VLBI观测中的快速射电暴搜索管线

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中国科学院上海天文台
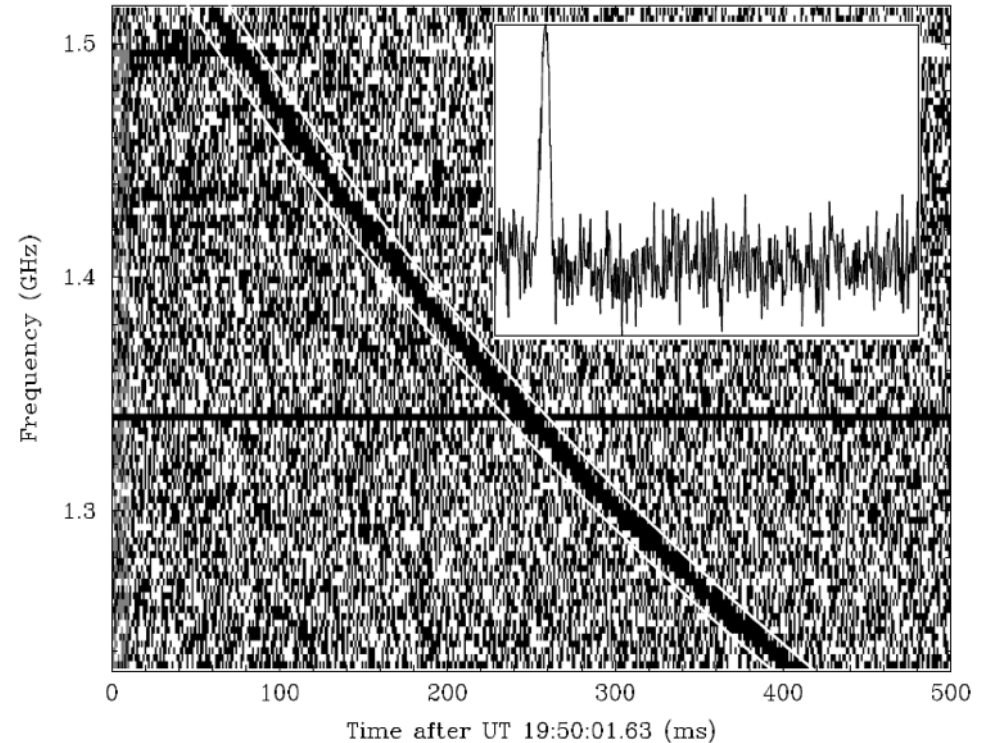
2019年11月29日于黑龙江大庆

Outline

- Single pulse search method

- Pipeline

  - EVN observation EL060

Fast Radio Burst (FRB)

- High energy
  - 0.1 ~ 100 Jy
- High dispersion measure
  - > 100 pc/cm^3
- Short duration
  - several milliseconds

- ~ 100 events
- ~ 10 repeating bursts
- Cosmological origin?
  - DM$_{MW}$ < 80 pc/cm3
    (Prochaska & Zheng 2019)

FRB 010724 (Lorimer et al. 2007)

$$t_1 - t_2 \sim DM \times (\frac{1}{f_2^2} - \frac{1}{f_1^2})$$

FRB search: large single dish telescope

Parkes 65 m
0.15deg @ 18cm

Arecibo 305 m
0.03 deg @ 18cm

GBT 100 m
0.1 deg @ 18cm

FRB search: wide field array

UTMOST
7.8 deg^2
15" X 8.4 deg @ 800 MHz
9 events
(Caleb et al. 2017;
Farah et al. 2019)

ASKAP
30 deg^2
10' X 10' deg @ 1.3 GHz
28 events
(Shannon et al. 2018;
Macquart et al. 2019)

CHIME
250 deg^2
0.3 deg @ 600 MHz
21 events (8 repeating)
(CHIME/FRB collaboration 2019a, b)

VLBI: Very Long Baseline Interferometry

- Astronomy and astrophysics
  - Event Horizon Telescope (EHT)
  - Square Kilometer Array (SKA)

M87 Center

- Deep space exploration
  - Chinese Lunar Exploration Project (CLEP)
  - MEX, VEX

- Geodesy (Geodetic VLBI)
  - Earth orientation parameters (UT1, polar motion)
  - Plate movement
  - 1 session: 10 stations, 24 hours, 10 TB

FRB search: VLBI

- ## Auto spectrum
  - PRESTO
  - V-FASTR, LOCATe

- ## Cross spectrum
  - Imaging method: *realfast*
  - Non-imaging method: this work

