LBL Peculiar-Velocity Program

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Measuring peculiar velocities using Type Ia supernovae is a primary research topic in the upcoming decade. Peculiar velocities have been cited as a part of the Small Projects Portfolio by the the Cosmic Visions Dark Energy Working Group (Dawson et al., 2018). This document presents a range of programs that the LBL SN scientists would like to pursue including established surveys such as ZTF, ZTF-II, DESI, LSST, and new but complementary initiatives.

1 Probing Gravity With SN Ia Peculiar Velocity Surveys

In the late 1990's, Type Ia supernovae (SNe Ia) were used as distance probes to measure the homogeneous expansion history of the Universe. The remarkable discovery that the expansion is accelerating has called into question our basic understanding of the gravitational forces within the Universe. Either it is dominated by a "dark energy" that is gravitationally repulsive, or General Relativity is inadequate and needs to be replaced by a modified theory of gravity. It is only appropriate that in the upcoming decade, with their sheer numbers, solid-angle coverage, and improved distance precisions, SNe Ia will provide measurements of the *inhomogeneous* motions of structures in the Universe that will provide an unmatched test of whether dark energy or modified gravity is responsible for the accelerating expansion of the Universe.

In the next decade, SNe Ia will be used as peculiar-velocity probes to measure the influence of gravity on structure formation within the Universe. Peculiar velocities induce scatter along the redshift axis of the SN Hubble diagram, which is pronounced at low redshifts and when the magnitude scatter (e.g. due to intrinsic magnitude dispersion) is small. The conservation of mass relates peculiar velocities with mass overdensities in the same volume through the continuity equation $Haf\delta(\mathbf{x}) + \nabla \cdot \mathbf{v}(\mathbf{x}) = 0$ where the linear growth rate $f \equiv \frac{d \ln D}{d \ln a}$, a is the scale factor, and D is the spatially-independent "growth factor". Though the fields are not directly comparable, the power spectra in different volumes are such that the peculiar velocity power spectrum and the overdensity power spectrum at the surface of last scattering are related by $P_{vv} \propto (fD)^2 P_{\delta\delta}(z_{\rm CMB})$ (Hui &

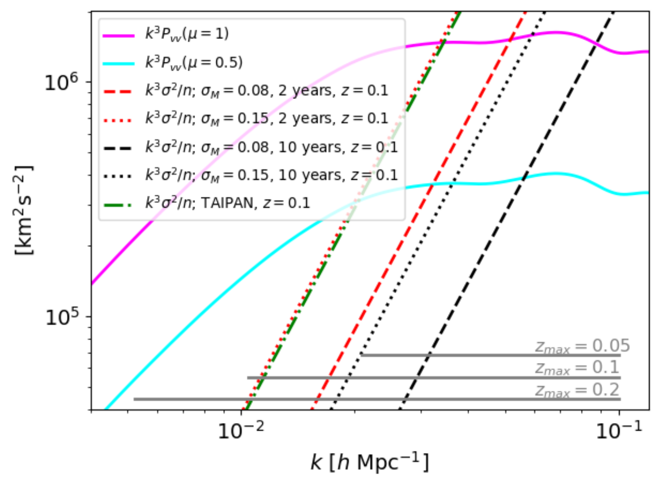

Figure 1: Dimensionless peculiar velocity power spectrum $k^3P_{vv}(z=0)$ for $\mu \equiv \cos(\hat{k}\cdot\hat{r}) = 1, 0.5$ (magenta, cyan) where $\hat{r}$ is the line of sight, as predicted for General Relativity in the linear regime. Overplotted are peculiar-velocity power-spectrum shot noise (diagonal lines) for various observing parameters. Red shows the shot noise expected from a 2-year LSST survey while black shows a 10-year LSST survey. The dotted and dashed lines indicate the assumed intrinsic magnitude dispersion, using 0.08 (dashed) or 0.15 mag (dotted). The expected shot noise from TAIPAN is shown in green (dash-dotted). The bottom solid grey horizontal lines show the approximate range of k expected to be used in surveys with corresponding redshift depths z_{max}.

