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

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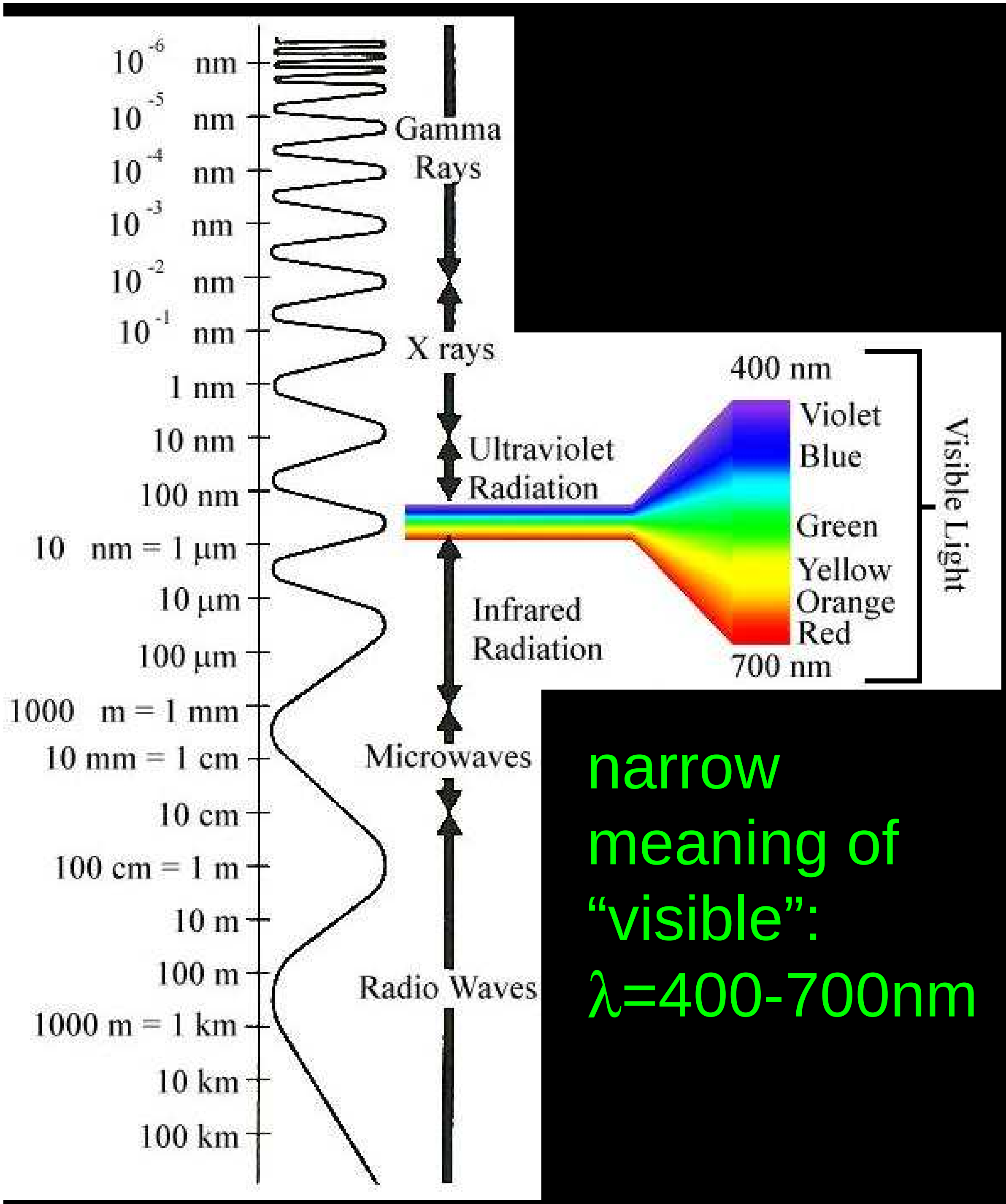
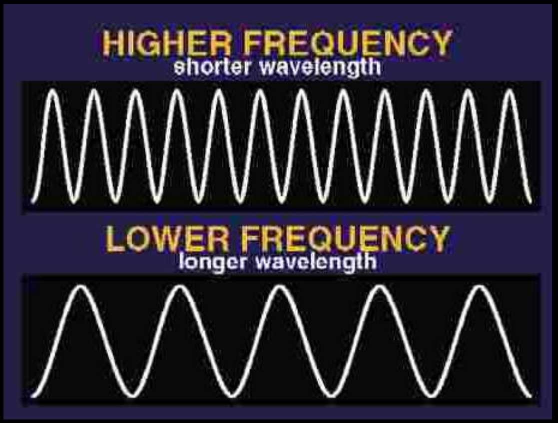
Light = Electromagnetic Waves



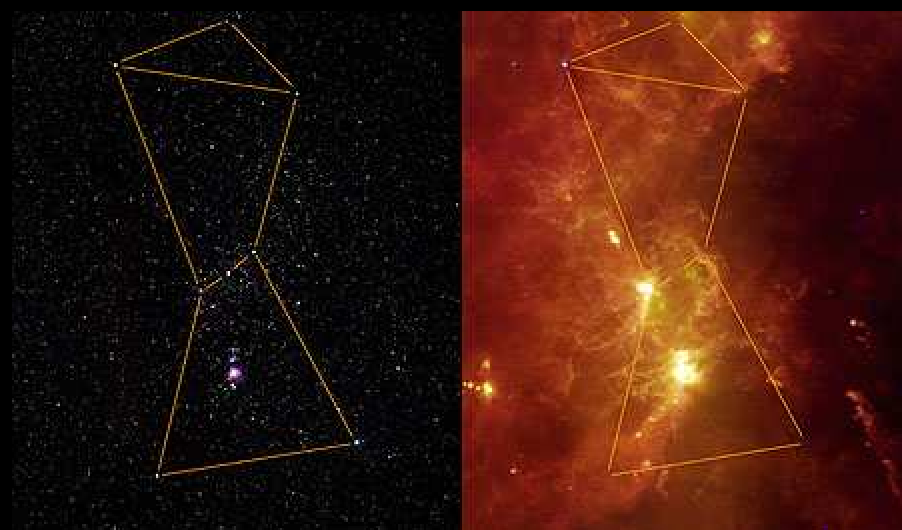
narrow meaning of "visible": λ=400-700nm

