Simulating E-ELT starburst cluster observations with METIS

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METIS – uniqueness of the mid-IR in starburst clusters

Penetrating the dust & reducing patchy extinction variations in the mid-IR.

JHKs LUCI LBT

4.5' x 4.5' = 2.5 x 2.5 pc

Bik et al. 2012

CHANDRA hard & soft X-ray

NASA/CXC/Penn State/L. Townsley et al.
Penetrating the dust & detecting the embedded population.
METIS – uniqueness of the mid-IR in star-forming regions

Penetrating the dust & detecting the embedded population.

Spitzer/IRAC

Blue  3.6 μm
Green 4.5 μm
Orange 5.6 μm
Red    8.0 μm

NASA/JPL/A. Marston (ESTEC)
METIS – uniqueness of the mid-IR in starburst clusters...
... and nuclear star-forming regions

A deep look into the nuclear furnace of the Milky Way & nearby galaxies.
METIS – uniqueness of the mid-IR in starburst clusters... and nuclear star-forming regions

A deep look into the nuclear furnace of the Milky Way & nearby galaxies.

NASA/JPL/S. Stolovy & GLIMPSE
METIS – uniqueness of the mid-IR in starburst clusters...  
... and nuclear star-forming regions

NASA/JPL, Robitaille et al

Counting the Youth in a Middle Aged Galaxy

Spitzer Space Telescope • IRAC

Understanding the nuclear star formation process...
METIS – bridging forming & formed clusters
“A Molecular Cloud Progenitor of an Arches-like Cluster”

How do we get from here... 

....to here?

GLIMPSE 3.6, 4.5, 8 μm
Benjamin et al. 2003

HERSCHEL 70 μm
Molinari et al. 2011

SCUBA 450 μm
Di Francesco et al. 2008

Longmore et al. 2012
METIS – bridging forming & formed clusters

“A Molecular Cloud Progenitor of an Arches-like Cluster”

How do we get from here...

....to here?

typical $\epsilon \sim 0.3 = 30\%$ of mass in cores ends up in stars

Courtesy D. Ward-Thompson

Shaping E-ELT Science & Instrumentation, Garching 26 Feb 2013
A. Stolte, Argelander Institut for Astronomy
Simulating E-ELT starburst cluster observations with METIS

Motivation

The idea:

* Understand E-ELT & METIS performance in what we call a *Crowding limited field* today

* Define the new science questions that can be uniquely addressed

* Define the distance scale

* Answer questions such as:

  - What can be done with METIS that could not be done before?
  - Which sensitivity do we ideally need, which do we realistically get?
  - What do we gain in the mid-infrared regime?

→ METIS simulator developed in Leiden: B. Brandl, E. Schmalzl, J. Meissner
The METIS starburst cluster science case

**Science Goals**

* **3D view**: proper motion of individual cluster members → Ric Davies

* **densely packed**: resolving the most compact clusters in nearby galaxies → Bernhard Brandl

* **deep & young**: deeply embedded clusters forming from dense cores

* **faint & cool**: free-floating low-mass objects (planets?) & variations in the substellar IMF → Ignas Snellen → Wolfgang Brandner
**Star cluster simulations – Technical Assumptions**

**METIS & E-ELT**

Pixel scale: 6.4 mas/pix

Filter characteristics: Lprime (3.8 micron, bandwidth 0.65 micron)

Telescope effective M1 area: 976.29 m²

Zeropoint = 25.0 (arbitrary)

**Sky level & noise**

Sky noise Paranal Lprime = 3.0 mag/arcsec²  *pessimistic?!

Sky flux = $6 \times 10^8$ photons/s/arcsec²  ~  $3 \times 10^4$ counts/s/6.4 mas pix²

Poisson noise added to sky

All other noise sources (PSF/stellar photon noise) ignored
Star cluster simulations – Technical Assumptions

METIS PSF

Simulated with METIS PSF simulator

→ Remko Stuik, Stefan Hippler

Central peak plus 1st Airy ring

63% of total flux

Stellar flux scaled to the peak value

4.4% of total flux

40 pix

METIS Field of View
Star cluster simulations – Technical Assumptions

**METIS PSF**

Simulated with METIS PSF simulator

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63% of total flux

Stellar flux scaled to the peak value

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Star cluster simulations – Science Assumptions

NGC 3603 – compact cluster template

- resolved starburst cluster in the Milky Way
- realistic “mixed age” population
- current limit: L < 15 mag
- numerous data sets:
  
  ISAAC, NACO, HST/WFPC2
NGC 3603 – what we need:

- current limit: $L < 15$ mag
  → many cluster stars missing

Faint & pre-main sequence:

- filled in K-L colour by populating a 2 Myr isochrone
- filled in central area & saturated high-mass stars
  → HST/WFPC2 \textit{optical}
  → vast assumptions about colours!!!
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Having L-banded all these stars, what do we get?
Star cluster simulations – Science Results

NGC 3603 – simulation:

Case 1: Milky Way @ 6.3 kpc

9.5 < L < 19.5 mag

(11.6 < Ks < 20 mag)

Not yet scaled to METIS resolution!

