Signal detection and data processing for LOFAR and SKA using GPUs

Wes Armour
James Martin Fellow
Oxford e-Research Centre

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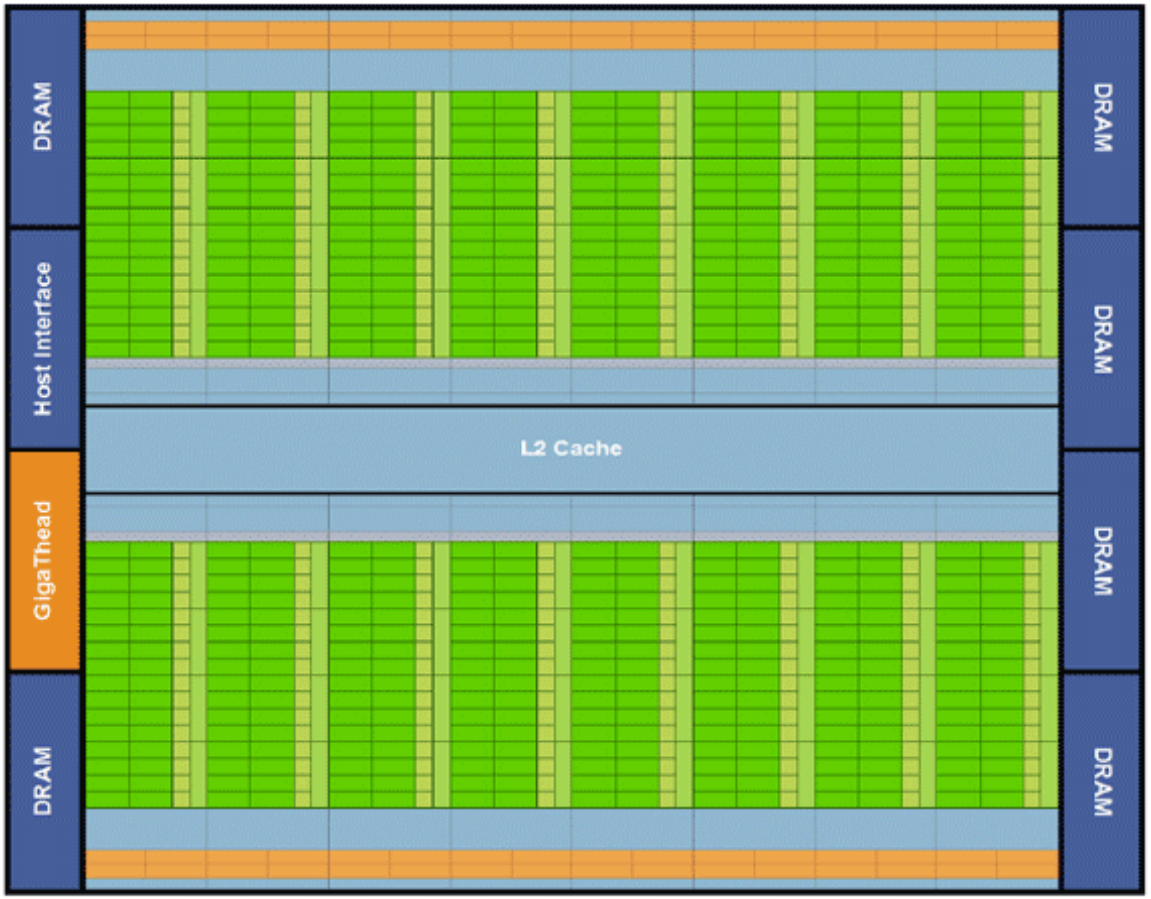
Current status of GPUs

