FRATS: Commensal Real-Time Searches for Fast Radio Transients

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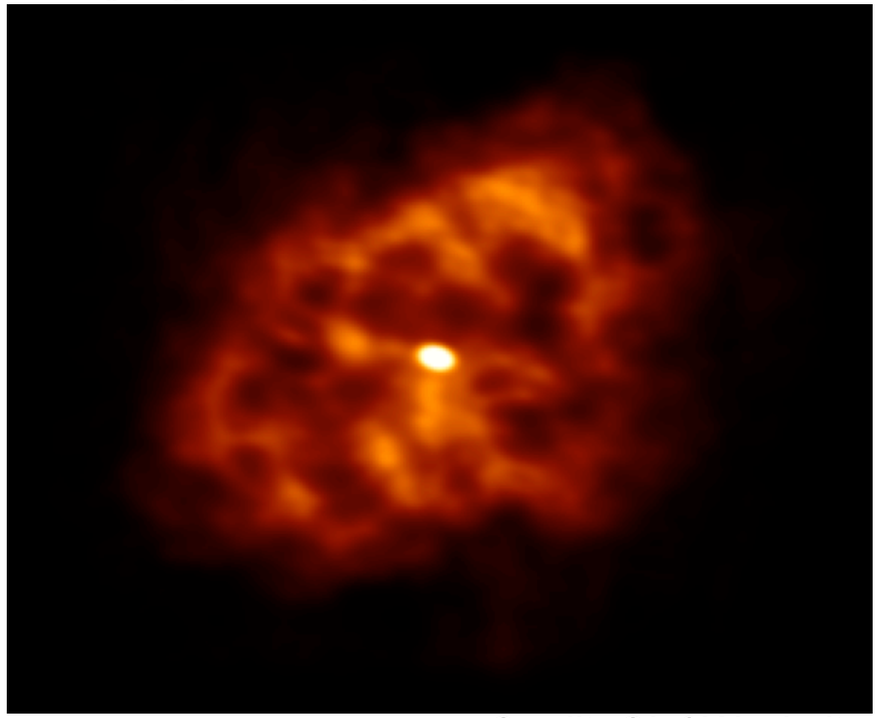
LOFAR Transients Key Science Project
LOFAR Cosmic Ray Key Science Project

Commensal LOFAR observing

Imaging data, spatial resolution, faint

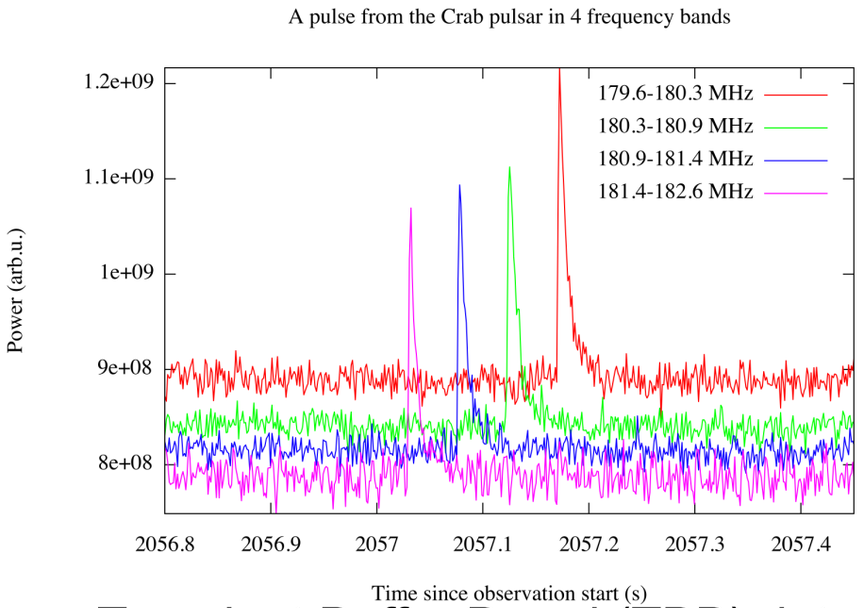


Credit: Olaf Wucknitz

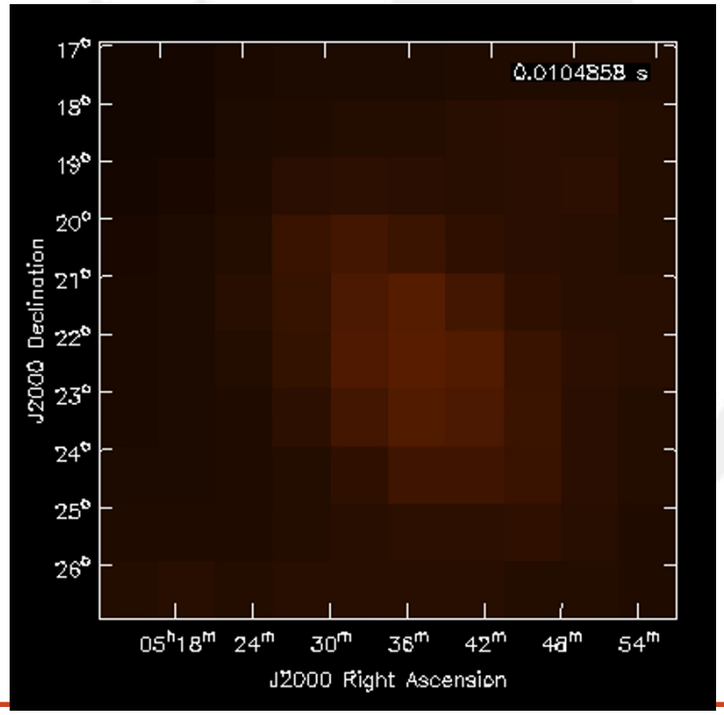
WHILE

DO

Beamformed data, time resolution, bright



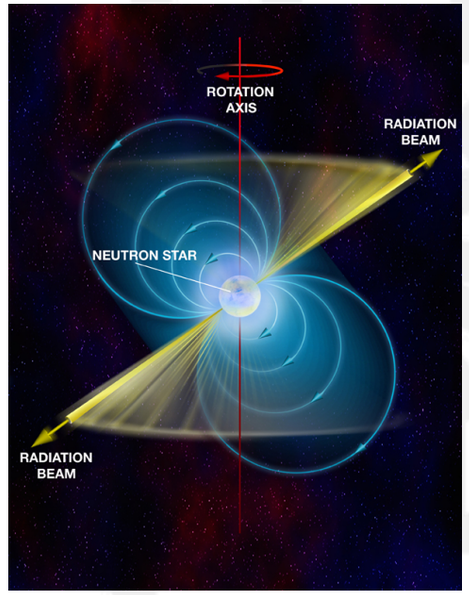
Transient Buffer Board (TBB) data
Time resolution, spatial resolution, all sky coverage

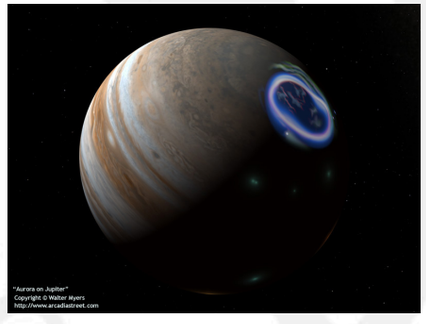


FRATS : Fast Radio Transients Search

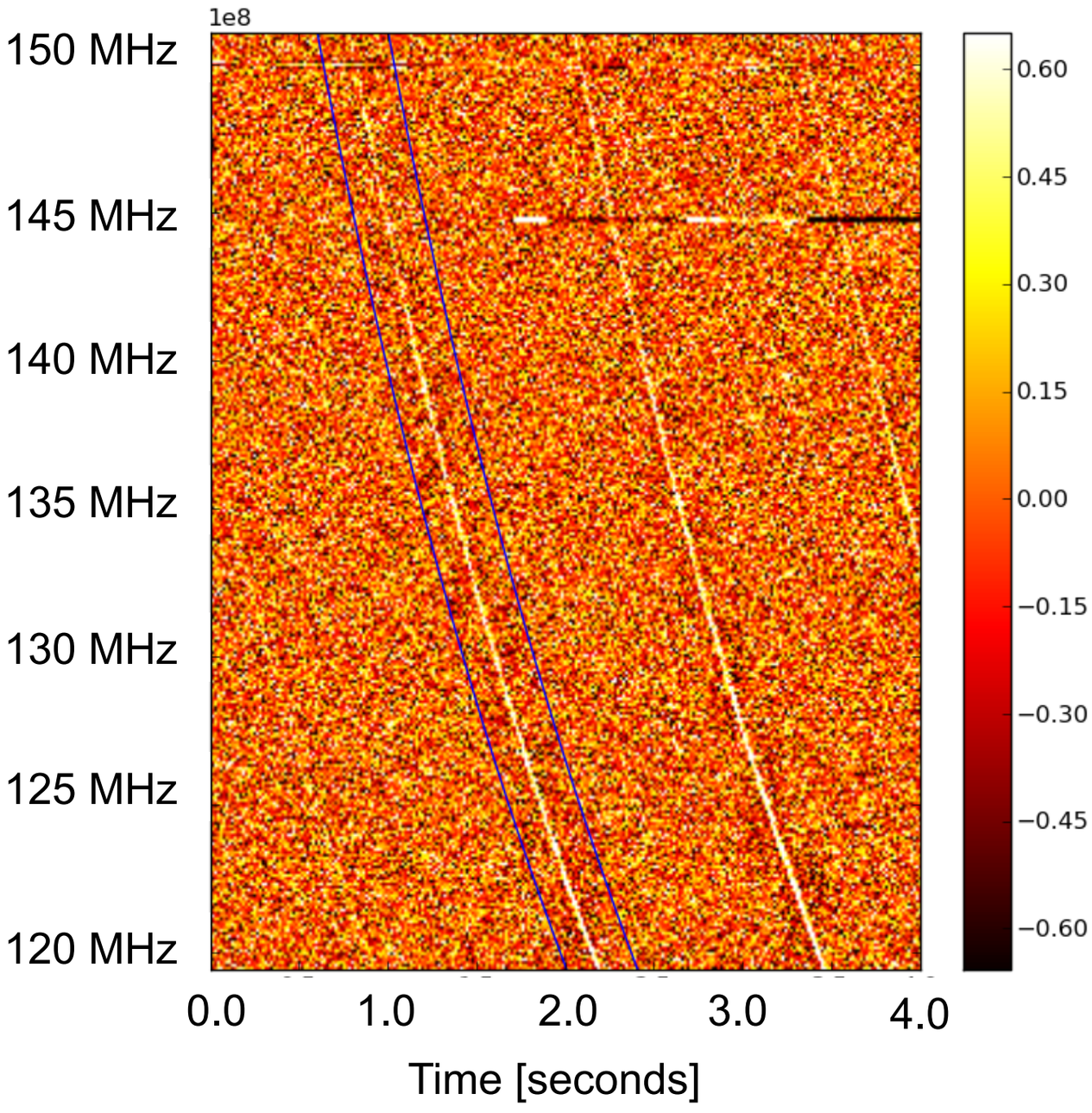
Searching for subsecond pulses possibly originating from:

- **Pulsars, Giant Pulses, RRATS**
- **“Lorimer” Bursts / FRBs**
- Flaring stars
- Lightning from Saturn
- Jupiter flares/aurora radio emission
- GRBs ?
- Exoplanets?
- ETI ??





FRATs: Detection of dedispersed pulses



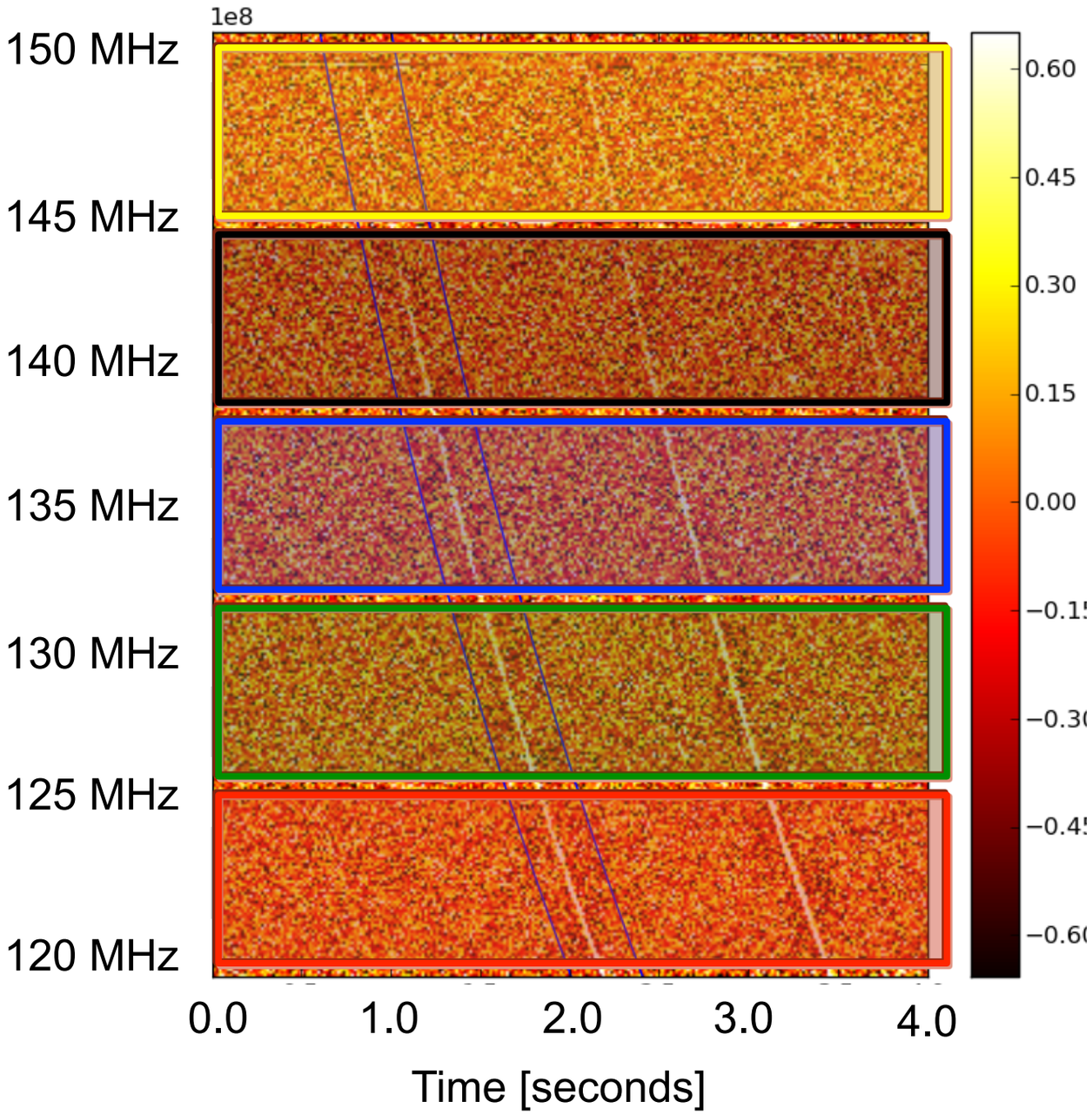
- Dispersed ms pulses

$$\Delta t_{DM} = 4.15\,ms\,DM(\frac{1}{v^2_{1,GHz}} - \frac{1}{v^2_{2,GHz}})$$

$$\mathrm{DM} = \int_0^D n_e(s)ds,$$

- DM, number of free electron to source,
- DM unknown parameter
- DM measured in pc cm^{-3}

FRATs: Detection of dedispersed pulses



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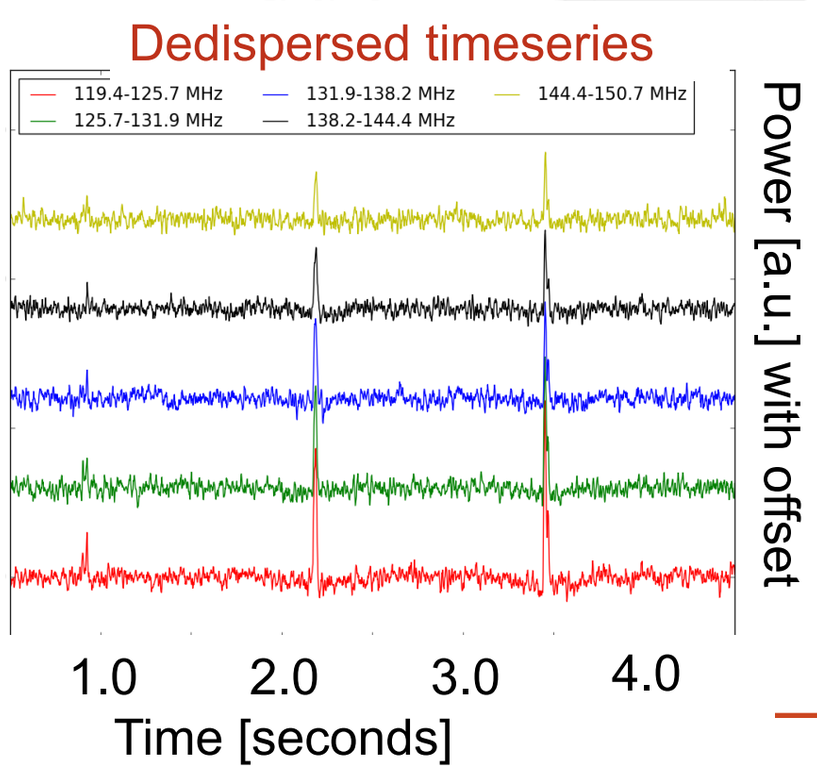
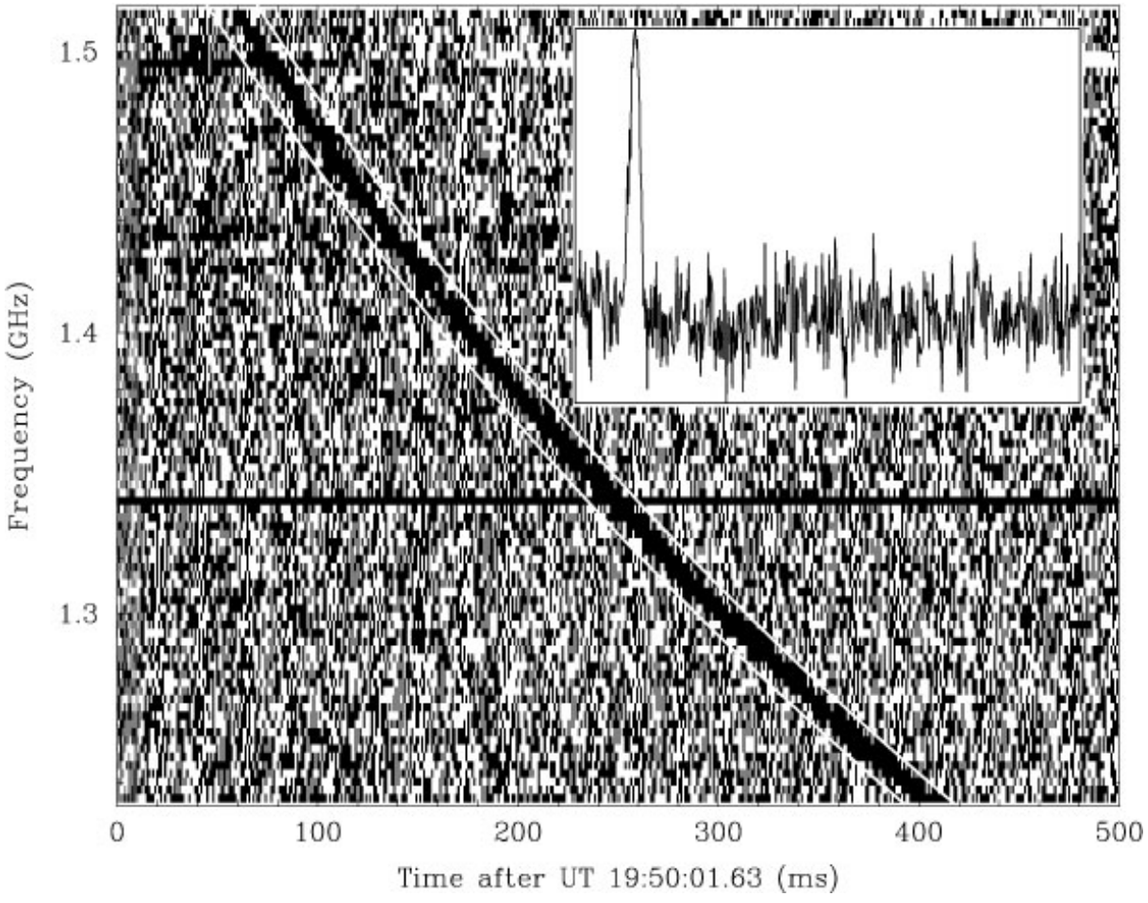
- Dedisperse in 4-5 frequency bands
- Coincidence between bands
  - RFI rejection > 99.9% !
- 400 Trial DM values Real-Time in current LOFAR hardware



