A Simple Guide to NEOWISE Data Problems

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In a paper recently submitted to a scientific journal and posted as a preprint on arXiv, I pointed out a number of weaknesses in results previously published – and widely cited – from the NEOWISE asteroid mission. The 110-page manuscript is full of detailed arguments about statistics and the physics of how asteroids absorb and reflect sunlight and then emit infrared light. It's all pretty complicated stuff, written for an audience of professional astronomers, physicists, and statisticians.

But the most egregious problems with the NEOWISE project are dead simple to explain; indeed, this might be a good project for a middle-school science class. In this guide, I show how anyone can examine the data themselves and spot the most critical errors. It's a great example of how scientific debates that seem complicated sometimes come down to really simple issues.

Background

Let's begin with a little background. NEOWISE is a NASA-funded project that spent millions of taxpayer dollars to estimate the diameter of more than 150,000 asteroids, as well as other physical properties of the objects. It did this by analyzing observations of the infrared (IR) light given off by the asteroids and picked up by the WISE satellite. WISE is a space telescope that is a bit like a supersized and more sophisticated version of the thermal cameras used to spot heat leaks in a building.

The NEOWISE project used a technique called thermal modeling to convert the brightness of each asteroid at several different infrared "colors" (wavelength bands) into an estimate of the object's diameter. The most widely used thermal model is NEATM (near-Earth asteroid thermal model), which dates from the 1990s and estimates the infrared emission due to the warmth of the asteroid itself. The NEOWISE team of astronomers modified the NEATM model to add infrared emissions due to sunlight reflected by the asteroid. Accounting for reflected sunlight is more important when analyzing data from the WISE space telescope than it has been for previous telescopes.

In addition to estimating diameter, the NEOWISE group also estimated other asteroid parameters, such as objects' albedo, both in visible light and in the infrared. (Albedo is a scientific term for reflectivity – how much of the sun's light reflects from the asteroid.) But the most important parameter is diameter because it effects all of the others.

In a series of scientific papers, the NEOWISE team published the diameter and other parameters for about 158,000 asteroids. That's a huge contribution. For comparison, the largest previous study provided data on about 2,200 asteroids. The large scope of these studies made them hugely influential. And the data sets have been used by many other asteroid researchers. That is why it is really important to get the NEOWISE data right.

There are at least three other ways than thermal modeling to estimate the diameter of an asteroid. One is to use radar from large radio telescopes to bounce signals off the asteroid. It's a great technique, but unfortunately it works for relatively few asteroids. A second method is called stellar occultation, which means blocked starlight. Every now and then (less often than one may think), an asteroid will move in front of a bright star, and observers on Earth see the star wink out for a short period. If you time the event accurately, you can use the duration of the wink to estimate the size of the asteroid. A third and even more accurate method is to visit the asteroid. Some space probes have flown close enough to asteroids to get nice pictures from which we can measure their diameters. Recently, for example, NASA obtained wonderful pictures of Ceres, one of the largest asteroids. I refer frequently in this guide to radar, occultation, and spacecraft analyses, which I lump together with the acronym ROS.

Unfortunately, ROS estimates are available for relatively few asteroids. Of the 158,000 asteroids studied by NEOWISE, ROS estimates have been published for only about 150 – so roughly one asteroid in a thousand. As a result, the main value of ROS estimates is that they let us check whether the estimates produced by thermal models are accurate or not.

The idea is simple. If we can gain confidence that thermal modeling works well on the ROS asteroids, then we can feel confident about our understanding of the vastly more numerous asteroids for which all we have are diameters estimated from thermal models.

The Problem

One big problem my new paper identifies with certain previous NEOWISE studies is that they didn't just use ROS diameters as described above – as a way to validate their thermal models. Instead they presented ROS diameters as estimates *produced by* their thermal models. The diameters were exactly copied.

The first paper to consider is (Masiero et al., 2011), which has the title "Main Belt Asteroids with WISE/NEOWISE. I. Preliminary Albedos and Diameters." Fortunately, *The Astrophysical Journal*, in which the NEOWISE group published its results, is open access, so you can download the paper here: http://iopscience.iop.org/article/10.1088/0004-637X/741/2/68.

The abstract sums up the purpose of this paper pretty well: "Using a NEATM thermal model fitting routine, we compute diameters for over 100,000 Main Belt asteroids from their IR thermal flux, with errors better than 10%."

Table 1 in the paper presents an excerpt of the most important results, presented at "Thermal Model Fits." This full table includes more than 100,000 entries and can be downloaded from http://iopscience.iop.org/0004-637X/741/2/68/suppdata/apj398969t1_mrt.txt or directly available from Caltech/JPL at http://wise2.ipac.caltech.edu/staff/bauer/NEOWISE_pass1/.

Here is a snapshot of Table 1, where I have added some colored graphics to make it easier to see the relevant part of the table. The "Object" columns lists the identifying number for each asteroid, and the D column lists the diameter generated by their model – or so they claim.

THE ASTROPHYSICAL JOURNAL, 741:68 (20pp), 2011 November 10 MASIERO ET AL.

Diameter

Table 1
Example of Electronic Table of the Thermal Model Fits

Object	H	G	D	p_V	η	p_{IR}	# obs (W1-W4)
00002	4.060	0.11	544.000 ± 42.916	0.1417 ± 0.0195	0.938 ± 0.049	0.0961 ± 0.0229	11 11 11 0
00002	4.060	0.11	544.000 ± 60.714	0.1419 ± 0.0456	0.774 ± 0.074	0.0816 ± 0.0155	11 11 8 0
00005	6.850	0.15	115.000 ± 9.353	0.2451 ± 0.0509	0.994 ± 0.065	0.3313 ± 0.0669	9 13 13 13
00006	5.710	0.24	185.000 ± 10.688	0.2685 ± 0.0488	0.840 ± 0.061	0.3810 ± 0.0346	14 14 14 13
00008	6.350	0.28	140.000 ± 1.160	0.2614 ± 0.0484	0.794 ± 0.029	0.4348 ± 0.0453	15 17 16 17
00009	6.280	0.17	204.528 ± 3.671	0.1300 ± 0.0184	1.059 ± 0.012	0.2665 ± 0.0366	15 15 14 15
00009	6.280	0.17	190.791 ± 4.901	0.1493 ± 0.0343	0.878 ± 0.026	0.3144 ± 0.0188	10 10 10 10
00010	5.430	0.15	453.239 ± 19.244	0.0579 ± 0.0051	0.928 ± 0.026	0.0648 ± 0.0054	11 11 6 0
00011	6.610	0.15	159.108 ± 5.944	0.1585 ± 0.0365	0.937 ± 0.048	0.2923 ± 0.0298	9 10 9 10
00012	7.240	0.22	126.643 ± 3.199	0.1400 ± 0.0137	0.947 ± 0.026	0.2818 ± 0.0341	17 19 14 21
00013	6.740	0.15	227.000 ± 25.948	0.0690 ± 0.0218	0.894 ± 0.139	0.0443 ± 0.1426	0 4 4 8

(This table is available in its entirety in a machine-readable form in the online journal. A portion is shown here for guidance regarding its form and content.)

