Searches for millisecond radio bursts with GPUs on LOFAR

Aris Karastergiou

Pulsars	Flares	GRB
Supernovae	Planets	Scintillation
Inspiraling neutron stars	Black holes	?

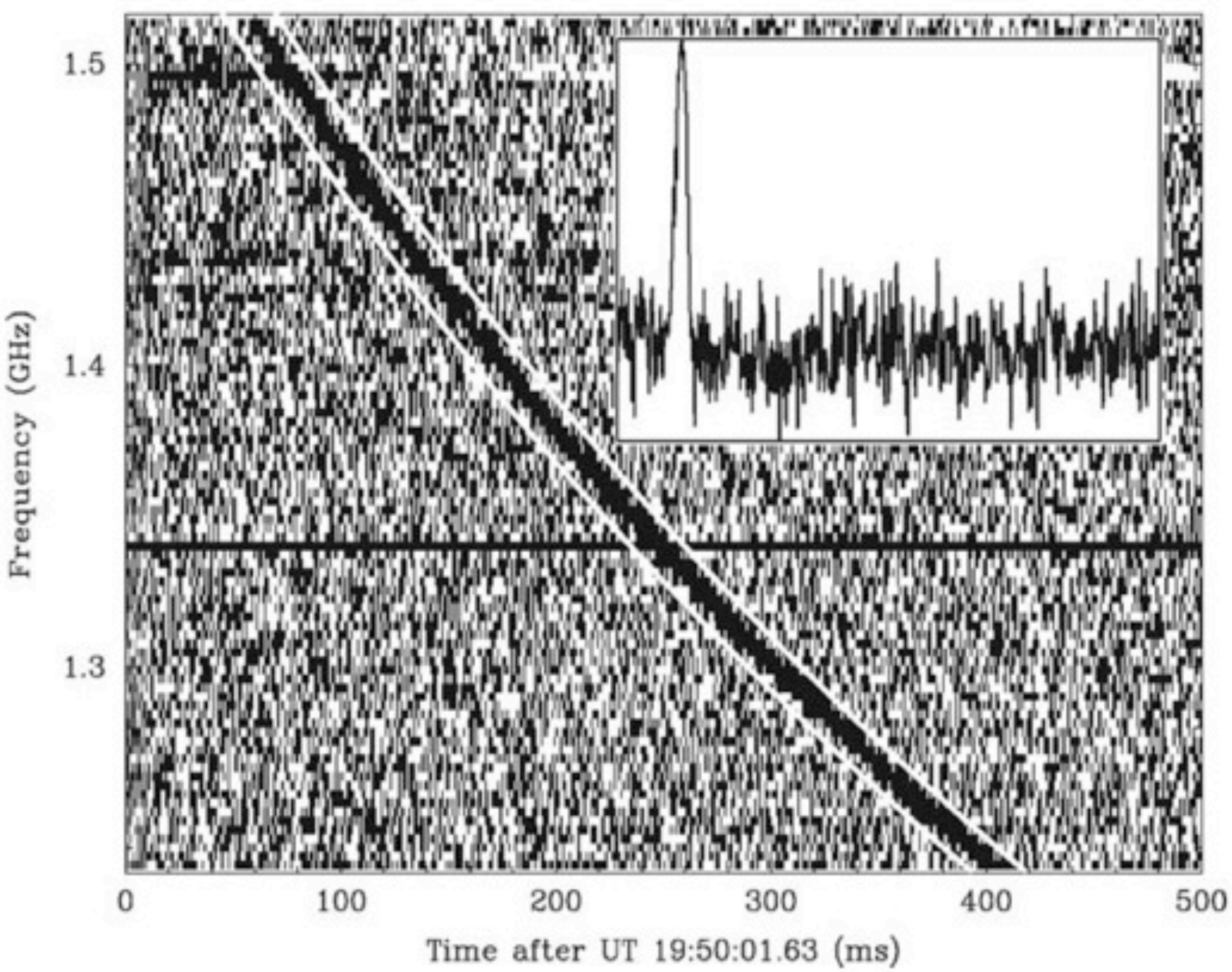
A Bright Millisecond Radio Burst of Extragalactic Origin

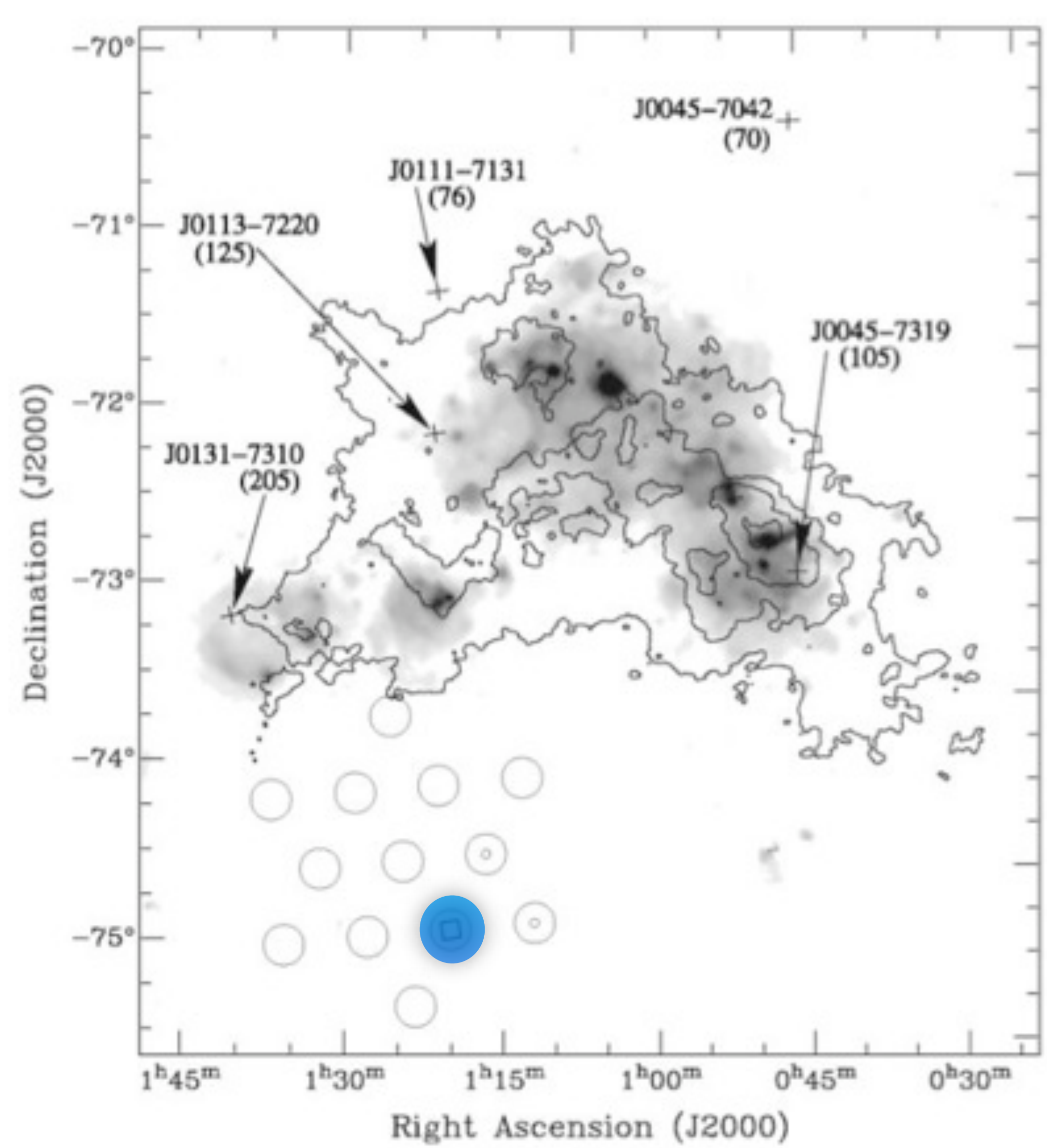
D. R. Lorimer,[1,2]* M. Bailes,[3] M. A. McLaughlin,[1,2] D. J. Narkevic,[1] F. Crawford[4]

Pulsar surveys offer a rare opportunity to monitor the radio sky for impulsive burst-like events with millisecond durations. We analyzed archival survey data and found a 30-jansky dispersed burst, less than 5 milliseconds in duration, located 3° from the Small Magellanic Cloud. The burst properties argue against a physical association with our Galaxy or the Small Magellanic Cloud. Current models for the free electron content in the universe imply that the burst is less than 1 gigaparsec distant. No further bursts were seen in 90 hours of additional observations, which implies that it was a singular event such as a supernova or coalescence of relativistic objects. Hundreds of similar events could occur every day and, if detected, could serve as cosmological probes.