wavelength λ = distance crest to crest

frequency ν = # of crests that pass by a point in one second



but what if we could see in millimeter or infrared waves…

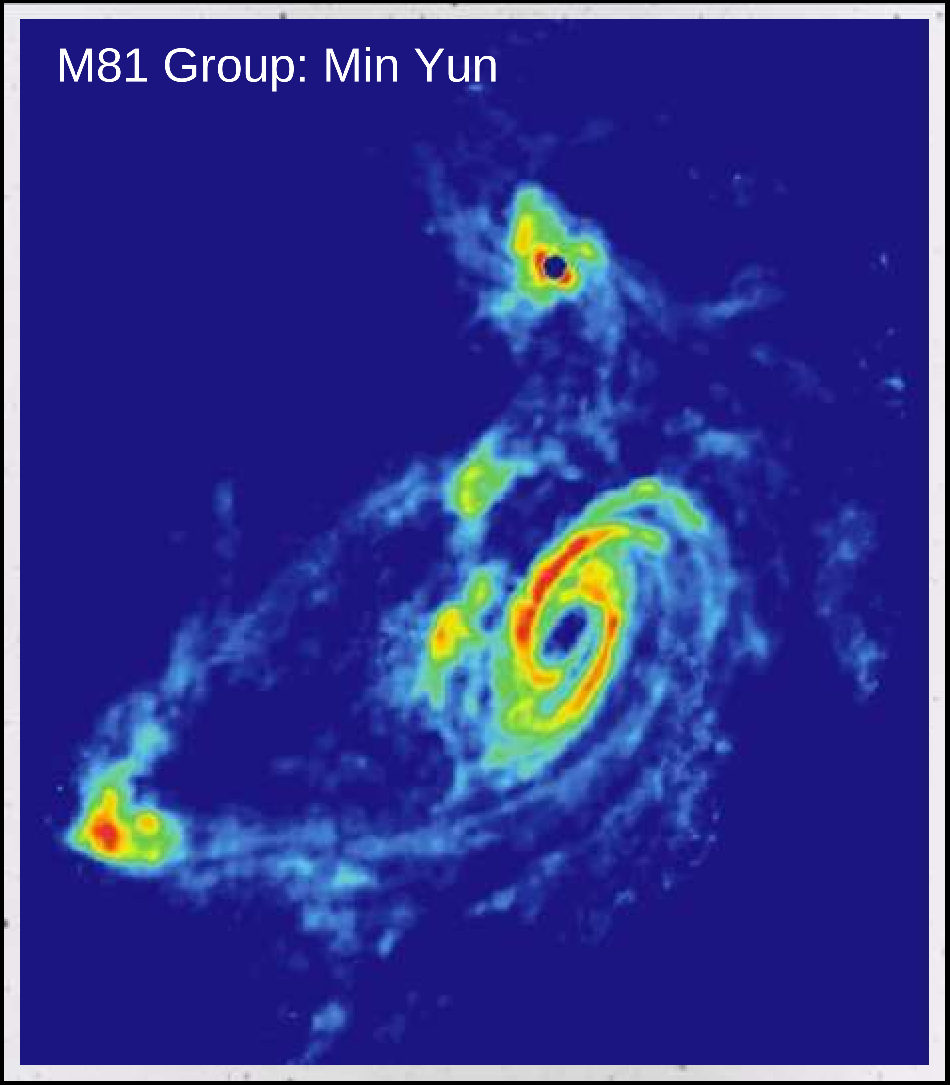


NASA/Spitzer

Orion Constellation & Star-Forming Cloud

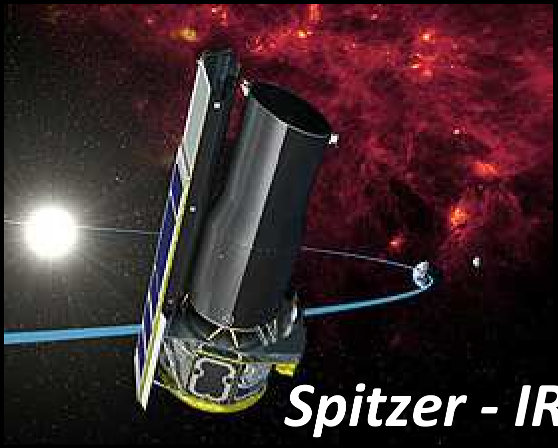
…or in the radio?

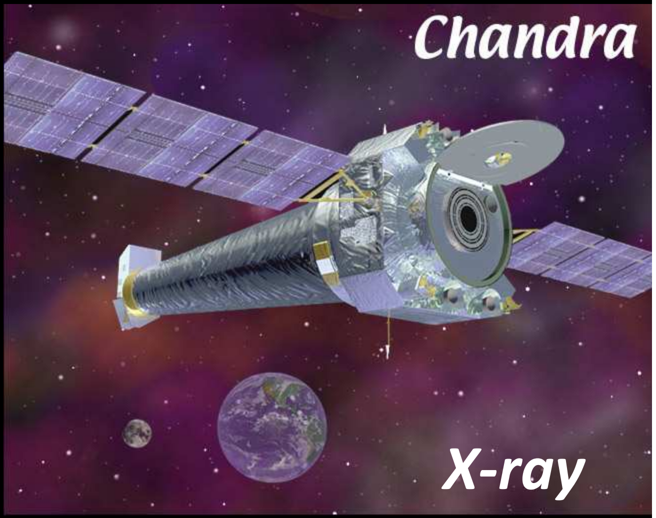
the invisible becomes visible

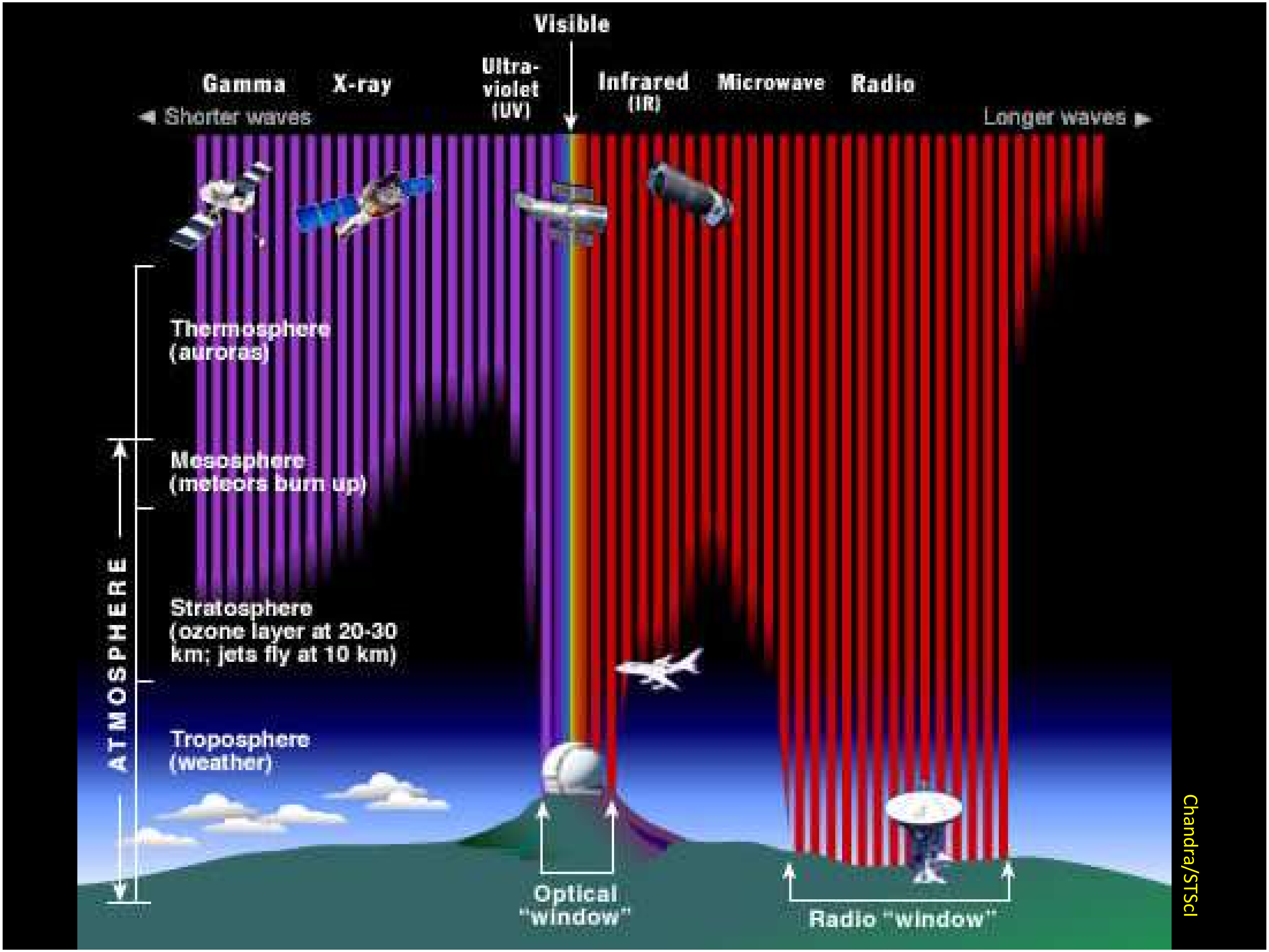


- stars are bright at optical/UV wavelengths
- the raw material (gas & dust) for new stars glows at radio/mm/IR wavelengths

Radio, IR, UV, X-ray, and γ-ray are visible to telescope "eyes"







Visible
Gamma
X-ray
Ultra-
violet
(UV)
Infrared
(IR)
Microwave
Radio
◄ Shorter waves
Longer waves ►
Thermosphere
(auroras)
Mesosphere
(meteors burn up)
Stratosphere
(ozone layer at 20-30
km; jets fly at 10 km)
Troposphere
(weather)
ATMOSPHERE
Optical
"window"
Radio "window"
Chandra/STScI

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”

