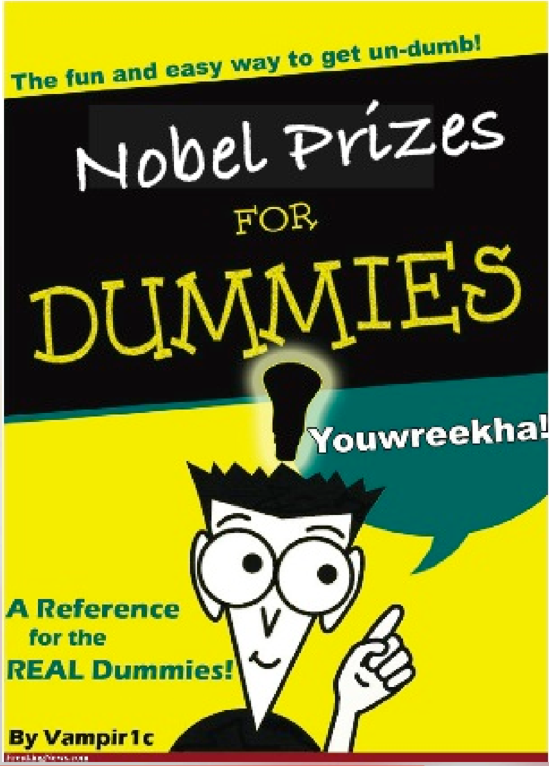
ICRAR

International Centre for Radio Astronomy Research

Transients

Jean-Pierre Macquart



Curtin University

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Pulsars and transients

...though similar, require subtly different detection strategies

– You cannot
  – trade integration time for instantaneous sensitivity on a transient
  – [usefully] perform a Fourier periodicity search on a transient
  – deduce its position to sufficient precision to be useful unless multiple stations observe it
  – verify it after the fact unless you have buffers holding station voltages

– The single greatest specifications driven by transients are
  - access to pre-correlation datastream
    – to enable high time resolution
  - a sizeable voltage-stream buffer
    – for after-the-fact verification and localization

What is there to find?
E.g. Lorimer Transients

- First detection of local ionized IGM?
  - DM suggests extragalactic
- Position poorly localised
- Verification difficult with single antenna
- Large FoV needed to detect even relatively common events (e.g. GRBs ~1 $sky^{-1}day^{-1}$)

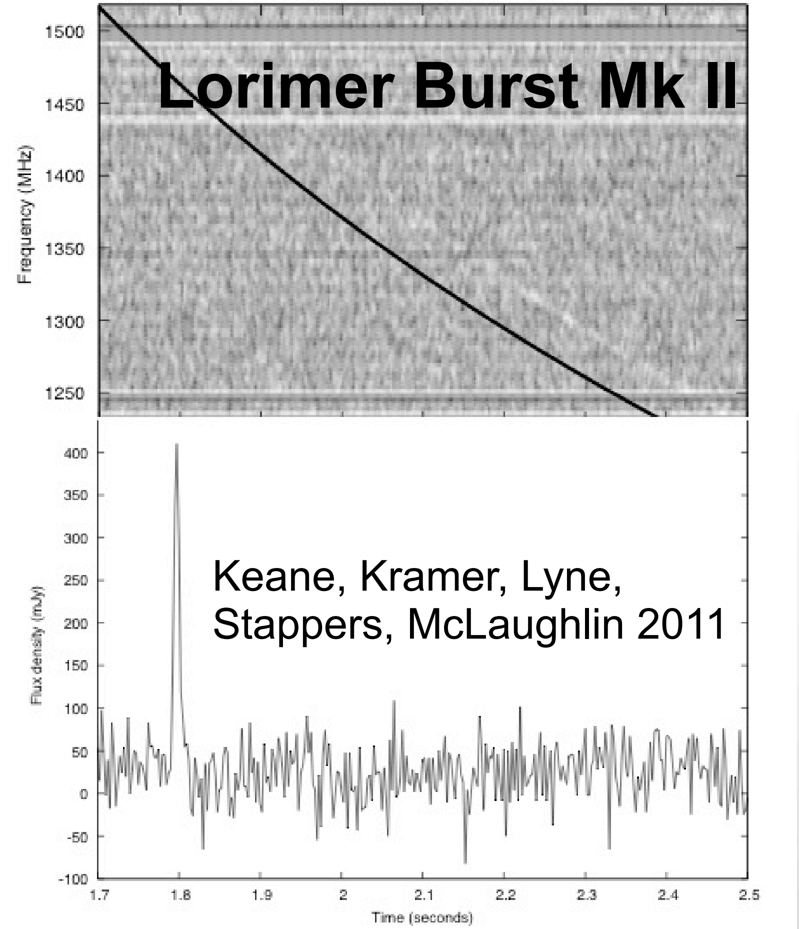
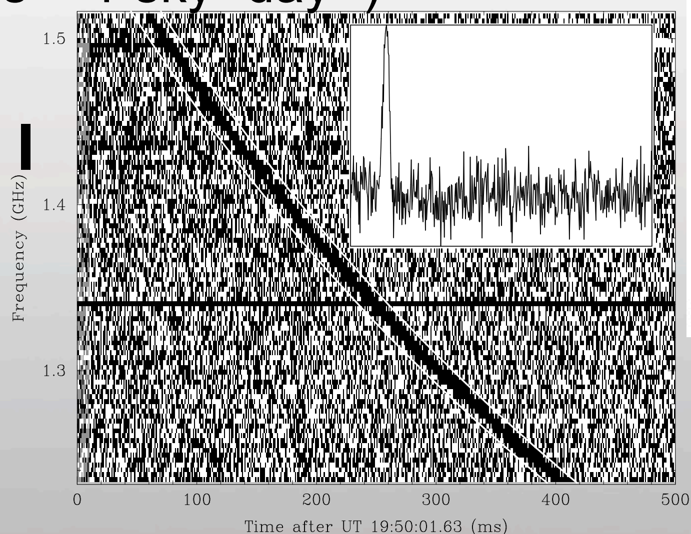


Figure 3. (Top) A plot of the J1852−08 burst in frequency-

Lorimer Burst Mk I



To detect one extragalactic burst may be regarded as a mistake; to detect two looks like carelessness.

