SETI in the solar neighborhood

with LOFAR

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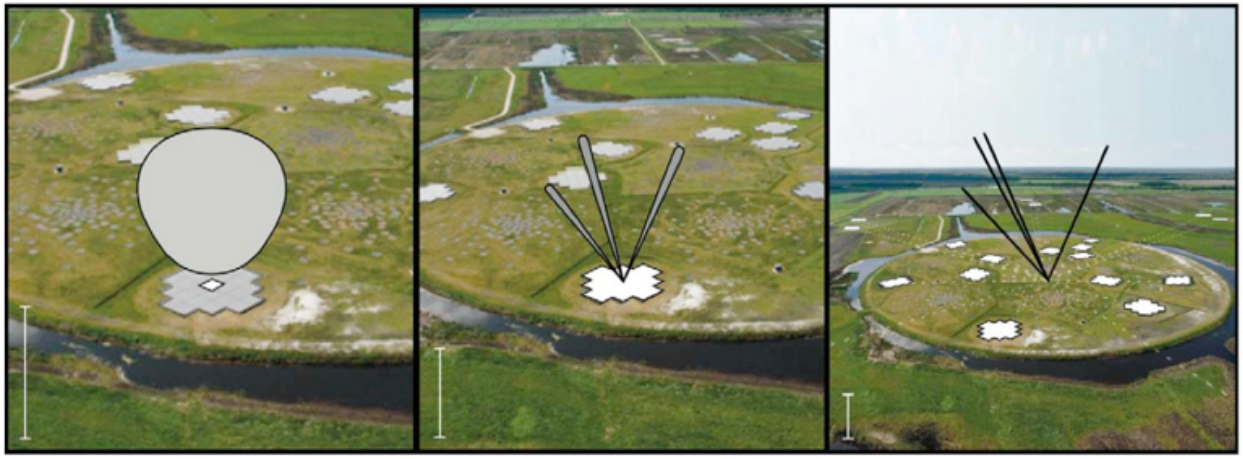


ASTRON
Netherlands Institute for Radio Astronomy

Radboud University Nijmegen

How common is intelligent life in the galaxy?

$$N = R^* \cdot f_p \cdot n_e \cdot f_l \cdot f_i \cdot f_c \cdot L$$

Frank Drake, 1961

R^* = the average rate of star formation per year in our galaxy

f_p = the fraction of those stars that have planets

n_e = the average number of planets that can potentially support life per star that has planets

f_l = the fraction of the above that actually go on to develop life at some point

f_i = the fraction of the above that actually go on to develop intelligent life

f_c = the fraction of civilizations that develop a technology that releases detectable signs of their existence into space

L = the length of time such civilizations release detectable signals into space

Sagan: "…the only significant test of the existence of extraterrestrial intelligence is an experimental one."

n_e hits towards common…

Based on *Kepler* ~5-50% of FGKM stars host an Earth-like planet.

e.g. Dressing et al 2013, Kopparapu 2013, Petigura et al. 2013

… but what about $f_l * f_i * f_c * L$?

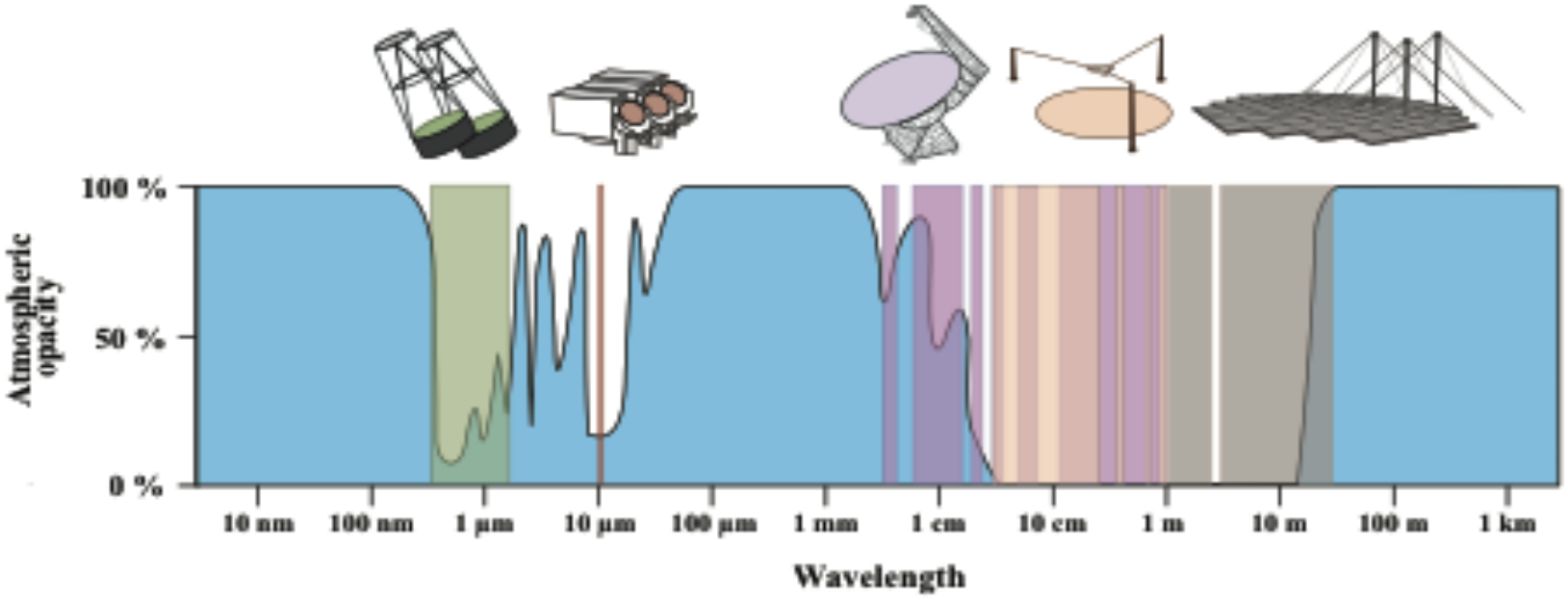
- From the lack of constraints, it is equally likely that we are the only civilization in the galaxy or that there are thousands of them.
- If intelligent life is common then nearby stars may show evidence of other civilizations. Even if the radio emission is not intentional, it can come in the form of radio leakage.

Low Frequency Radio SETI - leakage

- **United States Air Force Space Surveillance System "Space Fence"**
- 768 kW @ 217 MHz (originally 108 MHz)
- EIRP ~10^{10} W
- 120º x 1.5' Fan Beam (3000 times the solid angle of Arecibo Planetary Radar)

