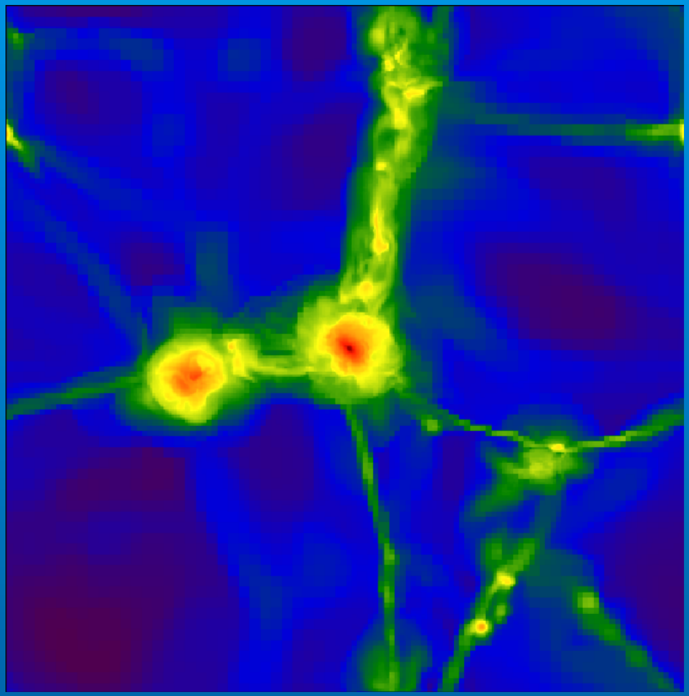
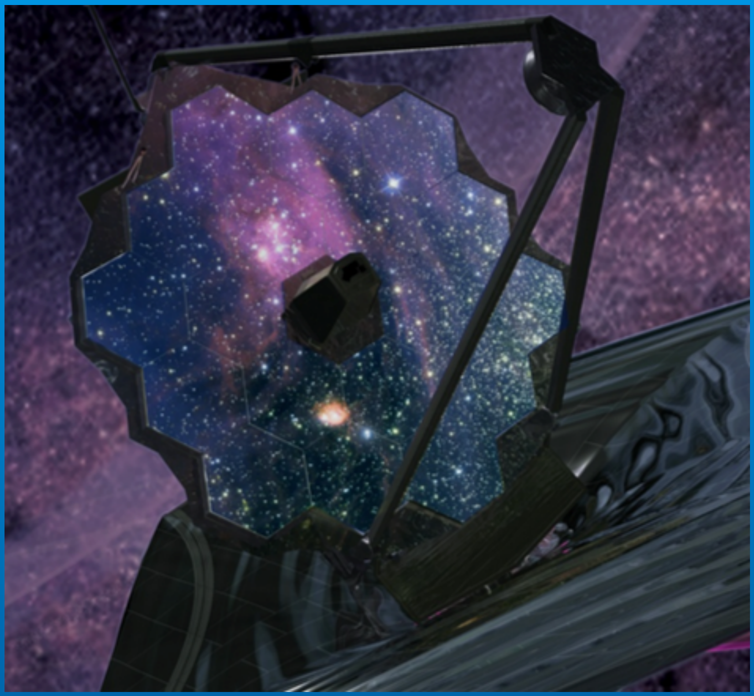
Unveiling the first cosmic sparklers: JWST and the first black holes





Haiman+; Tanaka+; Johnson+; Park+; Ricotti+; Khochfar+; Di Matteo+; Yoshida+ Schneider+
Dubois+; Bournoud+; Ferrara+; Milosavljevic+; Ricotti+; Abel+; Bromm+; Latif+; Whalen+

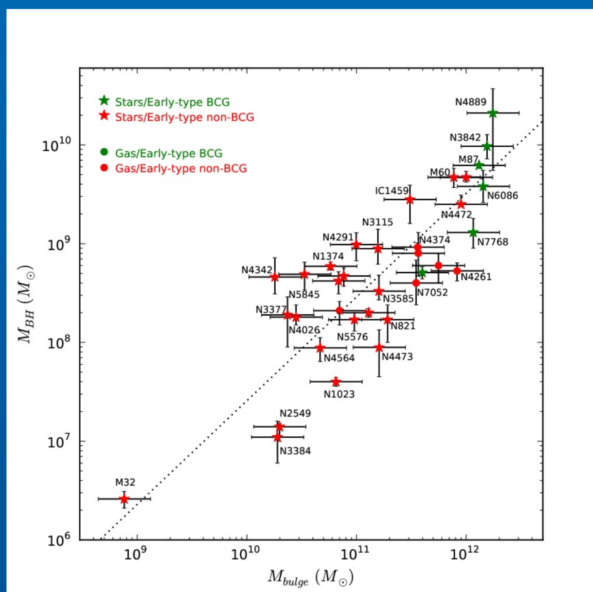
Priyamvada Natarajan
Yale University

Local Correlations Between M_{BH}-Host Galaxy Properties Do such correlations exist at high redshift?

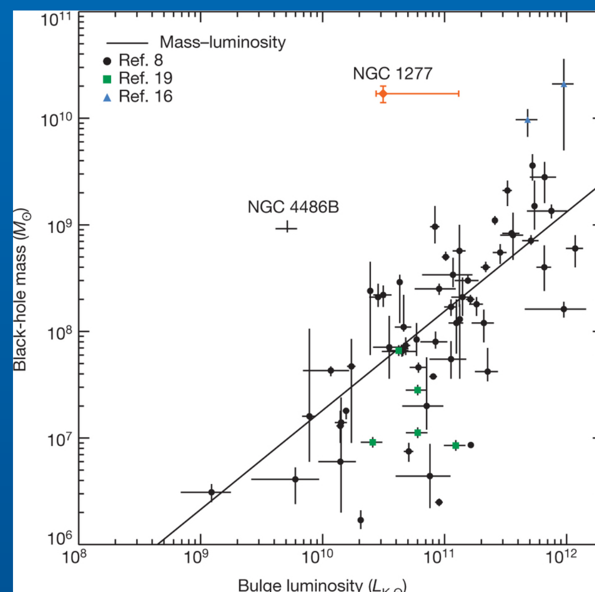
✦ Galaxy bulge mass [$M_{BH} \sim 10^{-3}\ M_{bulge}$] Dressler 89; Magorrian+ 98

✦ Galaxy bulge luminosity [M_{BH}-$L^{1.0\pm0.1}$] Kormendy 93; Kormendy & Richstone 95

✦ Stellar velocity dispersion [$M_{BH} \sim \sigma^4$]Tremaine+ 99; Ferrarese & Merritt 00



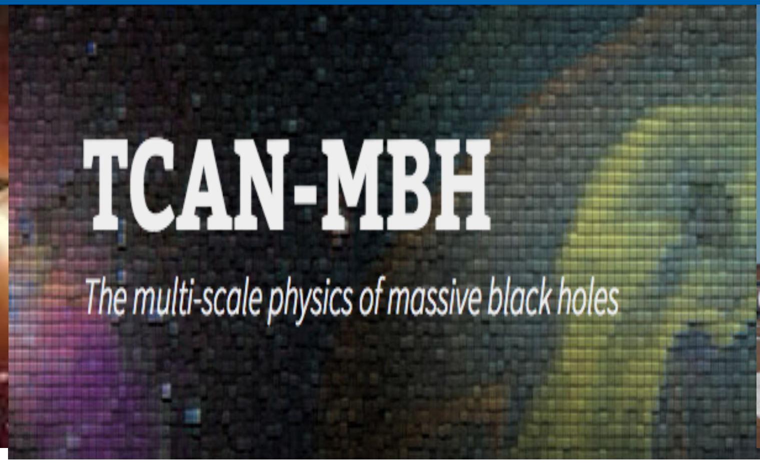
McConnell & Ma+13

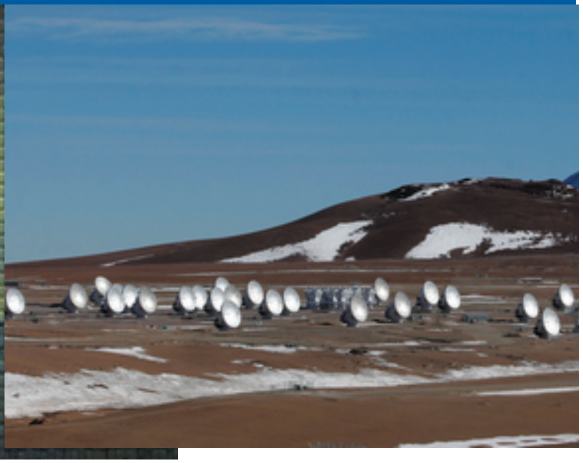


van den Bosch et al.+12

OPEN QUESTIONS THAT JWST WILL SHED LIGHT ON

Masses of initial BH seeds
Early accretion history of seed BHs
When do the correlations between BHs and their hosts get set-up
Importance of mergers
Contribution to Re-ionization
Observational signatures of Super-Eddington flows
Detection of signature of mergers – EM counterparts to gravitational waves