This station is now the ultimate power in the Universe. I suggest we use it.

Prominent Operational & Upcoming Projects

1. V-FASTR - a fully operational and automated transients detection pipeline
   – showcasing a suite of new detection algorithms

2. LOFAR Transients Key Science Project & Variants

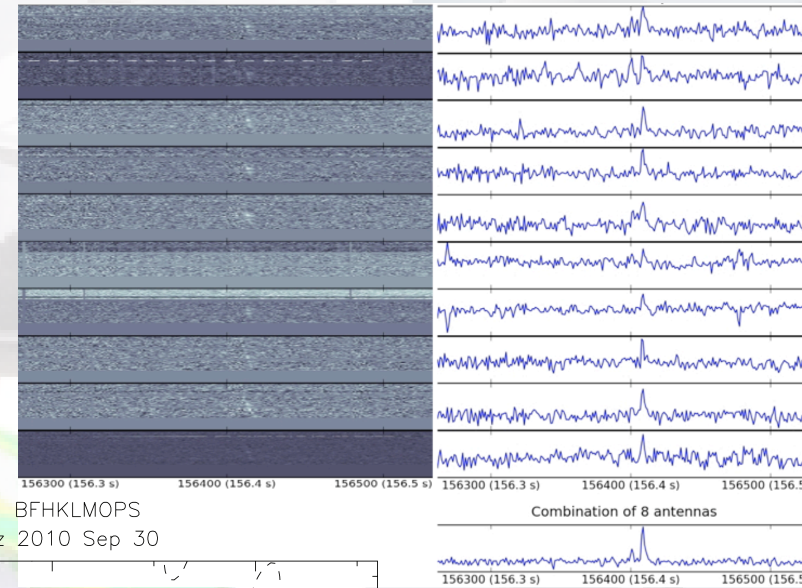
3. CRAFT (ASKAP)

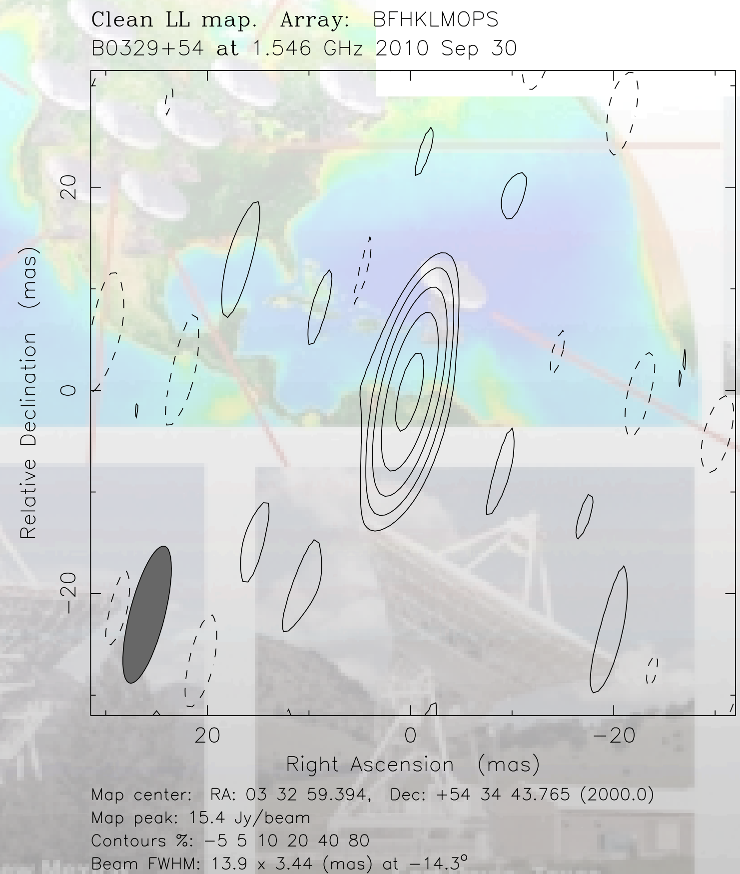
V-FASTR - incoherent power search with coherent followup

