GWPAW 2012

Gravitational Wave Physics & Astronomy Workshop

Noise line investigations in Virgo VSR2 - VSR4 data

Abstract. The monitoring and identification of noise lines in the science data of a gravitational wave interferometer is an important task for continuous wave (CW) searches as well as for detector characterization studies. The NoEMi (Noise Event Miner) framework was developed to monitor the noise lines during the science runs and record them in a database for off-line analysis purposes. We will show the results of the analysis of the lines detected by NoEMi in the Virgo runs VSR2-VSR4, which has led to the identification of the source of more than 90% of the lines and provided relevant information about the data quality of the runs. We will also discuss how the line database is used to identify and reject the fake signal candidates in the all-sky CW search.

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Motivations

Spectral noise lines are harmful for the search of continuous gravitational wave signals (CW)

Targeted search	All-sky search
Noise lines at known pulsar frequencies affect detector sensitivity	Noise lines give fake CW candidates
Need to monitor known pulsar frequencies during science runs to ensure data quality and warn detector experts if noise lines appear	Need to identify and catalogue all lines due to noise to safely reject fake candidates in the off-line analysis

NoEMi framework was conceived to fulfill the above requirements

NoEMi features

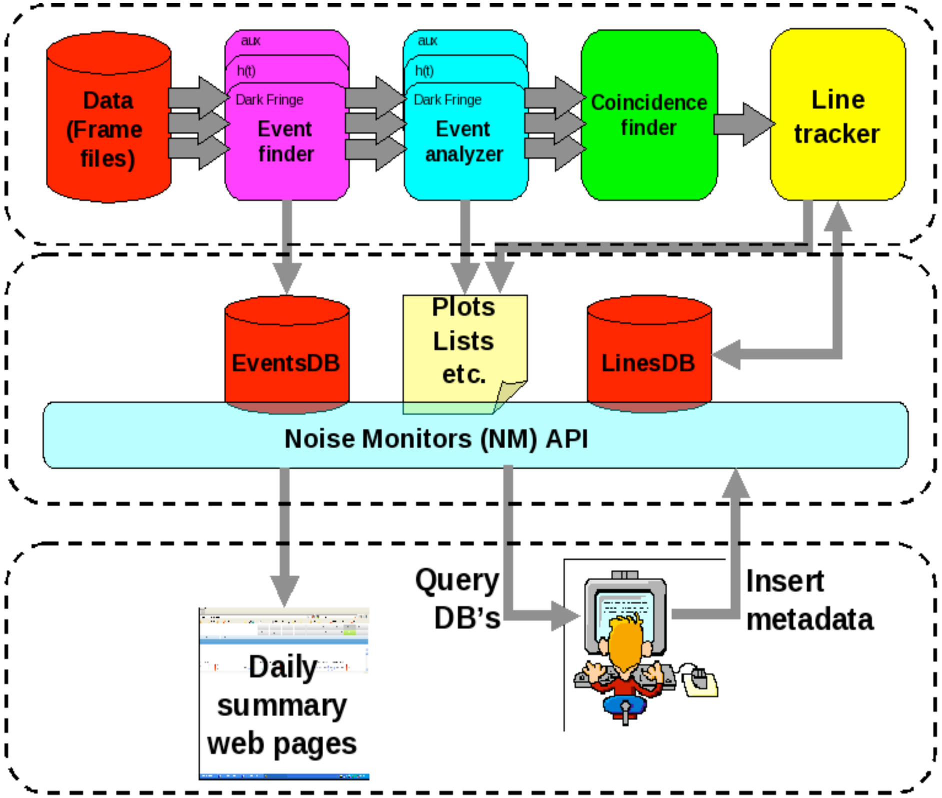
Uses part of the CW analysis code.

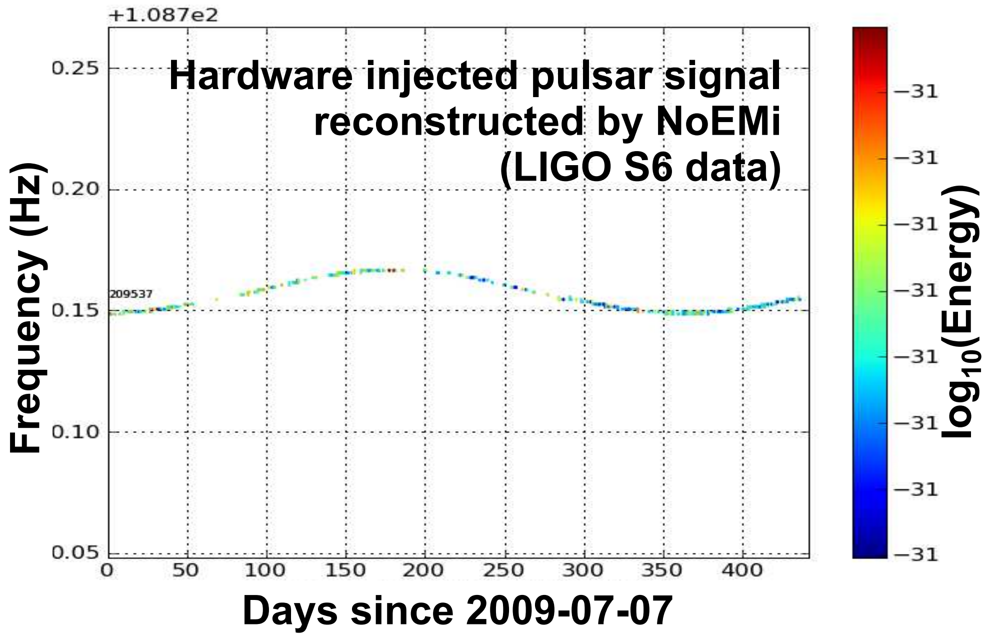
Runs in quasi-real-time with the data taking during the science runs.

