Uticaj sudara galaksija na njihovu dinamiku i evoluciju

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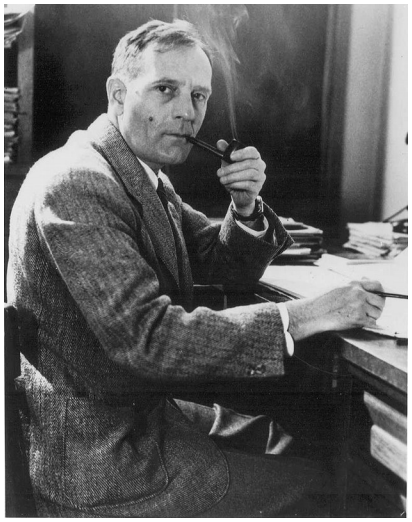
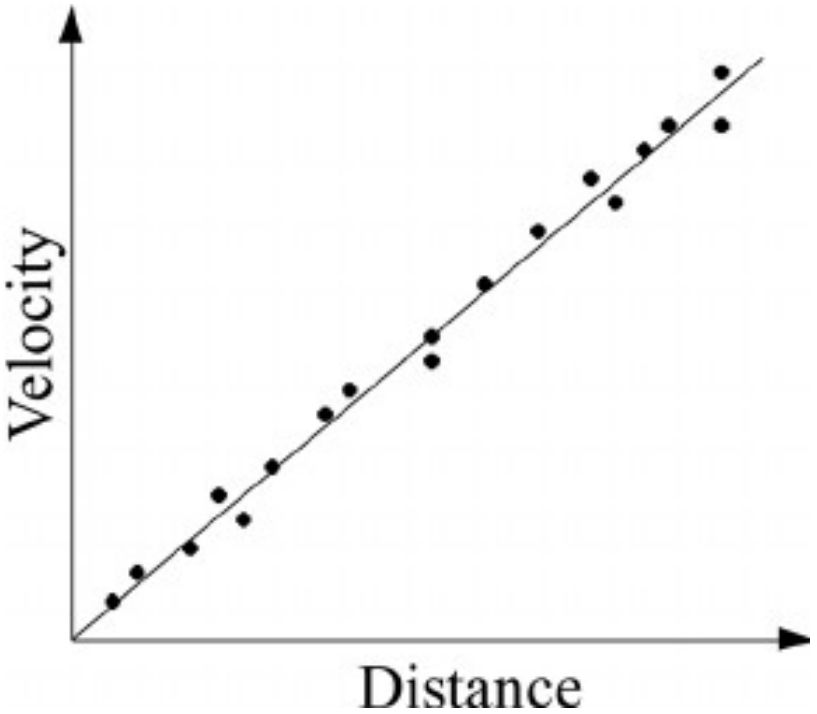
Vangalaktička astronomija

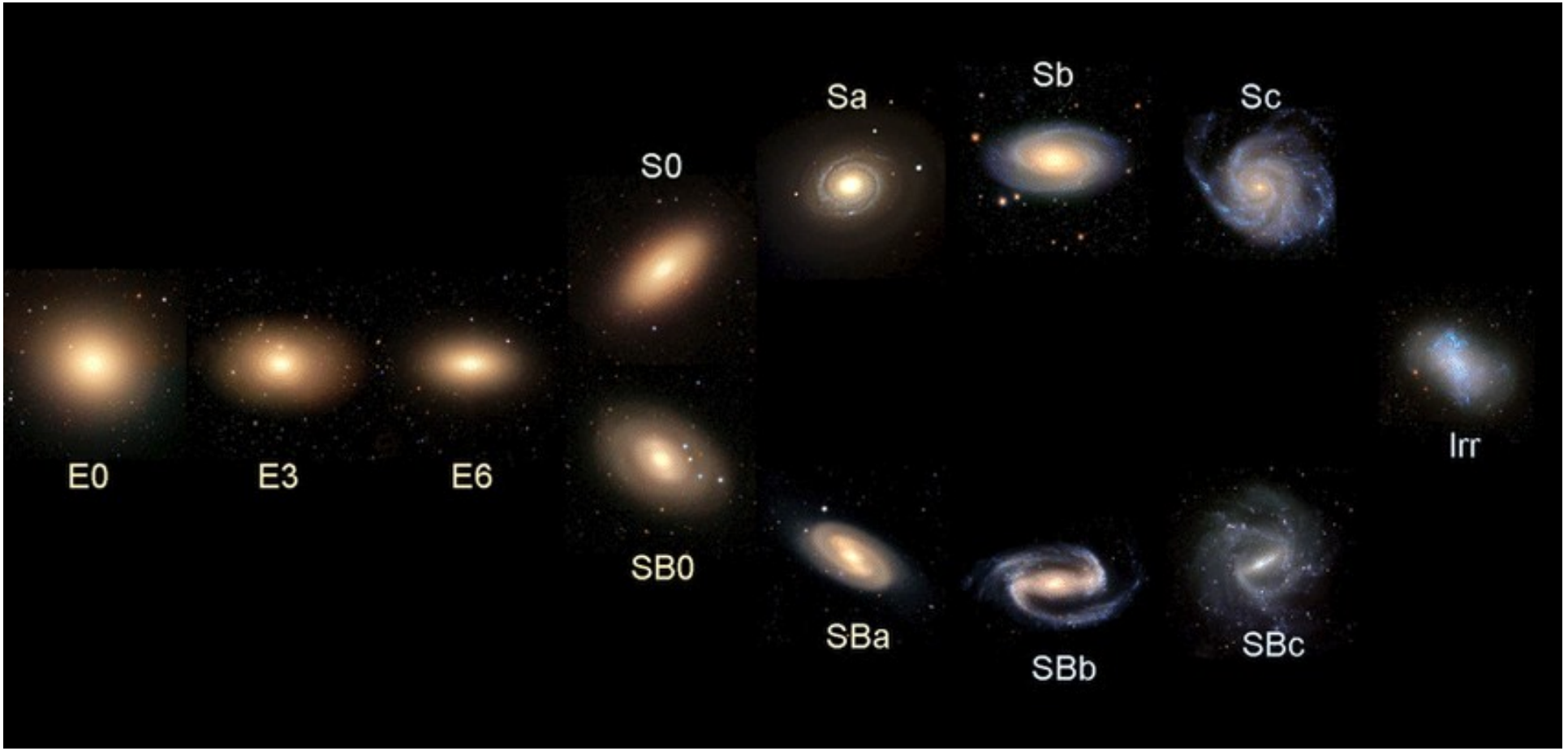
- Debata Šepli-Kertis
- Hablova posmatranja
- Širenje univerzuma
- Habl-Lemetrov zakon





Wallace & Prather 2012

Morfološka klasifikacija

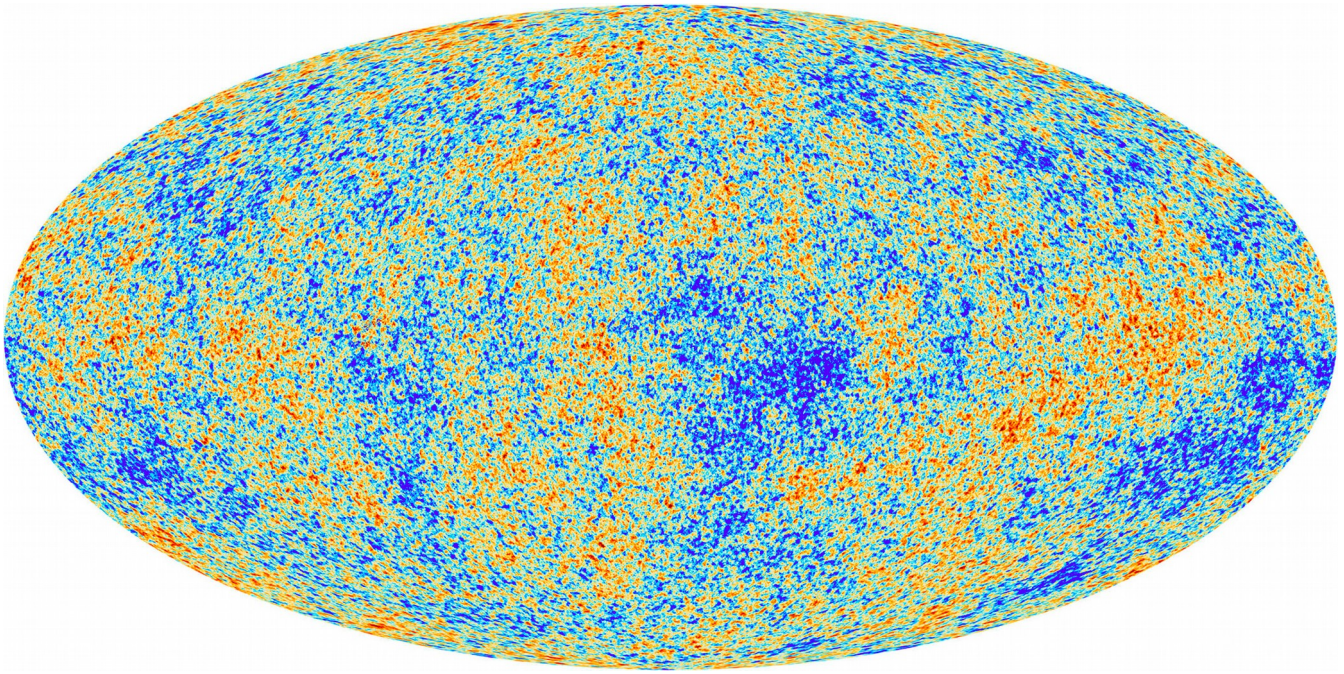


Fluktuacije gustine

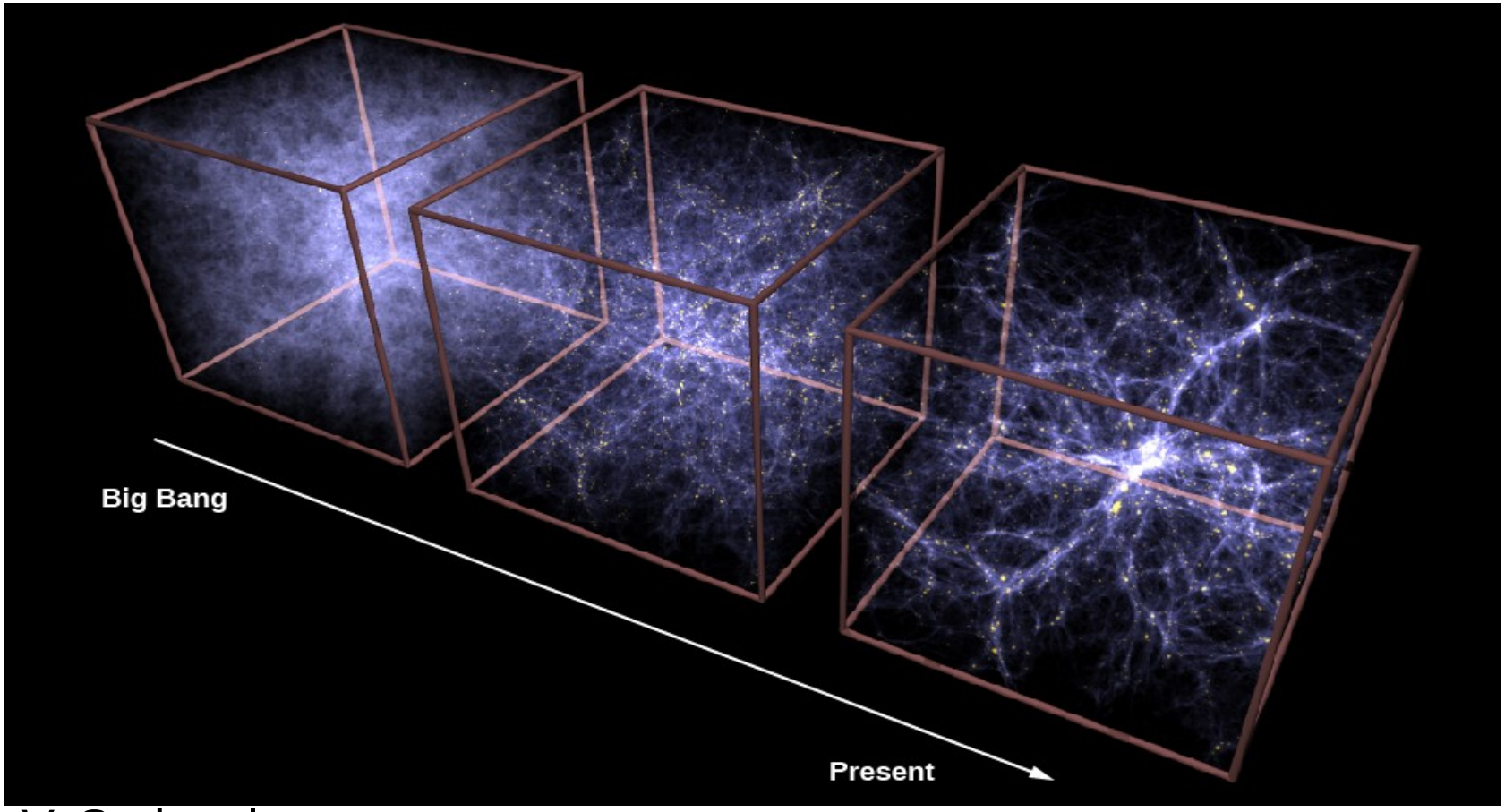
Kosmos je izotropan i homogen

U ranom kosmosu su postojale fluktuacije koje najlakše danas detektujemo kao temperaturne fluktuacije u pozadinskom kosmičkom zračenju!

