Title: Our Self-Annihilating Neighbours

Date: Sep 22, 2011 12:00 PM

URL: http://pirsa.org/11090110

Abstract: One of the most exciting, albeit slightly speculative, components of the Fermi mission is to search for evidence of energetic events related to dark matter decay or annihilation. The best targets for this search a regions where we suspect there is dark matter, but see few conventional gamma-ray sources such as molecular clouds, cosmic ray sources, or compact objects. Much emphasis has been placed on local dwarf satellites in particular, since many of these systems show evidence for relatively deep potential wells, but have few stars and no recent star formation. In this talk I will propose another possible target for indirect dark matter searches, among our nearby galactic neighbours.

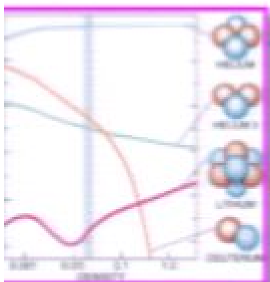
Our self-annihilating neighbours

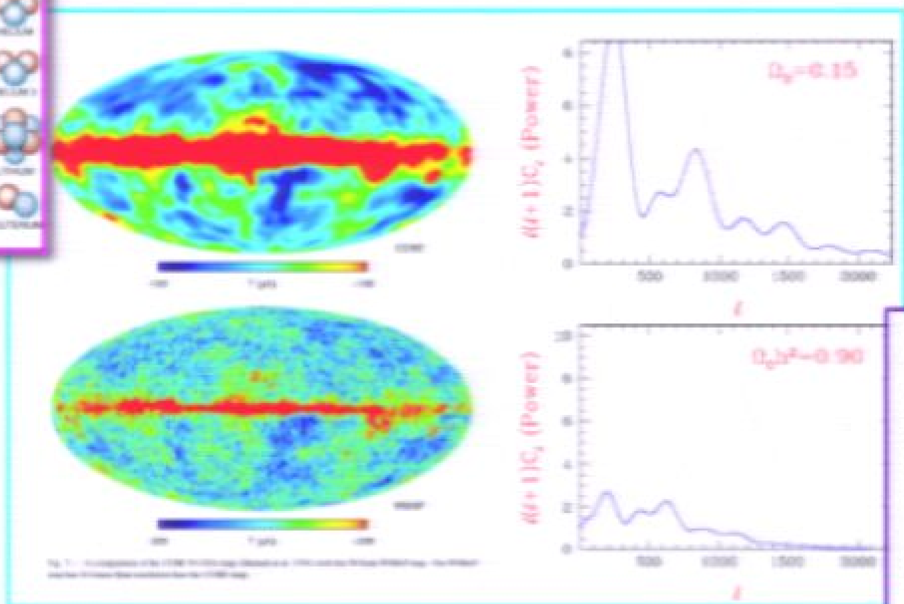
James Taylor + Niayesh Afshordi + Jesus Zavala
University of Waterloo

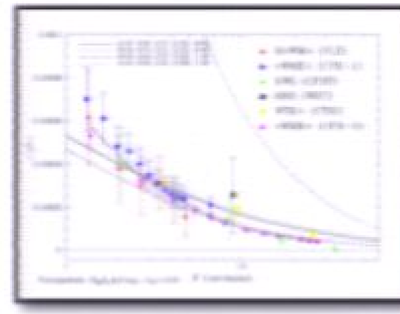
The Evidence for Dark Matter

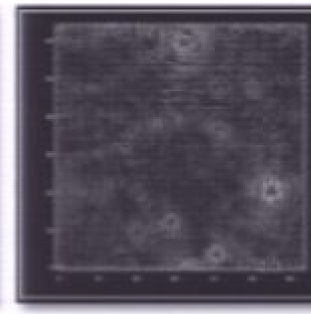
Over the past three decades, growing evidence from many different scales and redshifts:

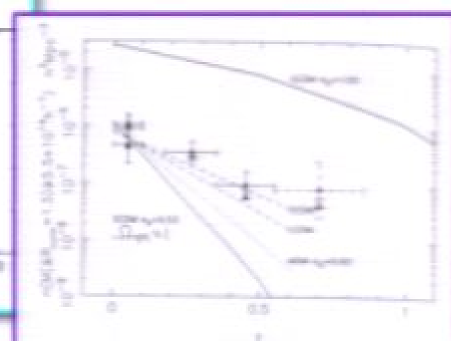
nucleosynthesis ; CMB ; local structure / cluster number counts / weak lensing

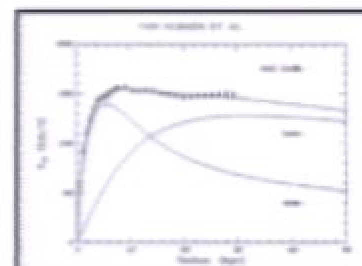






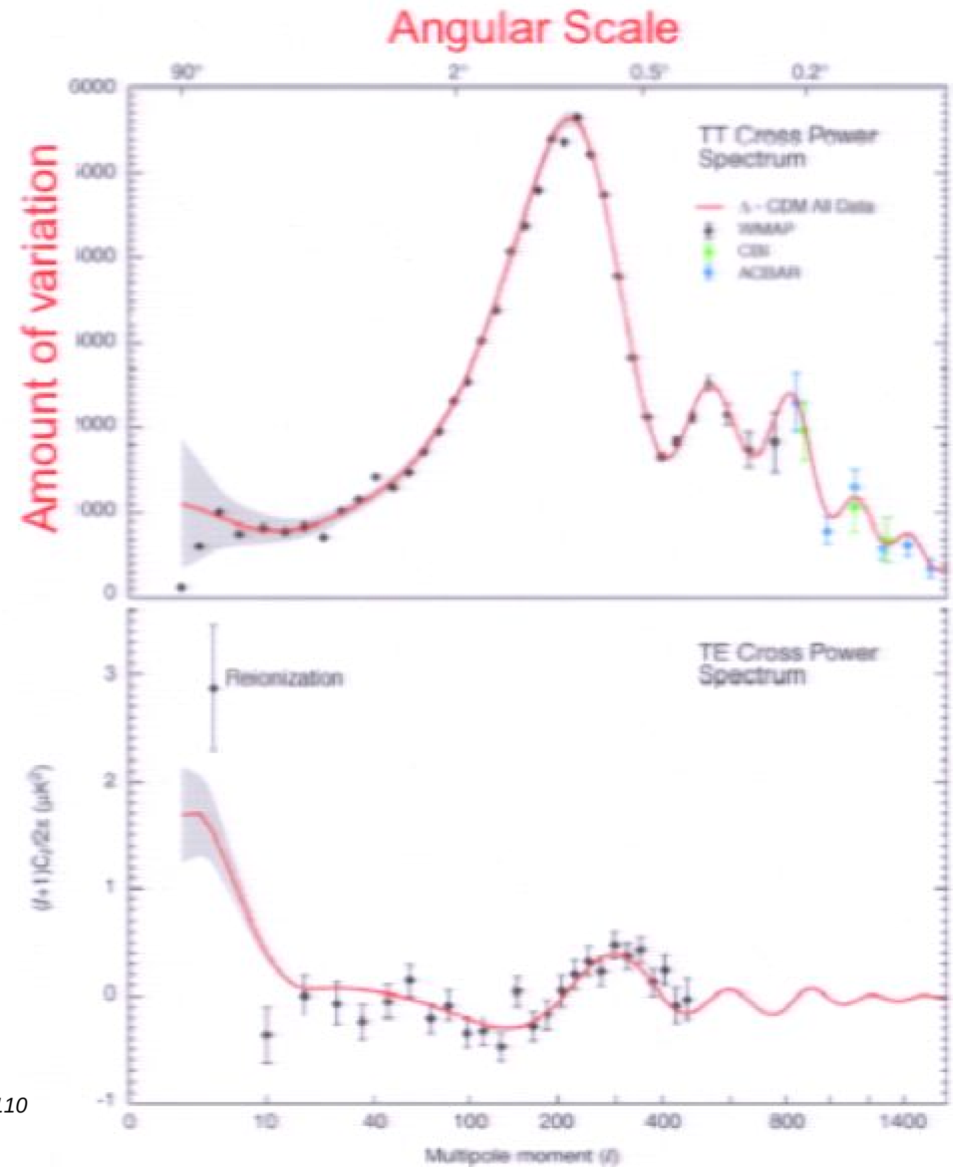






Ω_b	<<	Ω_m	<<	Ω_T
$0.0235h^{-2}$ +/- 0.0008	<<	$0.1345h^{-2}$ +/- 0.0055	<<	1.0
0.045 +/- 3%		0.23 +/- 4%		1.0

2003-2006: WMAP confirms the presence of dark matter on the largest scales



WMAP 7-year Results:

Total Matter density:
0.229 +/- 0.015

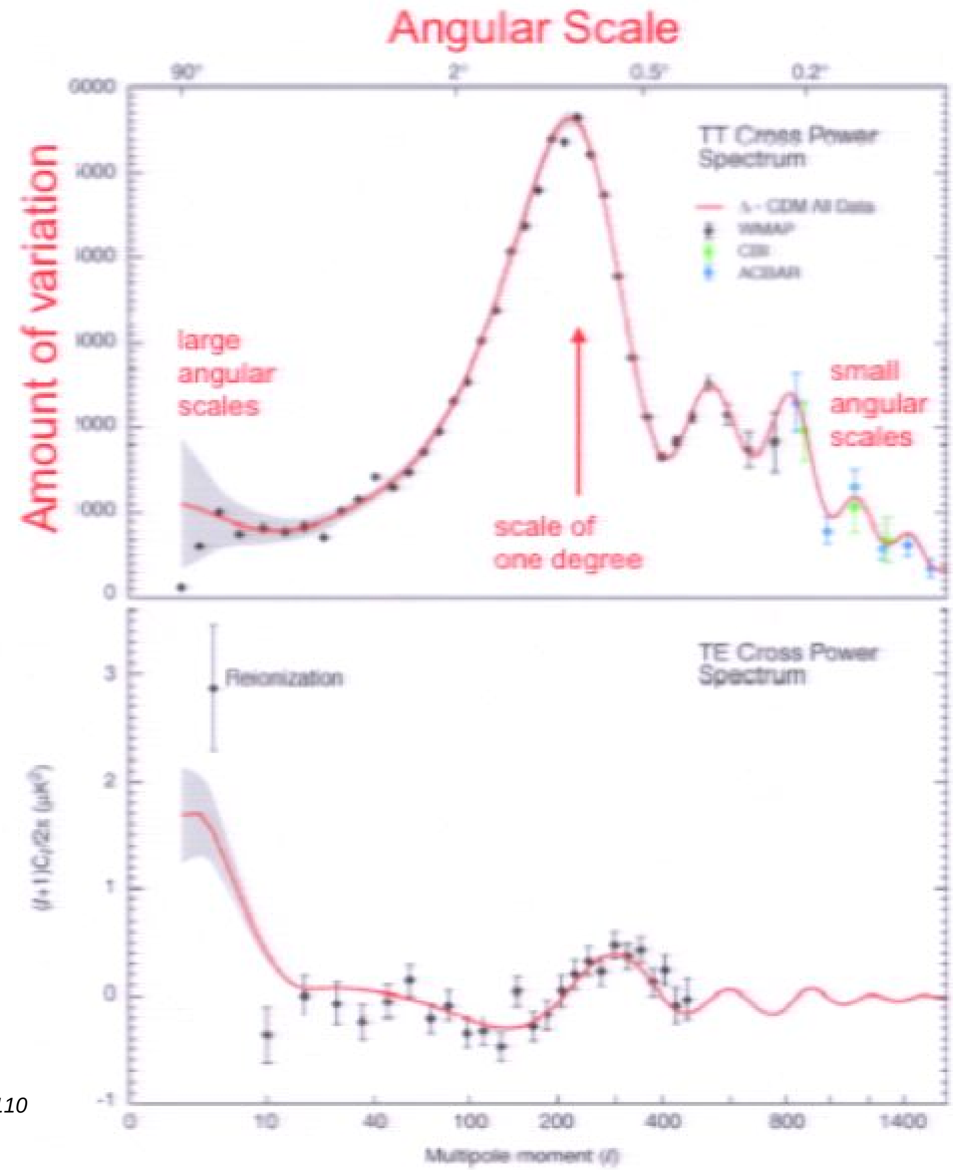
Baryonic Matter density:
0.0458 +/- 0.0016

(in units of the critical density for recollapse)

(WMAP5 + BAO + H_0)

(Bennett et al. 2003)

2003-2006: WMAP confirms the presence of dark matter on the largest scales



WMAP 7-year Results:

Total Matter density:
0.229 +/- 0.015

Baryonic Matter density:
0.0458 +/- 0.0016

(in units of the critical density for recollapse)

(WMAP5 + BAO + H_0)

(Bennett et al. 2003)

But how to pin it down the identity of the DM particle?

Direct (lab) or Indirect (observational) detection

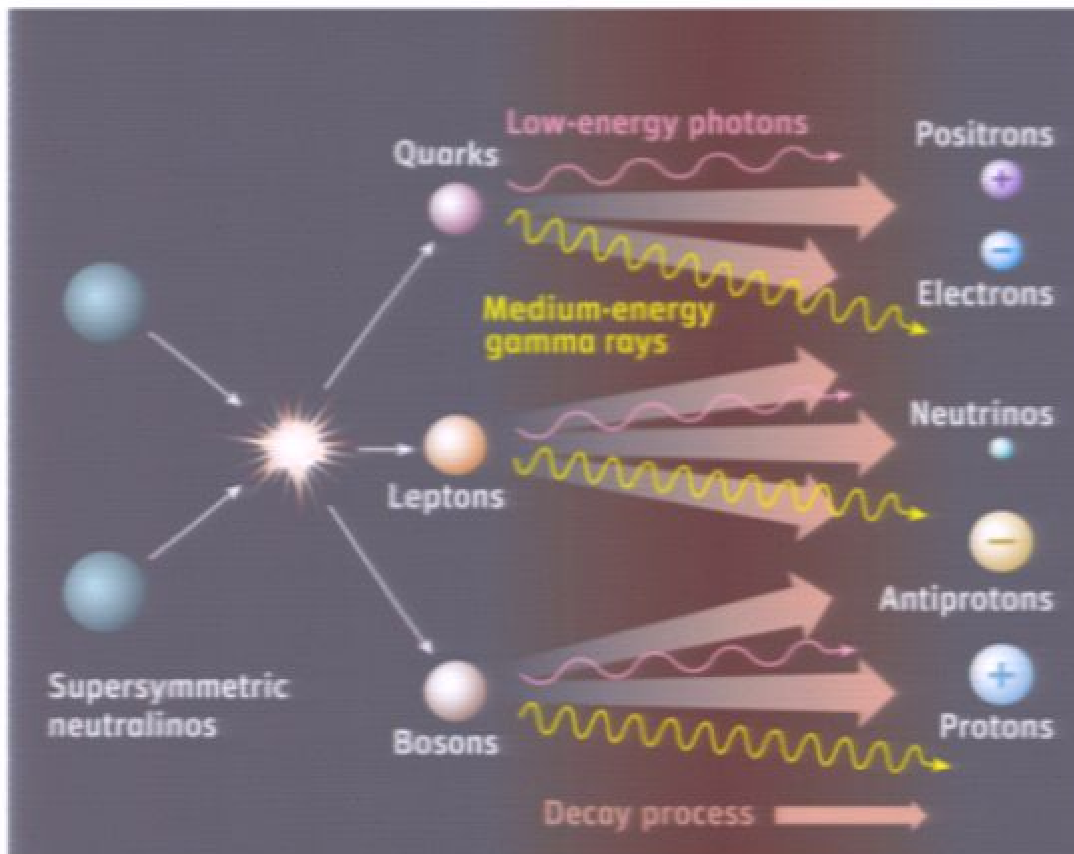
Direct detection: Identify DM particle in the laboratory

Indirect detection: Search for indirect products of dark matter annihilation, decay or interaction, e.g.:

- high-energy gamma-rays in the 100 GeV – TeV range

- high-energy neutrinos

- high energy cosmic-ray matter or anti-matter particles (electrons & positrons, protons)



Annihilation signals in the Gamma-ray range

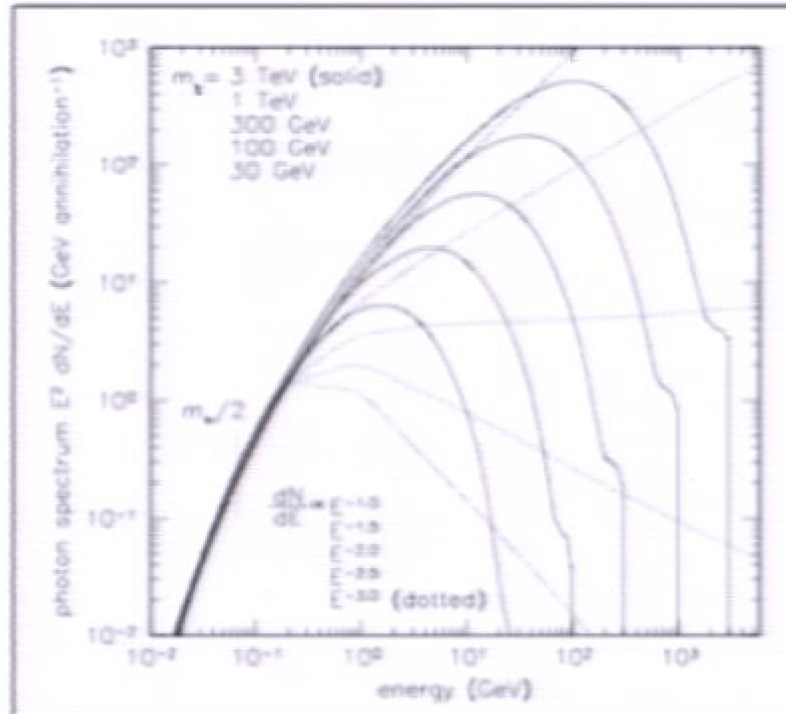
Majorana fermion WIMPs can annihilate with one another, producing pairs of quarks, leptons, photons, etc.

Direct (in-situ) photon production by various mechanisms (see below).

e.g. quark-antiquark pairs ⇒ hadronization ⇒pions

Resulting pion bump at ~ $m_\chi/25$ ranges from 1-100 GeV depending on WIMP mass

Spectrum has sharp energy cutoff at m_χ, so very different from, e.g., emission from power-law cosmic-ray proton spectrum



Baltz, Taylor & Wai 2007 - spectrum from DarkSUSY/Pythia

Photon yield

- In situ photons: Directly created in the annihilation process (annihilation channels).

