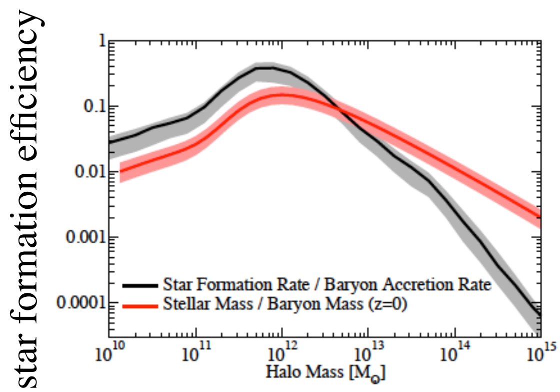
Theoretical ideas About Galaxy Wide Star Formation

Theoretical predictions are that galaxy formation is most efficient near a mass of $10^{12} M_\odot$ based on analyses of supernova feedback and gas cooling times (Silk 1977; Rees & Ostriker 1977; Dekel & Silk 1986; White& Rees 1978; Blumenthal et al. 1984- please read this classic paper).

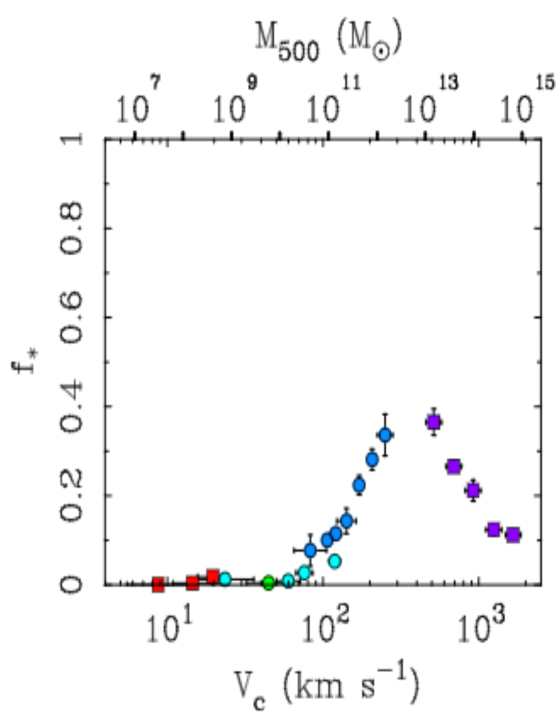
Hydrodynamical simulations show host dark matter halo mass strongly influences gas accretion onto galaxies

- For low halo masses, simulations predict that gas accretes in cold filaments ("cold mode accretion") directly to the galaxy disk, efficiently forming stars.
- Above a transition halo mass of $\sim 10^{11} M_\odot$ a shock develops at the virial radius which heats accreting gas ("hot mode accretion") and rapidly quenches instantaneous star formation



Star Formation Efficiency

- Efficiency of conversion of baryons into stars peaks at $v_{circular}$ ~250 (Near the mass o the Milky Way- McGaugh et 2010)

