

工作汇报与未来研究计划

面向大型射电阵列的软硬件研发与科学研究

门云鹏

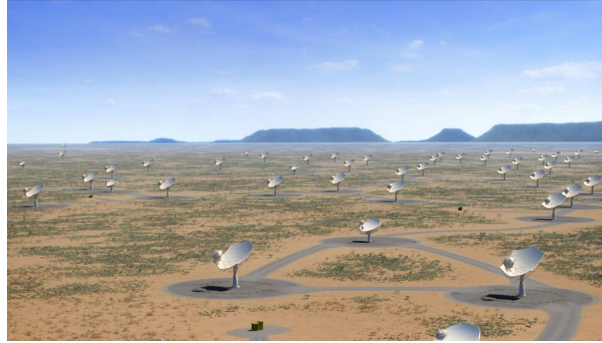
华中科技大学物理学院天文系

FPS15(贵阳)

Future radio facility



DSA-1650



SKA-mid



SKA-low



CHORD



HERA

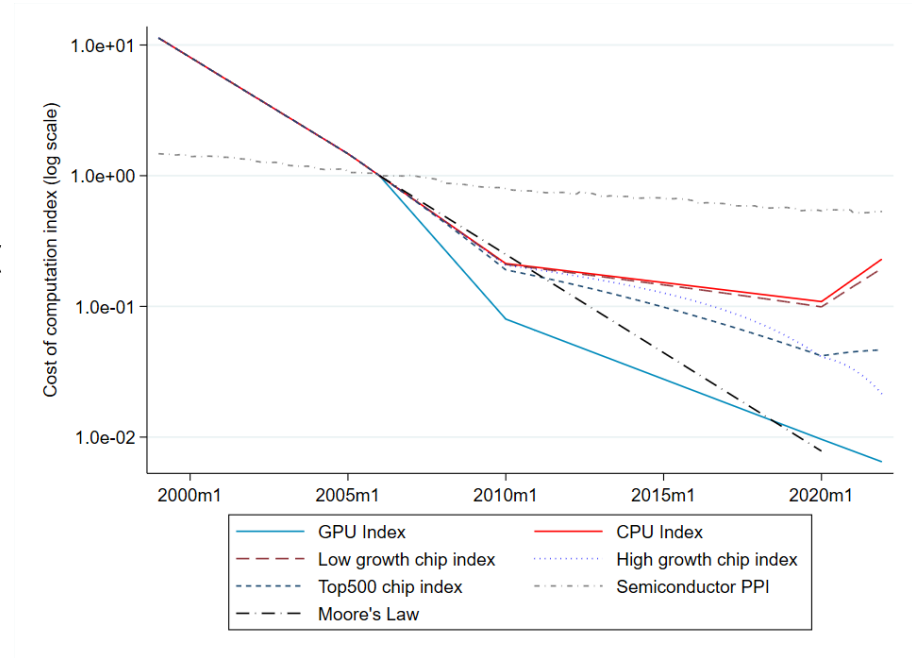
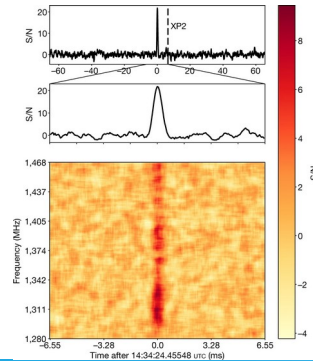


FAST core array

small-D, big-N

Why 'small-D, big-N'

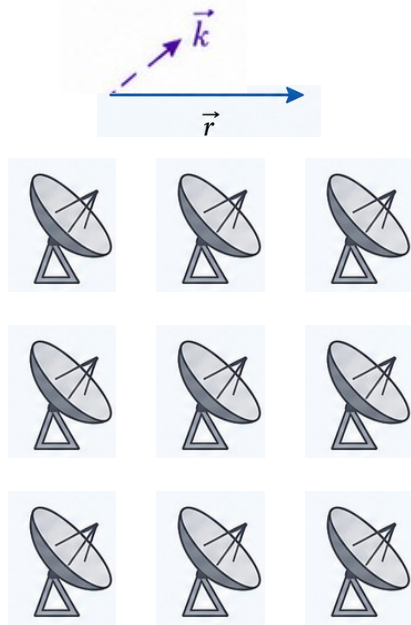
- Field of View (FoV) $\propto \lambda / D$
- Sensitivity $\propto N D^2$
- Localization precision $\propto \lambda / B$
- Telescope cost per sensitivity $\propto (N D^3) / (N D^2) = D$



Computing cost is cheaper

Digital backend for radio array

- Data rate $\propto N$
- Computing cost $\propto N (B / D)^2$



$$\begin{aligned}\phi &= \vec{k} \cdot \vec{r} \\ &= (\vec{k}_0 + \vec{k}_\Delta) \cdot \vec{r} \\ &= \vec{k}_0 \cdot \vec{r}_{//} + \vec{k}_\Delta \cdot \vec{r}\end{aligned}$$

↓ ↓

F-engine B-engine



Figure 3.2: A fish-eye view of the TRAPUM user supplied equipment (USE) at the KAPB. Top panel is the FBFUSE rack. Bottom panel shows APSUSE consisting of 7 racks from the left with the rest belonging to TUSE. (Credits: E. Barr)

