Pulsar & fast radio transient with phased ALMA: current status and beyond

Kuo Liu

Max-Planck-Institut für Radioastronomie

Bonn, Germany

ALMA proposal workshop

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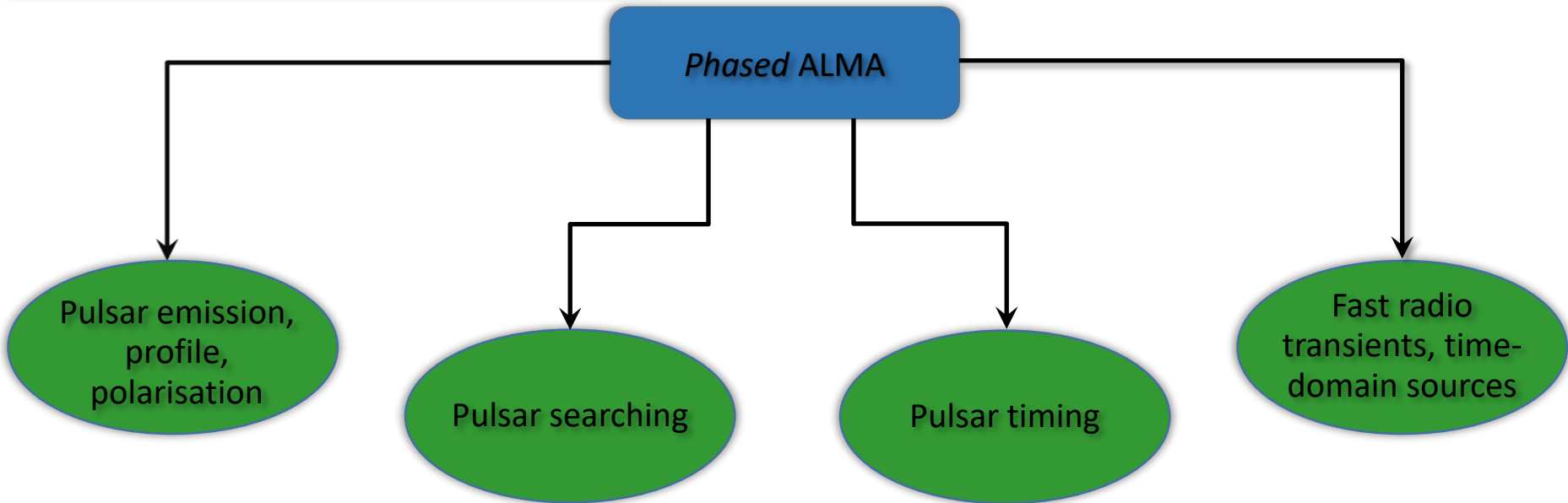
Phased-array observing mode with ALMA

- ➢ Form tied-array beam towards source;

- ➢ Interferometric data recorded in parallel;

- ➢ Available from Cycle-8 (**new mode**!), Band 3;

- ➢ Band 1, 3, 6, 7 in Cycle-10;

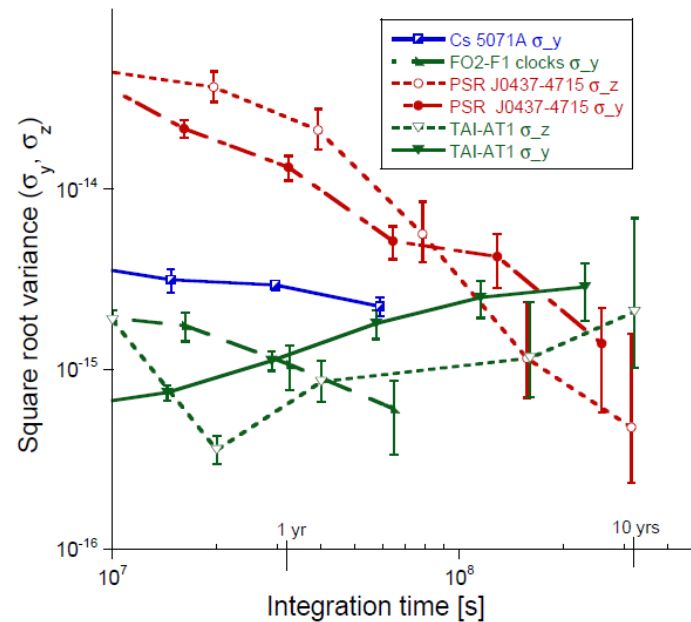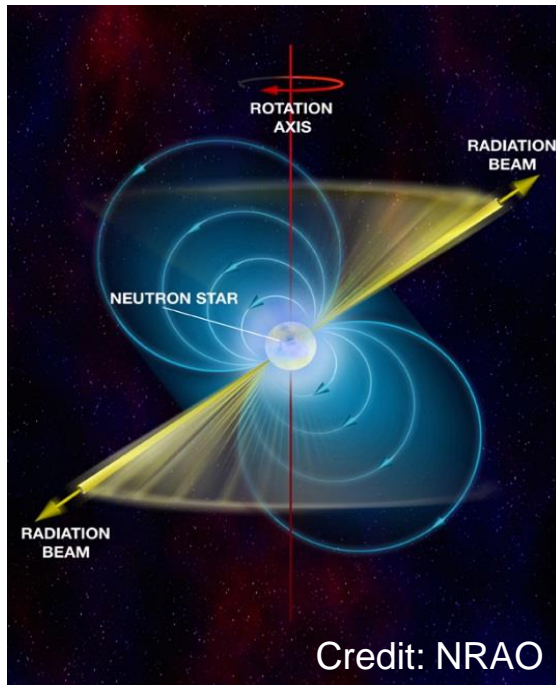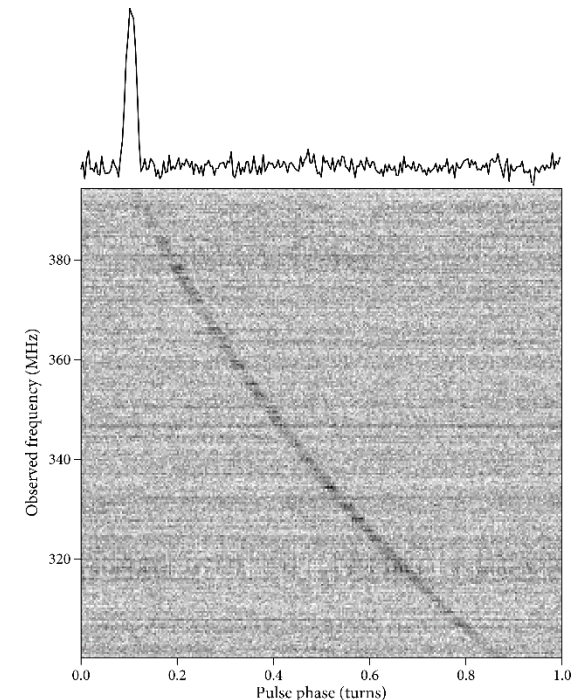**Pulsars** are:

➢ Fast-rotating magnetic dipoles, broad-band emission in radio;

→ cosmic "light houses"

➢ Highly regular rotation, precise celestial clocks;

➢ Probes of / affected by interstellar medium along line-of-sight;

Credit: NRAO

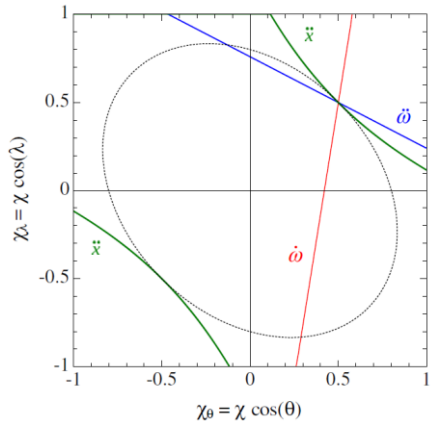
[Hartnett & Luiten 2011]

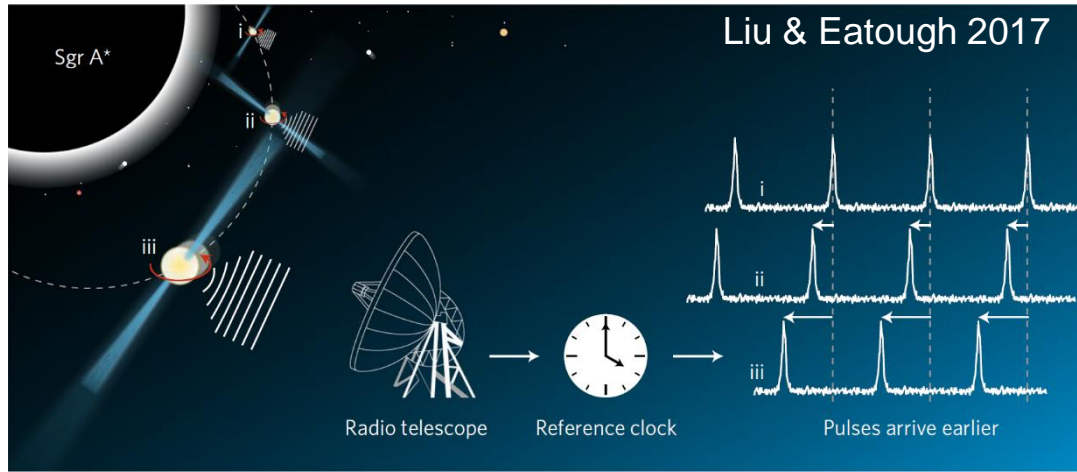# Joint venture on gravity with the Sgr A*

Spin

[Liu et al. 2012]

Liu & Eatough 2017

Radio telescope → Reference clock → Pulses arrive earlier

Quadrupole

Sgr A* April 7, 2017

$50\,\mu as \approx 10\,\theta_g$

Stars

EHT Shadow

Kerr

Pulsars

Black Hole Quadrupole Moment

Black Hole Spin

[Psaltis et al. 2016]

