The magneto-environment of FRBs and potential evidence for binary

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Now >600 published FRBs

Understand lots of things: some come from magnetars, some repeat, rates, morphology, etc

Moving forward, what are the observation that will help?

Few puzzles:

Not involving the messy emission mechanism, but related to the progenitor

- The long-term periodicity (CHIME/FRB+20, Rajwade+20)
- Localization: not tracing star-formation/stellar mass (Heintz+20); One in globular cluster (Kirstan+21)
- The active magneto-environment (see later slides)

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- The active magneto-environment (see later slides)

In this talk:

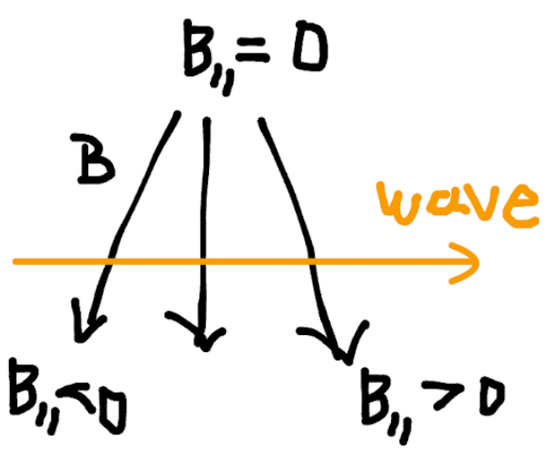
- The magneto-environment of FRBs
- Analogy in a pulsar binary
- Search for GC FRBs

The magneto-environment: some basics

- Stokes parameter:
  - I (total intensity), Q, U (components of linear polarization), V (circular polarization)
  - Linear polarization L=(Q^2+U^2)^0.5

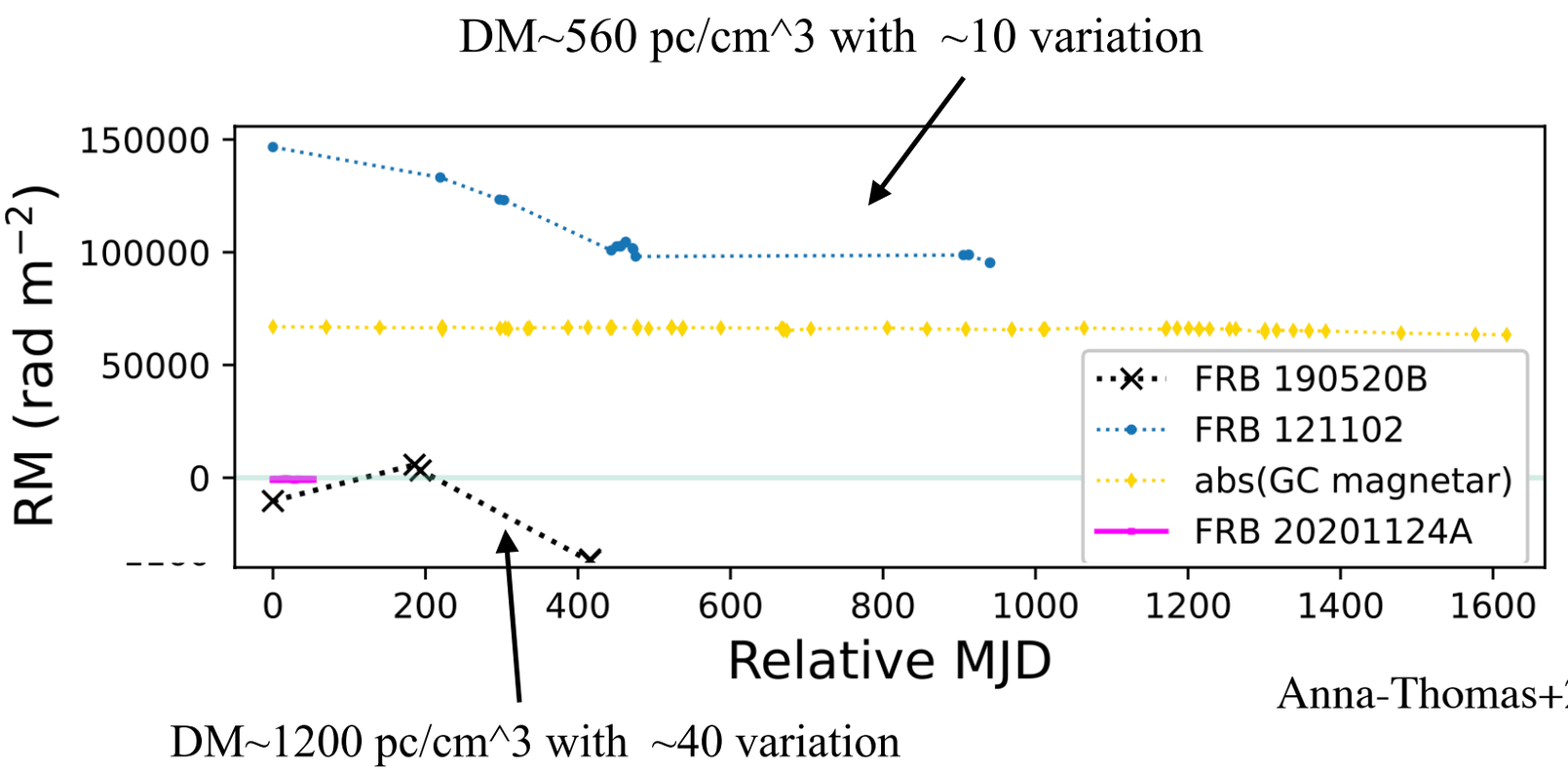
- Plasma eigenmode circular (typical ISM (micro G), IGM (nG)): Faraday rotation
  - Q, U rotate with wavelength^2, conserve L, V

- Plasma eigenmode linear: Faraday conversion
  - mix L and V
  - Relativistic electrons, pair plasma
  - Large magnetic field B>~500G f/GHz
  - B_// reversal $B \gtrsim 3\,G\,(\Delta \mathrm{DM}/1\,\mathrm{pc\,cm^{-3}})^{-1/3}(f/\,\mathrm{GHz})^{-4/3}$



What’s seen in FRB polarization

Unusual magneto-environment of FRBs: large RM



Anna-Thomas+22

Some FRB have extremely high RMs
—> highly magnetized medium around it

$$\mathrm{DM} = \int n_e ds$$

$$\mathrm{RM} \propto \int n_e B_{||} ds$$

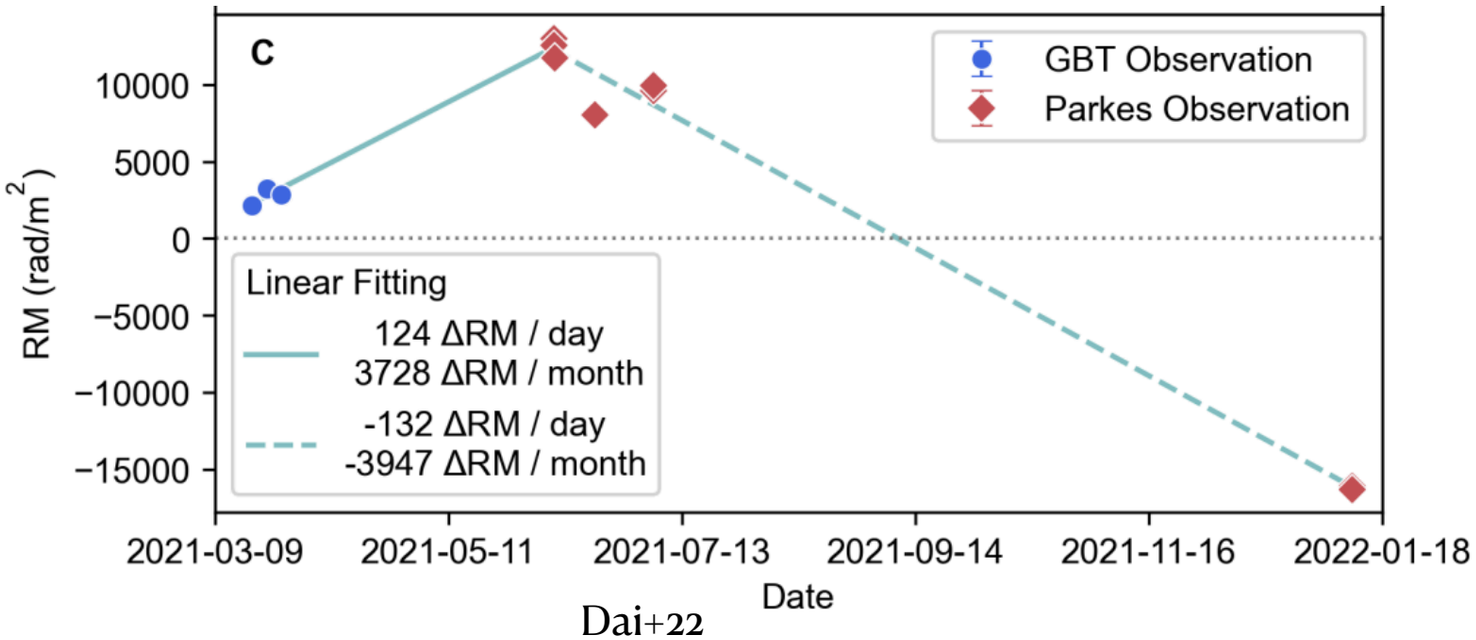
Unusual magneto-environment of FRBs: fast varying spatial structure

- Order 1 irregular RM fluctuation of repeaters (2 out of 6 FRBs with multiple RM measurements: e.g. Xu+22, Dai+22)

timescale: ~month
—>spatial scale: month * 100km/s ~ AU

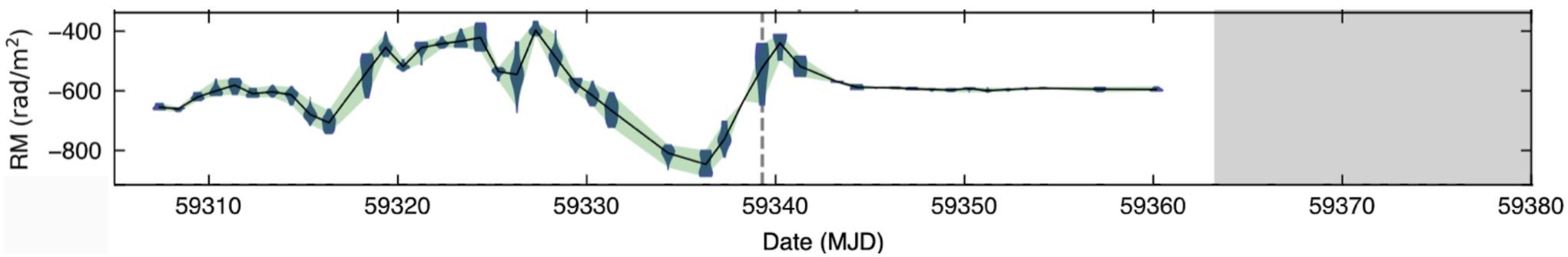
Current observed smallest structure in SNR is ~0.1pc, either smaller scale exists, or time variant.

FRB 20190520B



Dai+22

FRB 20201124A



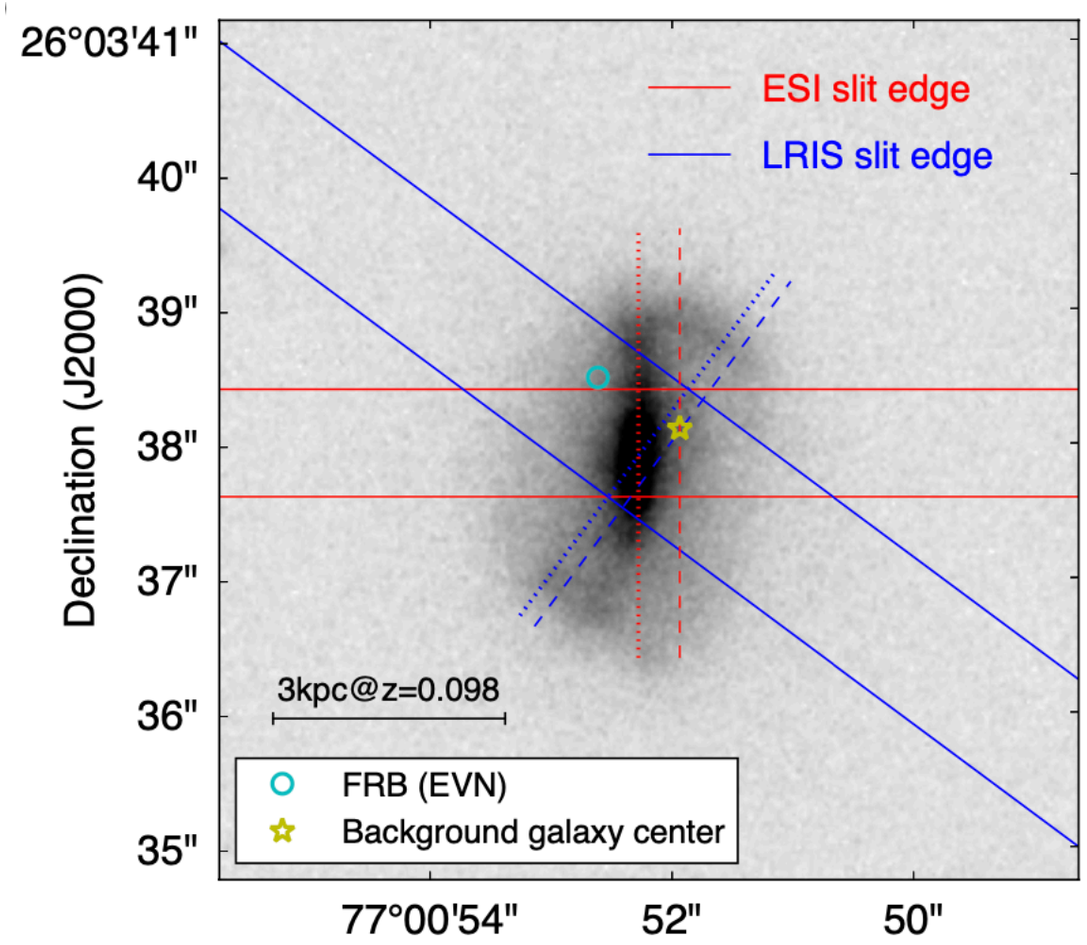
Xu+21

Unusual magneto-environment of FRBs: fast varying spatial structure

- Order 1 irregular RM fluctuation of repeaters (3 out of 6 FRBs with multiple RM measurements: e.g. Xu+22, Dai+22)

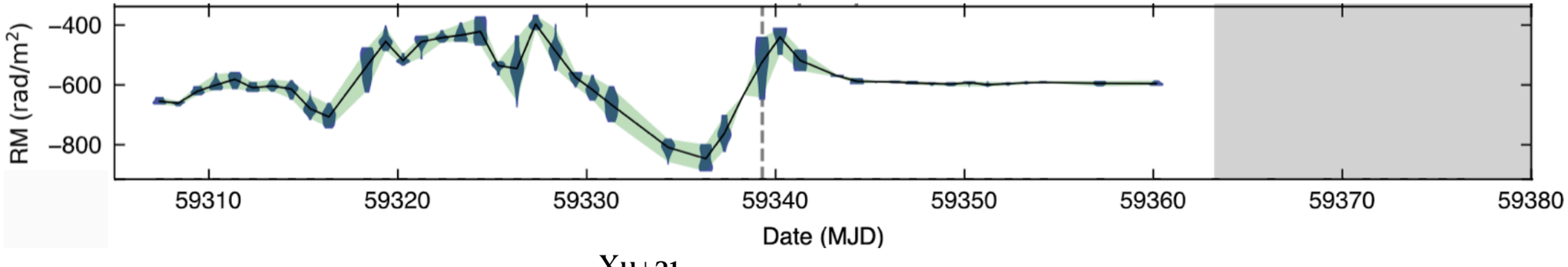
This FRB is not coincident with apparent star-forming region, with 260 mas (~600pc) away from the bar centre (Xu+21) —challenges young SNR?

