# A VLBI cross spectrum based single pulse search method

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# Outline

- Single pulse search method
  - Radio transients: FRBs, etc.
- Detection of fast variability of microquasar

# 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

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# FRB search: wide field array

**UTMOST**
7.8 deg$^2$
15” X 8.4 deg @ 800 MHz
3 events
(Caleb et al. 2017)

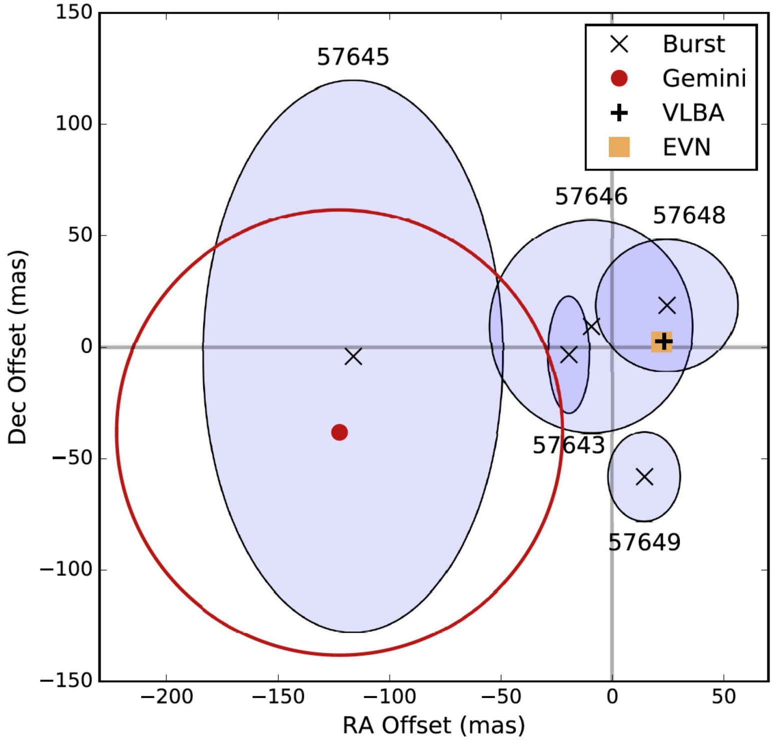
**ASKAP**
30 deg$^2$
10’ X 10’ deg @ 1.3 GHz
20 events
(Shannon et al. 2018)

**CHIME**
250 deg$^2$
0.3 deg @ 600 MHz
13 events (1 repeating)
(CHIME/FRB collaboration 2018)

# FRB search: VLBI

- Auto spectrum
  - PRESTO
  - V-FASTR, LOCATe
- Cross spectrum
  - Imaging method: *realfast*
  - Non-imaging method: this work

Chatterjee et al. (2017)



