Snowmass2021 - Letter of Interest

Narrow band imaging as a cosmological survey complement

Thematic Areas: (check all that apply □/■)

□ (CF1) Dark Matter: Particle Like
□ (CF2) Dark Matter: Wavelike
□ (CF3) Dark Matter: Cosmic Probes
■ (CF4) Dark Energy and Cosmic Acceleration: The Modern Universe
□ (CF5) Dark Energy and Cosmic Acceleration: Cosmic Dawn and Before
■ (CF6) Dark Energy and Cosmic Acceleration: Complementarity of Probes and New Facilities
□ (CF7) Cosmic Probes of Fundamental Physics
□ (Other) *[Please specify frontier/topical group]*

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Abstract: Future surveys will gather unprecedented data for cosmological studies, however with limited spectral resolution (in the case of LSST and other photometric surveys) or alternatively for relatively small, pre-selected samples of galaxies (in the case of DESI and other spectroscopic surveys). Their ability to probe dark energy and dark matter from measurements of the growth of structure and expansion history of the Universe can be substantially extended with coordinated narrower-band imaging that helps photometric redshift calibration, characterization of transients, and identification of line emission, besides several other astrophysical applications like examining galaxy dynamics. We propose to explore direct and indirect cosmological benefits of such strategies with simulated analyses and proofs-of-concept.

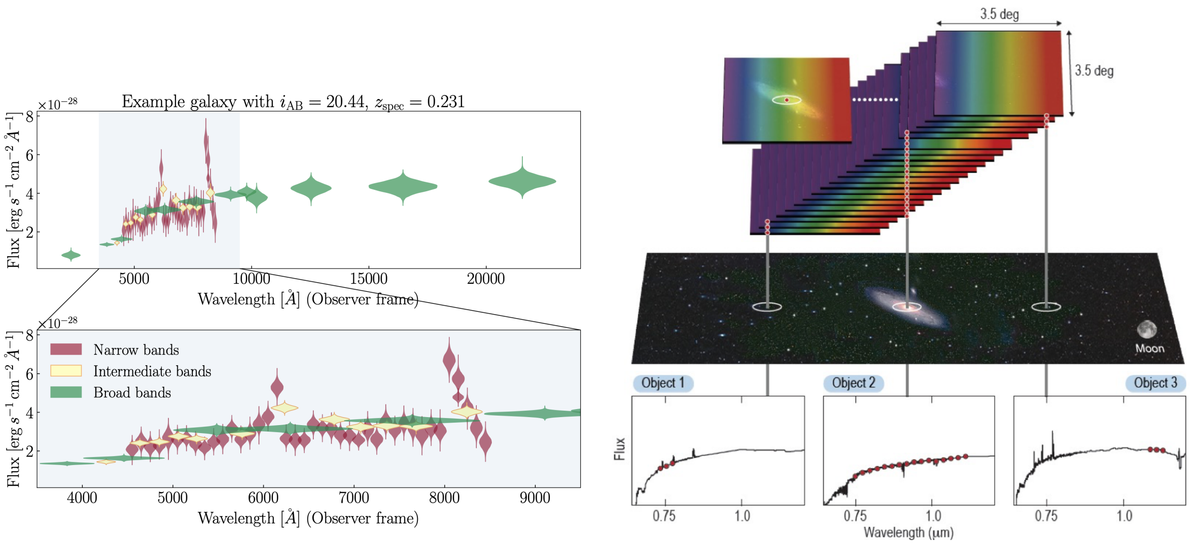

Figure 1: *Left:* Mapping of a galaxy SED by the PAU narrow-band survey (Alarcon+2020). *Right:* Hyperspectral imaging with a continuously varying filter (Source: SPHEREx).

The present and future of cosmological surveys is dominated by wide-field broad-band imaging (KiDS, HSC, DES, LSST, Euclid) and targeted multi-object spectroscopy (eBOSS, DESI, 4MOST, PFS). These are local optima of gathering information about galaxies: broad-band imaging by its efficiency of collecting photons of faint objects and at high cadence, targeted spectroscopy by its ability to measure the exact redshifts of sufficiently bright objects. Narrow-band imaging allows for a combination of features lost by these two approaches: surveys over contiguous fields without broadband pre-selection, cadence, and enhanced wavelength and with improved redshift resolution. Several projects have been and are exploring the benefits of this approach (e.g. ALHAMBRA, HSC-Deep, PAU, LAGER, JPAS, and SPHEREx), which was also recommended in the Cosmic Visions Dark Energy Small Projects Portfolio (Dawson+2018).

At resolutions $\Delta\lambda/\lambda$ of ≈ 10 to 100 instead of the ≈ 5 of a wide field survey, narrow-band imaging requires substantially larger exposure times to gather useful information on objects of the same brightness and broad spectral energy distribution (by a factor 10 to 100 if demanding the same signal-to-noise ratio in the individual narrow-band wavelength range). In the case of a prominent emission line that dominates the flux across a broad wavelength range, however, the reverse can be true. To cover the wide spectral range seen in a single shot by a spectrograph, they require a large number of different filters (or dithers with a continuously varying filter). This is offset by the substantive sky area imaged in a single take (of order sq. deg. - to be compared to the total area of less than 1/1000 sq. deg. covered by all DESI fibers).

