# Broadband Search for Continuous-Wave Gravitational Radiation with LIGO

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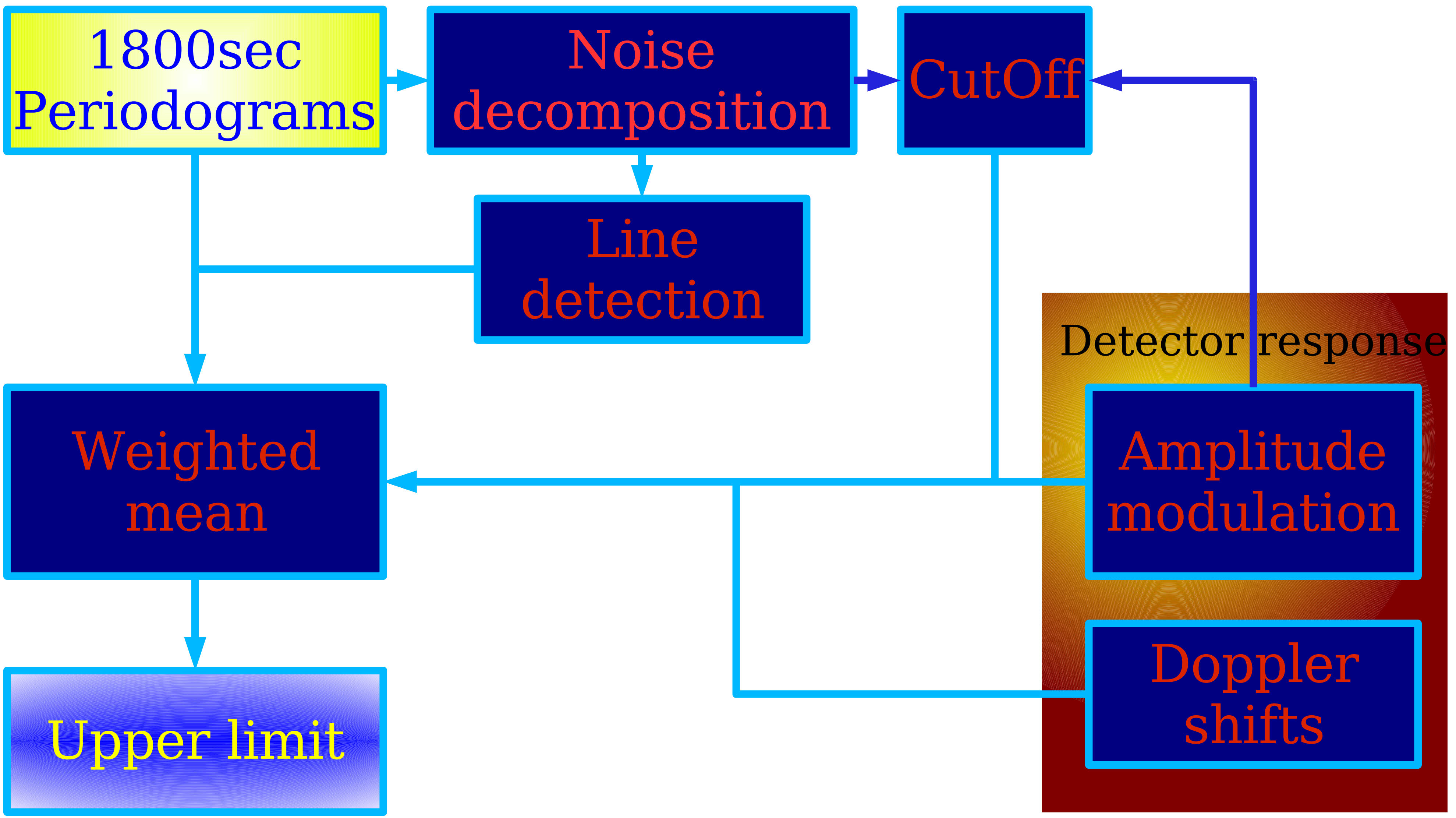
# Challenges of search for CW gravitational waves

- Gravitational waves from spinning neutron stars are expected to be weak – need to average over long time periods
- Several parameters to search for: frequency, sky position, spindown, polarization
- Coherent methods are very sensitive, but result in enormous search space size – broadband, all sky search is impractical for large time base
- PowerFlux – place sky-dependent upper limits and detect signals by averaging power. Practical for all-sky broadband searches.

