Morphology of QSO Host Galaxies - a look at the SED

Alexandre H. Andrei [1,2,3,4], *Bruno Coelho* [4], *Sonia Anton* [5]

1) *Observatório Nacional/MCTI - Brasil*
2) *SYRTE/Observatoire de Paris – France*
3) *Osservatorio Astrofisico di Torino/INAF - Italia*
4) Observatório do Valongo/UFRJ – Brasil
5) *SIM/Faculdade de Ciências da Universidade de LIsboa - Portugal*

Morphology of QSO Host Galaxies - a look at the SED

Abstract

We develop a program to study the host galaxies of QSOs present in the SDSS up to its 8th release. The main observational data thus comprises a large retrieved data bank of images in the five ugriz colors for the 105,783 objects spectroscopically found as QSOs, within frames large enough to contain tens of comparison stars and several field galaxies. Complementary, images of more than 300 bright quasars that will be used to link the future Gaia Celestial Reference Frame (GCRF) to the International Celestial Reference Frame (ICRF) were taken using 2m class telescopes, over the entire sky, in the Johnson B and R colors. The first scope of this program is to select QSOs for which the isophotes of the host galaxy are not pronounced so that the centroid determination is not affected over those fundamental grid-points of the GCRF. Ancillary we prepare templates upon which the Gaia observations of the ensemble QSO plus host galaxy can be interpreted. At the same time, this study in itself aims to discuss the characteristics of the QSO host galaxy on basis of this large, statistically complete sample of images. Since the target images come from relatively short exposures, our approach is to access disturbances of the target PSF relatively to the nearby stars, as well as the photometric ratio between the central and the peripherical portions, and the interpretation of best morphological fit. We review the data bank of the SDSS and obtained images, and the methods of analysis, emphasizing the one we developed using IRAF routines. We present the first results for absolute magnitude of QSOs combining the SDSS colors and the SED library from Gaia. Finally we discuss the findings from the point of view of the astrometric bearing, in particular for the Gaia mission .

Morphology of QSO Host Galaxies - a look at the SED

Abstract

We develop a program to study the host galaxies of QSOs present in the SDSS up to its 8th release. The main observational data thus comprises a large retrieved data bank of images in the five ugriz colors for the 105,783 objects spectroscopically found as QSOs, within frames large enough to contain tens of comparison stars and several field galaxies. Complementary, images of more than 300 bright quasars that will be used to link the future Gaia Celestial Reference Frame (GCRF) to the International Celestial Reference Frame (ICRF) were taken using 2m class telescopes, over the entire sky, in the Johnson B and R colors. The first scope of this program is to select QSOs for which the isophotes of the host galaxy are not pronounced so that the centroid determination is not affected over those fundamental grid-points of the GCRF. Ancillary we prepare templates upon which the Gaia observations of the ensemble QSO plus host galaxy can be interpreted. At the same time, this study in itself aims to discuss the characteristics of the QSO host galaxy on basis of this large, statistically complete sample of images. Since the target images come from relatively short exposures, our approach is to access disturbances of the target PSF relatively to the nearby stars, as well as the photometric ratio between the central and the peripherical portions, and the interpretation of best morphological fit. We review the data bank of the SDSS and obtained images, and the methods of analysis, emphasizing the one we developed using IRAF routines. We present the first results for absolute magnitude of QSOs combining the SDSS colors and the SED library from Gaia. Finally we discuss the findings from the point of view of the astrometric bearing, in particular for the Gaia mission .

Morphology of QSO Host Galaxies - a look at the SED

The GIQC

The latest, updated, and fully corrected version of the Gaia Initial QSO Catalog (GIQC), produced by the CU3 GWP-S-335-13000, contains 1,248,372 objects, of which 191,802 are considered and marked as Defining ones, because of their observational history and existence of spectroscopic redshift. Also objects with strong, calibrator-like radio emission are included in this category. The Defining objects represent a clean sample of quasars. The remaining objects aim to bring completeness to the GIQC at the time of its compilation. For the whole GIQC the average density is 30.3 sources per sq.deg., practically all sources have an indication of magnitude and of morphological indexes, and 90% of the sources have an indication of redshift and of variability indexes. Besides presenting morphological, variability, and classification indexes (plus a one-letter comment on the source main feature), the MDB version currently contains nearly 1 million more quasars than in the IGSL and should preferably be used to match Gaia own observations.

Available from the MDB Dictionary Tool

http://gaia.esac.esa.int/maindb/mdbtools/

The tables are below MDB/CU3/AuxData/InitialQso

Detailed description in Livelink as GAIA-C3-TN-GPA-AA-003-01

Morphology of QSO Host Galaxies - a look at the SED

What it is the GIQC

- ♦ It is a compilation of QSOs from the literature. And in the literature under QSO are included active galactic nuclei objects (AGN) at large, that is radio loud quasars, Blazars, radio quiet quasars, BL LACs, Seyfert galaxies, LINERS. Thus, in the GIQC a QSO is an object which can be seen as an extragalactic quasi stellar source from a certain point of view and a given set of parameters.
- ♦ It aims to completeness. Objects were excluded if the redshift was unknown (except for quasars) or unreliable; or if the magnitude was quoted brighter than 10; or if the astrometric accuracy was worse than 1 arcsec.
- ♦ The precisions on position and on magnitude are modest, just to suffice to unmistakable match to the actual Gaia observation.
- ♦ The redshifts are useless for the main purpose of matching but are invaluable to feed the supervised Artificial Neural Networks (ANN) at the basis of the Gaia autonomous QSO detection.
- ♦ The morphology and variability indexes are merely indicative, in the statistical meaning, but this knowledge is required to understand and model the astrometric error budget, and to accept an object to form the core GCRF.

What it is not

- ♣ A Celestial Reference Frame
- ♣ The QSOs in the IGSL do form one, the LQRF

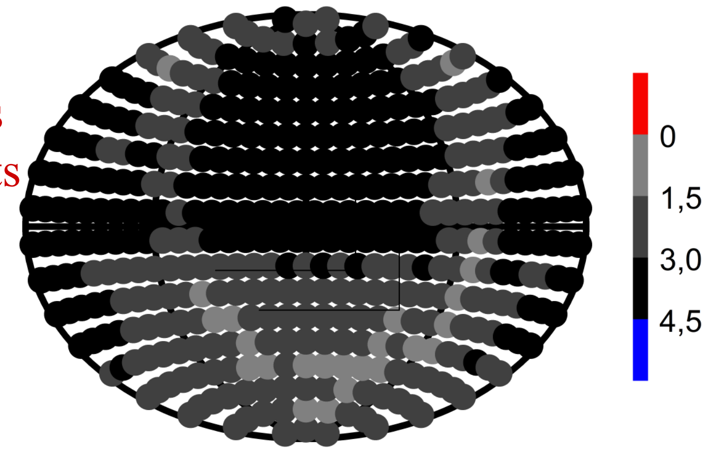
Morphology of QSO Host Galaxies - a look at the SED

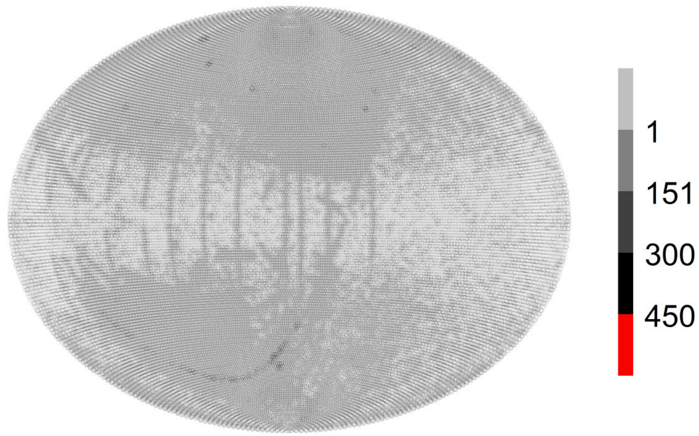
The GIQC_5 in a nutshell

Number of sources	1,248,372
Sources with magnitude	1,246,512
Sources with redshift	1,157,285
Astrometry precision	1 arcsec
Magnitude precision	0.5
Redshift precision	0.01
Average density	30.3 sources/deg^2
Average neighbor distance	3.7 arcmin (σ 4.9 arcmin)
Maximum distance to neighbor	5.2 deg
Maximum distance to neighbor (average of 100 larger values)	3.0 deg (σ 0.6 deg)