Greene, 2006; Davis et al., 2011). The ΛCDM prediction for the $z = 0$ peculiar velocity power spectrum given CMB data is shown in Figure 1.

Galaxy surveys complement peculiar-velocity surveys. As alluded to earlier, comparing a peculiar velocity survey with an overlapping galaxy survey provides a measure of f/b, where b is the galaxy bias. In addition, Redshift Space Distortions detected by the galaxy survey measure growth through $P_{\delta\delta}(\hat{k}) \propto (bD + fD\mu^2)^2 P_{\delta\delta}(z_{\mathrm{CMB}})$, where $\mu \equiv \cos(\hat{k}\cdot\hat{r})$. A single SN Ia peculiar-velocity survey, whose SN search maps SN overdensities, thus gives three measures of growth, though the large number density of galaxies compared to decades worth of SNe gives stronger constraints.

The growth of structure depends on gravity; Linder (2005); Linder & Cahn (2007) find that General Relativity, $f(R)$, and DGP gravity follow the relation $f \approx \Omega_M^\gamma$ with the growth index $\gamma = 0.55, 0.42, 0.68$ respectively (see Huterer et al., 2015, for a review or these models). Using this parameterization, peculiar velocity surveys probe gravity through by modeling $fD = \Omega_M^\gamma \exp\left(-\int_a^1 \Omega_M^\gamma d\ln a\right)$, where $\Omega_M(a)$ also depends on the gravity model. The γ-dependence of $fD(z)$ is shown in Figure 2 of Linder (2013).

A SN Ia peculiar velocity survey is composed of several components:

- Transient Discoveries – Wide-field cadenced imaging surveys detect and localize the angular coordinates of new supernovae.
- Discovery Screening – Galaxy redshift catalogs, supplemental imaging data can provide subsets of the discoveries for classification using relatively expensive follow-up resources.
- SN Ia Classification – Spectroscopy classifies the SN Ia from among the pool of transient discoveries.
- (Host-galaxy) Redshift – Spectroscopy provides redshifts. Host-galaxies generally have more/sharper features that provide more precise redshifts than the supernovae themselves. Resolution $R > 200$ is sufficient to ensure that statistical uncertainties are negligible for Peculiar Velocity analysis.
- SN Ia Distance – Imaging produces photometry and colors for light-curve fitting and getting distances. The transient search naturally provides some data for this, of quality that varies depending on the survey strategy. Spectroscopy and NIR photometry have been shown to provide more precise distances than with optical light curves alone.

The above suite of observations provide a pure sample of SNe Ia with observed redshifts and cosmological redshifts (inferred from the distances and the background Hubble law) whose difference is the radial peculiar velocity.

The precision in measuring γ can be projected for different peculiar velocity surveys. The primary parameters that affect the precision are: solid angle Ω, SN number density n, source intrinsic magnitude dispersion σ_M, and for a distance-limited survey the maximum distance $r_{\max}$ (alternatively redshift $z_{\max}$). The dependence is most simply discerned in the Fisher information matrix

$$F_{ij} = \frac{\Omega}{8\pi^2}\int_{r_{\min}}^{r_{\max}}\int_{k_{\min}}^{k_{\max}}\int_{-1}^{1} r^2k^2\mathrm{Tr}\left[C^{-1}\frac{\partial C}{\partial\lambda_i}C^{-1}\frac{\partial C}{\partial\lambda_j}\right]d\mu\,dk\,dr \tag{1}$$

where

$$C(k,\mu,a) = \begin{bmatrix} P_{\delta\delta}(k,\mu,a)+\frac{1}{n} & P_{v\delta}(k,\mu,a) \\ P_{v\delta}(k,\mu,a) & P_{vv}(k,\mu,a)+\frac{\sigma^2}{n}\end{bmatrix}, \tag{2}$$

and the peculiar-velocity uncertainty (σ) is related to magnitude uncertainty via $\sigma_M^2 = \left(\frac{5}{\ln 10}\right)^2\left(1-\frac{1}{Ha\chi}\right)^2\sigma^2$. The dependences of γ and other parameters enter through fD in the relations $P_{vv} \propto (fD\mu)^2$, the SN Ia host-galaxy count overdensity power spectrum $P_{\delta\delta} \propto (bD + fD\mu^2)^2$, and the galaxy-velocity cross-correlation $P_{vg} \propto (bD + fD\mu^2)fD\mu$. The density and velocity covariances depend on the parameter set $\lambda \in \{\gamma, \Omega_{M0}, b\}$. Taking

