Galaxy Formation and Evolution

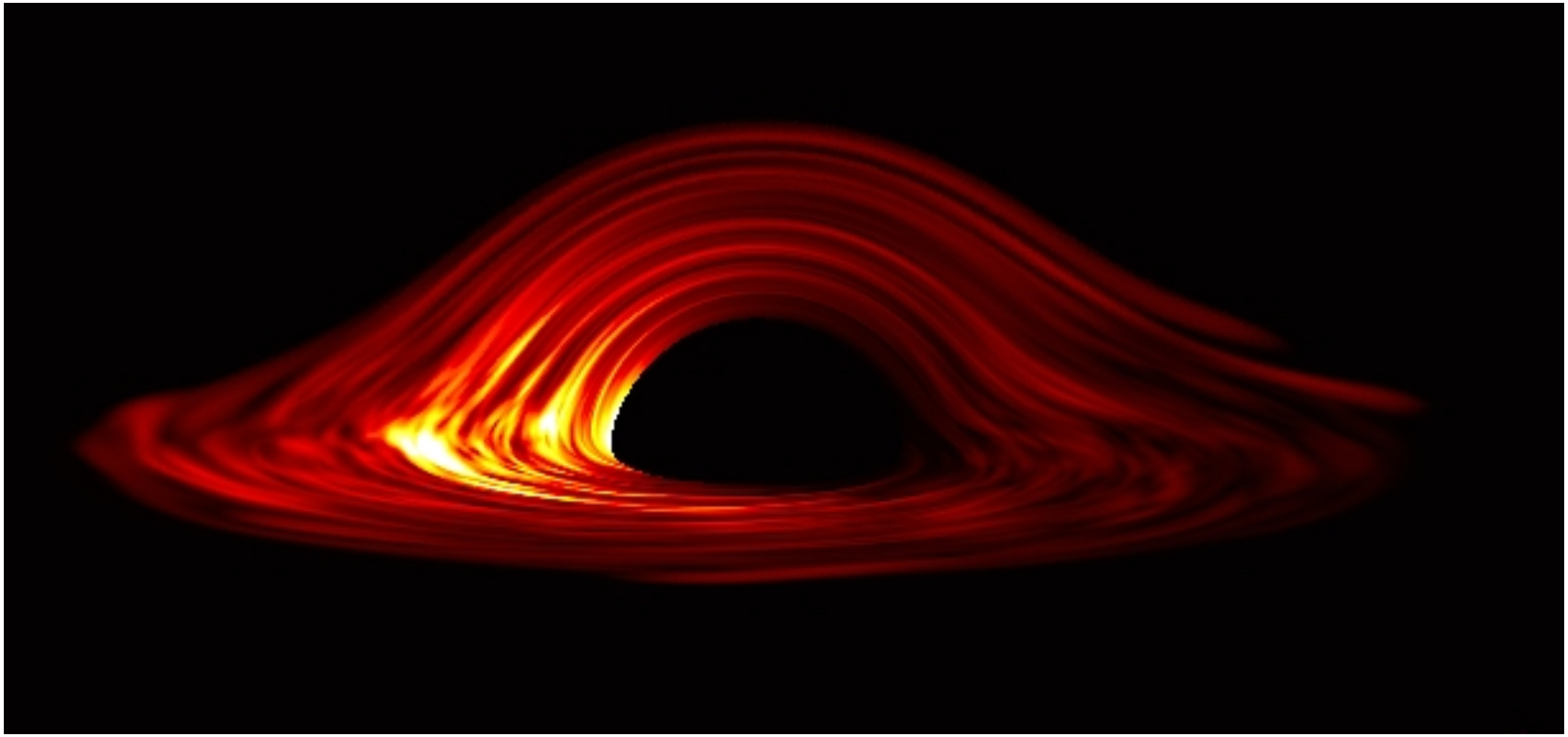
Lecture 13
Black hole growth and formation

