Wesleyan University

Exploring the Role of Environment in the Composition of ONC Proplyds

by

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If people sat outside and looked at the stars each night,

I'll bet they'd live a lot differently.

—Calvin & Hobbes

Contents

List of Figures

Chapter 1

Discussion

With the disks now fit, we may interpret our results. Since this project was framed around the question of how environment influences protoplanetary disks, we would like to compare our best fit values to other disks, including to one other from the ONC (Factor et al. 2017) as well as to others outside of it. We begin with a brief review of the relevant literature on the three disk features that we fit (densities, temperatures, and chemical abundances) so that we may frame our results in a meanigful context.

1.1 Physical Structure

To get a sense of how these disks' physical characteristics (i.e. mass and radius) compare to other protoplanetary disks, it is useful to compare our results to other disks in the Orion Nebula Cluster, as well as others in low-mass star forming regions (SFRs). It is worth again reiterating that many of the reported disk gas masses in the literature (as well as the value we use here from Williams et al. 2014) are calculated from continuum emission (which traces dust mass), and then scaled by the factor of 100 to return a gas mass. However, as briefly discussed in §**??**), this ISM-based gas/dust ratio has been shown to be neither constant across surveys disks nor best approximated by 100:1.

In an attempt to avoid relying on the use of the 100:1 gas/dust ratio, **?** presented a method to infer a disk's gas mass by comparing ratios of CO isotopologues. The method they present involves developing parametric disk models over a wide range of parameters (similar to the modeling process that we use) and calculating the resulting emission intensities of selected lines (generally $C^{18}O$ and ^{13}CO due to their relative abundances but lack of cloud contamination). By generating a large set - or "grid" - of models over a range of parameter values, observations of a disk can then be located on that grid, essentially through template fitting. In this process, they hold certain molecular and atomic abundance ratios fixed (most notably, their CO/H_2 ratio is held at the molecular cloud-level of 10^{-4}). Their application of the method to nine well-studied disks in Taurus yielded masses appreciably lower than a 100:1 gas/dust ratio would have implied, instead returning a wide range of ratios that were centered around 10:1. Analysis of 89 disks in Lupus (Ansdell et al. 2016) using this method also showed a similar trend, although due to insufficient $C^{18}O$ detections, only 11 of the disks' masses were able to be fully estimated, while another 25 had upper limits established.

Miotello et al. (2014), Miotello et al. (2016) and Miotello (2017) build on the methods of **?**, using CO isotopologue ratios to find gas mass, but avoid the use of fixed abundance ratios by integrating a full chemical-reaction network to reflect the effects of freeze-out and photodissociation (the two main effects driving chemical evolution), allowing the abundance ratios to self-equilibrate. With this addition, they were able to reanalayze and expand the sample of constrained gas masses from the Ansdell et al. (2016) survey from 11 to 34. Their results again show that the use of a fixed gas/dust ratio is inappropriate, and that 100:1 is typically far too high. Miotello (2017) notes that this deficiency could be the result either of an actual lack of gas, or could reflect a high rate of carbon depletion (through chemical evolution, locking-up in larger bodies, or loss of gas), but that these observations are insufficient to discern between them.

With this in mind, the values we use for the masses of disk A and disk B are 0.075 $M_\odot$ and 0.029 $M_\odot$ (78.66 and 29.88 Jovian masses), respectively, drawn from Williams et al. (2014). These values were calculated using the 100:1 gas/dust.

When calculating gas masses for the disks in d253-1536, Williams et al. (2014) found the disks' total dust masses from continuum data, respectively, then used the 100:1 gas/dust ratio discussed above to infer the gas masses. The uncertainty that this introduces is crucial to keep in mind, as the resulting gas masses are possibly up to an order of magnitude or two too large (according to the trends shown in Fig. 1.1). A table of the disks' masses and radii, as well as those from Factor et al. (2017), are presented in Table 1.1 for reference throughout this chapter.

Table 1.1: Disk Parameter List

Disk	Radius_{HCO^+} (au)	Radius (Reported)[a] (au)	Dust Mass ($M_\odot$)	Dust Mass ($M_\oplus$)	Gas Mass[b] ($M_\odot$)	Gas Mas ($M_{\rm Jup}$)
d253-1536a	340	268	7.5×10^{-4}	250	7.5×10^{-2}	78.66
d253-1536b	148	[-]	2.9×10^{-4}	95	2.9×10^{-2}	29.88
d216-0939	530	525	4.4×10^{-4}	145	4.4×10^{-2}	45.84

[a] Semi-major axis of 2D Gaussian fit.
[b] Inferred from dust mass using 100:1 gas/dust ratio.

With this in mind, we can compare these disks' masses and radii to others. The natural place to start for this is with the survey of ONC proplyds that originally provided these data (Mann et al. 2014). In it, the authors infer total disk masses and fit the disks with 2D elliptical Gaussians, and using the resulting semi-minor and -major axes of the disks as approximate measures of the disks' radial extents. Disk A in the present system was, by their measure, the most massive disk in the study, 75% (37σ) more massive than the study's next most massive disk, d216-0939 (which was the subject of Factor et al. 2017); disk B was the fifth most massive. Disk A had the study's fourth largest semi-major axis[1]. The authors did not fit disk B's radial extent; however, our fit for its radius would make it the eleventh (out of 22) largest disk in the survey. Thus, disk A is on the very high end of the study's mass and radius range, while disk B is apparently quite dense and of median radial extent.

This work was followed by a survey of 104 detected disks in the heart of M42 within 0.14 pc of θ^1 Ori C (Eisner et al. 2018). The authors measure the disks' dust masses (from continuum flux) and radii (again from fitting 2D elliptical Gaussians), and compare their distributions to similar measurements from other surveys of disks in low mass SFRs. These comparisons are summarized in Fig. 1.2 (see figure caption for references), showing the distributions of masses and radii of disks in each survey. From them, we see that these M42 disks are characteristically denser and radially truncated, as shown by the ONC track's relatively high position on the mass plot and relatively low position on the radius plot. By locating our two disks on these plots, we find that their dust masses are far greater than the M42 disks and that disk A is more massive than any of the disks in all the surveys. However, while the ONC disks in this plot exhibit an atypically high density (the highest-mass disks have mass/radius ratios of around 1.5 $M_\oplus$/au) relative to the other survey's disks (which are closer to of order 0.5 $M_\oplus$/au), disk A and B land at 0.75 and 0.65, respectively. This indicates that, while they are still somewhat more dense than the disks from low-mass SFRs, they show neither

[1]The authors' measurement of disk A's semi-major axis, at 268 au, is 2.6σ smaller than our fit measurements. The survey's reported semi-major axis for d216-0939 was also smaller than the fit value in Factor et al. (2017), though by less than 1σ. This probably reflects something about how we define gas/dust outer radii REWORK see how surf dens is implemented, and Hughes2008

the radial truncation nor high densities found in the M42 disks.

