

Inferring Cluster Masses using Intracluster Light *(is it even possible?)*

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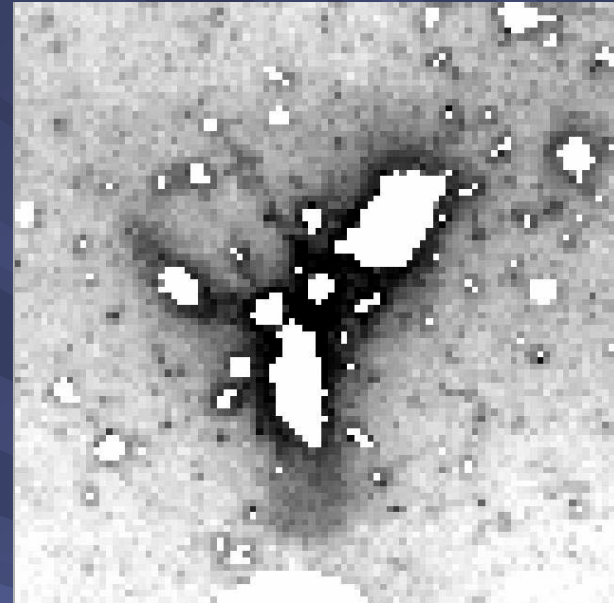
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Collaborators:

Computational: **Craig Rudick (CWRU)**, Cameron McBride (Vanderbilt), Andrew Schechtman-Rook (Wisconsin), Lucy Frey (LANL), Matt McJunkin (CWRU)

Observational: **Paul Harding (CWRU)**, Craig Rudick (CWRU), Steven Janowiecki (Indiana), John Feldmeier (Youngstown State), Heather Morrison (CWRU), Colin Slater (CWRU)

ICL in formation: Abell 1914



Merging cluster w/ extensive cluster-wide substructure.

From Feldmeier et al (2004).

See also Gregg & West (1998); Calcaneo-Roldan et al (2000), Gonzalez et al (2005); Zibetti et al (2005); Krick and Bernstein (2007), etc....

So why study ICL?

Tracer of cluster accretion history

Collisionless populations potentially hold information on accretion history and kinematics longer than hot gas.

Tracer of galaxy evolution in clusters

Indicators of interactions; orbital tracers; discrimination between gravitational and hydrodynamical effects

Photometrically and kinematically accessible

Deep imaging, discrete populations (red giants, globular clusters, PNe) give kinematic and population information.

Kinematics of the ICL

ICL kinematics in the Virgo Cluster have been measured via PNe.

(*Arnaboldi et al 1996, Freeman et al 2000, Arnaboldi et al 2002, 2004*)

Doherty et al 2009

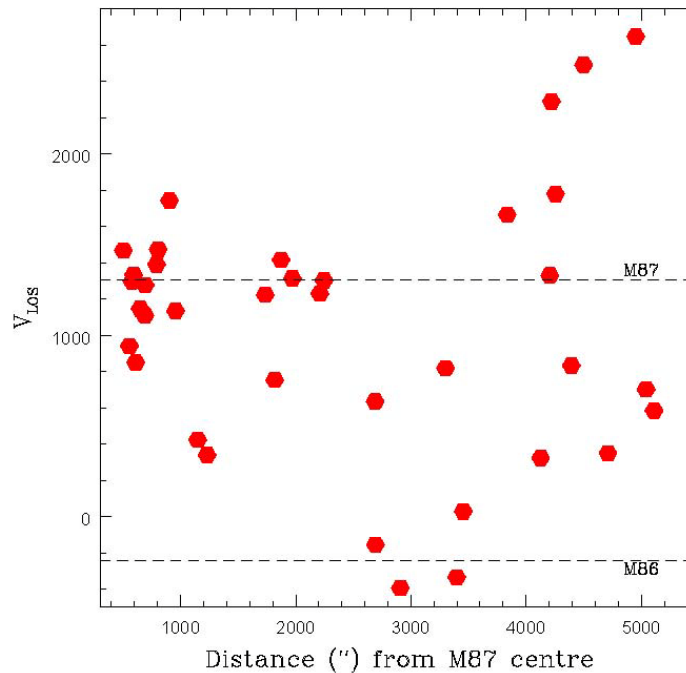


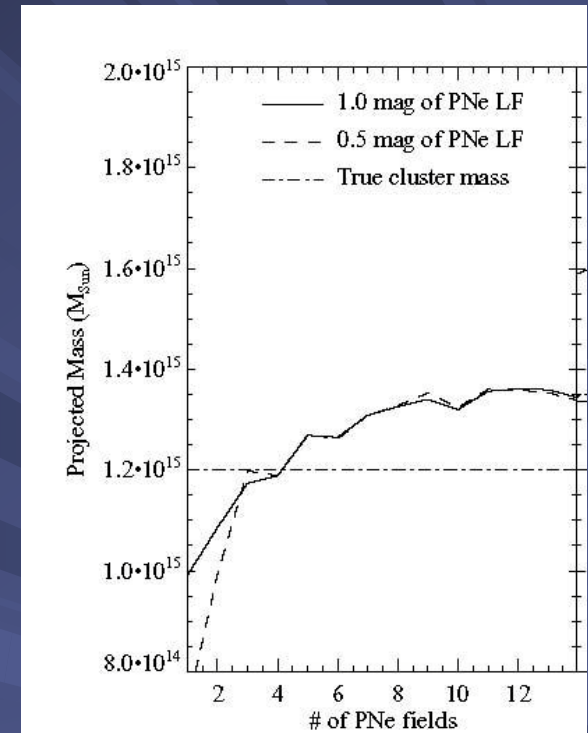
Fig. 8. Distribution of line-of-sight velocity versus projected distance from the center of M87 for all spectroscopically confirmed PNs in the new fields as well as the FCJ and Core fields of A04.

Can ICL kinematics be used to infer cluster mass?