What we think merits further exploration and proof-of-concept studies is how narrow-band surveys could interact and complement imaging and spectroscopic surveys of the next decades. This is in line with the recommendations of the Astro2020 white paper on narrow-band filters (Yoachim+2020) for LSST (see also Kahn+2020), but could also utilize other telescopes and instruments.

1 Narrow-band survey strategies

- **Deep and high-cadence fields.** The increased exposure times required to reach sufficient SNR in a narrow-band survey may favor a strategy of concentrating observations on a relatively small area of deep fields. If the observations are taken with suitable cadence, this in addition allows monitoring transients at otherwise unachievable spectral resolution.

- **Wide fields.** Over wider fields, narrow-band surveys remain unfeasible at the depth of broad-band surveys over full-wavelength coverage. It is, however, imaginable to use a small set of narrow-band filters to identify sufficiently bright line emitters at a distinct set of redshifts over moderately wide fields.
- **Coordination with imaging surveys.** The identification of an emission line in a narrow-band exposure requires the veto of a broad-band variability of the observed object. Hence narrow-band imaging benefits from simultaneous wide-band imaging in overlapping filter bands. This can in principle be achieved at no additional cost if observations are coordinated in time, e.g. between the hour-long pre-scheduled observing blocks of the LSST Deep Drilling fields and a narrow-band survey.
- **Follow-on to imaging surveys.** We note that there have been suggestions to follow-up the 10-year LSST survey with a narrow-band survey (Yoachim+2019). That white paper argues for the science potential of equipping the LSST Camera with a set of narrow-band filters, with a science case that also includes improved photometric redshift calibration.

2 Science cases for coordinated narrow-band surveys

- **Photometric redshift calibration** Inaccuracy in calibrating redshift distributions of galaxy samples for weak lensing studies are widely accepted to be a limiting factor for future and even present cosmology with imaging surveys. Use of spectroscopic redshifts is hindered by strong selection biases relative to the samples selectable by few- and broad-band photometry. A combination of high-fidelity photometric redshifts from narrow bands (e.g. Alarcon+2020) and differentiation of observable types of galaxies based on multi-band photometry that can then be followed-up spectroscopically (e.g. Sanchez+2019, Buchs+2019) is the most promising way forward for such color-redshift calibration approaches (see also Yoachim+2019).
- **Identification of emission-line samples for cross-correlation measurements** Narrow-band surveys have been used effectively to identify emission line galaxies and line-emitting regions with matching redshifted wavelengths. For sufficiently wide surveys, this can provide samples of galaxies, or unresolved emission for intensity mapping (e.g. Borisova+2016), with well determined redshift that can be used in auto- and cross-correlation studies for cosmology (e.g. White & Ferraro 2020).
- **Characterization and spectral monitoring of transients for cosmology** For a small subset of transients discovered by a survey like LSST, simultaneous narrow-band imaging of a subset of the area can constrain the redshift/type of a subset of transients, e.g. by chance matches of strong emission/absorption features in the SED of a SNIa with the narrow-band filter. Such a blind survey could possibly be crucial for constraining false identification rates.
- **Astrophysics:** Complementary to these cosmological use cases, narrow-band observations will inform models of star and galaxy formation and evolution from measurements of individual objects and the statistics of populations. These include variable stars and local SN remnants (Yoachim+2019), and UV continuum and emission line diagnostics of non-steady state galaxies (e.g. Barrow 2019).

3 Conclusions

Narrow-band surveys could have applications in the calibration and collection of complementary data for future cosmological surveys. We encourage the community to study these options with forecasts, mock analyses, and proof-of-concept scale experiments.

References: (hyperlinks welcome)

Papers referenced:

- Alarcon+2020: https://arxiv.org/pdf/2007.11132.pdf
- Barrow 2019: https://arxiv.org/pdf/1911.02023.pdf
- Borisova+2016: https://arxiv.org/pdf/1605.01422.pdf
- Buchs+2019: https://arxiv.org/pdf/1901.05005.pdf
- Dawson+2018: https://arxiv.org/pdf/1802.07216.pdf
- Kahn+2020: Snowmass21 LoI *Potential Future Uses of the Rubin Observatory Facility*
- Sanchez+2018: https://arxiv.org/pdf/1807.11873.pdf
- White & Ferraro 2020: Snowmass21 LoI *Large-Scale Structure at high redshift*
- Yoachim+2019: https://arxiv.org/pdf/1903.06834.pdf

Narrow-band surveys referenced:

- ALHAMBRA (Moles+2008): https://arxiv.org/pdf/0806.3021.pdf
- HSC (Hayashi+2017): https://arxiv.org/pdf/1704.05978.pdf
- J-PAS (Benitez+2014): https://arxiv.org/pdf/1403.5237.pdf
- LAGER: https://www.lagersurvey.org/ and publications linked therein
- PAU: https://www.pausurvey.org/ and publications linked therein
- SPHEREx (Doré+2014): https://arxiv.org/pdf/1412.4872.pdf

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