ΛCDM as our fiducial model, $\Omega_M = \frac{\Omega_{M_0}}{\Omega_{M_0}+(1-\Omega_{M_0})a^3}$. The uncertainty in the growth index is bounded by $\sqrt{F^{-1}_{\gamma\gamma}}$.

2 Current Results and Projections

2.1 Current Results

Peculiar velocity surveys have already been used to measure the effective fD in redshift bins (referred to as $f\sigma_8$), though not to a level where gravity models can be precisely distinguished. Adams & Blake (2020) use 6dFGS peculiar velocities using Fundamental Plane distances of elliptical galaxies to estimate absolute magnitudes with ~ 0.43 mag precision, yielding a 20% uncertainty in fD at $z \approx 0$. The upcoming TAIPAN survey (da Cunha et al., 2017) will obtain Fundamental Plane galaxies with densities of $n_g \sim 10^{-3}h^3\,\mathrm{Mpc}^{-3}$, and the WALLABY+WNSHS surveys (Johnston et al., 2008) will obtain Tully-Fisher distances (based on the ~ 0.48 mag calibration of absolute magnitude based on the HI 21cm line width) of galaxies with densities $n_g \sim 2\times10^{-2} - 10^{-4}h^3\,\mathrm{Mpc}^{-3}$ from $z = 0 - 0.1$ covering 75% of the sky. These surveys combined are projected to have 3% uncertainties in fD (Howlett et al., 2017). For reference, DESI projects a 10% precision of fD at $z \approx 0.3$ by looking for signatures (Redshift Space Distortions; RSD) expected from galaxies infalling toward mass overdensities. Relative to galaxies with Fundamental Plane or Tully-Fisher distances, SN Ia host galaxies currently have significantly lower number density but have better per-object peculiar velocity precision. Existing SN Ia samples have been used to test and ultimately find spatial correlations in peculiar velocities that may be attributed to the growth of structure (Gordon et al., 2007; Abate & Lahav, 2008; Johnson et al., 2014; Huterer et al., 2015, 2017). SNe Ia discovered by ASAS-SN, ATLAS, and ZTF (Shappee et al., 2014; Tonry et al., 2018; Bellm et al., 2019) over the next several years will provide first probative measures of fD at $z < 0.1$.

2.2 Projections

Two advances in the upcoming decade will make SN Ia peculiar velocities more powerful. First, the precision of SN Ia distances can be improved. The commonly-used empirical 2-parameter spectral model yields absolute magnitude dispersion $\sigma_M \gtrsim 0.12$ mag. However, SNe transmit more information than just the light-curve shape and single color used in current SN models. Recent studies indicate that with the right data, SN absolute magnitudes can be calibrated to $\sigma_M \lesssim 0.08$ mag (see e.g. Barone-Nugent et al., 2012; Fakhouri et al., 2015). Though not yet established, it is anticipated that such a reduction in intrinsic dispersion comes with a reduction in the magnitude bias correlated with host-galaxy properties that is observed using current calibrations. At this precision the intrinsic velocity dispersion at $z = 0.028$ is 300 $\mathrm{km\,s^{-1}}$, i.e. a single SN Ia is of such quality as to measure a peculiar velocity with $S/N \sim 1$. If corrections of all SNe Ia are not possible, the use of SN Ia subclasses is an option though at the expense of reducing the numbers of velocity probes. Secondly, in the upcoming decade cadenced wide-field imaging surveys such as ZTF2 and LSST will increase the number of identified $z < 0.2$ Type Ia supernovae from the hundreds to the hundreds of thousands; over the course of 10-years, LSST will find $\sim 150,000$ $z < 0.2$ SNe Ia for which good light curves can be measured, corresponding to a number density of $n \sim 5 \times 10^{-4} h^3\,\mathrm{Mpc}^{-3}$. This sample has comparable number density and more galaxies at deeper redshifts than projected by WALLABY and TAIPAN. With similar densities, the (two) ten-year SN Ia survey will have a (6) $29\times$ reduction in shot-noise, σ_M^2/n, relative to the Fundamental Plane survey of TAIPAN.

