2023
International Internship Pilot Program in Taiwan

Final Report

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Part I. Overview

- **What is your intention to come to Taiwan for this internship?**
- **Please describe your gains and experience acquired from this internship.**
- **Please describe your life in Taiwan, how to deal with difficulties?**
- **During the internship, what impressed you most and made you recommend the internship to your friends?**
- **If there is any other similar chance for you to choose, would you like to participate in this program again? And why?**
- **Please describe during your internship, which PI and institute have you communicated or interacted with?**

As far back as I can remember, almost all throughout my childhood, I have been captivated – by lights, by sounds, by trees swaying in the breeze, and water flowing down a tap; I have been captivated by the sounds frogs make, signalling the onset of a new spring, and the way the wind feels on my face, smelling of monsoon. And the stars - oh, the stars! Those little unassuming diamonds, glittering like a secret the universe whispers to you, if you dare to stare into the facade of a black sky. With all that said, I believe it is no surprise that I ended up pursuing science in high school. Somewhere along the line, though, something faded – the pulleys no longer seemed like a fun, goofy mechanism with limitless creative possibilities, but became numbers and laws that were promises of better grades. That exclamation of an "ah-hah!", when something that always seemed elusive to me, turned into a mere integration of simple, intuitive governing laws that are well within my grasp, seemed to disappear and something else showed up to take its place – the looming future. The fundamental reason why I delved into books and encyclopaedias changed. It was no longer because I wanted to, but because I had to, in order to become an engineer, or a doctor, or any other fantasy of the quintessential Indian parent.

I did not like it. I did not like it at all. I hated it. I knew that if there was one thing (well, a couple of things) I did not want to be, it would be an engineer, or a doctor; and although the threat of a fight with my parents over what career I am to pursue always loomed over me, hope showed up – in the form of a scholarship for students "exceptionally motivated to pursue research" in the country (perhaps the exceptional motivation for me was my teenage drive to defy my parents' expectations.) I had caught my big break – life in high school seemed to zoom by, and the next thing I know, I am pursuing an integrated Master's degree at an esteemed university in India – an Indian Institute of Science Education and Research. College went as it does, and along the way rekindled a curiosity in me. This time, the ember was brighter and fiercer than ever. For the first time in my life, I saw a firm possibility of me becoming a scientist, whatever that word means. It didn't matter what it meant, because I could become one anyway. All I cared about was that my love for the heavens showed a promise of flowering into more than just love – I could work on stars!

I felt it again – the little hop in my step every time I thought about the work I was going to go accomplish; the little spark in my chest when I thought about the direction my life was headed.

Amidst all the rush and constant feed of assignments and tests of my semesters, and the tides of my emotions and mental well-being, one thing prevailed – the hope of an internship during the summer. Actual research work. By me. It was going to be awesome.

Around the beginning of this year, I began looking for opportunities for a summer internship. The semester was exhausting, and was draining me of all vitality, and I knew I needed a huge break. I started looking for opportunities outside my country, because (a) I wanted to step out of my comfort zone, and do something new, and (b) I was already working at one of the top-in-its-field laboratories in India. After lots of searches on the internet, one thing caught my eye – Taiwan's commendable presence in the astrophysics department. I started considering the possibility of coming to Taiwan, and started looking into it more. I was pleasantly surprised when I found out more about the country, especially in terms of human rights, the bafflingly low crime rate, and the fact that the country may arguably be the most liberal in terms of LGBTQIA+ support in Asia. I knew that if I made it here, I would have a safe space, and wouldn't be worrying about much else other than work. I was especially keeping an eye out for research projects dealing with stellar physics, as that aligns intensively with my interests. I found Dr. Yueh-Ning Lee's project, and realised that it was for all means and purposes, perfect for my interests. I hastily uploaded my CV, and stared at the screen for a few seconds nervously before submitting my application. Next thing I knew, I was being interviewed, and by the looks of it, there was a high chance I might've been visiting Taiwan for the summer. Dr. Lee asked me to apply to the International Internship Pilot Program, and I realised that the benefits I'd enjoy if I made it into the program would mean a nearly completely hassle-free experience, while I work in Taiwan. Everything combined, it meant, with no exaggeration, an amazing opportunity for me to gain some serious experience in the field of research that I want to pursue, and broaden my horizons.