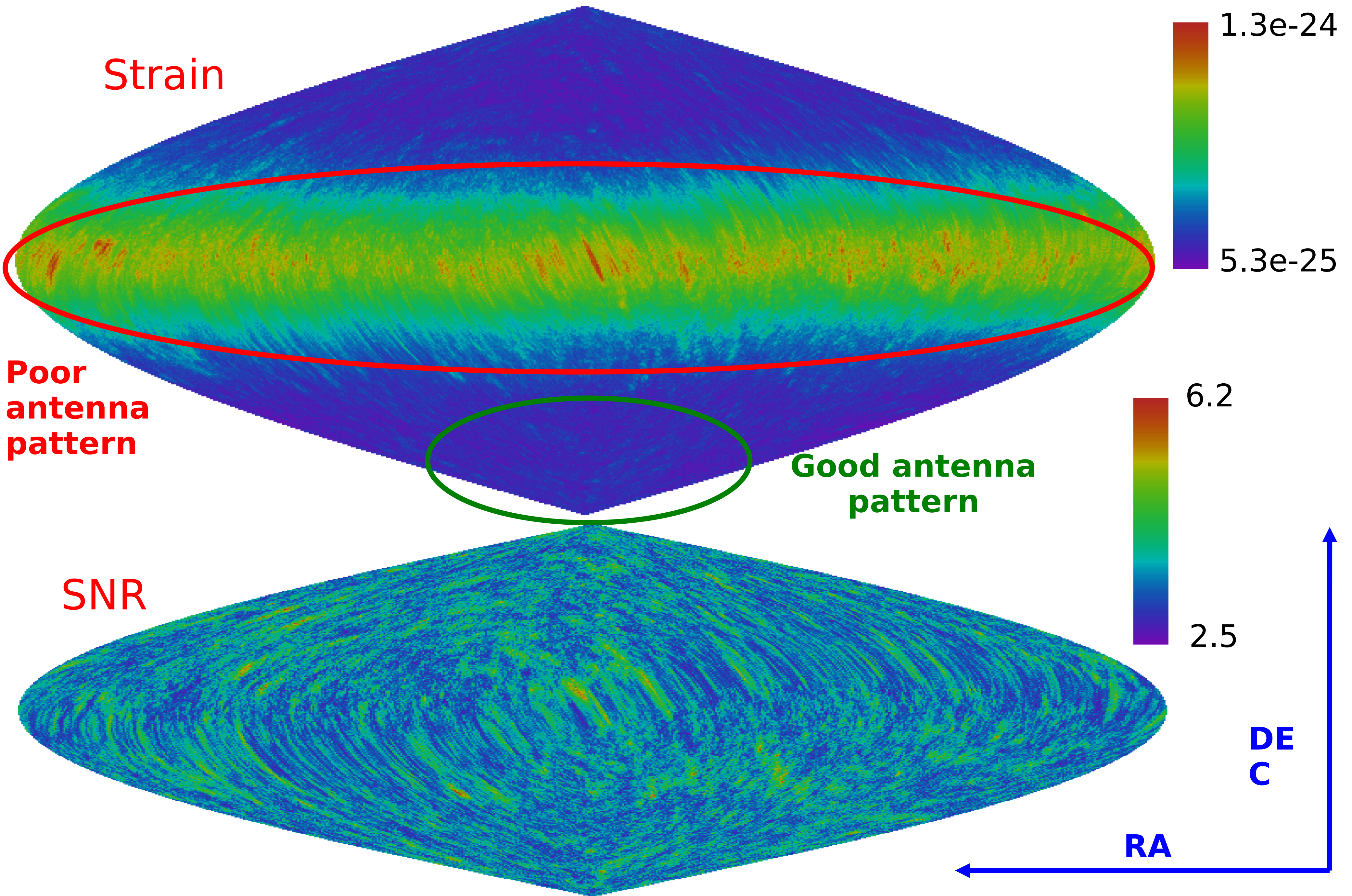
# PowerFlux analysis pipeline



# PowerFlux results

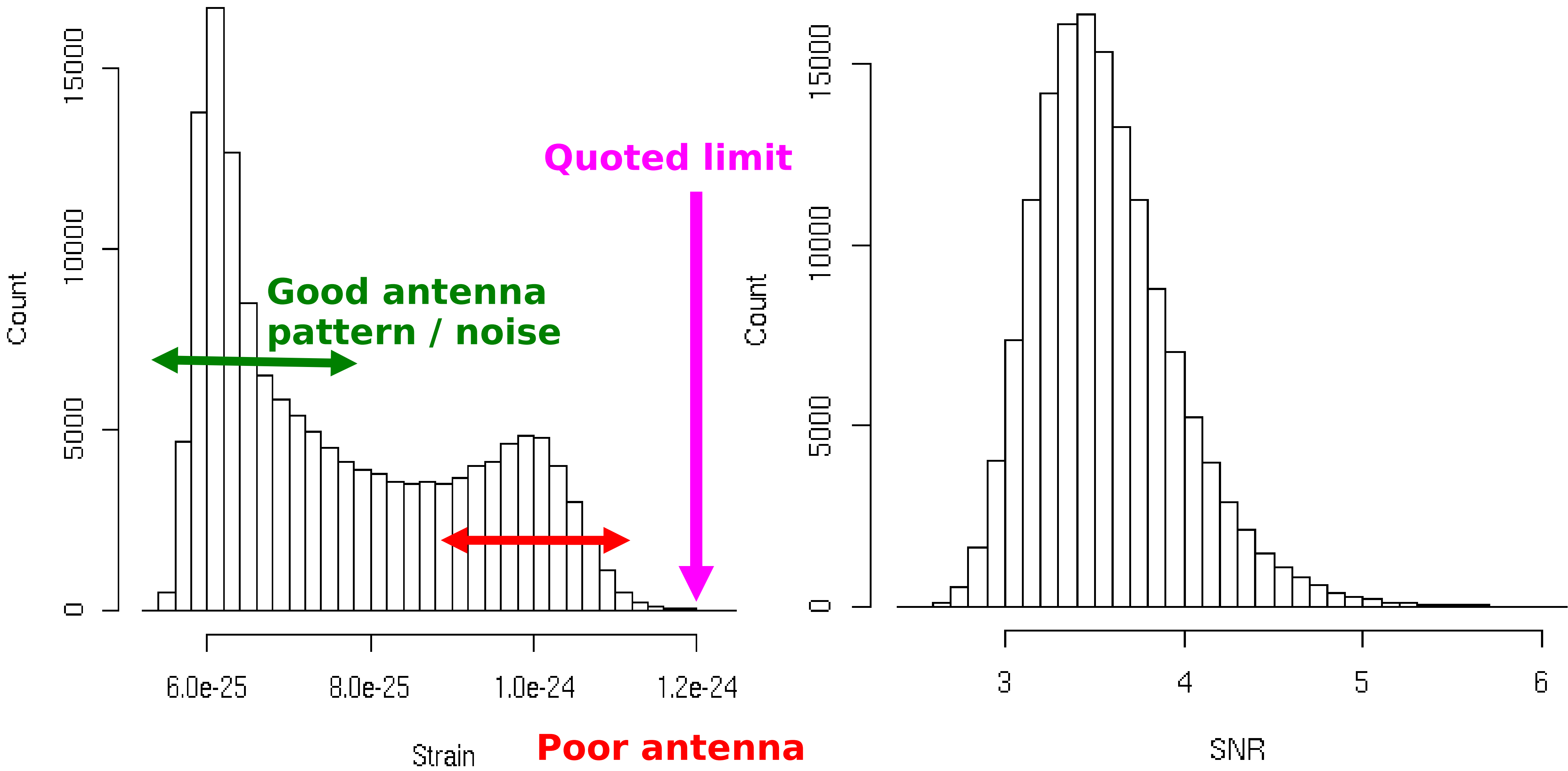
- PowerFlux produces a 95% CL upper limit for a particular frequency, sky position, spindown and polarization. One of three methods used in S4 all-sky search (arXiv:0708.3818 = Phys. Rev. D 77 (2008) 022001)
- Too much data to store, let alone present – the number of sky positions alone is ~10^5 at low frequencies and grows quadratically with frequency
- The upper limit plots show maximum over spindown range, sky and all polarizations
- Performed all-sky, multiple spindown (from 0 through -5e-9 Hz/s) searches
- Data from first 8 months of S5 science run: 7 Nov 2005 through 20 July 2006

# Hanford 4km, ~270 Hz, non-zero spindown
## (equatorial coordinates)



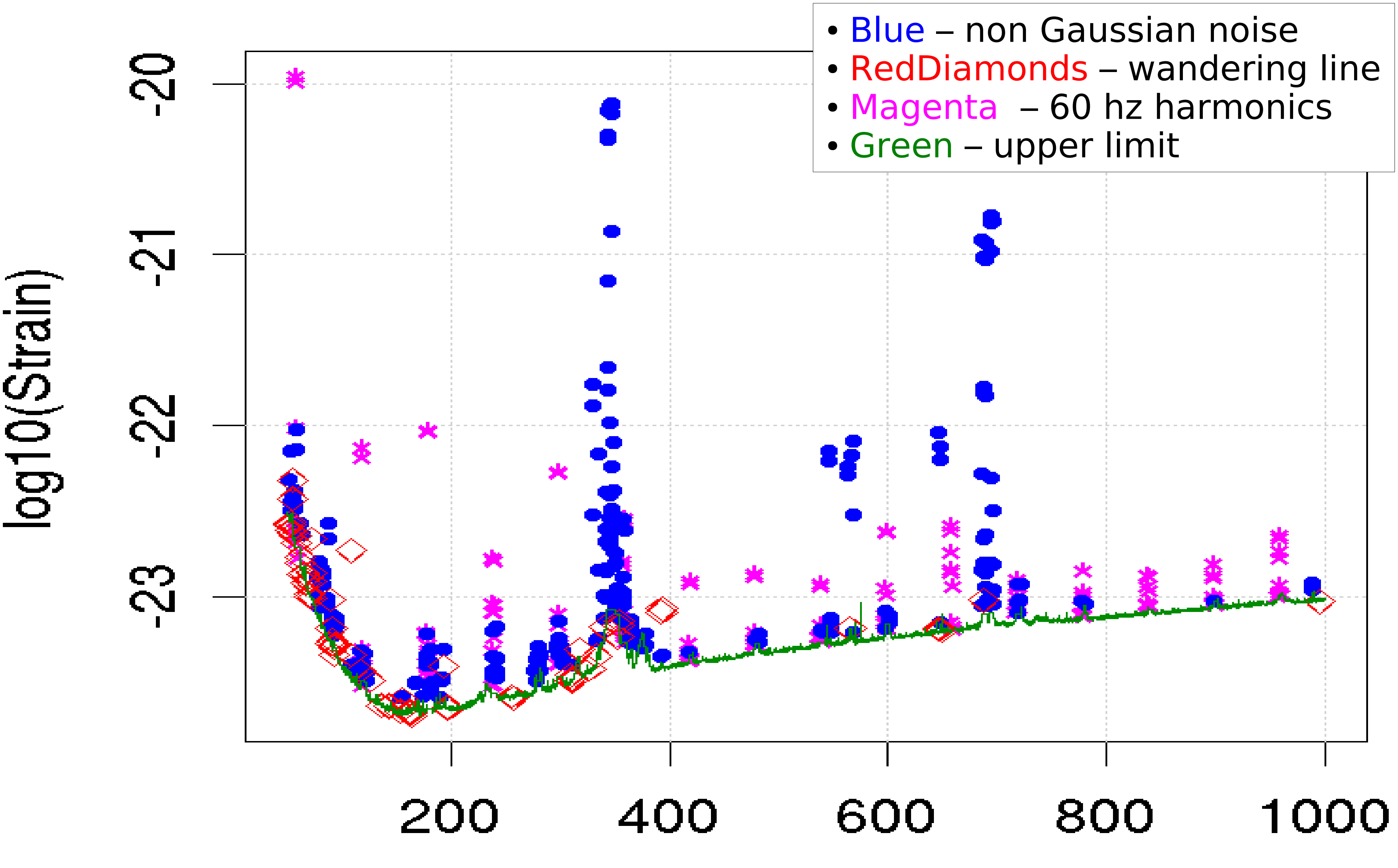
# Histograms

(one entry per sky point)