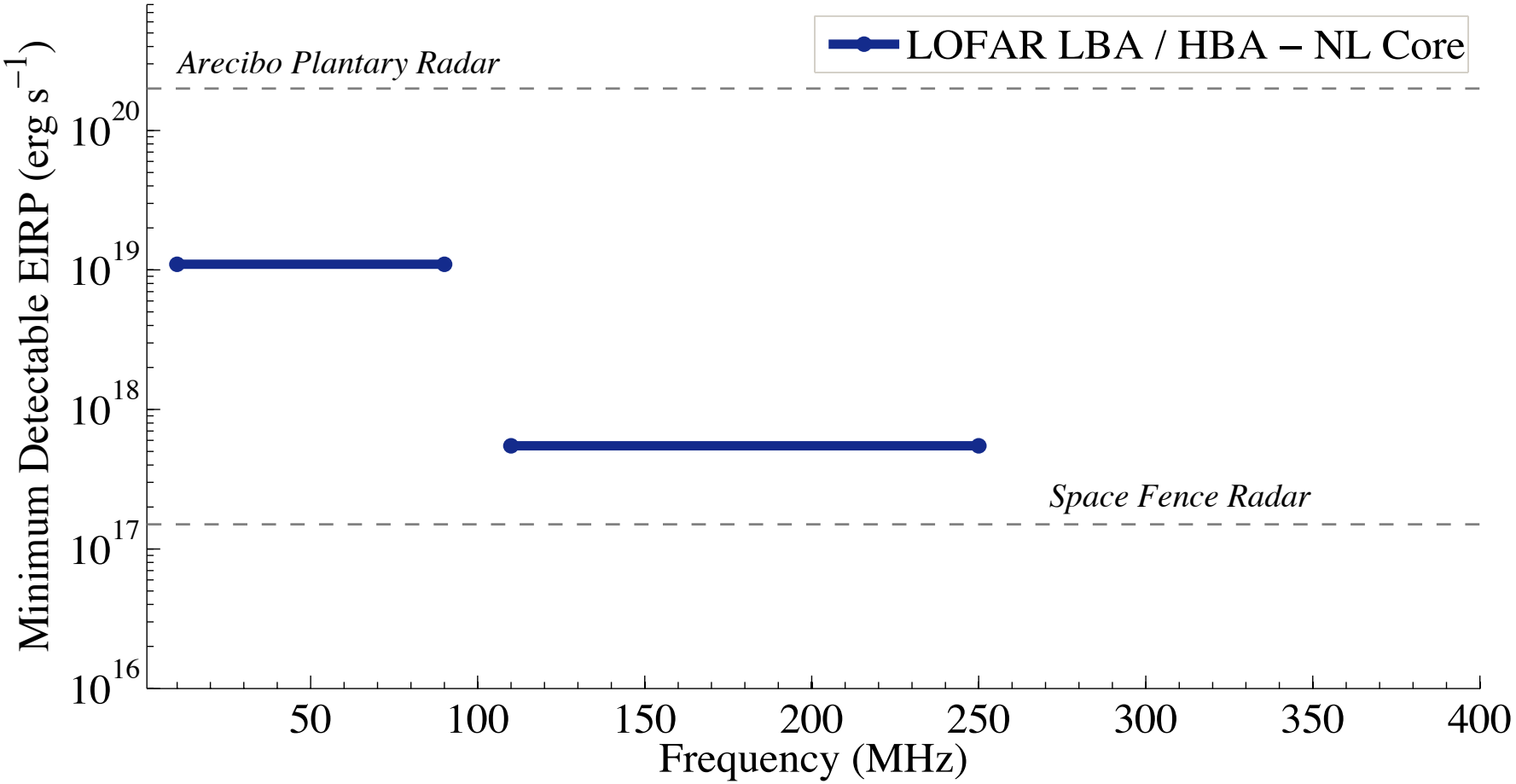
See also: Loeb and Zaldarriaga, 2006

The LOFAR frequency range

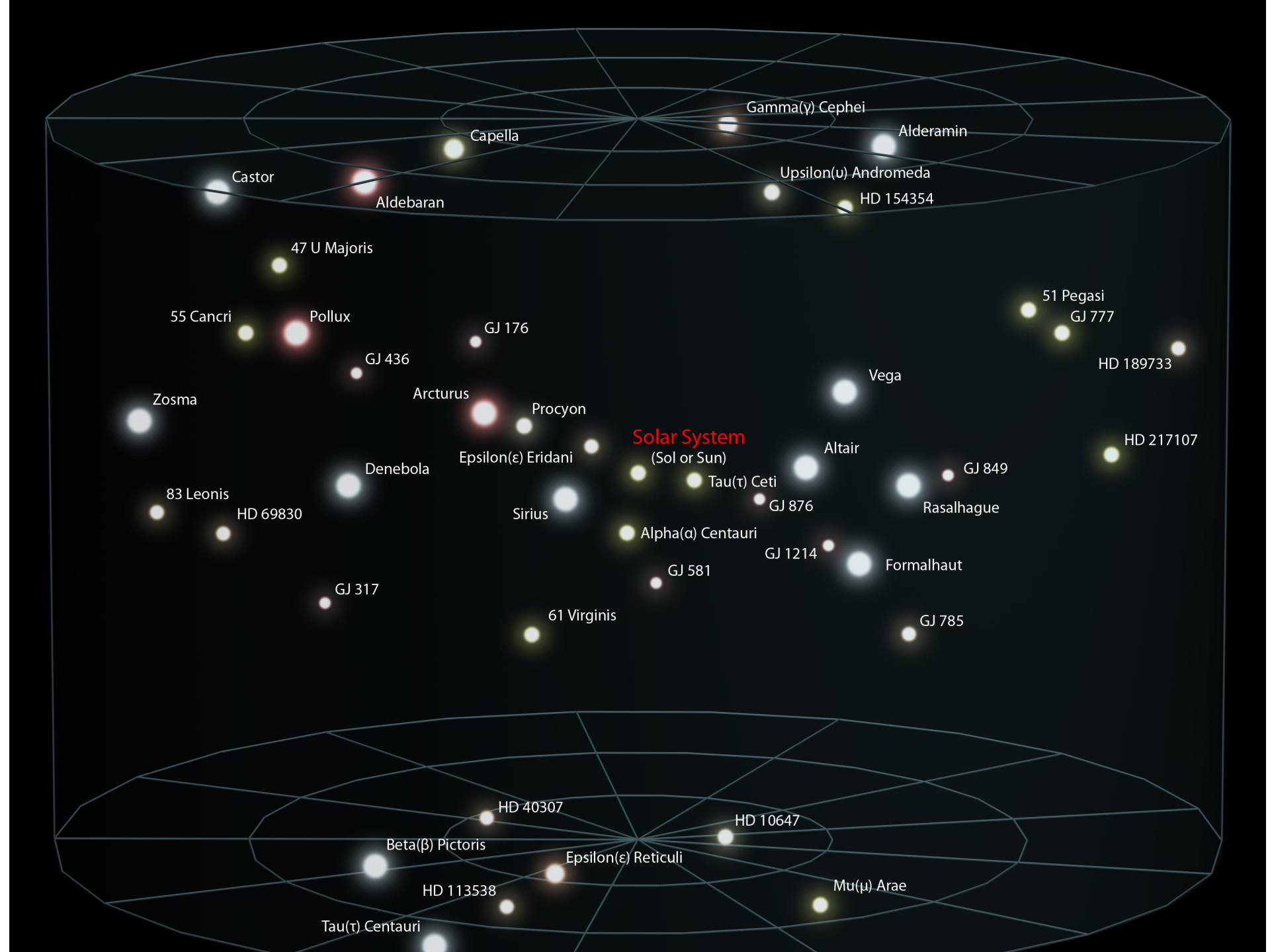


- First SETI experiment done at a wide range of low frequencies (or large wavelength).

How sensitive is the LOFAR Core?

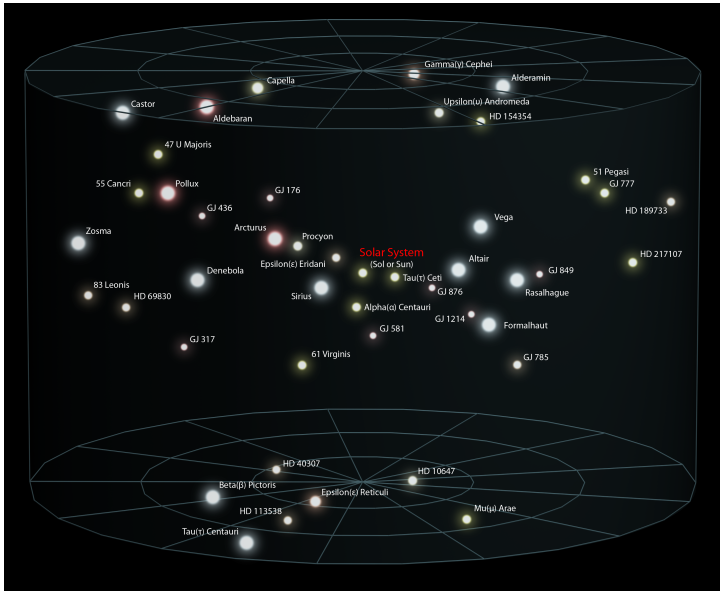


- Detection Threshold for a Star at 5pc (phased NL-core, SEFD 60 Jy w/ HBA, 1200 Jy LBA)

