The Assembly of Massive Black Holes in the Early Universe

Marta Volonteri
Institut d'Astrophysique de Paris

F. Pacucci, A. Ferrara
G. Dubus, J. Silk
G. Ghisellini, F. Haardt, T. Sbarrato

BLACK erc European Research Council Established by the European Commission
MBHG SEVENTH FRAMEWORK PROGRAMME

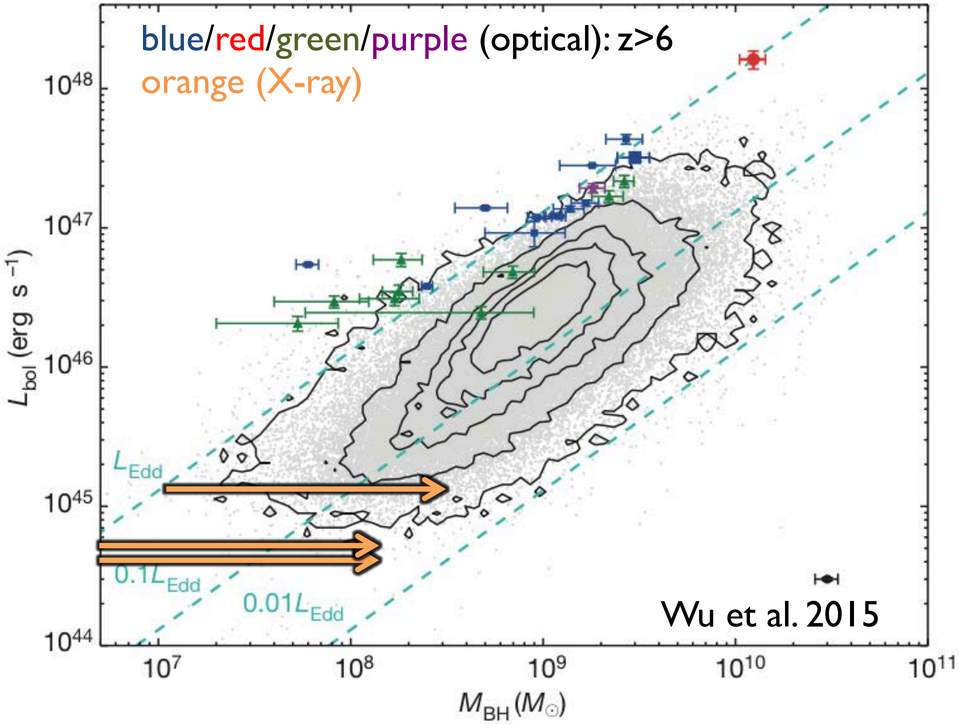
1. High-z quasars and MBHs

2. Eddington limit?

3. How do the first MBHs grow?

4. High-z jets

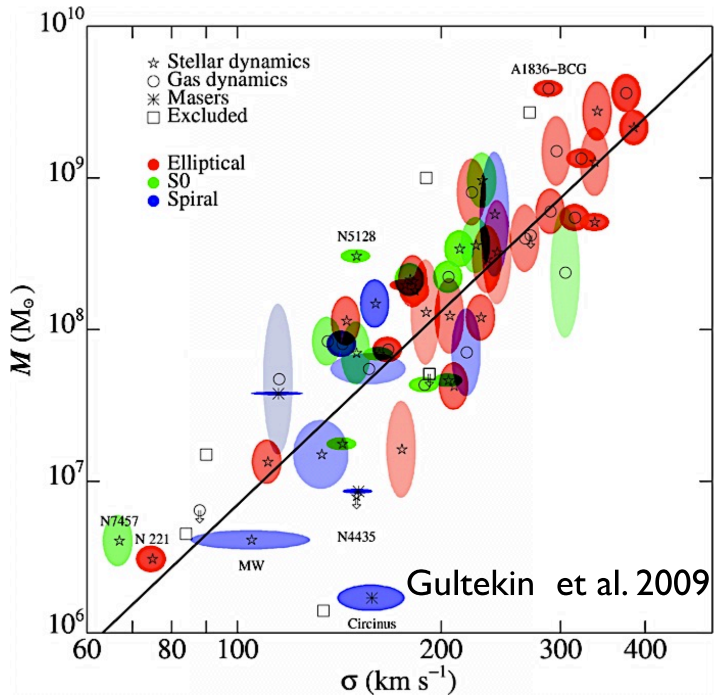
High-redshift quasars



High luminosity and large estimated MBH masses

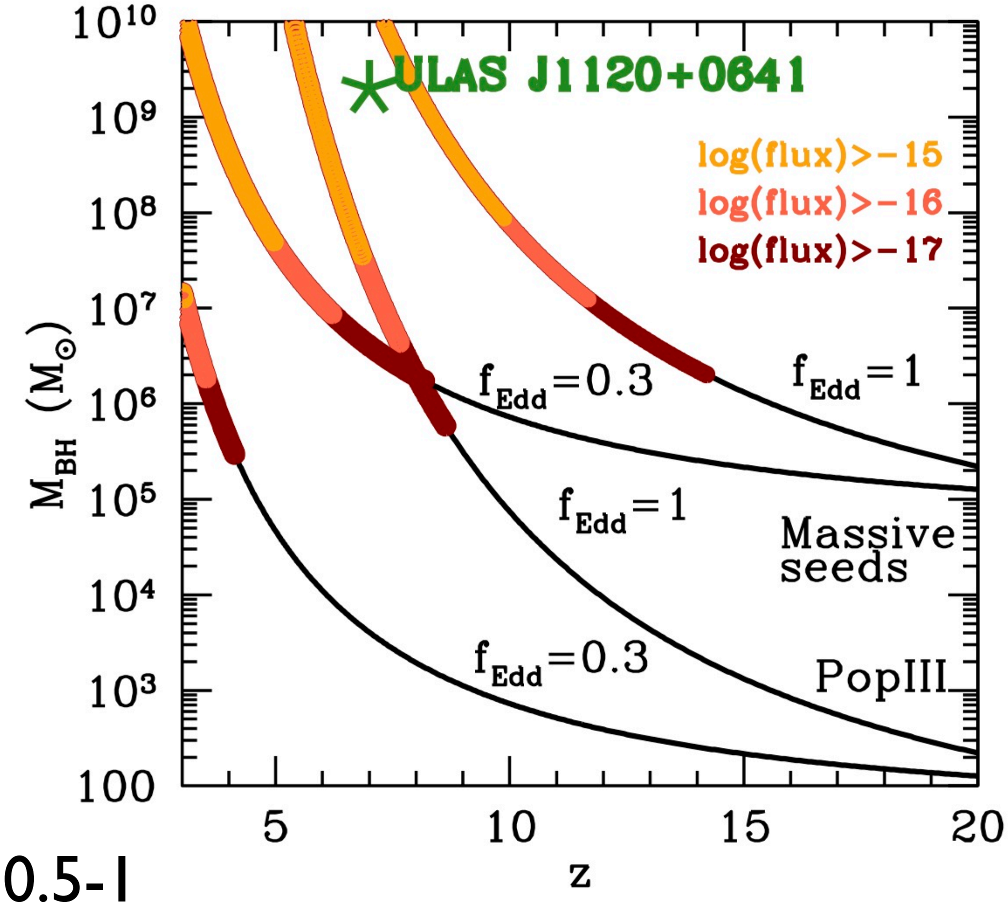
Some fainter sources found in X-ray (Fiore+12, Giallongo+15)

