Stellar Astrophysics

Day 1:

Aim: Find a relation between Gas Density and Star formation rate in galaxy M100.

The Carbon monoxide Spectral line emission was loaded into DS9 software. Note that H_2 cannot be used due to its symmetry it does not produce spectral lines easily. CO is the next most abundant.

The Scale was changed to a log scale

Brightness and colour were adjusted so the bright areas stood out.

15 Circular regions, each with radius 10 arcseconds, were drawn on bright areas of the spectral line emission. Note that FK5 and WCS need to be selected when changing circle radius.

The flux, number of pixels and other data was recorded for each circle (Shown in table 1). These regions were saved so they can be used for later images. ↑density

10 more regions were then drawn on areas with no emission (dark) with the same radius. The same results were taken (table 2)

Table 1.

Region Number	Sum - Hwrd	Sum(Jy/As^2km/s	Sum(Jy Km/s)	Error	S-B(Jy Km/s)	Error	NPix	Mean	Median	Min	Max	Var	Stddev	rms
1	2760.611	256.0863636	64.02159091	1.920647727	64.02159091	1.979886663	1255	2.2263	2.12073	0.127294	7.22164	2.55514	1.59848	2.74072
2	3549.0367	329.2241837	82.30604592	2.469181378	82.30604592	2.515535764	1255	2.82342	2.38339	0.114766	8.35988	3.71236	1.92675	3.41819
3	3071.3745	284.9141466	71.22853664	2.136856099	71.22853664	2.190255121	1255	2.4571	1.78218	0.108569	10.0677	4.36332	2.08885	3.225
4	3393.8366	314.8271429	78.70678571	2.361203571	78.70678571	2.409636033	1255	2.69566	2.65718	0.762523	5.44821	0.923519	0.960999	2.86184
5	2947.8905	273.4592301	68.36480751	2.050944225	68.36480751	2.106522186	1255	2.35455	2.46814	0.112547	4.52595	0.715759	0.846025	2.50193
6	4590.0412	425.7923191	106.4480798	3.193442393	106.4480798	3.229417568	1255	3.6574	2.95075	0.827699	10.0561	4.94925	2.22469	4.28087
7	5874.8705	544.9787106	136.2446776	4.087340329	136.2446776	4.115509018	1255	4.6626	3.61578	0.164648	13.8994	10.9719	3.31238	5.71941
8	12310.852	1142.008534	285.5021336	8.565064007	285.5021336	8.578542123	1255	9.84081	8.30119	1.01502	27.1685	33.6746	5.80298	11.4244
9	2906.9327	269.6598052	67.4149513	2.022448539	67.4149513	2.078788493	1255	2.32369	2.1867	0.295954	5.40439	0.685408	0.827894	2.46677
10	2984.2249	276.8297681	69.20744202	2.076223261	69.20744202	2.131142073	1255	2.38547	2.37399	0.919671	4.85307	0.702689	0.838266	2.52847
11	1389.1518	128.8638033	32.21595083	0.966478525	32.21595083	1.079418476	1255	1.12028	1.11654	0.124047	2.34835	0.203966	0.451626	1.20789
12	1130.2995	104.8515306	26.21288265	0.7863864796	26.21288265	0.9216654497	1255	0.918196	0.957632	0.115433	1.9006	0.120577	0.347242	0.981663
13	1144.4468	106.1638961	26.54097403	0.7962292208	26.54097403	0.9300776731	1255	0.971517	0.901067	0.112858	3.35861	0.34325	0.585875	1.1345
14	1897.7107	176.0399536	44.0099884	1.320299652	44.0099884	1.405081733	1255	1.66174	1.5024	0.110905	5.34392	1.53103	1.23735	2.07182
15	1961.7475	181.9802876	45.49507189	1.364852157	45.49507189	1.447026232	1255	1.56814	1.436	0.150566	3.39754	0.513998	0.716937	1.72426

Table 2.

Region Number	Sum - Hwrd	Sum(Jy/As^2km/s	Sum(Jy Km/s)	Error		NPix	Error	Mean	Median	Min	Max	Var	Stddev	Stddev(Jy/As^2k	Stddev(Jy Km/s)	rms	
1	429.93387	39.88254824	9.970637059	0.1666278019		1255	7.184990817	0.410242	0.388147	0.144004	1.18656	0.0411348	0.202817	0.01881419295	0.004703548237	0.457639	
2	412.14774	38.23262894	9.558157236	0.1436962172		1255	6.196180886	0.358701	0.328618	0.113865	0.980216	0.0305918	0.174905	0.01622495362	0.004056238404	0.399072	
3	335.36639	31.11005473	7.777513683	0.1568782635		1255	6.764590722	0.321849	0.272768	0.108462	1.2104	0.036462	0.19095	0.01771335807	0.004428339518	0.374231	
4	242.89058	22.53159369	5.632898423	0.1140647518		1255	4.918472096	0.260054	0.251931	0.110923	0.959023	0.0192759	0.138838	0.01287922078	0.003219805195	0.294795	
5	301.65067	27.98243692	6.99560923	0.152393328		1255	6.571200302	0.313241	0.271736	0.109859	1.18866	0.0344067	0.185491	0.01720695733	0.004301739332	0.364042	
6	323.87187	30.04377273	7.510943182	0.1393024756		1255	6.00672275	0.351271	0.3413	0.146003	1.13187	0.0287496	0.169557	0.01572884972	0.00393221243	0.390052	
7	302.07297	28.02161132	7.005402829	0.1466226397		1255	6.322368224	0.319993	0.283324	0.120402	1.11824	0.0318506	0.178467	0.01655538033	0.004138845083	0.366396	
8	331.77517	30.77691744	7.69422936	0.2050631818		1255	8.8423244	0.397812	0.335465	0.154539	1.40691	0.0623	0.2496	0.02315398887	0.005788497217	0.469632	
9	340.48166	31.58456957	7.896142393	0.1302249793		1255	5.615301106	0.305091	0.271293	0.110878	0.97134	0.0251247	0.158508	0.0147038961	0.003675974026	0.34381	
10	283.38375	26.28791744	6.57197936	0.1479593296		1255	6.380006292	0.283101	0.249778	0.107946	1.31578	0.032434	0.180094	0.01670630798	0.004176576994	0.335529	

