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The Purely Astrometric Quasar Survey

a color-blind approach to quasar identification

Jens-Kristian Krogager

gaia

UNIVERSITÉ DE GENÈVE

Overview

1. Quasars as cosmological probes
2. Quasars
3. Intervening Absorption Systems
4. Quasar identification
5. 4MOST—Gaia Purely Astrometric Quasar Survey
6. Summary

Quasars as Cosmological Probes

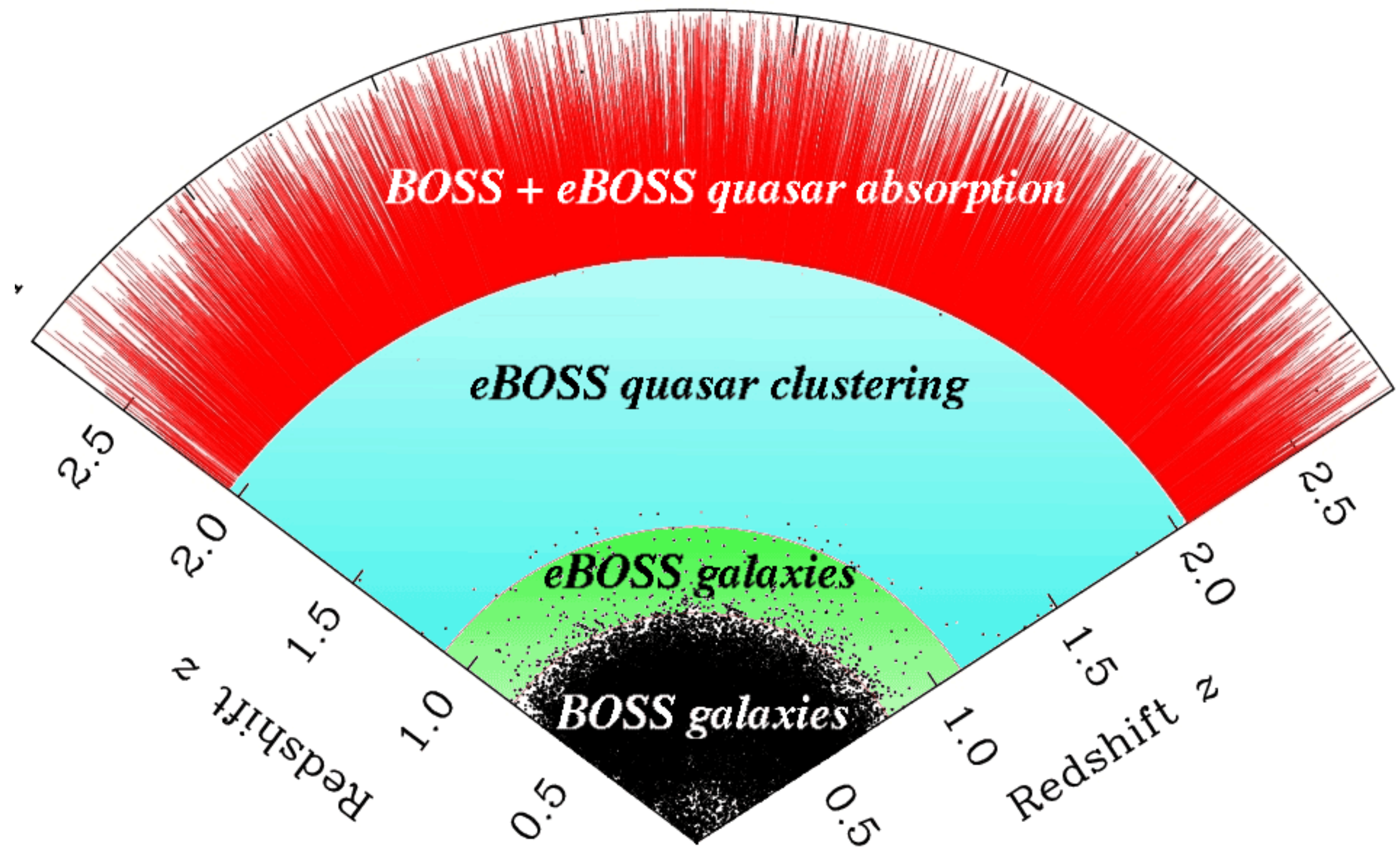
IGM absorption BAO using Ly-alpha forest

Quasar clustering

IGM tomography

SDSS-IV — e.g., Hou et al. 2021;
du Mas des Bourboux et al. 2020;
Neveux et al. 2020

Test of cosmological principle
quasar-frame vs CMB dipole
(Secrest et al. 2020)



The Quasar Phenomenon

Classical Quasar Unification

The different spectral types of quasars and AGN are determined by the viewing angle

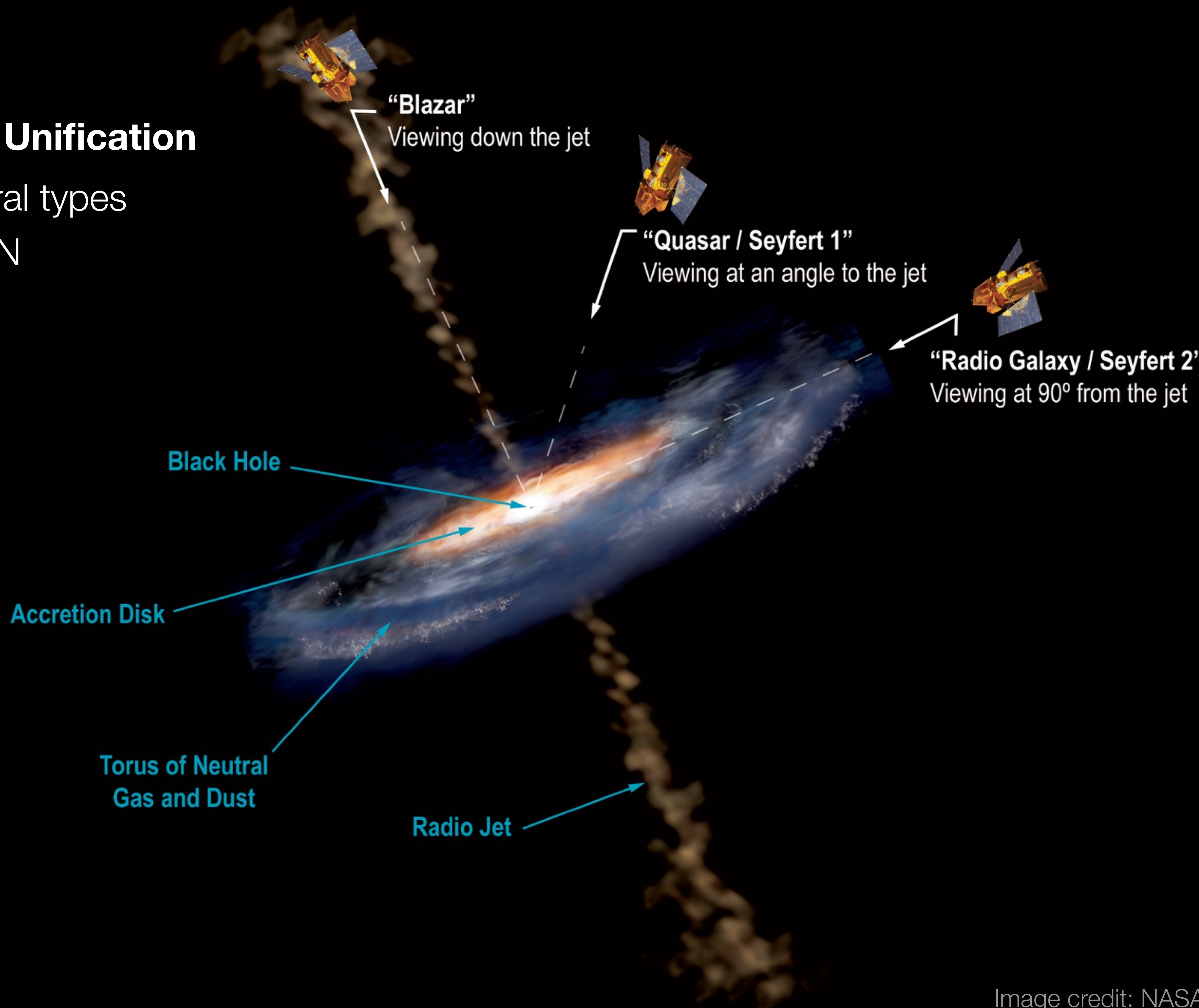


Image credit: NASA

The Quasar Phenomenon

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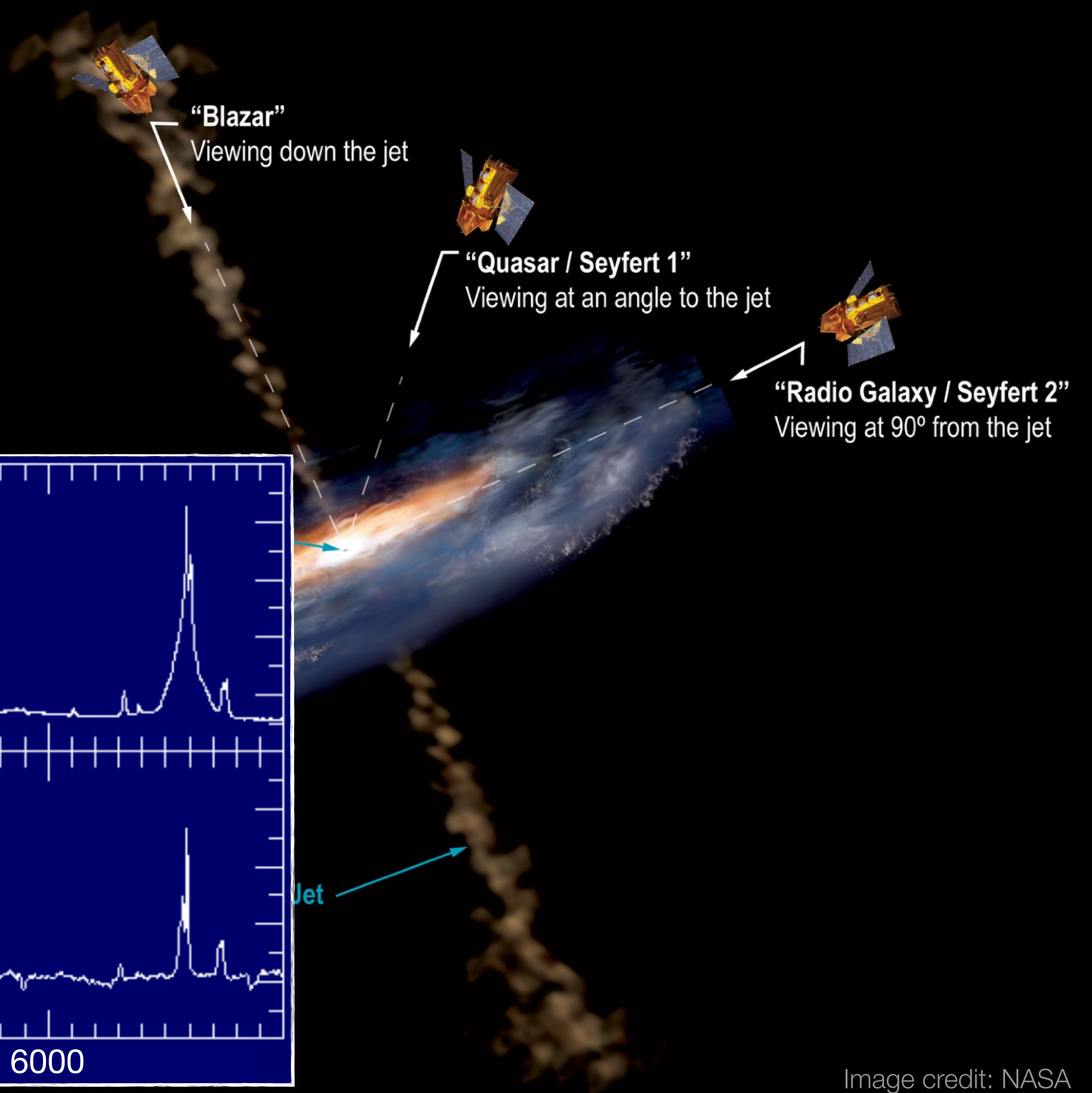


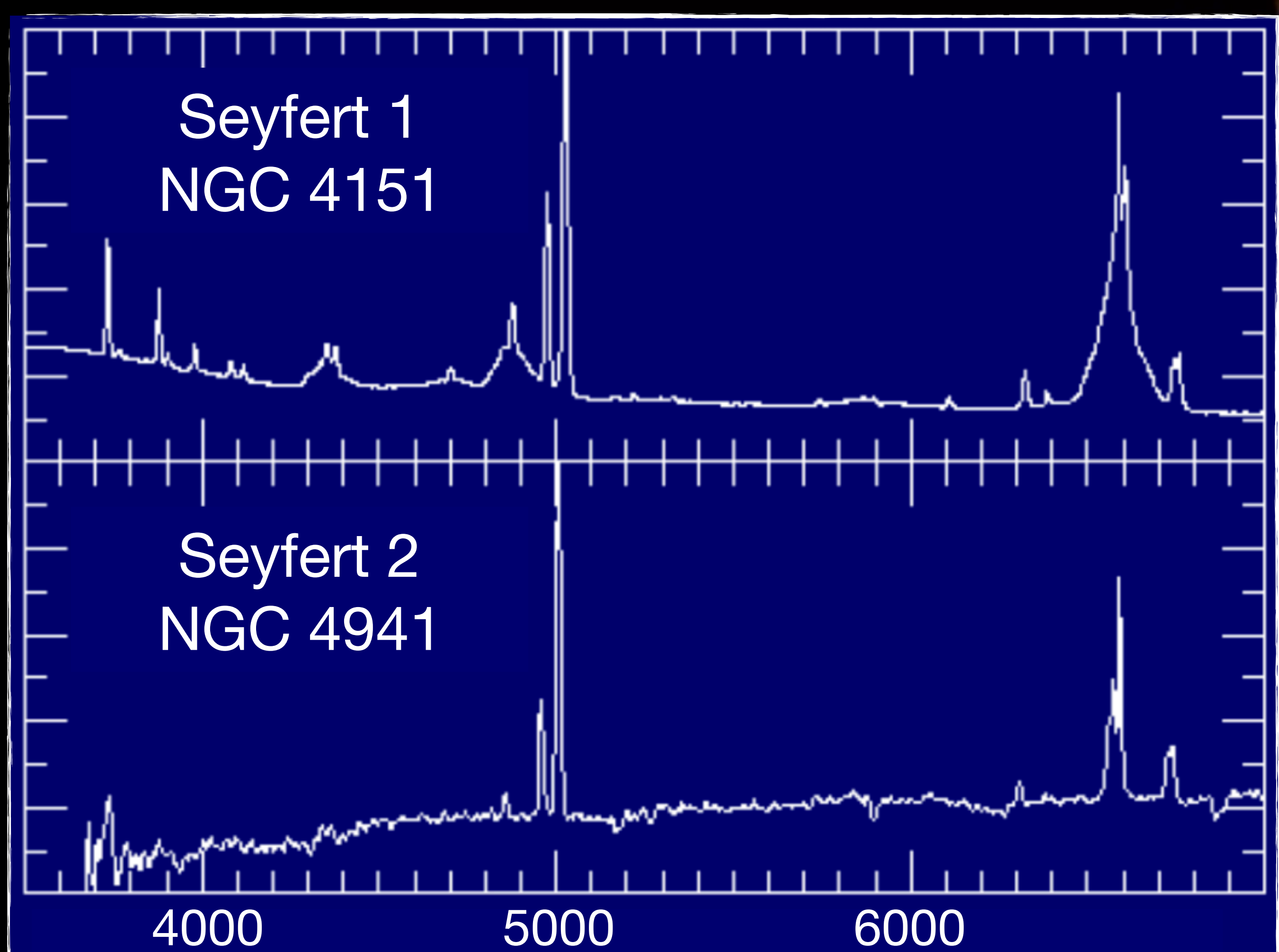
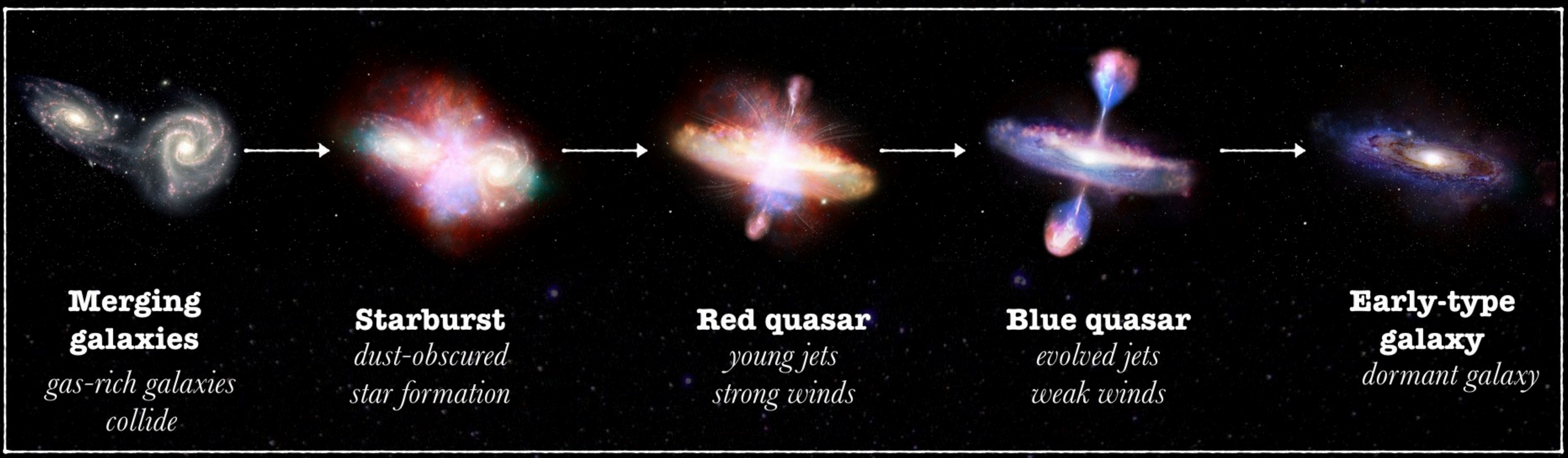


