

Acknowledgments

It is hard work, writing a thesis. If it were merely the innumerable taps of fingers upon the keyboard that have taxed my fingers these last few weeks, it could possibly be borne, though I suspect even then that most people would choose to avoid it and be considered wise for so choosing. Of course, however, it takes all the more doing than that, for beforehand Research must be Undertaken, data collected and plots pondered and heads scratched and inspirations received from above and all the rest of it. And meanwhile, the Student must be prodded, and fed, and housed, and entertained; he must be provided funding and a chair and a desk and be told how to access his email; she must find recreation facilities and the occasional softball on which to unleash the pent-up frustration of a thousand segmentation faults and misplaced factors of 2. And even with all of that, there can be no thesis without the previous rounds of prodding, feeding, and housing that bundle our prospective Scholar through high school and college! The telescopes that must be assembled to greet her arrival; the mountains of scientific thought on which he might build an additional mole-hill! The tax dollars! The after-school programs! Good Heavens, the diapers!

Surely, the production of even the least thesis is well beyond the strength of even the best woman or man, just as this one has been well beyond mine. Thankfully, this process has been supported and sustained by an incredible community of people. Whatever little or much the lasting worth of this thesis may be, it could not exist without them. Here are my thanks.

Leaving aside (with apologies) the past generations of humanity whose ceaseless strivings made possible the comforts and tools of the modern astronomer, the first actors in the story of this thesis are my parents. Mom and Dad, you taught me the most important lessons I know: to approach hard tasks and conversations head-on, to trust that difficult times breed wisdom and patience, and to seek to see the best, the *imago dei*, in all people (including myself) even when we are at our worst. Thank you. I could also mention how you taught me to love learning, teaching, creative expression, the wonders of nature, and many other essential aspects of life besides, but there is neither time nor space here – it would take many, many theses to do them justice, and I hope to only ever write this one. Hillary, my sister: as a child you taught me grace and patience in equal measure, my first lessons in collaboration, and you continue to inspire me to live with more discipline, more thought, more style, and more love. Thank you for these gifts.

After my immediate family, perhaps no body was more formative to me than the public school system of El Dorado County, California. Public school teachers are unaccountably maligned in times of budget

shortfalls and international standardized test comparisons, but mine (and I suspect, most) have been among the noblest and best people in all of humanity. Through these great Educators, I have learned to see the richness of the world around me: books, worms, art, soccer balls, and (certainly) stars. Similarly, they taught me that knowledge is not pursued to be kept in an ivory tower but to be shared and examined by eyes large and small, that only in teaching a rule or a subject do we fully understand it, and that the flash of understanding in a pupil's eyes provides a far more addictive high than most Schedule I controlled substances. Particular thanks go to April Hood of Gold Oak Elementary for fostering my love of math, and equal thanks go to Susan Prior of Union Mine High School for encouraging me not to major in it. Mrs. Prior likewise provided my first opportunity to teach a high school class, an experience that cemented my desire to educate.

I was not truly on the road to academia, however, until Roger McWilliams dragged me to his lab in my second term at UC Irvine. Roger taught me the difference between physics from a book and physics with a homemade Langmuir probe, a vacuum pump, and a highly-magnetized Argon plasma. It was exhilarating, and it made Real Science approachable. I thank Roger for teaching me that theorists don't have a monopoly on fun and that bow ties are a timeless and elegant accessory for any occasion. Andrea Ghez advised me during my summer at UCLA and set me down the path of observational astronomy. Her enthusiasm was palpable, her encouragement was unceasing, and she was the first person to tell me that I might have a future in research. She also set off my love affair with supermassive black holes, a phrase that makes me dizzy even after years of more galaxy-focused work. I would not be completing this degree if not for Roger and Andrea.

Of course, the majority of my own work on this thesis has come in the 6 years I have spent at Caltech. Tim Morton and Vera Gluscevic welcomed me to Pasadena and became my first friends here. I am grateful for their warm hospitality, their constant invitations to concerts and athletic activities, and our conversations that ranged from burritos to metaphysics. Upon beginning coursework, I quickly became acquainted with three exceptional classmates: Swarnima Manohar, Shriharsh Tendulkar, and Dmitriy Tselikhovich. Dmitriy is the most enterprising individual I've ever met – if I ever get to space, it will almost certainly be through knowing him. Thank you in advance, Dmitriy. Shriharsh is one of the most positive gentlemen I've ever met, and we shared many laughs from such storied sources as John Cleese, Bill Watterson, and P. G. Wodehouse. Furthermore, his astrophysical puns are truly, *ahem*, stellar. Swarnima has been my officemate for 5 of the last 6 years and my co-chair of Astronomy Outreach for nearly as long. We ran some pretty great events together, and she is responsible for almost everything I know about radio astronomy and subcontinental cooking. She, Shriharsh, and Kunal Mooley (the most excellent Bollywood dance instructor I have ever encountered) made me feel as Indian as I think any descendent of Irish-Italian immigrants has ever been privileged to feel.