A SN Ia peculiar velocity program hinges on SN discoveries, the number density n of which depends on the cadenced wide-field imaging survey used for the search. It is thus convenient to make projections for upcoming programs based on the imaging survey; the projections here use ZTF2 and LSST as canonical representatives. Keep in mind that other follow-up resources determine the distance precision σ_M, the other important parameter that affects projections.

The primary sources of systematic error in a high-redshift supernova Hubble diagram are not as important for a low-redshift peculiar velocity survey. A Hubble diagram that spans a broad redshift range requires absolute color calibration over the corresponding observer-frame wavelength range and control over the different populations over the span of cosmic time from which SNe are drawn. High-redshift peculiar velocity measurements do not have much sensitivity to γ, and a SN survey confined to lower redshifts is less sensitive to color-calibration uncertainties and population evolution.

Details on the assumptions made for the calculations that follow can be found in Kim et al. (2019). The results presented use the peculiar-velocity survey to measure overdensities. Improved results are possible using complementary galaxy surveys such as DESI are straightforward to calculated but haven't been yet done.

2.2.1 Near-Term: ZTF2

ZTF2 and TAIPAN are near-term surveys that will measure peculiar velocities, the former using SNe Ia and the latter using Fundamental Plane Galaxies. Both have roughly $z_{\mathrm{max}} = 0.09$ and $\Omega = 2\pi$. Uncertainties in γ for surveys with this depth and solid-angle coverage are shown as a function of number of sources N and σ_M in Figure 2.

The positions of ZTF2 and TAIPAN are marked in the figure, with the former showing both a conservative $\sigma_M = 0.12$ mag and aggressive $\sigma_M = 0.08$ mag. The former is the uncertainty that could be achieved with ZTF2 photometry alone, the latter with additional SN follow-up. ZTF2 and TAIPAN lie in opposite ends of the figure, there are small numbers of ZTF2 SNe with precise distances whereas there are many TAIPAN Fundamental Plane galaxies with imprecise distances. Conservative ZTF2 and TAIPAN are projected to give similar precisions $\sigma_\gamma = 0.060$, whereas aggressive ZTF2 gives a more constraining $\sigma_\gamma =$

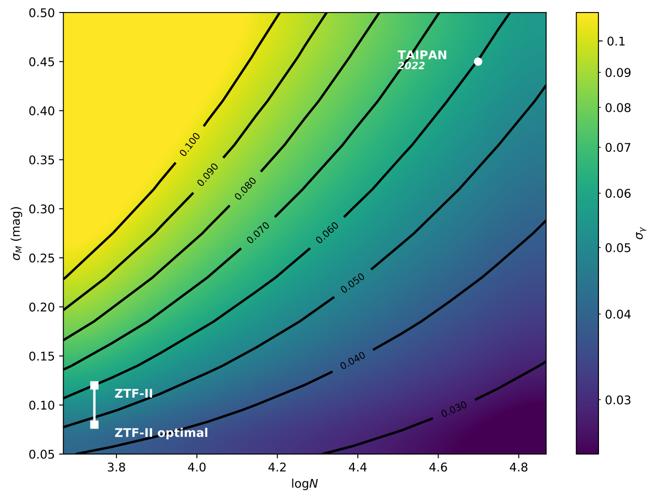

Figure 2: Uncertainties in γ for surveys with $z_{\max} = 0.09$ and $\Omega = 2\pi$ are shown as a function of number of sources N and σ_M. The positions of ZTF2 and TAIPAN are marked, with the former showing both a conservative $\sigma_M = 0.12$ mag and an aggressive $\sigma_M = 0.08$ mag.