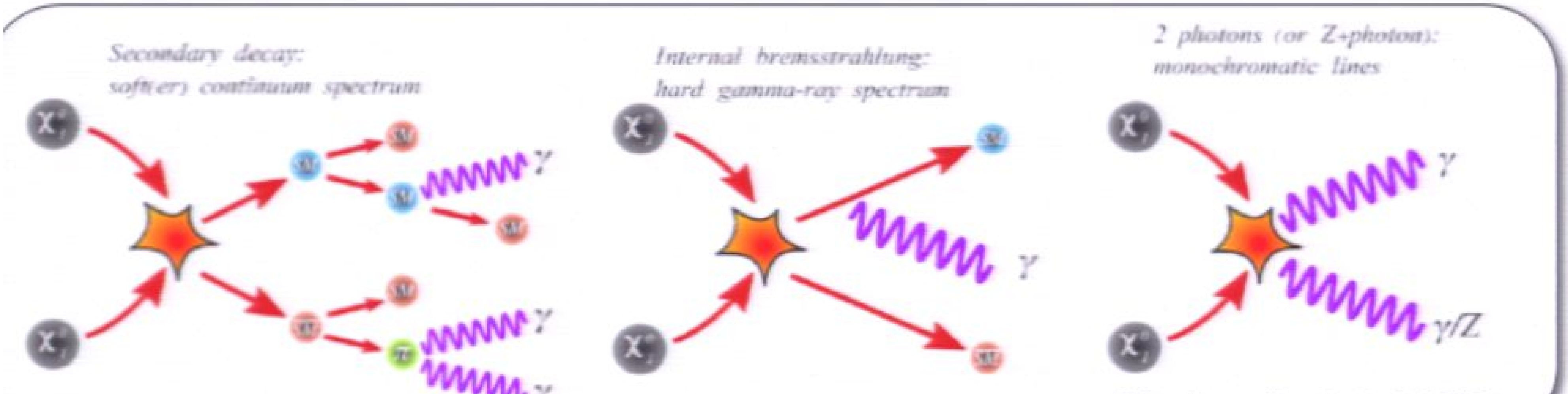
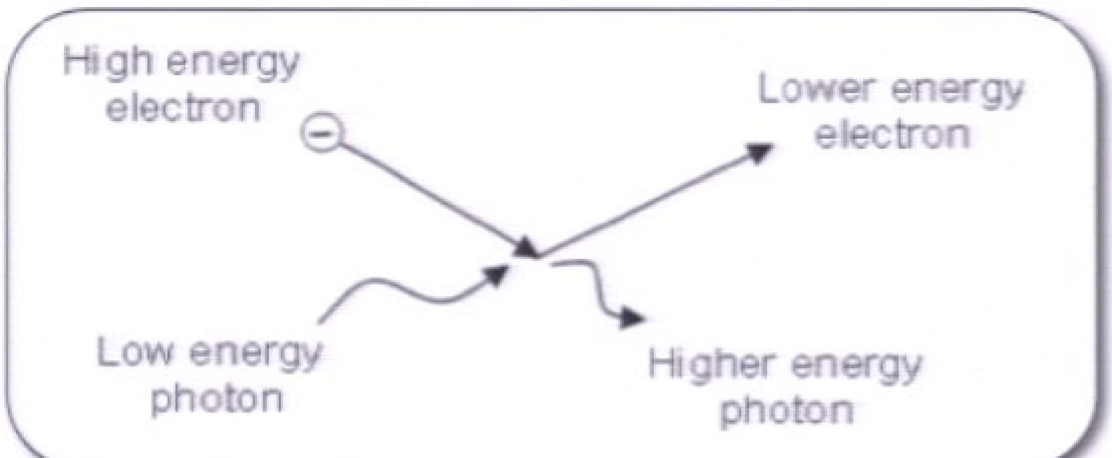


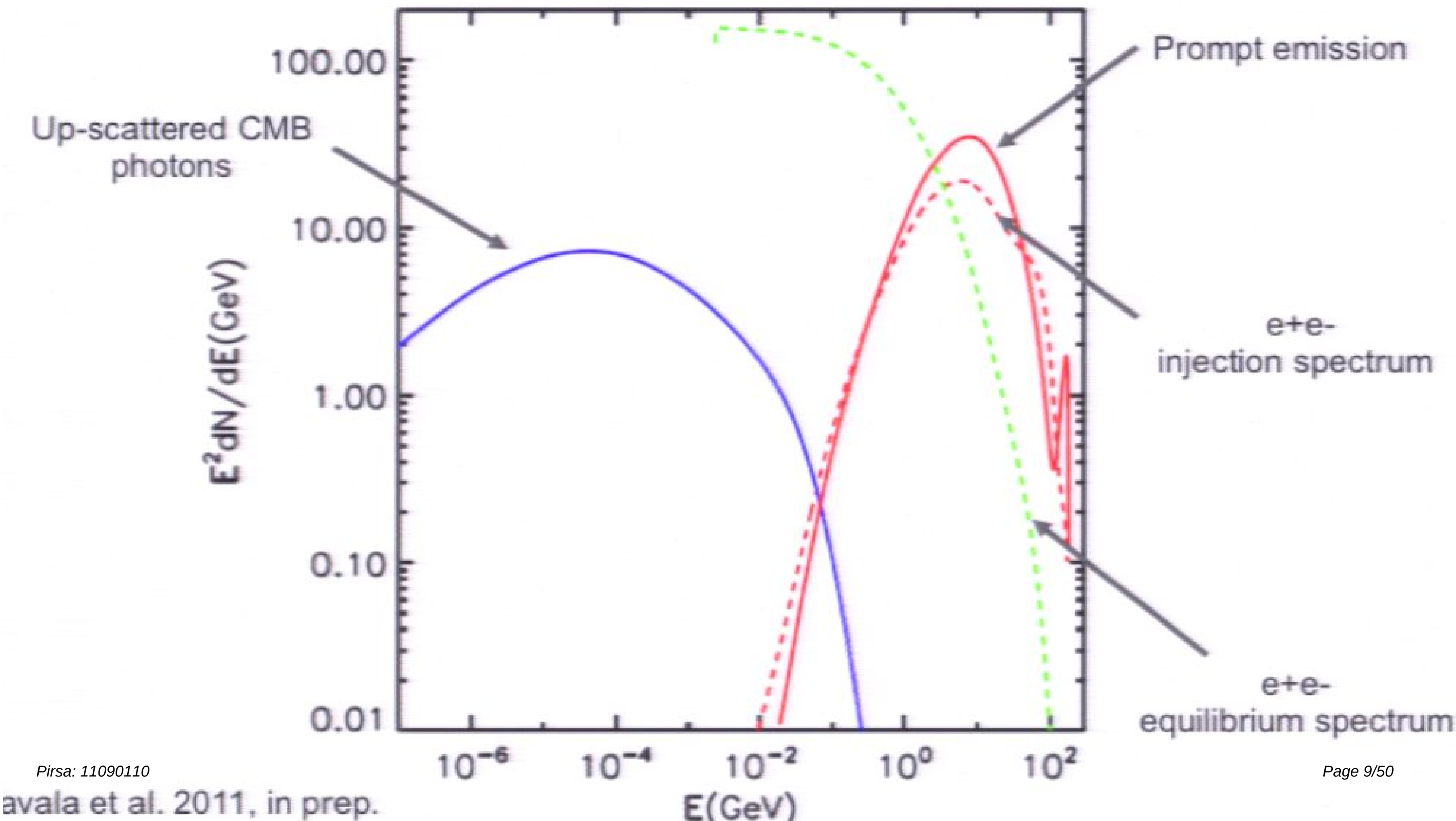
Fig. from Scott et al. 2009

- Up-scattered photons: Background photons gain energy through Inverse Compton scattering with electrons and positrons produced in the annihilation: e+e- injection spectra → e+e- equilibrium solution → photon background → final IC photon spectrum.



Photon yield (example)

$m_\chi \sim 200\ GeV, \chi\chi \to b\bar{b}$ and $\langle\sigma v\rangle \sim 6.2\times 10^{-27}\mathrm{cm}^3\mathrm{s}^{-1}$



avala et al. 2011, in prep.

The annihilation signal

The surface brightness of a distant CDM halo goes as:

$$\text{flux/solid angle} = J(x,y) \times \Phi(\Delta E)$$

where

$$J(x,y) = \int \rho^2(x,y,z)dz$$

and

$$\Phi(\Delta E) = \frac{1}{4\pi}\frac{\langle \sigma v\rangle}{m_W^2}\int_{\Delta E} E\frac{dN_\gamma}{dE}dE$$

J is the astrophysical factor, which depends only on the spatial distribution of CDM; Φ is the particle physics factor, which depends on the candidate particle.

Because of the ρ^2 weighting, the annihilation signal will trace the densest parts of the CDM distribution.

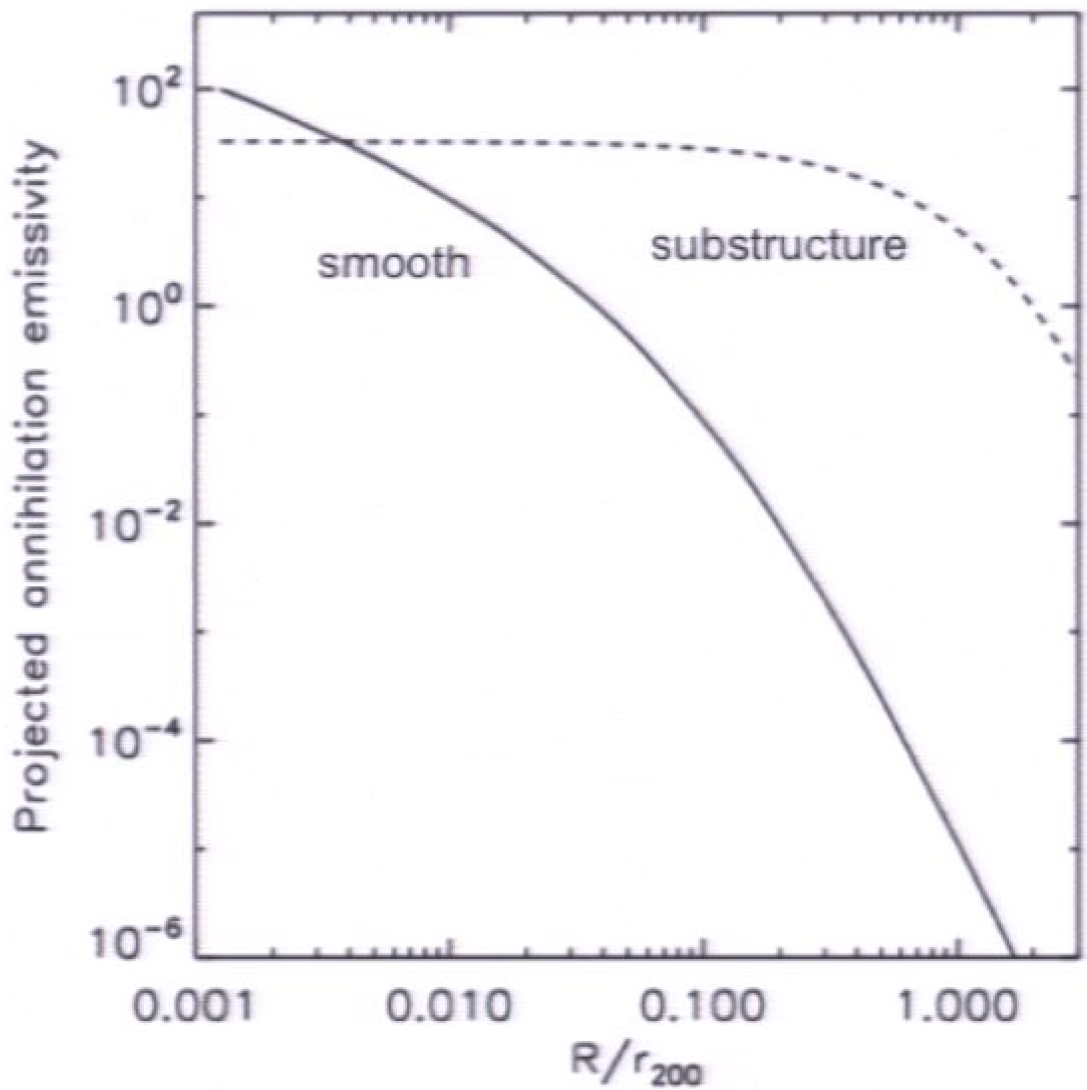
We can further distinguish two components to J, the contribution from smooth halos and the contribution from halo substructure.

The annihilation signal

The surface brightness profile from the smooth component should be very centrally concentrated, while the contribution from substructure is more extended.

Note that the relative normalization of the two components depends on the smallest scale on which there is CDM substructure

So how to look for this signal?

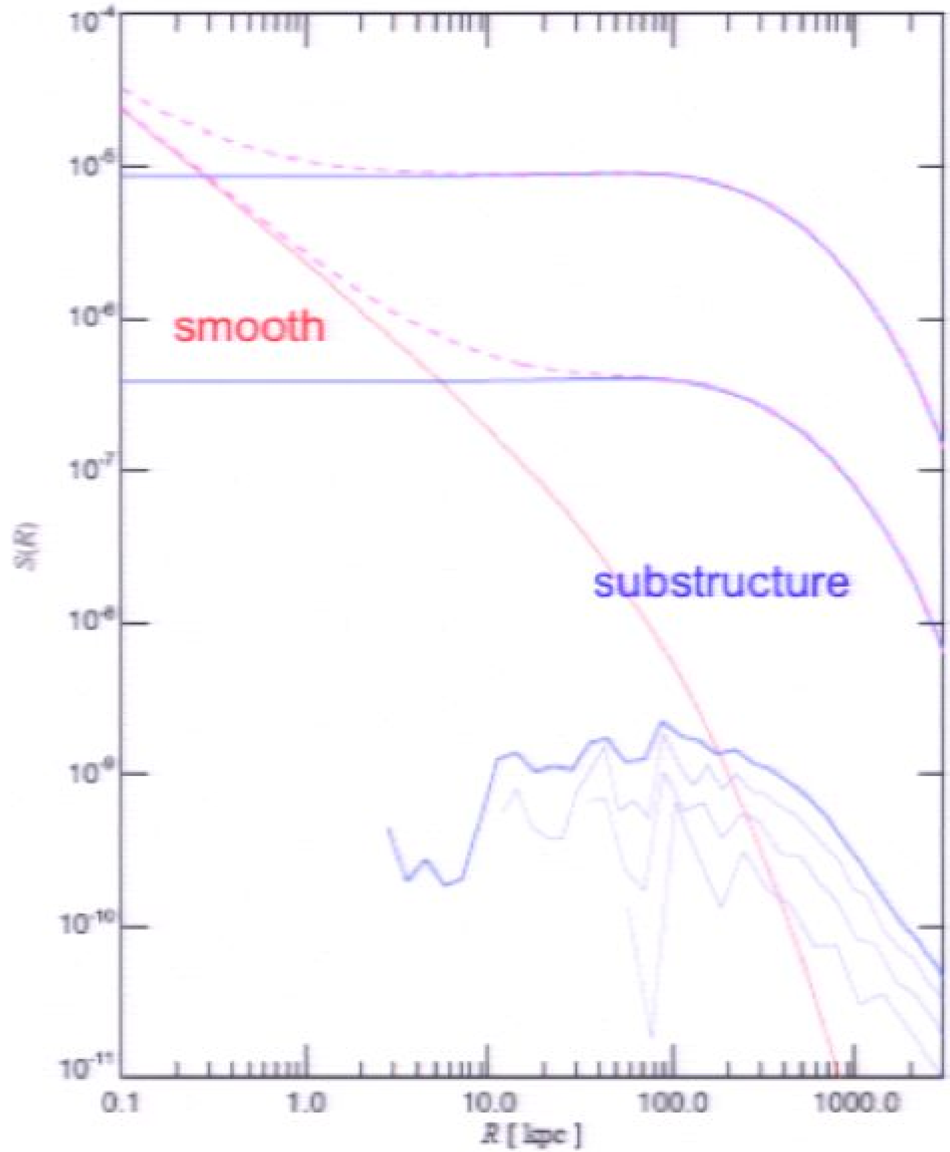


The annihilation signal

The surface brightness profile from the smooth component should be very centrally concentrated, while the contribution from substructure is more extended.

Note that the relative normalization of the two components depends on the smallest scale on which there is CDM substructure

So how to look for this signal?



Gao et al. 2011 — "Phoenix" cluster simulations

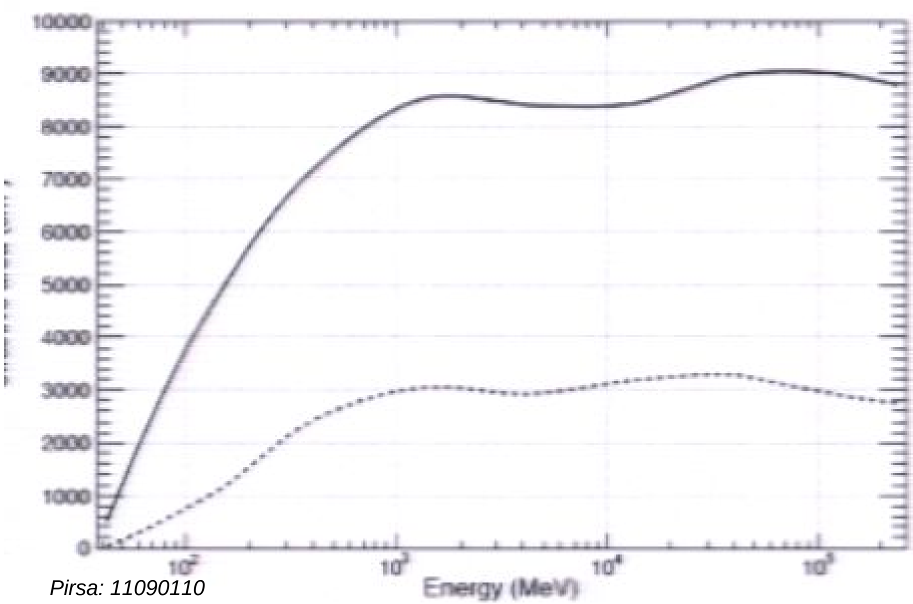
Summer 2008: Successful launch of the Fermi Gamma-ray Space Telescope

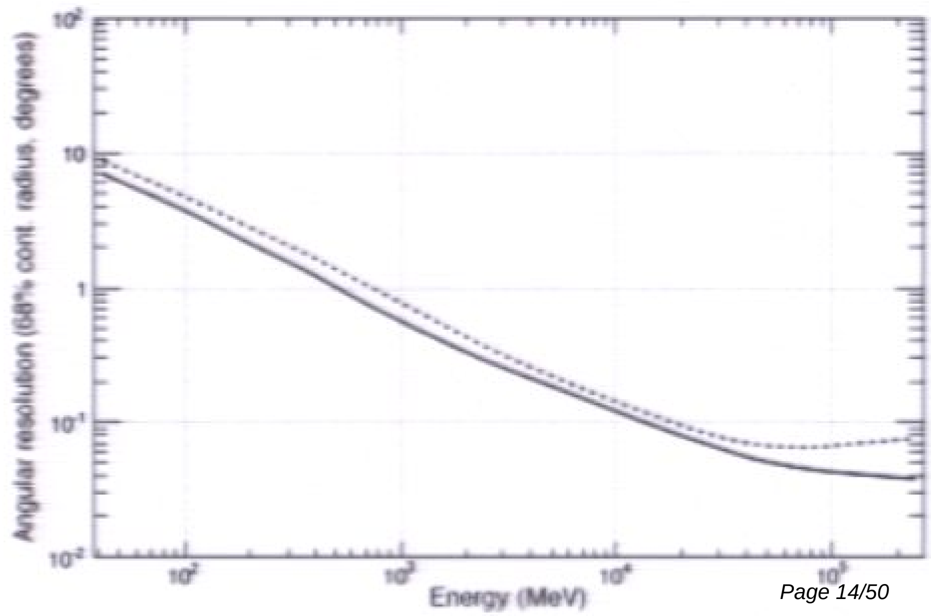
Fermi
Gamma-ray
Space Telescope

Summer 2008: Successful launch of the Fermi Gamma-ray Space Telescope

The Fermi Large Area Telescope (LAT):

FOV:	2.4 sr
Energy range:	20 Mev-300 Gev
effective area:	~ 8000-9000 cm^2
energy resolution:	~ 10%
angular resolution:	0.15 deg at 10 GeV
	0.6 deg at 1 GeV





Where to look?