As massive as the largest MBHs today, but when the Universe was ~ Gyr old!



For a BH accreting at a fraction f_{Edd} of the Eddington limit, mass grows in time as:

$$M(t) = M_{in}\, e^{\left(\frac{1-\eta}{\eta} f_{\rm Edd} \frac{t}{0.45\,{\rm Gyr}}\right)}$$



ULAS J1120 @ z=7.1

M=2x10^9 Msun

t~0.75 Gyr

η~0.1

⇒ M_{in}>300-ish Msun and f_{Edd}~0.5-1

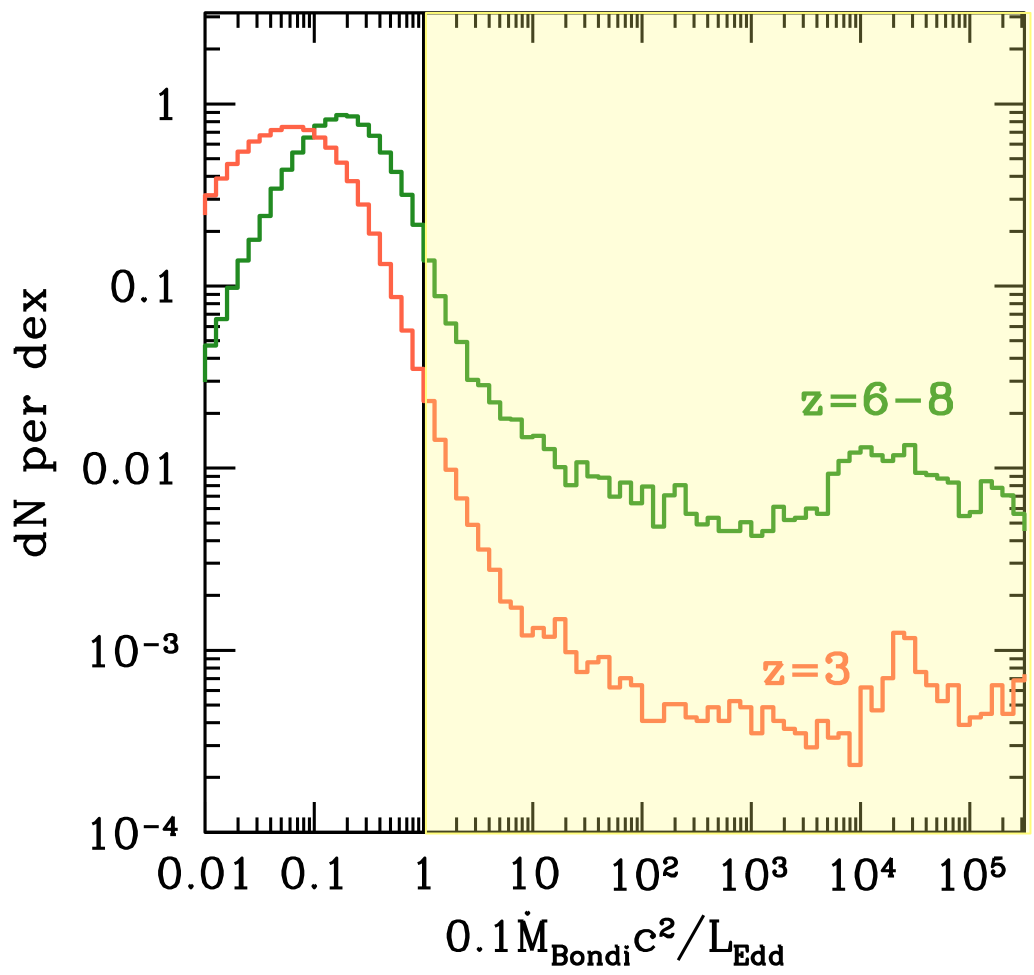
1. High-z quasars and MBHs

2. Eddington limit?

3. How do the first MBHs grow?

4. High-z jets

The feeding of high-z MBHs



- Estimate Eddington rate for BHs in Horizon-AGN -- $3x10^6$ Mpc^3 (Dubois+14)
- Supercritical inflows possible, ~10% at z>6
- What happens when they reach the MBH?

Super-Eddington accretion?