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exotic dark matter

DALE ROGERS, LITTLEREDPLANET.COM

hiding in plain sight: ultra compact dwarfs

Sombrero Galaxy • M104

Hubble Heritage

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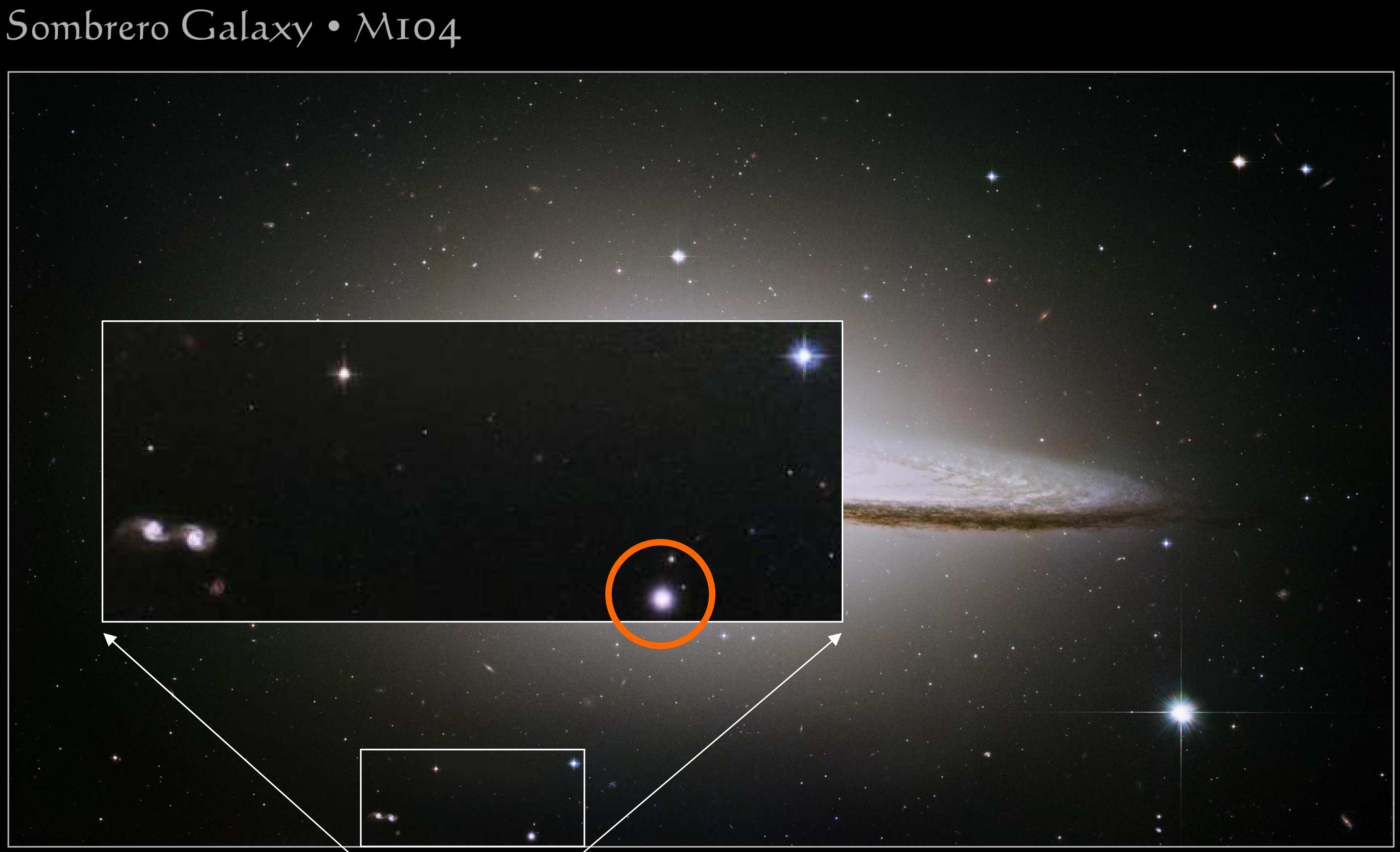
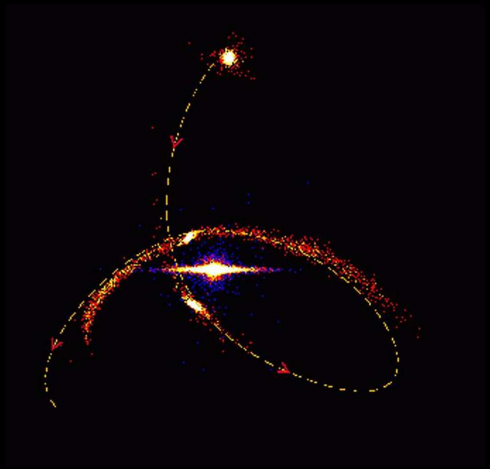


Hau et al. (2009) first to discover this dwarf!

Are ultra compact dwarfs galaxies or star clusters?

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

NGC 5907: Gabany/sciencedaily.com



simulations:
K. Johnston
M. Bate

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

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NGC 5907: Gabany/sciencedaily.com

Norris & Kannappan (2011): they're both!

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

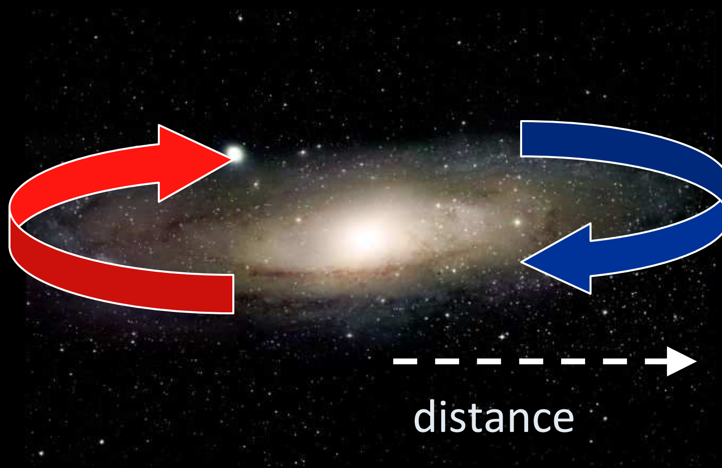
A: Yes, probably – dark matter.

A Brief History of Dark Matter

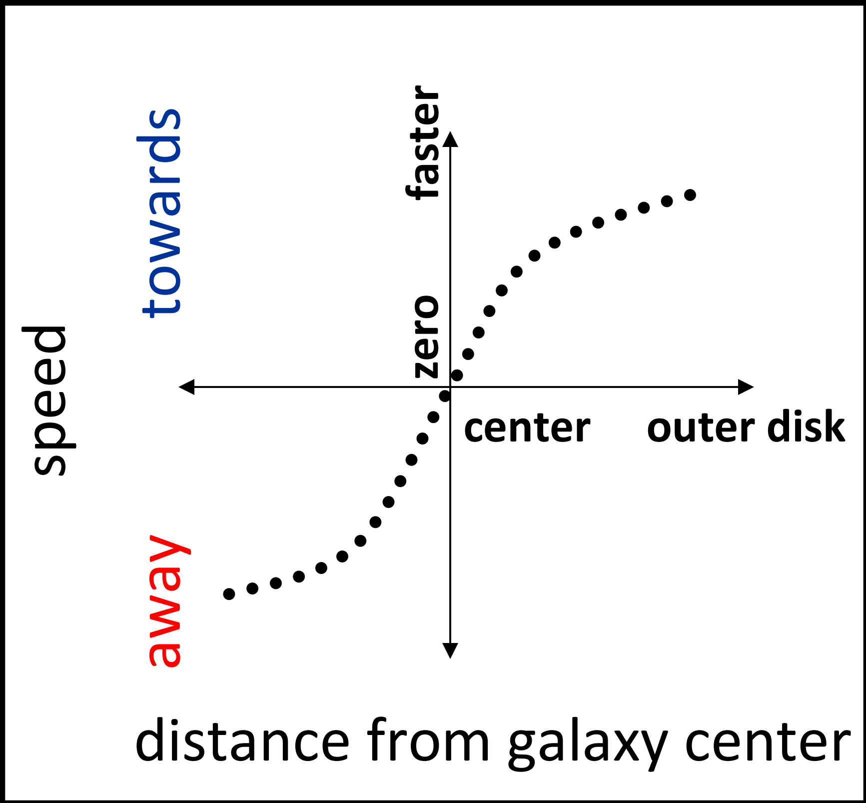
Fritz Zwicky notices in 1933 that galaxy cluster motions imply missing mass.

