General Astrophysics Drivers for HabEx, part 2

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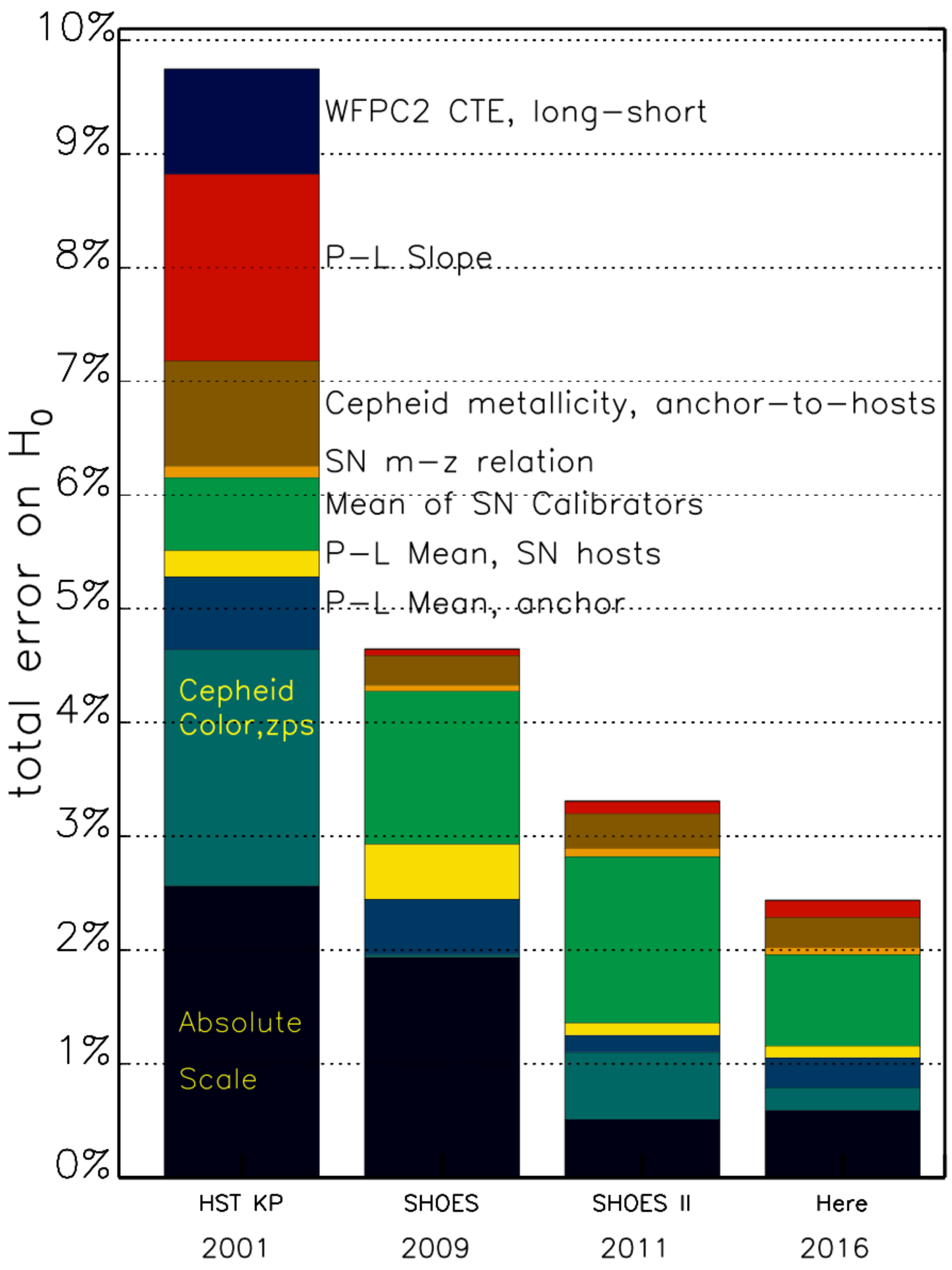
HabEx Face-2-Face
Pasadena

