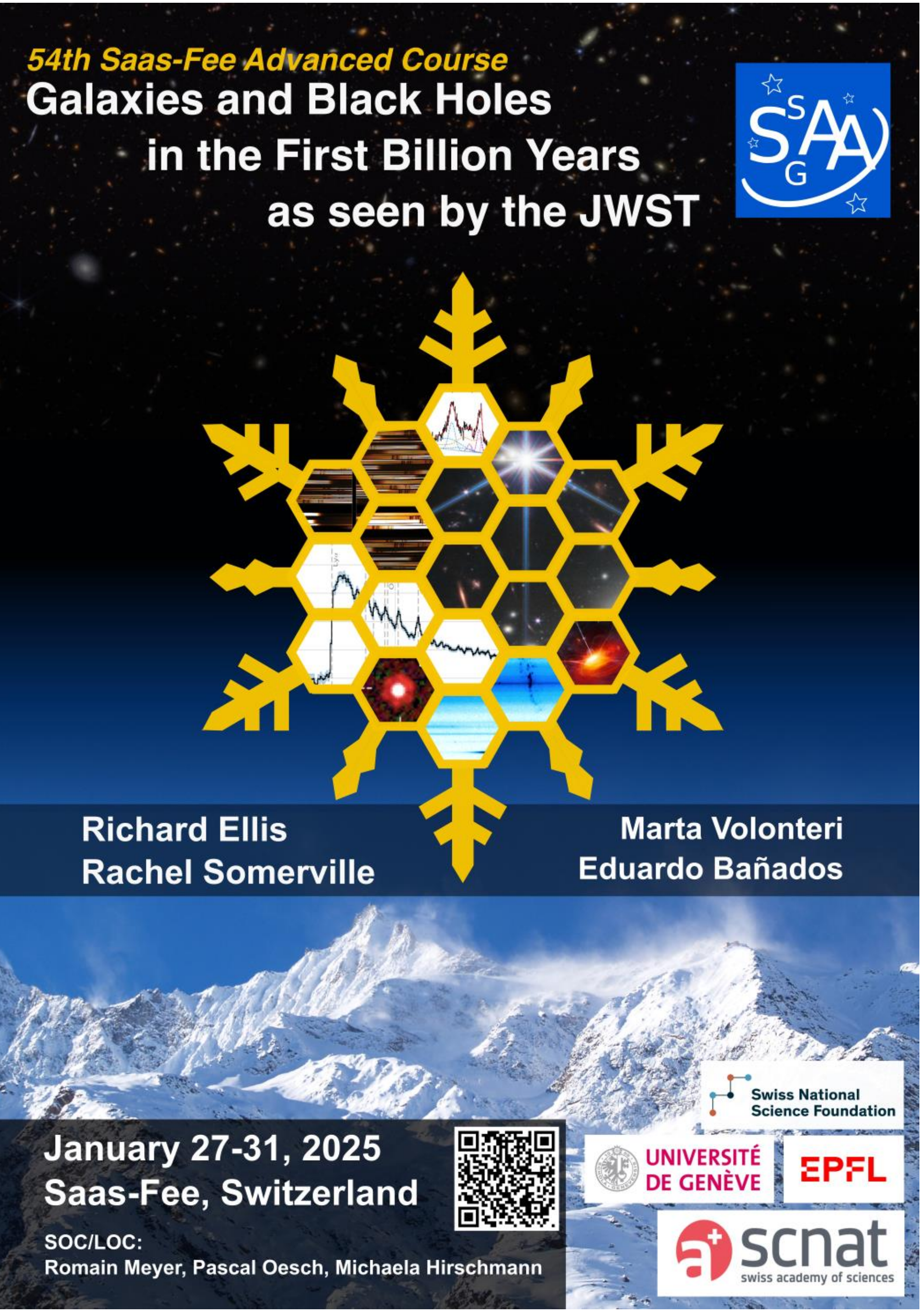
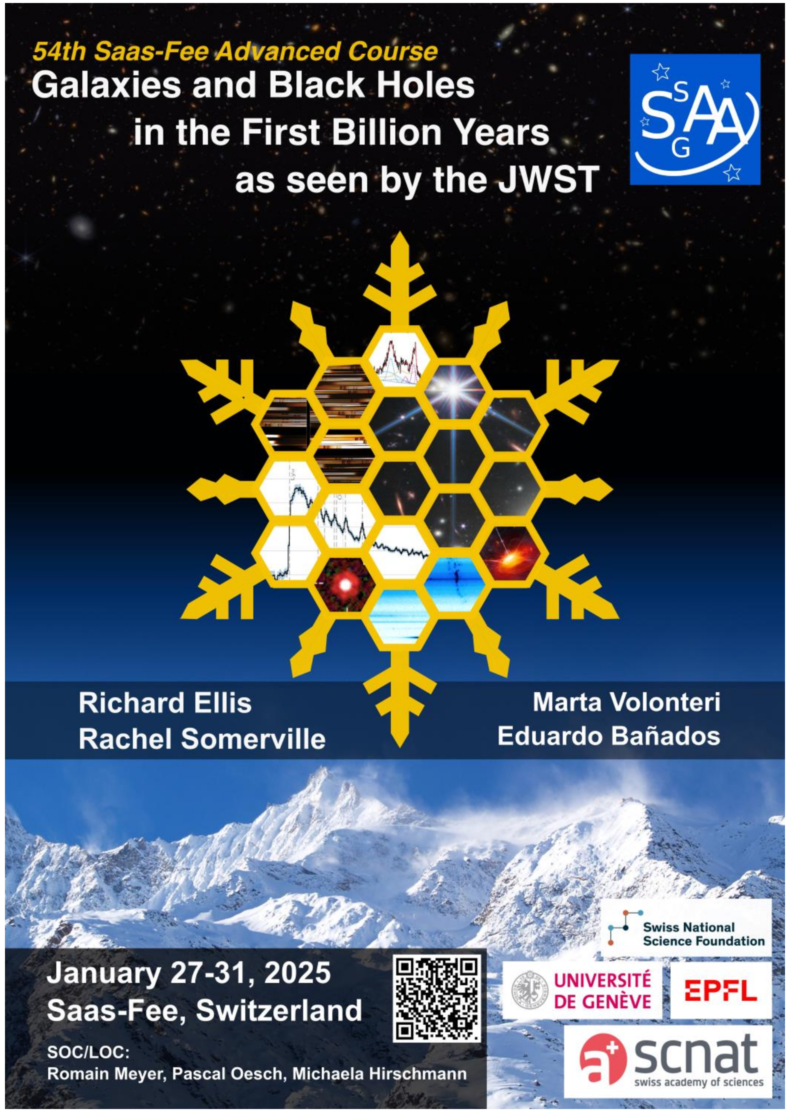


Observations of early black holes

before and after JWST

Eduardo Bañados
Max Planck Institute for Astronomy, Heidelberg

Observations of early black holes – some warnings

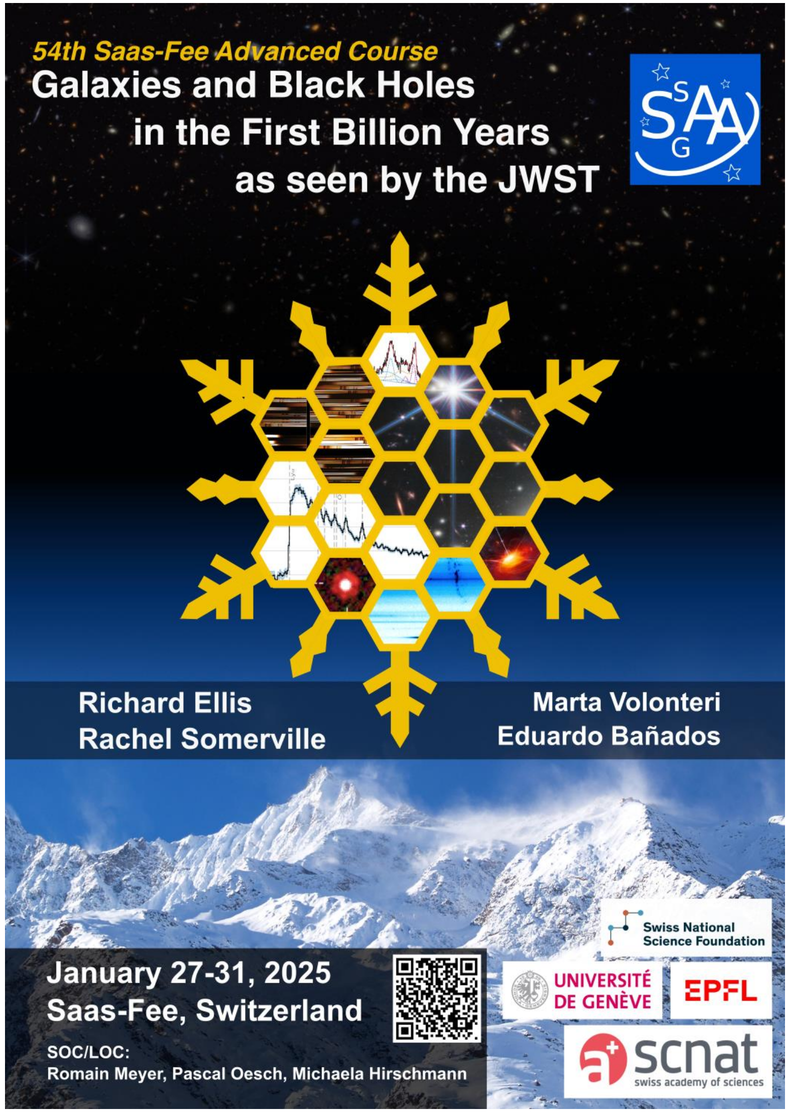


- *Observationally* focused

- Only scratch the surface and likely influenced by my own biases

- Main ideas, pointing to more literature and some anecdotes

Observations of early black holes – three lectures

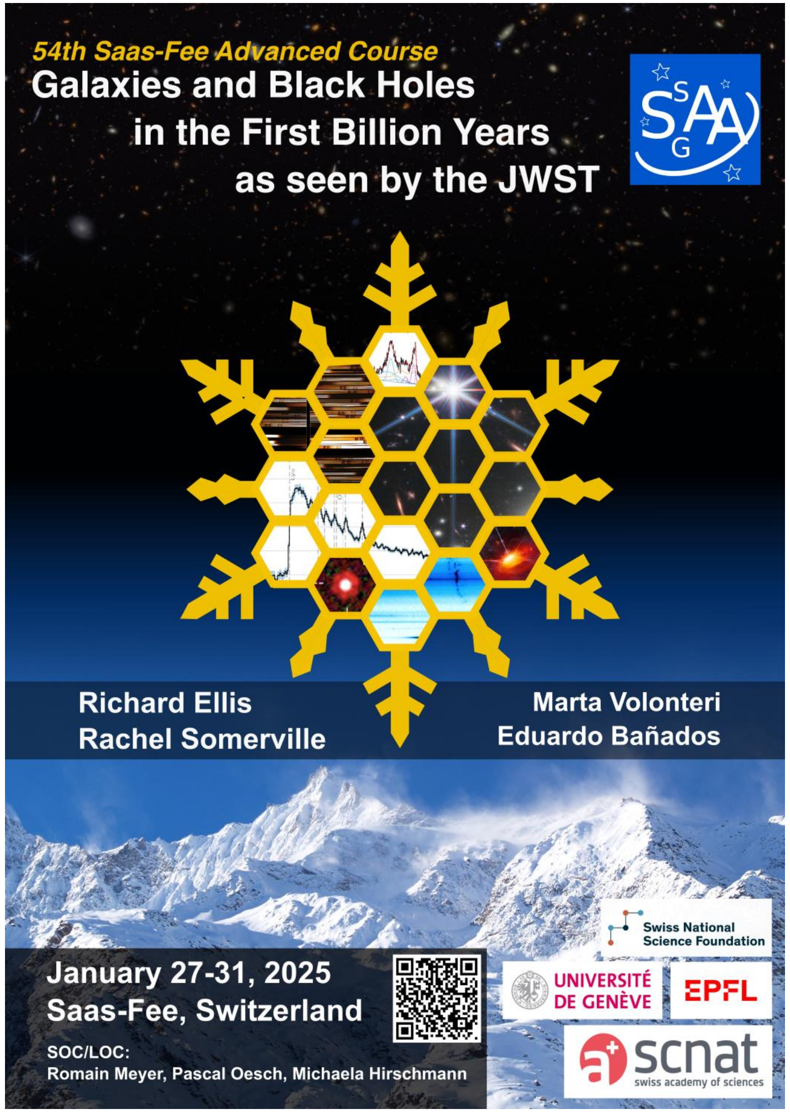


1.- Introduction to AGN and Quasars

2.- Quasars in the first billion years: What we knew before JWST

3.- JWST insights into Quasars in the early Universe

Quasars in the first Gyr: What we knew before JWST



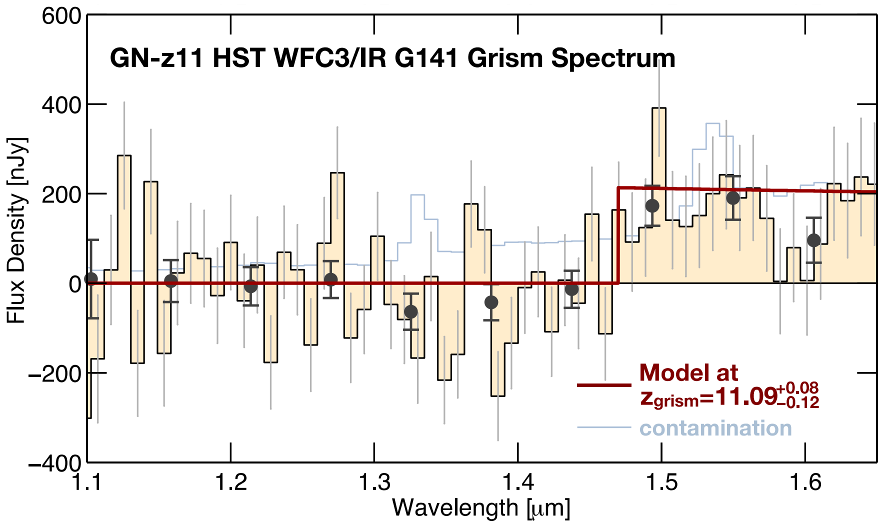
- Historical Overview – Redshift frontier

- Key pre-JWST observational results

- Key open questions

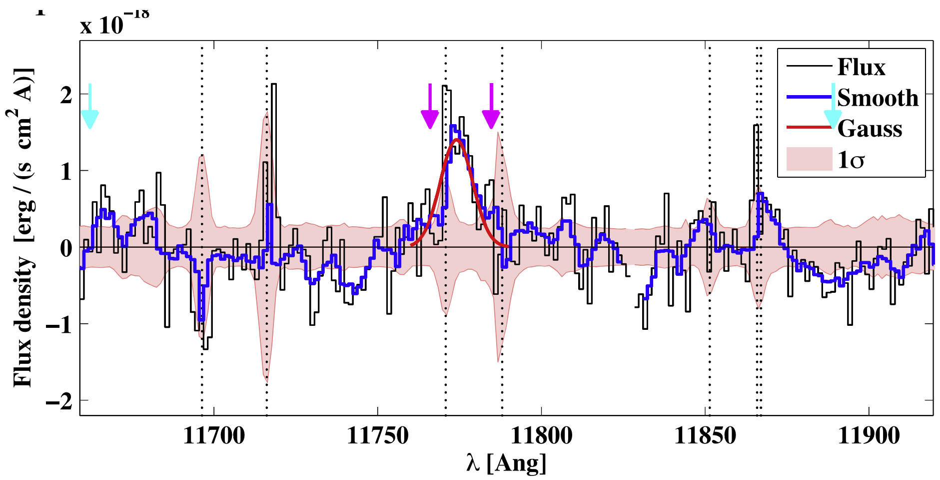
Most distant galaxies known pre-JWST

z=11.0



Oesch+ 2016

z=8.7

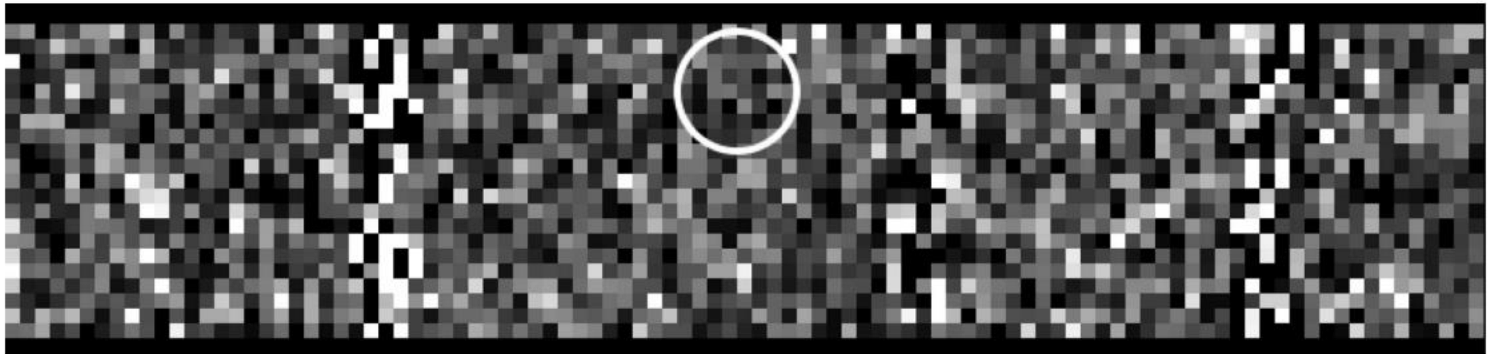


Zitrin+ 2015

Most distant galaxies known pre-JWST

Even confirmation is hard!

z=8.6 candidate



5 hours VLT and 11 hours Subaru

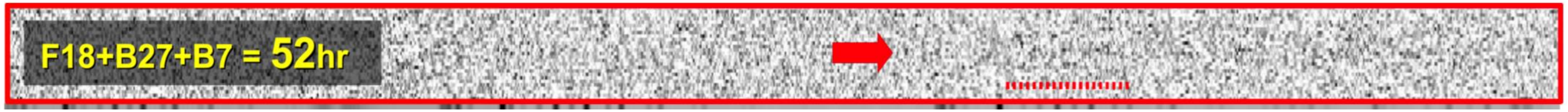
Bunker+ 2013

Most distant galaxies known pre-JWST

Even confirmation is hard!

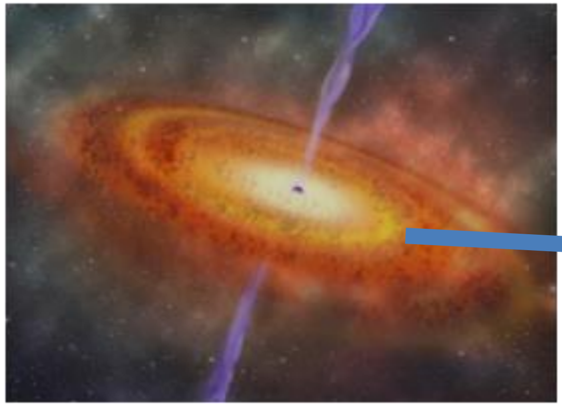
A 52 hours VLT/FORS2 spectrum of a bright $z \sim 7$ HUDF galaxy: no Ly-α emission★

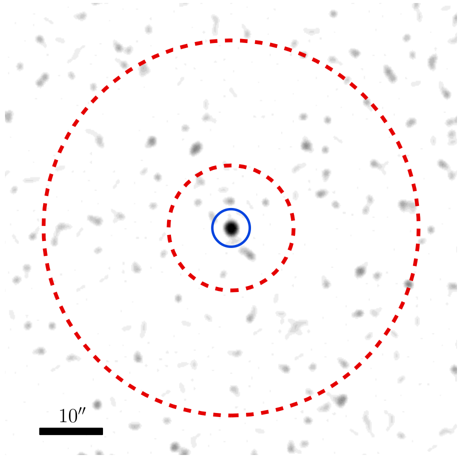
E. Vanzella[1], A. Fontana[2], L. Pentericci[2], M. Castellano[2], A. Grazian[2], M. Giavalisco[3], M. Nonino[4], S. Cristiani[4], G. Zamorani[1], and C. Vignali[5]



Vanzella+ 2014

Quasars are bright!





z=7.54 quasar
Bañados+ 2018b

X-rays

See also
Connor, EB+ 2019, 2020, 2021
Vito+ 2021 (incl. EB)
Wang+ 2021 (incl. EB)
Zappacosta+2023

Multiwavelength is key

- X-ray: Hot corona/jets
- UV/optical: accretion disk
- Mid-infrared: hot dust
- Far-infrared: cold dust/ISM
- Radio: jets

z=7.54 „Pisco“ quasar
Bañados+ 2018a

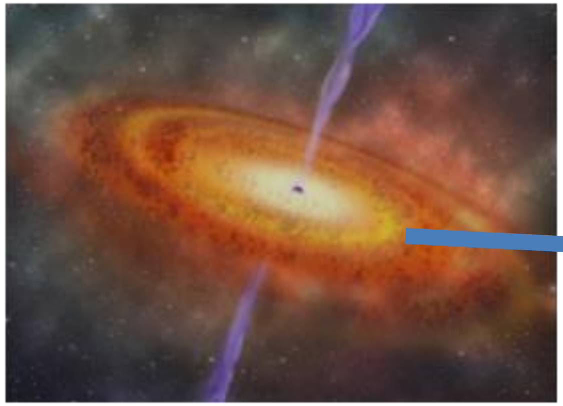
Key Differences at a Glance

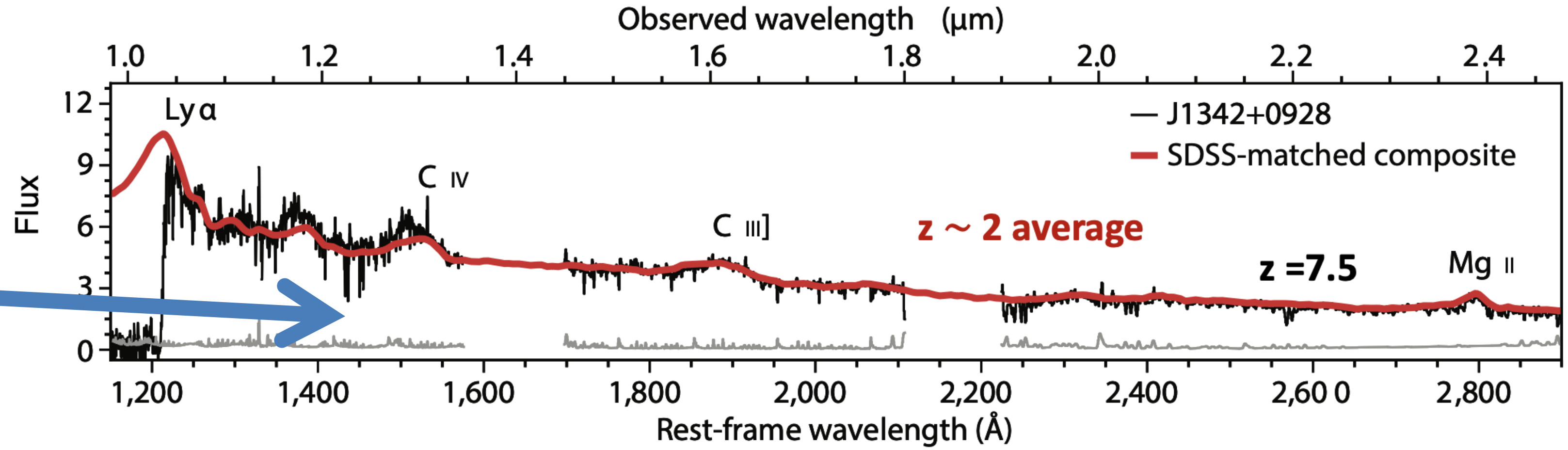
Aspect	AGN	Quasars
Definition	A broad category of active galactic centers.	A highly luminous type of AGN.
Luminosity	Covers a wide range, from faint to bright.	Among the brightest AGN, often outshining hosts.
Host Galaxy Visibility	Usually visible in lower-luminosity AGN.	Often invisible due to the quasar's brightness.
Distance (Redshift)	Found both locally and at high redshift.	Primarily at high redshift (early universe).
Examples	Seyfert galaxies, radio galaxies, LINERs.	3C 273, ULAS J1342+0928 (z ≈ 7.54).

Schmidt 1963
“The first quasar”

Bañados+2018
“The Pisco quasar”

Quasars are bright!



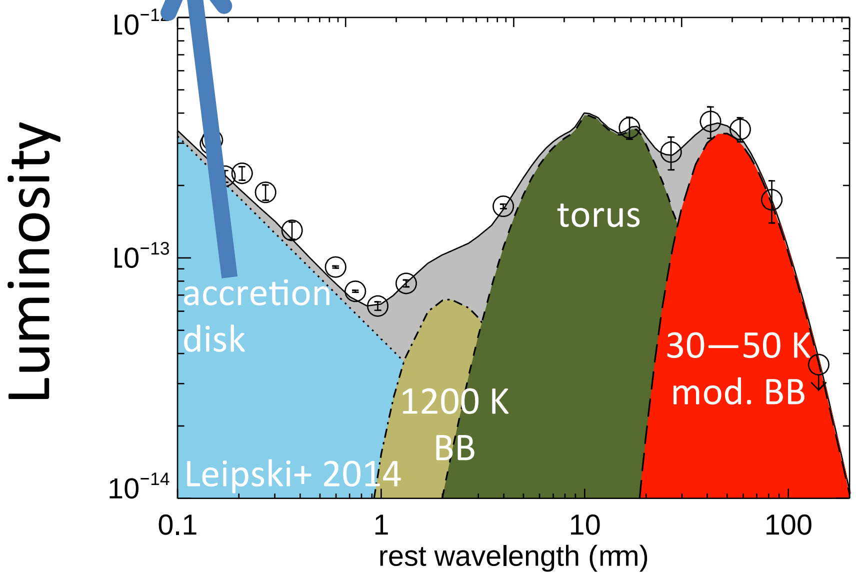


Rest-frame
UV

Multiwavelength is key

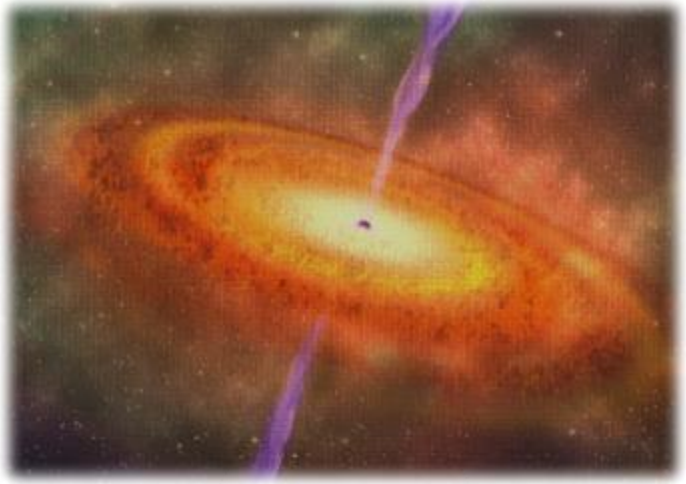
- X-ray: Hot corona/jets
- UV/optical: accretion disk
- Mid-infrared: hot dust
- Far-infrared: cold dust/ISM
- Radio: jets

z=7.54 „Pisco“
quasar
Bañados+ 2018a



Outline

- **Discovery and demographics**
- SMBH → ~pc scales
- Galaxy / Close envs. → ~kpc scales
- Environments /IGM → ~Mpc scales
- Obscured quasars/AGN?

