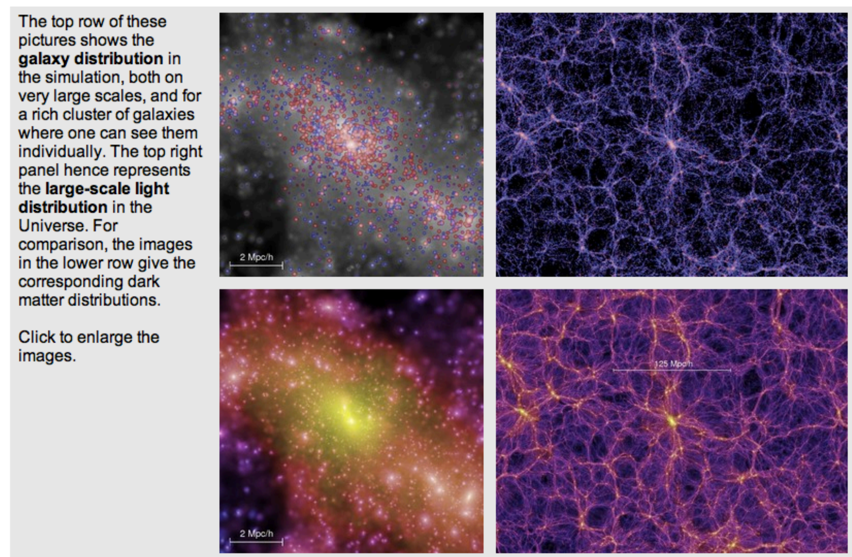
Evolucija galaksija

- Galaksije ne zive izolirano: skoro sve pripadaju skupovima (galaksije zaokupljaju veci udio volumena skupa galaksija nego zvijezde u zvjezdanim skupovima)
- Interakcije/sudari izmedju galaksija su vjerojatni te cesto opazeni (interakcije povecavaju disperziju brzina zvijezda u galaksiji te vjerojatno unistavaju diskove u kasnijim tipovima galaksija te omogucavaju relaksaciju na $r^{1/4}$ profil ranijih tipova galaksija)



Evolucija udjela bliskih parova galaksija

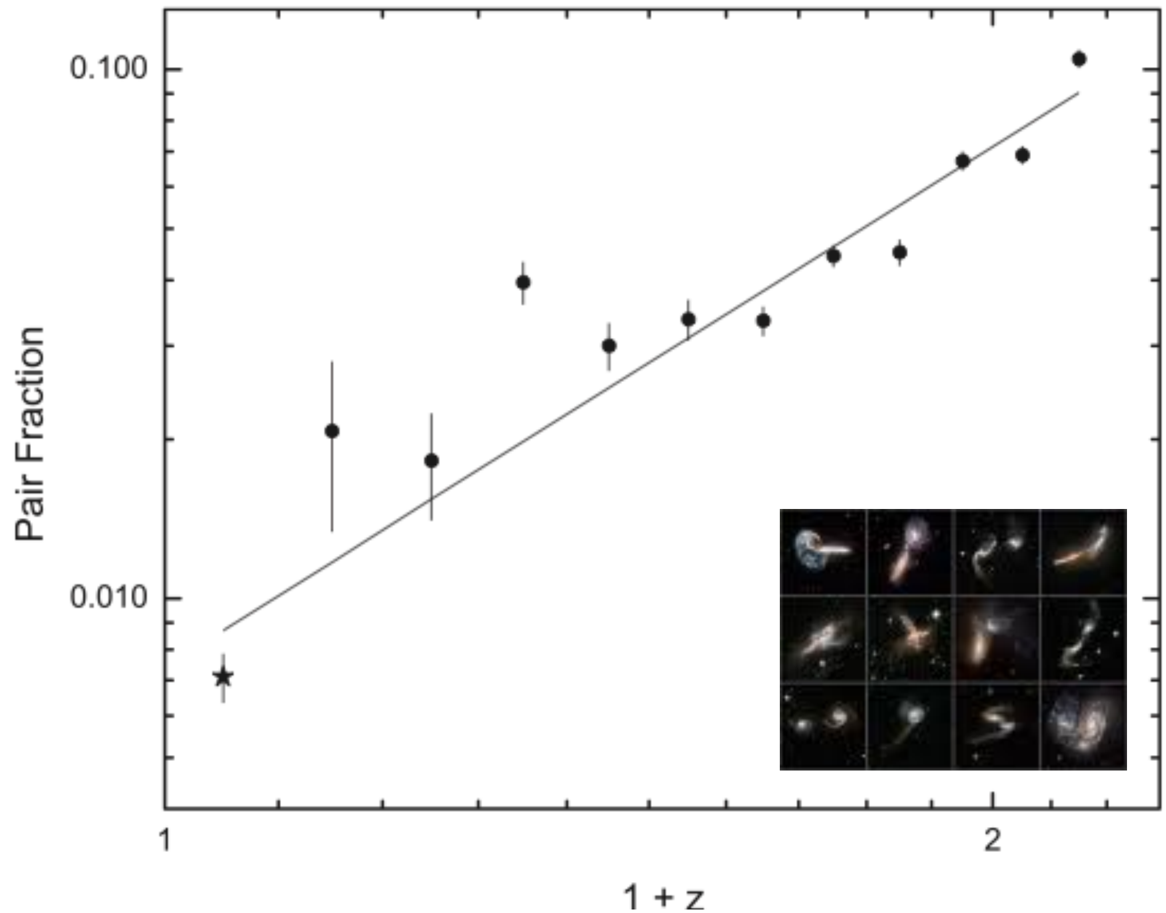
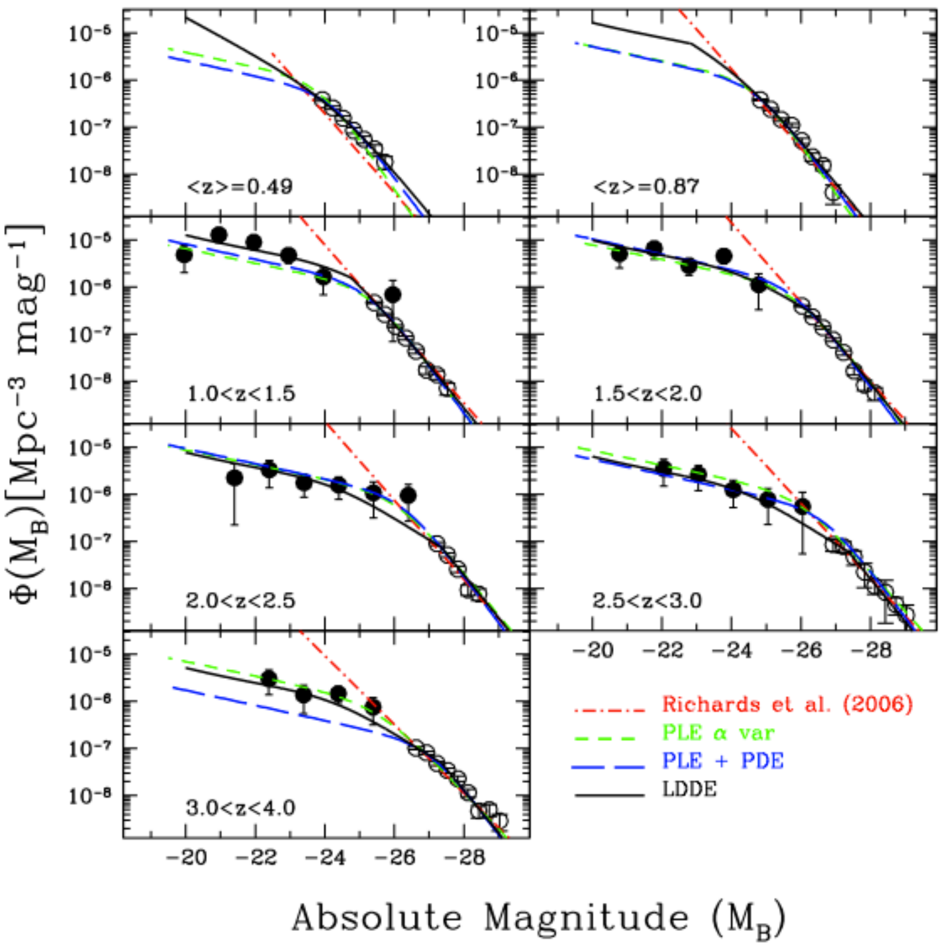
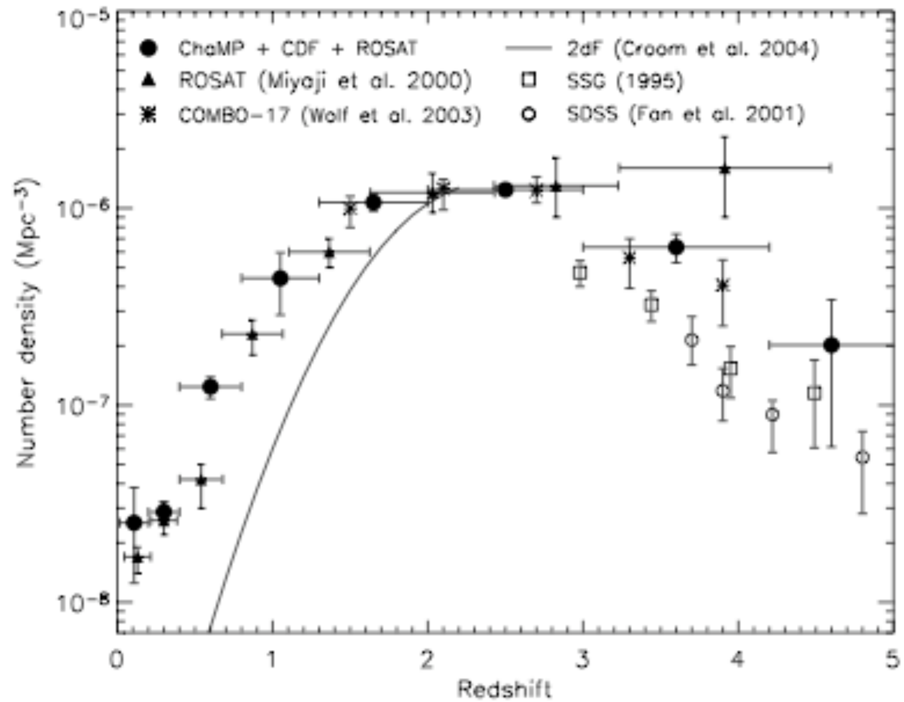