Big challenge in data processing

F-engine

Geometry delay $\vec{k}_0 \cdot \vec{r}_{//}$

Element 1

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Element 2

--	--	--	--	--

Integer sample delay

+

Fractional sample delay

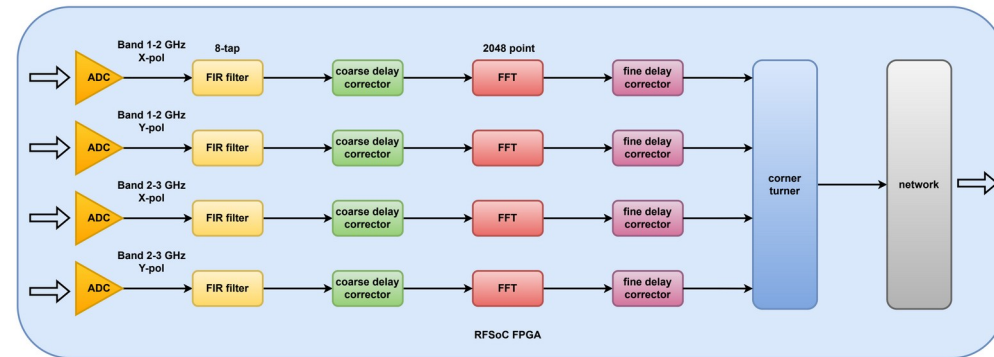
+

Complex gain

$$\mathfrak{F}[f(t - a)] = \text{Exp}[-j\omega a] \mathfrak{F}[f(t)]$$



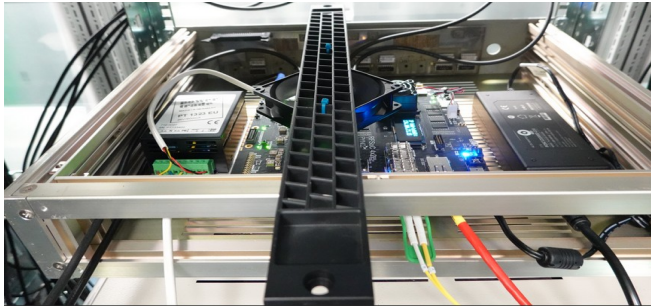
ARGOS



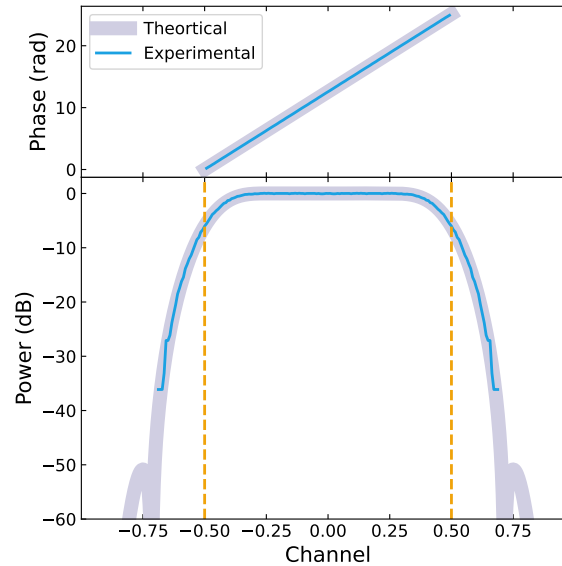
F-engine for ARGOS



Crete, Grace

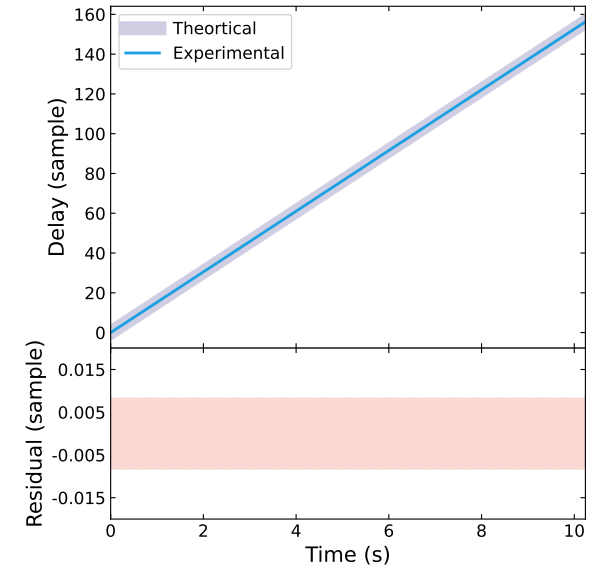


RFSoc 4x2



Frequency response

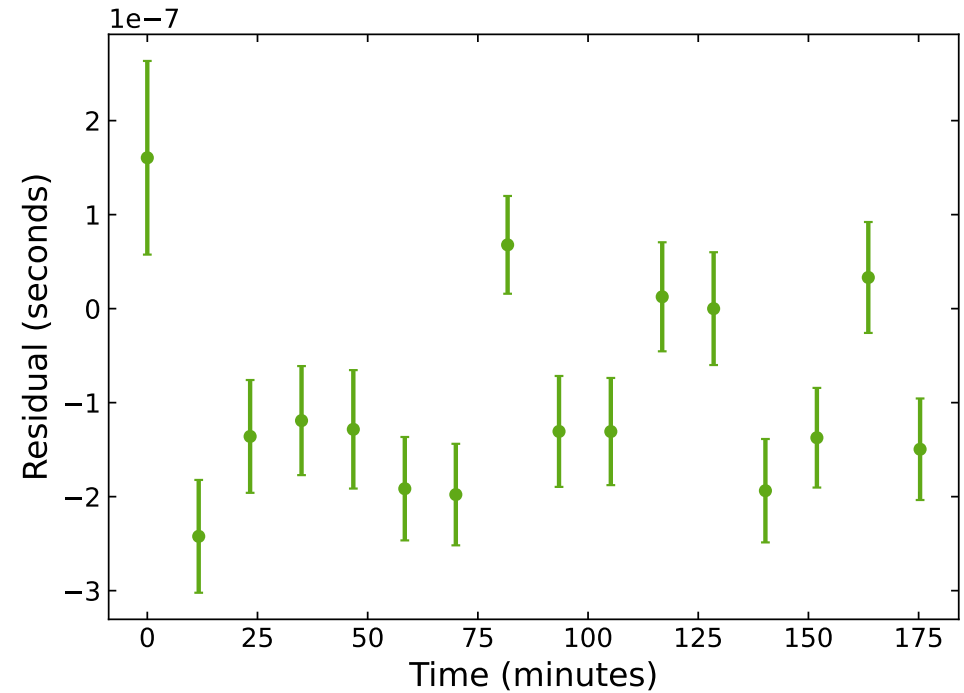
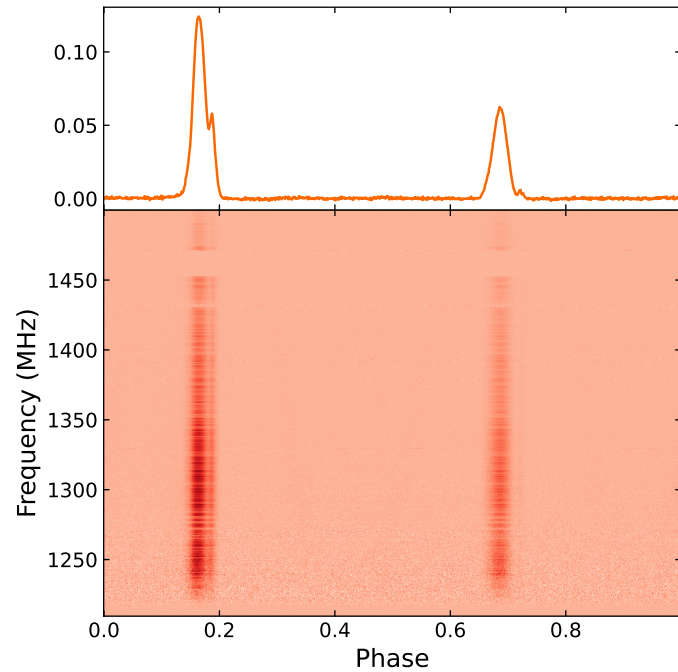
Men* et al. 2025,A&A