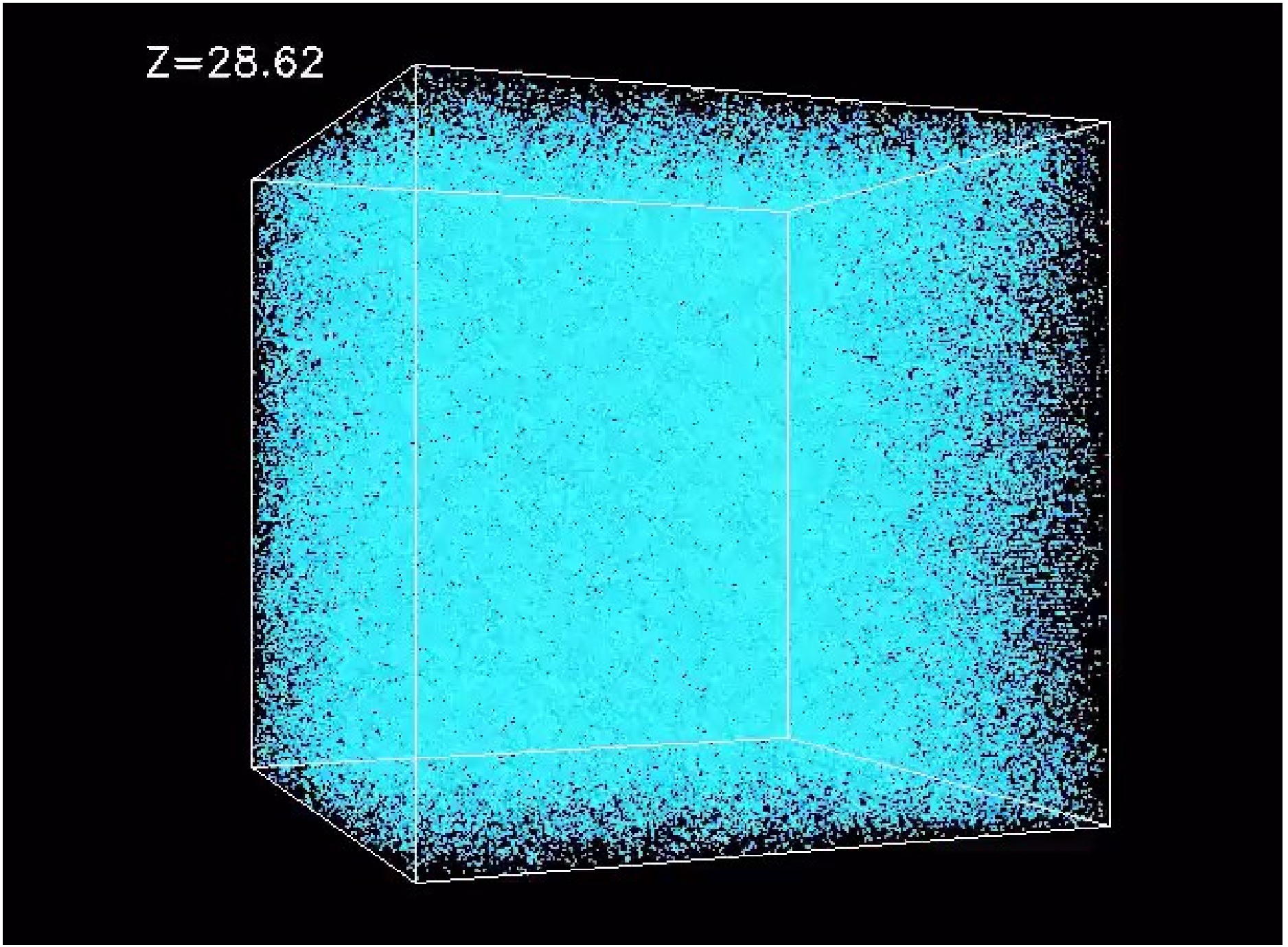
Te fluktuacije su odgovorne za stvaranje velikih struktura!



- Galaksije su “ćelije” Univerzuma
- U “bottom-up” modelu, velike galaksije se formiraju sudarima manjih galaksija