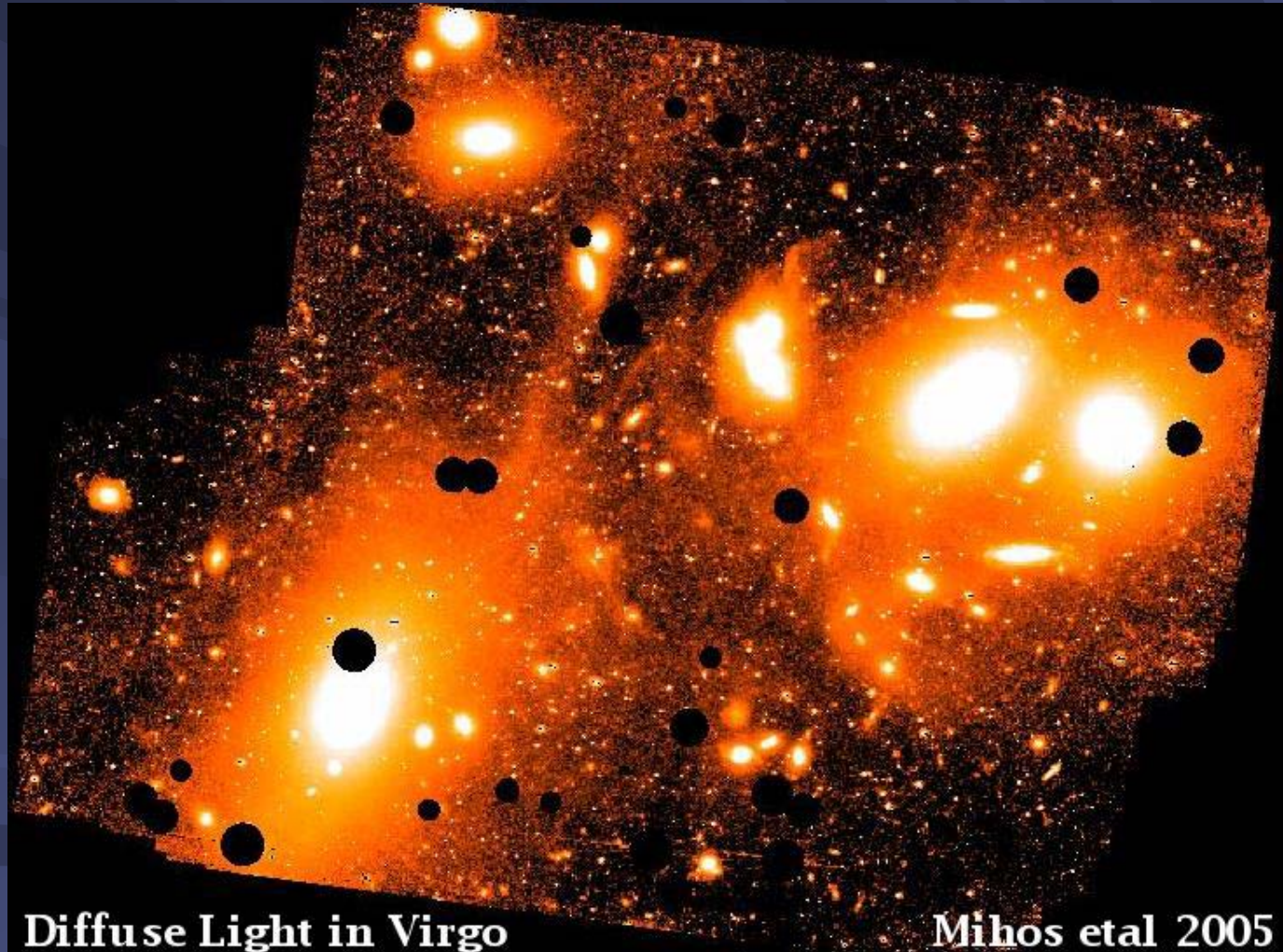
Potentially $O(10^4)$ IPNe to use as tracers.

Willman et al (2004): Used simulations to show that the mass inferred from IPNe velocities quickly converges to a value which is only slightly overestimated ($\sim 10\%$).

Surprising, given that ICL is likely to have significant kinematic substructure, and be more concentrated than the mass distribution (Murante et al 2004; Sommer-Larsen et al 2005; Zibetti et al 2005)



Intracluster Light in Virgo



Simulating ICL

- Dark matter simulation of a volume of the universe ~ 150 Mpc on a side.
- Choose a $z=0$ cluster mass halo, track particles back to $z=2$, identify galaxy-scale halos destined to end up in the cluster.
- Insert higher resolution galaxy models (E's and S's) into these halos
- Resimulate to $z=0$

Cluster properties:

