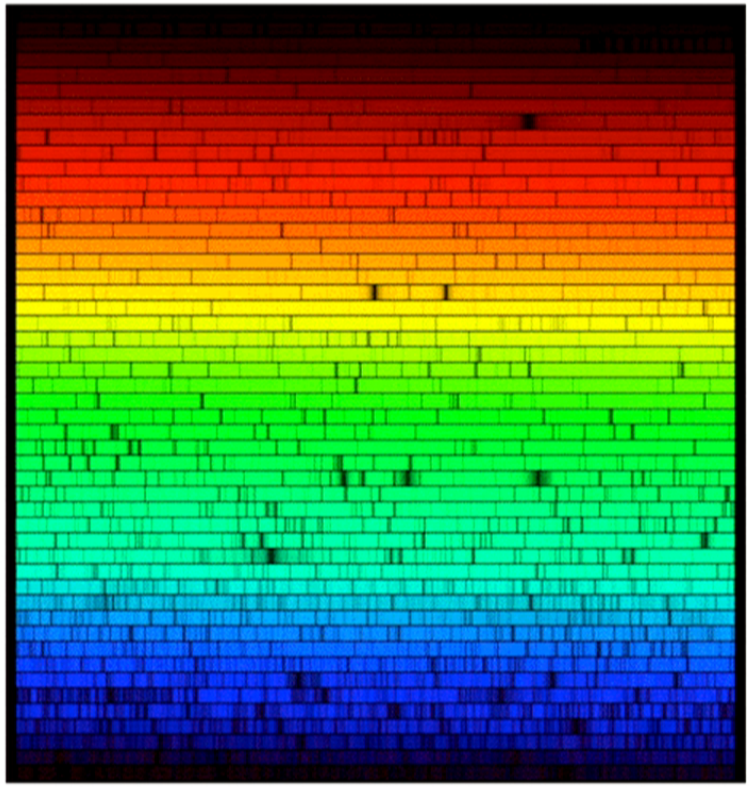
Title: Colloquium

Date: Mar 16, 2016 02:00 PM

URL: http://pirsa.org/16030110

Abstract:



Probing (free-streaming of) dark matter with the Lyα forest

Martin Haehnelt

in collaboration with:

George Becker, James Bolton, Ewald Puchwein, Debora Sijacki, Volker Springel, Matteo Viel (and quite a few more)

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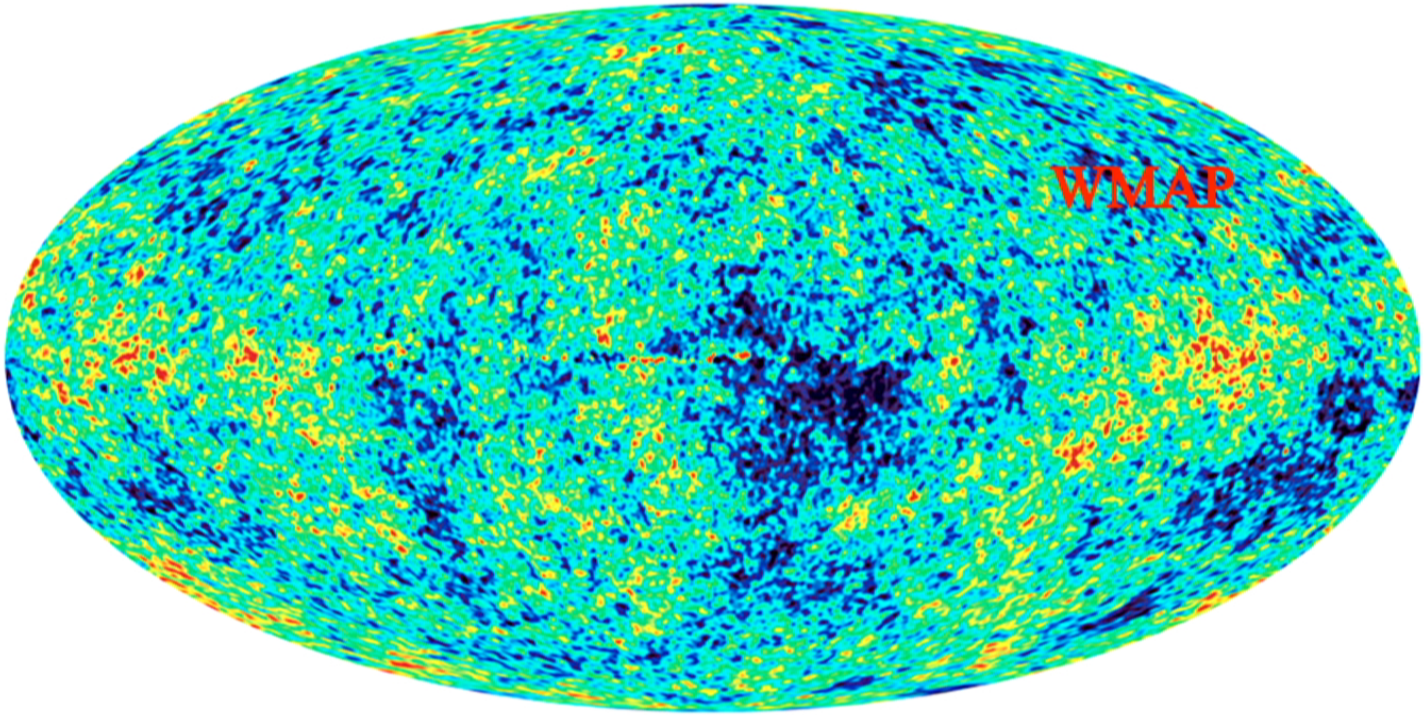