The Local Value of the Hubble Constant

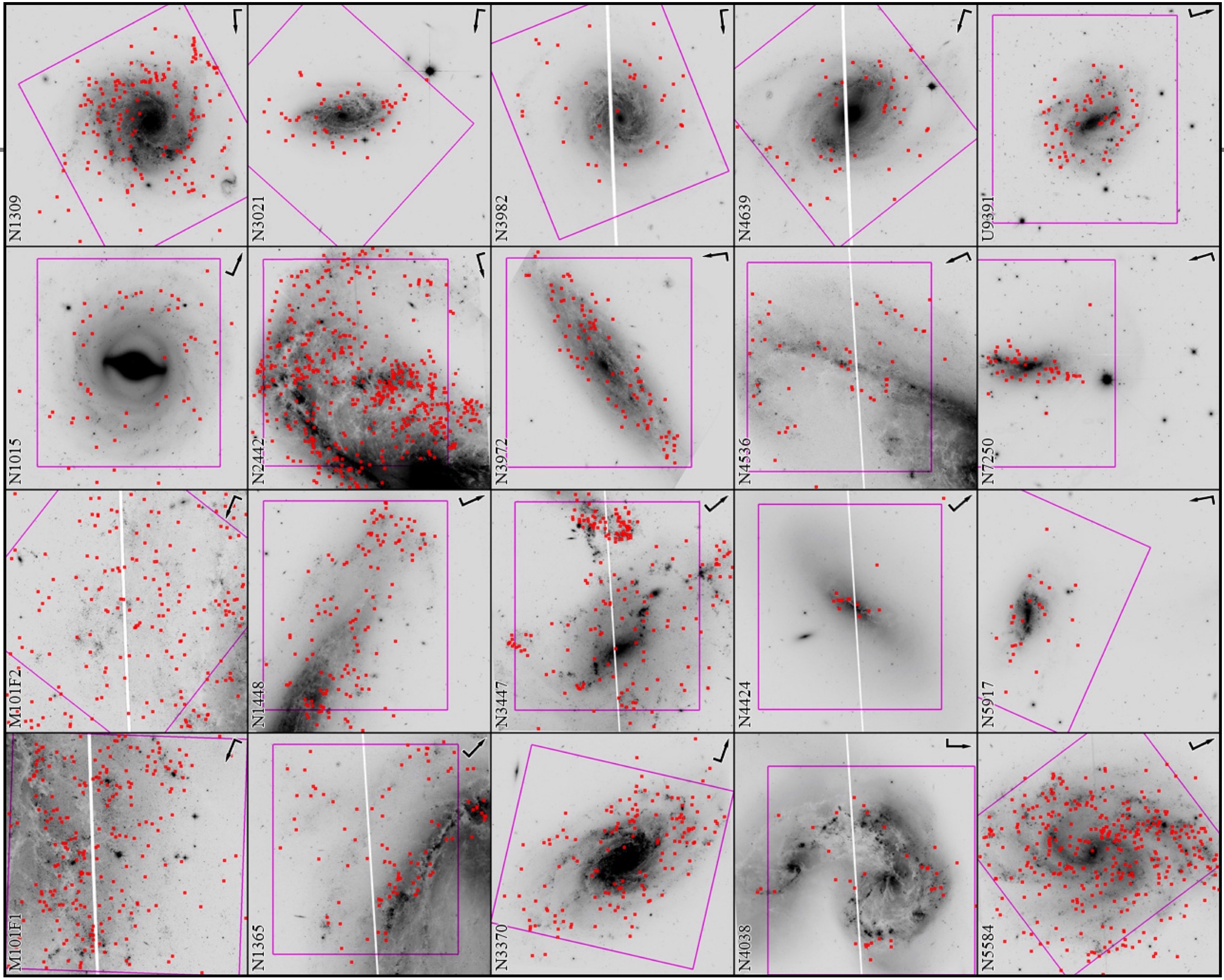


Riess et al. (2016; ApJ, **826**, 56):

