Pointing Issues and Progress seen by HIFI

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Special thanks to Frank Helmich

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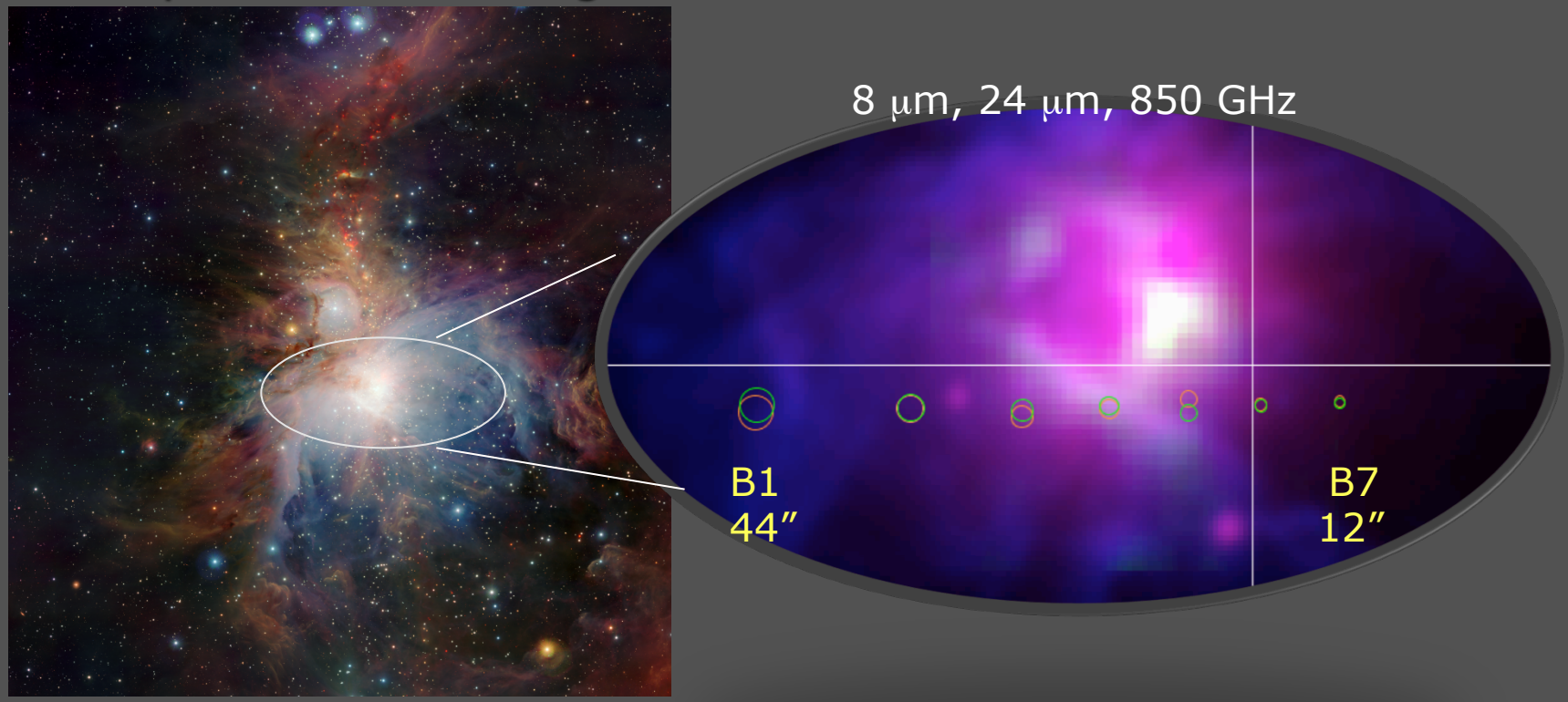
Why pointing is important to HIFI
Beam Sizes

- HIFI's mixer beams range in HPBW 43".5 (1a) to 12".1 (7b).
  - Nominal spatial resolution is canonically 1/10 the beam size at high S/N. These scales are meaningful in clumpy and complex extended regions of emission.