HOW IS THIS OCCUR IN INVIDIVIDUAL GALACTIC NUCLEI & THE POPULATION

How do BHs and the host galaxy know about each other

Do these scaling relations evolve through cosmic time

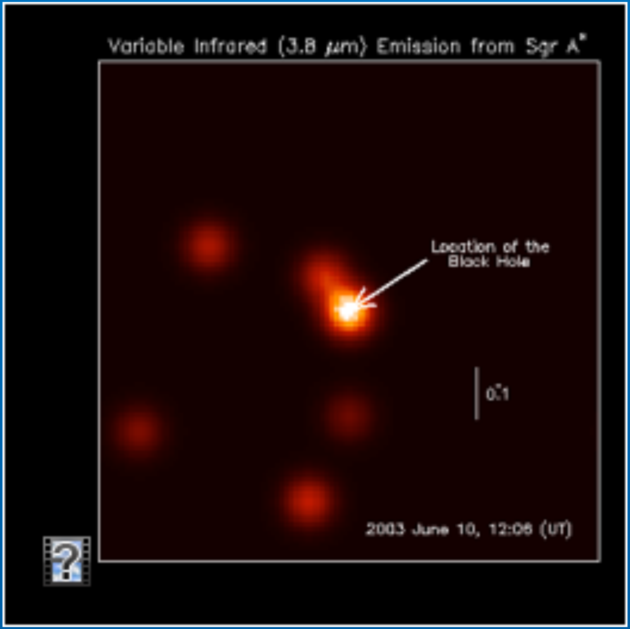
When are these correlations set up

Initial conditions? accretion physics? merger dynamics? self-regulated feedback?

How do seed BHs grow

How do seed BHs form

MULTI-WAVELENGTH DATA FOR ACTIVE & QUIESCENT BHs



$M_{BH} \sim 10^{6\ -9}\ M_{sun}$

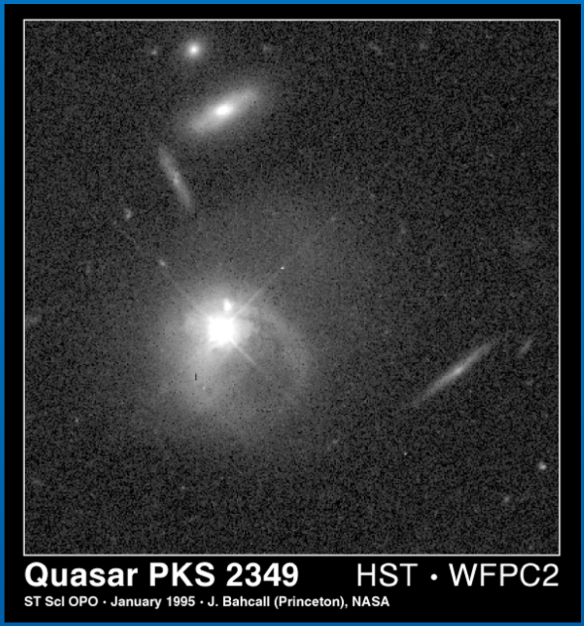
even $10^{10}\ M_{sun}$

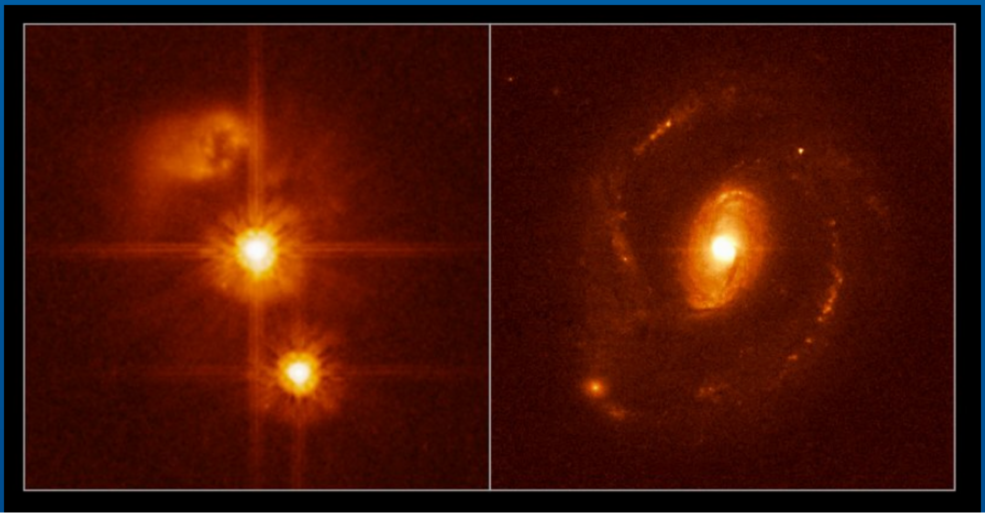
z ~ 0 – 7

z=7 660 Myr

550 Myr after

the Big Bang

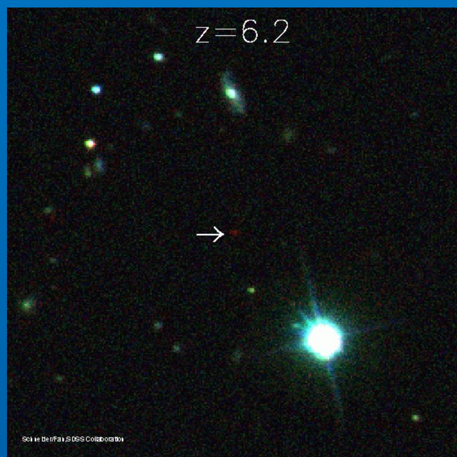




Urry+; Treister+; Scoville+; Sanders; Faber+; Wu+; Wang+; Ferguson+; Harrison+; Hasinger+; Comastri+; Gilli+

HIGH-z QUASARS & THE TIMING PROBLEM TO ASSEMBLE SMBHs

Bright quasars host 10^9 - 10^{10} M_{sun} BHs



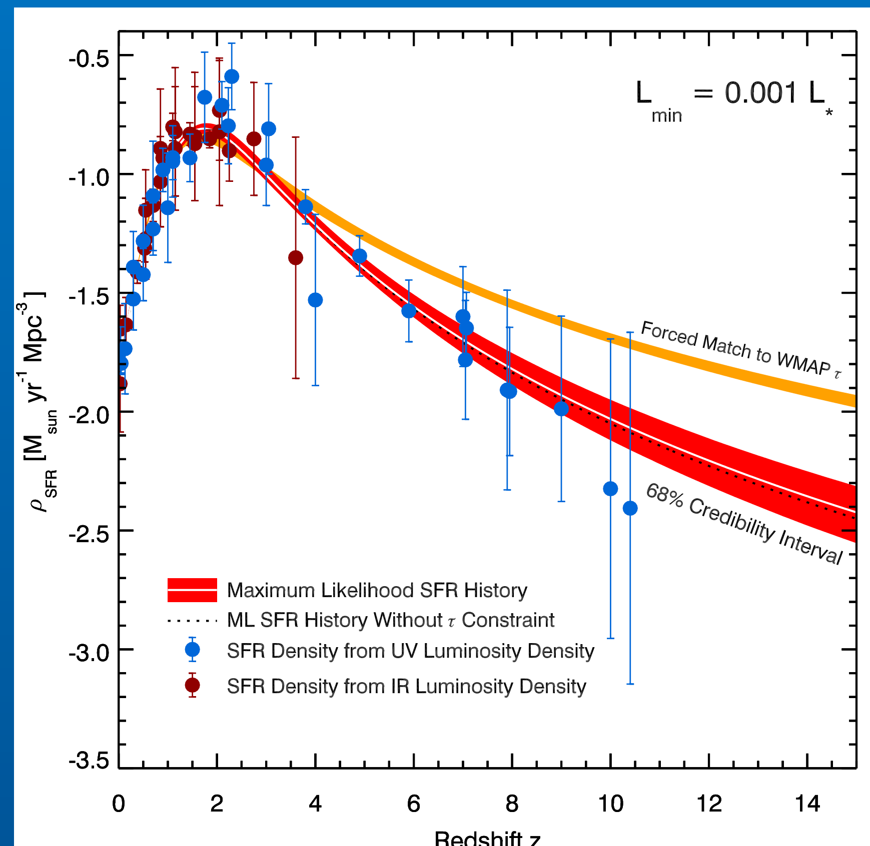
Age of the universe 1 Gyr

Eddington limit growth rate of mass

$$\frac{dM}{dt} = \frac{L_{acc}}{\eta c^2} < \frac{4\pi G M m_p}{\eta c \sigma_T}$$

$$M \leq M_0 e^{\frac{t}{\tau}}$$

$$\tau = \frac{\eta c \sigma_T}{4\pi G m_p} \approx 5 \times 10^7 \, yr$$



LATEST PLANCK RESULTS: first stars form even later!

