From the optical characteristics of HIFI to in-orbit flux calibration using Mars

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Outline of presentation

- Review of HIFI spatial calibration method
- Issues and questions related to current values
- What do optical models and ground measurements tell us?
- Possible routes for calibration improvement
- Discussion of preliminary results
- Final steps to be taken

HIFI spatial calibration method (1)

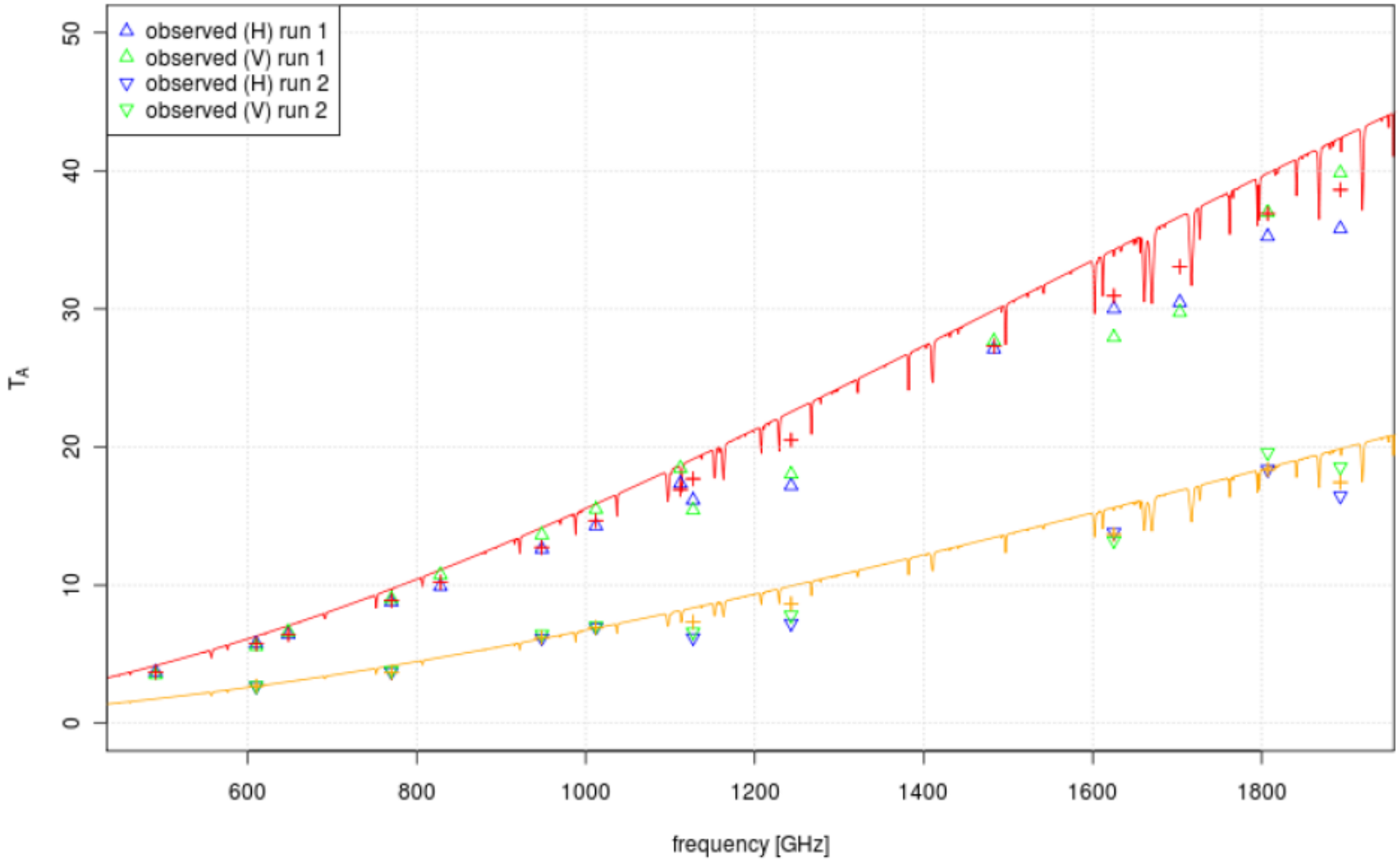
- Need good knowledge of η_{mb} and η_a across HIFI spectral range (ref. presentation Michael Olberg)
- Currently one of the limiting factors in final calibration accuracy
- Efficiencies are obtained by relatively sparsely sampled measurements on Mars:
  - Reasonable SNR in acceptable observing time
  - Detailed / high-SNR HIFI beam patterns excluded

HIFI spatial calibration method (2)

- Use relatively simple 1st order approach:
  - Measure beam profile on Mars
  - Fit 2D Gaussian to profile
  - Deconvolve for Mars (disk): $\theta_b = \sqrt{\theta_{obs}^2 - a \cdot \theta_s^2}$
  - Using T_{RJ} from Mars model Raphael Moreno
  - and coupling factor to Mars: $F_d = \frac{1}{1 - \mathrm{e}^{-x^2}}$
  - η_{mb} is ratio observed and predicted T_A
- Finally η_a via: $\frac{\eta_{mb}}{\eta_A} = \frac{A_{geom}\Omega_{mb}}{\lambda^2} \approx \frac{\pi D^2}{4} \frac{\pi}{4 \ln 2} \frac{\theta_b^2}{\lambda^2}$

