



Radio analiza sustava galaksija (koji uključuje galaksije sa savijenim mlaznicama) u polju Cosmos na crvenom pomaku $z=0.35$

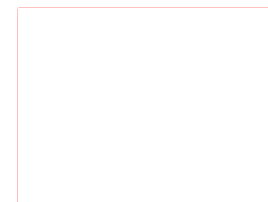
Paula Vulić
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Kozmološki crveni pomak

- Ubrzano širenje svemira
- Zračenje galaksija opažamo pomaknuto prema crvenom dijelu spektra

$$z = (\lambda_{\text{obs}} - \lambda_{\text{em}}) / \lambda_{\text{em}}$$

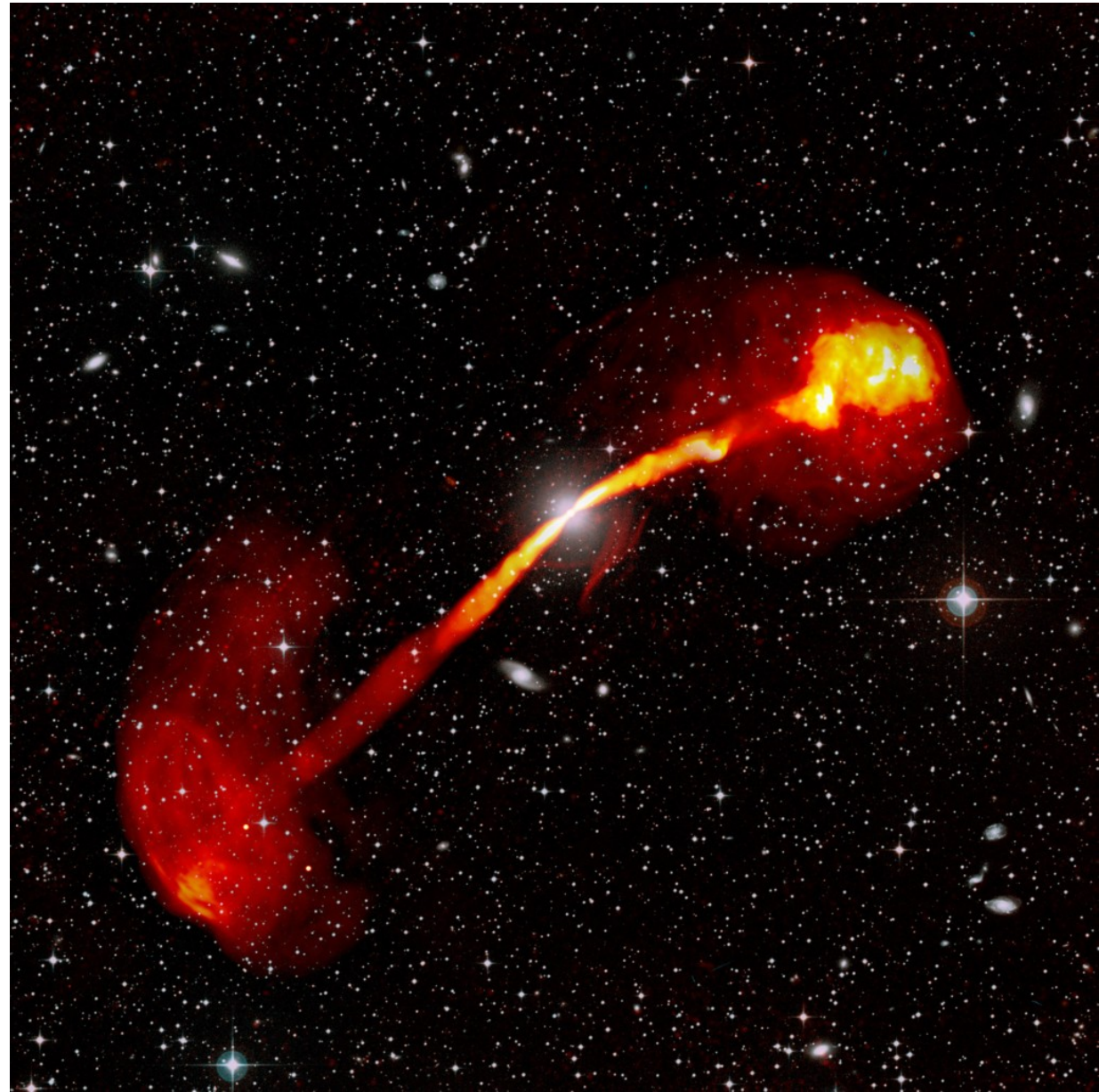
- Nije Dopplerov pomak!
- Mjera udaljenosti
- Sustav na $z = 0.35$



Aktivne galaktičke jezgre

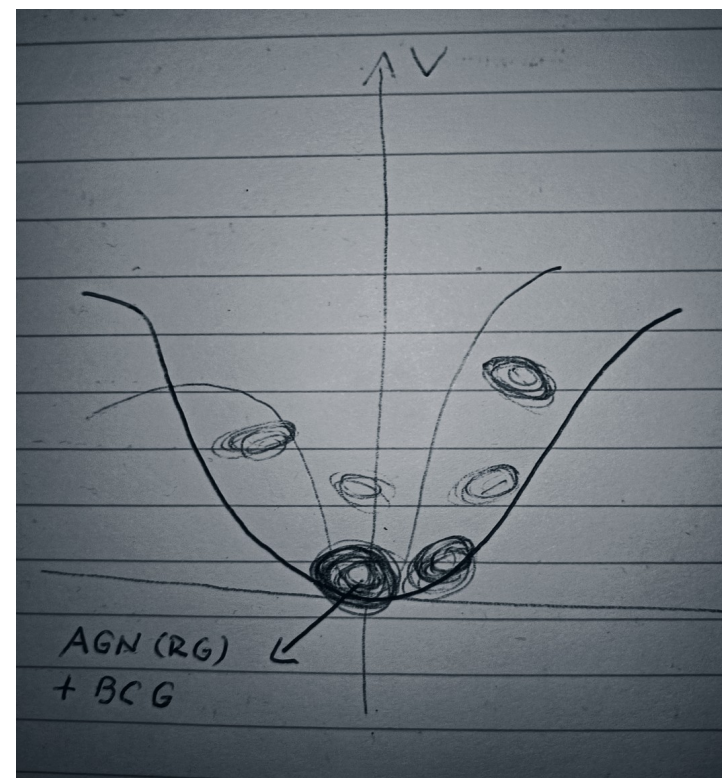
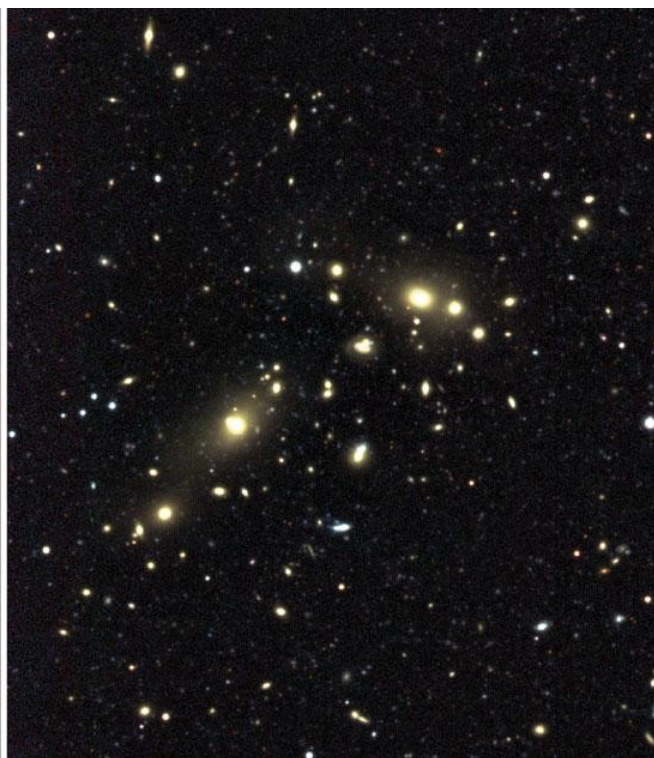
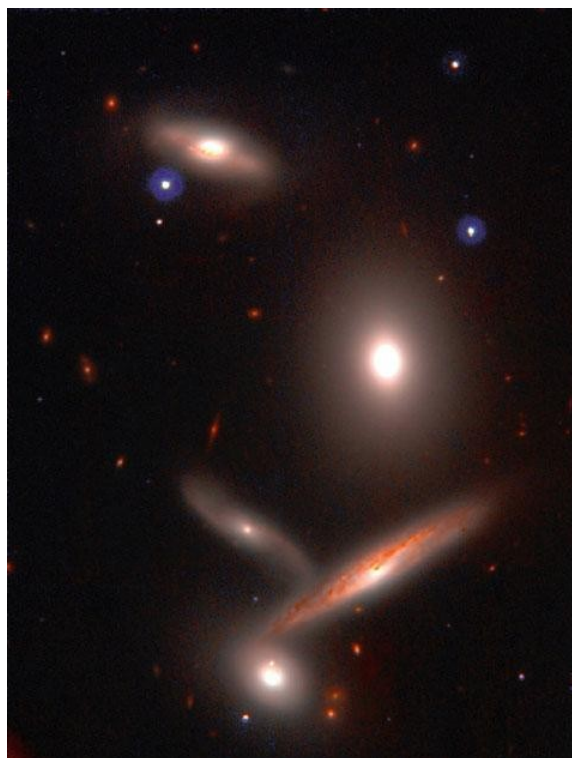
Preuzeto iz: J. J. Condon et al. Threads, Ribbons, and Rings in the Radio Galaxy IC 4296., 2021.

- Izvori iznimno velikog luminozитета
- Emisija kroz cijeli spektar
- Akrecija materijala na središnju supermasivnu crnu rupu
- Radio galaksije
- FRI i FRII galaksije



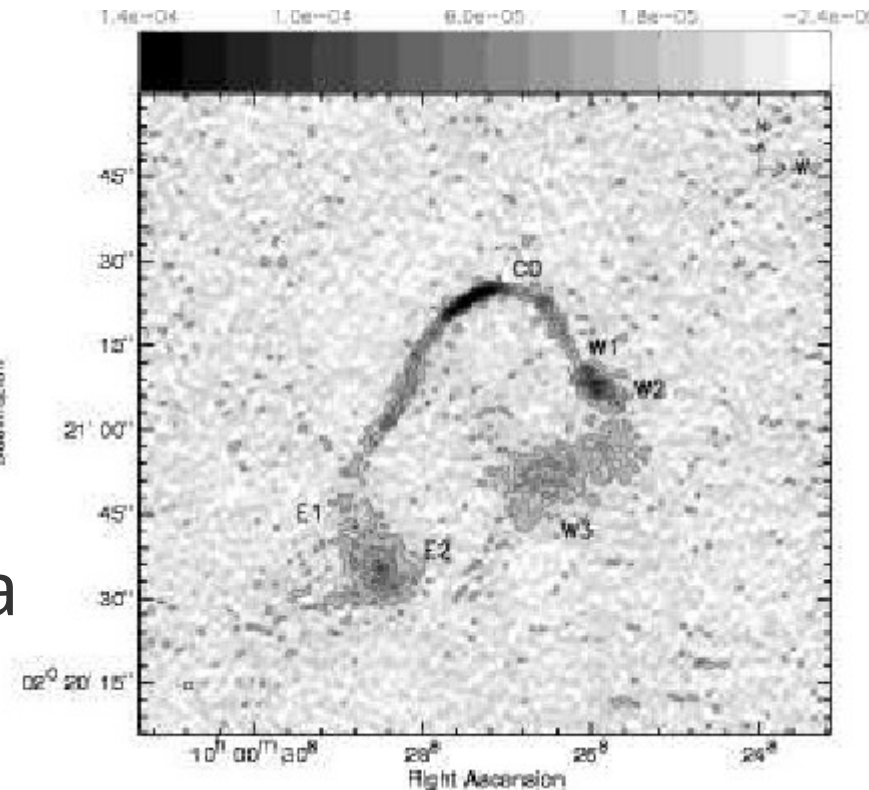
Skupovi i grupe galaksija

- gravitacijski vezane nakupine galaksija
- najsvjetlija galaksija skupa/grupe (BCG) - AGN
- pravilni/neppravilni → dinamički stari/mladi



