Pathfinder Technologies in the Post-HST Era

Charles L. Joseph, Rutgers University

Abstract

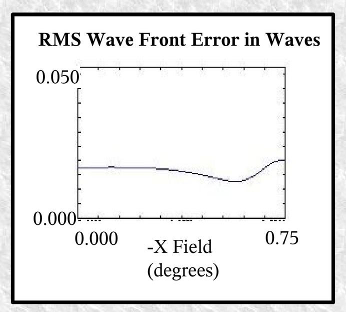
Novel optical designs as well as innovative detectors enable long-duration balloon (LDB) missions to achieve spatial resolutions comparable to HST over large fields ofview at UV-visible wavelengths. Improvements in balloon technology enable significantly larger masses to be flown at higher altitudes than were possible just a decade ago. During the eventual hiatus between the end of HST operations and future large UV-visible missions, a 2-3 meter telescope carried on an LDB can provide 2-3 weeks of dark-time observations per year for the general astronomical community. An LDB-borne telescope can also serve as a platform to fly new instrument concepts. For example, a 2-m telescope equipped with a Fabry-Perot instrument is ideal for producing 2-D velocity maps at an efficiency of 10x that of HST. Such a mission could study kinematically the assembly of galaxies from a z ~ 1.4 to the present, measuring empirically the dark and luminous matter as a function of galaxy radii for different epochs. Perhaps, it could also be used as a pathfinder to TPF-C. A proposed conventional balloon mission, called KITE, seeks to demonstrate the feasibility of the novel optical design plus new detector technologies, as well as verify that all pointing and thermal issues that have plagued previous missions have been mitigated. The telescope design and two example missions are discussed.