Super-Eddington accretion vs super-Eddington luminosity

Highly super-Eddington accretion does not imply highly super-Eddington luminosities

Low "effective" radiative efficiency: $\varepsilon << \eta \sim 0.1$

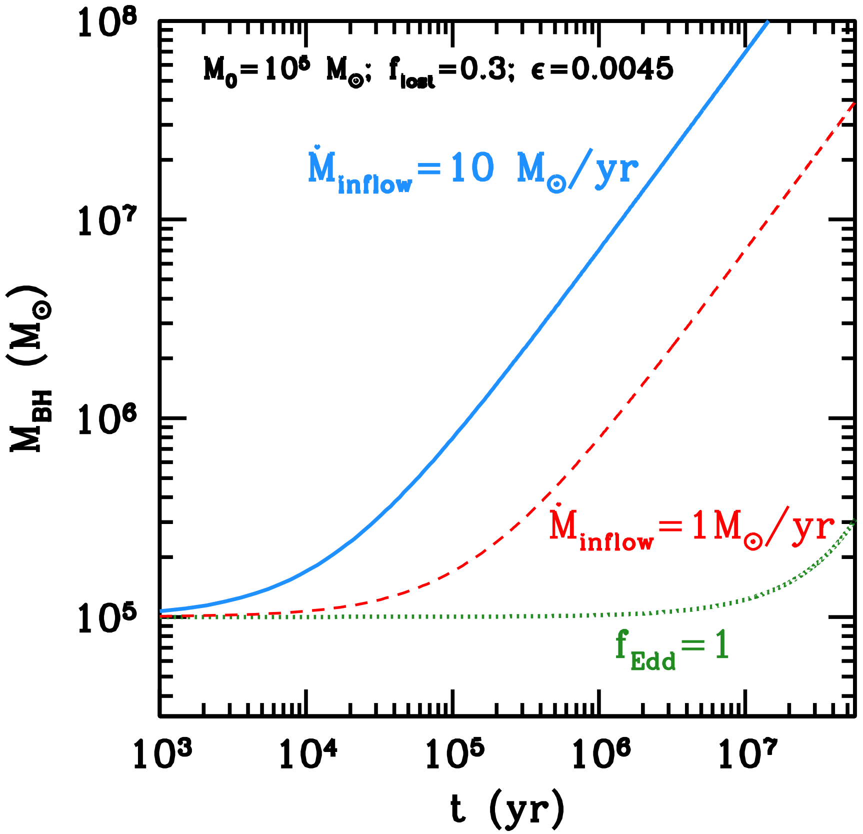
Trapping all of it

Trapping of radiation: the time for photons to escape the disk exceeds the timescale for accretion

Trapped photons are advected inward with the gas, rather than diffuse out

Luminosity highly suppressed $$\frac{L}{L_{Edd}} \sim \ln\left(\frac{\dot{M}}{\dot{M}_{Edd}}\right)$$

Trapping all of it



$10^5\ M_{sun}$ MBH could grow to $\sim 10^8\ M_{sun}$, in $\sim 10^6$ years => boost of $\sim 3\times10^2$ vs Eddington

- gas inflow rate: 1-10 Msun/yr (~1% of the free fall rate)
- only gas with low angular momentum (λ ~1% of the mean) is accreted

Only short periods needed to ease constraints

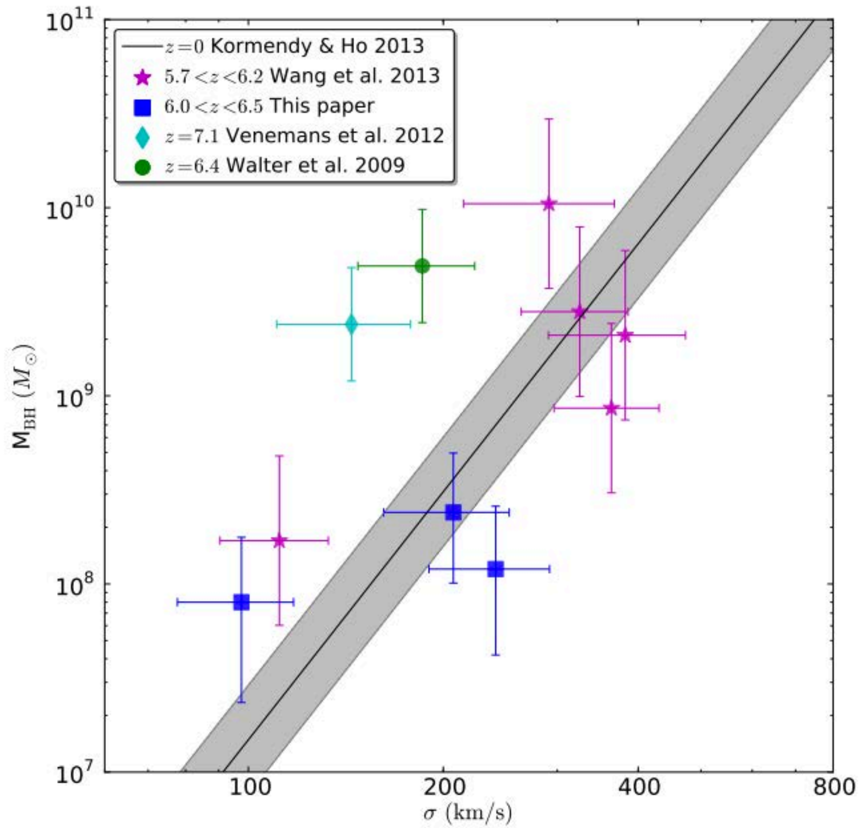
(e.g. Volonteri & Rees 2005, Volonteri, Silk & Dubus 2015)

Trapping all of it

Trapping condition:

$$M \leqslant \frac{\sigma^5 \sigma_T}{\pi \lambda^2 c m_p G^2}$$

The lower the gas angular mor
accretion can continue, the hig



In galaxies with much low-angular momentum gas near the center the MBH can get to a higher mass at fixed gas velocity dispersion.