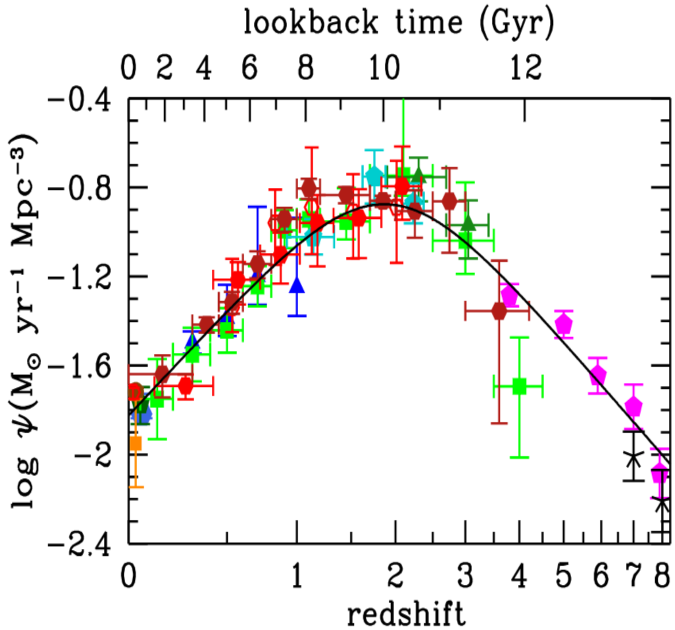


Cosmic Star Formation History

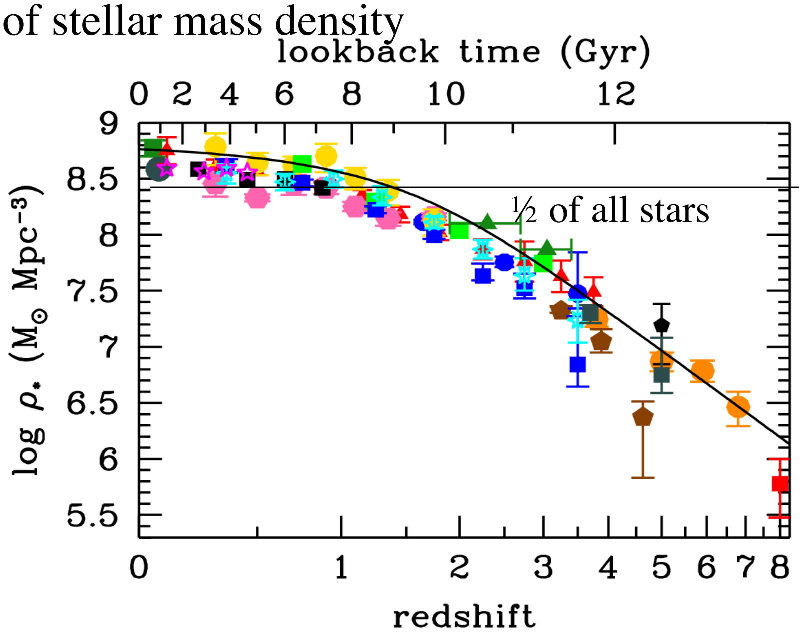
P Madau, M Dickinson ARAA 2014

- Use SFRs from rest-frame FUV (generally 1,500 ˚A) or MIR and FIR measurements

- **90% of all stars formed since z~3**
- **SFR has dropped by ~10x since z~1.**



Evolution of stellar mass density



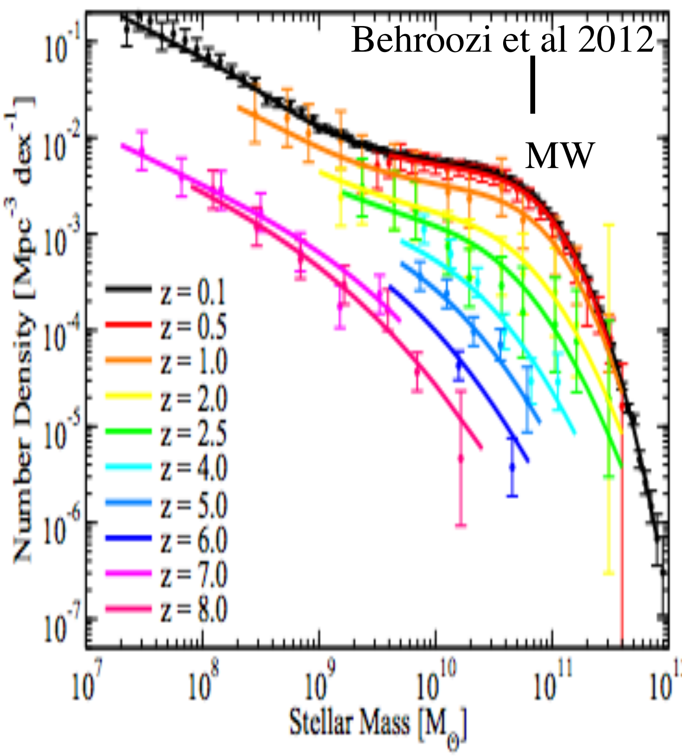
- Half of all stars form since z~1Madau and Dickinson 2014

Cosmic History of Star Formation

General Results

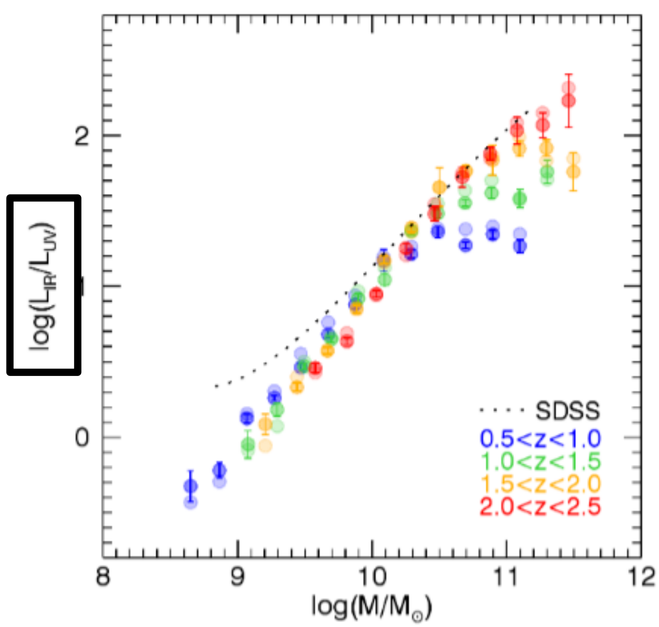
- The most massive galaxies
  - Form stars vigorously at z>2
- Massive galaxies form first and small one later (sort of)