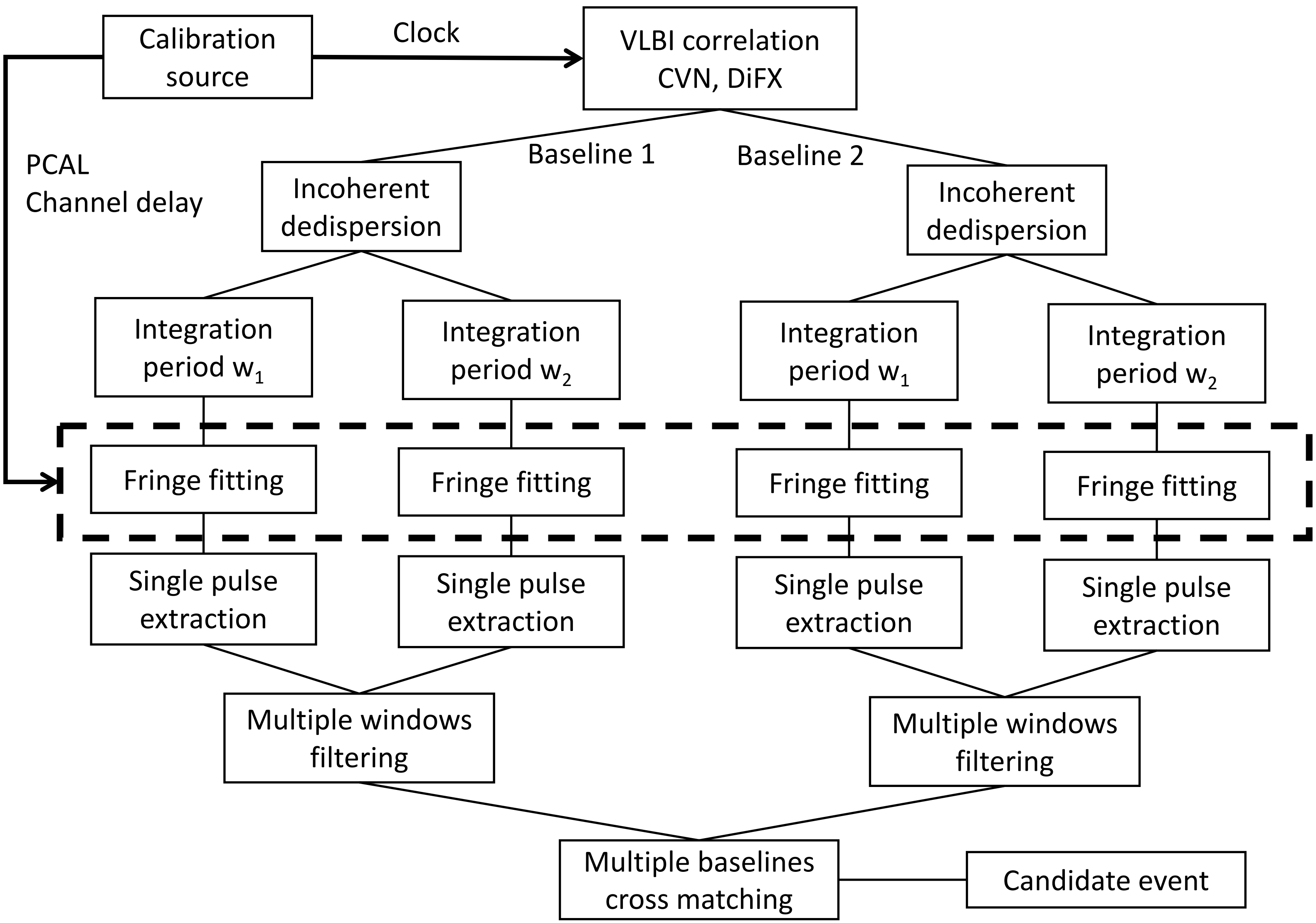
# Non-imaging single pulse search method

- 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

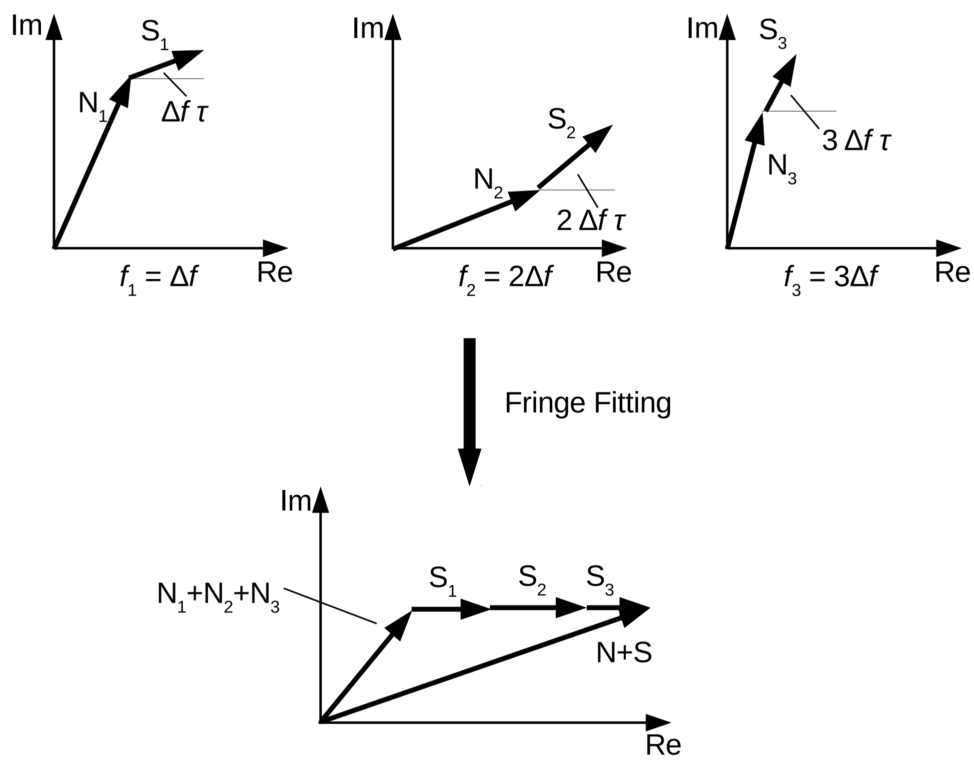
| | Baseline (km) | Resolution* (mas) | Map size** (pixel) |
|---|---|---|---|
| VLA | 36 | 781.7 | 2880 |
| CVN | 3000 | 9.4 | 240000 |