dio burst
rigin

rst





Science of radio transients

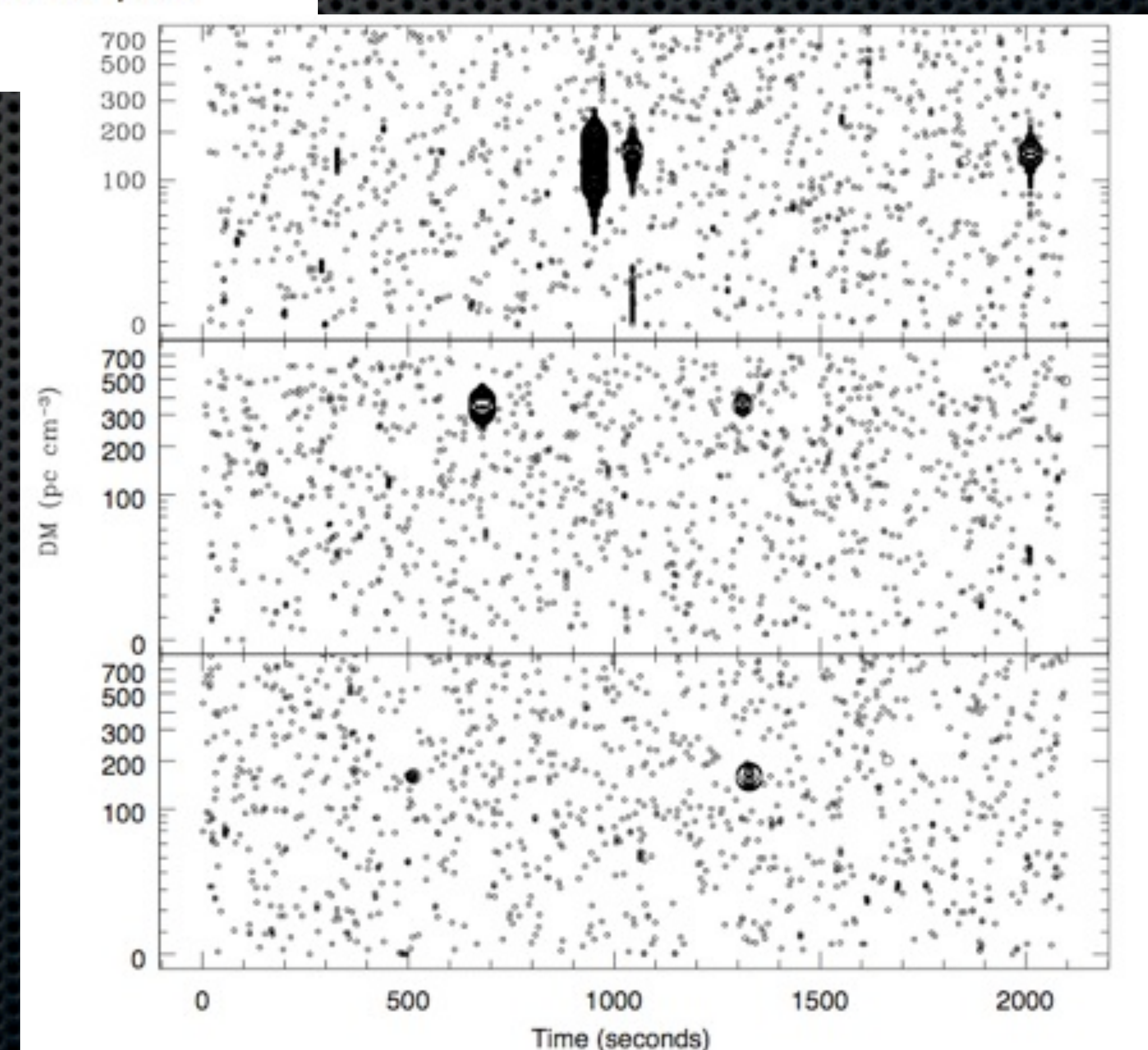
Letter

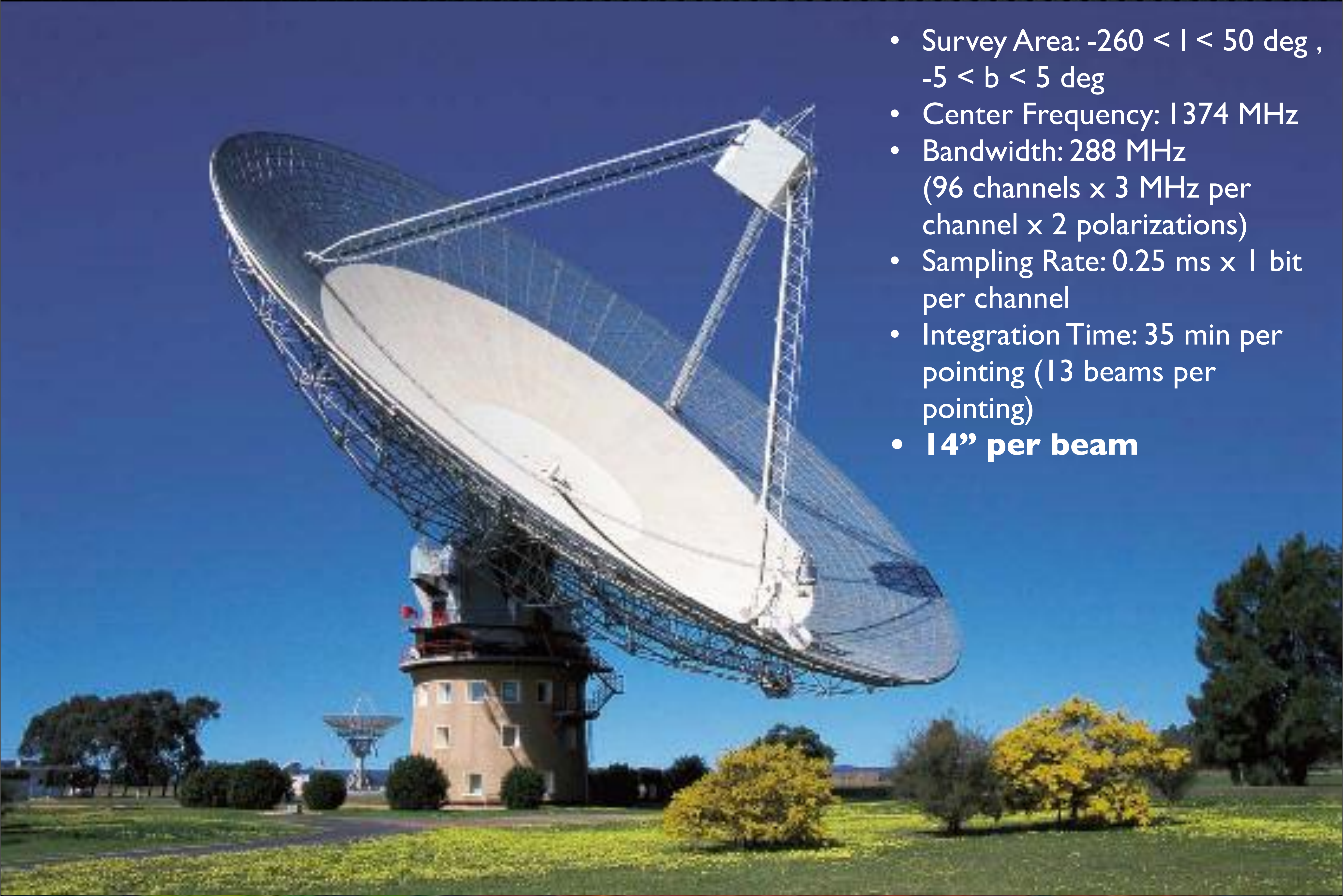
Nature **439**, 817-820 (16 February 2006) | doi:10.1038/nature04440

Transient radio bursts from rotating neutron stars

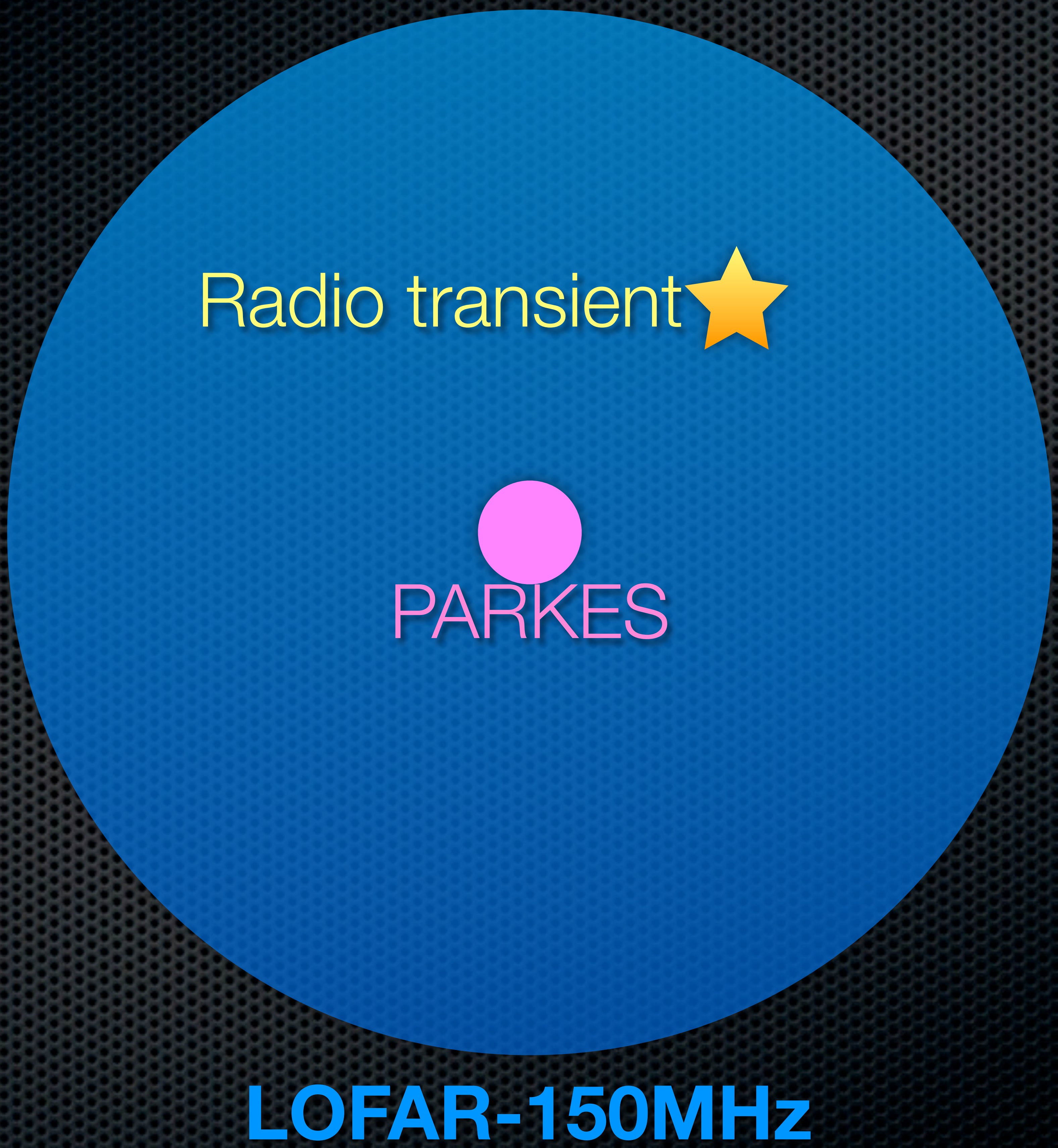
M. A. McLaughlin[1], A. G. Lyne[1], D. R. Lorimer[1], M. Kramer[1], A. J. Faulkner[1], R. N. Manchester[2], J. M. Cordes[3], F. Camilo[4], A. Possenti[5], I. H. Stairs[6], G. Hobbs[2], N. D'Amico[5,7], M. Burgay[5] and J. T. O'Brien[1]

Isolated bright bursts from neutron stars, not obviously periodic, found through individual pulse search



