# Investigating coherent radio emissions from neutron star magnetospheres using kinetic plasma simulations

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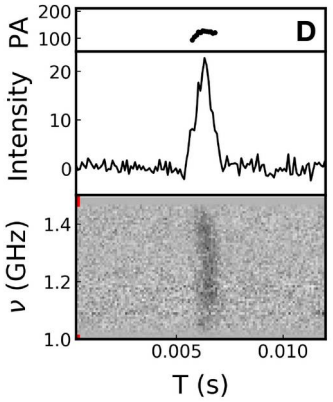
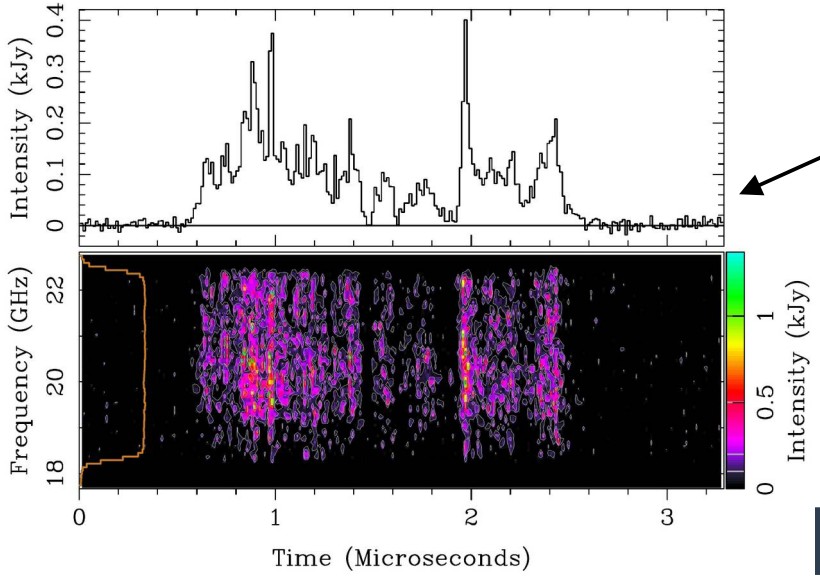
# Observations of coherent radio emissions for objects

## Fast radio bursts



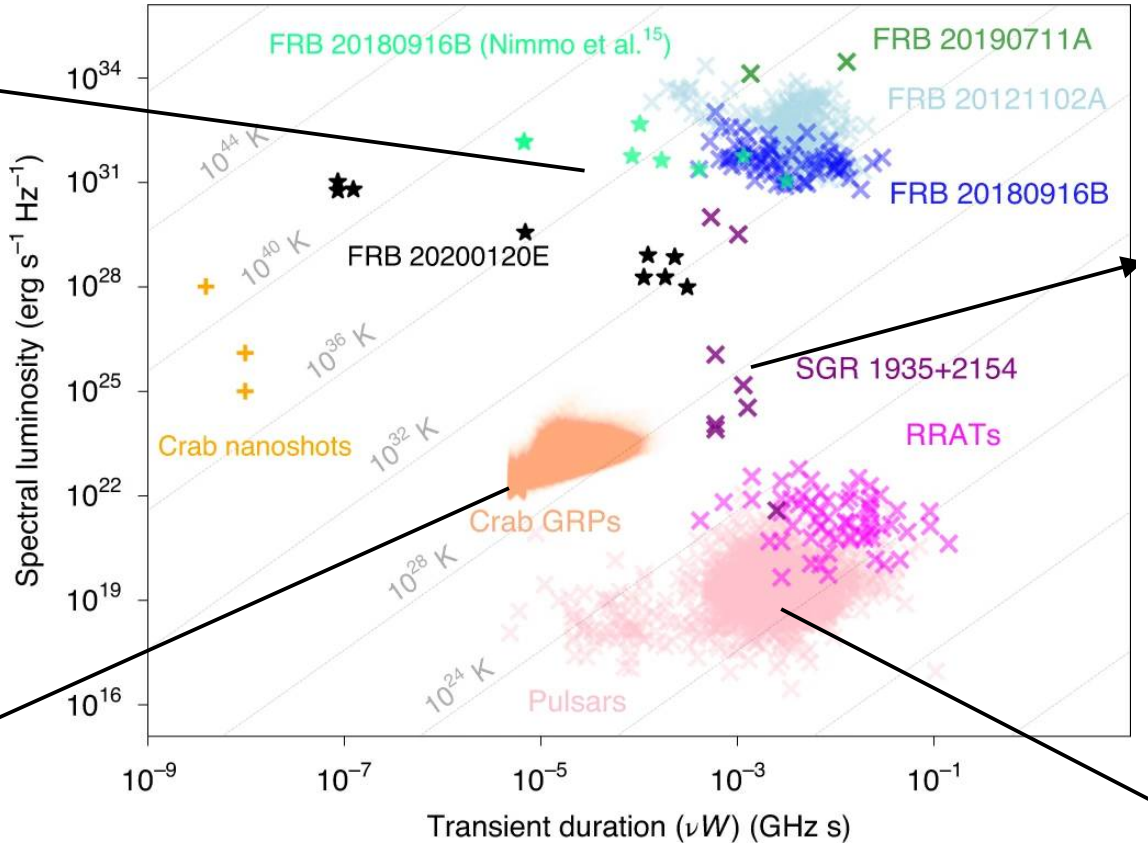

Zhu et al. (2023)

## Super-giant pulses

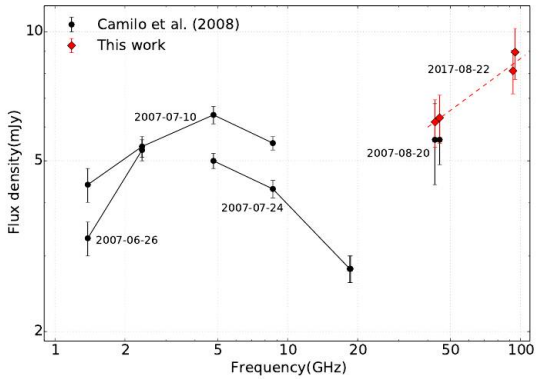



Hankins & Eilek (2016)