Overview of current GPUs - Fermi

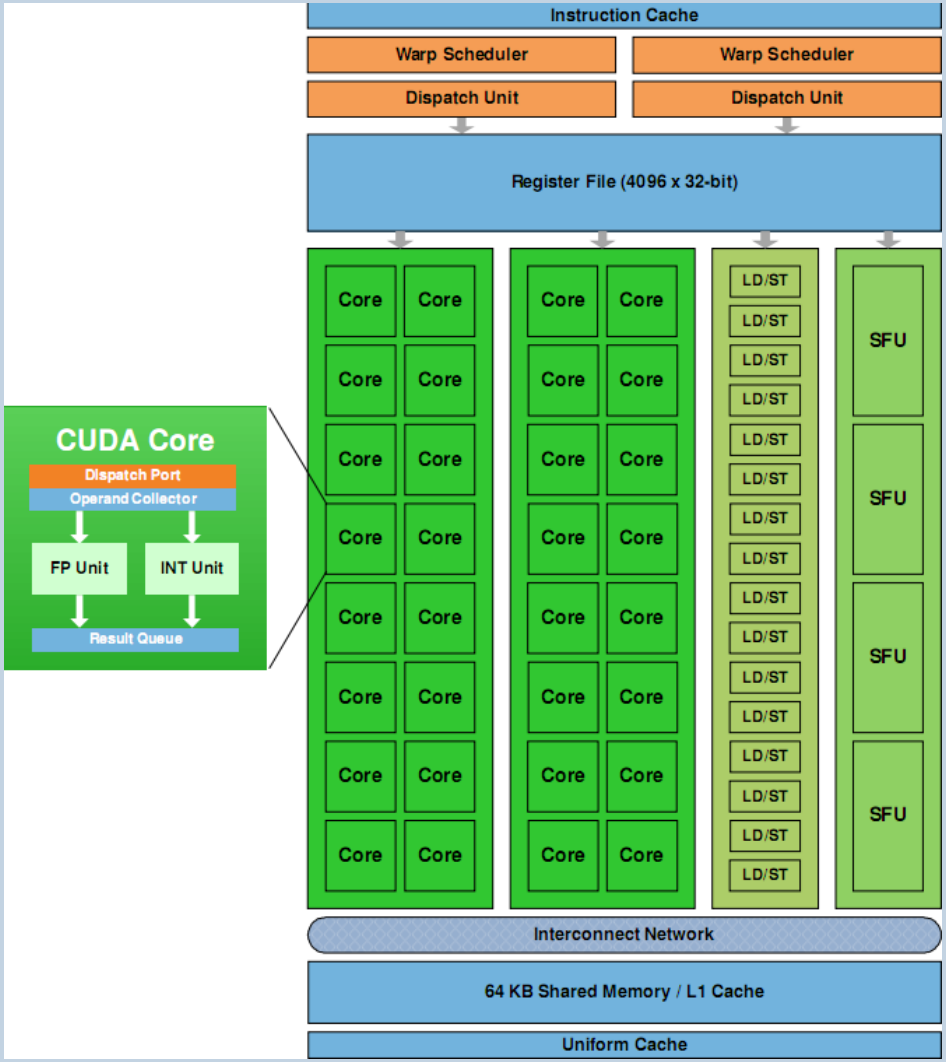
- Fermi released 2010
- 32 cores per Streaming Multiprocessor (SM)
- Configurable 16/48K or 48/16K L1 cache / shared memory (per SM)
- New L2 cache – 768K
- GigaThread – Concurrent kernel execution (16)
- ECC – slows things down, 10% - 25%
- Simple to use extensions - CUDA for C, C++ & FOTRAN

Fermi Design



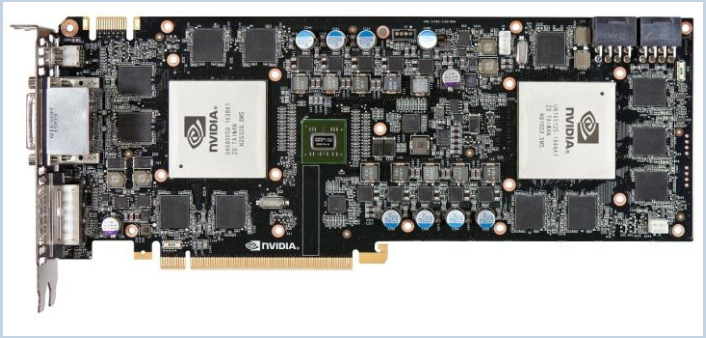
Fermi's 16 SM are positioned around a common L2 cache. Each SM is a vertical rectangular strip that contain an orange portion (scheduler and dispatch), a green portion (execution units), and light blue portions (register file and L1 cache).