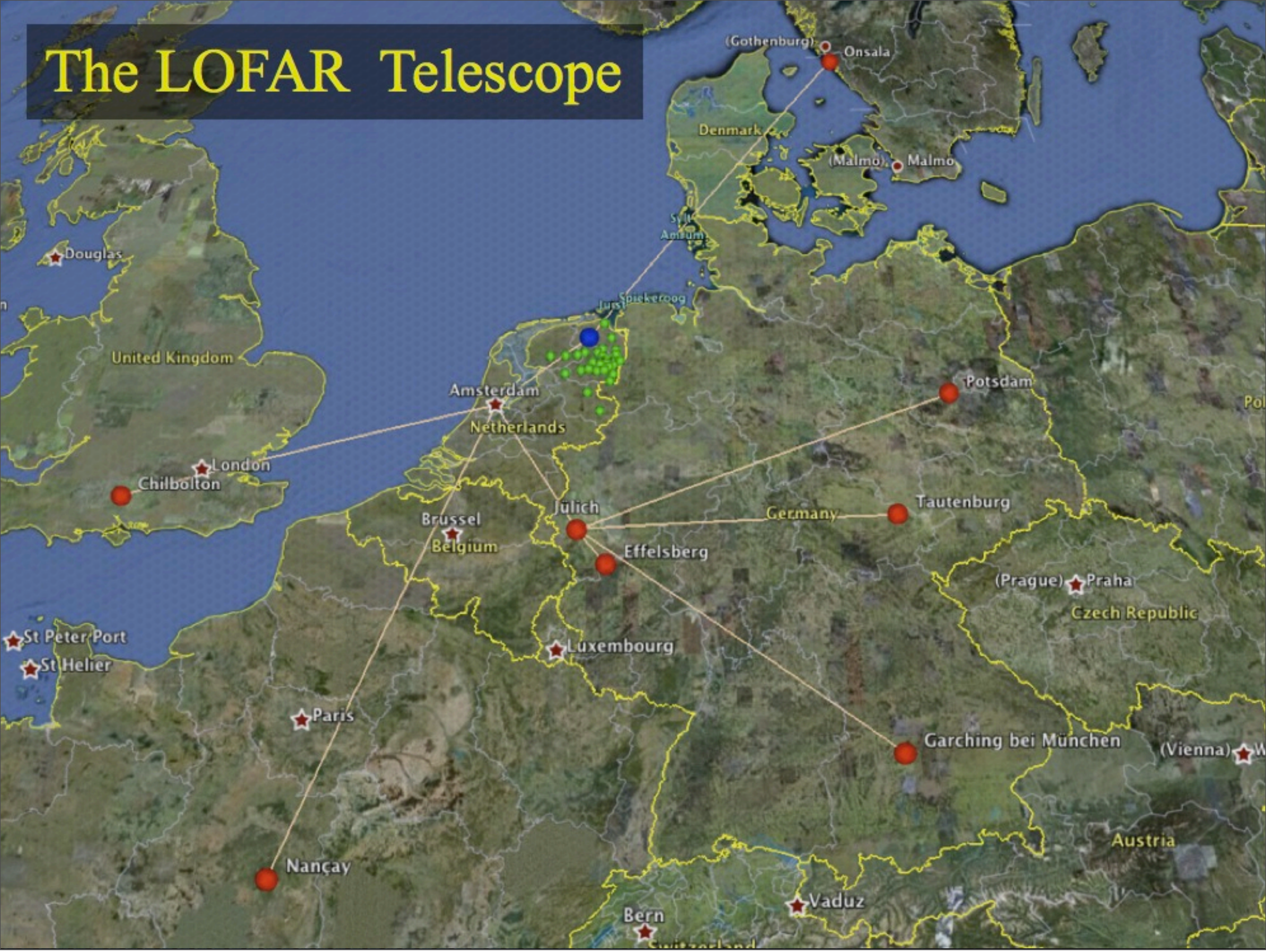


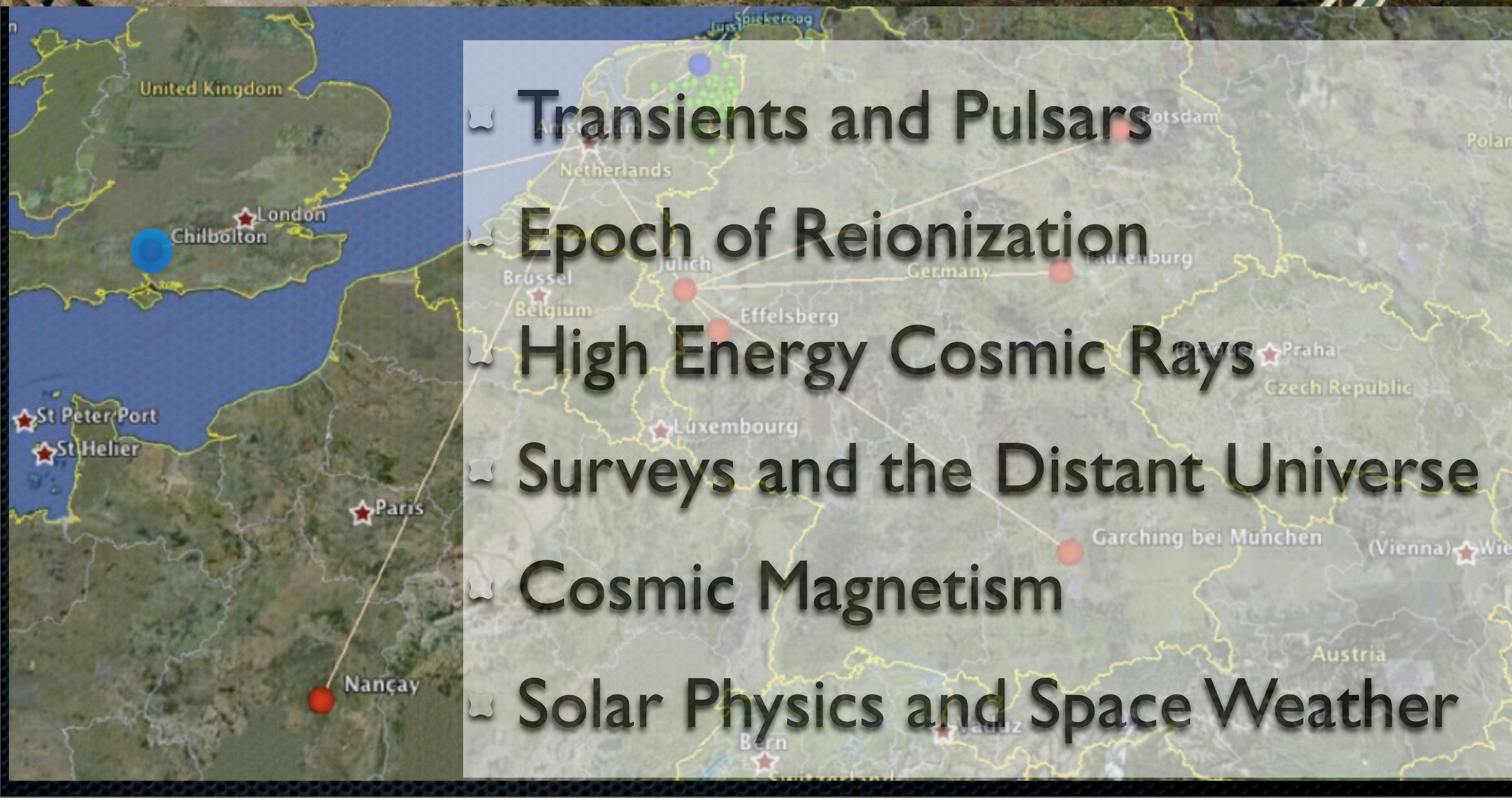
- Survey Area: -260 < l < 50 deg , -5 < b < 5 deg
- Center Frequency: 1374 MHz
- Bandwidth: 288 MHz (96 channels x 3 MHz per channel x 2 polarizations)
- Sampling Rate: 0.25 ms x 1 bit per channel
- Integration Time: 35 min per pointing (13 beams per pointing)
- **14” per beam**


Radio transient
PARKES
LOFAR-150MHz


Radio transient
PARKES
LOFAR-150MHz
Radio transient
PARKES
LOFAR-150MHz
Radio transient
PARKES
LOFAR-150MHz
Radio transient
PARKES
LOFAR-150MHz
Radio transient
PARKES
LOFAR-150MHz
Radio transient
PARKES
LOFAR-150MHz
Radio transient
PARKES
LOFAR-150MHz
Radio transient
PARKES
LOFAR-150MHz

The LOFAR Telescope

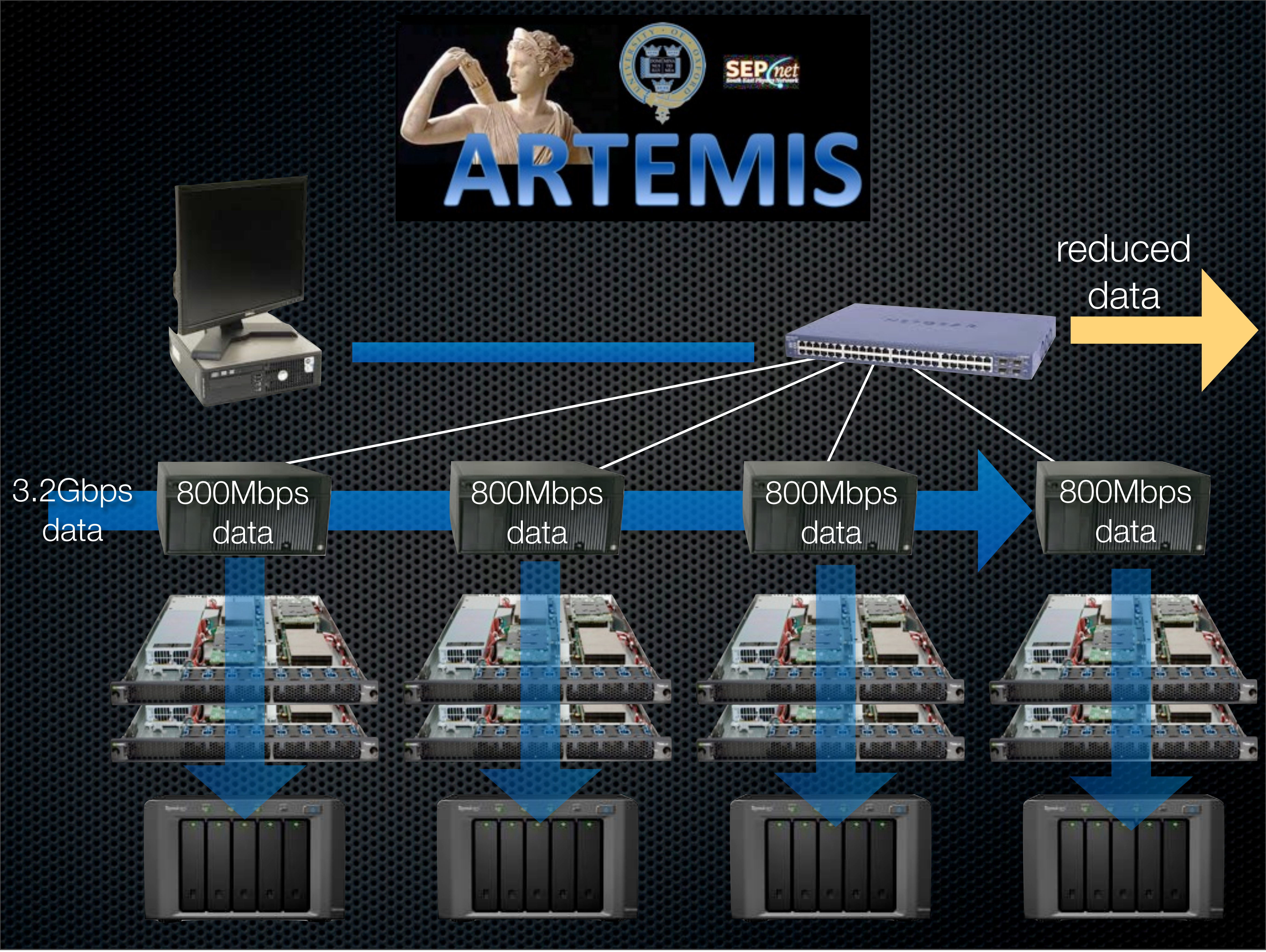




- Transients and Pulsars
- Epoch of Reionization
- High Energy Cosmic Rays
- Surveys and the Distant Universe
- Cosmic Magnetism
- Solar Physics and Space Weather

LOFAR international stations

- Large collecting area (96 coherently added dipoles), high sensitivity. 9 (+3) international stations, equivalent to 50m dishes
- Very fast sampling rate, 5.12μs data
- Large fields of view, 10 to 100s of square degrees
- Can be used for continuous monitoring of large parts of sky

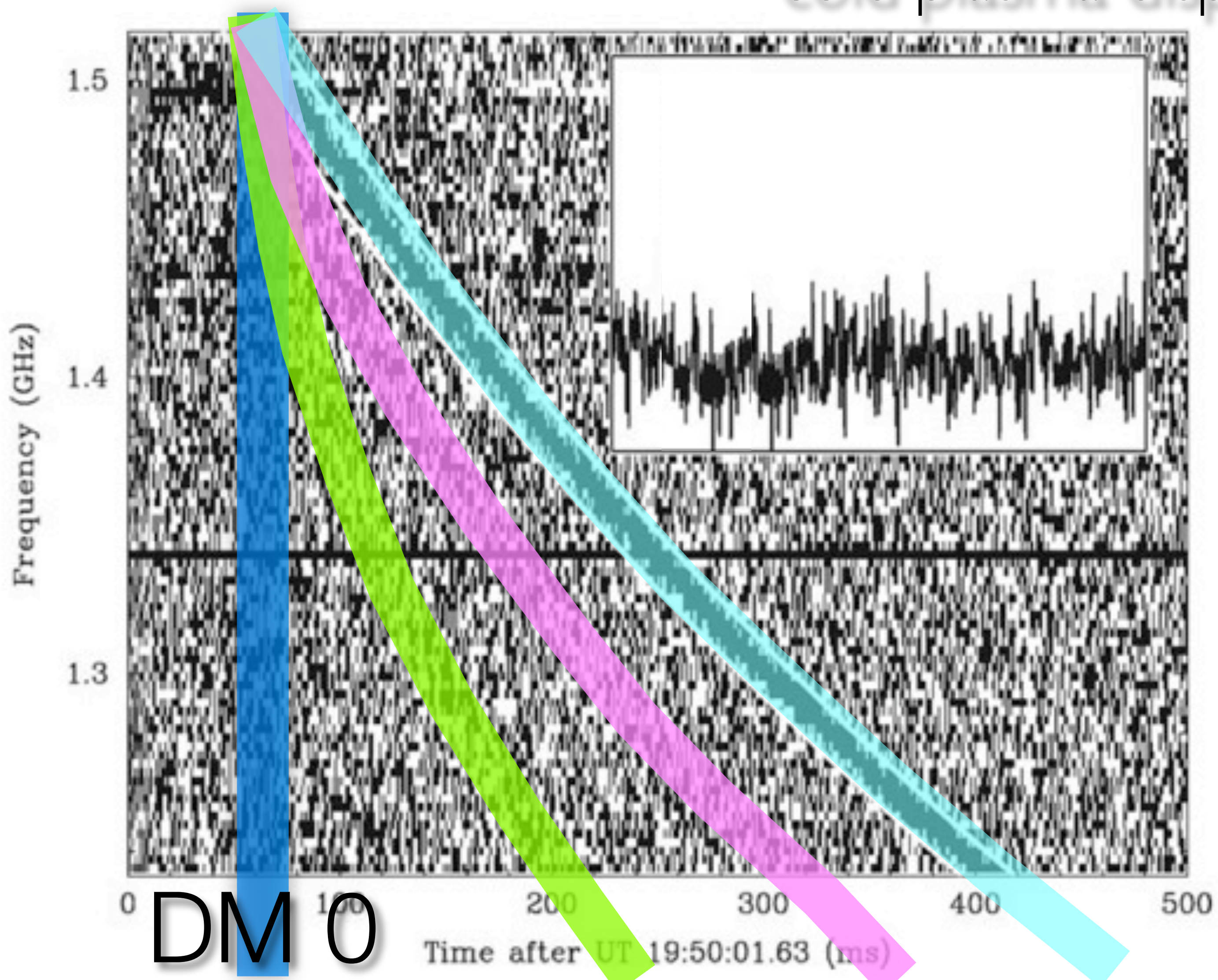

ARTEMIS
SEPnet
reduced data
3.2Gbps data
800Mbps data
800Mbps data
800Mbps data
800Mbps data

