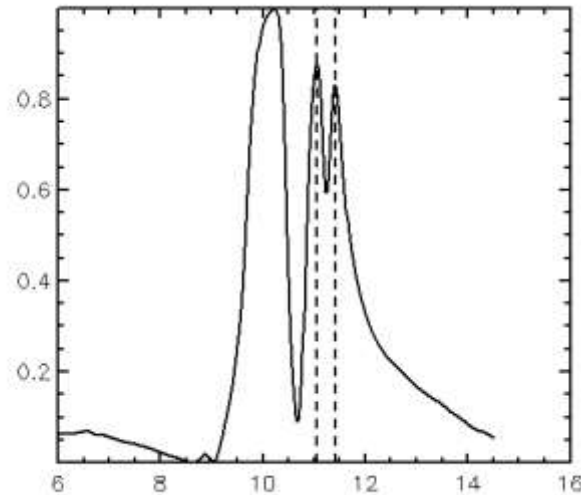
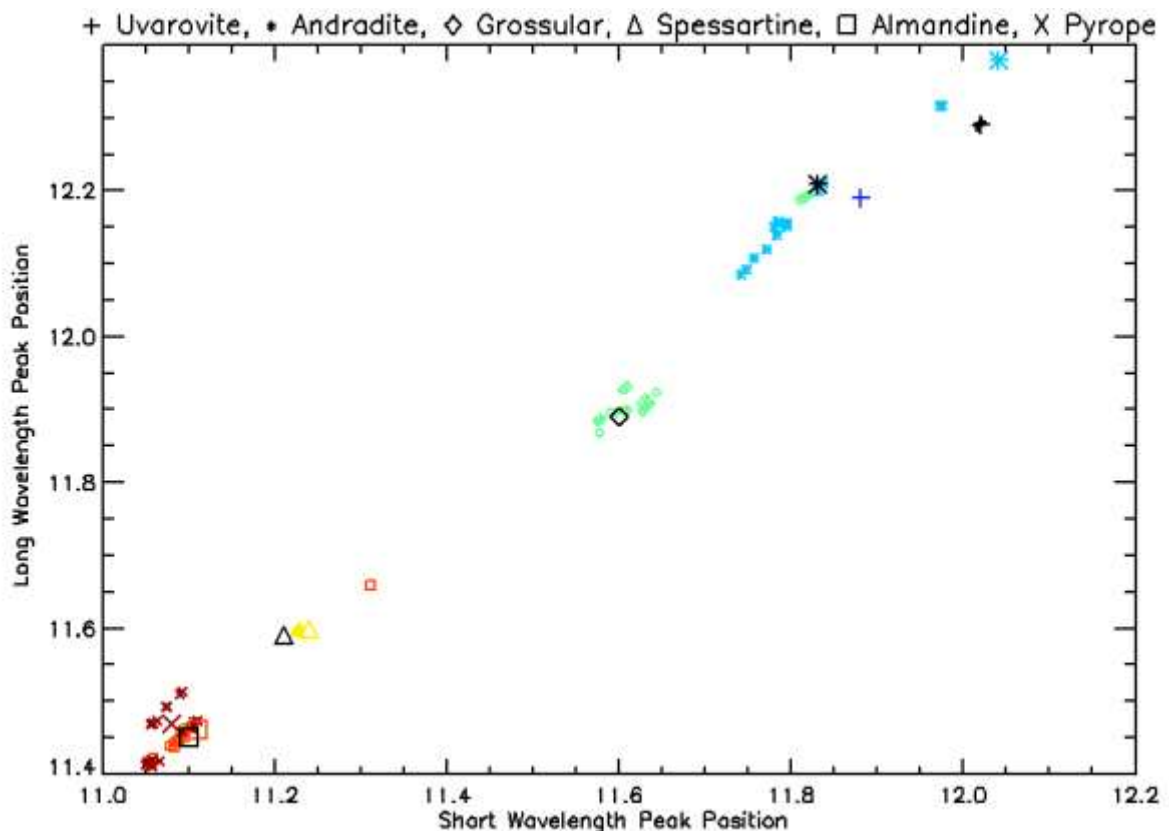


Garnets
Andy Green - 15 March 2013

This note describes an analysis of 85 garnet spectra from our TIR library. A typical garnet spectrum is shown below. It consists of three peaks, a relatively broad one at short wavelength and two narrower, approximately equal peaks at longer wavelength. The broad shorter wavelength feature can vary somewhat but the other two peaks are quite consistent. I have chosen to analyse these two peak positions to characterise the garnets.