<=> 8 x denser cluster

Science goals:

- orbits of individual stars
  In dense clusters:
    Starbursts & globulars

- the “far side” of the Milky Way

=> deeply embedded systems & clusters with high foreground extinction
**Star cluster simulations – Science Results**

**NGC 3603 – simulation:**

Case 2: LMC @ 48 kpc

13.0 < L < 23.5 mag

Scaled to METIS resolution

**Science goals:**

- resolving dense clusters in nearby galaxies
- what is the highest mass star?
- IMF & star formation process
- disc survival & existence of planetary systems
Star cluster simulations – Science to be done...

Back to the Milky Way....... 

a real NGC 3603 with METIS
Star cluster simulations – detecting brown dwarfs & planets

NGC 3603 – simulation:

- Case 2: Milky Way @ 6.3 kpc
  - $9.5 < L < 19.5$ mag
- Scaled to METIS resolution

Science goals:

- detection of brown dwarfs & free-floating planets
- disc survival & existence of planetary systems
- substellar mass function

METIS has the ideal bands to detect low-mass objects!

Leggett et al. 2009

Shaping E-ELT Science & Instrumentation, Garching 26 Feb 2013  A. Stolte, Argelander Institut for Astronomy
Star cluster simulations – resovling Milky Way clusters

NGC 3603 – simulation:

Case 2: Milky Way @ 6.3 kpc

9.5 < L < 19.5 mag

Scaled to METIS resolution

Science goals:

- detection of brown dwarfs & free-floating planets
- disc survival & existence of planetary systems
- substellar mass function

Now, this is a really fluffy cluster... so let's include some faint objects!
Star cluster simulations – adding the faint population

Trapezium cluster:
- detected faint PMS stars & brown dwarfs  *Muench et al. 2002*

Observed at Orion:  

\[
1.6 < L_p < 13.7 \text{ mag} \\
4.4 < K_s < 18.6 \text{ mag}
\]

At NGC 3603 distance:

\[
5.8 < L_p < 19.5 \\
10.2 < K_s < 24.4
\]

Assumption:
2 Myr PMS isochrone

\[
K - L (3603) = 0.3 \text{ mag}
\]

*Tognelli et al. 2012*
Star cluster simulations – the faint low-mass population

NGC 3603 – simulation:

Case 2: Milky Way @ 6.3 kpc

9.5 < L < 19.5 mag

Scaled to METIS resolution

Science goals:

- detection of brown dwarfs & free-floating planets
- disc survival & existence of planetary systems
- substellar mass function
- low-mass objects as tracers for IMBHs

=> measurement of accelerations
“Real photometry” on artificial images - Recovery success in cluster simulations

Run your favourite star-finding algorithm on these images & see what you get...

Milky Way starburst @ 6.3 kpc
8 x denser than NGC 3603
9.5 < L < 19.5 well recovered
“Real photometry” on artificial images - Recovery success in cluster simulations

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Input: 9.5 < L < 23.5 mag
Output: L < 19.5 = young Brown Dwarfs!

LMC @ 48 kpc
Input: 13.0 < L < 23.5 mag
Output: 13 < L < 19.5 mag

2.3 M

Compact Trapezium (6.3 kpc)
Input: 9.5 < L < 23.5 mag
Output: L < 19.5 = young Brown Dwarfs!
Real clusters as templates:

* NGC 3603 & Trapezium

Preliminary simulation results suggest:

* detect all brown dwarfs
  In all young Milky Way clusters

* obtain a full disc inventory in starburst clusters including dense clusters in nearby galaxies

To be confirmed/complimentary:

* orbits of stars around IMBHs

* free-floating planets & planetary systems in dense, rich clusters

NASA, ESA, R. O'Connell, F. Paresce, E. Young
Star cluster simulations – Science Assumptions

NASA, ESA, R. O'Connell, F. Paresce, E. Young