0.048. Recall that the difference in γ between GR and the $f(R)$ and DGP gravity is 0.13, meaning that the surveys can already distinguish between these models to $2-3\sigma$.

An important distinction between the surveys is that TAIPAN will observe almost all available Fundamental Plane galaxies in the local volume, meaning that no additional observing can increase the number density n and decrease σ_γ. On the other hand, the number density of supernova increases linearly with time, there is continued room for decreased σ_γ with longer surveys as ZTF2 is not sample-variance limited

ZTF2 and TAIPAN are not in competition but are complementary. Being in different hemispheres, the two surveys cover different parts of sky, meaning that their two independent results can be combined quadratically to produce a reduced joint uncertainty.

2.2.2 Long-Term: LSST

A long-term supernova peculiar-velocity survey can be performed with SNe Ia discovered by LSST. As a 10-year survey, LSST generates higher supernova number densities to fainter limiting magnitude than ZTF2, making possible significantly improved constraints on the growth index. All the proposed LSST surveys have complete SN Ia discovery out to $z = 0.3$. The expected distance uncertainties derived from LSST light curves vary greatly depending on observing strategy, but at best is expected to be $\sigma_M = 0.12$ mag. Some strategies provide SN discovery but much poorer light curves and distances. As with the ZTF2 survey, lower

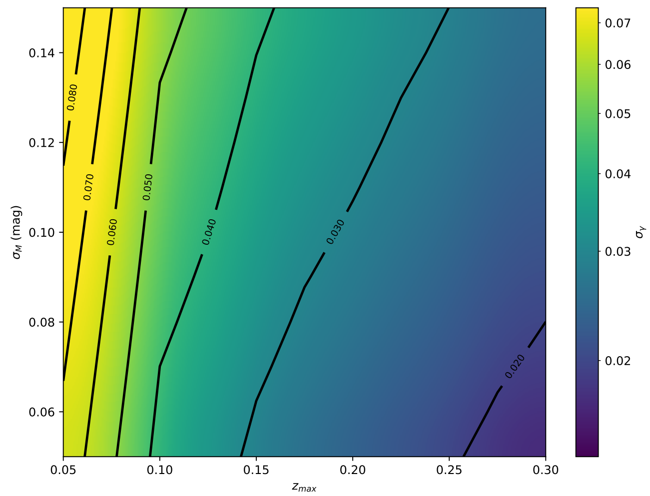

Figure 3: Uncertainties in γ for surveys with a 10-year duration and and $\Omega = 2\pi$ sky coverage are shown as a function of limiting redshift z_{max} and σ_M.

magnitude uncertainties can be achieved with supplemental data.

Uncertainties in γ for surveys with a 10-year duration and $\Omega = 2\pi$ sky coverage, applicable to the LSST WFD survey, are shown as a function of limiting redshift z_{max} and σ_M in Figure 3. The redshift depth afforded by LSST provides significant improvement relative to the shallower ZTF2 survey. After 10 years, the region with $z_{max} < 0.1$ has σ_γ that is only weakly σ_M-dependent, which reflects the relatively strong sample variance in the small local survey volume. As σ_γ quickly increases for surveys shallower than the $z_{\max} = 0.09$ of ZTF2, better growth index constraints are achieved by going to $z_{max} > 0.1$. The gradient in decreasing σ_γ does shallow out with increasing redshift despite the increased survey volume, as the velocity uncertainties degrade with redshift for a fixed σ_M.

2.3 Complementarity with High-z redshift surveys

Combined low-redshift peculiar velocity and high-redshift RSD fD measurements (i.e. from DESI) are highly complementary as together they probe the γ-dependent shape of $fD(z)$ (not just its normalization) and potential scale-dependent influence of gravitational models. The latter is true because the $k_{\max}$ of linear modes for the RSD measurement is higher than that of the low-redshift peculiar velocity measurement. Joint peculiar-velocity and RSD constraints on γ can be found in Kim & Linder (2020).

