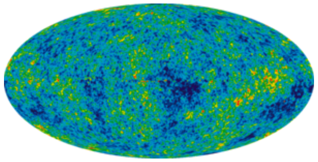
Concluding Remarks

David Spergel

Galaxies and Memory

- Schwarzschild's Halley lecture at the University Museum at Oxford in 1983
- Do the properties of galaxies reflect initial conditions or dynamics?



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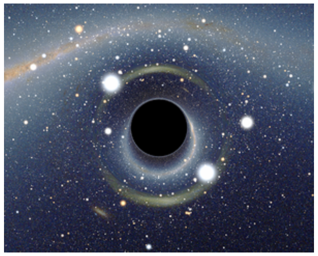
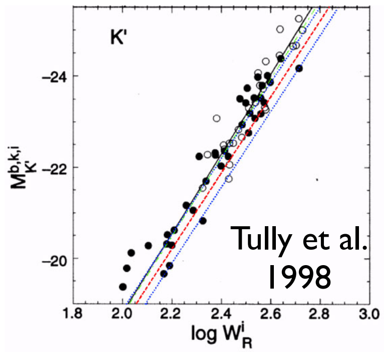
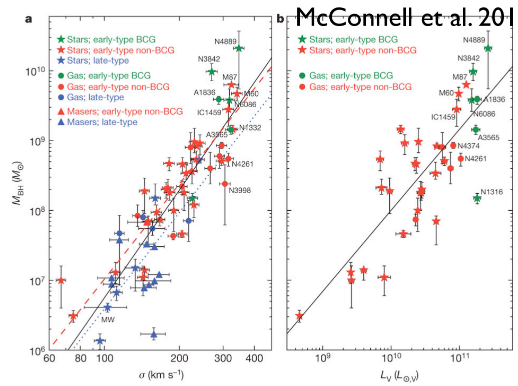


External Galaxies seem to be simple systems





M,J determine their basic properties

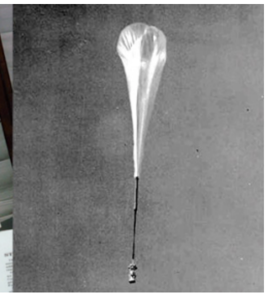
What determines the properties of M31?

M31 as a Laboratory for Understanding the Microphysics of Galaxy Evolution

- Stars (particularly, later stages of stellar evolution)
- Galaxy mergers and interactions
  - tidal stellar streams, extended HI structures,LG
  - M31 as a non-equilibrium system?
- Interactions between stars and the IGM
  - Wealth of multi-wavelength data: radio to X-ray tracing the multi-phase nature of the IGM
  - Why is the X-ray gas so cold?
  - Role of old stars in heating grains, energy injection
  - Can we do a proper accounting of the energy and mass flows in M31?
  - Globular clusters

NEW Telescopes:

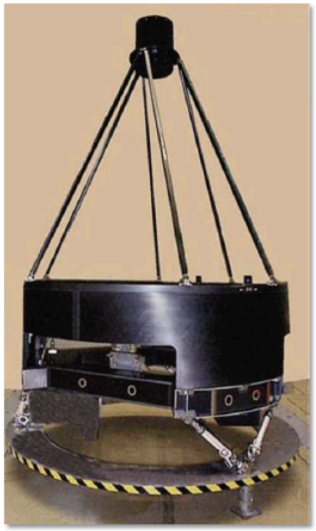
What are they?
What would Martin tell us to do?

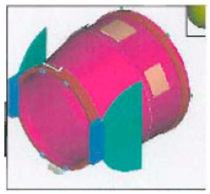
History

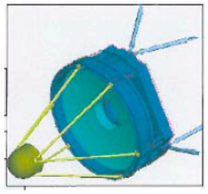
- 2 2.4 meter telescopes + 1 2.4 meter mirror
- "Residual space hardware" from Future Imagery Architecture, failed program cancelled in 2005
- Been in storage ~10 years
- NASA HQ learned of their availability about 18 months ago.

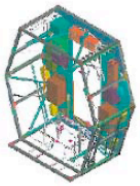
- Two 2.4-m telescopes have been transferred to NASA:
  - Designed as a TMA system but tertiary mirror is not applicable for science mission
  - Primary mirror is f/1.2, on-axis system
  - Compact design is similar to the dynamic test unit shown here
  - Thermal control heaters are already on the shell
  - 6 struts position the secondary mirror
    - 6 actuators at the base of the SM struts
    - 1 focus actuator on the SMA for fine focus
  - Long struts to spacecraft bus provide approximately 1.5m of available space for aft optics, instruments, etc.



