Quasar Science without Spectroscopy

Christina M. Peters

Hot-Wiring the Transient Universe 5
October 2016

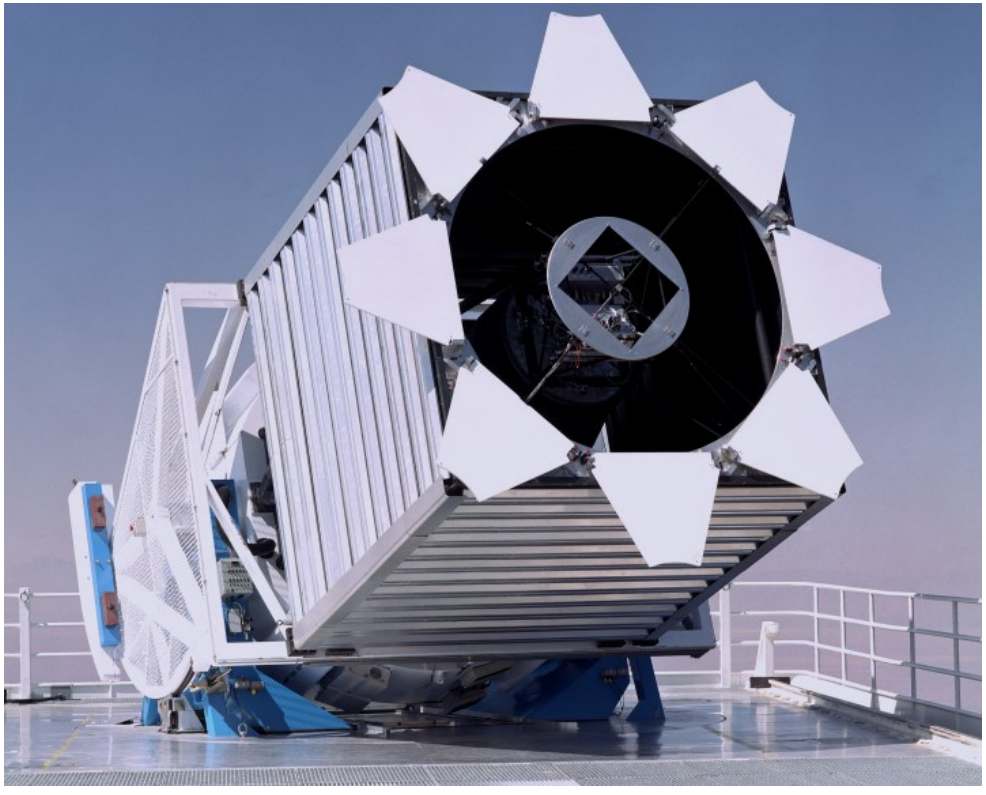
DUNLAP INSTITUTE
for ASTRONOMY & ASTROPHYSICS

Dunlap Institute for
Astronomy & Astrophysics
UNIVERSITY OF TORONTO

Motivation

- large catalogs of quasars are crucial for galaxy and cosmology science
- not enough spectroscopic follow-up in future surveys
- critical to have accurate classifications using photometry only
- as well as accurate redshifts

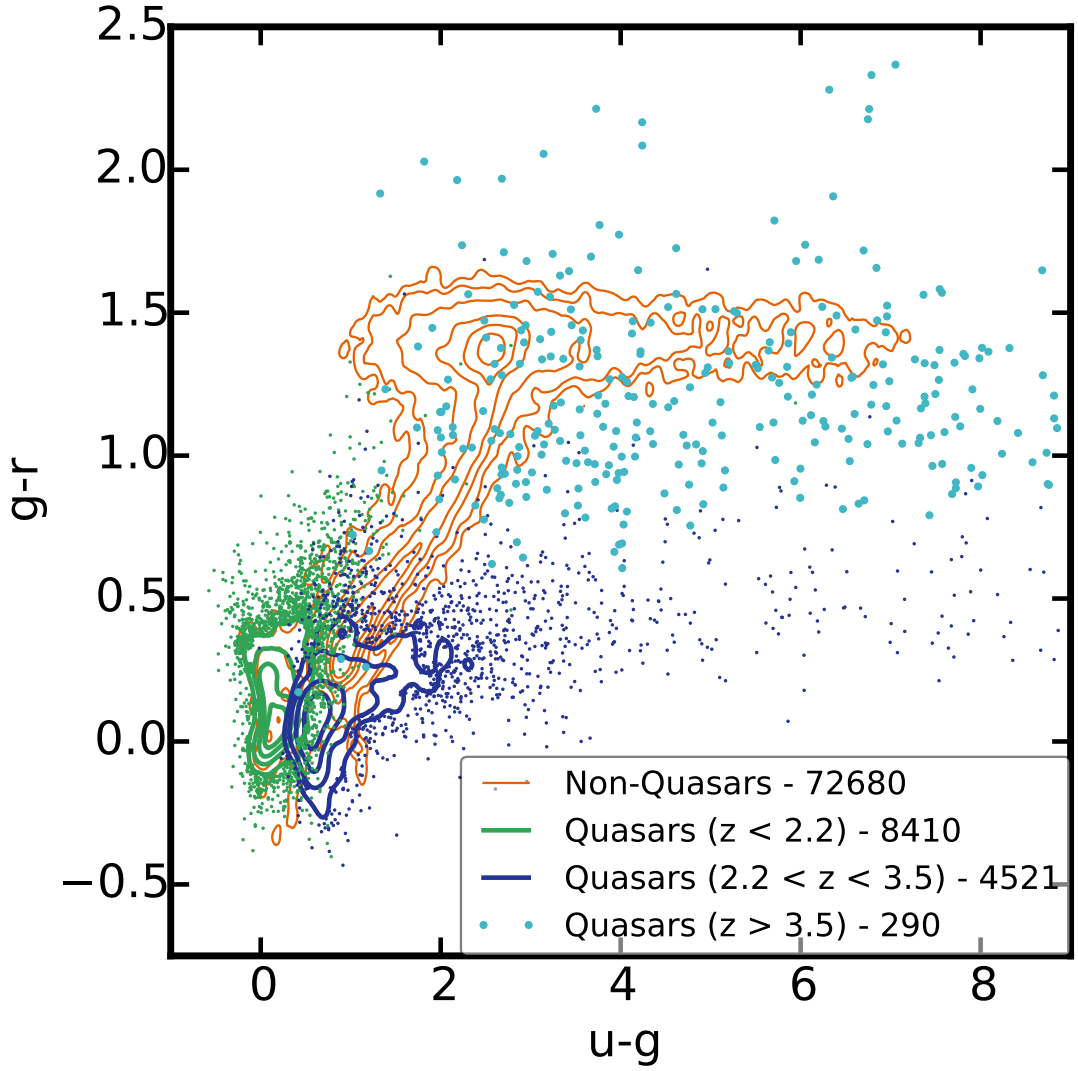
SDSS Stripe 82



Sloan Telescope (sdss.org)

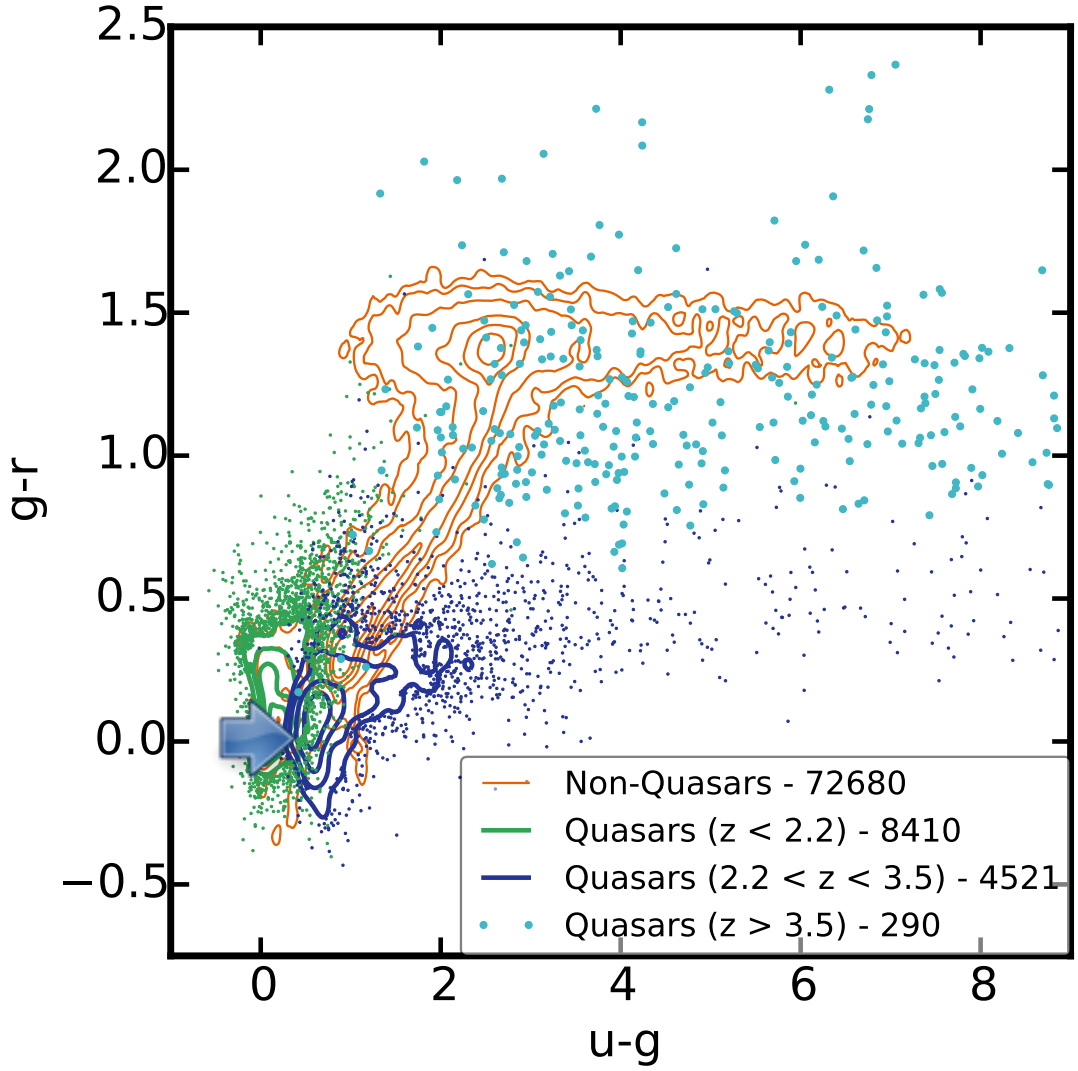
- 100 epochs (October 1999 to November 2007)
- Limit to point sources with good photometry
- Limit to at least 10 epochs of detections in each band
- Total objects: 916,587
- Quasars with spectra: 13,221

Quasars and non-quasars in the SDSS color space



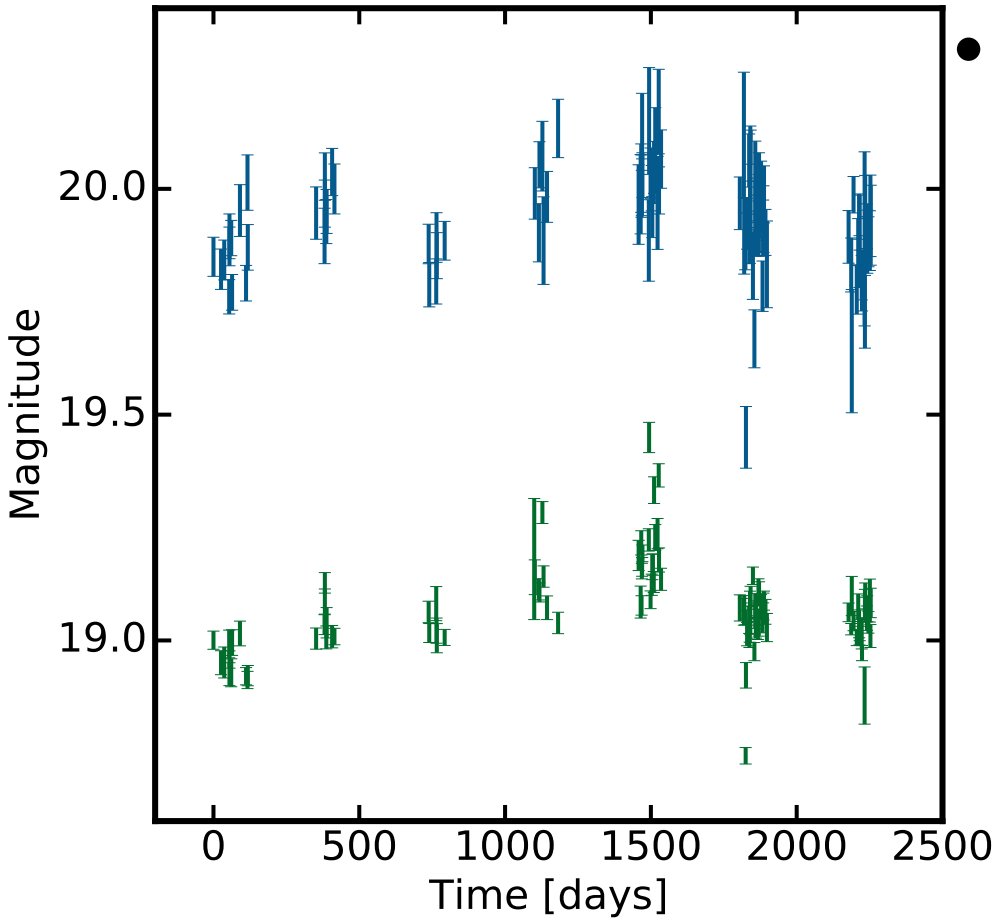
(Peters et al. 2015)

Quasars and non-quasars in the SDSS color space



(Peters et al. 2015)

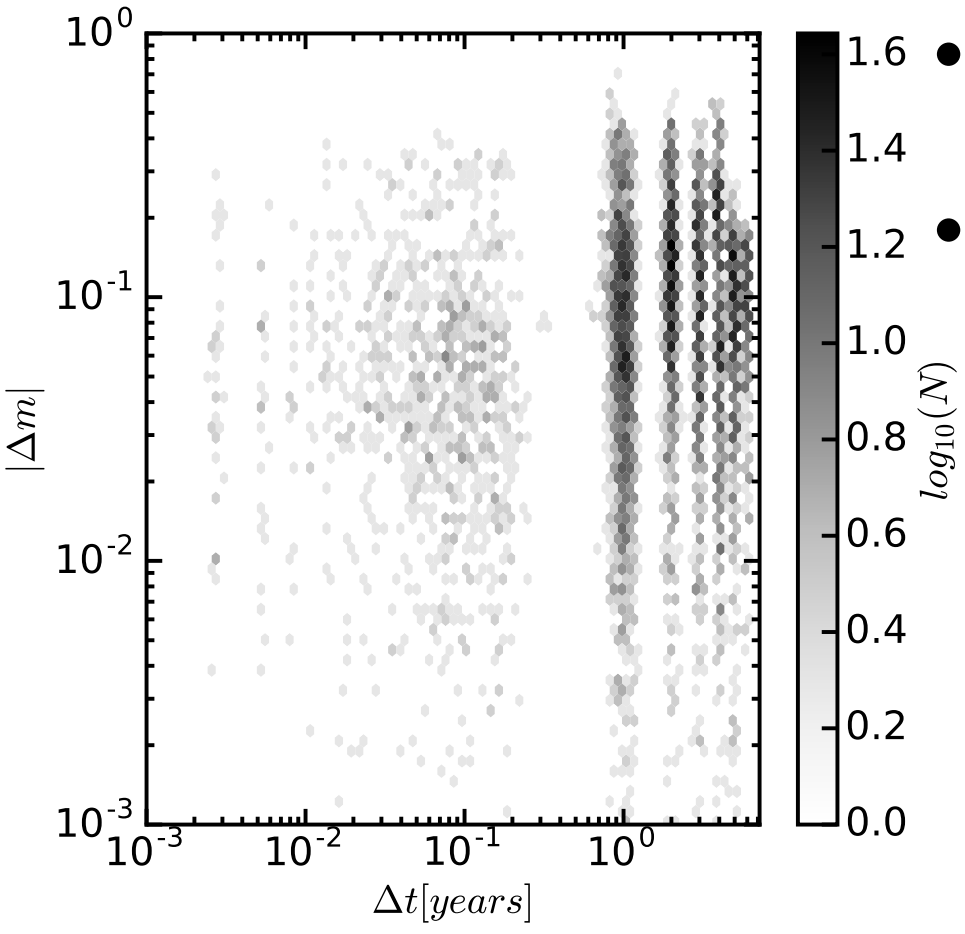
Variability



Lightcurve of one SDSS Stripe 82 Quasar. (Peters et al. 2015)

- Most quasars are variable sources in the optical.

