Black Hole Energetic Events

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BLACK erc
European Research Council
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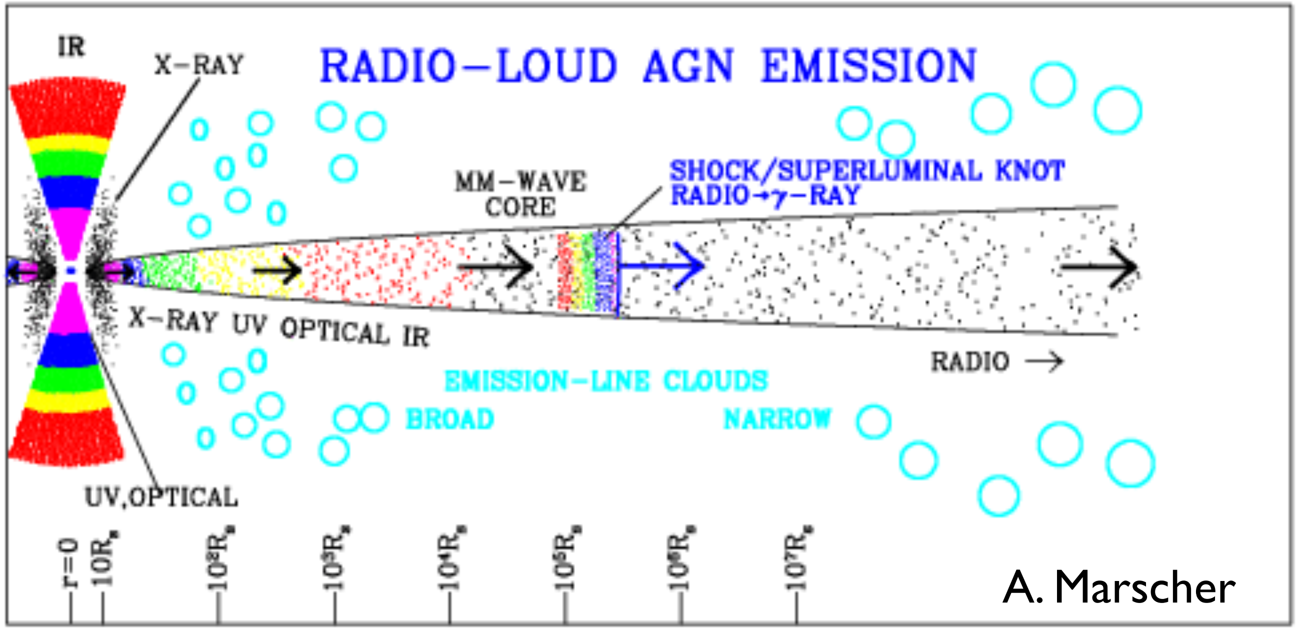
MBHG
SEVENTH FRAMEWORK PROGRAMME

Black holes: powerful engines

$$L = \eta \dot{M}_{acc} c^2$$

η up to 40%

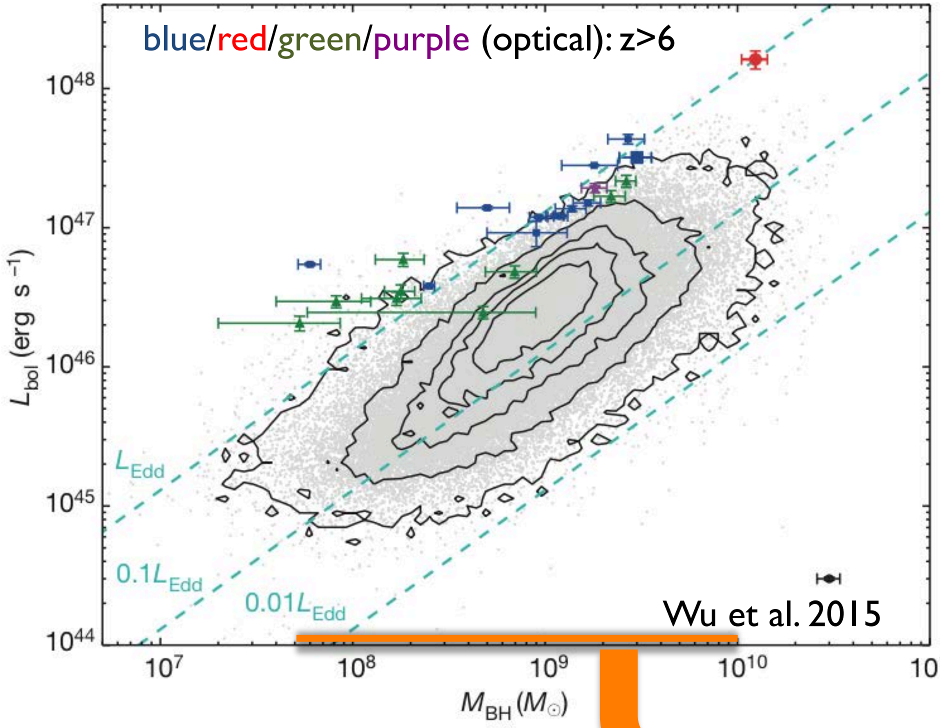
Energy emission up to hard X-ray and gamma-ray…



A. Marscher

1. High-z quasars and MBHs
2. Eddington limit?
3. How do the first MBHs grow?
4. High-z jets

High-redshift quasars

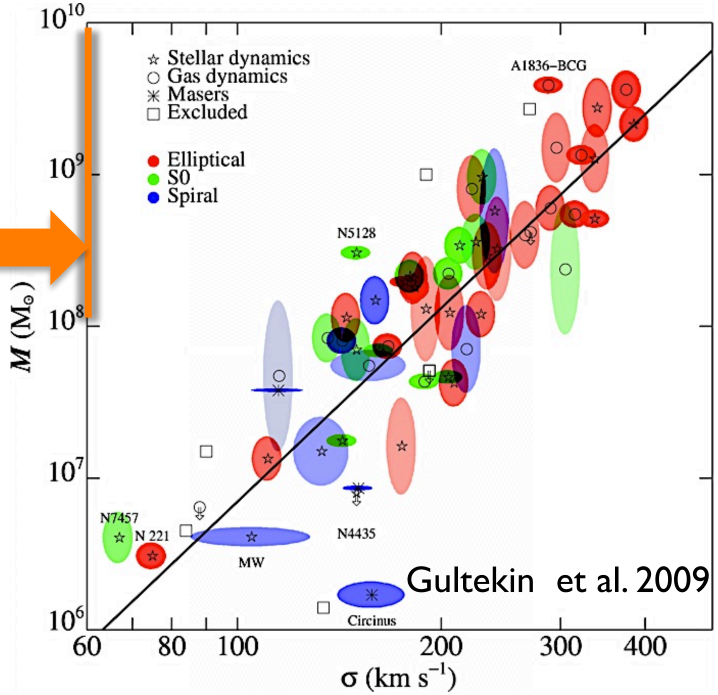


blue/red/green/purple (optical): z>6

Wu et al. 2015

High luminosity and large estimated MBH masses

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



Gultekin et al. 2009

For a BH accreting at the Eddington limit, mass grows in time as:

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

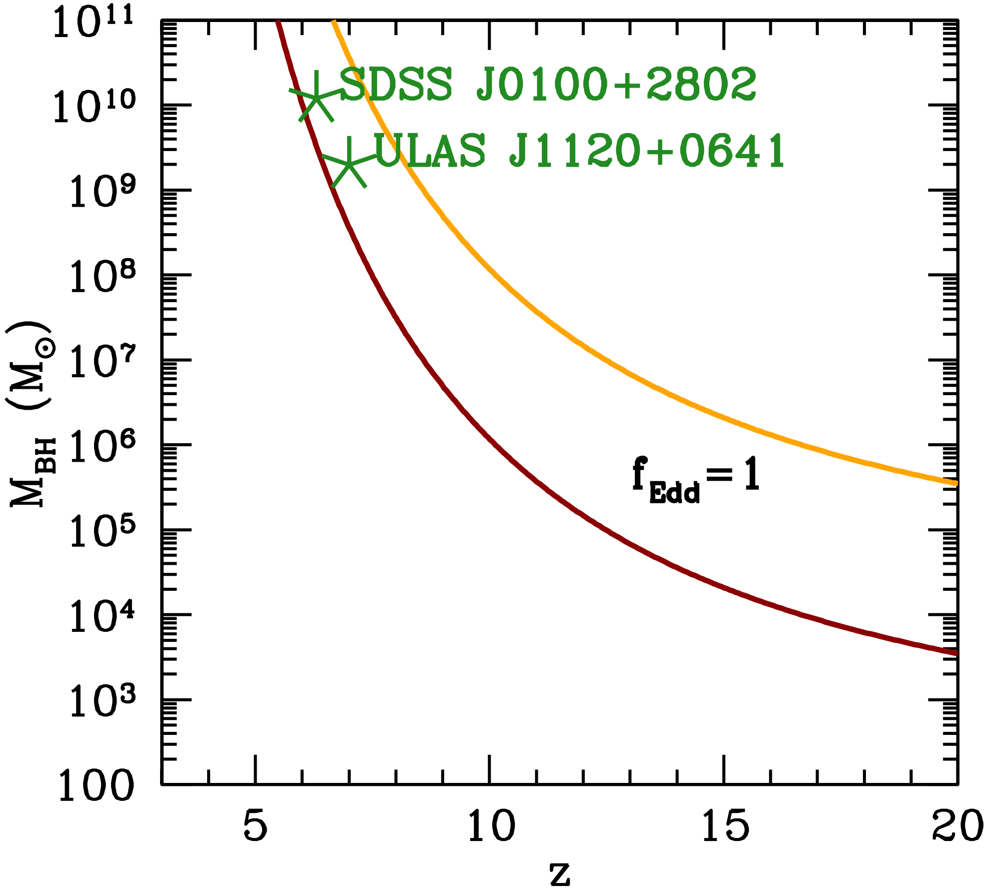
ULAS J1120 @ z=7.1

M=2x10^{9} Msun

t~0.75 Gyr

η~0.1

⇒ M$_{in}$>300-ish Msun



The Eddington limit:

outward radiation pressure equals inward gravitational force

$$a_{rad}(r) = \frac{\kappa(\rho, T)L(r)}{4\pi r^2 c}$$

$$g(r,t) = -\frac{GM_\bullet(t)}{r^2}$$

If $a_{rad}>|g|$ radiation pushes away the gas, and accretion is halted

$$L < L_{Edd} = 10^{44}\,\mathrm{erg/s}\ (\mathrm{M}_\bullet/10^6\mathrm{M}_{\mathrm{sun}})$$

$$f_{Edd} = \frac{L}{10^{44}\,\mathrm{erg/s}\ (\mathrm{M}_\bullet/10^6\mathrm{M}_{\mathrm{sun}})}$$

Note: spherical symmetry

Super-Eddington accretion?

Super-Eddington accretion vs super-Eddington luminosity

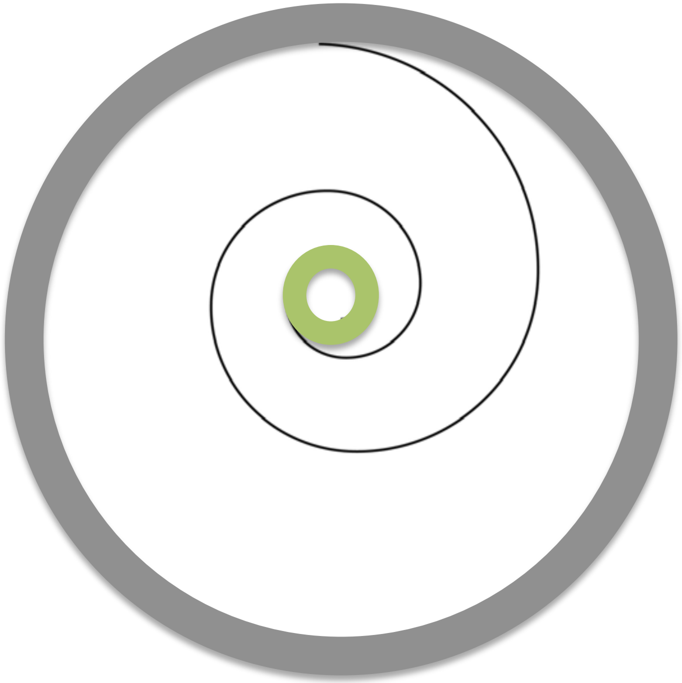
Highly super-Eddington accretion does not imply highly super-Eddington luminosities

