Cosmic Hide and Seek: Tracking Missing and Invisible Matter in the Universe

Sheila Kannappan
Physics & Astronomy Department
UNC Chapel Hill
Light = Electromagnetic Waves

wavelength $\lambda =$ distance crest to crest

frequency $\nu =$ # of crests that pass by a point in one second

narrow meaning of “visible”: $\lambda=400-700\text{nm}$
but what if we could see in millimeter or infrared waves…

Orion Constellation & Star-Forming Cloud

NASA/Spitzer
...or in the radio?

the invisible becomes visible

• stars are bright at optical/UV wavelengths

• the raw material (gas & dust) for new stars glows at radio/mm/IR wavelengths

M81 Group: Min Yun
Radio, IR, UV, X-ray, and $\gamma$-ray are visible to telescope “eyes”
Lost Sock Classification

- **black & blue socks** — hiding in plain sight (look like something else)

- **static-cling socks** — just barely possible to see (lumps in the sheets)

- **mind-bending socks** — have to exist, but invisible at any wavelength
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  *ultra compact dwarfs*

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  “*missing baryons*”

• mind-bending socks – have to exist, but invisible at any wavelength
  
  *exotic dark matter*
It’s a well-known fact that wormholes connect many locations in space and time. What’s not well known is that dryers in particular are very good at starting wormholes. Eventually, minute enthalpic fluctuations will cause one of these to open up and fling your socks, say, six hundred light years into space.
hiding in plain sight: ultra compact dwarfs

Sombrero Galaxy • M104
hiding in plain sight: ultra compact dwarfs

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Hau et al. (2009) first to discover this dwarf!
Are ultra compact dwarfs galaxies or star clusters?

- core left behind when a galaxy is shredded in an interaction

- giant globular cluster (perhaps made by merging several clusters)

NGC 5907: Gabany/sciencedaily.com

simulations: K. Johnston M. Bate
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Norris & Kannappan (2011):

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Q: Is there any important difference between a star cluster formed fresh vs. stripped from a galaxy?

A: Yes, probably – dark matter.
A Brief History of Dark Matter

Fritz Zwicky notices in 1933 that galaxy cluster motions imply missing mass.

Vera Rubin shows in the 1970s that many galaxies rotate too fast to hold together at large radii, promotes idea of dark matter.
Doppler shifts as a function of distance from the galaxy center show how fast the galaxy is rotating.

curve usually traced using gas emission in the radio
galaxy rotation curves flatten at large radii (or gently rise to the end)

excess speed implies excess mass
gravitational lensing can also map dark matter
Massive cluster lenses not only reveal dark matter, but also let us look back in time. Because light has a finite speed, far away is long ago.
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Hierarchical Galaxy Formation Simulation (A. Kravtsov):
Small galaxies form first (young) and merge into larger ones later (old).
It turns out we need dark matter to explain large-scale structure too.
Our Research with the SOAR Telescope

RESOLVE (REsolved Spectroscopy Of a Local VolumE)
first-ever census of orbital motions in galaxies and large-scale structure
→ create 3D map of dark matter in relation to gas and stars

AIMSS (Archive of Intermediate Mass Stellar Systems, PI Norris)
first multi-environment survey of ultra compact dwarfs;
use internal motions to quantify dark matter
→ assess merging/shredding history of galaxies
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Moffett et al., in prep.
But what is it???
Dark Matter Candidates

MACHOS
(<50%)

WIMPS
warm-hot or ultra-cold gas

10^5 K or 10 K

neutrinos

Modified Newtonian Dynamics

“\textit{I’m not dead yet.}”
two kinds of dark matter

- exotic
  - WIMPs
  - neutrinos (semi-exotic)
  - new theories of gravity (no dark matter)

- baryonic (="normal")
  - MACHOs
  - undetected gas

mind-bending - OR - static-cling?
“missing baryons” problem

• What are baryons?
  – really: protons or neutrons
  – in astronomer jargon: any “normal” matter

• How do we know they’re missing?
  – we see more matter in the distant universe, looking back in time, than at the present day (quasar backlight technique)
exciting new theory: cosmic “cold-flow” gas

- warm-hot gas traveling along large-scale filaments
- stays “cold” (=warm-hot) only in low-mass dark matter “halos” with internal velocity below threshold $V_t$
- nearly invisible gas phase but fuels galaxy growth

Simulation by L. Mayer & N-Body Shop
We’re after:

• large-scale patterns of gas and star formation in the RESOLVE Survey that will help disentangle baryonic dark matter (like cold flows) from exotic dark matter

• evidence of cold flows feeding galaxies with dark matter halos below an internal threshold (mass $M_t$ or velocity $V_t$)
eXtended UV-bright disks common in “red and dead” spheroid galaxies – fresh growth!

Thilker et al. (2010): rejuvenated galaxy

Moffett et al. (2011, submitted): XUV in >40% of low-mass spheroids
fueling most intense below a threshold

“dead” spheroid shapes (smooth/round) suddenly have blue optical colors (strong growth) 25% of the time below $M_t \leftrightarrow V_t$ (Kannappan, Guie & Baker 2009)
transition from bulgeless, gas-dominated dwarfs to bulged spirals may occur at threshold

Dalcanton et al. (2004)

Kannappan et al. (2011, in prep.)

Stern et al. (2011, in prep.)

Kannappan et al. (2010) data

(T>=1, b/a>0.5, z<0.025)

\log M_{\text{thresh}}=9.7

Nair & Abraham (2010) data

\textbf{bigger/bluer dots = more \textit{total} gas}

Stark et al. (2011, in prep.)
Where we stand on the lost socks

• still in search of dark matter
  – exotic particle type
  – gaseous “missing baryons” type

• but great prospects for the future
  – first comprehensive gas and dark matter census from RESOLVE Survey
  – ultra compact dwarf and blue spheroid research offer windows into merging and rebuilding of galaxies
  – Large Hadron Collider in Europe poised to identify nature of exotic particles
  – Hubble Space Telescope’s *Cosmic Origins Spectrograph* dedicated to finding missing baryons by quasar backlight technique