See TN v1.1 2010-11-17 by Michael Olberg

...ratio of T_A



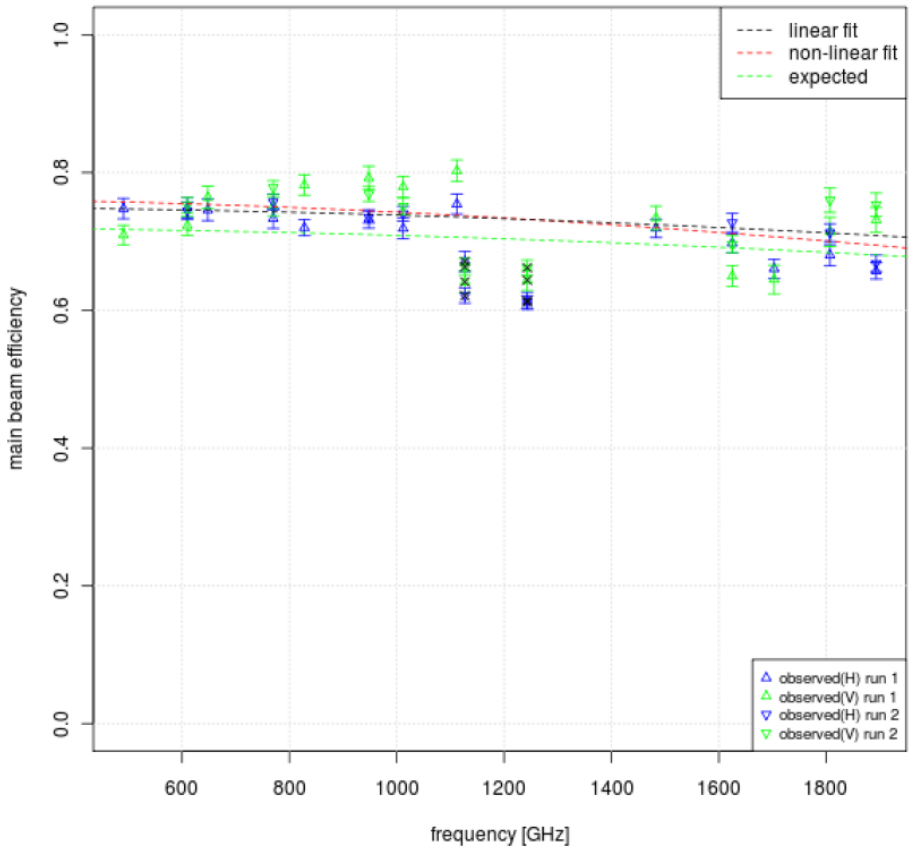
Plots taken from Michael Olberg

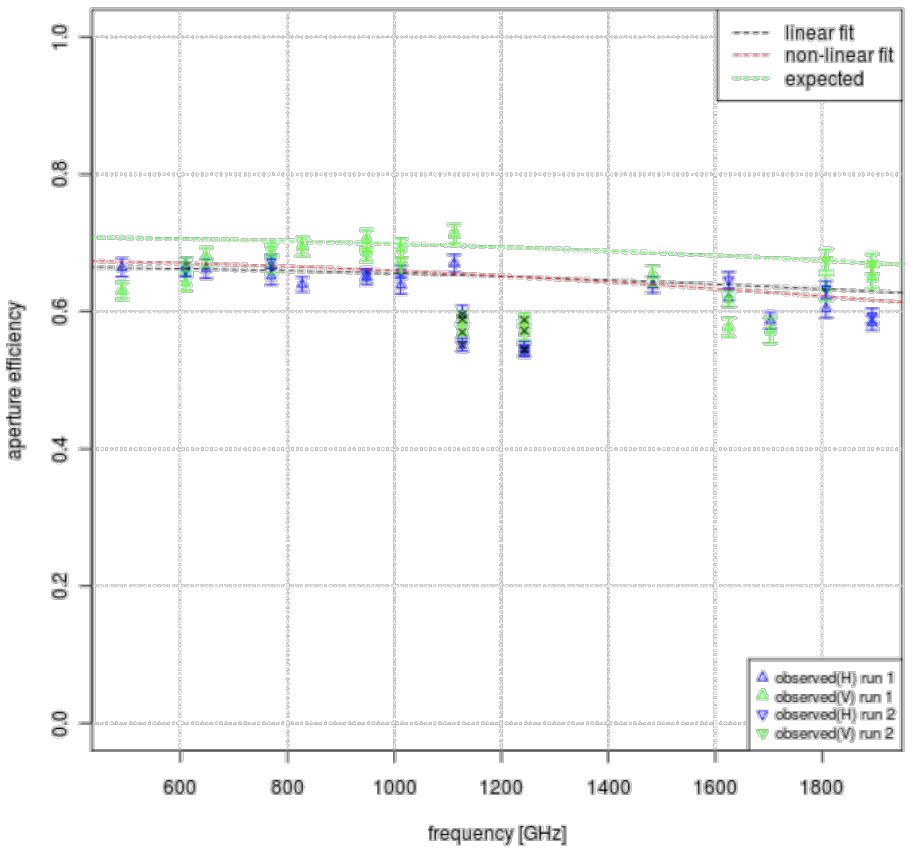
…and finally η_{mb} + η_a

- Frequency dependence through Ruze's eq.:

$$\eta_{mb} = \eta_{mb,0} \cdot \exp\left[-\left(\frac{4\pi\sigma}{\lambda}\right)^2\right]$$

$$\eta_A = \eta_{A,0} \cdot \exp\left[-\left(\frac{4\pi\sigma}{\lambda}\right)^2\right]$$





…current recommendation HIFI

- Use global trends and Ruze's equation:

bands	$\eta_{mb,0}$	$\eta_{A,0}$	σ [µm]	comment
1–4,6–7	0.76 ± 0.02	0.68 ± 0.02	3.8 ± 0.9	non-linear fit
5	0.66 ± 0.02	0.58 ± 0.02	3.8 ± 0.9	average

- Band 5 excluded from global trend and treated separately in view of large deviation

Issues and questions

- Results obtained in run 1 (OD-330 and -311) and run 2 (OD-390-391 and -406-407) are not consistent (θ_b run 2 < θ_b run 1)
- Ratio η_{mb} / η_A not as-designed (too large), η_{mb} and η_A higher than expected (cf optical model)
- Are local deviations (5-10%) for individual mixer bands real/systematic or (random) measurement errors (e.g. band 5)?
- Are our Gaussian approximations related to this?

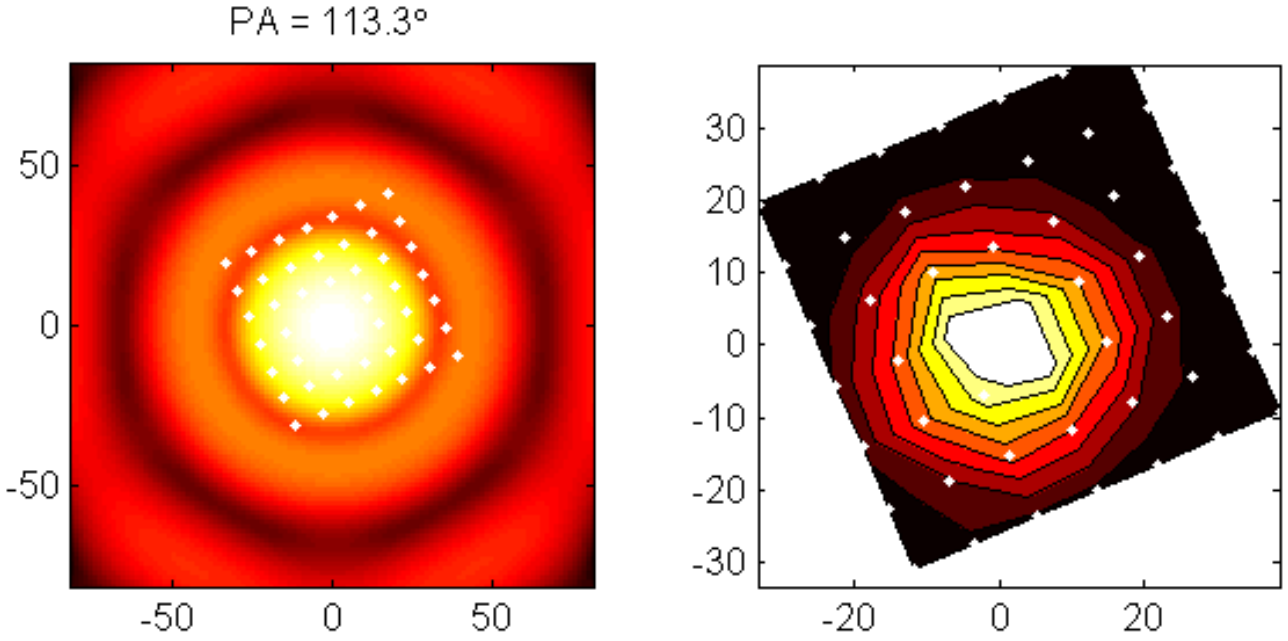
Optical model and ground results

- Based on validated EM simulations
- Gaussian illumination of Herschel telescope

T_e (dB)	θ_0 (λ/D)	θ_b (λ/D)	η_a (%)	η_{mb} (%)	1st sidelobe (dB)
-6.0	0.848	0.998	0.602	0.544	-17.2
-7.0	0.854	1.005	0.630	0.583	-17.6
-8.0	0.860	1.012	0.647	0.612	-17.9
-9.0	0.866	1.020	0.655	0.634	-18.2
-10.0	0.874	1.028	0.657	0.650	-18.5
-10.9	0.881	1.037	0.654	0.661	-18.9
-12.0	0.889	1.047	0.646	0.669	-19.2
-13.0	0.898	1.057	0.635	0.674	-19.5
-14.0	0.907	1.068	0.623	0.675	-19.8
-15.0	0.917	1.079	0.608	0.675	-20.1
			cf 0.68	cf 0.76	detectable?

