Evidence for Large Deviations from the Hubble Relation in Normal Spiral Galaxies

David G. Russell
Owego Free Academy, Owego, NY 13827
e-mail: dgruss23@yahoo.com; russeld1@oacsd.org

Hubble (1929) presented evidence for a linear relationship between the distance to a galaxy estimated from absolute magnitude criteria and the observed velocity redshift (c_z) of the galaxy. In the standard interpretation of the Hubble "law", deviations from a linear Hubble relationship are relatively small – no more than 1500 km s^{-1} – and are thought to result from bulk flows and peculiar motions gravitationally induced by large mass concentrations. Evidence has accumulated which indicates that some galaxies may deviate significantly from the linear Hubble flow – possibly by over 10,000 km s^{-1} in the most extreme cases. In many instances, evidence for interaction – including bridges - apparently connect two galaxies and sometimes quasars with very different redshifts. In these cases of "discordant redshift", the bridges are generally not considered to be real connections but instead are viewed as accidental projections of a foreground object with a higher redshift background object. However, if the bridges are real connections between objects with large redshift differences, then they would support the existence of a non-cosmological redshift component in some galaxies and quasars.

The best way to establish the existence of a non-cosmological redshift is to determine distances to galaxies using redshift independent distance indicators with small enough scatter to rule out large errors in the calculated distance. In this analysis the Ks-band Tully-Fisher relationship is used to determine distances to normal spiral galaxies. It is found that a number of spiral galaxies have deviations from Hubble's law ranging from 2500 km s^{-1} to 4000 km s^{-1}. Several tests and comparisons demonstrate that these deviations are unlikely to be false deviations resulting from large Tully-Fisher distance errors. Therefore these excessively large deviations from the Hubble law support the possible existence of a non-cosmological redshift component in some normal spiral galaxies.

1. Introduction

Hubble [1] presented evidence for a linear relationship between the distances to galaxies determined from absolute magnitude criteria and the observed redshift velocities of the galaxies – a result confirmed by numerous subsequent studies (see [2-6] for recent reviews and results). The Standard model of the Hubble relationship for galaxies in the local universe may be expressed with the equation: $c_z = H_0 r + V_{pec}$; where c_z is the observed redshift velocity of a galaxy, H_0 is the Hubble constant, r is the distance to the galaxy and V_{pec} is a peculiar velocity component. In this model $H_0 r$ is the cosmological component of the redshift which results from expansion of the universe and V_{pec} results from gravitationally induced motions against the Hubble flow caused by large mass concentrations such as galaxy clusters. Peculiar motions range from less than 100 km s^{-1} to ~1500 km s^{-1} in the most extreme cases [7-8]. In this standard model a galaxy which significantly deviates from the Hubble relationship is assumed to have a large error in the data used to calculate the distance r to the galaxy and therefore would be cut from samples used to determine H_0 or the peculiar velocity field [9-11].

While the standard model of the Hubble relationship treats the velocity-distance correlation as a "law" that all objects follow with small deviations only due to peculiar motions, a substantial body of evidence has accumulated which indicates that some quasars (QSO's), interacting galaxies, and normal galaxies may have significant deviations from the Hubble flow that are too large to be explained by peculiar motions (See [12-16] for reviews of the accumulated evidence). According to this research QSO's are not at the large distances implied by a cosmological interpretation of redshift. Instead quasars are local objects ejected from the cores of active galaxies [13]. Physical evidence for local quasars includes alignments of QSO's across the minor axis of local active Seyfert galaxies such as NGC 5985 [17], NGC 4235 and NGC 2639 [18], and NGC 3516 [19]. The Seyfert 2 galaxy NGC 7319 has a high redshift ULX QSO only 8 arc second from its nucleus [20]. The Seyfert galaxy NGC 4319 has an apparent bridge connecting it to the QSO Markian 205 [21].

If numerous QSO's are local objects, then in addition to the cosmological redshift component and a peculiar velocity redshift component there must also be a non-cosmological redshift component and the observed redshift $c_z = H_0 r + V_{pec} + V_{nc}$ where V_{nc} is the non-cosmological component which may have values ranging from negligible to almost the entire observed redshift in local QSO's. Note that in this model a cosmological redshift is still present so an underlying Hubble relationship is preserved. Most researchers prefer a model for the Hubble relationship that does not include a non-cosmological redshift component and attribute the evidence for local QSO's as simply resulting from chance alignments of low redshift foreground galaxies with higher redshift background galaxies despite the low calculated statistical probabilities of the QSO-galaxy associations being accidental alignments.

In order to demonstrate that a non-cosmological redshift component can exist in some quasars and galaxies it will be necessary to provide evidence in the form of redshift independent distances. In this paper some of the most compelling cases from the literature for galaxies with large deviations from the Hubble relationship will be discussed and then redshift independent Ks-band Tully-Fisher (K-TFR) distances to spiral galaxies will be presented which strongly support the existence of deviations from the Hubble flow at least as large as ~4000 km s^{-1}.

2. Bridges

If two galaxies with very different redshifts can be shown to be interacting, then a strong case for a non-cosmological redshift would be made. One of the strongest pieces of evidence for interaction between two galaxies is the presence of a bridge connecting the galaxies [22]. Zwicky [23] stated that *"these connecting links of intergalactic matter provide the first reliable criterion of whether two, three, or more galaxies are located at the same distance from us."* Johansson & Bergvall [24] provide criteria for considering two galaxies interacting which include the galaxies being *"physically connected via a well-defined bridge"*. Irwin [25] studied the NGC 5775/5775 interaction and concluded that *"Although no strong optical distortions or tidal tails are evident, we have detected a clear interaction in the form of two well-defined HI bridges connecting the galaxies…"*

Bridges make such a compelling case for interaction that Lopez-Sanchez et al [26] chose to include an object in their study for which a HST image suggested it might be a background object because the object was *"coincident with the eastern bridge of Mkn 1087"* and Trentham et al [27] proposed that the luminous filament flowing from UGC 10214 (Figure 1) which does not connect to any visible galaxy might actually be a case of *"…material that is being gravitationally pulled out by a dark companion…"*

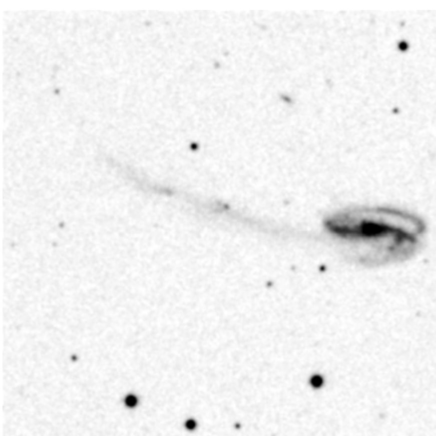

Fig. 1. DSS image of the spiral galaxy UGC 10214.