Star orbits at the Milky Way's center

UCLA
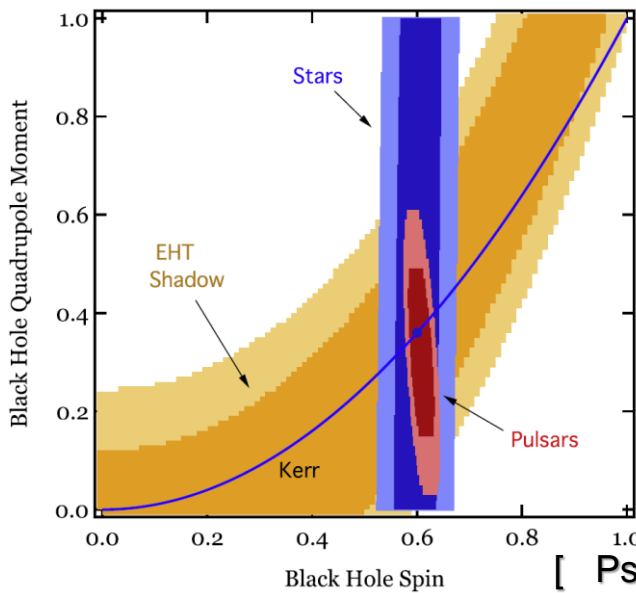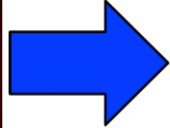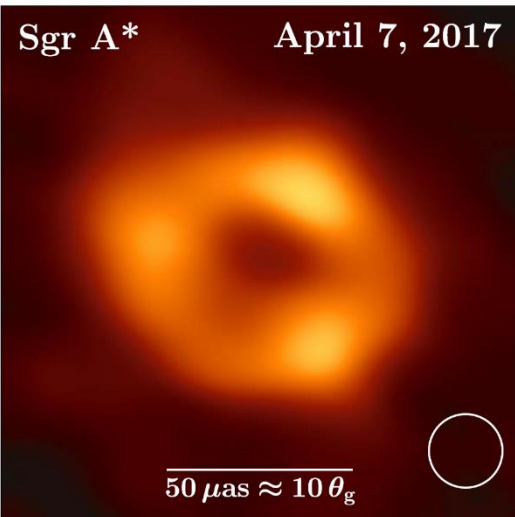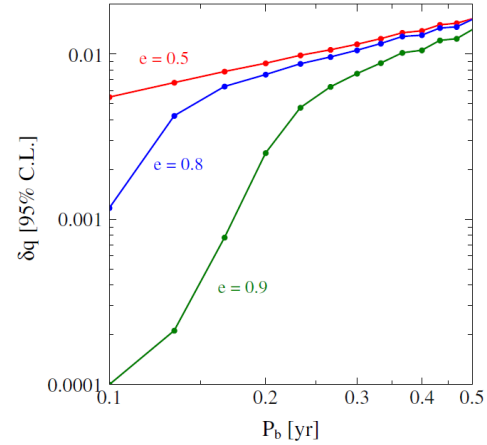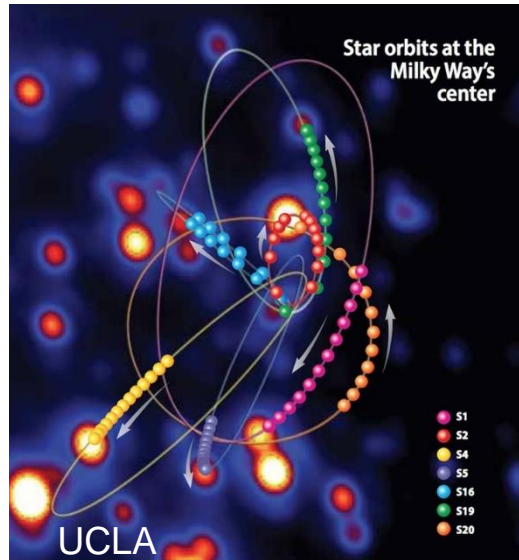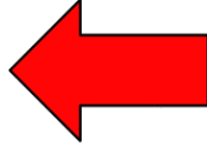
Unique strength of ALMA

- ➢ Highest sensitivity at mm-wavelengths (> 40 GHz), equivalent to a 74-m dish (others < 50 m);

- ➢ Excellent location, low and steady system temperature (~40 K at Q-band);

- ➢ (Mostly) Negligible impact by interstellar medium;
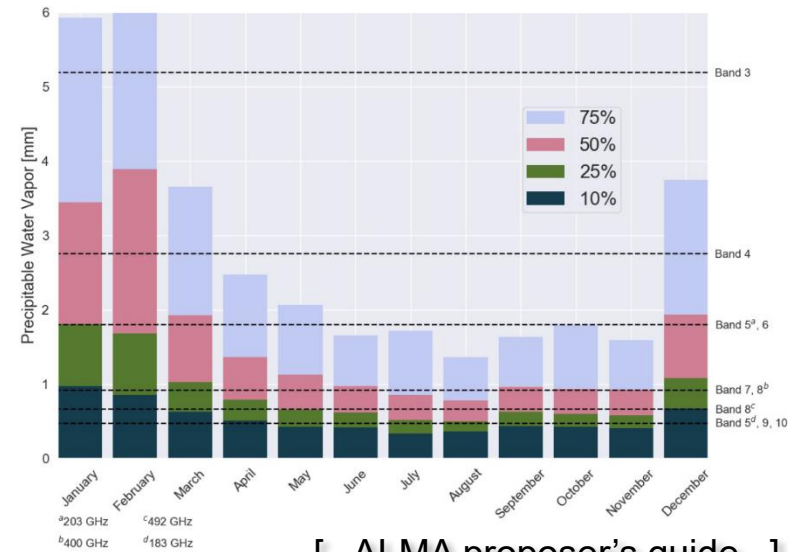
[ALMA proposer's guide]
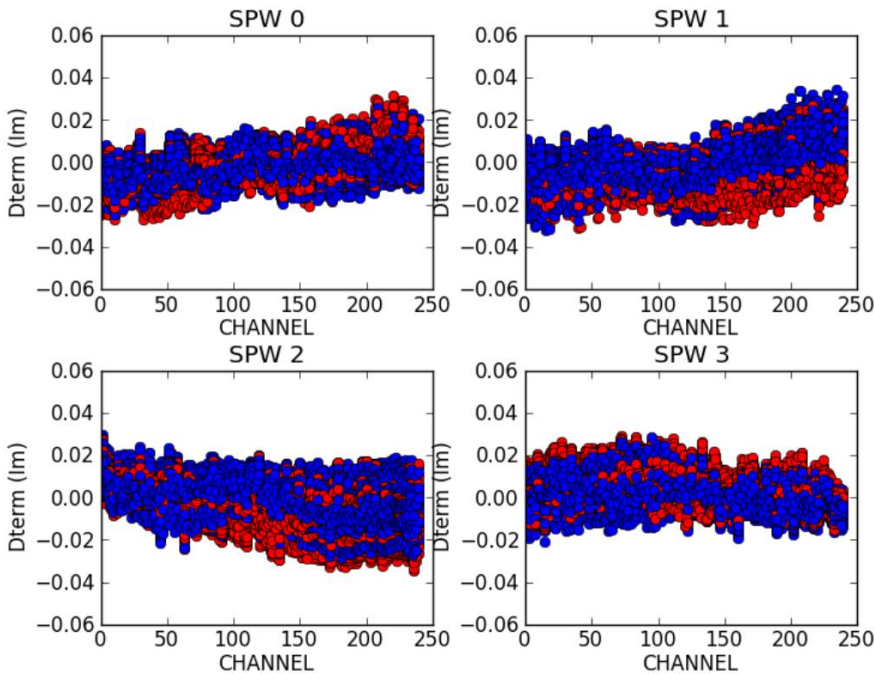
[Goddi et al. 2020]

