NUCLEAR STAR CLUSTERS IN
228 SPIRAL GALAXIES WITH HUBBLE

Iskren Georgiev

International Research Fellow
ESTEC, Noordwijk, Netherlands

In collaboration with: T. Böker, P. Goudfrooij, Th. Puzia, M. Hilker, S. Mieske, H. Baumgardth
Massive/globular star clusters

- Mass (~$10^5 M_\odot, 10^3-10^7 M_\odot$)
- Size ($r_{\text{eff}} = 3 \text{ pc}$)
- Density ($10^3 \star/\text{pc}^3$)
- Coeval stellar population

Bellini et al. (2010)
Massive/globular star clusters

- Mass (~$10^5 M_\odot, 10^3 - 10^7 M_\odot$)
- Size ($R_{\text{eff}} = 3 \ \text{pc}$)
- Density ($10^3 \ \star/\text{pc}^3$)
- Coeval stellar population
Massive/globular star clusters

- **Mass**: ($\sim 10^5 M_\odot, 10^3-10^7 M_\odot$)
- **Size**: ($R_{\text{eff}} = 3$ pc)
- **Density**: ($10^3 \star/\text{pc}^3$)

Bellini et al. (2010)

Image Credit: NASA/JPL-Caltech
Massive/globular star clusters

- Mass ($\sim 10^5 M_\odot, 10^3 - 10^7 M_\odot$)
- Size ($R_{\text{eff}} = 3 \text{ pc}$)
- Density ($10^3 \star/\text{pc}^3$)
- Coeval stellar population

Bellini et al. (2010)
Massive/globular star clusters

- Mass ($\sim 10^5 M_\odot$, $10^3-10^7 M_\odot$)
- Size ($R_{\text{eff}} = 3 \text{ pc}$)
- Density ($10^3 \star/\text{pc}^3$)
- Coeval stellar population

Globular Cluster NGC 2808

Hubble Space Telescope • ACS/WFC

NASA, ESA, A. Sarajedini (University of Florida) and G. Piotto (University of Padua [Padova])
Massive/globular star clusters

- **Mass** ($\sim 10^5 M_\odot, 10^3-10^7 M_\odot$)
- **Size** ($R_{\text{eff}} = 3 \text{ pc}$)
- **Density** ($10^3 \star/\text{pc}^3$)
- **Coeval stellar population**
Massive/globular star clusters

- Mass (~10^5 M☉, 10^3-10^7 M☉)
- Size (R_{eff} = 3 pc)
- Density (10^3 ✱/pc^3)
- Coeval stellar population

Omega Centauri
ESO/INAF-VST/OMEGACAM. Acknowledgement: A. Grado/INAF-Capodimonte Observatory

Globular Cluster G1 in Galaxy M31
HST · WFPC2

Michael Rich, Kenneth Mighell, and James D. Neill (Columbia University), Wendy Freedman (Carnegie Observatories) and NASA
Nuclear clusters in the Family of Stellar systems

E

dE
dSph

UCDs

NCs

GCs

Misgeld & Hilker (2011)
**Nuclear clusters in the Family of Stellar systems**

*NCs Formation channels*

- Connection to UCDs (stripped nuclei?)
- in situ via gas accretion
- in spiraled massive GCs
- cluster mergers
Nuclear clusters in the Family of Stellar systems

NCs Formation channels

- Connection to UCDs (stripped nuclei?)
- In situ via gas accretion
- In spiraled massive GCs
- Cluster mergers

* Galactic nuclei

- Cluster to BH dominated nucleus
- Connections and interplay between NCs and BHs
Nuclear Star Clusters in late type Spirals

1x1 kpc

NSC half-light radius $r_{\text{eff}} = 4$ PC

8x8 kpc

NGC 1325
20.7 Mpc
$M_v = -20.05$ mag
—The largest database of nuclear star clusters (NSCs) of >200 spiral galaxies with Hubble Space Telescope WFPC2 imaging in the archive.
Nuclear Star Clusters in late type Spirals

- The largest database of nuclear star clusters (NSCs) of >200 spiral galaxies with Hubble Space Telescope WFPC2 imaging in the archive

- A homogeneous measurement of structural and photometric properties of NSCs
The largest database of nuclear star clusters (NSCs) of >200 spiral galaxies with Hubble Space Telescope WFPC2 imaging in the archive.

A homogeneous measurement of structural and photometric properties of NSCs.