Variability

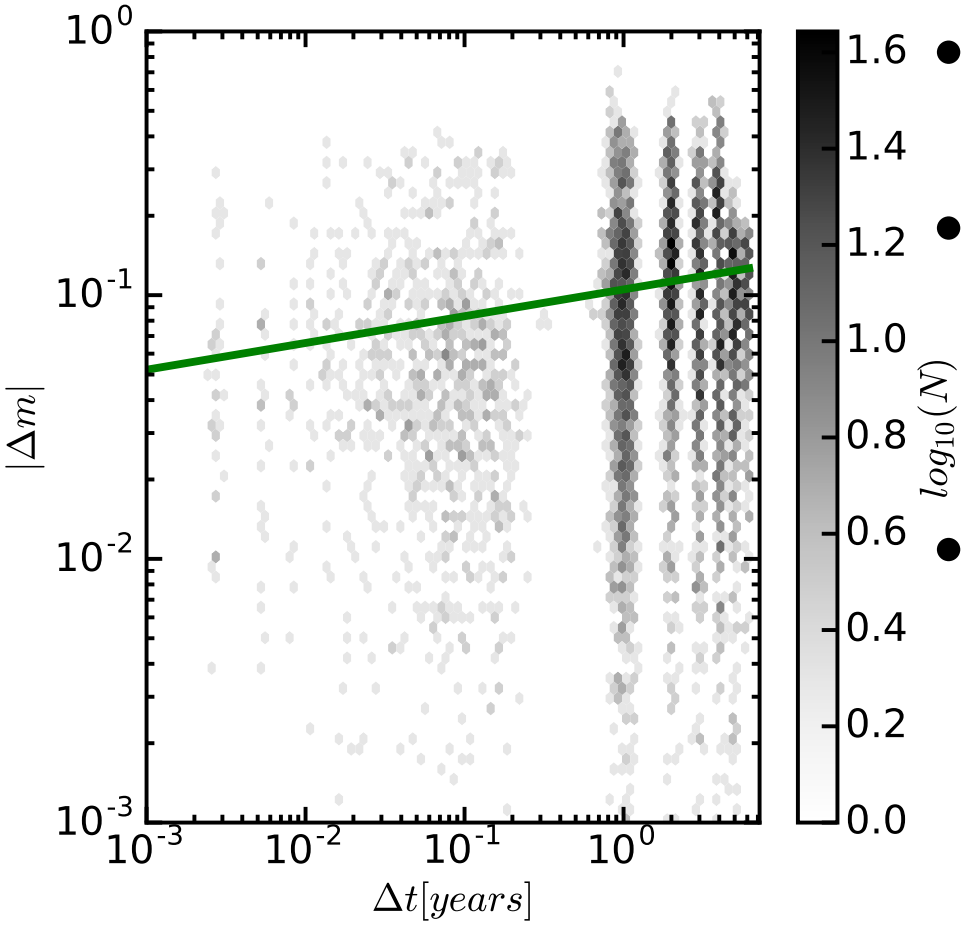


Structure function of one SDSS Stripe 82 Quasar. (Peters et al. 2015)

- Most quasars are variable sources in the optical.
- Structure function:

$$V^2(\Delta t) = \langle (m(t) - m(t+\Delta t))^2 \rangle \quad (1)$$

Variability



Structure function of one SDSS Stripe 82 Quasar. (Peters et al. 2015)

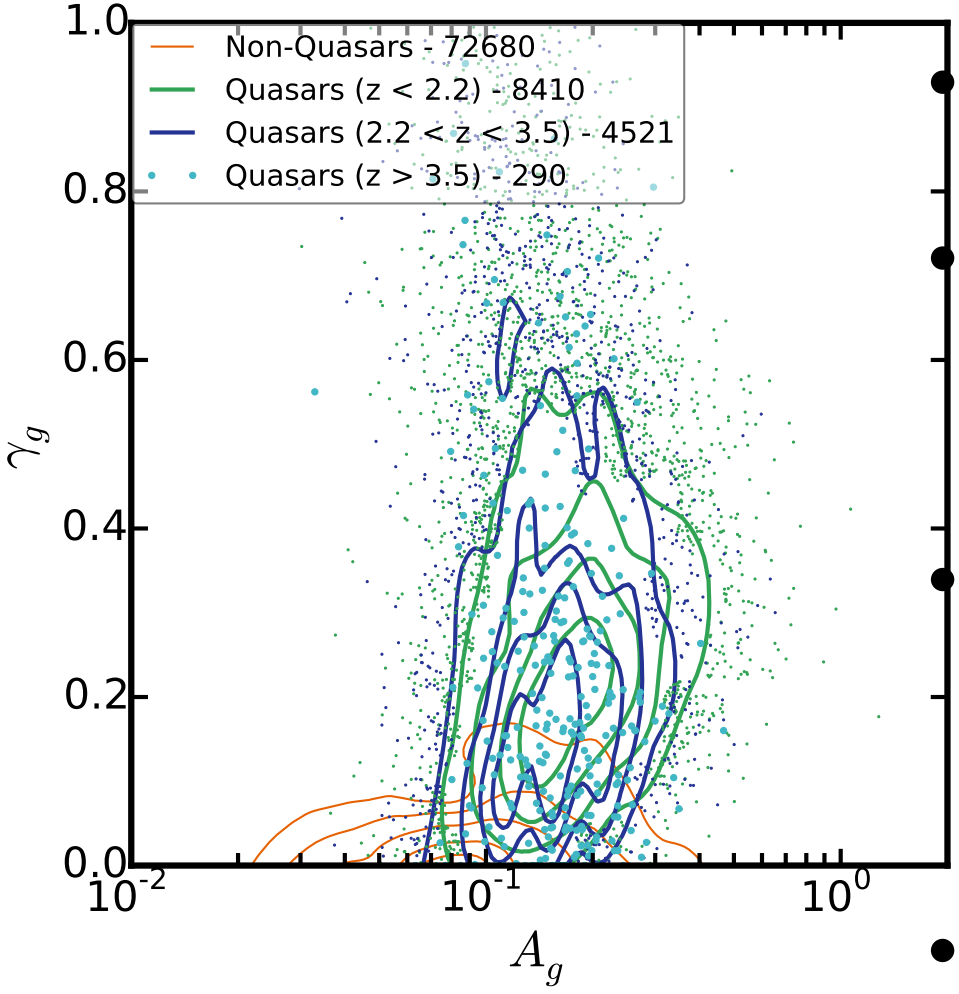
- Most quasars are variable sources in the optical.
- Structure function:

$$V^2(\Delta t) = \langle (m(t) - m(t+\Delta t))^2 \rangle \quad (1)$$

- Fit the structure function with a power law:

$$A(\Delta t)^\gamma \quad (2)$$

Variability



Quasars and Non-quasars in variability space. (Peters et al. 2015)

- Most quasars are variable sources in the optical.
- Structure function:

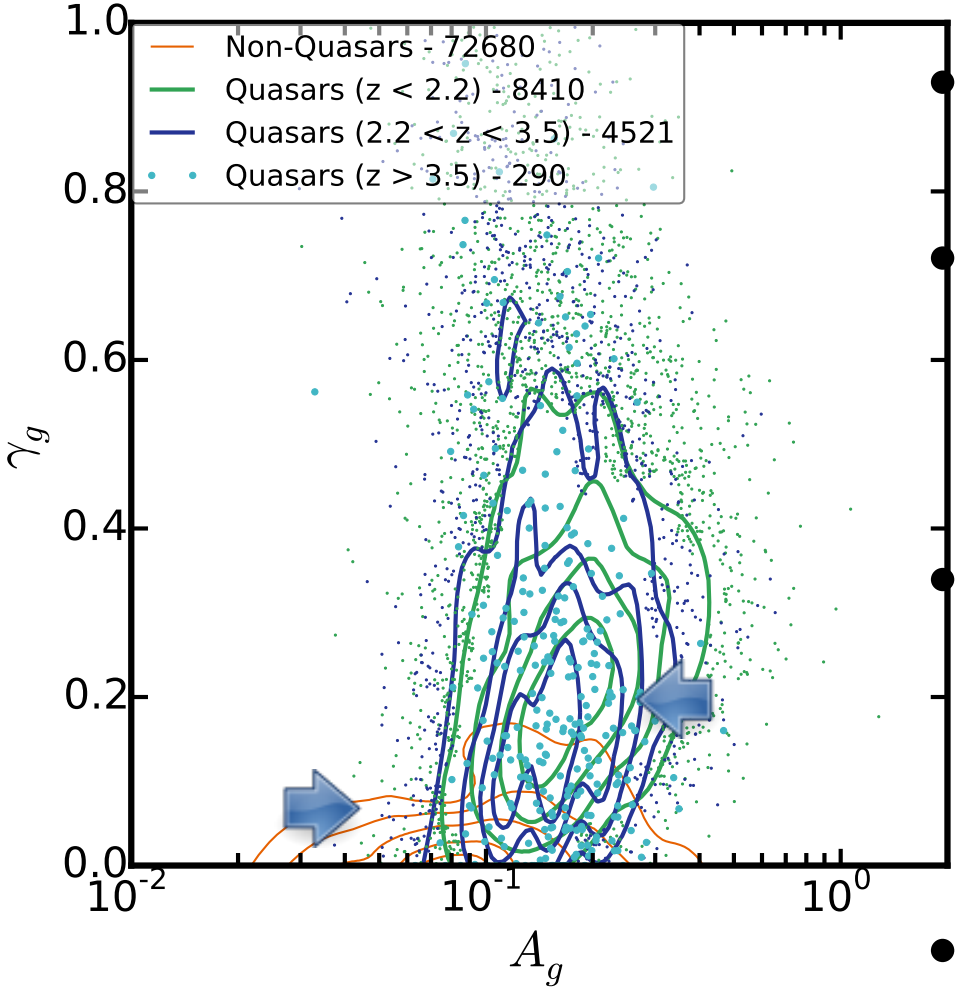
$$V^2(\Delta t) = \langle (m(t) - m(t+\Delta t))^2 \rangle \quad (1)$$

- Fit the structure function with a power law:

$$A(\Delta t)^\gamma \quad (2)$$

- We can separate quasars from non-quasars in variability space.

Variability



Quasars and Non-quasars in variability space. (Peters et al. 2015)

- Most quasars are variable sources in the optical.
- Structure function:

$$V^2(\Delta t) = \langle (m(t) - m(t+\Delta t))^2 \rangle \quad (1)$$

- Fit the structure function with a power law:

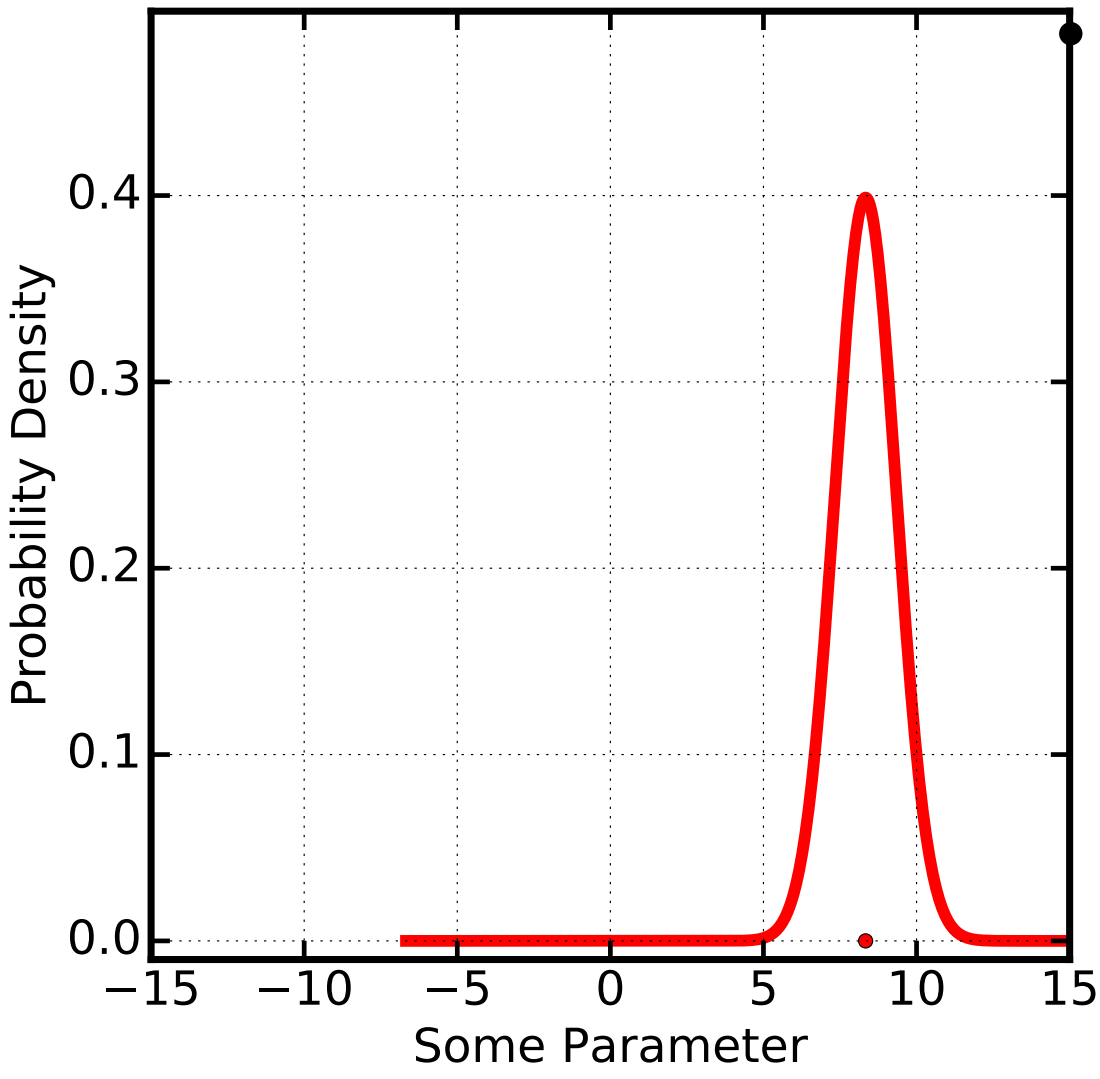
$$A(\Delta t)^\gamma \quad (2)$$

- We can separate quasars from non-quasars in variability space.

Classification by Kernel Density Estimation

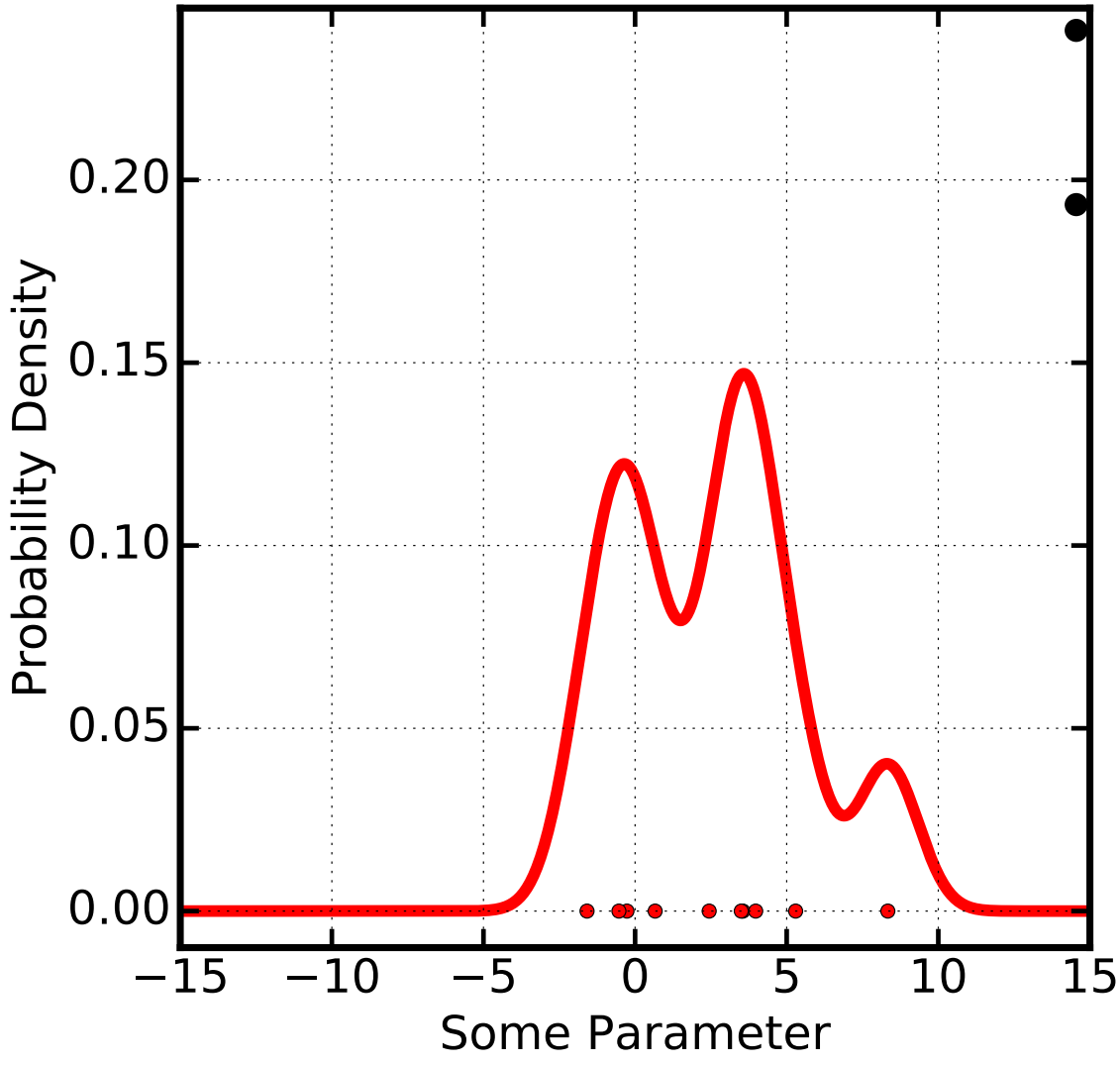
- Classification was performed using NBC based on applying KDE; see Richards et al. (2004).

