Interstellar scintillation and polarization of PSR B0656+14 in the Monogem ring

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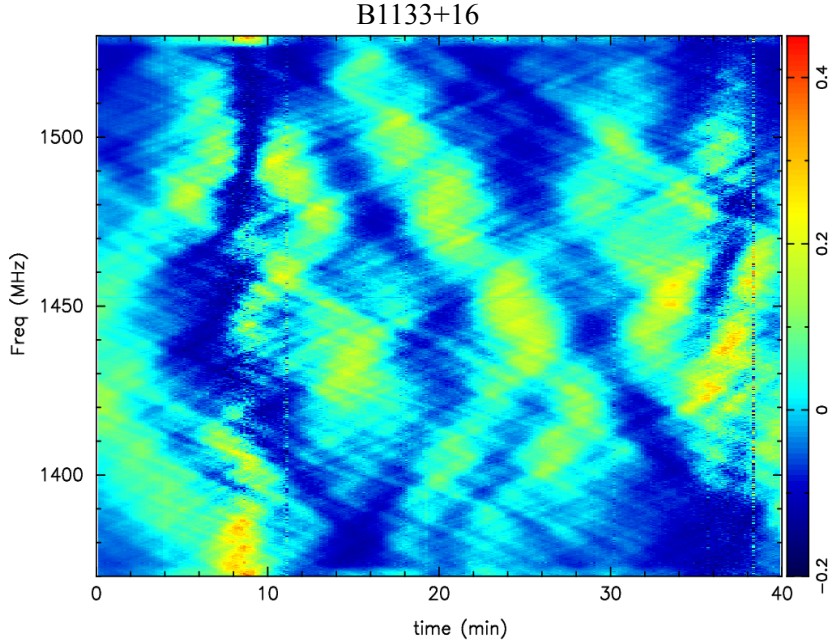
Outline

1. ISS arc detection of pulsar associated with SNR
2. 2D and 3D spin-velocity alignment
3. PSR B0656+14 and the Monogem ring
4. The DS and SS of PSR B0656+14
5. The pulse profile of PSR B0656+14
6. The polarization of PSR B0656+14
7. Summary

ISS arc detection of pulsar associated with SNR

1. Dynamic spectrum, ACF, SF, and secondary spectrum



ACF:

$$A(\Delta\nu, \Delta t) = \sum_{\nu}\sum_{t} \Delta F(\nu, t)\Delta F(\nu + \Delta\nu, t + \Delta t)$$

$$\rho(\Delta\nu, \Delta t) = C_0 \exp[-(C_1\Delta\nu^2 + C_2\Delta\nu\Delta t + C_3\Delta t^2)]$$

ISS timescale, bandwidth and velocity:

$$\Delta\nu_d = \sqrt{\frac{\ln 2}{C_1}} \qquad \Delta t_d = \sqrt{\frac{1}{C_3}}$$

$$V_{iss} = 3.85 \times 10^4 \left(\frac{\sqrt{x D_{kpc} \Delta\nu_{d,MHz}}}{\nu_{GHz}\Delta t_{d,s}}\right)$$

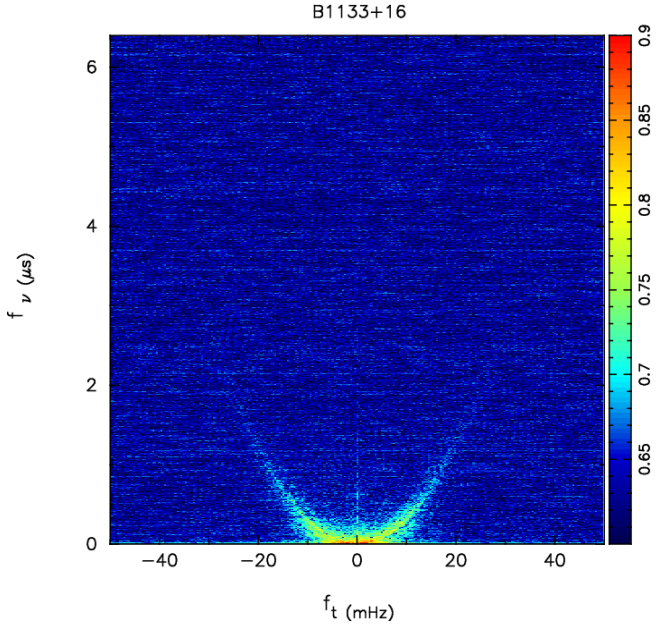
SS:

$$S(\nu, t) \longrightarrow S^{\dagger}(f_\nu, f_t),$$

$$S_2(f_\nu, f_t) = \left|S^{\dagger}(f_\nu, f_t)\right|^2.$$

$$\eta = 4625 \frac{D_{\rm kpc}}{\nu_{\rm GHz}^2 V_\perp^2}\left(\frac{s}{1-s}\right)$$

The location of the screen: $D_{\rm ps} = sD$



2. Six PSRs/SNRs systems

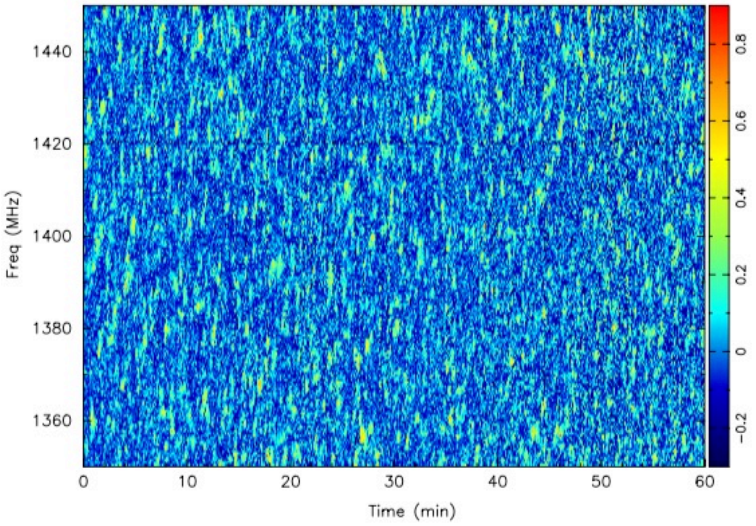
Jname	DM cm^{-3} pc	S_{1400} mJy	Distance kpc	Velocity km/s	$\tau_{sc,1\ GHz}$ s	SNR Type	Time min	Repeat
J0502+4654	41.83	2.50	1.32	71	2.172E−04	S	60	1
J0534+2200	56.77	14.00	2.00	141	1.237E−04	P	60	1
J0538+2817	39.57	1.90	1.30	357	*	S	60	4
J0659+1414	13.94	2.70	0.29	60	2.900E−09	S	120	1
J1952+3252	45.01	1.00	3.00	460	9.770E−07	C	120	2
J2337+6151	58.41	1.40	0.70	50	7.590E−07	S	60	1

J0502+4654 and J1952+3252: small scale patches in time, no ISS arc detections.