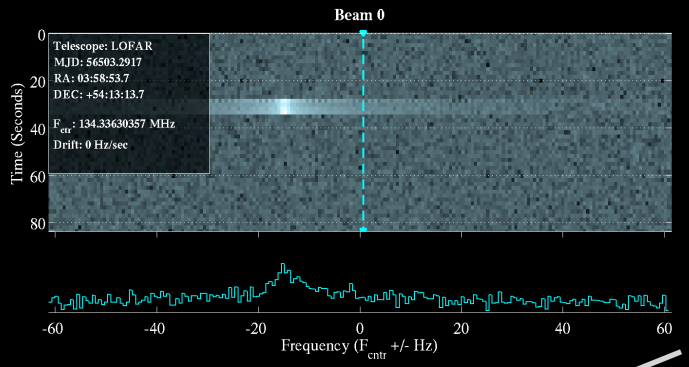

Gamma(γ) Cephei
Capella
Alderamin
Castor
Upsilon(υ) Andromeda
Aldebaran
HD 154354
47 U Majoris
51 Pegasi
55 Cancri
Pollux
GJ 777
GJ 176
HD 189733
GJ 436
Vega
Zosma
Arcturus
Procyon
Solar System
(Sol or Sun)
HD 217107
Epsilon(ε) Eridani
Altair
Denebola
GJ 849
Tau(τ) Ceti
83 Leonis
GJ 876
Rasalhague
HD 69830
Sirius
Alpha(α) Centauri
GJ 1214
Formalhaut
GJ 581
GJ 317
61 Virginis
GJ 785
HD 40307
HD 10647
Beta(β) Pictoris
Epsilon(ε) Reticuli
HD 113538
Mu(μ) Arae
Tau(τ) Centauri

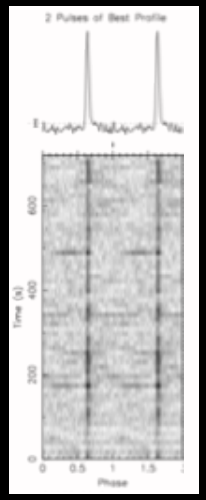
SETI in the solar neighborhood with LOFAR

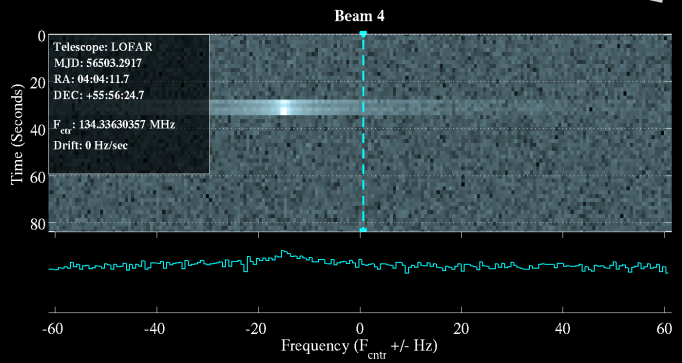
- Observations of all stars systems within 5pc (16.3 light years)
- Observations conducted between Aug. 2014 - Sep. 2014
- 10 - 250 MHz, LBA and HBA
- 12 min recording of CV data = 100TB! (or 400 laptops)
- Tied-array Mode with Core Stations