Credit: ESO

Commissioning of phased array mode

- ➤ NSF-funded ALMA Development Study "Pulsars, Magnetars, and Transients with Phased ALMA" (PI: J. Cordes, Cornell Univ.);

- ➤ Utilized ALMA phasing infrastructure developed by *ALMA Phasing Project*;

- ➤ Passive phasing mode: Adopt phasing from phasors on science source;

Jan. 29, 2017 ALMA Band-3:

- ➤ Phasing up 34 antennas;

- ➤ Target: **B0833-45** ("**Vela**");

- ➤ Scans switches between pulsar (5-10 min) and phasor (J0828-3731, 2-3 min);
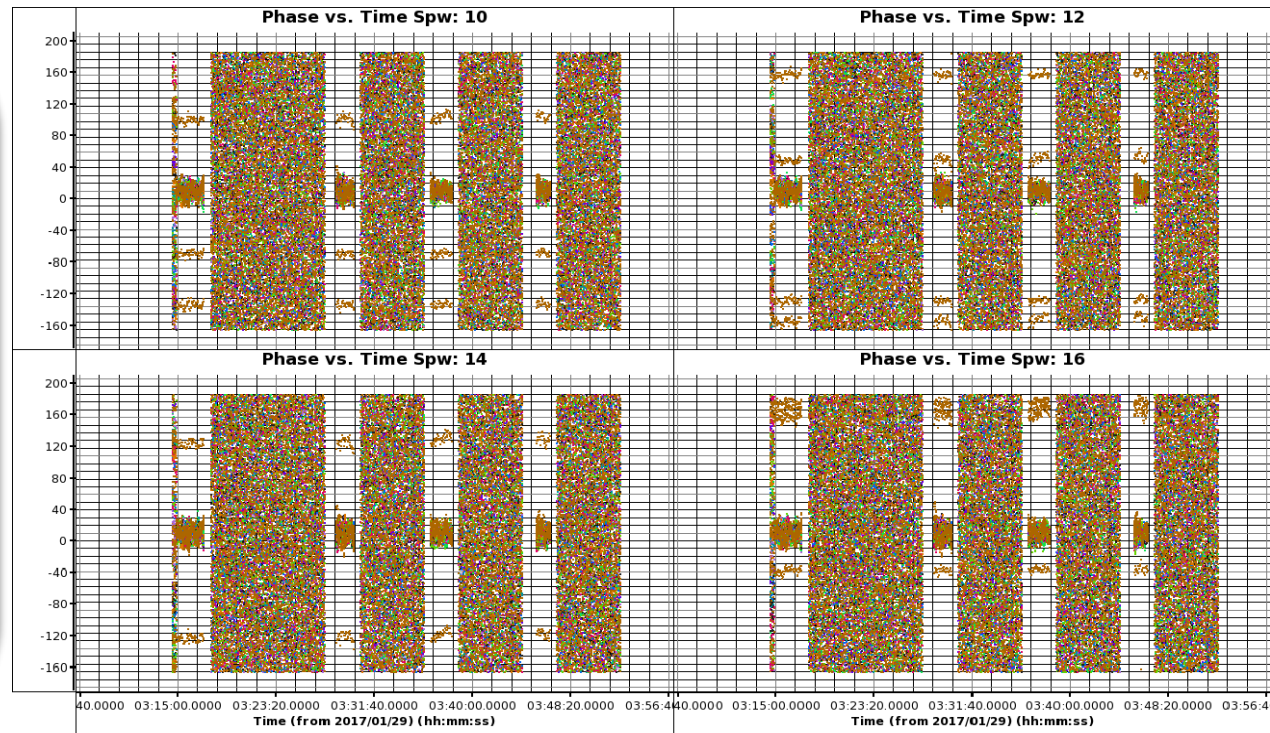
Commissioning of phased array mode

- ➢ Baseband data recorded on Mark6 in VDIF units;

- ➢ Dedicated software developed to convert data into PSRFITS search mode
  (*https://github.com/xuanyuanstar/MPIvdif2psrfits*);

- → Product directly reducible by standard pulsar software (*PRESTO, psrfits_util*, …);
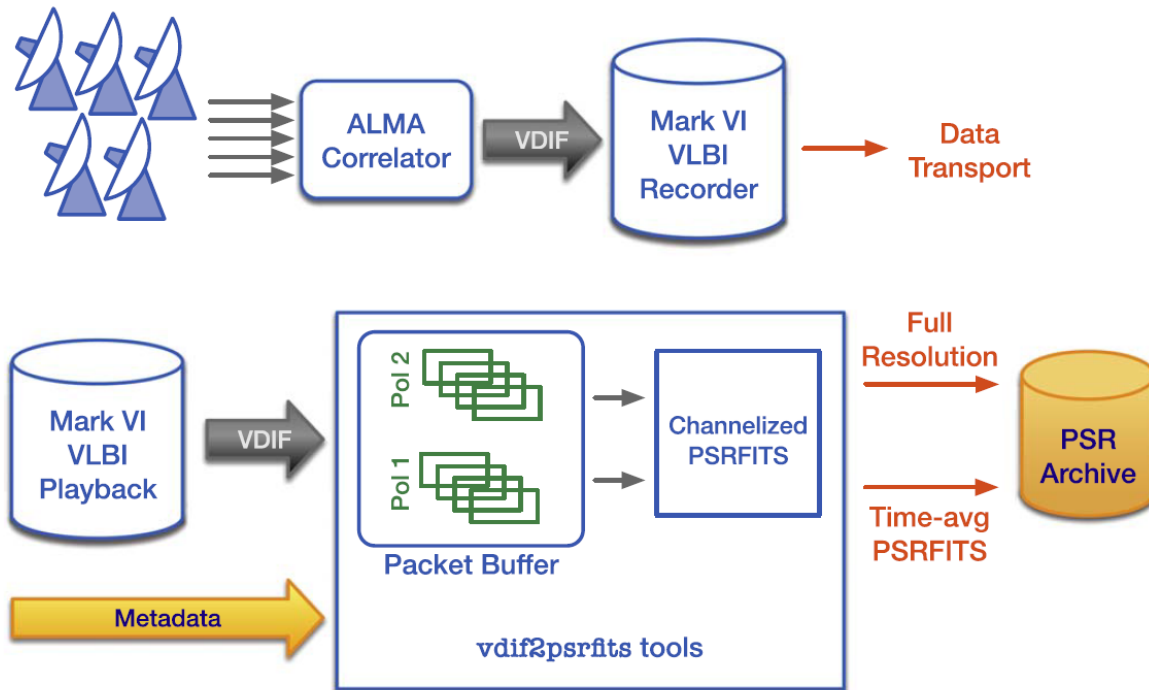
[Liu et al. 2019]