Image credit: NASA

The Quasar Phenomenon

Quasars as an evolutionary phase in galaxy evolution



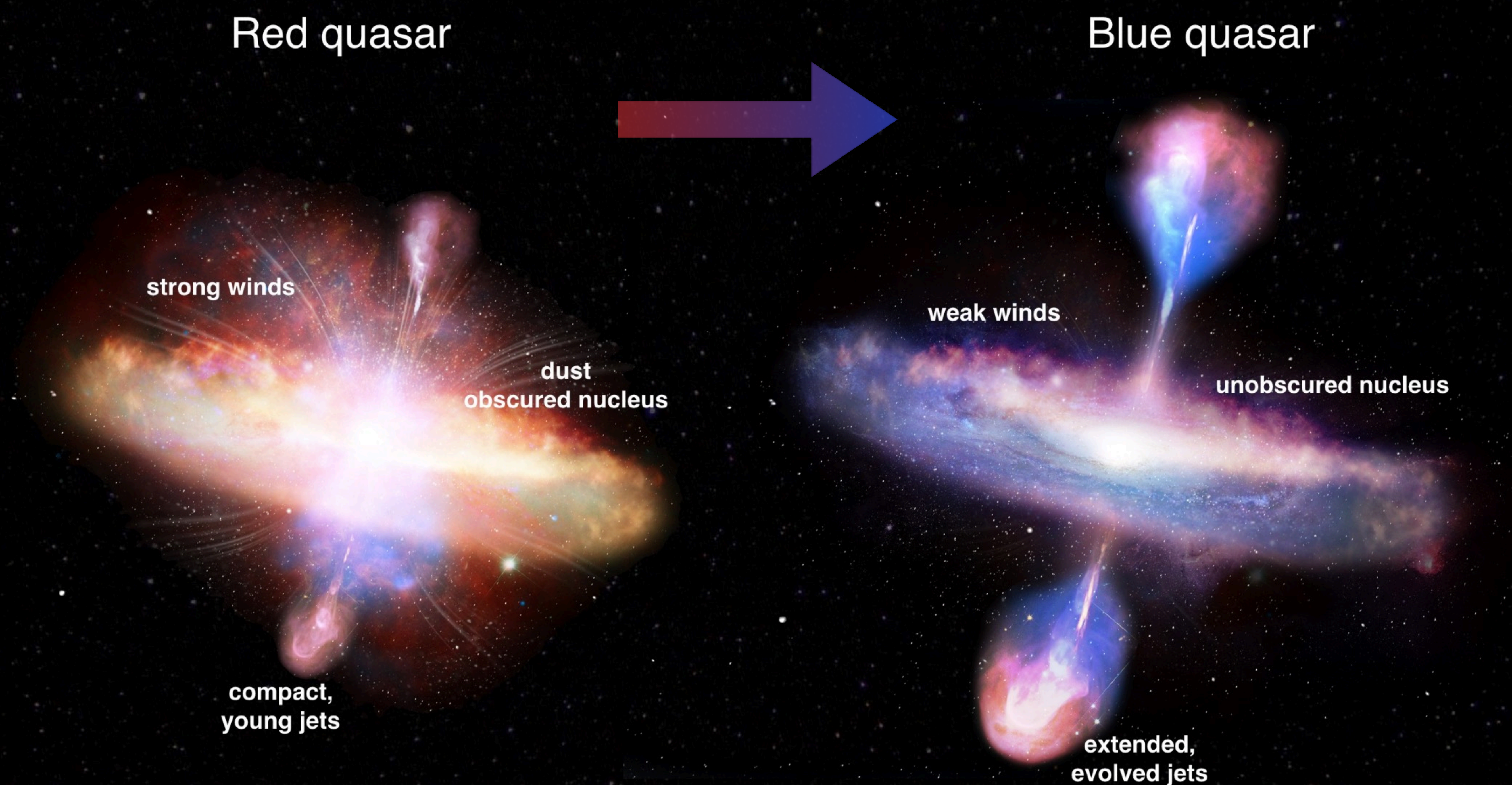
e.g., Glikman et al. 2012, Klindt et al. 2019, Fawcett et al. 2020

Image credit: Gemini Observatory

Jens-Kristian Krogager

The Quasar Phenomenon

Quasar Evolution from ‘red’ to ‘blue’



e.g., Glikman et al. 2012, Klindt et al. 2019, Fawcett et al. 2020

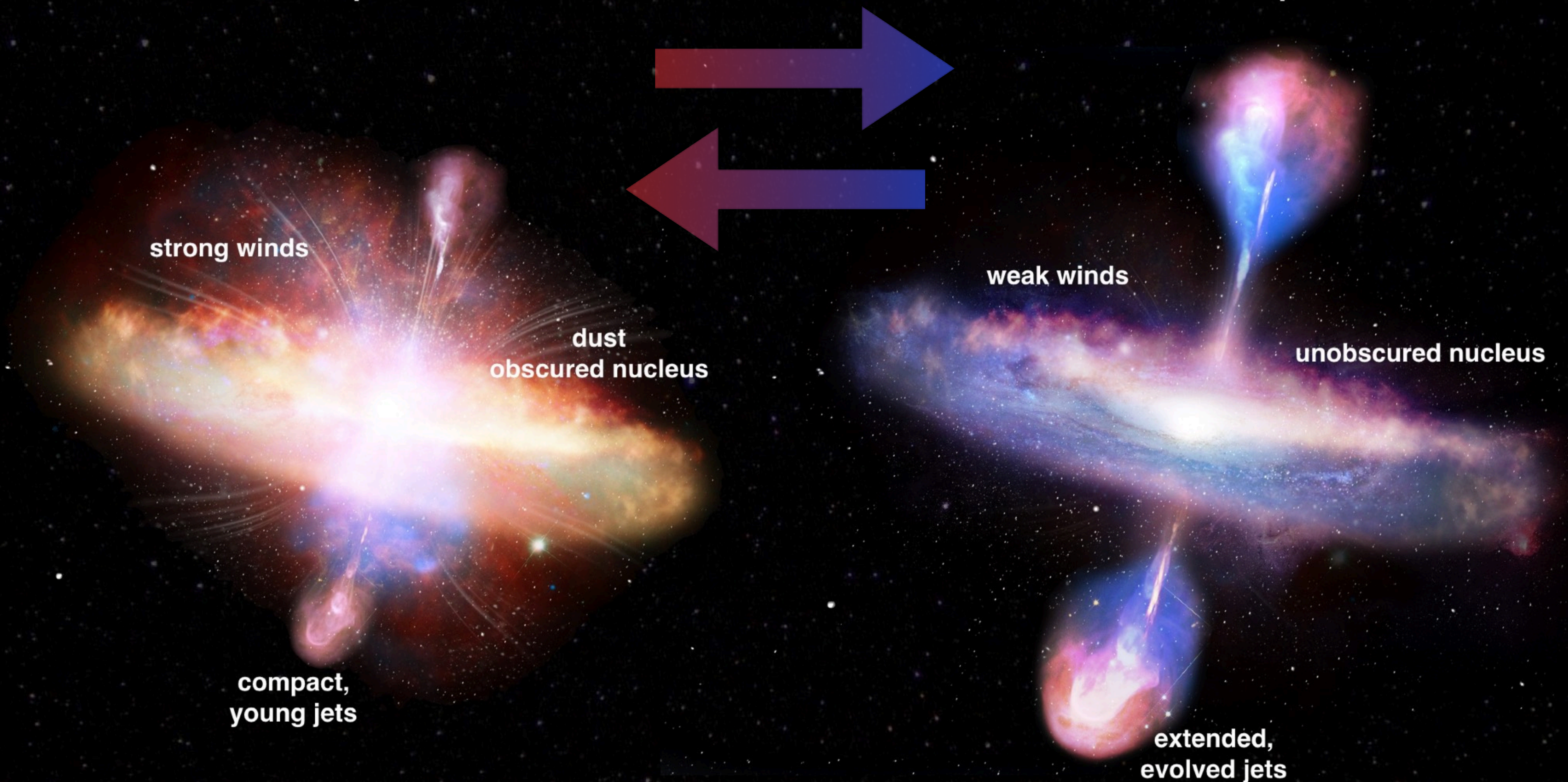
Image credit: S. Munro

The Quasar Phenomenon

Quasar may also change look both in radio and optical data possibly related to changes in accretion rate or jets in young AGN.

de Vries et al. 2004; Mooley et al. 2016;
Kunert-Bajraszewska et al. 2020; Nyland et al. 2020

Red quasar | Blue quasar

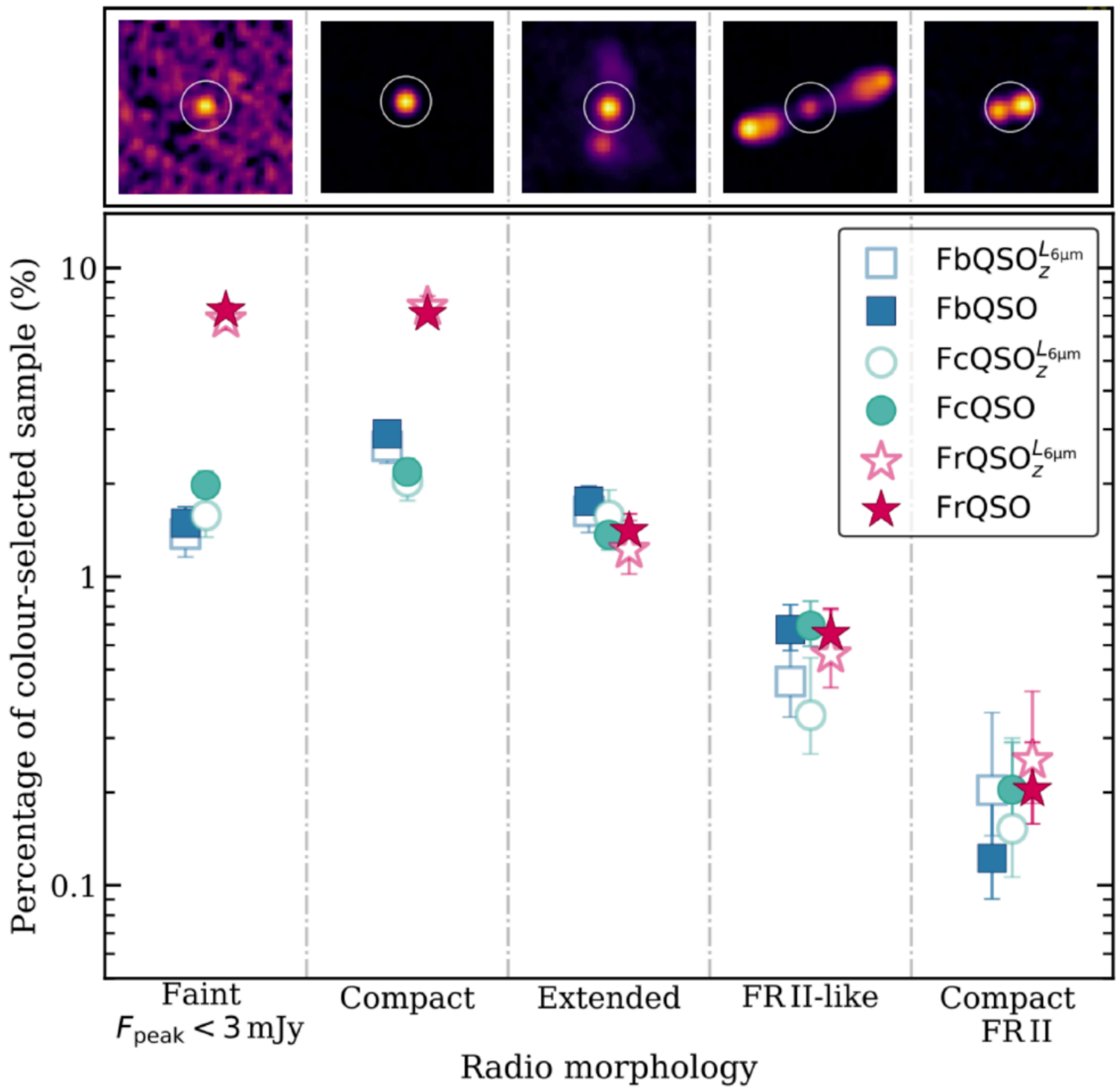


e.g., Glikman et al. 2012, Klindt et al. 2019, Fawcett et al. 2020

Image credit: S. Munro

The Quasar Phenomenon

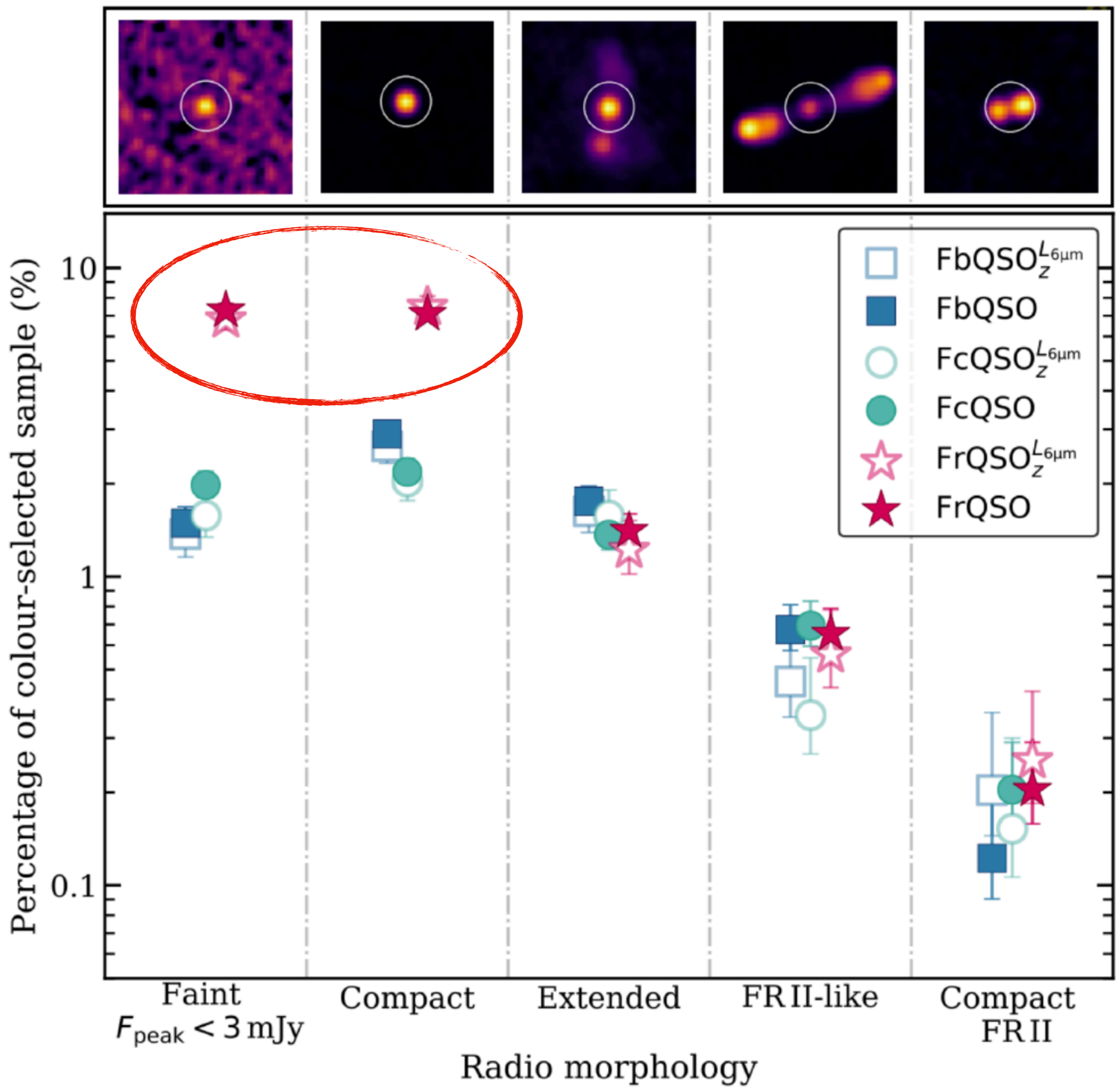
This evolutionary sequence is supported by recent observations of radio morphologies



Klindt et al. 2019

The Quasar Phenomenon

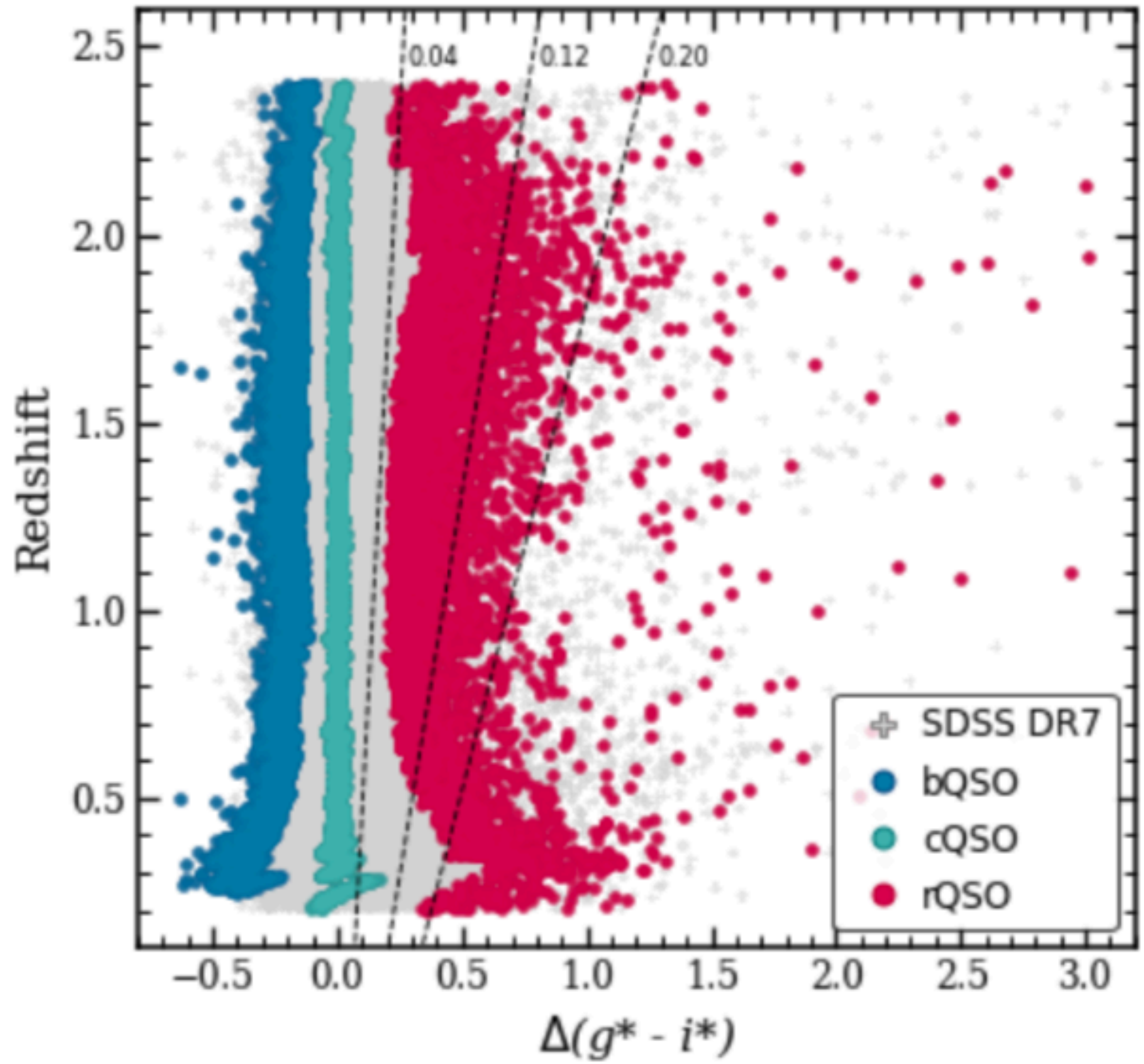
This evolutionary sequence is supported by recent observations of radio morphologies



Klindt et al. 2019

The Quasar Phenomenon

All large scale spectroscopic surveys use optical color criteria to select quasars and may therefore miss the very red quasars



Klindt et al. 2019

Quasar Feedback: Broad Absorption Lines

A fraction of quasars show direct evidence of powerful outflows as broad, blue-shifted absorption lines.