It is also worth noting that by using the methods described above to measure gas masses directly, Miotello (2017) found no disks more massive than 1.6 M_{Jup} (500), while Ansdell et al. (2016) and Ansdell et al. (2018) found masses reaching no higher than 10 M_{Jup}.

The results of these surveys, and the contextualization of our disks amongst them, indicate that the disks that are the subject of this thesis are atypically massive (and maybe wide)

1.1.1 Comparison to Binaries

We must also consider the fact that our disks are in a binary. While this work is not meant to be a complete review of multiple star systems (for a more comprehensive review, see **?**), some review of the relevant literature is warranted to frame our interpretation of the present system.

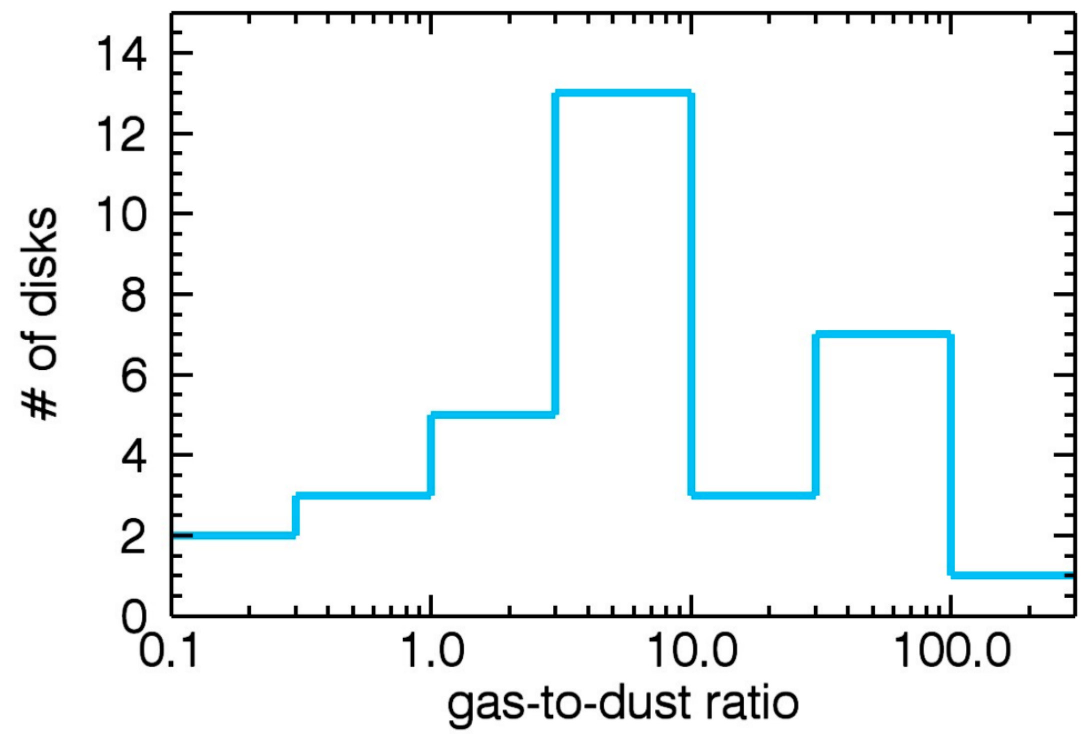
Binaries (and higher-order systems, which generally form as heirarchical pairs) are quite common, with around 30% of low- and intermediate mass Main Sequence stars presenting with companions; that number climbs to 70% for high mass stars (Sana et al. 2012), and surveys of younger, T Tauri stars in low-mass regions show even higher fractions, up to almost 80% in Taurus (Kraus et al. 2011), for example. However, regions of higher densities (like the ONC) seem to have the opposite effect, as Reipurth et al. (2007) found that the 781 sources within 60” of θ Ori C contained only 69 multiple systems (with apparent separations between 67 and 675 au), yielding to a companion fraction of just 9%. There is notable subsetting within that population, particularly with a defiency of wide (0.”5 - 1.”5, or around 200-600 au at the ONC’s Gaia-measured distance of 389 pc) binaries closer to θ_1 Ori C (see Fig. ??). Our binary, with an angular separation of 1."1, represents one of the widest pairs in the ONC, and is comfortably into the "flat" region (at $d = 591''$) of the radial distribution of binaries from θ_1 Ori C.

As one might expect, disks are not uncommon around disks in binaries. Several millimeter/sub-millimeter surveys have observed a number of disks in binary systems in various regions, most notably in Taurus and ρ Ophiucus. Since these regions are low-mass SFRs, they are qualitatively different environments than the ONC, but provide us with a good starting point to compare to.