One of the strongest cases for a probable interaction between two objects with very different redshifts is NGC 7603 - a Seyfert galaxy with a redshift of 8400 km s^{-1} that has a luminous bridge connecting it to a close companion PGC 71041 with a redshift of 16,300 km s^{-1}. In the center of this bridge are two HII galaxies with redshifts of z = 0.39 and z = 0.24 [28]. An equally compelling case is found in NEQ3 [29] which has a z = 0.124 galaxy connected by a filamentary bridge emanating outward from the galaxy to a tight cluster of three QSO's with redshifts of z = 0.1935, 0.1939, and 0.2229. The bridge itself has a redshift of z = 0.19 which matches the redshift of 2 of the QSO's. The third QSO is an anomaly in itself as its redshift is almost 9000 km s^{-1} greater than the redshifts of the two other QSO's it is clustered with.

These connecting bridges provide strong evidence for interaction between objects in the NGC 7603 and NEQ3 systems and therefore evidence for large deviations from a smooth Hubble flow. Ironically, while cosmologists will propose the possible existence of completely dark galaxies [27] when bridge like filaments are present but no companion is evident, the bridges are immediately dismissed as evidence for interaction if there is a significant difference in redshift between the two apparently connected objects. For example Borchkhadze et al [30] presented a study of 16 interacting galaxy systems and noted for ESO 234-19 that *"The reproduction (figure 1i) shows a diffuse object between them. However, the radial velocities differ with about 2200 km s^{-1} so that a connection is probably excluded."* It should be noted in both the NGC 7603 and NEQ3 case that if the companion galaxy is removed as a candidate, then there is no candidate to explain the formation of the bridge unless a hypothesis such as that of [27] is adopted. Clearly some form of interaction is causing these bridges or filaments and the higher redshift companions are the only candidates. Figure 2 shows Digitized Sky Survey (DSS) images of PGC 66146 (left panel) and NGC 7603 (right panel). The similarity of the bridges is apparent in the DSS images. The redshift difference in PGC 66146 is only 152 km s^{-1} compared with a difference of 7898 km s^{-1} in NGC 7603. While PGC 66146 is readily accepted as an interacting pair, NGC 7603 is not simply because of the redshift differential yet there is no other candidate that can explain the existence of the luminous bridge.

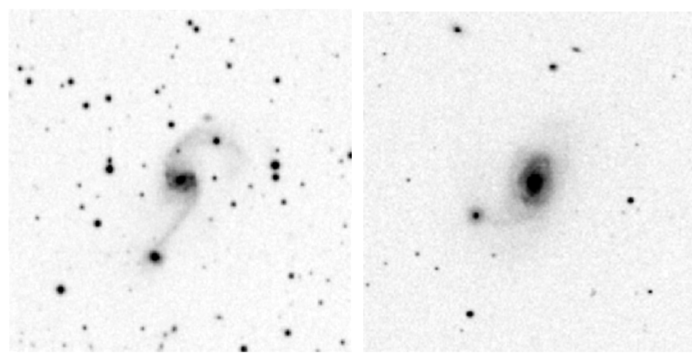

Fig. 2. Interacting galaxies with apparent bridges. PGC 66146 (left) has a redshift difference of only 152 km s^{-1} whereas NGC 7603 (right) has a redshift difference of 7898 km s^{-1}.

3. Centaurus and B2 1637 + 29 Clusters

The Centaurus cluster located at ~35 Mpc distance is known for an intriguing bimodal redshift distribution [31] with the giant elliptical galaxy NGC 4696 at the center of the Cen30 sample with a mean redshift of 3041 km s^{-1} and the giant elliptical galaxy NGC 4709 at the center of the Cen45 sample with a mean redshift of 4570 km s^{-1}. Lucey et al [31] concluded that despite the large velocity differential of the Cen30 and Cen45 groups that they were in fact a single cluster. This was confirmed using redshift independent Surface Brightness Fluctuation method distances to 7 of the elliptical galaxies within the Centaurus cluster [32]. NGC 4696 (Vcmb = 3248 km s^{-1}) has a SBF distance of 34.5 Mpc and NGC 4709 (Vcmb = 4939 km s^{-1}) has a SBF distance of 34.4 Mpc. The two galaxies are separated by 14.4 arc min or 1.4 Mpc at their

SBF distance. Adopting a Hubble constant of 70 km s-1 Mpc-1, NGC 4709 has a redshift excess of +2531 km s-1 relative to a smooth Hubble flow. This is 1000 km s-1 greater than the typical extreme maximum peculiar motions adopted by cosmologists. Two other Cen45 galaxies also have SBF distance in [32] and result in excess redshifts of +2192 km s-1 (NGC 4616) and +2190 km s-1 (ESO 323-34). The observed redshifts in the Centaurus cluster combined with redshift independent SBF distance strongly support the existence of devations from the Hubble flow as large as 2500 km s-1.

De Ruiter et al [33] studied the massive radio galaxy B2 1637 + 29 finding that it is a double galaxy with radio jets emanating from the brighter of the two galaxies. The fainter galaxy in the pair was found to have a redshift velocity that is 4300 km s-1 greater than the redshift of the brighter galaxy. A model that seemed capable of explaining the velocity difference as a result of the interaction between the two galaxies was developed [33]. However, de Ruiter et al [34] found that in the same field as B2 1637+29 there are additional galaxies with redshifts matching both components of the double galaxy. These new galaxy redshifts presented a difficulty for the standard interpretation of redshifts because B2 1637+29 has strong evidence for interaction and therefore the higher redshift component of the double galaxy is needed to explain the strong interaction signs [34-35]. This means the two redshift groups cannot simply be a chance superposition of two small galaxy groups at different distances. As de Ruiter et al [34] conclude:

> *"This alternative is perhaps not very attractive, because the Hubble flow is believed to be reasonably smooth, with deviations (for example due to 'great attractors') much less than a thousand km/s, while here we would have to admit a difference of ~ 4000 km/s in the same region of space, not of a single galaxy but of entire groups of galaxies. On the other hand if we dismiss this possibility, we are left with the question of why a rather anonymous galaxy located in a poor cluster of galaxies, with a background galaxy of similar magnitude at only 6 arcsec, produces such an unusual radio structure."*

Indeed the alternative is not very attractive as this important result has not been cited a single time in the literature by any researchers investigating the standard version of the Hubble relationship without a non-cosmological component. However, it is interesting to note how the B2 1637+29 system with two overlapping groups at the same distance with a 4100 km s-1 difference in redshift is simply a more extreme case of the ~1500 km s-1 difference in redshift found in the Centaurus cluster.