Wu+ 15; Robertson+ 15; Planck+ XIII 15

LIGHT SEEDS

PopIII

~10^{1-2} M_{sun}

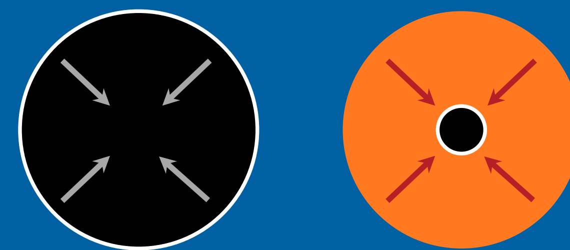
MASSIVE SEEDS

Direct collapse

Nuclear star cluster

~10^{3} M_{sun}

Supermassive Star



Quasi star

~10^{4-6} M_{sun}

Uncertainity in the masses of the first stars

A challenge to grow monster BHs seen by t < 2 Gyrs

New Planck results push first stars to later even ~550 Myrs after the Big Bang

In protogalaxies: need to avoid fragmentation and star formation, need to centrally concentrate mass

- Metal-free gas
- Prevent molecular H-cooling

First black holes in pre-galactic halos z = 20-30
JWST will offer the first view at z ~ 10 - 6

$M_{BH} \sim 1 - 100\ M_{sun}$ LIGHT SEEDS

Pop III remnants : Simulations suggest that the first stars have a range of masses (Bromm+ 02 ; Abel+ 02; Abel+ 00; Alvarez+ 08; Hirano+ 14) Metal free Pop III stars leave remnant BHs

Supra-exponential early growth boost: Super-Eddington growth in nuclear star clusters at high-z (Alexander & PN 14)

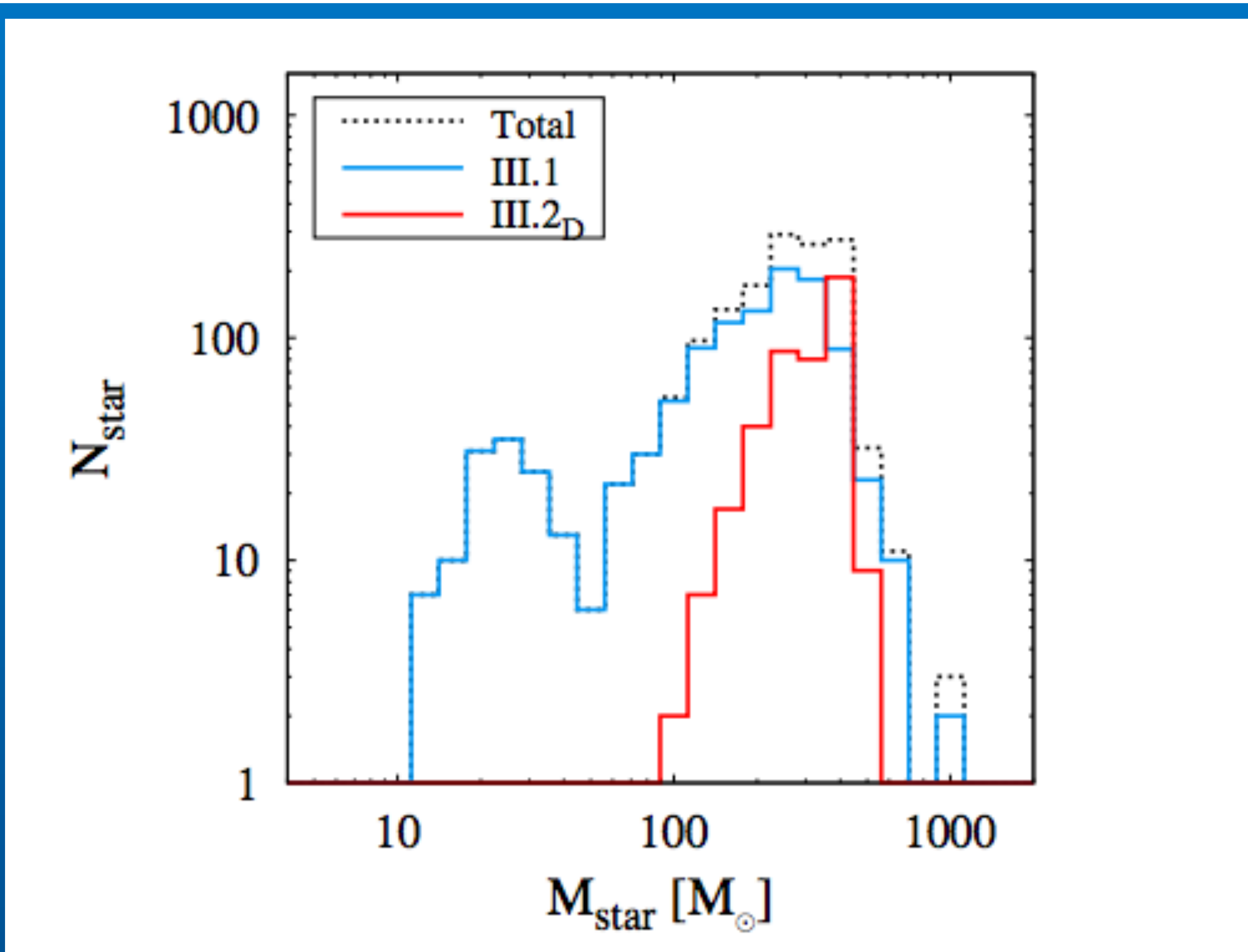
$M_{BH} \sim 10^3 - 10^6\ M_{sun}$ MASSIVE SEEDS

Direct Collapse – efficient viscous transport, H2 cooling suppressed, Lyman-Werner radiation, formation of central concentration (Eisenstein & Loeb 95; Koushiappas+ 04)+ proper dynamical treatment of disk stability (Lodato & PN 06, 07)

Supermassive star (Haehnelt & Rees 93)

Quasi-star - Bar unstable self-gravitating gas + large quasi-star (Begelman 08; 10; 12)

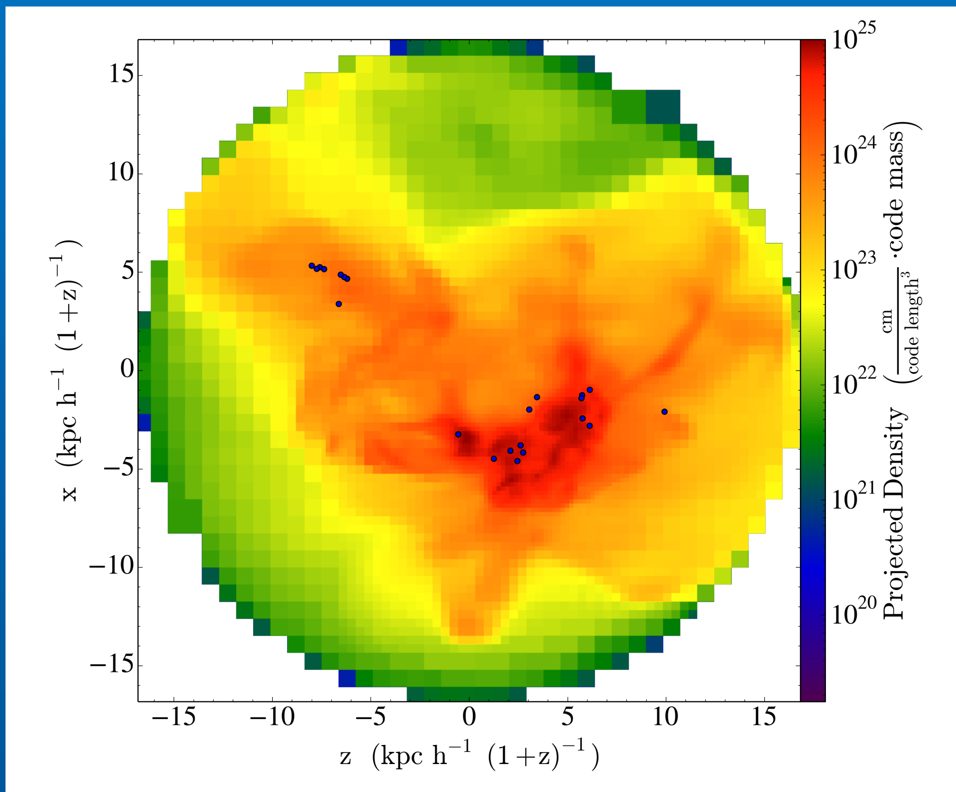
HOW MASSIVE ARE POP III STARS?

