Analyzing systematic trends in cosmic SFR evolution

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Abstract

New star formation rate (SFR) density measurements (from 2006 to current) were recorded into a database in order to study systematic trends in cosmic SFR evolution in Mathematica. Over 200 SFR densities were recorded along with other types of information provided by authors such as redshift, cosmological assumptions, extinction methods, types of indicators, standard calibration factors (metalicity and initial mass function, IMF), active galactic nuclei (AGNs) contamination, and statistical and systematic errors. We specifically made three different log plots to investigate the impacts of different types of indicators, extinction methods, and IMF. Then, the results were compared with Hopkin's and Beacom's SFR density database from 2006 to investigate any systematic shifts in SFR density measurements. Proving the robustness of SFR density measurements can support accurate predictions of the diffuse supernova neutrino background (DSNB), which in turn will help experimentalists to have a good target to build future experiments around.

I. Introduction

The diffuse supernovae neutrino background (DSNB) is the flux of antineutrinos and neutrinos produced by core-collapse supernovae explosions (CCSNe) throughout the reachable universe. CCSNe happen when massive stars reach the end of their lives in which their violent explosions birth either neutron stars or black holes. These evolution phases of massive stars are powerful sources of neutrinos because neutrinos can easily escape, via weak interaction, from the hot interiors of stars whereas photons get trapped. Although very challenging to detect, once detected neutrinos can help uncover the details of many physics and astrophysics phenomena such as the cosmic history of stellar birth and death, production of chemical elements essential to life, and provide more information on neutron stars and blackholes.

The couple dozen of neutrinos detected on Earth in 1987 from a nearby supernovae (SN1987A) lead to an increasing interest in neutrino physics and astrophysics. This was a major achievement but still more neutrinos needed to be detected. When looking in the range of the Milky Way Galaxy, supernovae explosions only occur a couple times a century. In order to detect more neutrino events, physicists have to look further into the universe at distances of Mpc and Gpc, where supernovae explosions happen at a greater rate. The downfall of this is detecting neutrinos at these distances requires very large and no background detectors. In order to learn more about the death rate of stars, physicists can study the birth rate since these two rates are nearly the same when looking from the cosmology timescale. The birth rate is known as the star formation rate (SFR) in the units of $M_\odot\ yr^{-1}\ Mpc^{-3}$. Studying the SFR can provide experimentalists with definitive knowledge in order to perform accurate and precise experiments involving supernovae and neutrinos [4, 33, 47].

In this paper, we create a database of around 200 current SFRs at low redshifts (z) to quantify and study their systematic trends among different indicators, dust extinction methods and initial mass functions (IMFs). We then compare the quantified results to Hopkins & Beacom 2006[21], hereafter HB06, SFR plot function found in their table 1. We also provide a gold and silver sample based on data we considered to use a standard dust extinction method, Kennicutt (1998)[23], and initial mass function (IMF), Salpeter (1955)[31].

II. Methods

The project began with reading two journal articles; "*On the Normalization of the Cosmic Star Formation History*"[21] published by HB06 and "*Cosmic Star Formation History*" [28] published by Madau and Dicksion in 2014. It was from those two papers that we built the database around. As seen in Tables 1 and 2, information such as redshift, SFR density measurement, statistical and systematic errors, active galactic nuclei (AGN) contamination, type of indicator, extinction methods, standard calibration methods and cosmology assumptions were recorded along with the hyperlink to each of the articles. Table. 1 and 2 (found in the appendix) are the first 5 rows of data from the database although the entire database can be found by clicking here or the link can be found below in the footnotes. [1]

To begin the search for SFR measurements, HB06 was selected as a reference point to locate other appropriate sources. Using the online Astrophysics Data System (ADS), we were able to look at all of the journal articles that referenced HB06, and we were able to find dozens of sources to fill the database with. Some sources even lead to more journal articles that were dated before 2014 that were appropriate for what we were looking for (capping it off at 2006). The same idea was used for papers that were similar to HB06 (similar to is a tab ADS uses to group together similar papers), this search also started from 2014 to current. We also used ADS's search engine with the phrase "cosmic star formation rate measurement mpc" to find papers unaffiliated with HB06. These three approaches lead to the discovery of 46 SFR published papers and over 200 SFR measurements.