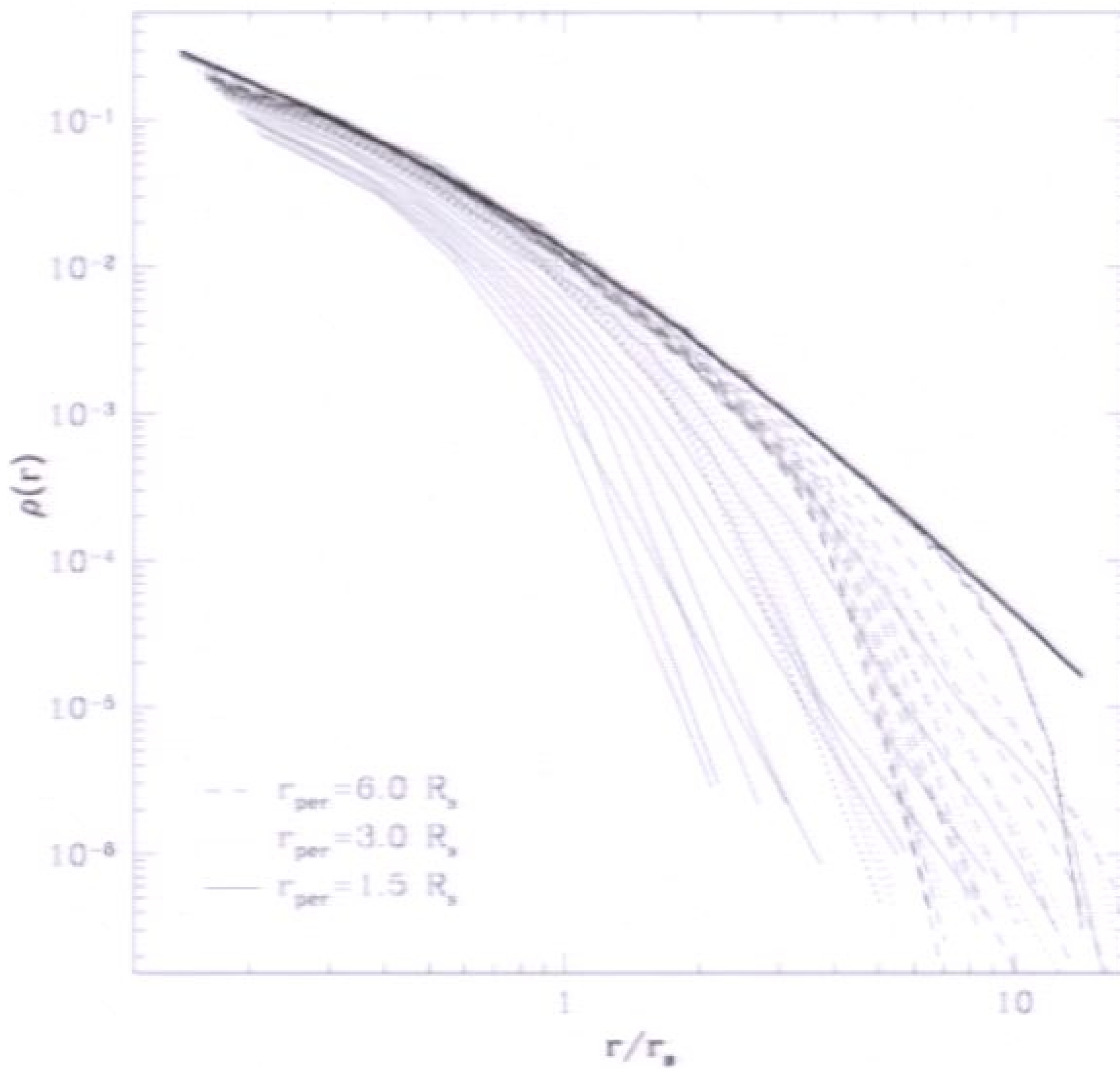
The Aquarius simulation (Springel et al 2008) - a superabundance of satellite subhalos

The Signal from Local Satellites

Theoretical prediction (Hayashi et al. 2003):

stripped satellites lose mass from the outside-in; system has a well-defined density profile at any time:

$$\rho(r) = \frac{f_t}{1 + (r/r_{te})^3} \rho_{\rm NFW}(r)$$



Evolution of the density profile as satellites loses progressively more mass (Hayashi et al. 2003)

Where to look?

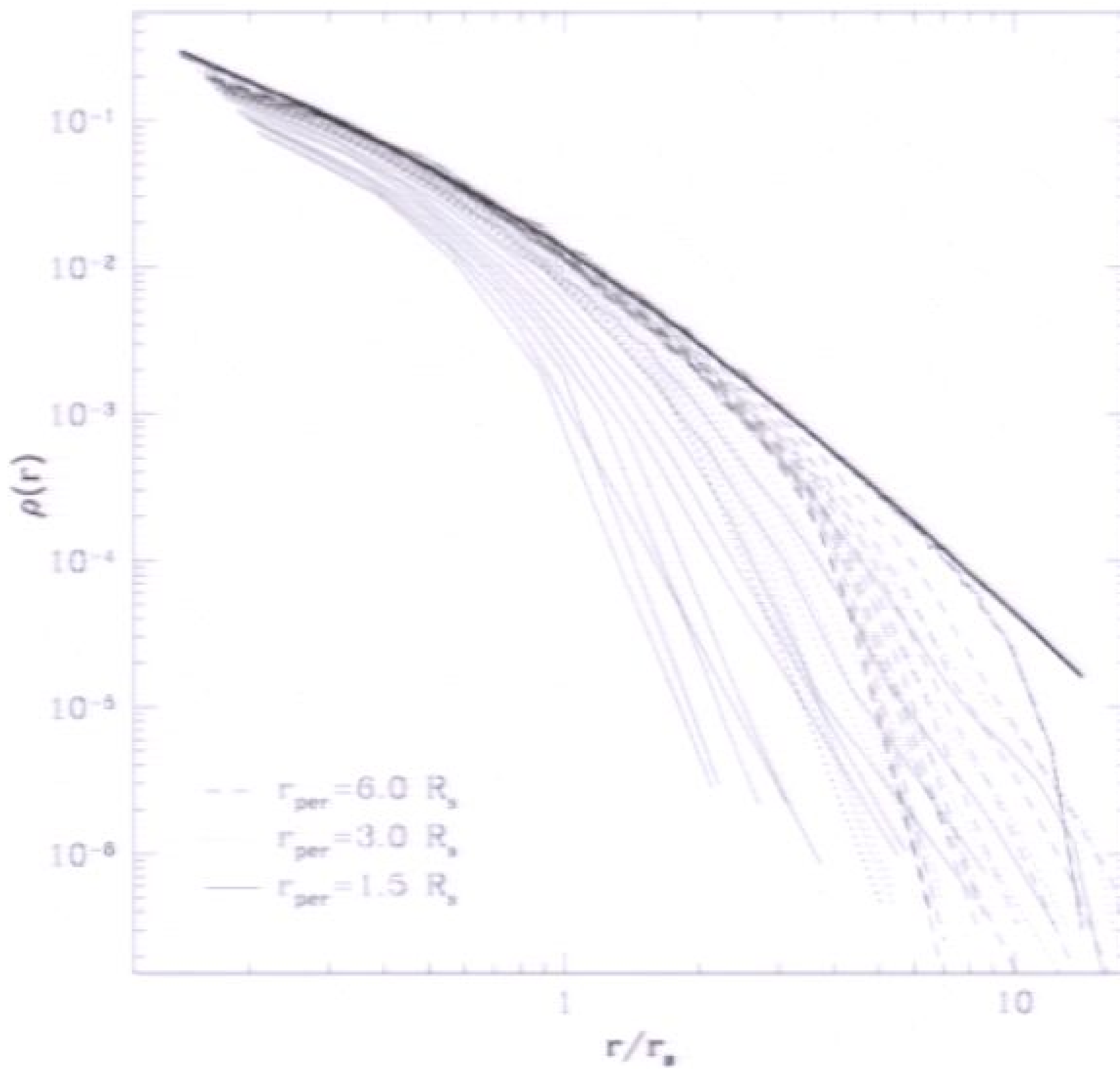
The Aquarius simulation (Springel et al 2008) - a superabundance of satellite subhalos

The Signal from Local Satellites

Theoretical prediction (Hayashi et al. 2003):

stripped satellites lose mass from the outside-in; system has a well-defined density profile at any time:

$$\rho(r) = \frac{f_t}{1 + (r/r_{te})^3} \rho_{\rm NFW}(r)$$

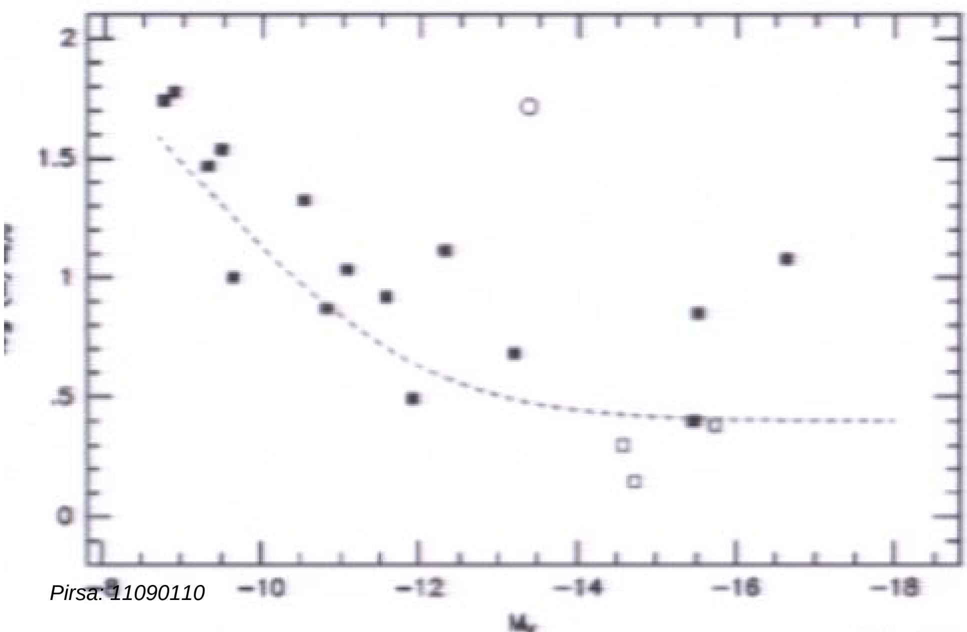


Evolution of the density profile as satellites loses progressively more mass (Hayashi et al. 2003)

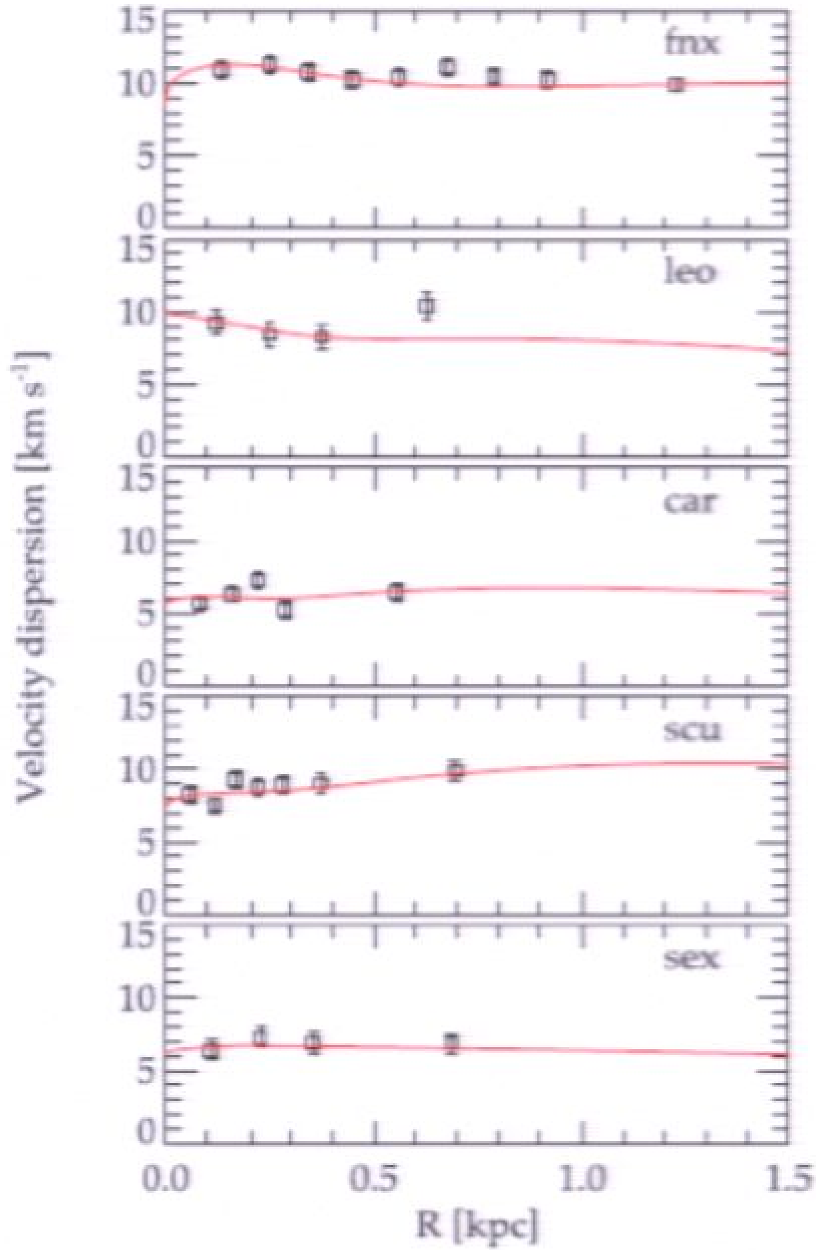
The Signal from Local Satellites

* Also there is observational evidence that these objects are indeed dark matter-dominated: velocity dispersions imply mass-to-light ratios of 100 or more

* Sizes well-suited to angular resolution of LAT (half-light radii of 0.05-1.3 deg)



Mateo 1998



Strigari et al. 2010

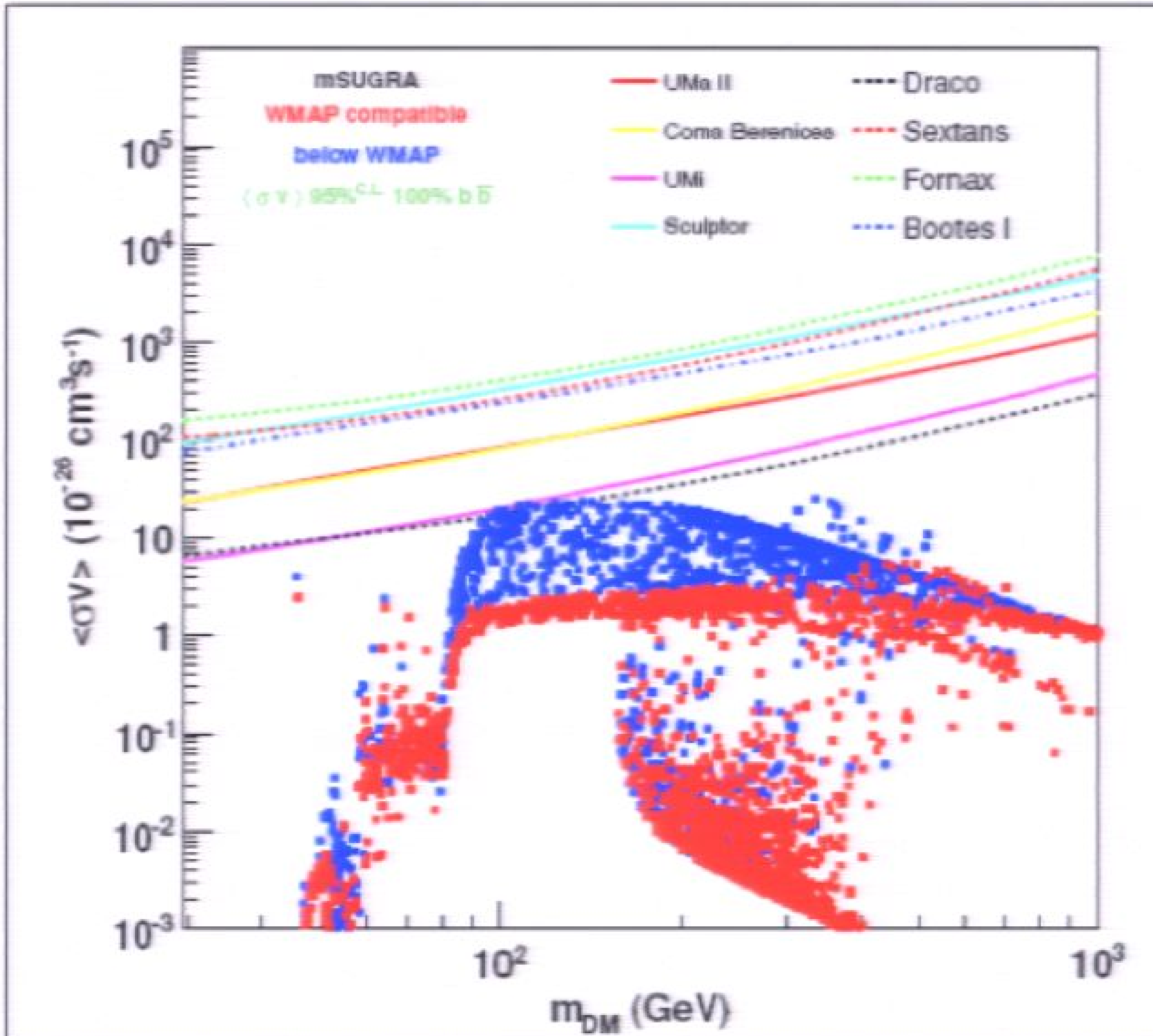
The Signal from Local Satellites

Abdo et 2010:

* search for an annihilation signal from 14 dwarf satellites of the MW

* no detection, only constraint on cross-section

* limit depends on specific WIMP model, but roughly $\langle\sigma v\rangle > 10^{-25} - 10^{-24}\ cm^3\ s^{-1}$



The Signal from Local Satellites

But are satellites the best place to look?

