This document contains brief summaries written after I read a paper to remind myself what I thought the most important points of the paper were.

De Looze, 2011: [CII] as a SFR indicator

This paper examines 24 nearby galaxies (w/o [NII]) and compares [CII] to SFR measured by the 24micron line and the UV emission from the galaxy. They find a good correlation for galaxies with moderate luminosities, but suggest that this relation might not be applicable to high or low luminosity galaxies. They also suggest that it may not work for high redshift galaxies as changes in metallicity change the number of photo-ejected electrons, therefore changing the [CII] emission. Would this be problematic with our method?

Croxall, 2017: The Origins of [CII] in star-forming galaxies

Also kingfish, but pacs spire spectroscopy instead of just pacs. Use this paper to replicate methods, get data on regions not in my sample. Results show a large fraction the [CII] emission comes from non-ionized regions in the ISM (~70%), further indicating that it might not be the best SFR indicator without refinement. They also compare [CII] to metallicity and find some amount of correlation. Could indicate same problem in red above. Do I need three parameters to get star-formation rate? [NII], [CII], and metallicity?

Boselli, 2002: [CII] as a star formation tracer

Should I normalize my sample, like they did here so size is not controlling correlation? Compare measurements of star formation rate given by Boselli and De Looze to what I get to try to show better correlation to H-alpha or UV sfr.

26 nearby galaxies of different type and luminosity, calibrate star formation rate using [CII] and H-alpha+NII star formation rates. Get that it is probably uncertain by a factor of ten and will not work for extremely bright or faint galaxies. Appendix has some info about where CII emission comes from and why it might be useful.

Kennicutt Annual Review 2012

Good source of info about pretty much everything star-formation. Lots about comparing measurements of the MW to measurements of extragalactic sources. Also has a lot of the equations I should probably use to get SFR and such (see table 2).

Brauher 2008

NGC6946 has low galactic latitude (b=+12), do I need to correct for Galactic CII? Equation 1 in this paper gives a way to do that…

This paper contains analysis FIR lines in 228 galaxies imaged with ISO. Sort of a pre-Herschel version of what we have. The second and third sections contain very detailed descriptions of the sample and data analysis process, with multiple histograms to show what types of galaxies are being examined. They also include graphs comparing the data gathered for this paper to archival data to show that there processing methods are correct. Section 5 contains good information about all the lines studying in this survey ([CII] 158, [NII] 122, [O1] 63 and 145, [OIII] 52 and 88, as well as some molecular lines that are not discussed as much). These lines are then compared to the FIR, measured with both 60/100 ratio and the FIR/B ratio. The C+ deficit is measured and described in detail in this paper, section 6. They also compare 158 emission to other line emission in section 6, including a graph of 158/122 emission as a function of temp. Conclusions support the C+ deficit as well as show that it does not originate in the most dense regions, where [OIII] 88 micron emission originates.

Diaz-Santos 2013

Would it be worthwhile to pull out AGN in my sample, vs. normal SF galaxies to see if trends are different?

Very nice explanation of the C+ deficit, with analysis that concludes that it must be caused by the increasing ionization parameter. This conclusion is reached by comparing the dust temperature to the CII/FIR ratio, as well as comparing the CII/FIR ratio to other measurements. This study focuses on LIRGS and ULIRGS in the local universe, so they are also able to investigate what role AGN activity plays with the C+ deficit. Galaxies in this sample show no real correlation between AGN activity and CII/FIR ratio, suggesting that the C+ deficit is not related to AGN activity. They use Herschel PACS spectroscopy, so similar to what I am doing, but no NII205 line, plus looks like they did not get maps? They had gaussians for CII which they found the area under the curve for, which is not what I'm doing. They do discuss HIPE which could be useful though. Intro has a nice summary of all the possible theories for why we see the C+ deficit.

Farrah 2013

Use Herschel PACS to observe far-ir lines in nearby ULIRGS ($z<0.27$), no NII205 though, just NII122, a bunch of oxygen lines, and CII158. Note the C+ deficit, and suggest that it is mostly caused by increased dust in this galaxies, as the C+ deficit is related to merger status. They do note that this only provides a partial explanation, and that charging of PAH's is probably also a significant factor. Again, no trend is seen between AGN activity and line deficits. In this paper, line relationships are found for a wide range of properties, but SFR is not investigated, and all relationships between CII and LIR are not significant.