Fast forward to late June, and I had landed in the Taoyuan Airport, and after appreciating the convenience of an Easycard, and a good night's sleep, my work began.

Work here has been really thorough and no-compromises from the very beginning. It began with a discussion about what exactly is the problem that we are dealing with, laying down the foundations which we shall be building upon, and lots of scientific papers being read. Being honest, it was mostly a lot of discomfort, unfamiliarity with the subject, and frustration starting out, because even though I was more or less familiar with the basic theoretical tools behind the problem (magnetohydrodynamics), I was at a complete loss about how it tied to actual research work. This led to a realisation that was the very first thing I learnt in my internship – that it's okay to not know things.

Dr. Lee asked me to cook up a short presentation showcasing what I shall be working on for the summer, mainly consisting of my expectations from this internship, what my goals are, and a short description of the problem. This was my first task at the internship. I presented an idea of the project – it deals with the formation of the protoplanetary disc with the system threaded by a horizontal magnetic field ($B_z = 0$). The formation of a disc under a vertical magnetic field has been studied, but the horizontal case was something that had not been attempted before by Dr. Lee. This made the project equally more thrilling as it made it scary; but, I did not have time to worry about all that – time was running out, and I only had a few weeks to get this done.

The next significant event (by significant, I mean different from the usual day spent at the office) was a three-day workshop organised by the National Center for Theoretical Sciences (NCTS), which was organising the summer program itself (Theoretical and Computational Astrophysics Summer Student Program, or TCA-SSP for short). The workshop essentially consisted of around 7 hours of

back to back lectures for a total of 3 days, by eminent researchers in the field. From the basics of numerical simulations, to black holes, the workshop had it all. It might seem like a trip to a fair for a popular science enthusiast, but it really involved a lot of nuance and in-depth descriptions of topics that the summer program's projects entailed.

To say that the workshop was enjoyable for me, would be an understatement. I made sure to be as interactive as I could with the lecturers, made sure I could take in as much information as I could, talked to the lecturers during the off-time, and to top it all off, got quite chatty with the fellow attendees. I also have had further communication with one of the lecturers, and there have been talks of possibilities of working together in the future. Admittedly, I ended up having exhausted myself by the end of the third day, but that helped me gladly engage in what came next for me – weeks of sitting in the office and working.

Okay, maybe that is a little misleading. My time in Taiwan was limited, and I was not going to spend what little time I had, monotonously sitting in an office, feeling like nothing changed compared to my days at my home institute. Although my days were still mostly that, they did have some star-studded days in their midst. The night market continued to captivate me every night, and just when I thought I had had almost everything there was to eat, a Taiwanese friend volunteered to tag along for eating out at some restaurant that I could almost swear did not exist. Every time this happened, some restaurant seemed to magically pop out of a corner which my eyes swore was empty before, and left an impression on my tongue.

Turns out, the other foreign students under Dr. Lee were just as fun and friendly, and we broke the ice on a hike up the Xiangshan hiking trail. One of the Taiwanese friends who accompanied us up the trail turned out to be a hiking enthusiast, and an active member of a hiking club. Having grown up close to the Himalayas myself, I have been consistently enthusiastic about hikes and treks. I quite vocally expressed this, which seemed to grab the attention of the hiking club friend. He proposed the idea of climbing up to the highest peak in the Yangmingshan National Park sometime, to which I gladly reciprocated. So a couple of weeks later, after some running and personal training, I found myself awake at 5 in the morning, slapping on handfuls of sunscreen, and soon after, I was at the top of the world! Okay, not quite, but at the top of Taipei City for sure. The other members of the hiking club turned out to be great individuals, and really fun to be around. It was interesting, and outright hilarious, comparing aspects of Taiwanese and Indian cultures, and observing differences – some of them very bizarre.

Aside from the constant influx of new Taiwanese cuisine, and the occasional hike, I also engaged in some recreation with badminton at the institute's indoor courts, a weekend out clubbing, and lots of walks at night – mostly alone. There's something about these walks through deserted streets, and traffic lights reflected off of the wet asphalt that teaches you secrets about the ebb and flow of the city.