Or maybe the varying RM comes from the plasma of companion (Wang+22)



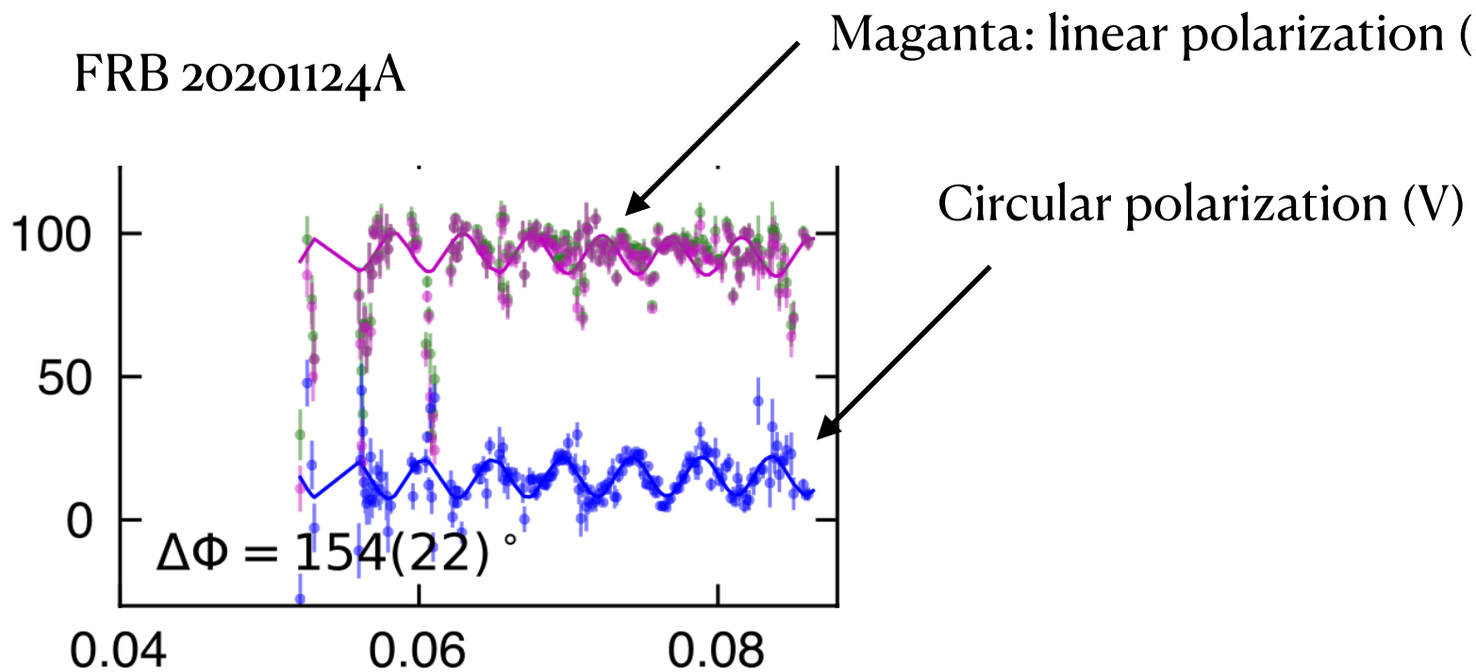
Xu+21

FRB 20201124A



Xu+21

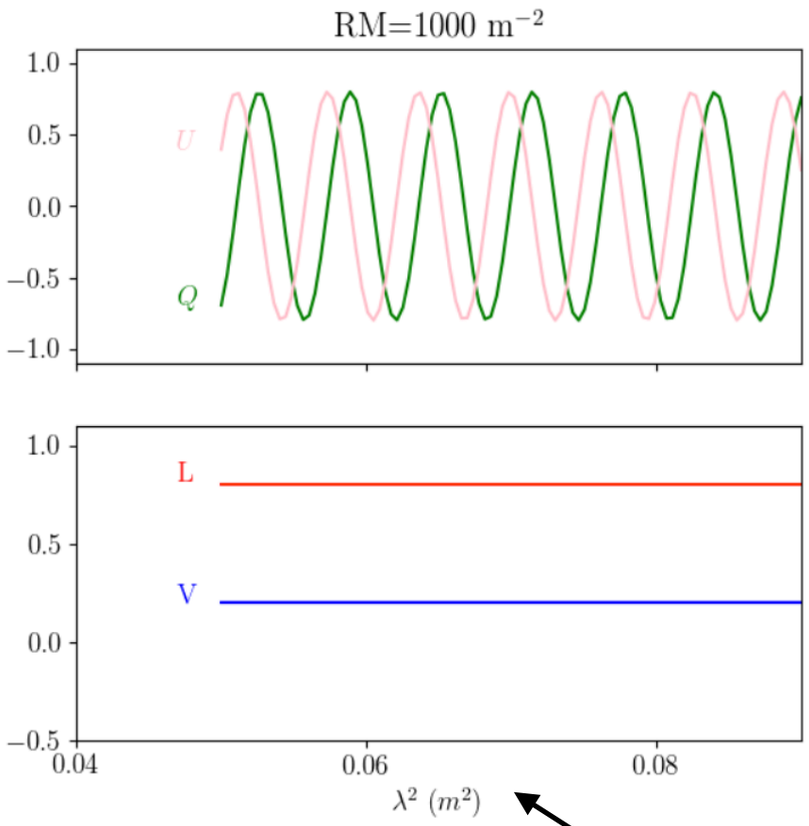
Unusual magneto-environment of FRBs: structure along LOS

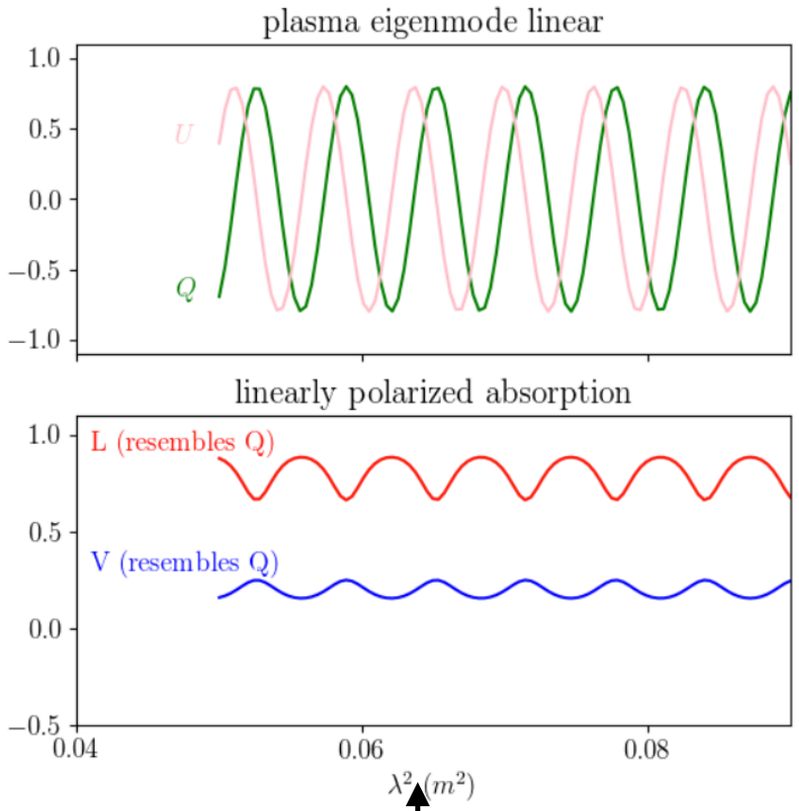


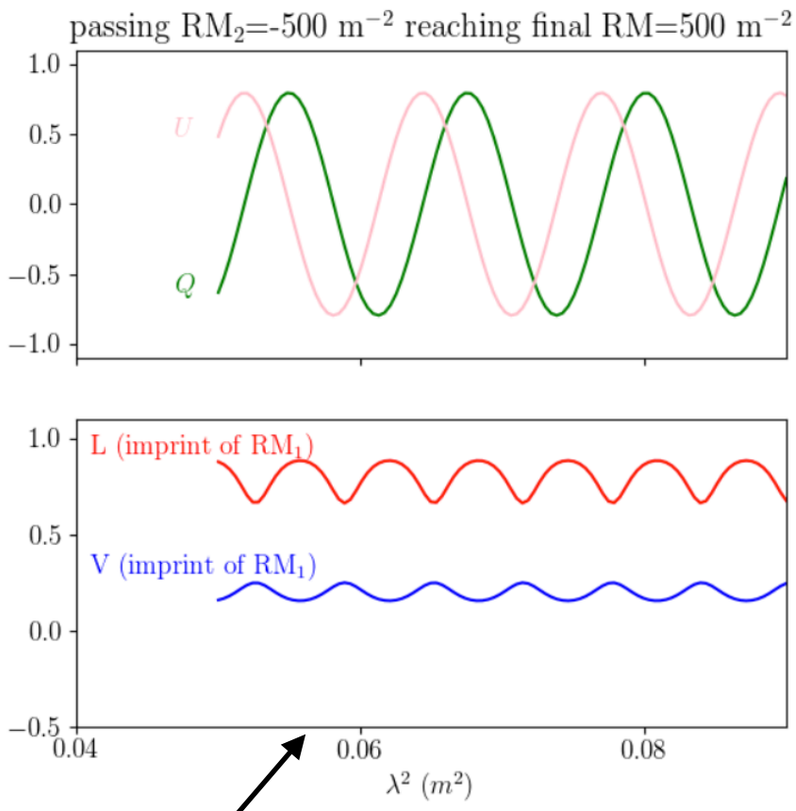
RM like-Oscillation in L ,V —> but RM does not change LV

—> have passed a region with plasma eigenmode linear

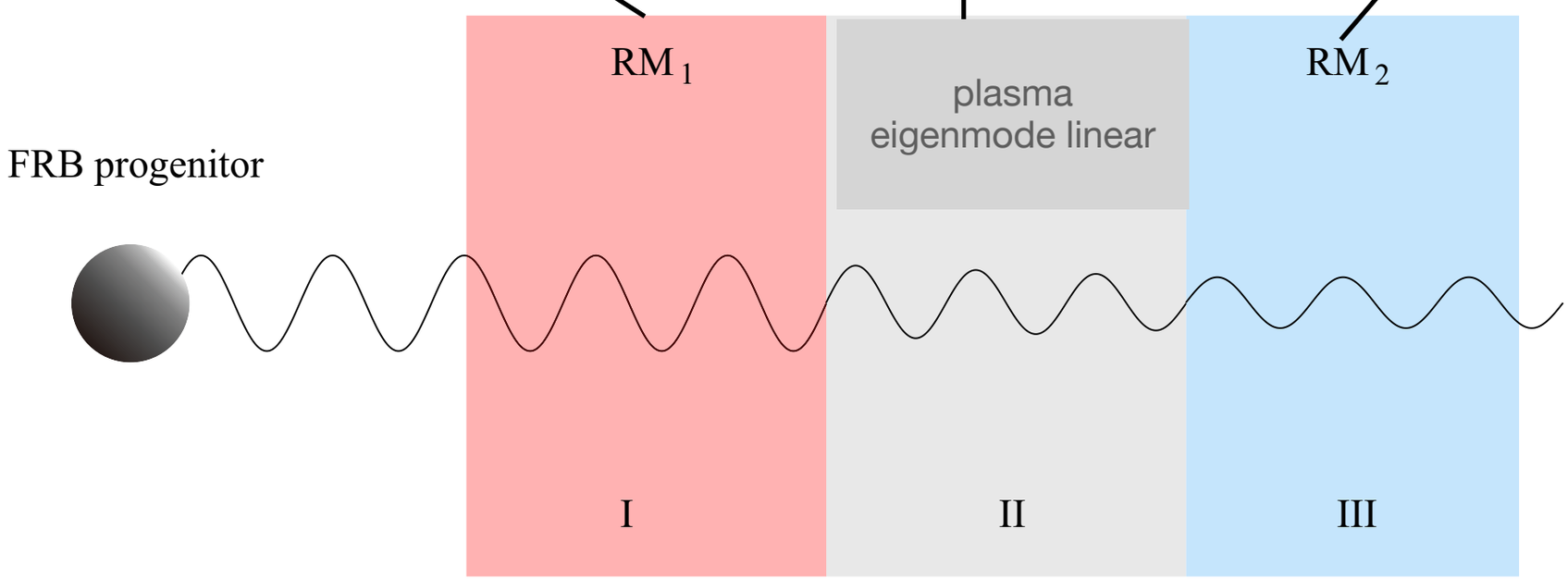
FRB20201124A (FRB wiggler): evidence of multi-layer medium



