Optimal Conditions for the Growth of Black Hole Seeds

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Goal & Outline

Identify the optimal conditions for black hole growth in the parameter space [black hole mass, gas density]

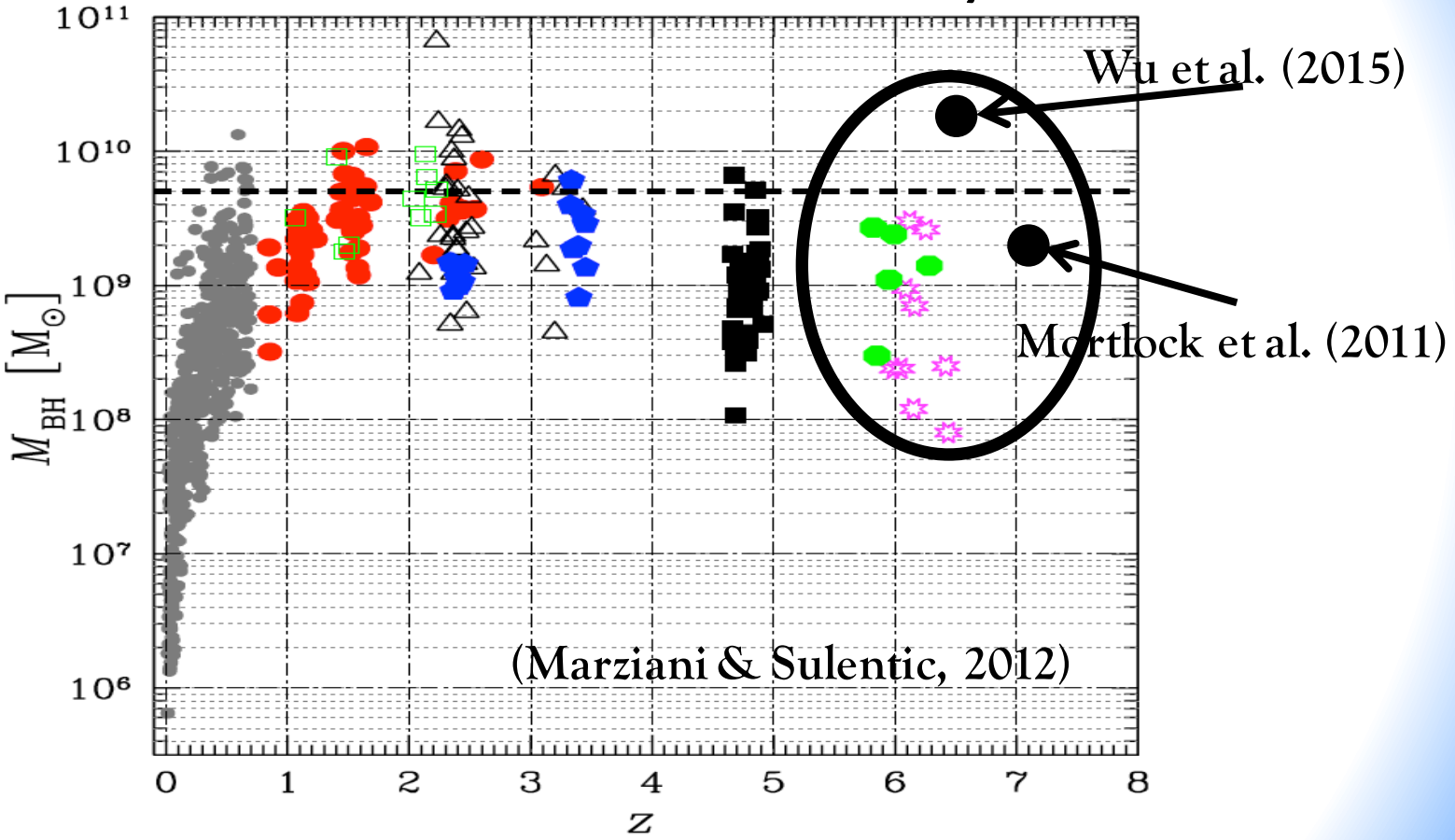
INTRODUCTION: THE FIRST BLACK HOLES

CONSTRAINTS ON BLACK HOLE GROWTH

A PARAMETRIC VIEW OF BLACK HOLE GROWTH

OBSERVATIONAL CONSEQUENCES

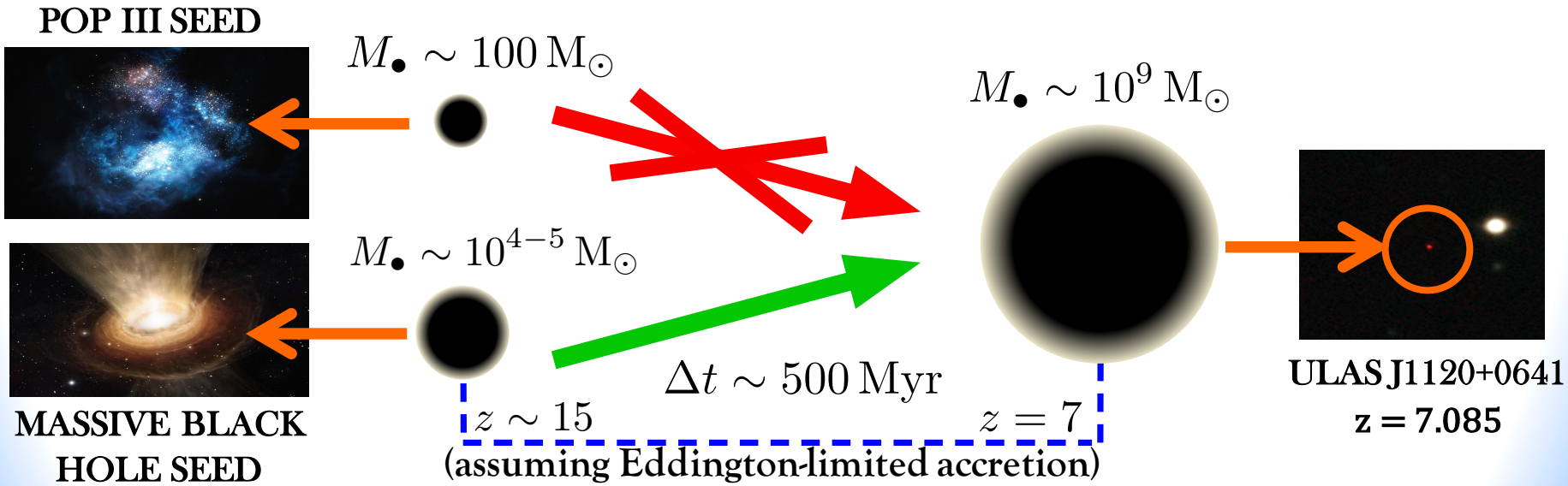
Massive Black Holes Family Portrait



The Billion (Dollars) Problem

Observations of $10^9\,\mathrm{M}_\odot$ SMBHs < 1 Gyr after the Big Bang

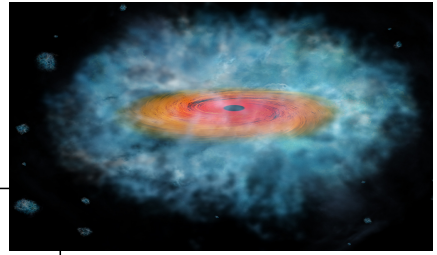
How did they grow up so rapidly?