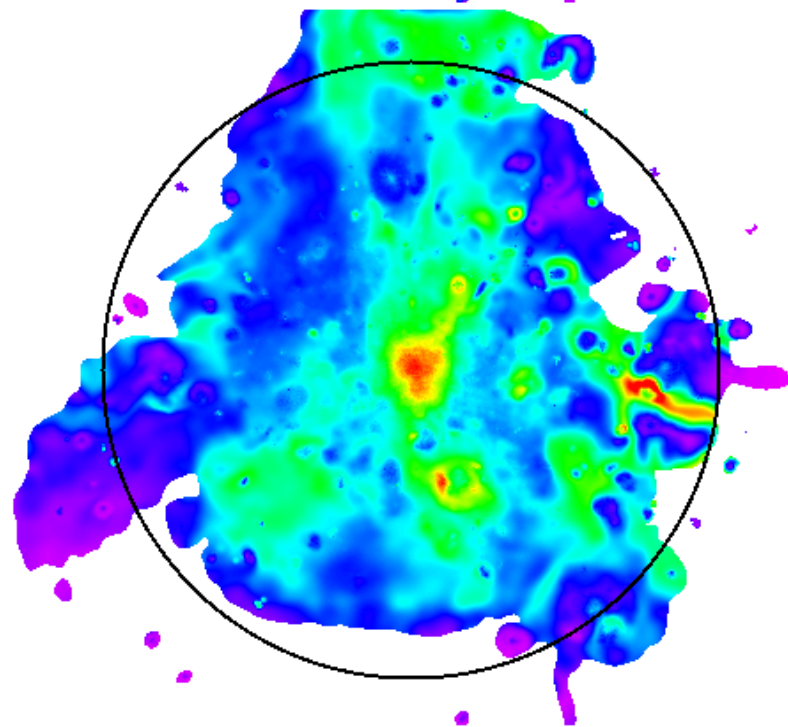
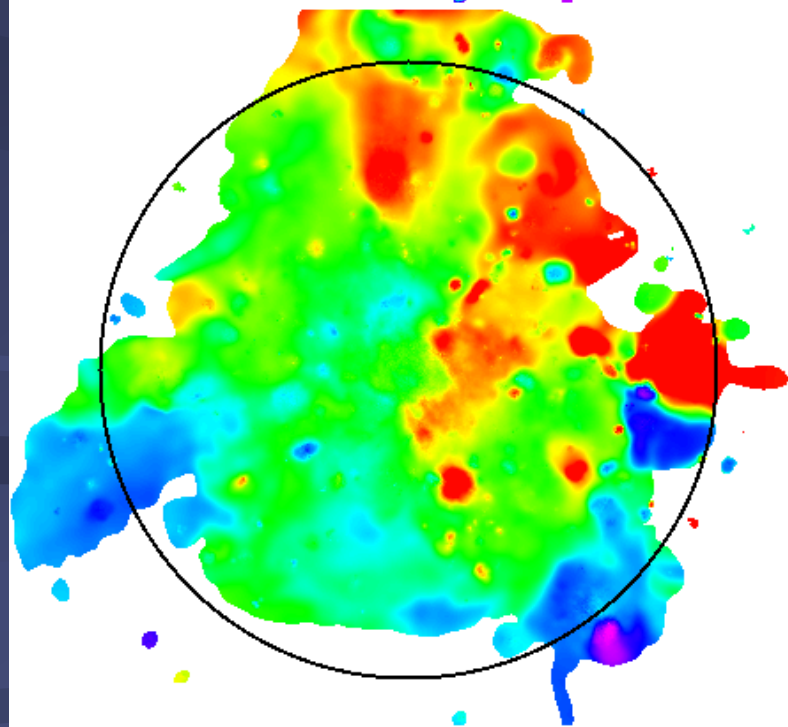
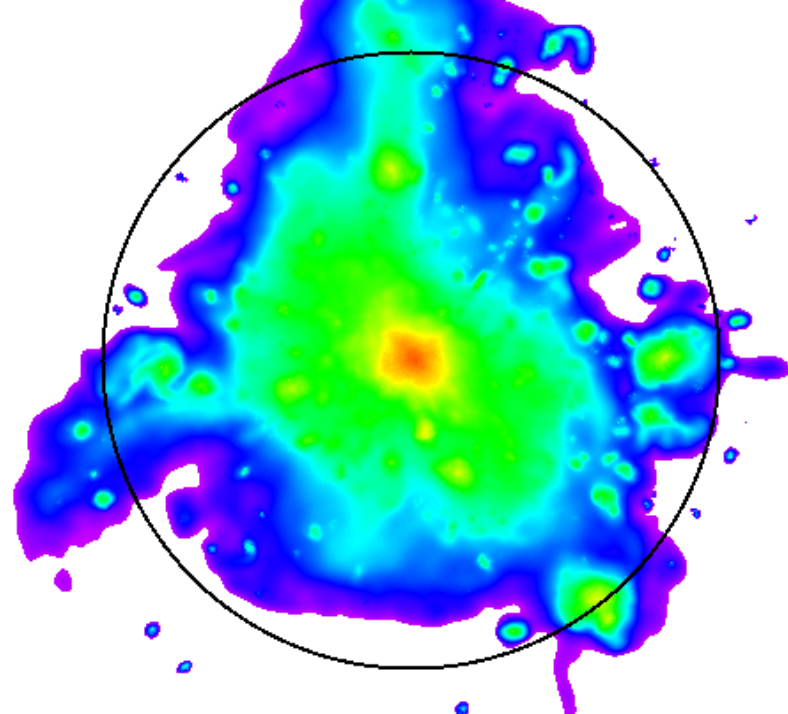
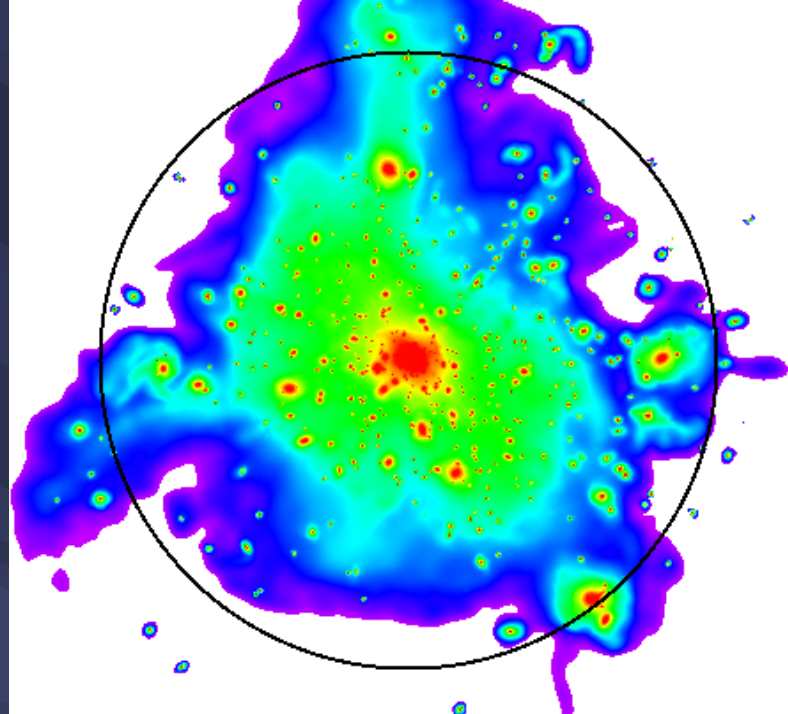
- $M_{200} \sim 7 \times 10^{14} M_{\text{sun}}$
- $R_{200} \sim 1.8$ Mpc
- initially ~ 900 galaxies down to 10% MW mass

