Roman Early-Definition Astrophysics Survey Opportunity:

(1) Submission Title or Survey Name: KRONOS-E: Kp Roman Observations: New Opportunities from Surveying the Euclid deep-fields[1]

(2) Contact author (with institutional affiliation and full contact details, including email):
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(3) Co-authors (names and institutions only): Alphabetical order: Anahita Alavi (Caltech/IPAC), Phil Appleton (Caltech/IPAC), Adam Bolton (NOIRLab), Nima Chartab (UC Irvine), Asantha Cooray (UC Irvine), Jean-Gabriel Cuby (U.Marseille, France), Arjun Dey (NOIRLab), Mark Dickinson (NOIRLab), Andreas Faisst (Caltech/IPAC), Kyle Finner (Caltech/IPAC), Shoubaneh Hemmati (Caltech/IPAC), Marziye Jafariyazani (Caltech/IPAC), Stephanie Juneau (NOIRLab), Dustin Lang (Perimeter Institute, Canada), Bomee Lee (KASI, S. Korea), Dan Masters (Caltech/IPAC), Hironao Miyatake (Nagoya, Japan), Robert Nikutta (NOIRLab), Pascal Oesch (U. Geneva, Switzerland), Knut Olsen (NOIRLab), Harry Teplitz (Caltech/IPAC), Sune Toft (Niels Bohr Institute, Denmark).

(4) Do you support the selection of a Roman Early-Definition Astrophysics Survey (as described in the "Request for Information"; yes/no, with supporting motivation, 10 lines max):

Yes. We strongly endorse an early-definition Roman survey using Roman/F213 and G150 grism.

We recommend a 610 hr survey which images 40 deg^2 in Kp and covers 2.8 deg^2 with the grism, in the Euclid Deep Fields. It will enable a cross-project comparison of shear, point spread function (PSF) undersampling, and redshift biases in the grism spectra which will refine the dithers, depth and bands, in the execution of the Roman HLS. It will also allow the identification of primordial stellar populations and seed black holes in rare, z>10 halos which will need timely JWST spectra.

By 2027, these areas will have data of exceptional sensitivity from Euclid imaging and grism spectroscopy, Subaru/HSC and PFS, CFHT, and ~5 years worth of Rubin/LSST imaging (Fig. 1). It has also been covered by Spitzer (Moneti et al. A&A). Through an early program selection, complementary preparatory observations with other U.S. facilities (e.g. Chandra, LMT, VLA) can be initiated. The fields have the lowest backgrounds and will encompass the Roman Deep Fields.

(5) Describe the science investigations enabled by the survey (as relevant, briefly describe: key science drivers and breadth of science areas engaged; datasets expected upon survey completion; comparison of science enabled, parameter space opened up, or complementarities with respect to ground/space-based state-of-the-art at time of Roman launch; key differences from, and/or complementarities with, Roman core community surveys; one page max):

In the area of Galaxy Evolution, a deep survey which extends the wavelength coverage to F213/Kp is unique for: 1) enabling path-breaking identification of ~25 seed black holes and primordial stellar populations in galaxies in the 10<z<17 range through their UV slopes (Fig. 2, Banados et al. 2018, Hashimoto et al. 2018);

[1] In Greek mythology, Kronos is the youngest child of primordial parents Earth and Sky.

2) enabling spectroscopic characterization of these z>10 sources with JWST/ELT while providing a large spectral library for studying physical properties of low-z galaxies;

3) the measurement of spatially resolved ages and masses of stellar populations through the Balmer break which falls between the F213 and the Euclid bands at z<4.3. This will distinguish between "inside-out" and "outside-in" growth of galaxies in different environments/densities which are traced by the Euclid weak lensing maps (e.g. Stauffer et al. 2018).

4) Roman weak lensing mass estimates of 2 massive clusters, one of which has a known Planck/SPT mass of 6E14 Msun derived from the Sunyaev-Zeldovich effect at z~0.4. It will also enable weak lensing mass estimates of about 40 smaller groups (detected in the X-rays by eROSITA) and trace galaxy properties in them.