Galaksije sa savijenim mlaznicama

- Wide angle tail galaksije
- Mlazovi savijeni u C oblik
- Interakcija s okolnim medijem (unutar-skupni medij ili ICM) tijekom relativnog gibanja
- Velike brzine → aktivna okolina
- Indikatori skupova, indikatori dinamički-mladih skupova galaksija

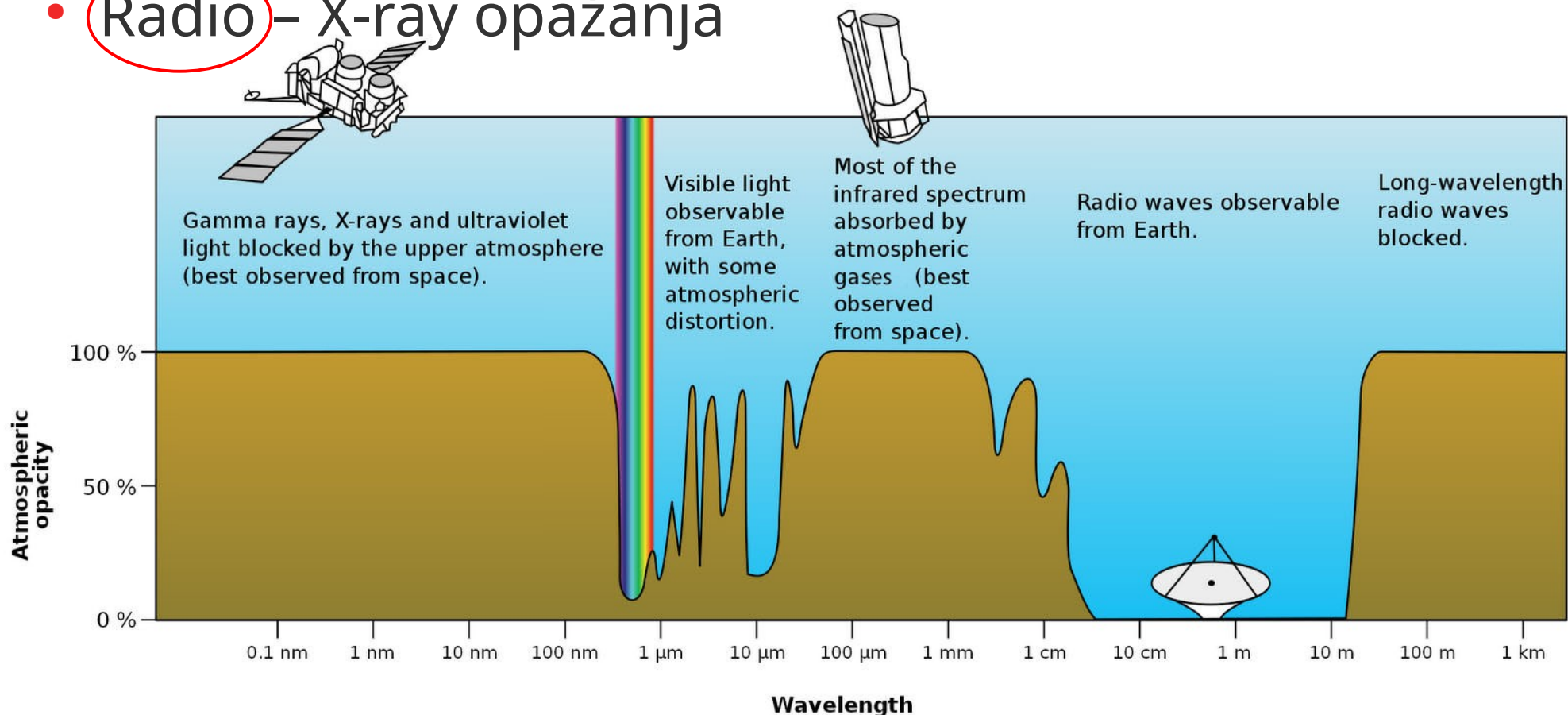


Preuzeto iz:

V. Smolčić et al. A Wide-Angle Tail Radio Galaxy in the COSMOS Field: Evidence for Cluster Formation, 2007.

Polje COSMOS

- 2 kvadratna stupnja
- Centar na RA = 10 h 00 m 28.6 s DEC = +02 °12 ' 21.0 "
- **Radio** – X-ray opažanja



Radio podatci

Slike preuzete s:

<https://www.vla.nrao.edu/>,

<https://3.imimg.com/data3/KU/YA/MY-1829035/giant-metrewave-radio-telescope-alias-gmrt-study-tour-500x500.jpg>

- Radio mape, mape šuma i katalogi na 4 radio frekvencije:

VLA-COSMOS 3 GHz kontinuirani mozaik (mapa)

- VLA-COSMOS 3GHz Large Project, 2017.
- Cirkularna zraka 0.75" rezolucija, 2.3 μ Jy/beam prosječni šum u mapi
- Mapa šuma i katalog objedinjenih podataka (3 GHz MW counterparts catalog)

VLA-COSMOS Deep 1.4 GHz mozaik (mapa)

- VLA-COSMOS Deep Project, 2010.
- Cirkularna zraka 2.5", 12 μ Jy/beam prosječni šum u mapi
- Mapa šuma i katalog

Giant Meter Radio Telescope (GMRT) radio mozaici (mape)

325 MHz

- Eliptična zraka 10.8" x 9.5" rezolucija
- 97 μ Jy/beam prosječni šum u mapi
- Mapa šuma i katalog

610 MHz

- Eliptična zraka 5.6" x 3.9" rezolucija
- 39 μ Jy/beam prosječni šum u mapi
- Mapa šuma i katalog



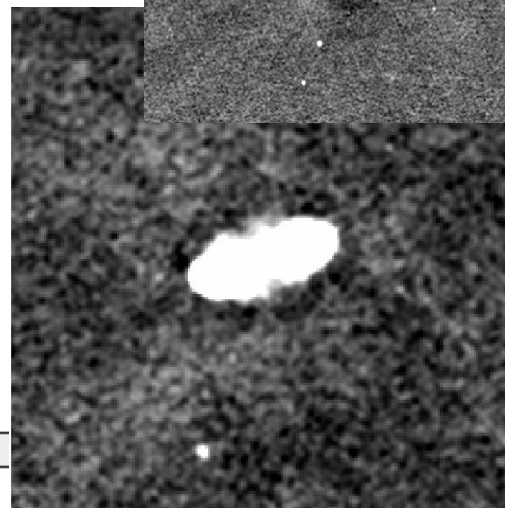
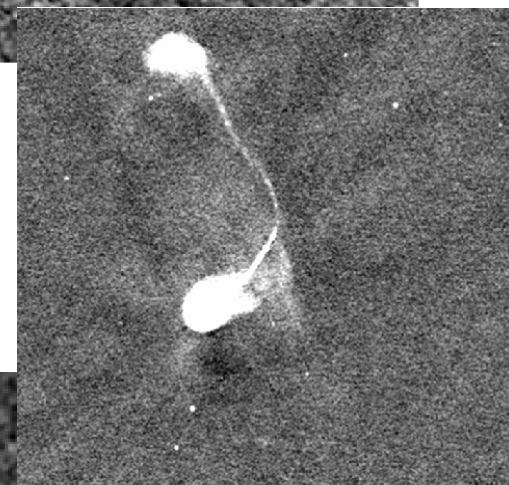
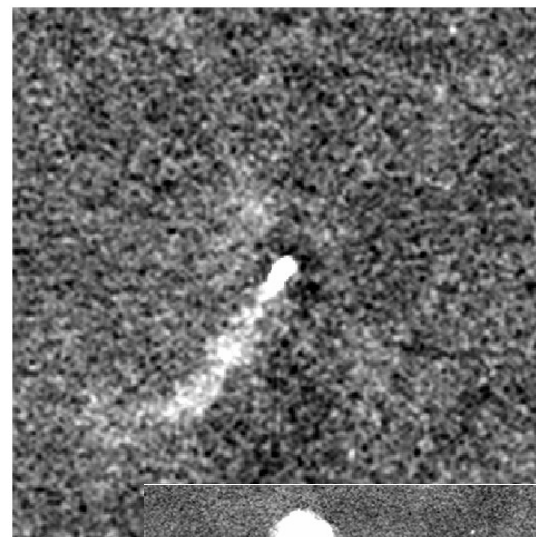
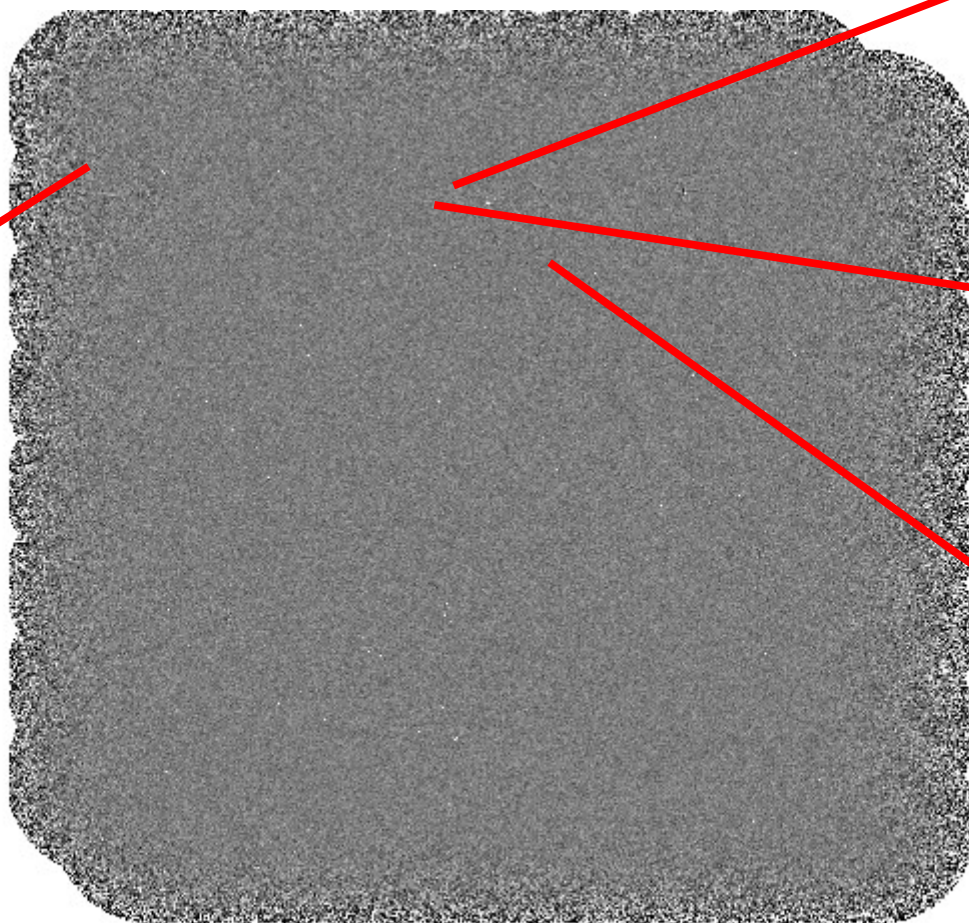
Radio mape (4 frekvencije)