These complex absorption lines can constrain the physical conditions of the outflow
e.g. Arav et al. 2013; Leighly et al. 2018

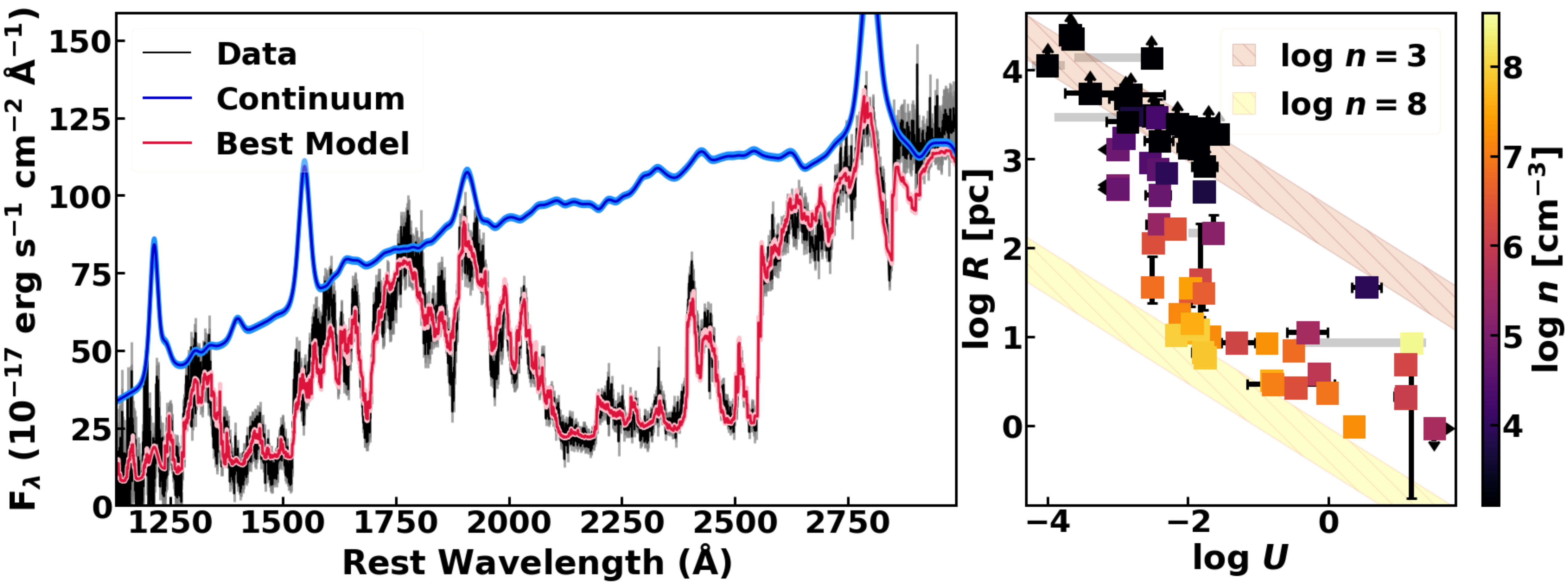


Figure courtesy of Karen Leighly

Quasar Feedback: Broad Absorption Lines

Many BAL quasars are missed in optical surveys due to the change in colors

~30% in specific survey of red quasars (Fynbo et al. 2013, Krogager et al. 2015, 2016)

~60% by Glikman et al. 2012

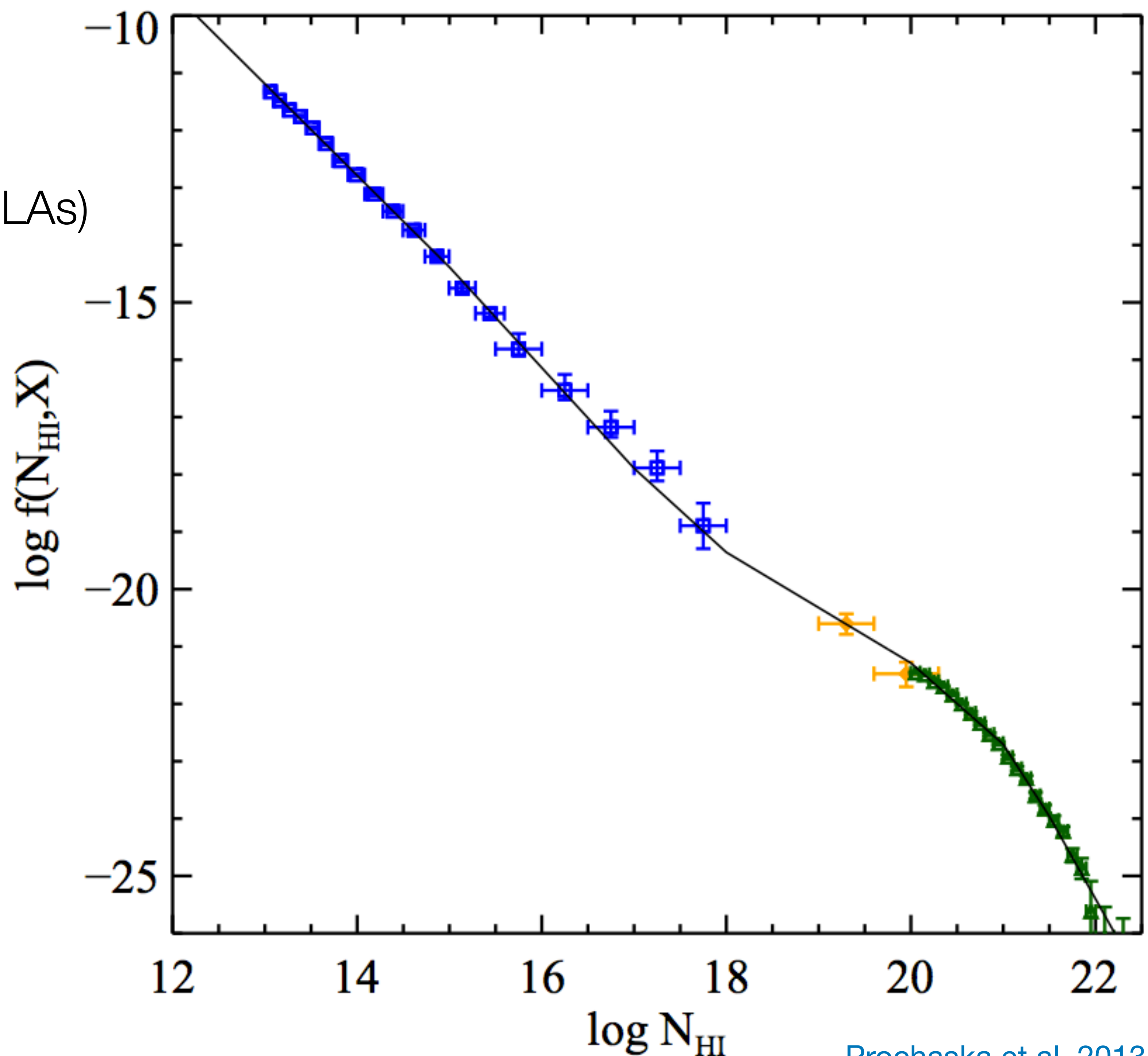
Both of these surveys rely on infrared selection of quasars

Quasars as Cosmological Probes

From the Intergalactic medium to the circumgalactic medium

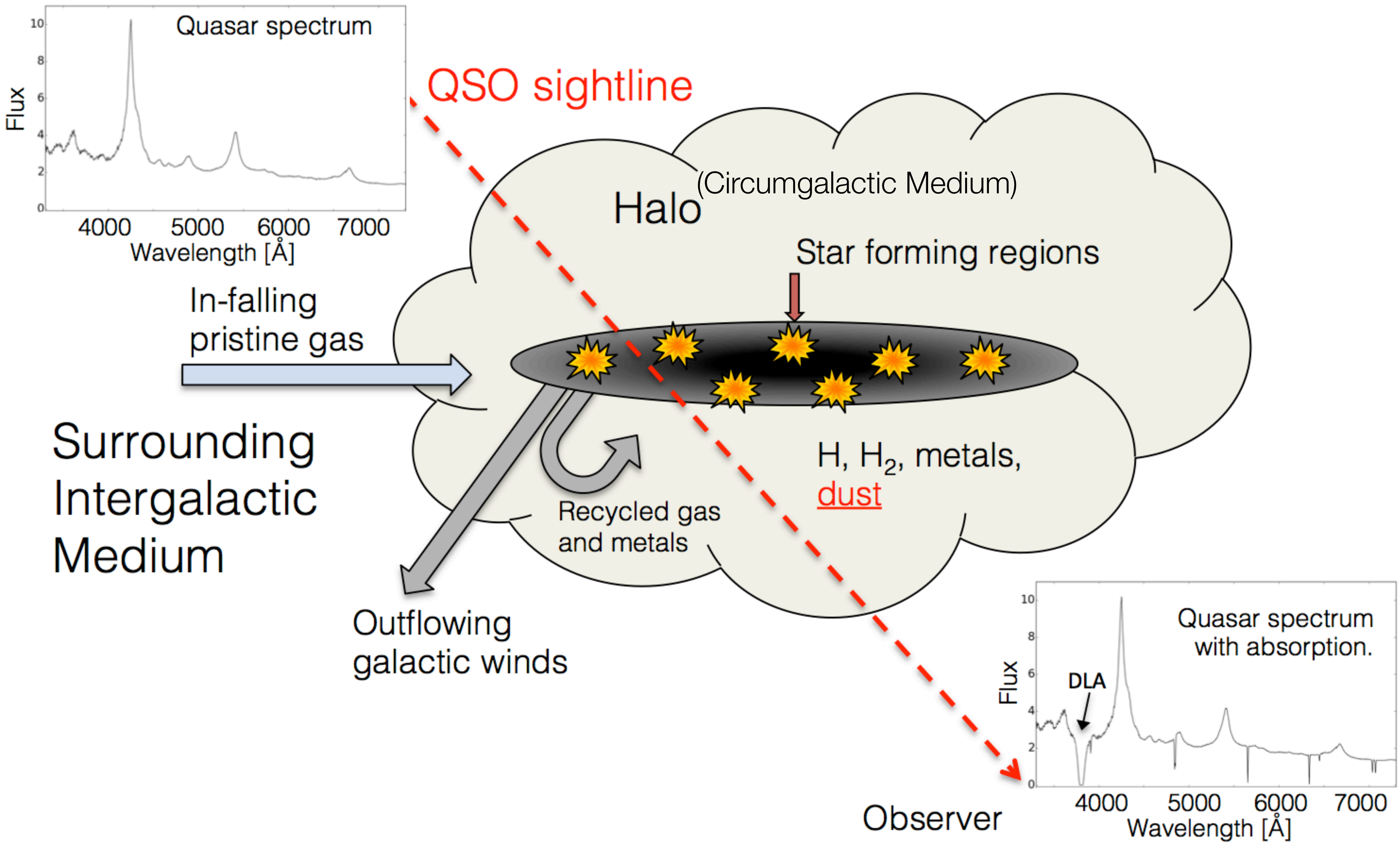
Lyman Limit Systems (LLS)
log $N_{HI} \gtrsim 17$

Damped Lyman-α Absorbers (DLAs)
log $N_{HI} \gtrsim 20.3$



Prochaska et al. 2013

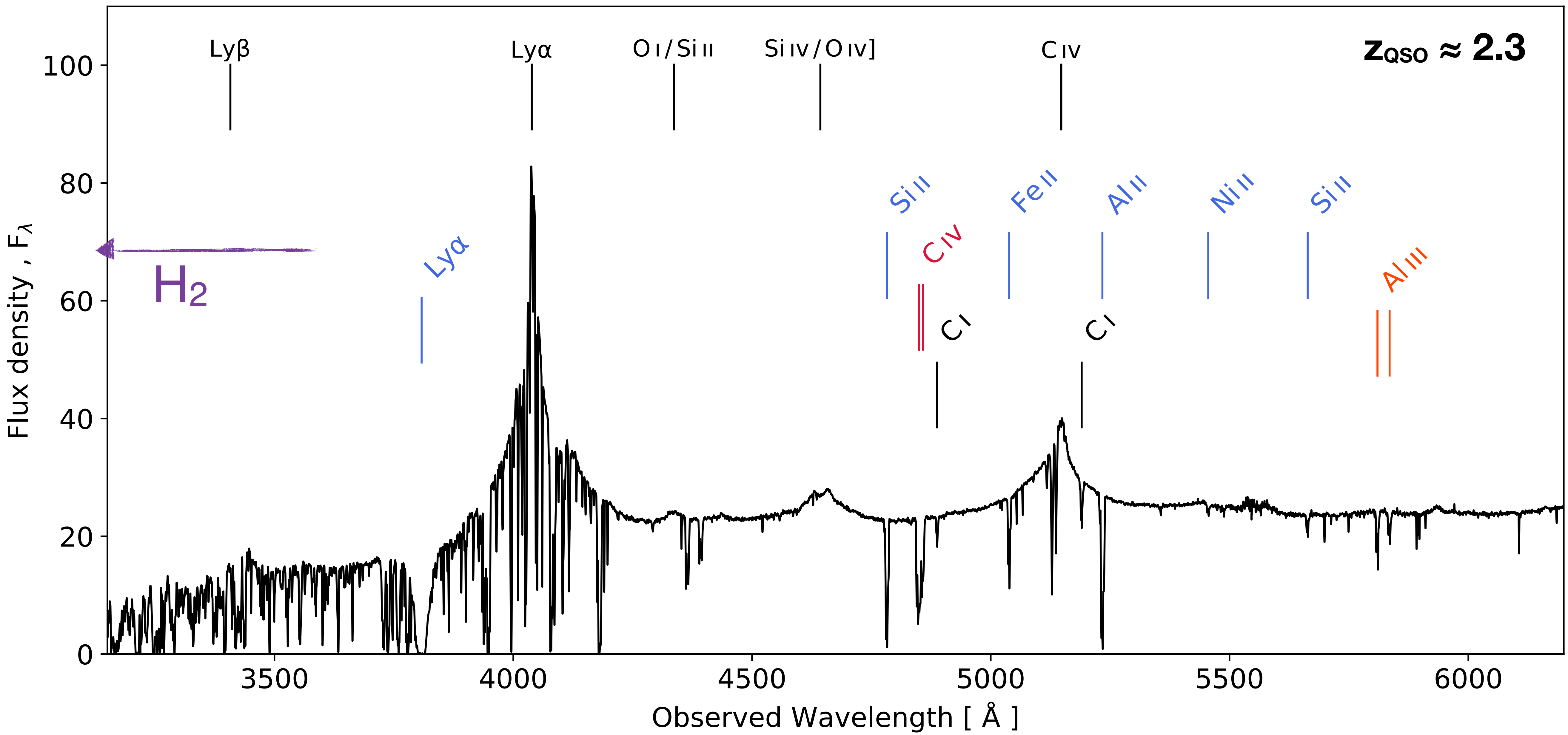
Quasars as Cosmological Probes



What are DLAs?

HI-selected absorbers trace neutral gas and the associated metals (neutral and ionized).

Historical definition:
$N_{HI} > 2\times10^{20}$ cm^{-2}

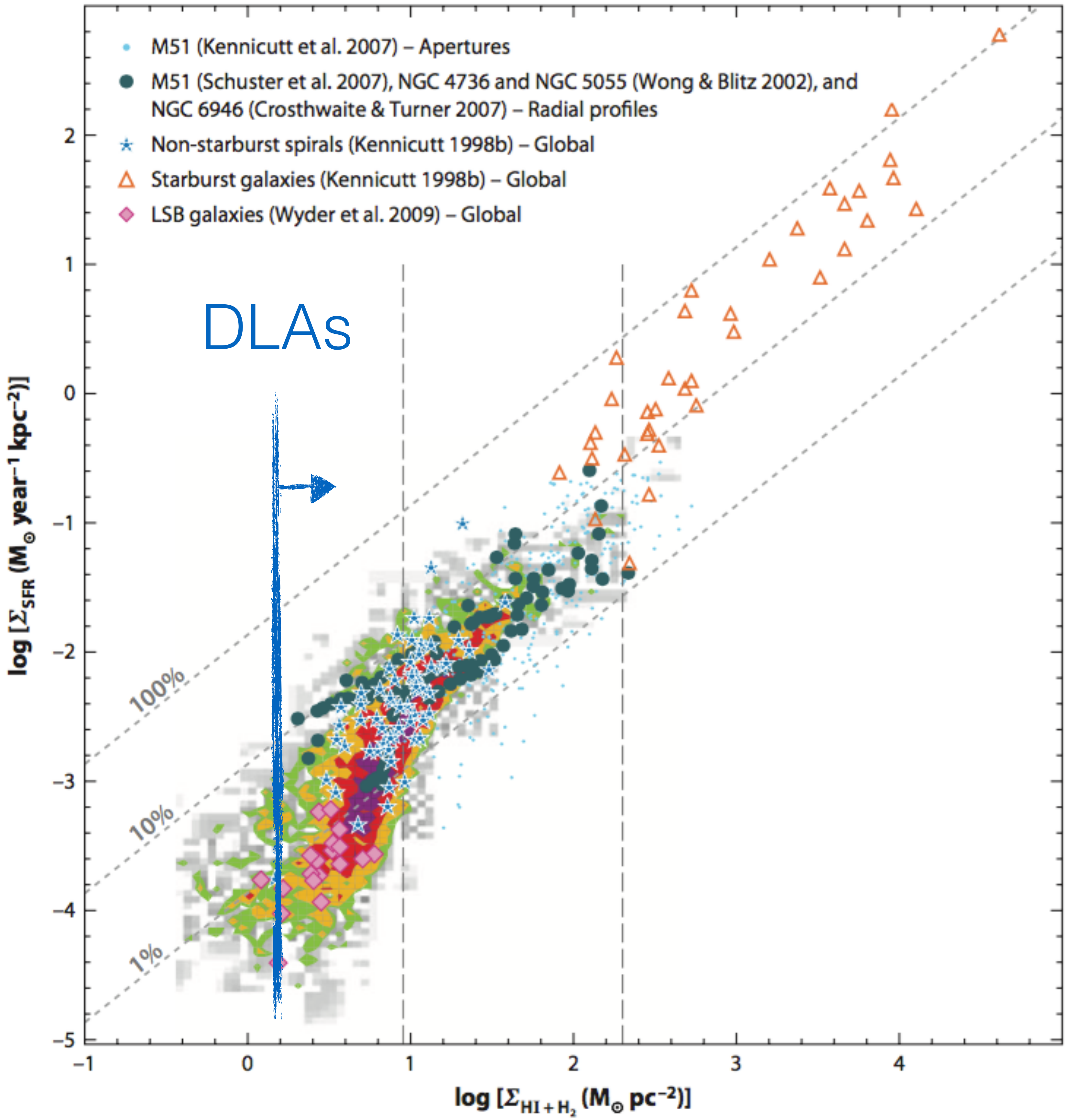


Star formation is related to the **gas density**

DLAs probe similar gas columns as local galaxies with active star formation.