Chatterjee et al. (2017)
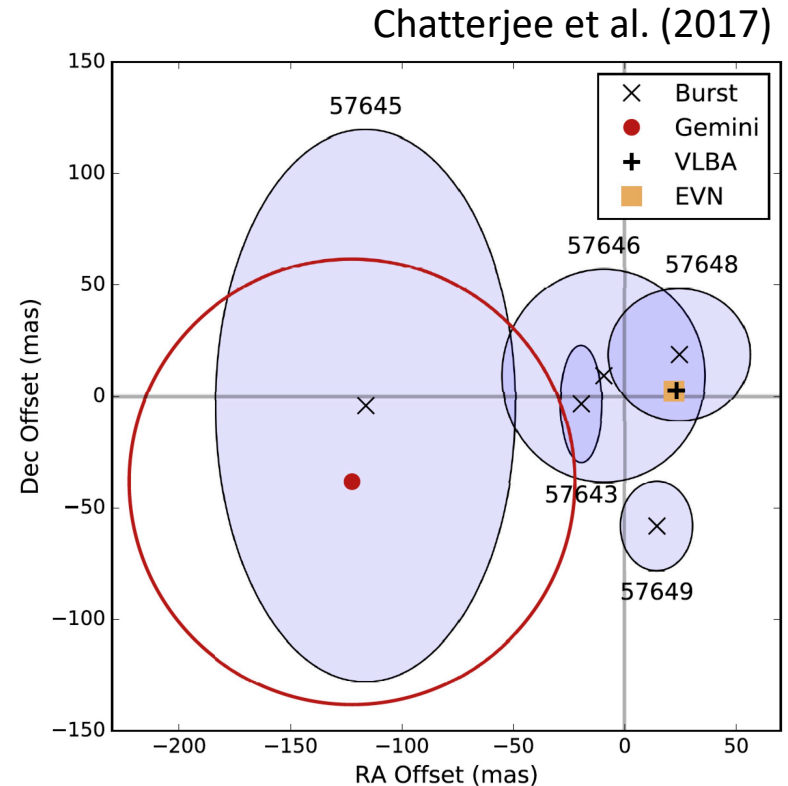
Non-imaging single pulse search method

- Independent search and localization
  - Inspired by geodetic VLBI data processing
  - Fringe fitting to maximize signal power
  - Geodetic solving for localization
- Extract signal from RFI contaminated data
- Fast speed, large searching area support

	Baseline (km)	Resolution* (mas)	Map size** (pixel)
VLA	36	781.7	2880
CVN	3000	9.4	240000

