Constraints on the Stellar Mass Function from Stellar Dynamics at the Galactic Centre

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astro-ph/0609812

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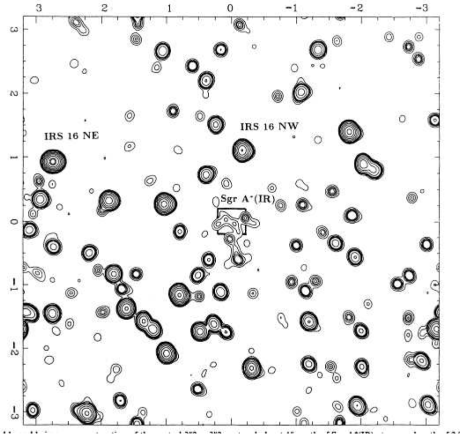
November 27, 2006
AIfA, Bonn

Galaxies


Galaxy Cluster Abell 2218
HST • WFPC2
NASA, A. Fruchter and the ERO Team (STScI) • STScI-PRC00-08

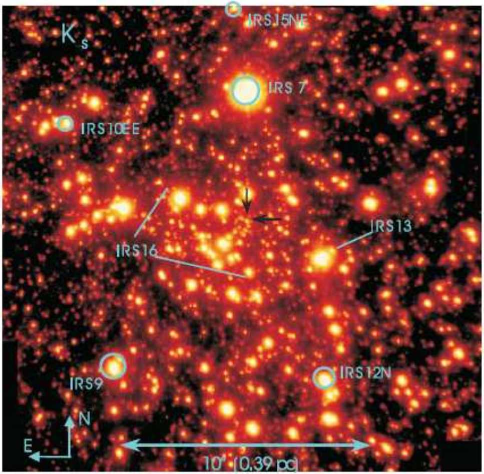
Focusing on the Galactic Centre



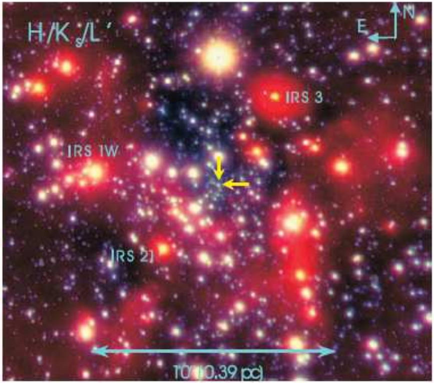
Eckart et al. (1995)

- distance to the Galactic Centre: $\sim$ 8 kpc
- successful location of a source: Becklin & Neugebauer (1968): $\lambda = 2.2\ \mu\mathrm{m}$, resolution 0.62 pc and 0.2 pc
- 2D speckle imaging:
  - 600 individual stars resolved, 0.15" resolution (0.006 pc) Eckart et al. (1995)
  - complex of NIR sources very close to Sgr A* Genzel, Eckart, Ott & Eisenhauer (1997)

The Central Parsec



Genzel et al. (2003)

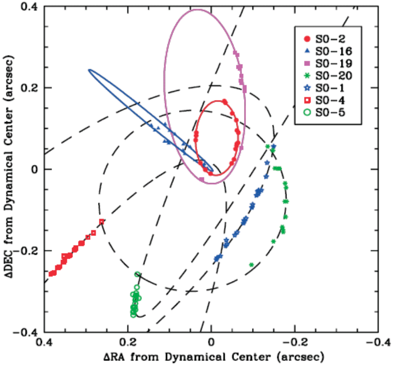


K-band: $\lambda = 2.20\ \mu m$

H-band: $\lambda = 1.60\ \mu m$

L-band: $\lambda = 3.45\ \mu m$

"Youth Paradox" – The S Stars



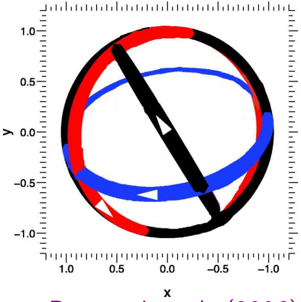
Ghez et al. (2005)

- number of B-type stars very close to GC ($\simeq 0.01$ pc)
- $M \sim 20\ M_\odot$, eccentric orbits, $a > 10^4\ R_g$ ($R_g \equiv \frac{2GM_{\rm BH}}{c^2}$ … Schwarzschild radius)
- S2 star:
  - $a \sim 930$ AU
  - $e \doteq 0.87$
  - $M \doteq 25\ M_\odot$
  - $P \sim 15$ yr
- hot topic: origin?
- further reading:
  - Genzel et al. (2003), Ghez et al. (2003), Schödel et al. (2003), Mouawad et al., (2003) & (2005)

Young Stars in Disks

Two coherent disks of massive O- & B-type stars $\simeq 0.1$ pc

- well defined inner (0.04 pc) and outer (0.5 pc) radii
- geometrically thick: $h/R \sim 0.13$
- significant eccentricities for some of stellar orbits
- young stars – (6 ± 2) Myr $\Rightarrow$ recent star formation in GC
- flat mass function, mass $\sim 10^4\ M_\odot$
- hot topic: origin?
- further reading:
  - Ghez et al. (2003), Genzel et al. (2003), Paumard et al. (2006), ...