Fast Radio Bursts (FRBs)

Highly dispersed bursts => Extra-galactic origin
Non-repetitive



Lorimer et al. 2007, first FRB
DM=375 pc/cc, 7% Galactic

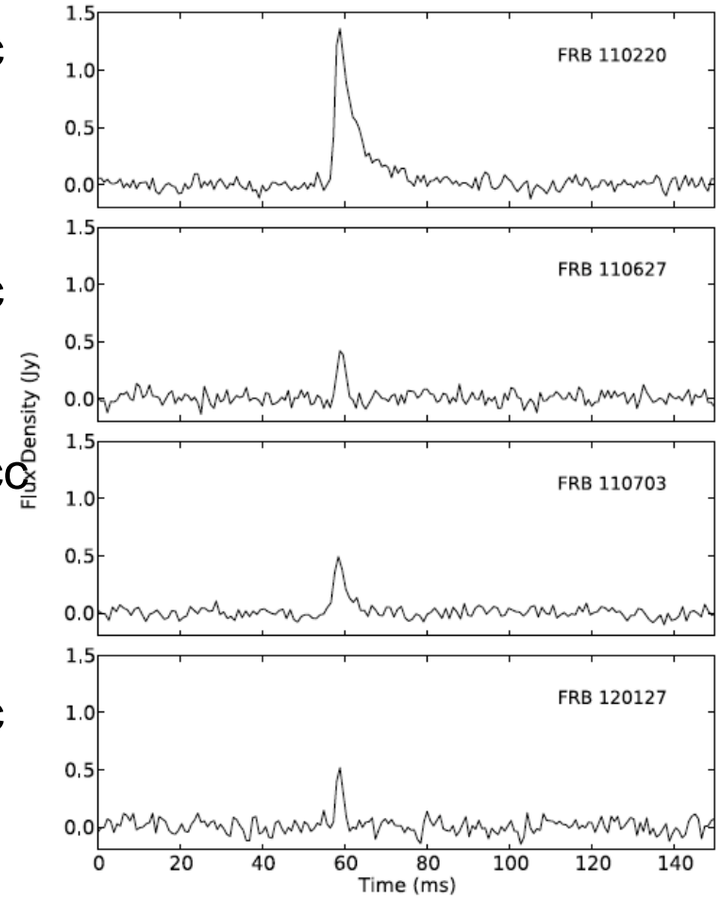
DM=944 pc/cc
4% Galactic

DM=723 pc/cc
7% Galactic

DM=1103 pc/cc
3% Galactic

DM=553 pc/cc
6% Galactic

Keane et al. 2011, possible FRB

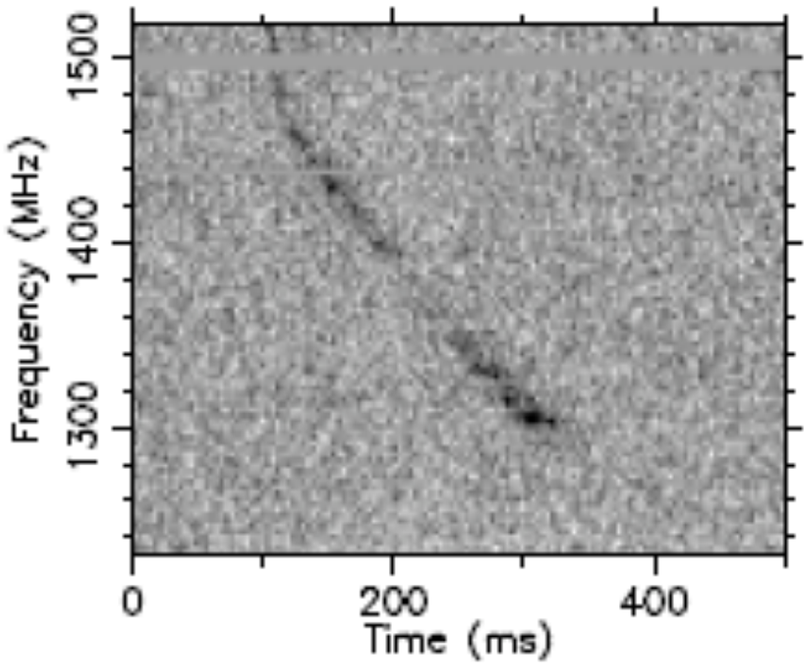


Thornton et al. 2013, 4 more FRBs!

Are Fast Radio Bursts Extra-Galactic, Galactic or Terrestrial?

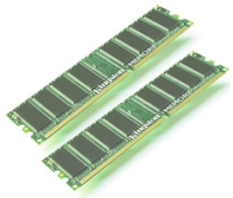
Is it a Peryton?