Classification by Kernel Density Estimation



Point represented by a kernel.

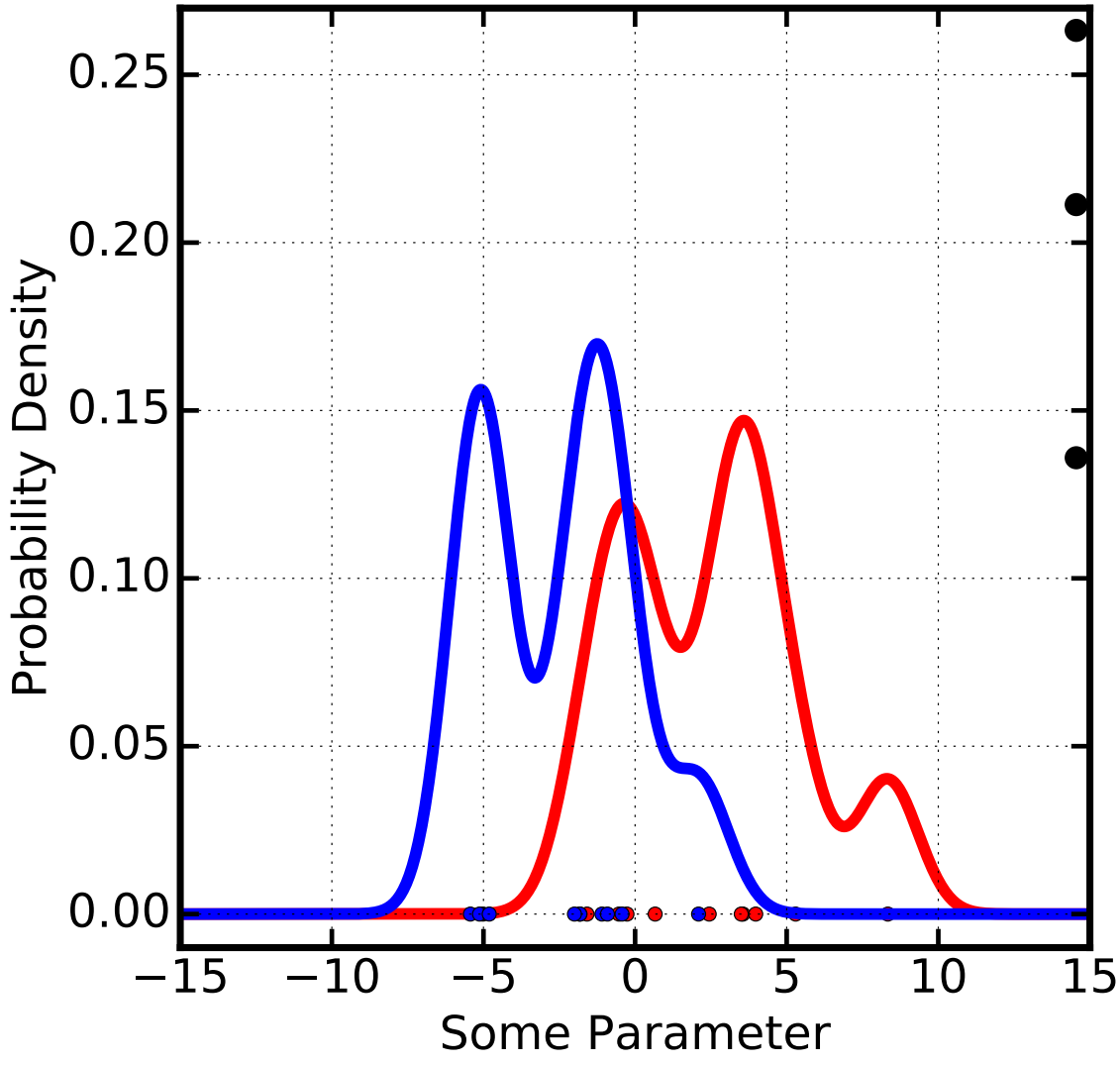
Classification by Kernel Density Estimation



Point represented by a kernel.

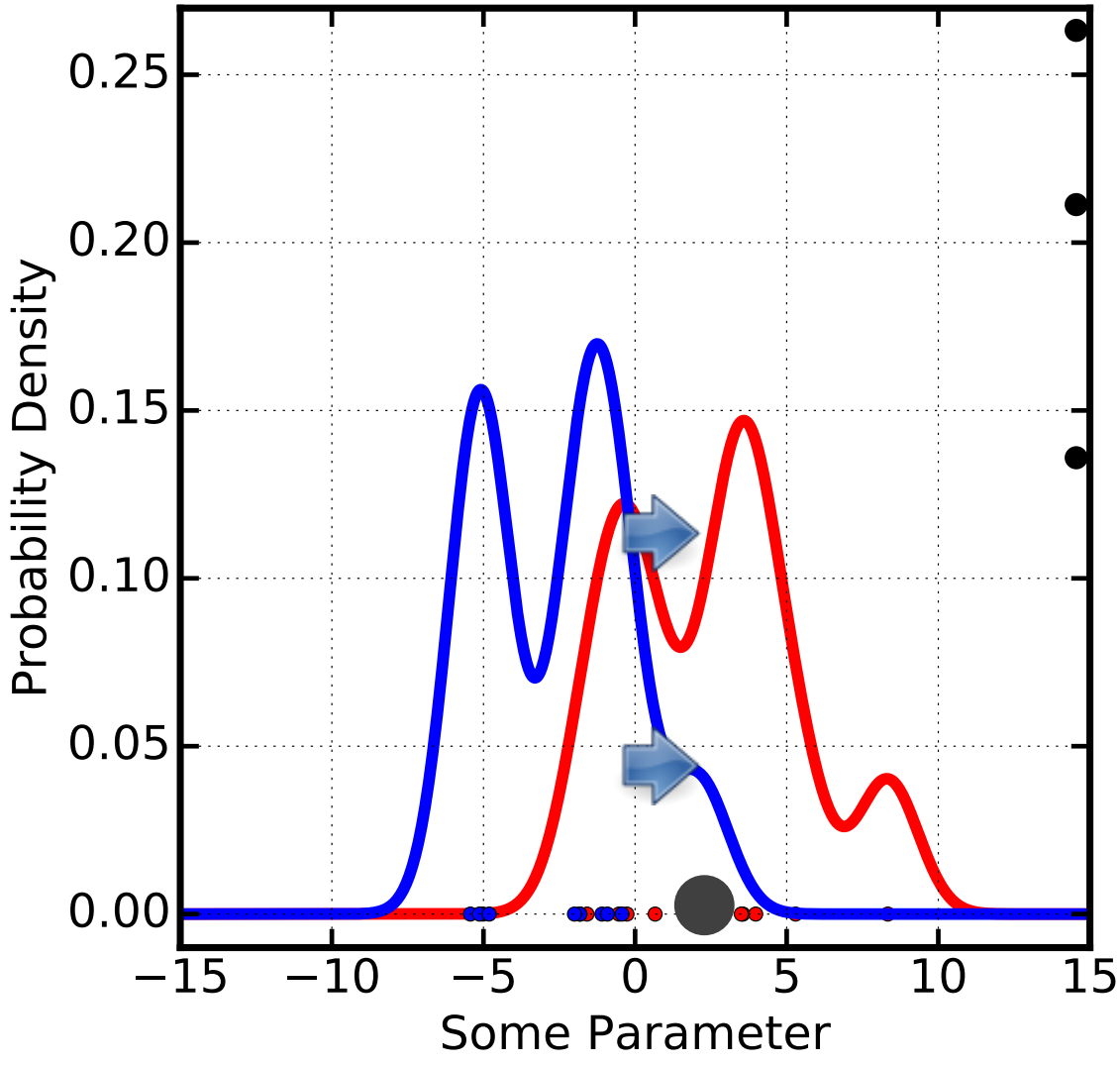
Kernels combine to a probability density function (PDF).

Classification by Kernel Density Estimation



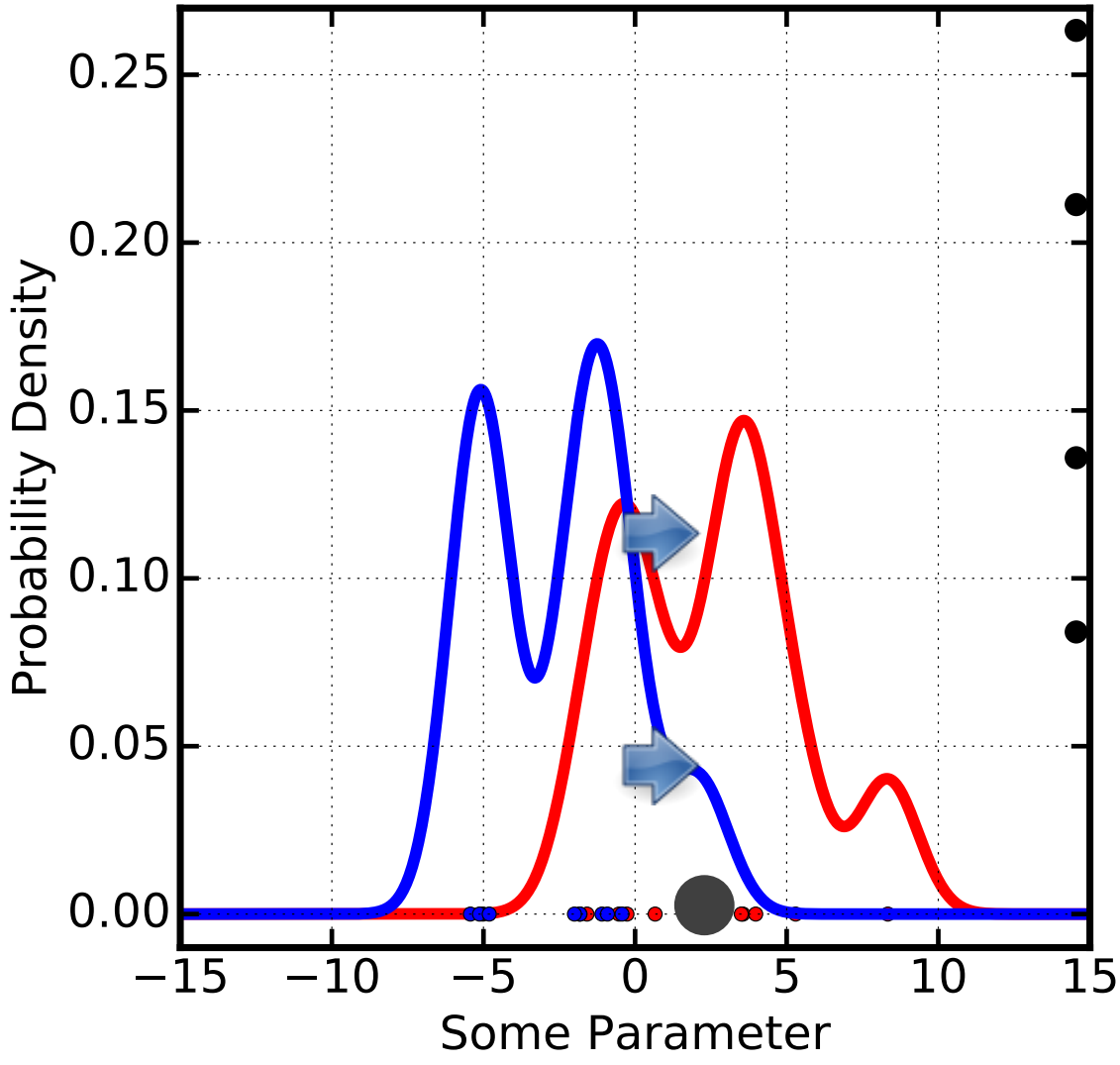
- Point represented by a kernel.
- Kernels combine to a probability density function (PDF).
- Relative "height" gives probability.

Classification by Kernel Density Estimation



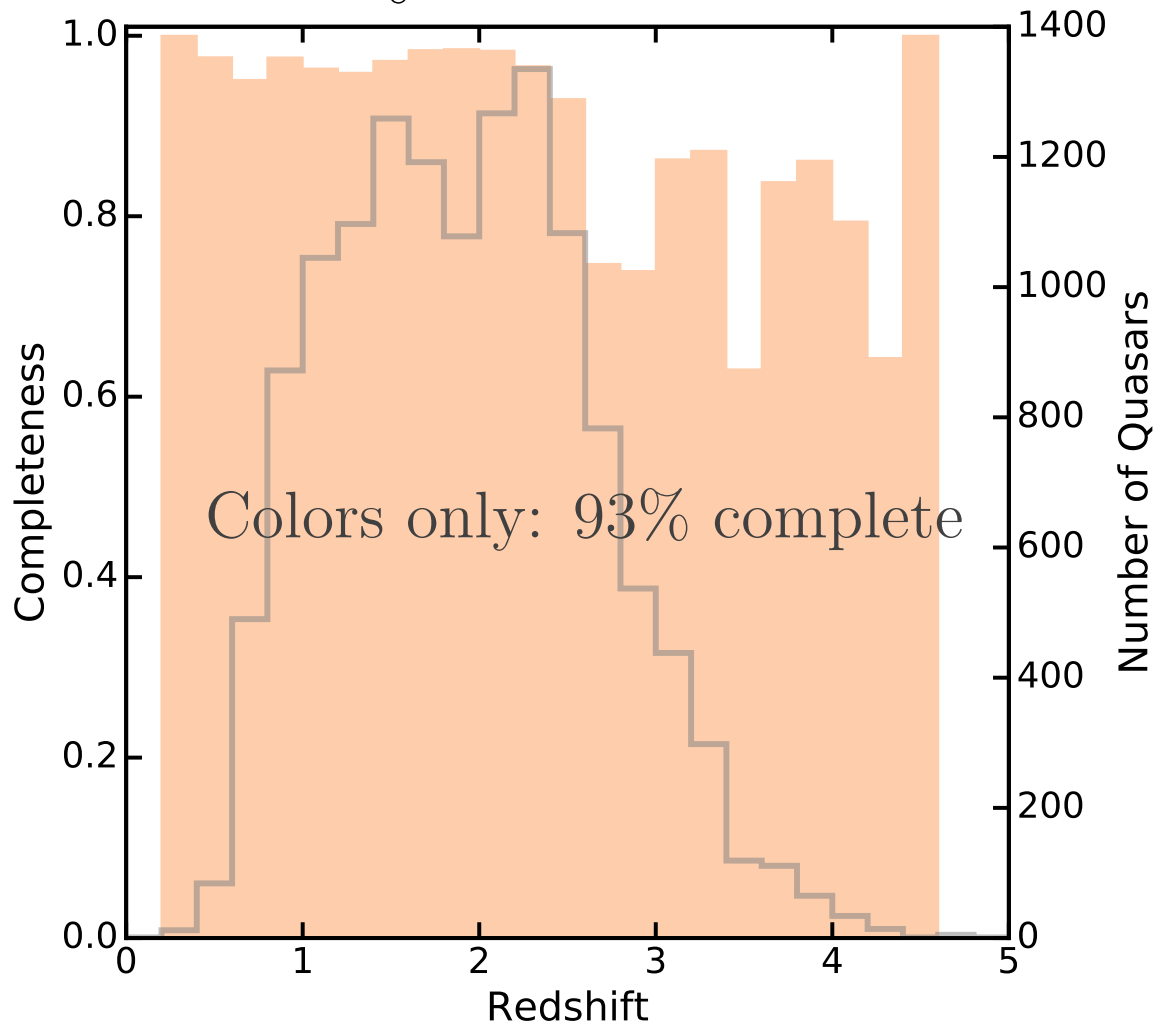
- Point represented by a kernel.
- Kernels combine to a probability density function (PDF).
- Relative "height" gives probability.