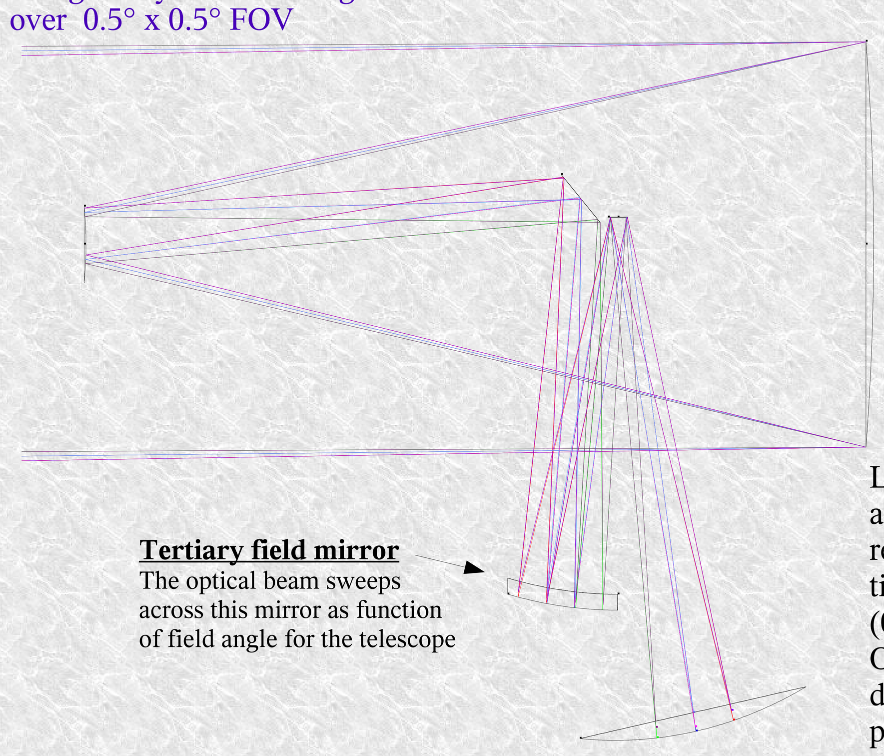
Novel Telescope Design

is shared by both balloon missions

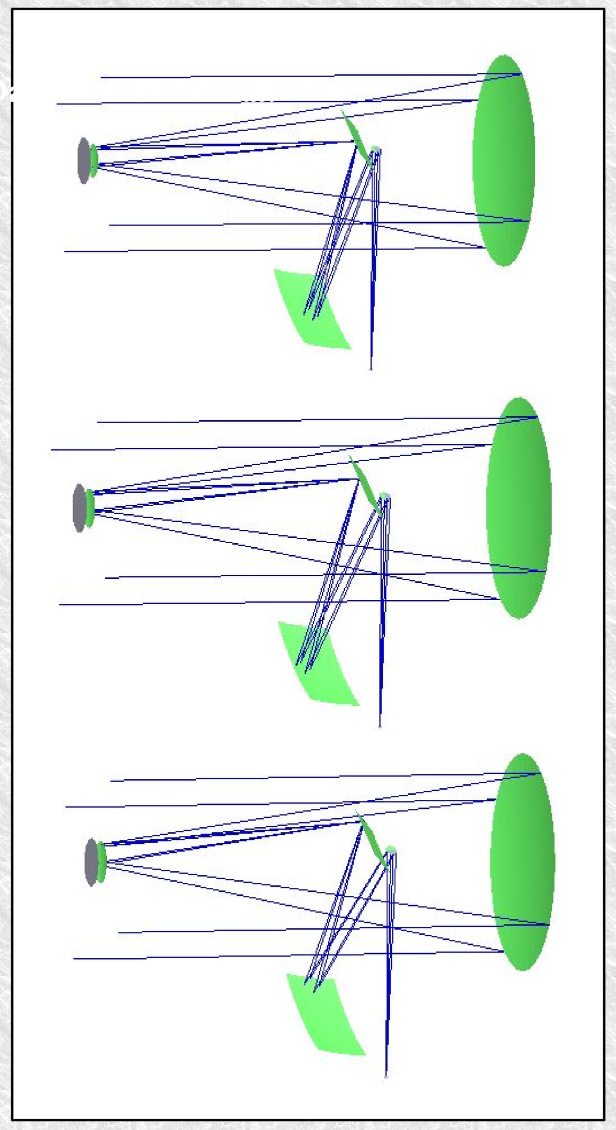
Excellent Performance

Designed by Col Jim Burge for < 20 nm RMSWE over 0.5° x 0.5° FOV



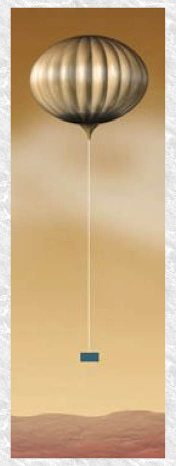


Tertiary field mirror
The optical beam sweeps across this mirror as function of field angle for the telescope



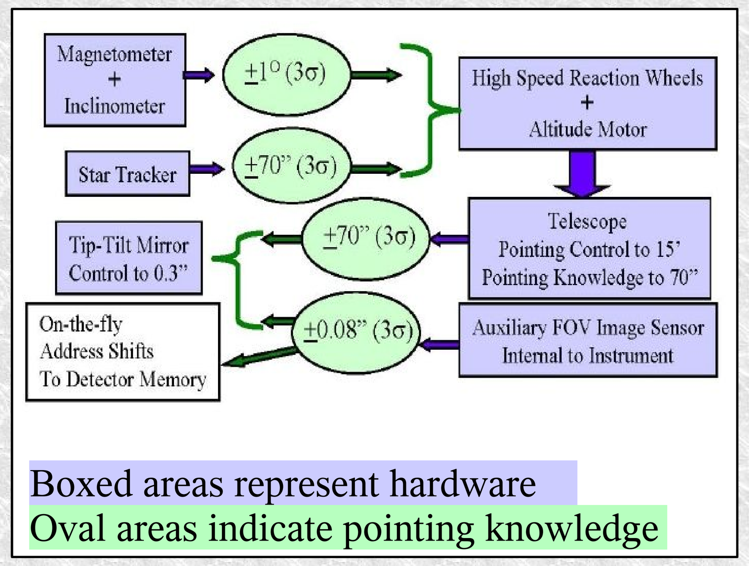
Large, off-axis asphere Tertiary allows gondola sway to be removed easily via a simple tip-tilt steering mirror over a large (0.5° x 0.5°) field of regard. Off-sets in the photon-counting detector memory provide mas pointing corrections, including rotational offsets.