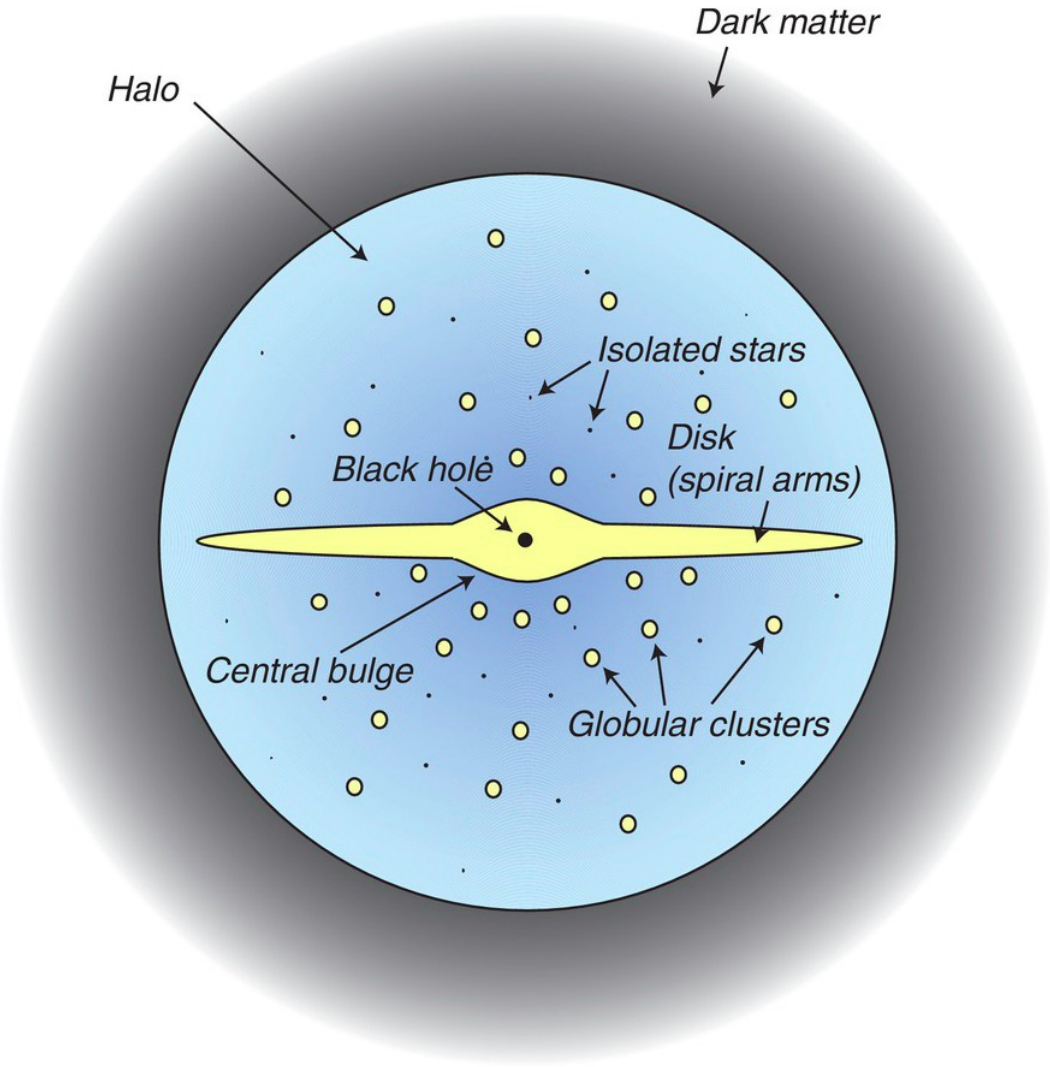


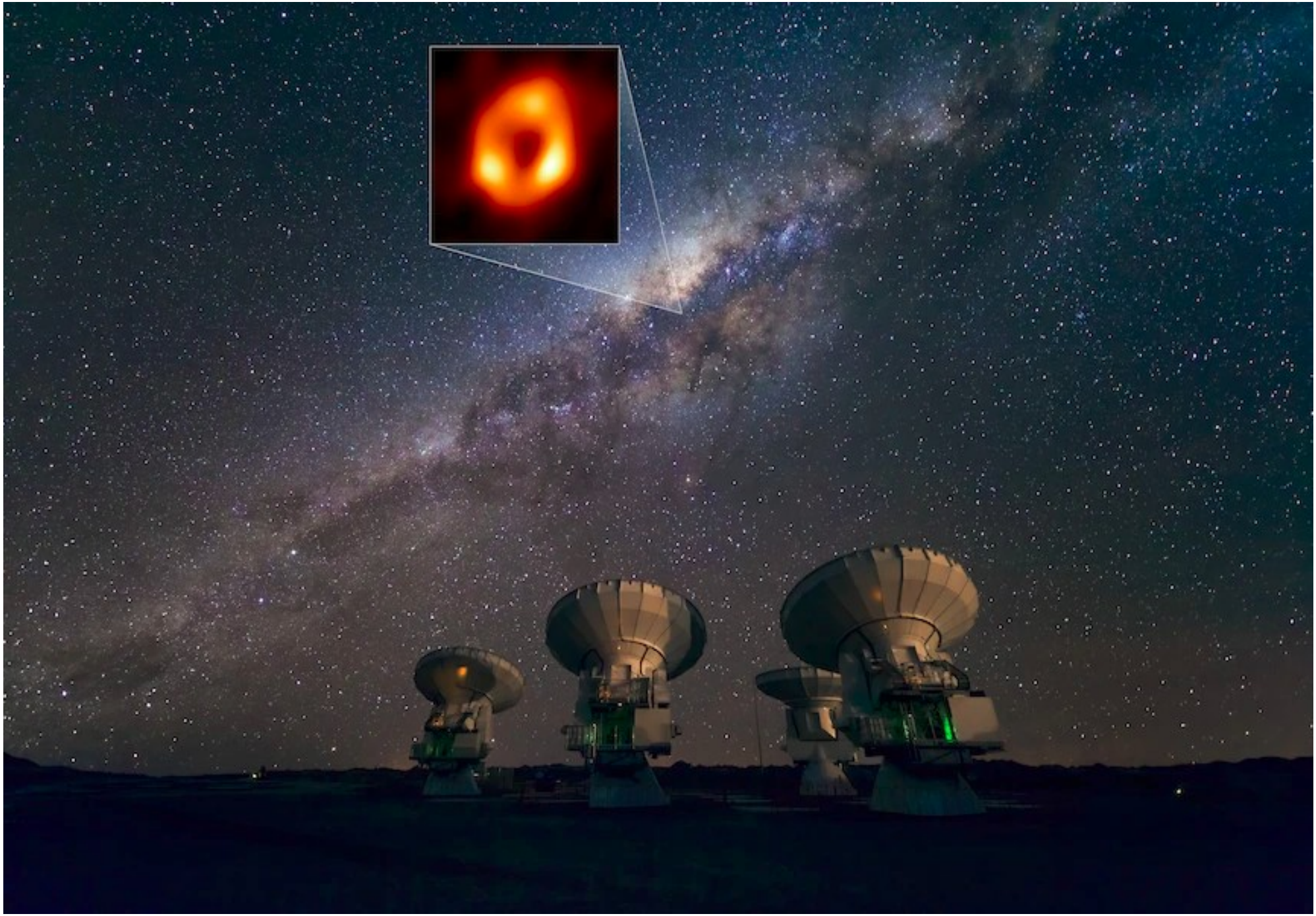
V. Springel


Z=28.62

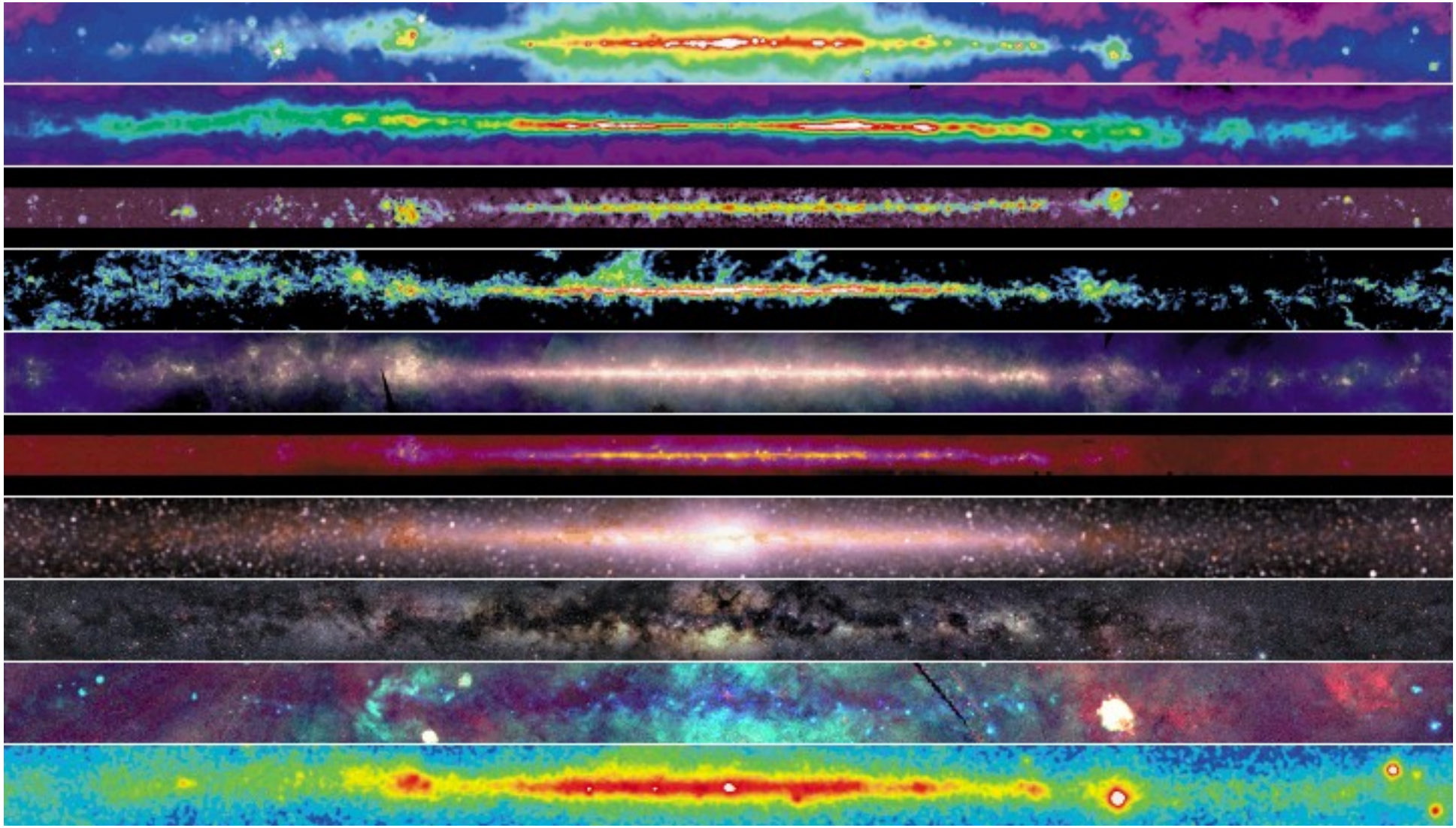
Spiralne galaksije

- Disk
- Centralni oval
- Halo tamne materije
- Međuzvezdana sredina
- Supermasivna crna rupa



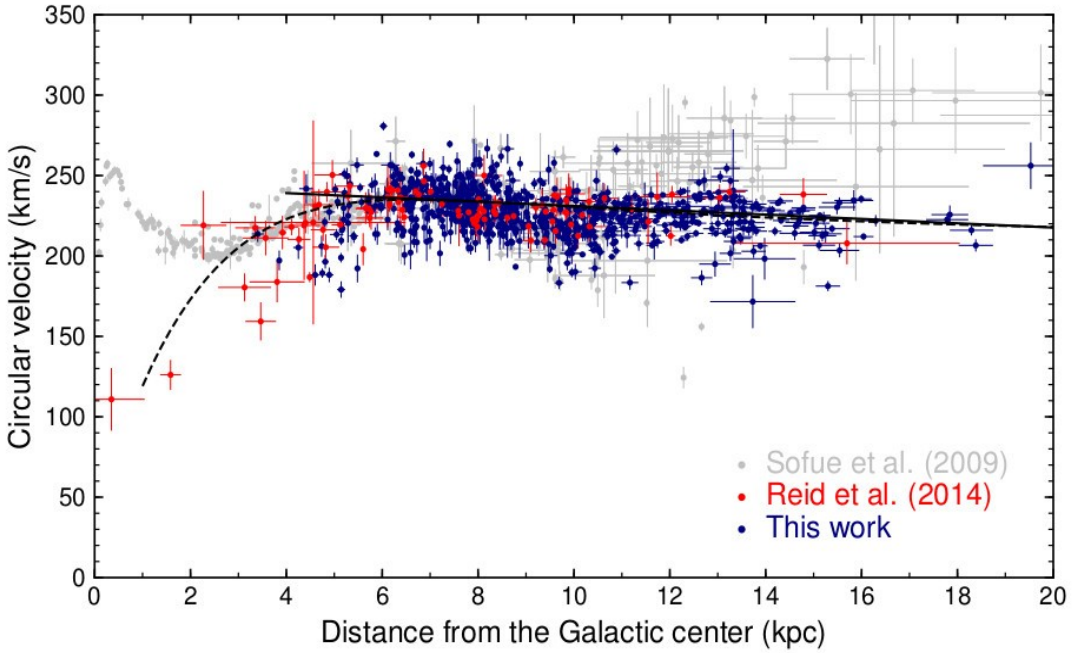


Mlečni put u različitim delovima spektra

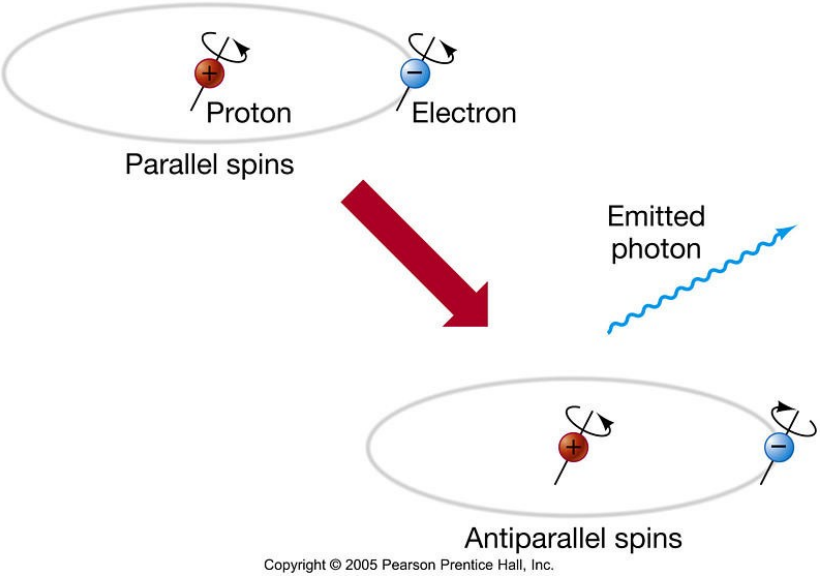


Rotaciona kriva

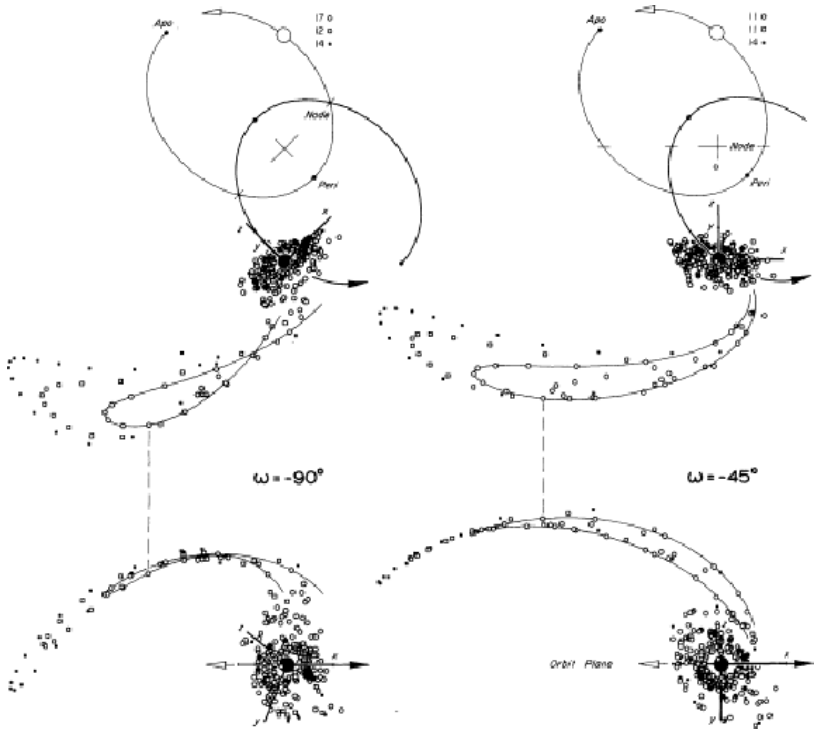
- Neutralni vodonik
- Nedovoljna masa gasa

