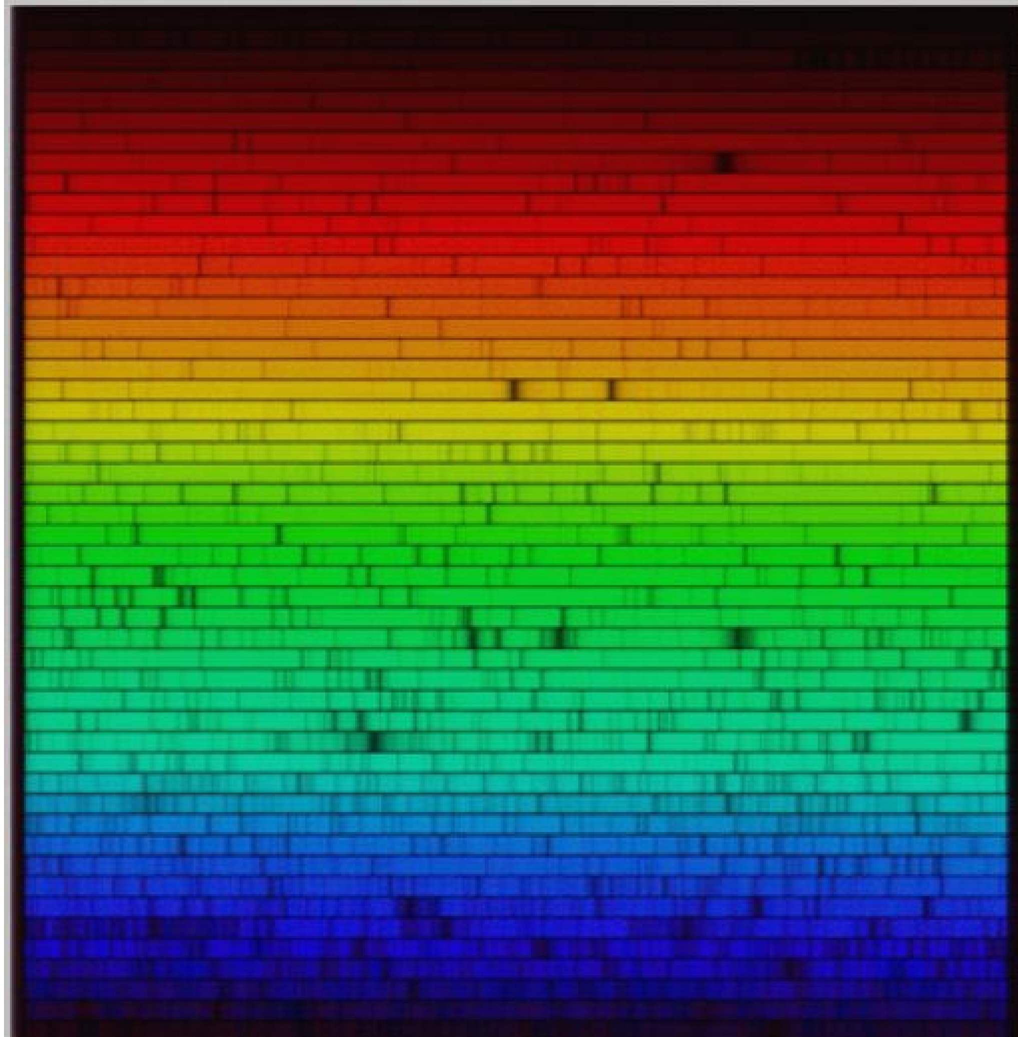
Title: How cold is dark matter?

Date: Dec 08, 2009 04:00 PM

URL: http://pirsa.org/09120105

Abstract:



Probing dark matter and the expansion history of the Universe with Lyα in absorption

Martin Haehnelt

in collaboration with:

James Bolton, Tae-Sun Kim, Joe Liske Matteo Viel, Volker Springel, George Becker, Bob Carswell, Antony Lewis, Julien Lesgourgues, Sabino Mattarese, Michael Rauch, Antonio Riotto, Wal Sargent and the CODEX team

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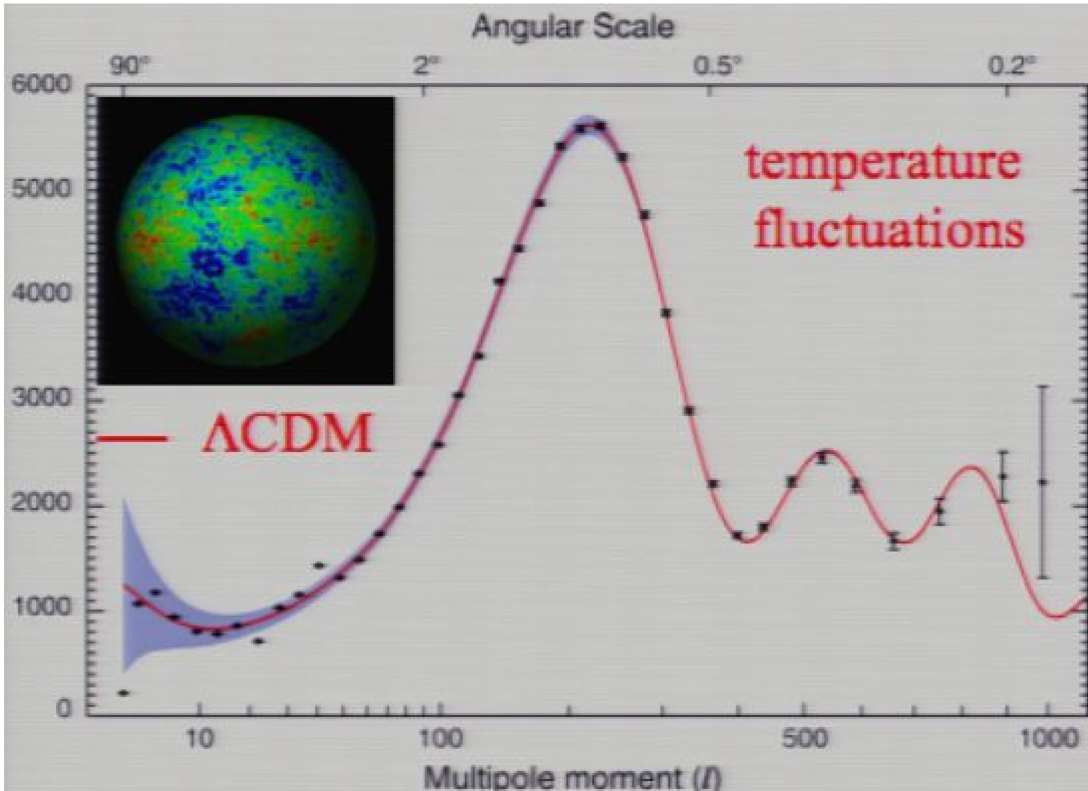

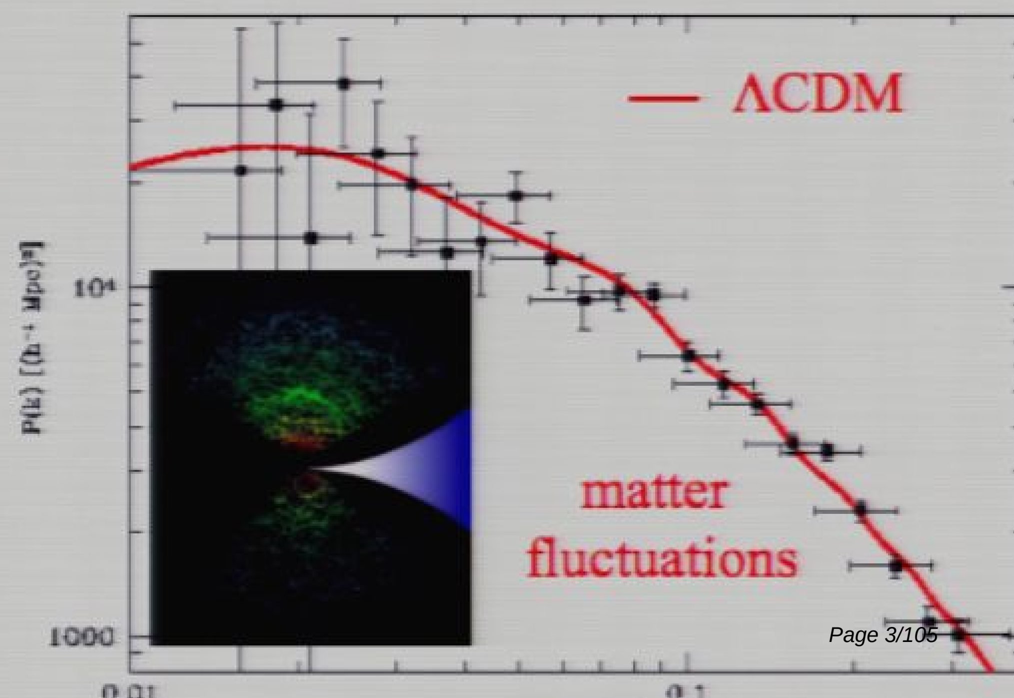

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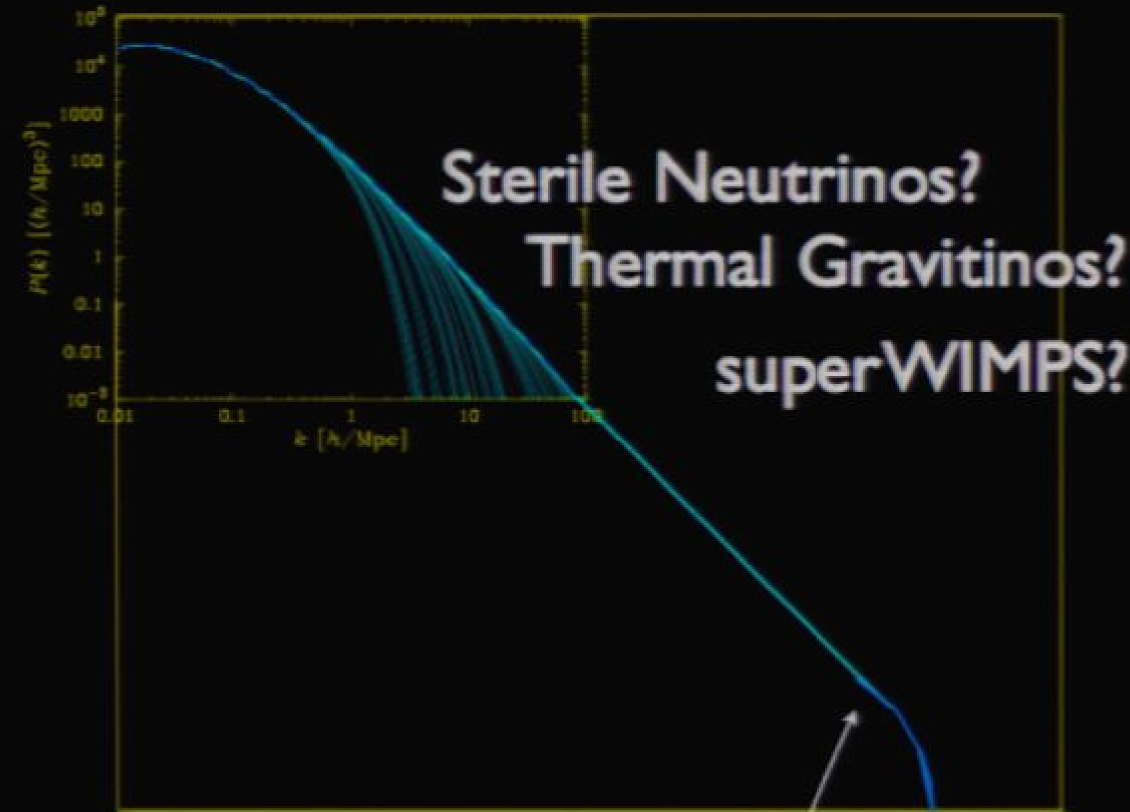
How cold is dark matter?

How far into the small-scale regime can we measure?



WIMP CDM
$k_c \sim 10^6\ h$ /Mpc
(Zaldarriaga & Loeb 2006)

Aberzajan

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cold dark matter: free streaming scale so small that it is astrophysically irrelevant

warm dark matter: free streaming on galaxy scales

hot dark matter: free streaming on galaxy cluster or larger scales

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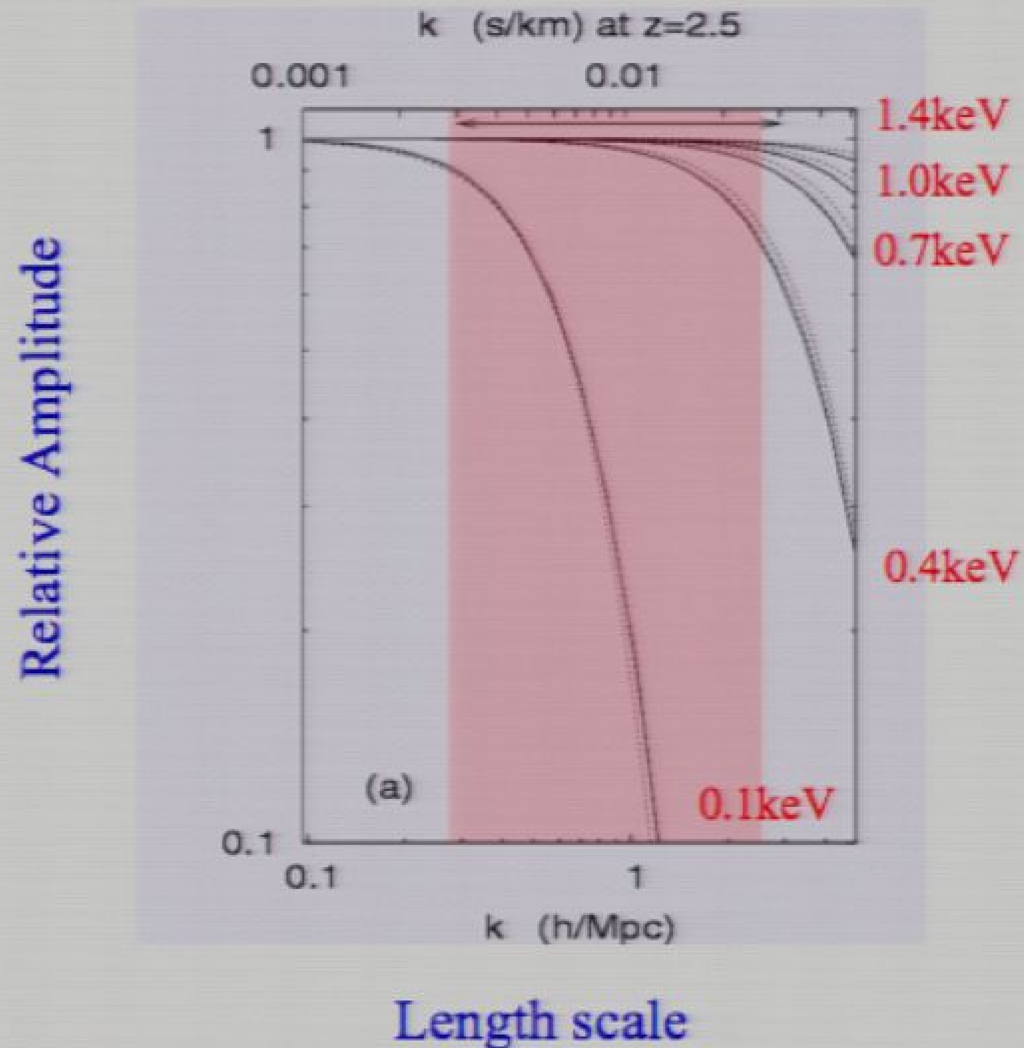
Potential problems with CDM aka "The small scale crisis"

- CDM may predict to many small mass objects
- CDM may predict DM haloes with profiles which are to cuspy at the centre

Warm Dark Matter candidates

- early decoupling thermal relics
- sterile neutrinos
- gravitinos
- and many more

Warm Dark Matter



all masses as for thermal relics

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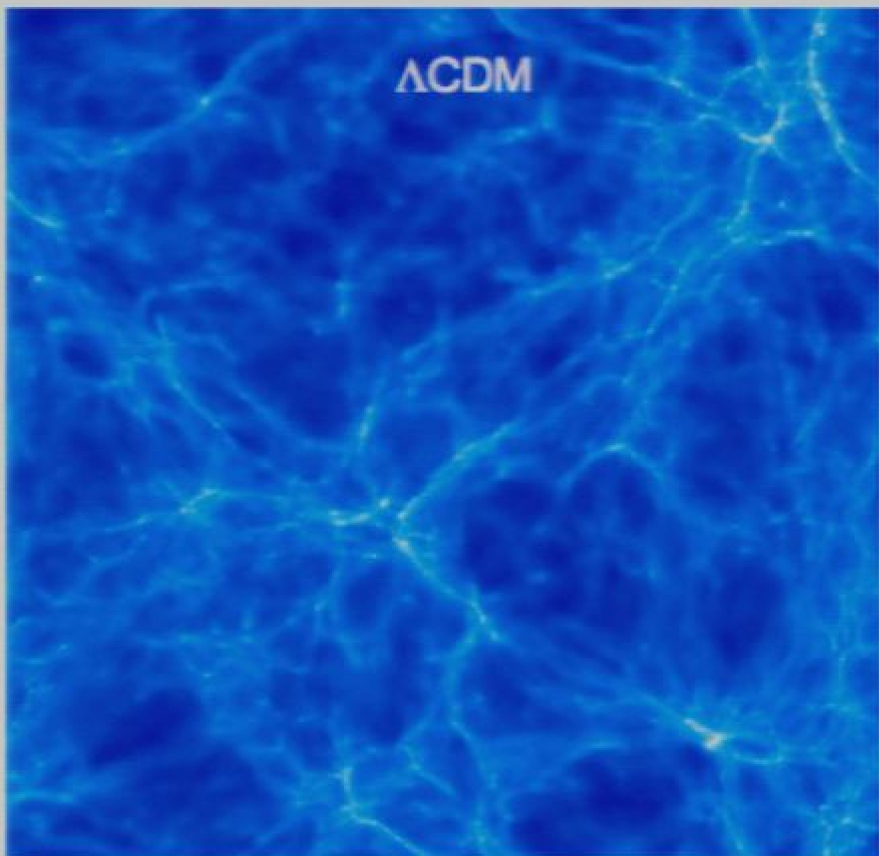
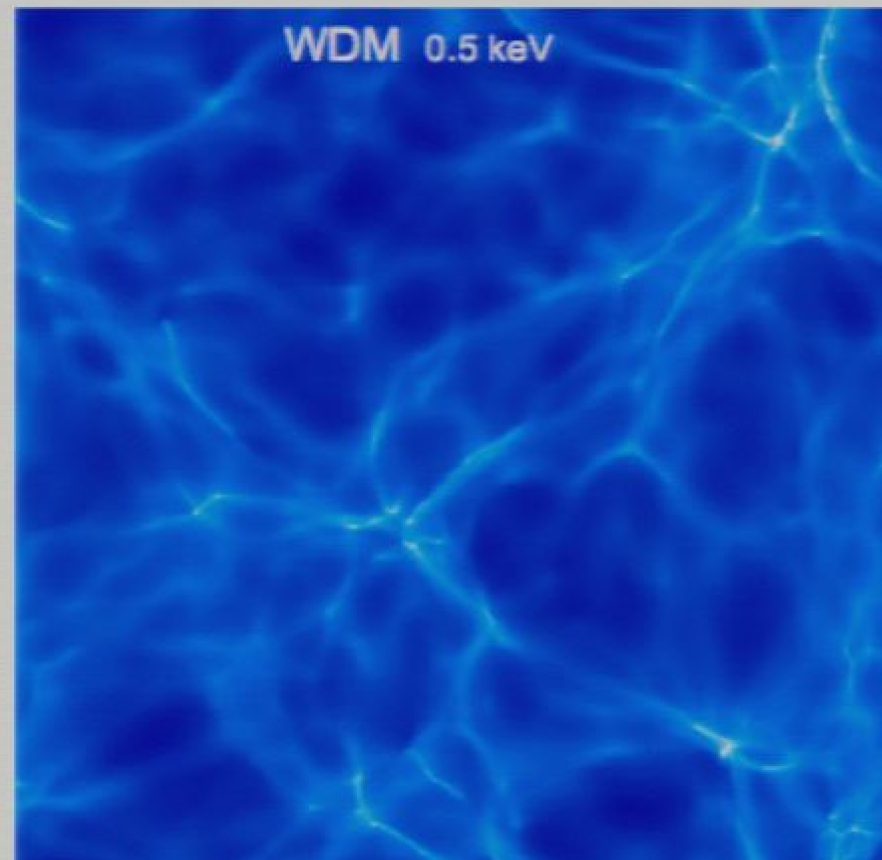
Free-streaming erases structure

cold dark matter



warm dark matter



30 comoving Mpc/h z=3

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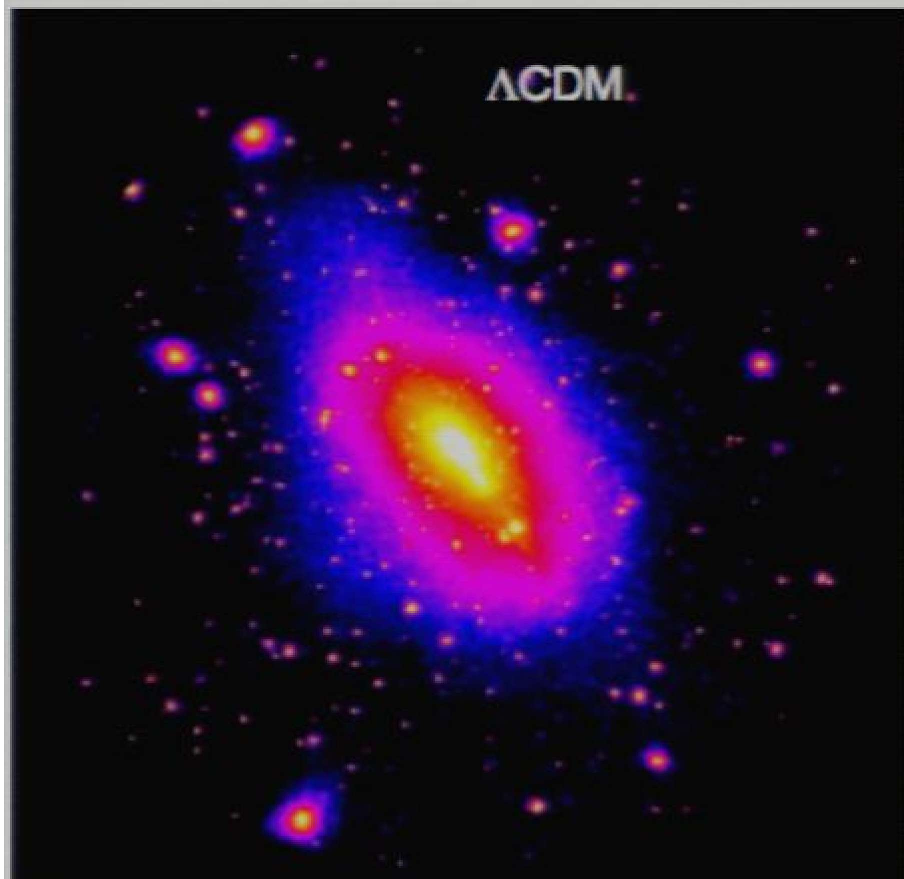
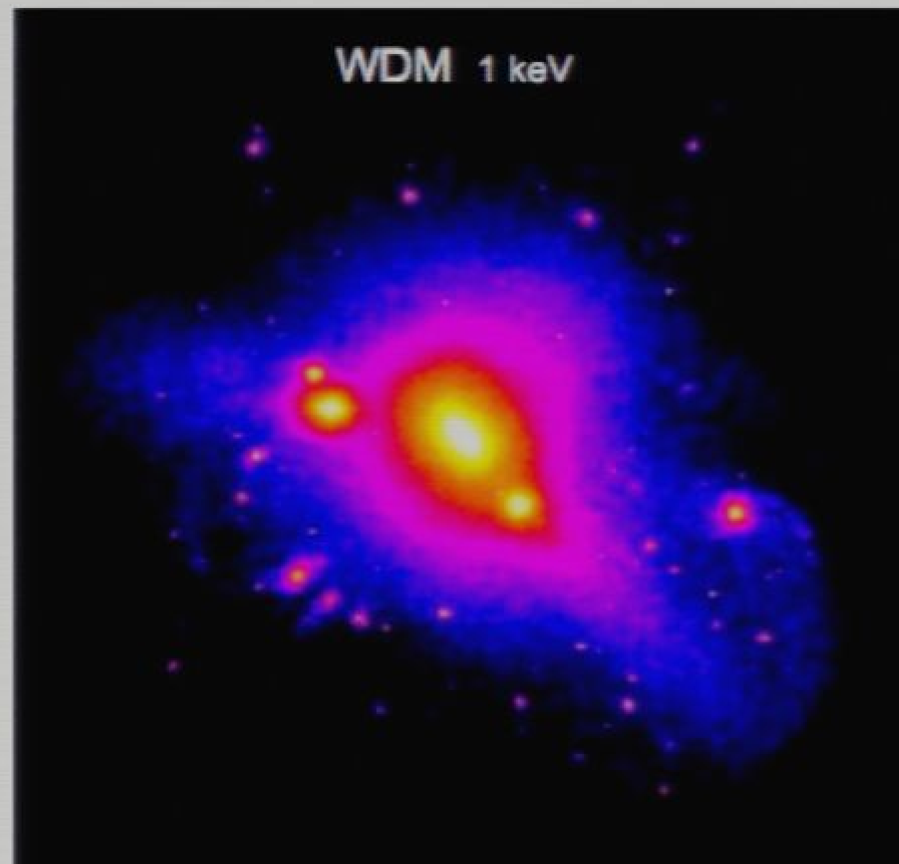
cold dark matter



warm dark matter



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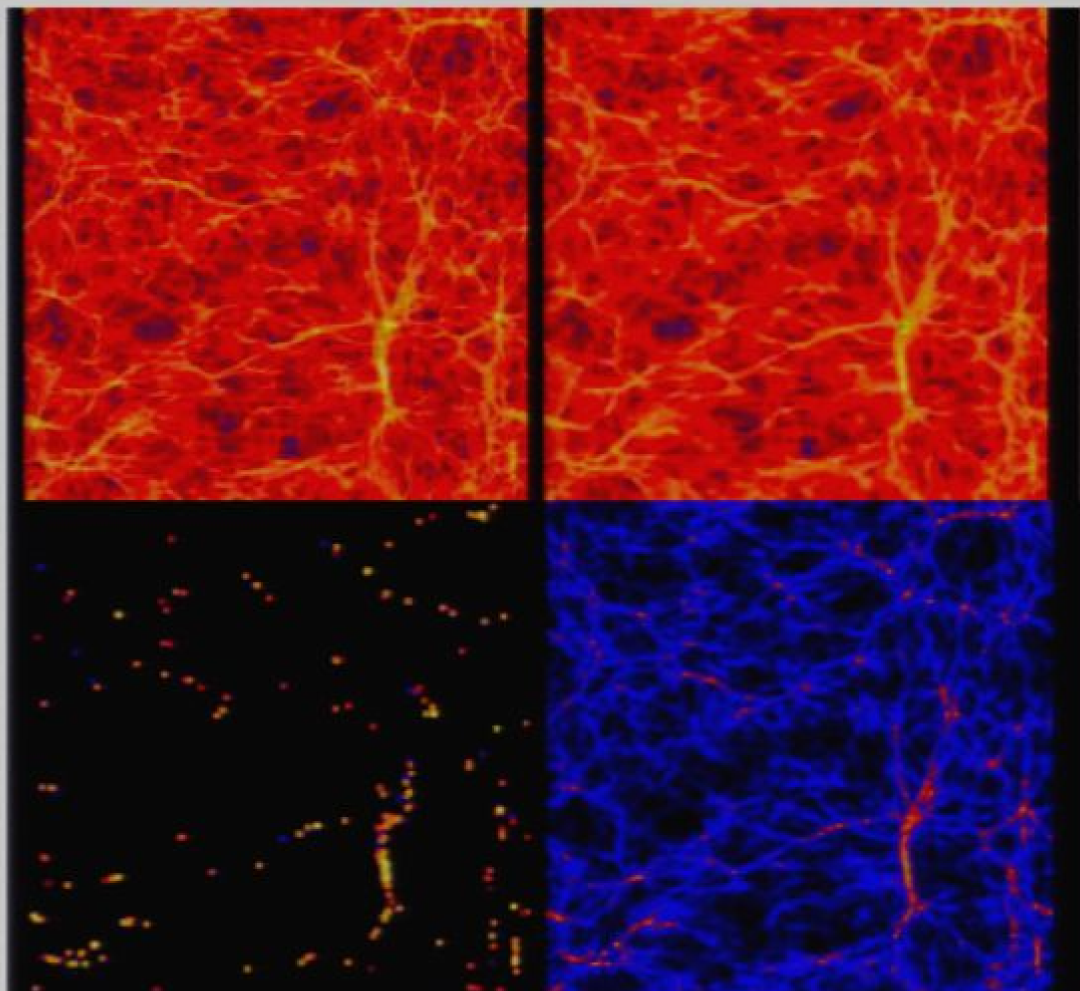

Neutral hydrogen is an excellent tracer of the matter distribution

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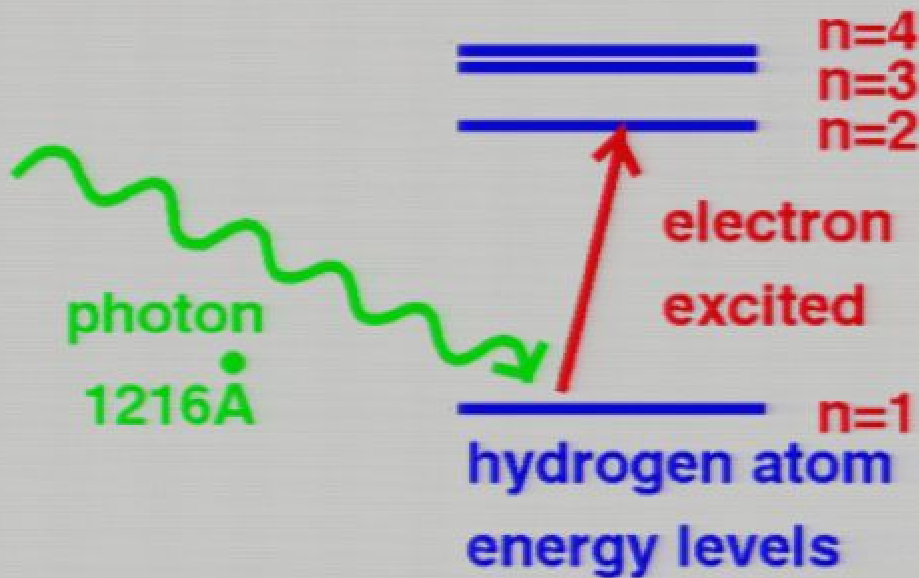
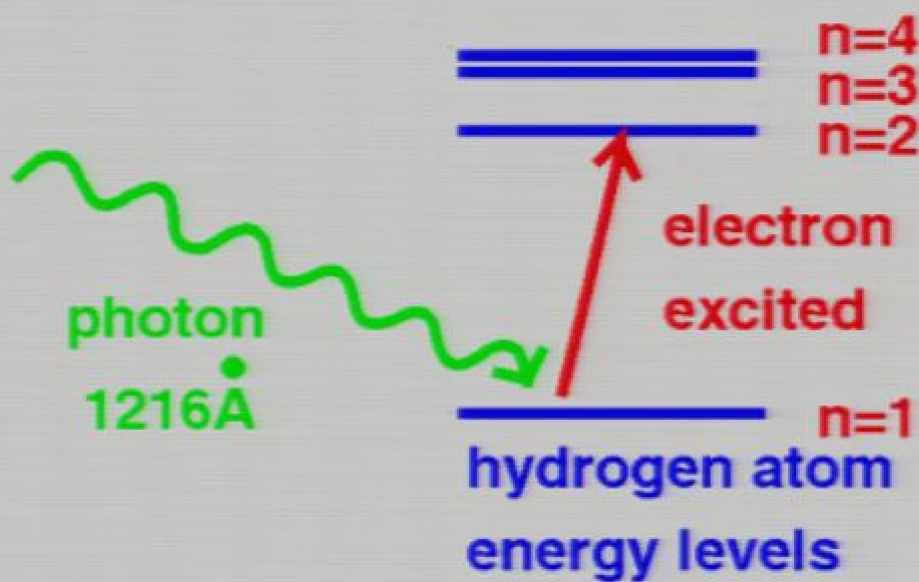
Absorption by neutral hydrogen



$$\lambda_{obs} = 1216\,(1+z)\ \text{Å}$$

Absorption by neutral hydrogen

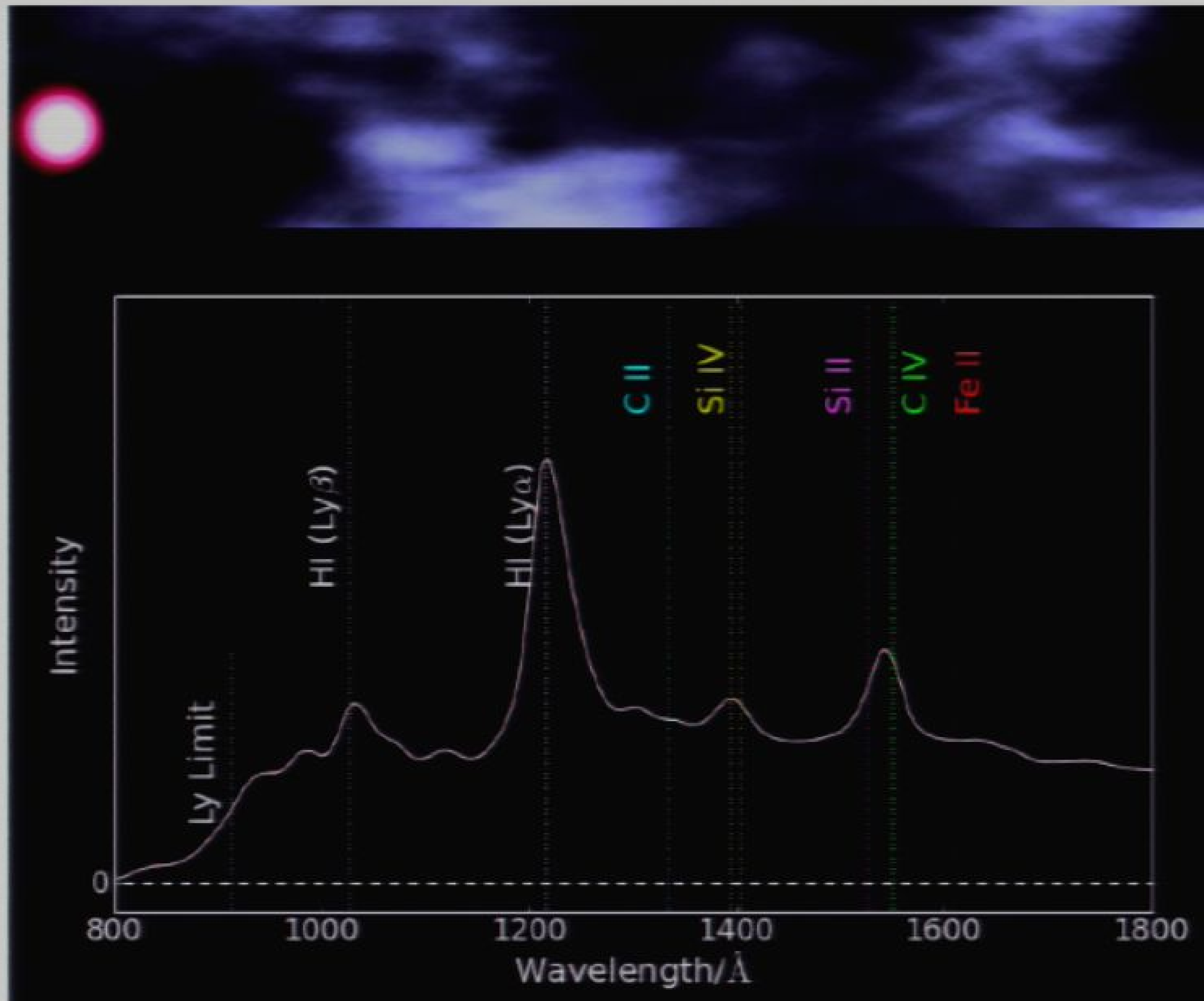


$$\lambda_{obs} = 1216\,(1+z)\ \text{Å}$$

Hydrogen in the IGM is photoionized:

Recombination **Photoionization**

$$\alpha\ n_{HII}\ n_e = \Gamma\ n_{HI}$$



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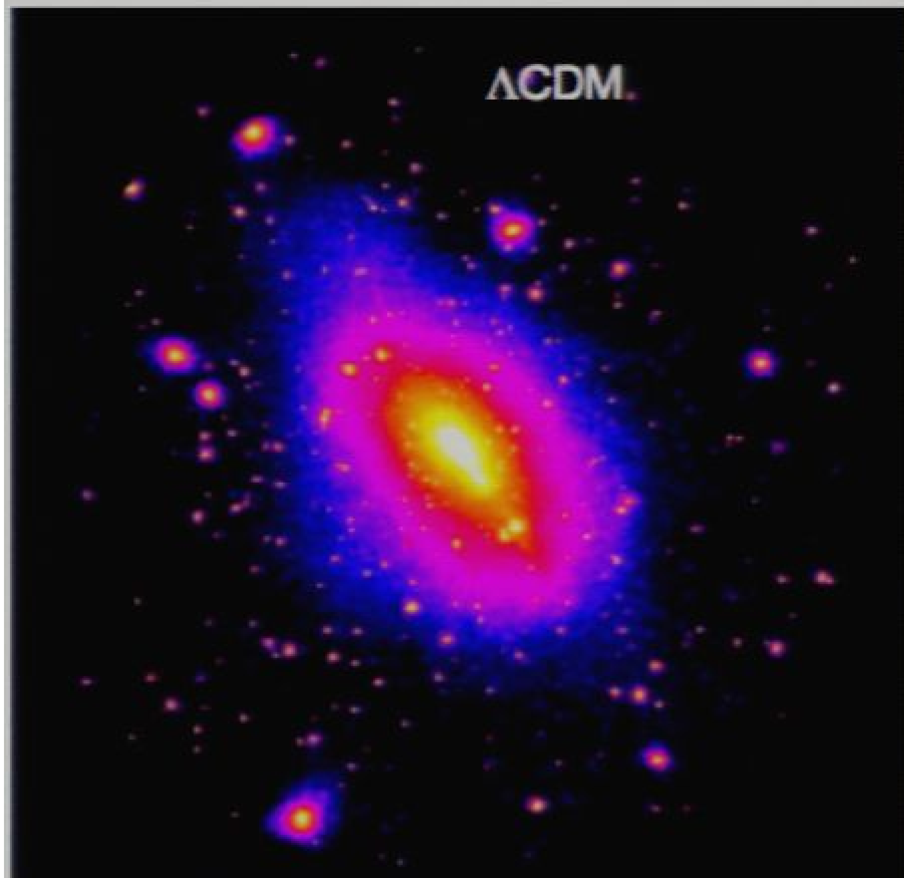
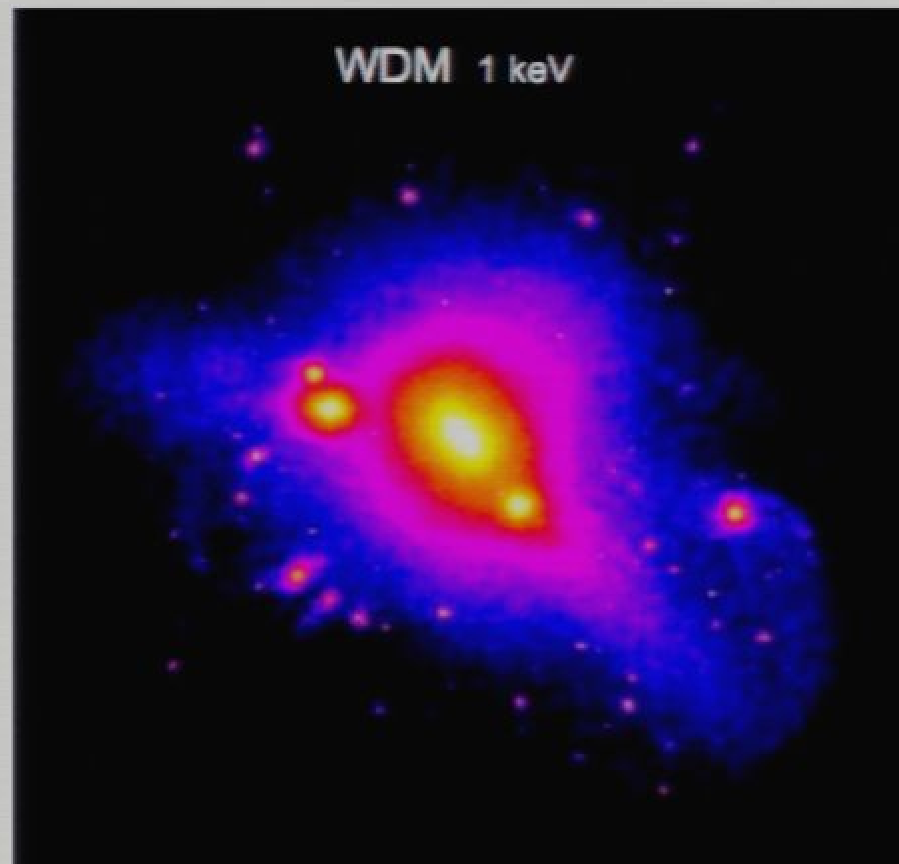
cold dark matter

warm dark matter





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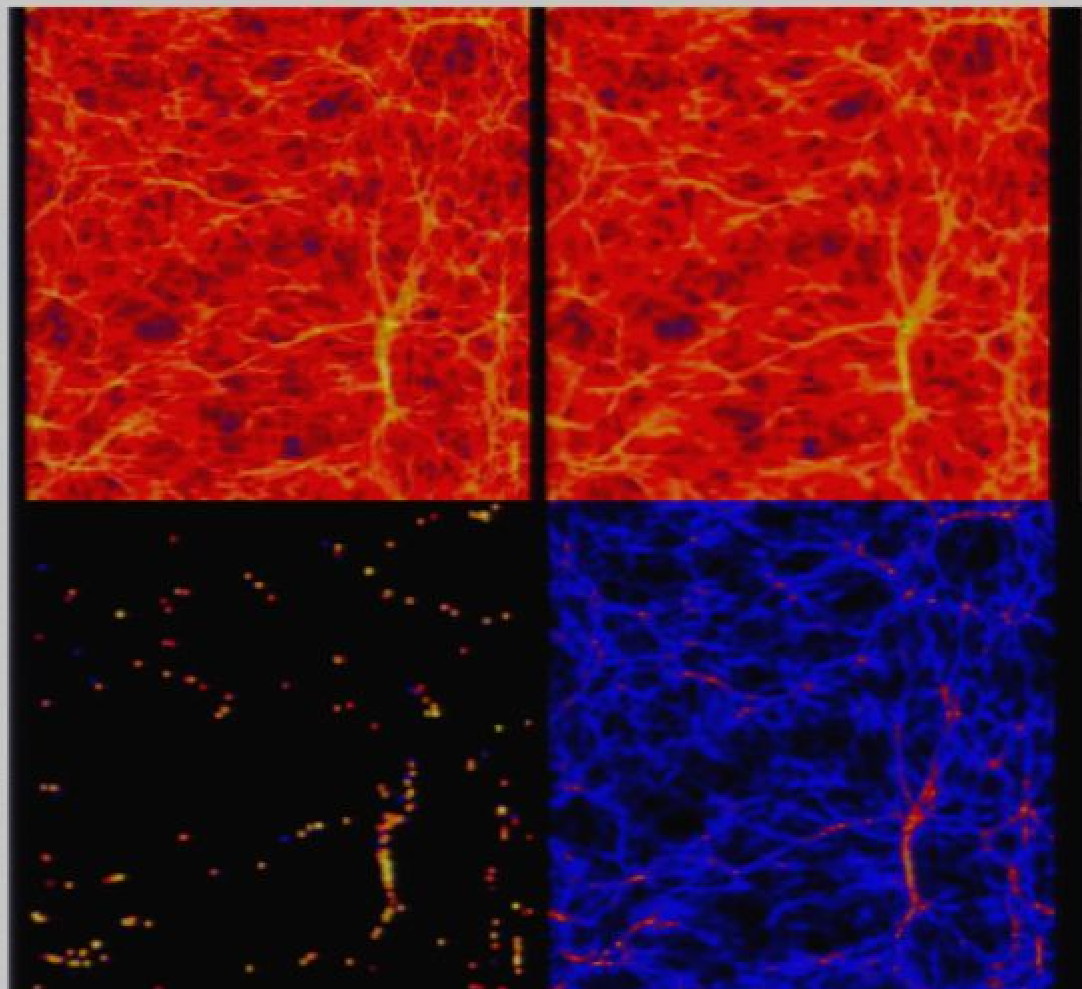

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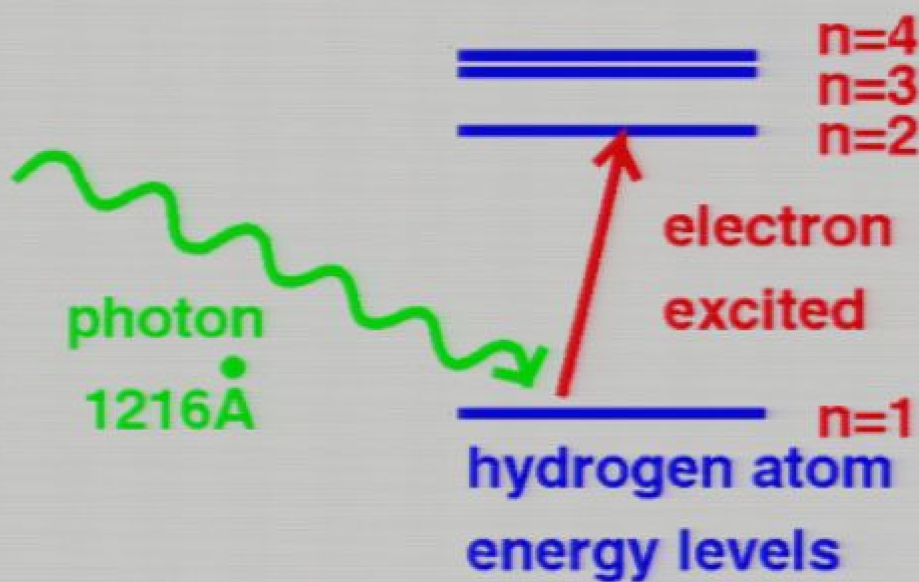

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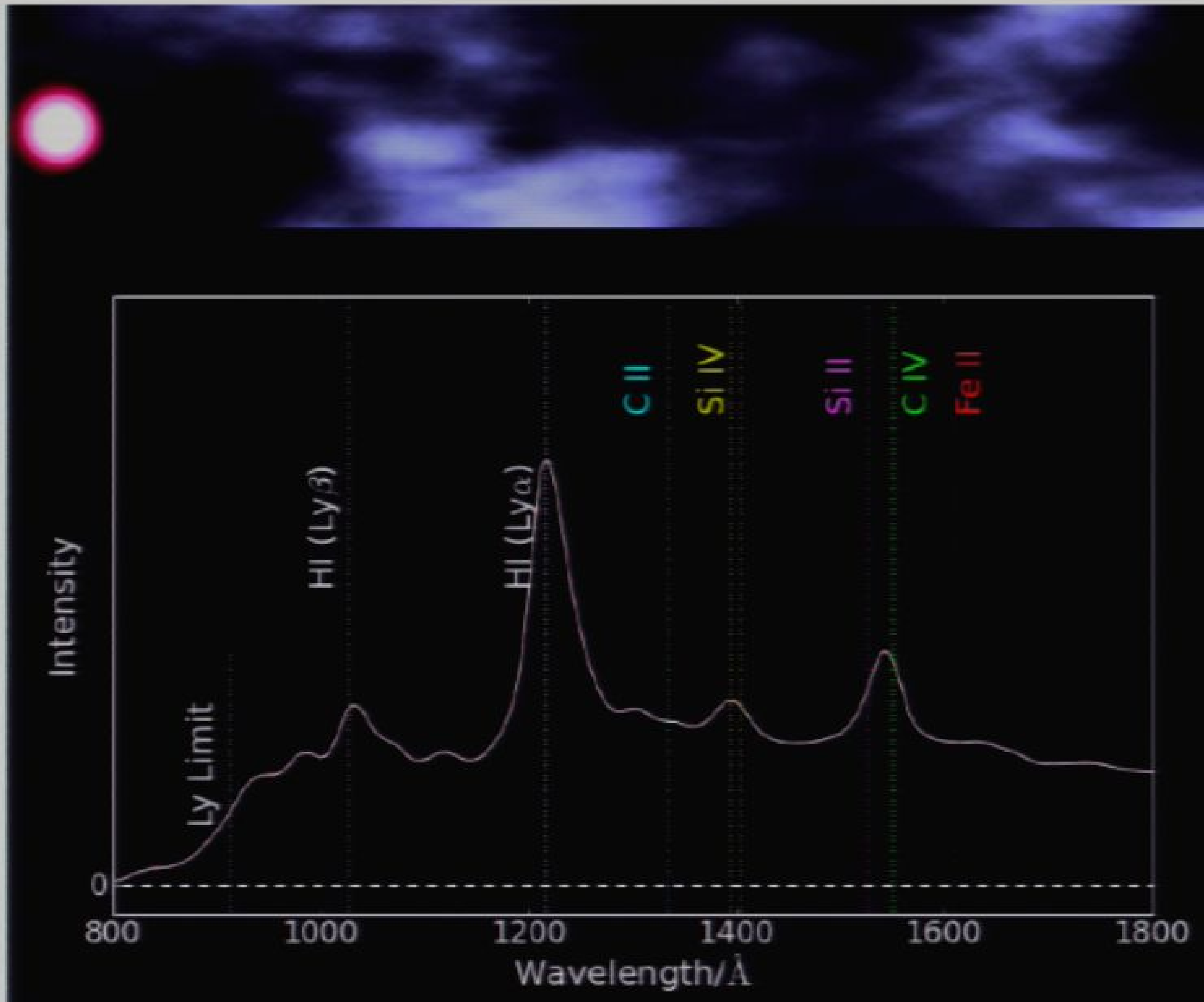

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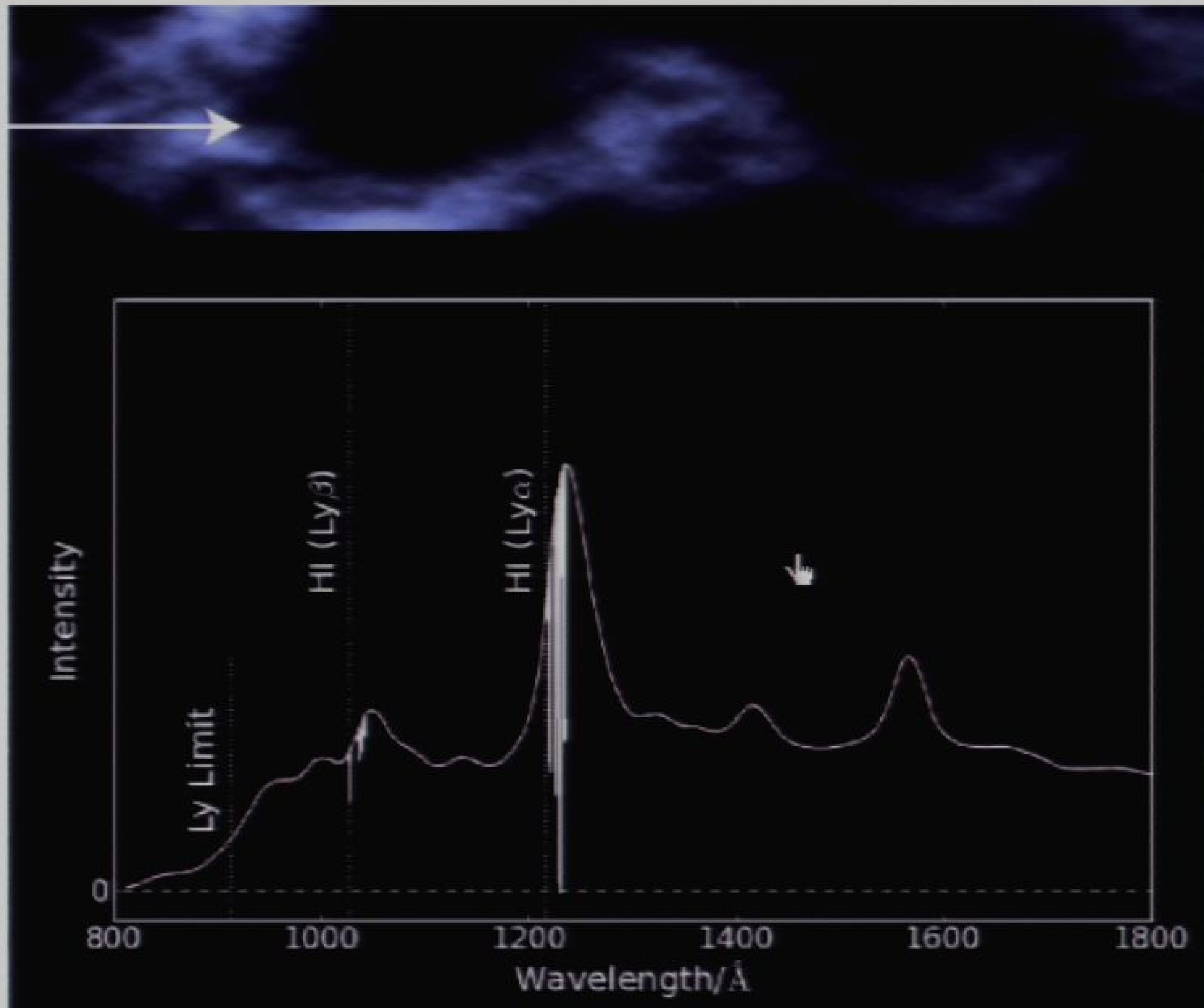

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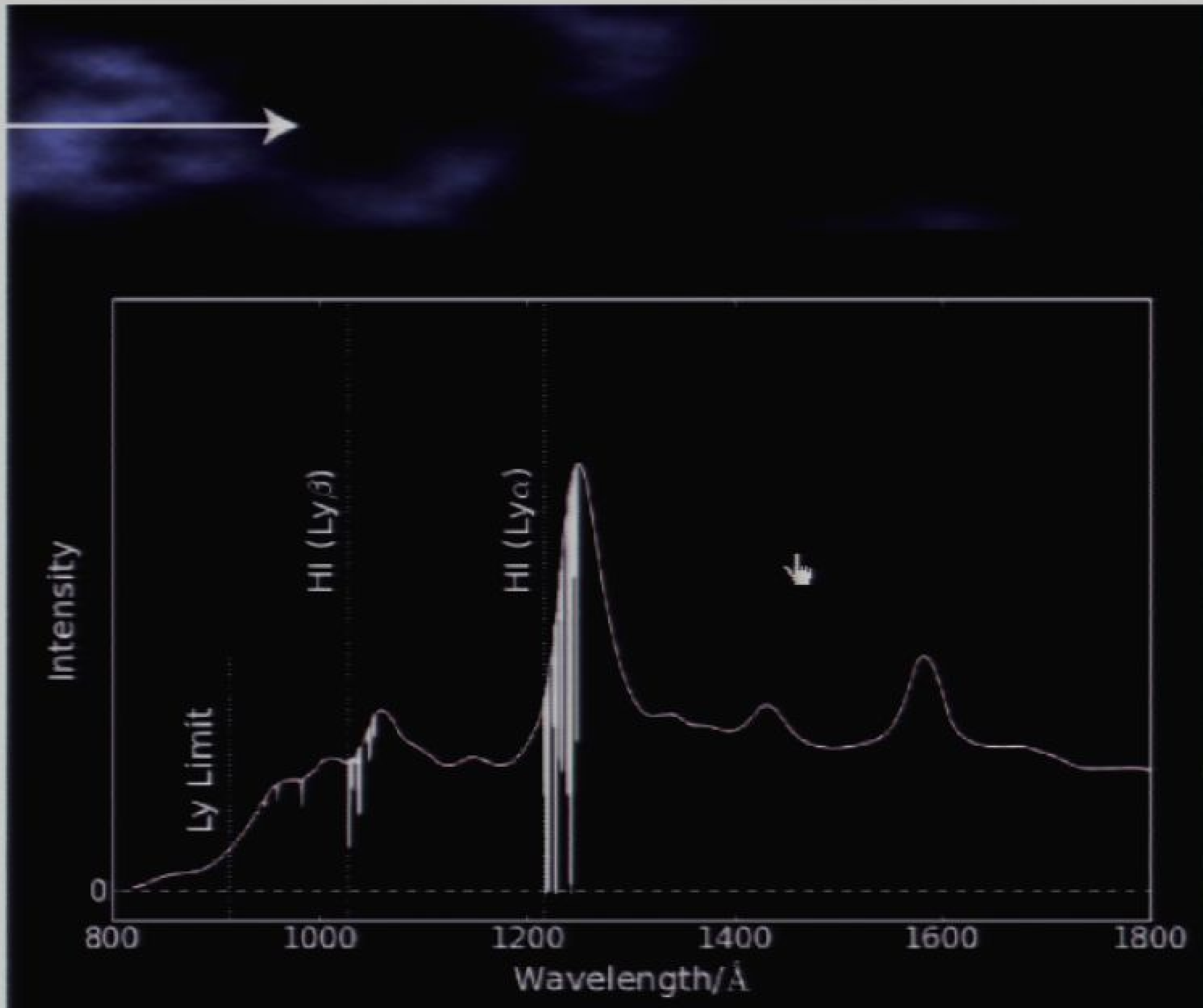

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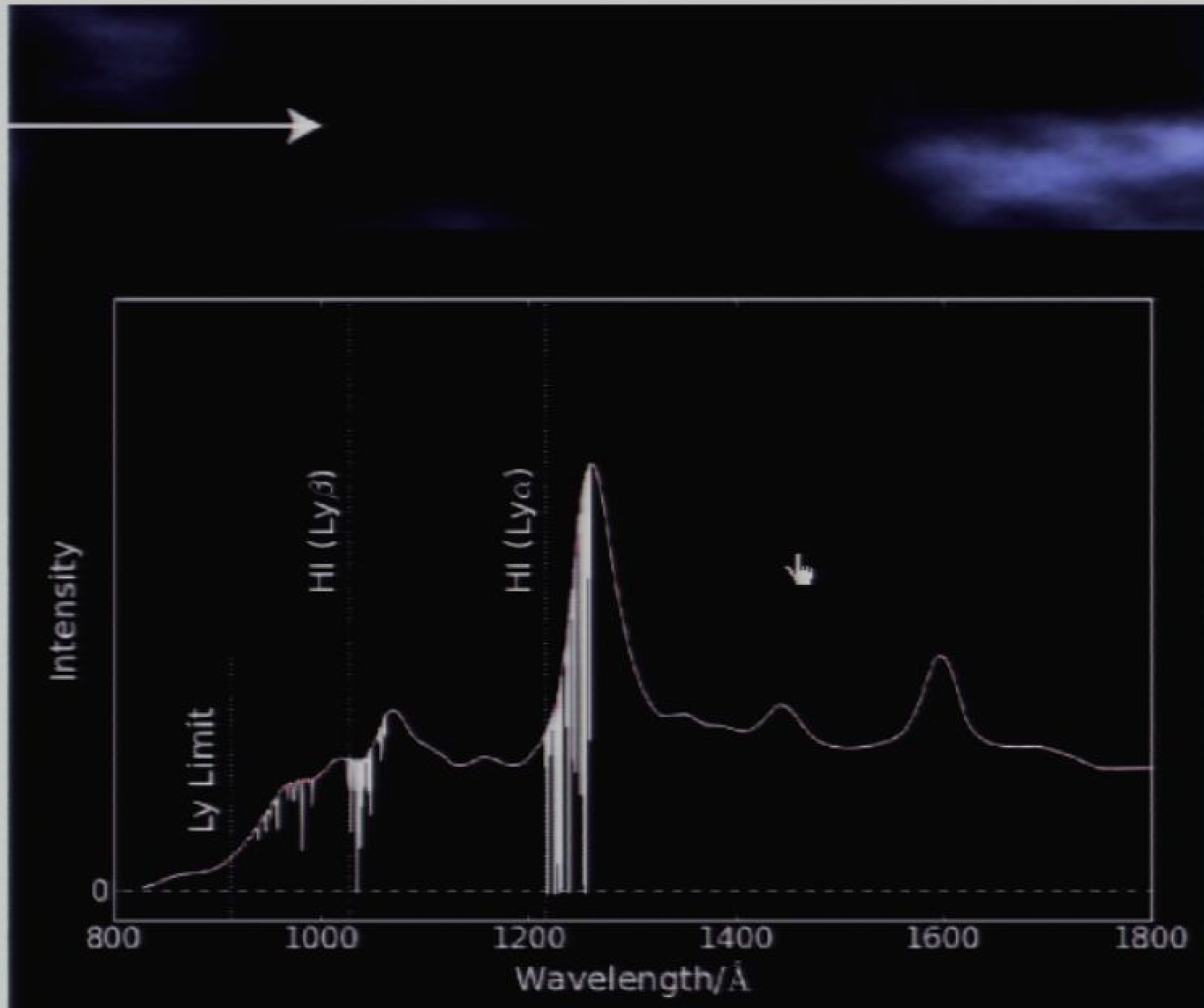

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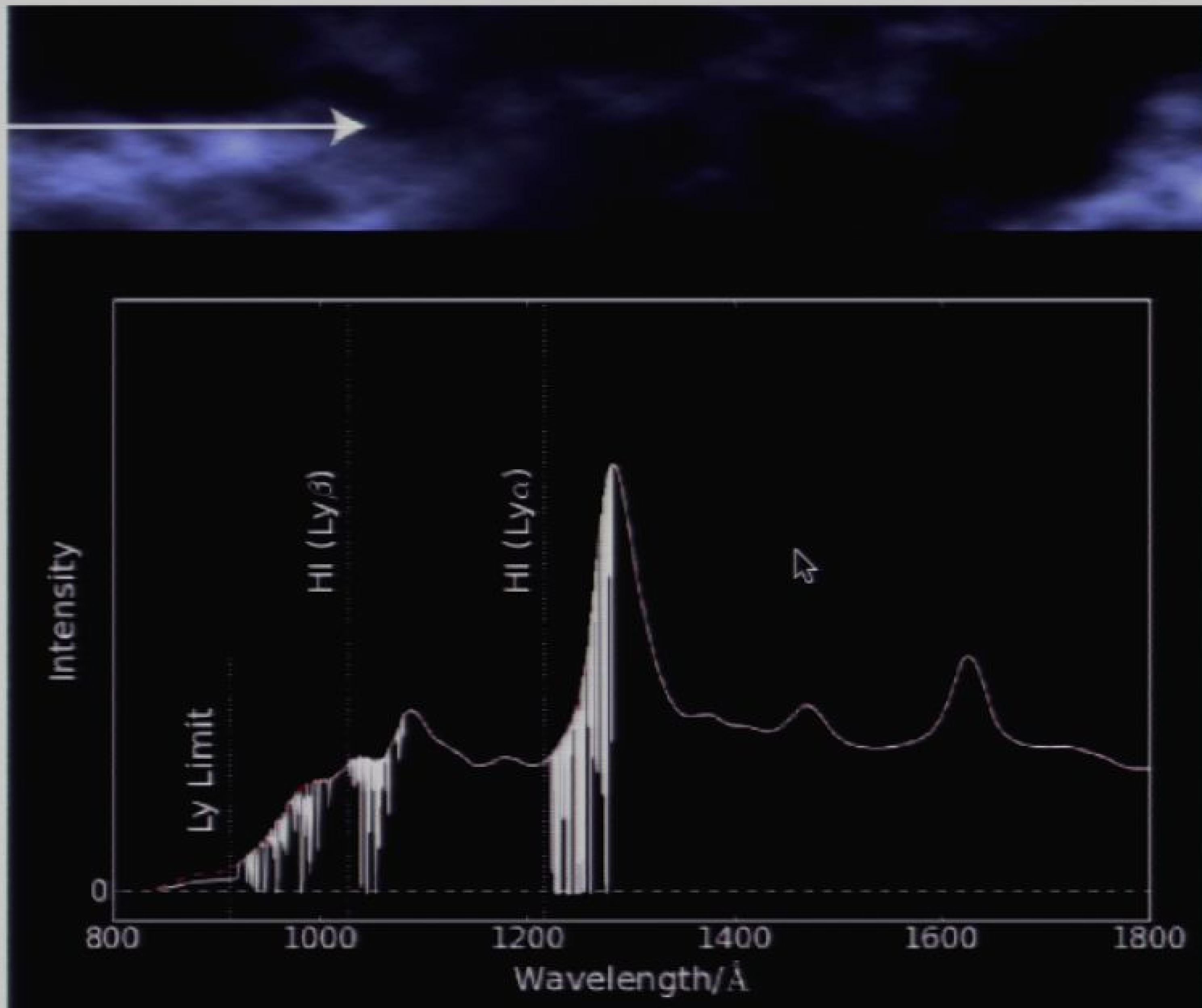
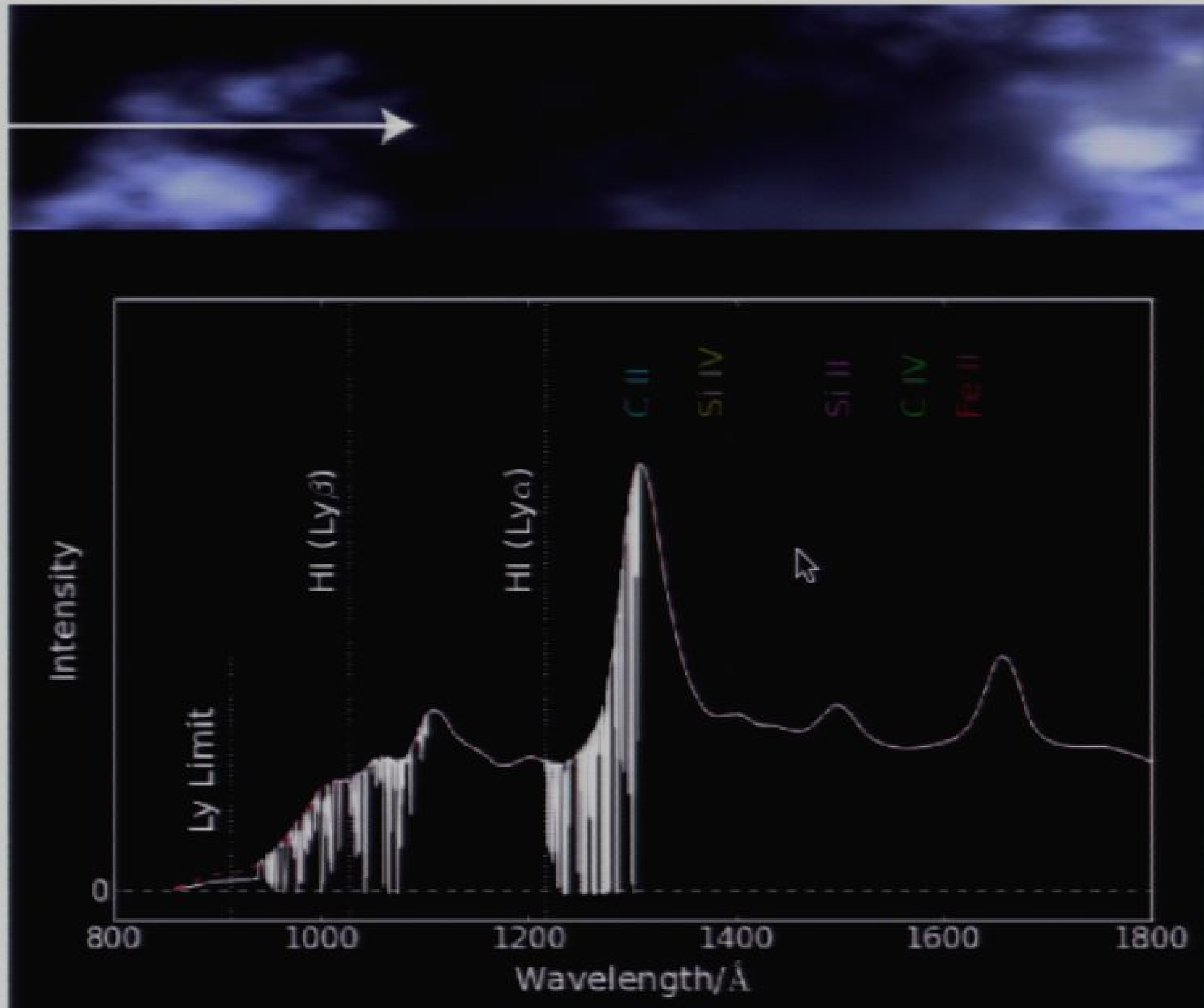

Intensity
0
800
1000
1200
1400
1600
1800
Wavelength/Å
Ly Limit
HI (Lyβ)
HI (Lyα)



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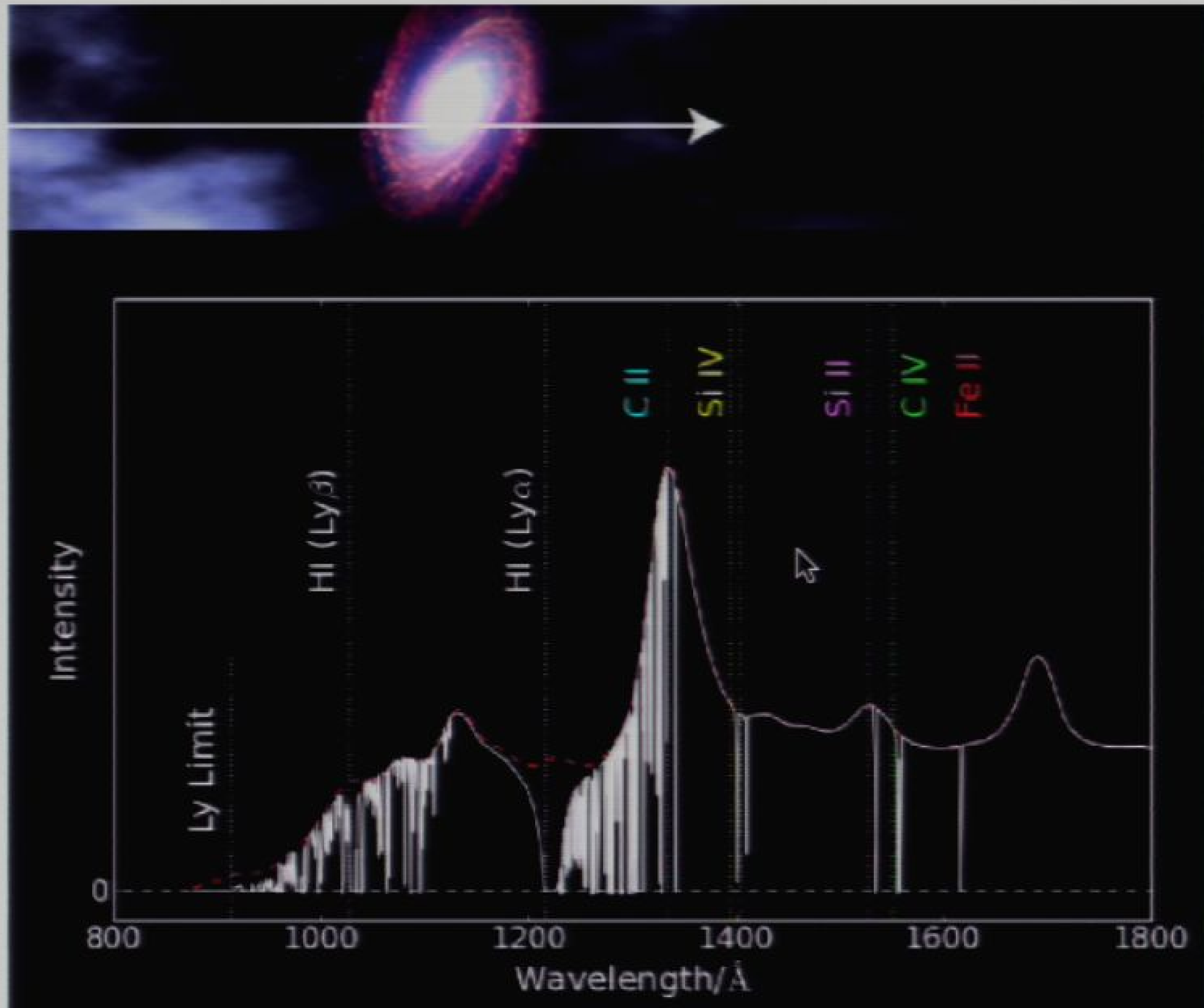
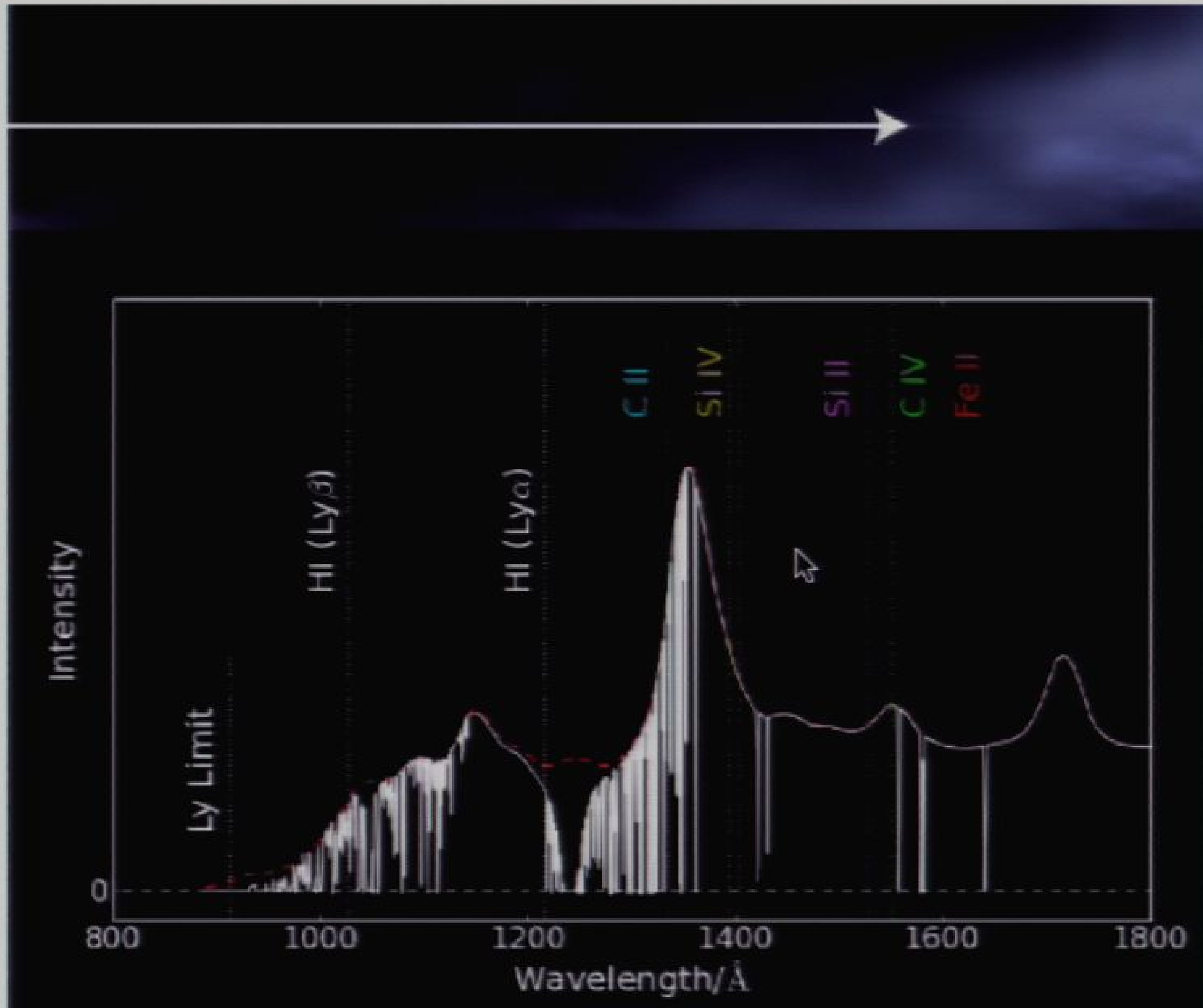