Low “effective” radiative efficiency: $\epsilon << \eta \sim 0.1$

The Eddington limit

If gas has angular momentum => gas forms an accretion disc

Super-critical accretion discs are different from sub-critical ones, e.g. slim discs (Abramowicz+88)



capture radius: where gas becomes bound to the BH

accretion disc radius: set by gas centrifugal support

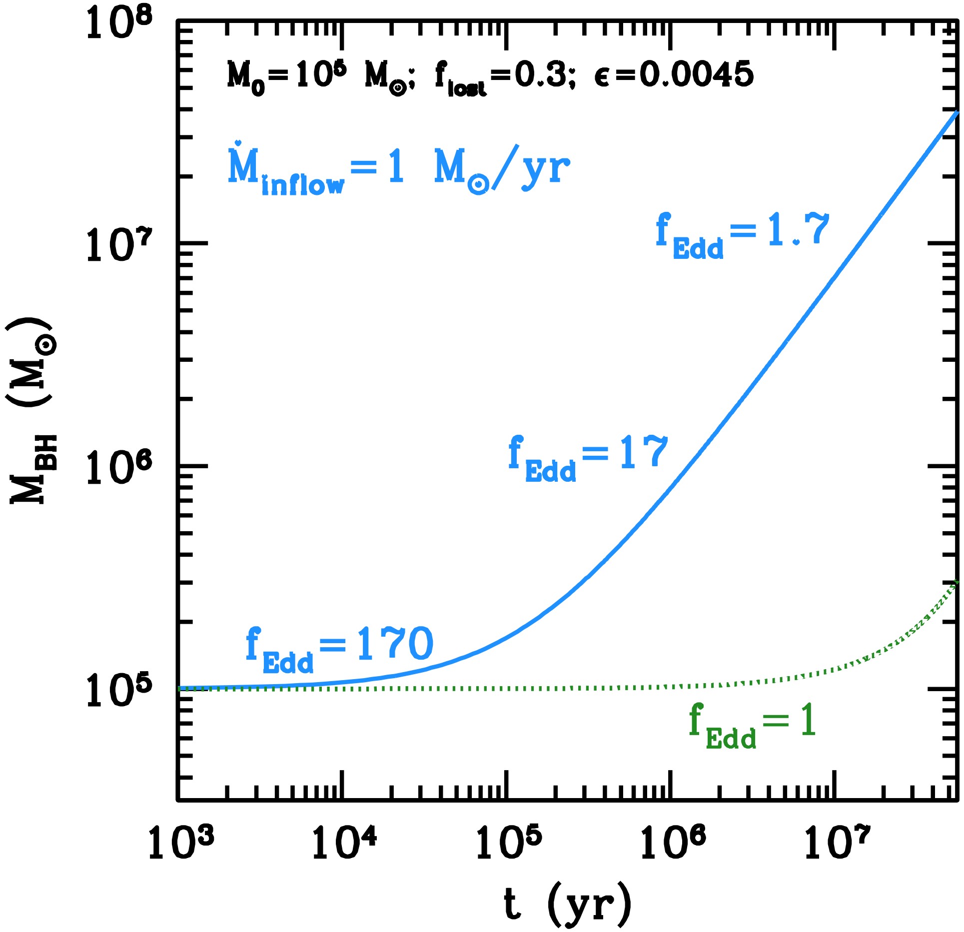
Trapping all of it

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 $\dfrac{L}{L_{Edd}} \sim \ln\left(\dfrac{\dot{M}}{\dot{M}_{Edd}}\right)$

Trapping all of it



10^5 M_{sun} MBH could grow to ~10^8 M_{sun}, in ~10^6 years

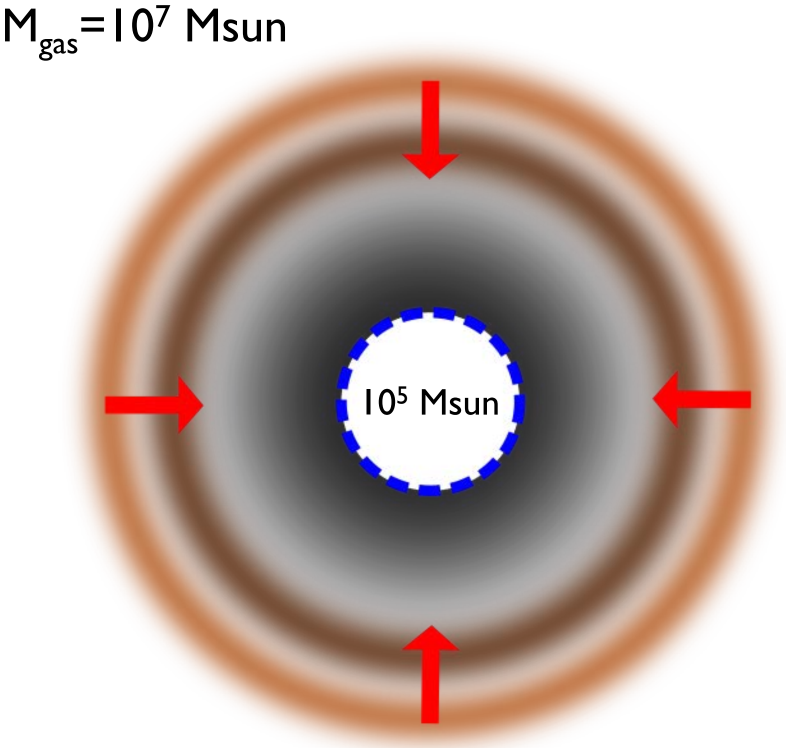
=> boost of ~3×10^2 vs Eddington

- gas inflow rate: 1 Msun/yr (~1% of the free fall rate)

Only short periods needed to ease constraints

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

How do the first black holes grow?