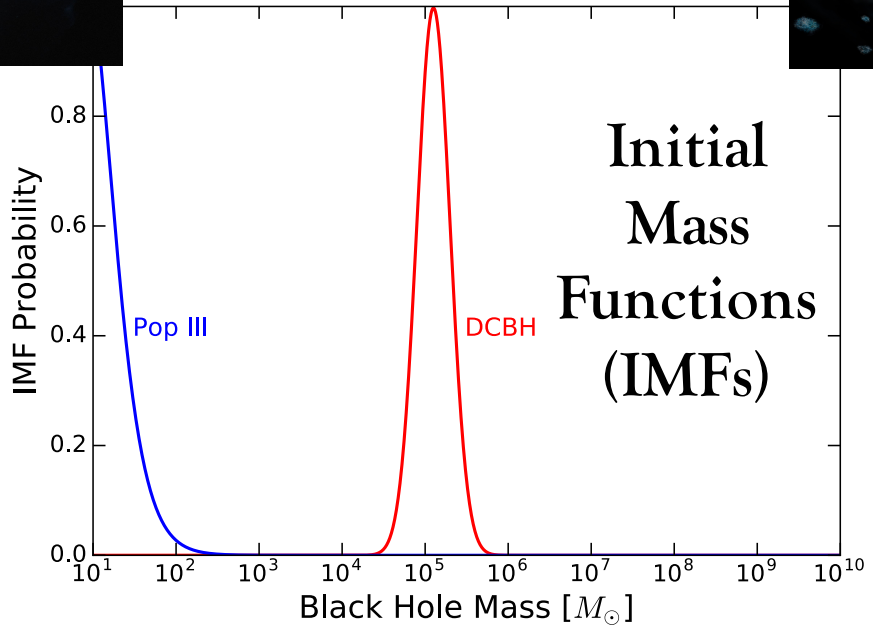


Categories of Black Hole Seeds

Pop III remnant

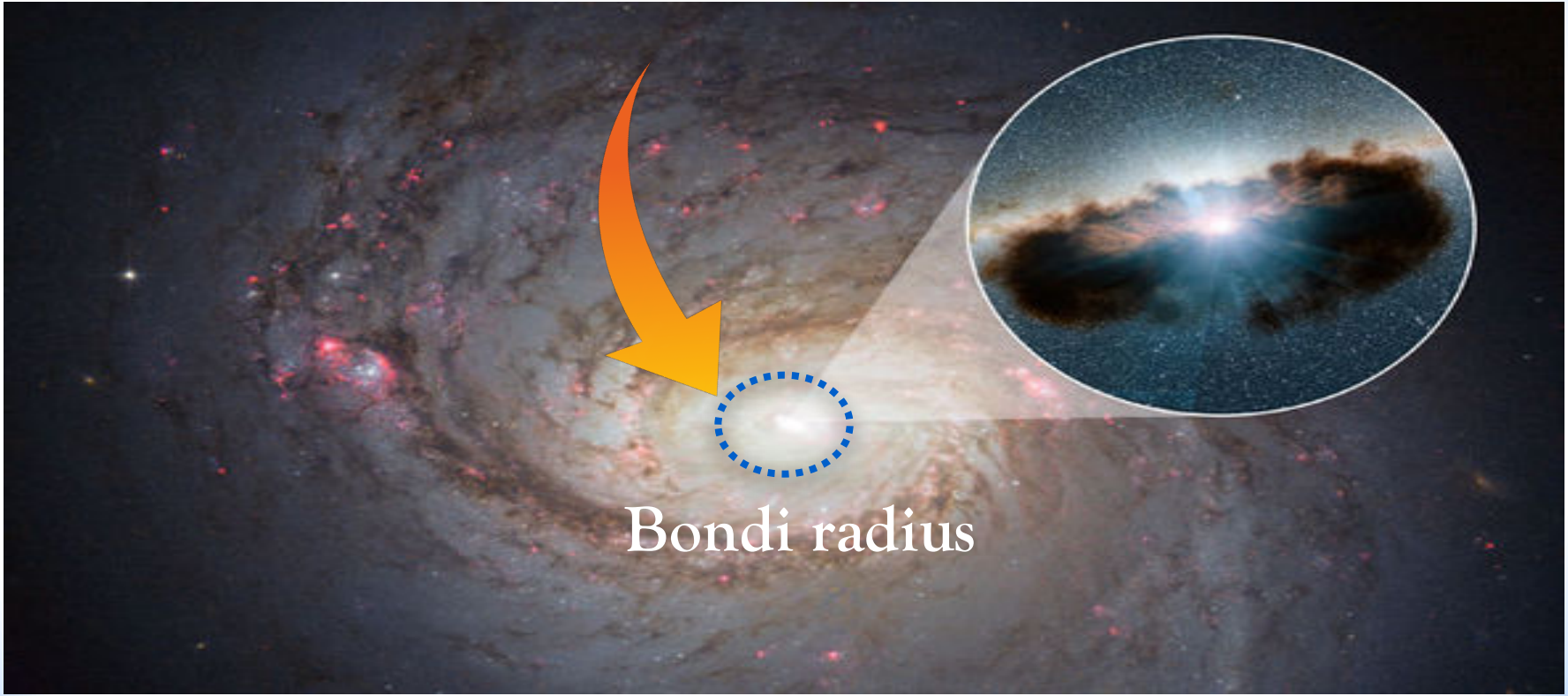
Direct Collapse Black Hole





Initial Mass Functions (IMFs)

The Multiple Scales of Black Holes



The Multiple Scales of Black Holes