Layered, Redundant Attitude Control System (ACS) makes use of photon-counting detector

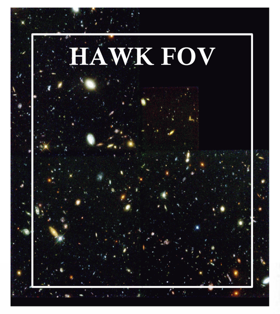


Pendulum swing, which has an amplitude of ~10′ and a period of 10 sec. is removed by our ACS

The technique of using address offsets in the detector memory to compensate for minor pointing errors was pioneered by Ed Jenkins at Princeton in the 1980s for the Interstellar Medium Absorption Profile Spectrograph (IMAPS) Mission.



Why Ground-based Telescopes with Adaptive Optics can't do it!

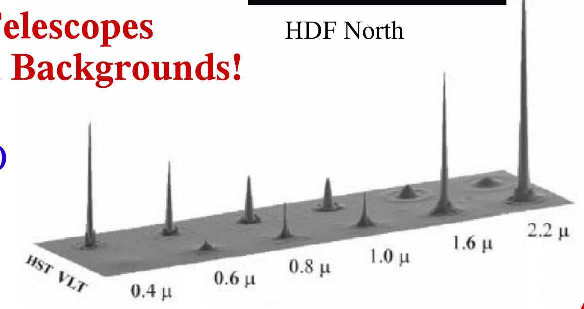


FOV on a ☐ 10 m with AO

HDF North

IR Ground-based Telescopes have large Thermal Backgrounds!

PSF of 10 m with AO only becomes comparable at IR wavelengths



PSF comparison by G. Kriss

Image Quality Comparison

Alt.	Aperture	r_0 (m)	FWHM(")	θ_0 (")	τ_0 (sec)
4 km	CFHT 3.8m	0.18	0.7	3	0.0036
35 km	2.4 m	~250	0.048	~600	~5
35km	10 m	~250	0.012	~600	~5

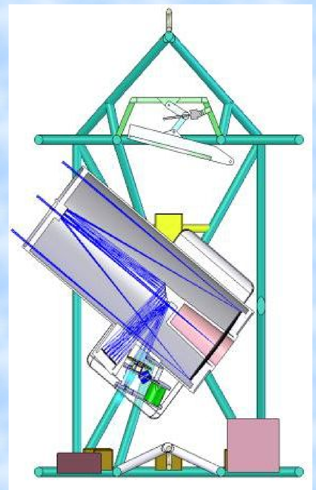
Atmospheric Parameters Comparison

h (km)	P (mbars)	T (K)	ρ (gm m^{-3})	H_2O Vapor (gm m^{-3})
4	680	253	937	0.68
35	4.7	222	7.4	0.00011