- reports on a major *HST* program (SH0ES) that reduced the uncertainty on H_O from 3.3% to 2.4%
- most of the improvement comes from WFC3 near-IR (F160W) imaging of Cepheids in 11 nearby SNe Ia host galaxies (bringing total to 19)
- their best value is:

  H_O = 73.24 ± 1.74 km/s/Mpc
- 3.4-sigma higher than *Planck* value:

  H_O = 66.93 ± 0.62 km/s/Mpc
- just statistics? unknown systematics in *HST* or *Planck* programs? or, perhaps, new physics?



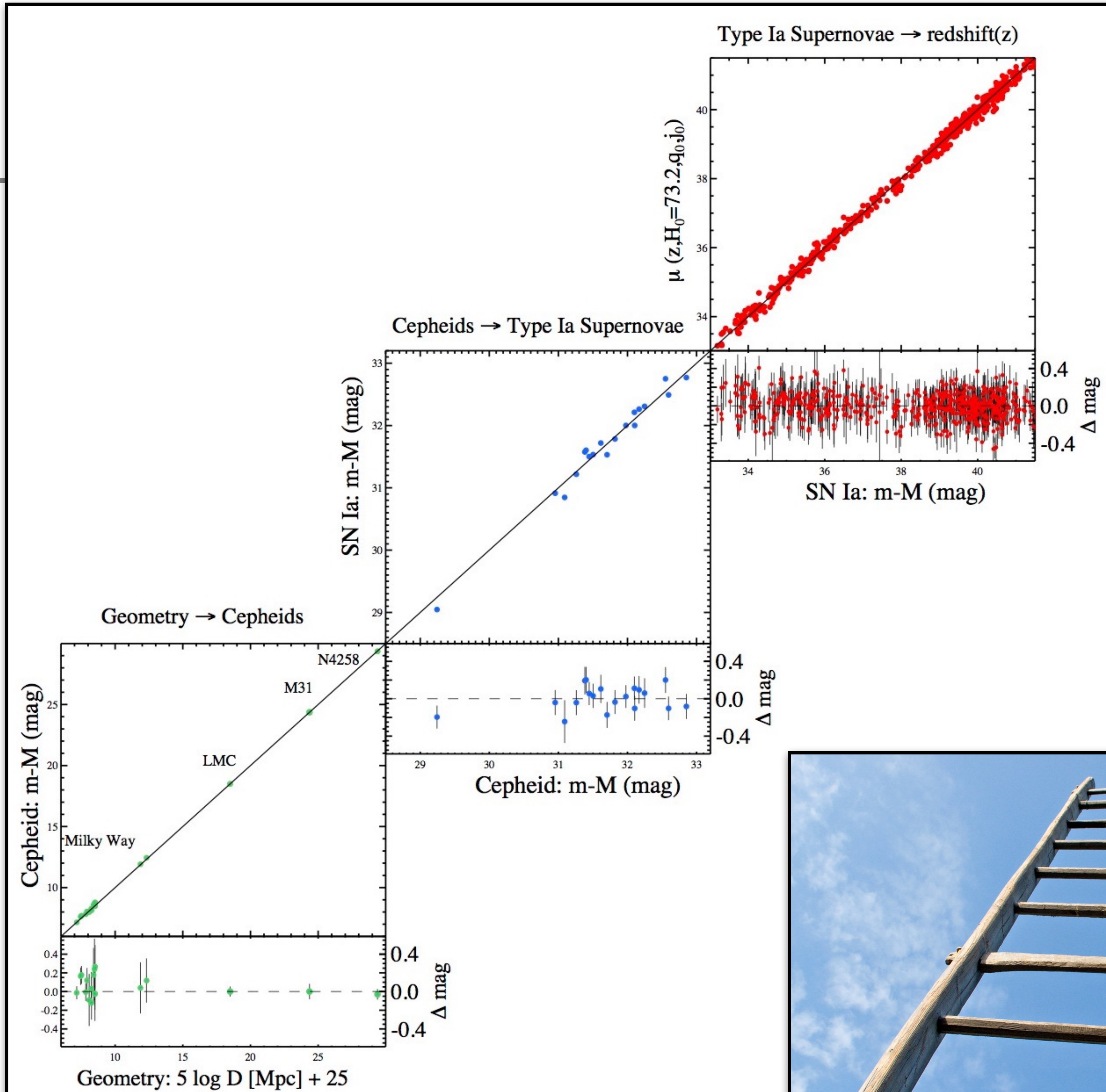
N1309
N3021
N3982
N4639
U9391
N1015
N2442
N3972
N4536
N7250
M101F2
N1448
N3447
N4424
N5917
M101F1
N1365
N3370
N4038
N5584