I have drawn a red and green boxes around some of the asteroid entries. In the red boxes, note that the diameters, which are in units of kilometers, all end in ".000." In contrast, the diameters for asteroids highlighted by the green box include non–zero digits all the way out to the nearest 0.001 km, which is the nearest meter.

Note also that some asteroids (such as asteroids 00002 and 00009) appear on multiple rows. That is because the NEOWISE team broke up the data in a non-standard way and performed separate curve fits on 3-day to 10-day segments rather than simply fitting all of the data available. It doesn't make any sense to do that, but that's a separate and more complicated issue that I discuss in my paper.

Here is the problem in a nutshell. The diameters boxed in red above – as well as more than 100 others not shown here – are exactly equal, to the nearest meter, to ROS diameters published in papers well before the NEOWISE studies.

Some of the supposed NEOWISE results aren't NEOWISE results at all – they were directly copied from the work of others.

You can check this yourself. Asteroid 2 (also known as Pallas or 00002) has a diameter of 544.000 km in the table above from Masiero et al., 2011. Compare it to the entry for that asteroid in Shevchenko and Tedesco, 2006, one of the ROS papers, which is available at http://www.sciencedirect.com/science/article/pii/S001910350600128X.

In Table 1 of the Shevchenko paper we find this:

Table 1
Aspect data of asteroids and results of calculations

Diameter

Asteroids	Date	α	λ_{2000}	β_{2000}	Class	D_{occ}	D_{IRAS}	p_{IRAS}	p_{pol}	H	p_H	$V(1,4)^a$	$p_{V(1,4)}$	Qua
1 Ceres	1984 Nov 13.19653	3.4	46.781	−8.657	G?,C	933	848	0.11	0.076	3.34	**0.0936**	3.73	0.0653	3e
2 Pallas	1978 May 29.22569	14.3	254.929	48.451	m,B	544	498	0.16	0.087	4.04	**0.145**	4.37	0.1066	3e

Here, column D_{occ} gives the diameter determined by the occultation method. It matches the Masiero value for asteroid 2 Pallas (aka 00002) exactly. Turning to another ROS source, Durech et al. 2011, available at http://www.sciencedirect.com/science/article/pii/S0019103511001072 or http://arxiv.org/abs/1104.4227, we find the following table.

Diameter

List of results

Asteroid	D [km]	λ_p [deg]	β_p [deg]	P [hr]	D_{IRAS} [km]	rms_1 [km]	rms_2 [km]	Reference
2 Pallas	539 ± 28	35	−12	7.81323	498 ± 19	14.2	16.6	Torppa et al. (2003)
3 Juno	252 ± 29	103	27	7.209531	234 ± 11	14.3	17.4	Kaasalainen et al. (2002b
5 Astraea	115 ± 6	126	40	16.80061	119 ± 7	3.2	3.4	Ďurech et al. (2009)

Check out the value for the diameter of asteroid 5 Astraea (aka 00005): it is 115 km, exactly equal to the diameter listed in the Masiero Table 1 above. You may also notice that asteroid 2 Pallas is also in this table, with a different diameter than in the Shevchenko or Masiero tables. That is typical; one almost never gets the same number from different ROS studies, mainly as a result of measurement error.

You can also see that asteroid 00002 in the Masiero table matches diameter reported by the Shevchenko and Tedesco rather than the estimate given by Durech et al. It is not clear why the NEOWISE authors copied from one source versus another in each case. But it is clear thatthese numbers were copied, not computed as claimed.

The excerpt from Masiero Table 1 includes six examples of copying for five asteroids. But if you compare the diameters given in the complete table of more than 100,000 asteroids to those in the ROS references (see links below), you will find, as I did, exact matches in 117 cases, involving 102 asteroids.

The same problem occurs as well in another one of the main NEOWISE papers: Mainzer, Grav, Bauer, et al., 2011, "NEOWISE Observations of Near Earth Objects: Preliminary Results." The paper is at http://iopscience.iop.org/article/10.1088/0004-637X/743/2/156, and its data table is available at http://iopscience.iop.org/0004-637X/743/2/156/suppdata/apj408731t1_mrt.txt. This paper presents 428 diameters, again stating that they are the results of thermal model fits. But six of the diameters, for three asteroids, exactly match ROS number previously published.

Between these two Masiero and Mainzer papers, I found 123 exact matches to ROS diameters for 102 asteroids. (The three asteroids that have the exact matches in Mainzer also appear in Masiero – even though that makes no sense because one is about main belt asteroids and the other is about NEOs.) The table at the end of this guide lists all 123 cases, along with references so that anyone can check them easily. (This list is also included in my paper as Table 4.) You can check them yourself because I also list the references and the URLs.

The matches are certainly not coincidence. All of the ROS papers pre-date the first NEOWISE papers, and in fact are referenced by one of them. The NEOWISE team definitely knew about them. Nor is it credible to think that the NEOWISE model fitting just happened to arrive at exactly the same estimates, down to the meter. In section 4.3 of my paper, I calculate the odds of this occurring by chance. Even under incredibly generous assumptions, those odds are less than 1 in 10^{210}, which is pretty much the same as saying it is impossible.

You might wonder whether the ".000" is important to the effect. Maybe they just rounded some diameters differently? This seems like a poor explanation to me. Estimates for the other asteroids in the same papers are carried out to the nearest meter. There is no valid reason to selectively round some asteroids and not others.

