Ad-Hoc Science Working Group
Next Generation Space Telescope **Design Reference Mission Proposal**

The Ages and Chemistry of the Oldest Stellar Halo Populations

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Scientific category: STELLAR POPULATIONS
Instruments: OPT/CAM
Days of observation: 36

Abstract

NGST is capable of reaching the main sequence turnoff of the oldest stellar populations ($M_V = +4.5$) out to a distance ≈ 2 Mpc. There is now evidence that the oldest, most metal poor star clusters are coeval to within 1 Gyr over a 200 kpc radius centered on the Milky Way. NGST can be used to make an equally definitive test of this in the halo and globular cluster system of M31, NGC 147, 185, and perhaps also M81.

We also propose to image field halo populations in galaxies spanning a full range of luminosity and Hubble type. The metallicity distribution can be measured using giants with $M_V < -1$, permitting study of galaxies as distant as the Virgo cluster ≈ 16 Mpc. This study will determine whether halo star properties correlate with Hubble type or galaxy luminosity, or whether halos are built from disrupted dwarf galaxies, globular clusters, and other low luminosity stellar systems (the so-called Searle-Zinn hypothesis). An excess of extreme blue horizontal branch stars at large radii in stellar halos could be the fossil remnant of a population III component.

Deep imaging in the outer disks of M31 and M33 will reveal the star formation histories of disk populations, which should agree with any inferred peak redshift of disk formation.

Observing Summary:

Target	RA	Dec	K_{AB}	Configuration/mode	Days
M31-CLUST	00 40	+41 00	V=30.5	OPT/CAM R10	1
M31-DISK	00 40	+41 00	V=30.5	OPT/CAM R10	1
M31-DWARFS	00 40	+41 00	V=30.5	OPT/CAM R10	1
M33 HALO, DISK	01 31	+30 23	V=30.5	OPT/CAM R10	1
VIRGO CLUST SURVEY	12 40	+20 00	V=32	OPT/CAM R10	20
SOUTH POLAR GROUP	00 30	-30 00	V=32	OPT/CAM R10	6
M81 GROUP	00 40	+41 00	V=32	OPT/CAM R10	4
NGC 5128, 5102	13 20	-36 00	V=30.5	OPT/CAM R10	2
				Grand total days	36

Scientific Objectives

Ever since measurement of early color-magnitude diagrams (CMDs) of Galactic globular clusters, there has been speculation that the most metal poor clusters such as M92 might be the oldest stars in the Milky Way. Recently, HST imaging has revealed globular clusters as old and metal poor as M92 but lying over a much larger volume, $\approx$ 100 kpc. Mighell et al. (1996) find the LMC globular cluster Hodge 11 to be a nearly perfect match for M92; when the loci are shifted to align the agreement in turnoff point is better than 0.05 mag. Harris et al. (1997) show that the extremely distant globular cluster NGC 2419 aligns just as well with M92, and Buonanno et al. (1998) claim that clusters with [Fe/H] $= -2$ in the Fornax dwarf spheroidal also overlay the M92 locus to within 0.1 mag. However, these HST measurements are still restricted to systems bound to the Milky Way that could arguably have been affected by the formation of the Milky Way. In order to test whether the oldest stars in galaxies are generally coeval, it would be desirable to push at least as distant as M31 and its satellites, and perhaps to M81. This would extend the investigation to other spiral galaxies, more luminous than our own. M31 does clearly have some old, metal poor globular clusters (Ajhar et al. 1996) and there is already evidence that the luminosity functions of old M31 clusters do not differ substantially from old Milky Way clusters (Rich et al. 1996). However, the best test would be to securely reach the main sequence turnoff of clusters in or beyond M31 (m-M)=24.5. At the same time, the age and metallicity distribution of the stellar halo field population would give us a tremendous window on the formation of the population II halo component of luminous spiral galaxies.