Vera Rubin shows in the 1970s that many galaxies rotate too fast to hold together at large radii, promotes idea of dark matter.

galaxy "rotation curve"

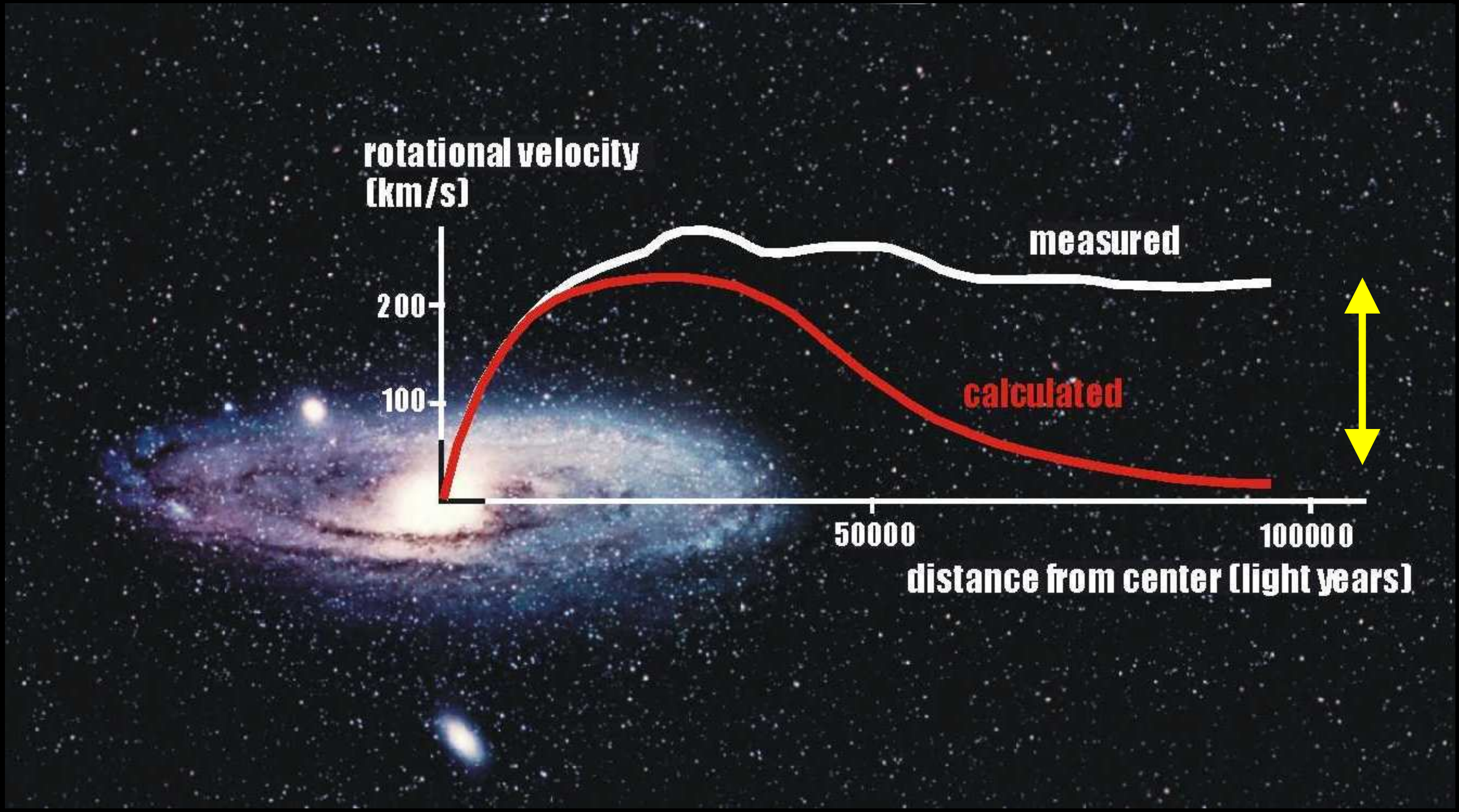


Doppler shifts as a function of distance from the galaxy center show how fast the galaxy is rotating.



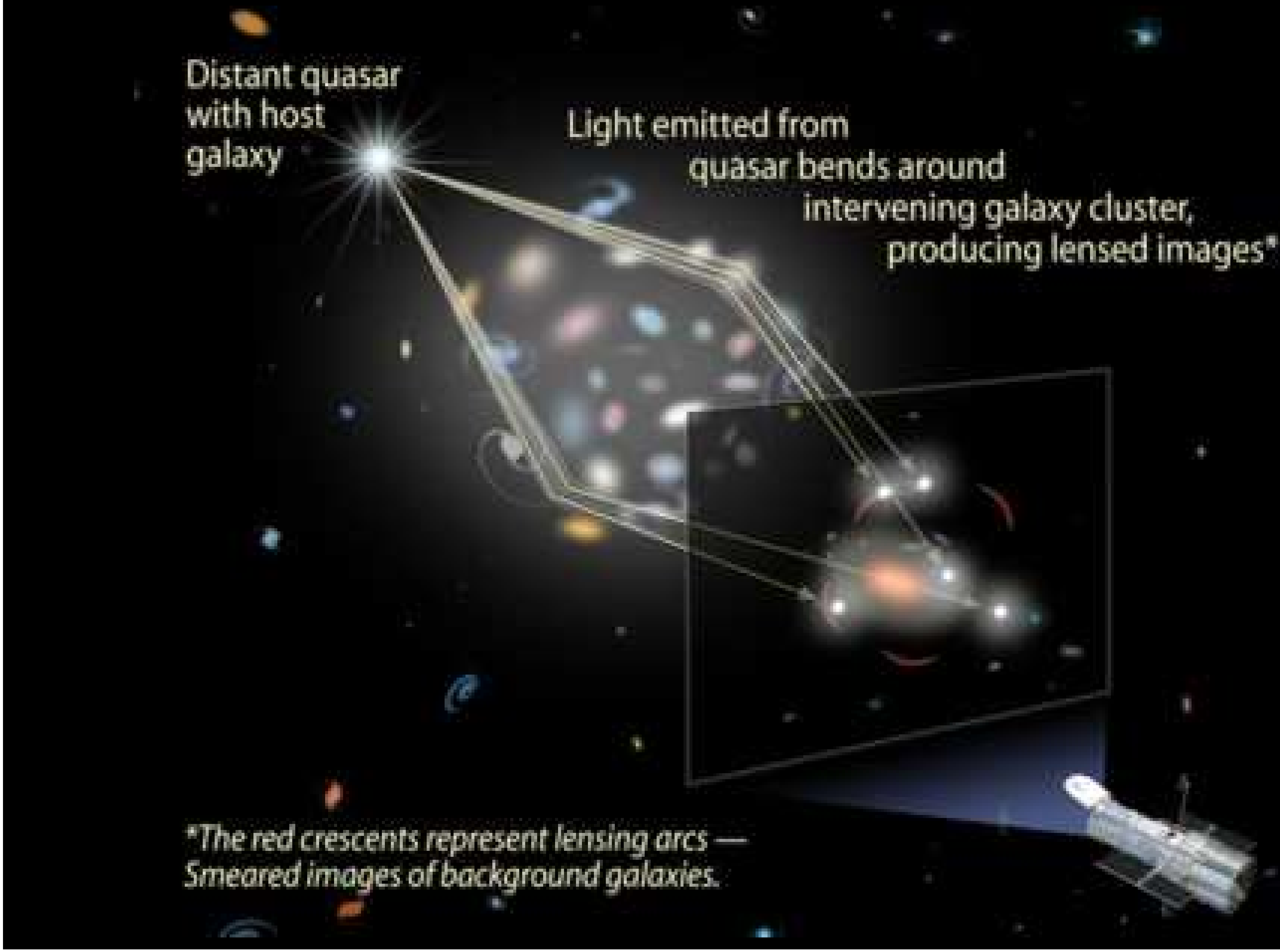
curve usually traced using gas emission in the radio

galaxy rotation curves flatten at large radii (or gently rise to the end)