Sky density distribution

10 deg cells
log10 counts
equatorial





1 deg cells, linear counts, galactic

Morphology of QSO Host Galaxies - a look at the SED

The GIQC_5 in the MDB

RA (deg)	DEC (deg)	MAG	z	Bshr	Bsrn	Bgrn	Rshr	Rsrn	Rgrn	Ishr	Isrn	Igrn	Vdisk	Vtorus	Class
0.001997	-0.451102	20.50	0.250						3.00				0.03	0.14	D S
0.005750	-30.607472	19.50	1.143				0.20	0.01	0.91				0.34	0.57	D
0.007333	-31.373833	19.86	1.331				0.73	0.44	0.00	1.82	1.14	1.37	0.32	0.55	D
0.008067	-0.240971	19.93	2.163						1.00				0.57	0.83	D S
0.013229	1.252967	20.74	2.354						1.00				0.41	0.69	D S
0.022875	-27.419556	19.14	1.930				0.12	1.01	0.41				0.88	1.08	D
0.027231	0.515332	20.49	1.823				0.73	0.48	0.26	0.63	1.07	0.20	0.30	0.54	D S
0.031618	0.495354	20.38	2.254						1.00				0.49	0.77	D S
0.033300	-63.593300	17.00	0.136				0.42	0.95	0.17				0.22	0.59	D S
0.033946	0.276292	20.02	1.839				1.18	1.10	0.49	0.71	1.07	1.09	0.43	0.68	D S
0.038609	15.298489	19.38	1.204	0.36	0.92	0.08	0.92	0.02	0.30	1.11	1.51	1.46	0.39	0.63	D S
0.038657	2.106112	19.46	1.432						1.00				0.48	0.71	D S
0.039099	13.938458	18.43	2.225	0.63	0.91	0.09	0.59	0.23	0.14	2.07	0.16	1.43	1.79	1.71	D S
0.039264	-10.464410	18.97	1.854						3.00				0.94	1.12	D S
0.040375	-31.279972	18.65	1.727				1.16	1.47	0.77	1.11	2.66	3.78	1.06	1.19	D
0.041250	-30.924944	18.37	1.787				0.39	0.07	0.03				1.37	1.41	D
0.047551	14.929367	19.36	0.460	0.07	0.09	0.02	0.18	0.76	0.04	0.17	1.33	0.59	0.12	0.31	D S
0.048197	-8.835659	19.06	3.220										3.65	2.84	D S
0.048583	-31.644417	19.38	2.680				0.95	0.43	1.43				1.60	1.64	D
0.049839	0.040359	17.85	0.480				0.42	1.11	0.44	0.36	1.16	0.18	0.37	0.63	D S
0.051083	-0.539051	20.33	1.436				0.99	0.27	0.38	0.01	0.41	0.29	0.25	0.48	D S
0.054310	4.734323	20.89	2.624						1.00				0.47	0.76	D S
0.054787	14.176304	19.12	0.949	0.86	1.20	0.30	0.36	0.96	0.48	0.40	1.99	1.41	0.36	0.59	D S

Morphology of QSO Host Galaxies - a look at the SED

Variability Indexes – for Gaia QSOs

♦ The preceding and following astrometric fields of view (i.e., separated by an angle of 106 deg) have a repetition observing pattern of: 1h46m-4h14m-1h46m-4h14m.

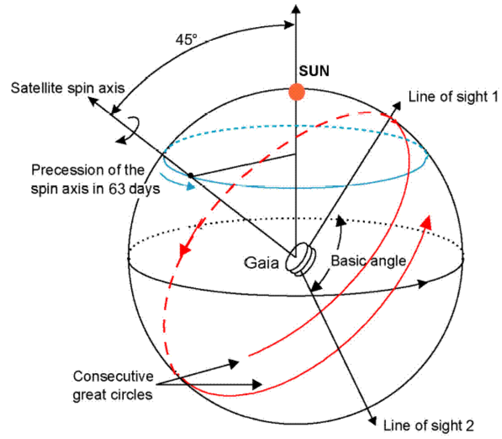
♦ Typically, the objects are observed during 4-5 orbits and then gaps of about 30-40 days will separate these grouped measurements (depending of the object position).

♦ When an object is temporarily at the node of the great circle of scanning, it is regularly observed for several days.

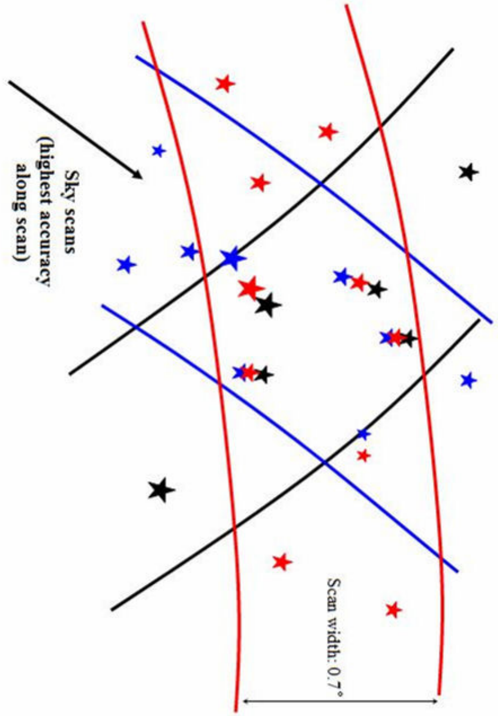
♦ Thus Gaia has excellent capabilities to derive QSO variability. Such a record will have an enormous impact for QSO astrophysics.

♥ But, before that, it can enable to recognize QSOs, and to enlarge the supervised the ANN at the basis of the Gaia autonomous QSO detection.

♥ On the other hand, in the cases in which the photometric variability relates to the photocenter jitter, it can alleviate the QSO's error budget – and exactly for those closer and brighter.



Spin axis	50° to Sun
Scan rate:	60 arcsec/s
Spin period:	6 hours



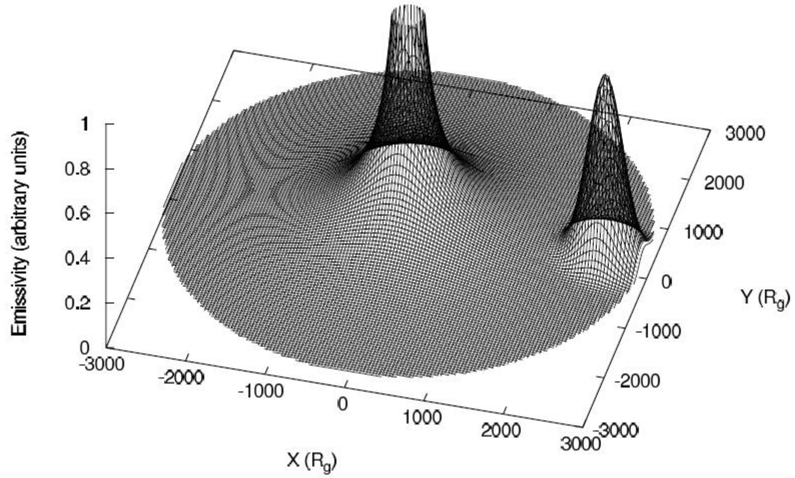
Morphology of QSO Host Galaxies - a look at the SED

Variability Indexes – Where variability comes from

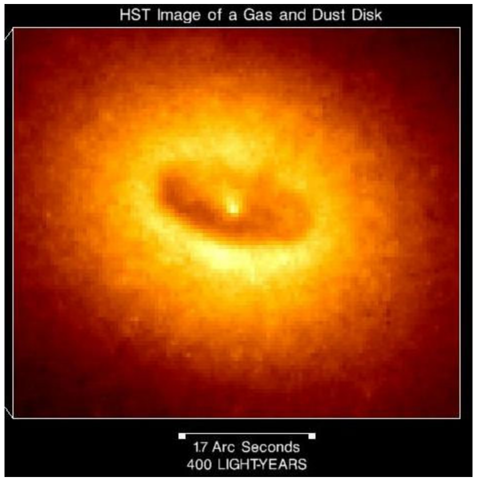
♣ **Popovic et al. (2011) model** – Associated astrometric (in *mas*) and photometric variability due to

(a) Instabilities in the accretion disk

M_{BH} ($M_\odot$)	z				
	0.01	0.05	0.10	0.15	0.20
10^8	0.036	0.007	0.004	0.003	0.002
10^9	0.355	0.074	0.039	0.028	0.022
10^{10}	3.550	0.744	0.394	0.278	0.220



(b) density irregularities in the dusty torus



L ($10^{11} L_\odot$)	z		
	0.01	0.05	0.10
0.50 μm			
3	1.579	0.208	0.039
6	8.400	1.886	0.860
10	8.170	1.353	0.693

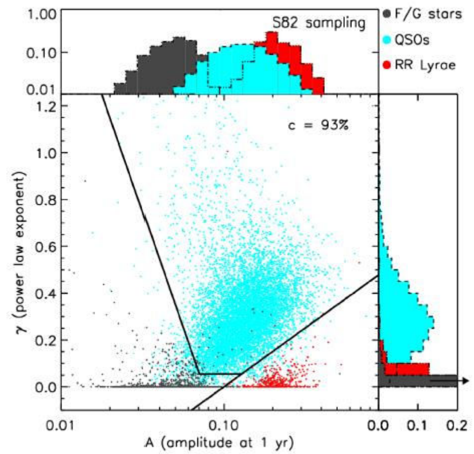
Morphology of QSO Host Galaxies - a look at the SED