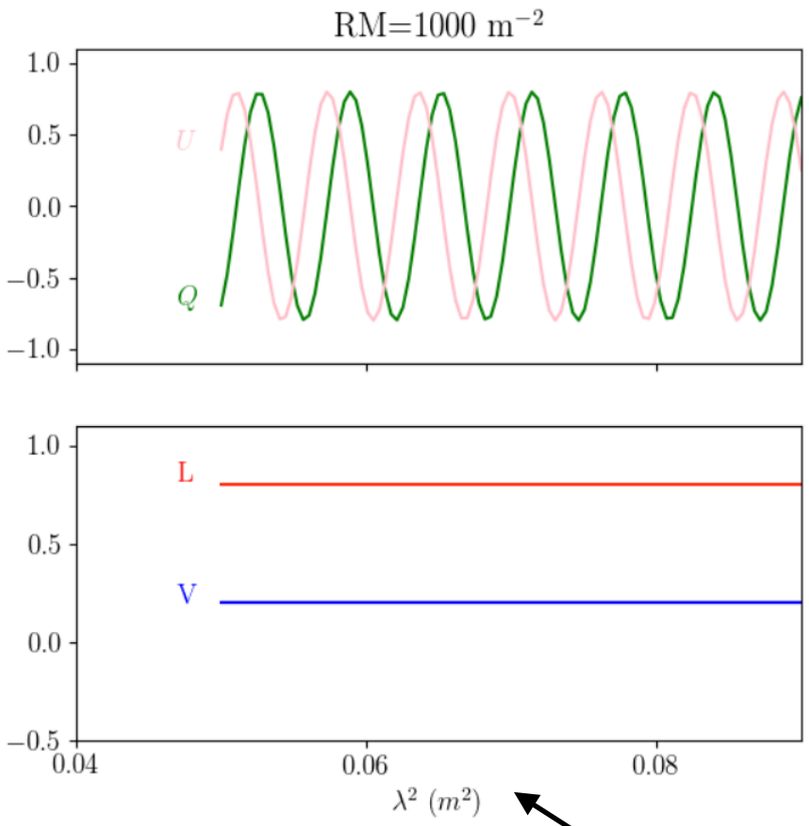


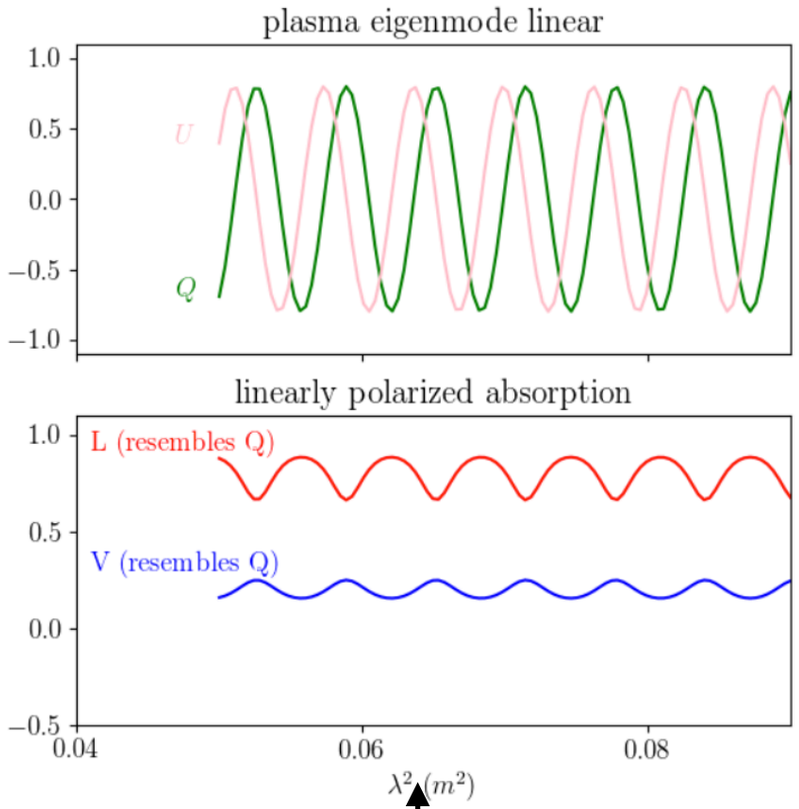


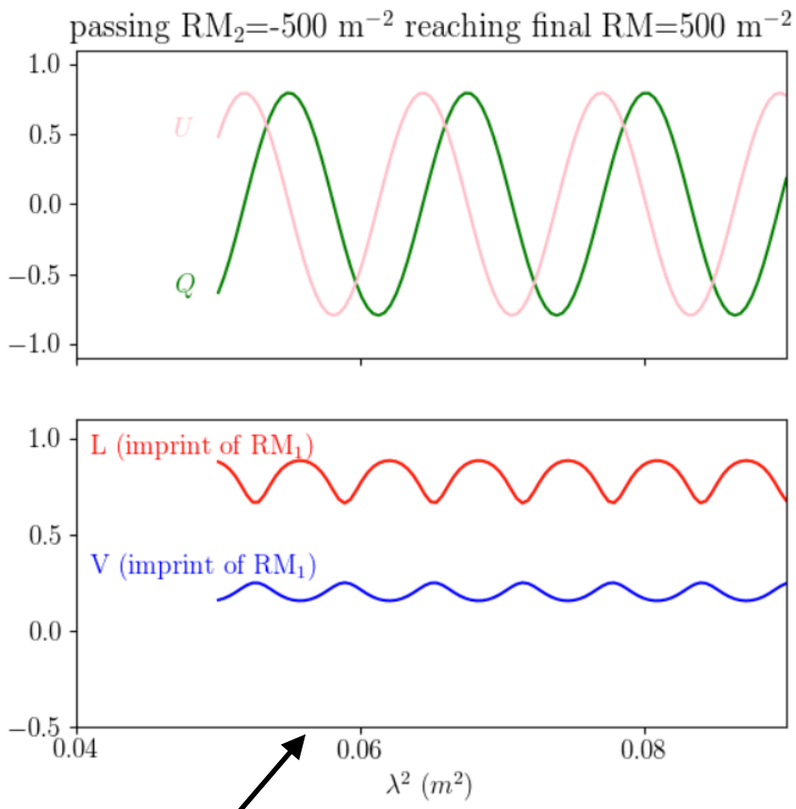
Oscillation in L, V are fossil RM1 from region I



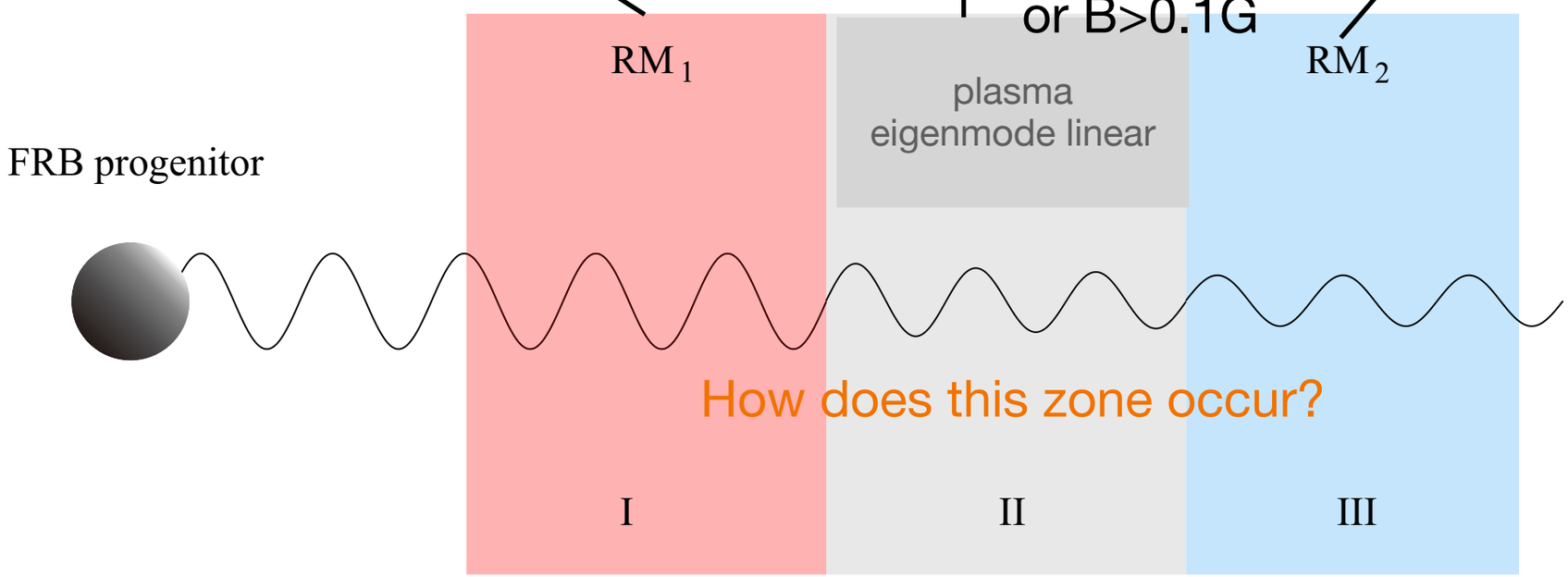
FRB20201124A (FRB wiggler): evidence of multi-layer medium







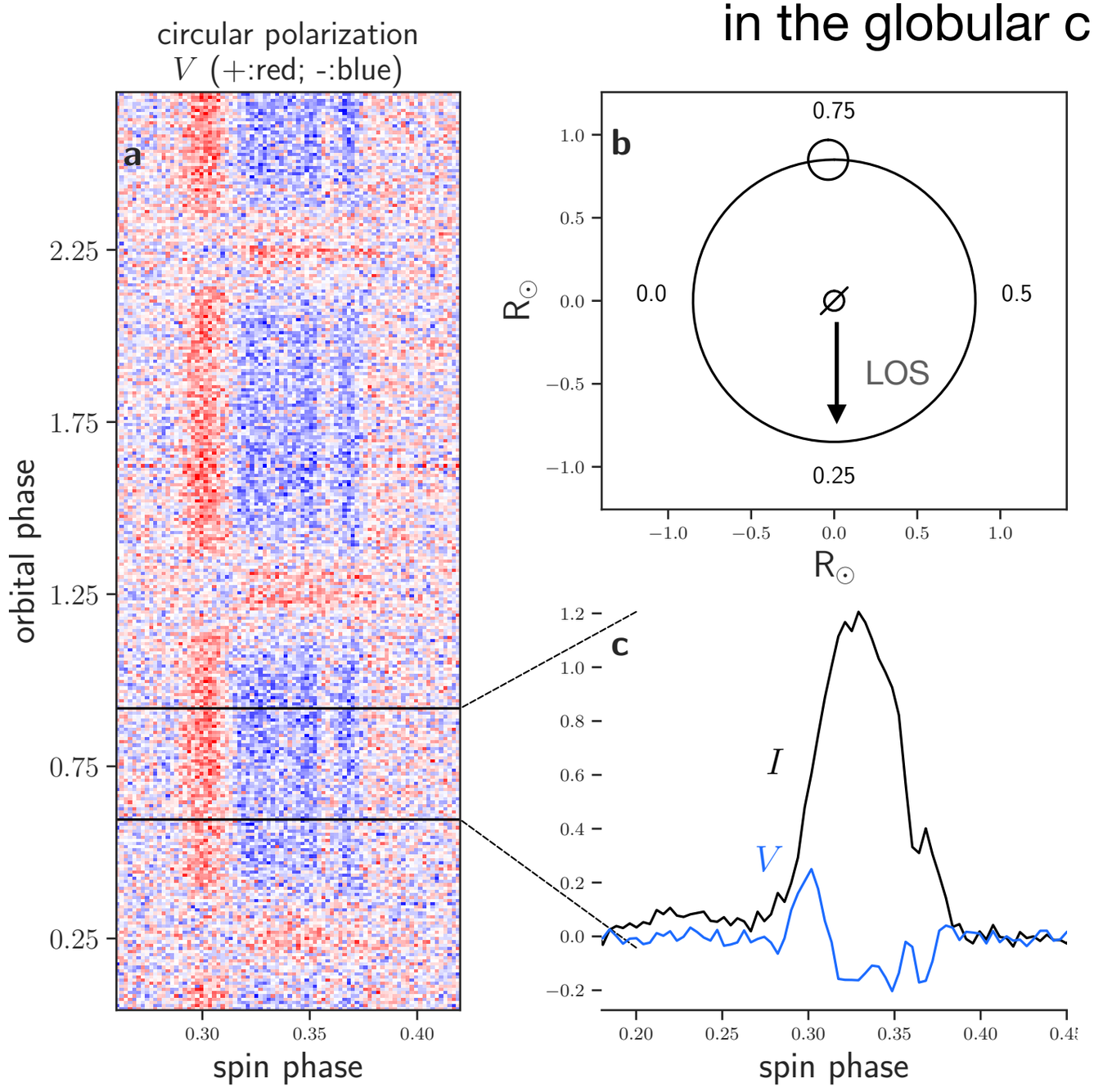
Relativistic electron or pair plasma/ or B>0.1G