* S band (2.2GHz, 13.6 cm)
** Pixel size ¼ resolution; half FoV
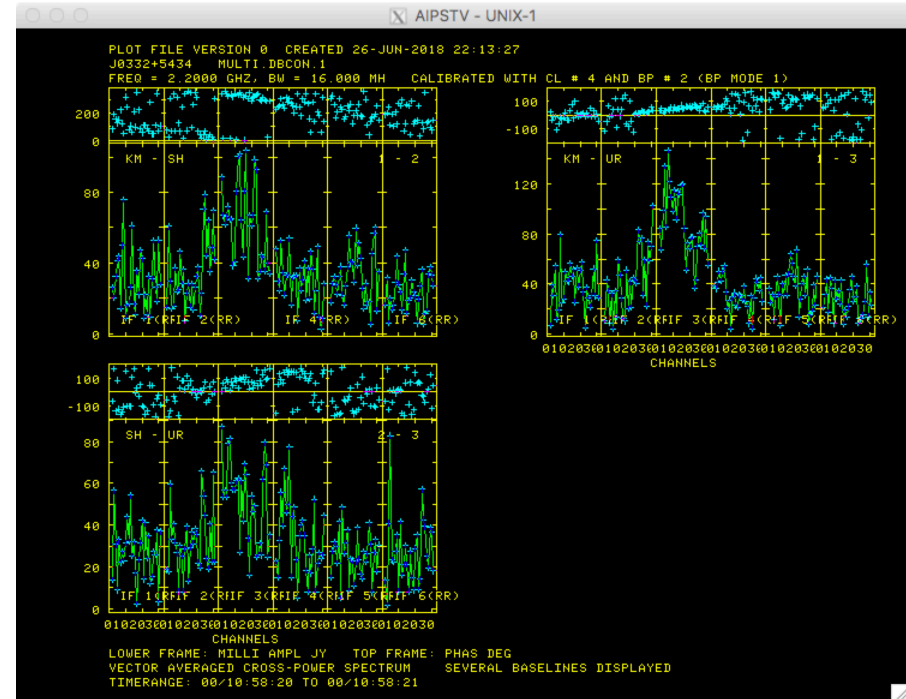
Searching pipeline
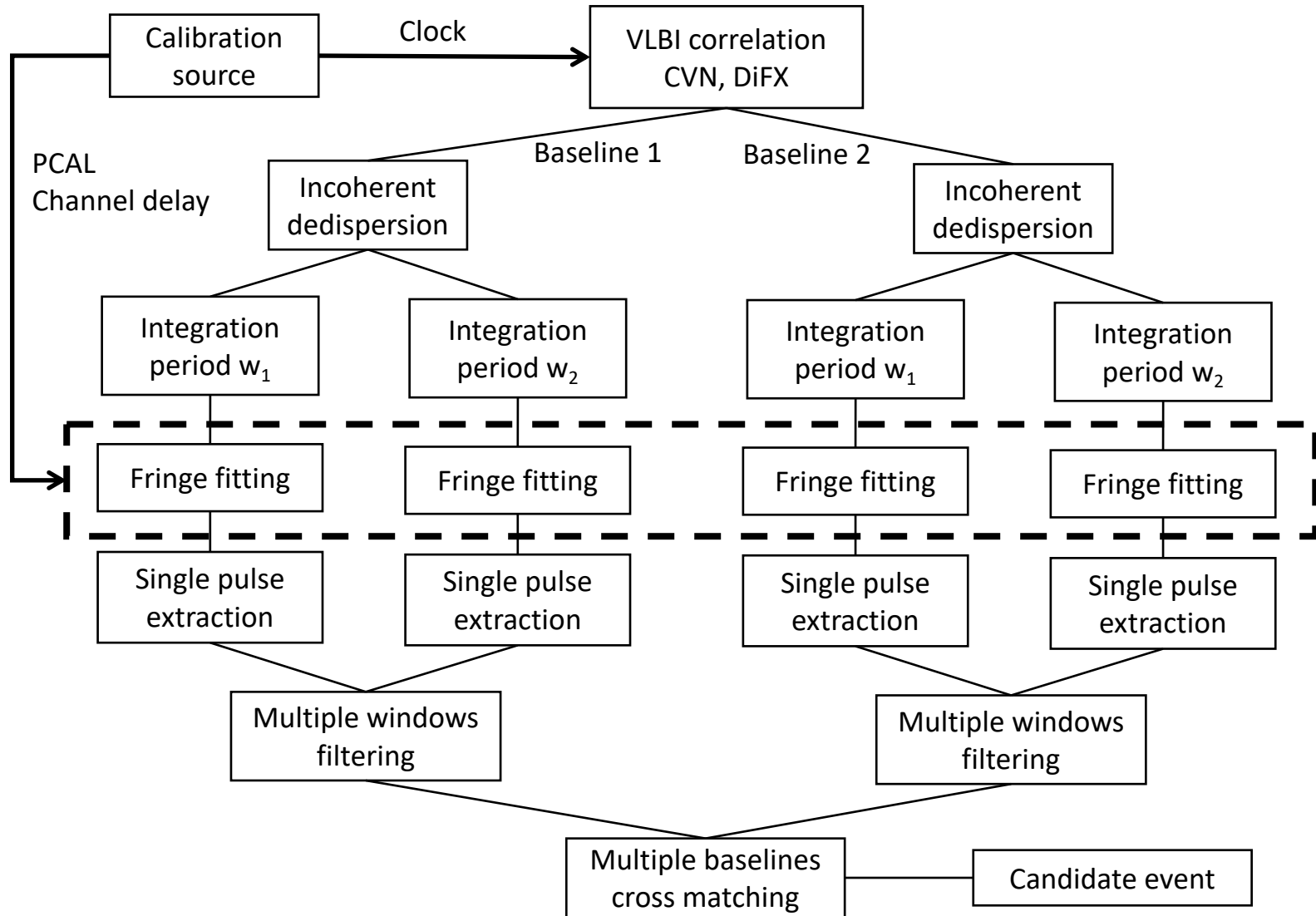
