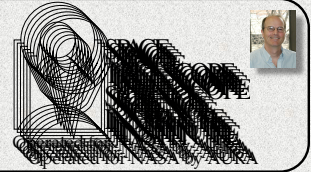


# WFC3: Spatially-scanned Spectra of Exoplanet Transits (and more)

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## ABSTRACT

Spatial scanning is expected to have some advantages over staring-mode observations with the HST WFC3 instrument, especially for very bright stars, i.e. those that intrinsically can provide the highest sensitivity observations. We analyze 1.1-1.7 micron spectra of a transit of the super-Earth GJ1214b obtained 2011-4-18 during re-commissioning of a technique for spatially scanning the Hubble Space Telescope. These are the first data of this type obtained with the HST instrument WFC3. Results are directly compared to staring-mode observations with the same instrument of the same target by Berta et al. (2011). We also describe a case study of the sub-Neptune-sized planet HD 97658b in terms of proposed observations and what they may reveal of that planet. We also summarize publicly-available descriptions of additional HST programs that use the spatial-scanning technique (Table 1).

## Table 1: HST Programs using Spatial Scans

Program, Title, Investigators, Targets (underline indicates some or all visits have been executed prior to Jan 2012)

11622 A Search for Water and Methane on a Neptune-Mass Transiting Planet, Knutson, H. et al. GJ 436

12181 The Atmospheric Structure of Giant Hot Exoplanets, Deming, L. D. et al., HD 209458 and HD 189733

12325 Photometry with Spatial Scans, MacKenty, J. W., McCullough, P. R., & GJ1214

12336 Scan Enabled Photometry, MacKenty, J. W., McCullough, P. R., & Deustua, S., Vega and other calibration stars

12449 Atmospheric Composition of the ExoNeptune HAT-P-11, Deming, L. D., et al., HAT-P-11

12473 An Optical Transmission Spectral Survey of hot-Jupiter Exoplanetary Atmospheres, Sing, D. K. et al., WASP-31, HAT-P-1

12495 Near-IR Spectroscopy of the Hottest Known Exoplanet, WASP-33b, Deming, L. D. et al., WASP-33

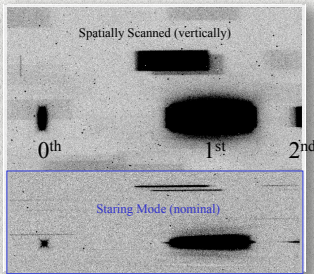
12679 Luminosity-Distance Standards from Gaia and HST, Riess, A., et al., Milky Way Cepheids

12685 Enabling Dark Energy Science for JWST and Beyond, Hines, D. C. et al., Calibration stars

12699 WFC3 Photometric Calibration & Calibration Flux Ladder, Deustua, S. E. et al., Calibration stars.

12713 Spatial Scanned L-flat Validation Pathfinder, McCullough & MacKenty, nearly identical double stars

## Scanned Spectroscopy of GJ 1214b



The spatially scanned spectrum of the star GJ1214 is labeled with its 0<sup>th</sup>, 1<sup>st</sup>, and 2<sup>nd</sup> order light and compared to a nominal staring-mode slitless spectrum of the same field (blue outlined inset). The images are 512 columns wide, of the detector's 1024. The scan was 40 pixels high. (4.8 arcsec).

In this engineering test, program 12325, we trailed the star GJ 1214 across the WFC3 IR detector repeatedly at a rate of 0.1 arcsec s<sup>-1</sup> perpendicular to the dispersion of the G141 grism. By coincidence we observed part of a transit of exoplanet GJ 1214b.

