Title: The formation and growth of supermassive black holes

Speakers: Anna-Christina Eilers

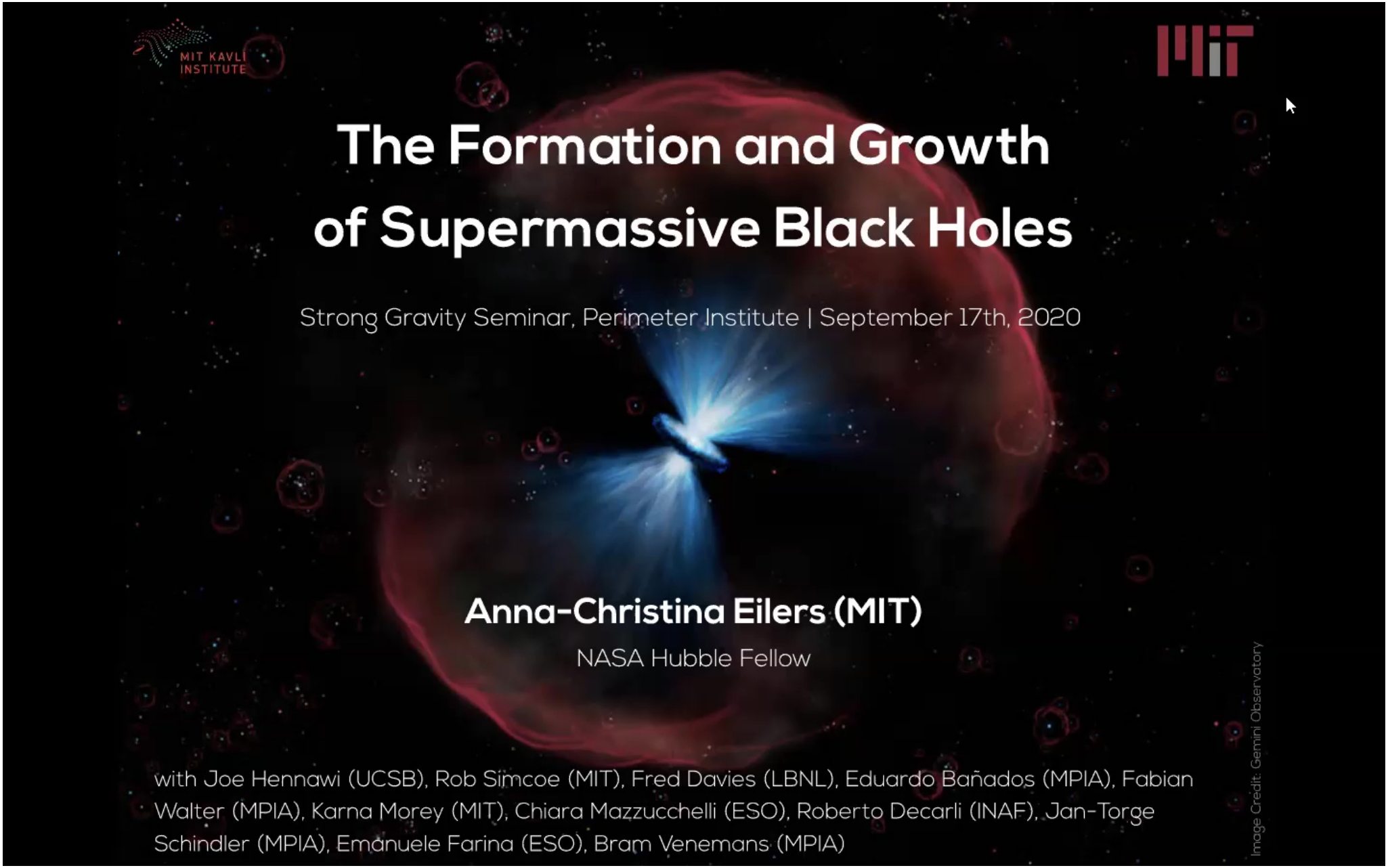
Series: Strong Gravity

Date: September 17, 2020 - 1:00 PM

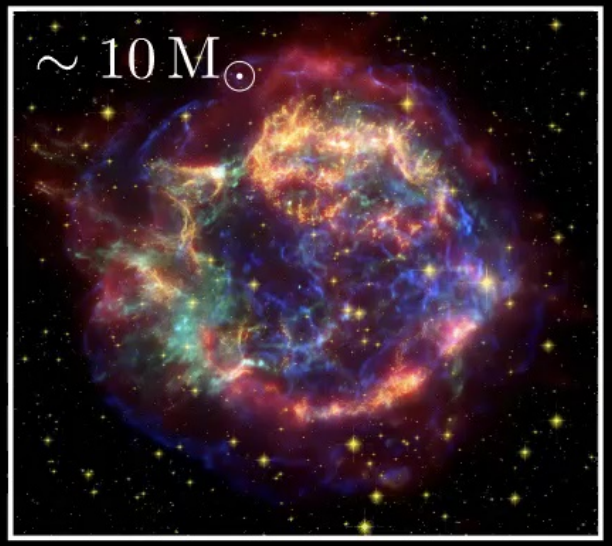
URL: http://pirsa.org/20090004

Abstract: Quasars are the most luminous objects in the universe powered by accretion onto supermassive black holes (SMBHs). They can be observed at the earliest cosmic epochs, providing unique insights into the early phases of black hole, structure, and galaxy formation. Observations of these quasars demonstrate that they host SMBHs at their center, already less than ~1 Gyr after the Big Bang. It has been argued that in order to grow these SMBHs in such short amounts of cosmic time, they need to accrete matter over timescales comparable to the age of the universe, and thus the lifetime of quasars - the integrated time that galaxies shine as active quasars - is expected to be of order ~10^9 yr at a redshift of z~6, even if they accrete continuously at the theoretical maximum limit.

I will present a new method to obtain constraints on the lifetime of high-redshift quasars, based on measurements of the sizes of ionized regions around quasars, known as proximity zones. The sizes of these proximity zones are sensitive to the lifetime of the quasars, because the intergalactic gas has a finite response time to the quasarsâ€™ radiation. Applying this method to quasar spectra at z>6, we discover an unexpected population of very young quasars, indicating lifetimes of only ~10,000 years, several orders of magnitude shorter than expected. I will discuss the consequences of such short lifetimes on the quasars' ionizing power, their black hole mass accretion rates, and highlight tensions with current theoretical models for black hole formation. Furthermore, I will present several modifications to the current SMBH formation paradigm that might explain our findings and show how we aim to disentangle the various scenarios by means of future observations with the upcoming James Webb Space Telescope, in order to shed new light onto the formation and growth of the first SMBHs in the universe.


MIT KAVLI INSTITUTE
The Formation and Growth of Supermassive Black Holes
Strong Gravity Seminar, Perimeter Institute | September 17th, 2020
Anna-Christina Eilers (MIT)
NASA Hubble Fellow
with Joe Hennawi (UCSB), Rob Simcoe (MIT), Fred Davies (LBNL), Eduardo Bañados (MPIA), Fabian Walter (MPIA), Karna Morey (MIT), Chiara Mazzucchelli (ESO), Roberto Decarli (INAF), Jan-Torge Schindler (MPIA), Emanuele Farina (ESO), Bram Venemans (MPIA)
Image Credit: Gemini Observatory

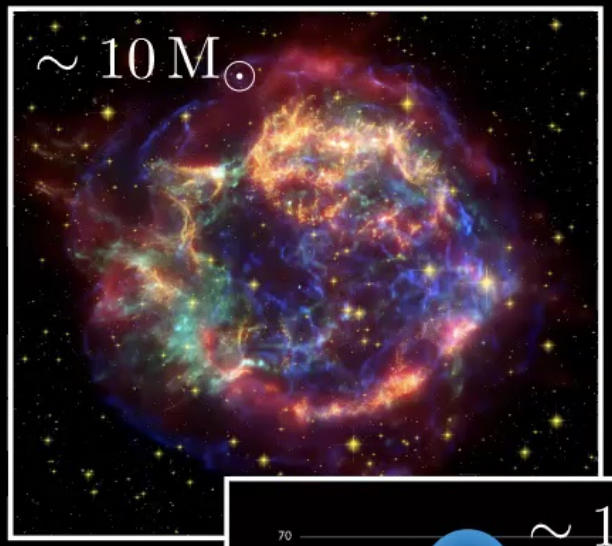
black holes exist in various sizes

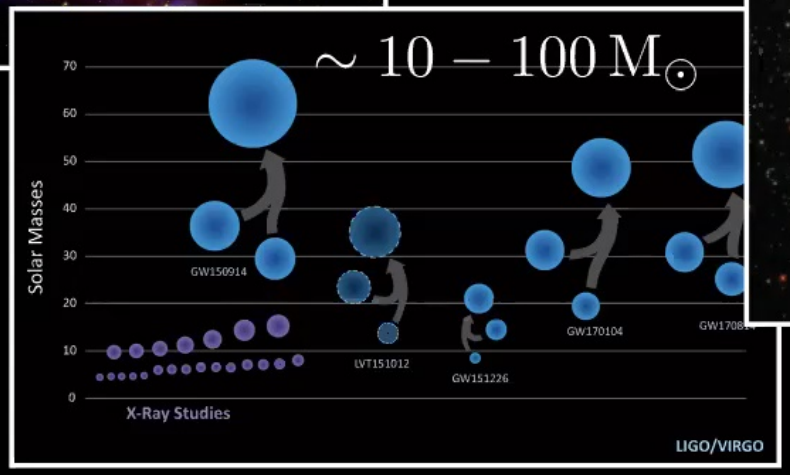


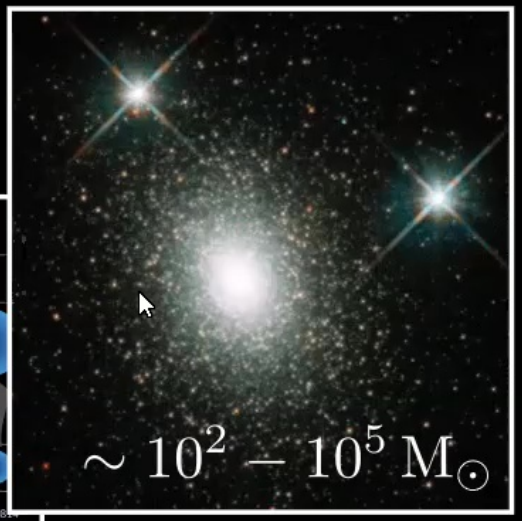
Anna-Christina Eilers, MIT

LIGO/VIRGO Collaboration, EHT Collaboration 2019

black holes exist in various sizes







Anna-Christina Eilers, MIT

LIGO/VIRGO Collaboration, EHT Collaboration 2019

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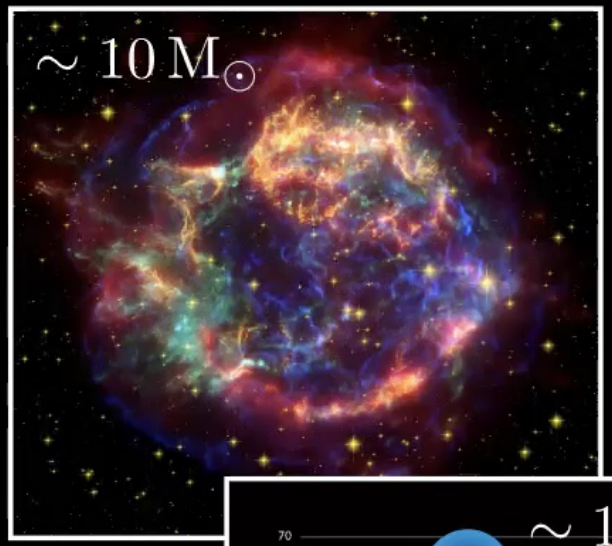

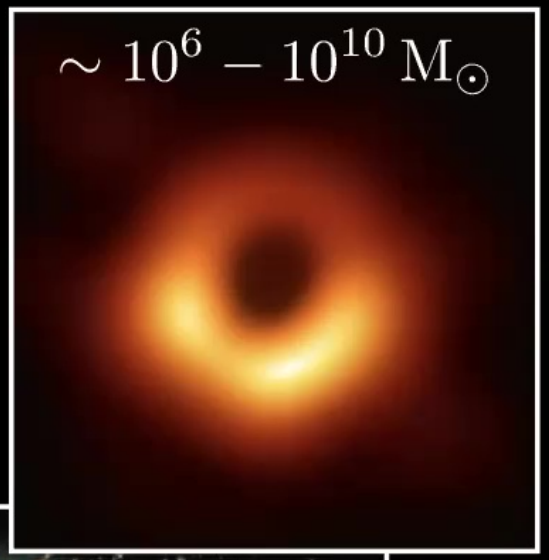

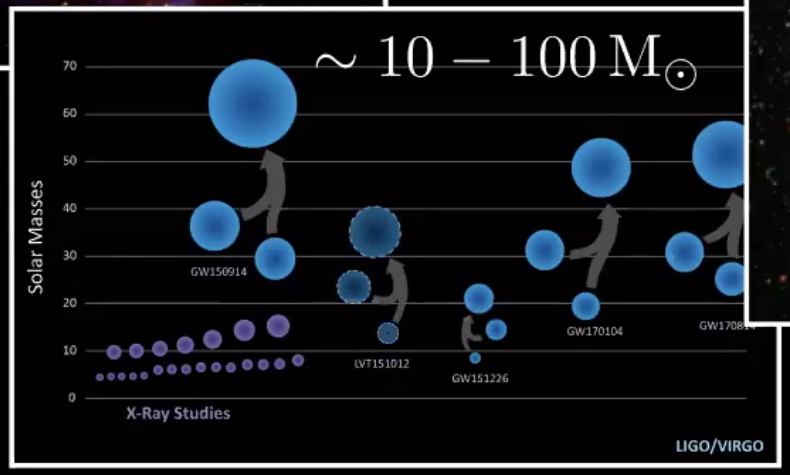

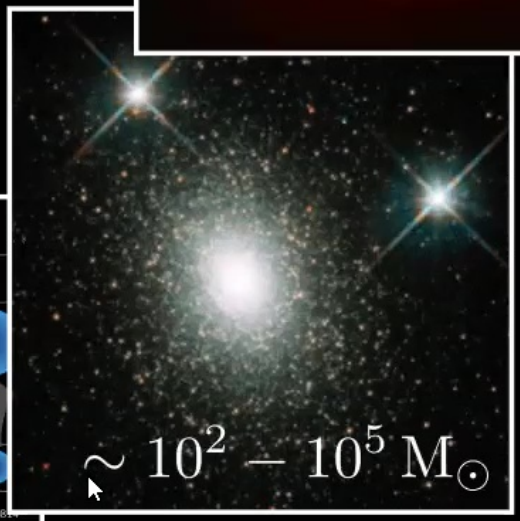

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supermassive black holes reside in the center of all massive galaxies

Anna-Christina Eilers, MIT

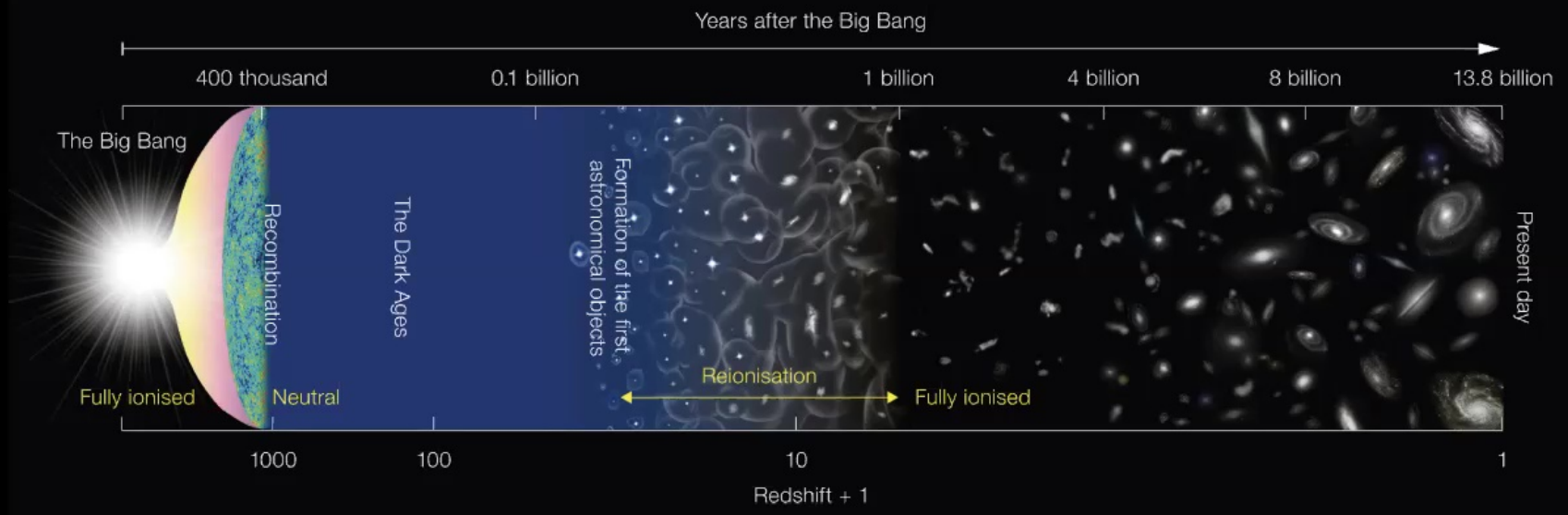
Soltan argument

"The integrated emission from quasars over cosmic time is proportional to the total mass in supermassive black holes today."