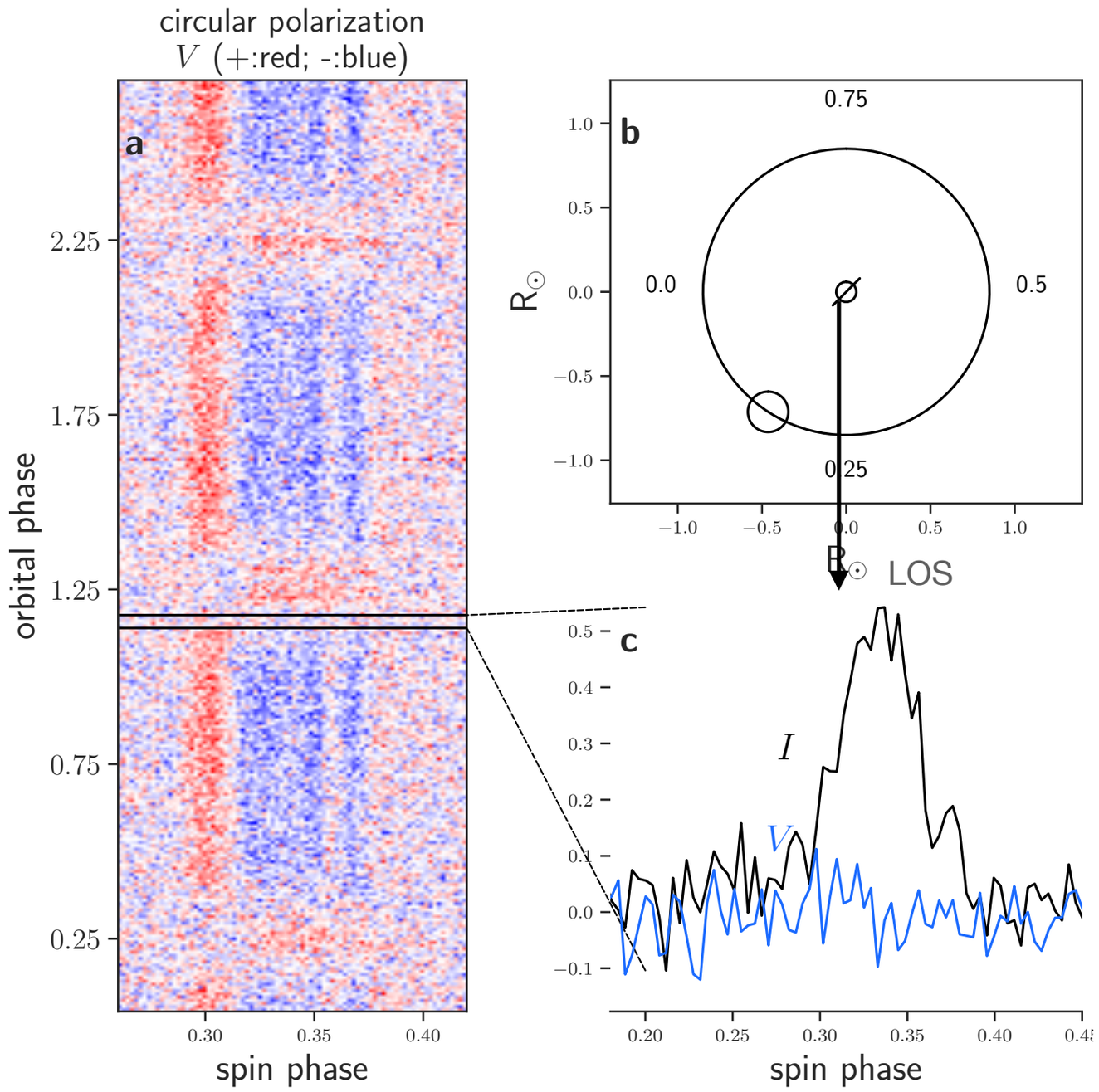
What can happen near a companion

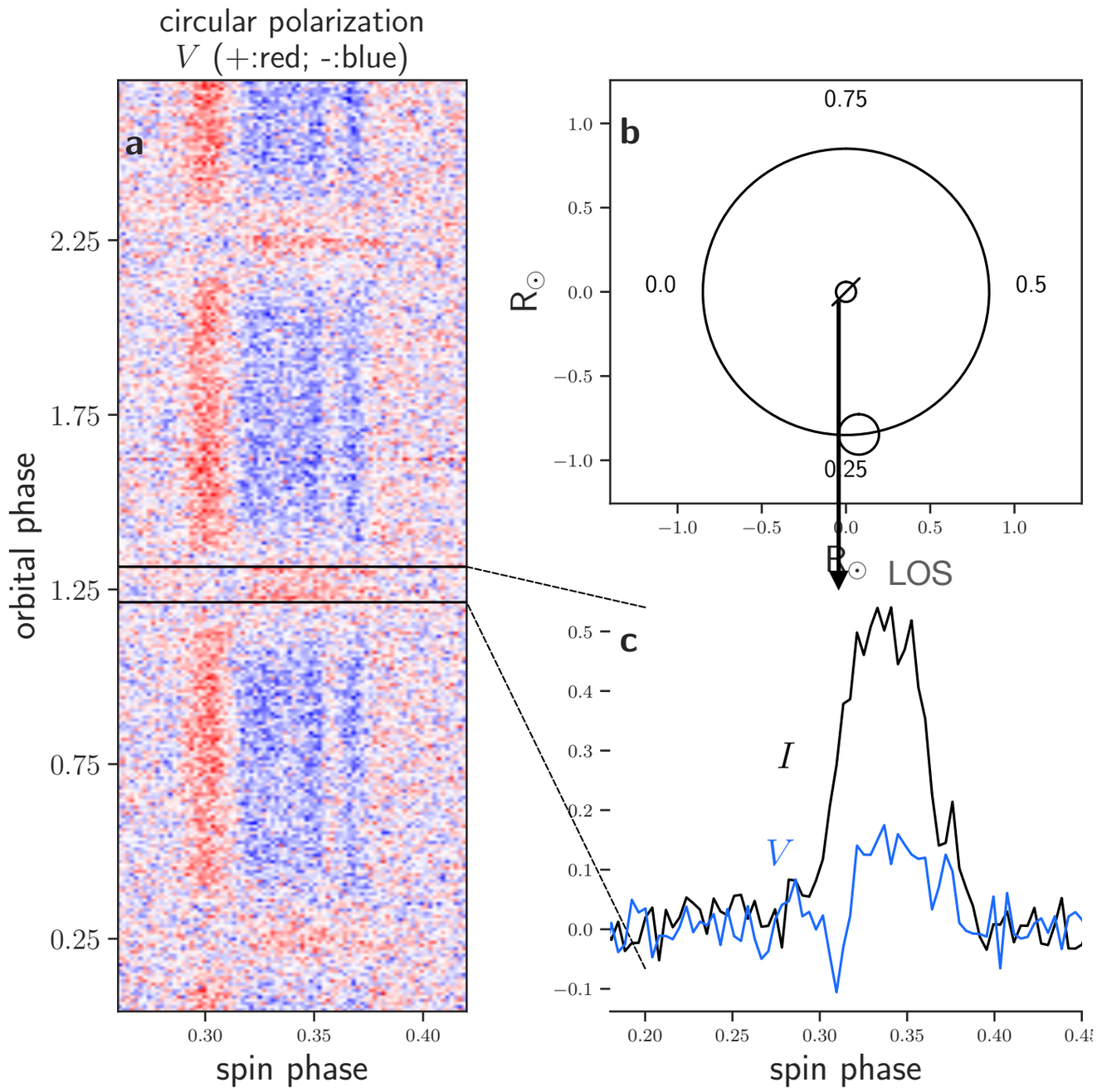
Change in circular polarization

Ter5A: PSR 1744-24A
Pulsar with a ~0.08 Msun companion
in the globular cluster Terzan 5



In collaboration with Anna Bilous, Scott Ransom, Robert Main, Yuan-pei Yang


circular polarization
V (+:red; -:blue)
a
orbital phase
2.25
1.75
1.25
0.75
0.25
0.30
0.35
0.40
spin phase
b
0.75
0.0
0.5
0.25
$R_\odot$
LOS
c
I
V
spin phase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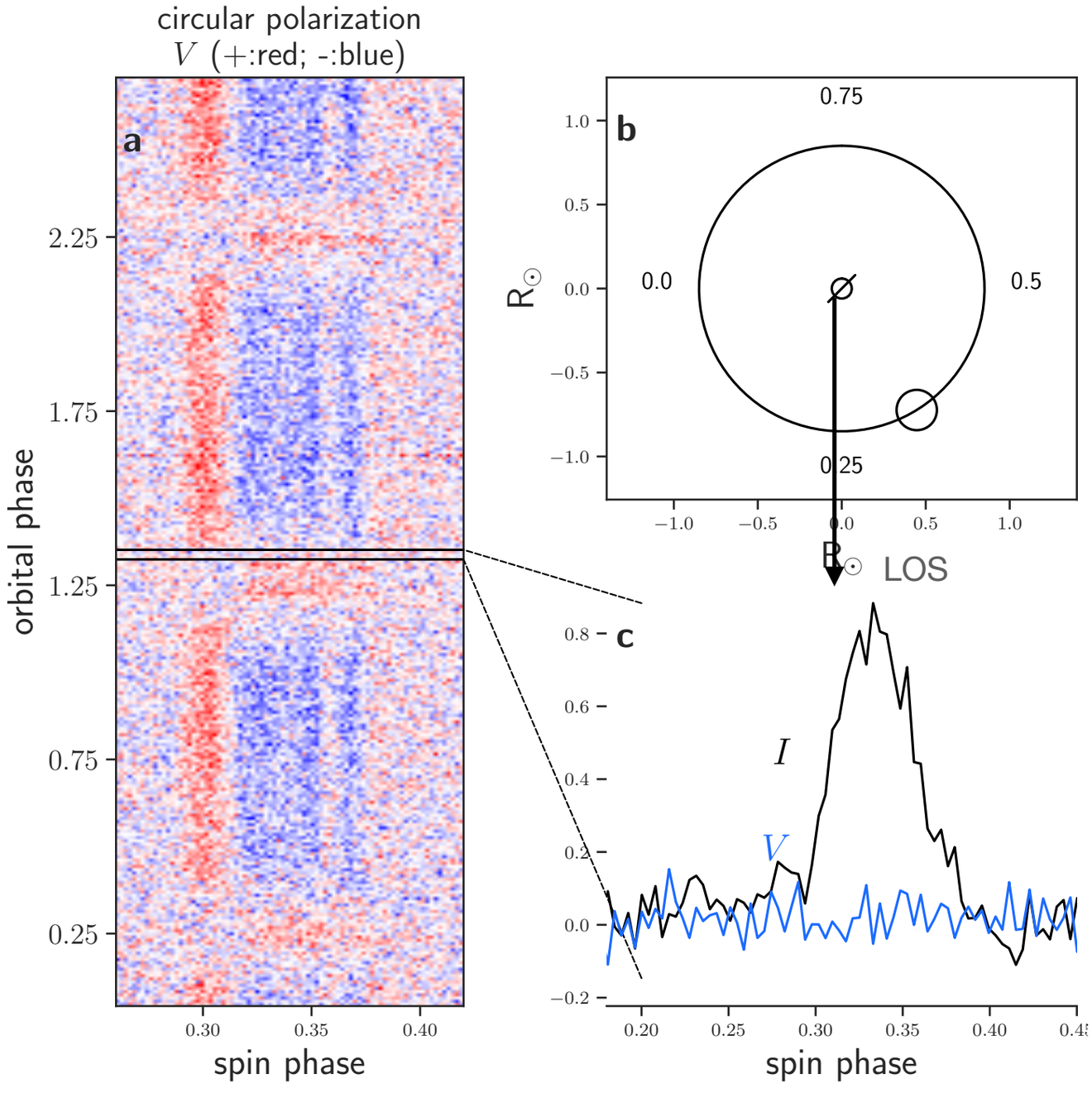
circular polarization
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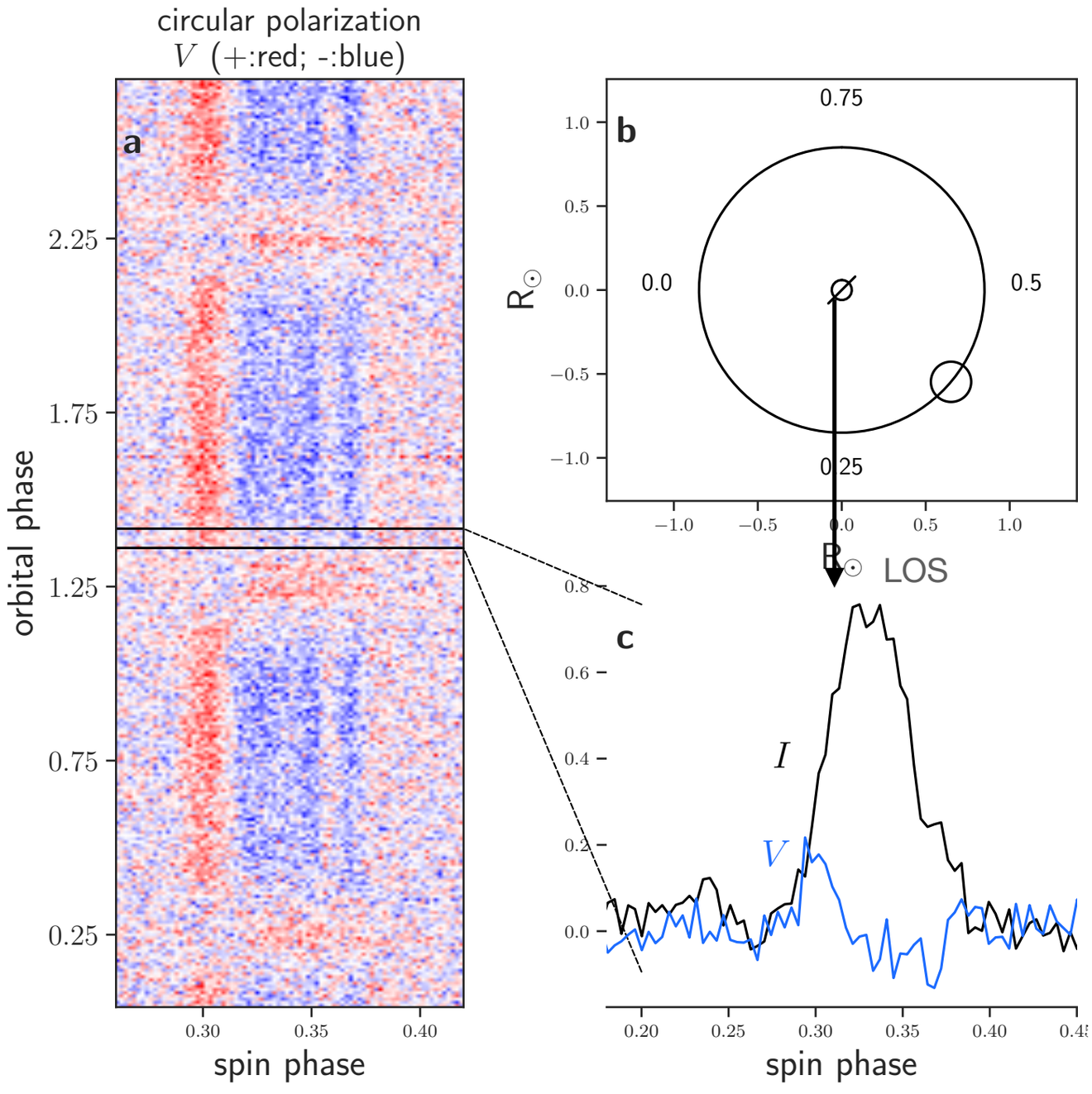
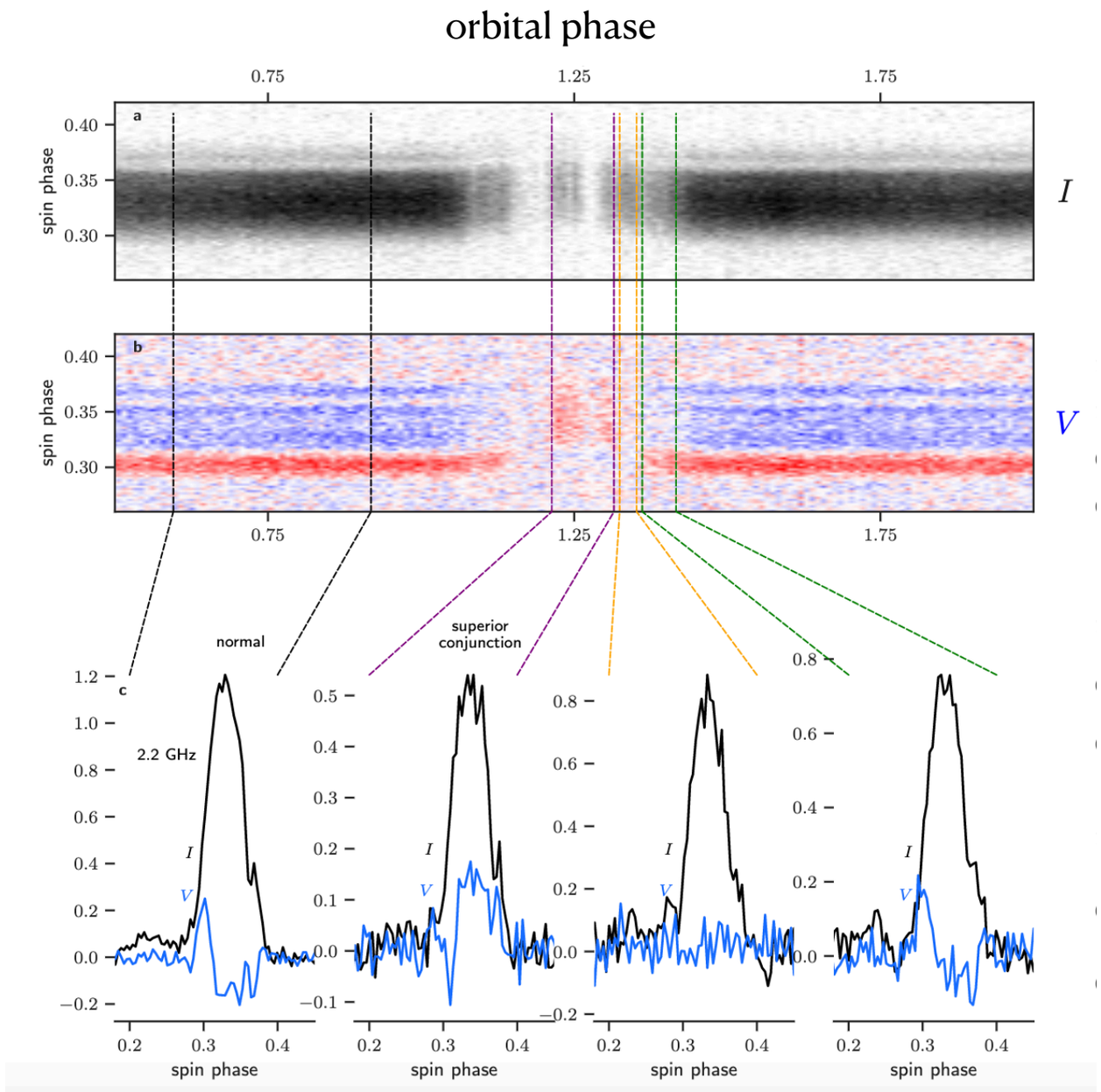
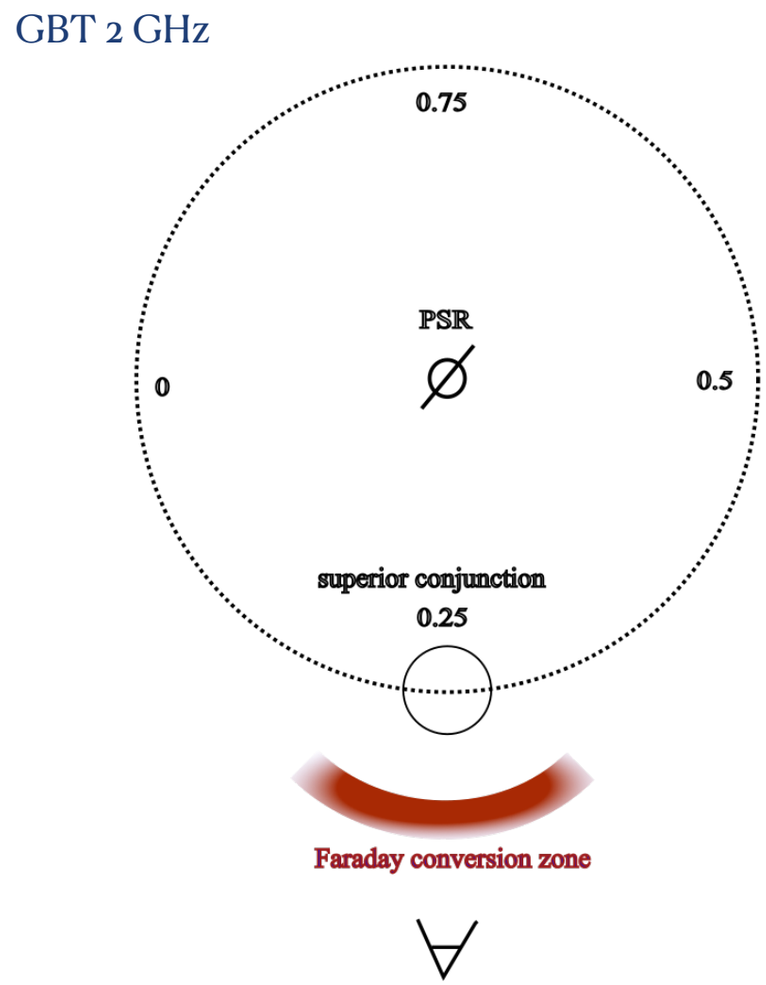
orbital phase
2.25
1.75
1.25
0.75
0.25
0.30
0.35
0.40
spin phase
b
0.75
0.0
0.5
0.25
$R_\odot$
LOS
c
I
V
0.8
0.6
0.4
0.2
0.0
−0.2
0.20
0.25
0.30
0.35
0.40
spin phase