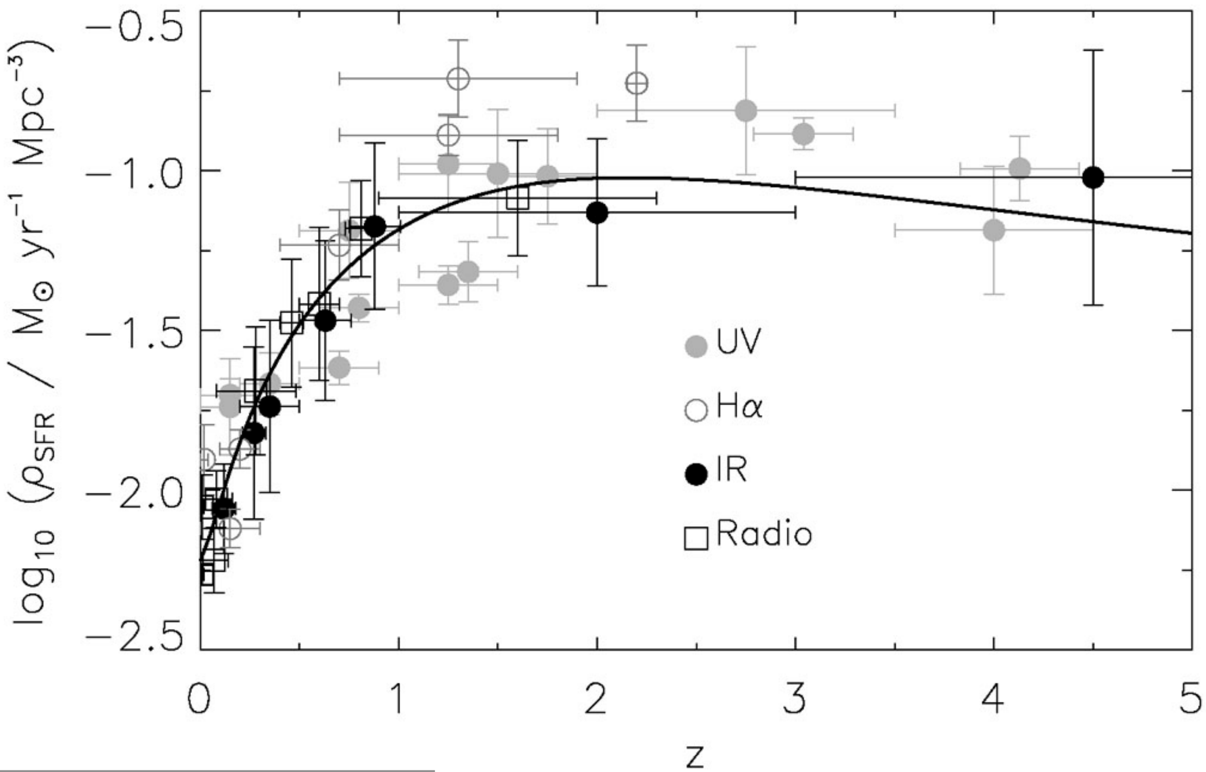
Fig. 2.— Fraction of $\geq L_V^{\star}$ galaxies in close pairs (5−20 kpc) versus $(1+z)$ for the COSMOS field. The star marks the local ($z = 0 - 0.1$) data point determined using data from the SDSS (see text). Vertical bars represent 1σ error. The straight line least squares fit to the data has a slope of $n = 3.1 \pm 0.1$.