Garcia-Carpio 2011

Used Herschel PACS to measure FIR emission lines (still no NII205). Measured a deficit in ALL lines, not just in CII, at LFIR/Mh2 ~ 80 L_solar/M_solar. This deficit is detected in all galaxies regardless of optical class/AGN presence. This deficit shows up as a drop by a factor of 3-10 in all FIR lines observed in this study (CII158, OI145, OI63, NII122, NIII57, OIII88, OIII52). They also note that these lines are both exclusive HII region lines and lines that have a large fraction of emission originating in PDRs, showing that this deficit appears regardless of environment. They then use the code Cloudy to model these environments and attempt to reproduce the observed line deficits by increasing the ionization parameter U. They find that this does reproduce the deficits for all lines except the NIII57 line and the two OIII lines which come from areas closer to the heat source. In the conclusions they suggest that this difference is caused by the different properties of starburst and slowly star-forming galaxies.

Helou 2001

This paper discusses the ratio of [CII] to PAH emission in star-forming galaxies, showing that the deficit seen in [CII]/FIR at increasing dust temperatures is not measured in the [CII]/PAH ratio. This suggests that small grains are the prominent heating source in the ISM, and [CII] is the primary cooling source. This is a good paper for discussion of the current knowledge of the [CII] deficit, as they mention the theories about why this occurs, and come to the current conclusion that it is a result of increasing photo-ionization values for small grains in hotter environments. They also consider [OII] 63 micron line as a potential cooling line, and compare the sum of [CII] and [OII] in these galaxies. They find that the ratio of this sum to PAH emission increases with dust temperature, which slightly confuses the matter, but suggests [OII] becomes a more significant cooling line in the hottest, densest environments. Finally, they mention that their results have a large amount of uncertainty, and more exact data would be required to fully prove their theories.

Herrera-Camus 2015

“In the dense gas interface between molecular clouds and Hii regions—also known as photodissociation regions (PDRs)—the excitation is dominated by collisions with molecular hydrogen” —> in intro, page 2. What does this mean for our f_neut fraction? If molecular hydrogen is exciting the transition, it might not be related to PAH emission or SFR here…

“with dens PDRs as the main source of emission (~47%), followed by atomic gas (~21%) and small contributions from the ionized gas (~4%). —> when we measure f_neut, what are we measuring? It would be both atomic and PDR (hopefully), otherwise would we have an issue?

Is scale a problem? If we want to measure SFR in distant galaxies, we want L_[CII] ~ SFR. According to this paper, the surface density of [CII] emission is better. With our small regions, which are we closer to? Could this effect a calibration?

distance effect with luminosities? Do we need to worry about this?

This paper uses part of the KINGFISH sample to determine a [CII] SFR relationship, looking both at L[CII] and surface density of [CII]. They find a linear relationship with a scatter of 0.21dex in both cases. They then go on to create an IR correction to their [CII] measurements to decrease the scatter and remove the effects of the [CII] deficit. This correction lowers the scatter as a function of a variety of variables (including U and PAH emission). They do not use [NII]205 anywhere. They do find that low metallicity galaxies tend to have underestimated SFR when [CII] is used as a tracer, even with the IR correction. They give some explanations for this, but do not come to a concise conclusion. To try to fix this, they include [OI] 63 micron measurements in their SFR measurement, but the scatter does not decrease. They do find that low metallicity galaxies have higher [OI]/[CII] ratios. This suggests that these regions have less of the FUV light pass through dust un-absorbed, meaning no free electrons to excite the [CII] line. They then use their relationship to compare SFR measured by [CII] surface density and [CII] luminosity to traditional SFR measurements, and find the surface density relationship with the IR correction works for five orders of magnitude in luminosity, but the luminosity relationship has high scatter in LIRGS and ULIRGS. They also do not use AGNs at all in their study. Finally, they compare their result to theory using the Starburst 99 code, and find a good connection between star formation and [CII] emission.

De Looze 2014

This paper examines the applicability of using three FIR cooling lines, [CII] 158, [OI] 66, and [OIII] 88, as SFR tracers in dwarf galaxies. They find that [CII] has the highest dispersion, while [OI] has the smallest dispersion. They show that this dispersion seems to depend heavily on the metallicity of the dwarf galaxies they study, with low metallicity galaxies underestimating the SFR and high metallicity galaxies greatly overestimating the SFR. They suggest that this is due to harder radiation fields in low metallicity galaxies and higher photon escape fractions in low metallicity galaxies. They also mention that as C+ has an ionization energy of only 24.4 eV, it is possible for C++ to be the dominate phase of carbon in diffuse ionized medium, making the [CII] 158 micron line impossible in those regions. As they studying star-forming dwarf galaxies, they suggest that their sample is a good representation of what galaxies in the distant universe might look like, so high-z galaxies might follow similar trends. To better understand these relationships, they expand their study to other samples with [CII], [OI], and [OIII] measurements. They divide these samples up to pure AGN, pure star-forming, composite galaxies, ULIRGS, and high-z galaxies. They again find that [OI] is the most reliable tracer of SFR, with [CII] relationships having a dispersion of a factor of 2. They note however that there are only [CII] measurements for the most distant galaxies, making it difficult to quantify the applicability of the oxygen lines to this subset of galaxies. Good source for methods to distinguish between types of galaxies and measure SFR (see appendix).