Volonteri, Silk, Dubus 2015

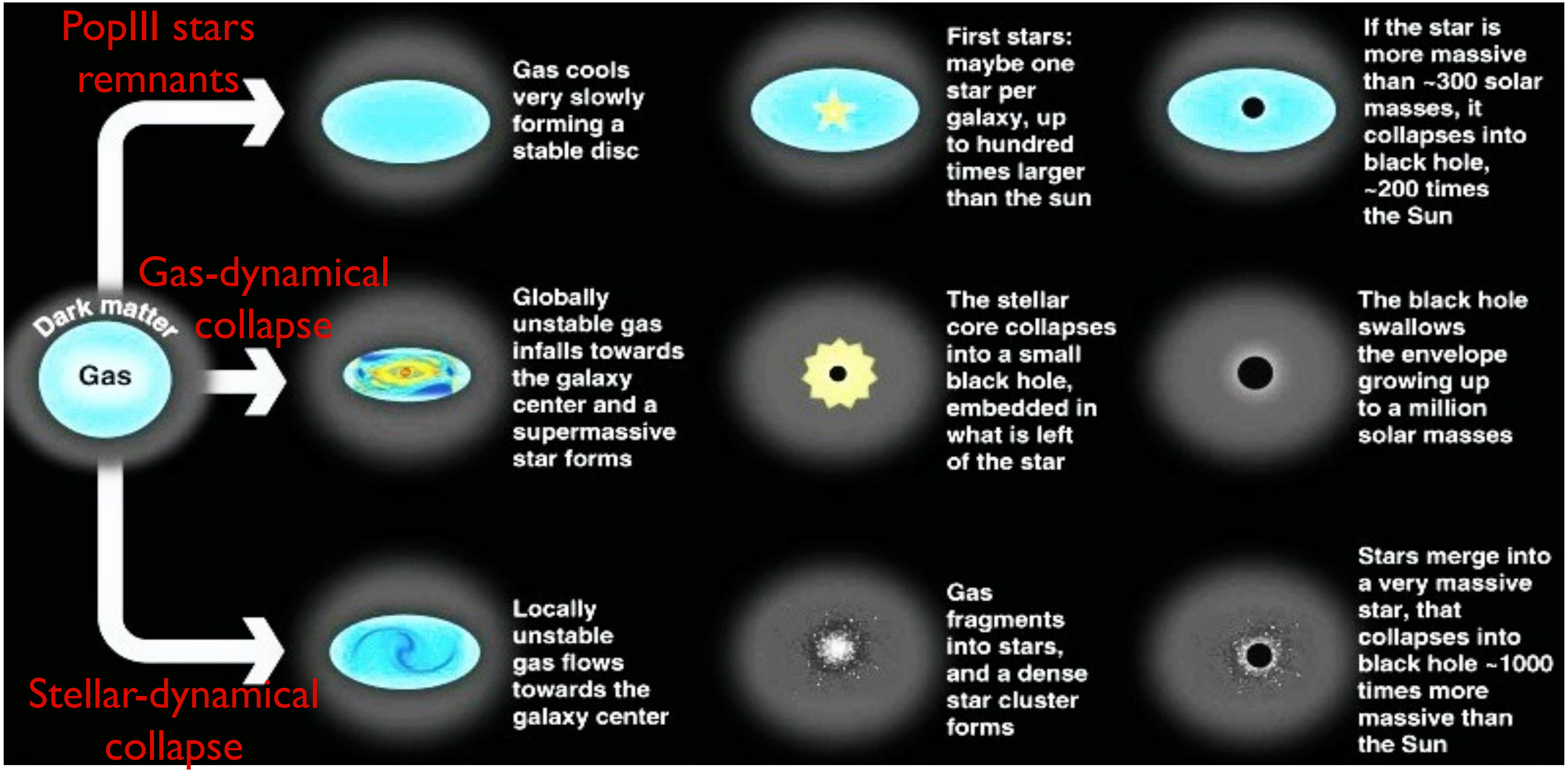
1. High-z quasars and MBHs

2. Eddington limit?

3. How do the first MBHs grow?

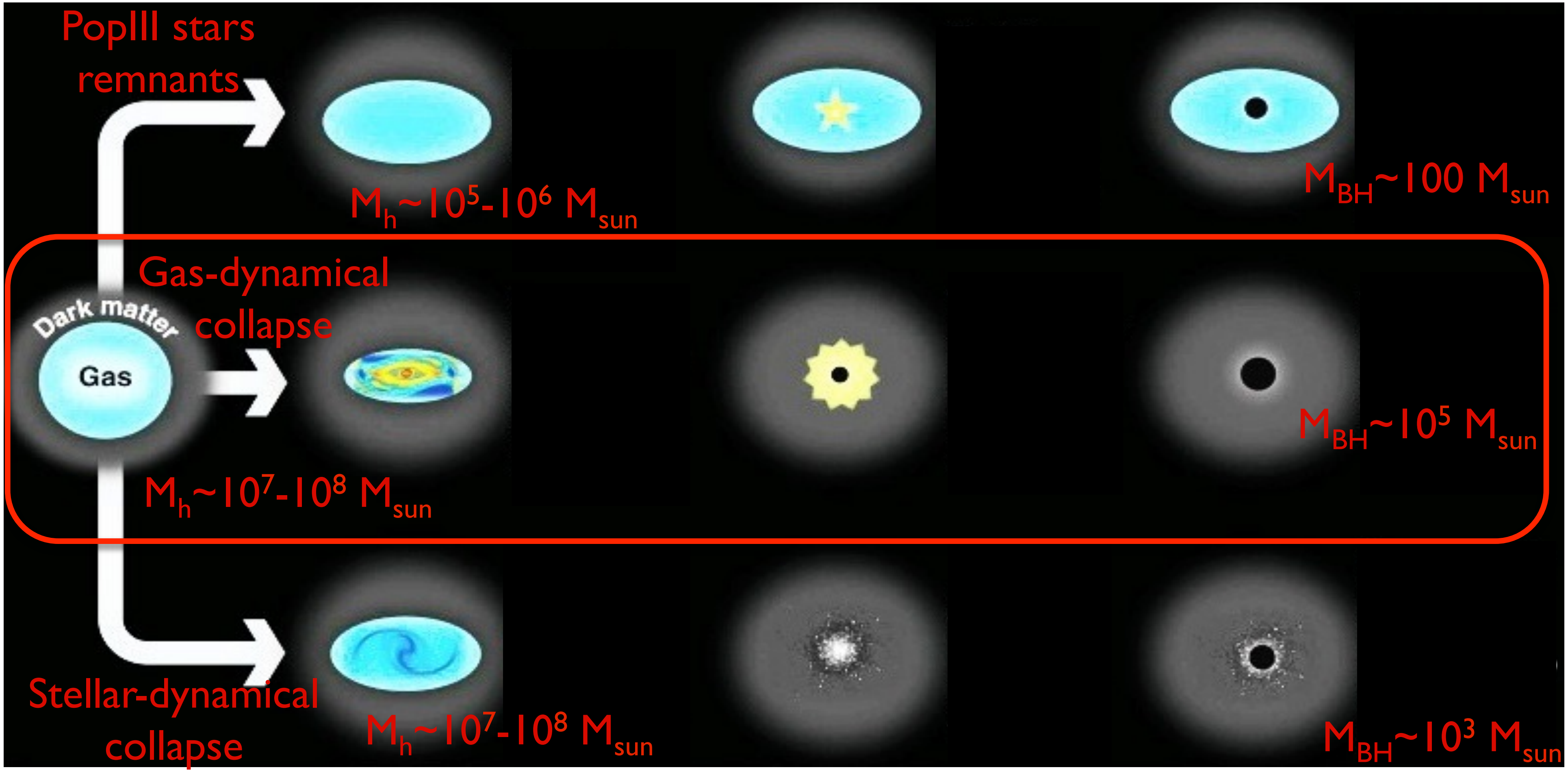
4. High-z jets

How do the first black holes grow?



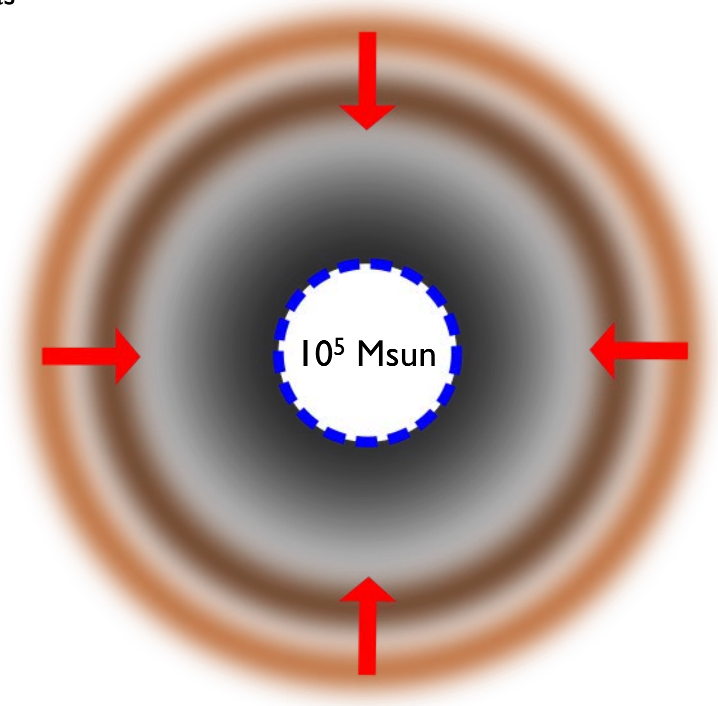
MV 2012, cf. Rees 1978

How do the first black holes grow?



How do the first black holes grow?

$M_{gas}=10^7$ Msun