The old main sequence turnoff lies at $M_V \approx +4.5$ corresponding to $M_V = +29$ at the distance of M31. While an HDF-level exposure with HST could in principle just reach this faint, in practice one must solidly reach at least 1 mag fainter than the turnoff point to achieve a secure age determination. The impact of measuring many clusters with great precision, as opposed to barely reaching the turnoff in a single M31 cluster, is an additional compelling argument for the use of NGST as opposed to HST. NGST could achieve such faint levels in an exposure of approximately 1 hour in each of V and I. A campaign to measure CMD's for 10 globular clusters and adjacent field populations in M31 could achieve outstanding results in 40 hours of integration (allowing for 2 hours of integration time in V,I to reach the turnoff with confidence). It would be desirable to also observe both NGC 147 and 185, and perhaps a halo field in M33 (the latter requiring 4 hours in each color due to the greater distance modulus). At a modulus of 26.5, M81 and the halo of the nearest giant elliptical, NGC 5128, reaching the old main sequence turnoff requires a more substantial investment of time and may well be at or beyond the capabilities of NGST. I propose a 2 day integration in the outer halo of NGC 5128, which could just reach $M_V \approx 32$. This exercise would be the first secure age dating of any portion of an elliptical galaxy, a morphological type substantially different from that of the Milky Way.

1 Abundances and Ages of Halo Populations Across the Hubble Sequence

Exposures deep enough to reach the main sequence turnoff will be possible only for the nearest galaxies, and even in those cases the photometric crowding may make it very difficult, in practice, to get turnoff photometry beyond the modulus of M31. On the other hand, NGST is capable of rapidly surveying the most luminous stars (horizontal branch and red giants) of halo populations out to a distance modulus of ≈ 28 (corresponding to V=30.9 in 3 hours). A study of halos across the Hubble Sequence would be aimed at answering whether the metallicity of the stars is correlated with the total luminosity of the parent galaxy, or with Hubble type. Presently it is believed that stellar halos are generally composed of subclumps (like the Fornax dwarf galaxy) accreted over many Gyr (Searle & Zinn 1978). On the other hand, a monolithic early collapse, while not as consistent with CDM, would be more successful at explaining the correlation between globular cluster system metallicity and parent galaxy luminosity seen in ellipticals (Forbes et al. 1997). Two marginal color-magnitude diagrams, at the limit of HST capabilities, find evidence for metal rich halo populations in NGC 5128 (Soria et al. 1996) and NGC 3115 (Elson et al. 1997). The CMD's appear similar to those obtained in the outer halo of M31 (Rich et al. 1996) – high metallicities of > -0.5 dex. The metallicity distribution is constrained by interpolating the observed giant branch between globular cluster giant branches of known metallicity. This is most successfully achieved using the Johnson V, I passbands because of the greater metal line blanketing in the V band. If the photometric accuracy is < 0.1 mag, the resulting abundance distribution function can be fit to chemical evolution models; broad distributions are consistent with one- zone models and wind outflow (Rich 1990). It is more difficult to constrain the ages of halo populations, but that is a problem in which the IR imaging of NGST will be a major advantage. The presence of large numbers of luminous giants brighter than the RGB tip would indicate a substantial intermediate age population. With improved AGB models and RGB luminosity functions, it is conceivable that one may routinely establish the fraction of intermediate age stars in these populations. The ages and metallicities of halo field stars and globular clusters in the Milky Way have provided an essential input into developing a picture of how the Galaxy formed. If undertaken, this survey can extend our vision to include most of the Hubble sequence, including elliptical galaxies.

The possibility of a very early stellar generation at high redshift has recently been revived (Ostriker & Gnedin 1996) and the direct imaging of such stars is a science goal of NGST. If these stars were extremely metal poor and the initial mass function extended below a Solar mass, their progeny today must include an extended blue horizontal branch that follows the r^{-2} spatial distribution characteristic of the dark matter. The blue HB stars would easily be detected as distant as the Virgo cluster, and a large survey of halo populations would place constraints on the nature of a stellar population III.

Because of redshift dimming, it will always be difficult to observe the low- surface brightness parts of high redshift galaxies, where the halo stars may actually be forming. In order to test theories of galaxy formation, we will want to know if cluster and halo field populations formed at the same time, or even connected with the same galaxy. There is no way to construct the future evolution of a high redshift galaxy with certainty, but constraints from study of the local fossil record are critical inputs toward a theory of galaxy formation and evolution.