I have also had some wonderful roommates here in Pasadena, and to them I owe a great debt as well. Ben Camp and I spent the last year of his bachelorhood living together, and he and his family gave me frequent solace during the stresses of my first year of graduate school. This solace usually took the form of PBR, bowling, and/or breakfast for dinner, a soul-filling trifecta guaranteed to purge the memory of even the most devilish problem set. Sam Lee and I decided to live together after that first year, and we shared many

adventures over the next two years, primarily of the culinary and musical varieties. Sam's knack for obtaining unobtainable tickets would have been enough to earn my eternal gratitude, but he is also somehow one of the kindest and smartest people I know. I have missed him often since he left for the "other" coast. Matt Schenker made the bold decision to join our apartment after only a single prospective visit. A profoundly proficient athlete (from tennis to skiing to mountaineering), Matt somehow still enjoys sharing these pursuits with those less physically blessed; I admire both his spirit of adventure and his patience. Thinh Bui was assigned to our apartment by lottery, but he and I lived together for almost 5 years. Thinh works as hard as anyone I know, but he was also always willing to stop for a shared meal or to provide a ride to the airport. He teaches me not to take anything for granted, to work hard, and to keep my friends and family close. Andrew Fuenmayor and I were no longer roommates by the time I came to Caltech, but conversations with him kept me grounded throughout my studies.

Many others at Caltech gave me more help than they are likely to know. Brian Brophy and the Theater Arts at Caltech (TACIT) kept me sane when I needed to indulge in some thoroughly non-astronomical pursuits. Brian and the other leaders of that group have created something truly magical: a world where novices and old hats can together make art that is lively, breathtaking, hilarious, and never "safe." If I can find a group half so bold at each stage of my academic journey, I will be blessed indeed. In our own department, Anu Mahabal and Patrick Shopbell are true Wizards, capable (and willing) to fix all manner of technological issues from across oceans and at any time of day or night. If this is not enough evidence of their wizarding prowess, they also throw the meanest Cinco de Mayo party this side of Puebla, MX, and Patrick's homebrew is responsible for $\gtrsim 90\%$ of the hair on my chest. Gita Patel, Gina Armas, Althea Keith, and Judy McClain are the friendliest and most competent group of administrators yet to be assembled. Without their help and advice, my time at Caltech would have been a nightmare of bureaucracy. Lynne Hillenbrand eased my transition to Pasadena with good seats at Chavez Ravine and better advice. Chris Hirata had an open door and the solution to any question I presented, always offered with a smile and many encouraging nods. He will be missed at Caltech.

Wal Sargent is missed as well. I did not know him as well or for as long as many did here, but his shrewd science, dry wit, and great stories have left a powerful legacy behind him. I do not know why he bothered to engage with a 22-year-old Liverpool fan who had never been to England, but I enjoyed our friendly rivalry, and his jibes and jests were no less incisive for being made in good fun.

Of all the students at Caltech who helped me along the way, none were so supportive as Gwen Rudie. Qualifying exams, candidacy, publishing papers, conferences, job applications, and talks: she crossed each threshold ahead of me and reached out her hand to help pull me across behind her. I don't know how, or if, I would have finished this degree without her perspective and encouragement. She and her husband Andrew Newman are as kind and generous as they are phenomenal scientists, and it has been a joy to share grad school, conferences, observing runs, and even wedding months with them – I look forward to many years of our continued collaboration and fellowship. I have not been half the mentor to Allison Strom that Gwen has been to me, but she clearly has the wit and skill to succeed without my help. We shared some excellent times

on multiple continents, and I admire her maturity, her attention to detail, and her sublime cocktails. I was a similarly poor mentor, I fear, to Trevor David and Michael Eastwood,¹ but they are such easy-going fellows that I'm sure they will forgive me. I've enjoyed my time spent with them both as colleagues and as friends.

All of this brings me to Chuck. I came to Caltech to work with Charles C. Steidel in large part because of his scientific reputation and the success of his students. I was amazed to find a most approachable and humble Giant. I will not waste words praising his scientific prowess and superhuman intuition; the MacArthur and Gruber Foundations have already provided ample documentation of these truths, and Chuck would hate to read it in any case. What I learned from Chuck is that good science speaks for itself and that projects worth doing are worth doing well. I greatly appreciate both the freedom he offered me and the guiding questions that kept me on track. Being a part of the MOSFIRE project, in particular, was a phenomenal experience. In the midst of his extraordinary scientific success and productivity, I especially respect his commitment to spend the vast majority of his evenings and weekends at home with his family. Being newly married myself, I think this balance might be the most important lesson he can teach me.

We are almost done now; there are two people left for me to thank and then these Acknowledgements (which, it seems to me, read more like a self-indulgent memoir) will be concluded. William Myron Keck, the great wildcatter and oil entrepreneur, built Superior Oil Company into the USA's largest independent oil producer. In so doing, he indirectly provided me with two great gifts: funding for the W. M. Keck Observatory in Mauna Kea, and a job for an immigrant Dutchman who would eventually become the grandfather of my wife. Even as I seek to limit my own fossil fuel dependence, I must acknowledge that I owe this man a great debt on both counts – much of my current happiness does indeed depend on his fossil fuels.

That happiness, most of all, is Elle. She came into my life at the end of a dark time and ever since has illuminated it by her presence. Already, she has given me strength and support through all manner of trials, and I owe most of my motivation and success to her relentless love and encouragement. I'm so glad to have a lifetime to pay her back.

¹Michael also brought me a refreshing drink on the hot day when I was writing this section, but I'm sure I would have thanked him anyway.