Some specific things we were looking for when finding SFR measurements papers were SFR density measurements taken at low redshifts, specifically redshifts 0-2 since most of the signal from the DSNB is mainly dependent upon redshifts 0-1 and partly 1-2. Higher redshifts don't contribute much towards the signal of DSNB.

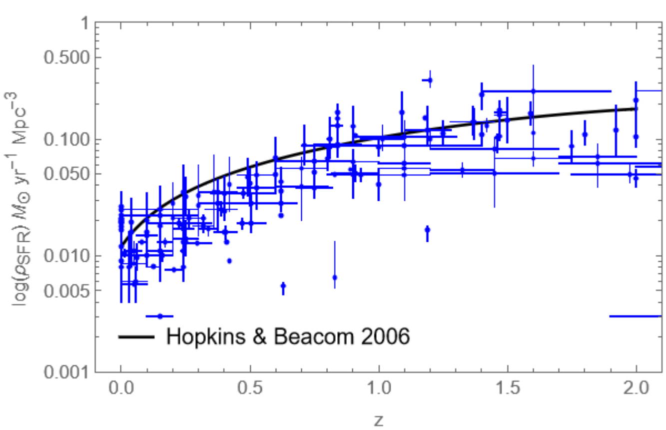

Fig. 1 - All SFR density measurements from the database created in this paper.. References for each of the measurements can be found below in section VII or more specifically the database since all measurements are linked with their journal article.

[1] https://docs.google.com/spreadsheets/d/1g52NqaG4yrjwQuzDvNbtl3IHKWea_A-tUt2FNr7zSG0/edit#gid=0

Although some higher redshifts were recorded in the database if papers conducted their research at a low redshift through a high redshift, all measurements above z=2 will not be provided in any of the plots or discussions below. Also, although we were recording all SFR measurements in an unbiased manner, any SFR measurement that used what we considered a non standard dust excision method or IMF was flagged with a red "x" in column 10 from the database.

Once the database was considered complete, we started organizing and coding the data into Mathematica. We were able to produce multiple different log plots to visualize systematic trends among the SFR measurements recorded.