Paumard et al. (2006)

black: the Galaxy and sky

blue: clockwise stellar disk

red: counter-clockwise stellar disk

Stellar Disks in the Galactic Centre

- massive O & B stars ("He I stars") in one or two coherent disks
  - Genzel et al. (2003), Ghez et al. (2005)
- age $\simeq 6$ Myr $\Rightarrow$ formed very close to current location
  - Paumard et al. (2006)
- similar disks detected in the centre of M31
  - Bender et al. (2005)
- clockwise disk: $e_{\rm rms} \in [0.2; 0.3]$ Paumard et al. (2006), Belobordov et al. (2006)
- counter-clockwise disk: $e_{\rm rms} \in [0.6; 0.7]$
- assuming originally circular orbits $\Rightarrow$ require presence of more massive stars in order to excite the eccentricities of these stars to those observed

Top-heavy Mass Function in the Galactic Centre

- more massive early type stars: total mass $\sim 3000\ M_\odot$
  - Genzel et al. (2003), Paumard et al. (2006)

- strong suggestion of a significantly top-heavy mass function in the GC system, with many fewer low-mass ($\lesssim 5\ M_\odot$) stars than expected from a standard Salpeter mass function
  - top-heavy mass function arises naturally for stars formed by fragmentation of an accretion disk around central BH Nayakshin et al. (2006)
  - "infalling cluster" scenario models predict similarly top-heavy mass function Gürkan & Rasio (2005), Freitag et al. (2006)

Constraints on the Stellar Mass Function

Alexander, Mitchell & Armitage, 2006, `astro-ph/0609812`

- modelling the effect of a varying mass function on the dynamical evolution of a stellar disk near the MBH
- bring in a simple analytical model
- test this model by N-body simulation
- apply the analytical model to a realistic situation, to the GC
- one-, two- or three-class mass model of the disk
  - $M \gtrsim 100\ M_{\odot}$ – removed due to their evolution
  - $M \sim 25\ M_{\odot}$ – can observe
  - $M \lesssim 5\ M_{\odot}$ – too faint, cannot see

Numerical Simulations

- N-body stellar dynamics code by Hut & Makino (2003)
- BH & stars considered as point masses
- high numerical accuracy
- strict limit on energy errors:

$$\frac{\text{typical energy of stellar encounters}}{\text{binding energy of a BH} - \text{star system}} = 10^{-4}$$

- system with 150 or fewer stars

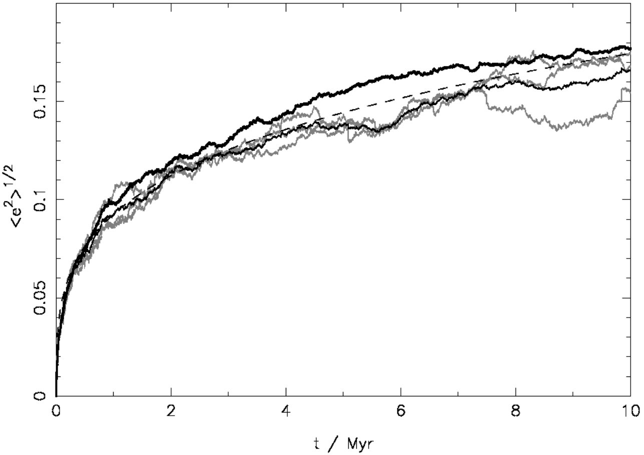
How to Generate a Single-mass Cluster?

- $M_{\rm BH} = 3 \times 10^6 \ M_\odot$
- system of 50 stars
- stars distributed in radial region between $R = (0.05 - 0.15)$ pc: $R_0 = 0.1$ pc and $\Delta R = 0.1$ pc
- spatial stellar distribution:
  - uniform in radius
  - uniform in azimuth
  - Gaussian in z
- velocity distribution:
  - Keplerian orbital velocities in the x-y plane
  - zero velocity in z-direction

Single-mass Cluster Simulation

- generate the initial conditions as discussed earlier
- integrate the system for 6000 orbital periods at R_0 ($\simeq 10^7$ yr for the parameters specified)
- each model computed with 2 different energy error tolerances $\Rightarrow$ check the numerical convergence
- compute orbital elements of each particle twice every orbital period $\Rightarrow$ plot the results