Fermi Streaming Multiprocessor (SM) design



Latest Fermi based cards

- GeForce GTX 590 – 2x GF110 GPUs
- 6.8 GFLOPS / watt
- Price point ~ £600



- M2070 – 1x GF100 GPU, 16 SMs
- 5.7 GFLOPS / watt
- Price point ~ £2.5K

Influence and Take-up

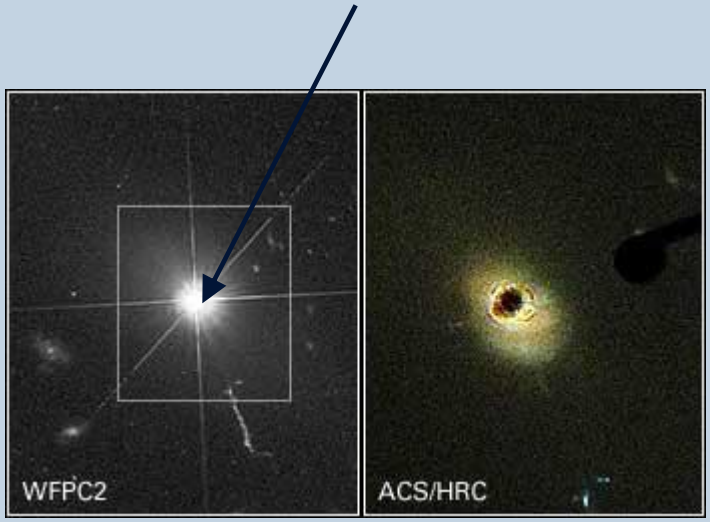
TOP 500 – 3 out of top 5 utilise Fermi/Tesla

- Tianhe-1A 2.5 petaflops
- Based on 14336 Xeon and 7168 M2050
- To achieve same performance using only CPUs 50000 CPUs, 2x floor space and 3x power (Estimates made by NVIDIA)
- Uses Lustre :-s

Dispersion and Dedispersion

Radio Astronomy and Radio Transients

Quasars – Energetic region of a distant galactic core, surrounding a supermassive black hole

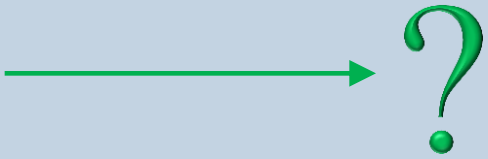


NASA and J. Bahcall (IAS)

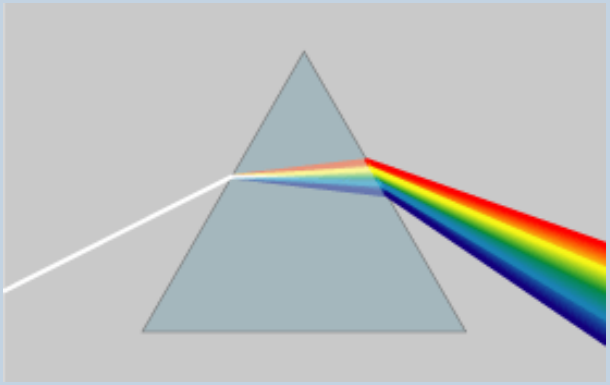
Hester et al.

Pulsars – Magnetized, rotating neutron stars. Emit synchrotron radiation from the poles, e.g. Crab Nebula

RRATS – Rotating Radio Transients. Short, bright irregular radio pulses. Discovered 2006

