350µm

SPIRE Observations of Asteroids and Stars

Photometer Routine Calibration Programme

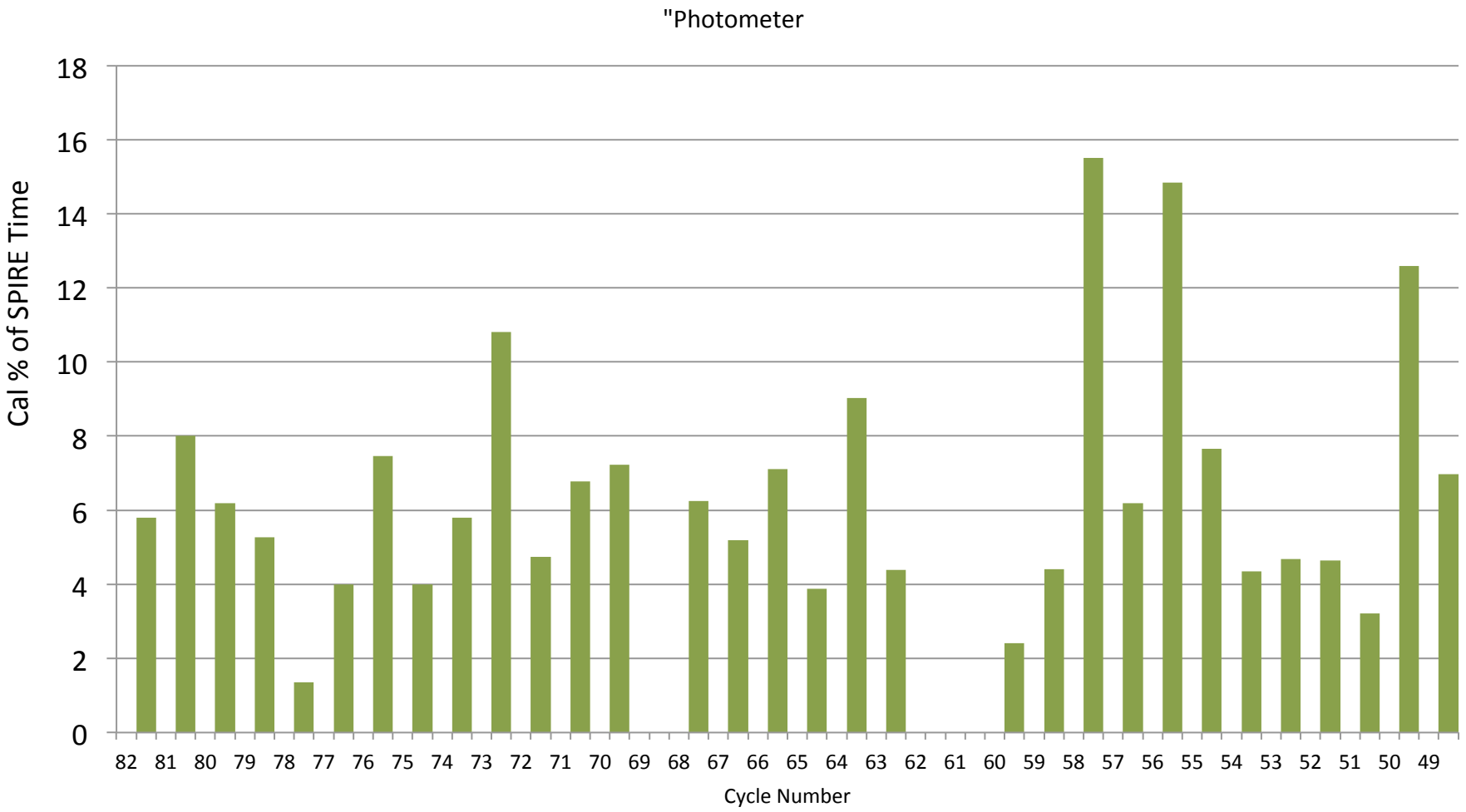
Main Elements:

- Observe Neptune and Uranus when visible
- Observe Gamma Dra every time photometer is used
- Observe dark sky every time photometer is used
- Observe 2-3 stars per week
- Observe 2-3 asteroids per week

On a less frequent basis

- Load curves of planets and bright asteroids
- Phase ups
- JFET noise tests
- BSM calibration check

Photometer Routine Calibration



Stars

- Before launch 8 stars selected with very good models
- SPIRE observations include these 8 stars plus some additional stars taken from a secondary list established before launch
- It was quickly established that small map mode should be the default mode for making routine observations
- Typically 4 scans were taken with each observation taking about 6 minutes
- 16 stars were observed in total:
  - One star, Delta Dra was too faint to have a reliable detection so was dropped after one observation
  - Gamma Dra is always visible so was observed almost every photometer pair of days - but it is relatively faint
- About 280 observations made over routine phase

Stars

Star	No. Obsrvations	Star	No. Observations
Alpha Ari	8	Beta UMi	27
Alpha Boo	13	Delta Dra	1
Alpha Cet	10	Eps Lep	10
Alpha Hya	10	Gam Cru	12
Alpha Tau	17	Gam Dra	119
Beta And	8	HR 7557	6
Beta Gem	7	Omega Cap	7
Beta Peg	15	Sirius	11

Stars

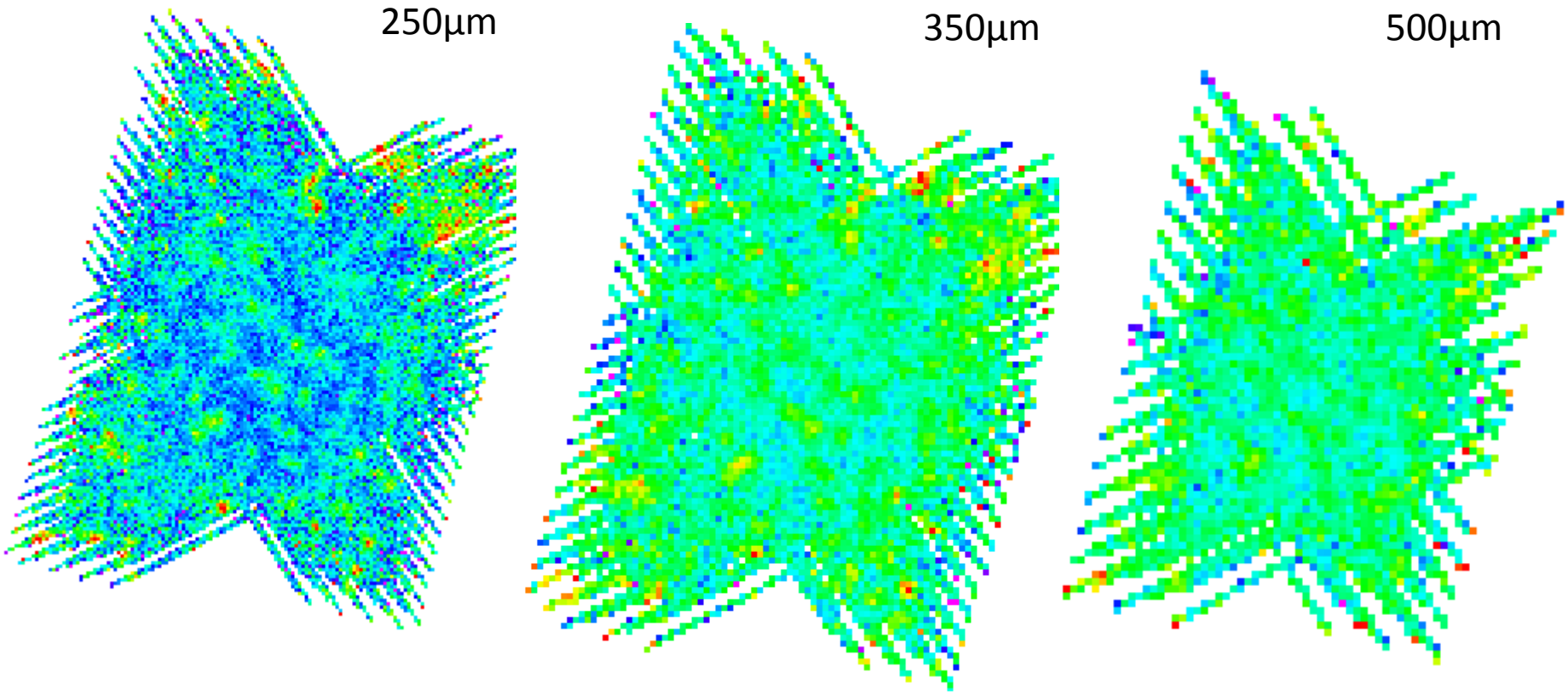
Name	HR	Sp type	F90	F180	F250 Model Leen	F250 Model Martin	F250 BB 0.5184	F350 Model	F350 Model M	F350 BB 0.26449	F500 Model	F500 Model M	F500 BB 0.1296
Alpha Ari	616	K2III	1028	253		126	131		64	67		31	33
Alpha Boo (Arcturus)	5340	K1.5III	9300	2286	1207	1145	1185	608	577	605	287	278	296
Alpha Cet (Menkar)	911	M1.5IIIa			386	361		195	182		95	88	
Alpha CMa (Sirius)	2491	A1V			219	206		110	104		53	50	
Alpha Hya	3748	K3II-III	1730	427		211	221		106	113		51	55
Alpha Tau (Aldebaran)	1457	K5III	8461	2082	1102	1043	1079	556	526	551	269	253	270
Beta And (Mirach)	337	M0III	3526	868	447	427	450	227	215	230	111	104	112
Beta Gem	2990	K0IIIb	1474	358		179	186		90	95		44	46
Beta Peg (Scheat)	8775	M2.5II-III	4957	1218	662	612	631	334	308	322	161	148	158
Beta UMi (Kocab)	5563	K4III			209	264		106	133		52	64	
Delta Dra	7310	G9III	257	63			33			17			8
Eps Lep	1654	K4III	713	175		100	91		50	46		24	23
Gamma Cru	4763	M3.5III	11920	2930		1397	1519		704	775		339	380
Gamma Dra (Eltanin)	6705	K5III	2012	495	259		257	165		131	64		64
Omega Cap	7980	M0III	517	127			66			34			16
HR 2131	2131	K5III	118	29			15			8			4
HR 7557	7557	A7V											
Theta Umi	5826	K5III	173	42			22			11			5