Kapala 2015

This paper uses Herschel PACS images of the Andromeda galaxy to measure how [CII]158 emission and star-formation relate on parsec scales. Since M31 is so close, each pixel in the [CII] images has a physical scale of about 20 parsecs, allowing them to trace how [CII] and H-alpha match at sub-kiloparsec scales without concerns of position that effect measurements in the Milky Way. They find that there is a linear trend at these scales, but the slope of this trend is much shallower than studies larger regions (like Herrera-Camus). They claim this is due to the more extended [CII] emission which can exist outside HII regions. Figure 5 shows this, as well as the IR and 24 micron emission, which is even more extended than the [CII] emission. They also examine the [CII] deficit at these scales, but as M31 is not a very active star-forming galaxy they do not reach the dust temperatures where the deficit becomes very significant. They do find that there is some trend between metallicity and [CII]/TIR ratio, which they believe is caused by the hardness of the radiation field in different metallicity environments, as this would change how dust absorbs UV radiation. They also discuss how the extended [CII] most likely probes a larger history of star formation, as it can be excited by B stars, where H alpha is almost exclusively created by the short-lived O stars.

Kaufmann 1999

Model paper that determines the values of n, Go, and T for different ratios of the FIR lines. They discuss how and why we see changes in [CII] emission for higher density and FUV emission areas from a theoretical standpoint. They use their model to see how changing metallicity and extinction changes the observations of these lines, and find that metallicity does not have a huge effect on the ratios they examine unless the extinction also increases. Good paper for understanding what physically is happening in PDRs. Shows that for high G and n areas, [OI] becomes the dominate source of cooling, meaning the [CII] line is less important. Also gives a method for determining other parameters (temperature) in the PDRs by comparing ratios of [CII], [OI], CO transitions, and total infrared emission.

Luhman 2003

This paper uses observations of 15 ULIRGs at low redshift to examine the [CII] deficit in IR bright galaxies that are likely very similar to high-z galaxies that have recently undergone mergers. Using ISO to measure [CII], [OI], CO and the 6.2 micron PAH emission feature, they track how different parameters compare to the infrared emission in these galaxies. They find that the [CII]/FIR ratio is about an order of magnitude lower in ULIRGs than in normal star-forming galaxies. In section three, they explore why this might be the case. They use the models in the Kaufmann 1999 to predict Go/n ratios, and find that they are very high in the ULIRGs, which would suggest that there is higher photoionization potential in these regions, which would lower the [CII]/FIR ratio. But, they suggest that these Go/n ratios are almost unreasonably high so they look for more data to explain why this might be. They next test to see if the filling factor for [CII] and FIR are the same by comparing the [CII], [OI], and CO ratios. They find that [CII] appears to be coming from a much smaller area than the CO emission, which would suggest that the FIR emission is more extended than the [CII] emission. Taking this into account, they get more reasonable values for the Go/n ratio and find the [CII]/FIR ratio is more similar to normal star forming galaxies. This seems to be there main point. They continue to show that self-absorption should not be an issue for [CII], as this requires an Av>130 mag, which is not present in these galaxies. They also state that the unchanging ratio of [CII]/6.2 PAH emission feature further supports the filling factor argument, as the 6.2 PAH emission feature should only be produced in areas where [CII] is produced, even if the FIR emission is more extended. They conclude by stating that the results of this paper make using [CII] as a probe of distant galaxies might be more difficult than previously thought, since the [CII] emission in ULIRGs that are likely very similar to many distant galaxies is less bright than in normal star forming galaxies.

Madden 2006

This paper uses ISO spectra of local low metallicity dwarf galaxies to measure the nature of the ISM in these low Z systems. They find that PAH values are much lower than in high Z environments, and suggest three reasons for this: PAH are destroyed by harder radiation fields, PAH are present but only at small spatial scales, PAHs never existed as these are low Z environments. By comparing the PAH emission/VSG (very small grain bb emission) to the ratio of [NeIII] and [NeII] lines (which measure the hardness of the radiation), they show that the PAH/VSG ratio decreases with harder radiation, suggesting that the PAH are destroyed by hard radiation in low Z galaxies, which is what is causing the decrease they noted earlier. Since low Z galaxies have low dust content, the UV photons have higher mean free paths, which allows them to destroy a greater fraction of the PAH molecules and decrease these features. This paper does not go into [CII] in low Z galaxies, but is a good reference for the ISM in low Z environments like early-universe galaxies.