SMALL SPATIAL SCALES
$r \ll R_B$

- Condition on radiation pressure

LARGE SPATIAL SCALES
$r \gtrsim R_B$

- Condition on radiation pressure
- Condition on angular momentum

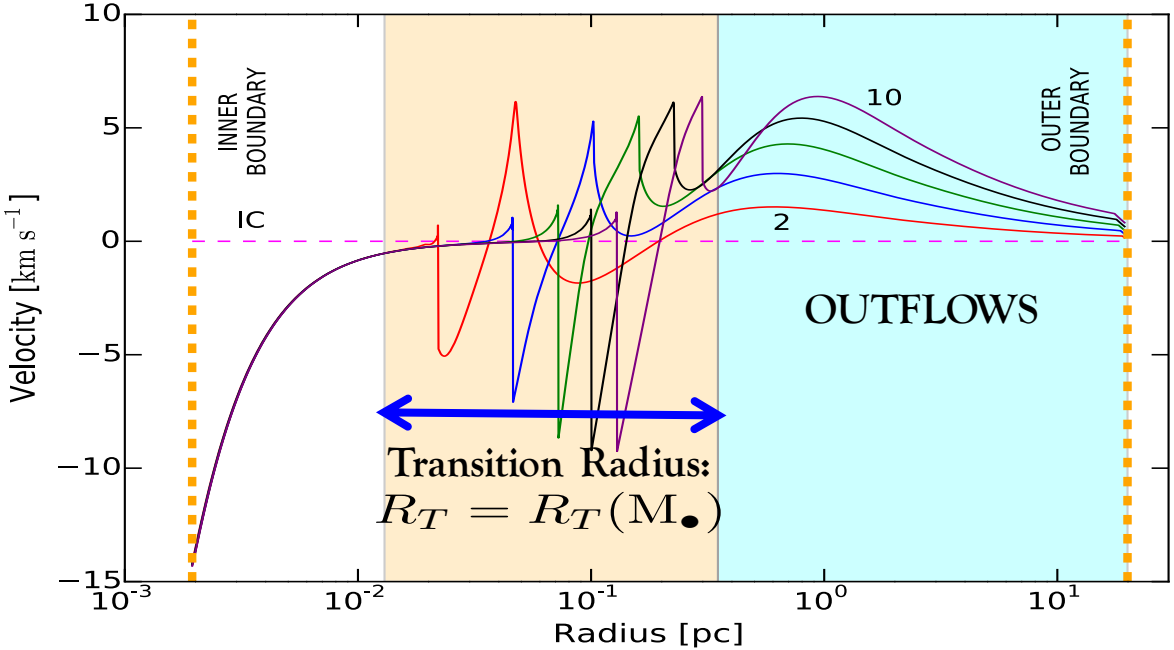
Express them as a function of black hole mass and gas density

