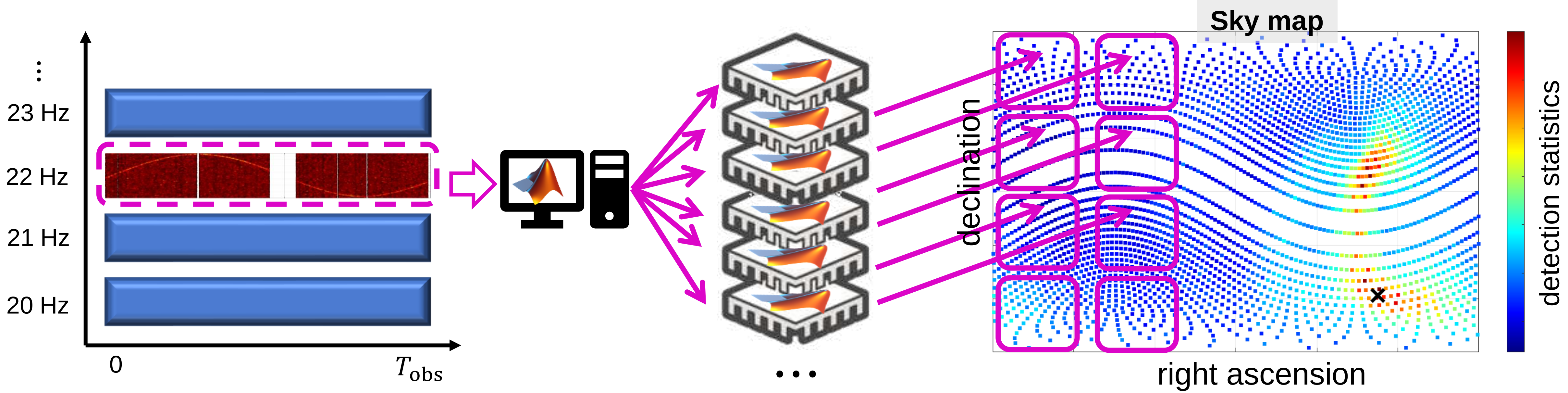
- Perturbations of the space-time, predicted by General Relativity.
- Emitted by rotating, deformed neutron stars (and more exotic sources).
- High scientific value.
- Can be detected by Earth-based detectors: LIGO, Virgo, KAGRA and by future Einstein Telescope.
- Not yet detected so far.



The algorithm and our project

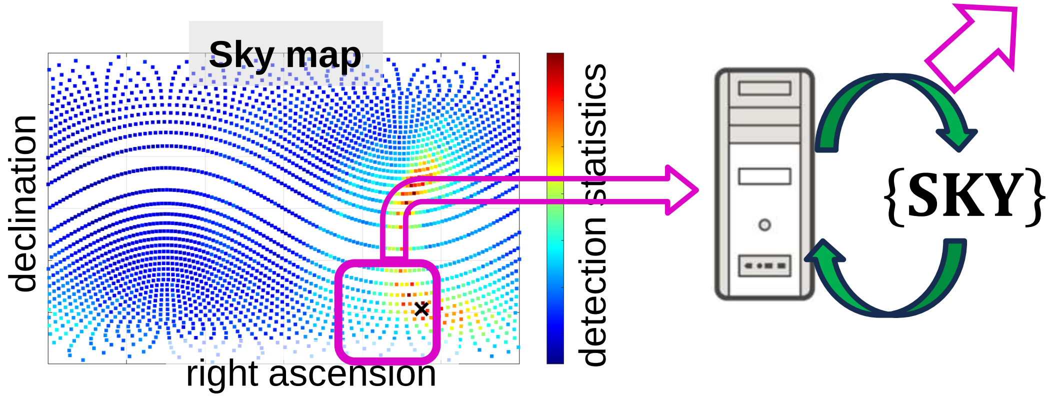
1) Implemented in Matlab.
2) The full search is divided in independent jobs.
3) Each job searches signals in one frequency band (from 20 Hz to 2000 Hz), from sources localized on a subset of directions from a discrete sky map.
4) To complete the full search, we need about **10^7 core hours for 1-year data for each detector!**
5) Using, e.g., **3500** (14HS06) **CPU** cores with no pauses between jobs, no crashes, no waiting queues → **9 months** to analyze data from 2 detectors.