Fringe fitting
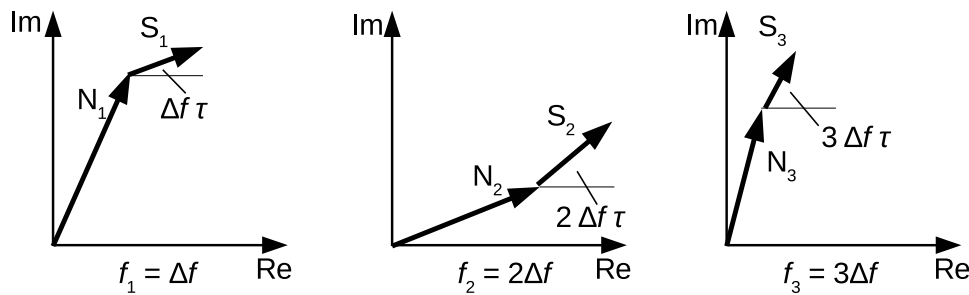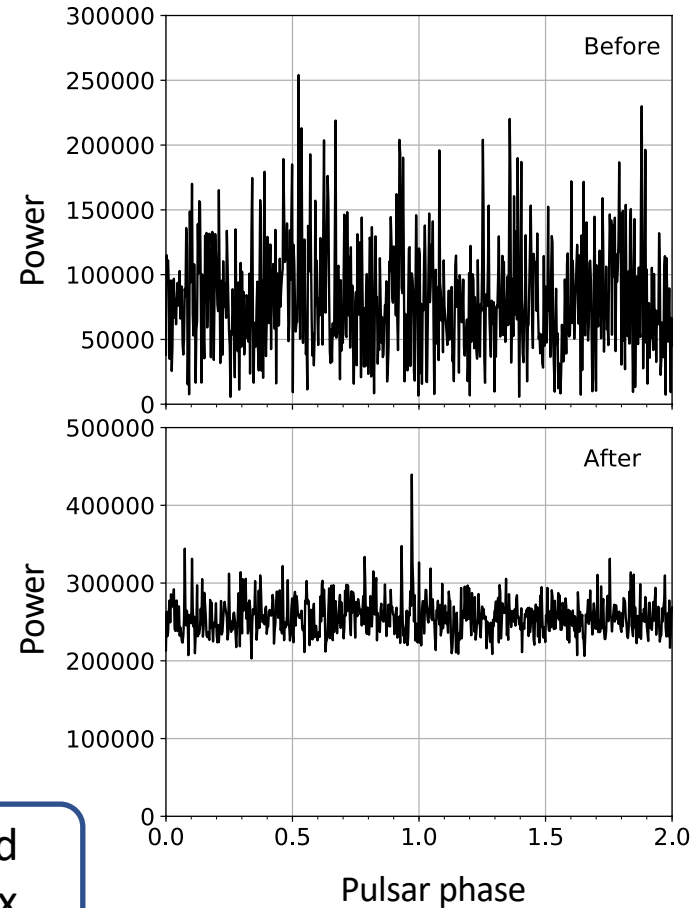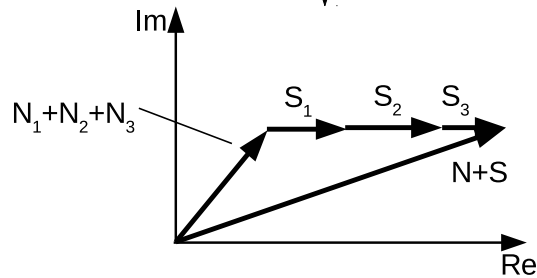