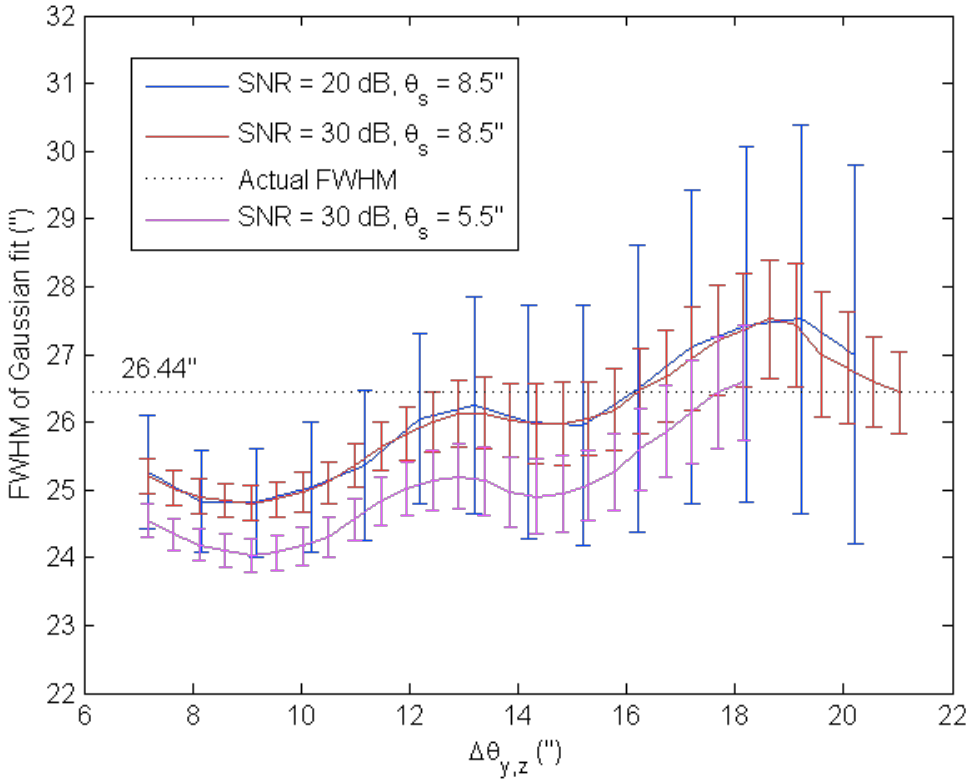
Simulating small and coarse raster

- Sky beams HIFI are not Gaussian
- Mars maps contain fraction of 1st bright ring
- Sample points cross 1st dark ring



Systematic errors due to sampling

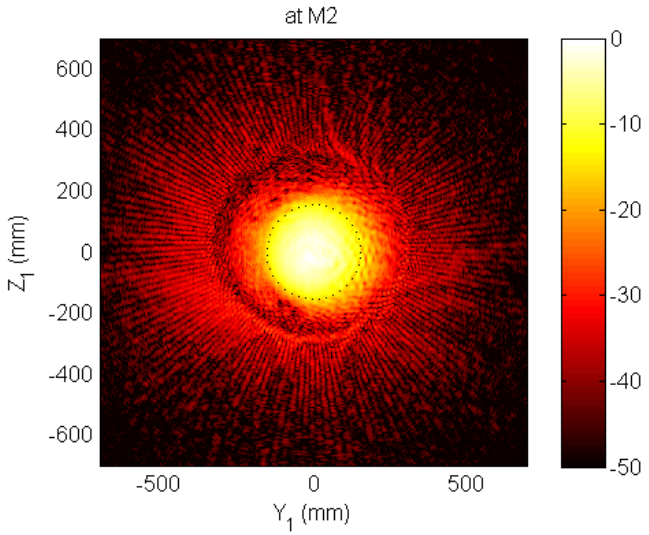
- Systematic errors due to:
  - Limited extent
  - Sampling interval
  - Convolution Mars
- Could explain the inconsistency seen in run 1 and 2

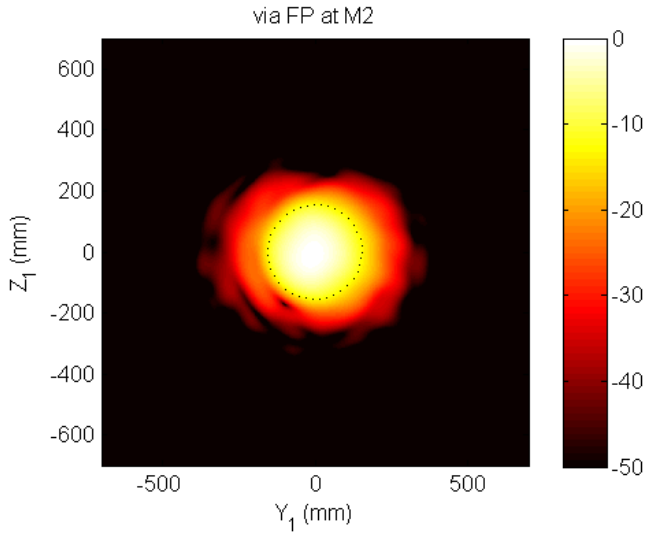


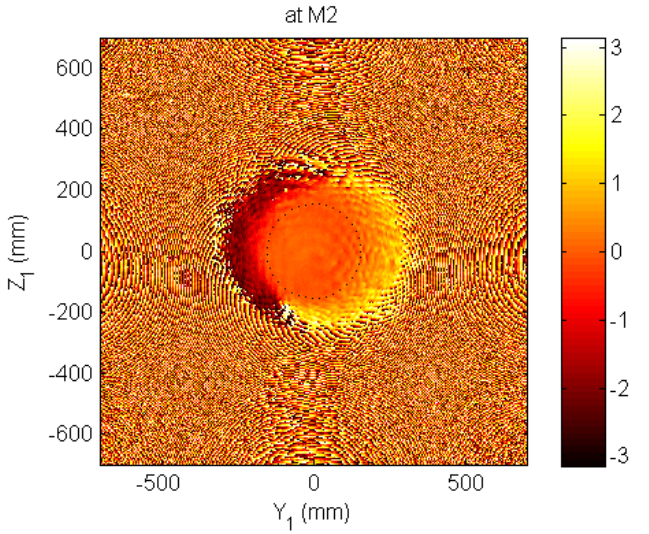
Using ground measurement data

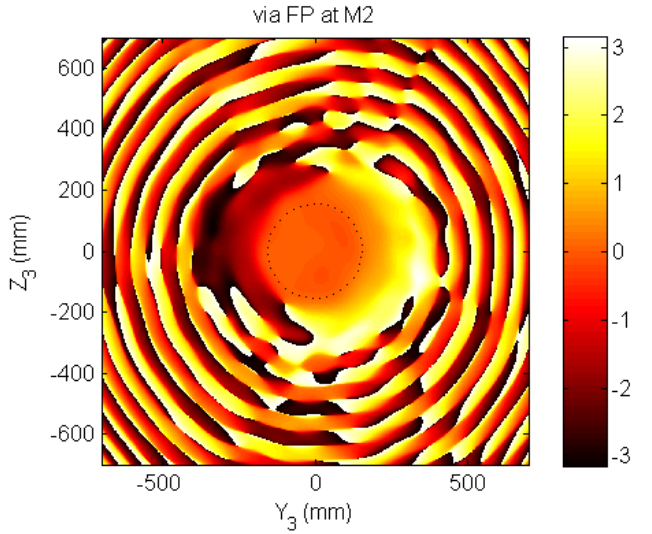
- HIFI has measured all its individual mixer beams in great detail (single-moded)
- Phase and amplitude of wavefront in the FP have been measured in cryogenic FM conditions
- Combined with telescope model industry forward model is feasible and potentially very accurate