Data from Ford *et al.* 2002

KITE: Kinematical Imaging Trailblazer Experiment

Swallow-tail Kite D.A. Rintoul, USGS



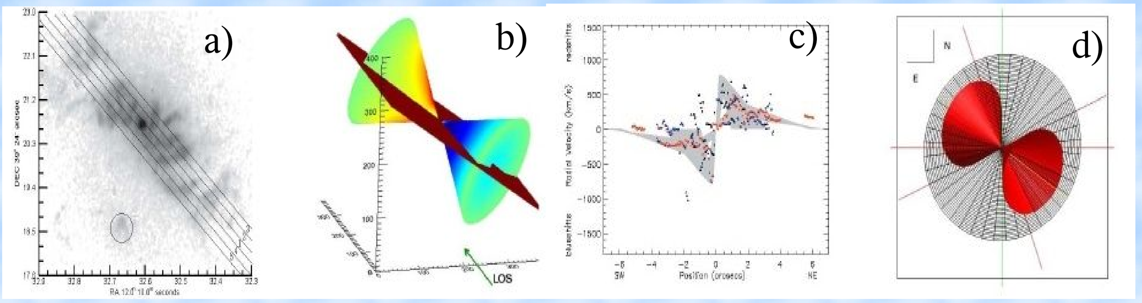
EBCCD Detector
25% QE Solar Blind

(50% Possible) c/f MAMA 10%
c/f WFPC2 system efficiency 0.25%
6x more than GALEX with 0.75 m

Balloon-borne 0.75 m Telescope
Near-UV (200 nm < λ < 400 nm)
Fabry-Perot + Long-slit spectrograph

KITE – Mass Outflows from AGN Studies

The Fabry-Perot will produce velocity maps of the NLR around near-by Seyferts for several species with different ionization potentials, providing important information on the physics of mass outflows such as for AGNs affecting the large-scale structure in the early universe.

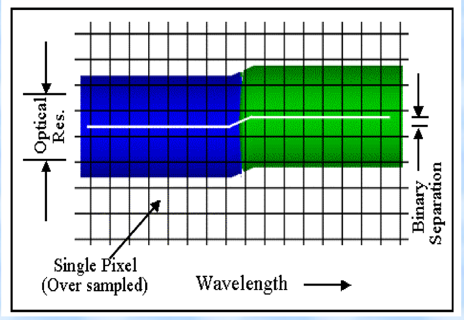


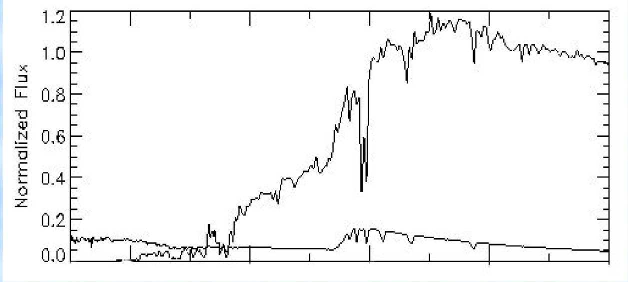
a) [O III] image of the NLR of NGC415. b) Model representing the geometry and velocity field. c) Extracted velocities (gray) compared to observed radial velocities of bright- (red) & inter-mediate- flux (blue) components at each location, excluding the low flux points in black. d) The NLR and host galaxy geometries as seen from our line of sight.

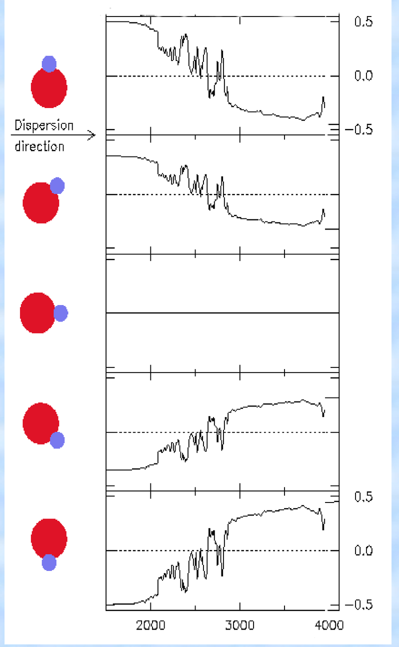
KITE – Stellar Evolution via Binary Studies

(resolving component separation below the diffraction limit)

The need for fundamental data for evolved supergiants is underscored by the long standing discrepancy between the pulsational and evolutionary masses of Cepheids. Stars in the upper right of HR diagram can have different masses, but same L & T.