ICRAR-Curtin/JPL/NRAO

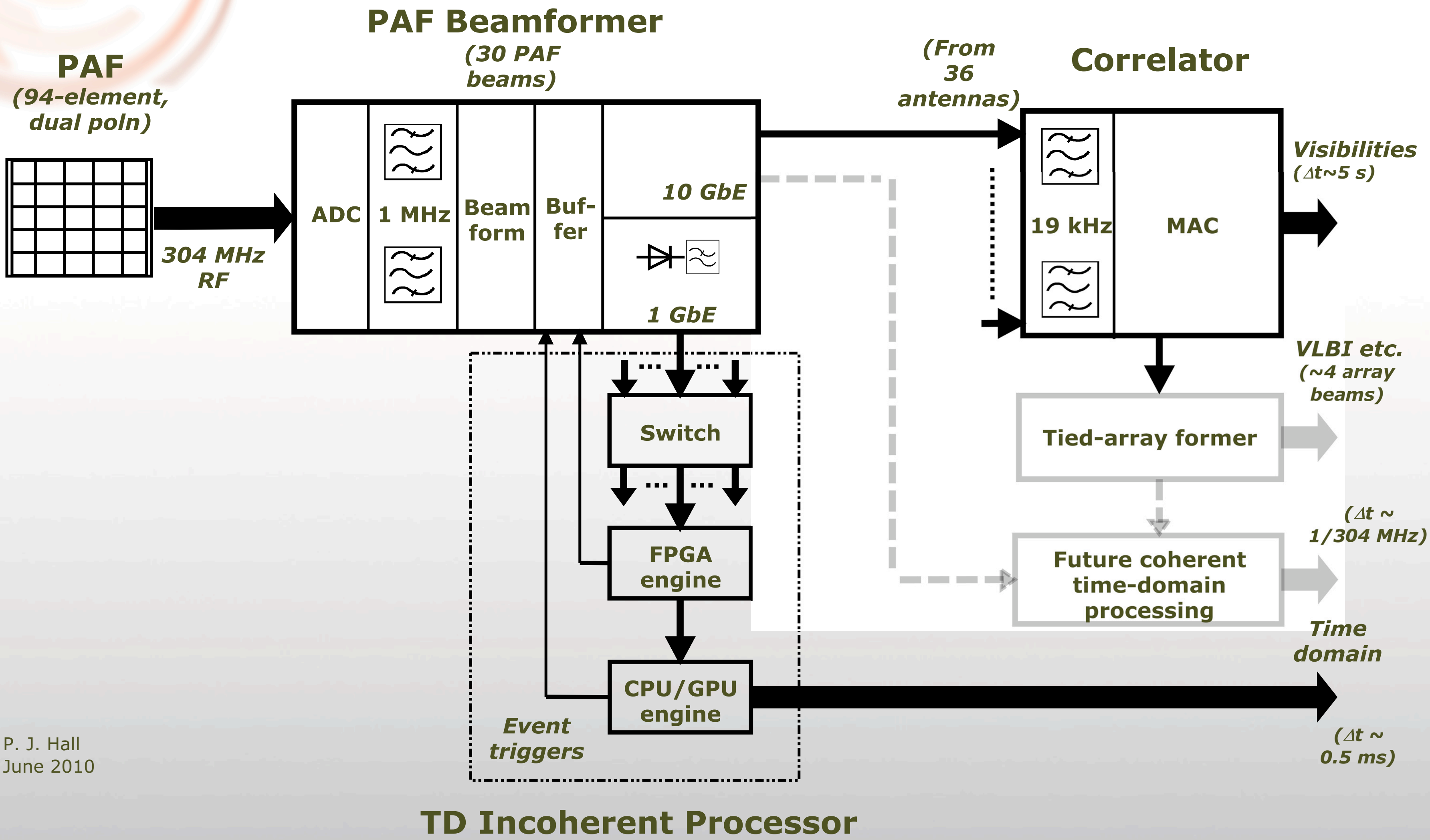
- [*incoherent*] DiFX software correlator pipes 1ms telescope powers to a dedispersion/search engine
- [*coherent*] Candidates identified and 1s sections of baseband data on candidates dumped

- Telescope separation - excellent signal localisation & false +ve rejection
- Proving ground for new approaches: JPL machine learning algorithms, FPGA-based dedispersion hardware



