On the variation of the energy scale 3

Parameters for galaxy rotation curves

by

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Summary

The hypothesis has been put forward that the flat rotation curves of spiral galaxies arise from variations in the energy scale. A galaxy model of a Gaussian density distribution embedded in a Gaussian energy scale variation gave good fits to a small sample of six galaxies. The model requires neither dark matter nor changes to Newtonian gravitation.

This paper applies the same model to a sample of 74 spiral galaxies. Reasonable fits to the rotation curves are obtained in almost all cases.

1 Introduction

1.1 The paper "On the variation of the energy scale: an alternative to dark matter" (Jo.Ke, 2015) is referred to in this paper as simply "Jo.Ke 1".

1.2 The paper "On the variation of the energy scale 2: Galaxy rotation curves" (Jo.Ke, 2015) is referred to in this paper as simply "Jo.Ke 2".

1.3 The rotation curves of many spiral galaxies remain flat in their outer regions and do not show the fall off in speed expected if the majority of the mass is concentrated in the galaxy centre. The widely accepted explanation for these observations is that galaxies are embedded in large haloes of dark matter.

1.4 'Jo.Ke 1' put forward the hypothesis that the flat rotation curves are caused by variations in the energy scale. The first model took a point mass galaxy and a Gaussian for the energy scale variation. This gave good fits to the outer regions of spiral galaxies. The model was applied to a small sample of just six galaxies.

1.5 'Jo.Ke 2' introduced an improved model for a spiral galaxy. This was made up of two components: (a) a narrow Gaussian density distribution, and (b) a broader Gaussian for the energy scale variation. As well as fitting the outer regions, this model also gave better fits to the inner regions.

1.6 The success of the fits to rotation curves in 'Jo.Ke 2' suggested the model should be applied to a much larger sample of spiral galaxies. This paper adopts the galaxy model of 'Jo.Ke 2' and applies it to rotation curves presented in Brownstein & Moffat (2006).

4 The galaxy model

4.1 'Jo.Ke 2' modelled a spiral galaxy as an axisymmetric disk with a Gaussian density distribution embedded in a Gaussian energy scale variation.

4.2 The rotation velocity is given by

$$v^2 = K^2 \frac{1}{Q(r)} \frac{\alpha}{r} \int_0^r Q(x) \ P(x) \, dx \tag{1}$$

where

$$K^2 = \frac{G\,M}{\alpha} \tag{2}$$

4.3 The energy scale variation term, Q, is given by

$$Q(r) = 1 + \gamma \, exp(-r^2/\alpha^2) \tag{3}$$

where γ is a pure number; α is the 1/e-width of the Gaussian energy scale variation.

4.4 The density distribution term, P, is given by

$$P(x) = \frac{2x}{\beta^2} \, exp(-x^2/\beta^2) \tag{4}$$

where β is the 1/e-width of the Gaussian density distribution.

4.5 The four adjustable parameters: $\alpha; \gamma; K; \beta$ are chosen to fit the observed rotation curves of spiral galaxies.

4.6 The Keplerian (Newtonian) rotation curve is given by setting $Q(r)=Q(x)=1$ in equation (1), i.e. no energy scale variation.

5 A sample of galaxy rotation curves

5.1 'Jo.Ke 1' and 'Jo.Ke 2' worked with just six galaxies.

5.2 This paper works with the galaxy rotation curves presented in Bernstein & Moffat (2006). The 101 galaxies has been reduced to 74 by selecting only those where the observed rotation curves extend out to at least 10kpc.

5.3 Table (1) gives the values of the four adjustable parameters found by fitting equation (1) to the observed rotation curves.

5.4 Following 'Jo.Ke 2' an estimate for the galaxy mass is given by

$$\boldsymbol{M = \frac{v^2\,\alpha}{G}\left\{\frac{1+\ \gamma/e}{1+\gamma}\right\}\left\{\frac{1}{1-exp(-\alpha^2/\beta^2)}\right\}} \tag{5}$$

where the velocity, $\boldsymbol{v}$, is evaluated at the point $\boldsymbol{r=\alpha}$.

6 Table of parameters for galaxy rotation curves

Table 1. Rotation curve parameters as derived from fitting equation (1) to the observed rotation curves for the listed galaxies. The rotation speed, $\boldsymbol{v(\alpha)}$, is measured at the point corresponding to the characteristic distance, $\boldsymbol{\alpha}$. The galaxy masses, $\boldsymbol{M}$, follow from equation (5) and are in units of 10^{10} solar masses.

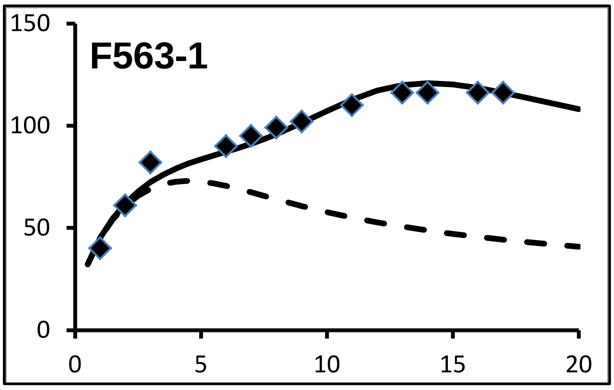
Galaxy	α kpc	γ	K km/s	β kpc	$v(\alpha)$ km/s	M
F563-1	7.0	8.0	69	4.0	91	6
F568-3	8.0	5.0	79	5.0	96	9
F571-8	6.5	5.5	101	4.6	121	12
F583-1	6.0	5.0	65	4.5	76	5
IC 342	9.0	2.7	148	3.8	190	42
Milky Way	9.0	3.4	164	3.9	215	49
NGC 55	13.0	7.0	65	5.5	90	11
NGC 224	11.0	2.1	230	6.0	275	117
NGC 247	6.0	5.0	77	4.5	90	6
NGC 300	7.5	3.3	75	5.0	89	8
NGC 660	9.5	3.7	107	2.7	145	23
NGC 801	30.0	2.8	165	10.0	217	175
NGC 891	6.5	2.1	178	3.5	228	50
NGC 1003	15.0	5.0	72	6.0	99	16
NGC 1097	17.0	1.7	235	6.6	290	119
NGC 1365	14.0	1.7	195	4.7	246	119
NGC 1417	5.5	6.0	160	2.7	215	28
NGC 1808	3.7	3.0	147	1.6	191	3
NGC 2403	11.0	3.2	101	5.5	129	18
NGC 2590	6.2	7.2	150	1.0	225	32
NGC 2841	17.0	2.4	220	5.2	287	78
NGC 2903	15.0	12.0	154	5.1	196	78

Galaxy	α kpc	γ	K km/s	β kpc	$v(\alpha)$ km/s	M
NGC 2998	16.0	4.4	148	5.3	204	75
NGC 3031	4.2	3.7	170	2.0	222	24
NGC 3079	6.0	3.6	170	2.4	226	36
NGC 3198	20	2.4	120	8.5	152	60
NGC 3379	5.6	1.1	190	1.5	229	46
NGC 3521	8.0	2.2	163	2.3	213	48
NGC 3621	14.0	4.5	101	5.3	140	31
NGC 3628	5.5	3.8	155	2.4	205	27
NGC 3672	5.8	4.3	149	2.8	196	25
NGC 3726	20.0	3.5	120	9.0	157	59
NGC 3769	16.0	3.5	88	5.5	118	26
NGC 3877	33.0	8.0	99	7.2	146	72
NGC 3893	8.5	2.4	147	3.7	186	38
NGC 3917	18.0	1.3	115	9.0	134	49
NGC 3953	10.5	2.5	178	5.5	219	66
NGC 3992	11.5	3.3	203	5.7	260	95
NGC 4010	4.5	4.2	131	7.0	93	13
NGC 4013	17.2	2.1	140	6.0	178	72
NGC 4051	4.0	10.5	79	1.0	120	6
NGC 4088	20.0	4.0	127	7.0	172	68
NGC 4100	16.0	0.8	156	7.0	177	84
NGC 4138	20.0	1.0	121	5.0	177	100
NGC 4157	18.0	2.6	140	6.0	183	76
NGC 4183	12.0	3.5	80	5.5	104	15
NGC 4217	12.0	2.4	140	5.0	178	49
NGC 4258	9.9	6.2	124	1.9	175	32
NGC 4303	6.0	3.0	115	2.0	153	17

