Netherlands Institute for Radio Astronomy

Efficient Imaging in Radio Astronomy using GPUs

Bram Veenboer, Matthias Petschow and John W. Romein

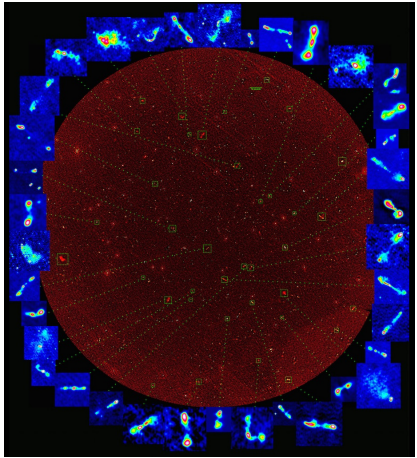
Tuesday 9th May, 2017, GTC 2017, San Jose, USA

ASTRON is part of the Netherlands Organisation for Scientific Research (NWO)

Radio Astronomy

- Array of antennas and/or dishes
- Radio frequencies (30-240 Mhz)
- Map of radio sources

LOFAR, The Netherlands

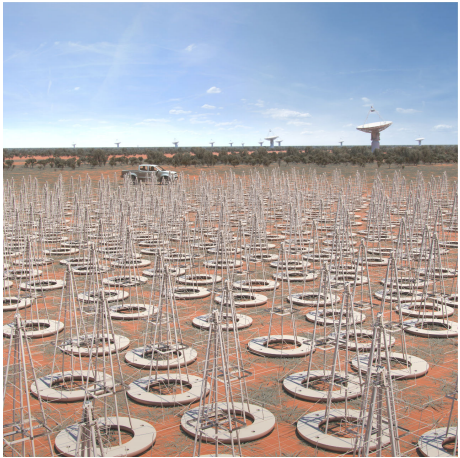


Boötes field, $>$ 1000 Megapixel

Image credits: Wendy Williams, Reinout van Weeren and Huub Rottgering

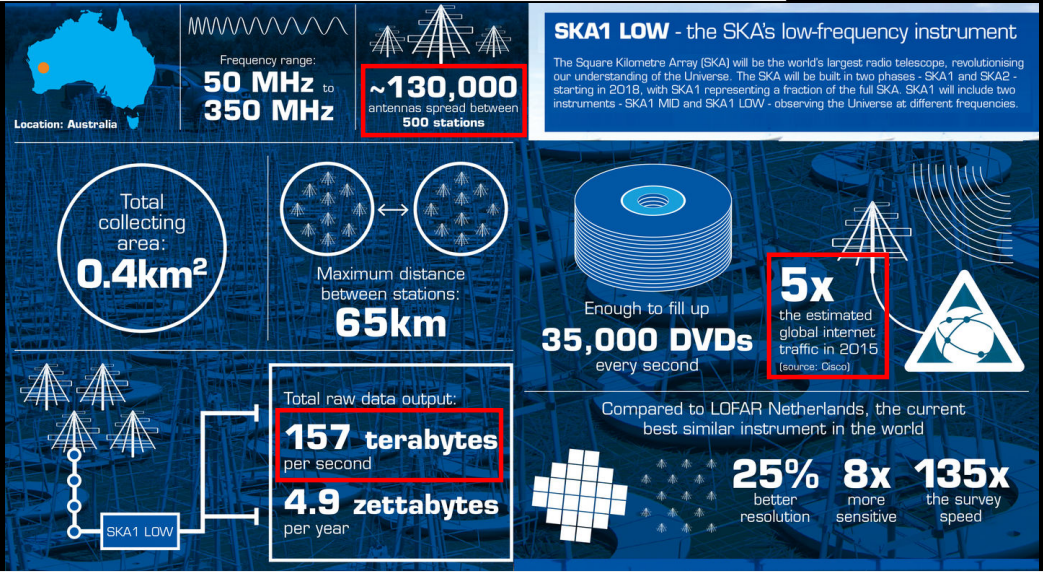
Square Kilometre Array

SKA1 Mid, Africa



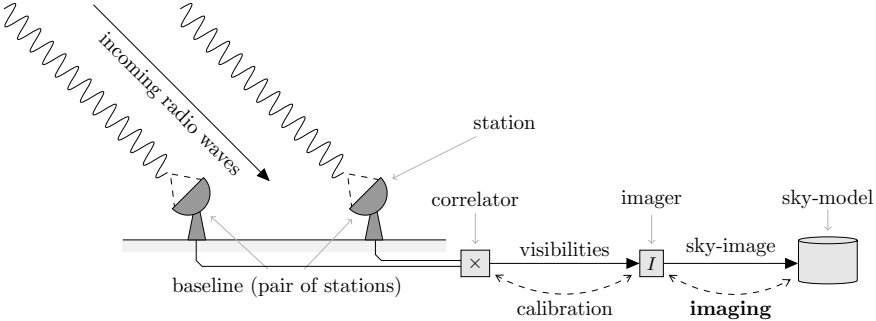
SKA1 Low, Australia

Square Kilometre Array



Imaging in Radio Astronomy

- Convert measurements (visibilities) into a sky-image:



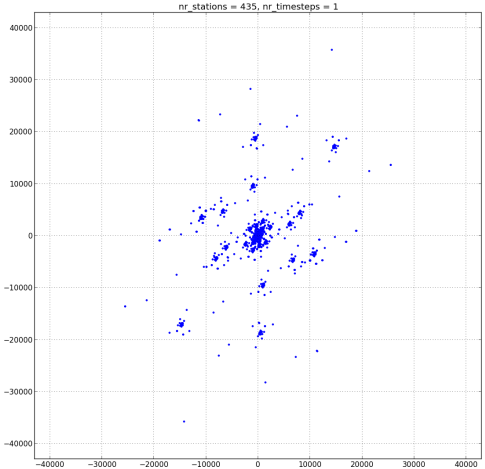