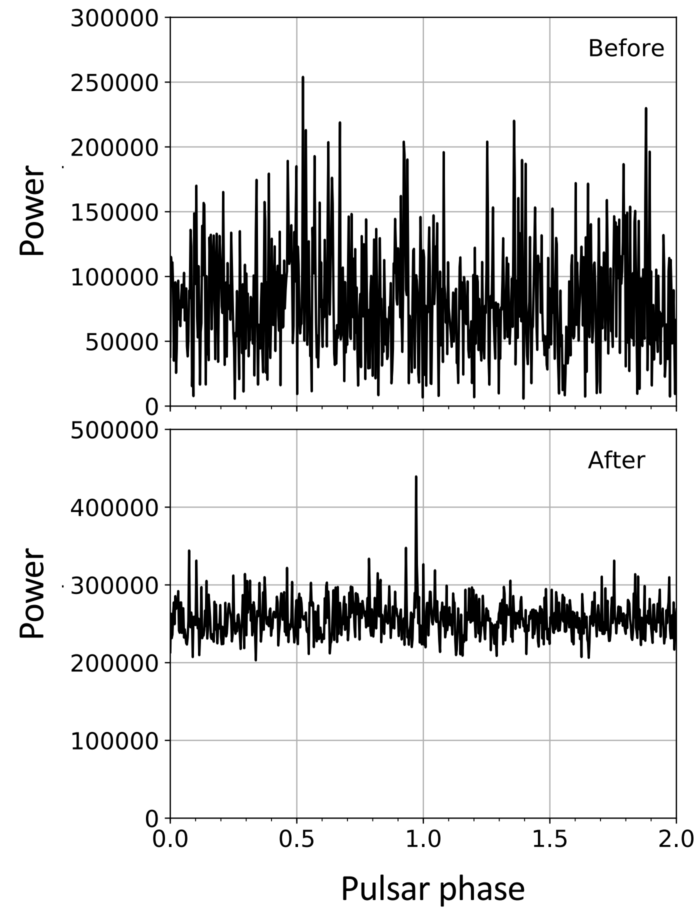
*   S band (2.2GHz, 13.6 cm)
** Pixel size ¼ resolution; half FoV