Lopez-Corredoira & Guitierrez [14] added further intrigue to this system when they discovered that along the same line that connects the two components at the center of B2 1637+29 and only 22.4 arcsec distant is a z = 0.568 quasar.

4. NGC 1275

Another criterion for establishing the existence of a large redshift deviation would involve having a higher redshift object clearly superposed in front of a lower redshift object. Such a case exists in NGC 1275 which is a peculiar galaxy with a redshift of 5200 km s-1 with an intervening late type galaxy – possibly an edge on spiral – with a redshift of 8200 km s-1 [36]. This system was found to have HI absorption of the lower velocity nucleus was occurring at the higher velocity and that dust patches were seen in the vicinity of the higher redshift matter [37]. NGC 1275 presents another unambiguous case of a large deviation from a smooth Hubble flow – in this case a galaxy with 3000 km s-1 greater redshift superposed in front of a large, lower redshift galaxy.

5. Ks-Band Tully-Fisher Distances

The Tully-Fisher relationship for spiral galaxies [38] utilizes the linear relationship between the observed rotational velocity of a spiral galaxy and the absolute magnitude of the galaxy to determine redshift independent distances. Observed Tully-Fisher scatter is typically +/- 0.30 mag to +/- 0.50 mag for global templates [39],[40],[41]. However, using strict selection criteria it is possible to significantly reduce the RMS scatter in the TFR. Russell [42] used Ks-band magnitudes from the Two Micron All Sky Survey (2MASS) and observed rotational velocities from the database of [41] to calibrate the morphologically type dependent TFR [43] in the Ks-band. The calibration sample included 36 calibrators with redshift independent Cepheid distances and SBF or Type Ia SN group distances (Fig. 3). Strict selection criteria eliminated galaxies most likely to have large TFR errors. These criteria included (1) restricting the sample to galaxies with rotational velocities > 150 km s-1 as slow rotators are known to have much larger TFR scatter than faster rotators; (2) restricting the sample to galaxies with inclinations between 35 deg and 80 deg to reduce the uncertainty in inclination corrections to both rotational velocities and magnitudes; (3) restricting the sample to galaxies with morphological T-types from 3.1 to 6.0 to reduce the morphological type effect. In addition DSS images of each

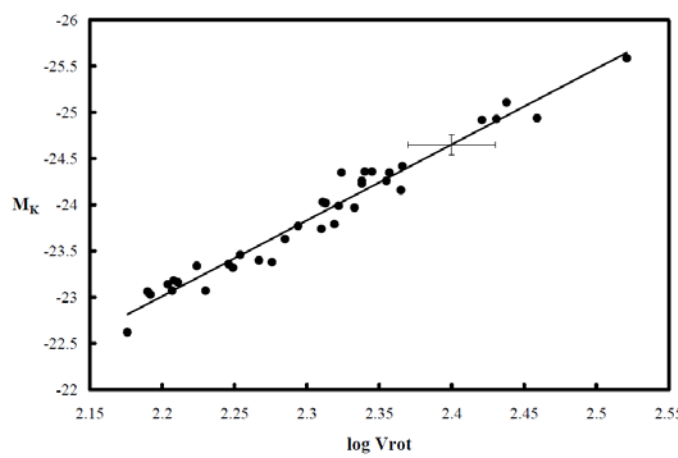

Fig. 3. Ks-band TFR calibration [42].

galaxy in the sample was inspected to ensure that the inclination derived from axial ratios was reasonable, that no superposed stars could contaminate the Ks-band magnitude, that there was no strong disturbance in morphology and that morphology was consistent with that reported in the databases. The resulting Ks-band TFR was found to have a small RMS scatter of only +/- 0.14 mag in the zero point. A scatter this small makes it possible to investigate for large deviations from the Hubble relationship.

The Ks-band calibration was then applied to determine distances to 147 spiral galaxies in clusters and 218 additional ScI galaxies from the sample of Mathewson&Ford [44]. Within the sample of ScI galaxies a sample of 24 galaxies was identified for which a peculiar velocity greater than +2400 km s^{-1} is required to account for the difference between the Ks-TFR distance and the Hubble distance ($H_0 = 70$ km s^{-1} Mpc^{-1}). For 12 of these the peculiar velocity would exceed +3500 km s^{-1}. Evidence demonstrating that the Ks-TFR distances are unlikely to contain large errors that would explain the difference between the Ks-TFR distance and the distance predicted from the Hubble Relation is presented here. In addition it is shown that there can be a significant range in the observed redshift for galaxies at the same distance and a significant range in distance for galaxies with the same redshift – both results suggest large deviations from a smooth Hubble flow.

ESO 501-75 is a spiral galaxy in the Hydra cluster with a rotational velocity of 187 km s^{-1}. The mean redshift for the Hydra cluster is 4080 km s^{-1} and the mean Ks-TFR distance to the cluster is 48.4 Mpc from a sample of 10 galaxies. ESO 501-75 has a Ks-TFR distance very close to the cluster mean (43.9 Mpc) but a redshift of 5587 km s^{-1}. While the ESO 501-75 redshift is 1507 km s^{-1} greater than the Hydra cluster mean it is 2514 km s^{-1} greater than expected if $H_0 = 70$ km s^{-1} Mpc^{-1}. Whereas the Ks-TFR distance modulus for ESO 501-75 is 33.21 +/-0.16, the Hubble distance modulus is 34.51 requiring an unlikely 8.1σ error in the Ks-TFR distance modulus in order for ESO 501-75 to actually be at its Hubble distance. The fact that the ESO 501-75 Ks-TFR distance modulus is consistent with the Hydra cluster mean supports it being at the closer Ks-TFR distance.