And due to the very high column density, the gas is mostly neutral.

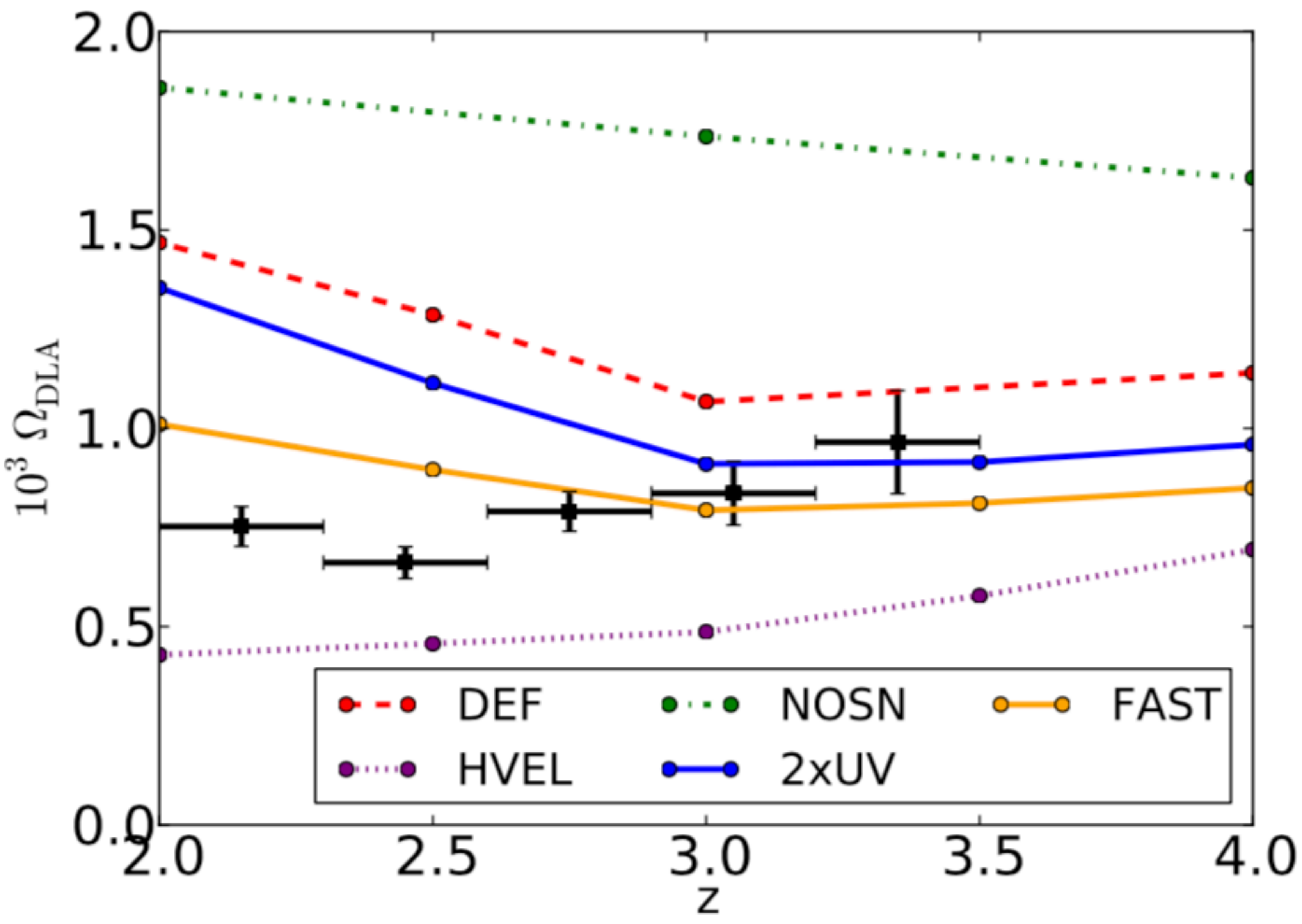
DLAs: $N_{HI} > 2\times10^{20}\ cm^{-2}$



Kennicutt & Evans 2012

DLAs Probe the Majority of HI at high redshift

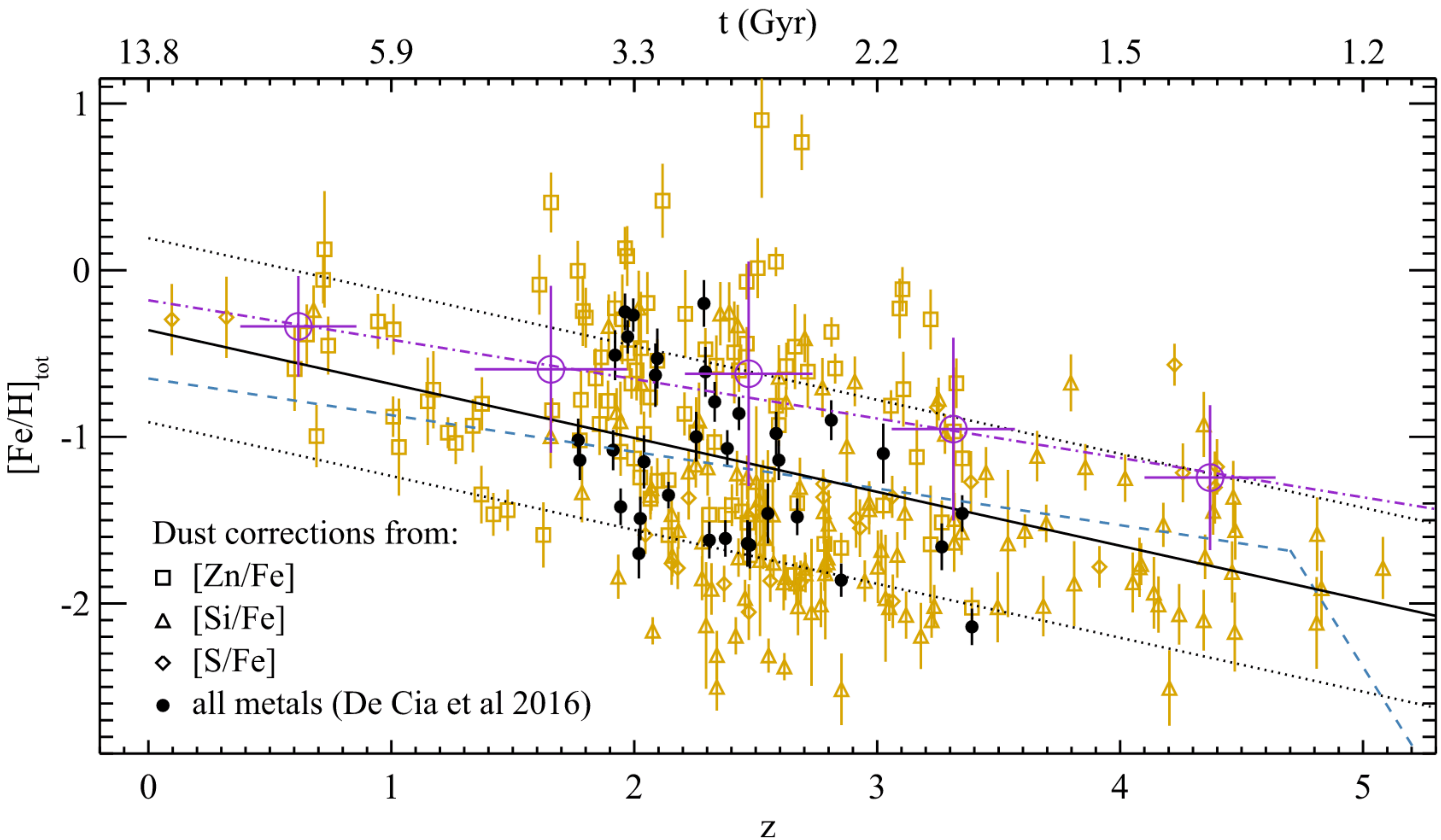
Simulations still struggle to reproduce the redshift evolution



Bird et al. 2014; see also Hassan et al. 2020

Metallicity evolution of the neutral gas

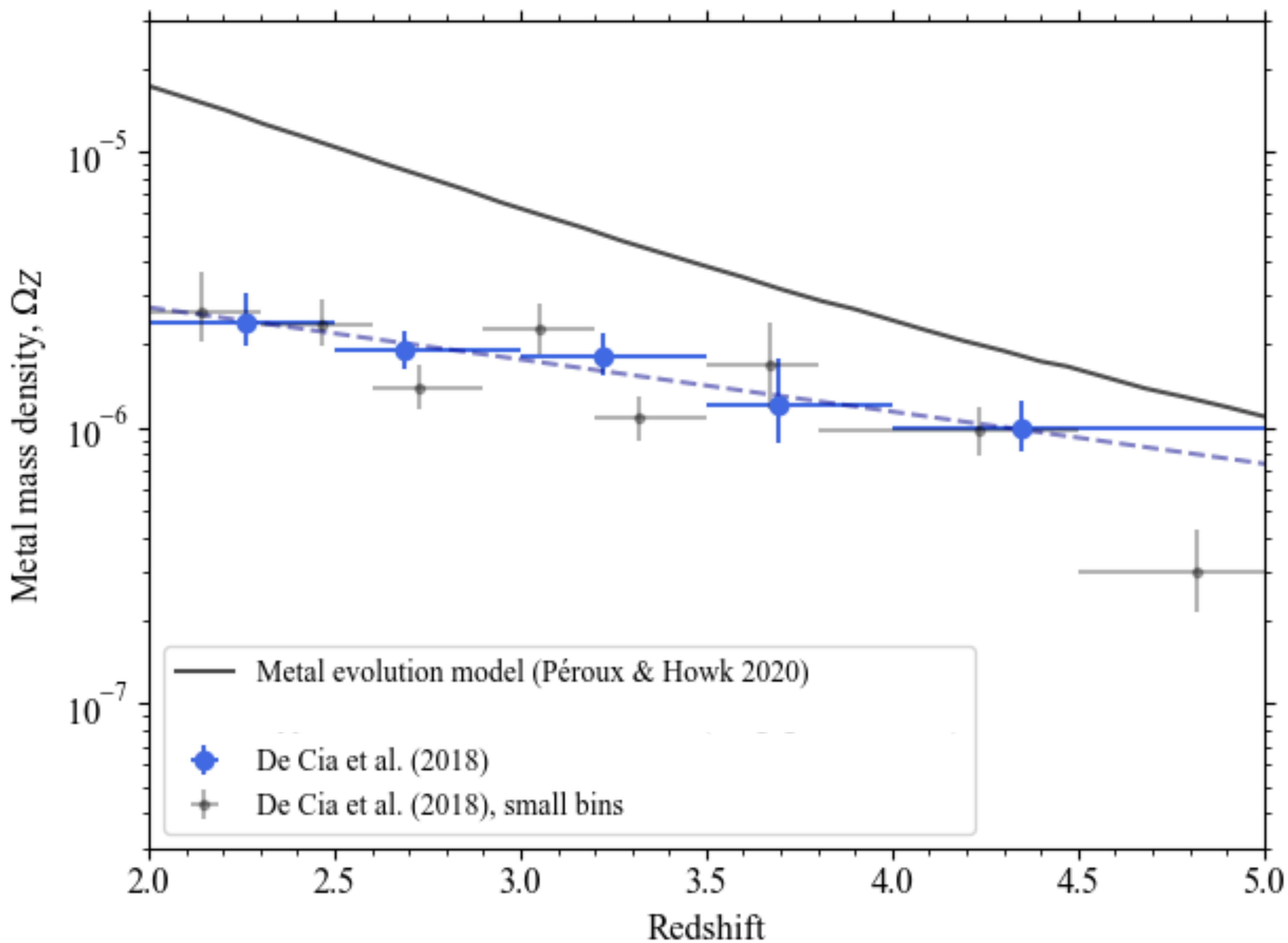
DLAs give us insight into the chemistry of the neutral ISM at high redshift



De Cia et al. 2018

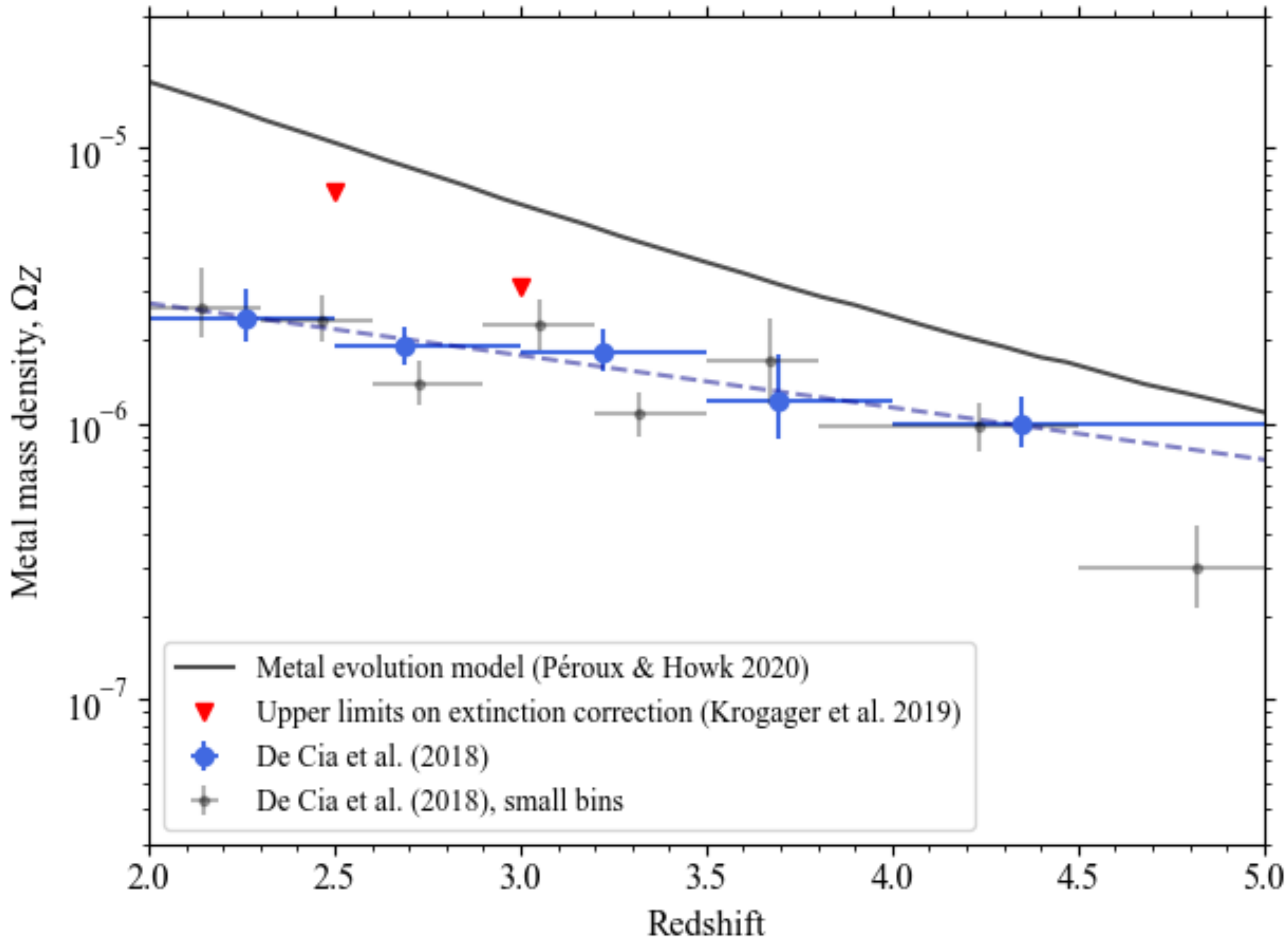
Metallicity evolution of the neutral gas

We can study the evolution of the mass density of metals



Metallicity evolution of the neutral gas

We can study the evolution of the mass density of metals
but results depend strongly on selection biases

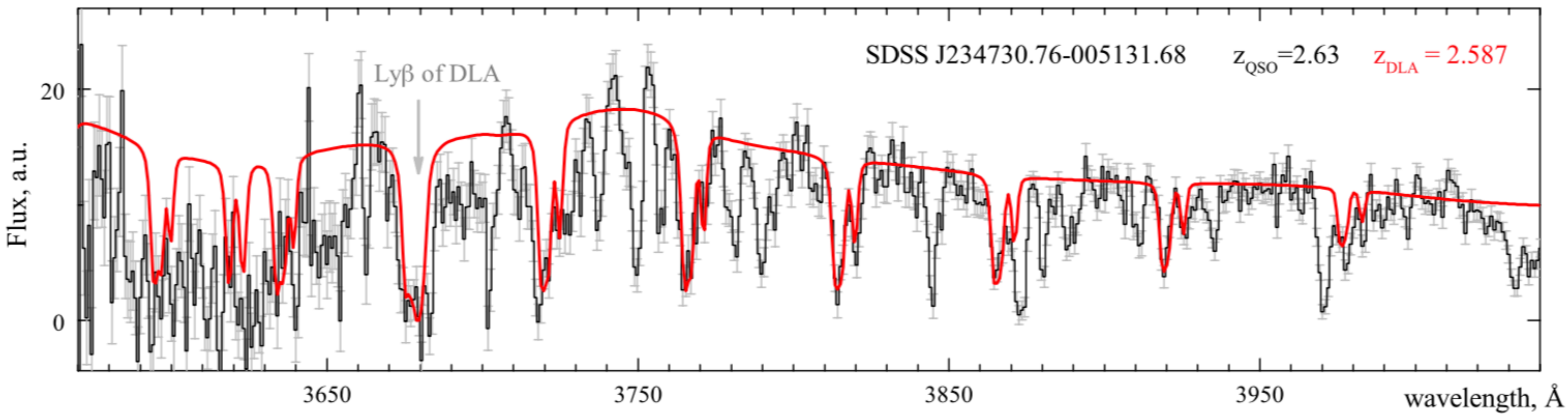


Physical Conditions in High-z ISM

We can identify molecular hydrogen directly in spectra from SDSS

Together with other neutral species, such as CI, we can study the physical conditions in the absorbing medium (density and temperature).