I wrote a simple algorithm to find these peaks in garnet samples and have plotted the results below. Our library data (that is all Martin's measurements) is in small coloured symbols. In larger coloured symbols I have also plotted the peak positions consolidated from the literature and the various libraries to which we have access (these results are summarized in appendix 2). In the large black symbols are the peak positions for spectra associated with each mineral in the new TIR Reference Set, MS6.



The most obvious separation is between the two main types

Calcium Garnets (short wavelength peak positions $> 11.5 \mu\text{m}$)

Andradite $\text{Ca}_3\text{Fe}_2(\text{SiO}_4)_3$

Grossular: $\text{Ca}_3\text{Al}_2(\text{SiO}_4)_3$

Uvarovite $\text{Ca}_3\text{Cr}_2(\text{SiO}_4)_3$

Fe-Mg-Mn Garnets (short wavelength peak positions $< 11.5 \mu\text{m}$)

Almandine: $\text{Fe}_3\text{Al}_2(\text{SiO}_4)_3$ (most common garnet)

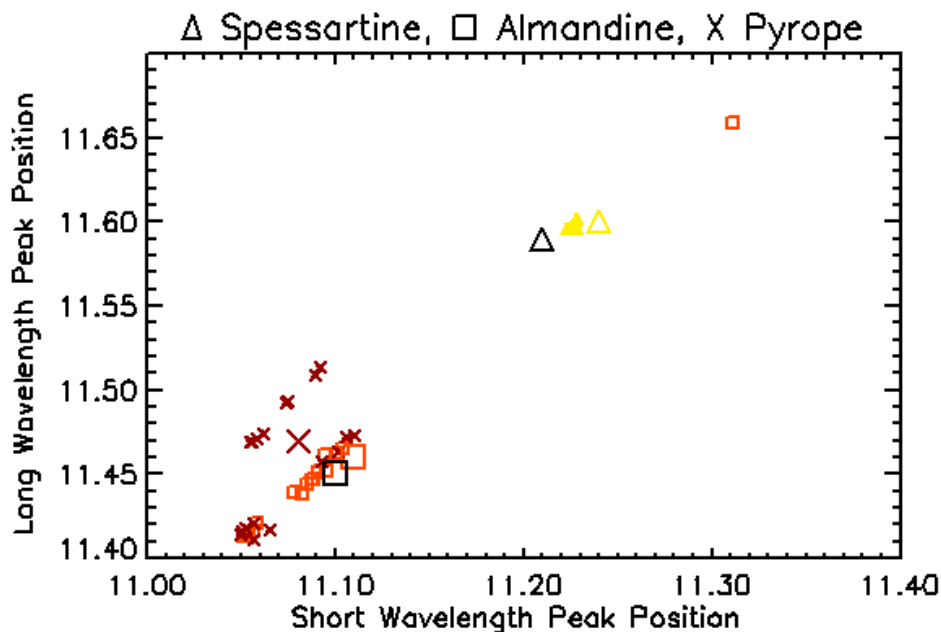
Pyrope: $\text{Mg}_3\text{Al}_2(\text{SiO}_4)_3$

Spessartine: $\text{Mn}_3\text{Al}_2(\text{SiO}_4)_3$

However when we consider how the individual garnets subdivide spectrally we start to encounter some questions.

1. Fe-Mg-Mn Garnets (see enlarged figure below)

- Spessartine (triangles) seems straightforward.
- Almandine (squares) Except for one sample this also seems straightforward. The literature average (large coloured square) and the MS6 sample (large black square) are close. However the anomalous almandine sample (number 14 in Appendix 1) would really be very interesting to investigate for its chemistry.
- Pyrope (crosses). Here there are two distinct clusters, one overlapping completely with the almandines. The literature average (large coloured cross) does not help resolve this uncertainty. Apparently pyrope and almandine are hard to distinguish in hand specimen and we probably have a misidentification problem. Again it would be interesting to investigate the chemistry of these samples.