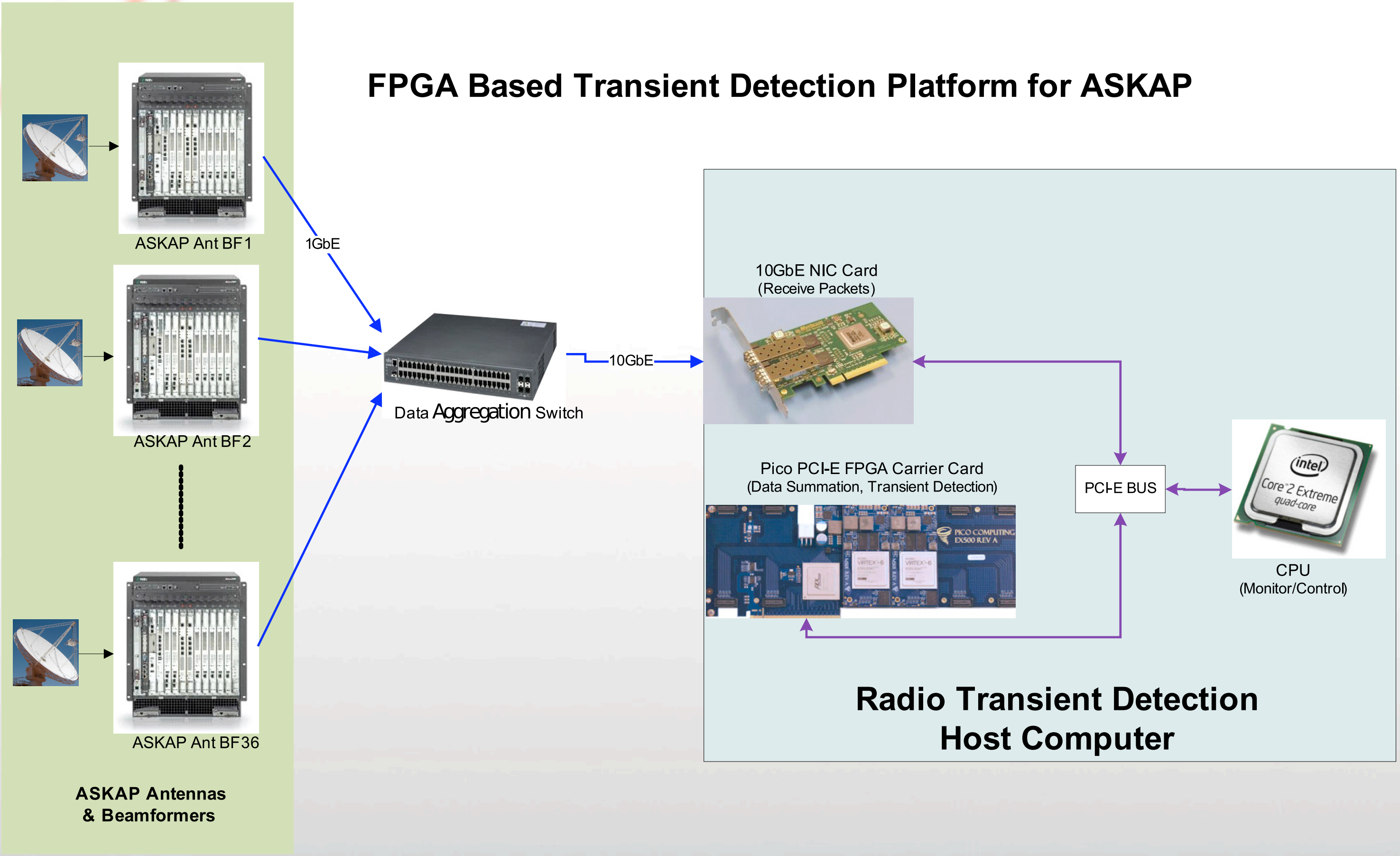


ASKAP and CRAFT



P. J. Hall
June 2010

Dedispersion & Detection on an FPGA
A detection solution for CRAFT



ARTEMIS

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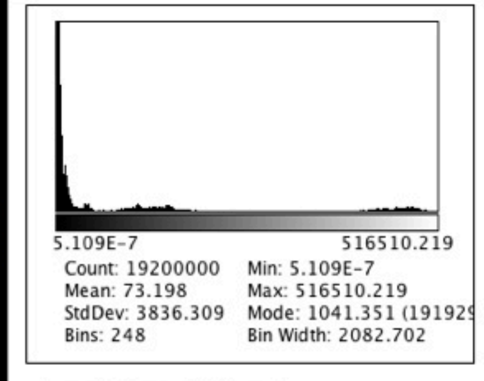
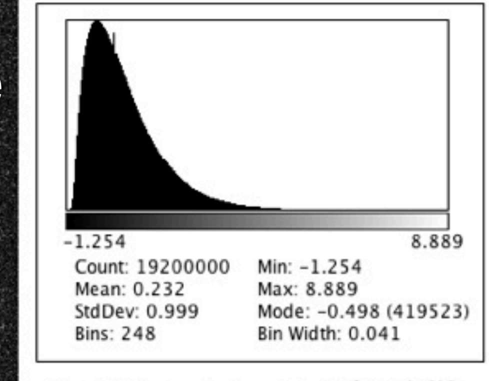