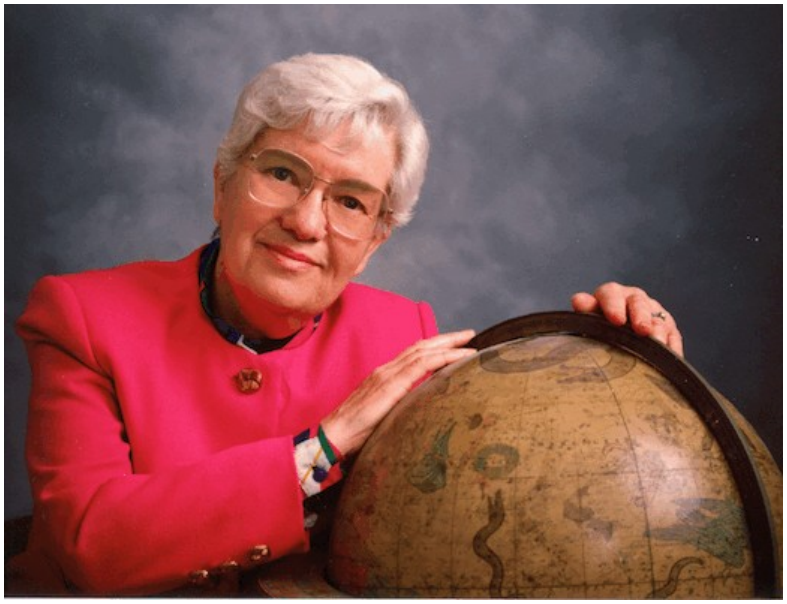


Mroz et al. 2019



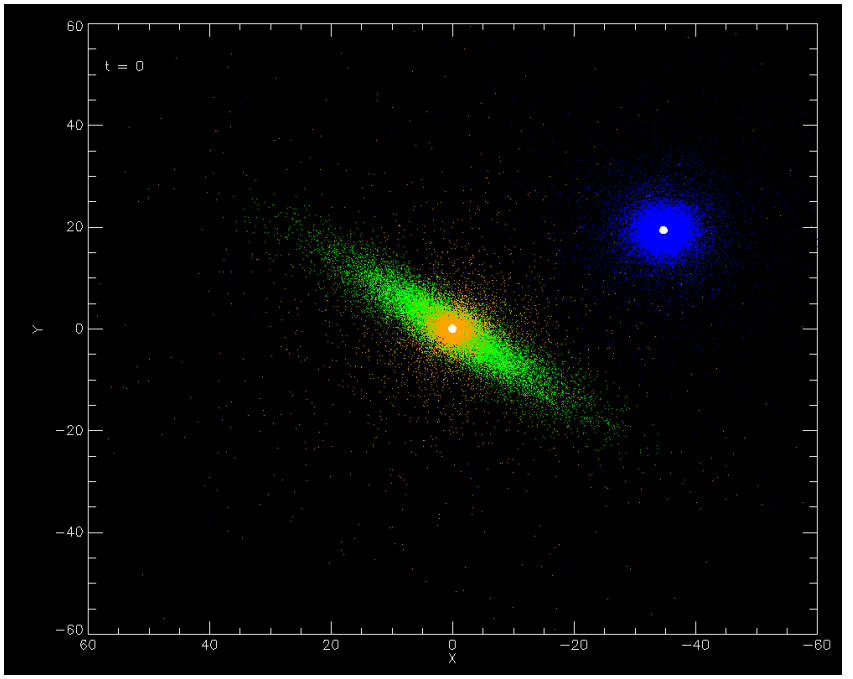
- Stabilnost diska (Toomre)
- Rotacione krive galaksija (Rubin)
- Tamna materija u jatima galaksija (Zwicky)





Interakcije galaksija

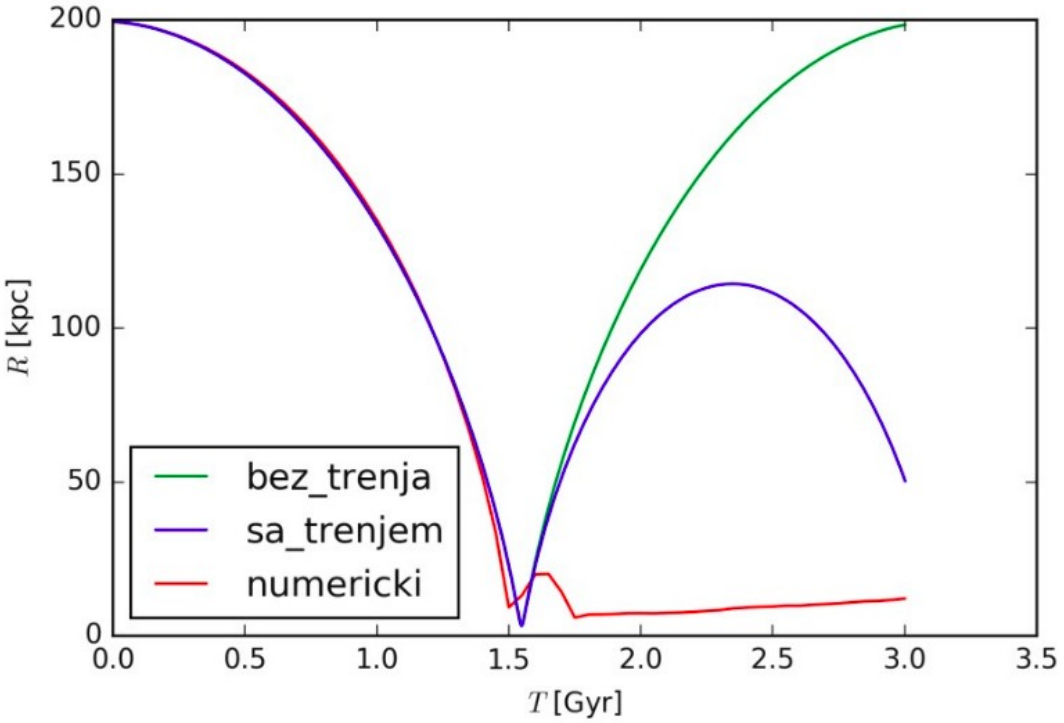
- Raspadanje usled plimskih efekata (*tidal disruption*)
- Proleti (*flybys*)
- Sudari (*mergers*)

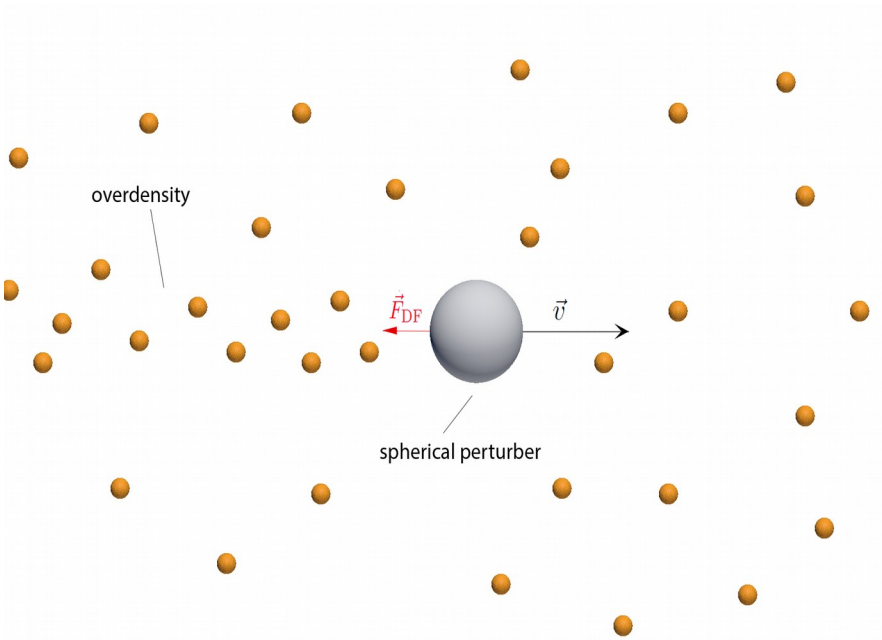


Fardal et al. 2003

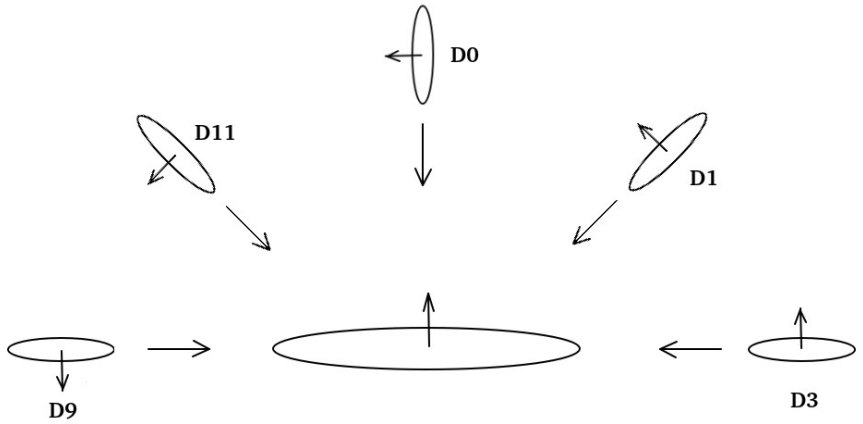
Credit: ALMA (ESO/NAOJ/NRAO). Visible light image: the NASA/ESA Hubble Space Telescope