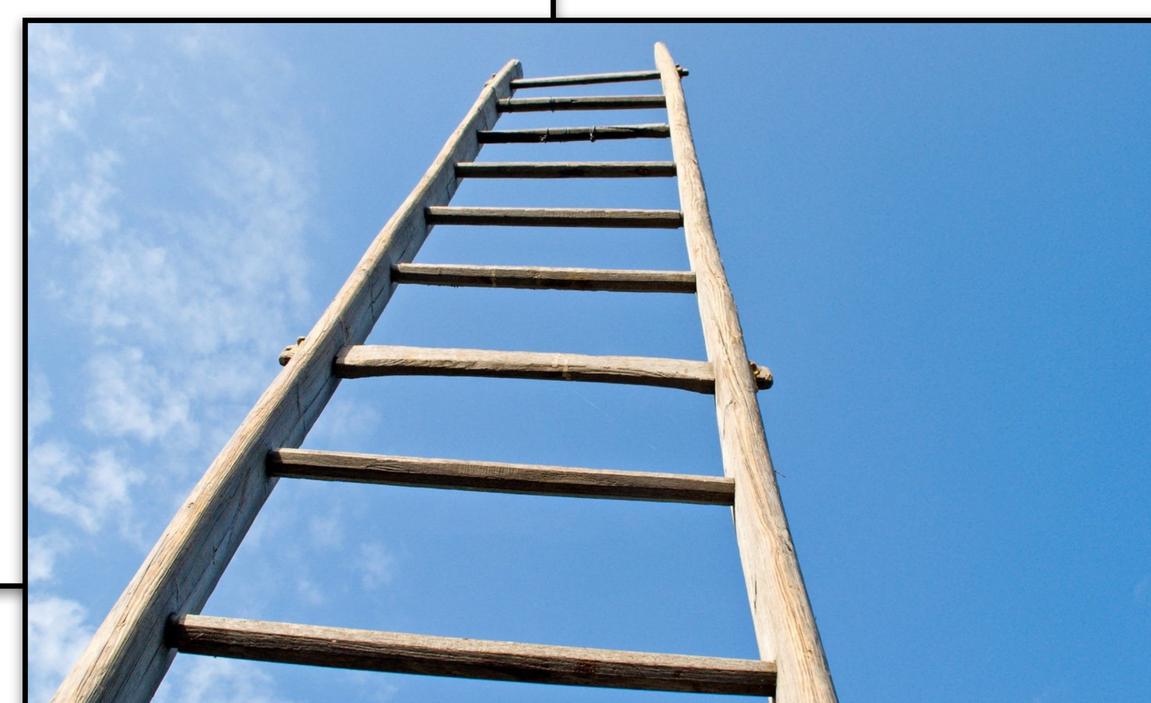
The Local Value of the Hubble Constant

Background

- CMB essentially probes the expansion rate early in the Universe, while nearby type Ia supernovae probe the local value
- we connect the two based on some assumed cosmology; tension between the values could point to new physics beyond the standard model, such as time-dependent or early dark energy, gravitational physics beyond General Relativity, additional relativistic particles (in the early universe), or non-zero curvature

- None of these theories "… has been excluded by anything more compelling than a theoretical preference for simplicity over complexity. In the case of dark energy, there is no simple explanation at present, leaving direct measurements as the only guide among numerous complex or highly tuned explanations."