Characterizing Kinematics

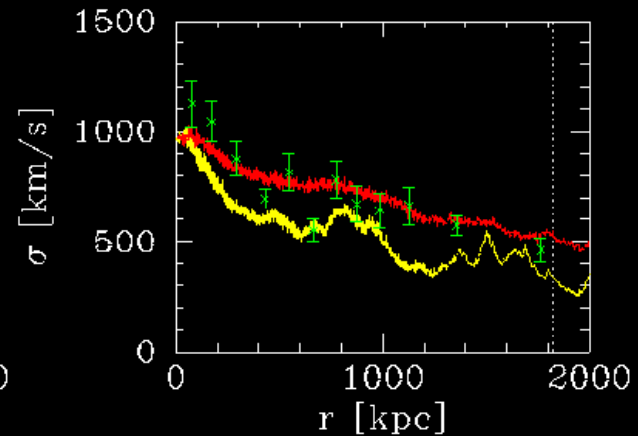
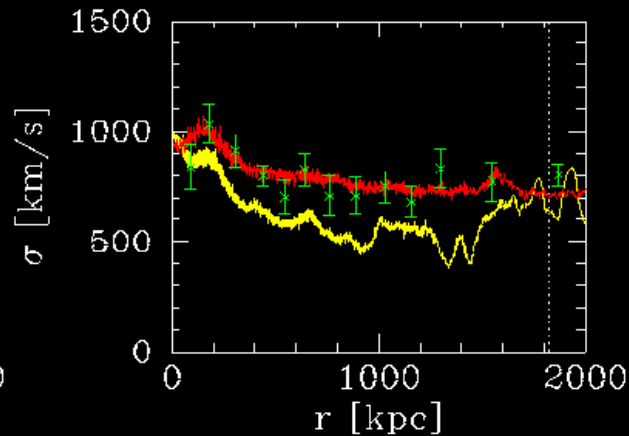
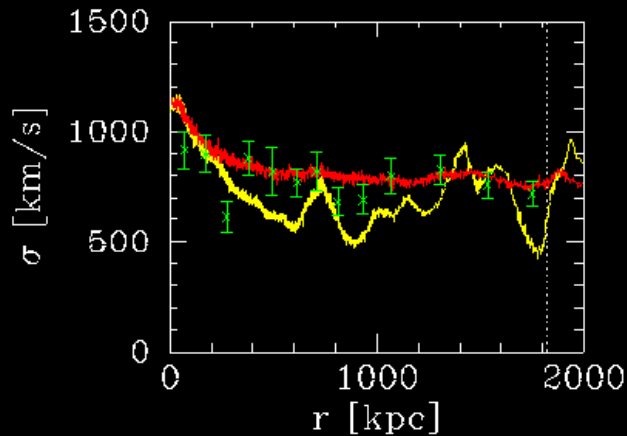
➤ *“nonequilibrium motion gives you more information to study, it’s just harder to mine it.” –Simon White*

So... calculate moments of the projected velocity distributions

- “ σ ” = second moment of the line-of-sight velocity distribution of a sample
- no attempt (yet) to fit/correct for any rotation...
- *often far from any gaussian-like profile*