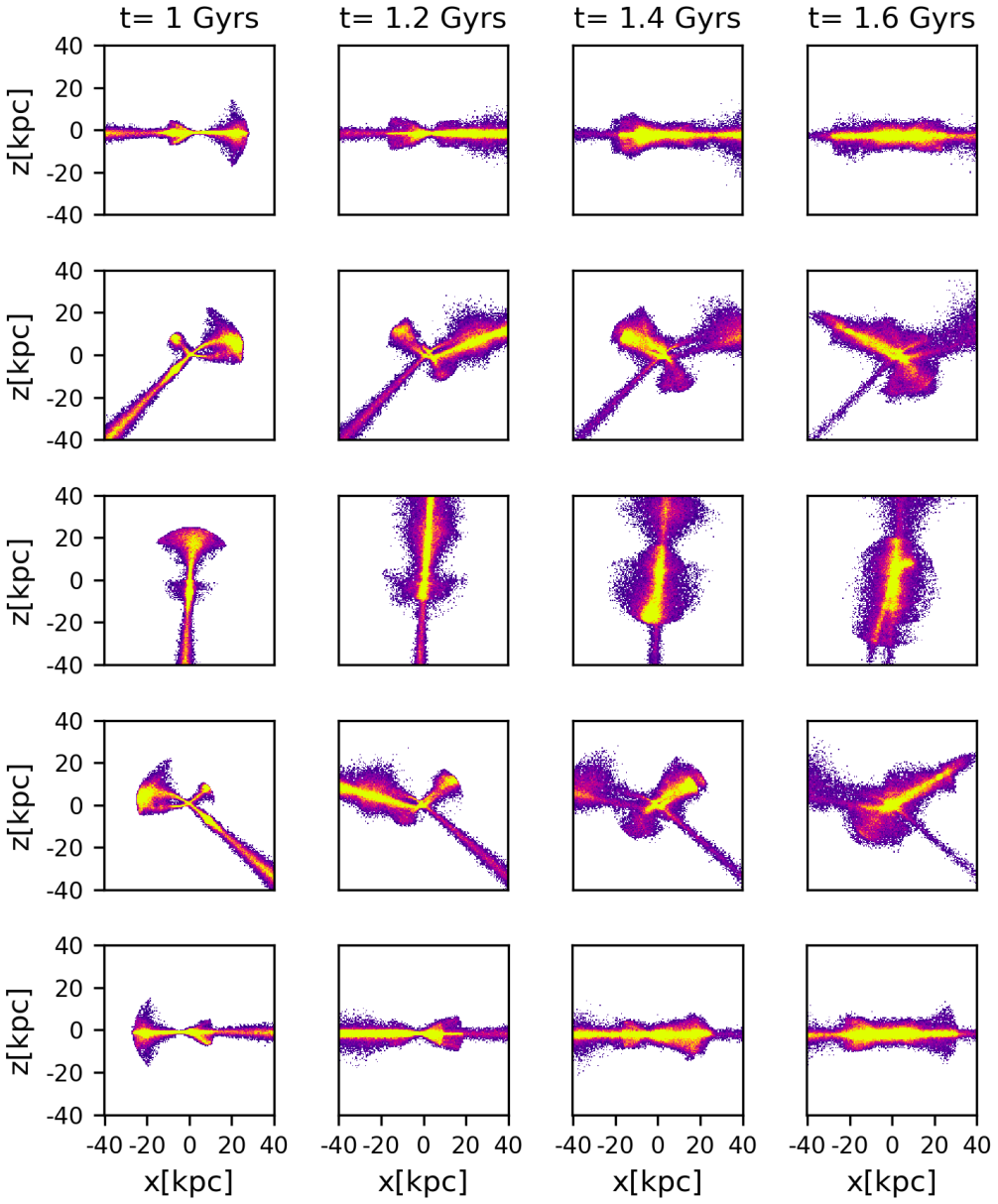
Dinamičko trenje

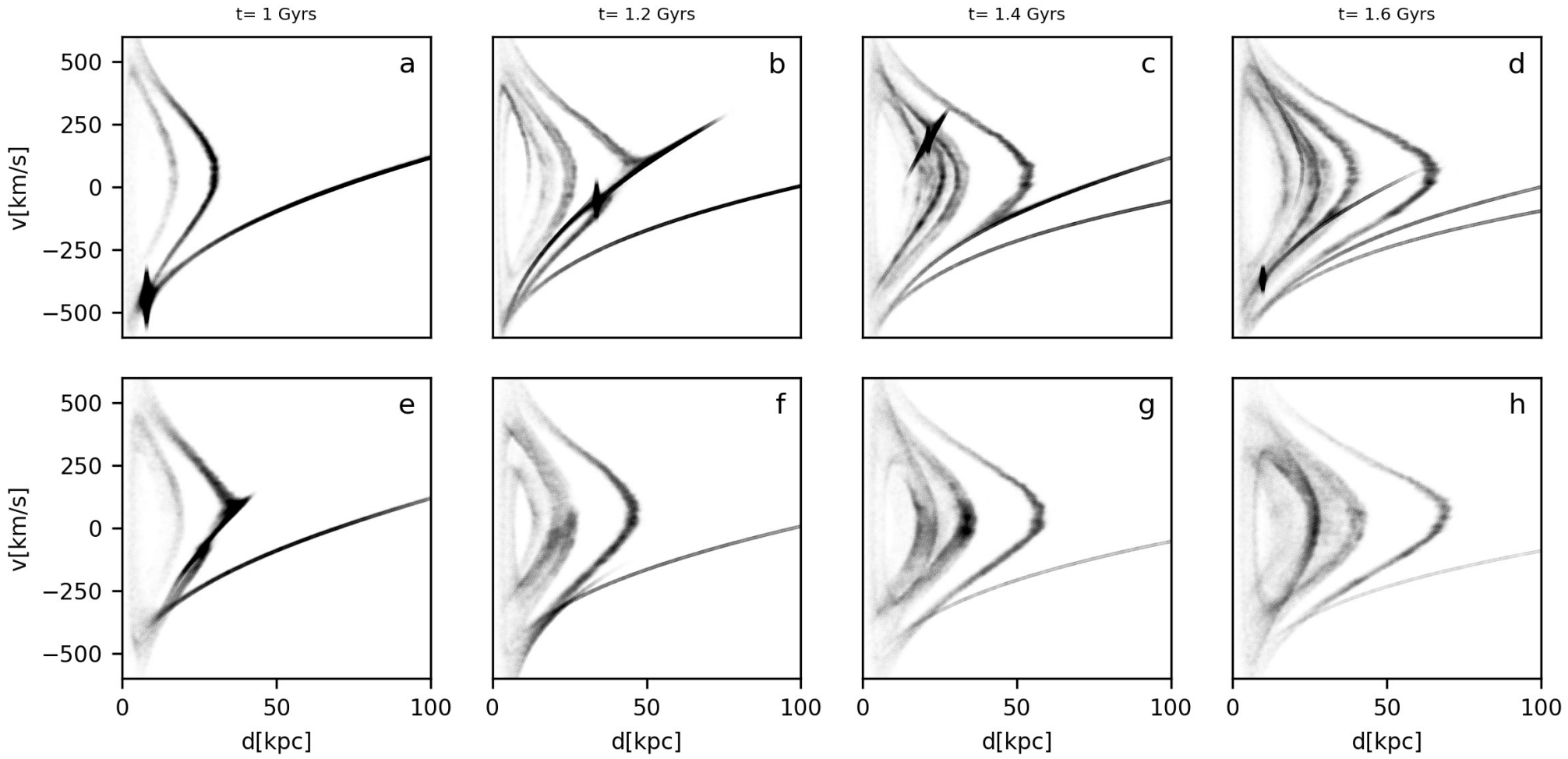




Formiranje struktura sudarima






t= 1 Gyrs
t= 1.2 Gyrs
t= 1.4 Gyrs
t= 1.6 Gyrs
a
b
c
d
e
f
g
h
v[km/s]
500
250
0
−250
−500
0
50
100
d[kpc]

Zvezdani tok u M31

- Veliki Južni tok (*The Giant Southern Stream*)
- Otkriven 2001 (Ibata et al. 2001)
- Analitički pristup (Fardal et al. 2007)
- *N*-body simulacije (Sadoun et al. 2014; Micky & Mory 2016; Milošević et al. 2022)
- Posmatranja (Ibata et al. 2001; McConnachie et al. 2003, Ibata et al. 2004, Conn et al 2016; Cohen et al. 2018, Escala et al. 2020)

- Vremenski interval sudara Andromede i satelita
- Fizičke osobine

Simulacije *N*-tela

- Početni uslovi: GalactICs (Widrow et al. 2008)
- Simulacije: Gadget 2 (Springel 2005)

```
8.3980460e-08 -5.7601852e+00 -8.3586826e+00  1.3729346e-01  1.0715003e+00 -6.4452440e-01 -6.7745186e-03
8.3980460e-08 -3.2683914e+00 -1.2225995e+00  5.4256629e-02  4.4615516e-01 -1.0100011e+00 -8.0632288e-03
8.3980460e-08 -1.1773534e+00  1.0208480e+00 -1.7793012e-01 -8.8093269e-01 -5.5847597e-01 -7.7964049e-03
8.3980460e-08 -1.3560295e-01  1.9172368e+00  1.9230828e-02 -9.1419613e-01  2.7906507e-01 -2.7448764e-02
8.3980460e-08 -3.4977484e+00  7.6453619e+00  4.1781828e-02 -1.0305365e+00 -1.7763868e-01 -5.2826763e-03
8.3980460e-08 -1.1233920e+00 -4.1701585e-01  1.8572435e-01  8.2892172e-02 -2.9119223e-01 -1.7251758e-02
8.3980460e-08  2.9514527e+00  1.0439217e-01  8.0984488e-02 -1.9003353e-01  1.1357864e+00  3.7941318e-02
8.3980460e-08 -3.3873072e+00  6.0780406e+00 -5.9422981e-02 -7.7407360e-01 -4.9165311e-01 -3.7220806e-02
8.3980460e-08 -6.5336428e+00 -3.2950118e+00 -1.2032726e-01  5.3568274e-01 -1.0418470e+00  1.2702351e-02
8.3980460e-08 -3.4735446e+00 -3.9292519e+00 -1.0753751e-01  1.0873061e+00 -8.2556772e-01 -3.0150101e-02
8.3980460e-08  1.0216451e+00  5.4123564e+00  1.6305377e-01 -1.1524673e+00 -7.7662721e-02  3.1002712e-02
8.3980460e-08 -1.1712967e+00  4.1944236e-01 -1.7722893e-01 -5.9392285e-01 -4.2081624e-01  1.8173087e-01
8.3980460e-08  5.4557872e-01  9.7778015e+00 -1.1140804e-01 -1.0061247e+00 -8.9997098e-02 -2.1888798e-02
```

Model spiralne galaksije

(Geehan et al. 2006; Sadoun et al. 2014)

Disk

$$\Sigma(R) = \Sigma_0 e^{\frac{-R}{R_d}} = \frac{M_d}{2\pi R_d^2} e^{\frac{-R}{R_d}}$$