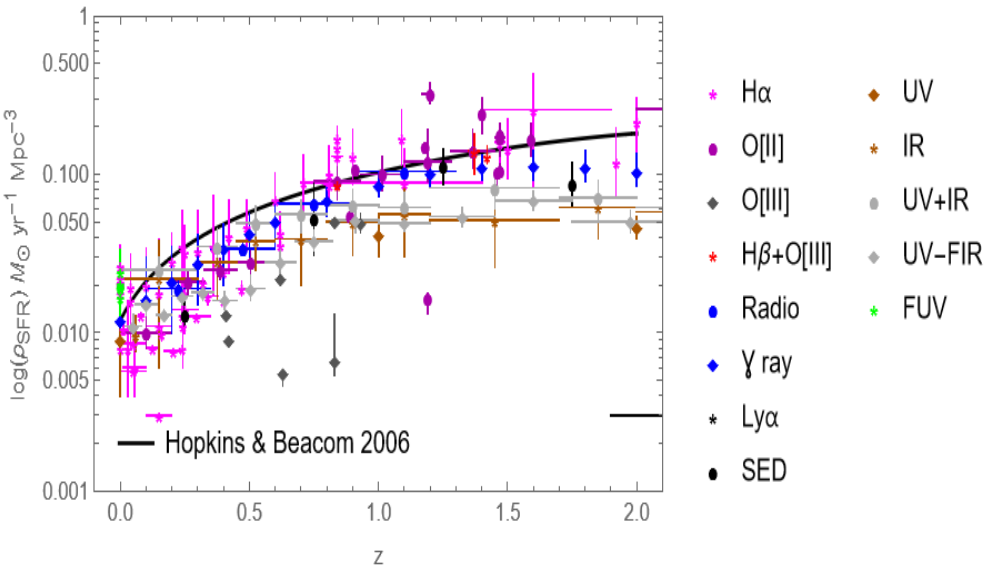

Fig. 2 - Indicator Log Plot, this can be seen in a greater view by clicking on the link below (as well as any of the other figures throughout this paper). [2]

Additionally, each of the log plots plot the parametric SFR function found in HB06[21], using the variables provided in their table 1. We used this function from 2006 to compare to more current SFR density measurements.

III. Results

All of the results from this 10 week project can be seen in figures 1-5. All plots were created after the making of the database and gathering of the SFR density measurements. In all of the plots, we consider measurements at z=0 to be like an anchor and it is useful because it's an easy measurement to take since it is at such a low redshift but there aren't enough nearby galaxies to get data from. So, using all the SFR density measurements at redshifts 0-2, the first log plot, fig. 1, was created. Fig. 1 is a good visual of all the data from the database in a general form. From fig. 1 we can observe that HB06 is systematically higher than the SFR measurements listed on this plot. In an attempt to observe more detailed systematic trends, the data was split into three different categories divided by types of indicators, different dust extinction methods and IMFs.

1. *Indicators*

In fig. 2, the data is color coordinated by the types of indicator used for each journal article. There are a little more than a dozen different types of indicators listed and in this case we have no standard indicator, but we can observe that Hα is visually more systematically consistent with HB06 when compared to the other indicators. Although, Hα also has consistently large error bars. Whereas most other indicators are systematically lower than HB06 and have mostly shorter error bars. This proves the importance of uncertainties because they can drastically affect systematic trends among other data points. These uncertainties are non negligible. There are also a handful of SFR measurements that don't have published errors which is very different from a small error that isn't visible in the figure.

2. Dust Extinction Methods

In fig. 3 the data is color coordinated by the type of extinction method described in each of the papers. For extinction methods we look to Kennicutt (1998) as the standard dust extinction method which is represented by the black dots on fig. 3. The standard method looks to be most consistent with HB06 and is systematically higher than the rest of the data points. There are multiple different extinction methods that fall under the category of "other" in the list plot; names of all of the methods used by the different journal articles can be found in column 22 of the database.