- 58593 FFTs per baseline (4 ms AP, ~ 240 s per scan)
- 66 baselines (12 stations)
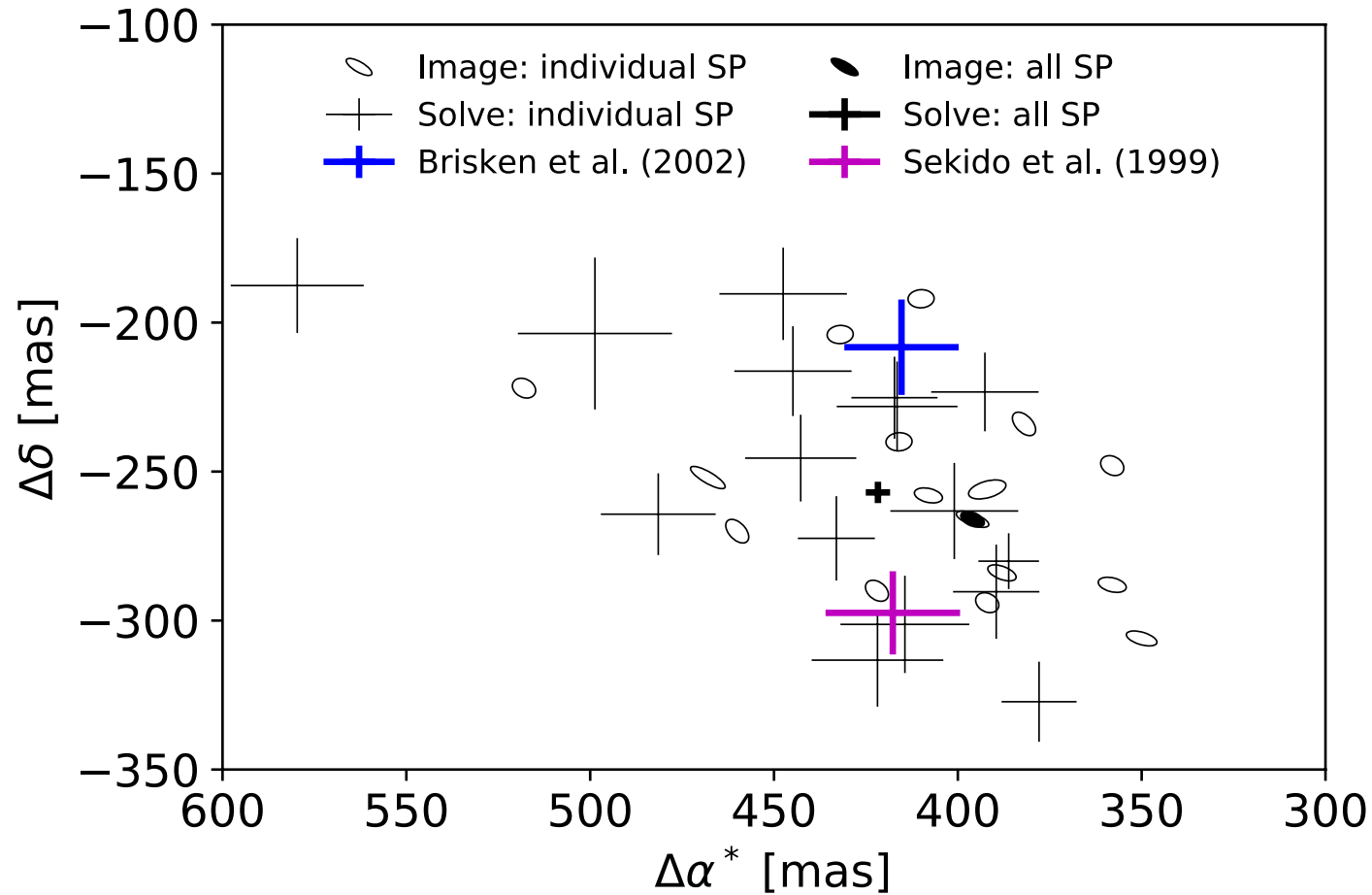- Multiple dispersions (100 – 1000 pc/cm^3)