Burke-Spoloar et al. 2010

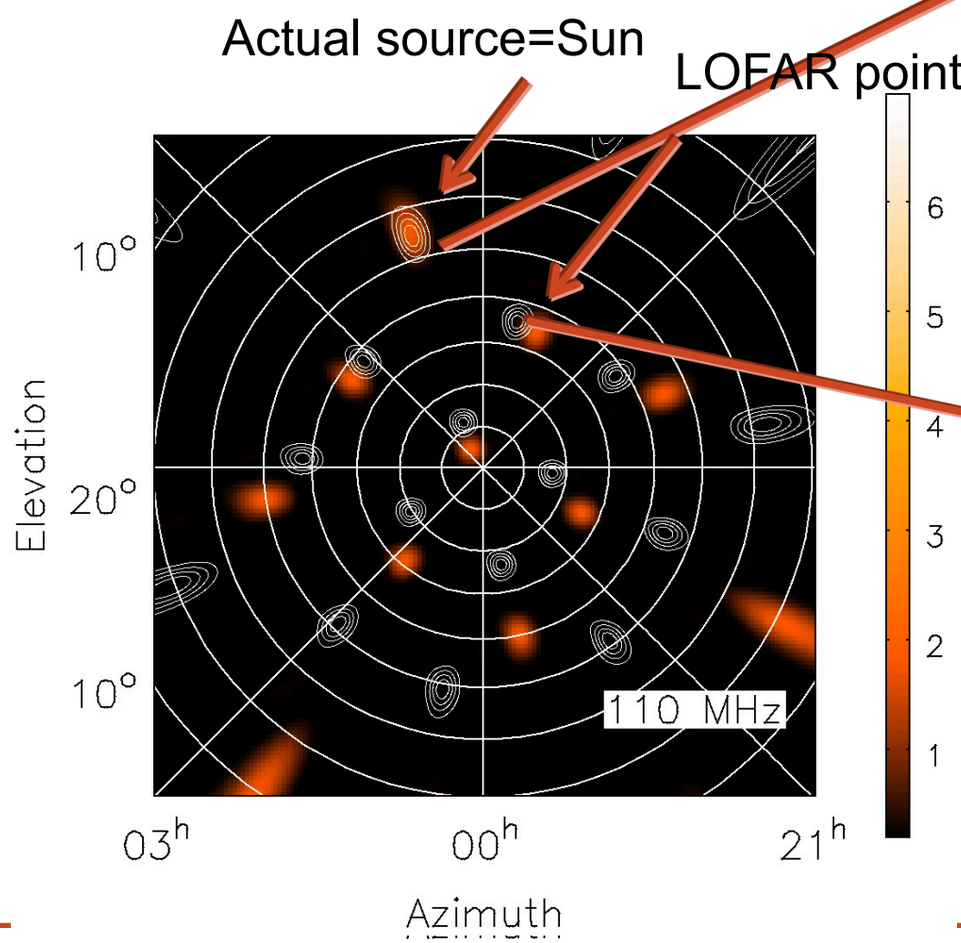


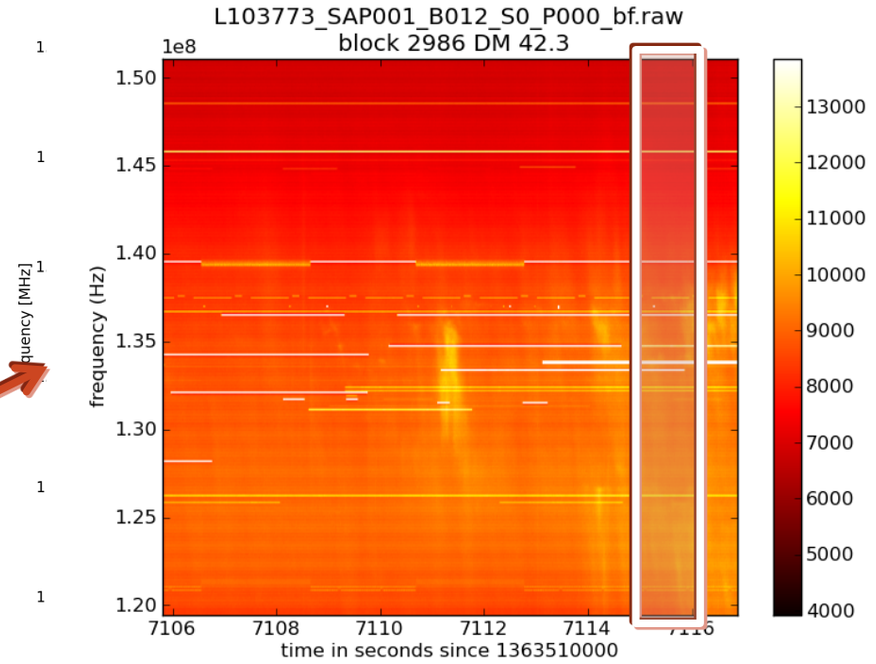
Where does the signal really come from?
Main lobe/side lobe?
Accurate position?
With LOFAR we can find out!

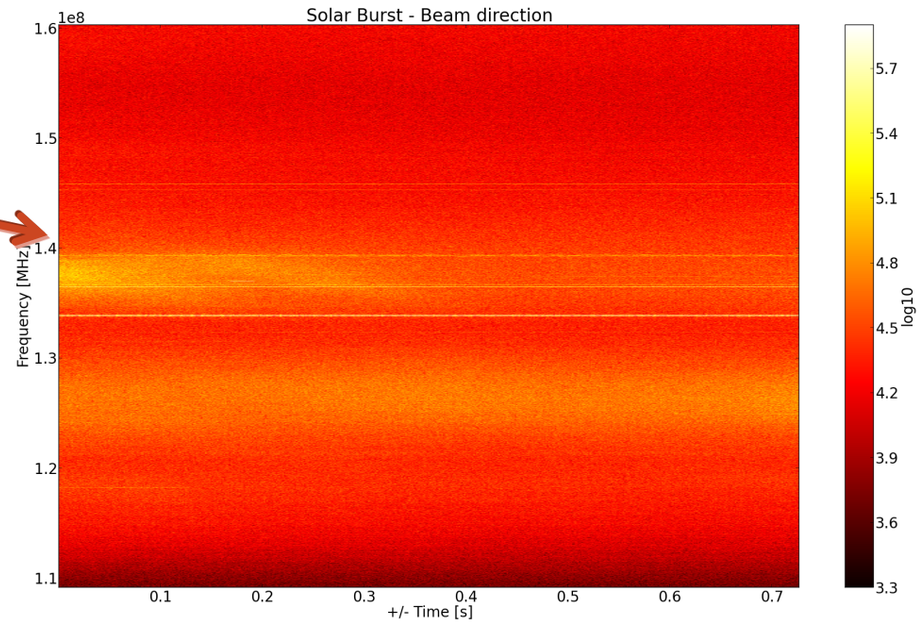
Transient Buffer Boards



- 5 second Ring Buffer for each Antenna/ Tile.
- Frozen and read out (currently after manual verification e-mail)
- Post-event beamforming
- All directions => Movie
- **Source verification and position**







Why commensal observing?