Projected “Velocity Dispersion” Profiles



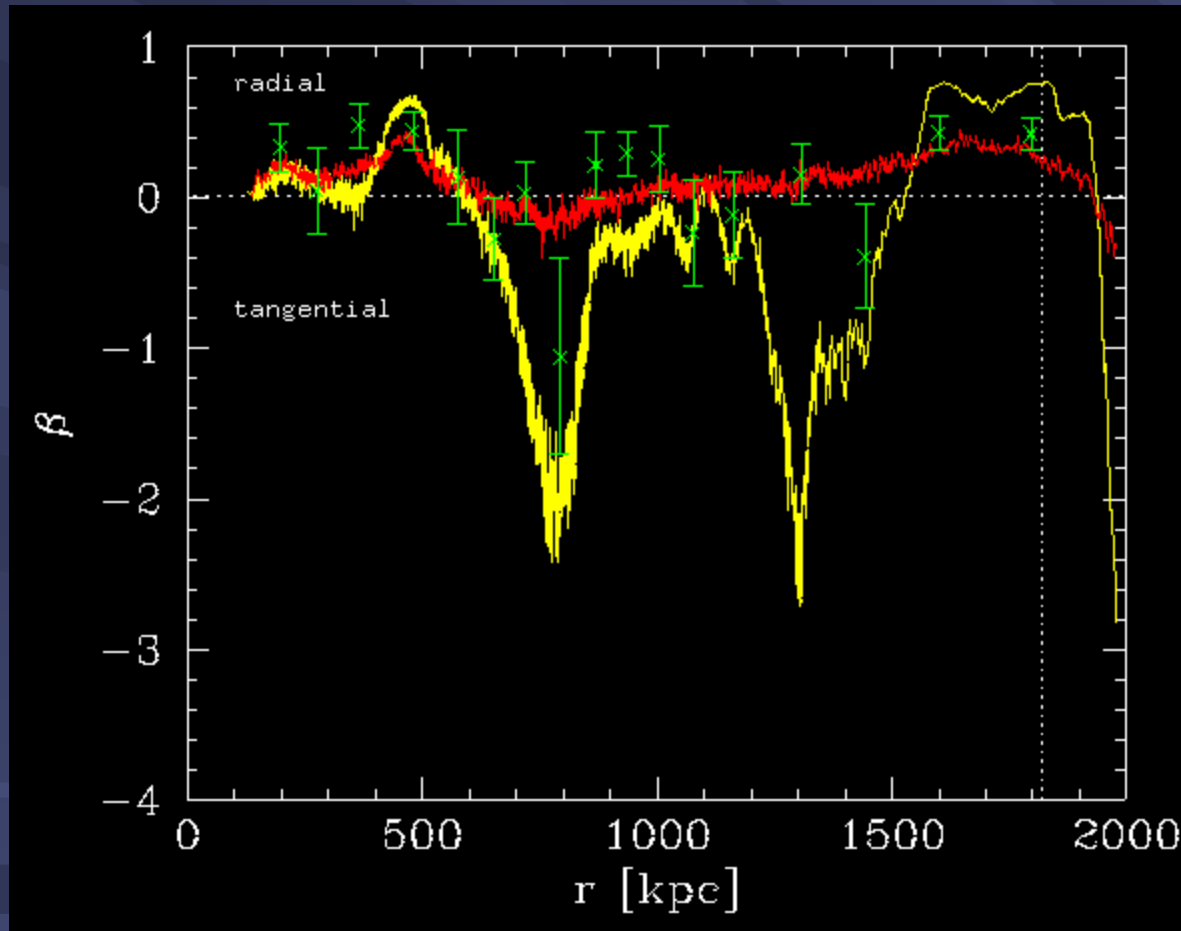
Red = Dark matter

Yellow = Intracluster Light

Green = Galaxies (*with bootstrap errorbars*)

(*compare also to simulations by Willman et al 2004, Sommer-Larsen et al 2005*)

Velocity Anisotropy Profile



Red = Dark matter
Yellow = Intracluster Light
Green = Galaxies (*with bootstrap errorbars*)

Kinematic Tracers - IPNe

The Good:

- Fair tracers of the underlying stellar population
- $\sim O(10^4)$ IPNe in Virgo
- Emission line objects: can measure their velocities

The Bad:

- Rare
 - ~ 1 bright PN per $10^8 L_{\text{sun}}$ in B
 - $\mu_v=26 \implies 0.01 \text{ PN/kpc}^2$
- Observational demands
 - Find them through narrowband imaging (4m class)
 - Get follow-up spectra (6-8m class)

Boldly go forth...

Simple question: Given that ICL has substructure, and that sampling is difficult (observationally and physically), how good (or bad) can a cluster mass estimate be using IPNe?

Following Willman et al (2004), use the projected mass estimator* (e.g., Heisler, Tremaine, and Bahcall 1985) to get a mass.

$$M = \left(\frac{32}{\pi GN} \right) \sum_{i=1}^N R_i (v_i - \bar{v})^2$$

* “use a method which is commensurate with the information content of the data” – Roeland van der Marel

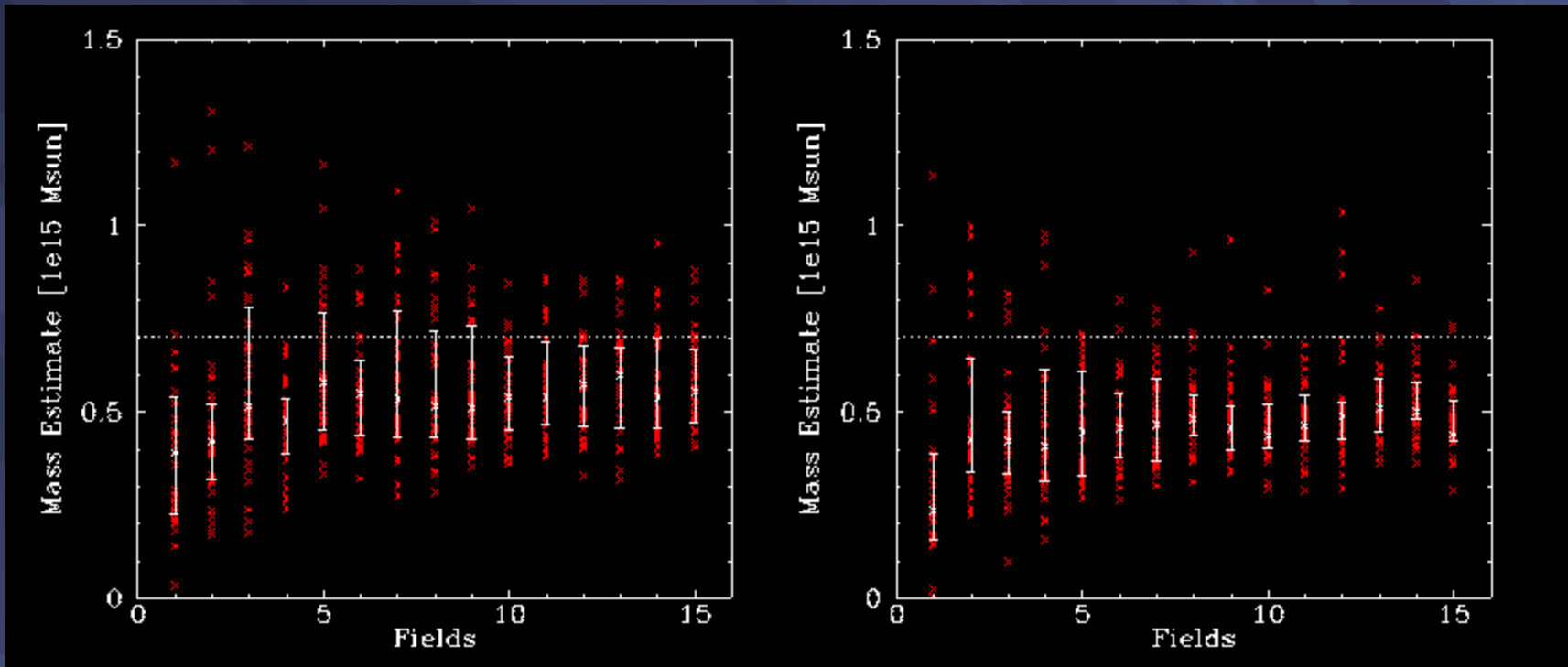
Boldly go forth...