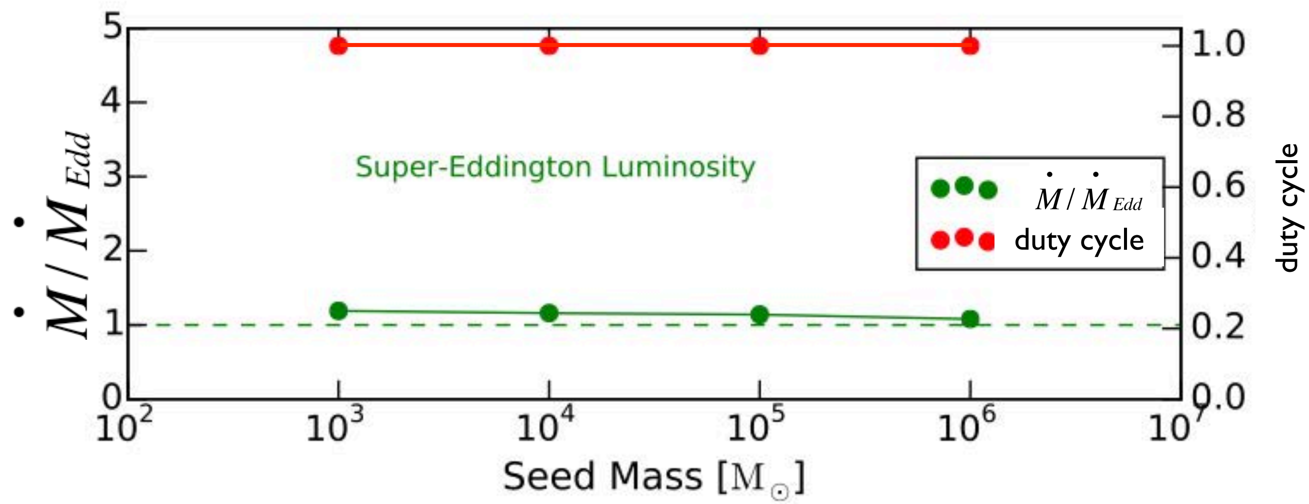


domain: 10^{-3} pc to 20 pc

- Spherical symmetry
- Radiation-hydrodynamic simulation
- Accretion disc is unresolved
- No magnetic fields
- Cooling: bremsstrahlung and atomic
- Opacity: Free-Free and Bound-Free
- Gas density profile extracted from cosmological simulations of direct collapse BH formation (Latif+2014)
- Standard thin accretion disc
- Slim disc (supercritical accretion)