- Measurement equation:

$$V_{pq} = \int_l \int_m A_p(l,m) \times B(l,m) \times e^{-2\pi i(u_{pq}l + v_{pq}m + w_{pq}n)} dl dm$$

A-term — phasor $e^{-i\phi}$ — W-term

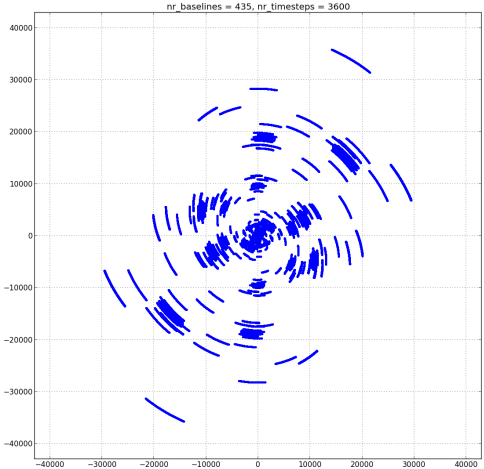
visibility — sky coordinates — source brightness — visibility coordinate u, v, w

Fourier sampling



instantaneous u,v-coverage

every baseline contributes one point (visibility)



u,v-coverage for one hour

'earth rotation synthesis'

‘Gridding’ visibilities

- Place visibilities onto a regular Fourier grid:

correct for ‘direction-dependent effects’ — A-term

phase correction — phasor $e^{-i\phi}$

correct for earth curvature — W-term

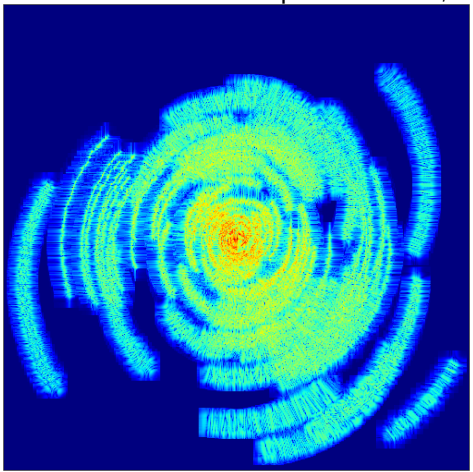
$$V_{pq} = \int_l \int_m A_p(l,m) \times B(l,m) \times e^{-2\pi i(u_{pq}l + v_{pq}m + w_{pq}n)} dl dm$$

visibility — sky coordinates — source brightness — visibility coordinate u, v, w — *floating-point numbers*

