Dark Energy Summary
Physics of the Cosmos
Program Analysis Group

Jason Rhodes
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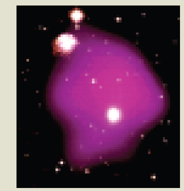
Understanding cosmic acceleration

Cosmic acceleration = a modification of Einstein's equations

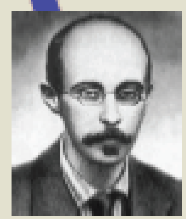
Deviations from GR?

$$G_{\mu\nu} = 8\pi G T_{\mu\nu}$$



New matter? interactions?

Λ?



Inhomogeneous universe?

Broad aim =Phenomenology
Distinguish which sector: new gravity, new matter or Λ?

Ambitious aim = Theoretical model
Learn something more about the underlying theory?

Concluding thoughts

- Invaluable opportunity to test the origins of cosmic acceleration and weak field gravity on cosmic scales
  - Theoretical developments, fast evolving.
  - General effective field theory for DE a useful phenomenological approach, with interesting implications for both expansion history and growth history
- Multiple, complementary astrophysical tracers key to finding DE origin
  - geometric techniques important record of expansion history
  - relativistic & non-relativistic LSS tracers distinguish gravity's properties
  - Surveys will give us information across z and from horizon to sub-halo scales
- Honest assessment of systematics essential
  - Theory and systematics can be tightly coupled.
  - Can significantly impact predictions (beware apples vs oranges)
  - Survey and algorithm development + x-corr key to mitigate these.
- FoMs useful but a high pass filter on data. Mapping to the underlying theory is the ultimate goal.

From Paul Schechter

1. Euclid is a dark energy mission. ✓

2. WFIRST is not a dark energy mission. ?

3. WFIRST is nonetheless a better dark energy mission than Euclid. ✗

4. WFIRST will also do many other things. ✓

Euclid

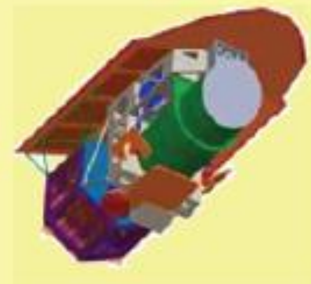
- Advantages
  - Large sky coverage
  - Lots of galaxies – $N_{\mathrm{gal,eff}} = 1.8\times10^9$
    - Past Fisher studies found total $N_{\mathrm{gal,eff}}$ ($=n_{\mathrm{eff}}A$) as the most important term
  - Highest resolution
  - PSF from space platform with small number of dynamic DOFs
- Disadvantages
  - Constructs only 1 shear map
    - No cross correlations, or comparison of auto correlations
    - Euclid × (anything else) does not provide check of multiplicative biases
    - Color corrections are large and have to be treated statistically
  - Low redundancy in observing strategy
    - Expect ~40% of galaxies to be "lost" to cosmic rays (get ≤2 clean exposures)
    - Lack of roll, small step dither are not ideal for internal calibration
  - Charge transfer inefficiency (generic space CCD issue)

WFIRST

- Advantages
  - 3 high resolution shape filters
    - Enables a suite of cross checks (auto vs cross, etc)
    - Color corrections implementable on every galaxy
  - Redundant passes within each filter
    - Enable internal null tests and embed relative calibration measurements in the science data itself
  - Unobstructed telescope
    - Simpler, more compact, less chromatic PSF – e.g. no diffraction spikes
    - Enables small PSF in NIR where galaxies are bright
  - PSF from space platform with small number of dynamic DOFs
- Disadvantages
  - Small area – only 3400 deg^2 (DRM1) or 2400 deg^2 (DRM2)
    - Extended missions could mitigate this
  - HgCdTe detectors exhibit unique effects
    - e.g. persistence, interpixel capacitance, rate dependent nonlinearity

Design Reference Mission Options

- ❑ **IDRM**
  - 1.3 meter off-axis telescope
  - 3-channel payload
  - 5 year mission
  - Atlas V Launch Vehicle



- ❑ **DRM1**
  - 1.3 meter off-axis telescope
  - Single channel payload
  - 5 year mission
  - Atlas V Launch Vehicle

- ❑ **DRM2**
  - 1.1 meter off-axis telescope
  - Single channel payload
  - 3 year mission
  - Falcon 9 Launch Vehicle

From Neil Gehrels

Conclusion

- The SDT and Project have completed the action of developing two compelling mission concepts.
- DRM1: Fully responsive to the objectives of NWNH at reduced cost
- DRM2: Capable low-cost near-infrared survey opportunity. The limited 3 year life precludes full compliance with NWNH goals.
- Recommended path forward:
  - Refine the innovations developed in DRM2 into a “DRM1-like” mission concept; determine whether performance of this new concept can be fully responsive to NWNH.
  - Urgent need to develop 4kx4k IR detectors for wide-field applications

Where might we be near the end of DRM1?