Galaxy	α kpc	γ	K km/s	β kpc	$v(\alpha)$ km/s	M
NGC 4321	9.0	4.1	190	3.9	251	65
NGC 4527	5.0	3.0	150	2.3	193	23
NGC 4565	11.0	3.2	195	5.0	252	85
NGC 4631	4.9	3.0	138	2.1	179	19
NGC 4736	5.5	1.0	130	1.9	153	20
NGC 4945	15.0	3.0	128	5.0	169	52
NGC 5033	11.0	3.0	165	4.0	217	63
NGC 5055	20	2.2	149	7.0	198	103
NGC 5194	10.0	-0.6	250	4.5	199	181
NGC 5236	13.5	2.1	145	5.3	183	60
NGC 5457	4.2	5.4	144	1.6	200	18
NGC 5533	29.0	2.3	200	9.2	261	23
NGC 5585	40.0	4.0	50.0	8.0	70	257
NGC 5907	8.5	3.5	203	5.0	251	67
NGC 6503	12.0	2.5	90	4.5	116	21
NGC 6674	35.0	2.2	190	10.0	246	278
NGC 6946	15.7	2.1	140	9.0	166	60
NGC 6951	5.5	6.0	140	1.4	202	24
NGC 7331	16.0	2.9	175	4.8	233	107
UGC 2885	36.0	4.0	203	13.0	275	313
UGC 6446	7.0	4.0	62	4.5	75	5
UGC 6614	30.0	3.5	148	12.0	196	136
UGC 6917	11.0	8.0	84	6.0	112	15
UGC 6930	9.0	3.4	82	5.0	103	12
UGC 6983	10.0	3.0	83	5.0	105	14