S/N calculation for a single source: (Springel et al 2008, Gao et al. 2011)

$$S/N = f_{\mathrm{shape}}(\theta_h/\theta_{\mathrm{psf}}) \left[\frac{tA_{\mathrm{eff}}}{B}\right]^{1/2} \frac{F}{(\theta_h^2 + \theta_{\mathrm{psf}}^2)^{1/2}},$$

Where B is the background, F is the source flux, Aeff is the effective area and t is the exposure time

Result: local dwarfs $6\mathrm{x}10^{-5}$ - $5\mathrm{x}10^{-3}$ times S/N_{MW}

versus massive galaxy clusters $2\mathrm{x}10^{-3}$ - $1.3\mathrm{x}10^{-2}$ times S/N_{MW}

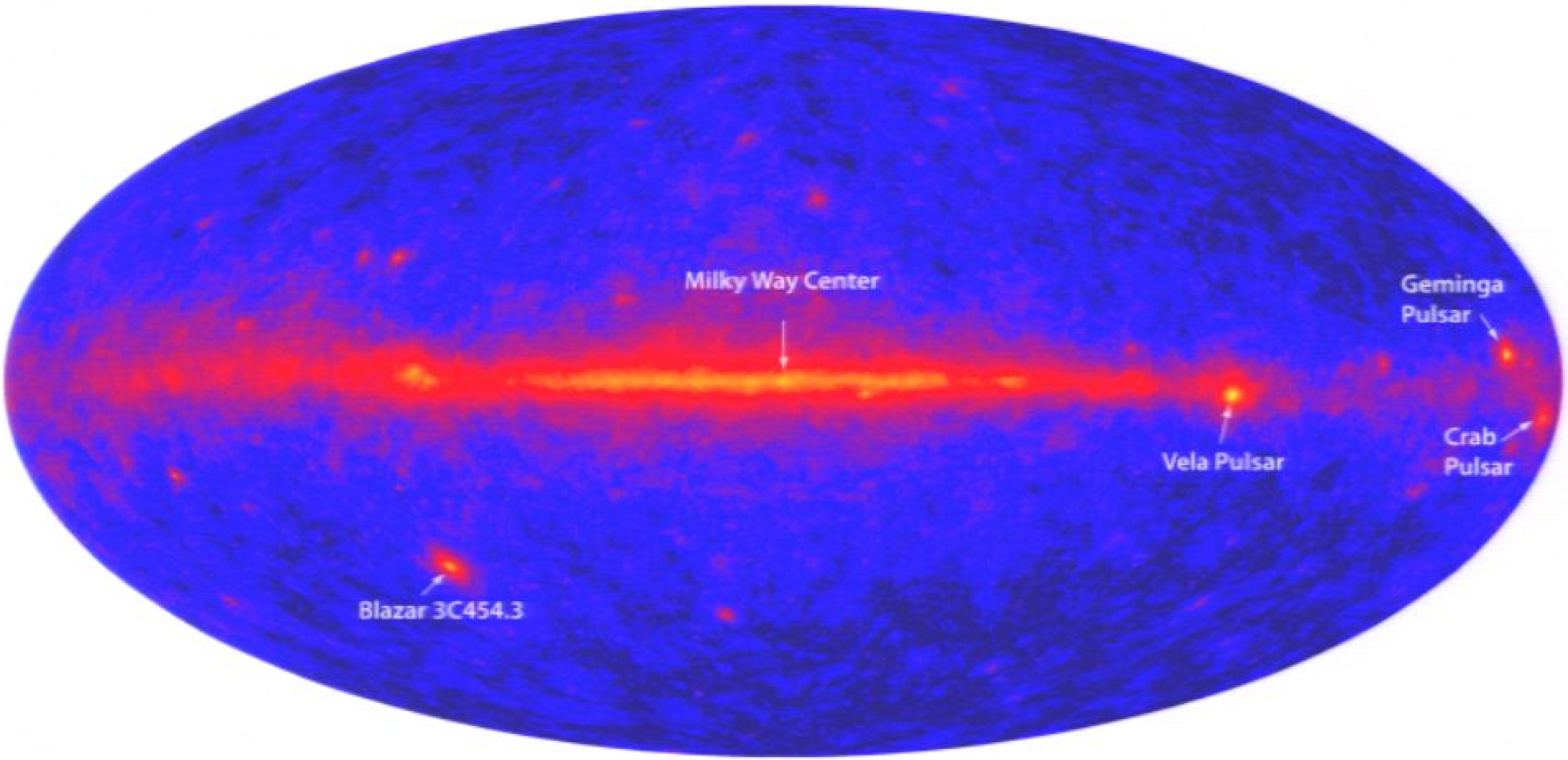
Also another problem with satellites: which subhalos do they trace?

N.B. finds that M31 has a an expected S/N $9\mathrm{x}10^{-3}$ times S/N_{MW}

so why not look at giant galaxies?

The main contributor to gamma-rays:

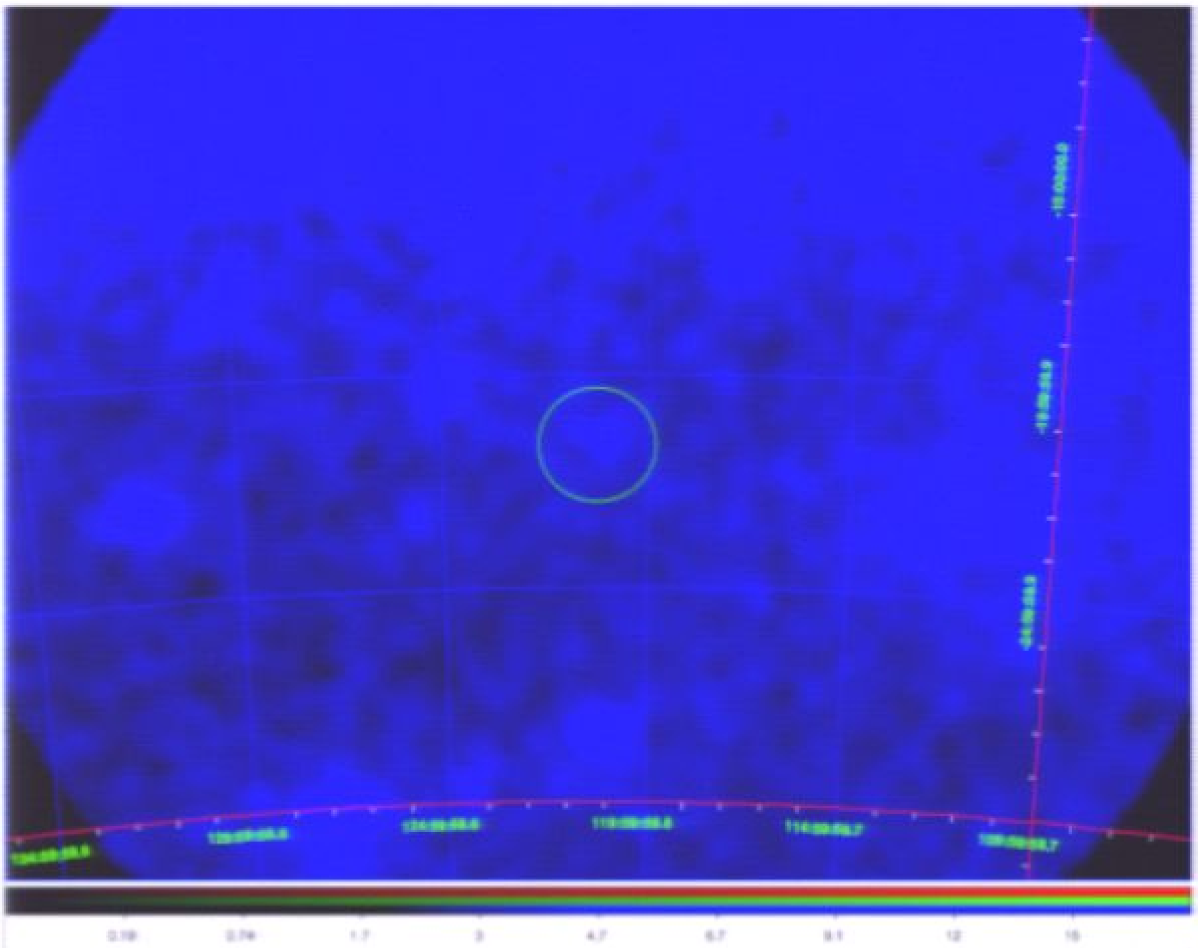
cosmic-ray/ISM interactions



Cosmic-ray protons collide with ISM protons, producing gamma-rays. Thus the gamma-ray flux traces both star formation (the source of cosmic ray protons) and dense gas in the ISM (HI or molecular gas).

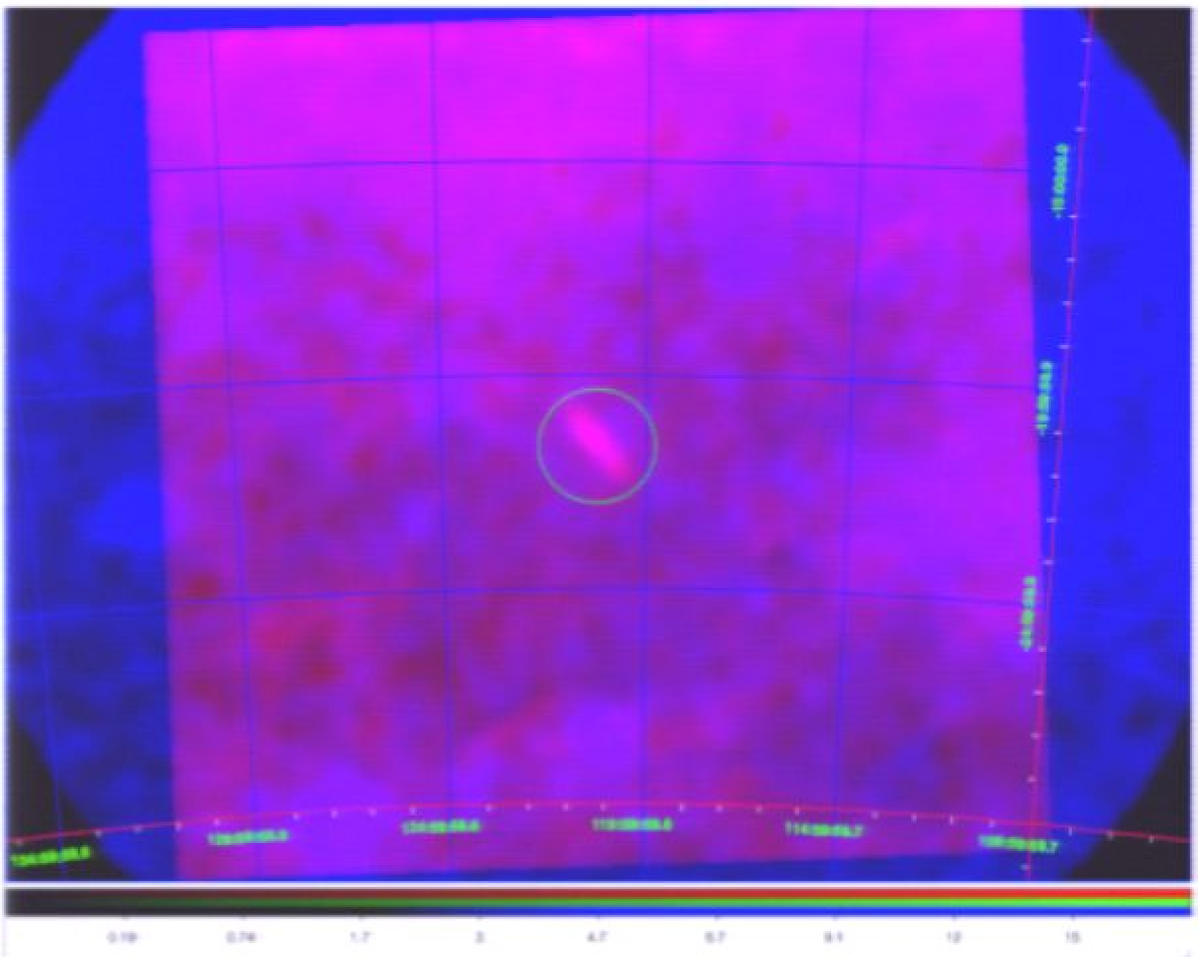
The detection of M31

Abdo et al. 2010 detect M31 in 2 years of Fermi data at 5σ significance, using 100 um template. Equivalent flux ~ 10^{-8} photons/cm^2 /s
Fail to detect M33.



The detection of M31

Abdo et al. 2010 detect M31 in 2 years of Fermi data at 5σ significance, using 100 um template. Equivalent flux ~ 10^{-8} photons/cm^2 /s
Fail to detect M33.

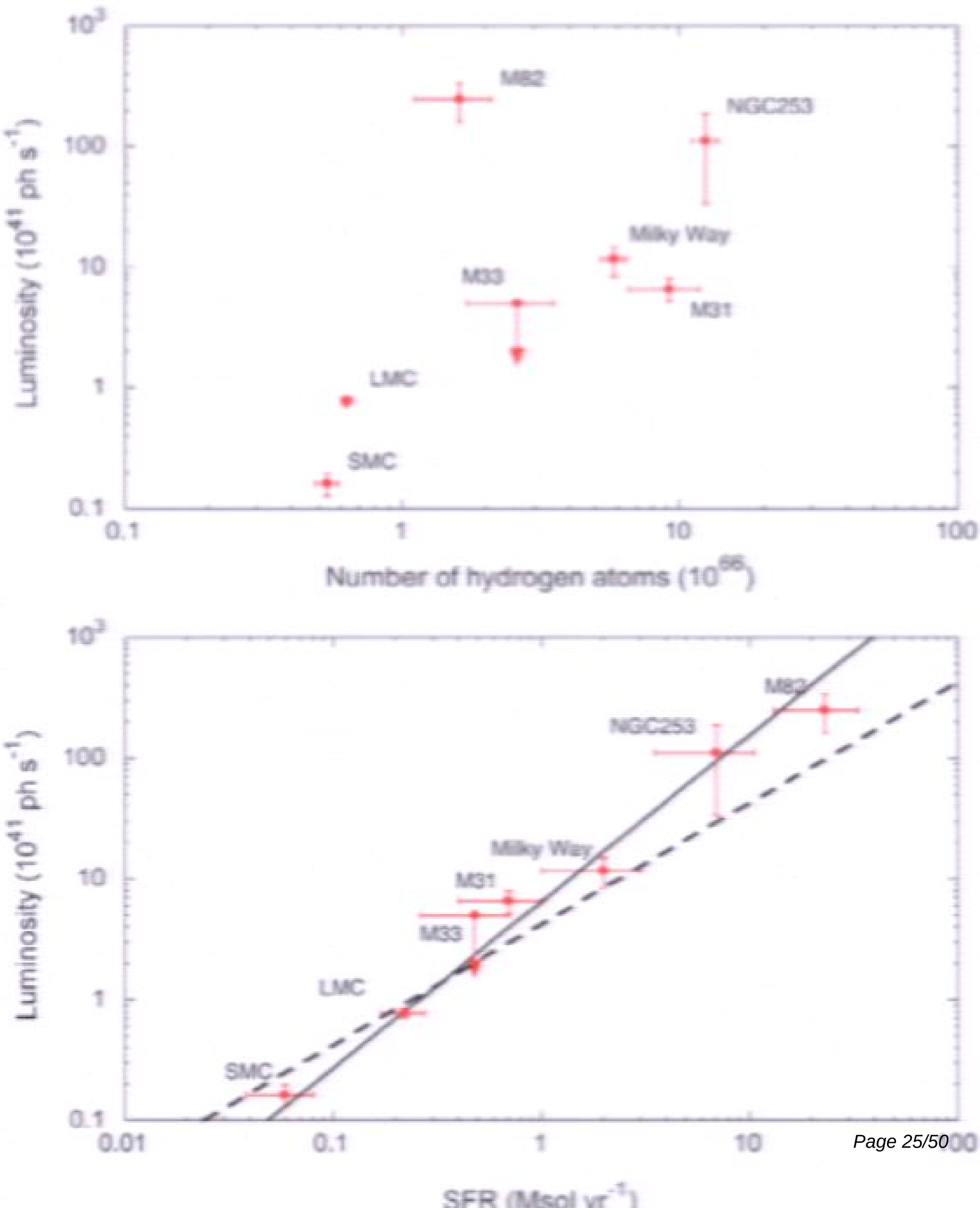


Scaling Relations

Abdo et al. 2010 also find a tight correlation between the star formation rate and the gamma-ray flux.

In this case, the gamma-rays from star formation become the dominant noise source in attempting to measure the annihilation flux.

But what about galaxies with little or no star formation?

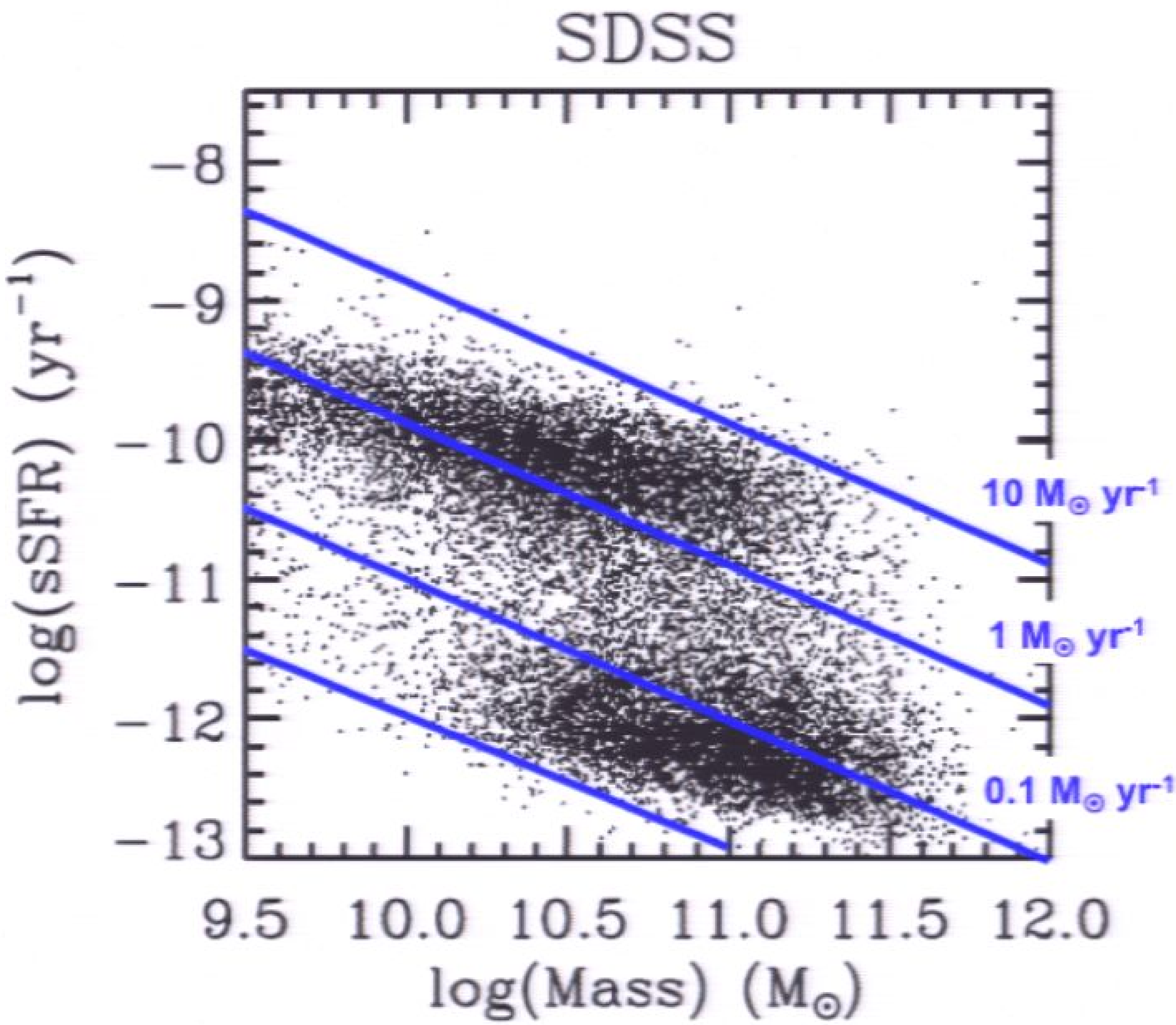


Other Targets?