# Searching pipeline



# Fringe fitting

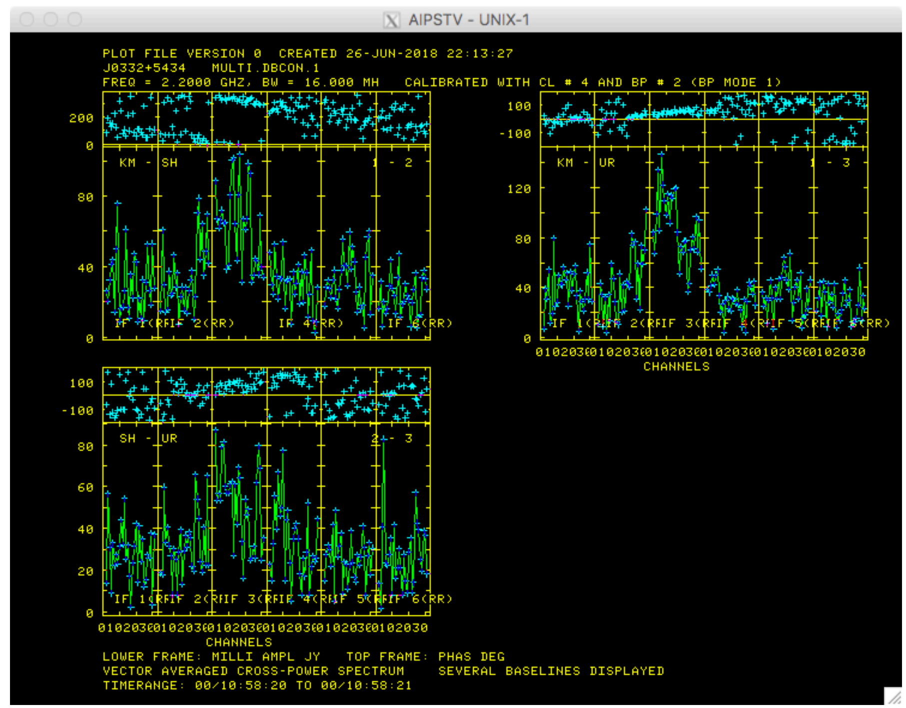


# Localization: geodetic solving

- Phase reference calibration with AIPS
- Fit fringe phase to derive group delay ($\Delta\tau$)
- Calculate partials: $\frac{\partial\tau}{\partial\alpha}$ and $\frac{\partial\tau}{\partial\delta}$
- Solve linear equations:

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

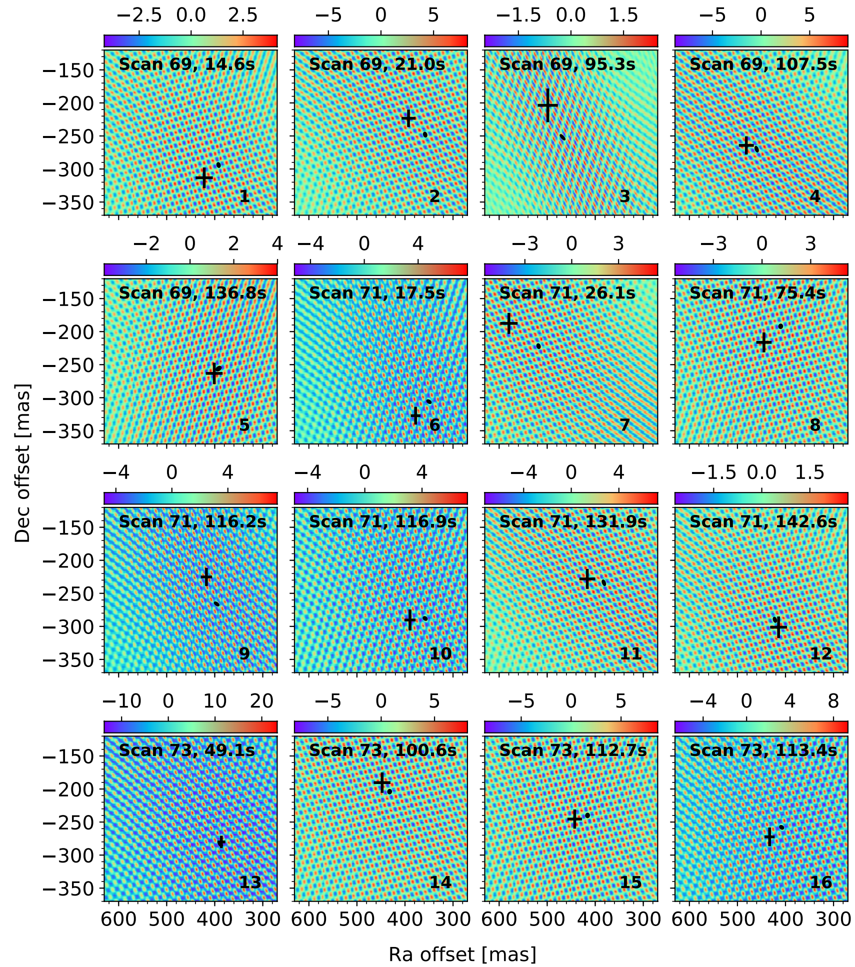


# Localization: imaging vs. geodetic solving



| No. | Scan | Time (sec) | Baseline Km-Sh | Baseline Km-Ur | Baseline Sh-Ur | Solving $\Delta\alpha^*$ (mas) | Solving $\Delta\delta$ (mas) | Imaging $\Delta\alpha^*$ (mas) | Imaging $\Delta\delta$ (mas) | SNR |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 69 | 14.565 | ✓ | ✓ | | 421.9±17.9 | -313.3±15.6 | 392.0 | -294.0 | 9.0 |
| 2 | 69 | 21.000 | ✓ | ✓ | | 392.6±14.6 | -223.3±13.2 | 358.0 | -248.0 | 9.6 |
| 3 | 69 | 95.306 | | ✓ | ✓ | 498.7±21.0 | -203.7±25.5 | 468.0 | -252.0 | 9.1 |
| 4 | 69 | 107.463 | ✓ | ✓ | | 481.5±15.6 | -264.3±13.7 | 460.0 | -270.0 | 9.4 |
| 5 | 69 | 136.765 | ✓ | ✓ | | 401.0±17.4 | -263.2±16.1 | 392.0 | -256.0 | 8.3 |
| 6 | 71 | 17.547 | ✓ | ✓ | ✓ | 377.9±10.2 | -327.2±13.4 | 350.0 | -306.0 | 11.1 |
| 7 | 71 | 26.122 | ✓ | ✓ | | 579.7±18.1 | -187.6±15.9 | 518.0 | -222.0 | 8.9 |
| 8 | 71 | 75.431 | ✓ | ✓ | | 444.9±16.0 | -216.3±15.1 | 410.0 | -192.0 | 8.4 |
| 9 | 71 | 86.636 | ✓ | ✓ | | 7673.9±16.8 | -2873.4±15.4 | -26.0 | 540.0 | 6.5 |
| 10 | 71 | 116.158 | ✓ | ✓ | ✓ | 417.2±11.7 | -225.2±13.8 | 396.0 | -266.0 | 11.8 |
| 11 | 71 | 116.872 | ✓ | ✓ | ✓ | 389.6±11.7 | -290.3±15.8 | 358.0 | -288.0 | 10.1 |
| 12 | 71 | 131.879 | ✓ | ✓ | | 416.5±16.4 | -228.2±15.1 | 382.0 | -234.0 | 9.1 |
| 13 | 71 | 142.605 | ✓ | ✓ | | 414.4±17.5 | -301.3±16.3 | 422.0 | -290.0 | 8.8 |
| 14 | 73 | 49.109 | ✓ | ✓ | ✓ | 386.2± 8.2 | -280.1± 9.4 | 388.0 | -284.0 | 10.7 |
| 15 | 73 | 100.557 | ✓ | ✓ | | 447.5±17.3 | -190.4±15.5 | 432.0 | -204.0 | 7.7 |
| 16 | 73 | 112.702 | ✓ | ✓ | | 442.7±15.1 | -245.5±14.6 | 416.0 | -240.0 | 8.6 |
| 17 | 73 | 113.418 | ✓ | ✓ | ✓ | 433.0±10.5 | -272.4±14.1 | 408.0 | -258.0 | 9.5 |