Temperaturfluktuationen $\frac{\Delta T}{T} \approx 10^{-5}$

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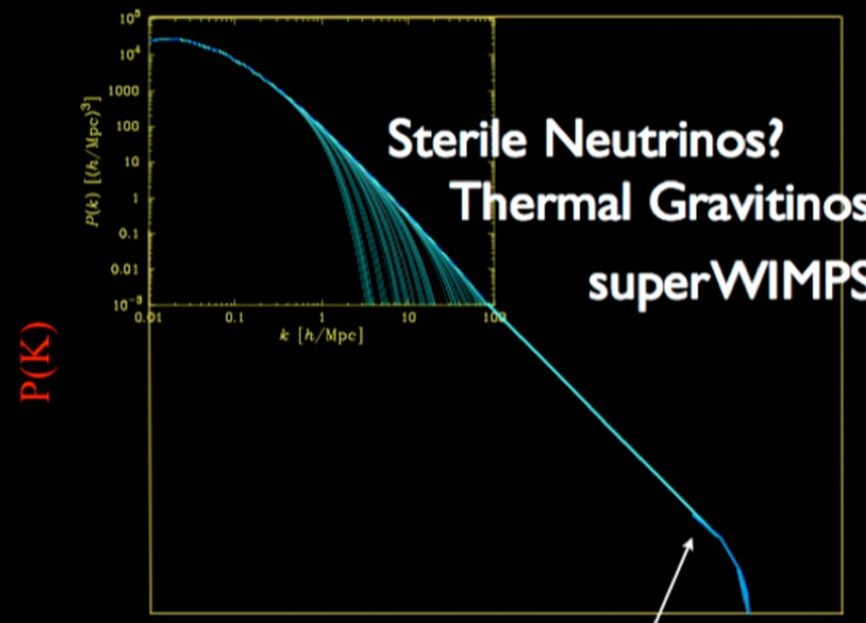
How far into the small-scale regime can we measure?



