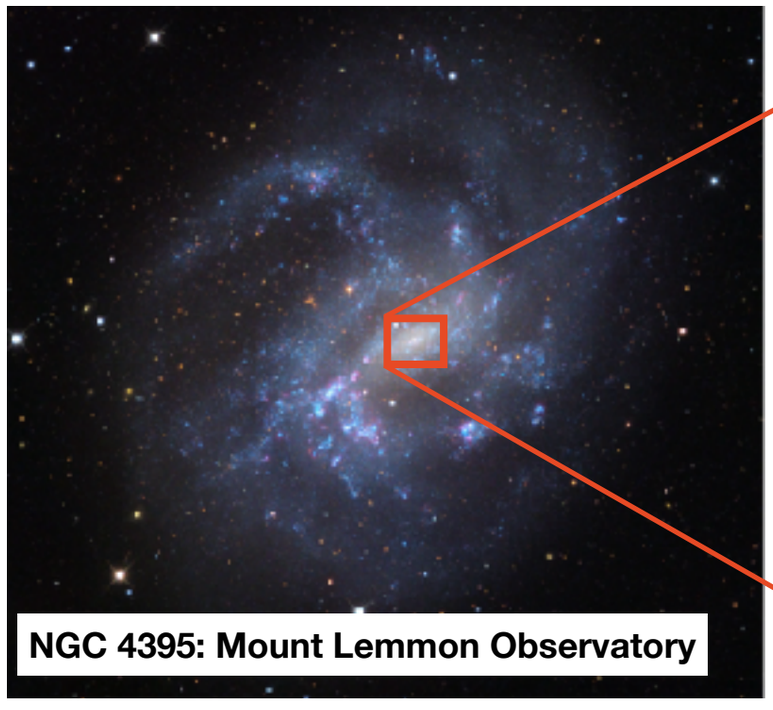
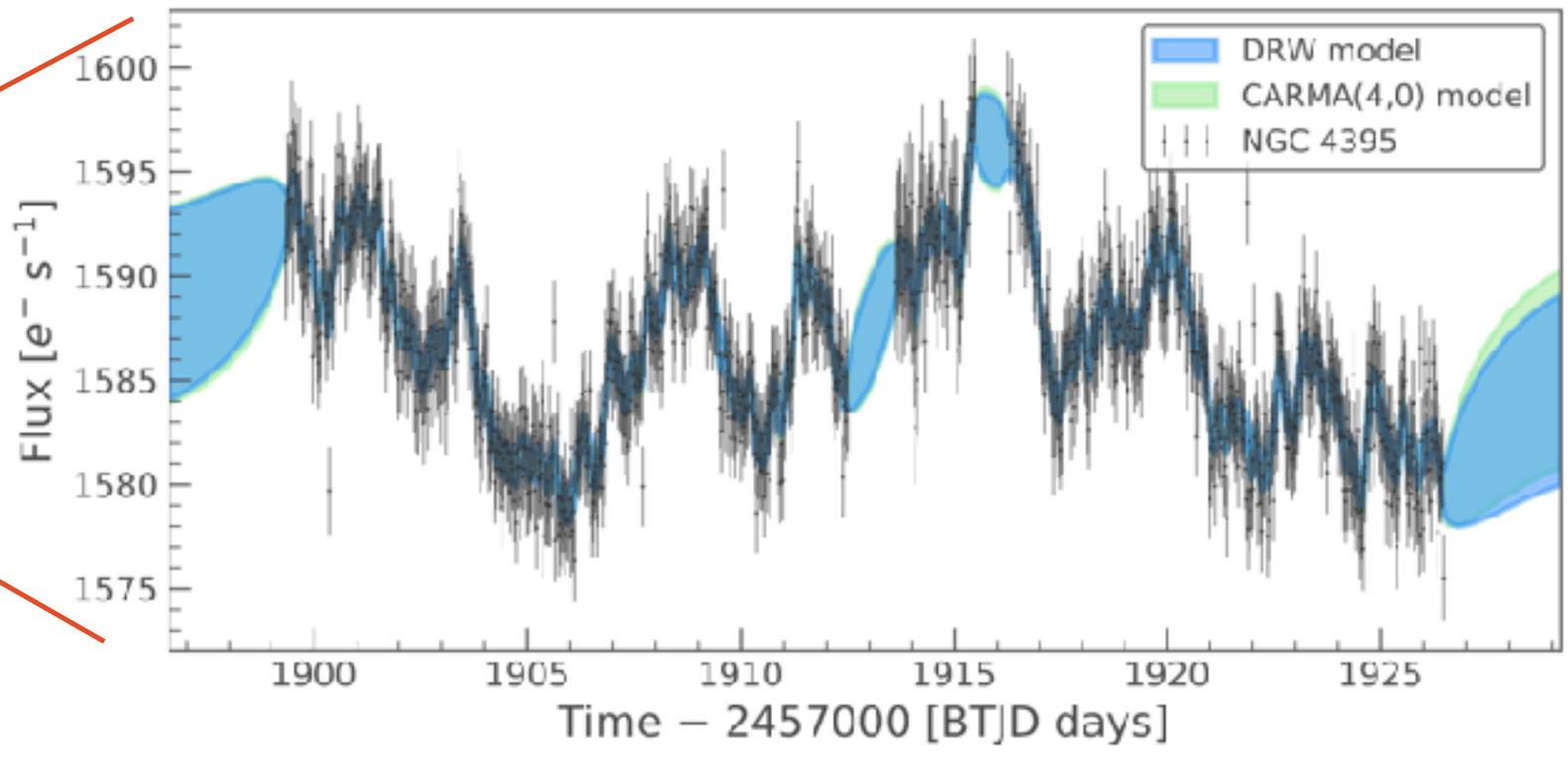
Intermediate-mass black hole demographics with Rubin Observatory