Nimmo et al. (2022)

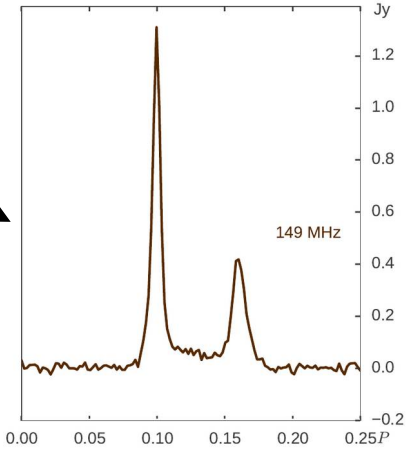



## Magnetars




Chu et al. (2021)

## Radio pulsars




Bilous et al. (2016)

# Pulsar radio emission mechanism at kinetic microscales is uncertain

- Origin of radio emission and polarization?
- Which plasma processes?

- **Coherent curvature emission by solitons -> Part 1**
  (Melikidze+ 1980, Mitra 2017, Rahaman+ 2020, Manthei+ 2021, Benáček+ 2024a, ...)
- **Polar cap pair discharges -> Part 2**
  (Ruderman+ 1975, Philippov+ 2020, Cruz+ 2020,2021, Benáček 2024b, Chernoglazov 2024)
- Linear acceleration emission
  (Melrose+ 2009, 2017, Reville+ 2010, Benáček et al. 2023)
- Electron cyclotron maser
  (Eilek+ 2016, Labaj, Benáček & Karlický 2024)
- Relativistic plasma emission
  (Eilek+ 2016, Melrose 2017, Benáček et al., in prep.)
- Conversion of Alfvén/Magnetoacoustic waves
- Coherent synchrotron
- Collisionless bremstrahlung
- Others

Philippov & Kramer (2022), Melrose et al. (2017,2020), Beskin (2018), Pétri (2016), Eilek & Hankins (2016)

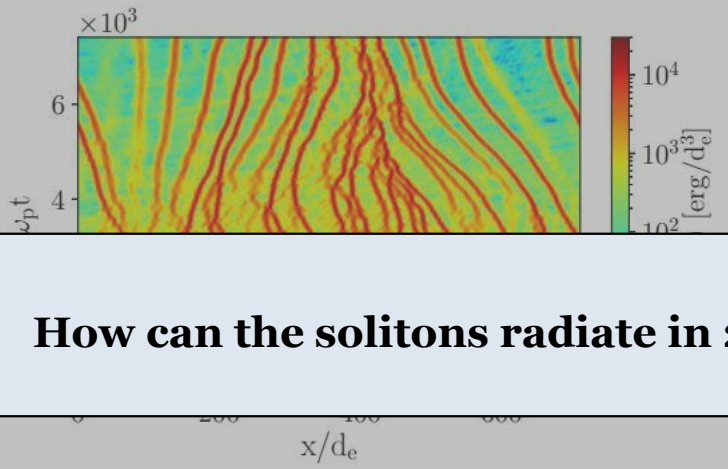
# No evidence of soliton-like waves

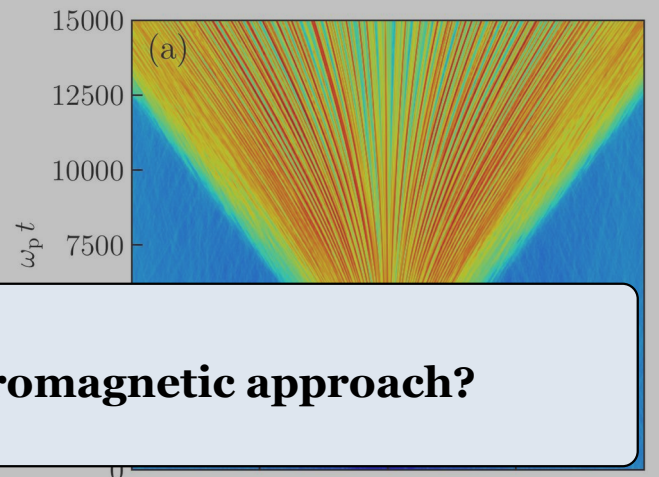
# We found that the solitary-like wave are formed in the pulsar **1D** plasma

