



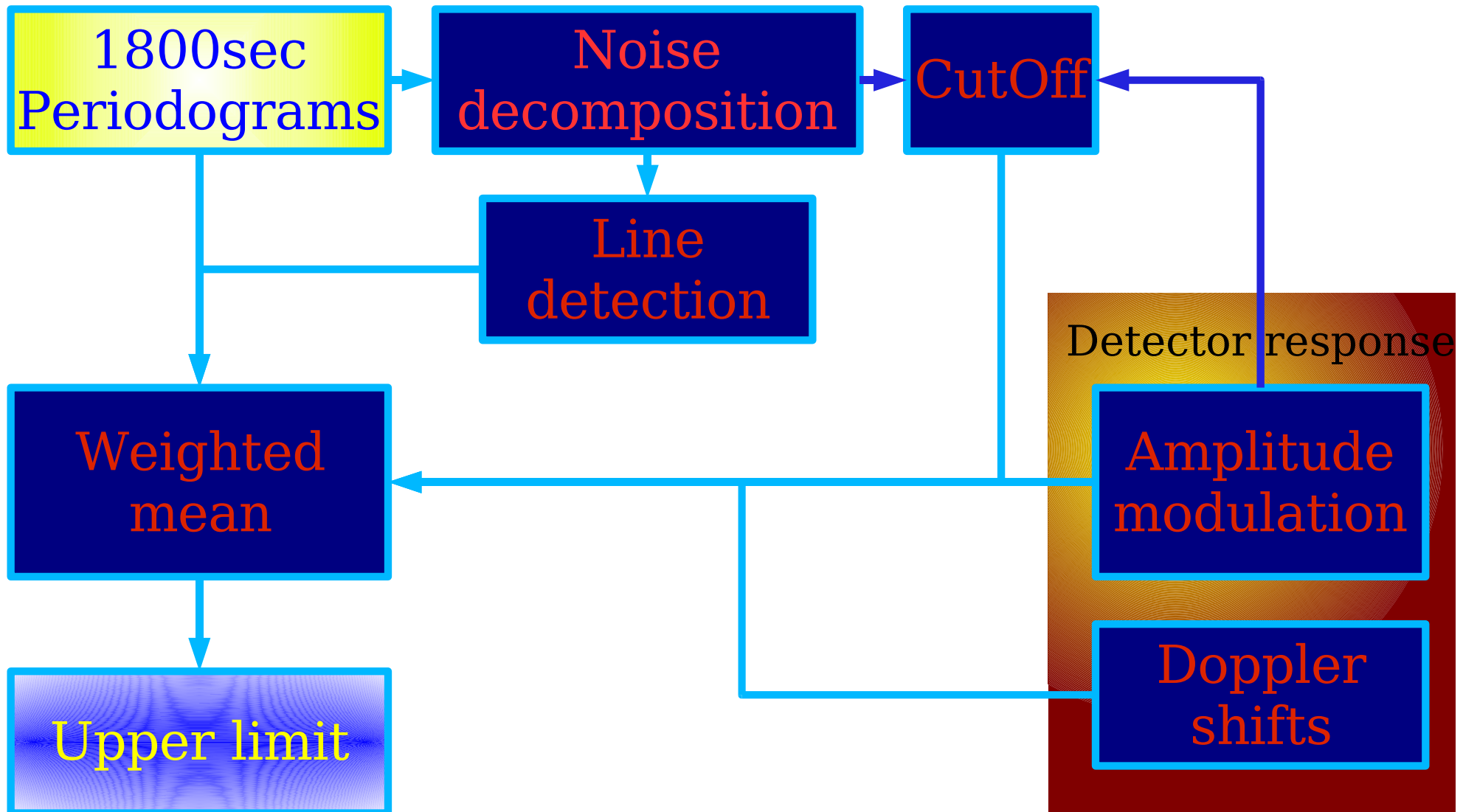
Broadband Search for Continuous-Wave Gravitational Radiation with LIGO

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for the LIGO scientific collaboration

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.

