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ACS dither and mosaic pointing patterns

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ABSTRACT

We provide some background on pointing ACS, and present the dither and mosaic patterns that will be provided as a convenience for HST Cycle 11 Phase II proposal writers. This report supersedes any previous documents which describe specific ACS dither and mosaic patterns -- namely, ACS Instrument Science Report 98-02 by Stiavelli, and the engineering versions of HST Phase II Proposal Instructions prior to Cycle 11. This is an updated version of the same report first published on 26 July 2001.

Introduction

Phase II proposers can use the Pattern Parameters Form to define complex pointing patterns which can be used with any exposure in their proposal. See the HST Phase II Proposal Instruction for details. Pointing patterns are often used to improve the removal of detector artifacts, improve PSF sampling, or increase the field-of-view. They must be carefully designed, because they tend to increase the overall number of exposures and associated overhead time. The Advanced Camera for Surveys (ACS) has some unique features which must be accounted for while planning telescope pointings.

The distortion of the ACS field-of-view, and the associated scale variation are significant -- see the ACS Instrument Handbook for details. The relationships between the relevant reference frames must also be understood (see Figure 1). In the HST focal plane reference frame (U2, U3), the detector pixel coordinate axes (AXIS1, AXIS2) are not orthogonal, they are about 85 degrees apart because of distortion. The POS TARG reference frame is an undistorted coordinate system (X-POS, Y-POS) used to define telescope pointings in units of arcseconds. We choose the Y-POS axis of each detector to be aligned with AXIS2, which leaves the X-POS axis about 5 degrees away from AXIS1. The POS TARG reference frame for each detector is related to the HST focal plane (U2, U3) by a simple translation and rotation. For the WFC, the Y-POS axis is approximately in the U3 direction and X-POS falls near -U2. However, for the HRC and SBC, the Y-POS axis is near the -U3 direction and X-POS falls close to the U2 direction.