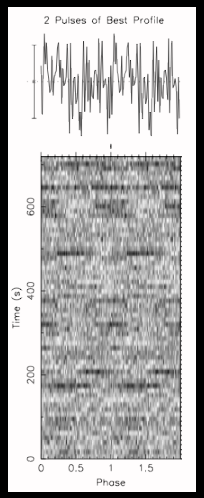


Observing Strategy



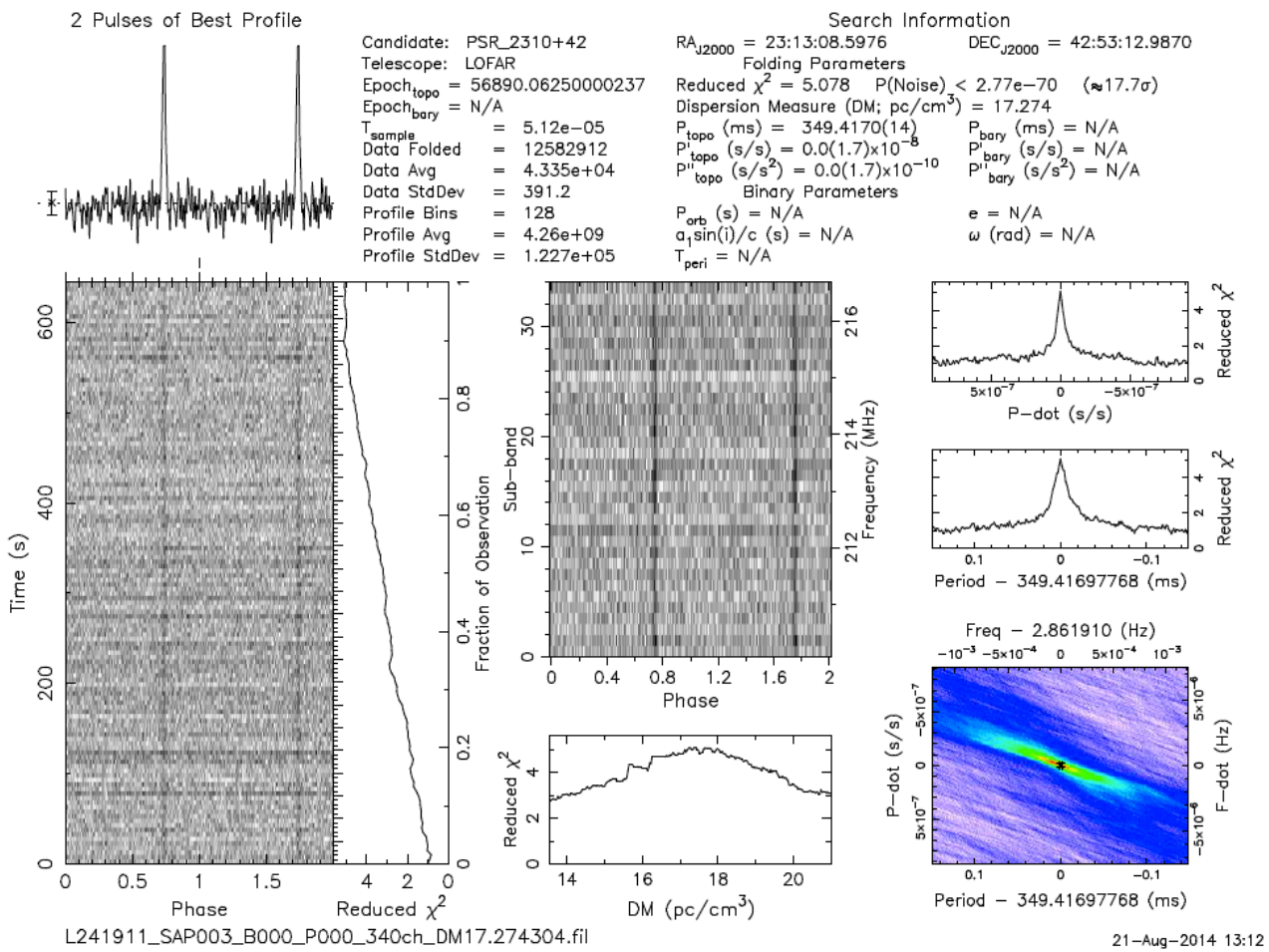






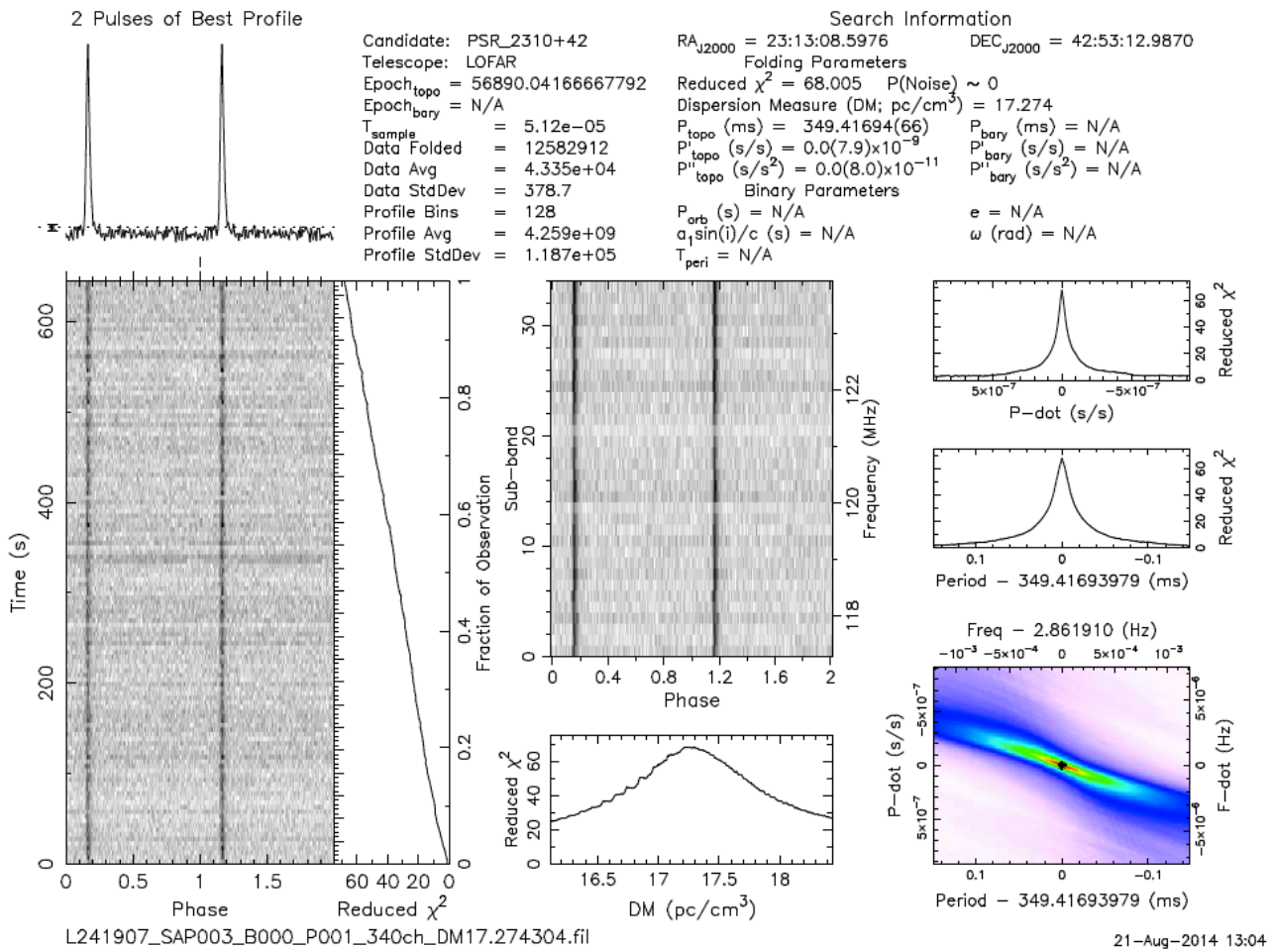
- Fields Chosen to be Coincident with a Bright Pulsar for Diagnostics
- Multi-beaming: Astronomical Sources Only Appear in a Single Beam, Interference in Many Beams
  → Excellent RFI Rejection