Classification by Kernel Density Estimation



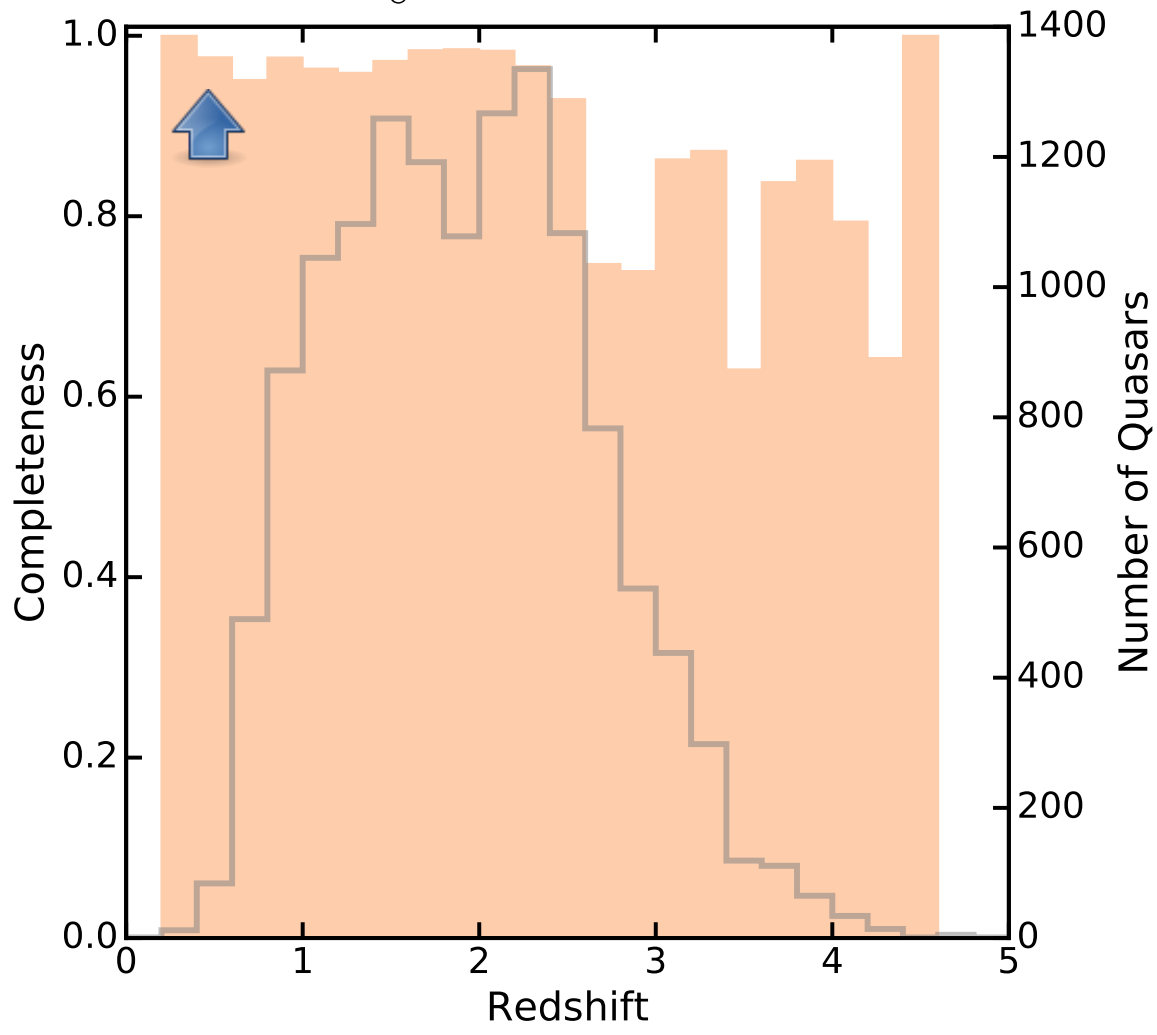
- Point represented by a kernel.
- Kernels combine to a probability density function (PDF).
- Relative "height" gives probability.
- Bayesian prior: scales relative height.

Color and Variability Classification



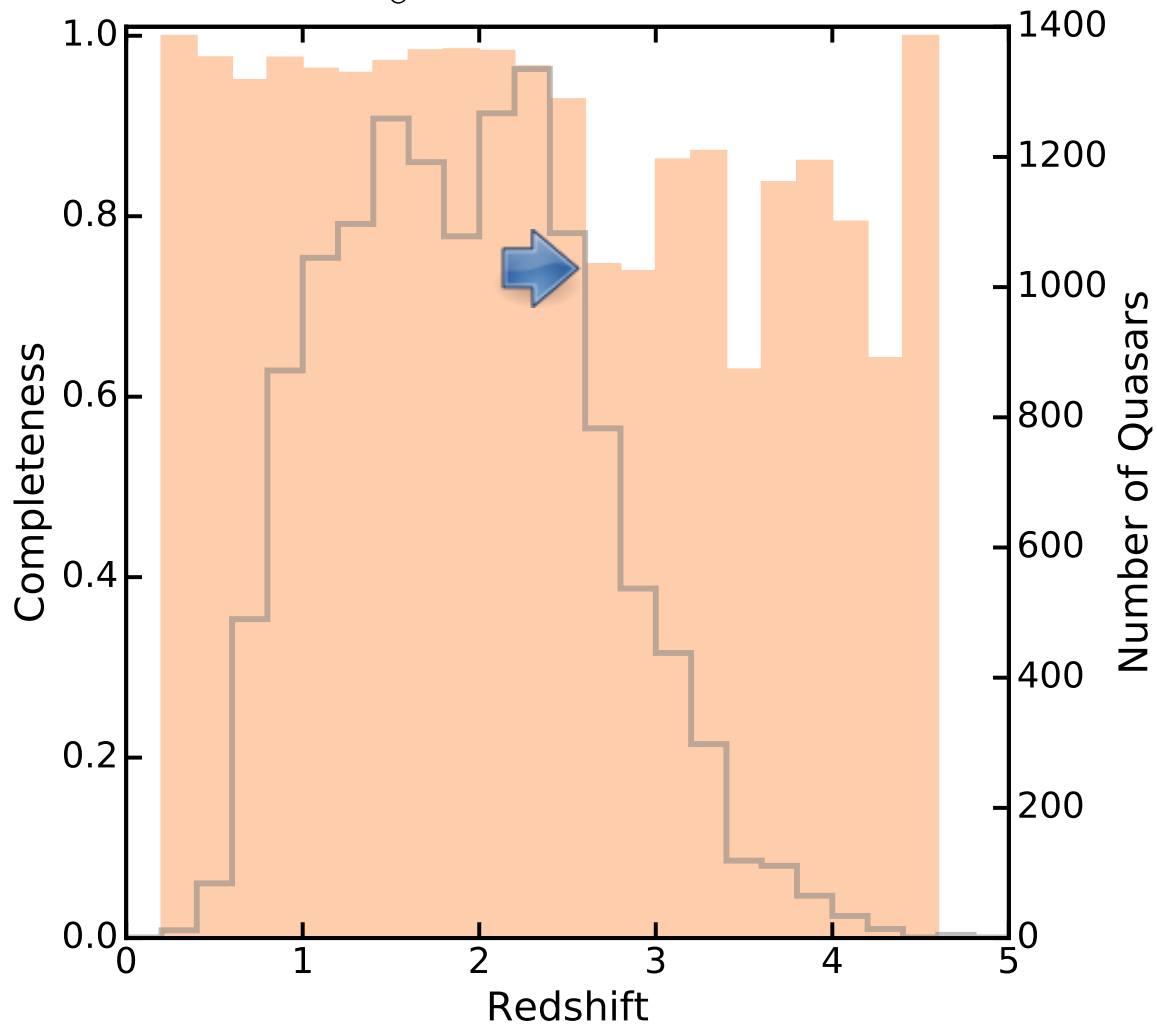
Quasars classified correctly, as a function of redshift. (Peters et al. 2015)

Color and Variability Classification



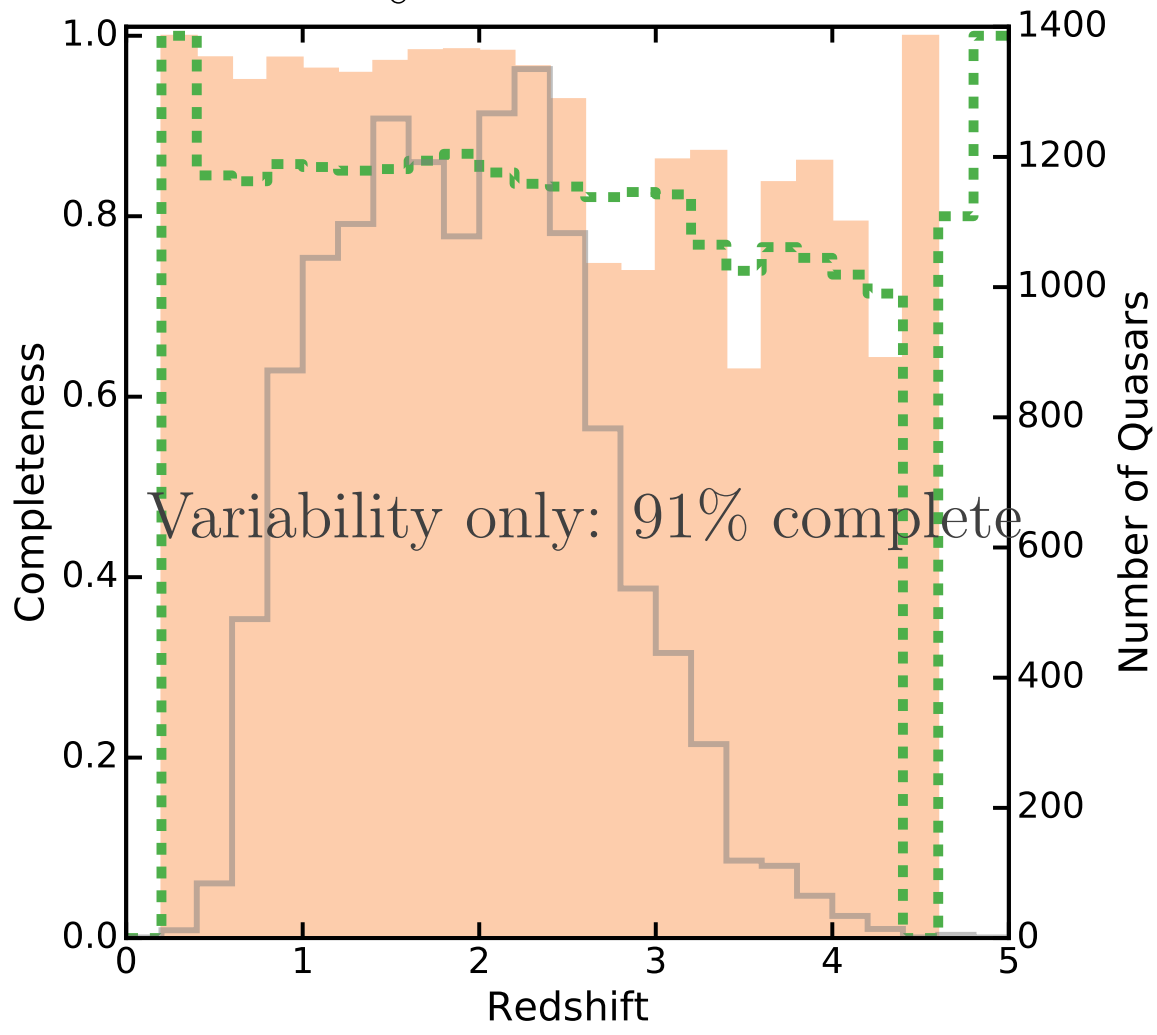
Quasars classified correctly, as a function of redshift. (Peters et al. 2015)

Color and Variability Classification



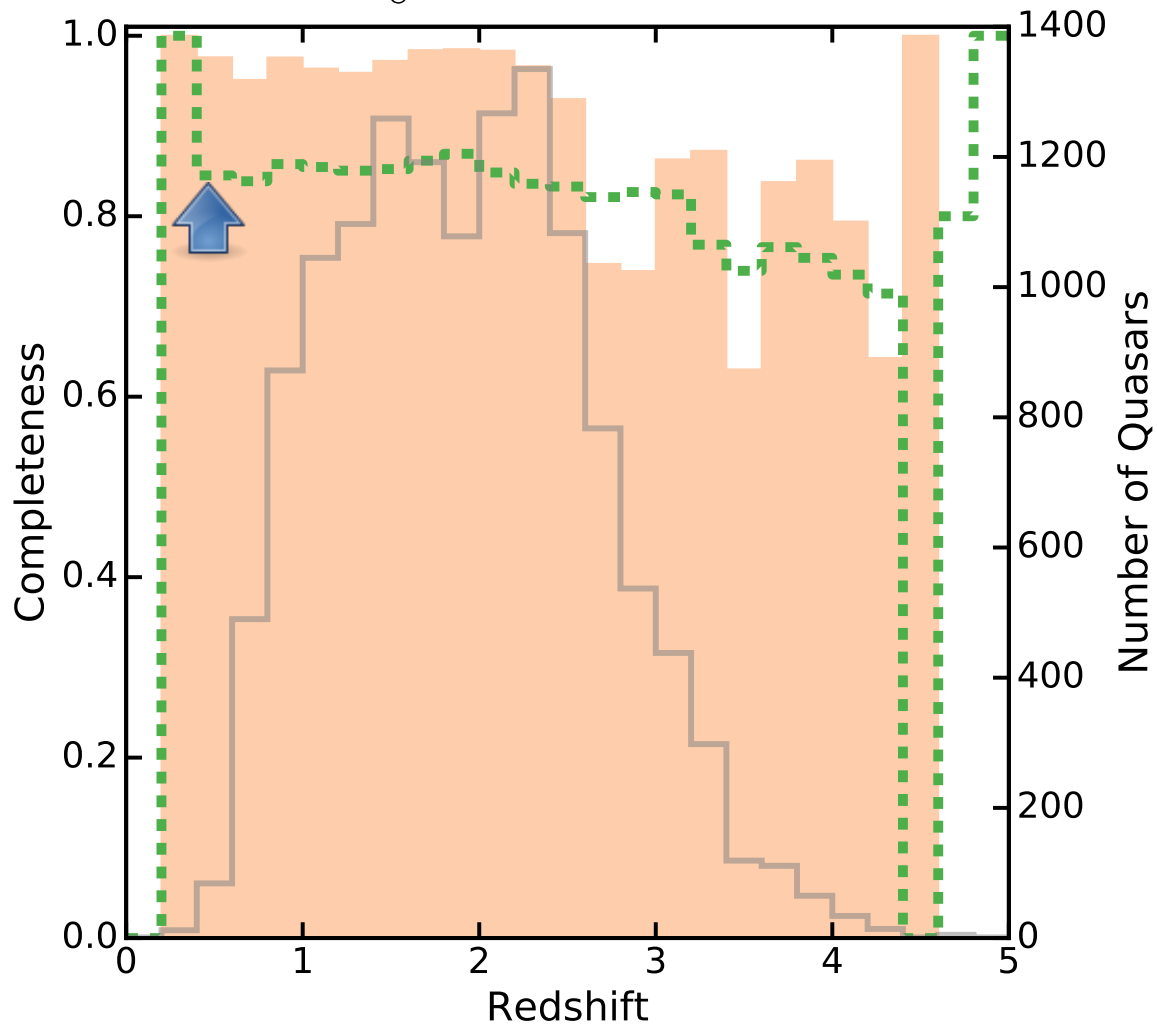
Quasars classified correctly, as a function of redshift. (Peters et al. 2015)

Color and Variability Classification



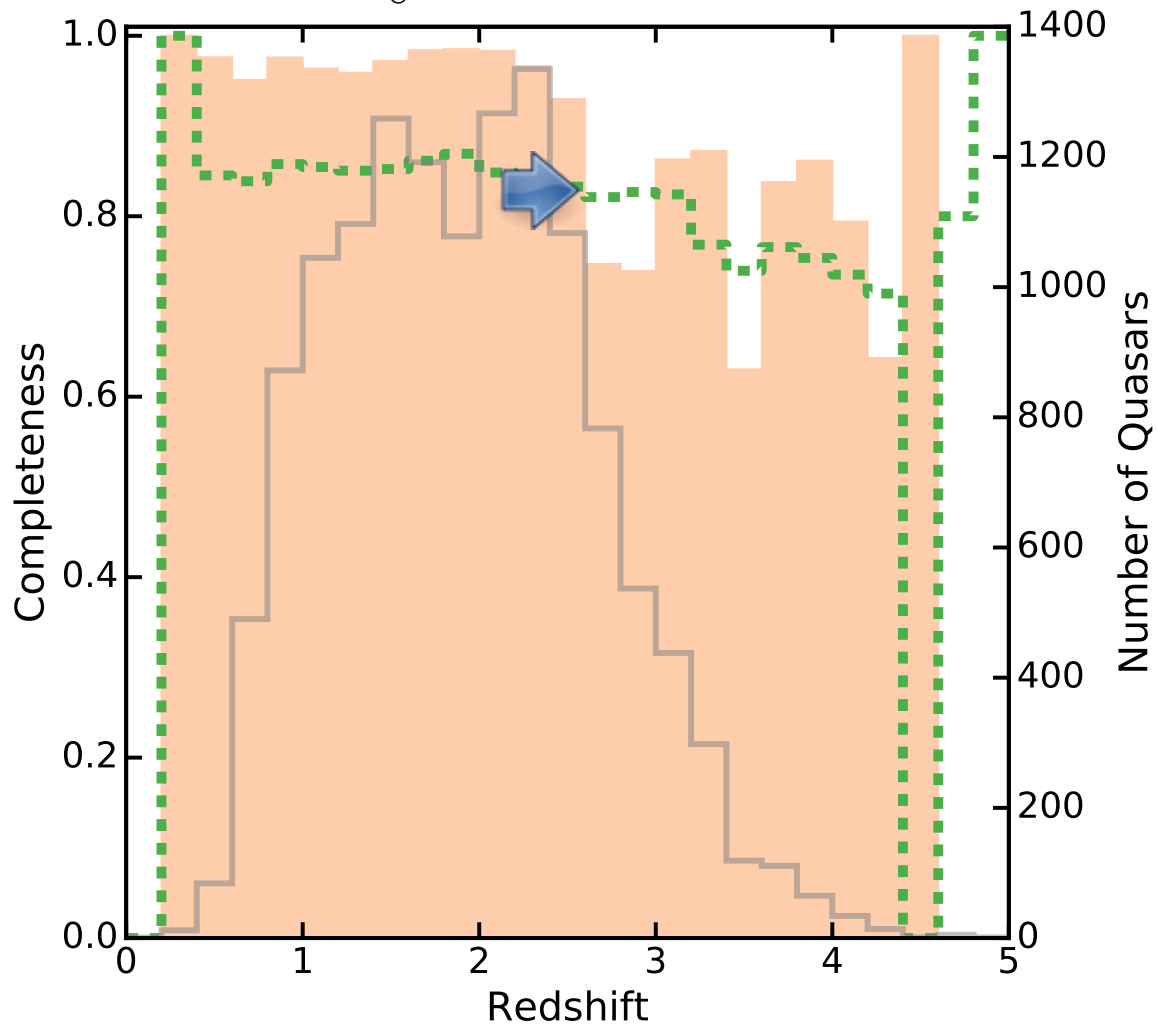
Quasars classified correctly, as a function of redshift. (Peters et al. 2015)