Relativistic streaming/beam instability

Plasma bunches

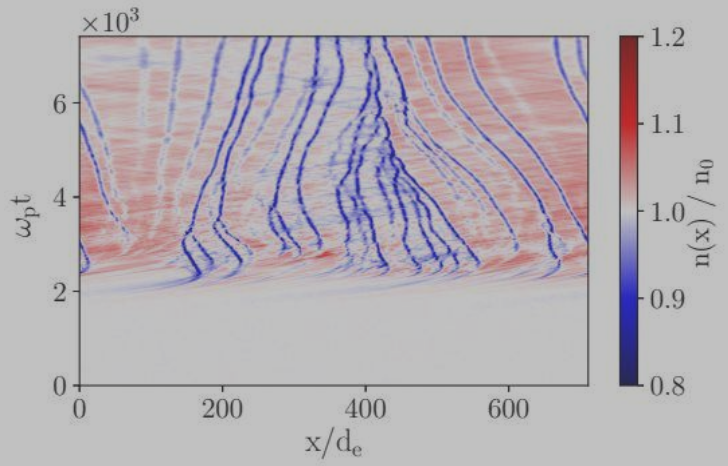
Electrostatic energy density

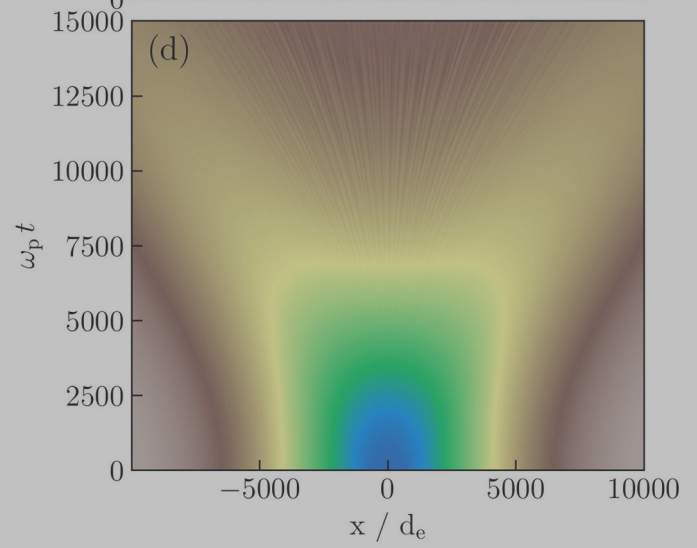


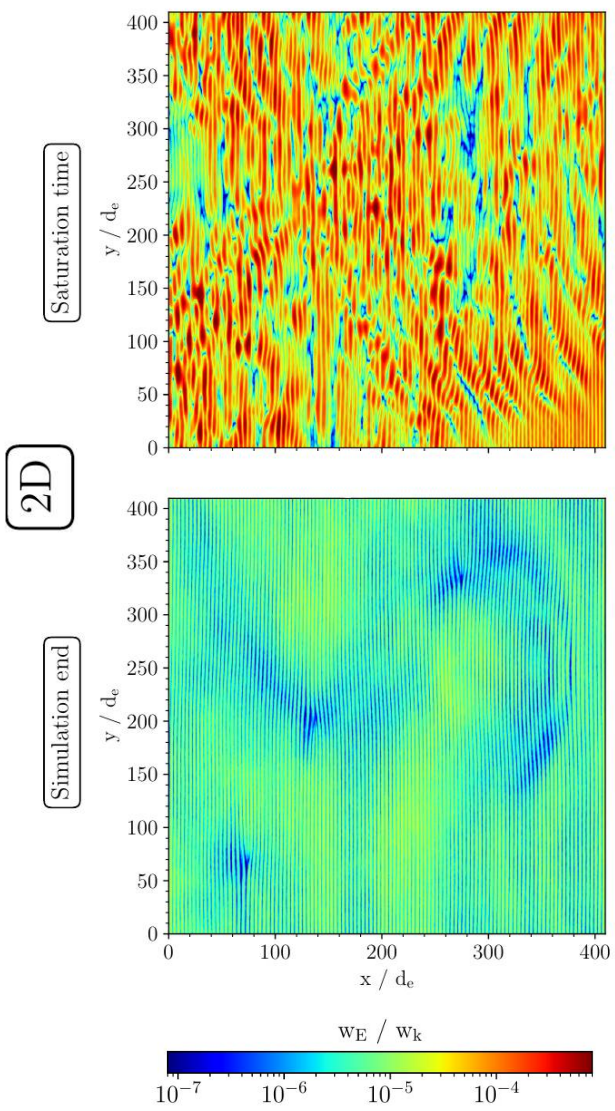

**How can the solitons radiate in 2D electromagnetic approach?**

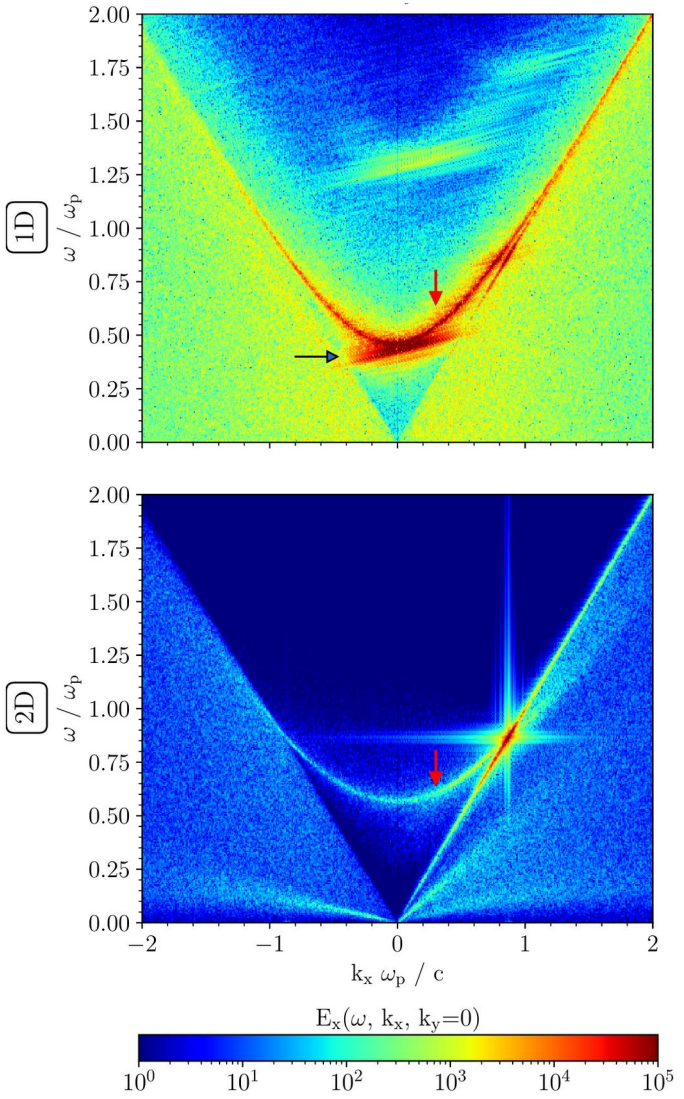
Plasma density