Analyses the detector science data and a subset of environmental sensor data, looking for lines matching in frequency (coincidences).

Publishes daily results on web pages.

Records results in a DB accessible to users through a web interface.





Classification of VSR2-VSR4 lines

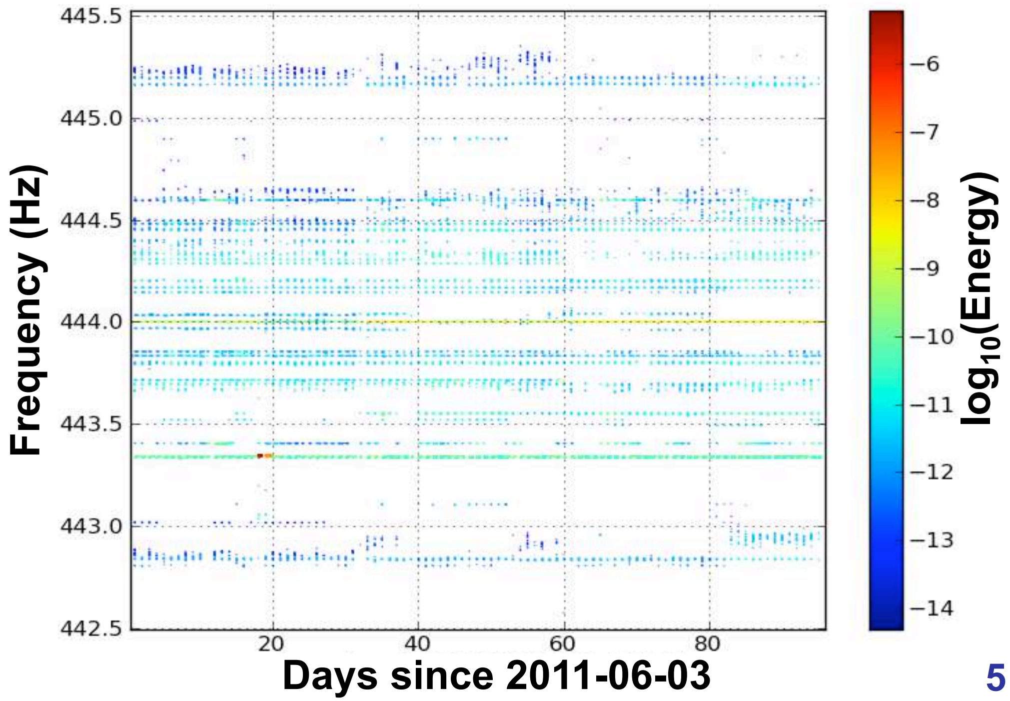
- ➡ Line frequency resolution: **1mHz**
- ➡ Lines present over more than **20%** of the run time considered
- ➡ In each run **~90%** of the lines have been identified (10-2048 Hz)

Line category		Number of identified lines		
		VSR2	VSR3	VSR4
Intrinsic lines	Violin modes	290	130	149
	Mechanical resonances	14	16	19
	Calibration and control	36	28	51
Noise lines	Power line and harmonics	40	40	40
	Vibration	21	15	26
	Magnetic	1	0	0
	Digital (harmonics of 1 Hz, 10 Hz, etc.)	23	72	322
	Sidebands	186	675	1133
Total identified		**611**	**975**	**1740**
Still unknown		**85**	**82**	**98**

E.g. line investigation: Sidebands

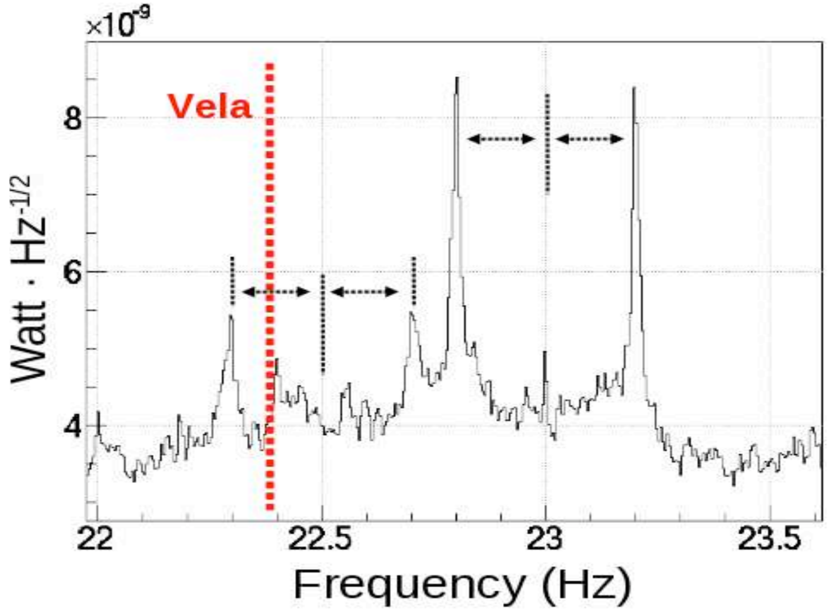
- ➡ Strongest lines have a comb of sidebands up to ±1.2 Hz around them
- ➡ Cause: coupling between the line and fundamental detector resonances
- ➡ In VSR3 and VSR4 sidebands appear around almost all harmonics of the 50 Hz power line, while in VSR2 only the first 3 power line harmonics and the strongest calibration lines showed sidebands
  - ➥ Indeed, VSR3 and VSR4 50 Hz lines are stronger than in VSR2. Investigation is in progress.