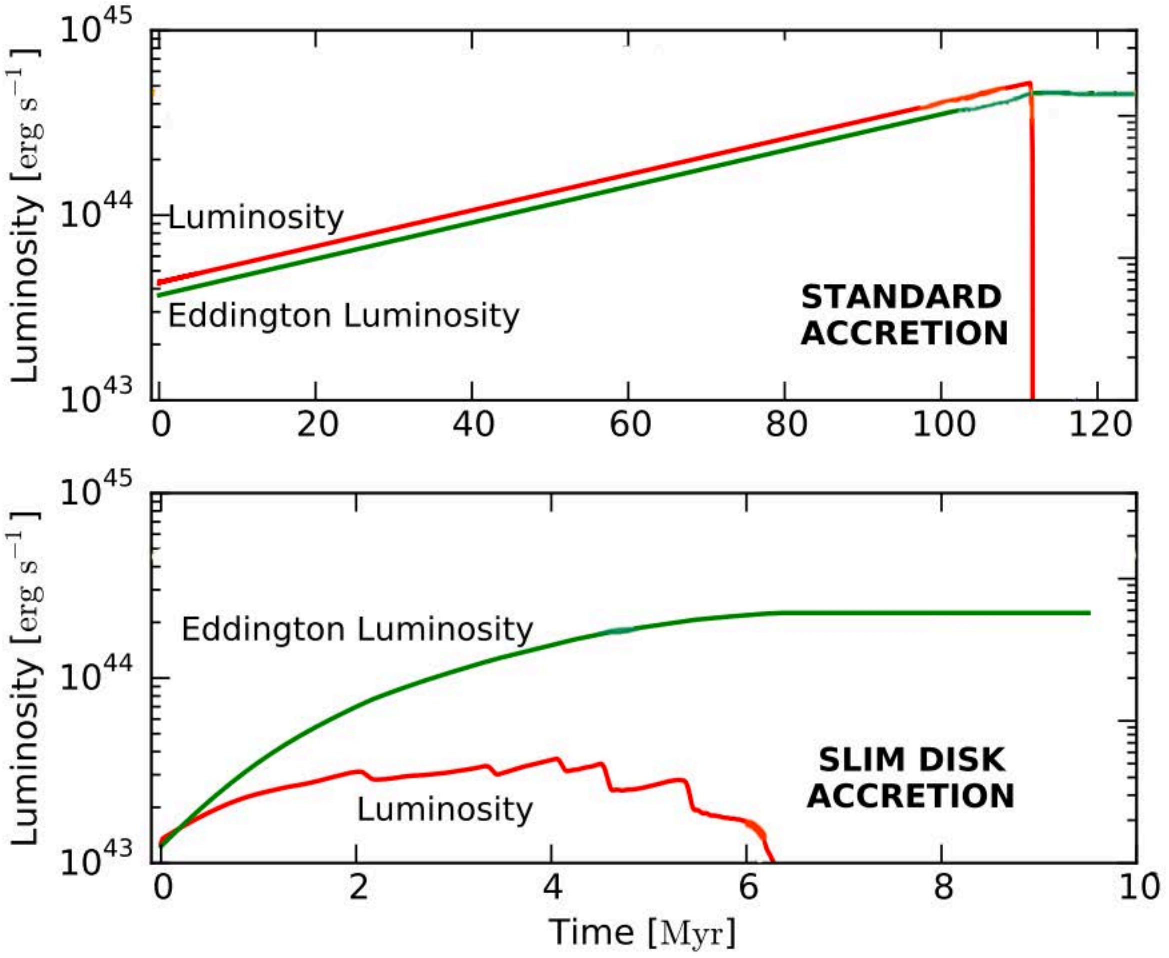
- Spherical symmetry
- Radiation-hydrodynamic simulation
- Gas density profile extracted from cosmological simulations of direct collapse BH formation (Latif+2014)
- MBH accretes until it has consumed most of the gas in the host halo

- Standard thin accretion disc
- Slim disc (supercritical accretion)

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

Pacucci & Ferrara 2015, Pacucci, Volonteri & Ferrara 2015

How do the first black holes grow?