Traditional approach: apply ‘convolution’ to each visibility

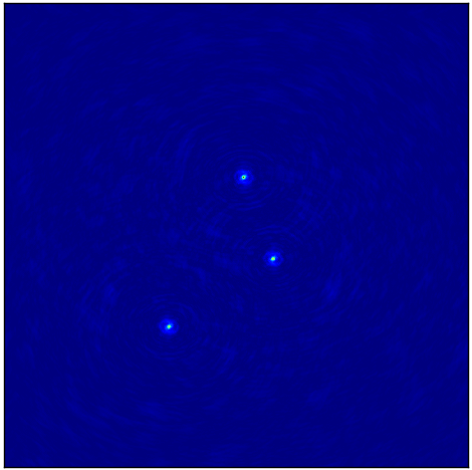
Imaging example

- Simulated three point sources, observed by 30 stations for 4 hours:



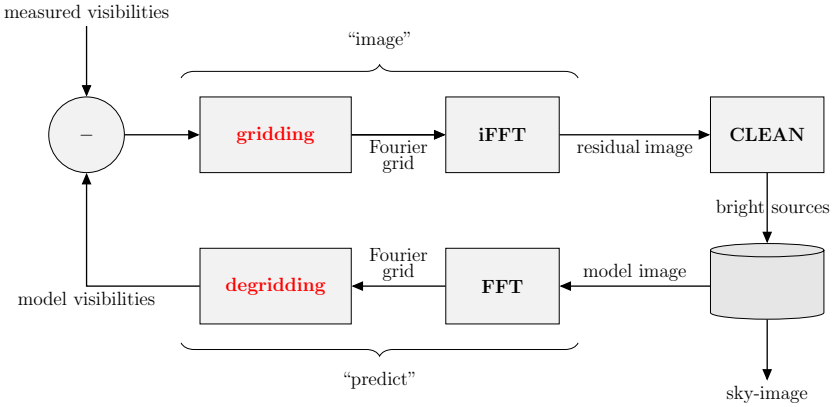
gridded visibilities

$\xrightarrow{2D\ FFT}$



sky image

Efficient Imaging in Radio Astronomy

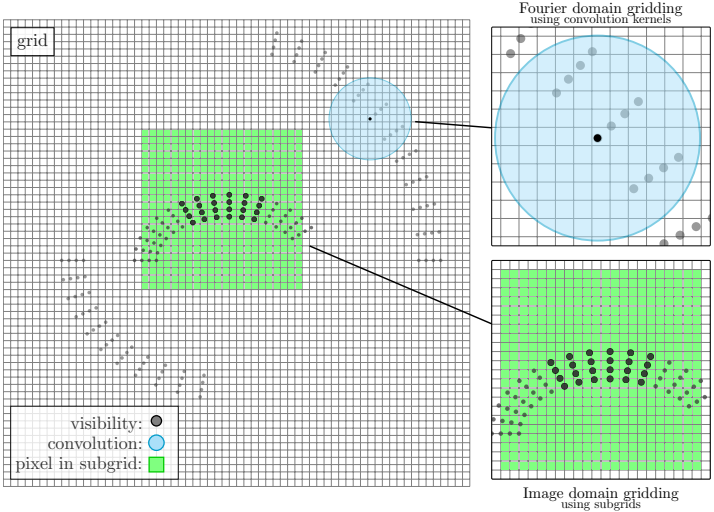


Problem: The 'gridding' and 'degridding' steps are computationally very expensive