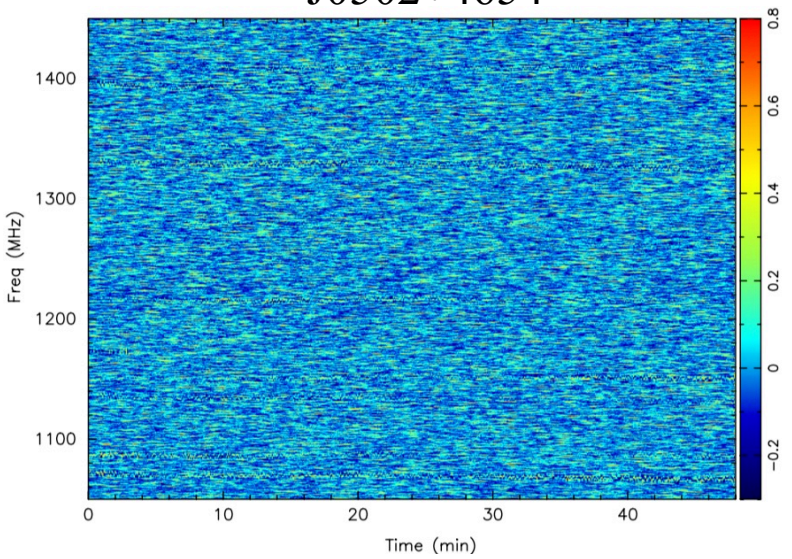
J0538+2817, B0656+14 and J2337+6151: detected ISS arcs.

2. The Dynamic spectra of J0502+4654 and J1952+3252

J1952+3252

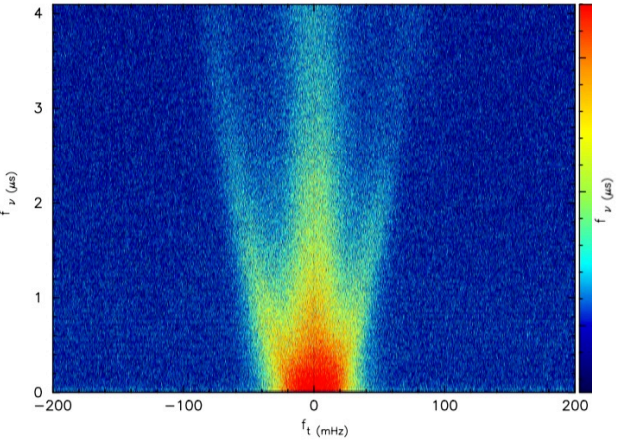


J0502+4654

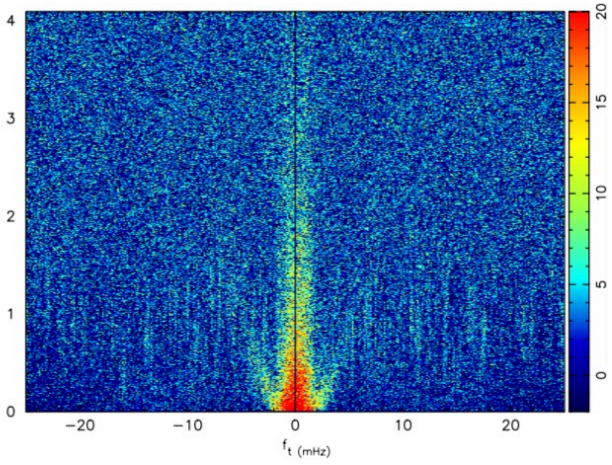


3. The secondary spectra of J0538+2817, B0656+14 and J2337+6151

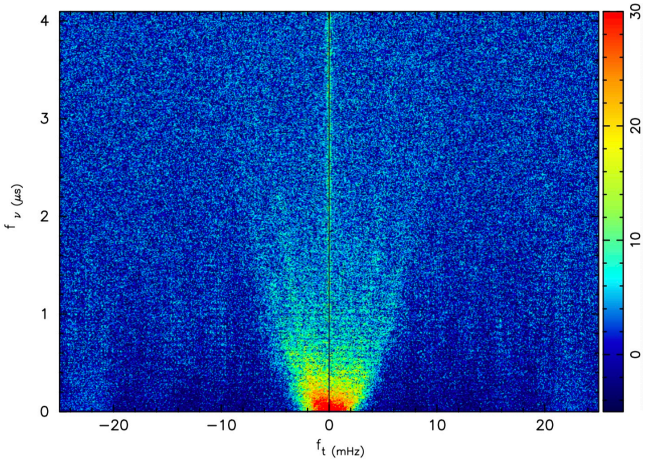
J0538+2817 (35 kyr)



J2337+6151 (40 kyr)



B0656+14 (110 kyr)



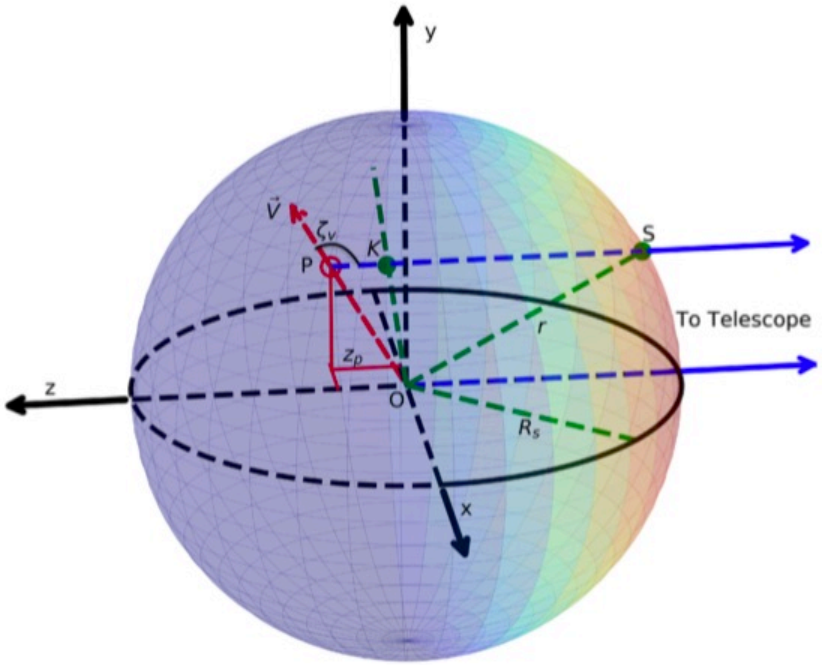
2D and 3D spin-velocity alignment

1. 2D velocity and 3D spin vector

I. Pulsar transverse velocity: VLBI, Timing, ISS and et al.

II. 3D spin vector: pulsar polarization and X-ray torus

2. 3D velocity and 3D spin-velocity alignment



ISS arc detection: new method for estimating pulsar radial location and velocity

J0538+2817/SNR S147: the first 3D spin-velocity alignment in pulsars

(Yao et al. 2021, accepted by NA)