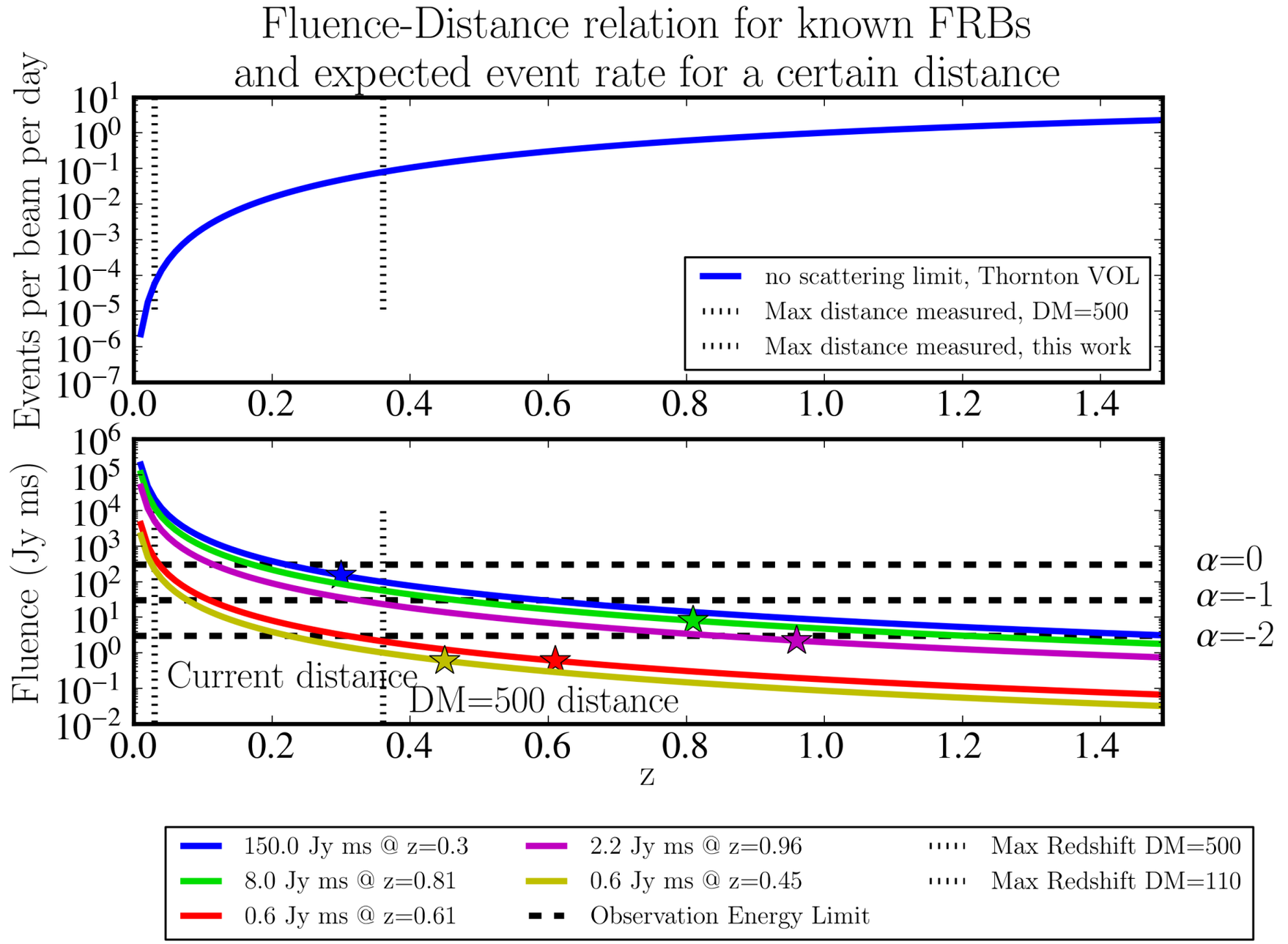
Expected Fast Radio Burst rate

Simulation Hassall et al. 2013
Thornton, no scattering:
17 per Gpc^3 per day

Calculate comoving volume with redshift

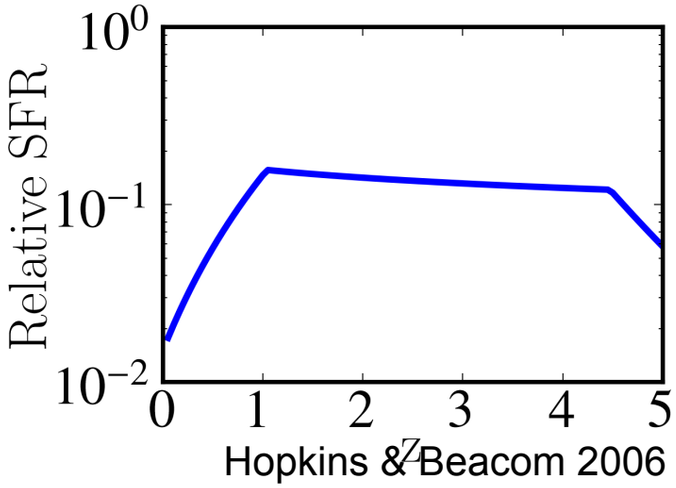
Calculate pulse intensity with Redshift

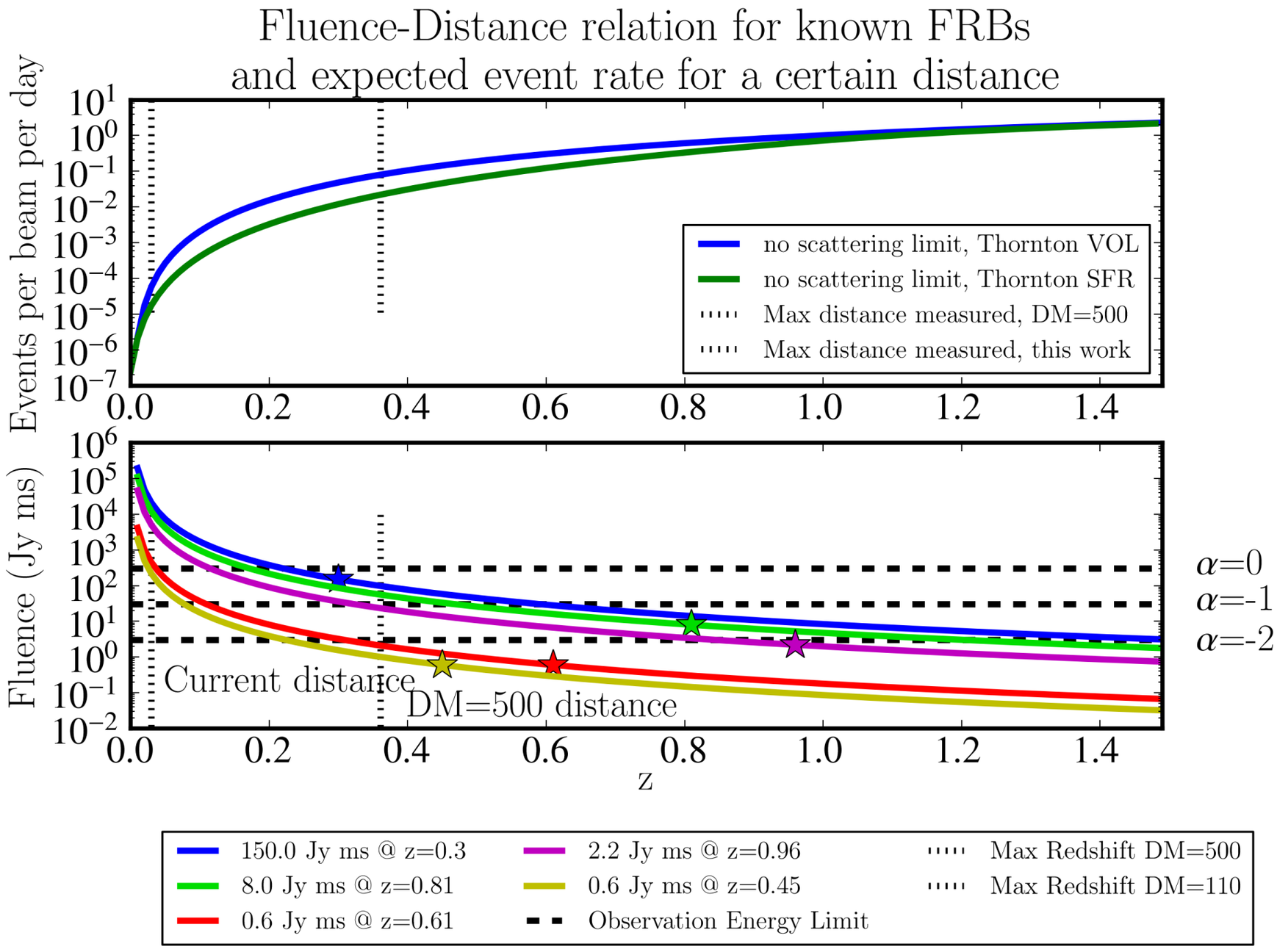
$DM=DM_{MW}+DM_{IGM}+DM_{HOST}$
$DM_{IGM}=1100z$



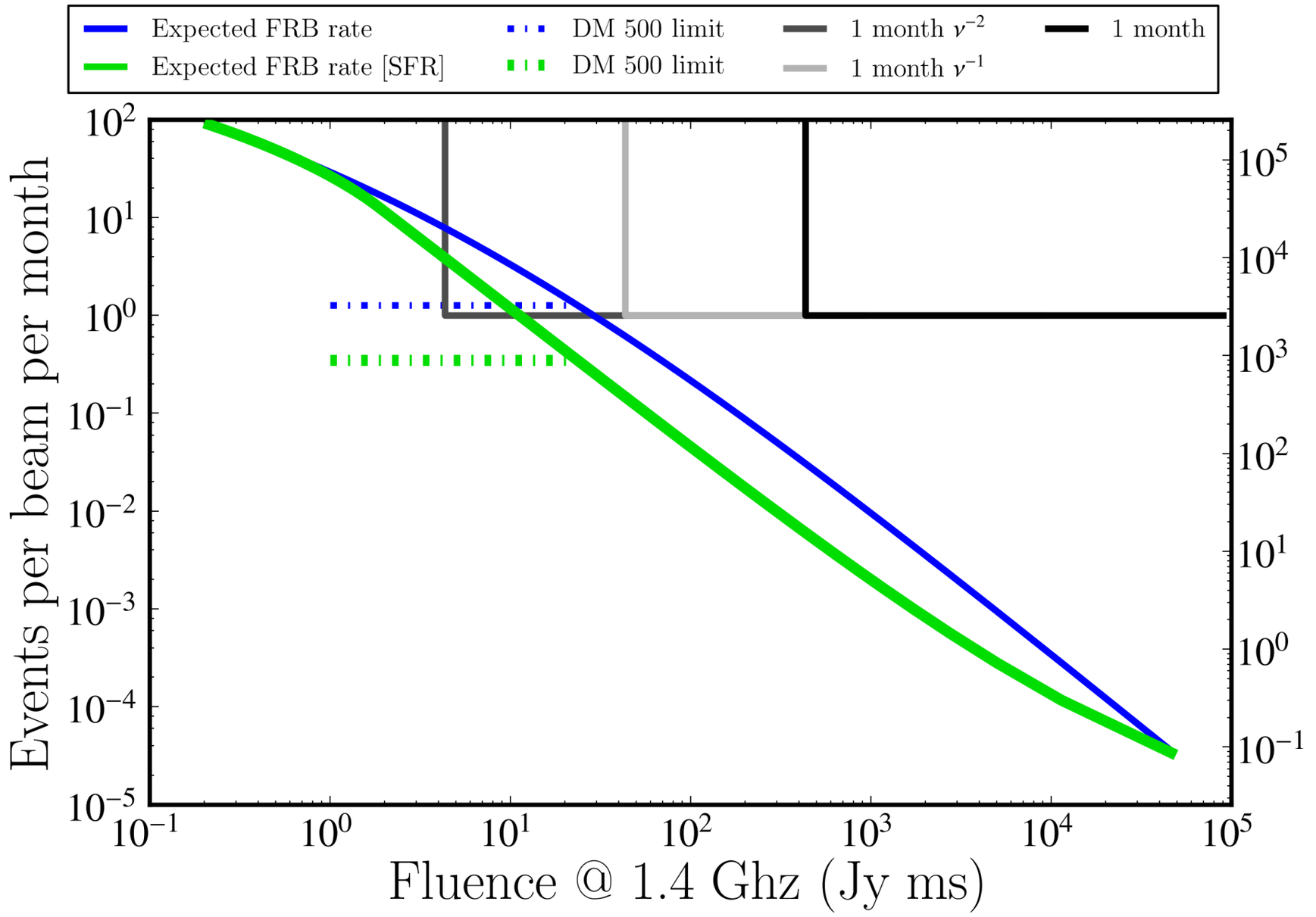
Influence of star forming on FRB rate

Assume rate follows
star formation (green line)





Expected FRB rate



LEGEND
Threshold 1 month (v^{-1} , v^{-2})
Thornton volume
Thornton SFR
Assumptions:
8.5 events per Gpc^3 per day with the brightness of the 2nd brightest Thornton burst

5 ms pulse
Eleveation 45°

Why commensal observing?