Delay correction

F-engine for ARGOS

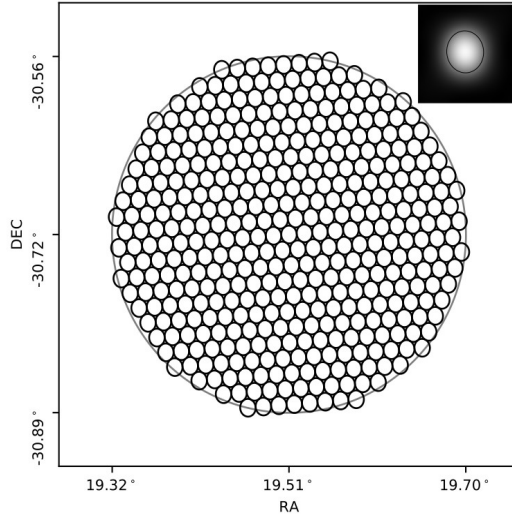
PSR J1939+2154



B/X-engine

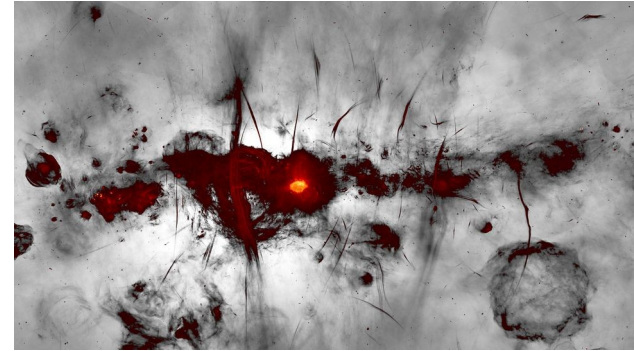
Beam-forming

$$\vec{k}_{\Delta} \cdot \vec{r}$$



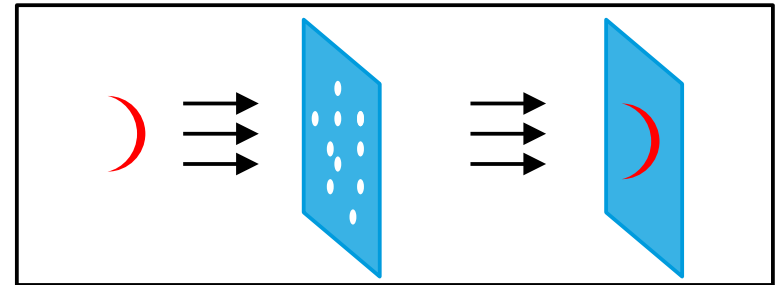
$\approx$

Radio imaging



$$I_{\nu}(l, m) = \iint V_{\nu}(u, v) e^{i2\pi(ul+vm)} du dv$$

$$\begin{pmatrix} B_0 \\ B_1 \\ \dots \\ B_{M-1} \end{pmatrix} = \begin{pmatrix} W_{0,0} & W_{0,1} & \dots & W_{0,N-1} \\ W_{1,0} & W_{1,1} & \dots & W_{1,N-1} \\ \dots & \dots & \dots & \dots \\ W_{M-1,0} & W_{M-1,1} & \dots & W_{M-1,N-1} \end{pmatrix} \begin{pmatrix} x_0 \\ x_1 \\ \dots \\ x_{N-1} \end{pmatrix}$$