Pulsar Detection Dependence on frequency



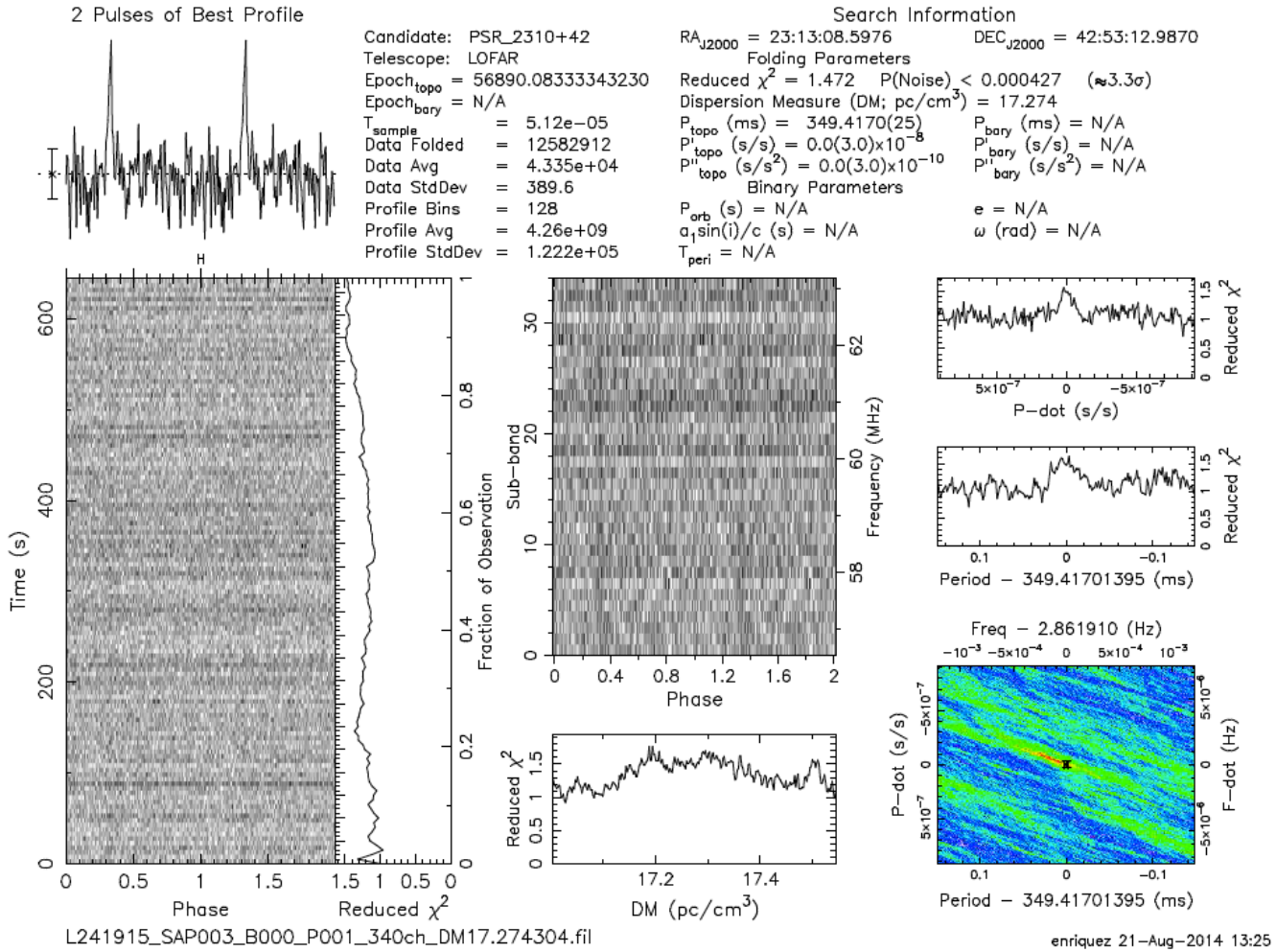
- PSR 2310+42
- 210 – 217 MHz

Pulsar Detection Dependence on frequency



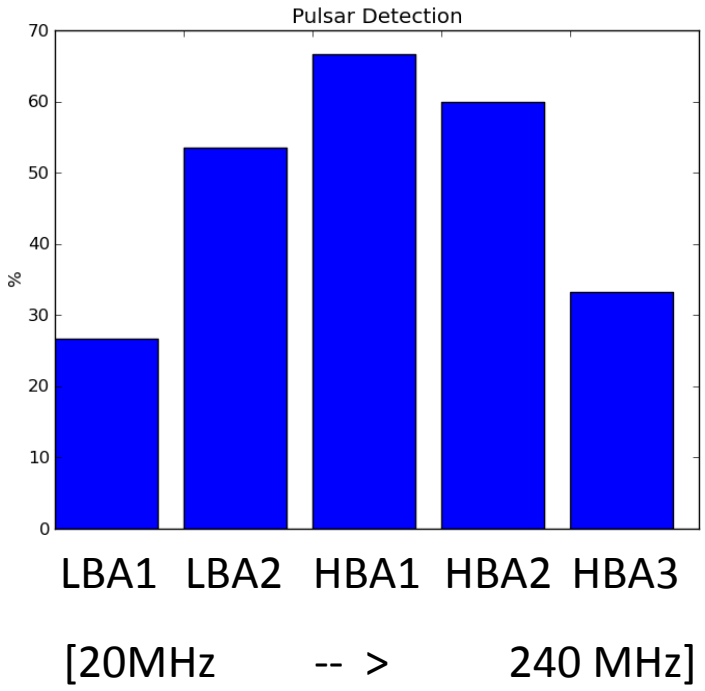
- PSR 2310+42
- 117 – 124 MHz

Pulsar Detection Dependence on frequency



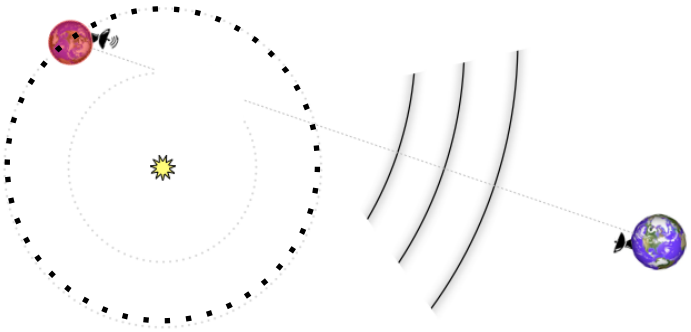
- PSR 2310+42
- 56 – 63 MHz

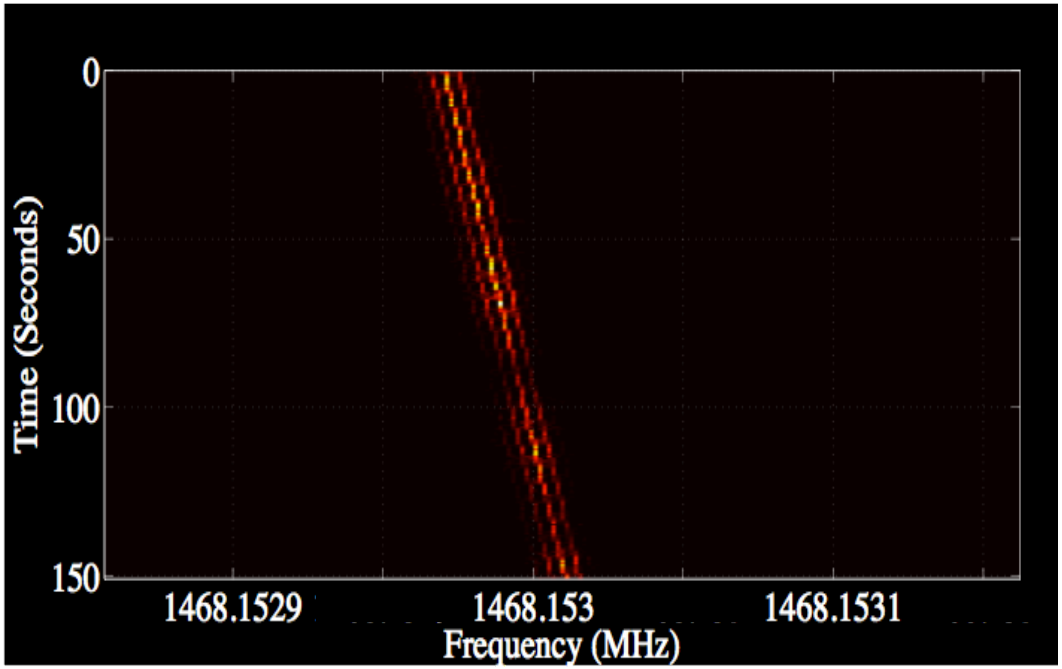
Pulsar Detection Dependence on frequency



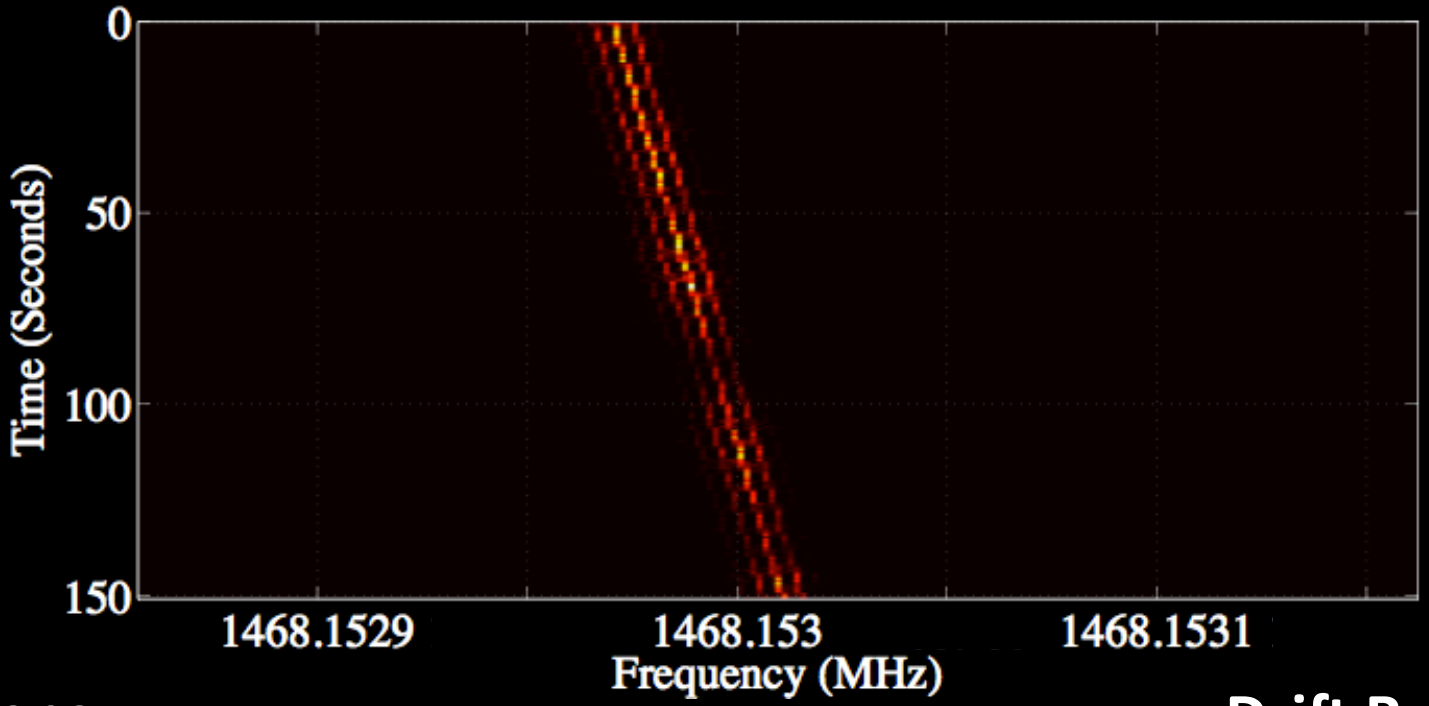
- Pulsar detection based on a single band of 7MHz.
- Increased sensitivity by adding the full bandwidth of 41 MHz. This done after processing with a different pipeline only on few selected targets.

