Galaxy Evolution and Cosmology: HPC, the MeerKAT/SKA and SALT

Prof Catherine Cress (UWC)
Astro People at UWC:

Prof Cress
Dr Olivier
Prof Kilkenny
Prof Koen
Dr Faltenbacher
(Dr Loubser)

+ Profs Maartems & Jarvis:
+4 postdocs/ research fellows

Postgraduates: Sean, Ando, Daniel, Solohery, Geoffrey

Undergraduates with SKA bursaries
Why Astronomy & Cosmology?

Astronomy -> fundamental physics  
(fundamental physics => technology => economic growth)

Growth of Astrophysics worldwide:  
20% of jobs in Physics Today  
13 Nobel Prizes in last 30 years

SALT & SKA & HESS: South Africa's “Great Observatories”  
and the Astronomy “business”

NRF “distinct SA research opportunity”
Scales of Interest

Earth $10^4$ km  
Sun $10^6$ km  
Solar System $10^{10}$ km  
Galaxy $10^{18}$ km
Scales of Interest

Galaxy $10^{18}$km

Cluster of Galaxies $10^{20}$km

Large-Scale Structure $>10^{22}$km
Timescales of Interest

- Cosmic microwave background
- Inflation
- Quantum Fluctuations
- Afterglow Light Pattern (400,000 yrs.)
- Dark Ages
- Development of Galaxies, Planets, etc.
- Dark Energy Accelerated Expansion
- 1st Stars (about 400 million yrs.)
- WMAP

Big Bang Expansion
13.7 billion years
Big Questions:

1. What is dark matter and dark energy or do we need gravity modified?

2. How do galaxies evolve? (especially radio data applications and simulations)
Multi-Wavelength Telescopes

Southern Africa Large Telescope (Optical)
twin to largest telescope in the world
~R200million: half from foreign partners

MeerKAT/SKA Radio Telescope
R10billion project! 17 countries either in SA or in Australia

HESS -in Namibia
Square Kilometer Array/ MeerKAT

SA Bidding to host SKA (decision 2012)

Currently building “pathfinder” called MeerKAT (80 dishes)
So far: 7 dishes constructed on site 90km from Carnarvon
+ first images!! (very impressive)

Funding to Universities:
over 100 bursary students supported
(Engineering+Science)
+ some postdocs & lecturers
+ 5 new Research chairs
+ UWC undergrad prog

> 15% DST budget
CHPC Consortium project: Modern SA Astronomy and Cosmology..

Profs Kavi Moodley (UKZN), Catherine Cress (UWC), Bruce Bassett (SAAO/UCT)

Many computationally intensive problems:

1. Instrument simulations for the Atacama Cosmology Telescope
2. N-body simulations for galaxy evolution and cosmology studies
3. Statistical techniques for experimental “forecasting” eg MCMC
Galaxy evolution and the nature of dark matter: A role for simulations

~50Mpc box (Frenk et al 1991)

Hot Dark Matter

Cold Dark Matter
Another role for simulations in galaxy evolution studies

Galaxy-scale simulations including gas

Observers thought they'd found a “starless galaxy” in HI-survey but simulations showed how the features could be explained by tidal stripping
Can reproduce properties of galaxies fairly well in Cold Dark Matter scenario. But some problems: Need additions to simple CDM theory?
Our N-body Simulation projects

1. Dark Matter-only simulation

2. Using galaxies simulated using semi-analytic techniques within dark matter structures to model eg radio galaxies

3. Dark matter AND gas simulation, with starformation, cooling etc

(using GADGET 2 & 3 at CHPC + Millenium simulation) (data exchange on LT03 tapes)

N-body code

Tree approach: $O(N \log N)$ for force calculations
(particles in hierarchy of groups, sum over multipole moments of groups)

Smoothed Particle Hydrodynamics for fluid
(represent fluid with particles which feel gravity and gas pressure)
(including prescriptions for starformation, cooling, feedback etc)

Parallel version
Simulation 1: Dark Matter only
(with students: Sean Passmoor, Daniel Cunnamo, Sarah Bryan)

512-cubed particles, 50 Mpc-cubed box
Initial conditions from CMB,
On iQudu
Simulation 2. 
Dark Matter + semi-analytic models of galaxy formation 

(students: Daniel Opolot, Fidy Ramamonjisoa, Ando Ratsimbazafy)

Millenium simulation:
10 billion particles
500 Mpc box
$10^9$ solar mass particles
run in at MPA in Germany

Modelling:
* Luminous red galaxies (for SALT cosmology expt using age-dating)
* Infra-red bright galaxies which contaminate CMB experiments
* Radio galaxies detectable with MeerKAT/SKA (AGN not HI)
Simulation 3. Dark Matter + Gas
GIMIC: Galaxies-Intergalactic Medium Interaction Calculation

students/postdocs: Daniel Cunnama, Andreas Faltenbacher, Sean Passmoor
In collaboration with Tom Theuns (Durham) and Virgo consortium)

Resimulated region from Millenium simulation at higher resolution, including gas physics
(gas dynamics, radiative cooling, star formation, chemodynamics and feedback from
supernovae-driven winds)

Used iQudu then Bluegene, then Sun M9000
Simulation 3; Dark Matter + Gas

* $5.5 \times 10^8$ particles (half gas particles, half dark matter particles)
* 18 Mpc radius sphere
* Dark Matter particle mass: $\sim 5 \times 10^6$ solar mass; gas particle $\sim 10^6$ solar

[quiz: Our galaxy mass $\sim 10^{12}$ solar, how many DM particles?]
* Sophisticated starformation, cooling, feedback winds, metal enrichment

(Other groups resimulating other regions of millennium eg low-density)

We reached $z=0$ just a few weeks ago!
Simulation 3: Dark Matter + Gas

Science Projects:


We reached $z=0$ just a few weeks ago!
Simulation 3: Gas and Stars
Summary:

* **Dark Matter + semi-analytic galaxy evolution**
  - Radio-emitting galaxies expected in MeerKAT/SKA
  - Luminous Red Galaxies ages to measure universe expansion
  - Infra-red bright galaxies contaminating CMB experiments

* **Dark Matter + Gas**
  - Planning for SALT & MeerKAT/SKA
  - Detailing theory predictions for comparison with data

Lessons: PEOPLE, PEOPLE, PEOPLE and Get-in-quick