Stars

- Data presented here uses HIPE 10
- Source fluxes extracted using the timeline fitter
  - This gives the most consistent results for SPIRE
- Proper motion is accounted for
- Colour correction assumes standard spectral index of 2
- Fluxes compare well with map based methods:
  - Gaussian fitting
  - Aperture photometry
  - Sussextractor
  - DAOPhot

- See poster by Chris Pearson for more details

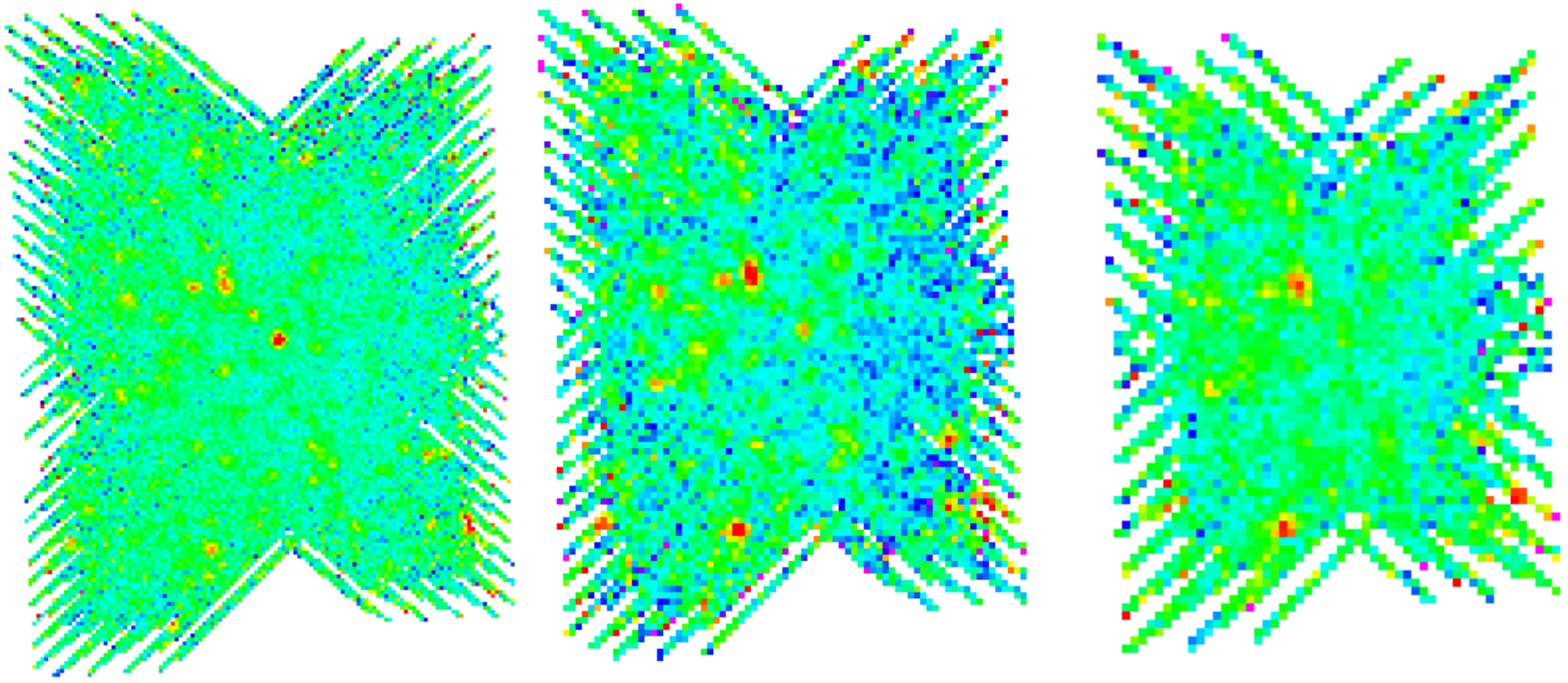
Stars



Delta Dra ~30 mJy at 250 µm is too faint to reliably pick out from background galaxies