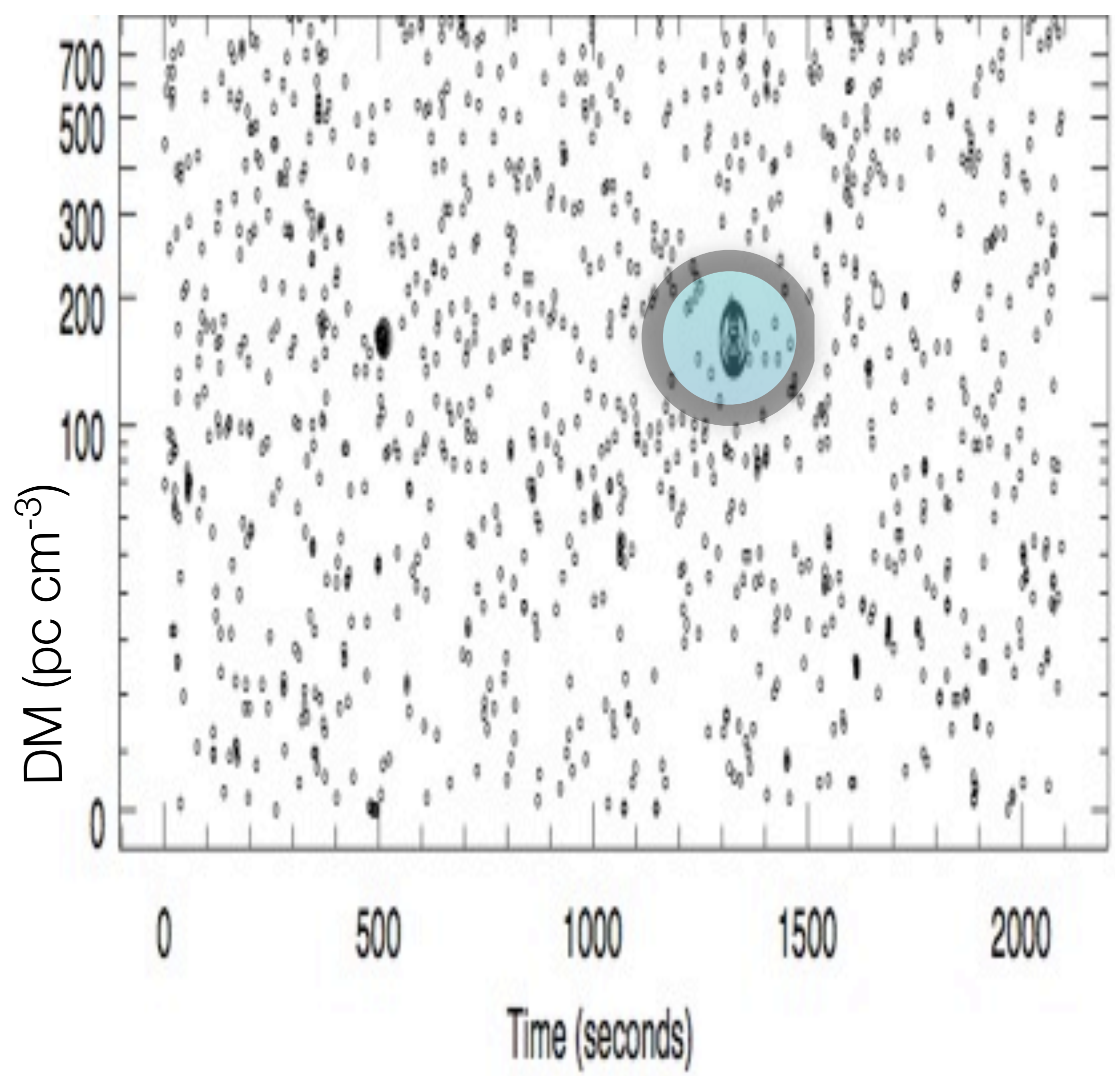
Brute-force dedispersion

$$\mathrm{DM} = \int_0^d n_\mathrm{e}\,\mathrm{d}l$$

$$\Delta t \simeq 4.15 \times 10^6\ \mathrm{ms}\ \times (f_1^{-2} - f_2^{-2}) \times \mathrm{DM}$$

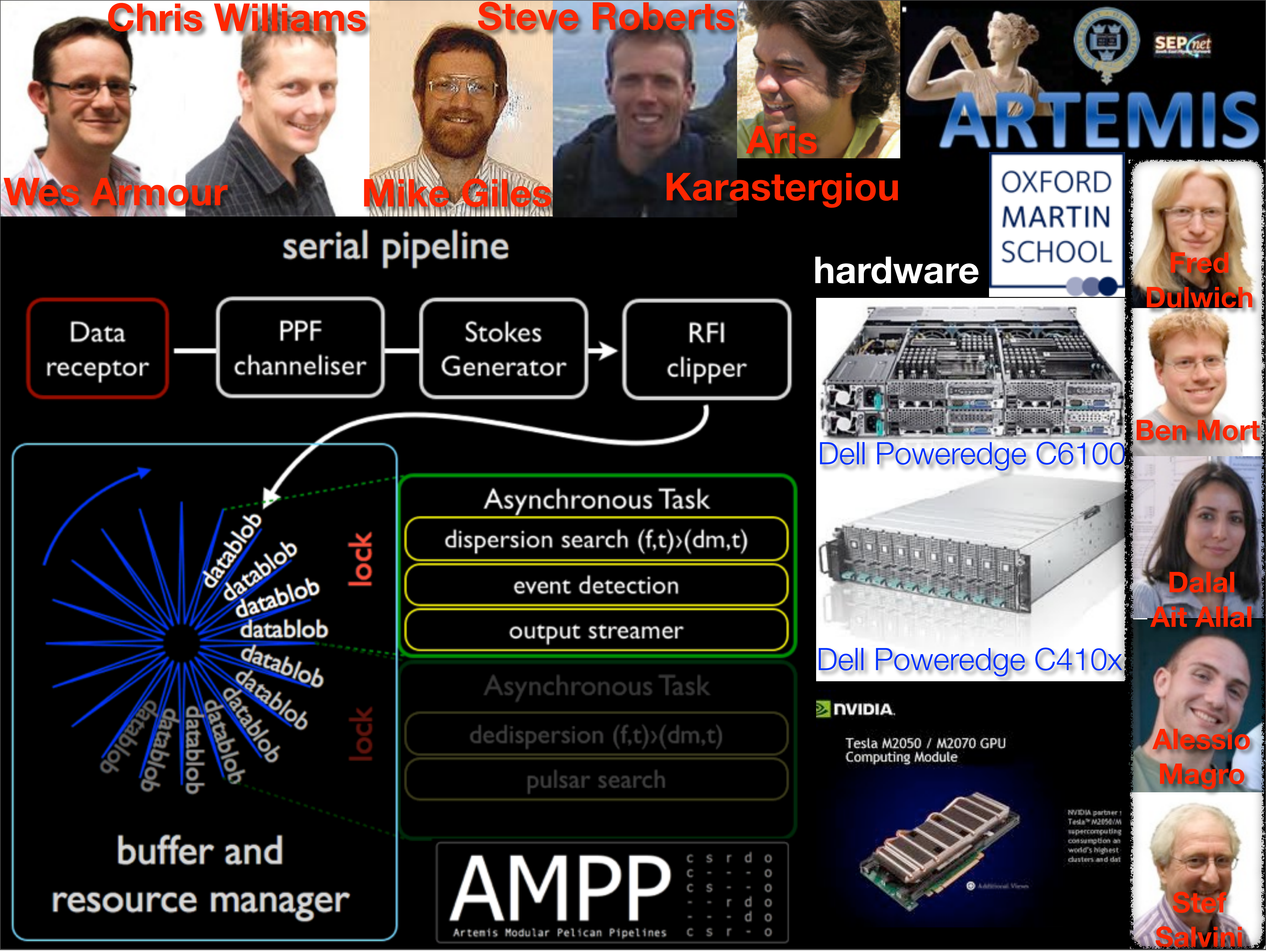
cold plasma dispersion law





1-bit data from **filterbank** spectrometer

N^2 process per time sample (100**μs**)


Chris Williams
Steve Roberts
Wes Armour
Mike Giles
Aris Karastergiou
ARTEMIS
SEPnet
OXFORD MARTIN SCHOOL
Fred Dulwich
Ben Mort
Dalal Ait Allal
Alessio Magro
Stef Salvini
serial pipeline
Data receptor
PPF channeliser
Stokes Generator
RFI clipper
datablob
lock
Asynchronous Task
dispersion search (f,t)›(dm,t)
event detection
output streamer
Asynchronous Task
dedispersion (f,t)›(dm,t)
pulsar search
buffer and resource manager
AMPP
Artemis Modular Pelican Pipelines
hardware
Dell Poweredge C6100
Dell Poweredge C410x
NVIDIA
Tesla M2050 / M2070 GPU Computing Module

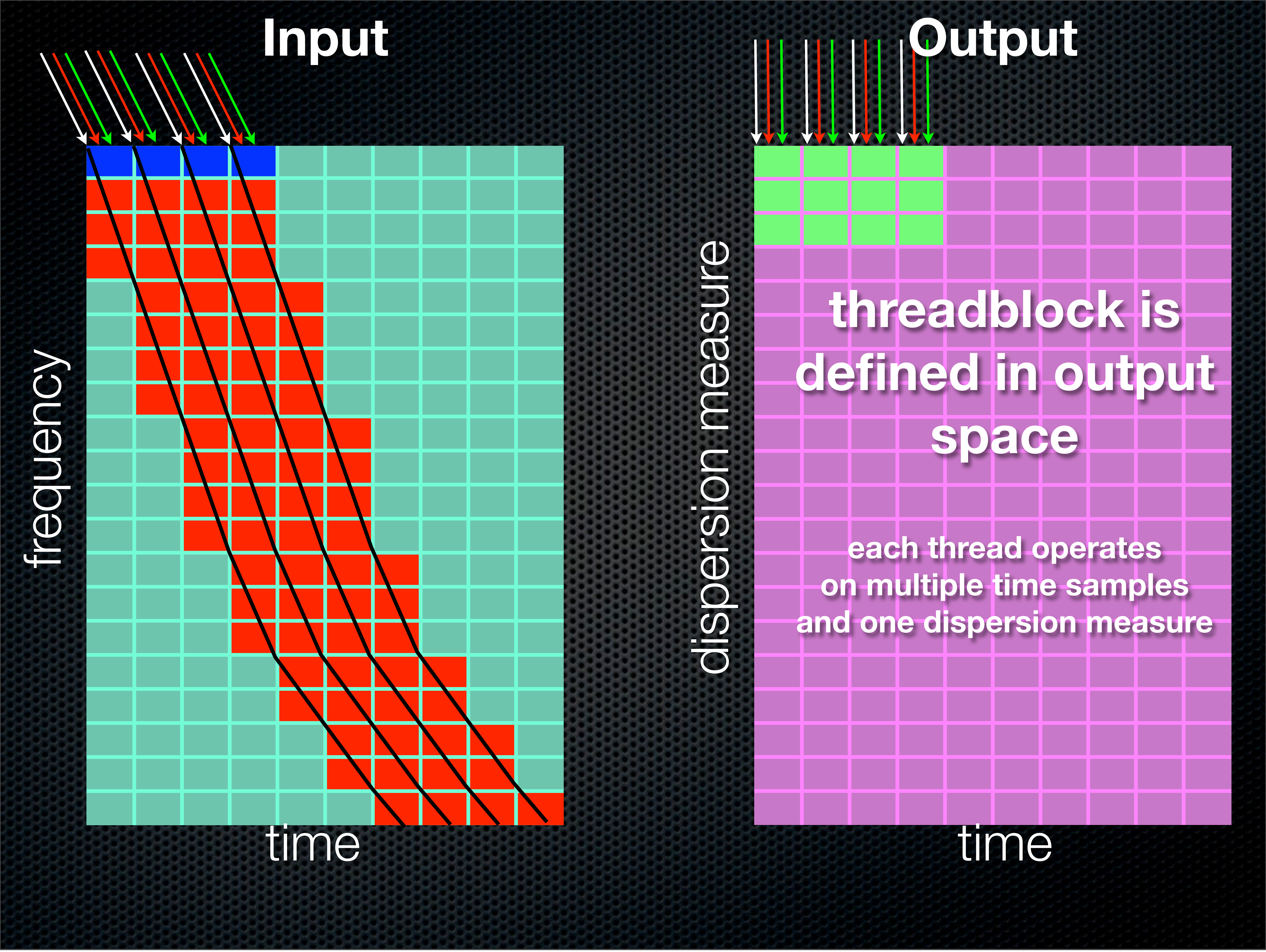
Optimisation:

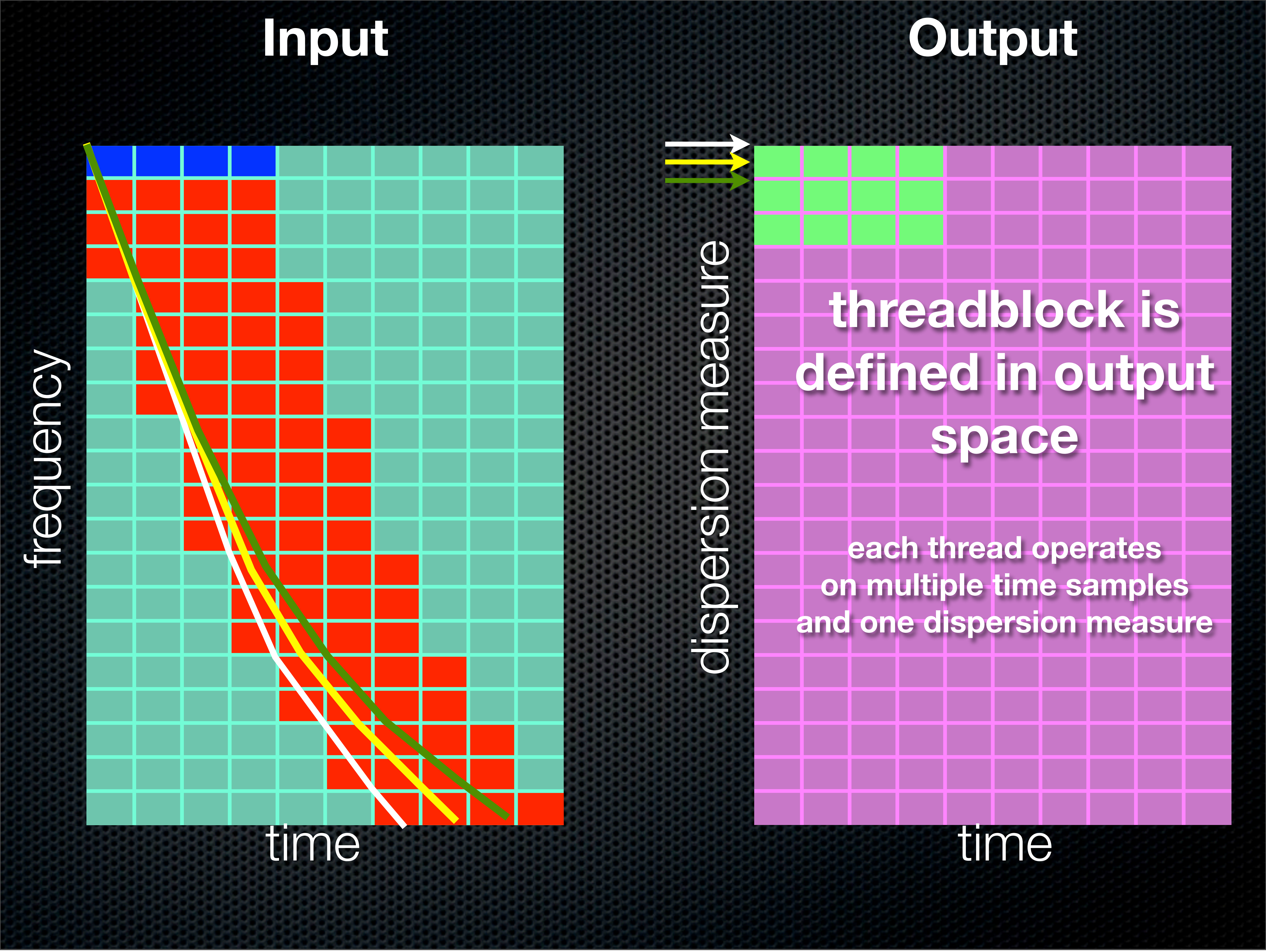
memory size:IOs

fast memory

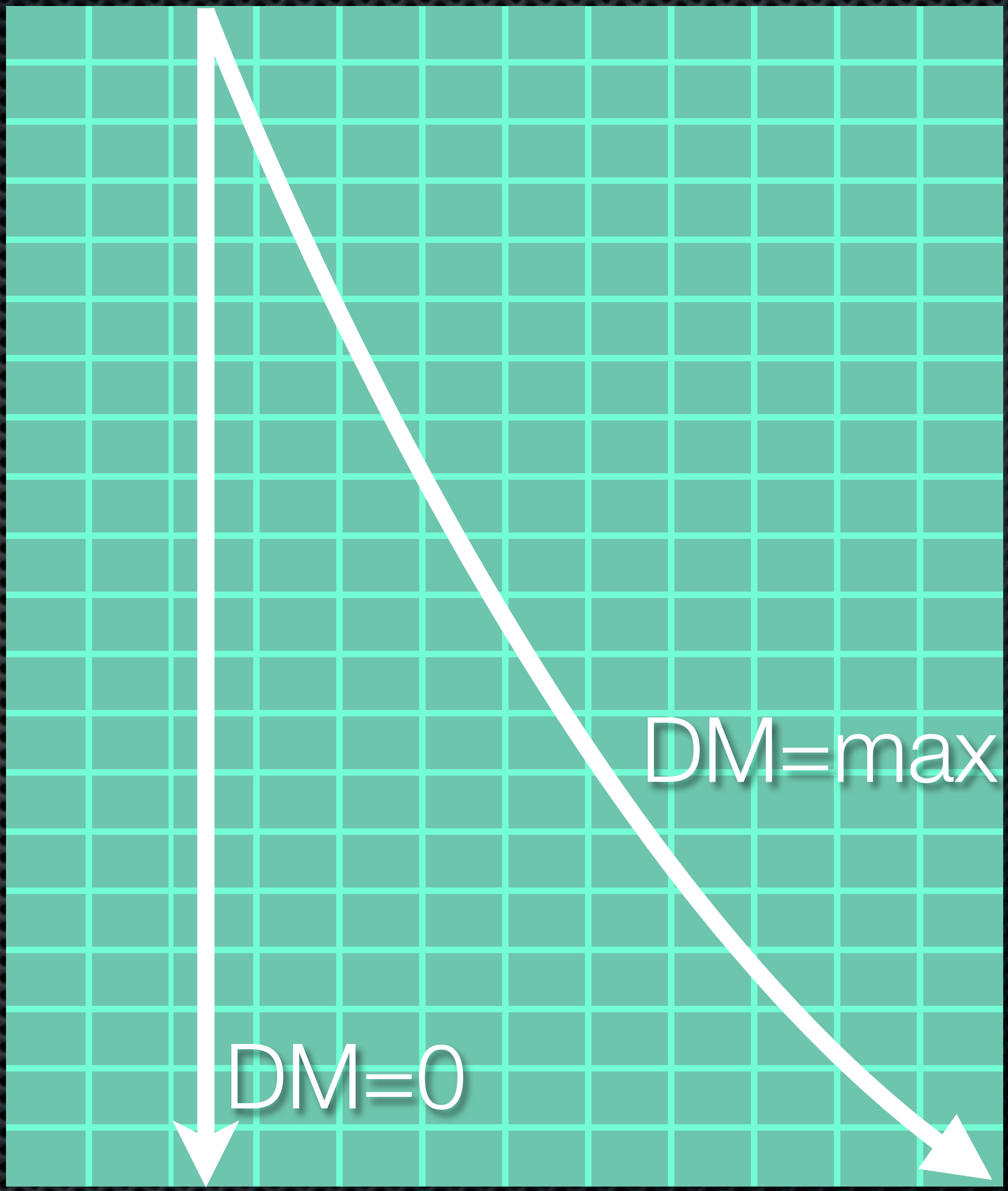
data reuse

thread occupancy


Input
Output
frequency
time
dispersion measure
threadblock is defined in output space
each thread operates on multiple time samples and one dispersion measure
time

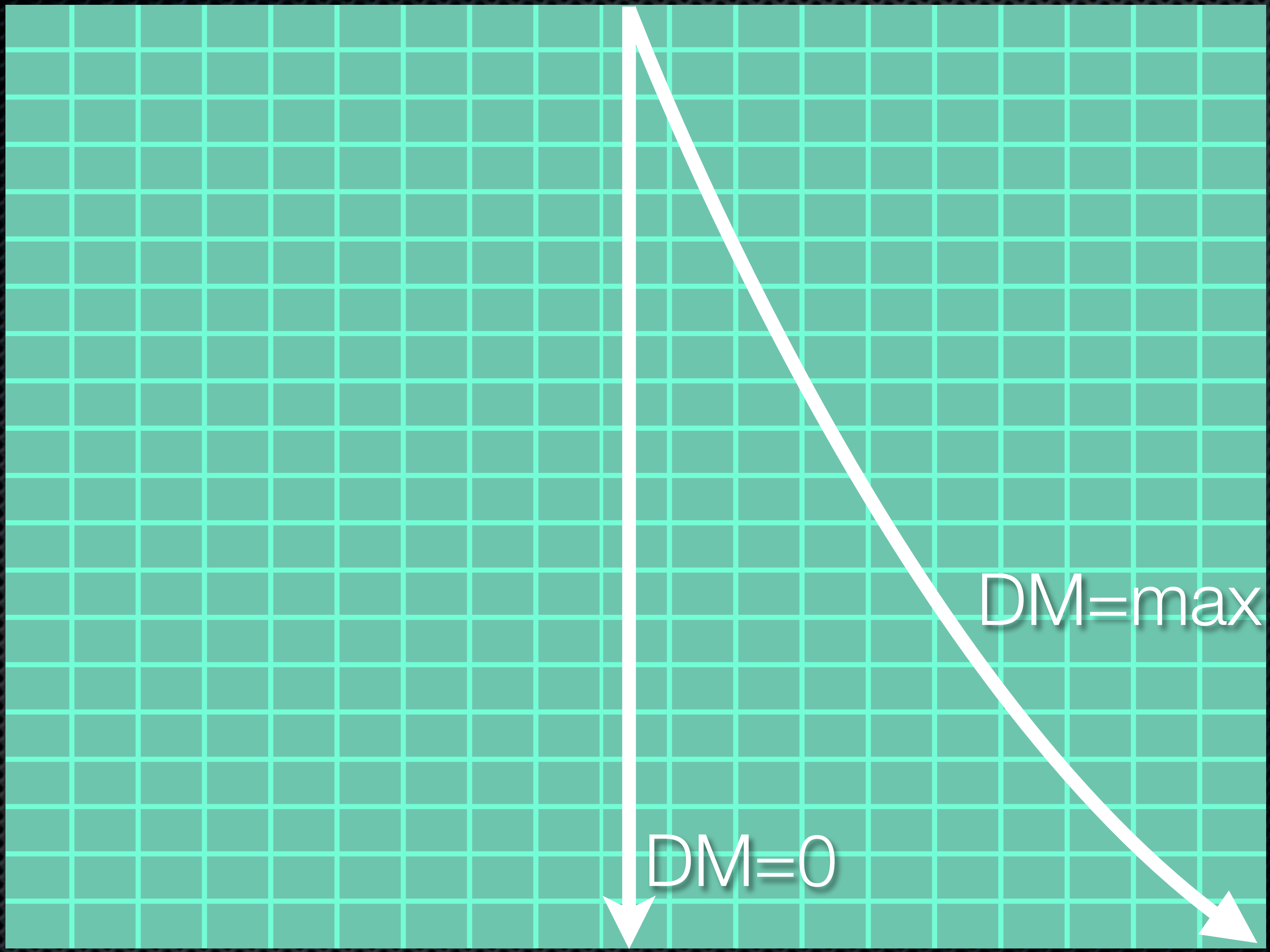

Input
Output
frequency
time
dispersion measure
threadblock is defined in output space
each thread operates on multiple time samples and one dispersion measure
time

