

# The Whys and Hows of Finding 10,000 Lenses

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- **The Hows Today**

- Flat spectrum radio surveys, quasar imaging surveys, serendipity

- **The Whys Today**

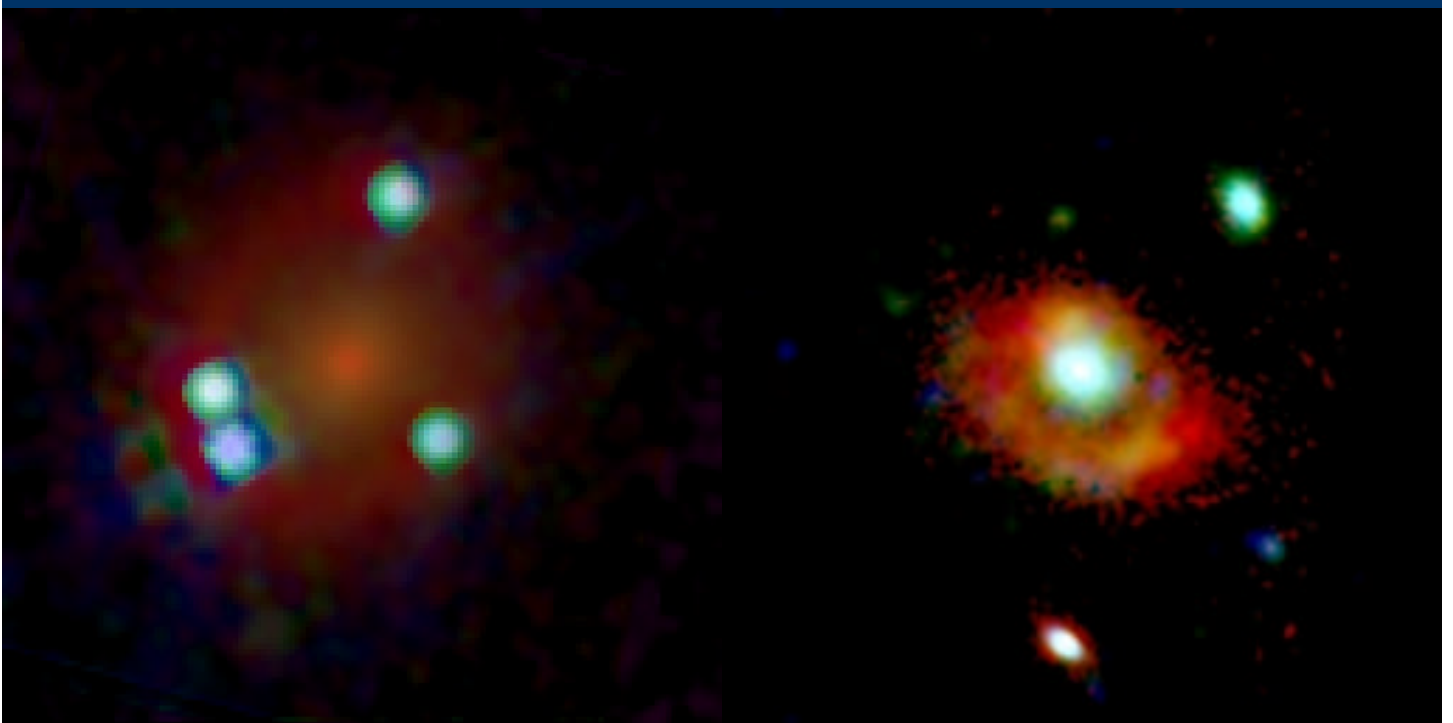
- Cosmology,  $H_0$ , galaxy evolution, dark matter, dust.....