Growth of galaxies



The Effects of Dust are Mass and SFR Dependent

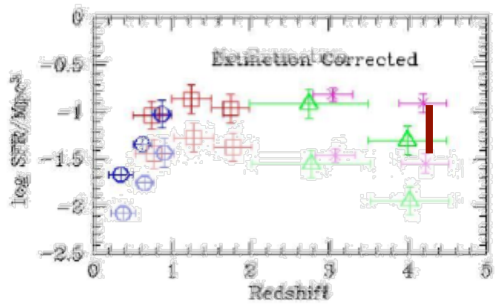
- The luminosity in the IR (L_{IR}) divided by the luminosity in the UV (L_{UV})for star forming galaxies is a measure of the effects of dust.
- The more massive the galaxy (and thus the higher the SFR) the more important dust is!



(Whitaker et al 2014)

Dust

- As we discussed before the effects of dust and how one treats is can be a very large effect.
- As an example take the star formation history of the universe as revealed by deep 'optical' studies- it shows that 'correcting for dust' introduces a factor of 3 change!
- Correcting for dust is not easy to do



For those interested in more details on starbursts see Peter Barthels course notes
http://www.astro.rug.nl/~pdb/starbursts.htm

Star formation Occurs in Giant Molecular Clouds

- Cooling to 10^4 K is not sufficient to form stars.
- The gas has to cool well below 100K and must be shielded from UV radiation by dust.
- Star formation occurs in giant molecular clouds with masses of 10^3-10^7 M and radii of 1-100pc.
- These clouds can become gravitationally unstable and collapse and form stars .
- The effects of feedback (e.g. stellar winds and SNR) are not at all clear

Summary of Situation

- Large scale SFR is determined by a hierarchy of physical processes spanning a vast range of physical scales:
  - the accretion of gas onto disks from satellite objects and the intergalactic medium(Mpc)
  - the cooling of this gas to form a cool neutral phase (kpc)
  - the formation of molecular clouds (10-100 pc);
  - the fragmentation and accretion of this molecular gas to form progressively denser structures such as clumps (~ 1 pc) and cores (~ 0.1 pc)
- The first and last of these processes operate on galactic (or extragalactic) and local cloud scales, respectively, but the others occur at the boundaries between these scales and the coupling between processes is not yet well understood.
- the challenge of explaining the low efficiency of star formation remains.
- Similarly, an understanding of the full IMF, remains elusive.

Kennicutt and Evans 2012

Next Lecture

- Spiral Galaxies

Possible Star Formation 'Laws'

- Define **star formation efficiency** SFE=$\Sigma_{SFR}/\Sigma_{gas}$
- to form stars in in spirals need
  - cold phase (n ~ 4–80 cm^{-3}, T ~ 50–200 K)
  - and gravitationally bound clouds
- A star formation law *should* predict the SFE from local conditions (physics)

1) Kennicutt-Schmidt law $\Sigma_{SFR} \sim \Sigma_{gas}^{1.5}$

- stars form on a characteristic timescale equal to the free-fall time in the gas disk, $\sim\rho^{-1/2}$
- since $\rho_{gas} \sim \Sigma_{gas}$ and $\Sigma_{SFR} \sim \Sigma_{gas}^{1.5}$
- expect SFE$\sim\Sigma_{gas}^{0.5}$

Disk free-fall time : if scale height of disk set by hydrostatic equilbrium then

$t_{ff} \sim \rho^{-1/2}$ related to the velocity field and density of stars and gas

or some other timescale such as orbital timescale such as orbital timescale $t_{orb}=\Omega/2\pi=2v(r)/2\pi r$

or perhaps gravitational instability - gas unstable against collapse when Toomre $Q=\sigma_g\kappa/\pi G\Sigma_{gas}<1$;κ is the epicyclic frequency; velocity dispersion of the gas σ_g