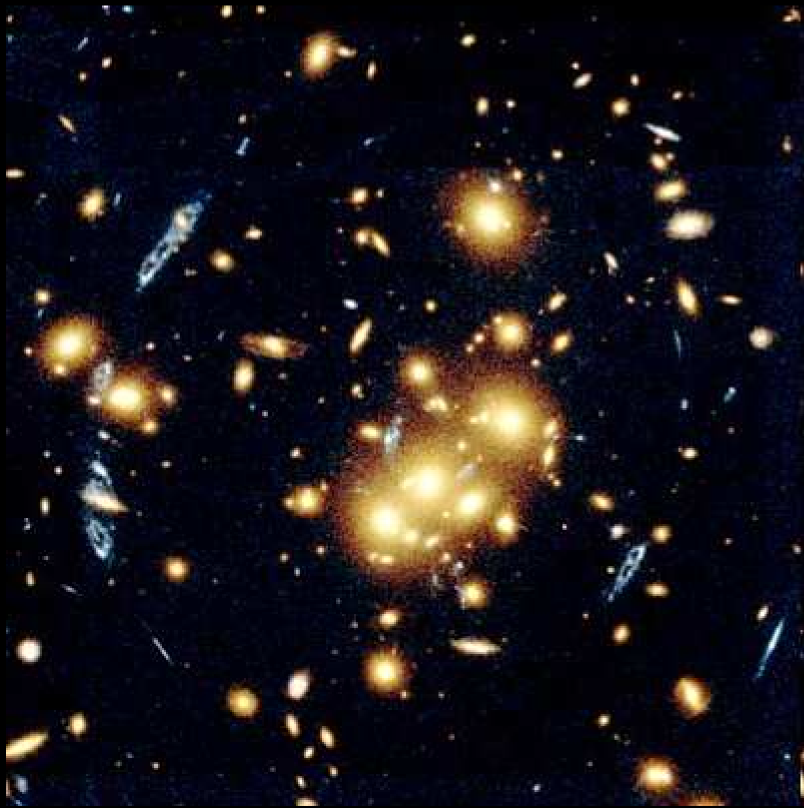
excess speed implies excess mass

gravitational lensing can also map dark matter

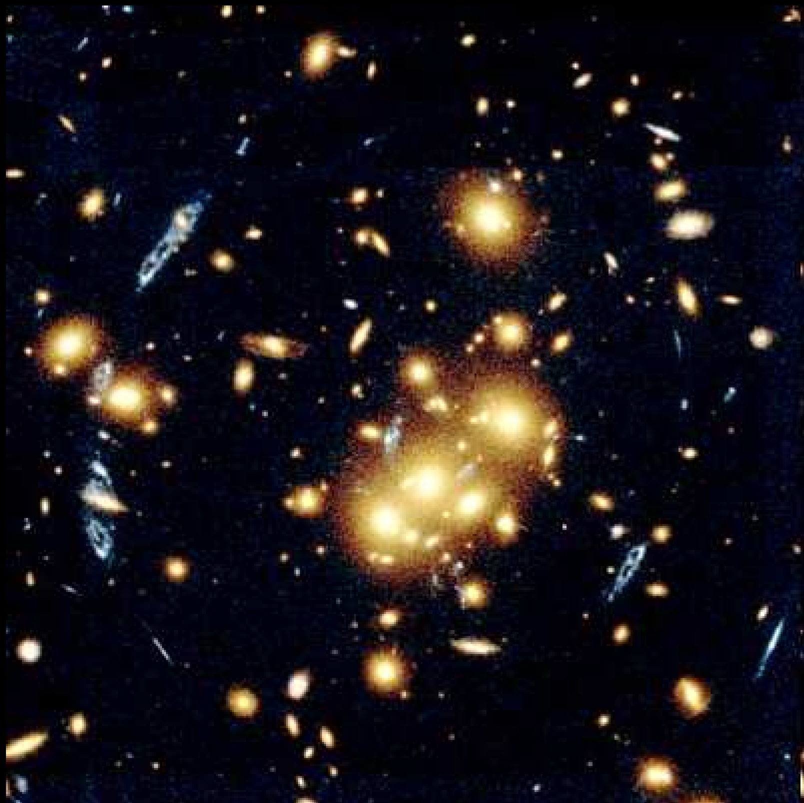


www.centauri-dreams.org

NASA: Colley/Turner/Tyson



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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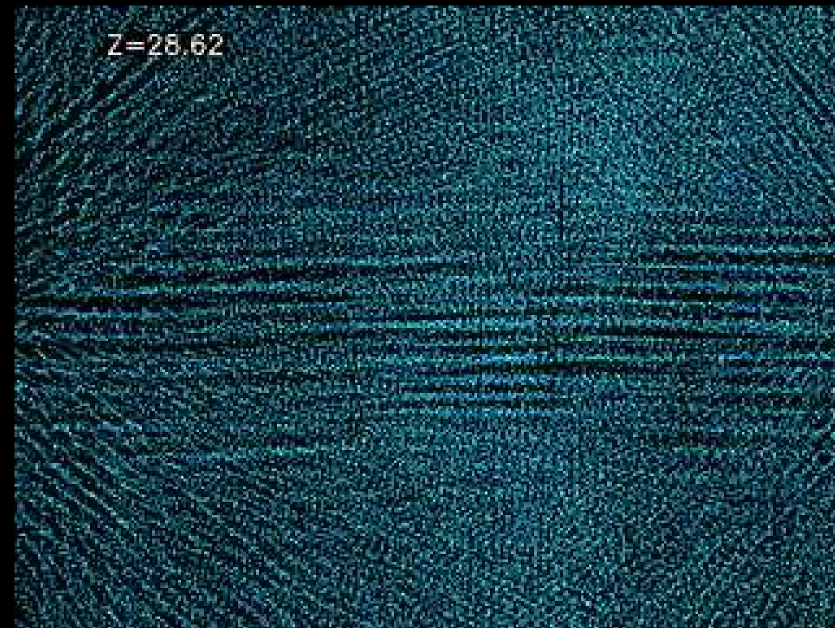

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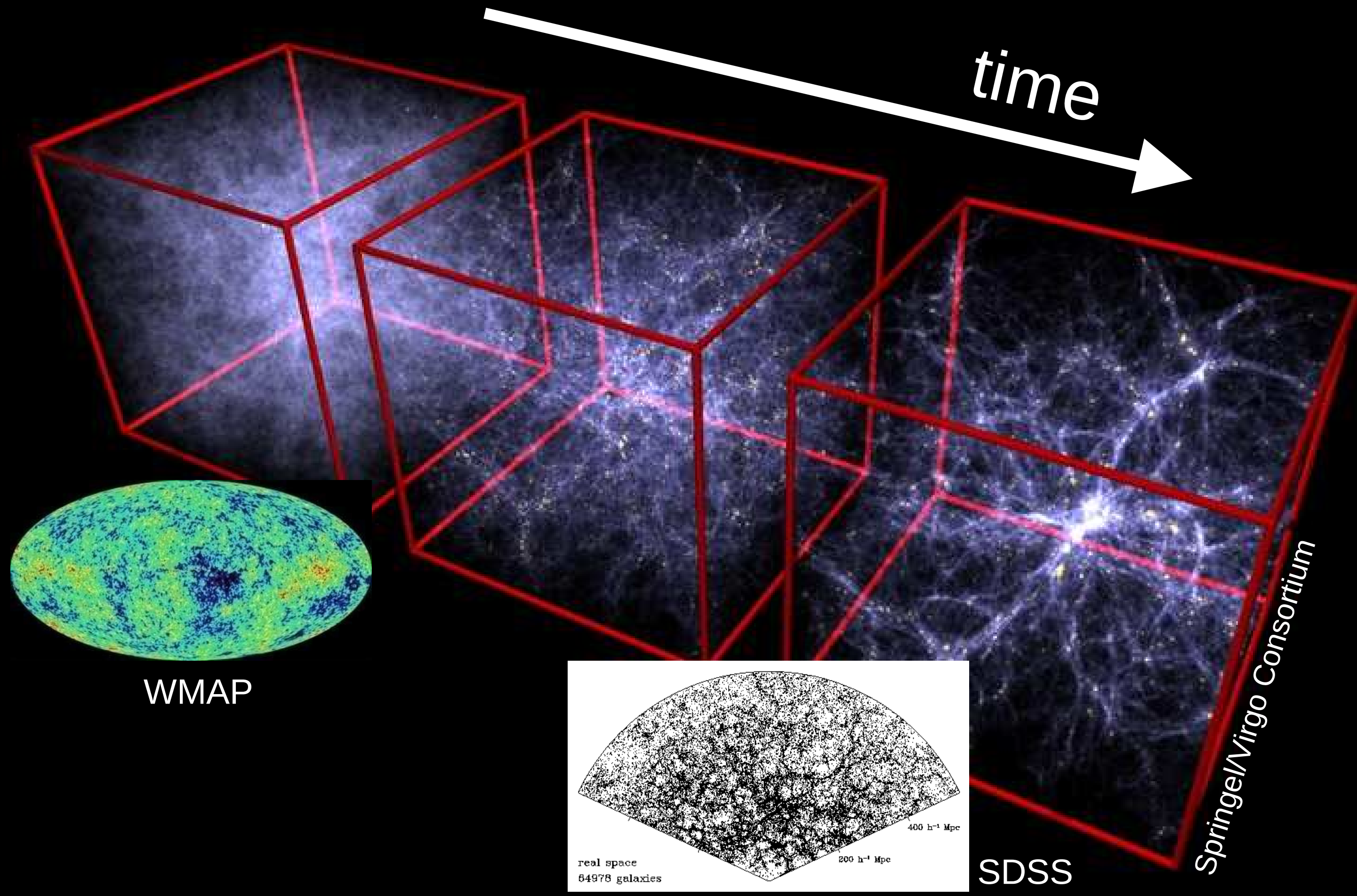
Hierarchical Galaxy Formation Simulation (A. Kravtsov):