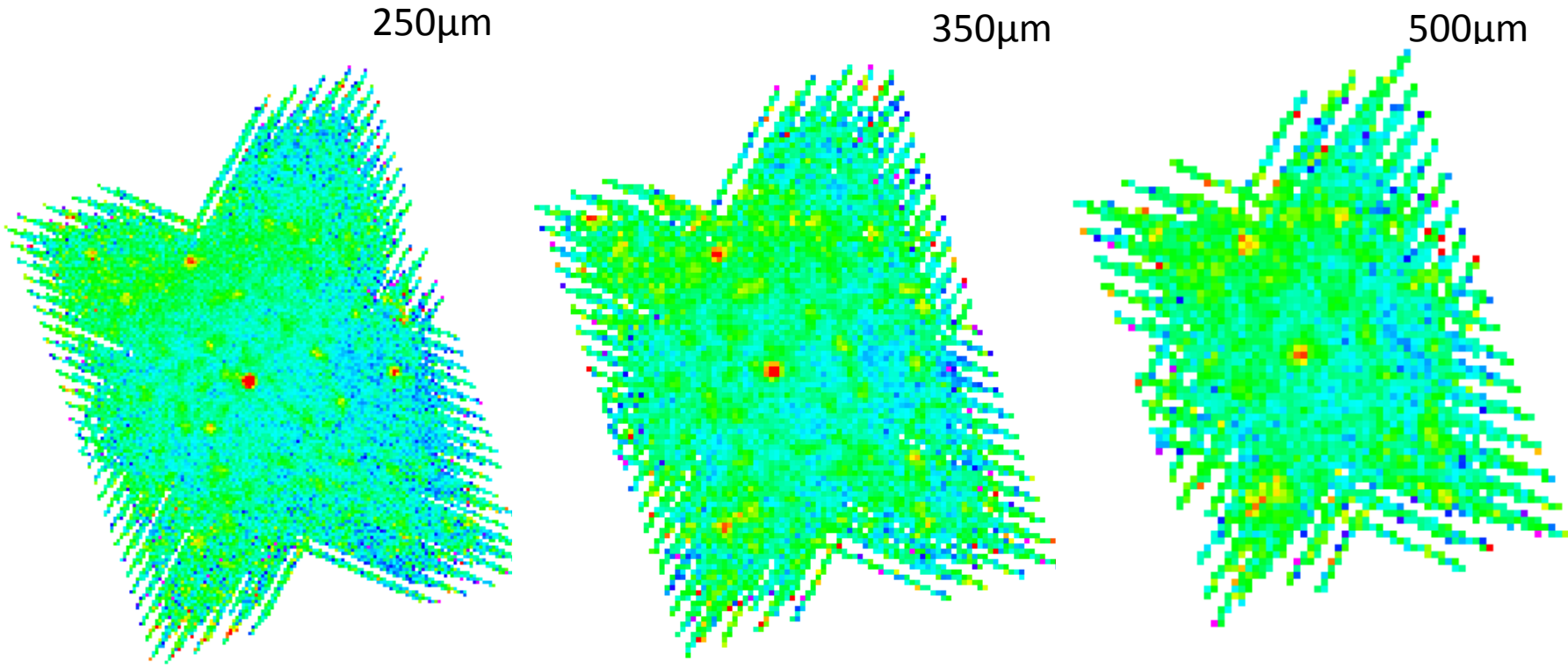
Stars

250µm 350µm 500µm



Eps Lep ~85 mJy at 250 µm is easily detected at 250 µm, just about detectable at 350 µm with fluxes of about 45 mJy and not detectable at 500 µm

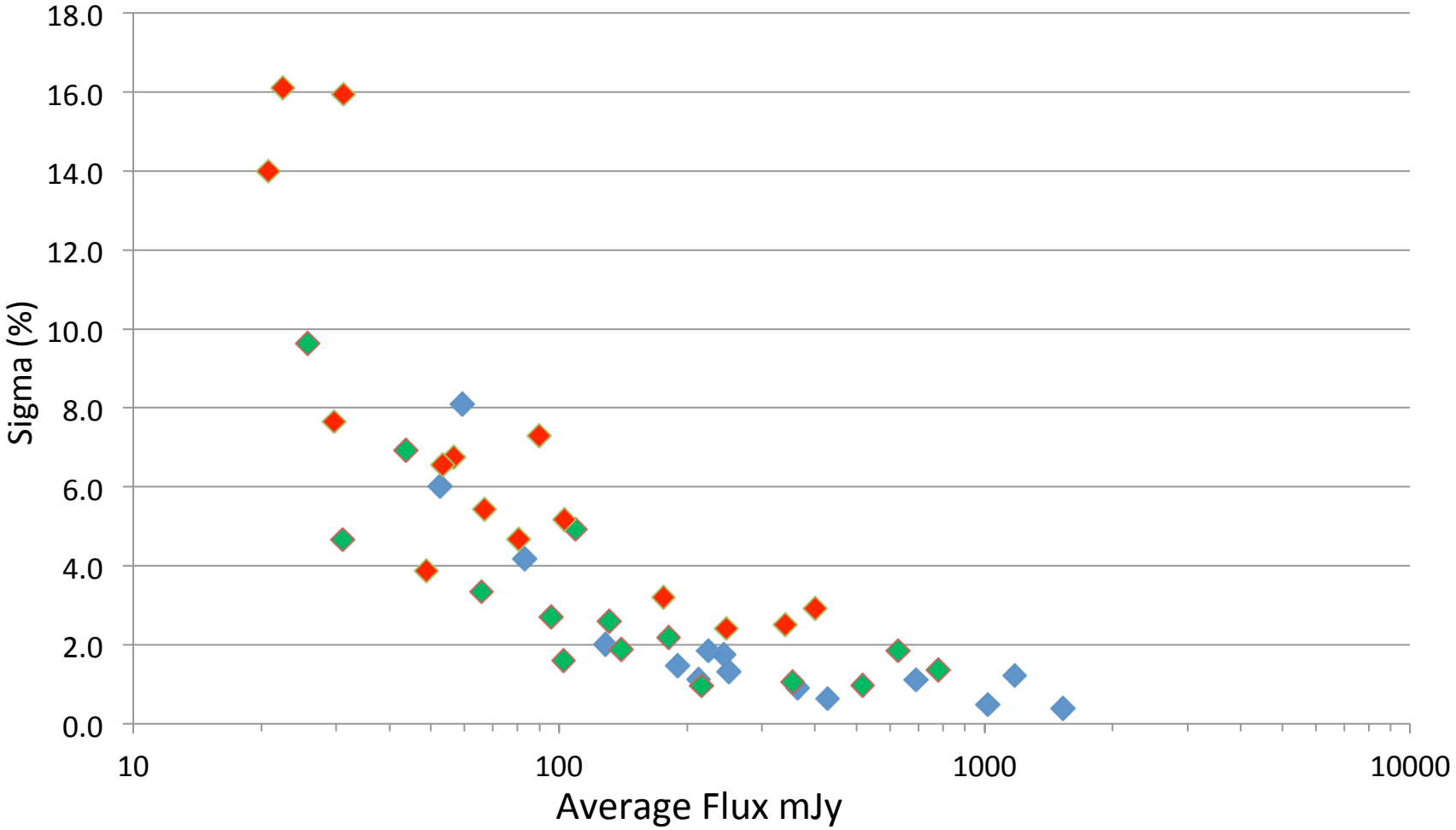
Stars



Alpha Hya ~210 mJy at 250 µm is detected in all bands, the flux at 500 µm is about 50 mJy

	Average			Stdev			Stedev (%)		
	250	350	500	250	350	500	250	350	500
Gam Cru	1530	777	400	6	11	12	0.4	1.4	2.9
Alpha Boo	1179	626	340	14	12	9	1.2	1.8	2.5
Alpha Tau	1020	517	247	5	5	6	0.5	1.0	2.4
Beta Peg	690	353	176	8	4	6	1.1	1.1	3.2
Beta And	427	216	103	3	2	5	0.6	1.0	5.2
Alpha Cet	364	181	90	3	4	7	0.9	2.2	7.3
Gam Dra	244	131	67	4	3	4	1.8	2.6	5.4
Beta UMi	251	140	81	3	3	4	1.3	1.9	4.7
Alpha Cma (Sirius)	224	110	57	4	5	4	1.9	4.9	6.8
Alpha Hya	213	103	53	2	2	3	1.1	1.6	6.6
Beta Gem	190	96	49	3	3	2	1.5	2.7	3.9
Alpha Ari	128	66	31	3	2	5	2.0	3.3	15.9
Eps Lep	83	44	21	3	3	3	4.2	6.9	14.0
Omega Cap	59	31	23	5	1	4	8.1	4.7	16.1
HR 7557	53	26	30	3	2	2	6.0	9.6	7.6