…starting with the raw data

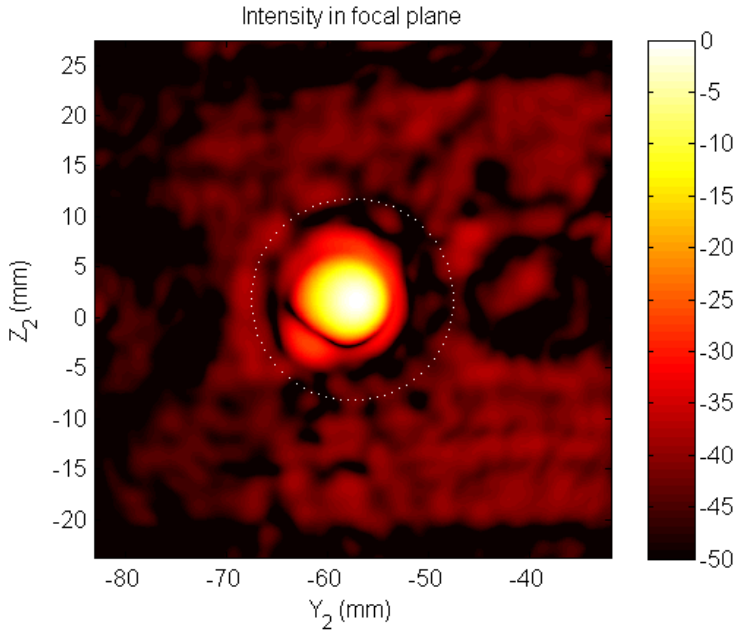


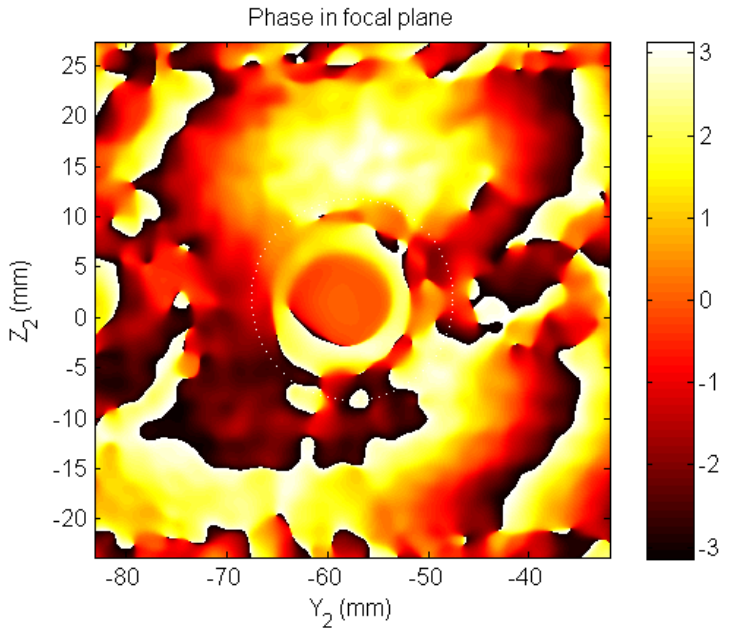




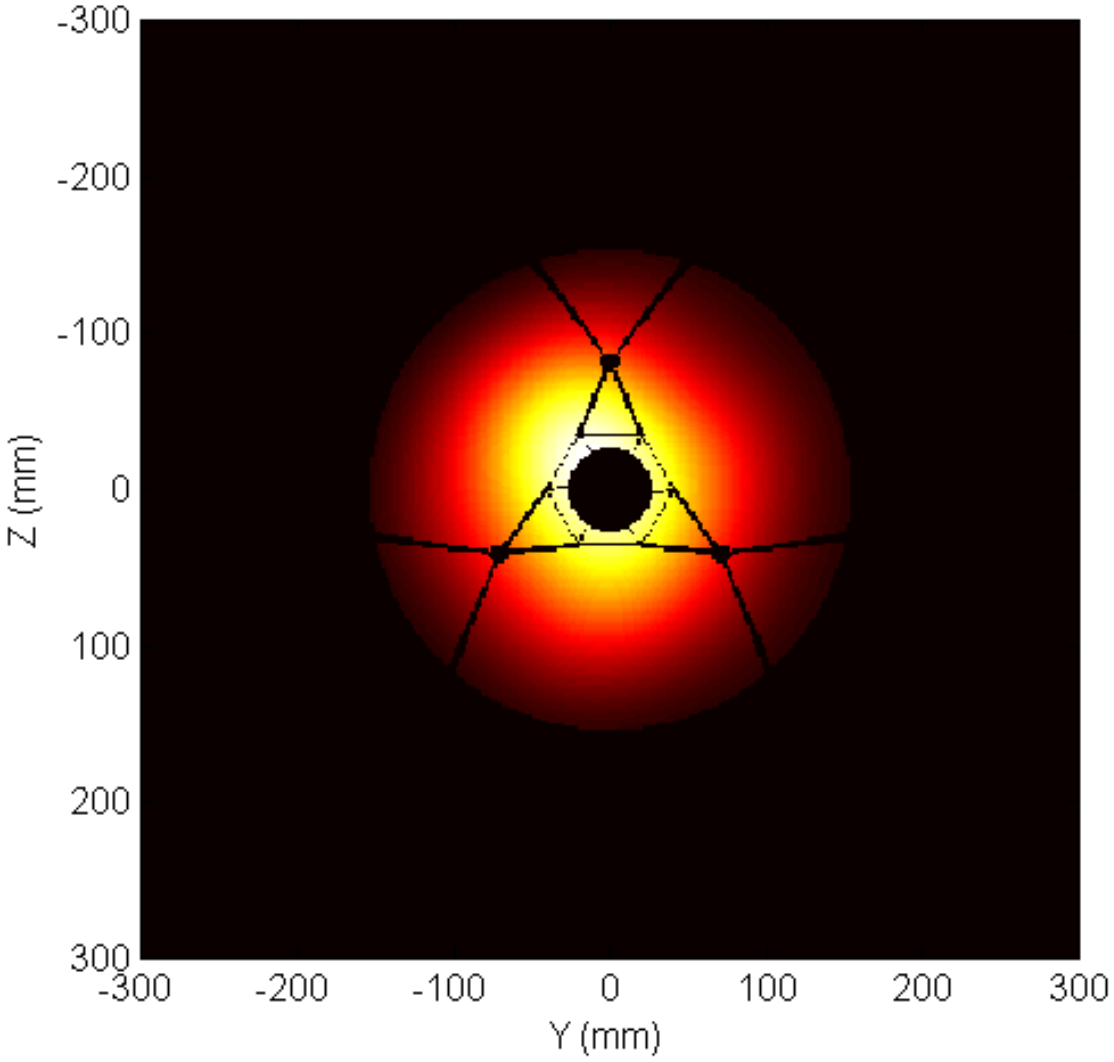


…propagation and spatial filtering

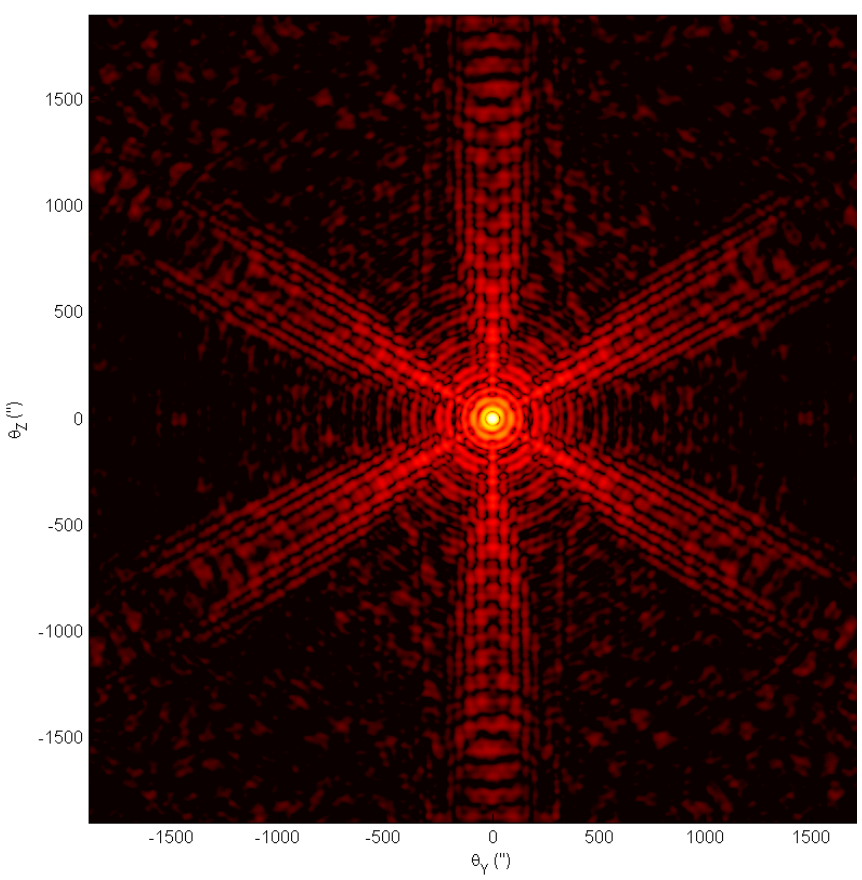


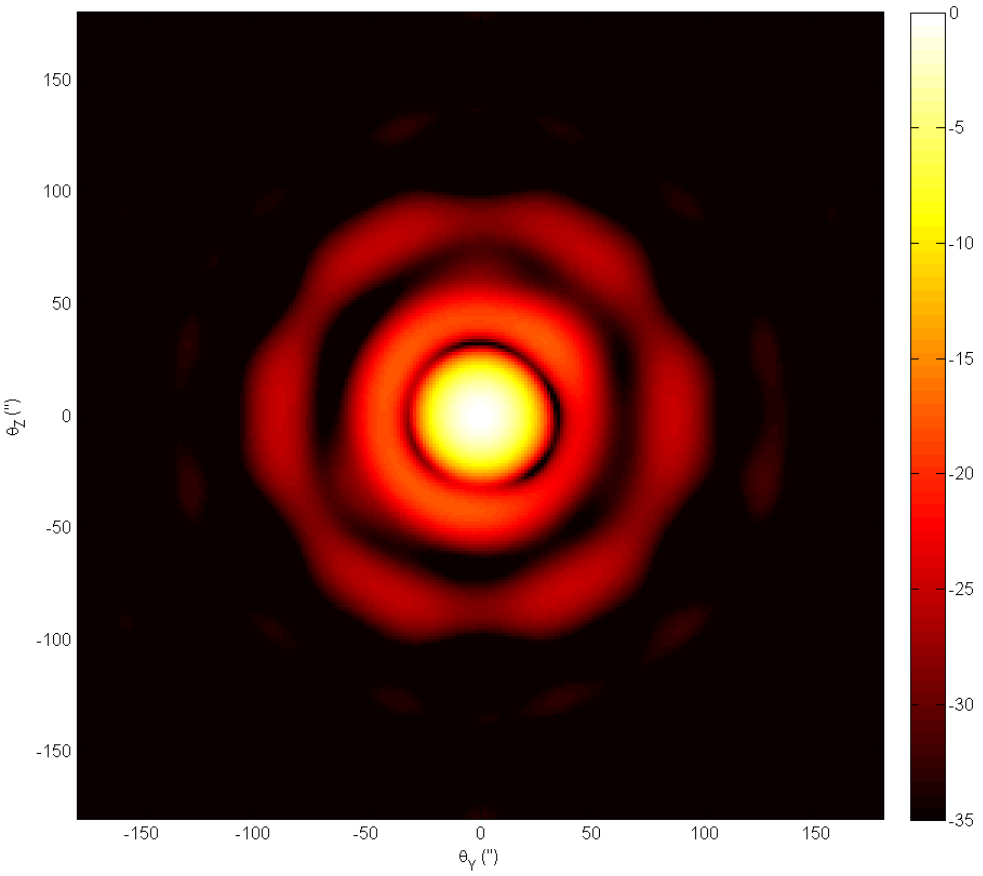


…running through telescope model

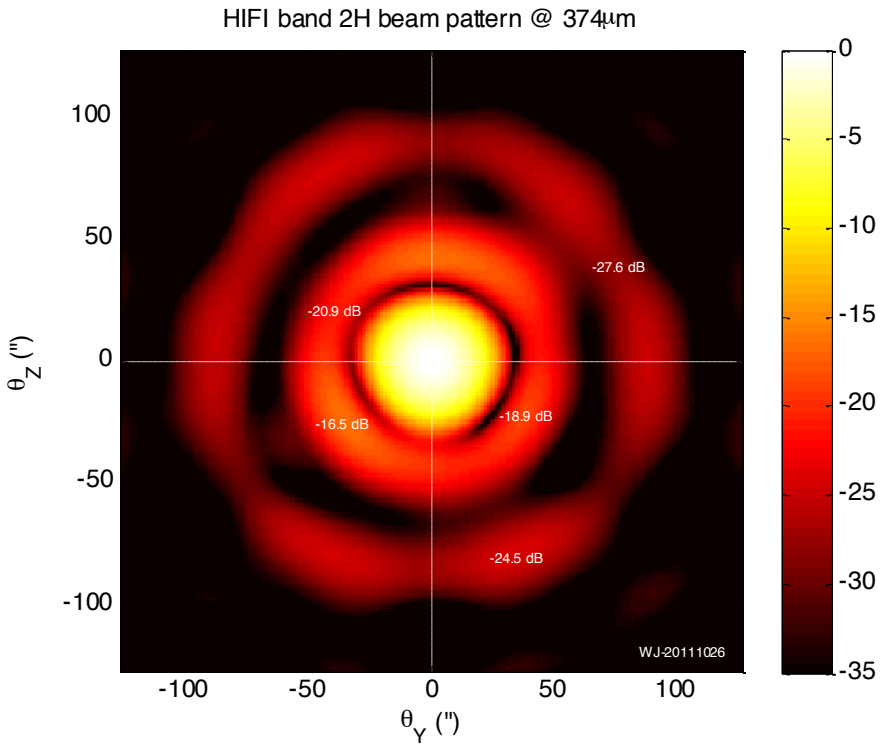


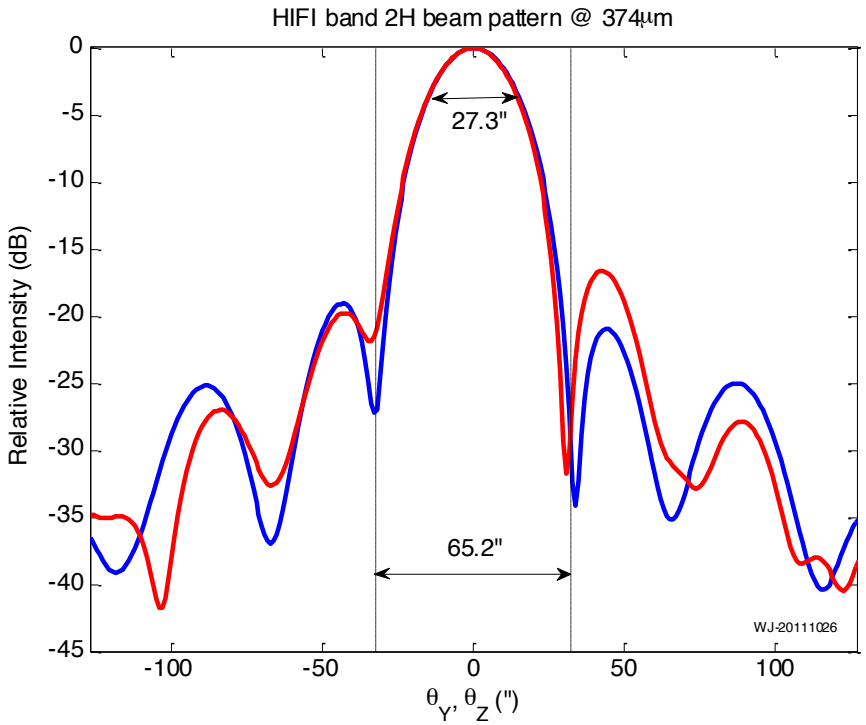
…yielding sky pattern





…example for band 2H





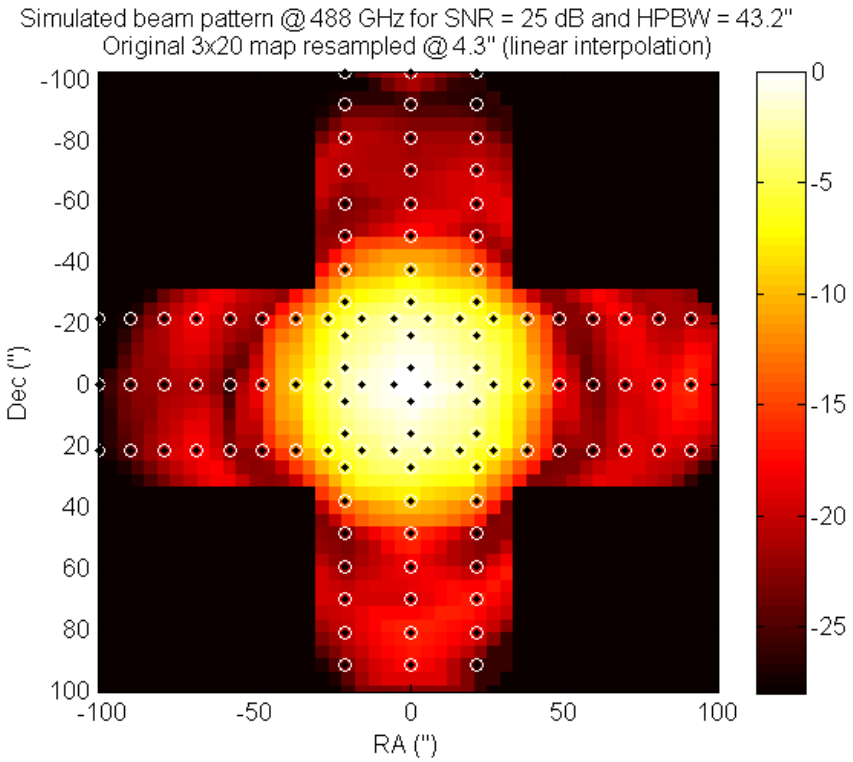
Possible calibration improvements