circular polarization
V (+:red; -:blue)
a
b
c
orbital phase
spin phase
spin phase
2.25
1.75
1.25
0.75
0.25
0.30
0.35
0.40
0.75
0.0
0.5
0.25
1.0
0.5
0.0
−0.5
−1.0
R⊙
R⊙ LOS
0.8
0.6
0.4
0.2
0.0
I
V
0.20
0.25
0.30
0.35
0.40





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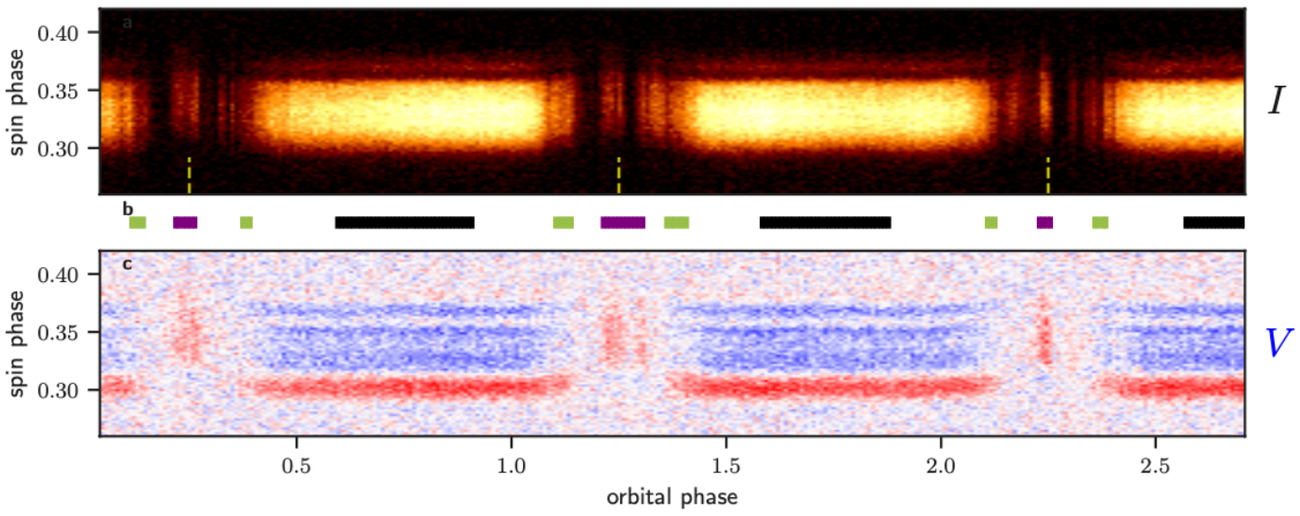
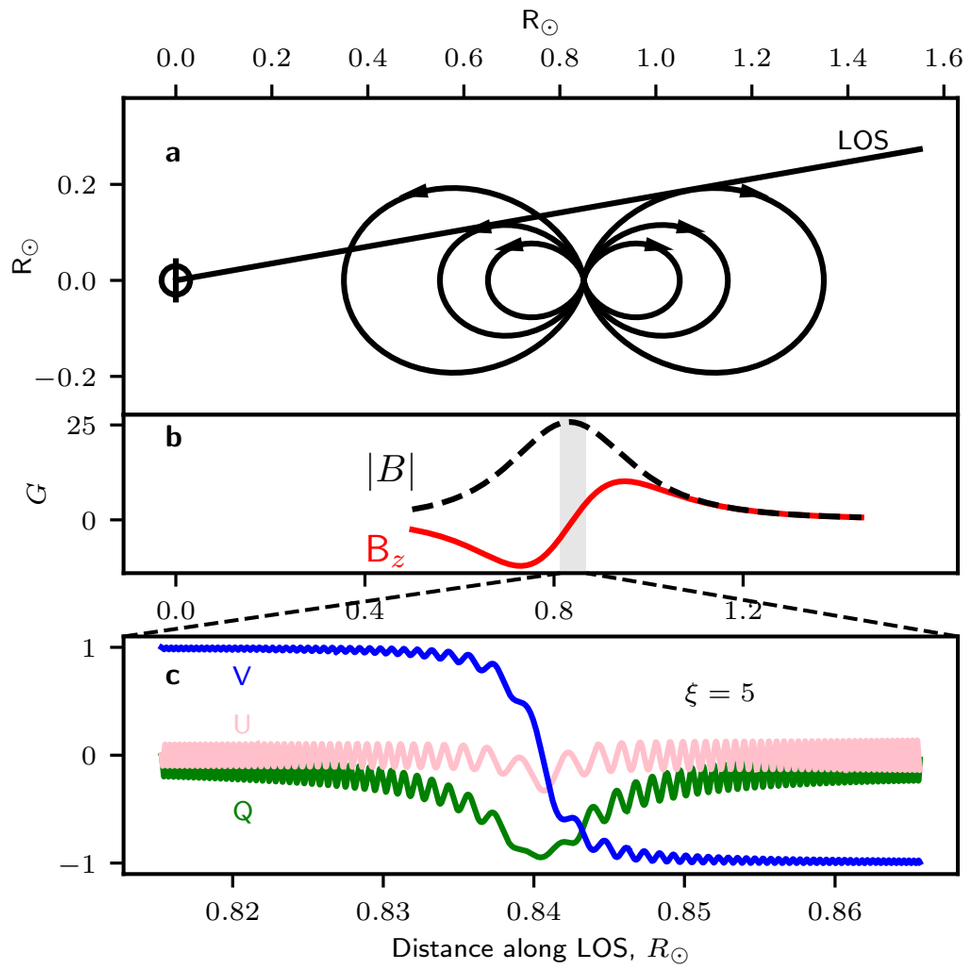
The circular polarization change (Faraday conversion/mode tracking)

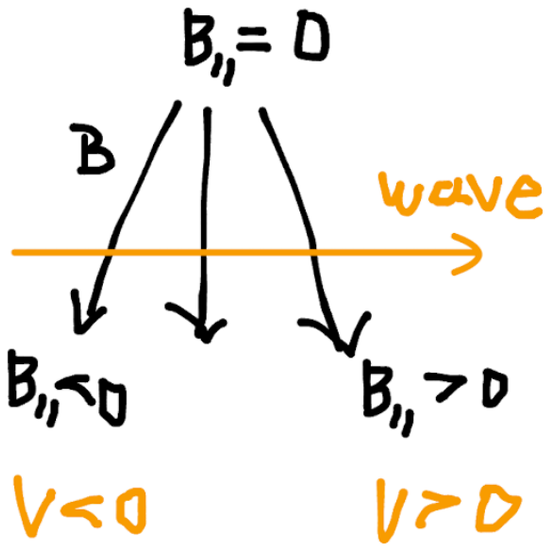
Sign flipping best explained with
the pulsar light passing the companion poloidal field





(Thompson+94, Melrose+95, Gruzinov, Levin 19)

We can explain it



The radio wave follows the B_z reversal

require: B>10 $G\,(\Delta \mathrm{DM}/0.1\,\mathrm{pc\,cm^{-3}})^{-1/3}(f/2\,\mathrm{GHz})^{-4/3}$

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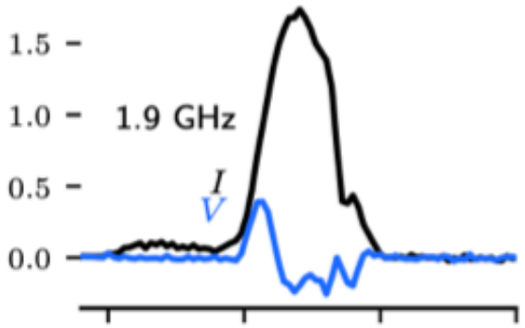
Modelling V

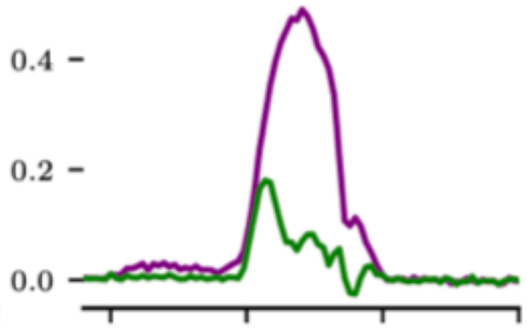
The complicated V profile enable us to distinguish different propagation effects

All spin phase going through the same propagation effect

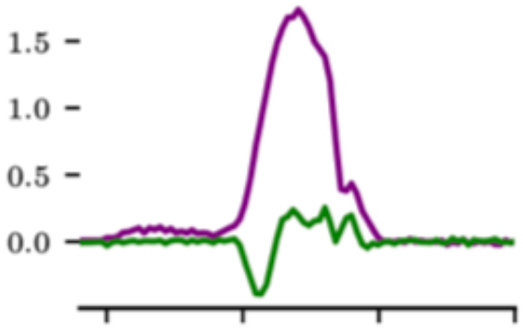
original profile (when cp behind the psr)



after circular absorption



after Faraday conversion



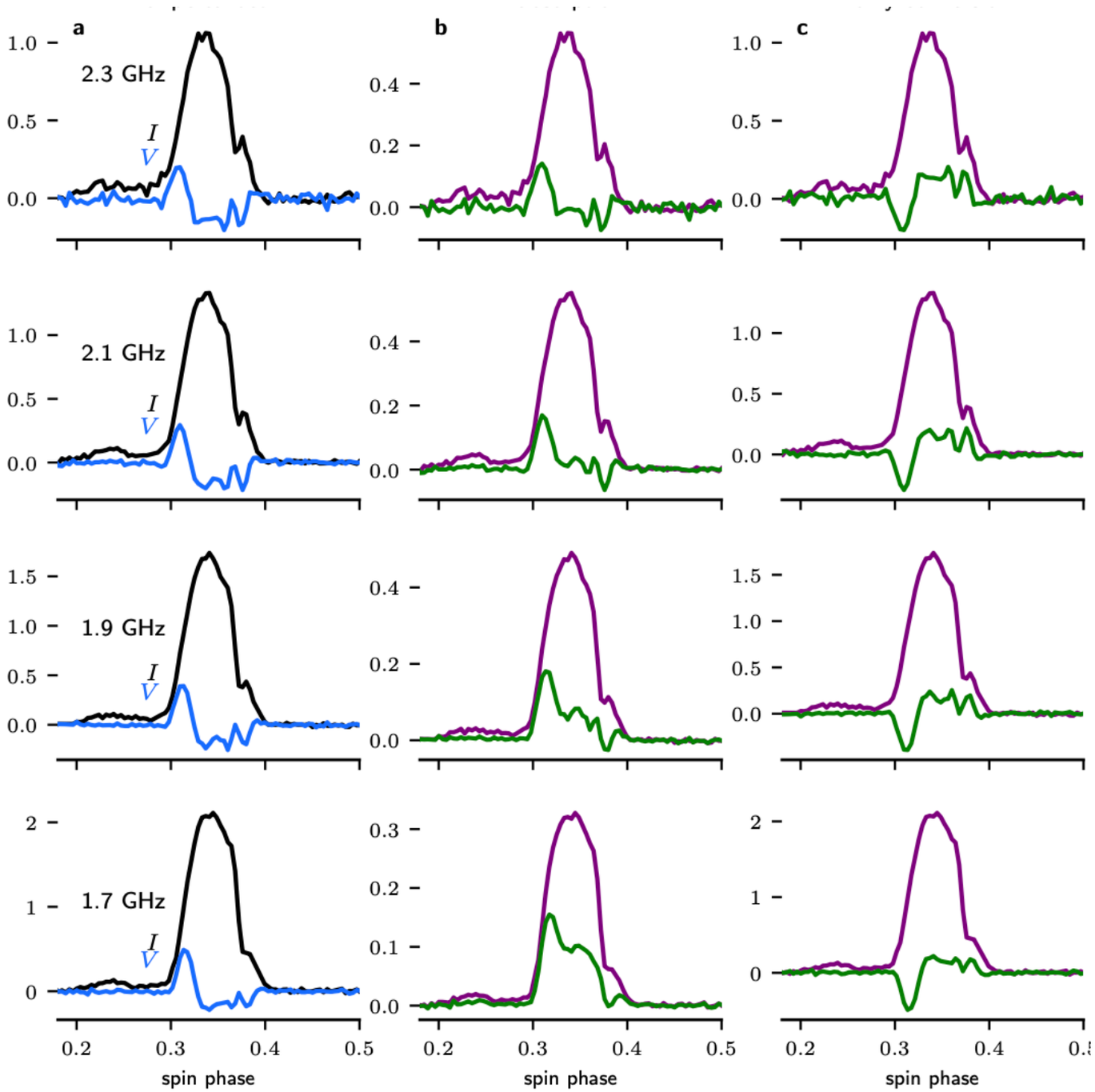
Companion behind VS companion in front —> isolated propagation effects