Life in Taiwan for me hasn't been all sunshine and roses, however. Of course, there's the obvious problem of a foreigner who did not even know the fact that Mandarin was a tonal language, thrown into the vicious, busy life of night markets. However, there are also nuances to this topic. I like to illustrate this through something I learnt of in a movie I quite like, "Arrival" – the Sapir-Whorf hypothesis. It asserts that the structure of a language determines a native speaker's perception and categorisation of experience. The essence of this statement is that a language not only determines how people communicate, but also manages to seep its influence into the way people think, feel, and live their lives. I often find myself thinking in ways quite different from my Taiwanese friends here; there is really no other way to describe this vague, abstract feeling. The feeling may be abstract but it

is very real, and its presence is undeniable. Ideas of decencies and indecencies, good and bad practices, body language, ideas of friendship and companionship, work culture, ideas of what is healthy and what is not, communication – all of these are aspects whose contribution to a culture shock are not immediately apparent, but the longer I spent here, the clearer it became. It is not a problem as such, owing to how uncompromisingly friendly and kind the Taiwanese are, but it is definitely a difficulty.

The other immense difficulty I had to face contrasts this quite beautifully, because as opposed to the culture shock which was due to how everyone except me was, this difficulty arose simply from inside my own self – a direct consequence of the person I am. I have described the frustration I had felt when I first took up the project above. Truth is, that's simply one manifestation of a deeper rooted problem – the impostor syndrome. This being my first proper research project, I spent a lot of time struggling to connect theory and work, and doubting myself for it. I spent a lot of time convinced that I did not deserve to be here, at such a good opportunity, and I coped with pressuring myself to spend days and nights at the office, rigorously punching numbers and looking up definitions and reading papers. The solution to this came rather as a surprise to me, however, as one day, I realised that I was more or less familiar and comfortable with most of the jargon that the subject entailed. This made me feel a lot better, and this is when I started to get most of my work done.

The thing that impressed me the most about this internship, however, was how the generous stipend paved the way for a pretty hassle-free stay here for me. I did not need to worry about how much my food cost me, or how much I need to restrict my average expenses per day to be able to afford my stay for as long as I'm here. This, in addition with what I already described as my initial awes about Taiwan were (which were absolutely true, by the way), made this experience an absolute positive for me, and I would definitely recommend this to my peers and friends. I know with certainty that if I am the one who's given a chance to participate in a program funded by IIPP again, I would take it. The generous stipend, and the minimal interference into my work, all make for an ideal environment for work to get done.

All through my internship, I was situated at the National Taiwan Normal University – I stayed in its newest dormitory, and worked at an office in the Science Education Building in the GongGuan campus of the university. Even before my work began, the first thing I noticed was the absolutely pristine condition of the dormitory. The cleanliness, the security (we use an access card), the student restaurant and convenience store right next to it, the great internet connection, and great room decor, made for an incredible stay, which honestly was so good that it took me a while to even get used to the upgrade. The university campus is lively, with a lot of prospects for sports, and everybody is friendly and willing to help a foreigner living at the mercy of Google Translate. It's fairly close to the Gongguan night market, too. I worked, with Dr. Lee of course, and also with the other students undertaking summer projects under here this summer. The working environment was fun yet civil, and everybody respected each other's boundaries. It was never hard to focus or get work done, and whenever our mind decided it was time for a break, there was always someone to chat with about absolutely anything.

I do not really have complaints at all, about any aspect of the summer I spent here. If someone has read through all the paragraphs I have typed down, I am certain that it's not really the hardest thing to imagine. Looking back, now that I am close to my return, I find it strange that I almost feel homesick about a place that is so new to me. Can I be blamed, though? The hospitality and genuine kindness that radiates from the smile of a mere stranger, on just about any occasion and interaction, reeks of a homeliness that I shall remember for a while. Farewell, Taiwan, and I shall love you.

