BOIZ! let's go!

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Research interests: cosmology stuff, proposing new experiments

11am - 12:20 ERC 545

weekly psets (~50%)
midterm (~20%)
final (~30%)

Foundational topics
Dark Matter Evidence
Speculative Dark Matter Properties

goal: aspects to understand DM research
interdisciplinary
try to avoid theology

What do we know about visible matter?

atoms $\mathcal{O}$(mm) → atom $\mathcal{O}$(Å) → protons/neutrons → quarks $\mathcal{O}$(fm)
fractional charge

Standard Model of Particle Physics

everything's unstable (will decay into other particles)

"complete" by Higgs Boson

wildly successful

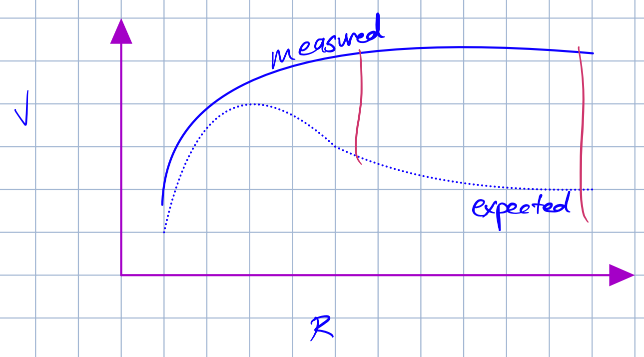
look really good until we look up

~13.7 billion years since crazy inflation

	13.7 BYA	Today	
Dark Energy	0%	72%	← doesn't dilate
Dark Matter	63%	23%	← like marbles
Atoms	12%	4.6%	
Photons	15%	0%	
Neutrinos	10%	0%	
	sensitive to time		

Whats the evidence

Rotational curves



requires 85% of matter to be "dark"
☆ Shell surround
doesn't agree @ large scales

pretty good evidence, not that good

Gravitational lensing

requires ~85% matter to be "dark"

light's effected by gravity

∡ of curvature to classify mass

Einstein rings

Galaxy Cluster Collisions

~85% total mass passed thru w/o scattering using gravitational lensing

Matter Power Spectrum

how matter clumps

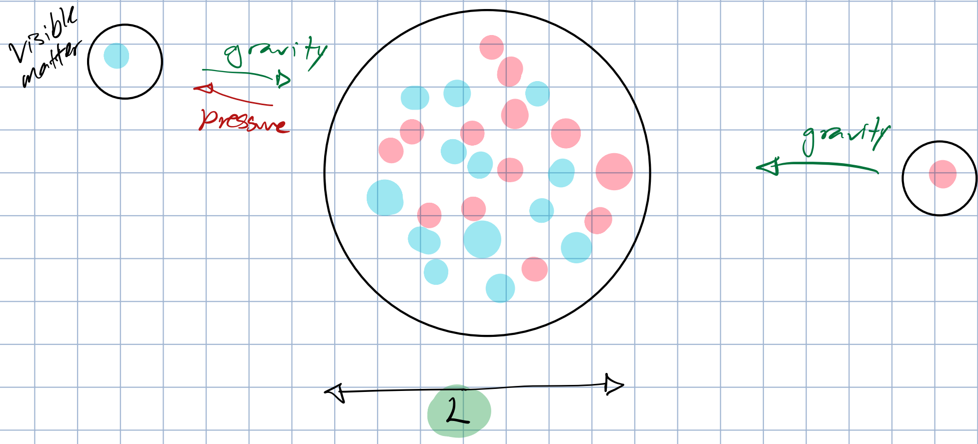
density contrast : $\delta(\vec{x}) = \frac{\rho(\vec{x}) - \bar{\rho}}{\bar{\rho}}$ $\bar{\rho}$ - avg mass density

correlation fn : $\xi(\vec{r}) \equiv \langle \delta(\vec{x}) \cdot \delta(\vec{x}+\vec{r}) \rangle$ fix $\vec{r}$. then characterize each $\vec{x}+\vec{r}$. re-do for different $\vec{r}$, correlates neighbors

power spectrum : $\xi(\vec{r}) = \int \frac{d^3k}{(2\pi)^3} \cdot P(\vec{k}) \cdot e^{i\vec{k}\cdot\vec{r}}$ $k \approx \frac{2\pi}{L}$ L - length scale