This conclusion is further supported by comparisons with other galaxies. For example, within the Hydra cluster the galaxy ESO 501-86 ($V_{\rm rot} = 178$ km s^{-1}) has a redshift of 4082 km s^{-1}. As a galaxy with very similar rotational velocity the redshifts imply that ESO 501-75 should have the appearance of a smaller background galaxy if it is not at the mean Hydra cluster distance. This idea is tested with Digitized Sky Survey images. Figure 4 presents DSS 5 arc min images of ESO 501-75 (upper left) and ESO 501-86 (upper right). These images support the relative accuracy of the Ks-TFR distances as ESO 501-75 clearly has a slightly larger angular diameter and similar resolution of features as expected if the Ks-TFR distances are accurate. For further comparison the galaxies NGC 4480 (lower left) and ESO 317-32 (lower right) are also included in figure 4. NGC 4480 has a rotational velocity of 177 km s^{-1} – only 10 km s^{-1} slower than ESO 501-75, a Ks-TFR distance of 41.3 Mpc – very close to the same distance as ESO 501-75, but a redshift velocity of 2765 km s^{-1} compared with the 5587 km s^{-1} redshift of ESO 501-75. It is readily evident when comparing the DSS 5 arc minute images that – given the very close rotational velocities, ESO 501-75 and NGC 4480 are very close to the same distance. In contrast, the Hubble relation would place ESO 501-75 at twice the distance of NGC 4480. Angular diameters support this interpretation as the 2MASS K_{20} angular diameter of ESO 501-75 is 1.45 arc min whereas the K_{20} angular diameter of NGC 4480 is 1.22 arc min. The ESO 501-75 distance predicted from the Hubble relation (H_0=70) is 79.8 Mpc – nearly twice the actual distance. As a final comparison, the lower right panel in Figure 4 is the galaxy ESO 317-32 which has a redshift of 5738 km s^{-1} – slightly higher than ESO 501-75 and therefore the two galaxies should be at nearly the same distance if the Hubble distances are accurate. ESO 317-32 has a significantly faster rotational velocity of 237 km s^{-1} than ESO 501-75. Once again the images support the Ks-TFR distances as the appearance of ESO 317-32 is noticeably smaller in the DSS image whereas the 50 km s^{-1} faster rotational velocity and close redshift value would lead to a prediction that ESO 317-32 should appear significantly larger than ESO 501-75 if the redshift distances are accurate. These comparisons support the conclusion that ESO 501-75 is at ~44 Mpc distance with an excess redshift of ~ +2500 km s^{-1} relative to the redshift predicted from a smooth Hubble flow.

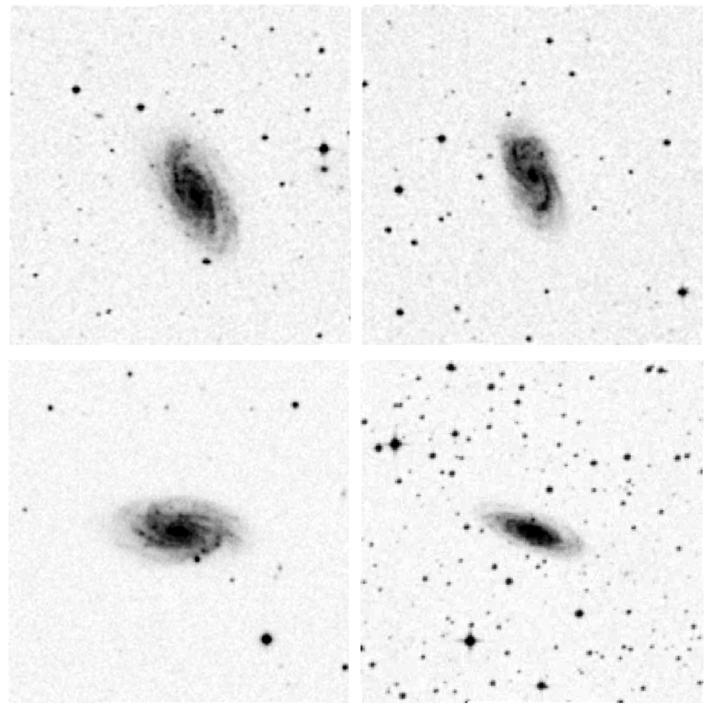

Fig. 4. ESO 501-75 (upper left); ESO 501-86 (upper right); NGC 4480 (lower left); ESO 317-32 (lower right).

ESO 445-27 has a rotational velocity of 250 km s^{-1}, a Ks-TFR distance modulus of 35.21 +/- 0.24 (110.2Mpc), and a redshift velocity of 11654 km s^{-1}. A smooth Hubble flow predicts a redshift of 7714 km s^{-1} at a distance of 110.2 Mpc and therefore ESO 445-27 has an excess redshift of +3940 km s^{-1}. This excess redshift is 2.6x larger than the most extreme +1500 km s^{-1} peculiar motions expected in local clusters. The Hubble distance to ESO 445-27 is 166.5 Mpc – or 56.3 Mpc more distant than the Ks-TFR distance. Differences between TFR and Hubble distances this large are usually attributed to errors in the TFR data. However, the data does not support that interpretation. The Hubble distance modulus for ESO 445-27 is 36.11 which is +0.90 mag larger than the Ks-TFR distance modulus. The uncertainty in the Ks-TFR distance modulus derived from uncertainty in the rotational velocity and Ks-band magnitude uncertainty is only +/- 0.24 mag – 3.6 times smaller than needed if the Ks-TFR distance contains significant error. In order to account for the difference between the redshift distance modulus and the Hubble distance modulus the rotational velocity of ESO 445-27 would need to be 322 km s^{-1} – which is 70 km s^{-1} larger than the observed rotational velocity of ESO 445-27. This could be achieved if the actual inclination of ESO 445-27 was 43 deg rather than the 61 deg reported by[41]. However, visual inspection of the ESO 445-27 image confirmed that the inclination should be within +/- 5 deg of 61 deg and cannot be close to 43 deg. In addition, the ESO 445-27 rotation curve in [44] (Figure 5) used by Springob et al [41] to derive the rotational velocity shows a nice flat profile which further reduces the odds of a larger rotational velocity error. A large error in the Ks-band magnitude is ruled out as the uncertainty in the 2MASS Ks-band magnitude was only +/-0.055 mag.