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.

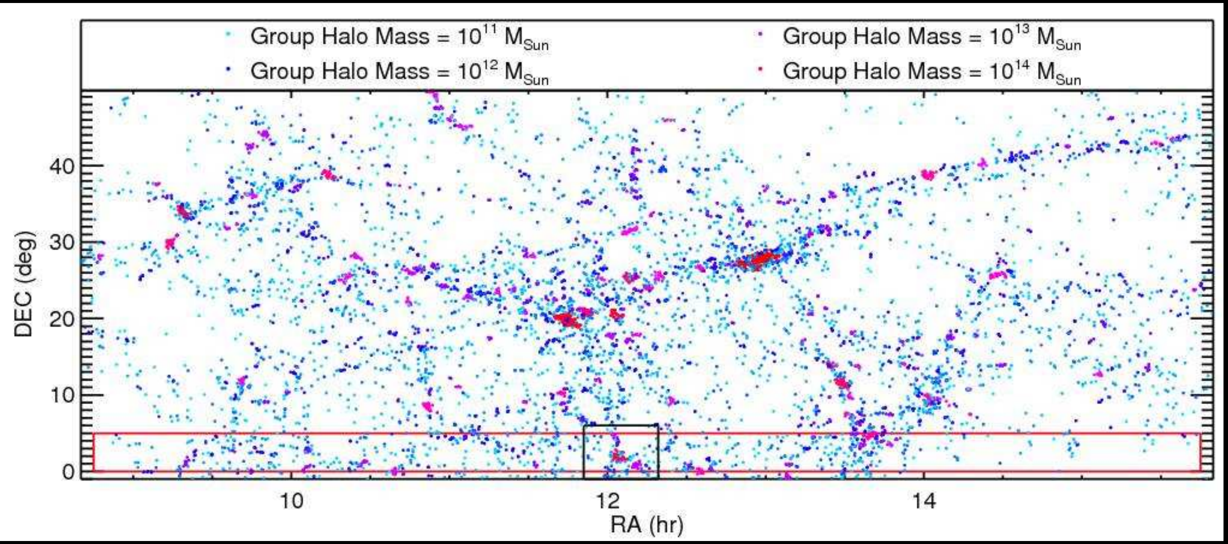


Our Research with the SOAR Telescope

RESOLVE (REsolved Spectroscopy Of a Local VolumE)

first-ever census of orbital motions in galaxies and large-scale structure

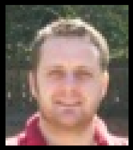
→ create 3D map of dark matter in relation to gas and stars



Moffett et al., in prep.

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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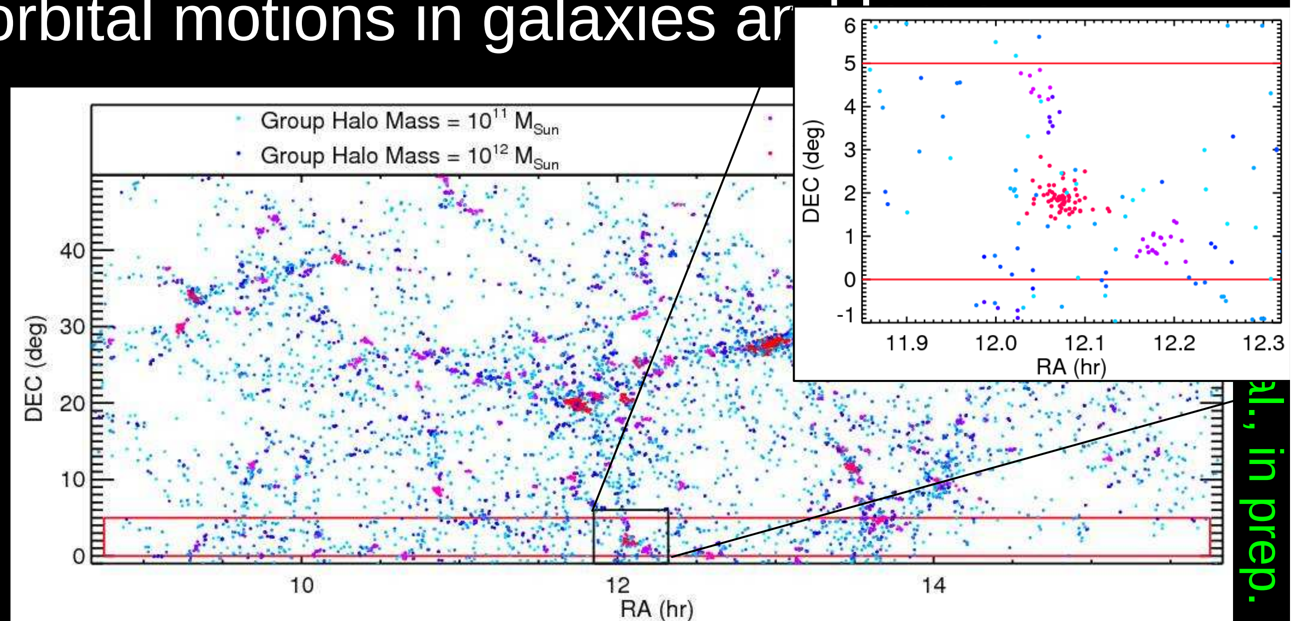

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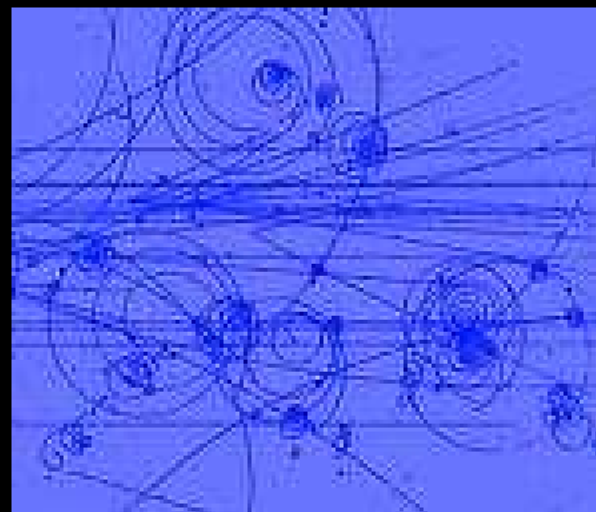
But what is it???