- This process was then repeated for the mid infrared image
- Regions used in the Cd image were loaded but new background regions were drawn

Same results were taken (Table 3 and 4)

Table3

IR

	Region Number	Sum	Sum(Janskys/AS^2)	Sum(Janskys)	Error	S-B(J)	Error	NPix	Mean	Median	Min	Max	Var	Stddev	rms
H	1	962.09936	0.02260721996	0.05086624491	0.002034649796	0.05086624491	0.002036966612	139	6.92093	4.95948	2.54973	23.5707	20.9543	4.57758	8.2978
	2	1156.5942	0.02717796637	0.06115491833	0.002446196733	0.06115491833	0.002448124107	138	8.38112	7.40106	3.03817	18.6469	19.3722	4.40138	9.46654
	3	983.49027	0.02311202135	0.05200204803	0.002080081921	0.05200204803	0.002082348191	140	7.02493	5.4319	2.26793	22.4204	20.9826	4.58067	8.38643
	4	558.84711	0.01313290709	0.02954904094	0.001181961638	0.02954904094	0.001185945403	142	3.93554	3.63996	1.73766	7.92129	2.56263	1.60082	4.24866
	5	323.03518	0.00759132673	0.01708048514	0.000683219408	0.01708048514	0.000690088358	138	2.34083	2.31915	1.47512	5.26194	0.384679	0.620225	2.42161
	6	1290.1561	0.03031866835	0.06821700379	0.002728680152	0.06821700379	0.002730409813	139	9.2817	7.085	2.77643	26.7922	34.12	5.84123	10.9668
	7	837.33004	0.01967725594	0.04427382587	0.001770953035	0.04427382587	0.001773614343	144	5.81479	4.52907	2.46273	19.1222	10.8092	3.28773	6.6799
M	8	4040.9867	0.09496318745	0.2136671718	0.008546686871	0.2136671718	0.008547238715	139	29.0718	15.7721	3.31154	102.609	813.264	28.5178	40.7239
	9	411.56597	0.009671800295	0.02176155066	0.000870462026	0.02176155066	0.000875863759	139	2.96091	2.87779	2.29004	4.13881	0.162994	0.403726	2.9883
	10	710.92568	0.01670675348	0.03759019533	0.001503607813	0.03759019533	0.001506741398	138	5.15164	4.87096	2.93722	9.27129	2.40592	1.5511	5.38008
	11	302.31734	0.00710445749	0.01598502935	0.000639401174	0.01598502935	0.000646735685	138	2.19071	2.11764	1.76794	3.04586	0.0929568	0.304888	2.21182
	12	326.1211	0.00766384585	0.01724365316	0.000689746126	0.01724365316	0.000696550719	139	2.34619	2.25719	1.58782	3.6242	0.131663	0.362855	2.37409
	13	306.30997	0.007198284295	0.01619613966	0.000647845586	0.01619613966	0.000655085559	140	2.18793	2.06997	1.54295	3.38272	0.22519	0.474542	2.2388
	14	438.20046	0.01029771081	0.02316984932	0.000926793972	0.02316984932	0.000931869225	140	3.13	2.87372	1.26111	6.03903	1.43902	1.19959	3.35201
	15	363.29424	0.00853741464	0.01920918294	0.000768367317	0.01920918294	0.000774481452	140	2.59496	2.28413	1.48547	8.17752	1.34604	1.16019	2.84251

Table 4

	Region Number	Sum	Sum(Janskys/AS^2)	Sum(Janskys)	Error	NPix	Mean	Median	Min	Max	Var	Stddev	Stddev(J/AS^2)	Stddev(J)	rms
Background M	1	-1.4324125	-0.00003366169375	-0.00007573881	0.000036442443	138	-0.0103798	-0.0119651	-0.159283	0.132992	0.00344219	0.0586702	0.000001378749	0.000003102186	0.0595813
	2	2.4540898	0.0000576711103	0.00012975999	0.000026504905	144	0.0170423	0.0217796	-0.0817908	0.111643	0.00174498	0.0417729	0.000000981663	0.000002208742	0.0451156
	3	5.0906102	0.0001196293397	0.000269166014	0.000036323187	140	0.0363615	0.0244292	-0.0708535	0.262169	0.00337085	0.058059	0.000001364388	0.000003069869	0.0685055
	4	2.6876953	0.0000631608395	0.00014211889	0.000033984808	143	0.0187951	0.0126774	-0.102035	0.240118	0.00323894	0.0569116	0.000001337422	0.000003009200	0.0599349
	5	0.36064874	0.0000084752459	0.000019069302	0.000029074439	144	0.00250451	0.0107071	-0.145573	0.11638	0.00209971	0.0458226	0.000001076831	0.000002422869	0.045891
H	6	-2.433353	-0.0000571837955	-0.00012866353	0.000026999087	137	-0.0177617	-0.0164251	-0.16301	0.0804946	0.00190317	0.0436253	0.000001025194	0.000002306687	0.0471025
	7	-1.7582474	-0.0000413188139	-0.00009296733	0.000026435123	138	-0.0127409	-0.0147643	-0.105403	0.0934884	0.00181127	0.042559	0.000001000136	0.000002250307	0.0444252
	8	-0.60052377	-0.0000141123086	-0.00003175269	0.000027158854	139	-0.0043203	-0.00276249	-0.117242	0.0981585	0.00189805	0.0435666	0.000001023815	0.000002303583	0.0437803
	9	-0.047884801	-0.0000011252928	-0.00000253190	0.000029875038	142	-0.0003372 17	-0.00290212	-0.137705	0.116863	0.00224816	0.0474148	0.000001114247	0.000002507057	0.047416
	10	-5.5211357	-0.0001297466891	-0.00029193005	0.000029751179	140	-0.0394367	-0.034275	-0.178223	0.0940208	0.00226141	0.0475543	0.000001117526	0.000002514433	0.0617792

And then for near ultraviolet:

Table 5

NUV

	Region Number	Sum (CPS)	SUM (Janskys)	Error	S-B(Janskys)	Error			NPix	Mean	Median	Min	Max	Var	Stddev	rms
	1	14.337457	0.0004824554281	0.000014473662	0.000464694556	0.00001457110227			139	0.103147	0.0800358	0.0268332	0.34363	0.00516562	0.0718722	0.125718
	2	8.8223776	0.0002968730062	0.000008906190	0.000279112134	0.00000906368186			140	0.063017	0.0506329	0.0156394	0.197993	0.00161495	0.0401864	0.0747401
	3	11.075671	0.0003726963292	0.000011180898	0.000349354573	0.00001130674152			138	0.0802585	0.0760576	0.0177717	0.189788	0.00198053	0.0445031	0.0917712
	4	13.020169	0.0004381286869	0.000013143860	0.000420367815	0.00001325108211			144	0.0904178	0.0613468	0.0165406	0.338096	0.00500834	0.0707696	0.11482
	5	4.7419979	0.0001595682293	0.000004787046	0.000141807357	0.00000507404406			140	0.0338714	0.0329497	0.0132541	0.0676743	0.000124382	0.0111527	0.0356603
	6	16.613599	0.0005590476064	0.000016771428	0.000541286734	0.00001685558984			139	0.119522	0.0735992	0.0234797	0.35496	0.00872456	0.0934053	0.151691
	7	6.8522757	0.0002305790773	0.000006917372	0.000212818205	0.00000711899888			144	0.0475852	0.0401796	0.0208828	0.182456	0.000691544	0.0262972	0.0543682
	8	46.490232	0.001564396307	0.000046931889	0.001546635435	0.00004696203072			144	0.322849	0.10817	0.0228545	1.74115	0.160676	0.400844	0.514692
	9	5.1742896	0.000174114845	0.000005223445	0.000156359732	0.00000548766878			138	0.0374949	0.0340326	0.0192398	0.0817685	0.000190883	0.013816	0.0399593
	10	9.9629282	0.0003352525339	0.000010057576	0.000317491662 1	0.00001019730066			141	0.0706591	0.0671141	0.031856	0.173766	0.000537687	0.0231881	0.0743666
	11	5.4029107	0.0001818079451	0.000005454238	0.000164047073 2	0.00000570778603			139	0.0388699	0.036019	0.0204567	0.0813764	0.000164471	0.0128246	0.0409309
	12	9.4614273	0.0003183770286	0.000009551310	0.000306161568	0.00000969833204			144	0.0657044	0.041724	0.0155535	0.255319	0.00325027	0.0570111	0.0869904
	13	6.4673856	0.0002176275254	0.000006528825	0.000199866536	0.00000674208211			139	0.046528	0.0436033	0.017094	0.102089	0.000342977	0.0185196	0.0500782
	14	13.787691	0.0004639558022	0.000013918674	0.000446194930 3	0.00001401997122			140	0.0984835	0.0690774	0.0270522	0.247288	0.00475615	0.0689649	0.12023
	15	4.4766643	0.0001506397537	0.000004519126	0.000132878881 8	0.00000482215794			140	0.0319762	0.0268892	0.0144764	0.0885643	0.000196189	0.0140067	0.0349094

Table 6.

:ground	Region Number	Sum	Sum(Janskys)	Error				NPix		Mean	Median	Min	Max	Var	Stddev	Stddev(Janksys)	rms
	1	0.4219752	0.0000141996454	0.000000463893				139		0.00303579	0.00268938	0.000894454	0.00582829	1.37E-06	0.0011693	0.000000039346	0.0032532
	2	0.39313562	0.0000132290136	0.000000475180				139		0.00282831	0.00271678	0.000452694	0.00589302	1.43E-06	0.00119775	0.000000040304	0.00307148
	3	0.5364921	0.0000180529591	0.000000511552				139		0.00385966	0.00374181	0.000927214	0.00744879	1.66E-06	0.00128943	0.000000043389	0.00406935
	4	0.50479195	0.0000169862491	0.000000568762				138		0.0036579 1	0.0035850 3	0.000447728	0.00762161	2.07E-06	0.00143882	0.000000048416	0.00393072
	5	0.46814263	0.0000157529995	0.000000538347				139		0.00336793	0.00313972	0.000895456	0.00808262	1.84E-06	0.00135697	0.000000045662	0.00363102
	6	0.49947302	0.0000168072671	0.000000531505				140		0.00356766	0.00358102	0.000895055	0.0062681 9	1.78E-06	0.00133493	0.000000044920	0.00380924
	7	0.86530955	0.0000291176663	0.000000653025				140		0.00618078	0.00623886	0.00222816	0.0107023	2.69E-06	0.00164014	0.000000055190	0.0063947
	8	0.56301502	0.0000189454554	0.000000557816				138		0.0040798 2	0.00402235	0.000446229	0.00803213	1.99E-06	0.00141113	0.000000047484	0.00431697
	9	0.4171513	0.0000140371412	0.000000445010				138		0.00302284	0.00313831	0	0.00672646	1.27E-06	0.00112576	0.000000037881	0.00322566
	10	0.60863303	0.0000204805014	0.000000544042				143		0.00425618	0.00418702	0.0018336	0.00774135	1.83E-06	0.00135201	0.000000045495	0.00446575
	AVG	0.527811942	0.0000177608718	0.000001682291													

Data analysis

UV:

- For the UV data, the flux density is in counts per second, it needs to be in Janskys. So the raw data was multiplied by 3.365×10^{-5}.
- The bright regions have an error of 3% So uncertainty was calculated by multiplying by 0.03. $\Rightarrow \sigma_{f,i}$
- Error on the background region was calculated by: $\sigma = \sqrt{N_{pix}} \times$ Stddev
- An average background reading in Janskys was calculated and the error on this (q in Janskys) was: $\sigma_b \sqrt{\sum \sigma_i^2}$ $\Rightarrow$ Square root of individual uncertainty squared.
  This was $(1.78 \pm 0.17) \times 10^{-5}$ Jy
- This average was then taken from each reading of the bright areas. (F - B)
- The error on this was then: $\sigma = \sqrt{\sigma_{f,i}^2 + \sigma_8^2}$