3 GHz radio mapa

pixel



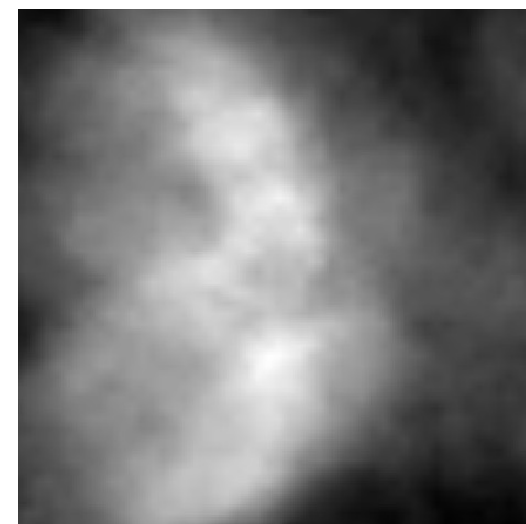
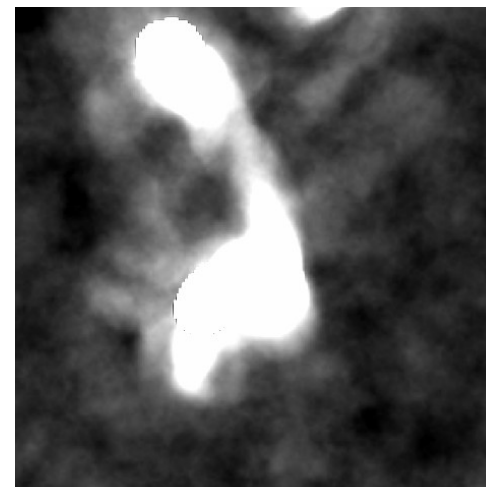
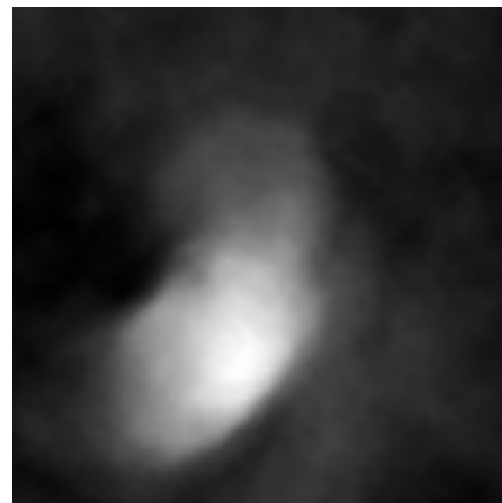
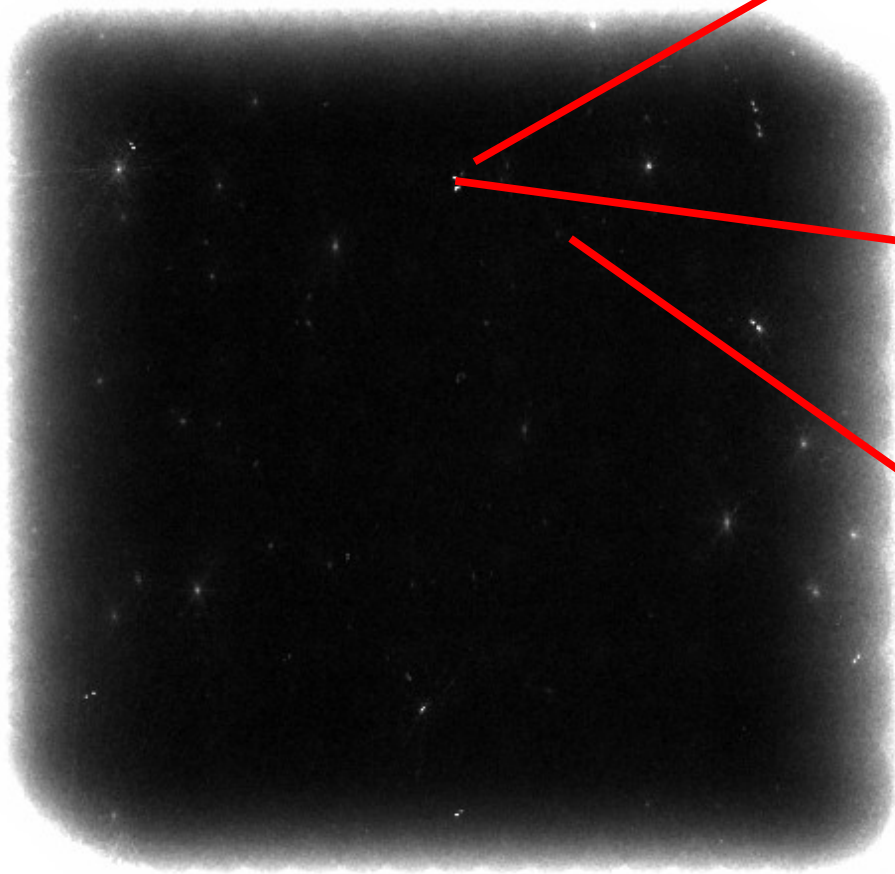
Gustoća
toka
zračenja
($\mu\text{Jy}/\text{beam}$)



-1.4e-05 -1e-05 -5.9e-06 -1.8e-06 2.2e-06 6.3e-06 1e-05 1.5e-05

Mape šuma

3 GHz mapa šuma



2.7e-06 3.4e-06 4.1e-06 4.8e-06 5.4e-06 6.1e-06 6.8e-06 7.5e-06

Ostali podatci

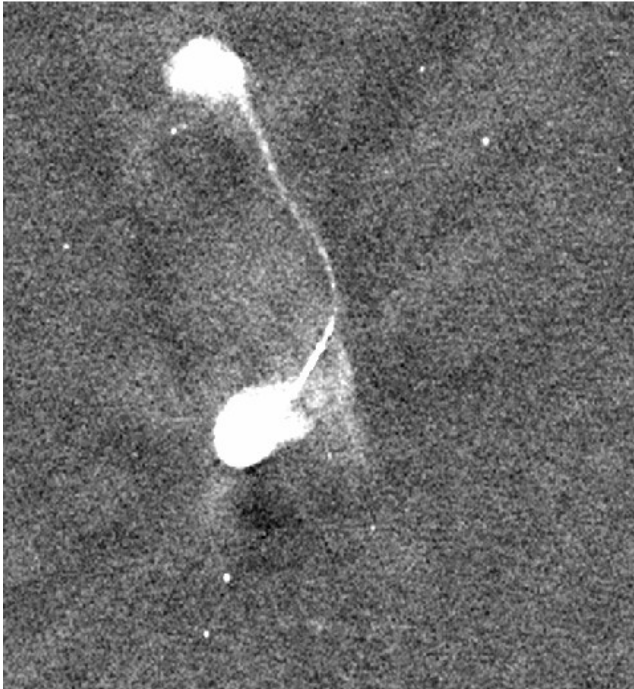
- Optički katalogi:
 - COSMOS CLASSIC 2020
 - COSMOS FARMER 2020
- Fotometrijski crveni pomaci iz 3 GHz
Multiwavelength counterpart kataloga
- UltraVISTA optičke mape (VISTA teleskop) – Ks
pojas (2.15 μm)

Izvori od interesa

- 3 radio galaksije:

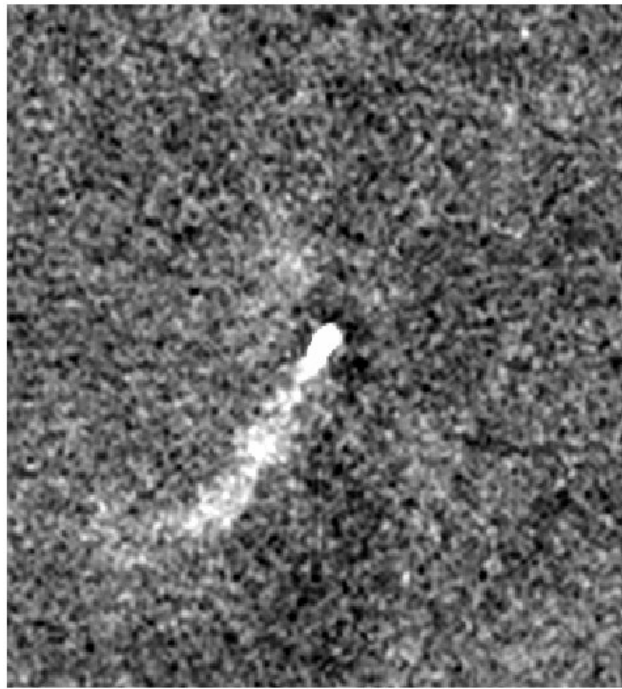
COSMOSVLA3 J100028.28+024103.3

10913



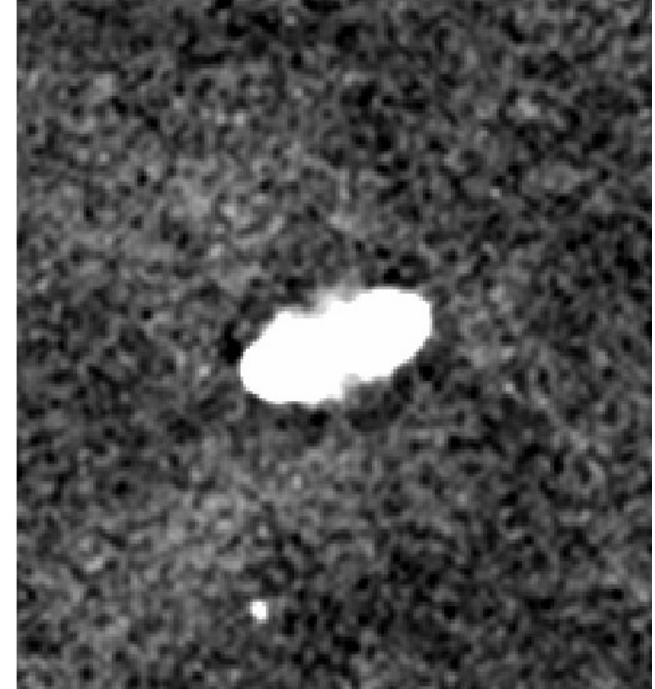
COSMOSVLA3 J100026.49+024229.7

44

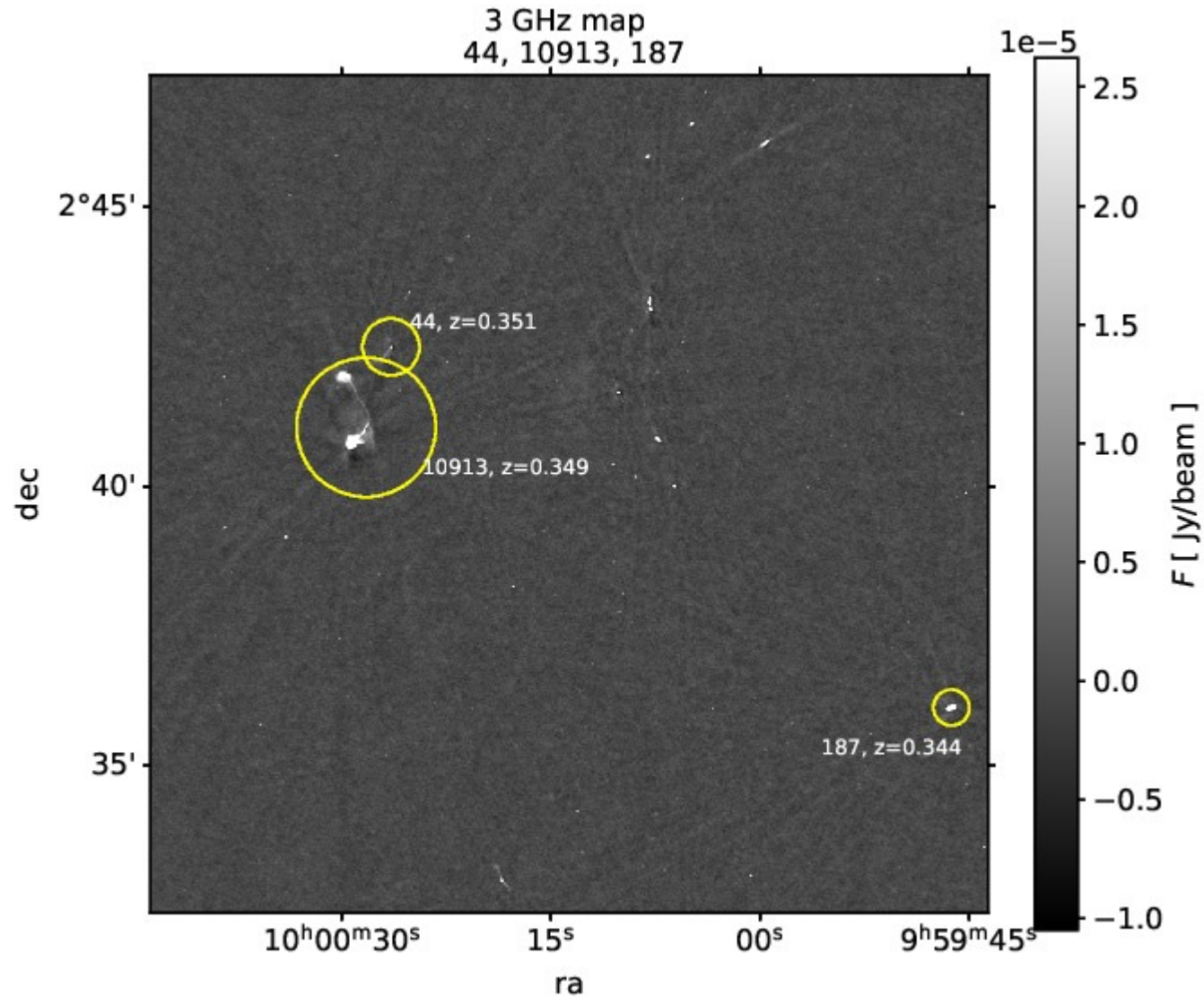


COSMOSVLA3 J095946.30+023602.1

187



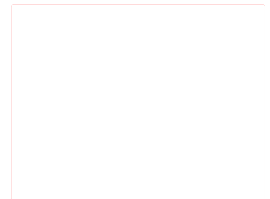
Izvori od interesa



3 GHz ID	name	RA	DEC	zbest 3GHz	3 GHz multi	1.4 GHz multi
10913	COSMOSVLA3 J100028.28+024103.3	150.117854	2.684271	0.349	yes	yes
44	COSMOSVLA3 J100026.49+024229.7	150.110399	2.708261	0.344	no	yes
187	COSMOSVLA3 J095946.30+023602.1	149.942948	2.600608	0.351	no	yes