Solution: Use the novel Image-Domain Gridding (IDG) algorithm on accelerators

Algorithm credits: Bas van der Tol

Placing visibilities onto a regular Fourier grid



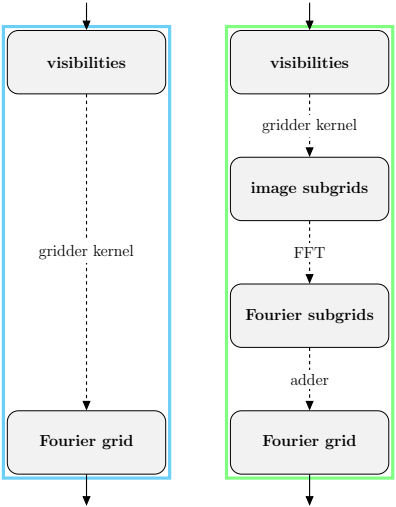
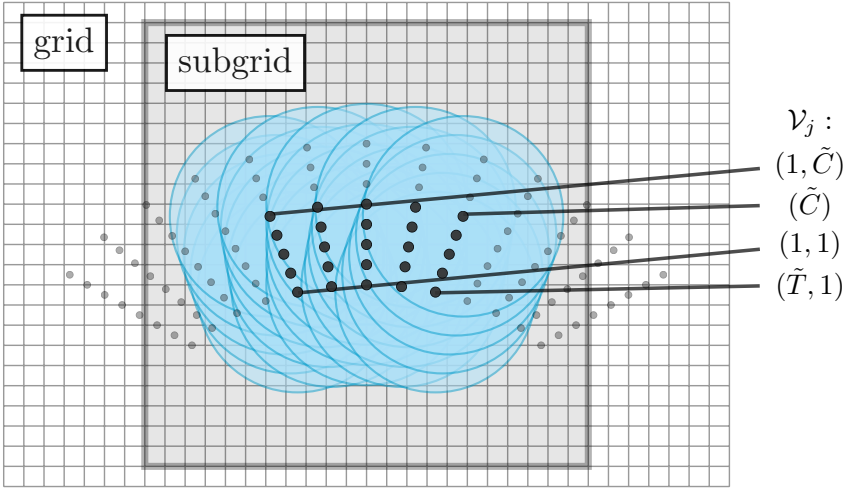
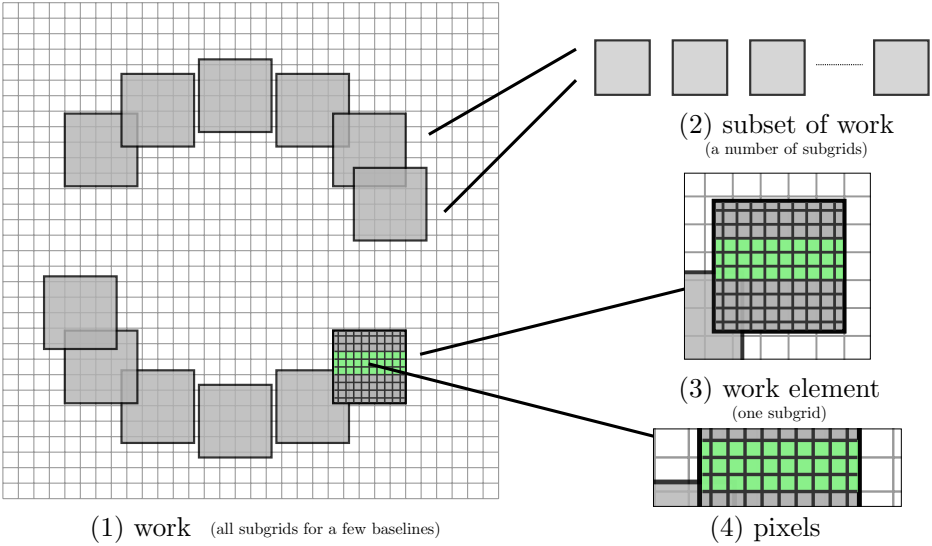