Anna-Christina Eilers, MIT

Soltan 1982, Kormendy & Richstone 1995, Yu & Tremaine 2002

timeline of the universe



Anna-Christina Eilers, MIT

Image Credit: ESO

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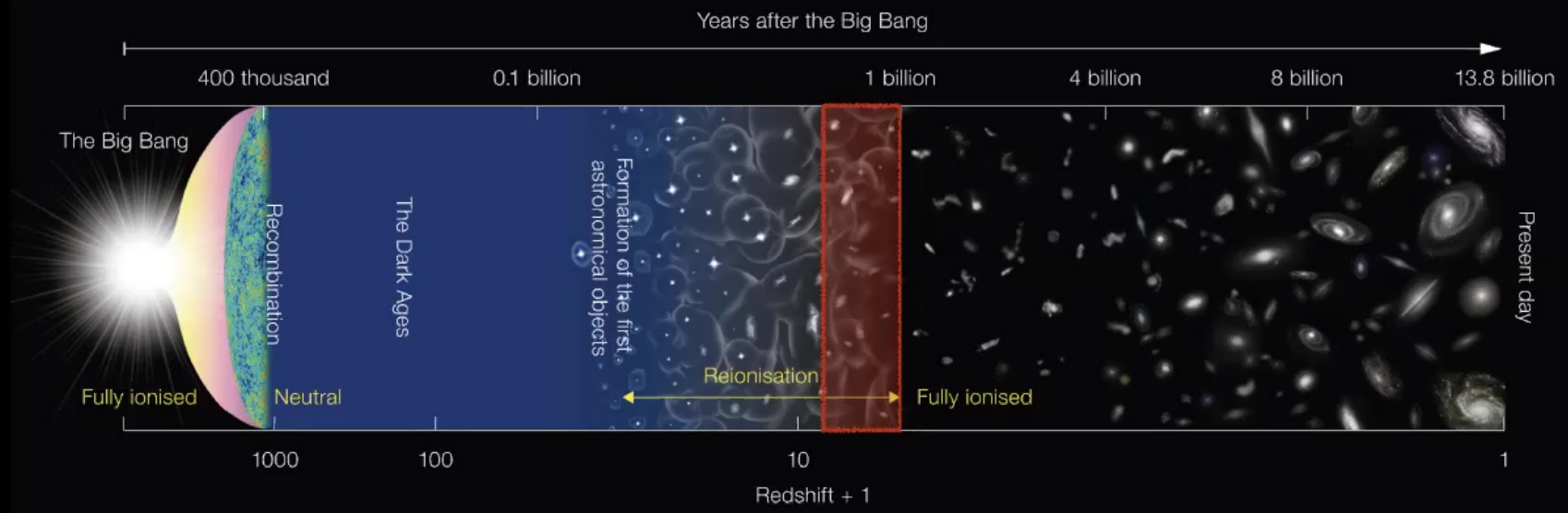


Anna-Christina Eilers, MIT

Image Credit: ESO

ESO Very Large Telescope,
Cerro Paranal

Keck Telescopes, Hawaii

Magellan Telescopes,
Las Campanas

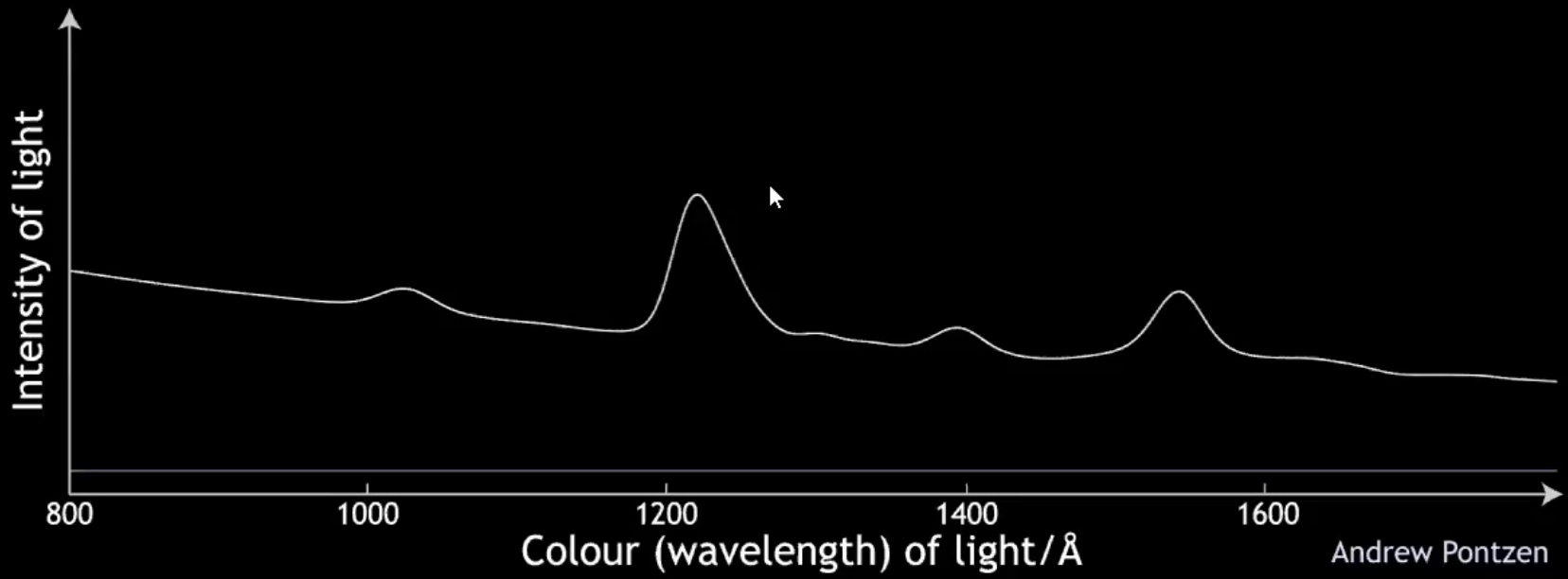
NOrthern Extended Millimetre Array

Atacama Large
Millimetre Array

Anna-Christina Eilers, MIT

Image Credit: ESO, L. Hatch, R. Trainor, ALMA, NOEMA

imprint of intergalactic gas absorption on quasar spectra



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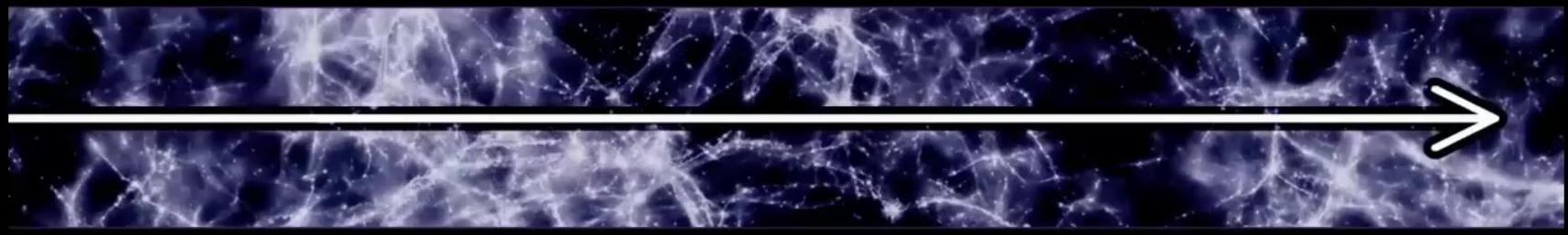

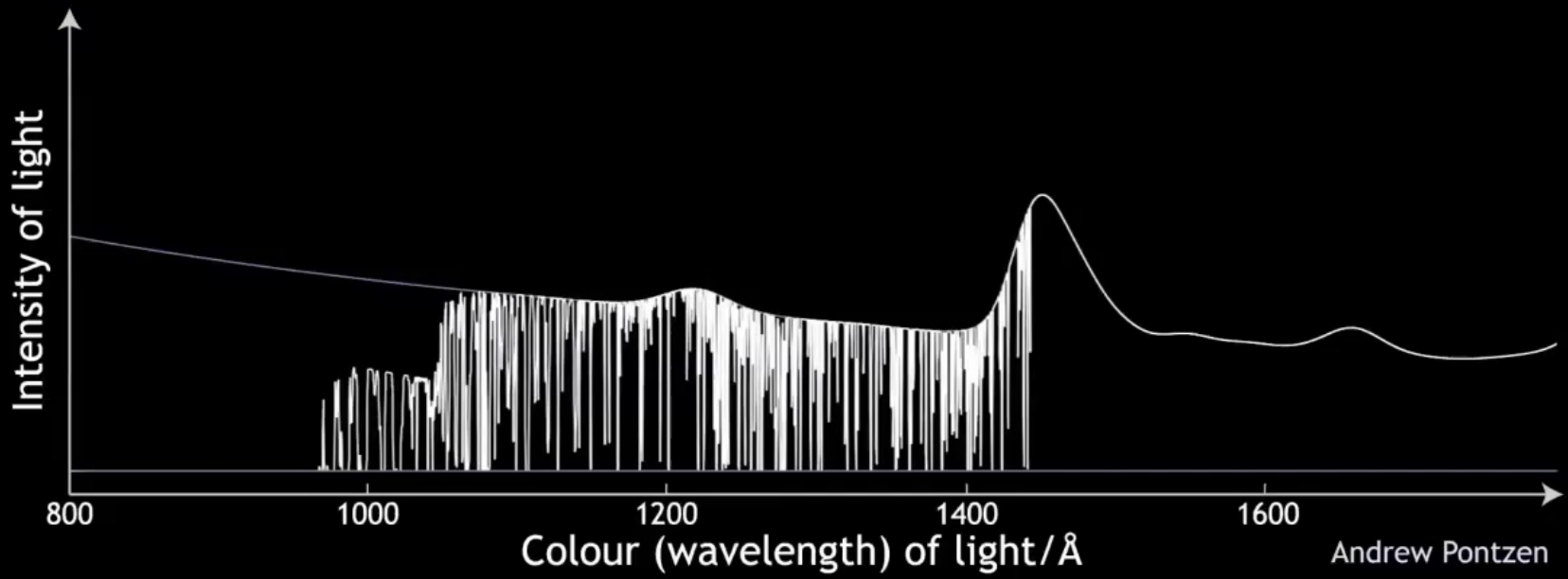

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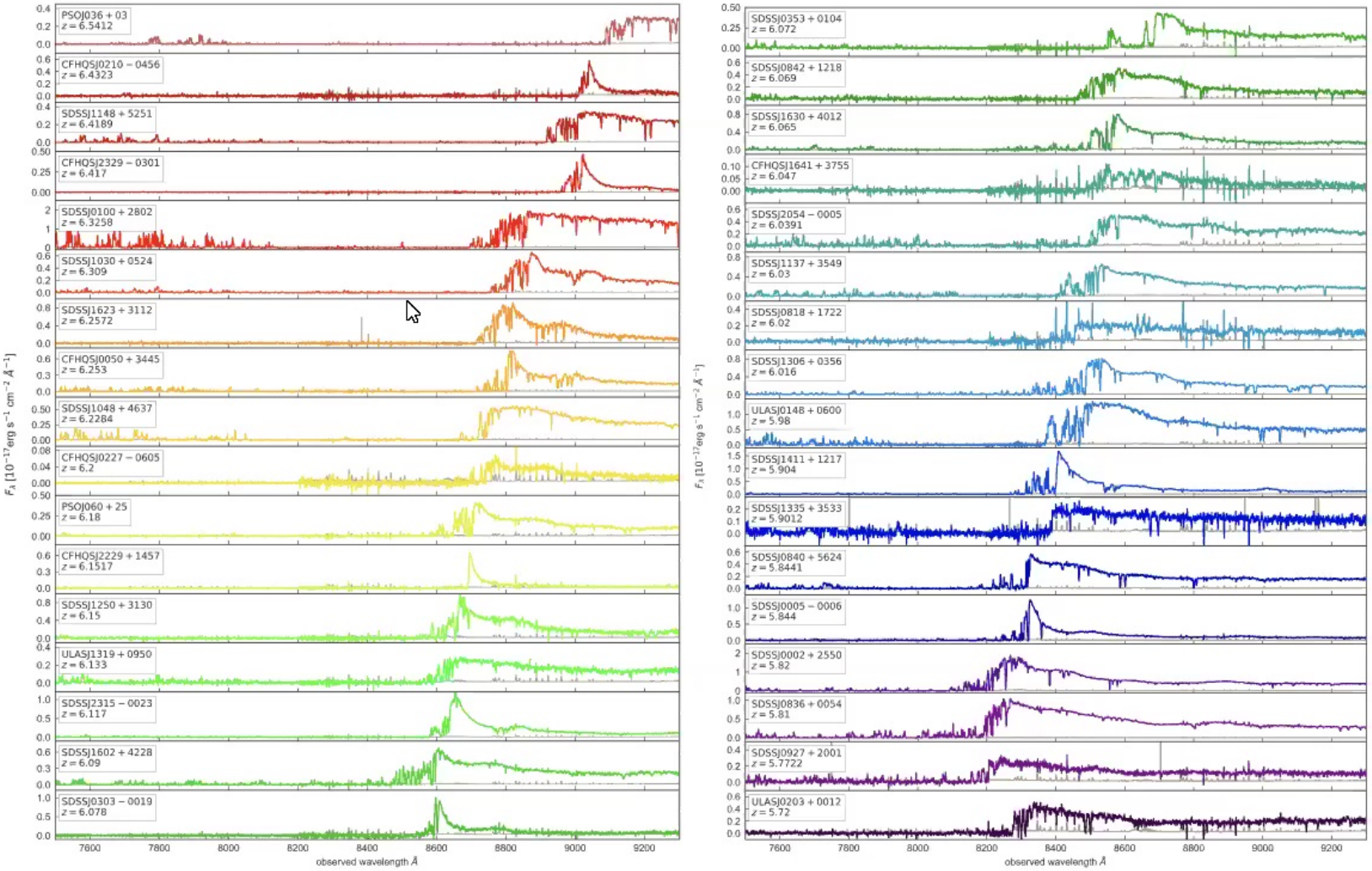
high redshift quasar spectra