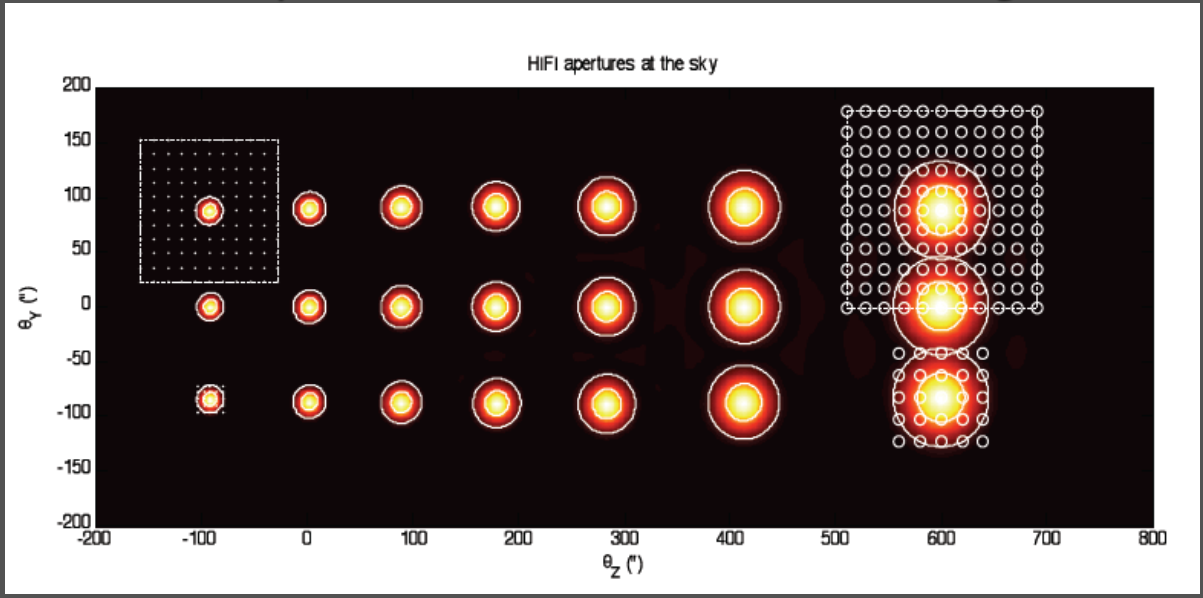


Why pointing is important to HIFI
Relation to the Absolute Pointing Error

- Over the mission the telescope APE has a time dependency, variably decreased and increased (fully within requirements) from maximum 2”.4 to current 0”.8.
  - Variable signal losses at these offset scales results in lower S/N ratios on compact sources, averages by up to 25% (5%) in Bands 6 and 7 when the APE is 2”.4 (1”.5).
  - Remember APE is a statistic (blissfully) quoted 1-[illegible] radial offset.

Why pointing is important to HIFI
Relation to relative offsetting performance and jitter

- HIFI's Beam Calibrations rely extensively on Dual-Beam Switched Raster Maps of point sources (chiefly Mars) at n x Nyquist sampling.
  - Detailed shapes relying on precision offsetting (SRPE) and co-alignment of the optically (almost)-independent H and V beams (SRPE and APE) depend critically on at least an accurate *knowledge* of the pointing uncertainties.



See earlier presentations by W. Jellema, M. Olberg

- HIFI's OTF line scanning mode is more sensitive to telescope jitter (RPE) and long term pointing drift (PDE) – More to follow.

HIFI's Outstanding Pointing Issues

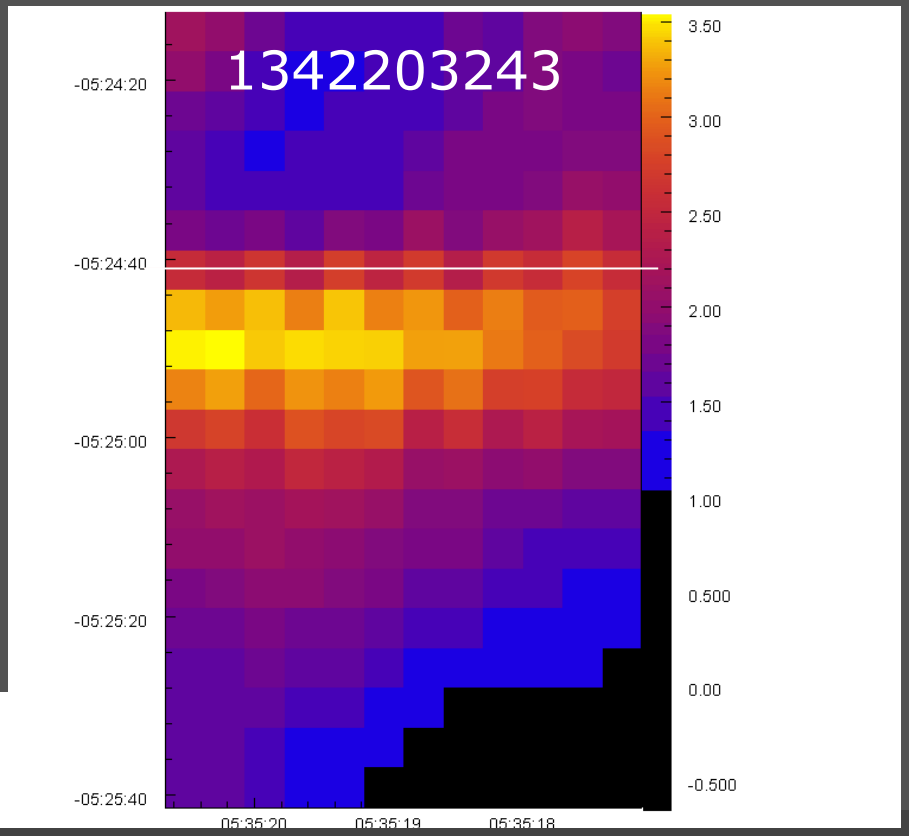
- The telescope's bulk pointing performance metrics can hide idiosyncrasies from differences in how the CUS pointing modes are applied in the AOTs.
  - Same allowable pointing mode parameter space is shared by the 3 instruments' AOTs, but manueuvers are different, and performance evaluation is (naturally) biased towards PACS data measurement.
  - HIFI's modes use schemes sky reference measurement, scan rates determined by readout rates set by sensitivities, etc, with associated pointing uncertainties which should in principle be -- but not guaranteed to be – within in the bulk parameters and reflected in the pointing history.