Narrow-band Signal Search - representative example

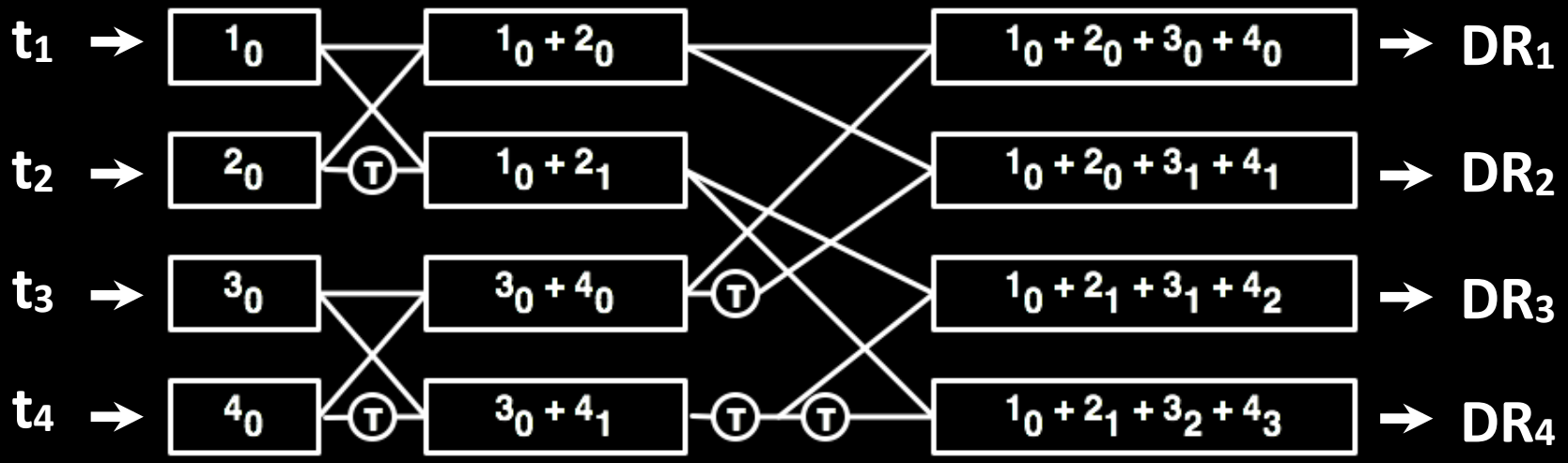




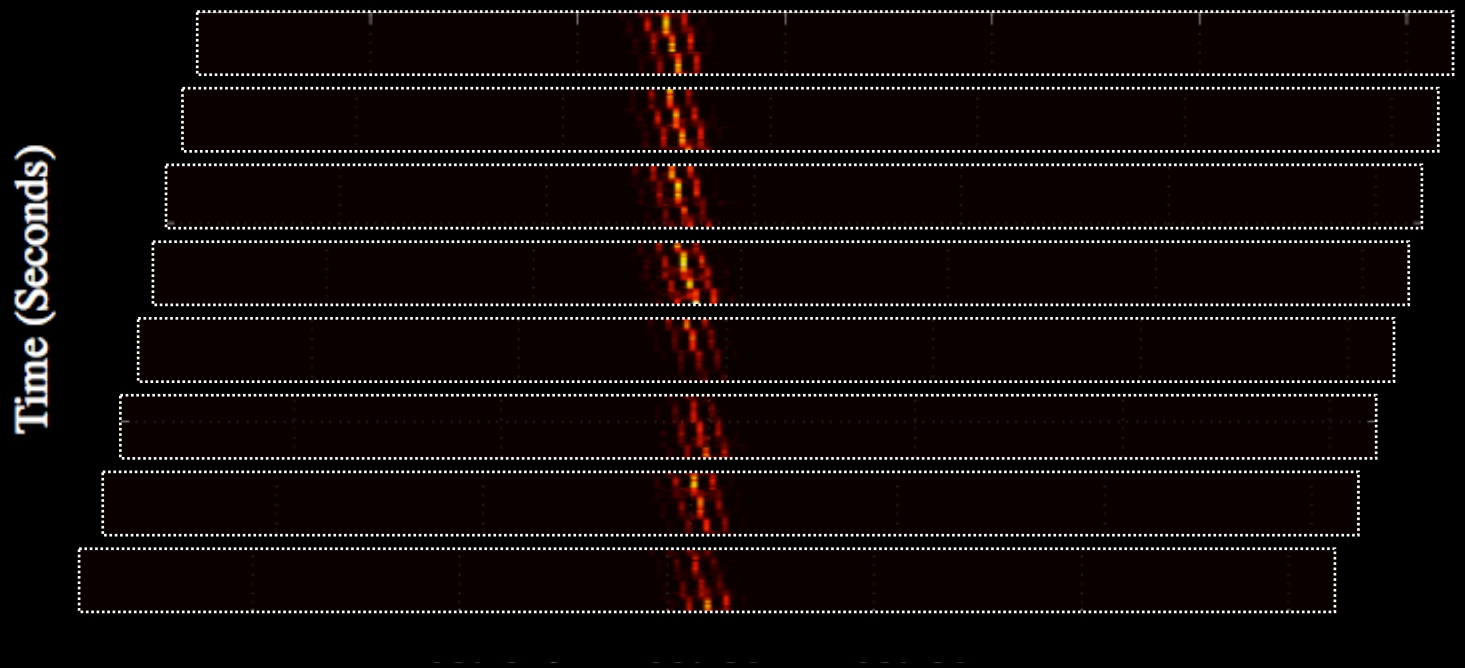
- Narrow band signals → artificial
- Can assume rotation around host stars
- Drifting signals