PSR B0656+14 and the Monogem ring

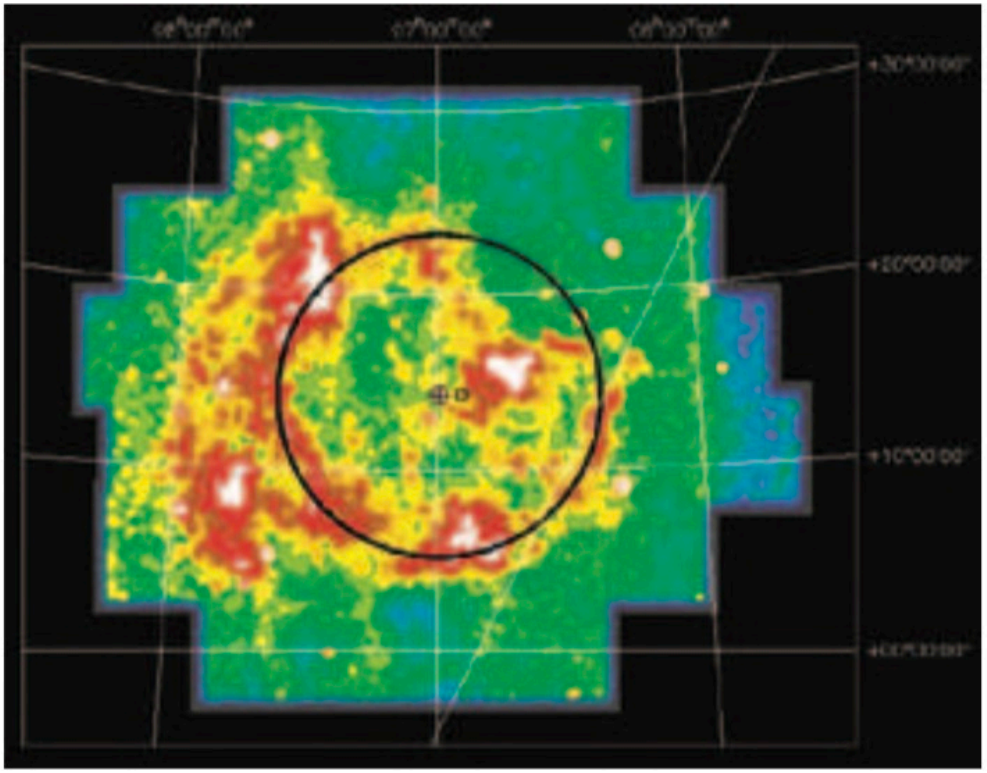


FIG. 1.— The Monogem ring, as seen in the *ROSAT* all-sky survey in the 0.25–0.75 keV x-ray band. PSR B0656+14 is marked with cross-hairs, and the 9.2° circle centered on this point shows the primary ring structure. The estimated position of the pulsar 10^5 yrs ago is marked with a small square. J2000 coordinates are shown, and the Galactic plane is indicated by a diagonal line. The ring is imperfect: there is an apparent blow-out to the west, at high galactic latitude, and a missing quadrant to the northwest, perhaps due to foreground absorption or to slower expansion into a dense region. The bright source at 06:17 +22:34 is the SNR IC443.

Thorsett et al. 2003

The Monogem ring:

300 pc, 25 deg, 110 kyr

-Radius of 64 pc

The PSR B0656+14:

288 pc, close to the center, 86 kyr

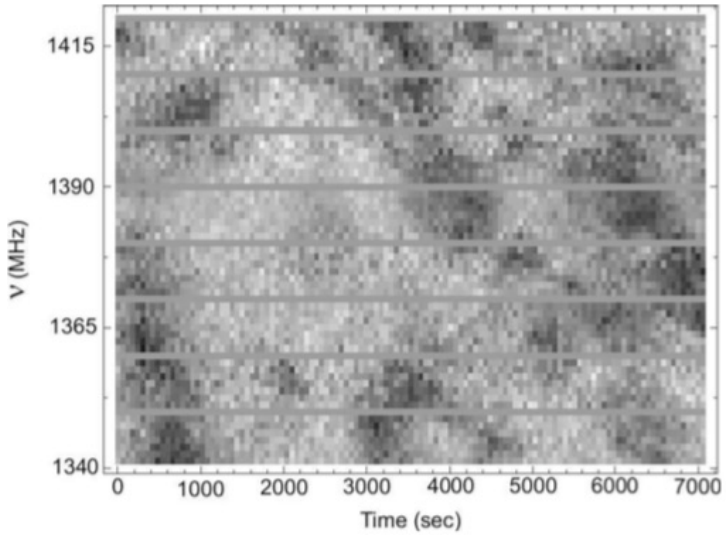
60+/7 km/s

Summary (association):

1. Location
2. Age
3. Reasonable proper motion
4. Distance

The DS and SS of PSR B0656+14

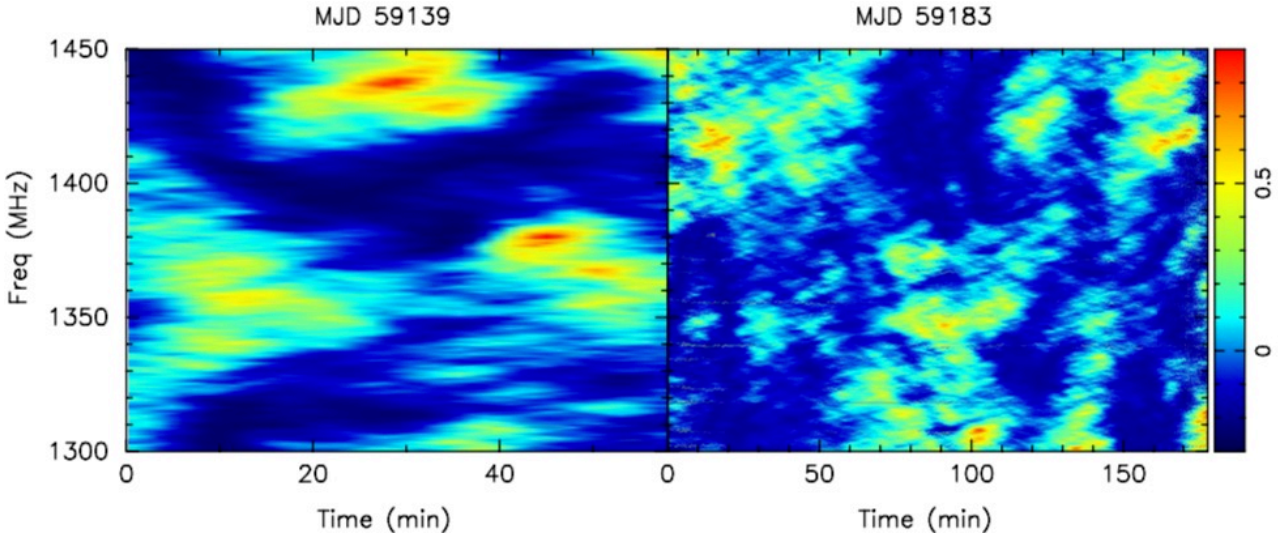
1. The dynamic spectrum of PSR B0656+14



Weltevrede et al. 2006:

WSRT, 1380 MHz, 2-h observations

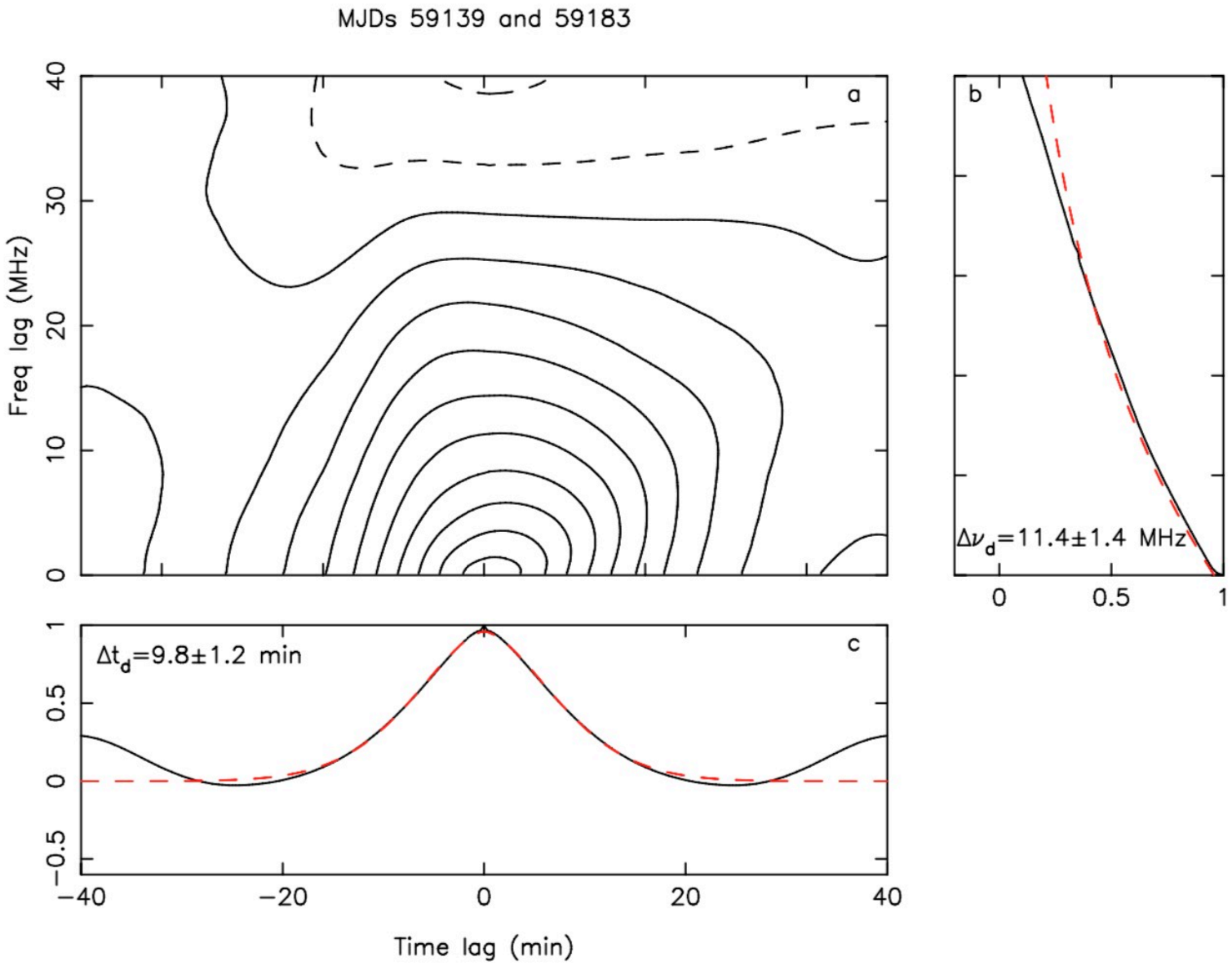
a thousand second - 17 min



Yao et al in prep. (2021):