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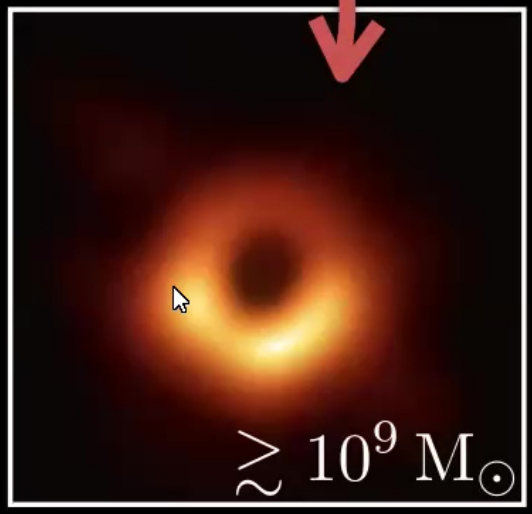
Eilers+ 2018

black hole growth



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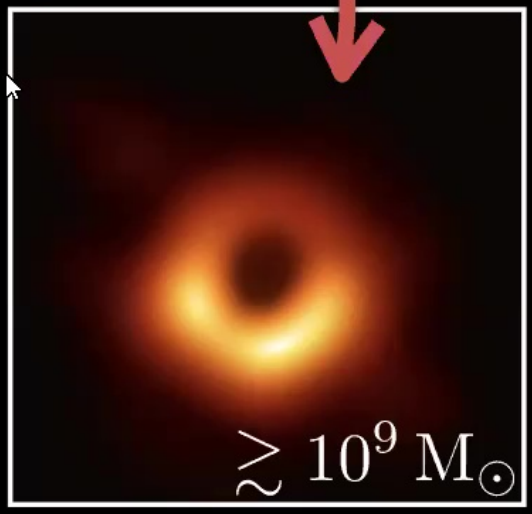
black hole growth

in less than ~800 million years?

- Initial black hole seeds?
- Mass accretion rate?
- Lifetime of quasars?



Anna-Christina Eilers, MIT

standard picture of black hole growth

Luminosity of gas accreting onto SMBH, can be described in terms of radiative efficiency:

$$L = \epsilon \dot{M} c^2$$

Black hole accretes the non-radiated component:

$$\dot{M}_{\rm BH} = (1-\epsilon)\dot{M} = \frac{1-\epsilon}{\epsilon}\frac{L}{c^2}$$

standard picture of black hole growth

quasar lifetime

mass of initial black hole seed

$$M_{\rm BH}(t_{\rm Q}) = M_{\rm seed} \cdot \exp\left(\frac{t_{\rm Q}}{t_{\rm S}}\right)$$

Salpeter "e-folding" time:

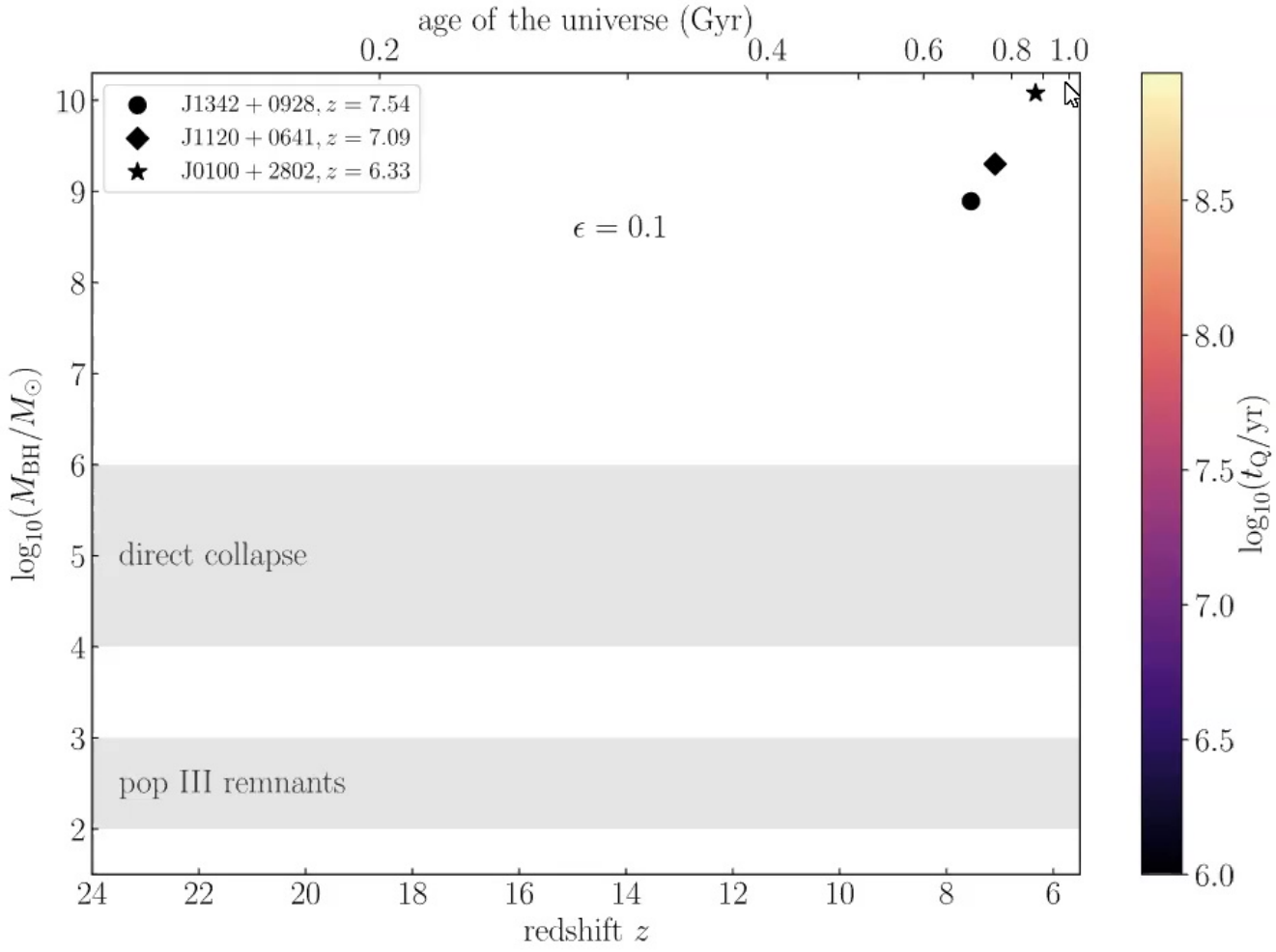
bolometric luminosity

$$t_{\rm S} \simeq 4.5 \times 10^7 \left(\frac{\epsilon}{0.1}\right) \left(\frac{L}{L_{\rm Edd}}\right)^{-1} \ {\rm yr}$$

radiative efficiency of the accretion

Anna-Christina Eilers, MIT

standard picture of black hole growth



Anna-Christina Eilers, MIT

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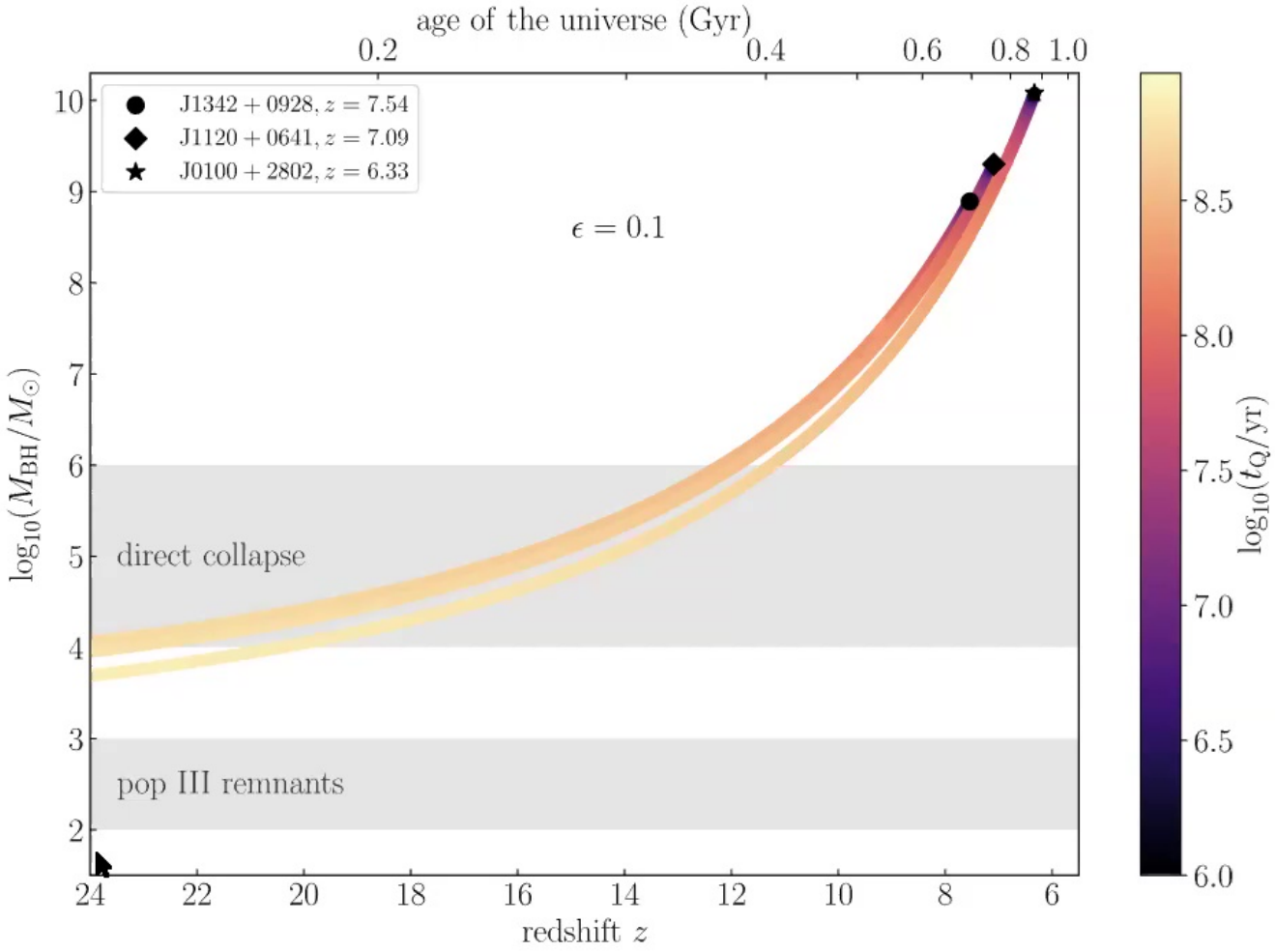

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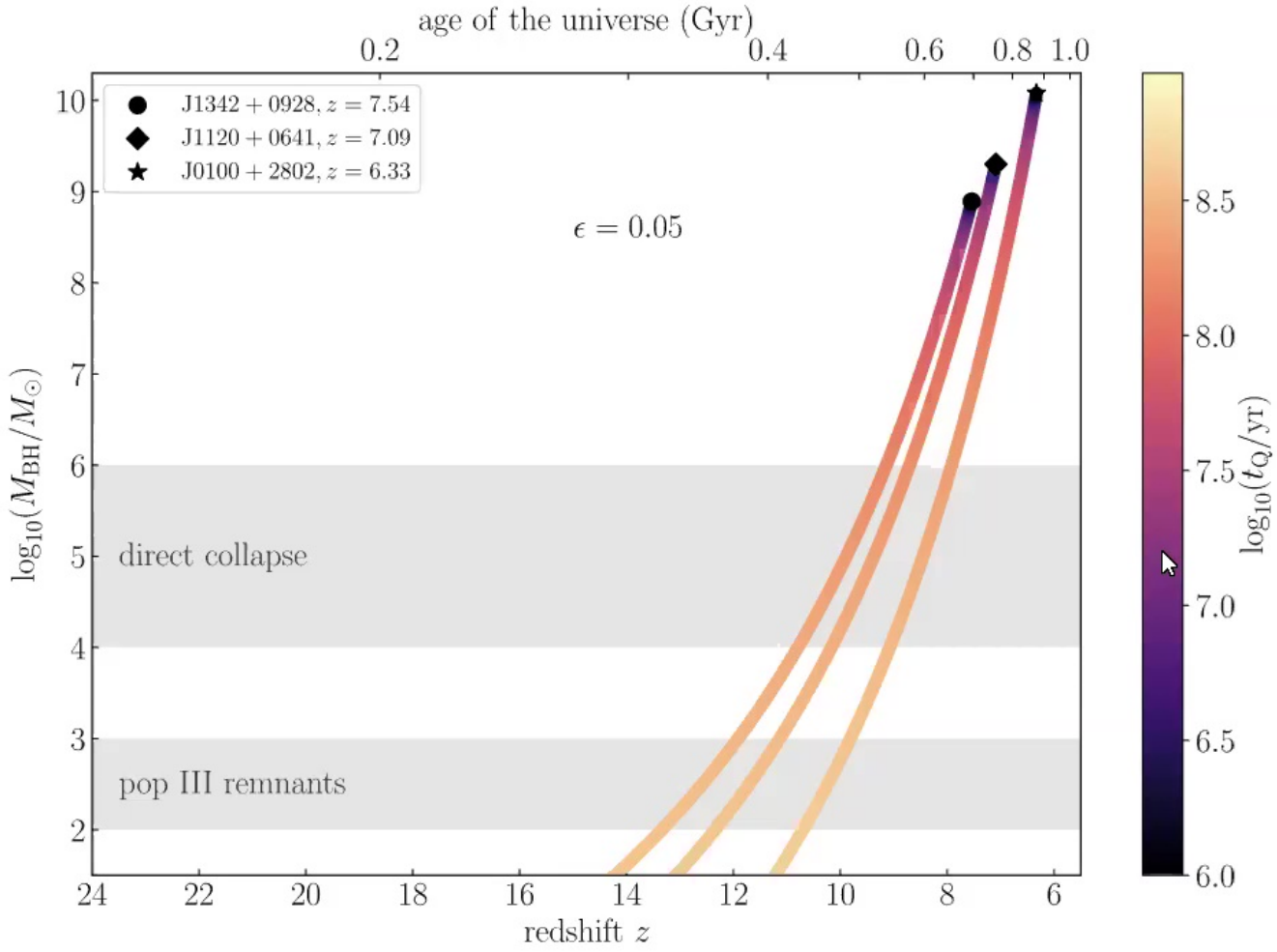