# No soliton-like waves appear in 2D



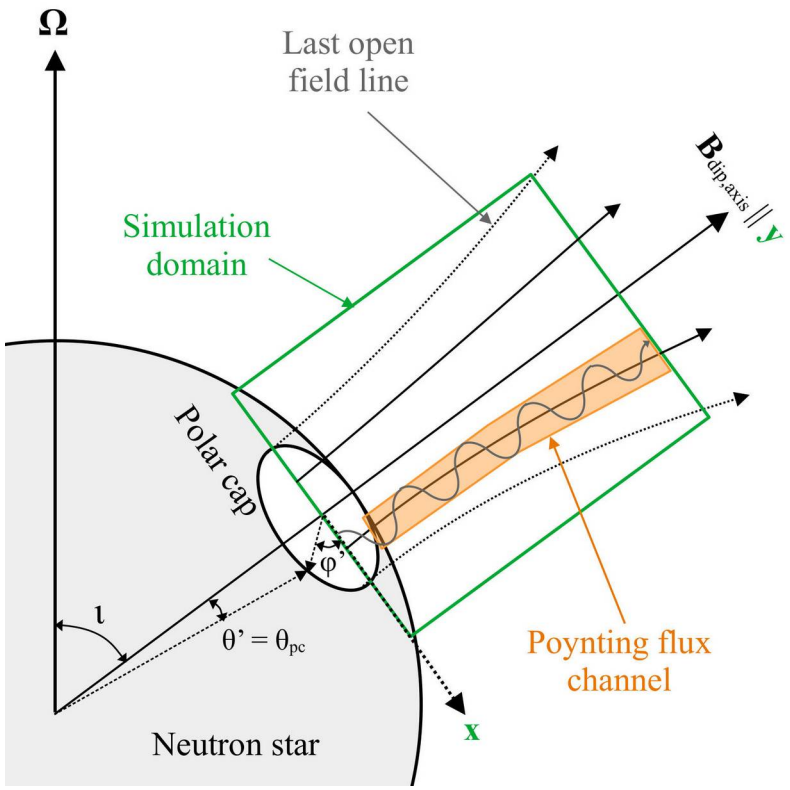

- No solitons are formed
- **No coherent curvature radiation** (from pulsar polar caps)

Benáček et al. (2024a)

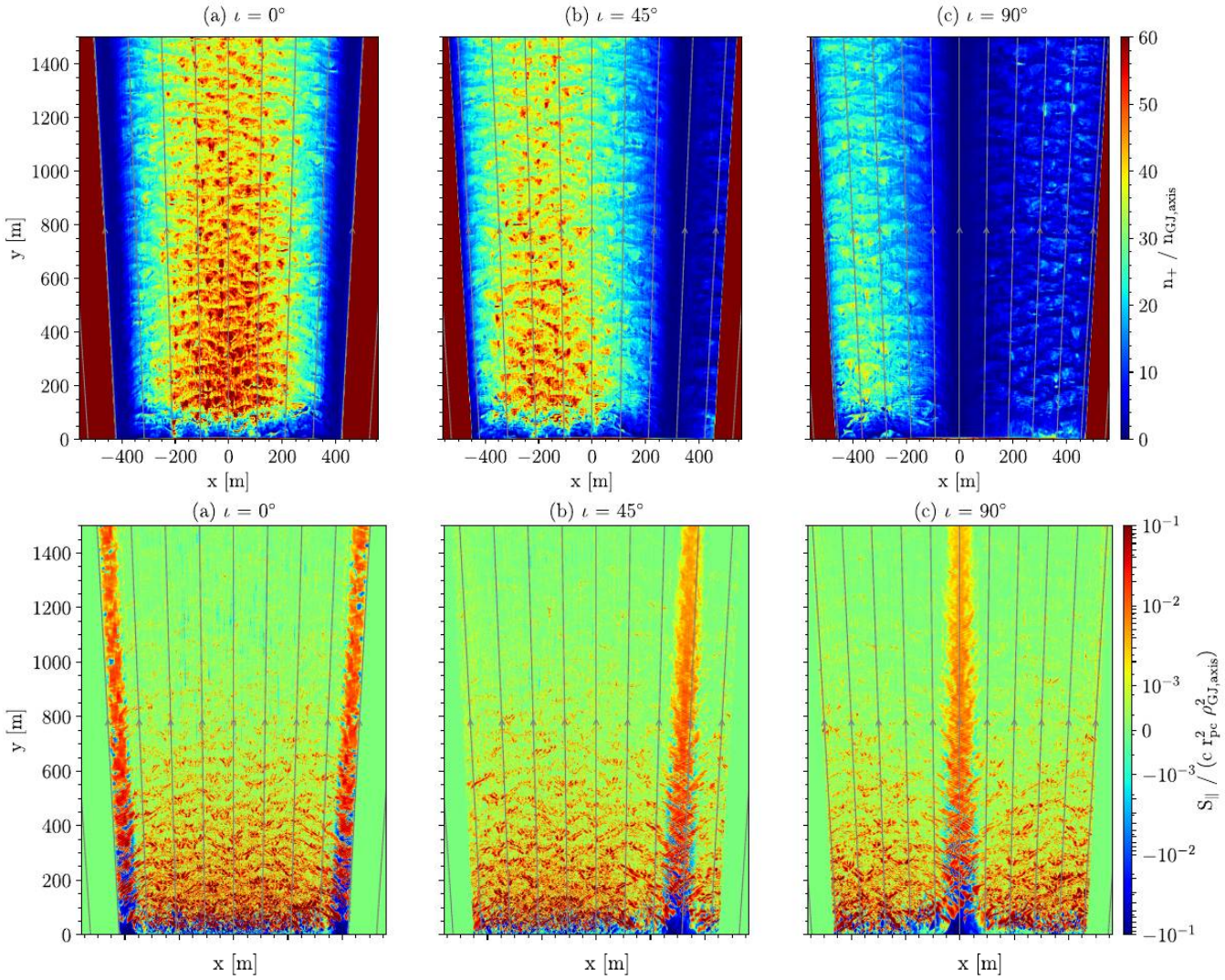
# Radiatiation of pair cascades in polar caps

# Poynting flux escapes along low-density mg. field lines

Benáček, Timokhin, Pohl, Büchner et al. (2024)