Evolucija kvazara



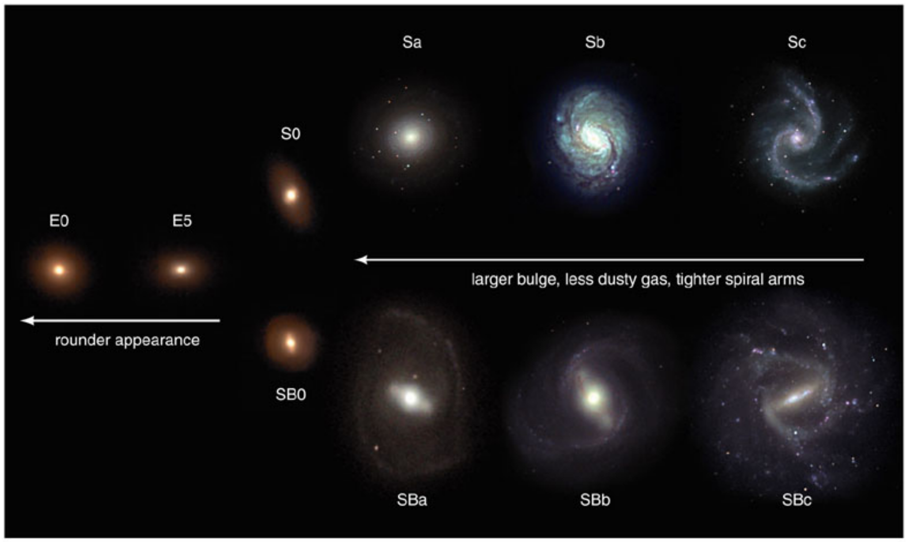


Povijest stvaranja zvijezda u svemiru

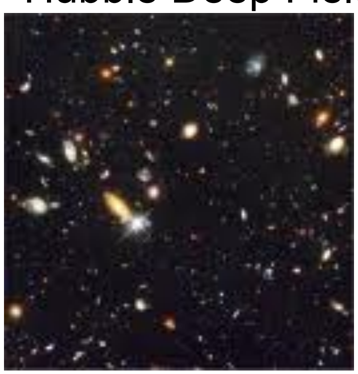


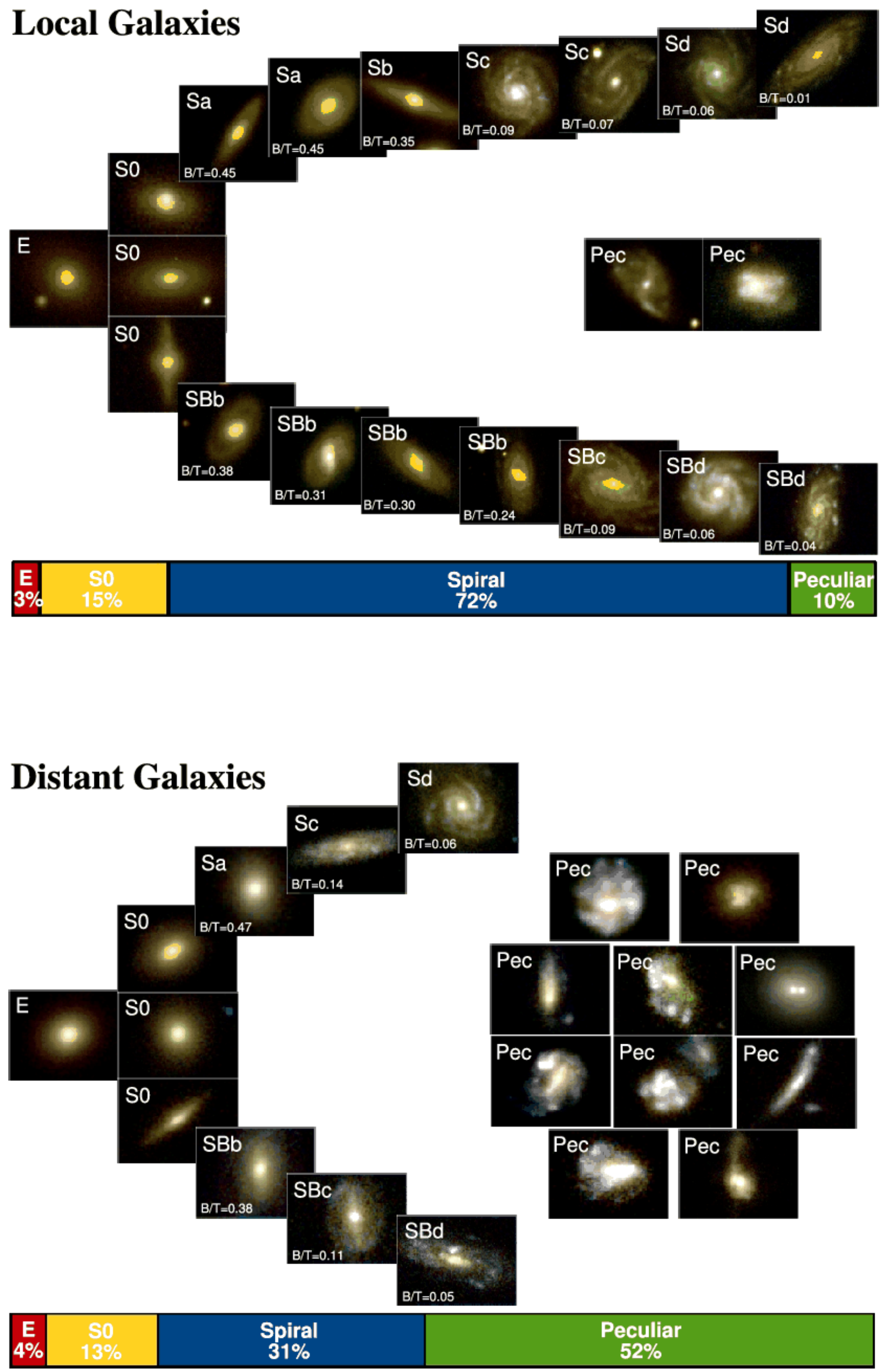
Star formation rate density
[$M_\odot$ / yr / Mpc^3]

Hubblova klasifikacija, z>>



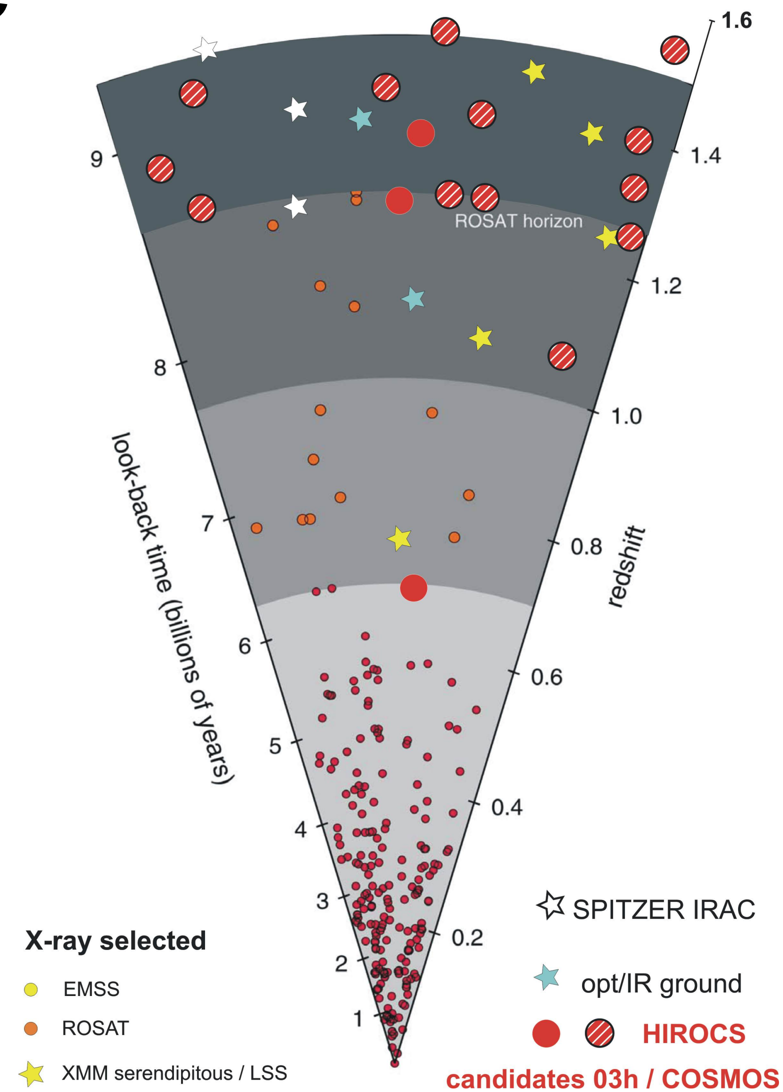
Hubble Deep Field





Skupovi galaksija & Butcher Oemler efekt

- Butcher Oemler effect:
  - skupovi galaksija na srednjem redshiftu (z~0.4) sadrze veci udio opticki plavih galaksija od blizih skupova
  - Udio plavih galaksija raste od ~3% (z<0.1), preko 25% na z~0.5 do ~70% na z~1



Updated from Mullis (2005)