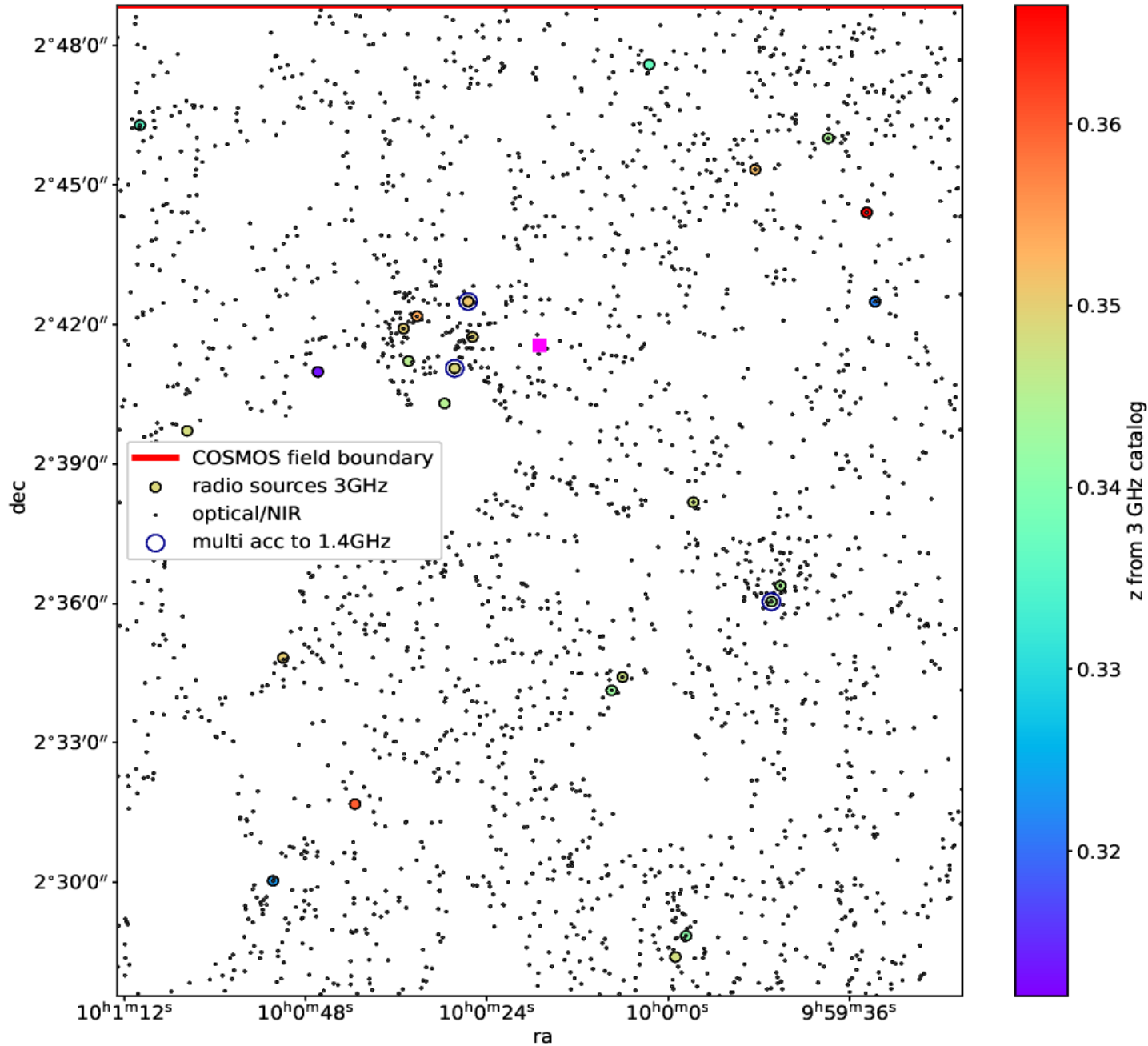
Identificiranje izvora od interesa

- Međusobna blizina
- Morfologija radio emisije:
 - Izdužena emisija
 - Više komponenti
 - WAT
- Znakovi potencijalno povećane lokalne gustoće galaksija u optičkom → grupe galaksija?



Identificiranje izvora od interesa

CLASSIC optical/NIR sources around 3 GHz RS $0.31 < z < 0.37$



$$0.31 < z < 0.37$$

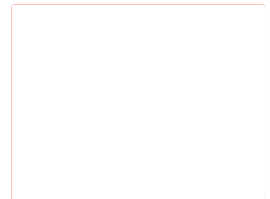
$$z = z_{mean} \pm \Delta z$$

$$\Delta z = 3 \sigma_{\delta z / (1+z)} \cdot (1 + z_{mean})$$

$$\sigma = 0.7 \%$$

Radio analiza

- Radio konture (3 GHz, 1.4 GHz, 610 MHz, 325 MHz)
- Mape spektralnog indeksa (3 GHz – 1.4 GHz)
- Ukupni radio luminozitet na 3 GHz
- Procijena efekta relativističkog usnopljavanja za radio galaksiju 44



Radio konture - metoda

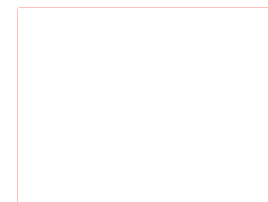
- Pretpostavka modela kontura

– $X\sigma \log 2$ ili $X\sigma \ln N$

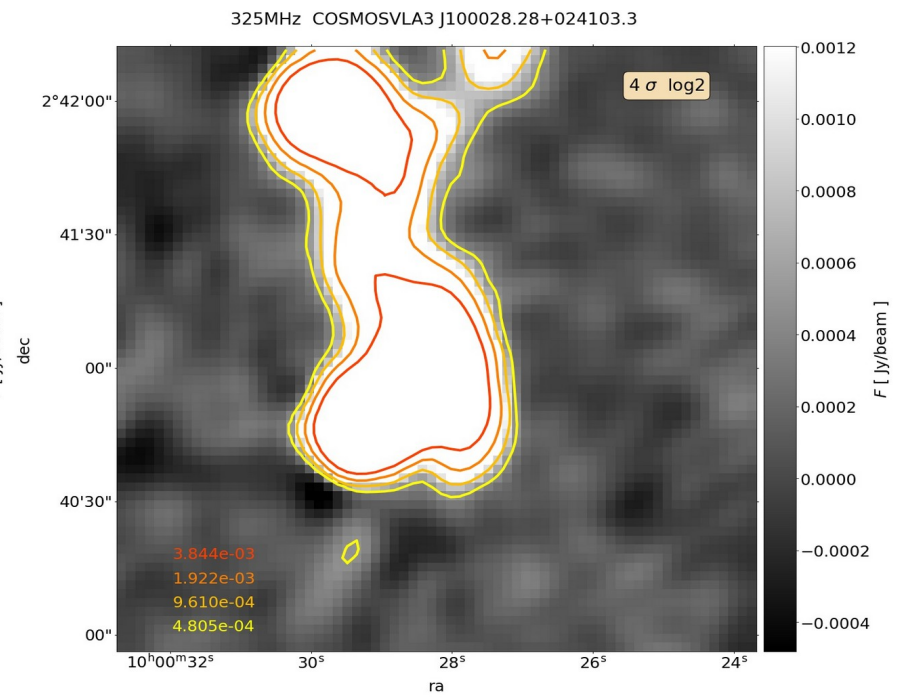
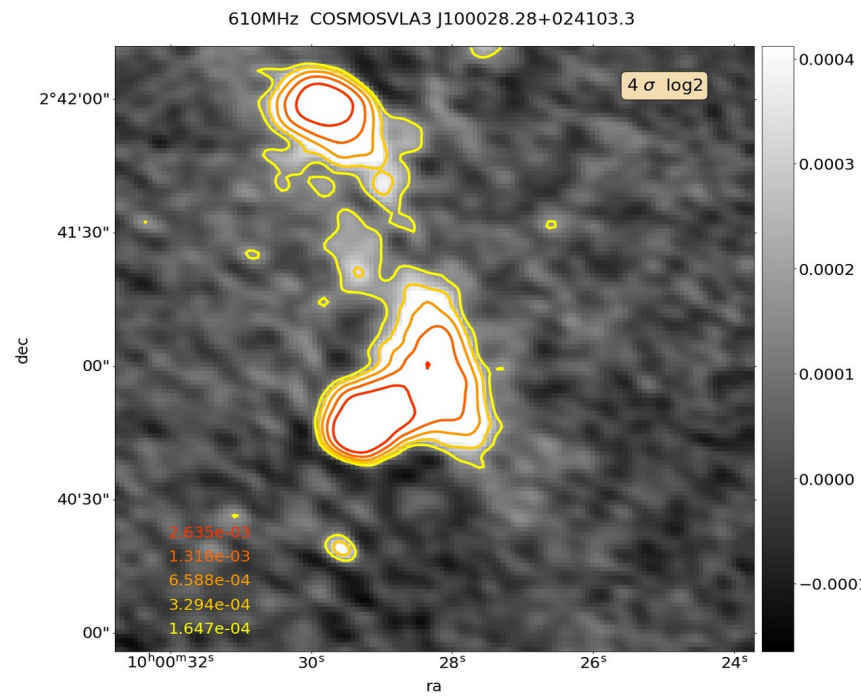
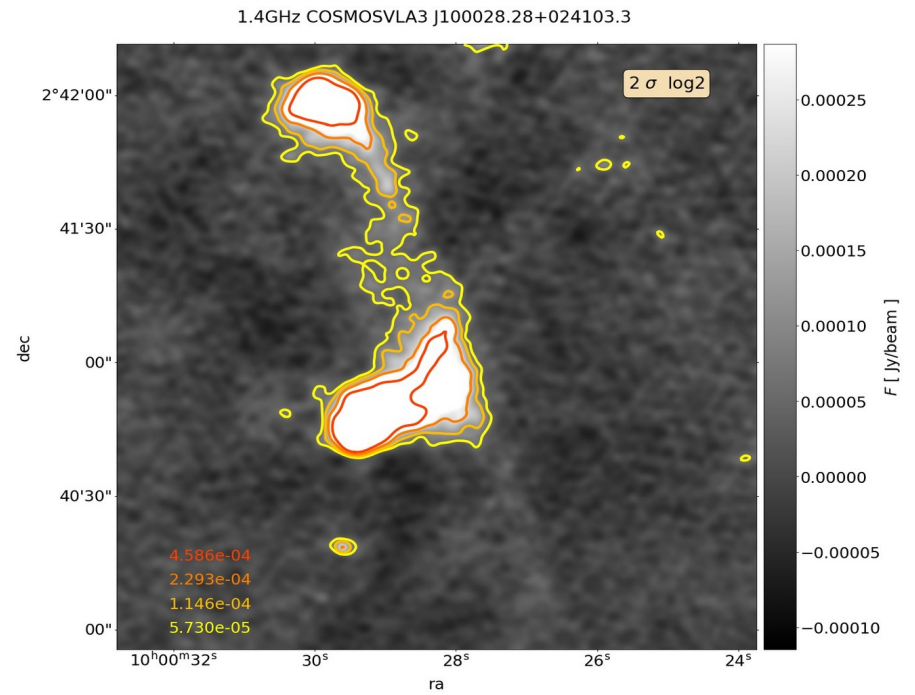
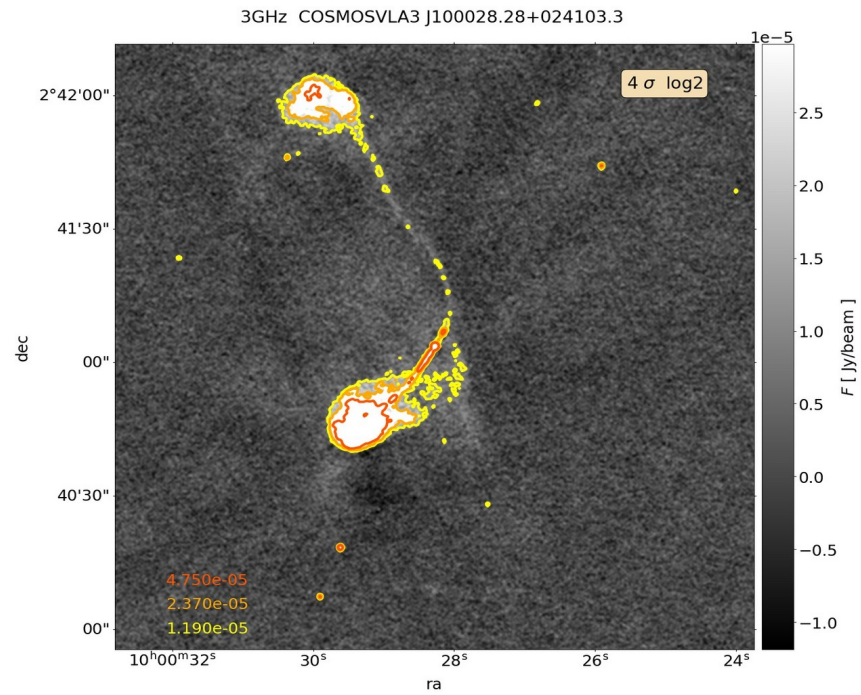
X početak
kontura (u σ)

