



# Mogu li se sudari super-ljuski vidjeti pomoću teleskopa LOFAR?

Marta Čolaković-Bencerić<sup>1</sup>, Vibor Jelić<sup>2</sup>

<sup>1</sup>Fizički odsjek, PMF, Sveučilište u Zagrebu, Bijenička cesta 32, 10000 Zagreb, Hrvatska

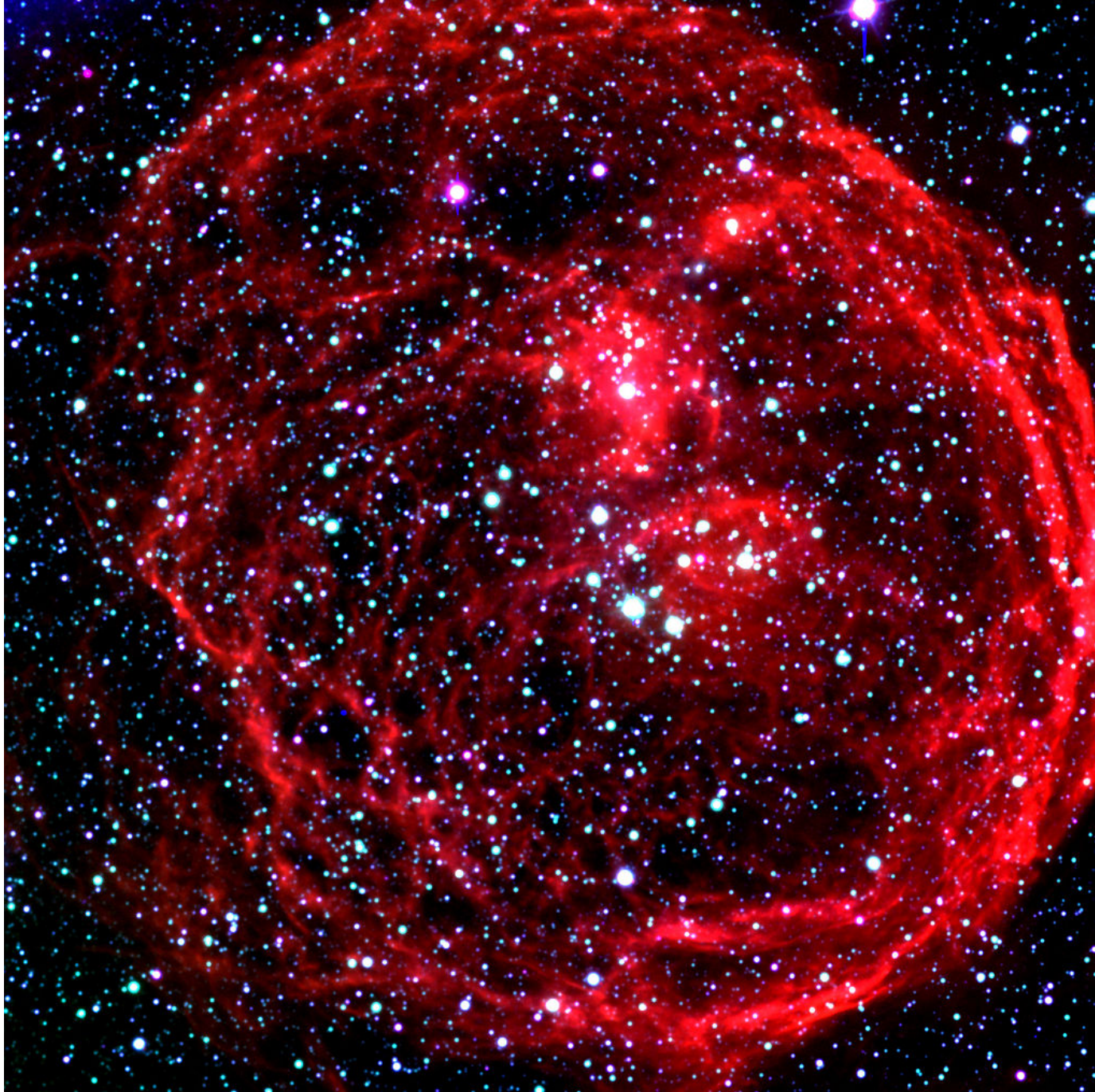
<sup>2</sup>Institut Ruđer Bošković, Bijenička cesta 54, 10000 Zagreb

# Sastav međuzvezdane materije (ISM-a)

- Molekularni oblaci, prašina, difuzni ISM, kozmičke zrake (netermalna plazma)
- Difuzni ISM – neioniziran, ioniziran ili djelomično ioniziran
- Ionizirane faze vodika: topla (8000 K) i vruća ( $\geq 10^6$  K)
- Djelomično ionizirana faza vodika,  $T \approx 5000$  K
- Prisutno magnetsko polje, jakost se određuje pomoću Zeemanovog efekta (u neutralnim fazama) i Faradayeve rotacije (u ioniziranim i djelomično ioniziranim fazama)

# Super-ljuske

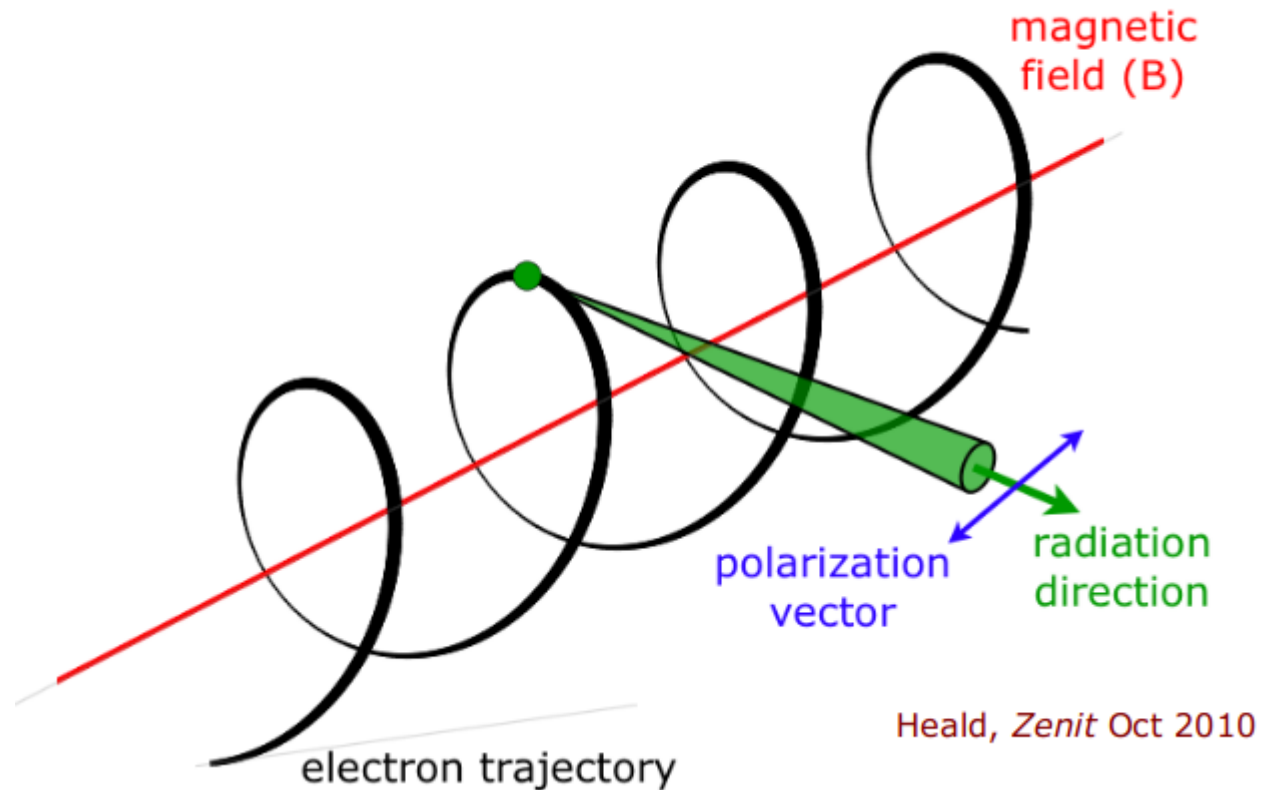
- Radijus, red veličine 100 pc
- Oko klastera mladih zvijezda
- Nastaju interakcijom šokova i udarnih valova eksplozija supernovi
- Tok tvari od laminarnog postaje turbulentan -> nehomogenosti u gustoći elektrona i magnetskog polja
- Sudari super ljuski nisu rijetki -> moguće objašnjenje detektiranih filamentarnih struktura u galaksiji