Aberzajan

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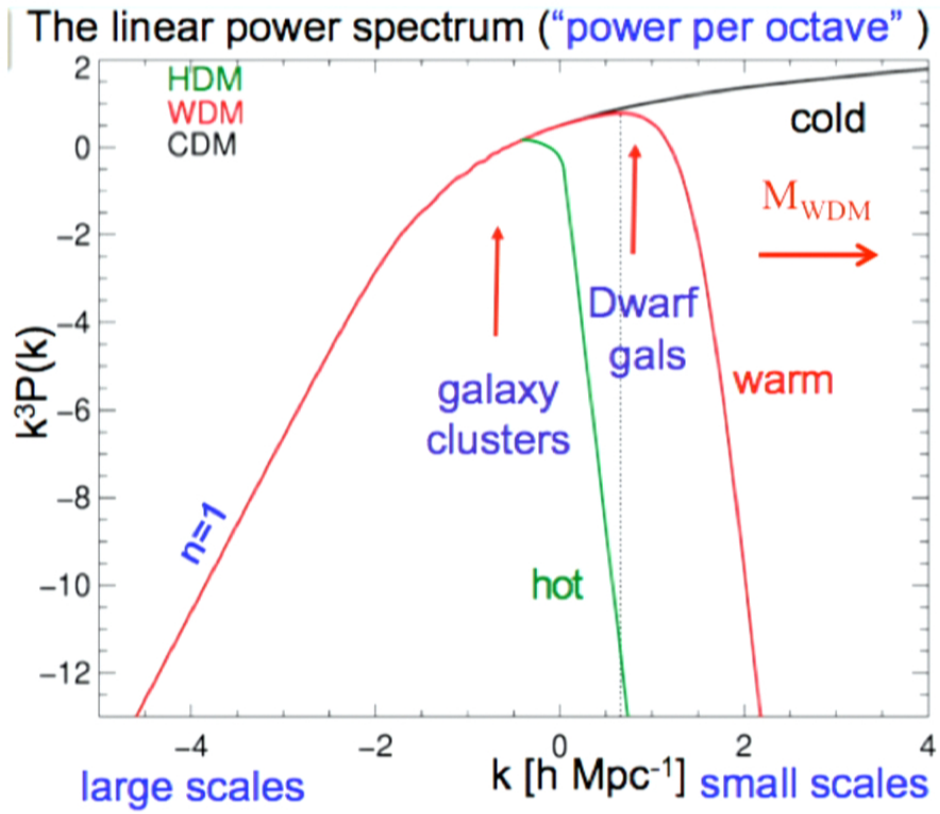
Cut-off in the matter power spectrum on astrophysically interesting scales due to free-streaming?



courtesy of Carlos Frenk

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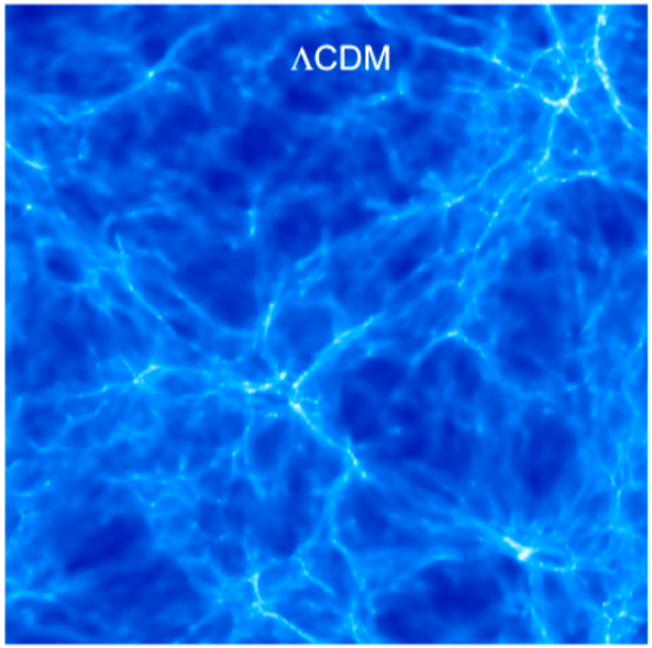
cold dark matter: free streaming scale so small that it is astrophysically irrelevant