7 Figures of galaxy rotation curves

The following figures show the galaxy rotation curves.
The vertical axis is the speed in km/s.
The horizontal axis is distance in kpc.
The diamonds are the data points taken from Brownstein & Moffat (2006).
The solid line is an eye-fit to the data using equation (1).
The dashed line is the Keplerian curve for the same mass distribution.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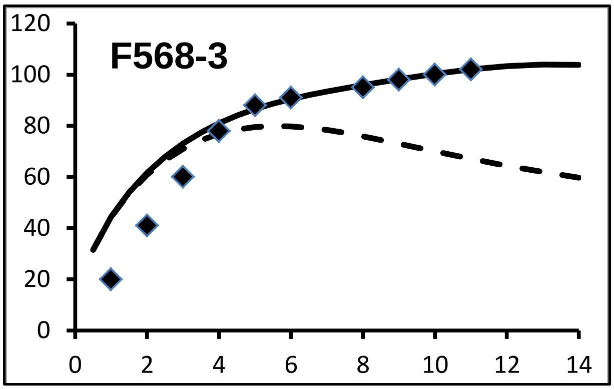
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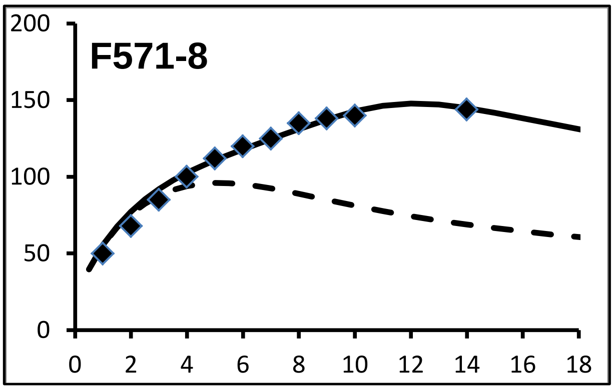
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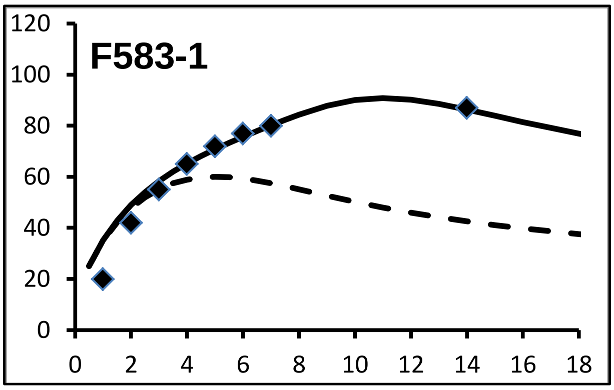
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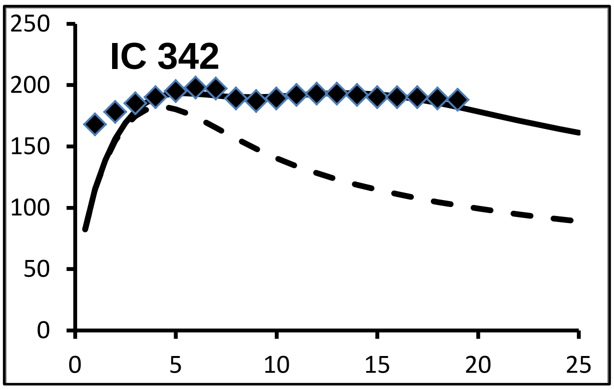
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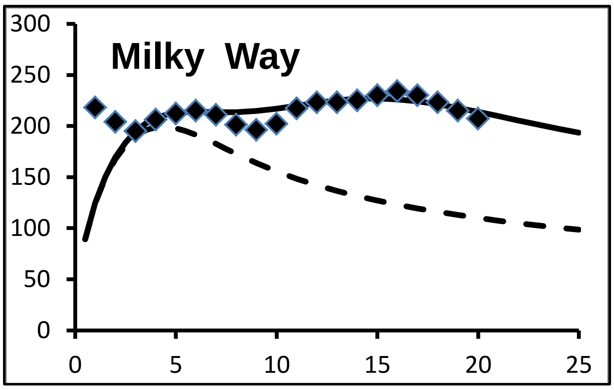
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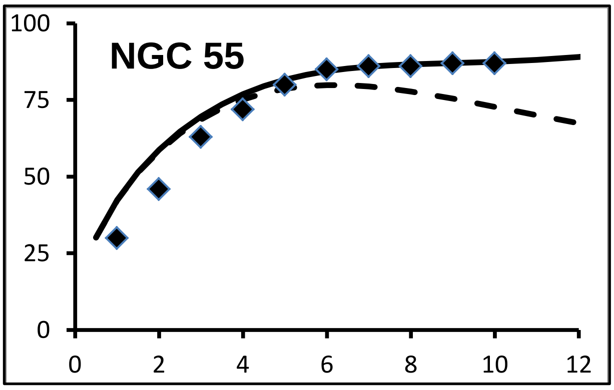
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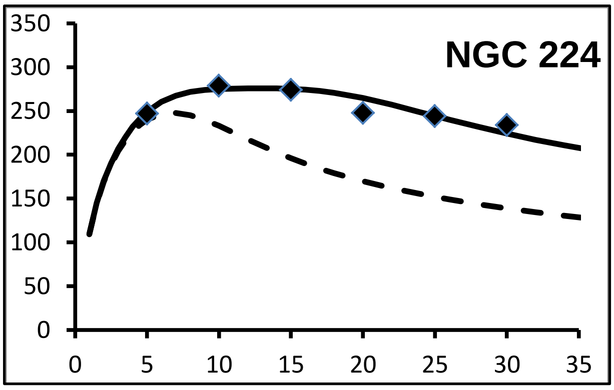
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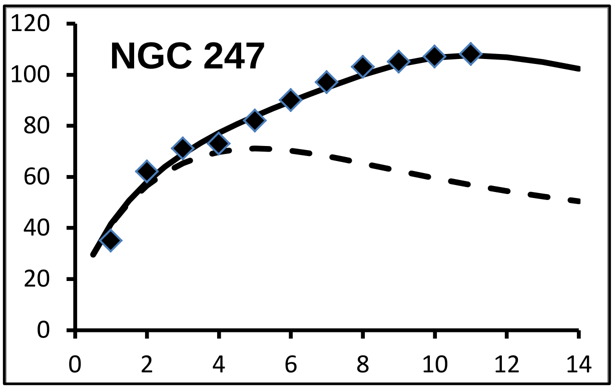
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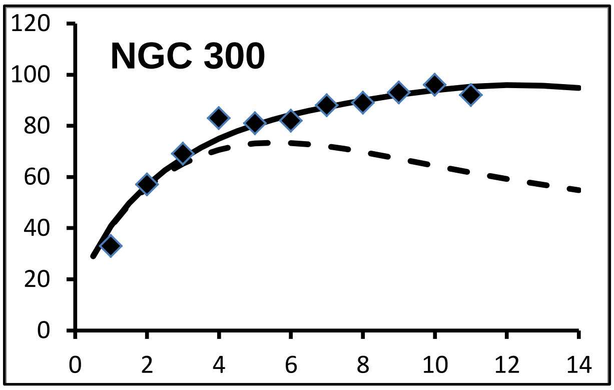
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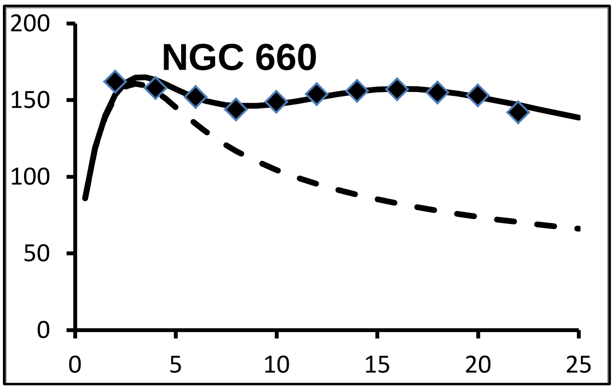
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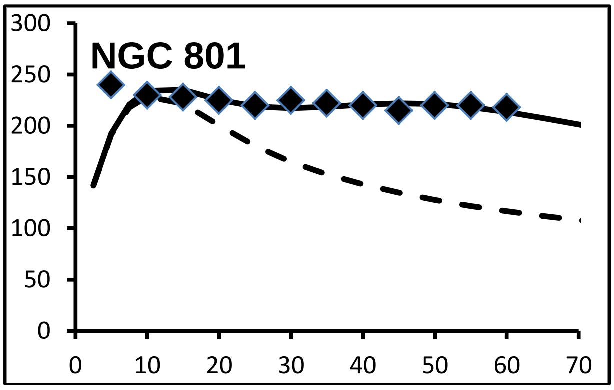
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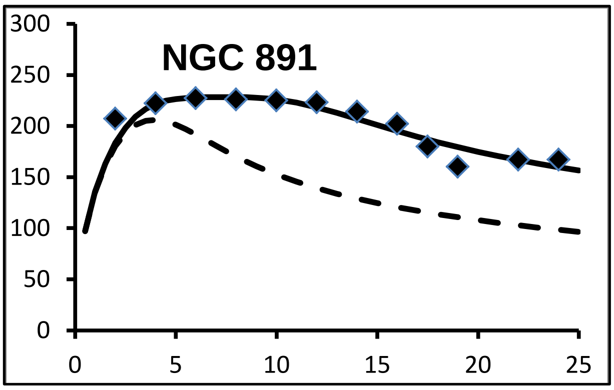