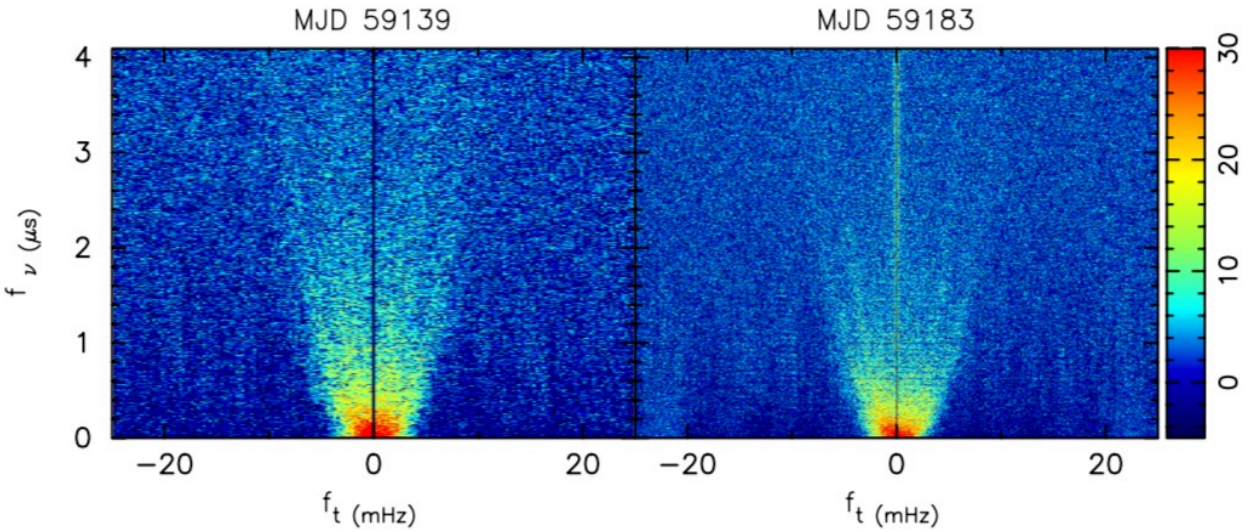
1-h and 3-h FAST observations

2. The ACF of PSR B0656+14

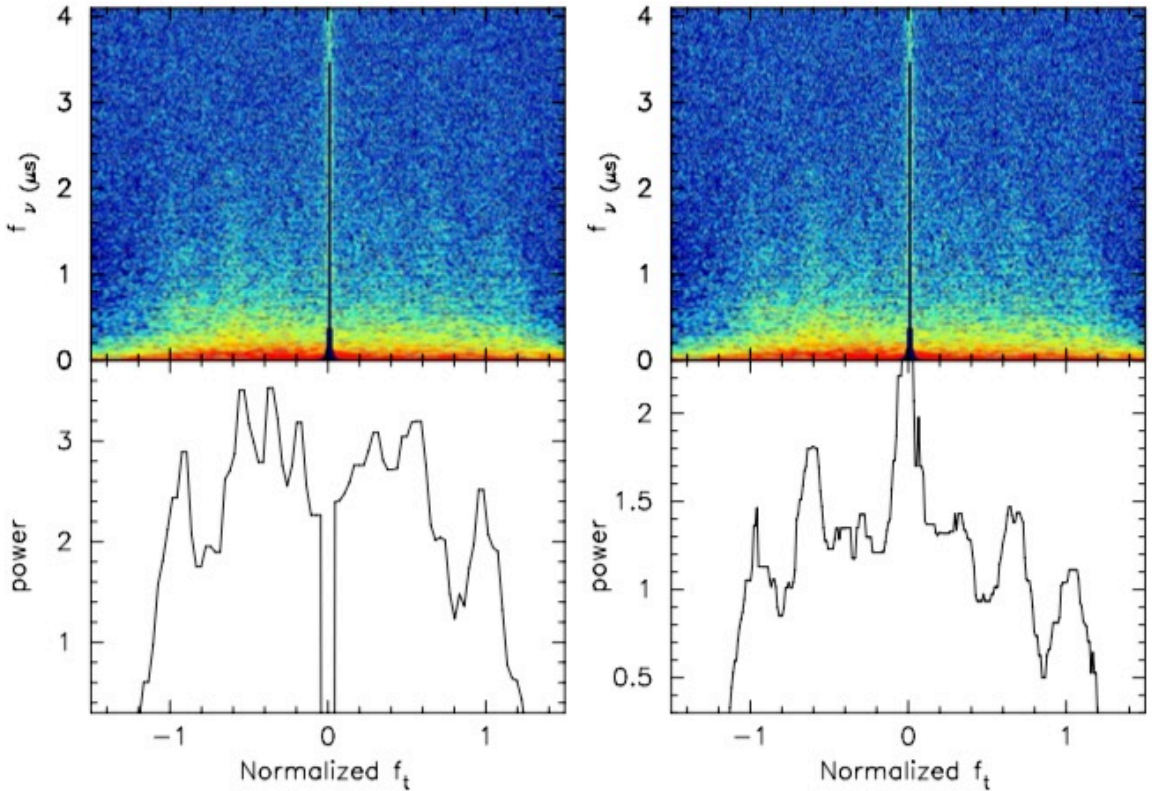


Using ACF, we obtained the scintillation timescale and scintillation bandwidth.