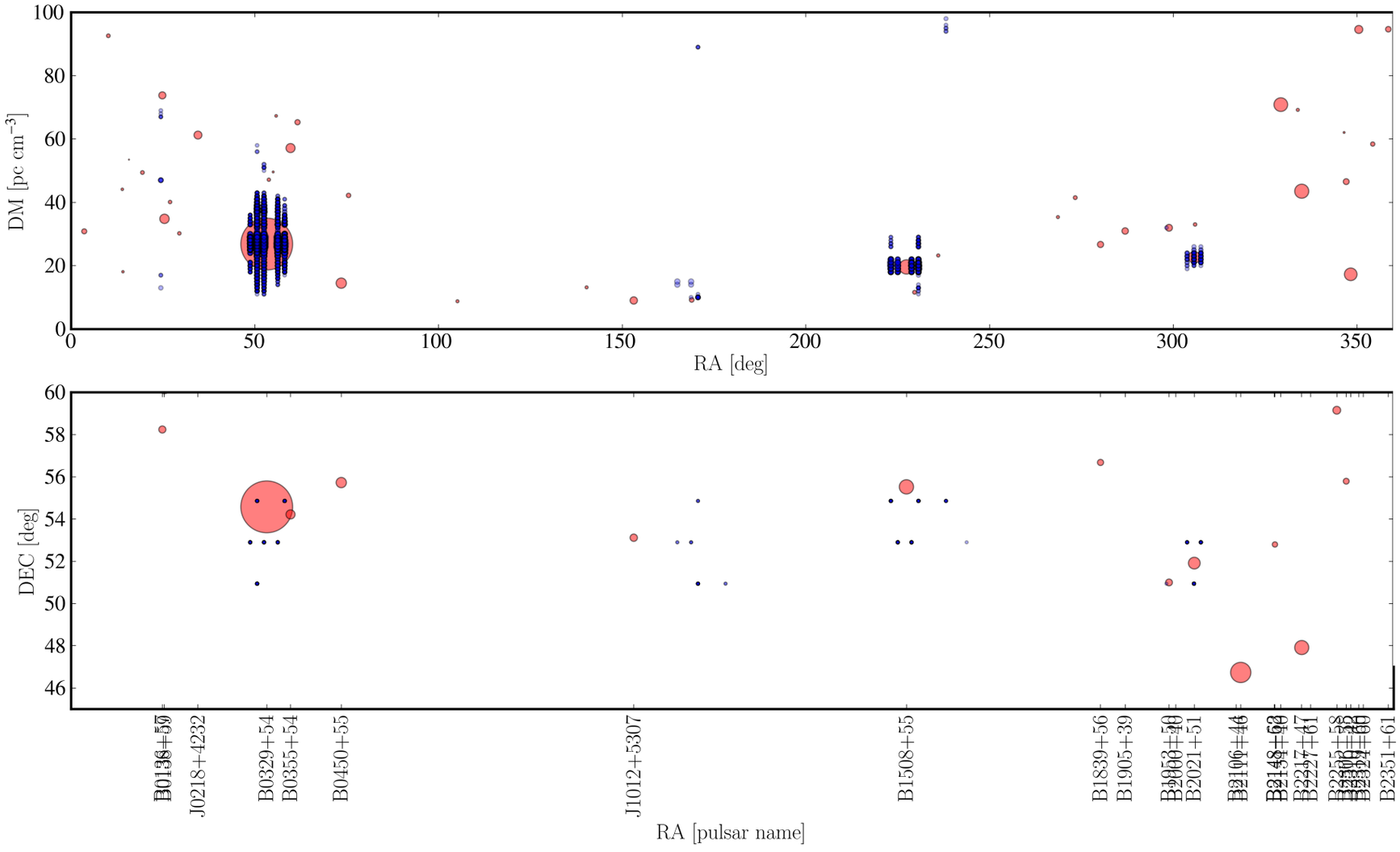
Rare events

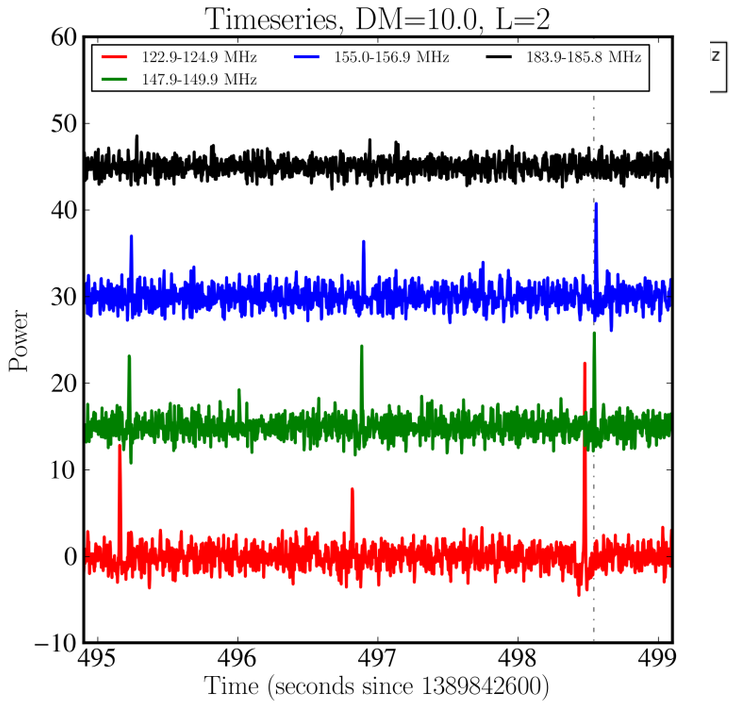
Extended phase space
(high/low freq, long dwell times)

Observations

The Radio Sky Monitor (RSM)	LOTAAS
Imaging Transient Survey, Zenith Scan	LOFAR Tied-Array All-sky Survey
6 beams, repeating same position twice	3 incoherent beams (searched), 217 coherent beams (not searched)
4 frequency bands (122.9-124.9, 147.9-149.9, 155.0-156.9, 183.9-185.8)	5 frequency bands 119-151 MHz
37 stations	6 stations (Superterp)
11 minute per pointing	60 minutes per pointing
24 hours, full zenith coverage	150-200 pointings per cycle
DM range 0-500 pc/cc	DM range 0-110/500 pc/cc
Real extra survey	Position information+Training

Results RSM: Pulsars



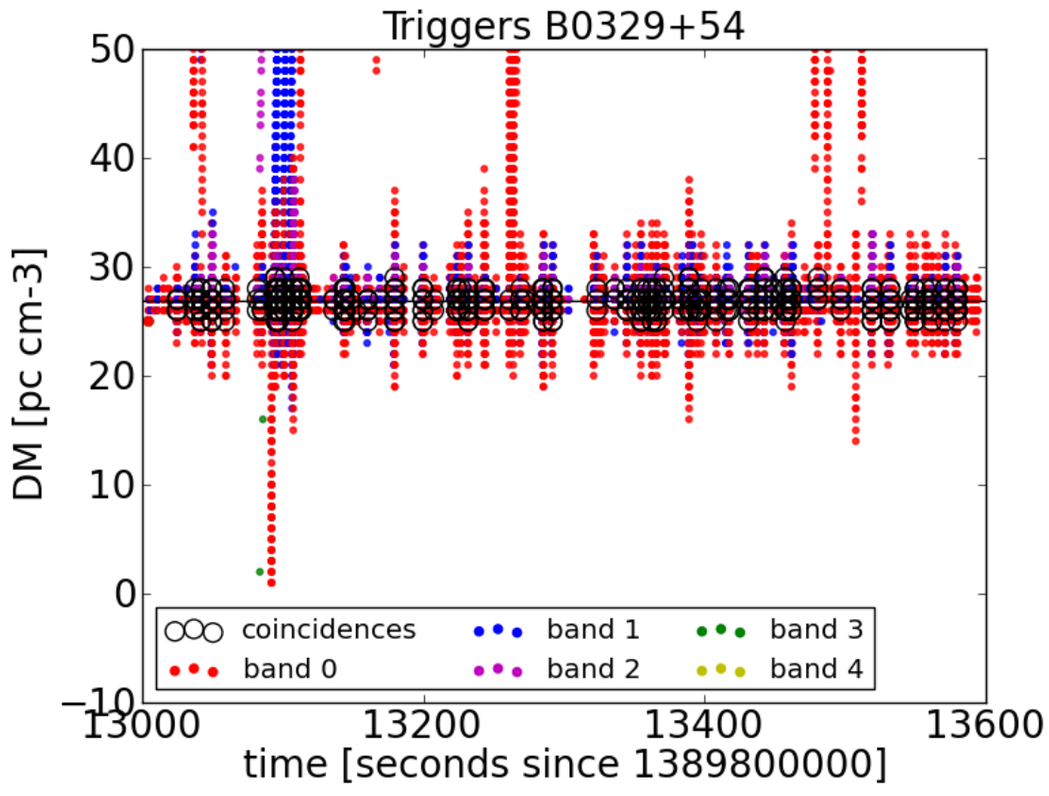


B1120+50, DM=9.2

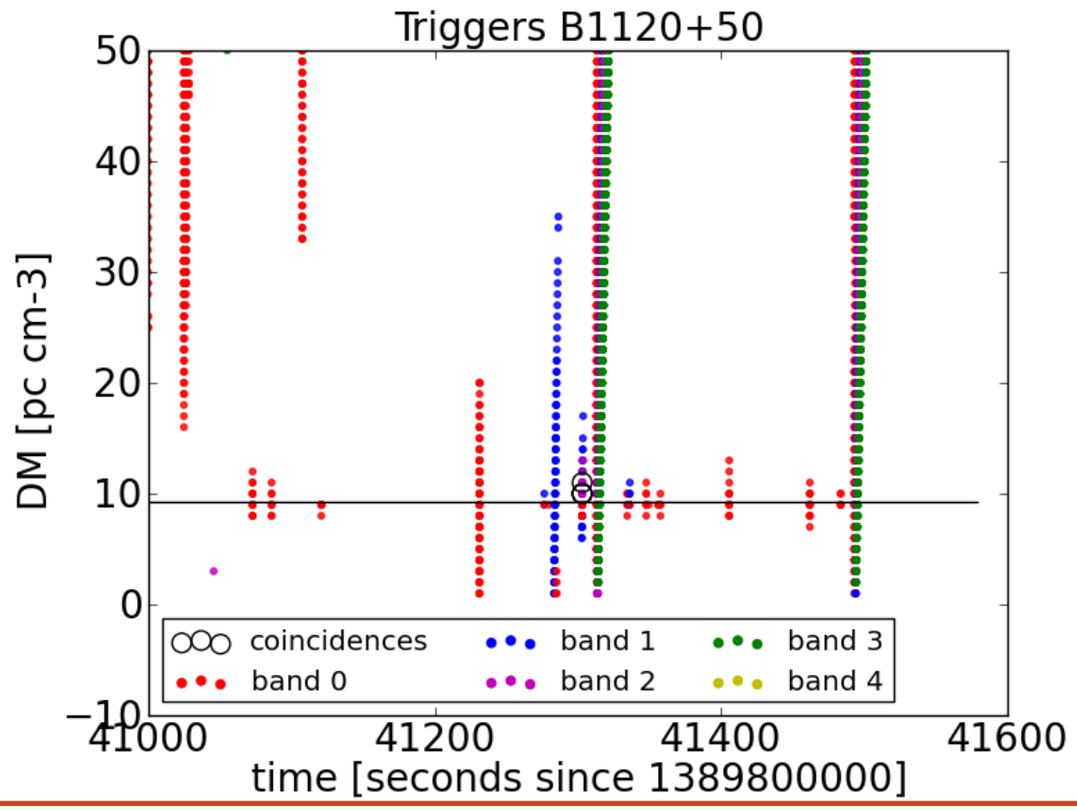
B1508+55, DM=19.6

Giant Pulses

- PSR B0329+54
- DM=26.83 pc / cc
- Very bright
- Almost all pulses visible



- PSR B1120+50
- DM=9.2 pc /cc
- Only few pulses visible
- Giant Pulses, >10x stronger than average