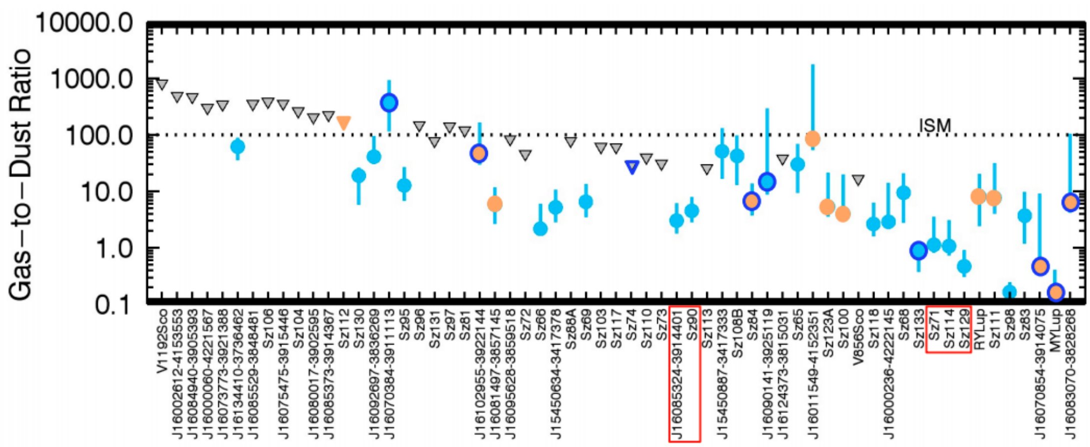
Harris et al. (2012) observed disks in 23 multiple-star systems in Taurus using the Submillimeter Array. In it, they found a strong anticorrelation between system brightness and projected separation between components, with wide pairs (>300 au) showing similar brightness to that of two single stars, while tight pairs (<30 au) suffer a 5× decrease from the equivalent sum of individual brightnesses (although the presence of circumbinary disks around binaries of any separation make the system significantly brighter; see Fig.??). Akeson et al. (2019) built on these results with an ALMA survey of additional binaries in Taurus, developing a sample of 151 sources with resolved millimeter detections, 99 of which were in binary systems. From this sample, they found that disks around the binaries' primary (more massive) star contribute, on average, 62% of the disks' total combined mass, although this distribution has a wide spread. They also developed the observation by Harris et al. (2012) (and previously in ?) that tighter binaries led to lower fluxes, finding that, as a function of stellar mass, disks in binaries have systematically lower masses than their isolated counterparts, and that this mass truncation is more apparent in tighter binaries (see Fig. 1.4). They found that $M_{disk}/M_\star$ for the primary and secondary stars are correlated in close systems but anticorrelated in wide systems, and that the rough correlation between disk mass and stellar mass shown in Andrews et al. (2013) did not hold in their sample. Finally, they note that the absence of a significant population of circumbinary disks in the sample suggests that they are either not common or quickly (<1-2 Myr) dissipated.

Disks in binary pairs have also been surveyed in the ρ Ophiucus region. Akeson & Jensen (2014) studied 17 pairs with separations ranging from 100-990 au using ALMA, measuring the systems' masses. In it, they found no correlation between disk mass and stellar masses, matching the results from the studies of Taurus binaries above. Cox et al. (2017) followed with a survey targeting 63 total sources, comprised of 11 binaries, three triple systems, and 34 single sources. In it, they, like Harris et al. (2012) and Akeson et al. (2019), found significantly lower fluxes from sources in binaries than isolated ones, and found that the disks' radii also exhibited systematic truncation. They note that this truncation is likely either due to tidal interactions between the disks or reflects a natural limit on the radii of disks in binaries, inherent to the disks' formation process, and that these decreased fluxes can be generally interpreted as being proportional to decreased masses. They also found no correlation between the ratios of the stellar masses and the ratios of the disk masses in the sample, indicating that environmental factors that both components share are likely not a dominant factor in determining disk masses.

Comparing the this thesis's binary pair to these surveys, however, immediately shows that its disks are neither faint nor small, neither in comparison to the disks in those surveys or to the disks in the survey that it was a part of. However, this is not really out of line from the morphological patterns presented in the surveys above since, at 428 au, the disks' projected separation is enough to put them beyond the reach of the most significant mass and radius truncations that closer binaries undergo, and its large distance from θ^1 Ori C likewise protects it.

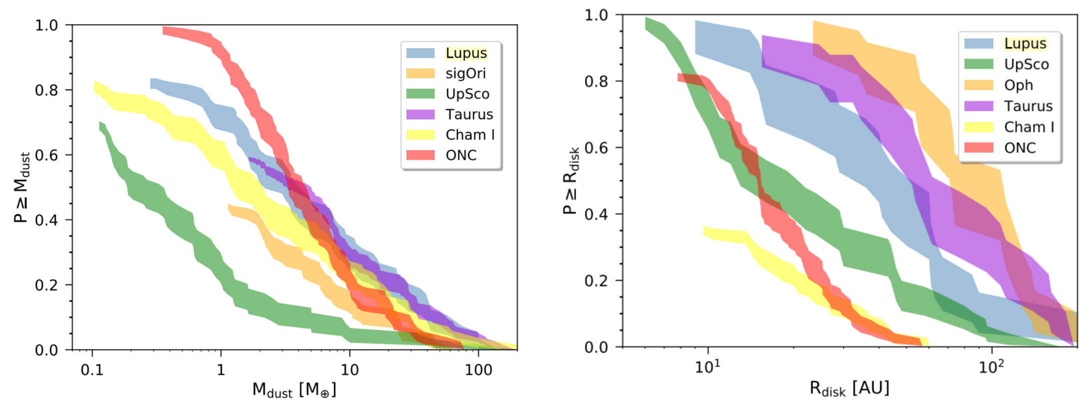


(a)



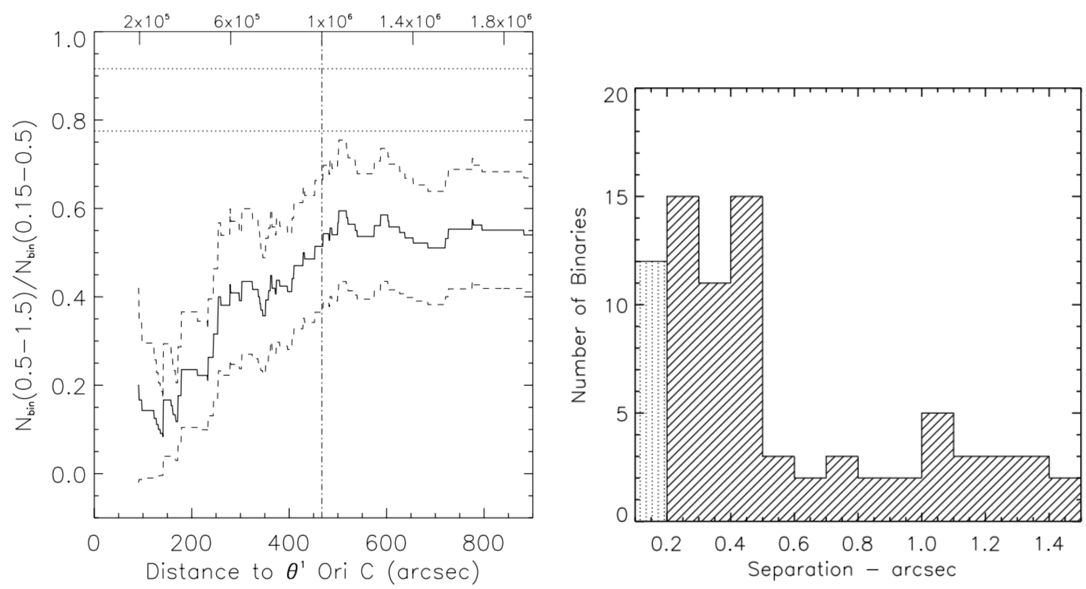
(b)