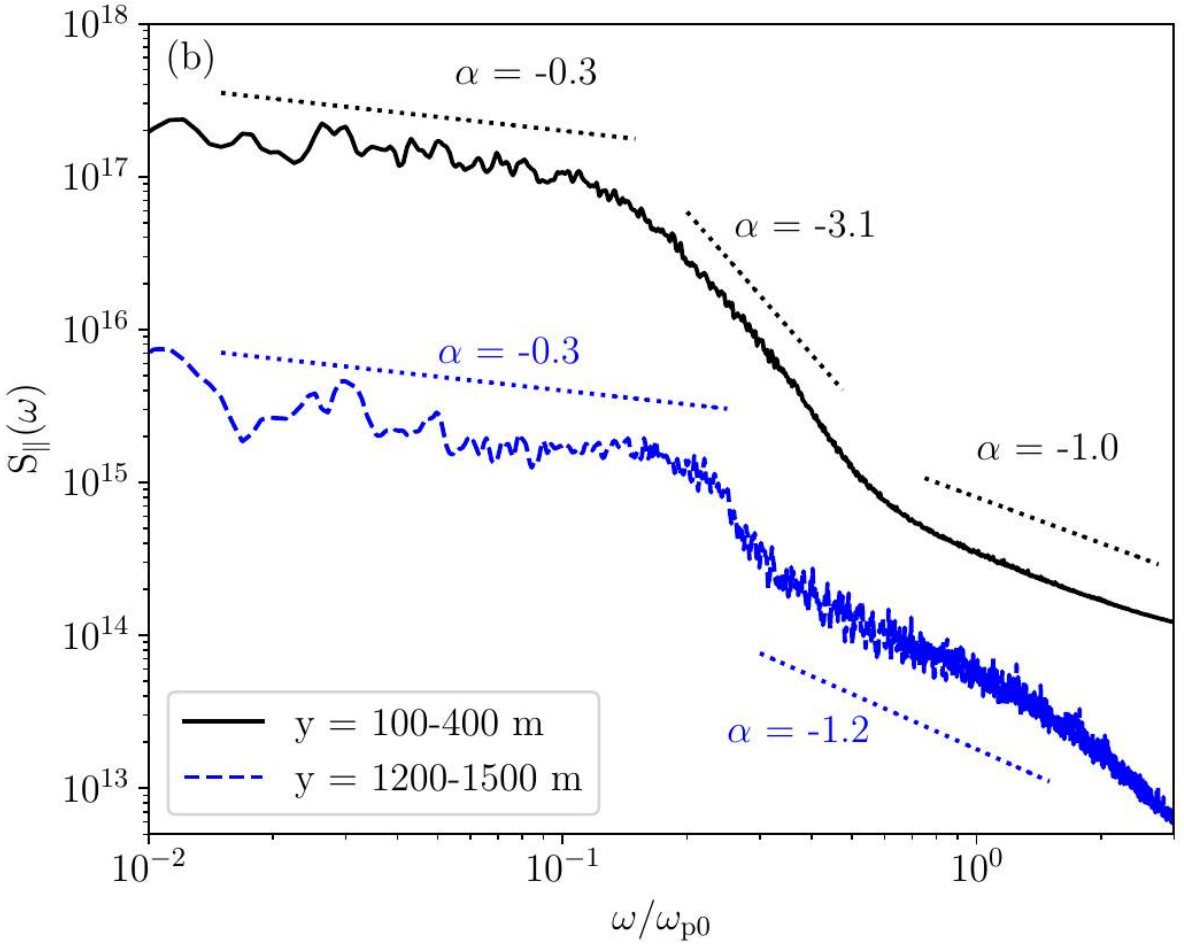

- $h_{gap} < r_{pc} \ll R_{star}$
- Inclinations 0°, 45°, 90°



# Poynting flux escapes along low-density mg. field lines

Benáček, Timokhin, Pohl, Büchner et al. (2024)

Spectrum in the poynting flux channel




- Radio waves associated with discharges and located in open magnetic field lines of no pair discharges
- In plasma-filled field lines, radio wave absorption
- Radio waves can follow the channel until plasma density drops below critical density