- Two issues which have been with HIFI since early times (PV-II):
  - Slew/settle – Telescope appears unsettled to within the RPE when ON integrations begin.
  - OTF Zig-Zag – Appearance of spatial shifts alternating by scan line in OTF maps.

HIFI OTF map 'zig-zag'

- Pointing information assigned to spectral datasets in HIFI Timeline Products (HTPs) of most OTF maps indicate a detectable shift in positions of each map point along a scan line that alternates by scan line. The appearance is a zig-zagging picket fence pattern:

- Fluxes over the mapped area show this pattern noise, from a few to 15% of the mean source flux.



OTF position switch
Orion Bar C+

What is causing the zig-zag?

- At first glance, the problem is a timing error in the attitude assignments to the spectral readouts at each map position.

- Tests on strong line flux sources (mainly Orion Bar) using different scan speeds, readout rates, etc, have for the most part eliminated internal timing effects in commanding and data time-stamping, time correlation errors in uplink/downlink chain, etc.

- An ad hoc approach of applying temporal shifts to the input pointing product to minimize the pattern noise has only marginal success. Treats the problem as 1-D.
  - On the scale of deltas < 1".
  - Different maps have different best fit temporal shifts, and seems not to be constant within the same map.
  - Mitigation is incomplete.

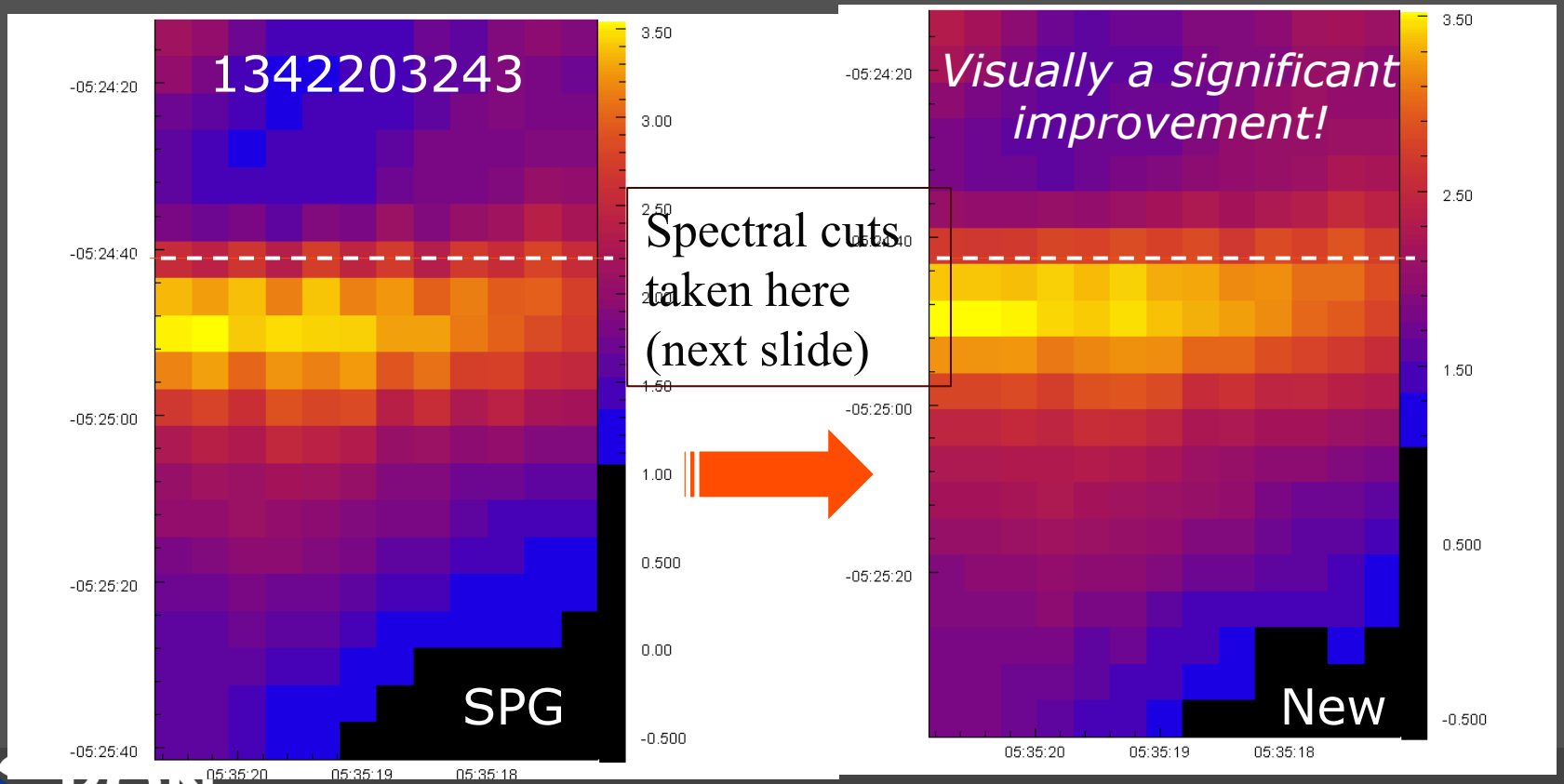
What about the Pointing History?
Pointing Reconstruction with better GYR drift fitting