Moreover, the odds against just the first three digits matching (i.e. matching at the kilometer level rather than to the meter) are still astronomical (pun intended). You just can't get that number of exact matches by coincidence.

It is interesting that while the diameters were copied the estimated errors (the numbers with ± in front of them) were not. That suggests that the NEOWISE team did their own error analysis after copying the diameters, while holding diameter fixed.

Remember that the scientific purpose of comparing diameters from thermal model fits to ROS diameters is to test whether the thermal models are able to come up with estimates that are close to the ROS diameters. The *only* possible way to perform such a test is to first compute diameters from your thermal models, then as a separate step, compare them to the ROS diameters.

Previous studies have done exactly that. Ryan & Woodward (2010), for example apply two different thermal models – STM and NEATM – to asteroids and then present a table comparing the results to ROS measurements. Here is an excerpt from that paper, which is available at http://iopscience.iop.org/article/10.1088/0004-6256/140/4/933:

RYAN & WOODWARD

Table 5
Asteroid Diameters from Thermal Model, Radar, and Occultation Measures

Asteroid Number	STM Diameter (km)	NEATM Diameter (km)	Radar or Occultation Diameter (km)	Source Reference[a]
1	855.463 ± 56.960	886.476 ± 27.304	933.750 ± 4.789	1
2	479.812 ± 20.180	523.982 ± 20.833	539.700 ± 21.108	1
3	248.481 ± 6.840	262.012 ± 12.047	269.550 ± 2.460	1
4	520.367 ± 6.840	515.855 ± 19.247	505.000 ± 4.252	1
5	97.968 ± 3.623	133.726 ± 6.468	110.500 ± 5.423	1

When Masiero et al. claim in their abstract that the diameters they obtain by fitting thermal models are accurate to "better than 10%," that implies they have compared their computed diameters to some gold-standard method of measuring diameters. The only standards available are the ROS diameters. They ought to include a table just like the one by Ryan and Woodward. One could then compute the percentage accuracy for each asteroid, and tally it up collectively for a group. But the Masiero et al. paper includes no such comparison, so there is no way to check their claim of high accuracy.

What is much worse is that copying the diameter of the ROS examples exactly complete defeats the ability for anyone else to make that comparison.

It strikes me as completely illogical to report thermal-modeling diameters for everything *except* the only asteroids that one could possibly verify the models with. Yet that's exactly what these two NEOWISE papers did.

The Red Herring Explanation

When my paper was released in preprint form, it was immediately covered by several media outlets. The reporters of course asked two of the principal WISE and NEOWISE astronomers, Dr. Amy Mainzer and Professor Ned Wright, about these curious matches to the ROS diameters. Unfortunately, the scientists skirted the topic by raising one red herring after another. That is why I have written this guide: to counter this feint, in the hope that others will press them to provide real answers to the substantive questions raised by my study.

In a written statement about my paper to a reporter for *The New York Times*, Dr. Mainzer said:

> In Mainzer et al. 2011 Astrophysical Journal 736, 100, radar measurements were used as ground truth in order to compute model WISE and visible fluxes, which were compared to the measured fluxes and found to be in good agreement (Figure 3). This is how the WISE flux calibration for asteroids was validated. The paper reported the radar diameters, because these were held fixed so that the predicted WISE fluxes could be computed. The caption for Table 1 of the paper states "The diameters and H values used to fit each object from the respective source data (either radar, spacecraft imaging, or occultation) are given."

And in a statement given to a reporter for *Science*, Dr. Mainzer reiterated, referring to section 4.3 of my paper, which discusses the copying of ROS diameters:

> The paper mischaracterizes the use of the radar/occultation/flyby diameters. In Mainzer et al. 2011 ApJ 736, 100, the NEOWISE team uses these diameters as calibrator targets to compute model brightnesses and compare them to the measured brightnesses for the objects. They are in excellent agreement. The radar/occultation/flyby sources are cited in this paper; later papers reference this calibration paper.

These "explanations" are actually a dodge, in two ways at once.

First, it's a dodge because it gives a misleading impression about a paper we haven't yet discussed, Mainzer, Grav, Masiero, et al., 2011, "Thermal Model Calibration for Minor Planets Observed with Wide-Field Infrared Survey Explorer/NEOWISE," available at http://iopscience.iop.org/article/10.1088/0004-637X/736/2/100/pdf. In this paper, Mainzer and her coauthors do argue that it is legitimate to use the ROS diameters – *in that paper alone* – to "calibrate" the colors and other aspects of their thermal model.

One might think that "calibration" means what it typically does in science – that one measures an empirical value of one or more parameters that then guarantees that you'll get the same result – at least for the calibration set, and hopefully more.

This is emphatically not the case here. The NEATM model has no calibration parameters. What Mainzer and coworkers mean by "calibration" is debatable, but they appear to mean more in the sense of validation – that when they calculate their color correction (to adjust to the properties of the WISE sensor), they get roughly the same observed IR flux from the test objects using the ROS diameters as they see from the asteroids they represent.

It would be surprising (suspicious, even) if thermal model fitting then produced diameter estimates that exactly match ROS diameters to six digits of precision.

Dr. Mainzer's explanations were a dodge in a second, even more important way. They don't bear at all on the two studies that I show unjustifiably copied ROS diameters, namely the Masiero et al. Main Belt study and the Mainzer et al. NEO study mentioned above. In those papers, the diameters match ROS figures for 102 asteroids – far more than the 47 that match in the calibration paper that Dr. Mainzer cited. There is no explanation in those papers that diameters were copied, let alone a justification for why it was done. Nor can I imagine any justification that would pass scientific muster.

The proper procedure these two papers should have taken is clear:

1. Fit thermal models to all of the asteroids in the same manner, regardless of whether an ROS diameter is available or not.
2. Then for asteroids which also have a ROS diameter, compare the unbiased thermal model result to the ROS diameter.

Ryan and Woodward followed this simple and logical approach, as has nearly every other research group working in this area except for the NEOWISE team. It's the standard because it is the only way to gain confidence that a thermal model generates good estimates for the 150,000 or so asteroids that lack ROS diameter measurements.

How could this happen?