3 Plan for a Peculiar Velocity Program

The projections for measuring γ with ZTF2 and LSST SN Ia discoveries show the power of peculiar velocities surveys at low redshift. This tracer provides an unmatched new window with which to test gravity and the source of the accelerating expansion of the Universe. We propose the following course of research for the upcoming decade. The general theme is that we will use public discoveries and data from ZTF-II and LSST, and supplement them with the additional data described in §1 necessary to make a peculiar velocity measurement.

3.1 SNfactory

We will perform a PV analysis using the precise and accurate distances of supernovae obtained by the SNFactory. Kim has developed a SNFactory/ZTF peculiar-velocity analysis framework with Graziani. Its distinguishing features is that it is likelihood-based including both density and peculiar velocities. The complexity of including fitting the underlying mass density field in the model is addressed through Hamiltonian Monte Carlo. Analytic expressions for the partial derivatives of the likelihood are coded, avoiding the computational limitations of *autodiff* in STAN. A end-to-end implementation is complete and a draft methodologies paper is expected within a week.

This work is done as part of the SNfactory and specifically with French IN2P3 colleagues.

3.2 DESI as TAIPAN-North

DESI has the potential to perform a compelling Peculiar Velocity Survey. Its northern hemisphere coverage complements the TAIPAN and WALLABY southern surveys. Its technical capabilities far exceed those of TAIPAN. While ideally a PV-optimized survey with the instrument would be preferred, we are examining how much can be done within the Bright Galaxy Survey (BGS).

The BGS targets objects to a fainter magnitude limit than TAIPAN. However, the DESI S/N and single visits are a point of concern. Indeed, previous Fundamental Plane surveys have found that per-observation systematic errors in measured velocity dispersion are the limiting source of error. For this reason, TAIPAN revisits each Fundamental Plane galaxy several times to $\sqrt{N}$-suppress this error. Kim is working with a PV subgroup within DESI to determine the statistical error in velocity dispersion from BGS observations. We are would like multiple visits of the same source during SV to quantify any extra variance that appears in the dispersion measurement.

While the tall pole is the velocity-dispersion measurement, the imaging component is well in hand. Kim has worked with DESI-colleague Parkinson to find that DESI Legacy Imaging Surveys DR8 performs as well as currently-used releases in measuring galaxy surface brightnesses and angular sizes, and have identified new Tractor per-band pixel-level reductions that could further increase the performance.

This work is done within the DESI collaboration, mostly with Howlett and Parkinson. Blake and Davis are interested as well.

3.3 DESI getting redshifts for SN Ia PV with ZTF, ZTF-II

The redshift precision obtained by ZTF's SEDMachine is poor enough to adversely affect peculiar velocity measurements. In addition, pre-existing host-galaxy redshifts aid in the classification of transients. As such, we have been in working with our DESY/Humboldt University colleagues on an external collaboration agreement with DESI, who would provide a precision redshift of ZTF transient hosts, the vast majority are already targets of the BGS survey. DESI members would gain access to ZTF Partnership SN Ia light curves.

This work has been done through the DESI Time Domain Working Group. A collaboration agreement between DESI and ZTF-II is also possible though it won't be initiated until there is a ZTF-II Partnership.

3.4 SN Ia Follow-up Network of ZTF-II, LSST, and Other Sources of SN Discovery

In the future, ZTF-II and LSST will provide public nearby SN discoveries and photometry and in the case of ZTF-II some spectroscopy. The ability to determine accurate from these public data varies. ZTF-II public *gr* photometry itself will not give precise distances. SEDMachine can provide classifications and perhaps precise distances, but only a small fraction of SNe will have public data. ZTF-II lacks precision redshifts . The LSST WFD survey observing strategy is yet to be specified. All strategies considered give complete discovery out to $z = 0.3$, but they vary widely on their ability to yield accurate distances or early classification. LSST provides no spectroscopy. Either way, none of these public data (nor any of the ZTF-II private) will provide the precision that spectrophotometry can. For this reason, LBL's primary interest is in developing a follow-up network covering the sky of both northern and southern hemisphere searches.