Interakcije

Dinamicko trenje

$$f_d \cong C \frac{G^2 M^2 \rho}{v_M^2}$$

M = masa objekta koji se giba kroz polje gustoce ρ brzinom v_m

C = dimenzionalna funkcija koja opisuje kako se v_m veze na σ

NB! v_m<< => f_d >> => sporo suceljavanje efikasnije

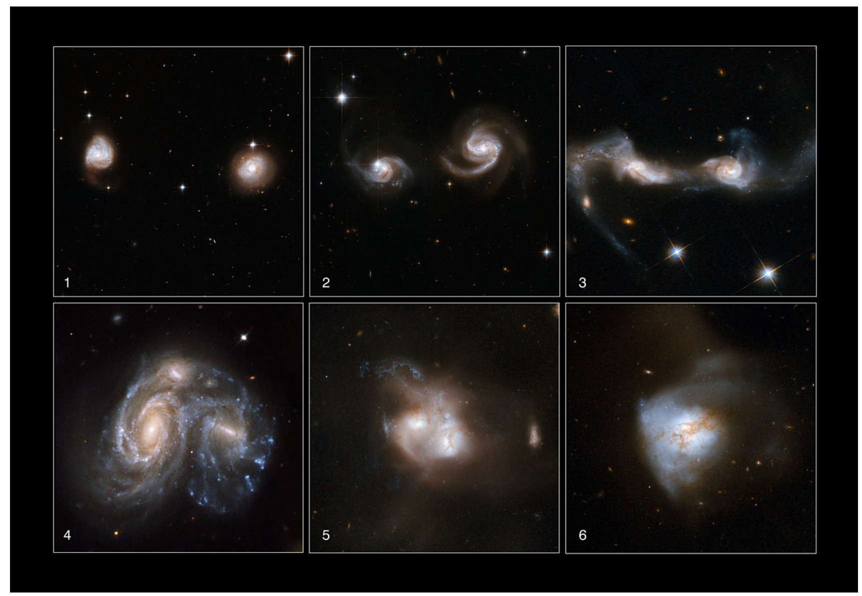
- Sudari galaksija; slijeganje objekata u dna potencijalnih jama (skupovi zvijezda/galaksija)
- Pr. Andromeda “guta” kuglaste skupove u orbiti oko njenog sredista; proracun udaljenosti od centra do skupova koju su mogli prezivjeti u zivotu M31

Brze interakcije

- Zvijezde u galaksiji nemaju vremena reagirati
- Potencijalna E galaksija ostaje ista, ali se unutarnja kineticka energija obje galaksije nasumicno poveca
- Nakon ponovne uspostave ravnoteze kin. E (E_K) se smaji za $2\Delta E_K$ =>
  a) promjena pot. E,
  b) tok zvijezda/plina ("isparavanje" koje hladi galaksiju i stavlja ju u novu ravnotezu)

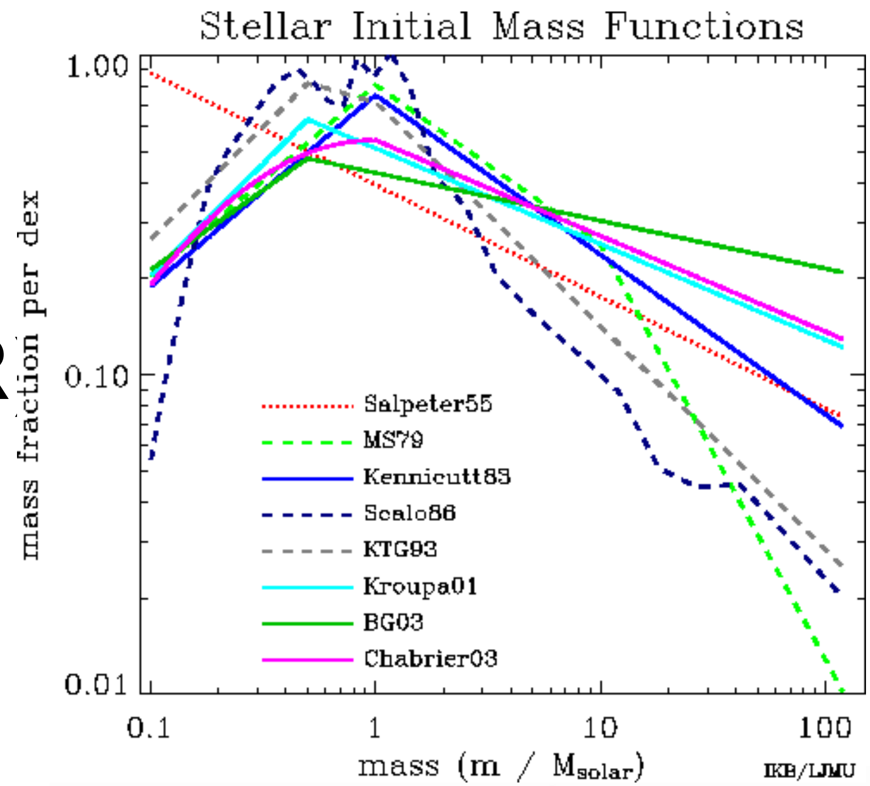
Kako nastaju elipticne galaksije?

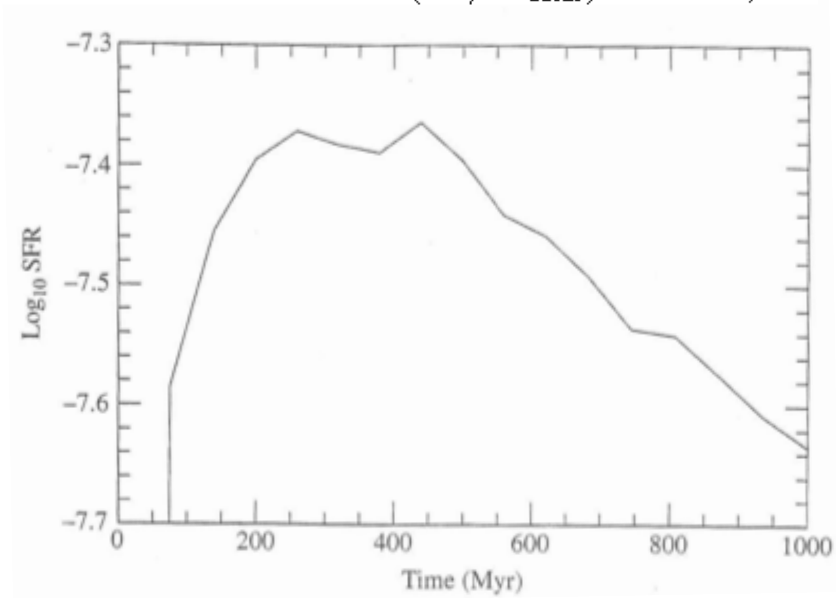
- Moguce je da su SVE velike elipticne galaksije (djelom) stvorene sudarima
- dE, dSph cini se nisu rezultat sudara (drukcija evolucija od ostalih sfericnih galaksija)



Vazni aspekti za stvaranje galaksija

Pocetna funkcija mase (IMF) & frekvencija stvaranja zvijezda (SFR)





- Frekvenicja stvarnja novih zvijezda, B(M,t) se izrazava putem frekvencije stvaranja zvijezda SFR=Ψ(t) i pocetne funkcije mase, IMF=ξ(M):

  $B(M,t)dMdt=\Psi(t)\ \xi(M)dMdt$

  $\xi(M)=dN/dM=CM^{-(1+x)}$

  – Salpeter x=1.35

Urusavanje plina (vremenske skale slobodnog pada i hladjenja)

$$-2\langle K\rangle = \langle U\rangle \Rightarrow t_{cool} = \frac{3}{2}\frac{kT_{virial}}{n\Lambda}$$

- $t_{cool} > t_{ff}$ => oblak ne moze efikasno izraciti grav. pot energiju otpustenu kolapsom => T adijabatski raste kako se oblak urusava, cime se povecava unutarnji pritisak te se konacno zaustavlja urusavanje
- Protogalakticki oblak: $T \sim 10^6$K, $n \sim 0.05$cm^{-3} => gornji limit mase koja se moze ohladiti i urusiti 10^{12} M_{Sun} @60kpc, ako $T \sim 10^4$ K onda $M_{limit} \sim 10^8 M_{Sun}$