# Rotating vector model

B0525+21

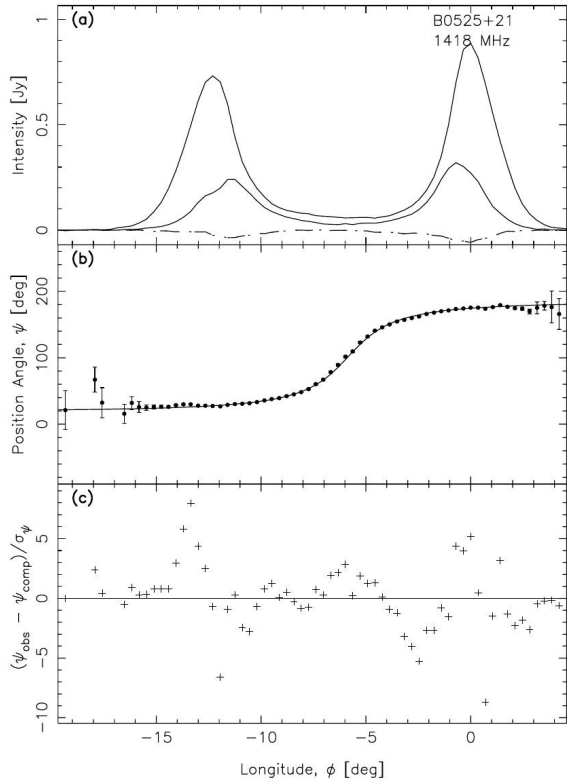



FIG. 4.—Pulsar B0525+21: See Fig. 3 legend for details

B0656+14

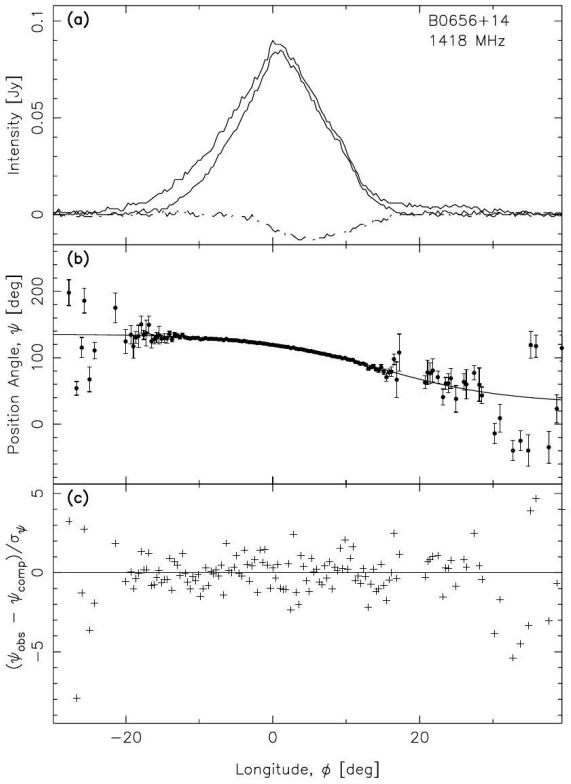
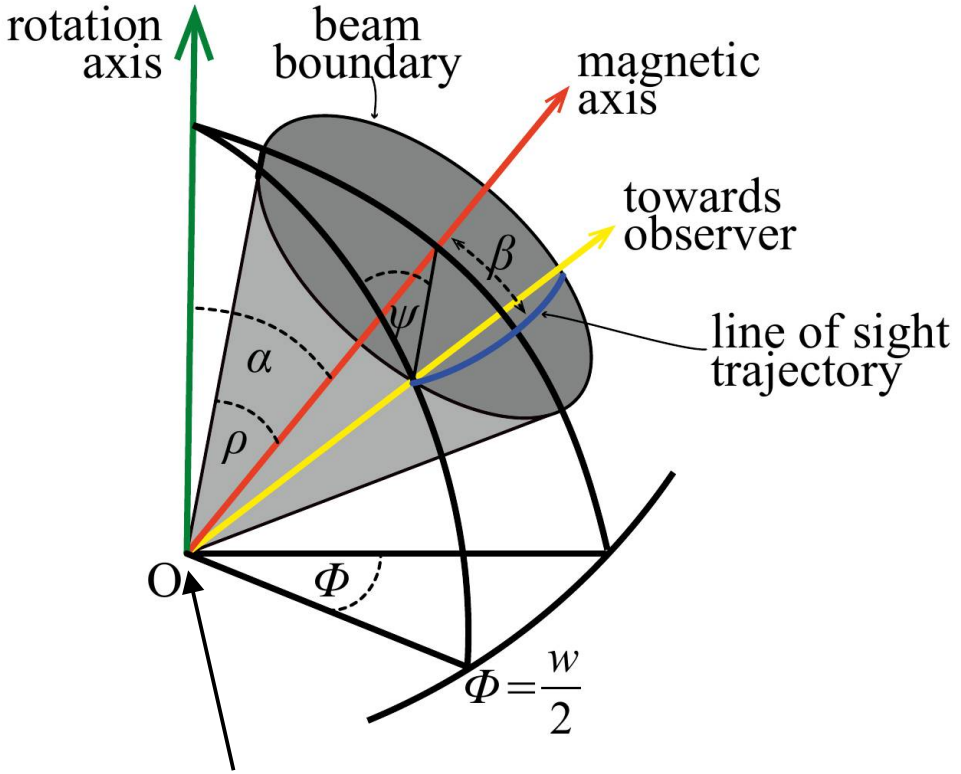