Color and Variability Classification



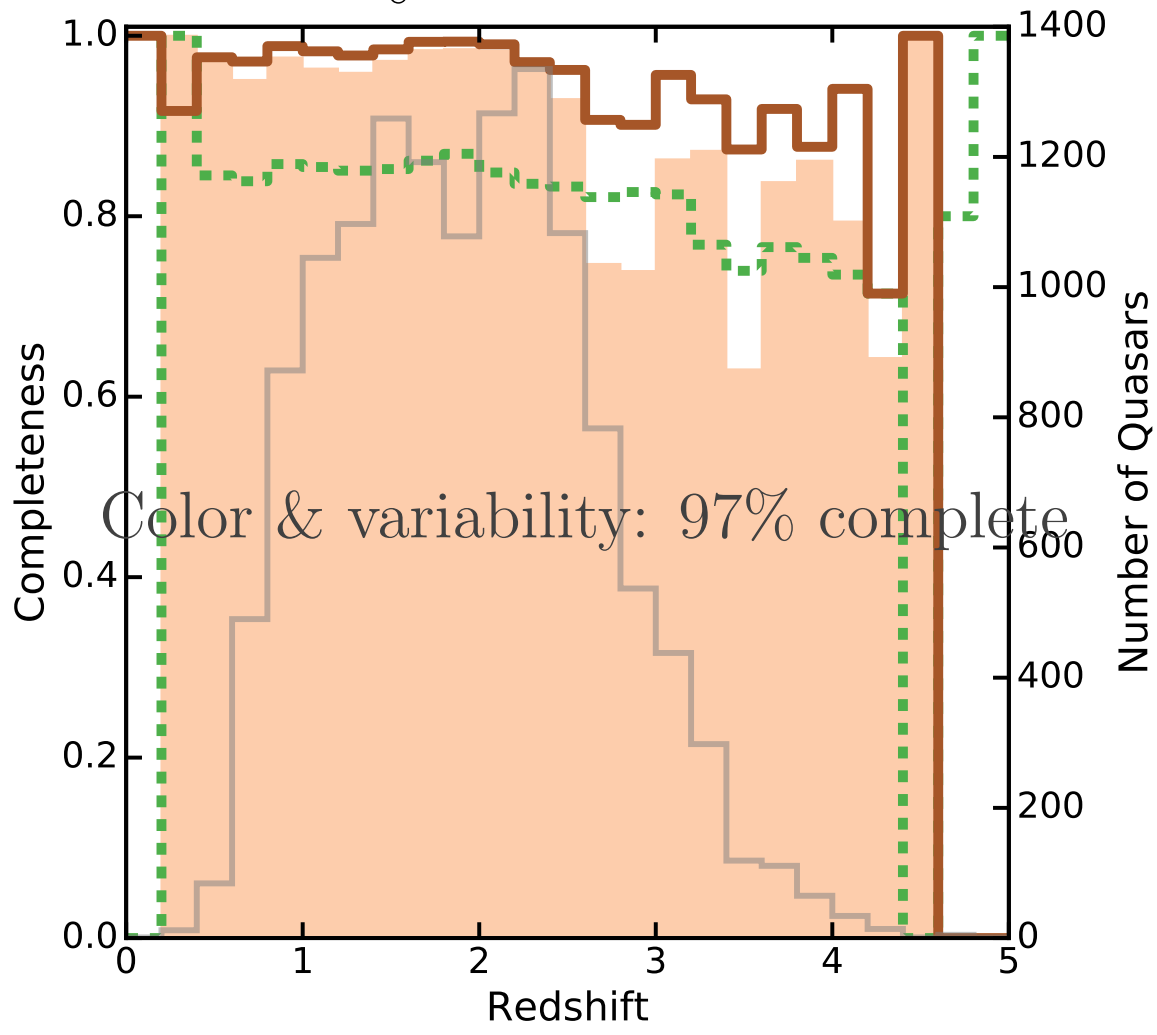
Quasars classified correctly, as a function of redshift. (Peters et al. 2015)

Color and Variability Classification



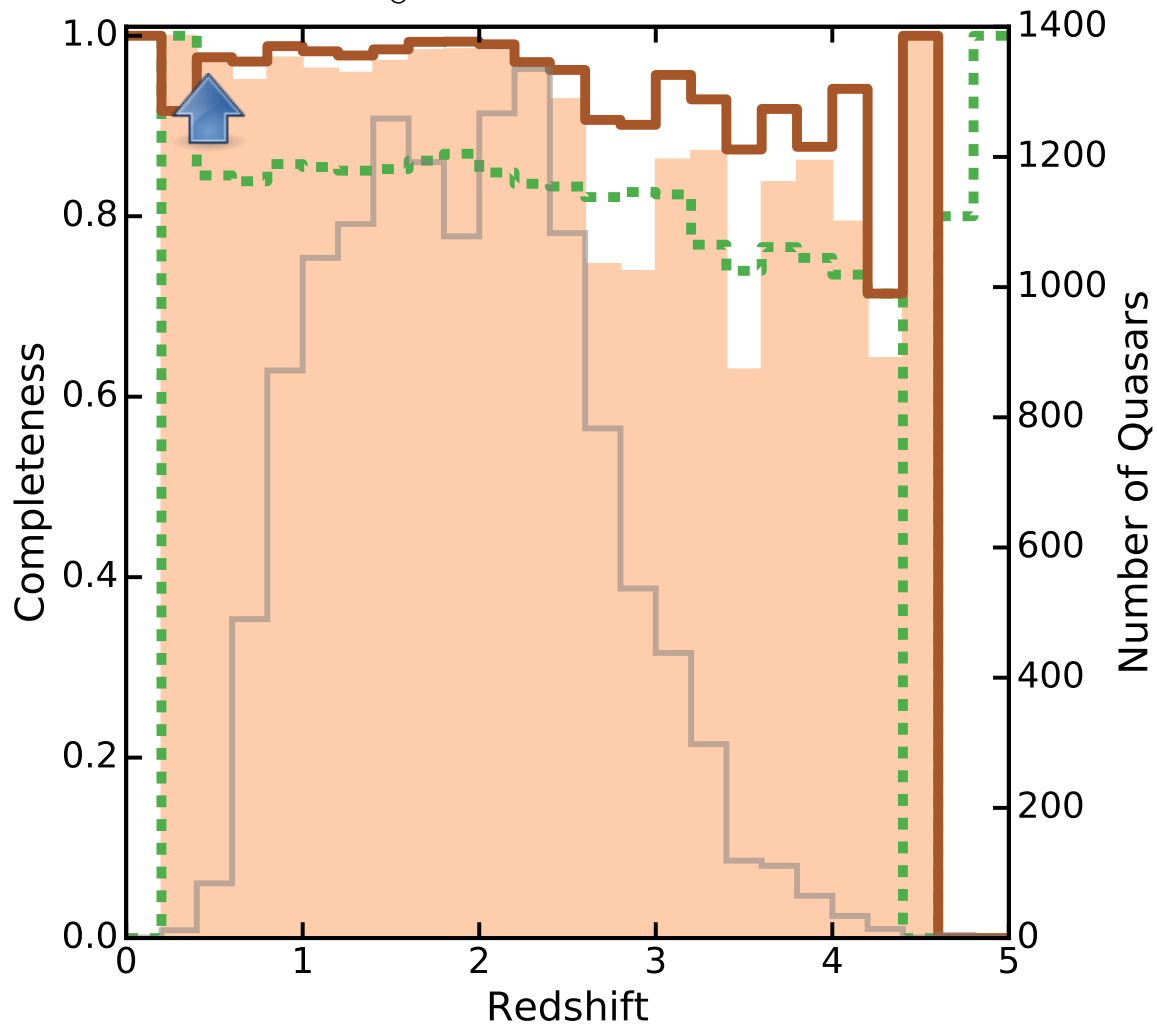
Quasars classified correctly, as a function of redshift. (Peters et al. 2015)

Color and Variability Classification



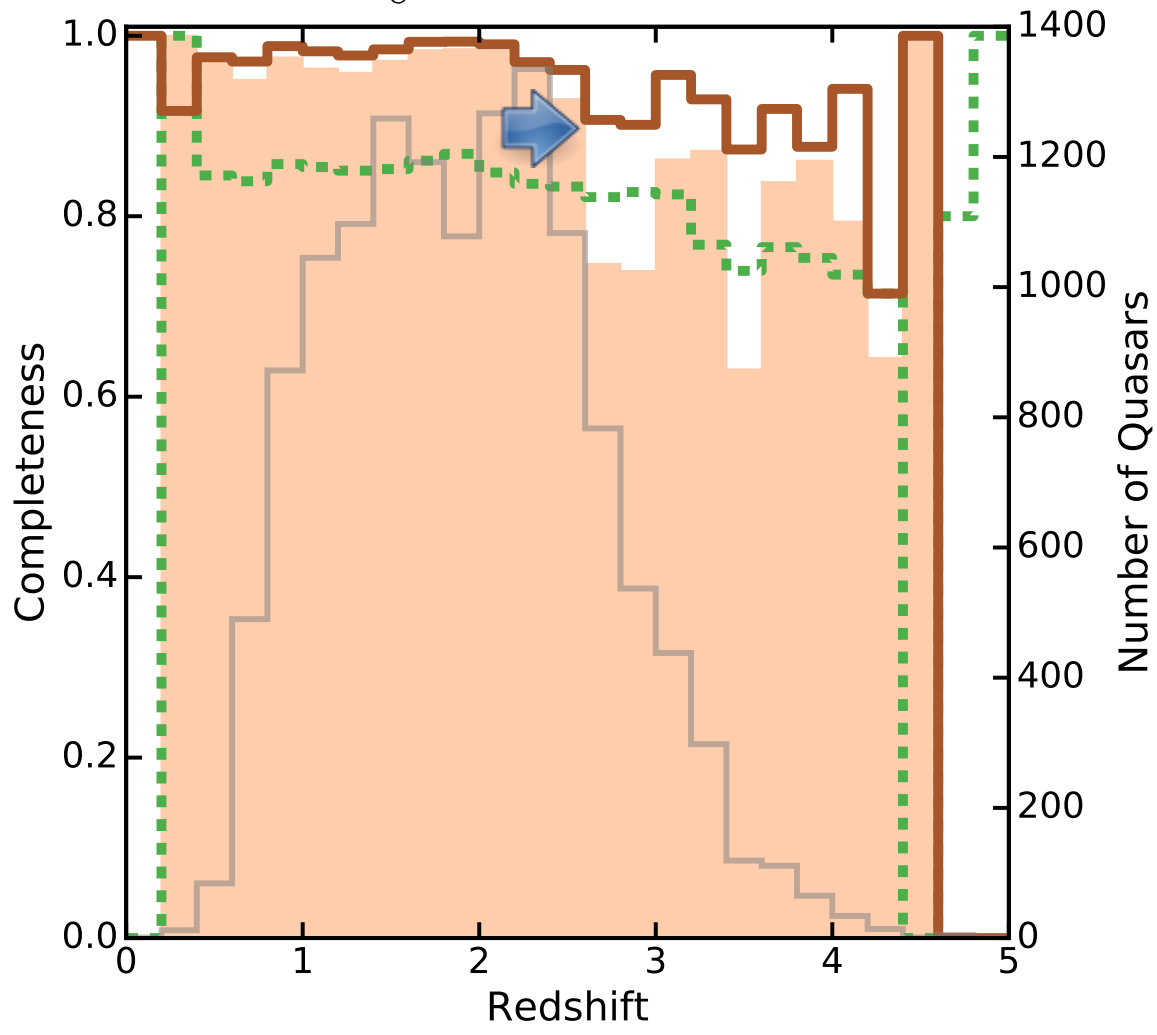
Quasars classified correctly, as a function of redshift. (Peters et al. 2015)

Color and Variability Classification



Quasars classified correctly, as a function of redshift. (Peters et al. 2015)

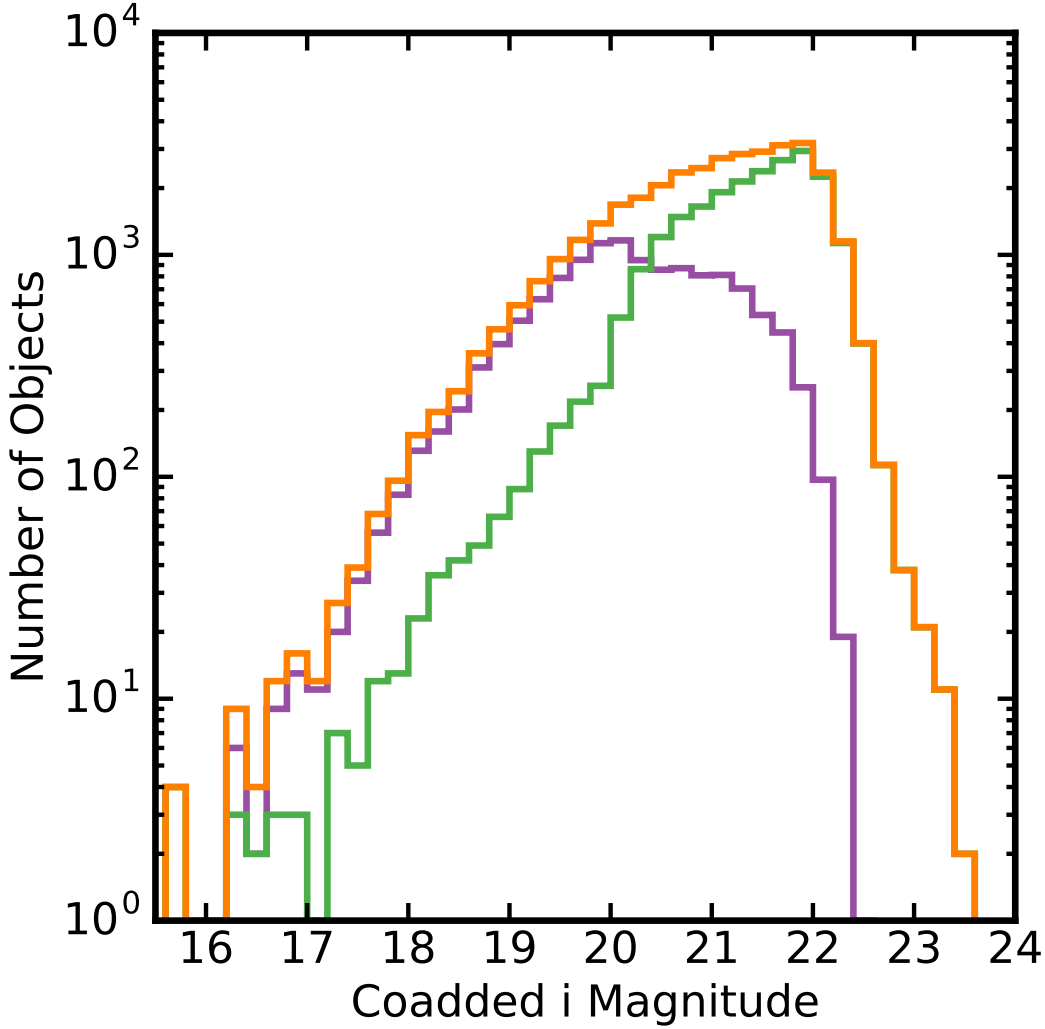
Color and Variability Classification



Quasars classified correctly, as a function of redshift. (Peters et al. 2015)