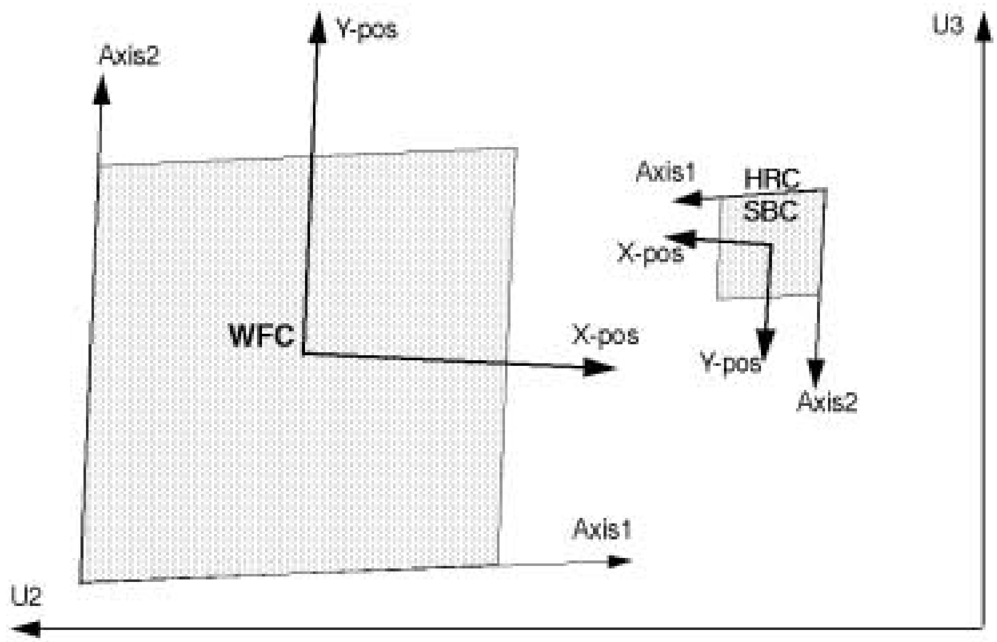


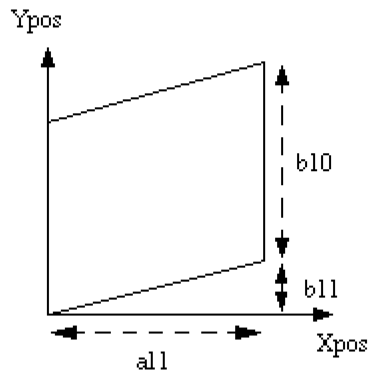
Figure 1: The relative orientations of the detector pixel axes (AXIS1, AXIS2), telescope pointing axes (X-POS, Y-POS), and the HST focal plane axes (U2, U3). This graphic does not reflect the relative positions of the WFC, HRC, and SBC apertures in the HST focal plane.

The patterns described in this report have been designed in terms of pixel coordinates. However, in Phase II proposals the shifts must be defined in arcseconds, and angles measured from the X-POS axis. For example, a displacement of one WFC pixel in the detector x direction is 0.0496 arcsec along X-POS plus 0.0038 arcsec in the Y-POS direction, and a displacement of one pixel in the y direction is 0.0497 arcsec along Y-POS. The angle of this 1x1 pixel shift turns out to be 47.17 degrees, not 45 degrees (see diagram below).

Using the distortion coefficients in Table 1, and the equations below, the POS TARG and Pattern Parameter Form values can be calculated for any (x,y) pixel shift. These distortion coefficients were derived from pre-flight ground calibrations, and were used to determine the pattern parameters below. They may be refined after on-orbit distortion calibrations are conducted, but we don't expect the values to change by more than a few percent. The a_{10} coefficient will always be zero, because we defined the Y-POS axis to be the same as the detector y axis (AXIS2).

Table 1. Coefficients for converting detector pixel shifts into POS TARGs in arcseconds.

Detector	a_{10}	a_{11}	b_{10}	b_{11}
WFC	0.0000	0.0496	0.0497	0.0038
HRC	0.0000	0.0283	0.0248	0.0028
SBC	0.0000	0.0337	0.0296	0.0034



$$XPOS = x \cdot a_{11} + y \cdot a_{10}$$

$$YPOS = x \cdot b_{11} + y \cdot b_{10}$$

$$PointSpacing = \sqrt{XPOS^2 + YPOS^2}$$

$$PatternOrient = \operatorname{atan}((YPOS)/(XPOS))$$

For box patterns, the Line_Spacing is calculated like the Point_Spacing, except using the (x,y) shift from the 2nd to the 3rd pointing. The Angle_Between_Sides is 180 degrees minus the Pattern_Orient of the second segment, minus the Pattern_Orient of the first segment. See the HST Phase II Proposal Instructions for more on pattern parameter definitions.

Convenience patterns

Proposers are always free to design their own pointing patterns, but since subtleties like those mentioned above are potential pitfalls, carefully optimized dither and mosaic patterns have been defined in the Phase II Proposal Instructions for each instrument. We strongly encourage the use of the Visual Target Tuner (VTT) to plan and verify pointing patterns (see Figures 3 and 4). In the following sections, we describe the “convenience” patterns designed for ACS users. We define them in the syntax required for HST Phase II proposals, and provide diagrams of each. The Pattern_Number can be any unique integer - the numbers we use here are merely to identify each pattern within this report. The Pattern_Purpose is just a descriptive comment that distinguishes small-scale dithers from large-scale mosaics. And although we include them below, the Line_Spacing and Angle_Between_Sides (for box patterns only) are not included in the Phase II proposal syntax because they are unchangeable. We also provide POS TARG equivalents for each pattern, *but using these will not automatically produce an associated dataset.*

In the original version of this report (26 July 2001), the POS TARG equivalents given for the mosaic patterns were correct for Center_Pattern=NO (where the target is placed at the specified aperture of the first pointing). In this version, they have been made truly equivalent, reflecting Center_Pattern=YES (where the target is placed at the center of the overall mosaic pattern). The POS TARG equivalents for the dither patterns (where Center_Pattern=NO) are unchanged from the original version of this report.