Image domain gridding: subgrids



A subset $(\tilde{T} \times \tilde{C})$ of visibilities from baseline j are placed onto a subgrid

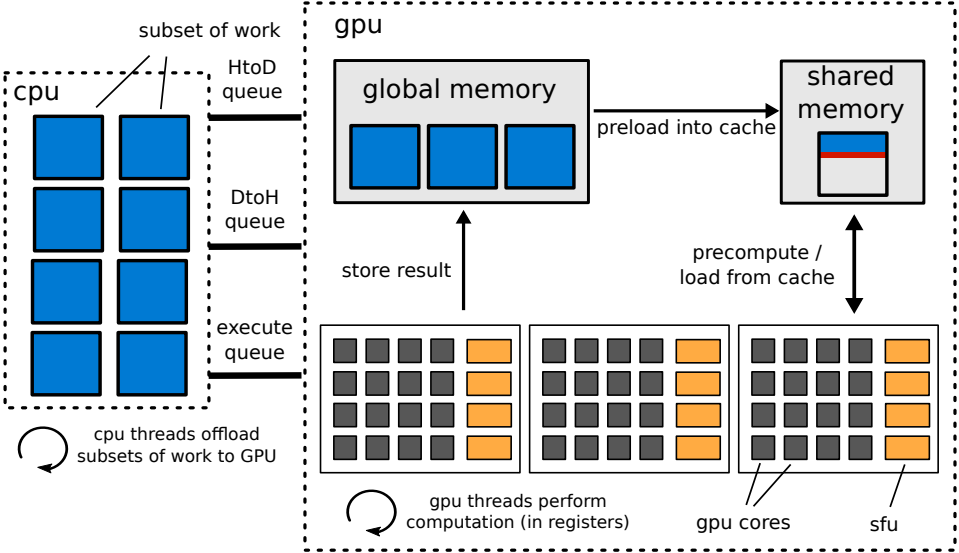
Image domain gridding: work distribution



Optimizations

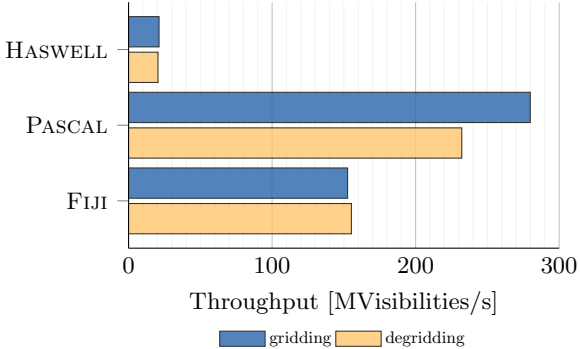
- General:
  - Coarse-grained parallelism, vectorization, libraries
  - Double buffering, shared memory
- Application specific:
  - Fine-grained parallelism
  - Data transpose (visibilities)
  - Data alignment (uvw coordinates)
- Architecture specific:
  - Computation of phasor term ($e^{-i\phi}$)
  - Nvidia: one special function unit (SFU) for every four/six cores
  - GCN: one transcendental operation per SIMD per four clock cycles