Preliminary results

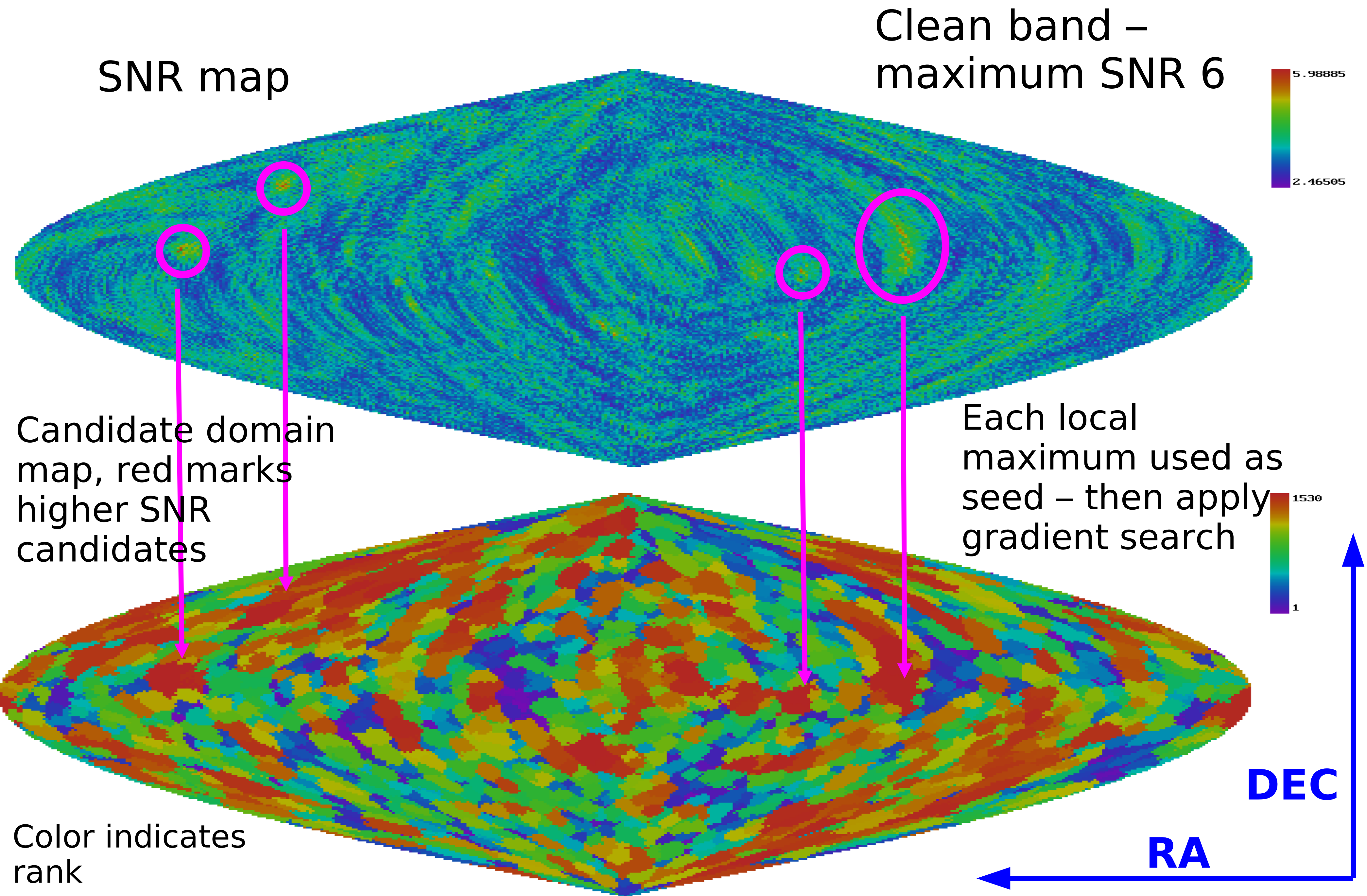
# H1 S5 0-spindown run




All-sky
50-1000 Hz

Preliminary
results

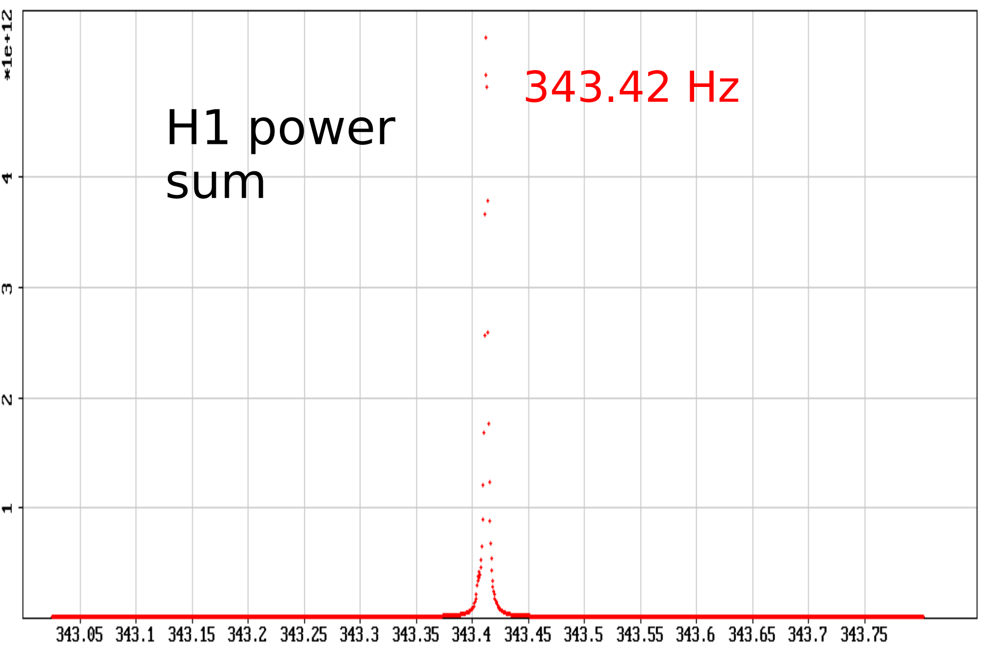
# Multiple outliers

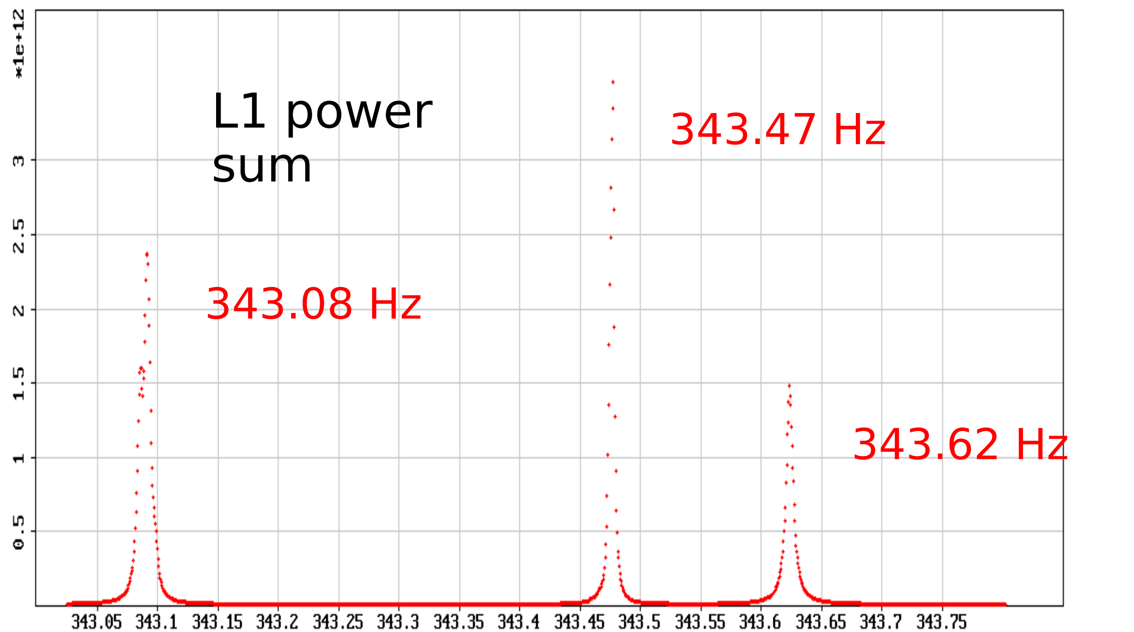


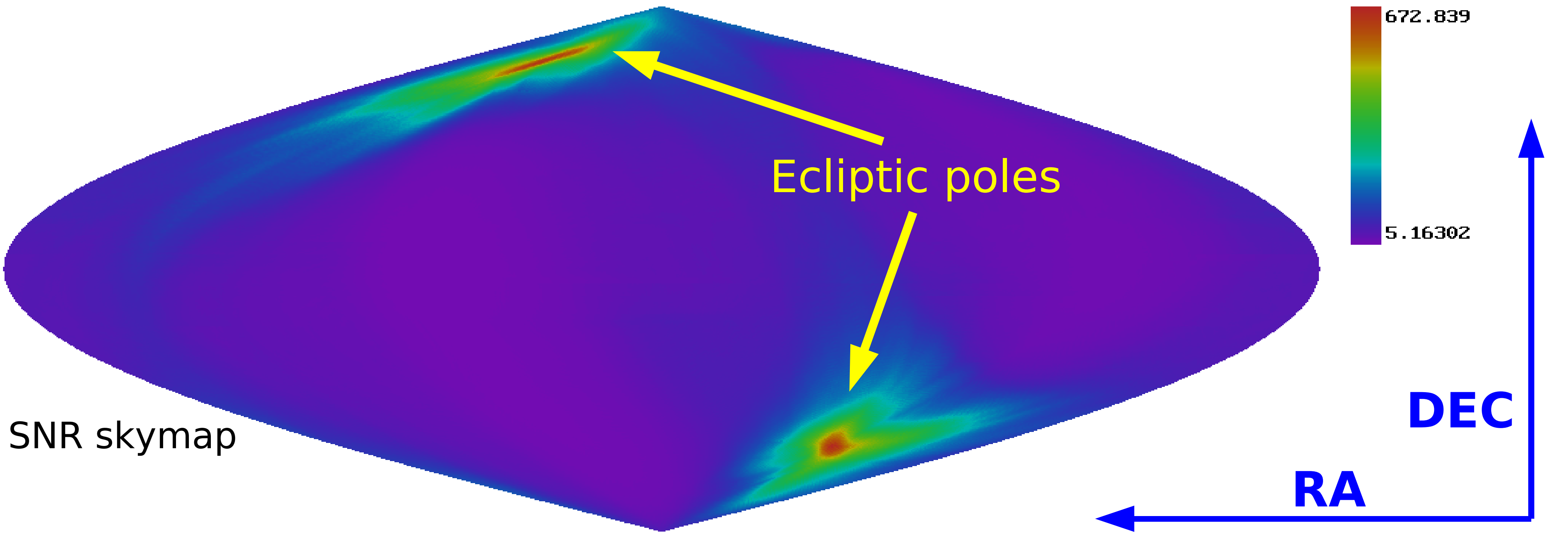
# Outlier followup

- Determine local SNR maxima, pick N highest (1000 from each of 10 sky slices)
- Apply a variation of gradient search to optimize SNR
- Look for outliers common to two interferometers:
  - SNR>6.25 for each interferometer
  - Difference in frequency less than 1/180 Hz
  - Difference in spindown of less than 4e-10 Hz/s
  - Closer than 0.14 radians (~8 degrees) on the sky
- Surviving coincidence candidates subjected to intensive followup