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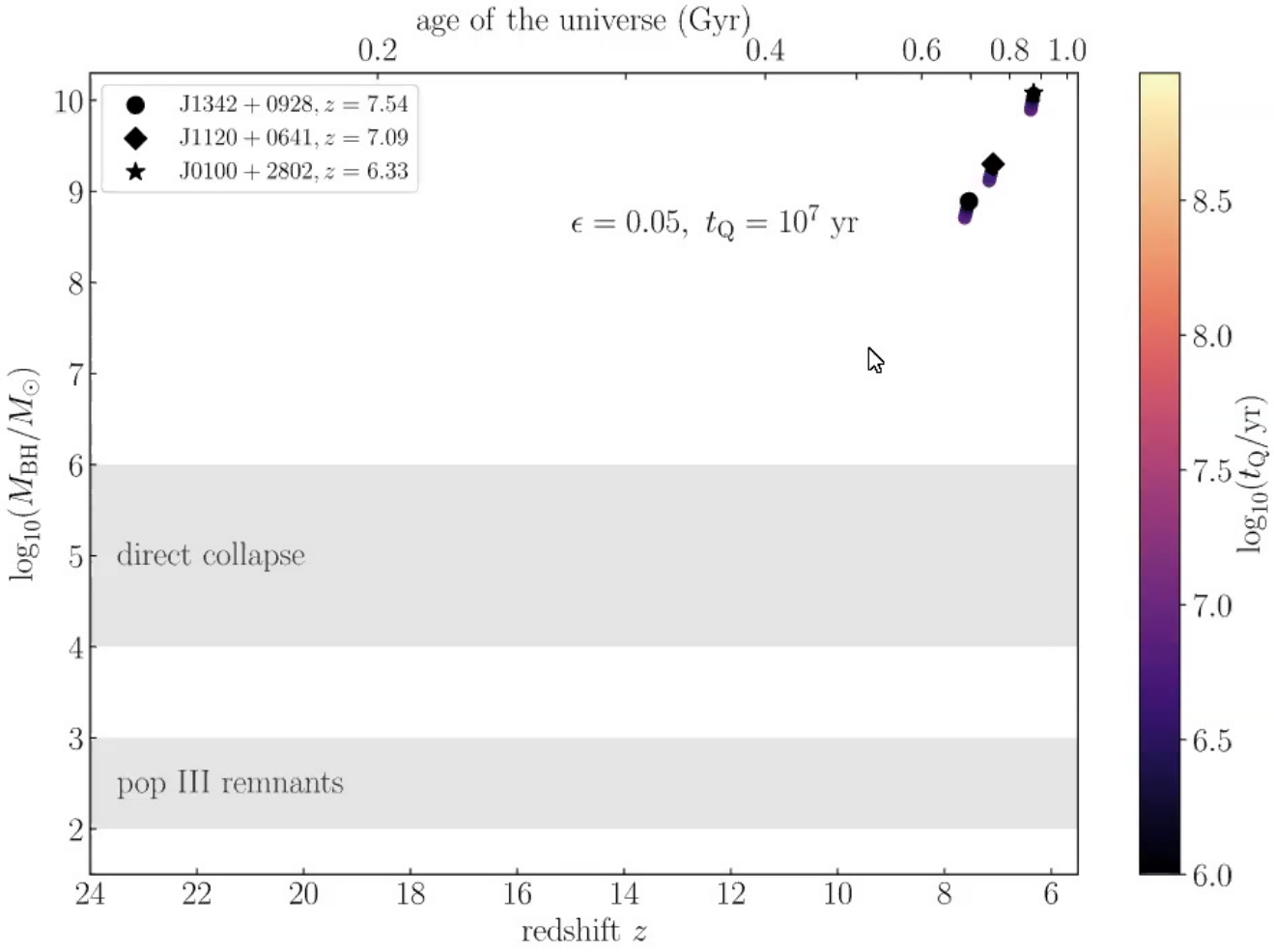

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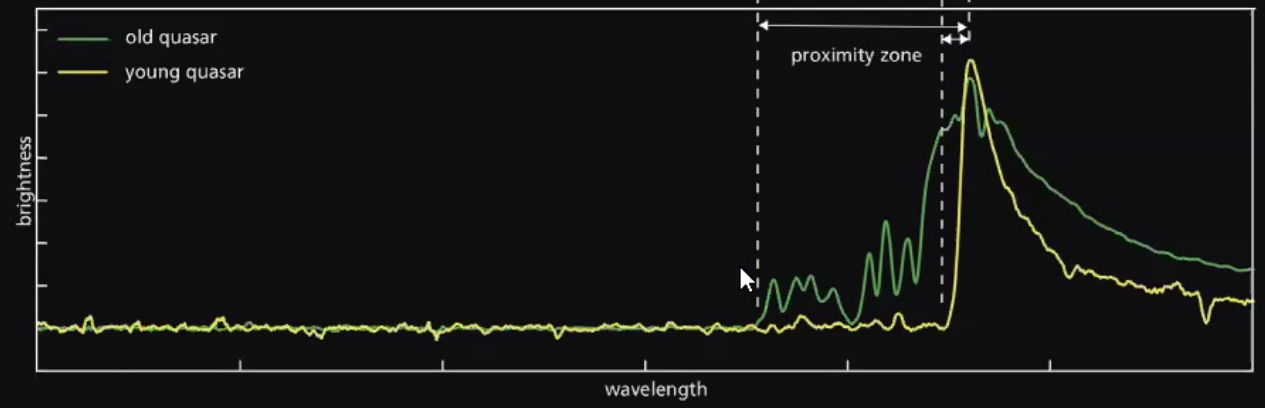
new approach to estimate quasar lifetimes

Light from the quasar

ionized gas around the quasar



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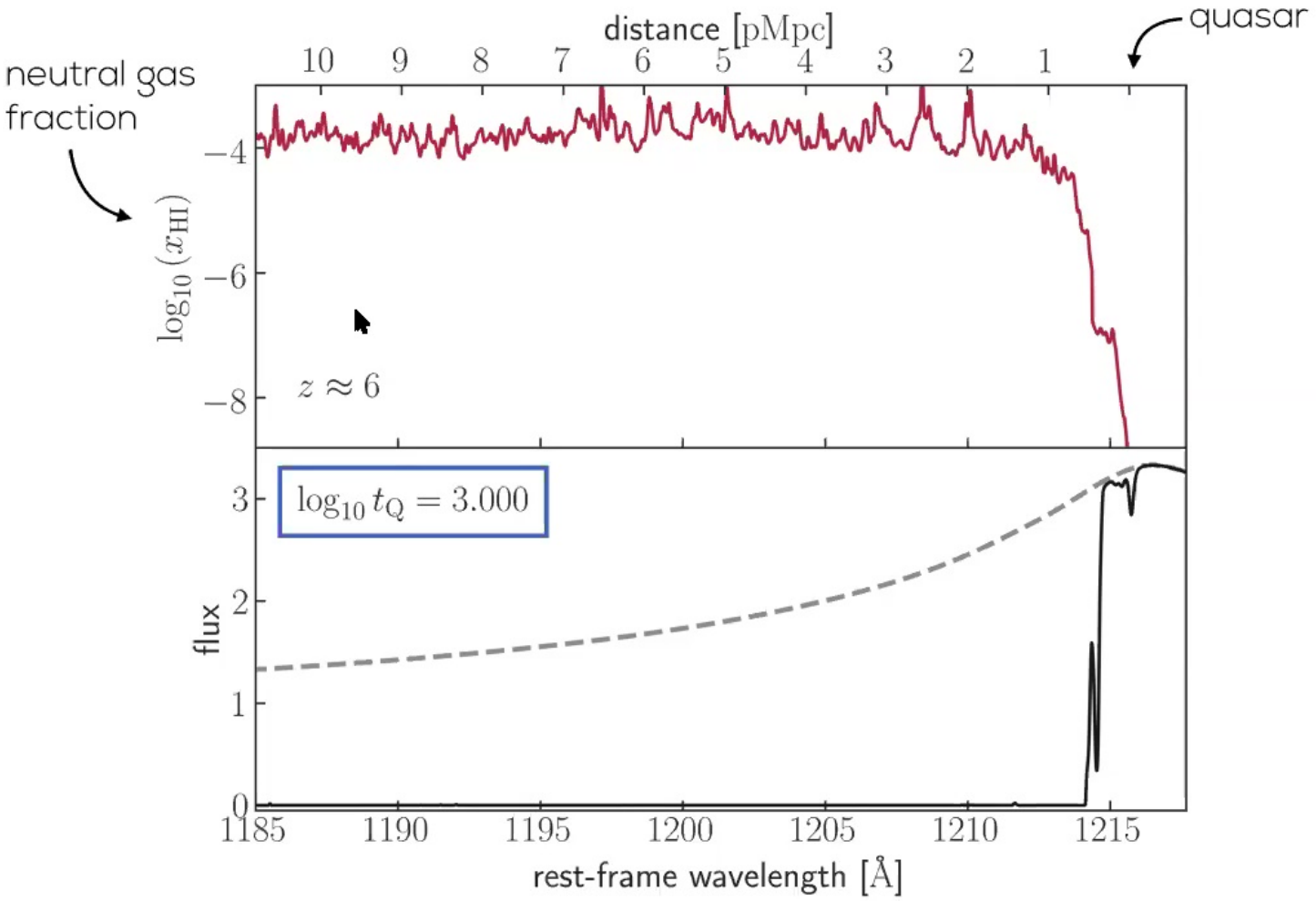
intergalactic gas responds to quasar's radiation



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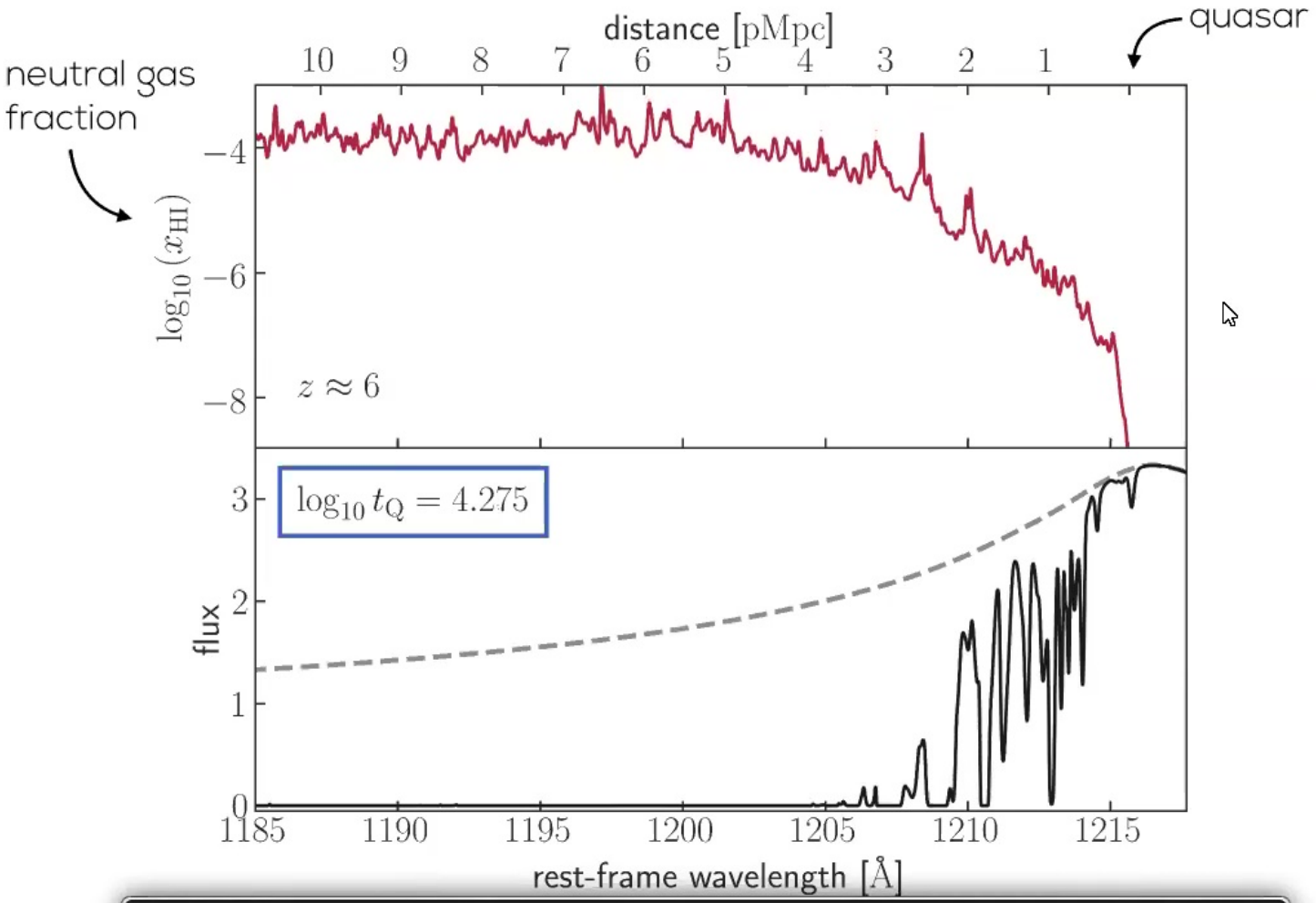

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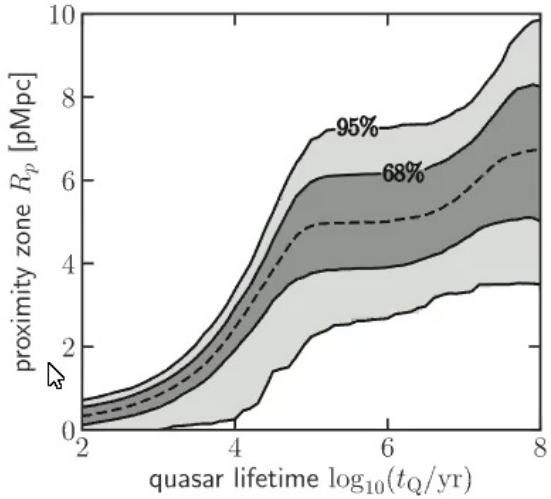
new approach to estimate quasar lifetimes