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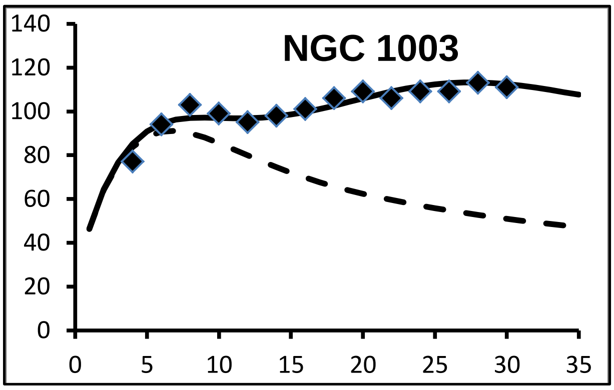
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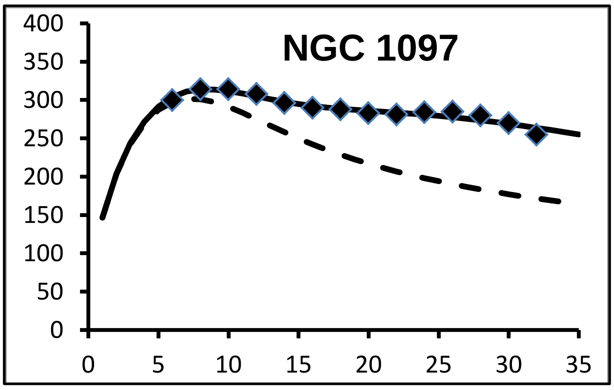
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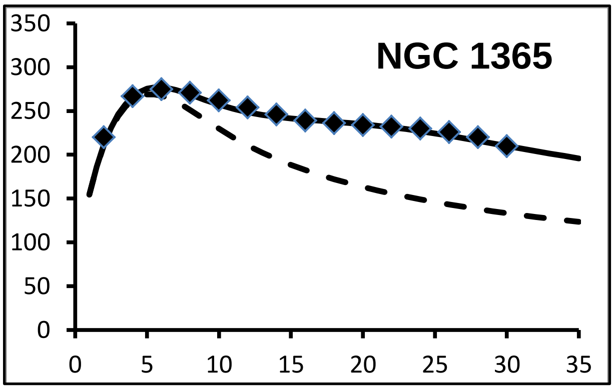
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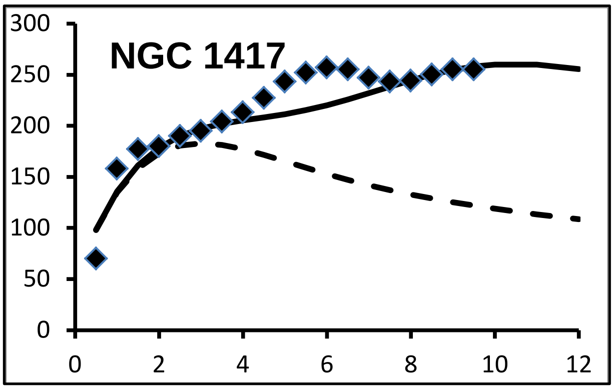
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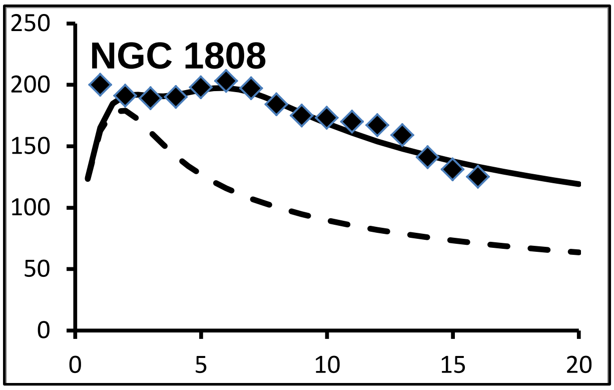
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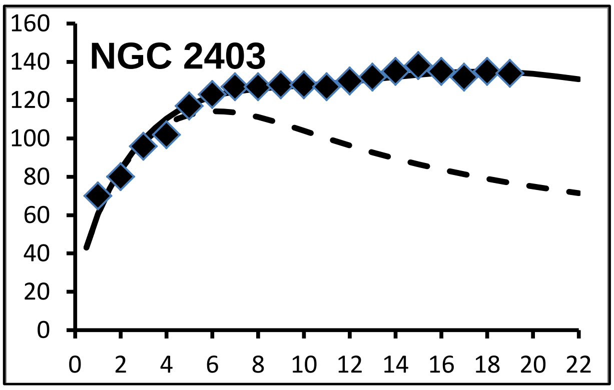
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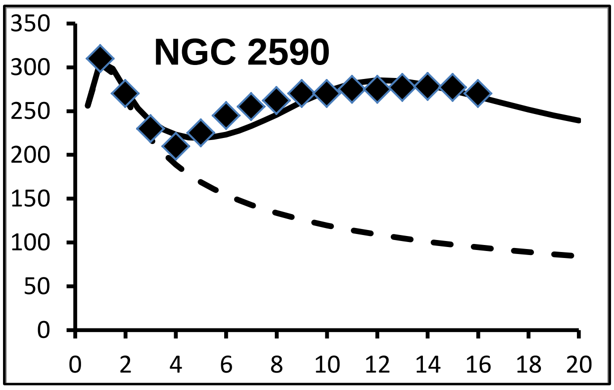
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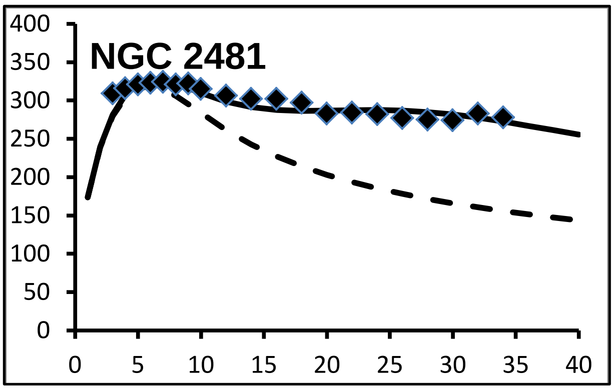
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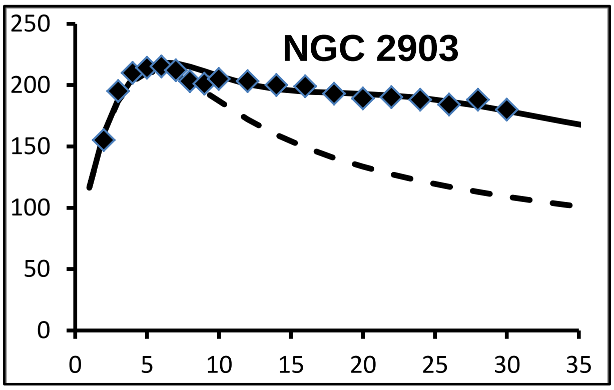
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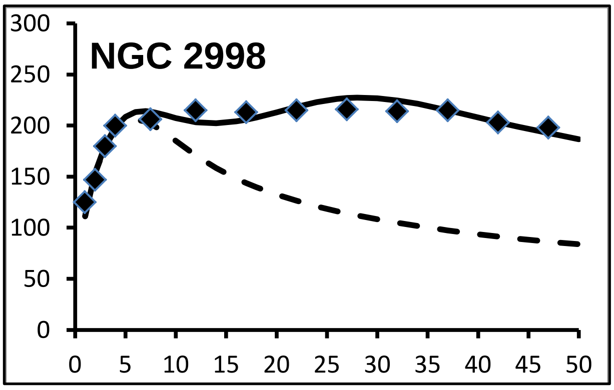
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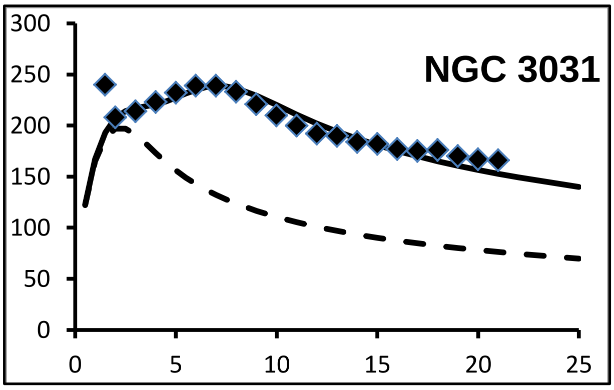
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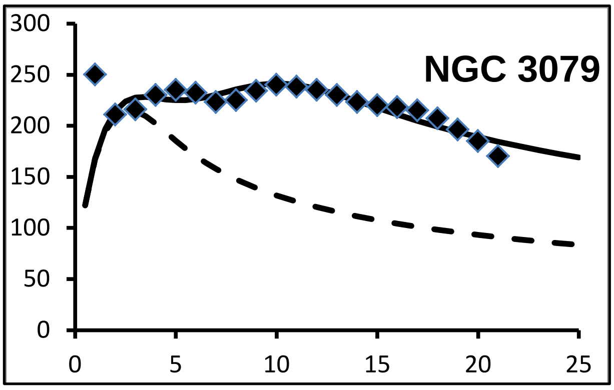
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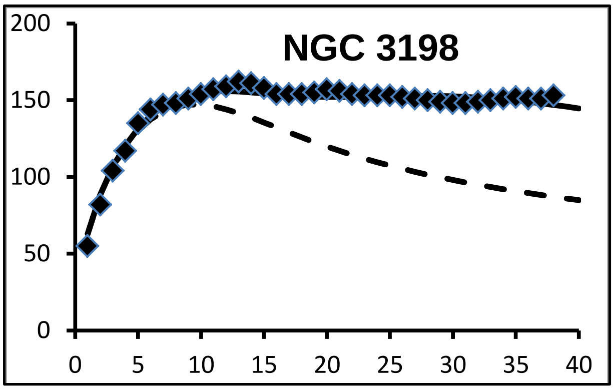
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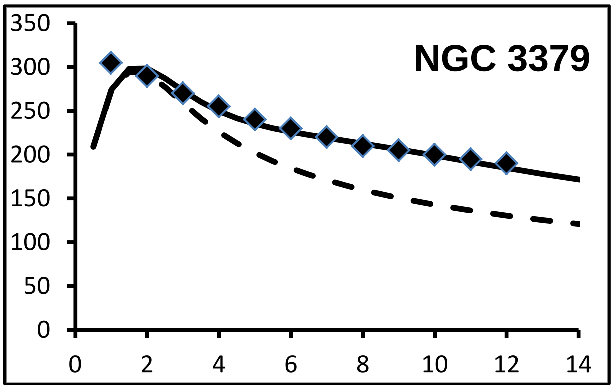
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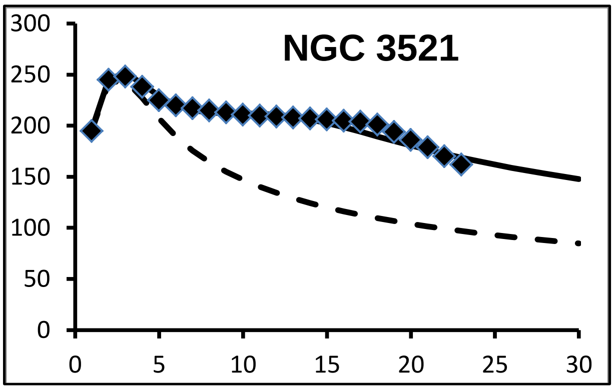
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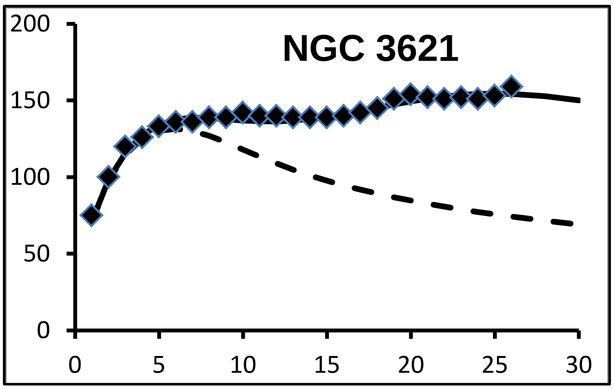