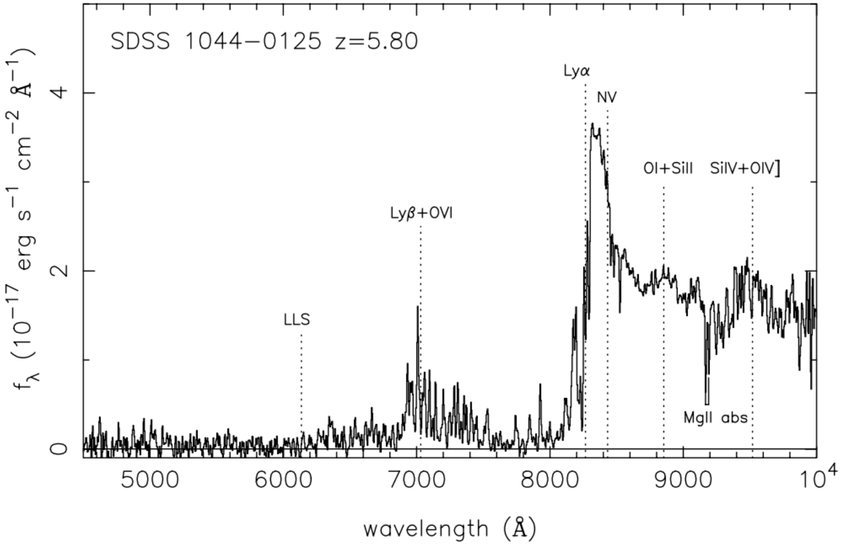


2000 - The first quasar in the first Gyr of the Universe

THE ASTRONOMICAL JOURNAL, 120:1167–1174, 2000 September

THE DISCOVERY OF A LUMINOUS $z = 5.80$ QUASAR FROM THE SLOAN DIGITAL SKY SURVEY[1]

XIAOHUI FAN,[2] RICHARD L. WHITE,[3] MARC DAVIS,[4] ROBERT H. BECKER,[5,6] MICHAEL A. STRAUSS,[2] ZOLTAN HAIMAN,[2]
DONALD P. SCHNEIDER,[7] MICHAEL D. GREGG,[5,6] JAMES E. GUNN,[2] G. R. KNAPP,[2] ROBERT H. LUPTON,[2]
JOHN E. ANDERSON, JR.,[8] SCOTT F. ANDERSON,[9] JAMES ANNIS,[8] NETA A. BAHCALL,[2] WILLIAM N. BOROSKI,[8]
ROBERT J. BRUNNER,[10] BING CHEN,[11] ANDREW J. CONNOLLY,[12] ISTVÁN CSABAI,[11] MAMORU DOI,[13]
MASATAKA FUKUGITA,[14,15] G. S. HENNESSY,[16] ROBERT B. HINDSLEY,[17] TAKASHI ICHIKAWA,[18] ŽELJKO IVEZIĆ,[2]
JON LOVEDAY,[19] AVERY MEIKSIN,[20] TIMOTHY A. MCKAY,[21] JEFFREY A. MUNN,[22] HEIDI JO NEWBERG,[23] ROBERT NICHOL,[24]
SADANORI OKAMURA,[13] JEFFREY R. PIER,[22] MAKI SEKIGUCHI,[14] KAZUHIRO SHIMASAKU,[13] CHRIS STOUGHTON,[8]
ALEXANDER S. SZALAY,[11] GYULA P. SZOKOLY,[25] ANIRUDDHA R. THAKAR,[11] MICHAEL S. VOGELEY,[26] AND



2006 – First SDSS sample of z~6 quasars

ANNUAL REVIEWS

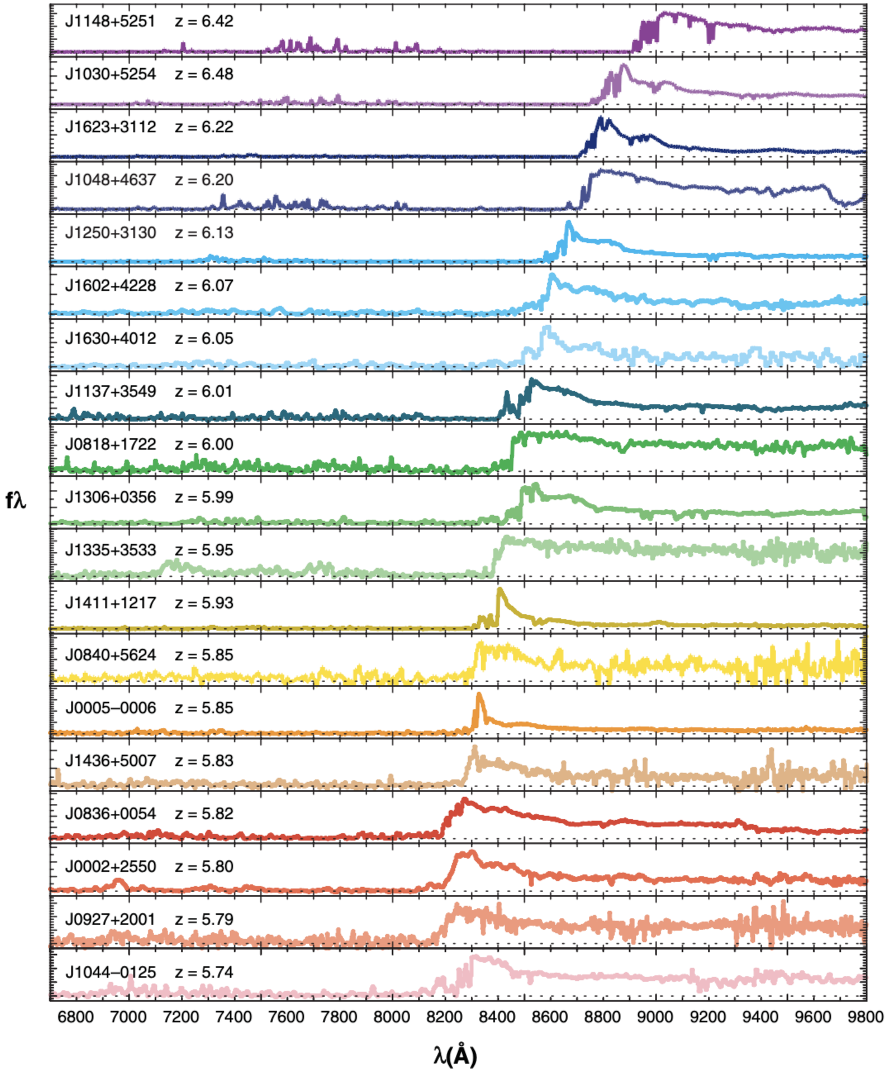
Observational Constraints on Cosmic Reionization

Xiaohui Fan,[1] C.L. Carilli,[2] and B. Keating[3]

[1]Steward Observatory, University of Arizona, Tucson, Arizona 85721; email: fan@sancerre.as.arizona.edu

[2]National Radio Astronomy Observatory, Socorro, New Mexico 87801; email: ccarilli@nrao.edu

[3]Department of Physics, University of California, San Diego, California 92093; email: bkeating@ucsd.edu



~2009

Extragalactic seminar – Assignment:
30 min talk sumarising this *recent* review

ANNUAL REVIEWS

Observational Constraints on Cosmic Reionization

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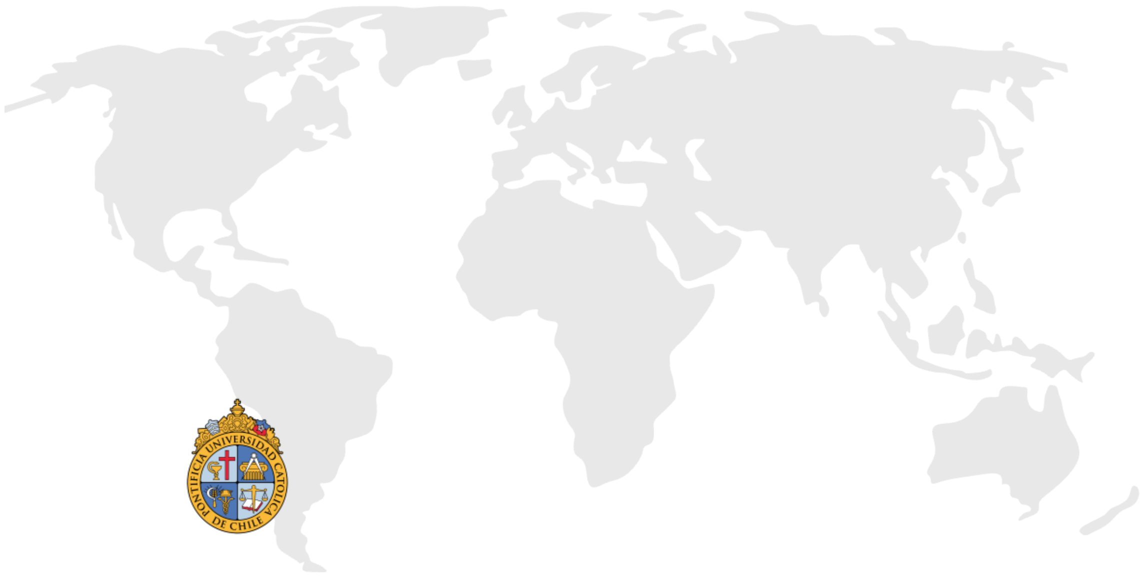
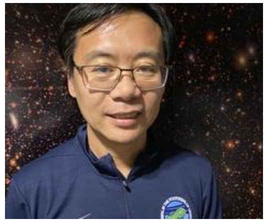


~2013-2014



ANNUAL REVIEWS

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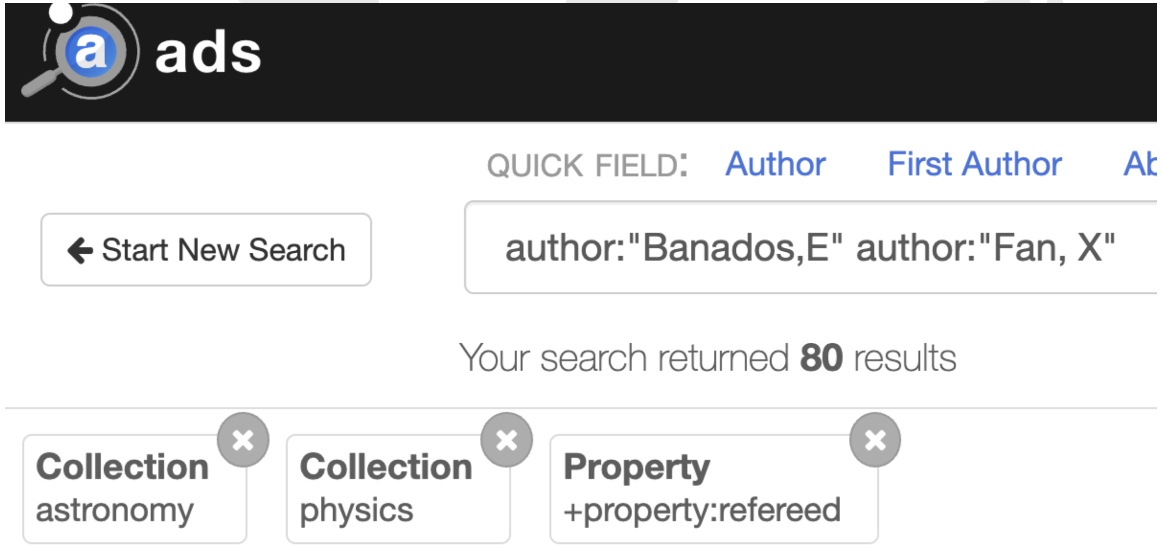
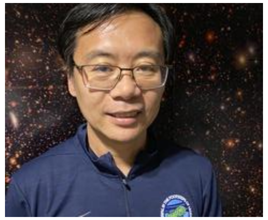


2018



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CARNEGIE SCIENCE

Observational Constraints on Cosmic Reionization

Xiaohui Fan,[1] C.L. Carilli,[2] and B. Keating[3]

[1]Steward Observatory, University of Arizona, Tucson, Arizona 85721; email: fan@sancerre.as.arizona.edu

[2]National Radio Astronomy Observatory, Socorro, New Mexico 87801; email: ccarilli@nrao.edu

[3]Department of Physics, University of California, San Diego, California 92093; email: bkeating@ucsd.edu

The Astrophysical Journal Letters, 861:L14 (4pp), 2018 July 10 https://doi.org/10.3847/2041-8213/aac511

A Powerful Radio-loud Quasar at the End of Cosmic Reionization

Eduardo Bañados[1,7], Chris Carilli[2,3], Fabian Walter[2,4], Emmanuel Momjian[2],
Roberto Decarli[5], Emanuele P. Farina[6], Chiara Mazzucchelli[4], and Bram P. Venemans[4]

[1] The Observatories of the Carnegie Institution for Science, 813 Santa Barbara Street, Pasadena, CA 91101, USA; ebanados@carnegiescience.edu

[2] National Radio Astronomy Observatory, Pete V. Domenici Array Science Center, P.O. Box 0, Socorro, NM 87801, USA

ads

QUICK FIELD: Author First Author Abstr

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author:"Banados,E" author:"Carilli, C"

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Property +property:refereed

Motivation for this lecture

ANNUAL REVIEWS

2006

ANNUAL REVIEWS

Observational Constraints on Cosmic Reionization

Xiaohui Fan,[1] C.L. Carilli,[2] and B. Keating[3]

[1] Steward Observatory, University of Arizona, Tucson, Arizona 85721; email: fan@sancerre.as.arizona.edu

[2] National Radio Astronomy Observatory, Socorro, New Mexico 87801; email: ccarilli@nrao.edu

[3] Department of Physics, University of California, San Diego, California 92093; email: bkeating@ucsd.edu

2023

ANNUAL REVIEWS

Annual Review of Astronomy and Astrophysics

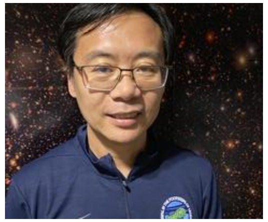
Quasars and the Intergalactic Medium at Cosmic Dawn

Xiaohui Fan,[1] Eduardo Bañados,[2] and Robert A. Simcoe[3]

[1] Steward Observatory, University of Arizona, Tucson, Arizona, USA; email: xfan@arizona.edu

[2] Max-Planck-Institut für Astronomie, Heidelberg, Germany; email: banados@mpia.de

[3] MIT Kavli Institute for Astrophysics and Space Research, Cambridge, Massachusetts, USA; email: simcoe@space.mit.edu



Outline

ANNUAL REVIEWS

Annual Review of Astronomy and Astrophysics

Quasars and the Intergalactic Medium at Cosmic Dawn

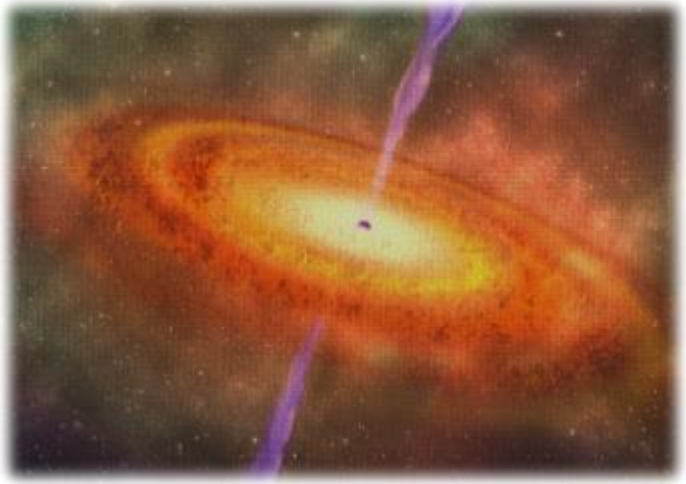
Xiaohui Fan,[1] Eduardo Bañados,[2] and Robert A. Simcoe[3]

[1] Steward Observatory, University of Arizona, Tucson, Arizona, USA; email: xfan@arizona.edu

[2] Max-Planck-Institut für Astronomie, Heidelberg, Germany; email: banados@mpia.de

[3] MIT Kavli Institute for Astrophysics and Space Research, Cambridge, Massachusetts, USA; email: simcoe@space.mit.edu

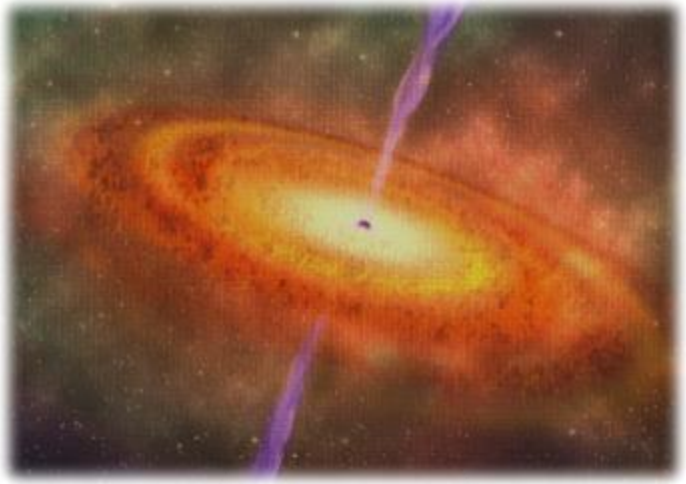
Fan, **Bañados** & Simcoe 2023
ARA&A 61, 373



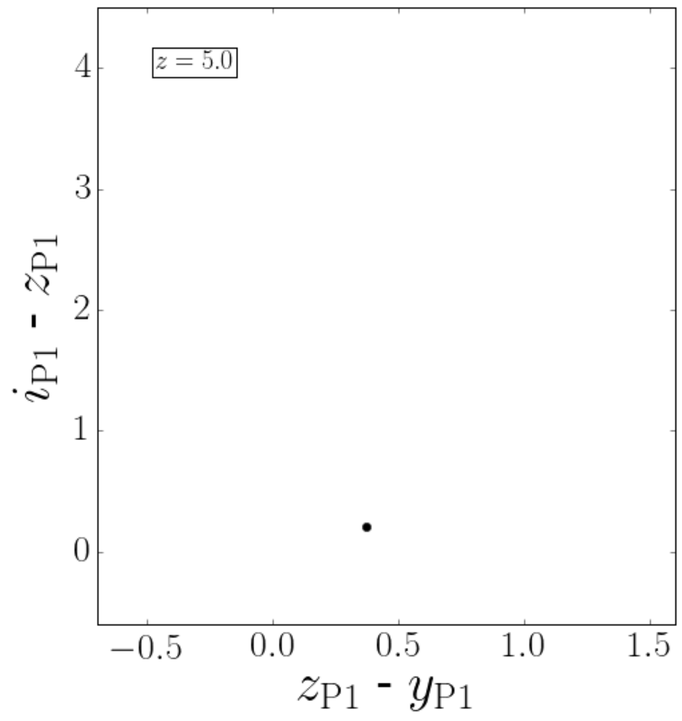
- Unobscured quasars at z>5.3
- IGM studies based only on quasars
- **Status of the field pre-JWST**

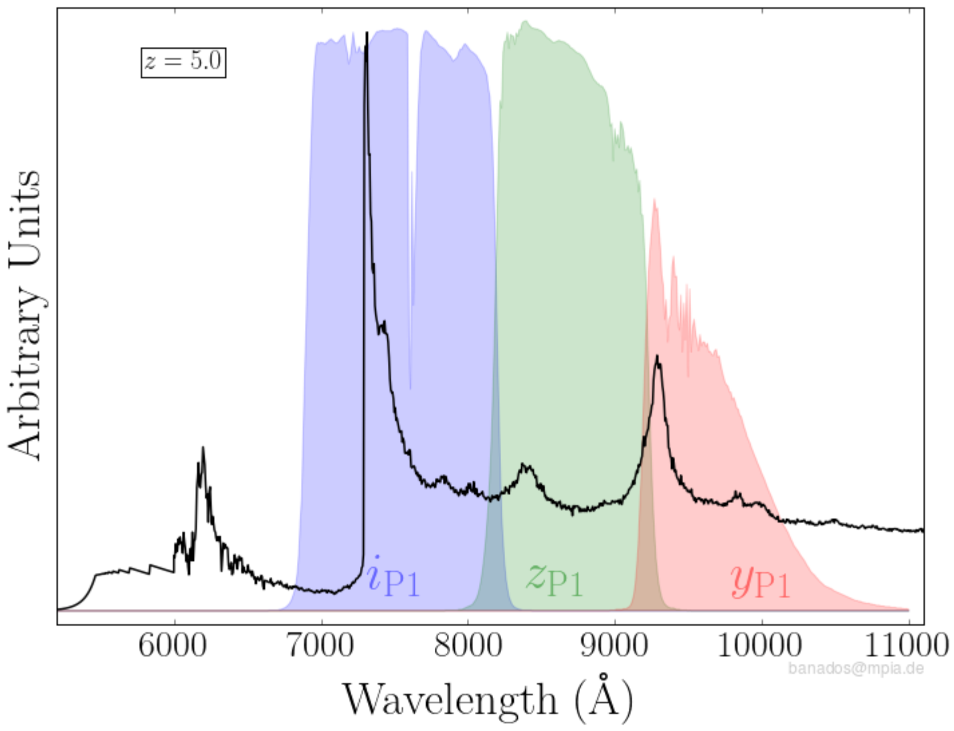
Outline

- Discovery and demographics
- SMBH → ~pc scales
- Galaxy / Close envs. → ~kpc scales
- Environments /IGM → ~Mpc scales
- (Obscured and jetted quasars/AGN?)