Localization: geodetic solving

- Phase reference calibration with AIPS

- Fit fringe phase to derive group delay ($\Delta\tau$)

- Calculate partials: $\dfrac{\partial\tau}{\partial\alpha}$ and $\dfrac{\partial\tau}{\partial\delta}$

- Solve linear equations:

$$\Delta\tau = \frac{\partial\tau}{\partial\alpha}\Delta\alpha + \frac{\partial\tau}{\partial\delta}\Delta\delta$$

Localization:
comparison with references

Liu et al. 2019, AJ, arXiv:1810.08933

FRB search in VGOS

- VGOS: VLBI Global Observation System

  - Large FoV

  - 24 hours continuous observation

  - Large bandwidth

- Fluence limit: 5.3 Jy ms (0.755 Jy, 7 ms)

- 2.78 events per year*

- 0.015 – 0.8 events per year**

- FFT size: > 3551 (32 MHz bandwidth)

VGOS antenna @ GGAO

- Diameter: 12 m diameter

- BW: 512 MHz (dual polarization)

- Band: 2 – 14 GHz, 4 bands

- SEFD: 2000 Jy

*Keane & Petroff (2015): 2500 events (> 1.4 GHz, > 2 Jy ms)

Caleb et al. (2017): spectral index 0.0, fluence index -1.0

**Luo et al. (2018)

Single pulse search: summary

- Geodetic VLBI based method: extracting single pulses from RFI contaminated data

- Localization
  - 4 ms integration
  - 2 or 3 baselines
  - 100 mas accuracy

- FRB search in VGOS: promising in science; feasible in technology

EVN (European VLBI Network) observation

- Task: EL060

- Mar. 11, 2019, 05h – 08h

- Jb, Wb, Ef, Mc, O8, Tr, Hh, Sv, Zc, Bd, Sr, Ir

- L band: 1594.49 MHz – 1722.49 MHz, 128 MHz, LCP, RCP

- Raw data
  - RRAT + pulsar + calibration + reference: 11 TB

- Correlated
 - RRAT: ~250 GB per scan, 16 scans, 4 TB total
  - Pulsar: 112 GB (scan 50)

RRAT	Flux (Jy)	DM (pc/cm^3)	Burst rate (1/h)
J1819-1458	3.6	196	16.02
J1854+0306	0.54	216	35.99

Total RRAT obs. time: ~80 min

Pulsar	Flux (Jy)	DM (pc/cm^3)	Period (s)
J0332+5434	0.1	26.833	0.7145

VOLKS pipeline

- VLBI Observation for frb Localization Keen Searcher
- DiFX/CVN support
- Single pulse search and localization (imaging, solving)
- Open source:
  - **`github.com/liulei/volks`**
- Python + numpy
- Running on clusters (mpi4py)
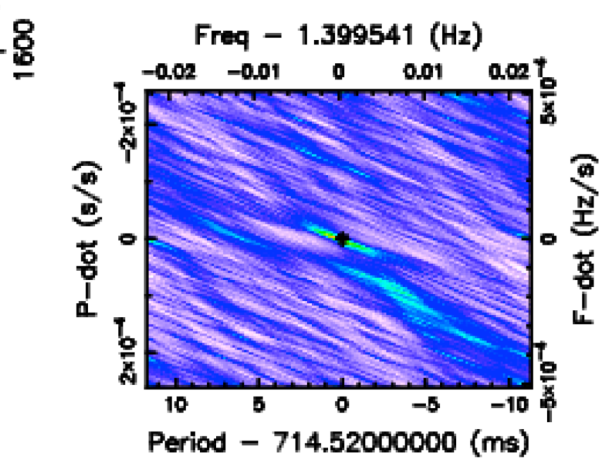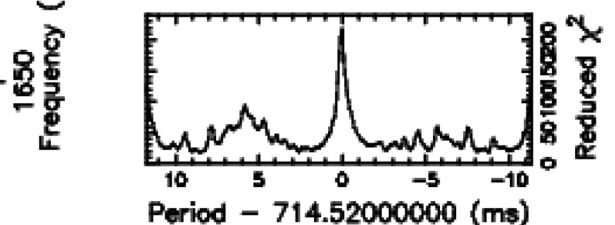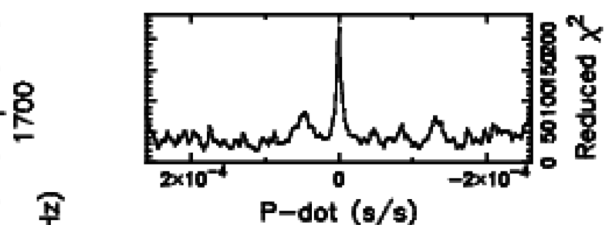- High scalable, automatic load balance
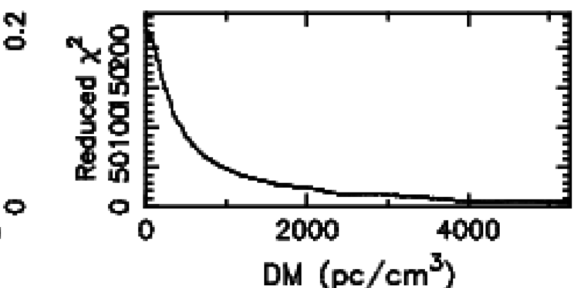- difx2fb, data visualization
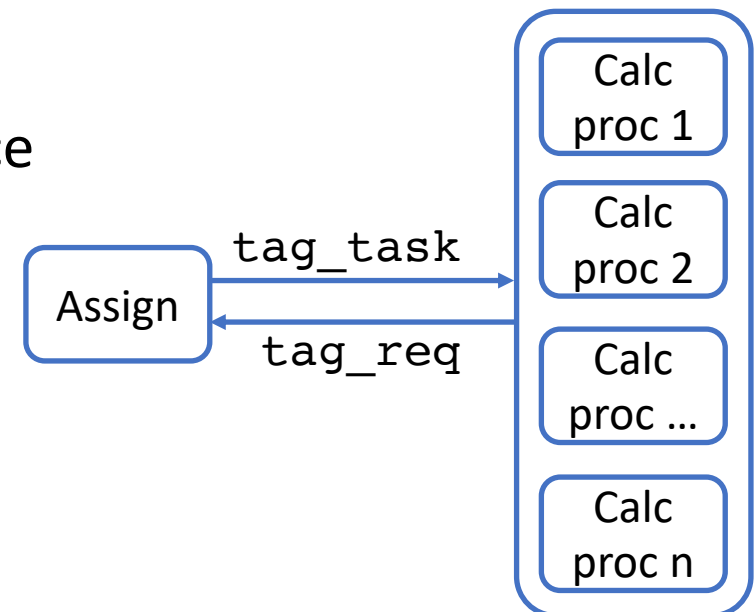
2 Pulses of Best Profile