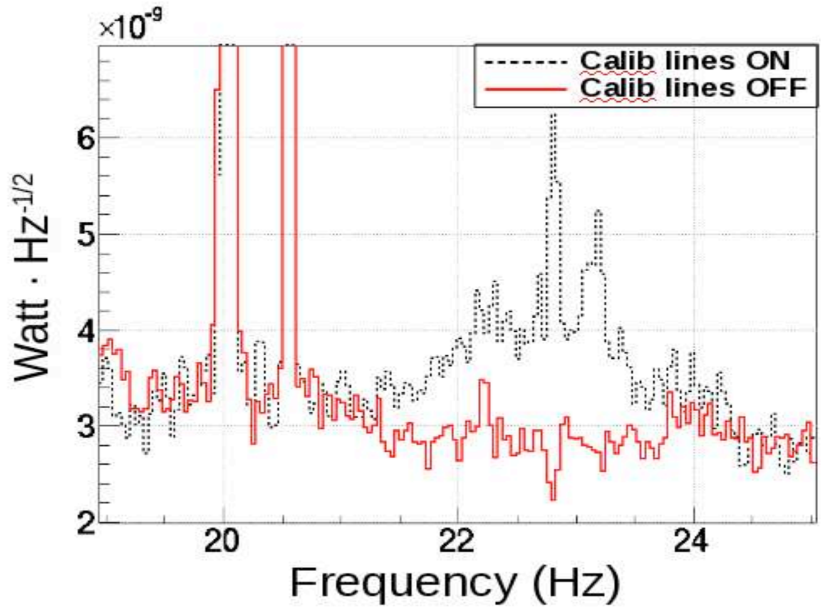
f (Hz)	source
0.031	ThetaY mode of suspended detection bench (SDB)
0.144	ThetaZ mode of NI payload
0.167	ThetaZ mode of WE payload
0.200	first pendulum mode of long SA
0.285	ThetaZ mode of PR payload
0.305	ThetaZ mode of BS payload
0.450	second longitudinal mode of long SA
0.595	pendulum mode of long SA last stage
1.200	BS suspension longitudinal mode



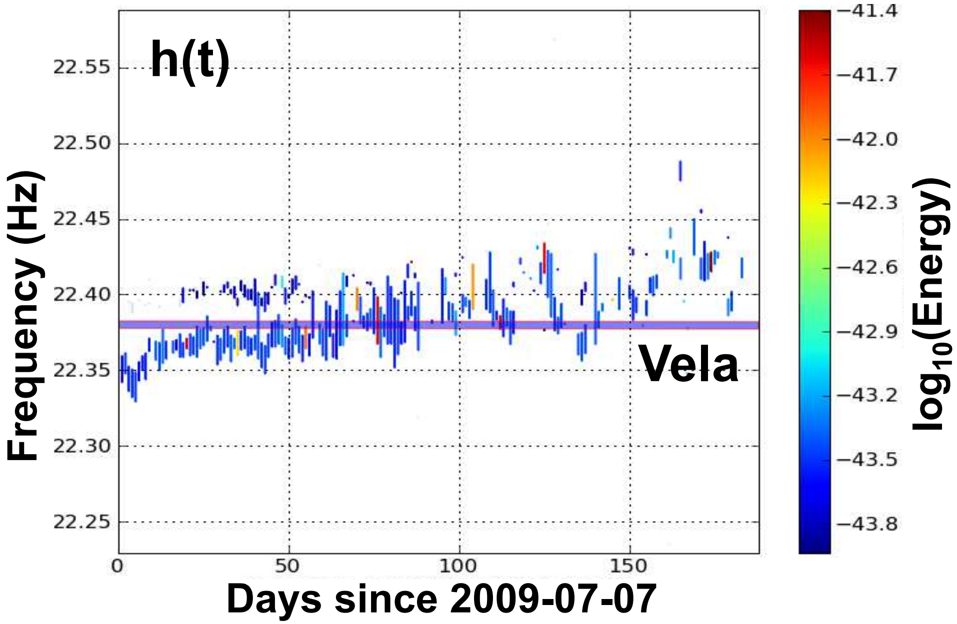
E.g. line investigation: "Vela bump"