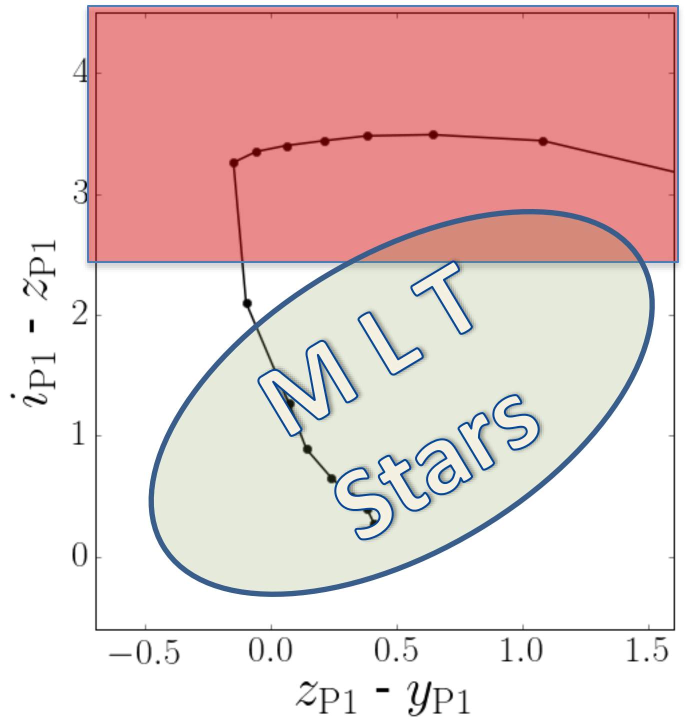


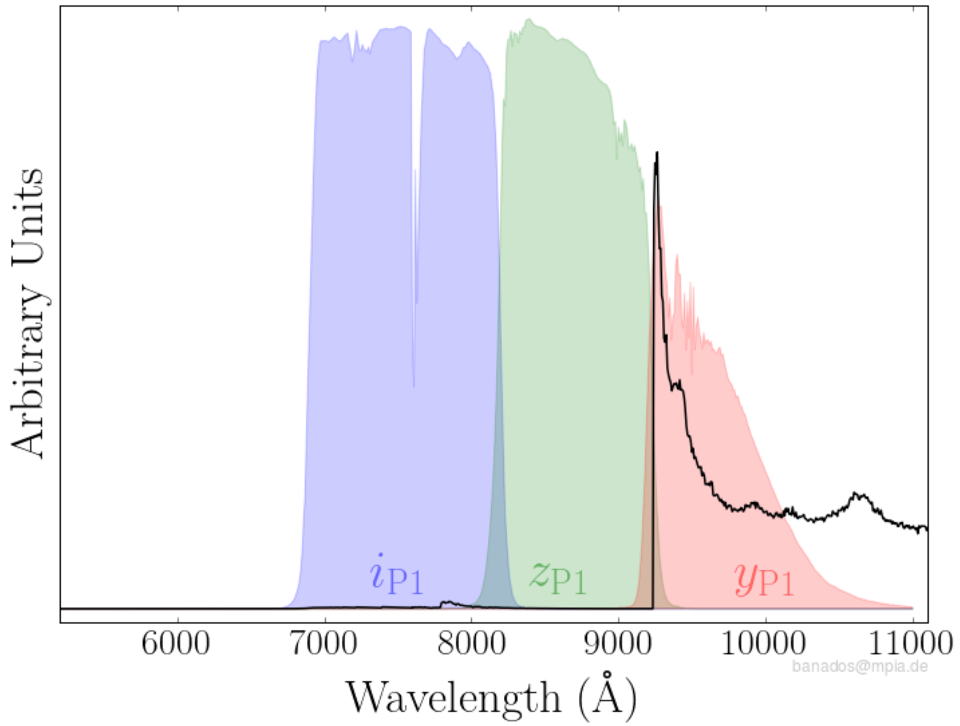
Quasar selection





Quasar selection





Finding the quasars in the haystack

Very **rare**

~<1 Gpc^{-3} at z=7

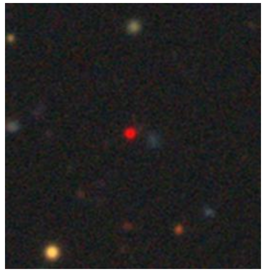
→ ~<1 per 100 deg^2

Schindler, Bañados+2023
Matsuoka+2023

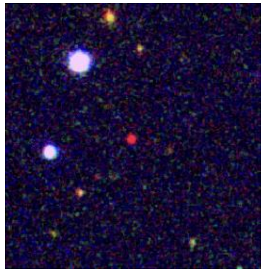
Overwhelming amount of contaminants

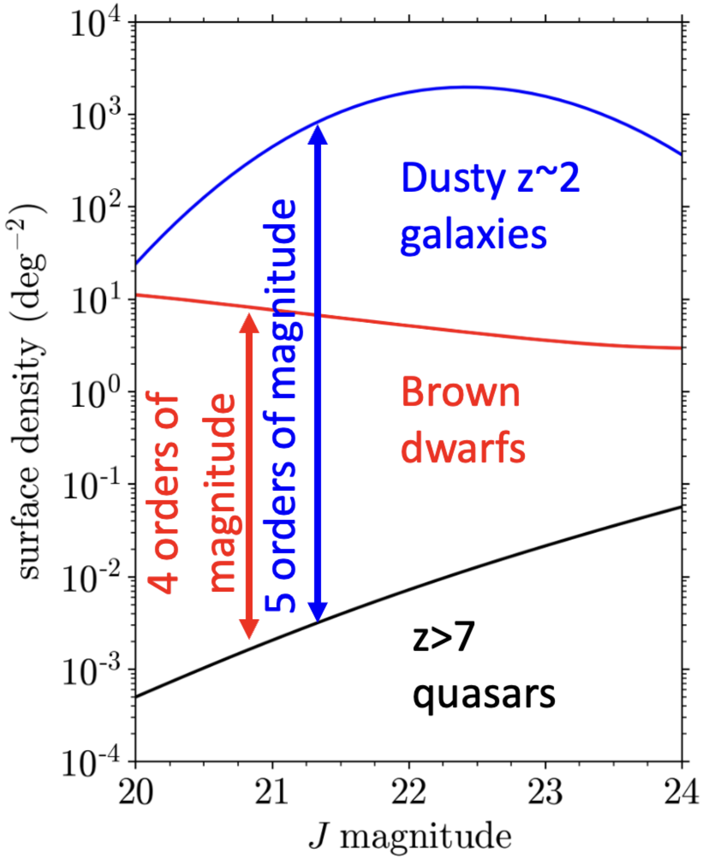
Dusty z~2 galaxy

T dwarf



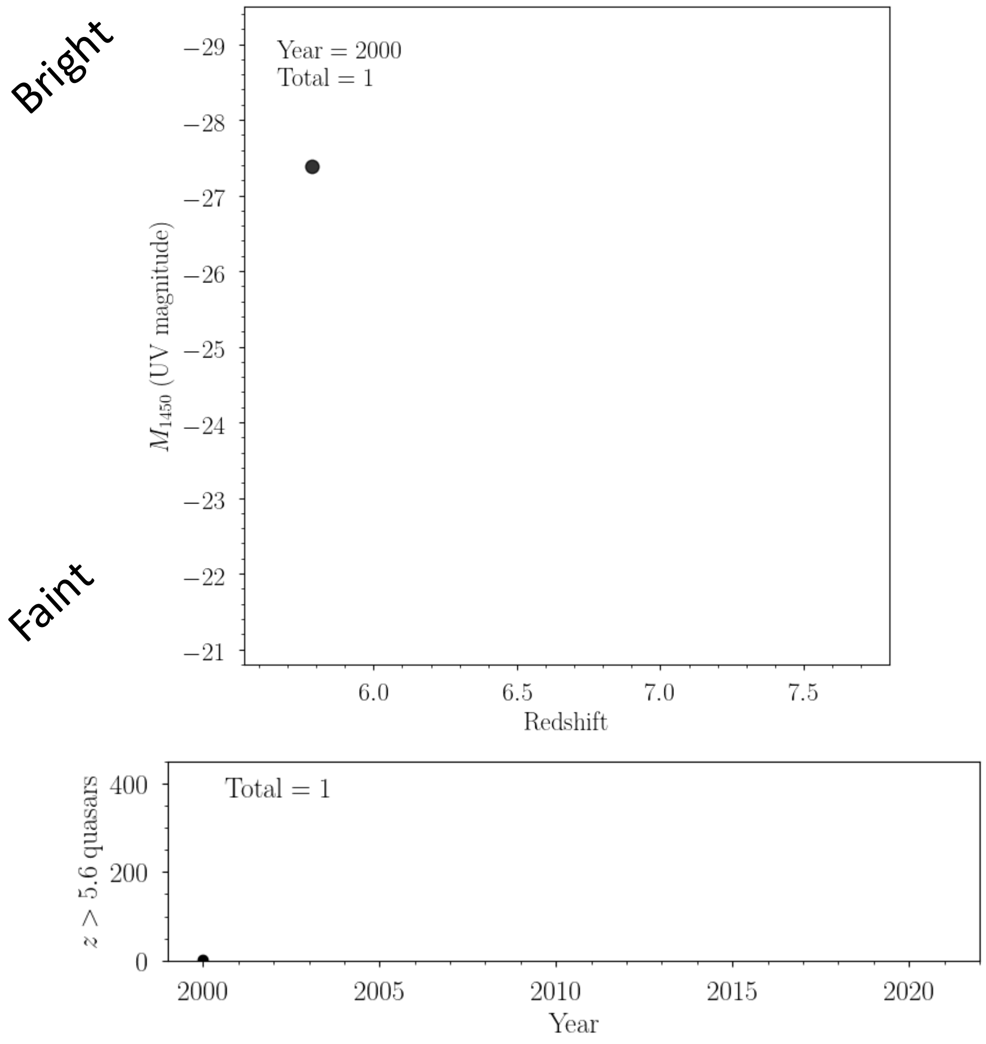
z=7.5 quasar





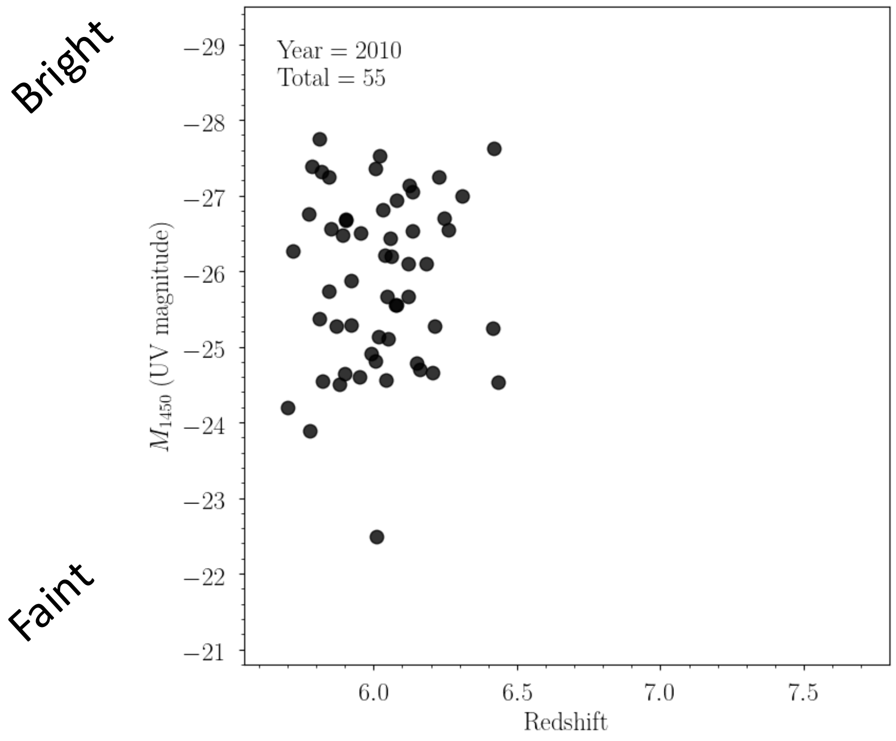
Euclid preparation V: Barnett+2019

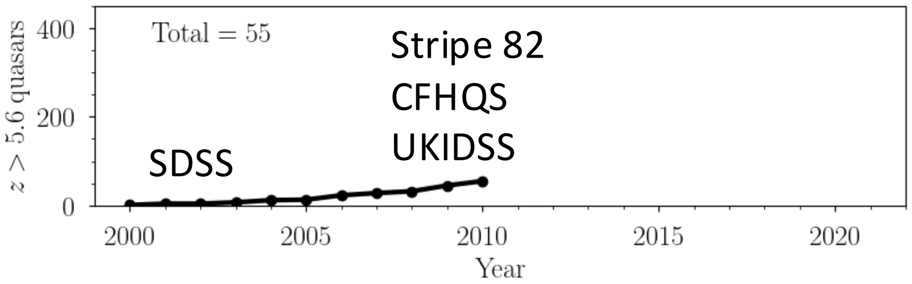
Finding the quasars in the haystack



Fan+2000

Finding the quasars in the haystack





Fan+ 2000-2006
Jiang+ 2008-2009
Willott+ 2007-2010

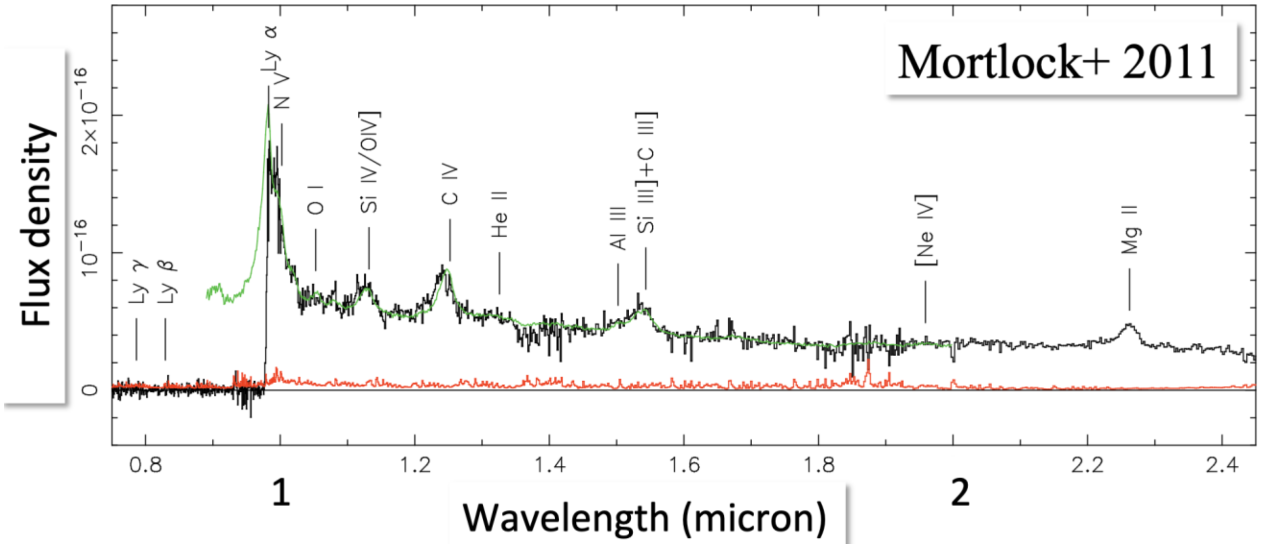
Finding the quasars in the haystack

LETTER

doi:10.1038/nature10159

A luminous quasar at a redshift of $z = 7.085$

Daniel J. Mortlock[1], Stephen J. Warren[1], Bram P. Venemans[2], Mitesh Patel[1], Paul C. Hewett[3], Richard G. McMahon[3], Chris Simpson[4], Tom Theuns[5,6], Eduardo A. Gonzáles-Solares[3], Andy Adamson[7], Simon Dye[8], Nigel C. Hambly[9], Paul Hirst[10], Mike J. Irwin[3], Ernst Kuiper[11], Andy Lawrence[9] & Huub J. A. Röttgering[11]



The search for quasars in the first Gyr

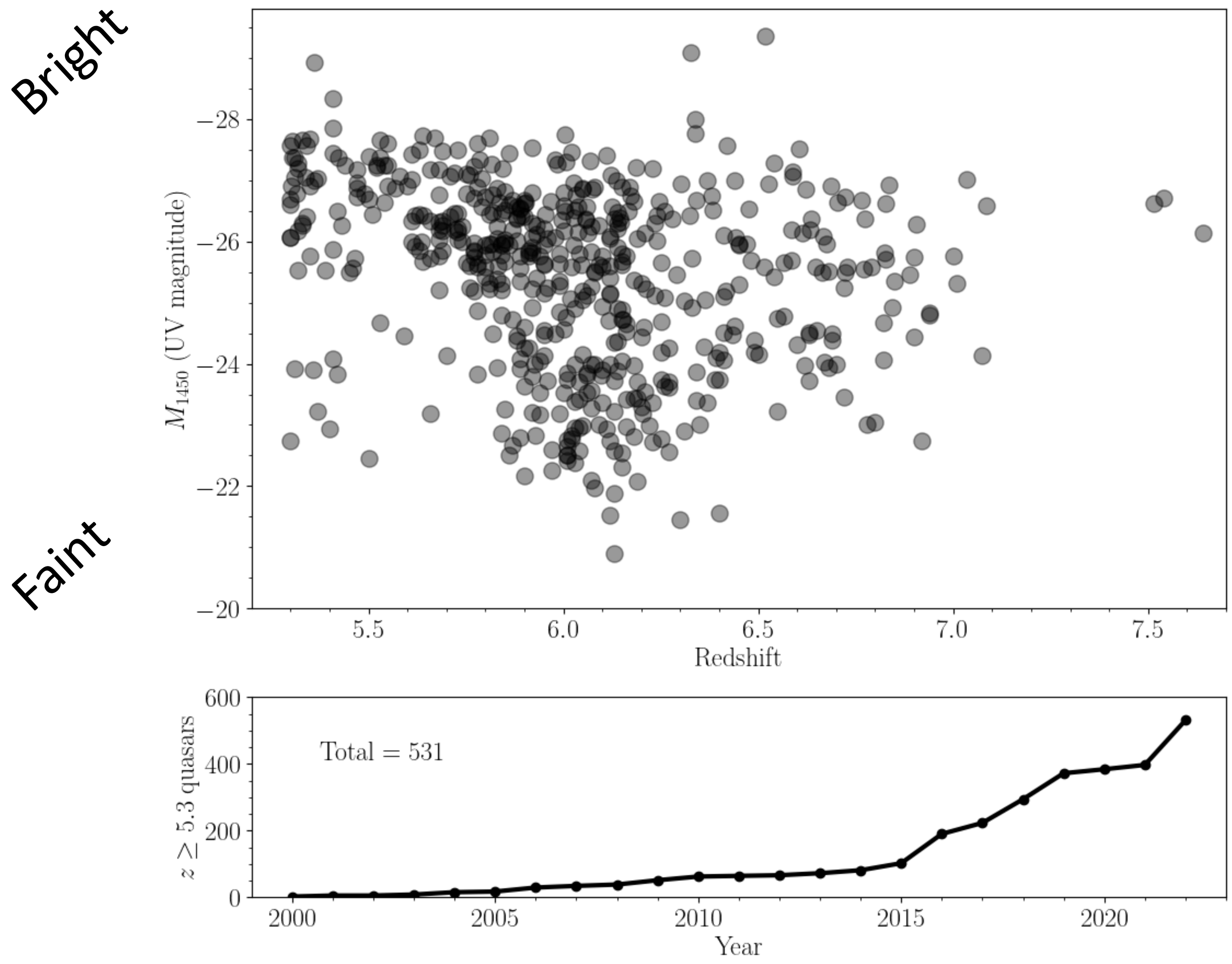


Fig. 1
Fan, Bañados, Simcoe 2023

The search for quasars in the first Gyr

Bright

Faint

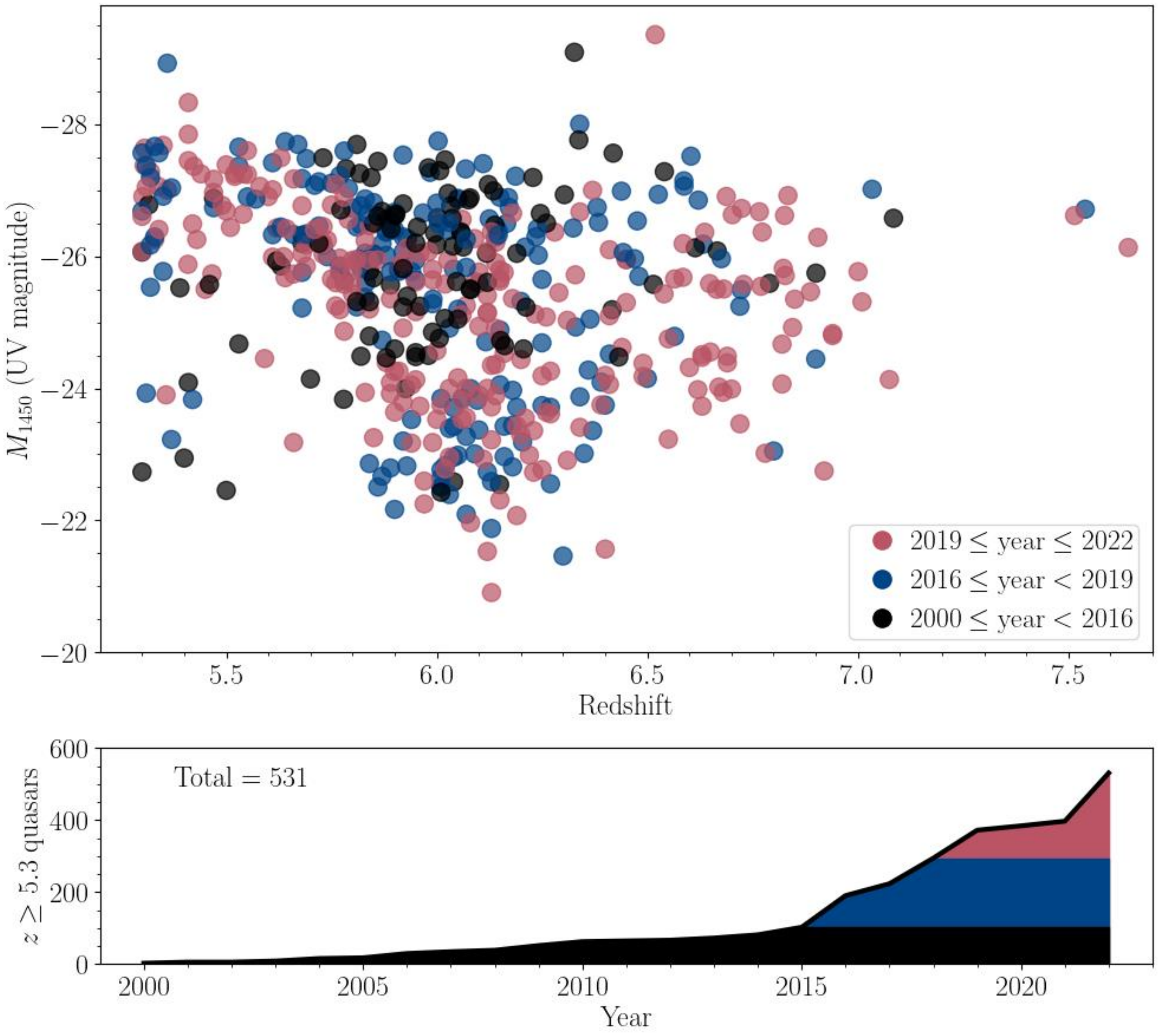


Fig. 1

Fan, Bañados, Simcoe 2023

The search for quasars in the first Gyr

Bright

Faint

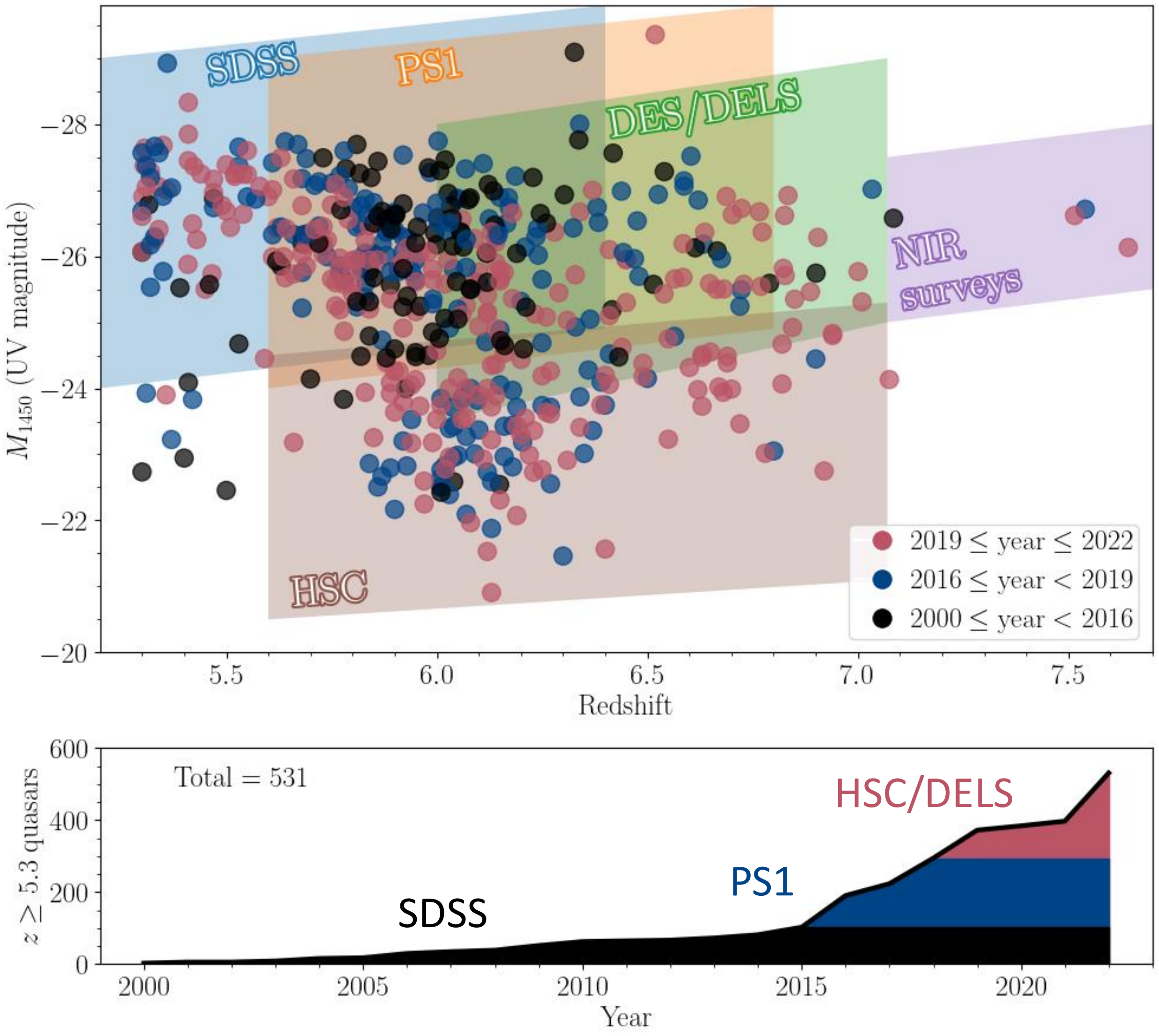
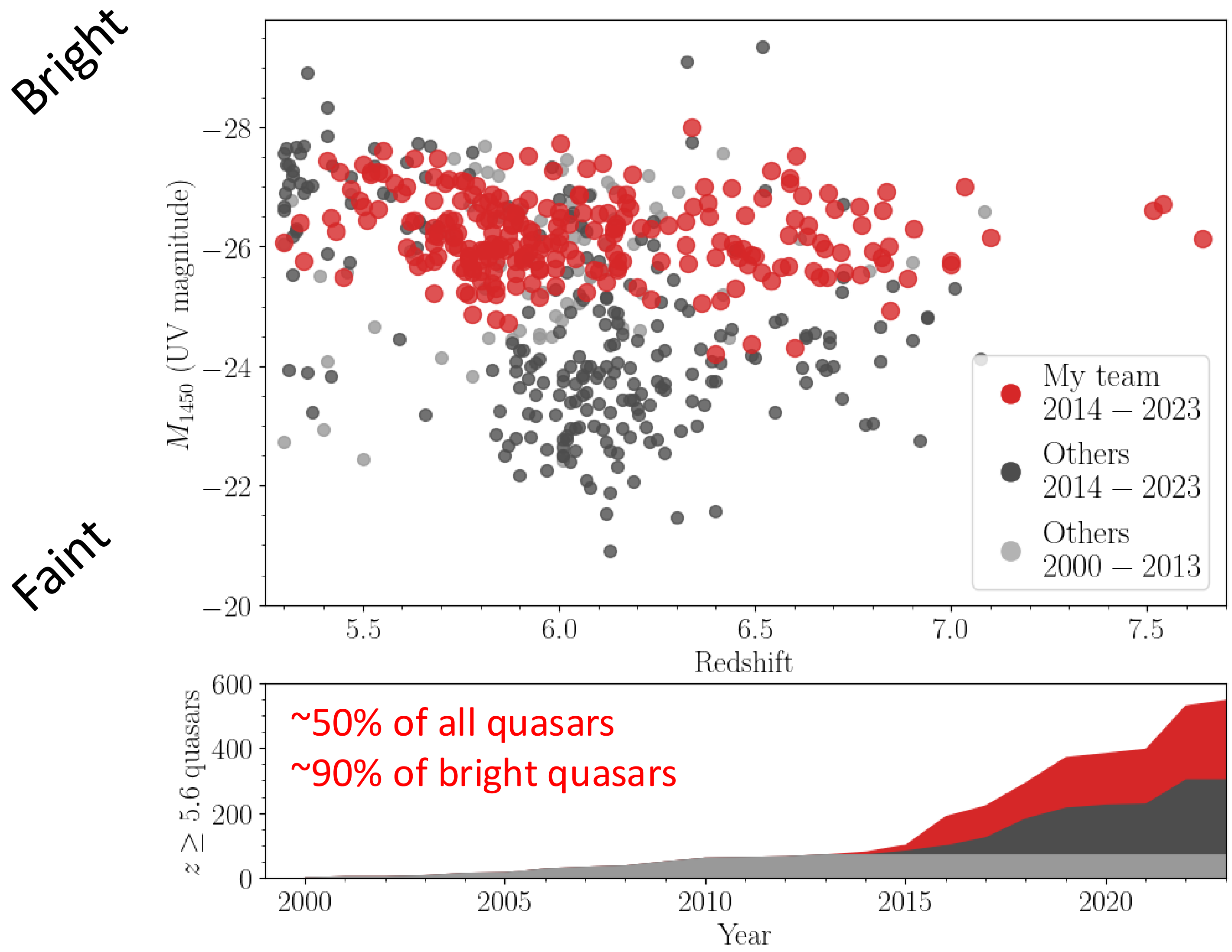