Figure 1.1: blah balh



(a) Disk mass distribution across surveys (b) Disk radius distribution across surveys

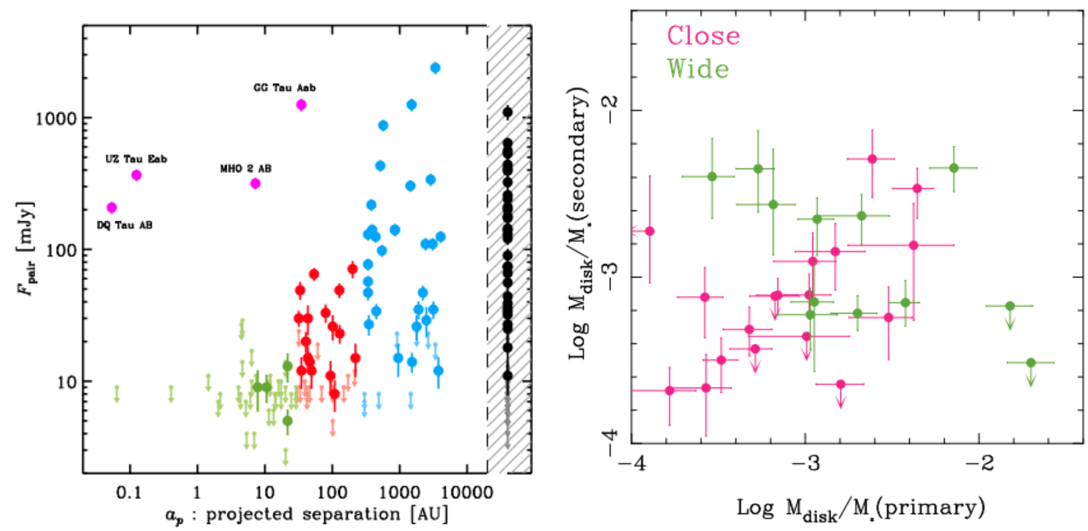
Figure 1.2: Plots of disk dust masses and radii frequencies (Eisner et al. 2018). *Survey References:* Lupus: Tazzari et al. (2017); σ Ori: Ansdell et al. (2017); Upper Sco: Barenfeld et al. (2017); Taurus & Ophiucus: **?**; Cham 1: Pascucci et al. (2016)



(a)

(b)

Figure 1.3: Statistics for binary pairs in the Orion Nebula Cluster (Reipurth et al. 2007). In (a), the vertical dotted line represents the point at which the distribution becomes flat. The present system is around 591" from θ_1 Ori C, putting it beyond the radius apparently affected by the massive star.



(a) Harris et al. (2012)

(b) Akeson et al. (2019)

Figure 1.4: Population trends from binary pairs in the Taurus star-forming region. (*a*): There is a clear upper limit on pair flux that is correlated to projected separation (green, red, and blue marks represent close, medium, and wide pairs). the presence of a circumbinary disk (magenta) yields an extra source of flux, and so pairs featuring such a disk do not follow the separation-limited flux pattern. (*b*): The mass of the disk around the secondary member of the binary in close systems (pink) is correlated to the mass of the primary, while in wide systems (green), the two are anti-correlated.

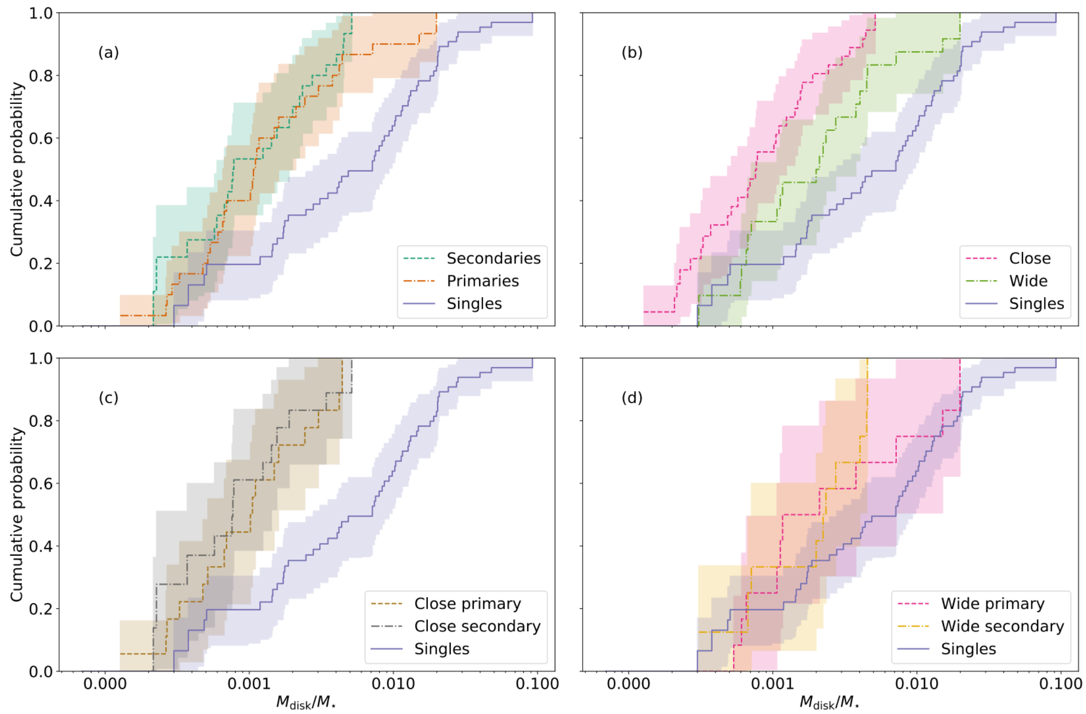
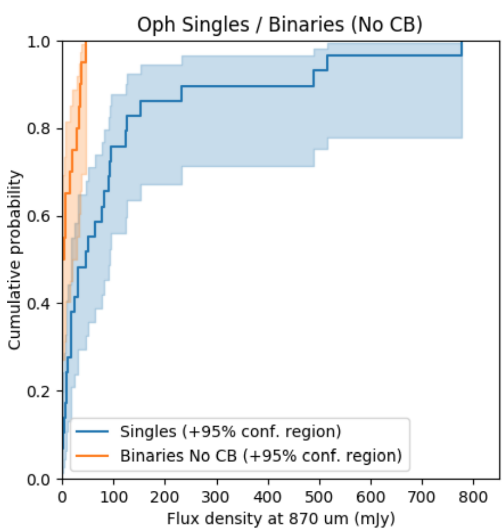
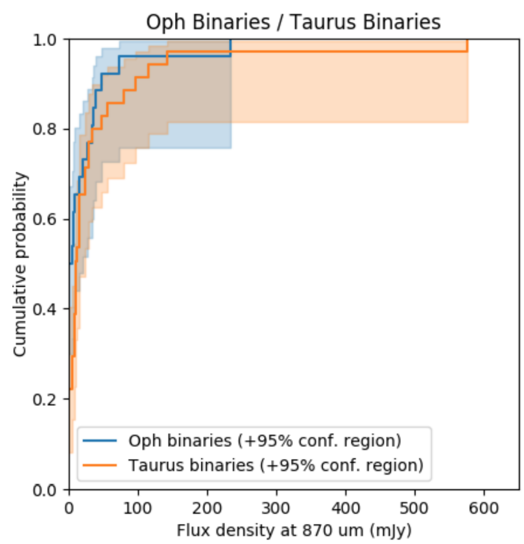