- Based on progress by the PACS ICC to improve GYR drift estimation and reduce the telescope pointing jitter to < 0”.1, H. Feuchtgruber produced “off-line” pointing products for eight of HIFI’s dedicated OTF zig-zag calibration C+ observations of Orion Bar, spanning ODs 463 to 1189.

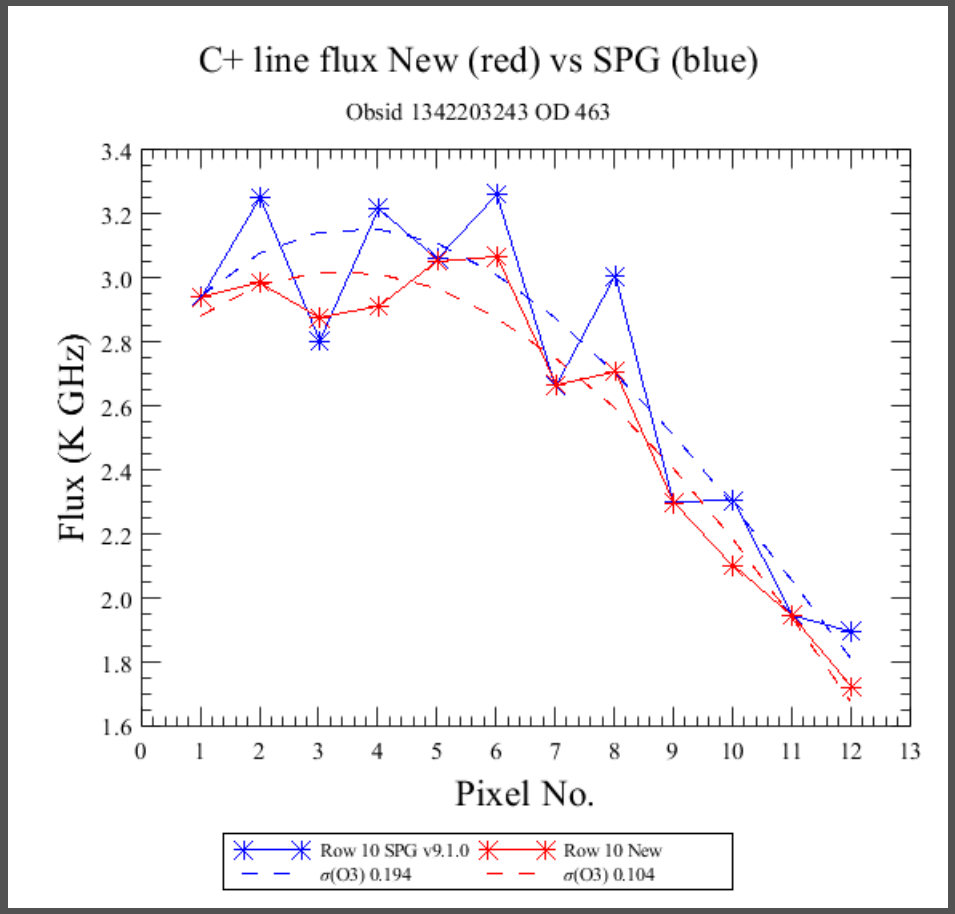
- New pointing products generated for the 8 OTF maps of the Orion Bar by HF use the raw sensor data of all 4 gyros along with CCD-subpixel corrected STR-based attitude from the standard pointing product. [PICC-ME-TN-042].
  - 200-second filter windows used.
  - Shorter and longer filter widths also produced for one obsid.