filterbank noise pre-filtering

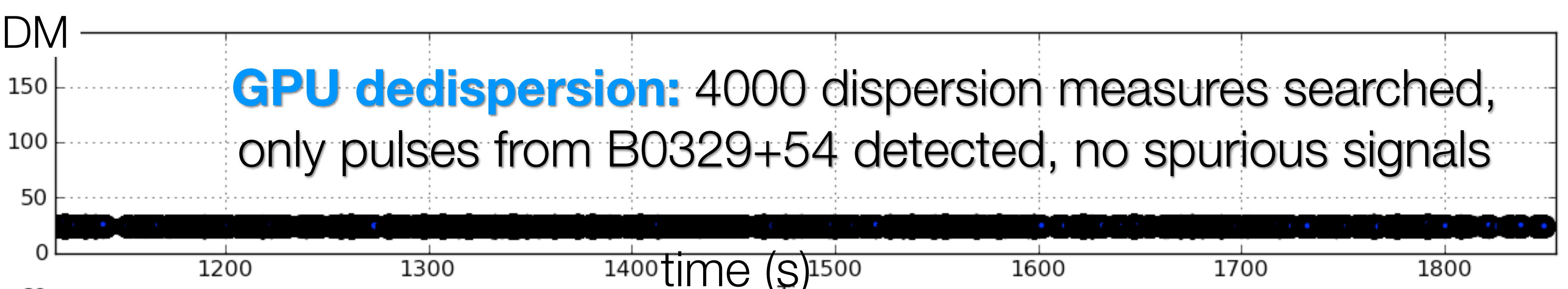
dynamic noise modelling

for effective RFI removal and transient detection



filterbank noise post-filtering

A CPU/GPU machine for real-time searches of fast transients

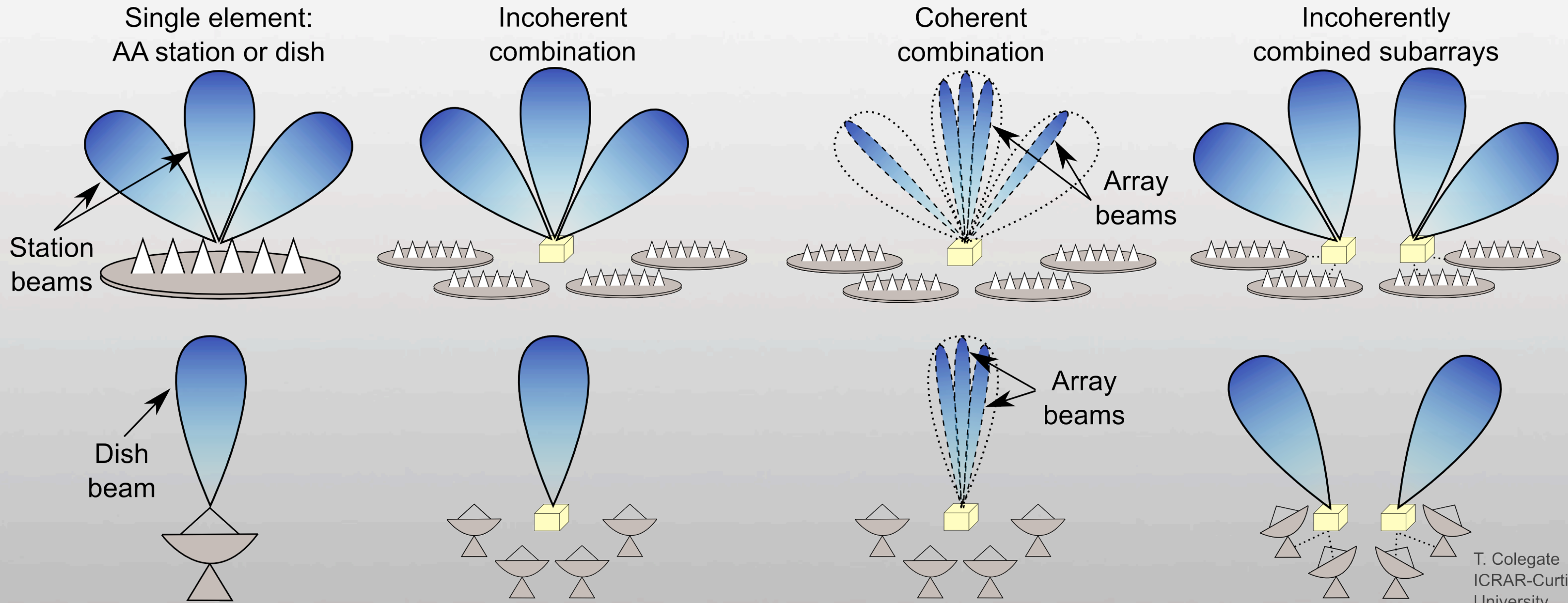


GPU dedispersion: 4000 dispersion measures searched, only pulses from B0329+54 detected, no spurious signals

Fly's Eye, Incoherent widefield, or coherent survey?

- For an array of N stations, each with limiting sensitivity S_0
  - **Fly's eye** covers N x primary field of view down to S_0
  - **Collimated Incoherent** covers 1 x primary FoV down to sensitivity $S_0/N^{1/2}$
  - **Coherent** covers $\xi\ \Omega_{synth}=\xi\ \pi(\lambda/d)^2$ $[\Omega_{synth} \ll \Omega_{primary}]$ down to S_0/N
- Which is best depends on the slope of the Rate vs S_0

$$\mathcal{R} \propto \Omega S_0^{-3/2+\delta}$$



T. Colegate
ICRAR-Curtin University

Fly’s Eye, Incoherent widefield, or coherent survey?

- Fly’s eye or coherent?

number of tied-array beams

$$\frac{\mathcal{R}_{\mathrm{coher}}}{\mathcal{R}_{\mathrm{fly's-eye}}} = \xi \frac{\Omega_{\mathrm{synth}}}{\Omega_t} N^{1/2-\delta}$$

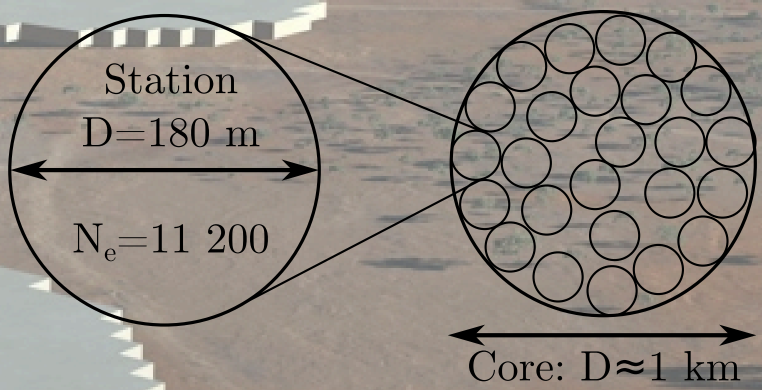
- ξ must be large for the coherent approach to win
- If 0.5<δ<1.5 we eventually lose for large N with a coherent survey
- Coherent or collimated incoherent?

$$\frac{\mathcal{R}_{\mathrm{coher}}}{\mathcal{R}_{\mathrm{col}}} = \xi \frac{\Omega_{\mathrm{synth}}}{\Omega_t} N^{3/4-\delta/2}$$