warm dark matter: free streaming on galaxy scales

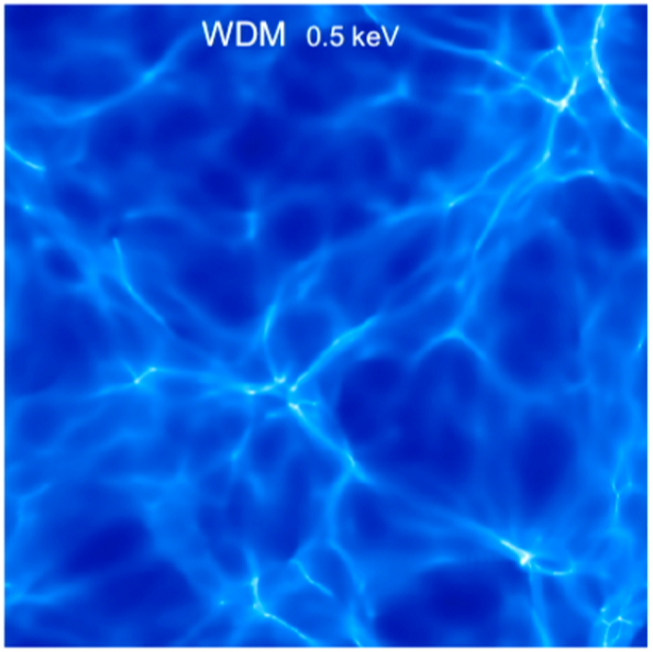
hot dark matter: free streaming on ~~galaxy cluster~~ or larger scales

Free-streaming erases structure

cold dark matter



warm dark matter



30 comoving Mpc/h z=3

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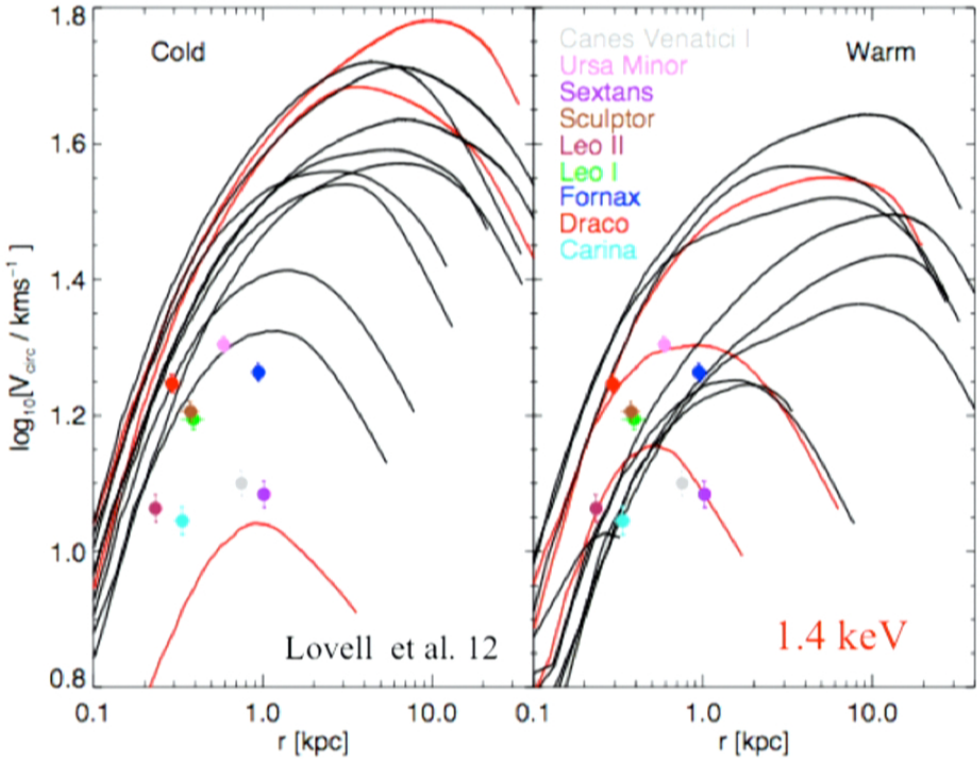
Potential problems with CDM aka "The small scale crisis"

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

The too-big-to-fail problem



WDM appears to do well.
Can stellar feedback solve this instead?
Dependence on mass of MW halo.