N korak
između
kontura (u σ)

- σ iz pripadne mape šuma
- Iterativno dolazimo do modela kontura koji daje najjasnije konture (međusobno razlučive)

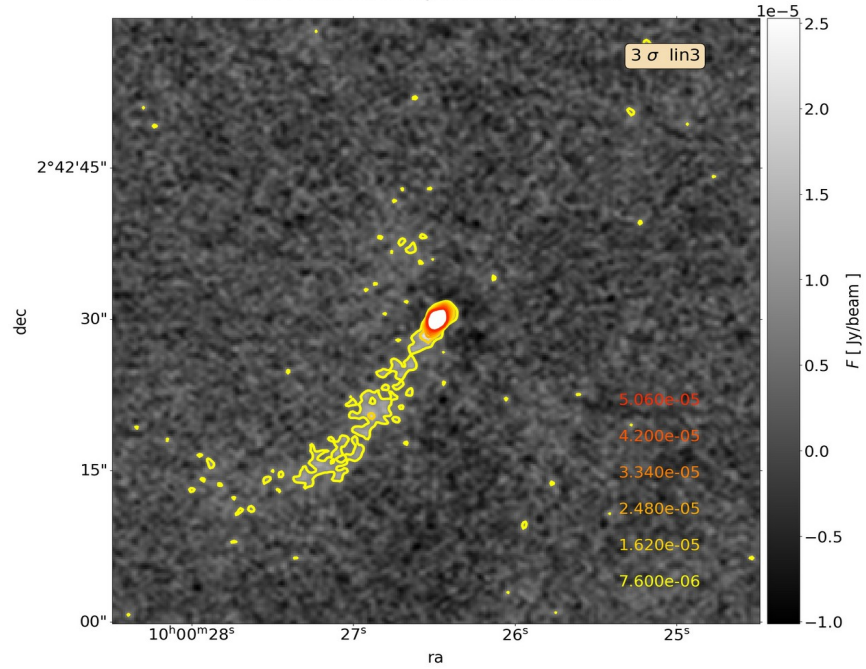


Radio konture (10913)

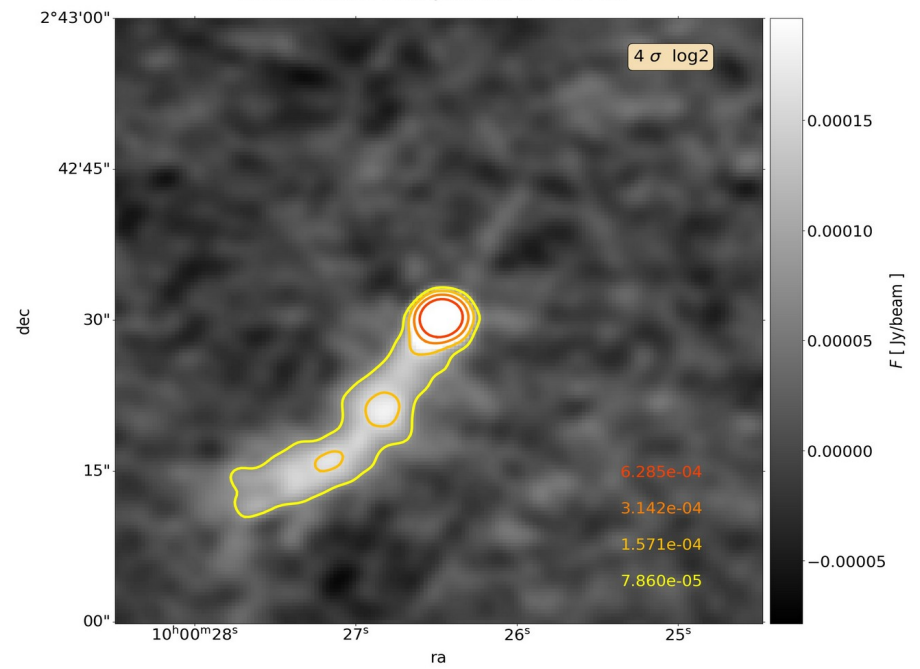


Radio konture (44)