ESO - <http://www.eso.org/public/images/eso9948d/>

# Sinkrotronsko zračenje

- Zračenje relativističkih nabijenih čestica (većinom elektrona) u magnetskom polju



- Sinkrotronsko zračenje - difuzno i polarizirano
- Zračenje ansambla elektrona  $n_e dE = kE^{-\gamma} dE$
- Spektralni indeks  $\alpha = \frac{\gamma - 1}{2}$
- Tipične vrijednosti  $\gamma = 5/2 \rightarrow \alpha = 0.75$
- Udio polariziranog intenziteta u ukupnom intenzitetu

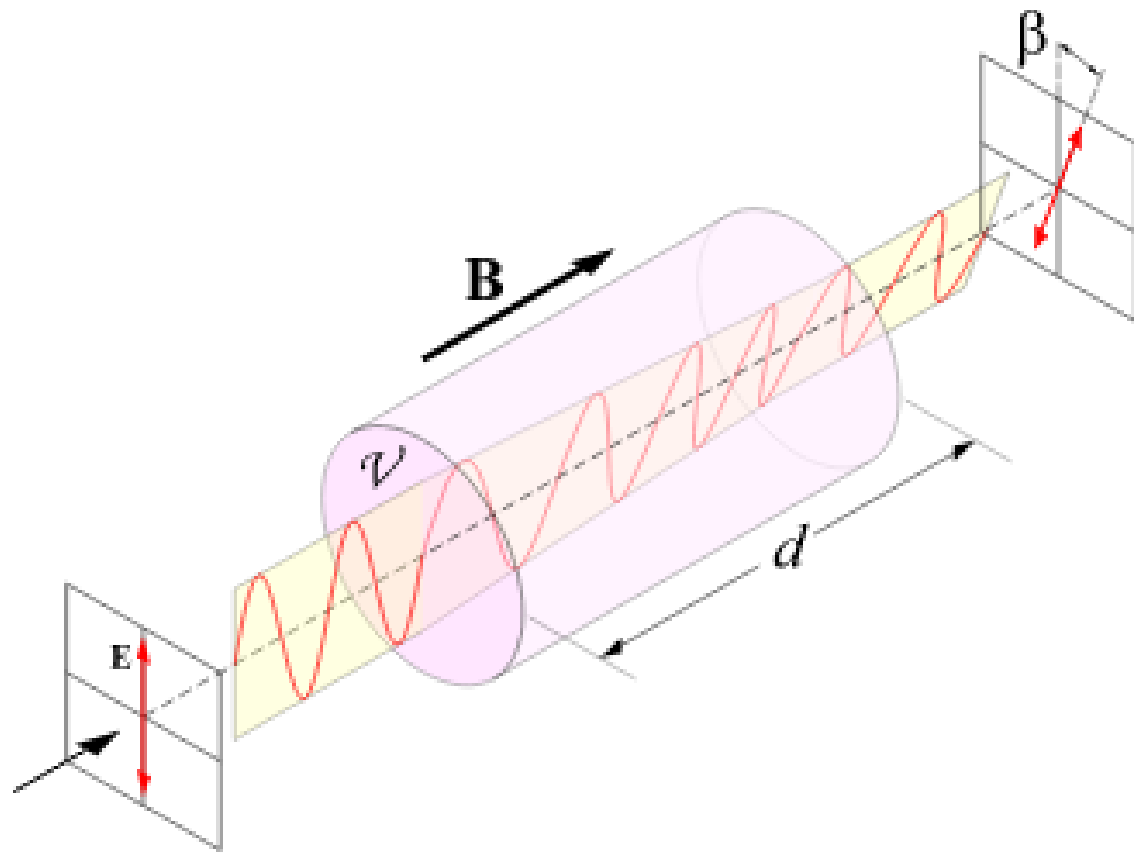
$$p = \frac{\alpha + 1}{\alpha + 5/3}$$

# Faradayeva rotacija

- Linearno polarizirani val = superpozicija dva kružno polarizirana vala
- Različiti indeks loma za dvije kružne polarizacije -> zakretanje kuta polarizacije

$$\Phi(\lambda^2) = 0.81 \int_{izvor}^{teleskop} n_e(s) B_{||}(s) ds \text{ rad m}^{-2}$$

$$\chi = \chi_0 + \Phi \cdot \lambda^2$$

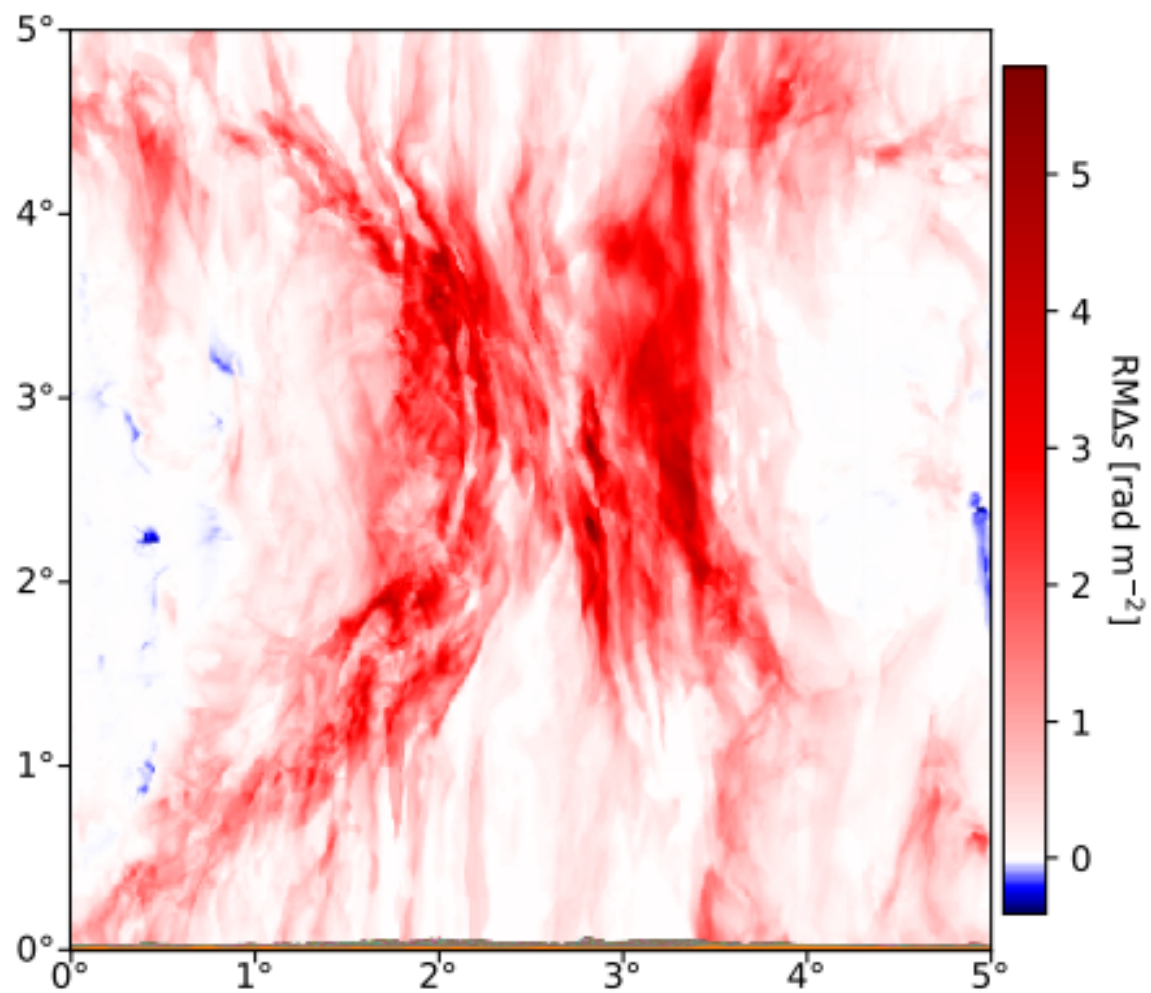




# Magnetohidrodinamičke simulacije

- Dimenzije  $5^\circ \times 5^\circ$ , što odgovara  $200 \text{ pc} \times 200 \text{ pc} \times 200 \text{ pc}$
- Sadrži podatke o mjeri zakretanja kuta u svakom prostornom pikselu