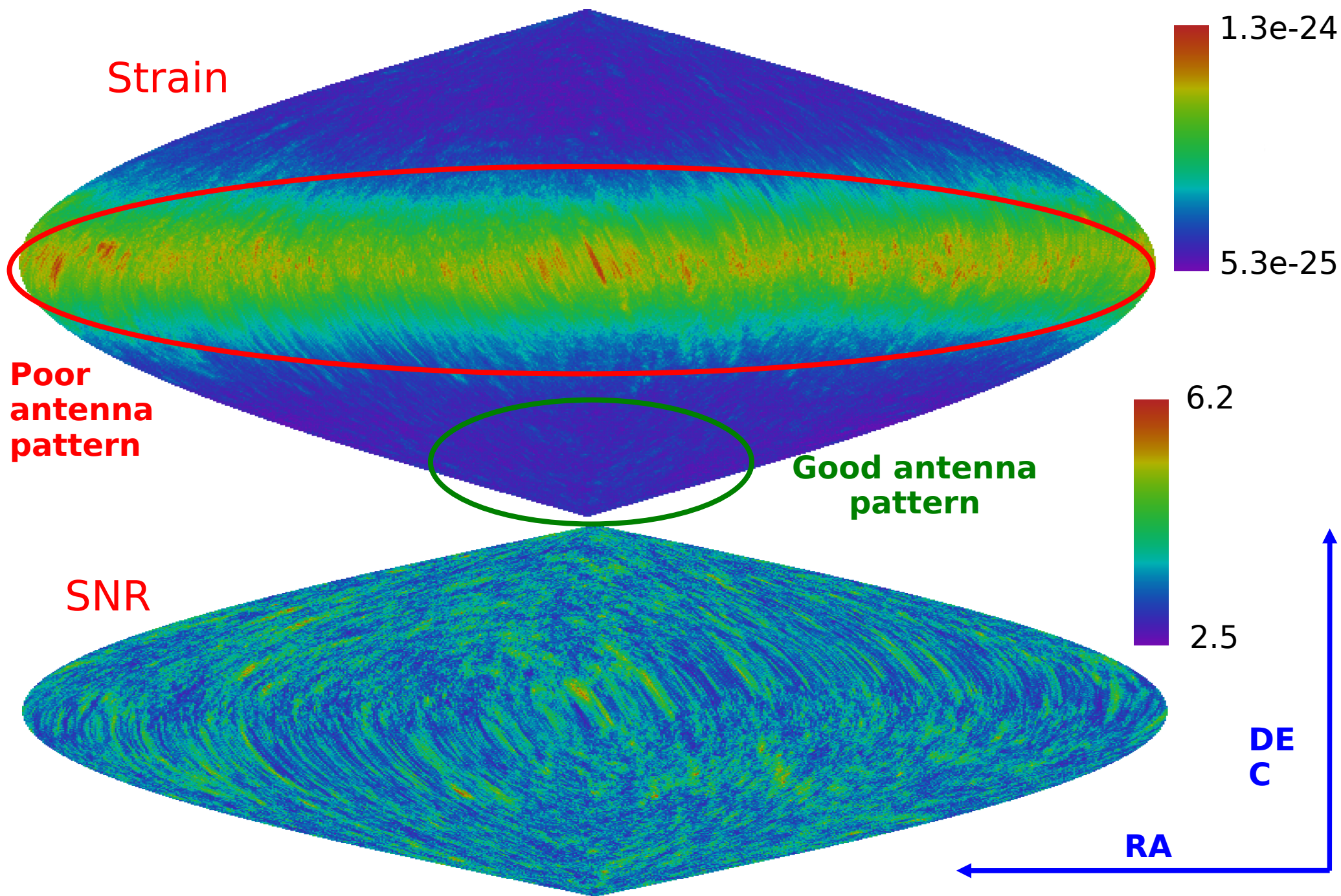
PowerFlux analysis pipeline



PowerFlux results

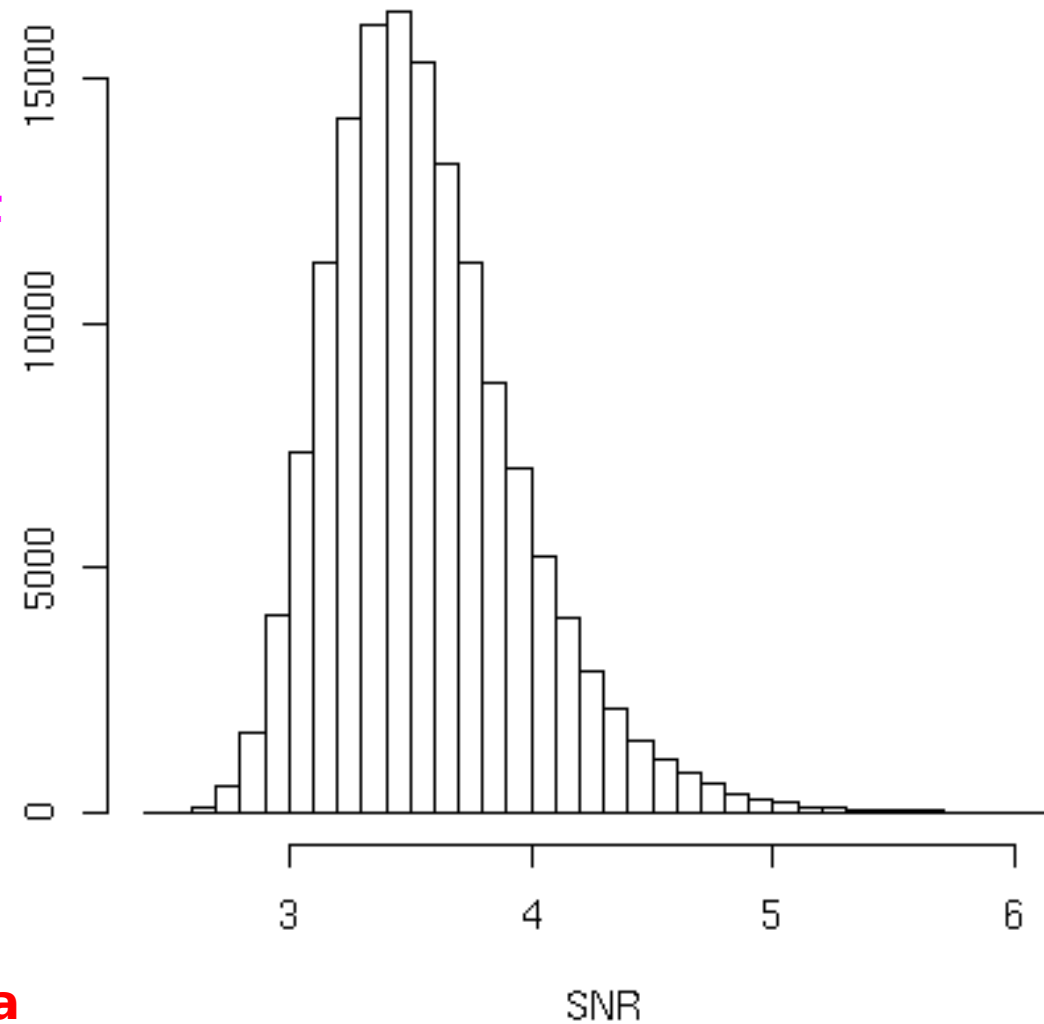
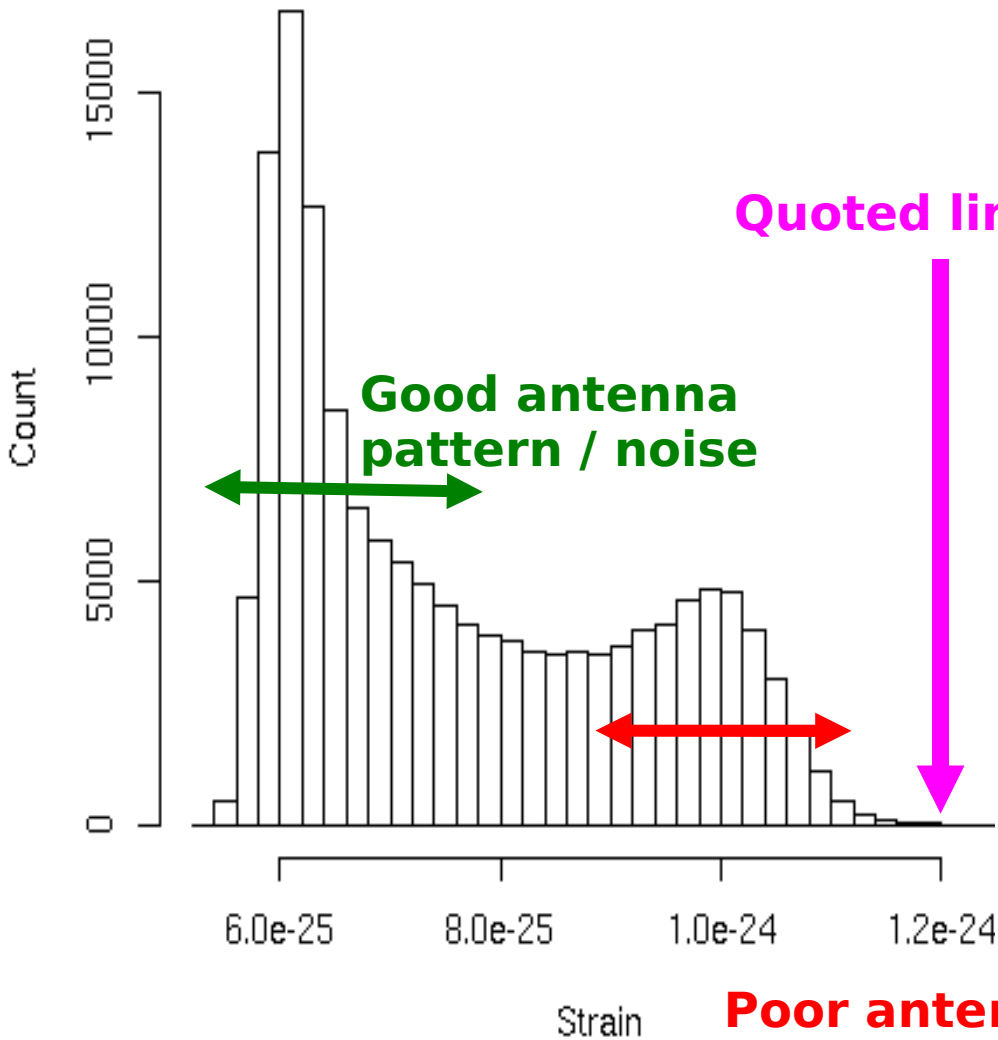
- PowerFlux produces a 95% CL upper limit for a particular frequency, sky position, spindown and polarization. One of three methods used in S4 all-sky search (arXiv:0708.3818 = Phys. Rev. D 77 (2008) 022001)
- Too much data to store, let alone present – the number of sky positions alone is $\sim 10^5$ 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)

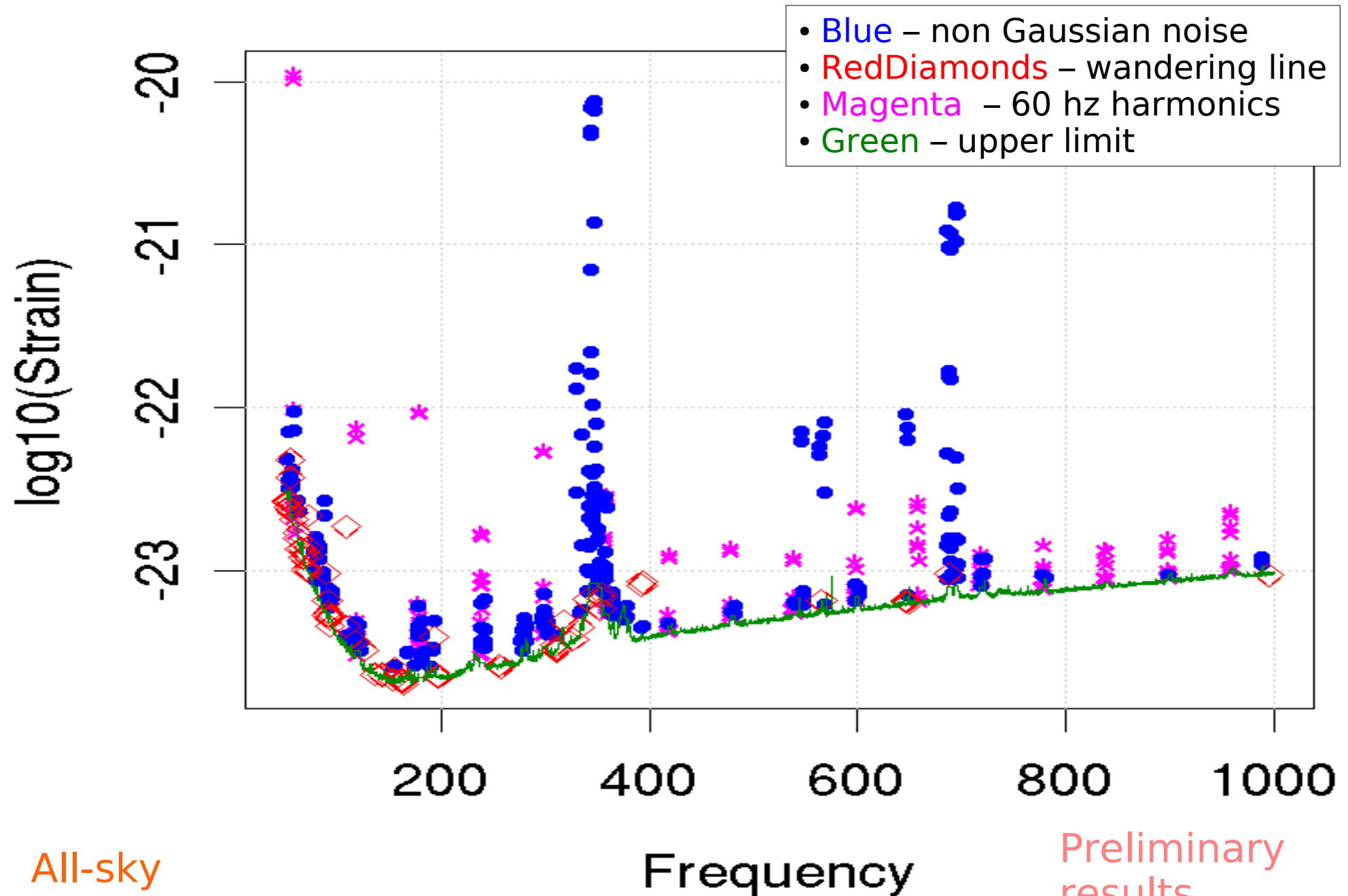


Histograms

(one entry per sky point)



H1 S5 0-spindown run



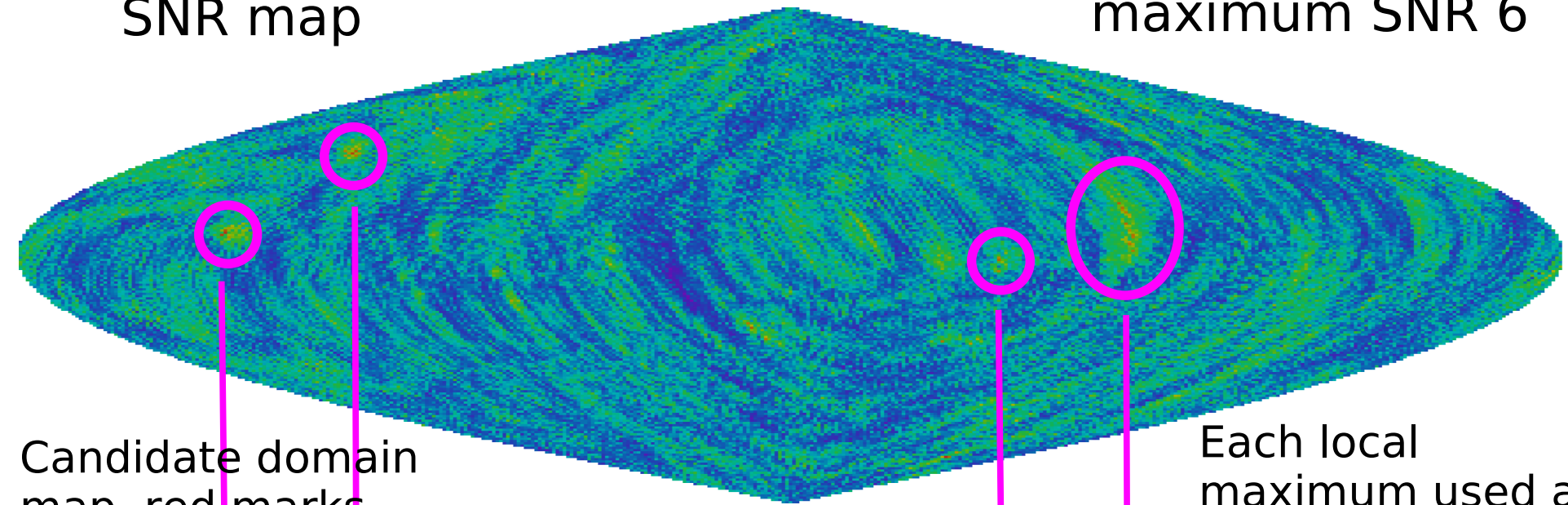
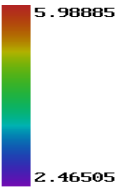
All-sky
50-1000 Hz