Intensity
Ly Limit
HI (Lyβ)
HI (Lyα)
C II
Si IV
Si II
C IV
Fe II
0
800
1000
1200
1400
1600
1800
Wavelength/Å



Intensity
Ly Limit
HI (Lyβ)
HI (Lyα)
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Si IV
Si II
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0
800
1000
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1400
1600
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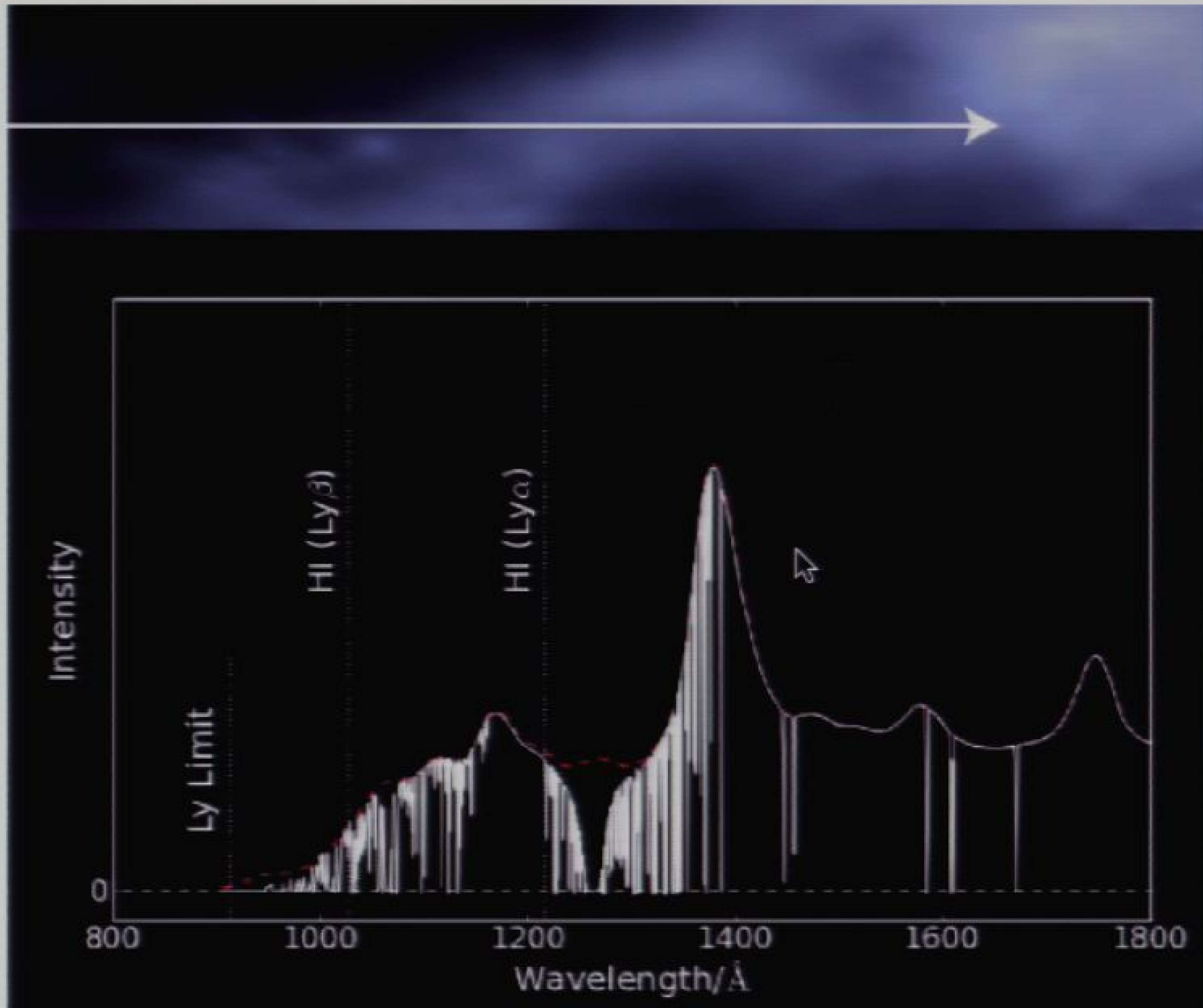
Wavelength/Å



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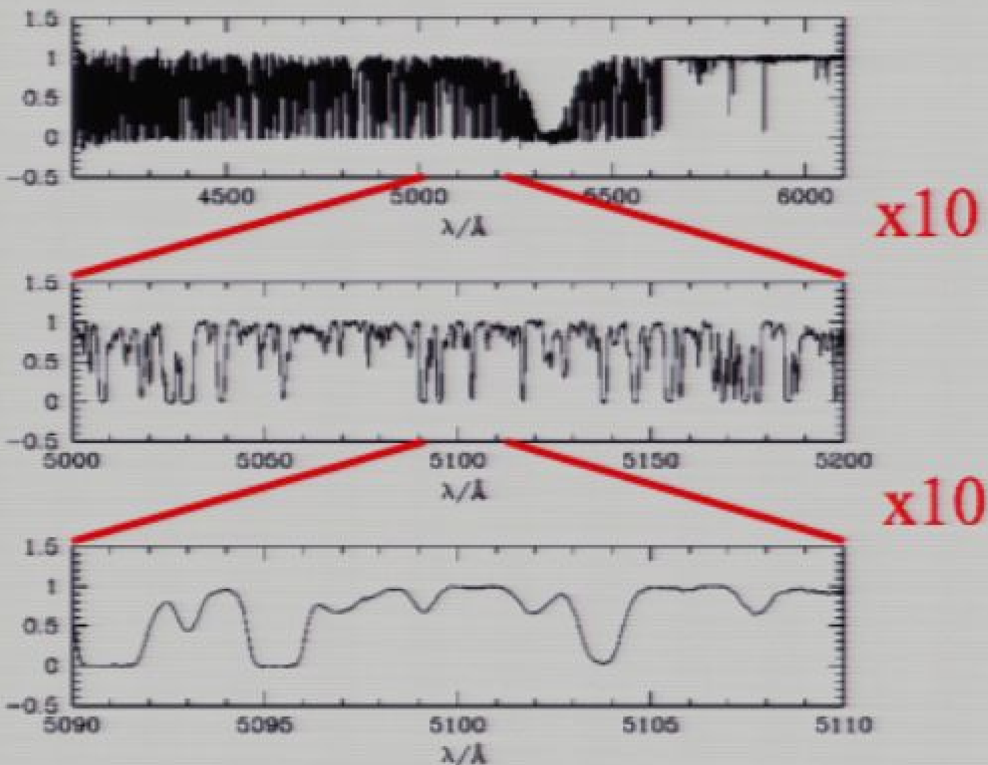
- matter power spectrum on small and intermediate scales
- redshift drift?
- (high-redshift galaxies)
- (metal enrichment)
- (ionization state of the IGM)
- (thermal history of the IGM
- (reionization)

High resolution – High S/N



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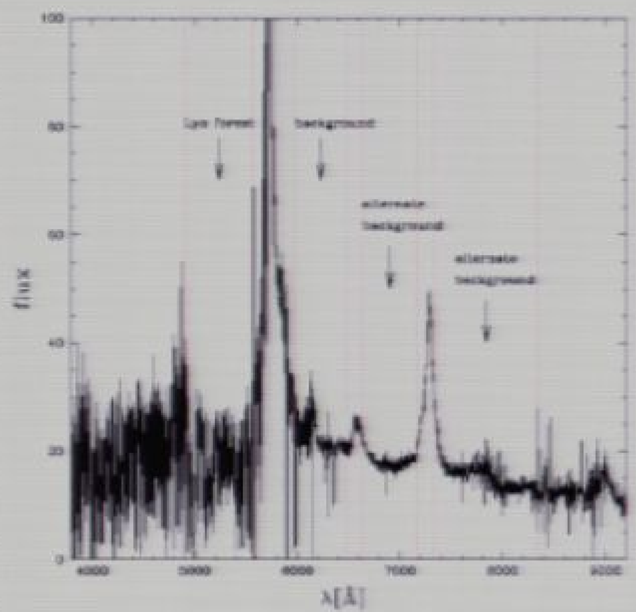
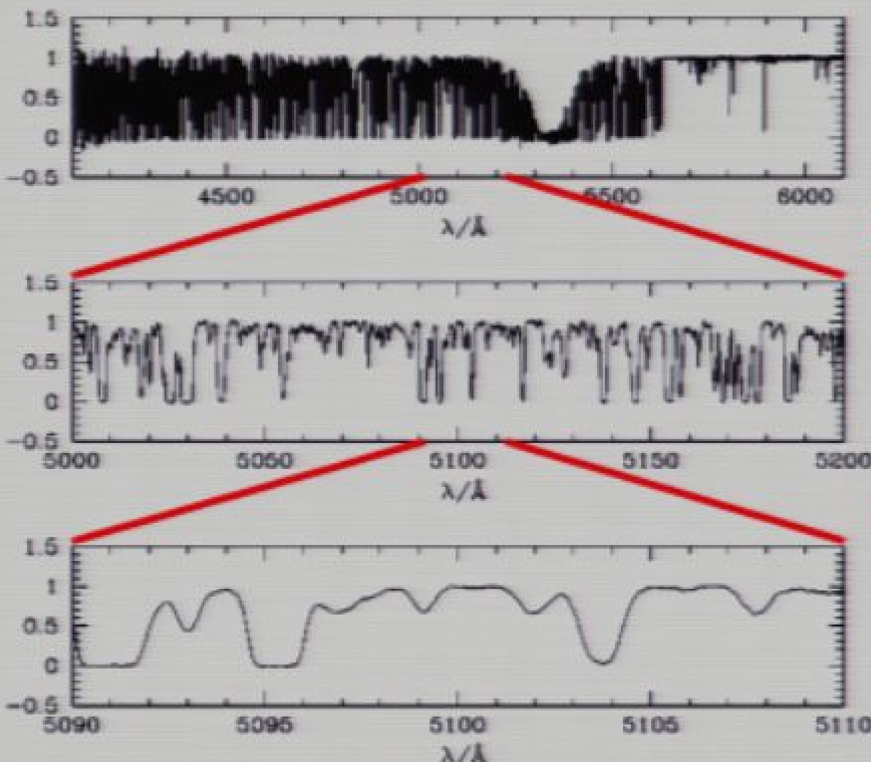
SDSS flux power spectrum



- 3035 SDSS spectra
- low S/N (~5-15)
- low resolution (~100 km/s)

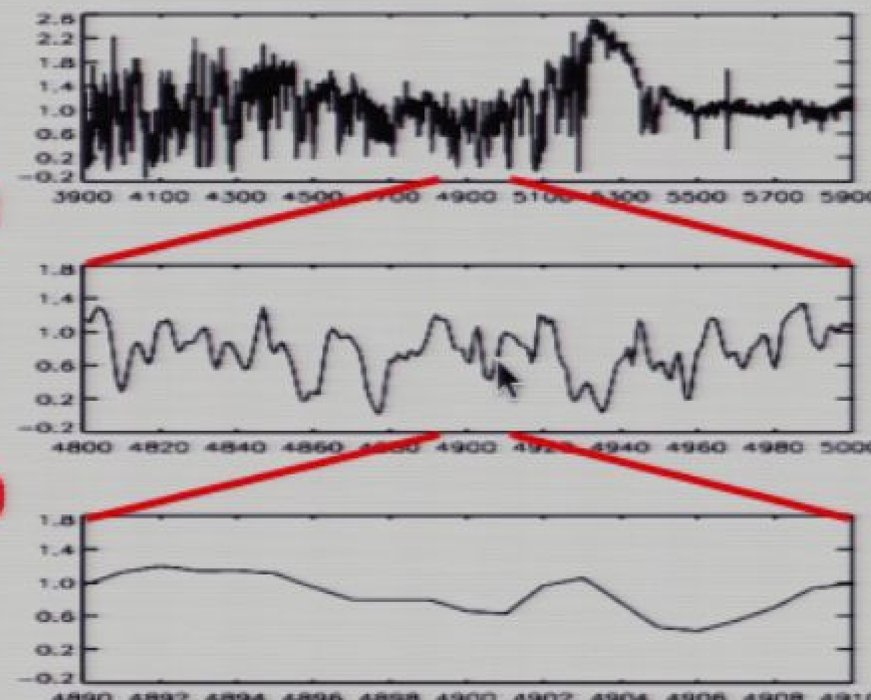
High resolution – High S/N

Low resolution – Low S/N



x10

x10



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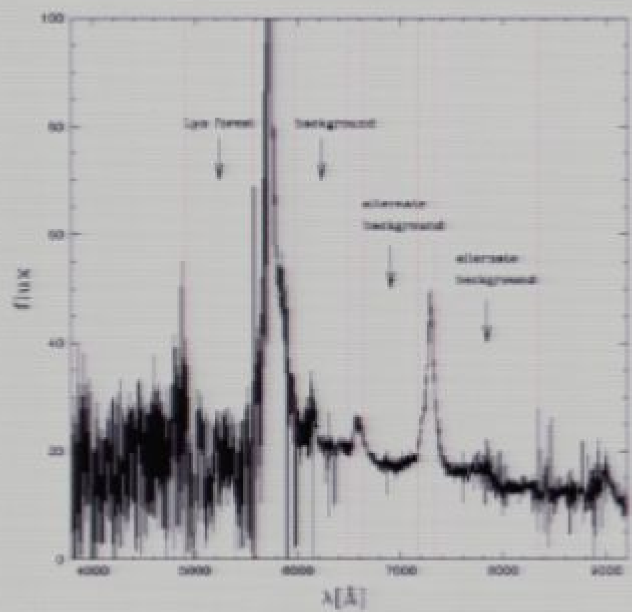
SDSS flux power spectrum



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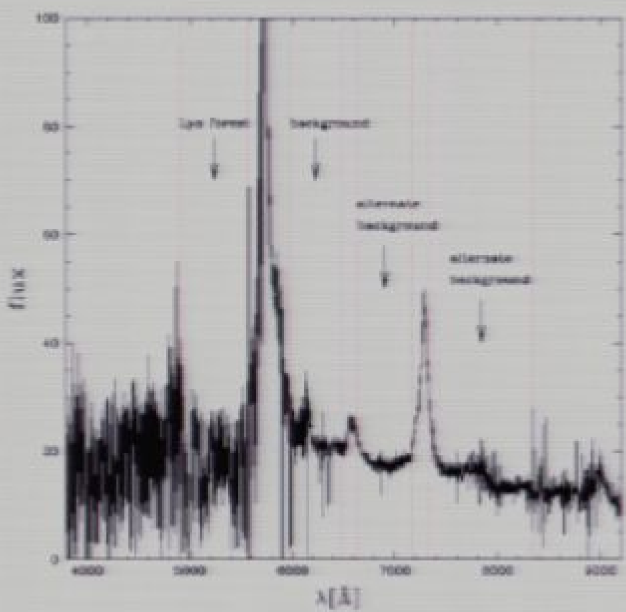

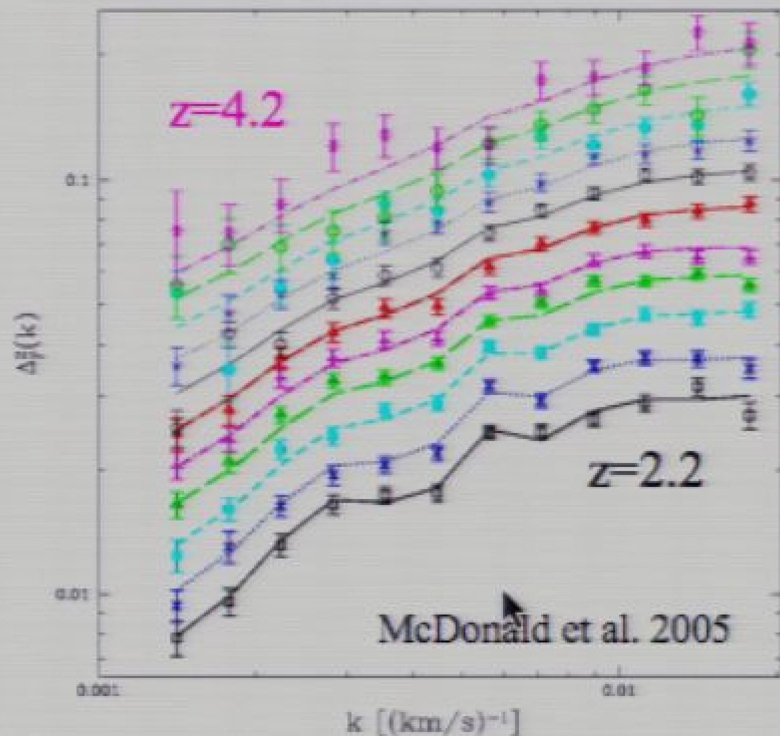

- 3035 SDSS spectra
- low S/N (~5-15)
- low resolution (~100 km/s)

Pros:

- small statistical errors
- split in many redshift bins over a wide redshift range

Cons:

- rather large corrections for noise and resolution

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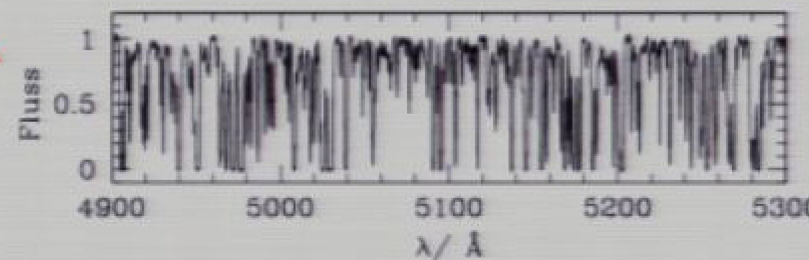
observed



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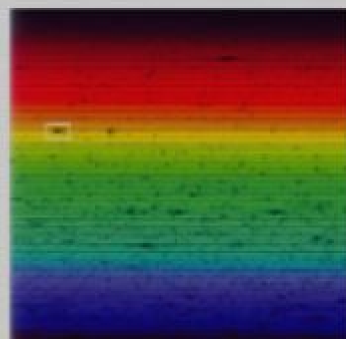
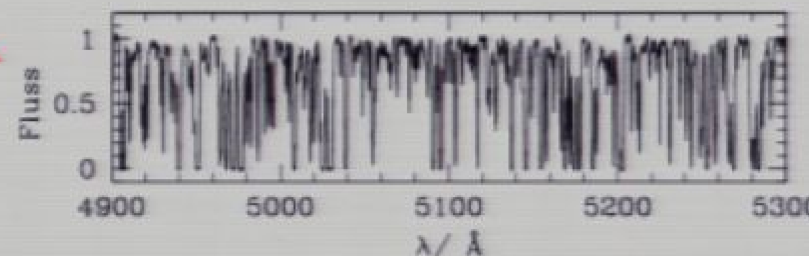
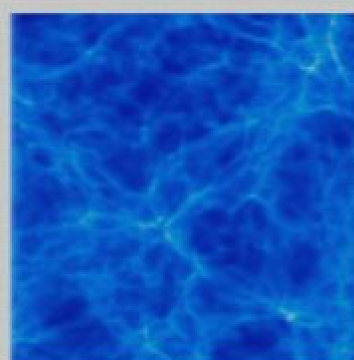
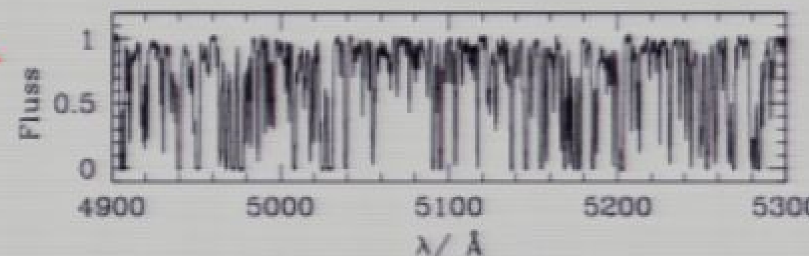


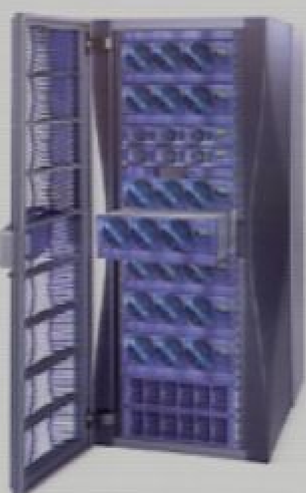
observed

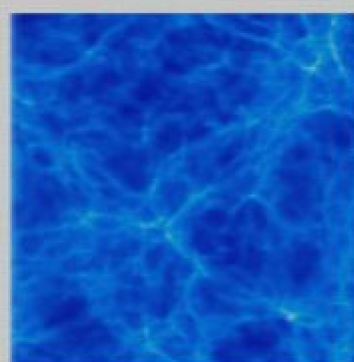




observed

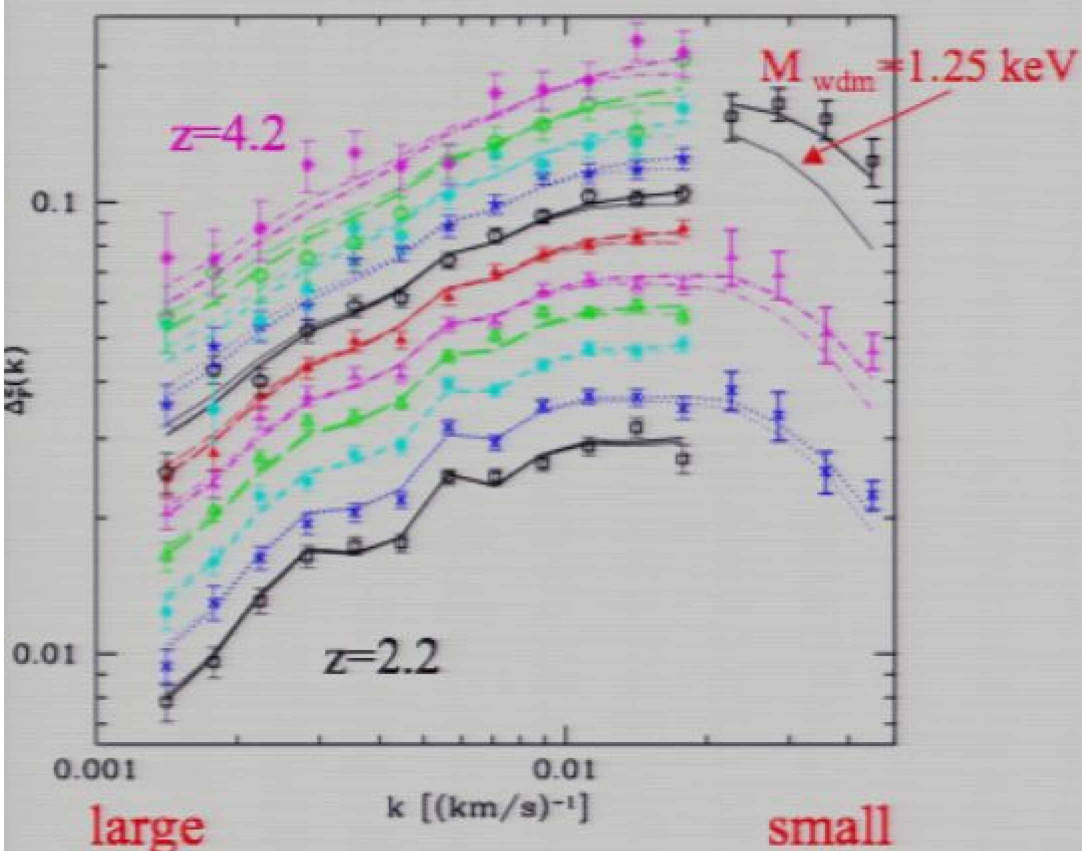






simulated

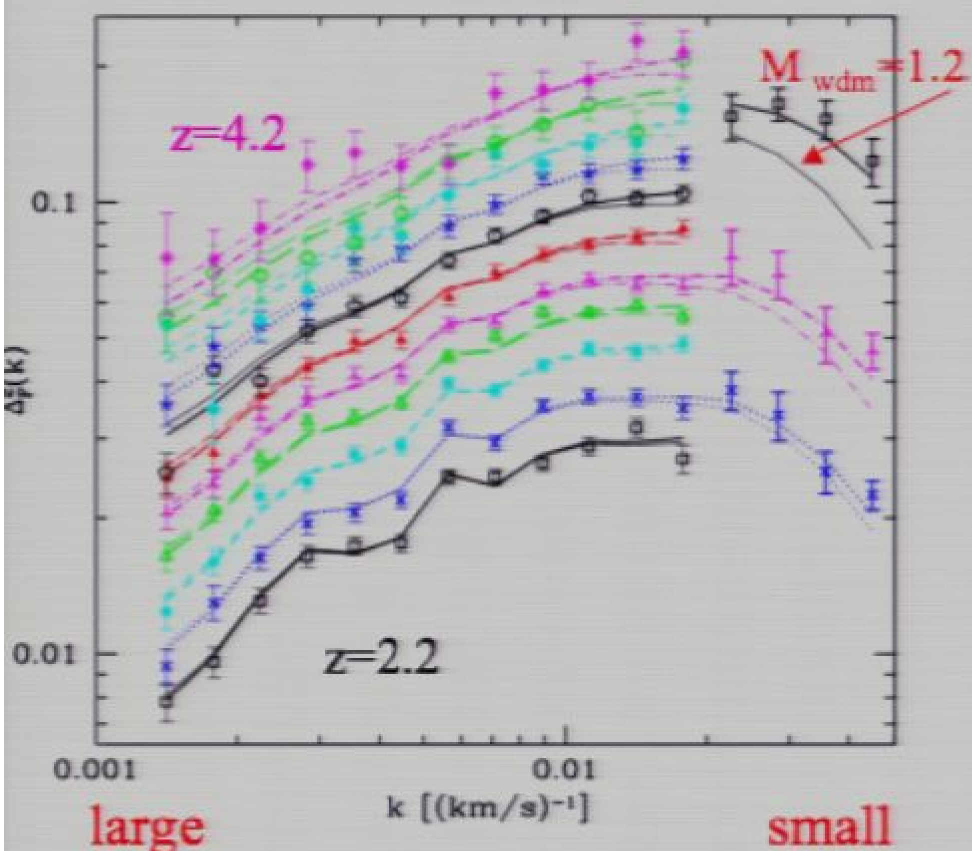
Seljak et al. 2006



$M_{wdm} > 2.4$ keV

These are the limits for thermal relics. For sterile neutrinos the story is more complicated.

Seljak et al. 2006



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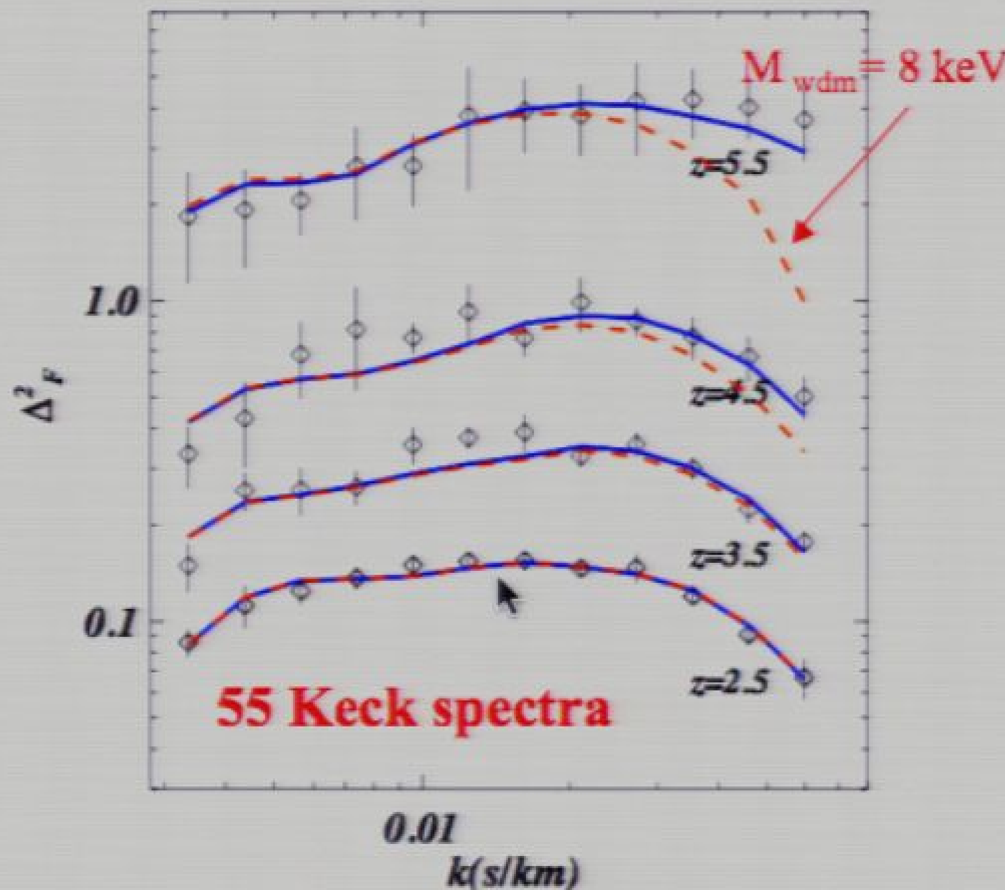
Viel et al. 2006,2007,2008



M_{wdm} > 4 keV

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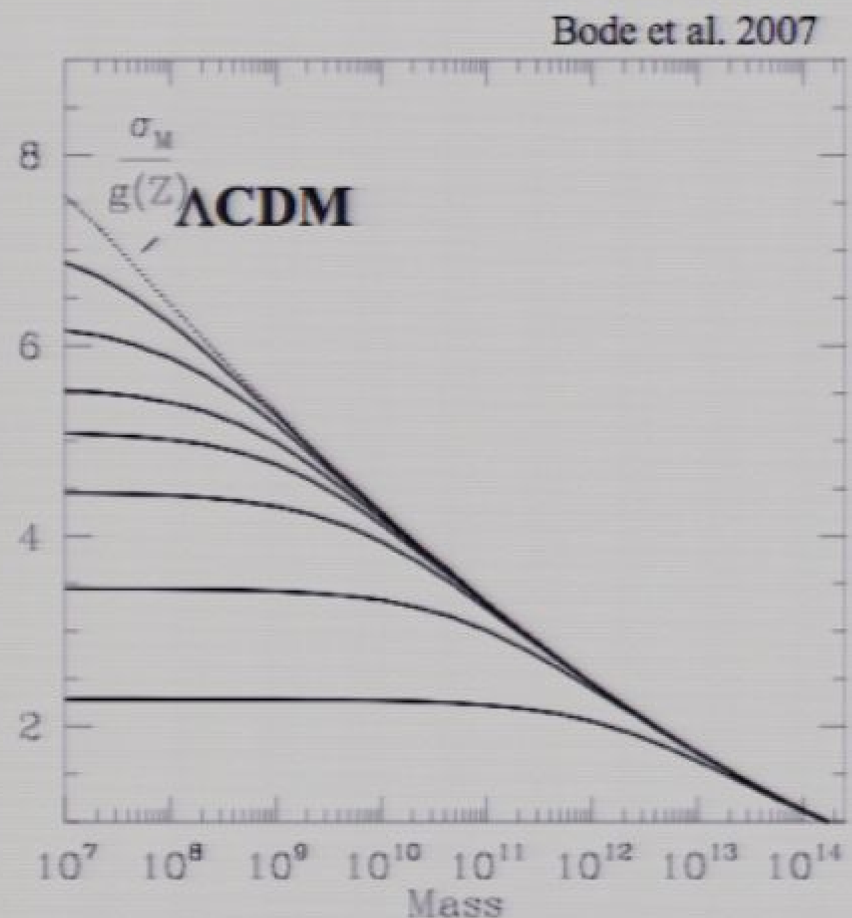
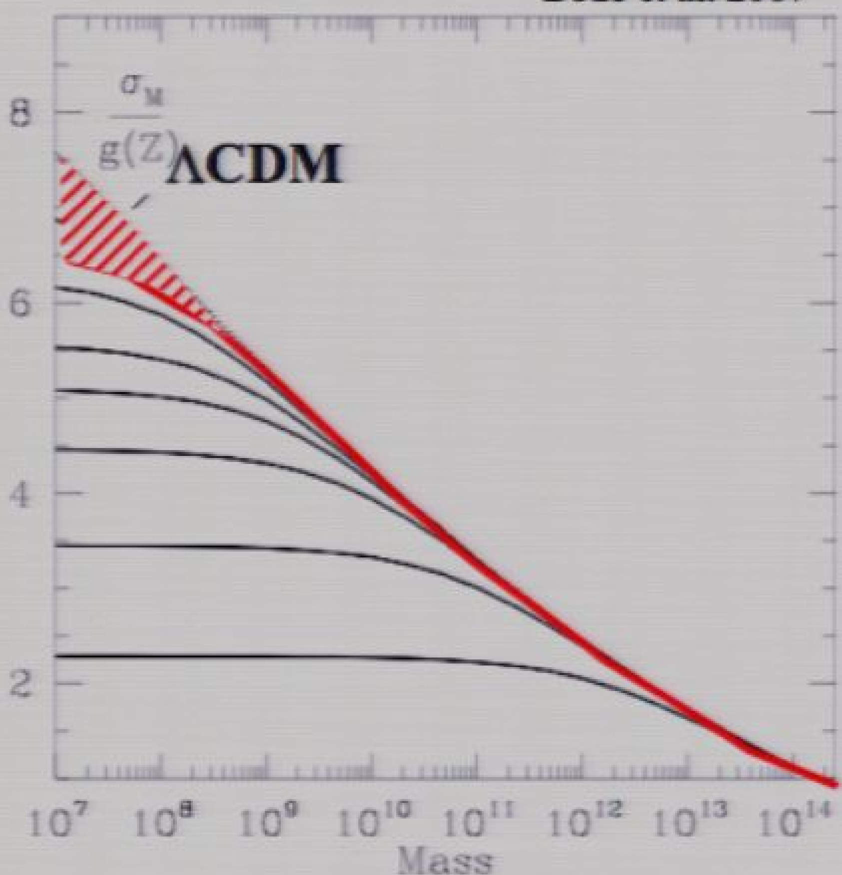
DM is pretty cold



DM is pretty cold

Bode et al. 2007



There is little room left for the effect of warm DM on the DM halo mass function (or DM halo profiles).

Our best bet to push this further is probably looking at neutral hydrogen before reionization with 21cm emission.