Anna-Christina Eilers, MIT

Eilers+ 2017, 2018, 2020ab

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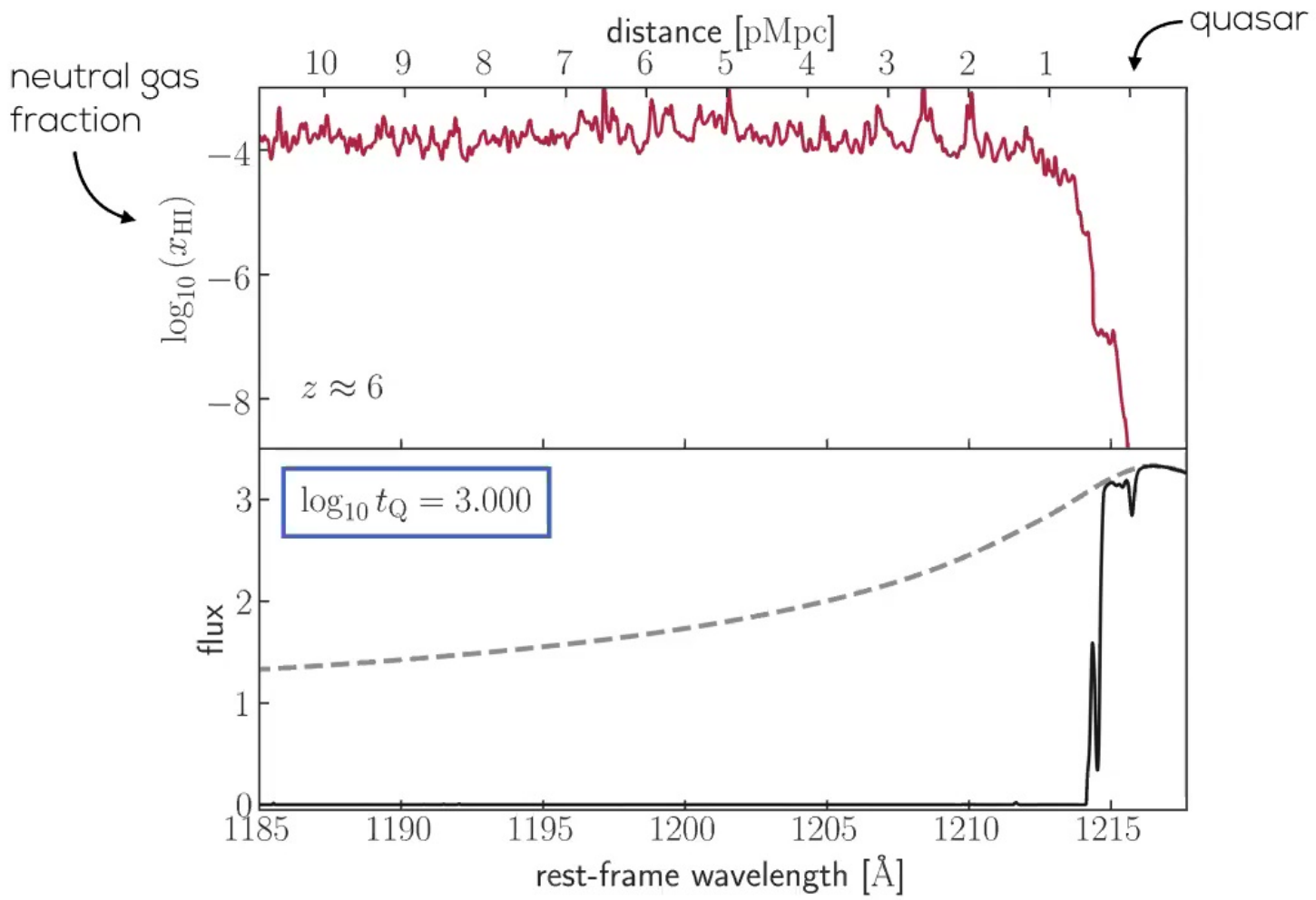
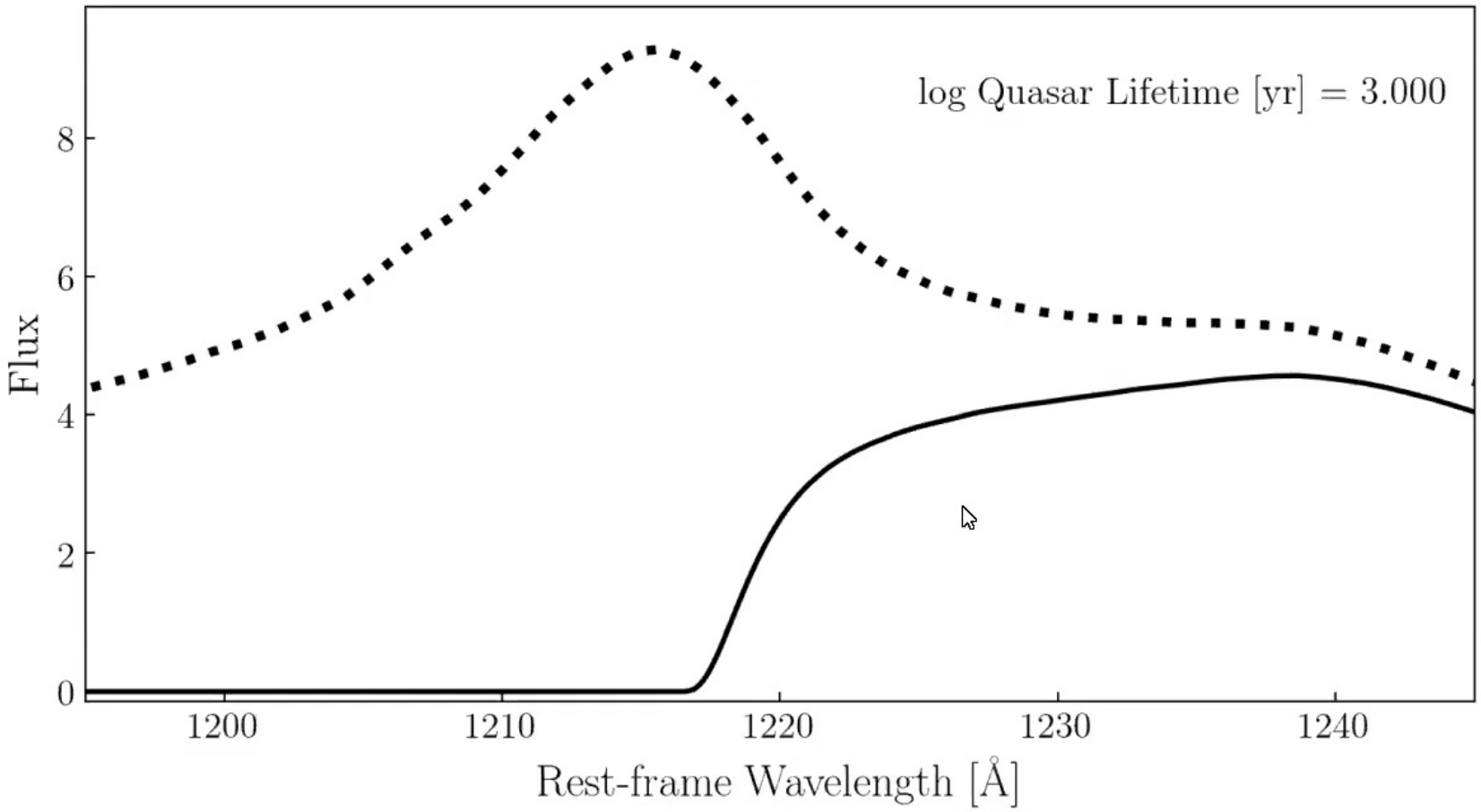


Anna-Christina Eilers, MIT

damping wing signature in neutral IGM



Anna-Christina Eilers, MIT

credit: F. Davies

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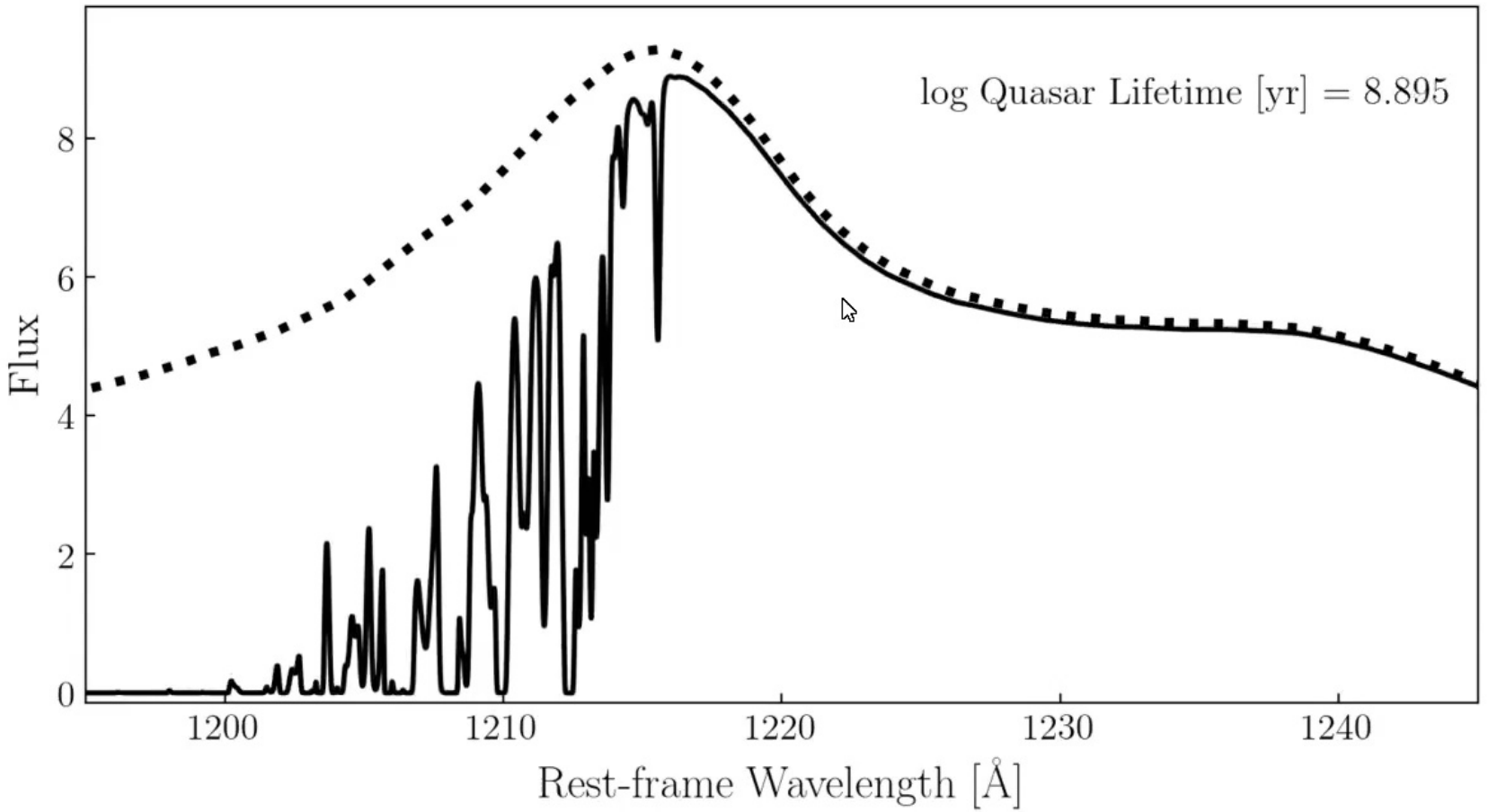

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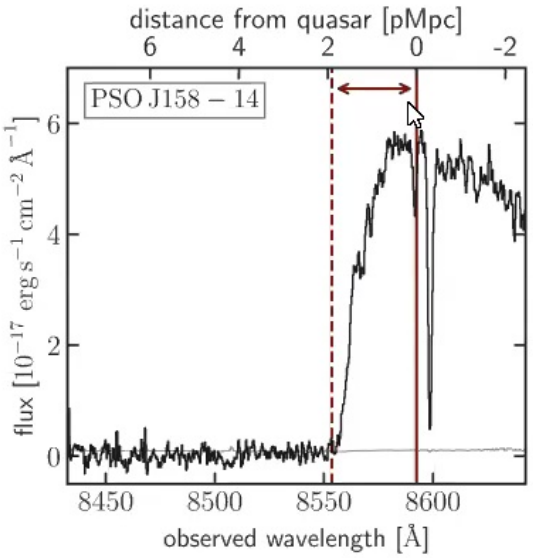
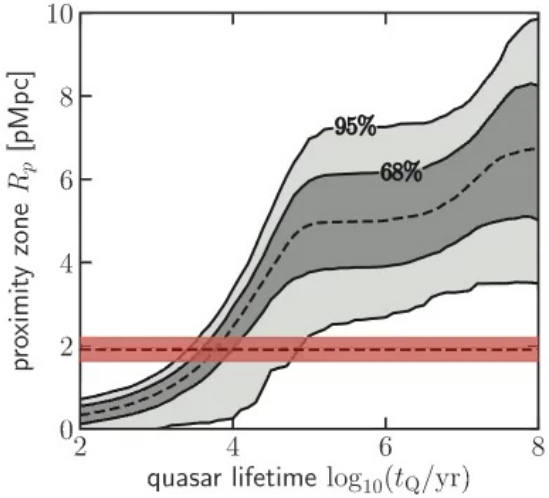
Anna-Christina Eilers, MIT credit: F. Davies

new approach to estimate quasar lifetimes





Anna-Christina Eilers, MIT

Eilers+ 2017, 2018, 2020ab

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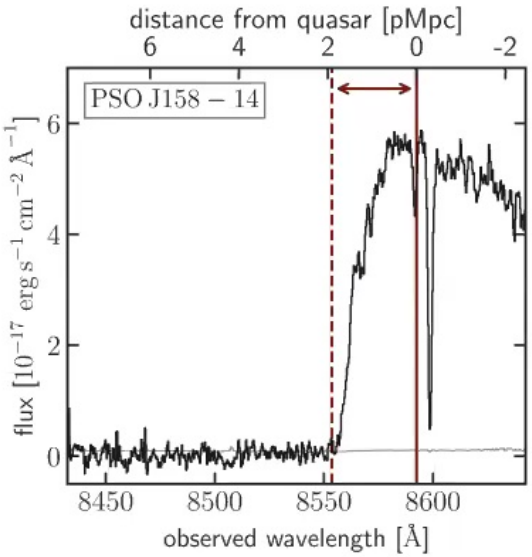
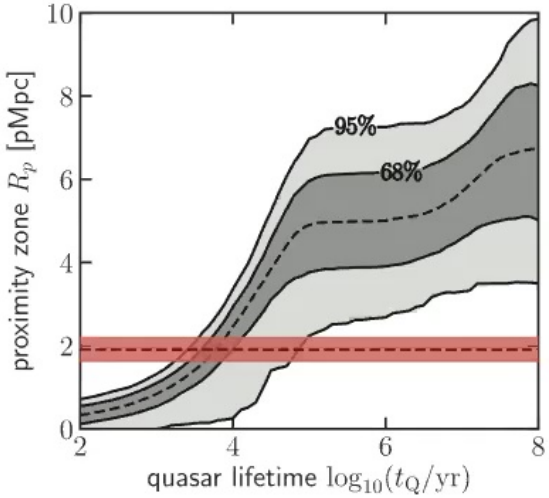
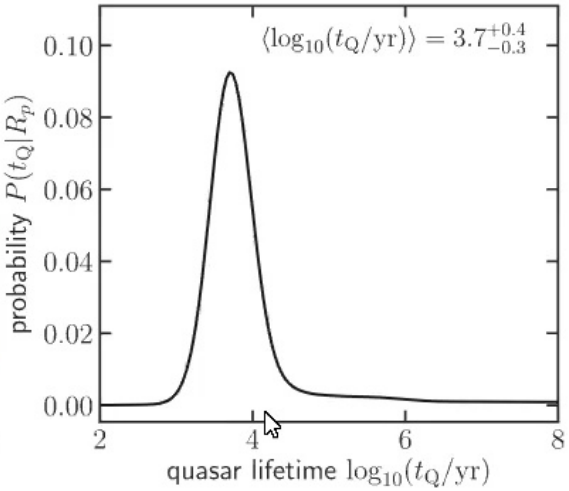