Pointing patterns with dimensions less than 130 arcseconds are automatically associated by the ground system software (i.e. TRANS), because they could be executed with one set of guide stars. In practice, the rule-of-thumb implementation limit is closer to 100 arcseconds -- all dependent on guide star availability in the target field. All of the ACS pattern dimensions described in this report are under 100 arcseconds, except the 4-point WFC mosaics (Pattern_Numbers 17 and 18). For now at least, these patterns would require the use of POS TARGs and multiple sets of guide stars. And although the 2-point WFC mosaic (Pattern_Number 15) shift is under 100 arcseconds, it too could require the use of two sets of guide stars, depending on the target field. Future enhancements to the ground system software may allow for mosaic patterns with any dimensions (involving any number of guide stars) to be associated. However, post-observation association tables can be manually constructed and used to reduce mosaicked WFC datasets, if necessary. Phase II proposers who design pointing patterns with any dimension approaching 130 arcseconds are advised to work closely with their Program Coordinator, to ensure that their pattern is implemented as efficiently as possible.

Each Pattern_Type has default values which reflect their most basic or common usage. If the default values are desired, then the Pattern_Type can be used like any other exposure-level special requirement in a Phase II proposal, and it is not necessary to provide a Pattern Parameters Form. However, we also provide variations on the line Pattern_Types (box patterns cannot be modified as freely), involving more pointings or different goals. These alternate patterns are merely examples or suggestions, which would require explicit definition in a Pattern Parameters Form (or the use of the corresponding POS TARG equivalents). A Secondary_Pattern form can also be defined, to achieve multiple goals in conjunction with a Primary_Pattern form.

Although the Number_Of_Points is extensible up to 9, each pattern below was tailored to the number of pointings. Furthermore, it may not be feasible to obtain more than six ACS exposures in one orbit. Patterns can be executed over multiple orbits, but guide star re-acquisitions will introduce additional pointing innaccuracies. We set Center_Pattern=YES for the mosaic patterns only, so the defined target will be centered in the expanded field-of-view.

It is not absolutely necessary to obtain multiple exposures at each pointing (CR-SPLIT) to remove cosmic rays. The dither package in IRAF (which includes the drizzle task) provides for the removal of cosmic rays from single-exposure dithered observations (Fruchter, 1997). This can significantly reduce the overhead time in a pointing pattern.

Simulated ACS images which incorporate these pointing patterns are available via the webpage below. These are useful for testing data reduction and processing, including image combination (e.g. drizzling). A sample of these simulations and the corresponding reductions will be also be available as a pre-flight ACS example in the next version of The Dither Handbook (Koekemoer, 2000).

`http://hst.stsci.edu/acs/analysis/drizzle/`

Pattern descriptions

Pattern_Numbers 11, 21, 31 are the default 2-point DITHER-LINE patterns for the WFC, HRC, and SBC, respectively. They are designed to remove detector artifacts such as bad rows or columns, hot pixels, and uncorrected flat field features. The WFC pattern is a 5x60 pixel shift which spans the interchip gap, which is about 2.5 arcseconds or ~50 pixels across. At least two exposures should be taken at one of the WFC pointings (CR-SPLIT), so that cosmic rays can be removed from the gap overlap region. Although this is defined as an integer pixel shift, the effect of the scale variation becomes significant (especially near the chip edges) over such a large shift. The HRC pattern is a smaller 5x5 pixel shift, since there is no gap. The SBC has about 5 bad rows near the center of the detector caused by a bad anode, so the default pattern is a slightly larger 10x10 pixel shift.

The following patterns are non-default examples of how these DITHER-LINE parameters could be modified for various purposes. **Pattern_Numbers 12, 22, 32** are very small 2-point sub-pixel dithers (2.5 x 1.5 pixels) designed to improve resolution (1/2 pixel PSF sampling) for the WFC, HRC, and SBC, respectively. **Pattern_Numbers 13, 23, 33** are small sub-pixel dithers which are similarly optimized for 3 pointings (1/3 pixel PSF sampling). **Pattern_Number 14** is a 5x5 pixel shift for the WFC -- better for removing WFC artifacts when the interchip gap is not a concern (i.e. for objects that fit on one WFC chip).