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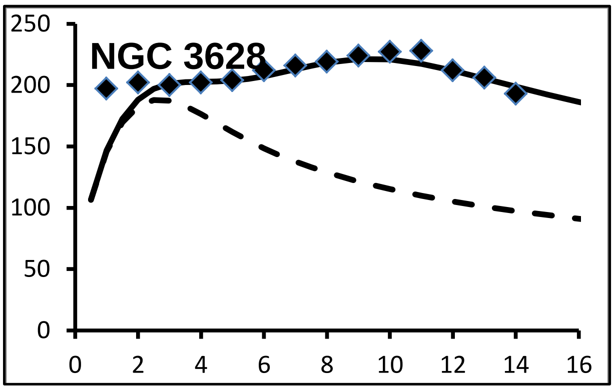
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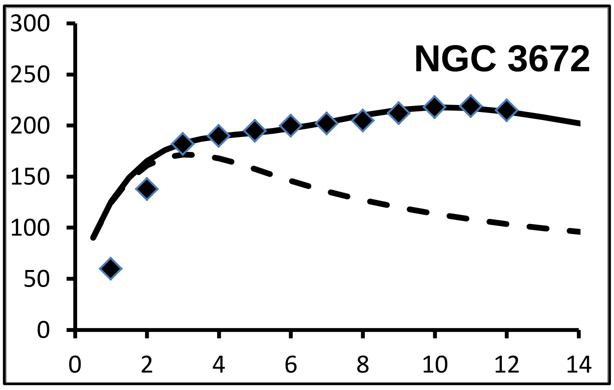
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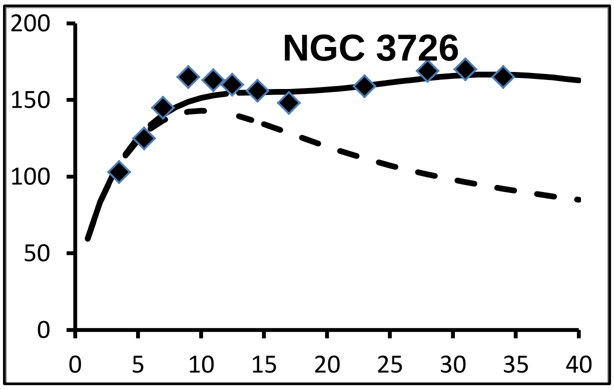
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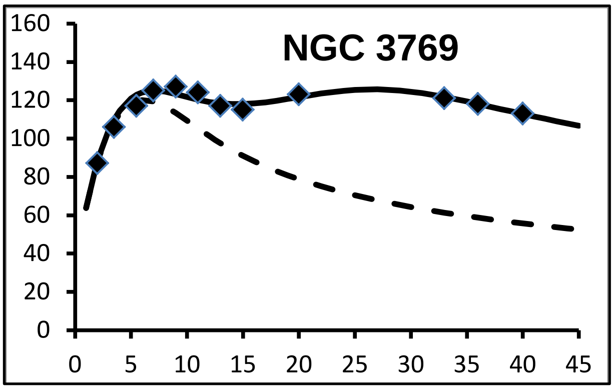
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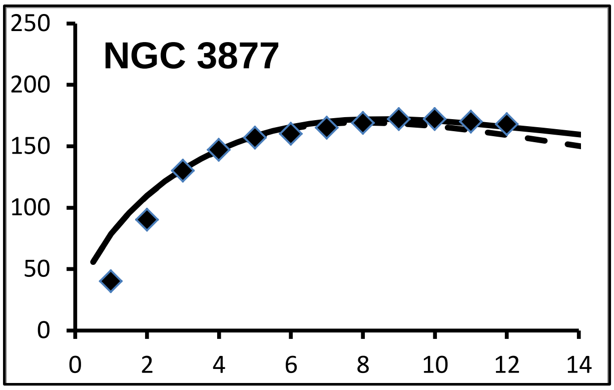
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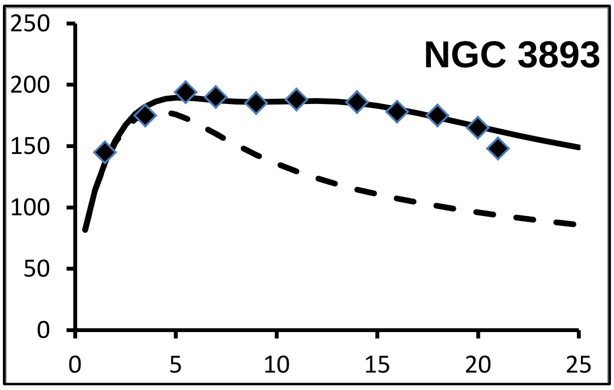
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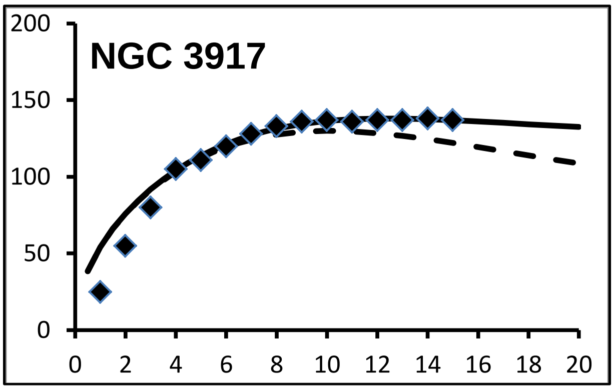
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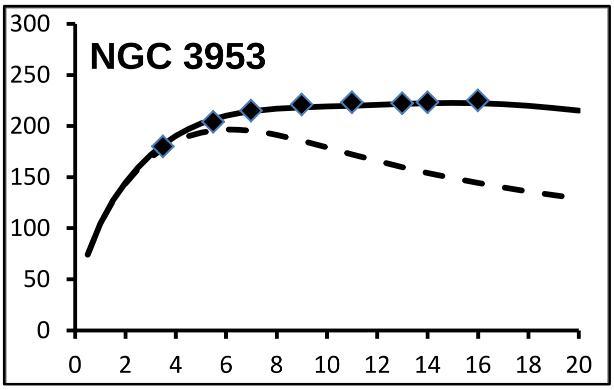
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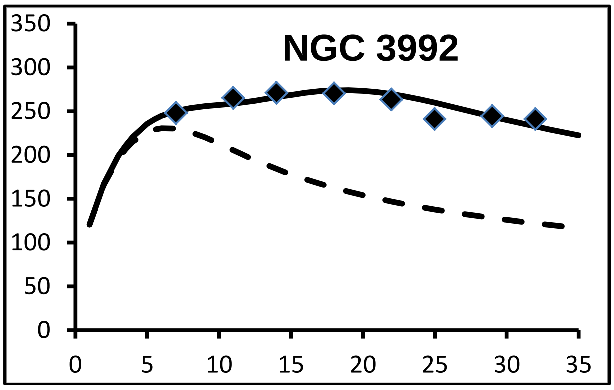
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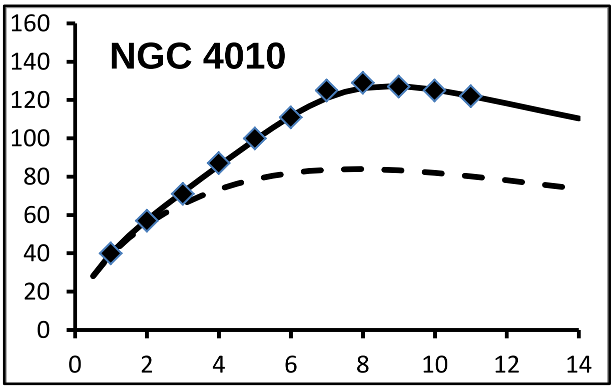
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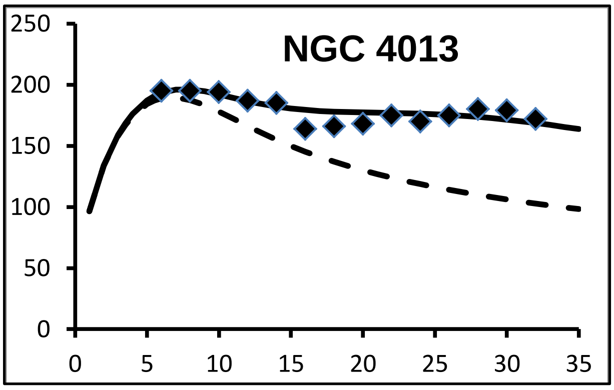
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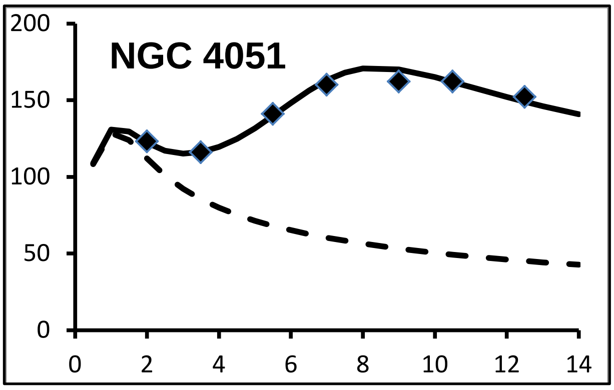
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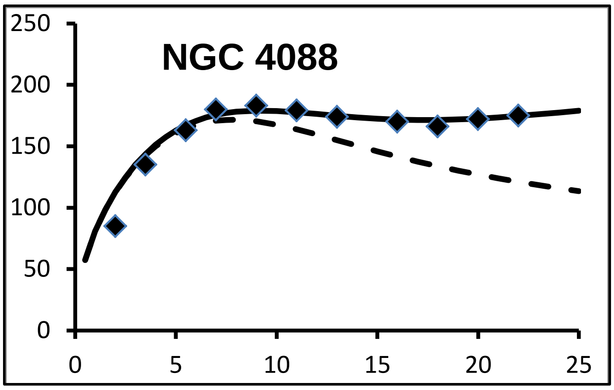
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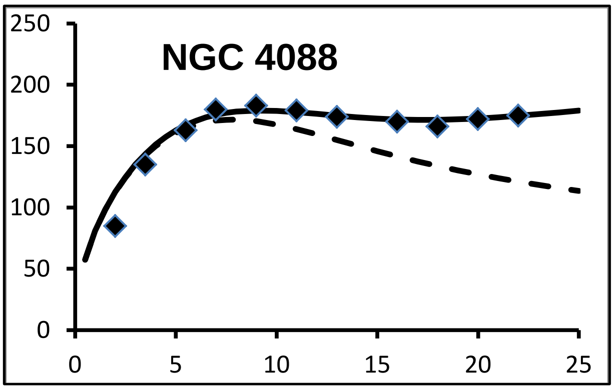
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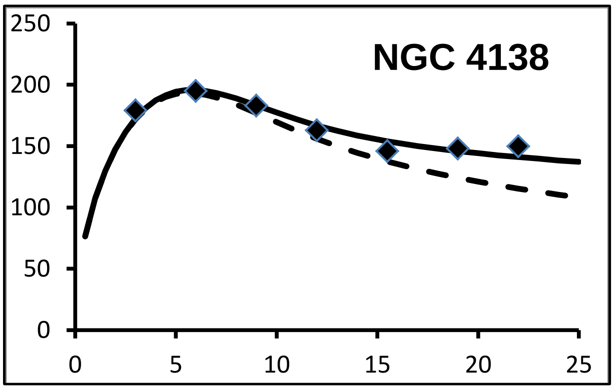
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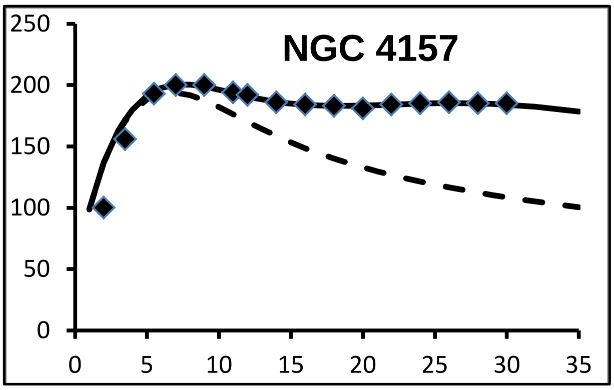