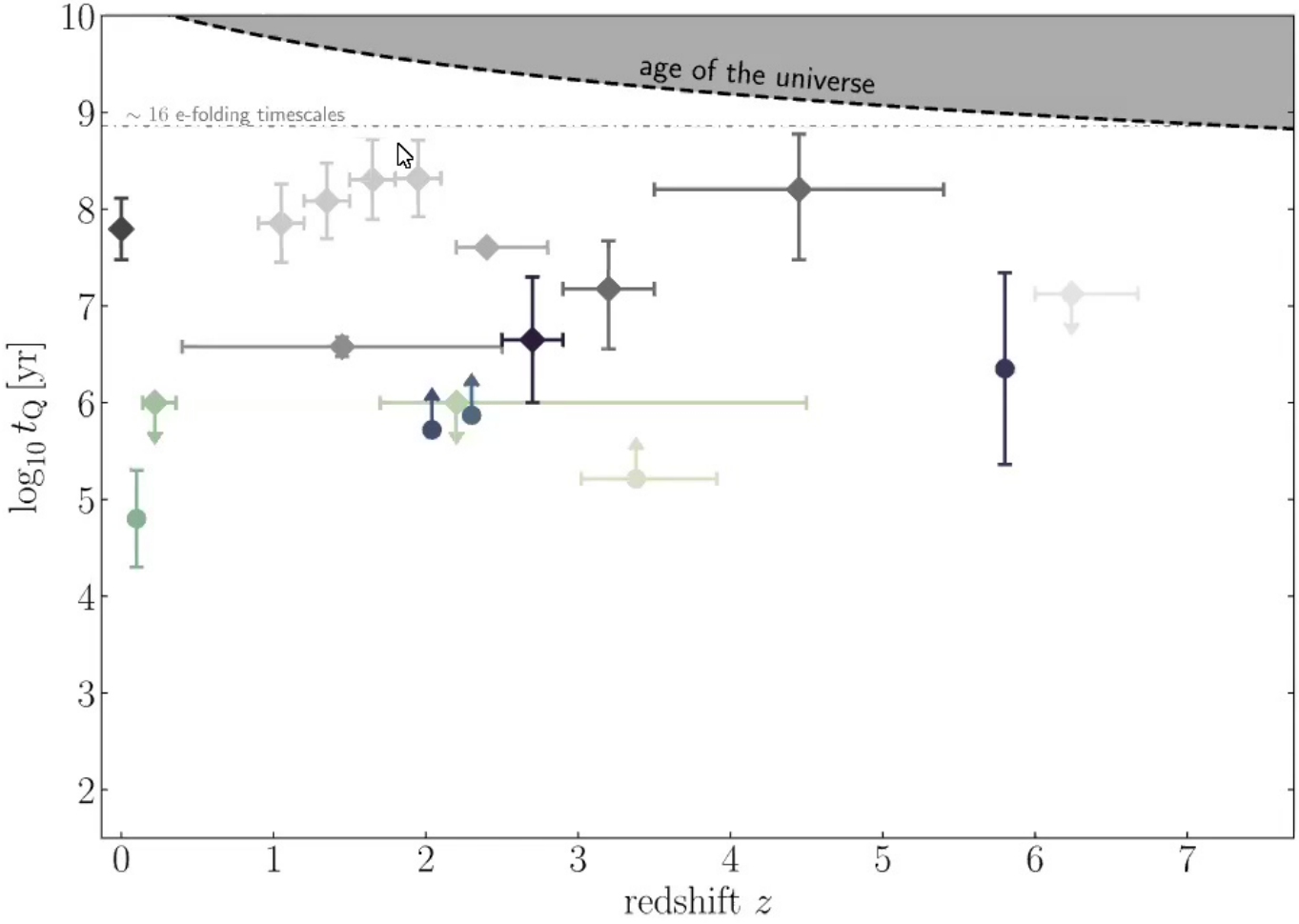




Anna-Christina Eilers, MIT

Eilers+ 2017, 2018, 2020ab

measuring timescales of quasar activity



Anna-Christina Eilers, MIT

Eilers+ 2020

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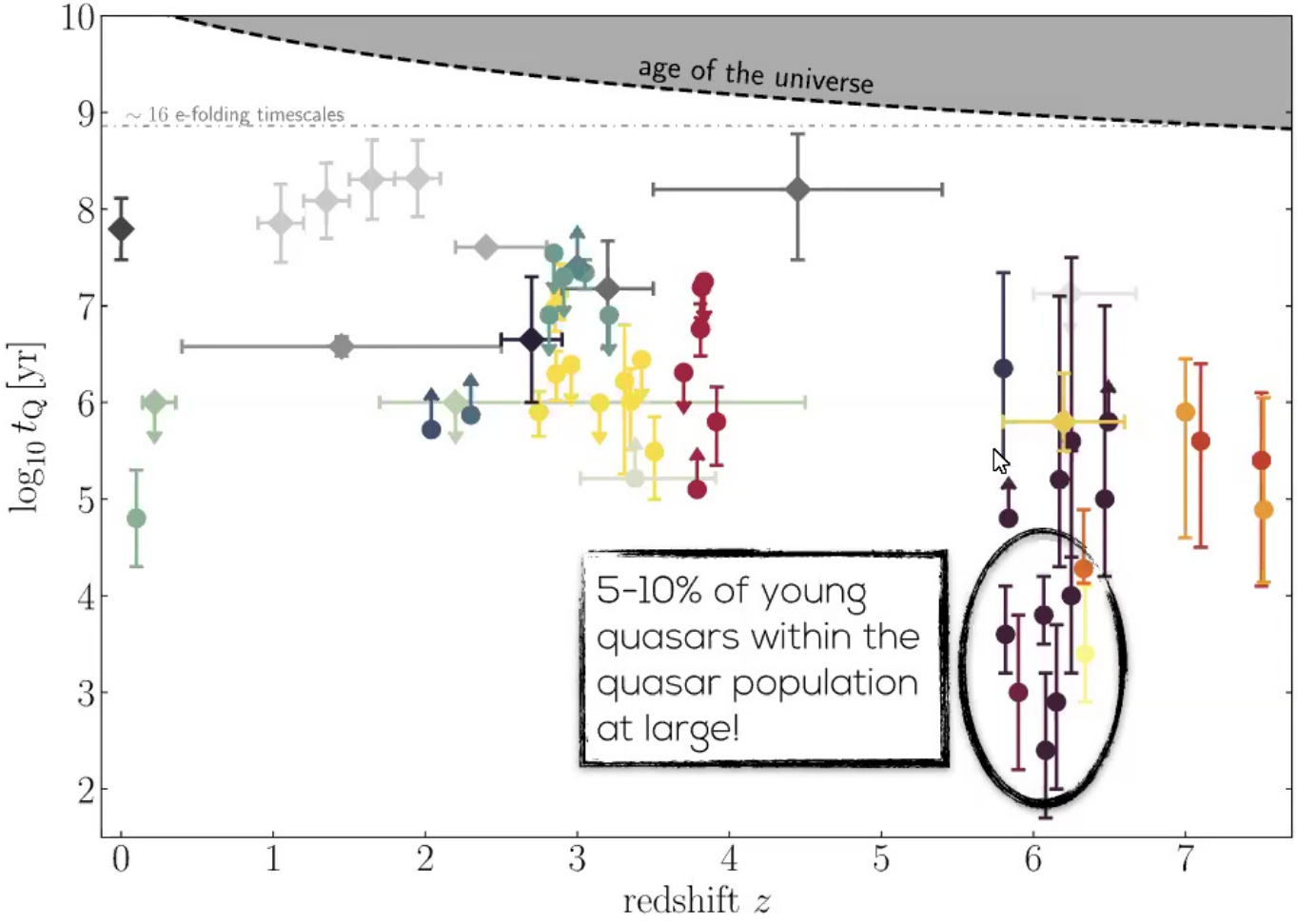
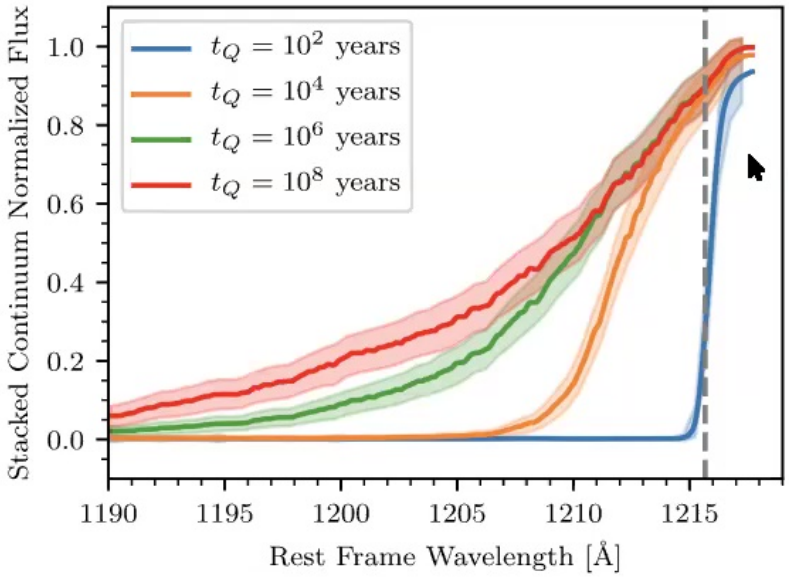


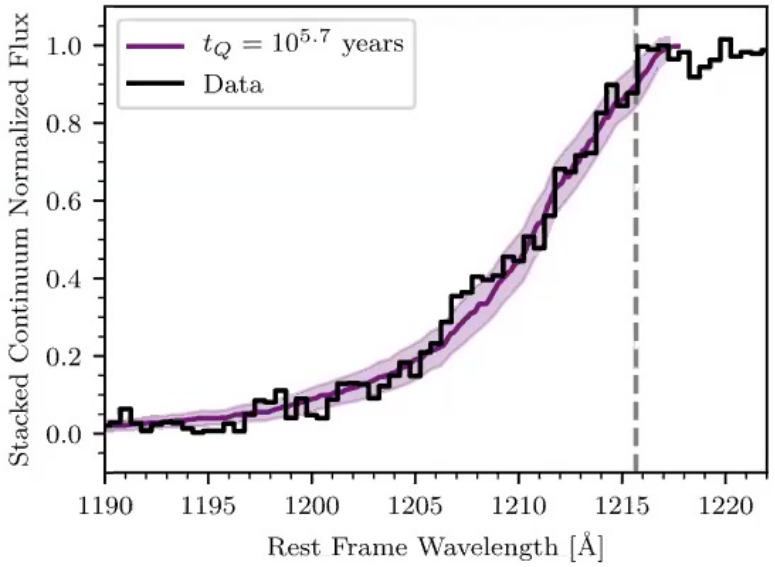
Anna-Christina Eilers, MIT

Eilers+ 2020

measuring timescales of quasar activity

Karna Morey, MIT

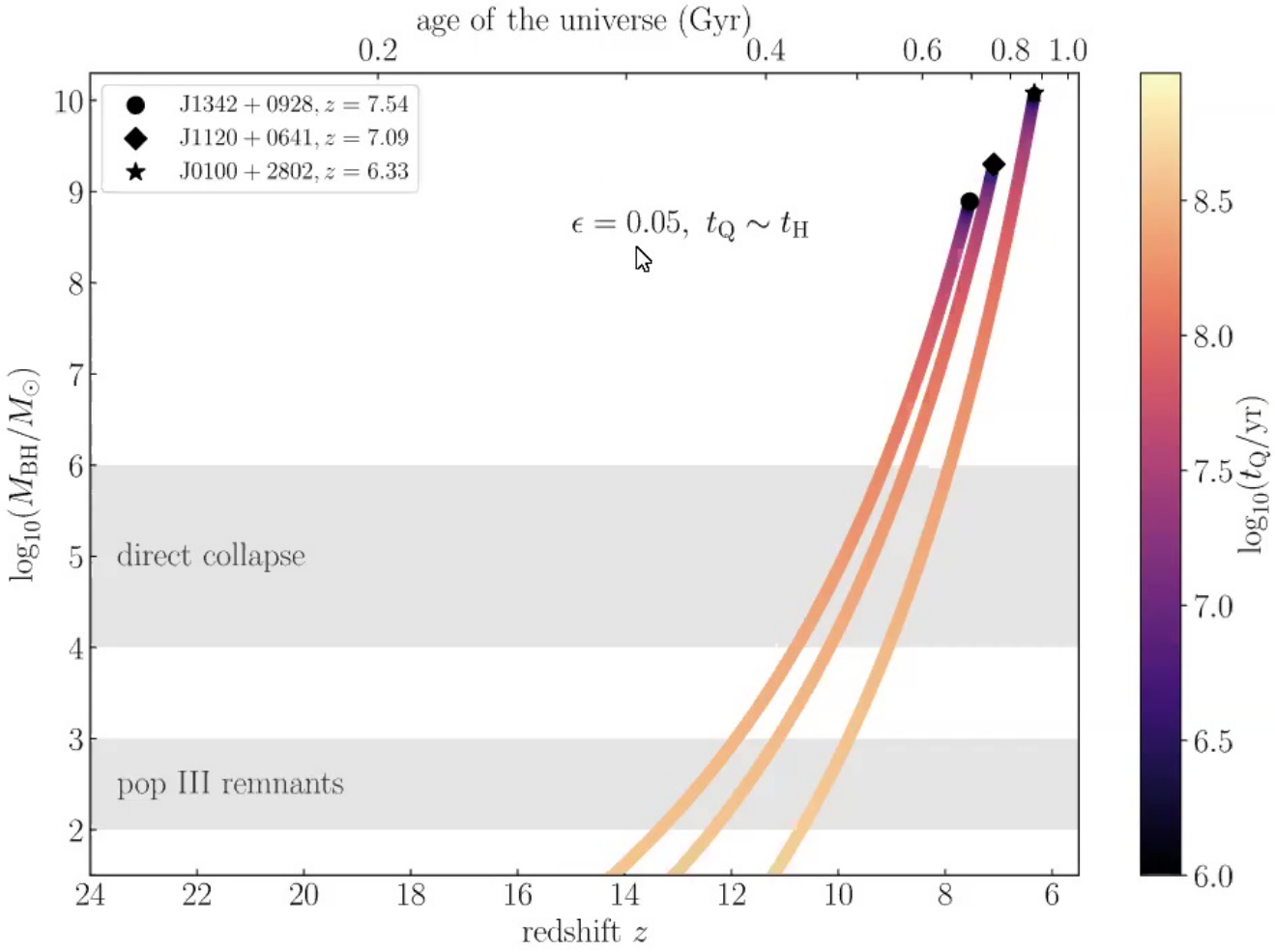




Anna-Christina Eilers, MIT

Morey, Eilers+ in prep.

too little time to grow a supermassive black hole!