Malhotra 2001

This is the paper that the [CII]/FIR decrease with increasing dust temperature is best explained. They examine the cooling lines in 60 normal star-forming galaxies using ISO-LWS, and find that there is a smooth decline in [CII]/FIR as a function of f(60)/f(100) fluxes, or dust temperature. By comparing this relationship to other cooling lines (primarily [OI]), they are able to reach the conclusion that absorption can not be causing this decline, as [OI] emission does not show the same decline, but should be more easily obscured by dust and self-absorption. They also show that the other cooling lines are not enough to make up for the lack of [CII] emission. These facts lead them to conclude that large amounts of FUV radiation in the high dust-temp galaxies leads the PAH molecules to become highly positively charged, which increases the energy necessary to free electrons and heat the gas around star-forming regions. This is the very important part of this paper, and the conclusion is reached in section 5.2. They go on to analyze the PDR regions in these galaxies by determining the fraction of [CII] from unionized regions using the [NII] 122 micron line, and assuming that they are missing half the [OI] emission from self-absorption. They use the information from these lines and the Kaufmann models to determine the Go and n values for the PDRs in the galaxies they study. Table 1 has a good summary of FIR line info, and all the different properties that these lines can probe is well-explained in this paper.

Smith 2017

They don’t use NGC1377 since it is very dusty and has a possible embedded AGN, should we skip it as well?

This paper uses 54 of the KINGFISH galaxies to obtain measurements of [CII] in 15,000 resolved regions of 11” each. These regions are used to explore the [CII] deficit at local levels instead of across the entire galaxy. The deficit is still present at these scales, which implies that it is caused by local physics as opposed to galactic properties. They compare this deficit to metallicity and find that for a given I(24), regions with higher metallicities experience greater [CII] deficits, which is sort of the opposite of what one might expect. They also obtain a relationship between the [CII]/L_IR ratio and the star-formation surface density for the galaxies in their survey, in the goals survey, and a few high-z galaxies and find good correlation in all subsections of their sample. Finally, the measure the [CII] deficit in AGN galaxies as a function of radius and find that the [CII]/L_IR ratio drops significantly in regions less than 1Kpc from the AGN nucleus.

Stacey 1991

This paper uses the Kuiper Airborne Observatory (KAO, precursor to SOFIA) to measure [CII] emission in 14 nearby star forming galaxies. By expanding previous studies, this group is able to better constrain the origin of the [CII] emission and begin to detect the [CII] deficit. The large beam (55”) means that most of these images are of the entire galaxies, not specific regions in the galaxies. By comparing the [CII] emission to CO emission and the 21 cm line, they find that the [CII] emission traces the CO emission fairly well, but the [CII] emission is not as closely tied to the 21cm line emission. This suggests that [CII] primarily originates from the same environments as molecular emission, the warm, dense surfaces of PDRs surrounding star-forming regions. They examine the [CII]/CO emission ratio in a variety of galaxy structures, and find that in non-star bursting galaxies the ratio is similar to the Milky Way, but in star burst it is much higher, suggesting that the ISM in starburst galaxies is significantly different. By comparing the [CII] emission to the FIR emission, they do see a deficit, which they suggest is caused by the inefficiency of UV heating in the most extreme star forming galaxies. They also suggest that the ratio of [CII]/CO could be used as a star formation tracer.

Stacey 2010

This paper uses the ZEUS system to obtain [CII] images of galaxies between z=1-2. They get detections in 13 out of the 14 galaxies they investigate, and include a previously studied high-z galaxy to end up with 14 [CII] detections in the high-z universe. They compute the [CII]/FIR ratio (R) for each galaxy to show that they are similar values to local star-forming galaxies, when no AGN is present. This indicates that the metallicity does not change by a large factor between the present and z~2, as that would likely change this ratio. They also investigate the [CII]/CO ratio for the galaxies in their sample where CO detections are available. They find similar values to local universe star forming galaxies here as well, indicating that the ISM of star forming galaxies is unchanged with time. They also use this ratio along with the FIR information to predict Go and n for these galaxies. As the AGN produces different results, the examination of these galaxies is done separately. They find that the AGNs typically have lower R values, which they believe to be caused by increased FUV radiation. Using the [OIII] 5007 angstrom line, they are able to predict that very little of the [CII] emission is created by the central AGN in the galaxies in their sample, meaning most of this emission is still originating in star-forming regions.

Madden 2013

I did not read this paper very carefully.