- **The Whys Tomorrow**

- The only **mass-selected** sample of halos

- **The Hows Tomorrow**

- Wide field imaging from space



# The Hows Today

About 70 lenses known at present

## • Finding lenses

- Flat spectrum radio surveys -- 1/3 of total --  
VLA->Merlin->VLBI imaging, 1/500 sources surveyed, running out of sources ( $>50\text{mJy}$ ) given VLA sensitivity
- Quasar imaging surveys -- 1/3 of total  
ground based imaging/HST snapshot, 1/100 of bright, dropping to 1/500 for faint

## • Lens Photometry and Astrometry

- HST imaging --- major bottleneck --  
it is currently impossible to use a lens as an astrophysical tool without HST images

## • Lens and Source Redshifts

- Ground based telescopes -- major bottleneck --  
many sources too red for optical spectra but too faint for existing IR capabilities

## • Dynamical Observations

- Initial phases - compare lens mass measurements to stellar dynamical measurements

## • Time Delay Measurements

- 9 at present, growing rapidly

# The Whys Today

## •Cosmology

- number of lenses goes as volume to source -- results limited by small sample size , missing redshifts

## •Hubble constant

- 5 clean systems with time delay measurements -- agree with local estimates only if dark matter is compact

## •Dark Matter/Halo Structure

- strong evidence that early-type galaxies have dark matter with nearly flat rotation curves
- clear evidence for a change in halo structure near galaxy/group mass scale ( $\log M=13$ ), estimates of cold baryon fraction needed for galaxies

## •Halo Substructure

- estimates of halo substructure fraction that do not depend on satellites being luminous -- consistent with CDM

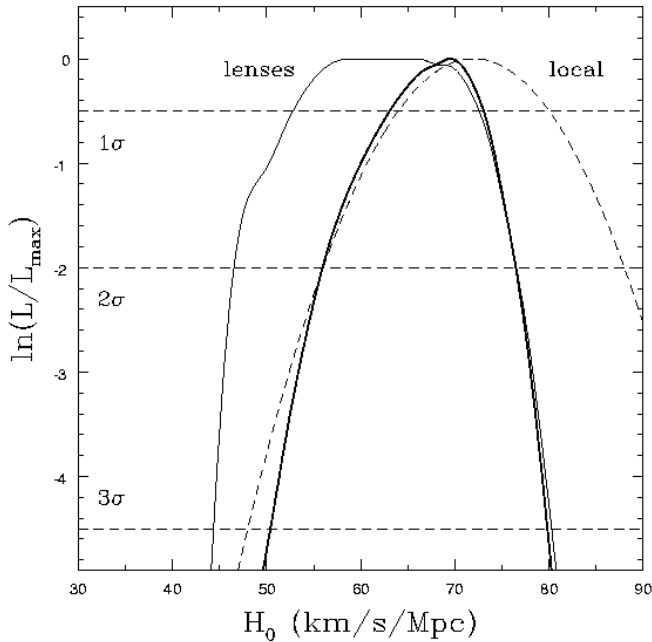
## •Galaxy Evolution

- best available estimates of early-type galaxy evolution to redshift unity
- mass-selected rather than luminosity/surface brightness selected -- immune to major problems of other methods