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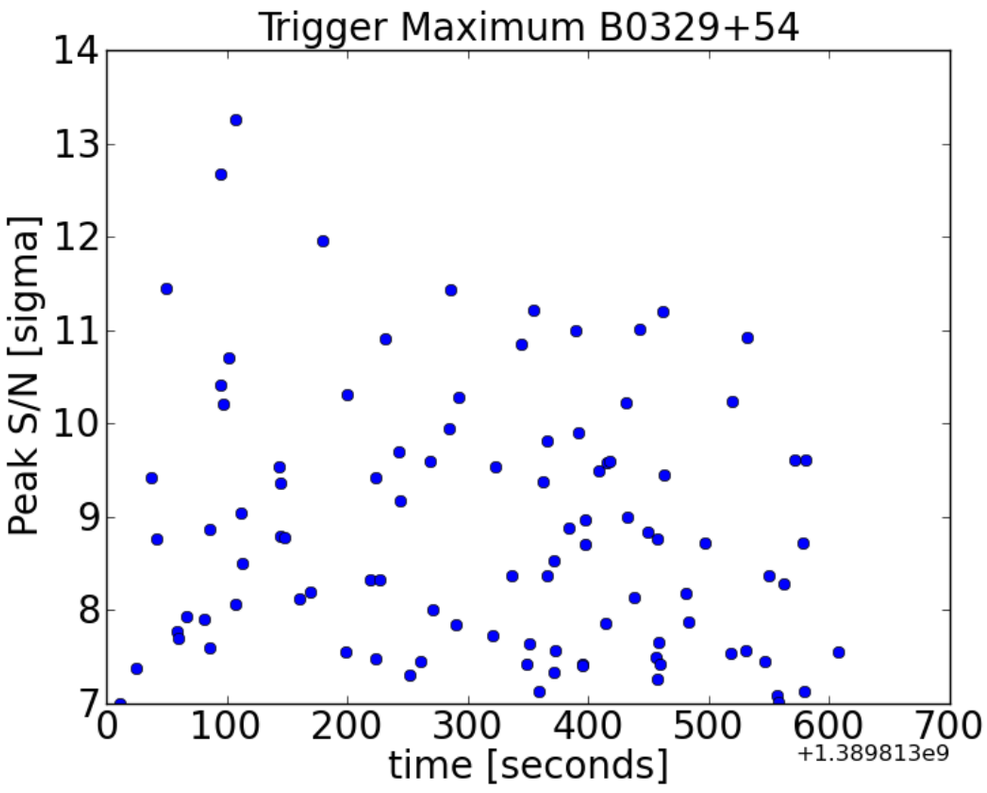

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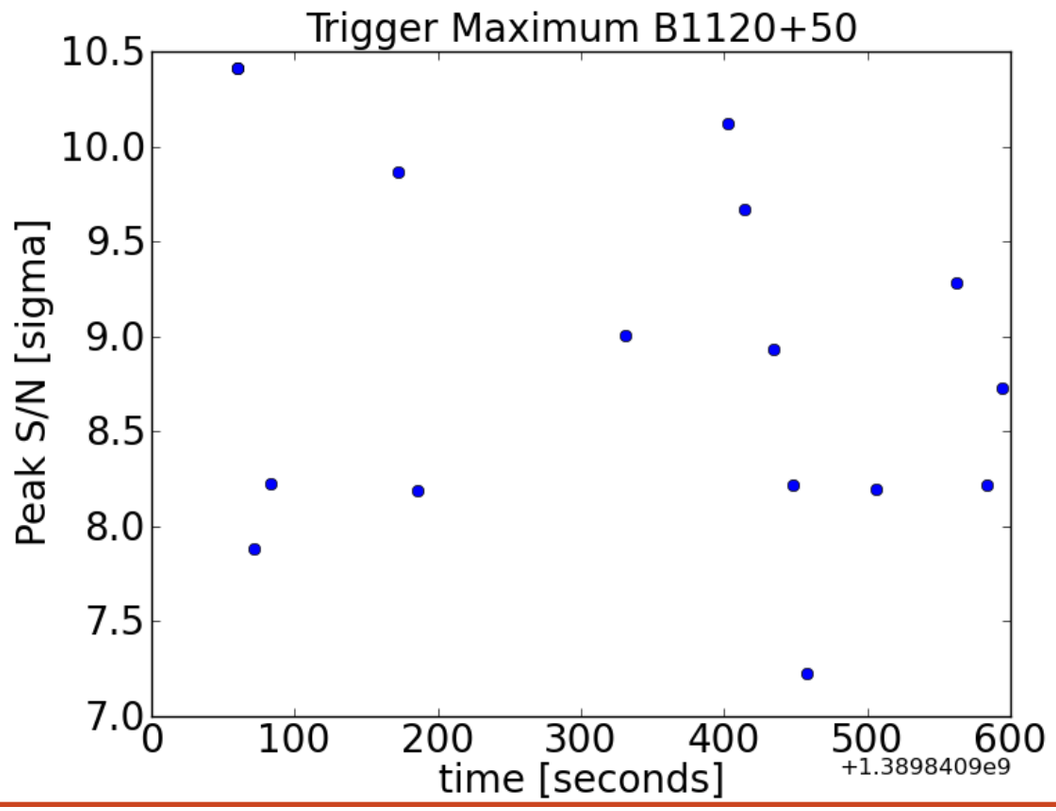
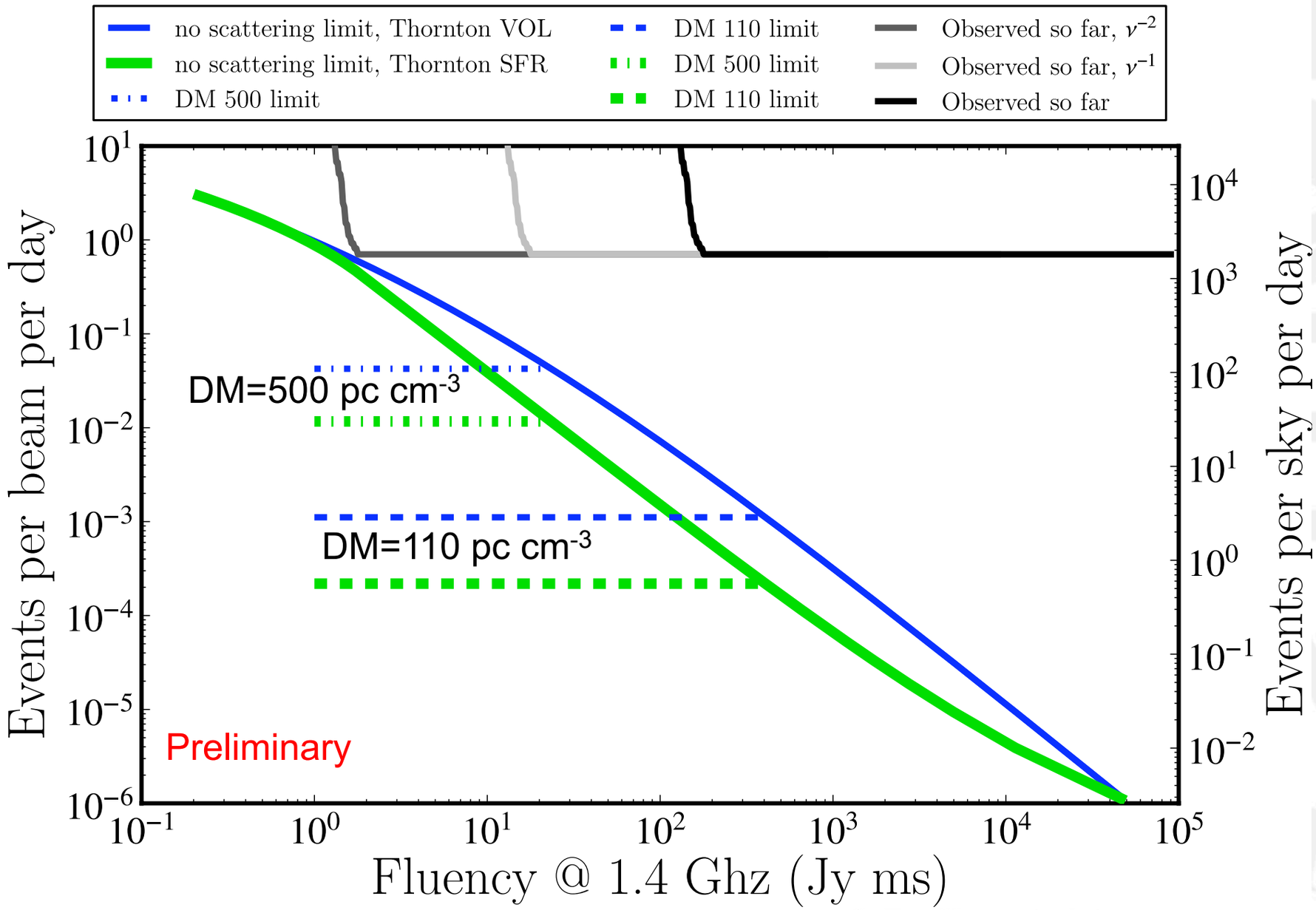


LOTAAS results

35 pointings
1 hour per pointing
Fully analysed for dispersed pulses and extragalactic contribution. None found apart from pulsars.