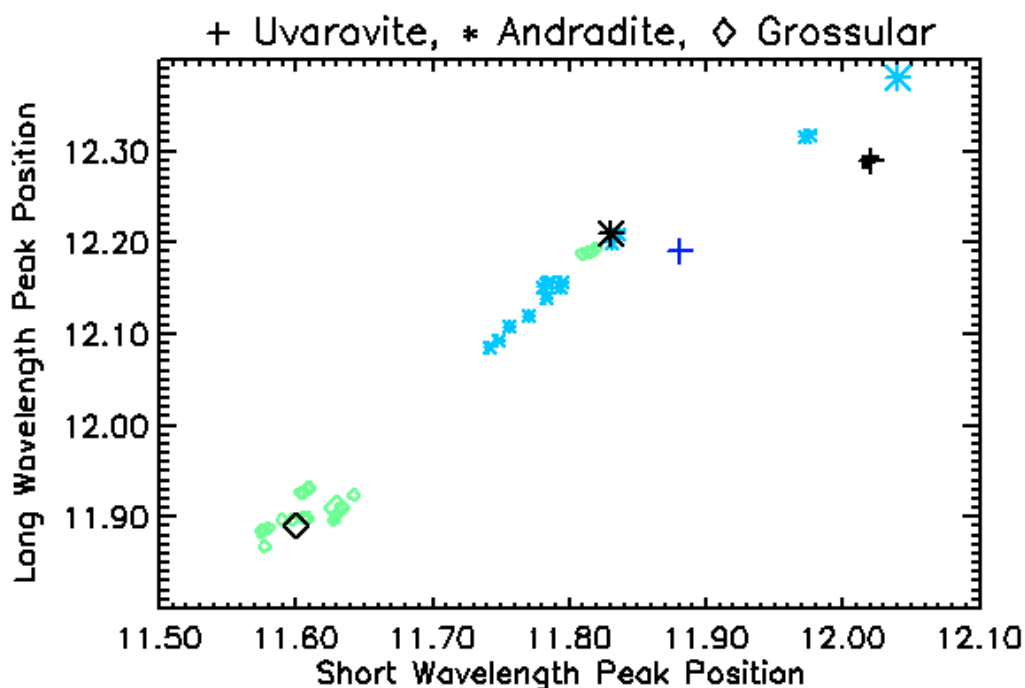


The MS6 does not include a pyrope because we could not distinguish the one we had chosen from almandine.