In this paper, Herschel, Spitzer, ISO, and other telescopes are used to determine the SEDs for 48 low-metallicity dwarf galaxies. These are compared to KINGFISH galaxies. They also discuss the possibility of using [CII] as a tracer of molecular gas, but there is no mention of star formation rate. They want to use [CII] to trace molecular gas in these low-Z galaxies as the X(CO) factor is not well defined for low-Z galaxies, so they hope that [CII] measurements could help constrain this factor. There does not seem to be much evidence that this is the case though.

Camus 2018 Paper 1

This paper is the first of two papers summarizing the results of the SHINING (Survey with Herschel of the Interstellar medium in nearby Infrared Galaxies) survey. This survey used PACS to obtain spectral maps ([CII] 158, [OI] 63 and 145, [NII] 122, [OIII] 88, and [NIII] 57 micron lines) of 52 star-forming, AGN, and LIRG galaxies. With this data, they discuss the line deficits as a function of FIR luminosities. All lines show a deficit, and the deficit is more tightly constrained when compared to FIR surface density or star formation efficiency (L_FIR/M_mol). They study these galaxies both globally and on a spatially resolved scale when possible, and find the same deficit in both cases. Finally, they use ratios of line strengths to discuss diagnostics of temperature, density, and ionization fraction of [CII], while also suggesting a new diagnostics of galaxy classification (AGN, SF, etc) based on line ratios. This paper has a lot of useful stuff, including nice summaries of our understanding of line deficits, explanations of the Herschel/PACS systems, and information about the various lines I use. They also show how deficits exists in [NII] line which seems like it could have significant implications for analysis of my results.

Camus 2018 Paper 2

This paper focuses on the analysis of the results of the SHINING survey (see above). They compare their measurements to two toy models of the ISM, one with young O&B stars closely associated with molecular clouds, and one with O&B stars more randomly distributed. They find their models fit their observations well, with both being needed to completely describe the sample, which is expected as the ISM is not uniformly one way or the other in any galaxy. Based on their findings, they suggest the [CII] deficit could be caused by high density environments, where n rises above the [CII] critical density, at least when O&B stars are close to the molecular clouds. This model also suggests some deficit caused by the fraction of UV light absorbed by dust, as at some point there might be a threshold where the fraction of UV light absorbed by dust as opposed to other processes becomes important. These models are limited though, as they only re-create the neutral [CII] emission. They also compare their observations to Cloudy model results, and get good matches. After this, they look at how the hardness of the x-ray emission in AGN could effect the [CII] emission, as these x-rays could make more C++ instead of C+ and can destroy PAH grains. They found that the [CII] values did fit with models of lower [CII] emission in these regions, but there was not a significant difference between AGNs and star-forming galaxies. They also found [OI] does not decrease, suggesting that it is doing more of the cooling. They continued to compare [CII] to SFR by looking at the how the [CII]/FIR fraction changes with the offset from the star-forming main sequence. They find a decrease, which suggests that an additional parameter, like FIR surface density, is needed to get a good prediction of SFR from [CII] luminosity. Finally, they look at using FIR lines to measure metallicity in galaxies.

Cooke 2018

Detection of 10 [CII] emitters at z~4.5 using ALMA. Find that they have large [CII] deficits. Good paper to show we can detect [CII] in high-z galaxies and that the deficit is still an issue.

Pineda 2013

GOT C+ paper 1 (Galactic Observations of Terahertz C+). GOT C+ used Herschel to obtain high-angular resolution, velocity resolved (0.1 km/s), observations of [CII] in the galactic disk, which allows for individual clouds to be measured and for separations of ISM phases along the line-of sight. They estimate 21% comes from atomic gas, 4% from ionized gas, 47% from PDRs, remaining 28% from boundaries between molecular and atomic gas. Some work also tying [CII]/CO ratio to FUV radiation.

Pineda 2014

GOT C+ Paper 3, focused on [CII] as a tracer of SF.

Zurita2000

Short paper describing the finding that 30-60% of the Halpha emission from a set of galaxies comes from the DIG and that the Lyman photons ionizing the hydrogen in the DIG are escaping from HII regions. Might be a good paper to cite in the discussion of what we see with [CII]-Ionized

Katz2019

This is a good paper for discussing the issues with dust absorption at high redshift. They argue that by comparing simulations to high redshift galaxy observations they find that the young stars in these early galaxies are likely more dust enshrouded than the older stars. They determine this using the strength of the Balmer break to compare models and observations. This could be a good paper to cite if I want to say that dust is a problem for high-z SFR calculations, as we don't really know what it's doing or how to correctly remove the effects it has.