Modelling V Against FREQUENCY

original profile (when cp behind the psr)

after circular absorption

after Faraday conversion



Modelling V

We can model the V profile

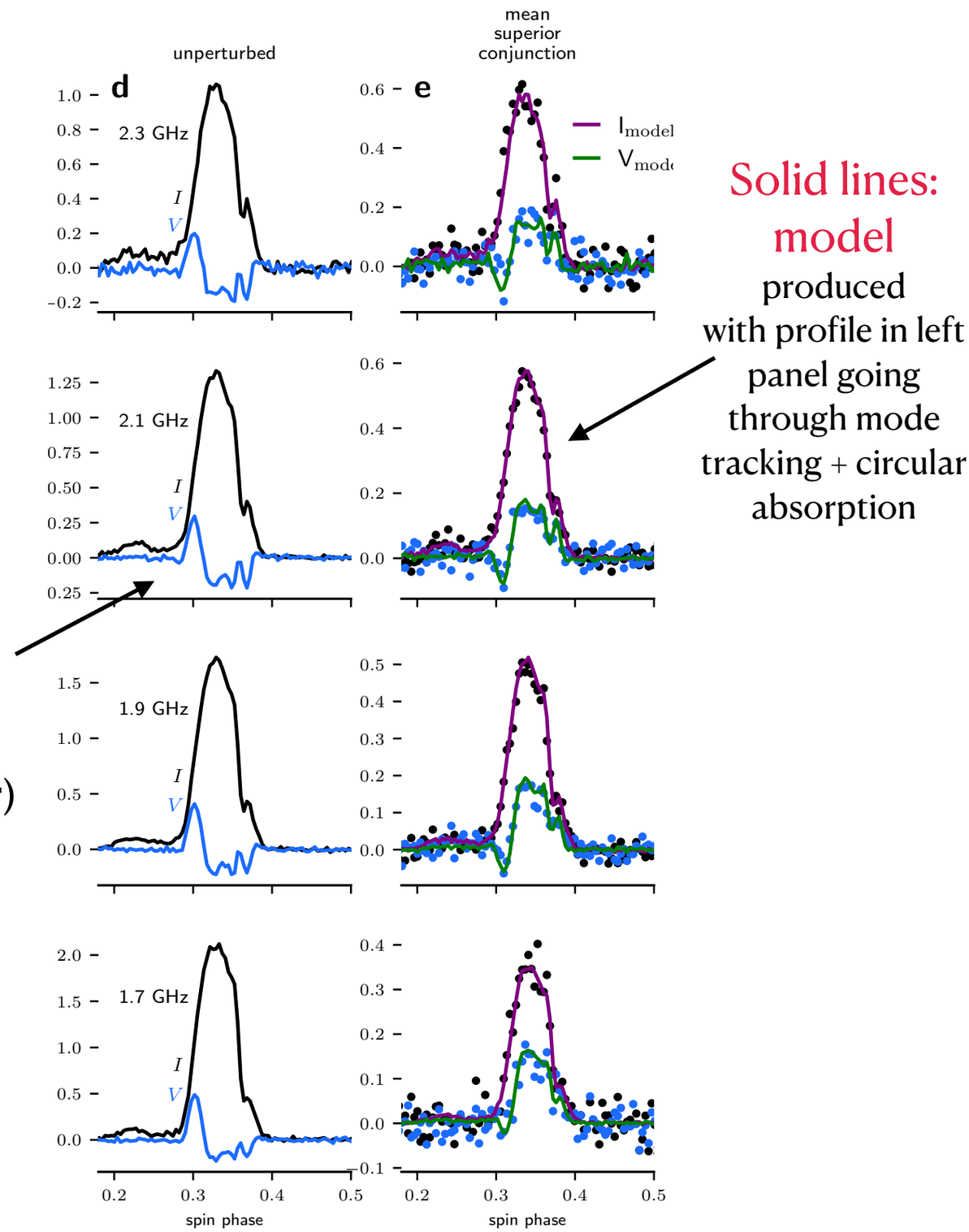
with 5 parameters (identical for all spin phases):

$$\tau = (f/f_I)^{-\alpha_I}, \tau_v = (f/f_v)^{-\alpha_v}$$

+ V flip sign (mode tracking)

Original profile
(cp behind the psr)

Model can reproduce the complex V profile



Solid lines: model produced with profile in left panel going through mode tracking + circular absorption

Dongzi Li+ arXiv: 2205.07917

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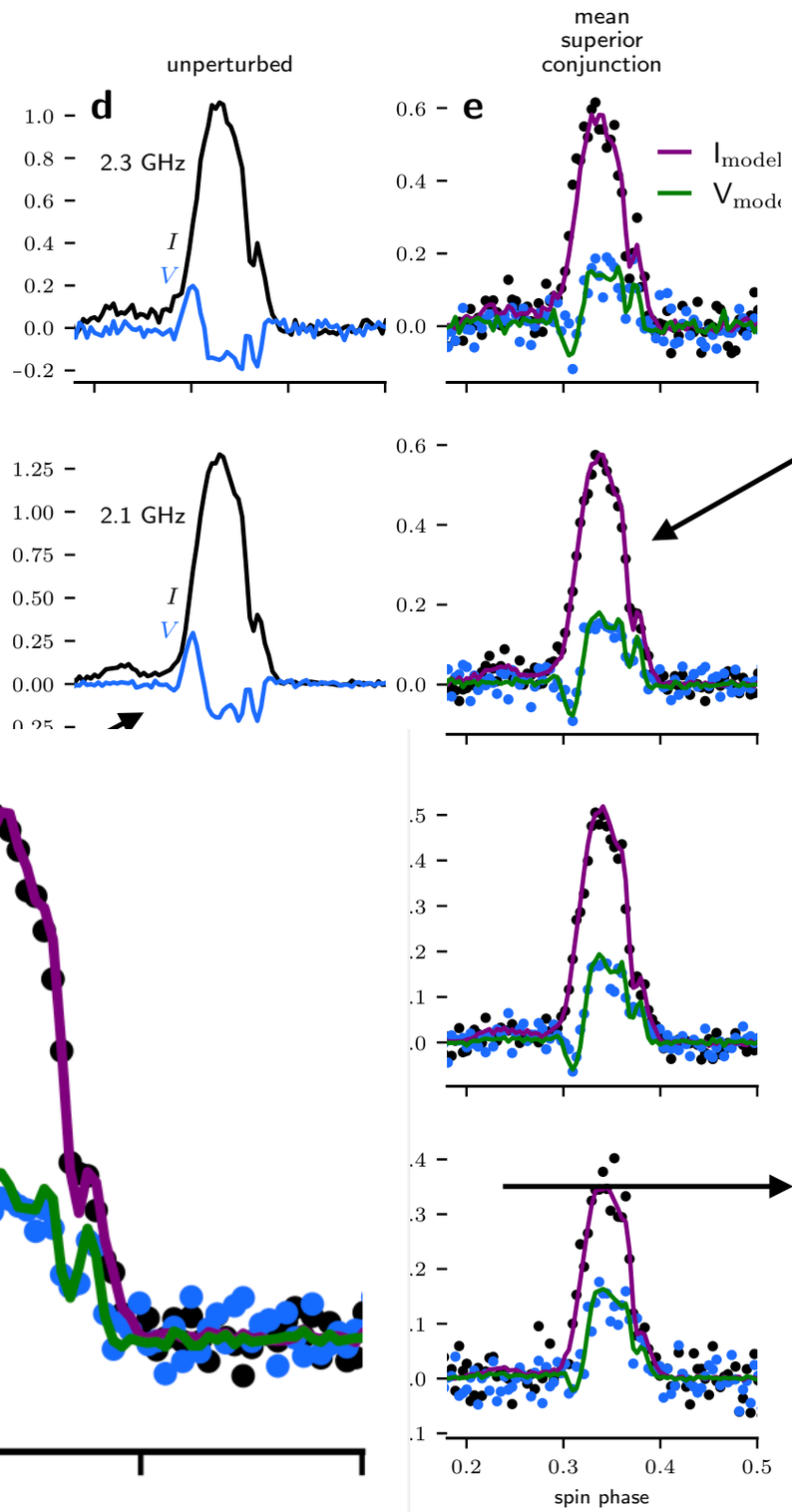

Solid lines: model produced with profile in left panel going through mode tracking + circular absorption

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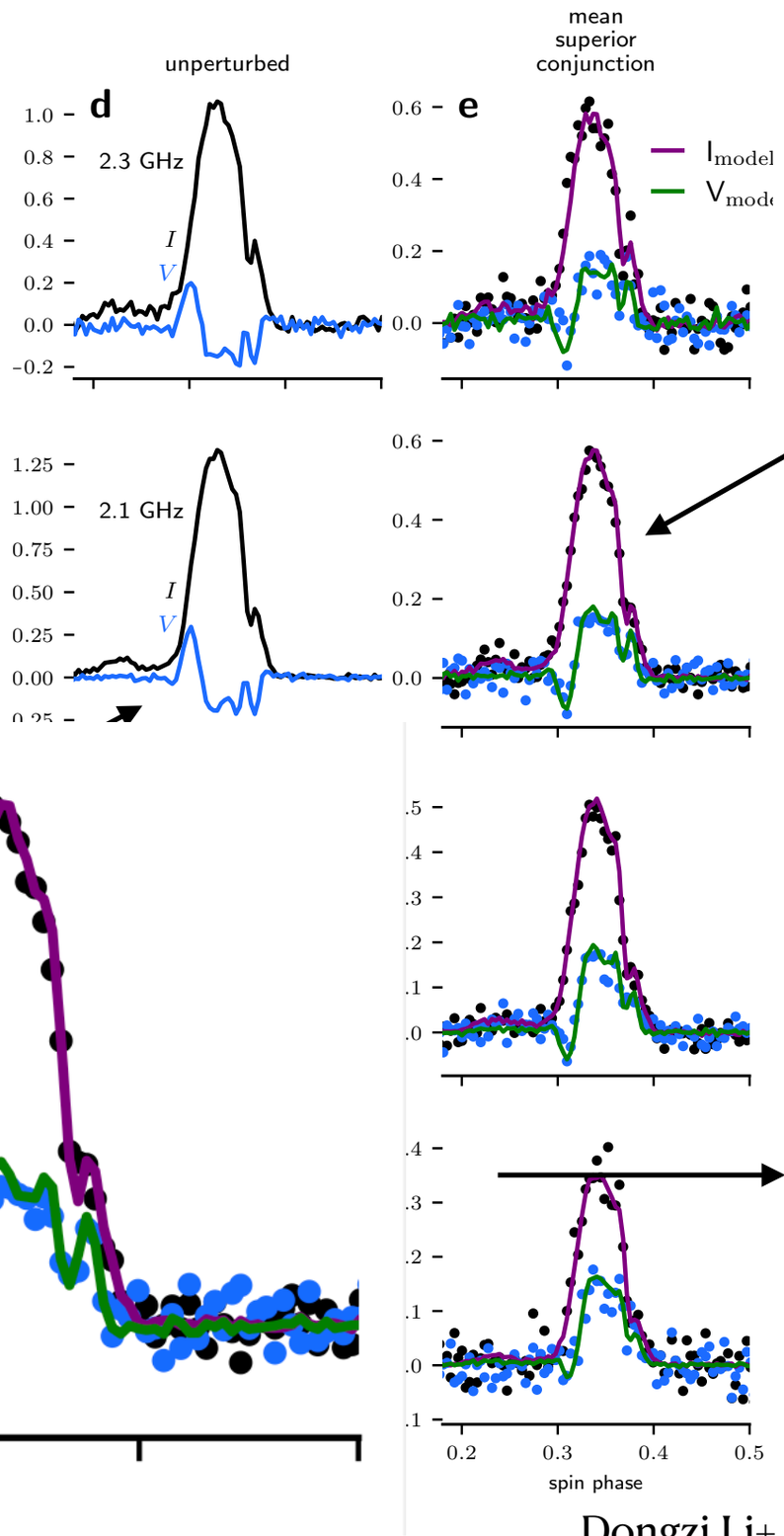
We have seen the pulse going through quasi-linear regime and can model it

We can model the V profile

with 5 parameters (identical for all spin phases):

$$\tau = (f/f_I)^{-\alpha_I}, \tau_v = (f/f_v)^{-\alpha_v}$$ + V flip sign

Model can reproduce the complex V profile



Solid lines: model produced with profile in left panel going through mode tracking + circular absorption

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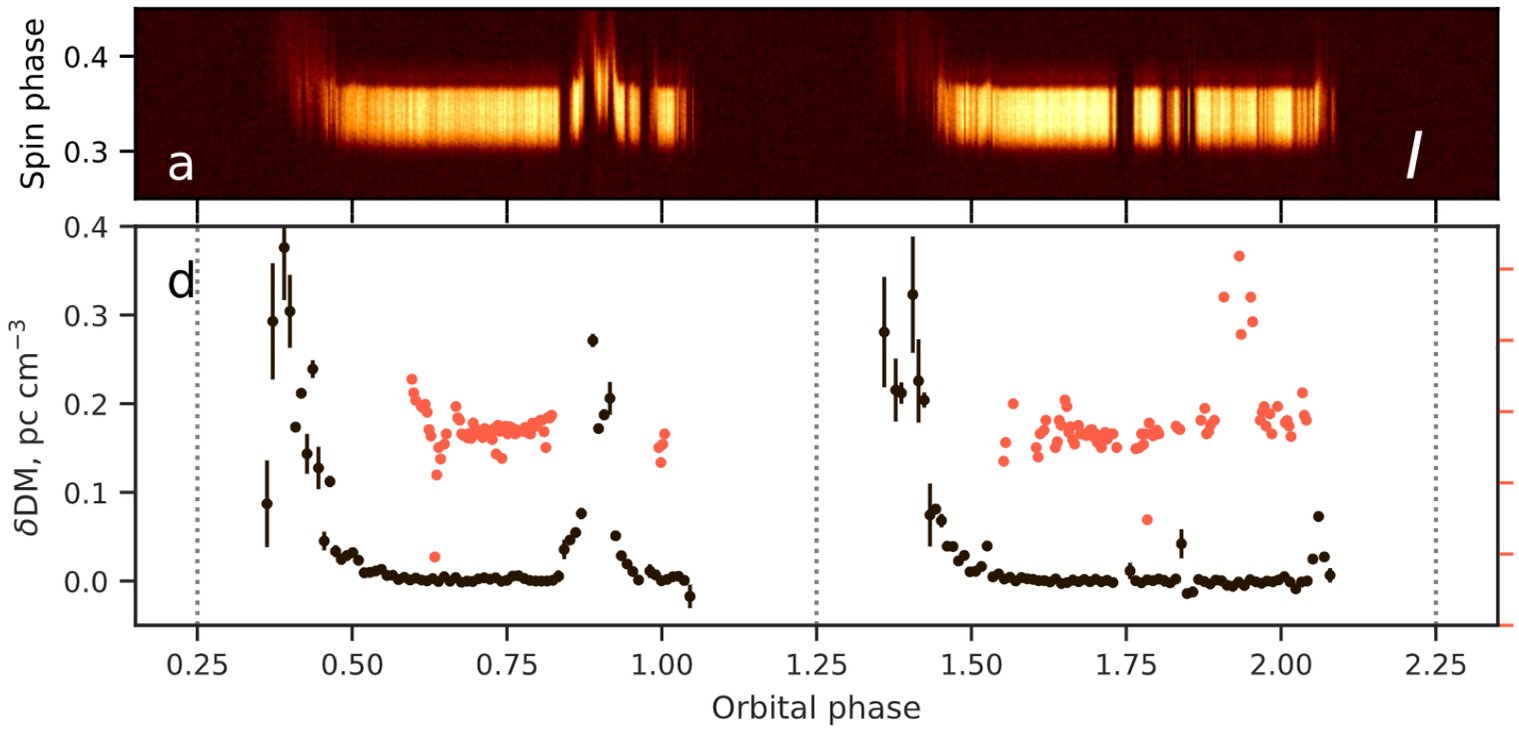
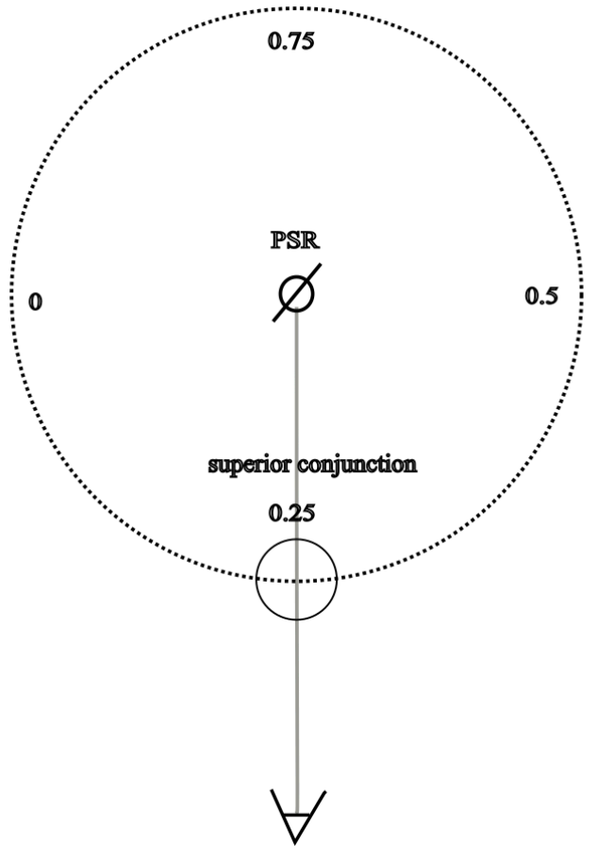
Not only Faraday conversion, also RM variation