2. Calcium Garnets (enlarged plot below)

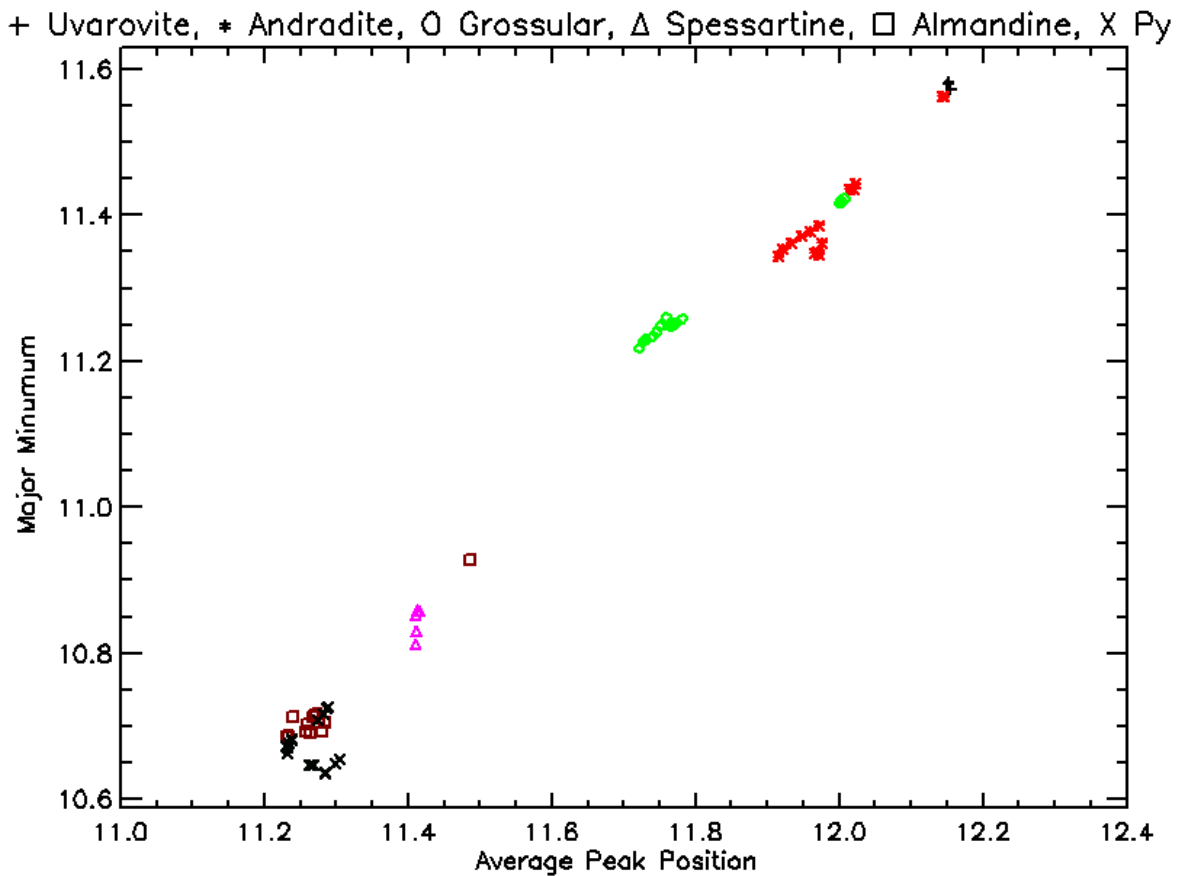
This plot presumably covers the full range of the grossular-andradite solid solution. The general view seems to be that the wavelength shift is linear with composition.

- Grossular (diamonds) . Some of the samples labelled grossular are closer to andradite. The MS6 grossular sample (large black diamond) seems fine.
- Andradite (stars). It seems that the MS6 andradite sample (the large black star) is nowhere near a pure andradite, the literature andradite (large light blue star) is a long way away. This MS6 sample is probably more like a 50/50 grossular/andradite mix.
- Uvarovite (cross). There is not much published information on this garnet. Our samples (small dark blue crosses under the large black cross that is the MS6 sample) are well away from the average of the published data (large blue cross). These results might suggest that the two peaks are closer together in uvarovite than in the other Ca-garnets but it is hard to be sure. We need more data.



It would be good if we could resolve these issues but it would require getting the samples back and doing further investigation. Perhaps some hand-held XRF would be the answer in this case.

It is sometimes hard to resolve the two garnet peaks discussed above but the major minimum is often still quite clear. In this case we will be interested in seeing the position of this feature as a function of mineralogy. From the plot below you can see that the major minimum position is well correlated with the average position of the two peaks.



So what can we say about the garnets based on the position of the major minimum? The above plot would indicate the following

- All garnets Minimum position > 10.6 μm
- Calcium Garnets minimum position > 11.1 μm
 - Andradite $\text{Ca}_3\text{Fe}_2(\text{SiO}_4)_3$minimum position > 11.3 μm
 - Grossular: $\text{Ca}_3\text{Al}_2(\text{SiO}_4)_3$ minimum position < 11.3 μm
 - Uvarovite $\text{Ca}_3\text{Cr}_2(\text{SiO}_4)_3$
- Mg-Fe-Mn Garnets (average peak position < 11.1 μm)
 - Almandine: $\text{Fe}_3\text{Al}_2(\text{SiO}_4)_3$ can't distinguish from pyrope
 - Pyrope: $\text{Mg}_3\text{Al}_2(\text{SiO}_4)_3$can't distinguish from almandine.
 - Spessartine: $\text{Mn}_3\text{Al}_2(\text{SiO}_4)_3$may be separated. We need more samples.