(Including DES, Subaru HSC/PFS, BigBOSS, Euclid, LSST)

- Errors 10× smaller, still consistent with ΛCDM
  $1+w = 0 \pm 0.01$ instead of 0 ± 0.1, more robust conclusion

- Hints of significant departure from ΛCDM, in expansion history or structure growth or both.

- Clear discrepancy with ΛCDM, more and better data needed to understand it.

At least in the second or third scenario, we will want to do more, and the details of what we will want to do will depend on what has been found.

From David Weinberg

Stray thoughts on NRO as WFIRST

Relative to the SDT designs, an NRO 2.4-m implementation of WFIRST would likely have:

- Larger aperture and étendue
- Higher angular resolution
- Bluer wavelength cutoff
- Uglier PSF

WL: Better statistics. Key issue is PSF control/correction.

BAO/RSD: Should be more efficient at covering large volume; loses the high redshift range of SDT DRMs, so less complementary to Euclid, but much better sampling. Net win.

SN: Probably less good because systematics get better in rest-frame IR. Might regain this ground with IFU spectroscopy and spectrophotometry, better matching of spectroscopic cohorts.

My view: Whichever implementation is more likely to happen, or to happen sooner, is the better one.

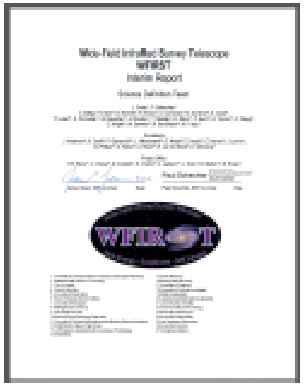
Manifest destiny

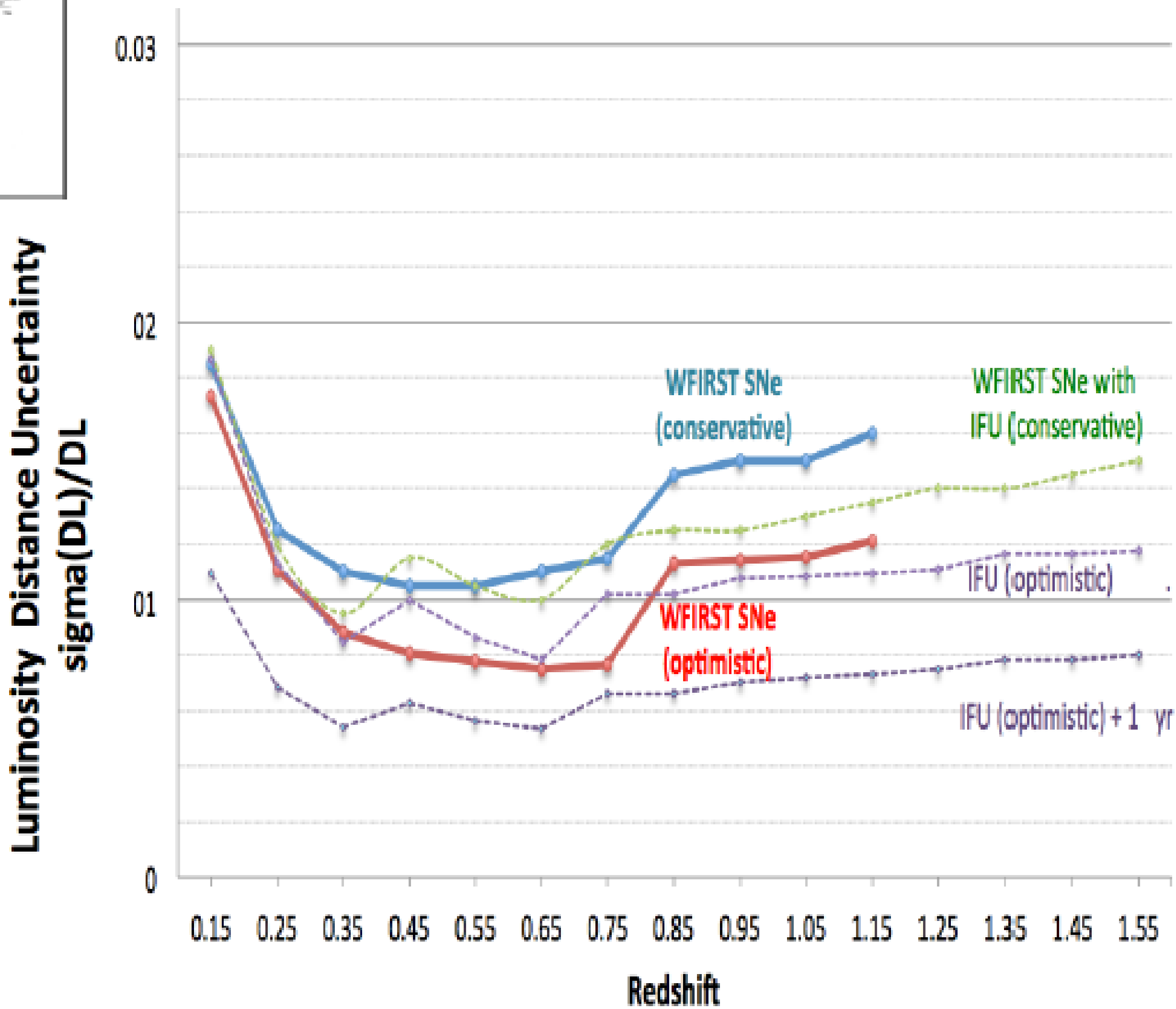
The solution to the cosmic acceleration puzzle could be around the corner, or it could be decades away, or more.