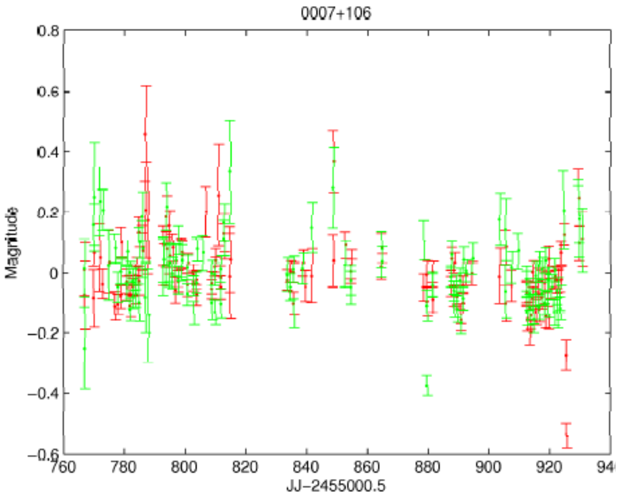
Variability Indexes – in action
(see Taris et al. this meeting)

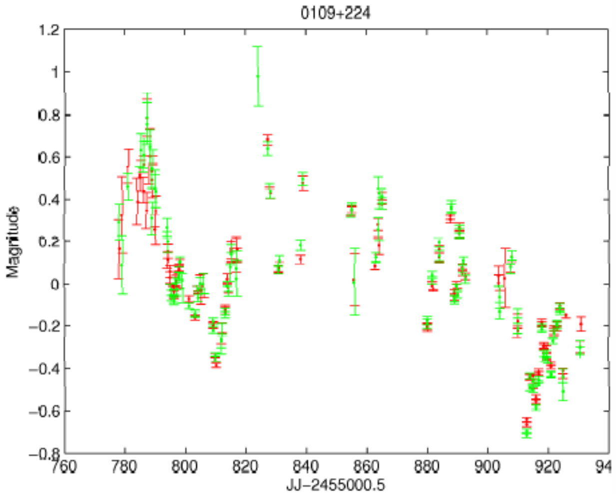
♣ Variability modulus based on Kelly et al. (2009):
$V = A\,(\Delta t/y)^{\gamma}$

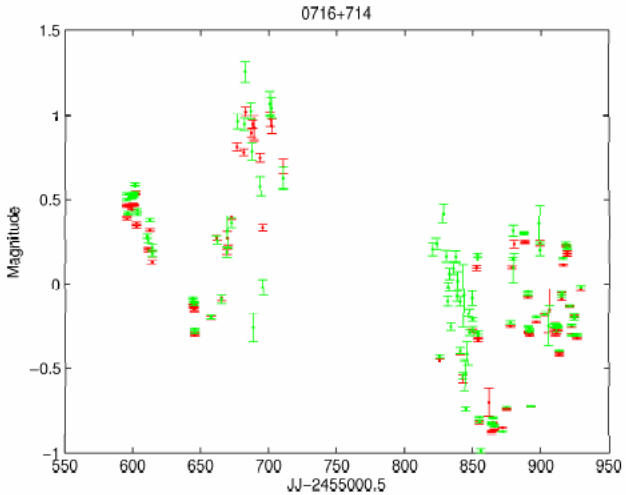
♦ Zadko Telescope Variability program

(Taris et al.)









$A = 0.348 \pm 0.006$

$\gamma = 0.484 \pm 0.0009$

$A = 0.394 \pm 0.003$

$\gamma = 0.558 \pm 0.0003$

$A = 0.390 \pm 0.003$

$\gamma = 0.613 \pm 0.0005$

Morphology of QSO Host Galaxies - a look at the SED

Morphology Indexes – Host galaxy review

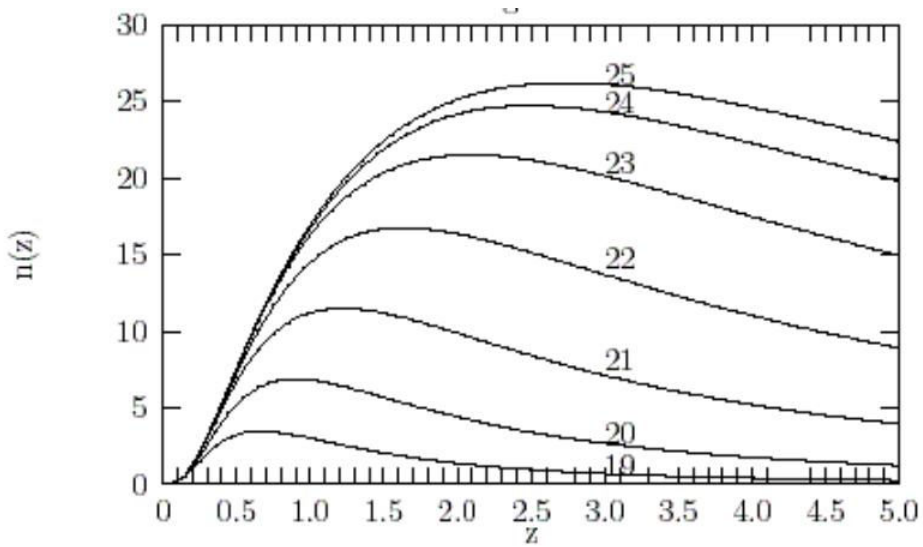
♠ The host galaxy luminosity seems to increase proportionally to the strength of the central source, i.e. QSOs host galaxies may expected to usually be brighter than those around less powerful AGNs. Its absolute magnitude should be brighter than -23.5.

♠ The size of the host galaxy also tends to follow the rule. Typical sizes for BLLac are 13kpc. Most of times it is an elliptical or bulge dominated galaxy.

♠ Host galaxies have regularly been resolved for AGNs to z < 1.5 and 1arcsec resolution.

♠ The QSO space distribution peaks at z=0.6 for B=19, and at z=1 for for B=20.

♠ The largest fraction of GAIA QSOs will be of nearby ones. Average z = 1.1 but z = 0.8 at MAGr ~<18



Number of quasars per deg^2 as function of redshift and magnitude (Crawford 1994)

Morphology of QSO Host Galaxies - a look at the SED

Morphology and the signature of the host galaxy

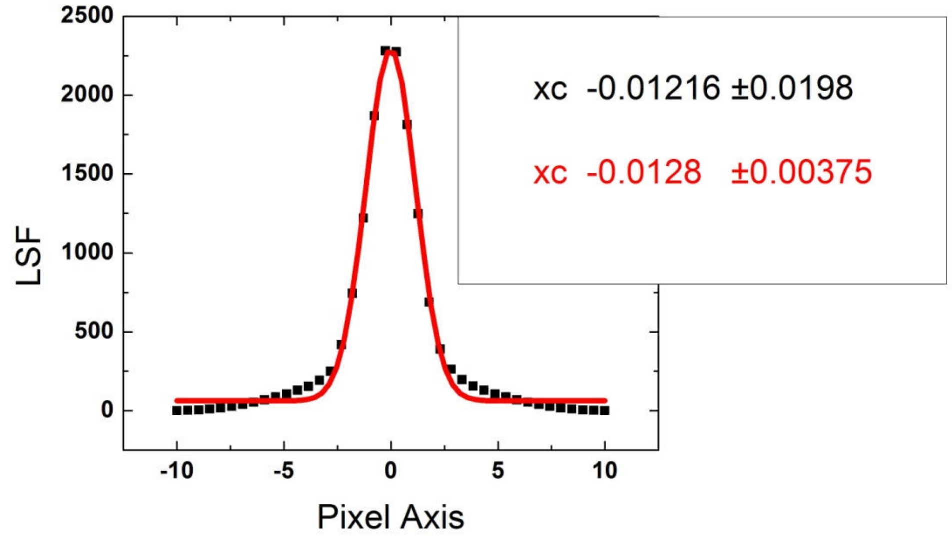
♣ At 60 × 12 pixels (59 ×177 mas/px) sampling; FWHM < 0.65asec

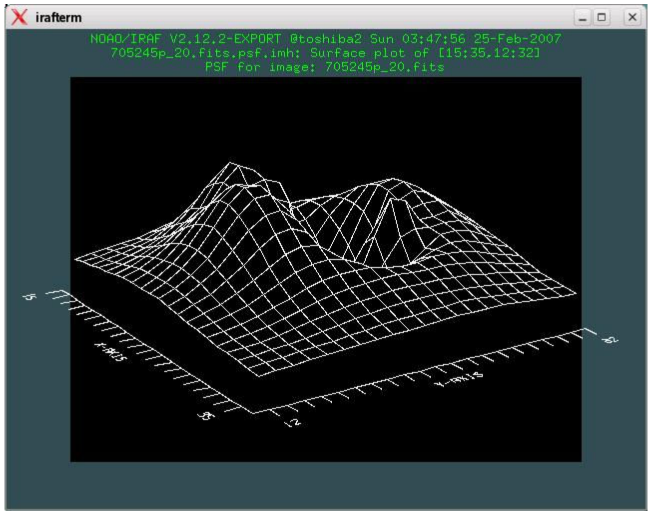
♦ One might expect a fair amount of contamination by alien AGNs among the GAIA extragalactic reference frame

♥ (because they would look alike by the GAIA QSO selection criteria, and because they still would look a lot pointlike).