Pattern_Numbers 15, 25, 35 are the default 2-point MOSAIC-LINE patterns designed to increase the field of view for the WFC, HRC, and SBC, respectively. For the HRC and SBC, this is a shift of ~95% of the y dimension of the detector (973 pixels) as projected on the sky, which nearly doubles the field-of-view. For the WFC, the shift is only about 47% of the y dimension of the combined WFC detectors (1948 pixels) as projected on the sky, resulting in a roughly 200x300 arcsecond field-of-view. This is a compromise which allows the 2-point WFC mosaic to be performed with one set of guide stars (and produce an associated dataset), and it simultaneously covers the interchip gap.

Pattern_Numbers 16, 26, 36 are the default 4-point DITHER-BOX patterns for the WFC, HRC, and SBC, respectively. They all have relative pixel coordinates (0, 0), (5.0, 1.5), (2.5, 4.5), (-2.5, 3.0) -- a parallelogram pattern with a combination of integer and sub-pixel shifts. This box pattern is relatively compressed in the y dimension compared to it's WFPC2 and STIS counterparts. This helps minimize the effect of scale variation across the detector.

Pattern_Numbers 17, 27, 37 are large 4-point MOSAIC-BOX patterns for the WFC, HRC, and SBC, respectively. They are designed to maximize the field-of-view with x and y shifts which are ~95% of the detector dimensions (3891 WFC pixels, and 973 HRC or SBC pixels). For the HRC and SBC, these are default patterns. However, this ~400x400 arcsecond WFC pattern is included here only for consistency and future reference, because it cannot currently be implemented (see the previous section), and only the POS TARG equivalents can be used. We do not give it a Pattern_Type, because even if such large WFC patterns can be implemented someday, we would make the more efficient Pattern_Number 18 (below) the default for WFC. And since the ground system doesn't allow box patterns to be modified like line patterns, each variation of a box pattern would have to be given a unique Pattern_Type.

Pattern_Number 18 would be the default 4-point MOSAIC-BOX pattern for the WFC if it could be implemented (see the previous section). For now, only the POS TARG equivalents could be used (or the 2-point WFC mosaic plus a POS TARG). The first two pointings are the same as Pattern_Number 15, and may only require one set of guide stars. But after the y shift between the first two pointings, almost any x shift will require another set of guide stars anyway, so we make full use of them: the last two pointings are also the same as Pattern_Number 15, but shifted by ~95% of the detector x dimension (3891 pixels) as projected on the sky. This creates a roughly 400x300 arcsecond field-of-view (see Figure 3).

WFC line pattern parameters

Pattern_Number:	11	12	13	14	15
Primary_Pattern:					
Pattern_Type:	ACS-WFC-DITHER-LINE	ACS-WFC-DITHER-LINE	ACS-WFC-DITHER-LINE	ACS-WFC-DITHER-LINE	ACS-WFC-MOSAIC-LINE
Pattern_Purpose:	DITHER	DITHER	DITHER	DITHER	MOSAIC
Number_Of_Points:	2	2	3	2	2
Point_Spacing:	3.011	0.150	0.138	0.365	96.816
Coordinate_Frame:	POS-TARG	POS-TARG	POS-TARG	POS-TARG	POS-TARG
Pattern_Orient:	85.28	34.13	32.99	47.17	90.00
Center_Pattern:	NO	NO	NO	NO	YES
POS TARG equivalent	0.248, 3.001	0.124, 0.084	0.116, 0.075 0.231, 0.150	0.248, 0.268	0.000, -48.408 0.000, 48.408