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Lya-absorption in the spectra of distant quasars as tracer of the matter distribution

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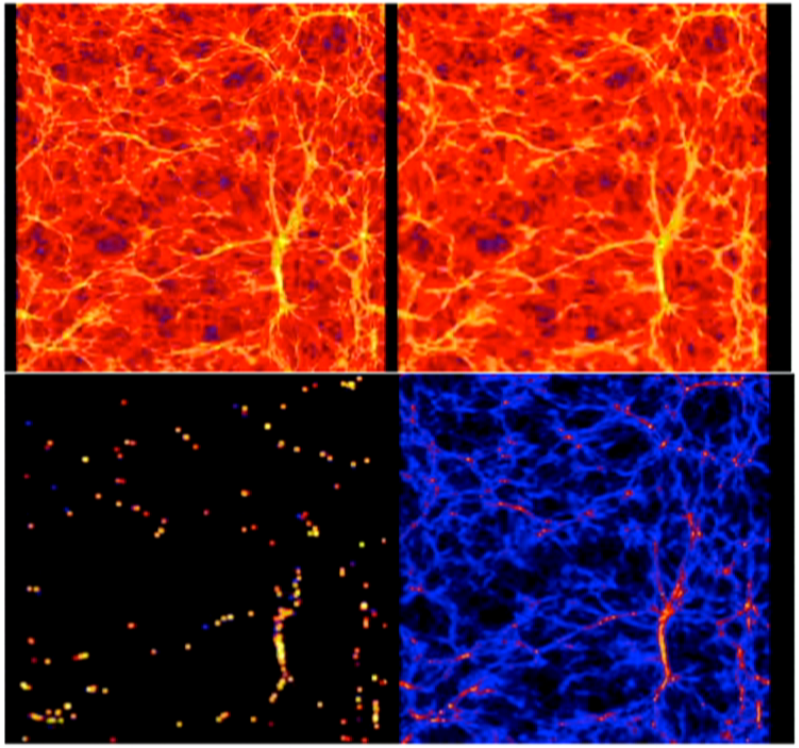
Dark Matter

Gas



Galaxies

Neutral hydrogen

Neutral hydrogen is an excellent tracer of the matter distribution.

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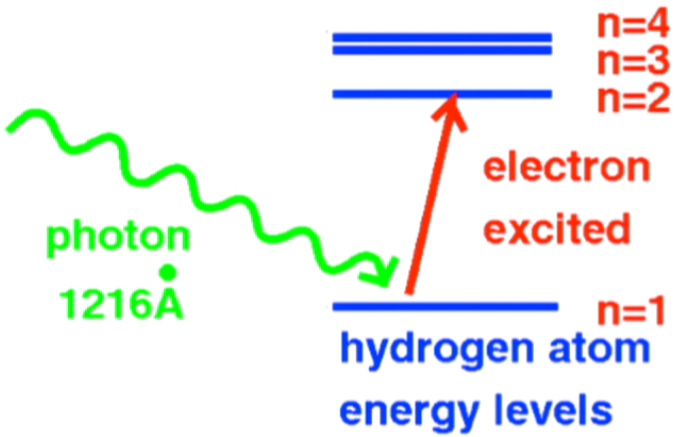
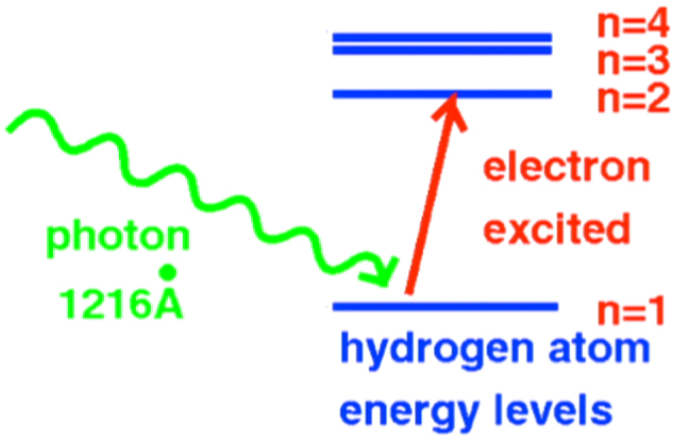
Lyα absorption by neutral hydrogen