Course contents

1. Historical introduction
2. Challenges and recent advances
3. Galaxy formation in theory
4. Spectral synthesis and star formation indicators
5. The fossil record for local galaxies
6. Survey astronomy
7. The Madau Diagram and Lyman Break galaxies
8. Studying galaxy evolution in the IR/sub-mm
9. The evolution of early-type galaxies
10. Morphological evolution and spiral galaxies
11. AGN discovery and observed properties
12. AGNs and supermassive black holes
13. <u>Black hole growth and formation</u>
14. The triggering of AGN
15. AGN feedback and outflows
16. The link between star formation and AGN activity
17. The far frontier and outstanding challenges
18. The future of the Universe

Supermassive black holes

The energy source for active galactic nuclei

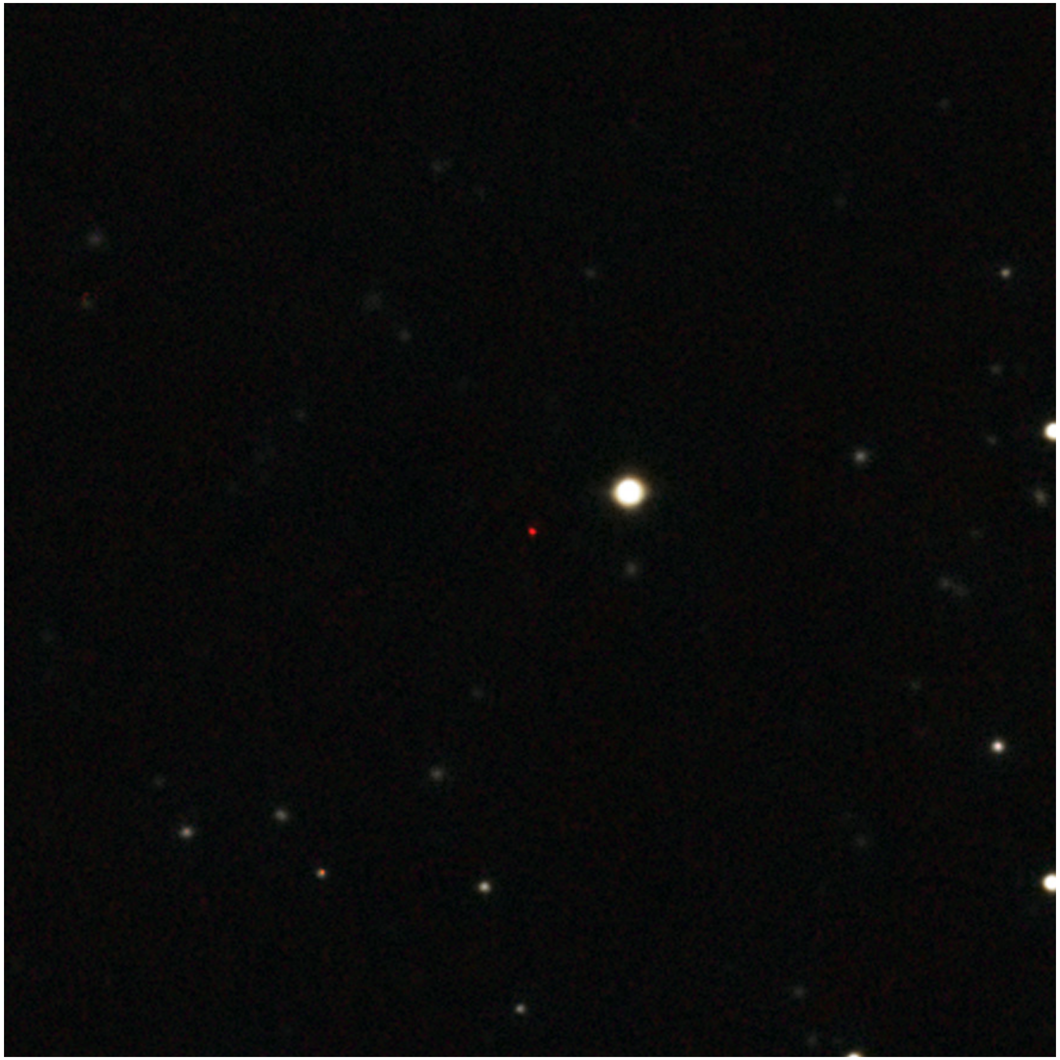


Armitage and Reynolds (2003)