♦ One might expect a fair amount of resolved host galaxies around the GAIA extragalactic reference frame QSOs

♥ (because the host galaxies do are large and bright enough, because of contamination by alien AGNs, and because the QSOs will be nearby ones).



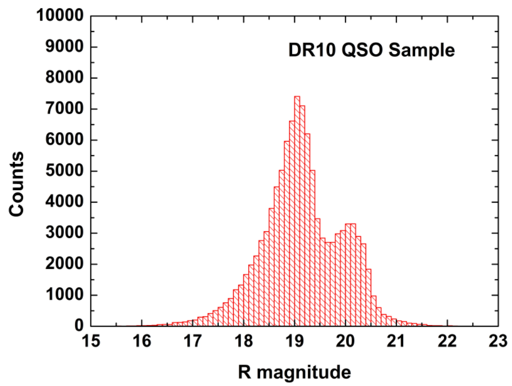


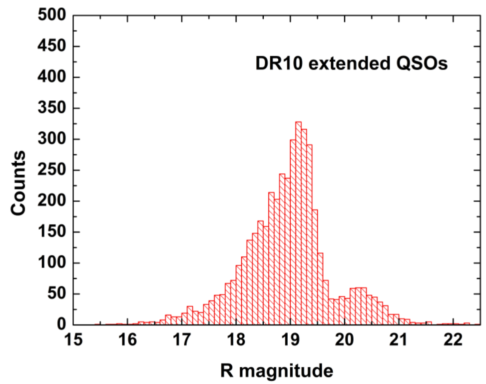
Morphology of QSO Host Galaxies - a look at the SED

At what rate is the QSOs host galaxy perceived?

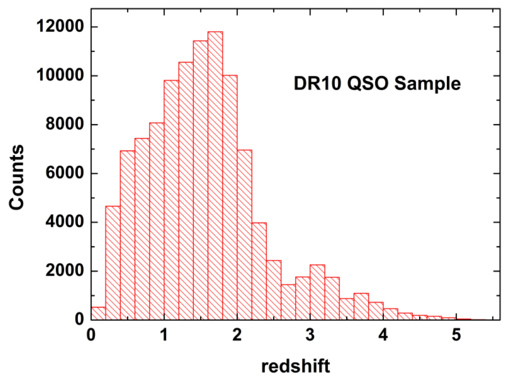
♠ SDSS galaxy/star classifier is given by the 0.145 threshold difference between a PSF fitting and a PSF+deVaucouleurs fitting. Thus very extended objects are privileged.

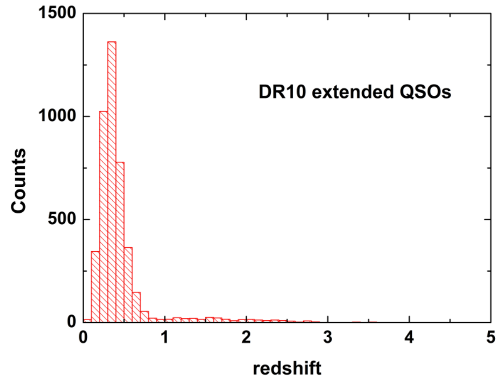
♦ On the DR10, 4.15% of the QSOs are signaled as galaxy-like.





Photometrically: same distribution





Cosmologically: differect distribution

Morphology of QSO Host Galaxies - a look at the SED

At what rate is the QSOs host galaxy perceived?

♠ Pioneer study for SDSS DR9 images of the ICRF sources (Ana Affonso & Sonia Anton – MsC thesis 2014. Mimicking the Gaia CU4 galaxy fitting – PSF + Sersic.

♥ 27.3% (out of 180 targets) were found needing a Sercic component.

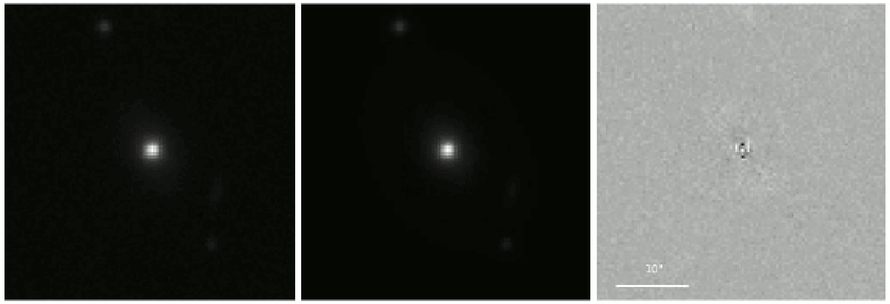
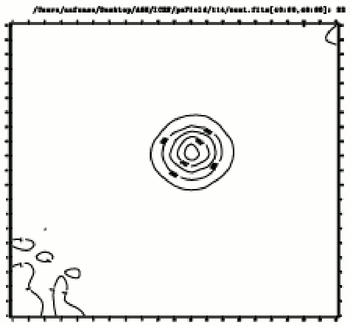


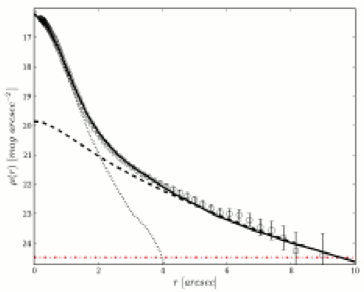
Figure 207: GALFIT results for galaxy 114.

Model	x_c	y_c	m	r_e	n	b/a	θ_{PA}
psf	51.14 ± 0.00	51.25 ± 0.00	15.58 ± 0.00	–	–	–	–
sersic	51.02 ± 0.02	51.45 ± 0.02	16.55 ± 0.01	9.26 ± 0.14	1.99 ± 0.04	0.72 ± 0.01	31.98 ± 0.81

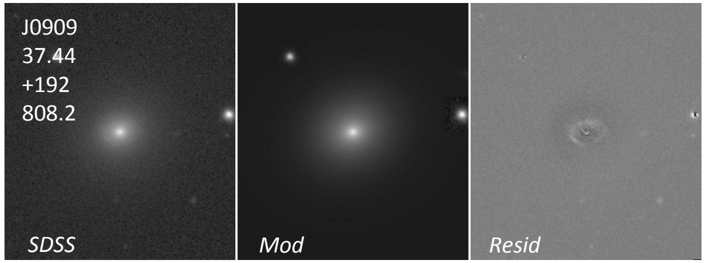
Table 104: GALFIT models for galaxy 114

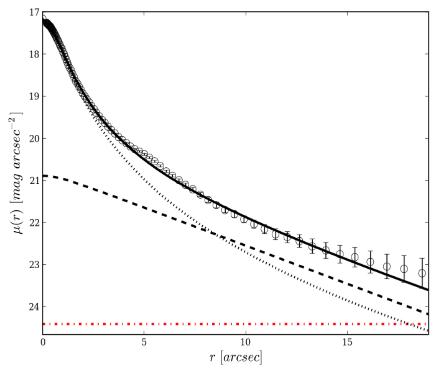
Residuals have significance 1.10 % (global) — 0.99 % (local)





GIBIS - GAIA **I**NSTRUMENT AND **B**ASIC **I**MAGE **S**IMULATOR





Morphology of QSO Host Galaxies - a look at the SED

Morphological Indexes for the GIQC

♦ $$I_{PC}(Q) = |P_Q - \overline{P_s}| / \sigma_s$$

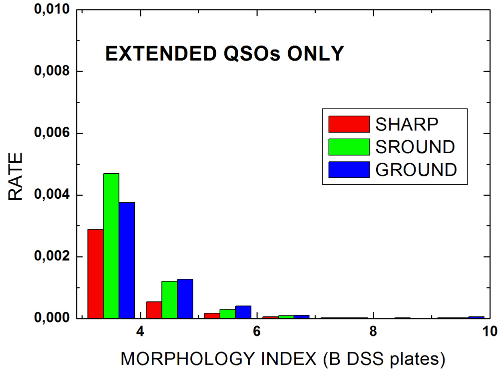
where I is the morphological index of quasar Q for the PSF parameter P in the color C, given in comparison to the mean value from the stars s, and normalized by the stellar standard deviation σ. Parameters are IRAF's sharp, Sround, and Ground.

