Combined Weak Lensing, Optical, and X-Ray Search for Galaxy Clusters

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AIP

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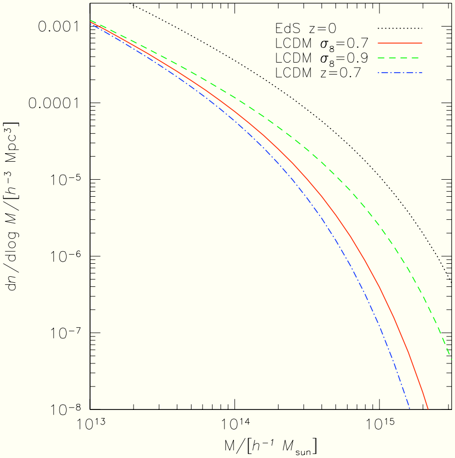
Galaxy Cluster Mass Function



Cluster mass function depends on

- cosmology (Ω_m, σ_8, ...)
- redshift

(Evolution of) Cluster mass function is cosmological probe.

Reliability of the Mass Function

Potential Problems

- Sample completeness.
- Mass function predicts dark matter halo number density.
  We observe baryonic matter.
- How reliable are our mass estimates?
  Need assumptions on dynamical/hydrostatic equilibrium.
- Do optical and X-ray cluster searches select the same population?
  Indication that this is not the case (Popesso et al. 2006).

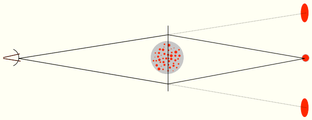
Possible Solution

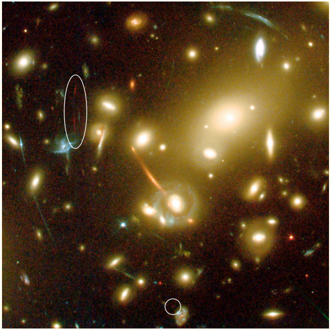
Gravitational lensing

- is sensitive to dark and luminous matter.
- makes no model assumption

Weak Lensing Overview

Strong Lensing – Weak Lensing





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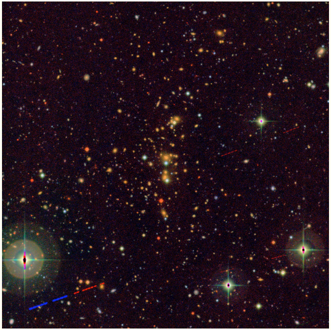
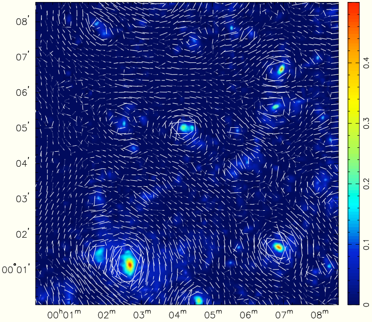


This work

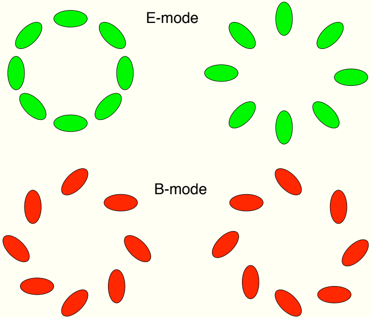
Lensing shears and magnifies background galaxies.

The Effect of Lensing on Background Sources



Projected mass κ can be recovered from shear.

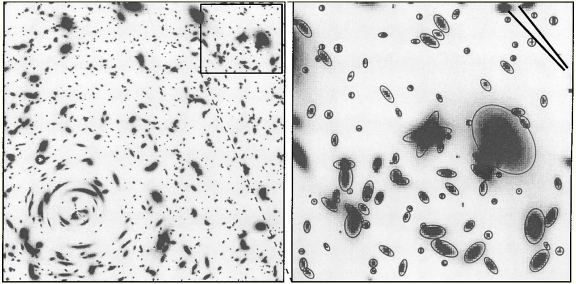
Lensing is always curl-free.