Input



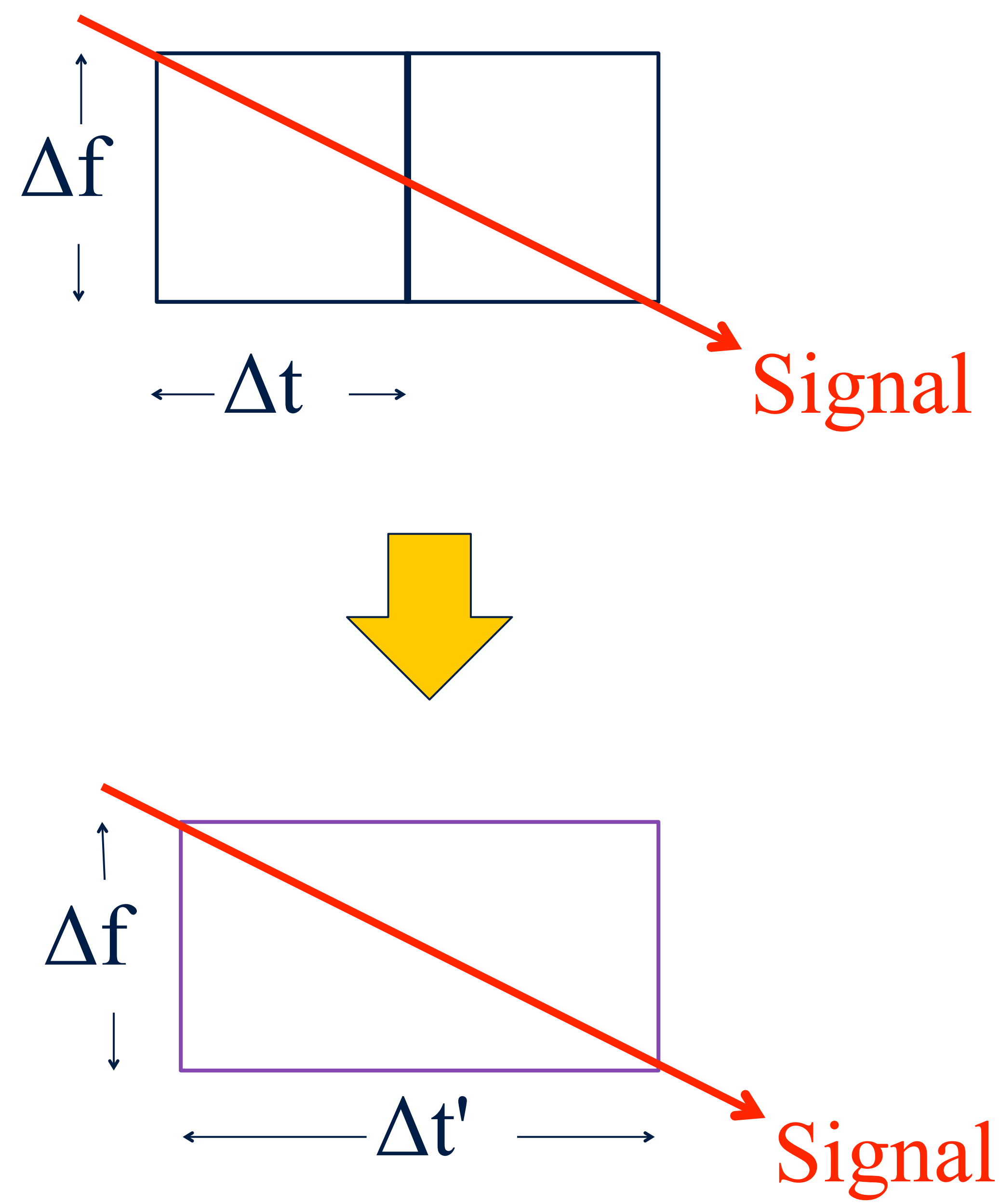
time

Input

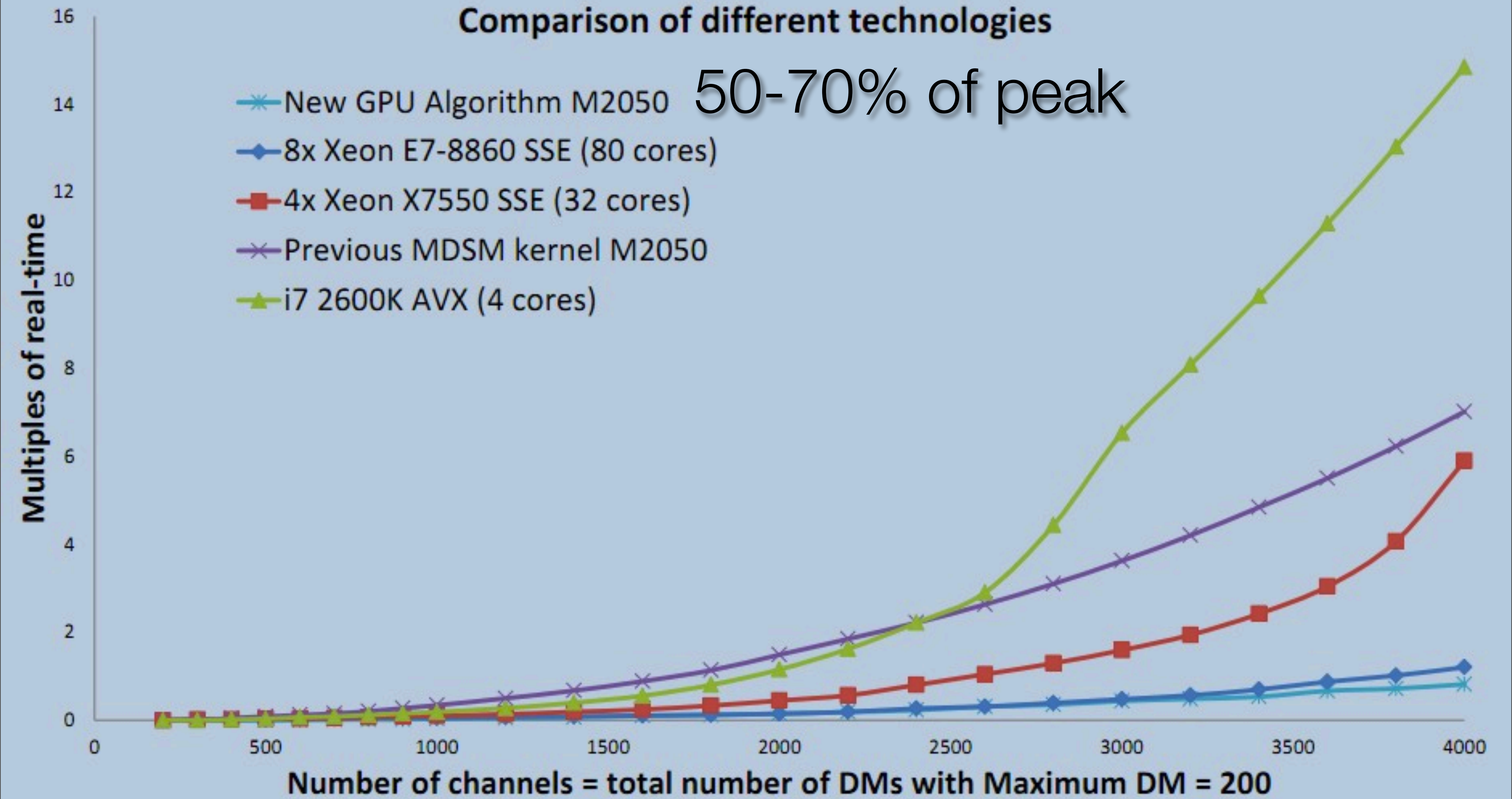


time

Additional optimisation



CPUs, GPUs...