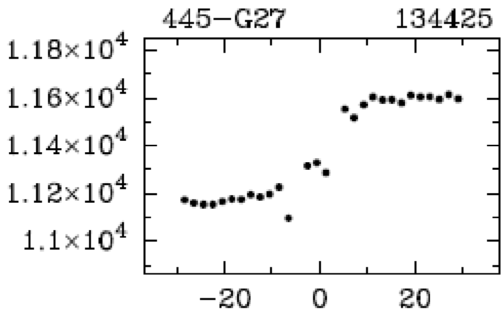

Fig. 5. ESO 445-27 rotation curve [44].

While large errors in Ks-TFR data seem ruled out and therefore the Ks-TFR distance modulus should be accurate to within +/-0.24 mag, there are further arguments supporting ESO 445-27 being at the Ks-TFR distance rather than the Hubble distance. Three other galaxies with angular separations that place them within 13 Mpc of ESO 445-27 and with redshifts within 1300 km s^{-1} of the ESO 445-27 redshift have Ks-TFR distances virtually identical to ESO 445-27. These galaxies are listed in Table 1 with their rotational velocity, Ks-TFR distance, redshift velocity, and difference between the predicted and observed redshift at their Ks-TFR distance. While it might be easy to infer ESO 445-27 is a TFR outlier, it becomes more challenging to explain four galaxies in relatively close proximity, all giving Ks-TFR distances in the narrow range of 109.7 to 115.3 Mpc and with very similar redshifts as multiple cases of bad Ks-TFR data. In fact, there is another redshift independent distance that supports the Ks-band TFR distances. The spiral galaxy IC 4232 (cz = 9801 km s^{-1}) has a Type Ia SN distance of 117.1 Mpc [3] and is only 208 arc min (6.7 Mpc) from ESO 444-31. This independent distance strongly supports the Ks-TFR distances and therefore the existence of large excess redshifts in these four galaxies ranging from +2476 km s^{-1} in ESO 444-31 to +3940 km s^{-1} in ESO 445-27.

Galaxy	**V_{rot} km s^{-1}**	**Distance Mpc**	**Redshift km s^{-1}**	**ΔV_{70} km s^{-1}**
ESO 445-27	250	110.2	11654	+3940
ESO 578-16	233	115.3	11270	+3199
ESO 444-31	218	112.2	10330	+2476
ESO 509-94	211	109.7	11521	+3842

Table 1. ESO 445-27 companion galaxies

Visual inspection of DSS 5 arc min images of ESO 445-27 and a sample of comparison galaxies overwhelmingly supports the accuracy of the ESO 445-27 Ks-TFR distance. Figure 6 compares ESO 445-27 with IC2104, ESO 527-11, and CGCG 476-111. These three comparison galaxies have similar rotational velocities to ESO 445-27, and have Ks-TFR distances ranging from 79.4 Mpc to 159.2 Mpc. Each of these galaxies is also has a Ks-TFR distance that is very close to the H_0=70 Hubble distance as can be seen with the data in Table 2. Comparing the IC 2104, ESO 527-11, and CGCG 476-111 images demonstrates the natural progression in appearance expected when comparing images of galaxies of similar rotational velocity at successively larger distances. As the distance increases angular diameter decreases and resolution of features is less evident. It is striking to note from inspection of the images in Figure 6 how closely ESO 445-27 (upper right) resembles ESO 527-11 (118.6 Mpc – lower left) in appearance – not only in overall apparent angular diameter but also in apparent resolution of features. This is what is expected from the Ks-TFR distances as ESO 527-11 has a slightly larger rotational velocity than ESO 445-27 and a slightly greater Ks-TFR distance. The 2MASS K_{20} angular diameters support the visual appearance in the images as ESO 445-27 has a K_{20} diameter of 1.01 arc min and ESO 527-11 has a K_{20} angular diameter of 0.92 arc min. Despite being 8.4 Mpc more distant than ESO 445-27, ESO 527-11 has a redshift (8007 km s^{-1}) that is 3647 km s^{-1} smaller than the redshift of ESO 445-27. This is evidence that there can be deviations from a smooth Hubble flow over 3000 km s^{-1}.

CGCG 476-111 (159.2 Mpc lower right in Figure 6) provides additional evidence for the large excess redshift of ESO 445-27 as it has a redshift of 11536 km s^{-1} - nearly the same as the redshift of ESO 445-27. According to the Hubble relation ESO 445-27 and CGCG 476-111 should be at virtually the same distance and given that CGCG 476-111 has a 36 km s^{-1} larger rotational velocity it should have a slightly larger angular diameter than ESO 445-27. Visual inspection of the images in Figure 6 clearly demonstrate that – given the rotational velocities ESO 445-27 and CGCG 476-111 cannot be at the same distance and that ESO 445-27 should be significantly closer than CGCG 476-111 – exactly as found using the Ks-TFR. Note the smaller apparent angular diameter of CGCG 476-111 and the lower resolution of features is a comparison made worse for the Hubble distances when the larger rotational velocity of CGCG 476-111 is factored into the comparison. The 2MASS K_{20} angular diameters again support the visual appearance as the K_{20} diameter of CGCG 476-111 is 0.66 arc min.

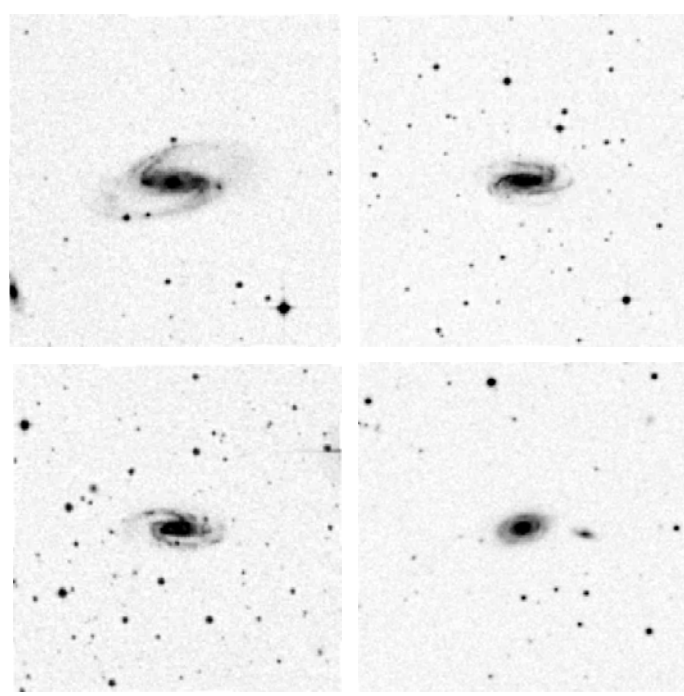

Fig. 6. IC2104 (upper left); ESO 445-27 (upper right); ESO 527-11(lower left); CGCG 476-111 (lower right).