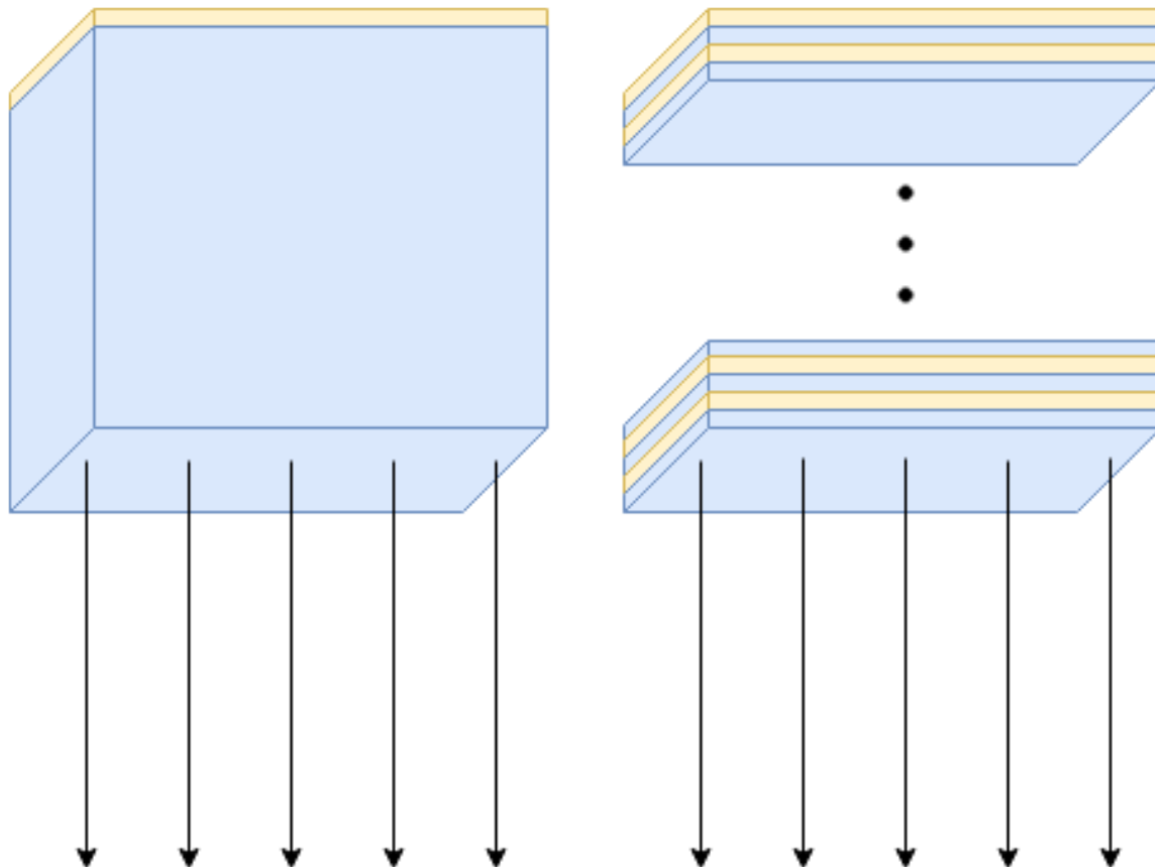
$$RM ds = 0.81 n_e(s) B_{||}(s) ds \text{ rad m}^{-2}$$




RM vrijednosti na polovici simuliranog prostora

# Parametrizacija i zračenje

- Promatramo 2 slučaja zračenja



- Funkcija intenziteta zračenja:  $I_{P,\nu} = I_{P,0} \left( \frac{\nu}{\nu_0} \right)^{-2.5}$   
, s  $\nu_0=150$  MHz i  $I_{P,0}=1$  K
- Promatrane valne duljine: 115-170 MHz
- Spektralna rezolucija:  $\delta\nu=0.2$  MHz
- Dodajemo termalni (Gaussijanski) šum s intenzitetom takvim da nakon RM sinteze omjer intenziteta signala i šuma bude 4
- Konvoluiramo s funkcijom teleskopa, PSF - 2DGaussian 3'x3'
- Iniciramo kod RM sinteze da promatra Faradayeve dubine od -25 do +25 rad m<sup>-2</sup>, s razmakom od 0.25 rad m<sup>-2</sup>



-> parametri odabrani u skladu s  
mjerenjima i karakteristikama  
visokofrekventnih antena LOFAR  
teleskopa

# RM sinteza

- Transformacija intenziteta polariziranog zračenja iz prostora valnih duljina u prostor Faradayevih dubina
- Definiramo kompleksni intenzitet polariziranog zračenja

$$P = pIe^{2i\chi} = U + iQ.$$

- Intenzitet zračenja u Faradayevoj dubini je tada

$$F(\Phi) = \frac{1}{\int_{-\infty}^{\infty} W(\lambda^2) d\lambda^2} \cdot$$

$$\int_{-\infty}^{\infty} W(\lambda^2) P(\lambda^2) e^{-2i\Phi\lambda^2} d\lambda^2$$

- Ograničavajući parametri

$$\Delta\lambda^2 \rightarrow \delta\Phi \approx \frac{2\sqrt{3}}{\Delta\lambda^2} = 0.94 \text{ rad m}^{-2}$$