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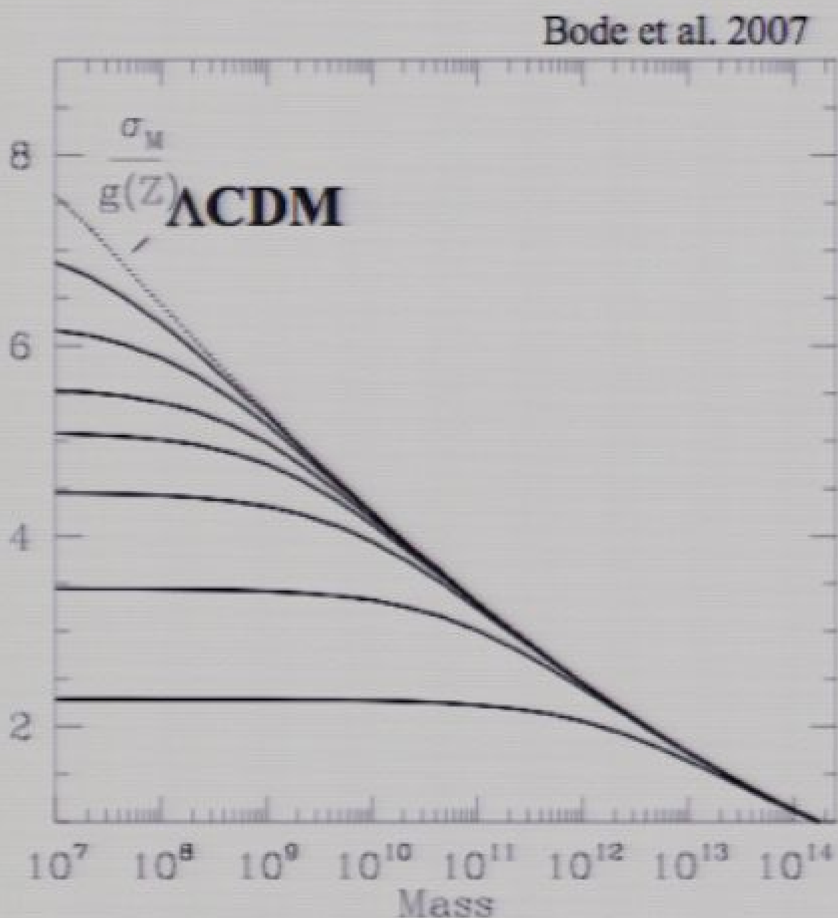

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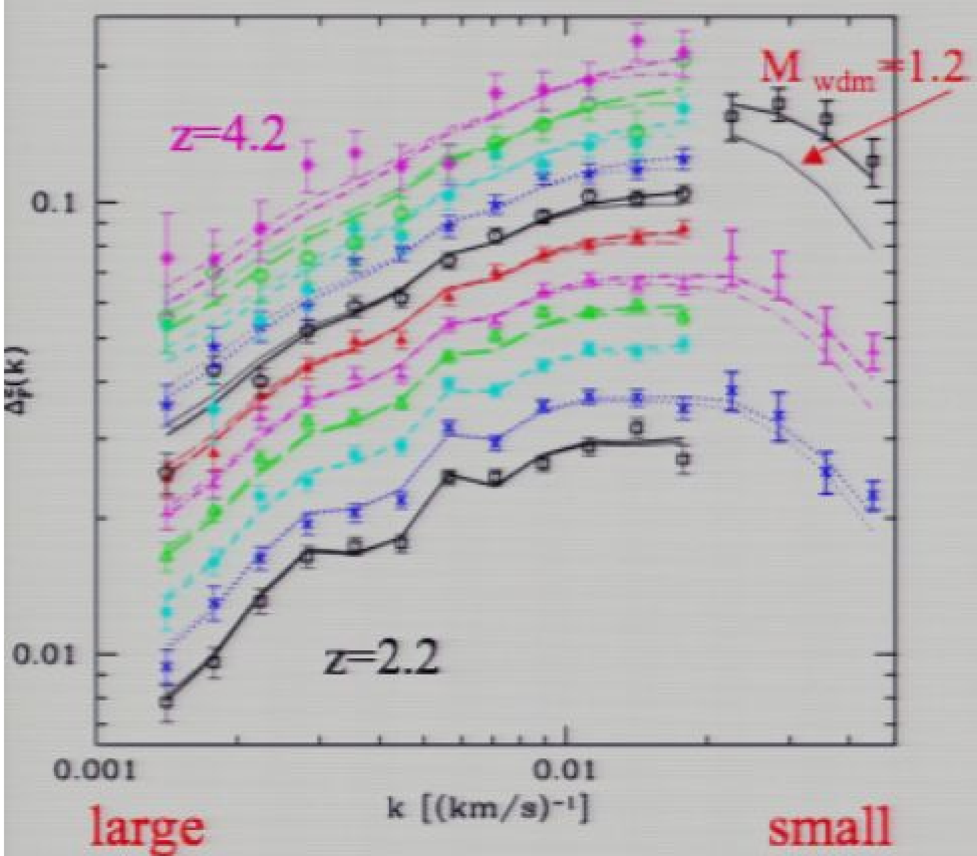
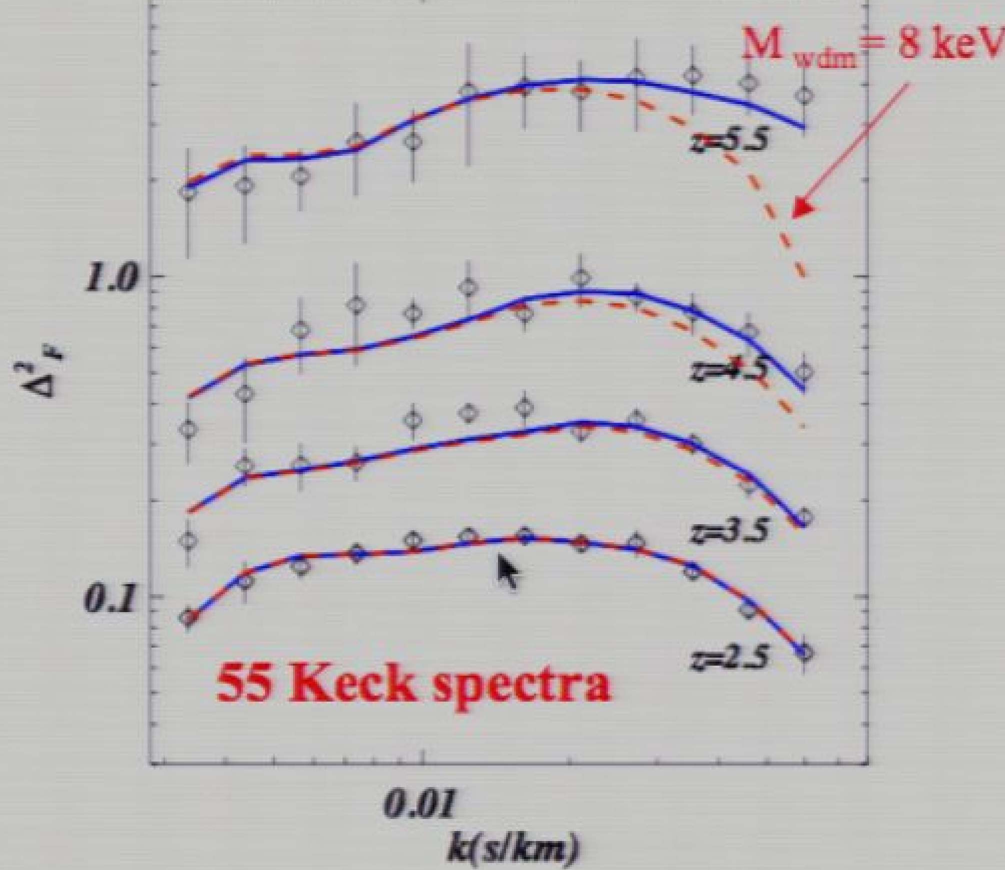
Seljak et al. 2006



Viel et al. 2006,2007,2008



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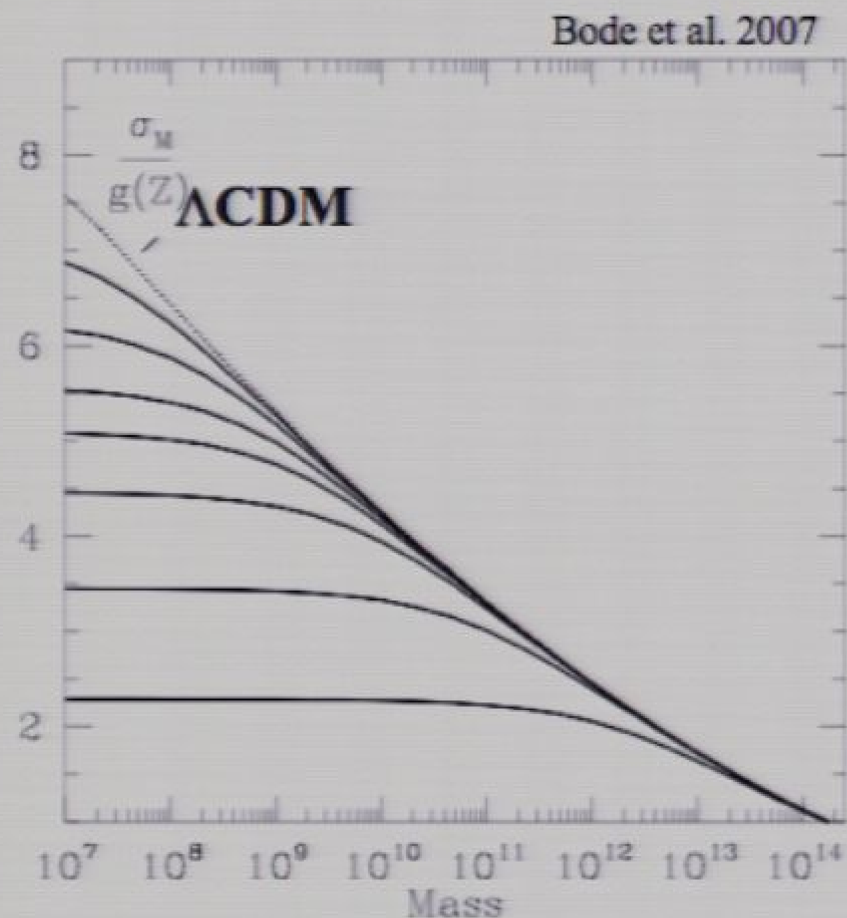

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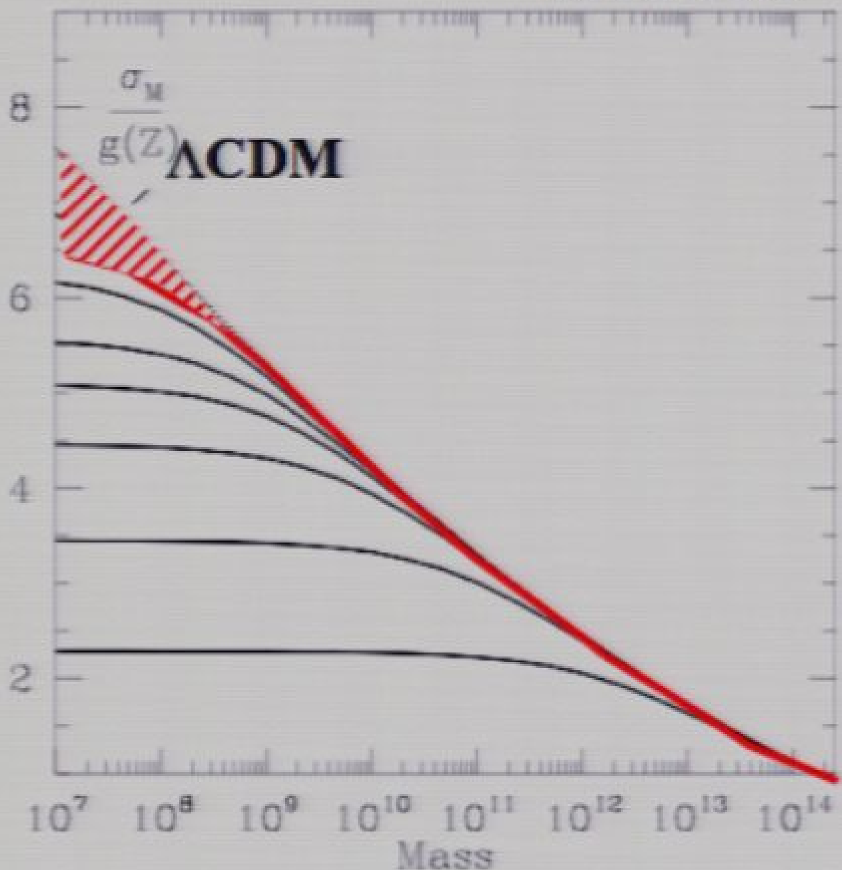

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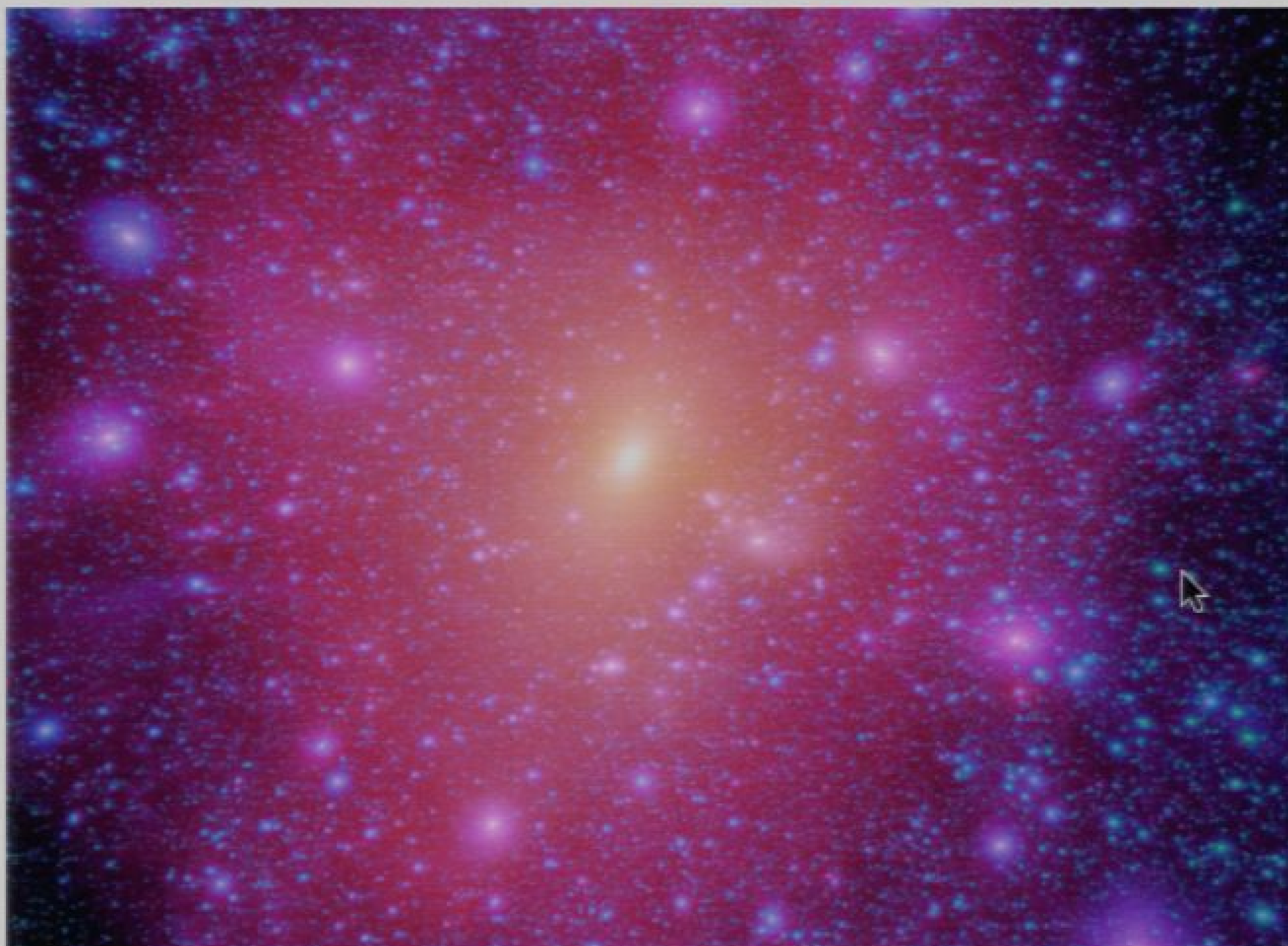

Springel et al.

The CDM paradigm predicts many low mass objects

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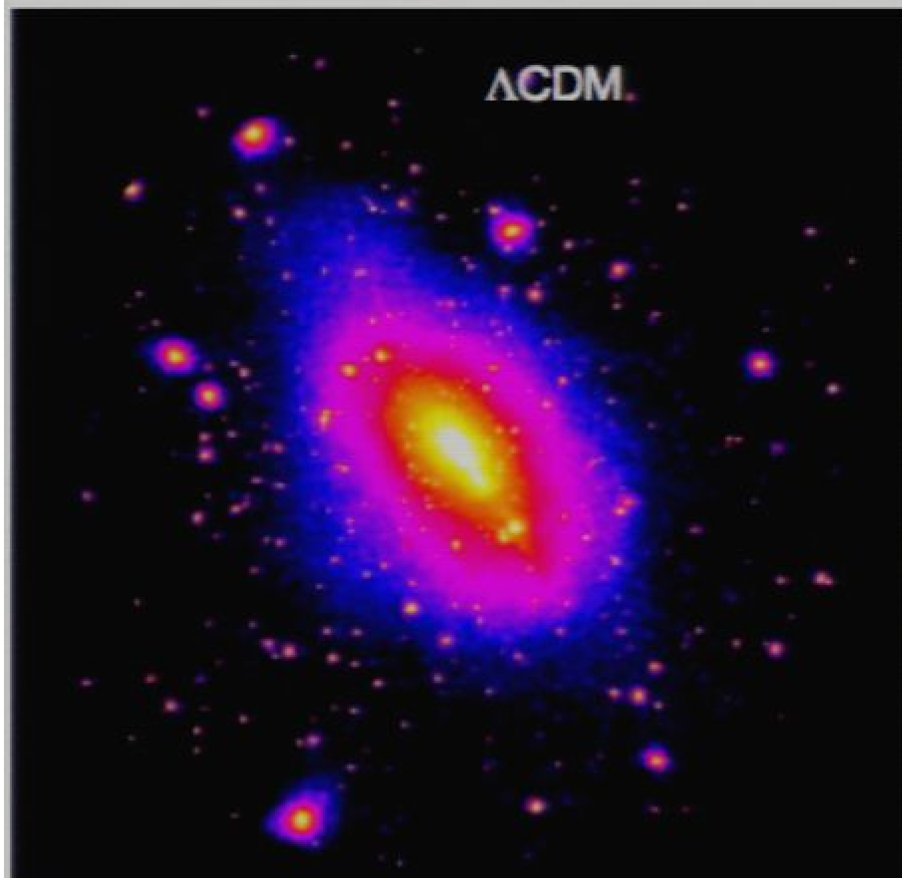
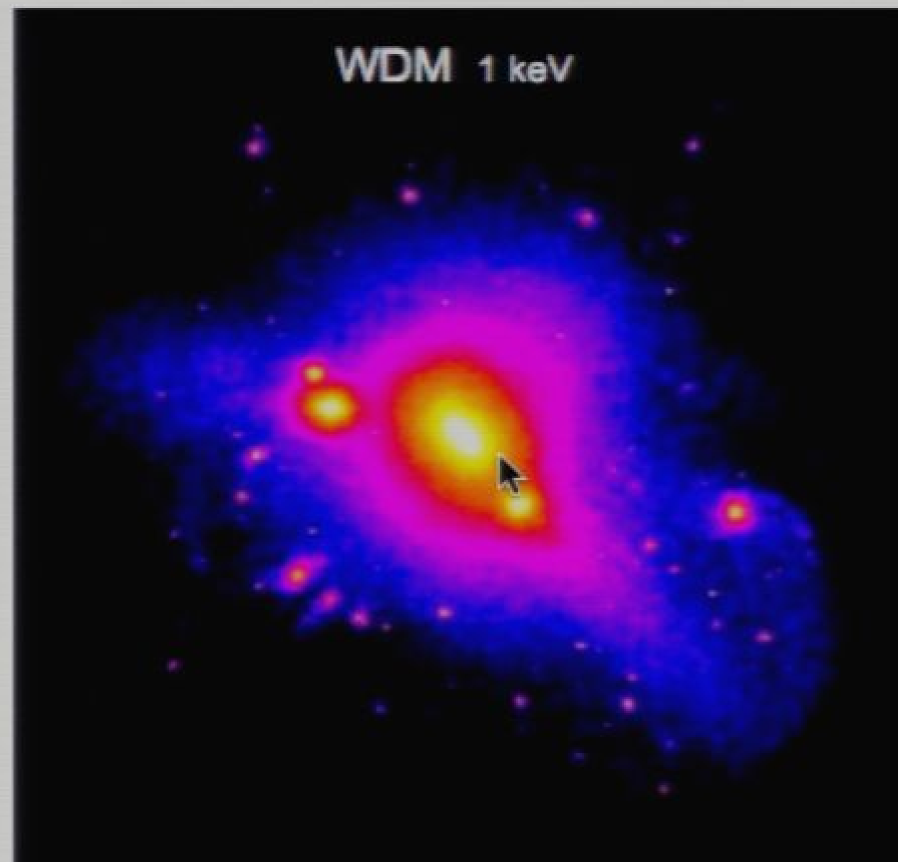
cold dark matter



warm dark matter



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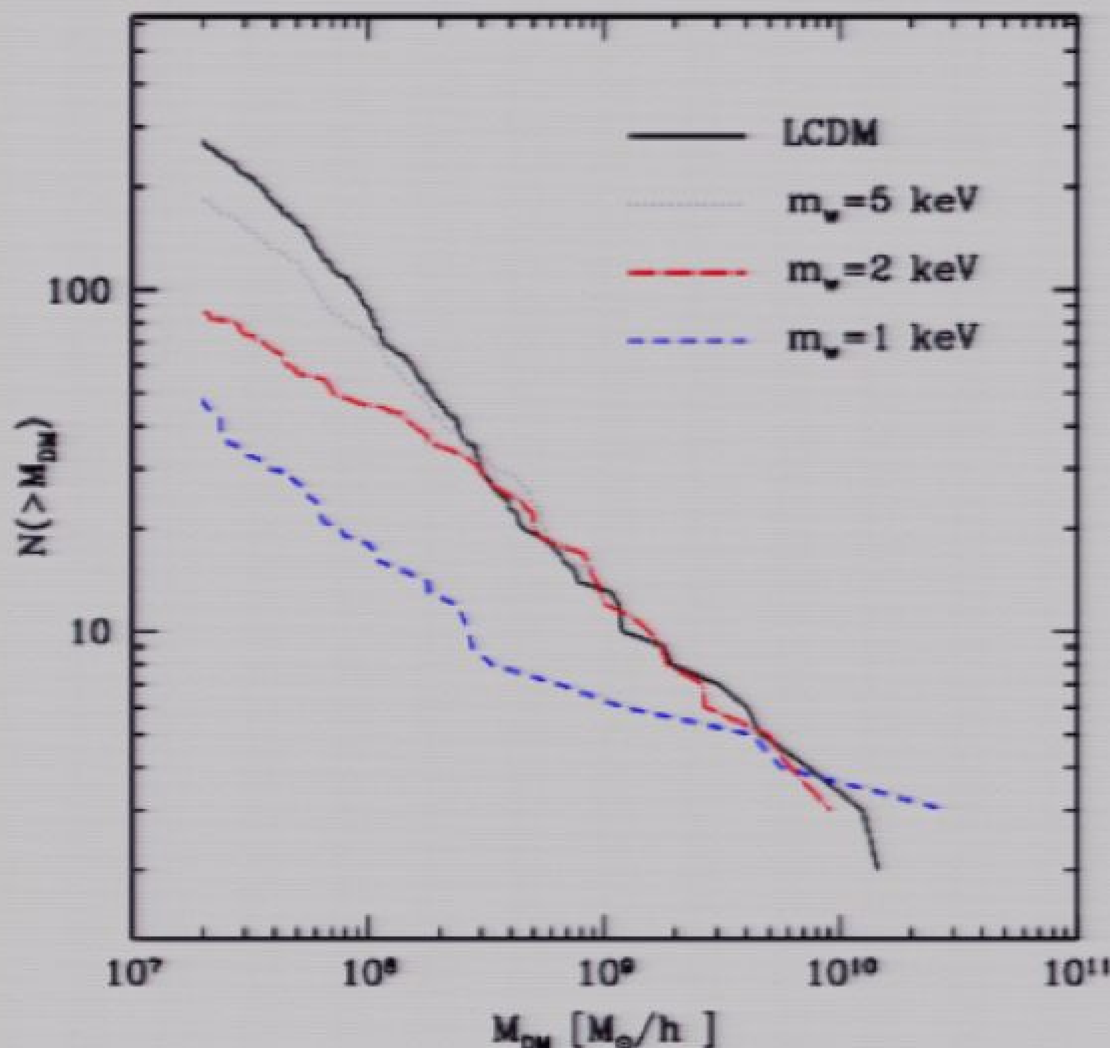
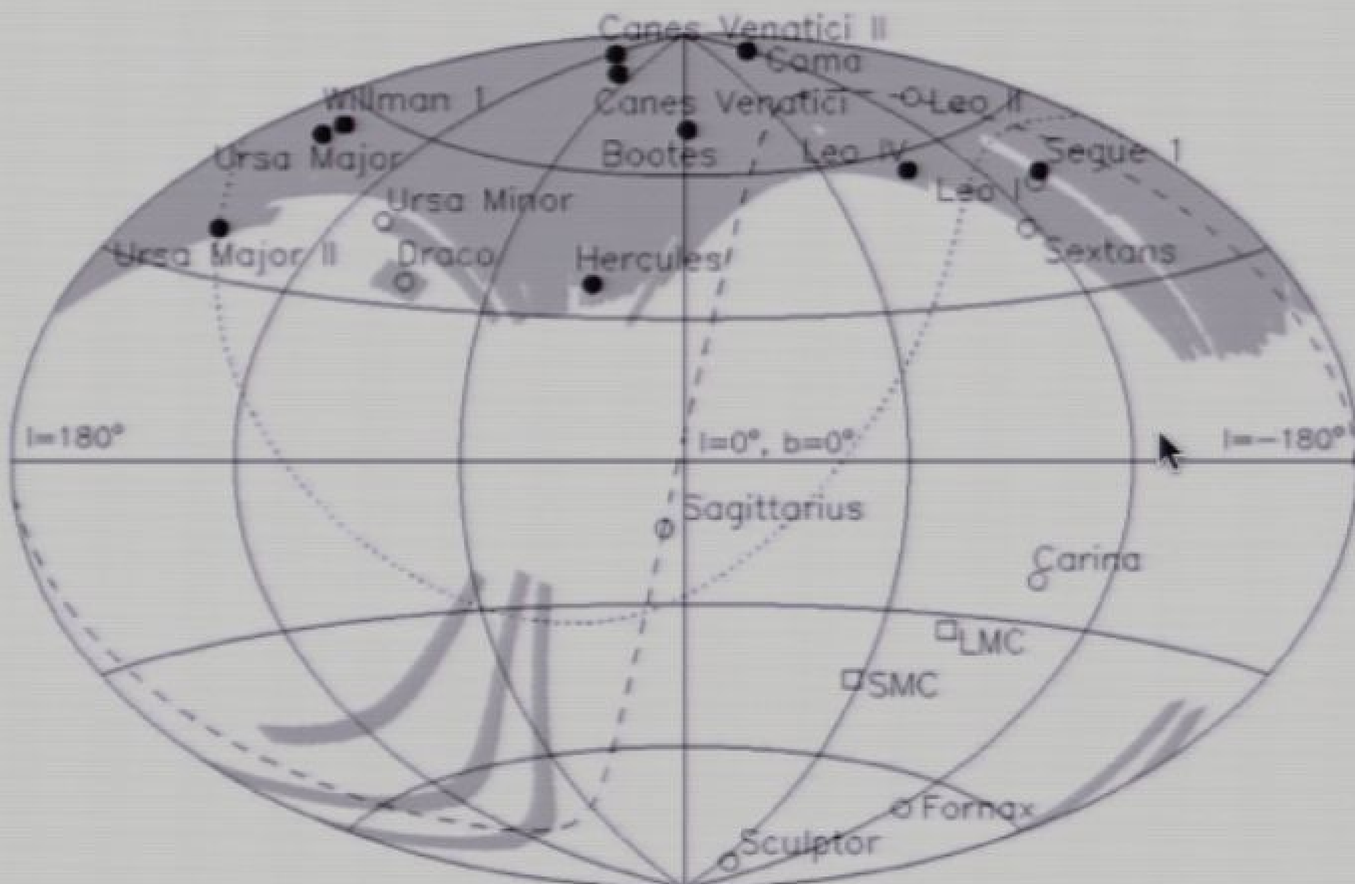
The halo mass function



Maccio & Fontanot 2009

CATS AND DOGS, HAIR AND A HERO: A QUINTET OF NEW MILKY WAY COMPANIONS†

V. Belokurov[1], D. B. Zucker[1], N. W. Evans[1], J. T. Kleyna[2], S. Koposov[3], S. T. Hodgkin[1], M. J. Irwin[1], G. Gilmore[1], M. I. Wilkinson[1], M. Fellhauer[1], D. M. Bramich[1], P. C. Hewett[1], S. Vidrih[1], J. T. A. De Jong[3], J. A. Smith[4,5], H.-W. Rix[3], E. F. Bell[3], R. F. G. Wyse[6], H. J. Newberg[7], P. A. Mayeur[7,8], B. Yanny[9], C. M. Rockosi[10], O. Y. Gnedin[11], D. P. Schneider[12], T. C. Beers[13], J. C. Barentine[14], H. Brewington[14], J. Brinkmann[14], M. Harvanek[14], S. J. Kleinman[15], J. Krzesinski[14,16], D. Long[14], A. Nitta[17], S. A. Snedden[14]



SDSS has substantially increased the number of sattelite galaxies in the Local Group

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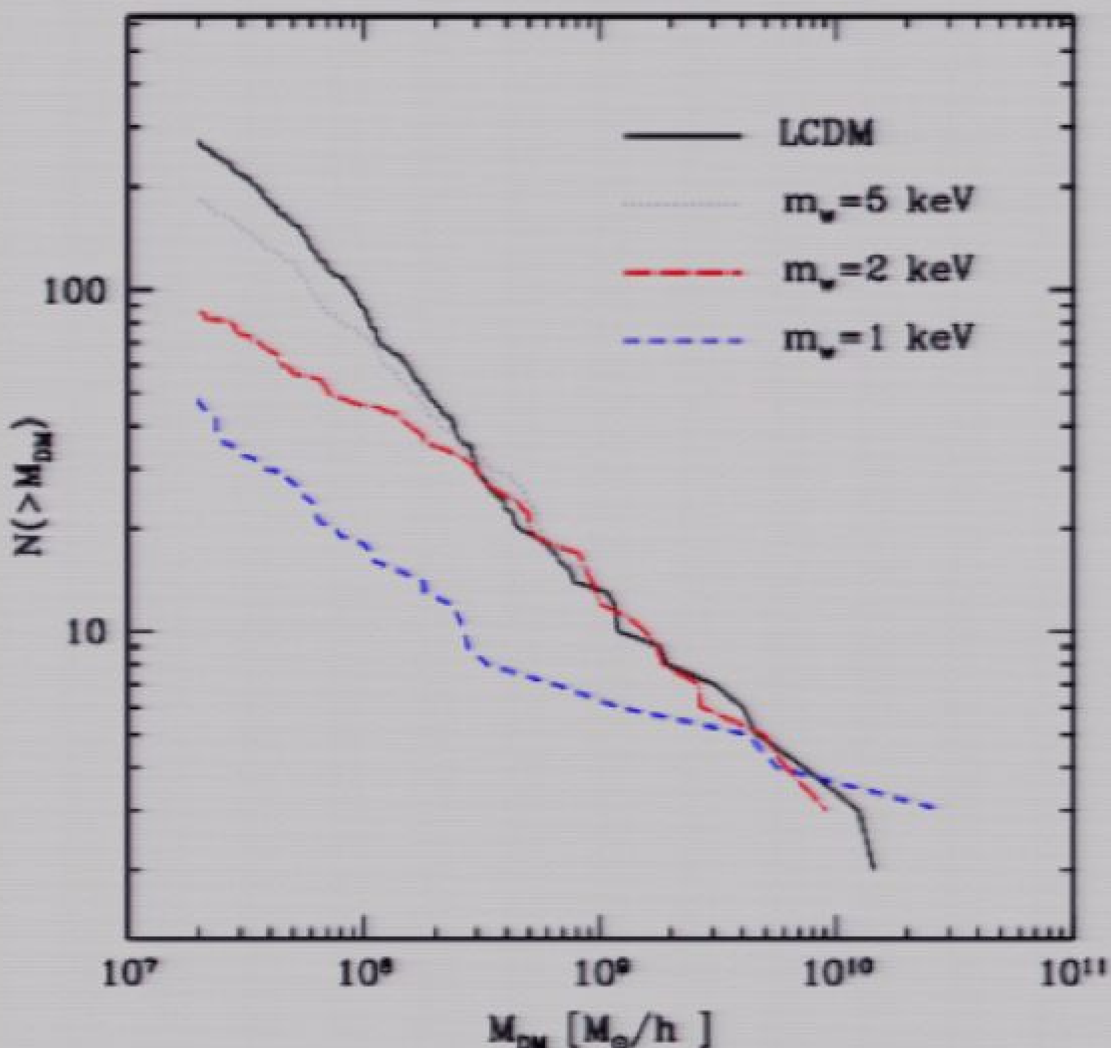
The halo mass function