3. The secondary spectrum of PSR B0656+14



The secondary spectra

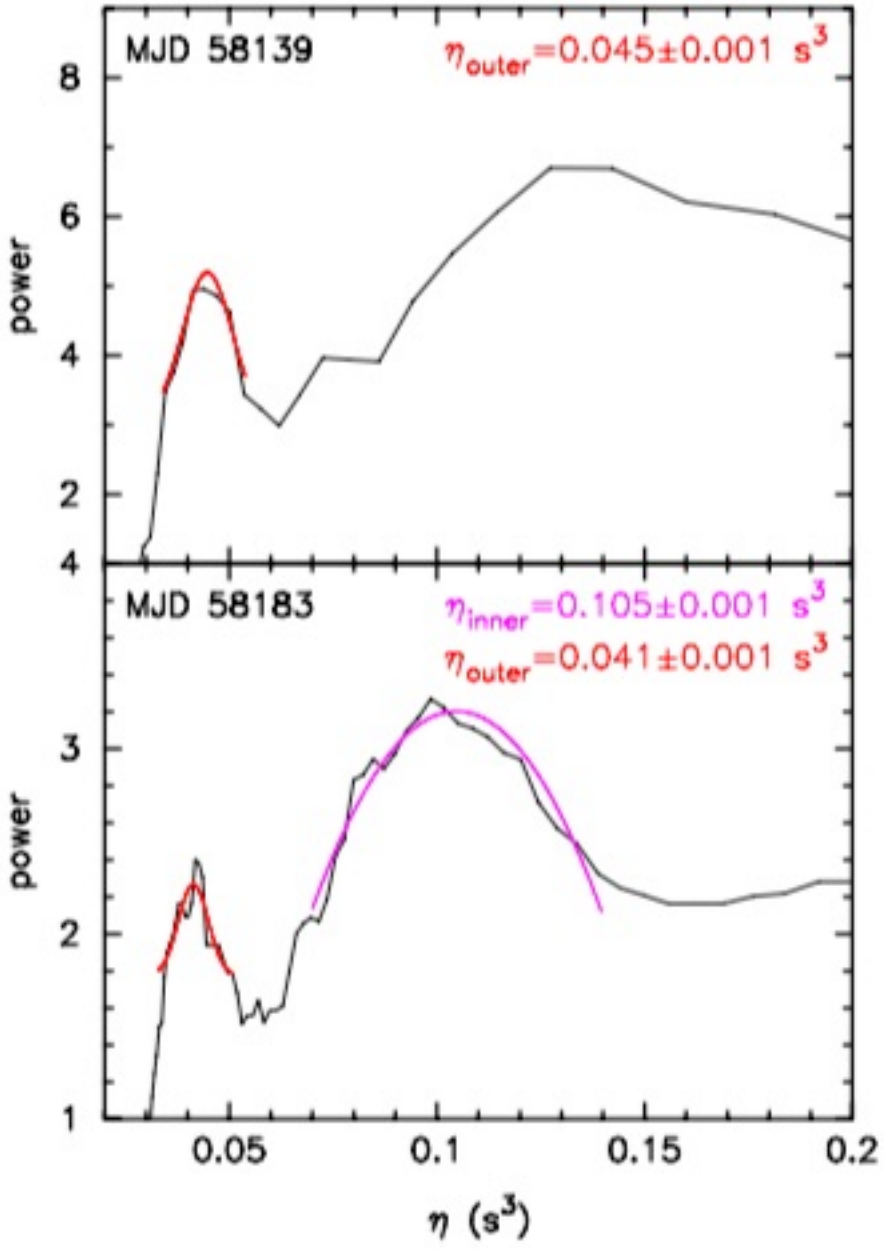


Normalize secondary spectra

&

Resample

4. The arc curvature and the distance between pulsar and screen



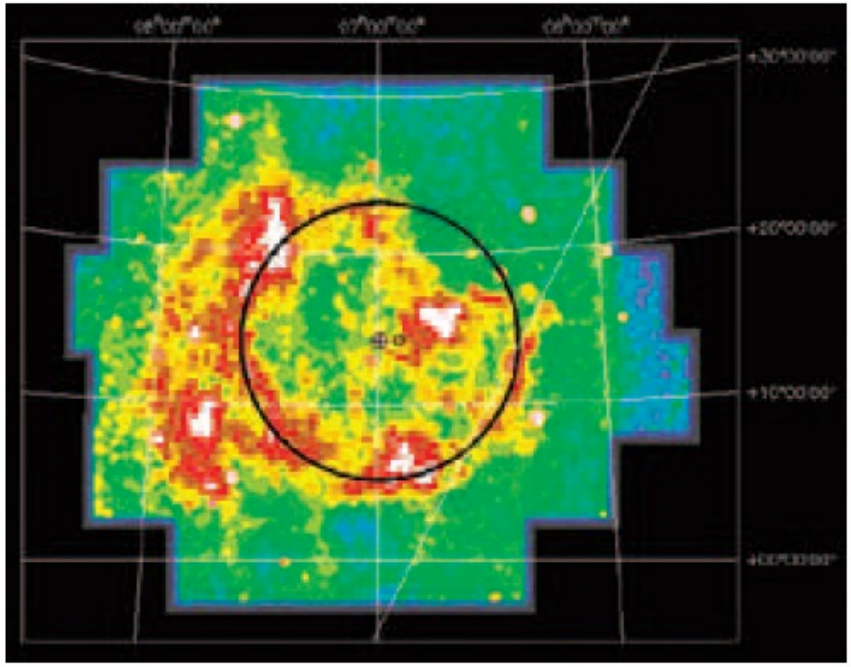
$$s_{\rm inner} = 0.359 \pm 0.025$$

$$s_{\rm outer} = 0.180 \pm 0.016.$$

$$D_{\rm sp1} = 103 \pm 13 \text{ pc}$$

$$D_{\rm sp2} = 52 \pm 7 \text{ pc}.$$

5. The two scattering screens



Outer arc - The shell of the Monogem ring:

- Radius of 64+/-7 pc
- Pulsar-to-screen 52+/-7 pc
- **Confirm the association**
- **Shell of SNR dominate scattering**

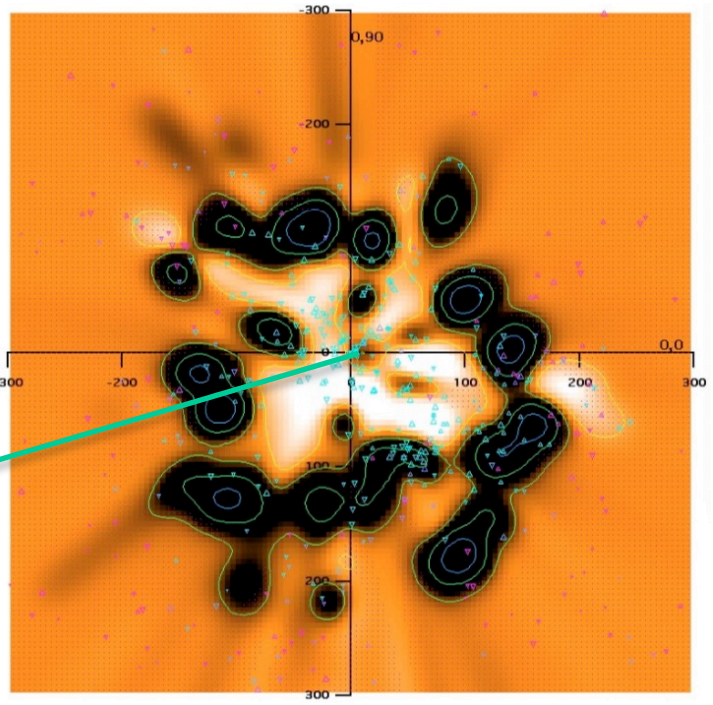
#	NAME		Gl (deg)	Gb (deg)
1	B0656+14	mlt+78	201.108	8.258

Inner arc - The shell of the local hot bubble:

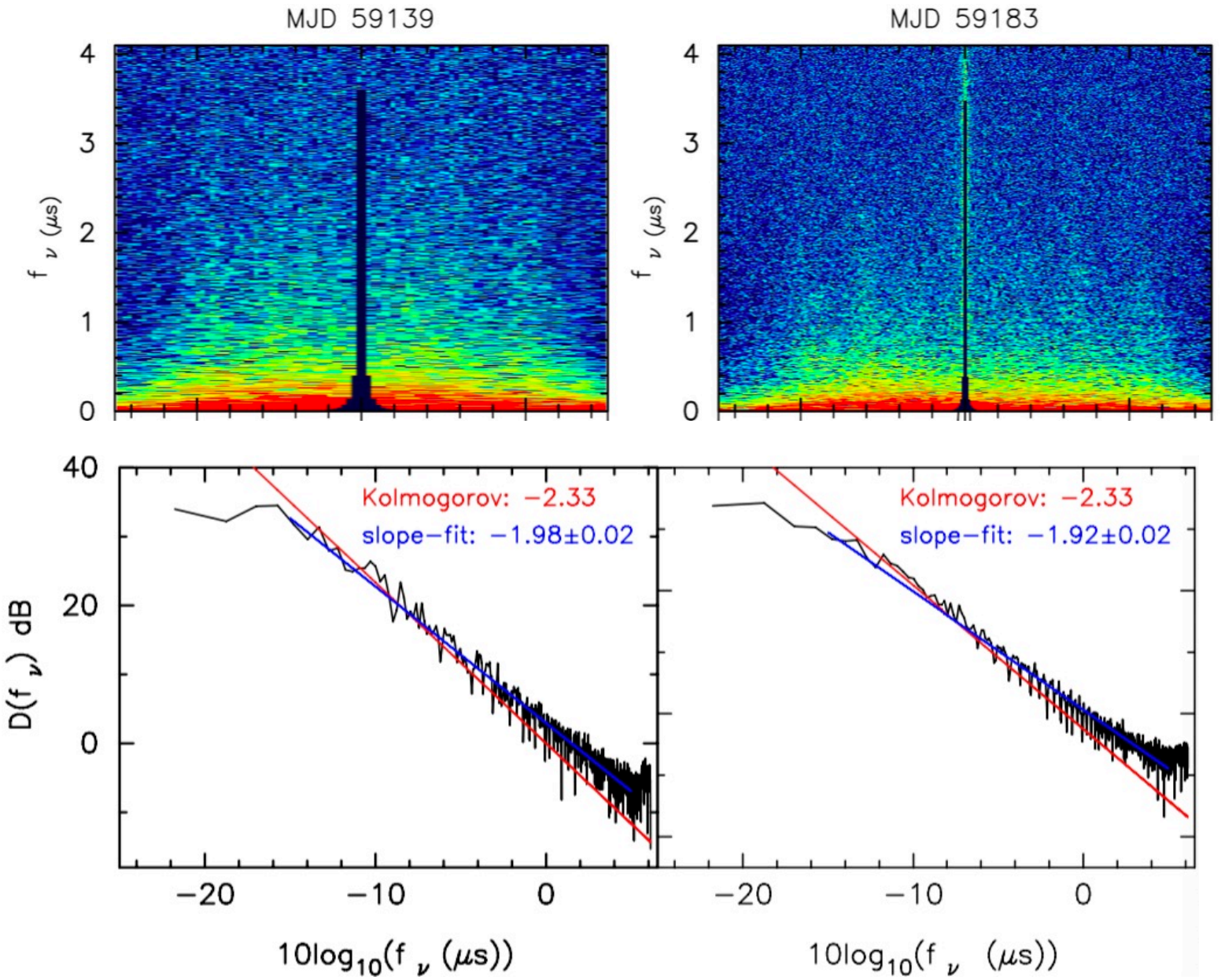
- 185±13 pc from the Earth

- Shell of LB: 150- 180 pc from the Earth

Gl=201 deg



6. The turbulent spectra for these two observations - Delay profile

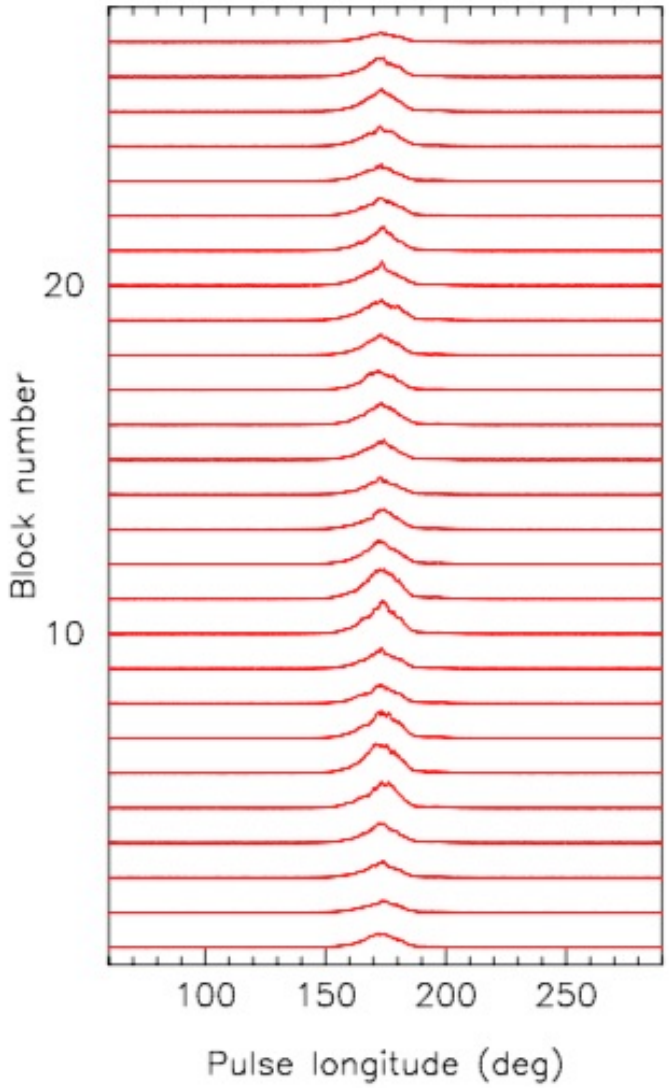


The slope is:
-(1+alpha)/2

Kolmogorov:
alpha=11/3
Slope: -2.33

The turbulent spectra for these two observations are flatter than the Kolmogorov.

The pulse profile of PSR B0656+14

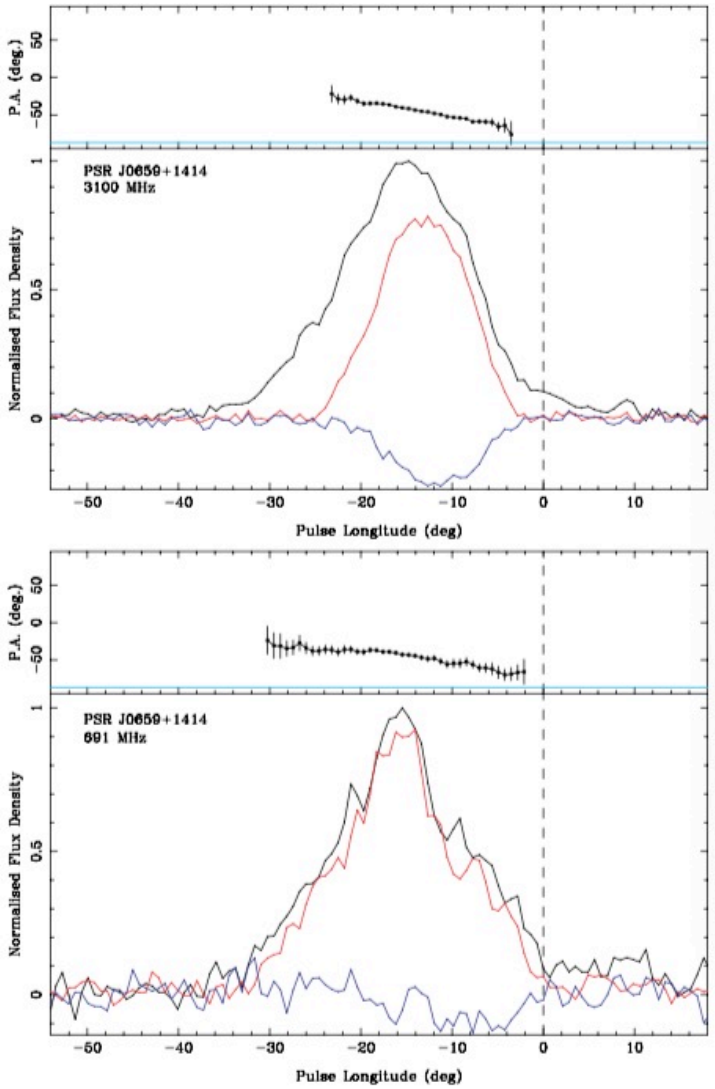


No stable pulse profile available may affect the S/N of the detected ISS arc.

The pulse profile of PSR B0656+14 at MJD 58183 obtained by averaging successive blocks of 1000 single pulses.