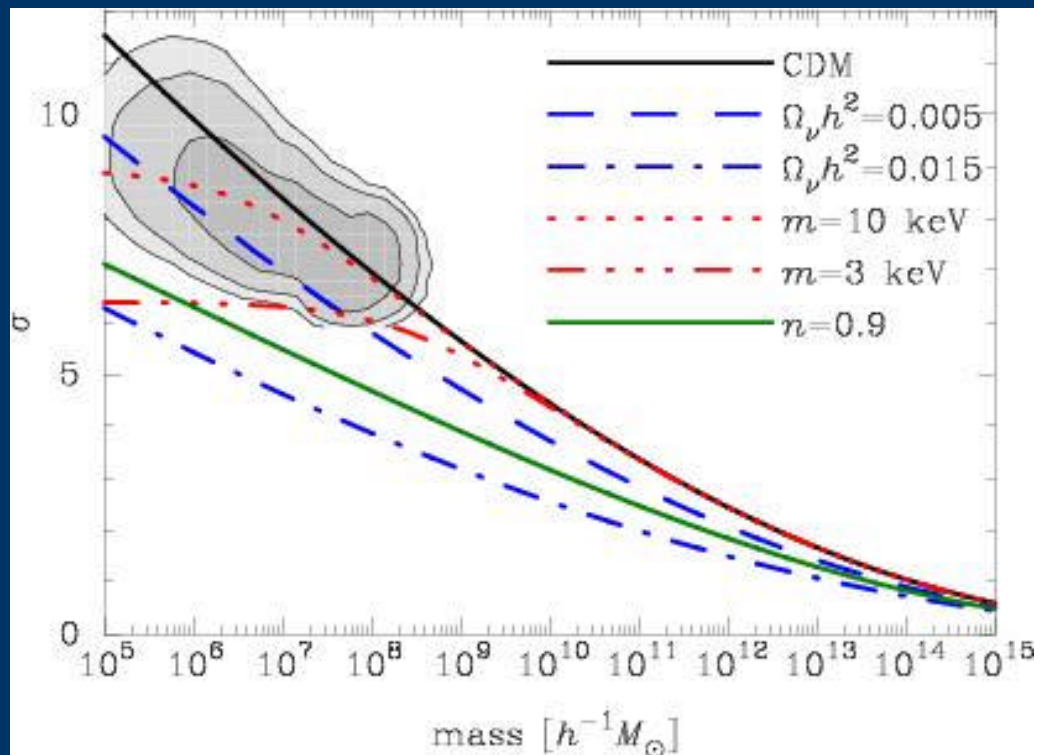
## •Interstellar Medium

- accurate differential extinction measurements
- only precision method for determining extinction laws at cosmological distances

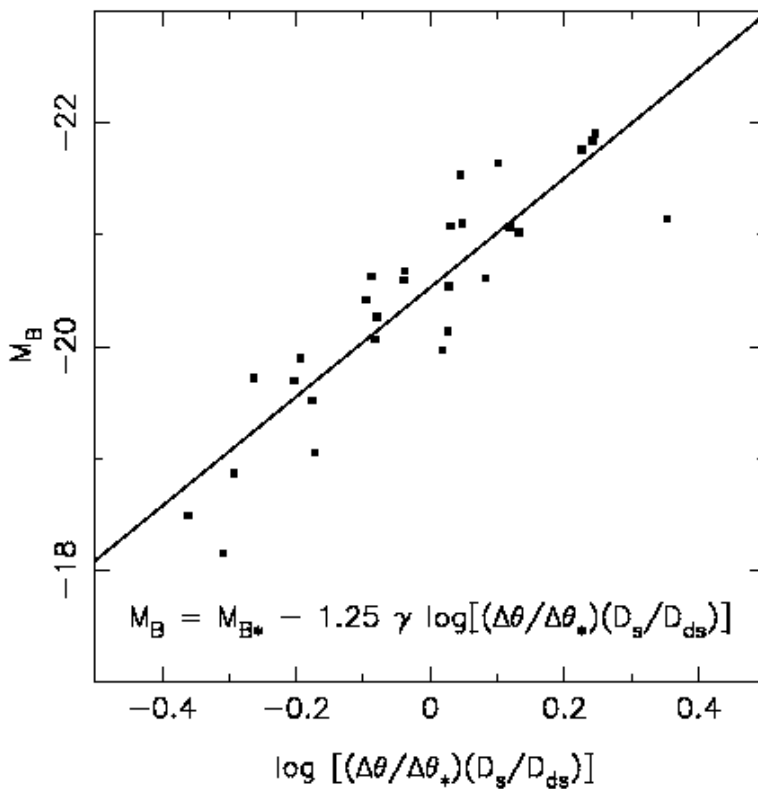
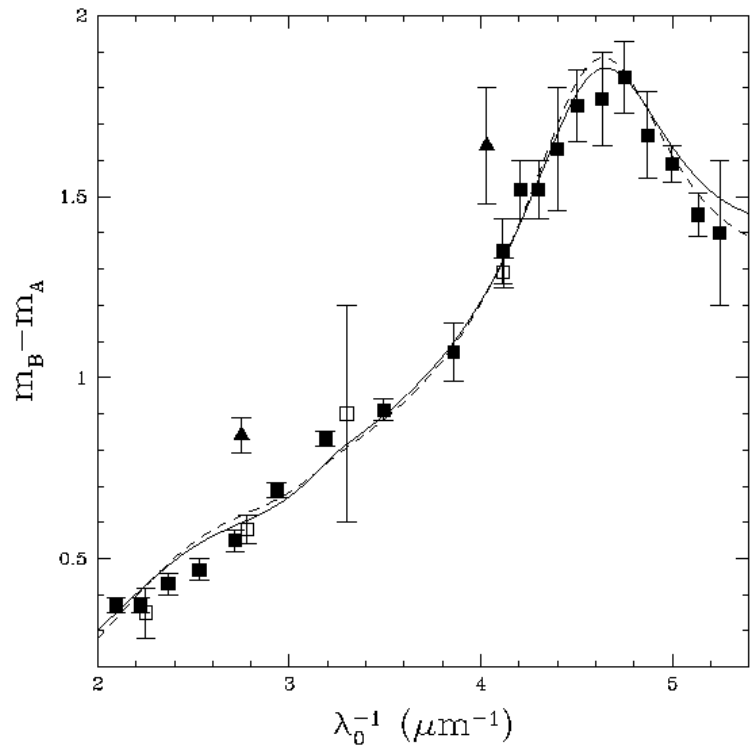
**H0 Estimates -- now competitive with local distance scale. Local estimates too high for galaxies with extended dark matter halos (Kochanek 2002)**



