DESI
(and Peculiar Velocities)

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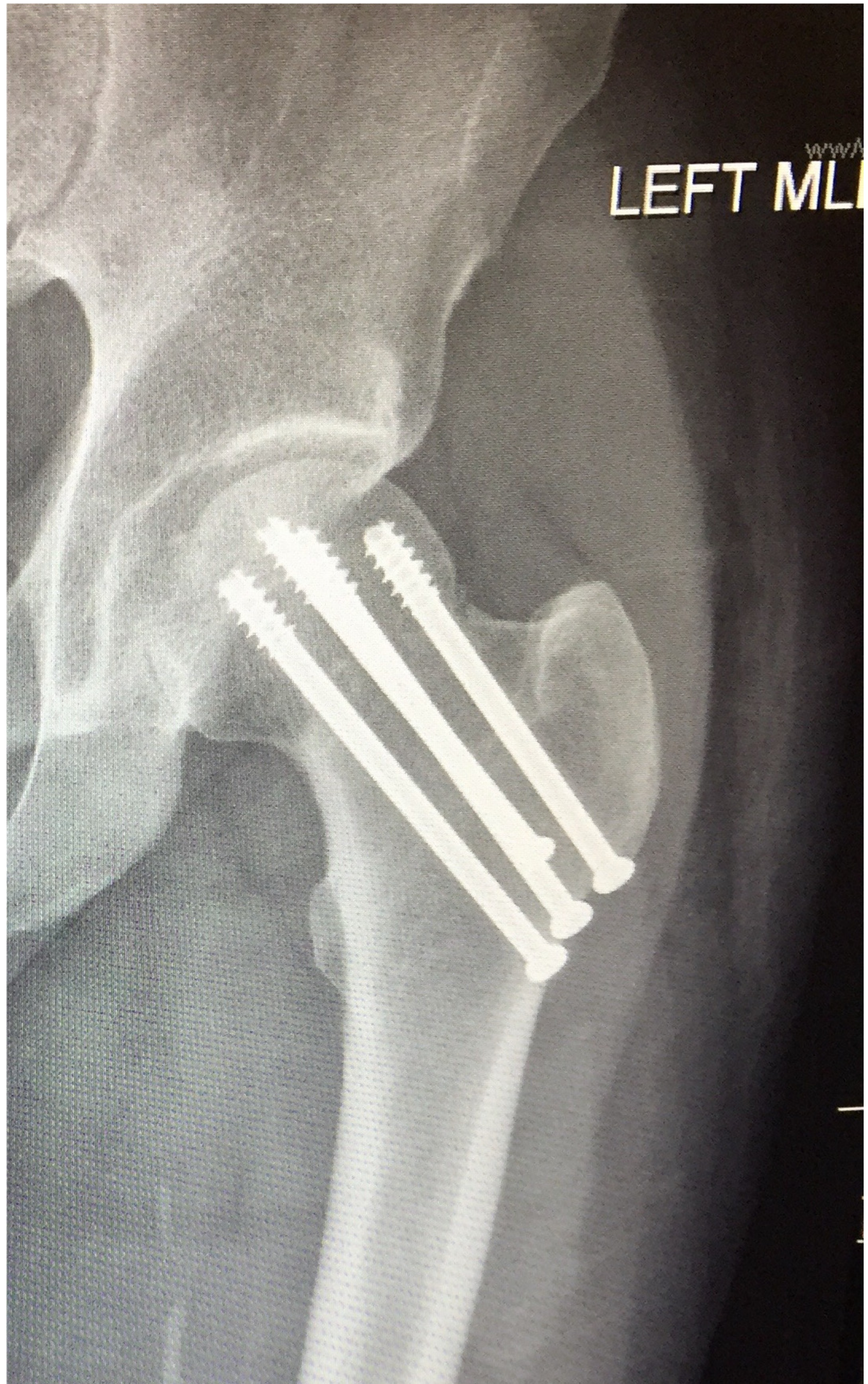
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Millenium Simulation

Probing Gravity with SN (Ia, IIP) Peculiar Velocities

- Contents in the Universe move due to gravity
- Peculiar velocities (motions on top of cosmological expansion) depend on mass overdensities and the law of gravity
  - Mass overdensities well measured at the surface of last scattering
  - Measuring velocities