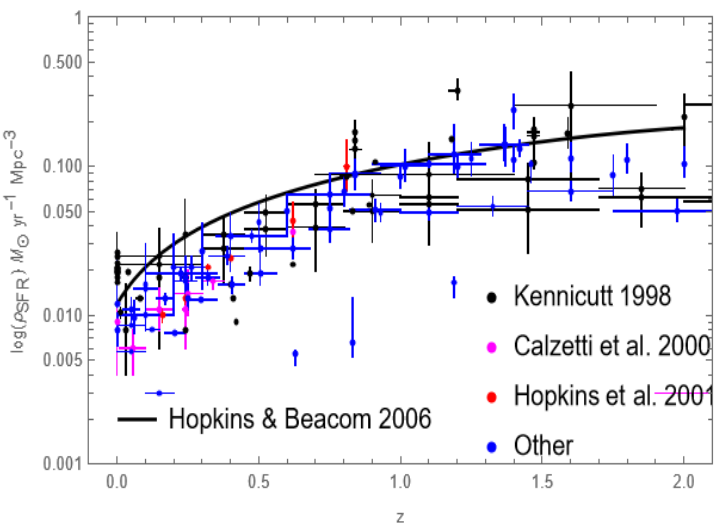

Fig. 3 - Dust Extinction Method Log Plot

More specifically, three of the outliers fall well below the HB06 parametric function in fig. 3. These data points are data points 132-134 from column 8; (0.63, .0055), (.83, .0065), and (1.19, .0166). They can be systematically categorized together as they originated from the same source, Drake (2014), and used the same extinction method. To perform their dust correction, they extracted equation 3 from Garn and Best (2010) to describe Hα extinction in magnitudes as a function of stellar mass. Using that equation they determined the values of $A_{H\alpha}$, magnitude of dust extinction in the Hα band, and applied it to the Cardelli, Clayton, Mathis (1989) reddening law that gave them values for $A_{O[III]}$ and $A_{O[II]}$ that they were able to convert those values to SFR density measurements using a conversion factor from Kewley et al. (2004)[10]. More detail on their dust extinction methods can be found in their section 3.3.1.

3. IMFs

In fig. 4, the plot is color coordinated by the IMF described in each of the journal articles. We considered Salpeter (1955)[31] to be the standard IMF. Although Salpeter (1955) is the standard, as can be seen there is not much difference between the Salpeter (1955)[31] and Chabrier (2009) on the plot. The difference is smaller than that of the length of the error bars for both of the IMFs.

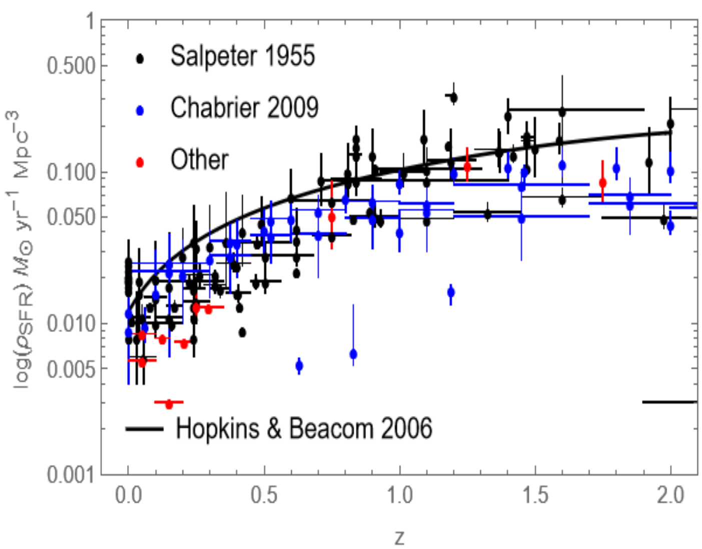

Fig. 4 - IMF Log Plot

4. Gold and Silver Samples

In fig. 5, we provide gold and silver data samples as a way to rate the measurements based on the usage of standard extinction methods and

IMFs. The definitions of gold and silver were defined before the database was analyzed. Gold is defined by measurements using the standard corrections of Kennicutt (1998)[23] dust extinction method and Salpeter (1955)[31] IMF. Silver is defined as any SFR measurement that utilizes any other dust extinction method such as Calzetti et al. (2002), Hopkins et al. (2001), or Kennicutt (2009) and any other IMF such as Chabrier (2009), keep in mind there are many other methods used throughout the database these few mentioned are only for example purposes. As seen in fig. 5, gold is systematically consistent with HB06 whereas silver is systematically lower than both HB06 and the gold sample data.