Curl not caused by lensing.

Measuring Shear

- Expectation value of intrinsic ellipticies vanishes, $\left\langle \varepsilon^{(\mathrm{s})} \right\rangle = 0$
- In weak lensing $\kappa \ll 1$, $|\gamma| \ll 1$: $\varepsilon \approx \varepsilon^{(\mathrm{s})} + \gamma$
- Estimate the shear from observed ellipticities



Y. Mellier

Galaxy Cluster Search

The XMM-Newton Follow-Up Survey

Dietrich et al. (2006, A&A 449, 837)

WFI imaging of deep, public XMM-Newton fields.

ESO Public Survey (EIS, SSC, AIfA)

- 15 (4 galactic & 11 extragalactic) fields in BVRI.
- Provide optical counterparts for X-ray sources.
- Public Data Release July 2005, available from ESO archive.

Private extension (AIfA, AIP)

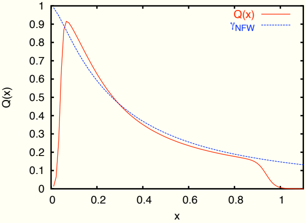
- 14 additional fields in B and R.
- Weak lensing search for galaxy clusters.

The total area of the public and private survey is $\sim 6\,\mathrm{sq.\,deg.}$

The Aperture Mass Statistic M_{ap}

Aperture mass M_{ap} is weighted integral of tangential shear:

$$M_{\mathrm{ap}}(\vec{\theta}_0) = \int \mathrm{d}^2\theta \, Q(|\vec{\theta} - \vec{\theta}_0|)\gamma_{\mathrm{t}}(\vec{\theta}; \vec{\theta}_0)$$



- Optimize for expected signal (matched filter technique).
- Unfortunately, weak lensing is very noisy ($\sigma_\varepsilon \gg \gamma$, LSS).

Consequences of Noise

Known problems

M_{ap} cluster finder is noisy. Consequences:

- Lensing search for clusters will always be incomplete, except at the highest masses.
- Lensing surveys will always have $> 15\%$ false detections (Hennawi & Spergel 2005)
- Lensing peak positions show large offsets from halo center.

What to do?

Use realistic ray-tracing simulations to

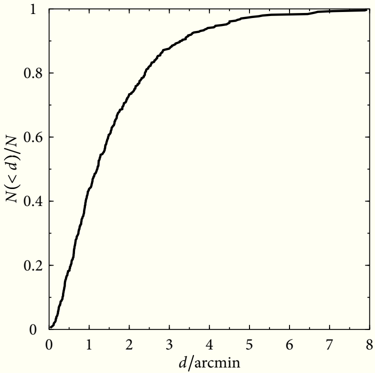
- Optimize the selection criteria (significance, M_{ap}-filter scales, ...)
- Fix search radius to associate with cluster candidates.

Ray-tracing Simulations

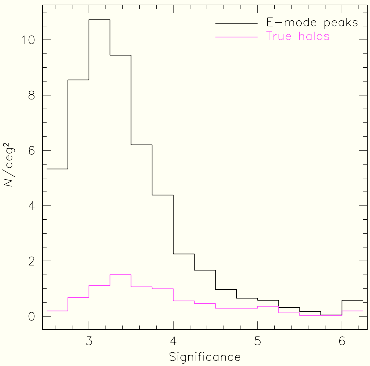
- Use GIF simulations of VIRGO consortium.
- Use masks from our catalogs to simulate the holes of bright stars.
- Compute M_{ap} in 9 filter scales, corresponding to masses from ~ 1–$20 \times 10^{14}\,h^{-1}\,M_{\odot}$.
- Output
  - M_{ap}
  - $M_{\mathrm{ap}_{\times}}$ rotation by 45 deg.
  - $M_{\mathrm{ap}_{\mathrm{random}}}$ with random galaxy orientation.
- Associate M_{ap}-peaks with DM halos $M > 10^{14}\,h^{-1}\,M_{\odot}$, $0.1 < z < 0.7$

Offsets between M_{ap}-Peaks and DM Halos

- Association of M_{ap}-peaks with DM halos: 434 matches.
- Expect 25% random matches.
- 75% of all matches made within $2\overset{\prime}{.}15$ (Hennawi & Spergel used $3'$).