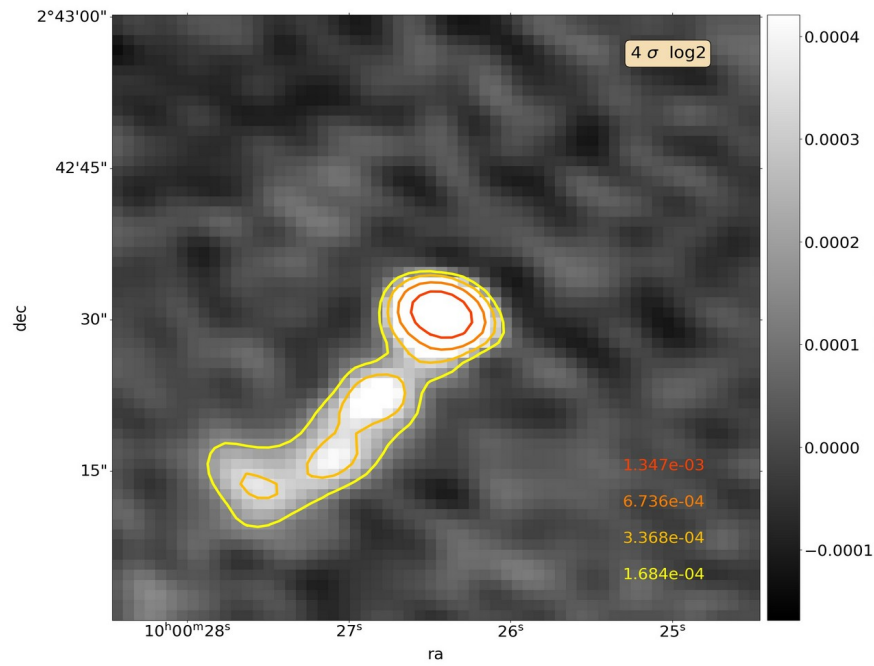
3GHz COSMOSVLA3 J100026.49+024229.7



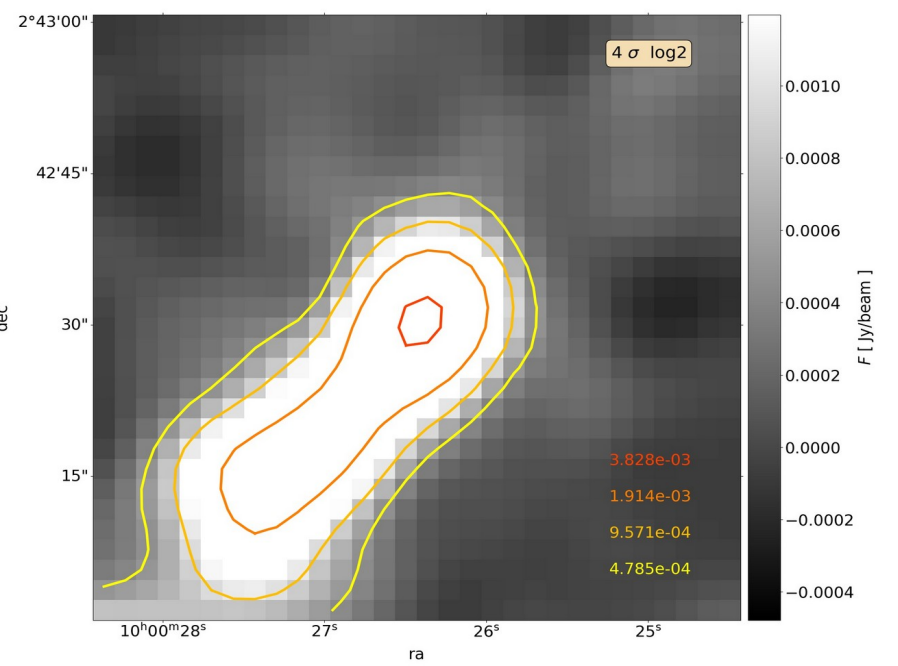
1.4GHz COSMOSVLA3 J100026.49+024229.7



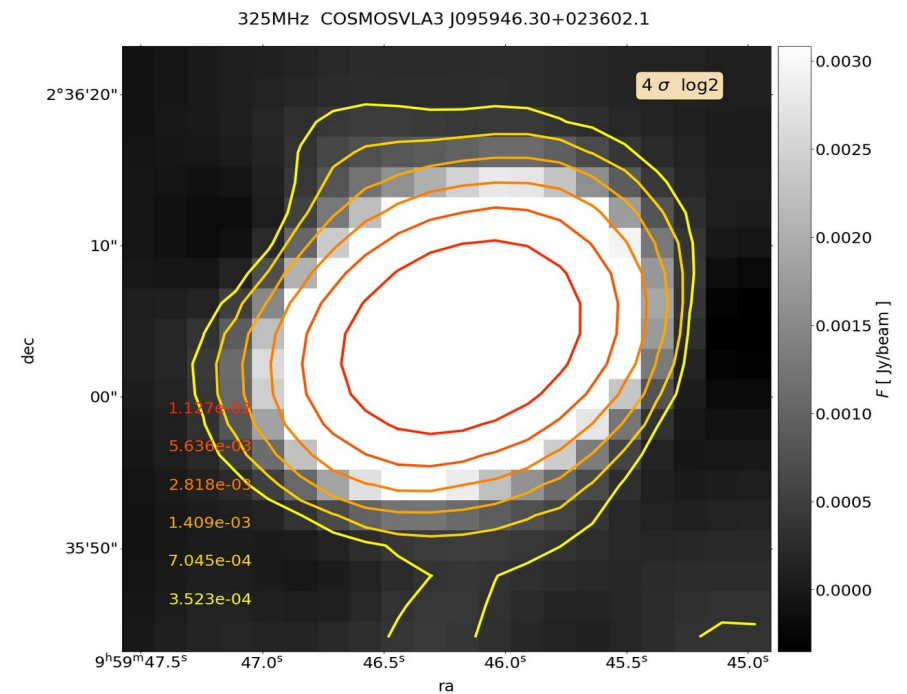
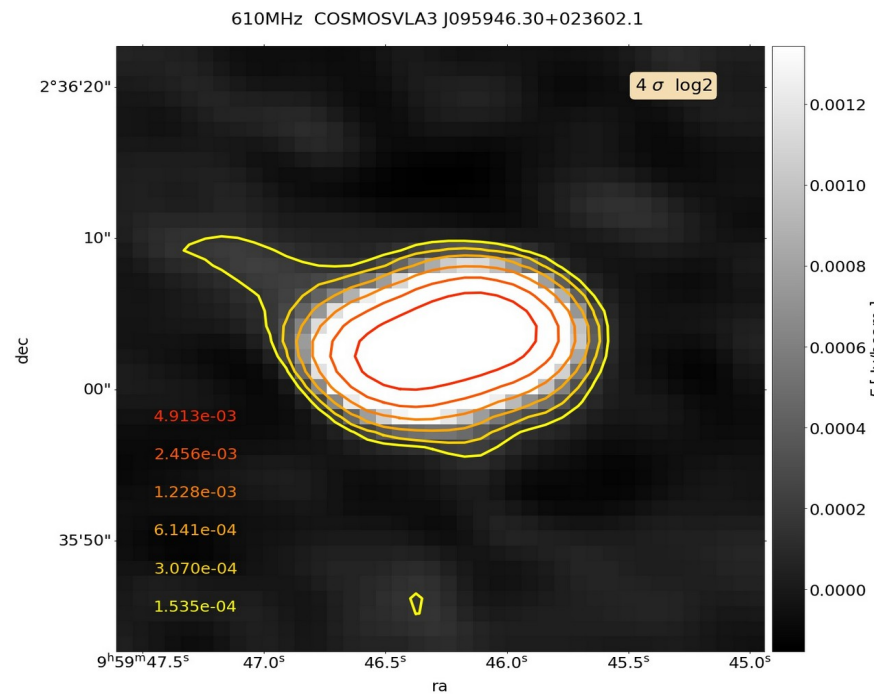
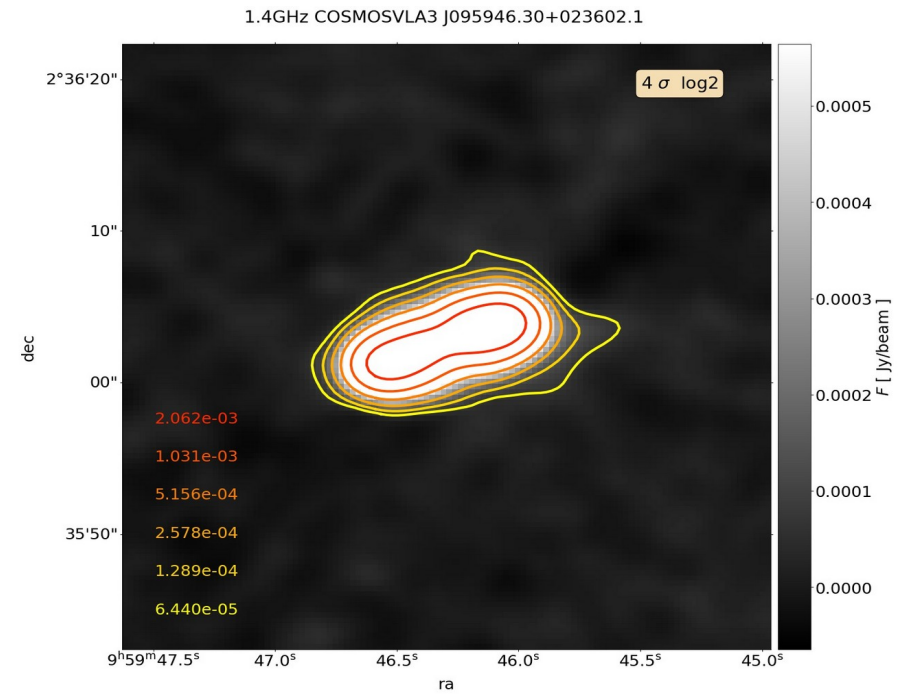
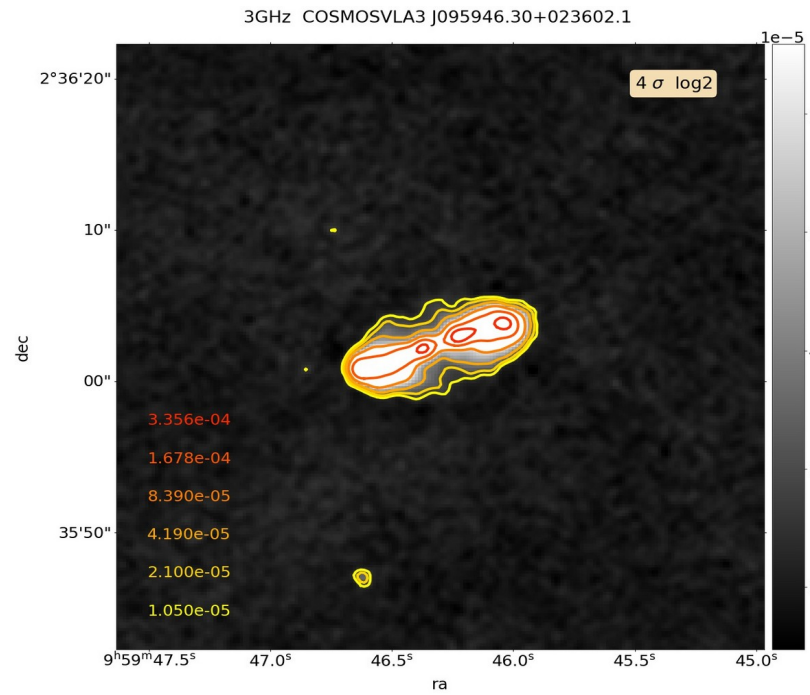
610MHz COSMOSVLA3 J100026.49+024229.7



325MHz COSMOSVLA3 J100026.49+024229.7

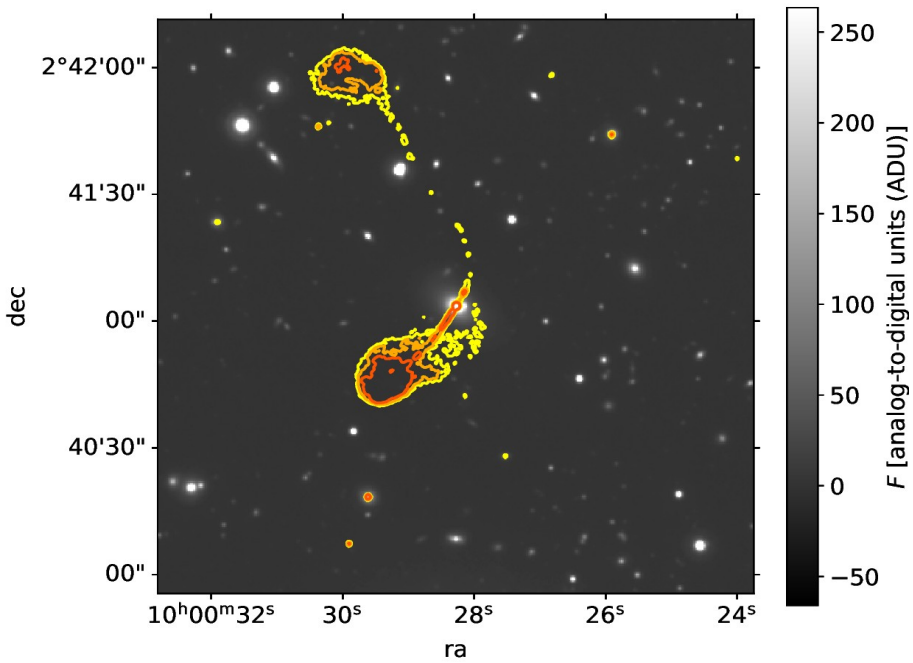


Radio konture (187)

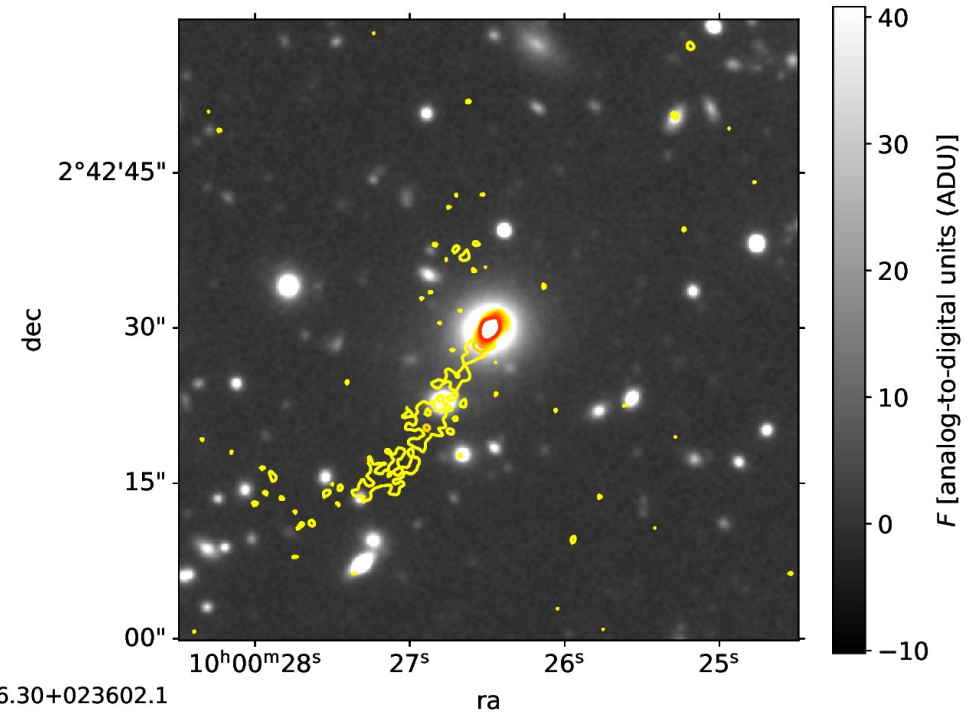


Radio konture u optičkom

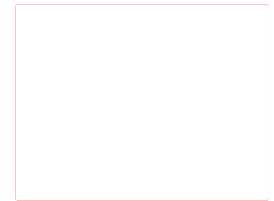
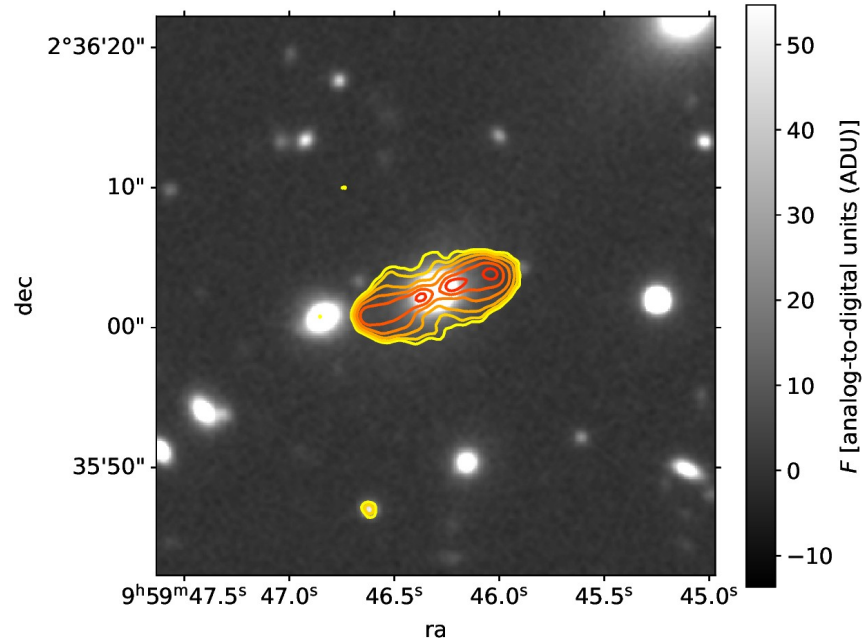
3GHz contours + NIR COSMOSVLA3 100028.28+024103.3