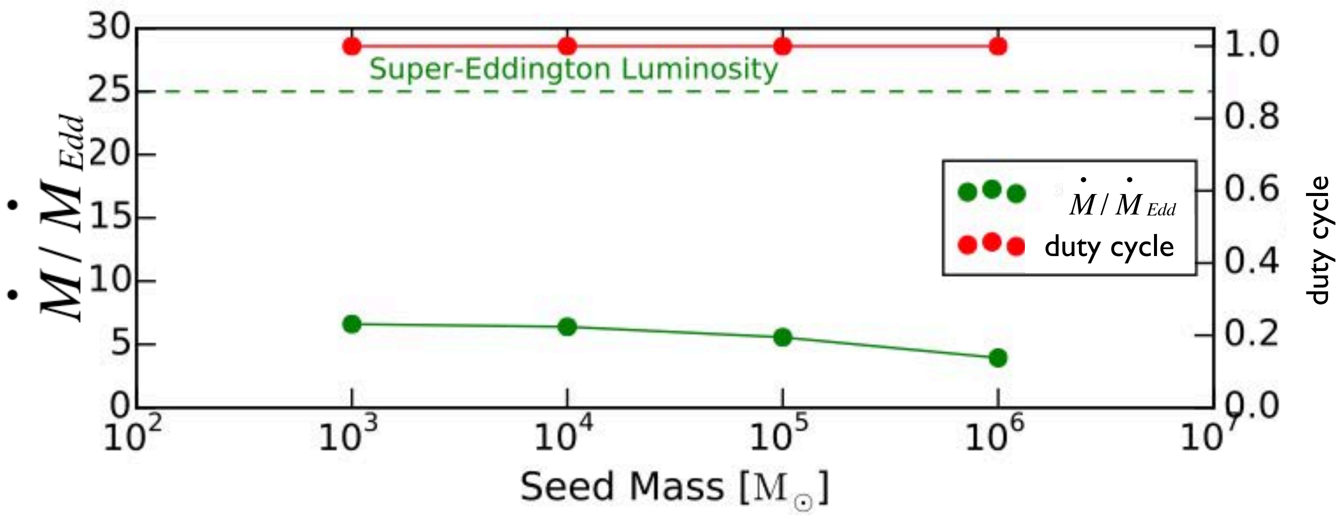
Pacucci & Ferrara 2015, Pacucci et al. 2015

How do the first black holes grow?



Standard accretion:
L \propto Mdot

Luminosity mildly super-Eddington

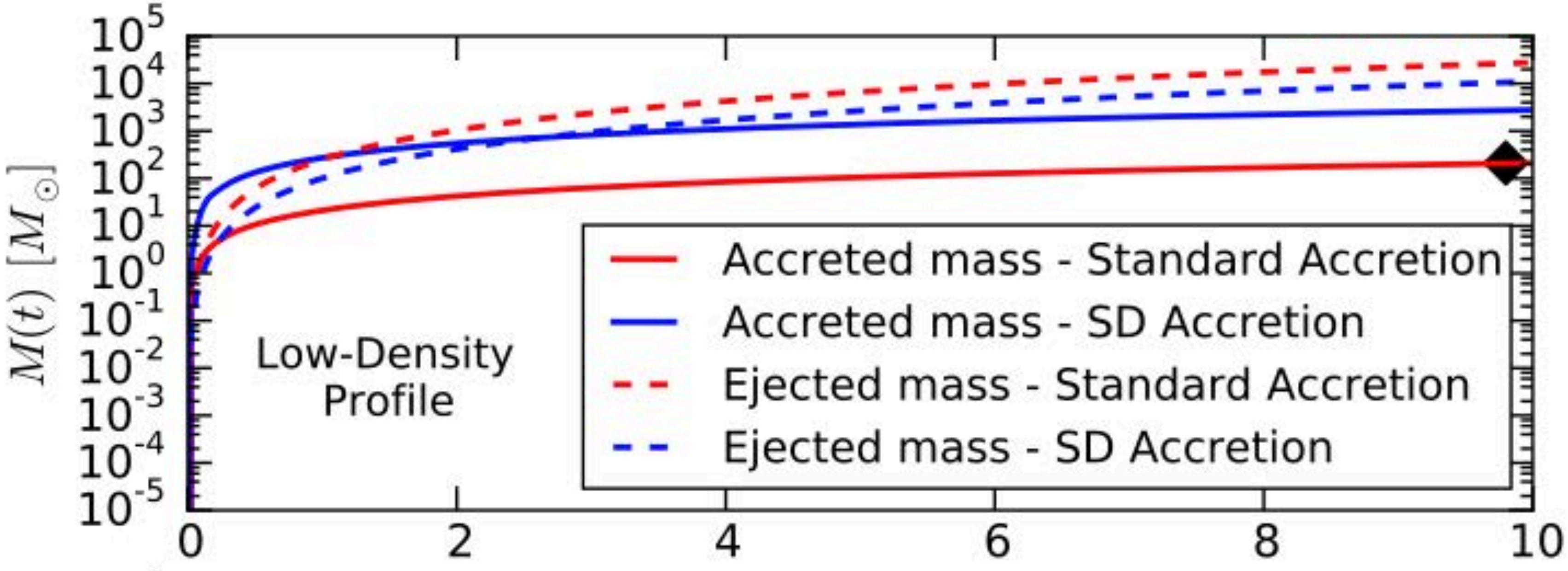


Slim disc accretion:
L \propto ln(Mdot)