Fig. 1
Fan, Bañados, Simcoe 2023

The search for quasars in the first Gyr



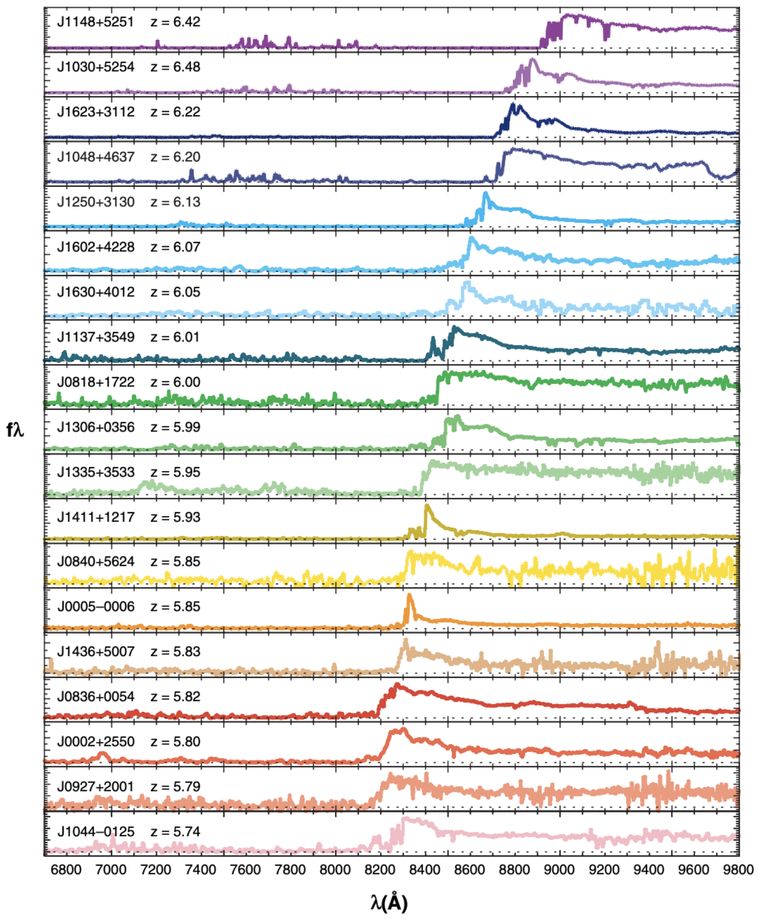
(Mostly)

Pan-STARRS1, DES, DECaLS

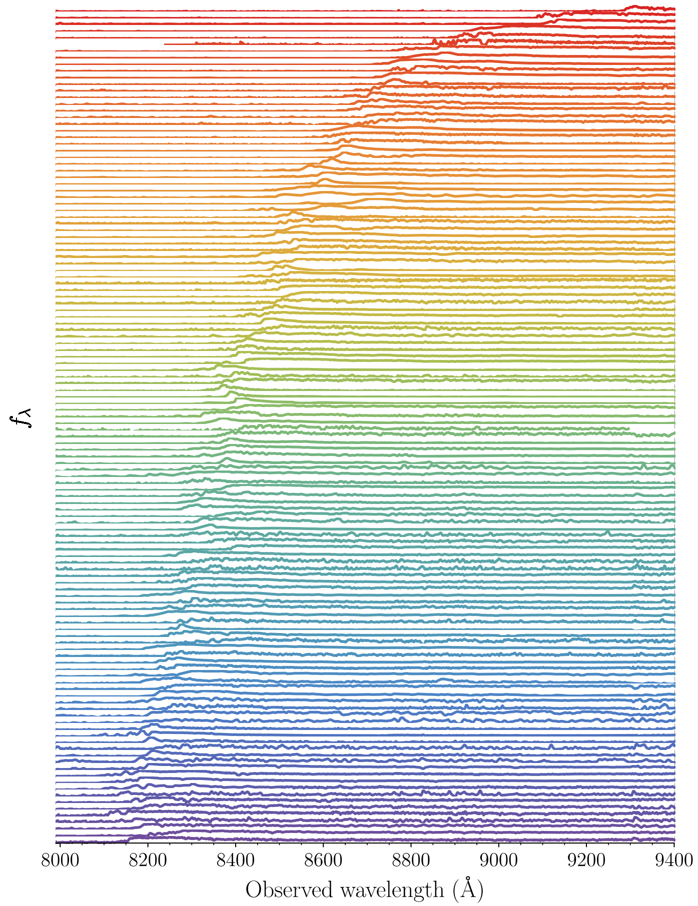
HSC

Reionization-era quasars

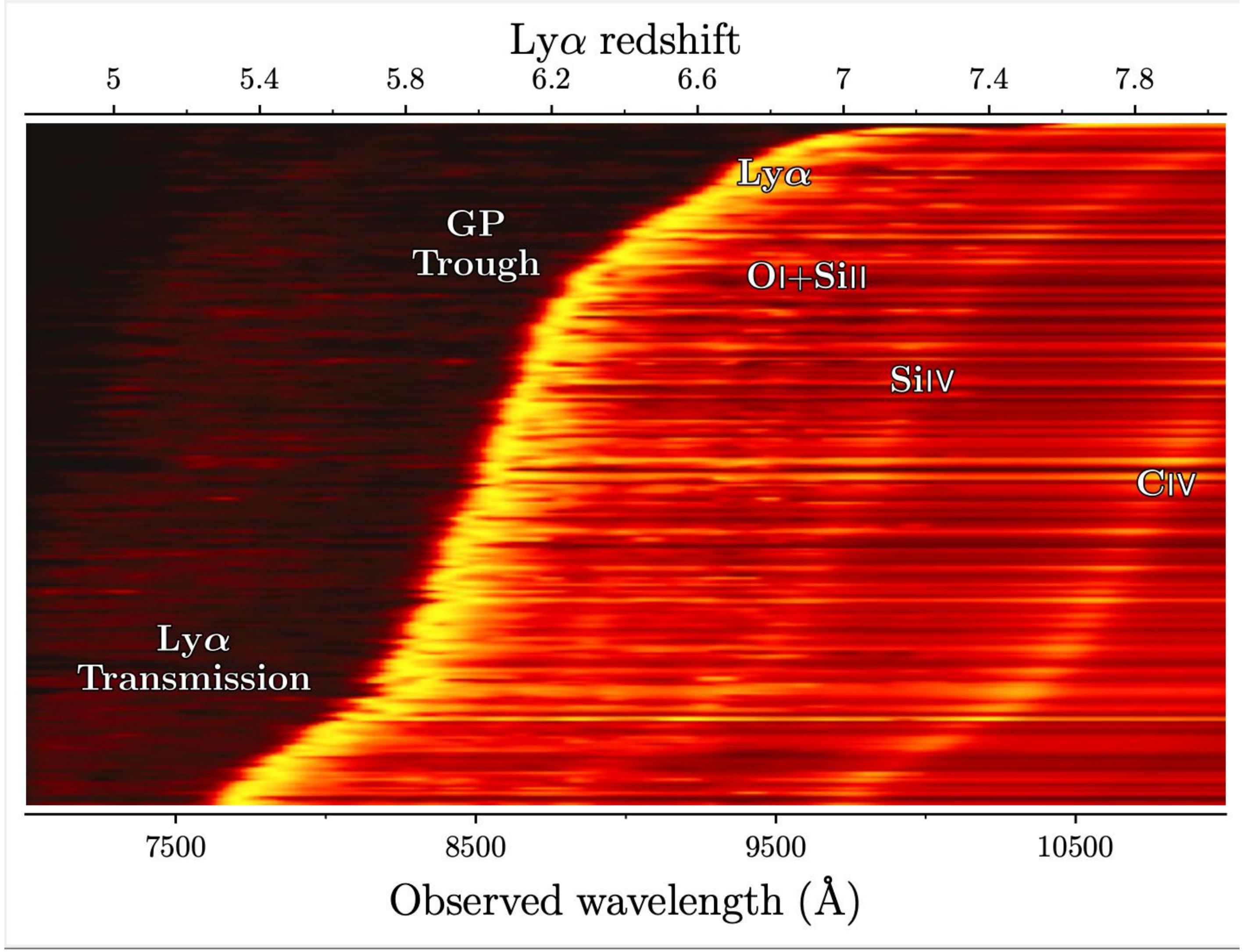
Fan+06 ARAA review



Fan+23 ARAA review [draft]



>500 Reionization-era quasars



~300 at z>6
8 at z>7
3 at z>7.5

Database with properties published with the review

Coordinates, redshifts, UV magnitudes, Black Hole Masses, references …

Fig. 3
Fan, Bañados, Simcoe 2023

Identifying and confirming quasars is not trivial

Identifying and confirming quasars is not trivial

Recent claim of a new z~7.5 quasar

Dense nitrogen-enriched circumnuclear region of the new high-redshift quasar ULAS J0816+2134 at $z = 7.46$

Ekaterina Koptelova[1] and Chorng-Yuan Hwang[1]

VIEW

Abstract

Citations (3)

References (99)

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Dense nitrogen-enriched circumnuclear region of the new high-redshift quasar ULAS J0816+2134 at z=7.46

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Maiolino, Roberto; Scholtz, Jan; Witstok, Joris *and 36 more*

2 2023ApJ...954..210A 2023/09

Subaru High-z Exploration of Low-luminosity Quasars (SHELLQs). XVIII. The Dark Matter Halo Mass of Quasars at z 6

Arita, Junya; Kashikawa, Nobunari; Matsuoka, Yoshiki *and 10 more*

3 2023RNAAS...7...72B 2023/04

On the Discovery Claim of a New z > 7 Quasar

Bosman, Sarah E. I.; Davies, Frederick B.; Bañados, Eduardo

Identifying and confirming quasars is not trivial

Recent claim of a new z~7.5 quasar

RNAAS RESEARCH NOTES OF THE AAS

OPEN ACCESS

On the Discovery Claim of a New $z > 7$ Quasar

Sarah E. I. Bosman[1], Frederick B. Davies[1], and Eduardo Bañados[1]

Published April 2023 •
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Citation Sarah E. I. Bosman *et al* 2023 *Res. Notes AAS* **7** 72

DOI 10.3847/2515-5172/accb5b

Figures ▾ References ▾

+ Article and author information

Abstract

Koptelova & Hwang (K22) recently claimed a new quasar discovery at $z = 7.46$. After careful consideration of the publicly available data underlying K22's claim, we find that the observations were contaminated by a moving solar system object, likely a main-belt asteroid. In the absence of the contaminated photometry, there is no evidence for the nearby, persistent WISE source being a high-redshift object; in fact, a detection of the source in DESI Legacy Imaging Surveys z-band rules out a redshift $z > 7.3$. We present our findings as a cautionary tale of the dangers of passing asteroids for photometric selections.

the new high-redshift quasar ULAS J0816+2134 at 7.46

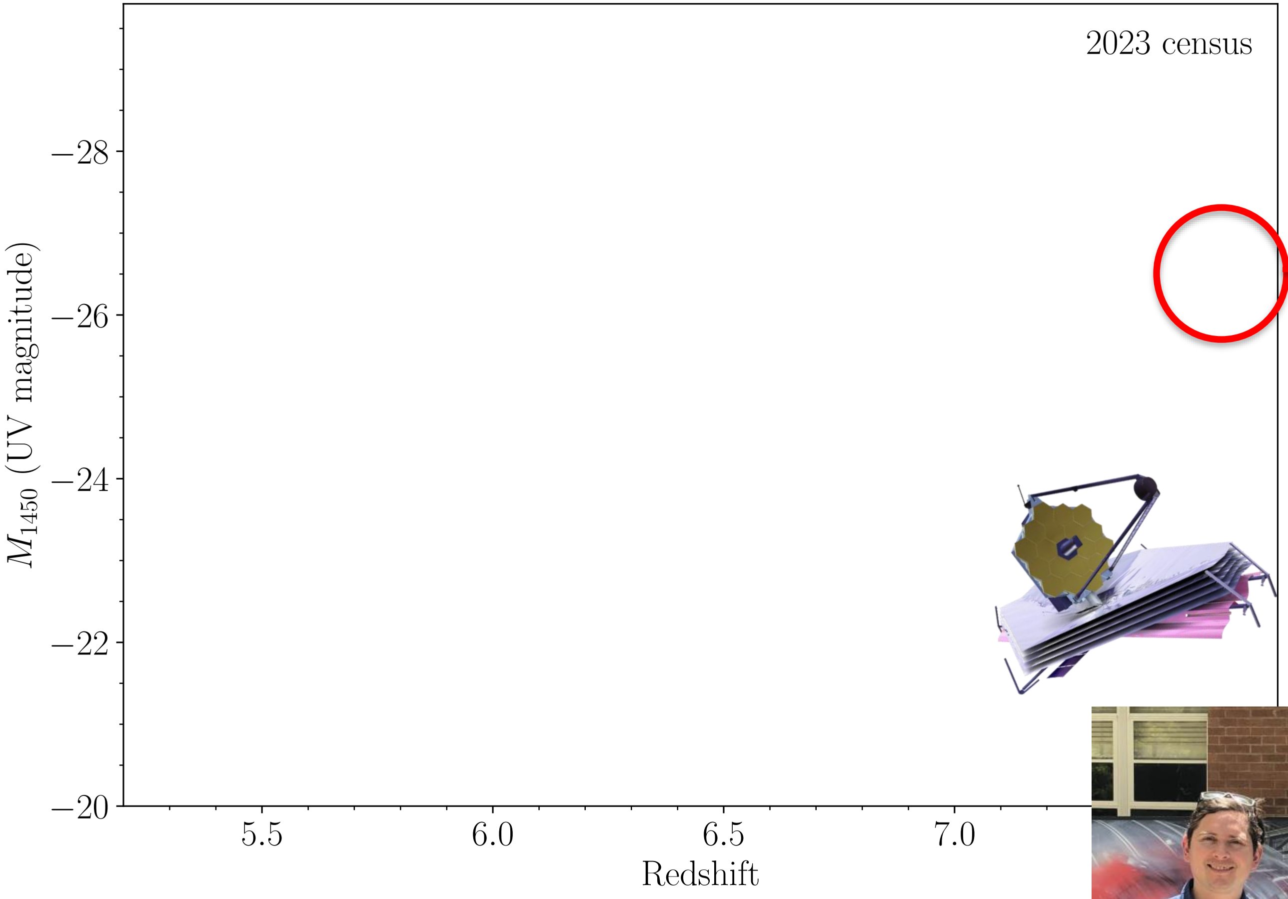
ND CHORNG-YUAN HWANG[1]

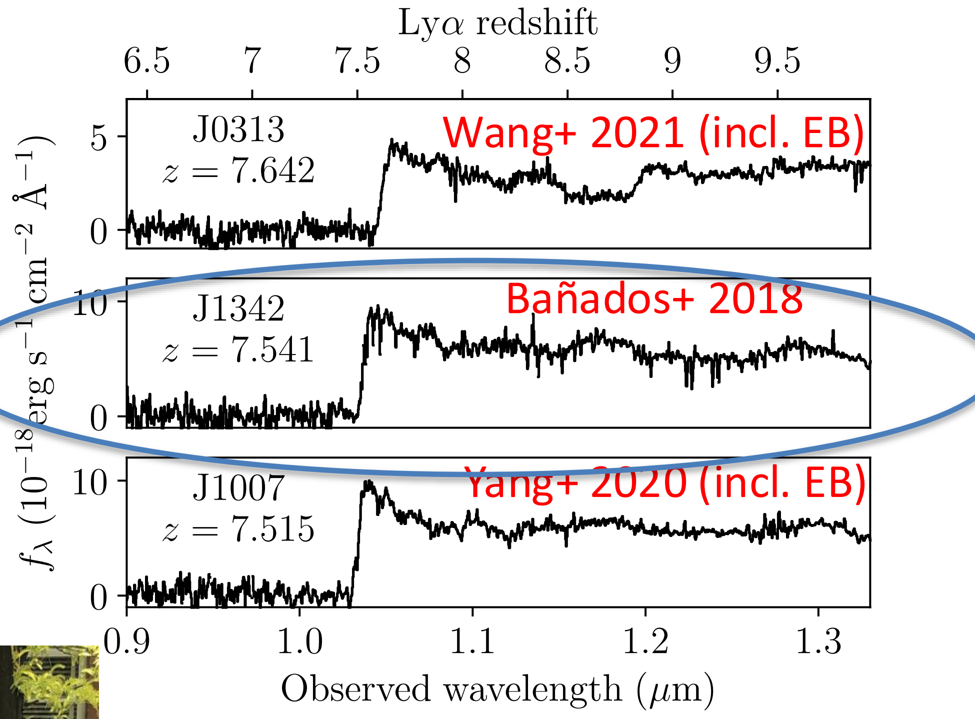
It's an asteroid!

(#43838) 1993 FW49

Bosman, Davies & Bañados 2023

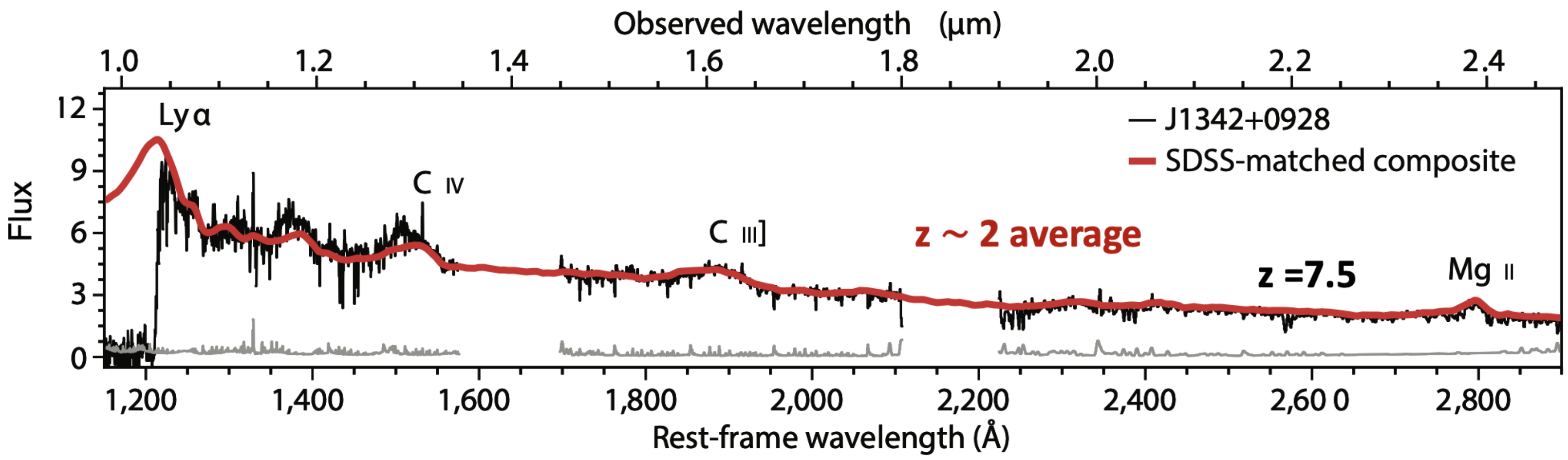
Quasars at the reionization frontier



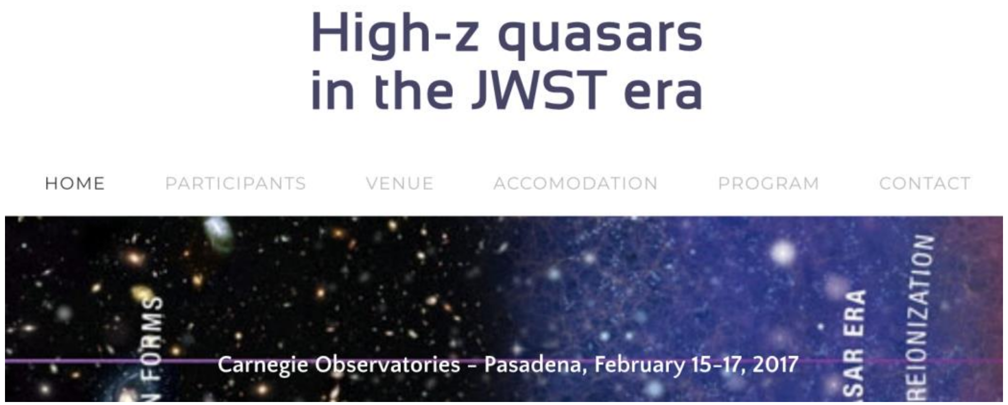


What does it take to make a Pisco Sour?

Credits: M. Novak



What does it take to make a Pisco Sour?



The most distant quasars

Where we are and where we are going

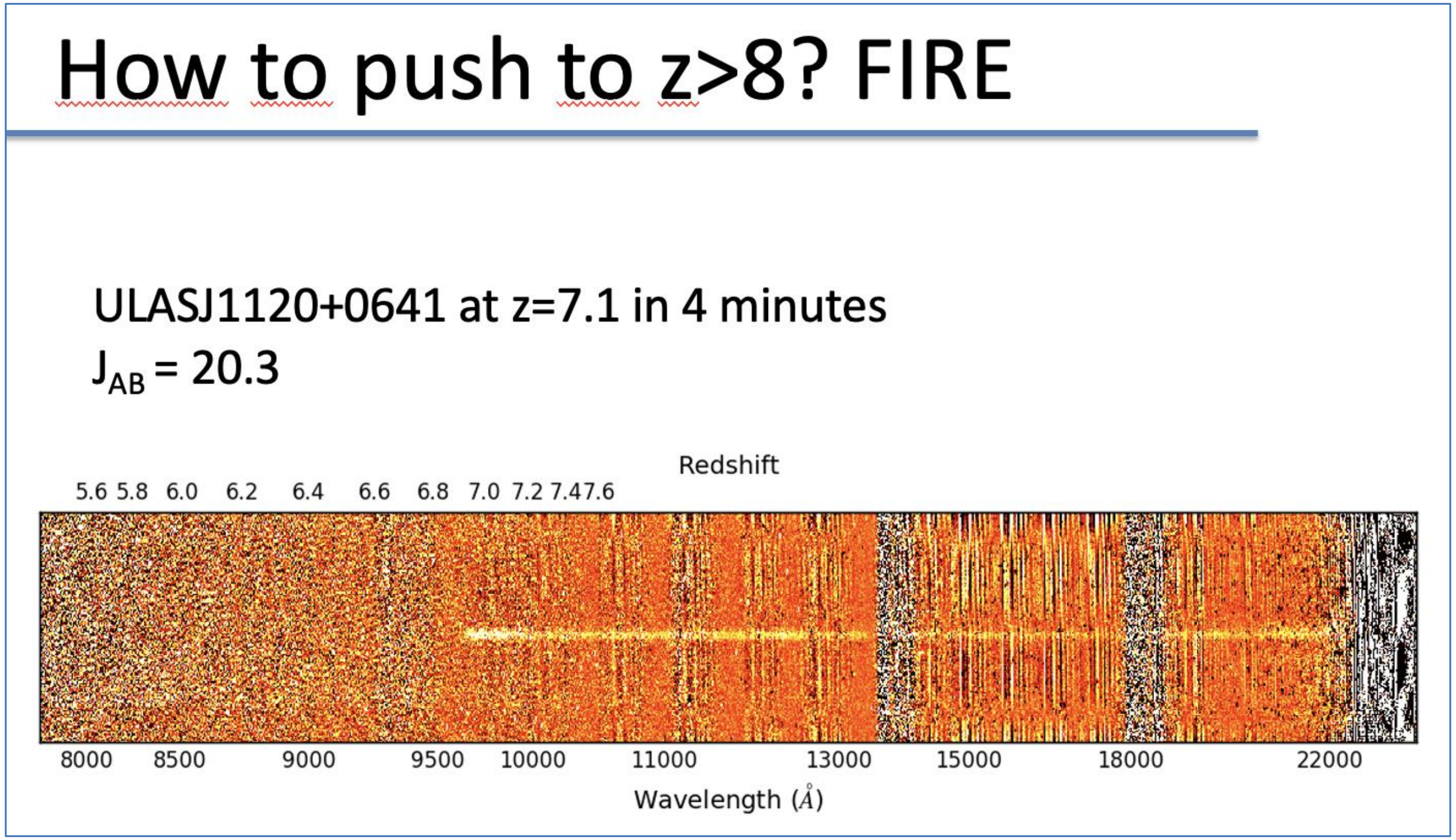
Eduardo Bañados

Carnegie-Princeton Fellow

Feb 15, 2017

What does it take to make a Pisco Sour?

In 2016 … testing Magellan telescope capabilities



What does it take to make a Pisco Sour?

How to push to z>8? FIRE

Semester: 2017a
Investigator: Eduardo Banados
Department: CIW
Email: ebanados@carnegiescience.edu
Telephone: 626 3040 236

Project No. 1: The Carnegie search for the first QSOs: pushing the redshift barrier
Priority: 1
Co-Investigators: Bram Venemans (MPIA), Fabian Walter (MPIA), Chiara Mazzucchelli (MPIA)

Observing Runs:

No.	Blocks	Nights	Max Moon	Telescope	Instr. One	Instr. Two	Service	Observers
1	2017_D02 (2017_D02-2017_D03)	2	|8|	Baade	FIRE	FourStar	No	Eduardo Banados
2	2017_D04 (2017_D04-2017_D05)	2	|8|	Baade	FIRE	FourStar	No	Eduardo Banados

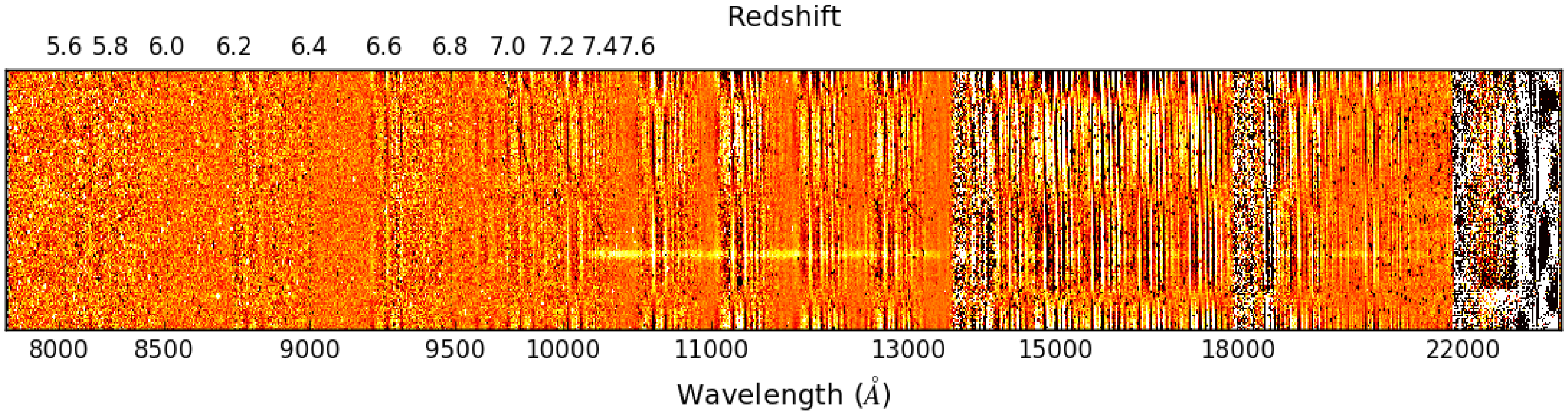
The PI has discussed these projects with the following TAC members: Dr. John Mulchaey and Dr. Gwen Rudie.