Part II. Research Finding

I. The Problem

A. Introduction

The formation of a stable protoplanetary disc in the presence of a magnetic field is a well-known problem that is being attempted in research. Purely hydrodynamic discs grow way too rapidly, and the conservation of angular momentum during gravitational collapse leads to unrealistic angular velocity and catastrophic results. However, the inclusion of a magnetic field and attempts using ideal magnetohydrodynamics leads to the magnetic catastrophe, which leads to so much angular momentum being lost through magnetic braking, that a disc is not formed at all. This does not agree with observations. The proposed way out is including non-ideal magnetohydrodynamic effects. The formation of a rotationally supported protoplanetary disc has been studied under the effect of a vertical magnetic field with non-ideal effects taken into account (Lee, 2021, et. al.). This project aims at theoretically establishing radii of stable protoplanetary discs when threaded by a horizontal magnetic field instead. This specific problem has been formulated with relevant approximations with B_z = 0, a singular isothermal sphere density profile in the disc's envelope, an accretion shock at the disc-envelope boundary, vertical hydrostatic equilibrium in the disc, and no axisymmetry in magnetic field.

B. The MHD Equations

The non-ideal magnetohydrodynamic equations have been solved for this problem with relevant initial conditions. The non-ideal magnetohydrodynamic equations are:

(a) The momentum conservation equation:

$$\frac{\partial \rho \boldsymbol{u}}{\partial t} = -\boldsymbol{\nabla} \cdot \left[\rho \boldsymbol{u}\boldsymbol{u} + \left(P + \frac{B^2}{2} \right) \mathbb{I} - \boldsymbol{B}\boldsymbol{B} \right] - \rho \boldsymbol{\nabla} \Phi$$

(b) The induction equation:

$$\begin{aligned} \frac{\partial \boldsymbol{B}}{\partial t} &= \boldsymbol{\nabla} \times (\boldsymbol{u} \times \boldsymbol{B}) - \boldsymbol{\nabla} \times \left\{ \eta_{\mathrm{A}} \frac{\boldsymbol{B}}{\|\boldsymbol{B}\|} \times (\boldsymbol{\nabla} \times \boldsymbol{B}) \times \frac{\boldsymbol{B}}{\|\boldsymbol{B}\|} \right. \\ &\qquad \left. + \eta_{\mathrm{H}} (\boldsymbol{\nabla} \times \boldsymbol{B}) \times \frac{\mathbf{B}}{\|\mathbf{B}\|} + \eta_{\mathrm{O}} \boldsymbol{\nabla} \times \boldsymbol{B} \right\} \\ &= \boldsymbol{\nabla} \times [(\boldsymbol{u} + \boldsymbol{u}_{\mathrm{A}} + \boldsymbol{u}_{\mathrm{H}}) \times \boldsymbol{B} - \eta_{\mathrm{O}} \boldsymbol{\nabla} \times \boldsymbol{B}] \end{aligned}$$

This set of equations are simplified with B_z = 0, and timescales for non-ideal MHD effects, radial advection and magnetic induction are

obtained from them. We also assume a more or less uniform distribution of pressure across the azimuthal axis for constant r. Ambipolar diffusion and Ohmic dissipation more or less work the same way, diffusing the magnetic field. Thus, their effects are subsumed into one diffusion coefficient. The Hall effect has a more complicated effect, and is ignored for simplicity first.

II. The Solution

A. Radii of the disc

Radii have been obtained for weak and strong field cases, by balancing timescales of non-ideal MHD effects and induction, and those of radial advection and magnetic braking. For a strong field configuration, we expect the field lines to be straightened horizontally, whereas for a weak field configuration, we expect the field lines to be straightened by vertical stretching. Thus, for a strong field, we balance the horizontal diffusion timescale with the induction timescale, whereas for a weak field, we balance the vertical diffusion timescale with the induction timescale. This combined with the balancing of radial advection timescales and magnetic braking, we obtain estimates for radii for the protoplanetary disc:

For strong fields,

$$r = \frac{\eta_{\rm A}^{\frac{2}{9}} \delta_\rho^{\frac{2}{9}} \delta_r^{\frac{2}{3}} G^{\frac{1}{9}} M^{\frac{1}{3}}}{(2\pi)^{\frac{2}{9}} B_r^{\frac{4}{9}}}$$

$$= 19.23\,\text{au} \left[\delta_\rho^{\frac{2}{9}} \delta_r^{\frac{2}{3}}\right] \left[\frac{\eta_{\rm A}}{10^{19}\,\text{cm}^2\text{s}^{-1}}\right]^{\frac{2}{9}} \left[\frac{M}{0.1\text{M}_\odot}\right]^{\frac{1}{3}} \left[\frac{B_r}{0.1\ \text{G}}\right]^{-\frac{4}{9}}$$