The NEOWISE group includes many highly respected scientists, who deserve the benefit of the doubt. One would expect the corresponding authors on the study to correspond with me and answer the questions I put to them as I uncovered these irregularities in their published work. Instead, with one exception, they flatly refused to correspond with me the moment I asked a simple physics question about NEOWISE (about Kirchhoff's law, but that's a separate topic.)

The only person connected with WISE/NEOWISE who would communicate was Professor Wright, who is the principal investigator of WISE but is not formally part of the NEOWISE group. He offered me some very important pointers. Yet he too declined to answer most of my questions or gave frustrating, cryptic responses like "you start out correct but then go astray."

Denied the help of those who could most easily address my concerns, I emailed other asteroid researchers who had published papers using WISE/NEOWISE data. They all said the same thing: first, that they could not replicate the results, and second, that the NEOWISE team did not answer their emailed questions either. A number of them, cited in the acknowledgements section of my paper, looked over my results and provided helpful feedback.

Clearly the NEOWISE team, as a federally funded research group, should be more transparent and cooperative with other scientists in the asteroid research community. And clearly they should offer full and forthright explanations about problems that I and others have pointed out in their published work.

Absent that cooperation, we are left to speculate about what went wrong. I have wracked my brain about this issue and talked with astronomical colleagues about it. So far I have been able to come up with just a few possibilities:

- **Colossal error.** It is possible that a software bug, file corruption or some other accidental source somehow copied the diameters of the ROS sources over the diameters that NEOWISE calculated.
- **Fraud.** While it is uncomfortable for scientists to confront this, the fact that is that in all walks of life people make things up. Scientific misconduct is unfortunately a well-known phenomenon.
- **Something else.** This is a complex area of science, and it is possible that there is some innocent explanation.

Let me be clear that I don't know which it is – only people inside the NEOWISE group know that. Their answers to date are quite disappointing, but perhaps they will come clean, or an investigative body can get them to. It's also possible that not all of them know the reason, even if it truly was a hidden error.

Let's consider each of the possibilities in turn.

Errors occur in science just as they do in any human endeavor. Some errors are minor, and some – the colossal variety – fundamentally undermine a study.

Professor Wright has pointed out some typos in my equations. He has used these to argue that my entire paper should be disregarded. But in fact they are minor and easily corrected.

Wright has also argued in interviews that I have a history of being associated with bad software, citing my years as chief technology officer at Microsoft. So I guess it is with his endorsement that I can offer my expert opinion on software bugs.

Everybody who programs computers creates software bugs. What matters in software development is not just how good you are at avoiding bugs, but also how good you are at testing to find them.

It certainly is possible that a bug or error could have caused the copying of diameters. But what bothers me is Masiero Table 1. Even a causal inspection reveals that all of the cases in the red boxes have diameters that end in ".000," and none of the others do. I did a wider search. Out of about 120,000 diameter estimates in that paper, for diameters bigger than 9 km, all but five of them have an exact match in a ROS source. That makes me wonder whether those five asteroids have an exact match as well, just in some other ROS study I haven't located.

The 000 endings are a red flag to anybody checking the results. They aren't hidden down in the giant text file with more than 100,000 entries – they are in a small table published directly in a highly regarded journal, should have drawn attention if they were simple accidental errors. The fact that they weren't caught and corrected either before or after publication doesn't reflect well on how much care the NEOWISE team took to insure good results.

Another lesson from software development is that when you find one bug, another almost certainly lies somewhere undetected. This major error in the central results of two NEOWISE papers, if it is due to a bug, throws all of the NEOWISE results, in all of their papers, into question.

It's hard to see how the accidental-error theory could account for the error estimates that accompany the copied diameters. Those are the numbers with $\pm$ in front of them in some of the tables above. The estimated error in the diameter is just as important as the diameter itself, so the two numbers go together.

But, with on exception, those errors weren't copied from the ROS sources like diameters were – they appear to have been computed by the NEOWISE authors. That different treatment strongly suggests that the NEOWISE team set the diameter equal and then did their error analysis (they use Monte Carlo simulation), while keeping the diameter fixed.

If a bug caused this, then it is a very tricky and strange bug indeed.

This brings us to a more troubling possibility: that the error originated not with a mistake, but from deliberate fraud or misconduct. I have no way to know whether this happened. I certainly hope it did not. But it would be unwise not to consider the possibility that it was deliberate.

One clear motive for misrepresentation would be to make the NEOWISE results meet a certain standard, even if the actual results didn't work out that way. Prior to NEOWISE, several other studies – all much smaller – had concluded that thermal modeling was accurate to around 10%.

Whether those studies actually achieved that degree of accuracy or not is harder to say because ROS diameters are themselves not perfectly accurate. So when one compares diameters derived from models with those from ROS studies, you can't possibly be more accurate than the ROS diameters. Nevertheless, the earlier studies primed the conventional wisdom in the field to expect ±10% accuracy from NEOWISE.

It was always going to be hard, perhaps even impossible, for NEOWISE to meet that high expectation, for several reasons. One is that NEOWISE analyzed a huge number of asteroids, most of them rather small. The asteroids that previous studies looked at tended to be either large and roughly spherical, or close to the earth and easier to see, or both. Smaller and more distant asteroids – the majority of NEOWISE cases – tend to be more irregular in shape. That translates into bigger errors on the estimates of the objects' diameters.

My paper shows that it's just not possible with the WISE data to achieve a goal of ±10% accuracy. In most cases, the data are too scattered, almost certainly because so many asteroids are shaped like potatoes or ducks or other irregular shapes, not spheres. Moreover, some objects that look to the WISE telescope like a single point of light are actually two asteroids orbiting each other. Cases like that add to the margin of error.

Yet NEOWISE came back with the answer everybody wanted; that "we compute diameters…with errors better than 10%" in the Masiero Main Belt paper discussed above.

This certainly suggests that they calculated the accuracy. As discussed above, the *only* way to do this is to estimate the diameter for the asteroids that have ROS diameters, then compare to that diameter. Yet, shockingly, that is not done in any of the NEOWISE papers.

Instead, the NEOWISE papers all refer back to the Mainzer et al. "Thermal Model Calibration" paper that is discussed in the previous section. That paper doesn't do the calculation either. Instead it presents an indirect, hand-waving argument about what the *minimum* error in diameter might be based on fluxes from the test objects with ROS diameters. Why not just do the obvious thing: compare the thermal model diameters to the ROS diameters? Good question.