# Sample outlier - caused by violin modes (5)

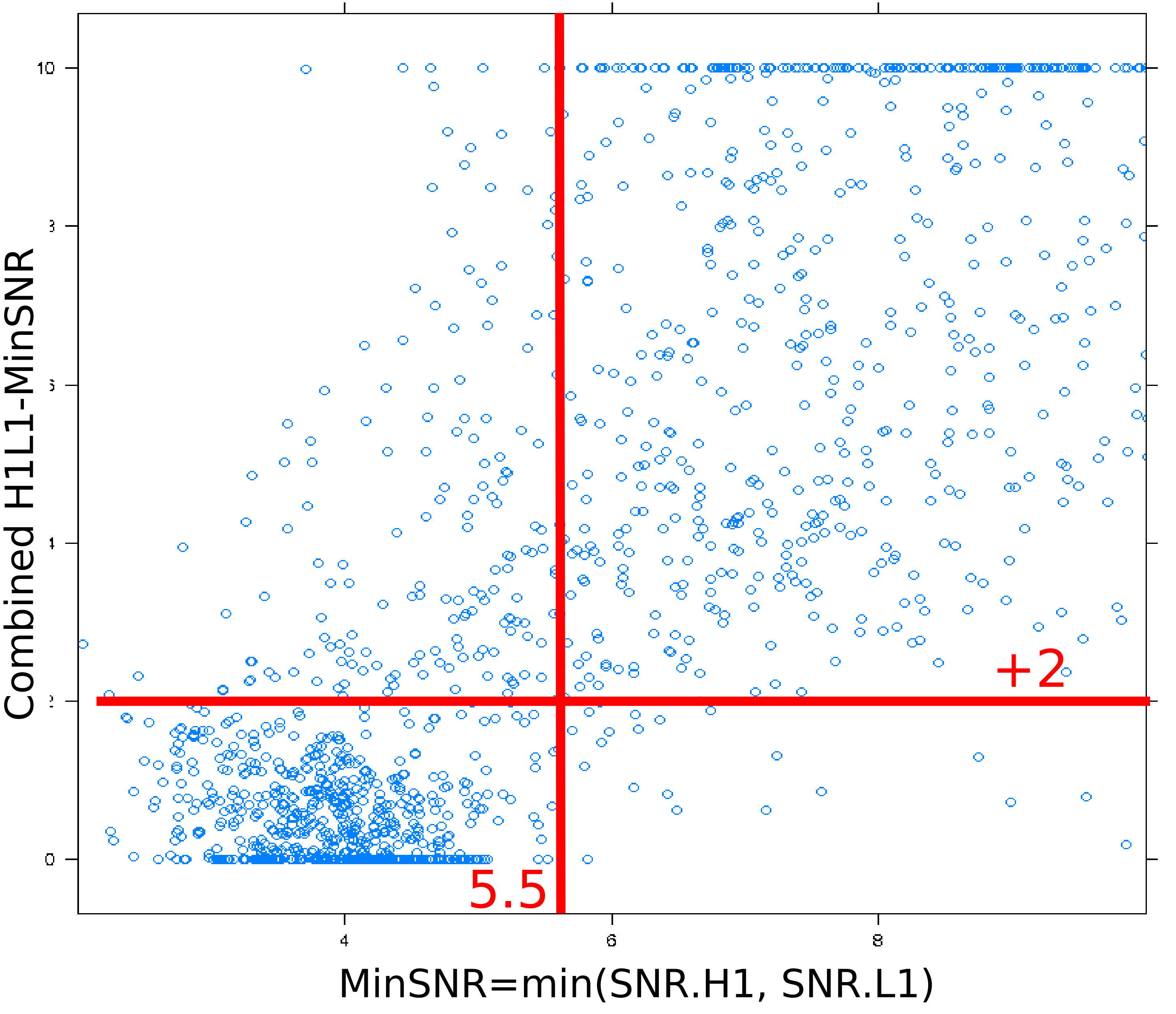


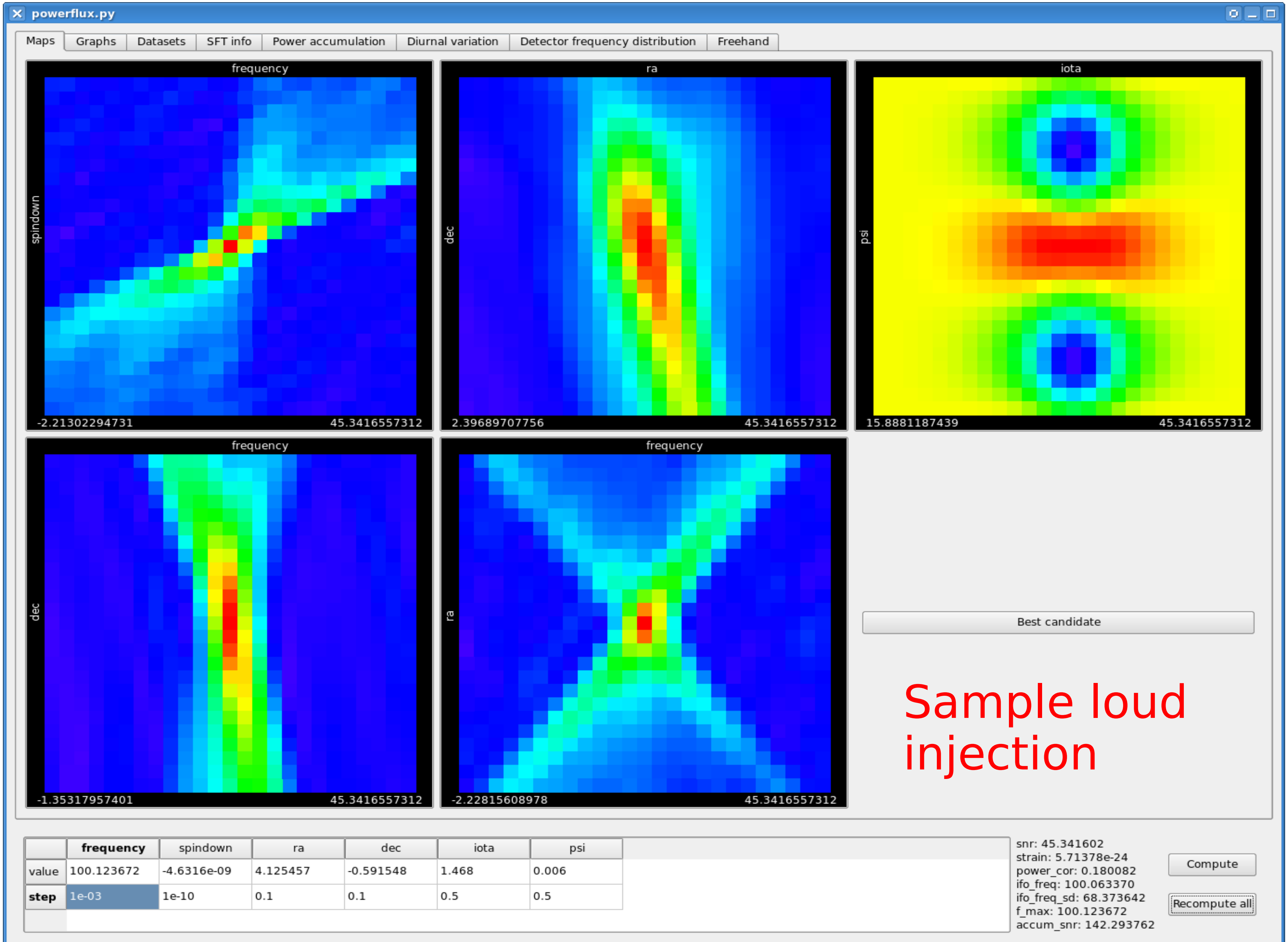



# Signal injections guide followup

- 860-870 Hz
- Separate runs for H1, L1 and combined H1-L1 data
- Search in 0.3 radian disk around the injection point
- Spindown mismatch can be as large as 5e-10 Hz/s



# Interactive interface




Sample loud injection

# Issues in followup

- Number of sky positions comparable with quantity of input data (especially at high frequencies) – SNR of the loudest outlier in pure noise can easily reach 6.0
- Relatively loose initial coincidence requirements are necessary not to miss real signals
- Sky partitioning that was done to reduce memory footprint introduces spurious initial coincidences – as partition boundaries are likely to be marked as local SNR maxima.
- Parameters that are narrow for a semi-coherent search are too wide for a comfortable coherent followup

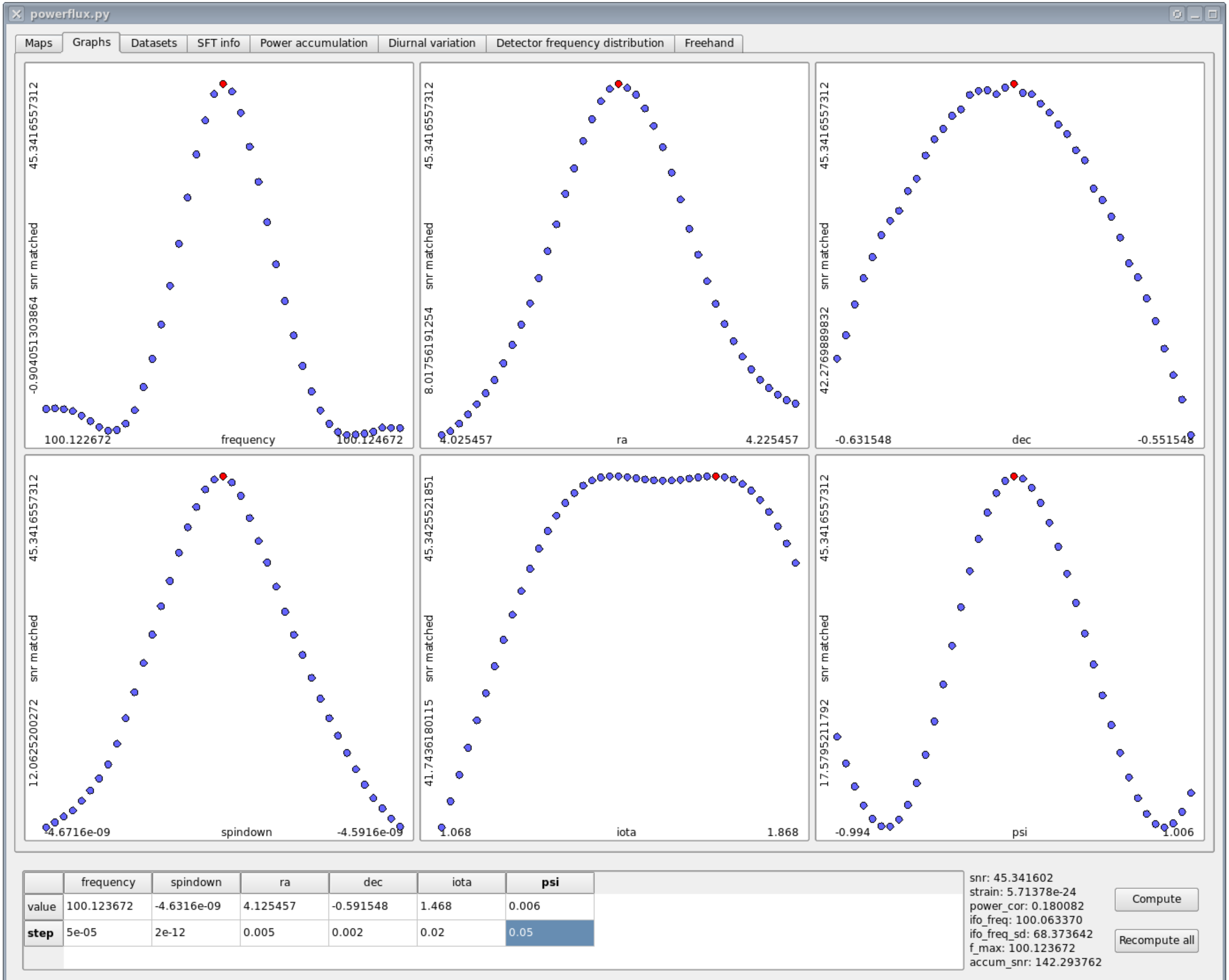
# Conclusion

- All-sky multiple-spindown run over first 8 months of data complete, followup in progress
- Looking in detail at the output of low-SNR coincidence algorithm
- Full S5 data is available, more results to follow