Effects of Standard SPG vs New pointing products

- SPG Pointing Product = Standard Kalman-filtering, latest version from the HSA with all updated STR calibrations. Usually 9.0.0 or 9.1.0.
- New Pointing Product = STR offsets filtered with new gyro drift estimation method, produced by H.F. 10/01/2013.



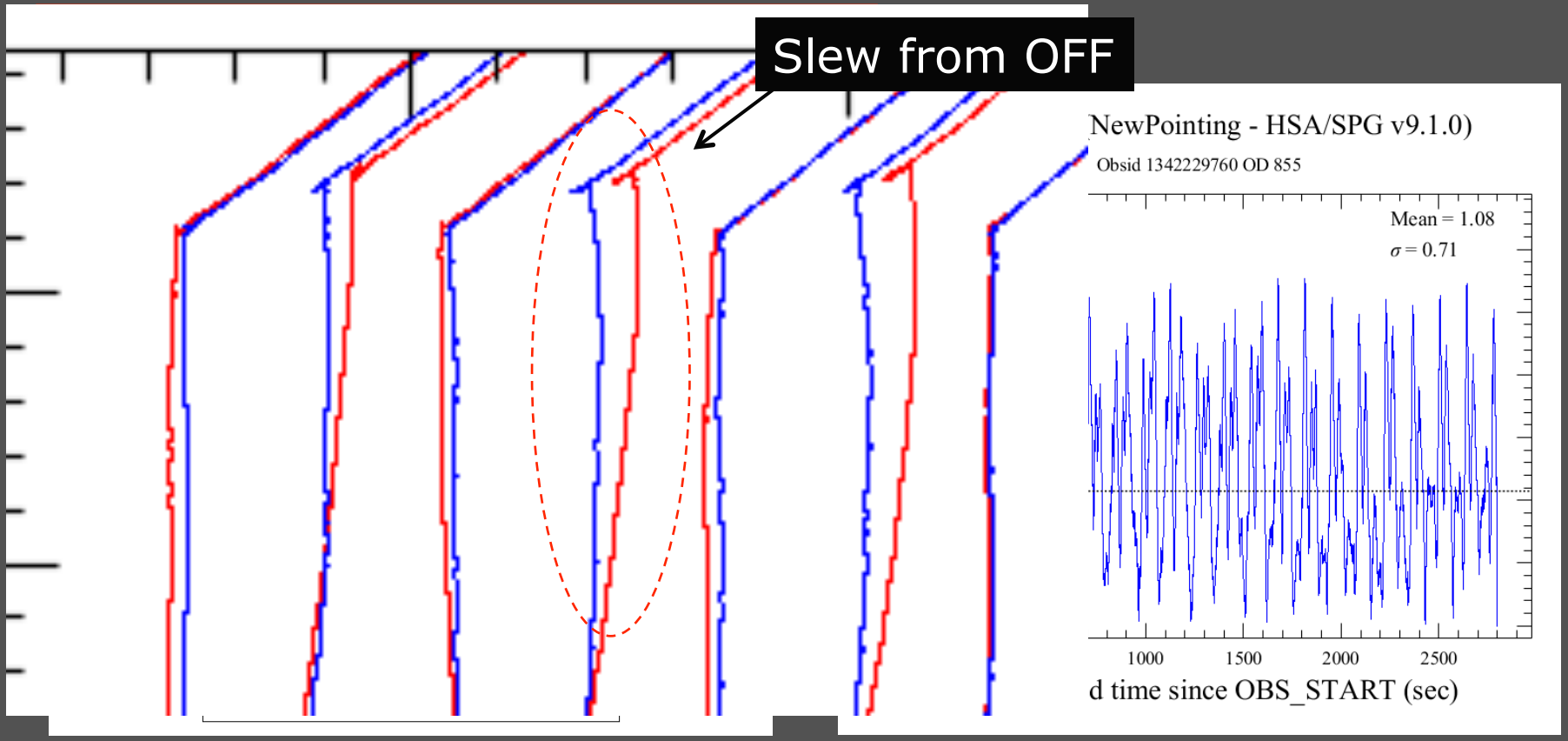
The new pointing history reduces the zig-zag



C+ line fluxes in spectra extracted from the cube in a slice across the Orion Bar.

Red is based on New pointing and shows ~2x lower noise around an approximating (3rd order) fit to the flux gradient across the PDR.