Type Ia Supernovae → redshift(z)
μ (z,H0=73.2,q0,j0)
Cepheids → Type Ia Supernovae
SN Ia: m-M (mag)
Δ mag
SN Ia: m-M (mag)
Geometry → Cepheids
N4258
M31
LMC
Milky Way
Cepheid: m-M (mag)
Δ mag
Cepheid: m-M (mag)
Δ mag
Geometry: 5 log D [Mpc] + 25



The Local Value of the Hubble Constant

Step I: improved geometrical distances to nearby Cepheids

- previous work often used LMC Cepheids since distances were better measured than Milky Way Cepheids, but LMC Cepheids tend to be shorter period, lower metallicity, introducing additional systematic uncertainties
- trigonometric distances to larger sample of Milky Way Cepheids (by *HST*)
- larger sample of Cepheids in LMC
- improved distance to LMC based on detached eclipsing binaries (DEBs)
- *HST* observations of Cepheids in M31
- 33% reduction in systematic uncertainty of the maser distance to NGC 4258
- infrared Cepheid observations minimize some of the metallicity systematics, as compared to previous optical Cepheid studies

Step II: improved calibration of SN Ia using Cepheids

- previously just 8 local galaxies that hosted modern SN Ia with *HST* Cepheid measurements; now 19

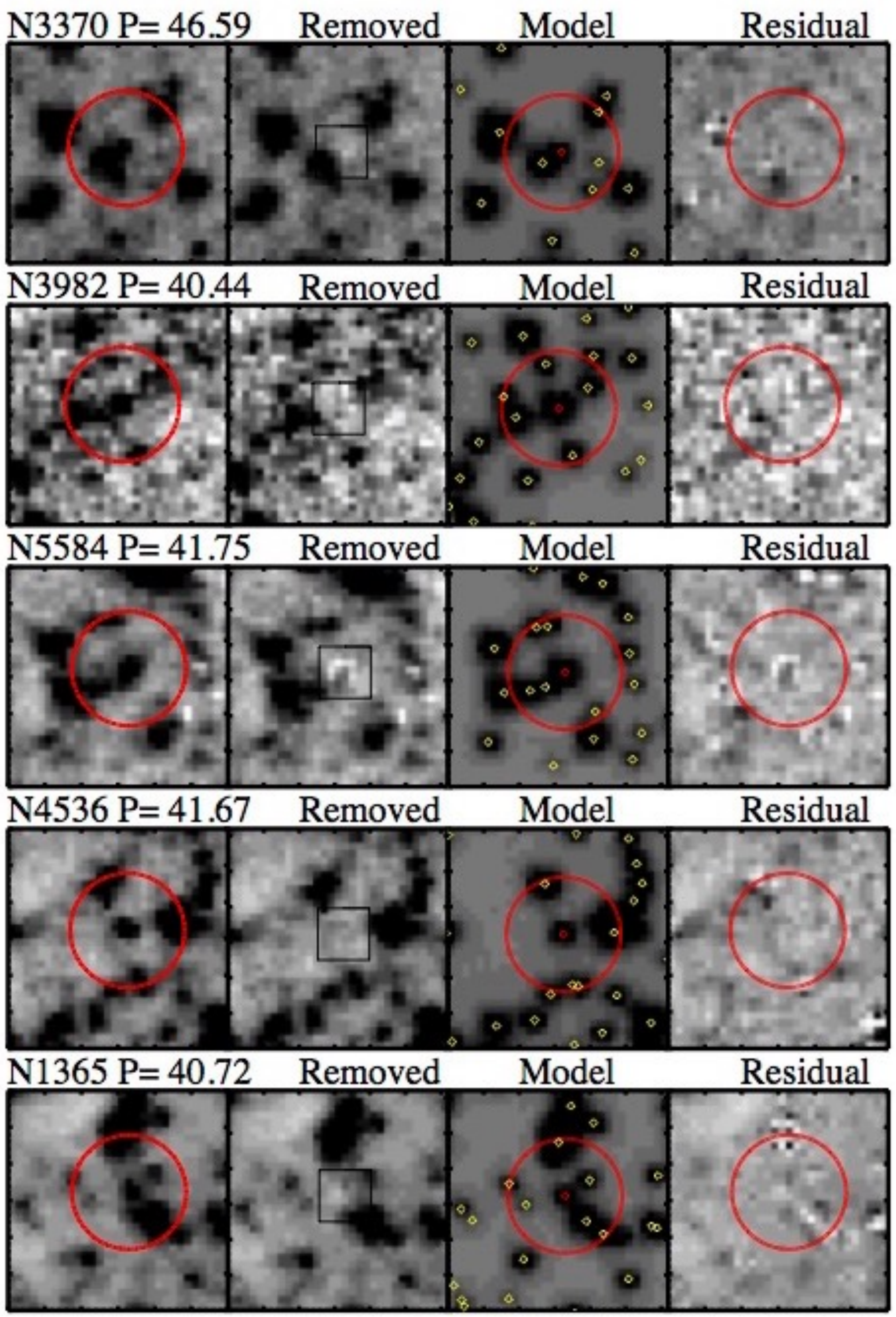
Step III: larger sample of SN Ia at cosmological distances