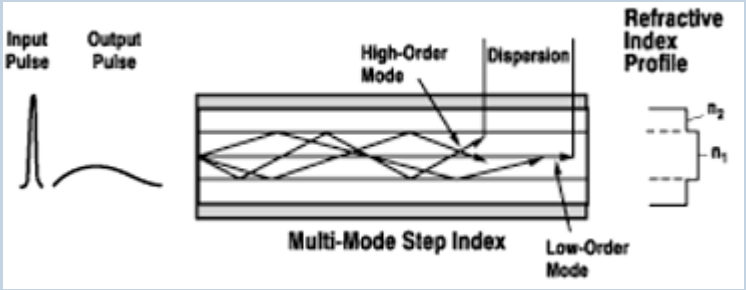


Dispersion



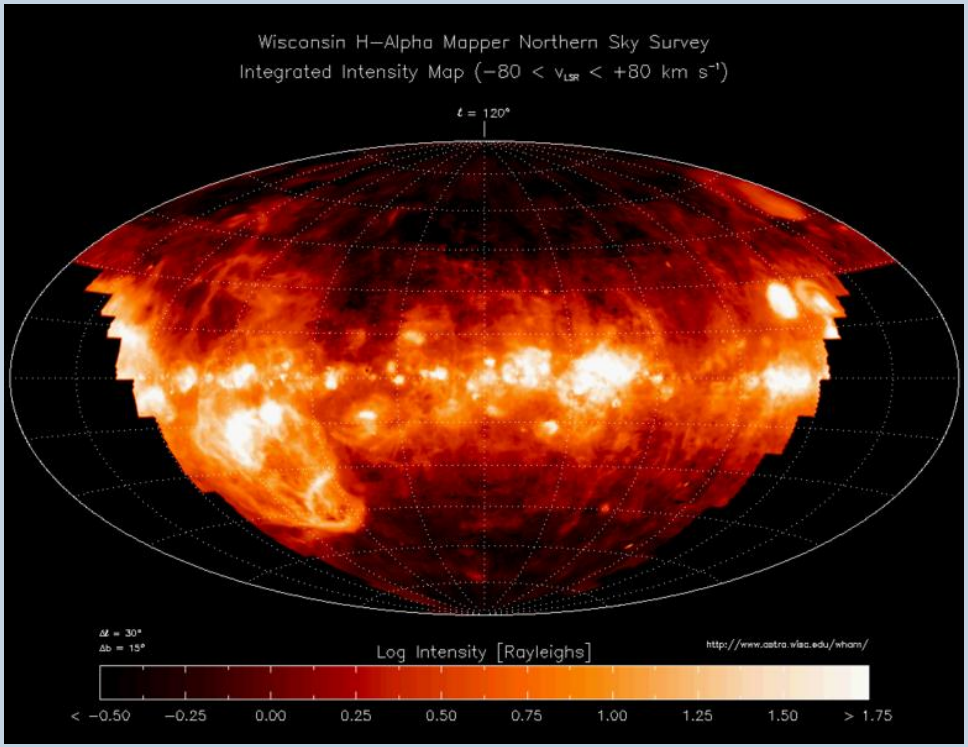
Chromatic dispersion is something we are all familiar with. A good example of this is when white light passes through a prism.

Group velocity dispersion occurs when pulse of light is spread in time due to its different frequency components travelling at different velocities. An example of this is when a pulse of light travels along an optical fibre.



Dispersion of Radio waves by the ISM

The interstellar medium (ISM) is the matter that exists between stars in a galaxy.



Haffner et al. 2003

In warm regions of the ISM (~8000K) electrons are free and so can interact with and effect radio waves that pass through it.

The Dispersion Measure - DM

The time delay, $\Delta\tau$, between the detection of frequency f_{high} and f_{low} is given by:

$$\Delta\tau = C_{DM} \times \mathrm{DM} \times \left(\frac{1}{f_{low}^2} - \frac{1}{f_{high}^2} \right)$$

Where C_{DM} is the dispersion constant. DM is the dispersion measure:

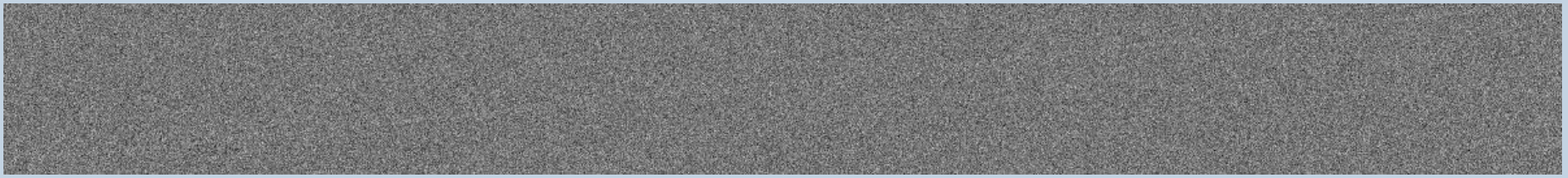
$$DM = \int_0^d n_e dl$$

This is the free electron column density between the radio source and observer.

We can measure $\Delta\tau$ and f and so can study DM

Experimental Data

Most of the measured signals live in the noise of the apparatus.