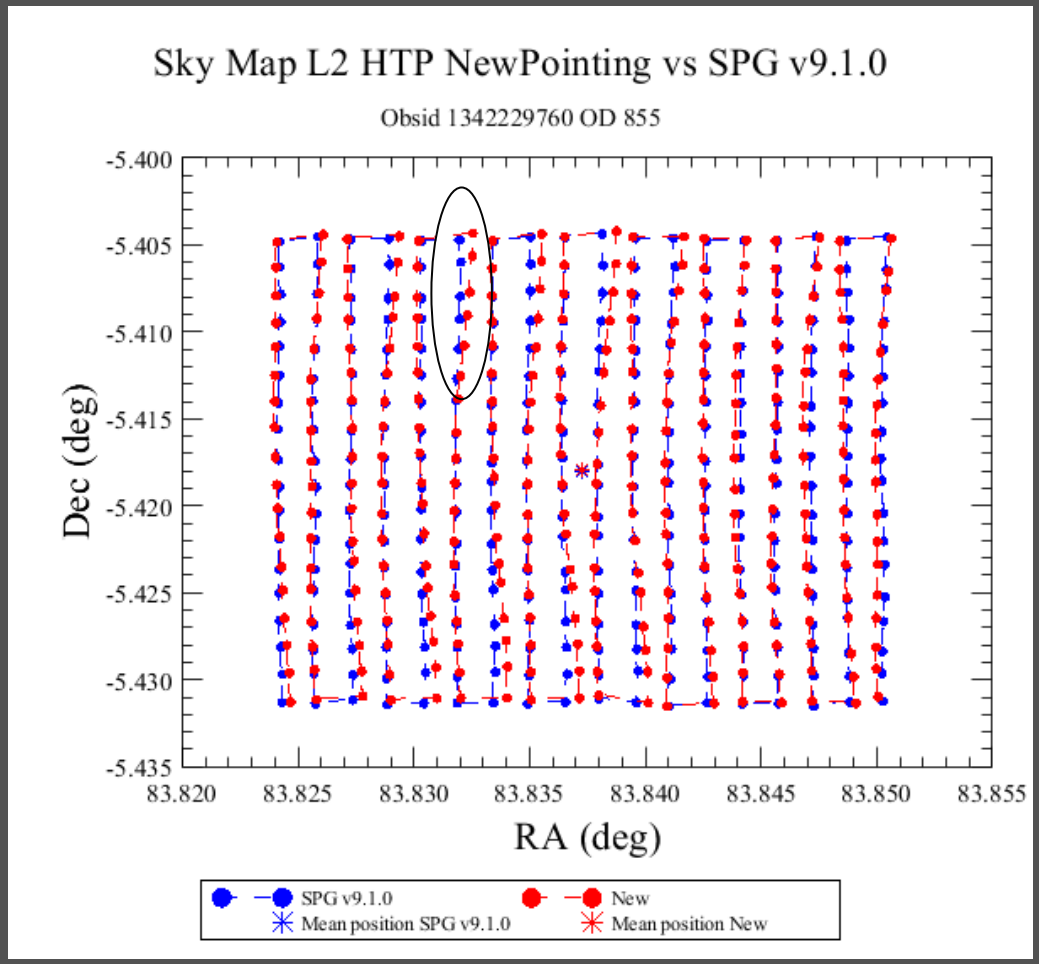
"New" pointing history indicates motion not seen before



- Each return from OFF, at **the beginning = alternating ends** of each scan line, has a wide deviation from the intended path.
- Not an undershoot or overshoot, more like "banking" near the intended start.
- The maximum deviations at the beginning of the scan is > 2".0 !
- Nominal convergence does not happen until half way through the scan line.

How this looks to spectral integration attitude values

- In addition to path deviations with errors projected in both RA and Dec, we see a general "stretch" then compression of points, where the telescope is apparently not matched to the expected line scan speed… OR, HIFI's integration timeline is wrong (but that is an unlikely conspiracy).
- Convergence to the expected path is roughly half way into each scan line.