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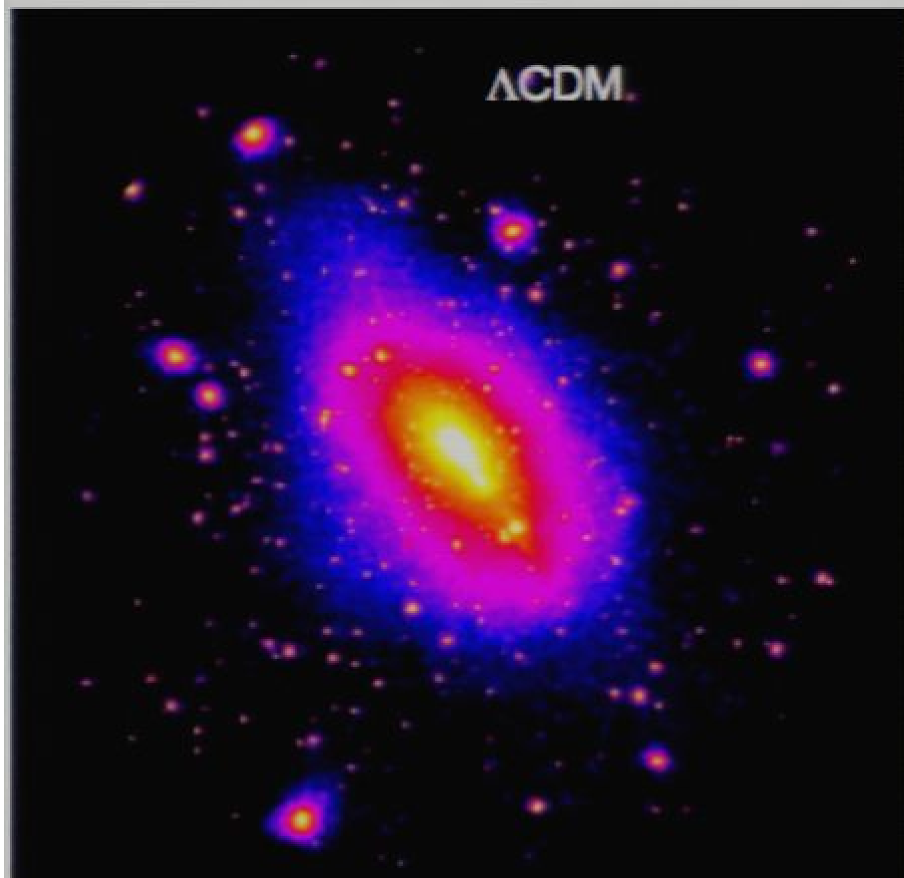
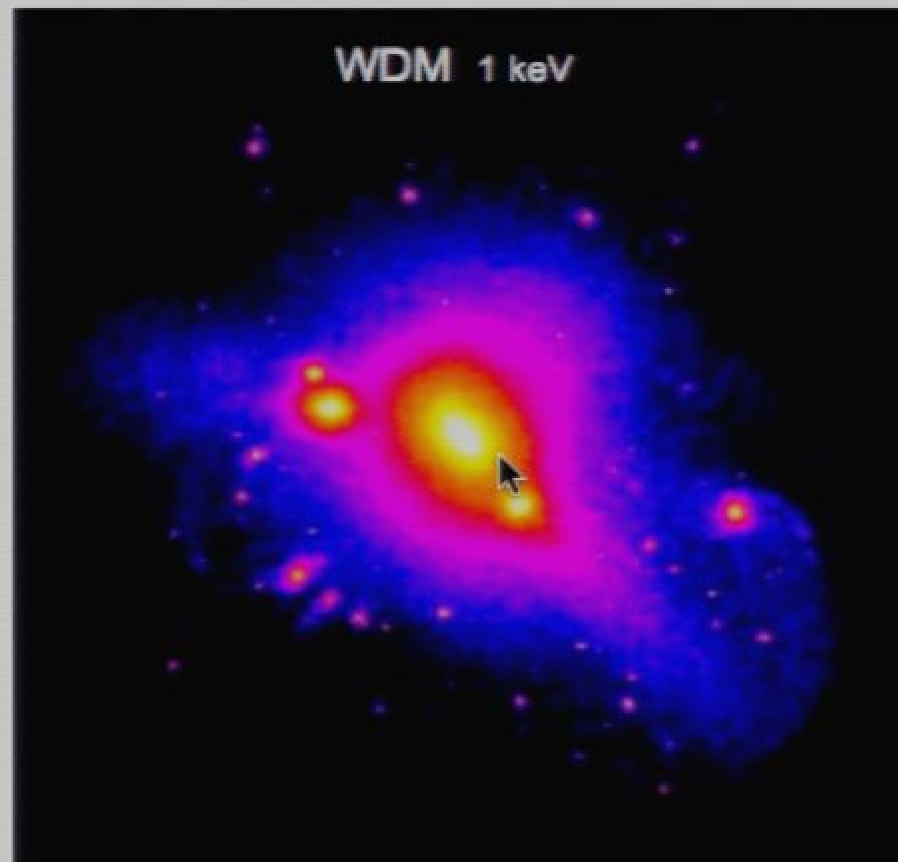
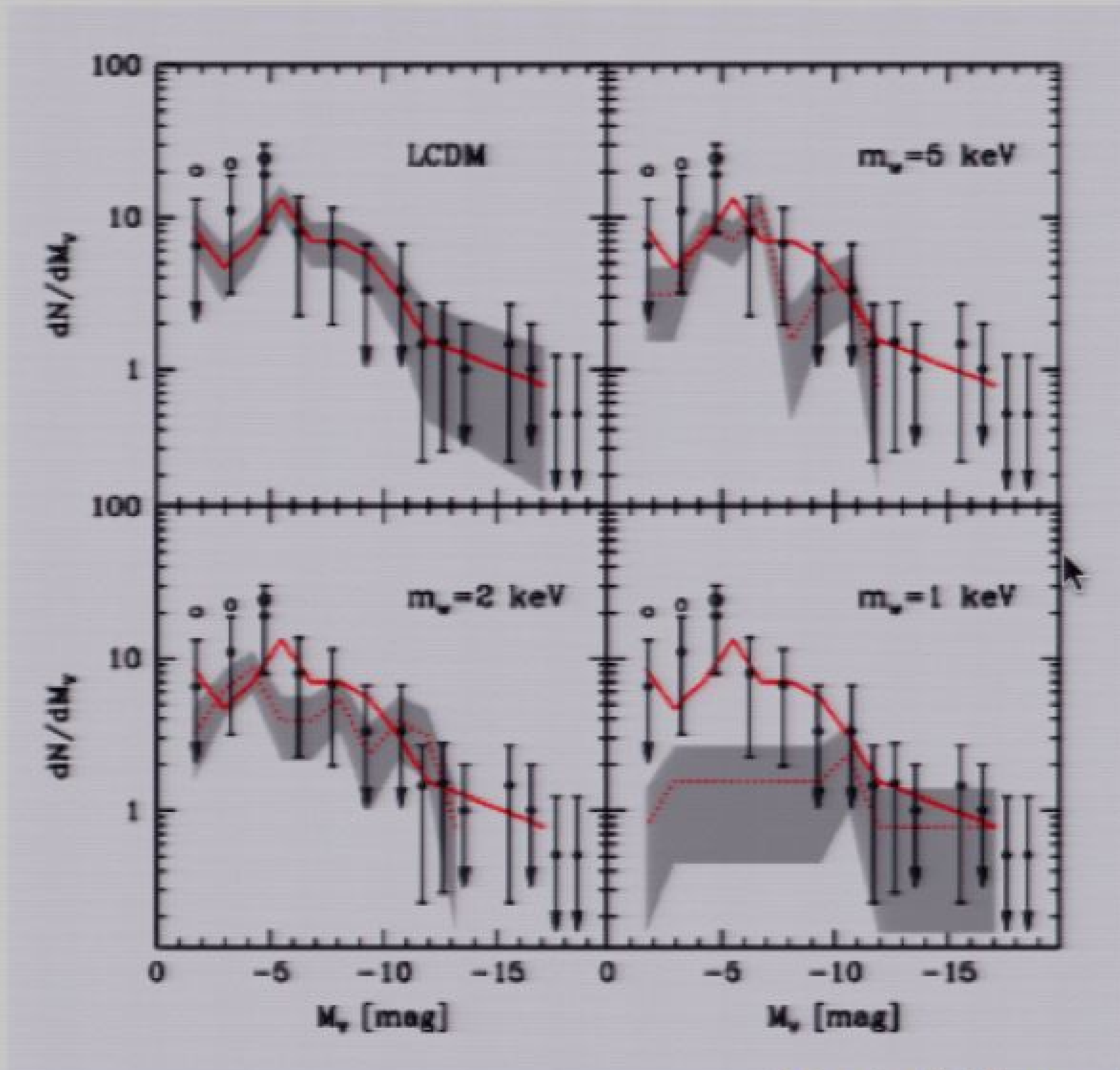
cold dark matter

warm dark matter



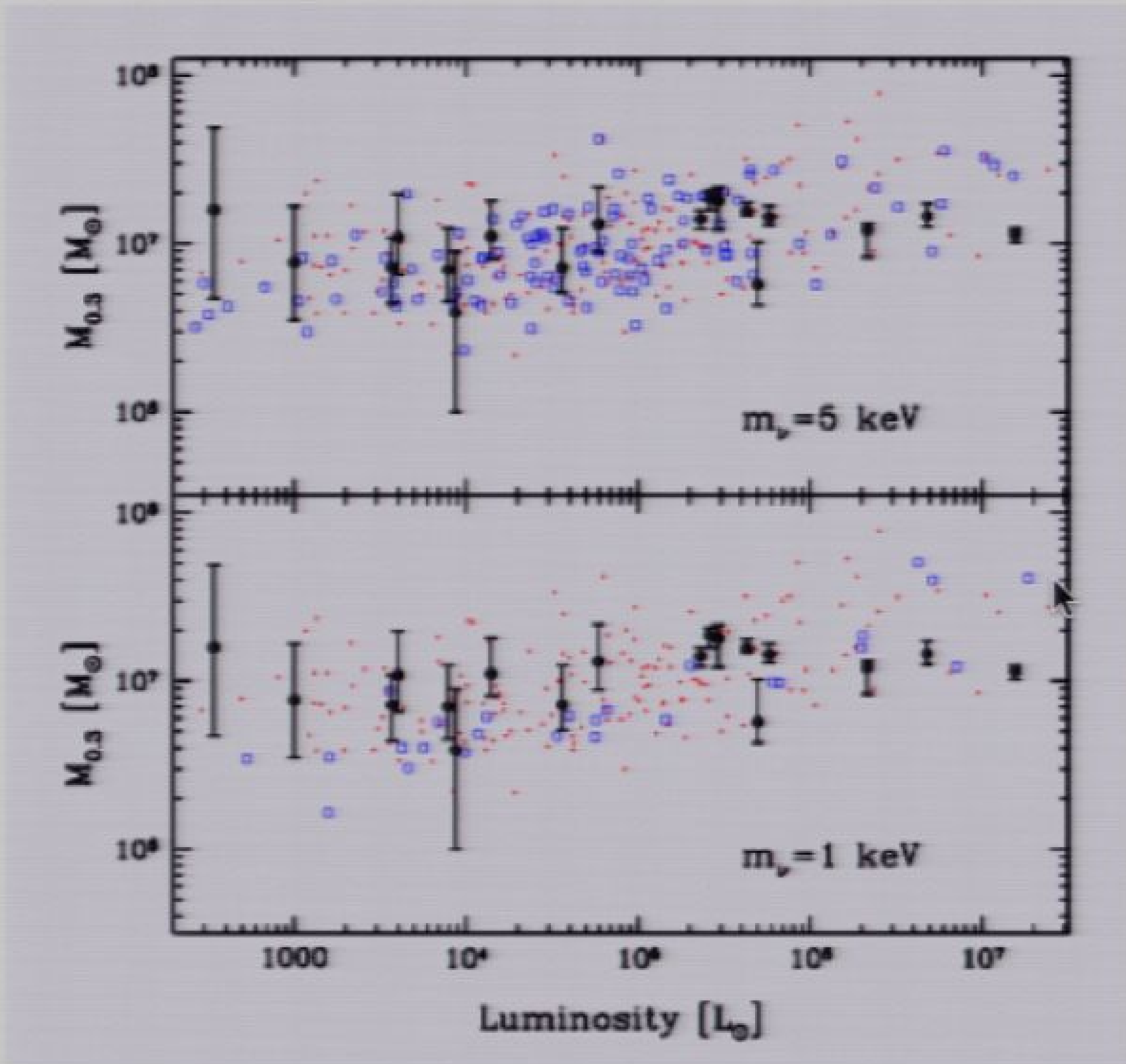


Maccio & Fontanot 2009



Maccio & Fontanot 2009

PI-CITA day, 8 December 2009

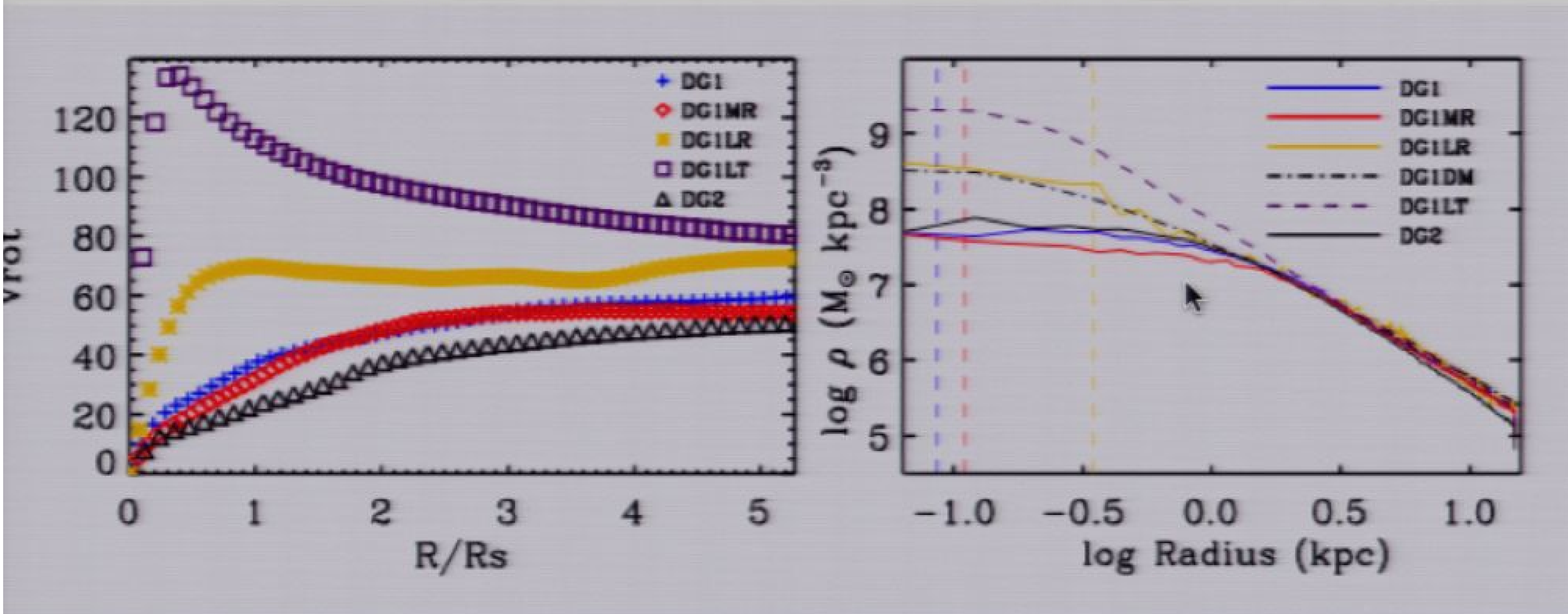


Maccio & Fontanot 2009

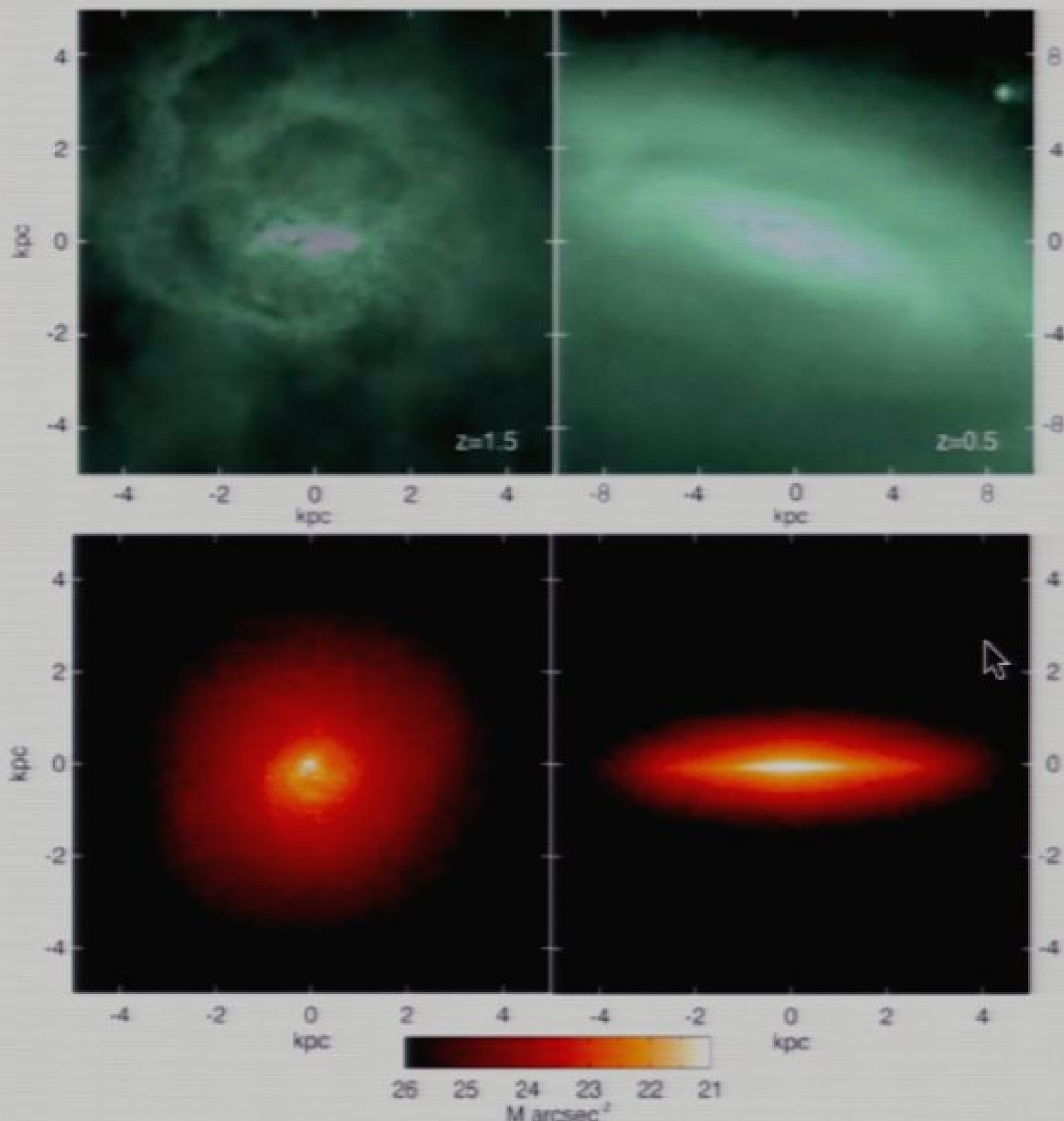
PI-CITA day, 8 December 2009

At the heart of the matter: the origin of bulgeless dwarf galaxies and Dark Matter cores

F. Governato[1], C. Brook[2], L. Mayer[3], A. Brooks[4], G. Rhee[5], J. Wadsley[6], P. Jonsson[7], B. Willman[8], G. Stinson[6], T. Quinn[1] and P. Madau[9]



The inner density profile of dwarf galaxies depends strongly on resolution and the way star formation is implemented.



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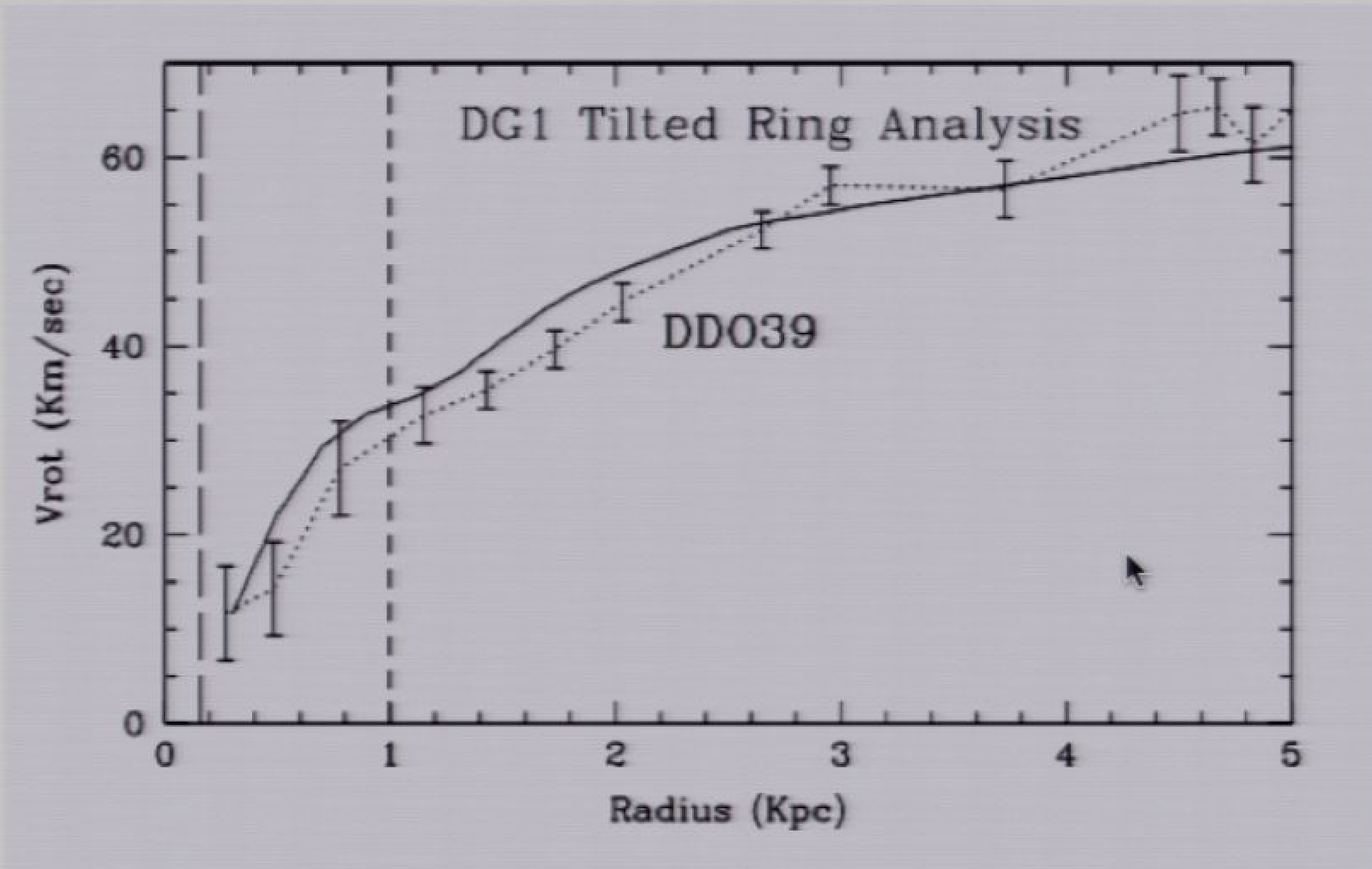
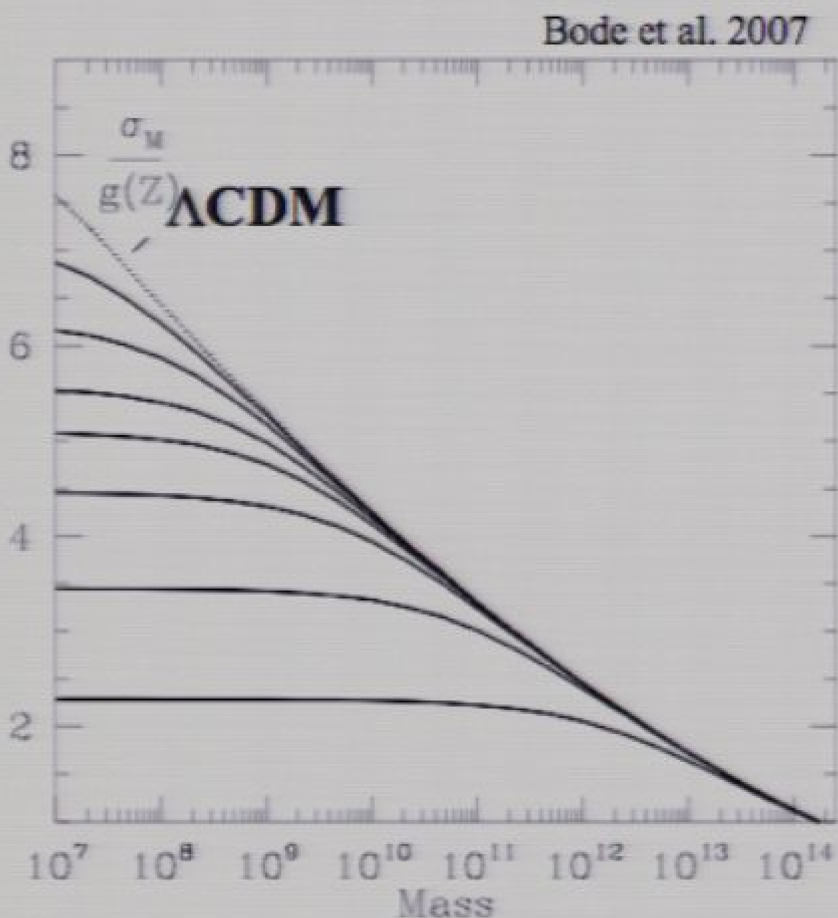


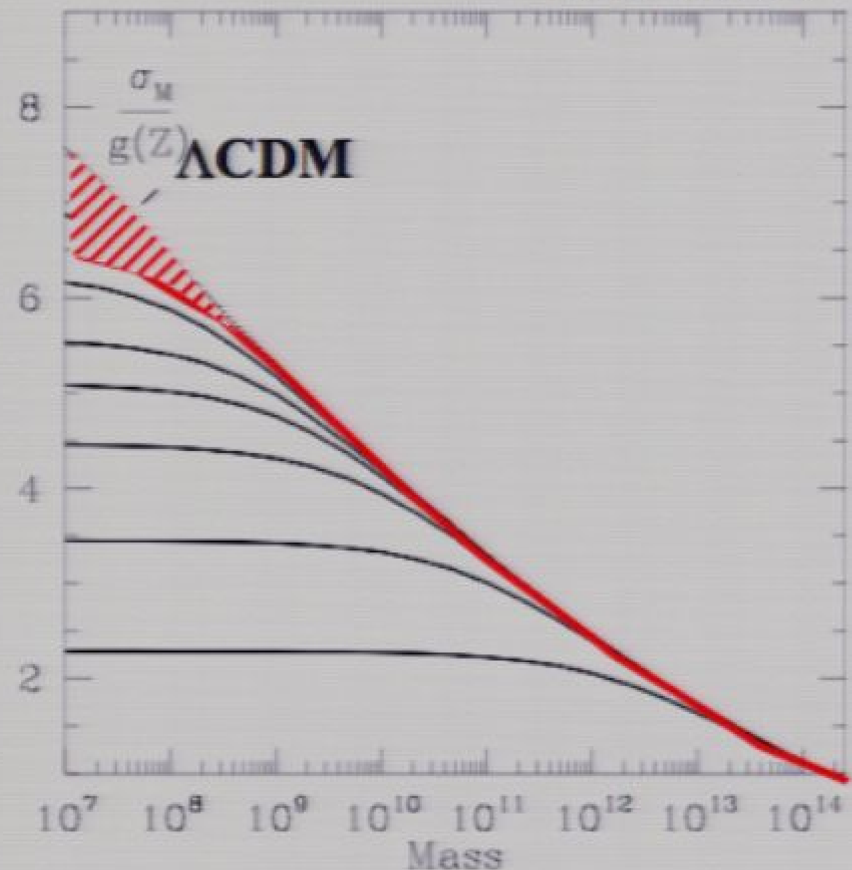
This appears to solve the cuspiness problem of CDM

DM is pretty cold



DM is pretty cold

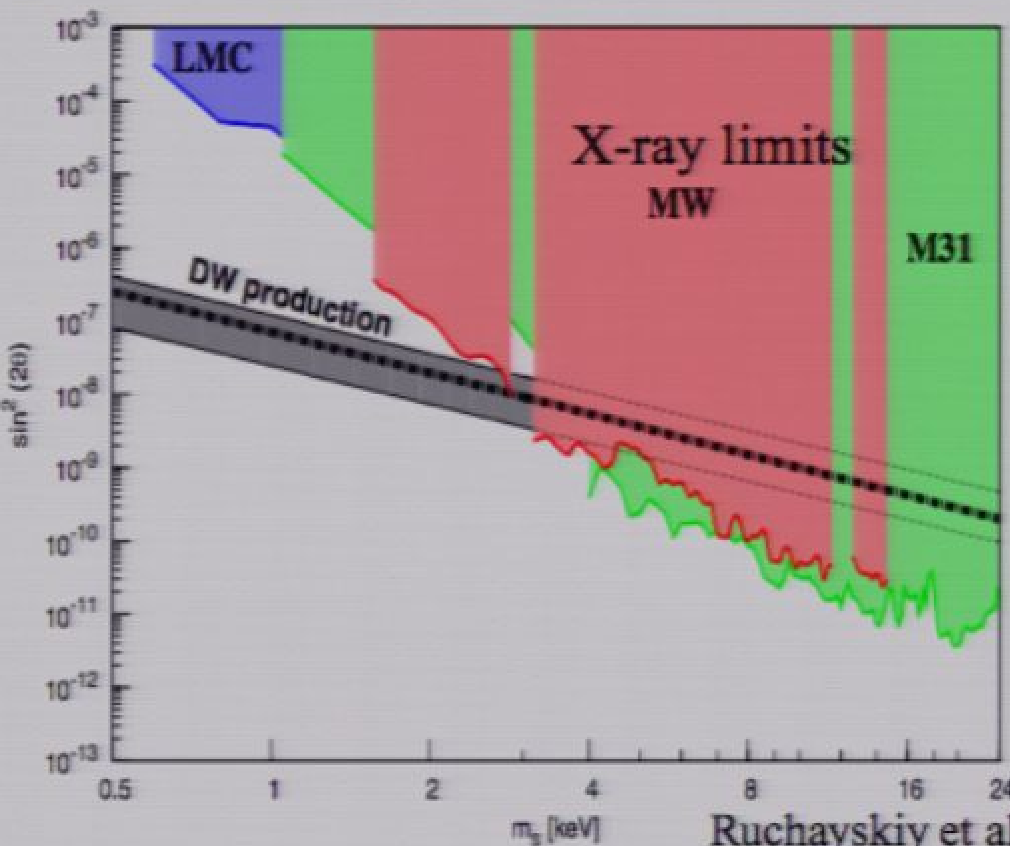
Bode et al. 2007



There is little room left for the effect of warm DM on the DM halo mass function (or DM halo profiles).

Our best bet to push this further is probably looking at neutral hydrogen before reionization with 21cm emission.

Limits for sterile neutrinos produced by the Dodelson-Widrow (DW) mechanism



Ruchayskiy et al.

Our Lyα limit translates into M_S>28 keV and completely closes the window for DM made up by sterile neutrinos produced by the DW mechanism. For νMSM the free-streaming and therefore the limits depend on the uncertain production mechanism.

arXiv:0912.0552v1 [astro-ph.HE] 3 Dec 2009

Dark Matter Search Using *Chandra* Observations of Willman 1, and a Spectral Feature Consistent with a Decay Line of a 5 keV Sterile Neutrino

Michael Loewenstein[1,2], Alexander Kusenko[3,4]

ABSTRACT

We report the results of a search for an emission line from radiatively decaying dark matter in the *Chandra* X-ray Observatory spectrum of the ultra-faint dwarf spheroidal galaxy Willman 1. 99% confidence line flux upper limits over the 0.4-7 keV *Chandra* bandpass are derived and mapped to an allowed region in the sterile neutrino mass-mixing angle plane that is consistent with recent constraints from *Suzaku* X-ray Observatory and *Chandra* observations of the Ursa Minor and Draco dwarf spheroidals. A significant excess to the continuum, detected by fitting the particle-background-subtracted source spectrum, indicates the presence of a narrow emission feature with energy $2.51 \pm 0.07(0.11)$ keV and flux $[3.53 \pm 1.95(2.77)] \times 10^{-6}$ photons cm^{-2} s^{-1} at 68% (90%) confidence. Interpreting this as an emission line from sterile neutrino radiative decay, we derive the corresponding allowed range of sterile neutrino mass and mixing angle using two approaches. The first assumes that dark matter is solely composed of sterile neutrinos, and the second relaxes that requirement. The detection is consistent with the sterile neutrino mass of 5.0 ± 0.2 keV and a mixing angle in a narrow range for which neutrino oscillations can produce all of the dark matter and for which sterile neutrino emission from the cooling neutron stars can explain pulsar kicks, thus bolstering both the statistical and physical significance of our measurement.

PI-CITA day, 8 December 2009

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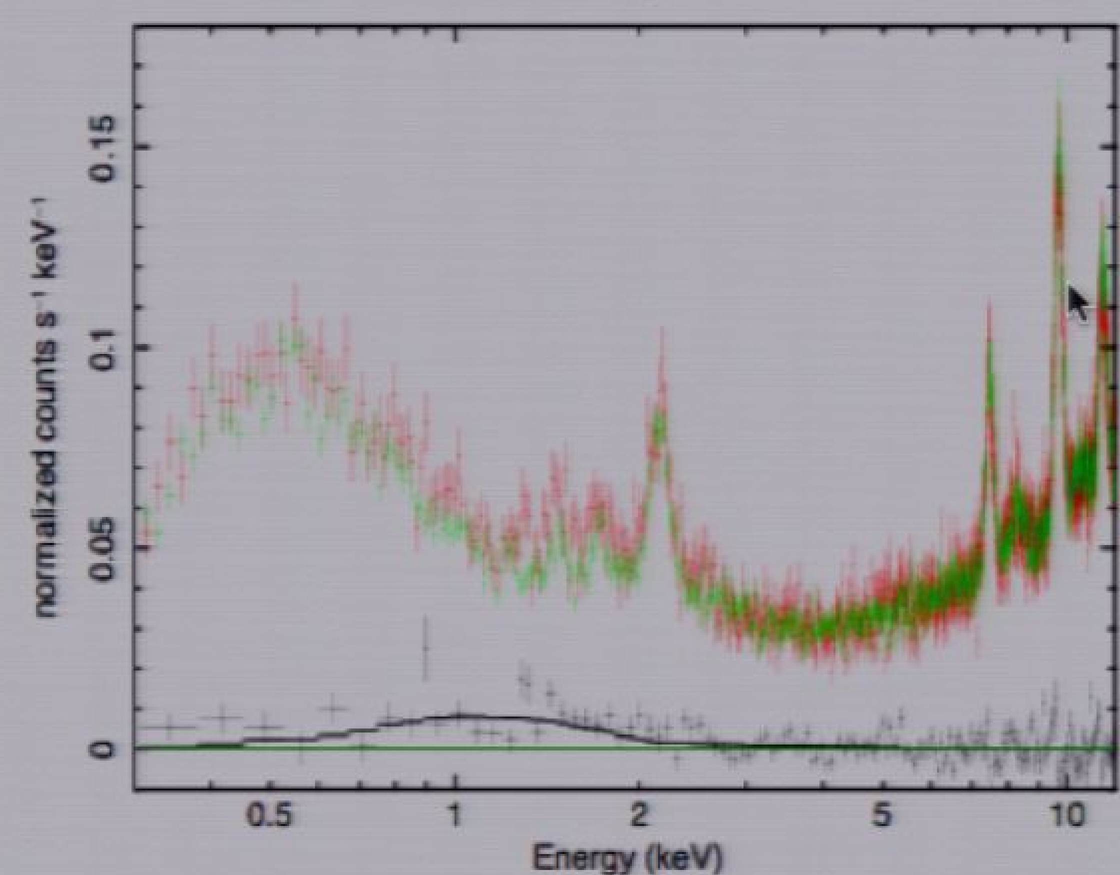

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Masses of active neutrinos

Cosmological redshift drift

$$ds^2 = c^2 dt^2 - R^2(t)\left[\frac{dr^2}{1-kr^2} + r^2(d\Theta^2 + \sin^2\Theta\, d\Phi^2)\right]$$

$$1 + z = \frac{R(t_0)}{R(t_e)}$$

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Measuring $\dot{z}$

$$dz = \frac{\partial z}{\partial t_0} dt_0 + \frac{\partial z}{\partial t_e} dt_e$$

$$\dot{z} = \frac{dz}{dt_0} = \frac{\partial z}{\partial t_0} + \frac{\partial z}{\partial t_e}\frac{dt_e}{dt_0} = \frac{\dot{a}(t_0)}{a(t_e)} - \frac{\dot{a}(t_e)}{a(t_e)}\frac{a(t_0)}{a(t_e)}\frac{1}{1+z}$$

$$\dot{z} = (1+z)H_0 - H(t_e).$$

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$$\dot{z} = (1+z)\; H_0 - \; H(t_e)$$

"It should be possible to choose between various models of the expanding universe if the deceleration of a given galaxy could be measured. Precise predictions of the expected change in $z=d\lambda/\lambda_0$ for reasonable observing

times (say 100 years) is exceedingly small. Nevertheless, the predictions are interesting, since they form part of the available theory for the evolution of the universe"