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

Lyα absorption by neutral hydrogen



$\lambda_{obs} = 1216\ (1+z)$ Å

Hydrogen in the IGM is photoionized:

Recombination **Photoionization**

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

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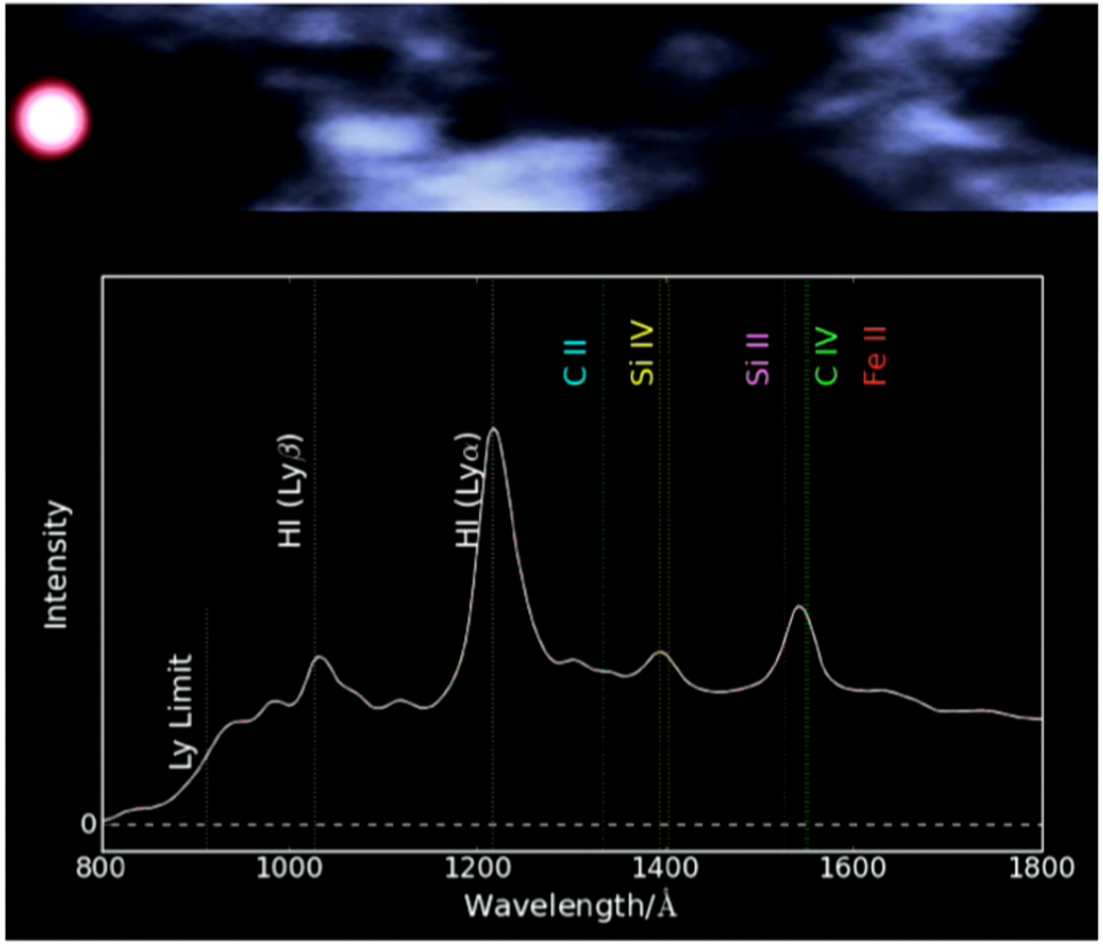
credit to