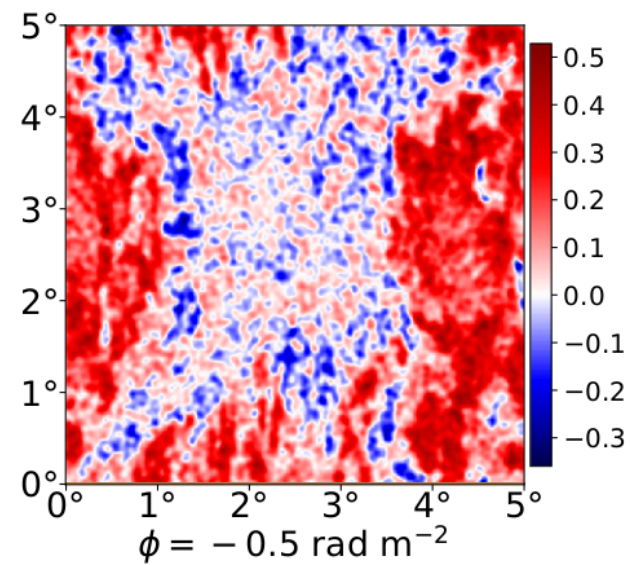
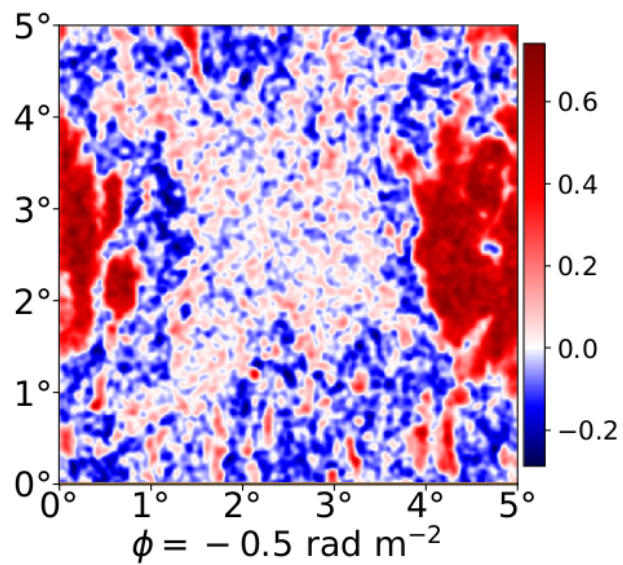
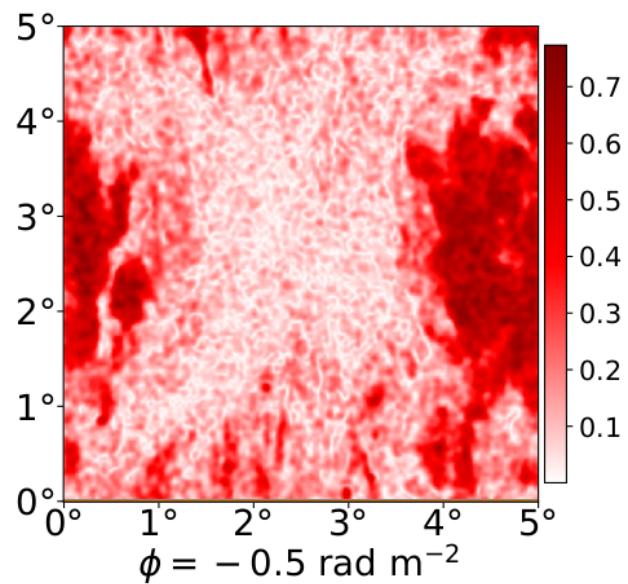
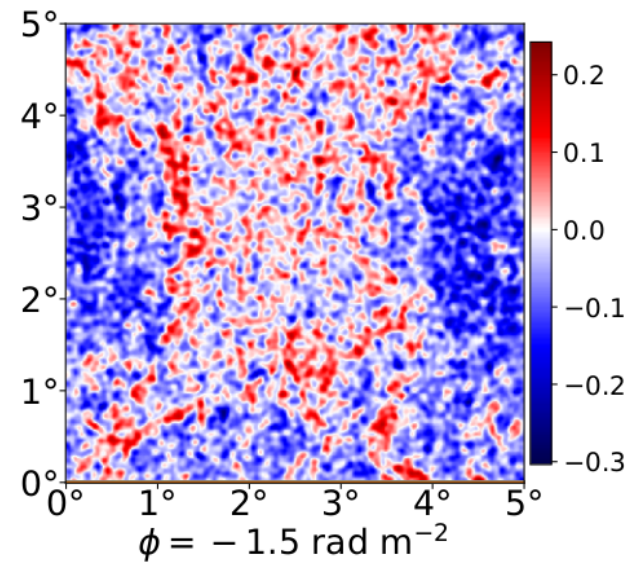
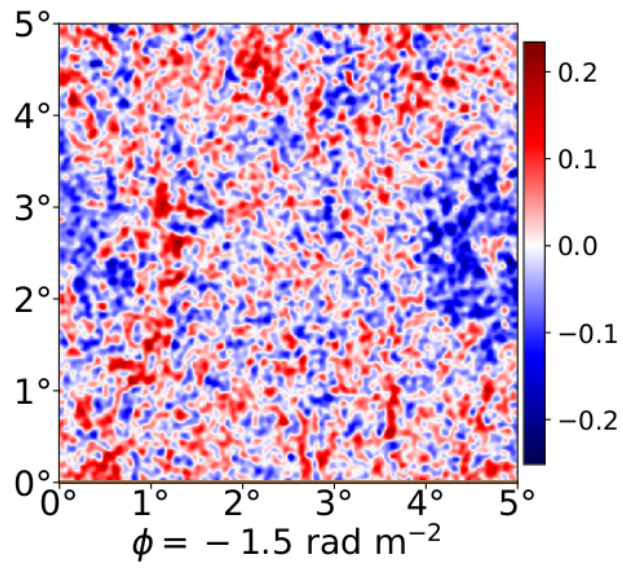
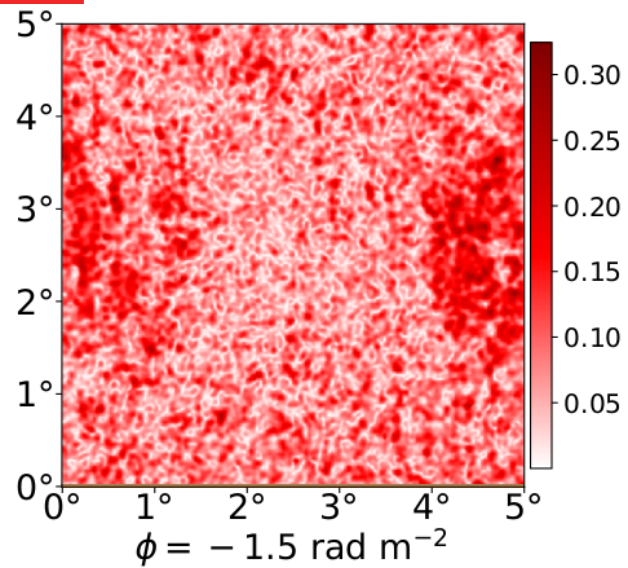
$$\delta\lambda^2 \rightarrow \Phi_{max} \approx \frac{\sqrt{3}}{\delta\lambda^2} = 160.5 \text{ rad m}^{-2}$$

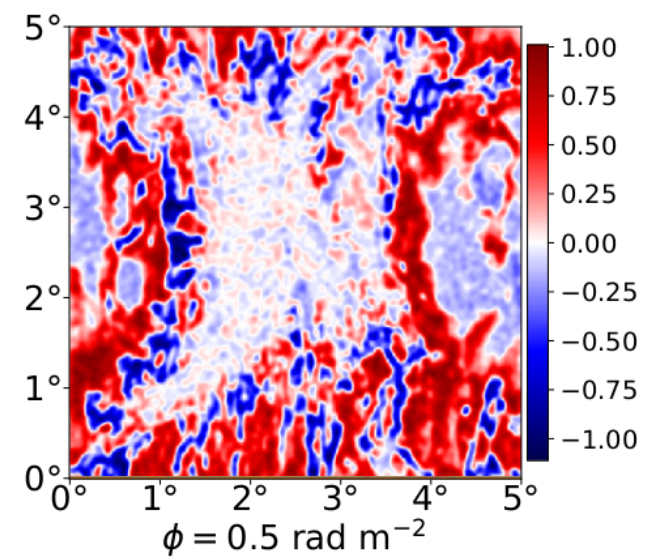
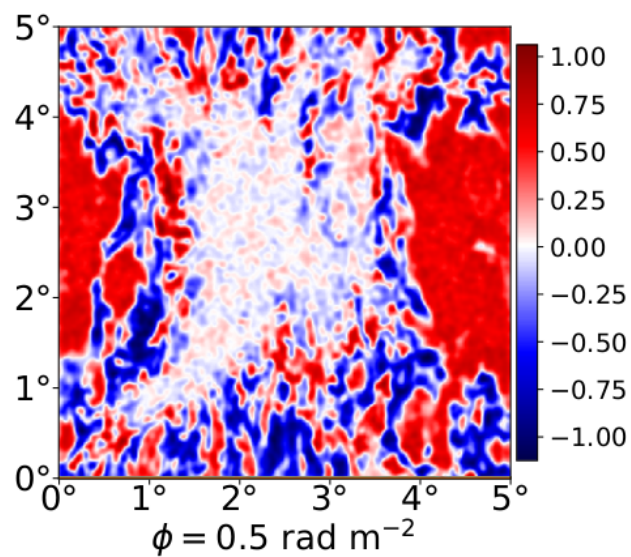
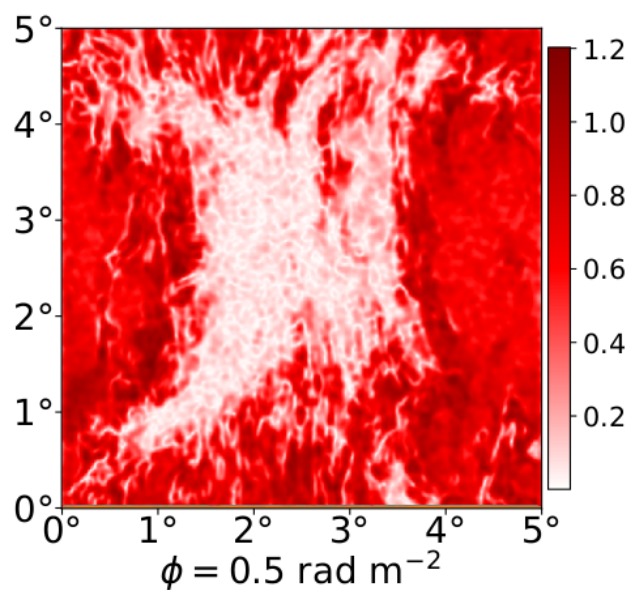
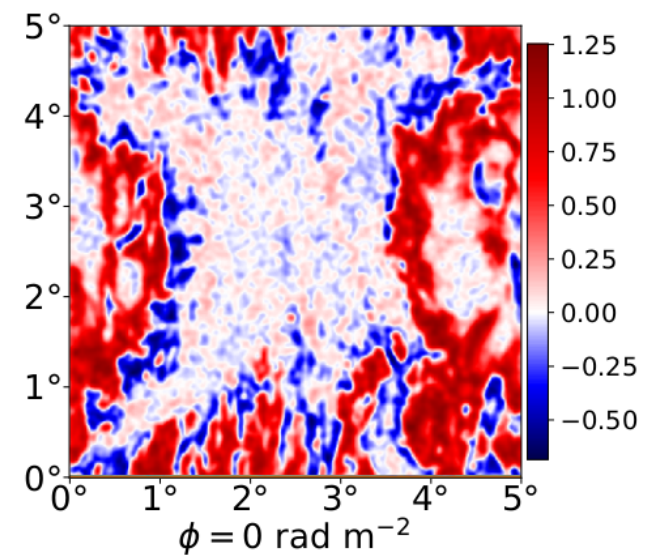
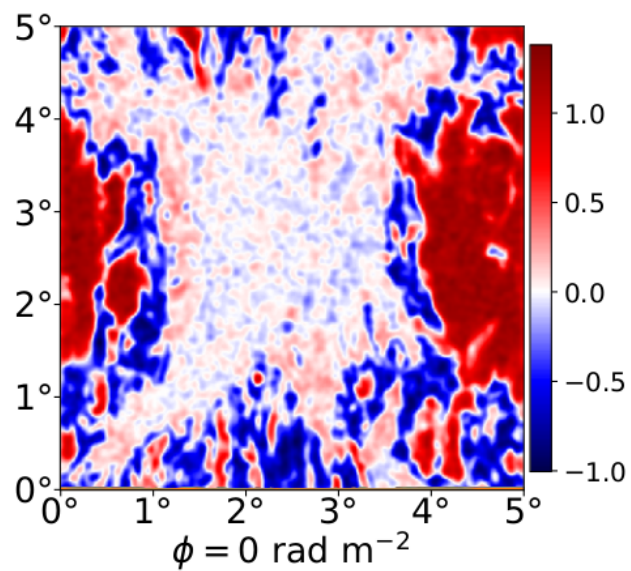
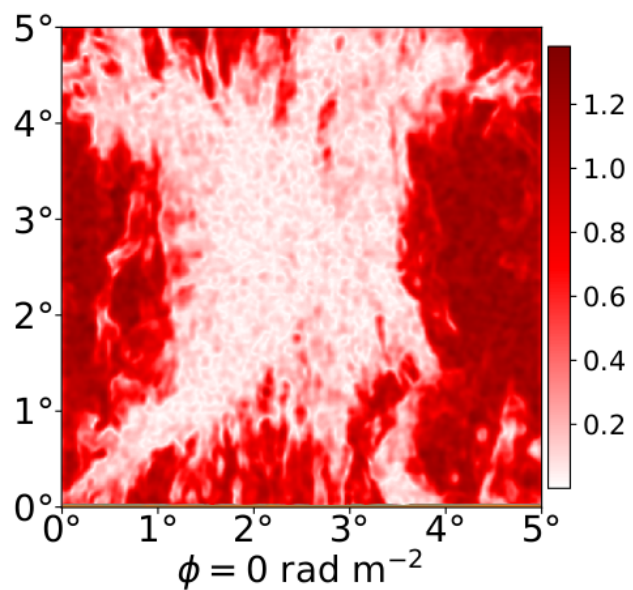
$$\lambda_{min}^2 \rightarrow \Delta\Phi_{max} \approx \frac{\pi}{\lambda_{min}^2} = 1.001 \text{ rad m}^{-2}$$