Sandage 1962 ApJ 136,319

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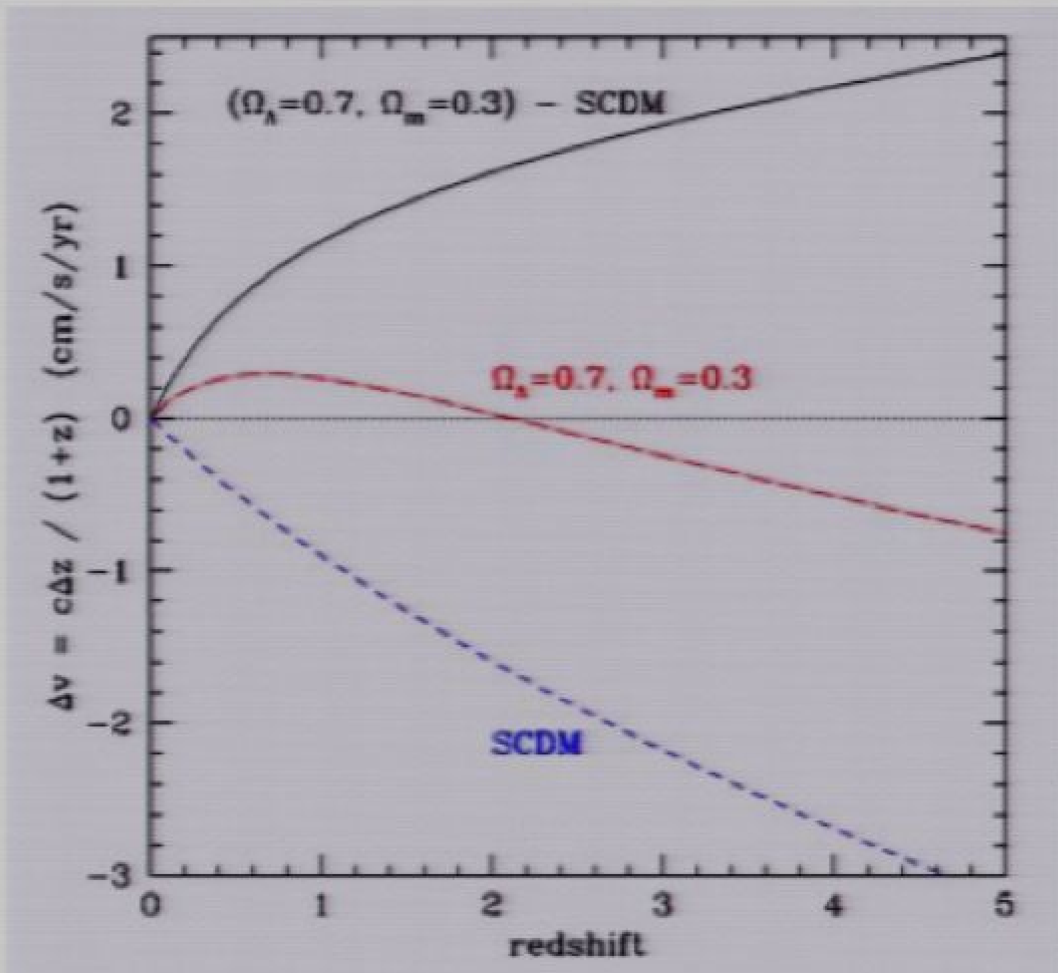
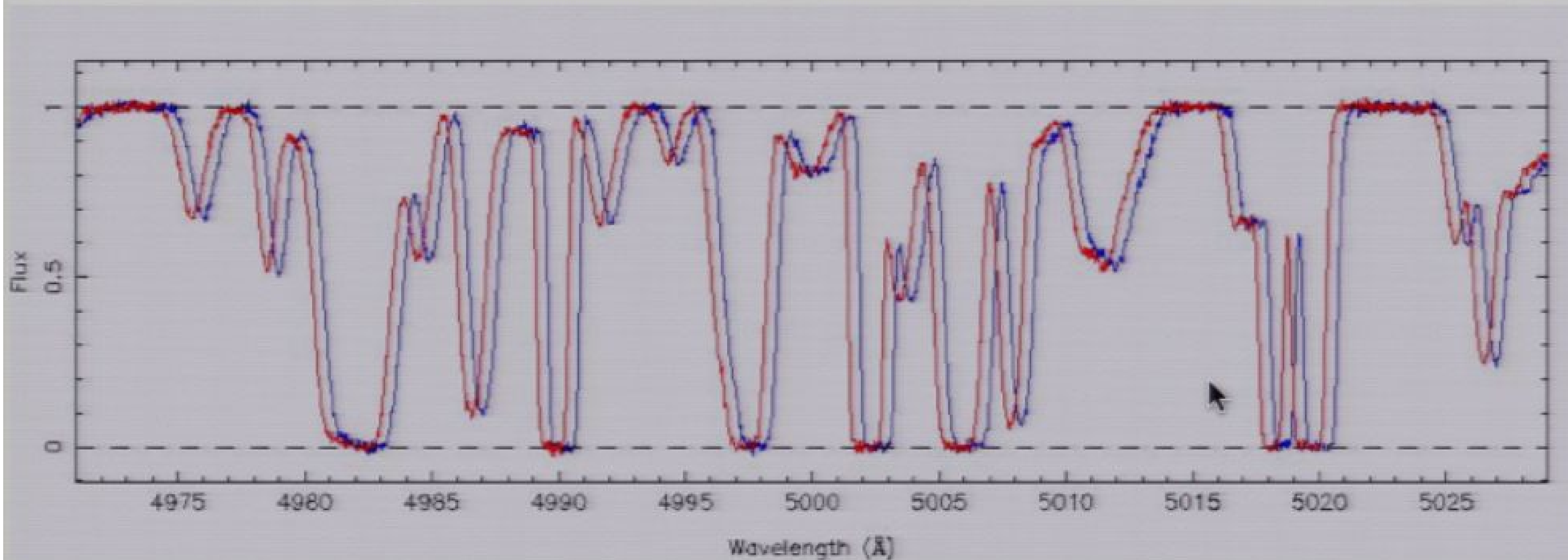


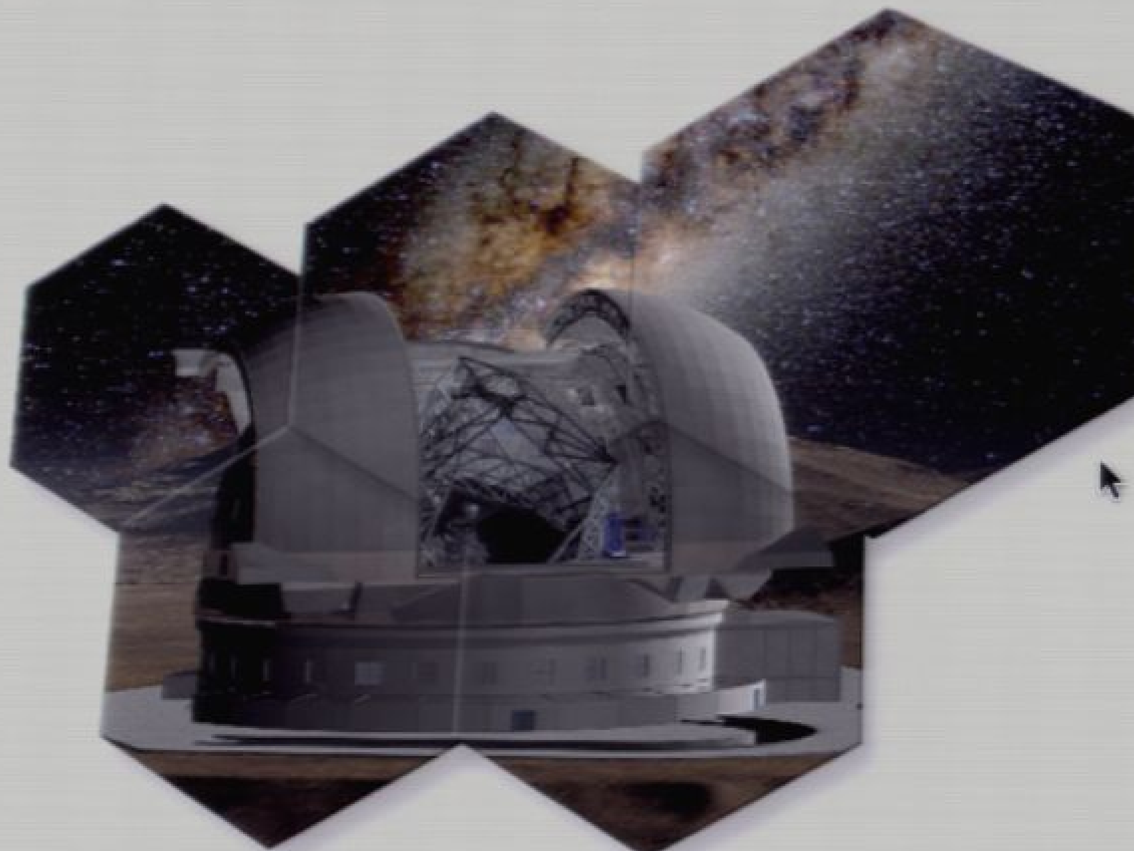
The signal is small!

The Lyα forest is the best bet



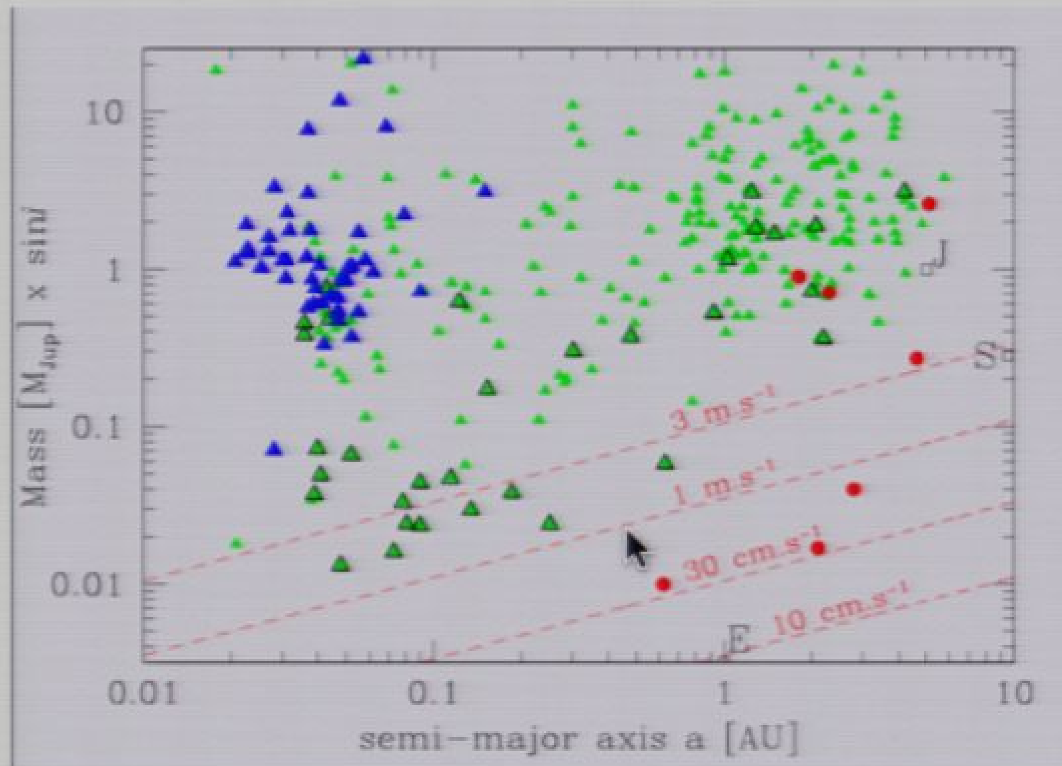
But this is for 10^7 years… Having somewhat less time at our disposal the shift is much smaller..

The E-ELT

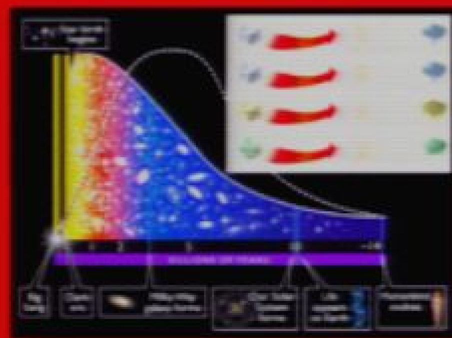


The HARPS experience

The HARPS Spectrograph and the 3.6m Telescope



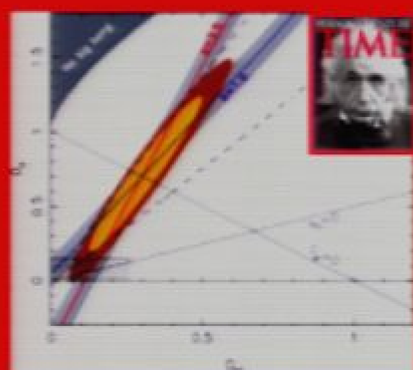
The number of known exoplanets approaches 300.

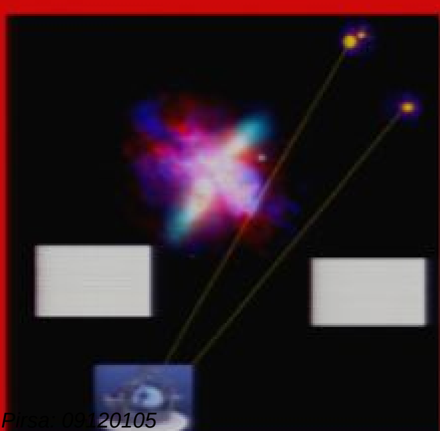


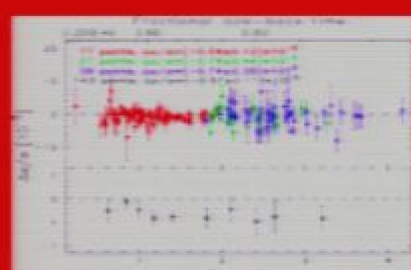
The science case for

CODEX

an ultra-stable high-resolution spectrograph for the E-ELT

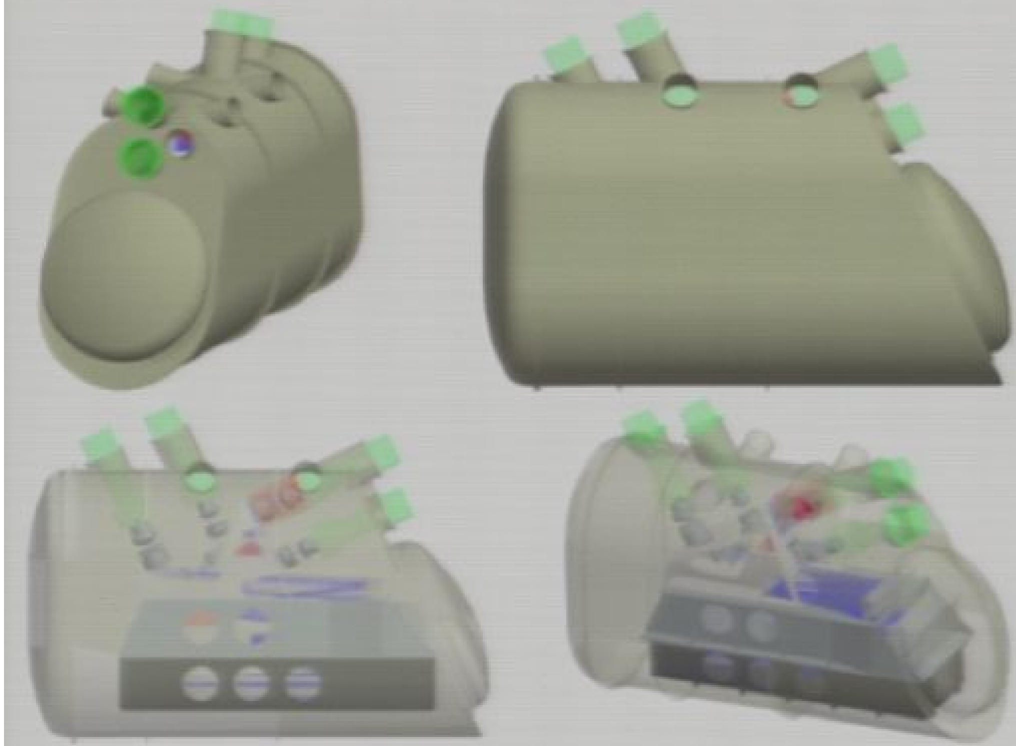






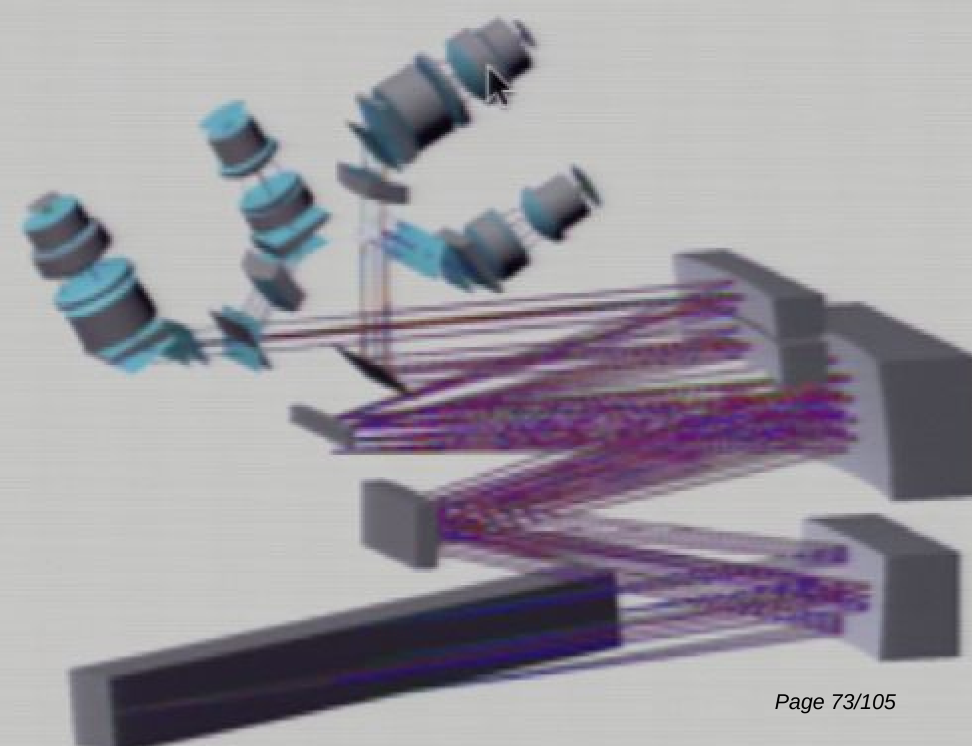
Show Cases

1. Cosmological redshift drift
2. Detecting Earth twins
3. Radioactive dating of stars in the Milky Way
4. Metals in the low-density IGM
5. Stability of fundamental constants



CODEX

Preliminary Design



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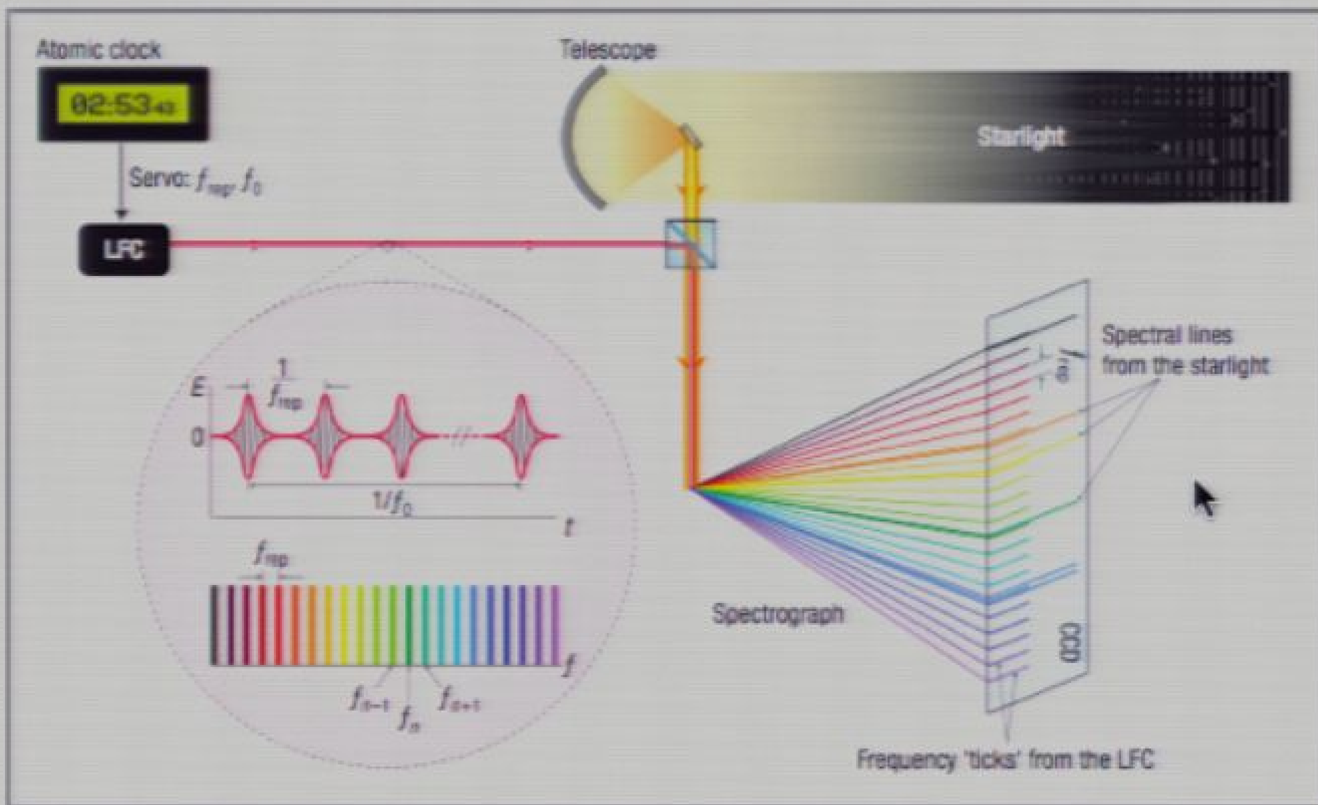
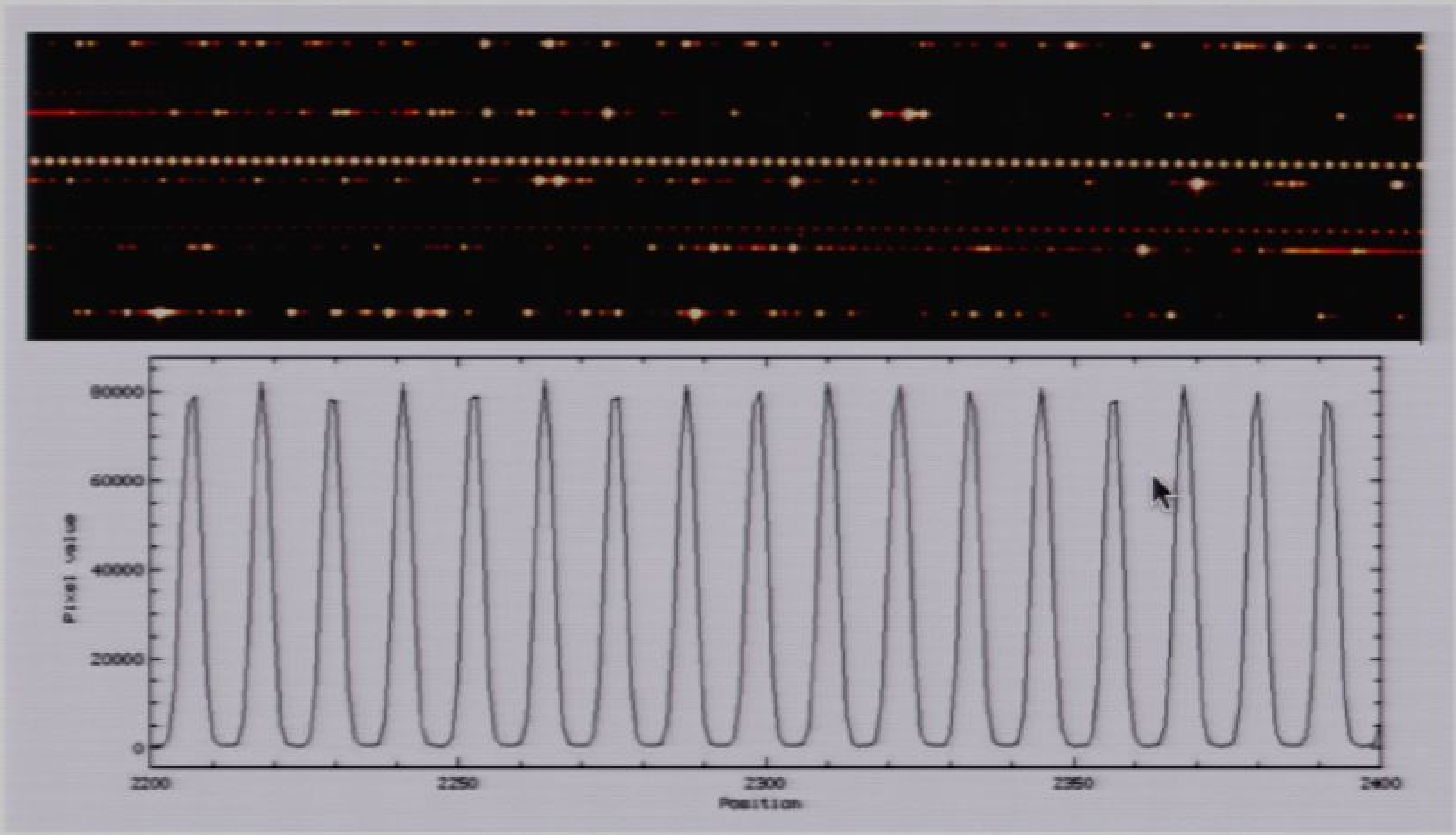
cm/s precision



The Laser Frequency Comb - Introducing an absolute and reproducible calibration standard into astrophysical spectroscopy.

And it works



Successful implementation at HARPS

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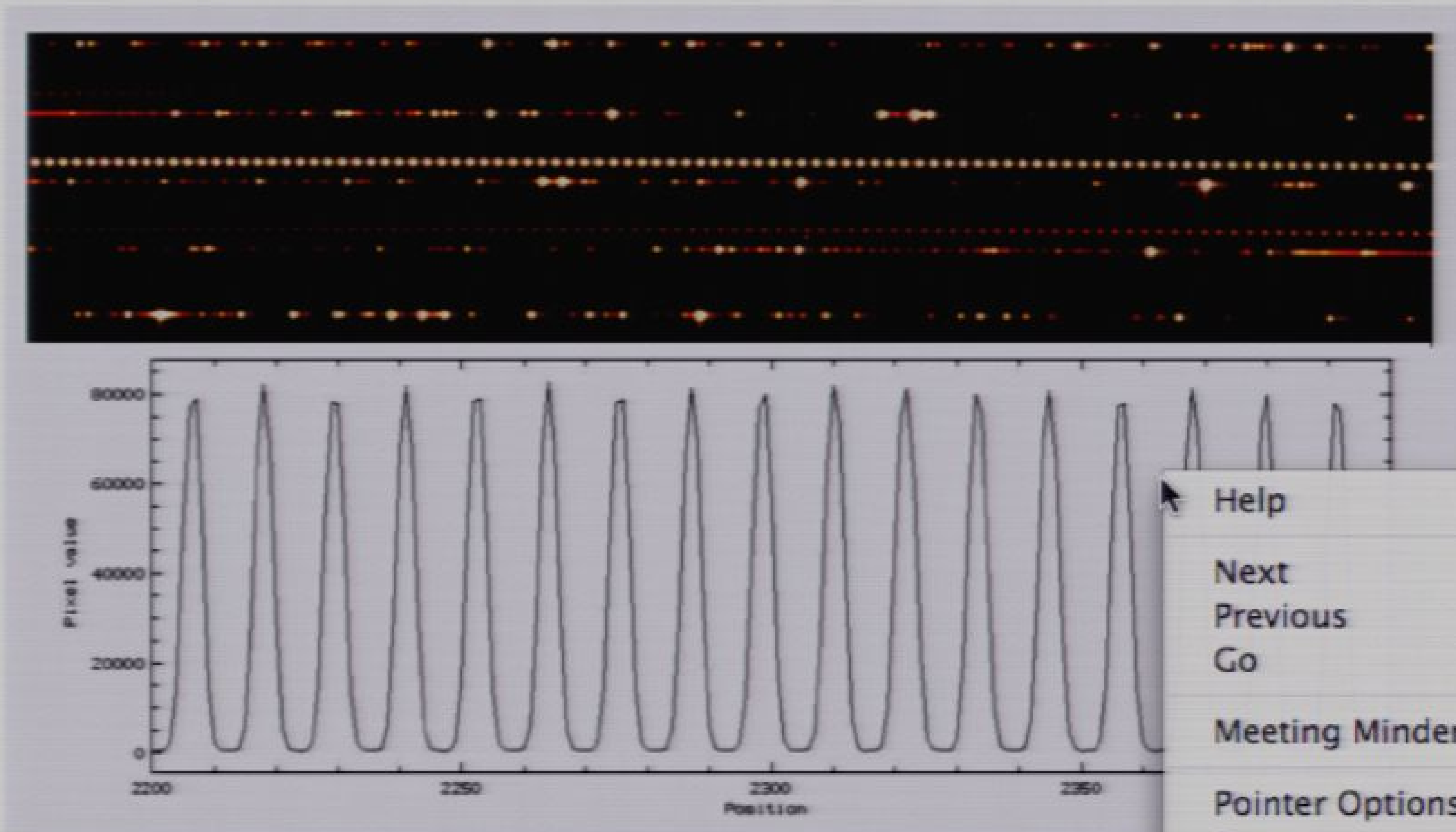
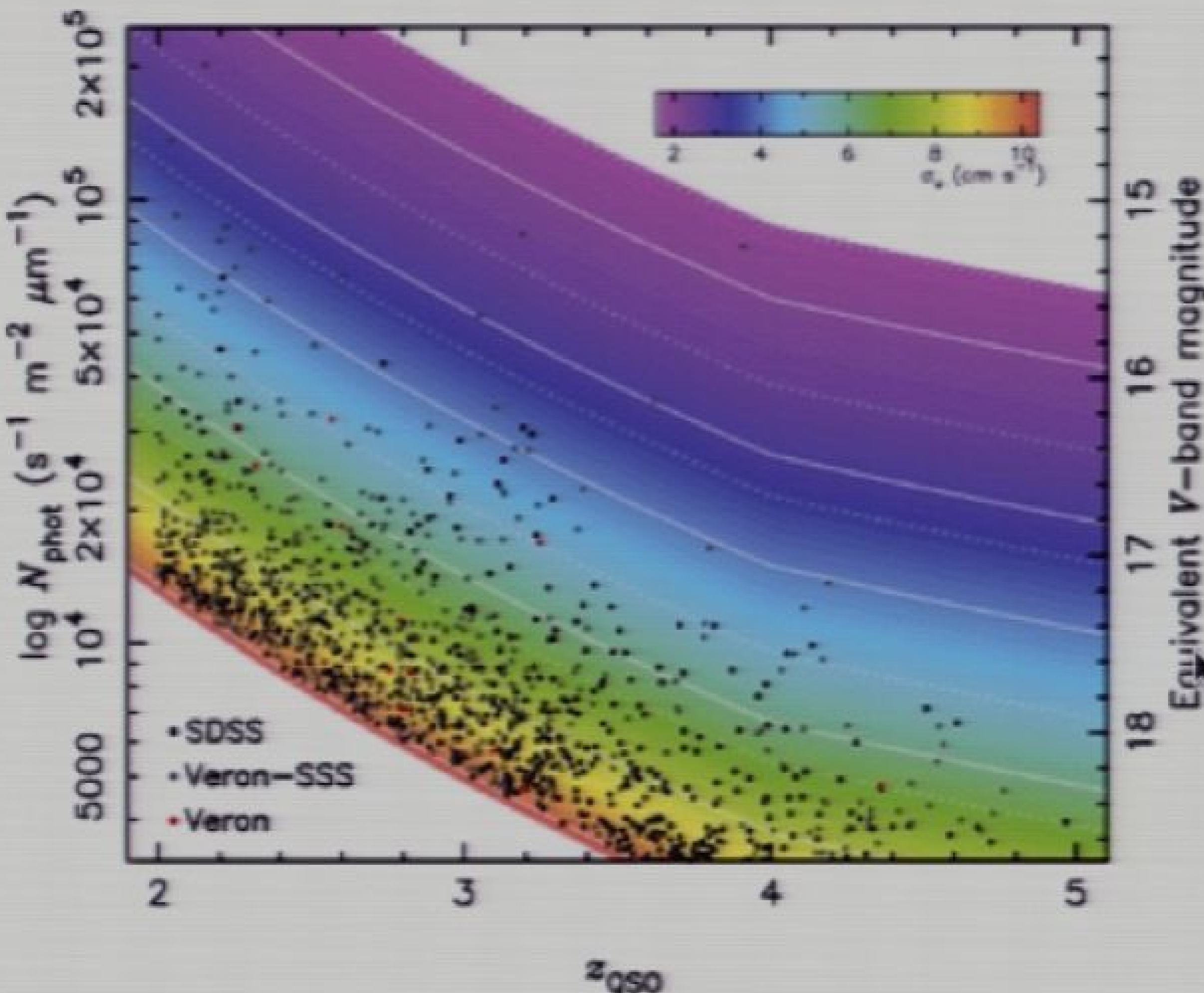
And it works



Successful implementation at HARPS

Help
Next
Previous
Go
Meeting Minder...
Pointer Options
Screen
End Show



The expected velocity accuracy for known QSOs.

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Design Reference Mission Proposal

1. Title — Category: **A–8**

Monitoring the redshift-drift of the Lyman-alpha forest – a direct measurement of the dynamical evolution of the Universe

2. Abstract / Total Time Requested

Total Amount of Time: 3660h — Total Number of Semesters: 30

We propose to monitor the redshift drift of the Lyα forest and associated metal lines of a sample of high (1000-3300) S/N spectra of 30 very bright QSOs in the redshift range $2 < z < 4.5$ with the ultra-stable high resolution optical spectrograph on the E-ELT for a period of 15 yrs. The redshift drift is sensitive to the difference of the expansion rate today and the expansion rate at the redshift of the absorbing structures and is directly related to the acceleration of the Universe. With the proposed observations we can achieve an overall measurement accuracy of 3.2 cm/s. By monitoring the drift of the Lyα forest over a wide redshift range we will measure the instantaneous expansion rate of the Universe today and the expansion rate at high redshift. The measurement of the expansion rate and its evolution at high redshift will be an important test of General Relativity. The measurement of the instanteneous expansion rate will test whether the Universe expands today at the rate expected from other astronomical measurements which generally constitute measurements of the expansion rate averaged over hundred Myrs or more. The observations proposed can be used as a first epoch measurement for more accurate measurements by future generation of astronomers and will thus leave a long lasting legacy. The acquired spectra will represent a unique resource for a wide range of QSO absorption line studies.

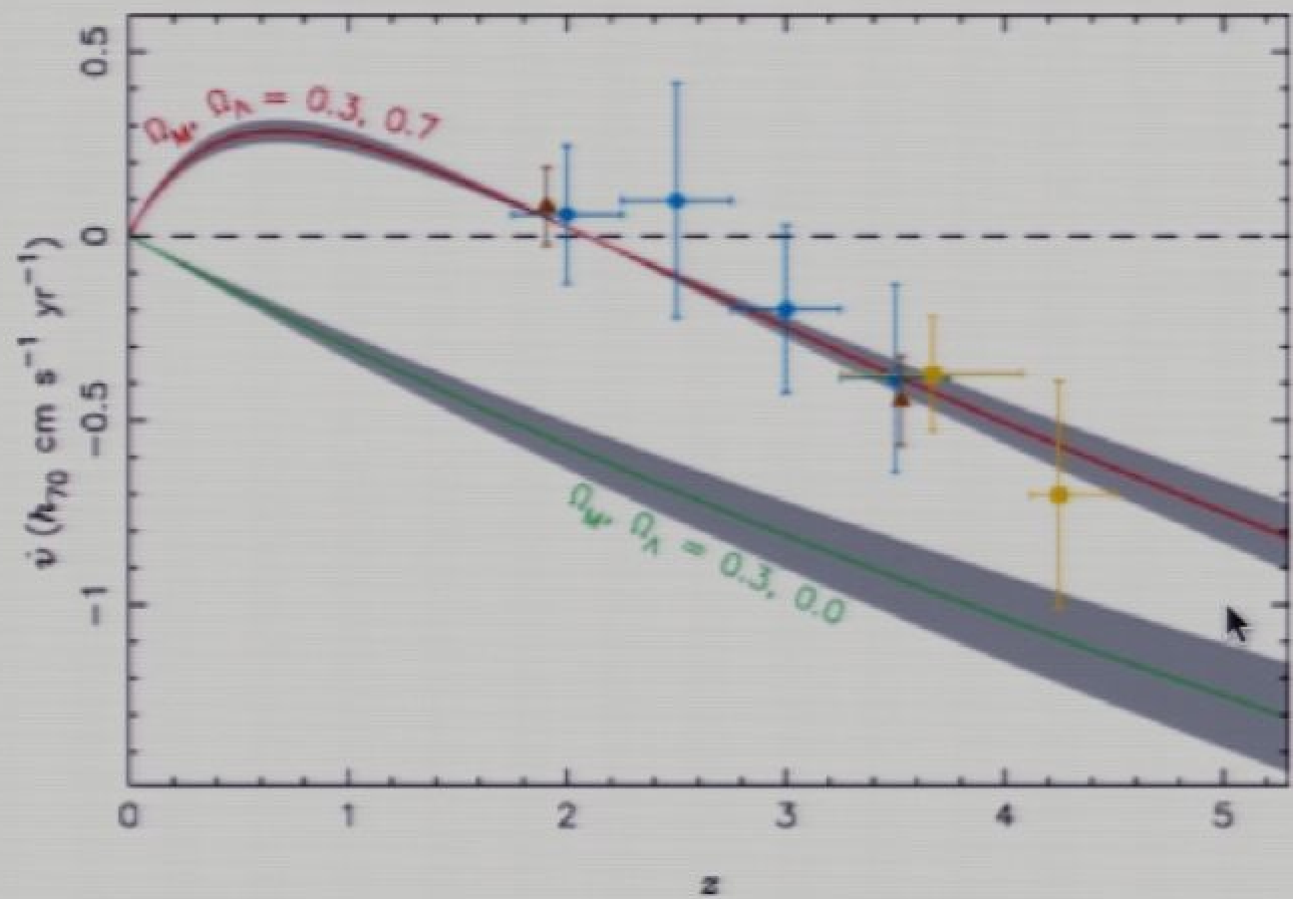
3.

Run	Period	Instrument	Time	Month	Moon	Seeing	Sky Trans.	Obs.Mode
A	80	UVES	122h	any	d	$\leq 0.8''$	PHO	s
B	81	UVES	122h	any	d	$\leq 0.8''$	PHO	s
C	82	UVES	122h	any	d	$\leq 0.8''$	PHO	s
D	83	UVES	122h	any	d	$\leq 0.8''$	PHO	s
E	83	UVES	122h	any	d	$\leq 0.8''$	PHO	s
F	83	UVES	122h	any	d	$\leq 0.8''$	PHO	s
G	83	UVES	122h	any	d	$\leq 0.8''$	PHO	s
H	83	UVES	122h	any	d	$\leq 0.8''$	PHO	s
I	83	UVES	122h	any	d	$\leq 0.8''$	PHO	s
J	83	UVES	122h	any	d	$\leq 0.8''$	PHO	s
K	83	UVES	122h	any	d	$\leq 0.8''$	PHO	s
L	83	UVES	122h	any	d	$\leq 0.8''$	PHO	s

Following runs moved to box 3a, last page...