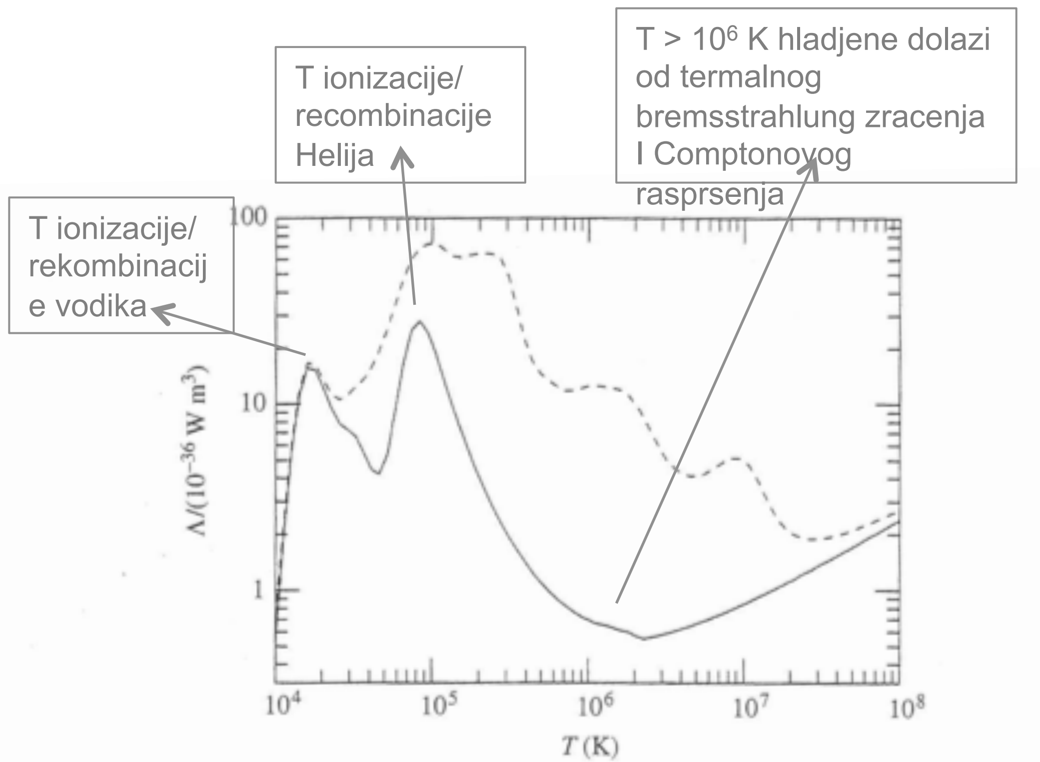
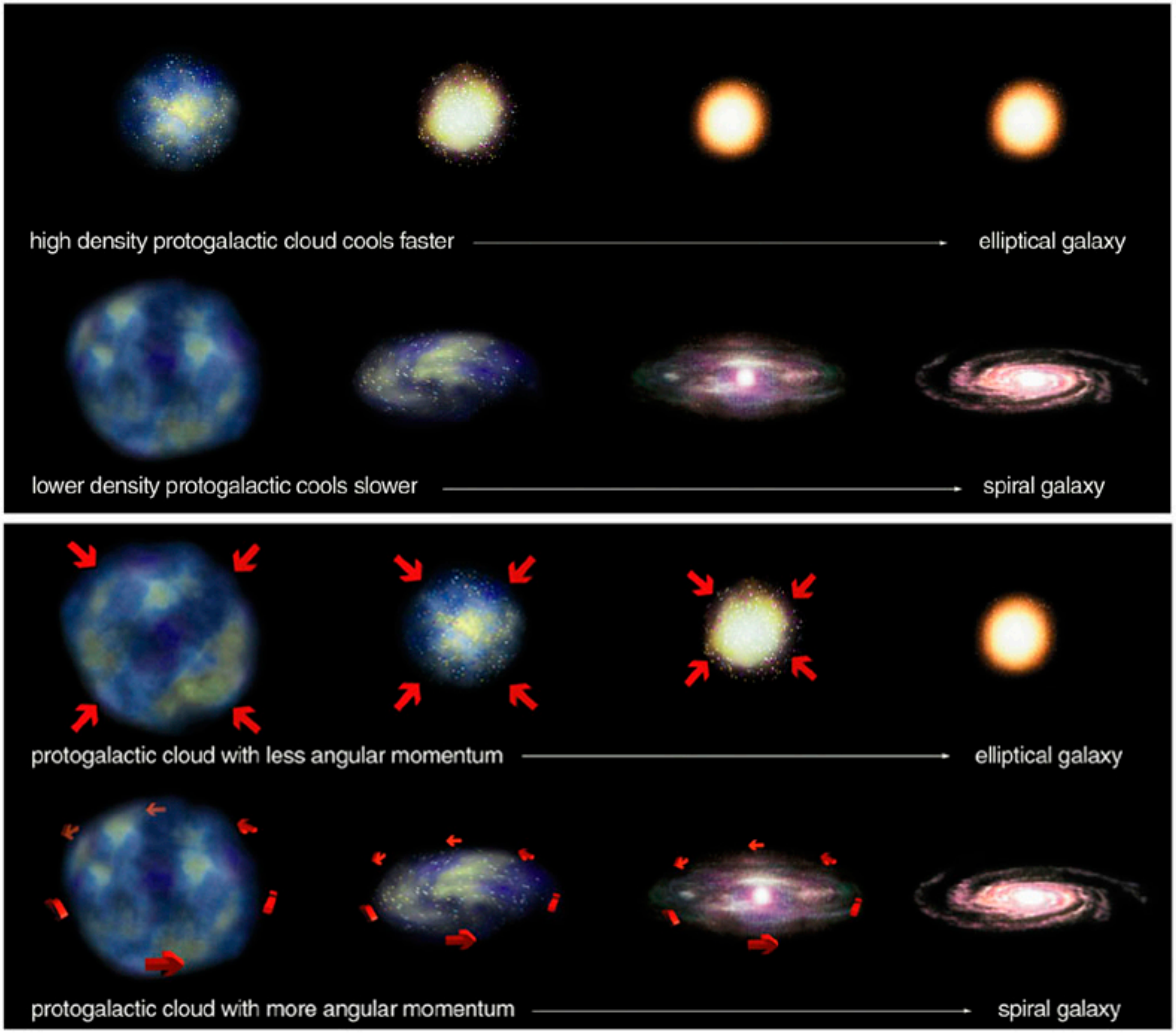


FIGURE 26.19 The cooling function $\Lambda(T)$. The solid line corresponds to a gas mixture hydrogen and 10% helium, by number. The dashed line is for solar abundances. (Figure adapt Binney and Tremaine, *Galactic Dynamics*, Princeton University Press, Princeton, NJ, 1987.)