The Local Value of the Hubble Constant

The Role of Hubble

- precision cosmology requires exacting control of systematics: pushes you to CCD observations from space
- also pushes you to using the same instrument for all measurements
- white-light filter (F350LP) important for efficient identification of Cepheids
- wider FoV of WFC important for identifying more Cepheids per pointing
- near-IR better than optical for measuring the Cepheids: increased robustness to systematic uncertainties (e.g., metallicity effects) and reduced impact from extinction — this more than compensates for the decreased resolution and larger statistical uncertainties

The Local Value of the Hubble Constant



The Role of HabEx

- only ~1 new local SN Ia host identified per year which is amenable to *HST* Cepheid studies; can't expect much improvement over Riess et al. (2016) in the remaining lifetime of *HST*
- small FoV of *JWST* (and lack of broad optical channel) suboptimal for this work
- likewise, *Euclid*/*WFIRST* have same resolution as *HST* (at best), so offer no gains
- even a 4-meter *HabEx* would roughly triple the number of galaxies hosting SNe Ia amenable to Cepheid calibration, and improve the measurements in current SH0ES sample (i.e., reduce uncertainties due to blending)
- perhaps push to RR Lyrae or tip of the red giant branch (TRGB) for early-type hosts?

The Local Value of the Hubble Constant

Concerns

- How much progress possible before *HabEx* — i.e., with *GAIA*-based Cepheid calibrations locally, and/or a dedicated *JWST* program?
- Can ground-based observations, e.g. with ELT's, make progress? [I doubt it.]
- What if additional systematics in local and/or CMB results are identified in next few years, eliminating/diminishing the discrepancy?

Next Steps

- Contact Adam Riess for input if we think this is a potential strong case?
- Simulations?