Liu et al. 2019, AJ, arXiv:1810.08933



# Localization: comparison with references

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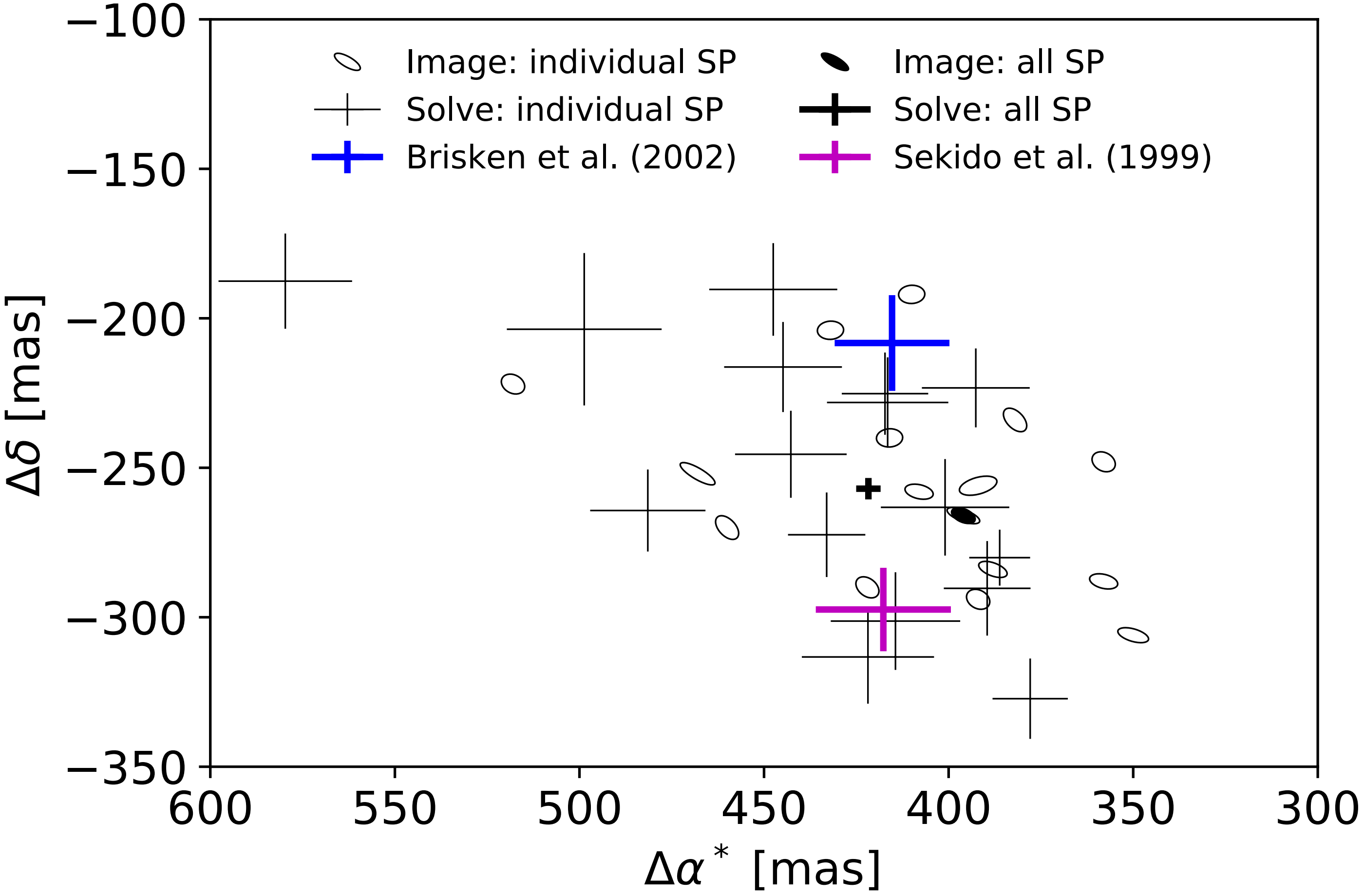


Liu et al. 2019, AJ, arXiv:1810.08933

# FRB search in VGOS

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- VGOS: VLBI Global Observation System
  - Large FoV
  - 24 hours continuous observation
  - Large bandwidth
- Fluence limit: 5.3 Jy ms (0.755 Jy, 7 ms)
- Detection rate: 0.0075 events per day*
- 1.39 events per year (50% efficiency)
- 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)