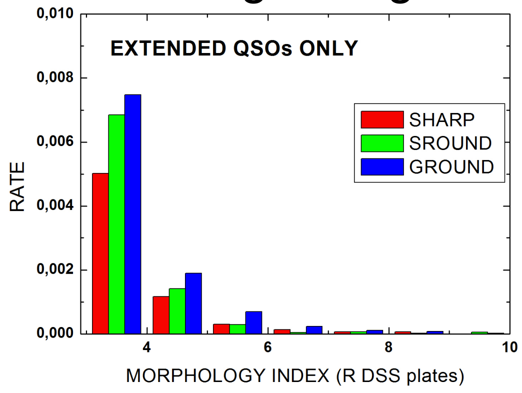
♥ 1,343 objects covering the SDSS spaces.

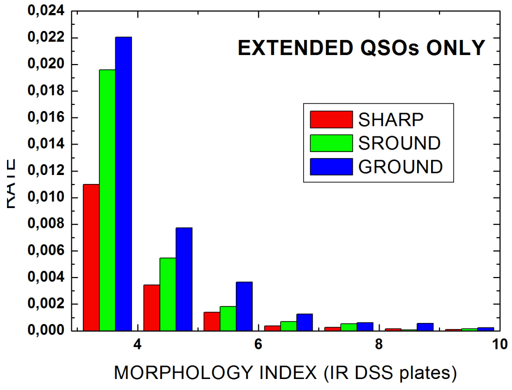
Correlation to the SDSS class = 0.86

Object	Morphological Indexes - Rate of non-pointlike objects					
	SHARP field	SROUND field	GROUND field	SHARP class	SROUND class	GROUND class
QSO(DR7) $_{IP>2}$	0.19	0.31	0.43	0.55	0.23	0.33
QSO(DSS2) $_{IP>2}$	0.13	0.39	0.41	0.27	0.32	0.36
STARall	0.01			0.01		
STAR $_{\Delta M=1}$	0.01			0.01		
QSO(DR7) $_{IP>3}$	0.06	0.17	0.20	0.40	0.11	0.17
QSO(DSS2) $_{IP>3}$	0.04	0.21	0.24	0.11	0.15	0.20

♠ The rate of "extended quasars" increases towards lower frequencies, showing the astrophysical and cosmological signature.





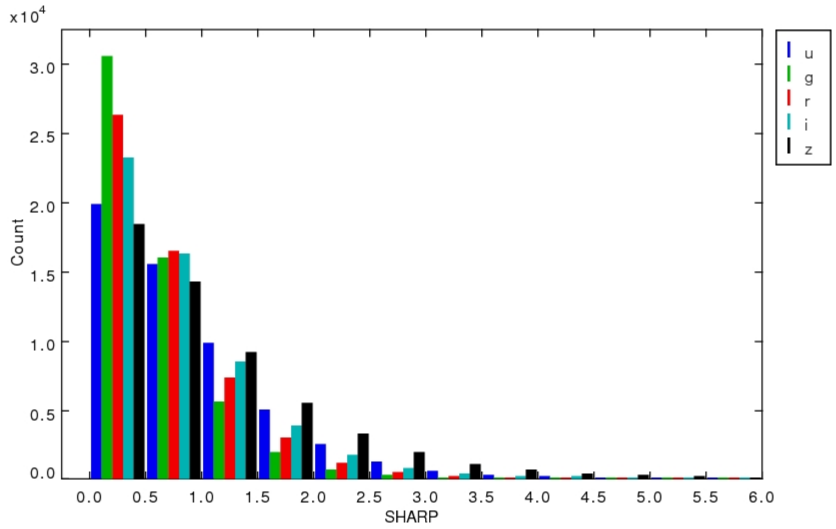


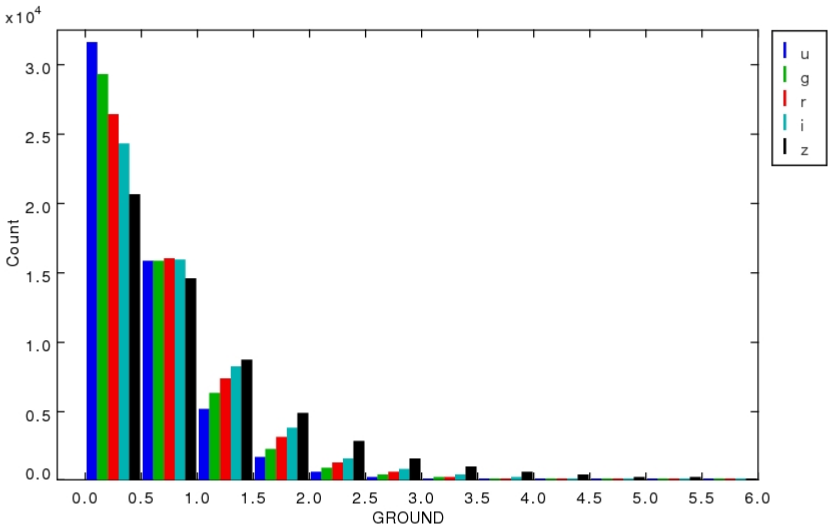
Morphology of QSO Host Galaxies - a look at the SED

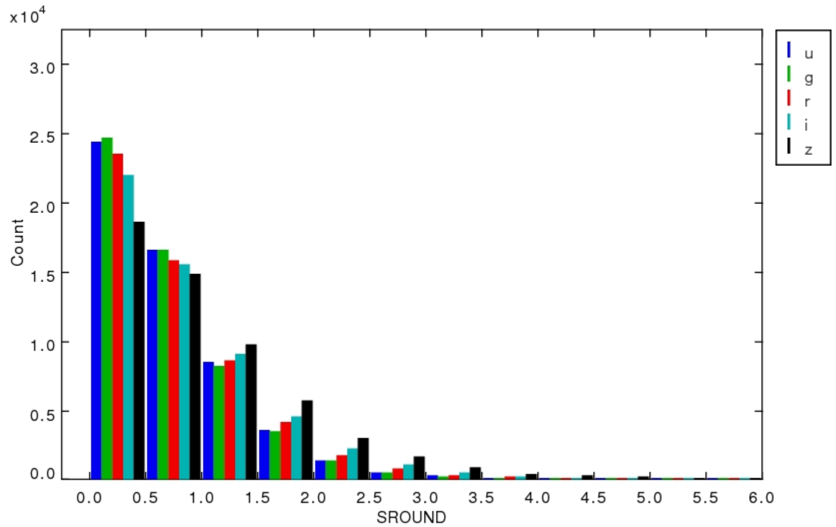
The SDSS DR10 ugriz Morphology Study

- ♣ We obtained frames in *u, g, r, i, z* bands for all SDSS DR7 QSOs. This meant: 528,915 frames with 2048x1489 pixels (0.39 arcsec/pix) and ~4 MB per frame totaling 1.5-2TB of data.

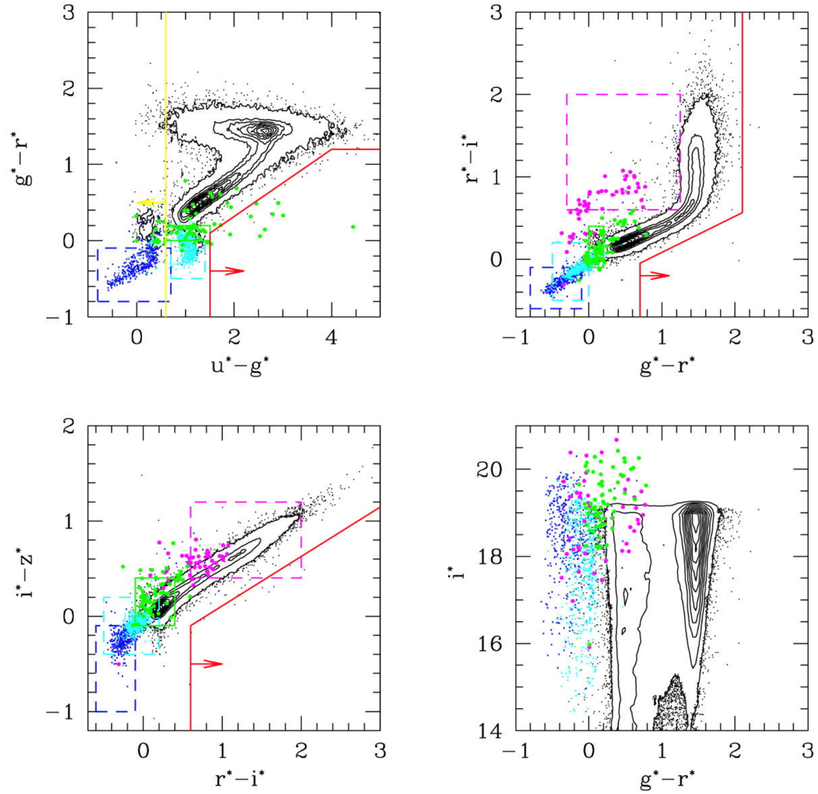
- ♦ The IRAF pipeline for morphology was run on all frames to issue the 3 PSF parameters.