WFC box pattern parameters

Pattern_Number:	16	17	18
Primary_Pattern:			
Pattern_Type:	ACS-WFC-DITHER-BOX	N/A	ACS-WFC-MOSAIC-BOX
Pattern_Purpose:	DITHER	MOSAIC	MOSAIC
Number_Of_Points:	4	4	4
Point_Spacing:	0.265	193.383	96.816
Line_Spacing:	0.187	193.559	193.559
Angle_Between_Sides:	69.05	265.62	265.62
Coordinate_Frame:	POS-TARG	POS-TARG	POS-TARG
Pattern_Orient:	20.67	90.00	90.00
Center_Pattern:	NO	YES	YES
POS TARG equivalent	0.248, 0.094 0.124, 0.233 -0.124, 0.140	-96.497, -104.084 -96.497, 89.298 96.497, 104.084 96.497, -89.298	-96.497, -55.801 -96.497, 41.015 96.497, 55.801 96.497, -41.015

Note:

The POS TARG rows in these tables are not a part of the Pattern Parameter Form. Rather, these are exposure-line equivalents to the pattern above. They are provided here for comparison and/or alternate use, and should not be included as a part of the Pattern Parameter Form. Conversely, if the POS TARG syntax is used, then a Pattern Parameter Form is not needed in the proposal.

HRC line pattern parameters

Pattern_Number:	21	22	23	25
Primary_Pattern:				
Pattern_Type:	ACS-HRC-DITHER-LINE	ACS-HRC-DITHER-LINE	ACS-HRC-DITHER-LINE	ACS-HRC-MOSAIC-LINE
Pattern_Purpose:	DITHER	DITHER	DITHER	MOSAIC
Number_Of_Points:	2	2	3	2
Point_Spacing:	0.198	0.083	0.077	24.130
Coordinate_Frame:	POS-TARG	POS-TARG	POS-TARG	POS-TARG
Pattern_Orient:	44.28	31.99	30.95	90.00
Center_Pattern:	NO	NO	NO	YES
POS TARG equivalent	0.142, 0.138	0.071, 0.044	0.066, 0.040 0.132, 0.079	0.000, -12.065 0.000, 12.065

HRC box pattern parameters

Pattern_Number:	26	27
Primary_Pattern:		
Pattern_Type:	ACS-HRC-DITHER-BOX	ACS-HRC-MOSAIC-BOX
Pattern_Purpose:	DITHER	MOSAIC
Number_Of_Points:	4	4
Point_Spacing:	0.150	24.130
Line_Spacing:	0.098	27.670
Angle_Between_Sides:	63.50	264.35
Coordinate_Frame:	POS-TARG	POS-TARG
Pattern_Orient:	19.89	90.00
Center_Pattern:	NO	YES
POS TARG equivalent	0.142, 0.051 0.071, 0.119 -0.071, 0.067	-13.768, -13.427 -13.768, 10.703 13.768, 13.427 13.768, -10.703

SBC line pattern parameters

Pattern_Number:	31	32	33	35
Primary_Pattern:				
Pattern_Type:	ACS-SBC-DITHER-LINE	ACS-SBC-DITHER-LINE	ACS-SBC-DITHER-LINE	ACS-SBC-MOSAIC-LINE
Pattern_Purpose:	DITHER	DITHER	DITHER	MOSAIC
Number_Of_Points:	2	2	3	2
Point_Spacing:	0.472	0.099	0.092	28.801
Coordinate_Frame:	POS-TARG	POS-TARG	POS-TARG	POS-TARG
Pattern_Orient:	44.40	32.12	31.08	90.00
Center_Pattern:	NO	NO	NO	YES
POS TARG equivalent	0.337, 0.330	0.084, 0.053	0.079, 0.047 0.157, 0.095	0.000,-14.400 0.000, 14.400

SBC box pattern parameters

Pattern_Number:	36	37
Primary_Pattern:		
Pattern_Type:	ACS-SBC-DITHER-BOX	ACS-SBC-MOSAIC-BOX
Pattern_Purpose:	DITHER	MOSAIC
Number_Of_Points:	4	4
Point_Spacing:	0.179	28.801
Line_Spacing:	0.116	32.957
Angle_Between_Sides:	63.65	264.24
Coordinate_Frame:	POS-TARG	POS-TARG
Pattern_Orient:	20.02	90.00
Center_Pattern:	NO	YES
POS TARG equivalent	0.169, 0.061 0.084, 0.142 -0.084, 0.080	-16.395, -16.055 -16.395, 12.746 16.395, 16.055 16.395, -12.746