Figure 1.5: Cumulative probabilities of disk masses for different combinations of disks in binary pairs (Akeson et al. 2019). (*a*): Both disks in binary pairs are systematically less massive than single (isolated) disks although, as expected, the primary has more representation at the more massive end. (*b*): Close pairs are more significantly truncated than wide pairs, although wide pairs are still under-massive as well. (*c*) Close pairs do not preferentially truncate either disk; each has a sharp upper limit. (*d*): Primaries in wide pairs have nearly the same mass probability as single disks.



(a)



(b)

Figure 1.6: Cox et al. (2017) showed that disks in binary systems (excluding circumbinary disks) in ρ Ophiucus have systematically lower fluxes than both isolated disks in the region (*left*) and disks in binaries in Taurus (from **?**).

1.2 Chemical Structures

We now explore the chemical nature of protoplanetary disks. These disks have strong radial and vertical gradients in their temperatures, densities, and radiation fields, creating a wide range of chemistries. These chemistries can be broadly divided into inner- and outer-disk regimes, thanks to (typically) exponential radial temperature decay. Inner disk temps are high and thus best suited to IR observations, while outer disks are cold and better suited to sub-millimeter observations. Because our investigation is rooted in ALMA observations, we will review the outer disk here. Working with the basic building blocks of hydrogen, nitrogen, oxygen, and carbon and a wide diversity of temperature, density, turbulence, and radiation environments, disks are able to develop an array of molecules in their outer regions, each with its own characteristic formation conditions and emission signatures. Understanding disk chemistry is a process of knowing which of these signatures to look for and make sense of what they are telling us.

Since the disks form out of molecular clouds, the abundances found there should provide reasonable initial values for our disks' chemical structures; Aikawa et al. (1999) showed these to be (for the molecules that we model) $X_{HCO}{}^{+} = 9 \times 10^{-9}$ and $X_{HCN} = 2 \times 10^{-8}$. However, since disks undergo complex chemical evolution, developing a parametric understanding of the chemical structure and evolution of protoplanetary disks guides our interpretation of data. Below is a brief overview

Aikawa et al. (1997) were some of the first to apply time-evolving chemical networks to protoplanetary disks, describing a radial model of the effects of cosmic rays in the outer disk and how they can convert CO and N_2 (which essentially define the disk's initial composition) into more complex organics, including HCN,

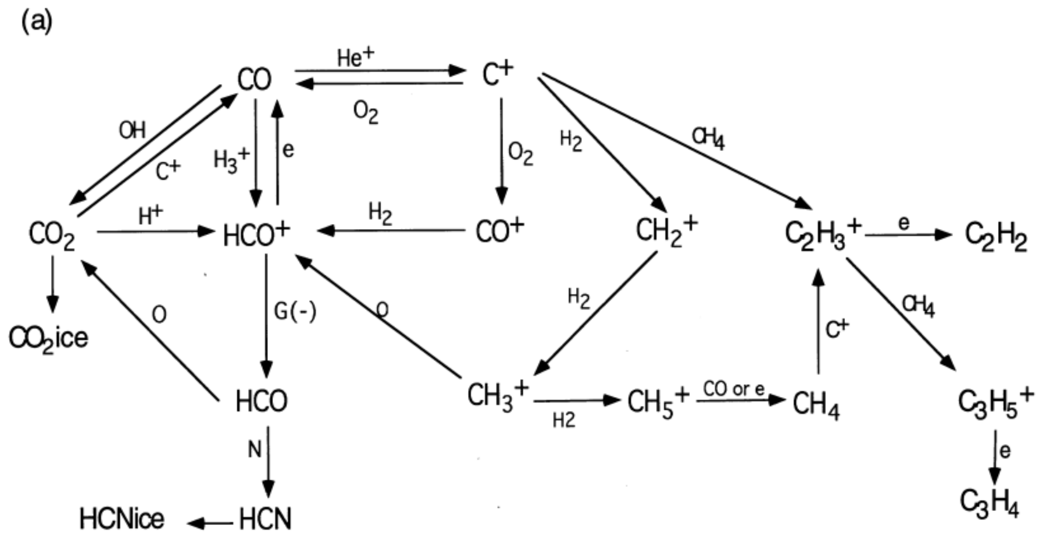


Figure 1.7: The chemical process leading to the generation of HCO^+ and HCN (Aikawa et al. 1999). We immediately see that the generation of HCO^+ is directly dependent on CO, while that same HCO^+ molecule can then combine with N to yield the disk's HCN.