Who wants to observe with me?

(observations in ~1 month)

What does it take to make a Pisco Sour?

~5 am of the last night … a new redshift-record was born …



What does it take to make a Pisco Sour?

Eduardo Banados March 10, 2017 at 3:22 AM

To: Fabian Walter, Venemans Bram, Roberto Decarli, Chiara Mazzucchelli, Xiaohui Fan, Feige Wang, and 2 more...

pisco sour quasar

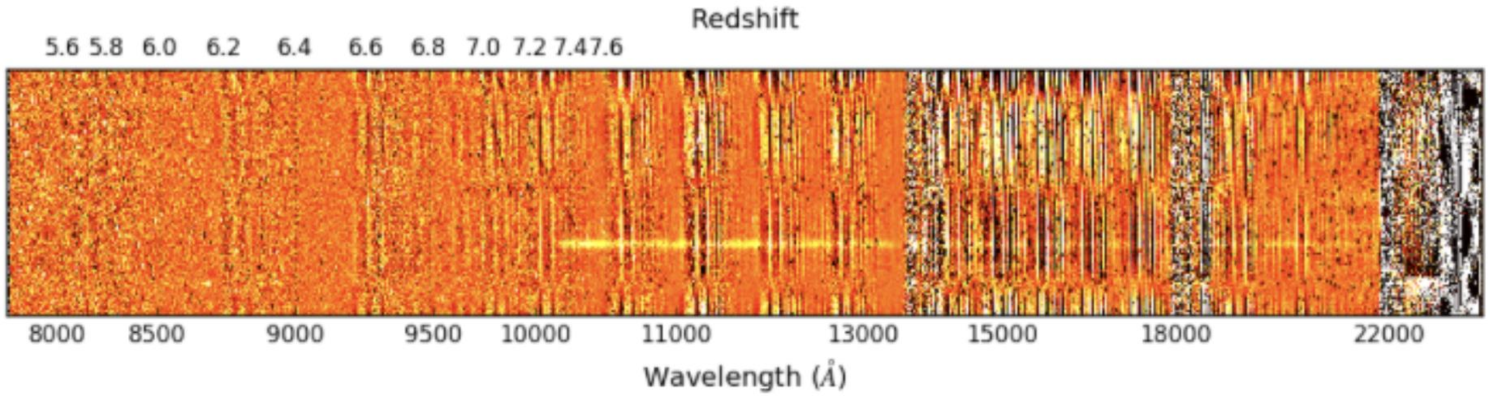
Dear all,

We are concluding the last night at Magellan. We observed more than 100 objects and we are happy to tell you that we have a winner! See attached the 'pisco sour' z>7.2 quasar.

Now is pisco sour time.

Cheers,

Eduardo & Dan



Slide from Xiaohui Fan

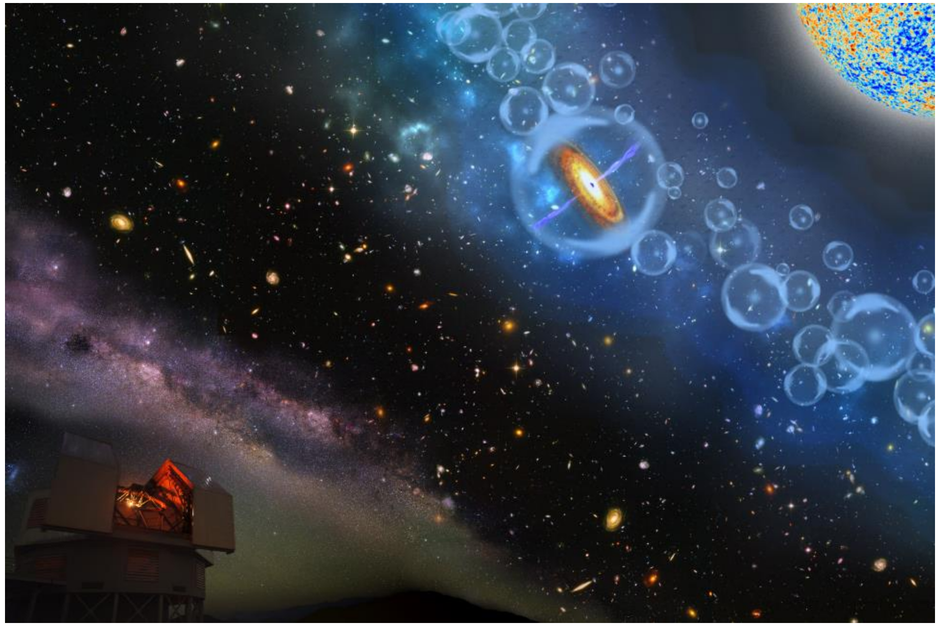
Pisco sour time

Wikipedia page in <1 hour

ULAS J1342+0928

From Wikipedia, the free encyclopedia

ULAS J1342+0928 is the most distant known quasar detected and contains the most distant supermassive black hole,[1][5][6][7] at a reported redshift of z = 7.54, surpassing the redshift of 7 for the previously known most distant quasar ULAS J1120+0641.[1] The ULAS J1342+0928 quasar is 13.1 billion light-years away from Earth[5][8] in the Boötes constellation.[3] The related supermassive black hole is reported to be "800 million times the mass of the sun".[5]



I never said this

Dawn of time? Oldest monster black hole ever found could 'prove Big Bang NEVER happened'

A SUPERMASSIVE black hole has left scientists questioning beginning of life.

Share Tweet 22

By **Jamie Micklethwaite** / Published 7th December 2017

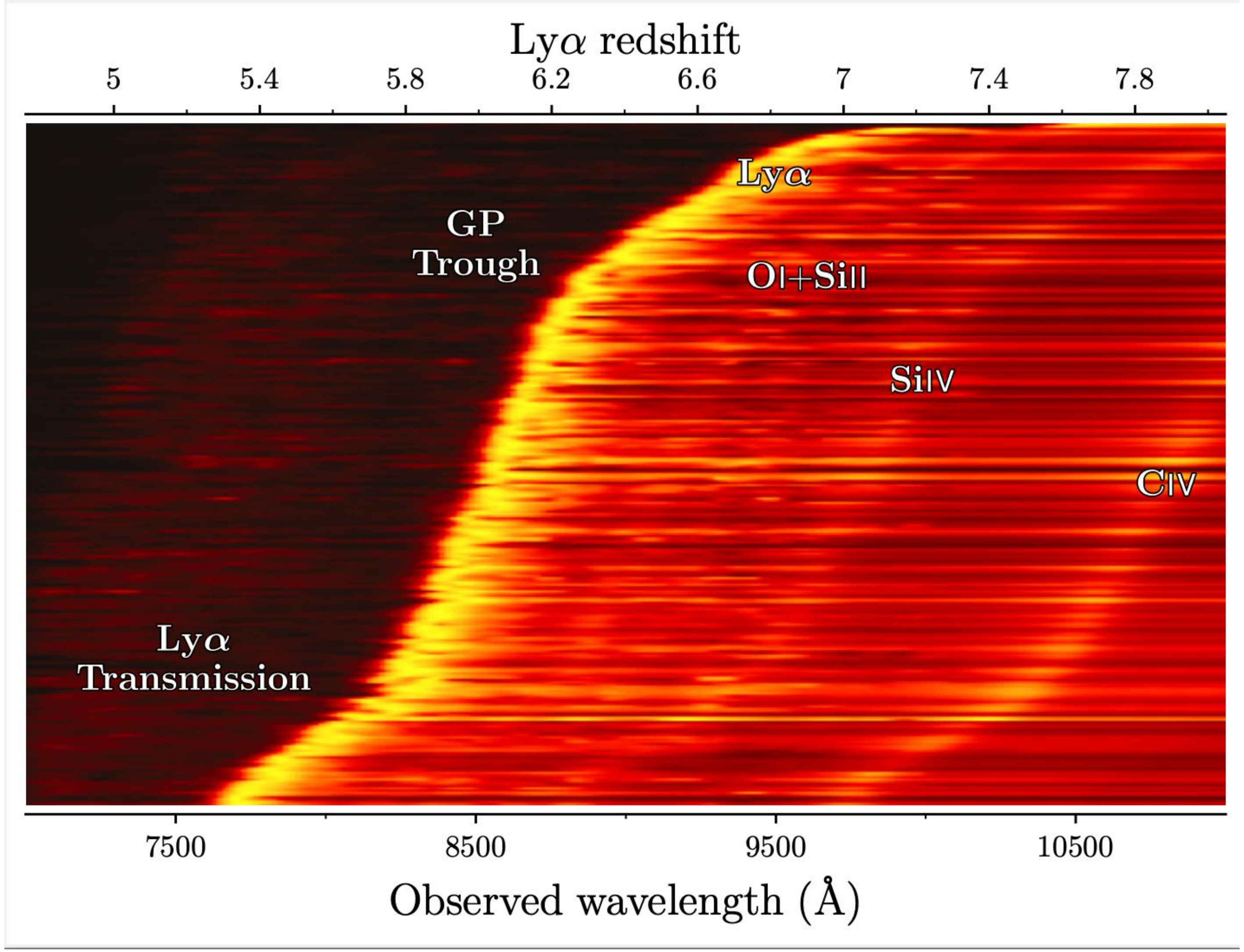
Big Bang theory wrong: Black hole found that's so big and old it makes Big Bang IMPOSSIBLE

ASTRONOMERS have spotted a black hole that is almost as old as the universe itself, putting a huge question mark over the Big Bang theory.

By SEAN MARTIN
PUBLISHED: 11:07, Mon, Dec 11, 2017 | UPDATED: 11:30, Mon, Dec 11, 2017

SHARE TWEET 99

>500 Reionization-era quasars



~300 at z>6

8 at z>7

3 at z>7.5

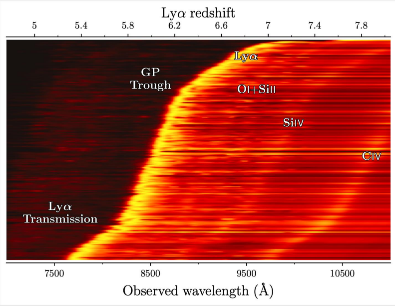
Database with properties published with the review

Coordinates, redshifts, UV magnitudes, Black Hole Masses, references …

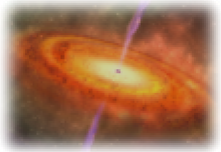
Fig. 3

Fan, Bañados, Simcoe 2023

Outline

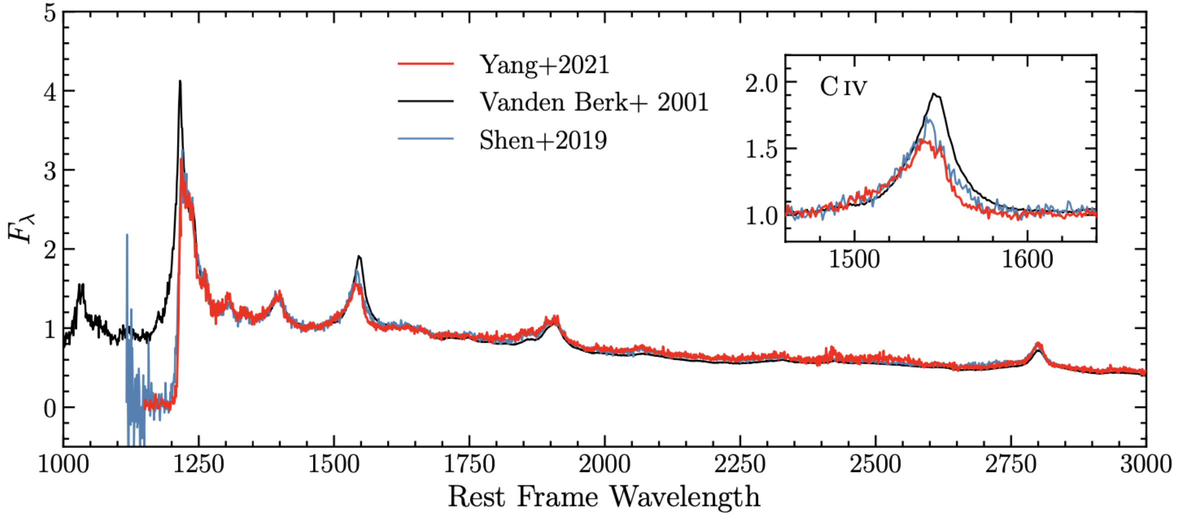


- Discovery and demographics

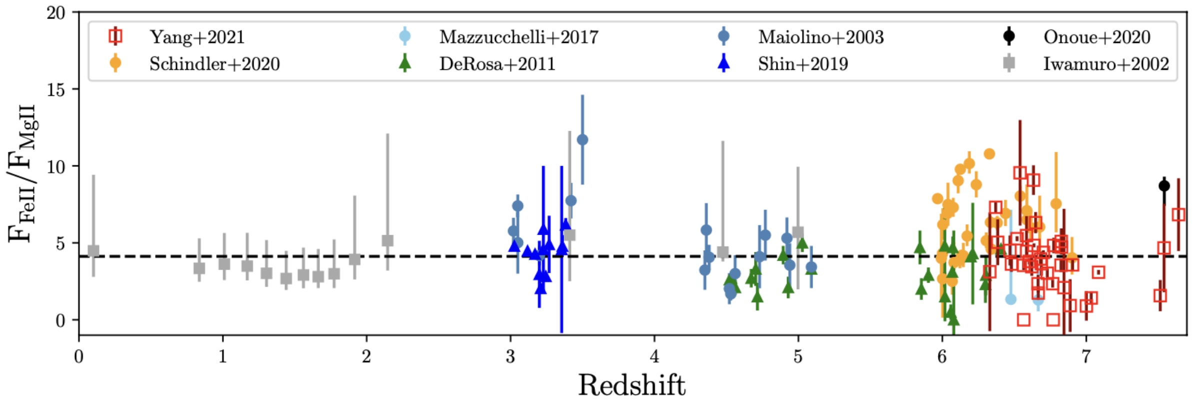


- **SMBH → ~pc scales**
- Galaxy / Close envs. → ~kpc scales
- Environments /IGM → ~Mpc scales

Quasars look the same across cosmic time



Composite spectra at z~2, z~6, and z~6.6

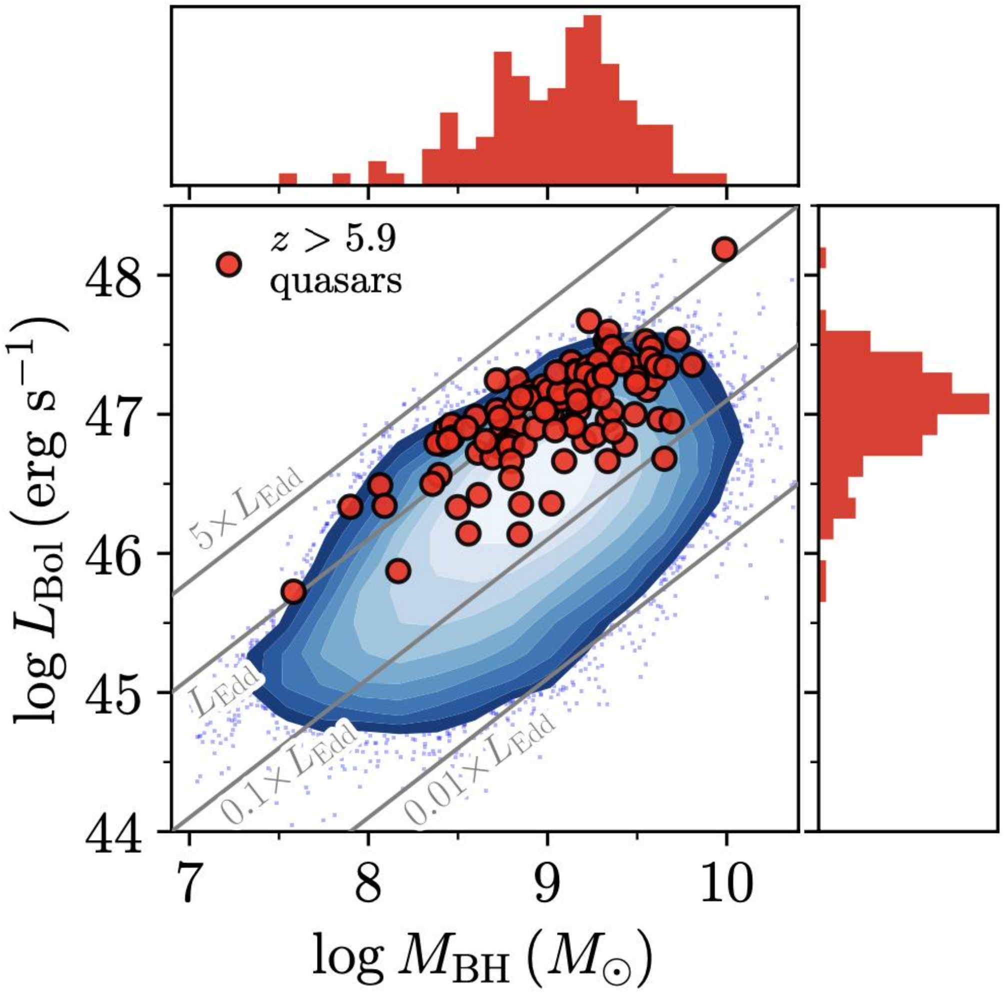


No evolution of the Broad Line Region metal enrichment up to z~7.5

Fig. 5
Fan, Bañados, Simcoe 2023
Adapted from Yang+2021

*See also Schindler+2020 (incl. EB), Onoue, Bañados+2020

The growth of supermassive black holes

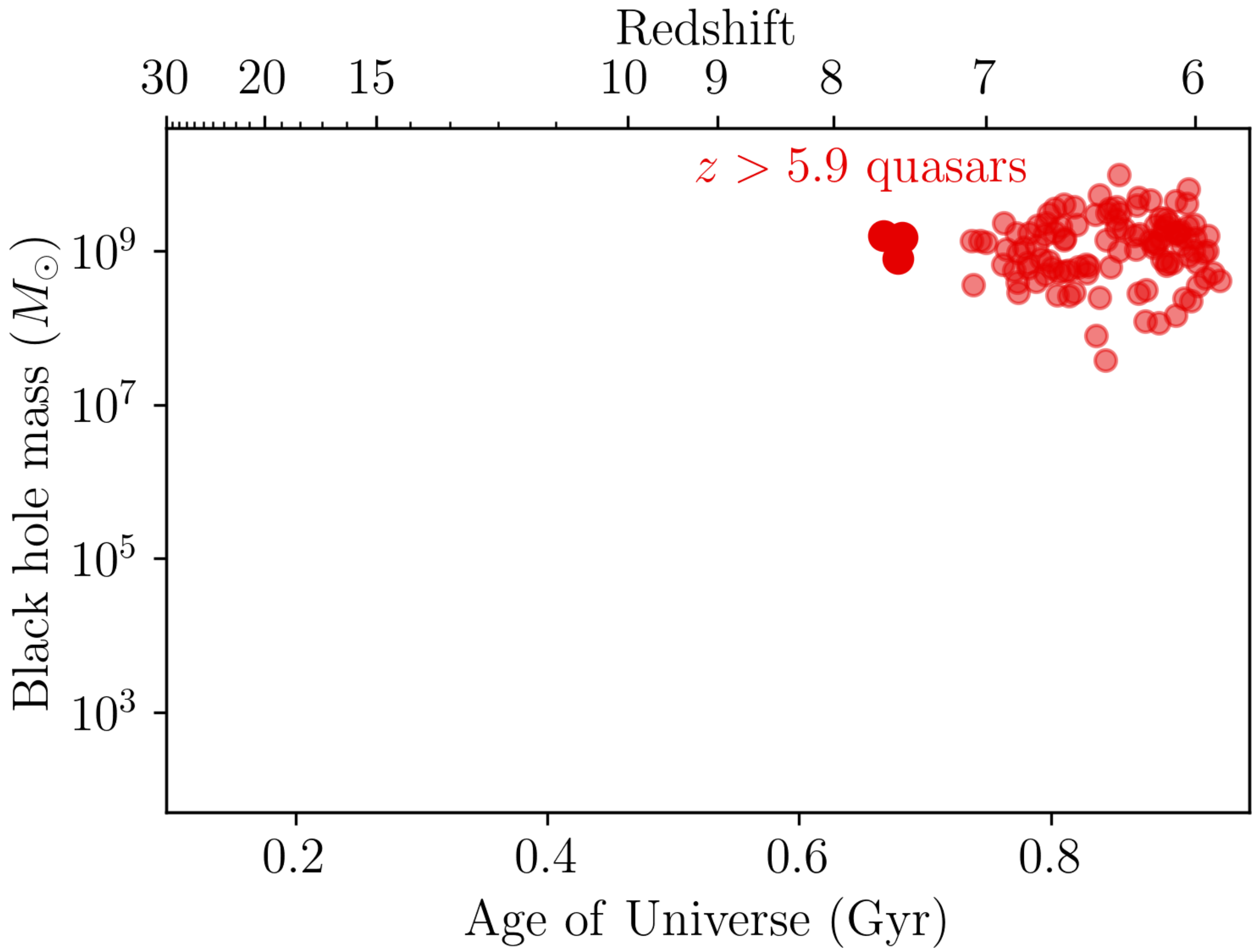


All MgII-based black hole mass measurements at z>5.9

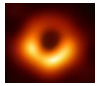
Eddington ratios 0.08 – 2.70
Mean: 0.92
Median: 0.79

Fig. 6
Fan, Bañados, Simcoe 2023

What were the “seeds” of supermassive black holes?



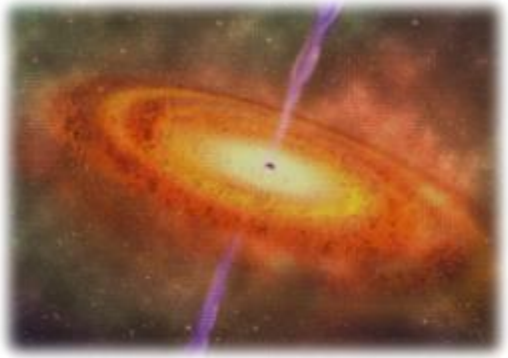
…
0
…
13.7



M87

Fig 7.
Fan, Bañados, Simcoe 2023

Mass growth of a black hole



HOMEWORK:
Derive the following equation:

$$M_{\rm BH}(t) = M_{\rm BH,seed} \times \exp\left[(1-\epsilon_r)\lambda_{\rm Edd}\frac{t}{t_{\rm Sal}}\right], \qquad 7.$$

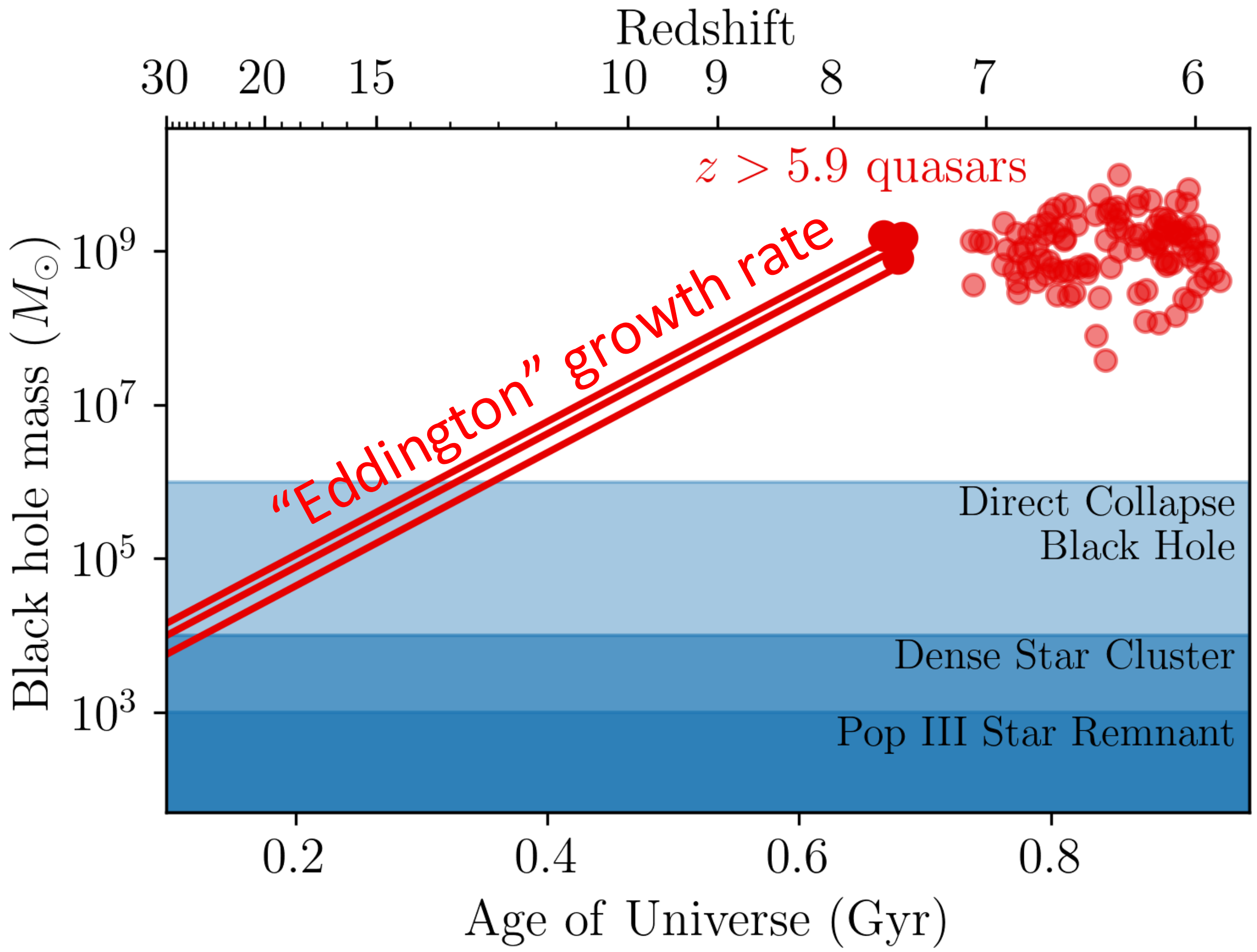
where ϵ_r is the radiative efficiency, which is the efficiency of converting mass to energy, and the Salpeter time is defined as

$$t_{\rm Sal} = \frac{\epsilon_r \sigma_{\rm T} c}{4\pi G m_{\rm p}} \approx \epsilon_r\, 450\,{\rm Myr}. \qquad 8.$$

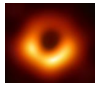
Assuming $\lambda_{\rm Edd} = 1$ and $\epsilon_r = 0.1$, Equation 7 is equal to

$$M_{\rm BH}(t) = M_{\rm BH,seed} \times \exp\left[\frac{t}{50\,{\rm Myr}}\right]. \qquad 9.$$

What were the “seeds” of supermassive black holes?