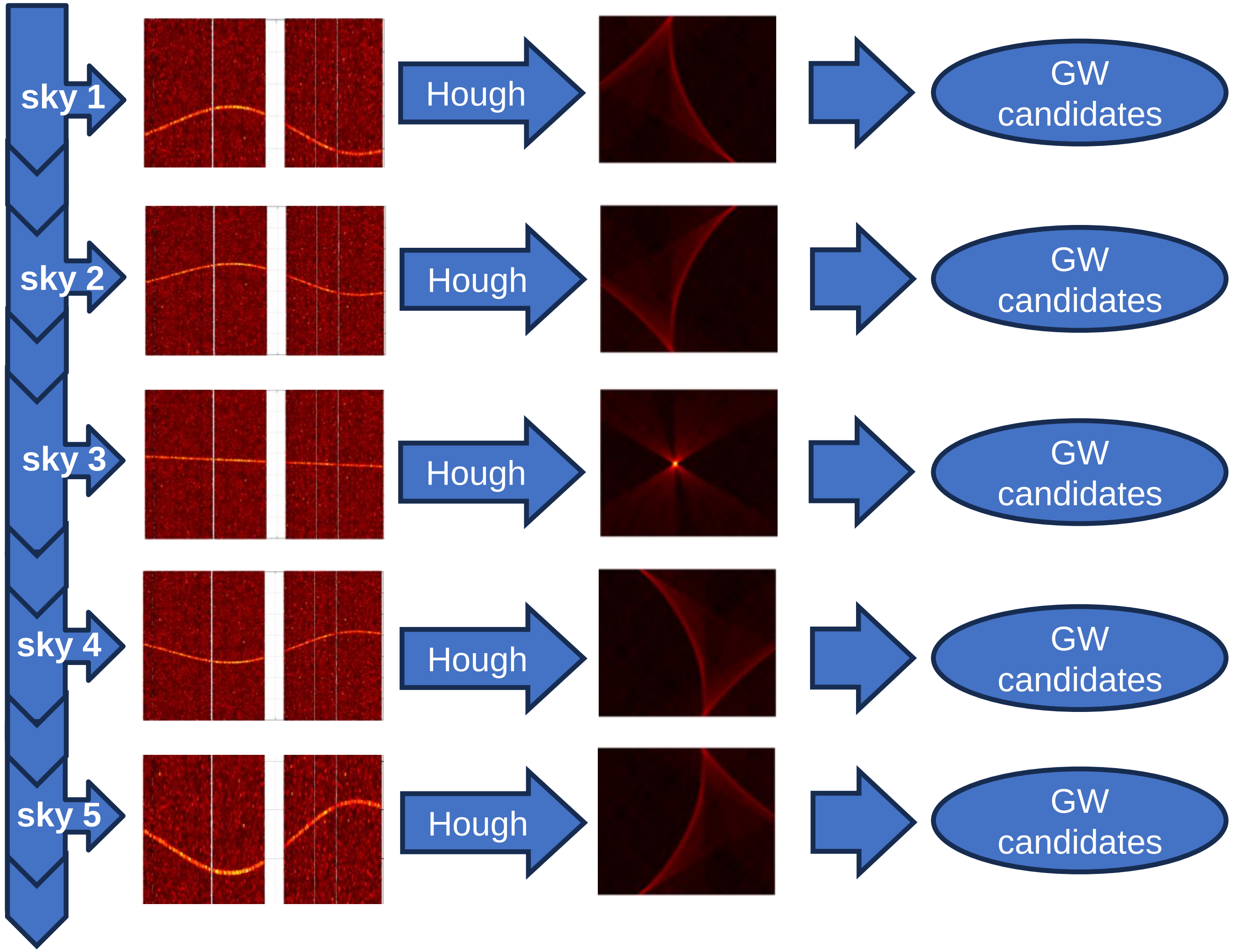
➢ HPC project at **ICSC**: resources and optimization.
→ **10^7 core hours** at INFN Grid (Napoli, Bari Tier2)
→ **400000 GPU hours** at CINECA (Leonardo)



The core: Hough transform

- The Hough transform is used to detect specific patterns inside an image.
- In our search, time-frequency maps are corrected for a specific sky position and then fed to the Hough transform.
- All the subset of sky positions is analyzed.
- Only the sky position that matches the real position of a source maximizes the output of the Hough transform.
- The Hough transform dominates the total computational cost of the search.