Local ellipticals have star formation rates of 0.1 $M_\odot$ yr^{-1} or less.

Thus we can stack 10s or 100s of them before the contamination from cosmic rays and the ISM becomes a problem.

May also be able to cut further, e.g. fast vs. slow rotators.



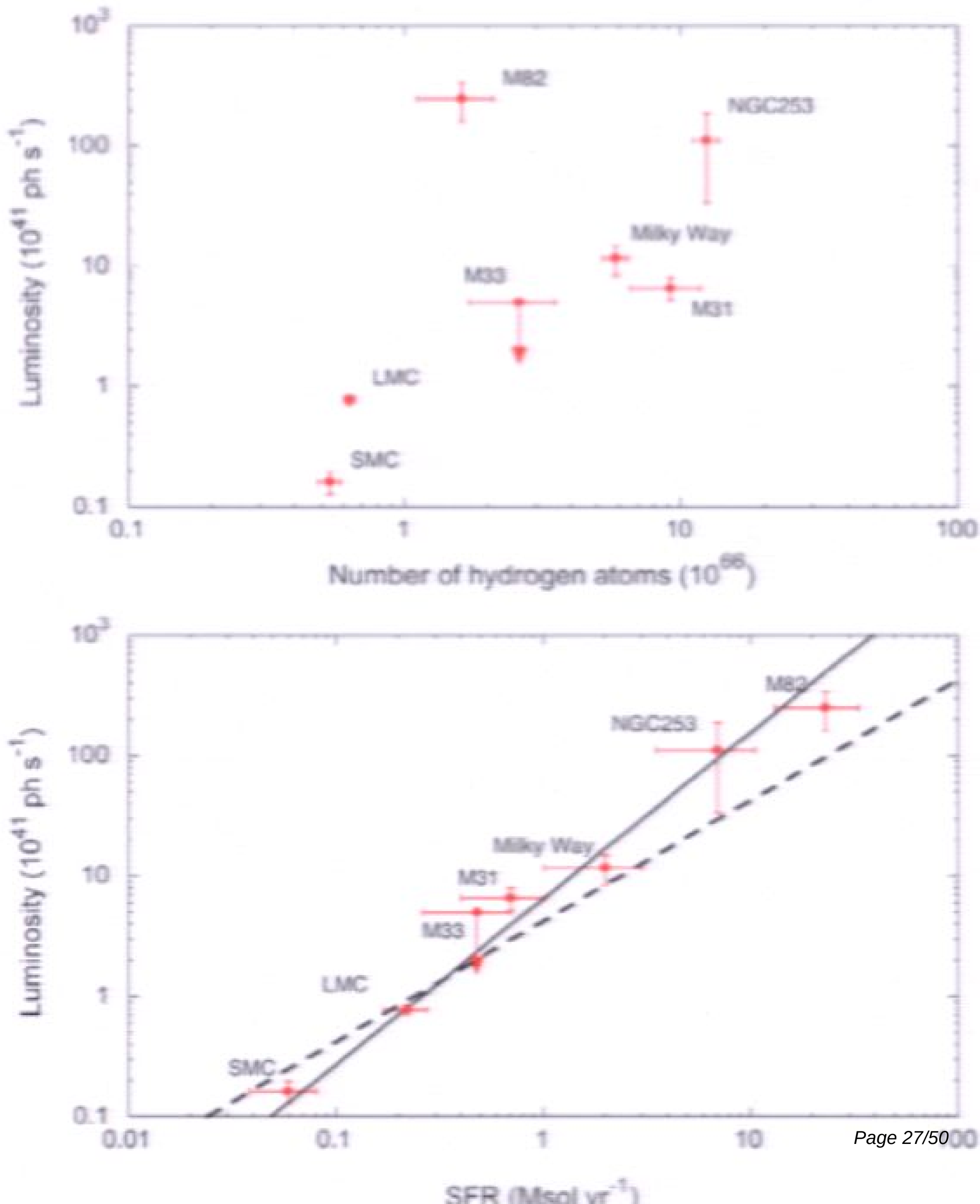
Damen et al 2009

Scaling Relations

Abdo et al. 2010 also find a tight correlation between the star formation rate and the gamma-ray flux.

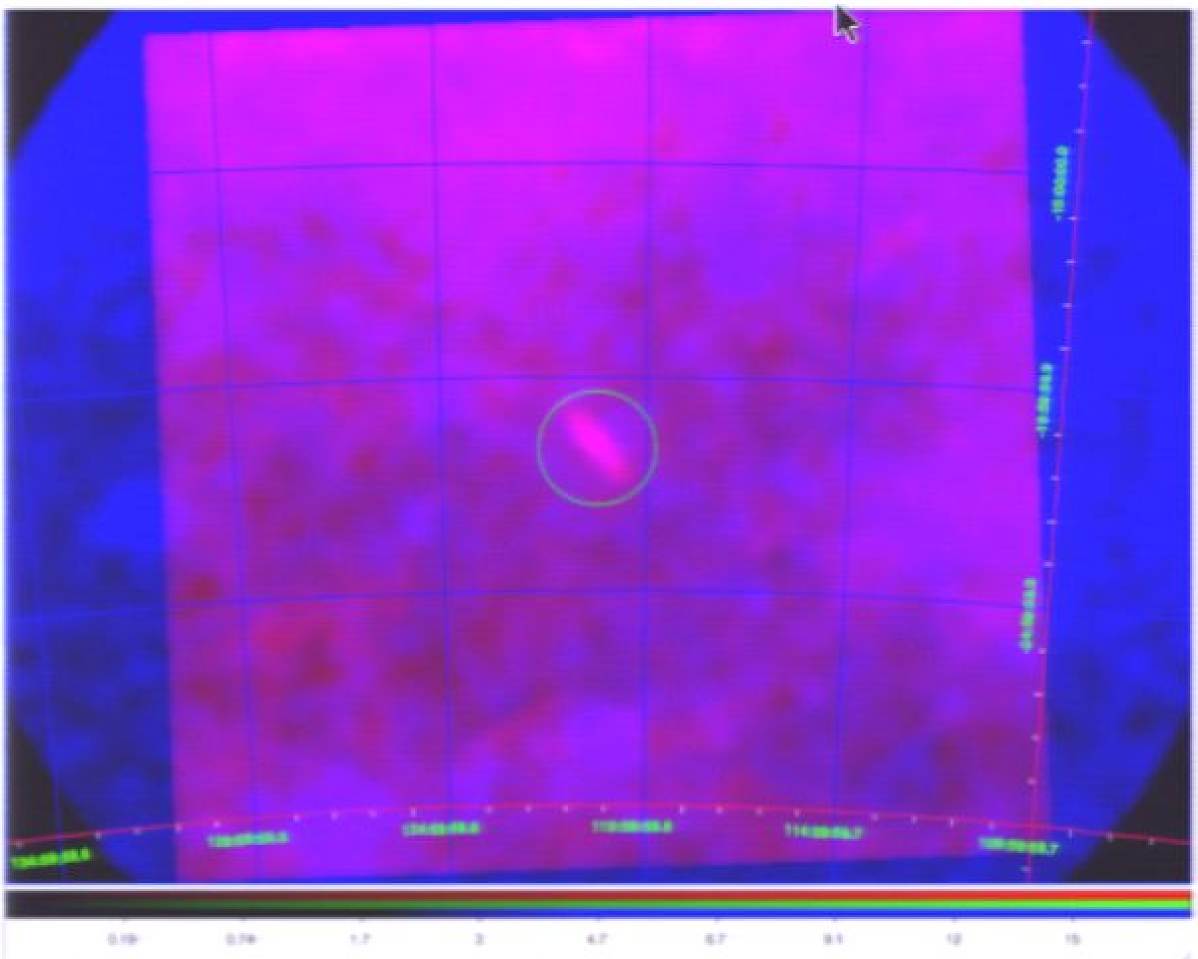
In this case, the gamma-rays from star formation become the dominant noise source in attempting to measure the annihilation flux.

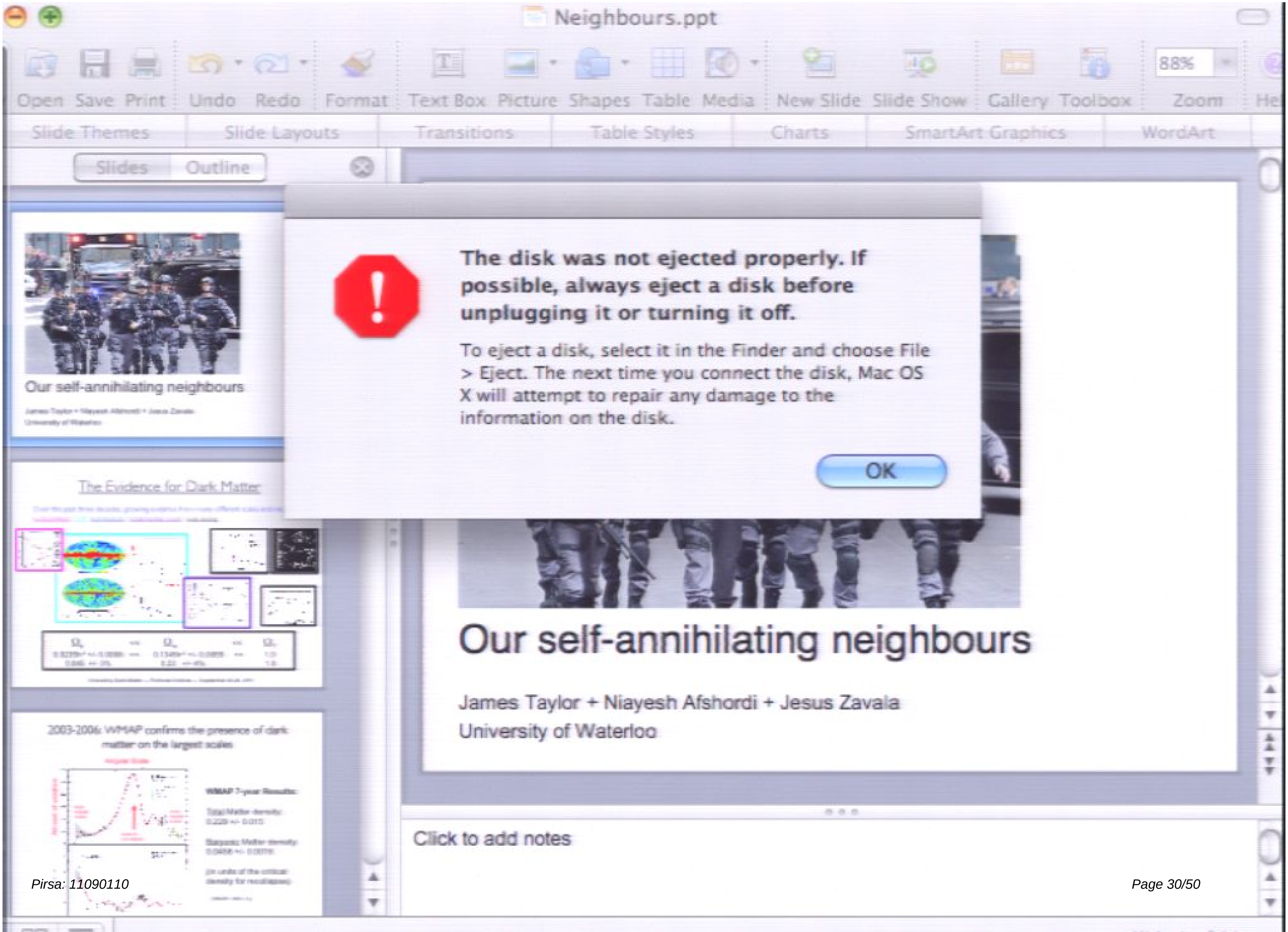
But what about galaxies with little or no star formation?

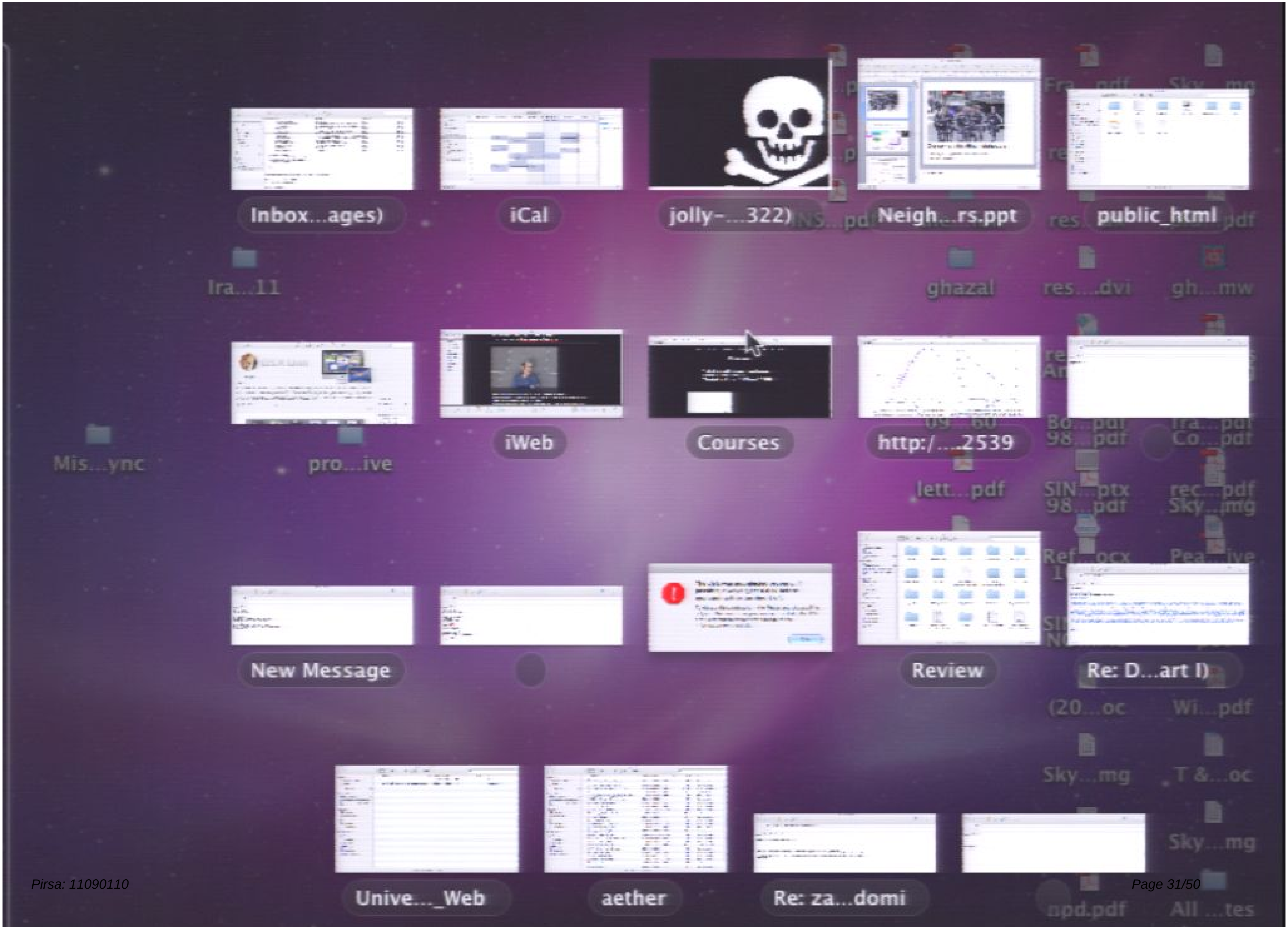


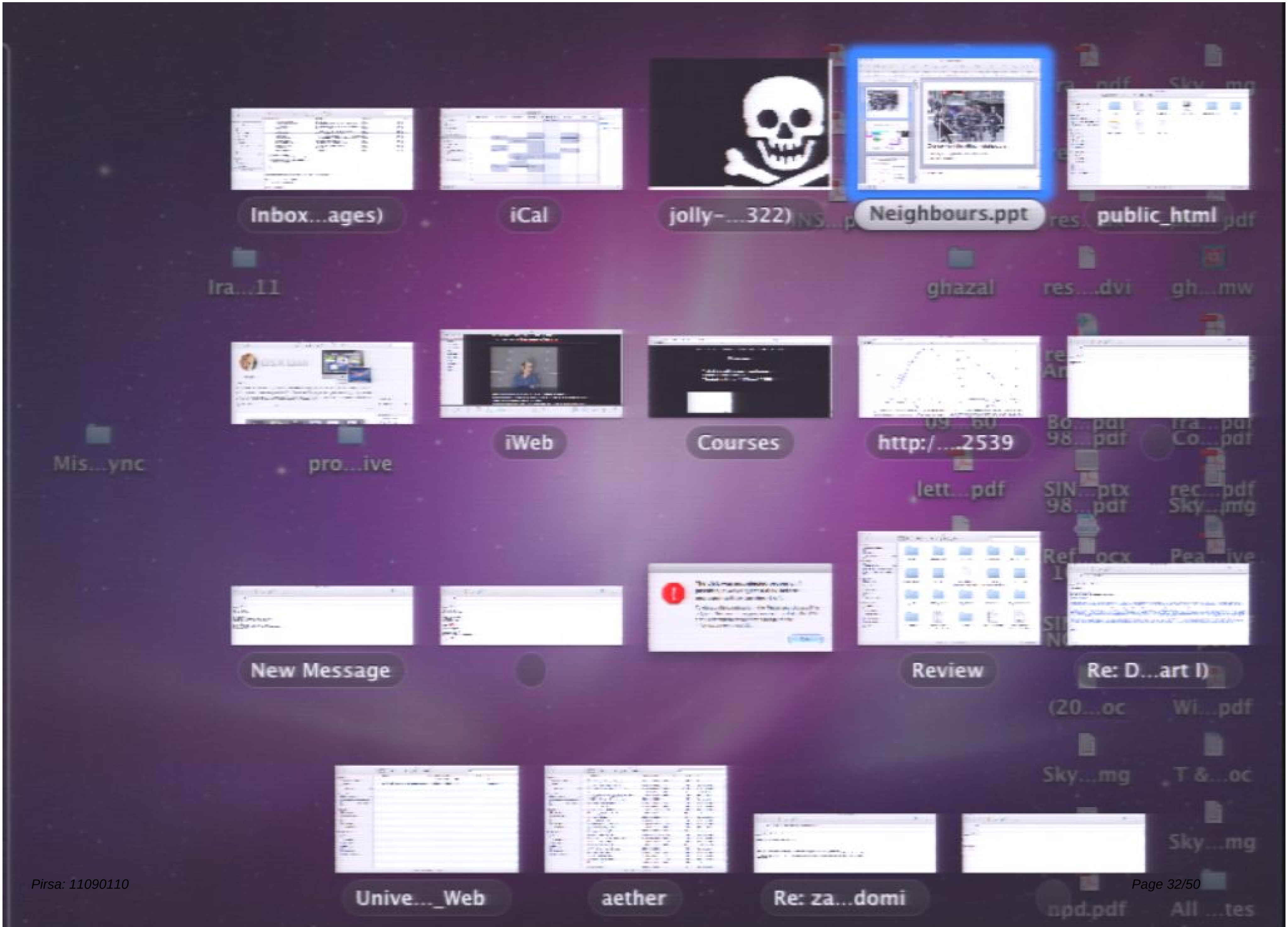
The detection of M31

Abdo et al. 2010 detect M31 in 2 years of Fermi data at 5σ significance, using 100 um template. Equivalent flux ~ 10^{-8} photons/cm^2 /s
Fail to detect M33.