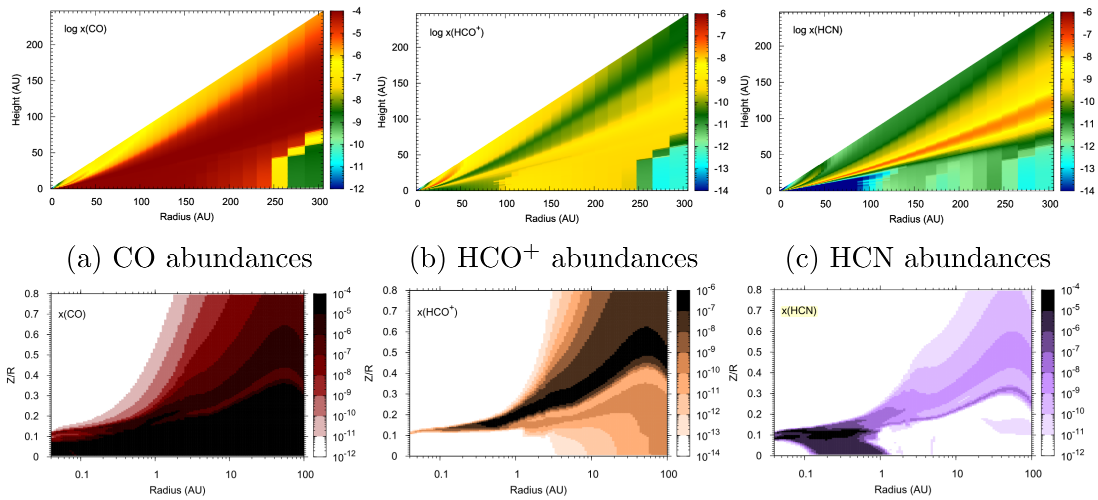
through chemically active ions (Fig. 1.7). Aikawa et al. (1999) expanded on the work, modeling the evolution of molecular abundances in an accreting protoplanetary disk. They show that the timescale of this chemical evolution is dependent on the disk's ionization rate and the size distribution of the dust grains, increasing with lower ionization rates and/or larger grains and vice versa. As grains grow, HCN abundances are lowered by orders of magnitude, since they depend heavily on the grain surface recombination of HCO^+ , which is significantly smaller in the case of larger grains. Later, **?** and **?** added a vertical dependence to the model, first with density and then with temperature, allowing a full (r, z) description of chemical evolution of a protoplanetary disk's temperature and density profiles and calculating the resulting interactions between the gas and dust, X-rays, and cosmic rays. They found that ionization in the mid-plane is driven by cosmic rays, while at significant heights from the midplane, X-rays from the central star also become a major source. These efforts yielded approximately radially constant distributions of HCO^+ and HCN, with HCO^+ presenting column densities about an order of magnitude above those of HCN (a reversal from the molecular cloud's conditions). This highlighted the role of ionization in protoplanetary disks and the need for a more complete description of the effects of high-energy radiation - both from the central star and cosmic rays, across a wide range of energies - on the evolution of their gas masses.

In Fogel et al. (2011), the authors show how strong radiation fields (i.e. from neighboring massive stars) will have the effect of amplifying the disk's natural CO-based photo-chemistry (already driven by the host star) and increase the size of the disk's warm gas layer.

Fogel et al. (2011) showed that HCN is disproportionately depleted with strong Lyman α radiation, which is typical in T-Tauri stars.

Additionally, the disk's dust evolution can affect the gas (Fogel et al. 2011; **?**), with grain growth and sedimentation leading to decreased UV shielding of the disk's inner layers and pushing the disk's molecular layer closer to the midplane. As these larger grains and the molecular layer both settle to the midplane, molecular freezeout in the region is slowed, leading to heightened column densities for many species, including CO and HCN.

To study the effects of this ionization in anticipation of the arrival of ALMA, Walsh et al. (2010) developed radial and vertical chemical models for an isolated protoplanetary disk around a T-Tauri star, tracing molecular abundance distributions throughout the disk for molecules within ALMA's reach. They showed that log abundances in their models for HCO^+ varied from -8 to -12, -7 to -12 for HCN, and -4 to -9 for CO. The authors then built on this model by adding functionality to model externally-driven UV and X-ray ionization (Walsh et al.



(a) CO abundances (b) HCO^+ abundances (c) HCN abundances

(d) CO abundances (e) HCO^+ abundances (f) HCN abundances

Figure 1.8: Models showing radial and vertical distributions of CO, HCO^+ , and HCN in a simulated disk around a T-Tauri star. The top row shows the profiles of isolated disks (Walsh et al. 2010), while the bottom row shows the profiles of disks being irradiated by a nearby O star (Walsh et al. 2013). Note that bottom row is on a log scale and only covers the inner 100 AU of the disk, while the top row is linearly scaled and shows a 300AU stretch. *It seems like only having one of these sets of images would make more sense.*

2012) and applied it to the same disk system, this time with an O star nearby providing ionizing photons (Walsh et al. 2013) and mapped molecular abundance distribution (see Fig.1.8). The authors note that, in their externally photoionized disk, HCO^+ column density increases by a factor of 6.3 relative to the isolated disk, whereas HCN and CO column densities remain constant through ionization. They also note that the ionized disks have much higher gas temperatures, $T \gg 50$ K; this is consistent with the high temperatures that we see in our disks.

Cleeves et al. (2013, 2014) also modeled the radiation and ionization environment in these disks, developing models to compare the relative contributions of stellar UV, stellar X-rays, and cosmic rays (see Fig.1.9). Their findings showed that HCO^+ traces high cosmic ray (CR) rates, with its abundances dropping significantly with decreased CR contributions, thanks to its precursor, CO, freezing

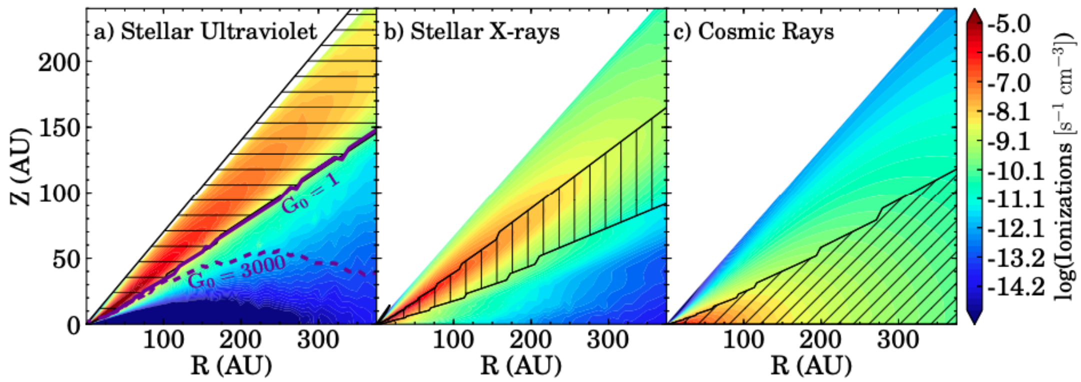


Figure 1.9: Radiation contribution on a protoplanetary disk from stellar UV, stellar X-rays, and cosmic rays (Cleeves et al. 2013). The $G_0 = 1$ contour represents the effects from a host-only UV field (i.e. an isolated star), while the $G_0 = 3000$ contour represents the effects of a UV field made up of both the host as well as from the interstellar radiation field. Fatuzzo & Adams (2008) showed 3000 to be a typical value for G_0 in clusters, thereby making it the more relevant model for our system.

