James Webb Space Telescope

Cycle 1 Guaranteed Time Observer Proposal

(delete italics before submission)

Principal Investigator:

Description of GTO position: ***e****.g. U.S. Miri Team lead, Interdisciplinary scientist*

Science summary:

GTOs must provide a short (typically 1 paragraph) description of each separate science investigation that will be undertaken within the Cycle 1 program. GTOs must identify investigations where the time will be shared between different GTO teams and indicate how the time will be divided. This section will be published in conjunction with the list of science observations.

CANUCS is a JWST spectroscopy and imaging survey of five massive galaxy cluster and ten parallel fields using the NIRISS low-resolution grisms, NIRCam imaging and NIRSpec multi-object spectroscopy. The primary goal is to understand the evolution of low mass galaxies across cosmic time. The resolved emission line maps and line ratios for many galaxies, some at resolution of 100pc, will enable determining the spatial distribution of star formation, dust and metals. Other science goals include the detection and characterization of galaxies within the reionization epoch, using multiply-imaged lensed galaxies to constrain cluster mass distributions and dark matter substructure, and understanding star-formation suppression and morphological transformation in the most massive galaxy clusters.

The CANUCS program has five distinct observations per target field:

1. **NIRISS Wide-Field Slitless Spectroscopy (WFSS) on the cluster field.** This will provide 1 to 2.3 micron low-resolution spectroscopy for every object in the field, with two orthogonal orientation grisms to mitigate the effects of confusion. The resulting redshifts, emission line fluxes and maps and continuum spectroscopy will enable a wide range of science projects.
2. **NIRCam Imaging on the cluster field.** There will be NIRCam imaging with one NIRCam module centred on the NIRISS field. The primary goal of the NIRCam imaging is photometry and morphology of galaxies at 0.8 to 5.0 microns to sample a wider wavelength range than with NIRISS to better sample both young and old stellar populations.
3. **NIRSpec Multi-Object R=100 Spectroscopy on the cluster field.** We will follow up the cluster field NIRCam and NIRISS observations with two NIRSpec Micro Shutter Array configurations to target galaxies for which NIRISS does not yield redshifts due to either contamination or a redshift with no emission lines in the NIRISS wavelength range

(5 < z < 7.3). We will prioritize very high-redshift and multiply-imaged galaxies, some of which are already known based on existing imaging.

4. **NIRISS WFSS on a parallel field.** These NIRISS grism observations will be shallower than those on the cluster field, but will survey a larger volume due to lower gravitational lensing magnification in the parallel field. The science goals are similar to the NIRISS WFSS on the cluster field, providing a wider range of luminosity at a given redshift.
5. **NIRCam Imaging on a parallel field.** The two science goals for these data are: 1) Determine the distance-dependent properties of galaxies at 3 to 8 arcminutes (1.0 to 2.5 Mpc) from the cores to infall regions of massive strong-lensing clusters. 2) Extend the NIRISS study of extreme emission line galaxies up to z = 8 by using medium-width bands that can be dominated by strong emission lines.

The total duration of this program in cycle 1 is 199.0 hours.

Coordination with other GTOs:

Observations of the clusters MACS J0416.1-2403 and MACS J1149.5+2223 are being coordinated with GTOs Rogier Windhorst and Massimo Stiavelli (J1149 only). There is no "time-sharing" between these GTOs, as each is submitting their own set of observations. We are coordinating the scheduling and field overlap of our NIRCam imaging with that of Rogier Windhorst to produce the best combined dataset for the variability science. The multiple epoch NIRCam imaging in these programs is therefore not a "duplication", as these data will be used to search for lensed variable objects such as caustic-crossing stars and supernovae.

Time constrained and time critical observations:

This program has no time-critical observations, only time-constrained.

The NIRSpec multi-object spectroscopy of each field will be targeted with a combination of known sources from existing imaging and NIRCam pre-imaging obtained in this program. We require at least 60 days between the NIRCam pre-imaging and NIRSpec observations to allow for data processing, analysis and target selection. All five target fields have two visibility windows in the cycle. Therefore we request the NIRCam pre-imaging to be observed in the first window and the NIRSpec observations in the second. We have defined these windows and constraints based on the nominal Cycle 1 start date of 1 April 2019. A significantly delayed start would require some re-adjustment of these windows.