$$\propto \operatorname{sech}^2 \frac{z}{z_0}$$

$$\rho(R,z) = \frac{\Sigma(R)}{2z_0} \operatorname{sech}^2 \frac{z}{z_0}$$

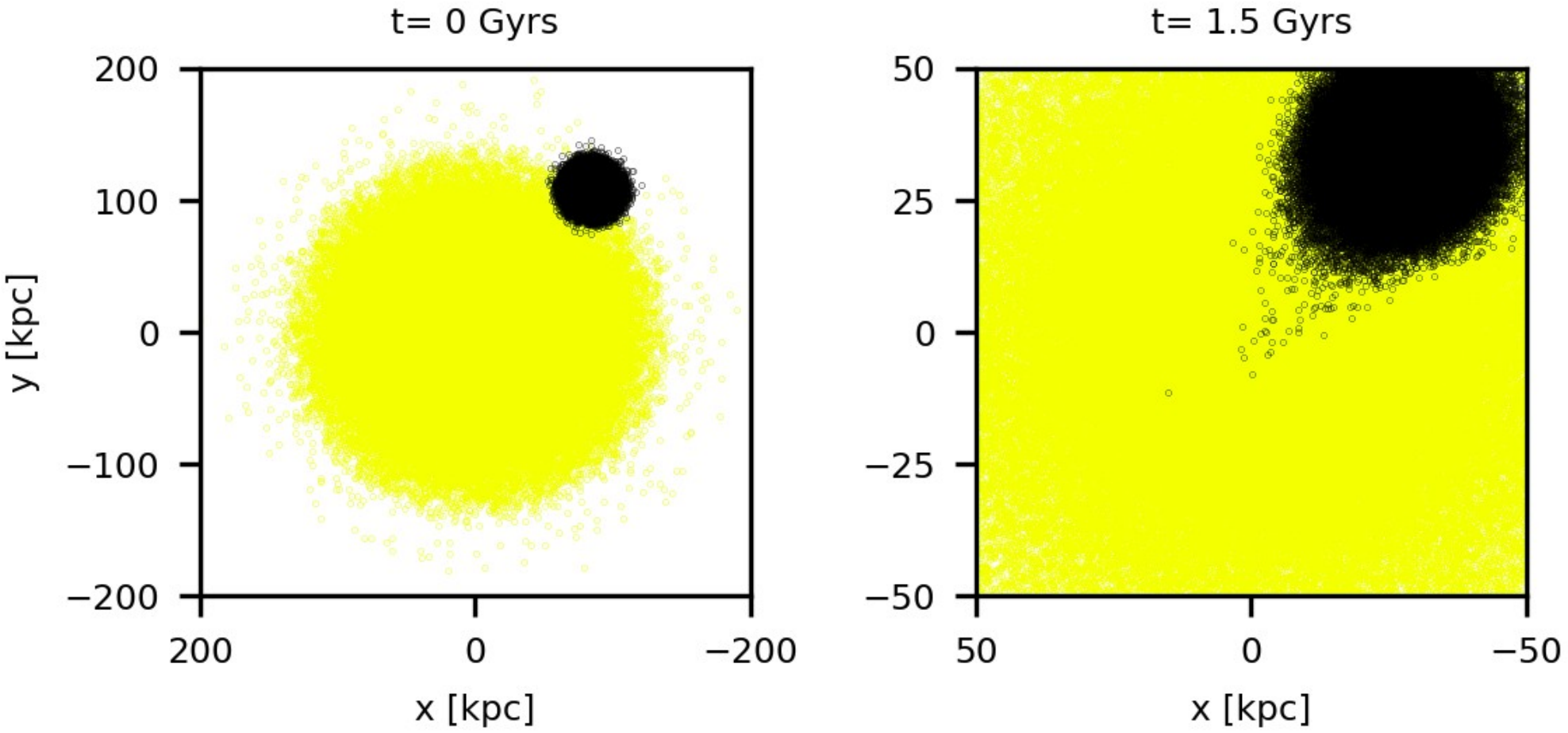
Centralni oval

$$\rho_b = \frac{M_b r_b}{2\pi r (r + r_b)^3}$$

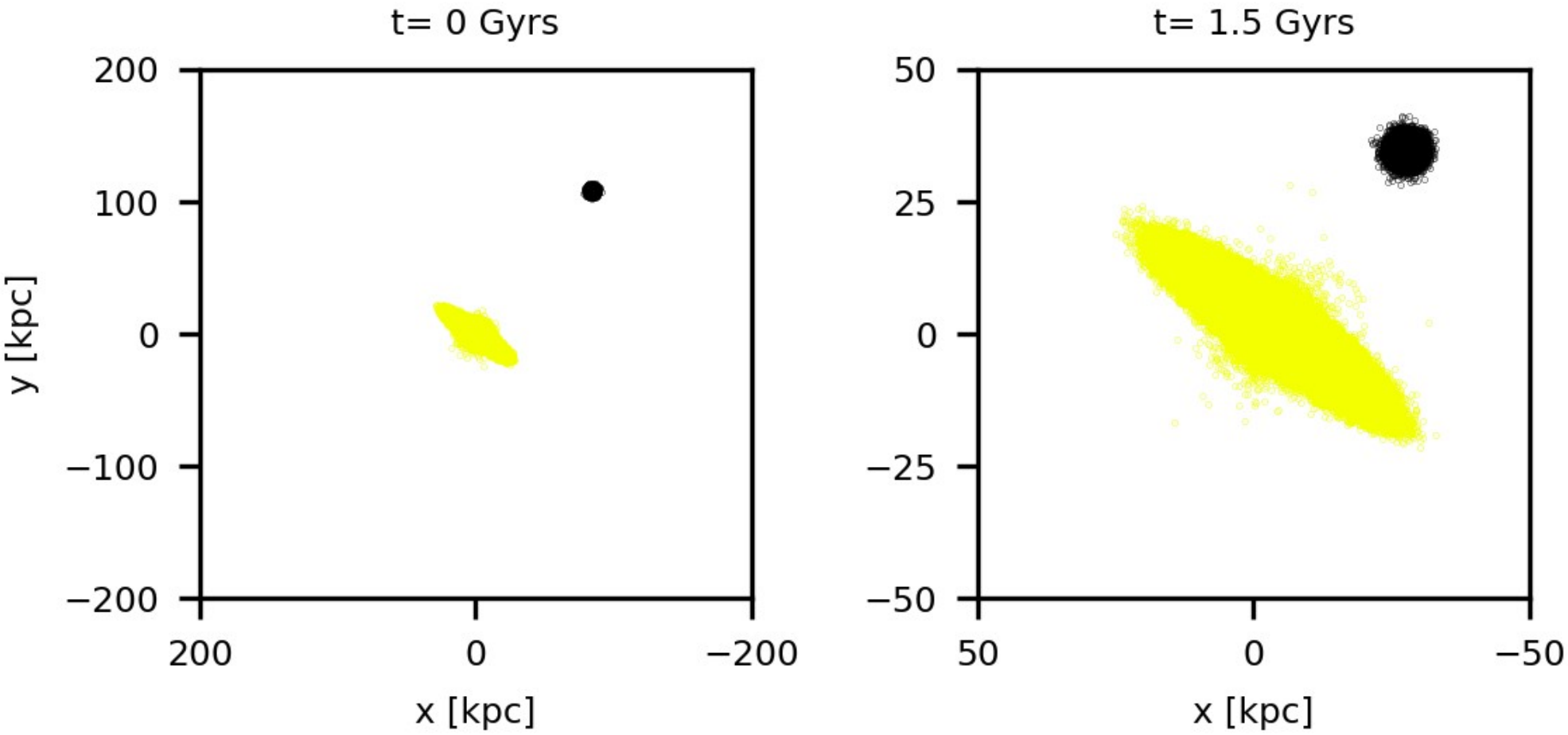
Halo

$$\rho_h(r) = \frac{\rho_0}{\frac{r}{r_h}(1 + \frac{r}{r_h})^2}$$

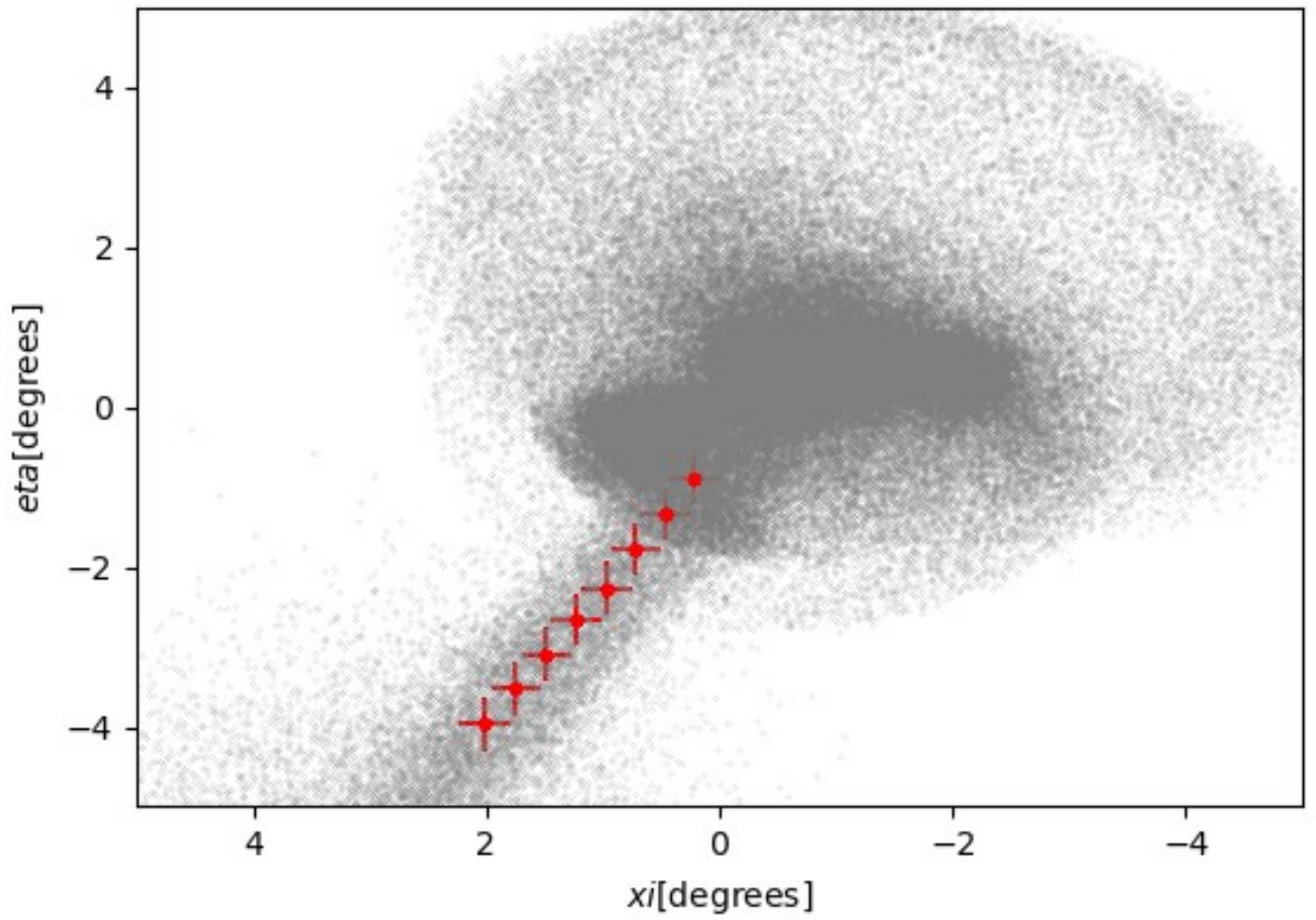
Halo tamne materije