Dither pattern diagrams

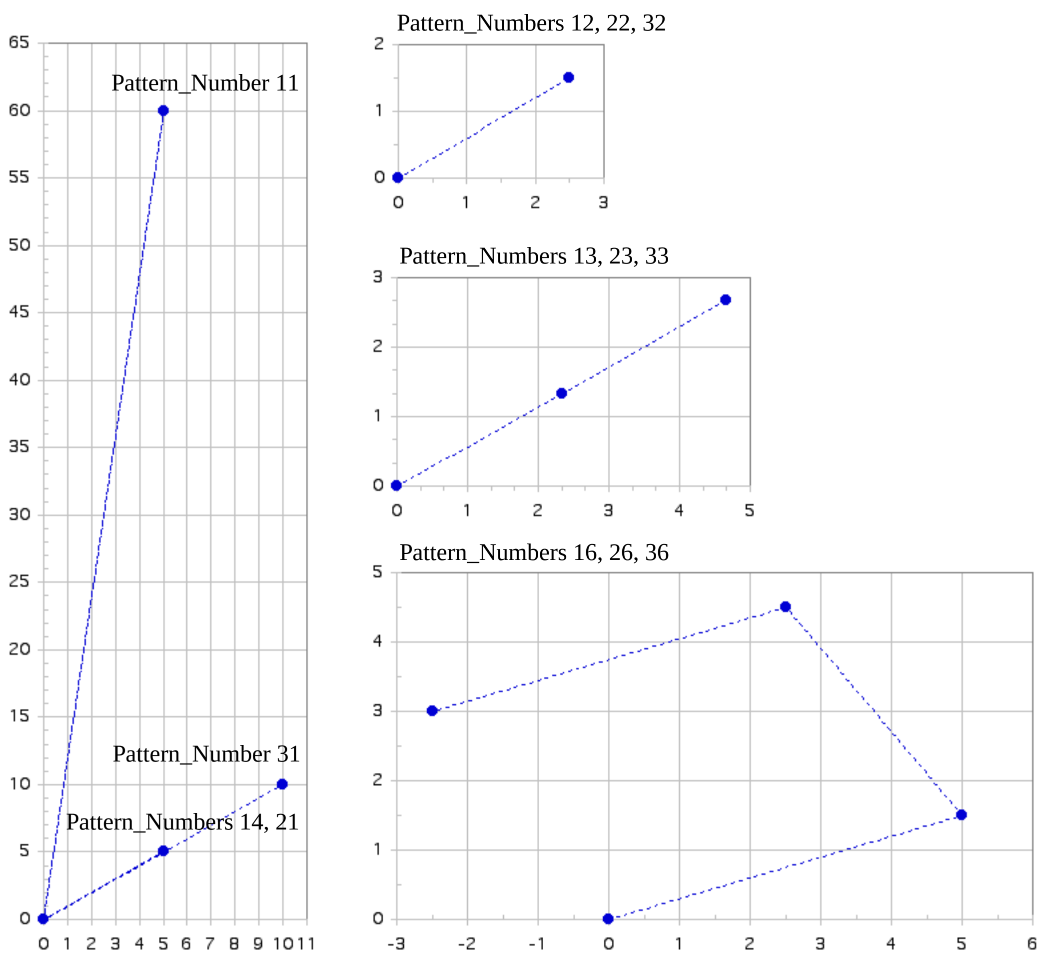


Figure 2: Diagrams of each dither pattern in relative pixel space.