Rubin PCW, August 2023





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Yale University

IMBH demographics motivation

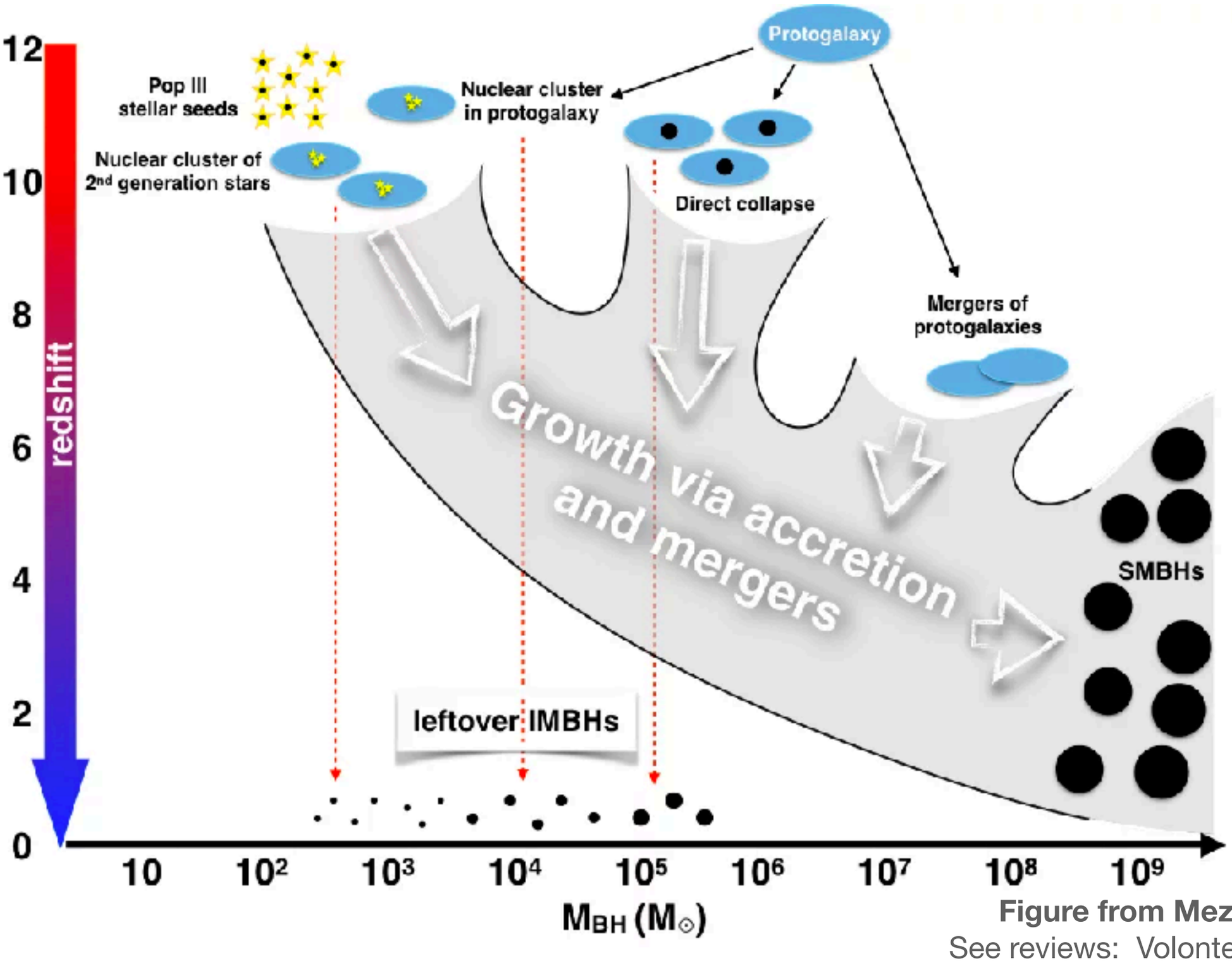


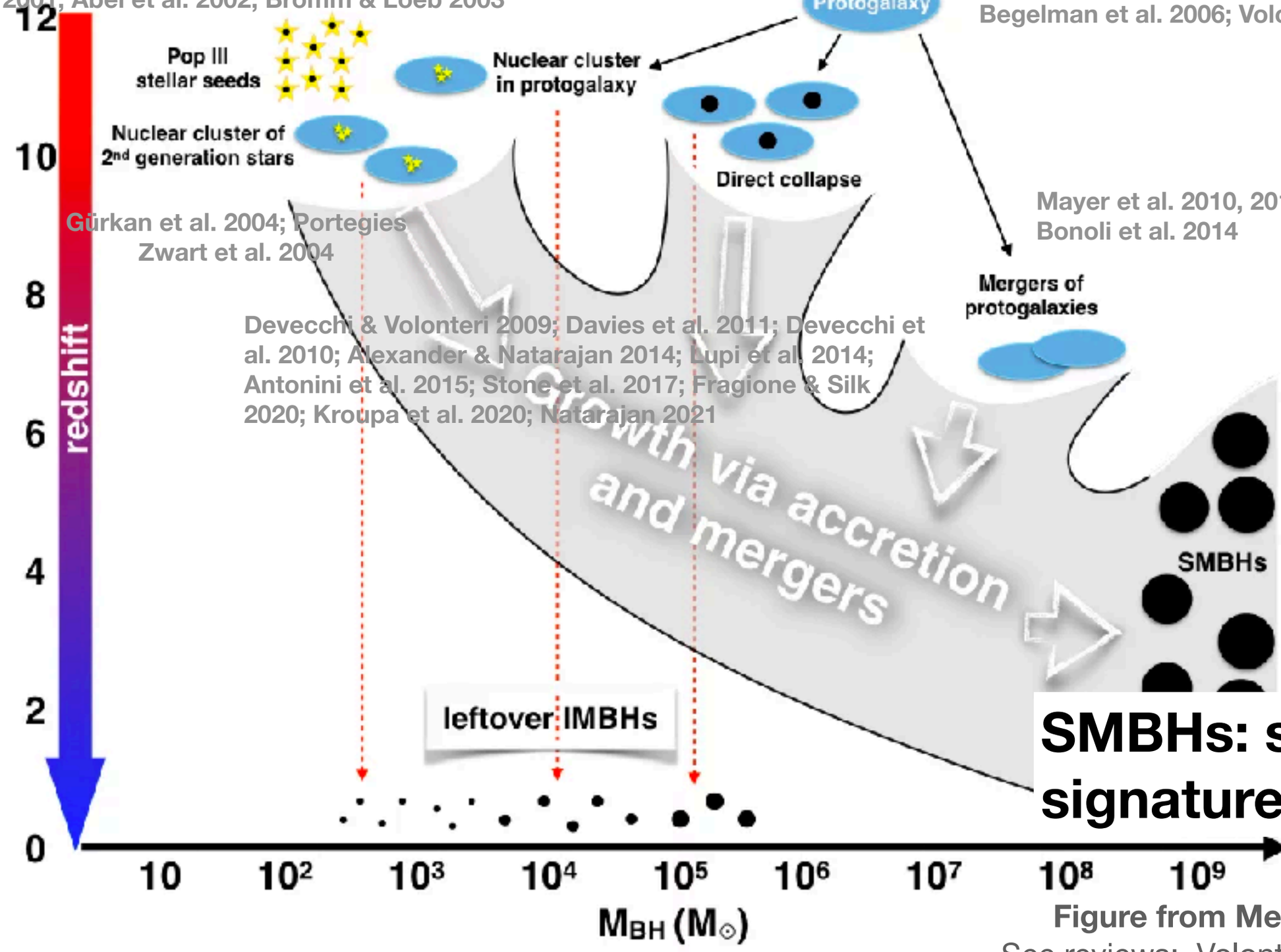
Figure from Mezcua 2017

See reviews: Volonteri et al. 2008, Greene 2012, Natarajan 2014, Inayoshi 2020

IMBH demographics motivation

Bond et al. 1984; Madau & Rees 2001; Fryer et al. 2001; Abel et al. 2002; Bromm & Loeb 2003

Haehnelt & Rees 1993; Loeb & Rasio 1994; Bromm & Loeb 2003; Koushiappas et al. 2004; Lodato & Natarajan 2006; Begelman et al. 2006; Volonteri et al. 2008a



Gürkan et al. 2004; Portegies Zwart et al. 2004

Mayer et al. 2010, 2015, Bonoli et al. 2014

Devecchi & Volonteri 2009; Davies et al. 2011; Devecchi et al. 2010; Alexander & Natarajan 2014; Lupi et al. 2014; Antonini et al. 2015; Stone et al. 2017; Fragione & Silk 2020; Kroupa et al. 2020; Natarajan 2021

SMBHs: seeding signatures erased

Figure from Mezcua 2017

See reviews: Volonteri et al. 2008, Greene 2012, Natarajan 2014, Inayoshi 2020

The fraction of dwarf galaxies with an IMBH traces seeding channels at high redshift