$$L_{BOL} = \eta \dot{M} c^2 ; \eta \sim 0.1 - 0.3$$

The (2nd) highest redshift quasar

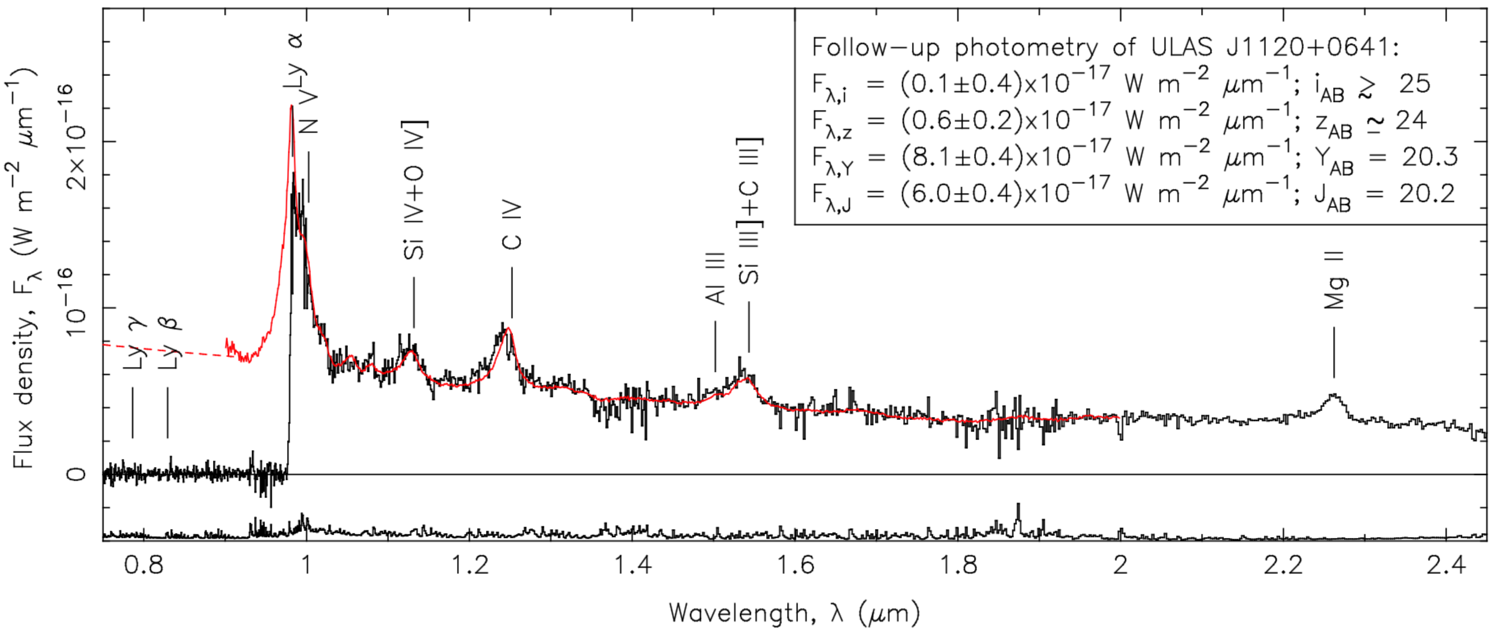
ULAS J112001.48+064124.3 ($z=7.085$)



Mortlock et al. (2011)

The (2nd) highest redshift quasar

ULAS J112001.48+064124.3 (z=7.085)



Virial black hole mass: M_{bh} = 2x10^9 $M_\odot$

Mortlock et al. (2011)

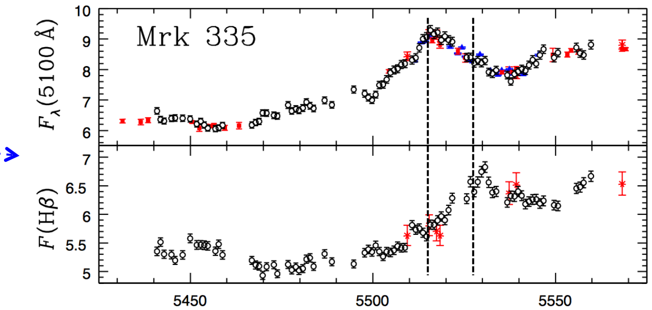
Age of the Universe at z = 7.085: 744 Myr