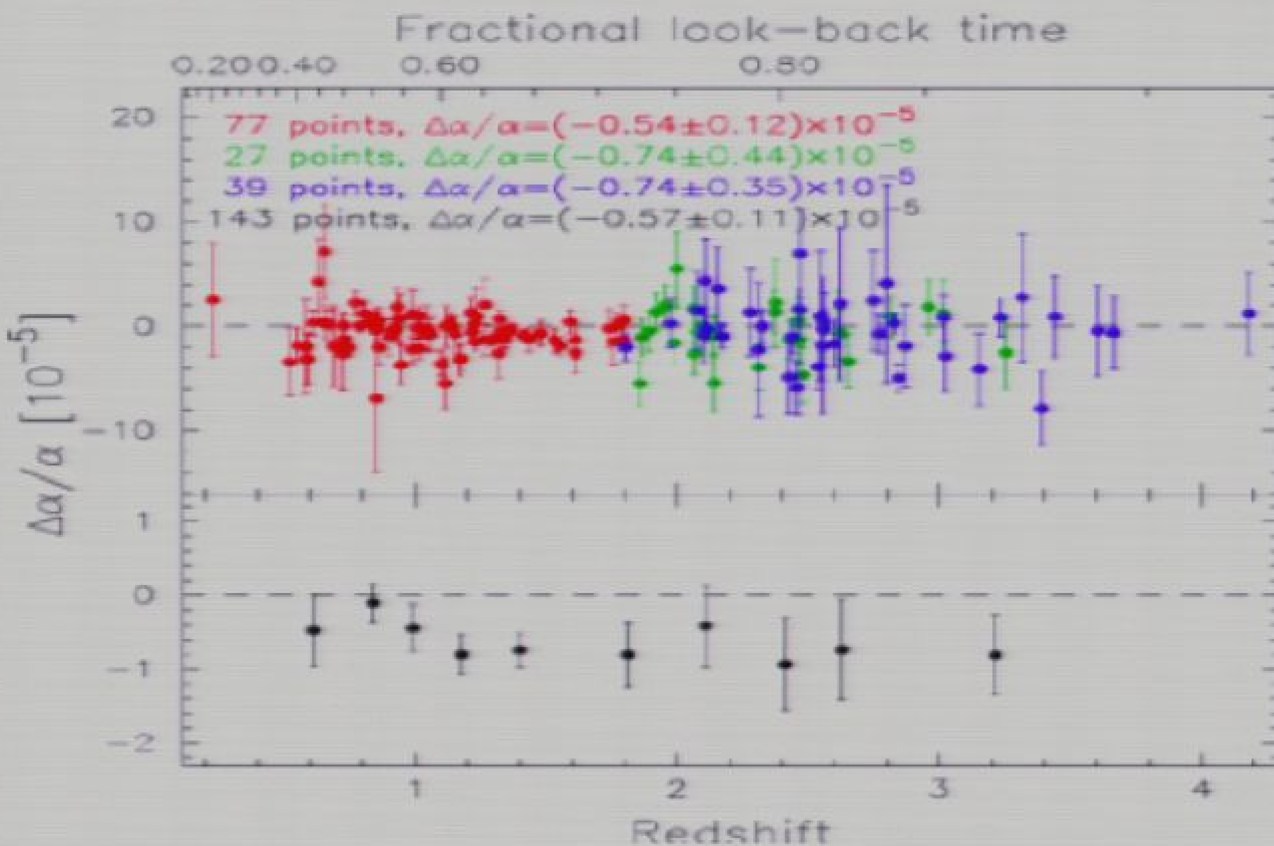
4. Principal Investigator: L. Pasquini (ESO, D, lpasquin@eso.org)

Col(s): M. Haehnelt (IoA, UK), on behalf of the CODEX team (OTHER, OTHER), and the ESO-ELT SWG (OTHER, OTHER)



This is what we can expect for a realistic observing campaign.

Stability of fundamental constants



Wavelength calibration?

Murphy et al. 2004

$$\frac{\Delta\alpha}{\alpha} = (-5.7 \pm 1.1) \times 10^{-6} \ ?$$

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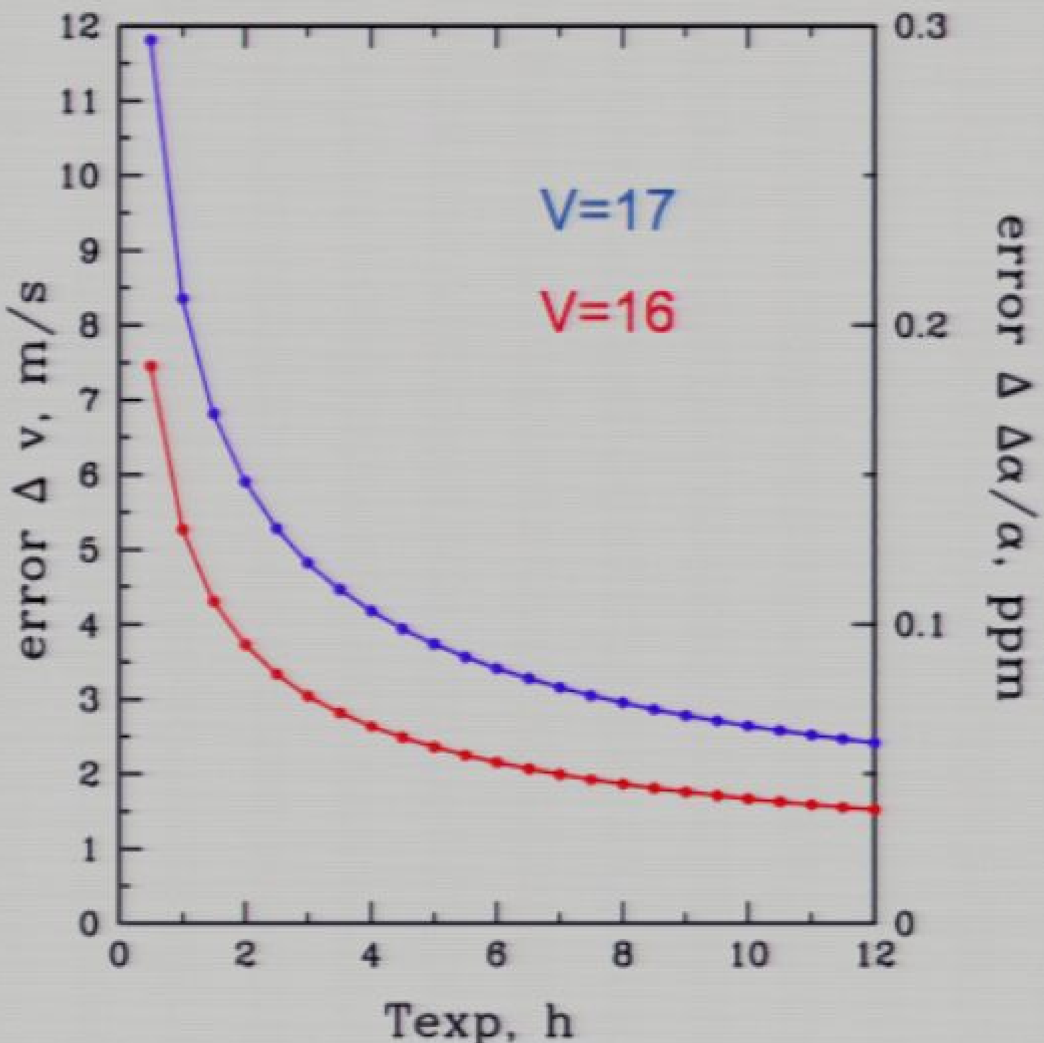
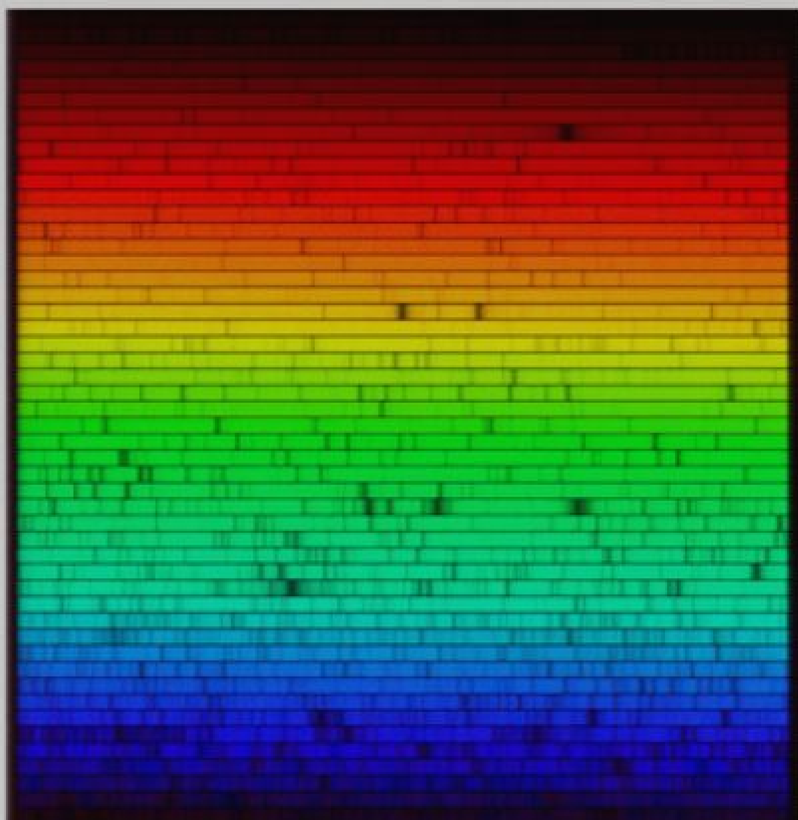


With Codex the errors will be photon-noise limited and the limits will improve by two orders of magnitude or more.

Be prepared for the unexpected



$$i\hbar\frac{\partial}{\partial t}\Psi(\mathbf{r}, t) = \hat{H}\Psi(\mathbf{r}, t)$$

The development of quantum mechanics built on astrophysical spectroscopy.

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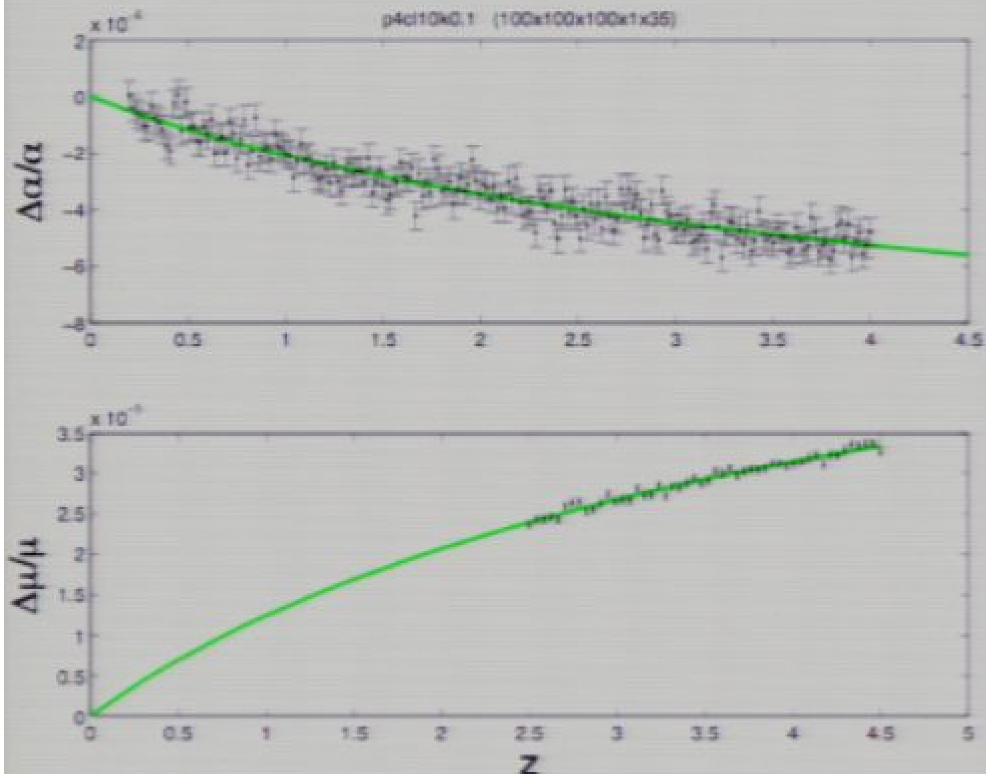
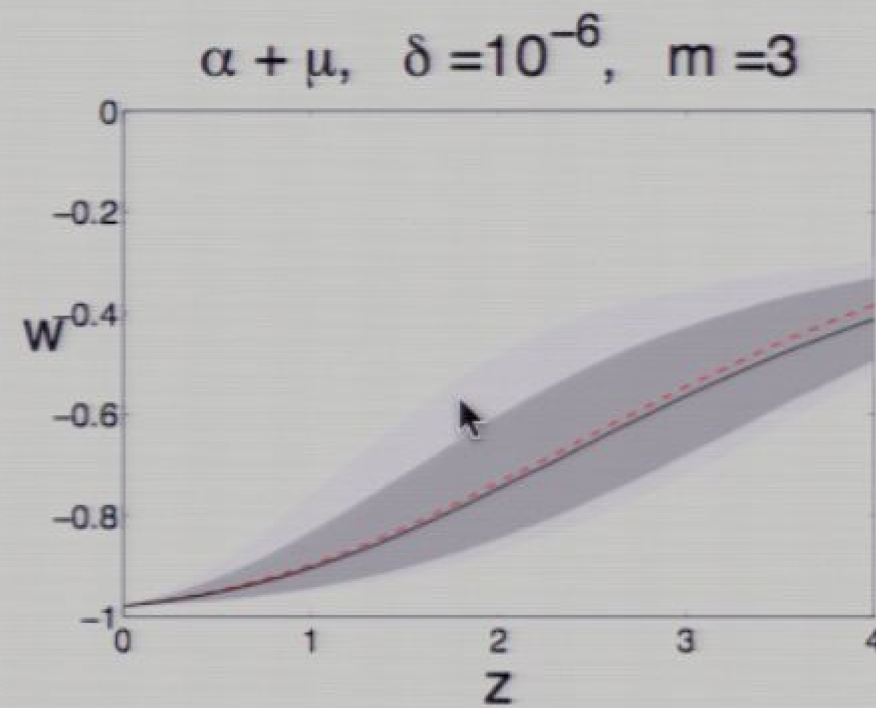
Perhaps the dark energy couples to electro-magnetic fields?





Avelino et al. 2006, Nunes

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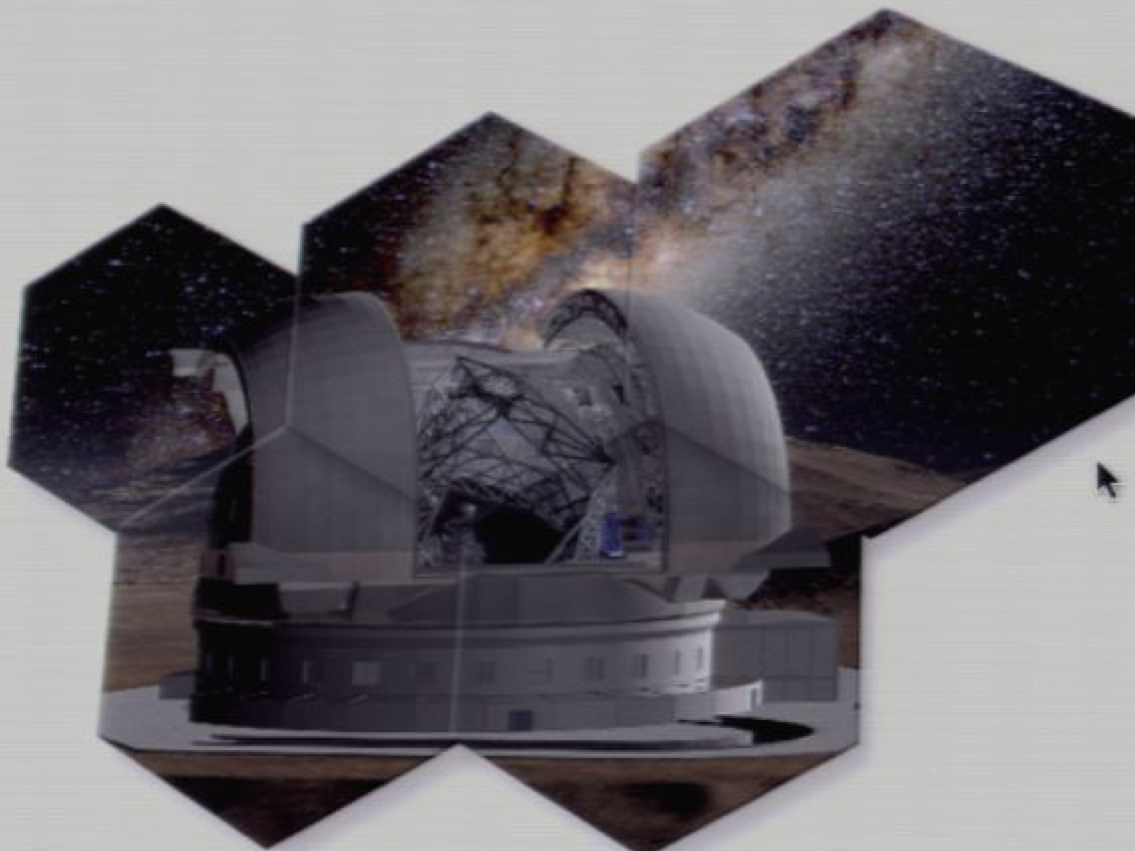
Summary

- for astrophysical (galaxies) purposes DM is cold
- interesting but production mechanism dependent constraints on sterile neutrinos
- cm/s spectroscopic accuracy in reach with ELTs

The End



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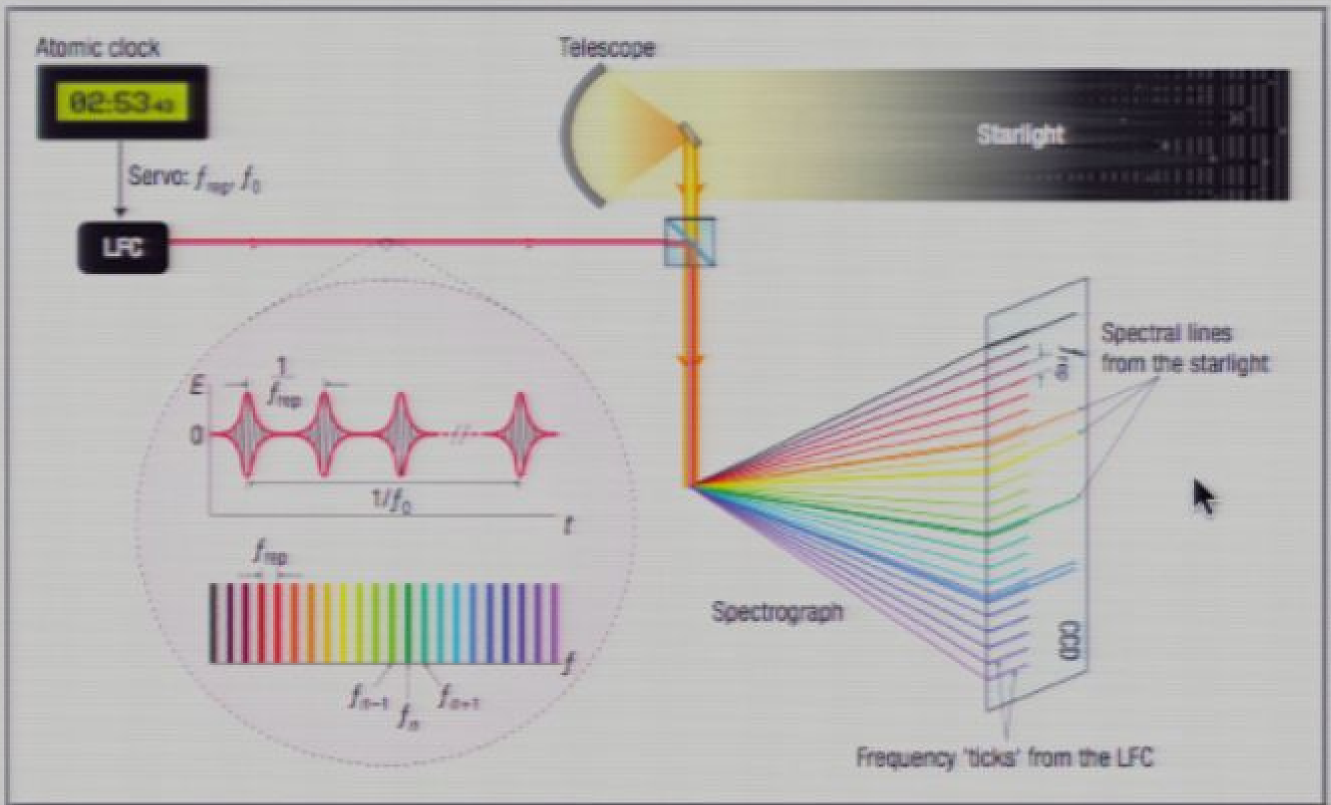

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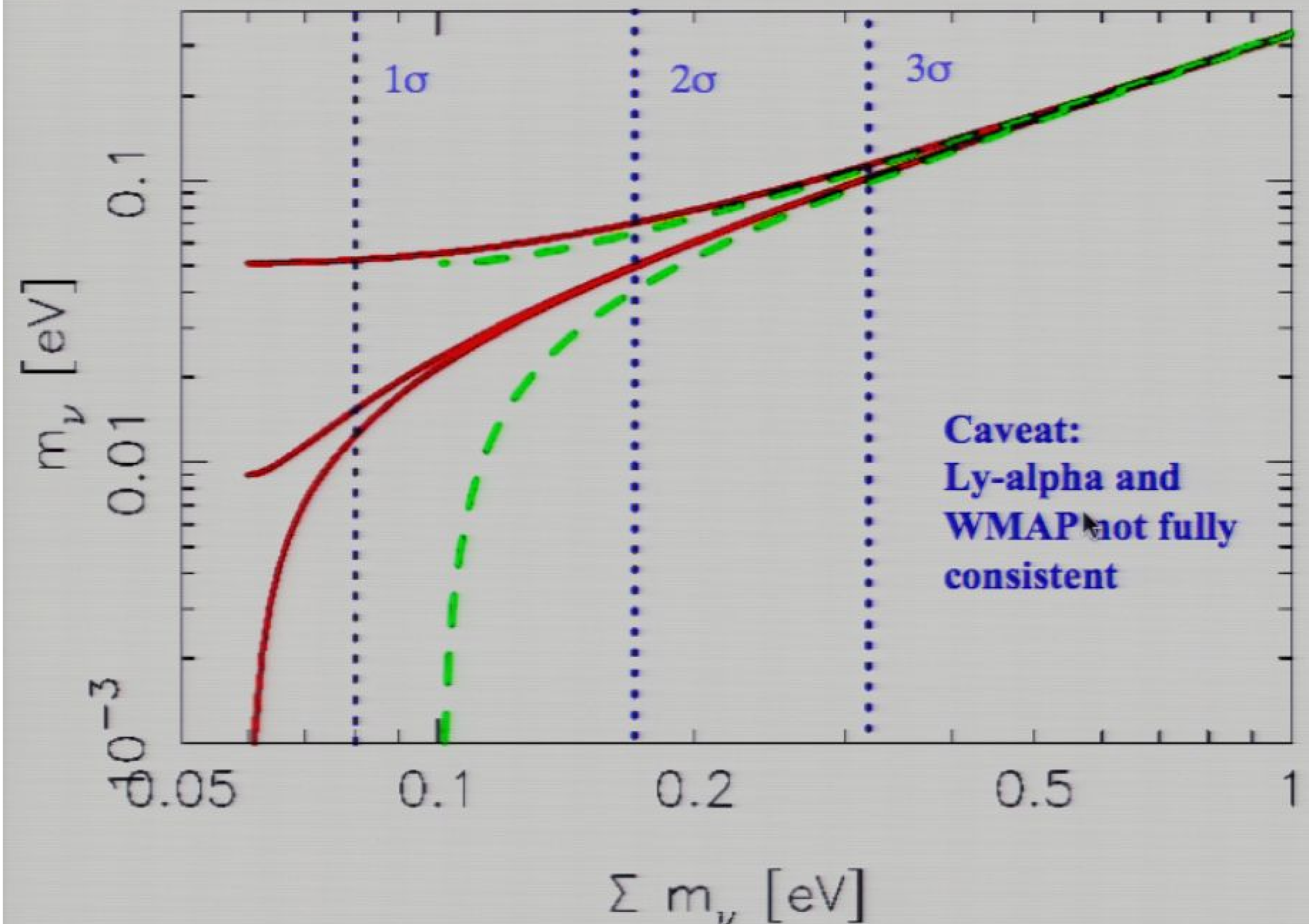

Seljak et al. 2006

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arXiv:0912.0552v1 [astro-ph.HE] 3 Dec 2009

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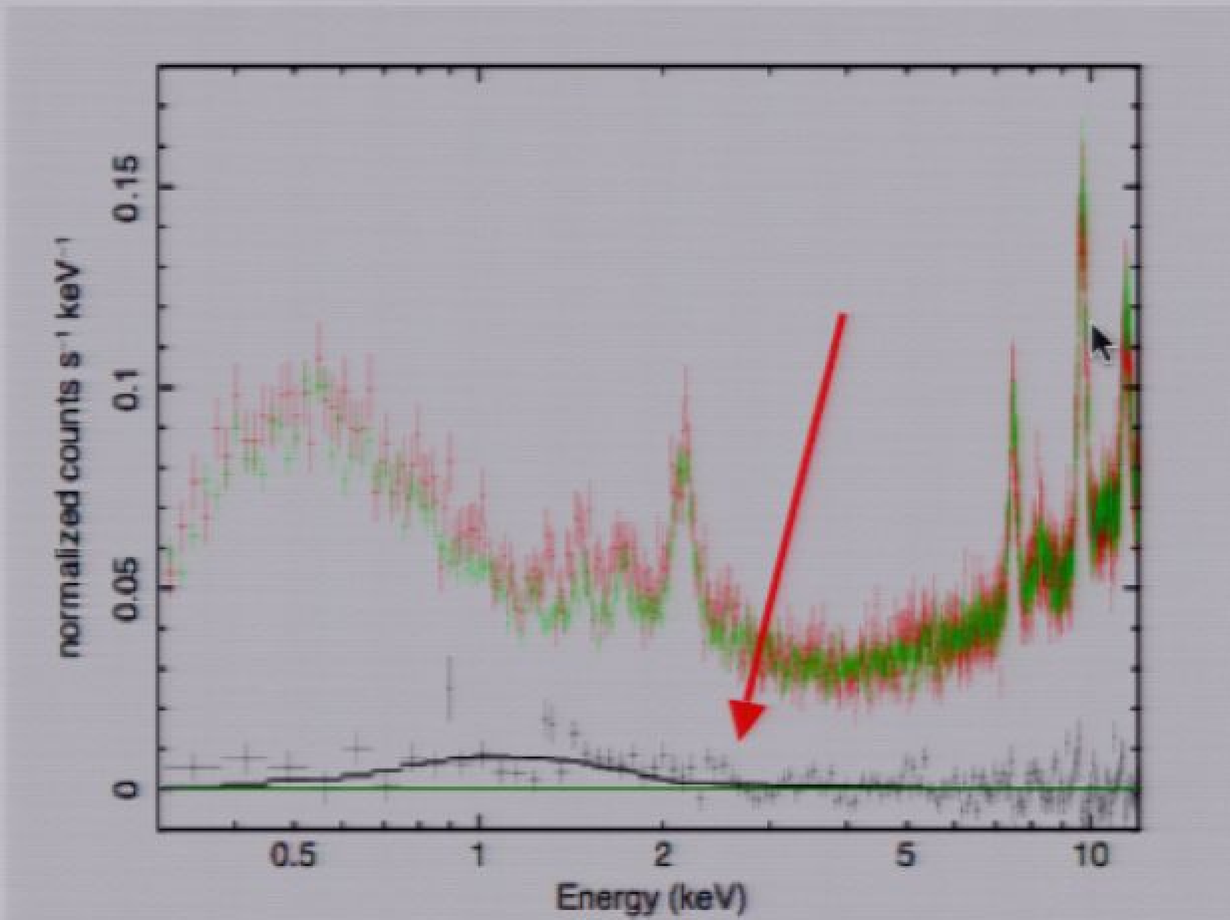

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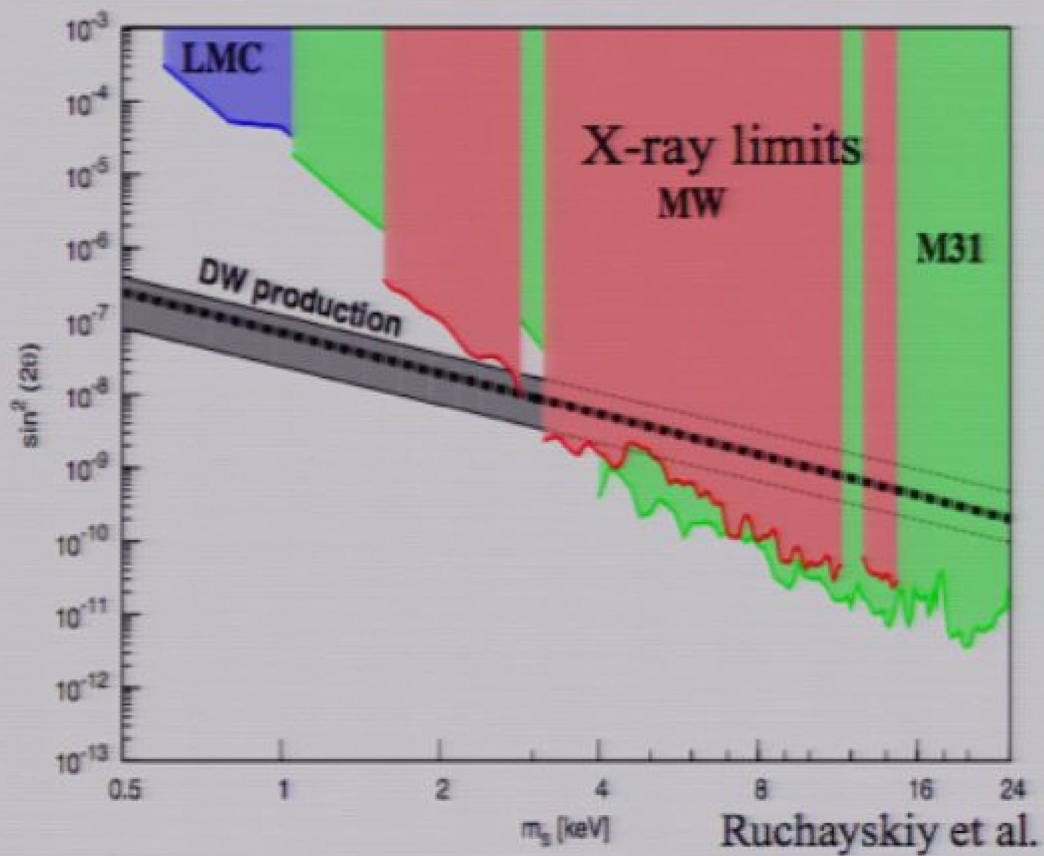

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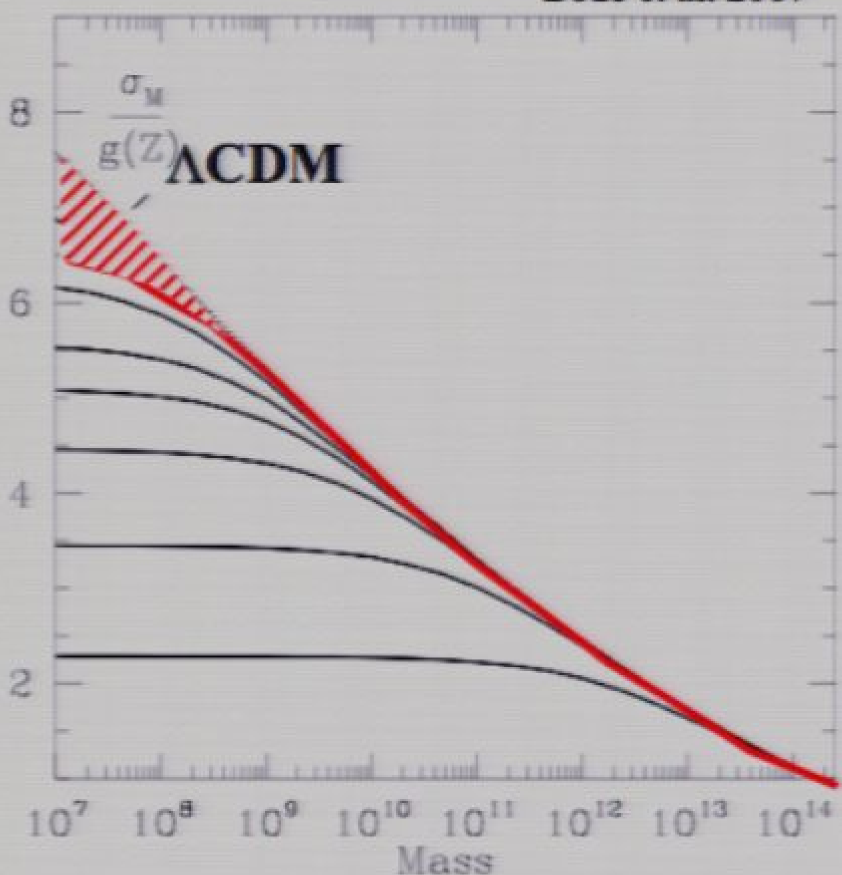
Bode et al. 2007



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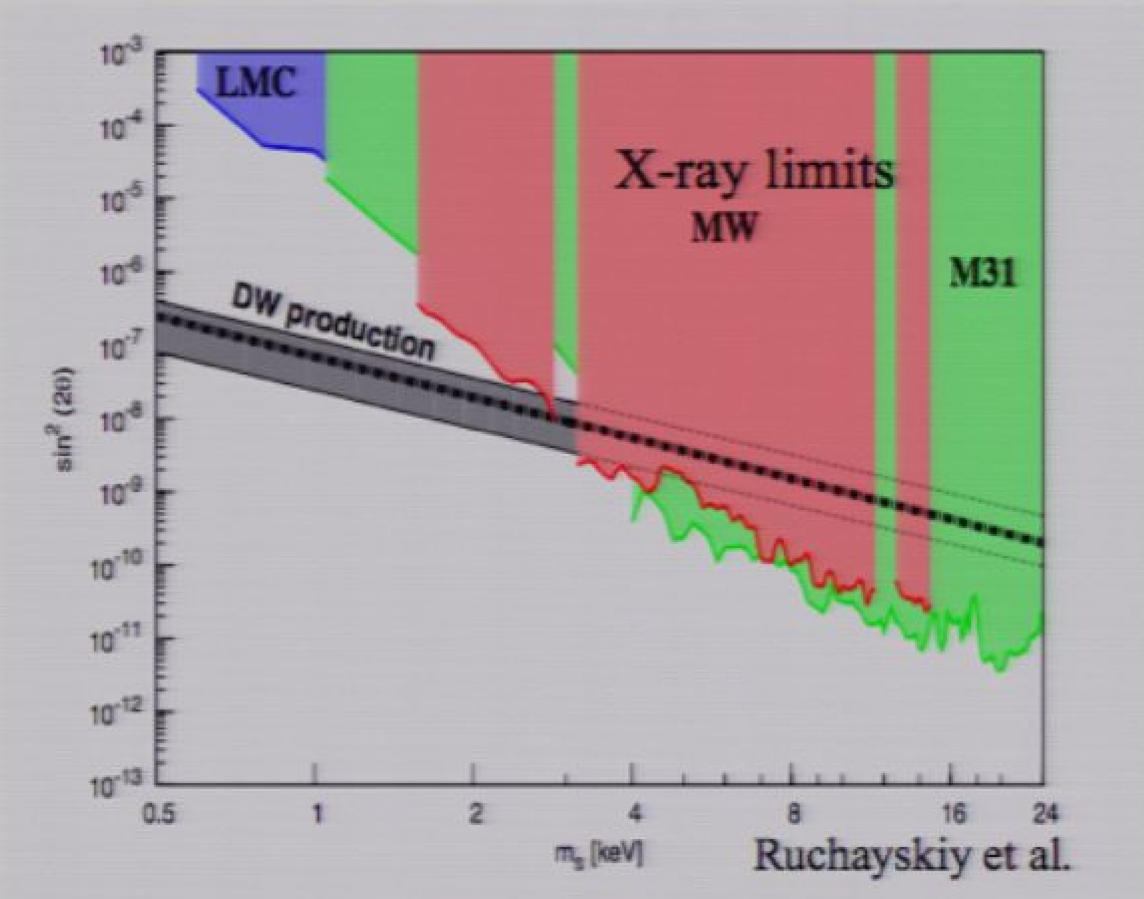