Appendix A –Garnets Used

Anomalous almandine (?) sample

Grossular suspected to be Andradite

Pyrope overlapping with Almandine

	Main minimum	Short Peak	Long Peak	Separation	Sample Label						
0	10.6922	11.0516	11.4129	0.361264	Almandine	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D47101_01_o1	100413	p
1	10.6891	11.0528	11.4141	0.361279	Almandine	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D47101_02_o1	100414	p
2	10.6907	11.0562	11.4156	0.359343	Almandine	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D47101_02_o2	100414	p
3	10.6908	11.0537	11.4127	0.358978	Almandine	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D47101_03_o1	100414	p
4	10.6890	11.0521	11.4132	0.361051	Almandine	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D47101_03_o2	100414	p
5	10.7163	11.0885	11.4471	0.358582	Almandine	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D51104_01_o2	100413	p
6	10.7211	11.0953	11.4519	0.356655	Almandine	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D51104_02_o1	100414	p
7	10.7180	11.0909	11.4519	0.360991	Almandine	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D51104_02_o2	100414	p
8	10.7167	11.0880	11.4467	0.358691	Almandine	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D51104_03_o1	100414	p
9	10.7187	11.0910	11.4507	0.359748	Almandine	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D51104_03_o2	100414	p
10	10.6934	11.0849	11.4440	0.359076	Almandine	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	MCU-GAR-1_01	-----	p
11	10.6958	11.0781	11.4391	0.361082	Almandine	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	MCU-GAR-1_02	-----	p
12	10.7130	11.0586	11.4208	0.362166	Almandine	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	MCU-GAR-1_03	-----	p
13	10.7061	11.0824	11.4380	0.355601	Almandine	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	MCU-GAR-1_04	-----	p
14	10.9286	11.3111	11.6589	0.347833	Almandine	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	MCU-GAR-2_02	-----	p
15	10.7068	11.1042	11.4658	0.361563	Almandine	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	UNSW-GAR17_01	-----	p
16	10.6950	11.1014	11.4628	0.361372	Almandine	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	UNSW-GAR17_02	-----	p
17	10.7064	11.0942	11.4614	0.367173	Almandine	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	UNSW-GAR17_03	-----	p
18	11.3866	11.7938	12.1519	0.358093	Andradite	Ortho- and ring silicates	Garnets	Ca Garnets	D37849_01_o1	100413	p
19	11.3776	11.7823	12.1393	0.357013	Andradite	Ortho- and ring silicates	Garnets	Ca Garnets	D37849_01_o2	100413	p
20	11.3621	11.7563	12.1079	0.351665	Andradite	Ortho- and ring silicates	Garnets	Ca Garnets	D37849_02_o1	100414	p
21	11.3544	11.7479	12.0925	0.344624	Andradite	Ortho- and ring silicates	Garnets	Ca Garnets	D37849_02_o2	100414	p
22	11.3702	11.7702	12.1199	0.349757	Andradite	Ortho- and ring silicates	Garnets	Ca Garnets	D37849_03_o1	100414	p
23	11.3443	11.7413	12.0857	0.344405	Andradite	Ortho- and ring silicates	Garnets	Ca Garnets	D37849_03_o2	100414	p
24	11.4353	11.8307	12.2072	0.376544	Andradite	Ortho- and ring silicates	Garnets	Ca Garnets	D44052_01_o1	100413	p
25	11.4456	11.8364	12.2098	0.373471	Andradite	Ortho- and ring silicates	Garnets	Ca Garnets	D44052_02_o1	100414	p
26	11.4356	11.8313	12.2006	0.369345	Andradite	Ortho- and ring silicates	Garnets	Ca Garnets	D44052_02_o2	100414	p
27	11.3526	11.7834	12.1551	0.371638	Andradite	Ortho- and ring silicates	Garnets	Ca Garnets	D57866_01_o1	100413	p
28	11.3655	11.7944	12.1569	0.362487	Andradite	Ortho- and ring silicates	Garnets	Ca Garnets	D57866_01_o2	100413	p
29	11.3485	11.7837	12.1578	0.374119	Andradite	Ortho- and ring silicates	Garnets	Ca Garnets	D57866_02_o1	100414	p
30	11.3512	11.7803	12.1519	0.371661	Andradite	Ortho- and ring silicates	Garnets	Ca Garnets	D57866_02_o2	100414	p
31	11.5687	11.9723	12.3167	0.344422	Andradite	Ortho- and ring silicates	Garnets	Ca Garnets	MCU-GAR-3_02	-----	p
32	11.5684	11.9755	12.3179	0.342422	Andradite	Ortho- and ring silicates	Garnets	Ca Garnets	MCU-GAR-3_03	-----	p
33	11.2691	11.6274	11.8973	0.269880	Grossular	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D44376_01_o1	100427	p
34	11.2583	11.6316	11.9067	0.275077	Grossular	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D44376_01_o2	100427	p
35	11.2538	11.6285	11.9022	0.273644	Grossular	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D44376_02_o1	100427	p
36	11.2566	11.6291	11.9027	0.273578	Grossular	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D44376_02_o2	100427	p
37	11.2638	11.6423	11.9243	0.281997	Grossular	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D44376_03_o1	100427	p
38	11.2552	11.6330	11.9116	0.278571	Grossular	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D44376_03_o2	100427	p
39	11.4163	11.8145	12.1894	0.374987	Grossular	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D47096_01_o1	100427	p
40	11.4175	11.8090	12.1882	0.379231	Grossular	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D47096_01_o2	100427	p
41	11.4190	11.8131	12.1909	0.377845	Grossular	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D47096_02_o1	100427	p
42	11.4230	11.8189	12.1942	0.375293	Grossular	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D47096_02_o2	100427	p
43	11.4182	11.8168	12.1913	0.374508	Grossular	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D47096_03_o1	100427	p
44	11.4211	11.8152	12.1907	0.375491	Grossular	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D47096_03_o2	100427	p