Smit2018

This paper has the detection of [CII] in two z~7 galaxies. These galaxies are thought to be 'normal' star forming galaxies for this epoch, and fall slightly above IDL and HC's CII-SFR relationship (opposite of most high-z sources?). Possible that these galaxies have higher than average metals for z~7 sources. Has some good info about ALMA [CII] detections and how to determine where to look. Also a bit about how to use [CII] ALMA detections to study rotation (as well as SFR and other properties).

Pallotini2017

This paper is a high-redshift model paper that predicts the [CII] luminosity in a normal, star forming galaxy at z~6. They find that the [CII] under-predicts the

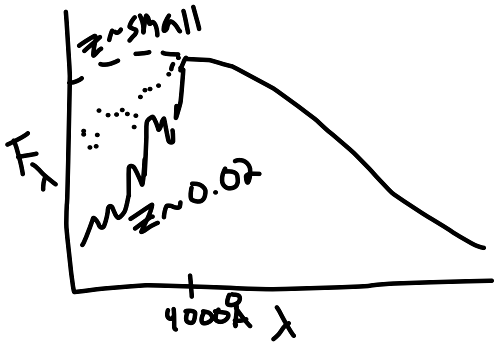
SFR, and suggest that this is probably due to metallicity differences and issues with the [CII] emission in low-density regions being effected by the CMB. There is also a potential issue with the efficiency of star formation in this galaxy, with things being so efficient that it hinders the [CII] emission (?). They also include an equation for [CII] luminosity based on n, Z, and stellar mass. It could be interesting to compute this predicted L([CII]) for my regions and see how it compares to the observed values.

Arata2020

[CII] and [OIII] photoionization models evolved with redshift. No actual data, just comparisons to other high-z detections. [OIII]/[CII] predictions are large at (very) high z as oxygen is formed before carbon.

Z = 0.019 (solar; [Fe/H]= 0.0; 12+logO/H = 8.69)
Z = .008 (LMC; [Fe/H]= -0.6; 12+logO/H = 8.3)
Z = .004 (SMC; [Fe/H]= ;12+logO/H = 8.0)
Z = .001 ;12+logO/H = 7.6

- metal poor star cluster will look blue compared to a metal rich star cluster of the same age. The transitions in the metals will absorb blue light (scattered or absorbed?)
    - Line blanketing - lots of Fe lines below 5000A absorb blue light. Think Lyman alpha Forrest
    - Opacity - more metals in the atmosphere of stars swell up the red giant stars cooling them. Aka redder



*Extinction and mass segregation the Arches cluster near MW center
(they find evidence of mass segregation via MF slopes in the inner, intermediate, and outer radii.
)-habibi 2012

(Lots of great references for how stars form from GMCs.

Unfortunately , observations of very young clusters (t << 1 Myr) are hampered by extinction due to those clusters still being embedded in their natal molecular clouds. Most often we are restricted to observing older clusters, which is problematic as these clusters may well have undergone significant dynamical evolution.

Clearly , mass segregation could be primordialÂ— clusters may form with the most massive stars concentrated at or near the center . Alternatively , mass segregation could be dynamicalÂ—the most massive stars migrate into the center of the cluster after formation due to two-body interactions. As well as potentially providing constraints on clustered star formation, the origin of mass segregation may help distinguish models of massive star formation. In particular, are the masses of the most massive stars set by the mass of the core in which they form (e.g., Krumholz et al. 2007), or by competitively accreting mass due to a favorable position in the cluster.

Figures 1 (a) and (b) show the stellar distributions initially and after 1 Myr of dynamical evolution, respectively . A comparison of the plots clearly shows that the cluster has evolved from a clumpy and non-mass segregated state to one which has erased substructure and appears to be mass segregated. compares the minimum spanning trees (MSTs) of high-mass stars to those of a random selection of stars to produce a quantitative measure of mass segregation. If the MST of the N most massive stars is significantly shorter than that of a number of sets of N random stars then the cluster is mass segregated.

The cluster is not mass segregated initially (Î› = 1), but after 1 Myr the 10 most massive stars develop a significant level of mass segregation (Î› > 3).In Figure 2 we can also see that the 20 and 50 most massive stars also mass segregate, but by a much smaller amount. Beyond the 50 most massive stars little mass segregation is seen. W e simulate 50 different clusters, varying only the random number seed used to create the fractal and initial mass function. Of these 50 simulations, 29 mass segregate within 1 Myr, and 44 show mass segregation within 4 Myr . Only six show no significant mass segregation by the end of the simulations at 4 Myr .

The mass segregation observed in these simulations is from a wholly dynamical origin, and arises from the collapse of the cluster. Interestingly , Allison et al. (2009) find that the ONC appears to be mass segregated down to 5 M but not below that mass. This is exactly the situation predicted in our simulationsÂ—mass segregation down to a few solar masses, but not below . Indeed, observations of the mass down to which a cluster is mass segregated (and the dynamical age of the cluster) should provide constraints on the density and duration of the dense phase undergone by the cluster and hence the initial conditions of the cluster.