IMBH demographics motivation

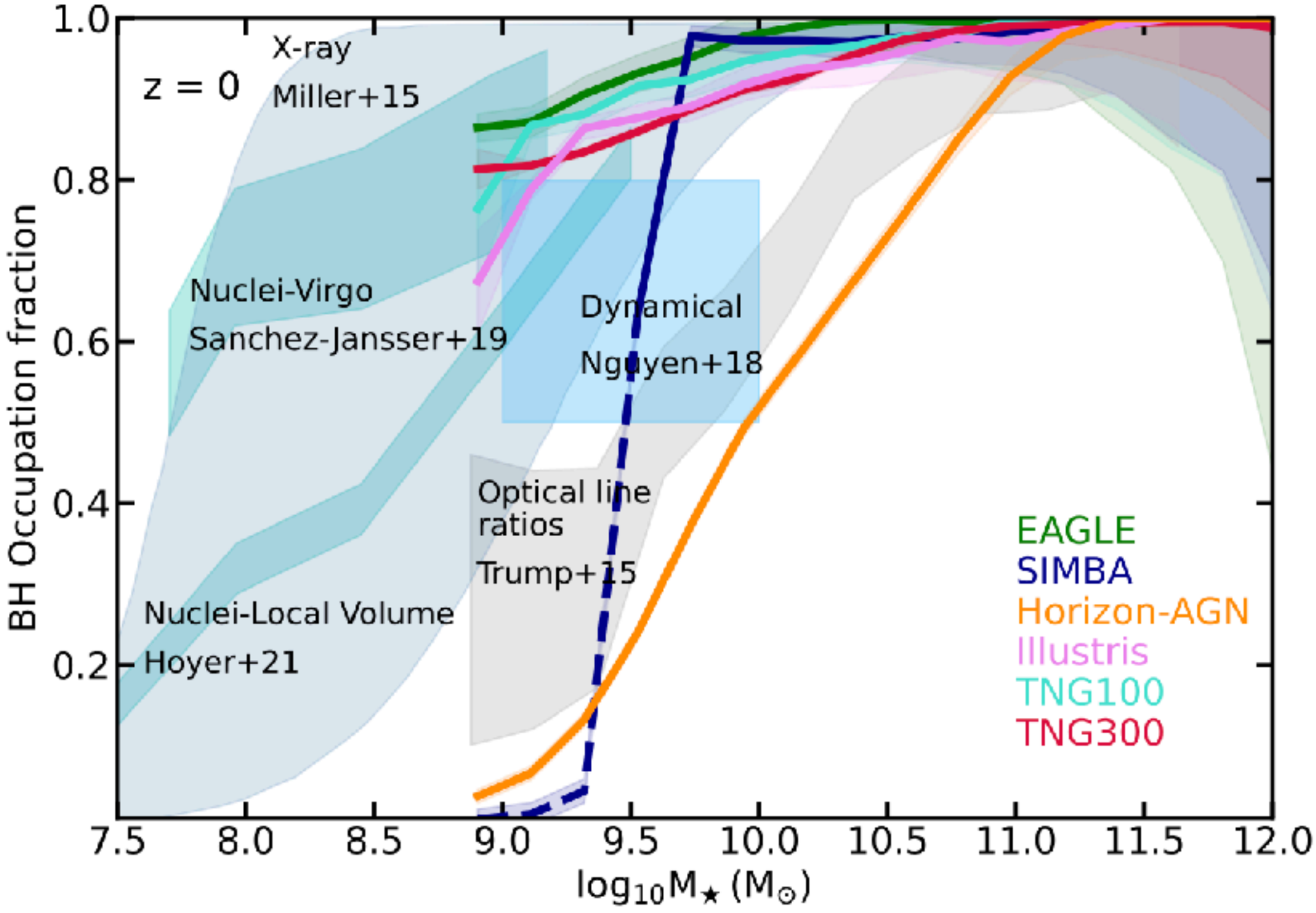
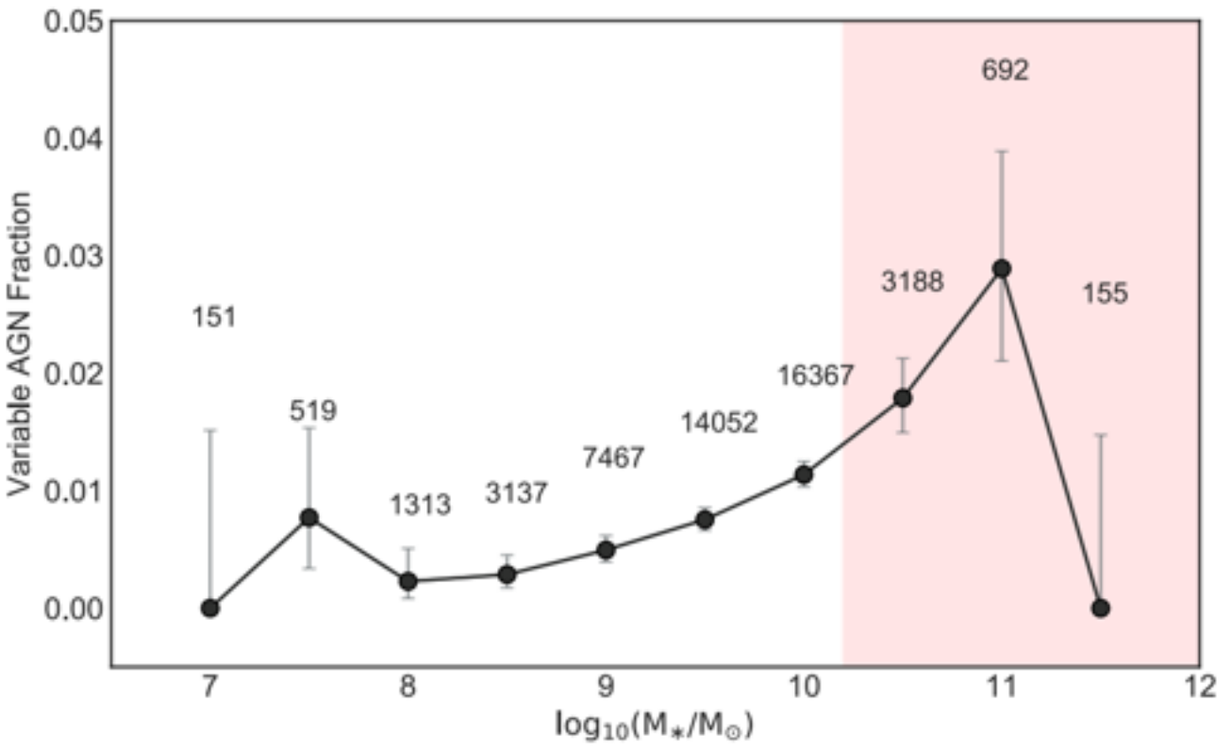


Figure from Haidair et al. 2022

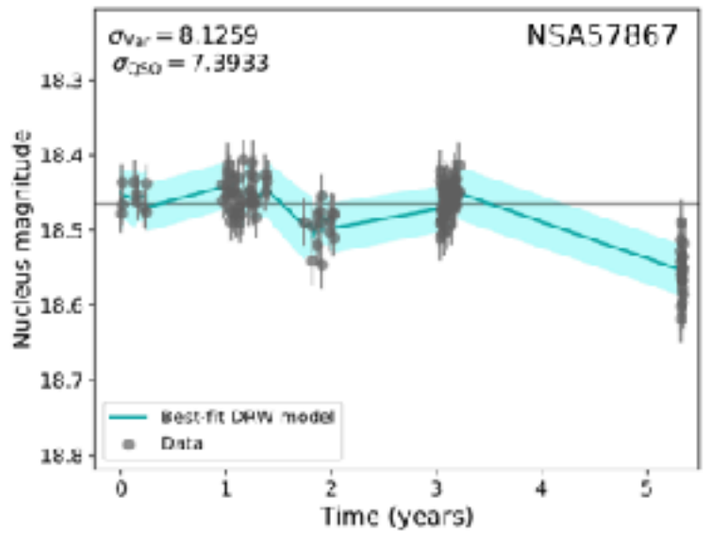
Variability-selected IMBHs

- **See Baldassare et al. 2018, 2020**
  - Identified optically-variable galaxies with $M_\star < 10^{10}\ M_\odot$
  - Restricted to SDSS galaxies with spectroscopic redshifts
  - Hard to constrain occupation fraction with variable AGNs fractions alone