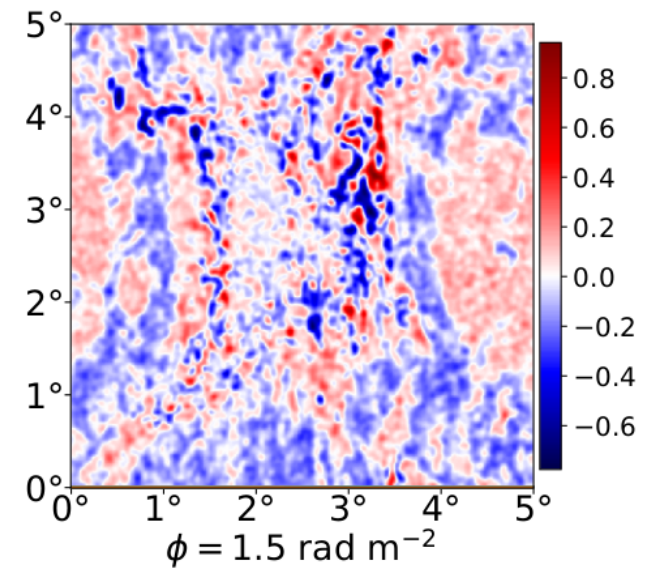
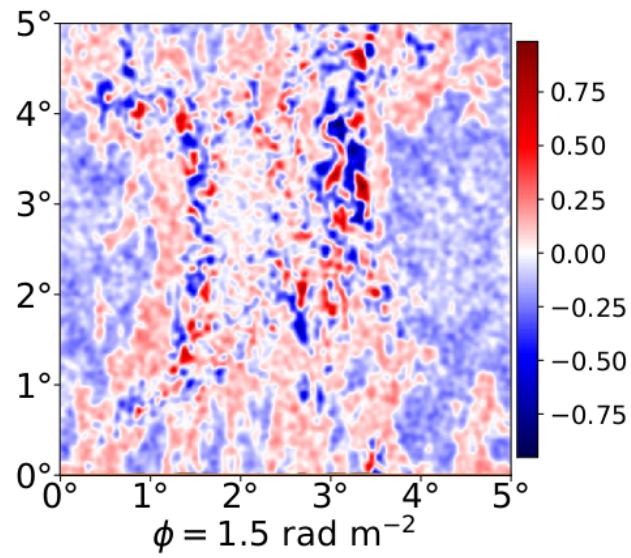
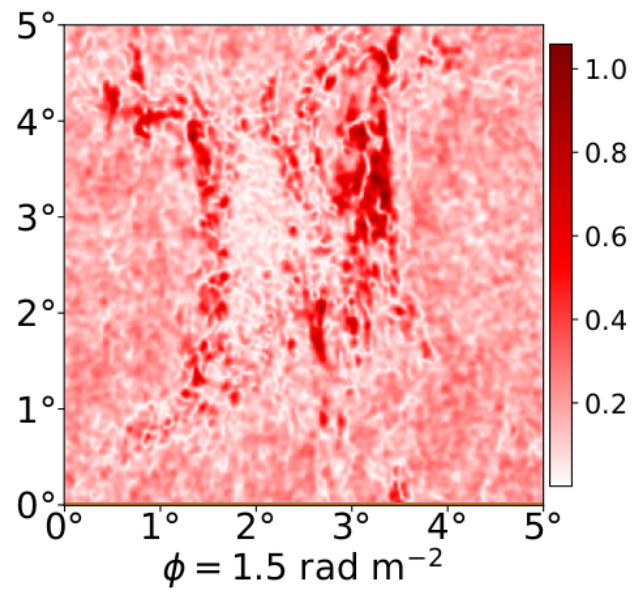
# Rezultati