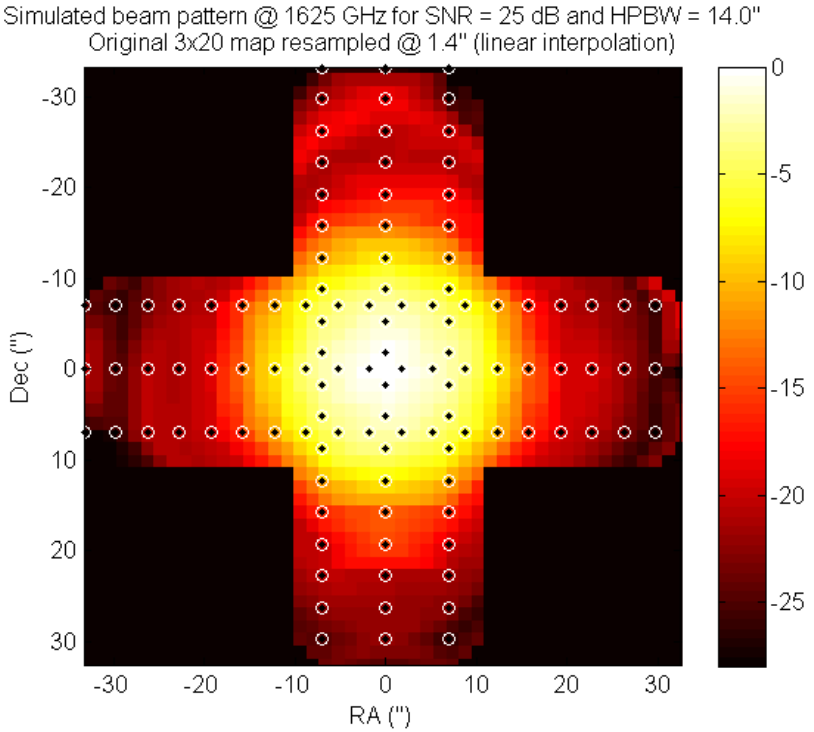
- Additional, complementary and optimized maps (repetition of Mars observations populating a composite/accumulative map)
- Improved models for data fitting:
  - Truncated and centrally obscured Gaussian
  - Forward model assuming incident Gaussian
  - Including full tripod occultation map and trefoil WFE
- Using wavefront propagated ground-based data (requires in-orbit verification and modelling)

Complementary maps

- In view of Herschel cross-calibration a Mars run 3 was scheduled on OD-895-897 and -903