New Candidate Quasars

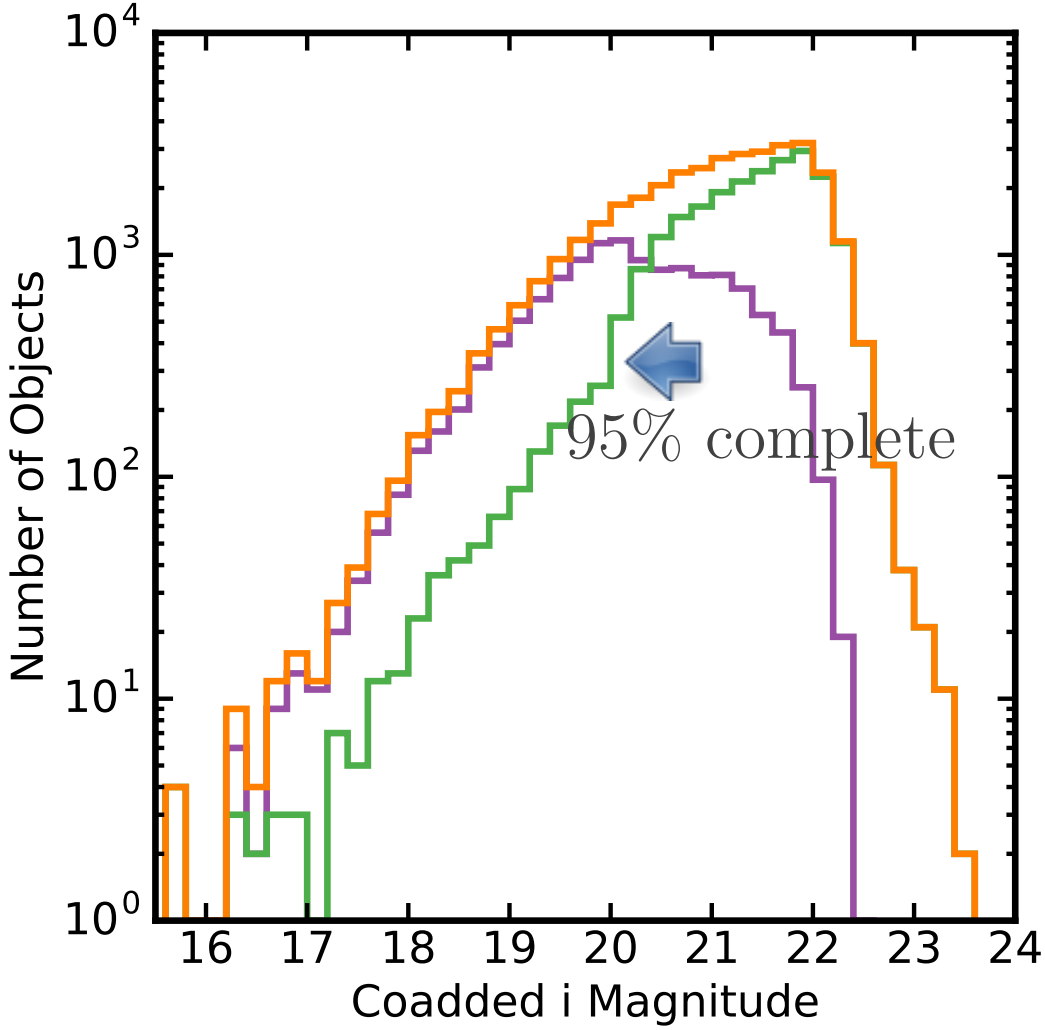
Total: 35,820
New: 22,867
Confirmed: 12,953



Quasar candidates as a function of magnitude. (Peters et al. 2015)

New Candidate Quasars

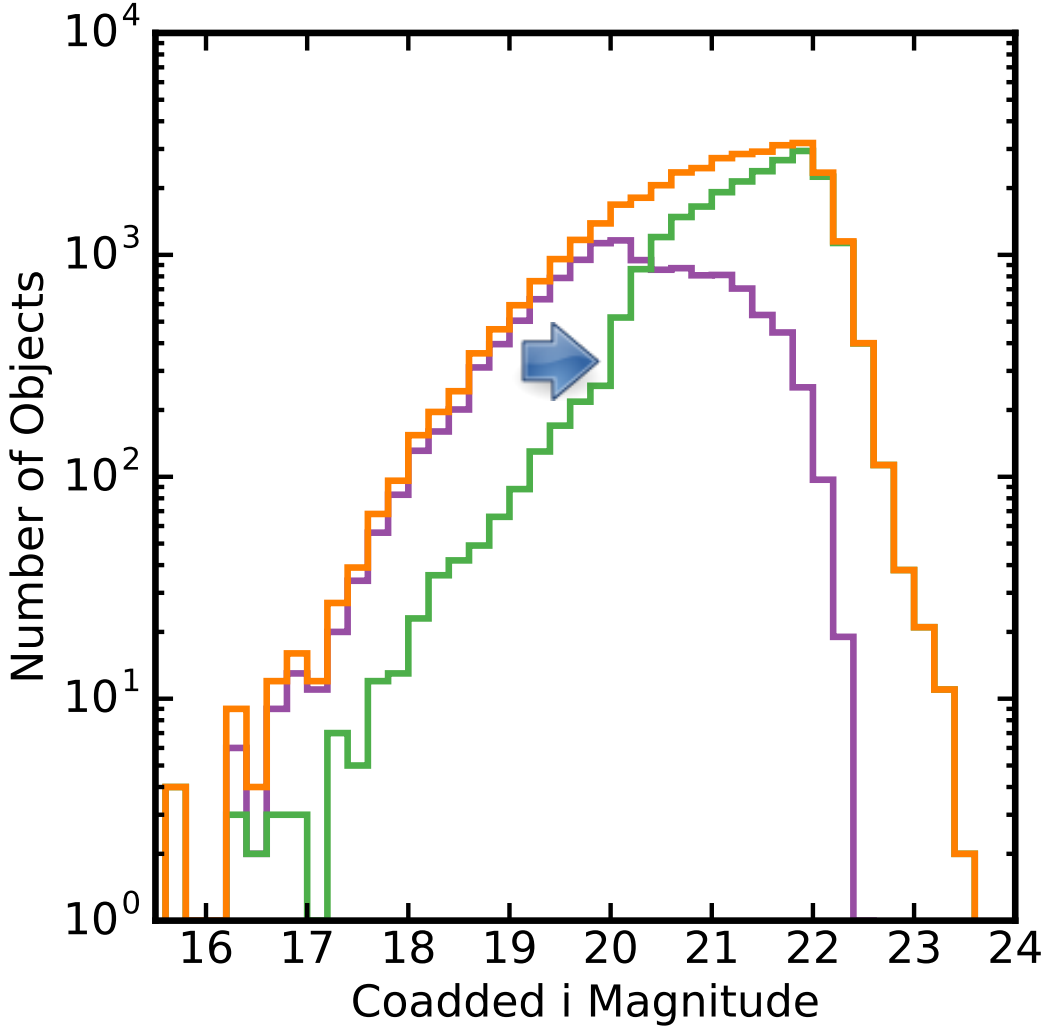
Total: 35,820
New: 22,867
Confirmed: 12,953



Quasar candidates as a function of magnitude. (Peters et al. 2015)

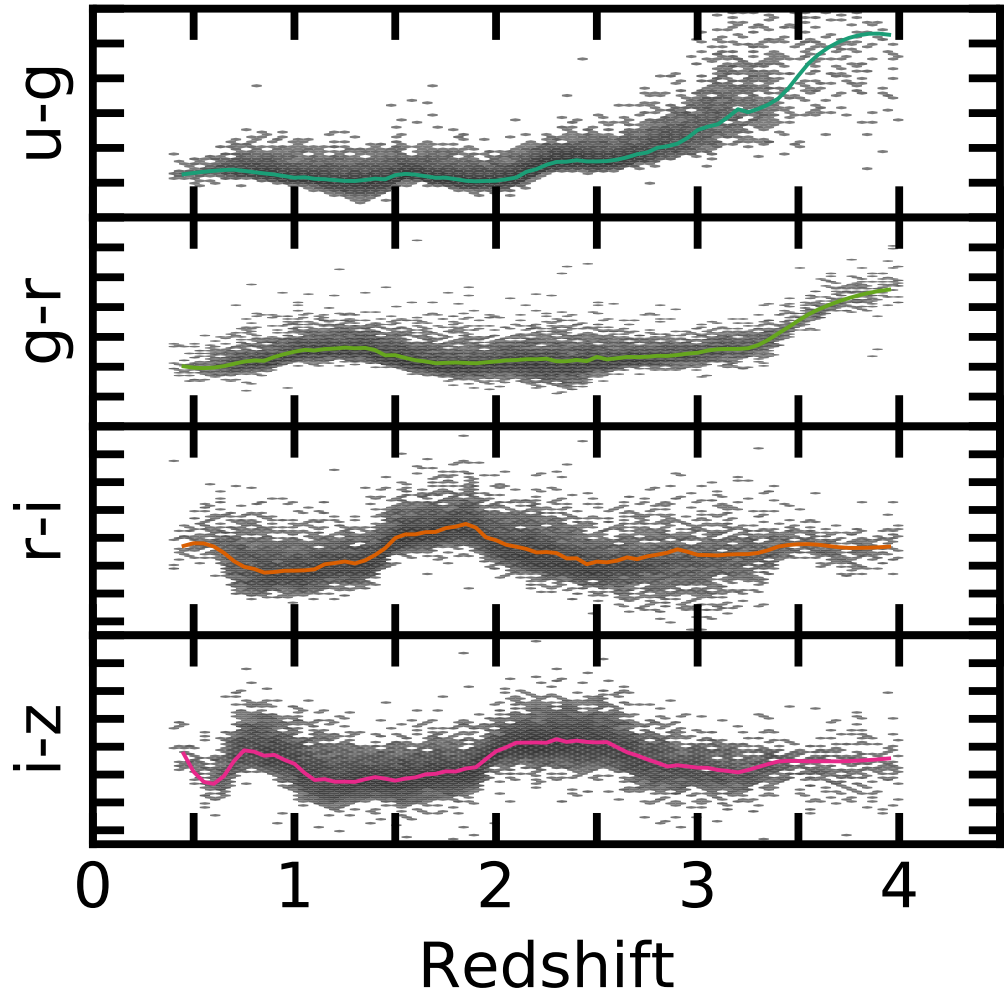
New Candidate Quasars

Total: 35,820
New: 22,867
Confirmed: 12,953



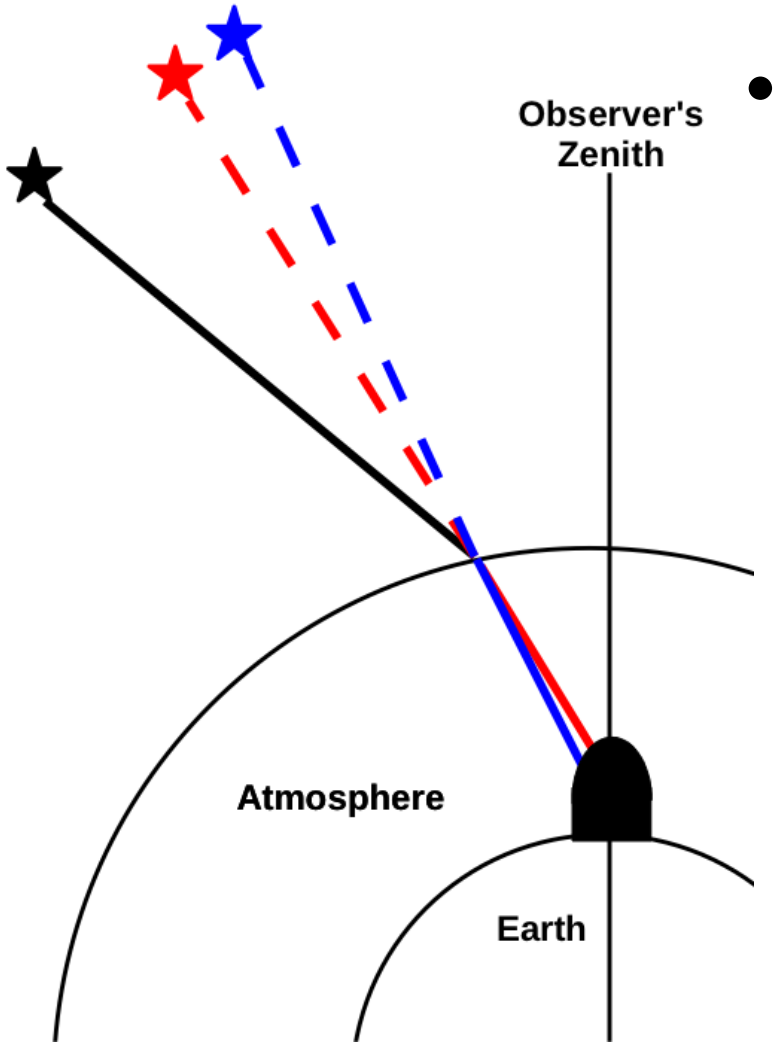
Quasar candidates as a function of magnitude. (Peters et al. 2015)

Redshift - Color Relation



Quasar color as a function of redshift.

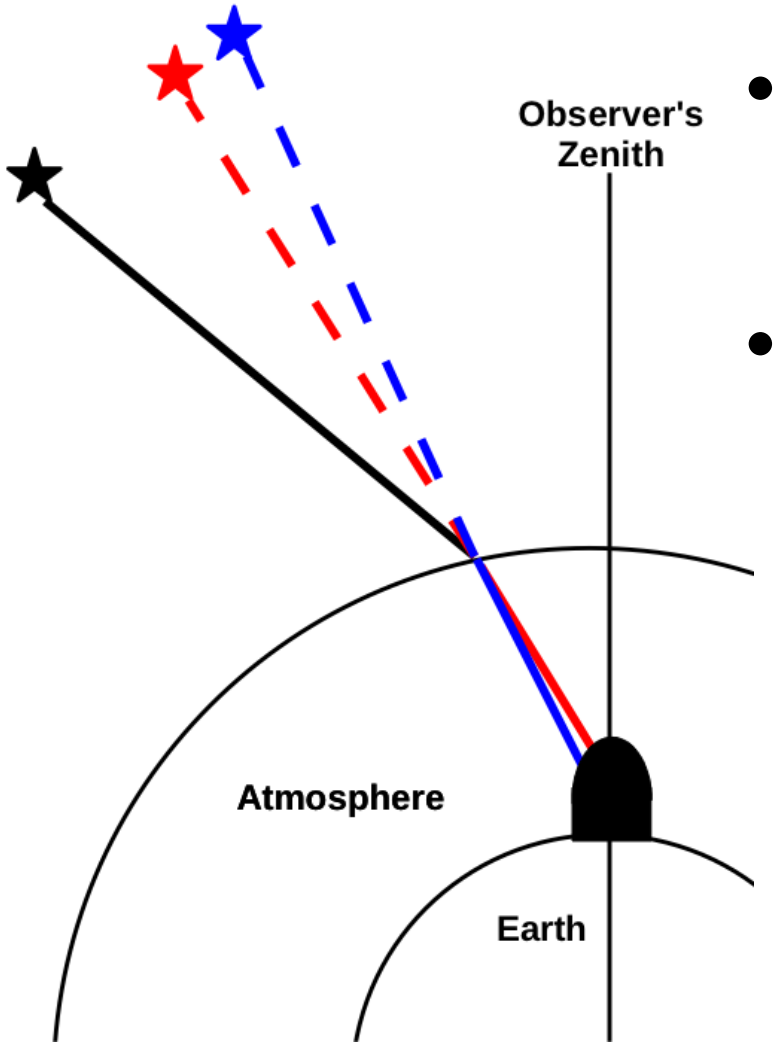
Astrometry



Differential Chromatic Refraction
(Kaczmarczik et al. 2009)

- Light bends according to Snell's Law, function of wavelength.

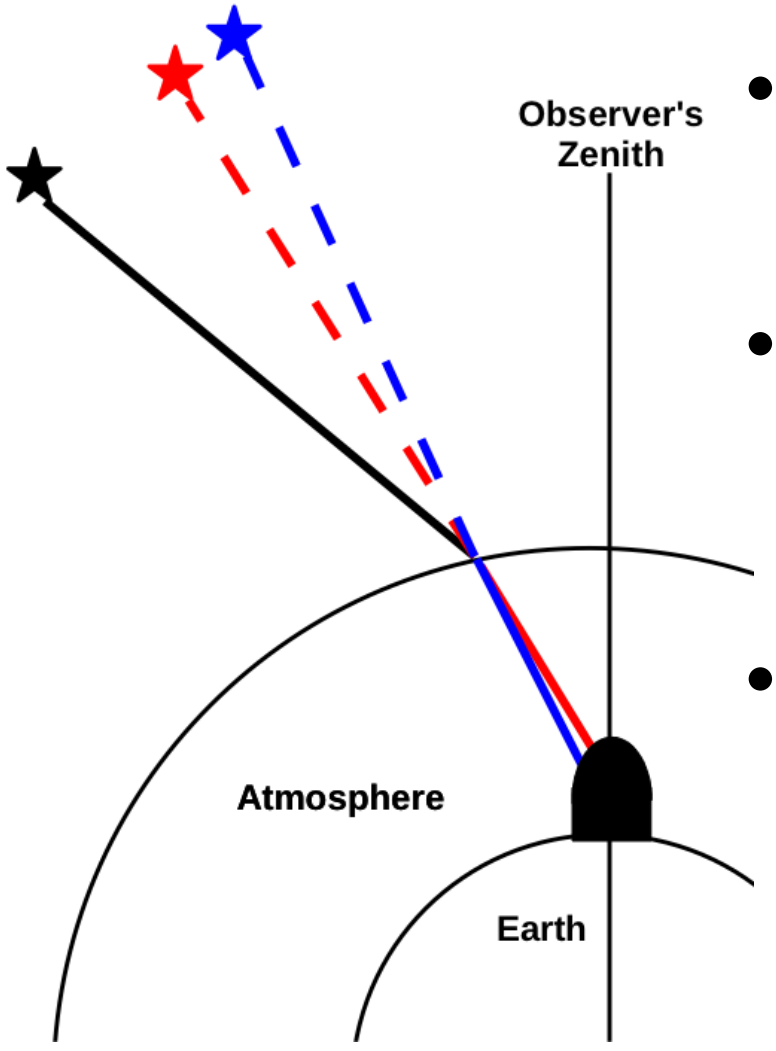
Astrometry



Differential Chromatic Refraction
(Kaczmarczik et al. 2009)

- Light bends according to Snell's Law, function of wavelength.
- Effective wavelength of the bandpass depends on Spectral Energy Distribution (SED).