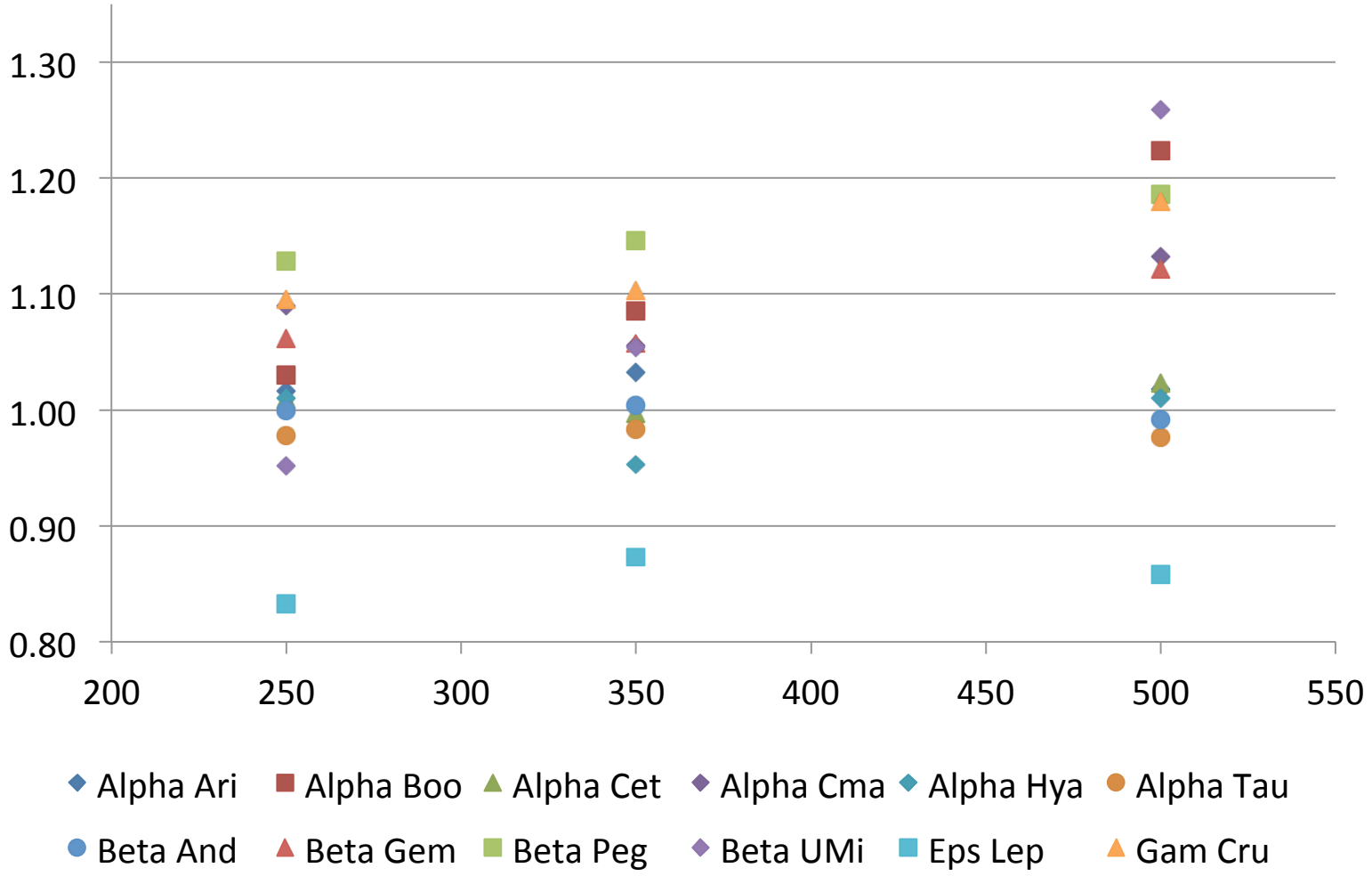
Repeatability at Stellar Fluxes



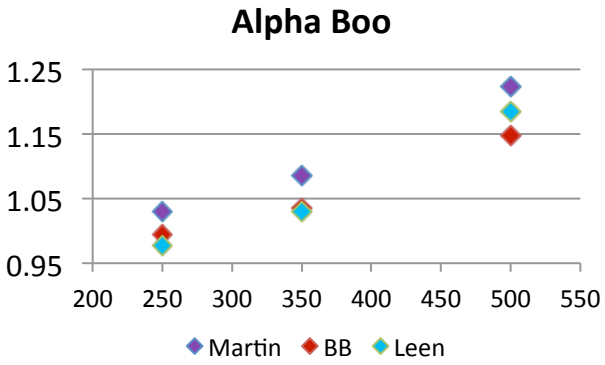
Measured/Model Stellar Fluxes

			Leen			Martin			BB		
	Av Measured PSW (mJy)	N_obs_used	Ratio PSW	Ratio PMW	Ratio PLW	Ratio PSW	Ratio PMW	Ratio PLW	Ratio PSW	Ratio PMW	Ratio PLW
Gam Cru	1253	10				0.90	0.90	0.96	**0.82**	**0.82**	**0.86**
Alpha Boo	1179	13	0.98	1.03	1.19	1.03	1.09	1.22	**0.99**	**1.04**	**1.15**
Alpha Tau	1020	15	0.93	0.93	0.92	**0.98**	**0.98**	**0.98**	0.94	0.94	0.92
Beta Peg	690	15	**1.04**	**1.06**	**1.09**	1.13	1.15	1.19	1.09	1.10	1.12
Beta And	427	7	0.96	0.95	0.93	**1.00**	**1.00**	**0.99**	0.95	0.94	0.91
Alpha Cet	364	8	0.94	0.93	0.95	**1.01**	**1.00**	**1.02**			
Beta UMi	251	26	1.20	1.32	1.55	**0.95**	**1.05**	**1.26**			
Gam Dra	244	114	0.94	0.79	1.04						
Alpha Cma (Sirius)	224	11	**1.02**	**1.00**	**1.07**	1.09	1.06	1.13			
Alpha Hya	213	10				**1.01**	**0.95**	**1.01**	0.96	0.90	0.93
Beta Gem	190	7				1.06	1.06	1.12	**1.03**	**1.01**	**1.05**
Alpha Ari	130	7				**1.02**	**1.03**	**1.02**	0.98	0.98	0.95
Eps Lep	83	8				0.83	0.87	0.86	0.92	0.95	0.92
HR 7557	53	6									
Omega Cap	59	7									
Delta Dra	33	1							0.83	0.69	1.19

Stars


1.30
1.20
1.10
1.00
0.90
0.80
200
250
300
350
400
450
500
550
Alpha Ari
Alpha Boo
Alpha Cet
Alpha Cma
Alpha Hya
Alpha Tau
Beta And
Beta Gem
Beta Peg
Beta UMi
Eps Lep
Gam Cru

Stars


Alpha Boo
1.25
1.15
1.05
0.95
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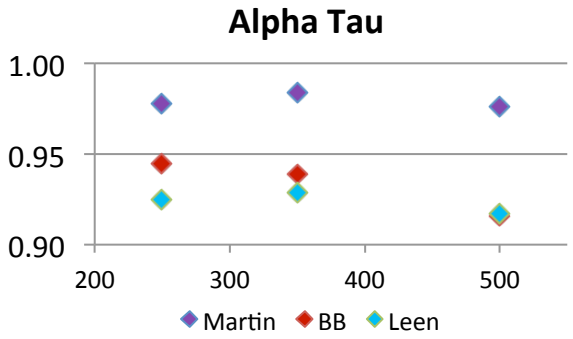
Martin BB Leen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0.90
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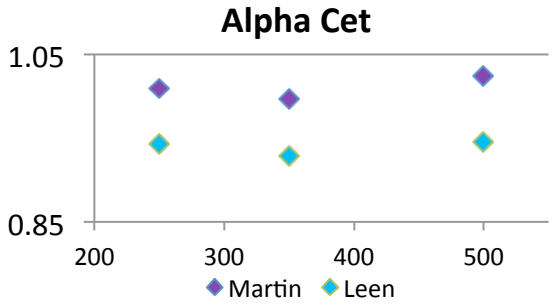
Martin BB Leen