- A final run 4 was done for a very limited set of bands spanning the full HIFI range (band 1 and 7) and covering the outlier band 5
- Using simulated sky patterns optimized 3x20 striped maps (orthogonal) were used
- In run 3 a single high-SNR 20x20 raster was requested (and granted) to demonstrate the potential of using ground-based data

…striped pattern AOR check run 3

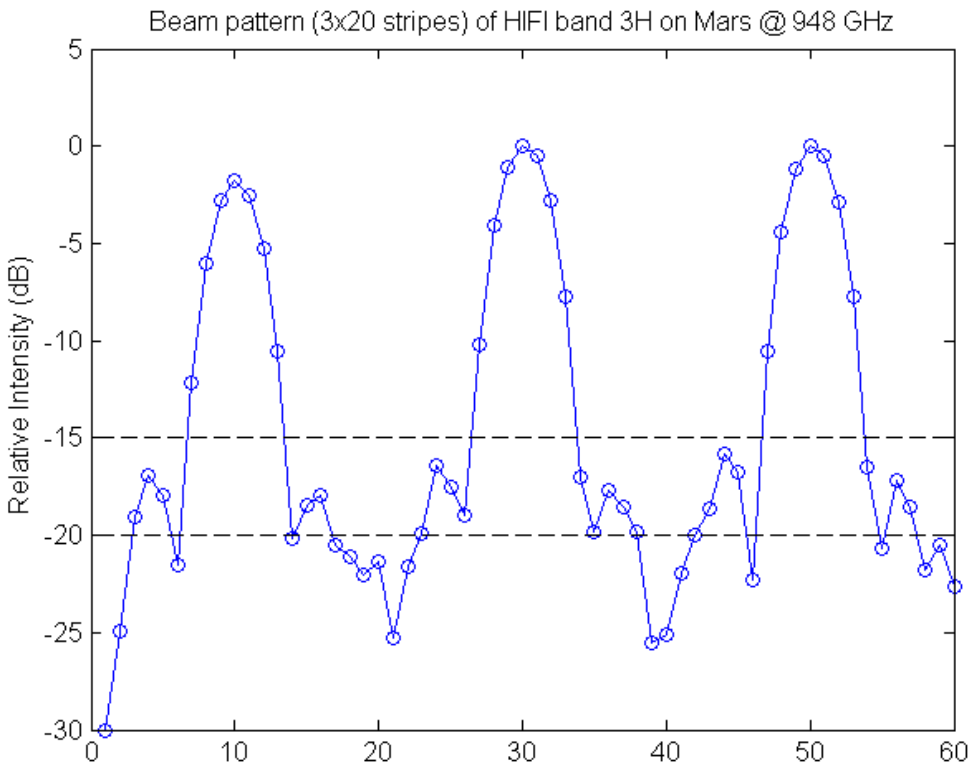




Discussion of preliminary results

- In run 3 striped patterns were first tested
- Homework correct: expected structure seen