The comparison of ESO 445-27 with CGCG 476-111 and ESO 527-11 demonstrates that (1) two galaxies at nearly the same distance can have significantly larger redshift differences than the generally expected +/-1500 km s^{-1} maximum peculiar motions and (2) galaxies with virtually identical redshift can be at significantly different distances. In this comparison it is seen that despite being at nearly the same distance ESO 445-27 has a 3647 km s^{-1} larger redshift than ESO 527-11 and despite having nearly the same redshift ESO 445-27 is 49.0 Mpc closer than CGCG 476-111.

Galaxy	V_{rot} km s^{-1}	Distance Mpc	Redshift km s^{-1}	H_0 km s^{-1} Mpc^{-1}
IC2104	79.4	245	5475	69.0
ESO 527-11	118.6	270	8007	67.5
ESO 445-27	110.2	250	11654	105.7
CGCG 476-111	159.2	286	11536	72.5
ESO 385-26	132.5	267	7806	58.9
ESO 509-52	152.8	250	12258	80.2
CGCG 108-139	173.9	270	11212	64.5

Table 2. Data for galaxies in Figures 6 & 7.

The ESO 445-27, ESO 527-11, and CGCG 476-111 comparison is just one example from numerous comparisons made using the Springob et al [41] TFR database. Figure 7 compares ESO 445-27 (upper left) with ESO 385-26 (upper right), ESO 509-52 (lower left), and CGCG 108-139 (lower right). Table 2 provides data on these galaxies. ESO 385-26 has a rotational velocity of 267 km s^{-1} and a Ks-TFR distance of 132.5 Mpc. Visual inspection of the images supports the relative Ks-TFR distances as despite the 17 km s^{-1} larger rotational velocity, ESO 385-26 clearly has a smaller angular diameter than ESO 445-27 – supporting its greater distance. The 2MASS K_{20} angular diameter of ESO 385-26 is 0.75 arc min which also confirms the relative Ks-TFR distances. *Remarkably, despite having a 22.3 Mpc greater distance than ESO 445-27, ESO 385-26 has a redshift of 7806 km s^{-1} or 3848 km s^{-1} smaller than the ESO 445-27 redshift!*

ESO 509-52 has a 208 arc min angular separation from ESO 445-27, a rotational velocity of 250 km s^{-1} which matches that of ESO 445-27, and a redshift velocity of 12,258 km s^{-1} which is only 604 km s^{-1} larger than the ESO 445-27 redshift. The Hubble relation would predict very similar distances and appearance in the DSS images. However, the Ks-TFR distance to ESO 509-52 is 152.8 Mpc. Visual inspection of the DSS image and the 2MASS K_{20} angular diameter of ESO 509-52 (0.58 arc min) both confirm that ESO 509-52 is more distant than ESO 445-27.

The lower right panel in Figure 7 is CGCG 108-139 which has a redshift of 11212 km s^{-1} and therefore would be at nearly the same distance as ESO 445-27 if the Hubble distances were correct. In fact, the Ks-TFR distance to CGCG 108-139 is 173.9 Mpc which is very close to its Hubble distance. Given the slightly larger rotational velocity, CGCG 108-139 should have a slightly larger angular diameter in the DSS image. Once again visual inspection of the image supports the conclusion that ESO 445-27 is much closer than its Hubble distance as ESO 445-27 shows a significantly larger angular diameter and a much greater resolution of features – consistent with what is expected if it actually lies at a Ks-TFR distance ~64 Mpc closer than CGCG 108-139.

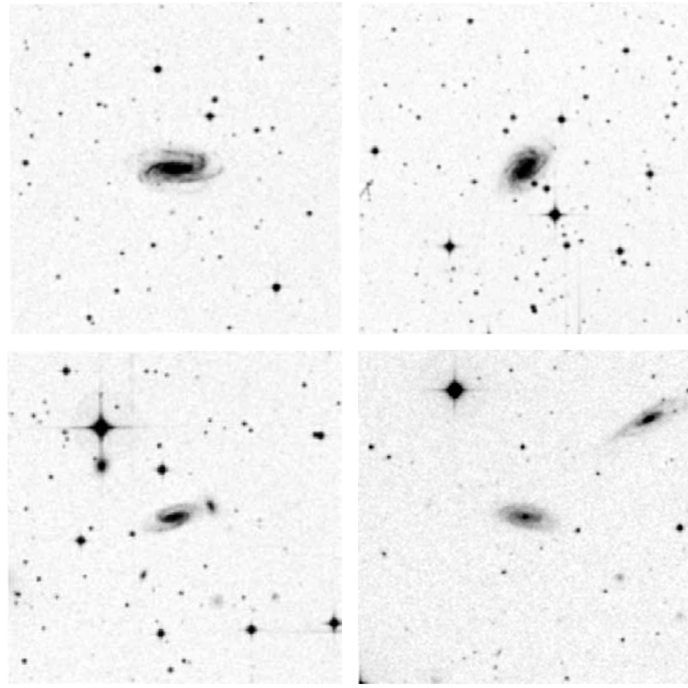

Fig. 7. ESO 445-27 (upper left); ESO 385-26 (upper right); ESO 509-52 (lower left); CGCG 108-139 (lower right).