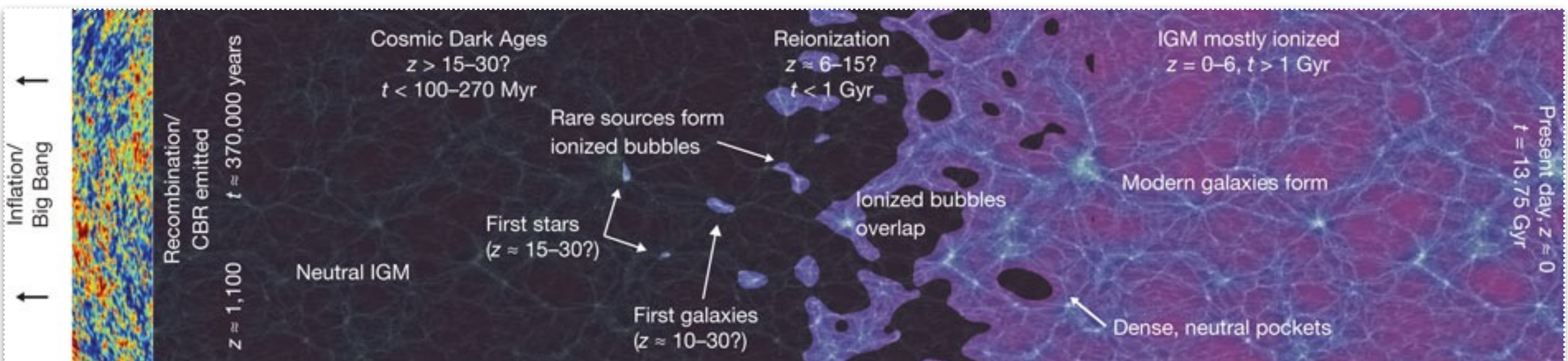
Desired HabEx Capabilities

- Broad optical filter w/ diffraction-limited FoV comparable to typical host galaxy sizes for reconnaissance of Cepheids
- near-IR filter w/ diffraction-limited FoV comparable to typical host galaxy sizes for measuring Cepheid fluxes

Galaxy Leakiness and Reionization

Background

- After CMB, reionization of the universe is the most important cosmic phase change, marking the end of the Dark Ages
- Current work strongly implicates star-forming galaxies, not AGN, for dominating reionization, but major uncertainties remain as to the UV flux (<912 Å) that leaks out of young, star-forming galaxies — i.e., the escape fraction, f_{esc}



Galaxy Leakiness and Reionization

Main Questions

- How is reionization initiated and sustained?
- What are the relative contributions of star-forming galaxies and AGN to the ionizing background over cosmic time (i.e., not just for reionization at z~6)?
- How does f_{esc} evolve with redshift?
- How does f_{esc} vary with metallicity?
- What local and global physics drive f_{esc}?
- Are there local analogs to the reionization sources?