Formation, evolution, relation to massive globular clusters and Ultra Compact Dwarf galaxies, and co-existence of NSCs and Massive Black Holes.
### Galaxy Sample, NSCs and WFPC2 Characteristics

<table>
<thead>
<tr>
<th>Galaxy Sample</th>
<th>Low-Inclination &lt; 88</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nearby</td>
<td>&lt; 35 Mpc</td>
</tr>
<tr>
<td></td>
<td>&gt; 5000</td>
</tr>
</tbody>
</table>
Galaxy sample, NSCs and WFPC2 characteristics

**Galaxy sample**

- Low-inclination < 88
- Nearby < 35 Mpc

**>5000**

HST/WFPC2 archive:

- 340 galaxies
- 47 programs
- 9 filters (UV to I)
- 65 GB raw data
Galaxy sample, NSCs and WFPC2 characteristics

ESA Hubble Science Archive

A classical search interface is available here. The HLA grism data is also available from a dedicated search interface.

Query form | Result table | Get data
-----------|--------------|---------

HST/WFPC2 archive: 340 galaxies, 47 programs, 9 filters (UV to I), 65 GB raw data

http://archives.esac.esa.int/hst

Download large preview as JPG or FITS
Send preview image to Aladin ...
Galaxy sample, NSCs and WFPC2 characteristics

**Galaxy sample**
Low-inclination < 88
Nearby < 35 Mpc
> 5000

**HST/WFPC2 archive:**
340 galaxies
47 programs
9 filters (UV to I)
65 GB raw data
Galaxy sample, NSCs and WFPC2 characteristics

Galaxy sample
Low-inclination < 88
Nearby < 35 Mpc
> 5000

HST/WFPC2 archive:
340 galaxies
47 programs
9 filters (UV to I)
65 GB raw data
Galaxy sample, NSCs and WFPC2 characteristics

Galaxy sample
Low-inclination < 88
Nearby < 35 Mpc
> 5000

HST/WFPC2 archive:
340 galaxies
47 programs
9 filters (UV to I)
65 GB raw data

Structure and photometry for
228 Nuclear Star Clusters
Measuring Nuclear Star Cluster properties
With the Hubble Space Telescope - Wide Field and Planetary Camera 2 (WFPC2)

TinyTIM PSFs
- POSITION
- FILTER
- BREATHING ETC.

Krist et al. (2011)

Georgiev & Böker (in prep.)
Measuring Nuclear Star Cluster properties
With the Hubble Space Telescope - Wide Field and Planetary Camera 2 (WFPC2)

TinyTIM PSFs
- position
- filter
- breathing etc.

Krist et al. (2011)

ISHAPE
- TinyTim PSF
- Analytic model
- Best $\chi^2$ fit model
- 10% of PSF FWHM

Larsen (1999)

Georgiev & Böker (in prep.)
## Measuring Nuclear Star Cluster Properties

**With the Hubble Space Telescope - Wide Field and Planetary Camera 2 (WFPC2)**

### TinyTIM PSFs
- Position
- Filter
- Breathing etc.

Krist et al. (2011)

### ISHAPE
- TinyTIM PSF
- Analytic model
- Best $\chi^2$ fit model
- 10% of PSF FWHM

Larsen (1999)

<table>
<thead>
<tr>
<th>Model</th>
<th>Object</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Model Image" /></td>
<td><img src="image2" alt="Object Image" /></td>
</tr>
<tr>
<td><img src="image3" alt="Residual Image" /></td>
<td><img src="image2" alt="Object Image" /></td>
</tr>
</tbody>
</table>

**NGC0300 F814W_1**
r$_{eff}$ = 1.92 pc
cll = 0.04, PA = -44.9
FTRAD = 16 pix
KINGx100
S/N = 724.5
CHISQR=4.
Central 5x5 pix:
STCG/StGsky= 0.1

<table>
<thead>
<tr>
<th>Model</th>
<th>Object</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Model Image" /></td>
<td><img src="image2" alt="Object Image" /></td>
</tr>
<tr>
<td><img src="image3" alt="Residual Image" /></td>
<td><img src="image2" alt="Object Image" /></td>
</tr>
</tbody>
</table>

**NGC5068 F814W_1**
r$_{eff}$ = 4.27 pc
cll = 0.04, PA = -29.3
FTRAD = 11 pix
KINGx15
S/N = 173.6
CHISQR=3.4
Central 5x5 pix:
STCG/StGsky= 10.4

Georgiev & Böker (in prep.)
Measuring Nuclear Star Cluster properties
With the Hubble Space Telescope - Wide Field and Planetary Camera 2 (WFPC2)

TinyTIM PSFs
- position
- filter
- breathing etc.