Preliminary
results

Multiple outliers

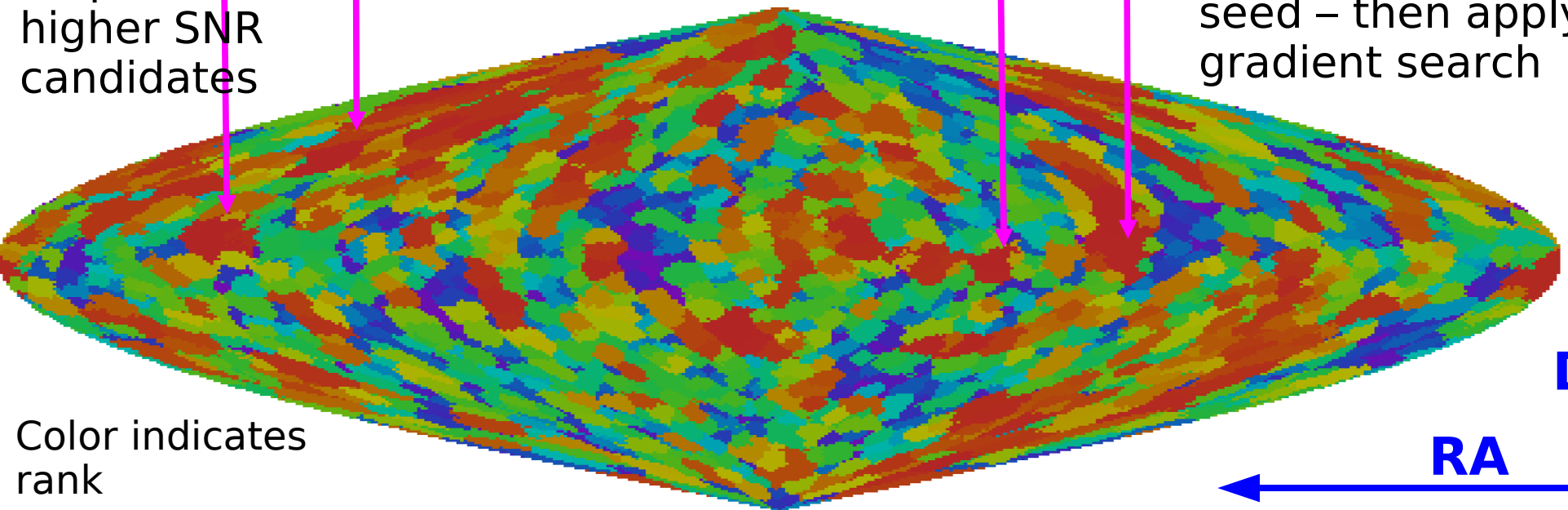
SNR map

Clean band –
maximum SNR 6



Candidate domain
map, red marks
higher SNR
candidates

Each local
maximum used as
seed – then apply
gradient search



Color indicates
rank

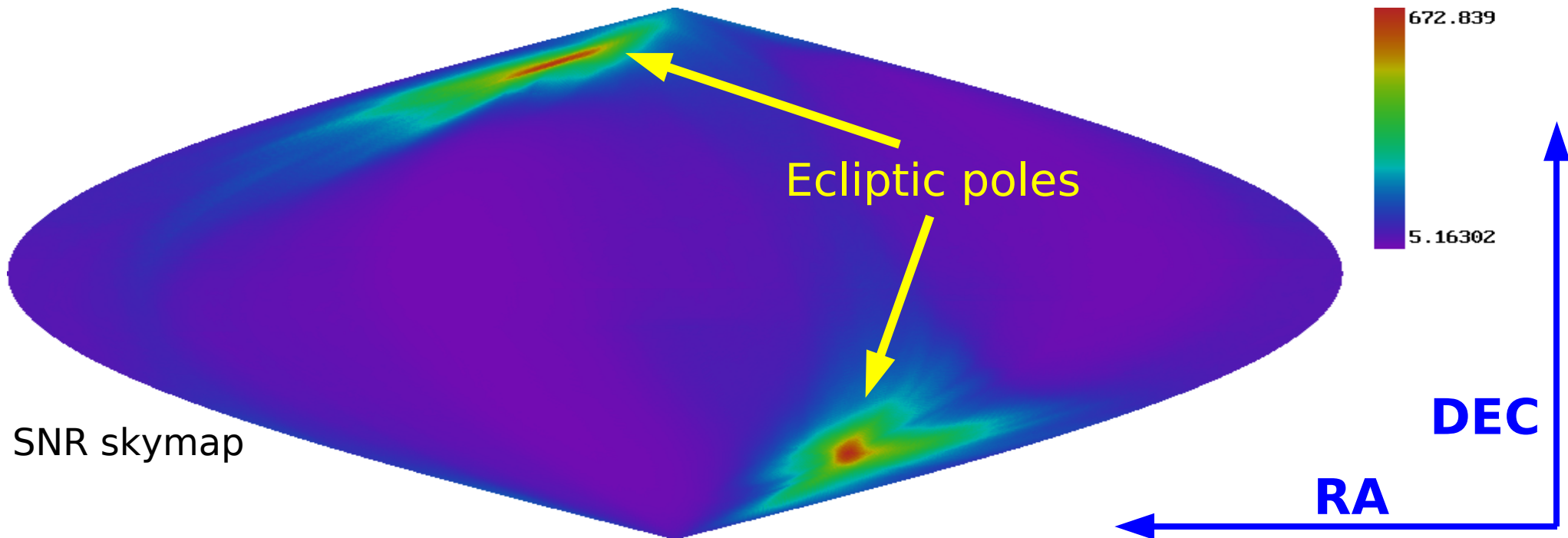
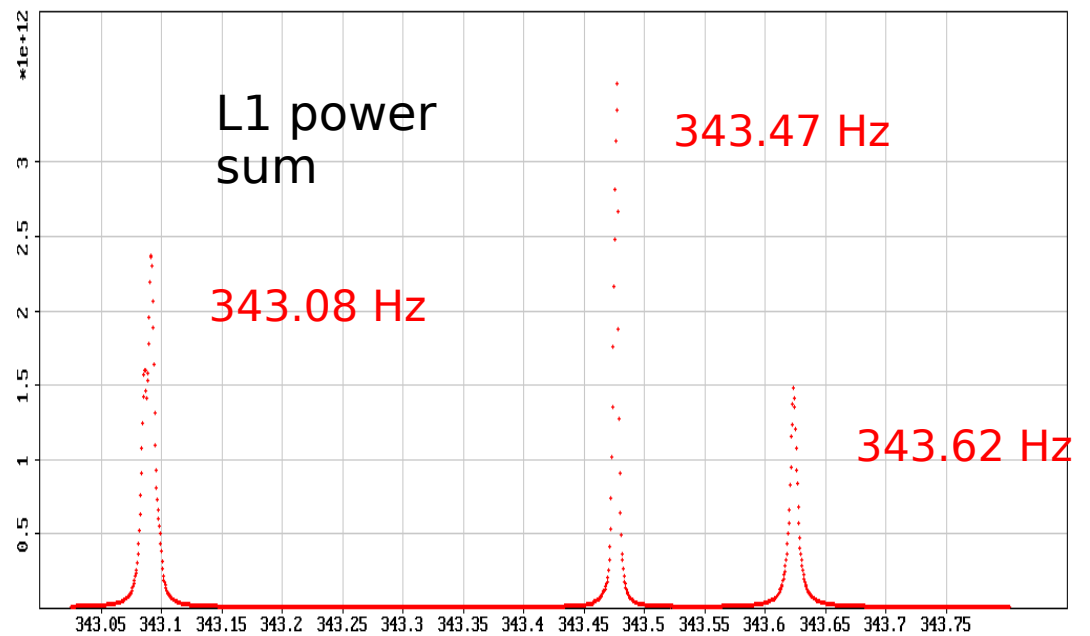
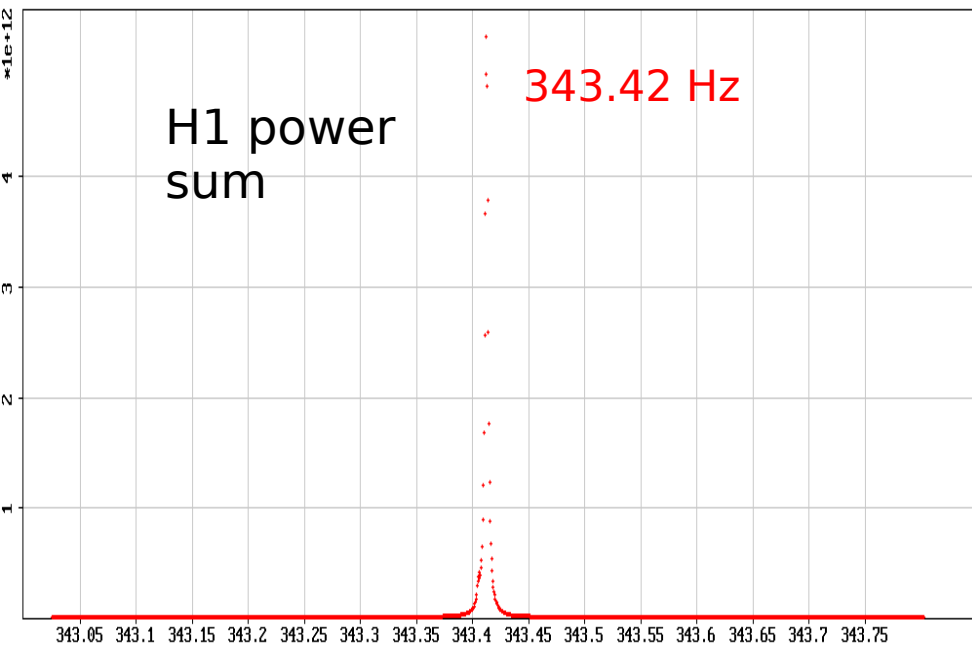
RA