- 2+ sets of space qualified telescope hardware:
  - 2.4m, f/8 with < 20% Obstructed Aperture
  - Field of View: 1.8 degrees unvignetted [error corrected on 6/7/12]
  - Wavefront Quality: < 60 nm rms
  - Stable, f/1.2, Lightweight ULE Primary Mirror
  - Stable, Low CTE Composite and Invar Structures
  - Actuated Secondary Mirror Positioning
  - 1,700 kg mass, including Telescope and Outer Thermal Barrel
- Our early looks indicate this hardware could enable many of the goals from the NWNH Report


Outer Barrel Assembly


Fore Optics Assembly

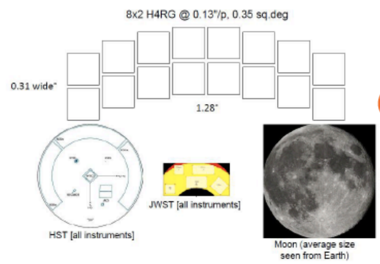

Payload Radiator Subsystem

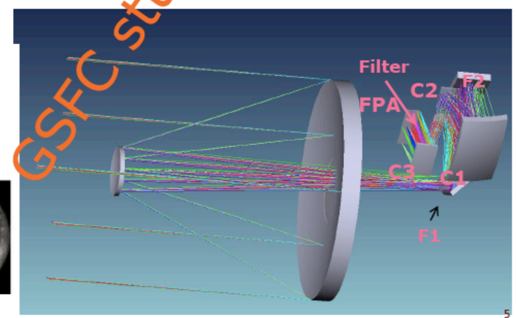
Preliminary Instrument Design:

- Based on existing telescope primary and secondary mirrors without changes
- Initial wide-field instrument shown; 2nd wide-field instrument would be a mirror image
  - 3 mirror camera, folded, with filter at pupil
- Filter & prism wheels (not shown) in ea. wide field instrument
- Fits within instrument volume implied by existing struts

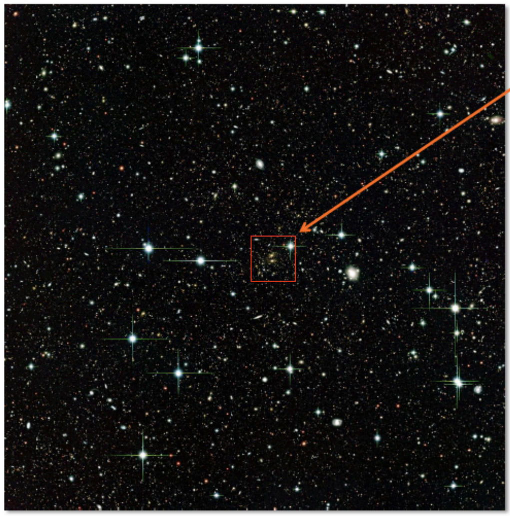
Potential Payload Overview:

- 2 wide field instruments
- 2 small, finer sampled instruments

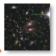




100x the Area as HST's WFC3/IR cam



0.25 sq deg FOV



HST WFC3/IR FOV

Existing telescope has a 2.4-m f/1.2 primary with a 9% obscuration secondary that produces a 1/20 wave near-IR optical system at about f/8 <u>assembled and tested.</u>

A preliminary 3-mirror design uses 16 Hawaii 4RG HgCdTe IR-detectors (10μm pixels) to cover 0.25 sq deg at 0.11"/pixel, compared to this telescope's 0.15" diffraction limit at 1.5μm

This is slightly better sampling than the SDT 1.5-m WFIRST with 0.18" pixels for a 0.24" diffraction limit.

One WFIRST/NEW pointing

Chris Hirata: Extragalactic Survey Programs – Imaging (Weak Lensing) and Redshift (BAO) -- with the 2-4m NRO-1 telescope

<u>Assumptions:</u>

- 2.4-m, obstructed, with mask at real exit pupil
- H4RG detectors @ 0.0975”/p (1 pix = 10 μm)
  - Same sampling relative to the diffraction spot as WFIRST-DRM1.
  - Assumed that a read noise of 20 e/CDS (with 5 e floor) reached for the mature devices.
- Area = 0.25 deg^2 --- this is 20 detectors. ← COULD DOUBLE THIS!
- Fore optics @ 250 K
- 4 filters for survey mode (F105/F129/F159/F194), similar to 2012 WFIRST DRM.
  - But with λ_{max} = 2.175 μm (where it gets painful).
  - Compare to red cutoff of 2.0 μm (WFIRST 2011 IDRM) or 2.4 μm (current WFIRST).
- Copied the WFIRST DRM1 observing sequence, but with longer exposures for the imaging mode (270 s) to get below the read noise at the lower frame rate.
- This is only a preliminary sensitivity calculation – would need a serious study to understand the issues involved.

Chris Hirata: (cont.)