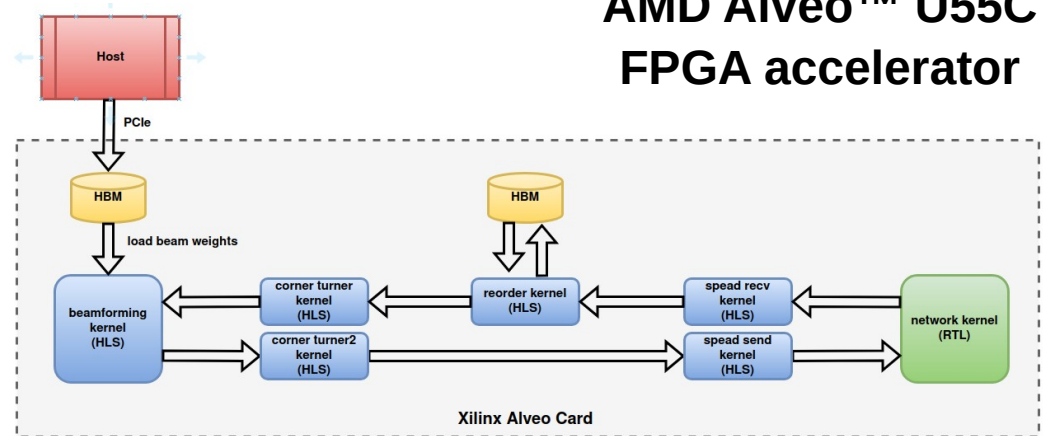
B-engine for MPIfR CryoPAF

- Dual-pol 128 elements
- S-band (1.3-2.6 GHz)

- Low cost
- Low latency
- Low power consumption



**AMD Alveo™ U55C
FPGA accelerator**



Survey with radio array

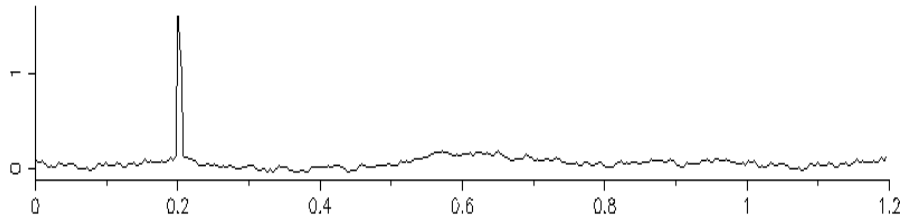
Strength:

- Better RFI mitigation
- Baseline subtraction
- Better candidate classification

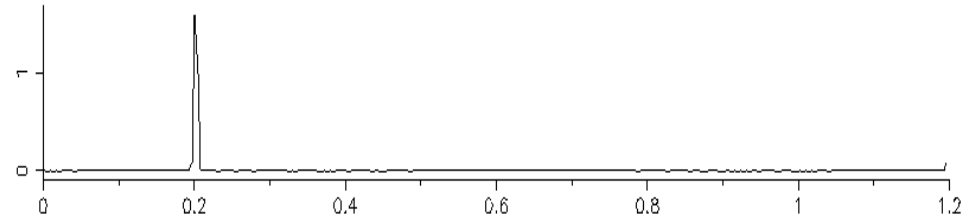
Weakness:

- Much more computing power required
- Much more power consumption

BC prd (ms): 8509.343145507 TC prd (ms): 8508.608401781 DM: 3.350 BC freq (Hz): 0.117517884
Corrn (ms): -0.484842798 Corrn (ms): -0.484800934 Corrn: -0.000 Freq err. (Hz): 0.000010075
Error (ms): 0.729539665 Error (ms): 0.729539665 Error: 14.861 Width (ms): 66.479
Best S/N: 561.22



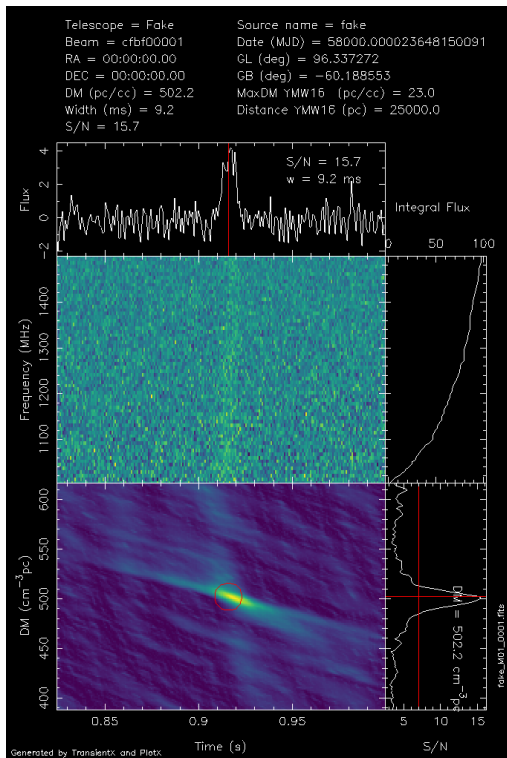
BC prd (ms): 8509.343145507 TC prd (ms): 8508.608401781 DM: 3.350 BC freq (Hz): 0.117517884
Corrn (ms): -0.484842798 Corrn (ms): -0.484800934 Corrn: -0.000 Freq err. (Hz): 0.000010075
Error (ms): 0.729539665 Error (ms): 0.729539665 Error: 14.861 Width (ms): 66.479
Best S/N: 560.52



We need to better software

TransientX

Men* & Barr 2024, A&A



widely used
around the
world

Table 4. Summary of detection results on FAST-FREX.