Sampling interval	8 μs
Sample bits	32-bit float
Bandwidth	4 x 2 GHz
Freq. resolution	62.5 MHz
Polarisation	I Q U V
Total data rate	256 MB/s

- Detection successful !

  → **First pulse profile detection with ALMA !**

  → **First pulse profile detection of Vela at mm (up to 101 GHz) !**

- Polarisation in line with low-frequency observation (P.A. overlap!);

- Phased-array mode available from cycle-8;

[Liu et al. 2019]
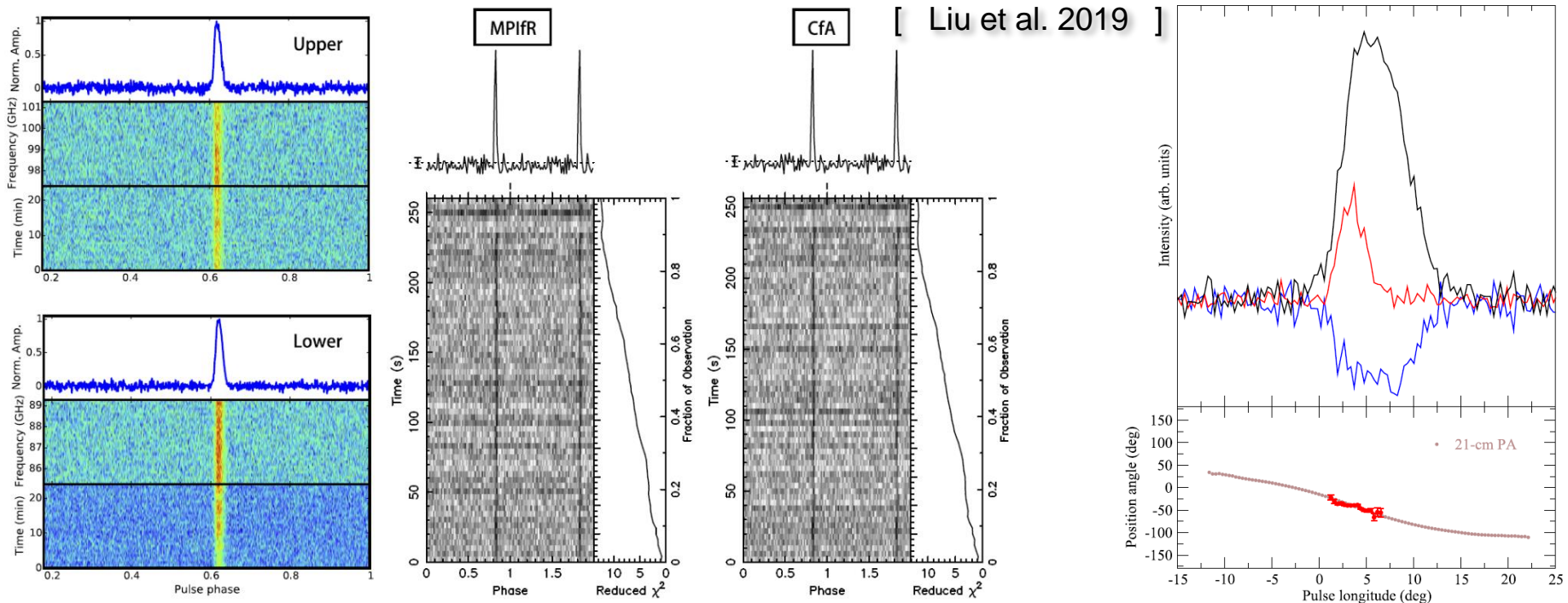
Commissioning of phased array mode

- Scans combined in phase;
- Clear low-frequency power in PSD (red noise, < ~ 20 Hz);
- Vela **detected in blind search** as the top candidate (harmonics seen by eye!);