Mosaic pattern diagrams

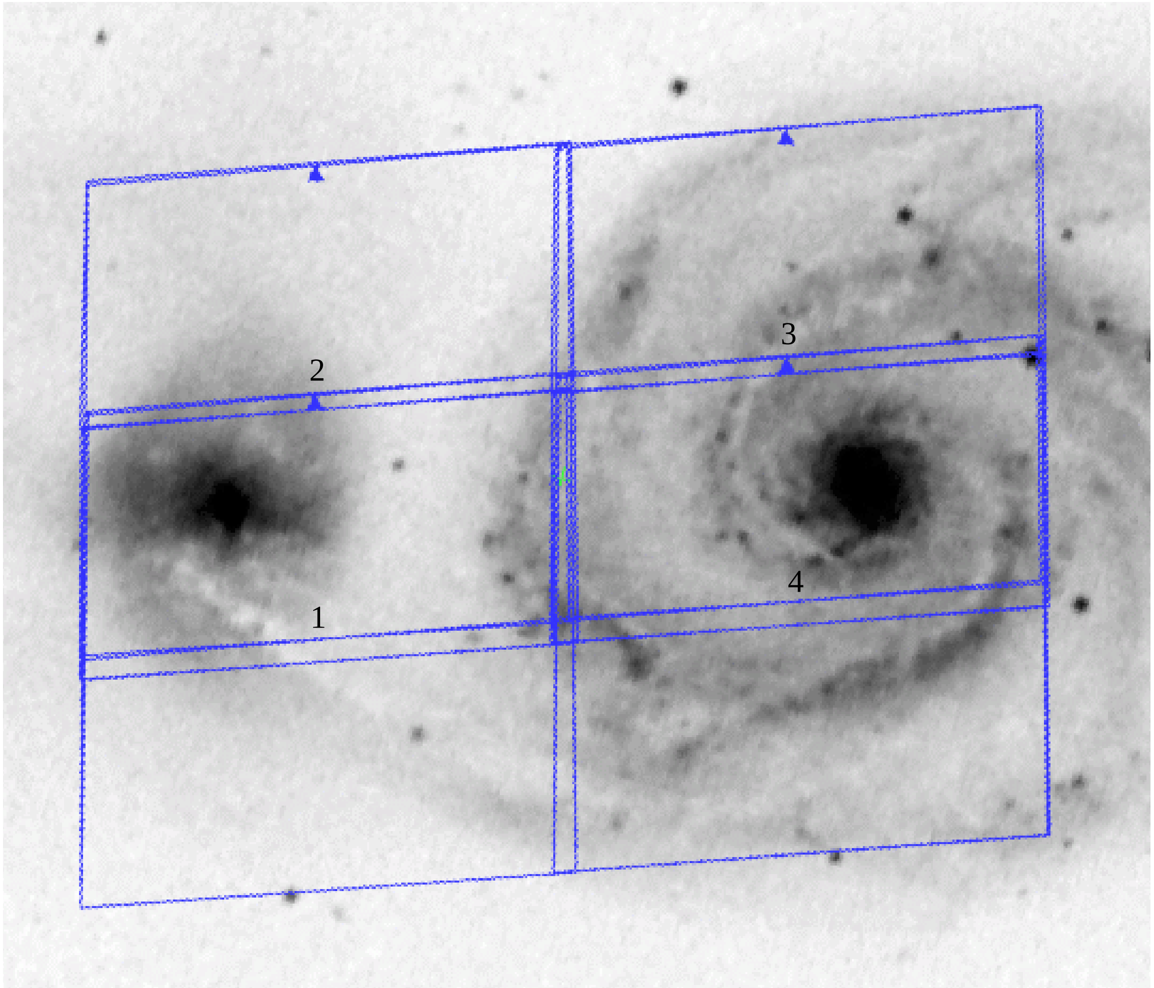


Figure 3. Diagram of the 4-point ACS-WFC-MOSAIC-BOX pattern (Pattern_Number 18). The sequence is indicated by the numbers located near the WFC-FIX aperture for each pointing. The 2-point ACS-WFC-MOSAIC-LINE pattern (Pattern_Number 15) would be the first two pointings. Pattern_Number 17 is similar, except the y shifts are larger, leaving ~5% overlap in y, rather than ~55% overlap. The edges of this graphic roughly correspond to the POS TARG axes. This graphic was produced with the Visual Target Tuner (VTT) and an image of the Whirlpool Galaxy M51 from the Digitized Sky Survey (DSS).