Standard accretion:
L \propto Mdot

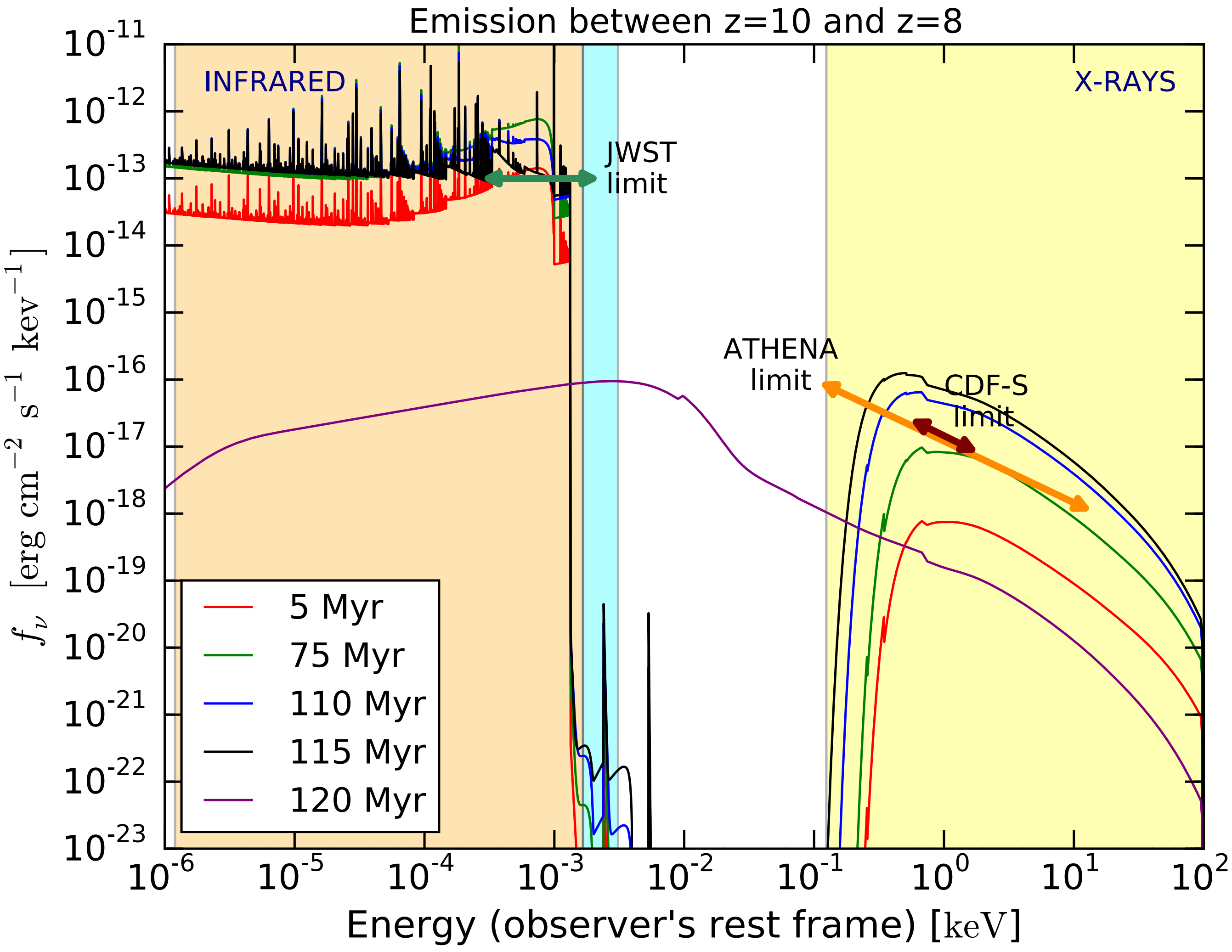
Luminosity mildly super-Eddington

Slim disc accretion:
L \propto ln(Mdot)

Luminosity sub-Eddington, while accretion super-critical

Pacucci, MV & Ferrara 2015

How do the first black holes shine?

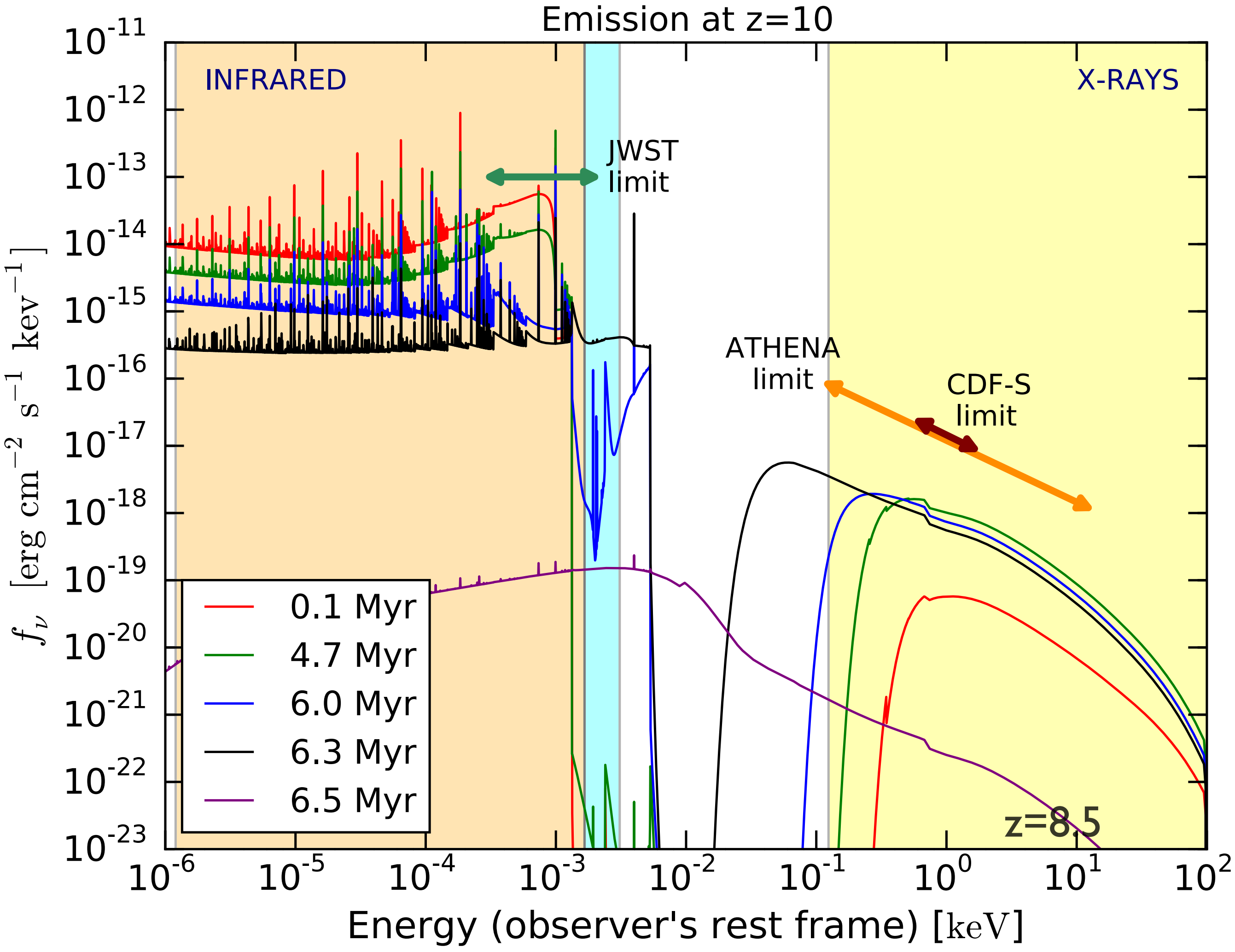


Standard accretion:
L \propto Mdot

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

Pacucci et al. 2015

How do the first black holes shine?



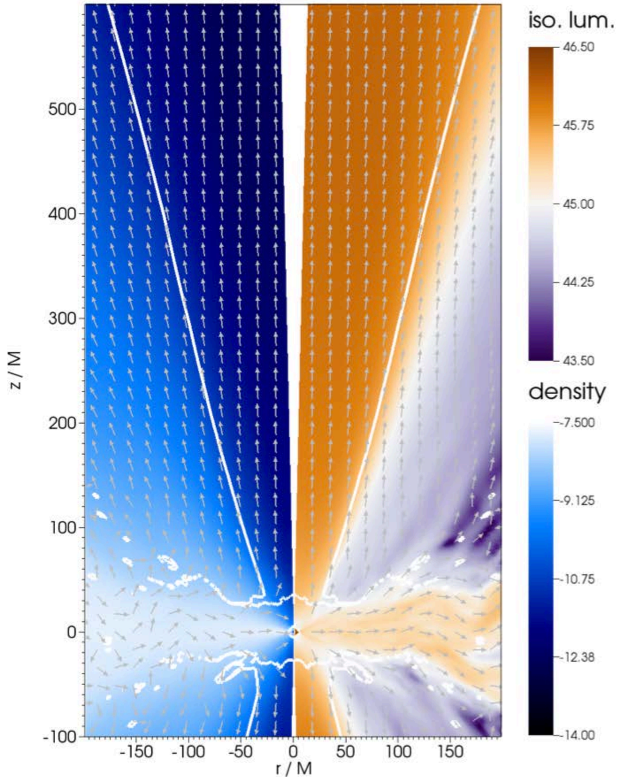
Slim disc accretion:
L \propto ln(Mdot)