5) studying the colors of extragalactic background light fluctuations, constraining their origins, and identifying the growth of ionizing bubbles at z>7 (e.g. Cooray et al. 2012);

In the area of Cosmology, KRONOS-E:

6) provides an early multi-wavelength data set which will yield the most accurate galaxy templates extending to the NIR, through the refinement of cross-project cataloging techniques (Euclid-Rubin-Roman, e.g. Lee & Chary 2020, Masters et al. 2019). This will result in the most precise photometric redshifts, impacting all extragalactic studies and cosmology.

7) exceeds ~50 galaxies/arcmin^2 surface density (e.g. Fontana et al. 2014) with well-sampled PSFs to provide an early comparison on cross-project shear measurements (e.g. Euclid/VIS and Roman) which will be crucial for refining the execution of the Roman HLS, and correcting the 3D weak lensing measurements from the Euclid wide-area survey for systematics;

8) provides the best dataset for the measurement of galaxy bulge/disk ratios[2] as a function of environment (e.g. Haussler et al. 2013), this will characterize shear bias in preparation for weak lensing studies in the Roman HLS (Fig. 3);

9) leverages deep Roman spectroscopy to validate the completeness and redshift accuracy of the emission line galaxy sample for BAO studies with Euclid and Roman (e.g. Wang et al.);

10) leverages the spatial resolution of Roman to observe ~25 strongly lensed arcs and 600 lensed galaxies. These will have been pre-identified by Euclid. The observations will break lens model degeneracies to place constraints on dark matter substructure, while characterizing lensed background star-forming galaxies out to z~17 (e.g. Boldrin et al. 2016).

In the area of time-domain astrophysics:

11) the survey will detect temporal variability of candidate pair-instability supernovae from the earliest generations of massive stars out to the highest redshifts, and have the spatial resolution to pinpoint 100s of variable AGN and other SNe within their host galaxies (e.g. Cooke 2008);

The sensitivity is chosen to measure blue UV slopes of zero-metallicity stellar populations at z~12-15, and to measure the bulge/disk ratios of Euclid/VIS galaxies for the weak-lensing analysis. The grism spectra will be used to trace the distribution of Lyman-alpha emitters surrounding the most massive z>7 halos. This will be the first step towards Ly-a tomography which will be used in conjunction with redshifted 21cm data and CDIM Probe spectroscopy (e.g. Cooray et al.) to study the growth of ionizing bubbles and the reionization history of the Universe.

[2] galactic bulges are brighter in the near-infrared out to z~4 while disks are brighter at rest-frame ultraviolet.

(6) Provide a possible observational outline of the survey (as relevant/known, touch upon: survey area covered, possible location, and/or (types of) targets observed; optical element (filters/grism/prism) choices; cadence or other timing constraint (if relevant); depth to be achieved; total time needed including estimated overheads; how the survey leverages the unique observational capabilities of Roman; half-a-page max):

The three fields targeted here with Roman/F213 are:
Euclid Deep Field-North (EDF-N, 10 square deg., RA, DEC of 17:58:56, +66:01:04),
Euclid Deep Field-Fornax (EDF-F, 10 square deg., RA, DEC of 03:31:44, -28:05:19), and
Euclid Deep Field-South (EDF-S, 20 square deg., RA, DEC of 04:04:58, -48:25:23).
All coordinates are J2000.

For the science goals outlined here, we recommend a total imaging depth in the WFI/Kp band of 3.2 hrs/pixel distributed as 5 visits of 40 minutes each, distributed over the 2 years of the Roman mission with a desired 5sigma point source depth of 26.8 AB mag. We estimate this would take 510 hours, including overheads and 1% overlap between adjacent pointings. A cadence of 3 visits within 35+/-5 days would enable the time-dilated, shock breakout phase of any rare, pair-instability supernova to be detected, with two additional visits ~12 months later to trace the long duration light curve such that it can be distinguished from other classes of variable objects.

For the spectroscopy, the Euclid blue and red grism spectra in these fields will be sensitive to 5sigma of 5×10^{-17} erg/cm^2/s but with x2 lower spatial resolution than Roman. We expect about ~8000 Lyman-break galaxies at z>7 at the depths of the continuum sensitivity shown in Figure 1. We expect to target with Roman/G150 spectroscopy the most massive ~0.1% that are pre-selected based on their Euclid and Spitzer brightness, and correspond to the most massive halos at those redshifts. These 10 targets are likely to have ~50 other LBGs in their vicinity within the Roman FOV. We expect ~10-20% of those to be Lyman-alpha emitters that will be detectable in the 10 hrs/pointing grism spectra with the exact fraction depending on the size of the ionized bubble.