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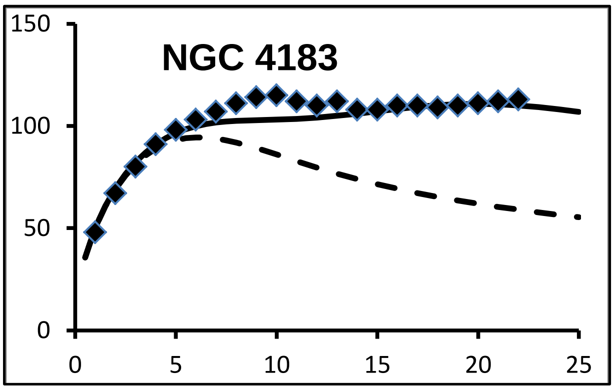
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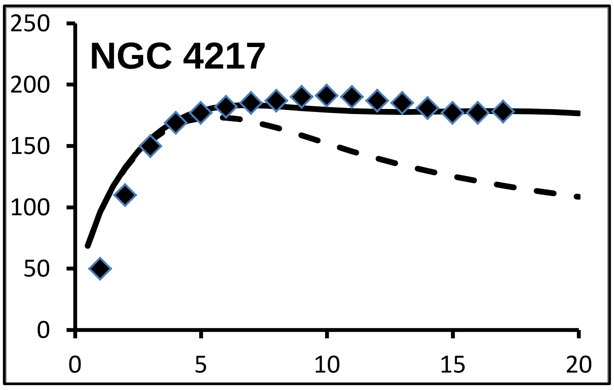
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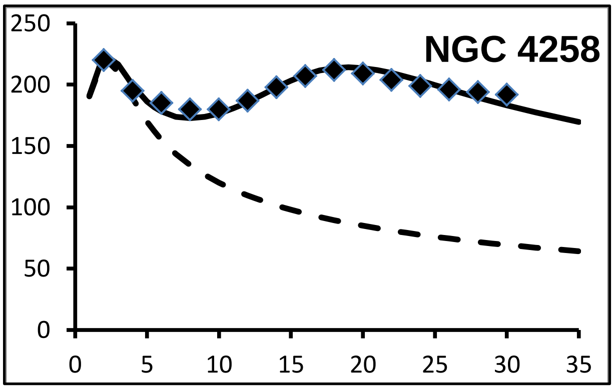
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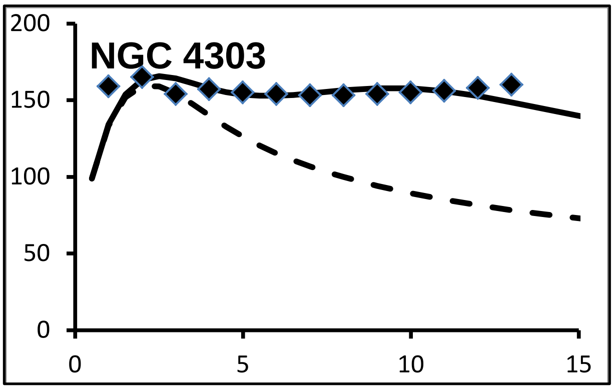
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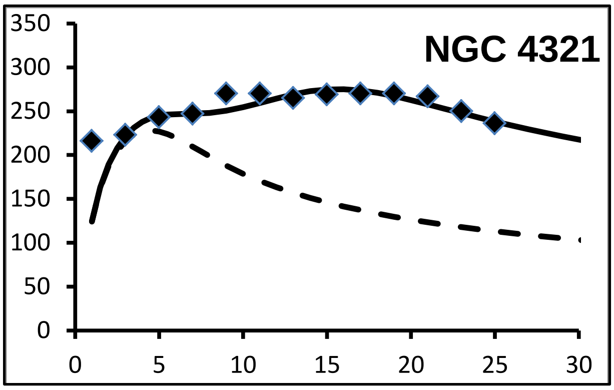
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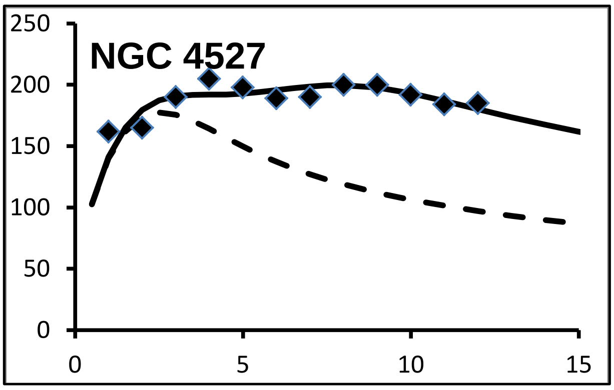
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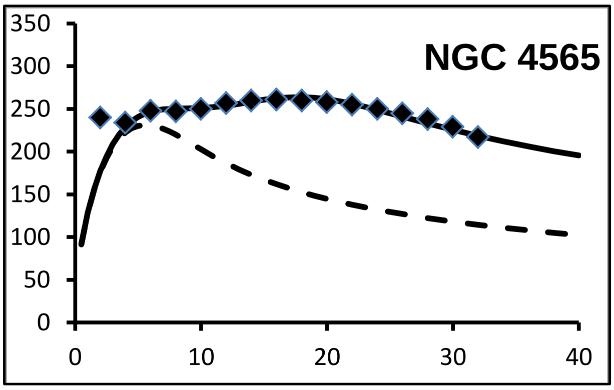
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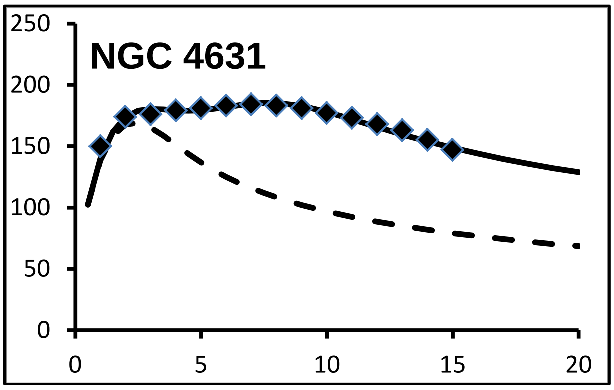
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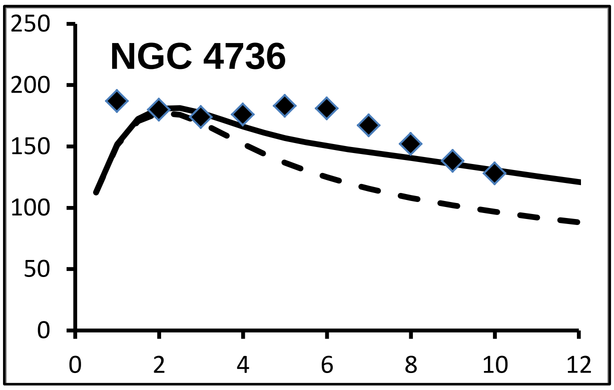
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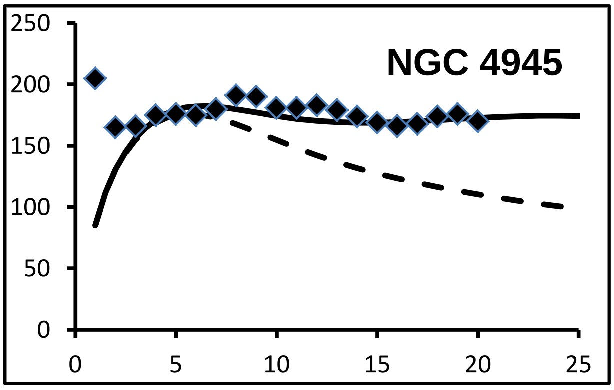
NGC 4945
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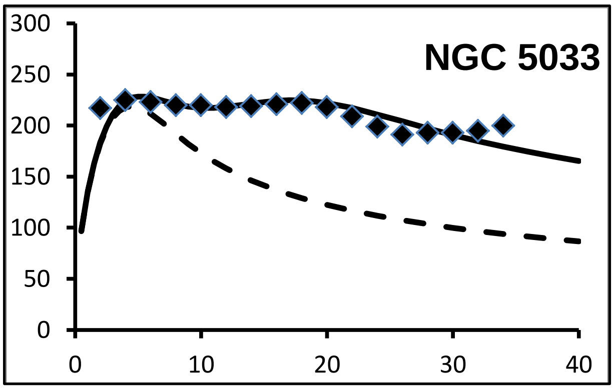
15
20
25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30
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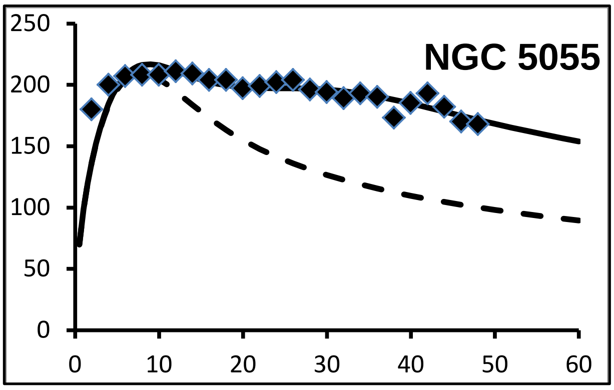
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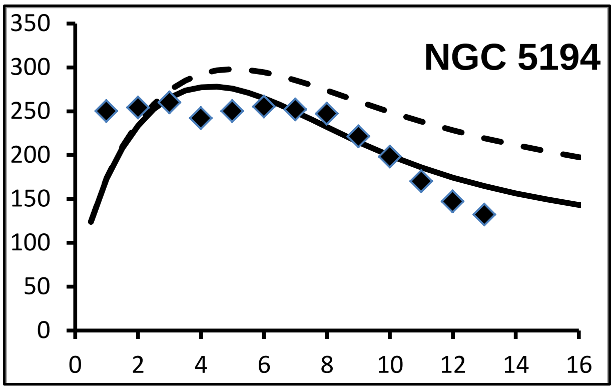
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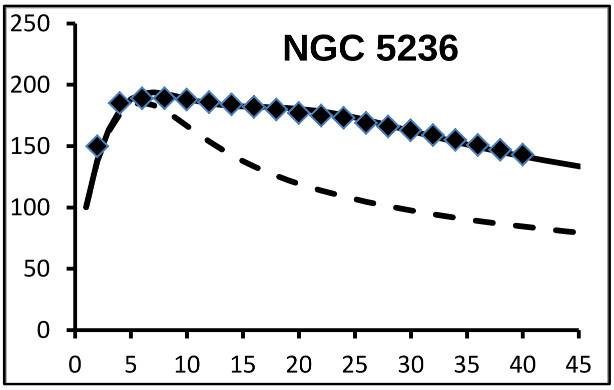
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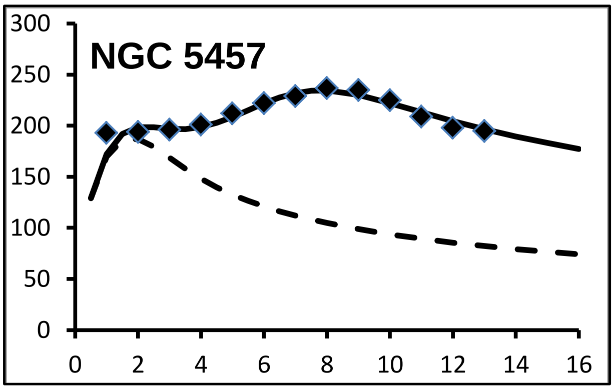