There are several classes of follow-up we have identified:

- Spectrophotometry around peak brightness. Spectrophotometry is expected to give 0.08 mag distance modulus uncertainties compared to the 0.12 mag uncertainties of a private ZTF or good-survey-strategy WFD LSST photometry. Spectrophotometry increases the power of a single supernova by $\times 2.25$ while also getting a host redshift.
  - SN Ia Classification – SNIFS can supplement SED Machine to go toward 100% SN Ia classifications while going deeper than the nominal 18.5 mag limit of SED Machine.
  - Host-galaxy redshift.
  - SN Ia Distance – SNIFS has already been used to standardize SNfactory SNe Ia magnitudes to $\sigma_M = 0.08$ mag. SNIFS follow-up of ZTF-II and LSST will be

designed to obtain this precision. This SN subset will have relatively smaller peculiar-velocity uncertainties relative to those with only photometry. The SNIFS IFU provides local host-galaxy properties, which may also improve SN distance precisions.

In the above SNIFS at the UH-88 is called out as an existing instrument that could do the job and Greg is communicating with UH about a robotized upgrade to follow-up ZTF discoveries. The University of Hawaii must allocate time and resources into the program. There is already UH expertise in supernovae and peculiar velocities and an existing relationship with LBL.

We estimate that 2 or 3 dedicated 2m telescopes instrumented with similar IFUs could provide complete followup of $z < 0.09$ discoveries in concurrent northern and southern searches. We submitted a proposal to instrument the CAHA 2m with an IFU to follow ZTF discoveries. IN2P3 Colleagues are interested in installing a MUSE clone on the VST.

LBL should actively be

  - Developing its ability to design and build IFU spectrographs. We can leverage the expertise used to design the DESI spectrographs. There are several IFU technologies. LBL/SSL experience with fibers makes a lens-array fiber-bundle IFU a natural technology to develop internally. Alternatively, Marseille and Lyon colleagues have expertise in the other IFU technologies, image slicer and lenslet arrays,
  - We need to identify available telescopes that we can instrument with IFU spectrographs built by LBL and collaborators.

- Optical imaging. LSST may choose a WFD strategy that while discovering SNe Ia, provide so little data on them as to render them useless. Even if LSST does have a good observing strategy, the closest SNe Ia that we are interested in will saturate the LSST Camera.

  The needed imaging depends on the selected WDF strategy and the amount of spectrophotometry we get. An extreme case occurs when early classification is not possible with LSST. Then a "ZTF-South" instrument capable of SN discovery early in their evolution and not saturating is needed. Greg and Peter think that a 1m-class Schmidts would be necessary. We have not identified such a telescope that fits the bill.

  If only a small number of supplemental observations are necessary of low surface density targets, a smaller FOV camera would suffice.

- NIR data, like spectrophotometry, have been used to get $\sigma_M = 0.08$ mag. UH and Carnegie colleagues have been interested in this. Perhaps LBL has a spare SNAP

HgCdTe sitting around that can be used for this.

- DESI can provide the following components to supplement surveys:
  - Discovery Screening – Provides redshifts for probable host galaxies of new transients, for use in early classification. A host galaxy may already have a DESI redshift, may be a BGS target without a redshift but whose observation could be prioritized, or non-DESI target for which we make a secondary-target fiber allocation.
  - SN Ia Classification – Spectroscopy of active transients through secondary-target fiber allocations within DESI survey pointings. There will be ~ 1 active $r < 21.5$ SN Ia in every three DESI pointings. Coordinating DESI pointings such that "every" pointing contains a ZTF2 discovery can significantly increase the number of classifications, relative to the random (from the transient perspective) default DESI pointings. Triggered observations of non-DESI pointings is possible, though does not take advantage of DESI multiplexing.
  - Host-galaxy redshift – Mopping up missing host-galaxy redshifts can be done efficiently with a single sweep of DESI's MOS.

  The $R > 2000$ resolution provides sufficiently precise redshifts so as to make their uncertainties negligible in the γ error budget.