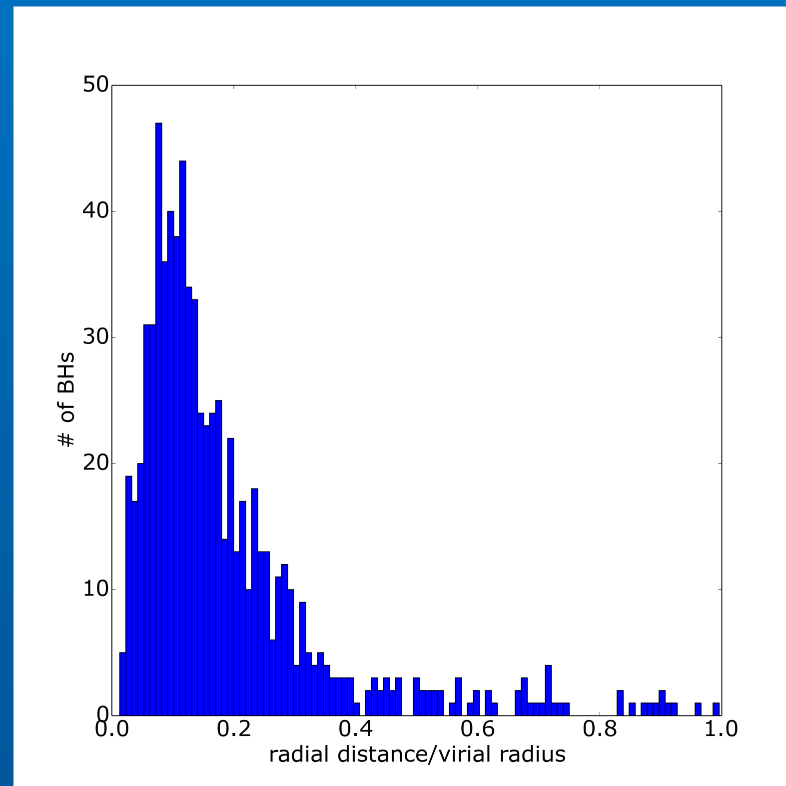


~ Mass distribution of Pop III stars formed at z = 30 -> 10

Hirano+ 14

WHAT ABOUT Pop III REMNANTS IN 10^9 M_{sun} HALOS AT z=15
Tracking the fate of Pop III remnant BHs in 3-sigma peaks



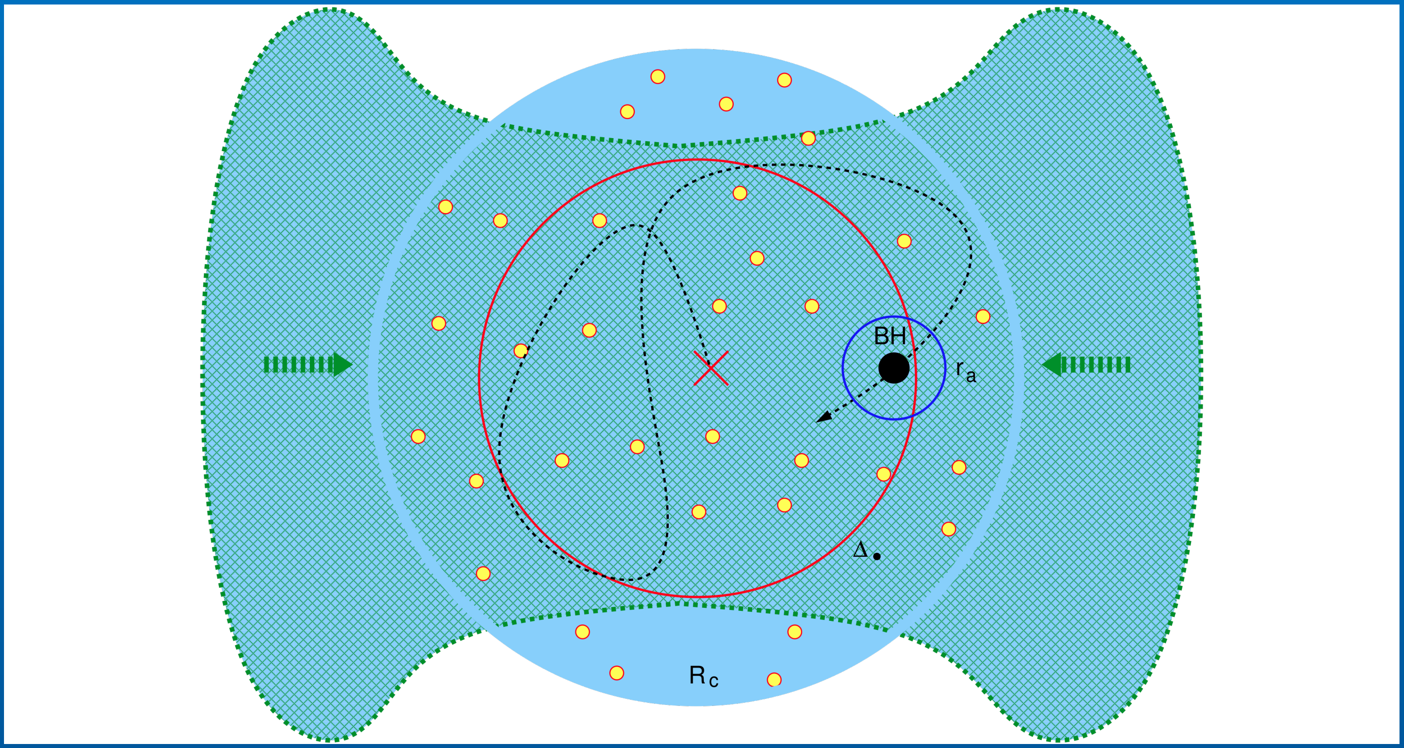


snapshot with 20 BH seeds, 300 Mpc^3 box, ENZO AMR 12 level refinements ~ 19 comoving pc, DM resolution ~ 3 X 10^4 M_{sun}