Rules of the game:

- You have to sample IPNe in individual fields (125 kpc or 250 kpc boxes)
- You get 30 IPN velocities *maximum* per field.
- Pick random fields around $0.5 R_{200}$.

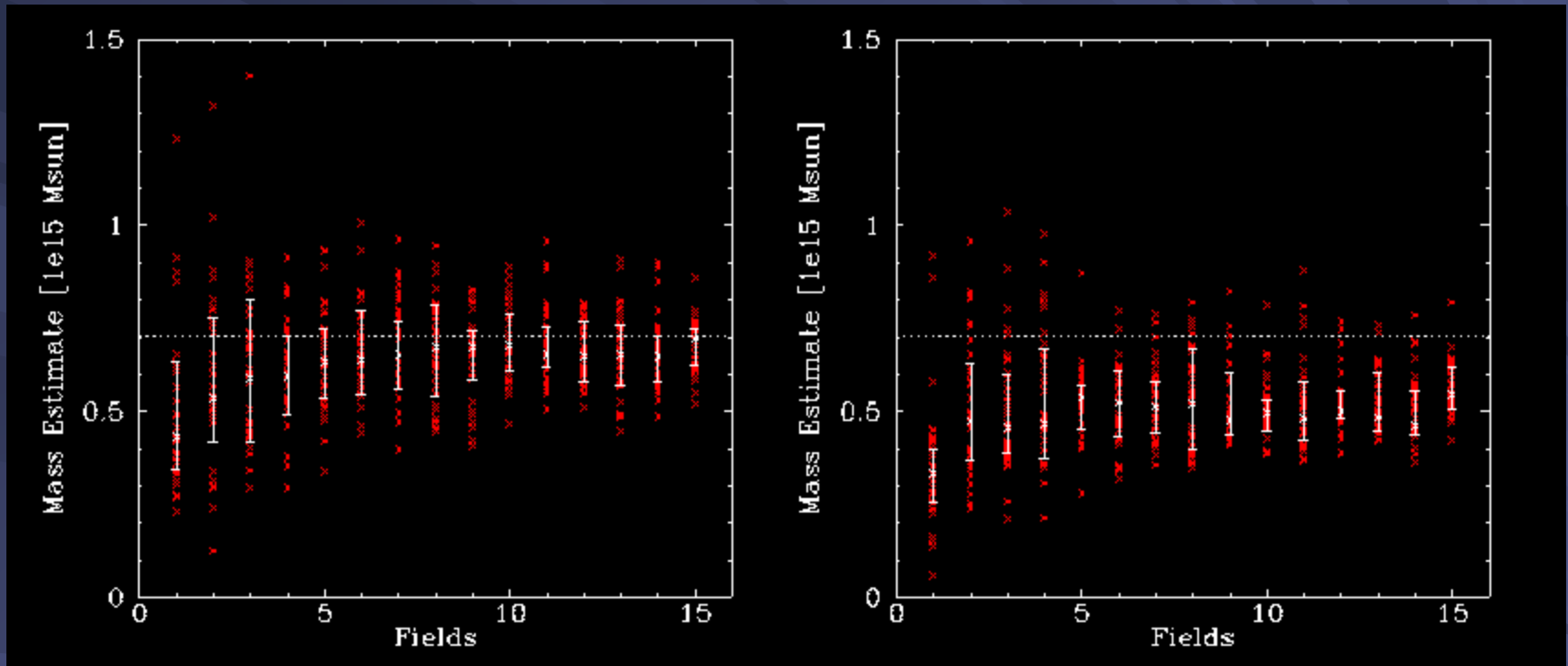
How well does it work? How quickly does it converge?

...and estimate a mass!