… 0



M87

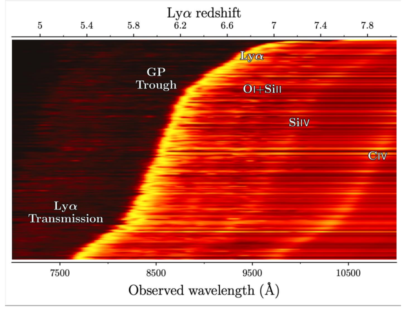
Seed formation models

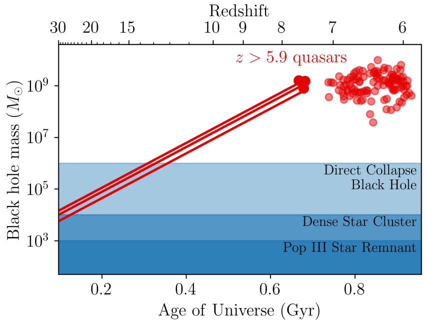
… 13.7

Fig 7.
Fan, Bañados, Simcoe 2023

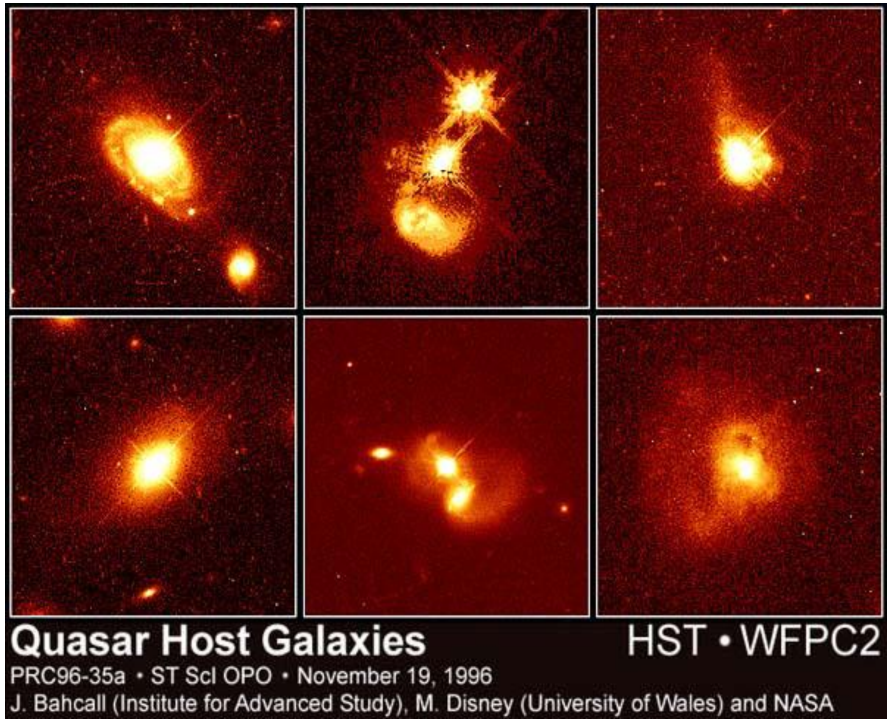
Outline

- Discovery and demographics
- SMBH → ~pc scales
- Galaxy / Close envs. → ~kpc scales
- Environments /IGM → ~Mpc scales

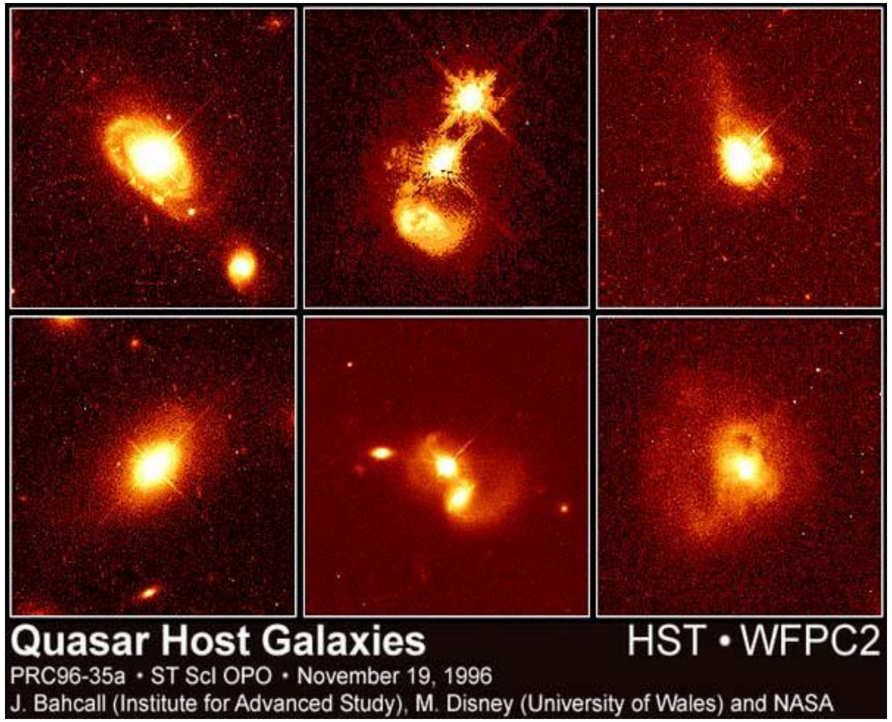




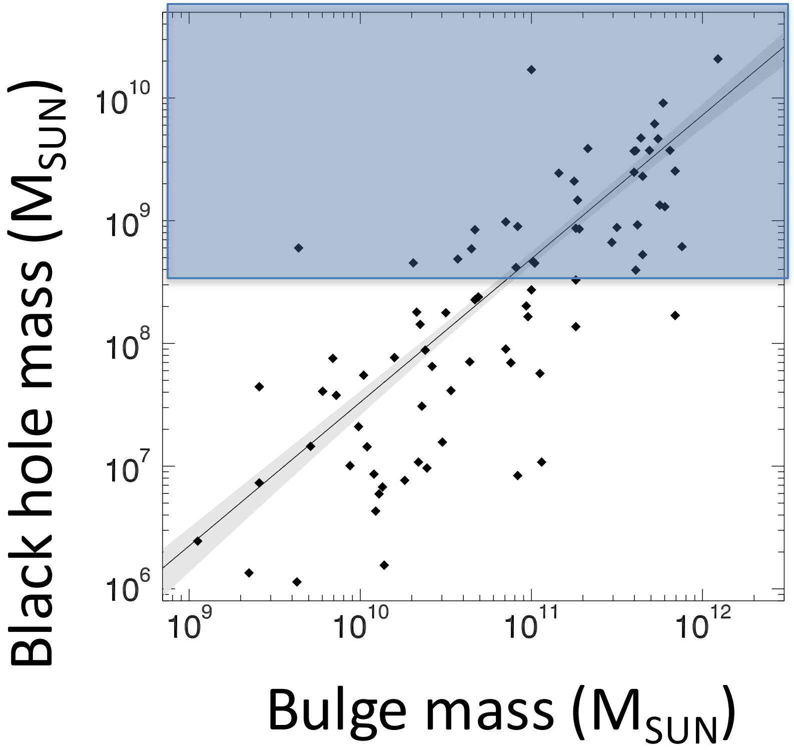
Quasar as a phase of a galaxy



Quasar as a phase of a galaxy



Local black hole – bulge mass relation

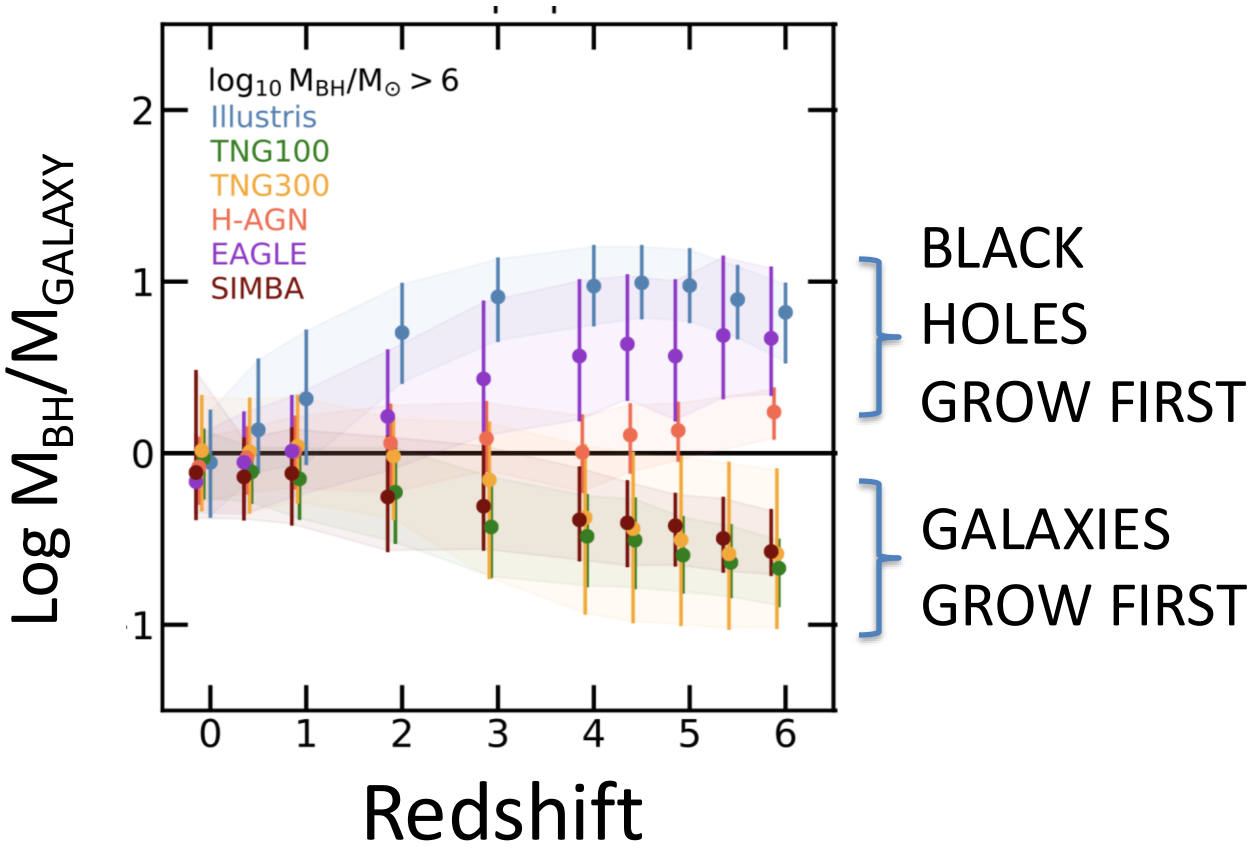


Häring & Rix 2004
Kormendy & Ho 2013

What came first, black holes or galaxies?

Observational test: In which galaxies do black holes live?

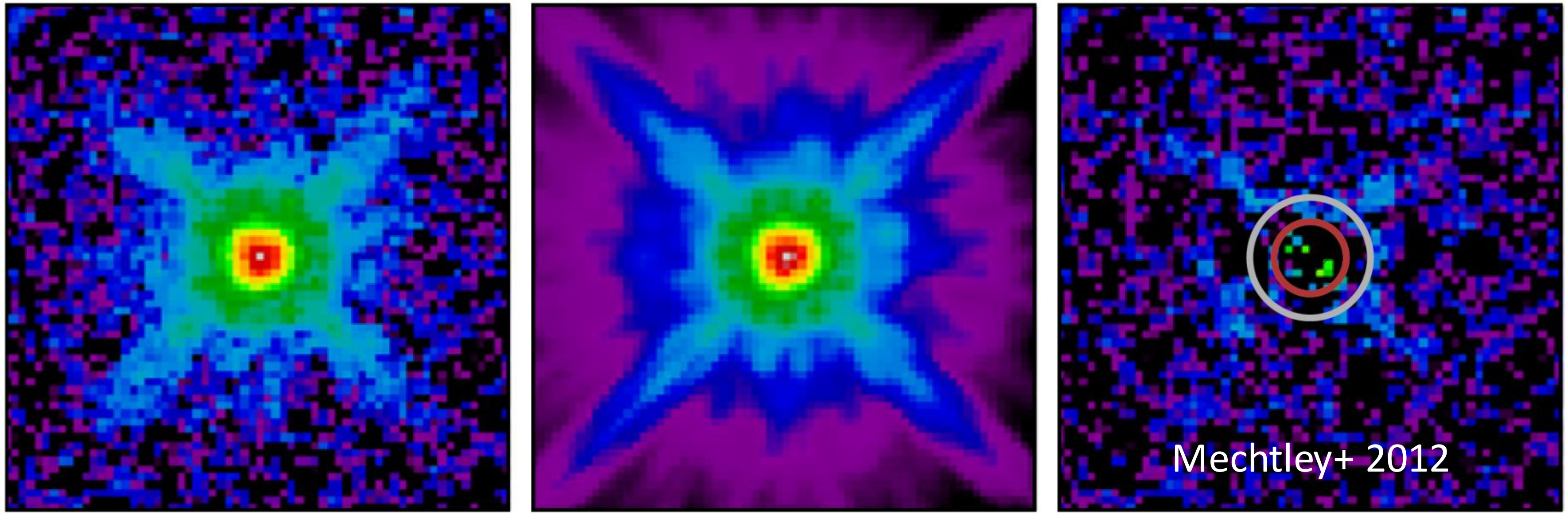
Simulations diverge at high redshift



Habouzit, Onoue, Bañados+2022

Where is the stellar light in z>6 quasars?

Extremely hard in the UV/Optical even with HST



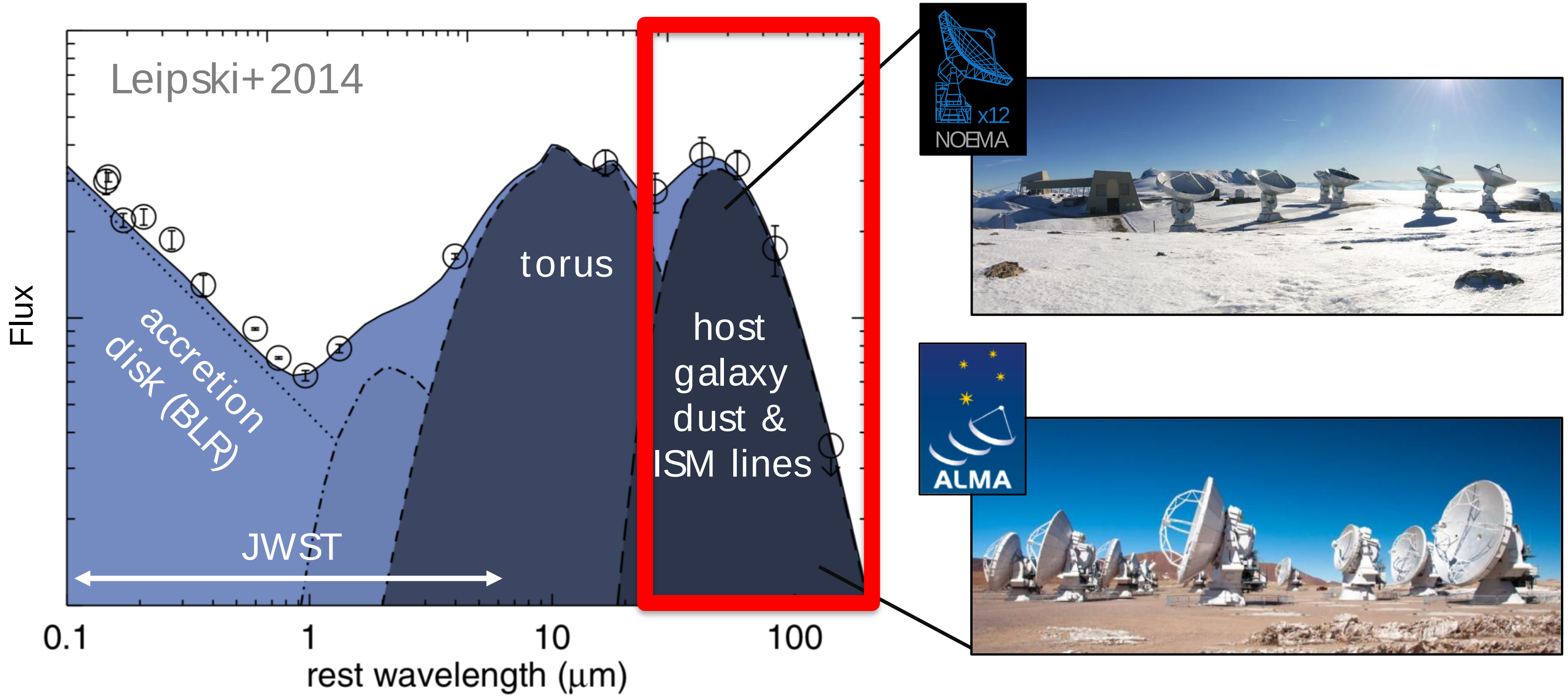
Quasar | PSF model | Quasar - PSF

See also Decarli+2012

Quasar host galaxies

The host galaxies dominate at rest-frame FIR

- Dust continuum
- Interstellar medium (ISM) lines: [CII], [OIII], CO, …



First [CII] on a z>6 quasar. - 2005

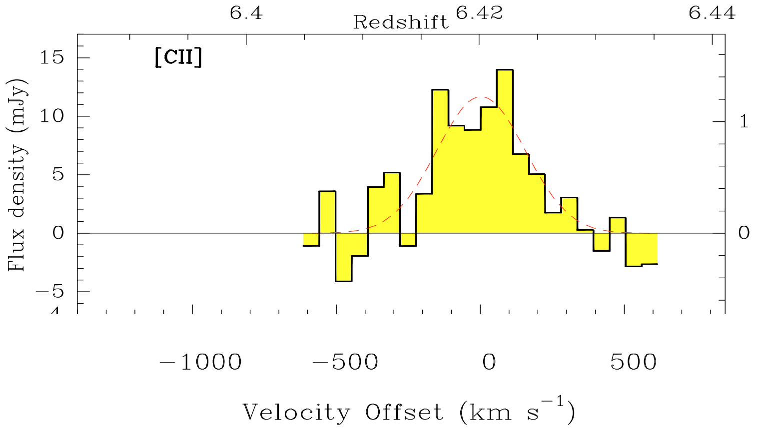
A&A 440, L51–L54 (2005)
DOI: 10.1051/0004-6361:200500165

Astronomy & Astrophysics

First detection of [CII]158 μm at high redshift: vigorous star formation in the early universe

R. Maiolino[1], P. Cox[2], P. Caselli[1], A. Beelen[3], F. Bertoldi[4], C. L. Carilli[5], M. J. Kaufman[6], K. M. Menten[3], T. Nagao[1,7], A. Omont[8], A. Weiß[9,3], C. M. Walmsley[1], and F. Walter[10]

[1] INAF – Osservatorio Astrofisico di Arcetri, L.go E. Fermi 5, 50125 Firenze, Italy
e-mail: maiolino@arcetri.astro.it



12.4 hours with IRAM/30m telescope

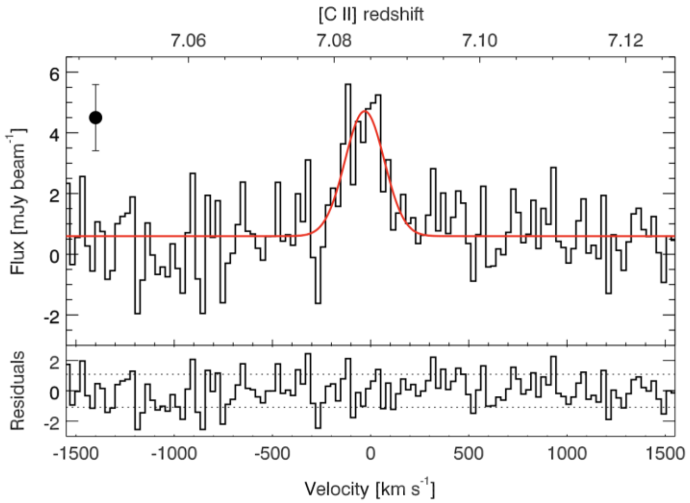
What was the highest redshift [CII] detection before?

Second [CII] on a z>6 quasar - 2012

THE ASTROPHYSICAL JOURNAL LETTERS, 751:L25 (5pp), 2012 June 1 doi:10.1088/2041-8205/751/2/L25

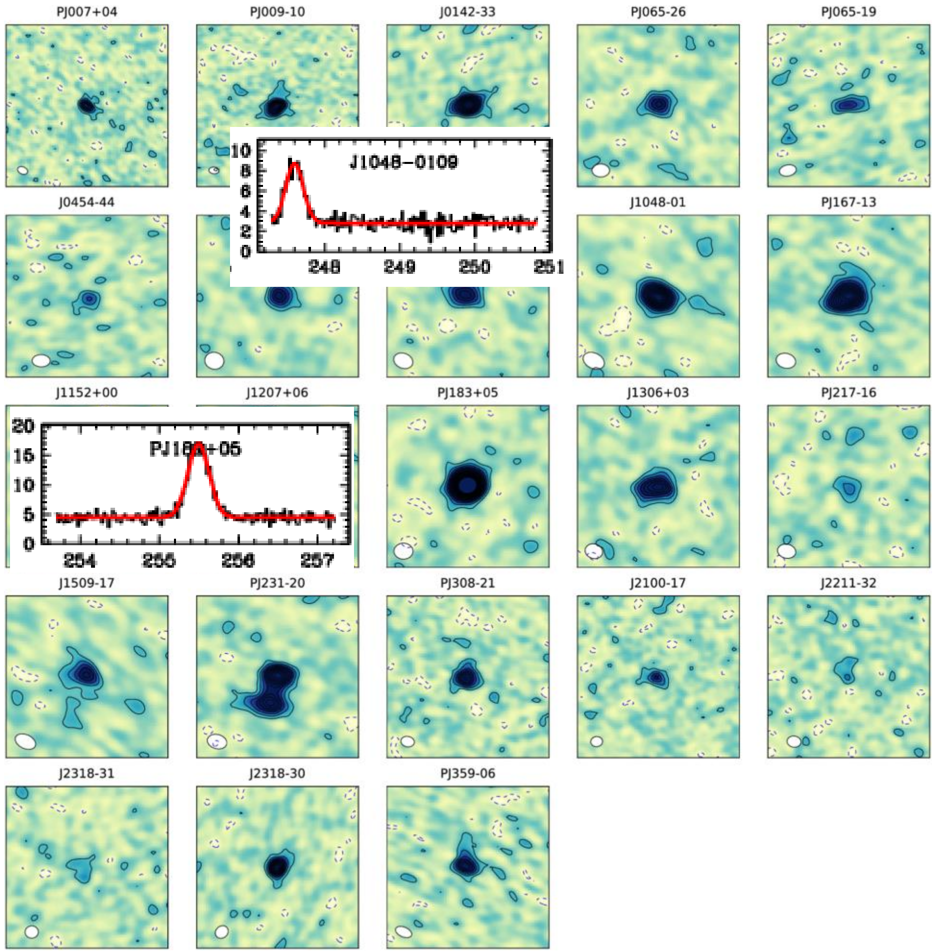
DETECTION OF ATOMIC CARBON [C II] 158 μm AND DUST EMISSION FROM A $z = 7.1$ QUASAR HOST GALAXY

B. P. VENEMANS[1,2], R. G. MCMAHON[3,4], F. WALTER[1], R. DECARLI[1], P. COX[5], R. NERI[5], P. HEWETT[3], D. J. MORTLOCK[6,7], C. SIMPSON[8], AND S. J. WARREN[6]
[1] Max-Planck Institute for Astronomy, Königstuhl 17, 69117 Heidelberg, Germany; venemans@mpia.de
[2] European Southern Observatory, Karl-Schwarzschild Strasse 2, 85748 Garching bei München, Germany



6.3 hours with IRAM/PdBI

Quasar host galaxies



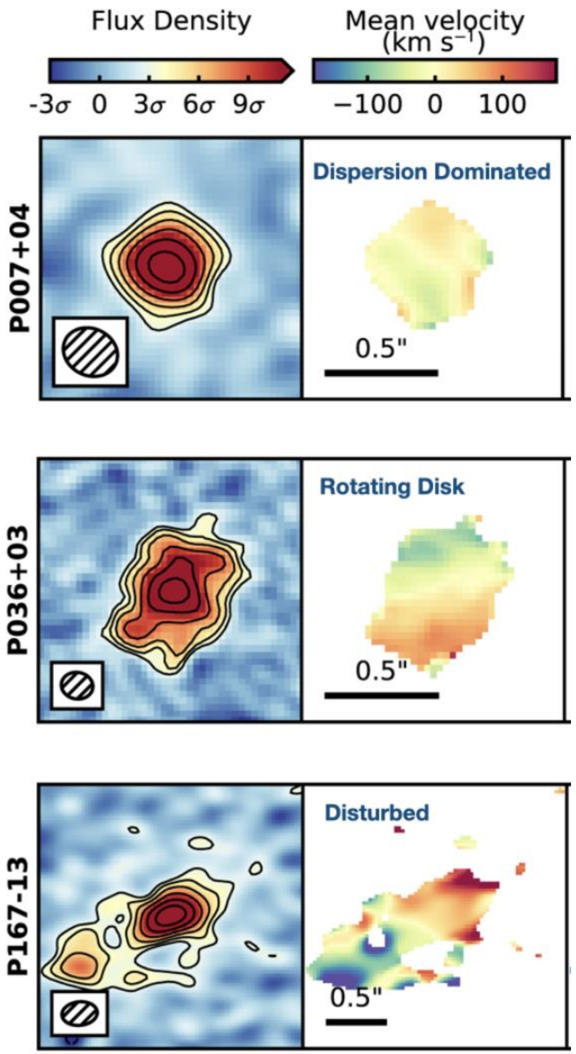
ALMA/NOEMA make it look „easy“

Before 2013: Only **two** [CII] detections at z>6
(Maiolino+2005, Venemans+2012;
See review by Carilli & Walter 2013)