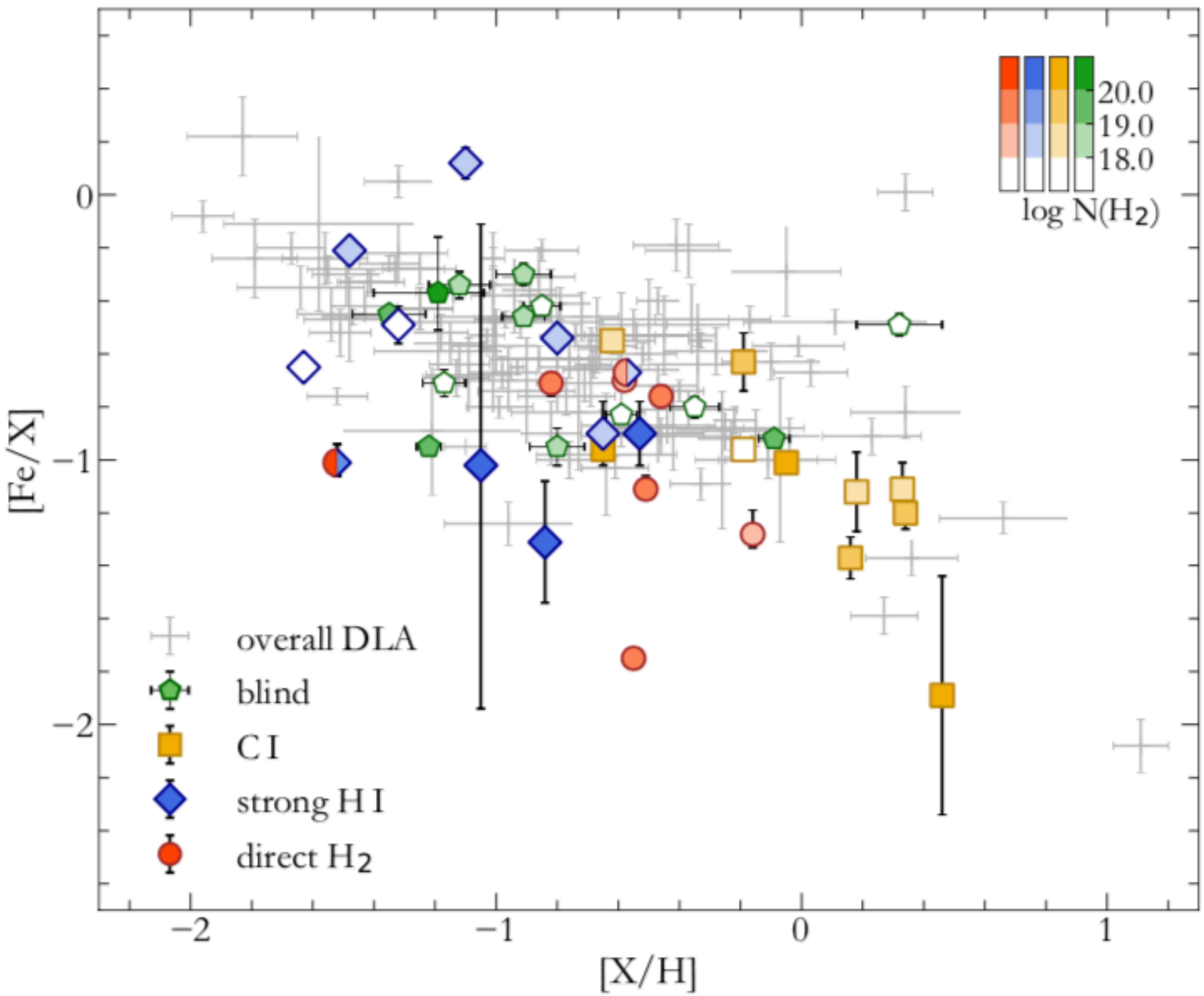
(Balashev+2014, Ledoux+2015, Noterdaeme+2018)



Balashev et al. 2014

Physical Conditions in High-z ISM

The cold gas phase is more dusty: higher levels of dust depletion



dust depletion indicator

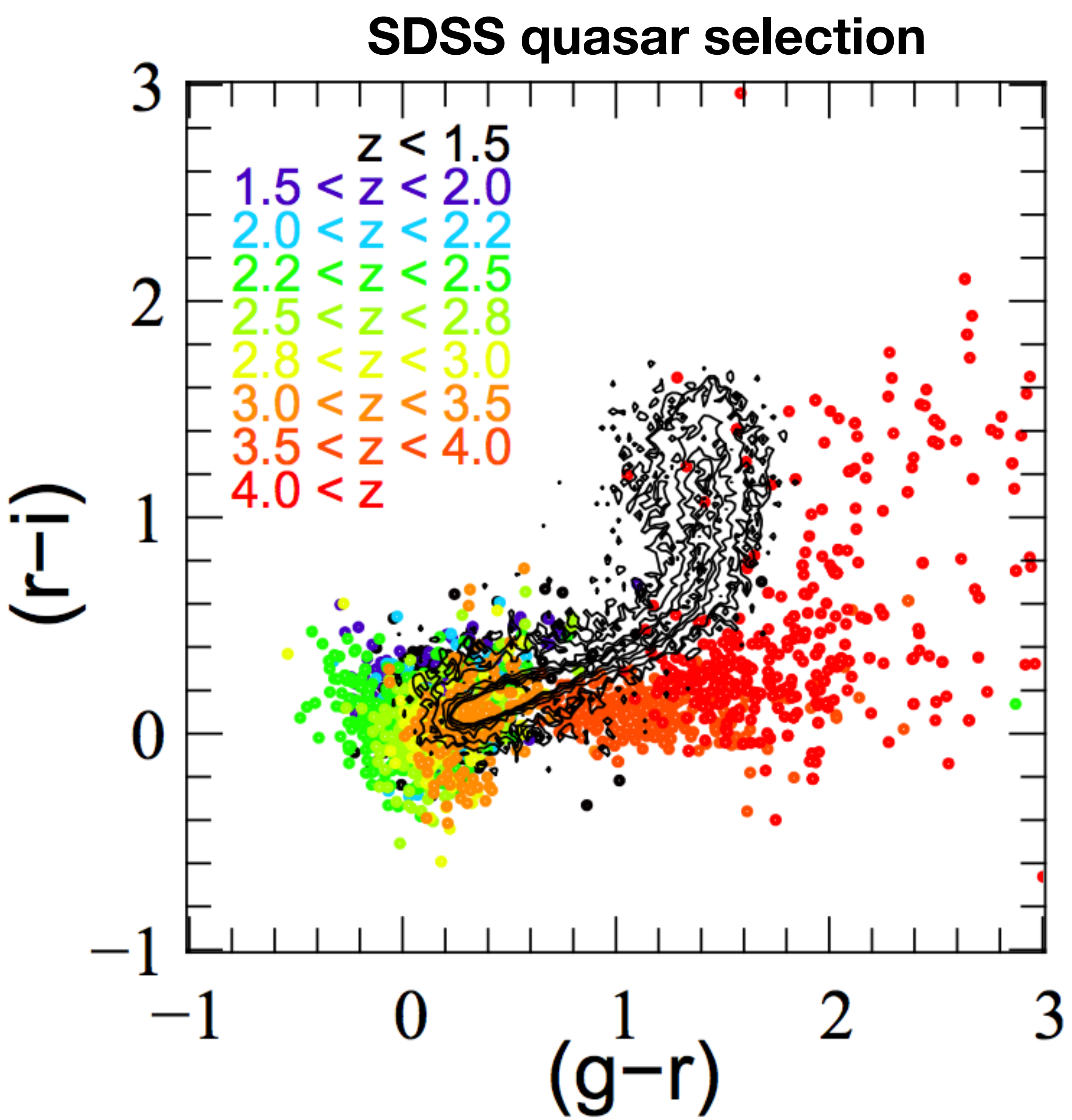
metallicity indicator

more dusty

Balashev al. 2019

Optical Selection of Quasars

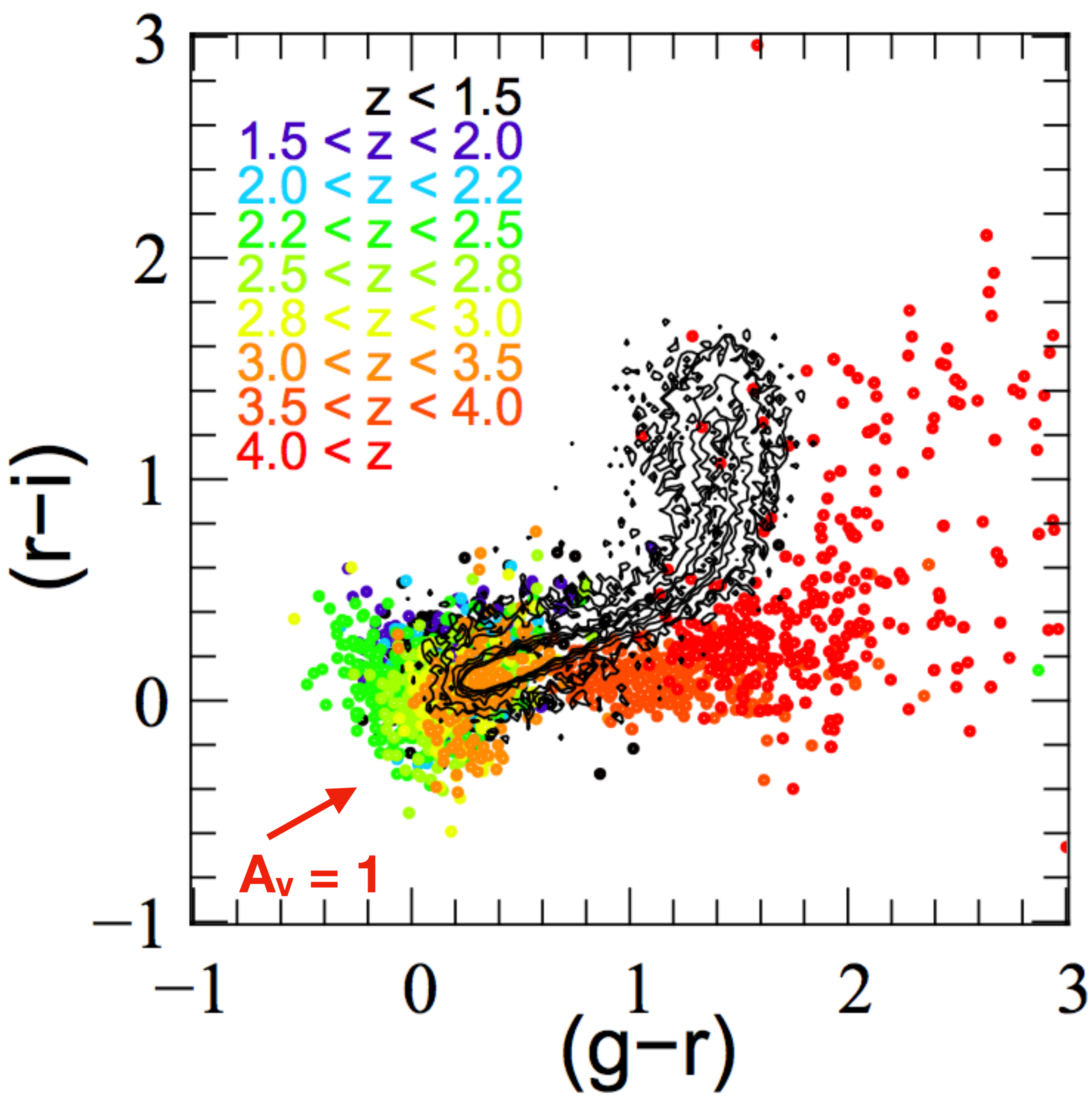
Current large-scale spectroscopic surveys rely on optical color criteria



Pâris al. 2012

Optical Selection of Quasars

Current large-scale spectroscopic surveys rely on optical color criteria
dust reddening makes the selection less complete



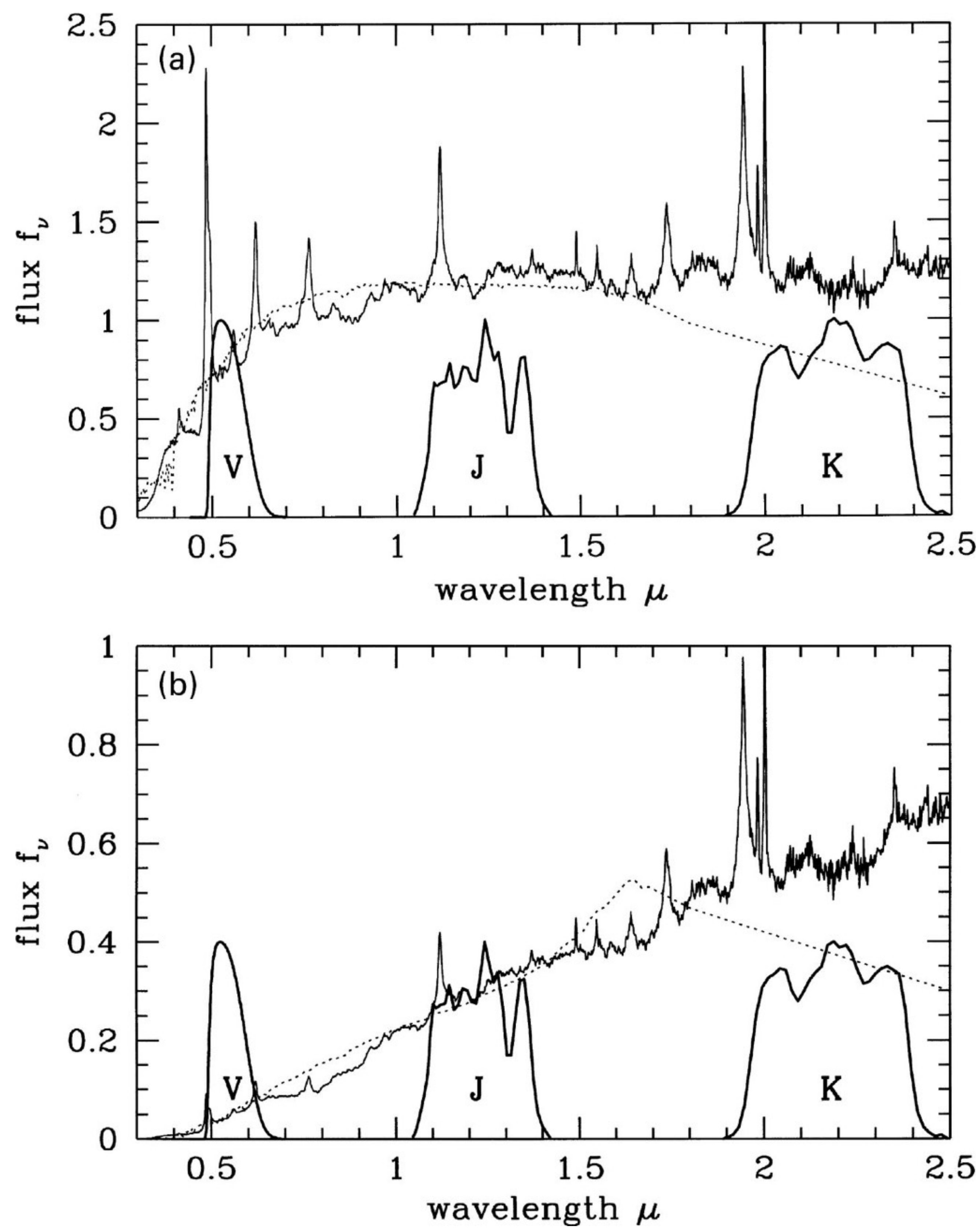
Pâris al. 2012

Multi-wavelength Quasar Selection

KX-selection

(Warren et al. 2000)

Very powerful method
but deep NIR data are scarce



Multi-wavelength Quasar Selection

KX-selection

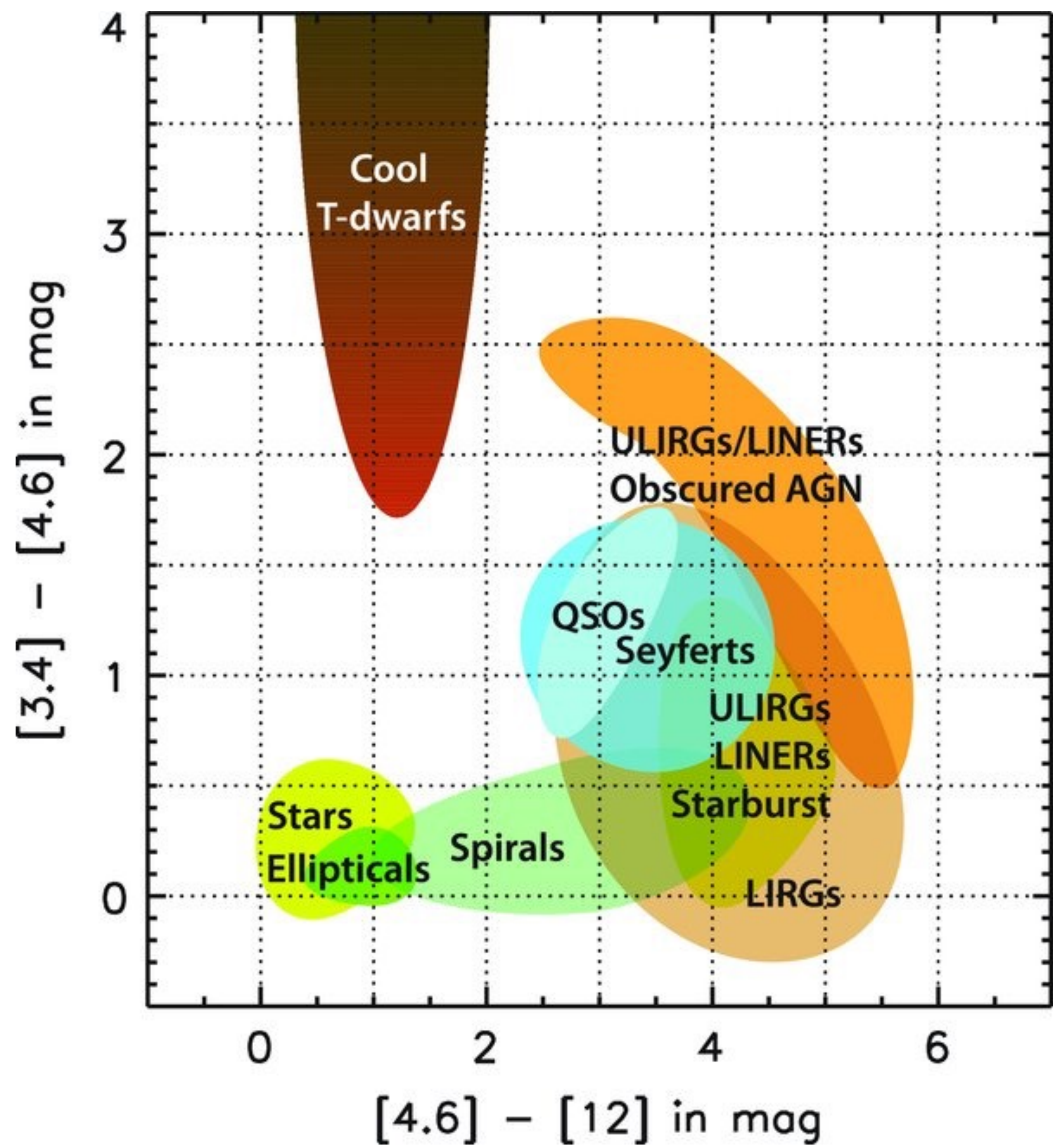
(Warren et al. 2000)

Spitzer/WISE

(e.g., Lacy et al. 2004; Stern et al. 2012)

All-sky, very efficient and complete in terms of colors.
But WISE data are not very deep.