**Halo substructure -- lenses require amount of substructure predicted by CDM to explain flux ratio anomalies (Dalal & Kochanek 2002ab)**



**Extinction --first UV extinction curve at a cosmological distance (z=0.83) -- consistent with Galactic, including 2175A bump(Motta et al. 2002).**



**Correlations of mass and light -- deflections, halo shapes and orientations well correlated with visible lens galaxies (eg Rusin et al. 2002)**

# The Whys Tomorrow

## Assumptions!

- CMB anisotropies agree with a standard CDM model
- SNAP/SNIa are not systematics limited and measure  $w$
- DEEP determines velocity function near redshift unity
- NGST does same at higher redshifts
- $H_0$  known precisely (5%) by some method
- Ground based AO competitive with HST image quality, but can go deeper and permits faint IR spectroscopy
- SZ/X-ray/weak lensing methods can trace massive clusters at most  $z$

## What does that leave?

**Lenses have one critical advantage over all other methods of finding halos**

**They are a mass-selected sample rather than luminosity-selected or surface brightness-selected**

# Where Does It Matter?

- **Galaxy versus Group Halos**

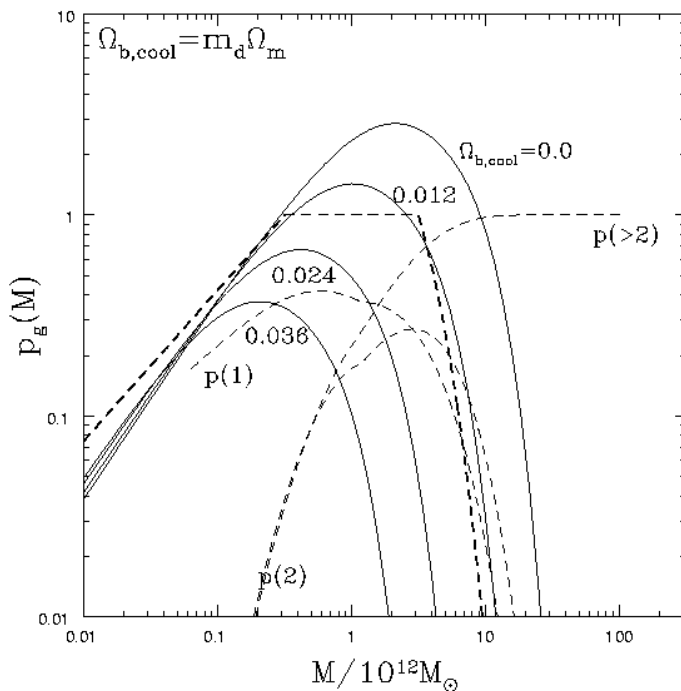
- Change in halo structure – compressed by baryons
- Cooling mass scale and its evolution

- **Star forming versus dark halos**

- Halos  $\rightarrow$  normal galaxies over a very restricted mass range
- Surface brightness selection effects