DEC

Outlier followup

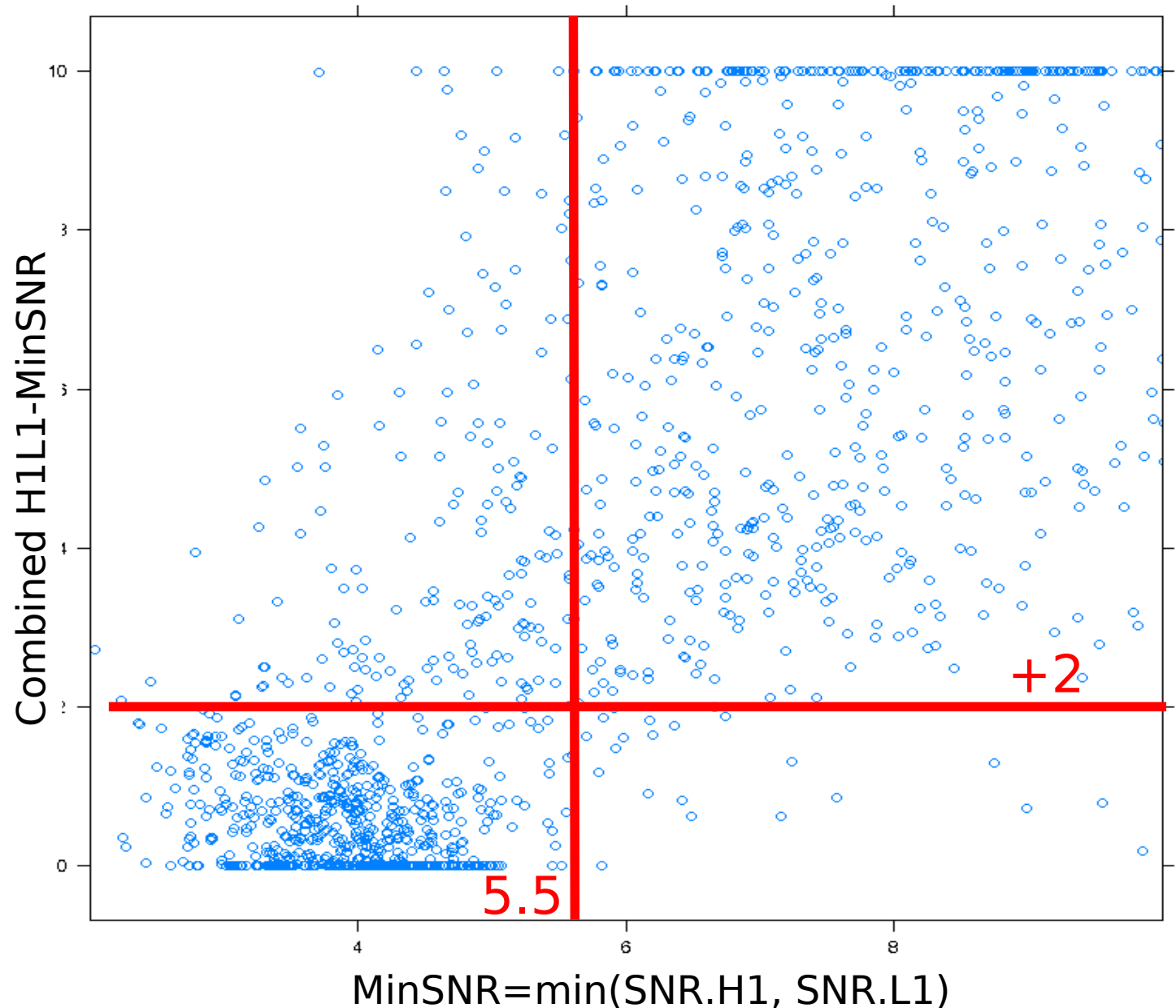
- Determine local SNR maxima, pick N highest (1000 from each of 10 sky slices)
- Apply a variation of gradient search to optimize SNR
- Look for outliers common to two interferometers:
 - $\text{SNR} > 6.25$ for each interferometer
 - Difference in frequency less than $1/180$ Hz
 - Difference in spindown 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⁾