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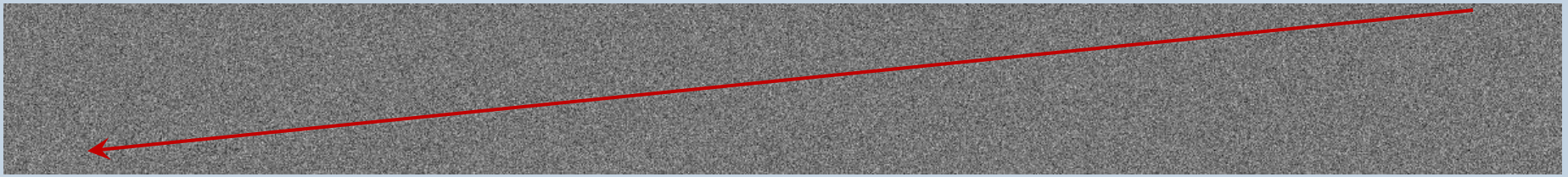
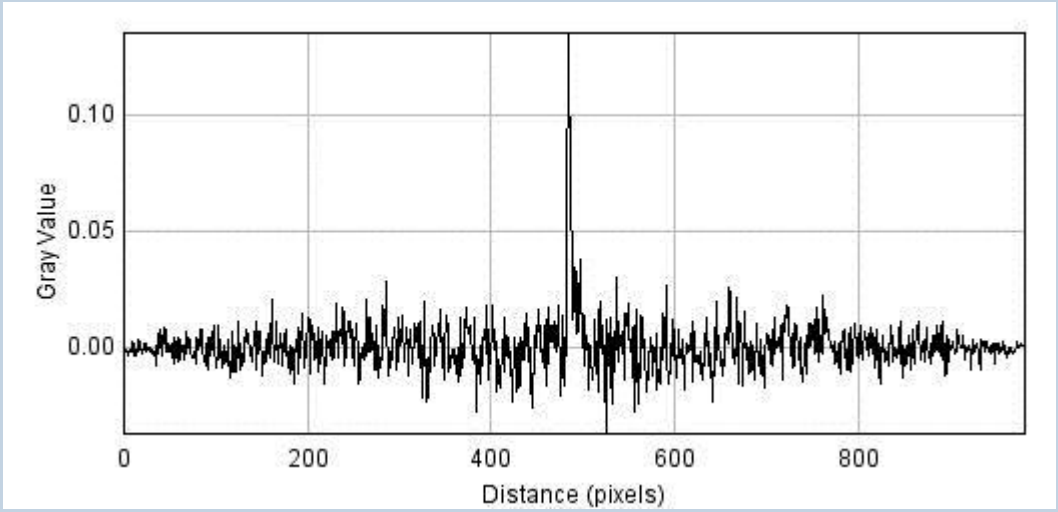


Hence frequency channels have to be “folded”



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MDSM – Alesseo, Brute force algorithm.

Algorithm 3.1 Brute-Force Dedispersion CUDA implementation

Require: nsamp, nchans, startdm, dmstep, tsamp, dm_shifts

$s \leftarrow threadId.x + blockIdx.x * blockDim.x$

$shift\_temp = {}^{startdm+blockIdx.y*dmstep}/_{tsamp}$

for $samp = 0$ to $nsamp$ **do**

$samp \leftarrow samp + blockDim.x * gridDim.x$

$soffset \leftarrow s + samp$

for $c = 0$ to $nchans$ **do**

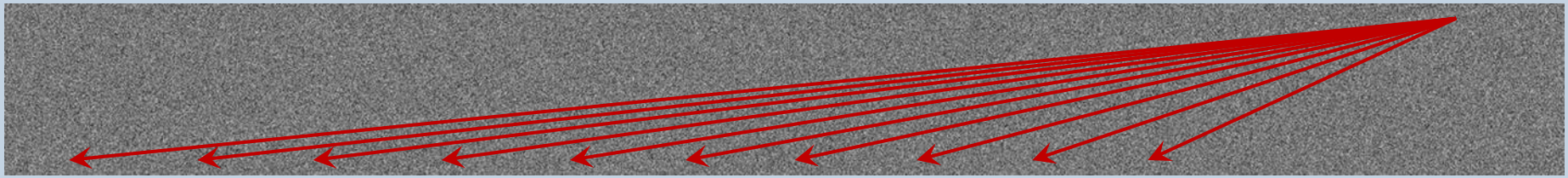
$index \leftarrow (soffset + dm\_shifts[c] * shift\_temp) * nchans * c$

$output[blockIdx.y * nsamp + soffset] += input[index]$

end for

end for

Every DM is calculated to see if a signal is present.



1st Stage – Memory access optimisation

- Begin by profiling the code using the Cuda Profiler.
- Identified bottle necks in memory access patterns
- By moving the variable that holds the running total from shared memory to a register kernel execution was 5x faster.

2nd Stage – Occupancy Optimisation

- Optimize GPU block size for each kernel to get the maximum occupancy of threads on the GPU
- Investigated the optimal block size for GPU hardware versions sm_13 and sm_20
- This produced a 1.25x speed increase.

Current Speedup

On-going and Future Work

- Mikes new algorithm for GPU

Acknowledgments