A Sample of 8 New Quasars from the Dark Energy Survey

Quasars in the Epoch of Reionisation

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Why?

Theories of black hole formation and evolution

Metal abundances in the early universe

Gas distribution and reionisation

$z = 2$
peak of galaxy and quasar activity

$z = 6 - 15$
Epoch of Reionization

$z = 6 - 8$
Start of Reionization

$z = 20 - 30$
first stars “Population III”

$z = 1100$
matter-radiation decoupling (CMB)
A quasar at $z \sim 6.2$

Between 6.0 and 6.5 the Lyman-$\alpha$ ($\lambda_{\text{rest}} = 121.6 \text{nm}$) emission line falls in the $z$ band.
Quasar Spectrum at $z \sim 6$

480 nm 640 nm 780 nm 920 nm 990 nm 1252 nm 2147 nm

DES VISTA
Currently Known Objects

Lots of quasars known at $z < 4.0$ (~88,000 in SDSS DR9)

Between $z = 5.7$ and $z = 6.5$ there are ~70 known objects

$z > 6.5$ there are 8, one is above $z = 7$

The Dark Energy Survey (DES)

First Light September 2012

Very large area when completed: ~5000 deg², currently have ~2000 deg²

Deep imaging: 10 σ limits for i and z are AB = 23.4 and AB = 23.2

Sophisticated camera, DECam

Credit: DES Collaboration
DECam

Mosaic of 62 2k by 4k CCDs (0.27” pixels)

Multi waveband imaging: Visible (400 nm) to Near IR (1050 nm), g, r, i, z and Y bands covered

Much more sensitive to red light than SDSS

Credit: DES Collaboration
DES - SDSS Comparison

SDSS was most sensitive to bluer light in the r band

DES is most sensitive to redder light in the z band
The VISTA Hemisphere Survey (VHS)

Will cover 10,000 deg$^2$ in the infrared when completed.

VHS-DES (J and K) overlaps DES and is deeper.

VHS-ATLAS (Y, J and K) is a shallower survey.
Loose colour cuts were used to cut down the list

Bad image areas were removed

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
<th>Number Removed</th>
<th>Number Remaining</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Steps 1-8b from paper 1(^1)</td>
<td>139,135,538</td>
<td>4,195</td>
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<tr>
<td>2</td>
<td>Y - J &lt; 1.0</td>
<td>3,235</td>
<td>960</td>
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<tr>
<td>3</td>
<td>Remove Chip Edges in z Band</td>
<td>498</td>
<td>462</td>
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<tr>
<td>4</td>
<td>Remove Bad Image Areas</td>
<td>105</td>
<td>393</td>
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<tr>
<td>5</td>
<td>Remove Objects Bright in r</td>
<td>246</td>
<td>147</td>
</tr>
</tbody>
</table>

Number of objects in database: 139,142,161
Model fitting was done to four different quasar models and brown dwarf models.

\( \chi^2 \) was done to each model and the candidates were ranked.

Brown dwarf models from Skrzypek+ 2015
Spectroscopic Follow up - $z \approx 6$

Spectra were taken using the NTT at La Silla and by Paul Martini using Gemini-S.
Spectroscopic Follow up - $z > 6.5$

Taken by Michael Rauch using Magellan
New quasars from DES/VHS compared to previously known objects.

Our large area allows us to find bright objects useful for follow-up studies.
Quasars and non quasars are separated well by $\chi^2$.

Working on a catalogue using no colour cuts and separating by $\chi^2$.

Currently limited by resolution of WISE catalogues; working on a new forced photometry catalogue using unWISE images and SExtractor.
Eight new quasars at $6.0 < z < 6.5$ and recovery of two already known ones from a combination of DES, VHS and WISE photometry.

No photometric follow-up required and very high success percentage

Working on a method to select quasars without using any colour cuts - can find more unusual objects.
Above $z = 6.5$ the Lyman-$\alpha$ has an observed wavelength of 9120 Å and starts to move into the Y waveband.

Also need near infrared colours to separate quasars from more numerous galactic cool brown dwarfs.
Colours at $z > 6.5$
Expected Numbers

5,000 deg$^2$ of DES footprint
z > 6.5 50-80 with Y < 22 [AB]
z > 7.0 3-10 with J < 21 [AB]

10,000 deg$^2$ of VHS + DES/VST-ATLAS
z > 6.5 20-30 with Y < 21 [AB]
z > 7.0 2-5 with J < 20 [AB]
Note brighter limits

Based off Manda Banerji’s calculations from Willott et al 2010
z ~ 6 Selection Criteria

VDES0224-4711

E(B-V) = 0.000
Best z: 6.5
Min $\chi^2$: 293.30
Min $\chi^2_{red}$: 32.59

E(B-V) = 0.025
Best z: 6.4
Min $\chi^2$: 121.53
Min $\chi^2_{red}$: 13.50

E(B-V) = 0.050
Best z: 6.3
Min $\chi^2$: 35.86
Min $\chi^2_{red}$: 3.98

E(B-V) = 0.100
Best z: 6.0
Min $\chi^2$: 80.84
Min $\chi^2_{red}$: 8.99

VDES0504-5644

E(B-V) = 0.000
Best z: 5.9
Min $\chi^2$: 95.54
Min $\chi^2_{red}$: 11.94

E(B-V) = 0.025
Best z: 5.9
Min $\chi^2$: 68.85
Min $\chi^2_{red}$: 8.61

E(B-V) = 0.050
Best z: 5.9
Min $\chi^2$: 131.35
Min $\chi^2_{red}$: 16.42

E(B-V) = 0.100
Best z: 5.4
Min $\chi^2$: 353.40
Min $\chi^2_{red}$: 44.17

Brown Dwarf
Best Type: L3
Min $\chi^2$: 1015.99
Min $\chi^2_{red}$: 112.89

Filter: giz, J, H, K, W1, W2, W3, M5, L0, L5, T0, T5
Stellar Type: Flux from Model, Actual values
Fitting of a quasar model to the optical discovery spectra

Fit for five lines, model Ly-α as a combination of exponential decay and a gaussian.
New quasars from DES/VHS compared to previously known objects.

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