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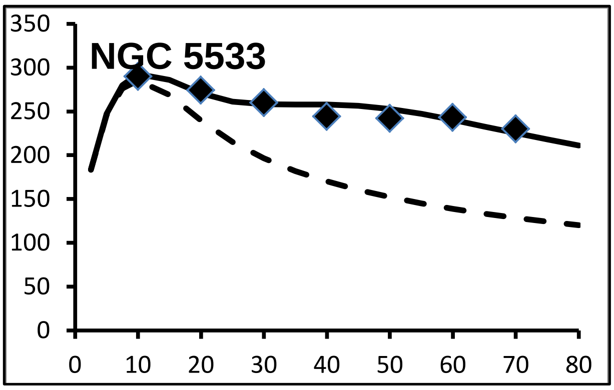
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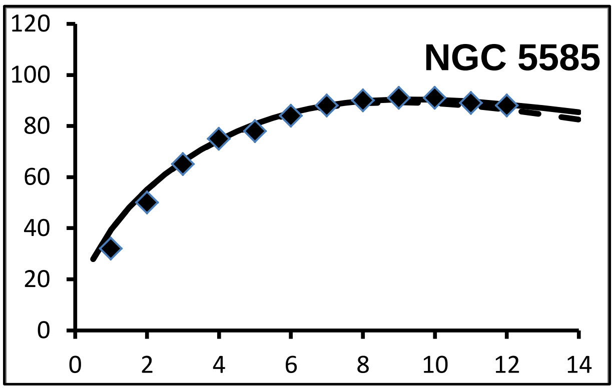
NGC 5585
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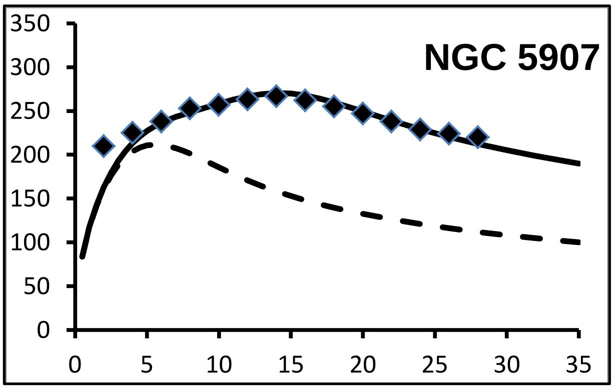
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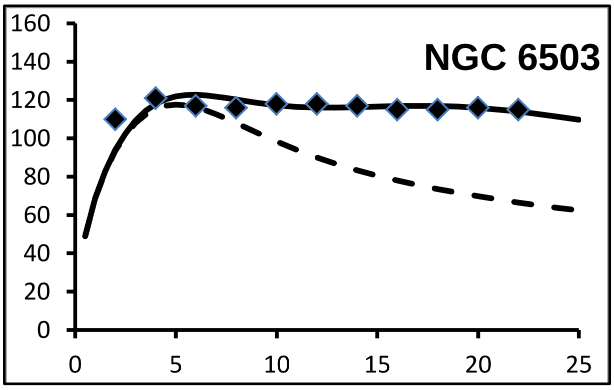
NGC 6503
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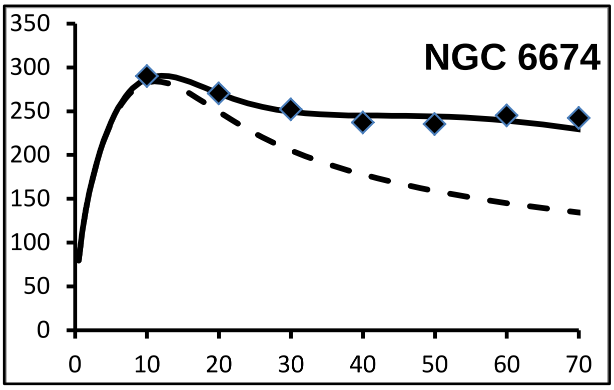
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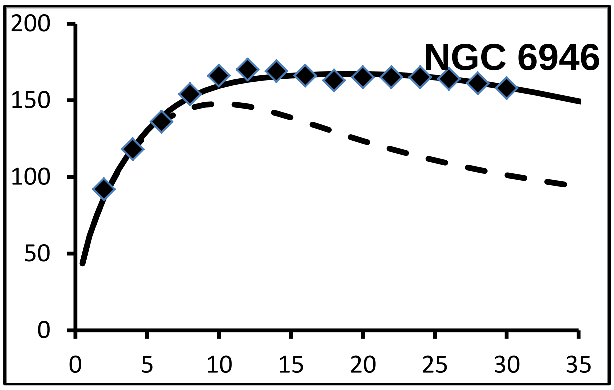
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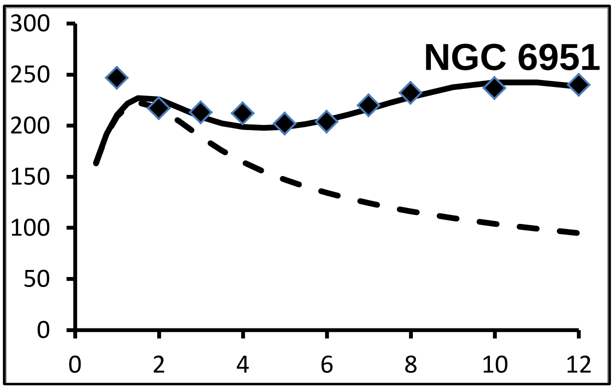
NGC 6951
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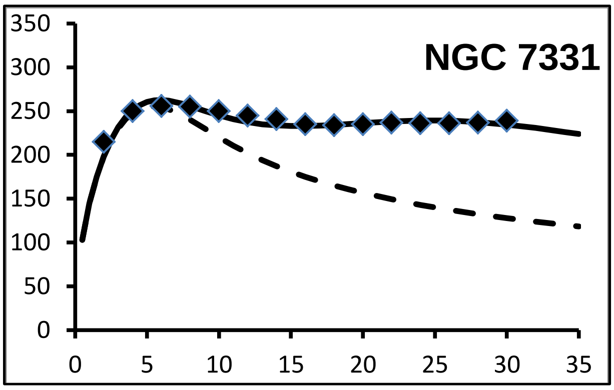
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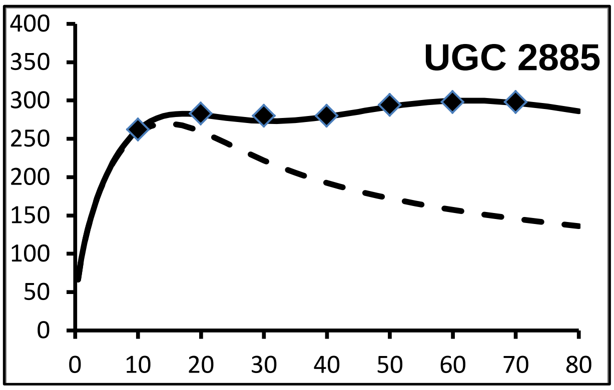
UGC 2885
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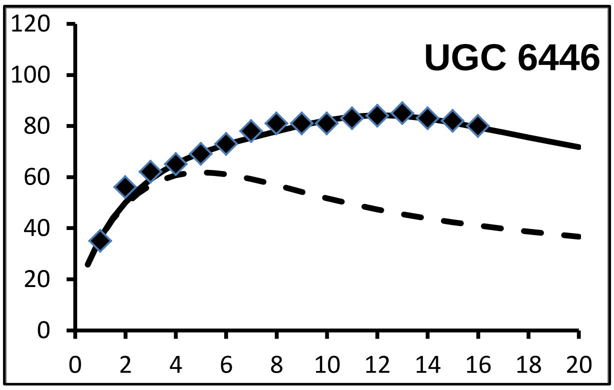
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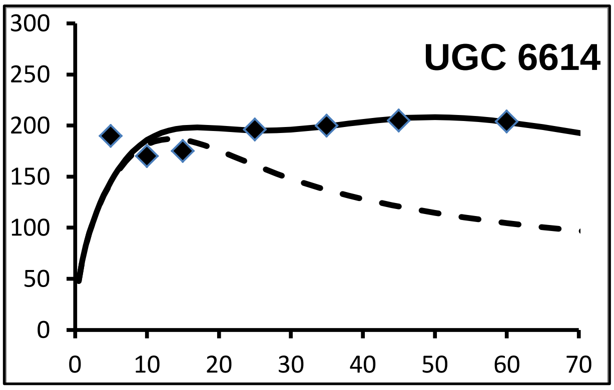
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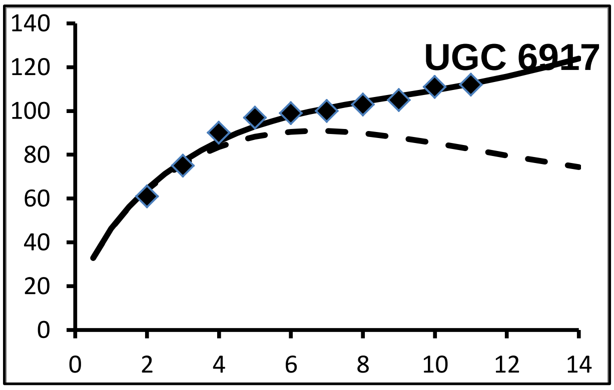
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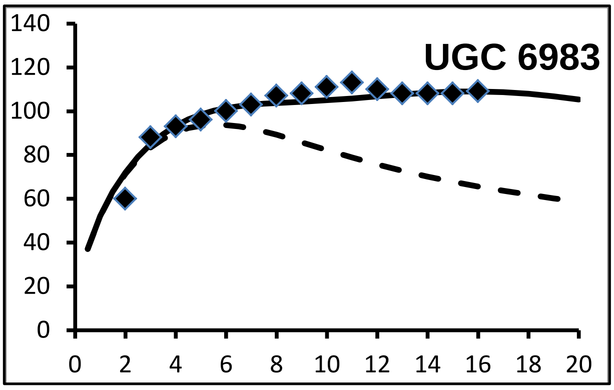
UGC 6983
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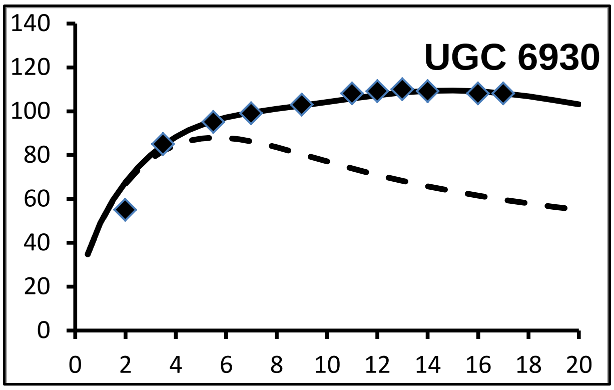
UGC 6930
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20
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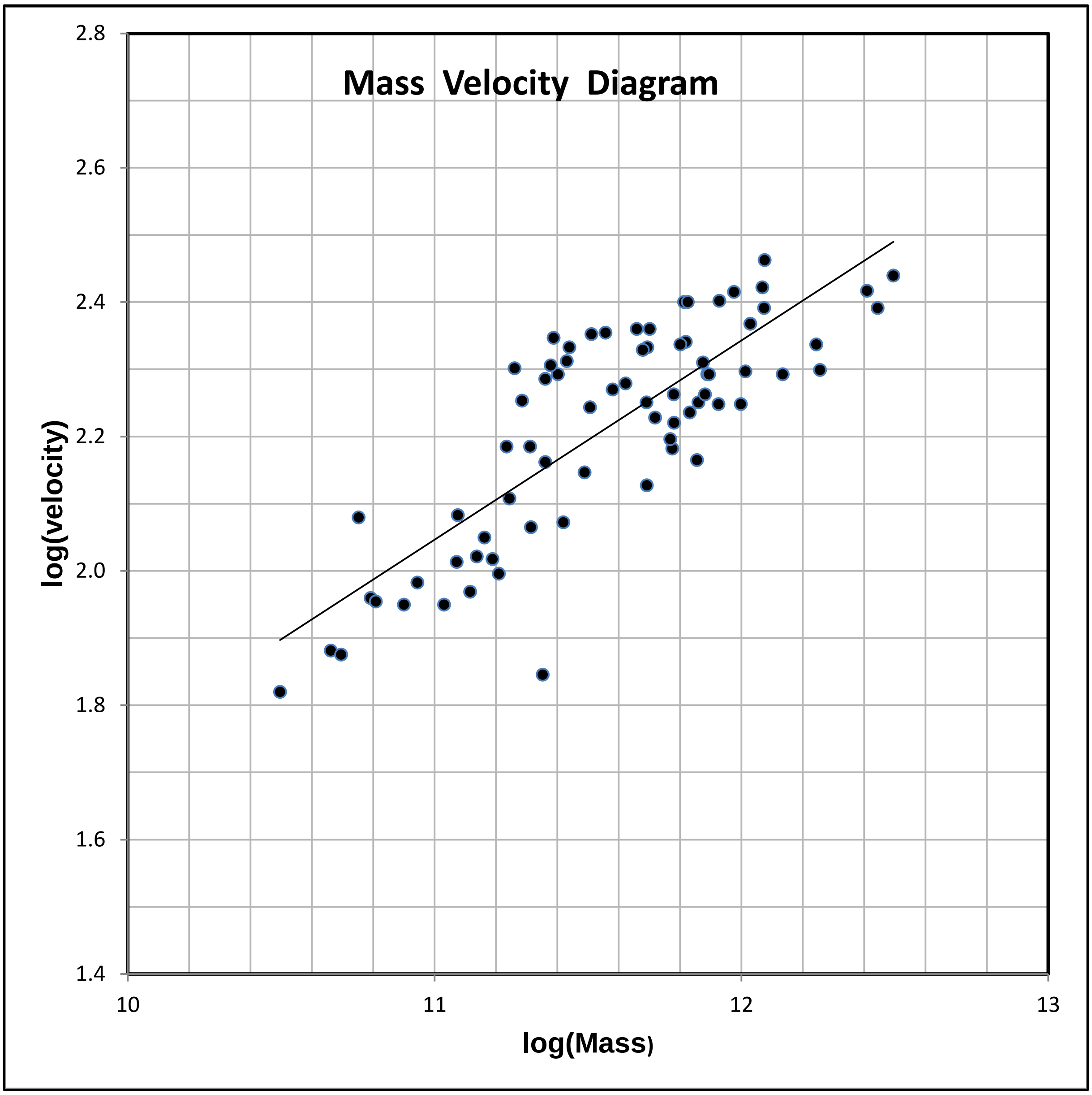
0 2 4 6 8 10 12 14 16 18 20