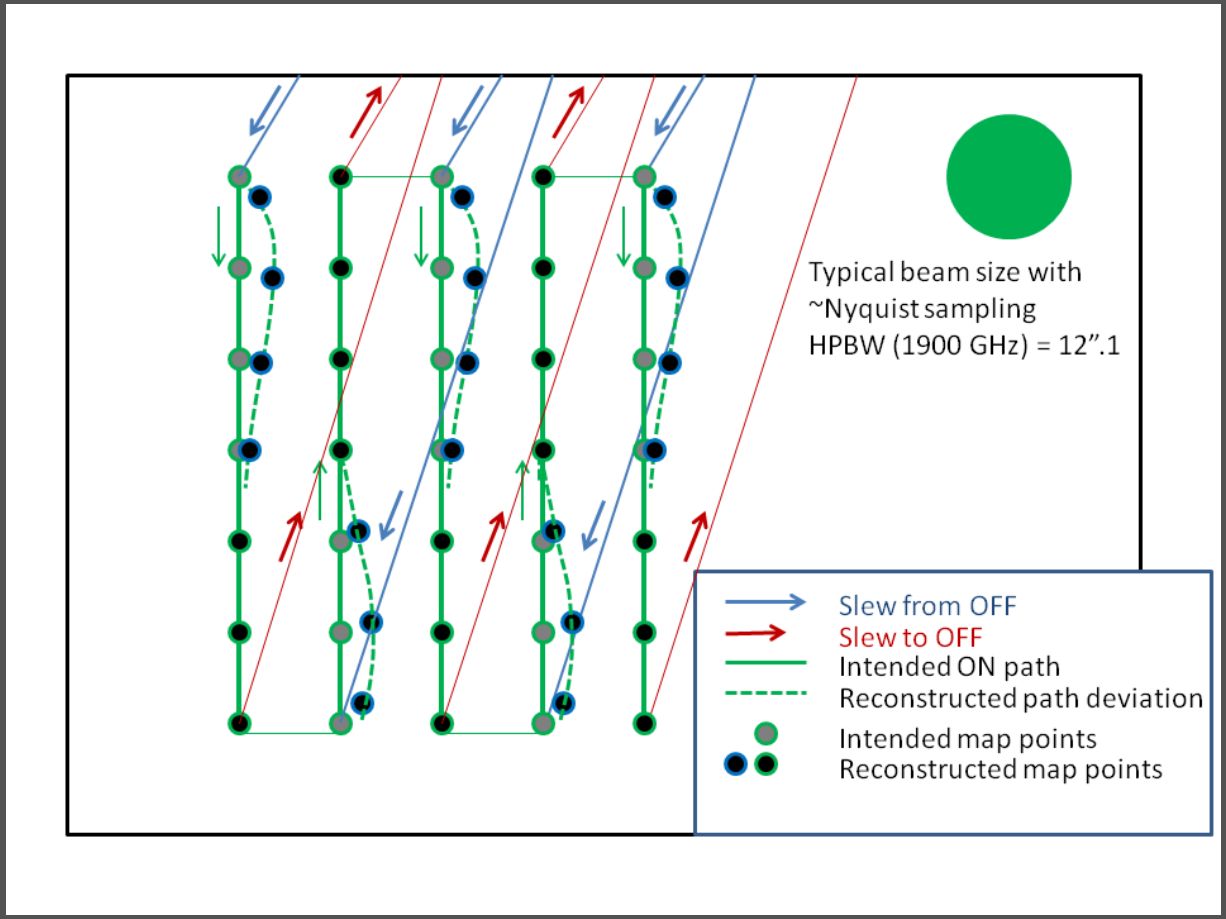


Our current picture

The "zig-zag" has components of slewing errors unrelated to timing errors in HIFI.

Errors are projected in both RA and Dec (not just along the scan line).

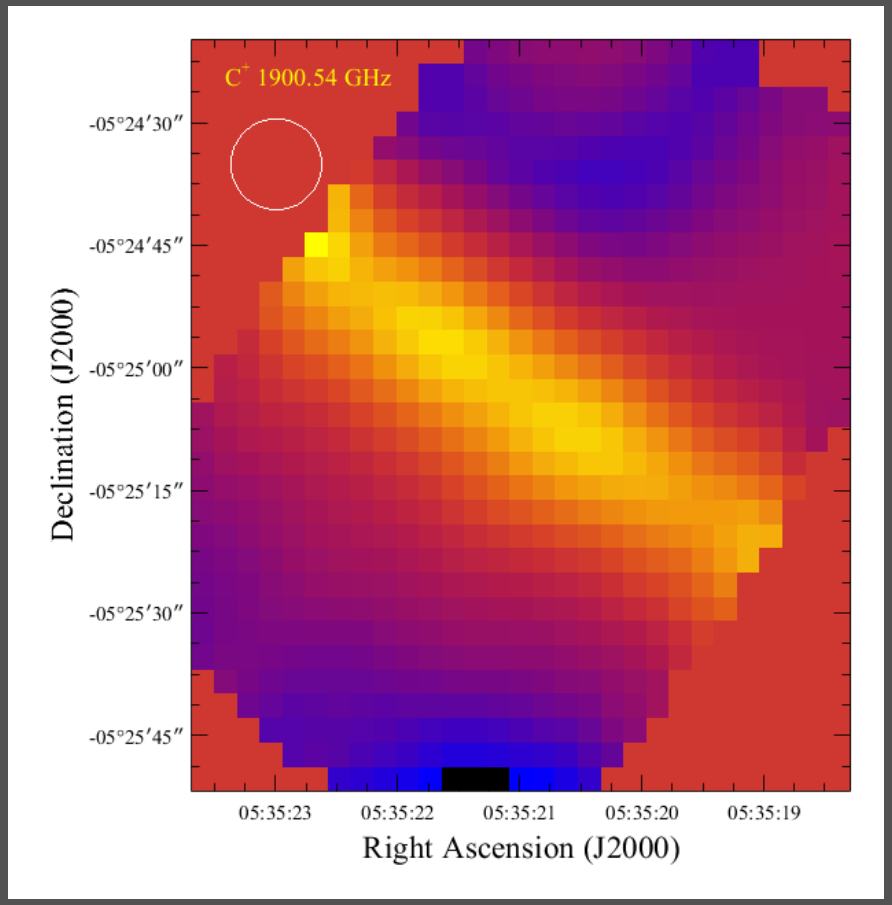
The telescope appears not to be matching the expected speed once scanning, causing map points to bunch up at the beginning.