~ DM halos where Pop III star clusters formed at z = 15

Shi+ 15

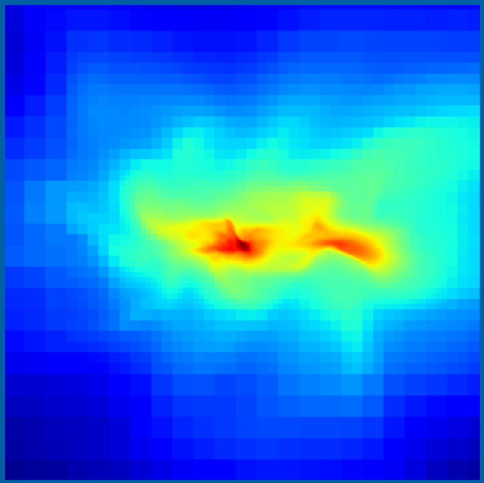
SUPER BOOSTING EARLY BH GROWTH
COSMIC SPARKLERS THAT JWST WILL DETECT

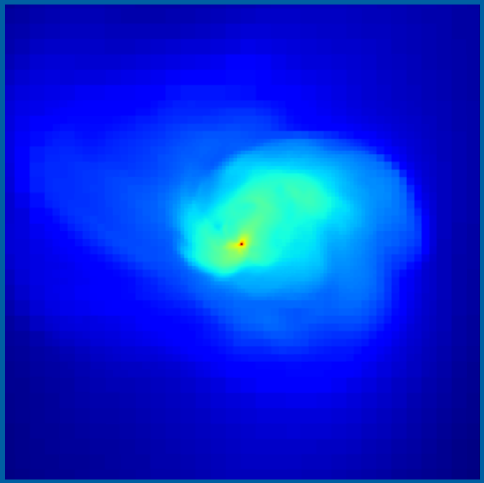


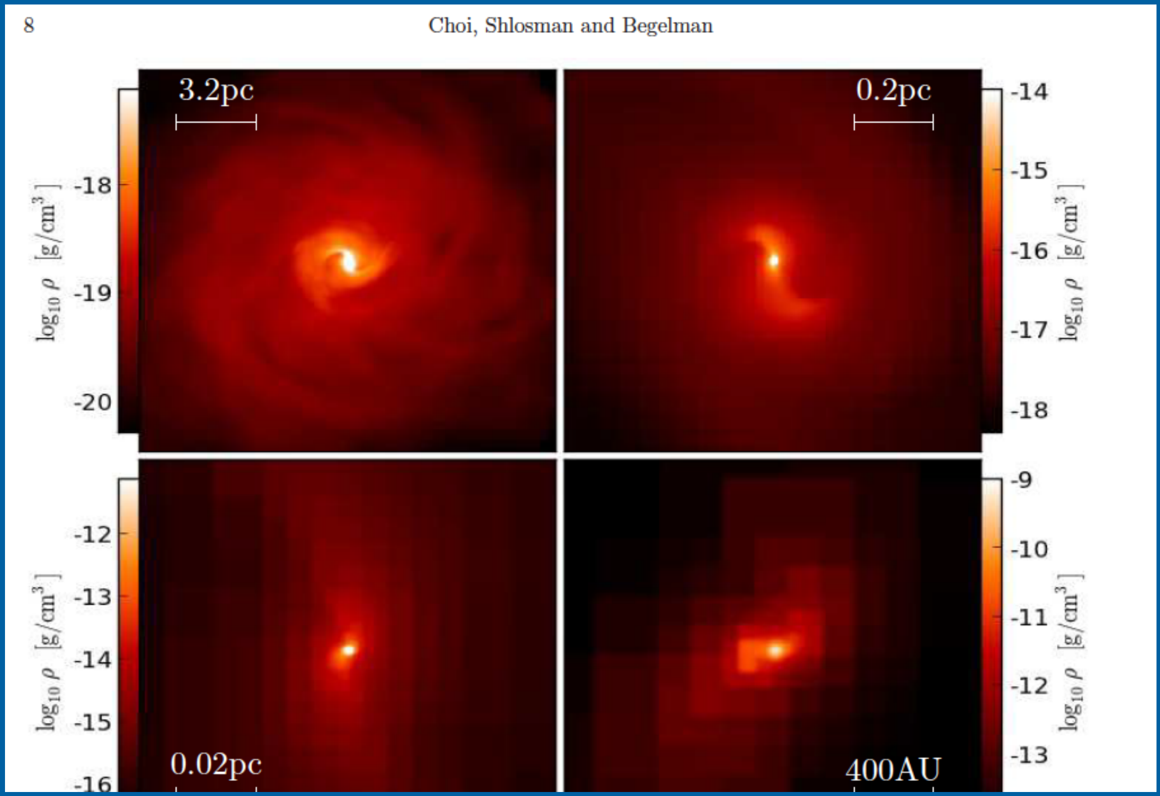
Circumventing the Eddington limit

Alexander & Natarajan 14

Massive BH seed formation simulations





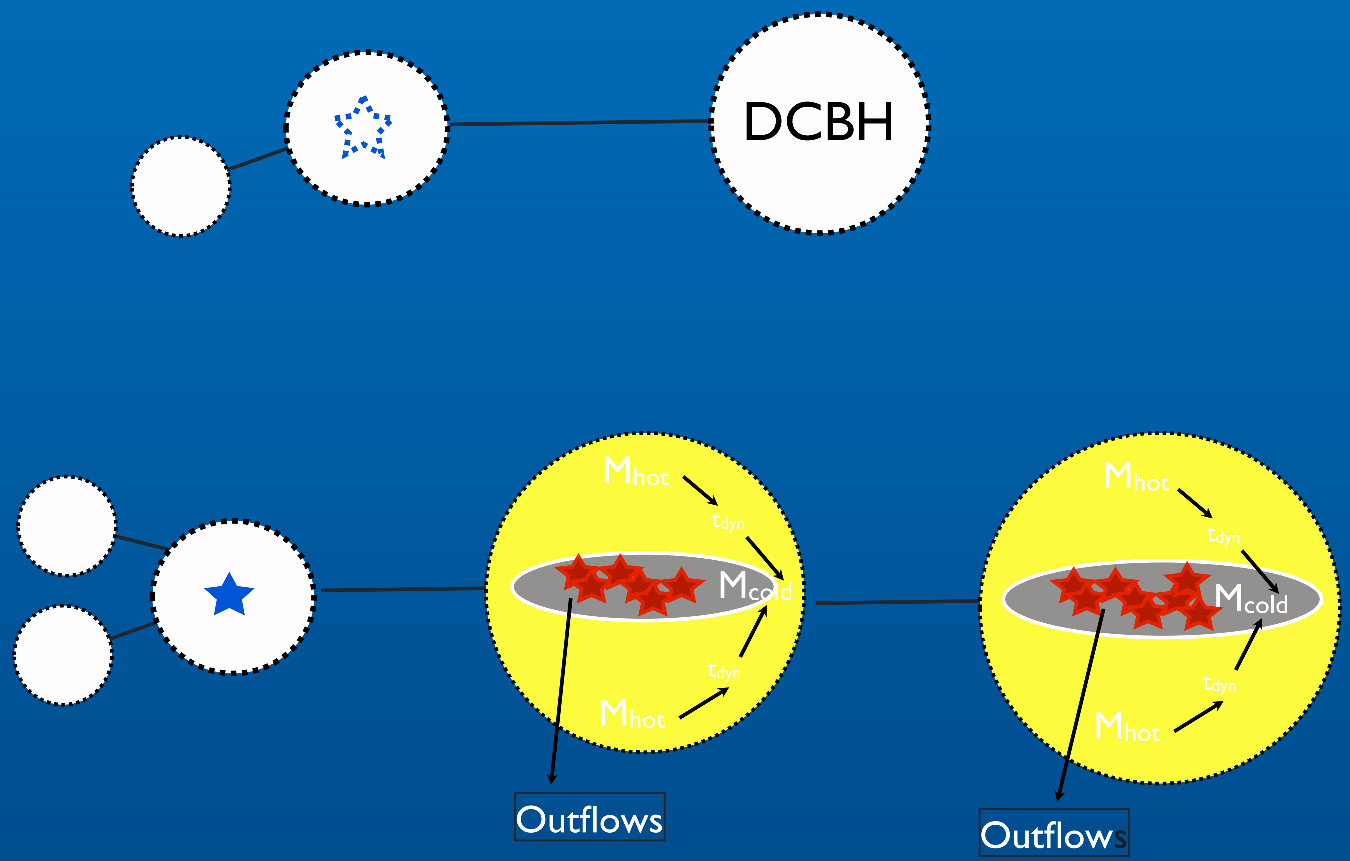


Smith, Davis & PN 15; Regan+ 08; 13; Hirano+ 14

Choi, Shlosman & Begelman 13

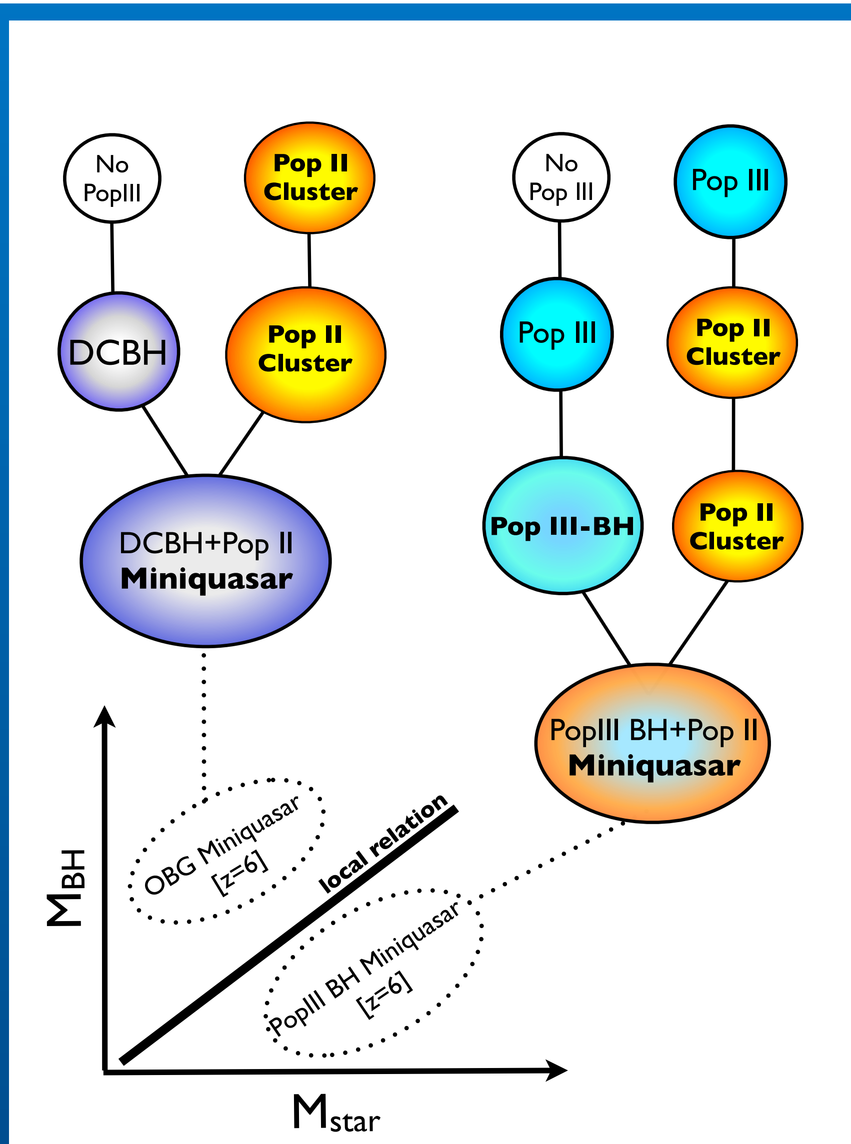