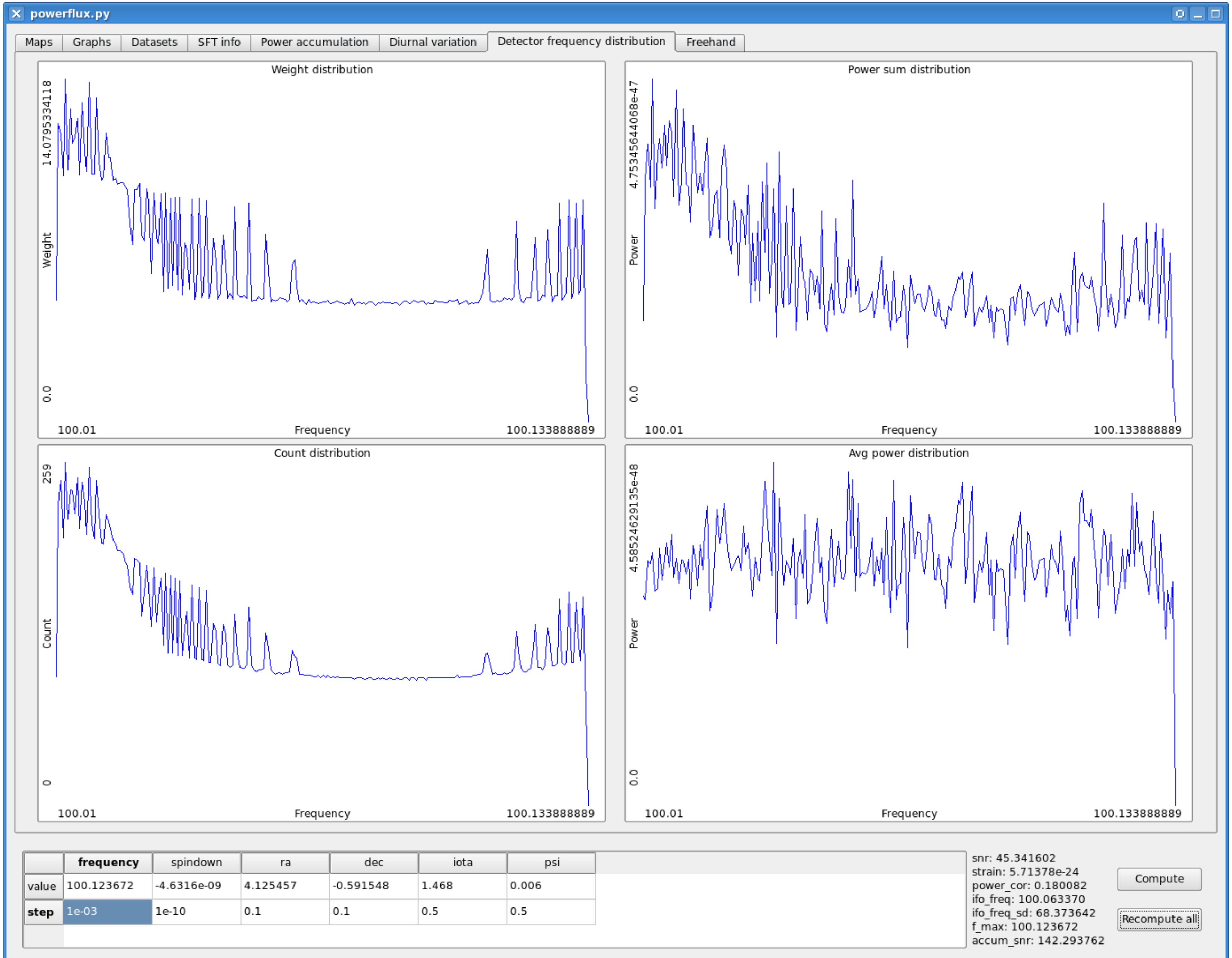
# End of talk

(supporting slides for questions follow)

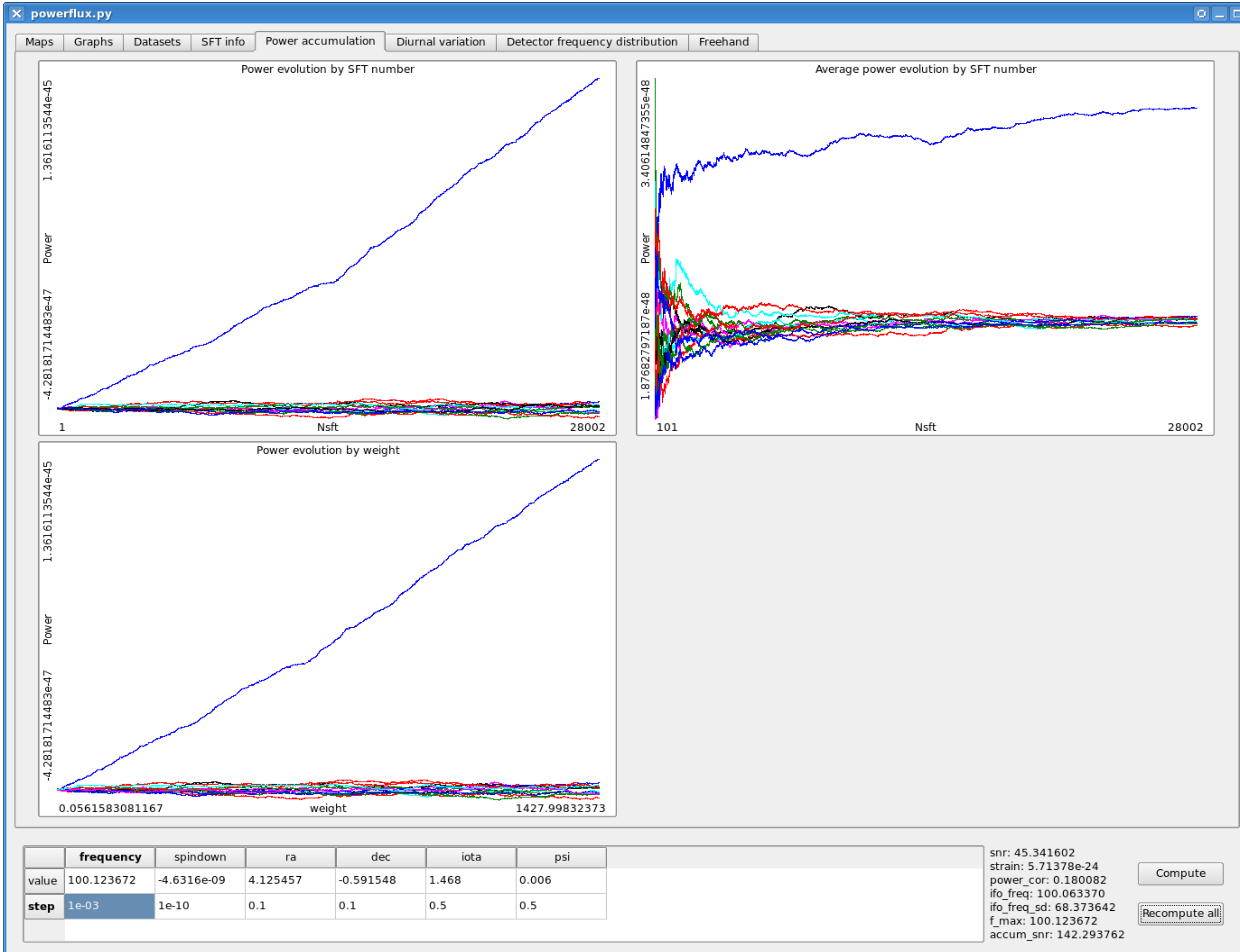
# Graphs


powerflux.py
Maps
Graphs
Datasets
SFT info
Power accumulation
Diurnal variation
Detector frequency distribution
Freehand
45.3416557312
snr matched
-0.904051303864
100.122672
frequency
100.124672
45.3416557312
snr matched
8.01756191254
4.025457
ra
4.225457
45.3416557312
snr matched
42.2769889832
-0.631548
dec
-0.551548
45.3416557312
snr matched
12.0625200272
-4.6716e-09
spindown
-4.5916e-09
45.3425521851
snr matched
41.7436180115
1.068
iota
1.868
45.3416557312
snr matched
17.5795211792
-0.994
psi
1.006
frequency
spindown
ra
dec
iota
psi
value
100.123672
-4.6316e-09
4.125457
-0.591548
1.468
0.006
step
5e-05
2e-12
0.005
0.002
0.02
0.05
snr: 45.341602
strain: 5.71378e-24
power_cor: 0.180082
ifo_freq: 100.063370
ifo_freq_sd: 68.373642
f_max: 100.123672
accum_snr: 142.293762
Compute
Recompute all