Only ~75% of SDSS sources have a match in WISE



Wright et al. 2010

Multi-wavelength Quasar Selection

KX-selection

(Warren et al. 2000)

Spitzer/WISE

(e.g., Lacy et al. 2004; Stern et al. 2012)

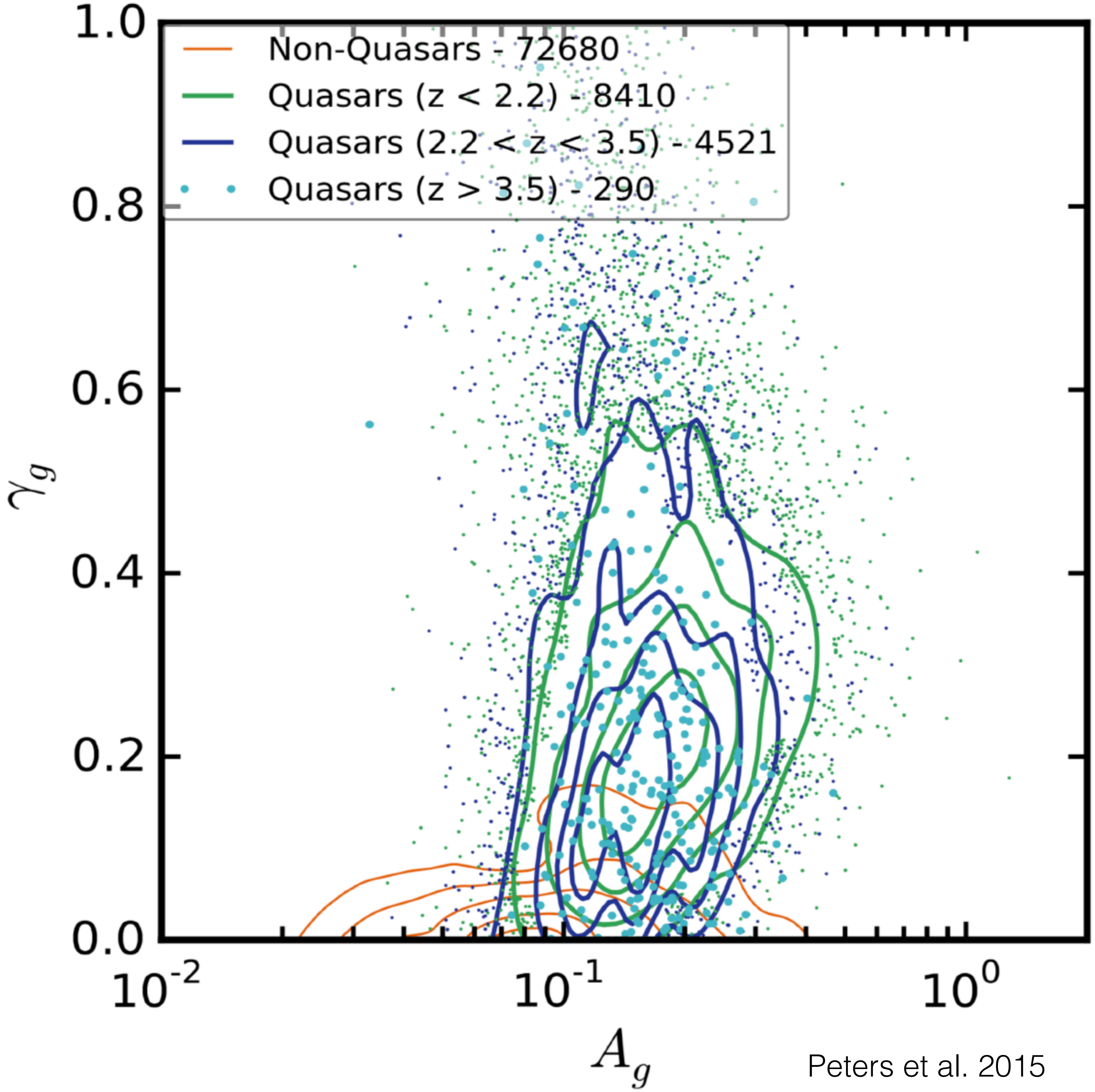
Variability

(e.g., Graham et al. 2014; Peters et al. 2015; Kozłowski et al. 2016)

Relies on differences in the variability structure function between stars and quasars

Highly complete but may depend on color

$$V(\Delta t) = A\,(\Delta t)^{\gamma}$$



Peters et al. 2015

Multi-wavelength Quasar Selection

KX-selection
(Warren et al. 2000)

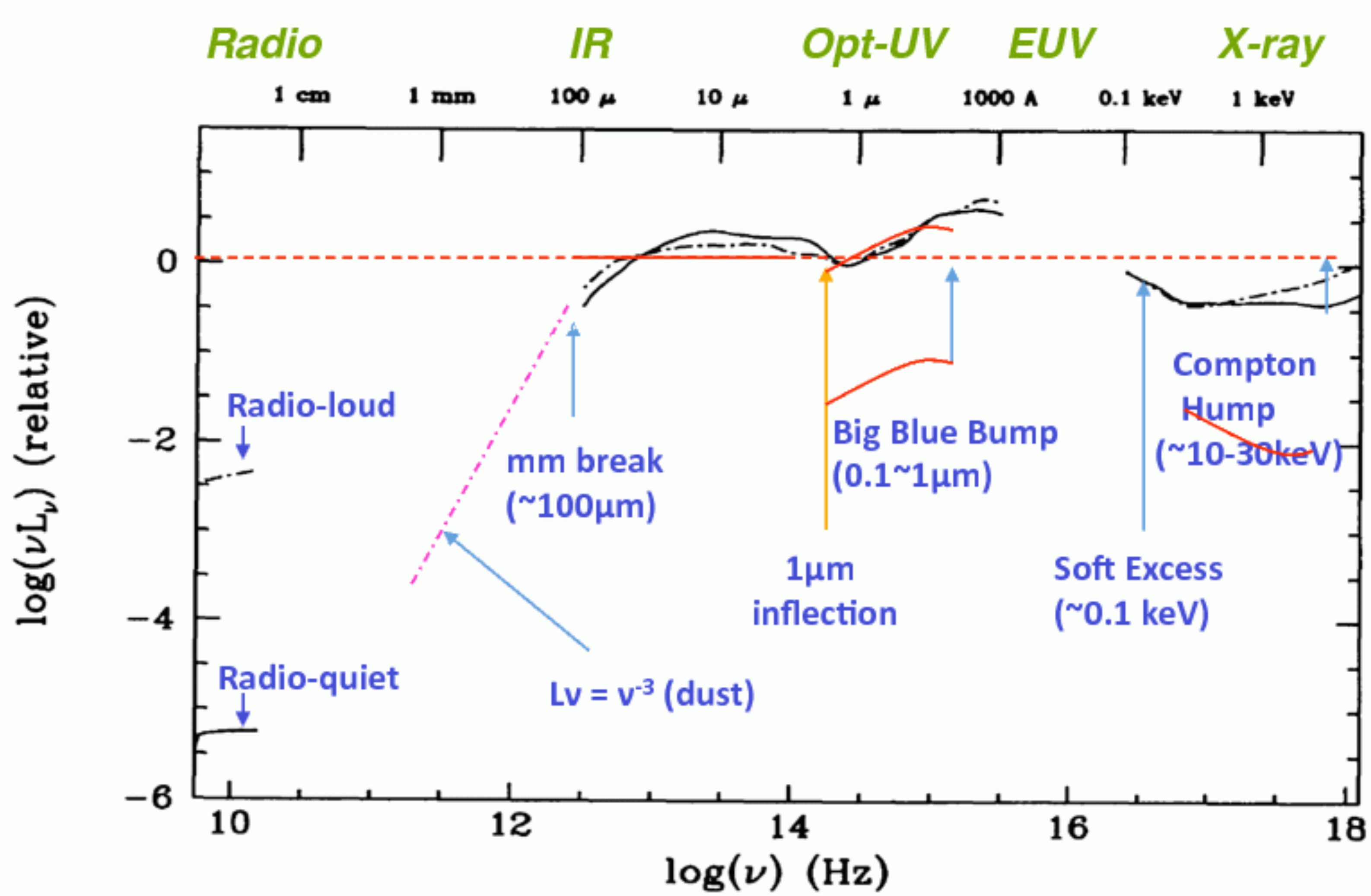
Spitzer/WISE
(e.g., Lacy et al. 2004; Stern et al. 2012)

Variability
(e.g., Schmidt, K.B. et al. 2012; Peters et al. 2015; Kozłowski et al. 2016)

Radio
(e.g., Webster et al. 1995; White et al. 2003)
~10% are radio loud
(e.g., Balokovic et al. 2012)

X-ray
(e.g., LaMassa et al. 2013)
~30% are X-ray bright, detected in XMM
(e.g., Glikman et al. 2018)

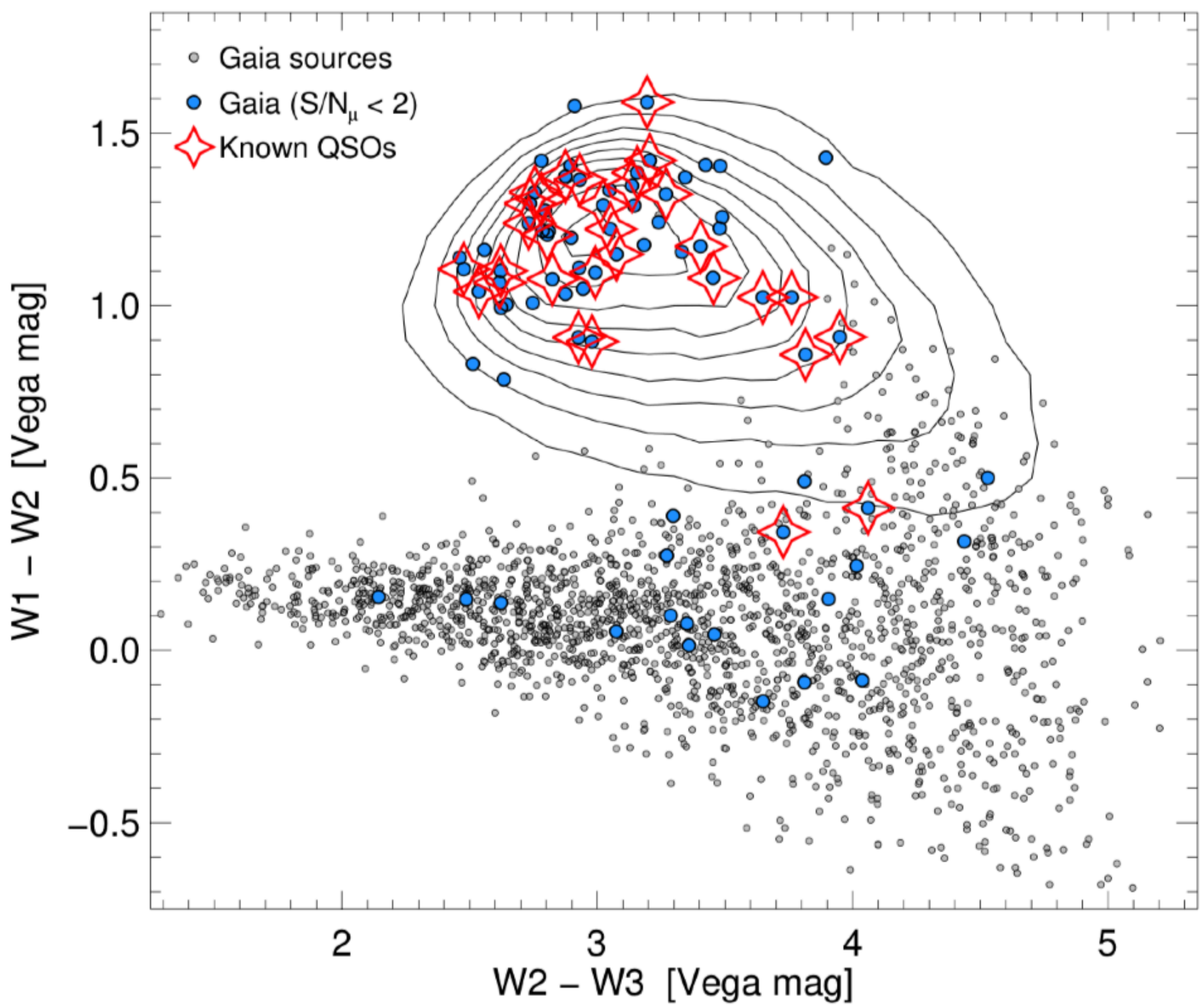
Quasar are known for being very luminous at both X-ray and radio energies

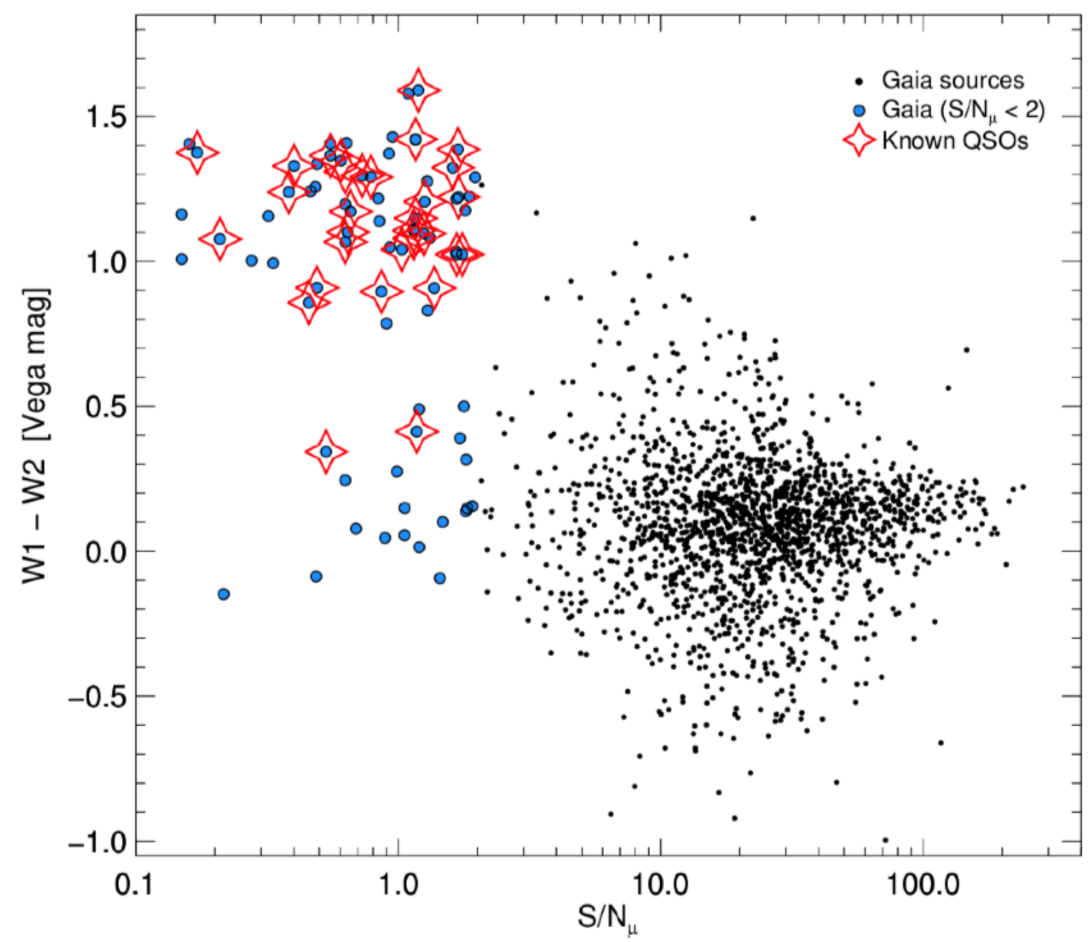


Elvis et al., 1994, ApJS, 95, 1

Astrometric Quasar Selection

Quasars are static sources in the sky and can be identified in Gaia.