OPTIMAL SITES FOR DCBH FORMATION

Low spin DM halos; satellite halos; Lyman-Werner radiation from nearby halos with star formation to dissociate mol H and prevent fragmentation



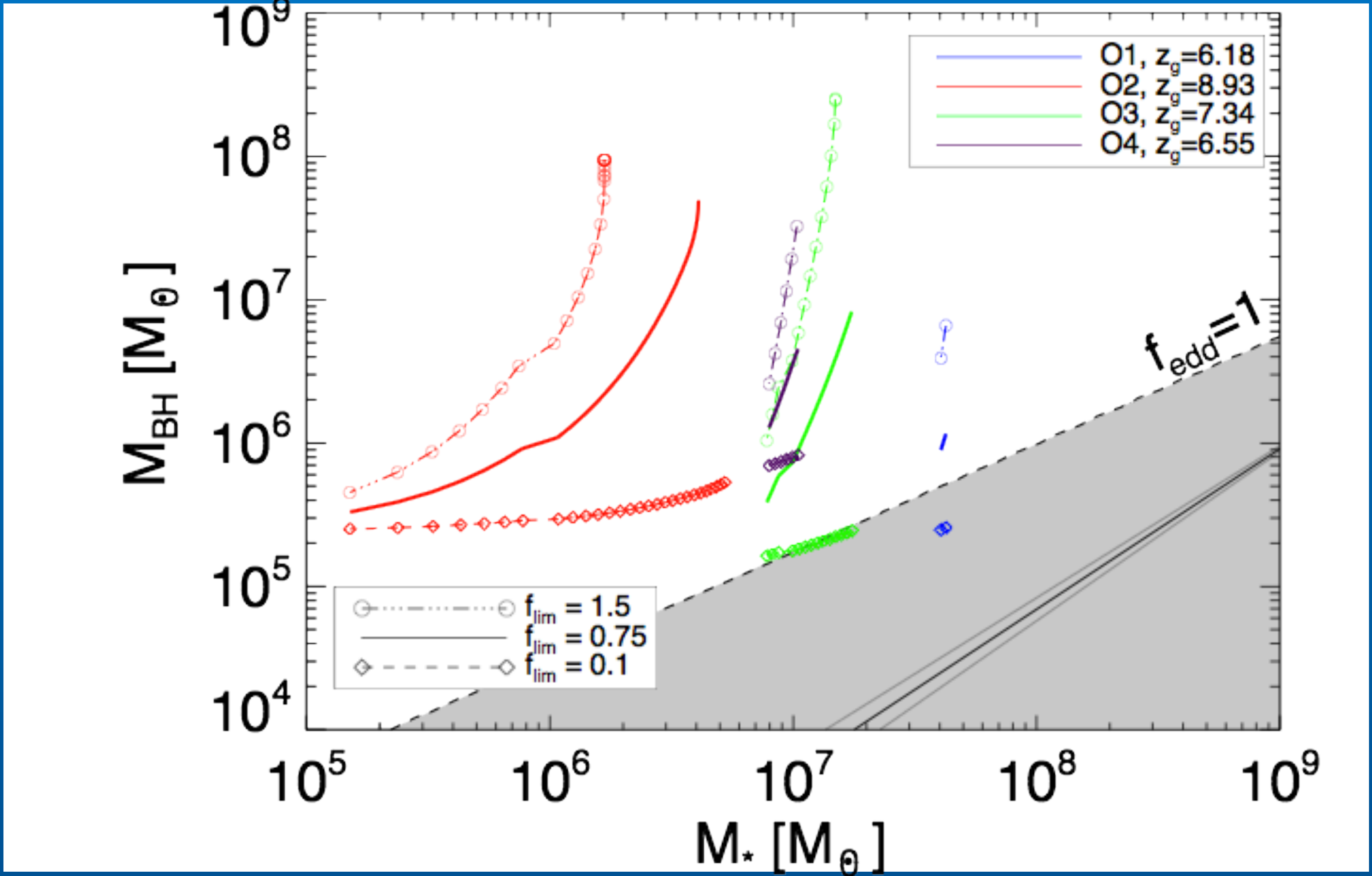
Agarwal+ 15

DIRECT COLLAPSE BHs AND THEIR OBESE BH HOST GALAXIES
JWST WILL PROBE ENVIRONMENTS OF HALOS THAT HOST DCBHs



Agarwal+ 12; 14

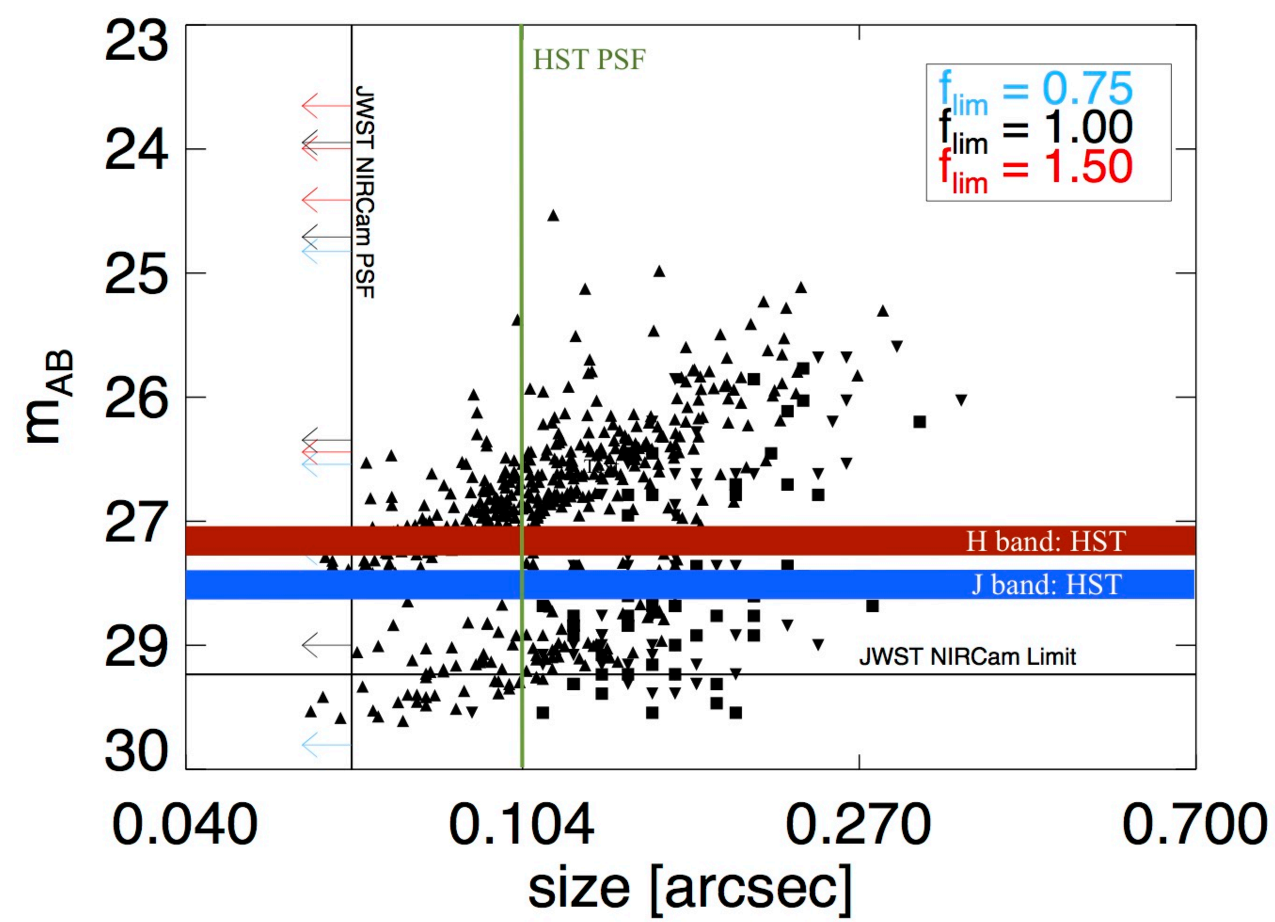
HIGH REDSHIFT SIGNATURE OF MASSIVE BH SEEDING MODELS



PREDICT NEW CLASS OF GALAXIES
OBESE BH GALAXIES (OBGs)