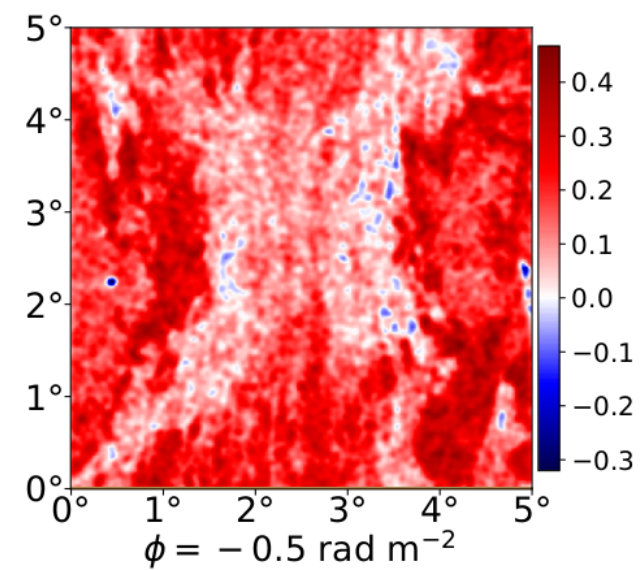
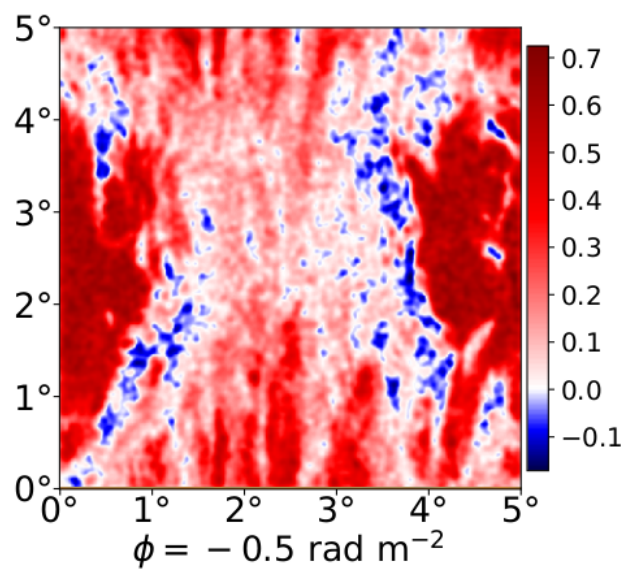
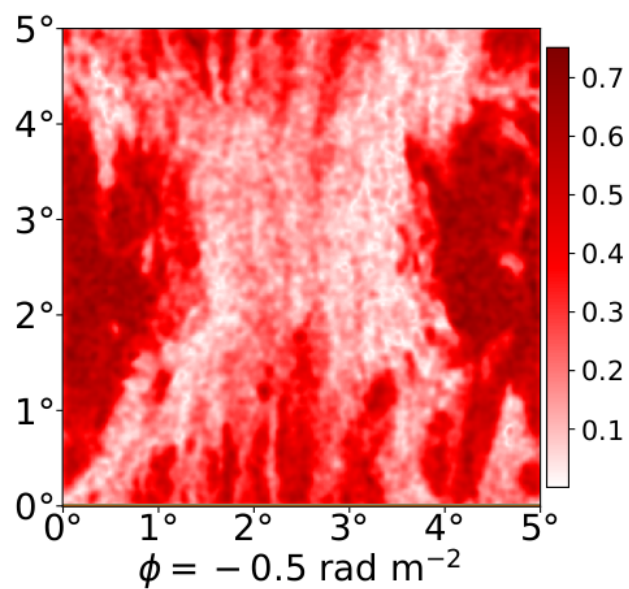
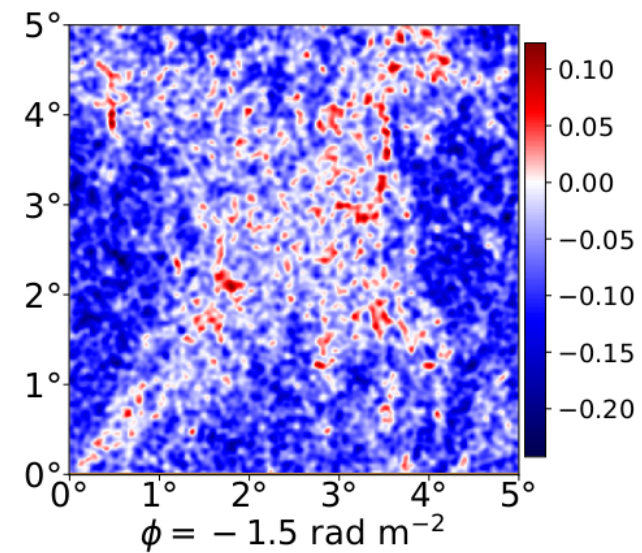
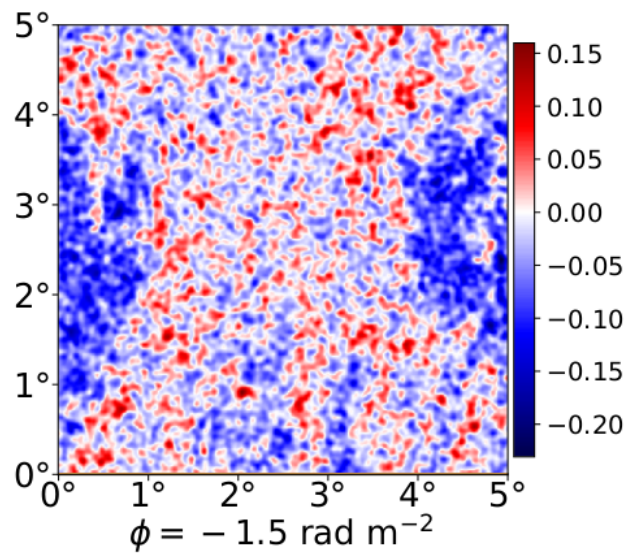
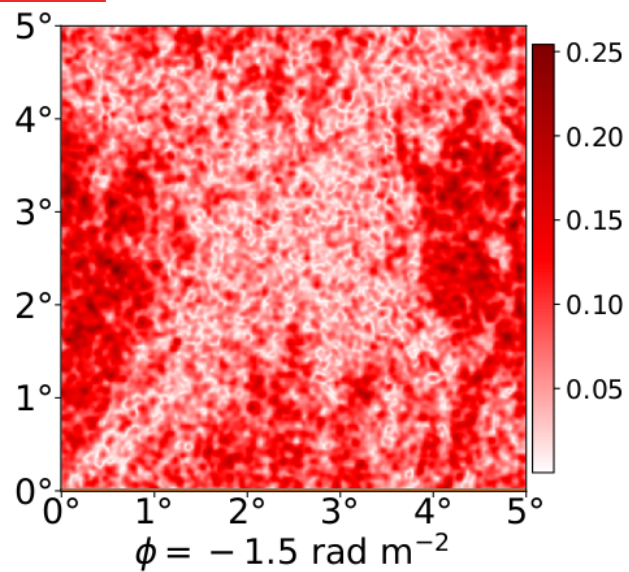
- RM kocke dimenzija 512x512x201
- Depolarizacija -> manjak toka polariziranog intenziteta -> svjetlija/bijela područja na slikama
- U jedinicama  $\mu\text{Jy PSF}^{-1} \text{ RMSF}^{-1}$