No.	Software	TP	FP	P (%)	R (%)	Total	Speed [s/it]	Bandwidth	Confidence
H1	HEIMDALL	487	8635	5.33	81.2	600	4.72	F	–
T1	TRANSIENTX	576	10044	5.42	96.0	600	3.13	F	–
A1	ASTROFLOW	571	3	99.5	95.2	600	0.25	F	0.4
A2	ASTROFLOW	584	28	95.4	97.3	600	0.67	F+L+H	0.5
A3	ASTROFLOW	588	49	92.3	98.0	600	0.65	F+L+H	0.4

NOTE—P: precision; R: recall. Bandwidth labels follow Table 2.

Lin et al. 2026, ApJS

Table 5. Benchmark comparison on the FAST-FREX dataset Guo et al. (2025) (600 FRB bursts). Best results are highlighted in **bold**. For FRTSearch, execution time is reported as *parameter-only* / *with diagnostic plots*.

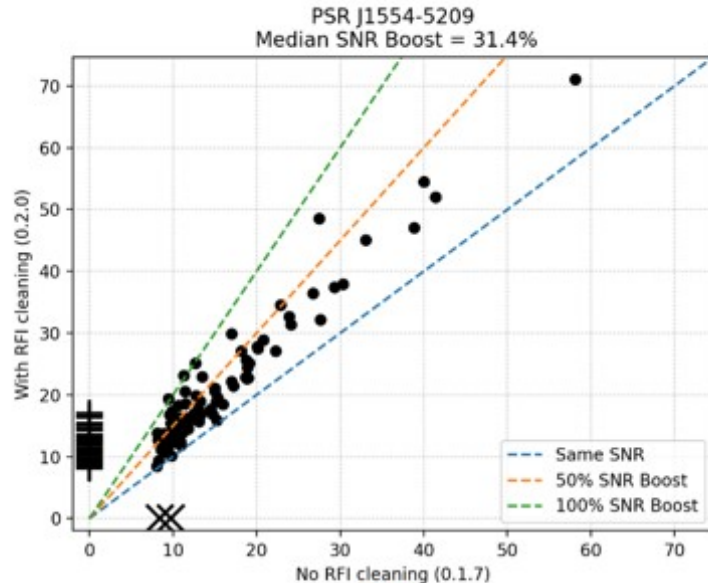
Method	Threshold	TP	#Candidates	Recall (%)	FPPI (per file)	Time (s/file)
PRESTO	$S/N \geq 5$	479	2,990,577	79.8	4,983.5	221.8
Heimdall	$S/N \geq 5$	505	29,901	84.2	49.0	16.0
TransientX	$S/N \geq 5$	600	49,405	100.0	81.3	60.3
FRTSearch	Confidence ≥ 0.1	588	3,050	98.0	4.1	8.7 / 16.0

Zhang et al. 2026, arxiv

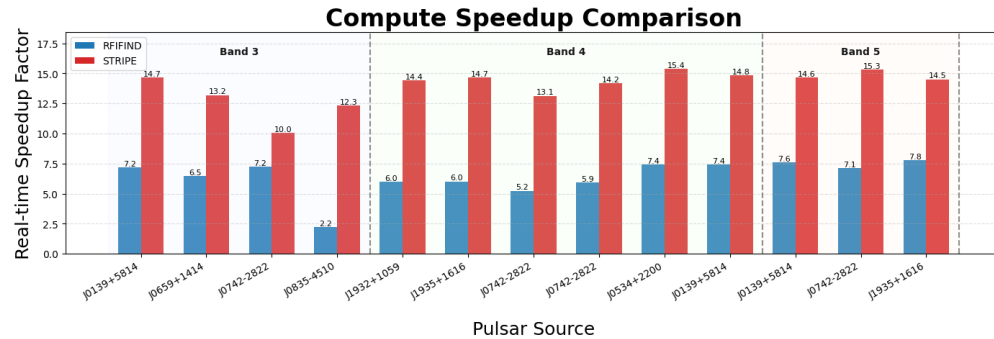
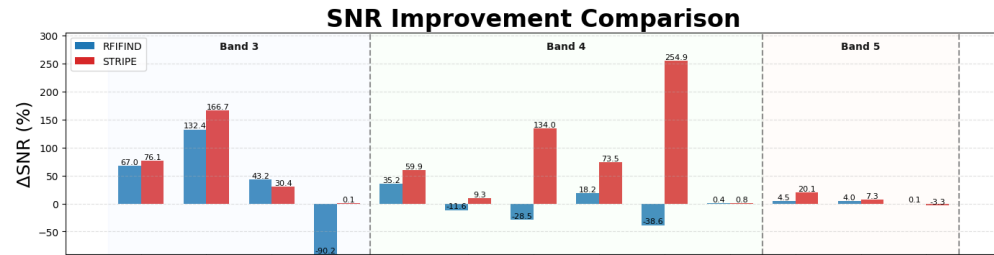
PulsarX