$\mathcal{F}(M_\bullet, n_\infty)$

$\mathcal{F}(M_\bullet, n_\infty)$

Combine them in a parametric plot

Small Scales: the Transition Radius



$$M_\bullet > 5 \times 10^{-7} n_\infty^2 \, \mathrm{M}_\odot$$

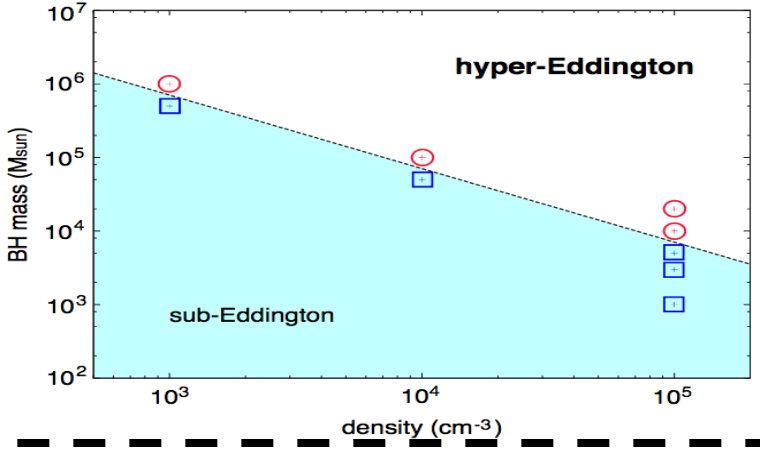
(Pacucci, Volonteri & Ferrara, 2015)

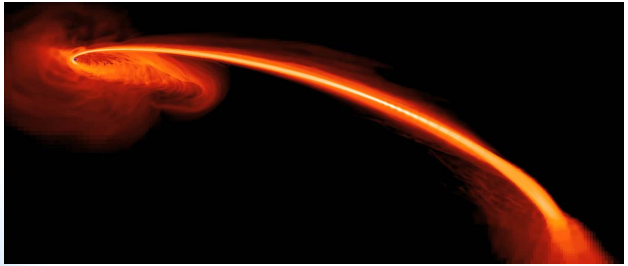
Large Scales: Radiation and Rotation

Radiation Pressure

$$M_\bullet > 10^9 n_\infty^{-1}\,\mathrm{M}_\odot$$

(Inayoshi, Haiman & Ostriker, 2016)