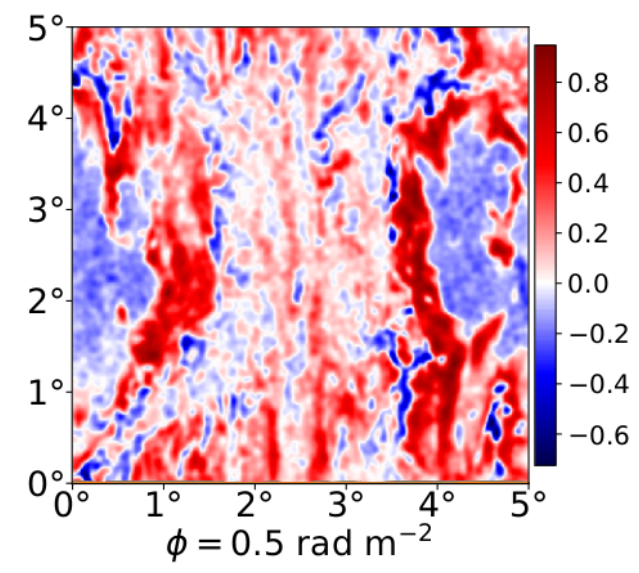
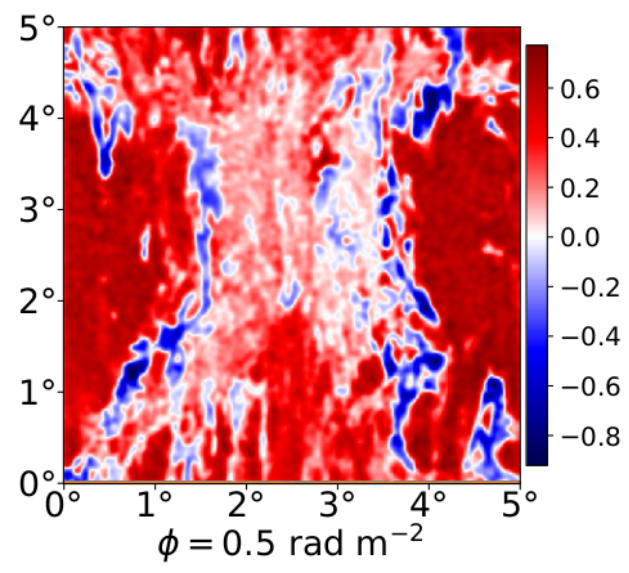
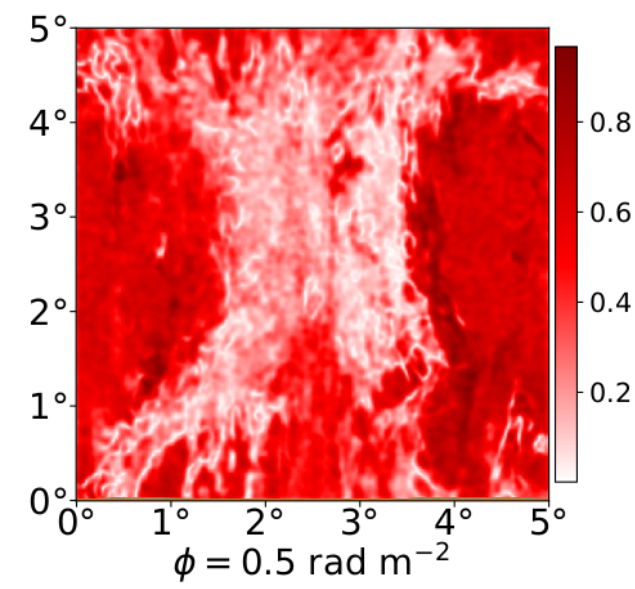
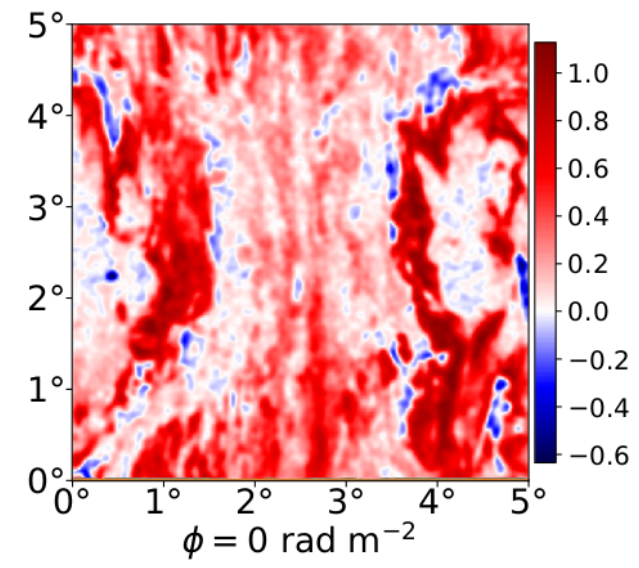
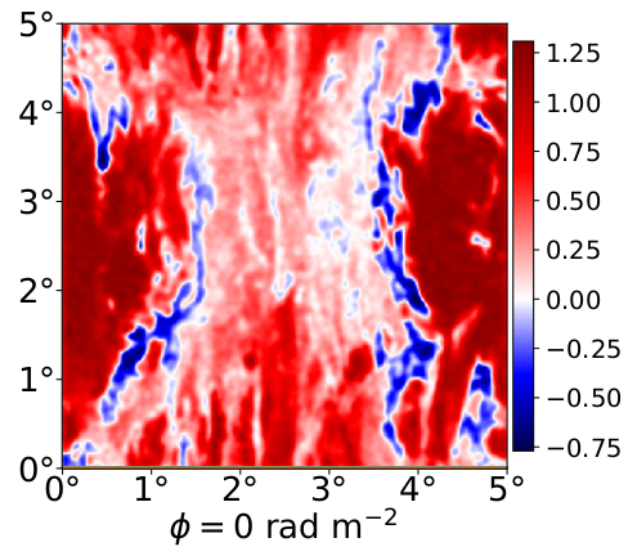
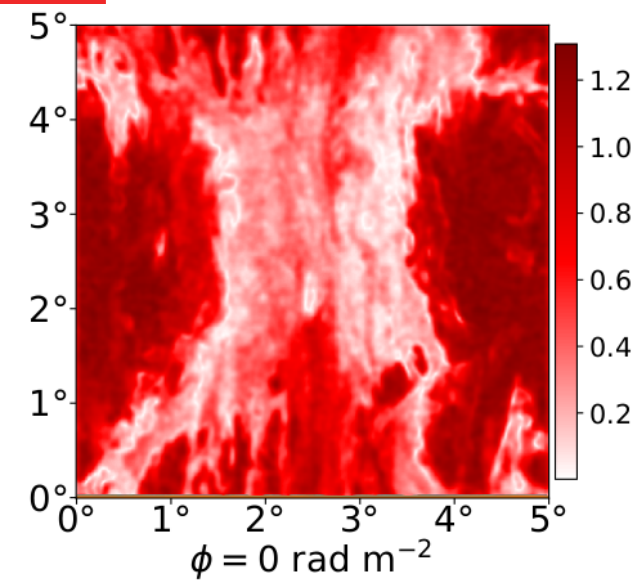


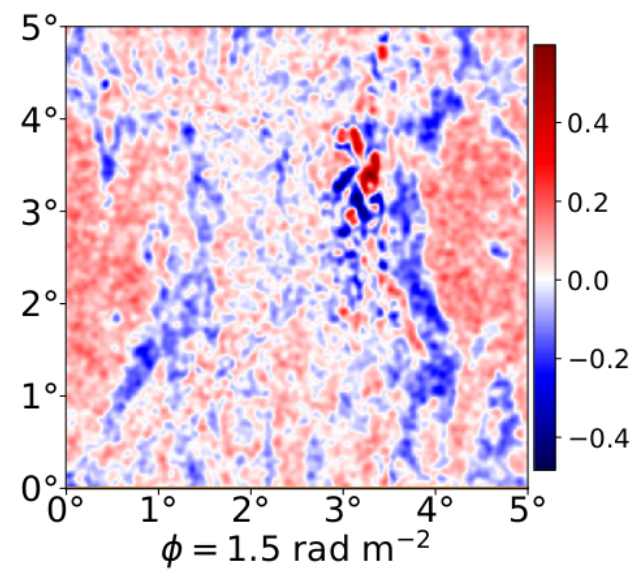
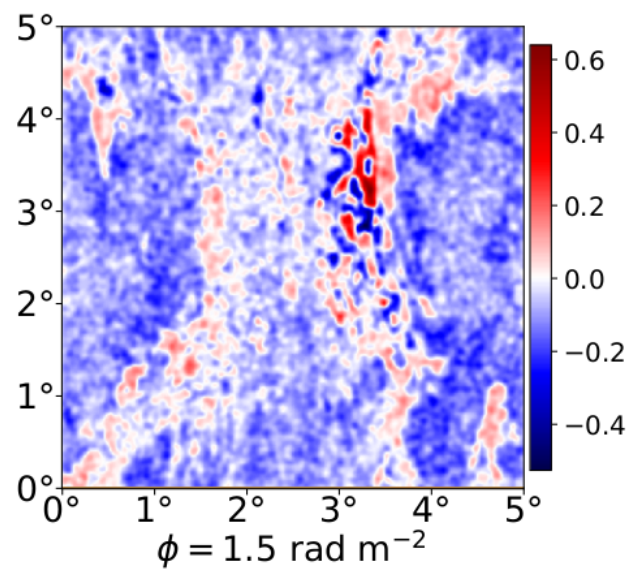
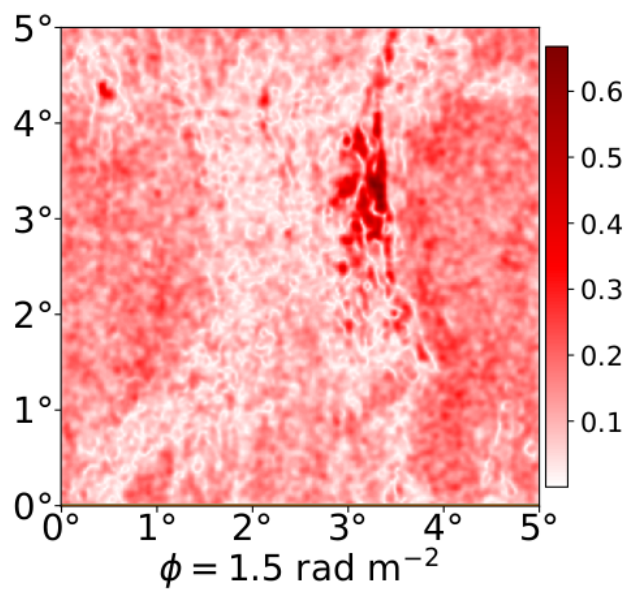