Anna-Christina Eilers, MIT

possible implications for the growth of SMBHs

- massive initial seeds?
  (e.g. Begelman+ 2006, Volonteri+ 2008, Dijkstra+ 2008, Agarwal+ 2012, Freese+ 2016, Habouzit+ 2016)
- flickering quasar light curves?
  (e.g. Novak+ 2011, Schawinski+ 2015, Davies+ 2019)
- obscured quasar growth?
  (e.g. Hopkins+ 2008, Polletta+ 2008, Merloni+ 2014, Vito+ 2018, Hickox & Alexander 2018)
- radiatively inefficient accretion?
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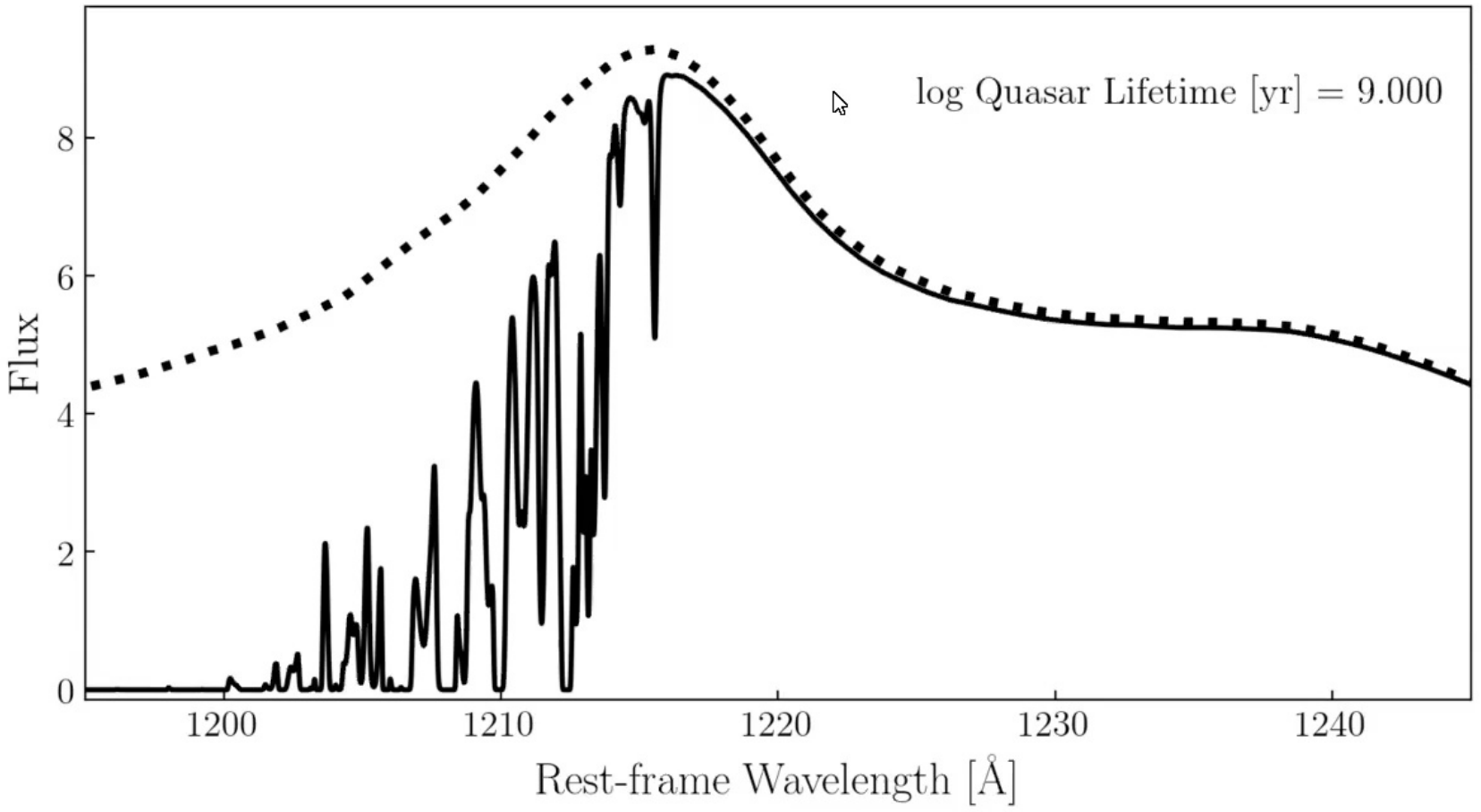

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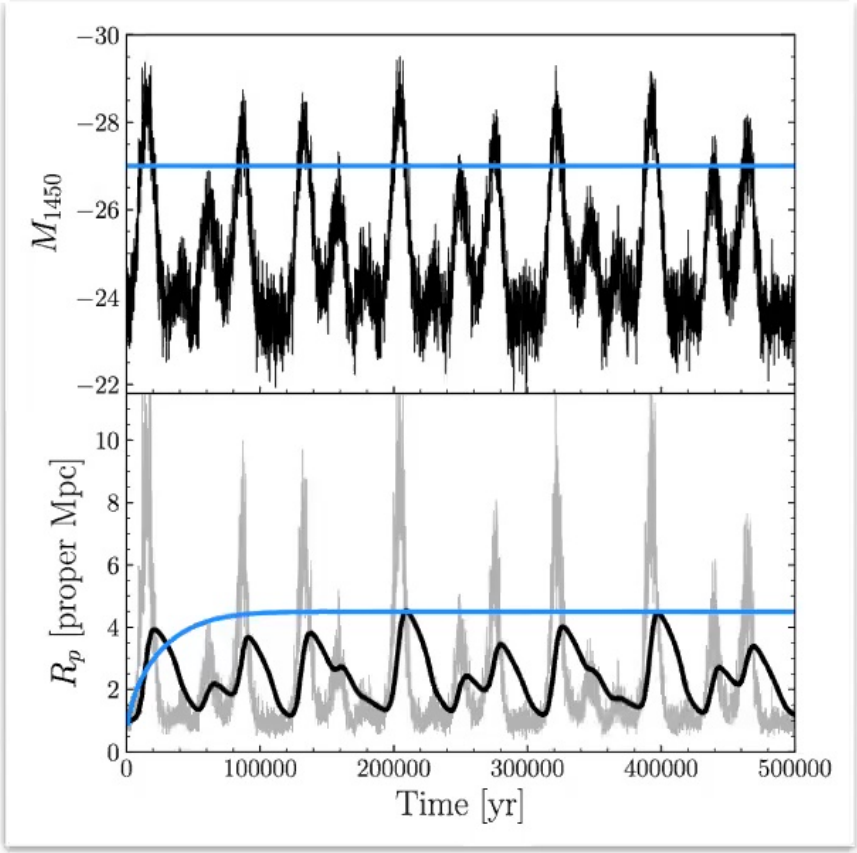
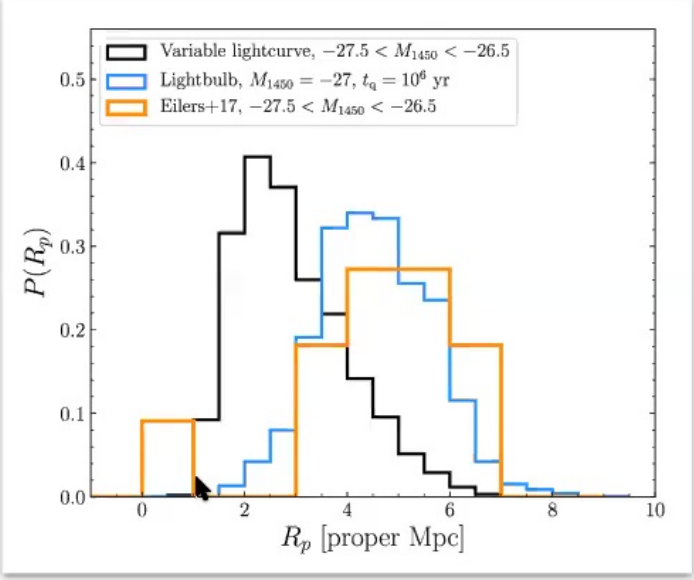
Anna-Christina Eilers, MIT credit: F. Davies

flickering quasar light curves





Anna-Christina Eilers, MIT

Davies, Hennawi & Eilers 2020

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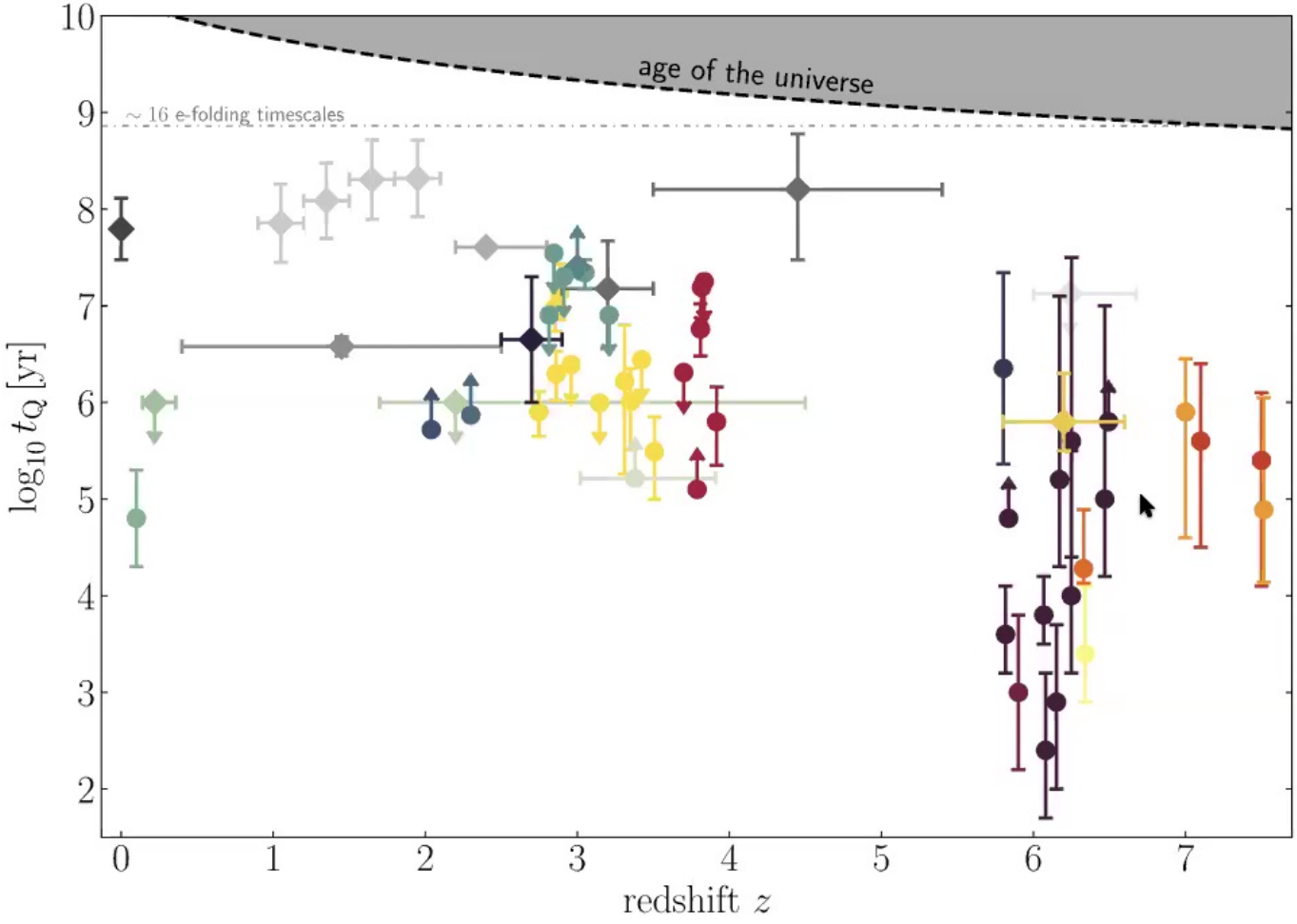

Anna-Christina Eilers, MIT

Eilers+ 2020

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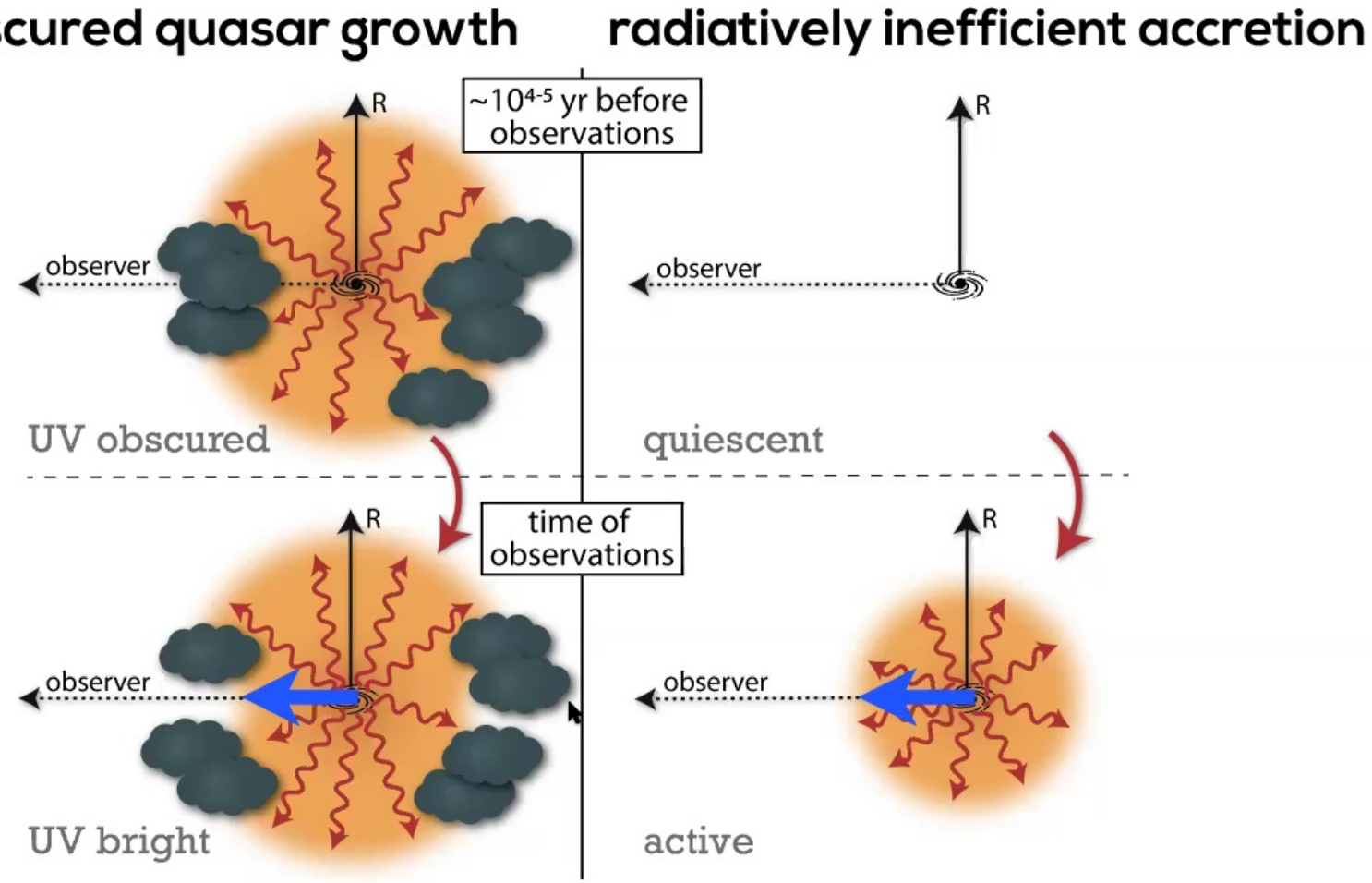
mapping the quasars' light echo