Variable fraction vs. host galaxy stellar mass



Example variable dwarf AGN

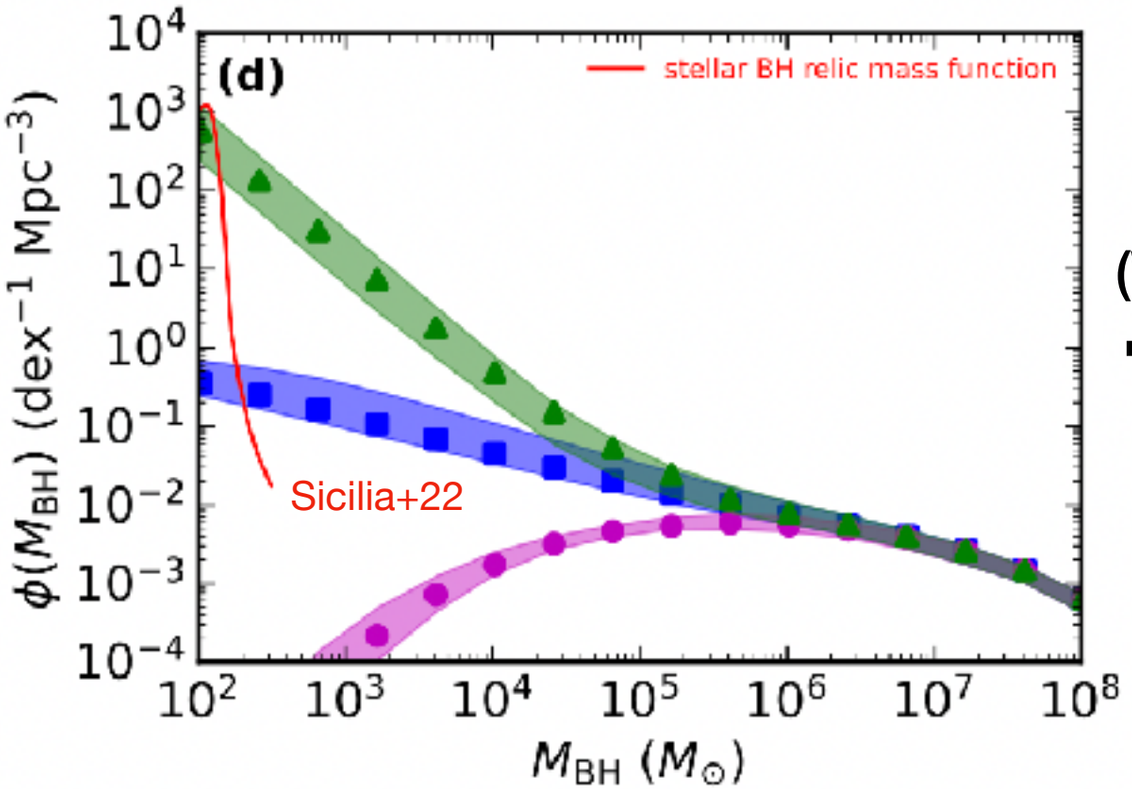


Baldassare et al. 2020

Forward model for IMBH demographics with optical variability

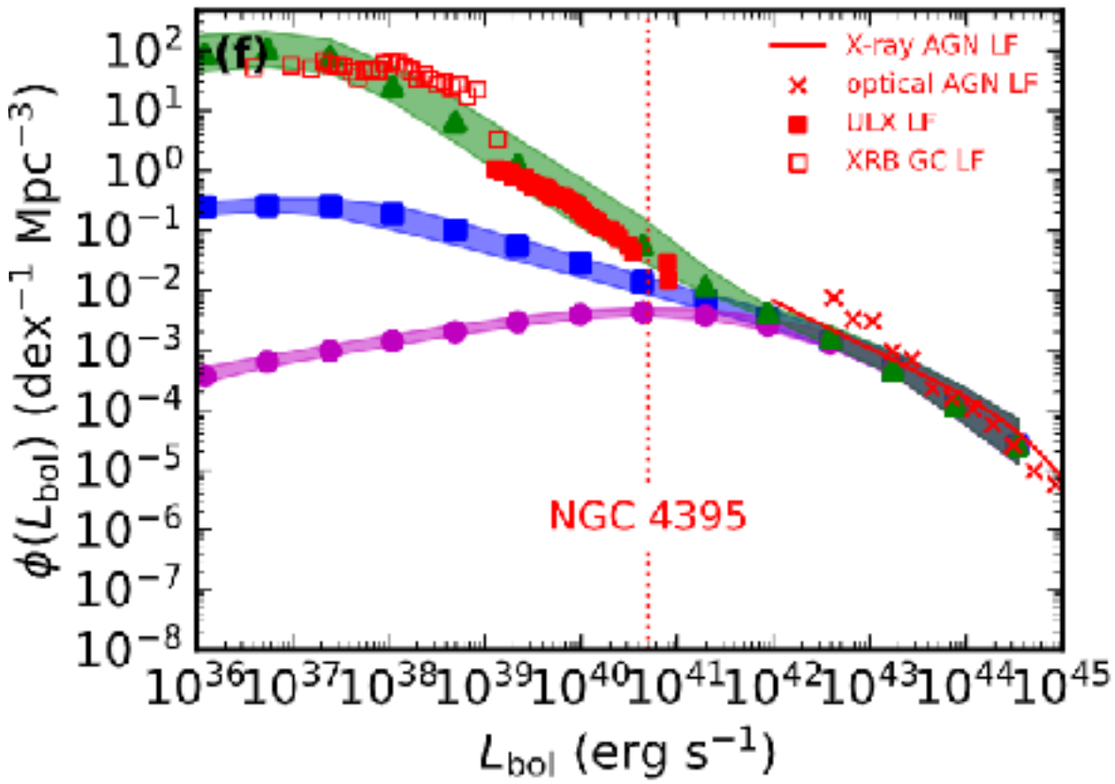
Input black hole mass function

Motivated by Ricarte & Natarajan 2018



ERDF (Weigel+17)

Bolometric black hole luminosity function (LF)