Finally, the star formation history of disks is an important problem and worthy of its own investigation. A pilot study of the low surface brightness outer disk fields in M31 and M33 would reveal the ages of bursts that contributed to the formation of those disks. Spiral disks contain moss of the stellar mass in spiral galaxies, and there is little constraint on the dominant age of their stellar populations (the age distribution of their constituent stars). Also disputed is whether disks form from the inside out. Evidence for disk formation at high redshift is difficult to verify, and there is some evidence (damped lyman alpha systems) that disks are in place at $z > 3$. NGST would be superb at attacking this problem.

2 NGST requirements

The single most important requirement is that NGST achieve the highest possible spatial resolution and that imaging in the V and I bands be possible. The stellar luminosity function increases by an order of magnitude below the main sequence turnoff, causing such great stellar crowding that only populations with a surface brightness equal to their distance modulus may be studied (e.g. 24.5 mag/ sq. arcsec at M31). A high quality mirror surface and nyquist sampling will be needed to work on this problem. Because the turnoff point is nominally located as the V magnitude of the bluest excursion of the main sequence locus, it is desirable to image these populations in V and I in order that differences in effective temperature correspond to the maximum possible differences in color. Further, simulations of the NGST psf show that even if the surface is imperfect, the optical offers great gains in spatial resolution. This science requires the capability for optical imaging at the highest possible spatial resolution. For relatively nearby systems such as M31, there may also be a benefit from wide field diffraction suppression (apodization) to permit detection of faint main sequence stars agains the background of bright giants.

3 References

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NGST Uniqueness/Relationship to Other Facilities

It is possible that the Advanced Camera on HST may just detect the turnoff in 1 or 2 M31 globular clusters, with a very large >20 orbit per filter integration time. However, a definitive proof that the M31 and Milky Way cluster systems are coeval demands excellent photometry at the turnoff point, which demands NGST

HST certainly cannot reach either M81 or NGC 5128. WFPC2 photometry of halo stars in NGC 3115 and NGC 5128 is disappointing even after 7000 sec of exposure time. More normal elliptical galaxies and S0 are found at modulus >30, NGST terrain.

Observing Strategy

For measuring the metallicity spread, the best filters are F555W and F814W (Johnson V, I equivalents) because the color spread of the giant branches in the range $-2 <$ [Fe/H] $< +0.5$ is > 2 mag in both magnitude and color, and only 0.3 mag in the infrared. Large metallic line blanketing in the V band gives greater sensitivity to temperature and metallicity.

Turnoff photometry could be done equally well in the optical and infrared, however, the observations would gain if the spatial resolution were as high as possible. For cluster observations in the halos of M31 and M81, it would be desirable to have a detector area no smaller than the WFPC2 (about 1.5 arcmin square) so that cluster and adjacent fields could be imaged in the same exposure.

Observing Plan: The NGST exposure time calculator estimates a 3 hr exposure to reach $V = 31$ at S/N=5; this would solidly reach the turnoff point of globular clusters and field populations in the halo of M31, provided imaging was done for low surface brightness (less crowded) regions; color-magnitude diagrams would be of Milky Way quality. To just reach the turnoff point at a modulus of 26.5, one must reach $V = 32$, requiring 1 day integration in each filter. A similar investment is desired to study the horizontal branches and giant branches of galaxy halos in the Virgo cluster.

The M31 halo can be observed in a total of 1 day. The disk fields of M31 and M33 need another day. NGC 147, 185, 205, and M33 halo fields need another day (to reach MS turnoff). Objects at distance modulus 26-27: (M81, NGC 5102, NGC 5128, NGC 3115 South Polar group, and some associated dwarfs). To reach the MS TO, these need 1 day in each filter, or 2 days per object; 12 days for initial campaign. Virgo cluster and NGC 3379: 2 days per object, 10 galaxies chosen to span range of Hubble type and luminosity, 20 days total. Estimate for full campaign: 34 days.

Special Requirements

Maximum FWHM: $100'$ at 1.0 μm
Minimum FOV: $1.5'$ at 0.5 μm

Precursor/Supporting Observations

Attempts to do some of this science with Advanced Camera are likely. HST imaging of M31 and M81 halo populations, deep luminosity function of the metal poor M31 globular cluster G219.