Upper limit of 1800 events per sky per day at DM < 110 pc/cc



S. Ter Veen et al. in prep

Conclusions

The FRATS project searches for Fast Radio Transients by adding an incoherent beam to LOFAR imaging observations.

The Transient Buffer Board data is used to find the location of the pulse to verify it’s origin.

In commensal observations with the Radio Sky Monitor 5 pulsars were re-discovered of which one only through Giant Pulses.

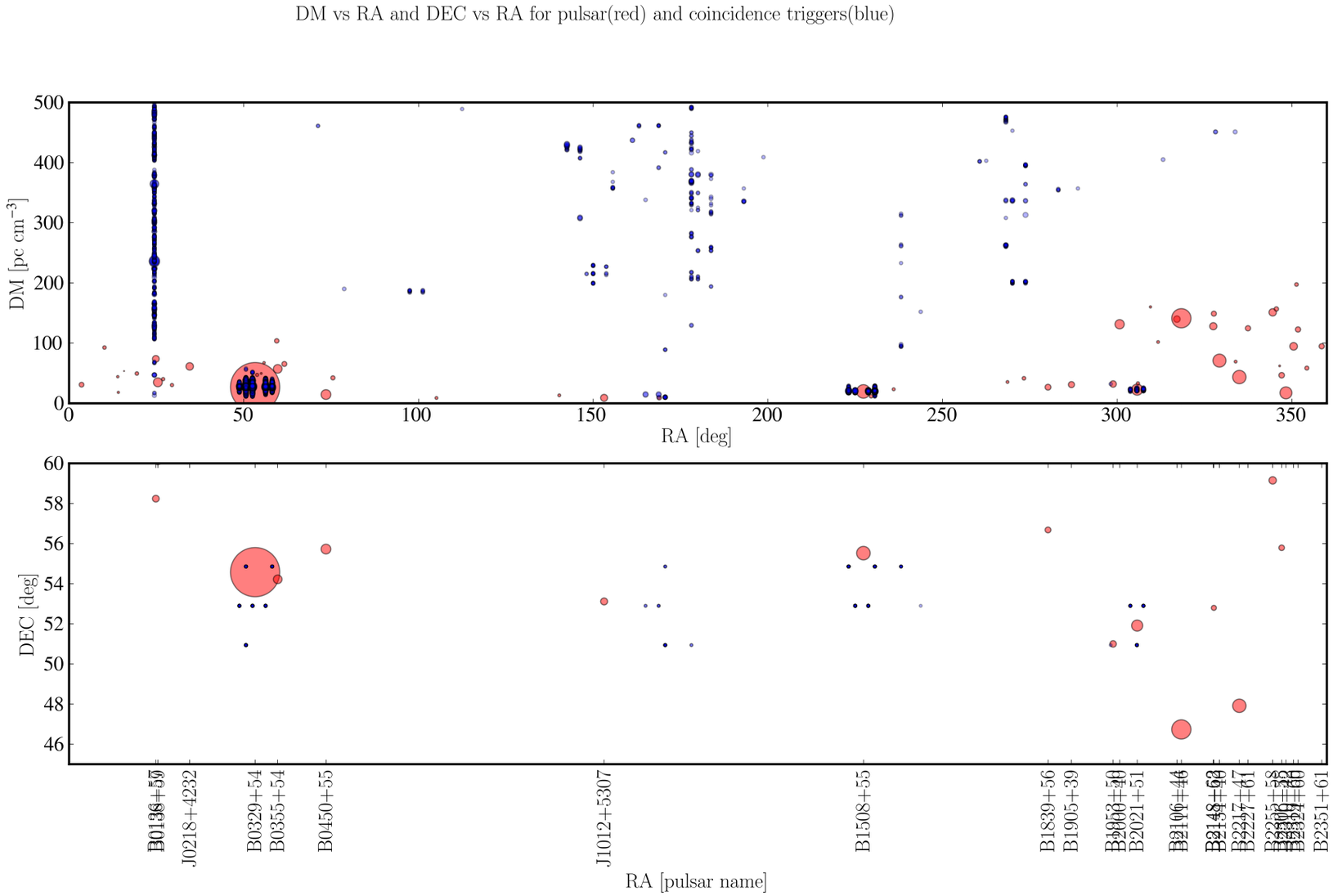
Estimated Fast Radio Burst rate is 1 per beam per month. Need for commensal observing.

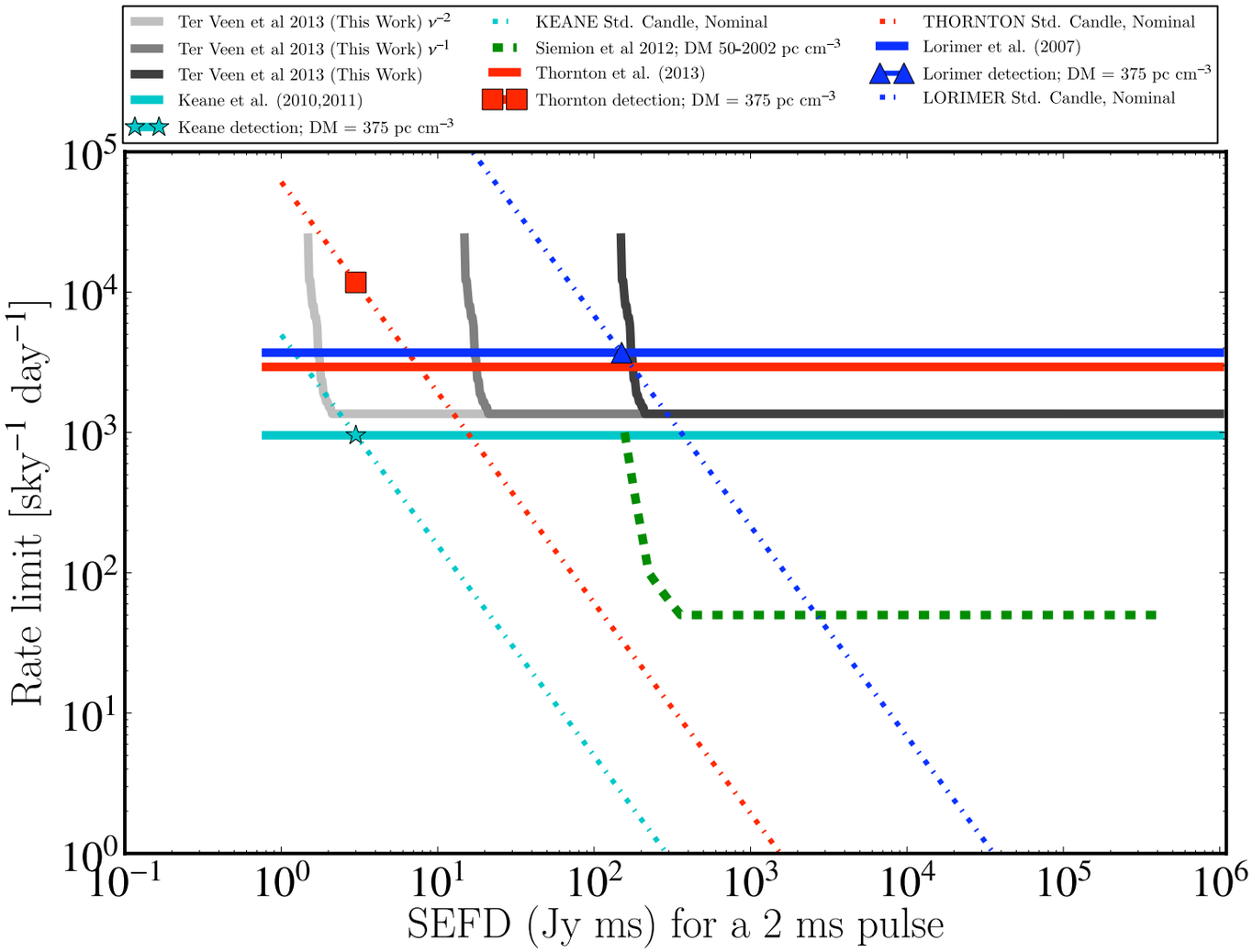
Initial LOTAAS observations set an upper limit on FRBs of 1800 events per sky per day up to a DM of 110 pc/cc.

Focusing on beamformed observations until COBALT can handle IM+BF

Backup

High DM triggers still need to be verified




Ter Veen et al 2013 (This Work) ν^{-2}
Ter Veen et al 2013 (This Work) ν^{-1}
Ter Veen et al 2013 (This Work)
Keane et al. (2010,2011)
Keane detection; DM = 375 pc cm^{-3}
KEANE Std. Candle, Nominal
Siemion et al 2012; DM 50-2002 pc cm^{-3}
Thornton et al. (2013)
Thornton detection; DM = 375 pc cm^{-3}
THORNTON Std. Candle, Nominal
Lorimer et al. (2007)
Lorimer detection; DM = 375 pc cm^{-3}
LORIMER Std. Candle, Nominal
Rate limit [sky^{-1} day^{-1}]
SEFD (Jy ms) for a 2 ms pulse