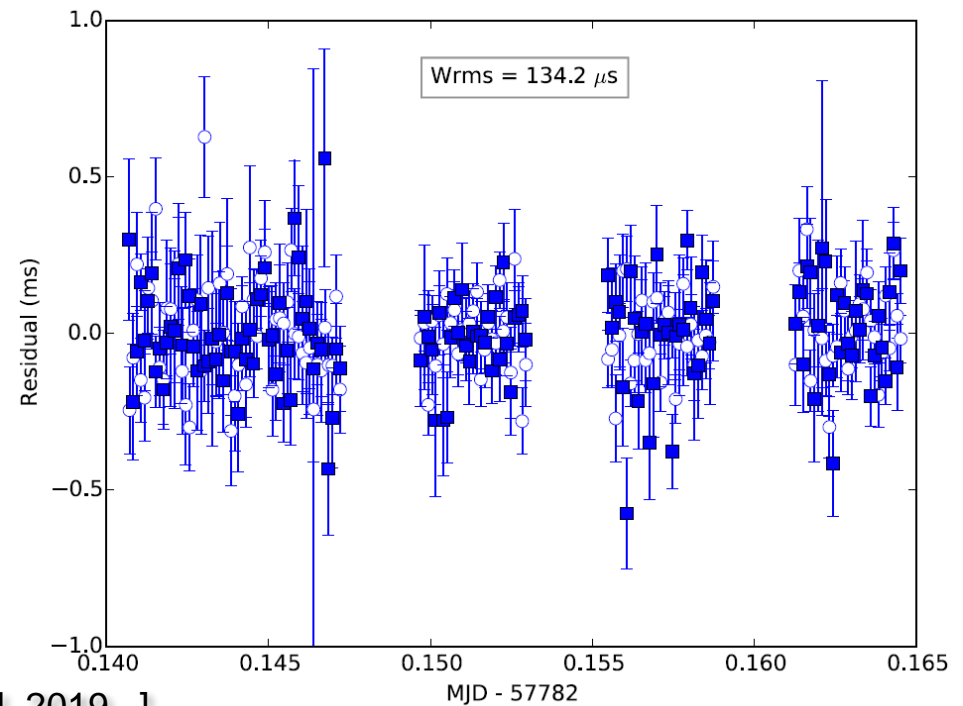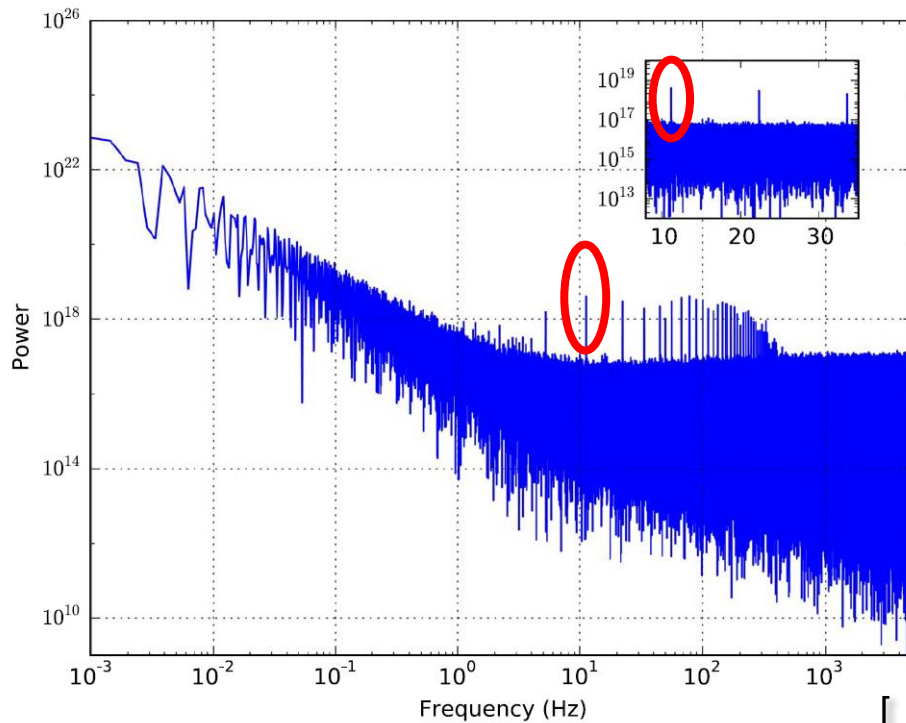- Time-of-arrival (ToA) from 20-s sub-integrations;
- ToAs aligned using ephemerides from low-frequency obs (no time offsets !);
- Fitted F0 = 11.1863846(1) Hz;

[Liu et al. 2019]

Search with GMVA+ALMA campaign

GMVA 2017 (PI: C. Brinkerink):

➤ One epoch, 03-Apr-2017, 29x5-min scans on Sgr A*;

GMVA 2018 (PI: M. Johnson):

➤ Effective one epoch, 17-Apr-2018, 18x5-min scans on Sgr A*;

Sampling interval	8 µs
Bandwidth	2 GHz
Freq. channels	32
Polarisation	I Q U V

Data logistics:

➤ VLBI mode, active phasing (on-source calibration);

➤ Baseband recorded at ALMA, shipped to Bonn correlator;
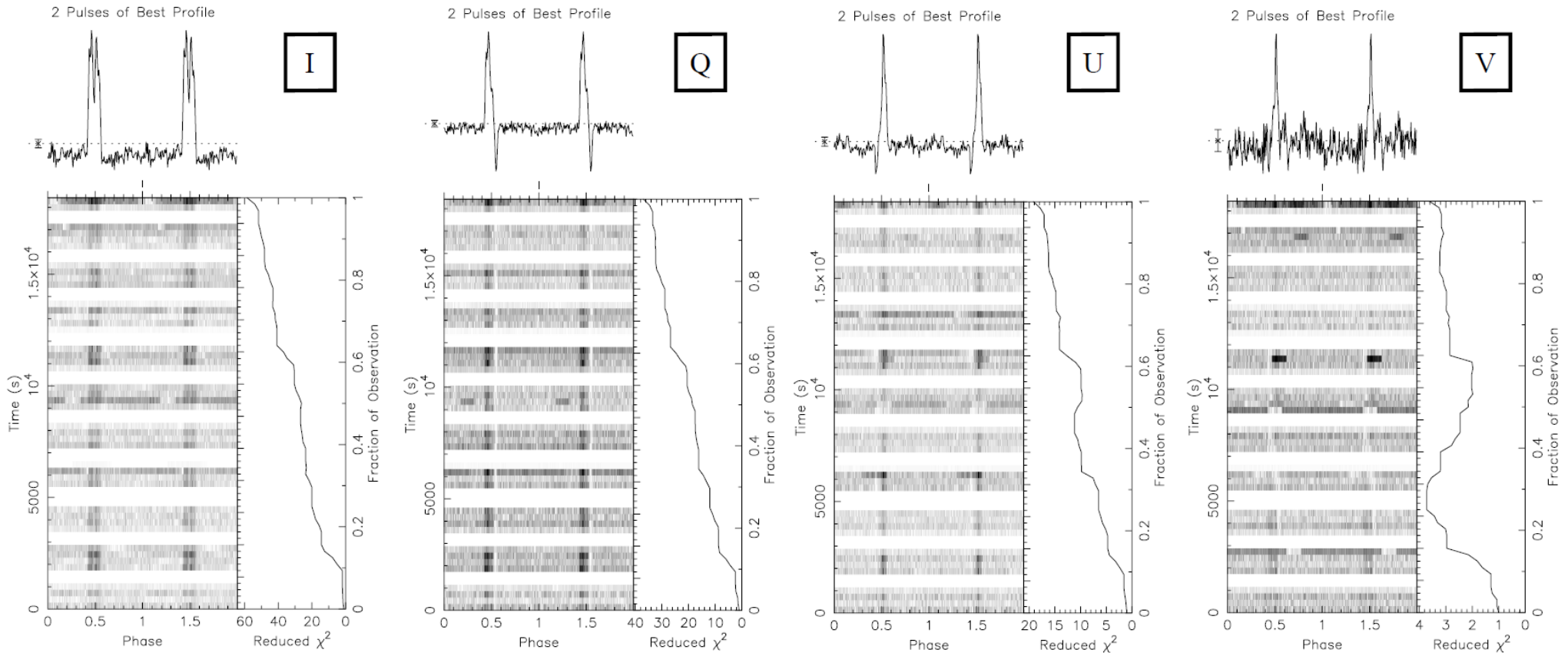
➤ Data conversion the same as phased-array mode;