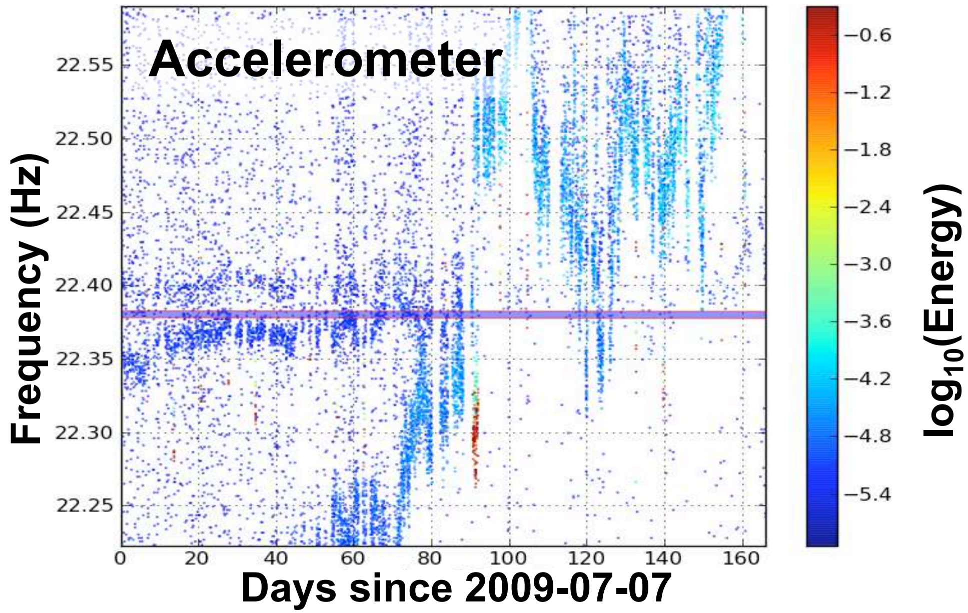
- ➡ Broad disturbance + comb of lines detected by NoEMi at the Vela pulsar frequency before VSR4 start
- ➡ Investigation started analyzing the lines, appearing as 0.2 Hz sidebands of particular frequencies: 22.5 Hz, 23 Hz
- ➡ Those frequencies are the difference between calibration and control lines at much higher frequencies, e.g. 379 and 356 Hz
- ➡ Test switching off calibration lines confirmed hypothesis: Vela bump disappeared
- ➡ Underlying bump likely caused by non-linear couplings among the different lines
- ➡ Actions: move calibration lines in frequency and reduce their strenghts
- ➡ Results: Virgo sensitivity at Vela frequency improved by ~50%

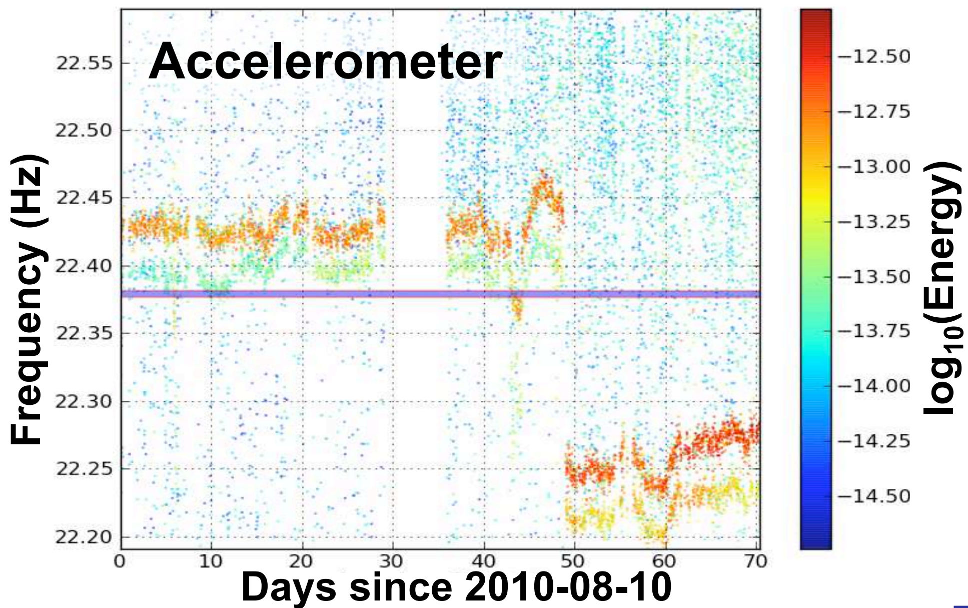




E.g. line investigation: “Vela killer”







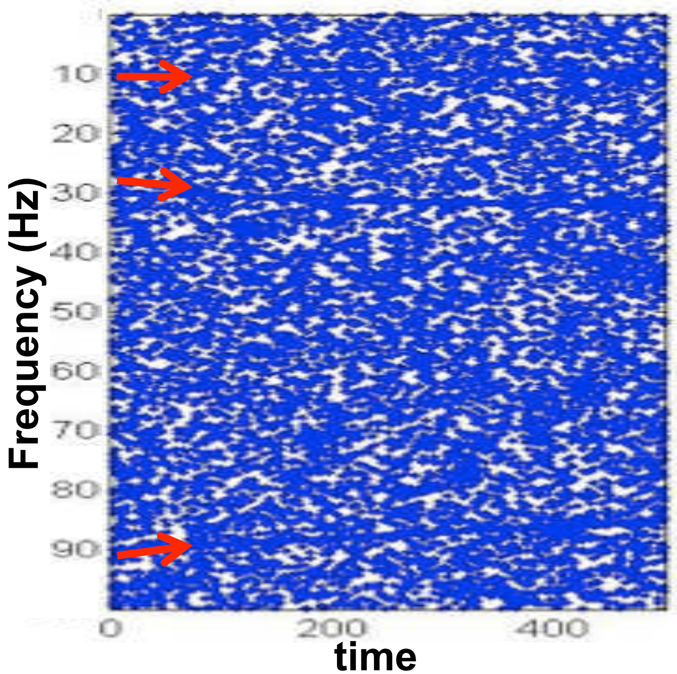
- ➡ Disturbance detected off-line on VSR2 data at the Vela frequency
- ➡ NoEMi found the line coincident with an accelerometer
- ➡ Source: vibrational noise due to chiller engines
- ➡ Action: change rotational frequency of chillers to move line away from Vela