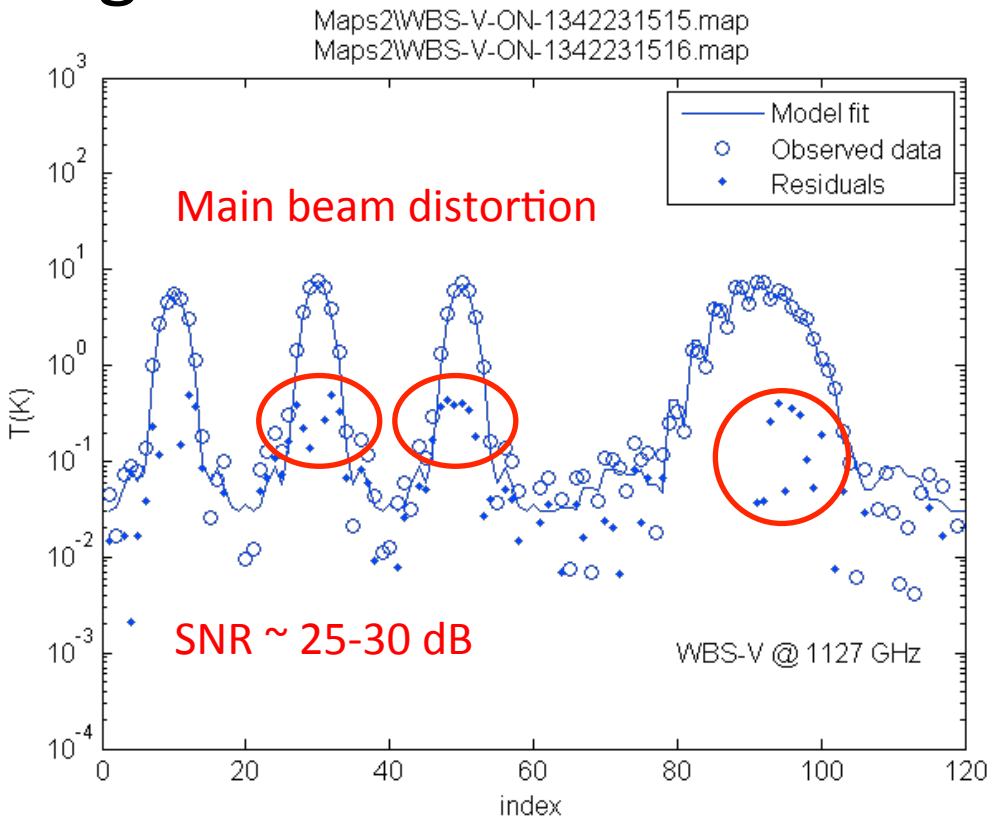
Sidelobes detected



In expected range

Analysis software adjusted

- Analysis software now includes improved models for fitting

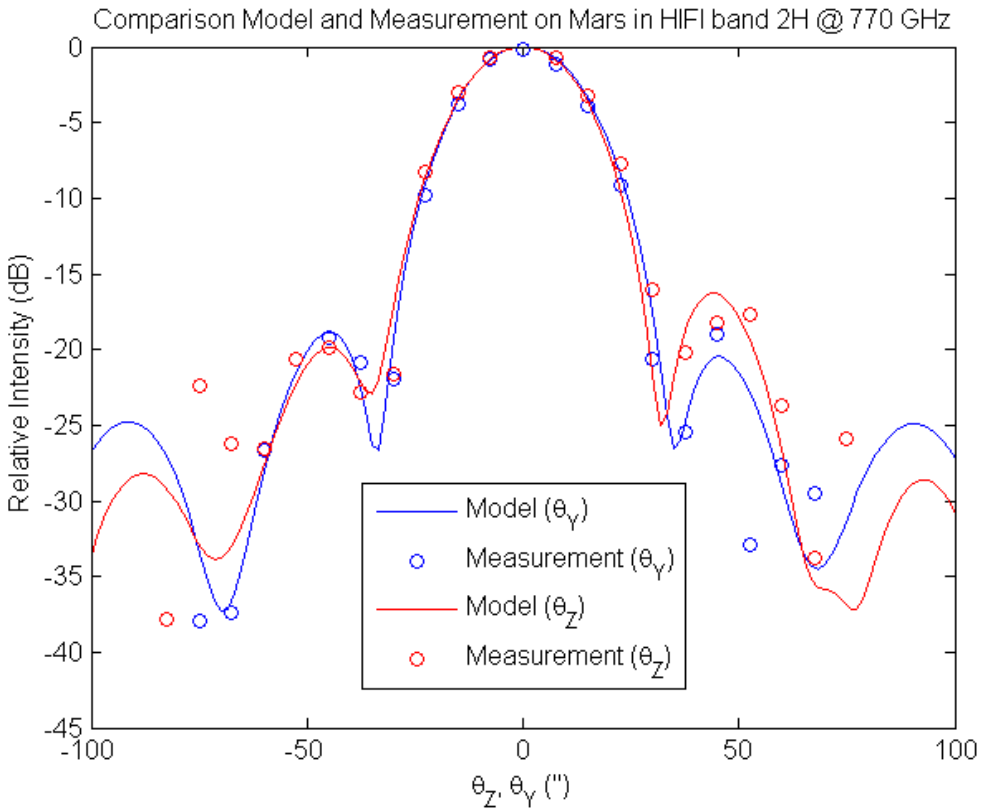


…truncated Gaussian results

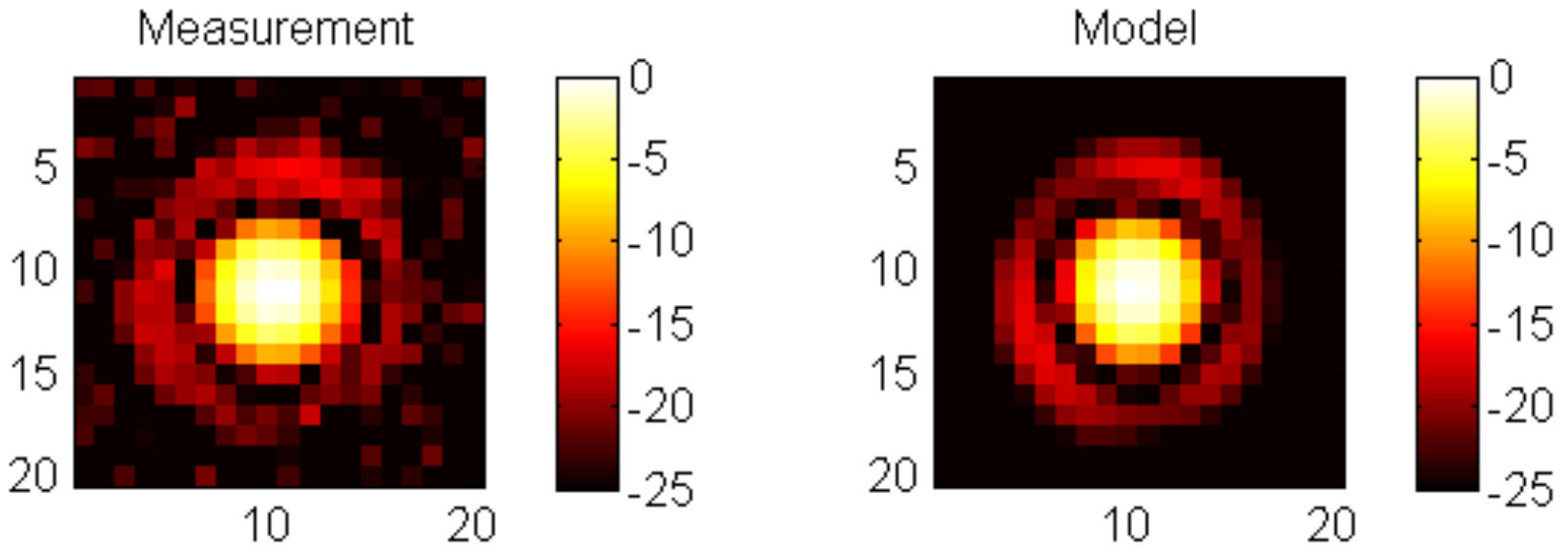
OBSID	Polarization	Frequency	Tpeak (K)	T0 (K)	dT (rms)	HSPOT	Te (dB)	dtheta_y ("	dtheta_z ("
x1437-1438	H	948	6.57	0.012	0.078	0.038	12.0	0.19	0.00
x1437-1438	V	948	6.93	0.006	0.102	0.038	10.4	-0.86	-0.80
x1461-1462	H	1893	19.61	0.091	0.387	0.418	10.7	-0.41	-1.05
x1461-1462	V	1893	21.86	0.137	0.770	0.418	9.9	-0.09	-1.18
x1497-1498	H	1112	8.92	0.020	0.147	0.075	11.5	-0.06	-0.26
x1497-1498	V	1112	9.08	0.019	0.142	0.075	11.0	-0.29	-0.09
x1515-1516	H	1127	7.62	0.023	0.256	0.098	14.0	0.78	-1.06
x1515-1516	V	1127	7.67	0.026	0.179	0.098	14.0	-0.10	-0.44
x1522-1523	H	488	1.92	0.002	0.027	0.022	11.3	-0.29	-1.11
x1522-1523	V	488	1.84	0.003	0.022	0.022	12.1	-0.18	-1.60
x1769-1770	H	1625	16.79	0.051	0.255	0.143	9.7	-0.76	-0.97
x1769-1770	V	1625	16.65	0.057	0.286	0.143	10.3	-0.75	-0.92
x1533	H	770	4.58	0.006	0.034	0.033	11.7	-0.36	-0.73
x1533	V	770	4.75	0.004	0.037	0.033	11.5	-0.39	-1.19