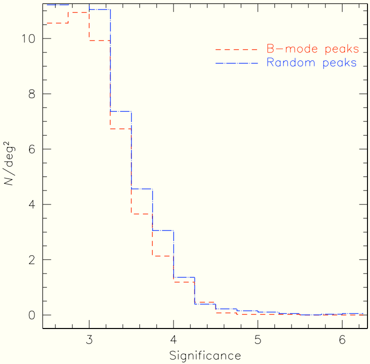


Peak Significances



- Significant fraction of false positives at all SNR.

Peak Significances



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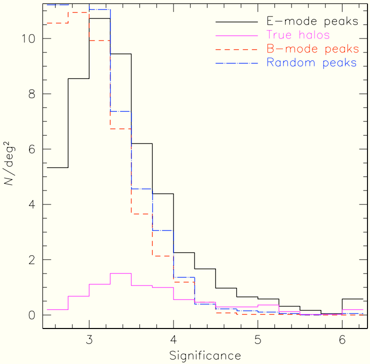

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- Shape noise dominates below $\sim 4.25\sigma$, then LSS projections take over

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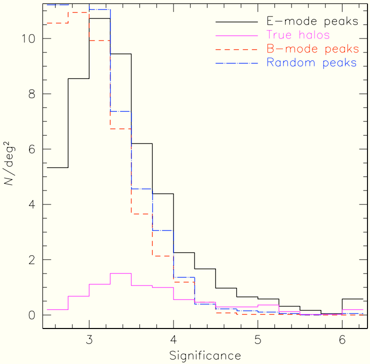

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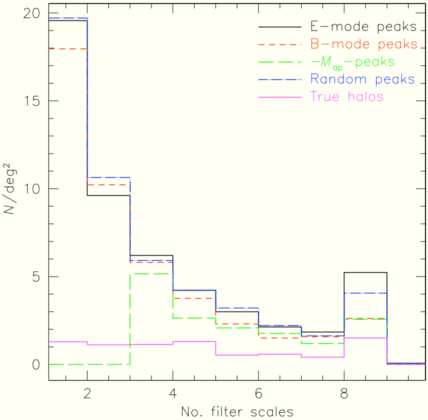
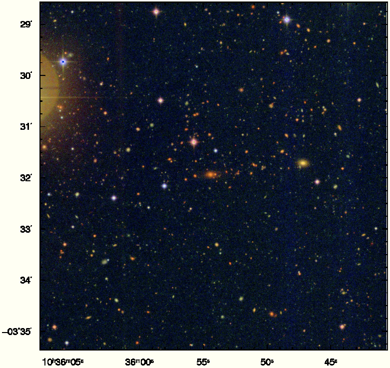
- 3σ M_{ap} not good enough.
- Not enough 5σ peaks in 6 sq. deg.
- Need to combine with other methods (optical, X-ray).

Dependance on Filter Scale



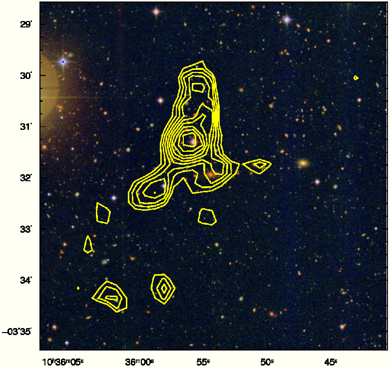
- Noise peaks preferentially in fewer filter scales.
- Real halos occur in all numbers of filter scales.