Max. baseline 155 m

Max. baseline 500 m

- In total ~6000 candidates, visually inspected, no new discoveries (pity!);
- GC magnetar detected from blind search, in all Stokes;
- Detection significance in Q higher than I (33 vs 28);

Search	N_I	$N_{Q,U,V}$
2017, full	153	61
2017, segments	2,165	111
2018, full	217	84
2018, segments	2,449	1,693

[Liu et al. 2021]

Polarization profile of PSR J1745-2900:

➢ First detection at 3-mm;

➢ Close to **100% linear component** !

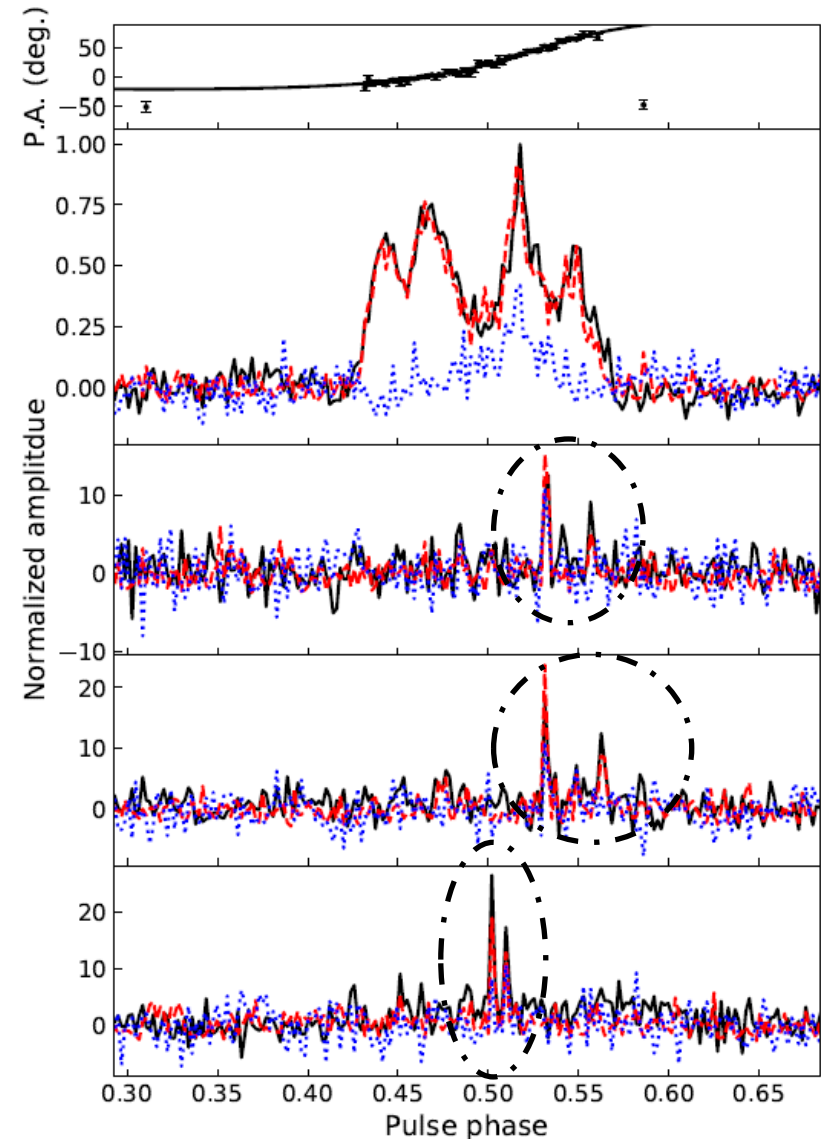**Linear pol position angle swing:**

➢ Well described by Rotating Vector Model

➔ α=110 deg, β=-20 deg

$$\tan(\Psi - \Psi_0) = \frac{\sin\alpha\sin(\phi - \phi_0)}{\sin(\alpha + \beta)\cos\alpha - \cos(\alpha + \beta)\sin\alpha\cos(\phi - \phi_0)},$$

Single pulses of PSR J1745-2900:

➢ Three found (above 7-σ) from blind search for bursts;
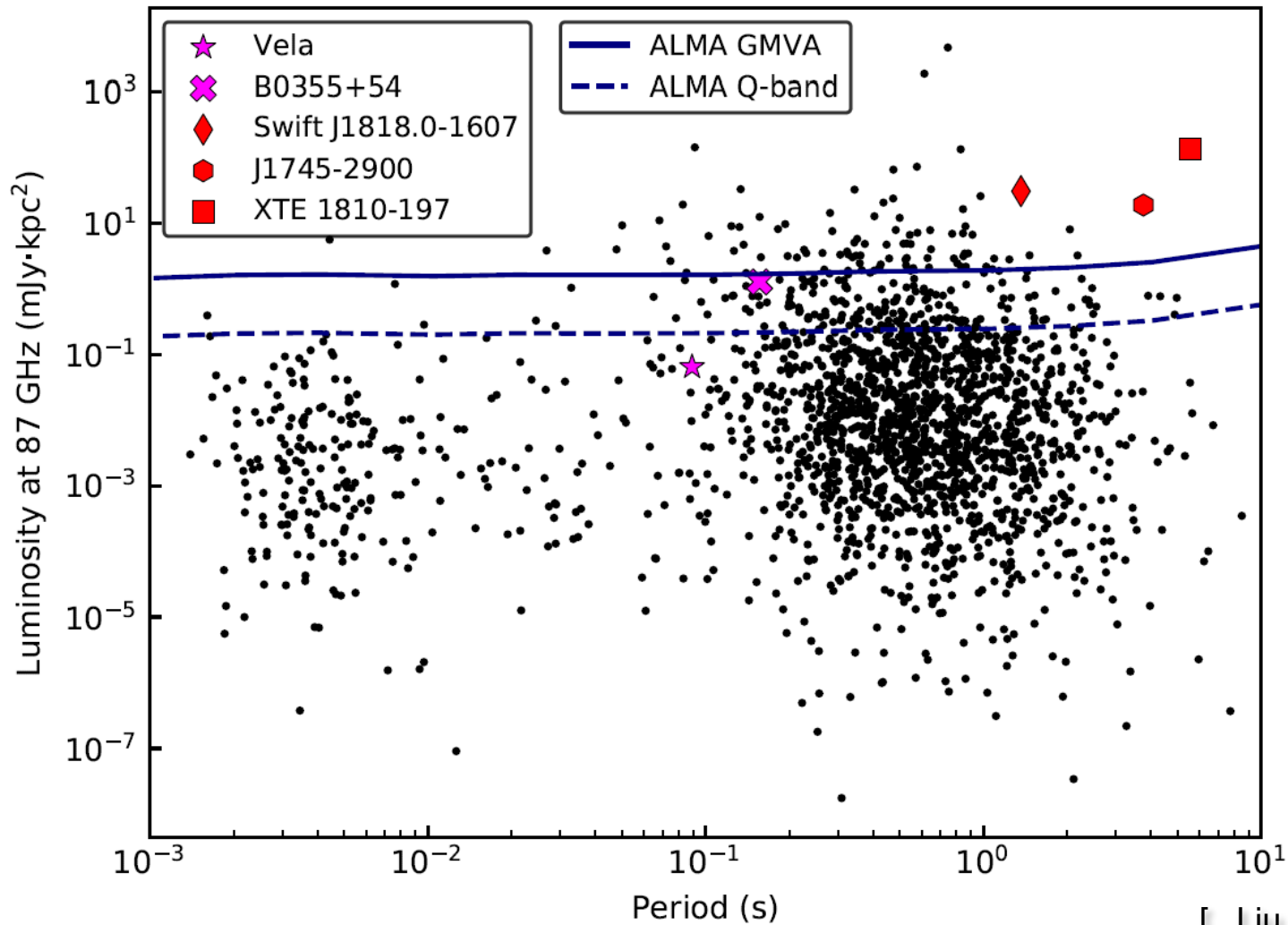
➢ Sub-pulse structure, highly linearly polarized;

[Liu et al. 2021]

Probe into GC Pulsar population: GMVA ALMA ⌣4%   ALMA Q-band ⌣14%
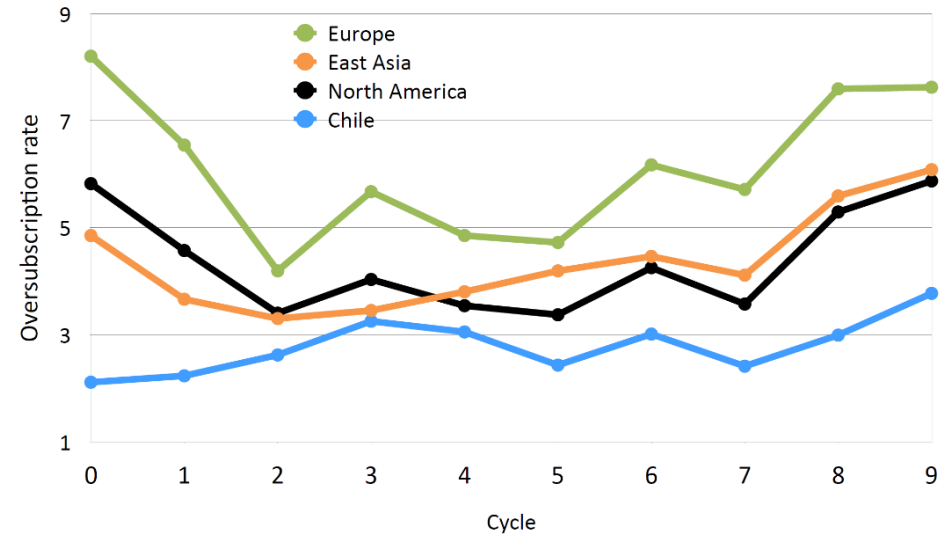

[Liu et al. 2021]

Phased-array mode proposal

> ➤ >10 proposals in 2 cycles, 1 accepted;

Challenges:
- ➤ New science cases in the canonical ALMA community;
- ➤ New observing mode, technical justification;
- ➤ High oversubscription rate with ALMA;

[ALMA newsletter   ]

Tips (may not work though...):
- ➤ Strong science case (novelty, impact, ...);
- ➤ Unique strength of ALMA (Can any other instruments do this?);
- ➤ Texts straightforward to understand for other (not time-domain) astronomers;
- ➤ Attention to technique details (band, Tobs, overhead, ...)