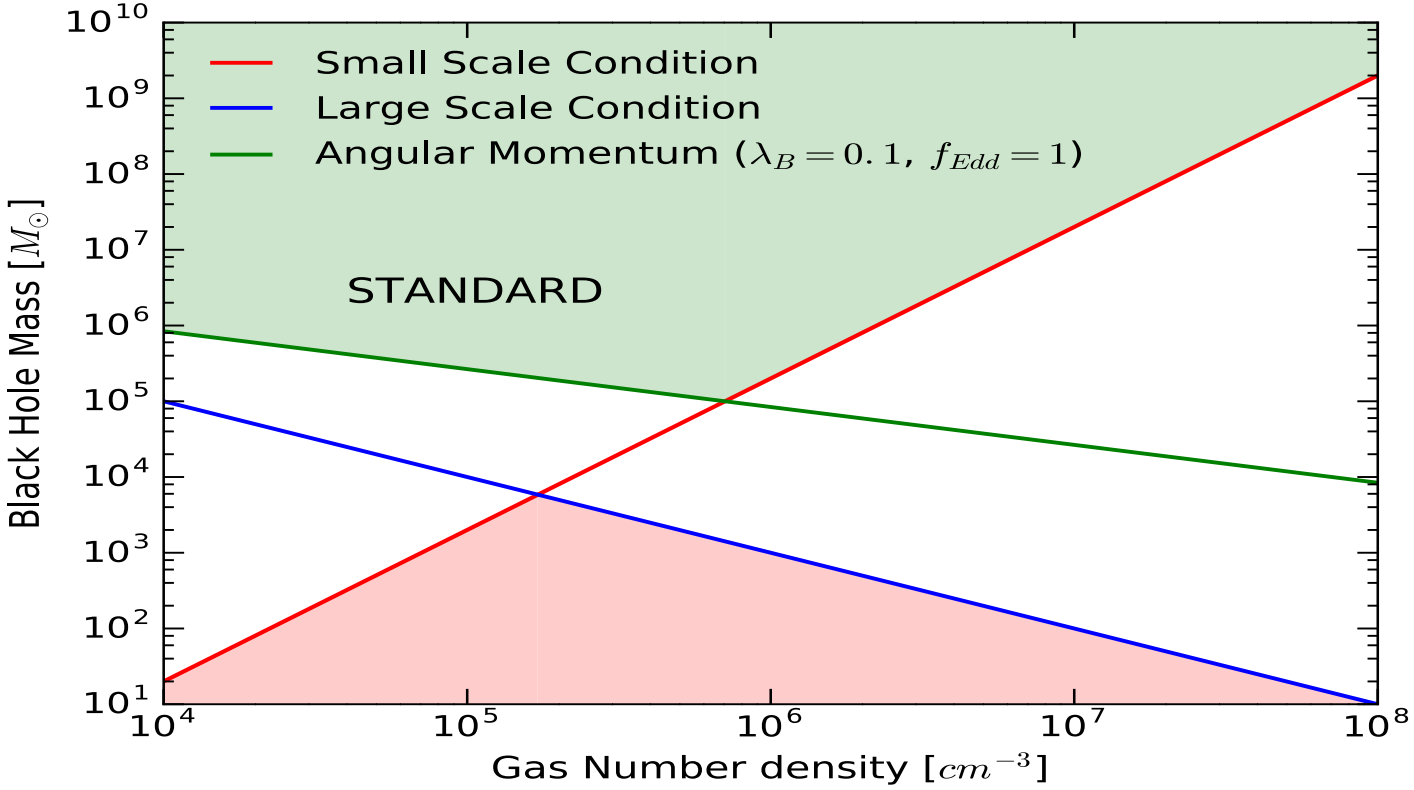
Angular Momentum

$$M_\bullet > 8 \times 10^8 n_\infty^{-1/2} \lambda_\mathrm{B}\,\mathrm{M}_\odot$$

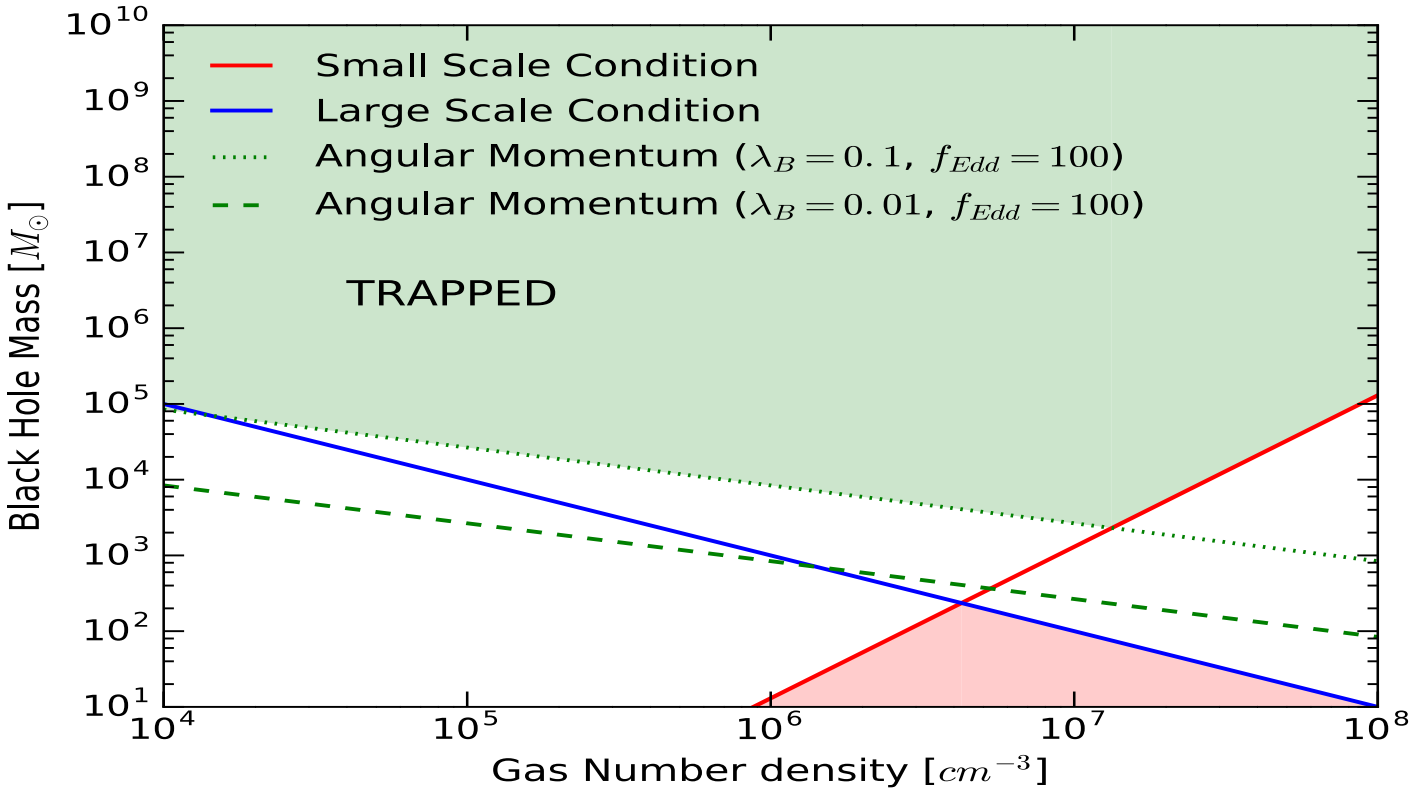
$$\lambda_\mathrm{B} = \frac{\ell_\mathrm{B}}{(GMR_\mathrm{B})^{1/2}}$$