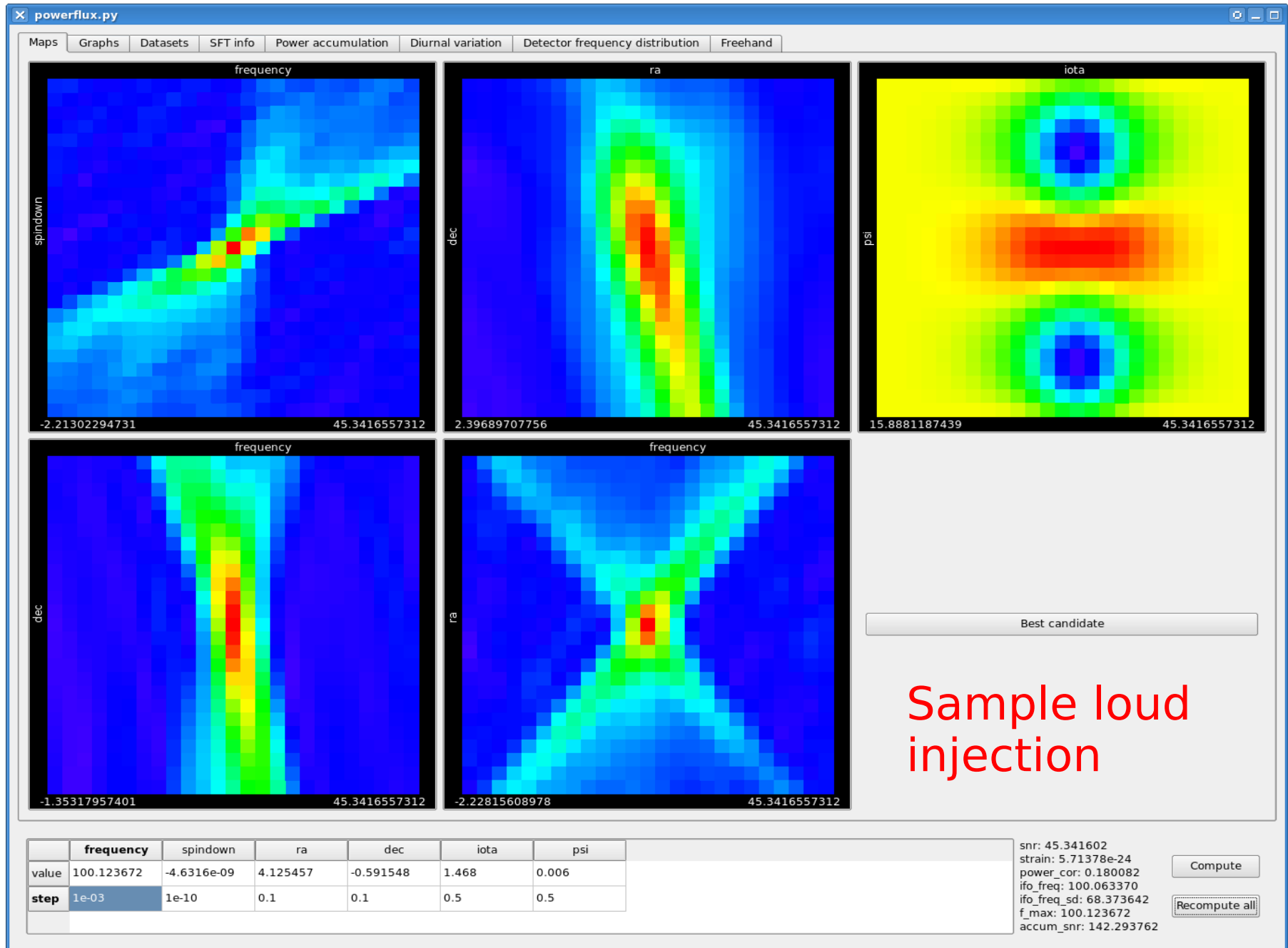


Signal injections guide followup

- 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 $5\text{e-}10$ Hz/s



Interactive interface



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

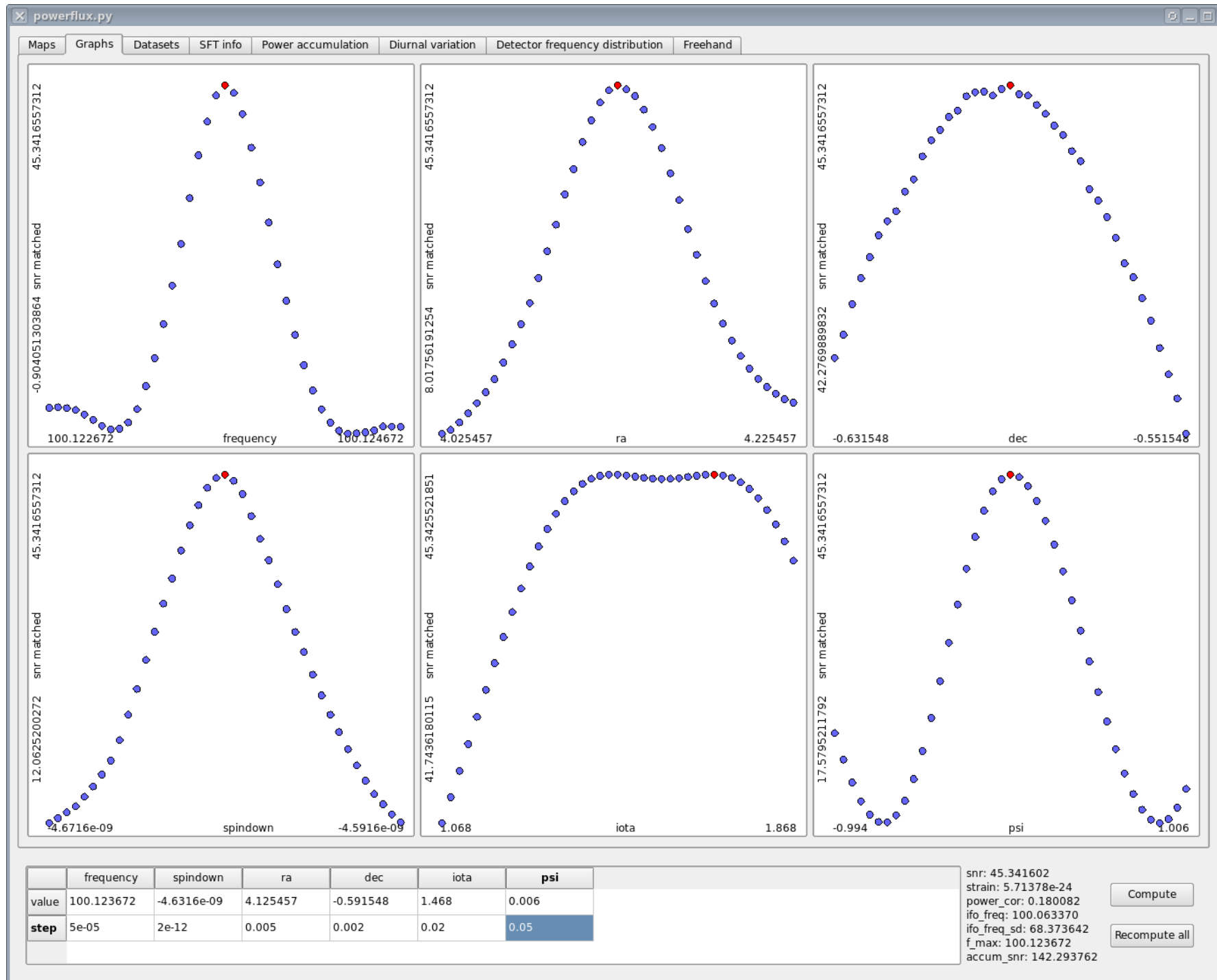
Conclusion

- 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

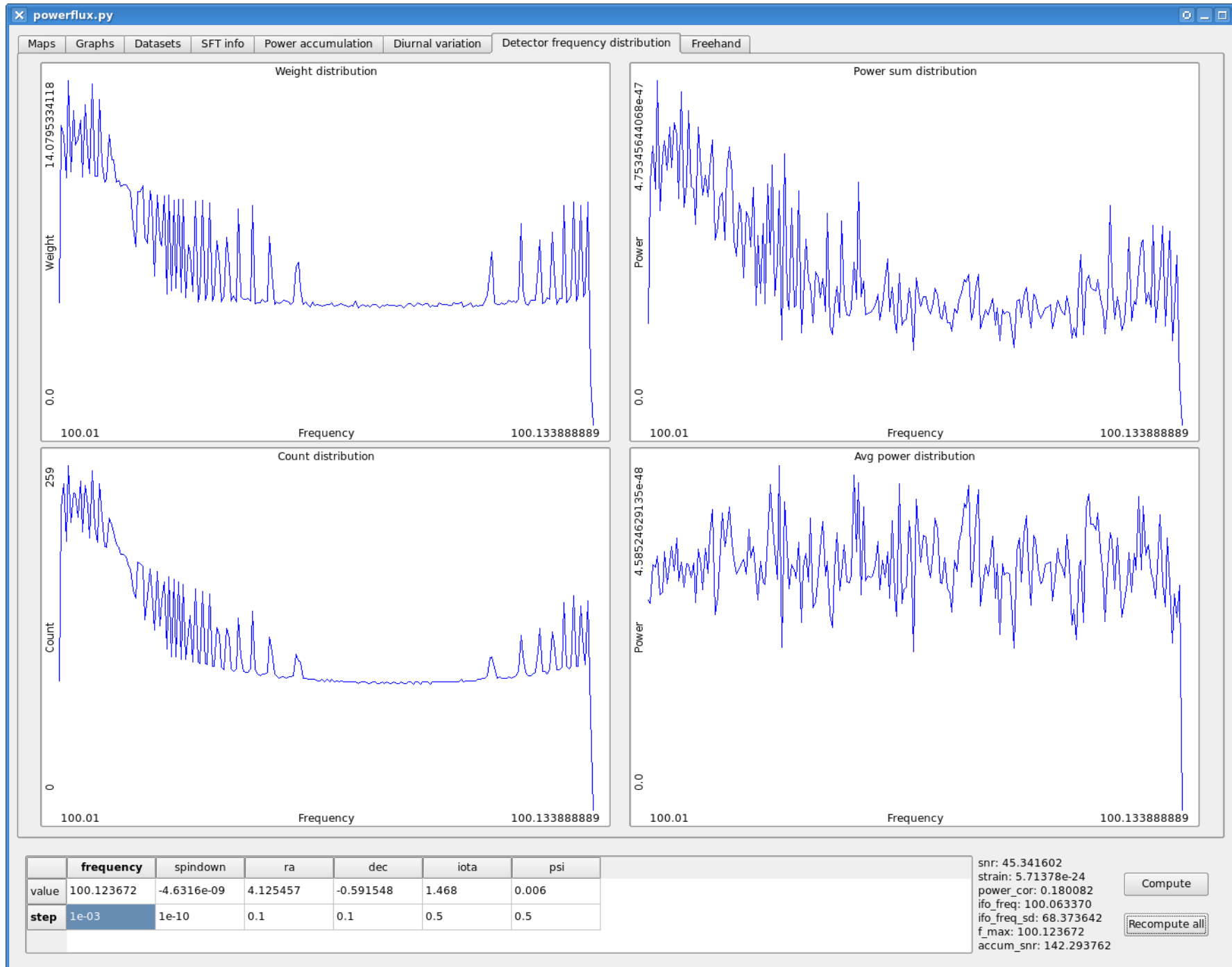
End of talk

(supporting slides for questions follow)