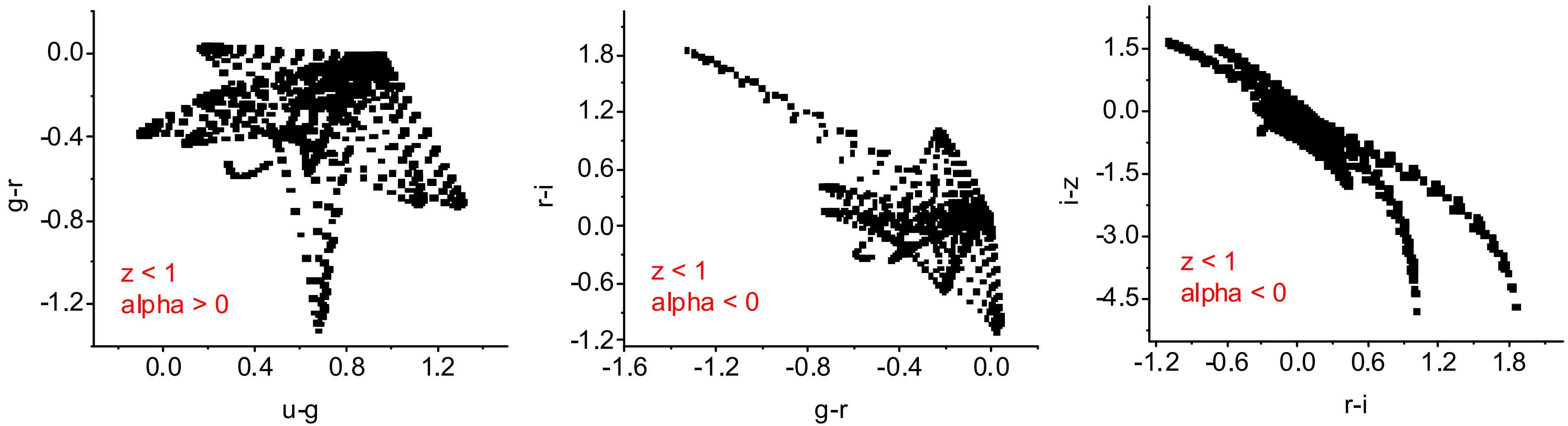
Morphology of QSO Host Galaxies - a look at the SED



QSO Synthetic Spectra Library (QSSL)

♣ QSSL was developed by Smette, Claeskens, Surdej & coll. (2003/04, Univ. of Liege).

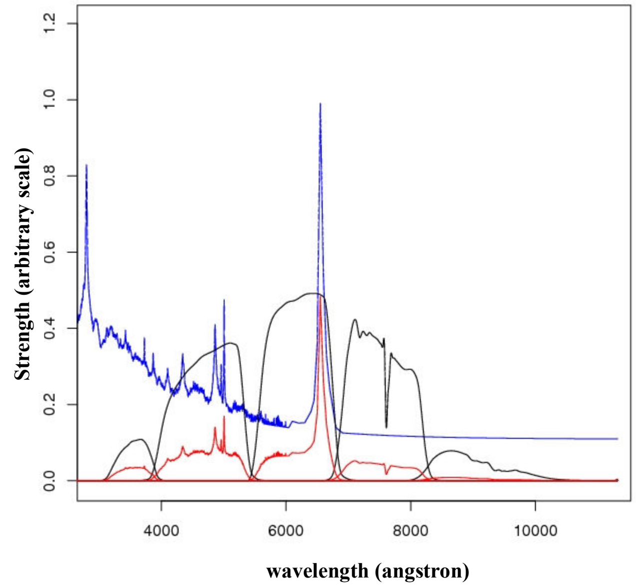
♦ By integrating the spectra over wavelength, ugriz colors are obtained. From them, the QSOs loci are found as much the same as in the SLOAN sample (Richards et al., 2002, ApJ 123, 2945).



The Reconstruction of Absolute Magnitudes – Flux at rest frame

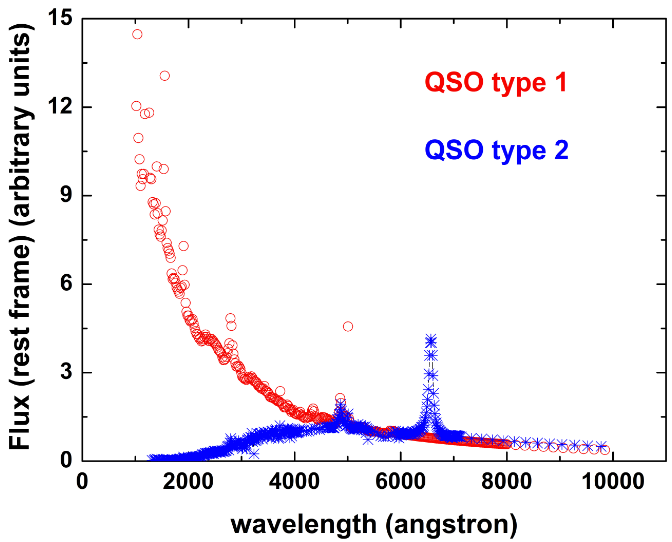
♣ The QSSL coverage:

λ range 2,500.5 // 10,499.5 **Å**, step 0.5 **Å**
α range -4 // +3 , step 1
W range 1exp2 // 1exp6, step ×1.58489 (arbitrary units)
z range 0.0 // 5.5, step 0.1019



♦ To be able to reach the rest frame emission corresponding to at least one SDSS color (*i-z*) we incorporate the SWIRE template library (Polletta, M. et al. 2006, ApJ, 642, 673)

λ range 1,000 **Å** // 1,000 **μ**, step 20log(λ) **Å**
α range QSO type 1 (face on) and QSO type 2 (edge on)
W range 1 // 20
z range rest frame



Morphology of QSO Host Galaxies - a look at the SED

The Reconstruction of Absolute Magnitudes – Filters and Galactic absorption

- ♣ The bandpass and integrated efficiency of the *ugriz* filters (Fukugita et al. (AJ, 111, 1748; 1996) is de-convolved from the apparent magnitudes.
- ♦ Schlegel et al. (ApJ 500, 525; 1998) combined IRAS and COBE/DIRBE measurements to create a high resolution (~few arc-minute) 100μ intensity map of the sky that is free of striping and accurately recalibrated to the absolute photometry of COBE/DIRBE.
- ♥ From the equatorial coordinates, the tables return the V band extinction as function (B-V), which can be extended to other bands and passbands

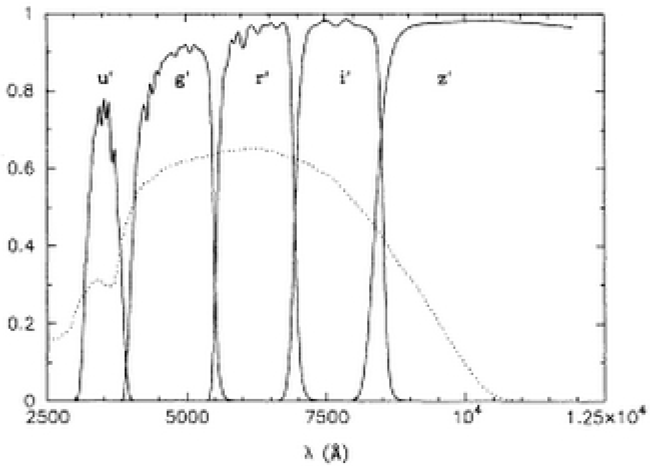


FIG. 1. Transmission of the $u'g'r'i'z'$ filters. Redleaks shortward of 11 000 Å are not shown. The dotted curve is the quantum efficiency of a thinned, UV-coated SITe CCD; this is the detector that is used in the definition of the SDSS system.