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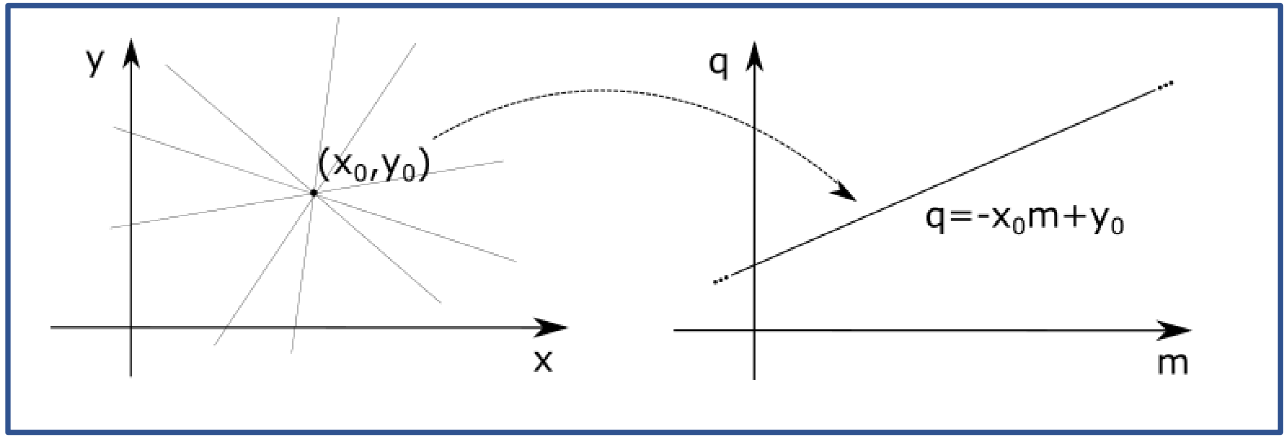
The optimization of the Hough transform

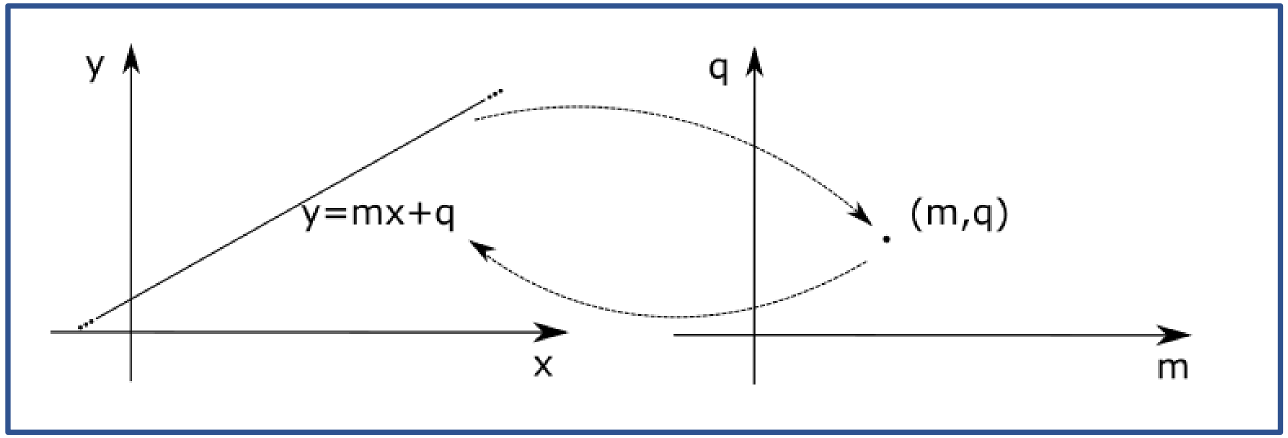
- The Hough transform is an integral transform: maps straight lines in the physical space into dots in the parameter space.

- Old implementation: direct writing.
  Each point is mapped as a line in the Hough map. The code was highly optimized, with a core compiled in c.
  But different points can write on the same memory locations → NOT parallelizable!

- New implementation: reading-writing.
  Each point in the Hough map is computed by integrating along the corresponding line.
  → Can be done in parallel!



Physical space (x, y) → $y = mx + q$ → Parameter space (m, q)