(Begelman & Volonteri, 2017)

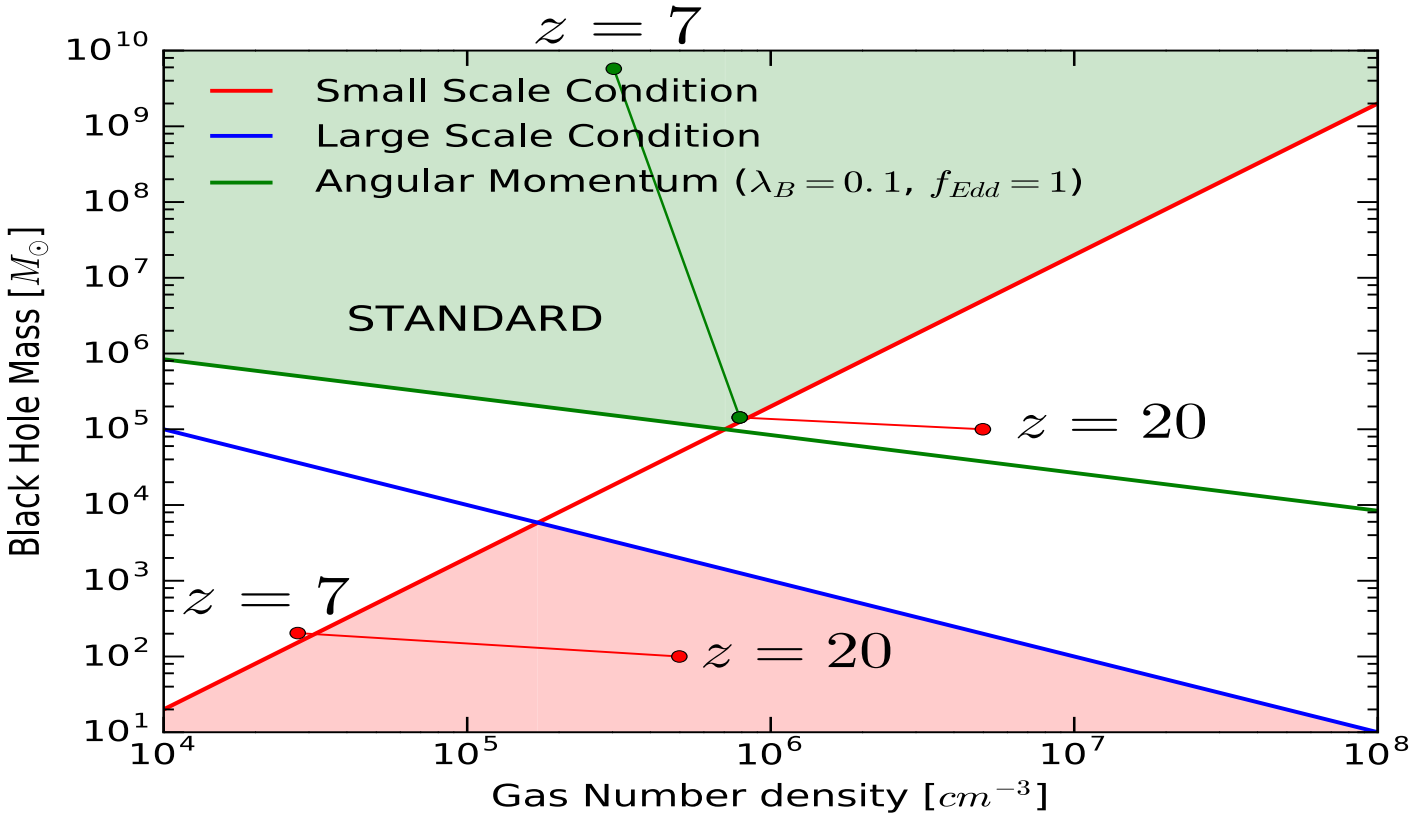
A Parameter Space for BH Growth



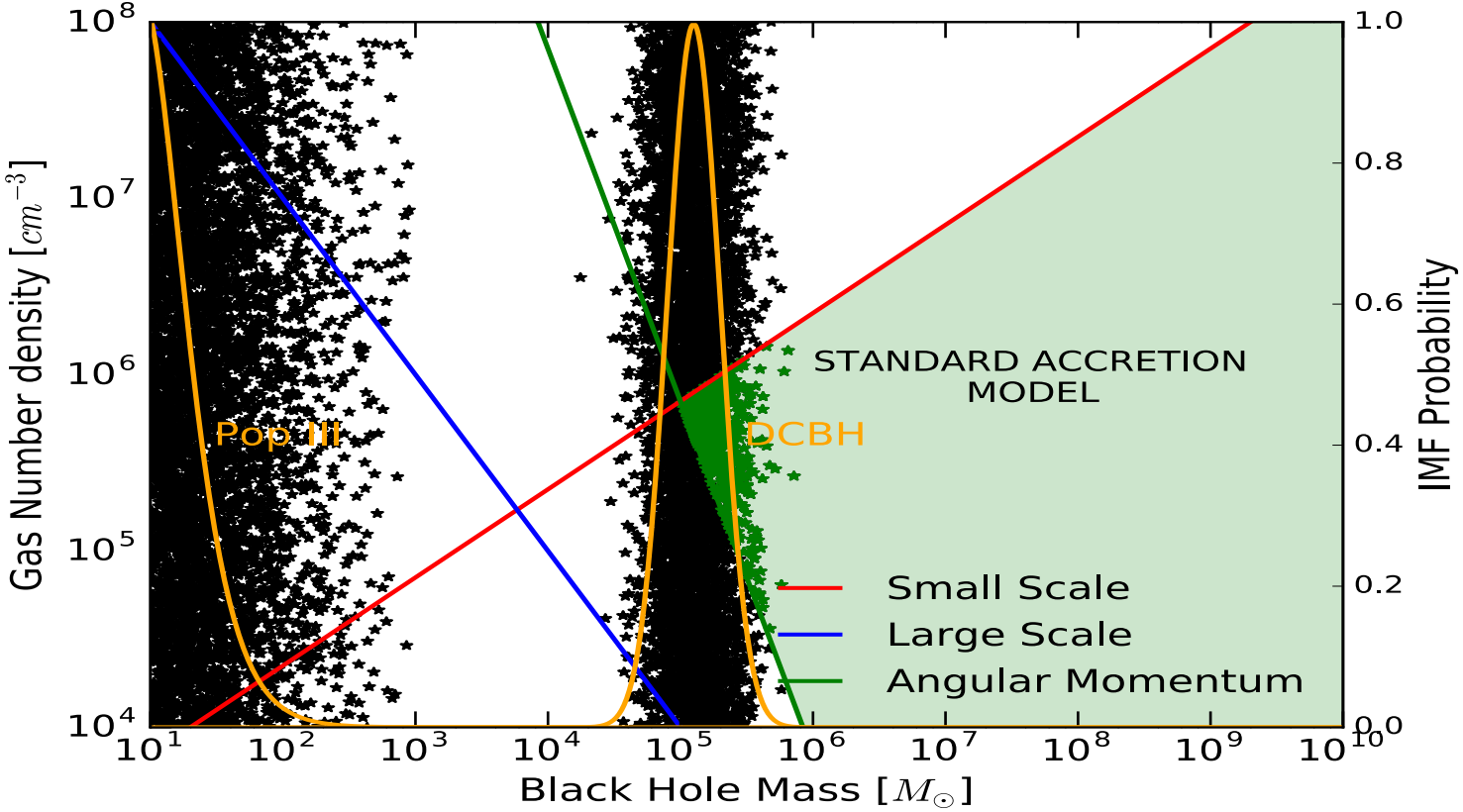
A Parameter Space for BH Growth



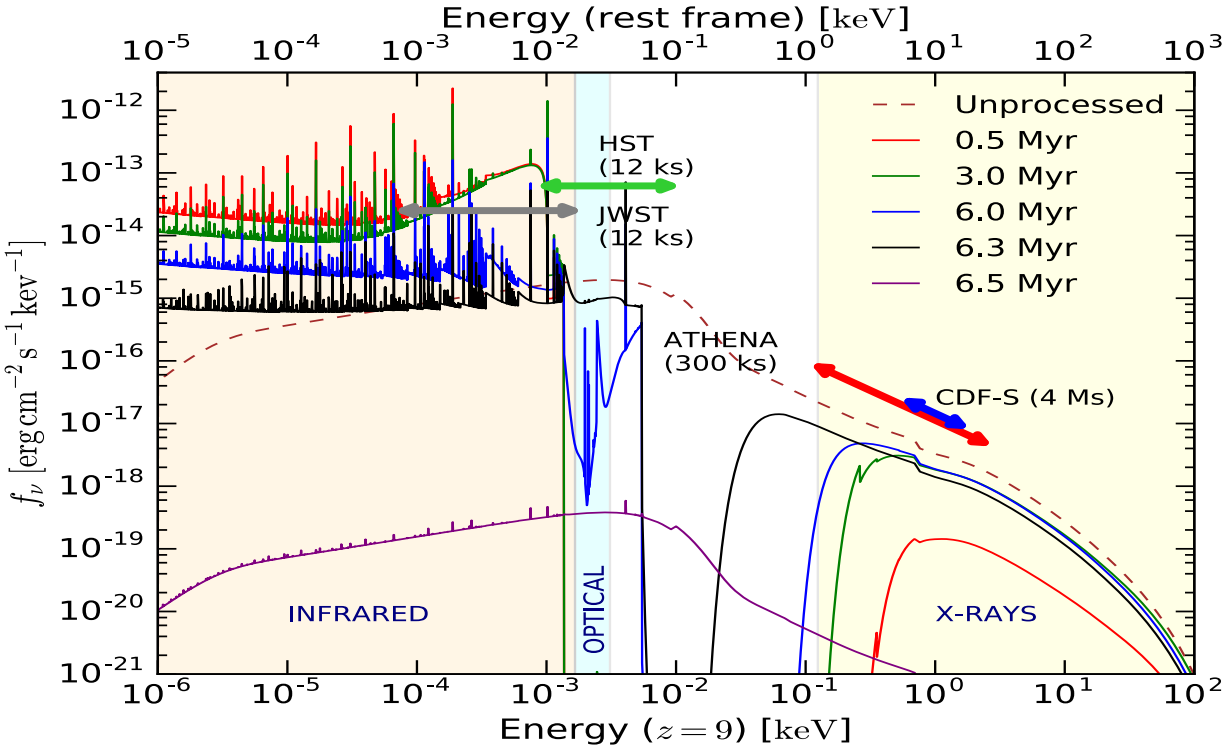
Cosmological Evolution of Seeds



A Probabilistic View of BH Growth