IR:

- Raw data was in Mega Jansky per steradian. This was converted to Jansky by multiplying by 2.35×10^{-5} and 2.25.
- Bright areas had uncertainty of 4%. So $\sigma_{fi} = 0.04 \times f(\text{Jansky})$
- Error on background was the same as before: $\sigma_i = \sqrt{N_{pix}} \times \text{Stddev}(\text{Jansky})$
- Average background was taken to be zero but the error was calculated by: $\sigma_b = \sqrt{\sum \sigma_i^2} = \pm 0.97 \times 10^{-4}$ Jy
- Background was taken from flux density readings (F - B) and the error was calculated by: $\sigma = \sqrt{\sigma_b^2 + \sigma_{fi}^2}$
  - In this was just F as B = 0

CO:

- Data was measured in Jy/beam km/s. This was converted to Jy km/s by multiplying by: $\frac{0.25}{10.75}$
- Bright areas had error 3% so $\sigma_{fi} = 0.03\ f(\text{Jansky km/s})$
- Error on background was: $\sigma_{bi} = \sqrt{N_{pix}}$ Stddev (Jy km/s)
- Average background was taken to be zero and error was: $\sigma_b = \sqrt{\sum \sigma_{bi}^2} = \pm 0.48$ Jy km/s
- Background was taken from flux density readings (F - B) and the error was calculated by: $\sigma = \sqrt{\sigma_b^2 + \sigma_{fi}^2}$
  - In this was just F as B = 0

Star formation rate:

The final values of $\hat{}$ flux density for UV and IR were taken and used in this formula to calculate star formation rate (SFR):

$$\text{in } M_\odot/\text{yr} \Leftarrow \quad SFR = \left[0.106 \frac{M_\odot/\text{yr}}{\text{Jy MPc}^2}\right] \left[f(UV) + 0.0213\, f(IR) \right] D^2$$

- The error on '$0.0213\, f(IR)$' was simply $\sigma_1 = 0.0213 \times \sigma_{fIR}$
- Error on the summed part was $\sigma_2 = \sqrt{\sigma_{uv}^2 + \sigma_1^2}$
- There was no error on D = 15.2 MPc
- Therefore the overall error was: $\sigma_{SFR} = 0.106 \times \sigma_2^2 \times 15.2^2$
- The $\log_{10}$ was taken for each SFR reading and error was calculated by: $\sigma = \frac{1}{\ln 10} \times \frac{\sigma_{SFR}}{SFR}$
- This is all displayed in table below:

F_IR(J)	Error	F_UV(J)	Error	F_IR*0.0213	Error	(F_UV+AF_IR)	Error	D(MPc)	SFR	Error	Log10 SFR	Error
0.0508662449	0.0020369666	0.0004646946	0.0000145711	0.0010834510	0.0000433874	0.0015481456	0.0000457688	15.2	0.0379144566	0.001120888757	-1.421195164	0.01283931896
0.0611549183	0.0024481241	0.0002791121	0.0000090637	0.0013025998	0.0000521450	0.0015817119	0.0000529269	15.2	0.0387365039	0.001296192285	-1.411879578	0.01453226544
0.0520020480	0.0020823482	0.0003549355	0.0000113067	0.0011076436	0.0000443540	0.0014625791	0.0000457725	15.2	0.0358189127	0.001120979356	-1.445887602	0.01359156691
0.0295490409	0.0011859454	0.0004203678	0.0000132511	0.0006293946	0.0000252606	0.0010497624	0.0000285253	15.2	0.0257089328	0.000698590680	-1.589915951	0.01180111519
0.0170804851	0.0006900884	0.0001418074	0.0000050740	0.0003638143	0.0000146989	0.0005056217	0.0000155500	15.2	0.0123827966	0.000380823669	-1.907181262	0.01335640278
0.0682170038	0.0027304081	0.0005412867	0.0000168556	0.0014530222	0.0000581577	0.0019943089	0.0000605510	15.2	0.0488411040	0.001482909449	-1.311214528	0.01318601216
0.0442738259	0.0017736143	0.0002128182	0.0000071190	0.0009430325	0.0000377780	0.0011558507	0.0000384429	15.2	0.0283070610	0.000941475775	-1.54810522	0.01444437254
0.2136671718	0.0085472387	0.0015466354	0.0000469620	0.0045511108	0.0001820562	0.0060977462	0.0001880157	15.2	0.1493352677	0.004604548525	-0.8258376151	0.01339087576
0.0217615507	0.0008758638	0.0001563540	0.0000054877	0.0004635210	0.0000186559	0.0006198750	0.0000194463	15.2	0.0151808876	0.000476243569	-1.818702836	0.01362436506
0.0375901953	0.0015067414	0.0003174917	0.0000101973	0.0008006712	0.0000320936	0.0011181628	0.0000336747	15.2	0.0273840759	0.000824700813	-1.56250191	0.01307924409
0.0159850294	0.0006467357	0.0001640471	0.0000057078	0.0003404811	0.0000137755	0.0005045282	0.0000149112	15.2	0.0123560167	0.000365177645	-1.908121515	0.0128354178
0.0172436532	0.0006965507	0.0003006162	0.0000096983	0.0003672898	0.0000148365	0.0006679060	0.0000177251	15.2	0.0163571775	0.000434092717	-1.786291634	0.01152546471
0.0161961397	0.0006550856	0.0001998667	0.0000067421	0.0003449778	0.0000139533	0.0005448444	0.0000154968	15.2	0.0133433708	0.000379520404	-1.874734445	0.01235247222
0.0231698493	0.0009318692	0.0004461949	0.0000140200	0.0004935178	0.0000198488	0.0009397127	0.0000243009	15.2	0.0230137901	0.000595135523	-1.638011853	0.01123083477
0.0192091829	0.0007744815	0.0001328789	0.0000048222	0.0004091556	0.0000164965	0.0005420345	0.0000171868	15.2	0.0132745545	0.000420908955	-1.876980046	0.01377058923

Molecular gas mass:

The data from the CO image was used in calculating the molecular gas mass (MGM) using this equation:

$$MGM = 7860\, I\, D^2 \Rightarrow \text{in } M_\odot$$

where I is the CO data.