Alpha Cet
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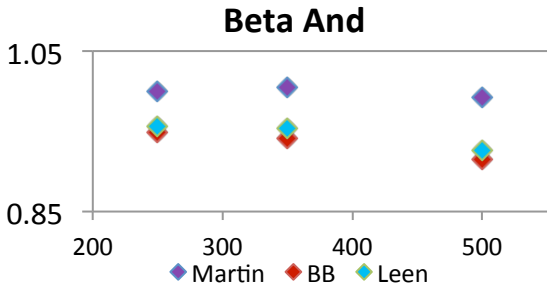
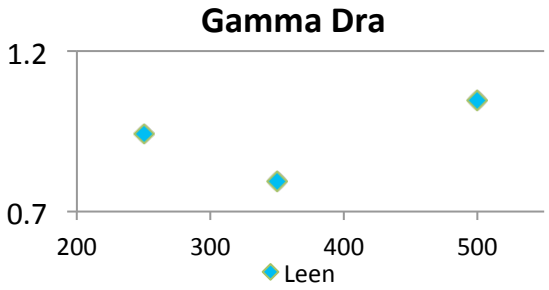
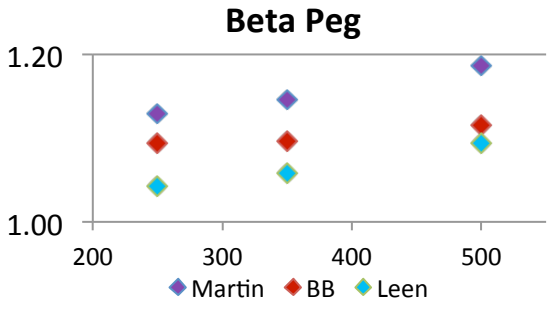
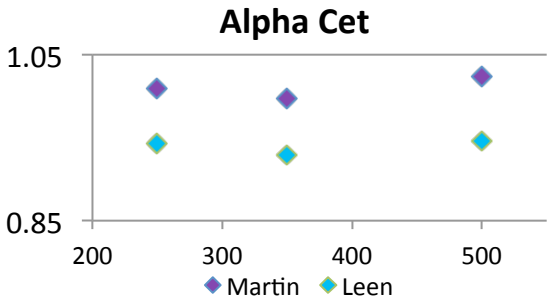
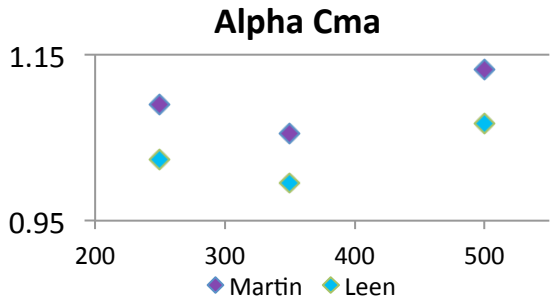
Martin Leen


Beta And
1.05
0.85
200 300 400 500
Martin BB Leen


Gamma Dra
1.2
0.7
200 300 400 500
Leen


Beta Peg
1.20
1.00
200 300 400 500
Martin BB Leen

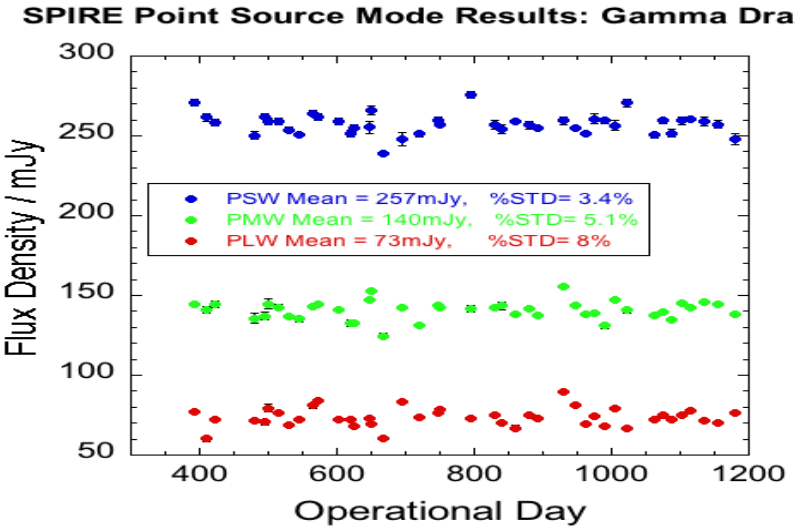

Alpha Cet
1.05
0.85
200 300 400 500
Martin Leen

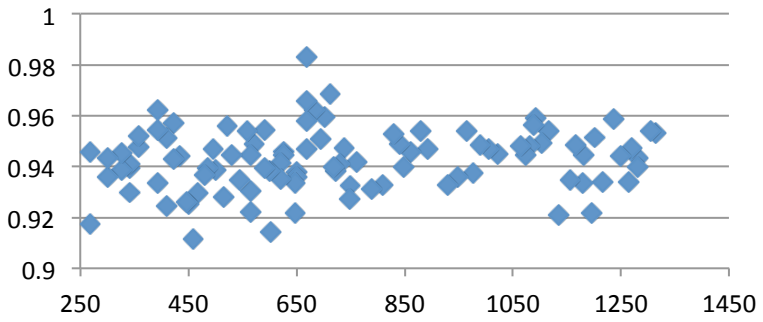

Alpha Cma
1.15
0.95
200 300 400 500
Martin Leen

Stars

- In addition to the small map observations some stars have also been observed as a 7 point jiggle.
- The two stars observed most often were Gamma Dra and Beta UMi

Small Map		Jiggle	
Gamma Dra			
244	4	257	8
131	3	140	7
67	4	73	6
Beta Umi			
251	3	264	5
140	3	147	6
81	4	85	3





Asteroids

- List of Asteroids which have good models were provided to the calibration team before launch
  - Starting with the brightest objects we initially selected objects which were visible in PV phase
  - This list of objects was extended in routine phase depending on what was visible
  - Lutetia was added later as work was on-going to make this a prime calibrator
- The observations were taken in the same mode as the stars also with 4 scans per observation taking about 6 minutes
- During this time the spacecraft is tracking the asteroid