3GHz contours + NIR COSMOSVLA3 100026.49+024229.7



3GHz contours + NIR COSMOSVLA3 095946.30+023602.1

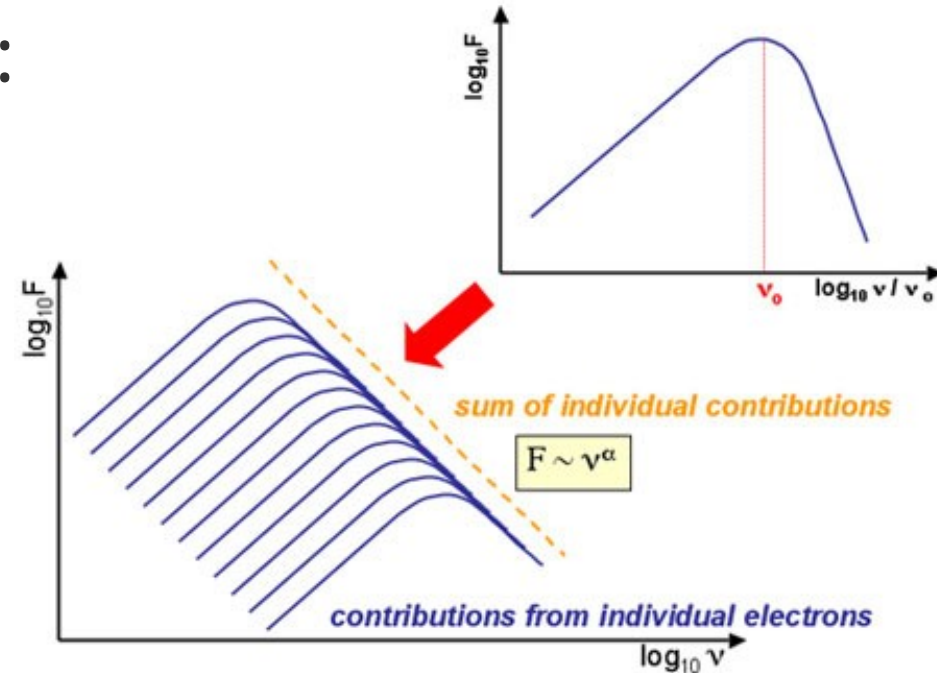


Mape spektralnog indeksa

- Spektralni index α – nagib spektralne energetske distribucije u log-log ravnini:

$$F_\nu \propto \nu^{-\alpha}$$

$$\alpha = - \frac{\partial \log F_\nu}{\partial \log \nu}$$



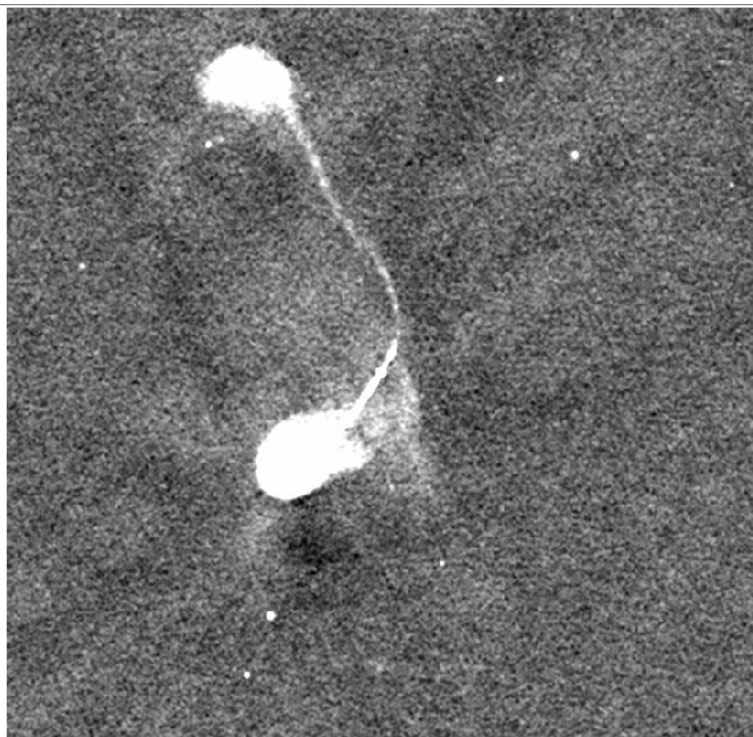
- Račun spektralnog indeksa (piksel po piksel)

$$\alpha_{\nu_1 \nu_2} = - \frac{\log F_1 - \log F_2}{\log \nu_1 - \log \nu_2}$$

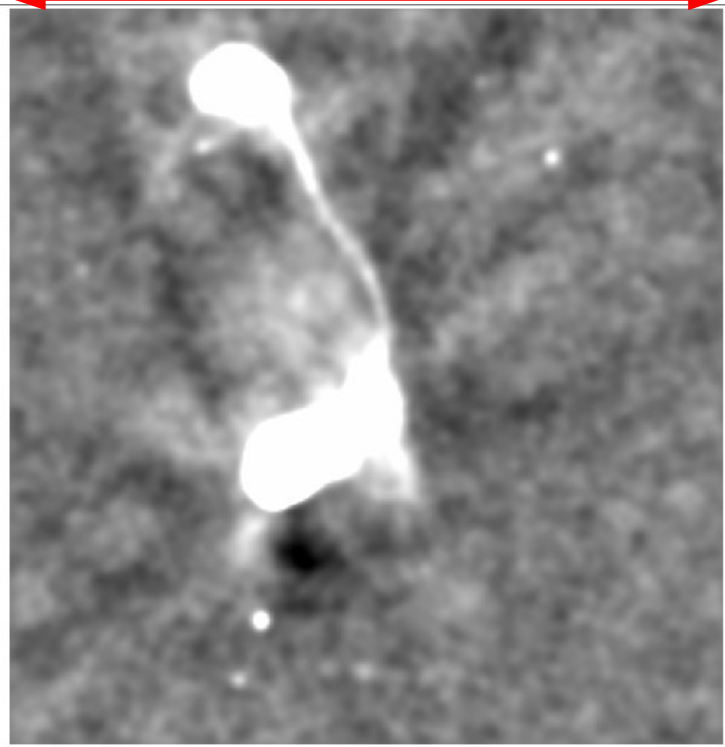
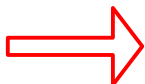
Spektralni indeks računat iz podataka na 3 GHz i 1.4 GHz

Mape spektralnog indeksa - metoda

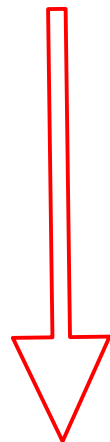
- Priprema mapa za račun:
 - 1) Maskiranje pixela ispod 3σ u obje mape
 - 2) Prilagodba 3 GHz mape na rezoluciju 1.4 GHz mape → zamućivanje (SMOOTH CASA)
 - 3) Prilagodba 3 GHz mape na mrežu mape 1.4 GHz → isti broj pixela (REGRID CASA)
- Pixel po pixel račun spektralnog indeksa
- Dodatno maskiranje rubnih pixela koji daju negativne vrijednosti



680



680



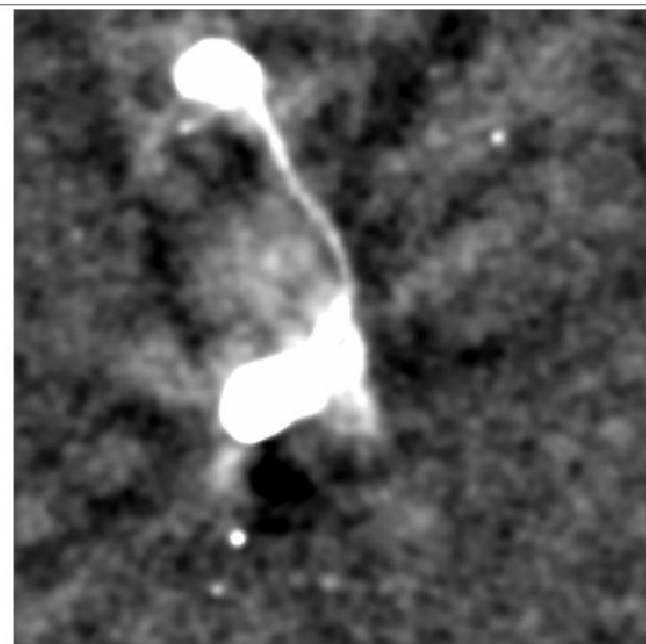
-7.6e-06 -4.7e-06 -1.8e-06 1.1e-06 4e-06 6.9e-06 9.8e-06 1.3e-05

-5.1e-05 -3.6e-05 -2.1e-05 -6e-06 9.1e-06 2.4e-05 3.9e-05 5.5e-05



390

α

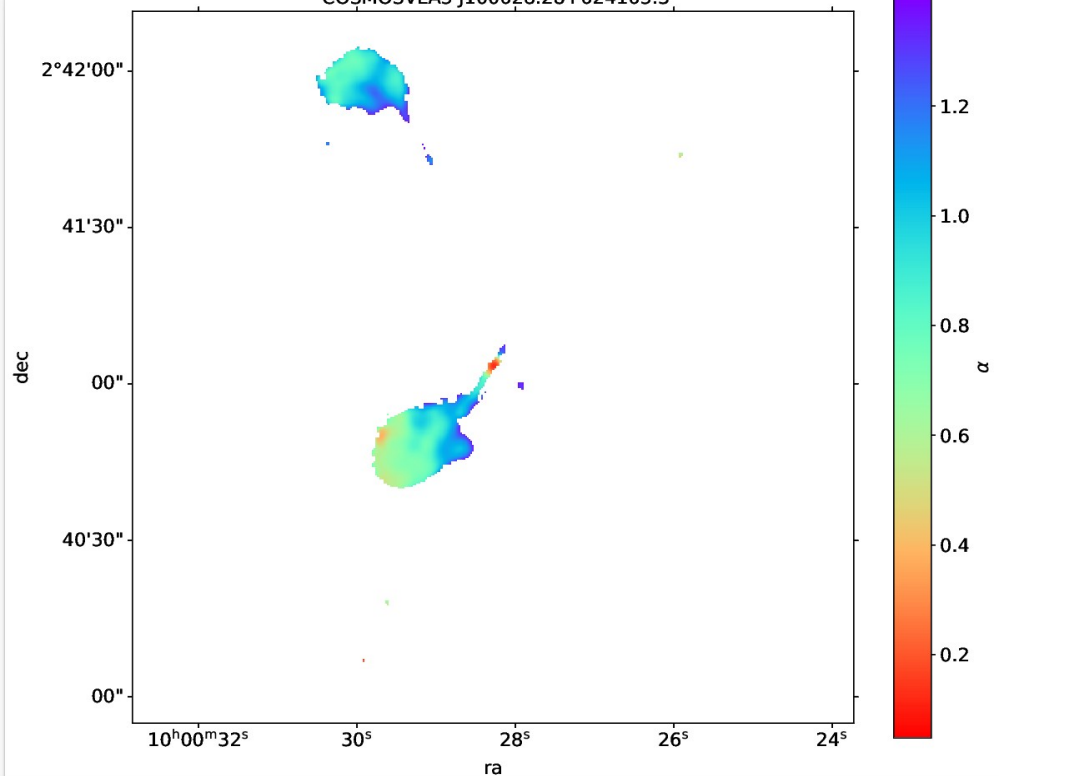


390

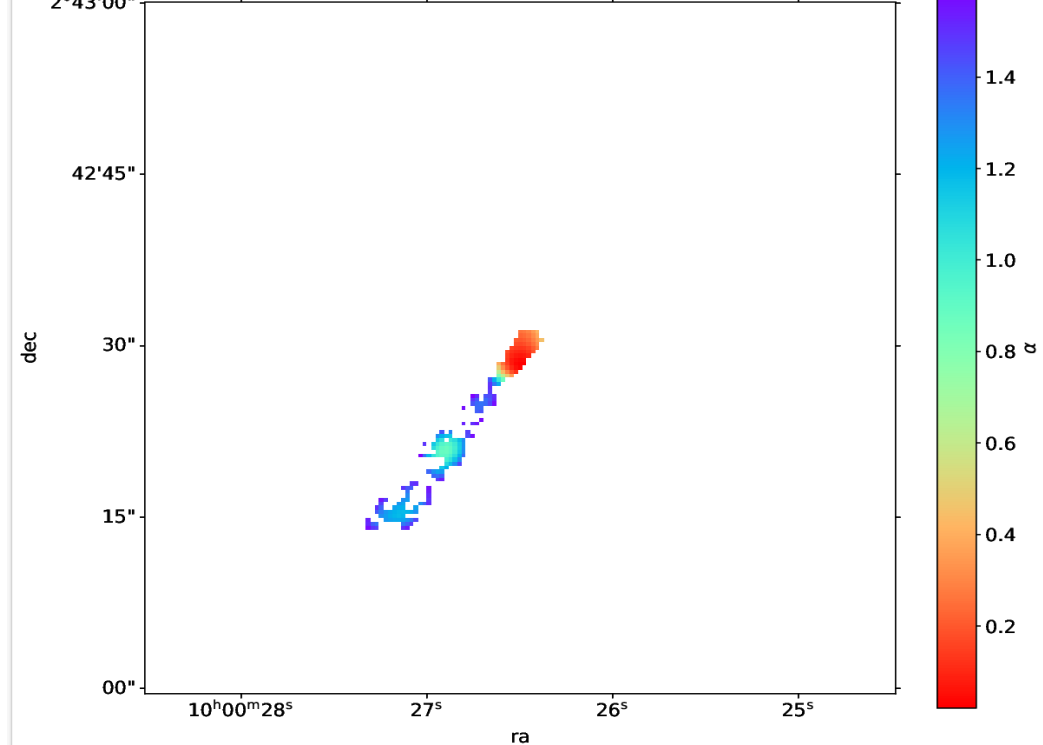
0.00024 0.00056 0.00088 0.00120 0.00152 0.00184 0.00216 0.00248