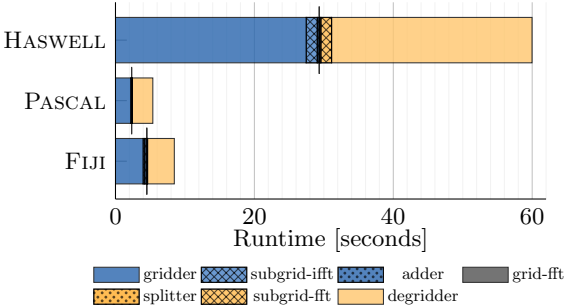
GPU implementation



Results: throughput/runtime

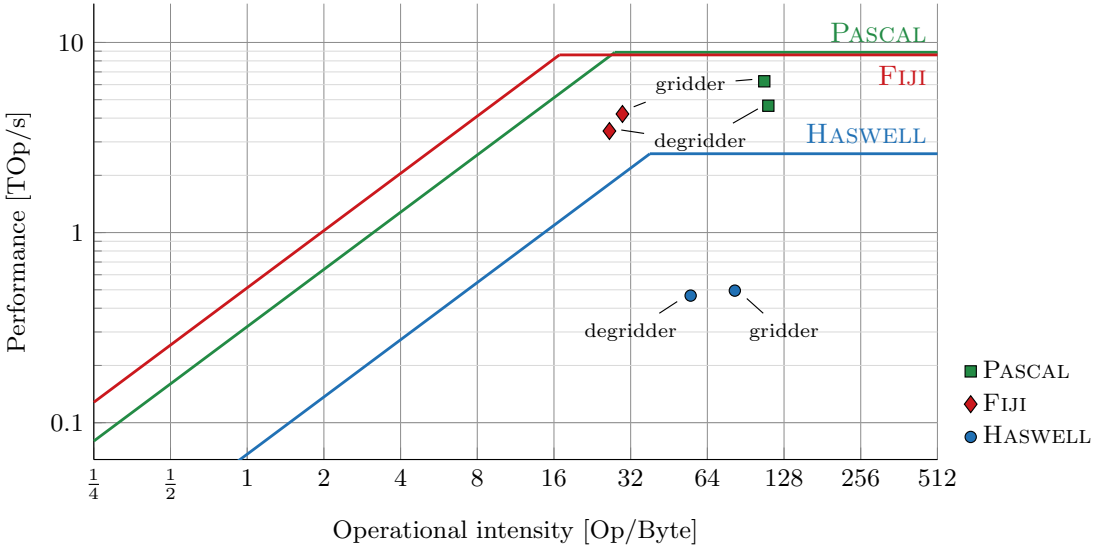
Throughput: number of visibilities processed per second



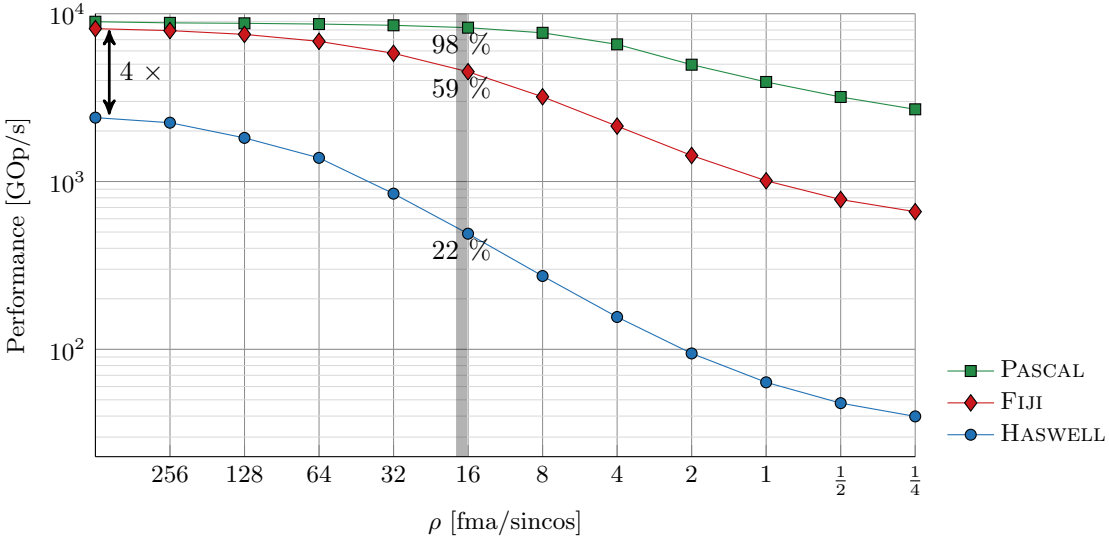


- Most time spent in gridder/degridder
- GPUs perform > order of magnitude better than CPU