Spot check 2H forward model

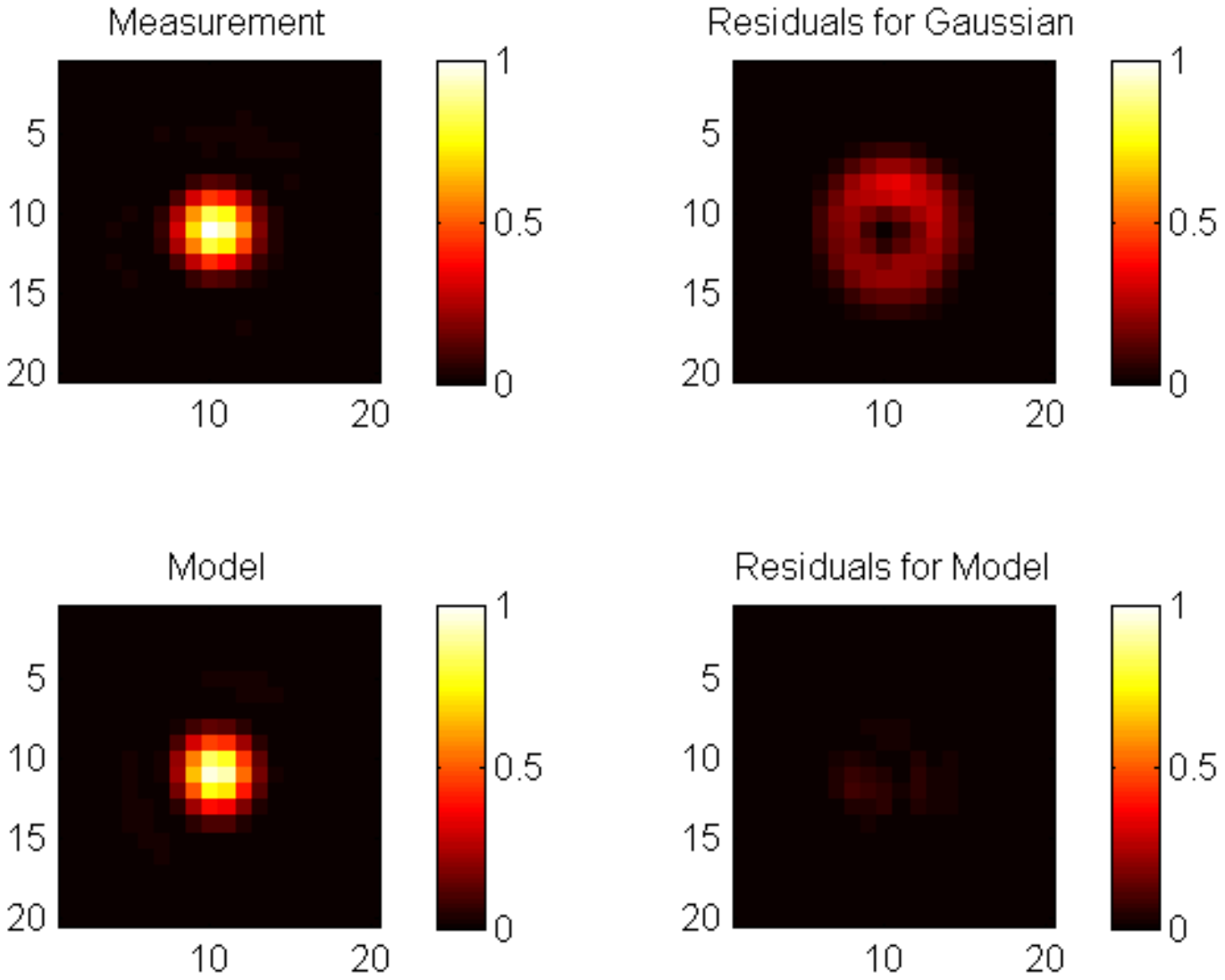
- Blind forward model calculation vs spot check 2H 20x20 raster on Mars



…telescope trefoil WFE effect



…forward model vs Gaussian

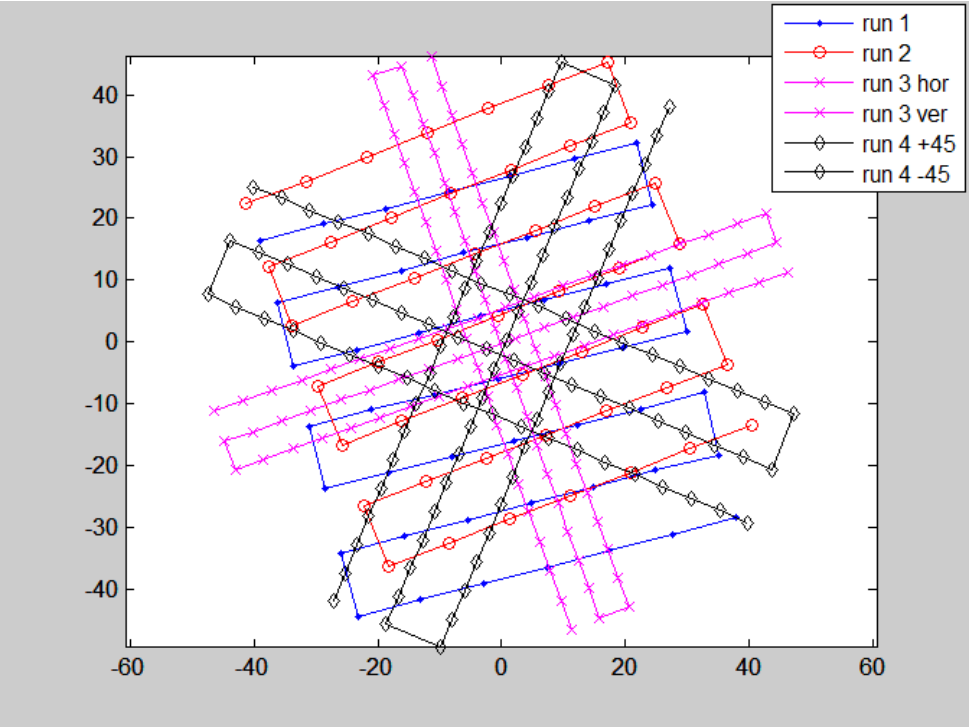


Final steps to be taken

- All ingredients present to tidy-up final calibration
- Coherent re-reduction of Mars beam data:
  - All data from run 1 – 4
  - Using single version of:
    - HIPE (9.0 UR)
    - SPG (8.2.1)
    - Analysis script:
      - Bug fixes: error calculation, map geometry
      - Upgrade: retrieve Mars ephemeris on the fly
  - Matching Mars temperature models created
  - HIFI Interested in improving a-posteriori pointing calibration

…final steps

- Simultaneous fit of multiple runs / data sets taken for different Mars apparent diameters



Example band 5 collection

…final steps

- Finally extract best beam profiles possible (model fit or ground-based)
- Beam profiles to be incorporated in numerical evaluation of calibration quantitities (beam solid angle, source coupling, etc…)
- Release of patterns to community
- Latter activities foreseen for post-operations and -calibration