The error on this was then: $\sigma_{mgm} = 7860 \times (15.2)^2 \times \sigma_I$

The $\log_{10}$ of MGM was taken

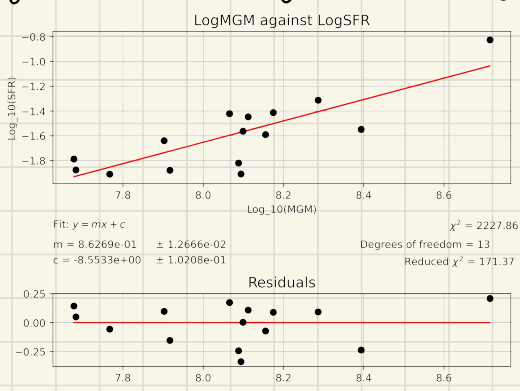
↳ error on this $\Rightarrow \sigma = \frac{1}{\ln 10} \times \frac{\sigma_{mgm}}{mgm}$

This is summarised in table below:

S-B(Jy Km/s)	Error	(MPc)	MGM	Error	Log10 MGM	Error
64.02159091	1.979886663	15.2	116261570.1	3595423.495	8.065436184	0.0134306855
82.30604592	2.515535764	15.2	149465672.4	4568148.55	8.17454146	0.01327342711
71.22853664	2.190255121	15.2	129349199.1	3977447.229	8.111763744	0.01335441886
78.70678571	2.409636033	15.2	142929508	4375837.349	8.155121899	0.0132960789
68.36480751	2.106522186	15.2	124148740.3	3825390.363	8.093942317	0.01338189918
106.4480798	3.229417568	15.2	193306987.8	5864539.63	8.286247554	0.01317560854
136.2446776	4.115509018	15.2	247416846.7	7473659.019	8.393429268	0.01311862516
285.5021336	8.578542123	15.2	518464565.7	15578412.88	8.71471908	0.01304933683
67.4149513	2.078788493	15.2	122423825.7	3775026.686	8.087865947	0.0133917826
69.20744202	2.131142073	15.2	125678943	3870099.447	8.099262519	0.01337346411
32.21595083	1.079418476	15.2	58503341.99	1960196.318	7.767180676	0.01455134725
26.21288265	0.9216654497	15.2	47601923.85	1673720.862	7.677624505	0.01527013356
26.54097403	0.9300776731	15.2	48197729.38	1688997.244	7.683026579	0.0152190195
44.0099884	1.405081733	15.2	79921012.29	2551592.458	7.902660976	0.01386547158
45.49507189	1.447026232	15.2	82617885.88	2627762.593	7.917074078	0.01381326552

$\log_{10}(Mgm)$ was plotted against $\log_{10}(SFR)$ using LSFR. Therefore only error on y was accounted for:

↳ log(SFR)



$\log_{10}$ SFR increases linearly with $\log_{10}$ MGM with

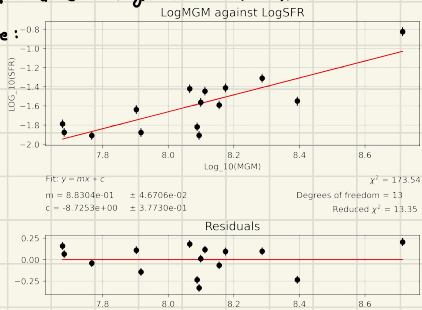
$m = 0.862 \pm 0.0126$

However $\chi^2_{reduced} = 171.37$. This is very large indicates that errors are underestimated.

Due to the high $\chi^2_{reduced}$ I researched the distance to galaxy M100, this gave me $D = 15.2 \pm 1.6$ Mpc.

I then repeated the analysis with this error.

This gave:



New $\chi^2_{reduced}$ is much smaller but still too big to represent a good model so there may still be unresolved errors.

Discussion Questions:

1. IR and UV are very similar, same regions are bright. The IR image is brighter, flux density is higher than UV.
In the IR image the galaxy generally has a higher flux density everywhere whereas the UV image has distinct bright arms.
The centre is much brighter for IR.

2. The CO image is much less clear than the UV and IR, there are less bright areas but the arms are less clear - the brightness spreads from the arm more.

3. The data does follow a positive linear trend, this was expected as the same region were bright for each image.
The point at $\log_{10}(M_{gas}) = 8.7$ does not fit the model so high M_{gas} does not fit the model?

4. The calibration had an uncertainty of 3% or 4% depending on the image. But the uncertainty on the background noise was 9.46%. The other background noise cannot have a percentage as they are zero.
Therefore for the UV the background is the highest error but for CO and IR it was the calibration.
However when I accounted for the error on D this was the largest error.
As only the error on SFR contributed to the error on the gradient then only the error on the Calibration and Distance contributed.

5. A wide region would include areas that include both bright and faint region whereas a narrow region could just include a bright area. Therefore a narrower region would be better suited to a measurement for the flux to decrease the amount of noise. A wide region would be more suitable when measuring background regions or large bright regions like the centre.

Day 2:

Aim: Comparing Ultraviolet and infrared star formation rates.

- 4 galaxies were selected from the Sample of Spitzer Infrared Nearby Galaxies Survey. They needed to be a Spiral galaxy and needed to be face on (shown by the diameter being roughly equal in both directions).
- The galaxies selected were: NGC 0628, NGC 1291, NGC 4736, NGC 4321.
- For each galaxy an infrared and ultraviolet image was selected.
- Similarly to day 1, 15 regions were drawn on the bright areas for each image. The flux, number of pixels and standard deviation were recorded for each. 10 regions were also drawn on darker regions to measure the background flux. The same readings were taken.
- Note that for each region the coordinates were set to FK5 and WCS was selected. Units were in Arcseconds and the radius of each region was 10 arcsec.
- These regions were loaded onto the other image for each galaxy and the same measurements were taken.
- Data for NGC 0628 is shown below but not all data included due to its size.

in d/s

log scale was selected.

The distance to the centre of the galaxy was also recorded.