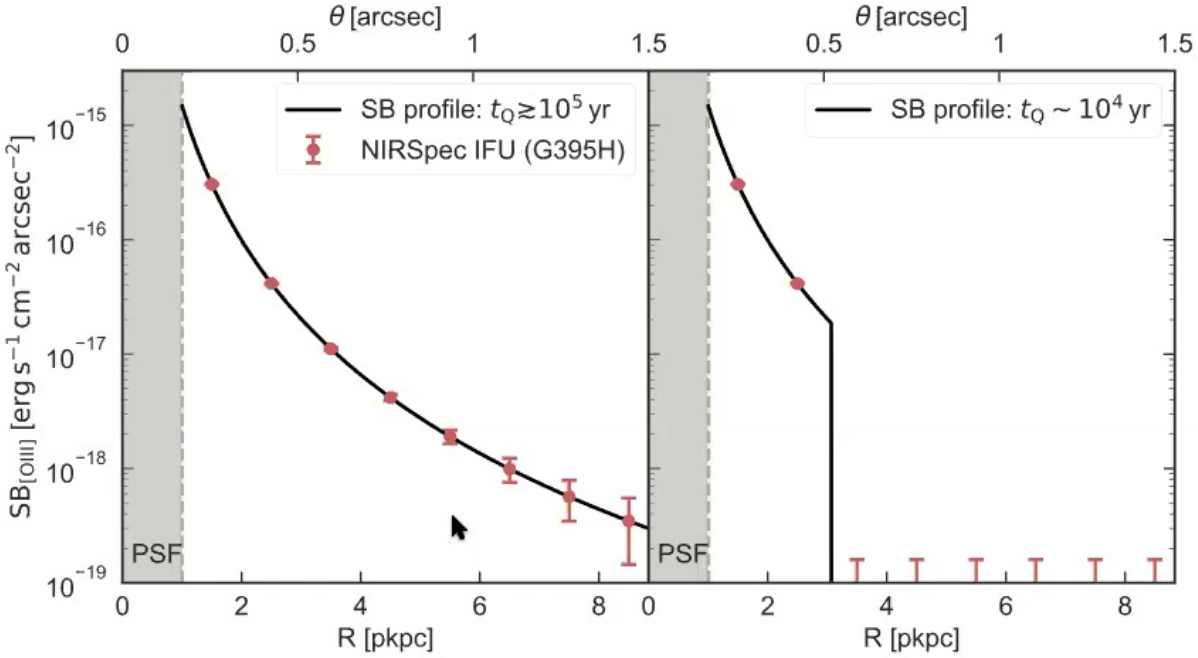


Anna-Christina Eilers, MIT

Eilers+ 2018

mapping the quasars' light echo

James Webb Space Telescope

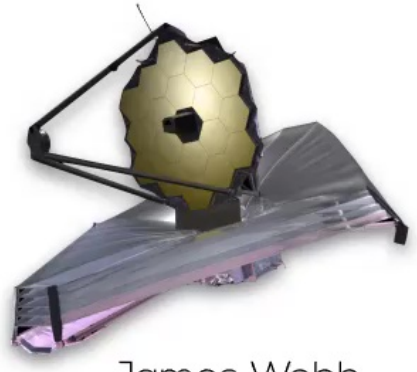


Anna-Christina Eilers, MIT

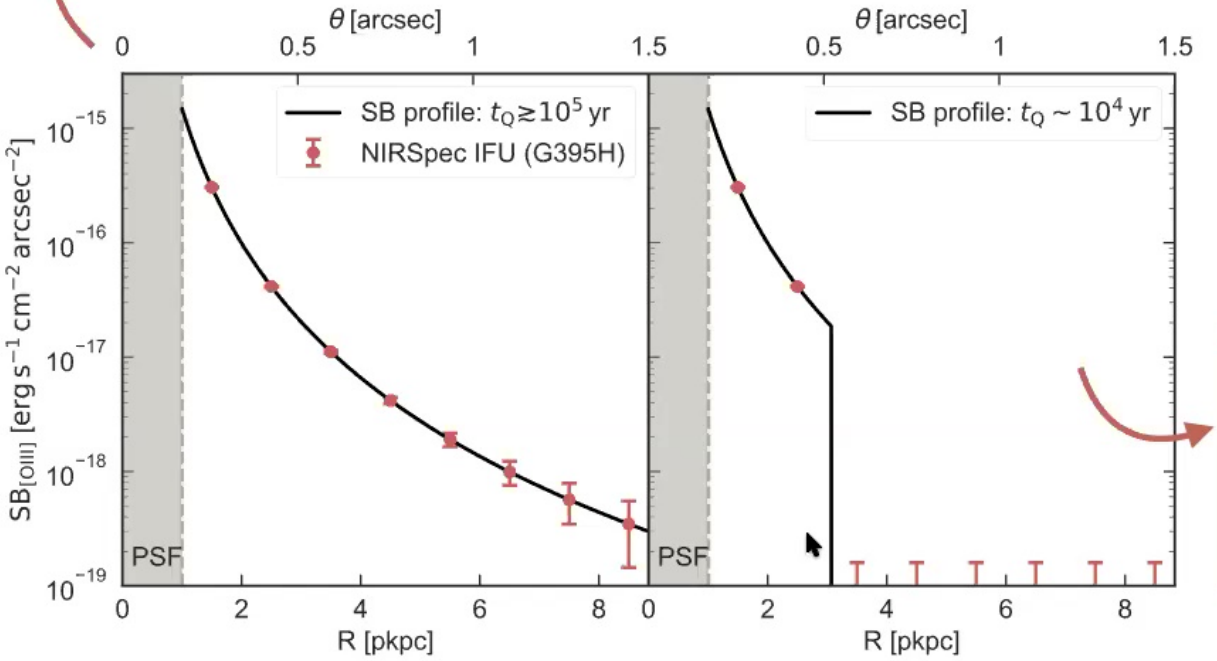
Eilers+ 2018

mapping the quasars' light echo

UV obscured, dust-enshrouded black hole growth phases –> large fraction of obscured quasars in the early universe



James Webb Space Telescope

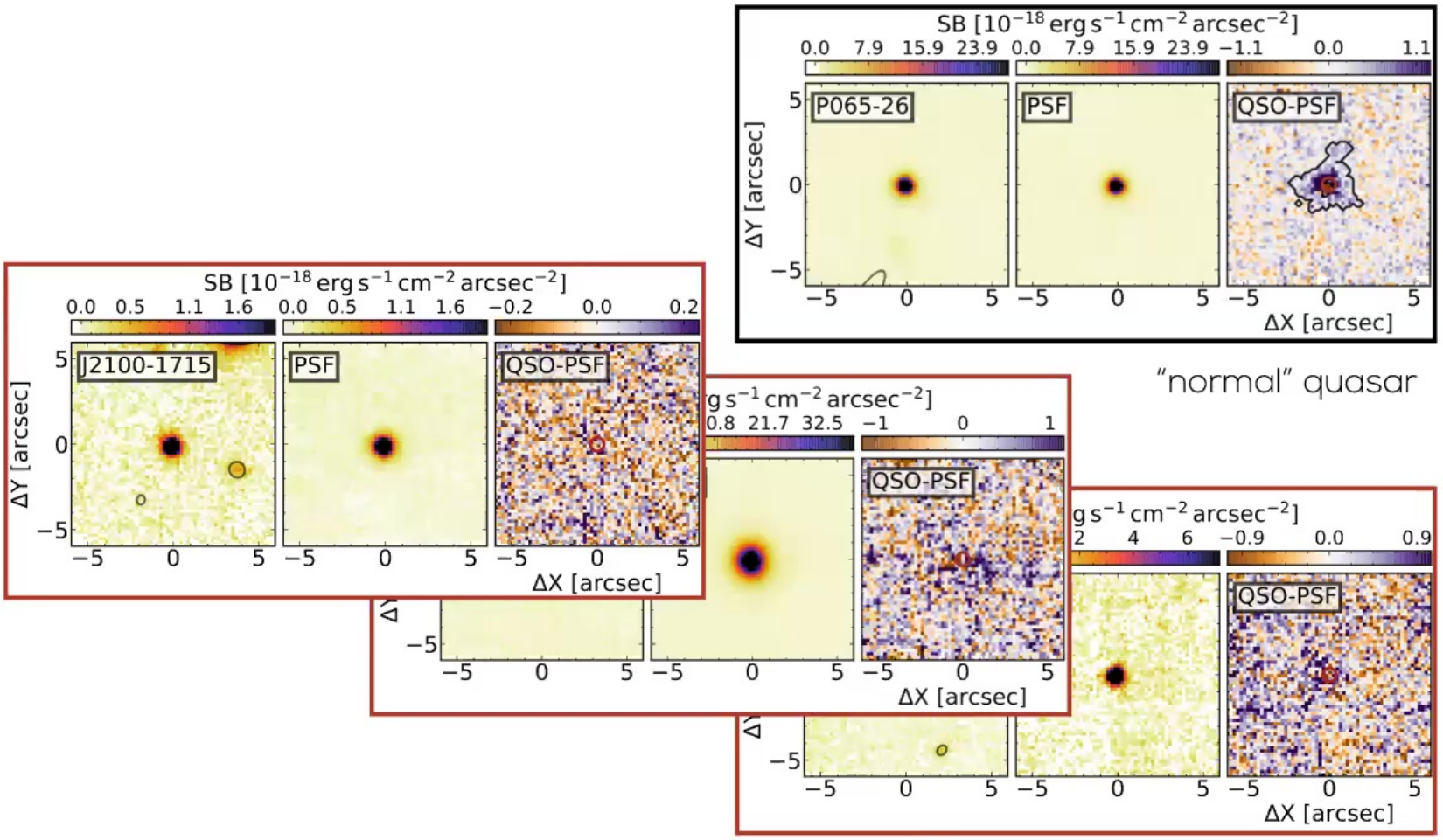


quasar activity has just turned on –> potential evidence for highly radiatively inefficient accretion

Anna-Christina Eilers, MIT

Eilers+ 2018

no extended emission around three young quasars detected with VLT/MUSE



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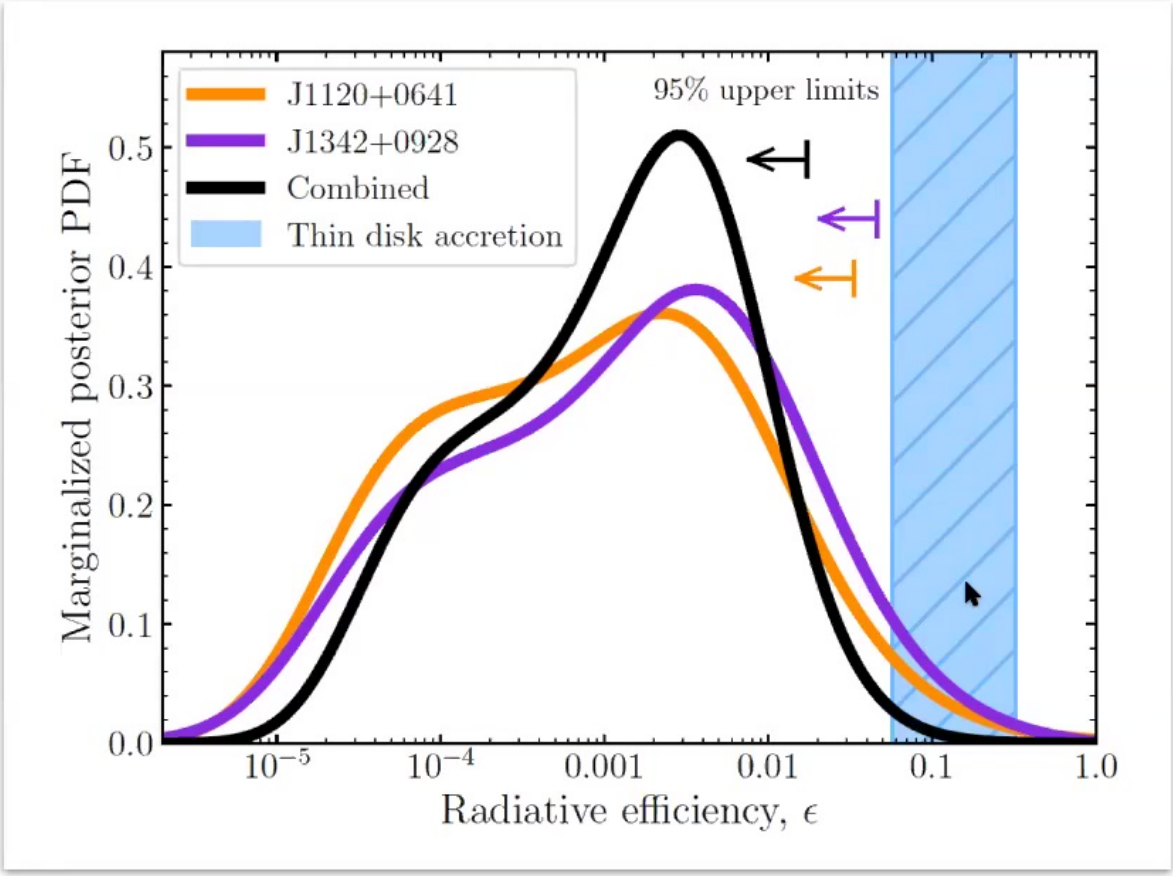
Farina+ 2019, Drake+ 2019, Eilers+ in prep.

highly radiatively inefficient accretion



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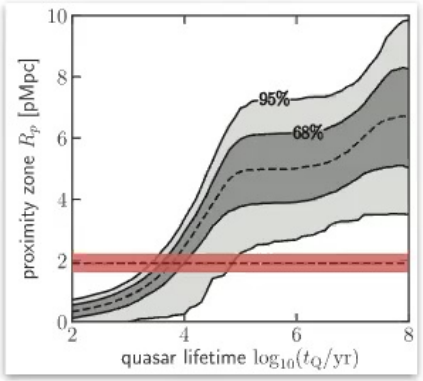
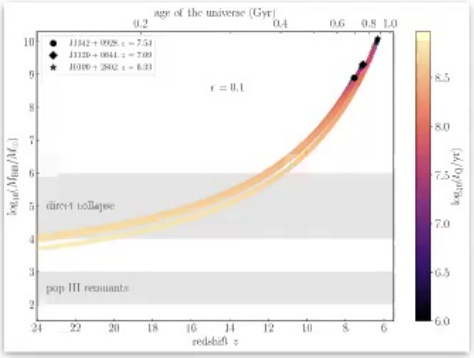
Davies, Hennawi & Eilers 2019

summary & conclusions

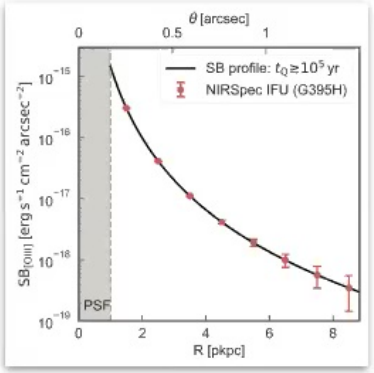
- new method to constrain quasar lifetimes by measuring their proximity zone sizes.





- short quasar lifetimes pose significant challenges on black hole formation models.

- mapping out the light echo of quasars will give new insights about the growth and obscuration of SMBHs.



Anna-Christina Eilers, MIT

summary & conclusions

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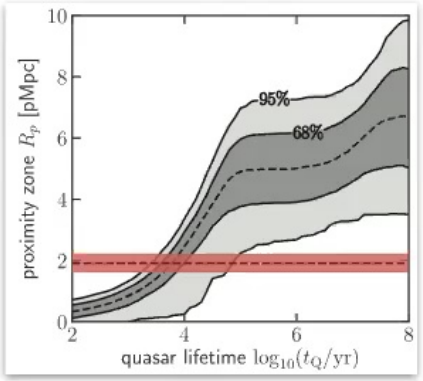

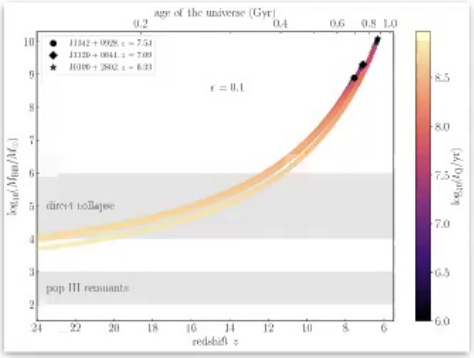

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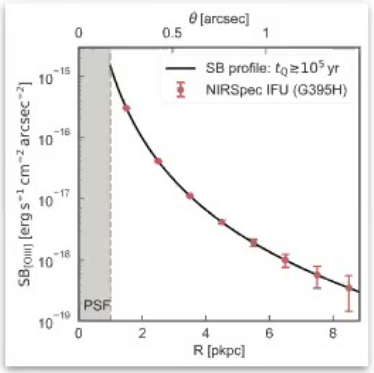

Thank you!

Anna-Christina Eilers, MIT