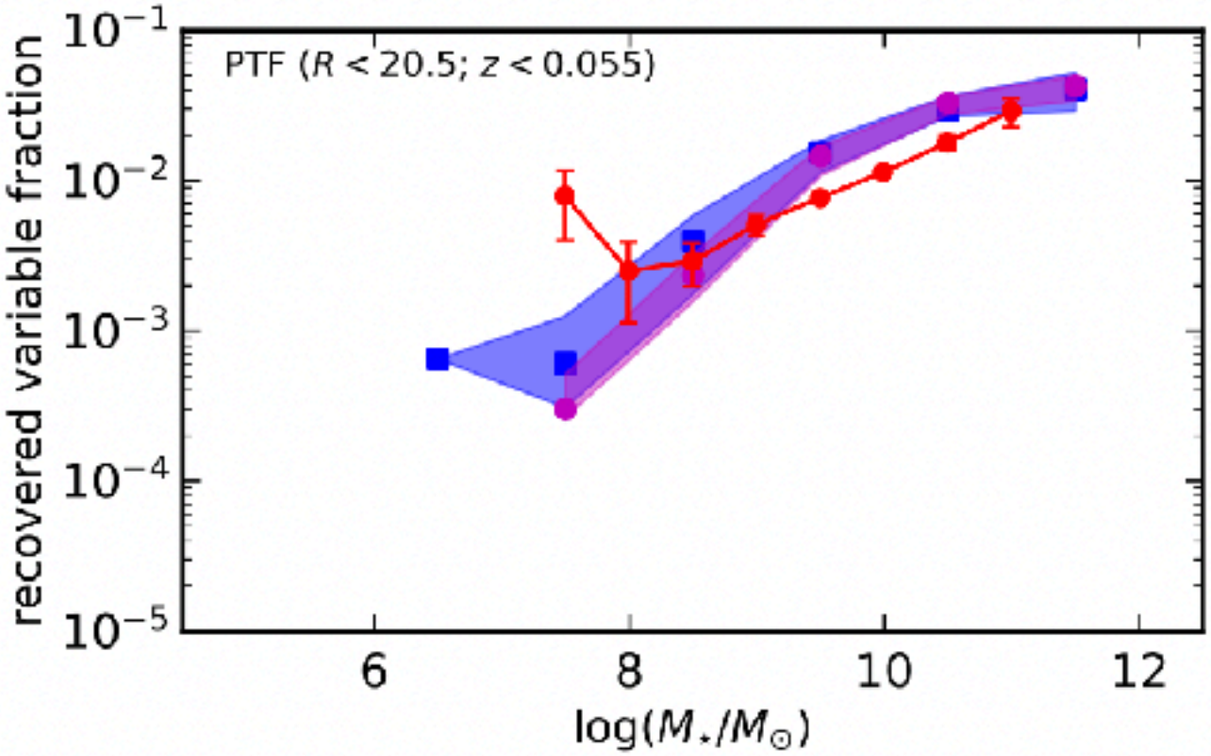
Consistent with observed luminosity functions

- AGN LF: Schulze+09; Hao+05
- ULX LF: Wolter+18
- XRB in GC LF: Lehmer+20

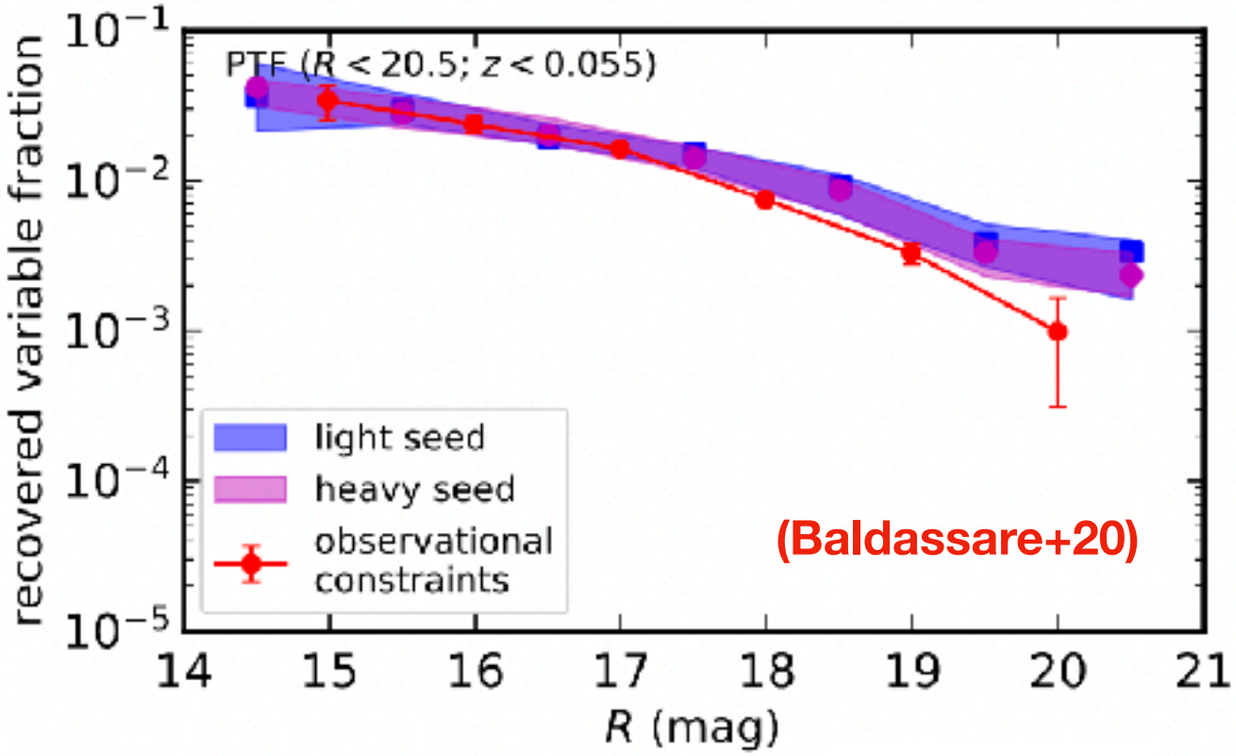
See also:
Greene, Strader & Ho (2020) review
Gallo & Sesana (2019)