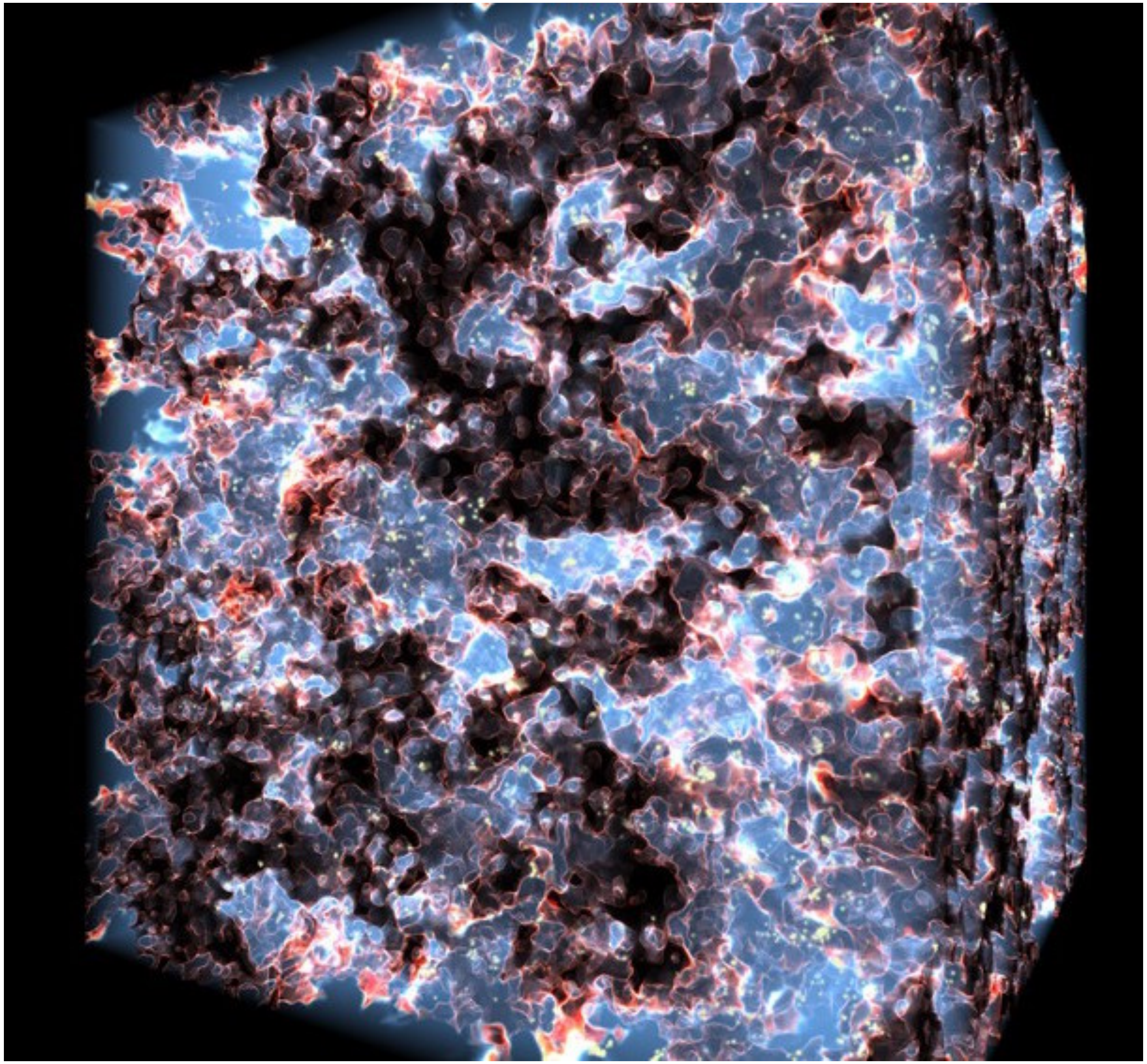
Measurement Requirements

- Need to probe to (redshifted) Lyman limit
- Can't be done at z>3.5 due to opacity of IGM
- Not something that *JWST*, *Euclid*/*WFIRST*, ELTs, or LSST will solve — points to UV capabilities (but see concerns on later page)

Galaxy Leakiness and Reionization

Current State of the Field

- Most galaxies have non-detections, implying f_{esc} less than a few percent
- However, a small fraction of galaxies have escape fractions of 20-30%
- Theory predicts higher escape fractions for smaller haloes



Galaxy Leakiness and Reionization

Concerns

- Cosmic redshifts *do* help: can do some of this work from ELTs at z~3 — but can you push sufficiently down the galaxy luminosity function? Relatedly, what redshift offers the best opportunity to find Pop III galaxy analogs?

Next Steps

- Several strong groups working/worked on this problem (e.g., Finkelstein, McClandiss, Malhotra/Rhoads, Scarlata/Siana/Teplitz). Could solicit input?

Desired HabEx Capabilities

- coverage down to Lyman limit (912 Å), ideally — but can also let cosmic redshifts help out
- *R*~200 spectroscopy (slitless grism w/ a filter?)
- need aperture sufficient to measure 1% escape fractions — but can integrate longer too

Next Steps

Brainstorming other ideas

- High-resolution AGN studies: directly study the torus with AO + measure black hole masses with resolved kinematics
- Weak-lensing studies: e.g., substructure in galaxy clusters — 4m in space should beat *Euclid*, *WFIRST*, and ground-based MCAO on ELTs
- Strong-lensing studies: precision modeling requires space?

Next steps?

- Keep brainstorming other ideas — send notes to the Graces if you attend an interesting talk….
- Engage experts for most promising killer apps
  - how many killer apps for report?
  - coordinate with LUVOIR for some of these?

Backup Slides