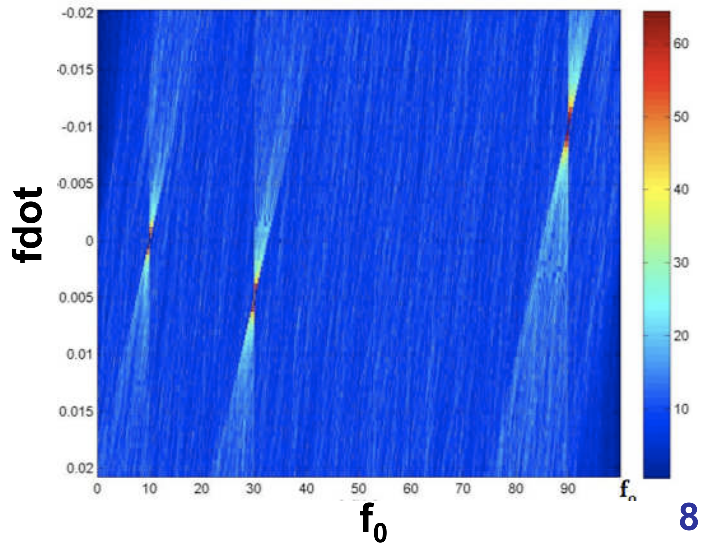
CW all-sky search: overview

- ➡ 4 search parameters: **f**, **fdot**, **sky position**

1. Start: **peakmap database** (set of frequency peaks in time-frequency plane)
2. For each position in the sky construct the **Doppler shifted** peakmap
3. Frequency – Spin-Down **Hough transform**: each point in the time-frequency plane is mapped to a set of points (a line) in the f-fdot plane
4. The peaks in the Hough plane are the candidates for the next steps of the analysis
   - ➥ See also poster of P. Astone *et al*

- ➡ Problems:
  - ➥ computational cost limits number of candidates
  - ➥ Noise lines create high number of candidates which survive the Doppler correction





Noise line vetoing procedure

1. Run the Hough search with **no doppler correction**
2. Look for the PEAKS in the Hough plane with a high threshold (6 sigma)
   - ➥ 10 spin down steps used for statistical reasons
3. Select the peaks corresponding to **ZERO spin down** or to the first, positive or negative, spin down step
   - ➥ This means the line is constant or varying in ±1 frequency bin during the run
4. In the time-frequency peakmap **veto** the bins corresponding to the candidate
   - ➥ Only the bins of the line, and the adjacent bins, are removed from the peakmap
5. The search is done on the "cleaned" peakmap
   - ➥ This step of the procedure is fast, and it needs to be done only once for each frequency band

The vetoed peaks are investigated using the NoEMi line database

NoEMi line lists

From the NoEMi database it is possible to extract lists of "known" (i.e. its source has been identified) and "unknown" (not yet identified) lines.

Lists for VSR2-VSR4 are available on the Virgo web server.

Line parameters (width, duration*, amplitude, etc.)
are available in the list, e.g.:

freq	Δf	duration	CR	Log10(amp)	comment
30.000	0.001	0.98	18.53	-44.40	%%% Id: 72 - Part of 10Hz comb

* Line duration is given as a fraction of the run duration. A threshold of 0.2 in the line duration has been set to build the current lists.

Noise peak vetoing: some numbers

Example taken from VSR4 analysis

- ➡ Frequency range 10-1024 Hz
- ➡ frequency resolution 1 mHz (the same as NoEMi):