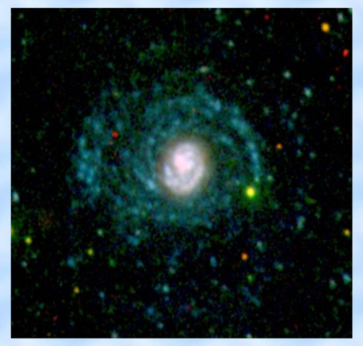






Above: Kurucz models of binary components for wd + M giant. Right: relative centroids of components for various slit orientations compared to binary orientation. Upper RT: when each component dominates the flux at adjacent wave-lengths, Cross-Dispersion Imaging measures separations less than the optical resolution for certain slit orientations.

A Versatile Instrument for Other Studies



- Star Formation Rates in XUV galaxies
  (Previously unknown SF regions)
- Post-AGB and post-early-AGBs
  (underabundant by 100x compared to models)
- New classes of objects discovered by GALEX
- Jets and circumstellar shells.

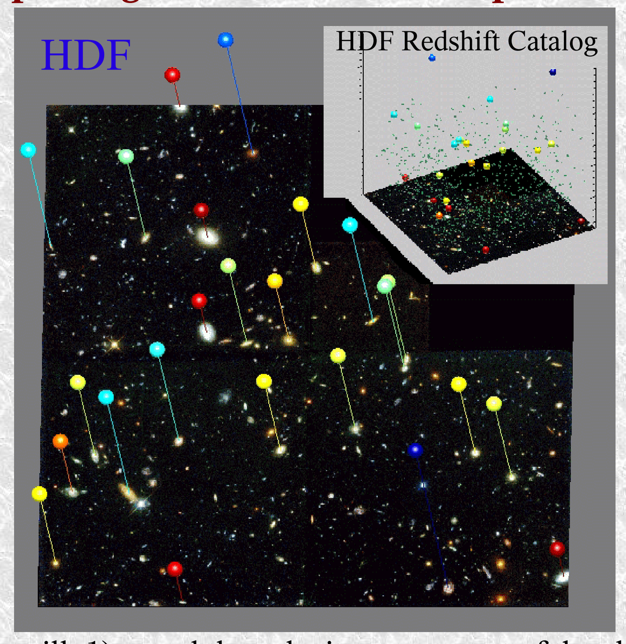
Composite picture of NGC 4625. UV more extended than visible image (white).

HAWK

Hierarchical Assembly through Wide-field Kinematics

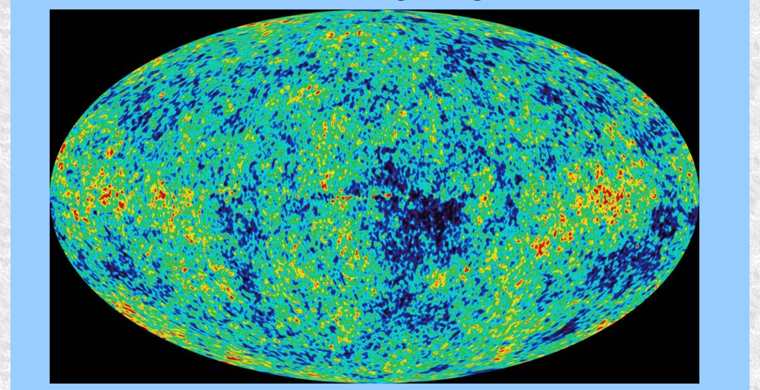
- 2 m telescope on long-duration balloon (LDB)
- Nearly diffraction limited 2-D velocity maps.
- DM and luminous mass content as a function of radius.
- Empirically measure how galaxies evolve from z ~ 1.4
- Measure the Tully-Fisher Relation (TFR) for spiral galaxies

HAWK – Measure velocities for a flux-limited sample of gas emission in 10 Mpc^3 volume



Data will: 1) reveal the velocity component of the clustering hierarchy, finding gravitationally bound substructures. 2) determine DM and luminous masses. 3) enhance HDF studies such as gravitational lensing.