Due to the equal fields-of-view of NIRISS and one NIRCam module, any rotation between the NIRCam and NIRISS prime observations of the cluster field will cause a gap in simultaneous coverage, which is bad for our science that requires data from both instruments. Therefore we request the NIRISS and NIRCam observations at the same ORIENT (we note observing them sequentially would also be efficient for telescope operations). For some target fields, particular ORIENTS for the NIRCam/NIRISS observations are not ideal due to the elongation of the cluster or contamination by bright stars that would affect data quality. For these cases an additional ORIENT constraint requirement is set. Windows of observable dates for the NIRCam/NIRISS observations are in the range 2 weeks to 6 weeks.

For the NIRSpec observations, ORIENT offset links will be set so as to roughly align the axes of the prior NIRCam/NIRISS observations and the NIRSpec MSA. Alignment of these axes provides twice as much of this area with double coverage for our NIRSpec pointing setup, compared to when the axes are misaligned by 45 degrees. Windows of observable dates for the NIRSpec observations (for a given NIRCam ORIENT) are in the range 2 weeks to 6 weeks.

The approximate range of observable dates for all schedule constraints as determined with the APT Visit Planner is specified in the excel file.

Scientific justification for coordinated parallel observations (if appropriate):

Coordinated parallel observations should have science goals that support or complement the prime science program. GTOs requesting such observations must provide a scientific justification. This should clearly indicate the role played by the parallel observations and whether they are essential for the interpretation of the primary observations or to the science program as a whole, or whether they address partly or unrelated issues.

The justification will be assessed by an independent review panel that will make a recommendation to the STScI Director regarding their implementation. If the coordinated parallels are not implemented, the prime observations will be available for pure parallel observations.

This section will not be made public.

The CANUCS program has multiple science goals related to the properties of galaxies located within rare overdense environments at $0.35<z<0.55$ and at higher redshift behind the clusters. Most of the time on our program uses coordinated parallels with NIRISS and NIRCam. The NIRSpec observations will not have coordinated parallels. The similarities between NIRCam and NIRISS imaging (same LW pixel scale, some of the same filters, similar sensitivity) makes using the two instruments together very attractive to cover a larger region than can be done with a single instrument. We specify three particular cases where coordinated parallels enhance the science output of our program:

1. **Cover a larger area/volume to improve statistics.** Whilst we are obtaining NIRCam imaging on the cluster cores, we will make NIRISS WFSS observations in a parallel

field. Because of the gravitational lensing reduction in survey volume behind the cluster (volume inversely proportional to magnification), the parallel NIRISS WFSS observations will cover more than twice the survey volume of the cluster fields (see Fig.1). But with a combination of lower exposure time and no lensing magnification, the parallel field will contain intrinsically more luminous sources. This gives a Deep + Wide “wedding cake” arrangement allowing access to a wider range of galaxy luminosities at each redshift than a survey without the coordinated parallels. We note that recent works on the high-z galaxy luminosity function using the Hubble Frontier Fields and their parallel fields are a good example of this strategy.

2. **Cover different physical zones of the massive clusters.** Imaging with NIRCam and NIRISS will be available at distances from 0 to 8 arcminutes (0 to 2.5 Mpc) from the core, past the virial radius to the infall and filament regions of massive, strong-lensing clusters (see Fig.1). Multi-filter imaging of an unprecedented number of low-luminosity galaxies within the cluster and in the periphery will allow a study of the morphological transformation and star-formation suppression of galaxies as they fall into the cluster.

3. **Extend the redshift range for extreme emission line galaxies.** One of the key science goals of the NIRISS WFSS program is to identify large numbers of extreme emission line galaxies (EELGs), believed to be representative of the physical conditions in galaxies in the early universe (compact, low metallicity, high ionization parameter). Because NIRISS WFSS only covers wavelengths 1 to 2.3 microns we can only identify strong H-alpha or [OIII] emitters at redshifts $z<3.5$. The parallel NIRCam observations will use a suite of medium-band filters from 1 to 5 microns to identify similar galaxies up to redshifts $z=8$, enabling this important population to be traced across most of cosmic history.