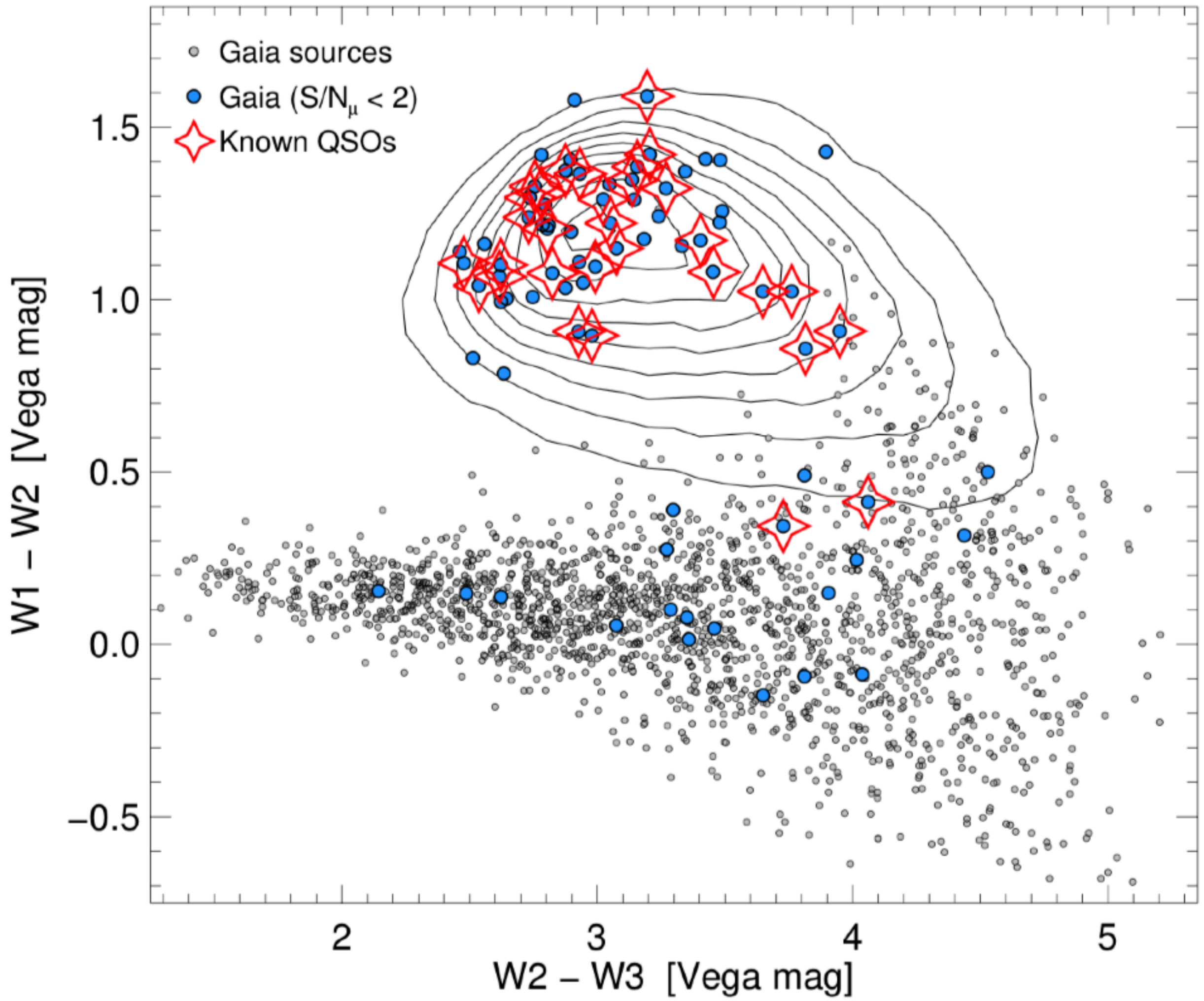
Significance of proper motion

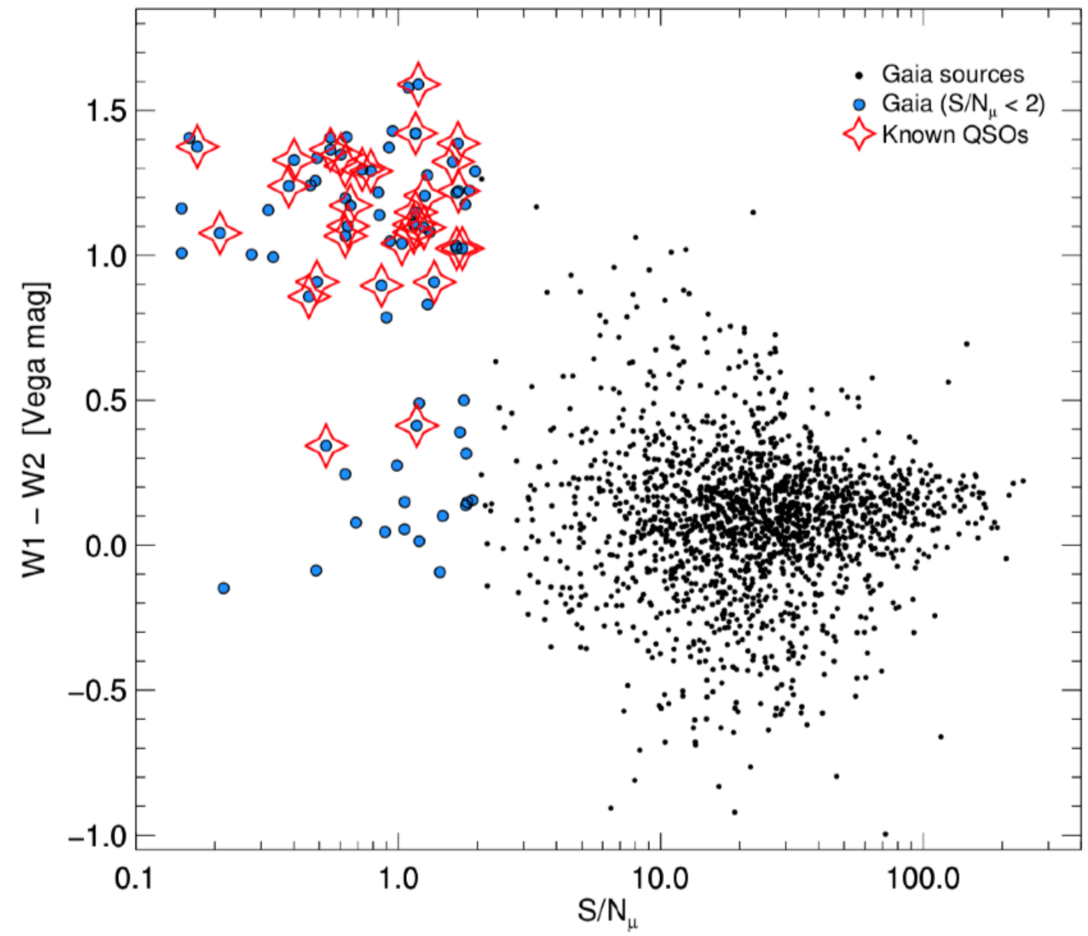
Heintz et al. 2018

Astrometric Quasar Selection

Quasars are static sources in the sky and can be identified in Gaia.

Pro: No assumption on SED shape, only flux limited in G-band



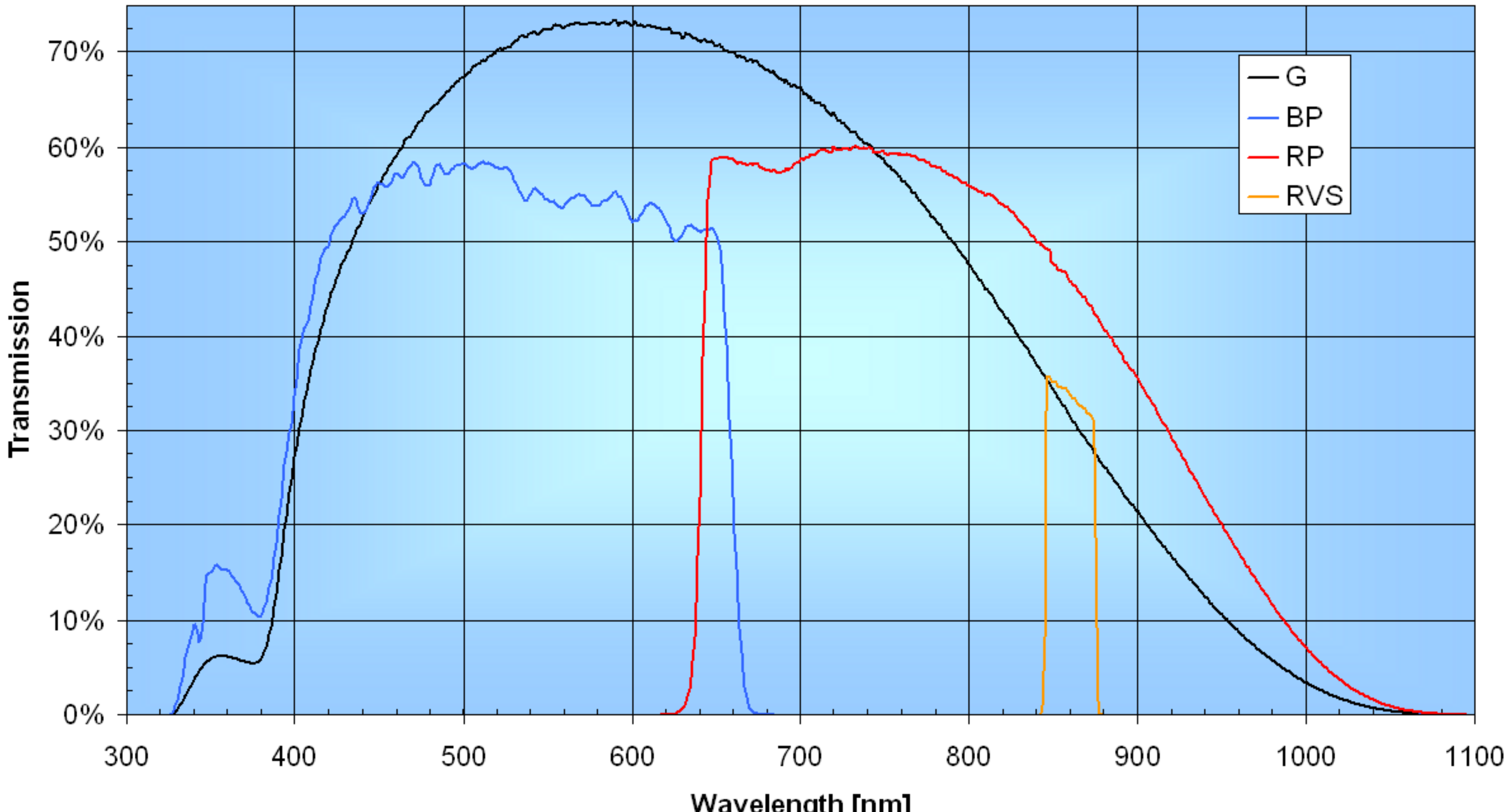


Significance of proper motion

Heintz et al. 2018

Astrometric Quasar Selection

Pro: Sensitive to a wide range of optical colors due to the broad filter of Gaia

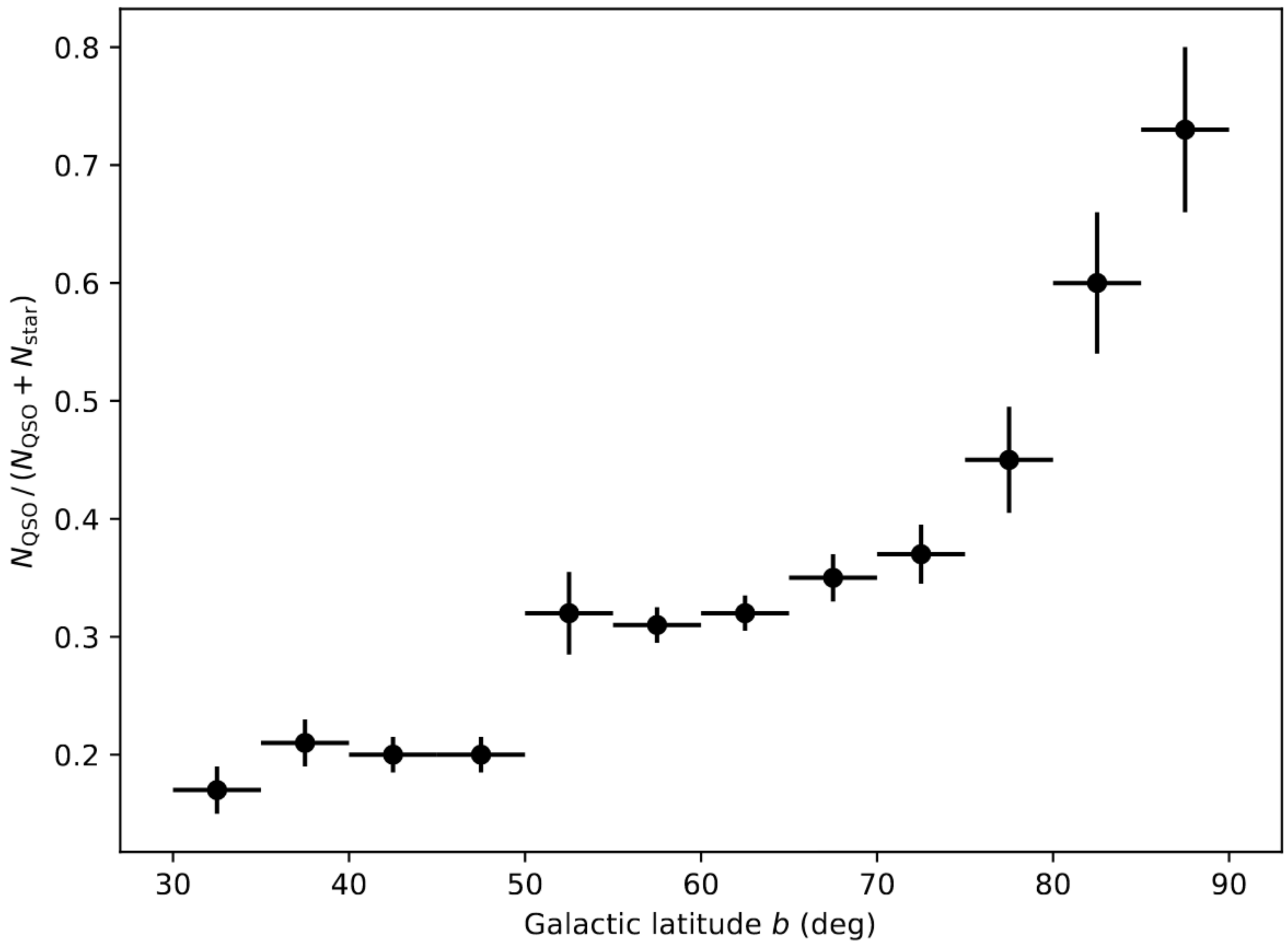


ESA/Gaia website

Astrometric Quasar Selection

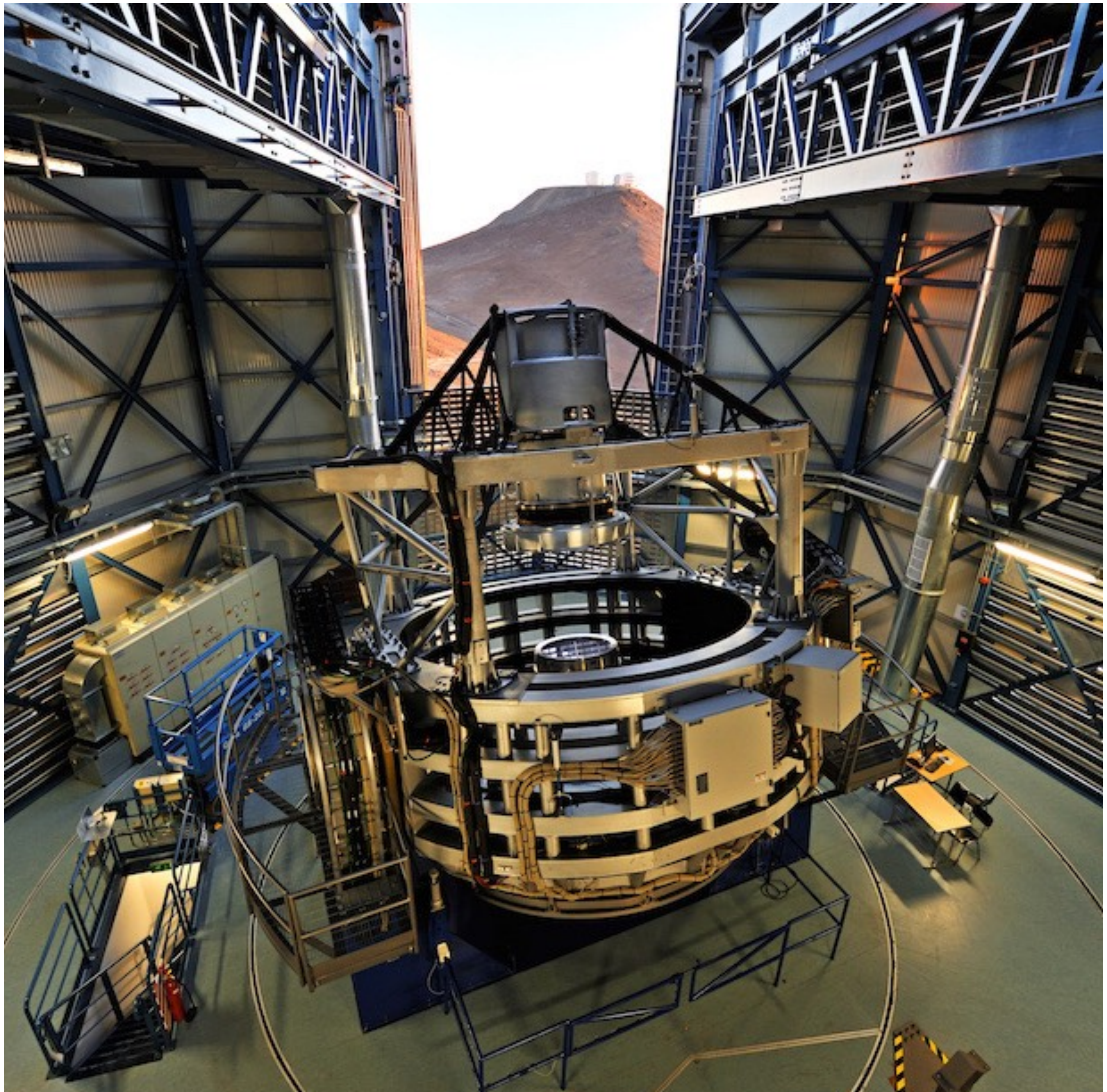
Con: Only feasible at high galactic latitude where stellar density is low