It's deeply disingenuous for Masiero et al. to claim that they compute diameters to "better than 10%" when their data set includes more than 100 main belt asteroids that have copied ROS diameters. Obviously they did not check against them, and neither can we.

When one finds citations like this that don't back up what is claimed, it is a warning sign. That's particularly the case when the cited claims are crucial to meet a very high standard, one that could affect how the field views the success of the project.

Irreproducible results are another warning sign. NASA, as a public entity, is obliged to make all of the data and results it produces publically accessible. In this case, the observational data from WISE is available. The NEOWISE results are available. But how they arrived at those results is not.

Scientists like myself who don't receive NASA funding ought to be able to use the WISE data and our own implementation of the NEOWISE data analysis methods to reproduce the diameter estimates that the NEOWISE studies published.

I tried mightily to do this, but it is not possible. The NEOWISE results are irreproducible because they don't describe how they got them. The analytical procedures they applied are unnecessarily complicated by all kinds of ad-hoc rules that make no sense from a statistics standpoint.

The studies also reference steps in other papers that don't exist. Here is one example from the Mainzer et al. NEO paper:

> As described in Mainzer et al. (2011b, hereafter M11B) and Cutri et al. (2011), we included observations with magnitudes close to experimentally-derived saturation limits, but when sources became brighter than W1 = 6, W2 = 6, W3 = 4 and W4 = 0, we increased the error bars on these points to 0.2 magnitudes and applied a linear correction to W3 (see the WISE Explanatory Supplement for details).

Here's the problem: that Mainzer et al. paper cited does not provide any further details as claimed. And the Cutri et al. 2011 paper, also known as the WISE Explanatory Supplement (or WES, available here http://wise2.ipac.caltech.edu/docs/release/allsky/expsup/), contains no "linear correction" to W3.

I emailed the corresponding authors for the details but received none. Prof. Wright, after many requests, at least did admit in email that he couldn't find the linear correction to W3 either. He referred me to a much more recent paper by Chinese astronomers looking at stars, not asteroids, that found only the very slightest correction to the W3 band.

My paper enumerates many other such examples. Some are more serious than the one above. The group never explains, for example, how they do curve-fitting. There are several different ways to do this, and you can get enormously different results depending on which approach you take.

To sum up, a large research group, generously funded by the government and dominant in its field, has published what appear to be obviously erroneous results, have repeatedly failed to follow norms of rigorous statistical analysis, have described their methods misleadingly and incompletely, and have refused standard requests by other scientists for the information needed to replicate their work.

All that is left, then, for an independent researcher wanting to assess the accuracy of the NEOWISE results is to compare them to ROS results. Yet this is not possible because, in almost every case, NEOWISE set their results equal to the ROS results. Could this step have been taken to prevent anyone second-guessing their accuracy?

I stress yet again that this is circumstantial and I am in no way proposing that this constitutes proof that the diameters were deliberately copied. But the NEOWISE group certainly has displayed very bad behavior by the professional standards of science, and that certainly does not bode well. At this point it seems clear that the possibility of misconduct must be investigated – even if the NEOWISE group claims it was all a mistake. Bugs happen, but they aren't always accidental.

The answer could also be none of the above. Perhaps what happened was deliberate but has an innocent explanation. A colleague suggested, for example, that maybe the NEOWISE team used the ROS diameters so that they could provide better estimates. After all, if part of the NEOWISE mission is to come up with the best possible estimates, why not use the ROS value where they exist?

Unfortunately, that doesn't really work. If the ROS diameters actually are much more accurate than those estimated by NEOWISE thermal modeling, then the right thing to do is to report that so that we know how to evaluate the estimates for the 150,000 asteroids that have no ROS data. Just adopting the ROS numbers for 102 asteroids, at the cost of making it impossible to check the accuracy of the rest, is fundamentally deceptive – not innocent.

But maybe I am just not thinking creatively enough. Suppose that there is an innocent explanation. Then why did they forget to tell us? The Masiero and Mainzer articles assert repeatedly that the results are NEOWISE thermal-modeling results. That's very clear – but also clearly incorrect.

Copying diameters from the ROS data set is a huge exception to what they describe. No scientist could possibly consider that something that doesn't warrant clear and careful explanation. If there is some innocent, or even desirable reason, then it should have been disclosed along with the copying.

Questions for NEOWISE

My paper, obviously controversial and 110 pages long, will take some time to go through peer review. In that process, experts will judge whether the detailed analyses I present are right, wrong, or need additional justification.

But my research isn't the issue here. As this guide shows, anyone can see the irregularities in the NEOWISE data. That isn't a deep question for experts – these exact matches in the data are quite obvious.

The NEOWISE papers went through peer review themselves, but we are constantly reminded of published scientific discoveries that were wrong. The "discovery" of faster-than-light particles at CERN turned out to be due to a miscalibrated GPS time standard. Solid state physicist Hendrik Schön faked his research – including 17 peer reviewed papers.

The burden of explaining this clear and obvious problem falls squarely on Dr. Mainzer and her team.

Dr. Mainzer has important questions to answer. **What is the explanation for the copied diameters? Is it colossal error, fraud, or something else which is deliberate-but-innocent?**

We need details. A simple brush-off or diversion is not sufficient.

For Prof. Wright, who was initially helpful but has since become an outspoken critic and apologist for NEOWISE, the question is: **Did**

you know about this issue and go along with it? If not, why aggressively defend the project before you know all the details?

As a private citizen, all I can do is raise these questions and pursue my own research. I can't make anyone answer anything; indeed my track record of getting the NEOWISE team to respond is quite poor. But my hope is that research managers at NASA, JPL, *The Astronomical Journal*, and elsewhere will be able to get answers to these questions quickly.

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Table of exact matches

Below is Table 4 from my paper, showing all of the exact matches.