Krist et al. (2011)

ISHAPE
- TinyTim PSF
- Analytic model
- Best $\chi^2$ fit model
- 10% of PSF FWHM

Larsen (1999)

Output
- Model magnitude
- Structural parameters:
  $r_{\text{eff}}$, effective radius
  $\epsilon$, ellipticity,
  PA, position angle,
**Measuring Nuclear Star Cluster properties**

**With the Hubble Space Telescope - Wide Field and Planetary Camera 2 (WFPC2)**

<table>
<thead>
<tr>
<th>Model</th>
<th>Object</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Model Image" /></td>
<td><img src="image2.png" alt="Object Image" /></td>
</tr>
</tbody>
</table>
| Residual | NGC0300 F814W_1  
  $r_{\text{eff}} = 1.92$ pc  
  ell $= 0.04$, PA $= -44.9$  
  FWHM = 15 pix  
  S/N = 724.5  
  CHISQR = 1.4  
  Central 5x5 pix:  
  SIG/SIGsky = 0.1 |

<table>
<thead>
<tr>
<th>Model</th>
<th>Object</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image3.png" alt="Model Image" /></td>
<td><img src="image4.png" alt="Object Image" /></td>
</tr>
</tbody>
</table>
| Residual | NGC5068 F814W_1  
  $r_{\text{eff}} = 4.27$ pc  
  ell $= 0.04$, PA $= -29.3$  
  FWHM = 11 pix  
  S/N = 173.6  
  CHISQR = 1.4  
  Central 5x5 pix:  
  SIG/SIGsky = 10.4 |

**TinyTIM PSFs**
- position
- filter
- breathing etc.

**Krist et al. (2011)**

**ISHAPE**
- TinyTIM PSF
- Analytic model
- Best $\chi^2$ fit model
- 10% of PSF FWHM

**Larsen (1999)**

**Output**
- Model magnitude
- Structural parameters: $R_{\text{eff}}$, effective radius, $\epsilon$, ellipticity, PA, position angle,

**As free of contaminating flux as possible flux and size measurement of 228 NCSs**

Georgiev & Böker (in prep.)
Distance and S/N dependent resolution limits

Georgiev & Böker (in prep.)

Distance to NSC host galaxy [Mpc]

S/N
1640
190
170
150
130
110
90
70
50
30
10

r_{eff} [pc]

0.2pix WF
0.2pix PC

PC
WF

Georgiev & Böker (in prep.)
Distance and S/N dependent resolution limits

Georgiev & Böker  (in prep.)

More than 90% of the NSCs (S/N > 30) with robust $R_{\text{eff}}$ measurement.
Stellar populations in Nuclear Star Clusters

NGC4487
NGC1487
NGC7424
NGC4900
NGC7713
NGC0959
NGC5112
NGC2500
NGC5474
NGC3913
NGC3274
NGC4525
NGC5964
NGC1258
NGC1084
NGC0428
NGC5204
NGC5334
IC0396
NGC7090
UGC09215
NGC3041
NGC4635
NGC2344
NGC3423
NGC3756
UGC03574
M074
NGC4041
NGC1325
NGC3338
NGC4651
NGC3370
NGC4001
NGC2841
NGC4078
NGC5813
NGC4030
NGC6744

NCs model colours
S/N<30 or unresolved
1Z

F450W - F606W [mag]
Luminosity vs. effective radius of Nuclear Clusters

Mislged & Hilker (2011)

Georgiev & Böker (in prep.)
Luminosity vs. effective radius of Nuclear Clusters

- NSCs
- NSCs in late-types
- NSCs in early-types
- UCDs
- MW GCs

Georgiev & Böker (in prep.)
**Summary**

- Largest homogeneous analysis of NSCs in late-type spiral galaxies
- NSCs span a wide range in age and mass
- NSCs can be the progeny of massive GCs and UCDs

**Outlook**

- NSCs in Spiral galaxies - release of a database of structure and photometry of 228 NSCs
- Studying the formation and co-evolution of nuclear objects - nuclear clusters and BHs
- Stellar pops of NSCs in the NIR: HST/WFC3 (JWST)