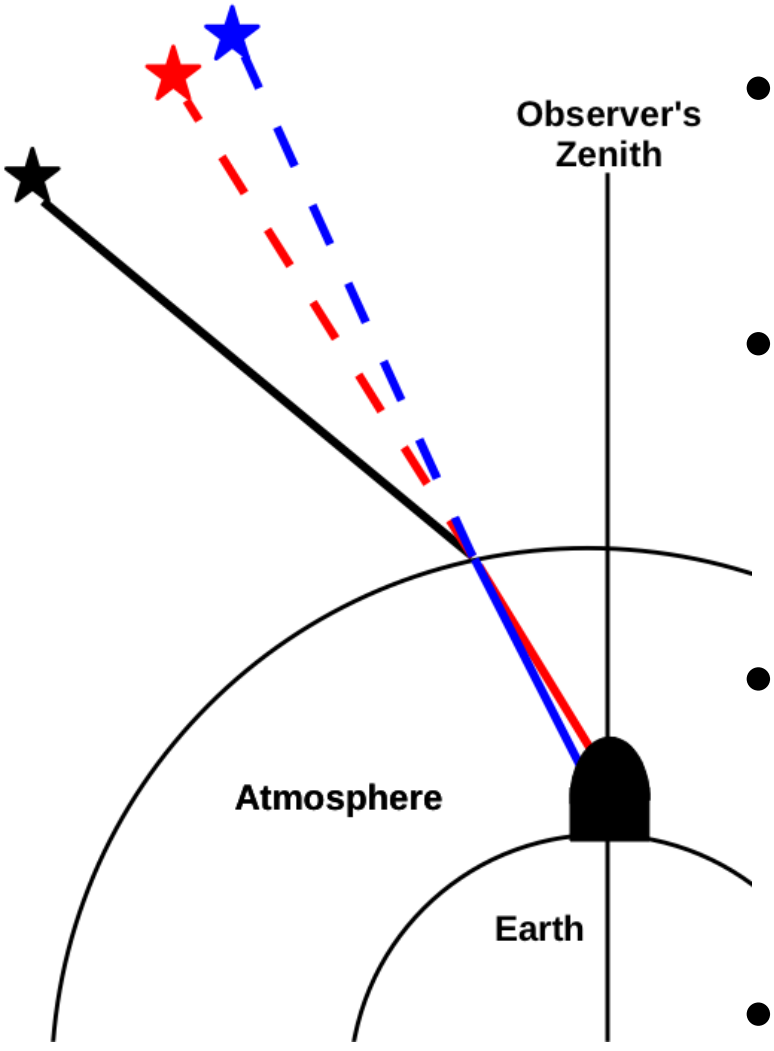
Astrometry



Differential Chromatic Refraction
(Kaczmarczik et al. 2009)

- Light bends according to Snell's Law, function of wavelength.
- Effective wavelength of the bandpass depends on Spectral Energy Distribution (SED).
- Emission lines in quasar SED change the effective wavelength as a function of redshift.

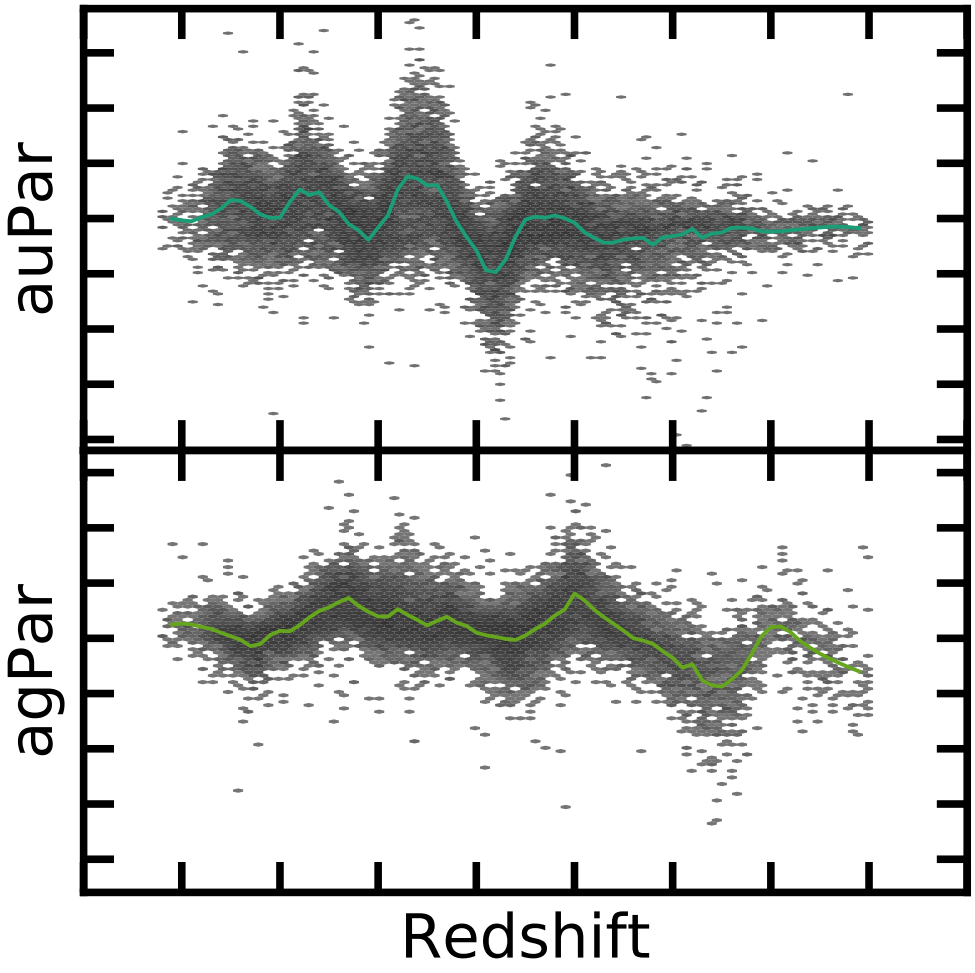
Astrometry



Differential Chromatic Refraction
(Kaczmarczik et al. 2009)

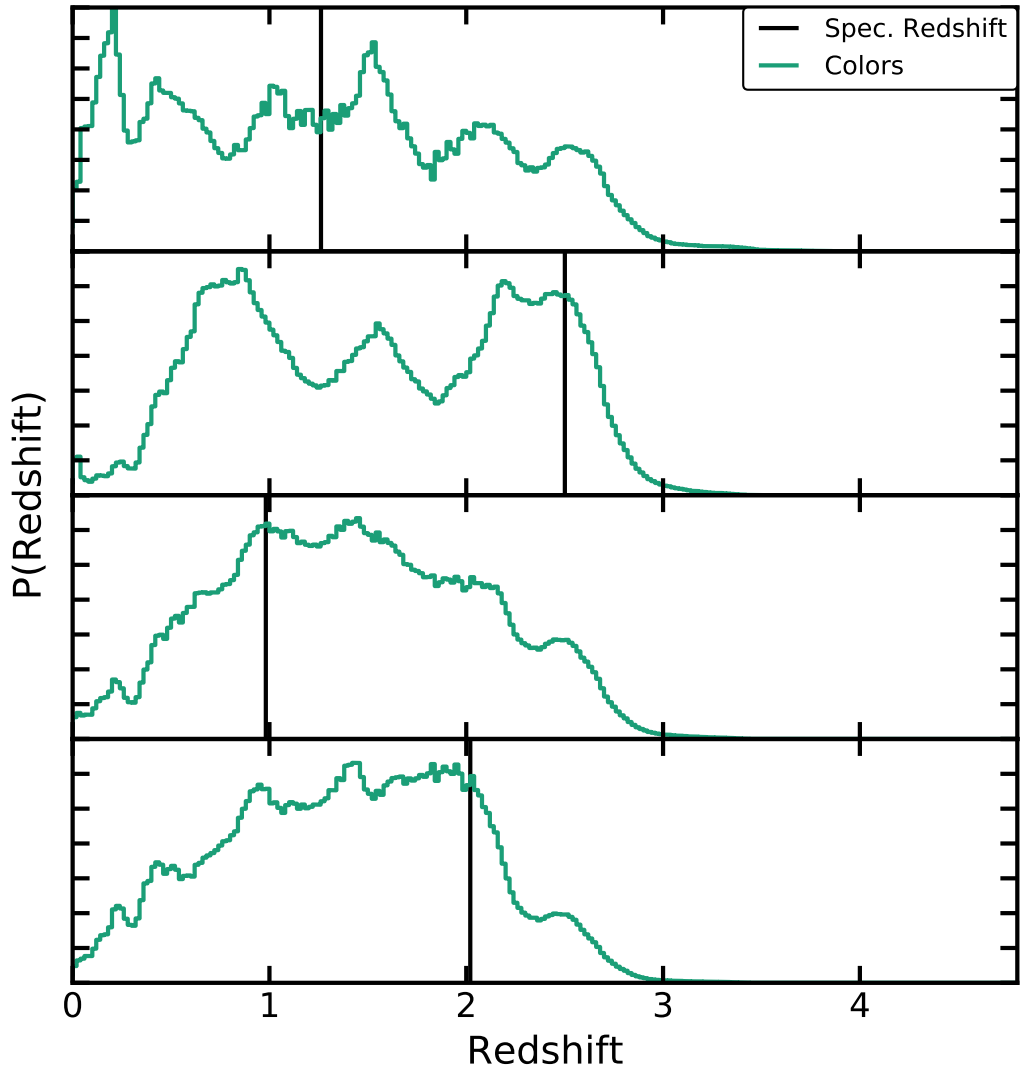
- Light bends according to Snell's Law, function of wavelength.
- Effective wavelength of the bandpass depends on Spectral Energy Distribution (SED).
- Emission lines in quasar SED change the effective wavelength as a function of redshift.
- Pipeline correction assumes a power law SED.

Redshift - DCR Relation



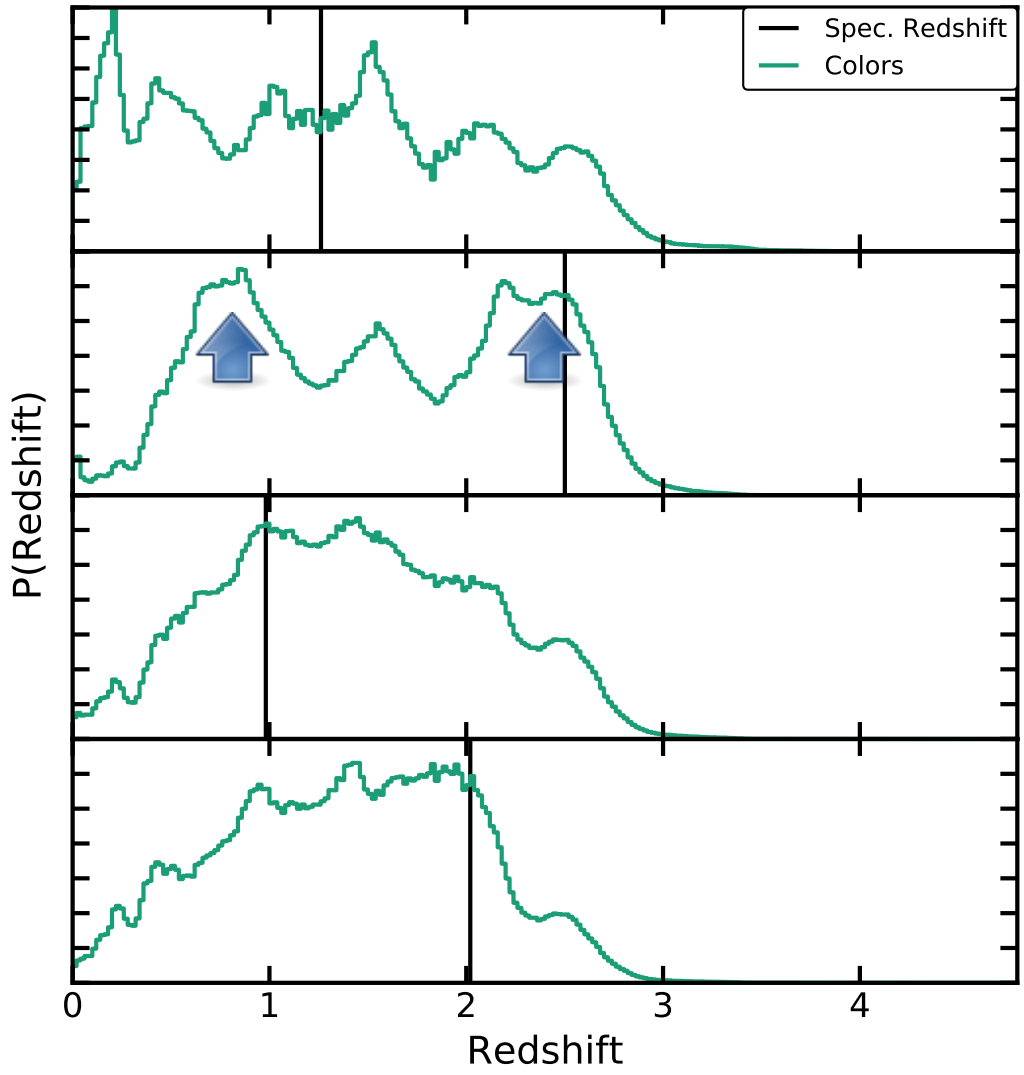
Astrometric offset as a function of redshift.

Astro-Photometric Redshifts



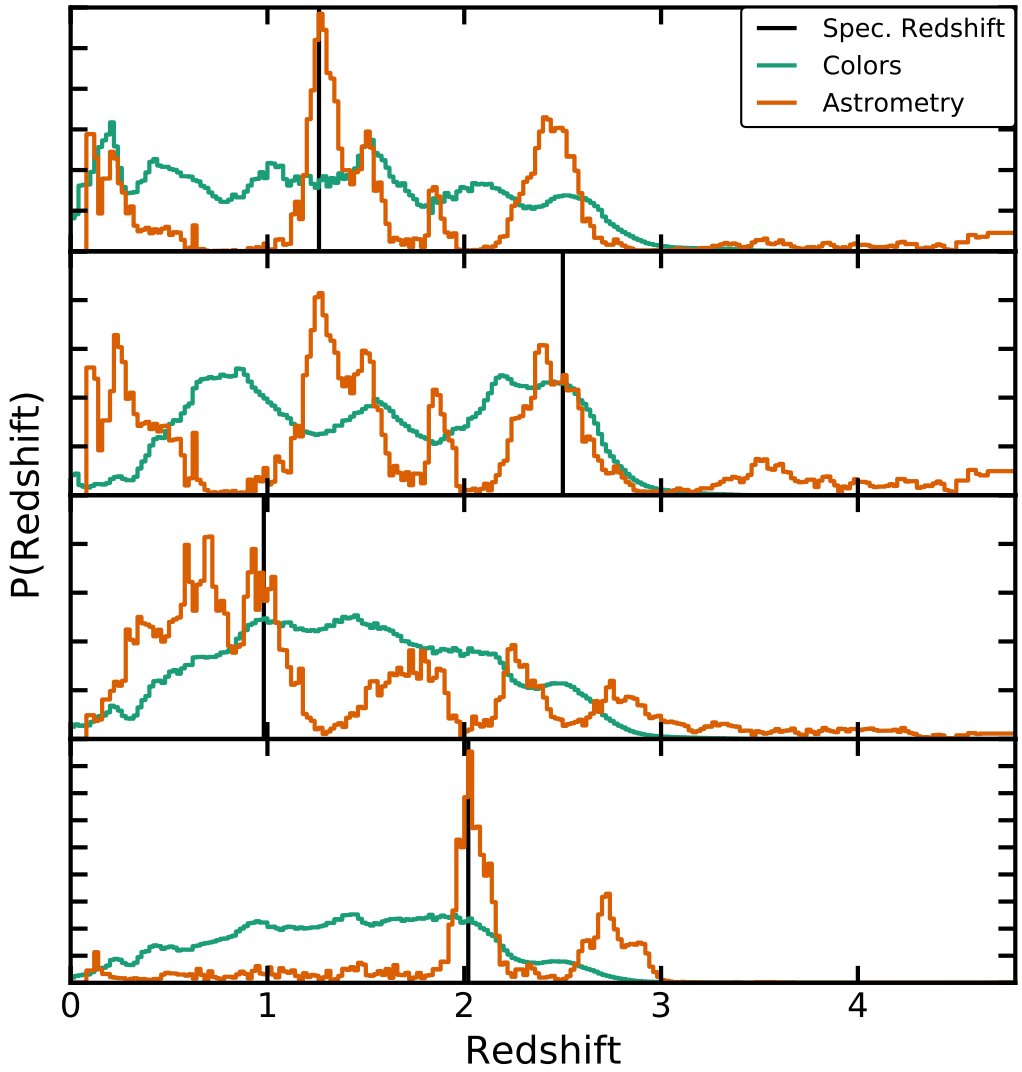
Probability as a function of redshift.
(Peters et al. 2015)