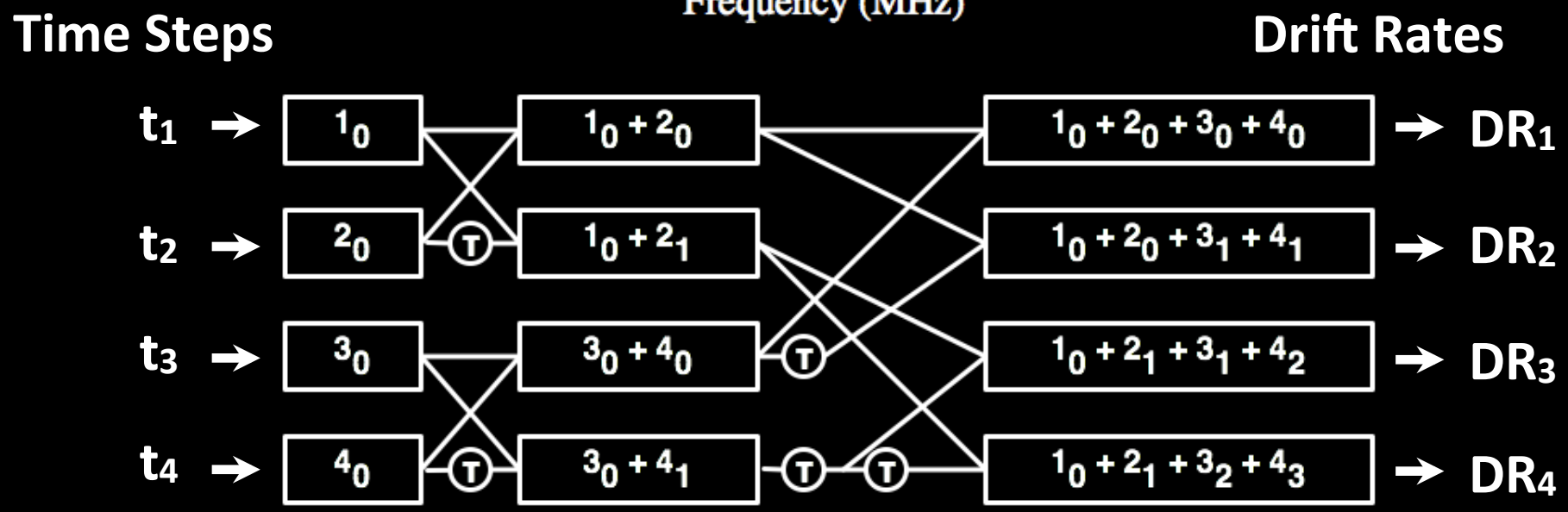


Time Steps **Drift Rates**



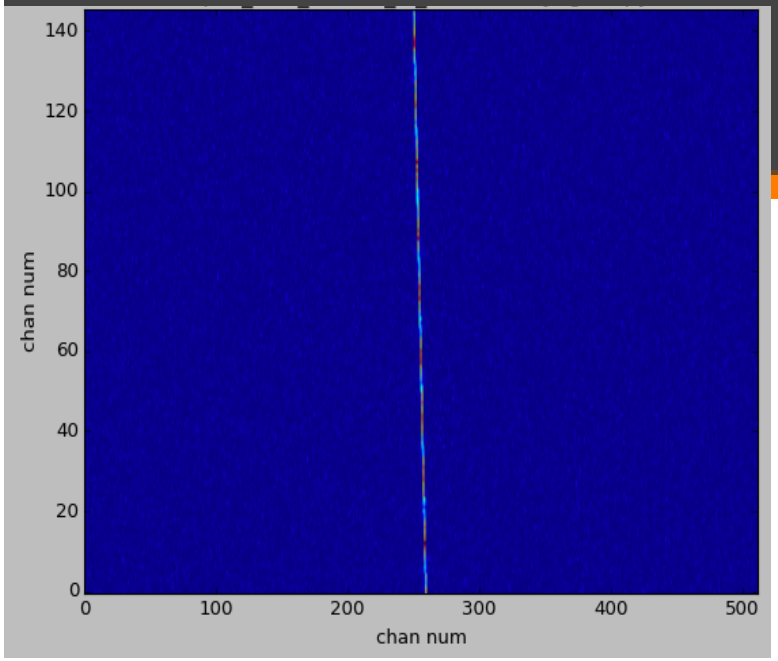
Taylor, 1974

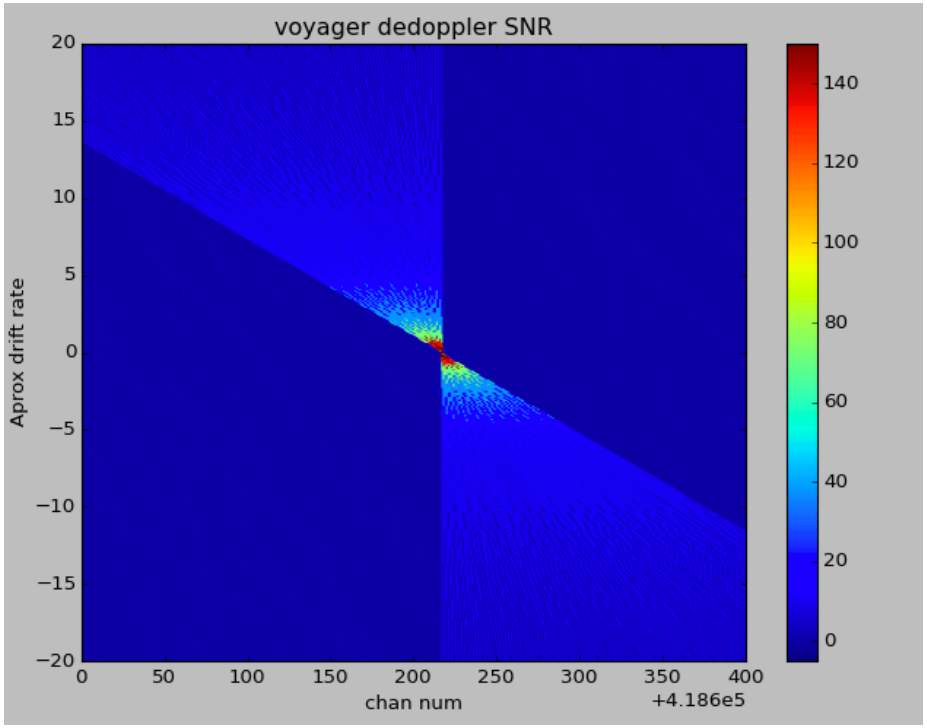

Time (Seconds)
Frequency (MHz)

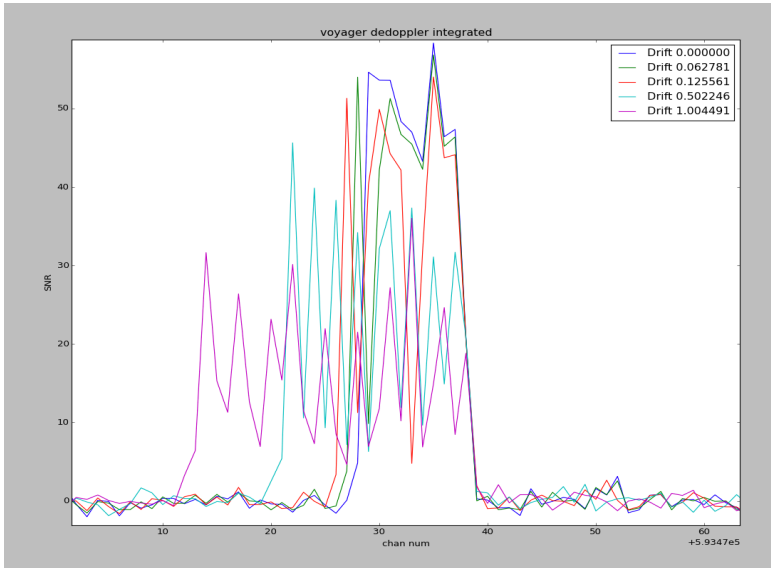

Time Steps
Drift Rates
t1
t2
t3
t4
10
20
30
40
10 + 20
10 + 21
30 + 40
30 + 41
10 + 20 + 30 + 40
10 + 20 + 31 + 41
10 + 21 + 31 + 42
10 + 21 + 32 + 43
T
DR1
DR2
DR3
DR4