out in regions where CRs are the primary energy source but deficient. They also note that HCO^+ abundances can suffer from particularly high UV fluxes (from either Herbig host stars or high radiation environments), as CO can be photodissociated before having a chance to form HCO^+ .

Since our disk model produces a single, flat relative abundance for each molecule across the disk, we are inherently unable to resolve the level of detail presented in the models. However, we may use their predictions to inform how we read the results. According to Walsh et al. (2013), HCO^+ is a tracer of cold, dense material and is generally more abundant in the outer midplane, whereas HCN follows warmer material closer in to the disk's center (since it is non-volatile, it freezes out more easily). Their models predict that, in an isolated disk, the line strength (in units of mJy km s^{-1}) ratio of HCN/HCO^+ should be 27.1/54.1 (0.50), while in an irradiated disk it is 71.9/86.9 (0.83). Using our fit abundances as a proxy for line strength[2], we find in both disks ratios of around unity. This, combined with the high disk temperatures, seem to hint at these disks being irradiated. This would make sense, since between a high mass (F or G) star and a heavily accreting M star, high-energy radiation is to be expected. However, while the system's surrounding environment is known to have some far-UV radiation field due to the bubble being blown out by θ^1 Ori C (Pabst et al. 2019), it is largely a quiet region, indicating that, unless background radiation is stronger than expected, this ionization in the disks is likely driven primarily by the stars.

On the temperature side, we expect in an ideal disk to find $q = -0.5$ (recalling that the radial temperature structure is generally assumed to go as $T(r) \propto r^q$). This can be found by recalling that the energy that a star emits decays as something. Such a structure invokes the assumption of a smooth, consistent distribution of emitting material, so variations from that value indicate variations in the structure. Studies of individal disks (in low-mass SFRs) have largely been in line with this prediction (e.g. Dartois et al. 2003; Panić et al. 2008, 2010; Hughes et al. 2008; **?**; Qi et al. 2004; Isella et al. 2007; Rosenfeld et al. 2012; Flaherty et al. 2015, 2017; Zhang et al. 2017; Flaherty et al. 2018, , whose values range from -0.22 to -0.7). In their study of another ONC proplyd, Factor et al. (2017) found that their HCN emission traced a moderately-high structure of $q = -0.18$, but that their HCO^+ line showed $q = 0.17$.

The literature on disk temperatures is less well constrained, but it seems that higher ionization leads to higher temperatures.

Table **??** presents molecular abundances and temperature structure parameters for disks from a selection of studies. While the list is not comprehensive (see Panić et al. 2008, 2010; Hughes et al. 2008; **?**; Qi et al. 2004; Isella et al. 2007, for more

[2]Although line strength is also degenerate with total mass, temperature, q, REWORK

example)), its members were selected to highlight features from a diversity of emission lines. The most immediately relevant of these is the work by Factor et al. (2017), the only other study to do forward-modeling of emission using a ray tracing code. In it, they characterize another ONC proplyd from the same survey as our binary, and thus represents the only other study to model a disk that is also in a high-mass star forming region. The other studies listed are focus on disks in low-mass regions. We may compare our temperature profiles and abundance to these other systems and look for variations from typical values.

There are several points of note here. Save for the CO line, which shows nonphysical temperatures, our atmospheric temperatures are notably higher than those found in the other studies. Additionally, our temperature structures for both HCO^+ and HCN are solidly positive, reflecting a structure that increases with radius. As with the atmospheric temperature, this is contrasted by all other results, which have moderately negative values, save again for that of the Factor et al. (2017) HCO^+ line, which is also positive but less so than in our fits. Our positive values stand somewhat in contrast to the q value of $-0.5^{0.2}_{-0.1}$ predicted by Dartois et al. (2003) for a geometrically flat, optically thin disk. Schwarz et al. (2016) note that a flatter, non-negative structure is to be expected when observing emission that originates from layers just above freeze out temperature in the disk.

1.3 How d253-1536 Stacks Up

With a theoretical structure now in place, we can now compare our results to that literature, as well as other specific disks.

blah blah

Factor et al. (2017) found HCO^+ abundances in line with these predictions, but a significant excess of HCN, consistent with high ionization rates REWORK AND SOMETHING ELSE?

Our fits show disk A having a notable excess in both lines and more typical abundances in disk B.

That each disk's abundances are so different from one another is something of a surprise. Both disks have similar ratios of the two emitting molecules: disk A's HCO^+ /HCN ratio of log abundances is 1.09, while disk B's is 0.95, becoming 1.21 for disk A and unity for disk B if the disk B radius cut is made.

We see in the HCN channel maps an area of significant flux coming from between disks around $v = 9 - 11$ $\mathrm{km\,s^{-1}}$. This may be region where the two disks are interacting, a possibility that our model does not take into account. The feature is less clearly present in HCO^+ and invisible in CO, likely overrun by cloud contamination. Smith et al. (2005) note that disk A "exhibits distortions that we attribute to tidal interactions with the companion star" (before they knew that there is a second disk).

1.4 Implications

With this context, how do now we make sense of our current observations and fits? Our results show a wide (428 au separation) binary pair of stars with disks that are massive[3] and radially large (both compared to other disks in the ONC and disks in binaries in Taurus and ρ Ophiucus). The two disks have appreciably different chemistries, and are physically interacting, as shown by the HCN residuals.