Men* et al. 2023, A&A

~50 times faster than presto



MeerTRAP



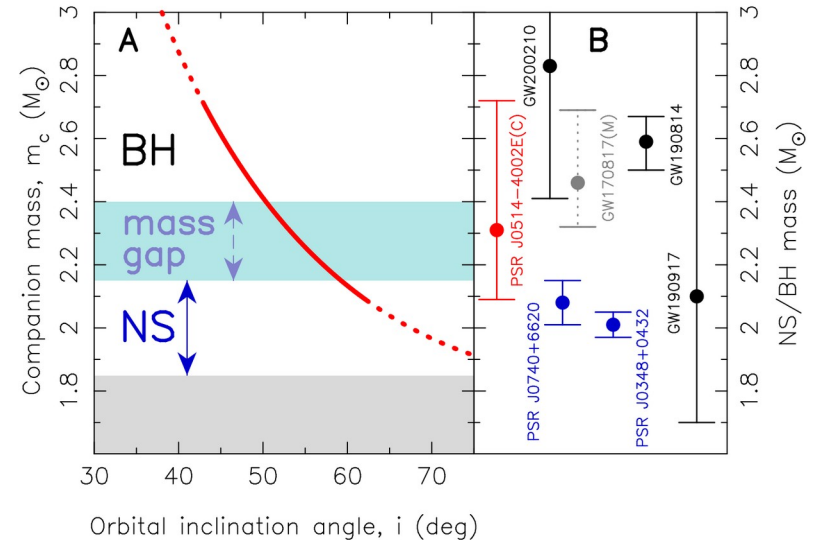
SPOTLIGHT, GMRT

Transients and Pulsars with MeerKAT



Targeted pulsar searches:

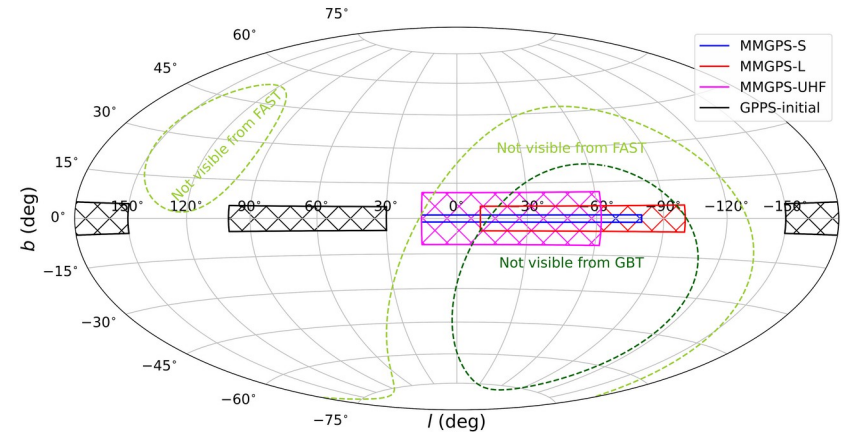
- SNRs, PWNe
- unidentified Fermi gamma-ray sources
- Globular Cluster Searches
- Extragalactic pulsar and transient searches



Barr* et al. 2025, Science
A possible first pulsar black-hole binary system!

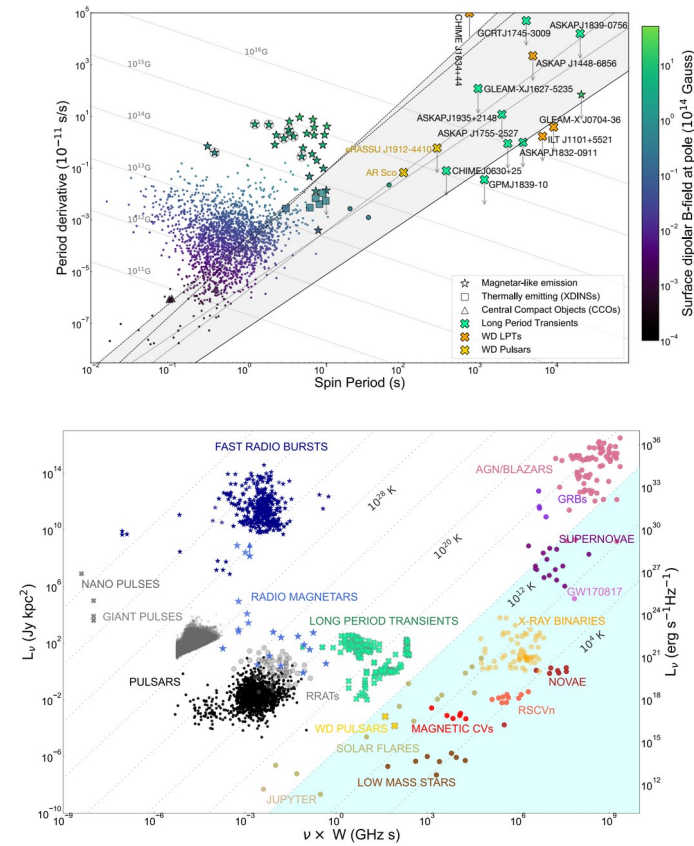
MPIfR-MeerKAT Galactic Plane Survey (MMGPS)

- **MMGPS-L (complete): 78 discoveries**
17 binaries
- **MMGPS-S (ongoing): 9 discoveries**
6 close to Galactic center
- **MMGPS-UHF (ongoing): 66 discoveries**
in 100 hrs, 300 hrs left