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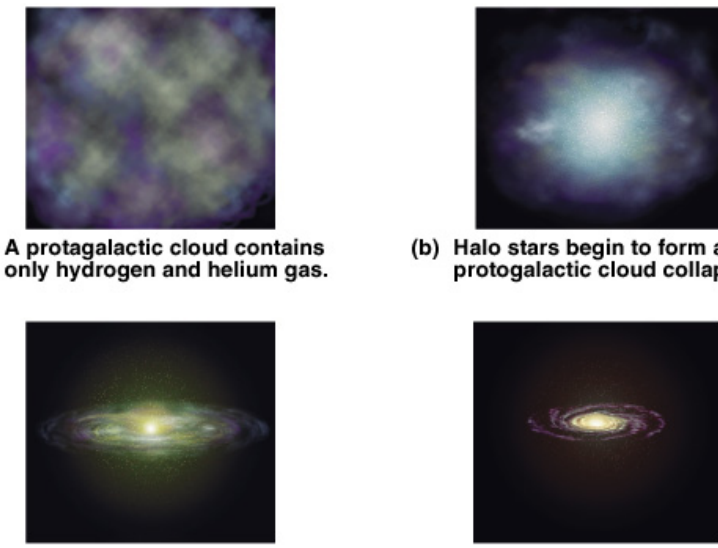
$$t_{cool} = \frac{3}{2}\frac{kT_{virial}}{n\Lambda}$$

Stvaranje galaksija

Top-down scenarij

- Eggen, Lynden-Bell, Sandage (1962)
- Model razvijen za Mljecni Put
- Brzi kolaps velikog proto-galaktickog oblaka
- Najstarije zvijezde u halo-u su stvorene najranije u kolapsu (radijalne trajektorije u kolapsu => vrlo elipticne orbite visoko/nisko od diska te malo metala)
- Brz kolaps usporen kad je porasla ucestalost sudara medju cesticama te je E_K disipirana (pretvorena u termalnu E nasumicnog gibanja cestica)
- Zbog pocetnog angularnog momenta, oblak rotira brze kako mu se radijus smanjuje => kombinacija povecane disipacije te angularne brzine je dovelo do stvaranja diska s Pop-I (kemijski obogacenim) zvijezdama



(a) A protagalactic cloud contains only hydrogen and helium gas.

(b) Halo stars begin to form as the protogalactic cloud collapses.

(c) Conservation of angular momentum ensures that the remaining gas flattens into a spinning disk.

(d) Billions of years later, the star–gas–star cycle supports ongoing star formation within the disk. The lack of gas in the halo precludes further star formation outside the disk.

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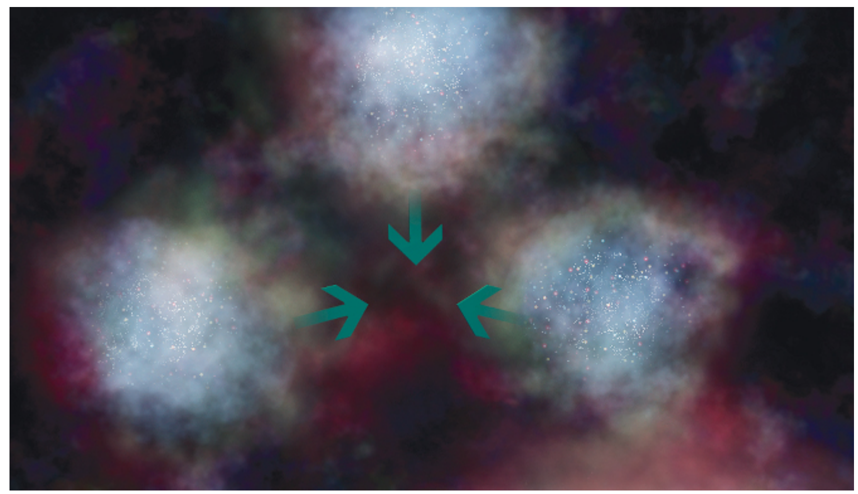
Problemi top-down scenrija

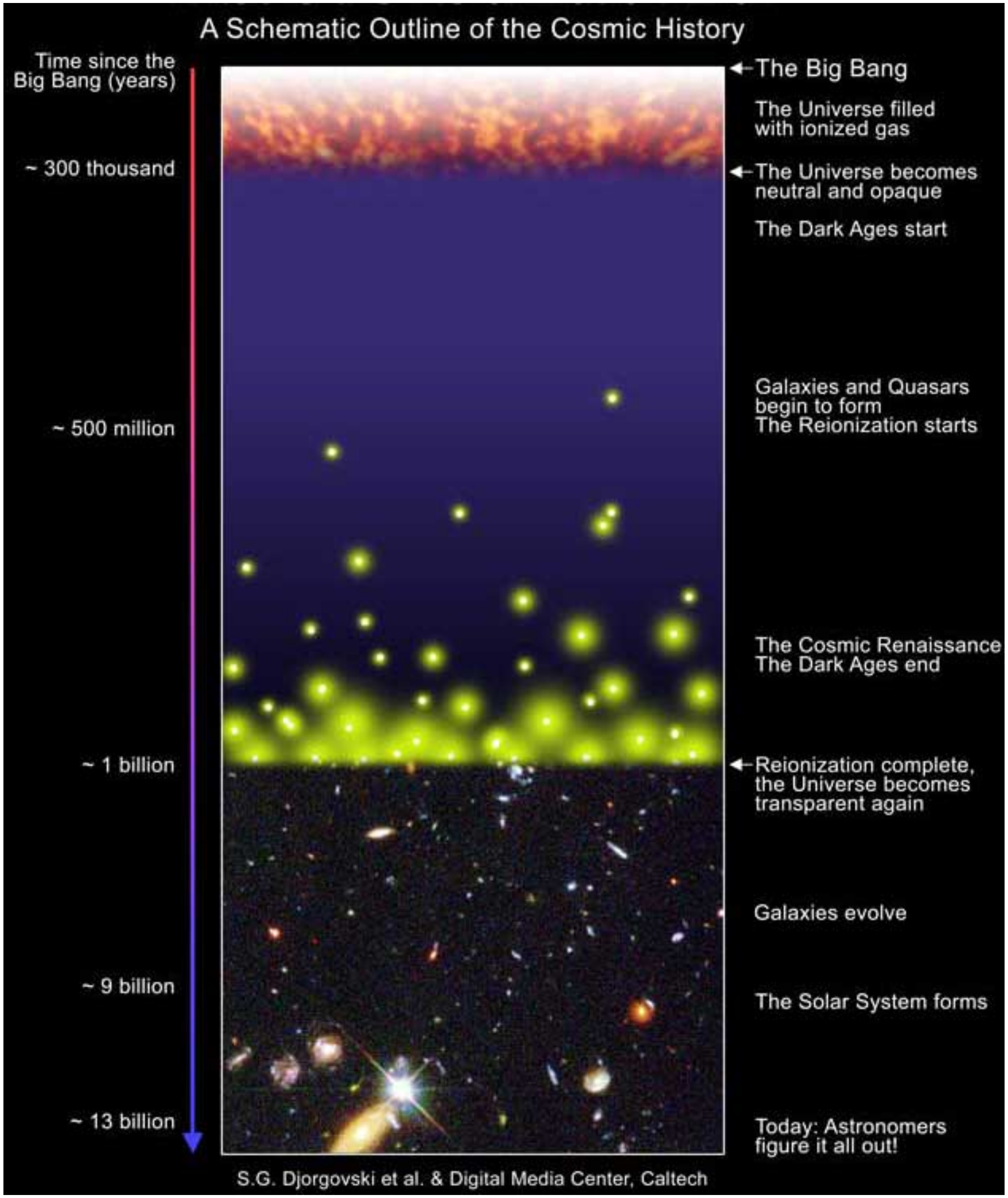
- Zbog pocetnog angularnog momenta sve halo zvijezde/zvjezdani skupovi trebali bi se kretati u istom smjeru (nije slucaj)
- Opazena razlika u starosti kuglastih skupova implicira mnogo duzi kolaps nego model zahtjeva
- Ne objasnjava disk od vise komponenti zvijezda razlicitih starosti
- Kuglasti skupovi razlicitih kompozicija (i u halo-u i u disku) dok model predvidja samo “metal-poor” u halou