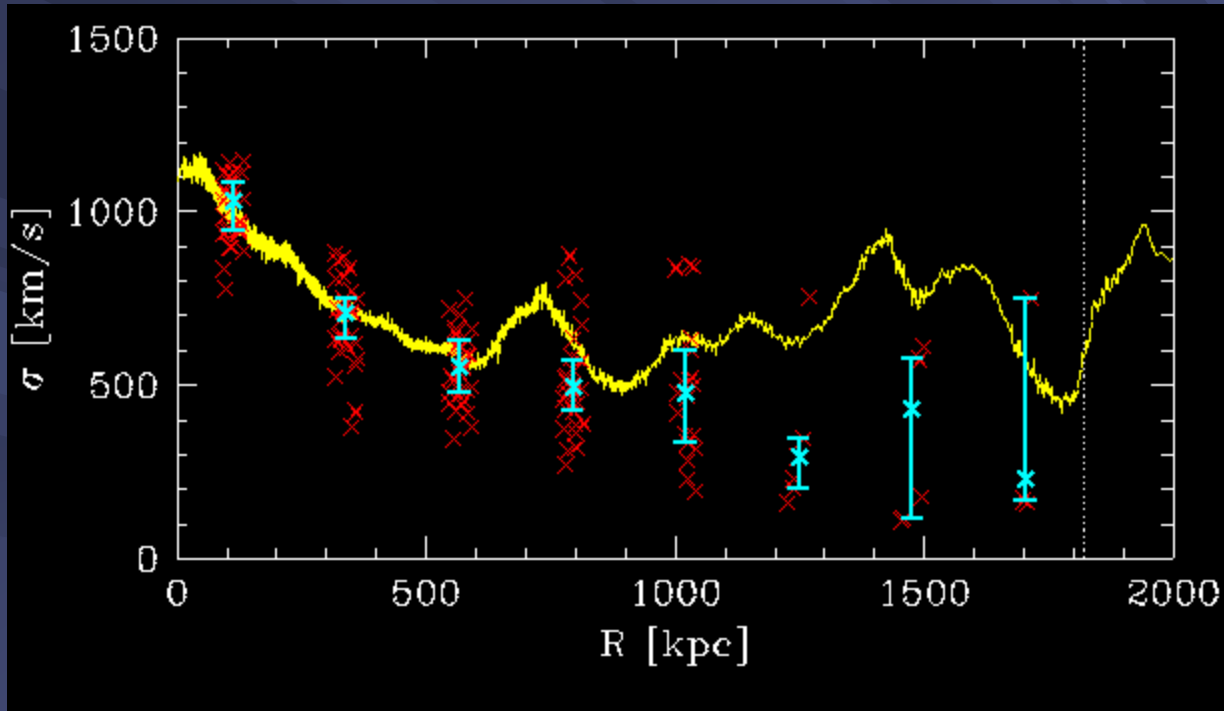
125 x 125 kpc² fields

...and estimate a mass!



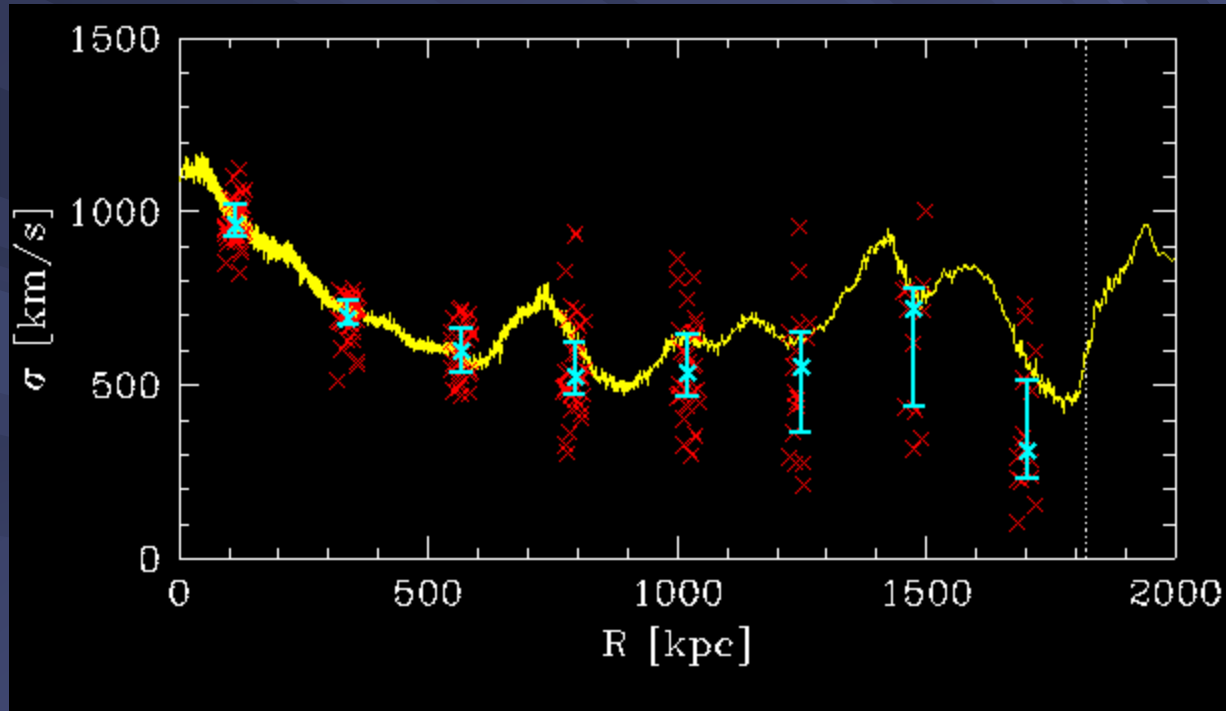
250 x 250 kpc² fields

What about recovering the dispersion profile?



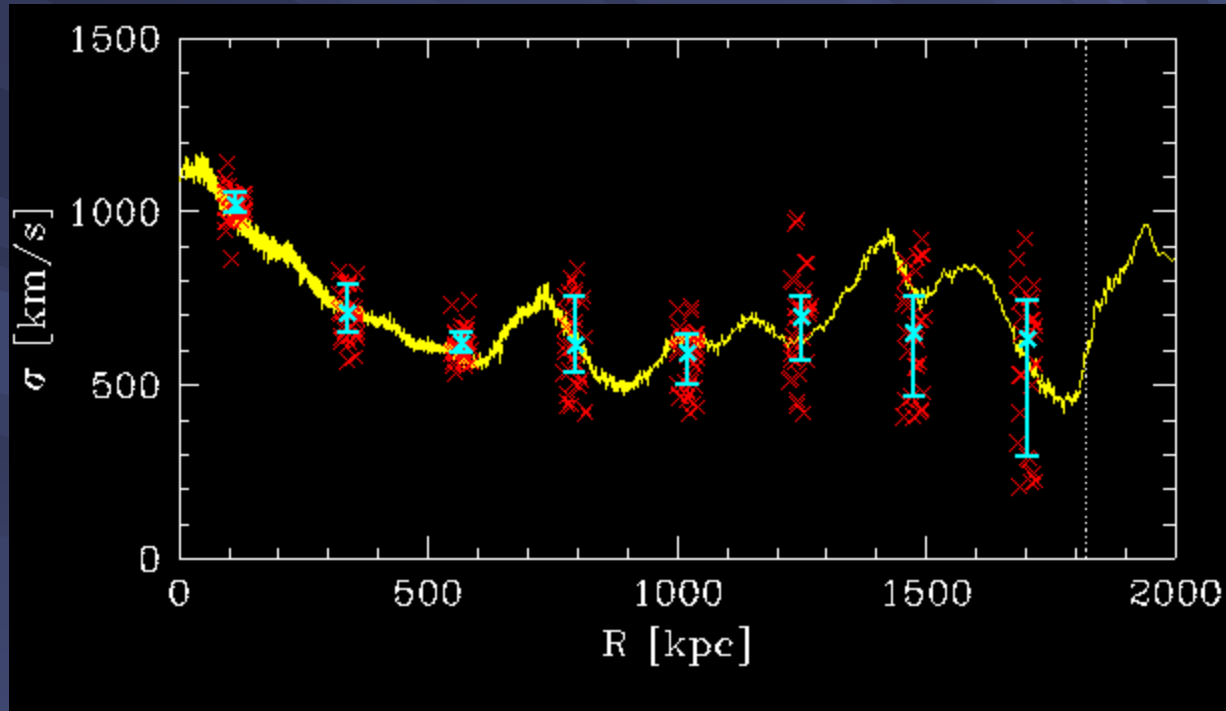
Three 125 x 125 kpc² fields per radius bin