Now: More than 90 [CII] detections at z>6

(see e.g., Andika+2019; Bañados 2015, 2019, 2024, Decarli+ 2018-2022, Eilers+2020, Venemas+2020, Yang+2021, Khusanova+2022, Izumi+ 2018-2021, Pensabene+ 2021)

Quasar host galaxies – a diverse population



Morphology

- 1/3 dispersion dominated
- 1/3 rotating disk
- 1/3 disturbed, merger/companion

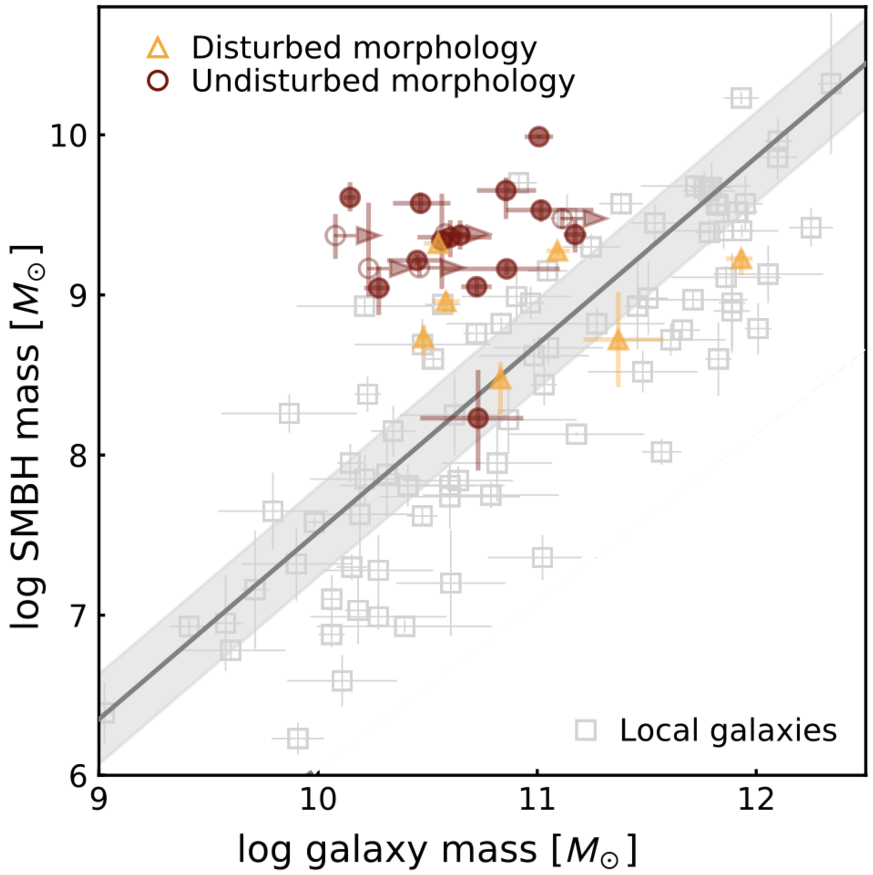
General properties

- [CII] Sizes: 1 – 5 kpc (average ~2kpc)
- SFRs = 50 – 1500 $M_{SUN}yr^{-1}$
-

  M_{DYN} = 1 – 10 x 10^{10} M_{SUN}
- M_{GAS} = 4 – 40 x 10^9 M_{SUN}
- M_{DUST} = 0.5 – 5 x 10^8 M_{SUN}

Fig. 9
Fan, Bañados, Simcoe 2023
Adapted from Neeleman+2021

Galaxy/Black Hole co-evolution



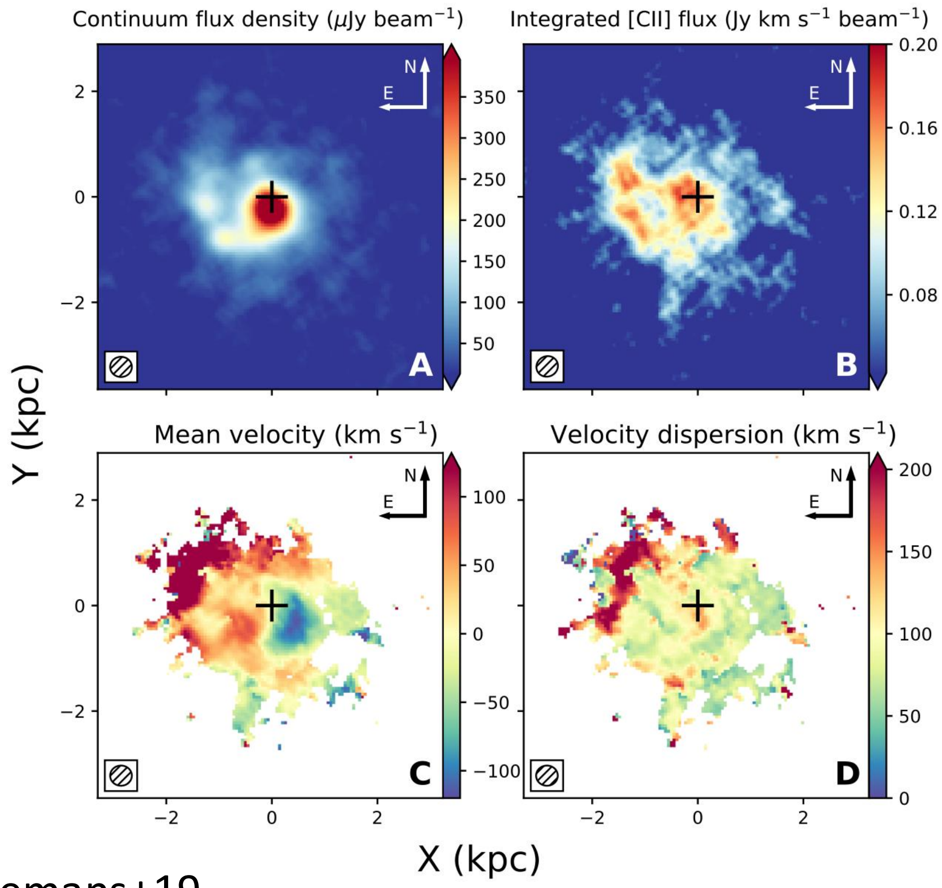
Current measurements ~10 times above local M-sigma relation

Fig. 10
Fan, Bañados, Simcoe 2023
Adapted from Neeleman+2021

Pushing ALMA resolution to the limits

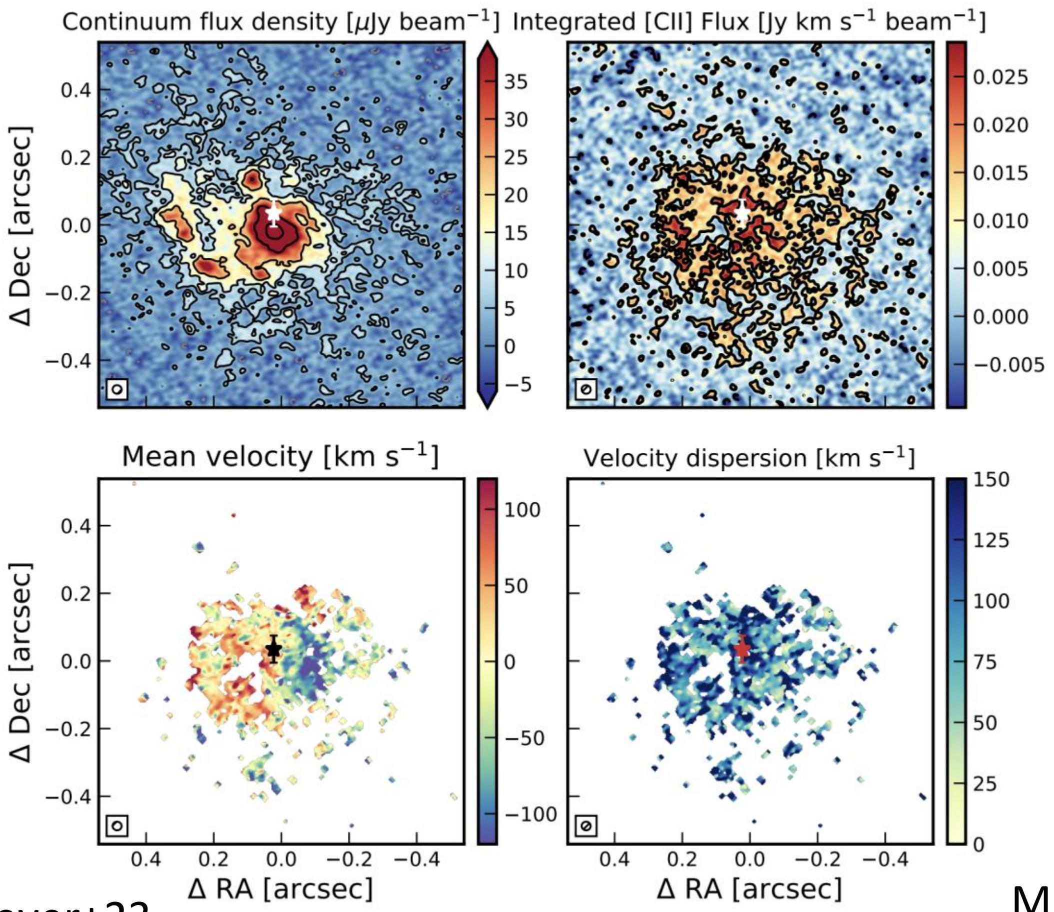
z=6.6 Quasar host

400 pc resolution



Venemans+19

140 pc resolution

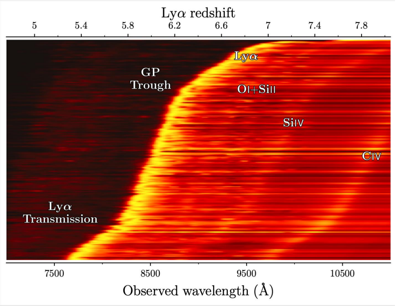


see also Walter+22, Meyer+23

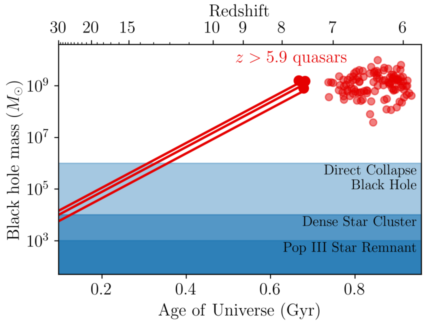
Meyer+25

Outline

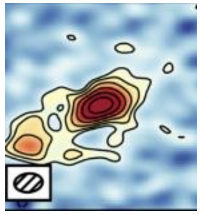
- Discovery and demographics



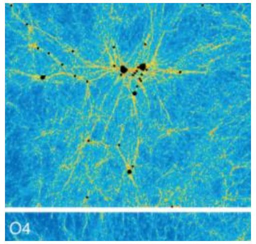
- SMBH → ~pc scales

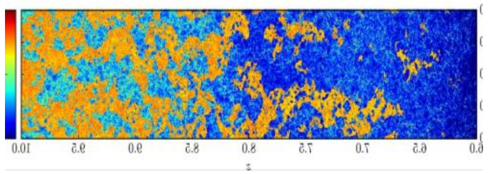


- Galaxy / Close envs. → ~kpc scales

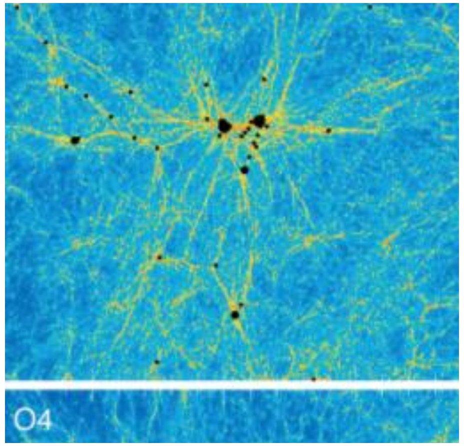


- **Environments /**IGM → **~Mpc scales**



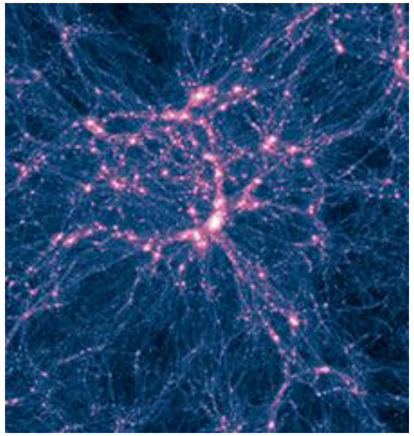


Overdensities around high-z quasars?



z=6.2
Costa+ 2014

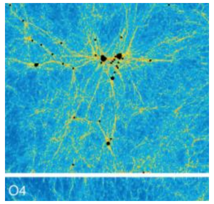
?

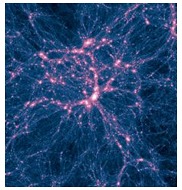


z=0
Illustris simulation

Observations (*before JWST)* are still inconclusive …

Overdensities around high-z quasars?





Overdensity

same field
- Zheng+ 2006
- Bosman+ 2019
- Overzier+2022

Utsumi+ 2010

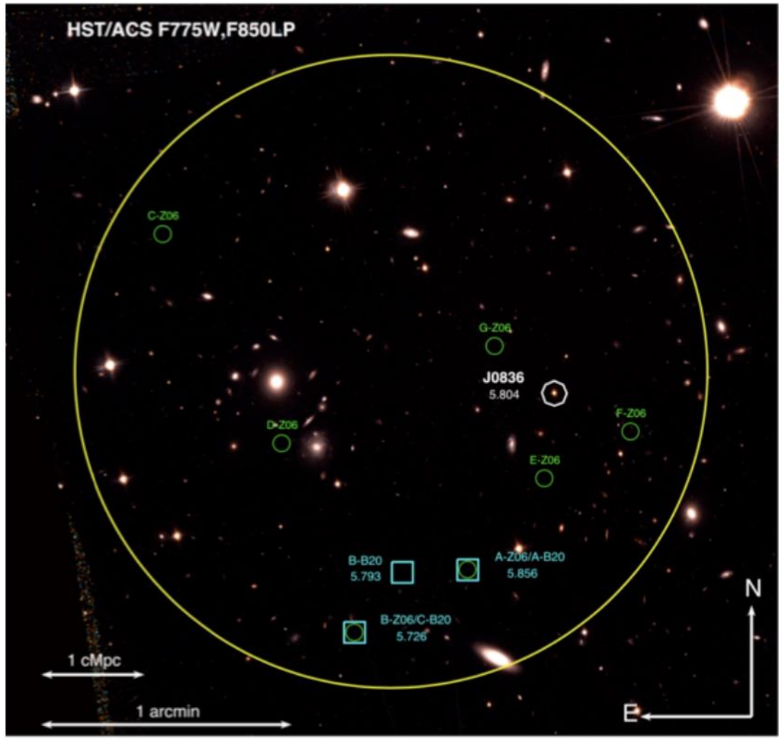
same field
- Stiavelli+ 2005
- Kim+ 2009
- Morselli+ 2014
- Balmaverde+ 2017
- Decarli+ 2019
- Mignoli+ 2020

No overdensity

Willott+ 2005
Kim+ 2009
Bañados+ 2013
Husband+ 2013
Simpson+ 2013
Mazzucchelli, Bañados+ 2017
Goto+ 2017
Ota+ 2017

Before JWST: Two confirmed Mpc overdensities

J0836+0054 at z=5.8



J1030+0524 at z=6.3

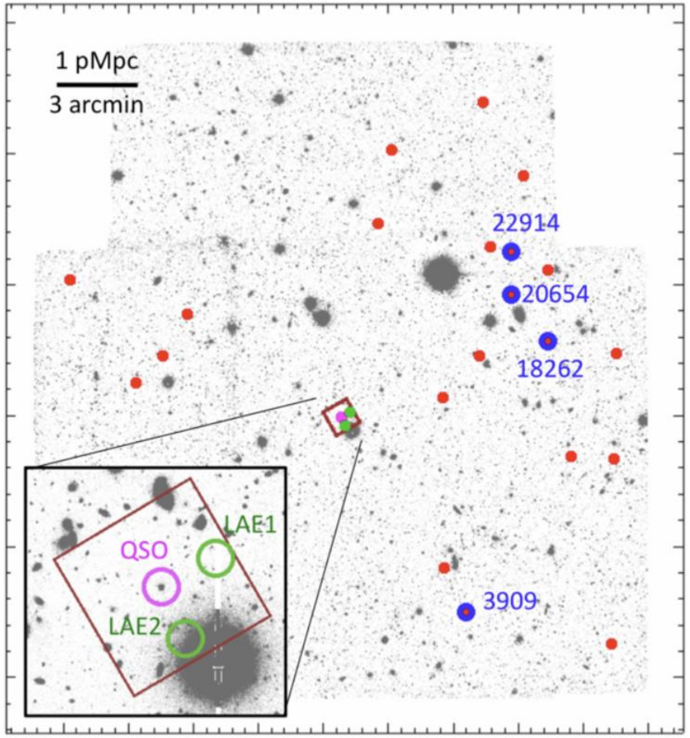
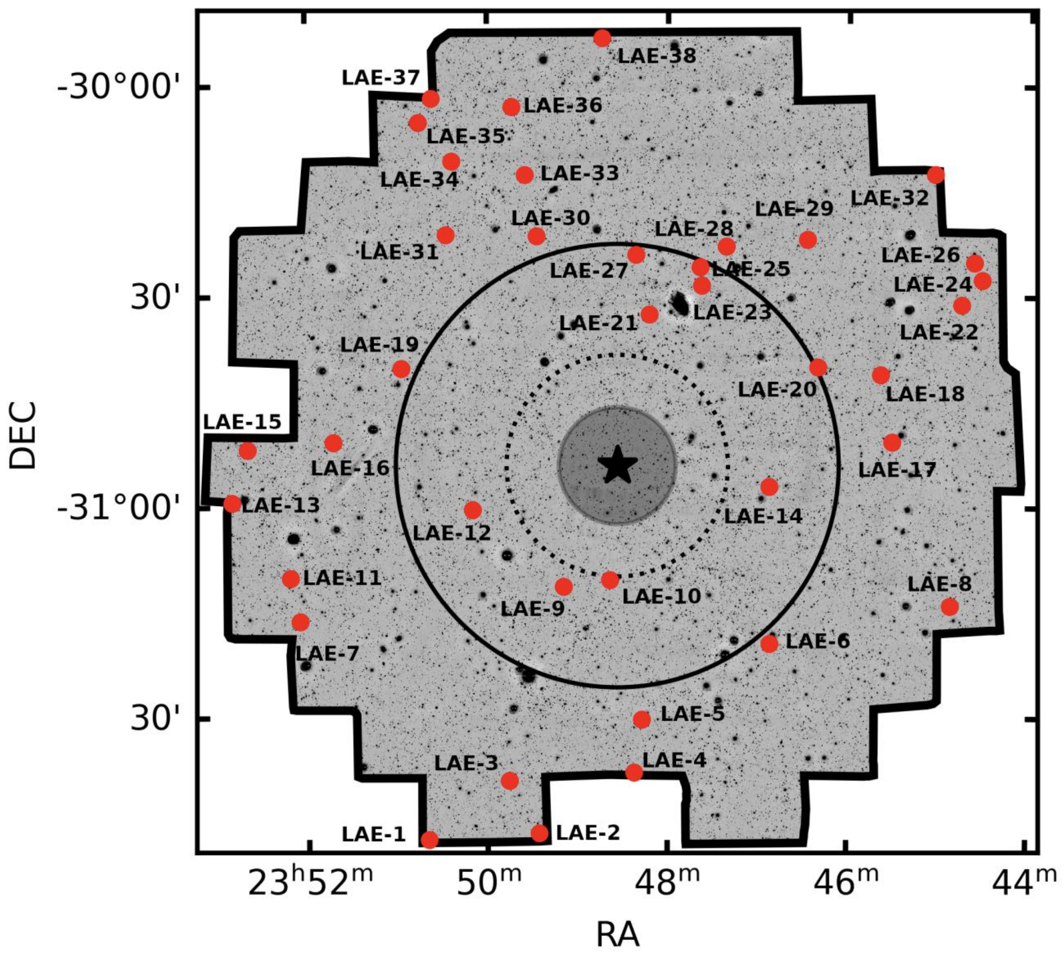


Fig. 11
Fan, Bañados, Simcoe 2023
Adapted from Overzier+2022
and Mignoli+2020

A recent interesting result



Search for LAE over 3 deg^2 centred on a z=6.9 quasar

< 5 Mpc – Nothing

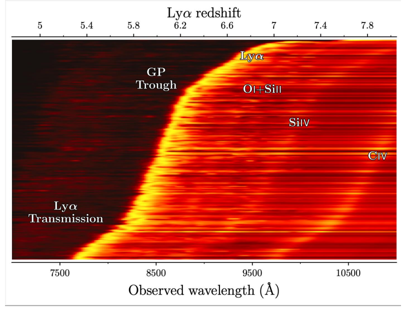
>10 Mpc – Overdensity!

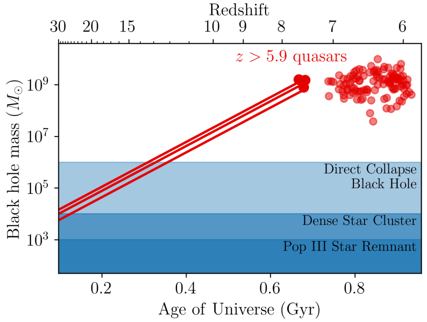
Argue previous experiments had FOV too small

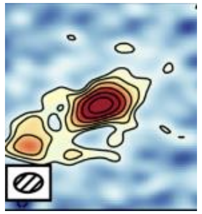
Lambert+24 (incl EB)

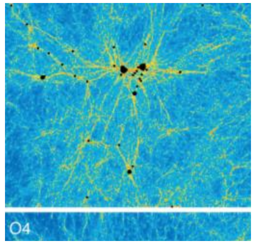
Outline

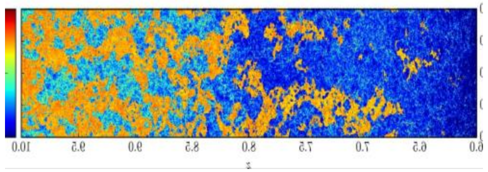
- Discovery and demographics
- SMBH → ~pc scales
- Galaxy / Close envs. → ~kpc scales
- Environments **/IGM → ~Mpc scales**



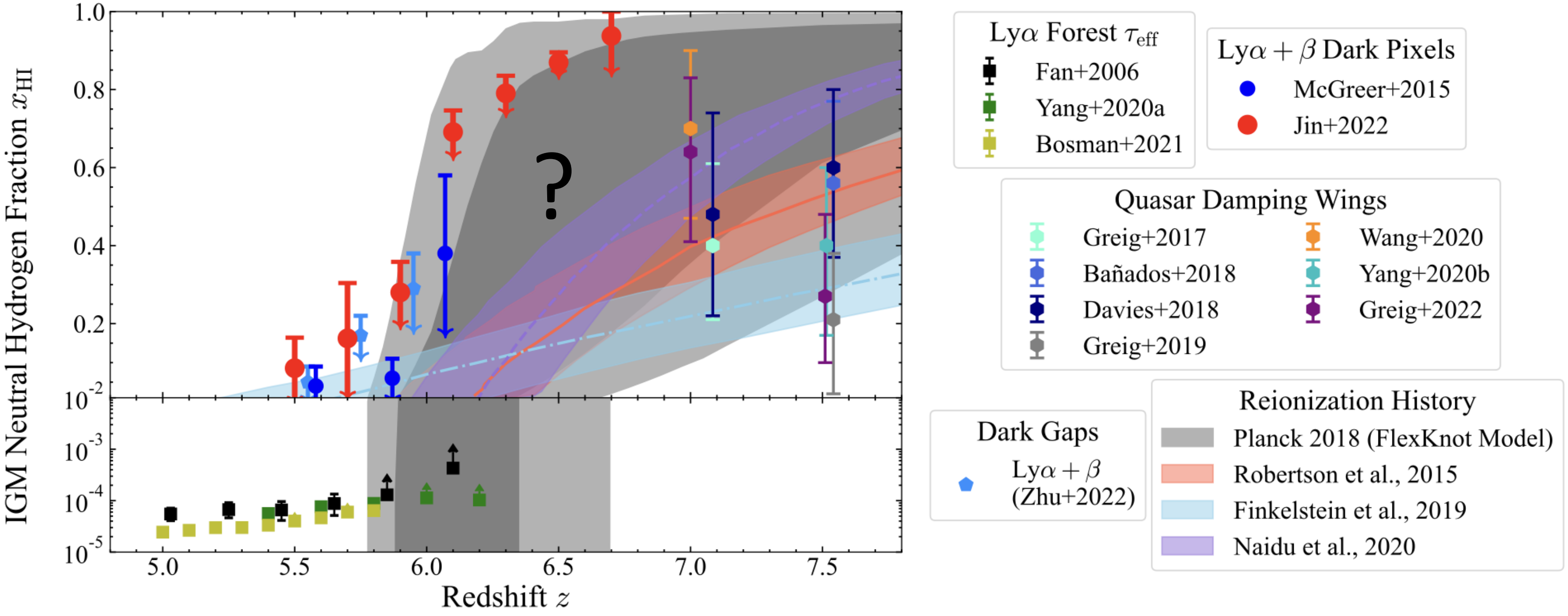








Mapping reionization with quasars



- Ends at z~5.3
- Rapid transition at z>6
- Largely neutral at z~7.5

Fig. 16
Fan, Bañados, Simcoe 2023
Adapted from Jin+2022

Quasar damping wings …

THE ASTROPHYSICAL JOURNAL, 501:15–22, 1998 July 1

REIONIZATION OF THE INTERGALACTIC MEDIUM AND THE DAMPING WING OF THE GUNN-PETERSON TROUGH

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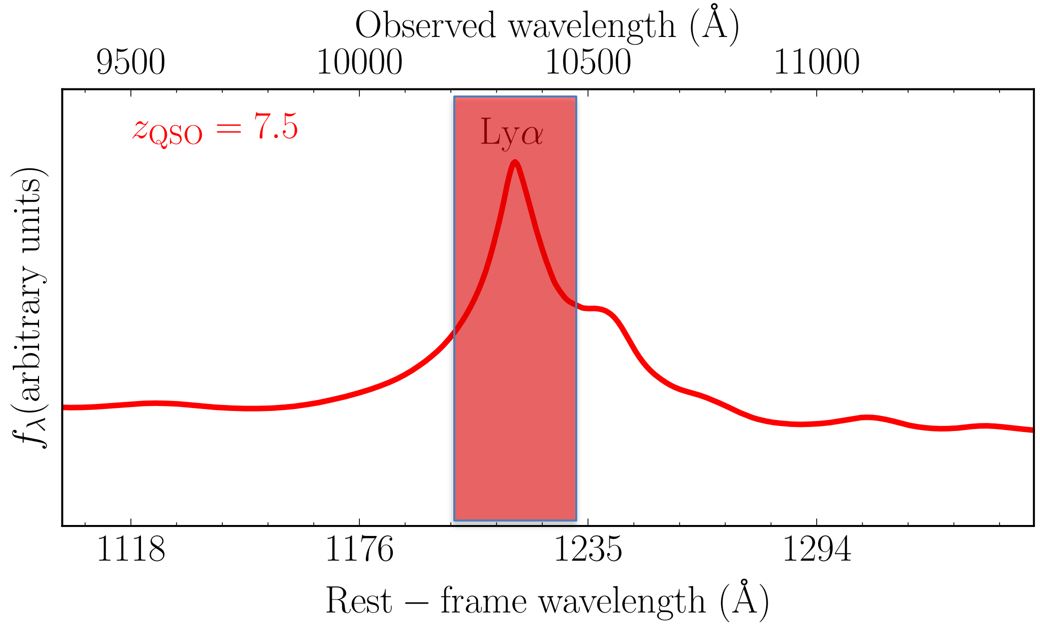
ABSTRACT

Observations of high-redshift quasars show that the intergalactic medium (IGM) must have been reionized at some redshift $z > 5$. If a source of radiation could be observed at the rest-frame Lyα wavelength, at a sufficiently high redshift where some of the IGM in the line of sight was not yet reionized, the Gunn-Peterson trough should be present. Longward of the Lyα wavelength, a damping wing should be observed, caused by the neutral IGM whose absorption profile can be predicted. Measuring the shape of this damping wing would provide irrefutable evidence of the observation of the IGM before reionization and a determination of the density of the neutral IGM. This measurement might be hindered by the possible presence of a dense absorption system associated with the source.