If the pre-stellar cores are clumpy (fractal) , as opposed to a smooth distribution, then stars that form react more violently to virialize making them dynamically older than one would expect when equilibrium has been reached. The faster and older nature of virialization causes the most massive stars to clump together in the center...mass segregation. This is evidence that the massive stars do not need to form at the center, but can segregate on a timescale of 1-2 Myr.
)-Allison 2012

(Instead, as shown in Figure 2, we find that the system fragments as it collapses, as discussed in detail by Aarseth et al. (1988), and the fragments mass segregate quite early on during the collapse process.
)-McMillan 2009 conf

(simulations show that the globular cluster metallicity bimodal ity seen in local universe galaxies can be explained by the higher metallicity GCs formed in the galaxy and lower metallicity formed in another galaxy that formed at higher red shift and collided with this galaxy.
)-tonini 2012

(they test a new method of getting age and mass info on low mass cluster affected by stochasticity. They remove the brightest stars responsible for the greatest fluctuations in unresolved phot and base the age and mass on the unresolved stars in the cluster.

The unresolved colors are in general bluer than the colors given by the SSP models, since not all of the evolved, red (super)giant stars' light is included.

There is a slight bias toward underestimating the mass.

Due to the monotonic variation in unresolved color, as seen in Figure 5, many of the sources of color degeneracies in integrated light are not present for the unresolved light. This leads to greater accuracy in deriving the cluster ages and masses.

For the fits to integrated light, there is a bias of 0.09 dex toward older ages, and the average error for all test clusters is 0.26 dex in age. 36% of the clusters' ages are recovered to better than the resolution of the grid of mod- els, and 83% are recovered within 0.5 dex.

recovered v alues of A_V are biased by 0.16 mag toward lower extinctions.

independent estimates of its parameters:
1) spectroscopy to age-date this cluster as 33 Myr, with a factor of 2 uncertainty . Its mass was found to be log(M cl / M
) = 3.88, and A V was 0.68 mag.
2)discrete models from F ouesneau & Lan con 2010 gives an age of 41 Myr, log(M cl / M) = 3.9, and A V = 0.3 mag.
3)CMD analysis suite MA TCH (Dolphin 2002). This gives an age of 20 Myr (log(t= yr) = 7.3 +/- 0.1), log(M cl) = 3.8 +/- 0.3, and an Av = 0.9 +/- 0.15 mag.

This study:
unresolved light analysis gives a best fit age of 40 Myr, with log(M cl) = 3.62 M and A V = 0.42 mag.

Traditional unresolved method:
traditional in- tegrated light fitting. This method gives a best fit age of 80 Myr, log(M cl) of 3.86 M , and A V of 0.28 mag.

-The underestimate of the cluster's mass could indicate that the mass-to-light scaling needs to be recalibrated for use with unresolved light.

-T o optimize this method for a general use, M lim could be a parameter that is solved for during the 2 minimization as well.

***Great illustration of stochastic star formation! Figure 1
)-beerman et al. 2012 (PHAT)

(they only choose one value of completeness for measuring individual stars in an open cluster. In the center low mass stars will be obscured and you will find mass segregation...aka high mass stars are preferentially found in the center...bad news.
)-Dan Weisz presentation of 2mass open clusters

(Dense star clusters expand until their sizes are limited by the tidal field of their host galaxy. During this expansion phase the member stars evolve and lose mass. We show that for clusters with short initial relaxation time scales (. 100 Myr) the dynamical expansion is largely powered by mass loss from stars in the core, but happens on a relaxation time scale. That is, the energy release following stellar mass loss is in balance with the amount of energy that is transported outward by two-body relaxation.
)-gieles 2012 ASP conference

[Although the LFs of the individual cluster systems are most of the time within a few % compatible with a -2 power law , a comparison between the different results shows that the deviations from the -2 power law are not randomly scattered, but instead show some systematic variations, in the sense that the LF is

1. steeper at higher luminosities (Whitmore et al. 1999; Benedict et al. 2002; Larsen 2002; Mengel et al. 2005; Gieles et al. 2006a,b; Hwang & Lee 2008);

2. steeper in redder filters (e.g. Dolphin & Kennicutt 2002; Elmegreen et al. 2002; Gieles et al. 2006a,b; Haas et al. 2008; Cantiello et al. 2009).