Dark Matter Candidates

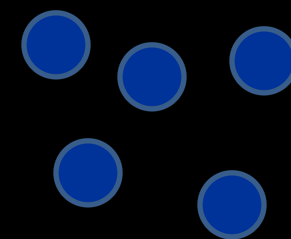
MACHOS
(<50%)

nationalgeographic.com

WIMPS

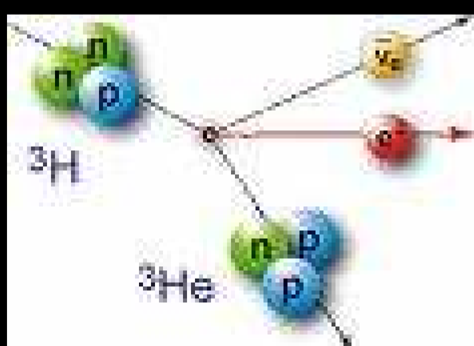


warm-hot or ultra-cold gas



10^5 K or 10 K

neutrinos



OR:

Modified Newtonian Dynamics

two kinds of dark matter

- exotic
  - WIMPs
  - neutrinos (semi-exotic)
  - new theories of gravity (no dark matter)
- baryonic (="normal")
  - MACHOs
  - undetected gas

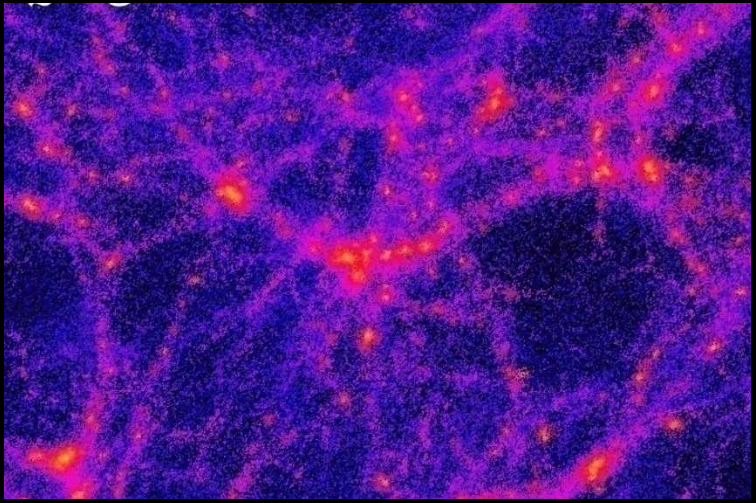
mind-bending - OR - static-cling?

“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



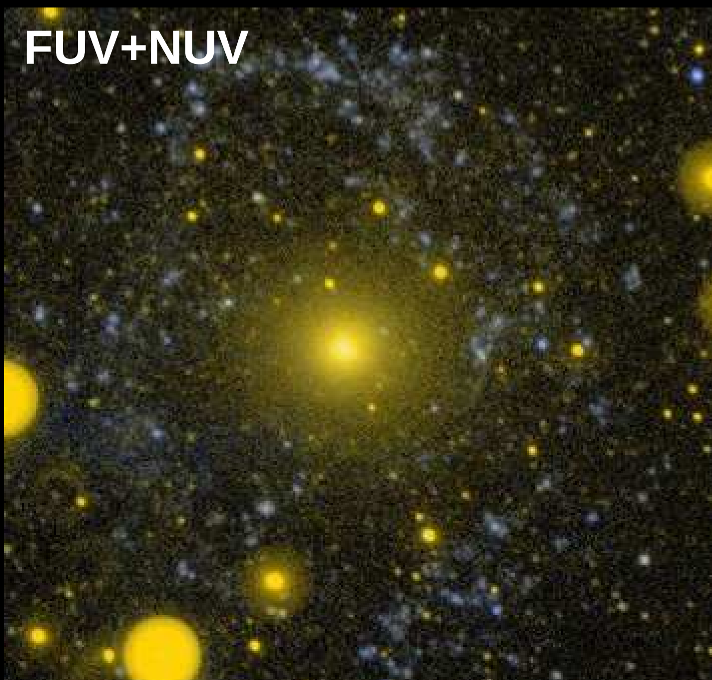
Simulation by L. Mayer & N-Body Shop

We’re after:

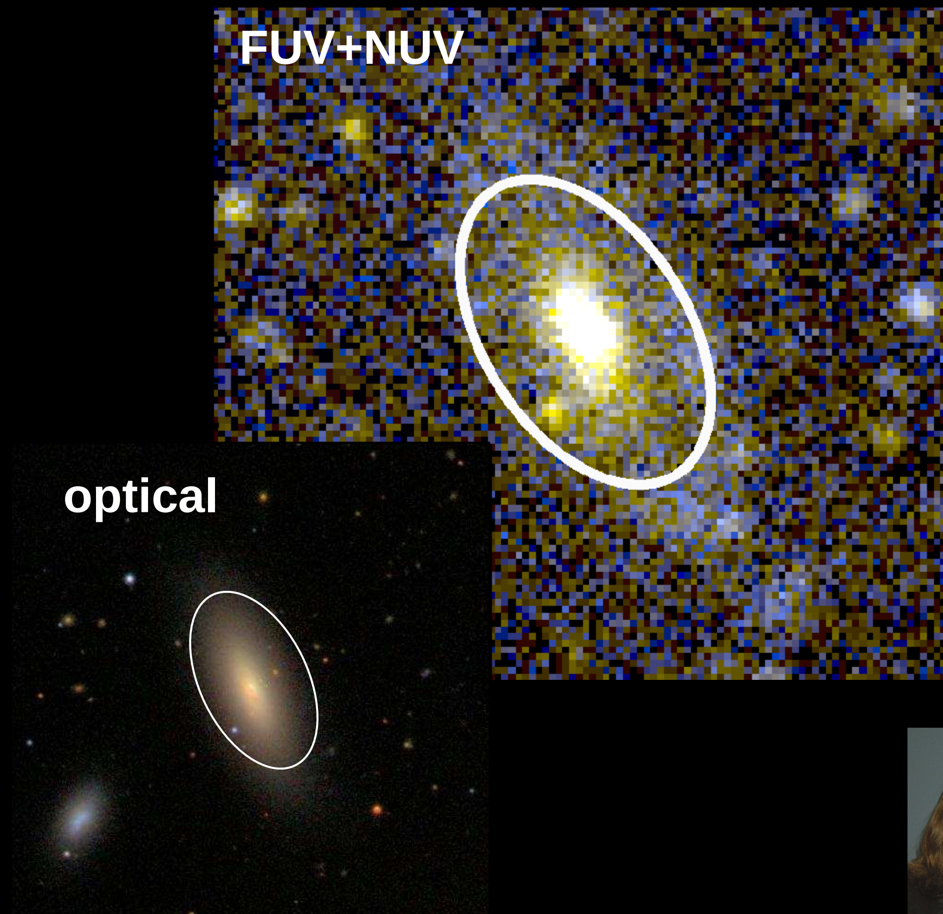
- large-scale patterns of gas and star formation in the RESOLVE Survey that will help disentangle baryonic dark matter (like cold flows) from exotic dark matter

- 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!