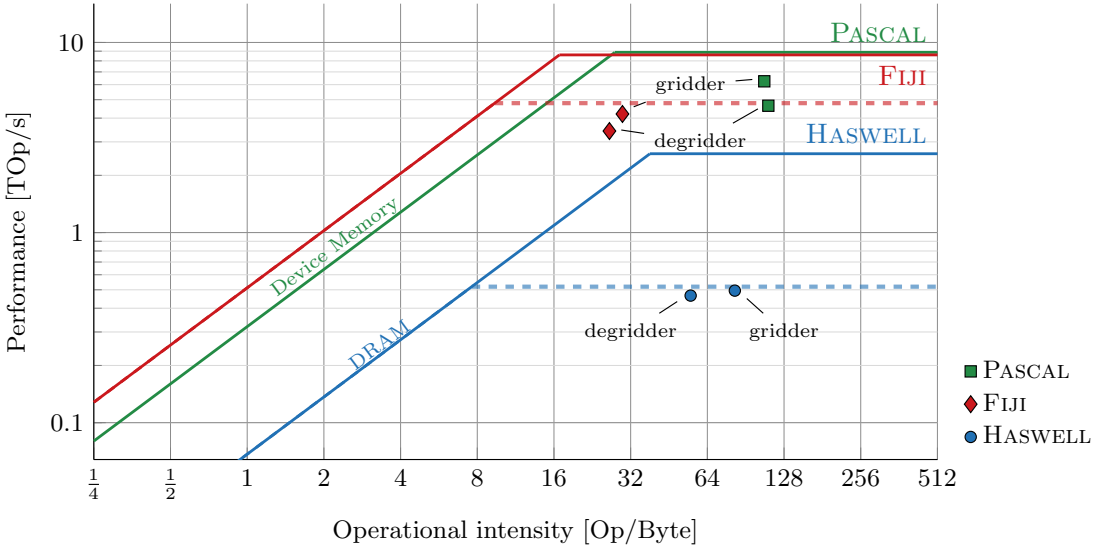
Roofline analysis: overview



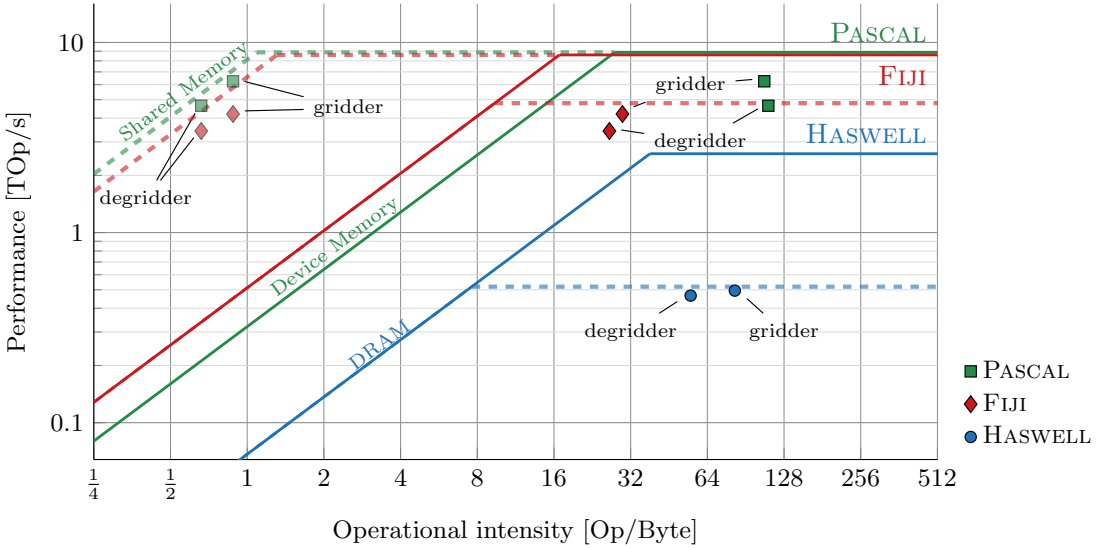
Performance for FMA/sincos instruction mix