What about recovering the dispersion profile?



Seven 125×125 kpc² fields per radius bin

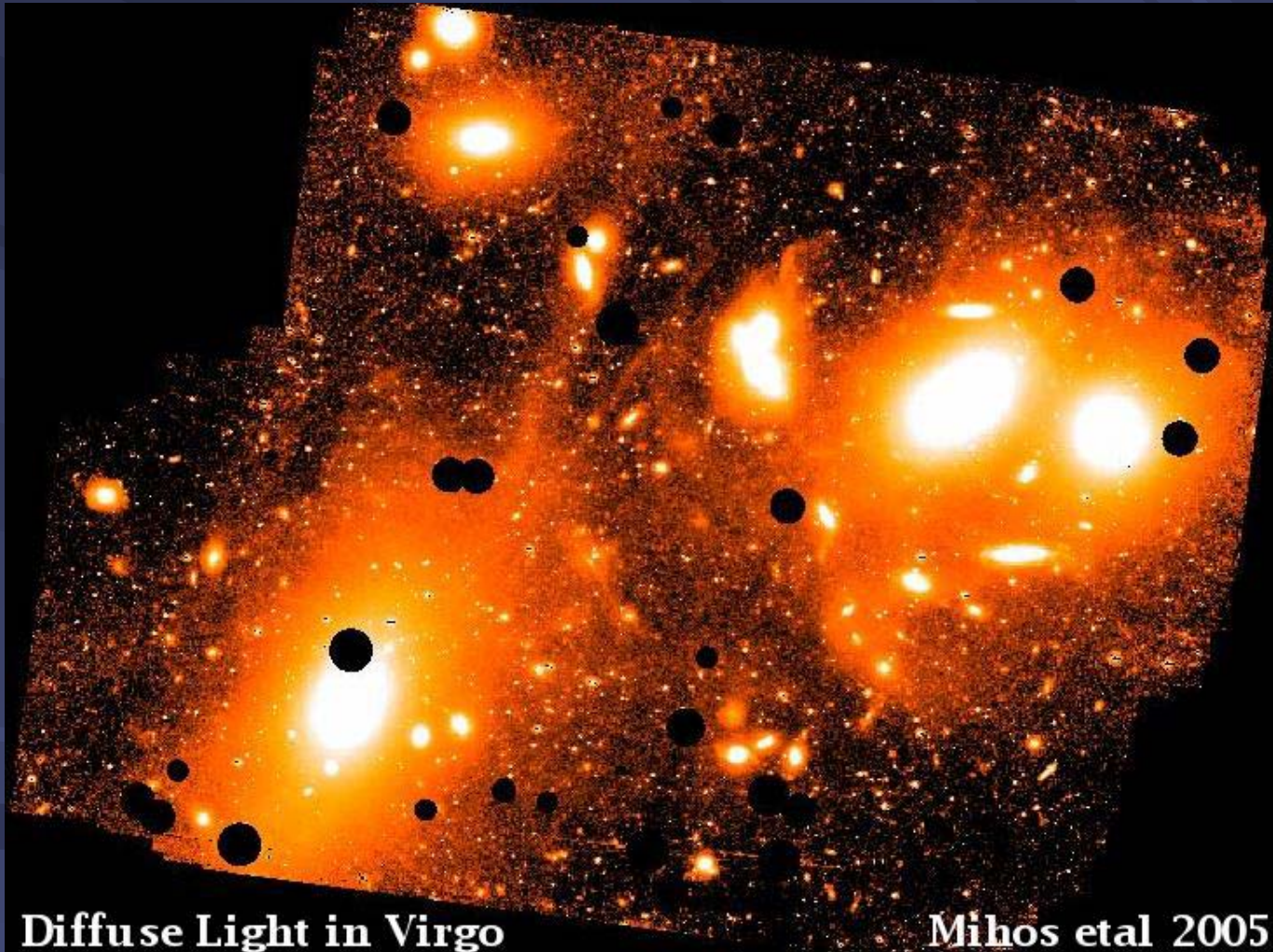
What about recovering the dispersion profile?



Seven 250×250 kpc² fields per radius bin

The “Gentler Way” of ICL kinematics

Don't fight the substructure – embrace it!



Target streams
for kinematic
studies:

- PNe
- GCs
- RGBs

Diffuse Light in Virgo

Mihos et al 2005

Summary

- The ICL is beginning to be characterized both photometrically and kinematically (with a lot of work!).
- It has significant spatial and kinematic substructure at very faint surface brightnesses.
- Using the ICL as a mass estimator yields rough results, with very significant scatter.
- As a tracer of dynamical events, it holds potentially more interesting information, but we need larger, spatially targeted kinematic samples to tap this information.