6. Conclusion

ESO 445-27 and ESO 501-75 are not isolated cases. Figure 8 and Table 3 provides DSS images and data for several additional examples. However, the cumulative evidence presented above provides a strong case that the galaxy ESO 445-27 has an excess redshift of +3940 km s^{-1} relative to the redshift expected from a smooth Hubble flow. An excess redshift of this magnitude is significantly larger than expected from peculiar motions and could indicate the presence of a non-cosmological redshift component in this galaxy. Note also that the ESO 445-27 excess redshift is nearly the same magnitude as the redshift differential in the B2 1629+37 clusters and half the magnitude of the redshift differential in the NGC 7603 bridged association. Accurate redshift independent distances are required to establish the existence of large deviations from the Hubble relation. The Ks-TFR distance to ESO 445-27 provides exactly this test of the Hubble relation. Combined with the Ks-TFR distances to ESO 444-31, ESO 509-94, and ESO 578-16, the Type Ia SN distance to IC 4232 and the comparisons made by visual inspection of DSS images the existence of large deviations from the Hubble relationship is well-established. These deviations do not prove, but do strongly support the existence of a non-cosmological redshift in normal spiral galaxies.

Galaxy	V_{rot} km s^{-1}	Distance Mpc	Redshift km s^{-1}	ΔV_{70} km s^{-1}
ESO 147-2	198	118.0	11878	+3618
ESO 532-23	194	127.1	6940	-1957
ESO 578-16	233	115.3	11270	+3199
ESO 467-17	232	113.2	8318	+ 394
ESO 509-94	211	109.7	11521	+3842
ESO 378-21	207	114.3	8514	+ 513

Table 3. Data for galaxies in Figure 8.

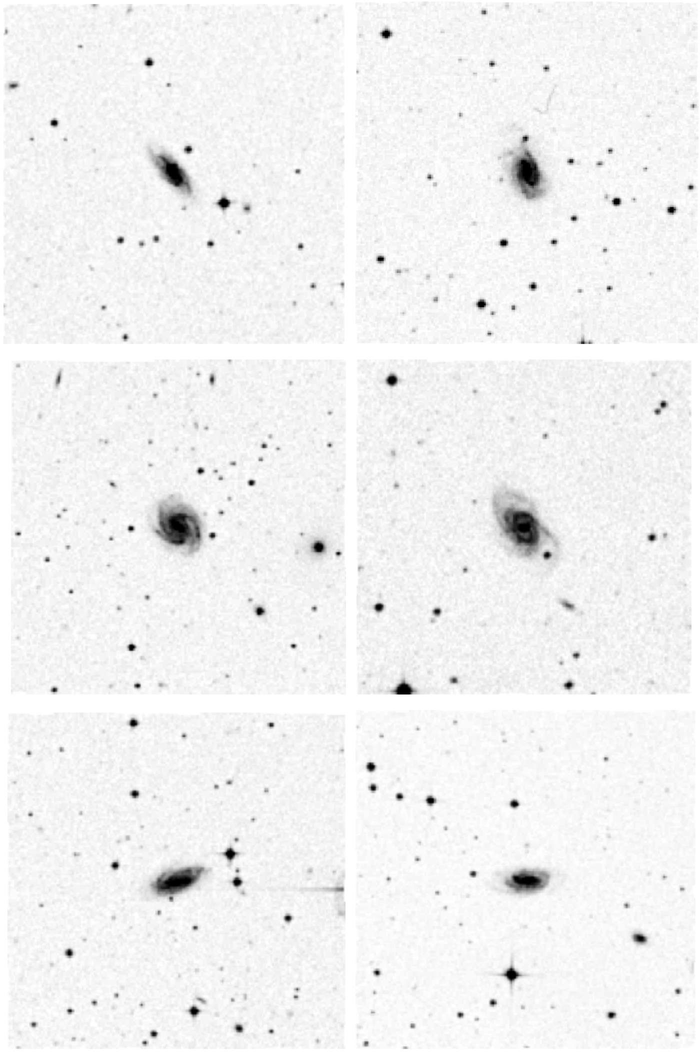

Fig. 8. ESO 147-2 (upper left); ESO 532-23 (upper right); ESO 578-16 (middle left); ESO 467-17 (middle right); ESO 509-94 (lower left); ESO 378-21 (lower right).

Acknowledgements

This research has made use of the NASA/IPAC Extragalactic Database (NED) which is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration. This research has made use of the HyperLeda database (http://leda.univ-lyon1.fr). Figures 2 and 4 are images extracted from the Digitized Sky Survey. The Digitized Sky Surveys were produced at the Space Telescope Science Institute under U.S. Government grant NAG W-2166. The images of these surveys are based on photographic data obtained using the Oschin Schmidt Telescope on Palomar Mountain and the UK Schmidt Telescope.This research also makes use of data from Two Micron All Sky Survey, which is a joint project of the University of Massachusetts and the Infrared Processing and Analysis Center, funded by NASA and the NSF.

References

[1] E. W. Hubble, "A Relation between Distance and Radial Velocity among Extra-Galactic Nebulae", *Proceedings of the National Academy of Sciences of the USA* **15** (3): 168-173 (1929).

[2] V. Trimble, "H_0: The Incredible Shrinking constant 1925-1975", *Publications of the ASP* **108**: 1073-1082 (1996).

[3] W. L. Freedman et al, "Final Results from the Hubble Space Telescope Key Project to Measure the Hubble Constant", *The Astrophysical Journal* **553**: 47-72 (2001).

[4] G. A. Tammann, "The Ups and Downs of the Hubble Constant", astro-ph/0512584 (2005).

[5] G. A. Tammann et al, "The expansion field: the value of H0", *The Astronomy & Astrophysics Review* **15** (4): 289-331 (2008).

[6] A. Sandage et al, "The Linearity of the Cosmic Expansion Field from 300 to 30,000 km s^{-1} and the Bulk Motion of the Local Supercluster with Respect to the Cosmic Microwave Background", *The Astrophysical Journal* **741**: 1441-1459 (2010).

[7] I. D. Karachentsev et al, "The Linearity of the Cosmic Expansion Field from 300 to 30,000 km s^{-1} and the Bulk Motion of the Local Supercluster with Respect to the Cosmic Microwave Background", *Astrofizika* **46** (4): 399-414 (2003).

[8] J.B. Jensen et al, "The Extragalactic Distance Scale", astro-ph/0304427 (2003).

[9] Y. N. Kudrya et al, "The bulk motion of flat edge-on galaxies based on 2MASS photometry", *Astronomy & Astrophysics* **407**: 889-898 (2003).

[10] I. D. Karachentsev, "A list of peculiar velocities of RFGC galaxies", astro-ph/0107058 (2000).