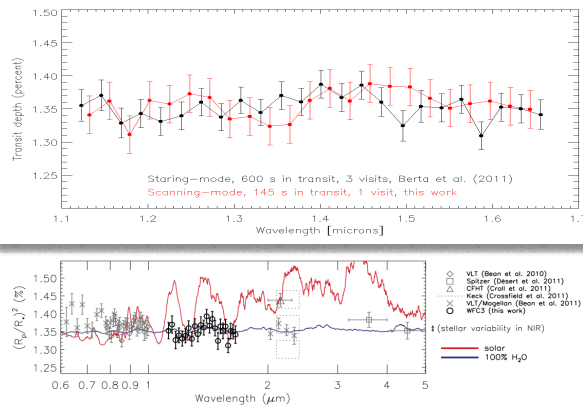


Figure 12. GJ1214b's transmission spectrum from WFC3 in the context of observations from the VLT (0.6-1  $\mu\text{m}$ ; Bean et al. 2010 [2011]), CFHT (1.25 + 2.15  $\mu\text{m}$ ; Crull et al. 2011), Magellan (2.0-2.3  $\mu\text{m}$ ; Bean et al. 2011), and Spitzer (3.6 + 4.5  $\mu\text{m}$ ; Desert et al. 2011a). While they do not measure an absolute transit depth, observations from NIRSPEC on Keck (2.1-2.3  $\mu\text{m}$ ; Crossfield et al. 2011) disfavor models they tested that had amplitudes larger than 0.05% in their wavelength range; we represent these constraints with the dashed rectangular boxes. Two extremes of the models explored in this paper are shown, normalized to the MEarth-measured transit depth (see Miller-Ricci & Fortney 2010). It is important to note that stellar variability could cause individual data sets to shift up or down on this plot as much as  $\Delta D = 0.014\%$  in the near-IR or 2 - 3x more in the optical, depending on the stellar spot spectrum.

## Discussion

(Above) we compare the transit spectrum of GJ1214b from WFC3 in staring mode (from Berta et al. (2011), in **black**) with the same obtained in scanning mode (this work, in **red**). The uncertainties of the scanned-mode spectrum in this case are larger than those for the staring mode, commensurate with the aggregate in-transit exposure times: scanning (145 s), staring (600 s). **This work confirms that the transit spectrum of GJ 1214b is both flat and featureless.**

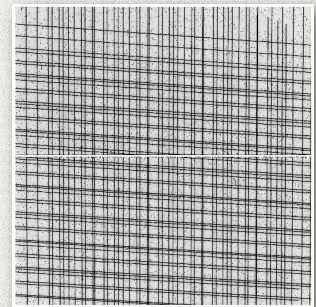
(Below) Figure 12 from Berta et al. (2011) compares many observations of GJ1214b. The flat WFC3 spectrum rejects the solar-composition planetary atmosphere model (red line, with large undulations) and supports a steam atmosphere model (blue line, with very small amplitude features) or a haze model (not shown).

## Potential for HD 97658b

The bright K dwarf star HD 97658 ( $H=5.8$  mag) hosts a transiting low-density super-Earth (Henry et al. 2011). We are planning HST WFC3 spectrophotometry of HD 97658b in order to better characterize the planet's atmosphere. Scaling from the demonstrated performances of WFC3 on GJ 1214b (Berta et al's work and this work), and aiming for a 50% duty cycle of observation, we predict that in a single transit of HD 97658b we should be able to collect 80 times more photons than the total number of photons in 3 transits of GJ 1214b observed by Berta et al. If we can achieve near-Poisson limited performance, then the implied 9 times greater sensitivity will exactly offset the 9 times shallower transit depth of HD 97658b ( $0.147\% \pm 0.026\%$ ) compared to GJ 1214b (1.35%). Hence, from a single transit of HD 97658b we should be able to produce a spectrum nearly identical to that shown for GJ 1214b, except that the vertical scale will be less by a factor of nine. Also, if it has a solar-composition atmosphere, HD 97658b's spectral features are expected to be approximately twice as large in fractional transit depth as those shown for GJ 1214b (red line in Figure 12 of Berta et al. (2011) reproduced above). These plans are contingent upon confirmation of HD 97658b's transit depth and ephemeris from additional ground-based observations or Spitzer observations (Knutson PI).

## Additional Potential

Spatial scanning also has potential for unique new methods of calibration. **Program 12713** weaves bright star trails across the UVIS detector to validate traditional flat fields (right). **Program 12336** obtains infrared spectra of Vega (see Deustua's poster at this meeting) to connect WFC3's magnitude zero point to Vega magnitudes, **directly**, and thereby greatly reduce one term in error budgets for accurate space-based photometry. **Program 12679** uses star trails to obtain precision trigonometric parallaxes. More programs are listed in Table 1, but the best program of all is missing: yours (of course).



## Acknowledgments

Zach Berta (Harvard), the P.I. of HST program 12251, "The first characterization of a Super-Earth Atmosphere," graciously agreed to our request to use GJ 1214 also for our engineering test, program 12325. Many persons, especially Merle Reinhart, Alan Welty, and William "Bill" Januszewski (STScI) helped plan the observations. Art Bradley (SSES) and Mike Wenz (GSFC) provided FGS data and analysis.

## References

Berta et al. 2011, The Flat Transmission Spectrum of the Super-Earth GJ1214b from Wide Field Camera 3 on the Hubble Space Telescope, accepted to ApJ.  
Henry, G. W., Howard, A. H., Marcy, G. W., Fischer, D. A., Johns, J. A. 2011, Detection of a Transiting Low-density Super-Earth, submitted to ApJ