Applications of GL: Unique insights into galaxy formation & evolution

Why galaxies ?

"Galaxies are much more interesting than clusters"

Contents:

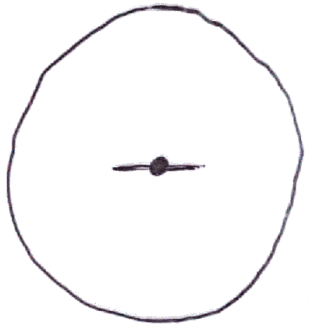
- DM halos – outer region
- DM halos – inner cusps
- CDM substructure
- SMBHs, *s & DM halos

} 1/2 day each

- Synergy: GL + other methods to measure mass

} 2 days

Galaxies



The challenge:

Simulate a galaxy needs 10^{large} CPU hours and 10^9 particle halo now ~ achievable

Core (DM only):

perhaps no power-law cusp

Sersic profile also OK

$\rho \propto r^{-3/4}$ from 'analytic' solutions

$r^{-1.5}$ ruled out

triaxial shape of halos

→ gas orbits not circular

→ $V_{rot}(R)$ different from $V = \sqrt{\frac{GM}{R}}$

→ solves 1. DM Crisis !?!

asymmetric rotation curves observed in LSBs

after biases corrected, observed V(R)

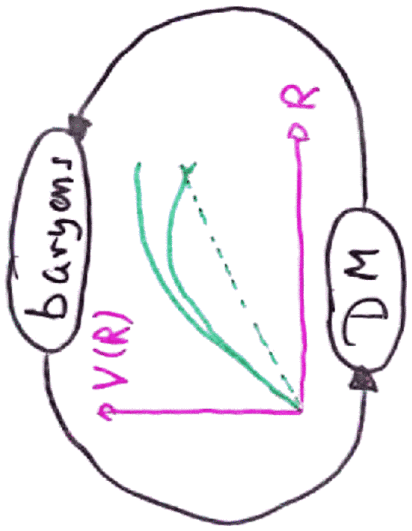
compatible with $\rho \propto r^{-0.0\ldots -1.0}$

but: any feature in light yields feature in V(R)

dogs & tails in V(R):

what fellows what?

maybe an elephant?



The real core (w. baryons):

used the word 'conspiracy' very frequently

(we've been taped!)

DM & disk well aligned – cf. galaxy lenses

more concentrated, $\rho \propto r^{-2}$

new model for adiabatic contraction

$\rho \propto r^{-2}$ solves H_0 problem from lenses?

$\rho \propto r^{-2}$ from lensing: LSD, SLACS, CLASS, ...

5% scatter (same slope as just around Fermat circle?)

$\rho \propto r^{-<2}$ for J 1632, otherwise no third image (or finite core ~5 mas)

influence of central SMBH:

$$R_E \sim 20 \sqrt{\frac{M}{10^8 M_\odot}} \text{ mas}$$

0218 needs SMBH to suppress 3. image

contraction makes halos rounder

→ dynamical studies of tidal streams

direct test: non-radial motion of hypervelocity *s

tidal stream in M31

"conspiracy": $f_{DM} \sim 0.4$ within $2R_e$

not so clear evidence from dynamical methods alone;

X-ray sas in hydrostatic equ.?

evidence for DM also in small E's?

a modified FP – from dSp to ICL!

we are allowed to call it "fundamental" | not a plane really!

Substructure

far more DM subhalos in gls. than observed → 2nd DM Crisis

hurray! flux-ratio discrepancies

but

needs substructure in the inner ~ 10 kpc (proj.)

tidal disruption

DM subhalos cannot explain flux-ratio discrepancy.

N.B.: 10 new MW satellites detected on ~12% of sky! V_c?

Is substructure involved in lens systems ?

YES !

- no other way known to explain flux-ratio discrepancy in 6 radio quads (no ML)
- in ~~two~~ three of them (2016, 0414, 2045), substructure is seen → tip of the iceberg
- saddle vs. minimum image

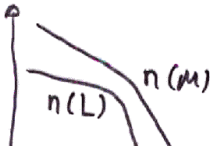
Is the substructure in the lens or on l.o.s. ?
expected l.o.s. lensing too low ?