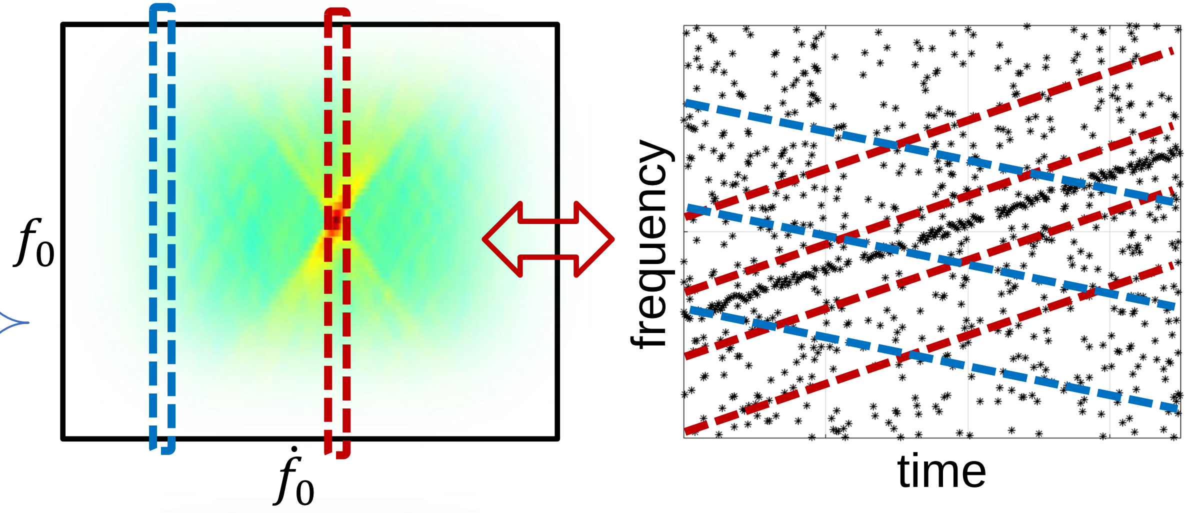


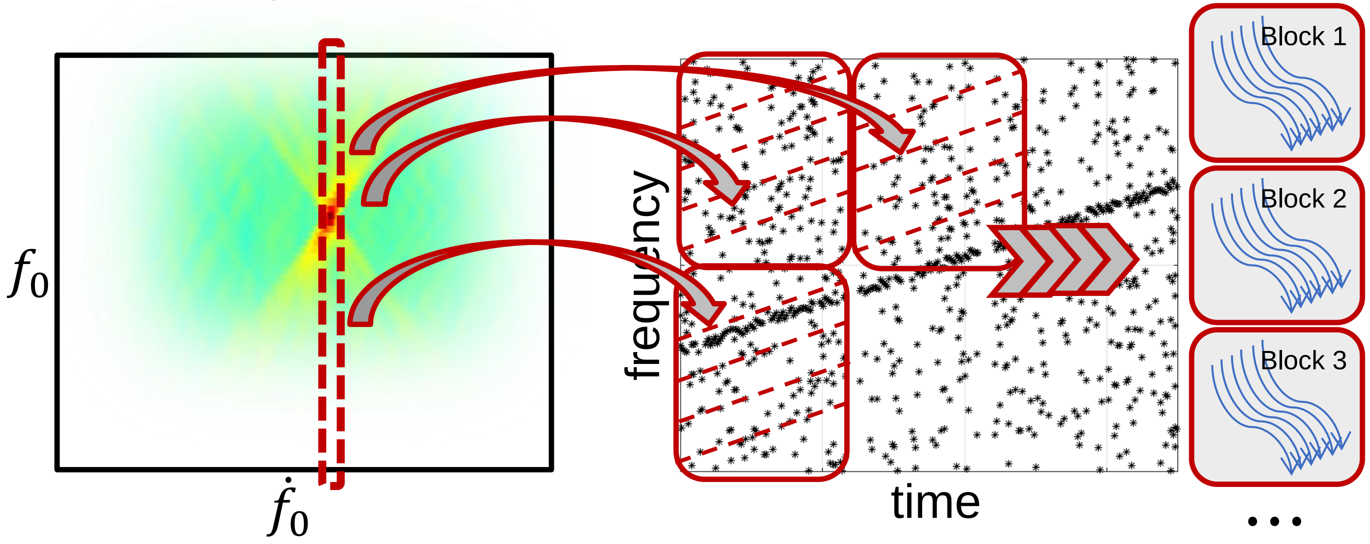
The workflow through the milestones

- **MS7**: new implementation on CPU. Same performances of the old one when running in single core, but it can exploit hyperthreading.

- **MS8**: first implementation on GPU → Algorithm 1
  Hough map computed column-by-column, as histograms following different slopes.

- **MS9**: second implementation on GPU → Algorithm 2
  Compiled CUDA kernel: the whole computation is distributed in blocks, outputs recombined.