Growth of Structure and Gravity: Math and Notation

$\rho(\mathbf{x}, t)$**:** mass density

$\delta(\mathbf{x}, t)$**:** mass overdensity

$$\delta(\mathbf{x}, t) \equiv \frac{\rho(\mathbf{x},t)-\bar{\rho}(\mathbf{x},t)}{\bar{\rho}(\mathbf{x},t)}$$

$\delta(\mathbf{x}, t) = D(t)\delta(\mathbf{x})$ to first order

$D(t)$**:** "linear growth factor"

$f(t) \equiv \frac{d \ln D}{d \ln a}$**:** "growth rate"

Peculiar velocities sensitive to the combination fD (literature often uses notation $f\sigma_8$)

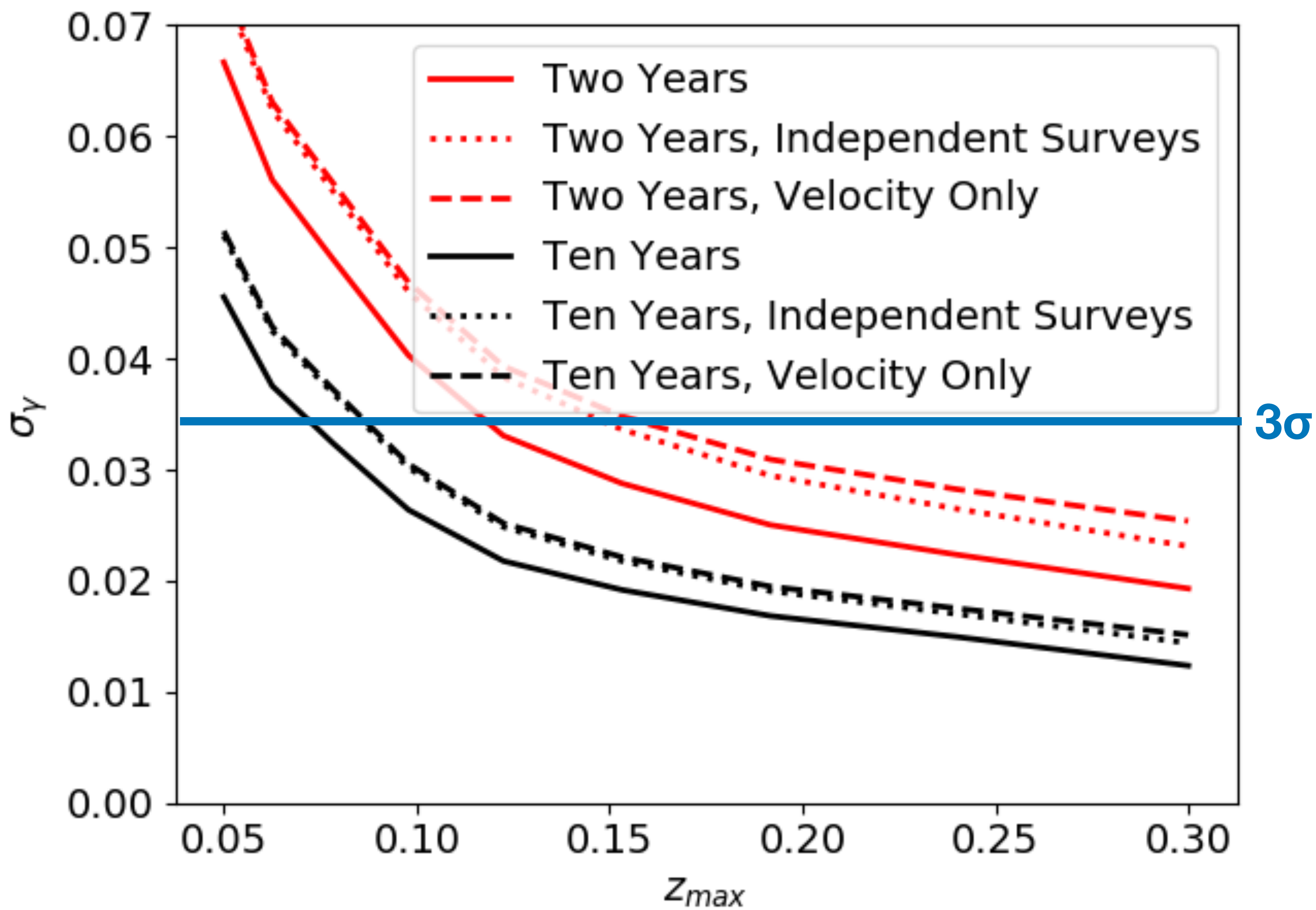
Growth rate depends on gravity. An excellent empirical parameterization is:

$$f = \Omega_M^\gamma$$

$$fD = \Omega_M^\gamma \exp\left(\int_a^1 \Omega_M^\gamma d \ln a\right)$$

General Relativity, $f(R)$, and DGP gravity predict values of the growth index of $\gamma = 0.55, 0.42, 0.68$

SN Ia Peculiar Velocity Surveys Will Precisely Measure γ



- Projected precision in γ for realistic surveys
- Moderately short, low-z SN Ia surveys can distinguish aforementioned gravity models to 3σ
- Type IIP also useful
- No other approaches I know of come close to comparable precision

Opportunities Beyond Nominal DESI Collaboration or Program

- Early sharing of spectra/data of DESI targets, DESI transient discoveries with “External Collaborators”
- Secondary science targets
    - Fiber overrides or free fibers
        - Y12 - No secondary targets
        - Y345 - Secondary targets
        - Table of targets per year
    - Non-DESI pointing and/or exposures
        - Y45 - “Pilot Studies” for DESI2

DESI the Instrument

- Mayall 4-m telescope at Kitt Peak in Arizona
- 8 square degree field-of-view
- 5000 fibers rapidly positioned by individual actuators
- Optical fibers feed 10 triple-arm high-throughput spectrographs
    - simultaneously covering 360–980 nm
    - R = 2000-5000 (blue - red)

Surveys and Targets

Survey	Object Class	# of Targets	Redshift Range
Bright Galaxy Survey (BGS)	Bright Galaxies r<19.5	20M	0<z<0.4
Bright Galaxy Survey (BGS)	Milky Way Stars	10M	N/A
Main	Luminious Red Galaxies	4.2M	0.4<z<1.0
Main	Emission Line Galaxies	18M	0.6<z<1.6
Main	Quasars	2.4M	0.5<z<3.5

14k deg sq

Preliminary Survey Strategy

Strategy document prepared by BGS WG over last few months.

- 14,000 deg^2, same imaging data used for dark time target selection
- Magnitude-limited, 2 tiers:
  - Priority 1: $r \leq 19.5$, 818 gal/deg^2 (11.4M over 14k deg^2)
  - Priority 2: $19.5 < r \leq 20.0$, 618 gal/deg^2 (8.7M over 14k deg^2)
  - Priority 3: Milky Way Stars
  - Priority 4: galaxies with redshift from previous pass
- Exposure times per pass are 300 secs under nominal conditions.
- Galaxies are reobserved until they yield a successful redshift.
- Two-tier strategy yields high completeness for brighter sample.
- Current tests with exposure time calculator imply 97% redshift completeness in 5-minute exposures to r = 19.5, 92% to r=20.
- Fiber assignment ("tiling") tests imply 92% fiber-assignment completeness for priority 1 targets, 77% for priority 2. Implies 17.2M galaxies over 14k deg^2

Executed during bright time (2.5x brighter than dark at 7200 Å)

Progression of BGS Observing Over 5-Years (Fiducial)