At lower redshift where BAO studies with emission line galaxies are being undertaken, at the Euclid line sensitivities, only about 1% of objects will have both Halpha and Hbeta detected while 10% will have [OIII] and Halpha detected. This makes measures of dust extinction, metallicity, ionization parameters and redshift accuracy challenging. KRONOS-E will be about 20% deeper than the Euclid line flux limit, but with better spatial and spectra resolution which will result in better spectral decontamination. As a result, it will be able to characterize the [OIII]/Halpha ratio and/or Hbeta/Halpha ratios of 1000 Halpha emitters. These can be correlated with galaxy SED properties and result in a better selection function of line emitting galaxies for BAO studies with both Euclid and Roman while enabling studies of galaxy physical properties.

KRONOS-E will require about 306 hrs of Roman/F213 imaging in the first year and 204 hrs imaging + 100 hrs of spectroscopy in the second year of the Roman mission for a total of 610 hrs.

(7) Describe specific preparatory activities enabled by early definition (e.g., supporting facility observations, software development work, theoretical/simulation efforts etc.; describe the benefits of conducting these activities early; half-a-page max):

Almost 50% of the Euclid and Roman-detected sources are expected to be blended in the seeing-limited Rubin data which will have spatial resolution of 0.7-0.8". At the same time, the space-platform datasets are relatively insensitive to low surface brightness features. This makes isophotal-matched millimag-precision photometry and extraction of limits challenging. A hybrid cataloging tool which leverages the location and morphologies of sources, and combines it with models fits to low-surface brightness emission in the ground-based data will result in more accurate joint photometric catalogs that can be applied to all the future surveys.

Similarly, analyzing the proposed deep Roman spectroscopy will require modification of the spectral decontamination module being developed for Euclid by the P.I./ENSCI. The current model for spectral decontamination (~30 contaminants per source) builds a model for the contaminant based on a power-law fit to the photometric data. With the deep field spectroscopy proposed, it will be possible to investigate if priors on the range of spectral models for galaxies can be applied which will allow fainter line emitters to be extracted while reducing spurious redshifts.

Finally, the Euclid Deep Fields are already the targets of surveys in the millimeter with LMT/Toltec. Identifying the EDF as the definitive targets for Roman, will allow the building up of sensitivity in the millimeter, radio and X-rays; this will allow a range of new science not discussed in this white paper, such as the obscured star-formation rate at z>3, the evolution of dust properties as a function of metallicity, identifying submillimeter galaxy overdensities as a tracer of cluster formation, build-up of the stellar-mass-black-hole mass relation etc.

[It is allowed to add <u>two additional pages</u> with figures, tables, or references, as needed to support the preceding answers. This can include any past/planned white papers, community building/engagement activities, working groups, workshops, or cross-project/cross-mission planning relevant to the survey; You may use this MS Word template or any other software for editing your responses (12pt font). Once finished, please create, and submit a pdf file.]

References:

Boldrin, M., et al., 2016, MNRAS, 457, 2738; Banados, E., et al., 2018, Nature, 553, 473; Cooray, A., et al., 2012, ApJ, 756, 92; Cooke, J., et al., 2008, ApJ, 677, 137; Fontana, A., et al., 2014, A&A, 570, A11, Hashimoto, T., et al., 2018, Nature, 557, 392; Haussler, B., et al., 2013, MNRAS, 430, 330; Lee, B., et al., 2018, ApJ, 866, 157; Lee, B. & Chary, R., 2020, MNRAS, 497, 1935; Masters, D., et al., 2019, ApJ, 877, 81; Stauffer, J., et al., arXiv:1806.00554; Wang, Y. et al., 2021, arXiv:2110.01829