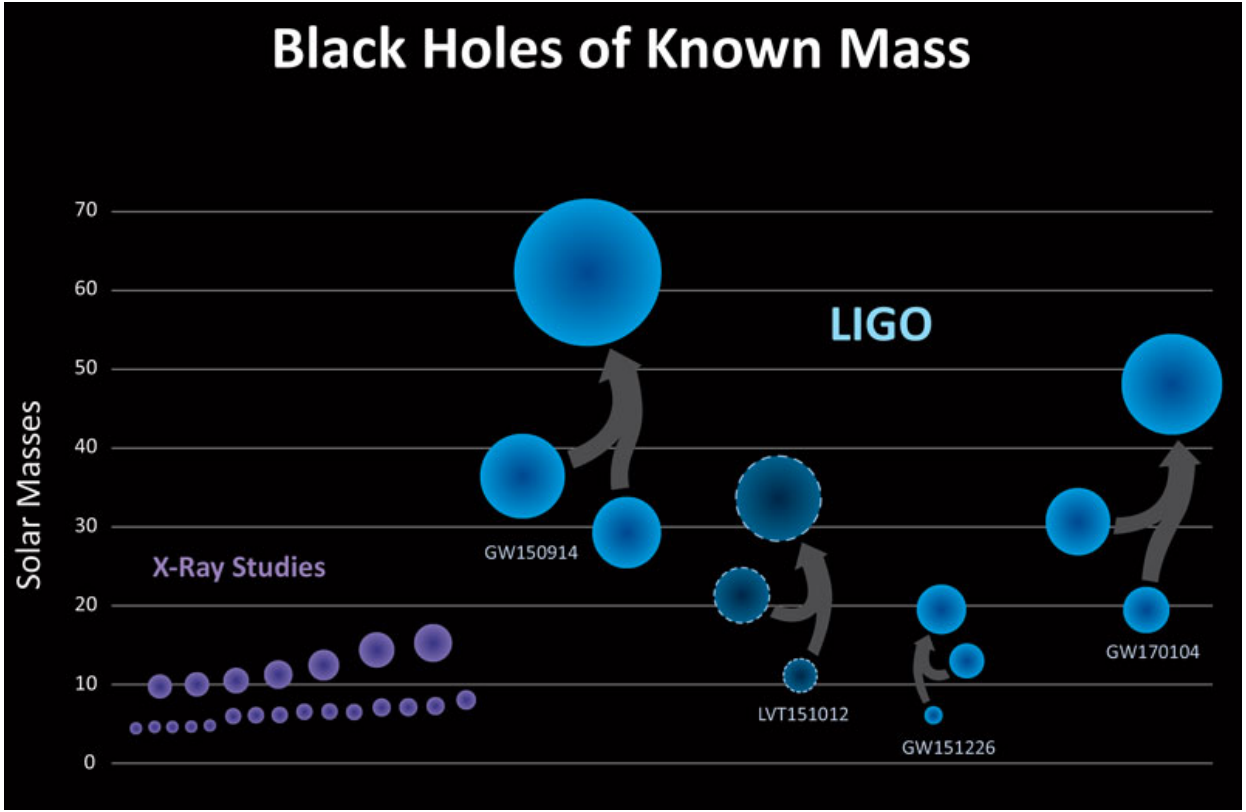


Hidden Black Holes



(see e.g. Pacucci et al. 2015, Comastri et al. 2015, Natarajan et al. 2016, Pezzulli et al. 2017)

Implications for LIGO sources



Conclusions

THEORY

- "Optimal" growth conditions minimize the time to reach a final mass
- Parameter space [black hole mass, gas density] to describe growth
- High and low efficiency regions are localized in the parameter space

OBSERVATIONS

- "Hidden" population of quasars might be low-efficiency growers
- Implications for LIGO sources?