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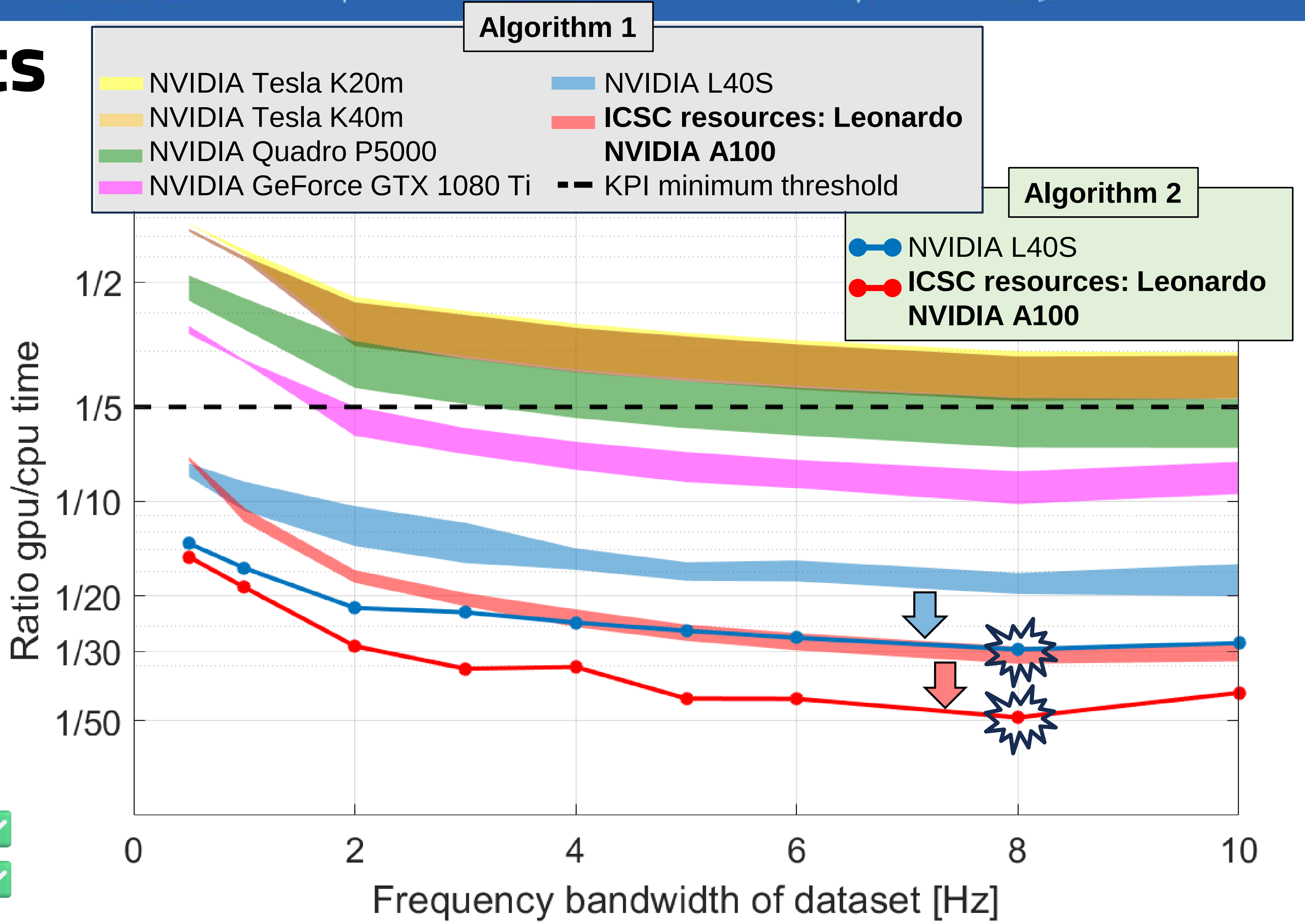
Performance tests

- For comparison, we run the original code on a recent CPU (Intel Xeon Gold 6430).
- In practice, our gain is higher since in the past we run at CNAF on 11-14 HS06 cores.
- With modern GPUs (L40S, A100) the computing time ratio is significantly below the $^1/_5$ threshold.
- With Algorithm 1 the best reduction is by $^1/_{30}$.
- With Algorithm 2 the best reduction is by $^1/_{50}$.
- **KPI 2.1 – TAR 3.12 fulfilled** ✅
- **KPI 2.2 – TAR 3.19 fulfilled** ✅



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Conclusions and next targets

- Code optimization and HPC are crucial for future gravitational-wave searches.

- Past milestones (MS 7/8/9): new implementations of the Hough transform, to exploit parallel architectures like hyperthreading and GPUs. The performances of the new algorithms are well beyond the minimal thresholds.

- Next milestone (MS10): double target.
  ↪ TAR 3: alternative implementation in python (easier deployment), comparative tests.
  ↪ TAR 4: optimization of the full pipeline and extensive testing of the computing infrastructure, with long runs and different algorithms.

- New milestone for ICSC extension? Maybe we have!

Thank you for your attention!