Hough: 1289 peaks

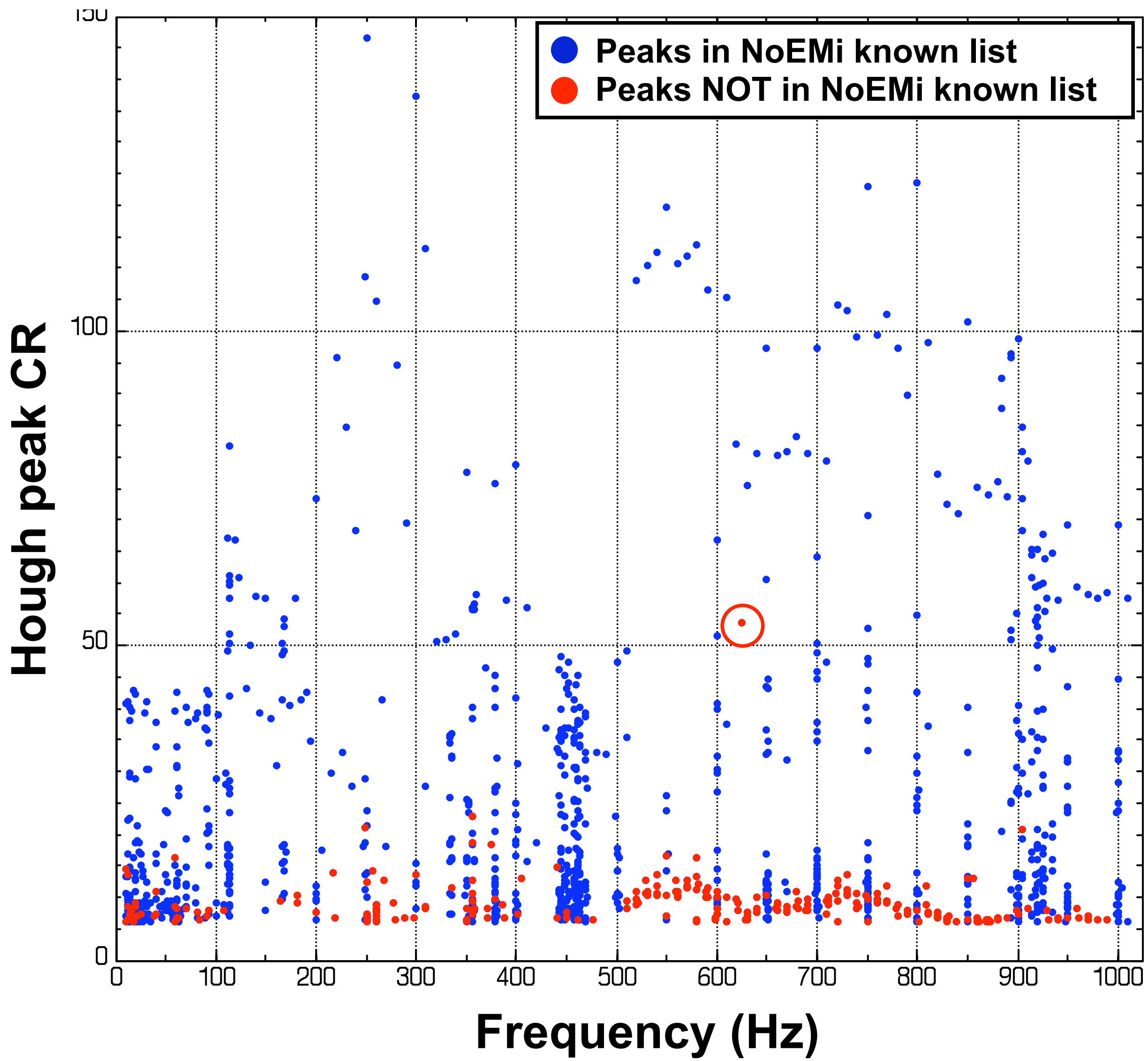
NoEMi: 1253 known lines

- ➡ 1263 matches in frequency
  - ➥ A line in one list can match more lines in the other

246 lines found in the Hough and not in NoEMi

395 lines found in NoEMi and not in the Hough

Hough & NoEMi line matching



Almost all "missing" peaks have low CR, as expected since NoEMi uses a higher threshold than the all-sky search.

The high CR missing peaks corresponds to one of the ~100 still unknown NoEMi lines

Noise peak identification policy

Peaks matching in frequency with known NoEMi lines are safely vetoed

Peaks not matching known lines are further investigated

Look in NoEMi's unknown line list: the line may be found by NoEMi but its source not yet understood. These lines should be accurately followed up with the help of the noise experts

Even if the peak does not match any listed line, it can still be investigated with the NoEMi databases:

- The line may be too "short" and thus it has not been included in the list
- The line may have a CR lower than the NoEMi threshold, but can be associated to a "well known" family (e.g. harmonic of 1 Hz, 10 Hz ...)
- The line may be in a very noisy region (e.g. sidebands)

If no clear evidence is found that the peak is due to noise, the all-sky analysis is repeated in a small frequency band around the peak

Unknown line investigation example

Let's consider these candidates not found in the NoEMi lists:

Frequency (Hz)	Frequency (Hz)
59.403	60.166
59.832	60.595
60.0186	

Looking in the NoEMi database:

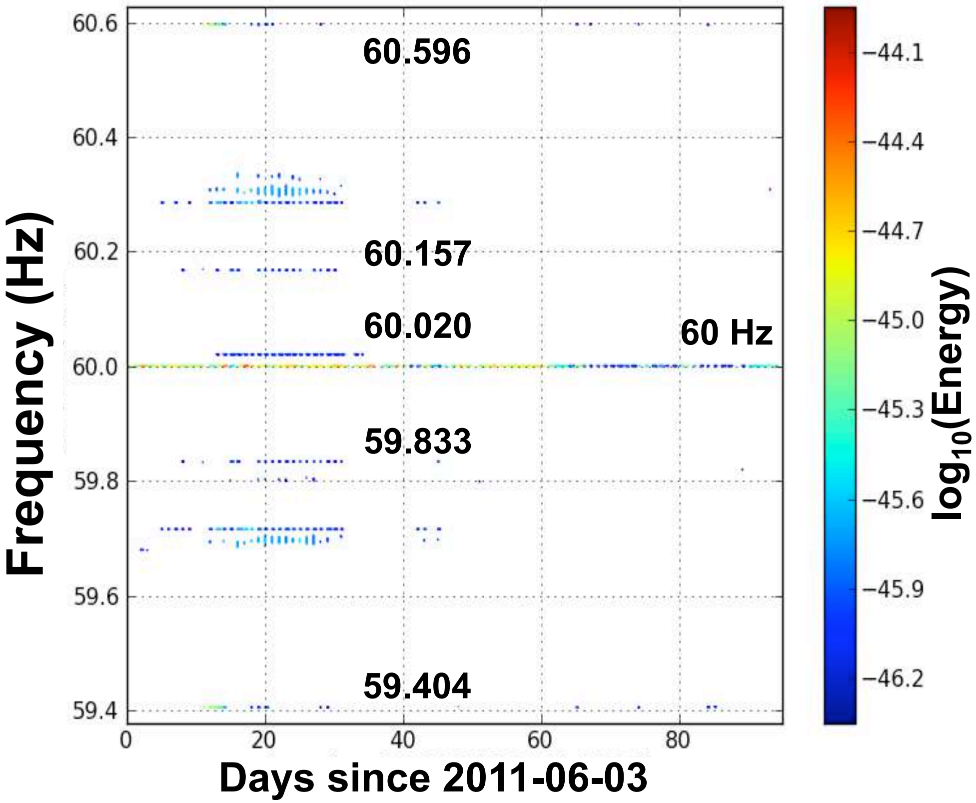
Frequency (Hz)	Δf (Hz)	Duration	CR	Comment
59.404	0.001	0.16	9.48	
59.833	0.001	0.20	5.67	
60.020	0.001	0.23	5.93	coincident with Em_MABDWE01(100.0%) Em_MABDCE01(52.4%)
60.167	0.001	0.18	5.67	
60.596	0.001	0.17	9.09	