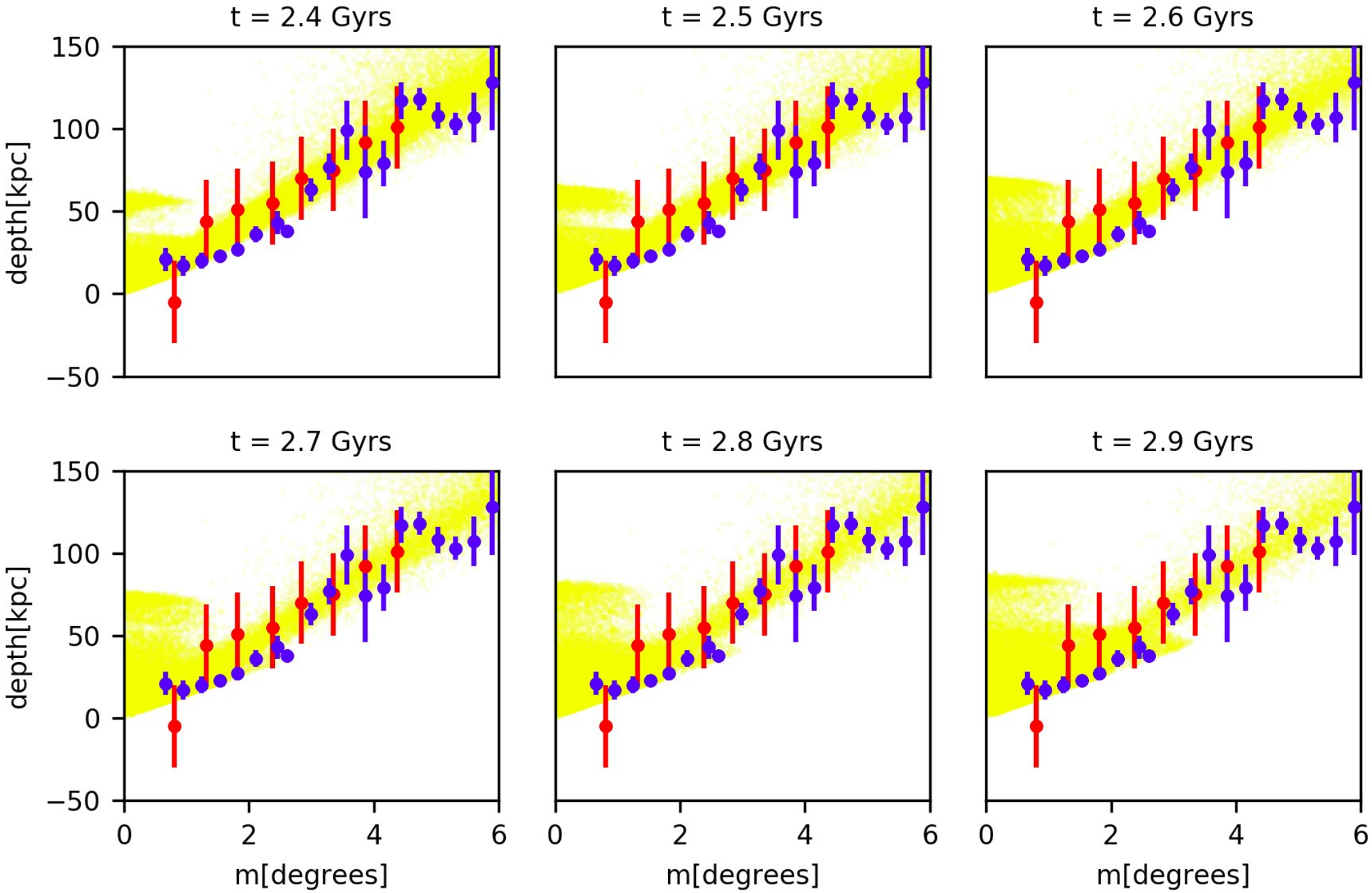


Barionska materija



Prostorna raspodela materije i brzine

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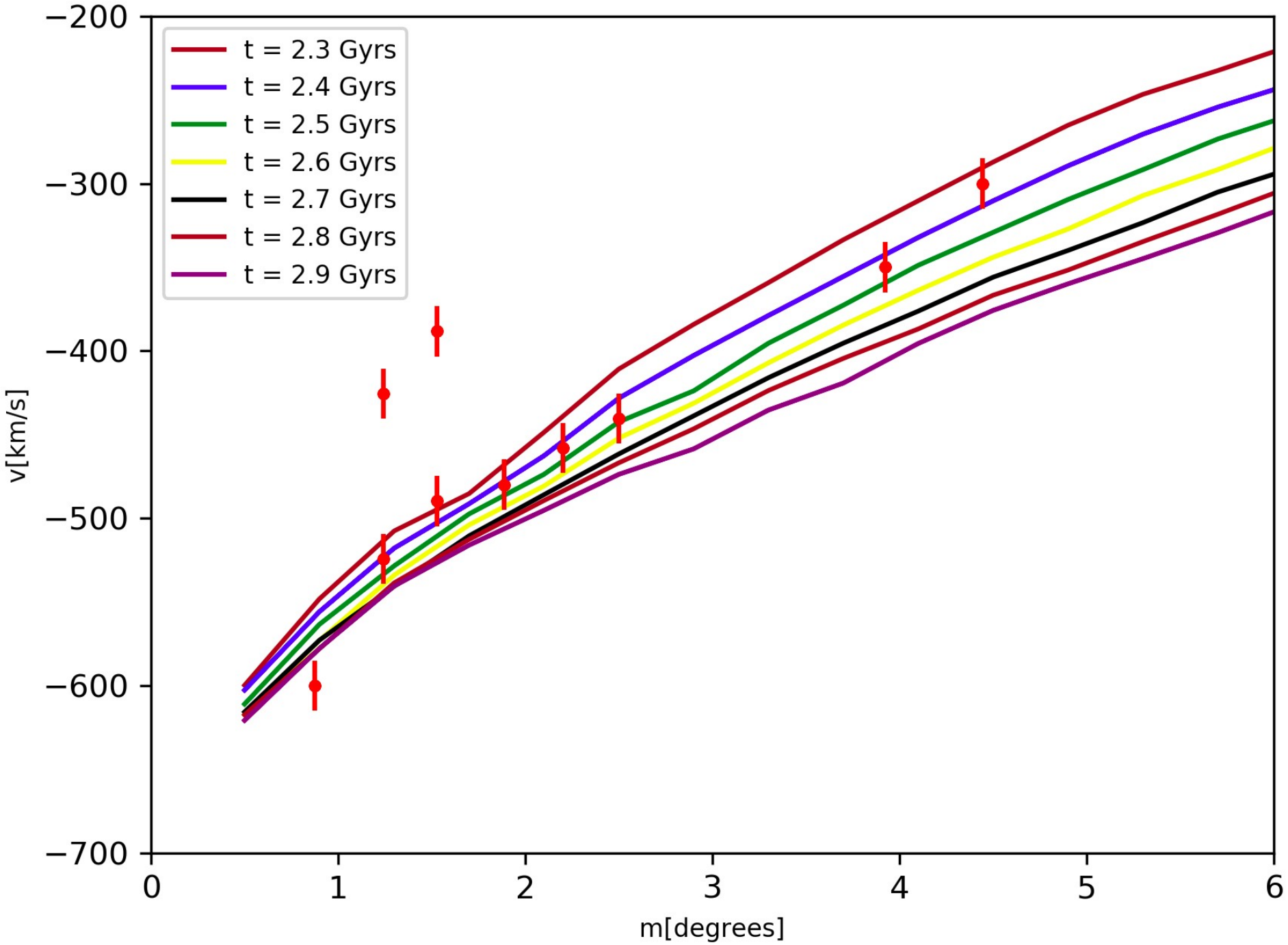
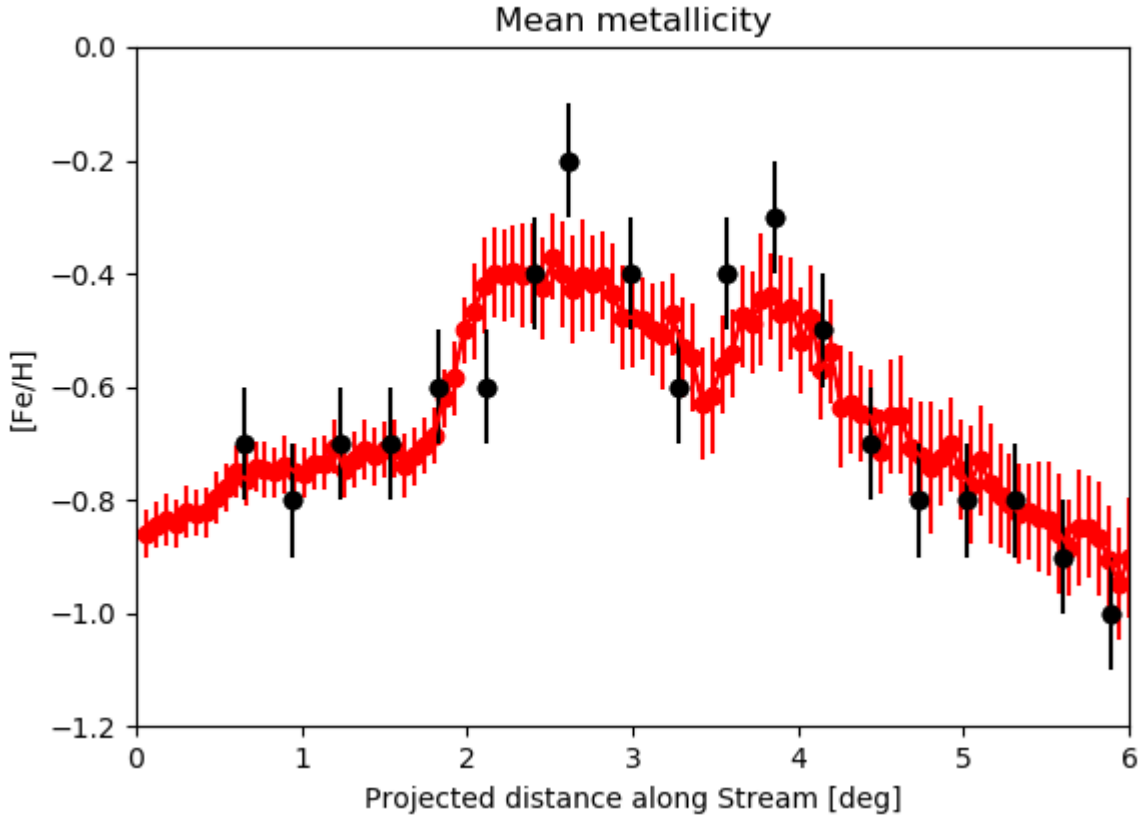
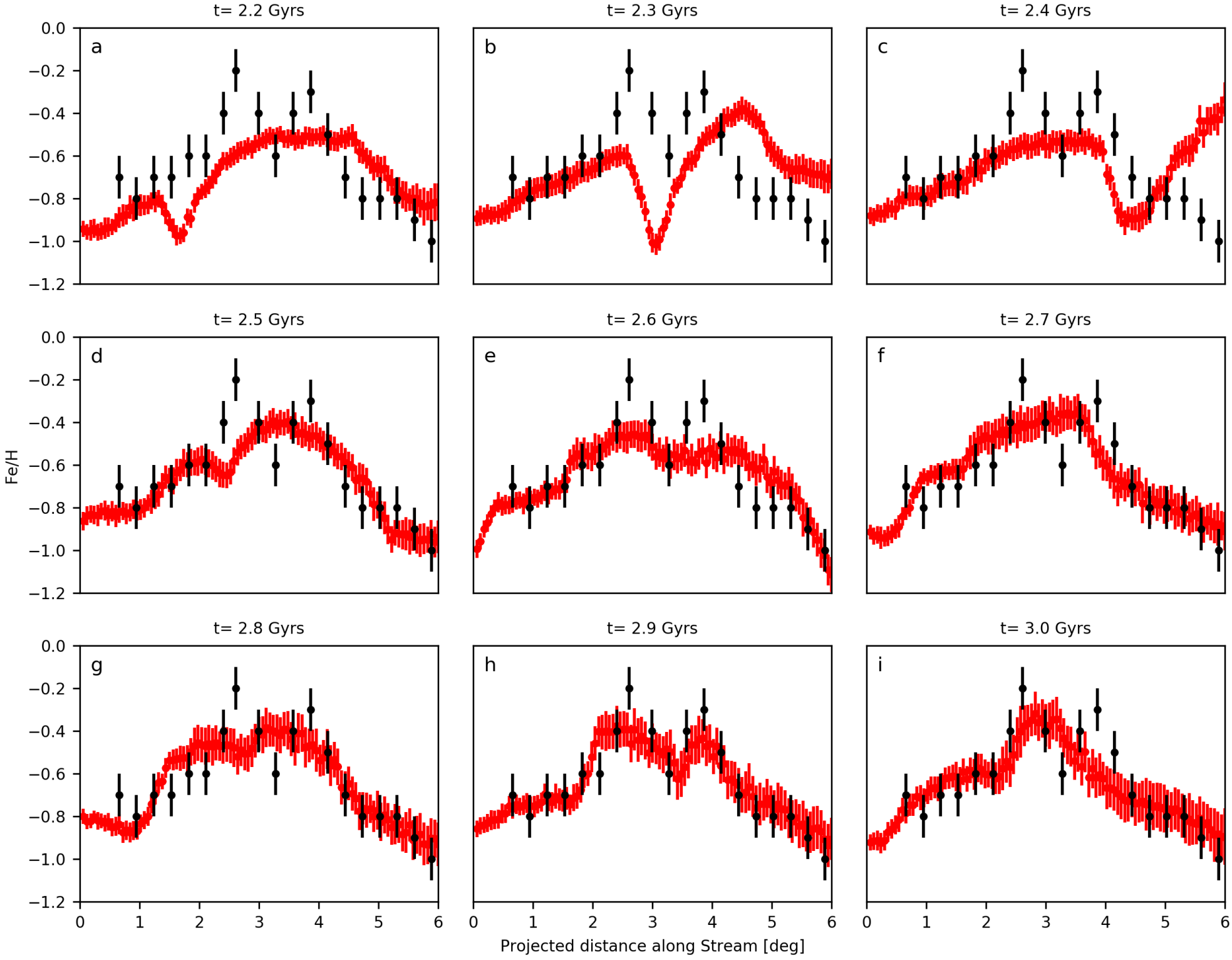
t = 2.5 Gyrs
t = 2.6 Gyrs
t = 2.7 Gyrs
t = 2.8 Gyrs
t = 2.9 Gyrs
depth[kpc]
m[degrees]
150
100
50
0
−50
0
2
4
6

