High cluster concentrations
- A comparison using SUBARU and MareNostrum -

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Zentrum für Astronomie
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INAF - Osservatorio Astronomico di Bologna

January 26th, 2010

with: M. Meneghetti, M. Bartelmann, T. Broadhurst, M. Oguri
Strong lensing clusters

- Extremely powerful cosmological probes
  - Inner DM profile
  - Additional information to weak lensing
  - Arc statistics
- Several aspects can alter the lensing properties
  - Substructure, asymmetries and projection effects
  - cD galaxy properties
  - Gastrophysics
  - Dynamical state
- One has to be careful while interpreting individual results
The MareNostrum Universe (Gottlöber et al. 2006)

- Large cosmological hydro-simulation using GADGET2
- Gas is included, but only with adiabatic physics
- Box size: $500 \, h^{-1} \text{Mpc}$
- DM: $1024^3$ particles with a mass of $8.24 \times 10^9 M_\odot h^{-1}$
- Gas: $1024^3$ particles with a mass of $1.45 \times 10^9 M_\odot h^{-1}$
- WMAP-1 cosmology:
  - $\Omega_{m,0} = 0.3$
  - $\Omega_{\lambda,0} = 0.7$
  - $\Omega_{b,0} = 0.045$
  - $\sigma_8 = 0.9$
  - $n = 1$

Strong lenses
Selecting clusters (Meneghetti, Fedeli, Pace, Gottlöber, Yepes in prep.)

The MareNostrum Universe contains:

- $\sim 957000$ halos with $M > 5 \times 10^{11} h^{-1} M_\odot$
- $\sim 4000$ halos with $M > 5 \times 10^{14} h^{-1} M_\odot$

Two classes of strong lenses:

- Producing critical lines
- Producing giant arcs with $L/W > 7.5$

For these objects the lensing cross section $\sigma$ is measured

- 49366 critical lenses
- 6375 clusters producing giant arcs
- 11347 projections with $\sigma > 0$

Figure: inner: 50%, outer: 90%
Concentrations

Strong lenses
Orientation and triaxiality

3D shape

orientation

2D shape \(<R_{2500}\)

2D shape \(<R_{200}\)
Concentrations revisited

The analysis in Meneghetti et al. in prep. exceeds the scope of this talk. Also X-Ray luminosities and the dynamical state of the strong-lensing sample are discussed.

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Focusing on reality: Reconstruction tools (JM et al. 2009)

*SaWLens in a nutshell*

- Fully nonparametric joint reconstruction method
- Can make use of:
  - Ellipticity
  - Flexion
  - Multiple-image system
  - Critical-curve estimators
- Fully applicable to wide fields (tested with the COSMOS catalogues)
- MPI implemented
- Extensively tested

For pure strong lensing analysis we usually use *Lenstool* (Kneib et al. 1993, Jullo et al. 2007).
SaWLens performance (Meneghetti, Rasia, JM et al. 2009)
Next generation codes: AMR (Bradač et al. 2009, JM et al. 2009, JM et al. in prep.)
Next generation codes: GPU/CUDA (JM et al. in prep.)

- Problem: CPU time.
- In our case:

\[ F_{lk} = a_i b_j C_{ij} D_{il} E_{jk} \]
\[ G_l = a_i b_j C_{ij} E_{il} \]
\[ l, k, i, j \sim O(\text{grid\_dim}^2) \]

- A lot of simple arithmetic operations with no need for double precision.
  ⇒ GPU implementation
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- \(\Rightarrow\) GPU implementation

NVIDIA Tesla C1060

- 240 streaming cores
- 4 GB DDR3 GPU memory
- 933 GFLOPS peak performance
- CUDA interface (C-based)
- Host-code allows for MPI
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⇒ GPU implementation

- Gains a lot of momentum in the astrophysics community, suggestions welcome!

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Expected performance (on the back of an envelope)

- Right now: 3hrs for a highly resolved reconstruction on a 24 core, InfiniBand, Linux cluster.
- $\sim 60$ GFLOPS on a state-of-the-art quadcore CPU $\Rightarrow 360$ GFLOPS on the cluster.
- Because of process communication $\Rightarrow$ effectively $\sim 300$ GFLOPS.
- $933/300 \sim 3 \Rightarrow 1$hr runtime on a desktop machine.
- But, GPU+MPI possible $\Rightarrow$ minute scale already in range if you need it.
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Possible targets (JM et al. in prep)

- SUBARU sample Broadhurst et al. 2008
- SUBARU sample Oguri et al. 2008
- SUBARU cluster CL0024+1654 Umetsu et al. 2009
- LBT cluster A611 Donnarumma et al. in prep.
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  **TABLE 1**

  **The Subaru Distortion Measurements Combined with the Einstein-Radius Constraint**

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<td>SDSS2111</td>
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  ![Table 1: The Subaru Distortion Measurements Combined with the Einstein-Radius Constraint](image)

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<td>43 ($z_s = 1.5$)</td>
<td>0.606</td>
<td>0.088</td>
<td>2.93$^{+0.08}_{-0.12}$</td>
<td>7.75$^{+0.61}_{-0.62}$</td>
</tr>
<tr>
<td>RX J1347−11</td>
<td>0.451</td>
<td>$V_R R_c$</td>
<td>35 ($z_s = 1.8$)</td>
<td>0.553</td>
<td>0.066</td>
<td>1.47$^{+0.28}_{-0.33}$</td>
<td>10.42$^{+1.23}_{-2.13}$</td>
</tr>
</tbody>
</table>

- SUBARU sample Oguri et al. 2008

<table>
<thead>
<tr>
<th>Name</th>
<th>Weak lensing</th>
<th>Strong and Weak lensing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$M_{vir}$ $(10^{15} M_\odot)$</td>
<td>$c_{vir}$</td>
</tr>
<tr>
<td>A1703</td>
<td>1.95$^{+0.55}_{-0.50}$</td>
<td>3.3$^{+1.4}_{-1.1}$</td>
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<tr>
<td>SDSS1446</td>
<td>0.83$^{+0.29}_{-0.25}$</td>
<td>9.1$^{+1.4}_{-1.1}$</td>
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<tr>
<td>SDSS1531</td>
<td>0.56$^{+0.26}_{-0.26}$</td>
<td>11.5$^{+2.1}_{-2.4}$</td>
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<tr>
<td>SDSS2111</td>
<td>0.92$^{+0.41}_{-0.32}$</td>
<td>14.1$^{+2.9}_{-2.5}$</td>
</tr>
</tbody>
</table>

- SUBARU cluster CL0024+1654 Umetsu et al. 2009
- LBT cluster A611 Donnarumma et al. in prep.
CL0024+1654 (JM et al. in prep.)
CL0024+1654 (JM et al. in prep.)

Strong lenses
Conclusions

1. Strong lensing clusters are important cosmological probes, but we have to understand better their properties.
2. The MareNostrum Universe delivers a large sample of strong lenses.
3. High cluster concentrations are not surprising for effective gravitational lenses.
4. Second generation nonparametric codes allow for a reliable comparison between observations and simulations.
5. GPU implementations will radically reduce the runtime of these methods.