Search Information
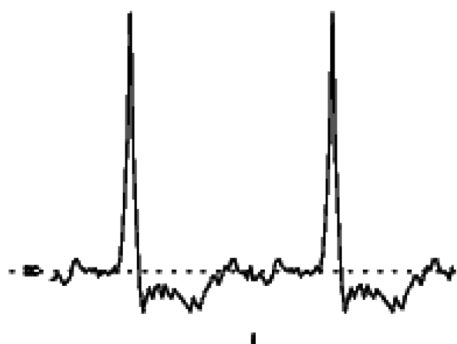
Candidate: 714.52ms_Cand
Telescope: Unknown
Epoch$_{topo}$ = 58553.32740741334
Epoch$_{bary}$ = N/A
T$_{sample}$ = 0.001024
Data Folded = 172800
Data Avg = 6.479e+04
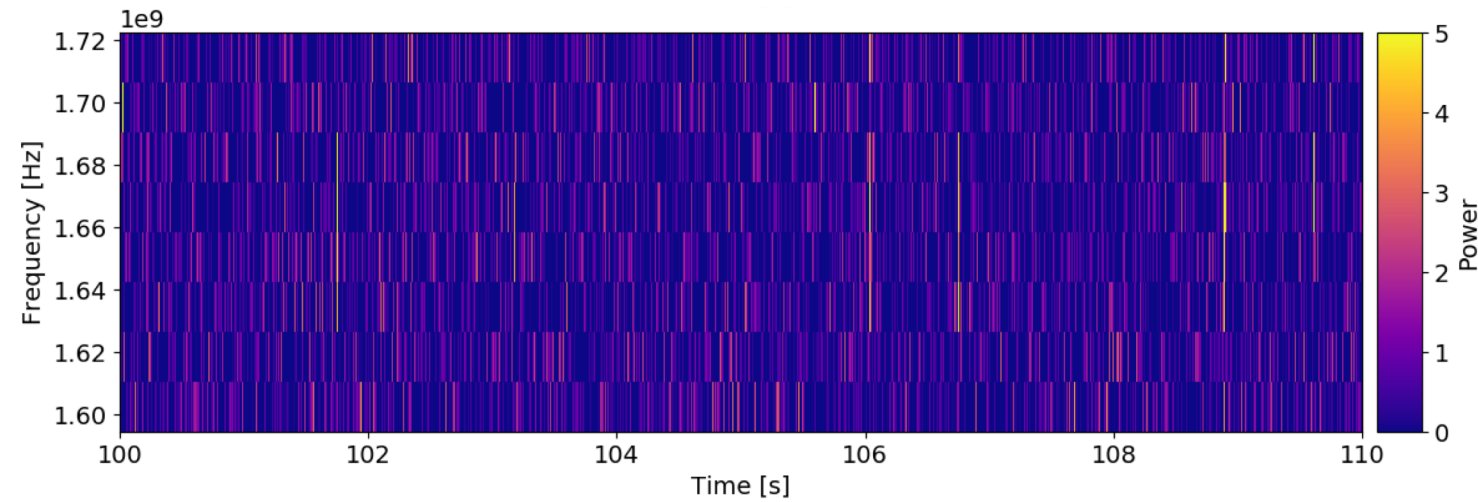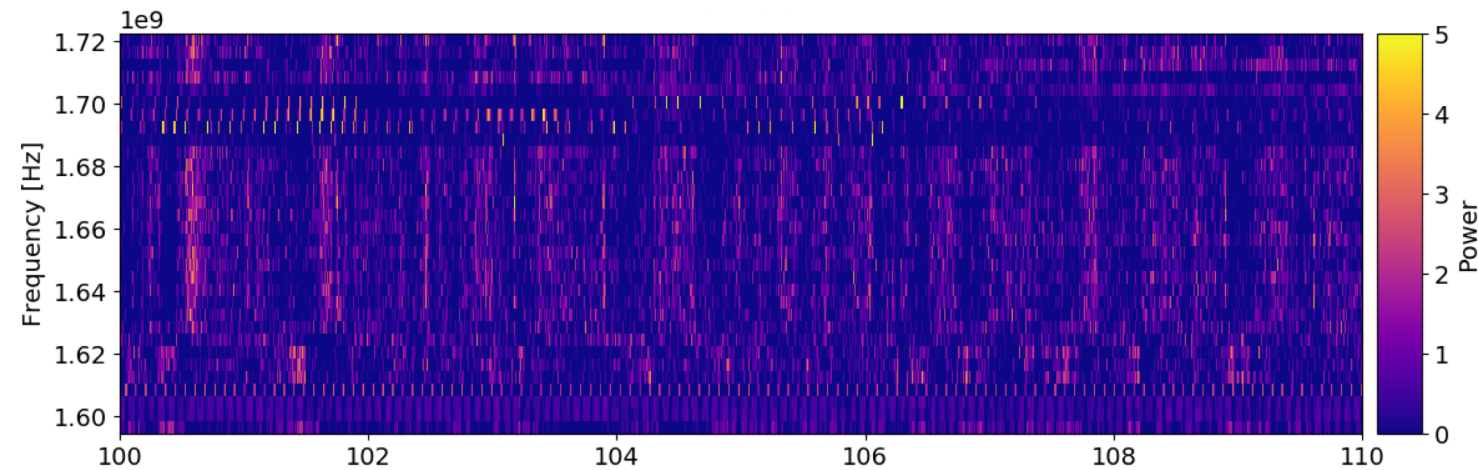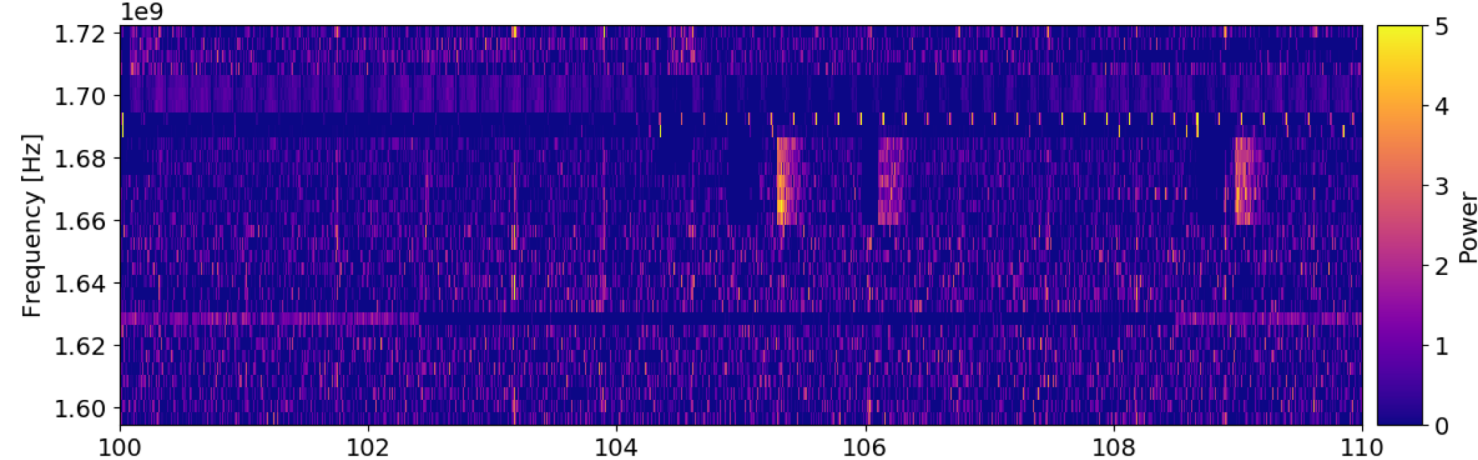Data StdDev = 1018
Profile Bins = 64
Profile Avg = 1.745e+08
Profile StdDev = 5.289e+04