The polarization of PSR B0656+14

1. Previous polarization results



Johnson et al. 2007 (Parkes)

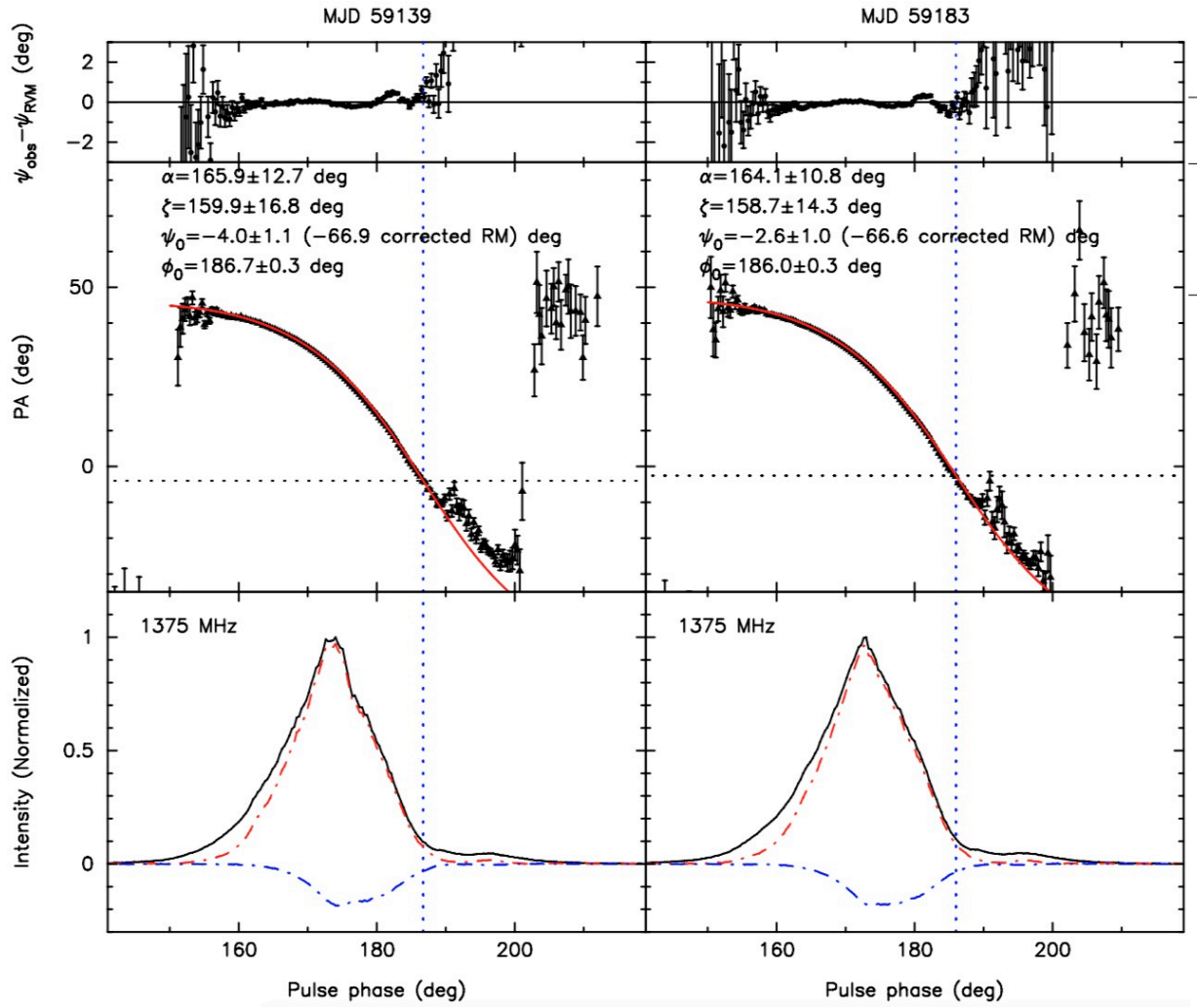
Noutsos et al. 2013

PSR	log τ_c (yr)	PA_v (°)	Reference	PA_0 (°)	Reference	Ψ (°)
J0139+5814	5.6	30(13)	1	−71(5)	18	11(14)
J0152−1637	7.0	173(3)	5	92(9)	19	8(9)
J0304+1932	7.2	−9(11)	2	12(10)	18	21(15)
J0332+5434	6.7	−61(1)	3	−4(5)	18	33(5)
J0358+5413	5.8	69(16)	4	−33(5)	18	12(17)
J0452−1759	6.2	72(23)	5	47(3)	20	25(23)
J0454+5543	6.4	−72(3)	1	−66(11)	18	6(11)
J0525+1115	7.9	132(16)	5	−65(4)	21	17(16)
J0534+2200	3.1	292(10)	6	124.0(1)[b]	22	12(10)
J0538+2817	4.6	−24.1(2)	7	−49(10)	18	25(10)
J0543+2329	5.4	57(20)	1	−100(5)	18	23(20)
J0630−2834	6.4	294(3)	8	26(2)	21	2(4)
J0659+1414	5.0	93.1(4)	9	−86(2)	20	1(2)

The angle between spin and velocity is 1+/-2 deg.

—— near-perfect 2D spin-velocity alignment

2. FAST polarization (1-h and 3-h observations)



The new measured RM is consistent with old measures.

MJD and UT	RM_{obs} rad m^{-2}	RM_{iono} rad m^{-2}	RM_{ism} rad m^{-2}
59139 (UT 22 h)	+23.05 ± 0.12	+0.59 ± 0.08	+22.46 ± 0.14
59183 (UT 18 h)	+23.57 ± 0.18	+0.90 ± 0.06	+22.67 ± 0.19
59183 (UT 19 h)	+23.58 ± 0.18	+0.91 ± 0.07	+22.67 ± 0.19
59183 (UT 20 h)	+23.45 ± 0.15	+0.84 ± 0.04	+22.61 ± 0.16

New: $\mathrm{RM_{ism}} = +22.58 \pm 0.09\ \mathrm{rad\,m^{-2}}$

Old: $\mathrm{RM_{ism}} = +22.73 \pm 0.08\ \mathrm{rad\ m^{-2}}$

(Sobey et al. 2019, LOFAR)

2D-Velocity (VLBI):
-86 deg from North

2D-Spin (FAST Pol):
-66 deg from North

The angle between spin and velocity is 20 deg, not 1deg - far from near-perfect alignment.

Summary

Detected ISS arcs for three pulsars, PSRs J0538+2817, B0656+14 and J2337+6151

We detected two ISS arcs for PSR B0656+14

Outer arc - from the shell of the Monogem ring, Inner arc - the shell of the Local Bubble

Confirm the association and the shell of SNR dominate pulsar scattering

The angle between spin and velocity is 20 deg, which is far from near-perfect alignment

Thanks