Astro-Photometric Redshifts



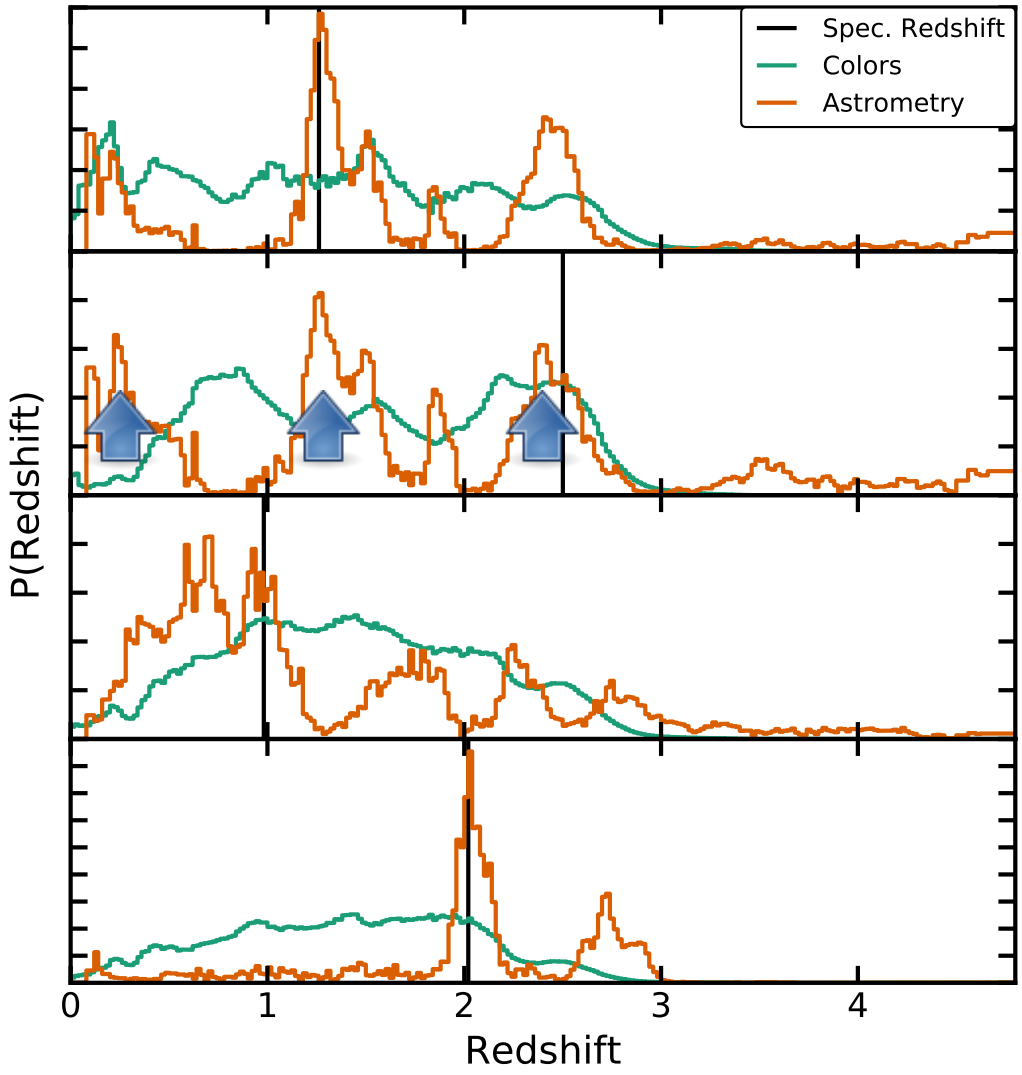
Probability as a function of redshift.
(Peters et al. 2015)

Astro-Photometric Redshifts



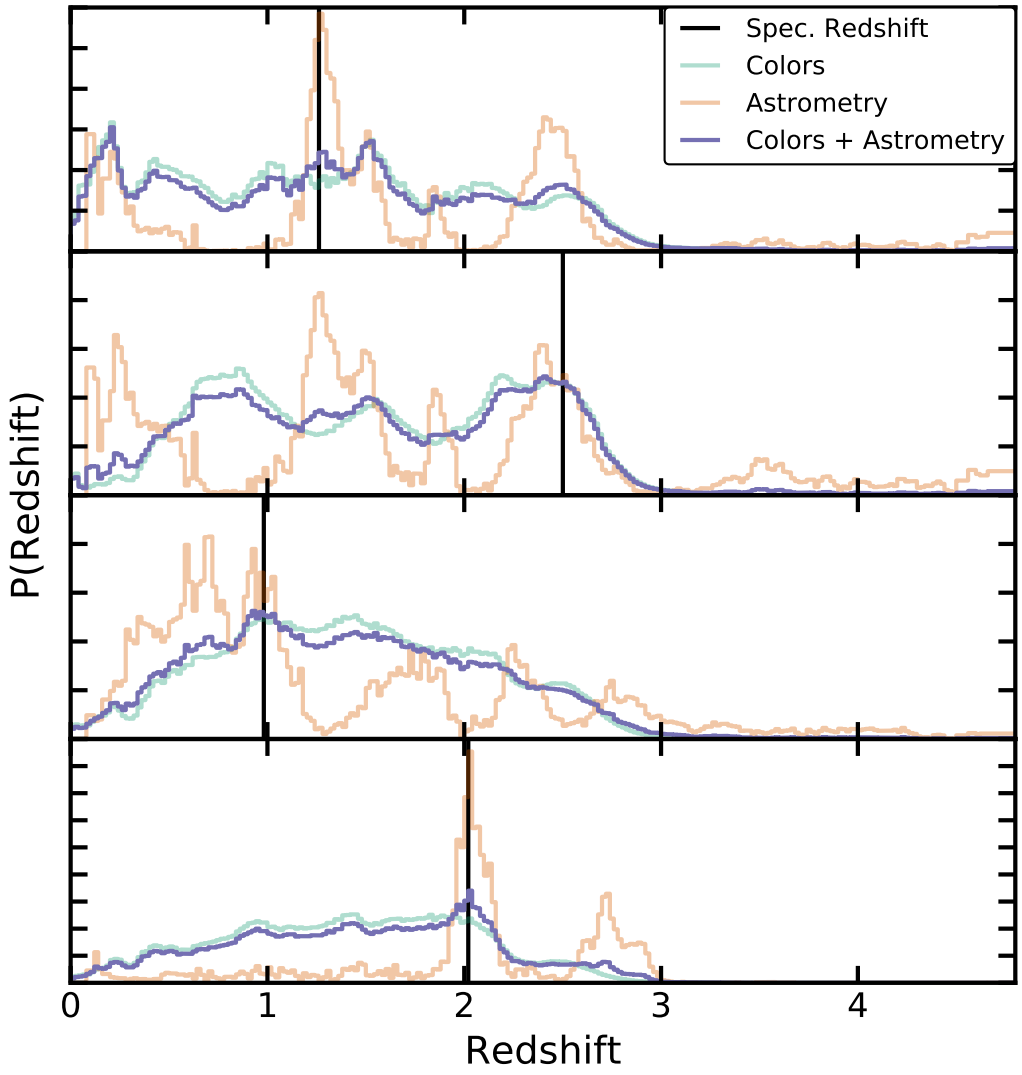
Probability as a function of redshift.
(Peters et al. 2015)

Astro-Photometric Redshifts



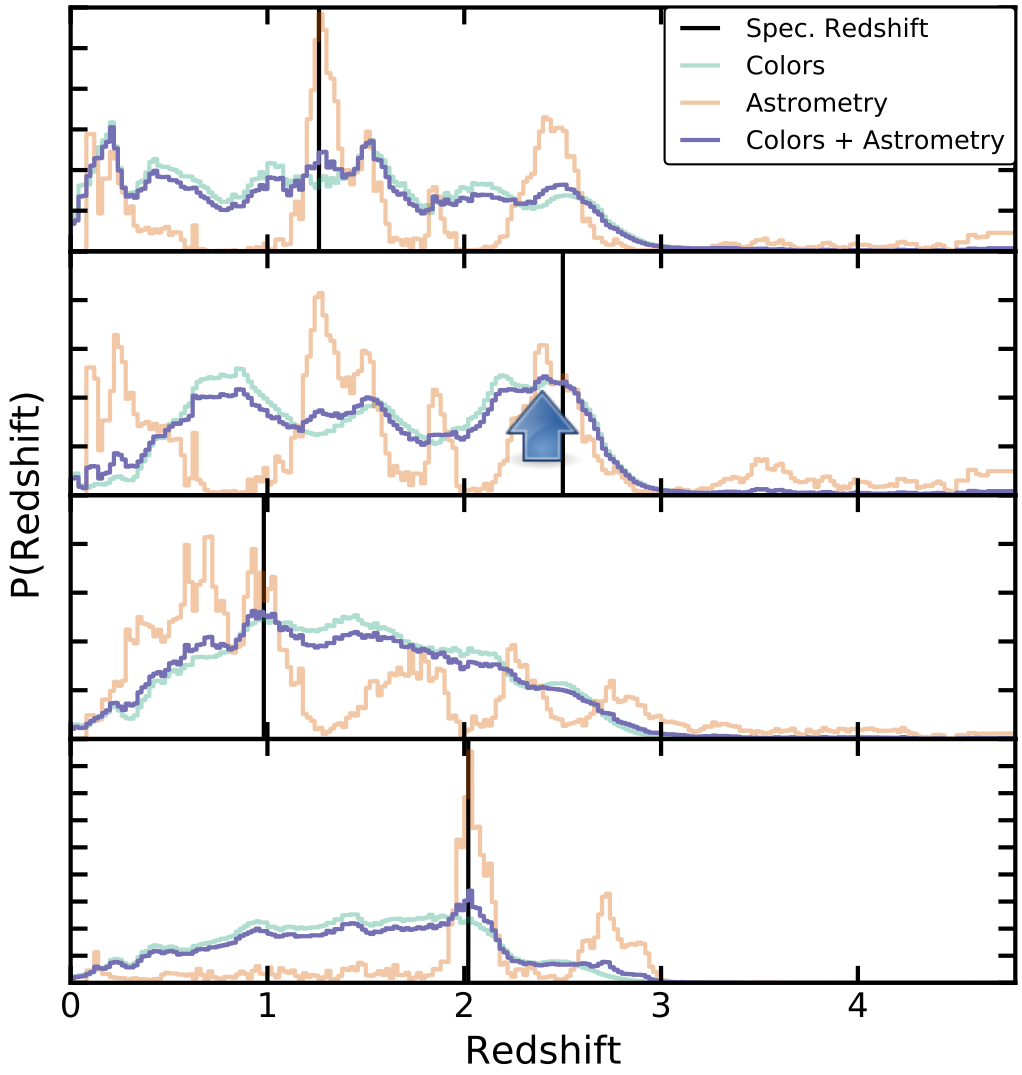
Probability as a function of redshift.
(Peters et al. 2015)

Astro-Photometric Redshifts



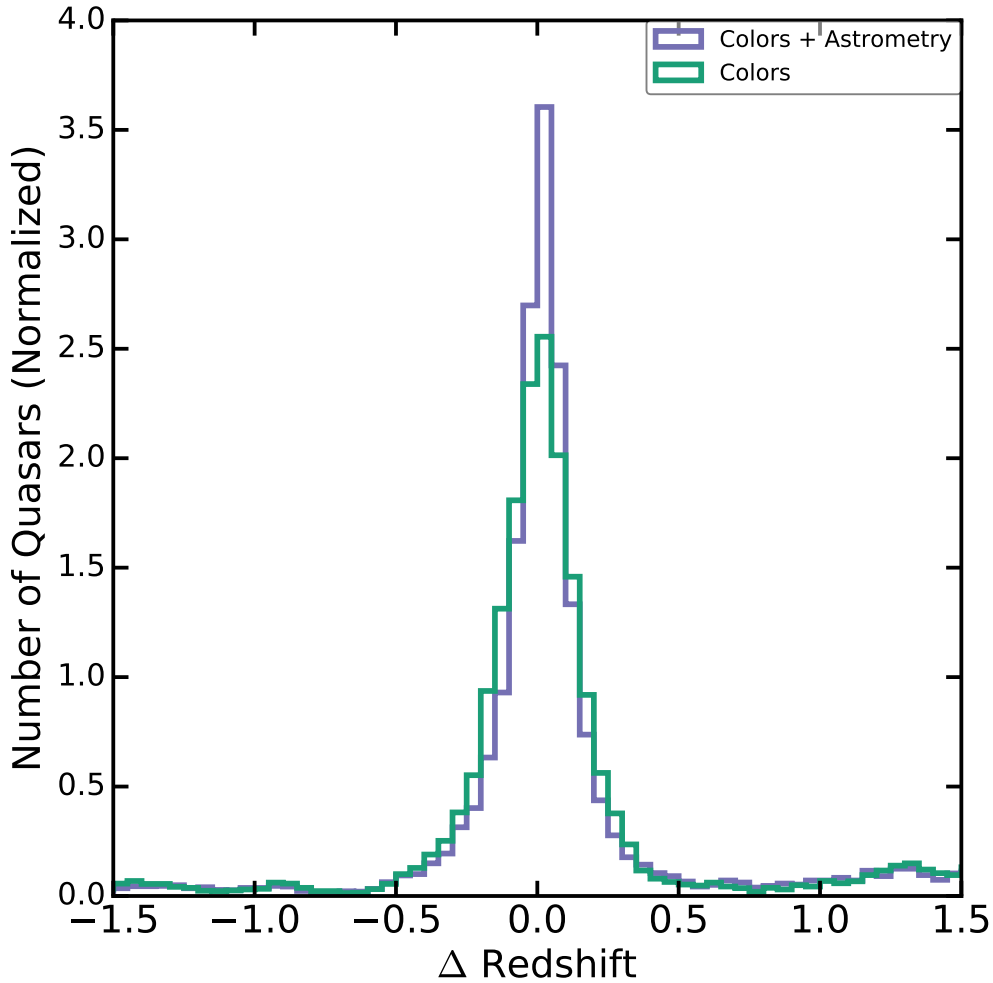
Probability as a function of redshift.
(Peters et al. 2015)

Astro-Photometric Redshifts



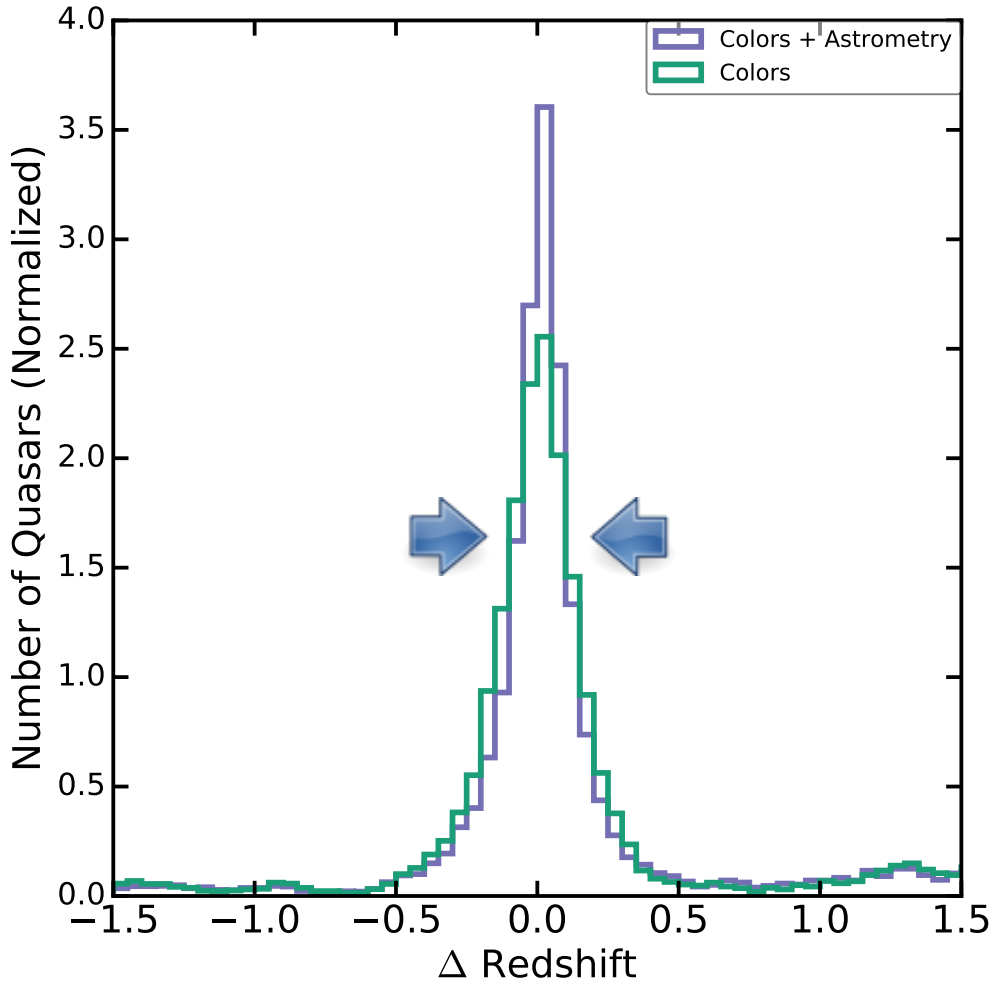
Probability as a function of redshift.
(Peters et al. 2015)

Astro-Photometric Redshifts



Spectroscopic redshift - most probable astro-photometric redshift. (Peters et al. 2015)

Astro-Photometric Redshifts



Spectroscopic redshift - most probable astro-photometric redshift. (Peters et al. 2015)

Summary

Quasar classification:

- more complete and uniform with both colors and variability
- plan to do selection in Pan-STARRS and DES

Summary

Quasar classification:

- more complete and uniform with both colors and variability
- plan to do selection in Pan-STARRS and DES

Redshift estimations:

- necessary for future surveys w/o spectra
- break degeneracies by adding new dimensions
- astrometry will be useful in LSST era