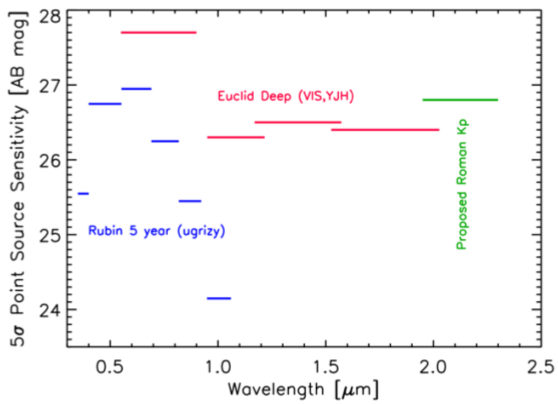

Figure 1: 5-sigma sensitivities expected for the Euclid deep field observations (red) in the Euclid VIS, Y, J and H bands compared to the Rubin/LSST 5-year depths (blue). The Subaru/HSC observations of EDF-N and EDF-F will be a magnitude deeper in griz through the H2O survey while the Rubin/DDF in EDF-F will be even deeper than that. Also shown is the proposed Roman survey in the Kp band (green, 5-sigma=26.8 AB mag). Not shown is the Euclid blue and red grism spectroscopy which will achieve continuum sensitivity of ~20.5 AB mag, or the Spitzer 3.6 and 4.5 micron data (5sigma of 24 AB mag). KRONOS-E leverages a unique bandpass on Roman to extend the wavelength coverage and improve the spatial sampling for a better handle on systematics, in preparation for the HLS.

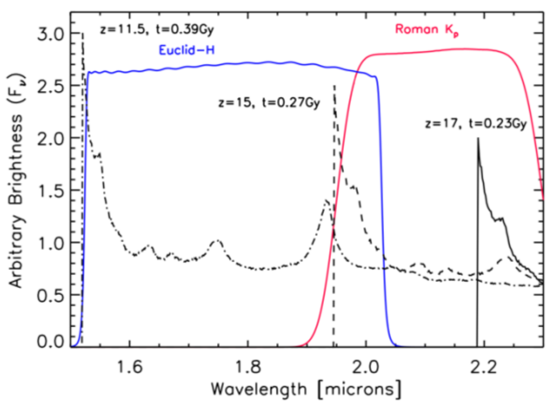

Figure 2: Stacked spectrum of high-z quasars (SDSS) with strong Ly-alpha, at z~11.5, 15 and 17. The Euclid-H and Roman Kp filter are overlaid (red). Roman Kp provides a unique opportunity to identify primordial stellar populations and seed black holes by measuring the UV slope of Euclid H-band sources and advancing the detection of rare drop-out galaxies to z~17, 230 Myr after the Big Bang. Once the sources are identified through the joint processing of the Euclid-Rubin-Roman datasets, they will be prime targets for spectroscopic characterization with JWST.

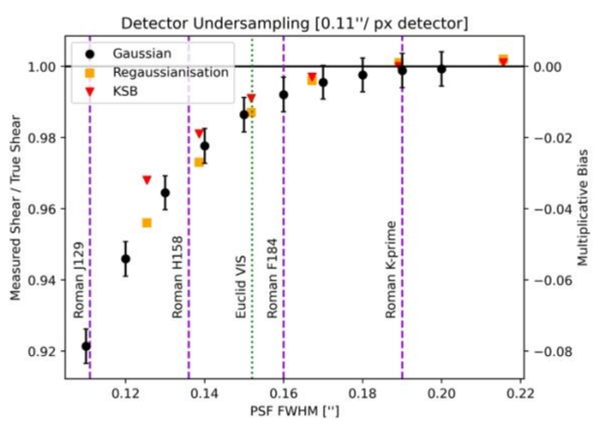

Figure 3: One of the key goals of the early science survey will be to measure the shear and shear bias in the Roman dataset in preparation for the Roman/HLS. Roman Kp has the best sampled PSF of any of the bands shown in Figure 1. The multiplicative shear bias will be negligible as a result. KRONOS-E allows a comparison of shear measurements in different bands which trace different components of a galaxy, across projects, and improves the photometric redshifts of the lensed galaxies. This will set the stage for precision studies of dark energy in the HLS with Roman and increase the fidelity of weak lensing measurements obtained with Euclid.