

### Probing quantum materials with novel scanning tunneling microscopy techniques

Bastiaans, K.M.

### Citation

Bastiaans, K. M. (2019, December 10). Probing quantum materials with novel scanning tunneling microscopy techniques. Casimir PhD Series. Retrieved from https://hdl.handle.net/1887/81815

Version:	Publisher's Version
License:	<u>Licence agreement concerning inclusion of doctoral thesis in the</u> <u>Institutional Repository of the University of Leiden</u>
Downloaded from:	https://hdl.handle.net/1887/81815

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

Cover Page



# Universiteit Leiden



The handle <u>http://hdl.handle.net/1887/81815</u> holds various files of this Leiden University dissertation.

Author: Bastiaans, K.M.

**Title:** Probing quantum materials with novel scanning tunneling microscopy techniques **Issue Date:** 2019-12-10

# Probing quantum materials with novel scanning tunneling microscopy techniques

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 10 december 2019 klokke 11.15 uur

door

#### Koen Mathijs Bastiaans

geboren te Leiden in 1990

Promotor:	Prof. dr. J. Aarts	
Co-promotor:	Dr. M.P. Allan	
Promotiecommissie:	Prof. dr. J.C. Davis	University of Oxford
	Dr. I. Swart	Universiteit Utrecht
	Prof. dr. E.R. Eliel	
	Prof. dr. J.M. van Ruitenbeek	
	Prof. dr. J. Zaanen	

Casimir PhD series, Delft-Leiden 2019-40 ISBN 978-90-8593-423-3

An electronic version of this thesis can be found at https://openaccess.leidenuniv.nl/.

Copyright © 2019 Koen Mathijs Bastiaans Cover design by Ilse Modder (www.ilsemodder.nl) Printed by Gildeprint - Enschede

This work was supported by the European Research Council (ERC StG SpinMelt) and by the Netherlands Organization for Scientific Research (NWO/OCW), as part of the Frontiers of Nanoscience program (NanoFront), as well as through the Vidi talent scheme (Project No. 680-47-536).

For Arnold and Jan, two amazing grandfathers

# **CONTENTS**

1	Intr	oducti	ion	1
	1.1	A scar	nning tip to explore quantum matter	. 4
	1.2	The n	oise as the signal	. 5
	1.3	Probi	ng the condensate	. 6
	1.4	Outlin	ne of this thesis	. 7
	Bibl	iograp	hy	. 9
2	Amj	plifier	for scanning tunneling microscopy at MHz frequencies	11
	2.1	Intro	duction and motivation	. 13
	2.2	Noise	sources in STM	. 14
	2.3	Ampli	ifier and circuit	. 16
		2.3.1	General idea	. 16
		2.3.2	Circuit elements and printed circuit board design	. 17
	2.4	Noise	e spectroscopy performance on atomically Au(111)	. 21
	2.5	MHz	differential conductance measurements	. 21
	2.6	Concl	lusions and outlook	. 22
	Bibl	iograp	hy	. 24
3	Charge trapping and super-Poissonian noise centers in cuprates			27
	3.1	Intro	duction	. 29
	3.2	Noise	as the signal	. 29
	3.3	Disco	wery of super-Poissonian noise centers	. 31
	3.4	Noise	spectroscopy on noise centers	. 31
	3.5	Modu	ılated transport by polaronic charge trapping	. 33
	3.6	Concl	lusions and outlook	. 35
Appendices		28	. 37	
		3.A	Correlation to low-energy features	. 37
		3.B	Determination of impurity states	. 37
		3.C	Various super-Poissonian noise centers	. 40
	Bibliography			. 41

4	Ima	aging doubled shot noise in a Josephson STM 45		
	4.1	Intro	duction	47
	4.2	Expe	rimental setup	48
	4.3	Josep	hson tunneling spectroscopy	49
	4.4	Noise	espectroscopy	51
	4.5	Doub	eled noise due to Andreev reflections.	52
	4.6	Spati	ally resolved noise doubling	53
	4.7	Conc	lusions and outlook	55
	Bib	iograp	hy	56
5	A st	strongly inhomogeneous superfluid in an iron-based superconductor 6		
	5.1	Intro	duction	63
	5.2	Spect	roscopy in a Josephson STM	63
	5.3	Visua	lizing the inhomogeneous superfluid	66
	5.4	Corre	lation between superfluid density and quasiparticle coherence . $% \mathcal{A}_{\mathrm{rel}}$ .	68
	5.5	Conc	lusions and outlook	71
	App	endice	28	72
		5.A	Accessing the superfluid density with Josephson STM	72
		5.B	Determining the critical current from Josephson tunneling	
			spectra	72
		5.C	Visualizing the superfluid density for samples with inhomoge-	
		•	neous normal state junction resistance	74
	Bib	lograp	hy	77
6	Mel	ting th	ne Mott state in electron doped iridates	81
	6.1	Intro	duction	83
	6.2	Low c	loping: frozen Mott state	85
	6.3	Highe	er doping: pseudogap and local order	86
		6.3.1	Phase separation: Mott and pseudogap	86
		6.3.2	Emergent order	88
	6.4	Doping evolution: impurity band Mott transition		88
	6.5	Conclusions and outlook		91
	App	pendices		92
		6.A	Experimental setup	92
		6.B	Extraction of $\Delta_{Mott}$ and $\Delta_{PG}$	92
	Bibliography			

Samenvatting	97
Curriculum Vitae	101
List of Publications	103
Acknowledgements	105