The fact that the LF gets steeper at the bright-end is an indication that the CIMF is truncated at some upper mass Mup .
]-gieles 2009 conference

[simulations show that low M/low N clusters could be disrupted by stellar dynamics and that gas expulsion of this low mass would have matching low mass gas and wouldn't cause disruption. Me-efficiency goes up as cluster mass goes down?
]-Moeckel et al 2012

[The Halpha-R color is sensitive to the mass of the most massive star in a cluster when the cluster is young, whereas FUV-NUV does not distinguish O stars from B stars well
]-koda et al (2012)

[Portegies Zwart, McMillan & Gieles (2010, hereafter PZMG10) have shown that there exists a continuous distribution of stellar structures at young ages (from loose groups to dense clusters), while at older ages (> 10 Myr) a bimodal distribution develops, with bound and unbound groups that are clearly distinguishable. GPZ11 found that for groups with ages less than 10 Myr, was a continuous distribution, with no distinct break at pi = 1. However, for groups older than 10 Myr, the distribution became bi-modal, with clusters (pi > 1) and associations (pi < 1) becoming distinct populations.

The observed radius distribution of clusters is in general adequately described by a log-normal distribution with a peak at 3-4 pc. This has been found for young populations in M51 (Scheepmaker et al. 2007) and M101 (Barmby et al. 2006) as well as for populations of old globular clusters (e.g. Jordan et al. 2005) . In fact, the peak of the distribution has been suggested to be a distance indicator (Jordan et al. 2005).

Clusters fit well with a schechter function, aka a truncation at high mass clusters. The cause of the truncation is not clear from the present data, but it is likely related to the form of the GMC mass function, from which clusters form. Rosolowsky et al. (2007) have shown that the mass function of GMCs in M33 is truncated at high masses. Such a truncation in the GMC MF would then relate directly (if a cluster forms from a fixed fraction of the GMC mass) or indirectly to a truncation in the cluster MF, which would be lower by a given factor (the fraction of mass of the GMC turned into stars within the cluster).
]-Bastian 2012

- whitmore+14 (F814W),
    - 20 galaxies of all types
- Thilker+2002 (Halpha)
    - 11 spiral galaxies
    - There is no convincing evidence for correlation between Hubble type and alpha, the CMF slope. At this point we are inclined to downplay this negative result, as it probably just reflects the statistics of a small galaxy sample (even with accurate determination of the LF). Note that our judgment regarding this issue is further hindered because our sample consists mainly of late-type spiral galaxies. We reserve extended discussion until more galaxies can be consistently analyzed.
    - "A recent study by Scoville et al. (2001) using the Hubble Space Telescope (HST) for H⍰ and Pa⍰ photometry of H ii regions in M51 has shown that ⍰50% of H ii regions

have their nearest neighbor within 46 pc"

- VanZee+2000 (Halpha), 1-35 Mpc
    - 34 galaxies; mostly dwarfs
    - simply state that their results are consistent with previous ones: earlier type galaxies have steeper slopes compared to later type galaxies.
- Elmegreen & Salzer+1999
    - 11 galaxies of all types
    - find a correlation between Hubble type and slope (later-types have shallow slopes)
    - possibly due to earlier-type galaxies have less O-type stars than later type galaxies (Oey+1998)
    - find no difference in slope between outside and inside
- Youngblood and hunter+1999 (Halpha), composite LF (N=), 1-10 Mpc,
    - 35 galaxies mostly dwarfs
    - ultimately claim that their trends are inconclusive due to poor statistics.

"alpha vs SFR/area is very marginal at best"

  - "had a more representative sample of Im galxies compare to Kennifcutt+89 and found that giant HII regions are rare in Im galaxies"
  - alpha vs
    - galaxy type: Im galaxies tend to have flatter slopes...?
    - Mb
    - SFR/A --> flatter for small SFR/A (weak)
      - due to 2 possibilities: age, or different LFs are sampling different parts of the LF (i.e., lower and higher luminosities). The low L ones are generally below the L dist peak (aka probably below completeness), the high L ones generally agree at -1.6 in slope
    - Avg size of regions

        - they are not consistently fitting above their completeness limit for all galaxies...
    - composite
        - with more Im galaxies than Kennicutt+89, they find that the irrelgular galaxies do not show a hump at high L (as Kennicutt+89 did), suggesting that Im galaxies tend to form more giant HII regions than spirals per galaxy Luminosity.
        - They find that Im galaxy LFs are truncated at high L compared to spirals
        - excludes interacting galaxies
    - all images to a common 30-75pc physical scale
- Kennicutt+89
    - 30 galaxies
- Bradley+06

- reasons for change in LF slope
- Age
    - older regions = steeper (Oey,Clarke+98)
    - me: bright clusters will dim due to loss of massive stars -> move to lower L --> reduce N of high L and increase N of low L