Luminosity sub-Eddington,
while accretion super-critical

Pacucci et al. 2015

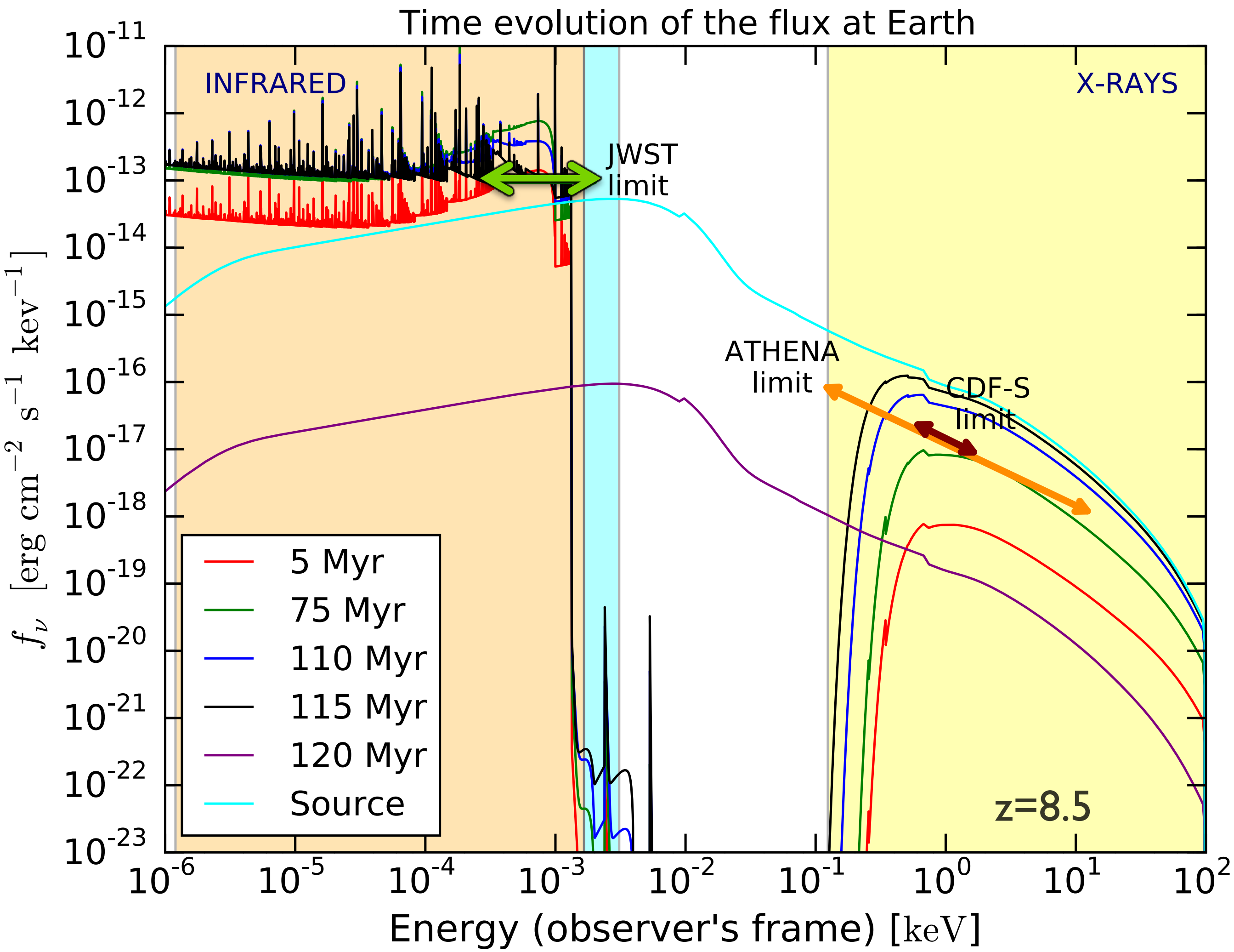
How do the first black holes grow?



time (10^4 yr)

Pacucci et al. 2015

How do the first black holes shine?



MBH accretes until it has consumed most of the gas

Physical accretion rates are ~0.02-0.15 M_{sun}/yr

N_H~10^{23}-10^{24} cm^{-2}

CDF-S already gives constraints on the number density of these accreting BHs!

Standard accretion: L \propto Mdot

Pacucci et al. 2015

1. High-z quasars and MBHs

2. Eddington limit?

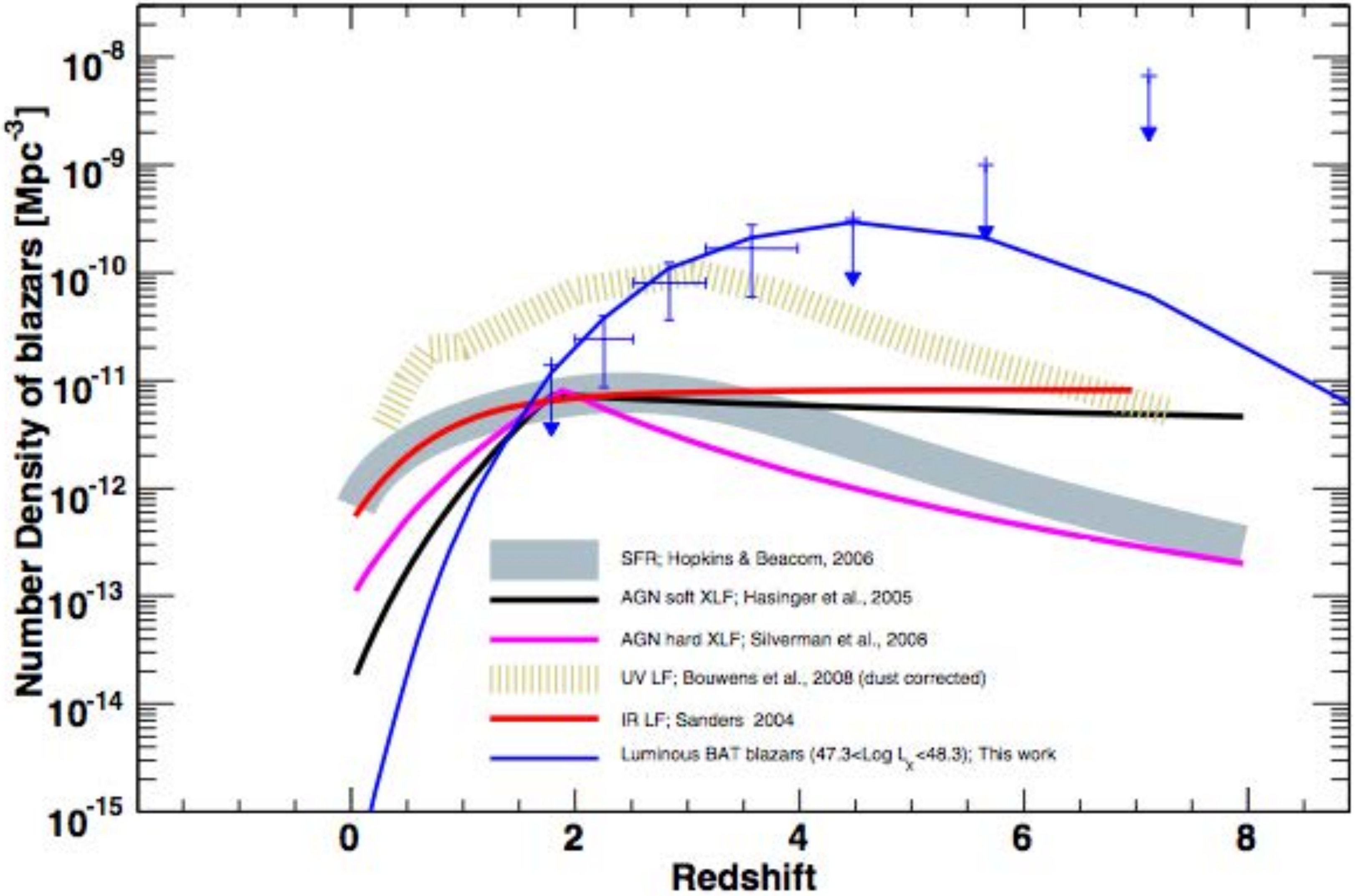
3. How do the first MBHs grow?