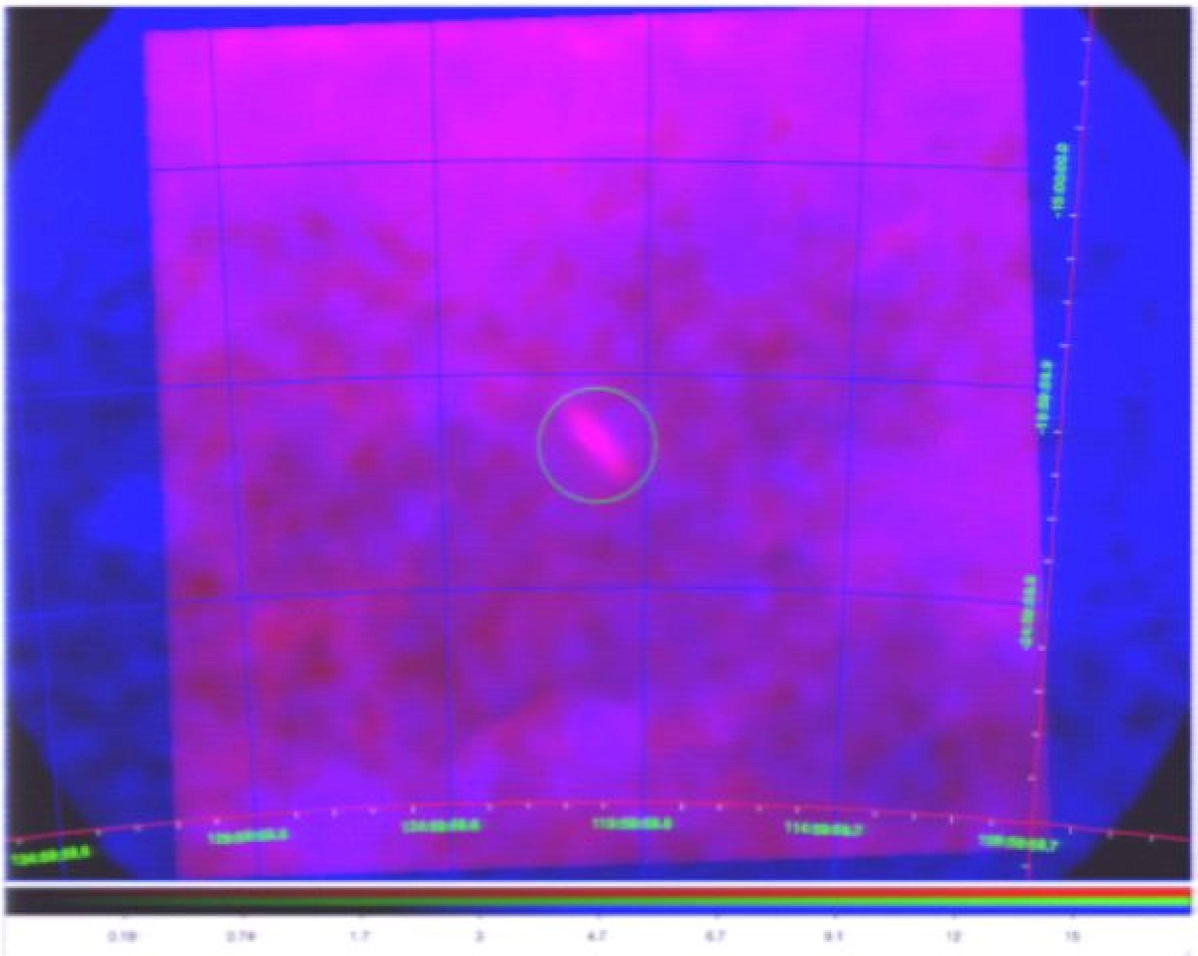

Neighbours.ppt
Open Save Print Undo Redo Format Text Box Picture Shapes Table Media New Slide Slide Show Gallery Toolbox Zoom
88%
Slide Themes Slide Layouts Transitions Table Styles Charts SmartArt Graphics WordArt
Slides Outline
Our self-annihilating neighbours
The Evidence for Dark Matter
WMAP 7-year Results:
The disk was not ejected properly. If possible, always eject a disk before unplugging it or turning it off.
To eject a disk, select it in the Finder and choose File > Eject. The next time you connect the disk, Mac OS X will attempt to repair any damage to the information on the disk.
OK
Our self-annihilating neighbours
James Taylor + Niayesh Afshordi + Jesus Zavala
University of Waterloo
Click to add notes


Inbox...ages)
iCal
jolly-...322)
Neigh...rs.ppt
public_html
Ira...11
ghazal
res....dvi
gh...mw
Mis...ync
pro...ive
iWeb
Courses
http:/....2539
lett...pdf
New Message
Review
Re: D...art I)
(20...oc
Wi...pdf
Sky...mg
T &...oc
Unive..._Web
aether
Re: za...domi
npd.pdf
All ...tes


Inbox...ages)
iCal
jolly-...322)
Neighbours.ppt
public_html
Ira...11
ghazal
res....dvi
gh...mw
iWeb
Courses
http:/....2539
Mis...ync
pro...ive
lett...pdf
New Message
Review
Re: D...art I)
(20...oc
Wi...pdf
Sky...mg
T &...oc
Unive..._Web
aether
Re: za...domi
npd.pdf
All ...tes

The detection of M31

Abdo et al. 2010 detect M31 in 2 years of Fermi data at 5σ significance, using 100 um template. Equivalent flux ~ 10^{-8} photons/cm^2 /s
Fail to detect M33.

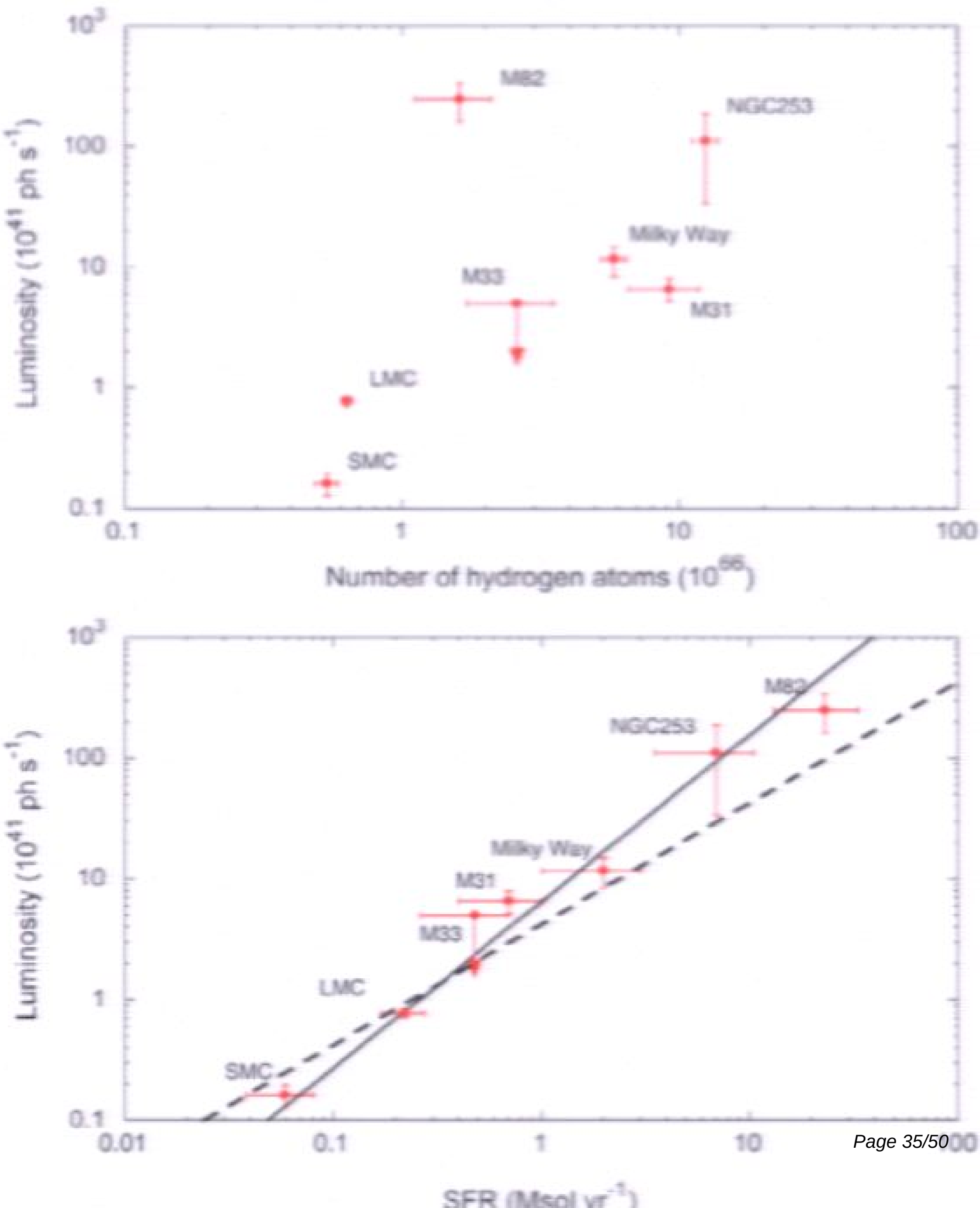


Scaling Relations

Abdo et al. 2010 also find a tight correlation between the star formation rate and the gamma-ray flux.

In this case, the gamma-rays from star formation become the dominant noise source in attempting to measure the annihilation flux.

But what about galaxies with little or no star formation?

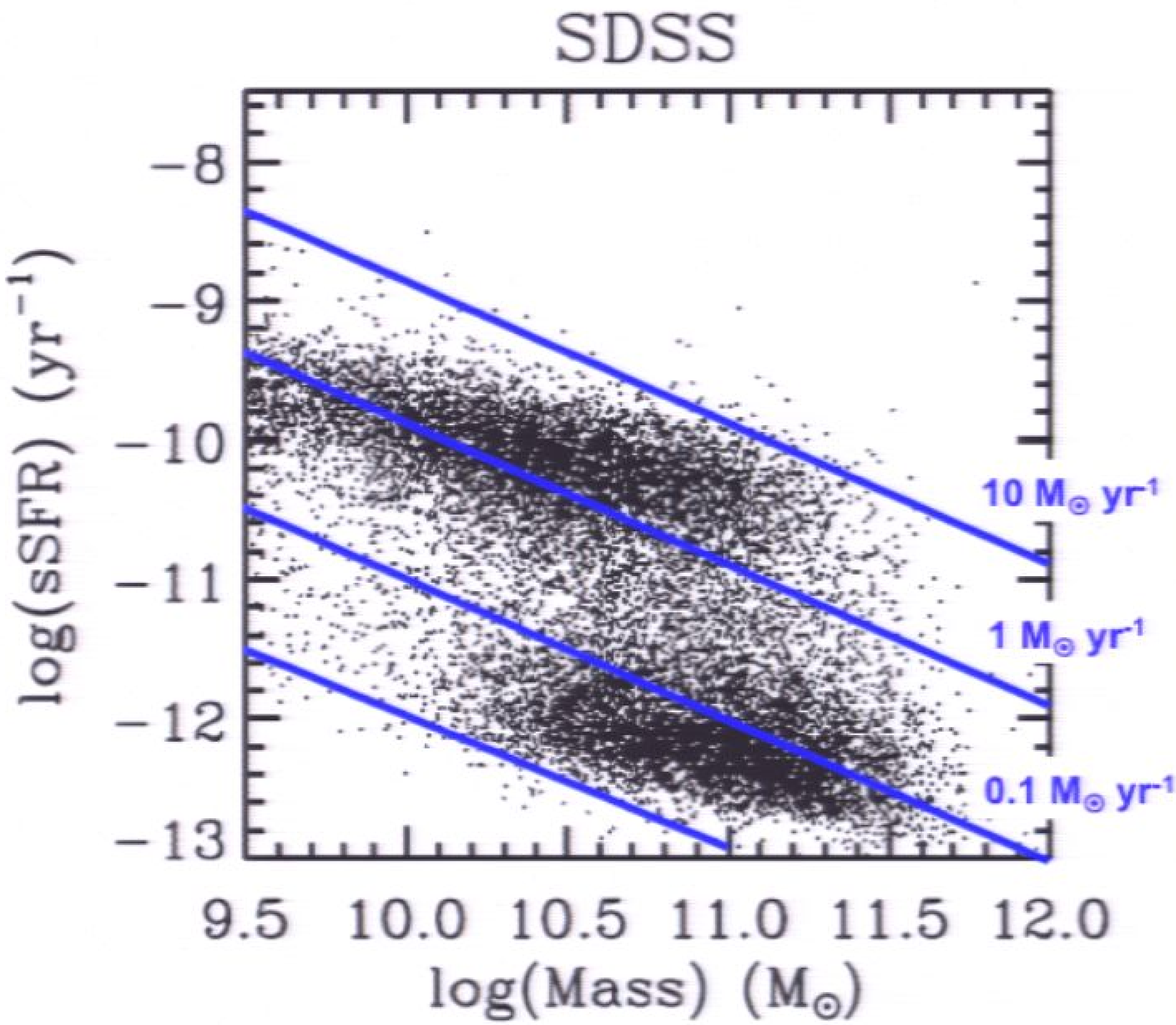


Other Targets?

Local ellipticals have star formation rates of 0.1 $M_\odot$ yr^{-1} or less.

Thus we can stack 10s or 100s of them before the contamination from cosmic rays and the ISM becomes a problem.

May also be able to cut further, e.g. fast vs. slow rotators.



Damen et al 2009

The Atlas3D sample (Capellari et al. 2011)

A volume-limited sample of Early-type galaxies from within 42 Mpc

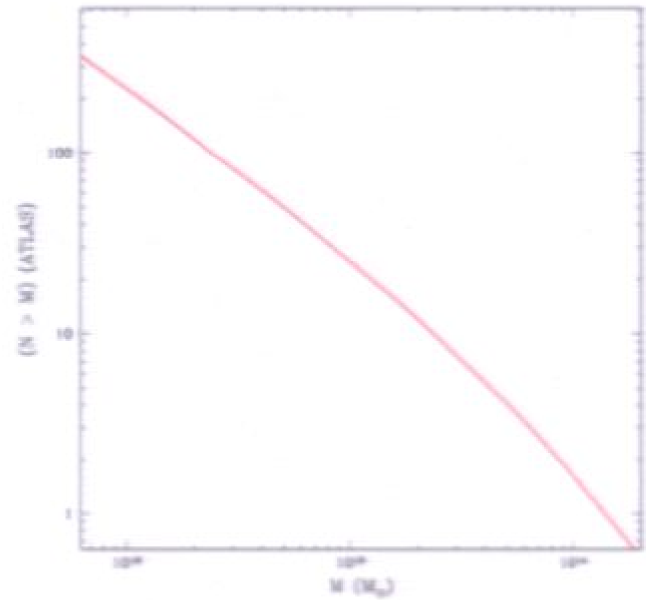
The Atlas3D sample (Capellari et al. 2011)

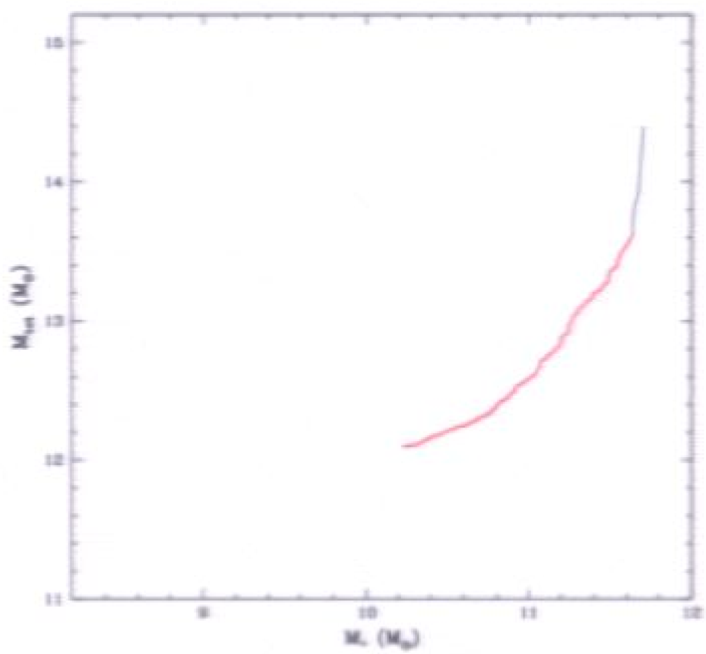
Sample has M_K , but how to estimate halo mass?