[11] T. Goto, "Velocity dispersion of 335 galaxy clusters selected from the Sloan Digital Sky Survey: statistical evidence for dynamical interaction and against ram-pressure stripping", *Monthly Notices of the RAS* **359** (4): 1415-1420 (2005).

[12] H. Arp, "Peculiar Galaxies and Radio Sources", *The Astrophysical Journal* **148**, 321-365 (1967).

[13] H. Arp, **Seeing Red** (Apeiron, 1998).

[14] M. Lopez-Corredoira & C. M. Gutierrez, "Research on Candidates for Non-Cosmological Redshifts", astro-ph/0509630 (2005).

[15] M. Lopez-Corredoira, "Apparent Discordant Redshift QSO-Galaxy Associations", arXiv:0901.4534.

[16] M. Lopez-Corredoira, "Pending Problems in QSO's', arXiv:0910.4297.

[17] H. Arp, "A QSO 2.4 arcsec from a dwarf galaxy – the rest of the story", *Astronomy&Astrophysics* **341**: L5-L8 (1999).

[18] H. Arp, "Pairs of X-ray sources across Seyferts: the NGC 4235 field", *Astronomy&Astrophysics* **328**: L17-L20 (1997).

[19] Y. Chu et al, "Quasars around the Seyfert Galaxy NGC 3516", *The Astrophysical Journal* **500**: 596-598 (1998).

[20] P. Galianni et al "The Discovery of a High Redshift X-Ray Emitting QSO Very Close to the Nucleus of NGC 7319", *The Astrophysical Journal* **620**: 88-94 (2005).

[21] J. W. Sulentic & H. Arp, "The galaxy-quasar connection - NGC 4319 and Markarian 205. I - Direct imagery. II – Spectroscopy", *The Astrophysicsl Journal* **319**: 687-708 (1987).

[22] A. Toomre & J. Toomre, "Galactic Bridges and Tails", *The Astrophysical Journal* **178**: 623-666 (1972).

[23] F. Zwicky, "Luminous Intergalactic Matter", *Publications of the Astronomical Society of the Pacific* **64** (380): 242-246 (1952).

[24] L. Johansson & N. Bergvall, "A study of a complete sample of interacting galaxies. I - Presentation of the sample and the UBVRIJHK photometry", *Astronomy & Astrophysics Supplement* **86**: 167-188 (1990).

[25] J. Irwin, "Arcs and Bridges in the Interacting Galaxies NGC 5775/NGC 5774", *The Astrophysical Journal* **429**: 618-633 (1994).

[26] A. R. Lopez-Sanchez et al, "The tidally disturbed luminous compact blue galaxy Mkn 1087 and its surroundings", *Astronomy & Astrophysics* **428**: 425-444 (2004).

[27] N. Trentham et al, "Completely dark galaxies: their existence, properties and strategies for finding them", *Monthly Notices of the Royal Astronomical Society* **322**: 658-668 (2001).

[28] M. Lopez-Corredoira & C. Gutierrez, "Two emission line objects with z > 0.2 in the optical filament apparently connecting the Seyfert galaxy NGC 7603 to its companion", *Astronomy & Astrophysics* **390**: L15-L18 (2002).

[29] C. Gutierrez & M. Lopez-Corredoira, "QSO+Galaxy Association and Discrepant Redshifts in NEQ3", *The Astrophysical Journal* **605**: L5-L8 (2004).

[30] T. M. Borchkhadze et al, "Sixteen Southern Interacting Galaxy Systems with Emission Lines", *Astronomy & Astrophysics Supplement* **30**: 35-43 (1977).

[31] J. R. Lucey, "The Centaurus cluster of galaxies. II - The bimodal velocity structure", *MNRAS* **221**: 453-472 (1986).

[32] J. L. Tonry, "The SBF Survey of Galaxy Distances. IV. SBF Magnitudes, Colors, and Distances", *The Astrophysical Journal* **546**: 681-693 (2001).

[33] H.R. de Ruiter et al, "B2 1637+29, A Massive Radio Galaxy Probing a Poor but Gas-Rich Group", *The Astrophysical Journal* **329**: 225-231 (1988).

[34] H. R. de Ruiter et al, "The peculiar radio galaxy B2 1637+29: a high velocity encounter of two galaxy groups?", *Astronomy & Astrophysics* **337**: 711-713 (1998).

[35] L. Colina & L. de Juan, "Collisions of Ellipticals and the Onset of Fanaroff-Riley type I Radio Sources", *The Astrophysical Journal* **448**: 548-562 (1995).

[36] V. Rubin et al, "New Observations of the NGC 1275 Phenomenon", *The Astrophysical Journal* **211**: 693-696 (1977).

[37] W. Keel, "Dust in Backlit Galaxies: Properties of the Foreground systems in NGC 3314 and NGC 1275", *The Astronomical Journal* **88**: 1579-1586 (1983).

[38] R. B. Tully & J. R. Fisher, "A new method of determining distances to galaxies", *Astronomy & Astrophysics* **54**: 661-673 (1977).

[39] S. Sakai et al, "The Hubble Space Telescope Key Project on the Extragalactic Distance Scale. XXIV. The Calibration of Tully-Fisher Relations and the Value of the Hubble Constant", *The Astrophysical Journal* **529**: 698-722 (2000).

[40] R. B. Tully & M. J. Pierce, "Distances to Galaxies from the Correlation between Luminosities and Line Widths. III. Cluster Template and Global Measurement of H_0", *The Astrophysical Journal* **533**: 744-780 (2000).

[41] C. Springob, "SFI++. II. A New I-Band Tully-Fisher Catalog, Derivation of Peculiar Velocities, and Data Set Properties", *The Astrophysical Journal Supplement* **172**: 599-614 (2007).

[42] D. G. Russell, "The Ks-band Tully-Fisher Relation — A determination of the Hubble parameter from 218 ScI galaxies and 16 galaxy clusters", *Journal of Astrophysics and Astronomy* **30**: 93-118 (2009).

[43] D. G. Russell, "Morphological Type Dependence in the Tully-Fisher Relationship", *The Astrophysical Journal* **607**: 241-246 (2004).

[44] D. Mathewson & V. Ford, "Parameters of 2447 Southern Spiral Galaxies for Use in the Tully-Fisher Relation", *The Astrophysical Journal Supplement* **107**: 97-102 (1996).