Based on DR2 — better results with new EDR3



Heintz et al. 2020

4MOST—Gaia Purely Astrometric Quasar Survey



Southern Hemisphere

4MOST—Gaia Purely Astrometric Quasar Survey

PI : J-K Krogager
J.P.U. Fynbo
K. E. Heintz
P. Noterdaeme
M. Vestergaard
P. Møller
N. Gupta
R. Srianand
J. Prochaska
S. Ellison
J. Richard
S. Lopez
T. Berg
S. Balashev
A. De Cia
C. Konstantopoulou
T. Zafar
B. Milvang-Jensen
L. Christensen
C. Ledoux
E. Glikman
F. Bauer
K. Leighly
S. Geier
T. Tripp
L. Morabito
D. Terndrup
H. Choi
M. Pettini
D. Kosenko
K. Telikova
K. B. Schmidt
S. Raimundo

Southern Hemisphere

CoIs from 13 countries

4MOST: The Basics

2400 spectra at once

~1600 at low resolution (R ~ 4000-7700)
Covering 370-950 nm

~800 fibres for high resolution (R ~ 20,000)
393 – 435 ; 516 – 573 ; 610 – 679 nm

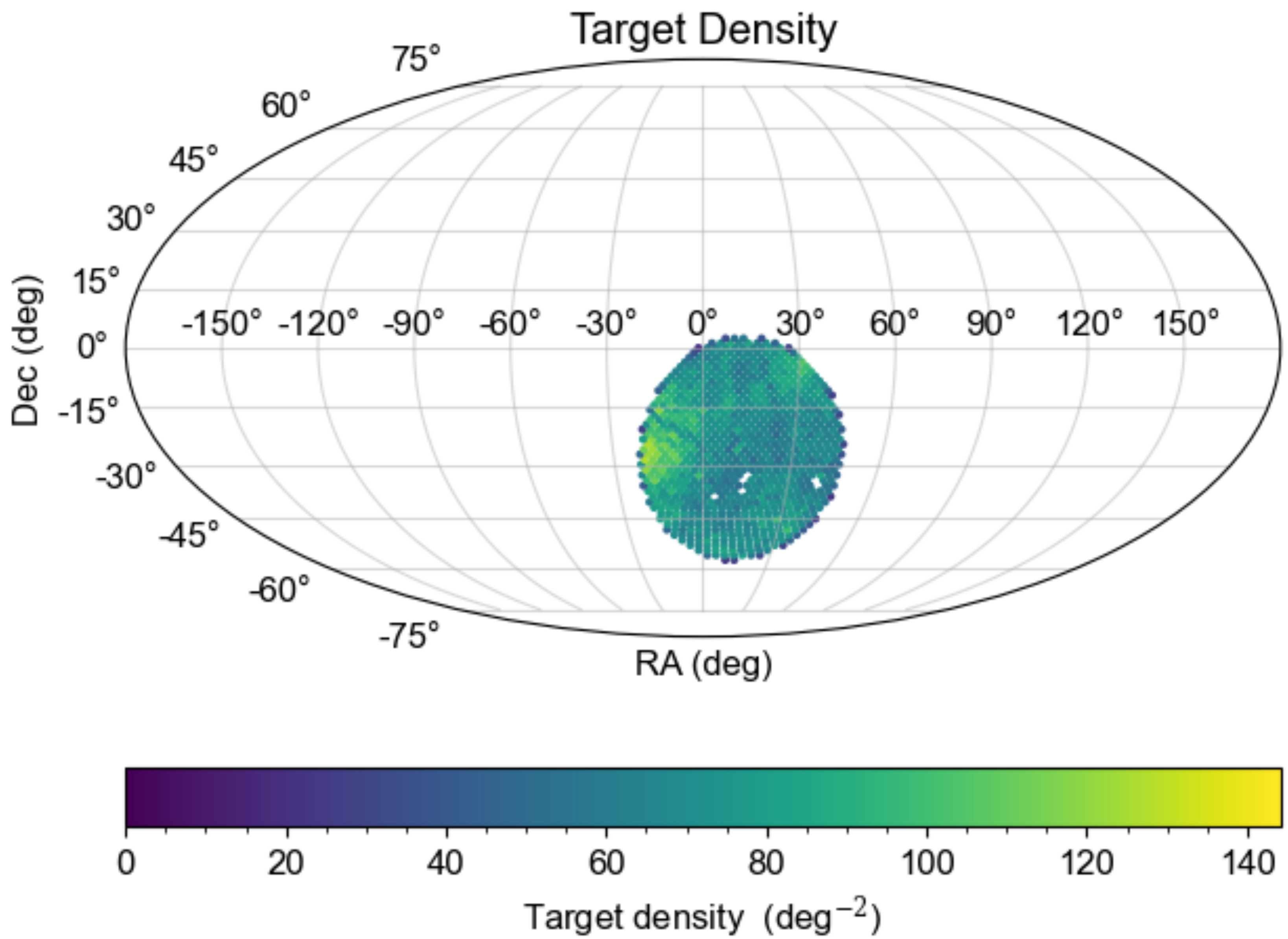
Magnitude limit at ~20 mag (AB) for SNR / Å ~ 10

First light expected ~2023

Southern Hemisphere

4MOST—Gaia Purely Astrometric Quasar Survey

We will observe a total of ~100,000 quasars over 5 years



4MOST—Gaia Purely Astrometric Quasar Survey

Main goals:

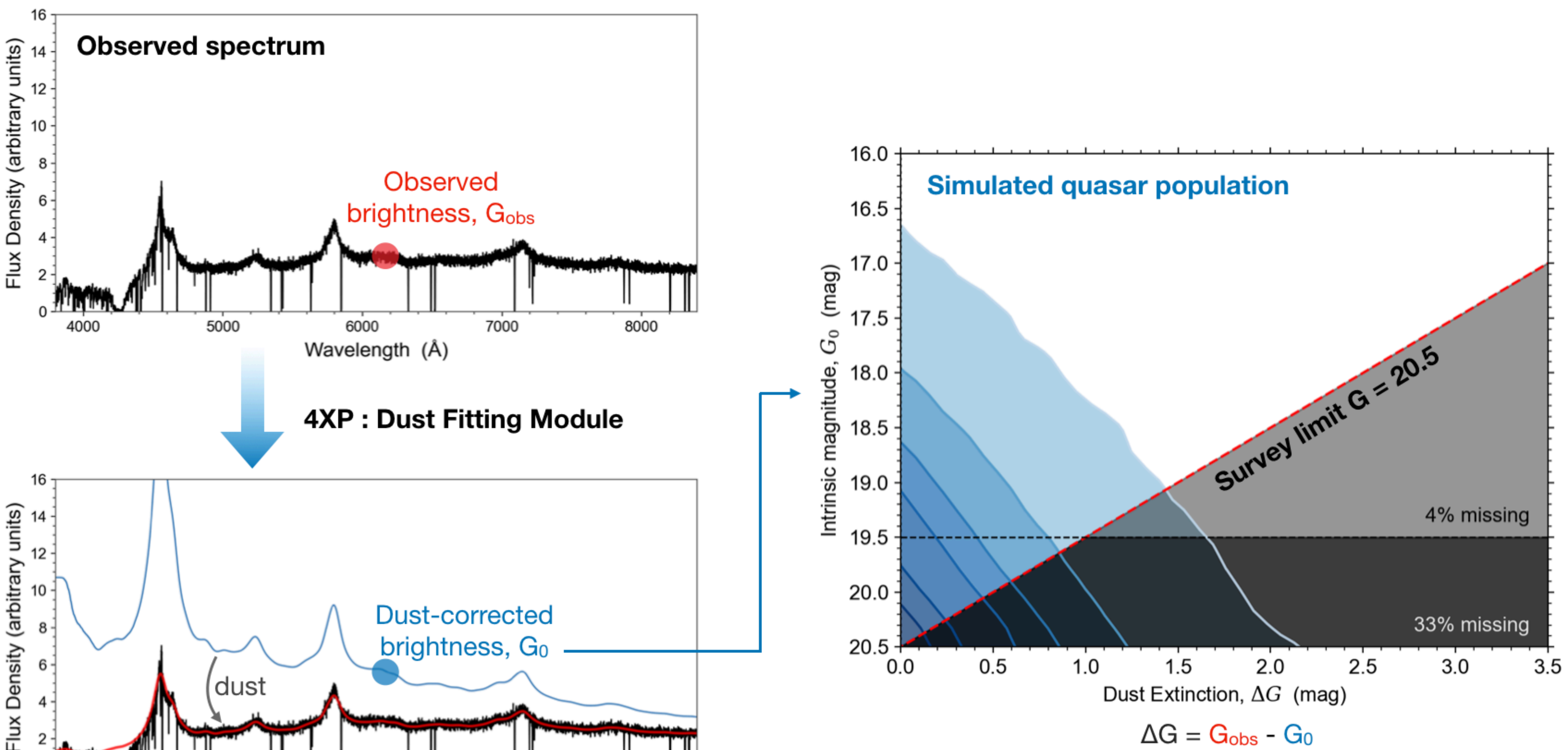
- To quantify DLA statistics (NHI and metals) with no dust bias
- To identify cold gas absorbers
- Obtain robust fraction of BAL quasar and red quasars
- Derive detailed outflow properties from BAL quasars
- To identify rare types of quasars

Additional science:

- Quasar variability in color un-biased sample
- Highly complete comparison sample to test various selection methods

4MOST—Gaia Purely Astrometric Quasar Survey

Correcting for dust obscuration: the main principle



4MOST—Gaia Purely Astrometric Quasar Survey

Based on our pilot study at the North Galactic Pole
and a small sample of IR-selected quasars, we can test our concept.

64 Gaia-selected quasars (sample G; $G < 20$) (Heintz et al. 2018)

33 Infrared-selected quasars (sample J; $J < 20$) (Heintz et al. 2016)

We define 'red quasars' as having $A_V > 0.15$ mag:

8/64 red quasars in sample G
12/33 red quasars in sample J

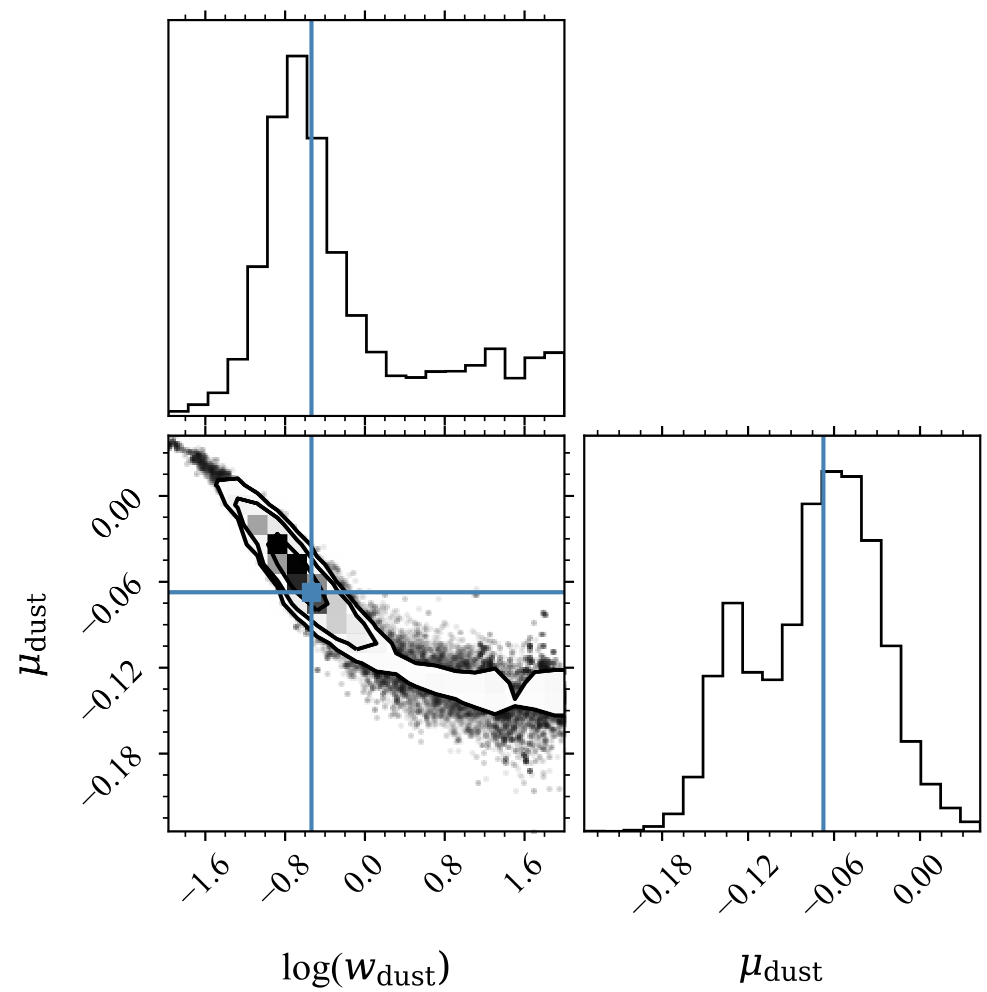
We can then model the intrinsic quasar population (Krogager et al. 2019)
and the distribution of dust reddening in order to match the statistics

4MOST—Gaia Purely Astrometric Quasar Survey

We assume an exponential dust reddening distribution (following Krawczyk et al. 2015):

$$p(E_{B-V}|w_{\rm dust}, \mu_{\rm dust}) = \frac{1}{w_{\rm dust}} e^{(E_{B-V} - \mu_{\rm dust})/w_{\rm dust}}$$

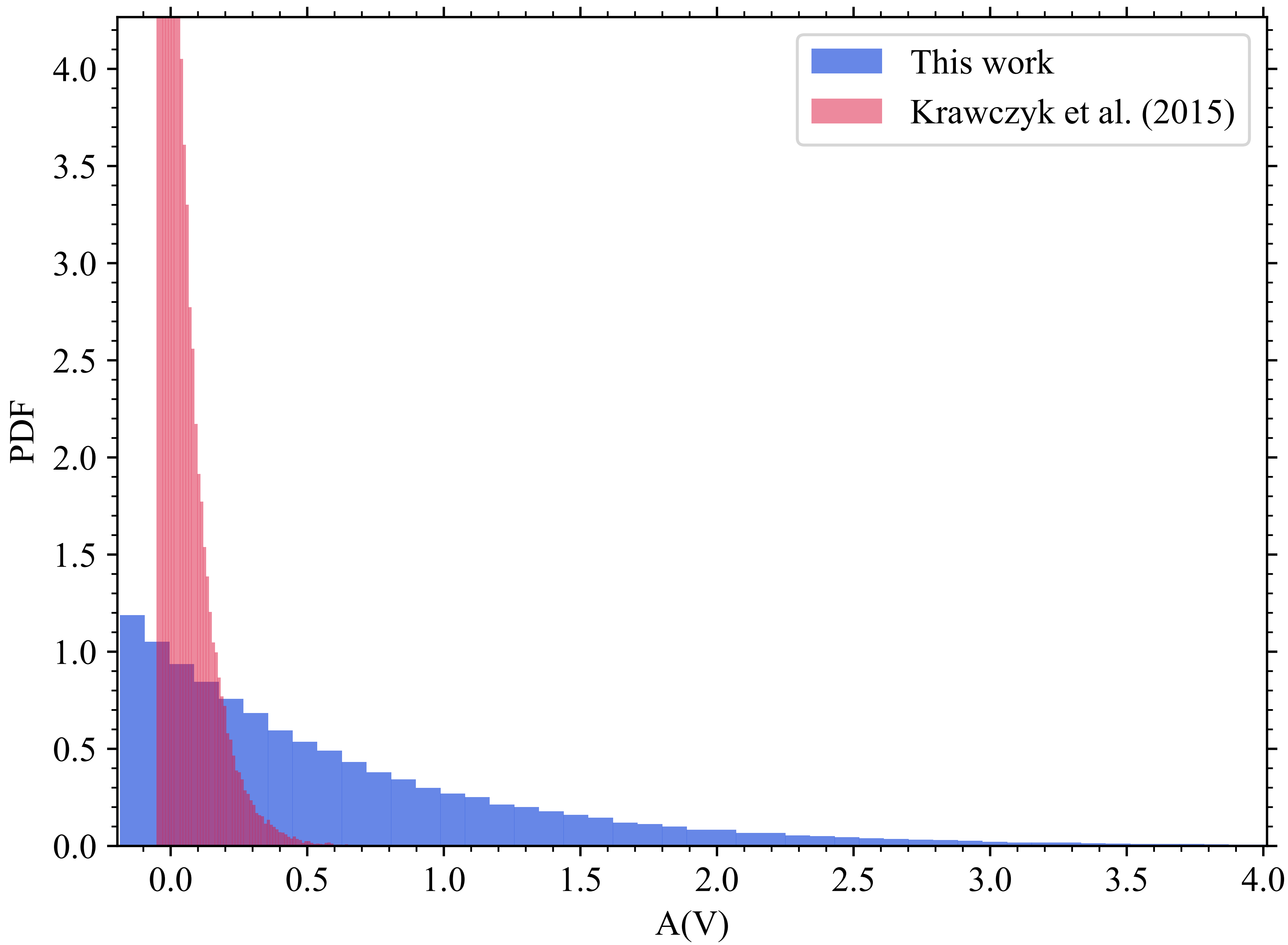
We can the randomly assign a value of $E_{B\text{-}V}$ to our modelled quasar population and obtain best-fit w and μ :



4MOST—Gaia Purely Astrometric Quasar Survey

The best-fit intrinsic distribution of reddening is much wider than what Krawczyk et al. (2015) find but results are still tentative.

Warning — Low number statistics!



Møller et al., in prep.

Summary

Quasars are extremely important probes of the universe!

They allow us to study cosmological parameters and assumptions,
large-scale structure and intervening gas inside and around galaxies
but dust in galaxies may bias our samples due to optical color selection.

They also provide powerful sources of feedback onto the galaxies
and are thus important for galaxy evolution studies.

Constraining the fraction of dust-reddened quasars is crucial to constrain
quasar evolution and feedback duty-cycle
but color selection makes it hard to judge current samples.

Broad Absorption Line quasars hold crucial information about quasars outflows
but are often missed in optical samples.

Using Gaia astrometry we can obtain a color-unbiased sample to robustly identify
absorption systems and to infer proper statistics about the quasar population.

gaia

Thank you!

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