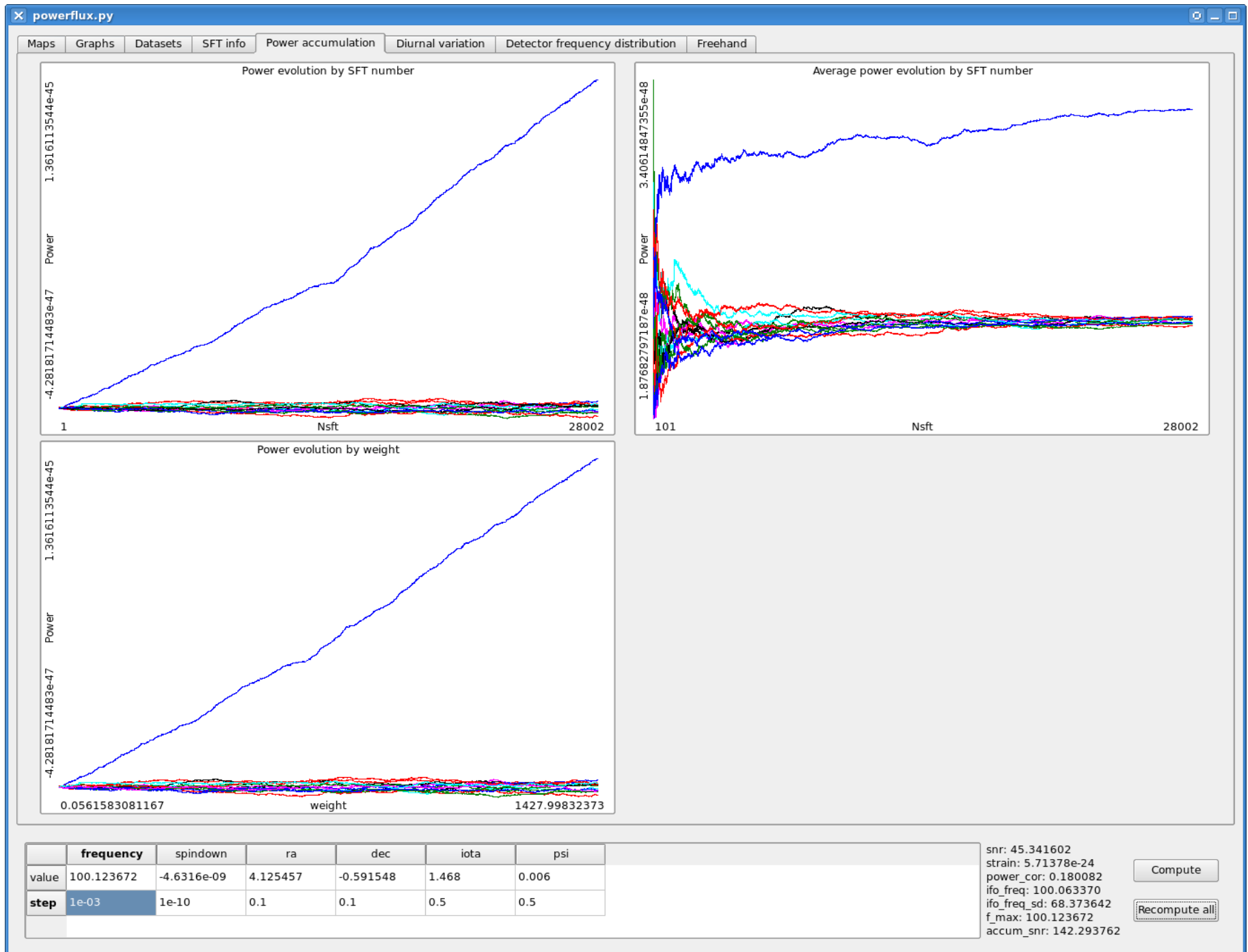
Graphs



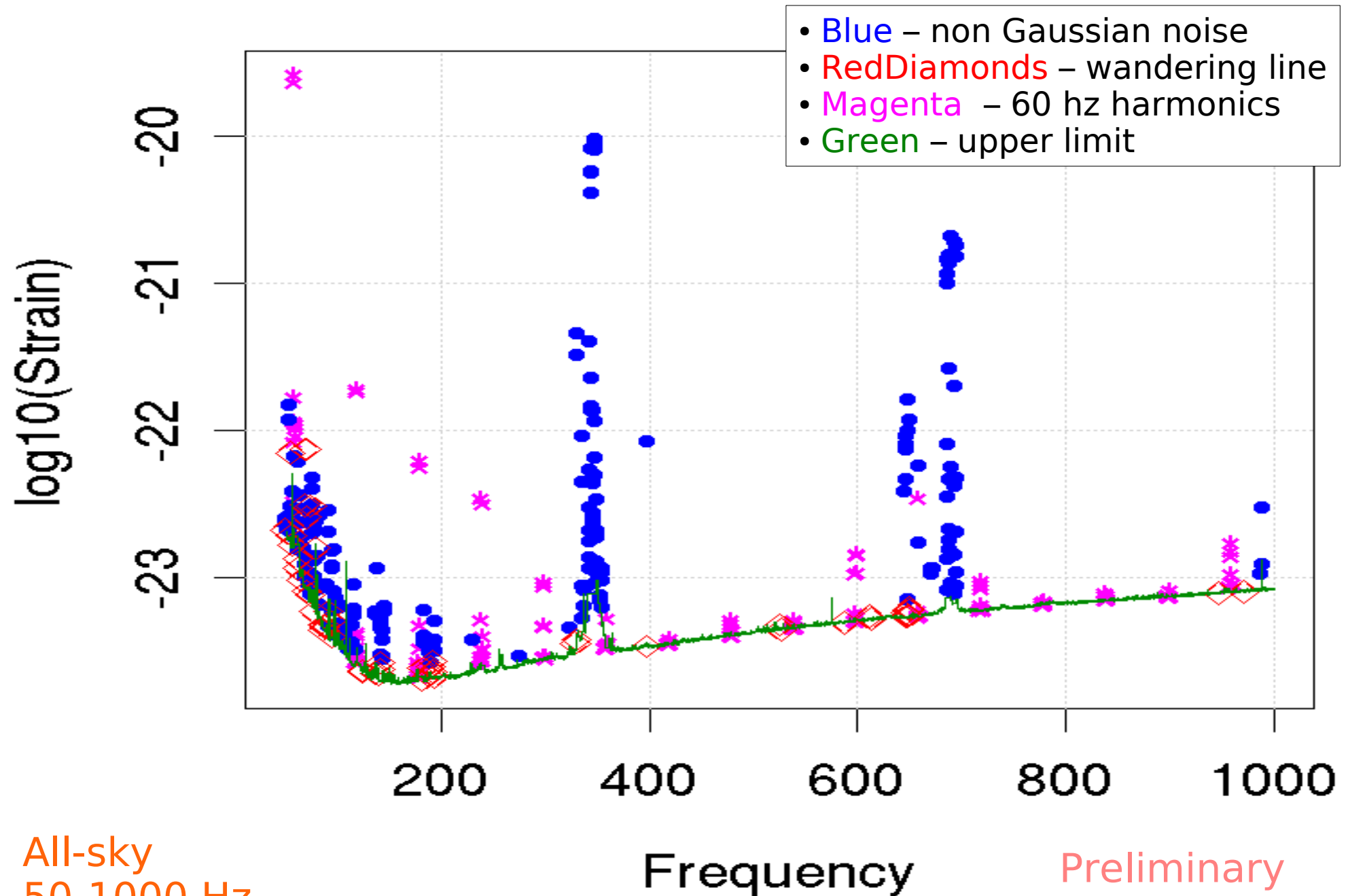
Frequency distribution



Power accumulation



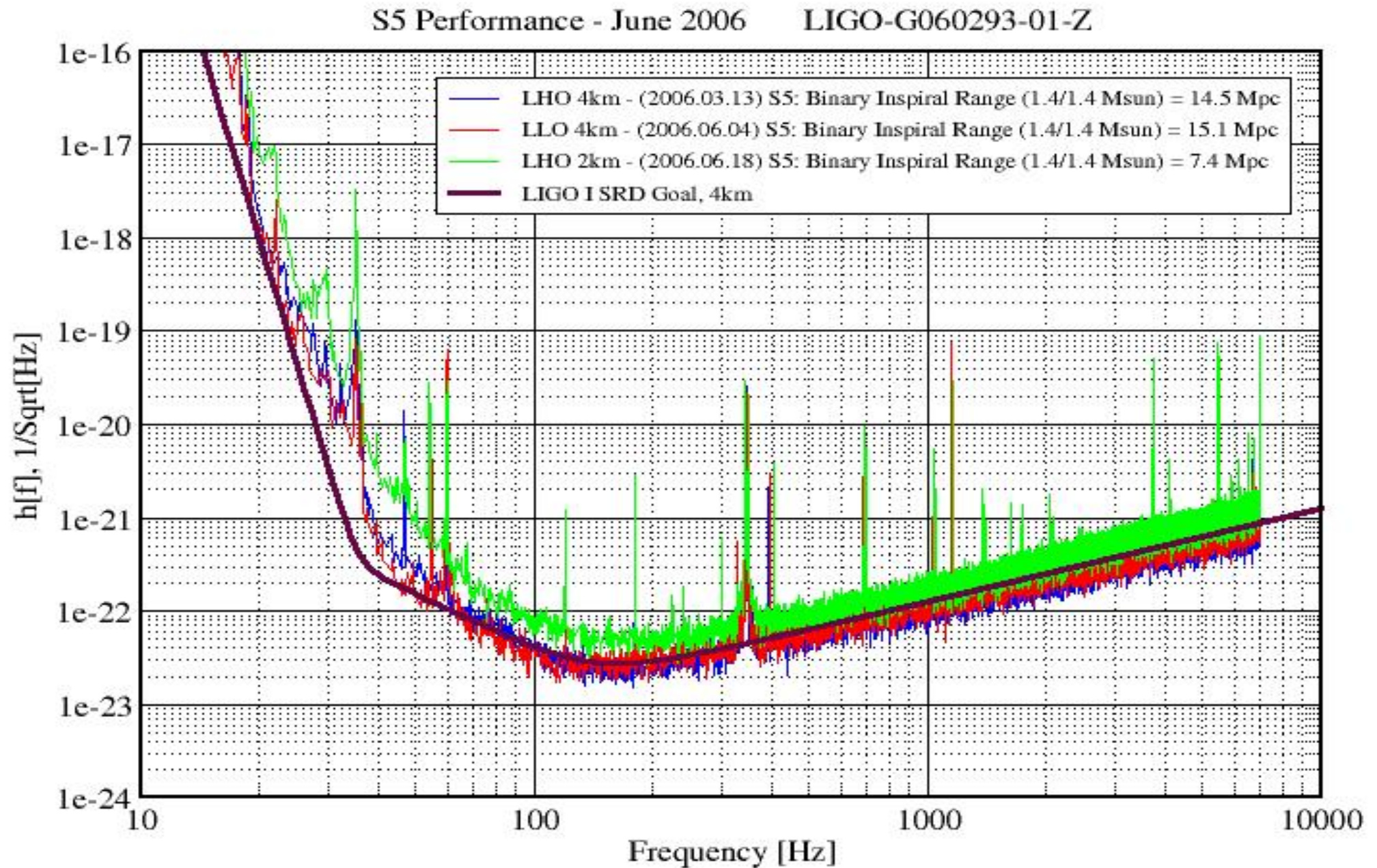
L1 S5 0-spindown run



All-sky
50-1000 Hz

Preliminary
results

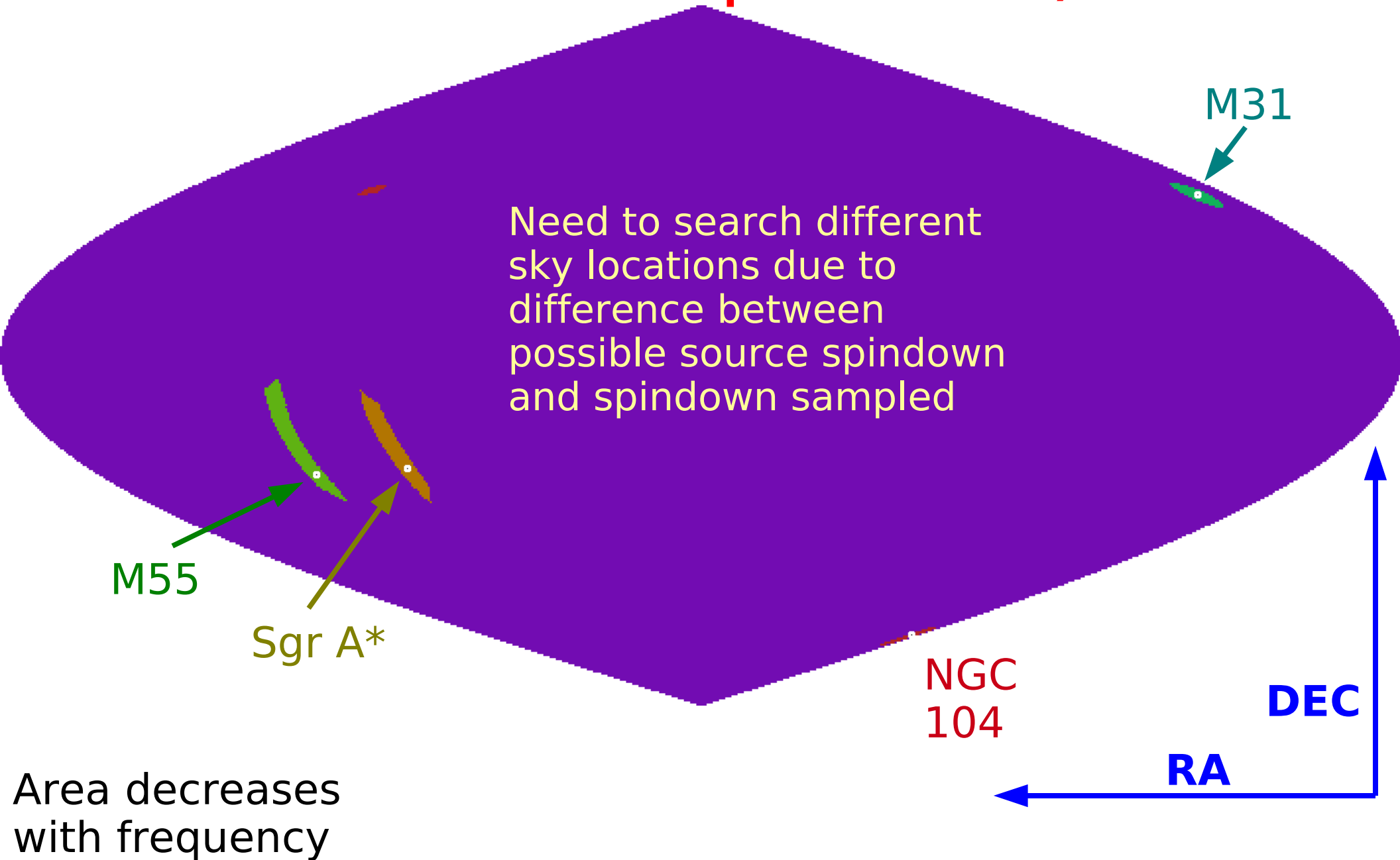
S5 science run sensitivity



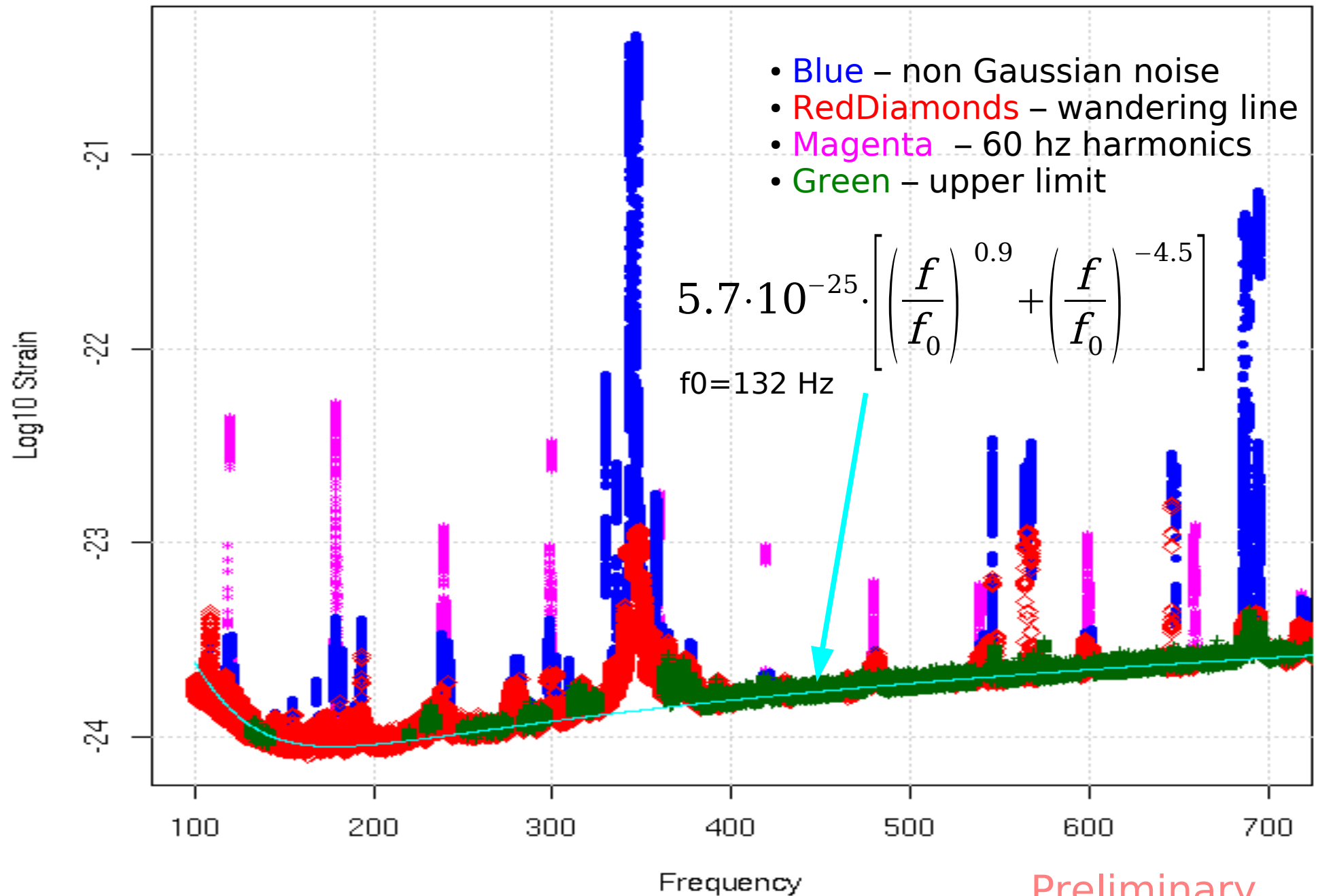
Partial sky (targeted) run