RELATIVE EXTINCTION FOR SELECTED BANDPASSES

Filter	λ_{eff} (Å)	$A/A(V)$	$A/E(B-V)$	Filter	λ_{eff} Å	$A/A(V)$	$A/E(B-V)$
CTIO U	3683	1.521	4.968	Sloan u'	3546	1.579	5.155
CTIO B.........	4393	1.324	4.325	Sloan g'	4925	1.161	3.793
CTIO V	5519	0.992	3.240	Sloan r'	6335	0.843	2.751
CTIO R.........	6602	0.807	2.634	Sloan i'	7799	0.639	2.086
CTIO I	8046	0.601	1.962	Sloan z'	9294	0.453	1.479

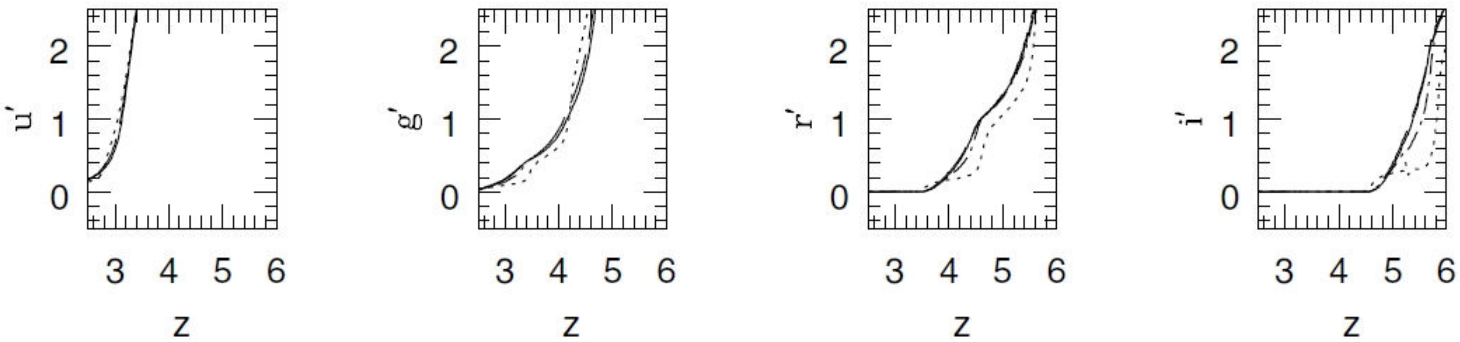
NOTE.—Magnitudes of extinction evaluated in different passbands using the $R_V = 3.1$ extinction laws of Cardelli et al. 1989 and O'Donnell 1994. The final column normalizes the extinction to photoelectric measurements of $E(B-V)$.

Morphology of QSO Host Galaxies - a look at the SED

The Reconstruction of Absolute Magnitudes – Lyman $_{\alpha}$ absorption

♣ Hydrogen is the commonest compound in the Universe, thus the Lalpha forest absorption must be accounted for. The models are however controversial, because the size and density of hydrogen clouds and blobs vary in redshift.

♦ We adopted the model of Meiksin (MNRAS 367, 807; 2006). This model computes the attenuation for different system of astronomy filters, including the SDSS *ugriz*.

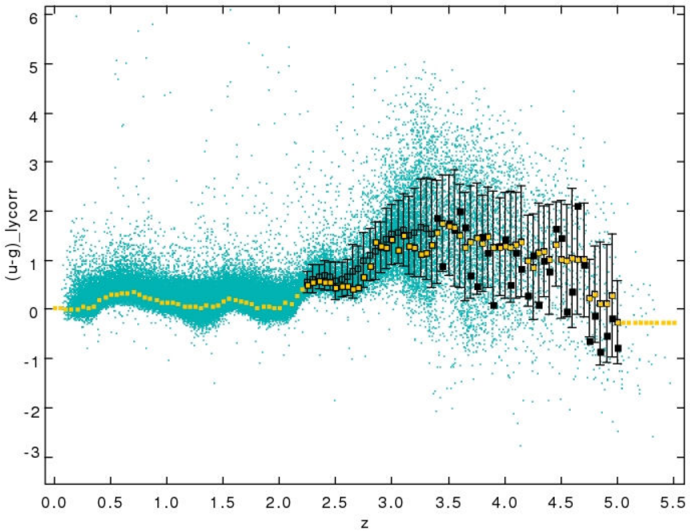


K-attenuation (magnitudes) as function of the redshift, for AGNs and QSOs (dotted lines) – from Meiksin (2006).

The Reconstruction of Absolute Magnitudes – Intergalactic dust reddening

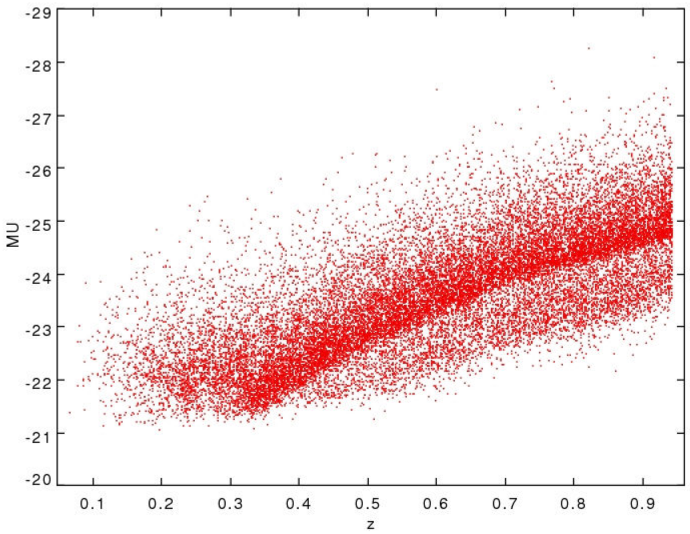
♣ Intergalactic dust includes from micro particles to large molecules. There are models and examples of increasing dust column density along the line of site. However, for most cases the amount of reddening is uncorrelated to the amount of extinction due to the L-alpha forest. And the lines associated to gas accompanying the dust are better explained at the rest frame.

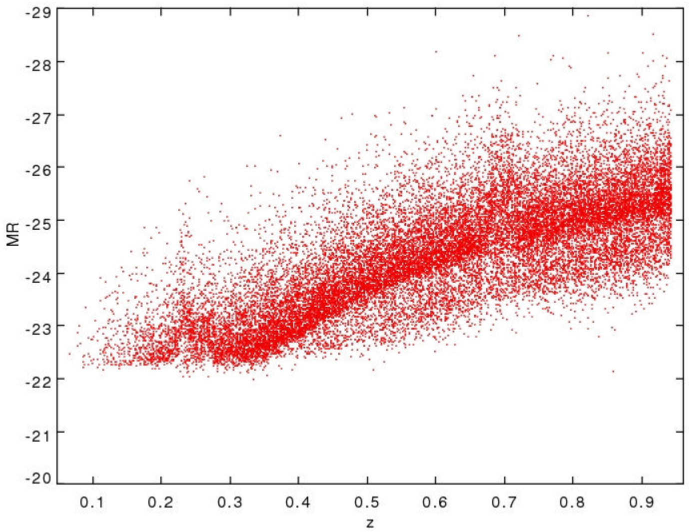
♦ We adopted the model of Hopkins et al. (AJ, 128, 1112; 2004). This model assumes the reddening toward quasars as dominated by SMC-like dust at the quasar redshift. It computes the color attenuation based of a large sample of SDSS QSOs

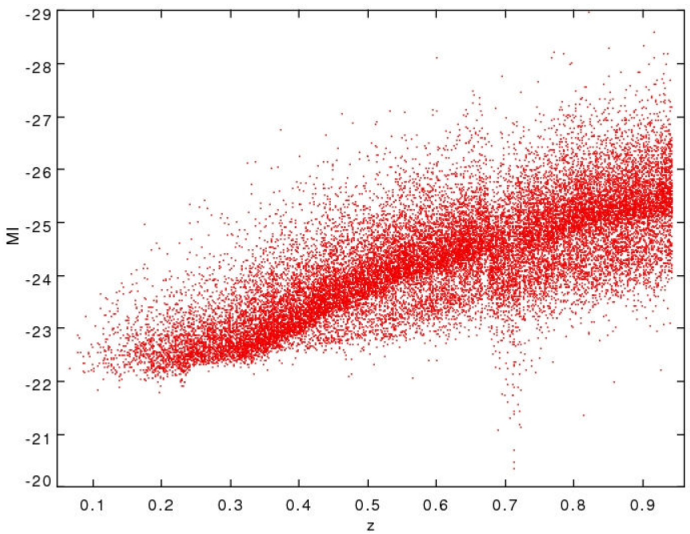


Dust reddening correction. The modal value (yellow) – or mean value (black) where the samples are too small – corresponds to the intrinsic color of QSOs at a given redshift; the excess to it must be corrected to the obtained rest-frame color (hence absolute magnitude).