black: DM red: RM



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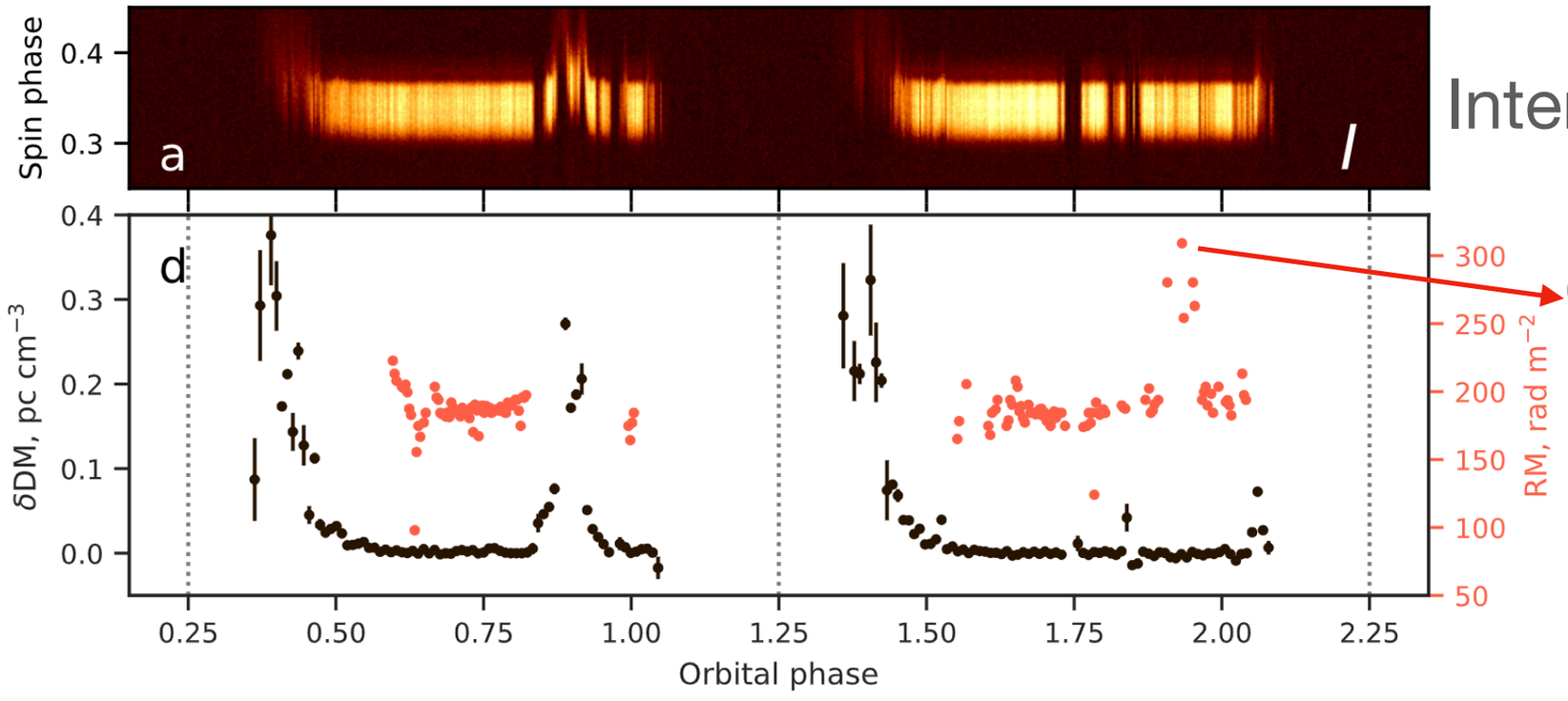
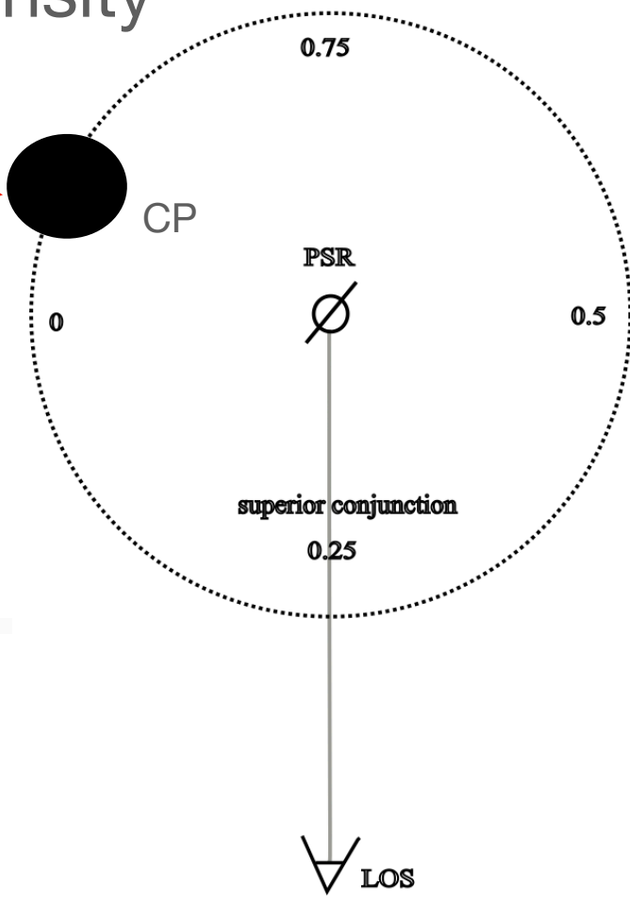
Large RM variation in the wind

Mini eclipses/RM/DM variations at random phases





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Dongzi Li+ arXiv: 2205.07917

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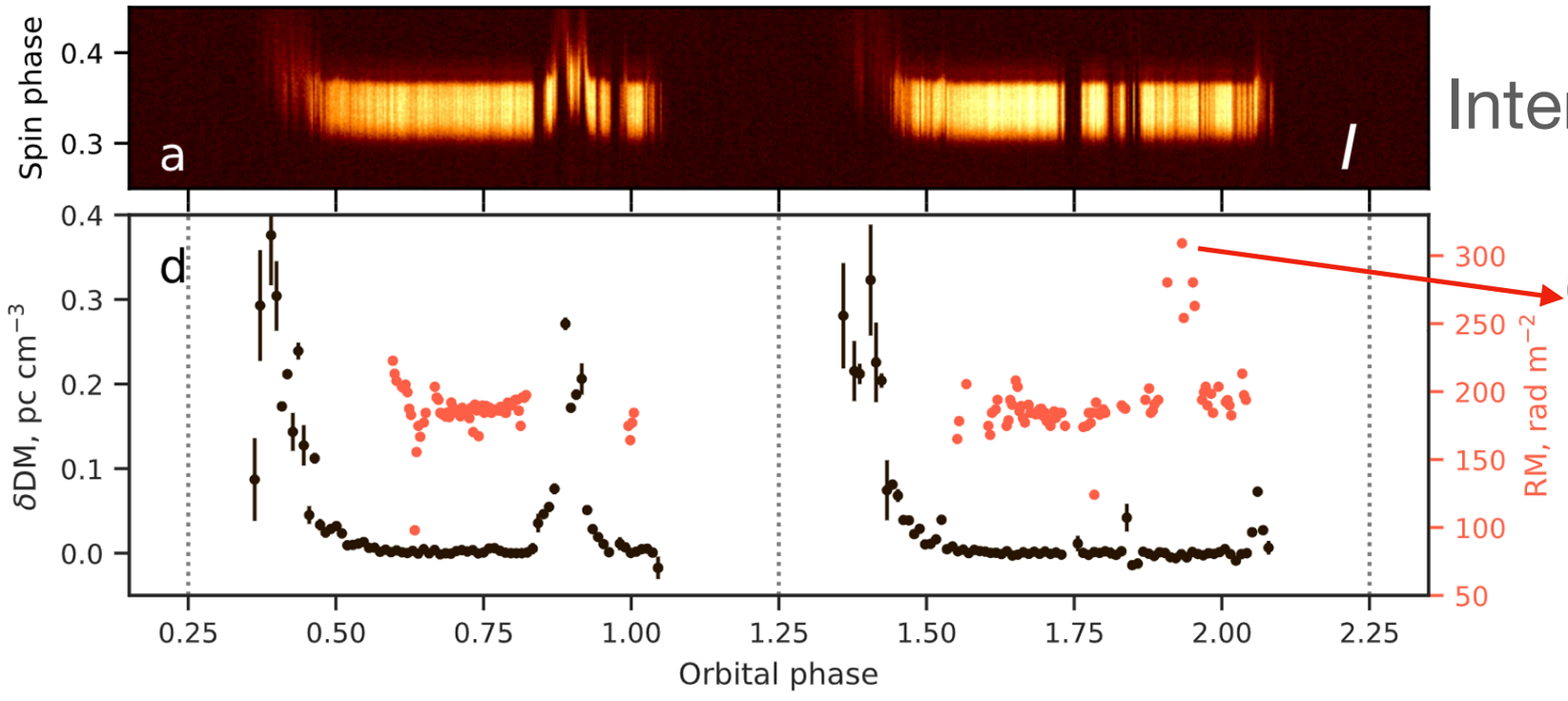