Increasing complementarity with EUCLID

Summary: Extragalactic Surveys

	WFIRST DRM1	WFIRST DRM2	Big Telescope
Implementation	1.3 m unobs 36 H2RG 0.18″/p	1.1 m unobs 14 H4RG 0.18″/p	2.4 m obs 20 H4RG 0.0975″/p
Imaging Survey* [4 filters for all; depths are 5σ isolated pt src]	0.92—2.40 μm 26.0—26.2 mag AB 2800 deg^2/yr EE50 = 0.15—0.21″	0.92—2.40 μm 25.8—26.0 mag AB 2900 deg^2/yr EE50 = 0.18—0.25″	0.92—2.17 μm 26.9—27.3 mag AB 1080 deg^2/yr EE50 = 0.11—0.14″
Weak Lensing [reddest 3 filters]	30, 33, 32 gal/am^2	24, 26, 25 gal/am^2	79, 82, 72 gal/am^2
Redshift Survey [≥7σ Hα detections]	z = 1.28—2.66 4900 gal/deg^2 2900 deg^2/yr	z = 1.59—2.66 2900 gal/deg2 4400 deg^2/yr	z = 1.13 – 2.20 4900 gal/deg^2 4000 deg^2/yr

* The big telescope could in principle support an accelerated imaging mode matching the WFIRST DRM1 survey rate of 2800 deg^2/yr. This reaches depth of 25.8—26.0 mag AB and 26/31/32 galaxies per $arcmin^2$. This survey is heavily read noise limited (90 s exposures) so may not be the best use of a big telescope.

How do we use them?

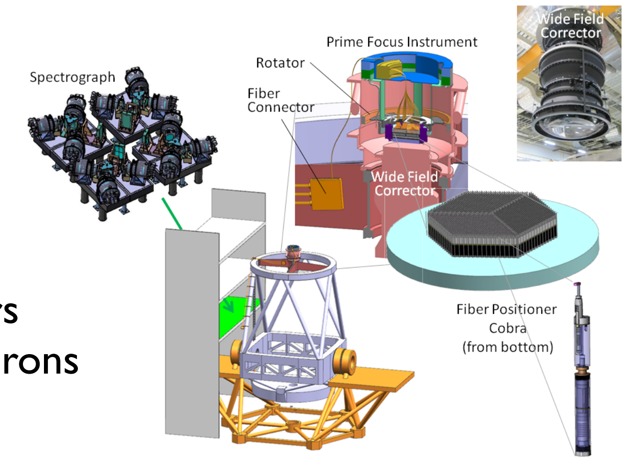
- Telescope 1: WFIRST
  - Faster, better, and possibly, cheaper
  - Keep it simple! IR camera, no bells and whistles
  - Don’t modify the telescope! (Operate at 250 K)
  - WFIRST = dark energy science + infrared sky survey + microlensing

Decade of the “Great Surveys”

- Building on SDSS, (and now DES, KIDS, HSC, etc), we are about to enter the epoch of the “Great Surveys”
- Euclid + WFIRST/NEW surveys at space resolutions
- LSST
- Prime Focus Spectrograph

Prime Focus Spectrograph

- 2400 fibers
- 0.38 - 1.3 microns
- R/3000



- http://sumire.ipmu.jp/pfs/index.html

Telescope 2

- Opportunity to be clever (develop compelling ideas and technologies for the next decadal survey)
- UV? Exoplanet imager?
- Precursor to 8 meter class telescopes

Coronagraphy with the NRO-1 2.40-m Telescope

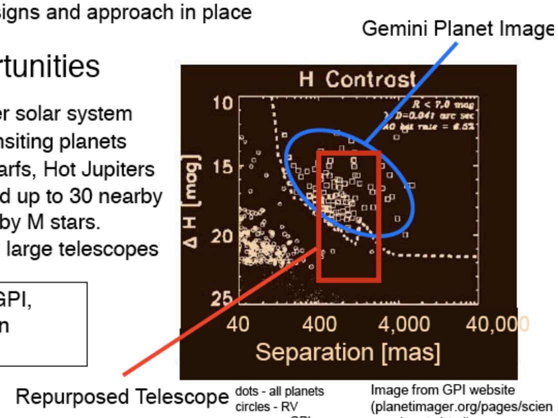
Recent advances allow high-contrast imaging at small angles with on-axis telescopes

- Uncorrected contrast of up to 10^{-5}, Corrected (with DM) to 10^{-8} or better
- Corrected contrast limited by telescope stability
- Another order of magnitude possible via post-processing
- Inner working angles from 2.5-3 λ/D depending on contrast
- Experimental verification of designs and approach in place

Rich Scientific Opportunities

- Exozodi characterization at inner solar system
- Characterization of RV and Transiting planets
- Protoplanetary disks, brown dwarfs, Hot Jupiters
- Explores habitable zones around up to 30 nearby GFK stars and many more nearby M stars.
- Technology pathfinder for future large telescopes

Compliments ground systems (GPI, SPHERE, Subaru) – Observes in unexplored search space.



dots - all planets
circles - RV
squares - GPI

Image from GPI website (planetimager.org/pages/science_planets.html)

Thanks to Tod Lauer, Keren Fedida and all of the participants!

Thanks to Martin!