Burke et al. 2023

Comparison to variability-selected AGNs



Variable fraction vs. host galaxy stellar mass



Variable fraction vs. aperture R mag

- Current observations can not distinguish between heavy/light seed occupation fractions

- Ultimate goal of constraining the **occupation fraction/BHMF at z~0** with Rubin Observatory

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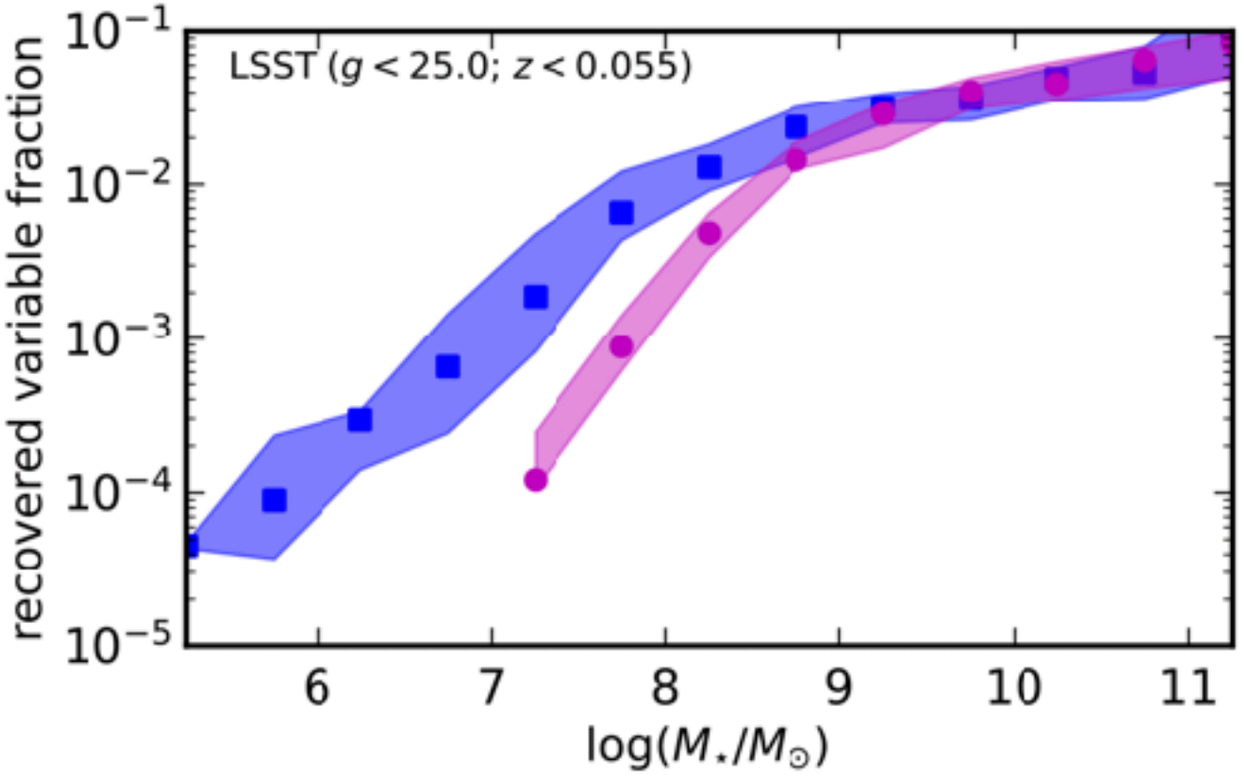
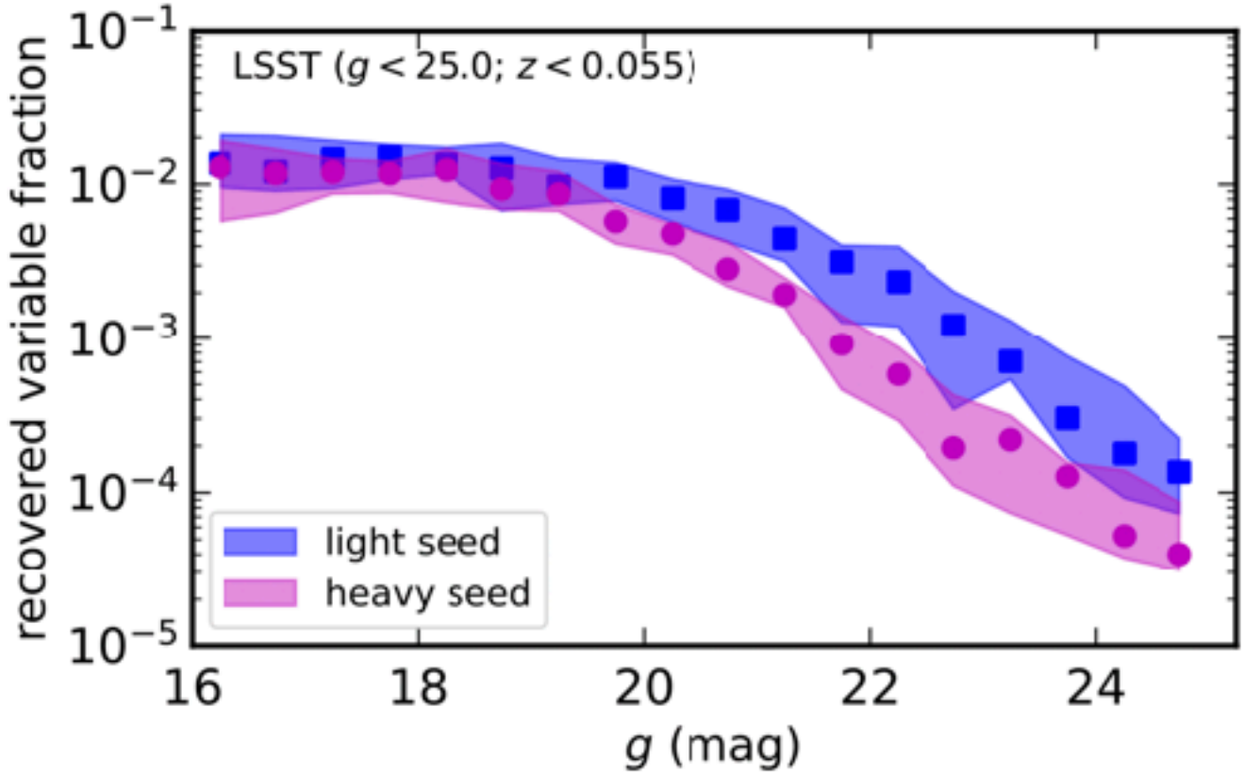
(Optimistic) LSST Rubin Forecast