First, assume constant M/L_k

Then try abundance matching to predictions for the equivalent volume (1.16e5 Mpc^3), i.e. 6th brightest elliptical lives in 6th most massive halo

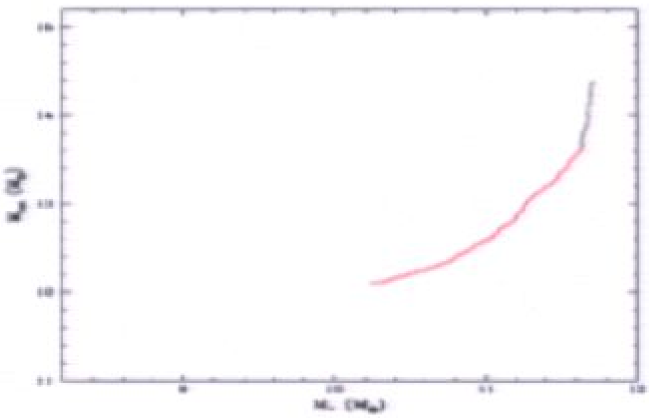
Then remove a number of the most massive systems, since these correspond to clusters

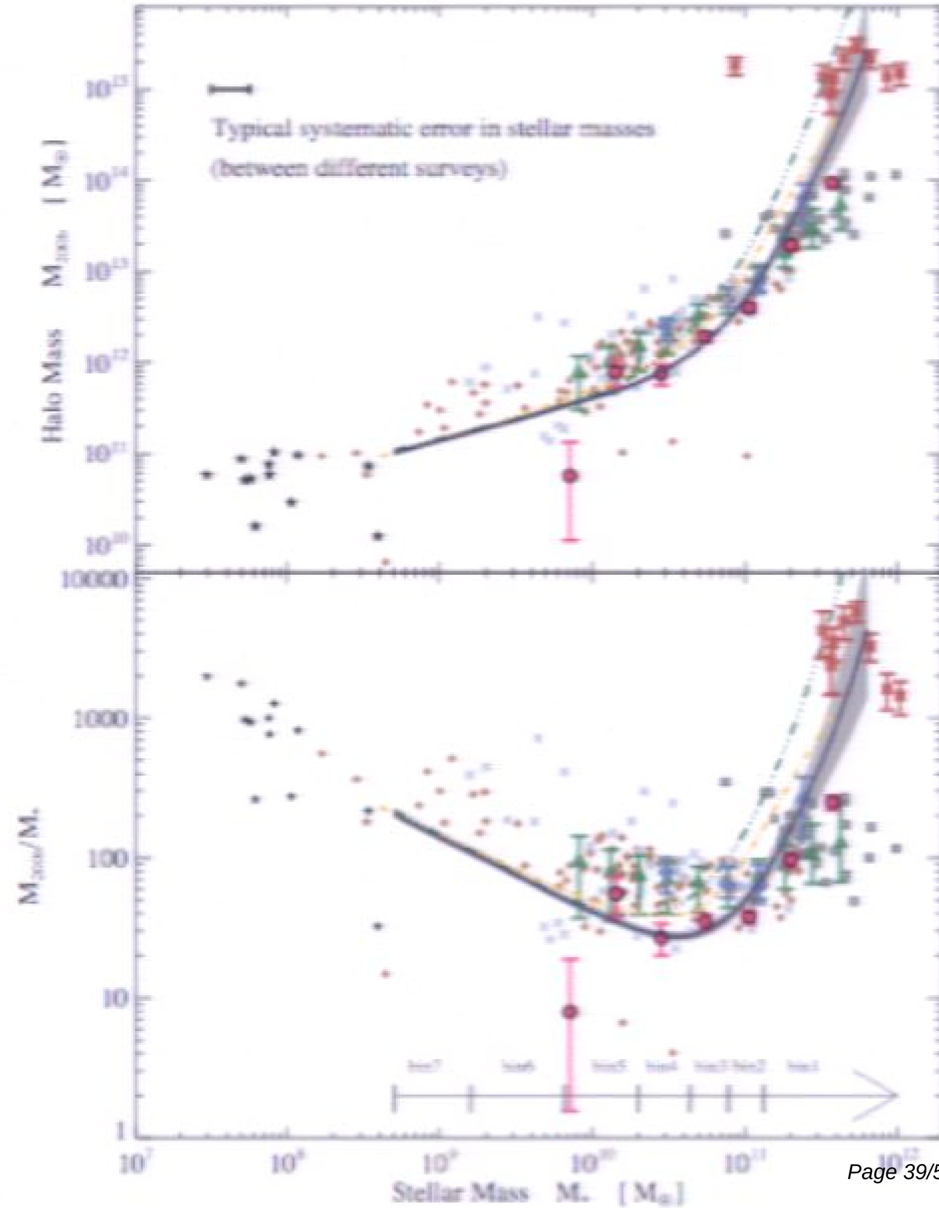




Unravelling Dark Matter   Perimeter Institute   September 22-24, 2011

The Atlas3D sample (Capellari et al. 2011)



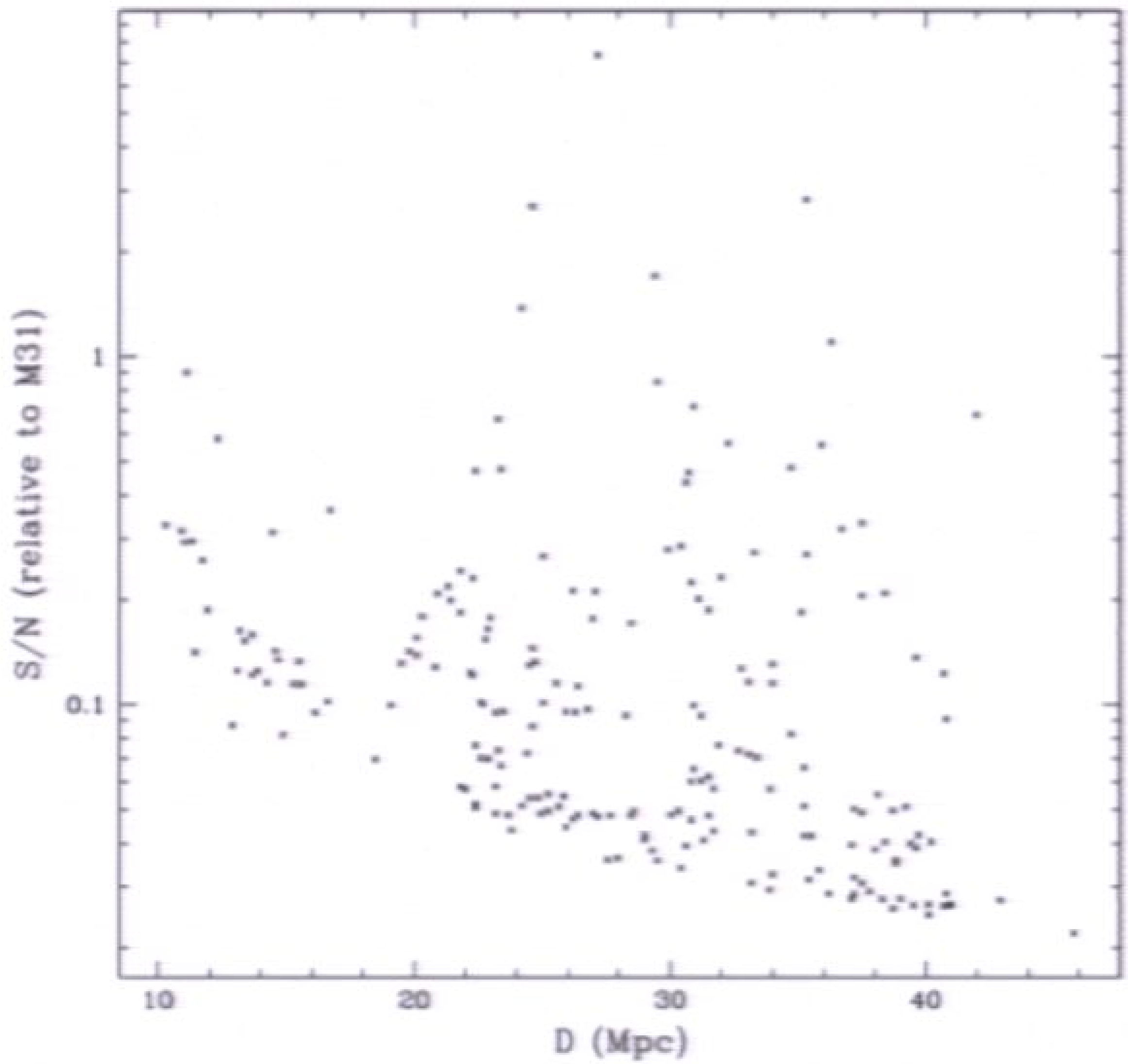


Resulting total-to-stellar mass ratio agrees well with other determinations compiled by Leauthaud et al. 2011, so these should be a good estimate of individual halo masses

The Atlas3D sample (Capellari et al. 2011)

Calculating S/N as:
$S/N \sim F/\theta \sim L/D^2(R/D) \sim M/D$, we find most sources are around 0.1x the S/N of M31

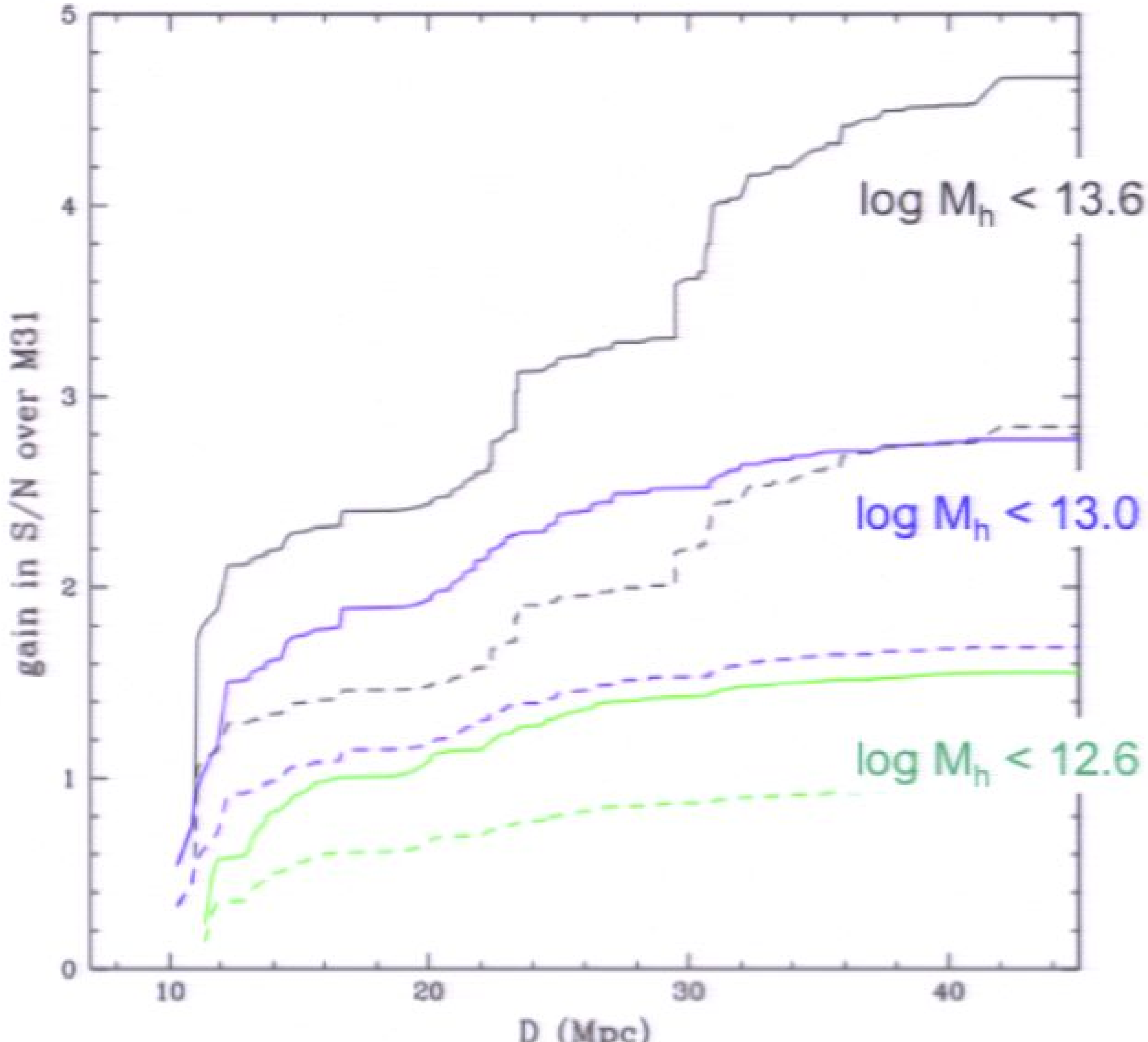
The advantage, however, is that we have hundreds of sources…



Gain in sensitivity relative to M31

The gain in sensitivity depends on whether we can use all halos or only those below some mass limit (colours), and also on whether we use ATLAS3D or an all-sky sample.

In principle, we may be able to attain a sensitivity of 5x M31,
or $<\sigma v> \sim 10^{-25}$ cm^3 s^{-1}

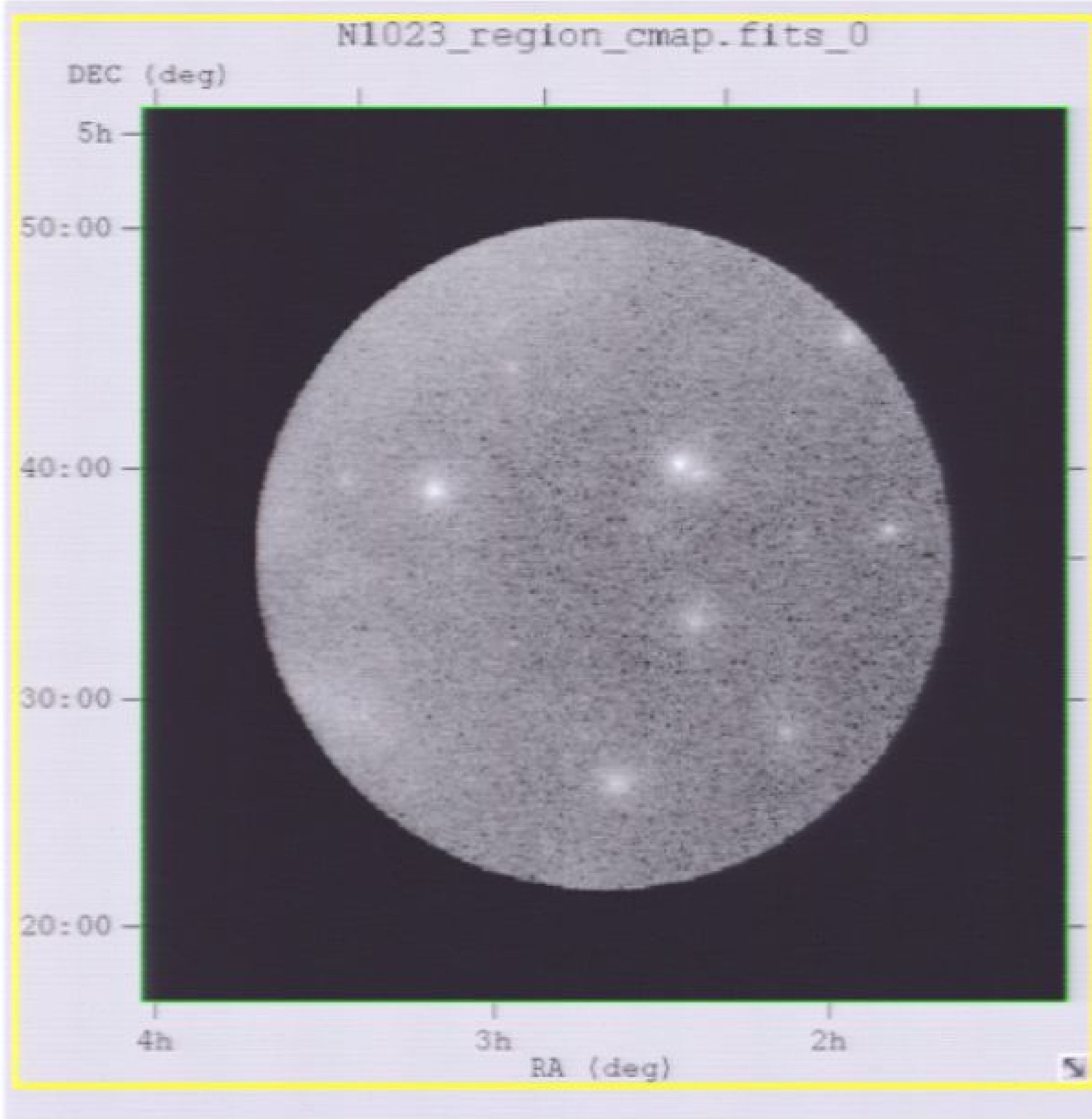


Let the Search Begin!

we are now starting to search through the ATLAS3D sample

e.g. NGC1023 (left)

Nothing so far (this is a good thing); the next step after eliminating AGN is to start stacking.



Caveats

* We have ignored the contribution from SFR in satellite galaxies; these can be masked or subtracted off, but
the area we can integrate over

* Ellipticals may also harbour AGN; probably want to exclude these from target list

* Backgrounds and point sources may also limit the number of usable objects or the integration region around each one

* We have ignored variations in concentration in our scaling arguments

* We have ignored the energy dependence of the psf, the backgrounds etc.

Conclusions

The search for emission from annihilating dark matter remains an important part of the ni mission

* Much of the initial focus was on dwarf satellites as potential sources.

* More recent work (Gao et al. 2011; Pinzke et al. 2011) has shown that clusters are a more promising target.

* Nearby early-type galaxies may be an even better target, increasing the sensitivity by a factor of 5 relative to the constraint from M31

* Should get limits competitive with other sources, e.g. clusters

Caveats

* We have ignored the contribution from SFR in satellite galaxies; these can be masked or subtracted off, but the area we can integrate over

* Ellipticals may also harbour AGN; probably want to exclude these from target list

* Backgrounds and point sources may also limit the number of usable objects or the integration region around each one

* We have ignored variations in concentration in our scaling arguments

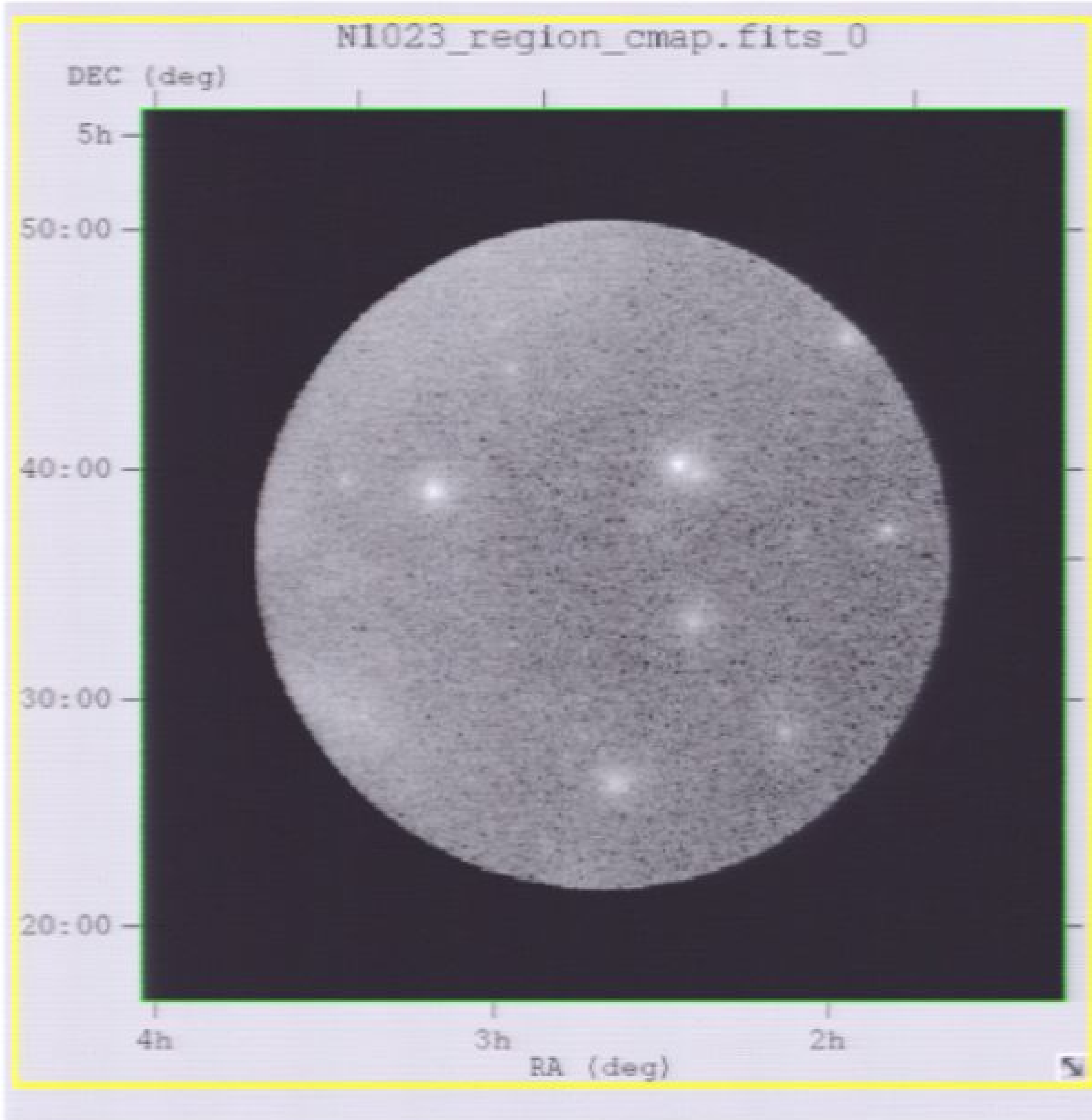
* We have ignored the energy dependence of the psf, the backgrounds etc.