FIG. 5.—Pulsar B0656+14 See Fig. 3 legend for details

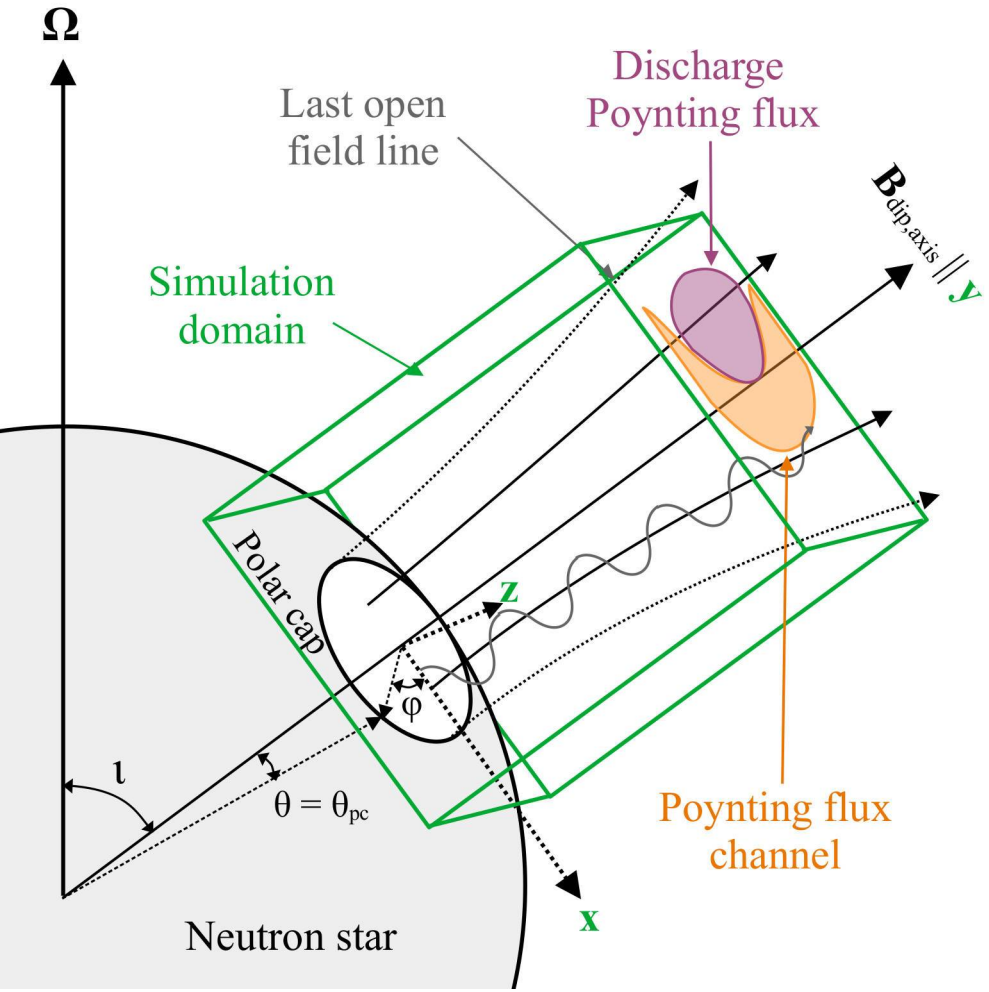
Geometry of Rotating Vector Model

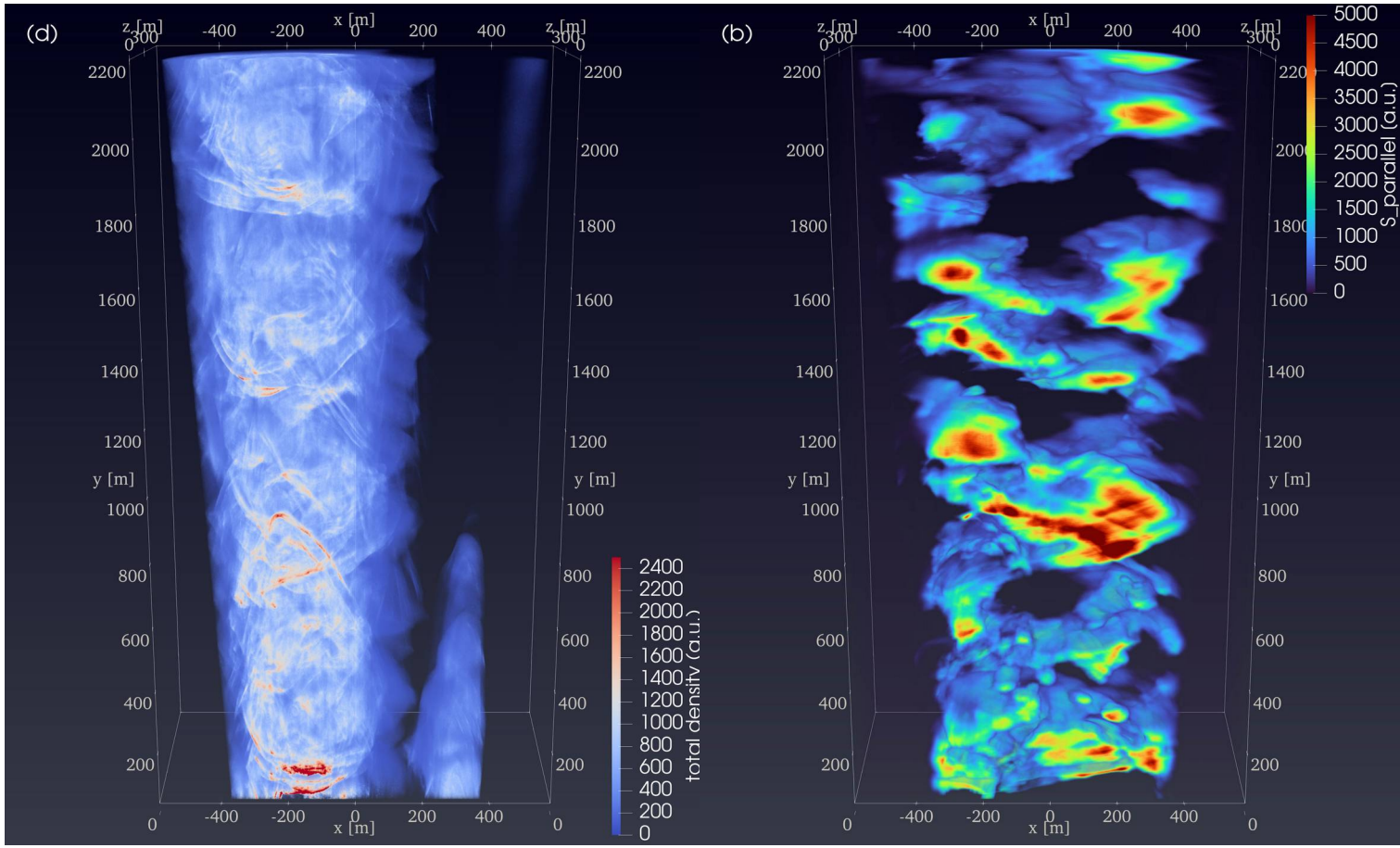



Neutron star is here

Everett and Weisberg (2001)