-6.9e-06 5.1e-06 1.7e-05 2.9e-05 4.1e-05 5.3e-05

COSMOSVLA3 J100028.28+024103.3



COSMOSVLA3 J100026.49+024229.7



- Ravan spektar

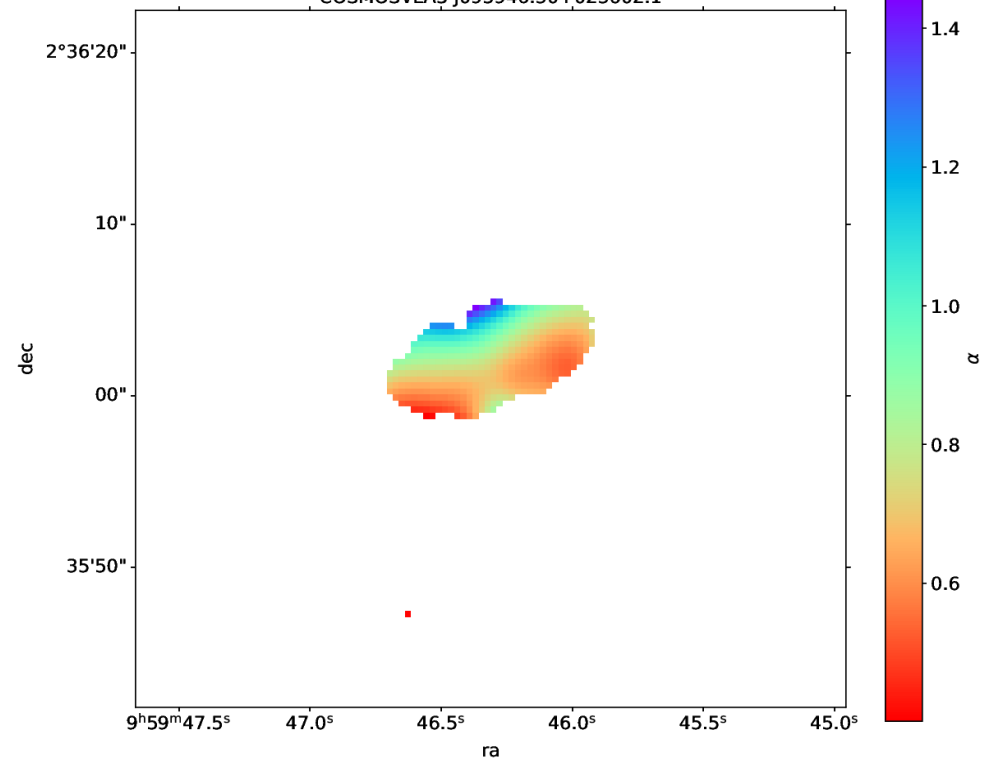
termalno zakočno zračenje
(dolazi od slobodnih elektrona u LTR dok ubrzavaju prolazeći kraj iona u ioniziranom plinu/mediju)

Sinkrotronska emisija u AGN dijelu

- Strm spektar

Sinkrotronska emisija relativističkih elektrona

COSMOSVLA3 J095946.30+023602.1



Račun ukupnog luminoziteteta

- 3 GHz podatci, monokromatski luminozitet

- Prema izrazu: $L_{3 \text{ GHz}} = \frac{F_{3 \text{ GHz}} 4\pi D_L^2}{(1+z)^{1-\alpha}}$

$$F_{3\text{GHz}} = \frac{\sum_{i=1}^N F_i}{\text{velicina zrake u pikselima}} \quad [\mu\text{Jy}]$$

$$D_L(z, H_0, \Omega_M, \Omega_\lambda)$$

$$H_0 = 69.6 \text{ km s}^{-1} \text{ Mpc}^{-1}$$

$$\Omega_M = 0.286, \quad \Omega_\lambda = 0.714$$

4 σ

Račun ukupnog luminoziteta - rezultati

3 GHz ID	$F_{3 \text{ GHz}}^{>4\sigma}$ [μJy]	$F_{3 \text{ GHz}}^{\text{catalog}}$ [μJy]	R	$L_{3 \text{ GHz}}^{>4\sigma}$ [10^{50}W Hz^{-1}]
10913	29933	32090	6%	12.16
44	2489	2250	10%	1.15
187	9238	9294	0.6%	3.43

Razlike?

- Razlike u metodi u odnosu na metodu korištenu prilikom konstrukcije 3 GHz kataloga (BLOBCAT softver (multi), Smolčić et al. 2017.)
- na 3σ bolje poklapanje za 10913, lošije za 44 (30% greška!), 187 → problem u više-komponentnosti izvora

Relativističko usnopljavanje

- Asimetrija u opaženom luminozitetu mlazova (sinkrotronsko zračenje) zbog nagiba mlazova prema smjeru doglednice
- Fluks (luminozitet) približavajućeg mlaza raste
- Fluks (luminozitet) udaljavajućeg mlaza pada
- Relativistički efekt
- Pretpostavka simetrije mlazova (Laing et al., 1999. i ostali)

Relativističko usnopljavanje

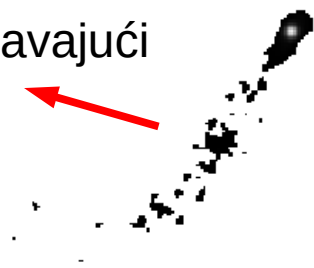
Metoda i rezultati

$$L_{\nu}^{app} / L_0 = \delta^{2+\alpha} = [\gamma(1 - \beta \cos\theta)]^{-(2+\alpha)}$$

$$L_{\nu}^{rec} / L_0 = \delta^{2+\alpha} = [\gamma(1 + \beta \cos\theta)]^{-(2+\alpha)}$$

$$R = L_{\nu}^{app} / L_{\nu}^{rec} = F_{\nu}^{app} / F_{\nu}^{rec} = \left(\frac{1 + \beta \cos\theta}{1 - \beta \cos\theta} \right)^{2+\alpha}$$

Približavajući
mlaz



$F > 4\sigma$
 $\sigma = 2.3 \mu\text{Jy}/\text{beam}$

$$F_{3 \text{ GHz}}^{\text{udaljavajući}} \lesssim 262 \mu\text{Jy}$$

$$F_{3 \text{ GHz}}^{\text{približavajući}} \approx 320 \mu\text{Jy}$$

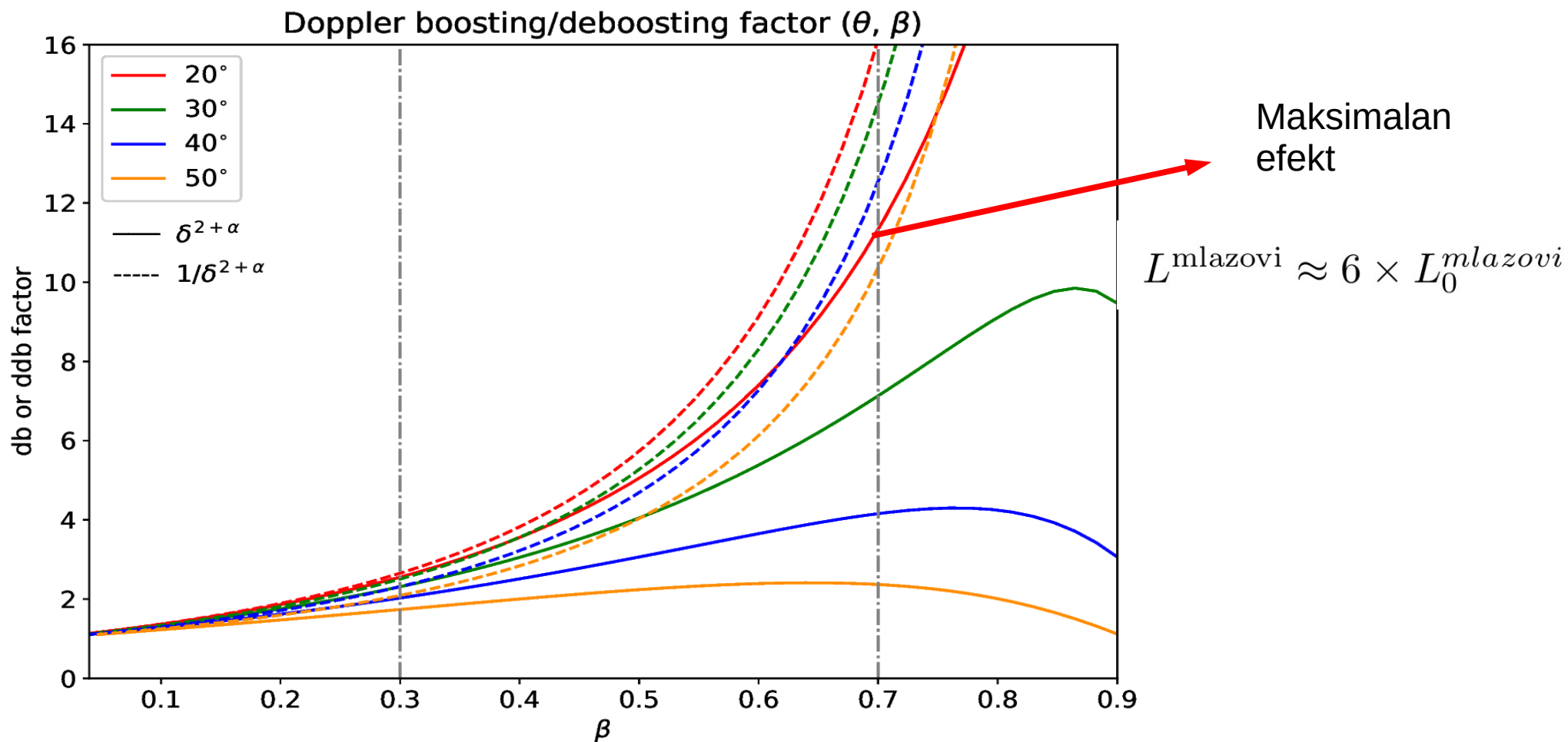
$$R \approx 1.2$$

$$\beta \cos\theta \gtrsim 0.03$$

Relativističko usnopljavanje

Metoda i rezultati

- Različite kombinacije brzine i kuta orijentacije zadovoljavaju nejednakost
- WAT galaksije: brzina mlazova $0.3 c < v < 0.7 c$



Sažetak

- 10913 je WAT radio galaksija pod utjecajem relativističkog usnopljanja; 44 je radio galaksija s jednim mlazom, pod utjecajem relativističkog usnopljanja, potencijalno WAT; 187 je radio galaksija sa simetričnom emisijom
- 44 i 187 su FRI, a 10913 FR II tipovi galaksija prema radio konturama i mapama spektralnog indeksa
- Medijan spektralnog indeksa je izračunat iz mapa za galaksije je: 1.196 (44), 0.91 (10913), 0.719 (187)
- Ukupni monokromatski 3 GHz luminozitet galaksija je $1.26 \times 10^{51} \text{ W Hz}^{-1}$ (10913), $1.15 \times 10^{50} \text{ W Hz}^{-1}$ (44), $3.43 \times 10^{50} \text{ W Hz}^{-1}$ (187)
- Za efekt relativističkog usnopljanja kod radio galaksije 44 omjer luminoziteta mlazova daje granicu $\beta \cos \theta \gtrsim 0.03$

Procijena Doppler boosting faktora: $\approx 1.75 - \approx 11$

Procijena Doppler deboosting faktora: $\approx 2 - \approx 16$

Za maksimalan efekt: ukupni opaženi kombinirani luminozitet mlazova je ≈ 6 puta veći od intrinzičnog luminoziteta