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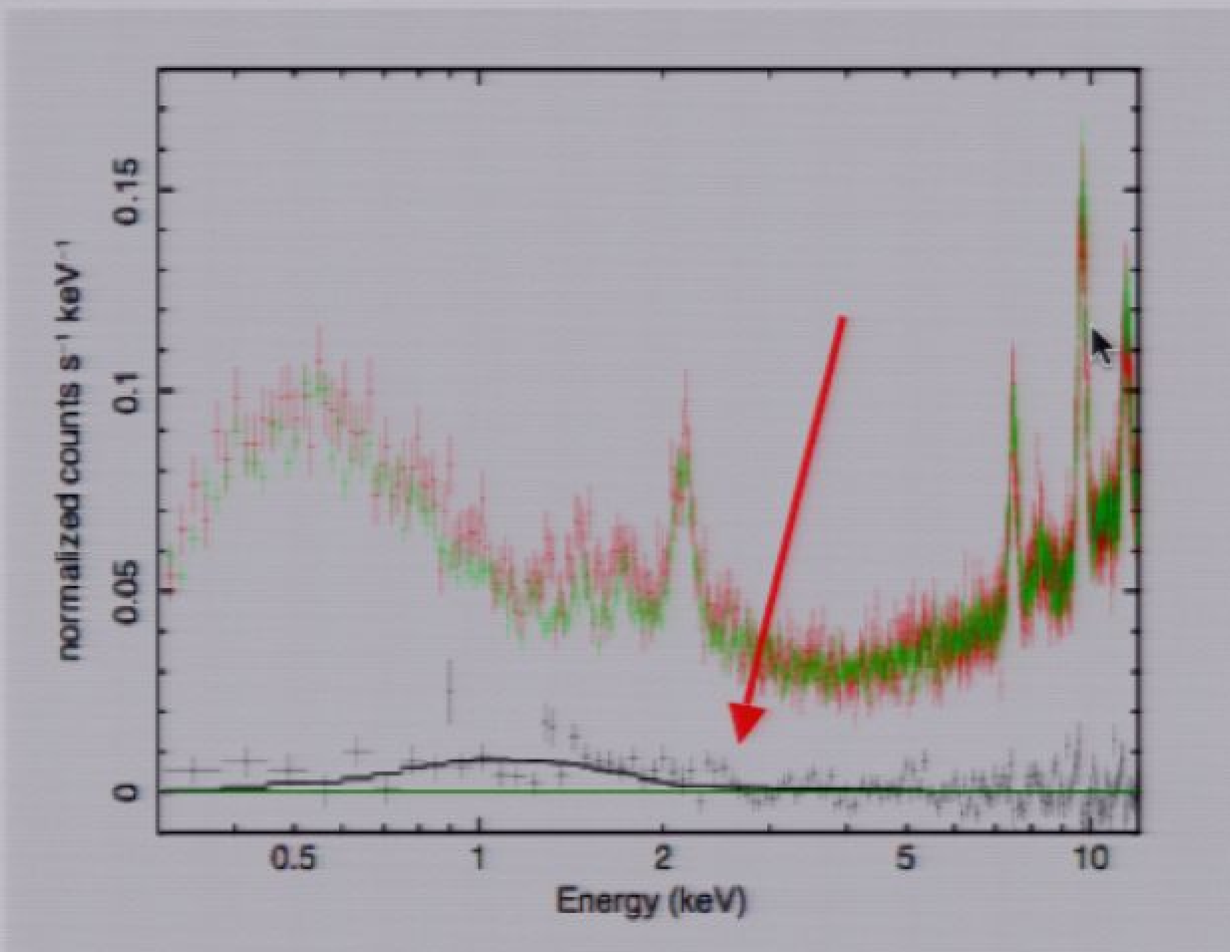

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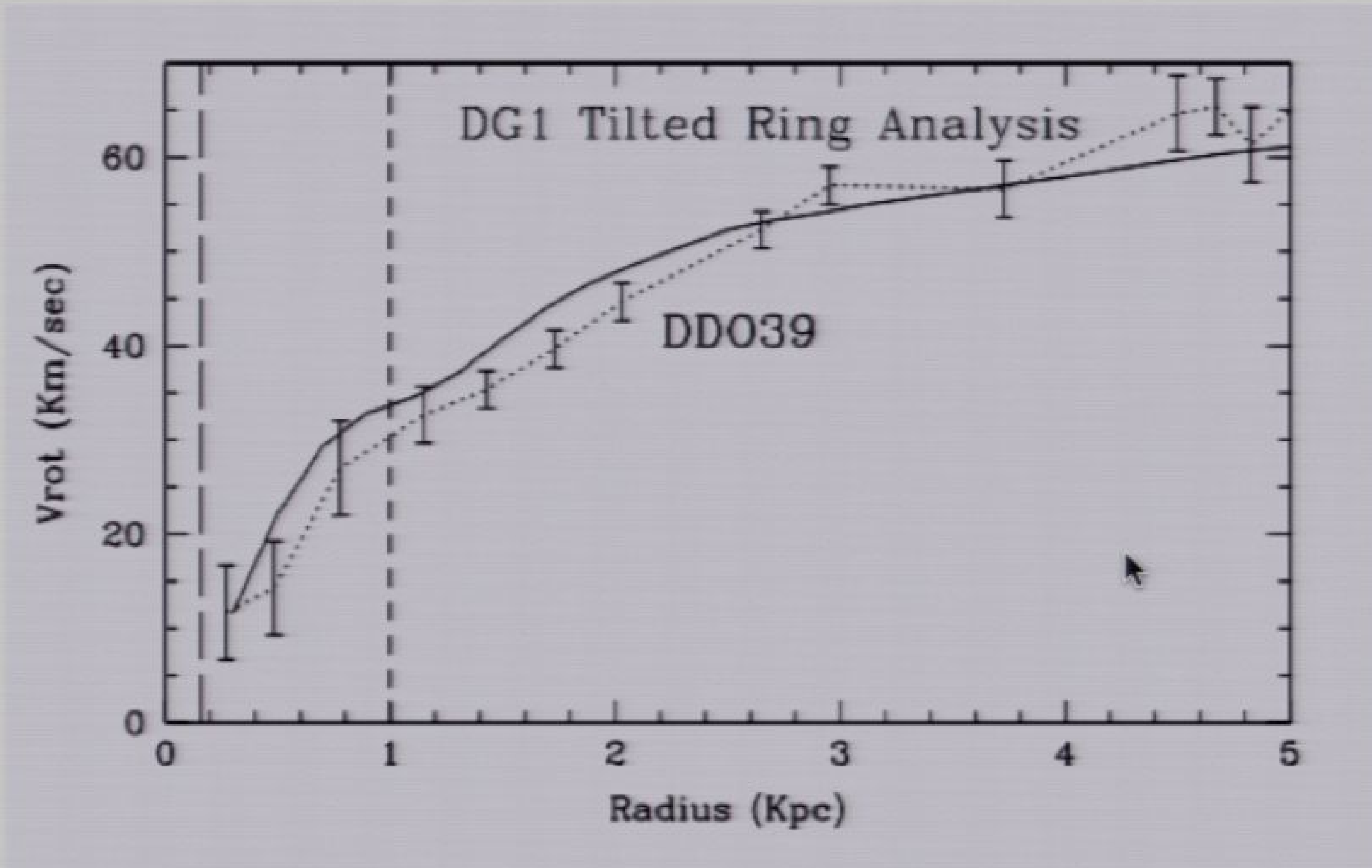
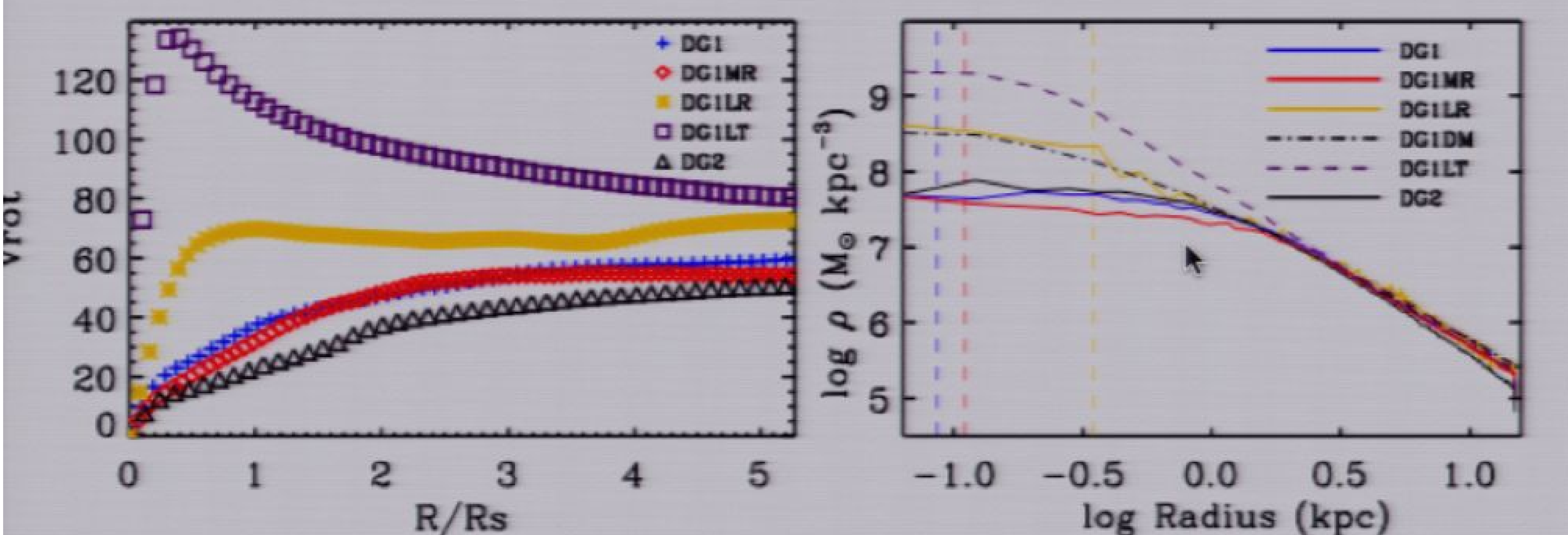


This appears to solve the cuspiness problem of CDM

At the heart of the matter: the origin of bulgeless dwarf galaxies and Dark Matter cores

F. Governato[1], C. Brook[2], L. Mayer[3], A. Brooks[4], G. Rhee[5], J. Wadsley[6], P. Jonsson[7], B. Willman[8], G. Stinson[6], T. Quinn[1] and P. Madau[9]



The inner density profile of dwarf galaxies depends strongly on resolution and the way star formation is implemented.

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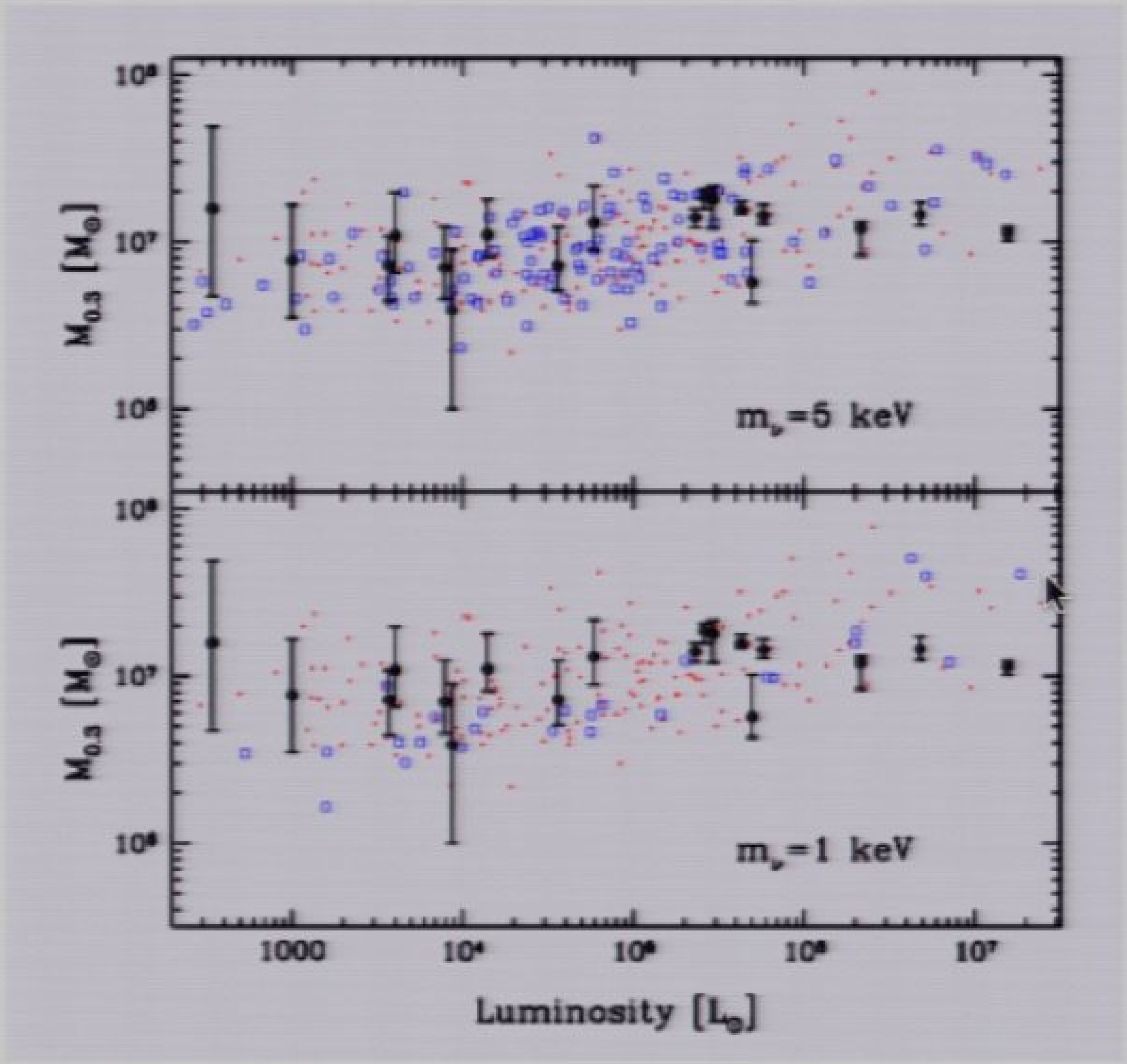

Maccio & Fontanot 2009

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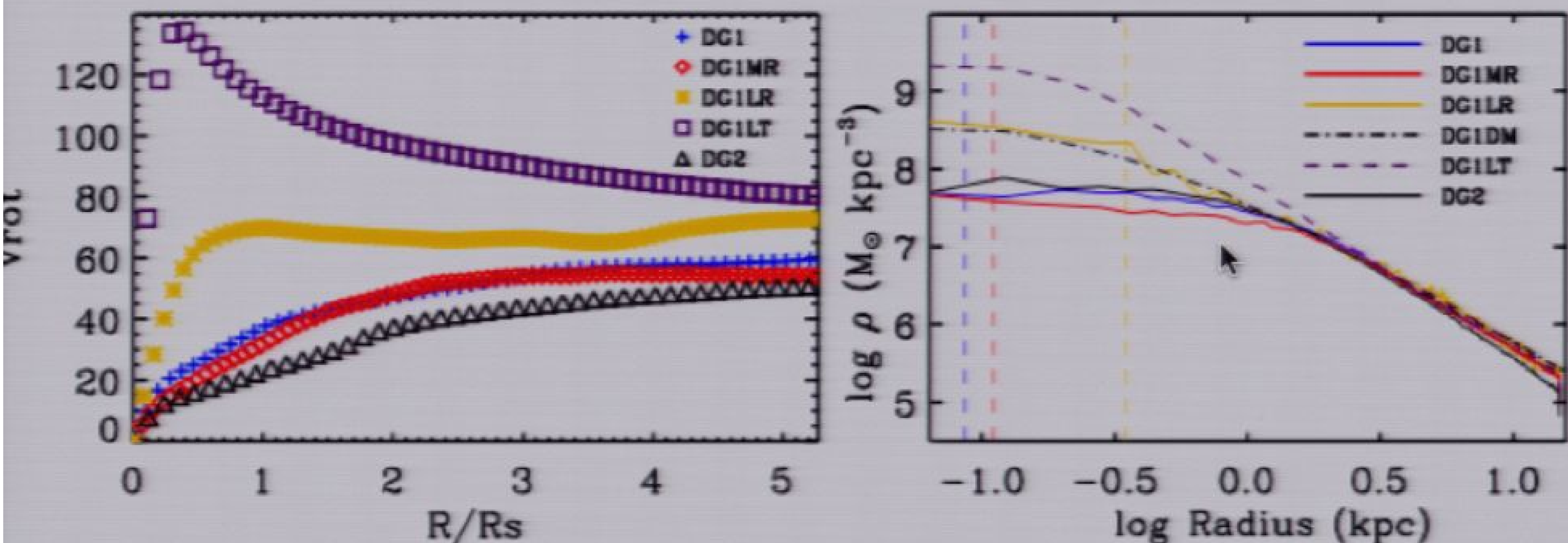
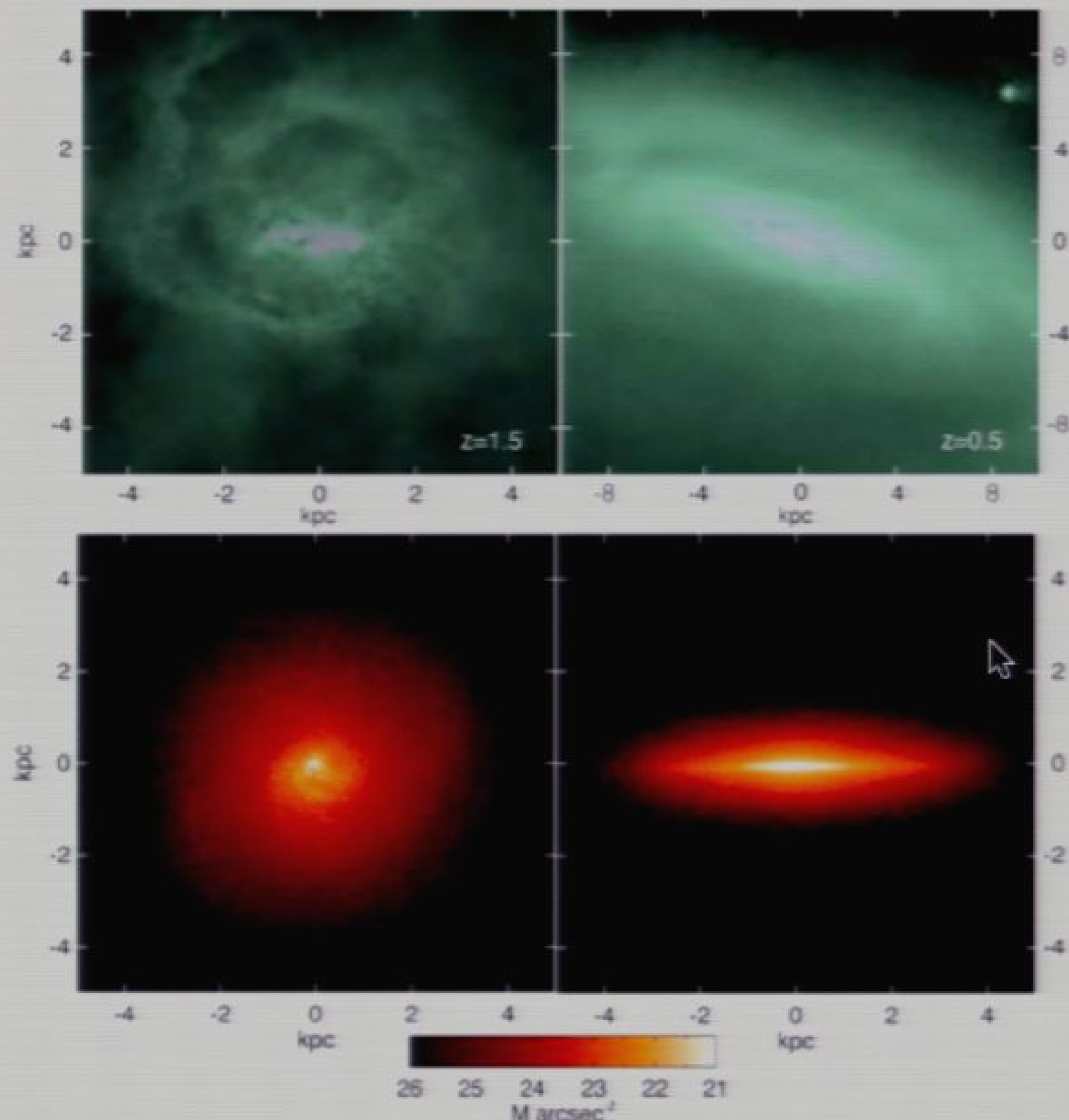
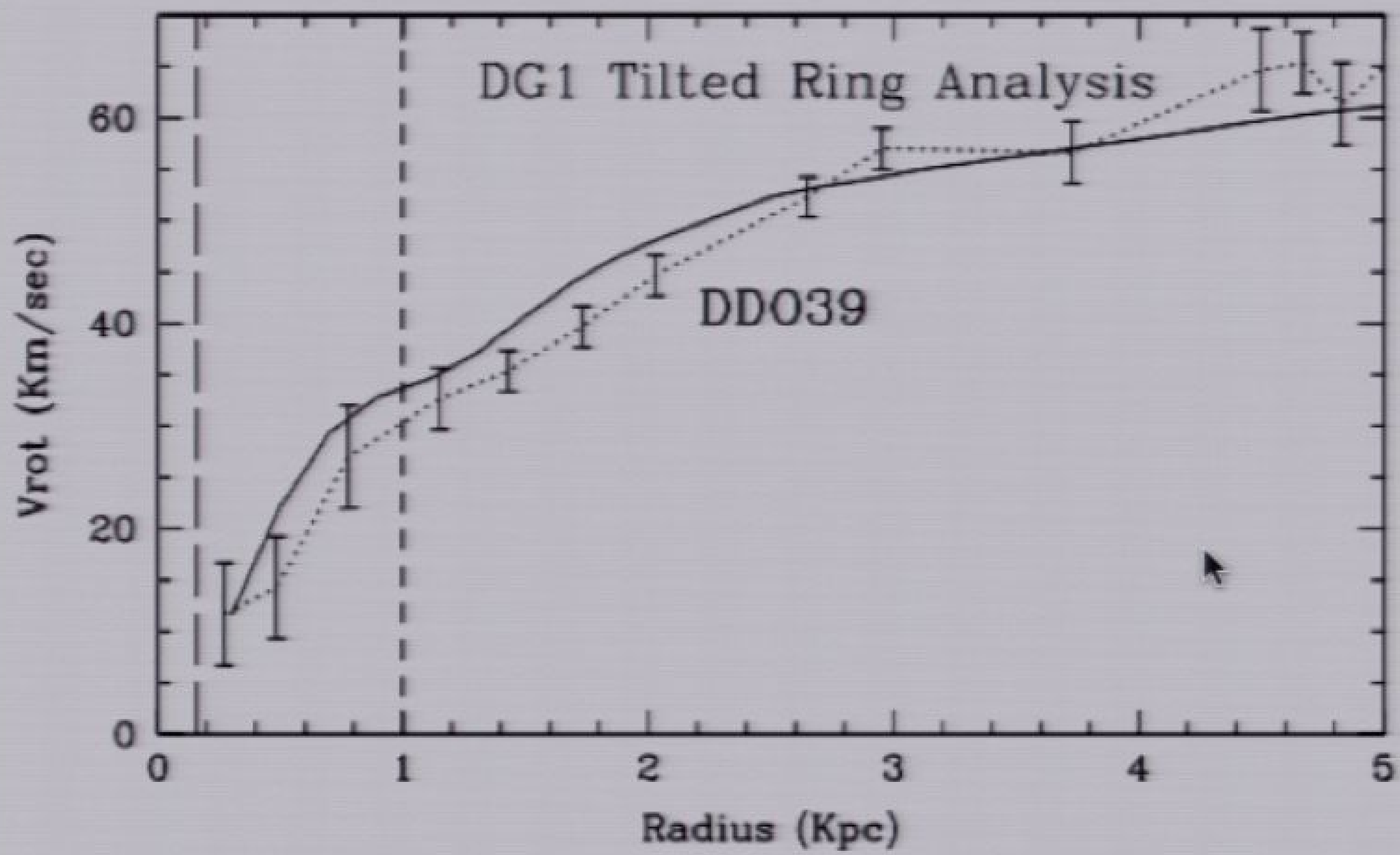


The inner density profile of dwarf galaxies depends strongly on resolution and the way star formation is implemented.

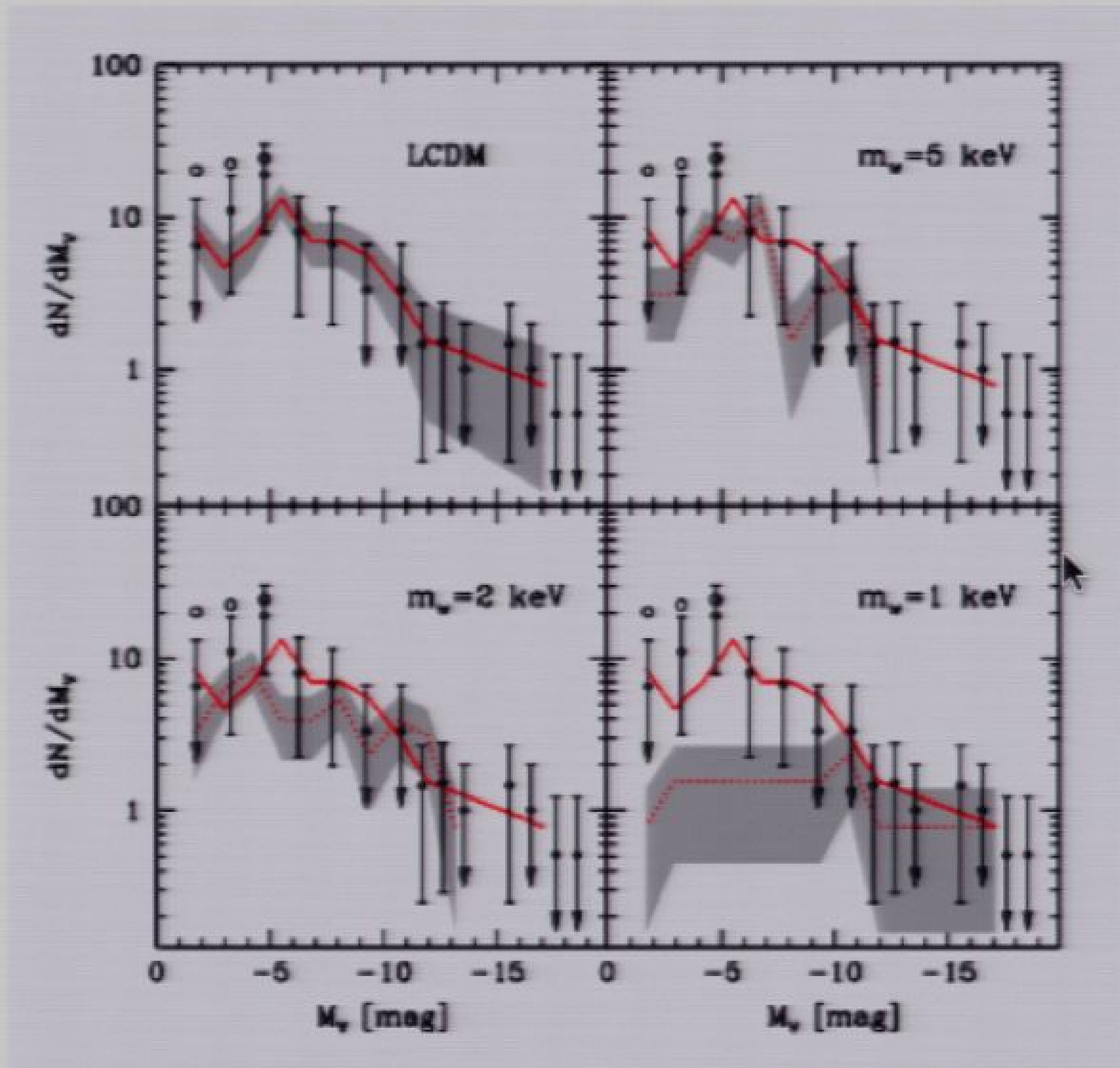
PI-CITA day, 8 December 2009



PI-CITA day, 8 December 2009

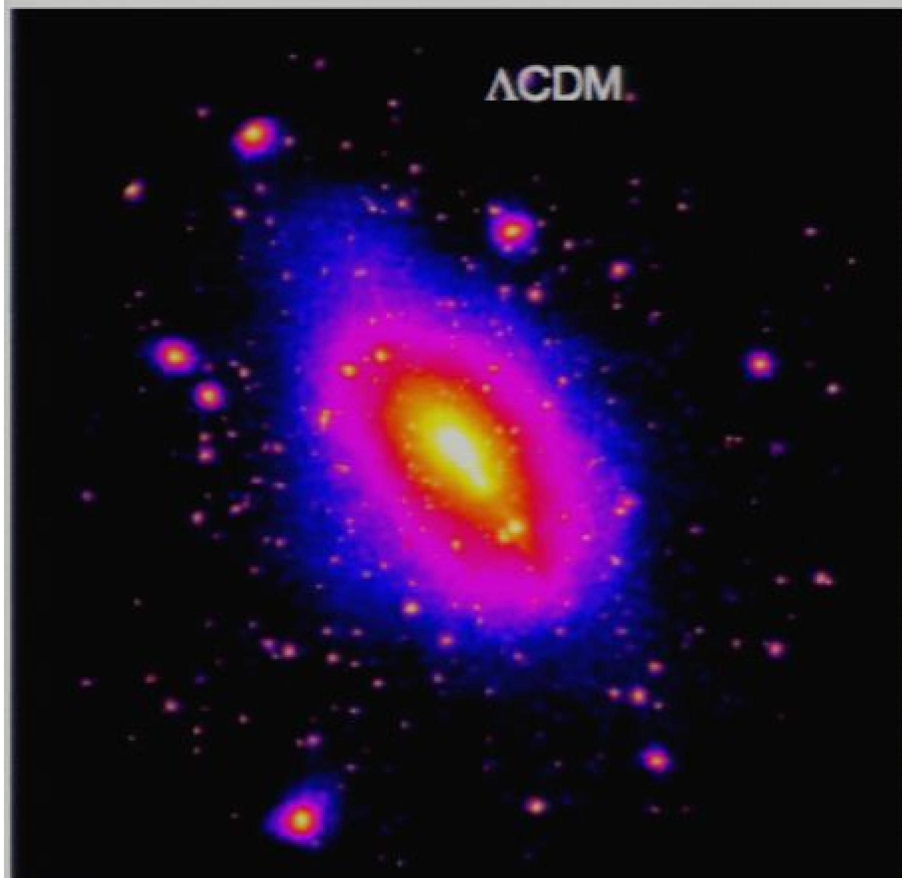


This appears to solve the cuspiness problem of CDM

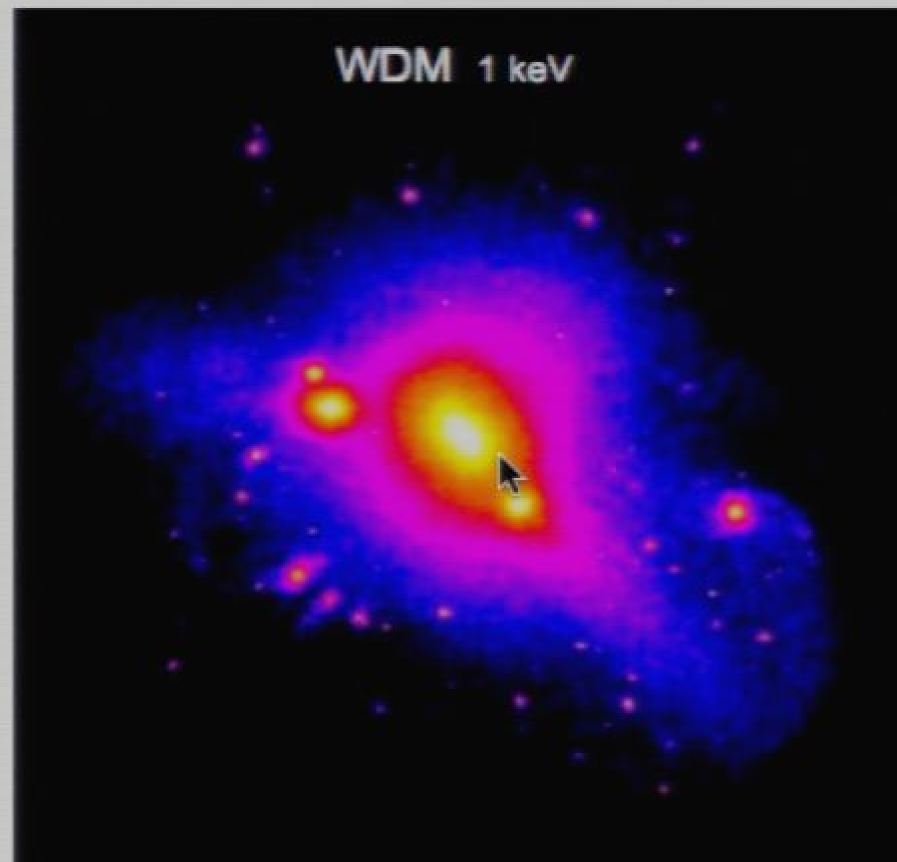


Maccio & Fontanot 2009

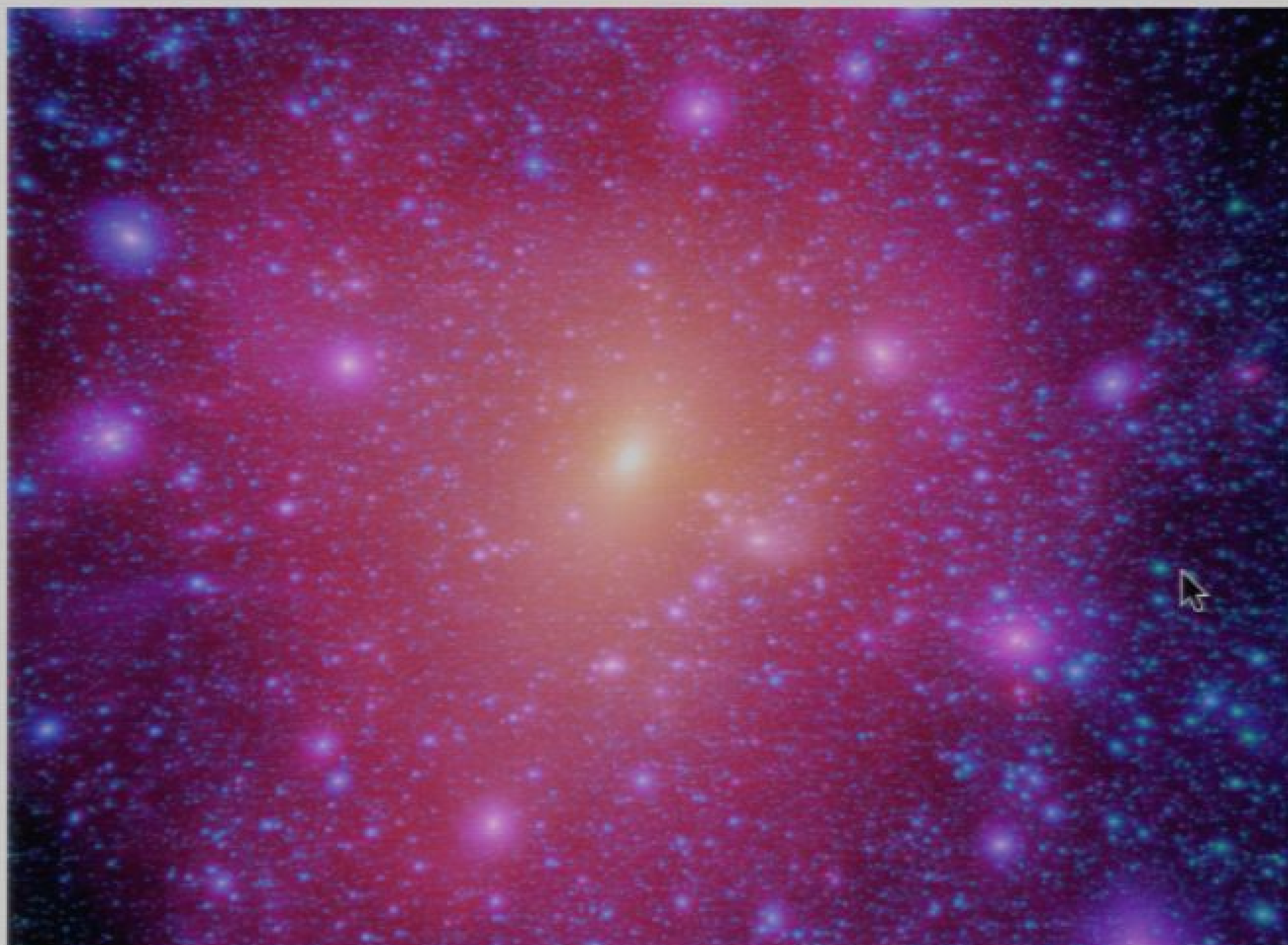
cold dark matter



warm dark matter



Maccio & Fontanot 2009



Springel et al.

The CDM paradigm predicts many low mass objects

PI-CITA day, 8 December 2009