Weak Lensing Selection Criteria



- At least 3 filter scales and
- SNR > 3
- M_{ap} peak within 2'.15 of X-ray, matched filter, or previously known cluster or
- SNR > 5

Weak Lensing Selection Criteria



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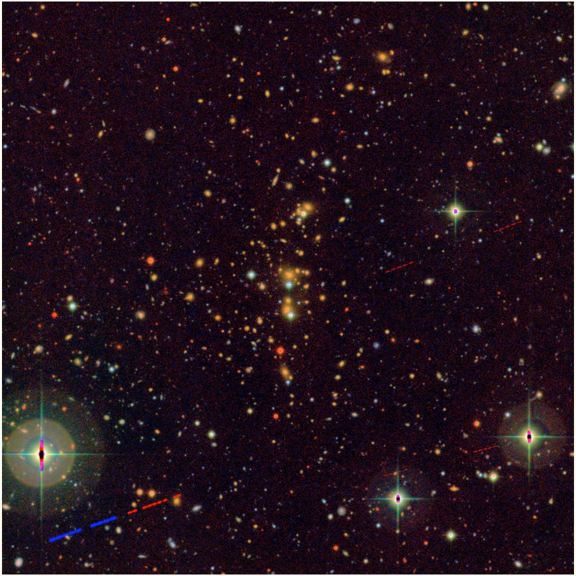
- $M_{\rm ap}$ peak within 2′.15 of X-ray, matched filter, or previously known cluster or
- SNR > 5
- One example of 31 cluster candidates: BLOX J1035.9−0331.9, $\sigma = 3.7$.

Another Weak Lensing Cluster



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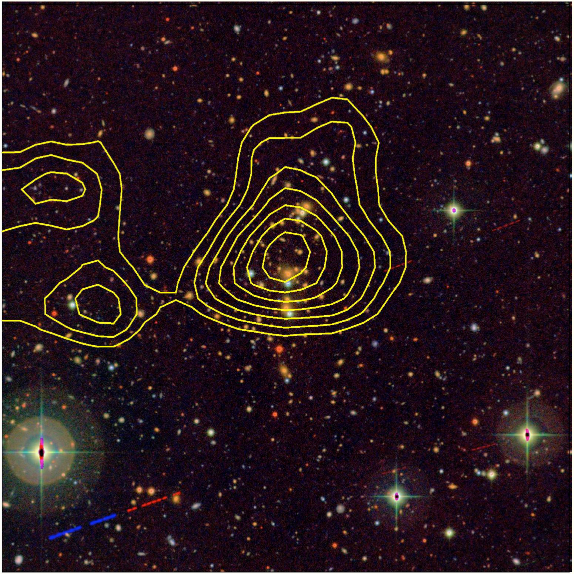
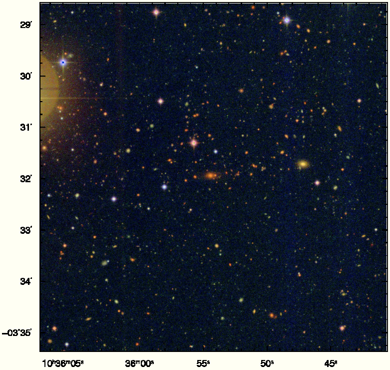


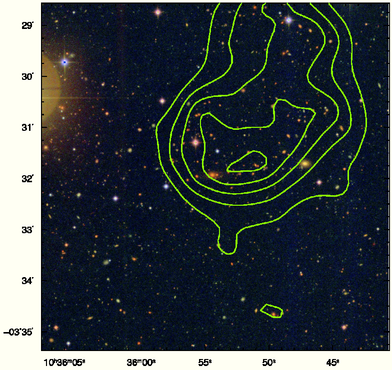
Optical Cluster Search



Optical Matched Filter (Postman et al. 1996):

- Single passband method.
- Convolve galaxy catalog with radial filter (Hubble, NFW, . . .) and luminosity filter (Schechter function).
- Redshift dependence of luminosity function gives z estimate.