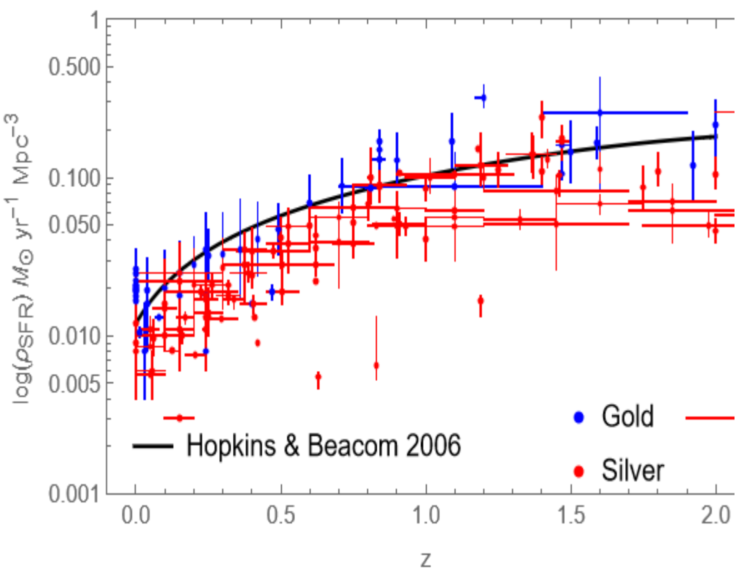

Fig. 5 - G/S Log Plot

IV. Conclusion/Future Work

The goal of this paper was to create a database containing all current SFR density measurements to study systematic trends in a generalized and detailed form. Generally speaking, Fig. 1, HBO6 is systematically higher than most of the current measurements provided from the journal articles in the database, but looking in a detailed perspective, Figs. 2-4, physicists and astrophysicists can see exactly what systematic changes have the greatest effect on the SFR density measurements. We can conclude that the dust extinction correction can have a major effect on the results of the SFR density measurement compared to the other systematic changes such as indicator and IMF. This can be seen especially in the gold and silver sample data where the new measurements support HB06 as long as the standard set for gold is used. We know that the IMF differences are very little so that means the SFR measurements are more so affected by the extinction corrections. In the gold sample data the following indicators are used; FIR, UV, gamma rays, Hα, Lyα, Radio, Hβ+O[III], and O[II]. With this range of indicators found in the gold sample, proves again the major effect the method of dust excision has on SFR density measurements.

For the future, continuing the search for more SFR journal articles to add to the database will be imperative. We will have to come up with new methods to discover these papers while remaining unbiased to the data we find. For the IMF data the goal is to eventually convert all of the Chabrier IMFs to Salpeter IMF for better comparison on the log plot, Fig. 6. Also, for the gold and silver sample log plot, Fig. 7, we would like to add a bronze category based on systematic differences in the dust extinction methods to produce more detail about those methods in particular when compared to the HB06 parametric SFR function.

V. Acknowledgements

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VI. Appendix

Hyperlink	x	Redshift			SFR	Stat. Err.		Sys. Err.	
		z	min	max	(Msun*yr^-1*Mpc^-3)	(+) δ	(-)δ	(+) δ	(-) δ
Blanc et al. 2011	x	z	1.90	2.80	0.003	0.002	0.001		
Cai-Na Hao et al. 2018	x	2.23	2.20	2.26	0.724	0.897	0.401		
Coughlin et al. 2018	x	0.62			0.043	0.009	0.007	0.011	0.009
Geach at al 2008		2.23			0.170	0.160	0.090		
Ly et al. 2007		z	0.07	0.09	0.013				

Table 1 - First five entries in the database, the link to the full database can be found in the footnote of the second page.

AGN		Indicator	Extinction Method		Std. Calibration		Cosmology Assump.		
(+) δ	(-) δ				Metalicity	IMF	Ho	Ωm	ΩΛ
N		Lyα	Y host, Calzetti et al. 2000	Y host, Calzetti et al. 2000	Y	Y	70	0.3	0.7
N		Lyα	Y host, Calzetti et al. 2000	Y host, Calzetti et al. 2000	Y	Y	70	0.3	0.7
Y		Hα	Y host, Hopkins et al. 2001	Y host, Hopkins et al. 2001	Y	Y	71	0.27	0.73
Y		Hα	Y host, Kennicutt 1998	Y host, Kennicutt 1998	Y	Y	70	0.3	0.7
N		Hα	Y host, Kennicutt 1998	Y host, Kennicutt 1998	Y	Y	70	0.3	0.7

Table 2 - First five entries in the database, there are 201 total entries and 46 total sources.

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