- **Substructure in halos**

- Mass fraction, scale, distribution
- Internal structure of satellites

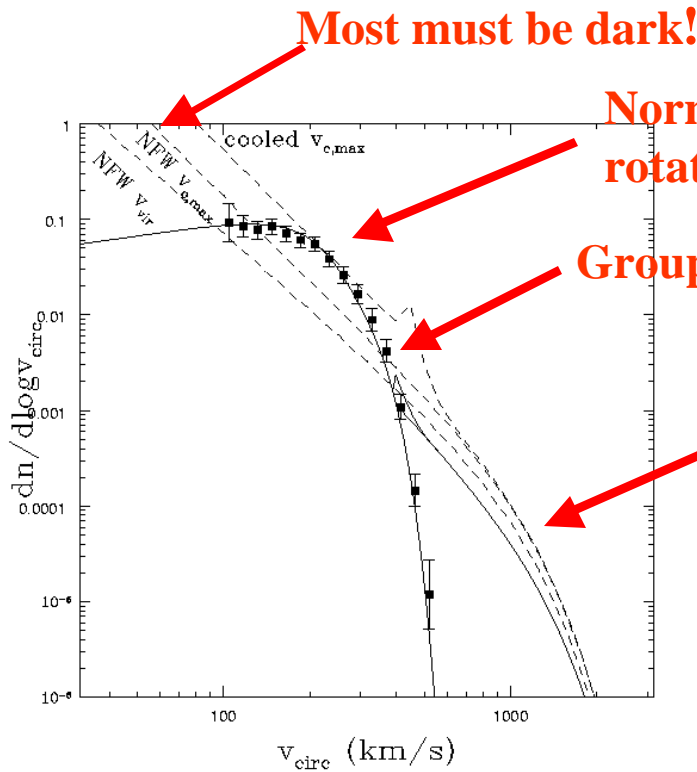


**Halos turn into galaxies with near unit probability only over a very restricted range of masses**

- lower mass halos seem to be dark, as in the halo substructure problem
- higher mass halos are poor groups

# Velocity Functions

consider problem of matching the velocity function of halos to observations



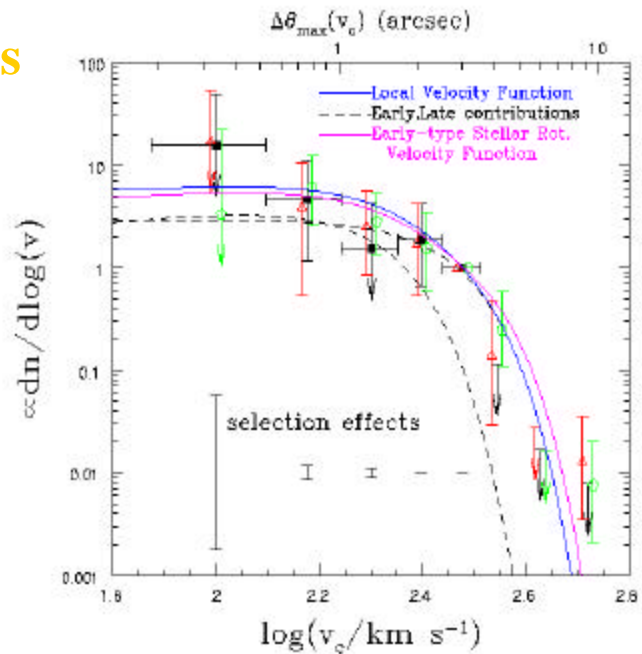
Normal galaxies -- inhomogeneous -- rotation curves, velocity dispersions

Group/galaxy interface -- very hard!