Taylor, 1974

GBT – Voyager data

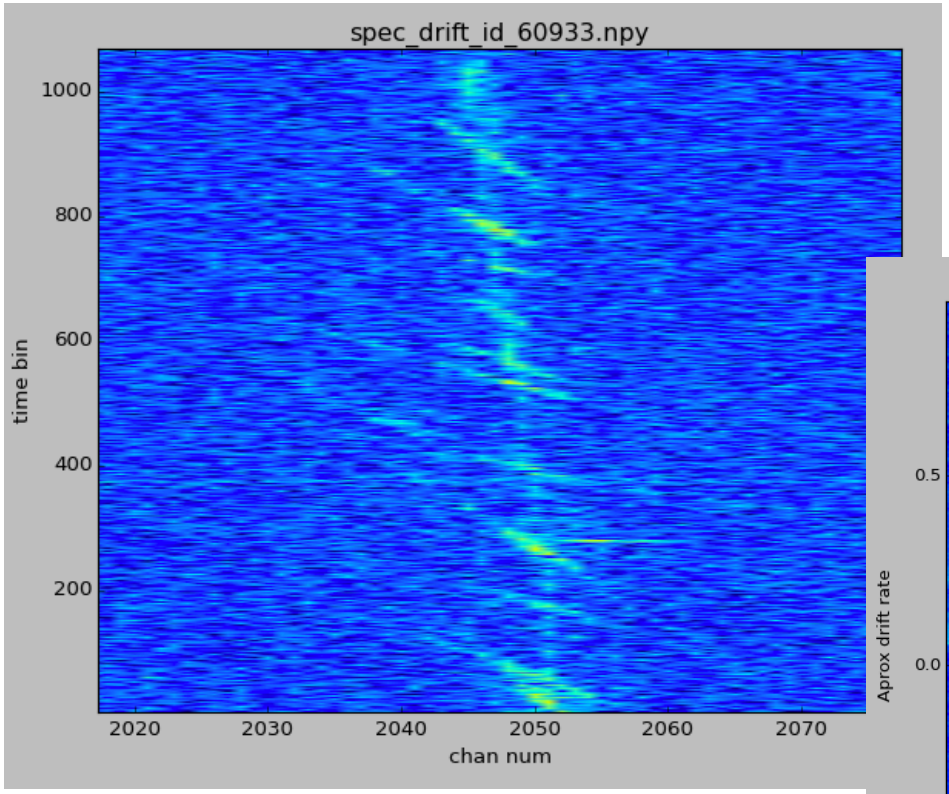


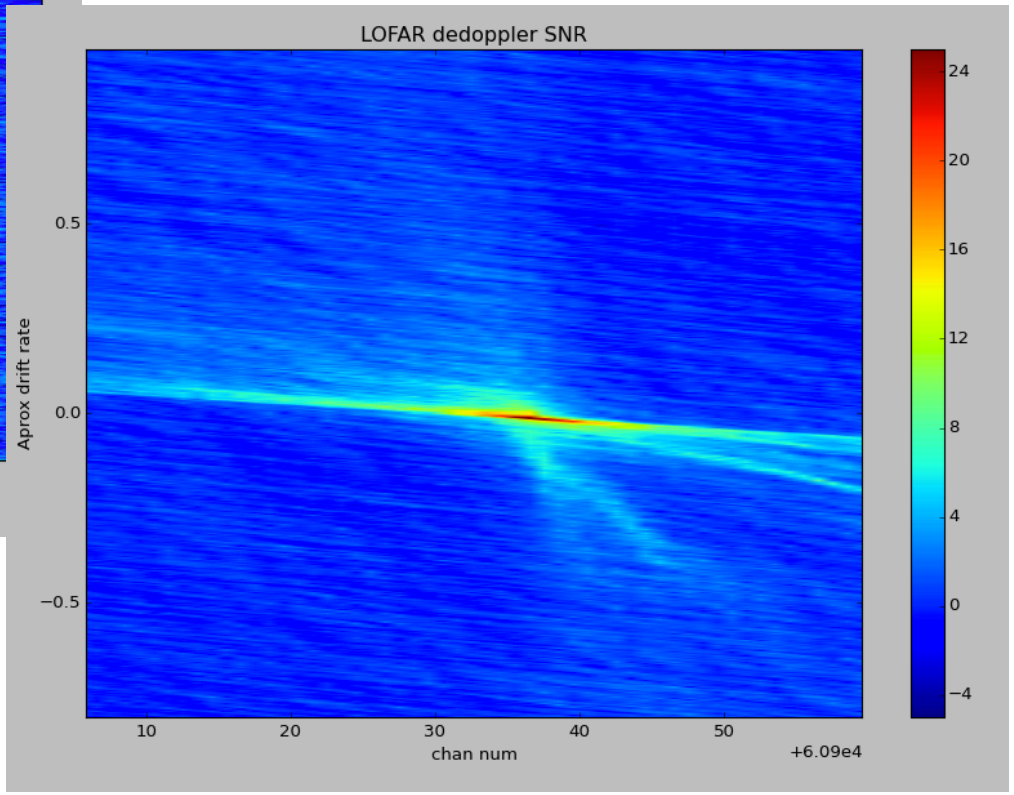




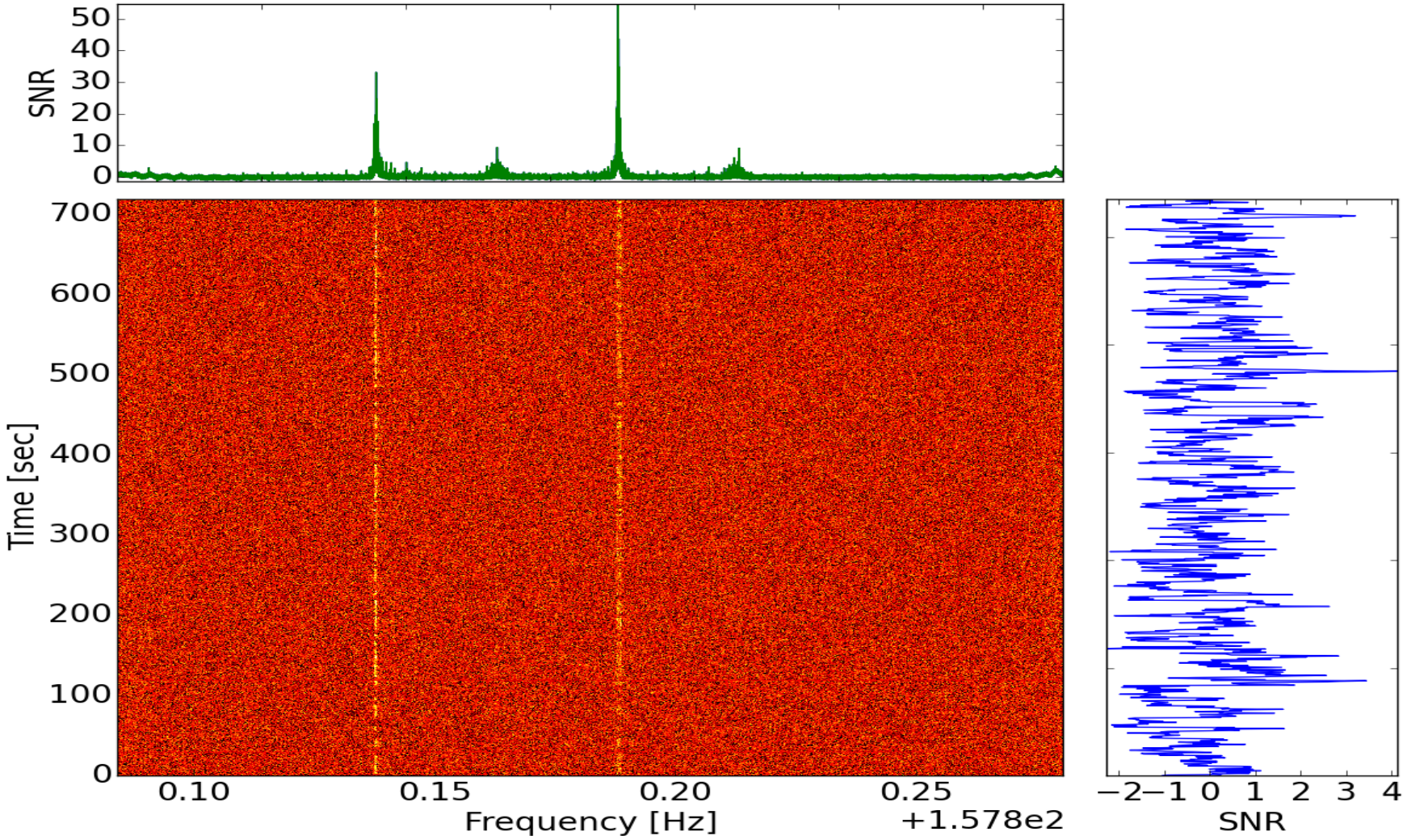
- Drift rate vs frequecy show our algorithms are working well !
- And may give extra information on the signal.

LOFAR

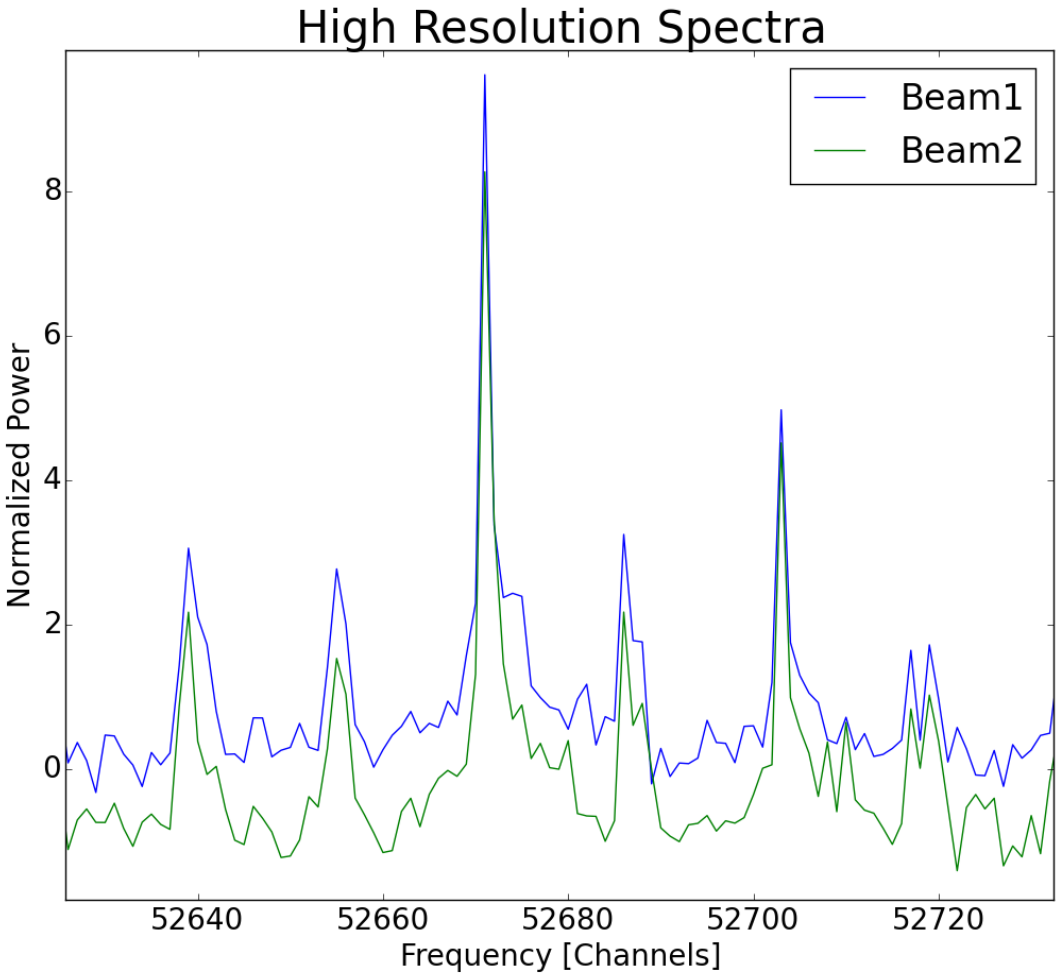

spec_drift_id_60933.npy
time bin
1000
800
600
400
200
2020
2030
2040
2050
2060
2070
chan num


LOFAR dedoppler SNR
Aprox drift rate
0.5
0.0
−0.5
10
20
30
40
50
+6.09e4
chan num
24
20
16
12
8
4
0
−4

LOFAR Single Subband - Dedoppler search unit



Multi-beam RFI Rejection



- Threshold search with 5 sigma ~ 10 hrs per subband.
- Threshold search with 3 SNR ~ 8 days!!

Computation time is important!

- 10 (hours) x 204 (subbands) x 4 (beams) x 80 (obs) = 2 years with a single computer!
- Using SURFSara computing facilities (in Amsterdam)
- Awarded
  - 100k hours Grid
  - 100K Hadoop

SURF SARA

Multi-beam RFI Rejection

- From a 5 SNR threshold, the rejection rate from multi-beam is about 88%.
- We are looking into other techniques to search the remaining 12 %
- Multi-beam has great potential and will be useful in future observatories (SKA).