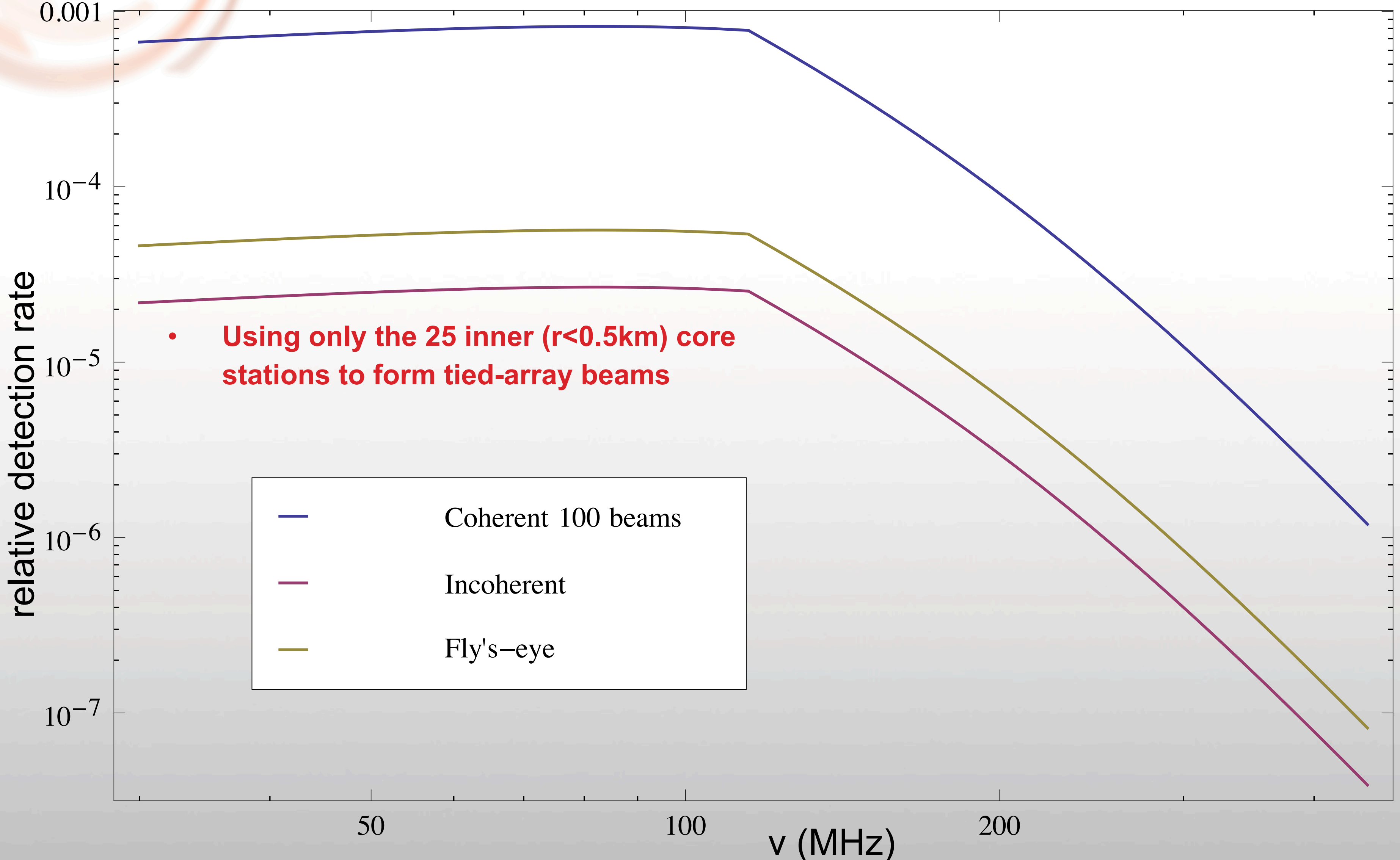
Maximising bang for buck

see Colegate & Clarke, PASA 2011

- We consider the AA-lo layout of Memo 130 (Dewdney et al. 2010)
- Diameter 180 m, 50 stations, 11200 elems/station
  - 25 stations at (r <0.5 km)
  - 10 stations (0.5 < r < 2.5 km)
  - 15 stations (2.5 < r < 100 km)
- 70 - 450 MHz
- Dense-sparse transition at 115 MHz
- T_{sys} = 150K + T_{sky} --- T_{sky}=60 $\lambda^{2.55}$ K