Quasar damping wings …

Sensitive to neutral IGM: $f_{HI} > 0.1$

Example with a QSO at z=7.5

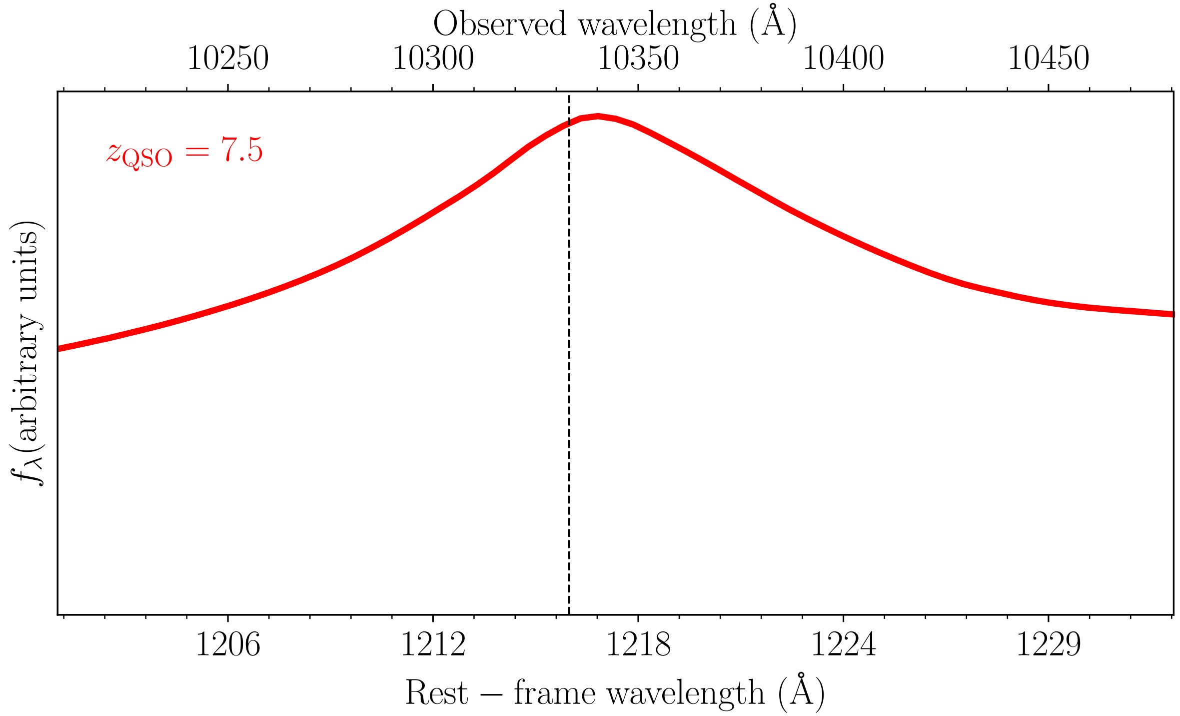


Miralda-Escude 1998

Quasar damping wings …

Sensitive to neutral IGM: $f_{HI} > 0.1$

IGM
ionized

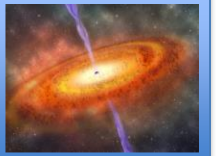


Miralda-Escude 1998

Quasar damping wings …

Sensitive to neutral IGM: $f_{HI} > 0.1$

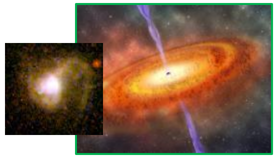
IGM
10% Neutral

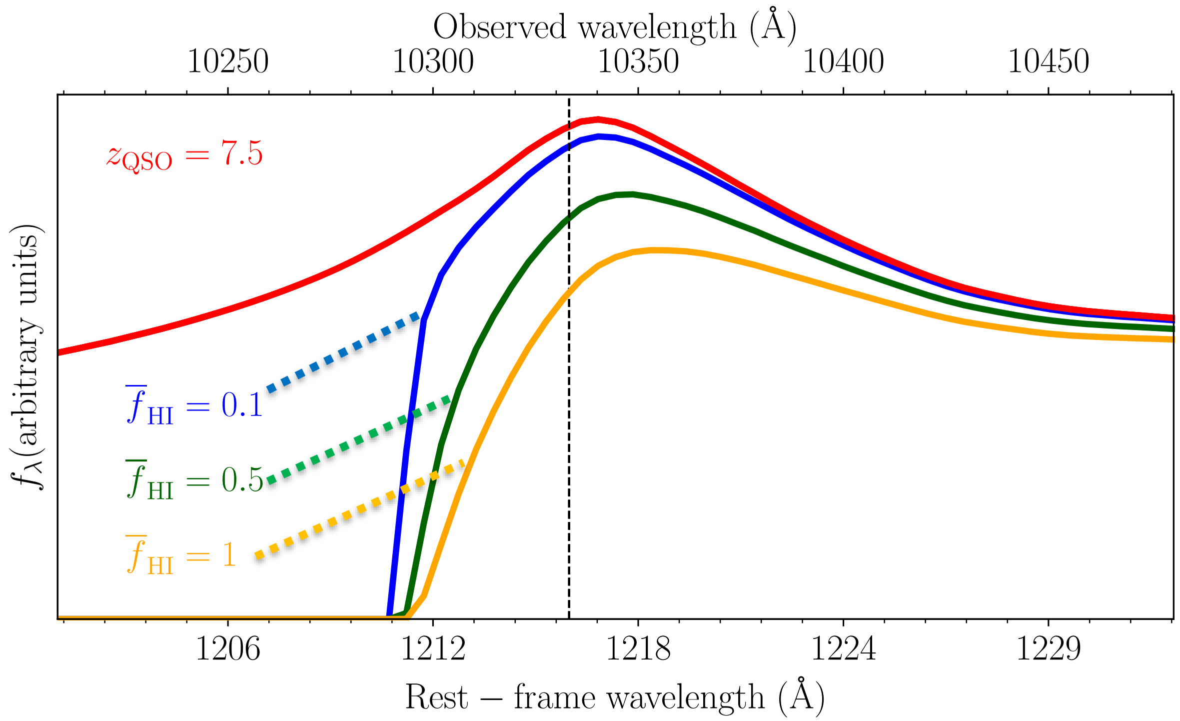


IGM
50% Neutral

IGM
100% Neutral

IGM
Ionized
+ DLA





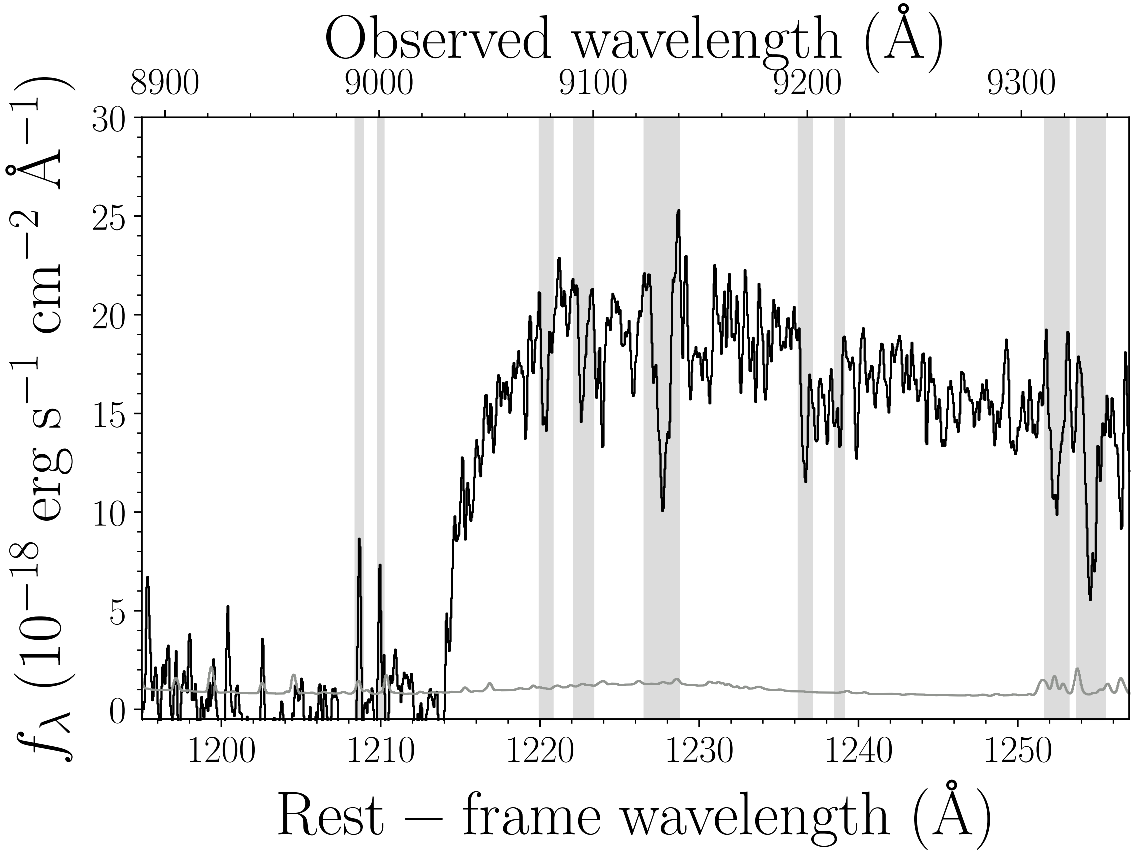
Miralda-Escude 1998

Did I find an IGM damping wing at z=6.4??

IGM

100% Neutral

z=6.4 (15% of cosmic time)

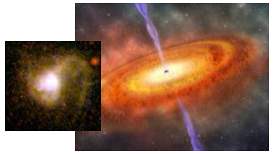


Bañados+ 2019b

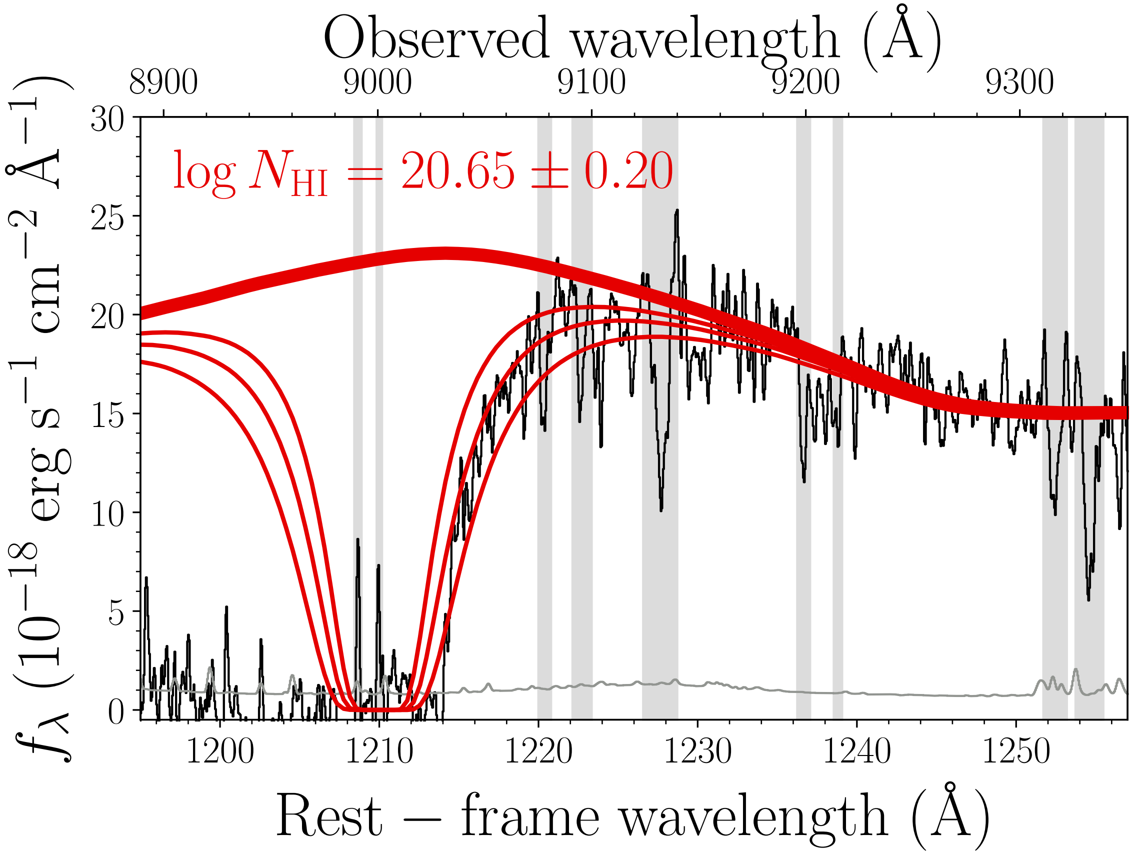
Proximate DLA at z=6.4

IGM
100% Neutral

IGM
Ionized
+ DLA



z=6.4 (15% of cosmic time)

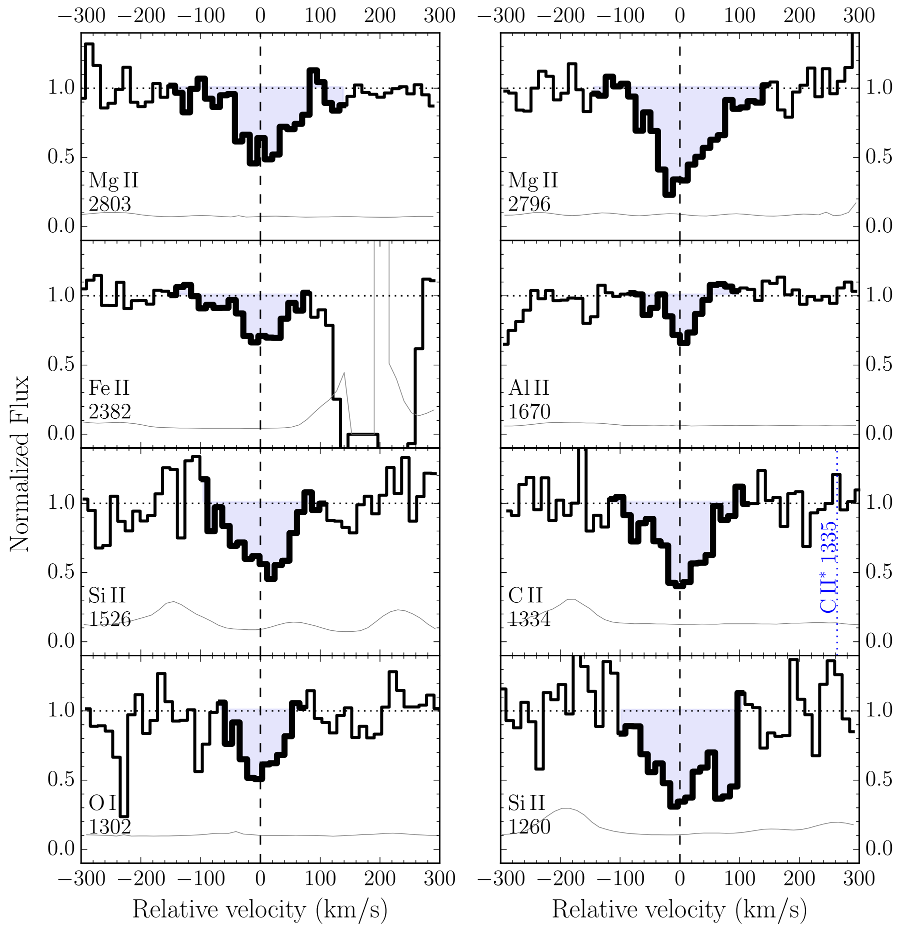


Bañados+ 2019b

*PDLAs are rare: <1% of quasars at z=3

Proximate DLA at z=6.4

No indications of Pop III yields yet (cosmic age: 850 Myr)



See also
D'Odorico+18 for a similar result on a z=6.0 quasar
Sodini+24 for "a sample"

Bañados+ 2019b

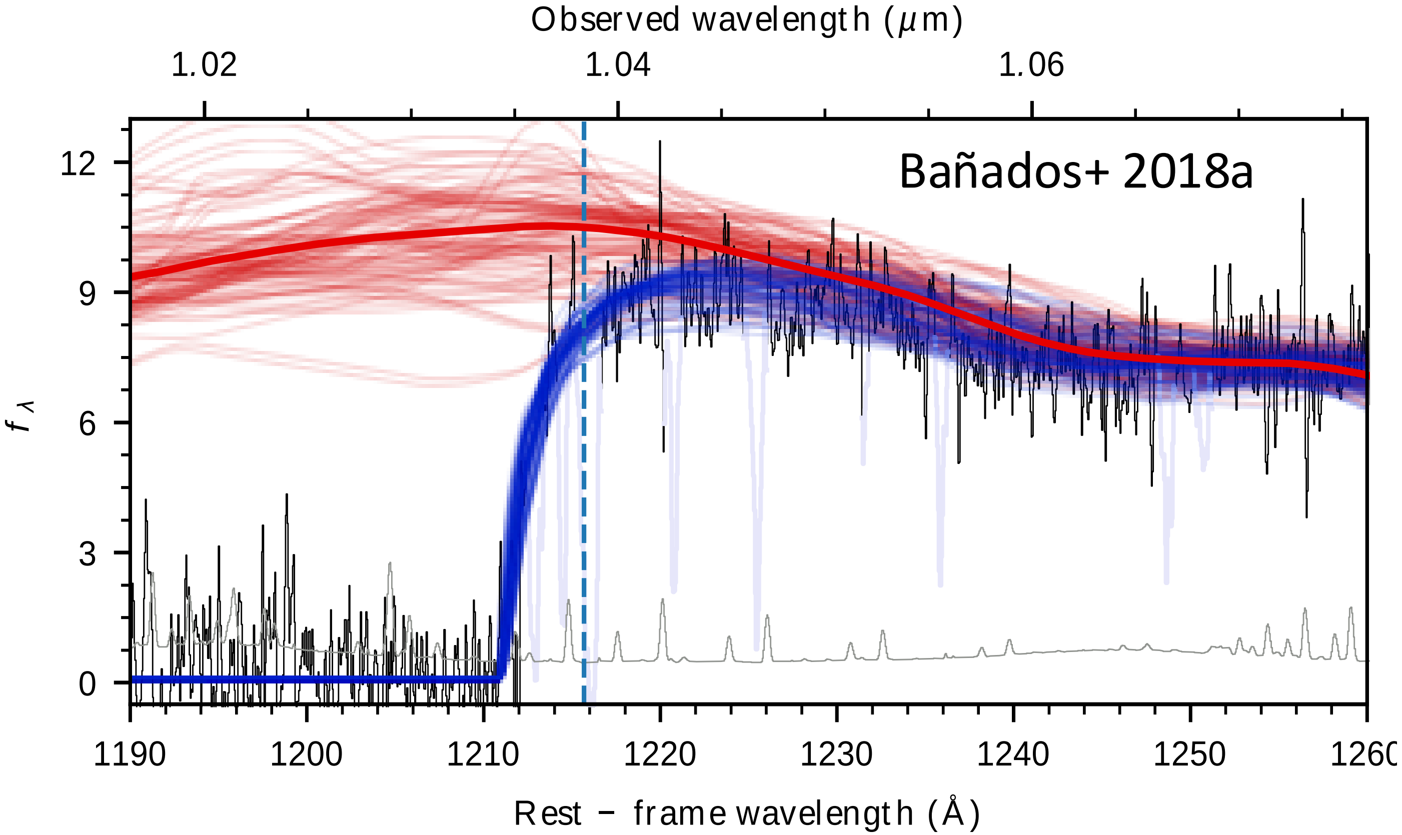
IGM damping wings at z>7

Eduardo Banados <ebanados@c... Tue, Mar 14, 2017, 1:53 AM

to Fabian, Xiaohui, Venemans

This is the combined spectrum from both nights, and probably our final FIRE spectrum for the paper. It shows a clear damping wing and I can't identify metals at a similar redshift.

IGM damping wings at z>7



IGM
50% Neutral

See also
Greig, Mesinger & Bañados 2019
Davies, Hennawi, Bañados+ 2019
Ďurovčíková+2020, Reiman+2020

We need more quasars at z>7

All z>7 quasars show IGM damping wing signatures*

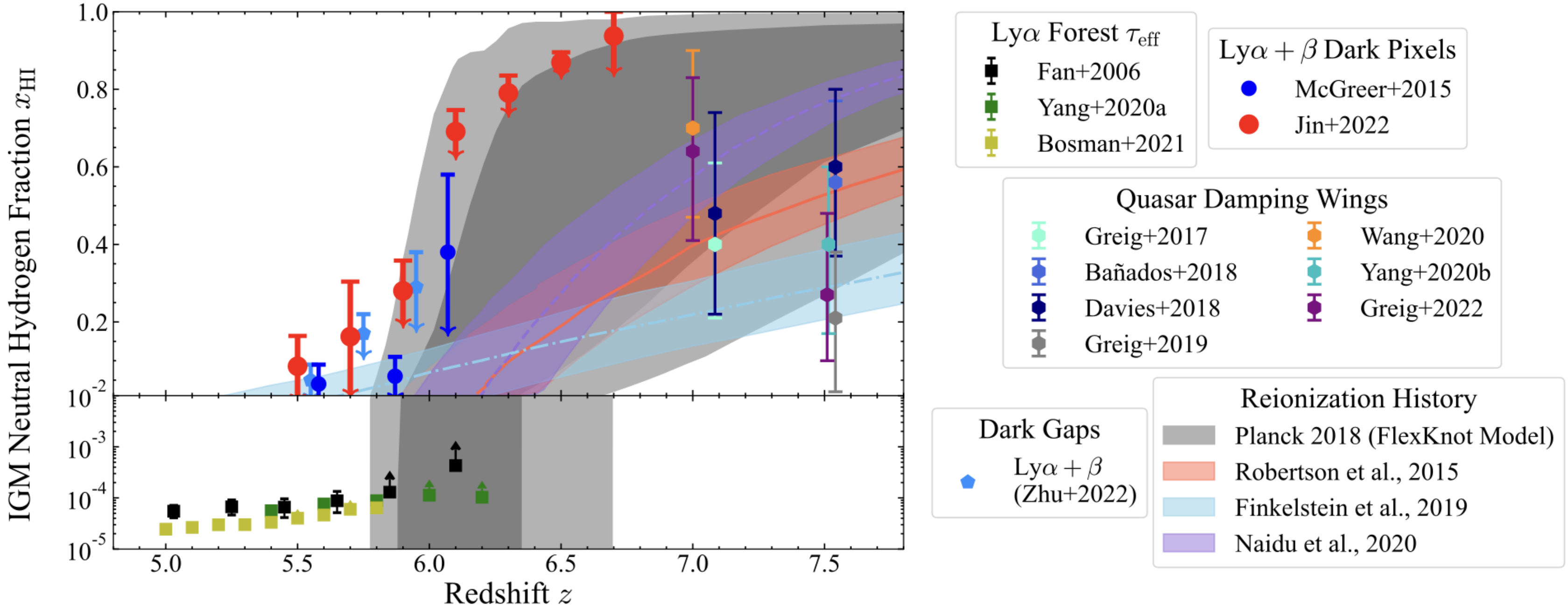
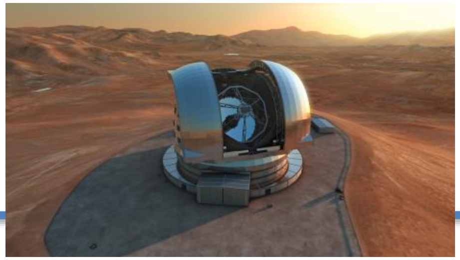
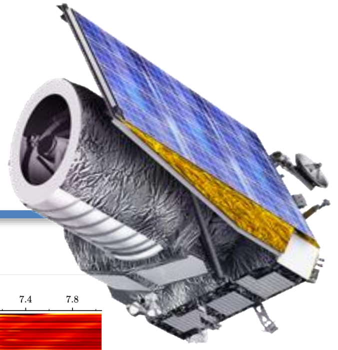


Fig. 16
Fan, Bañados, Simcoe 2023
Adapted from Jin+2022

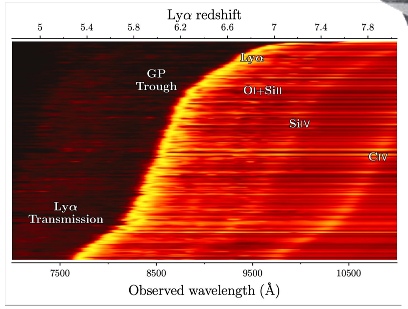
*All that have a good S/N spectrum and are not Broad Absorption line quasars

Future is bright

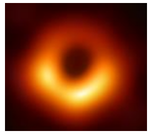




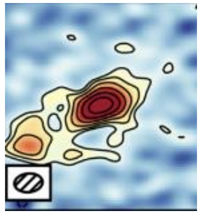
- Discovery and demographics



- SMBH → ~pc scales



- Galaxy / Close envs. → ~kpc scales



- Environments /IGM → ~Mpc scales