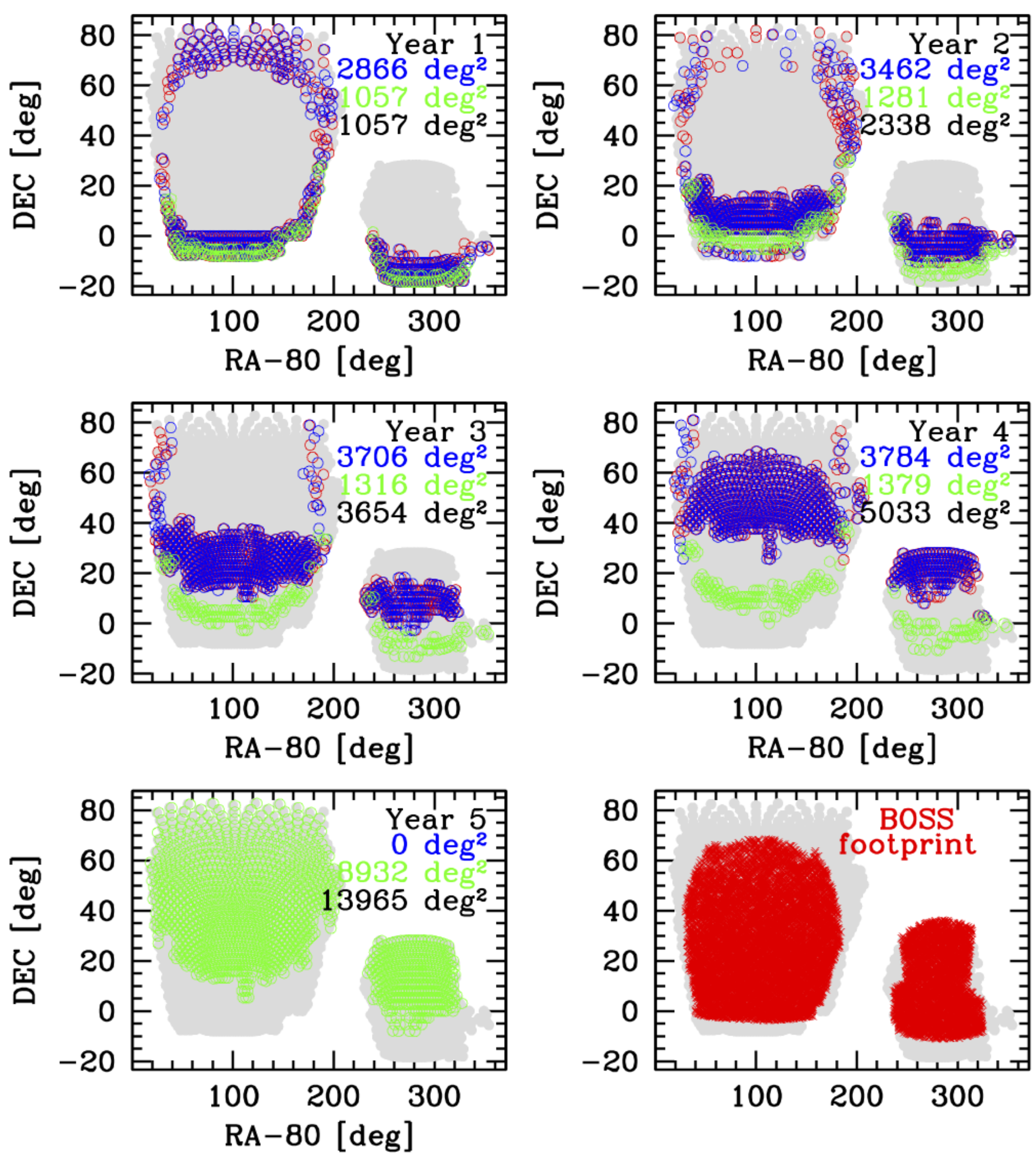


Figure 1: Year-to-year coverage of the fiducial strategy. Fields are color-coded by pass number: passes 1, 2, and 3 are red, blue and green, respectively. In each panel, the numbers in the upper right represent, from top to bottom, the 2-pass coverage in that year, the 3rd-pass coverage in that year, the total cumulative coverage is 3 passes. The lower right panel compares the DESI footprint to the BOSS footprint, which covers $\sim 10,000$ deg^2.