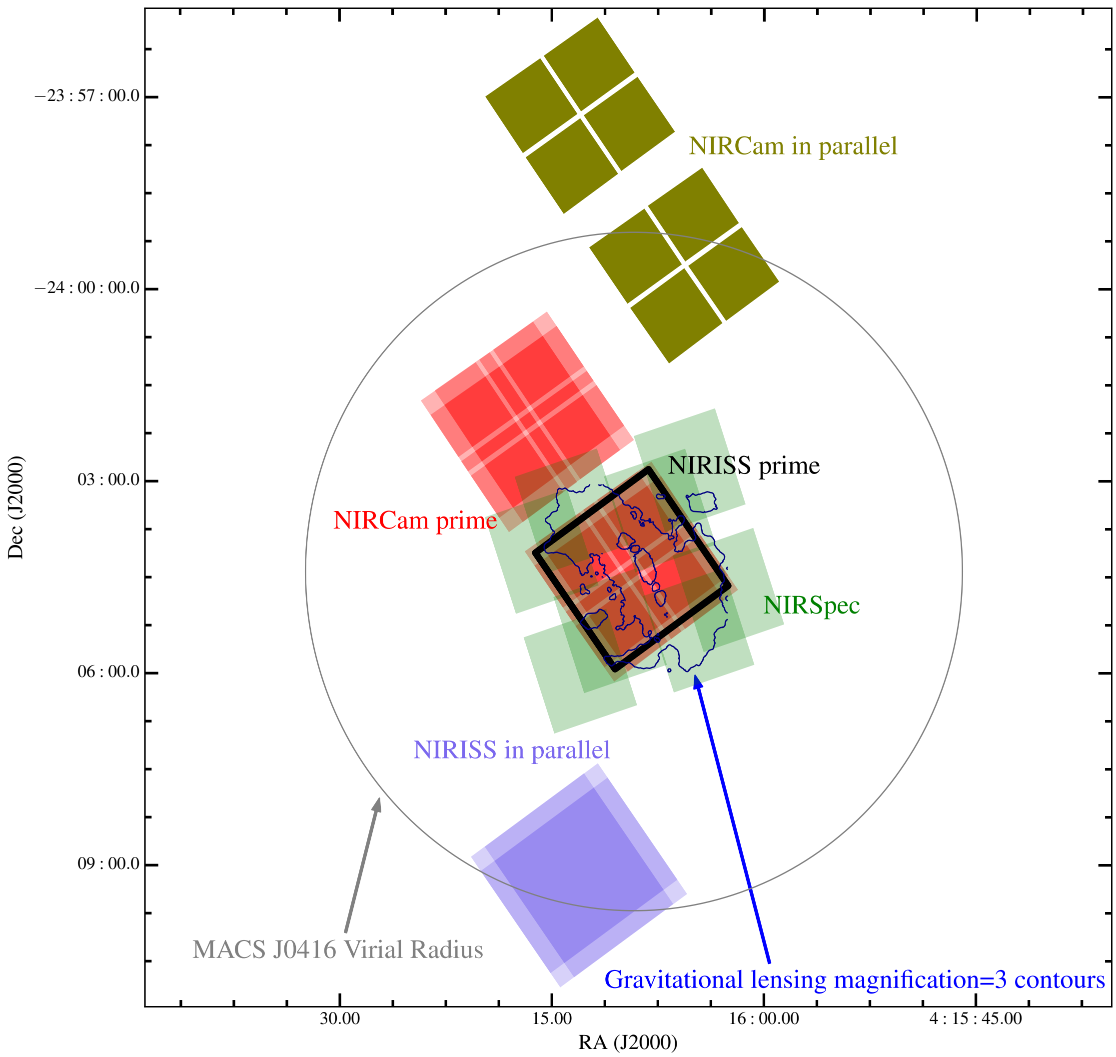

Figure 1. Field layout for one of our target cluster fields (MACS J0416.1-2403) highlighting the regions observed with coordinated parallels. These regions have low lensing magnification and a wide range of distance from the cluster center, including outside the cluster virial radius.

Detailed description of triggering conditions for Target of Opportunity Observations (if appropriate):

GTOs must provide clear definition of the specific criteria that would lead to triggering ToO observations of a particular target or phenomenon. Those criteria will be assessed by an independent review panel that will make a recommendation to the STScI Director regarding *their clarity. GTOs may be requested to refine the trigger criteria should those criteria be deemed insufficiently precise.*

This section will not be made public.

Summary of hours to charge:

For each observation described in the observation specifications workbook, indicate which program IDs are to be charged, and for how much total wall-clock time. Add more columns and rows as necessary. In a paragraph or two below the table, provide a technical description of how these total times, including overhead values, were determined.

This section will be used to track total GTO Cycle 1 usage, in accordance with NASA-SMD JWST Policy 9, and will not be made public.

Row IDs	Method used to estimate the duration	Comments
R20.01 R20.02 R20.03 R20.04 R20.05 R20.06 R20.07 R20.08 R20.09 R20.10 R20.11 R20.12 R20.13 R20.14 R20.15	The durations were estimated using the expected observation sequences and the timing model of APT 25.0.3. We expect to have to make some revisions to the observation sequences for later versions of the APT.	Smart accounting was executed.