For weak fields,

$$r = \frac{\eta_{\rm A}^{\frac{2}{11}} M^{\frac{5}{11}} \delta_\rho^{\frac{2}{11}} \delta_r^{\frac{6}{11}} G^{\frac{3}{11}}}{(2\pi)^{\frac{2}{11}} B_r^{\frac{4}{11}} C_s^{\frac{4}{11}}}$$

$$= 45.53\,\text{au} \left[\delta_\rho^{\frac{2}{11}} \delta_r^{\frac{6}{11}}\right] \left[\frac{\eta_{\rm A}}{10^{19}\,\text{cm}^2\text{s}^{-1}}\right]^{\frac{2}{11}} \left[\frac{M}{0.1\text{M}_\odot}\right]^{\frac{5}{11}} \left[\frac{B_r}{0.1\ \text{G}}\right]^{-\frac{4}{11}}$$

B. Discussion

1. The Radii.
   The obtained radii agree well with expected results (Hirano et al. 2020), pointing towards bigger discs when the magnetic field is misaligned with the rotation axis, compared to the vertical case (Lee et al. 2021).

2. The Magnetic Flux.

   2.1. In simplifying the problem, we made an assumption that the magnetic field approaches the disc-envelope boundary at a uniform

angle (i.e. $dB_r/d\phi = 0$). To justify this assumption, we point out that the term containing this derivative in the simplified induction equation vanishes to zero on integration along the azimuthal axis (fundamental theorem of calculus, and the fact that B_r is a conservative field.)

2.2. It is worth discussing when the components of $\boldsymbol{B}$ (B_r and B_ϕ) dominate over each other.

We notice that demanding $B_r > B_\phi$ leads us to the condition that $B_r > 0.002$ G, which is a very small intensity for circumstellar environments. This implies that regardless of the initial conditions, B_r dominates over B_ϕ.

2.3. It is also worth investigating when we are in the strong-field configuration or the weak-field configuration.

During the formulation of the problem, we found:

$$\tau_{\mathrm{adv,H}} = \frac{r^2}{\eta_{\mathrm{A}}}, \quad \text{and } \tau_{\mathrm{adv,V}} = \frac{z^2}{\eta_{\mathrm{A}}}$$

We notice by comparing the timescale of vertical diffusion (in case of a weak field) and the timescale of horizontal diffusion (in case of a strong field), that at all points on the disc-envelope boundary,

$$\tau_{\mathrm{adv,H}} \gg \tau_{\mathrm{adv,V}}$$

Thus, at all points in the boundary, we have the weak-field case (vertical diffusion).

C. Conclusion

1. A stable protoplanetary disc forms under the influence of a horizontal magnetic field threading the disc-envelope system.

2. The radii of protoplanetary discs formed under a strong field (horizontal diffusion), and weak field (vertical diffusion) are obtained, and they are larger than when the magnetic field was aligned (parallel or antiparallel) with the rotational axis. This agrees with work previously done (Hirano, 2020).

3. The magnetic field lines approach the disc-envelope boundary at a uniform angle.

4. Regardless of initial conditions, $B_r > B_\phi$.

5. At all points along the boundary, we are in the weak-field case, i.e. vertical diffusion dominates.

References

Hirano, S. (2020). The Effect of Misalignment between the Rotation Axis and Magnetic Field on the Circumstellar Disk. *The Astrophysical Journal*, *898*(2), 23. https://doi.org/10.3847/1538-4357/ab9f9d

Lee, Y.-N. (2021). Universal Protoplanetary Disk Size under Complete Nonideal Magnetohydrodynamics: The Interplay between Ion-Neutral Friction, Hall Effect, and Ohmic Dissipation. *The Astrophysical Journal*, *922*(1), 13. https://doi.org/10.3847/1538-4357/ac235d