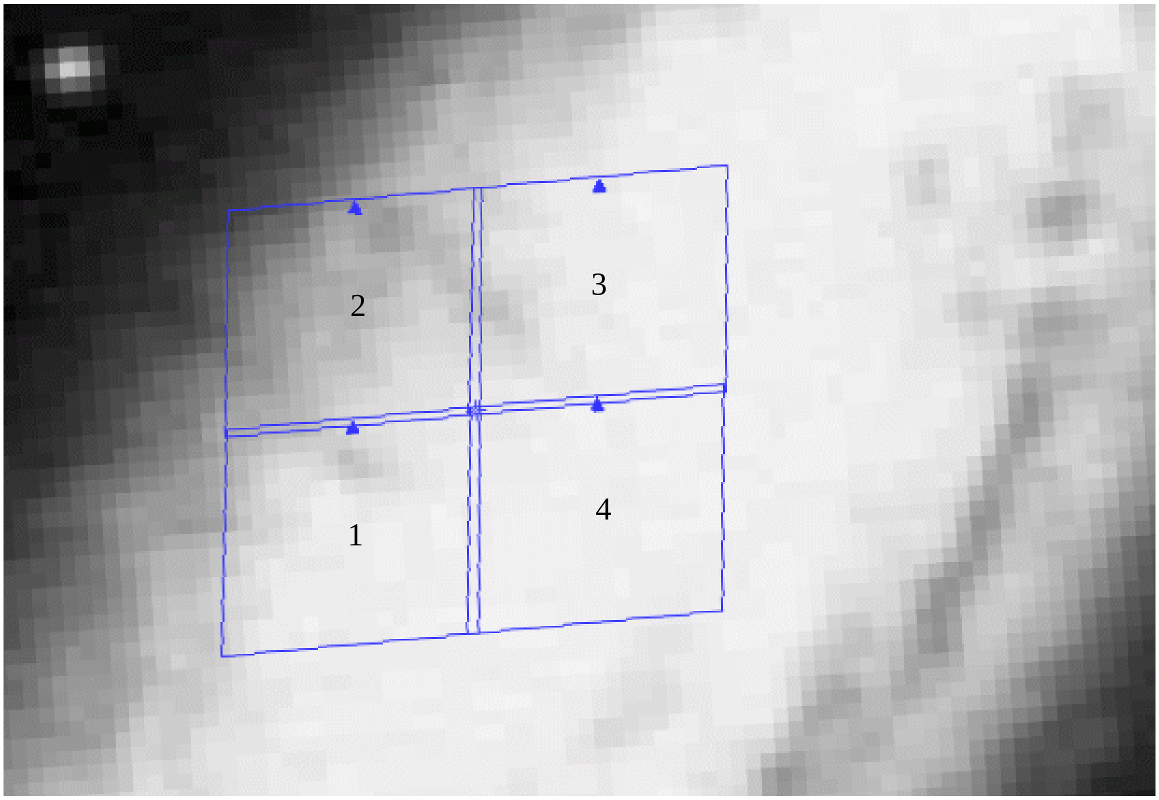


Figure 4. Diagram of the 4-point ACS-HRC-MOSAIC-BOX pattern (Pattern_Number 27). The ACS-SBC-MOSAIC-BOX pattern (Pattern_Number 37) is very similar. The sequence is indicated by the numbers located near the HRC-FIX aperture for each pointing. The 2-point ACS-HRC-MOSAIC-LINE pattern (Pattern_Number 25) would be the first two pointings. The edges of this graphic roughly correspond to the POS TARG axes. This graphic was produced with the Visual Target Tuner (VTT) and an image of the starburst galaxy NGC 1808 from the Digitized Sky Survey (DSS).

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