Data for UV:

	REGION	Sum	FLUX IN JY/AS2	Error	Diff	Error	Log_10(Flux)	Error	NPIX	Stddev	DISTANCE ARCSEC
NUV	1	10.190833	0.000001091553133	0.0000000032746594	0.000001037506422	0.00000003345760951	-5.984009206	0.01400517133	137	0.0343702	91.239
	2	17.596977	0.000001884834673	0.00000005654504018	0.000001829998958	0.0000000056971907	-5.737549158	0.01352054586	139	0.0916506	170.817
	3	19.199347	0.000002056466569	0.00000000616939970	0.000002001630854	0.00000006208547248	-5.698616013	0.01347070467	139	0.120773	125.814
	4	17.132418	0.000001835075165	0.00000005505225495	0.000001779844949	0.0000000554969109	-5.74961783	0.01354163023	140	0.112262	229.998
	5	13.458696	0.000001441578111	0.00000004324734334	0.000001386347895	0.00000004381197382	-5.858127773	0.01372476457	140	0.0765551	101.738
	6	15.683249	0.000001679852823	0.0000000503955847	0.000001624622607	0.00000005088095225	-5.789247508	0.01360150763	140	0.0855038	143.03
	7	11.2075	0.000001200449634	0.00000003601348901	0.000001144035913	0.00000003671861936	-5.941560342	0.01393898005	143	0.0417757	52.279
	8	25.969006	0.000002781573387	0.00000008344720162	0.000002726737673	0.00000008373704125	-5.564356642	0.01333701269	139	0.345569	249.892
	9	12.54639	0.000001343859851	0.00000004031579553	0.000001289024136	0.00000004091234516	-5.889738951	0.01378407529	139	0.058047	114.357
	10	14.805408	0.000001585826153	0.00000004757478459	0.000001530595937	0.00000004808863143	-5.815139444	0.01364476853	140	0.0696623	88.977
	11	14.991759	0.000001605786446	0.00000004817359339	0.000001550161729	0.00000004868835781	-5.809622989	0.01364056713	141	0.0631803	1.889
	12	8.3146556	0.000000890593376	0.00000000267178013	0.00000008349686591	0.00000002763515863	-6.078329826	0.01437394897	141	0.0463292	128.057
	13	10.494496	0.000001124078865	0.00000003372236595	0.000001069243151	0.00000003443333536	-5.970923523	0.01398578755	139	0.0349381	81.724
	14	9.6313315	0.000001031624213	0.00000003094872641	0.000000974815991	0.00000003177780785	-6.011077355	0.01415746841	144	0.0489142	144.131

BACKGROUND	REGION	Sum	SUM IN JY/AS2	Error	NPIX	Stddev	Stddev(IN JY/ARCSEC	rms	
	1	0.50340357	0.00000005392019	0.00000002242079	139	0.00177545	0.00000000190170	0.0040334	
	2	0.47110765	0.00000005046094	0.00000000191066	140	0.0015076	0.00000000161480	0.00368734	
	3	0.50727002	0.00000005433433	0.00000000211674	140	0.0016702	0.00000000178897	0.00398977	
	4	0.53020234	0.00000005679064	0.00000000248490	140	0.0019607	0.00000000210013	0.00426461	
	5	0.48705567	0.00000005216915	0.00000000213636	139	0.00169174	0.00000000181204	0.00389101	
	6	0.5559811	0.00000005955184	0.00000000226674	144	0.00176354	0.00000000188950	0.00424467	
	7	0.52309207	0.00000005602905	0.00000000213416	143	0.00166619	0.00000000178467	0.00401958	
	8	0.44986788	0.00000004818592	0.00000000203788	139	0.00161375	0.00000000172850	0.00361647	
	9	0.55296377	0.00000005922865	0.00000000236874	140	0.00186904	0.00000000200195	0.00436964	
	10	0.59012833	0.00000006320939	0.00000000246656	140	0.00194623	0.00000000208463	0.00464282	
	average		0.51710724	0.00000005538801	140.4	0.001746444			
				Error					
	FLUX/PIXL	0.000000000394	0.00000000050080						

Data for IR:

REGION	Sum	ln JY/AS2	Error	Error on Dif	Log_10(flux)	Error	NPIX	Stddev	DISTANCE ARCSEC
1	304.11489	0.007155644471	0.000286225778	0.000291617336	-3.543291254	0.01769900677	139	0.904187	91.239
2	178.23145	0.004193681176	0.000167747247	0.000176916933	-3.775344598	0.01832138514	140	1.32407	170.817
3	760.51004	0.01789435388	0.000715774155	0.000717978484	-3.145223987	0.01742527816	140	5.01575	125.814
4	95.97443	0.002258221882	0.000090328875	0.000106182766	-4.044173397	0.02042075232	139	0.147667	229.998
5	345.91491	0.008139174353	0.000325566974	0.000330385104	-3.487359657	0.01762886768	140	1.56585	101.738
6	263.12469	0.006191169176	0.000247646767	0.000253859007	-3.606167337	0.01780755183	139	1.24258	143.03
7	375.82331	0.008842901412	0.000353716056	0.000358218957	-3.451345226	0.01759292674	141	1.01601	52.279
8	6.4196849	0.000151051409	0.000006042056	0.000056142503	-5.218815227	0.161417756	139	0.0657325	249.892
9	727.88659	0.01712674329	0.000685069731	0.000687505765	-3.16426522	0.01743355144	144	3.1823	114.357
10	296.05455	0.006965989412	0.000278639576	0.000284096501	-3.554957199	0.01771199116	138	1.0578	88.977
11	456.73419	0.01074668682	0.000429867472	0.000433527976	-3.366665416	0.01751970735	140	0.618492	1.889
12	633.53637	0.01490673812	0.000596269524	0.000598839005	-3.224557387	0.0174466388	138	6.89055	128.057
13	650.39129	0.01530332447	0.000612132978	0.000614600072	-3.213154222	0.01744179316	137	4.10598	81.724
14	359.69541	0.008463421412	0.000338536856	0.000343107384	-3.470394043	0.0176063127	139	0.788749	144.131