SNe Ia With a DESI BGS Redshift

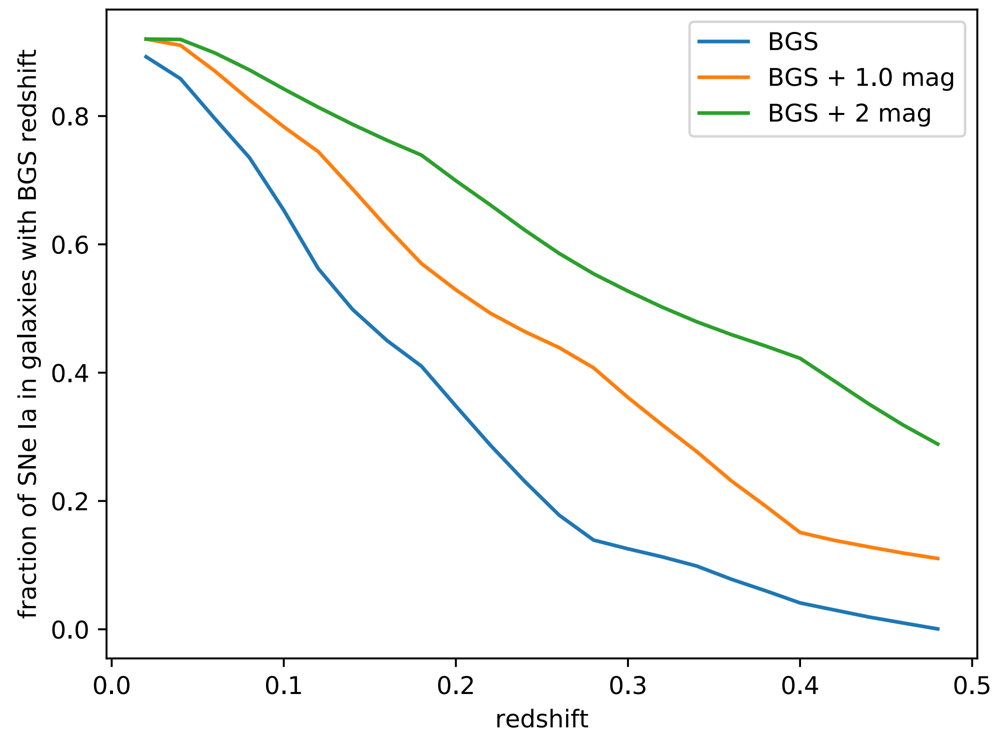


Figure 2: Fraction of supernovae in the DESI footprint that occur in a host galaxy with a successful DESI redshift from the BGS. Also shown are the fractions of supernovae that would occur in a host galaxy with a successful DESI redshift (now assuming 100% fiber-allocation efficiency) in observations 1 or 2 mag deeper than the nominal BGS exposure (Made with mock.py.)