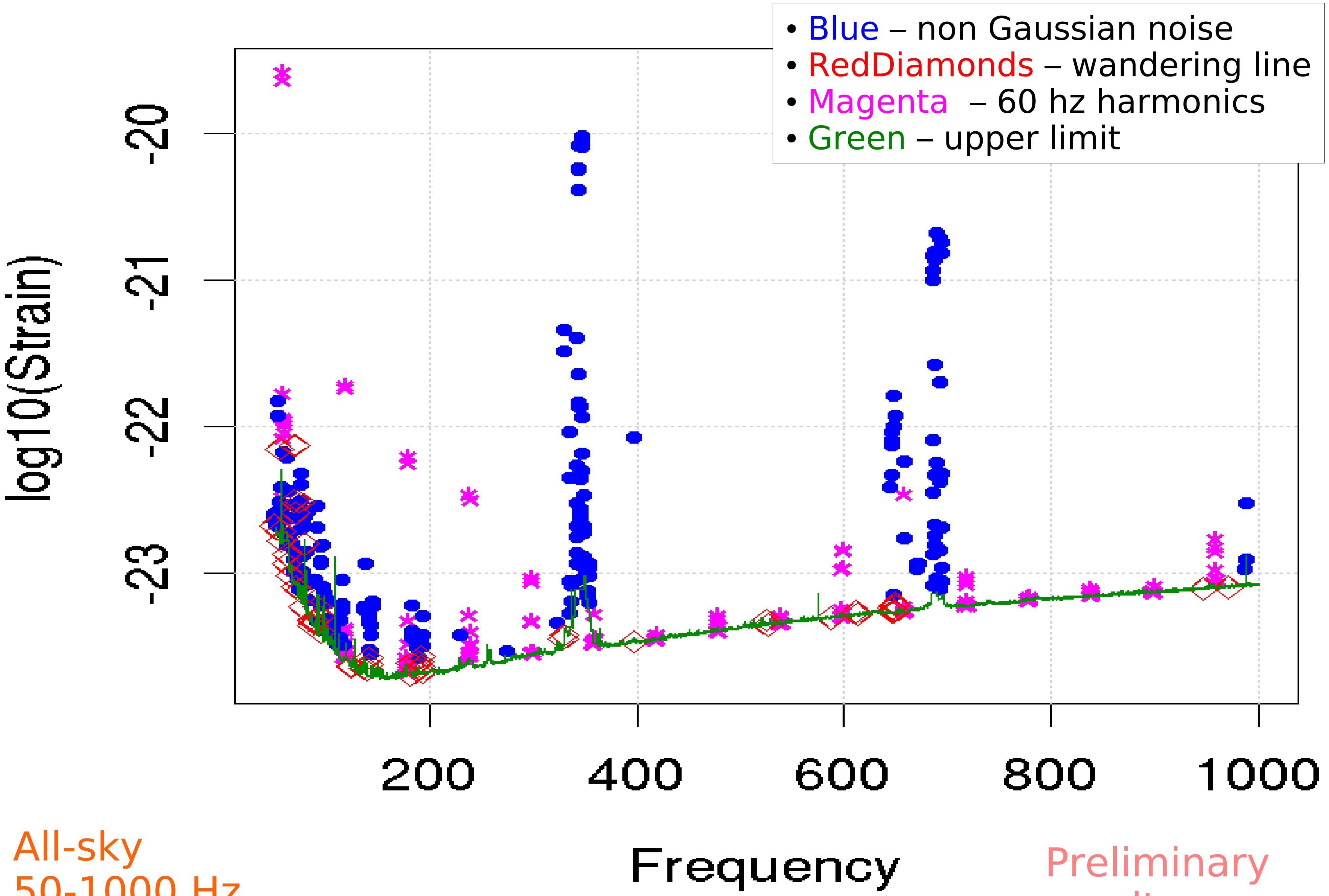
# Frequency distribution



# Power accumulation



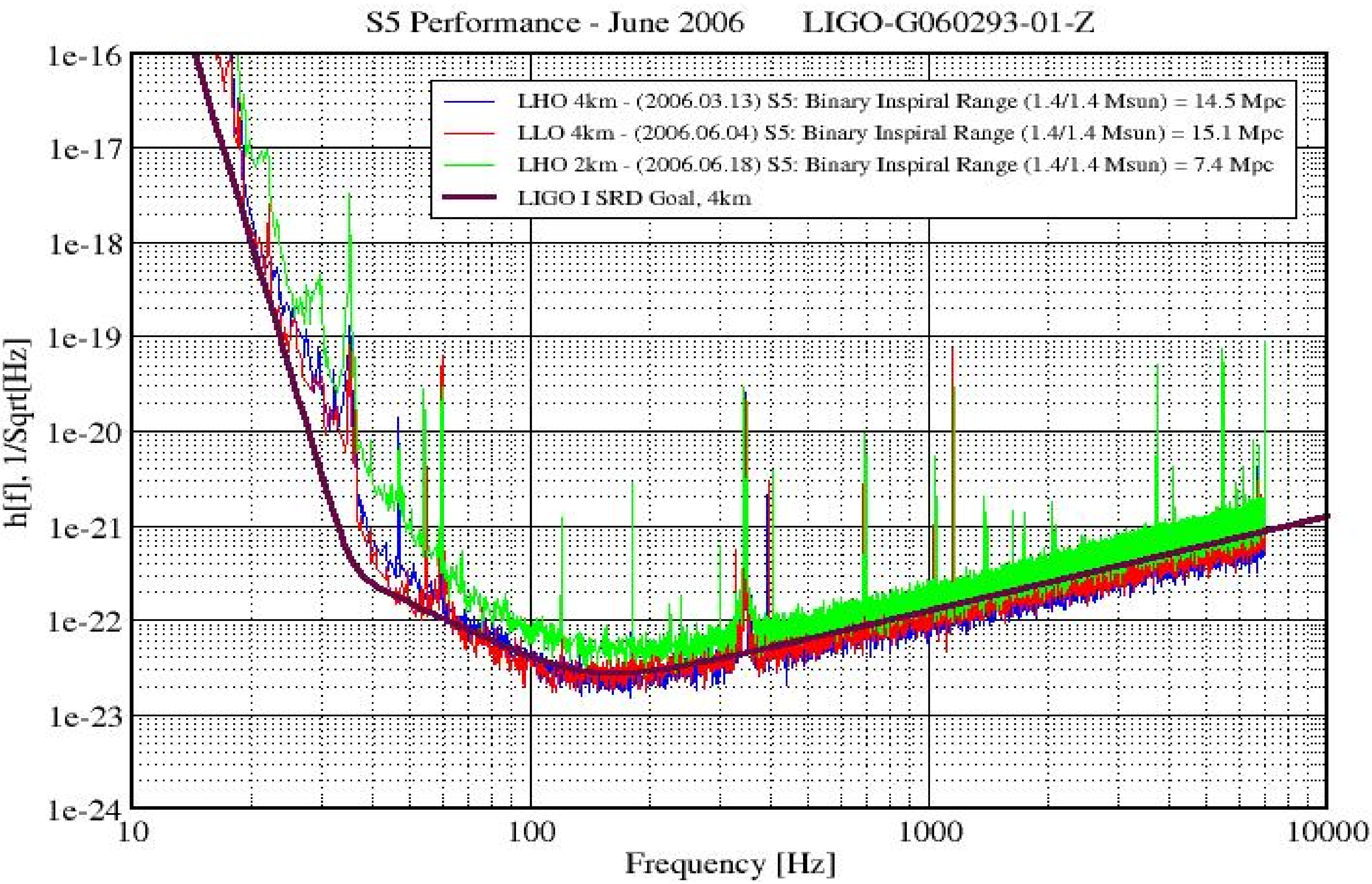
# L1 S5 0-spindown run




All-sky
50-1000 Hz

Preliminary
results

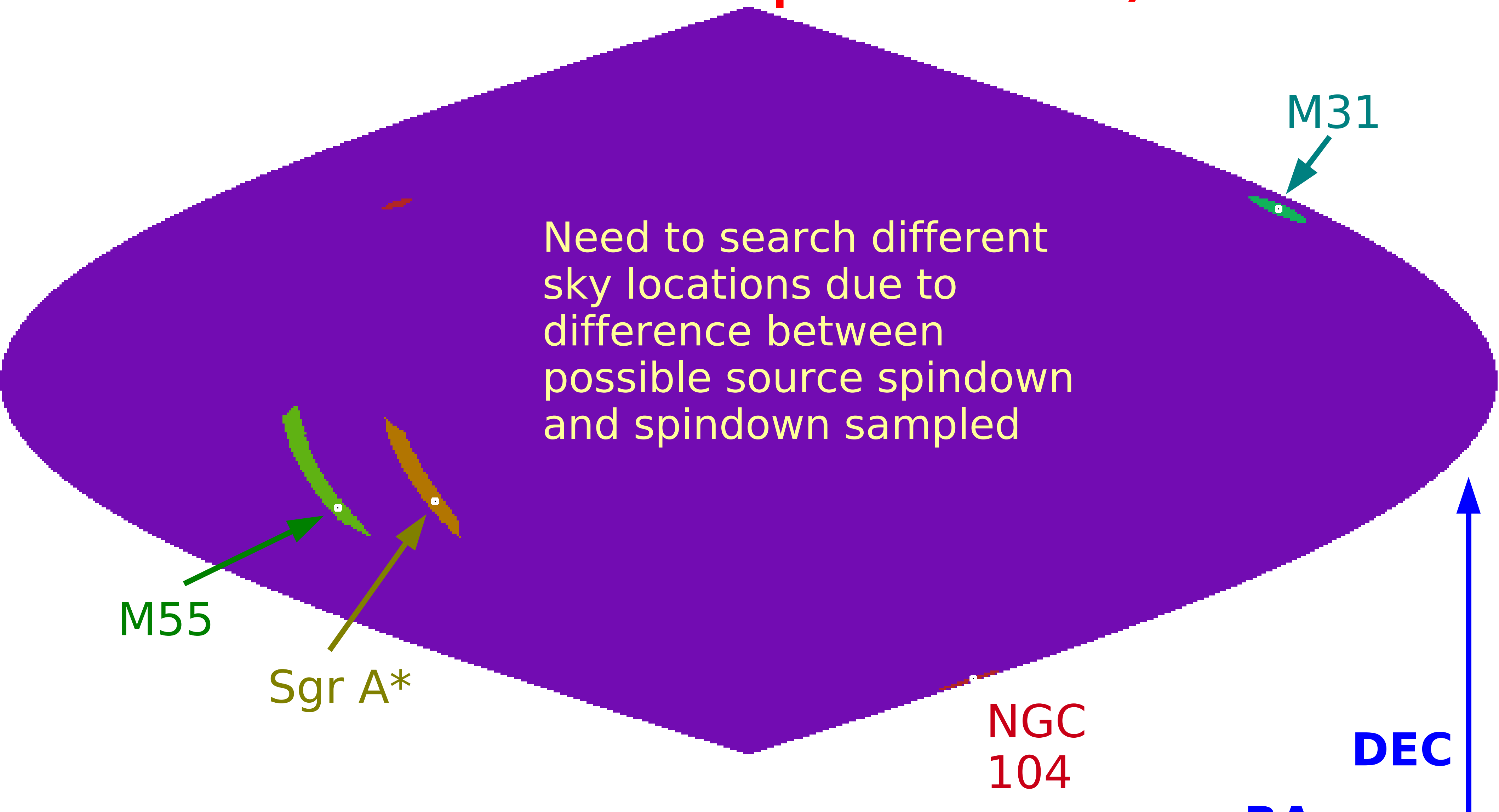
# S5 science run sensitivity



# Partial sky (targeted) run

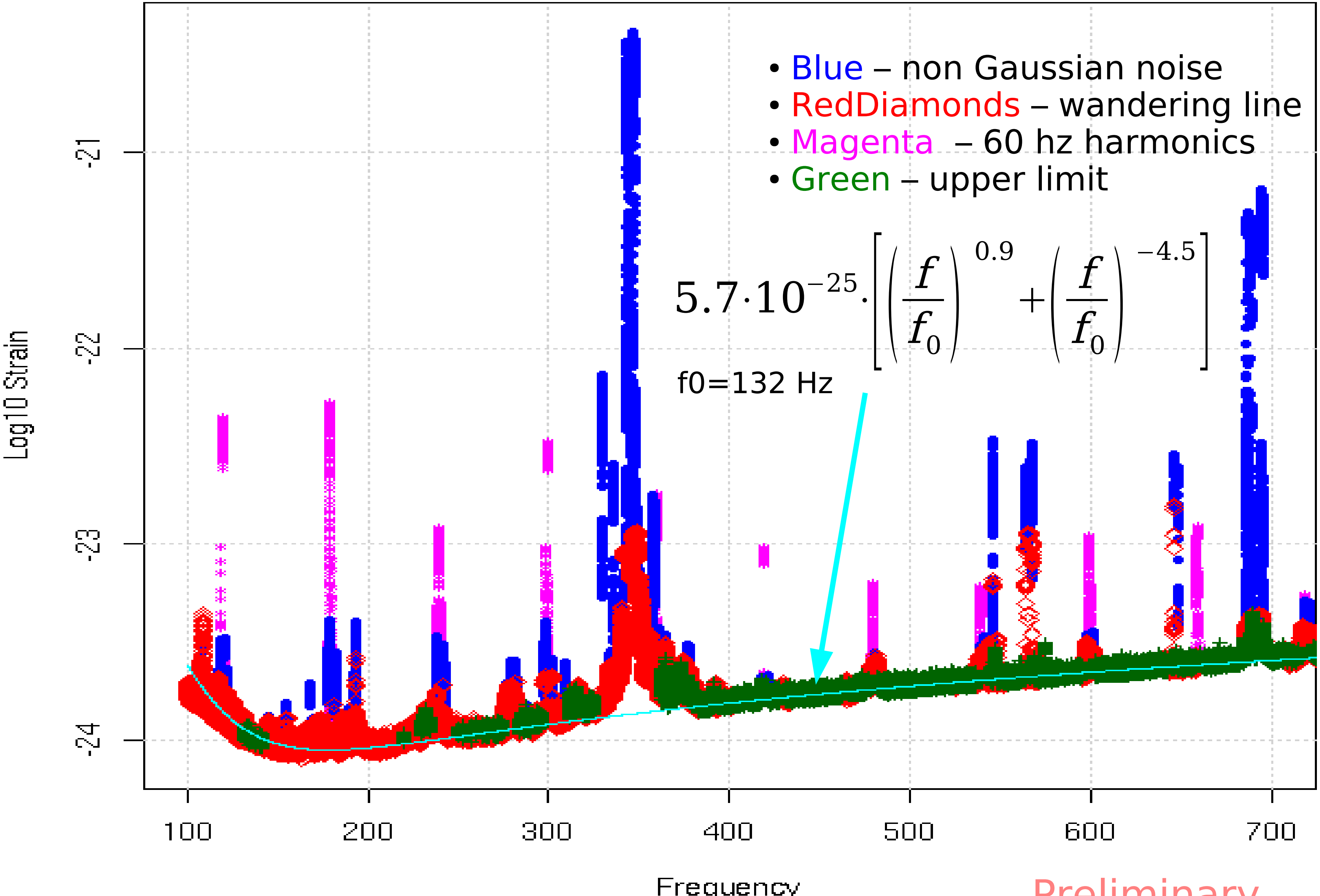
- Searched sky around
  - globular clusters M55, NGC104
  - galactic center Sgr A*
  - Andromeda M31 (control)
- 100-700 Hz
- -1.01e-8 Hz/s through 1.01e-8 Hz/s in 2e-10 Hz/s steps

# Search area (for ~270 Hz, non-zero spindown)




Area decreases with frequency