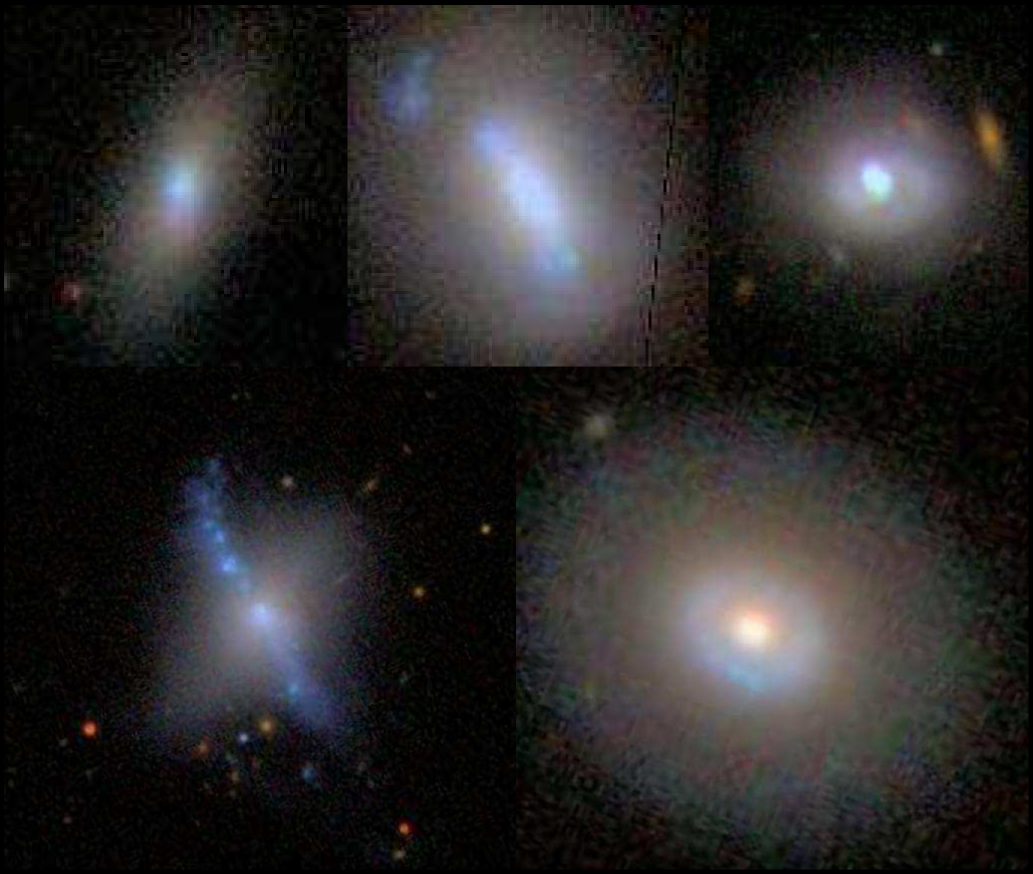


Thilker et al. (2010):
rejuvenated galaxy

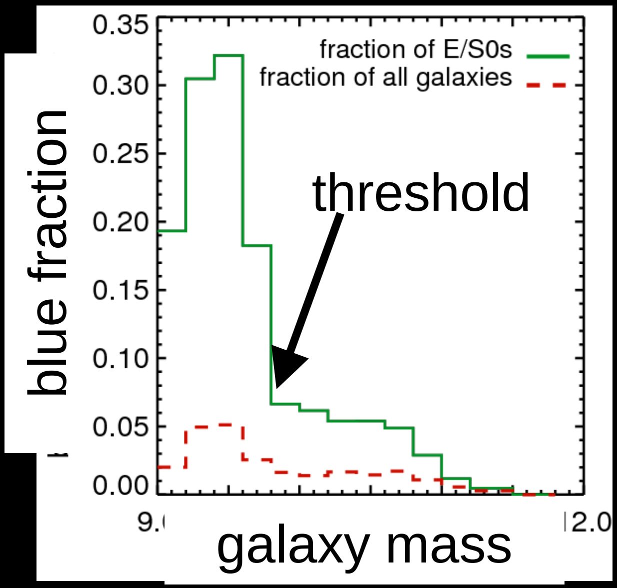


Moffett et al. (2011, submitted):
XUV in >40% of low-mass spheroids

fueling most intense below a threshold

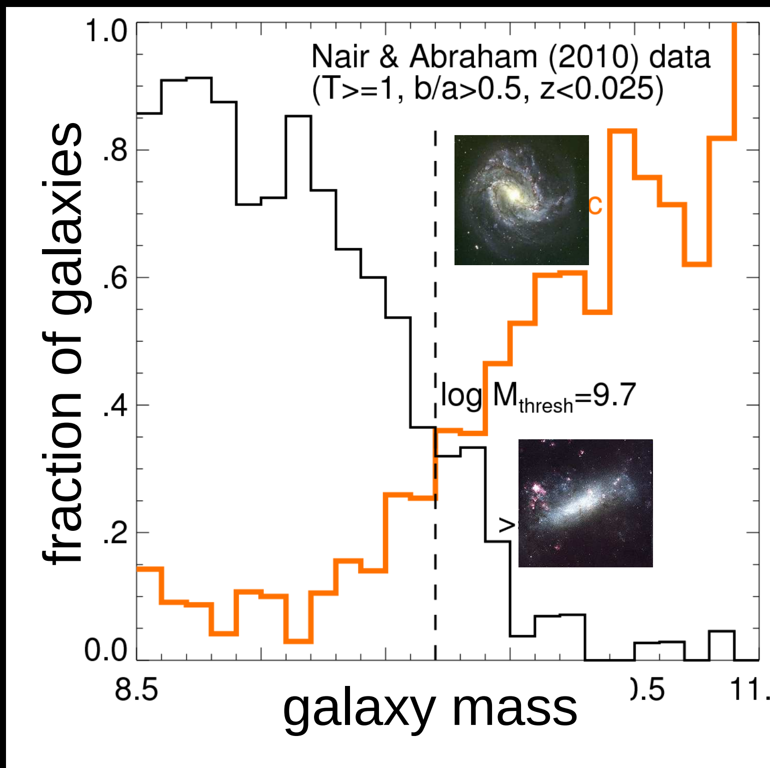


"dead" spheroid shapes (smooth/round) suddenly have blue optical colors (strong growth) 25% of the time below $M_t \Leftrightarrow V_t$
(Kannappan, Guie & Baker 2009)

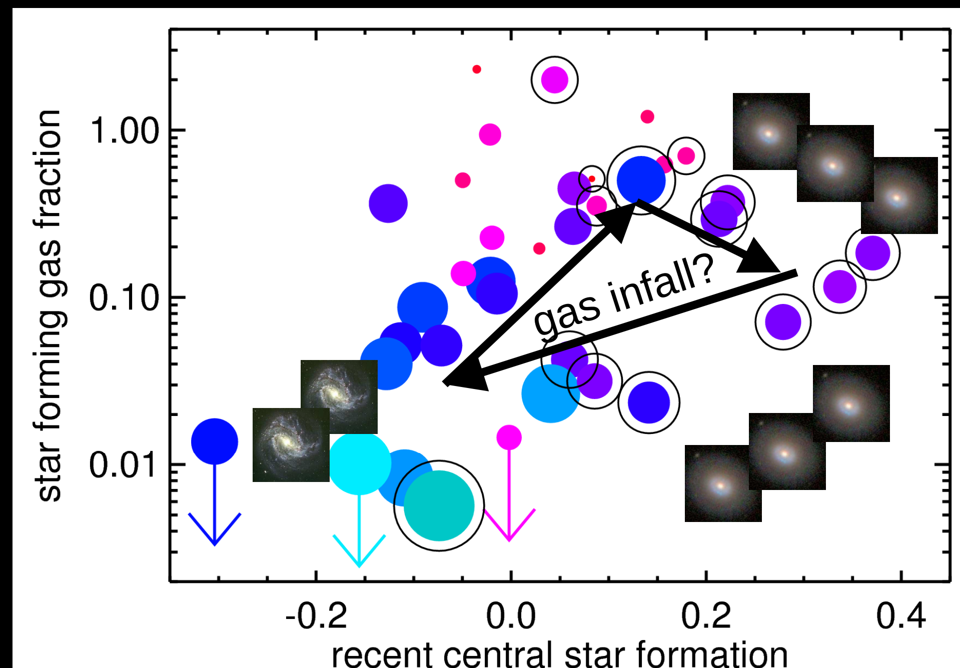


transition from bulgeless, gas-dominated dwarfs to bulged spirals may occur at threshold

Kannappan et al. (2011, in prep.)

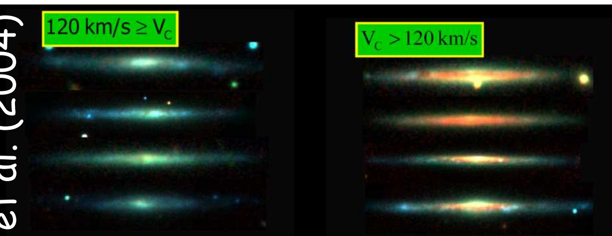


= blue spheroids in “fueling cycle”



bigger/bluer dots = more *total* gas

Dalcanton et al. (2004)



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