The Absolute Magnitudes



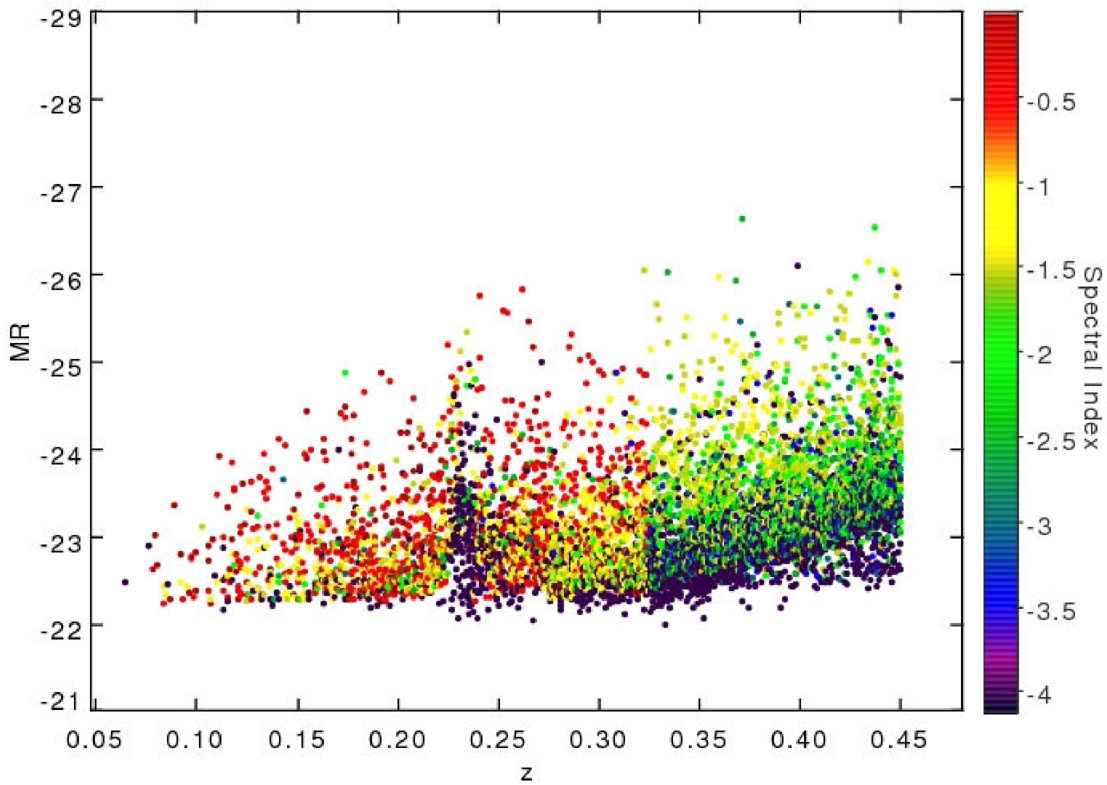




Both the effects of the blue-bump and of the cosmological increase of brightness are well recovered.

Morphology of QSO Host Galaxies - a look at the SED

The Absolute Magnitudes – Into the Quasar

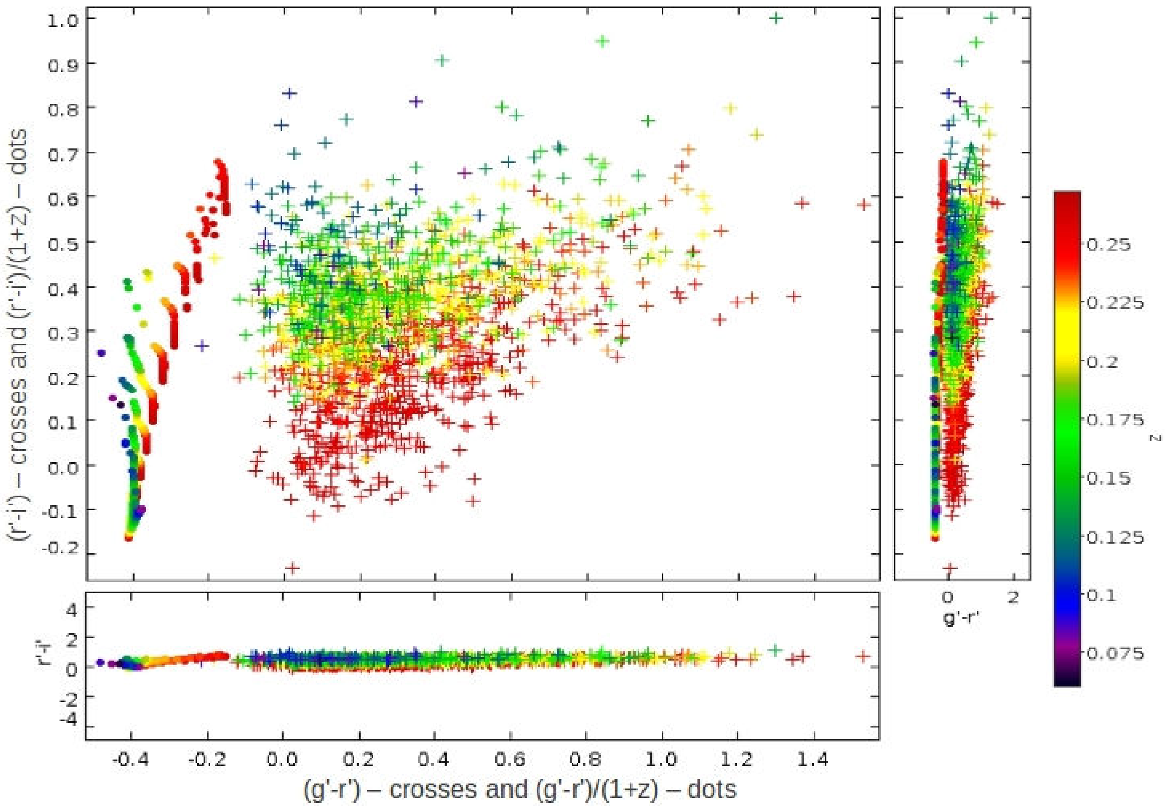


Color map of the power-law spectral index (from the GSSL) showing flatter non-thermal spectra for the optically dimmer QSOs.

Thus, quasars of best Gaia astrometry will preferentially be Tipe 1, face-on population. Though there is not a perfect alignment between the accretion disk and the host galaxy disk, Type 1 QSOs should more often present a symmetric shape for the different lines-of-sight at each Gaia observation.

Morphology of QSO Host Galaxies - a look at the SED

The Absolute Magnitudes – Color analysis



Color-color space. Dots correspond to the apparent colors. Crosses correspond to the frame of rest (1+z) colors. Notice that the chromatism depicts redshift.

The redshift-doppler obviously segregate the apparent and frame of rest colors. Gaia will observe preferentially bright red objects. These are strong line emitters, thus might be prone to exhibit high variability.

Morphology of QSO Host Galaxies - a look at the SED

A program for the ICRF quasars **(see Damljanovic et al., this meeting)**

♣ The Gaia GWP-S-335-15000 “Alignment to ICRF source list” (Bourda & Charlot) is conducting the VLBI observations of 328 QSOs candidate to establish the alignment between the radio ICRF and the GCRF.

♠ These objects are being followed for variability. We also undertake their observation to determine the magnitudes and verify whether there is a signature of the host galaxy.

♦ The program used 2m class telescopes (NOT/Spain, CASLEO/Argentina, LNA/Brasil), taken short R and B images to be co-added and analyzed by B-R subtraction.

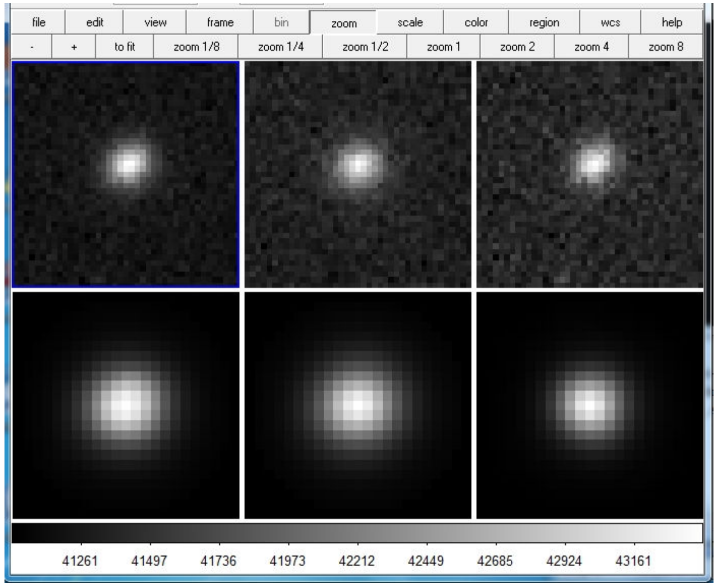


Image	Elipticity
R single image	0.15
B single image	0.12
R co-added	0.16
B co-added	0.12
R-B co-added & normalized	0.33

On the left, co-added images – and corresponding stellar PSF in the fields, in the filters R, B, and for the normalized and subtracted R-B image. On top, the ellipticity for the QSO.