Optical Cluster Search



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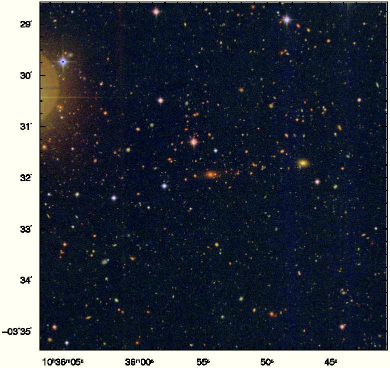
- Redshift dependence of luminosity function gives z estimate.
- One example of 116 cluster candidates: BLOX J1035.9−0331.9, $z = 0.4$.

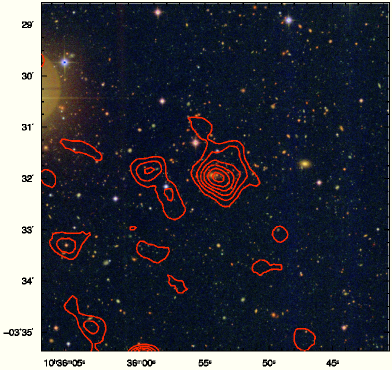
X-ray Search



Search for extended X-ray sources:

- Galaxy clusters are extended source. (Nearly) everything else is a point source.
- Detect X-ray sources on XMM-Newton images. Perform multi-PSF fit to get extent likelihood.

X-ray Search



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- Detect X-ray sources on XMM-Newton images. Perform multi-PSF fit to get extent likelihood.
- Same example: BLOX J1035.9−0331.9 One of 59 X-ray detected cluster candidates.

Results

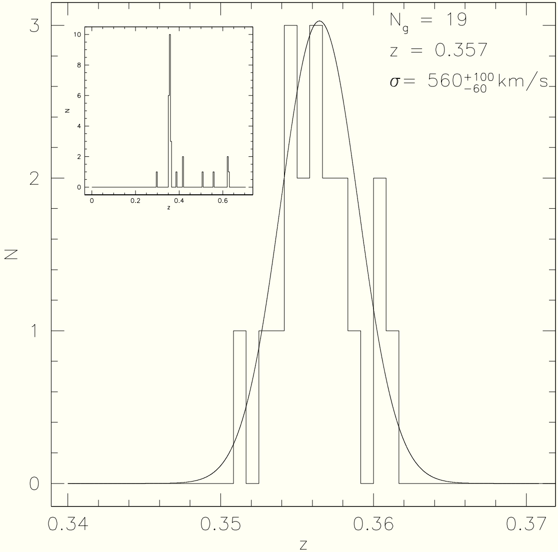
Catalog

- 116 optical matched filter selected cluster candidates.
- 59 X-ray selected cluster candidates
- 31 weak lensing selected cluster candidates.
- 15 with X-ray counterparts.
- 26 with matched filter counterparts.
- 12/31 cluster previously known.
- 12 detected in both X-ray and optical matched filter.
- 6/12 of those previously known.

Comparison with Ray-Tracing

	Simulation	Survey
Number density (all clusters)/sq. deg.	6.1	4.8
Number density ($\sigma > 4$)/sq. deg.	2.3	1.6

Spectroscopic Confirmation – BLOX J1035.9−0031.9



Cluster Search Summary

- Second biggest lensing selected cluster sample to date.
- Lensing is not suited to generate reliable cluster catalogs. Cosmology is still possible by direct comparison with ray-tracing simulations
- Dominant noise source at low significances is shape noise, projections of LSS take over at SNR $\geqslant 4.25$
- Matching radii in the literature preferentially too large, efficiency even lower.
- We now have a cluster sample that allows a detailed comparison of cluster properties and selection effects.
- Follow-up spectroscopy underway. First confirmation made.
- Details available in Dietrich et al. 2007, A&A 470, 821.