Asteroids

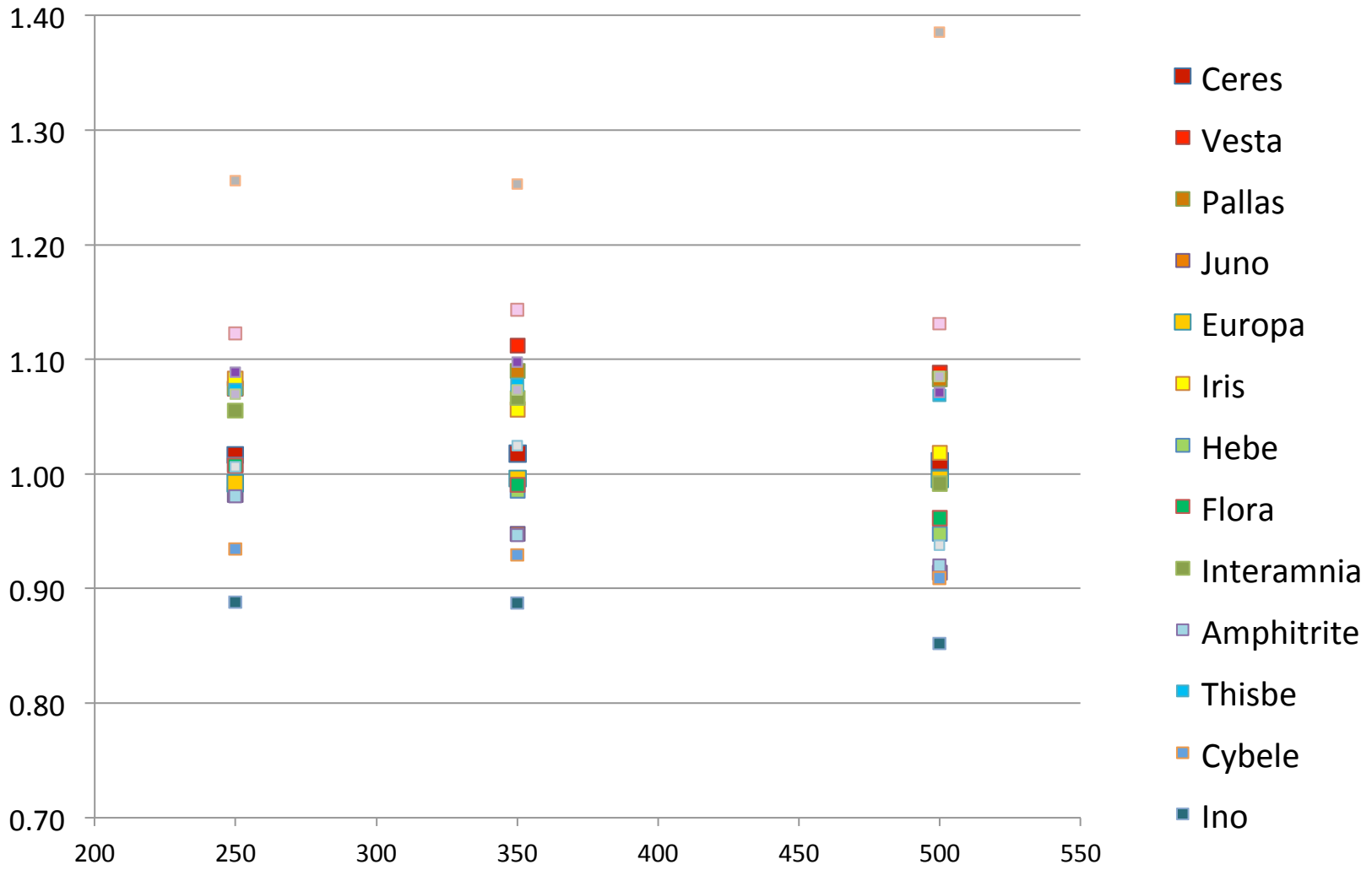
- 25 asteroids were observed in total:
  - 23 as calibration observations, some also as science targets
  - 1 object, Mathilde in open time only
  - 1 object was observed within a TNO programme map
- Higher number due to more constrained visibility
- Fluxes range from ~300 mJy at 250 µm to 30000 mJy at 250 µm
- About 260 observations have been made over routine phase

- For each observation the timeline data was corrected for asteroid motion then a the position at the start of the observation is used as an input to the timeline fitter.

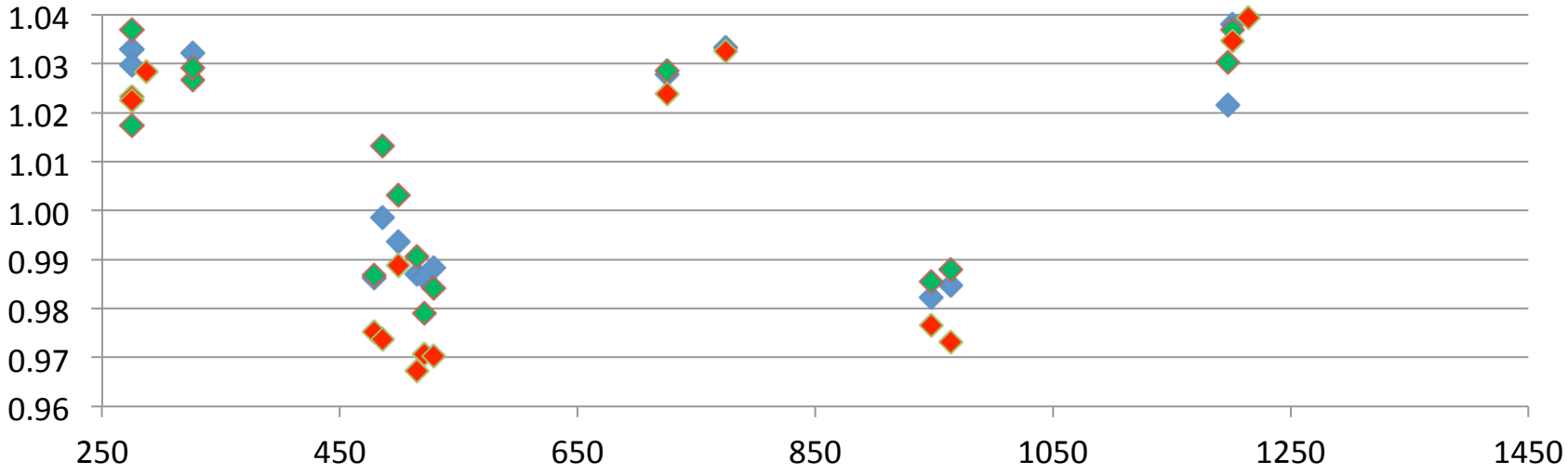
Asteroids

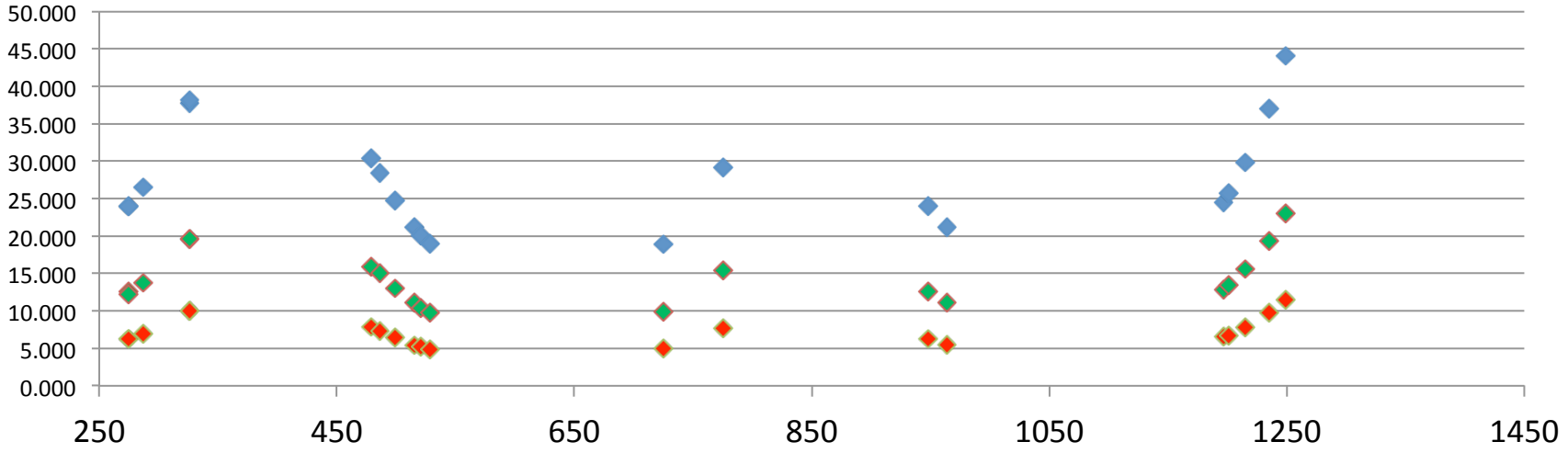
Asteroid	No. Observations	Asteroid	No. Observations
Ceres	21	Harmonia	5
Hygiea	15	Aglaja	6
Ino	6	Davida	8
Fortuna	7	Europa	11
Pallas	15	Alenandra	7
Massalia	5	Hebe	14
Lutetia	6	Cybele	9
Mathilde	1	Iris	6
Amphritrite	6	Interamnia	10
Juno	12	Flora	8
Fides	6	Thisbe	9
Vesta	32	Minerva	4