NEOWISE Published Results				Prior Radar/Occultation/Spacecraft References		
Asteroid	D	σ_D	Paper	D	σ_D	Paper
2	544000	60714	Masiero/MB:Pre	544000	N/A	Shevchenko et al., 2006
				522000	N/A	Shevchenko et al., 2006
				539000	28000	Durech et al., 2011
5	115000	9353	Masiero/MB:Pre	115000	6000	Durech et al., 2011
	115000	12000	Mainzer/TMC			
	108290	3700	Masiero/MB:NIR			
				120000	14000	Magri et al., 1999
6	185000	10688	Masiero/MB:Pre	185000	10000	Magri et al., 1999
	195640	5440	Masiero/MB:NIR			
				180000	40000	Durech et al., 2011
8	140000	1160	Masiero/MB:Pre	140000	7000	Durech et al., 2011
	140000	14000	Mainzer/TMC			
	147490	1030	Masiero/MB:NIR			
				138000	9000	Magri et al., 1999
				141000	10000	Durech et al., 2011
				160800	N/A	Shevchenko et al., 2006
13	227000	38000	Mainzer/TMC	227000	30000	Magri et al., 2007
	227000	25948	Masiero/MB:Pre			
15	259000	35511	Masiero/MB:Pre	259000	30000	Magri et al., 2007
	231690	2230	Masiero/MB:NIR			
19	223000	43596	Masiero/MB:Pre	223000	41000	Magri et al., 1999
	196370	300	Masiero/MB:NIR			
				210000	10000	Timmerson et al., 2010
36	103000	11451	Masiero/MB:Pre	103000	11000	Magri et al., 2007
	103000	1000	Mainzer/TMC			
38	116000	15501	Masiero/MB:Pre	116000	13000	Magri et al., 2007
	92250	490	Masiero/MB:NIR			
39	163000	14025	Masiero/MB:Pre	163000	12000	Durech et al., 2011
	163000	16000	Mainzer/TMC			
	179480	1680	Masiero/MB:NIR			
				177900	N/A	Shevchenko et al., 2006
46	124000	9641	Masiero/MB:Pre	124000	9000	Magri et al., 1999
				124000	9000	Magri et al., 2007
47	138000	13000	Mainzer/TMC	138000	N/A	Shevchenko et al., 2006
	138000	11108	Masiero/MB:Pre			
	125140	3510	Masiero/MB:NIR			

	NEOWISE Published Results			Prior Radar/Occultation/Spacecraft References		
Asteroid	D	σ_D	Paper	D	σ_D	Paper
50	100000	7596	Masiero/MB:Pre	100000	13000	Magri et al., 2007
	84070	240	Masiero/MB:NIR			
51	142600	12503	Masiero/MB:Pre	142600	N/A	Shevchenko et al., 2006
	138160	970	Masiero/MB:NIR			
53	115000	8000	Mainzer/TMC	115000	14000	Magri et al., 2007
	115000	10324	Masiero/MB:Pre			
54	142000	14758	Masiero/MB:Pre	142000	9000	Durech et al., 2011
	142000	14000	Mainzer/TMC			
				135000	20000	Durech et al., 2011
				165000	19000	Magri et al., 2007
60	60000	3519	Masiero/MB:Pre	60000	7000	Magri et al., 2007
	43220	570	Masiero/MB:NIR			
64	50300	9389	Masiero/MB:Pre	50300	N/A	Shevchenko et al., 2006
	58290	1080	Masiero/MB:NIR			
				51000	10000	Durech et al., 2011
				52000	10000	Durech et al., 2011
80	79000	9125	Masiero/MB:Pre	79000	10000	Magri et al., 1999
	79000	1393	Masiero/MB:Pre			
	68560	1030	Masiero/MB:NIR			
	74250	3000	Masiero/MB:NIR			
				67000	11000	Durech et al., 2011
83	84000	2283	Masiero/MB:Pre	84000	9000	Magri et al., 2007
	84000	8000	Mainzer/TMC			
	89640	2650	Masiero/MB:NIR			
				81000	2000	Shepard et al., 2010
84	79000	4867	Masiero/MB:Pre	79000	13000	Magri et al., 1999
85	163000	18648	Masiero/MB:Pre	163000	15000	Durech et al., 2011
	163000	16000	Mainzer/TMC	163000	19000	Magri et al., 2007
	169460	4520	Masiero/MB:NIR			
				163700	N/A	Shevchenko et al., 2006
				175900	N/A	Shevchenko et al., 2006
94	187500	7256	Masiero/MB:Pre	187500	N/A	Shevchenko et al., 2006
	187500	27000	Mainzer/TMC			
	173770	4190	Masiero/MB:NIR			
97	83000	6000	Mainzer/TMC	83000	5000	Shepard et al., 2010
	83000	5099	Masiero/MB:Pre	83000	10000	Magri et al., 1999
	100720	640	Masiero/MB:NIR			
105	119000	17337	Masiero/MB:Pre	119000	17000	Magri et al., 1999
	119000	11000	Mainzer/TMC			

NEOWISE Published Results				Prior Radar/Occultation/Spacecraft References		
Asteroid	D	σ_D	Paper	D	σ_D	Paper
				103700	N/A	Shevchenko et al., 2006
109	89000	6165	Masiero/MB:Pre	89000	9000	Magri et al., 2007
	82590	620	Masiero/MB:NIR			
				88200	N/A	Shevchenko et al., 2006
110	89000	6336	Masiero/MB:Pre	89000	9000	Shepard et al., 2010
	88200	2710	Masiero/MB:NIR			
111	135000	18583	Masiero/MB:Pre	135000	15000	Magri et al., 2007
	126340	230	Masiero/MB:NIR			
114	100000	11926	Masiero/MB:Pre	100000	14000	Magri et al., 2007
	100000	8874	Masiero/MB:Pre			
	100000	9000	Mainzer/TMC			
	100000	16000	Mainzer/TMC			
	94180	950	Masiero/MB:NIR			
	99150	3180	Masiero/MB:NIR			
128	188000	9002	Masiero/MB:Pre	188000	29000	Mainzer/TMC
	188000	29000	Mainzer/TMC			
	162510	1300	Masiero/MB:NIR			
				141000	37000	Magri et al., 2007
129	129500	14772	Masiero/MB:Pre	129500	N/A	Shevchenko et al., 2006
	128720	610	Masiero/MB:NIR			
				113000	12000	Shepard et al., 2010
				118000	19000	Durech et al., 2011
134	112200	10798	Masiero/MB:Pre	112200	N/A	Shevchenko et al., 2006
135	77000	8000	Mainzer/TMC	77000	7000	Shepard et al., 2010
	77000	7833	Masiero/MB:Pre			
	71040	2650	Masiero/MB:NIR			
137	144000	11272	Masiero/MB:Pre	144000	16000	Magri et al., 2007
	128680	530	Masiero/MB:NIR			
139	164000	19000	Mainzer/TMC	164000	22000	Magri et al., 1999
	164000	25212	Masiero/MB:Pre			
	151120	1600	Masiero/MB:NIR			
				160200	N/A	Shevchenko et al., 2006
141	137100	14556	Masiero/MB:Pre	137100	N/A	Shevchenko et al., 2006
	117920	1360	Masiero/MB:NIR			
145	151000	23000	Mainzer/TMC	151000	18000	Magri et al., 2007
	151000	11272	Masiero/MB:Pre			
	151000	8563	Masiero/MB:Pre			
	124470	510	Masiero/MB:NIR			
	127780	360	Masiero/MB:NIR			