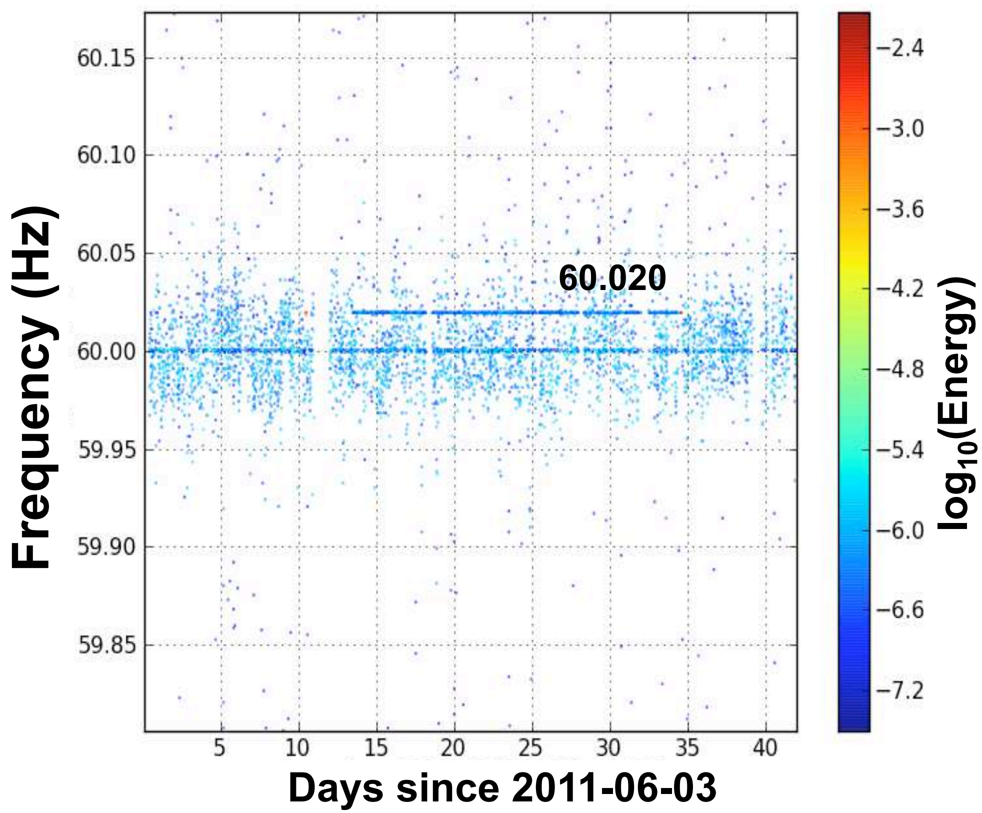
➡ All but the the 60.020 are clearly sidebands of the 60 Hz line (digital line, part of the 10 Hz comb), but their duration is lower than the cut applied for the lists.

➡ The remaining line is seen also in the magnetometers!

Unknown line investigation example

60.020 Hz line seen in the magnetometer





Conclusion: All the lines in this example have a clear instrumental origin, and can be safely discarded in the analysis

Effect of peak vetoing on analysis efficiency

Reconstruction parameters of injected pulsar:

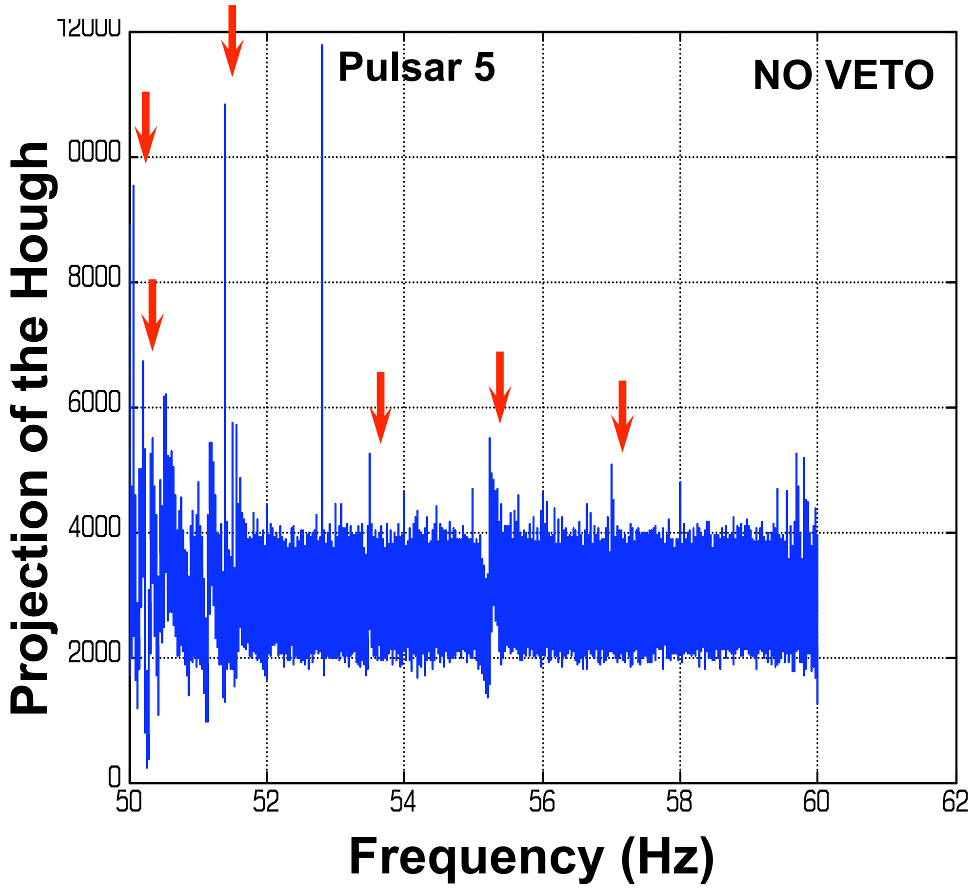
➡ Frequency: 52.808324 Hz

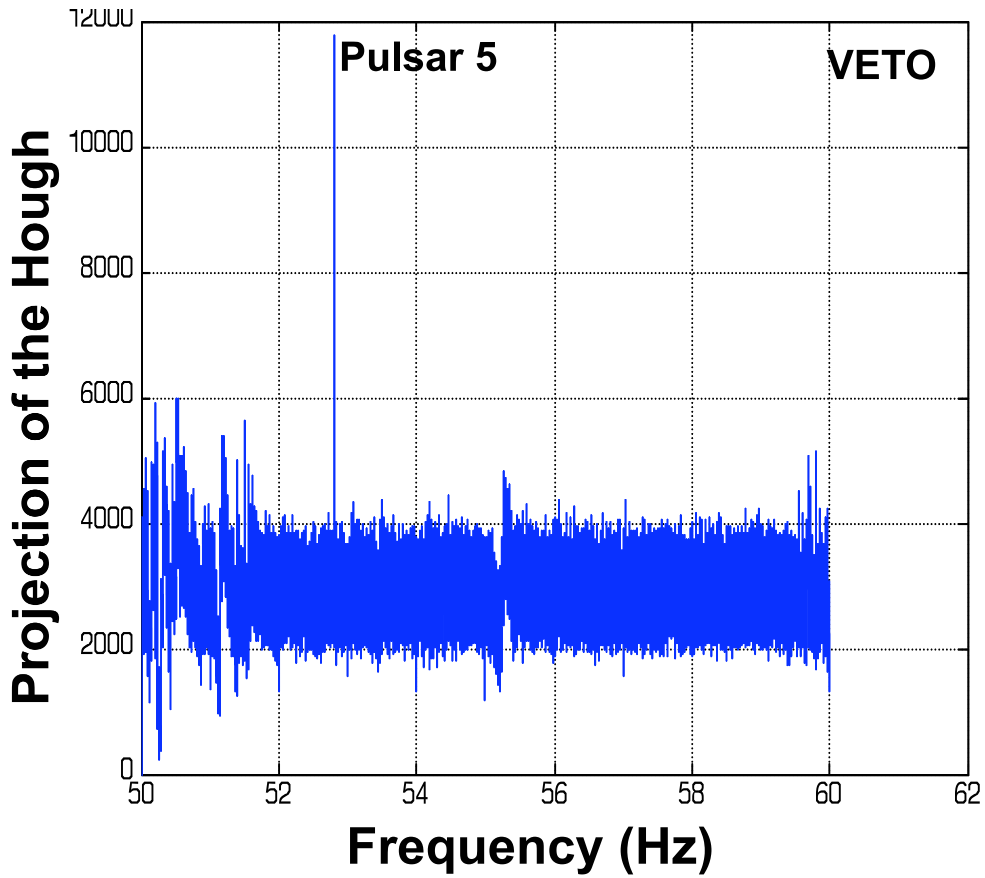
➡ Spin down: $-4.08 \cdot 10^{-18}$ Hz/s

➡ h: $3.7 \cdot 10^{-24}$

	Frequency (Hz)	Spin-down	CR
Without veto	52.808289	0	19.14
With veto	52.808289	0	20.56

Effect of peak vetoing on analysis efficiency





N.B. In this analysis the doppler correction has been applied!

Conclusions & future developments

Noise line identification for VSR2-VSR4 almost completed

- <100 lines over ~1000 still unknown in each run, analysis is ongoing

Known line lists used to veto fake candidates in all-sky search

- The majority of the lines that cross our threshold have been found and have a known origin.
- For lines unknown or not found by NoEMi we will ask some help to detector and noise experts
  - they are not so many thus we don't expect this to be difficult

NoEMi will be used on the Advanced Virgo and LIGO detectors

- To this purpose the framework has been upgraded in order to run on on LIGO farms and analyse O(100) auxiliary channels in parallel
- Tests on current LIGO Hanford test data are ongoing.