Rich clusters -- X-rays SZ, weak lensing -- best understood

## Velocity function without lenses

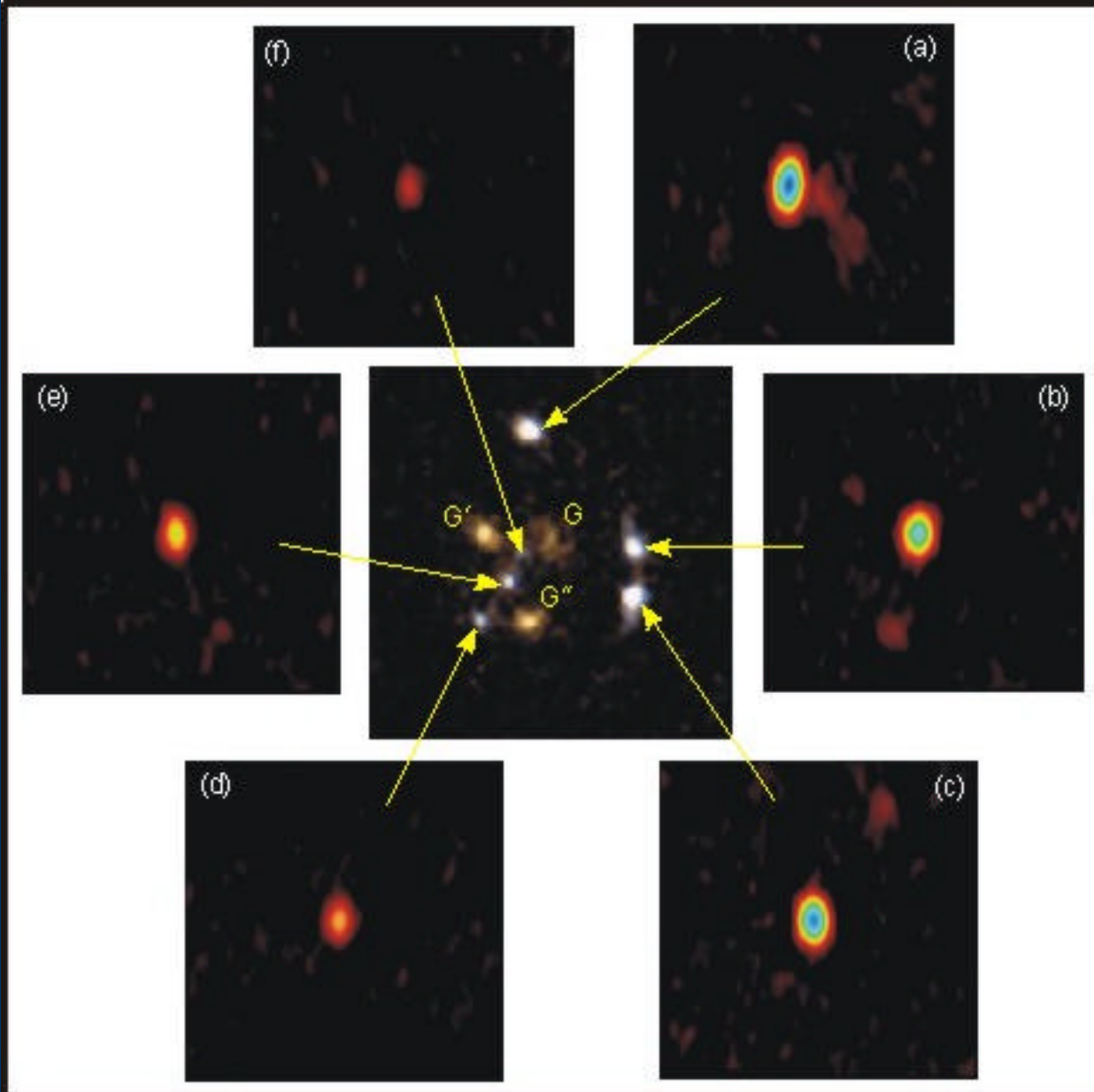
- Limited by statistics today but
- finds both dark and luminous halos
- same method at all mass scales
- covers wider mass range



## Velocity function from lenses

## But you need lots of lenses

- high mass halos (groups/clusters) are relatively rare and are inefficient lenses because the baryons did not cool
- low mass halos are common but produce small image separations and have small cross sections (worse if also lacking cold baryons to compress the halos)



We need many examples of systems like B1359+154, a six image lens produced by a compact group near  $z=1$   
(Rusin et al. 2001)

# The Hows Tomorrow

- fortunately, lenses are common! About 1/500 sources above redshift unity are lensed
- about 1 lensed AGN/square degree at typical depths
- about 100 lensed galaxies/square degree at typical depths

## Image the Sky At High Resolution

- objective is the SDSS imaging survey in space -- same area, 10 times deeper, 10-20 times the resolution
- infrared preferred because higher redshift galaxies are red

## Planned Projects Should Find 1000+

- SDSS will find 100-200
- EVLA -- FIRST survey at 0.1'' resolution to find 1000
- SNAP can find roughly 1000