	NEOWISE Published Results			Prior Radar/Occultation/Spacecraft References		
Asteroid	D	σ_D	Paper	D	σ_D	Paper
182	44000	15494	Masiero/MB:Pre	44000	10000	Magri et al., 2007
	44000	4279	Masiero/MB:Pre			
	39520	390	Masiero/MB:NIR			
	44980	510	Masiero/MB:NIR			
192	93000	6795	Masiero/MB:Pre	93000	9000	Magri et al., 2007
	93000	8366	Masiero/MB:Pre			
	87120	4160	Masiero/MB:NIR			
	98780	1240	Masiero/MB:NIR			
				95000	13000	Magri et al., 1999
198	57000	7000	Mainzer/TMC	57000	8000	Magri et al., 2007
	57000	10064	Masiero/MB:Pre			
	54320	340	Masiero/MB:NIR			
208	45000	5000	Mainzer/TMC	45000	10000	Durech et al., 2011
	45000	5000	Mainzer/TMC			
	45000	4195	Masiero/MB:Pre			
	45000	4591	Masiero/MB:Pre			
	40060	590	Masiero/MB:NIR			
	40900	600	Masiero/MB:NIR			
				44300	N/A	Shevchenko et al., 2006
211	143000	21629	Masiero/MB:Pre	143000	16000	Magri et al., 2007
	143000	13000	Mainzer/TMC			
	141130	2490	Masiero/MB:NIR			
216	138000	19374	Masiero/MB:Pre	138000	20000	Magri et al., 2007
	119190	3400	Masiero/MB:NIR			
				104300	N/A	Shevchenko et al., 2006
				124000	15000	Shepard et al., 2010
225	128000	16129	Masiero/MB:Pre	128000	16000	Magri et al., 2007
	95930	1250	Masiero/MB:NIR			
230	109000	16000	Mainzer/TMC	109000	14000	Magri et al., 1999
	109000	13025	Masiero/MB:Pre			
	111330	1230	Masiero/MB:NIR			
				101800	N/A	Shevchenko et al., 2006
238	146500	8679	Masiero/MB:Pre	146500	N/A	Shevchenko et al., 2006
	155660	750	Masiero/MB:NIR			
				145300	N/A	Shevchenko et al., 2006
247	134000	13425	Masiero/MB:Pre	134000	15000	Magri et al., 2007
	130940	510	Masiero/MB:NIR			

	NEOWISE Published Results			Prior Radar/Occultation/Spacecraft References		
Asteroid	D	σ_D	Paper	D	σ_D	Paper
248	54000	4913	Masiero/MB:Pre	54000	N/A	Shevchenko et al., 2006
	50120	310	Masiero/MB:NIR			
306	51600	6333	Masiero/MB:Pre	51600	N/A	Shevchenko et al., 2006
	47200	130	Masiero/MB:NIR			
				49000	5000	Durech et al., 2011
				53000	5000	Durech et al., 2011
308	144400	13864	Masiero/MB:Pre	144400	N/A	Shevchenko et al., 2006
	144000	13000	Mainzer/TMC			
	128580	1560	Masiero/MB:NIR			
				117100	N/A	Shevchenko et al., 2006
313	96000	7809	Masiero/MB:Pre	96000	14000	Magri et al., 2007
324	229000	8145	Masiero/MB:Pre	229000	12000	Magri et al., 1999
				229000	12000	Magri et al., 2007
	220690	1440	Masiero/MB:NIR			
				235500	N/A	Shevchenko et al., 2006
334	174100	12788	Masiero/MB:Pre	174100	N/A	Shevchenko et al., 2006
	198770	5600	Grav/Hilda			
336	69000	3364	Masiero/MB:Pre	69000	9000	Magri et al., 2007
345	99000	9000	Mainzer/TMC	99000	N/A	Shevchenko et al., 2006
	99000	11469	Masiero/MB:Pre			
347	51000	3218	Masiero/MB:Pre	51000	5000	Shepard et al., 2010
	48610	120	Masiero/MB:NIR			
350	99500	10675	Masiero/MB:Pre	99500	N/A	Shevchenko et al., 2006
	99500	6354	Masiero/MB:Pre			
	99500	5000	Mainzer/TMC			
	121360	2460	Masiero/MB:NIR			
	128730	1200	Masiero/MB:NIR			
354	165000	15613	Masiero/MB:Pre	165000	18000	Magri et al., 2007
	148970	420	Masiero/MB:NIR			
356	131000	9686	Masiero/MB:Pre	131000	15000	Magri et al., 1999
	118480	1540	Masiero/MB:NIR			
404	98700	3450	Masiero/MB:Pre	98700	N/A	Shevchenko et al., 2006
	94970	950	Masiero/MB:NIR			
405	125000	17427	Masiero/MB:Pre	125000	16000	Magri et al., 2007
	108890	310	Masiero/MB:NIR			
420	144000	5683	Masiero/MB:Pre	144000	N/A	Shevchenko et al., 2006
	138700	3450	Masiero/MB:NIR			
429	70000	6683	Masiero/MB:Pre	70000	10000	Magri et al., 2007
	72210	2190	Masiero/MB:NIR			