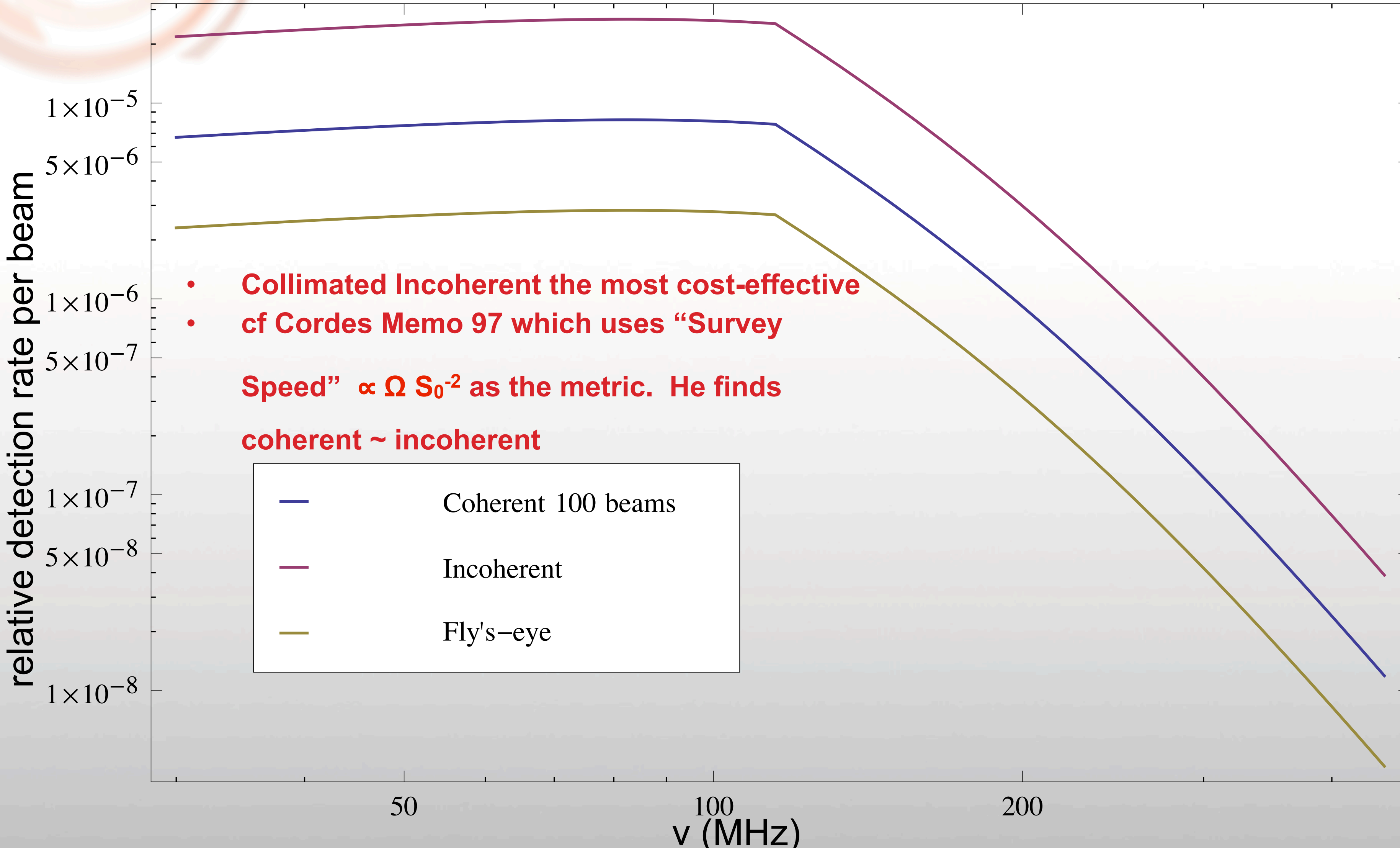


Relative Detection Rate
assuming $R \propto \Omega S_0^{-3/2}$



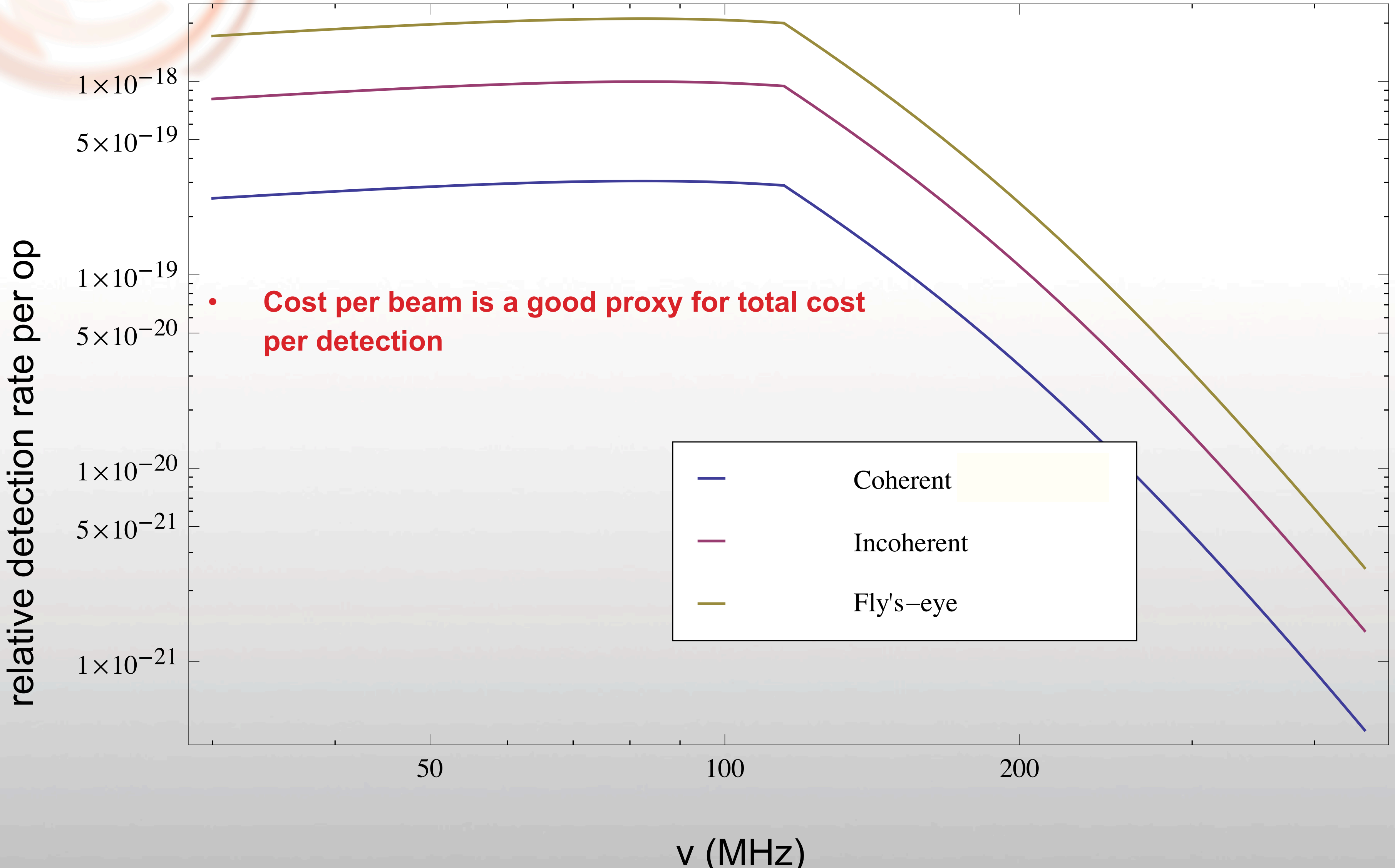
- **Using only the 25 inner (r<0.5km) core stations to form tied-array beams**