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

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



H1 Sgr A* upper limits

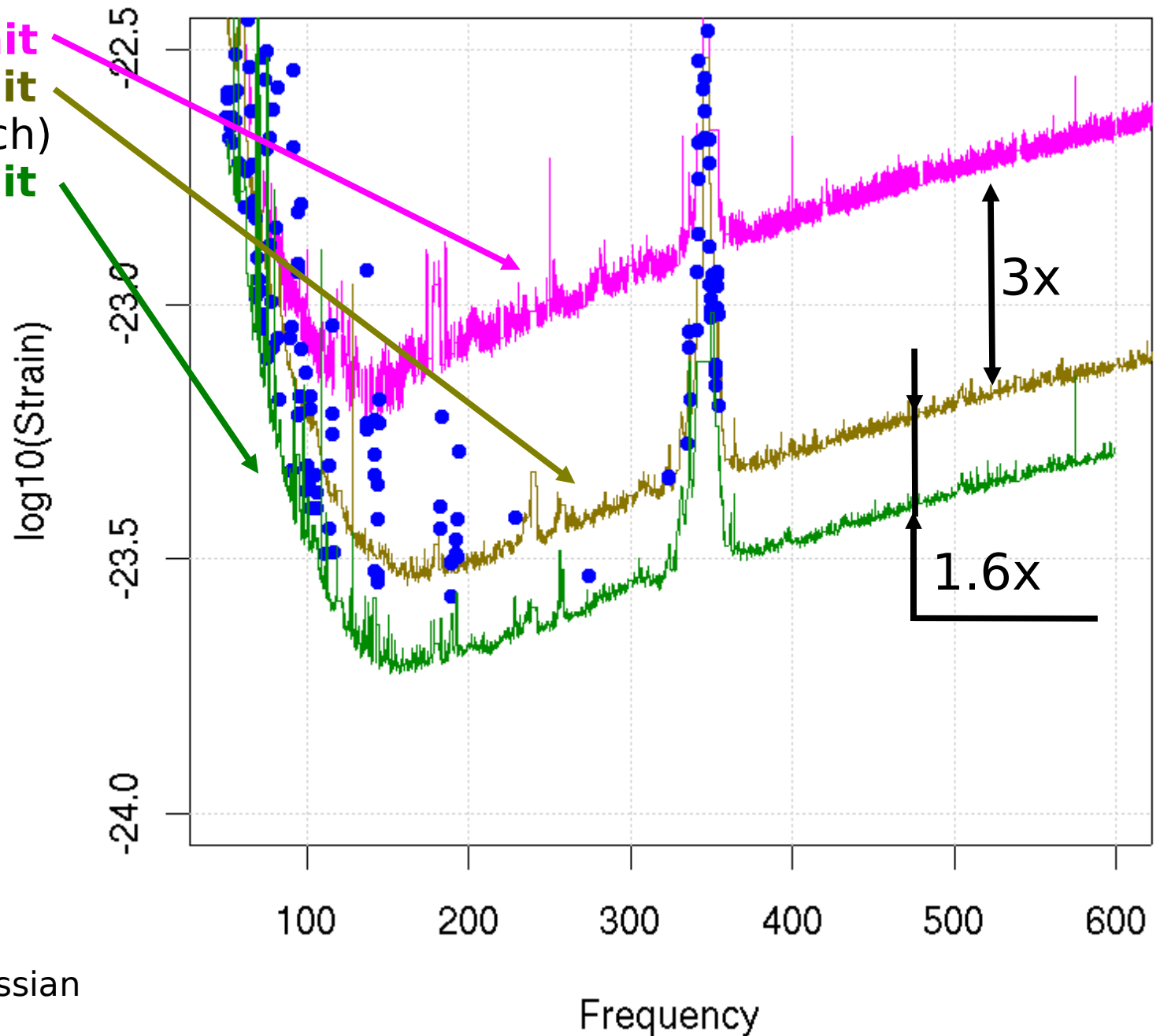


Preliminary
results

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

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

Average detector acceleration

Average detector velocity

Spindown (Hz/s)