45	11.2456	11.5964	11.8972	0.300774	Grossular	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D51637_01_o1	100427	p
46	11.2236	11.5765	11.8686	0.292109	Grossular	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D51637_01_o2	100427	p
47	11.2540	11.6086	11.8994	0.290755	Grossular	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D51637_02_o1	100427	p
48	11.2508	11.6051	11.8992	0.294082	Grossular	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D51637_02_o2	100427	p
49	11.2347	11.5796	11.8886	0.309060	Grossular	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D52153_01_o1	100427	p
50	11.2328	11.5770	11.8861	0.309097	Grossular	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D52153_01_o2	100427	p
51	11.2336	11.5757	11.8854	0.309739	Grossular	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D52153_02_o1	100427	p
52	11.2329	11.5744	11.8848	0.310394	Grossular	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D52153_02_o2	100427	p
53	11.2398	11.5896	11.8972	0.307641	Grossular	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D52153_03_o2	100427	p
54	11.2514	11.6034	11.9272	0.323838	Grossular	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D52981_01_o1	100427	p
55	11.2542	11.6085	11.9322	0.323725	Grossular	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D52981_01_o2	100427	p
56	11.2554	11.6096	11.9322	0.322590	Grossular	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D52981_02_o1	100427	p
57	11.2518	11.6050	11.9274	0.322464	Grossular	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D52981_02_o2	100427	p
58	10.6875	11.0564	11.4207	0.364374	Pyrope	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D04232_01_o1	100419	p
59	10.6777	11.0495	11.4137	0.364126	Pyrope	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D04232_01_o2	100419	p
60	10.6819	11.0524	11.4183	0.365829	Pyrope	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D04232_02_o1	100419	p
61	10.6673	11.0505	11.4155	0.365056	Pyrope	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D04232_02_o2	100419	p
62	10.6492	11.0892	11.5093	0.420137	Pyrope	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D42219_01_o1	100419	p
63	10.6564	11.0916	11.5134	0.421835	Pyrope	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D42219_01_o2	100419	p
64	10.6381	11.0734	11.4926	0.419115	Pyrope	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D42219_03_o1	100419	p
65	10.6371	11.0749	11.4933	0.418420	Pyrope	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D42219_03_o2	100419	p
66	10.7232	11.1016	11.4634	0.361820	Pyrope	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D51107_01_o1	100419	p
67	10.7113	11.0926	11.4572	0.364667	Pyrope	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D51107_01_o2	100419	p
68	10.7308	11.1053	11.4723	0.366939	Pyrope	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D51107_02_o1	100419	p
69	10.7316	11.1098	11.4735	0.363759	Pyrope	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D51107_02_o2	100419	p
70	10.6865	11.0649	11.4173	0.352474	Pyrope	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D51107_03_o1	100419	p
71	10.6776	11.0567	11.4110	0.354304	Pyrope	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D51107_03_o2	100419	p
72	10.6471	11.0560	11.4695	0.413543	Pyrope	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D52009_01_o1	100419	p
73	10.6469	11.0547	11.4689	0.414198	Pyrope	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D52009_01_o2	100419	p
74	10.6480	11.0618	11.4745	0.412663	Pyrope	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D52009_02_o1	100419	p
75	10.6486	11.0581	11.4707	0.412631	Pyrope	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D52009_02_o2	100419	p
76	10.8605	11.2265	11.5977	0.371287	Spessartine	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D35063_01_o1	100419	p
77	10.8615	11.2274	11.5989	0.371533	Spessartine	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D35063_01_o2	100419	p
78	10.8550	11.2231	11.5962	0.373165	Spessartine	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D35063_02_o1	100419	p
79	10.8618	11.2280	11.6013	0.373308	Spessartine	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D35063_02_o2	100419	p
80	10.8144	11.2250	11.5968	0.371781	Spessartine	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D52466_01_o1	100419	p
81	10.8347	11.2279	11.5958	0.367891	Spessartine	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D52466_01_o2	100419	p
82	11.5845	12.0179	12.2886	0.270645	Uvarovite	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D21971_01_o1	100419	p
83	11.5740	12.0208	12.2943	0.273506	Uvarovite	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D21971_01_o2	100419	p
84	11.5816	12.0157	12.2888	0.273092	Uvarovite	Ortho- and ring silicates	Garnets	Mg-Fe-Mn Garnet	D21971_01_o2a	100419	p