Bolometric luminosity: L_{bol}= 2x10^{40} W

Eddington ratio: L_{bol}/L_{edd}= 1.2

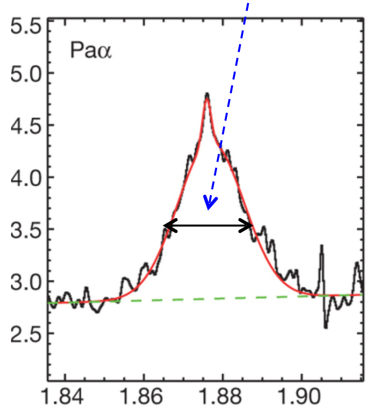
Virial black hole mass estimates

$$M_{bh} = f\left(\frac{\Delta v^2 R}{G}\right)$$

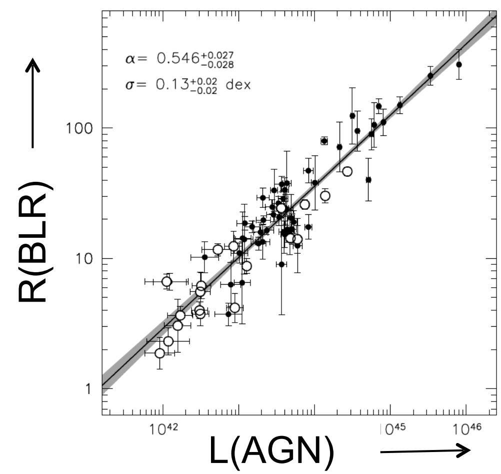


In principle, radius of BLR (R) determined from lag between continuum and line variations

Factor *f* depends on the geometry, structure and inclination of the BLR and is highly uncertain.



Δv is a measure of the emission line width (e.g. FWHM)