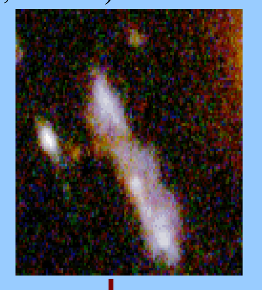
---The Big Bang ---



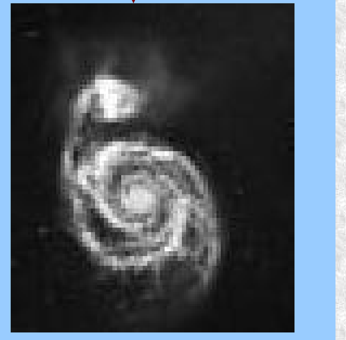
Cobe, MAP, Planck Missions measure the structure of the very early universe. (15 Billion Yrs. Ago. z > 100)

The Dark Ages
To Be Explored by JWST
First Star Formation
Earliest Galaxy Structures

Galaxies Not Well Organized
(11 Billion Yrs. Ago; z ~ 1.5)

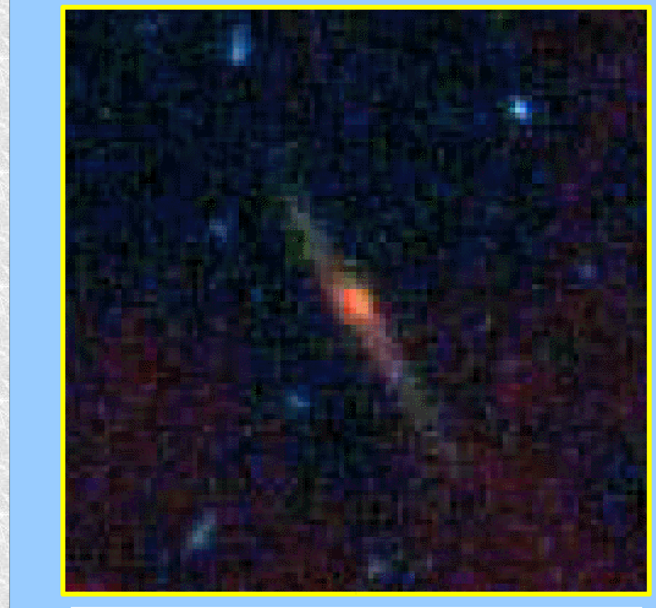


Galaxy Evolution
DM + Visible Matter
To be observed by HAWK



To Well-Organized Galaxies

Most distant galaxies should have dwarf satellites



GSS-104-4024 (z=0.81). HST/NICMOS+WFPC2 A high-redshift galaxy showing the satellite dwarfs predicted by models. (Data taken by N. Vogt.)

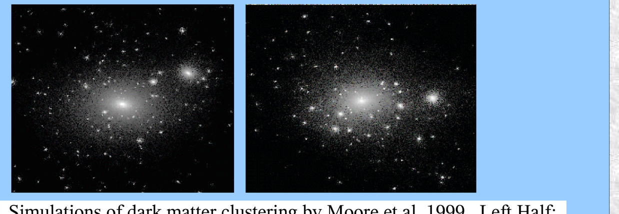


Figure 1.1 Simulations of dark matter clustering by Moore et al. 1999. Left Half: galaxy cluster showing many galaxy-size clumps. Right Half: galaxy halo with many more sub-clumps than are seen as dwarf satellite galaxies today. VIRGO will detect a population of dwarfs at z ~ 1, if they have any significant star formation, even though HST would have missed them.