Relative Detection Rate *per beam*
assuming $R \propto \Omega S_0^{-3/2}$



- **Collimated Incoherent the most cost-effective**
- **cf Cordes Memo 97 which uses "Survey Speed" $\propto \Omega S_0^{-2}$ as the metric. He finds coherent ~ incoherent**

Relative Detection rate per Operation
(beamforming dominates ops count)



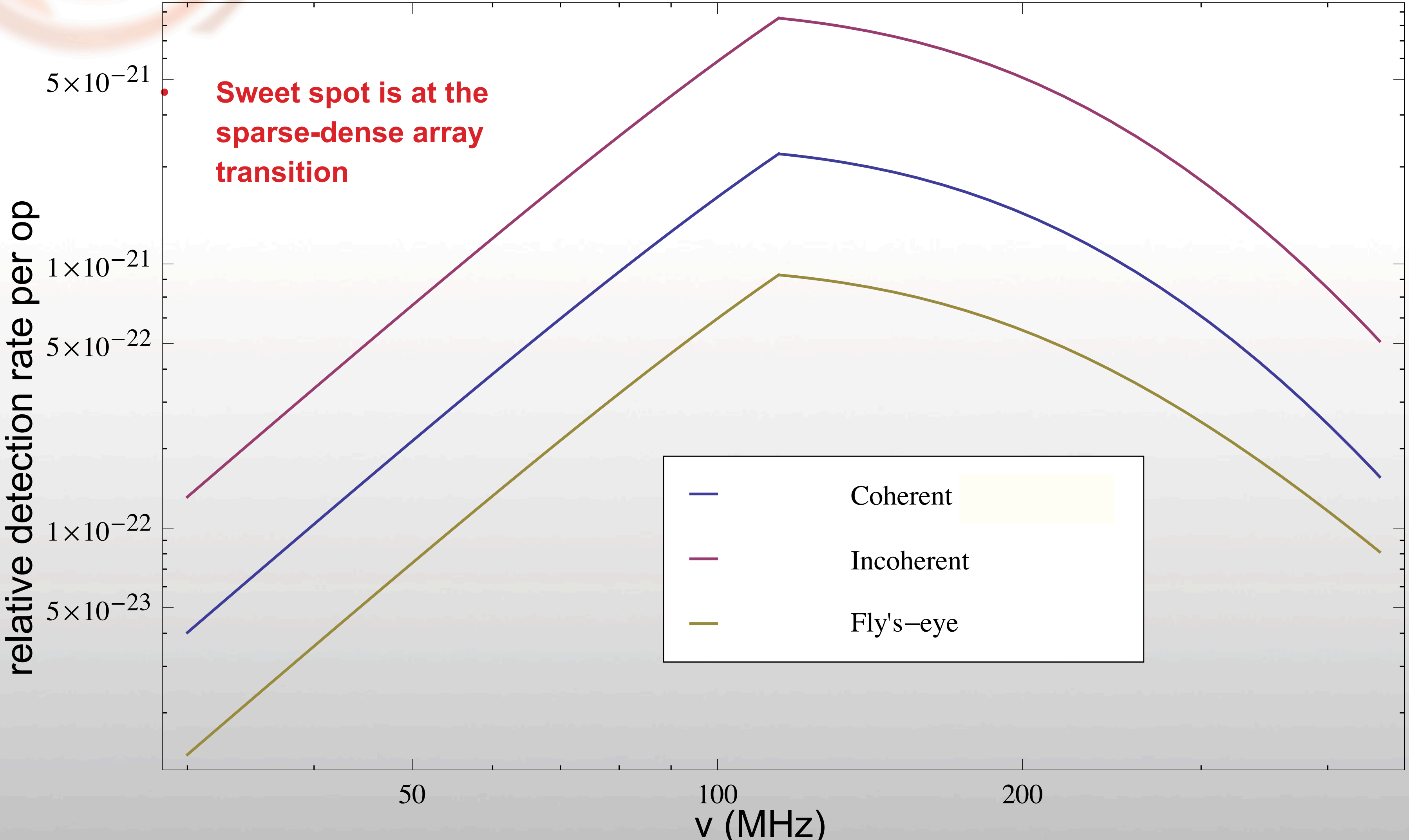
- **Cost per beam is a good proxy for total cost per detection**

Relative Detection rate per Operation

(if beamforming paid for us, so dedispersion dominates)

assuming $R \propto \Omega S_0^{-3/2}$

- Sweet spot is at the sparse-dense array transition



Transients detection is compute and I/O limited

- Cannot possibly tile the entire array FoV using a coherent approach involving all stations
  - Follow LOFAR approach and just use the inner stations
- N_{pix}~(max baseline/station diameter)^2~309000
  - could be as low as 192 if we use inner 2.5km stations
  - but localisation only to 3’ at 150 MHz
  - arguments that longer baselines better for ionospheric correction for observations over a wide FoV
- Find a better solution to the detection and disdispersion problem than the brute force approach

What do we what?

– A modular/spigot-based philosophy to system design that enables us to
  - access total powers of stations
  - access station voltages
  - place buffers at a variety of levels in the hierarchy (lowest access point TBD, but likely close to the station-level, certainly not antenna level)

When do we want it?

- we are not so foolish as to believe that the SKA itself will furnish purpose-built transients detection hardware *gratis*
- Spigots allow us to attach hardware as its capabilities improve

Good systems design is 99% of our requirement

- Transients are a no-/low-cost addition that ensures good systems design is built into the telescope from the beginning
- Must be built into AA precursors AAVS1/2
- Transients science is one of the few useful scientific things such low sensitivity instruments could do
- They ensure a modular design that future proofs the hardware for correlator upgrades 15++ years down the track
- Needs to be included in the SKA DRM for Phase I
  - ensure that engineers at the end of the production line do not design out functionality even though it may not be immediately required