[3]Although this mass is, of course, still handicapped by the assumptions about gas/dust ratios

Andrews et al. (2013) showed that the masses of disks in Taurus are linearly correlated with the mass of their host stars, going as $M_{disk} \approx 0.4\% M_\star$ and ranging by up to a factor of 40. Our disks have masses approximately equal to 2% and 7% of their host stars for disk A and B, respectively, which is consistent with their linear fit and the associated uncertainty. There is also sufficient uncertainty in the measurement of these disks' masses - from the 100:1 gas/dust ratio and dust temperatures assumed in the mass calculation - that these values lack the precision necessary to

Regarding the disks' differing chemistries and high temperatures, several explanations are possible. The most obvious explanation is that, since the disks are hosted by stars of very different masses and spectral types (disk A's host is a 3.5 $M_\odot$ F or G star, and disk B is hosted by an accreting 0.4 $M_\odot$ M2.5 star), theory predicts that they have different chemistries. Since the more massive star would be a stronger emitter of UV radiation, and since, as described above, the resulting ionization leads to expansion of the warm molecular layer and significant increases in the abundances of these molecules as well as heightened disk temperatures. As discussed above, it is predicted that high incident UV fluxes should lead to the increased production of HCO^+ and, in turn, HCN, and that these abundances reflect that.

Another known way to increase the abundances of these species is by increasing the dust mass around them. A simple calculation of the dust mass-to-radius ratio for these disks reveals that this pseudo-measure of density is not the same for the two disks (maybe do the error propogation thing here?).

A less probable but still fascinating possibility is that these disks did not form together. Williams et al. (2014) posit that wide binaries (systems with separations $\geq$ 300 au), such as this one, do not form in the same initial cloud structures. If this were the case, then it might be reasonable to expect each disk to reflect different chemical histories from the regions of the cluster in which each formed. However, binary capture is rare, as a third star is required for this proces to create a bound pair

Mansbach1970, and it is unclear whether the local stellar environment shows history of such an event. It is also unclear how the binary's stellar mass ratio - around 9:1 - would affect the capture process.

Density fluctuations could also contribute to variations in the disks' chemistries as well, be it in the form of embedded planets or turbulence. Since we do not fully resolve disk A and do not resolve disk B, this becomes a particularly speculative step, but Miotello et al. (2016) propose that disks could preferentially chemically depleted through molecules being locked up in larger bodies that are invisible in the radio.

Regardless of what the primary driver of this chemical asymmetry between the two disks, the radiation environment in which these disks exist is a fascinating one, thanks to the unique combination of a relatively high-mass star (d253-1536a), an heavily-accreting M-star (d253-1536b), and, even though they are far from the Trapezium cluster, Pabst et al. (2019) recently showed that marginal ionization from Trapezium is still present well past M43 (see Fig.**??**).

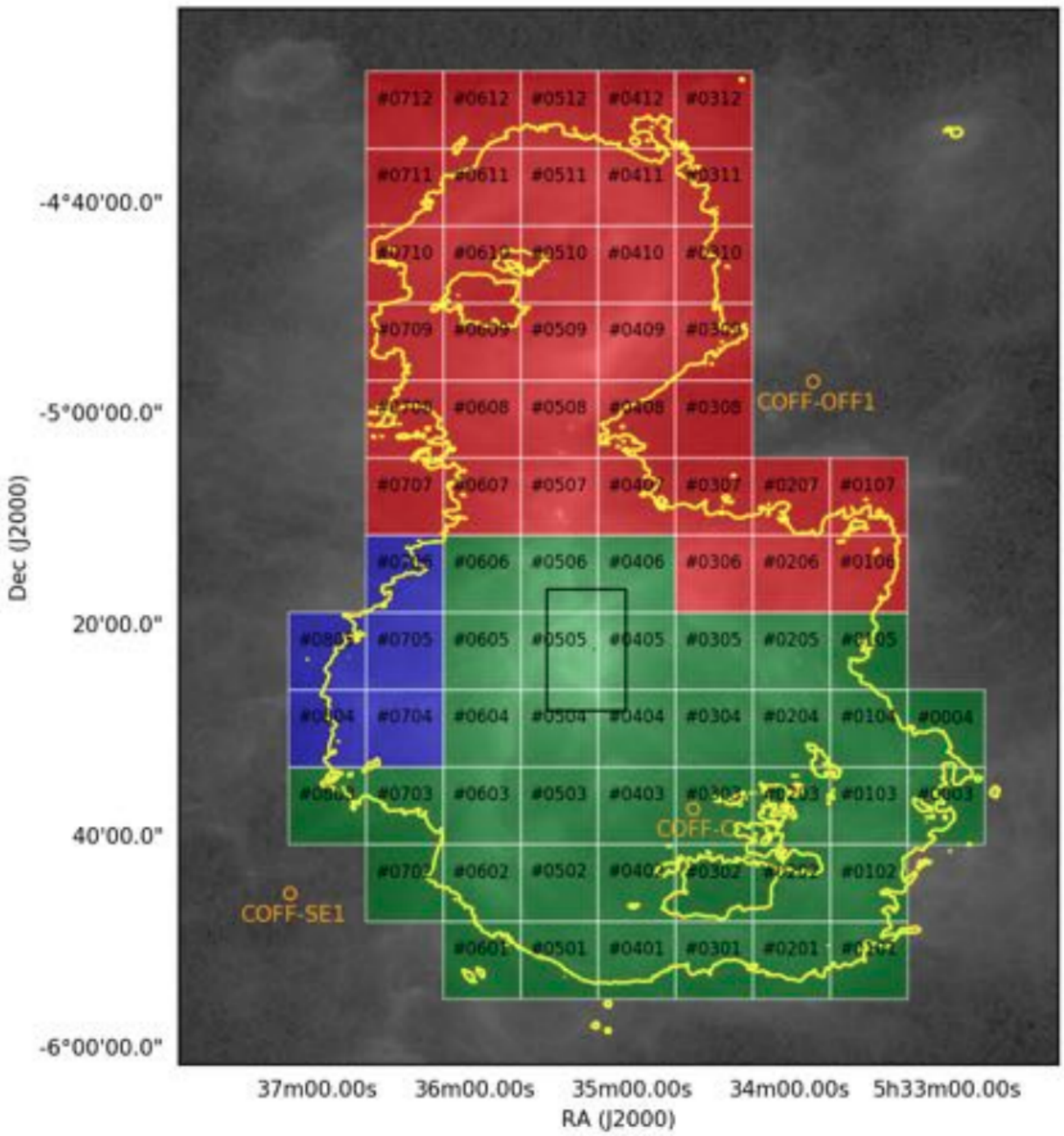


Figure 1.10: blah blah

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