# Magnetospheric current across polar cap

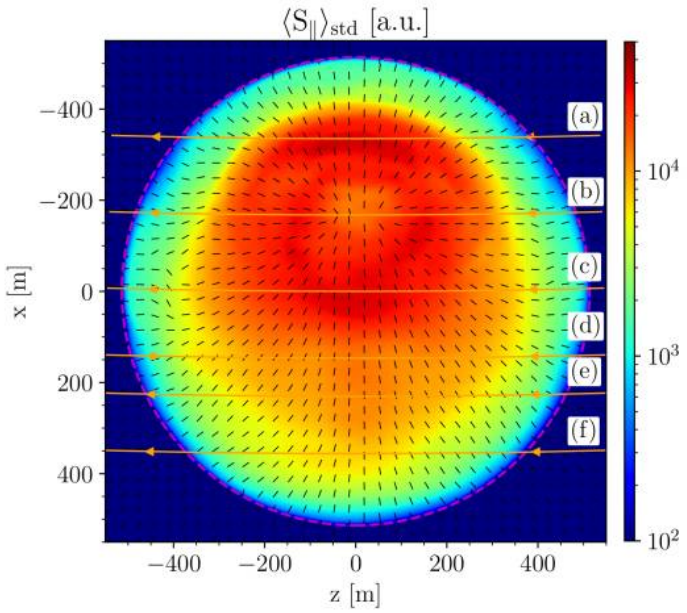


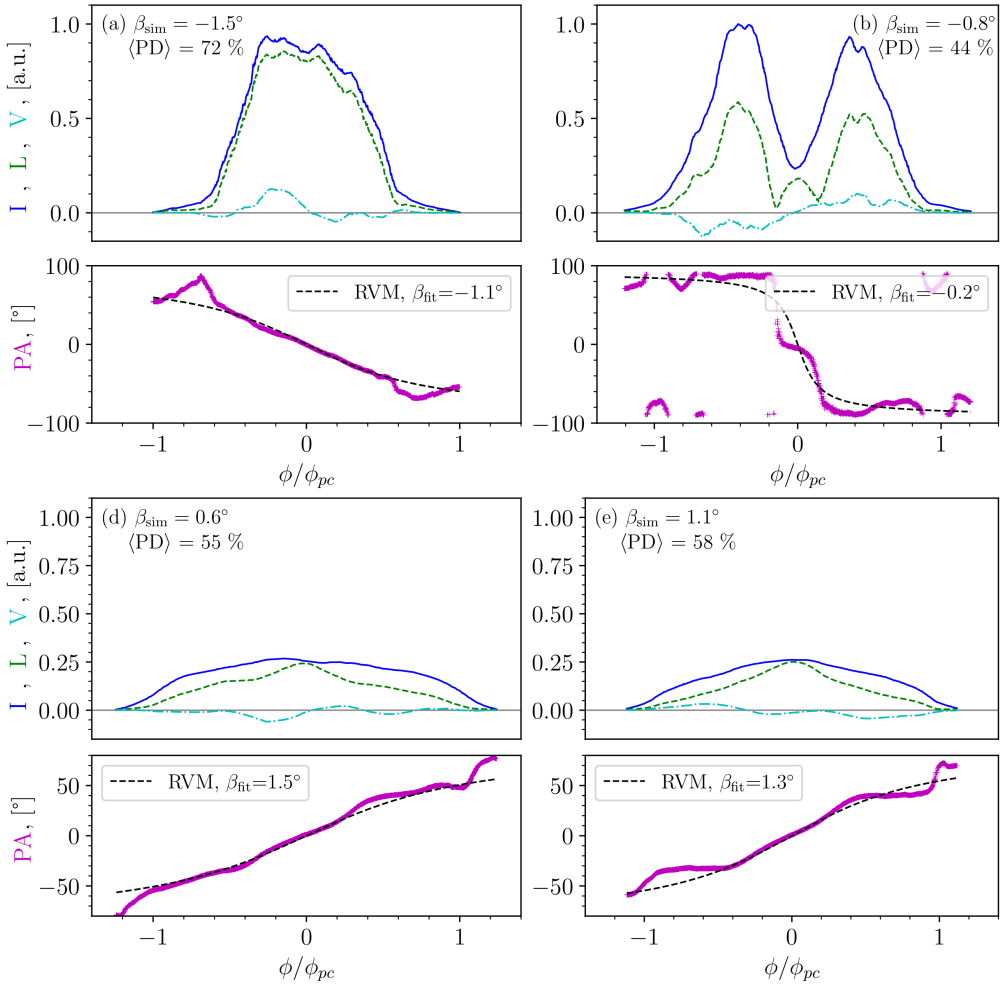

Assuming: magnetic dipole with an inclination ι = 60°

# Polarization profiles of radiation escaping polar cap

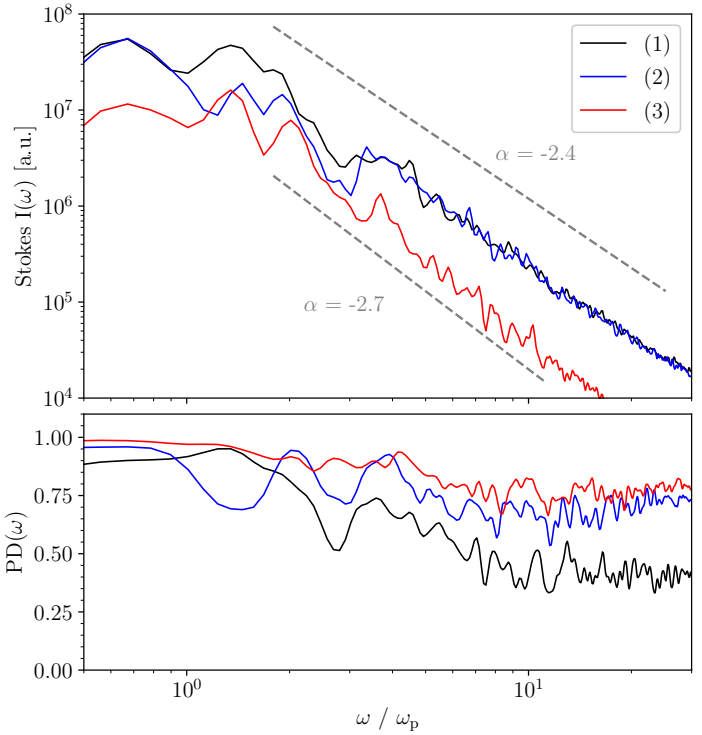
Selected observer angles β




Stokes profiles and polarization angle swings




Spectra




Polarization degrees

# Polarization profiles of radiation escaping polar cap

✓ Our model can reproduce

1. Total radio flux
2. One to three pulses
3. High linear polarization
4. Low circular polarization
5. PA swing (not following RVM)
6. Polarization degree decrease with increasing frequency
7. No radius-to-frequency mapping of generated waves

✗ Could be interpreted by radiative transfer or non-dipolar components:

1. High circular polarizations
2. Orthogonal pulses
3. Pulse widening with increasing frequency
4. More than three pulses

→ Polarization angle **does not follow the RVM**

→ There is **no radius-to-frequency** mapping in wave emission/generation

# Conclusions

- Pulsar radiation does not originate by coherent curvature radiation
- Our model can well reproduce several of observed parameters
- Poynting flux channels are formed in field lines of low plasma density
- Polarization does not follow RVM but is oriented along plasma density grandies

Papers on arXiv: 2309.15613
2405.20866
2503.17249

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