Asteroids

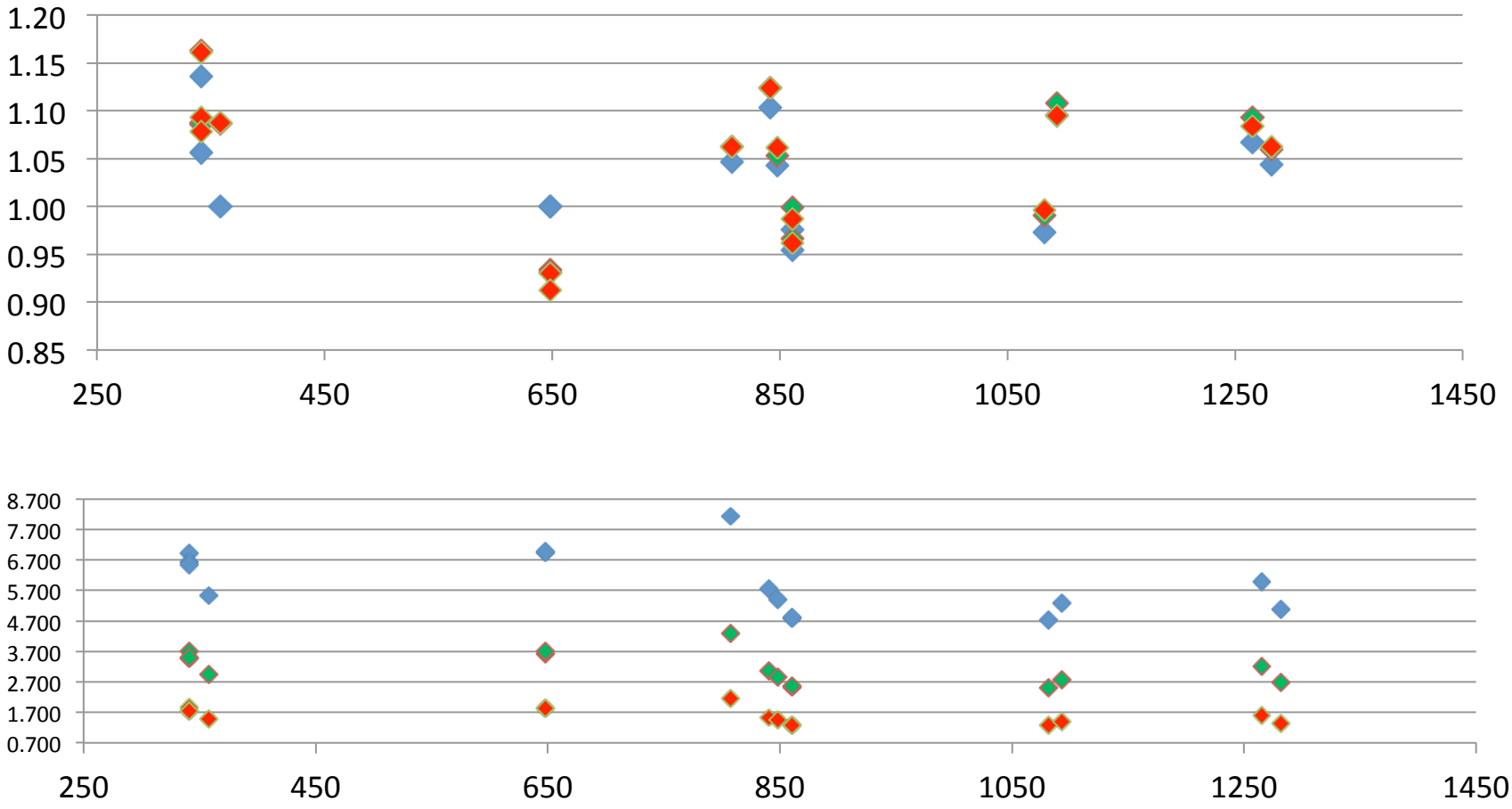

1.40
1.30
1.20
1.10
1.00
0.90
0.80
0.70
200
250
300
350
400
450
500
550
Ceres
Vesta
Pallas
Juno
Europa
Iris
Hebe
Flora
Interamnia
Amphitrite
Thisbe
Cybele
Ino

Asteroids - Ceres



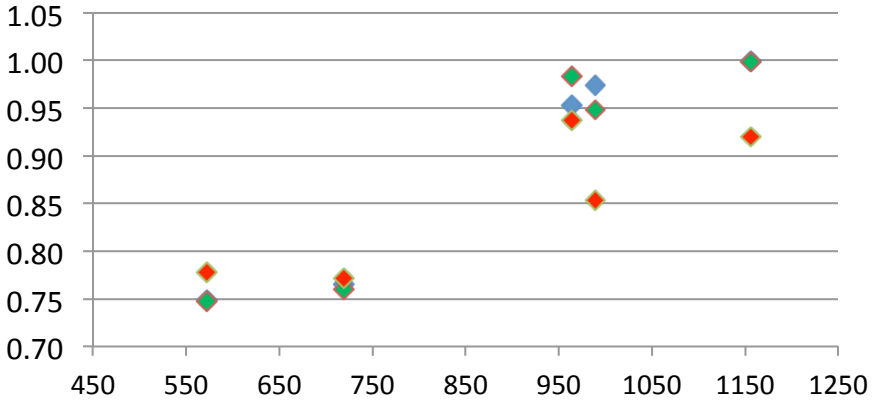


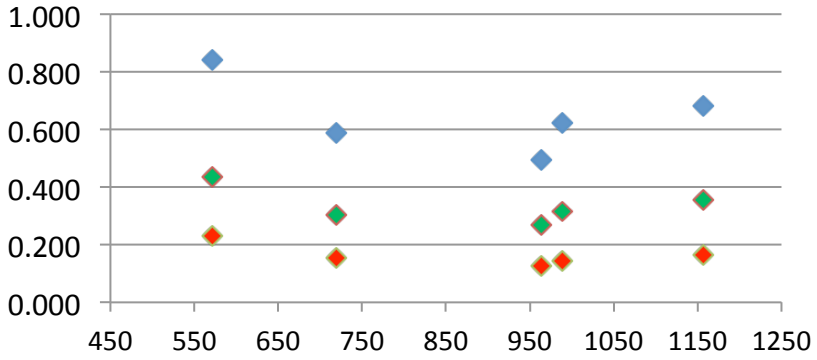
Asteroids - Hygiea



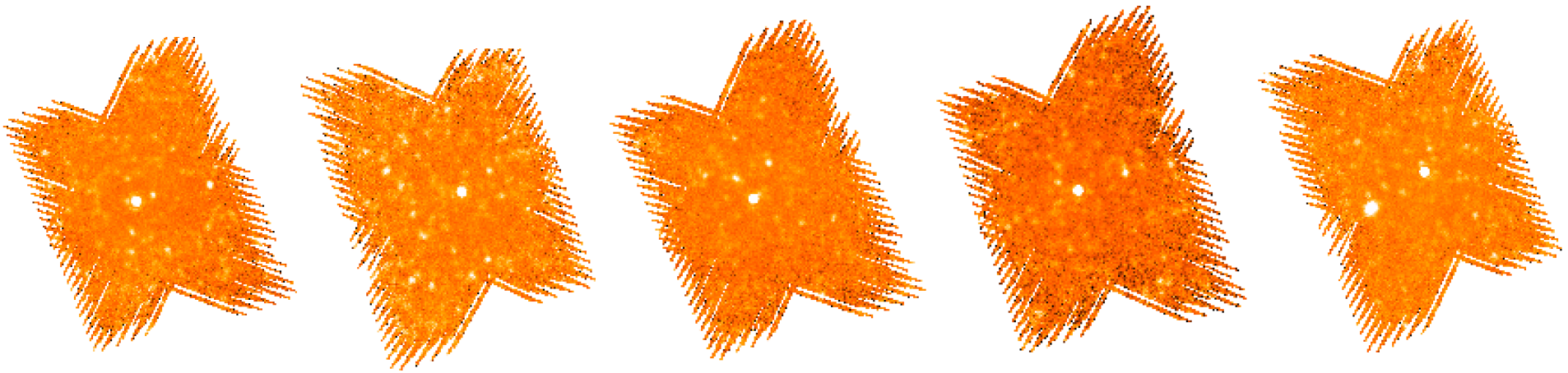
Hygiea is a bright asteroid, up to 8000 mJy at 250 µm.