- Vast majority of z<0.1 SN Ia hosts have successful BGS redshift

ZTF as large sample detection engine

- We can after 6+ months of operations *show*:
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- 1. The survey depth matches expectations
- **2. The number of SNe detected agrees with predictions, taking the spectroscopic survey depth into account**
- 3. 100% detection and alert efficiency
- 4. Have developed tools to work with LSST size transient samples
- 5. Photometric quality already at PTF level, can be improved
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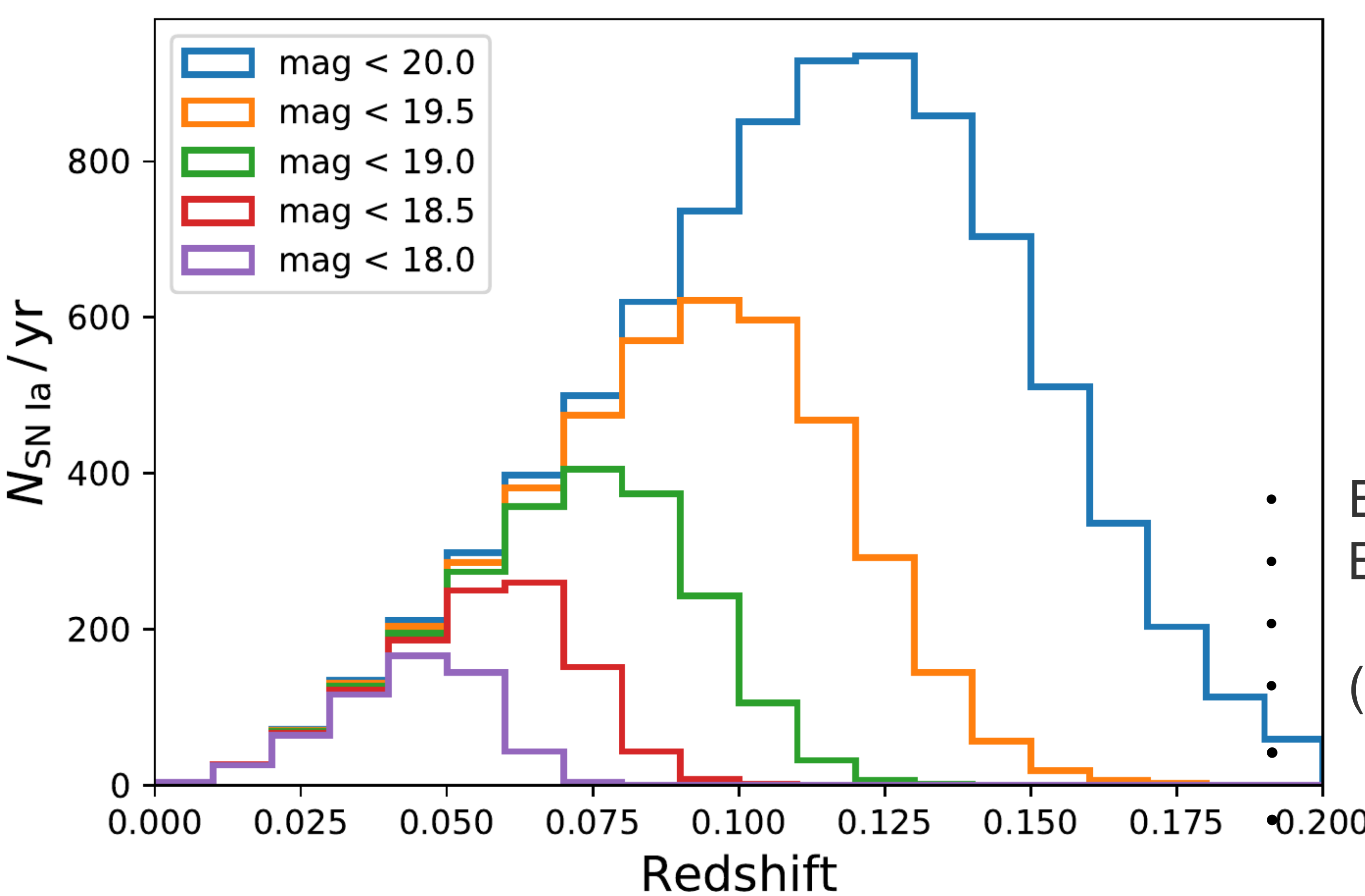

- Expected detected # SNe Ia / year
- Bright sample agrees with RCF
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- (Feindt, to be submitted)

Coordinated SN Ia Peculiar Velocity Program

- Necessary ingredients: SN Discovery, SN Typing (early and late), SN Distance (through multi-band light curves plus supplemental data), Host Galaxy Redshift

- ZTF+SED Machine contribute to the ingredient list
  - Transient discovery
  - Coarse host redshift
  - SN Ia typing
  - SN Ia distance

- DESI contributes to the ingredient list
  - Host-galaxy redshifts *before* discovery aid typing
  - Precise host-galaxy redshifts with <0.5% accuracy
  - SN typing of a subset of targets

Conclusions and Addenda

- Low-redshift SN peculiar velocity surveys a sensitive probe of gravity
  - Provides unmatched accuracy
  - Synergy with Redshift Space Distortion measurements at large z, together span the bump in fD as a function of redshift
  - High-z RSD sensitive to higher k-modes than low-z SNe so provides k-dependent test of gravity
- Cadenced wide-field imaging surveys plus spectroscopy necessary for success
  - DESI BGS survey plus potentially deeper survey powerful to get low-z host transient hosts
  - Spectrophotometry of the supernova will improve measurements drastically, we want to develop such a program