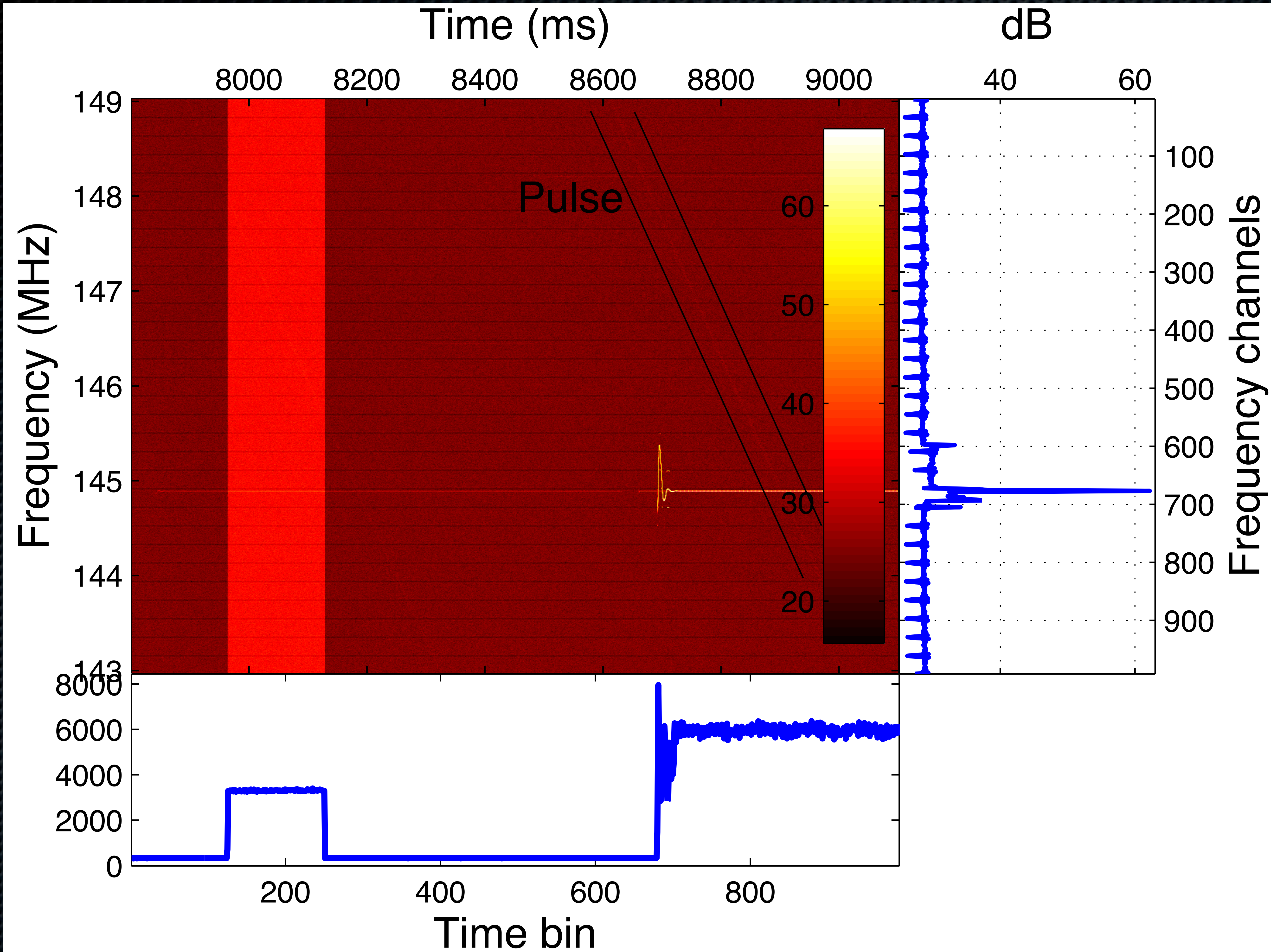


50-70% of peak

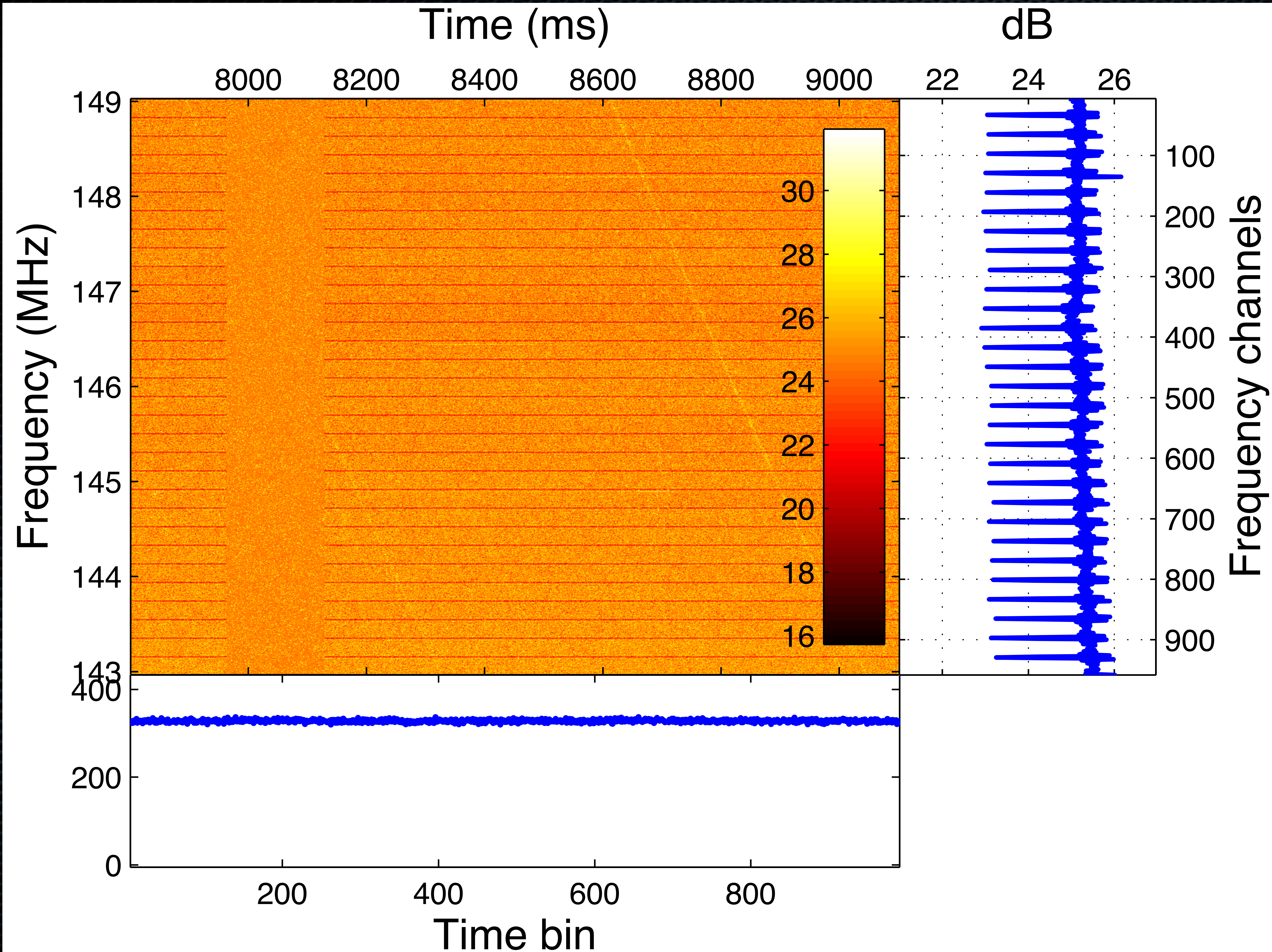
Wes Armour

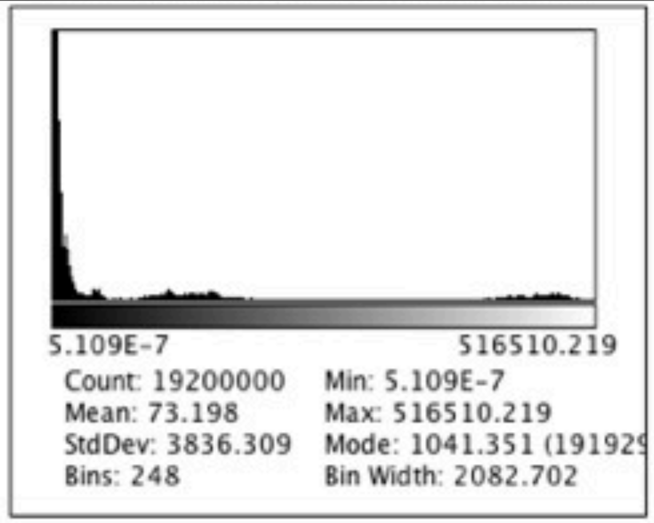
GPU de-dispersion : http://www.oerc.ox.ac.uk/research/wes

ARTEMIS: http://www.oerc.ox.ac.uk/research/artemis



Time (ms)
8000
8200
8400
8600
8800
9000
dB
40
60
149
148
147
146
145
144
143
Frequency (MHz)
Pulse
60
50
40
30
20
100
200
300
400
500
600
700
800
900
Frequency channels
8000
6000
4000
2000
0
200
400
600
800
Time bin


Time (ms)
8000
8200
8400
8600
8800
9000
dB
22
24
26
149
148
147
146
145
144
143
Frequency (MHz)
30
28
26
24
22
20
18
16
100
200
300
400
500
600
700
800
900
Frequency channels
400
200
0
200
400
600
800
Time bin

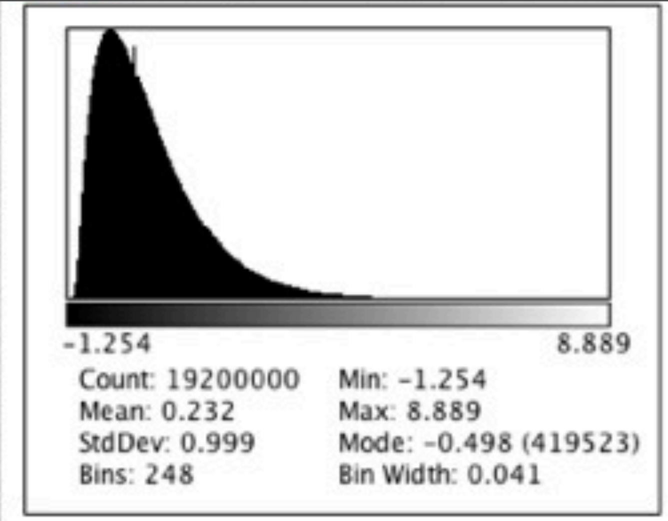


filterbank noise pre-filtering

dynamic noise modelling

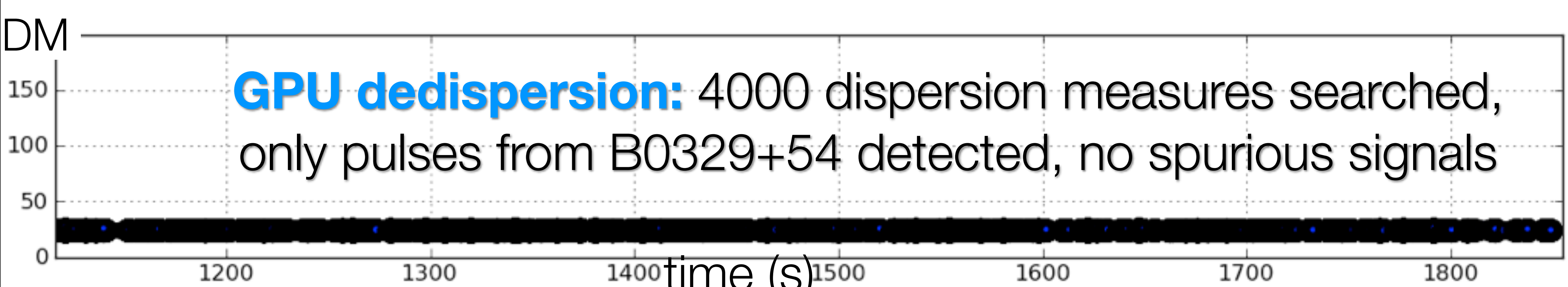
→

for effective RFI removal and transient detection



filterbank noise post-filtering

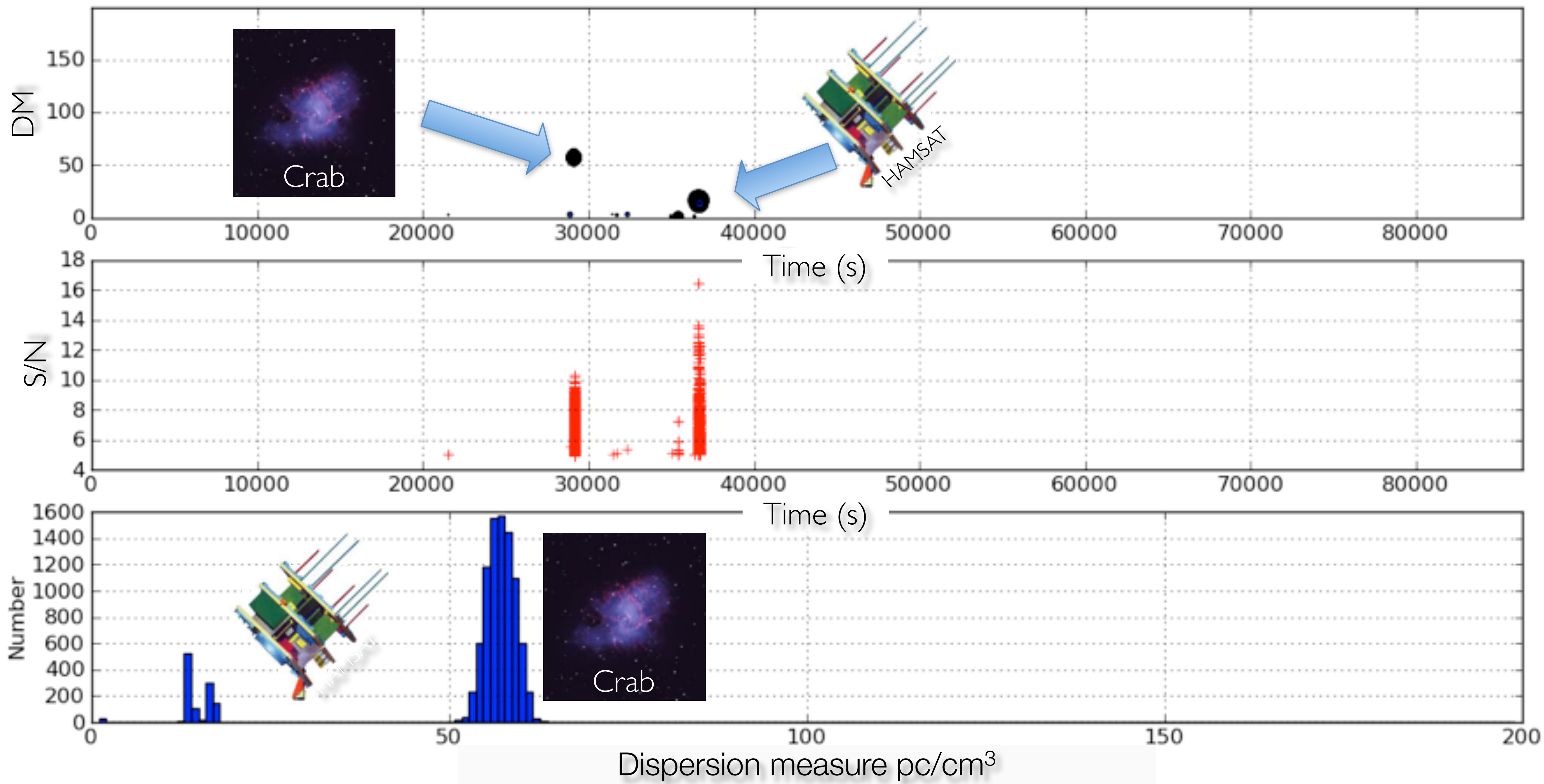
GPU dedispersion: 4000 dispersion measures searched, only pulses from B0329+54 detected, no spurious signals



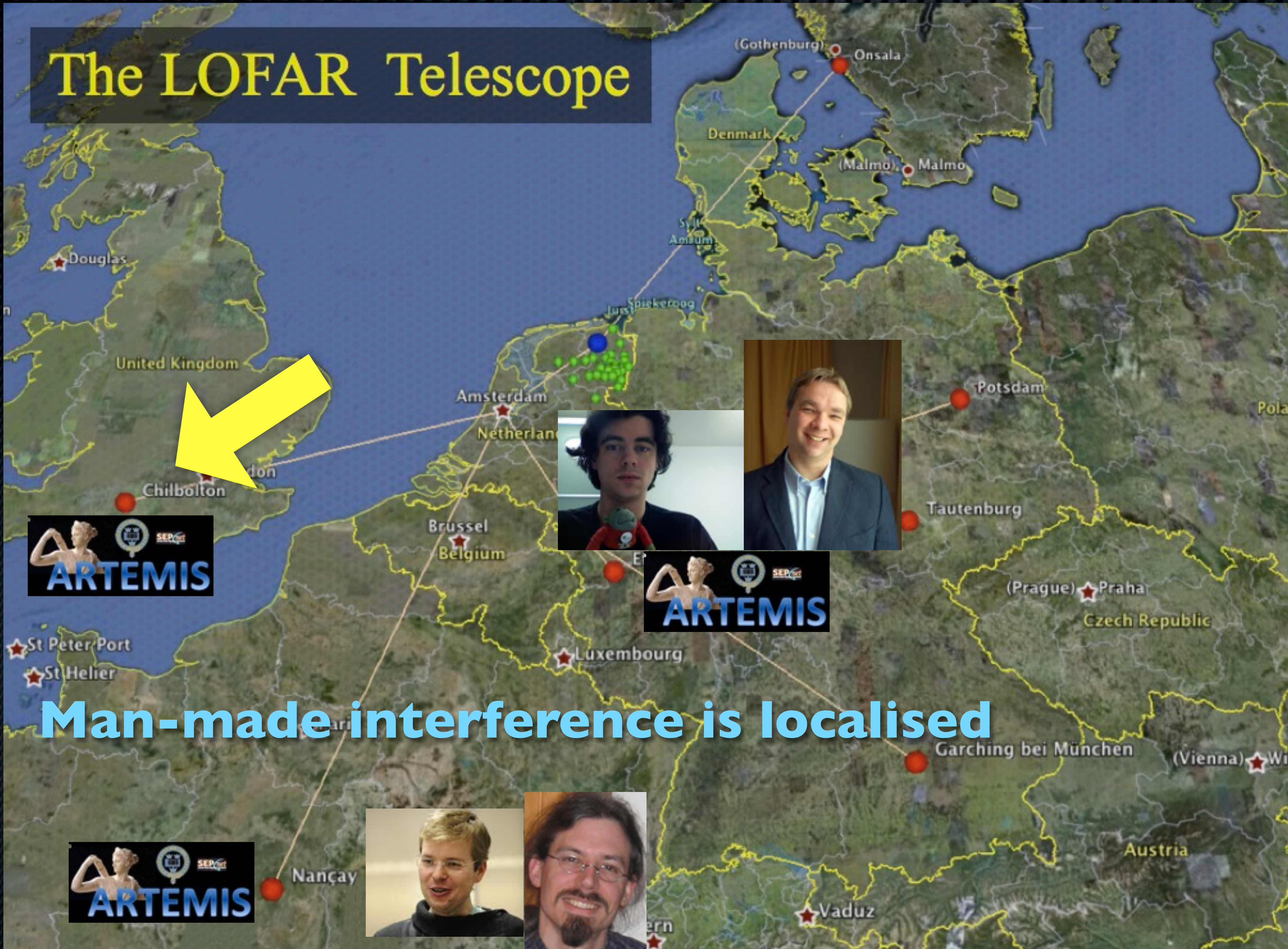
Karastergiou et al. 2012

- Working prototype for non-image processing
- Real-time searches for Individual Radio Pulses using CPU/GPU
- Dedispersion over 4000 DMs per beam in real time with GPUs
- Pilot survey 1: 8 beams tracking circumpolar targets
- Pilot survey 2: 8 beams fixed on the meridian from 8° to 28° dec