Super-critical BHs are short-lived and fainter than Eddington-limited ones

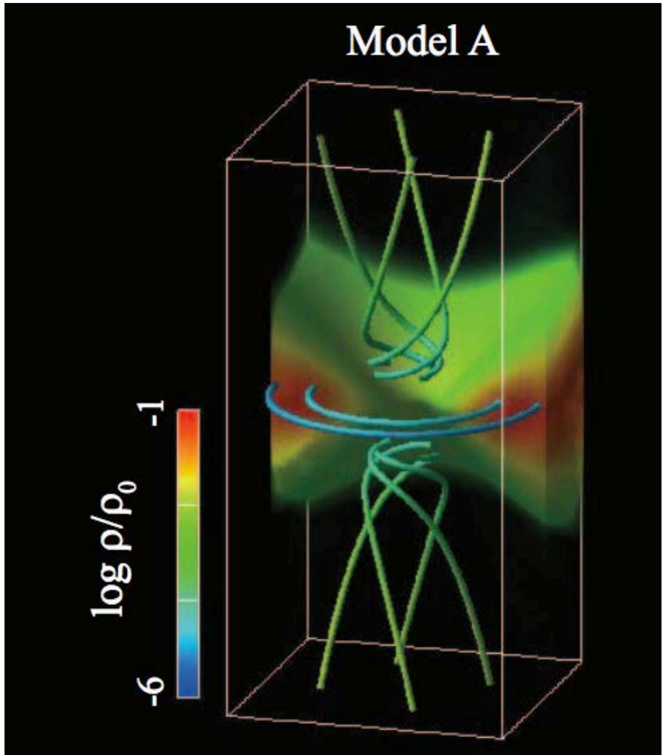
Pacucci et al. 2015

Jet production

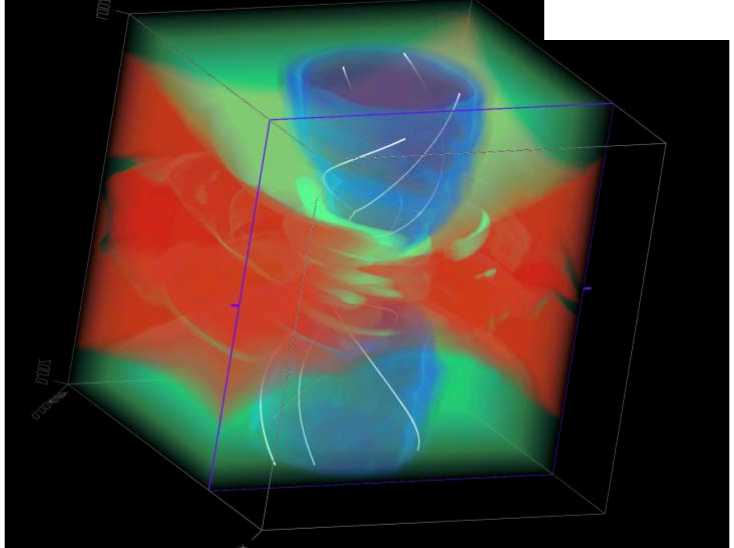
BHs accreting at super-critical rates are likely to be characterized by strongly collimated outflows or jets