LBL, through the project, would support a broad community interested in peculiar velocities. There are interested groups at the University of Hawaii, the University of Michigan, the University of Pittsburgh, the University of Rochester, Yale University, Brookhaven National Laboratory, the Carnegie Observatories, several IN2P3 labs, Humboldt University, the University of Toronto, the University of Queensland, African Institute for Mathematical Sciences. There is expressed interest from South Africa and Australia in using their resources for peculiar-velocity follow-up observations.

3.5 ZTF-II Partnership

ZTF is soon concluding. LBL plans to use public ZTF-II discoveries as the source of SNe for a near-term peculiar-velocity program. There are advantages to being members of the partnership. for the following reasons:

- Being a partner brings a voice as to how partnership ZTF and SNM time are to be used. A peculiar-velocity survey is already being touted as a primary science driver, and we can push for it.
- It would be ready to start Fall 2020.
- It is cheap, with a cost ranging from zero to access public data, to an amount (\$200k/yr) smaller than building a new facility.

- ZTF2 includes SEDMachine for classification of $m < 18.5$ mag transients.

- It is in the Northern Hemisphere, which complements and is not superseded by LSST. Even after the nominal 3-year survey and simultaneous with LSST, the facility remains important for peculiar-velocity studies.

- It is anticipated that the public plus private collaboration surveys can be designed to generate distance precisions of $\sigma_M = 0.12$ mag, which allow good velocity measurements with SNe Ia. (Additional follow-up can lower this uncertainty further.)

- The limiting redshift $z_{\mathrm{max}} = 0.09$ is sufficiently deep to have a scientifically interesting result $\sigma_\gamma < 0.053$. There are other SN searches that do not achieve this depth.

ZTF2 SN Ia discoveries and pubic/partnership data can be supplemented with data from other facilities, as described above, to form a complete PV program. The active SN spectrophotometric and NIR follow-up provide significant distances estimates over what ZTF2 photometry can do alone.

I think (?!) the expectation would be that the science would be run through the partnership. Value-added data would be shared with other ZTF-II partners interested in the same science.

Option A: Do not join the partnership and use ZTF-II public data. ZTF-II public should provide discoveries and classifications of $z < 0.09$ efficiently. SEDMachine spectra for a fraction of the bright objects. Public pixels will be available in two months. The pro is that the discoveries are free. Cons are that to be competitive we nonetheless need to get more external data to make up for the lack of (competing) partnership data we don't get. Either way precise redshifts have to come from somewhere.

Option B: Join the ZTF-II partnership. Private buy-in probably gives slightly more solid-angle, i photometry, and more SEDMachine spectra. With the third band distance precisions are expected to be usable for PV, though not as good as with spectra at maximum. This is a low-risk option to give reasonable science. It gives a say as to how to steer partnership time, though there is no guarantee that you can generate a majority.

Option C: Side-door entry through DESI. Early DESI host redshifts and ZTF-II discovery follow-up of interest to ZTF-II.

3.6 LSST +

The DESC SN Ia Working Group is interested in peculiar velocity science. There is an official peculiar-velocity project. A peculiar-velocity metric was included in the DESC response to the Project call for white papers on observing strategies. Informal meetings have been held by DESC members. Building a community via DESC is a natural way to socialize the need for a follow-up work network through DOE and perhaps IN2P3.

4 Conclusions

In the next decade, the high number of SN discoveries together with improved precision in their distance precisions will make $z < 0.2$ SNe Ia, more so than galaxies, powerful probes of gravity through their effect on the growth of structure. No other probe of growth of structure or tracer of peculiar velocity can alone provide comparable precision on γ in the next decade. At low redshift, the RSD measurement is quickly sample variance limited (as are the planned DESI BGS and 4MOST surveys) making peculiar velocities the only precision probe of fD. TAIPAN and a TAIPAN-like DESI BGS will be able to measure FP distances for nearly all usable nearby galaxies, so at low-z the Fundamental Plane peculiar-velocity technique will saturate at a level that is not competitive with a 2-year SN survey.

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