



Universiteit
Leiden
The Netherlands

Faint quasars at very low frequencies

Retana Montenegro, E.F.

Citation

Retana Montenegro, E. F. (2019, October 16). *Faint quasars at very low frequencies*. Retrieved from <https://hdl.handle.net/1887/79263>

Version: Publisher's Version

License: [Licence agreement concerning inclusion of doctoral thesis in the Institutional Repository of the University of Leiden](#)

Downloaded from: <https://hdl.handle.net/1887/79263>

Note: To cite this publication please use the final published version (if applicable).

Cover Page



Universiteit Leiden



The following handle holds various files of this Leiden University dissertation:
<http://hdl.handle.net/1887/79263>

Author: Retana Montenegro, E.F.

Title: Faint quasars at very low frequencies

Issue Date: 2019-10-16

Faint Quasars at Very Low Frequencies



Edwin Retana-Montenegro
Leiden Observatory
Leiden University

A thesis submitted for the degree of
Doctor of Philosophy

2019

Faint Quasars at Very Low Frequencies

Proefschrift

ter verkrijging

van de graad van Doctor aan de Universiteit Leiden,

op gezag van Rector Magnificus prof. mr. C.J.J.M. Stolker,

volgens besluit van het College voor Promoties

te verdedigen op dinsdag 16 October 2019

klokke 10.00 uur

door

Edwin Fernando Retana Montenegro

geboren te San José, Costa Rica

in 1986

Promotiecommissie

Promotor: Prof. dr. Huub Röttgering (Leiden University)

Co-promotor: Dr. Reinout van Weeren (Leiden University)

Overige leden: Prof. dr. Marijn Franx (Leiden University)

Prof. dr. Paul van der Werf (Leiden University)

Prof. dr. Peter Barthel (University of Groningen)

Dr. Lingyu Wang (SRON)

Contents

1	Introduction	1
1.1	Quasi-Stellar objects: Short historical perspective	1
1.2	Quasar Properties	2
1.3	Supermassive Black Holes	4
1.4	Very Low-Frequency Radio Astronomy	5
1.5	Outline of this thesis	7
1.6	Future prospects	9
2	Probing the Radio Loud/Quiet AGN dichotomy with quasar clustering	11
2.1	Introduction	12
2.2	Data	17
2.2.1	Sloan Digital Sky Survey	17
2.2.2	FIRST survey	18
2.2.3	Cross-matching of the SDSS and FIRST catalogs	19
2.2.4	Final quasar sample	22
2.3	Clustering of quasars	24
2.3.1	Two-point correlation functions	24
2.3.2	Error estimation	27
2.3.3	Bias, dark matter halo and black hole mass estimations	28
2.4	Results	29
2.4.1	Projected correlation function $w_p(r_p)$	29
2.4.2	Quasar bias factors	32
2.4.3	Bias and host halo mass redshift evolution	35
2.4.4	Clustering as a function of radio-loudness	35
2.4.5	Clustering as function of BH masses	37
2.4.6	Clustering as a function of redshift	38
2.4.7	Clustering and AGN unification theories	40
2.4.8	The role of mergers in quasar radio-activity	42
2.4.9	Black hole properties involved in quasar triggering	44
2.5	Summary	45
2.6	Acknowledgements	48
3	Deep LOFAR 150 MHz imaging of the Boötes field: Unveiling the faint low-frequency sky	49
3.1	Introduction	50
3.2	Observations	53
3.3	Data reduction	54
3.3.1	Direction independent calibration	54
3.3.2	Direction dependent calibration	57
3.3.3	Combined facet imaging	61
3.4	Images and sources catalog	62
3.4.1	Final mosaic	62
3.4.2	Noise analysis and source extraction	63
3.4.3	Astrometry	64
3.4.4	Bandwidth and time smearing	67
3.4.5	Flux density scale accuracy	68

3.4.6	Resolved sources	69
3.4.7	Completeness and reliability	70
3.4.8	Source catalog	72
3.5	Source counts	75
3.5.1	Size distribution and resolution bias	75
3.5.2	Visibility area	79
3.5.3	Completeness and reliability	79
3.5.4	Multiple-component sources	81
3.5.5	Differential source counts	81
3.5.6	Cosmic variance	82
3.6	Conclusions	86
3.7	Acknowledgements	86
4	On the Selection of High-z Quasars Using LOFAR Observations	87
4.1	Introduction	88
4.1.1	Method Overview	90
4.1.2	Optical selection	90
4.1.2.1	Selection of Ly α break objects	90
4.1.2.2	Separating quasars and stars	90
4.1.3	Mid-infrared selection	91
4.1.4	LOFAR detection	91
4.1.5	Visual inspection	91
4.1.6	Fitting the UV/optical to MIR spectral energy distributions of the candidate quasar sample	92
4.2	Results	92
4.2.1	Selecting candidate quasars in the NDWFS-Botes field	92
4.2.1.1	Data	92
4.2.1.2	Candidate quasars selection	93
4.2.1.3	Performance of the selection method	99
4.2.1.4	Effect of the radio spectral index distribution on the candidate quasar selection	99
4.3	Limitations	101
4.4	Summary	102
4.5	Conflict of Interest Statement	103
4.6	Author Contributions	103
4.7	Funding	103
5	The luminosity function of LOFAR radio-selected quasars at $1.4 \leq z \leq 5.0$ in the NDWFS-Boötes field	104
5.1	Introduction	105
5.2	Data	109
5.2.1	NOAO Deep Wide-field survey	109
5.2.2	SDSS, Pan-STARRS1, WISE, and Spitzer surveys	110
5.2.3	Spectroscopic quasars with optical and mid-infrared photometry	113
5.3	Classification	113
5.3.1	Training sample	113
5.3.2	Target sample	116
5.3.3	Classification algorithms	117
5.3.3.1	Random forest	117
5.3.3.2	Support vector machines	118
5.3.3.3	Bootstrap aggregation on K-nearest neighbors	118
5.3.3.4	Performance	118
5.3.3.5	Classification results	119
5.3.3.6	Radio data	120
5.4	Photometric redshifts	121
5.4.1	Nadaraya-Watson kernel regression	121
5.4.2	Quasar training sample	123
5.4.3	Redshift estimation	123
5.4.4	Final quasar sample	126
5.4.5	LOFAR and wedge-based mid-infrared selection of quasars	131
5.5	Luminosity Function of radio-selected quasars	139

5.5.1	Selection completeness and accuracy of photometric redshifts	139
5.5.2	Simulated Quasar Spectra	140
5.5.3	K-correction	141
5.5.4	Quasar Luminosity function	142
5.6	Results	145
5.6.1	Model-fitting	145
5.6.2	Comparison to previous works	148
5.6.3	Density evolution of RSQs	152
5.6.4	Contribution of RSQs to IGM Photoionization	156
5.7	Discussion	160
5.7.1	The origins of radio-emission in RSQs	160
5.7.2	The environment of RSQs	161
5.7.3	RSQs and their location in spectroscopic parameter spaces	162
5.8	Conclusions	163
5.A	Appendix: A sample of false color RGB ($R=B_W$, $G=R$, $B=I$) images	165
References		168
Dutch Summary		193
English summary		200
Publications		205
Curriculum vitae		207
Acknowledgements		208