Let the Search Begin!

we are now starting to search through the ATLAS3D sample

e.g. NGC1023 (left)

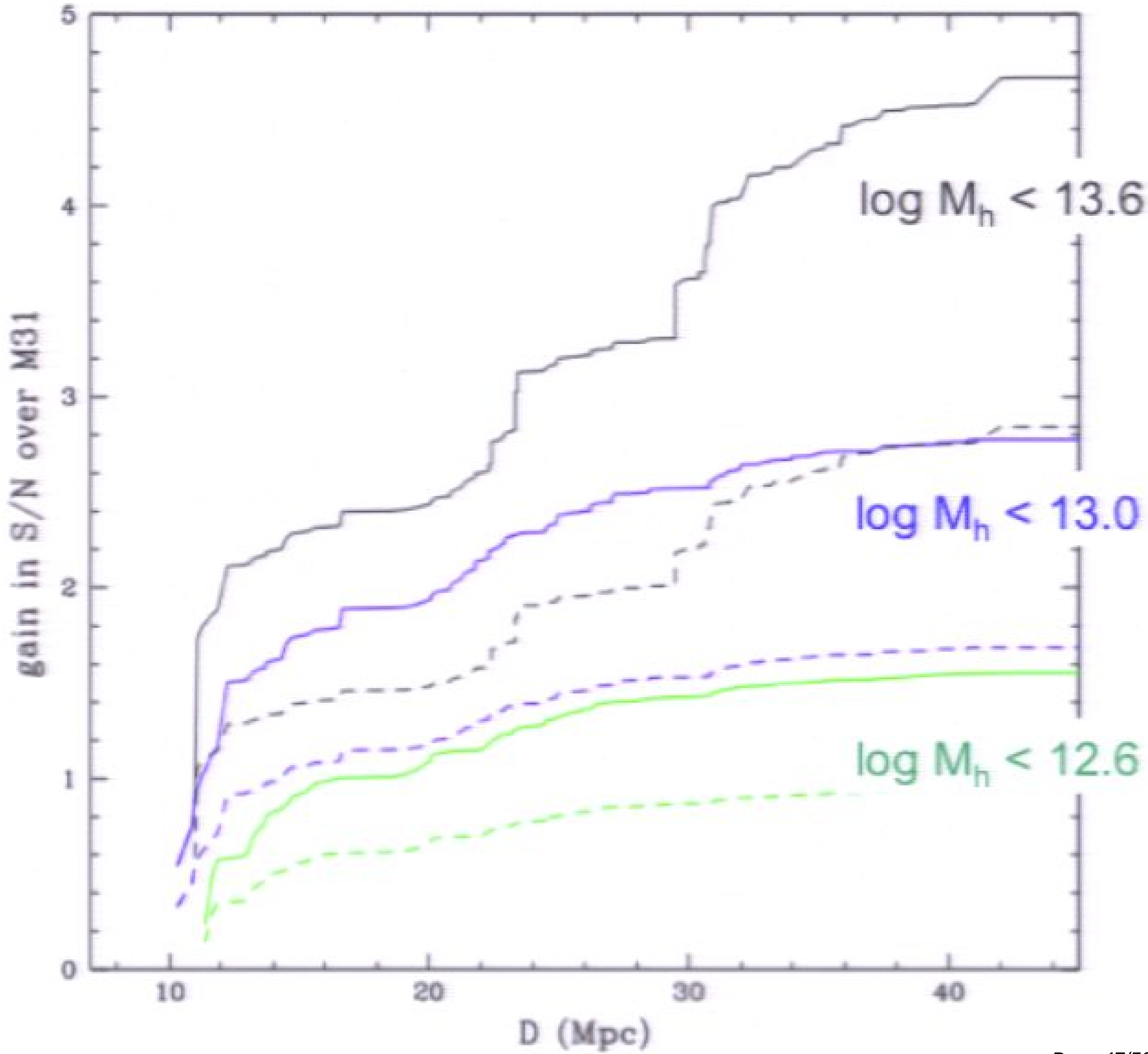
Nothing so far (this is a good thing); the next step after eliminating AGN is to start stacking.



Gain in sensitivity relative to M31

The gain in sensitivity depends on whether we can use all halos or only those below some mass limit (colours), and also on whether we use ATLAS3D or an all-sky sample.

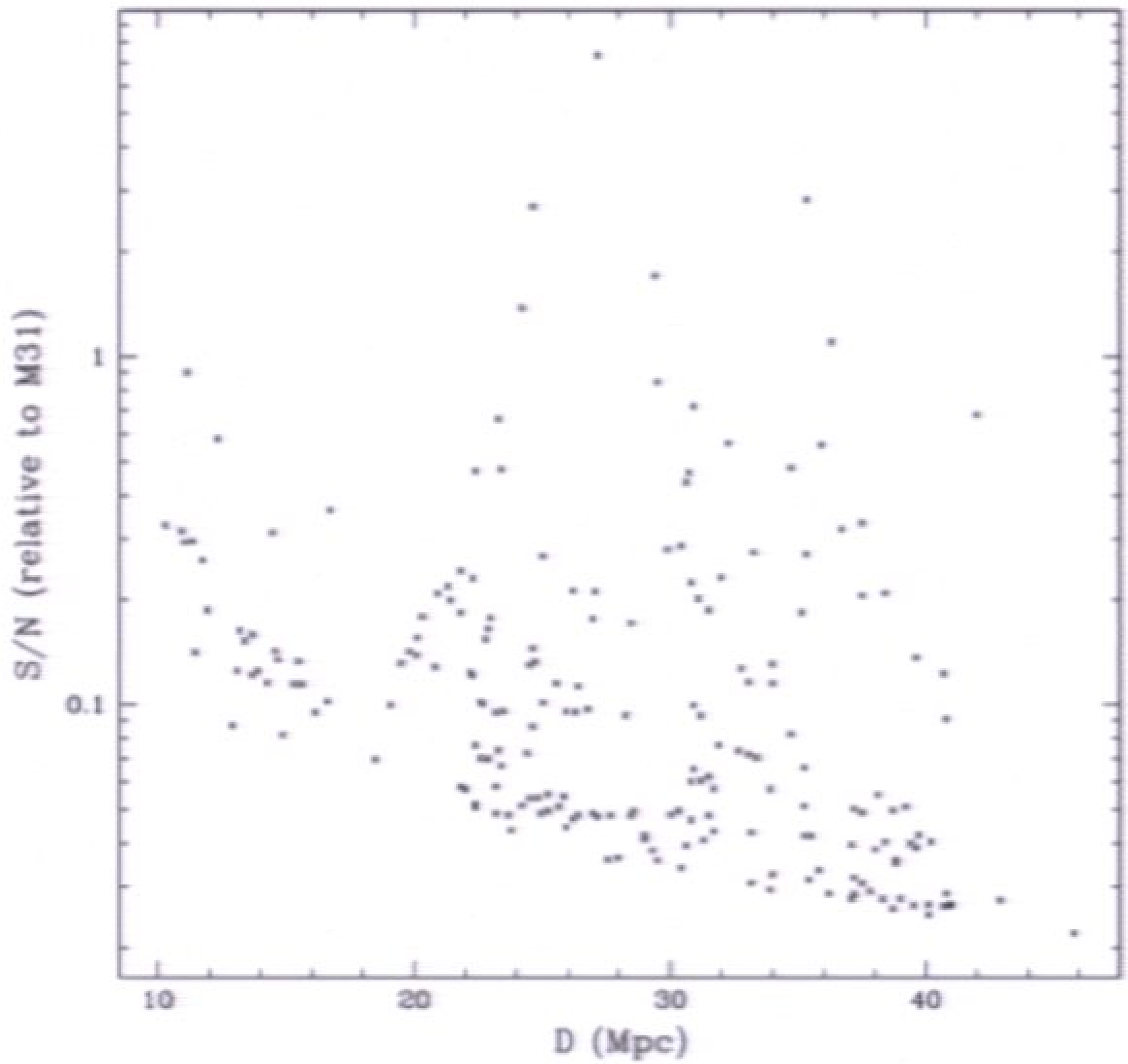
In principle, we may be able to attain a sensitivity of 5x M31,
or $\langle\sigma v\rangle \sim 10^{-25}$ cm^3 s^{-1}



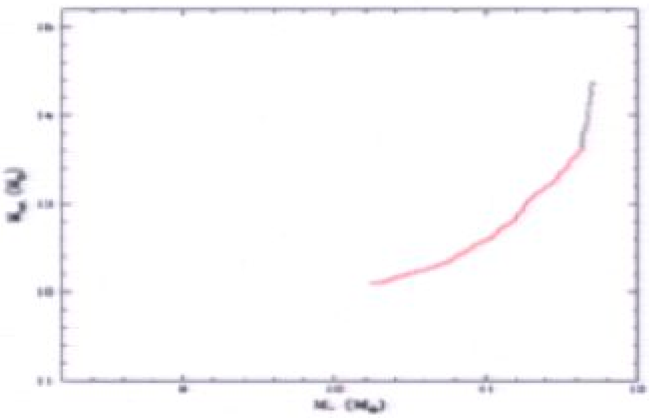
The Atlas3D sample (Capellari et al. 2011)

Calculating S/N as:
$S/N \sim F/\theta \sim L/D^2(R/D) \sim M/D$, we find most sources are around 0.1x the S/N of M31

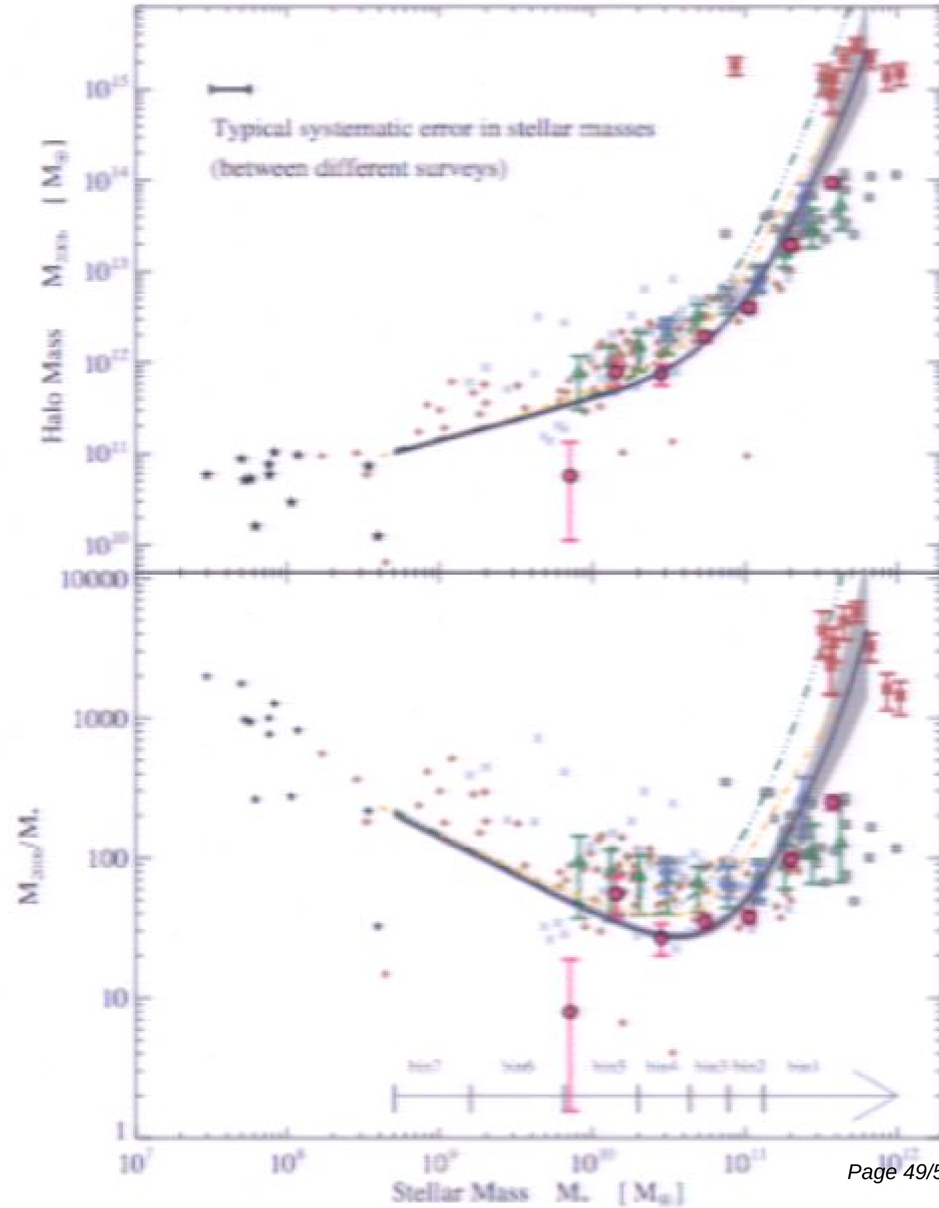
The advantage, however, is that we have hundreds of sources…



The Atlas3D sample (Capellari et al. 2011)



Resulting total-to-stellar mass ratio agrees well with other determinations compiled by Leauthaud et al. 2011, so these should be a good estimate of individual halo masses



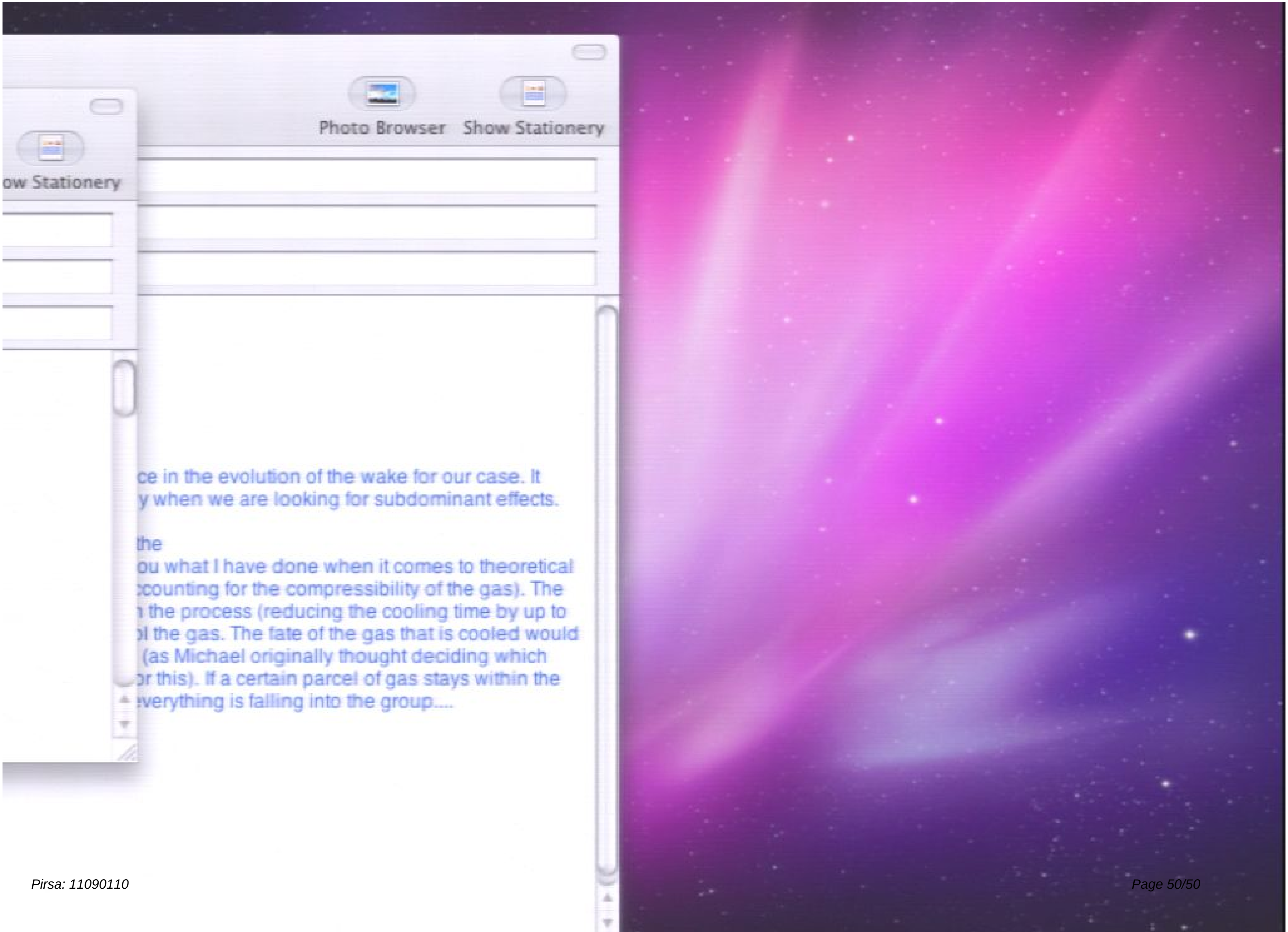


Photo Browser
Show Stationery
ow Stationery
ce in the evolution of the wake for our case. It
y when we are looking for subdominant effects.
the
ou what I have done when it comes to theoretical
ccounting for the compressibility of the gas). The
the process (reducing the cooling time by up to
ol the gas. The fate of the gas that is cooled would
(as Michael originally thought deciding which
or this). If a certain parcel of gas stays within the
everything is falling into the group....