A crucial part of the rationale for studying cosmic acceleration is that the data sets needed to do so are rich, supporting a wide range of astronomical discovery.

These data sets fall within the “manifest destiny” of astronomy: to map the observable universe with the greatest achievable sensitivity and resolution.

When a major next step on this path is feasible (technologically, financially), it makes sense to take it.

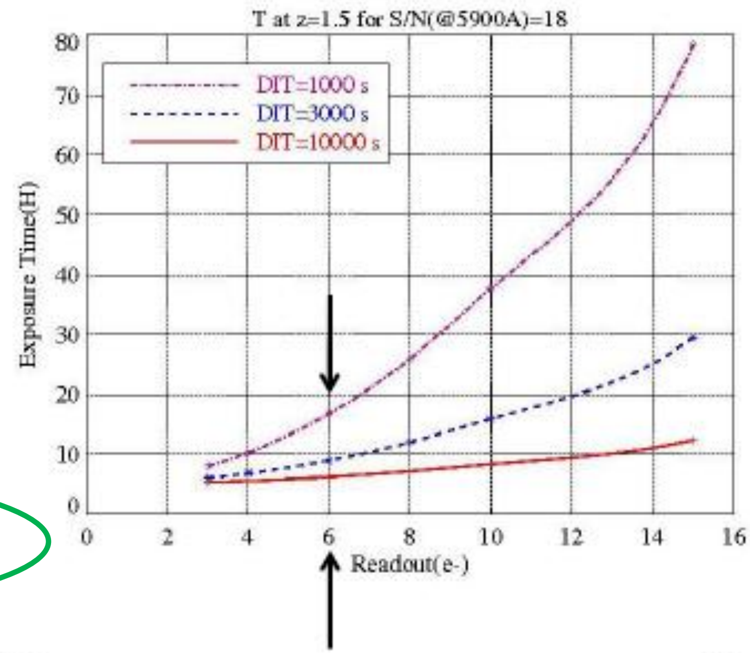




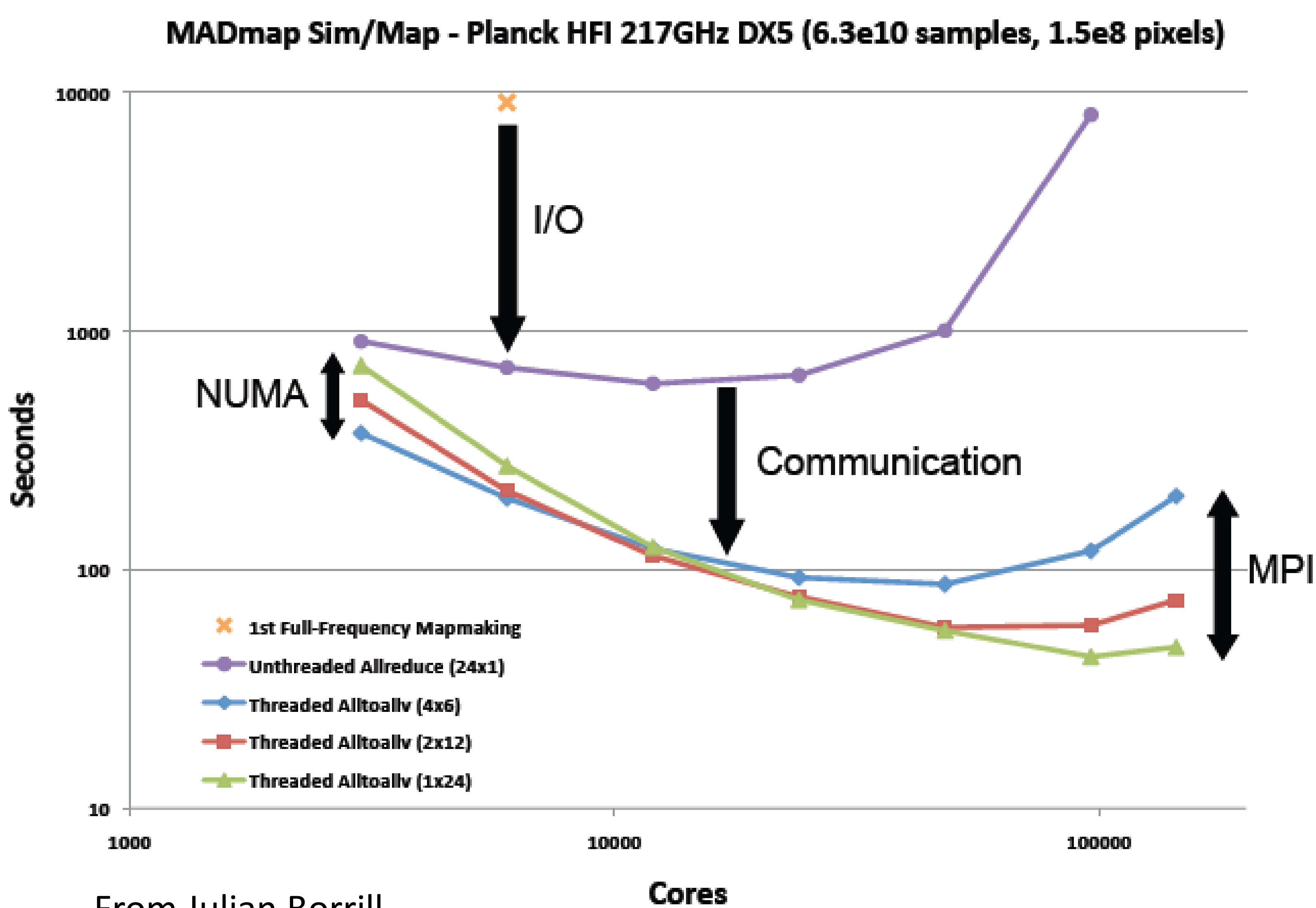
From Greg Aldering

Technology Needs

- Detector critical – especially if aperture or throughput drops
- Simulations assume 6 e-, but can probably do better
- Need to worry about tiny offsets that add across many SNe
  - For grism this could come from contaminating spectra, zodi spectral changes, flatfield or reference
  - For IFS this could come from dark current or electronics
- Stable electronics important
- Stable darks important
- IFS requires just one, but very good, detector



Example – Monte Carlo SimMap



From Julian Borrill

Conclusions

Understand your data challenge:

- Know the scaling and efficiency of your algorithm and its implementation, both in theory and practice.
- Make *informed* algorithm/science trade-offs
  - often implementation is the issue
  - Moore's Law is your friend!
- Remember that the computational challenge is dynamic
  - implementations evolve with the scale and balance of each new generation/class of HPC system.
- Don't shoot yourself in the foot!
  - build in data efficiency from the outset.
- Find the resources for the problem, not the problem for the resources.

Technology Needs

- Highest priority is H4RG-10 for WFIRST (NRO, DRM2)
  - SAT call insufficient to develop and retire risks
    - ~$5M per year needed
  - Directed funding is necessary
  - Will reduce *overall* cost of WFIRST
  - Needs for an IFU must be defined
- Calibration is key, especially for SN
  - ACCESS sounding rocket is a start, but a concerted effort is needed

NRO Telescopes for WFIRST

- Need studies for trade-offs
- Must understand *scientific* pros and cons
- Also want to define *new* science enabled
- Such studies are being planned by HQ