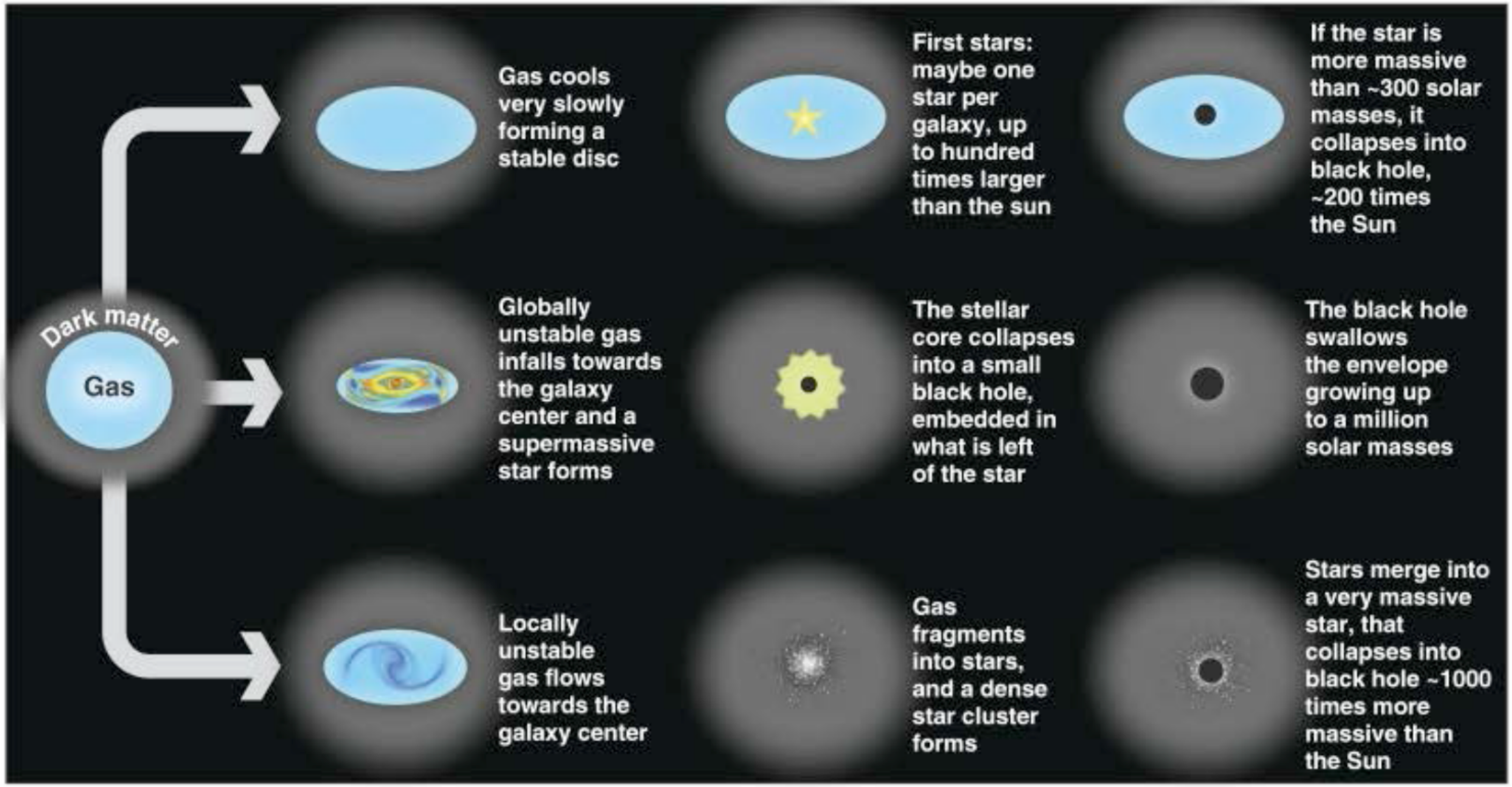


In practice, use R vs L relation calibrated for local AGN to estimate radius of BLR

Implications of high-z quasar detection and its black hole mass

- The results for the z=7.088 quasar suggest that it is necessary to form a ~2×10^9 solar mass black hole only 744 Myr after the Big Bang
- Even if the black hole grew continuously at the Eddington rate for 744 Myr, this represents a severe challenge to black hole growth/formation models
- One possibility is that the initial black hole seed mass was relatively large…
- Alternatively, perhaps super-Eddington accretion is possible for a non-spherical accretion flow

The formation of black holes in the early Universe



Volonteri (2012)

Seed black hole formation I

Single massive star

- Due to low metallicities in the early Universe, and resulting slow collapse of proto-stellar clouds, the first stars to form were likely to be very massive
- Stars more massive than a few hundred solar masses would be likely to collapse on a short timescale to form a black hole of 100s of solar masses
- But controversial whether the first stars and resultant black holes really have such high masses

Seed black hole formation II

Small black hole swallows its envelope

- The primeval gas cloud collapses to form a disk, then instabilities in this disk lead to further collapse and the formation of a supermassive star (e.g. $\sim 10^6$ solar masses) at the centre of the galaxy
- The core of the star collapses to form a small black hole (~10s solar masses), which then swallows the remainder of the stellar envelope, until radiation pressure dominates and disperses the remaining gas
- In principle, this could lead to the formation of a $\geq 10^5$ solar mass seed black hole.

Seed black hole formation III

Single super-massive star

- The primeval gas cloud collapses to form a disk, then instabilities in this disk lead to further collapse and the formation of a v. dense cluster of stars in galaxy centre
- The stars collide in the cluster and merge to form a single star of $\geq$1,000 solar masses
- This massive star collapses directly, without losing much mass to stellar winds (because metallicity low), to form a black hole of ~1,000 solar masses

Lecture 14: learning outcomes

- Understanding of the Eddington luminosity and how it is derived from first principle
- Familiarity with results on the most distant quasars and their significance for models of the formation of massive black holes
- Understanding of the virial technique for determining black hole masses
- Knowledge of the possible formation mechanisms for seed black holes in the distant universe