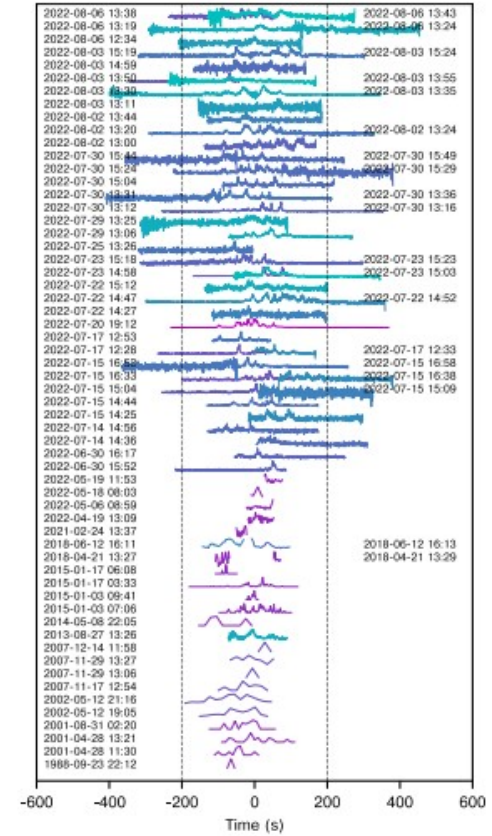
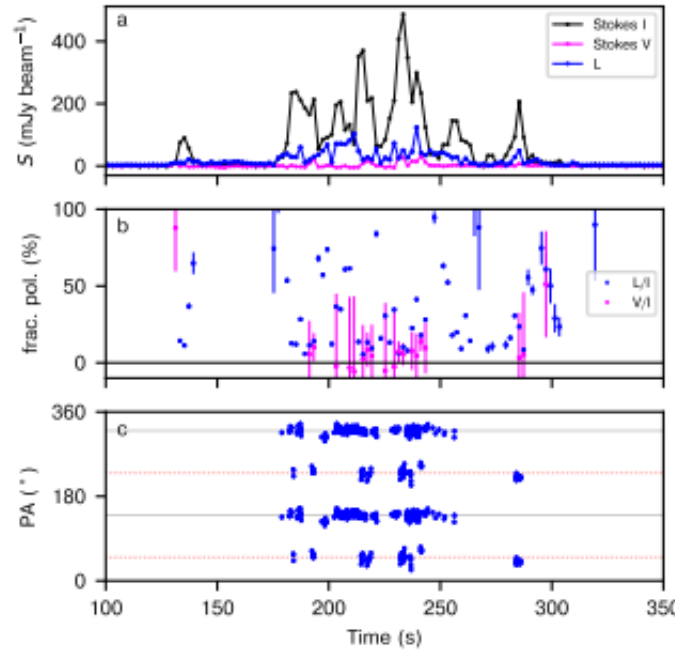


Padamanabh* et al. 2023, MNRAS

Long-period Transient (LPT)



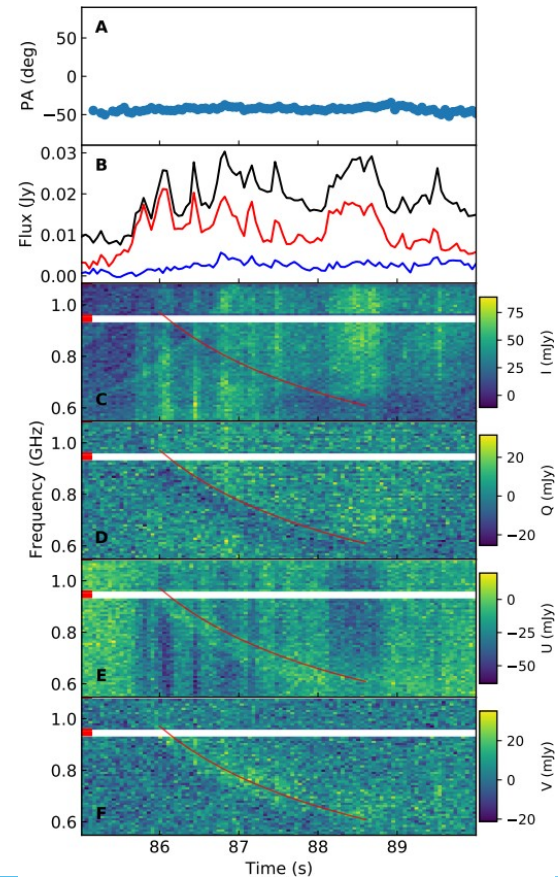
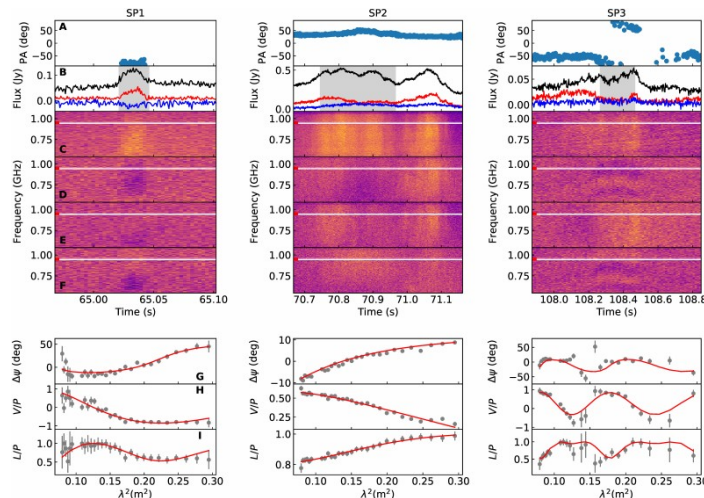
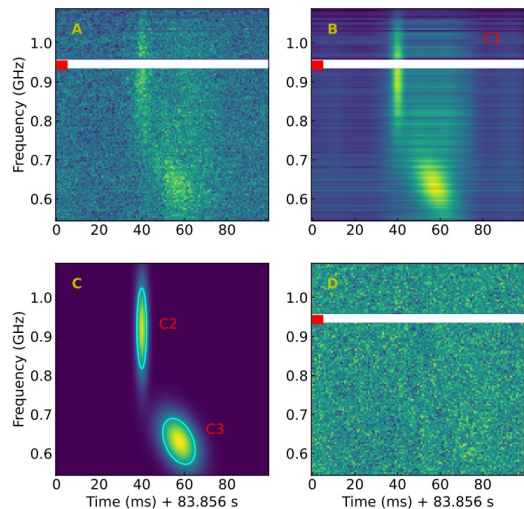
GPM 1839-10