Strong Lines in H II Regions

Spectral Feature	Rest λ (Å)	Relative Photon Strength	z Range
H I	6563	1	0.00 – 0.37
[O III]	5007	0.56	0.00 – 0.80
H I	4861	0.24	0.00 – 0.85
[O II]	3727	0.21	0.21 – 1.42
C III]	1908	0.17	1.36 – 3.72

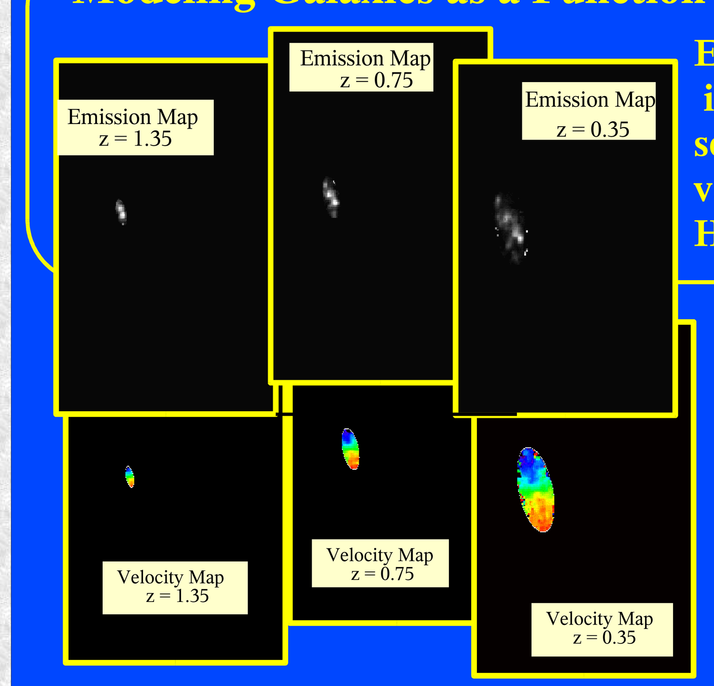
Exposure Calculations*

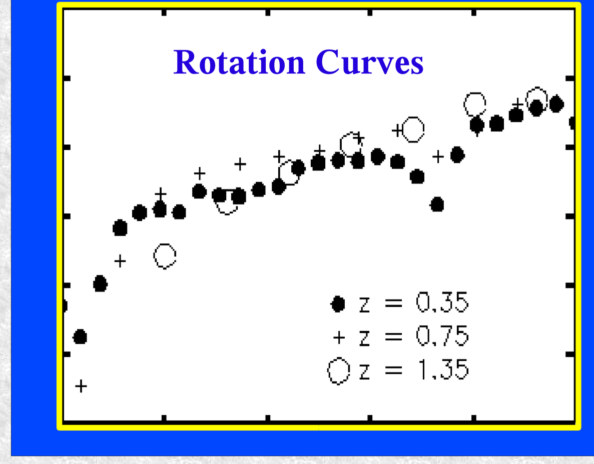
z	Size	Pixelation	Exposure
0.35	2.65"	50x50	45 min
0.75	1.93"	25x25	180 min
1.35	1.30"	16x16	630 min

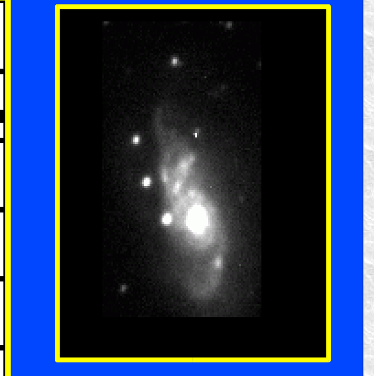
*Exposures scaled from mean luminosity of galaxies observed at 0.8<z<1.0 (Glazebrook et al. 1999).

Modeling Galaxies as a Function of Z

E263g14 as it would be seen at various z by HAWK







E263g14