REGION	Sum	ln JY/AS2	Error	NPIX	Stddev	ln JY/AS2	rms
1	-2.2639685	0.000053269847	0.000019708996	138	0.071304	0.000001677741	0.0731669
2	-4.6194296	0.000108692461	0.000015511131	141	0.0555166	0.000001306272	0.0644627
3	-1.7266536	0.000040627143	0.000016038144	140	0.0576075	0.000001355470	0.0589129
4	-3.6179572	0.000085128404	0.000020638571	140	0.0741318	0.000001744277	0.0785071
5	-0.53444917	0.000012575274	0.000016996102	139	0.0612676	0.000001441590	0.0613882
6	0.88657232	0.000020860525	0.000013142188	139	0.047375	0.000001114705	0.0478024
7	-4.4623099	0.000104995527	0.000023934234	139	0.0862782	0.000002030075	0.0920572
8	-3.2483707	0.000076432251	0.000015336481	141	0.0548915	0.000001291564	0.05953
9	5.3958873	0.000126962054	0.000018528807	139	0.0667927	0.000001571592	0.0772541
10	0.84418705	0.000019863224	0.000014739724	140	0.0529437	0.000001245734	0.053286
	Average	0	Error	139.6			
	FLUX/PIX	0	0.000000401557				

Data analysis:

- For UV, the raw data was converted to Jansky/Arcsec^2 by multiplying by 3.365×10^{-5} and dividing by the region area (100").
- The error on the reading was 3%.
- The reading for the background was converted the same way but the error was calculated by multiplying the square root of the number of pixels by the Standard deviation.

The average flux was calculated for the background and this was divided by the average number of pixels to find the average flux per pixel.

- The error on this was calculated by square rooting the sum of the squared individual uncertainties and dividing by the average pixels.

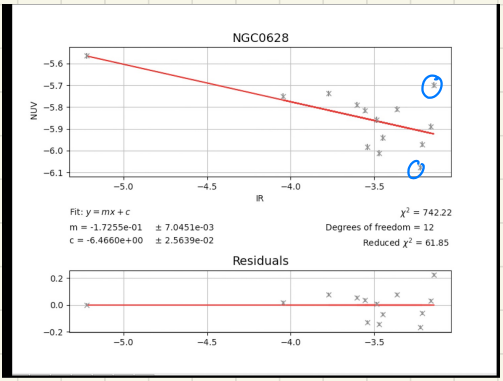
The flux minus the background was calculated by taking the flux per pixel and multiplying this by the number of pixels in the region. this was then taken from the flux reading.

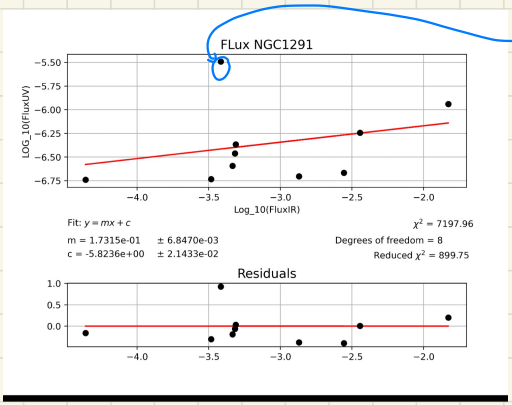
The error on this was found by adding the fractional uncertainties in quadrature.

The $\log_{10}$ was taken for each new flux value and the error was: $\sigma = \frac{1}{\ln 10}\left(\frac{\text{error on flux}}{\text{flux}}\right)$

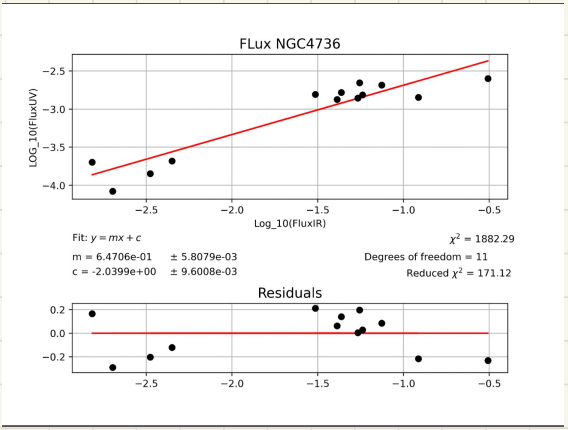
The same method was followed to find the $\log_{10}$ of the flux for IR but the flux was in MJy/s. So was converted by multiplying by 10^6 and dividing by (4.25×10^{10}). The error on the readings was 4% instead of 3%.

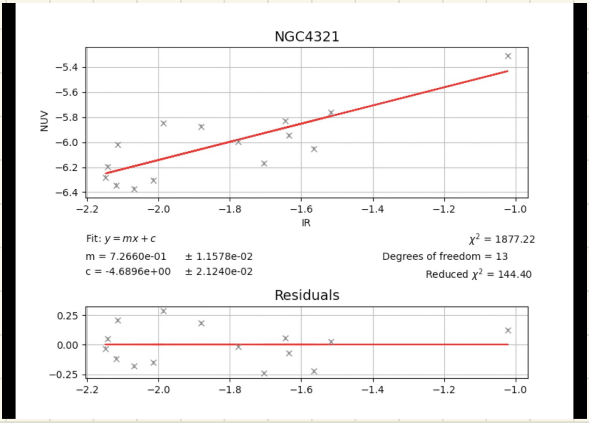
$\log_{10}$(Flux IR) was plotted against $\log_{10}$(flux UV) for each galaxy:





After removing this point χ^2_R = 197.51





The Correlation Coefficient was calculated for each graph using this code:

```
import numpy as np

data = np.genfromtxt("Astro/NGC1291.txt",dtype='float',delimiter=',',skip_header=0)

x = np.array(data[:,0])
y = np.array(data[:,1])

np.corrcoef(x,y)
```

```
array([[1.        , 0.31063819],
       [0.31063819, 1.        ]])
```

CC:

NGC0628 = -0.6646 : weak negative correlation

NGC1291 : 0.3106 : very weak positive correlation

NGC 4736 : 0.9404 } : Strong positive Correlation

NGC 4321 : 0.8191 }

→ The removal of anomolis (circled) will move this close to 1 or -1.