Earth orbit angular velocity

Frequency

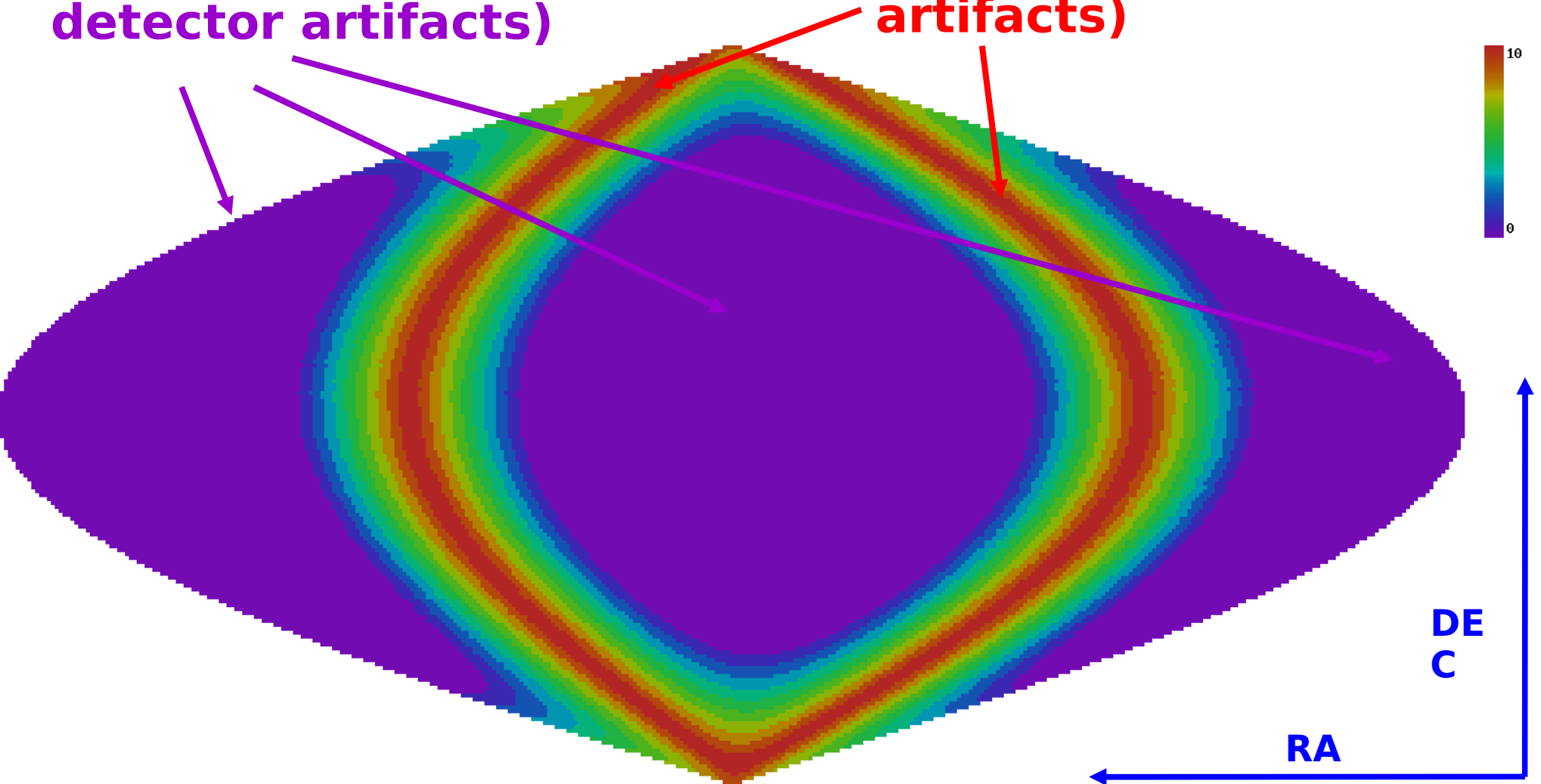
Unit sky position vector

The diagram shows the equation $S := s + \frac{\vec{u} \times \vec{v}_{\text{avg}}}{c} f \cdot \hat{r}$ with several green arrows pointing to its components. An arrow points from the text 'Spindown (Hz/s)' to the variable s . Another arrow points from 'Earth orbit angular velocity' to the vector $\vec{u}$. A third arrow points from 'Frequency' to the variable f . A fourth arrow points from 'Unit sky position vector' to the unit vector $\hat{r}$. A fifth arrow points from 'Average detector velocity' to the vector $\vec{v}_{\text{avg}}$. A sixth arrow points from 'Average detector acceleration' to the cross product $\vec{u} \times \vec{v}_{\text{avg}}$.

Doppler Skybands

Skyband 0 (good – only exceptionally strong detector artifacts)

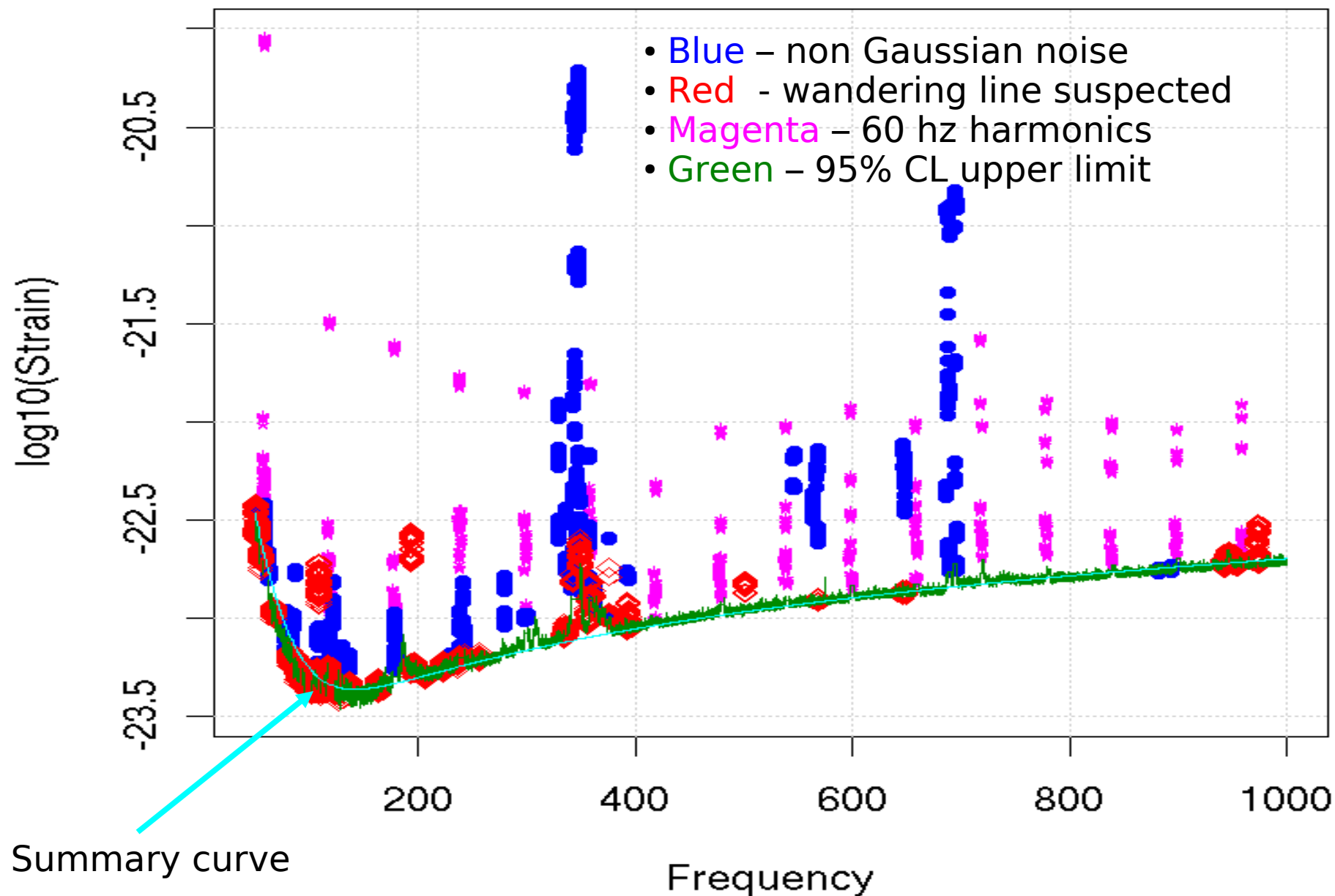
Skyband 10 (worst – many detector artifacts)



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

S4 run results

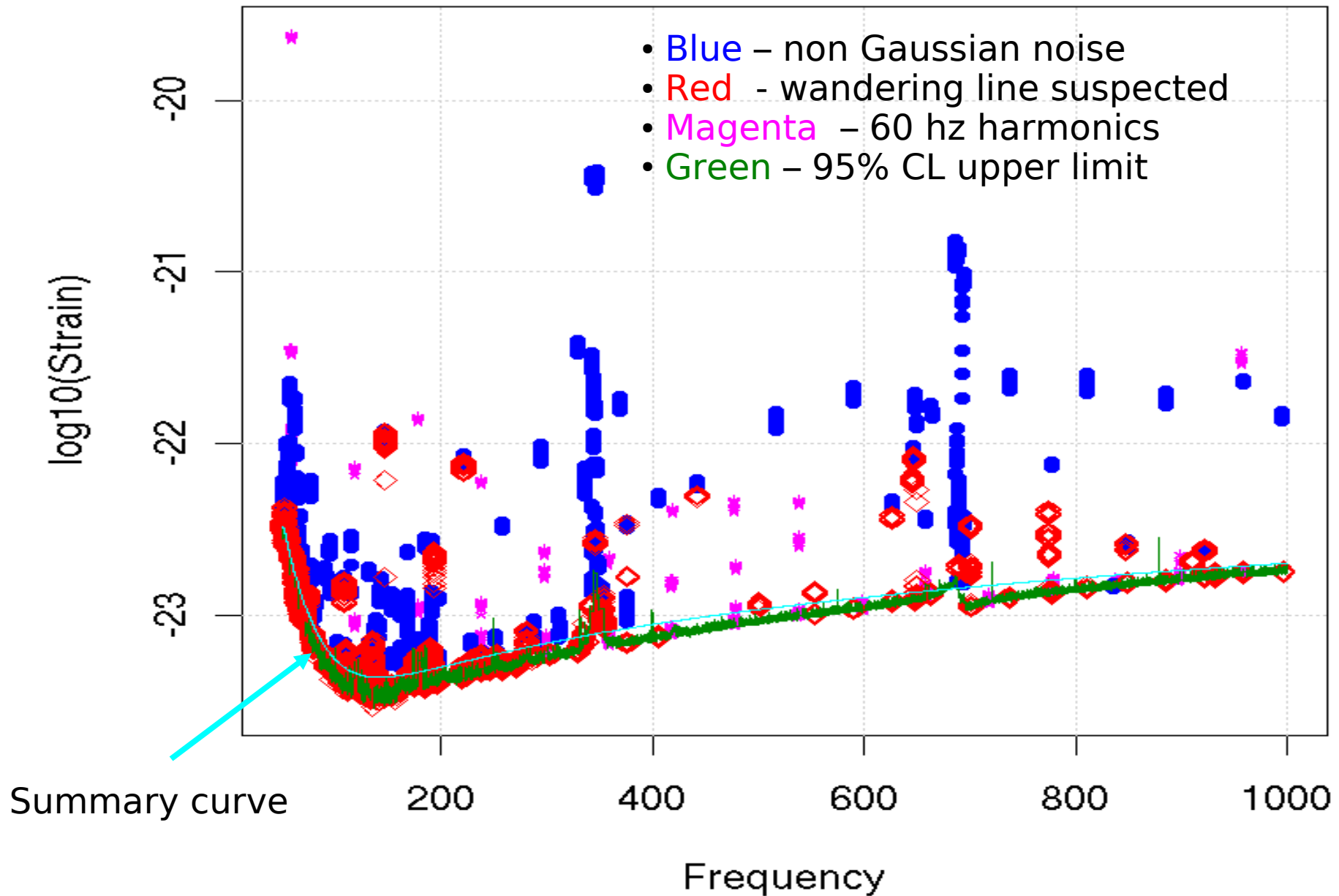
Hanford 4km



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

S4 run results

Livingston 4km



S5 summary curve deviation