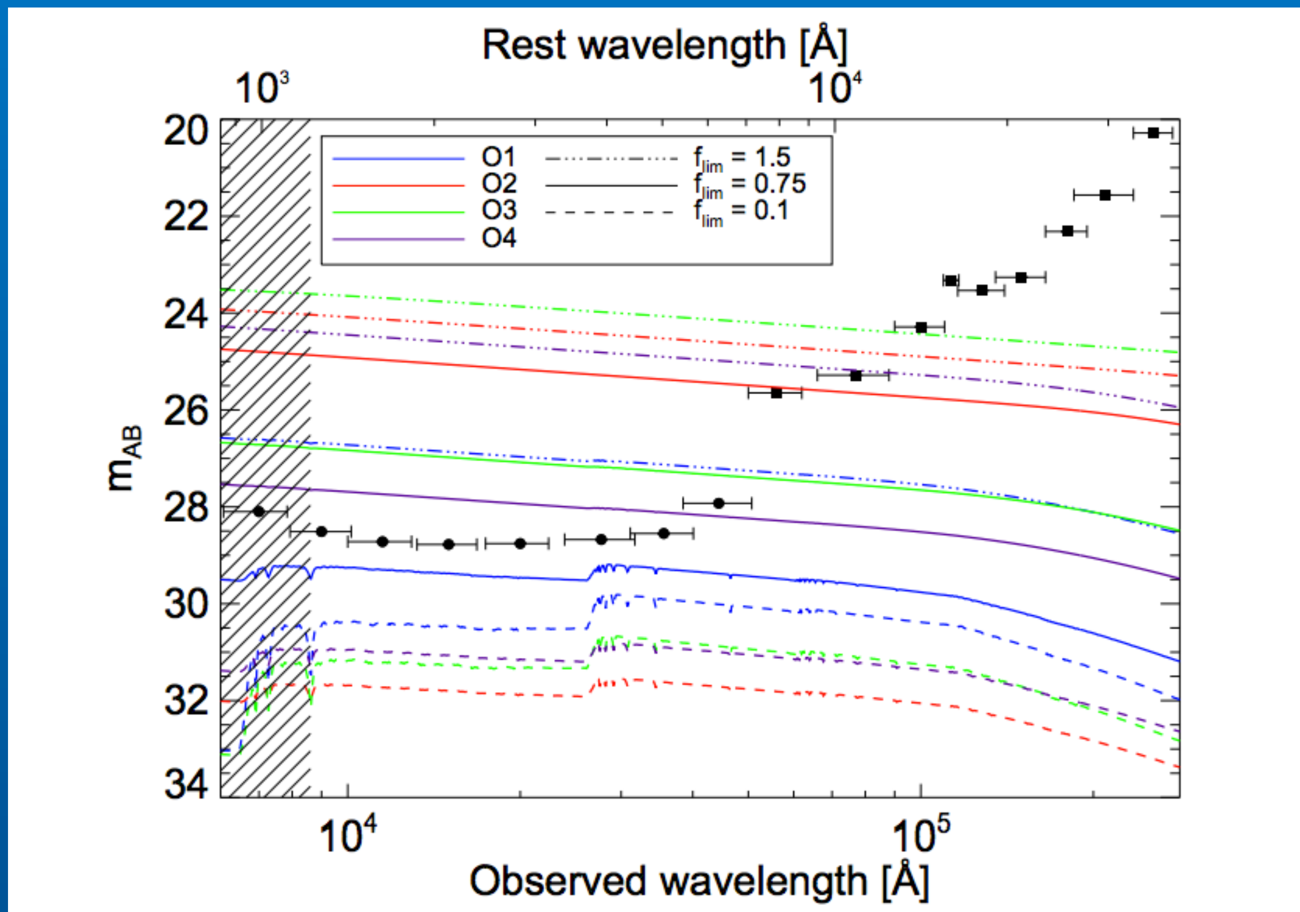
Agarwal+ 12; 14

DETECTING THE POPULATION OF OBGs WITH NIRCAM



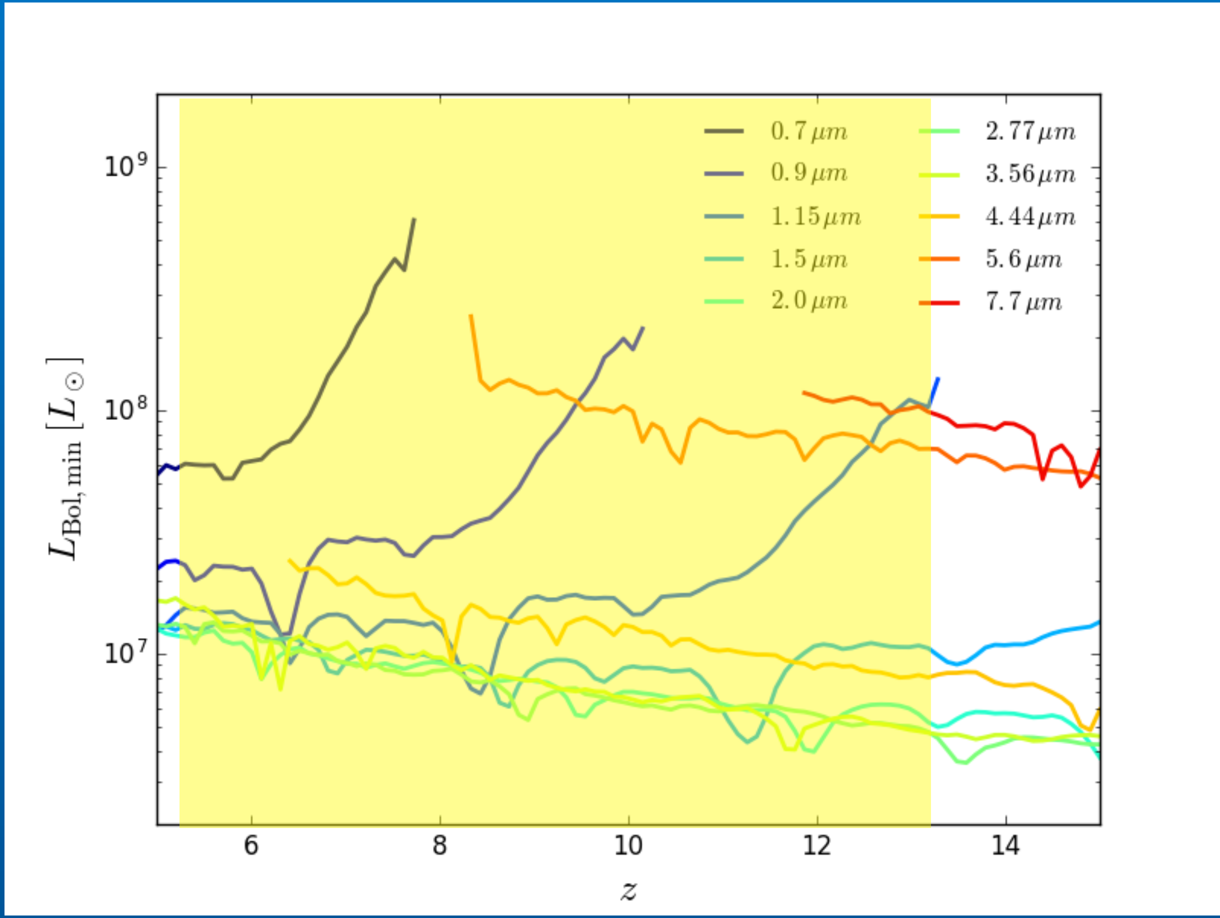
OBGs: bright and unresolved

JWST NIRCAM & MIRI detectability of DCBHs/OBGs



OBGs: Strongly accreting DCBHs have no Balmer break

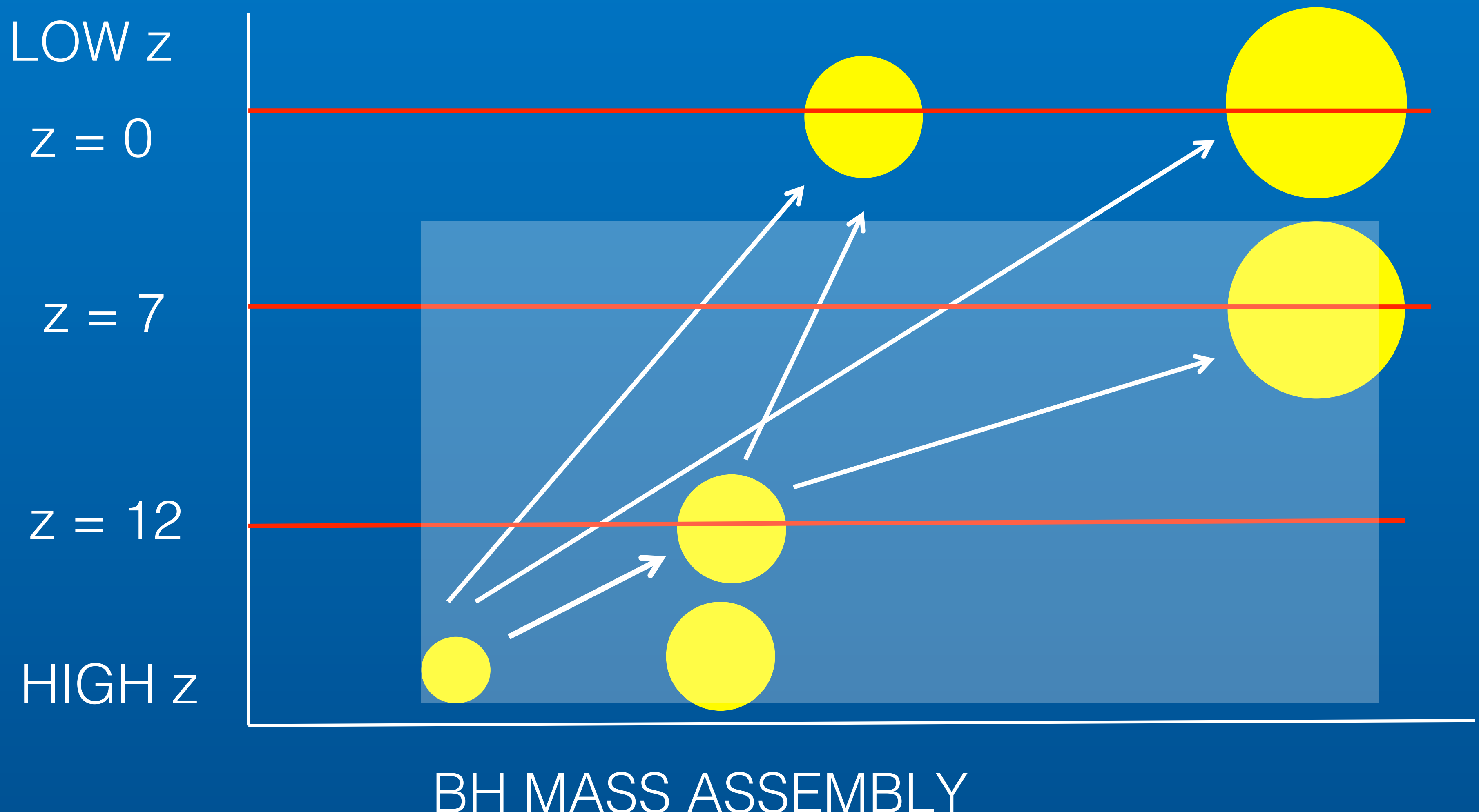
DETECTING EARLY QUASARS WITH JWST



Detectability of quasars (with emission lines) by NIRCAM

Ricarte & PN 16

Exploring growth histories

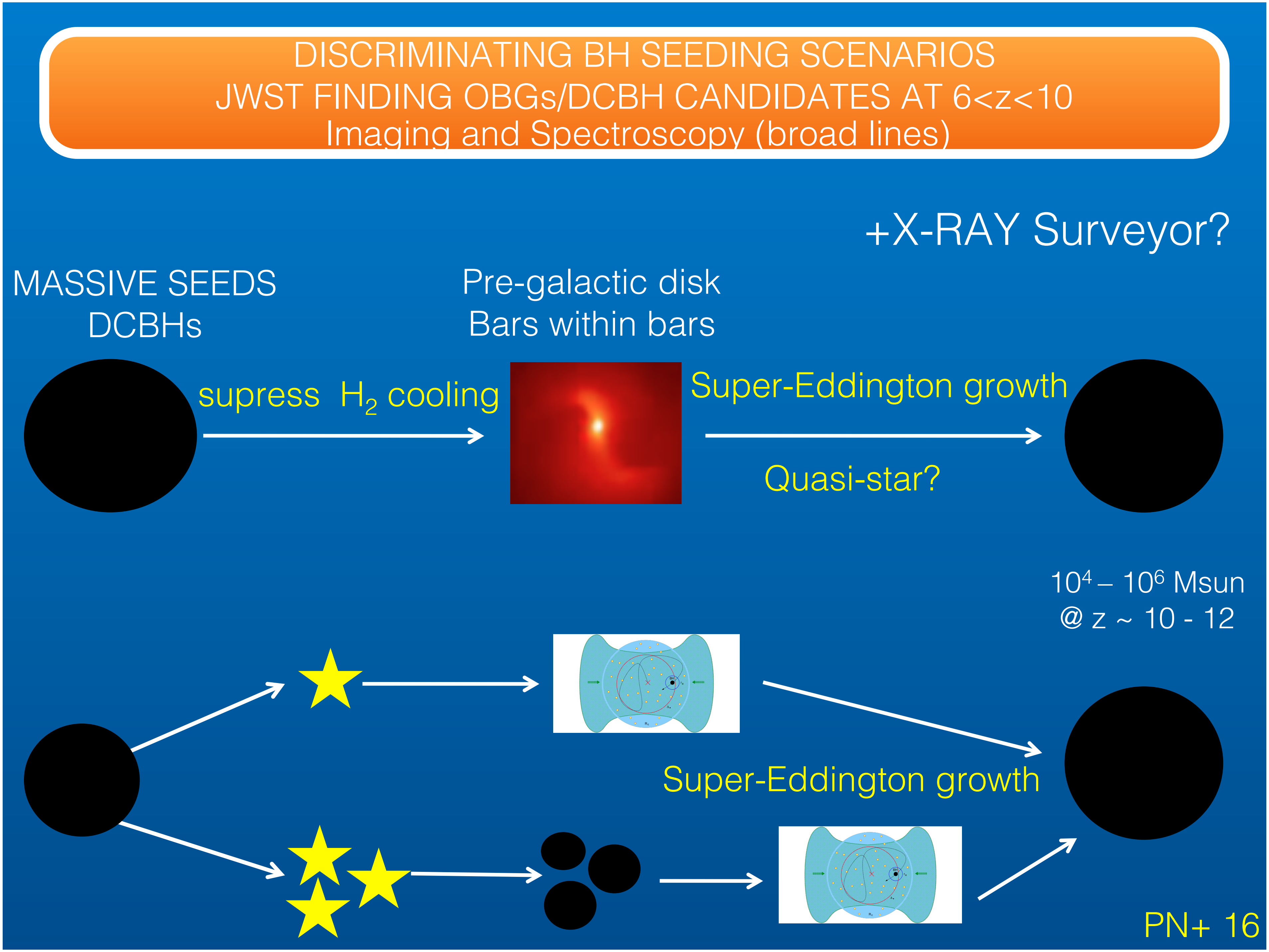


Finding sources in this parameter space 10<z<6 and M_{bh}> 10^4 Msun
JWST WILL SHED LIGHT ON COSMIC ACCRETION HISTORY OF BHs

TRACKING M-sigma with JWST

discriminating journey to M-sigma for light & massive seeds

Ricarte & PN 16


DISCRIMINATING BH SEEDING SCENARIOS
JWST FINDING OBGs/DCBH CANDIDATES AT 6<z<10
Imaging and Spectroscopy (broad lines)
+X-RAY Surveyor?
MASSIVE SEEDS
DCBHs
Pre-galactic disk
Bars within bars
supress H_2 cooling
Super-Eddington growth
Quasi-star?
$10^4 – 10^6$ Msun
@ z ~ 10 - 12
Super-Eddington growth
PN+ 16