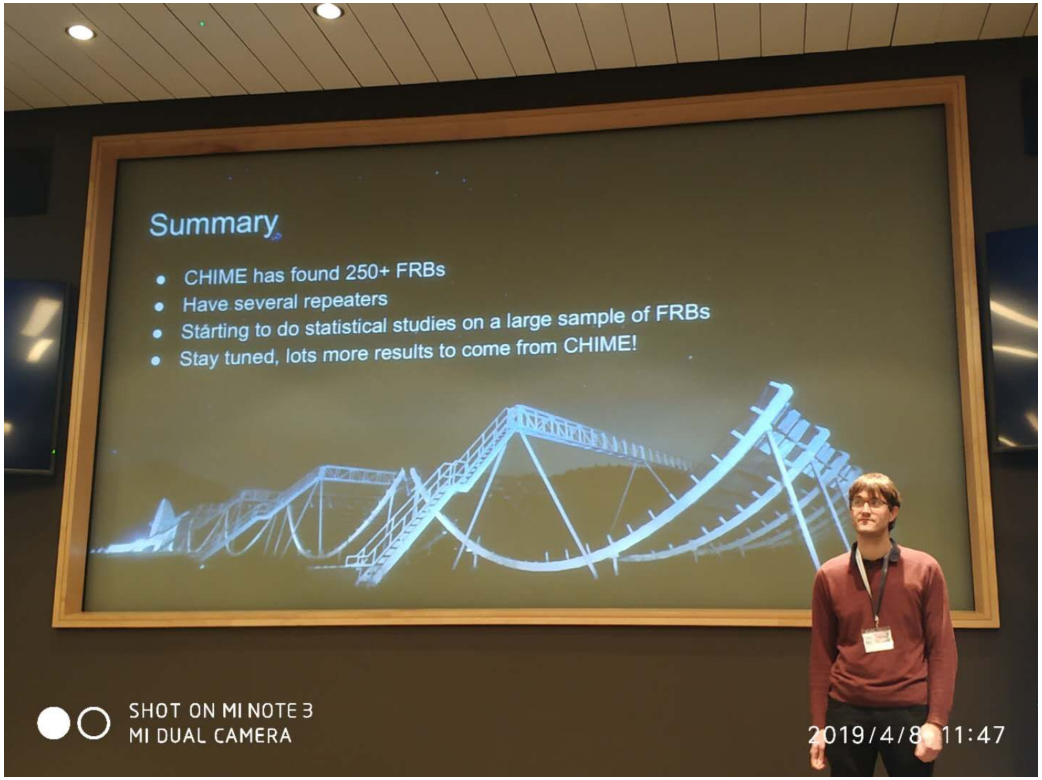
Caleb et al. (2017): spectral index 0.0, fluence index -1.0

# 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
- VOLKS (人民) pipeline: VLBI Observation for frb Localization Keen Searcher
  - DiFX/CVN support
  - Single pulse search and localization (imaging, solving)
  - Open source: https://github.com/liulei/volks

# Possible applications

- Giant pulse
- Magnetar
- Microquasars



# Fast variability of microquasar

- Microquasar
  - Binary system of normal star and compact source (neutron star or black hole)
  - Comparable with SMBH
  - Relativistic jet from accretion disk
    - Small size (high angular resolution)
    - Short time scale (short integration period)
- Multi-band observation of fast variability
  - Quasi periodic oscillation (QPO): sub second
  - X-ray, optical, near IR, UV
  - Radio?
- Co-observation in radio and X-ray band
  - X-ray: HXMT
  - Radio: EVN, VLA
    - Fringe fitting to maximize signal power of every sub-second integration period