Root-mean-square Eccentricity for Single-mass Cluster



$$e_{\rm rms} = \sqrt{2}\frac{\sigma_\star}{v_{\rm K}}$$

Three-class Model of a Cluster

- consider three classes of stars in cluster: stellar counts N_1, N_2, N_3, masses M_1, M_2, M_3
- clockwise disk: 53 OB and Wolf-Rayet stars Paumard et al. (2006), masses $\simeq 20 - 30\ M_\odot \Rightarrow N_2 = 50,\ M_2 = 25\ M_\odot$
- three different IMFs:
  - Salpeter with $\Gamma = 2.35$: $M_1 = 125\ M_\odot$, $M_3 = 1\ M_\odot$
  - Salpeter with $\Gamma = 2.35$ and “low-mass cutoff”: $M_1 = 125\ M_\odot$, $M_3 = 5\ M_\odot$
  - significantly flatter MF with $\Gamma = 1.35$ Paumard et al. (2006): $M_1 = 125\ M_\odot$, $M_3 = 5\ M_\odot$
- choose N_1 and N_3 as number of stars prescribed by the mass function at exactly M_1 and M_3

Root-mean-square Eccentricity for Three-mass Cluster

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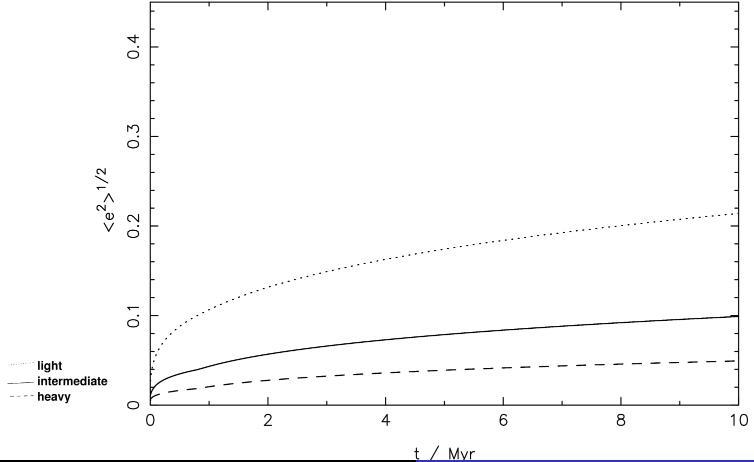

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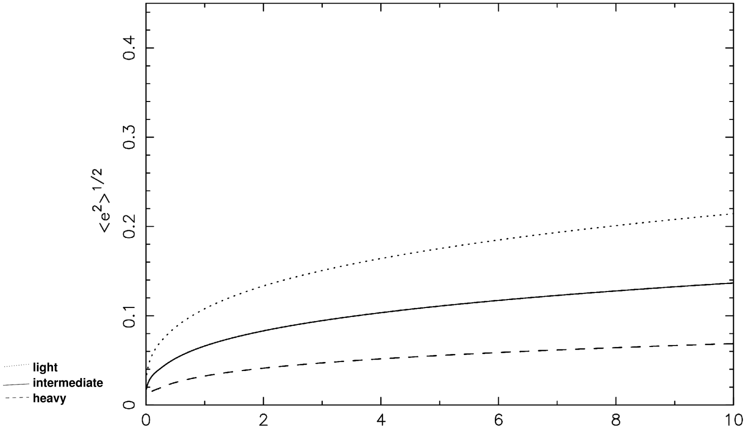

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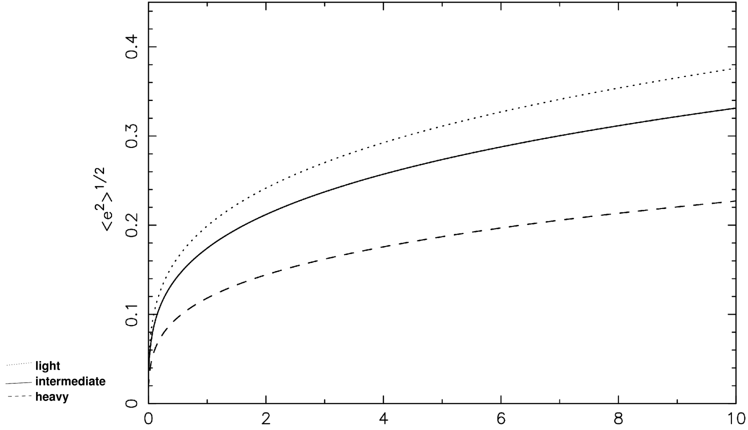

Constraints on the Stellar Mass Function

Conclusions:

- total mass in low-mass ($\simeq 5\ M_\odot$) stars must be significantly lower than expected from Salpeter mass function
- significant population of massive ($> 100 M_\odot$) stars must be present in order to produce eccentricities in the range 0.2-0.3 (observed by Paumard et al. (2006))
- dynamical relaxation alone cannot produce root-mean-square eccentricities larger than $\simeq 0.4 \Rightarrow$ counter-clockwise system is unlikely to originate in a circular disk
    - origin in eccentric accretion disk?
    - capture of a eccentric molecular cloud? Nayakshin et al. (2006)

The End