Asteroids – Ino

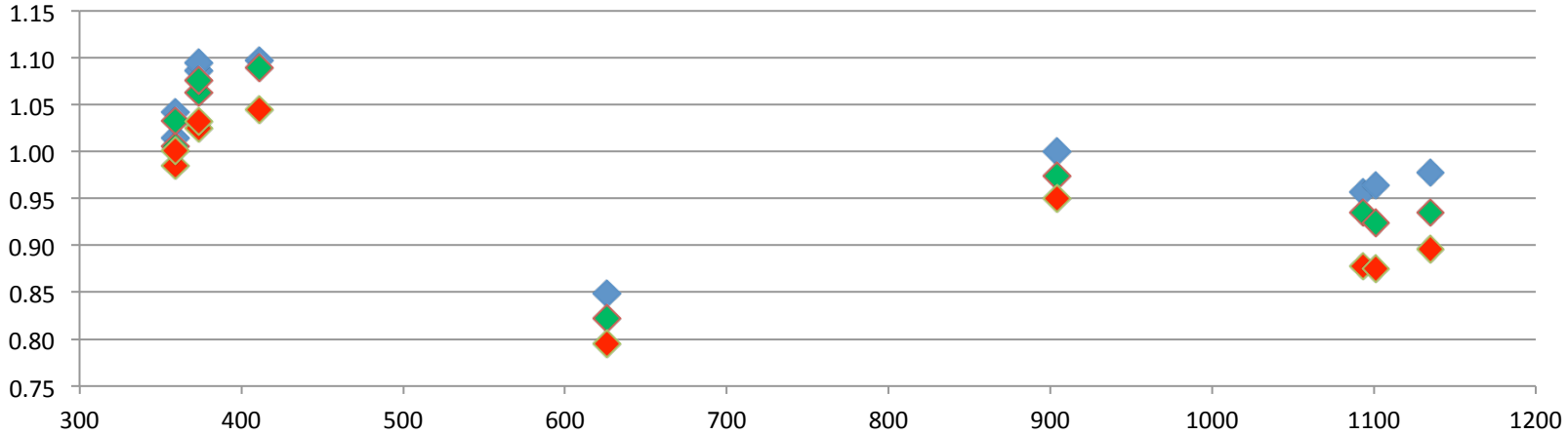


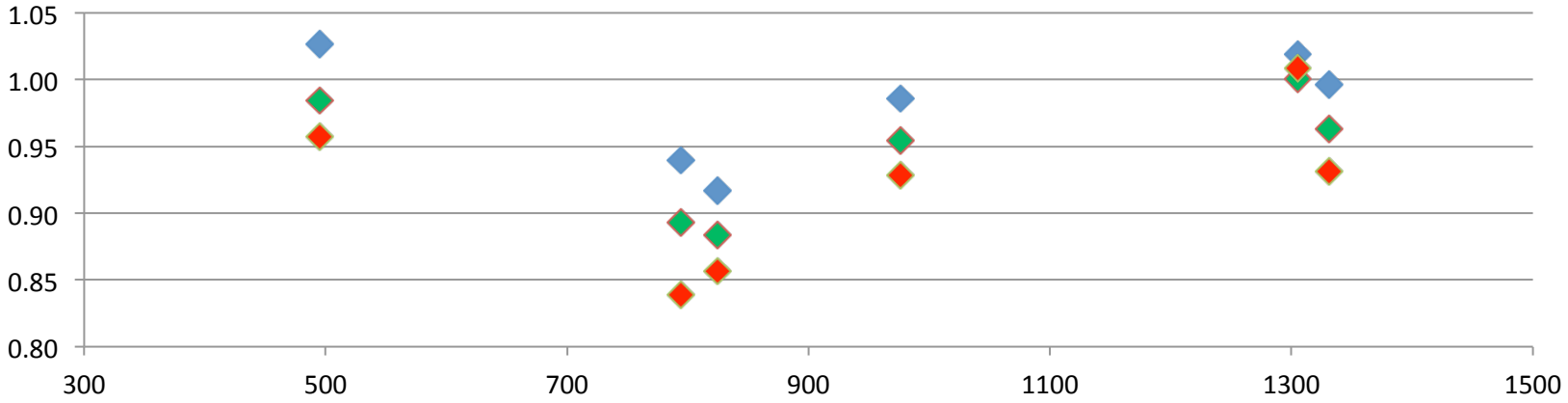


Ino shows a long term trend in ratio with model but no obvious correlation to measured flux



Asteroids – Hebe, Amphritrite





Hebe and Amphritrite show a consistent difference in ratio between SPIRE bands

Asteroids

	Max PSW Model (Jy)	Ratio PSW	Ratio PMW	Ratio PLW	Stdev	Stdev	Stdev
1 Ceres	36.60	**1.02**	**1.02**	**1.01**	0.02	0.02	0.03
4 Vesta	15.51	**1.07**	**1.11**	**1.09**	0.03	0.02	0.03
2 Pallas	10.45	**1.07**	**1.09**	**1.08**	0.03	0.04	0.03
10 Hygiea	7.64	**1.04**	**1.05**	**1.05**	0.05	0.07	0.07
3 Juno	5.89	**0.98**	**0.95**	**0.91**	0.03	0.03	0.06
52 Europa	4.58	**0.99**	**1.00**	**1.00**	0.03	0.03	**0.04**
7 Iris	4.27	**1.08**	**1.06**	**1.02**	**0.16**	0.15	0.15
6 Hebe	3.86	**1.01**	**0.99**	**0.95**	0.08	0.08	0.08
8 Flora	3.16	**1.01**	**0.99**	**0.96**	0.02	0.03	0.05
704 Interamnia	2.29	**1.05**	**1.07**	**0.99**	0.05	0.05	0.05
29 Amphitrite	1.80	**0.98**	**0.95**	**0.92**	0.04	0.05	0.06
511 Davida	1.61	**1.06**	**1.09**	**1.05**	0.05	0.05	0.06

Asteroids

	Max PSW Model (Jy)		Long Term Trend?	Channel Differences?	Highest Difference	Variable Ratios Short Term?
1 Ceres	36.60		N	N		N
4 Vesta	15.51		M	Y	PMW	Y
2 Pallas	10.45		N	N		Y
10 Hygiea	7.64		N	M	PLW	Y
3 Juno	5.89		Y	Y	PSW	Y
52 Europa	4.58		N	N		N
7 Iris	4.27		Y	Y	PSW	M
6 Hebe	3.86		M	Y	PSW	M
8 Flora	3.16					
704 Interamnia	2.29		N	N		N
29 Amphitrite	1.80		M	Y	PSW	Y
511 Davida	1.61		N	N		M

Summary

- During SPIRE routine observations we have observed a good set of stars and asteroids and have enough data to:
  - Use the stellar models to say something about the SPIRE calibration at low fluxes
  - Use the fixed fluxes of stars to see how repeatable SPIRE is at low fluxes
  - Compare asteroid fluxes with models providing a good range of intermediate flux objects
- Stellar fluxes are well established, good understanding of ability to recover flux for faint objects
- No obvious trend in comparison with stellar models - no trend in calibration with flux
- Asteroid comparison good overall but still work to do on models.

Comparison of Photometry Methods

See poster from Chris Pearson et al.

- **Source Extraction and Photometry algorithms within HIPE**
  - SUSSEXtractor : peak search in smoothed convolved image
  - DAOphot : FIND for detection, APER for photometry
- **Photometry algorithms within HIPE**
  - Timeline Fitter
  - Aperture Photometry
  - Gaussian Fitting
- **All these methods are now in reasonable agreement**
- **7% of flux density for calibration uncertainty**
  - ~2-3% statistical reproducibility down to ~ 100mJy
  - 5% absolute level of Neptune model

See poster from Chris North et al.

- **New calibration framework for extended sources**
  - Accounts for changing size of beam across band, including the colour correction
  - Difference compared to current calibration is a few percent