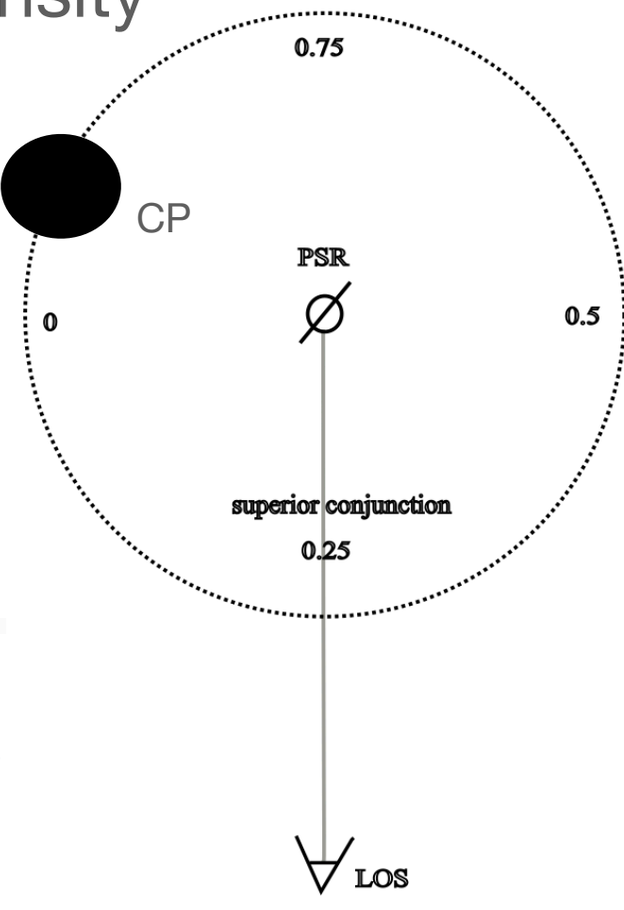

black: DM red: RM

~100 rad/m^2 RM variation in the wind when LOS is far from the companion

no DM change measured: dDM<0.01pc/cm^3

<B>>10 mG

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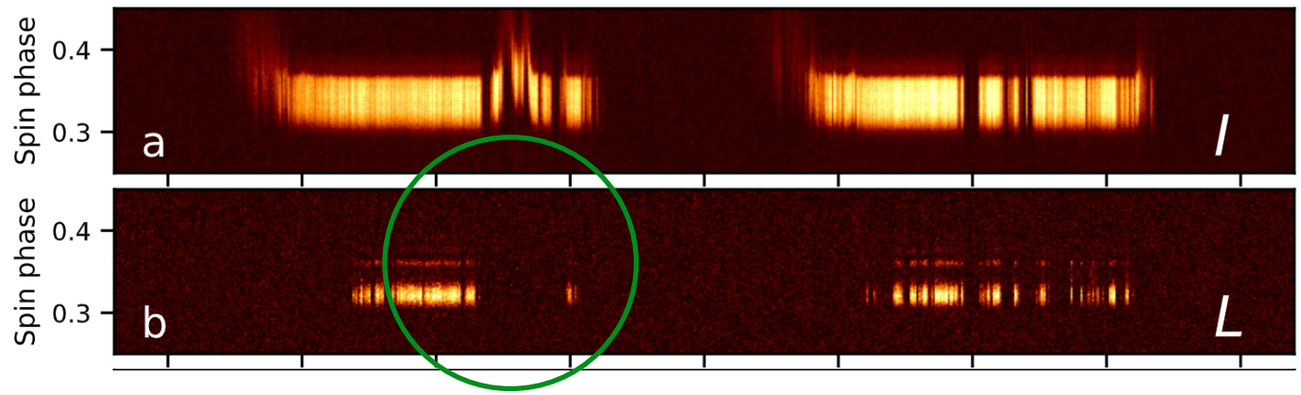
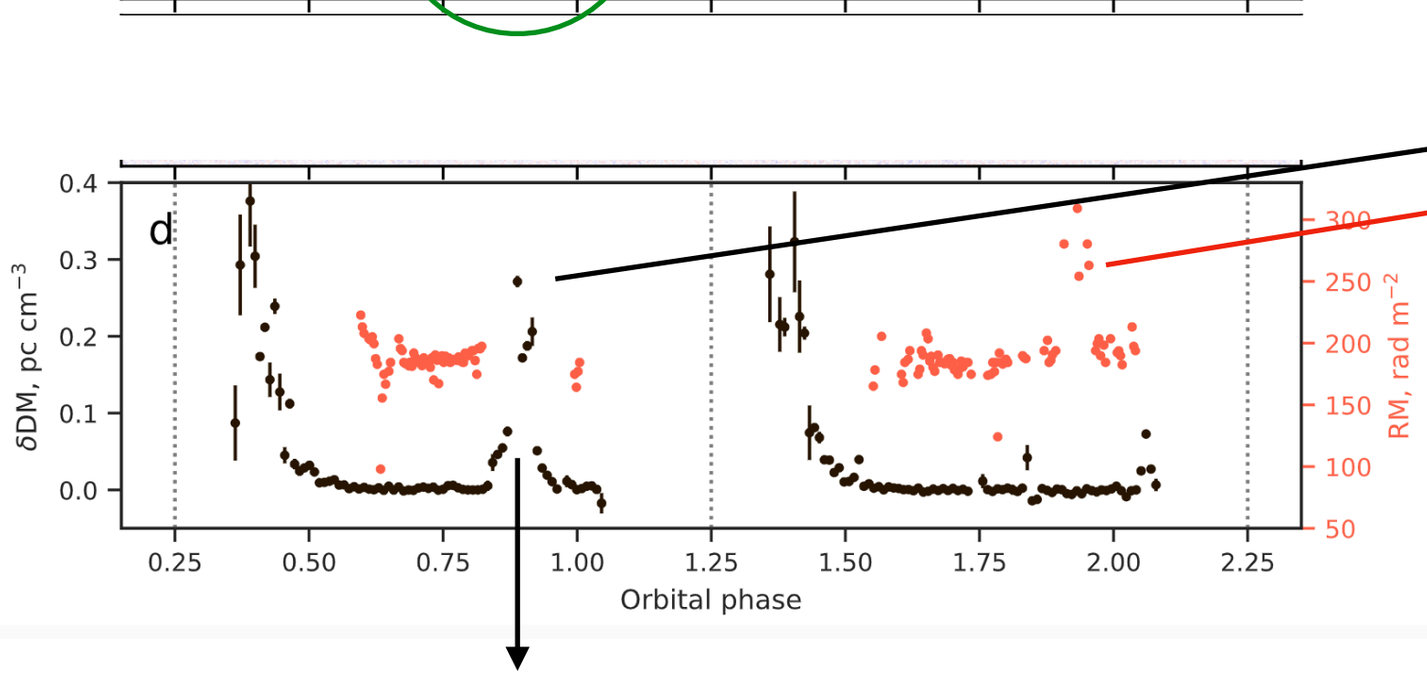
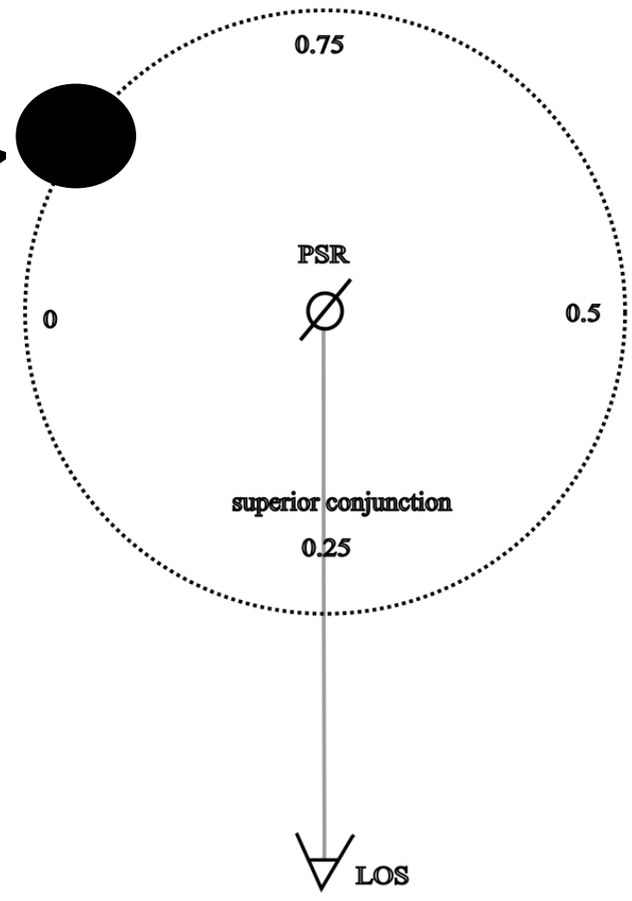
Large RM variation in the wind

depolarization when DM varies —> existing higher RM change







dDM ~0.3 pc/cm^3
Given <B> > 10 mG,
expect dRM > 3000 rad/m^2

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FRB: The magneto environment

Ter5A	FRBs
• Large irregular RM variation	• 5/6 repeaters with more than one RM measurements show RM variations (eg. Michilli+18; Pleunis+21; Xu+21; Luo+20, Dai+22,Anna-Thomas+22,Mckinven+22)
• Depolarization due to fast RM variation	○ Possibly FRB 20121102A, FRB 20190520B (Feng+22)
• Polarized absorption and Faraday conversion	○ Possibly FRB 20201124A, FRB 20181112 (Xu+22, Kumar+22,Cho+20)
• Propagation increased V	○ Possibly FRB 20201124A (Xu+22)
• Indicated extreme RM	• FRB 20121102A (Michilli+18)

We can model/understand Ter5A well,

our methods and understandings may help the study of FRBs

Maybe some FRBs are in binary

Advantage:

- The magneto-environment: eg. introducing large, fast varying RMs, Faraday conversion and polarized absorption
- Diverse behavior, depending on the orbital inclination angle, separation, companion
- May explain the long-term periodicity
- Abundant in globular clusters, and can have longer age, so offset from the star-forming region. Does not trace star formation and stellar mass.

Challenge:

- AU spatial scale —> require massive companion —> again, why offset from the star forming region?
- Strong wave effect. For bright bursts, eg. FRB 121102 (R1), the plasma at AU separation will oscillate with the wave: effectively relativistic, so not able to produce enough RM.

Maybe some FRBs are in binary

Advantage:

- The magneto-environment: eg. introducing large, fast varying RMs, Faraday conversion and polarized absorption
- Diverse behavior, depending on the orbital inclination angle, separation, companion
- May explain the long-term periodicity
- Abundant in globular clusters, and can have longer age, so offset from the star-forming region. Does not trace star formation and stellar mass.

Challenge:

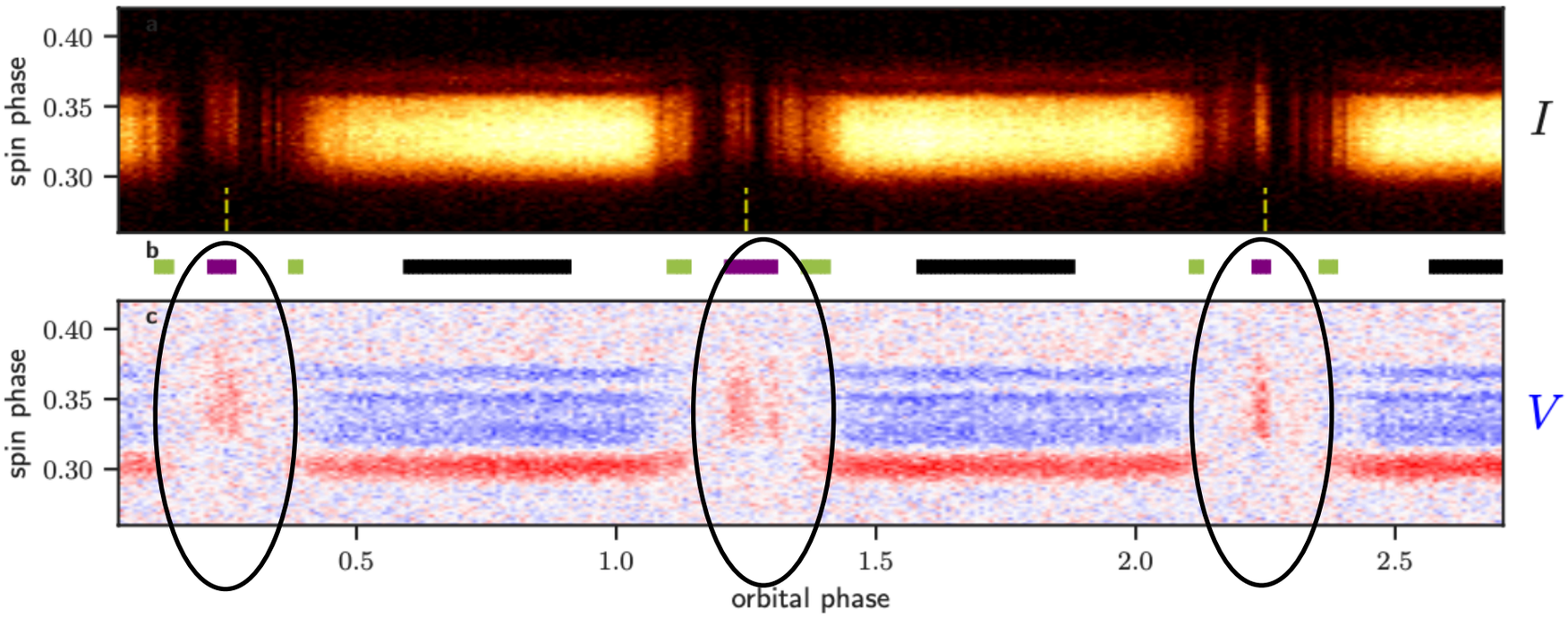
- AU spatial scale —> require massive companion —> again, why offset from the star forming region?
- Strong wave effect. For bright bursts, eg. FRB 121102 (R1), the plasma at AU separation will oscillate with the wave: effectively relativistic, so not able to produce enough RM.

- Need more evidence!

Moving forward: Polarization as a way to search for binary

- We see semi-periodic modulation of V

- A potential way to infer binary:
  - search for period in V
  - look at higher frequency for extreme LOS



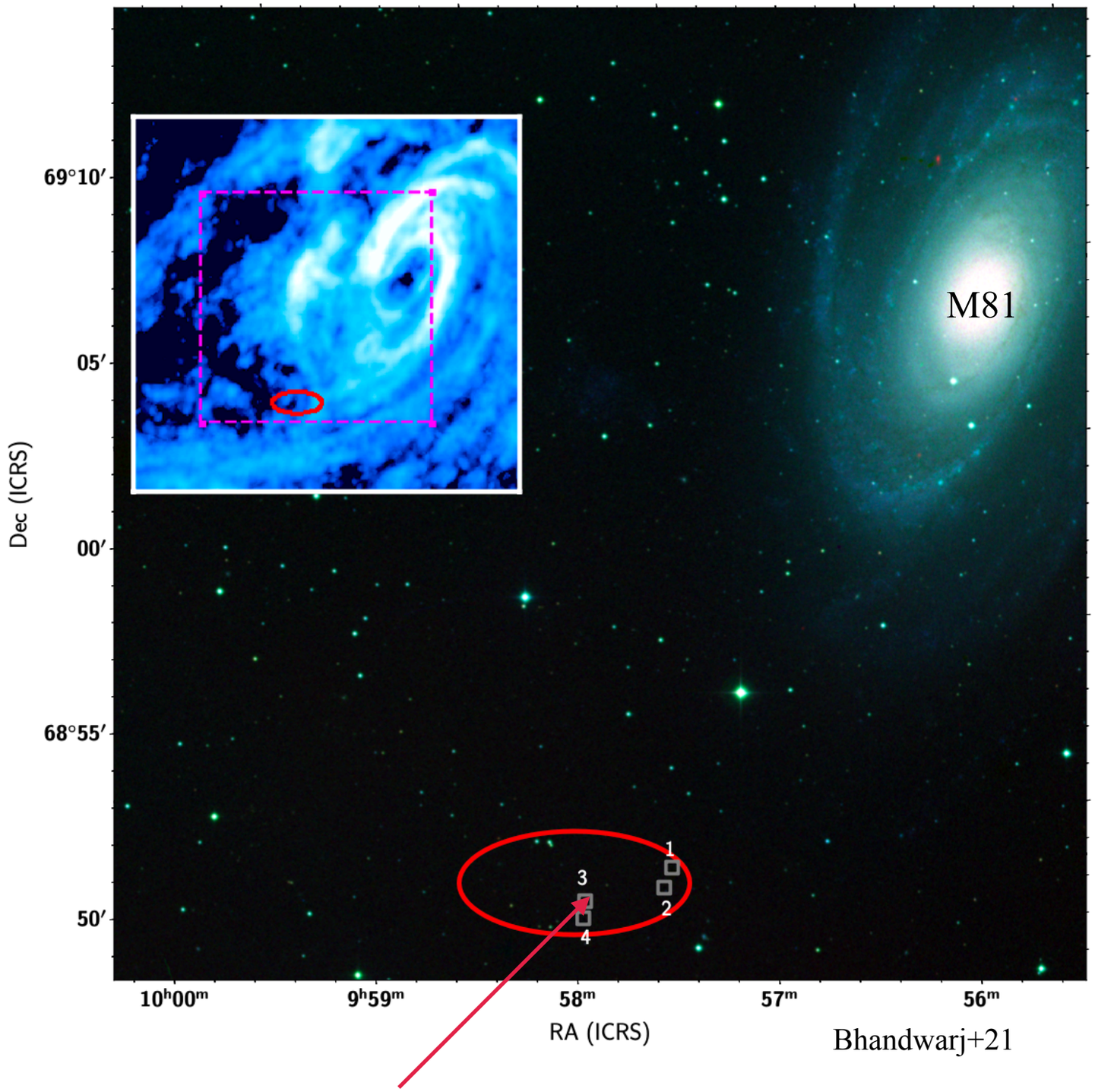
Moving forward: finding more GC FRBs

- An FRB localized to a globula cluster (GC) Bhandwarj+21, Kirsten+21

  - GC is old, low star formation
  - —>not normal magnetar, merger-formed magnetar? Binary?

  - only ~0.001% stellar mass in GC compared to galaxy
  - Orders higher FRB density per unit mass at GCs

  - Finding special FRBs by looking at galaxies with large number of GCs



Bhandwarj+21

GC[PR95] 30244 & FRB 20200120E

Search for GC FRBs

- Known:
  - one source found in M81 (3.6 Mpc)
  - In total ~1300 GCs up to the distance (Harris+13).
- Best Target:
  - Virgo A (16Mpc): 15000 GCs —> **~10 sources**

- Instrument: FAST
  - 19 beam, cover ~6000 GCs (~4 sources)
  - Avoid the central black hole, Sensitivity 200x CHIME

Previous effort only looks at the centre of Virgo A
missing the majority of GCs and non-optimal sensitivity due to BH.
(eg. Suresh+19)

- Expected rate: R~4 * 0.07/h * [(0.02Jy ms/5 Jy ms) * (3.6Mpc/16Mpc)^2]^{-1.4}

  R~ 5/h

Useful discussion with Ue-Li Pen, Kyle Kremer

Li + in prep

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- Observation
  - 2021Jun, 2021July, 2021Aug, 2022Sep
  - Effective ~2h, search DM: 50-20000pc/cm^3 —> non-detection

Observed with the help from Bing Zhang, WeiWei Zhu, Jiarui Niu, Dejiang Zhou

Li + in prep

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  R~ 5/h
- Observation
  - 2021Jun, 2021July, 2021Aug, 2022Sep
  - Effective ~2h —> non-detection
  - Should have more observation in the future!
  - And there are other promising galaxies (Kremer+in prep, chat with me for more info)
- Instrument: FAST
  - 19 beam, cover ~6000 GCs (~4 sources)
  - Avoid the central black hole, Sensitivity 200x CHIME

Li + in prep

Summary:

- Some FRBs observed to have exotic polarization behavior: highly variate, magnetized medium
- Similar polarization behavior observed in a pulsar binary, and we can understand/model it very well!
- Maybe some FRBs have companion, but we need more evidence —> searching exotic polarization behavior, searching more GC FRBs

Thanks!

Dongzi Li

- In collaboration with Anna Bilous, Scott Ransom, Robert Main, Yuanpei Yang
- Valuable discussion with Kyle Kremer, KJ Lee, Bing Zhang, Tony Piro, Ue-Li Pen, Sterl Phinney, Vikram Ravi, Jim Fuller, Harish Vedantham, Chris Thompson, Weiyang Wang