Variable fraction vs. host galaxy stellar mass



Variable fraction vs. aperture R mag

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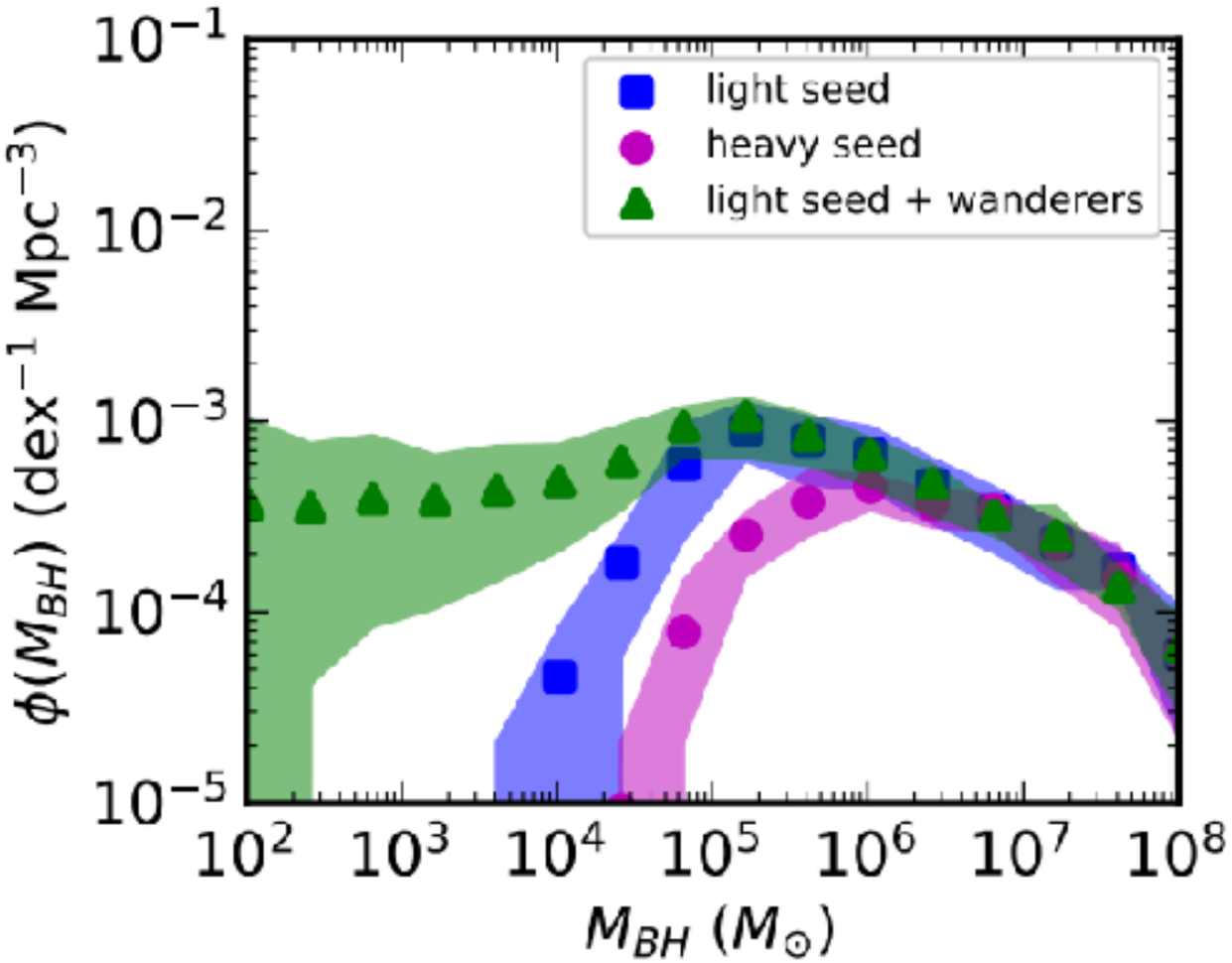
Recovered BHMF for Rubin WFD



Seeding Scenario	Number IMBHs[a]	Number massive BHs[b]
light (i)	$3.9^{+4.1}_{-3.0} \times 10^2$	$1.5^{+0.6}_{-0.6} \times 10^3$
heavy (ii)	$5.9^{+5.9}_{-5.9} \times 10^0$	$5.9^{+1.5}_{-1.1} \times 10^3$
light + wanderers (iii)	$9.7^{+6.2}_{-6.9} \times 10^3$	$2.1^{+0.3}_{-0.7} \times 10^4$

[a] $10^2\ M_\odot < M_{\rm BH} < 10^4\ M_\odot$.
[b] $10^4\ M_\odot < M_{\rm BH} < 10^6\ M_\odot$.

Burke et al. 2023

Summary & Future Directions

Why study IMBHs?

1. **Test understanding of accretion physics on human timescales**
   - Identify & weigh IMBH with ~hourly-days cadence light curves
2. **Constrain models of SMBH seeding & growth**
   - Demographics model & extending beyond the local Universe
3. **Test black hole - host galaxy co-evolution**