The ratio of the 2 fluxes was calculated and the $\log_{10}$ was calculated. This was plotted against the distance:

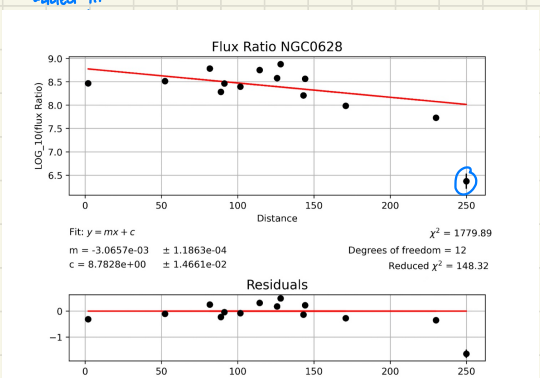
$\log_{10}\left(\frac{IR}{UV}\right)$

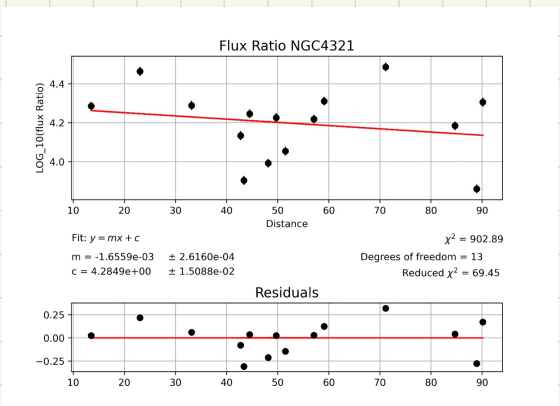
Ratio	Error	Log(Ratio)	Error	DISTANCE ARCSEC
6896.964028	358.4288649	8.467046891	0.02256988401	91.239
2291.630363	120.1504923	7.988533498	0.02277011888	170.817
8939.887114	453.3811418	8.579720965	0.02202499043	125.814
1268.774498	71.5837223	7.731773371	0.02450271157	229.998
5870.946521	302.0213683	8.397097054	0.02234157869	101.738
3810.835298	196.6234288	8.209409109	0.02240780917	143.03
7729.566276	399.4869378	8.516544055	0.02244562844	52.279
55.39638481	20.65978474	6.371870354	0.1619677988	249.892
13286.59628	679.9263734	8.751802669	0.02222452356	114.357
4551.161573	234.3025699	8.286511184	0.022358317	88.977
6932.622979	354.436981	8.469286512	0.0222037208	1.889
17853.05108	929.2588859	8.880101378	0.02260521211	128.057
14312.29601	736.768618	8.78409824	0.02235661875	81.724
8682.070759	451.6491707	8.567012251	0.02259239161	144.131

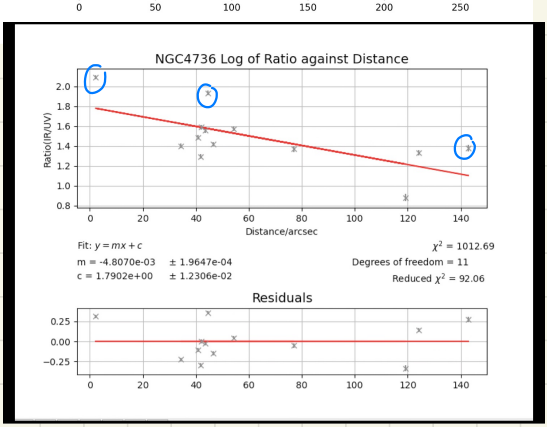
fractional errors added in

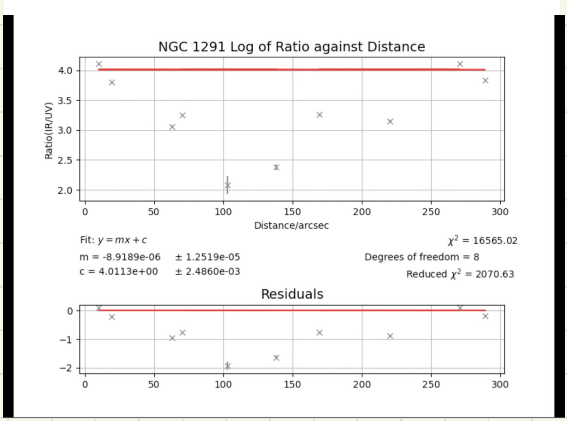
$\frac{1}{\ln 10}\left(\frac{\text{error on ratio}}{\text{ratio}}\right)$

=> example from NGC 0628.









The Correlation Coefficient was calculated again using the same code:

CC:

NGC 0628 : -0.7122 = reasonably strong negative correlation

NGC 1291 : 0.1216 } = no noticable correlation

NGC 4321 : -0.2 }

NGC 4736: -0.64899 = negative correlation but slightly weak.

These 2 have anomalis (circled) that would move the correlation coefficient close to -1

Discussion Questions

1. The same regions are bright in both the IR and UV images but there are a few anomalies on the plots of the respective fluxes. These have been circled. These represent regions that have a high flux of IR or UV but low flux of the other.

2. All galaxies sampled follow a linear relationship between UV flux and IR flux apart from NGC 1291. This is explained by the galaxies having similar bright regions for UV and IR. However, NGC 1291 has a bright area around the centre in the IR image which isn't in the UV image. Therefore there is no relation in this region. The anomaly circled on the NGC 1291 graph represents a region with low UV flux but high IR flux.

3. Galaxies NGC 0628 and NGC 4736 have a correlation but NGC 4321 and NGC 1291 have no correlation. for the galaxies with a correlation, this indicates that the dust is evenly distributed from the centre but if there is no correlation it shows the dust is randomly distributed and areas of low flux represent areas with a lot of dust. For the linear correlation, the amount of dust is linear so the flux varies linearly.

4. For the ratio plot the errors are higher for a smaller ratio ($\text{ratio} = \frac{IR}{UV}$). This is a lower IR flux. This may be due to the IR readings having a 4% error but UV having a 3% error. The IR readings have a higher overall uncertainty. This could also be attributed to a 4% error on the raw data.