RA$_{J2000}$ = 00:00:00.0000   DEC$_{J2000}$ = 00:00:00.0000

Folding Parameters

DOF$_{eff}$ = 60.04 χ^2_{red} = 218.530   P(Noise) ~ 0   (115.6σ)
Dispersion Measure (DM; pc/cm^3) = 27.367
P$_{topo}$ (ms) = 714.5200(92)   P$_{bary}$ (ms) = N/A
P'$_{topo}$ (s/s) = 0.0(4.0)x10^{-7} P'$_{bary}$ (s/s) = N/A
P''$_{topo}$ (s/s^2) = 0.0(1.5)x10^{-8} P''$_{bary}$ (s/s^2) = N/A

Binary Parameters

P$_{orb}$ (s) = N/A   e = N/A
a$_1$sin(i)/c (s) = N/A ω (rad) = N/A
T$_{peri}$ = N/A

Time (s)

Fraction of Observation

Phase   Reduced χ^2

Sub-band

Frequency (MHz)

Phase

Reduced χ^2

DM (pc/cm^3)

P-dot (s/s)

Reduced χ^2

Period − 714.52000000 (ms)

Reduced χ^2

Freq − 1.399541 (Hz)

P-dot (s/s)

F-dot (Hz/s)

Period − 714.52000000 (ms)

scan0050_BD_J0332+5434_8bits.fil

flule1 12-Nov-2019 15:50

BD (auto spec)

ZC (auto spec)

BD-ZC (cross spec)
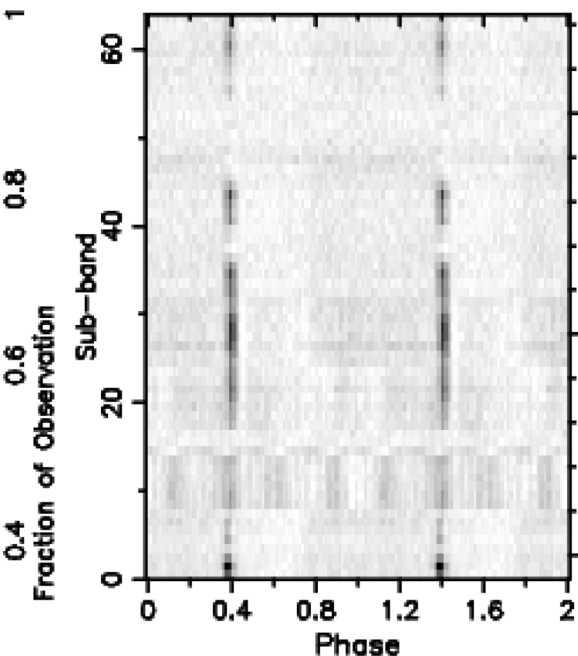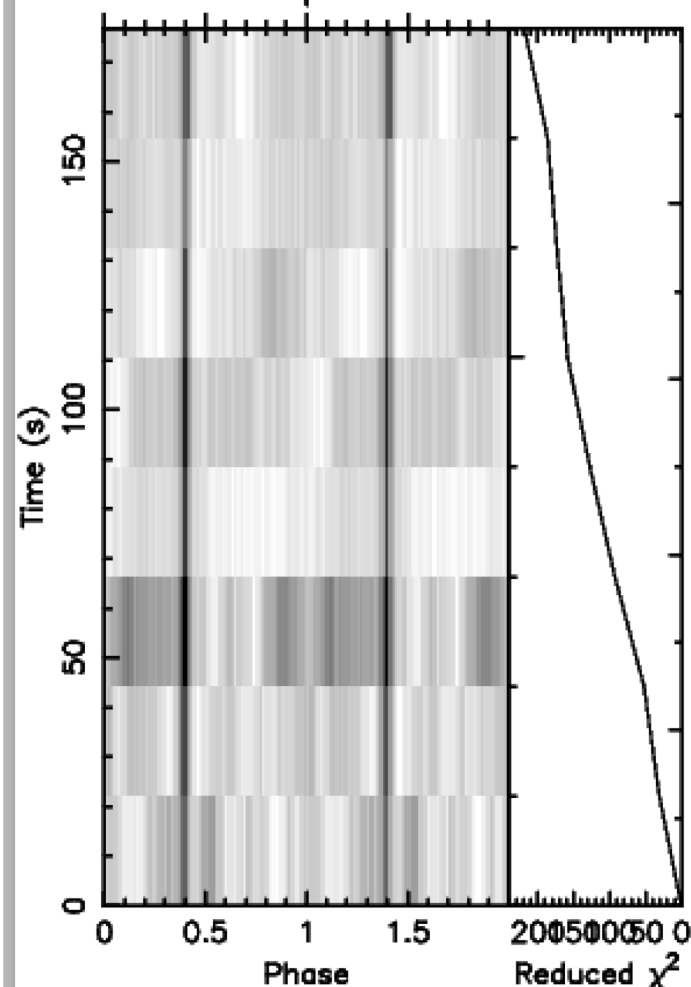
Pipeline test: summary

- CPU cluster, Intel Xeon 2.6 GHz, 64GB memory, 10 nodes

- running on 9 nodes, 8 procs per node, ~30 min per scan

- Pulsars: yes

- RRAT: no single pulse detected within 80 min

- Future:
  - GPU support
  - Fully automatic

Thank you!