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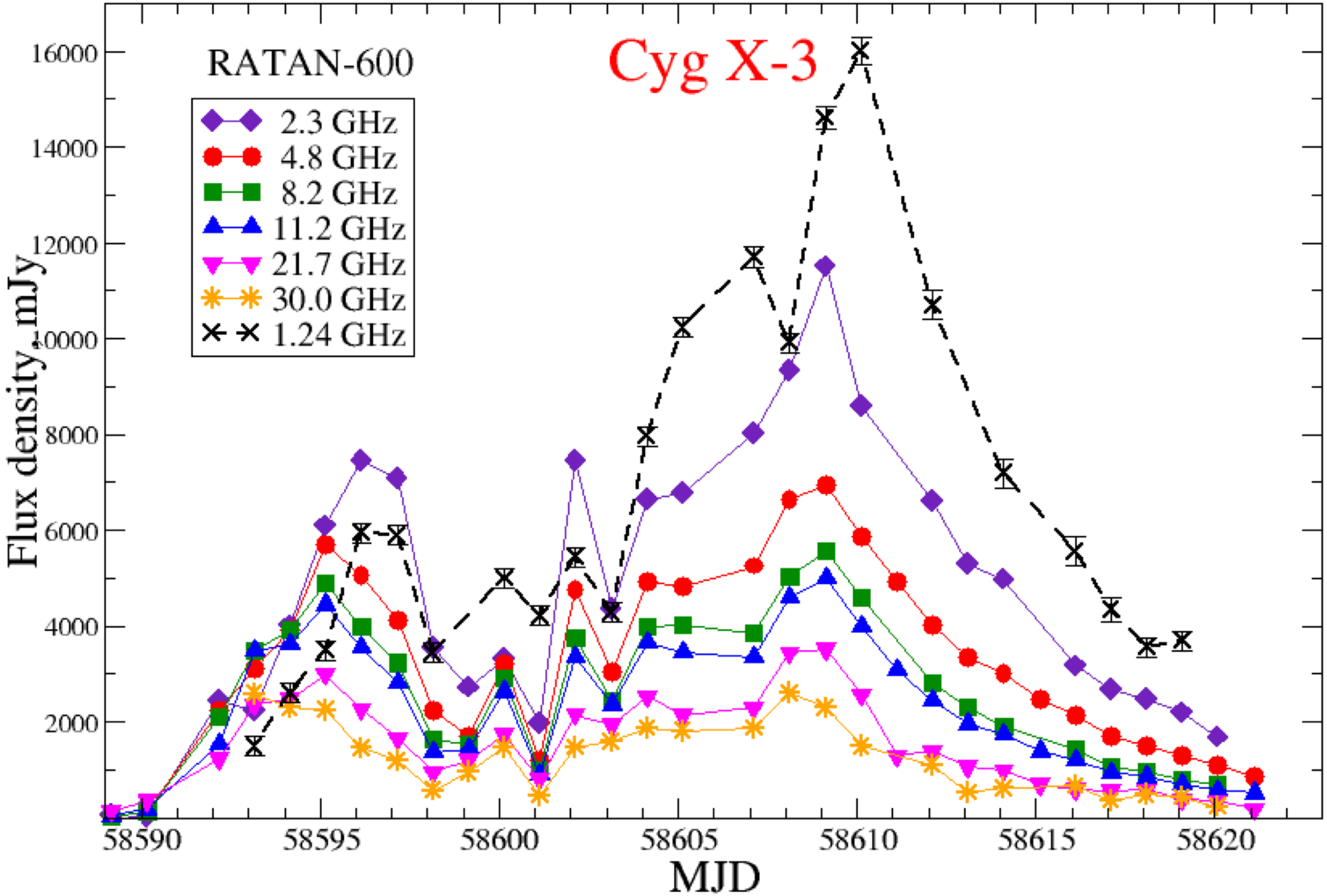
# Target: Cyg X-3, Cyg X-1, GRS 1915+105



# HXMT observation

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<table>
<tr><td>APPID</td><td>A02050018</td><td>Title</td><td>利用 X 射线和射电高时间分辨观测探究微类星体喷流快速光变特征</td><td>PI</td><td>Dr.Zhen Yan</td></tr>
<tr><td>ABSTRACT</td><td colspan="5">最近几年，多波段快速光变成为研究微类星体吸积和喷流物理的一个非常重要的手段。微类星体的射电辐射主要来自于喷流，利用射电波段的快速光变以及它们同 X 射线快速光变的相关关系，进而可以研究吸积对于喷流的作用，喷流结构和运动等科学问题。本提案计划利用 HXMT 协同地面射电望远镜阵列（EVN 或者 VLA）开展针对明亮微类星体的高时间分辨联合观测，获取同时的射电和 X 射线波段的快速光变特征，进而研究喷流和吸积的相互作用以及喷流物理。针对射电观测，我们计划应用一种新数据处理方法探测微类星体射电波段的快速光变信号。</td></tr>
<tr><td>Target</td><td>Rank</td><td>Exposure Time (ks)</td><td>ToO?</td><td>Note1</td><td>Note2</td></tr>
<tr><td>GRS 1915+105</td><td>A</td><td>10</td><td>Y</td><td rowspan="2">Coordinate observations</td><td></td></tr>
<tr><td>Cyg X-1</td><td>A</td><td>10</td><td>Y</td><td></td></tr>
<tr><td>Cyg X-3</td><td>A</td><td>10</td><td>Y</td><td></td><td></td></tr>
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# Thank you!