The deviations are clearly correlated with the slews from OFF, Looks like slew → deceleration → scan transition bugs.

What's the fix?

- While the new pointing products indicate pathalogical behavior by the telescope in attaining nominal scanning after a slew from OFF, that behavior is not the (only) problem.
- The problem is that this behavior has not been well represented in the standard Pointing Products. Errors range up to 3".
- Once more representative attitudes are assigned, map convolution does its job and zig-zag noise is reduced.



The zig-zag free "truth" of the Orion Bar. All C+ maps combined (H+V also) using new pointing.

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Next Steps

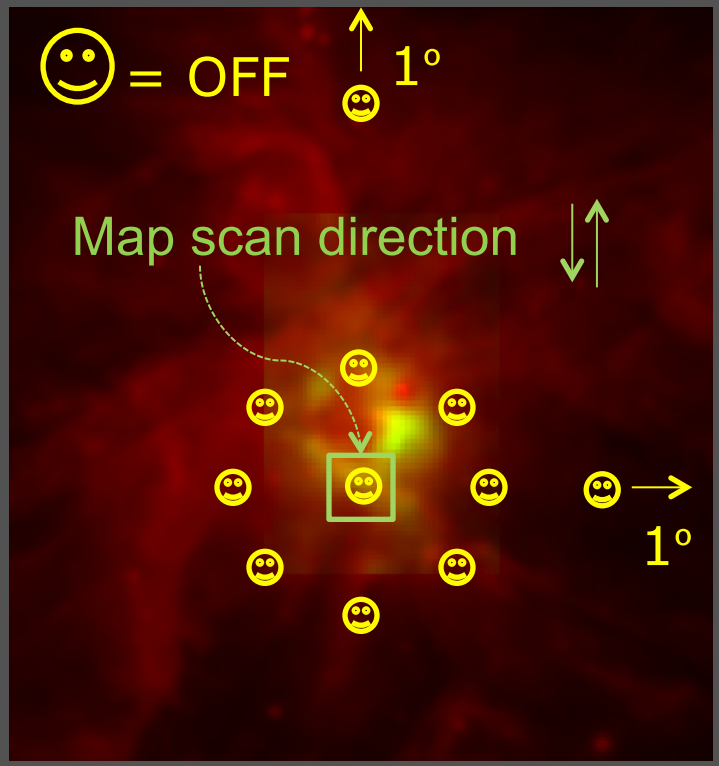
- Zig zag noise is now is hypothesized to depend on:
  - The OFF schedule (number of scan lines per OFF).
  - Angle between the OFF and scan line direction.
  - Distance to the OFF (whether telescope reaches maximum slew rate 60”/sec).
  - Scan speed.
- Telescope body rates during deceleration are a diagnostic.

- We have a small number of final tests with a cold instrument on the Orion Bar to sample these variations (now that we know what to look for).

- EoHe warm pointing tests will provide a more systematic set of experiments, using pointing histories and integration schedules (but no source data obviously).

EoHe Pointing Tests

- We will run OTF map AORs (on Orion Bar to keep the STR field mostly the same), and vary the OFF position systematically.
  - 10 arcmin from map center
  - Map center
  - Distant slews (< 1 deg).
  - Also very slow scanning.
- This will probe the anomalous decelerations, in terms of angular and distance (body rate vs scan speed) dependencies.
- Other modes (raster maps), beam calibrations will be explored also.



- We rely fully on the PACS method for analysis (not yet in HCSS). Pat will go to MPE. We anticipate adopting the new products in the HIFI pipeline in HIPE 12, filters parameters and modes TBD.

Prognosis

- In addition to the post-cryo tests, we must examine other cases already in the database, including DBS Raster Maps used in beam measurements. Effects are anticipated.

- The slew/settle problem also indicating line flux 'jitter' on fixed positions (not discussed) also needs to be revisited with the improved pointing history, once this is available in the HCSS.

- We do NOT anticpate an implementation for new HIFI pointing products in the pipeline, until the effects are well studied in AORs using different mapping and fixed point modes. Probably HIPE ≥ 12.

- Thanks (again) to Helmut, PACS-ICC, and Pointing WG!

Appendix

- HCSS-14194: OTF zig-zag
- HCSS-15600: Slew/Settle errors on short maneuvers
- PICC-ME-TN-042: Method of pointing reconstruction using “widened” gyro drift filtering.
- HIFI TN “Image Reconstruction of HIFI OTF Maps with Zig-Zag” analysis using offline pointing products using new gyro drift approach. Distributed to Pointing WG.