Bottom-up scenarij

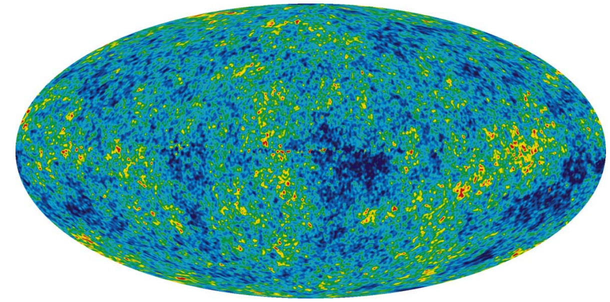
- Larson (1969)
- Vece strukture se stvaraju sudarima manjih
- Podrzano mnogim opazanjima sudara galaksija (cini se da su sudari 'standardni' u zivotu galaksija)



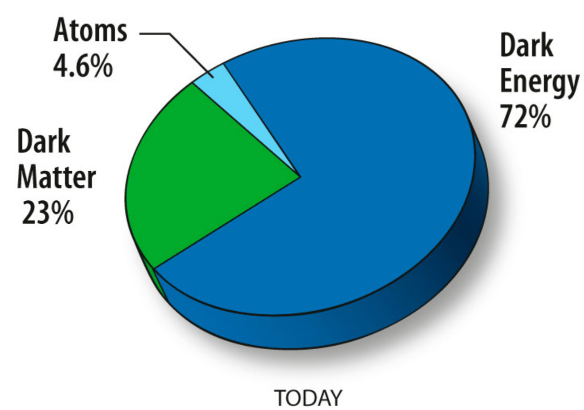
Danasnji pogled na razvoj strukture u svemiru



Kozmicko mikrovalno zracenje (WMAP)



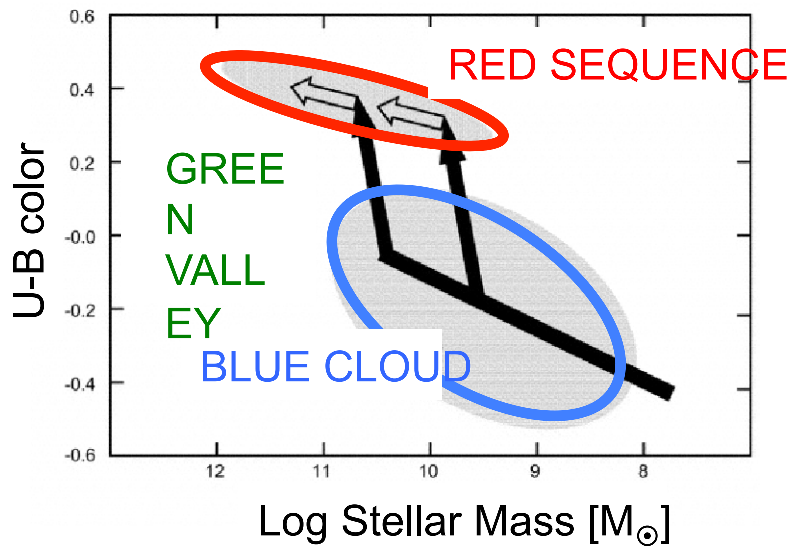
ΛCDM model svemira
Struktura raste hijerarhijski



- Ubrzo nakon Velikog Praska => fluktuacije gustoce materije (najvece na najmanjim skalama mase; tj. mnogo cesce na skalama 10^6-$10^8 M_{Sun}$, nego $10^{12} M_{Sun}$)
- Privuceni gravitacijom protogalakticki fragmenti su se poceli spajati => sferoidna distribucija => stvaranje zvijezda, kuglasti skupova u centrima (kemijsko obogacenje)
- U centrima n>> => kolaps brzi => brza frekvencija stvranja zvijezda i kemijsko obogacenje => brze stvaranje centralnog zadebljanja
- Sudarima raste T => usporavanje kolapsa te pro- i retro-gradne orbite kuglastih skupova
- Sudarima oblaka plina u sudarajucim protogalaktickim fragmentima kolaps je postao disipativan => plin se poceo slijegati prema centru

- Zbog pocetnog angularnog momenta (zbog zakretnog momenta uzrokovanog susjednim oblacima) kolabirajuci plin postaje rotaciono podrzan i slijeze se u disk oko centra
- Thick disk formiran kad je T~10^6 K u ioniziranom plinu diska => hladjenje se nastavlja, @10^4 K stvara se HI => stvaranje zvijezda => grijanje na 10^6K (self-regulating process)
- U podrucjima gdje je plin bio vece gustoce hladio se brze => nastavak kolapsa => hladan molekularni plin se slijeze u tanki disk (stari & mladi tanki disk)
- Mlade zvijezde u sredisnjem zadebljanju dolaze od nedavnih sudara sa satelitskim galksijama bogatim plinom
- Smatra se da se elipticne galaksije (cesto) stvaraju sudarima spiralnih

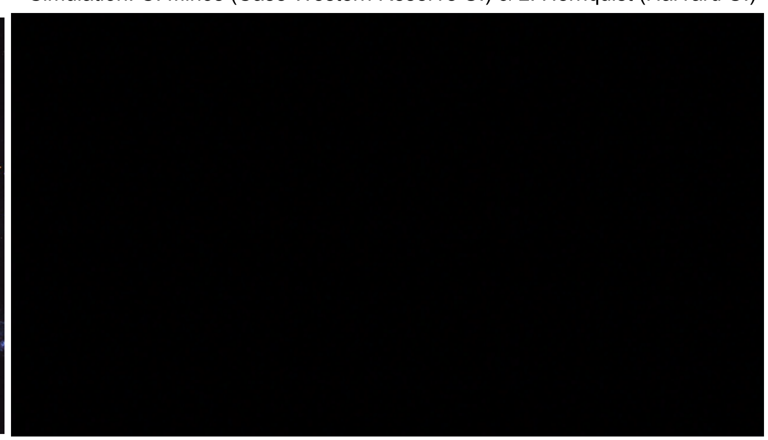
Stvaranje masivnih crvenih elipticnih galaksija



- Blue-to-red galaxy formation
- Sanders & Mirabel 1996, Bell et al. 2004, Borch et al. 2006, Faber et al. 2007, Hopkins et al. 2007 & many others

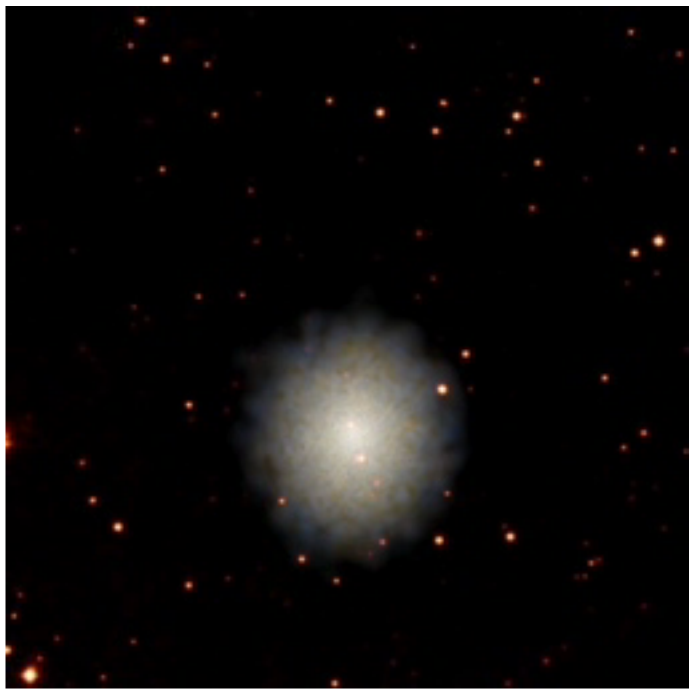
M101; The Pinwheel Galaxy; Copyright: A. Block, U. Arizona

Visualization: F. Summers (Space Telescope Science Institute).
Simulation: C. Mihos (Case Western Reserve U.) & L. Hernquist (Harvard U.)