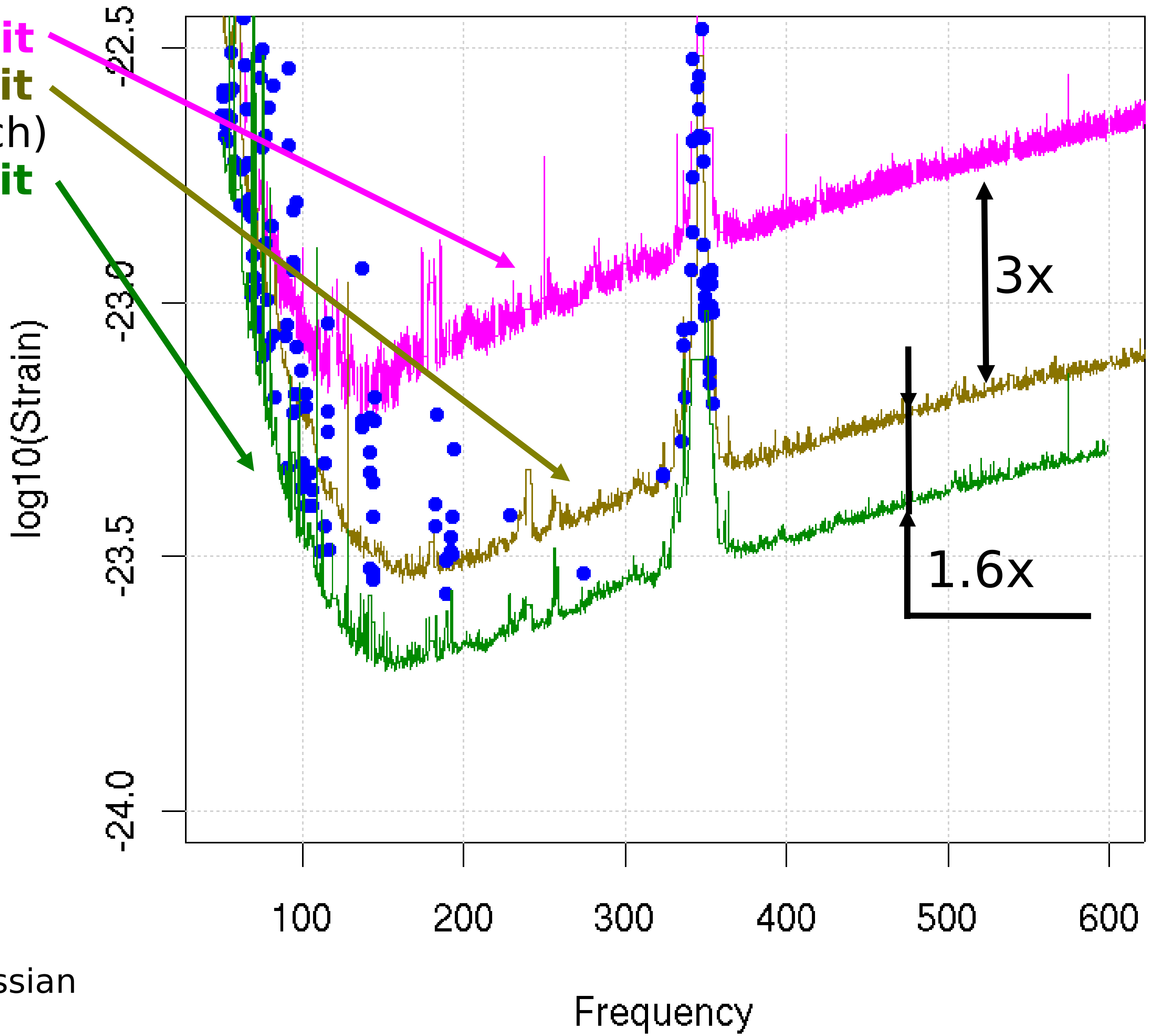
# H1 Sgr A* upper limits




Preliminary results

# S5 spindown-0 run

- **S4 L1 upper limit**
- **S5 L1 upper limit** (data through March)
- **S5 L1 upper limit** (data through July)




July L1 SFTs=
3x March SFTs

- 60 Hz lines excluded
- Blue points – non-gaussian noise in July run

# “S parameter”

When S is closer to 0 susceptibility to stationary artifacts increases

$$S := s + \frac{\overbrace{\vec{u} \times \vec{v}_{\mathrm{avg}}}}{c} f \cdot \hat{\vec{r}}$$

Average detector acceleration

Average detector velocity

Spindown (Hz/s)