	NEOWISE Published Results			Prior Radar/Occultation/Spacecraft References		
Asteroid	D	σ_D	Paper	D	σ_D	Paper
431	68600	3617	Masiero/MB:Pre	68600	N/A	Shevchenko et al., 2006
	94580	1030	Masiero/MB:NIR			
444	163000	36000	Mainzer/TMC	163000	27000	Magri et al., 2007
	163000	12600	Masiero/MB:Pre			
	163000	22144	Masiero/MB:Pre			
	158860	2320	Masiero/MB:NIR			
	159330	490	Masiero/MB:NIR			
				172400	N/A	Shevchenko et al., 2006
488	150000	21000	Mainzer/TMC	150000	21000	Magri et al., 2007
	150000	11326	Masiero/MB:Pre			
	148840	3490	Masiero/MB:NIR			
497	40000	4881	Masiero/MB:Pre	40000	8000	Shepard et al., 2010
	40930	320	Masiero/MB:NIR			
522	83700	4850	Masiero/MB:Pre	83700	N/A	Shevchenko et al., 2006
	84000	9000	Mainzer/TMC	84000	9000	Mainzer/TMC
566	134000	15000	Mainzer/TMC	134000	N/A	Shevchenko et al., 2006
	134000	6627	Masiero/MB:Pre			
	167380	3490	Masiero/MB:NIR			
568	75800	5641	Masiero/MB:Pre	75800	N/A	Shevchenko et al., 2006
	85190	980	Masiero/MB:NIR			
622	29000	5417	Masiero/MB:Pre	29000	8000	Magri et al., 2007
	21870	240	Masiero/MB:NIR			
654	127000	13000	Mainzer/TMC	127000	18000	Magri et al., 2007
	127000	20474	Masiero/MB:Pre			
	116300	2380	Masiero/MB:NIR			
678	42000	2371	Masiero/MB:Pre	42000	4000	Shepard et al., 2010
	39590	580	Masiero/MB:NIR			
704	312000	30000	Mainzer/TMC	312000	33000	Magri et al., 2007
	312000	17000	Mainzer/TMC			
	312000	19727	Masiero/MB:Pre			
	312000	34517	Masiero/MB:Pre			
	306310	1030	Masiero/MB:NIR			
	308300	1510	Masiero/MB:NIR			
				326100	N/A	Shevchenko et al., 2006
				332800	N/A	Shevchenko et al., 2006
757	36700	2272	Masiero/MB:Pre	36700	N/A	Shevchenko et al., 2006
	32890	240	Masiero/MB:NIR			
758	85000	9365	Masiero/MB:Pre	85000	7000	Shepard et al., 2010
	88980	630	Masiero/MB:NIR			

	NEOWISE Published Results			Prior Radar/Occultation/Spacecraft References		
Asteroid	D	σ_D	Paper	D	σ_D	Paper
771	29000	2544	Masiero/MB:Pre	29000	2000	Shepard et al., 2010
	29000	1403	Masiero/MB:Pre			
	28170	330	Masiero/MB:NIR			
	29320	170	Masiero/MB:NIR			
779	77000	6578	Masiero/MB:Pre	77000	2000	Shepard et al., 2010
	80570	2220	Masiero/MB:NIR			
791	82500	5957	Masiero/MB:Pre	82500	N/A	Shevchenko et al., 2006
	99800	11030	Masiero/MB:NIR			
796	45000	5133	Masiero/MB:Pre	45000	2000	Shepard et al., 2010
				45000	6000	Magri et al., 1999
	43580	300	Masiero/MB:NIR			
914	77000	13126	Masiero/MB:Pre	77000	10000	Magri et al., 2007
	76190	490	Masiero/MB:NIR			
				91200	N/A	Shevchenko et al., 2006
925	58000	6000	Mainzer/TMC	58000	16000	Durech et al., 2011
	58000	4841	Masiero/MB:Pre			
	57500	440	Masiero/MB:NIR			
				59200	N/A	Shevchenko et al., 2006
951	12000	1000	Mainzer/TMC	12000	1000	Mainzer/TMC
	12200	813	Masiero/MB:Pre	12200	N/A	Thomas et al., 1994
	13210	130	Masiero/MB:NIR			
976	65000	3598	Masiero/MB:Pre	65000	N/A	Shevchenko et al., 2006
	83200	540	Masiero/MB:NIR			
1512	65000	7000	Mainzer/TMC	65000	N/A	Shevchenko et al., 2006
	65000	4137	Masiero/MB:Pre			
	79870	770	Grav/Hilda			
1627	9000	817	Masiero/MB:Pre	9000	900	Ostro et al., 1990
	9000	1000	Mainzer/TMC			
	8370	75	Mainzer/NEO:Pre			
				10200	N/A	Veeder et al., 1989
1866	8700	1000	Mainzer/TMC	8700	1000	Mainzer/TMC
	8700	590	Masiero/MB:Pre			
	6597	189	Mainzer/NEO:Pre			
1963	45000	7925	Masiero/MB:Pre	45000	9000	Magri et al., 2007
	35540	230	Masiero/MB:NIR			
7335	900	400	Mainzer/TMC	900	400	Mainzer/TMC
	932	153	Mainzer/NEO:Pre			
	950	417	Masiero/MB:Pre			
				1000	N/A	Mahapatra et al., 2002

	NEOWISE Published Results			Prior Radar/Occultation/Spacecraft References		
Asteroid	D	σ_D	Paper	D	σ_D	Paper
68216	1400	200	Mainzer/TMC	1400	200	Mainzer/TMC
	1400	145	Mainzer/NEO:Pre			
	1400	145	Masiero/MB:Pre			
	1400	262	Mainzer/NEO:Pre			
	1400	262	Masiero/MB:Pre			
164121	1100	300	Mainzer/TMC	1100	300	Mainzer/TMC
	1100	186	Masiero/MB:Pre			
	1100	88	Masiero/MB:Pre			
	1100	186	Mainzer/NEO:Pre			
	1100	88	Mainzer/NEO:Pre			
	1717	550	Mainzer/PP:3			
	1738	577	Mainzer/PP:3			
2005 CR37	1000	123	Masiero/MB:Pre	1000	N/A	Benner et al., 2006
	1000	200	Mainzer/TMC			
	1201	236	Mainzer/NEO:Pre			