Pipeline diagnostic plot from Pilot survey – daily summary from one of six beams



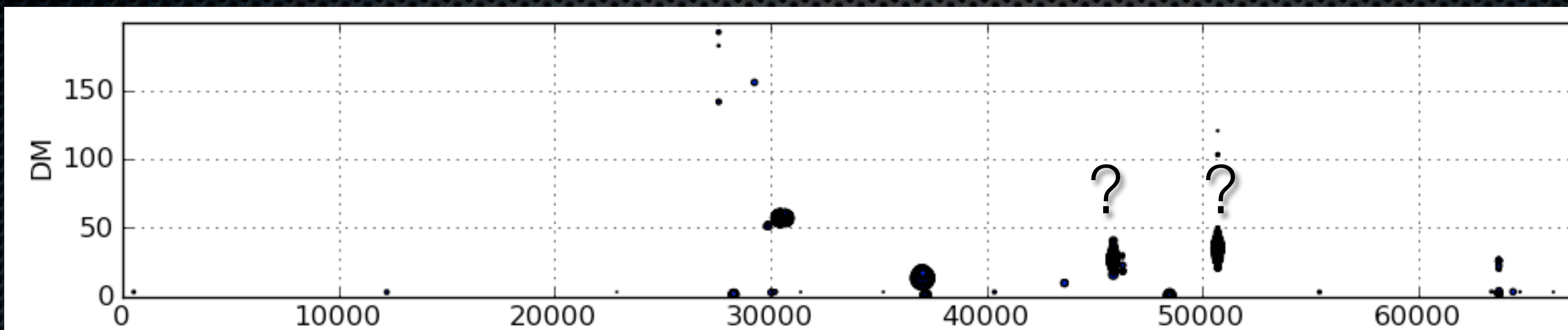
The LOFAR Telescope



Man-made interference is localised

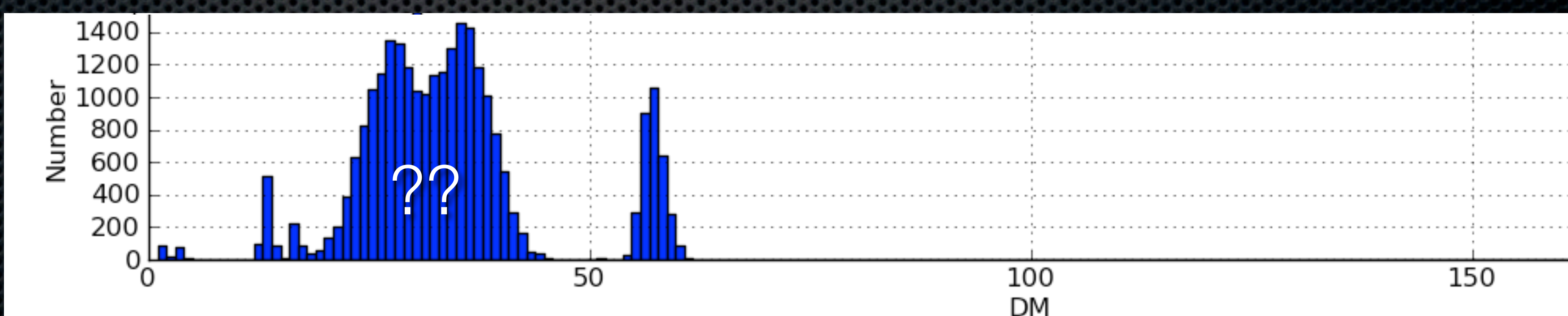
ARTEMIS

- Real time detection system which would easily detect RRATs and Lorimer burst as they happened.
- Affordable and scalable hardware
- Fastest ever dedispersion code on NVIDIA GPU
- RFI rejection performing well in very contaminated environment

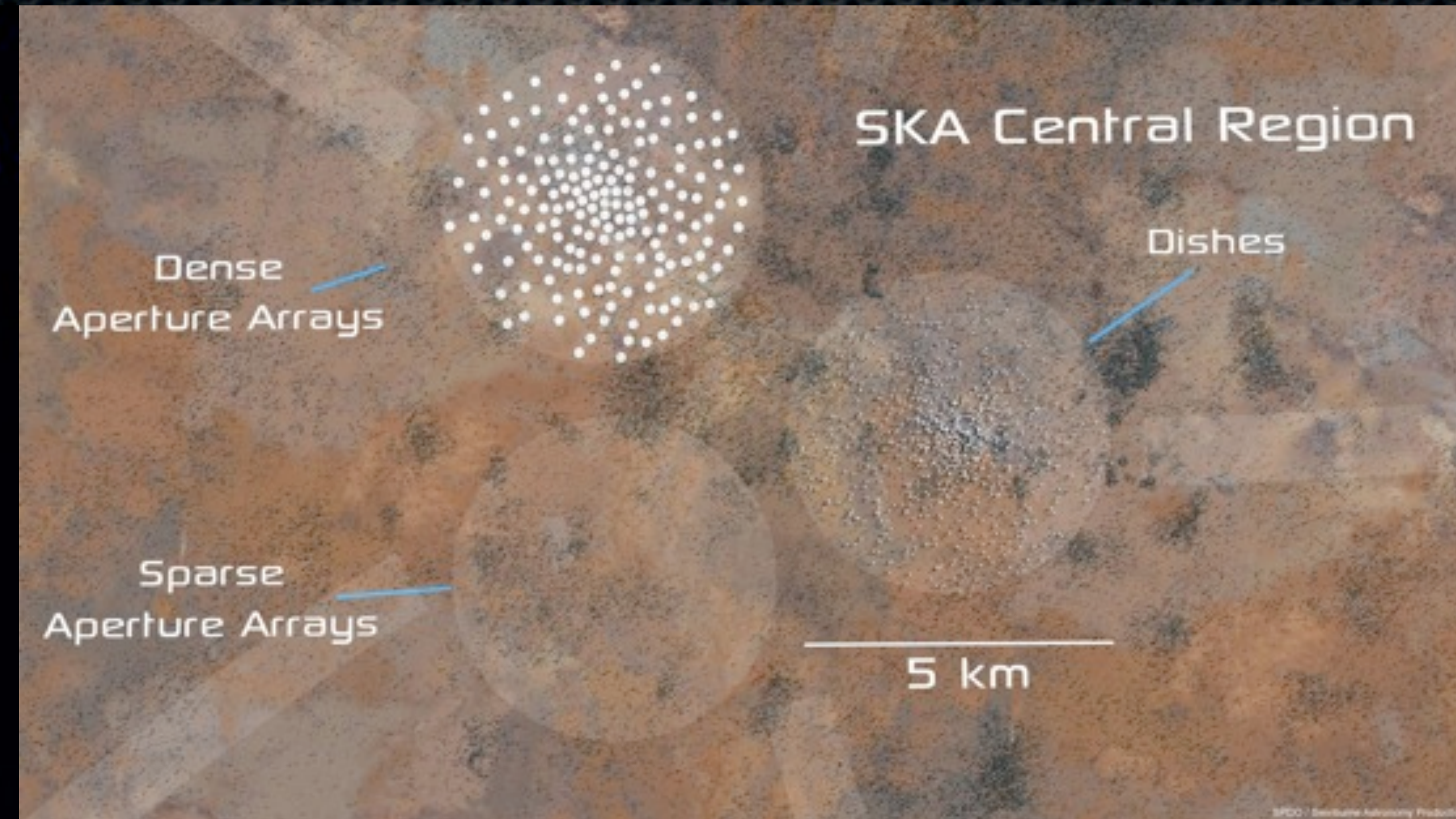


26 December 2011

drift scan with beam at Dec=+21°



The future



Number of ~1 Gbps beams to process:

LOFAR: ~10-200
MeerKAT: ~500
SKA: x10000

Processing will including folding, to search for periodic signals from pulsars

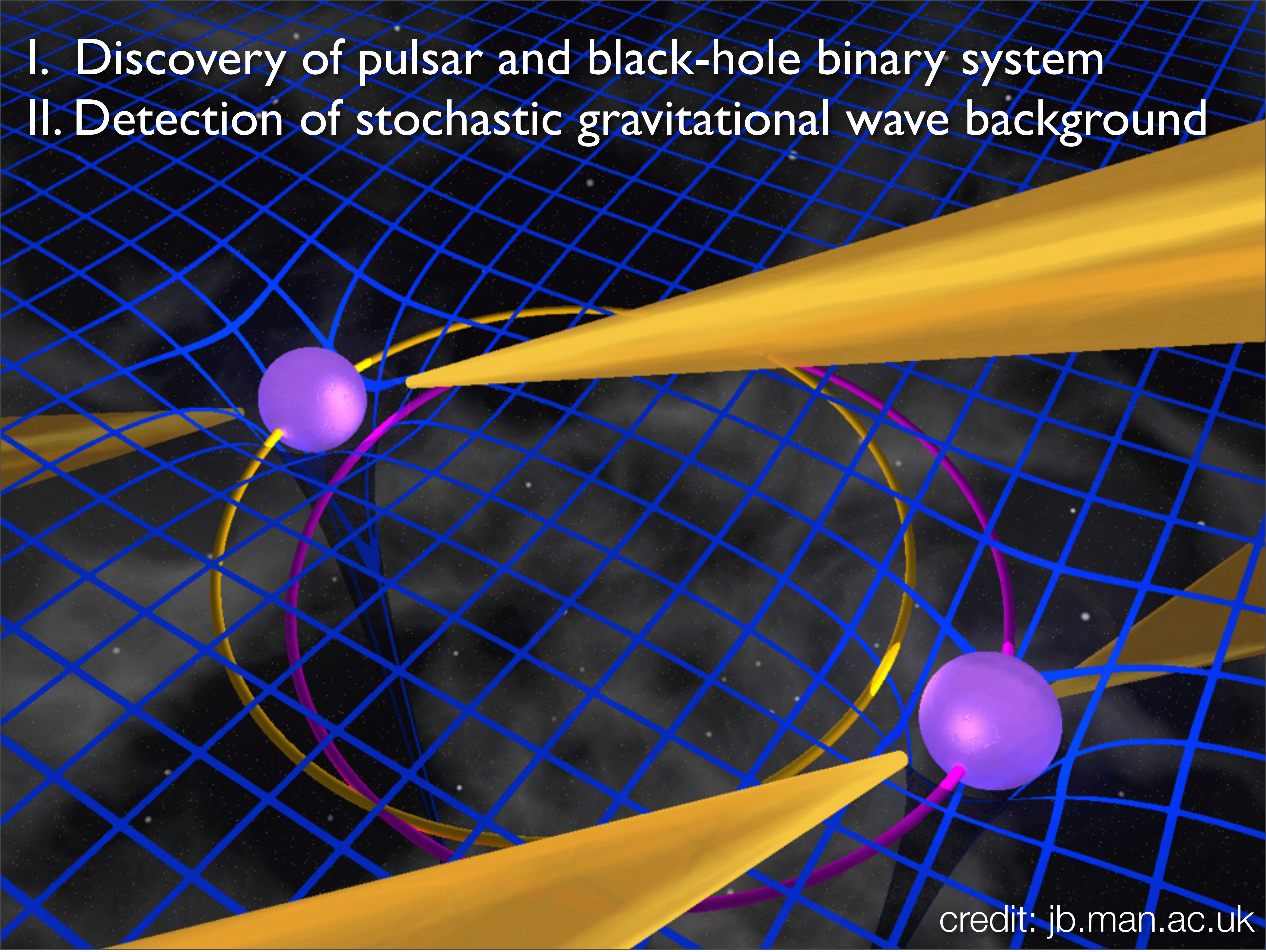
SKA

SQUARE KILOMETRE ARRAY

www.skatelescope.org

The Square Kilometre Array

I. Discovery of pulsar and black-hole binary system
II. Detection of stochastic gravitational wave background



credit: jb.man.ac.uk

Thank you