Is it CDM-subhalo-substructure ?

- S vs. M
- what else ? $(\alpha = R_{31}(r)\, e^{31 i \varphi}$?$)$

Are the results from simulations pure particle noise ?

Conclusion : "It's a big mess"



"do we know a single $10^9\, M_\odot$ object with $M/L = 10^3 - 10^4$" ?
NO – but how to find it ?

Galaxy formation & evolution: *'s, DM, SMBHs

"microscopic" view : merging of pair of E's
global view: Millennium Run + SAM

- FP conserved in dry mergers
- Projections of FP curved (orbit dependence)
- blue/red bimodality – requires non-stellar feed back
- AGNs are important for galaxy evolution !
- in case you need some 25 million gals. ....
- SMBHs form cores in E's ; seen in lensing ?
- mergers drive DM into cores

Random selection of additional highlights

Lens in 'Cloverleaf' detected

4 planets detected via ML

SPH fails (many new papers can be written!)

breaking MSD with lensing of FP

Cosmic strings lens – not a lens

Cluster lensing

~ 10–20 clusters with strong lensing features well known (and more to come....)

best case: A 1689

30 multiple image systems, many long arcs
21 redshift systems + weak lensing

at least three serious attempts of modeling:

Broadhurst et al. → c = 27/12/7
Hakola et al. → c = 6
Kneib et al. → c = 7

?

rms $(\vec{\theta}_{obs} - \vec{\theta}_{mod}) \simeq 0.''5 \ldots 1.''5$

⇒ each image yields $\chi^2 \geq 100$!

What is robust?

- overall mass profile?
- c? r_s?
- outer slope?
- M ($\leq 40''$)?
- M/L (galaxies)?
- R_{Einstein} (r)?

Do we expect and formally bad fit ?

How can we improve on it ?

Is it a small / large - scale problem ?

Is there unseen substructure ?

C - discrepancy : is it all due to parametrization ?

mass - sheet degeneracy — mass measurement

cosmology from strong lensing in clusters ?

Think of JWST !

7/10 $z = 0.2$ X-ray clusters are not relaxed

→ implications for X-ray cluster cosmology ?

Does bullet cluster prove DM ?

Yes ! But we "believed" in it anyway ...

... and the other camp ?

GL as a convenience

telescopes & beam splitters

high-z objects behind clusters

* - form @ $z \sim 6 - 9$ ..... JWST

blind spectroscopic search near critical curves

view of reionization ("the last big baryon party")

support first light machine

Lyα forest ; LBG @ $z = 3 .... 6+$

transverse correlation of absorbers

especially C IV (coherence scale ~ 1kpc)

peculiar motion of gas

- super Hubble-flow expansion (edge of voids)
- gravitational collapse on small scales

Cosmology from strong lensing ?

lens frequency + mass function → Ω's

vs.

lens frequency + Ω's → mass function

Δt + mass profile → H_0

vs.

$\Delta t \cdot H_0$ → mass profile

upper bound on H_0 from mass follows light

Problem of environment: adds to κ & γ, (MSD)

$\sqrt{\langle \kappa^2 \rangle} \sim 5\%$ for $z_s = 2 \ldots 3$!

highly skewed distribution

l.o.s. (multi)structure not worse than "normal" MSD

but also not better

are lenses situated in random l.o.s. ?

↳ selection : magnification bias $\Delta\theta$

Arc statistics : size/shape distribution of sources ✓

observational effects (PSF, noise) ✓

small scales : baryons ARE important

Cosmology from weak lensing

Yes! (we hope ..... expect)

perhaps most promising method to learn something about DE

technical issues to be solved, though

(PSF, phot-z, model predictions, ...)

... and a few financial issues as well

(DES, LSST, Dark Cam, DUNE, SNAP, PS4)

The STEP Project :

a joint effort of many weak-lensing groups,

thanks for the hyphen !

blind-testing shear measurement methods.

Finally .....

THANKS

TOMMASO

&

LEON