8 Tulley-Fisher relation

8.1 The figure below plots the rotation velocity at $r=a$ against the derived mass as set out in the table.



8.2 A correlation is apparent. The line plotted has a slope of 0.3. The scatter in the data points suggests that mass varies as either the cube or fourth power of the velocity.

9 Comments

9.1 The rotation curve fits are remarkably good considering the simple nature of the model, namely a simple Gaussian density distribution and a simple Gaussian energy scale fluctuation.

9.2 Spiral galaxies are not smooth distributions of matter, but possess spiral arms and clumps of matter scattered across their disks. So it is not surprising that deviations from the fitted curves are in evidence.

9.3 In several cases the model does not fit the innermost regions of the galaxies. Some galaxies have a linear velocity curve indicating a central region with solid-body rotation.

9.4 The fits have all been done by eye. In many cases the fit is quite loose and it is possible to trade off one parameter against another. A better fitting procedure would be to carry out a grid search against a chi-squared test.

9.5 No attempt has been made to take error bars into account. In just about all cases the apparently poor fit are within the errors.

9.6 The table shows the well-known result that the Andromeda galaxy (NGC 224) is more than twice as massive as the Milky Way.

10 Conclusion

10.1 The hypothesis that variations in the energy scale can explain the rotation curves of spiral galaxies has been extended to a sample of 74 galaxies. No obvious flaws in the hypothesis have been found.

10.2 No modifications have been made to Newton's law of gravitation. No dark matter has been introduced.

10.3 A simple Gaussian density distribution for the galaxy and a simple Gaussian for the fluctuations in the energy scale go a considerable way to reproducing the observed rotation curves.

11 References

Brownstein, JR; Moffat, JW. (2006) The Astrophysical Journal, **636**, 721.
Galaxy rotation curves without non-baryonic dark matter.

Jo.Ke 1. (2015). "On the variation of the energy scale: an alternative to dark matter".

Jo.Ke 2. (2015). "On the variation of the energy scale 2: galaxy rotation curves".