Hurley-Walker et al. 2023, Nature

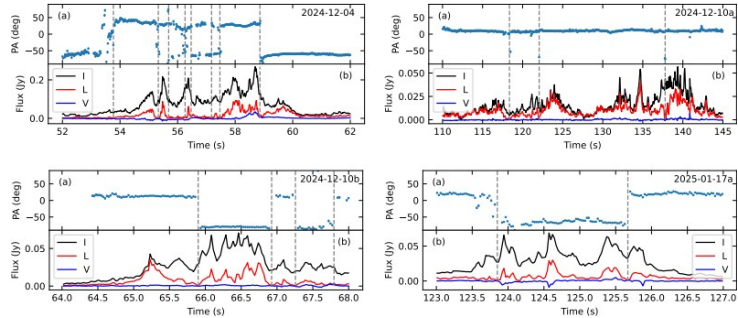
GPM1839-10 with MeerKAT

- Down-drift sub-structure similar to repeating fast radio bursts
- Faraday conversion behavior
- Down-drift polarization conversion with absorption

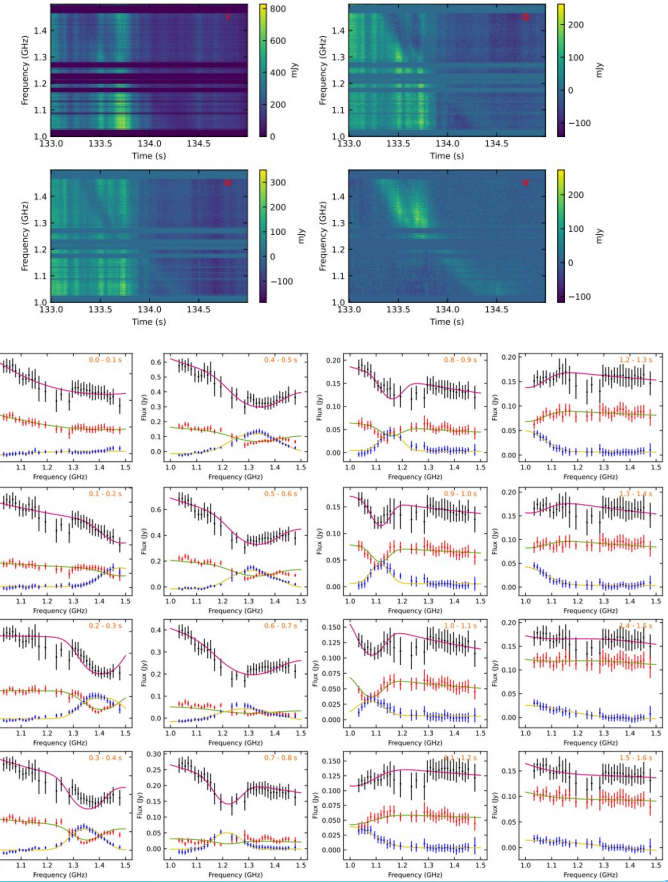
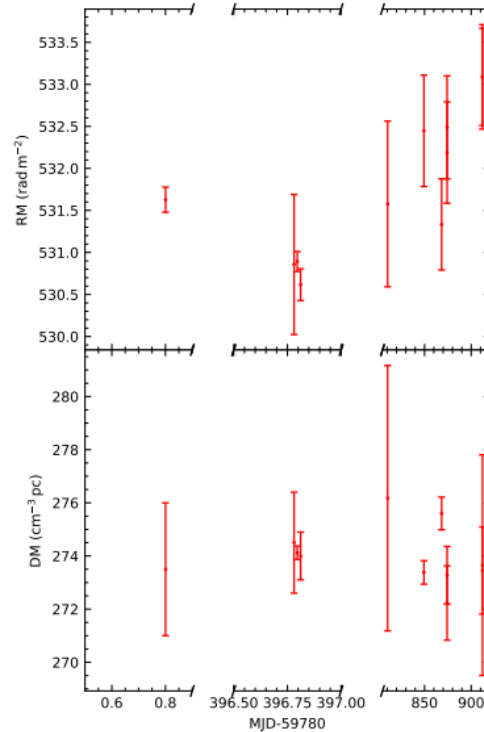


GPM1839-10 with FAST

- Incoherent summation of OPMs
- Stable DM and RM
- Cyclotron absorption



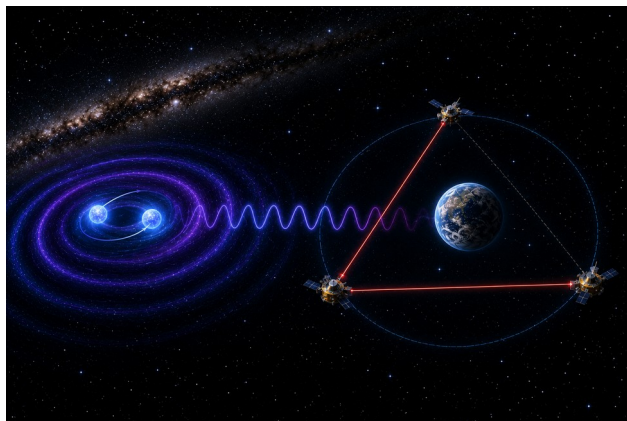
Men* et al. 2026, SCPMA



未来研究计划

- 长周期源研究
- 密近双星搜寻
- 建设超宽带大视场阵列

一期建设4x8面2米口径抛物面天线, 预计每月探测到1-2个FRB; 天线、馈源、前端系统、数字终端系统和数据处理流水线全部实验室自研, 成本大约200万。



武汉军山

希望各位老师同学多多支持, 感谢!