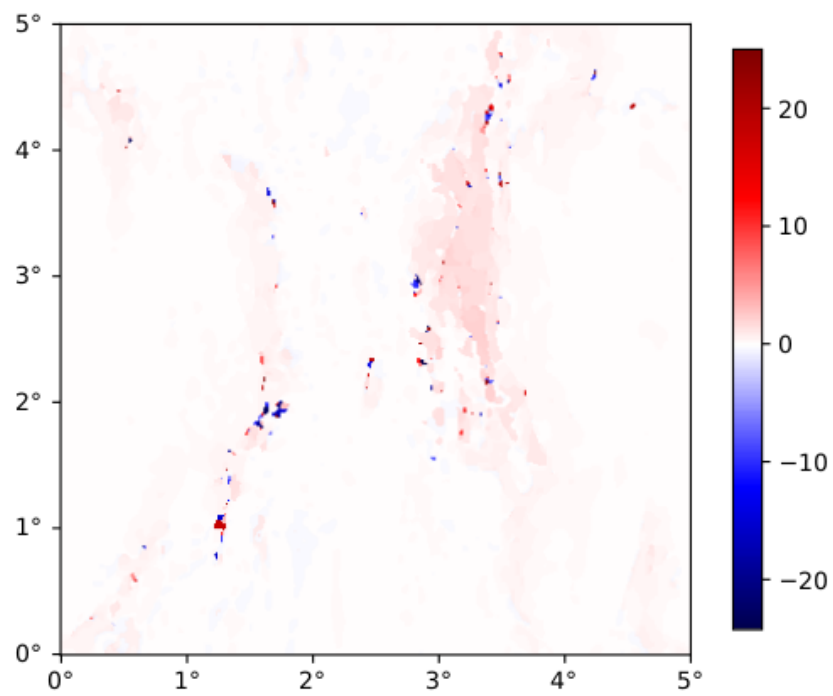
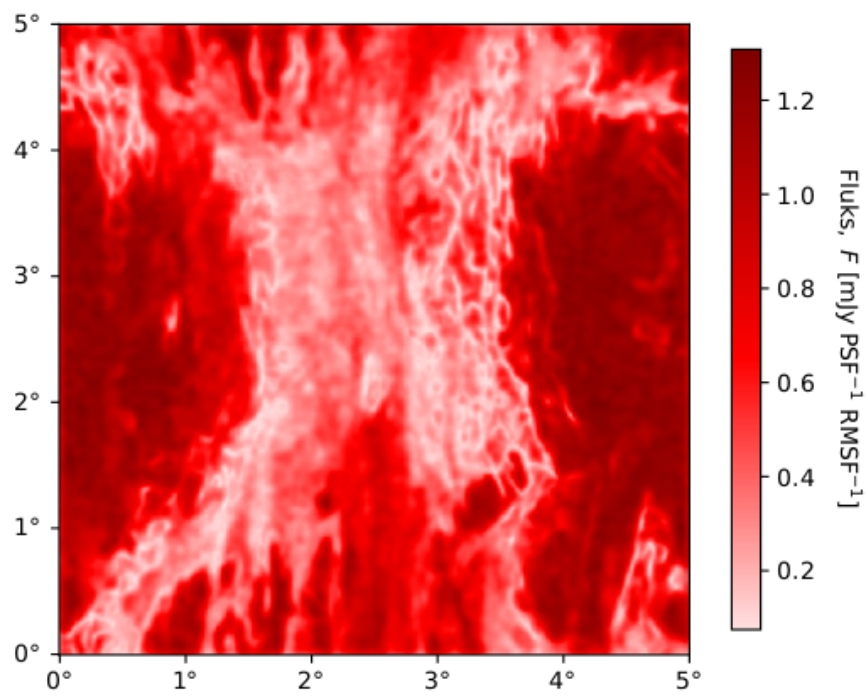
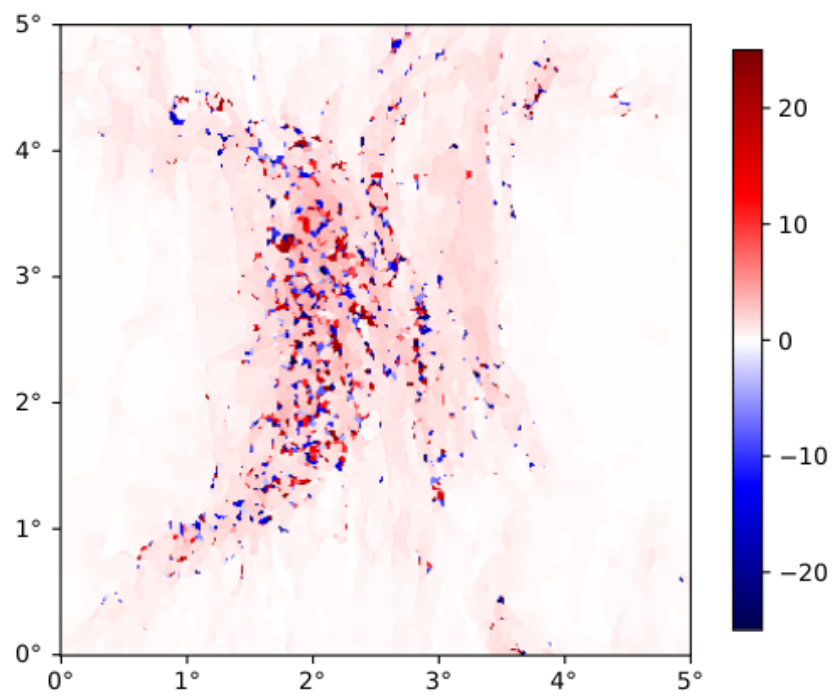
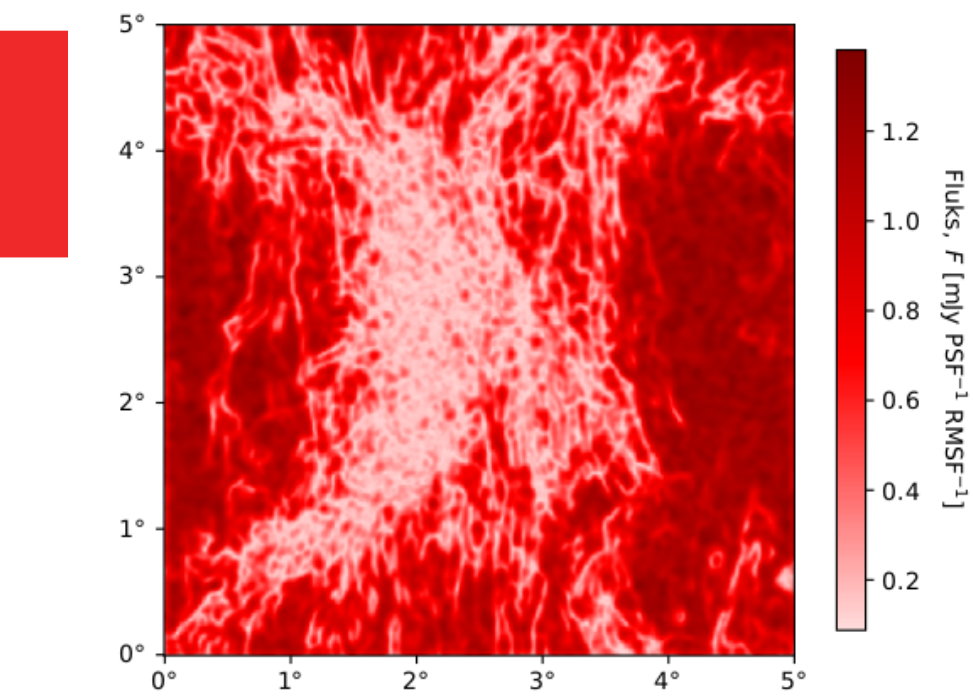








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- Maksimum i položaj maksimuma toka polariziranog intenziteta u Faradayevoj dubini





# Zaključak

- Super-ljuske su vidljive teleskopom s karakteristikama poput LOFAR-ovih.
- Potrebano je mjeriti na većem broju valnih duljina da bi se povećala moć razlučivanja metode.
- Ovom metodom (ukoliko nema više struktura duž doglednice) moguće je odrediti umnožak gustoće elektrona i jakosti paralelne komponente magnetskog polja. Druge metode su potrebne da bi se razvezale te dvije veličine.



Hvala na pažnji!