Sadowski & Narayan 2015

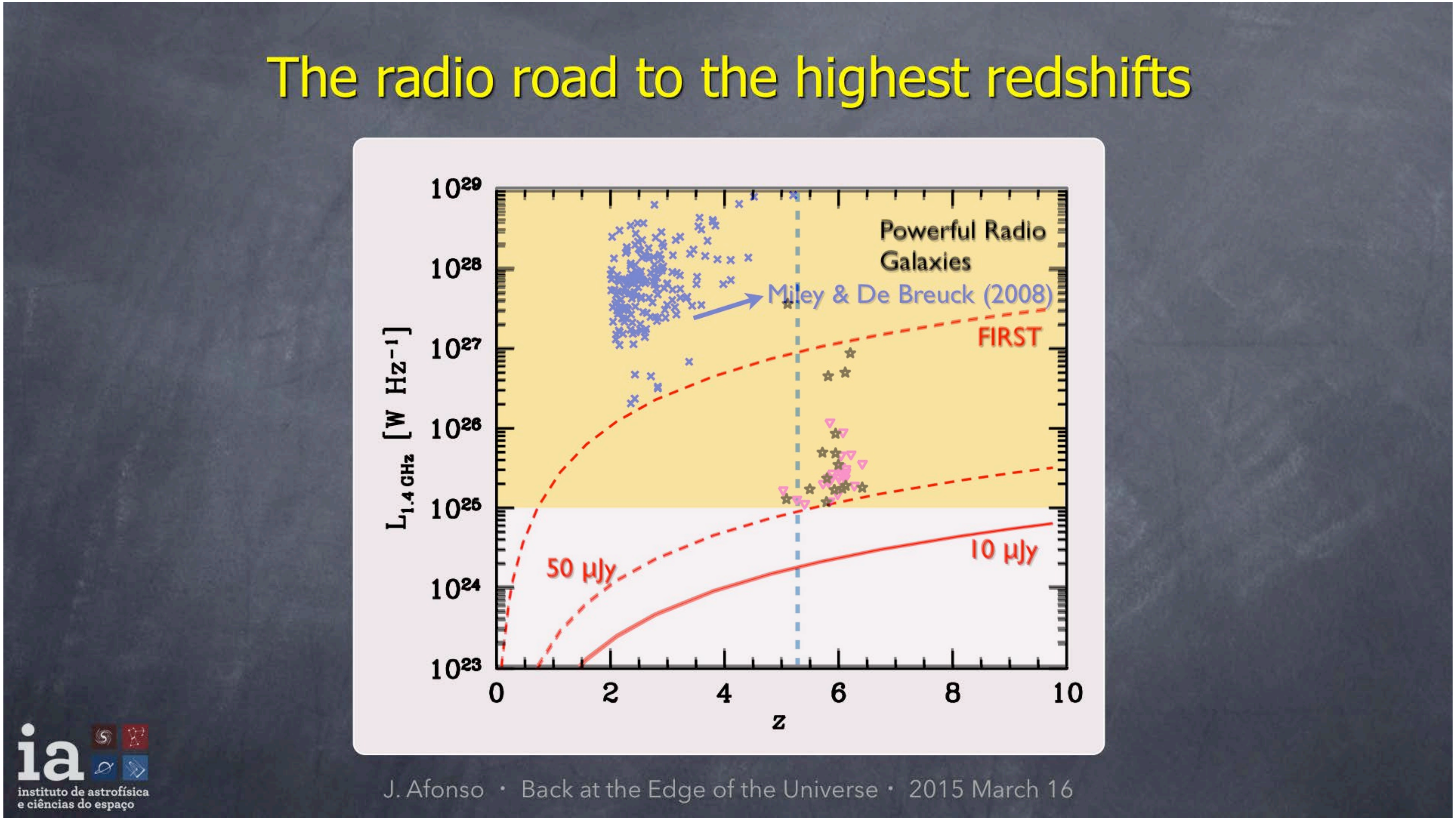


Ohsuga & Mineshige 2011



McKinney et al. 2014

Radio jets from high-z BHs?



The radio road to the highest redshifts

J. Afonso · Back at the Edge of the Universe · 2015 March 16

instituto de astrofísica
e ciências do espaço

CMB “muting”

At high-z, the CMB energy density $\propto (1 + z)^4$ can exceed the magnetic energy density in the lobes of radio–“loud” AGN

The relativistic electrons cool preferentially by scattering off CMB photons, rather than by synchrotron emission.

This makes more distant jets less luminous at radio wavelengths

Ghisellini et al. 2014, Casanellas et al. in prep

Jetted quasars at z=6: blazars

We can estimate the number of high redshift jetted AGN through the census of their aligned proxies, i.e., 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/gamma-ray selection optimal for detecting high-z blazars because of SED => Swift & Fermi

Where is the peak of quasar and blazar activity?

Select heavy and actively accreting MBHs with Swift & Fermi:

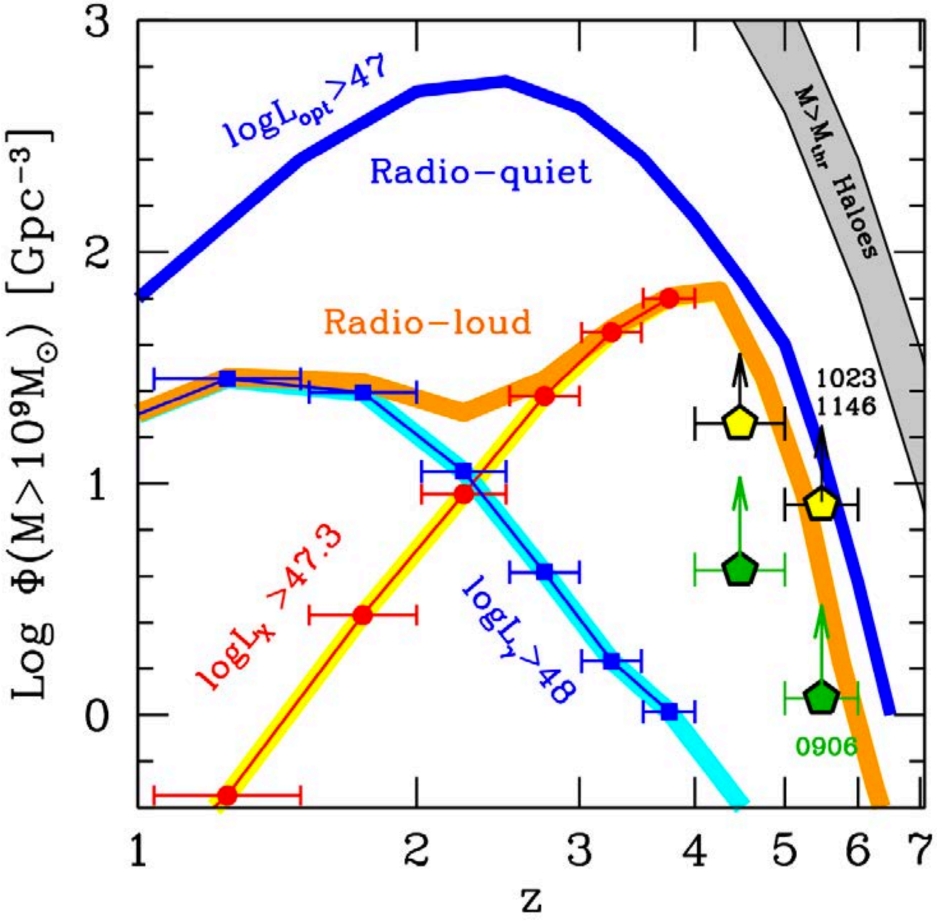
(i) $L > 10^{47}$ erg/s

(ii) $(L_d/L_{Edd}) > 0.1 \Rightarrow f_{Edd} > 0.1, M > 10^9 M_\odot$

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

Assuming an SED => detectability in different bands

High-z blazars



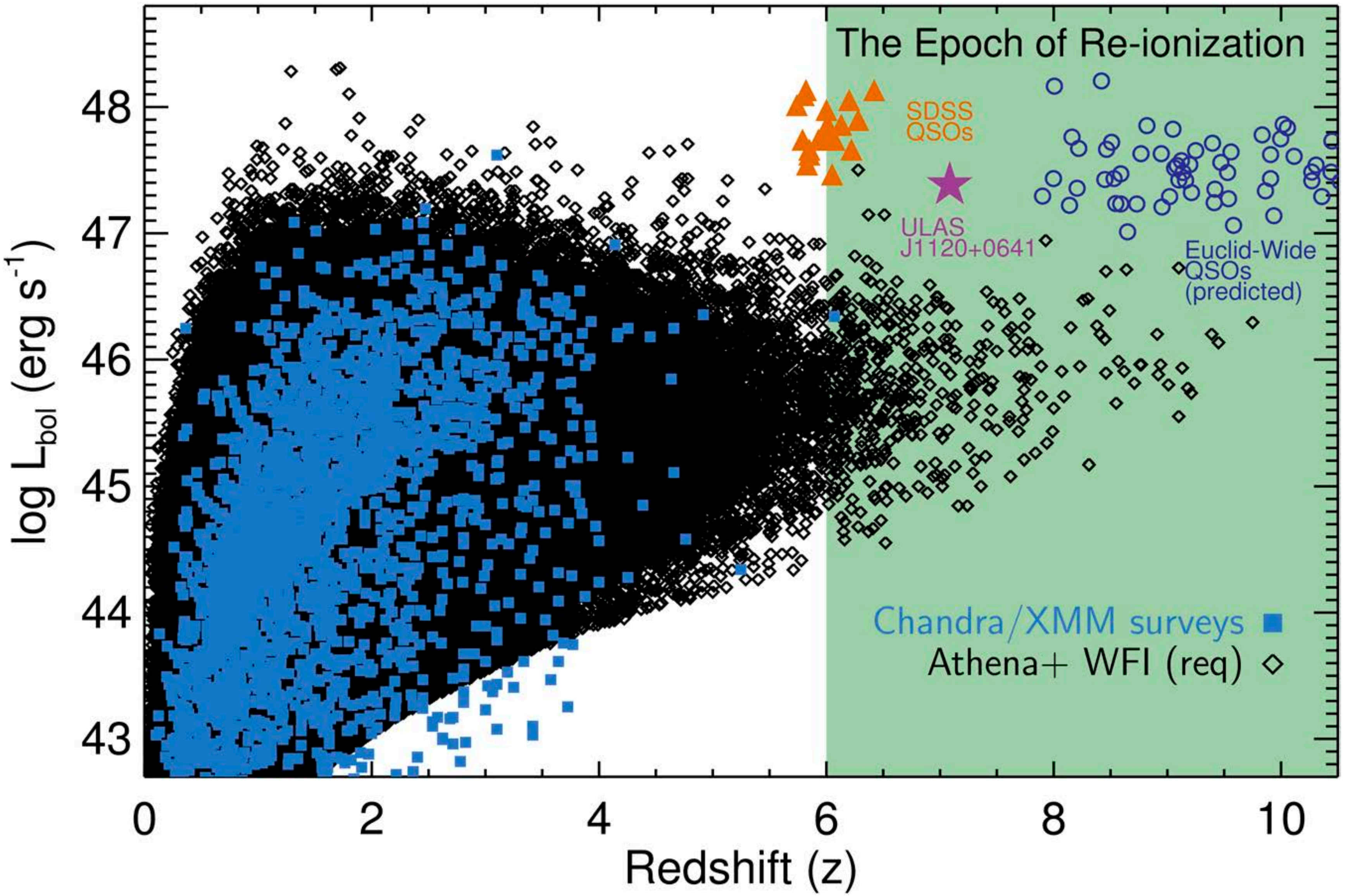
Heavy and active MBHs:
(i) M > $10^9 M_\odot$
(ii) $(L_d/L_{Edd}) > 0.1$

Pentagons: lower limits from detected sources

Peak of jetted population is at higher z than radio-quiet

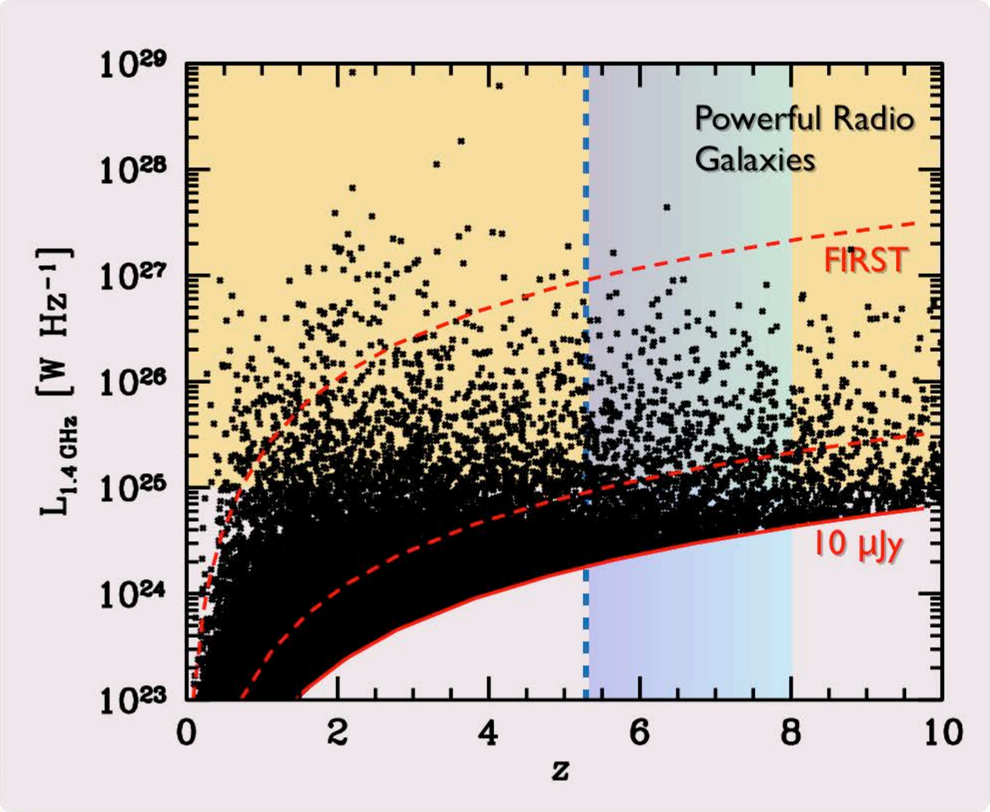
Volonteri et al. 2013, Ghisellini et al. 2013, Sbarrato et al. 2012, 2013, 2015

The future is bright (and energetic)



The future is bright (and energetic)

CMB “muting” less important at low frequencies



SKA simulated skies:
- 10 square degrees
- $S_{1.4GHz}$>10 μJy

1. High-z quasars and MBHs
    - need to find lower luminosity/mass MBHs

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