Summary Results from Literature

	Almandine		Pyrope		Spessartine		Grossular		Andradite		Uvarovite	
Hof & Chop 1991 (Reflectance)	889	865	906	878	884	861	860	842	821	795		
	11.25	11.56	11.04	11.39	11.31	11.61	11.63	11.88	12.18	12.58		
Hof et al 1996 (Reflectance)	894	868	901	871								
	11.19	11.52	11.10	11.48								
Mac & Hof 1993 (Reflectance)							856	834	830	812		
							11.68	11.99	12.05	12.32		
Mac & Hof 1995 (Reflectance)							856	837	825	807		
							11.68	11.95	12.12	12.39		
Moore & White (Transmission)	897	870	897	870	895	861	860	841	831	812		
	11.15	11.49	11.15	11.49	11.17	11.61	11.63	11.89	12.03	12.32		
Geiger et al (Transmission)	900	878	907	877			860	843				
	11.11	11.39	11.03	11.40			11.63	11.86				
Tarte 1973 (Transmission)	900	876	898	871	883	860						
	11.11	11.42	11.14	11.48	11.33	11.63						
Parthasarathy 1999							860	840			842	819
							11.63	11.90			11.88	12.21
USGS Library	906	875			893	864	864	840	837	810	842	822
	11.04	11.43			11.20	11.57	11.57	11.90	11.95	12.35	11.88	12.17
JHU Library	908	876	904	869	894	864	863	839	838	812		
	11.01	11.42	11.06	11.51	11.19	11.57	11.59	11.92	11.93	12.32		
ASU Library	904	875	903	869								
	11.06	11.43	11.07	11.51								
Average	900	873	902	872	890	862	860	840	830	808	842	821
	11.11	11.46	11.08	11.47	11.24	11.60	11.63	11.91	12.04	12.38	11.88	12.19
Standard Deviation (um)	0.08	0.06	0.05	0.05	0.07	0.03	0.04	0.04	0.10	0.10		
Separation	0.34		0.38		0.36		0.28		0.33		0.31	
MS6	901	873			892	863	862	841	845	819	832	814
	11.10	11.45			11.21	11.59	11.60	11.89	11.83	12.21	12.02	12.29
Separation	0.36				0.38		0.29		0.38		0.27	

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