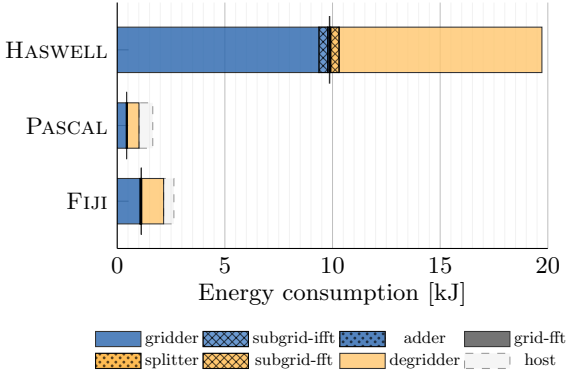
Roofline analysis: instruction mix

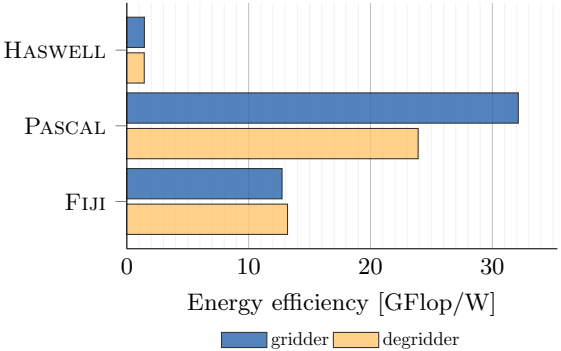


Roofline analysis: shared memory



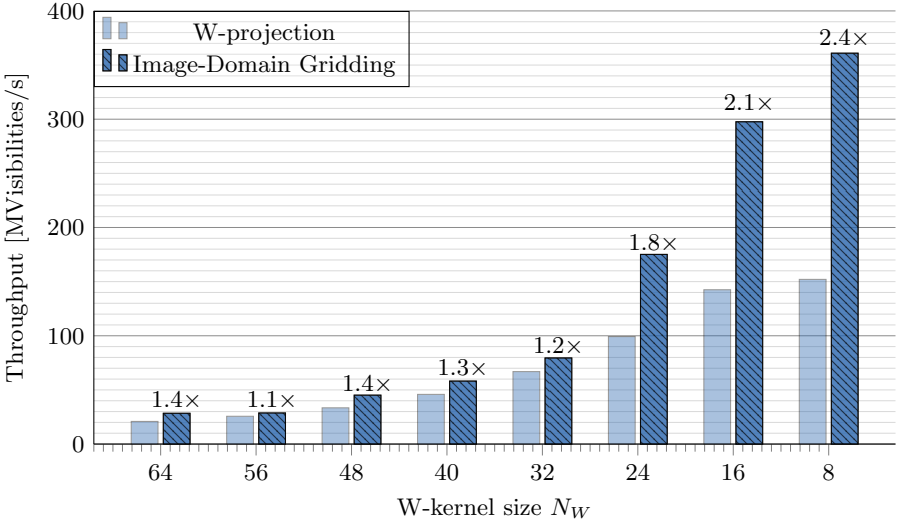
Results: energy consumption/efficiency





- *Most energy spent in gridder/degridder*
- *GPUs perform > order of magnitude better than CPU*

Results: AW-projection at the cost of W-projection



Conclusion

- First implementations of the IDG algorithm on CPUs and GPUs
- First efficient degridding implementation on GPUs ever
- A thorough (roofline) analysis of the achieved performance
- An assessment of energy efficiency

IDG on GPUs is a candidate to meet the demanding computational and energy efficiency constraints imposed by future telescopes such as the Square Kilometre Array (SKA).

Image-Domain Gridding on Graphics Processors,
Bram Veenboer, Matthias Petschow and John. W Romein, IPDPS 2017