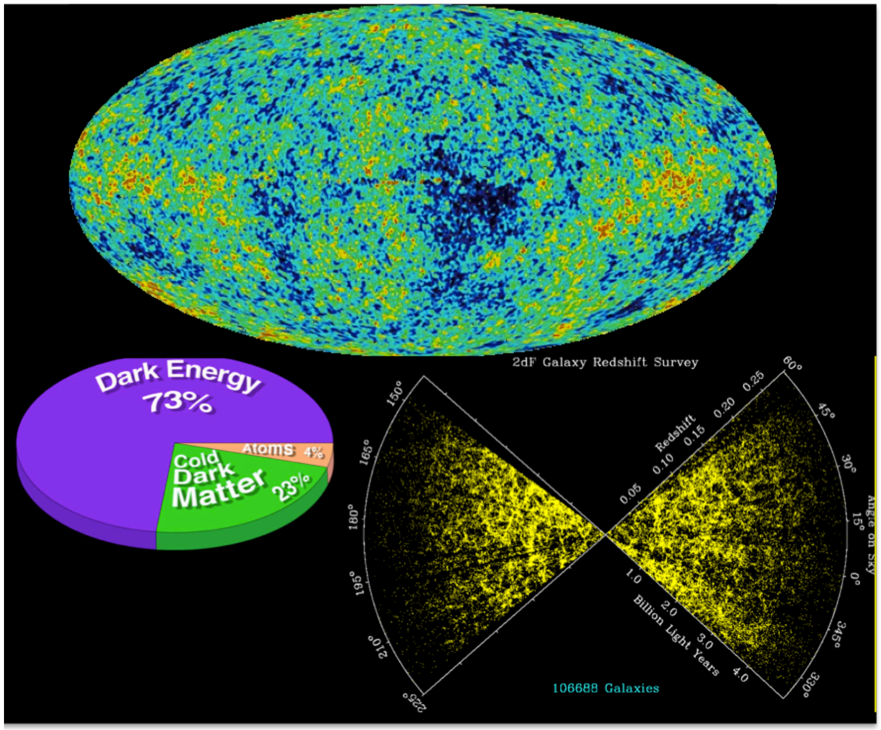
M87; Virgo cluster; Copyright: R. Gendler

Stvaranje masivnih elipticnih galaksija putem sudara dvaju spiralnih: Simulacije



Model svemira: ΛCDM

- ΛCDM: cold (= nerelativisticke brzine) dark matter + dark energy (kozmoloska konstanta, Λ≠0)
- Standardni model “Big Bang” kozmologije
- Model se odlicno slaze sa sirokim nizom opazanja, npr. CMB, galaxy clustering, type 1a SN, udjeli elemenata, starost zvijezda, udio bariona u skupovima galaksija, boje galaksija…



Merger Tree for the Growth of a Dark-matter Halo

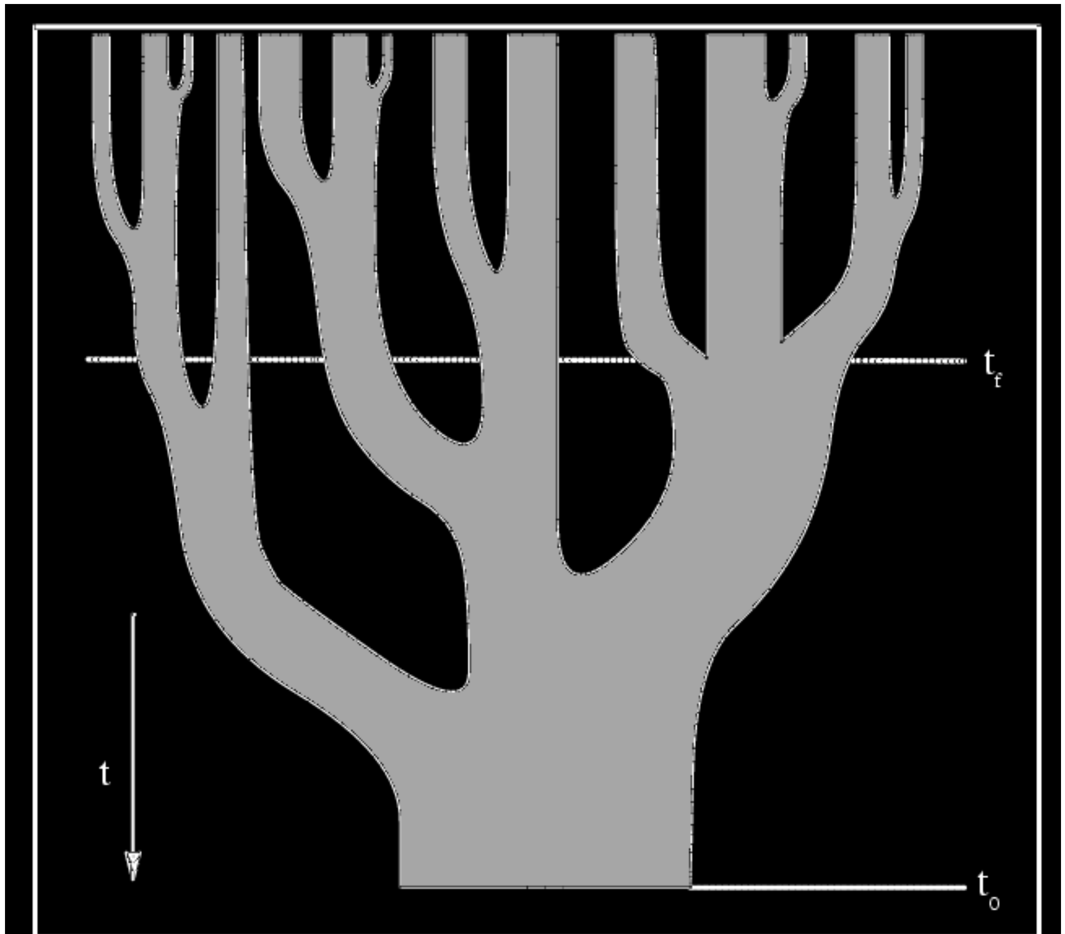
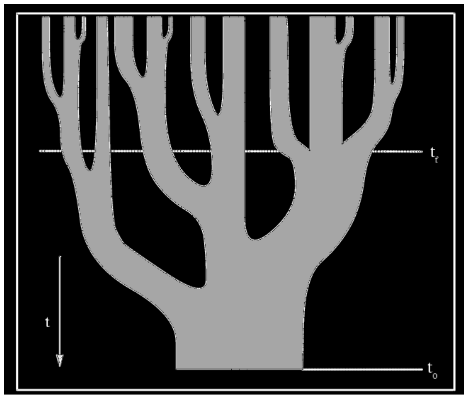


Figure 6. A schematic representation of a "merger tree" depicting the growth of a halo as the result of a series of mergers. Time increases from top to bottom in this figure and the widths of the branches of the tree represent the masses of the individual parent halos. Slicing through the tree horizontally gives the distribution of masses in the parent halos at a given time. The present time t_0 and the formation time t_f are marked by horizontal lines, where the formation time is defined as the time at which a parent halo containing in excess of half of the mass of the final halo was first created.

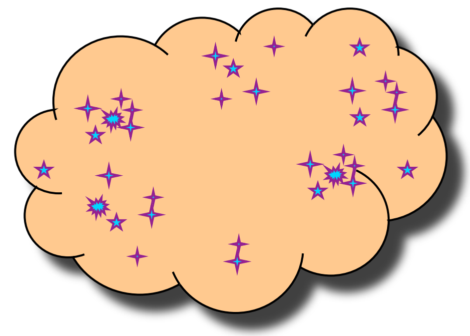
Struktura u svemiru raste hijerarhijski; sudarima manjih fragmenata stvaraju se veci

Semi-analytic Galaxy Formation Models



N-body merger trees

+



"Messy" fizika
(hladjenje plina, stvaranje zvijezda, prasina, feedback od supernovae, AGN-ova, etc…)

=

Millenium simulation