Earth orbit angular velocity

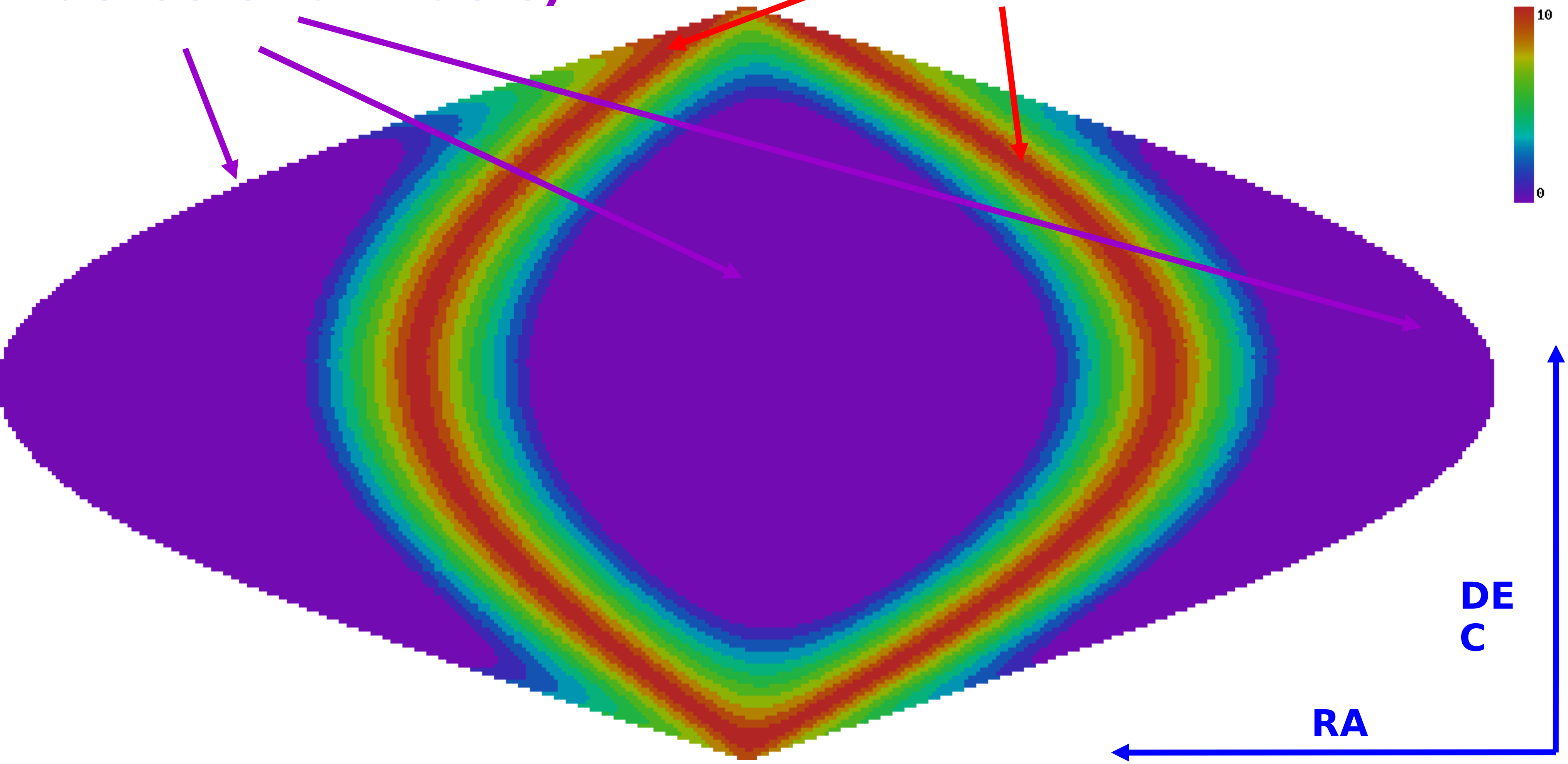
Frequency

Unit sky position vector

# Doppler Skybands

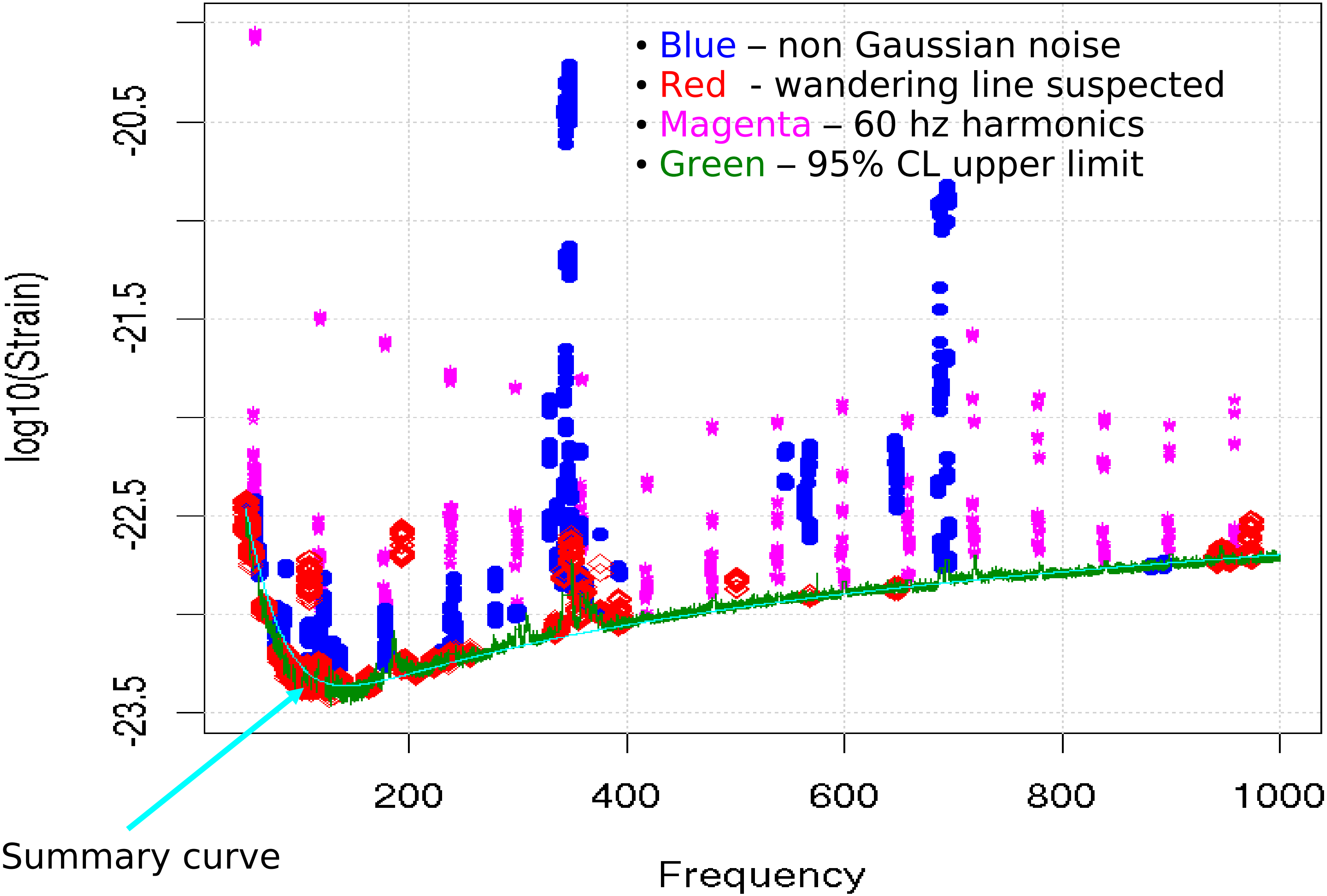
**Skyband 0 (good – only exceptionally strong detector artifacts)**

**Skyband 10 (worst – many detector artifacts)**



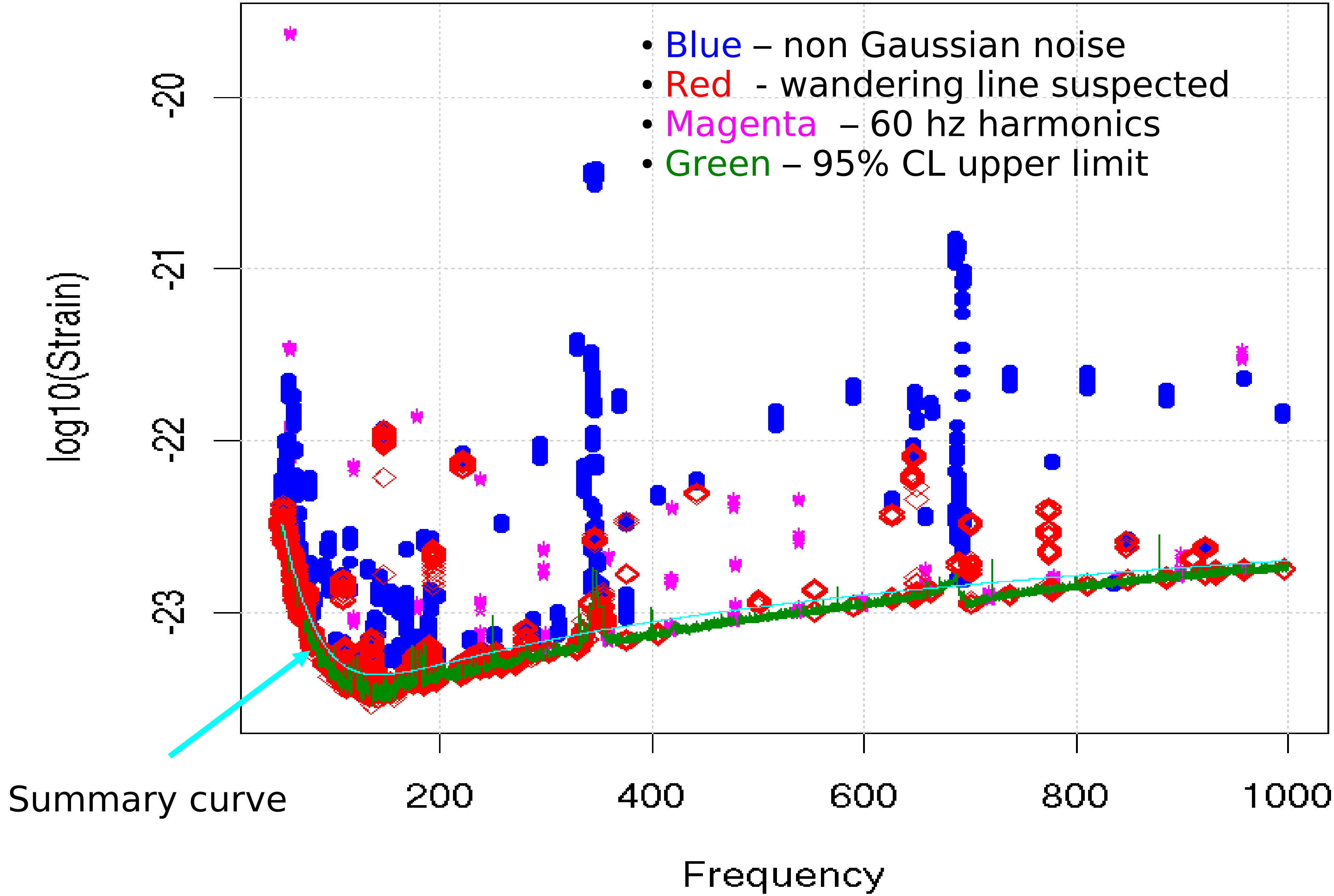
# S4 run results
## Hanford 4km

Hanford 4km upper limits are slightly higher than the summary curve, but much cleaner in low frequency range



# S4 run results
## Livingston 4km

Livingston 4km upper limits are slightly lower than the summary curve, but not as clean in low frequency range



# S5 summary curve deviation