4. High-z jets

Radio-loud quasars at z=6: blazars

- Blazars' jets point as us: viewing angle <$1/\Gamma$ (Γ=Lorentz factor)
- For each detected blazar there are $2\Gamma^2=450(\Gamma/15)^2$ misaligned sources with same intrinsic properties, but not detectable as such
- Hard X-ray selection optimal for detecting high-z blazars because of SED => Swift BAT
- Include also gamma-ray detections => Fermi/LAT survey => ϒ–rays

High-z blazars



Swift/BAT selected L>10^{47}erg/s

Ajello et al. 2009

Where is the peak of quasar and blazar activity?

Select heavy and actively accreting MBHs in BAT & LAT:

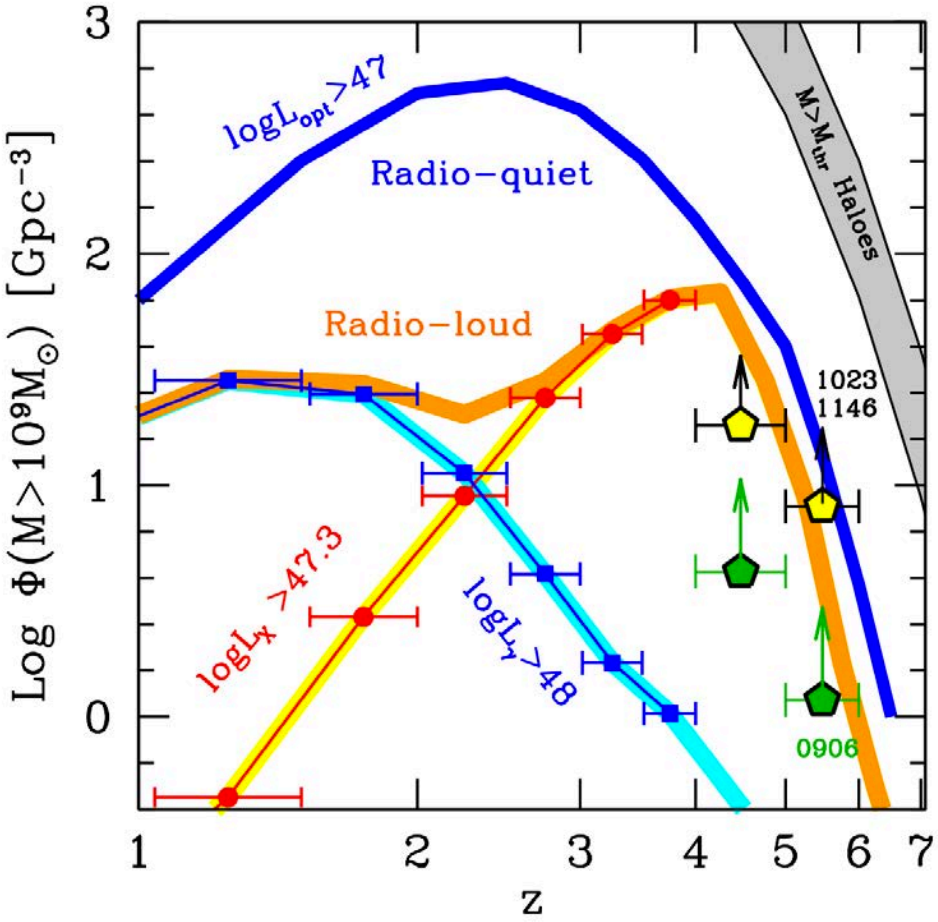
(i) $M > 10^9 M_\odot$

(ii) $(L_d/L_{Edd}) > 0.1$ => $f_{Edd} > 0.1$

=> $L_d > 0.1\ L_{edd} = 10^{46}$ erg/s $(M/10^9 M_\odot)$

Assuming an SED => detectability in different bands

High-z blazars



Heavy and active MBHs:
(i) $M > 10^9 M_\odot$
(ii) $(L_d/L_{Edd}) > 0.1$

Pentagons: lower limits from detected sources

Peak of jetted population at z higher than radio-quiet

Ghisellini et al. 2013, Sbarrato et al. 2012, 2013, 2015

Do jets help a BHs grow faster?

η: accretion efficiency – $0.05 \lesssim \varepsilon \lesssim 0.32$

A fraction $(1-\eta)$ goes into the BH

A fraction $\eta_d \leq \eta$ is radiated away: $L = \eta_d \dot{M} c^2$

A fraction of η may amplify the magnetic field: $\eta = \eta_d + \eta_{jet}$

$$t_{acc} = 0.45 \frac{\eta_d}{1-\eta} \ln\left(\frac{M_{fin}}{M_{in}}\right) \mathrm{Gyr}$$

Growth time decreases by a factor η_d/η!

1. High-z quasars and MBHs
    - need to find lower luminosity/mass MBHs
    - possible contribution to reionization (10-20%)

2. Eddington limit?
    - Eddington luminosity *is not* Eddington rate

3. How do the first MBHs grow?
    - Supercritical rates possible
    - Absorption/obscuration may be an issue

4. High-z jets
    - complementary way to search
    - do jets help MBHs grow fastter?