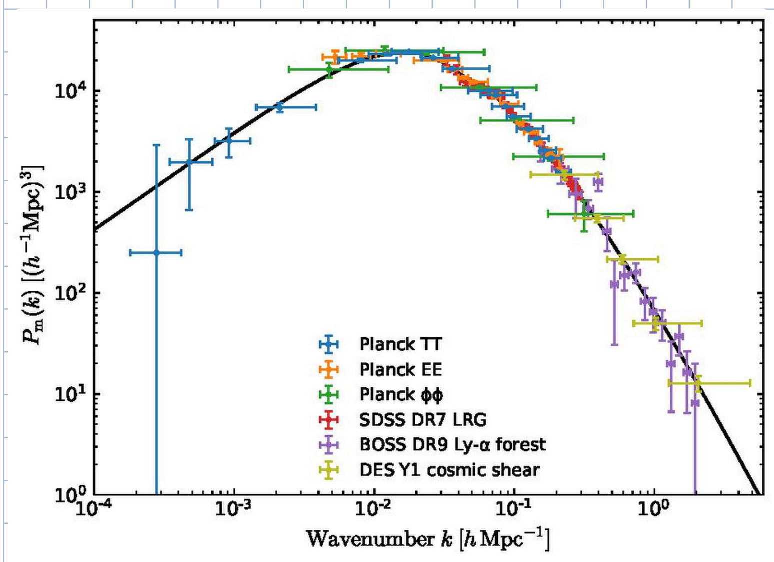
$P(\vec{k})$ is "morally" a 3D Fourier Transform (or waveform decomposition)

Overdense region grows by accreting dark matter & visible matter



if $L >> Mpc$, then we're interested

$P(k)$ is f^n of L



draw a circle. look @ $S(\vec{x})$ & compare w/ neighbors

MOND & NoDM don't agree w/ black curve

$$k = \frac{2\pi}{L}$$

CMB

$$\frac{\Delta T}{T} = \sum_{\ell m} c_{\ell m} \cdot Y_\ell^m(\theta, \phi)$$

don't care about density. look @ diff. in temperature

Big Bang Nucleosynthesis

light elements made early on.

can find amt. by measuring today & looking back

missing: how many visible matter needed.

Still! 15% to 85% dark matter

dark matter being made up of visible matter would fuk things up

Hella evidence @ all scales & time ($z \sim 3400 \to 0$)

holy grail: extend knowledge to smaller scales

What do we know about DM? (from first principles)

1. currently based on gravity
2. extremely stable & long lived
3. largely unrelativistic since CMB era
4. can't interact much w/ strong or E&M forces
5. MIGHT interact w/ weak or (new) fifth forces

Where to start

SI units

$[mass] = kg$ $[temp] = K$

$[energy] = J = kg\,m^2 s^{-2}$ $[current] = A = C s^{-1}$

price to pay: weird constants

$\hbar = \frac{h}{2\pi} = 1.054 \cdot 10^{-34}$ Js

$c = 2.997 \cdot 10^{8}$ ms^{-1}

$R_{atom} \sim 10^{-10}$ cm

$R_{galaxy} \sim 10^{23}$ cm

much more easy to define $c = \hbar = k_B = 1$ & dimensionless

1. standard in literature
2. don't have to keep writing constants
3. will learn to love

redefine familiar tings

$c = 2.997 \cdot 10^8 \, ms^{-1} \implies s = 2.997 \cdot 10^8 \, m$ (seconds)

$[length] = [time]$

$[\hat{x}, \hat{p}] = \hat{x}\hat{p} - \hat{p}\hat{x} = i\hbar$

set $\hbar = 1$. RHS dimensionless $\to$ $[length] = [time] = [momentum]^{-1}$

$E = \frac{mc^2}{\sqrt{1 - \frac{v^2}{c^2}}} \to \frac{m}{\sqrt{1-v^2}}$ $\qquad p = \frac{mv}{\sqrt{1-\frac{v^2}{c^2}}} \to \frac{mv}{\sqrt{1-v^2}}$

$[length] = [time] = [energy]^{-1} = [mass]^{-1} = [momentum]^{-1}$

statistical weights in thermal equilibrium $\exp\left(-\frac{E}{k_B T}\right) \to \exp\left(-\frac{E}{T}\right)$

$[length] = [time] = [energy]^{-1} = [mass]^{-1} = [momentum]^{-1} = [temp]^{-1}$

electron charge $e = 1.602 \cdot 10^{-19} \, C$

$e = \sqrt{4\pi\alpha} \qquad \alpha = \frac{1}{137}$

$c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$

$[\rho] = [volume]^{-1} = [length]^{-3}$

$\vec{\nabla} \cdot \vec{E} = \rho \to [E\,field] = [length]^{-2} = [energy]^{-2}$

$\vec{\nabla} \times \vec{B} = \frac{d\vec{E}}{\partial t} \to [E\,field] = [B\,field]$

$[E\,field] = [B\,field] = [energy]^2$

standard choice: $[energy] = GeV = 10^9 eV$

$[length] = [time] = [energy]^{-1} = [mass]^{-1} = [momentum]^{-1} = [temp]^{-1} = GeV$