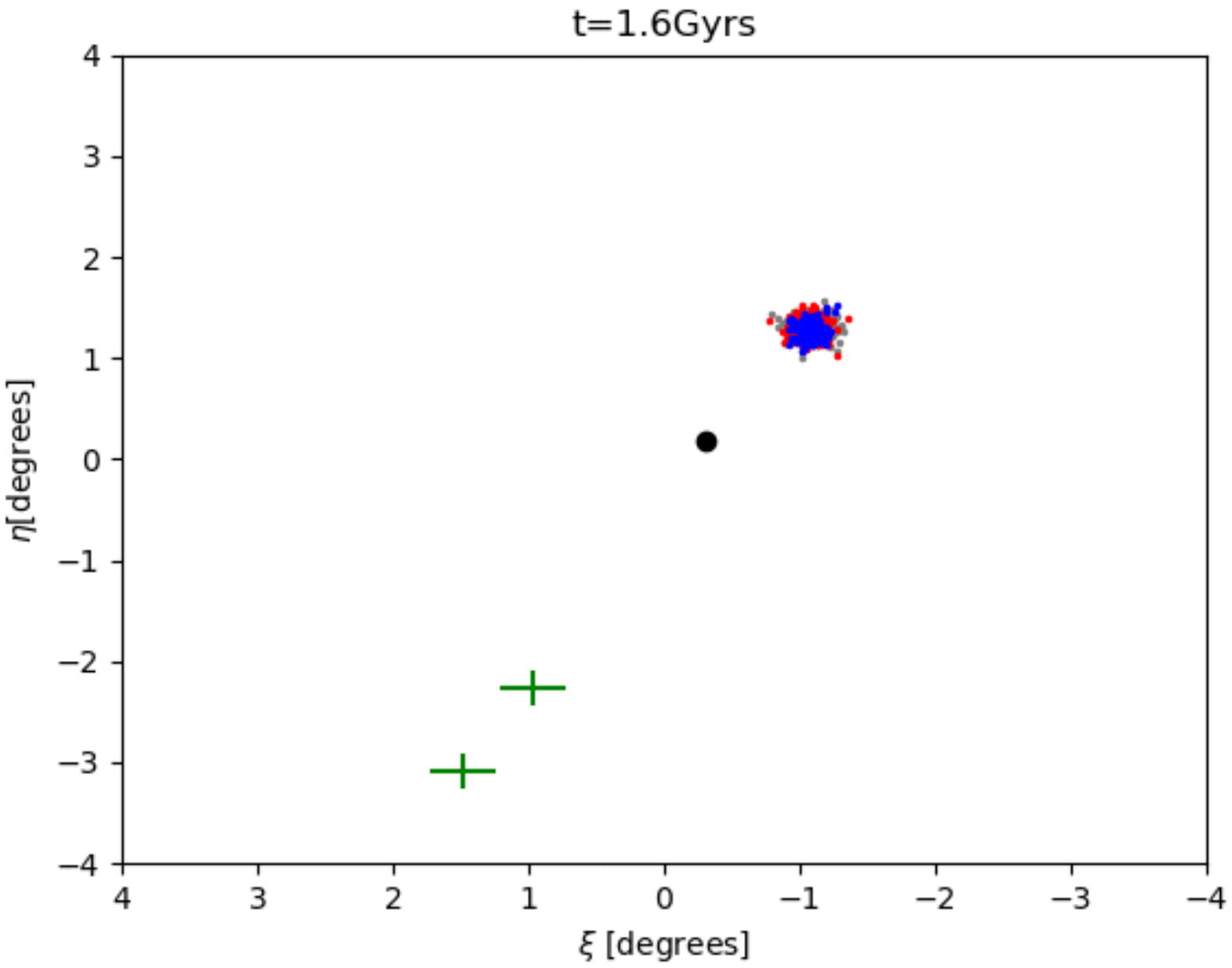

t = 2.3 Gyrs
t = 2.4 Gyrs
t = 2.5 Gyrs
t = 2.6 Gyrs
t = 2.7 Gyrs
t = 2.8 Gyrs
t = 2.9 Gyrs
−200
−300
−400
−500
−600
−700
v[km/s]
0
1
2
3
4
5
6
m[degrees]

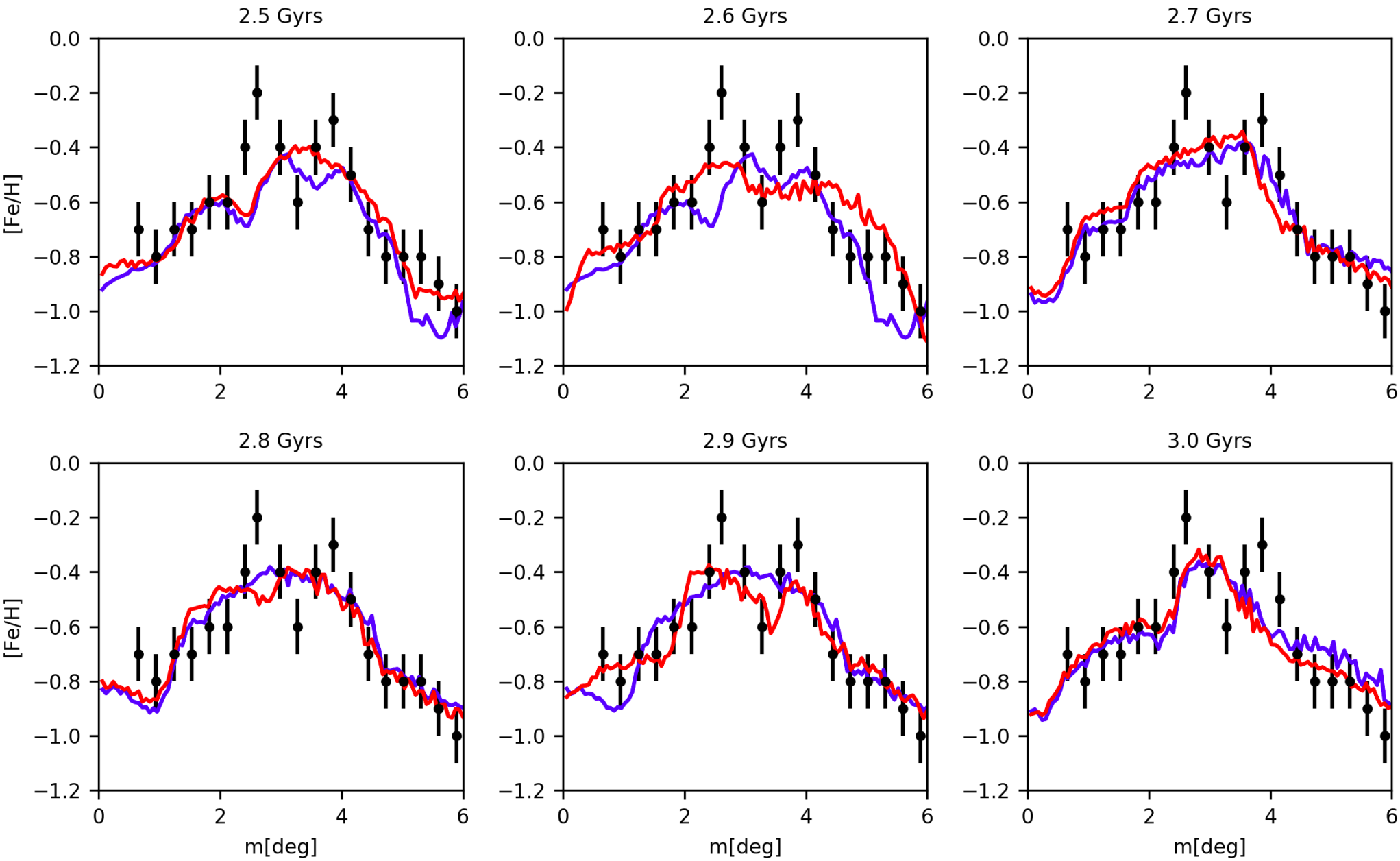
Metaličnost

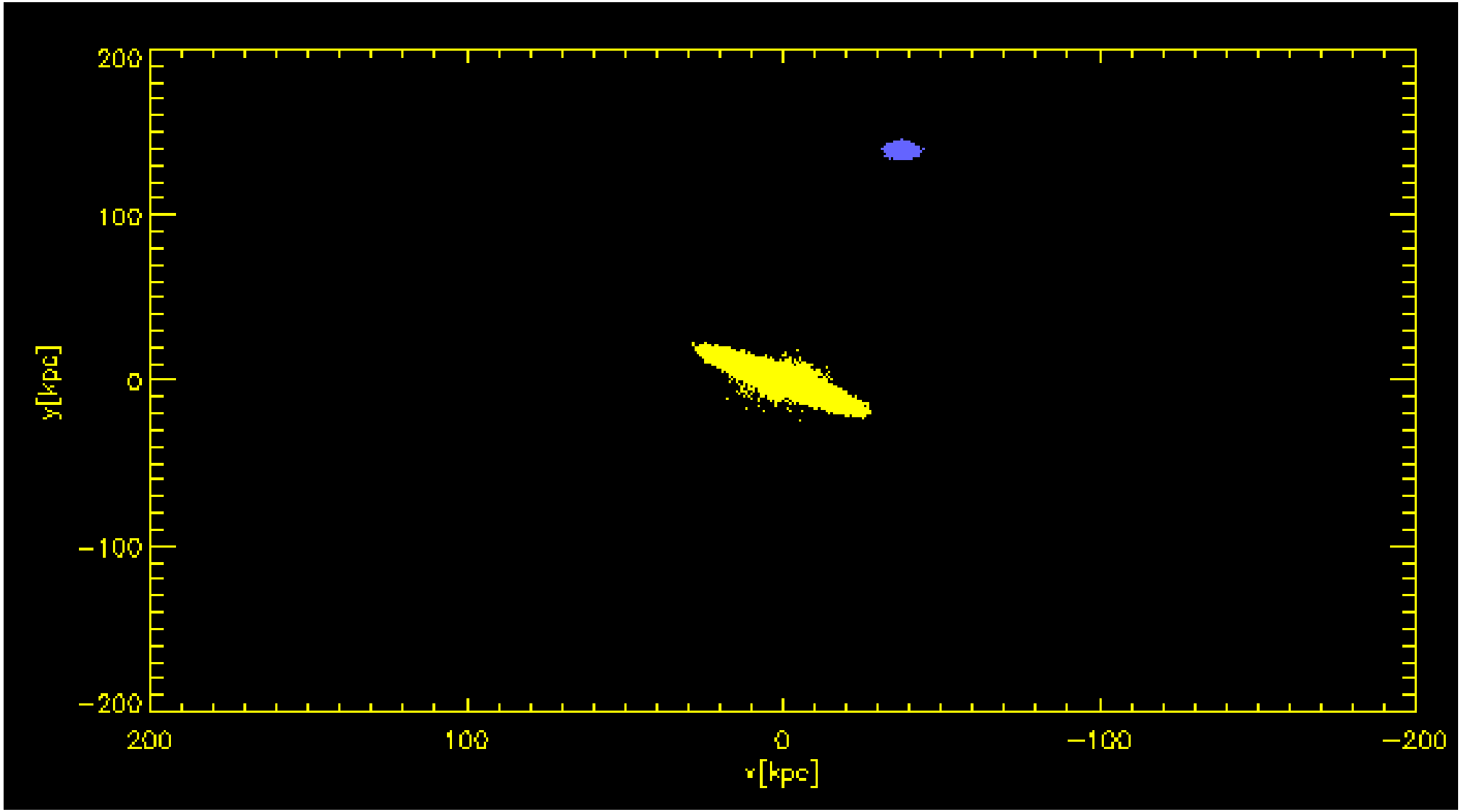
- Patuljasta galaksija podeljena u ljuske
- Monte Carlo metodom svakoj čestici dodeljana metaličnost
- Na kraju simulacije, u posmatranim regionima računamo simuliranu metaličnost




t= 2.2 Gyrs
t= 2.3 Gyrs
t= 2.4 Gyrs
t= 2.5 Gyrs
t= 2.6 Gyrs
t= 2.7 Gyrs
t= 2.8 Gyrs
t= 2.9 Gyrs
t= 3.0 Gyrs
a
b
c
d
e
f
g
h
i
Fe/H
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
−1.2
0
1
2
3
4
5
6
Projected distance along Stream [deg]


t=1.6Gyrs
4
3
2
1
0
−1
−2
−3
−4
η[degrees]
4
3
2
1
0
−1
−2
−3
−4
ξ [degrees]


2.5 Gyrs
2.6 Gyrs
2.7 Gyrs
2.8 Gyrs
2.9 Gyrs
3.0 Gyrs
[Fe/H]
m[deg]
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
−1.2
0
2
4
6


200
100
0
−100
−200
y[kpc]
200
100
0
−100
−200
x[kpc]

Zaključak

- Sudarima se formiraju strukture koje posmatramo
- Iz fizičkih karakteristika struktura možemo da odredimo istoriju sudara
- Sudarni proces zavisi od masa galaksija, njihovih orbita, momenta impulsa
- Karakteristike formiranih struktura zavise od karakteristika patuljastih galaksija – morfologije, mase, metaličnosti,...
- Određivanje masa galaksija iz dinamike satelita
- Procena količine tamne materije u galaksijama

Hvala na pažnji!