Andrew Pontzen



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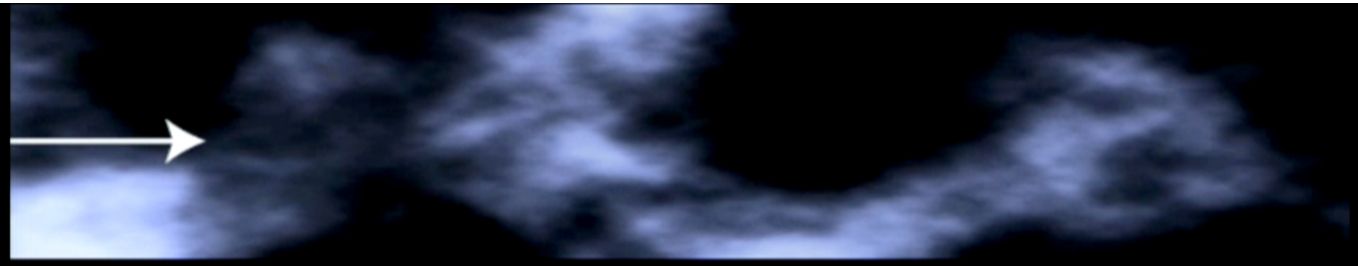
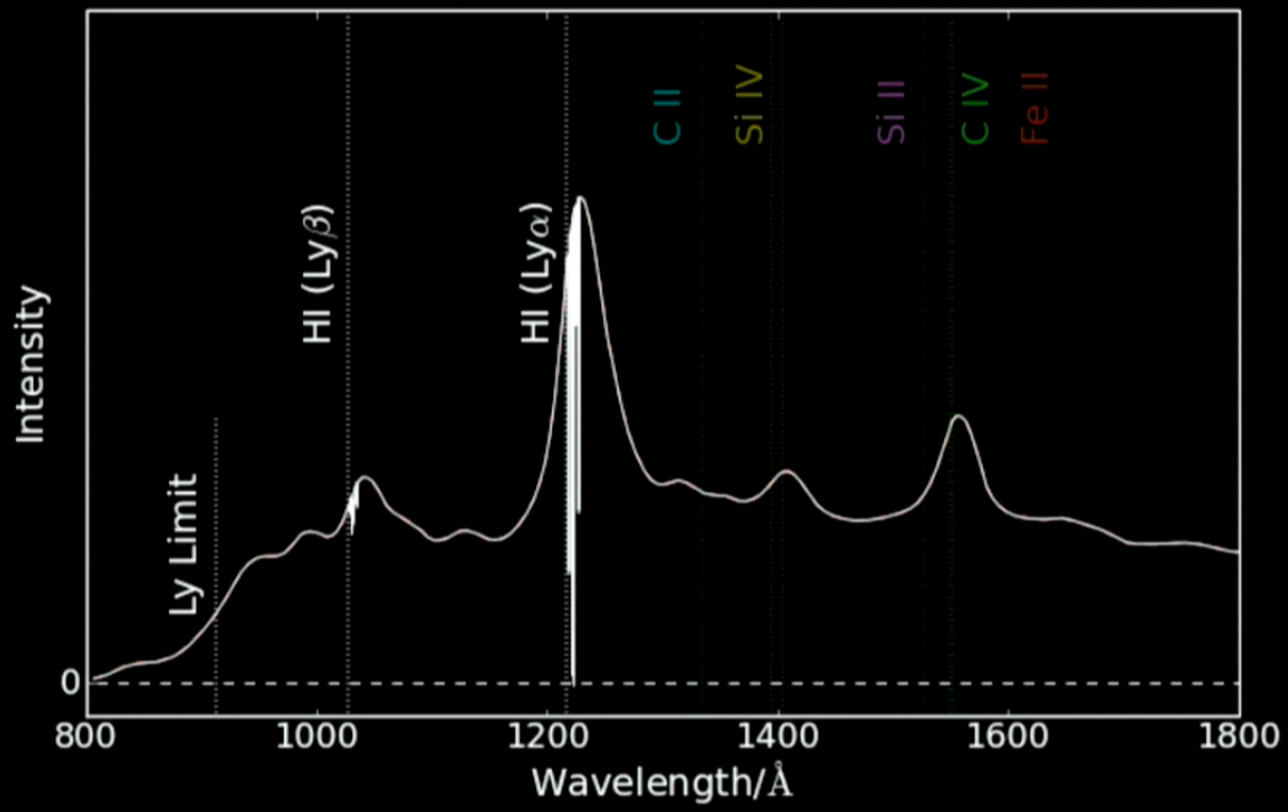
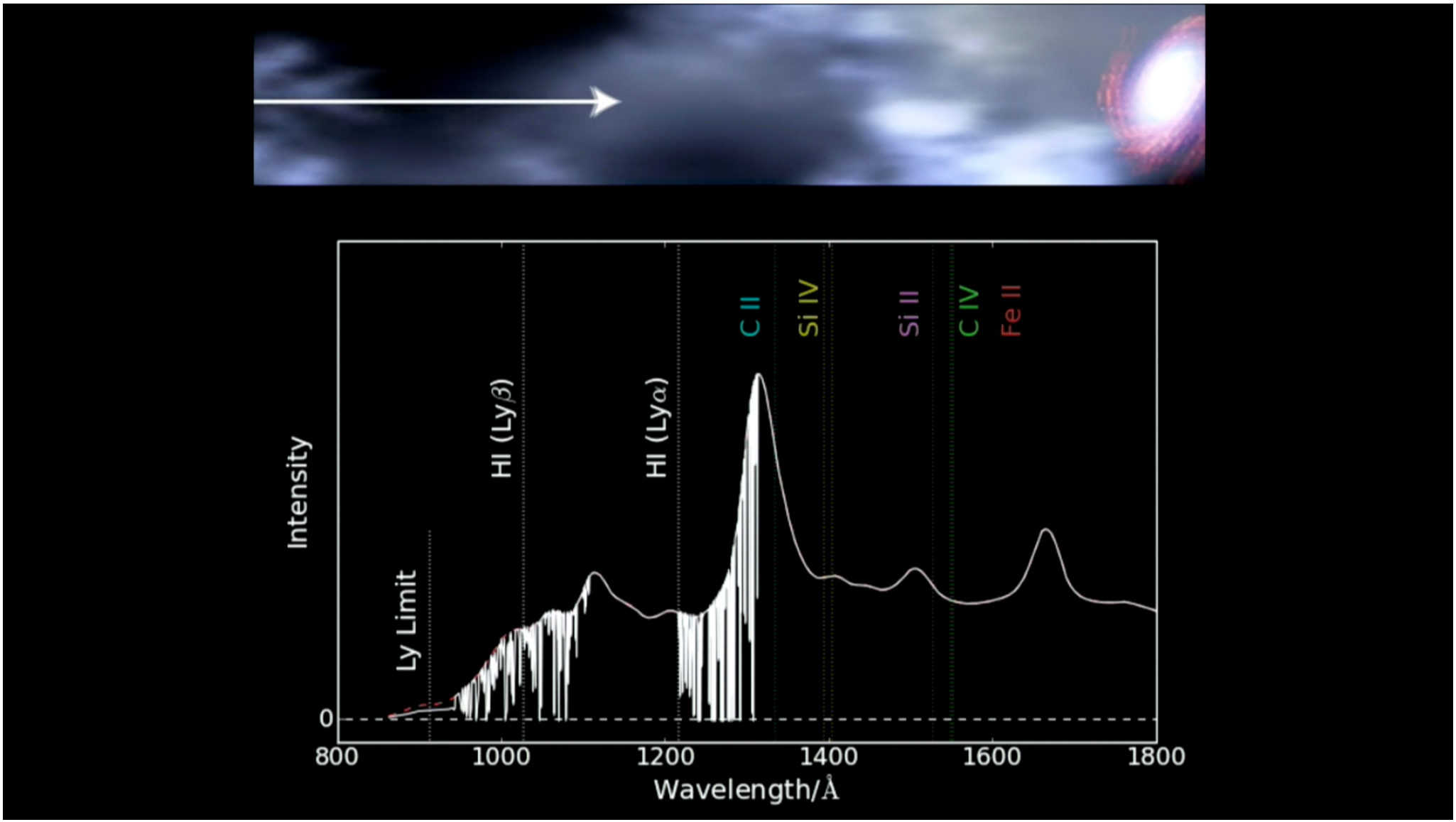



Intensity
0
Ly Limit
HI (Lyβ)
HI (Lyα)
C II
Si IV
Si II
C IV
Fe II
800
1000
1200
1400
1600
1800
Wavelength/Å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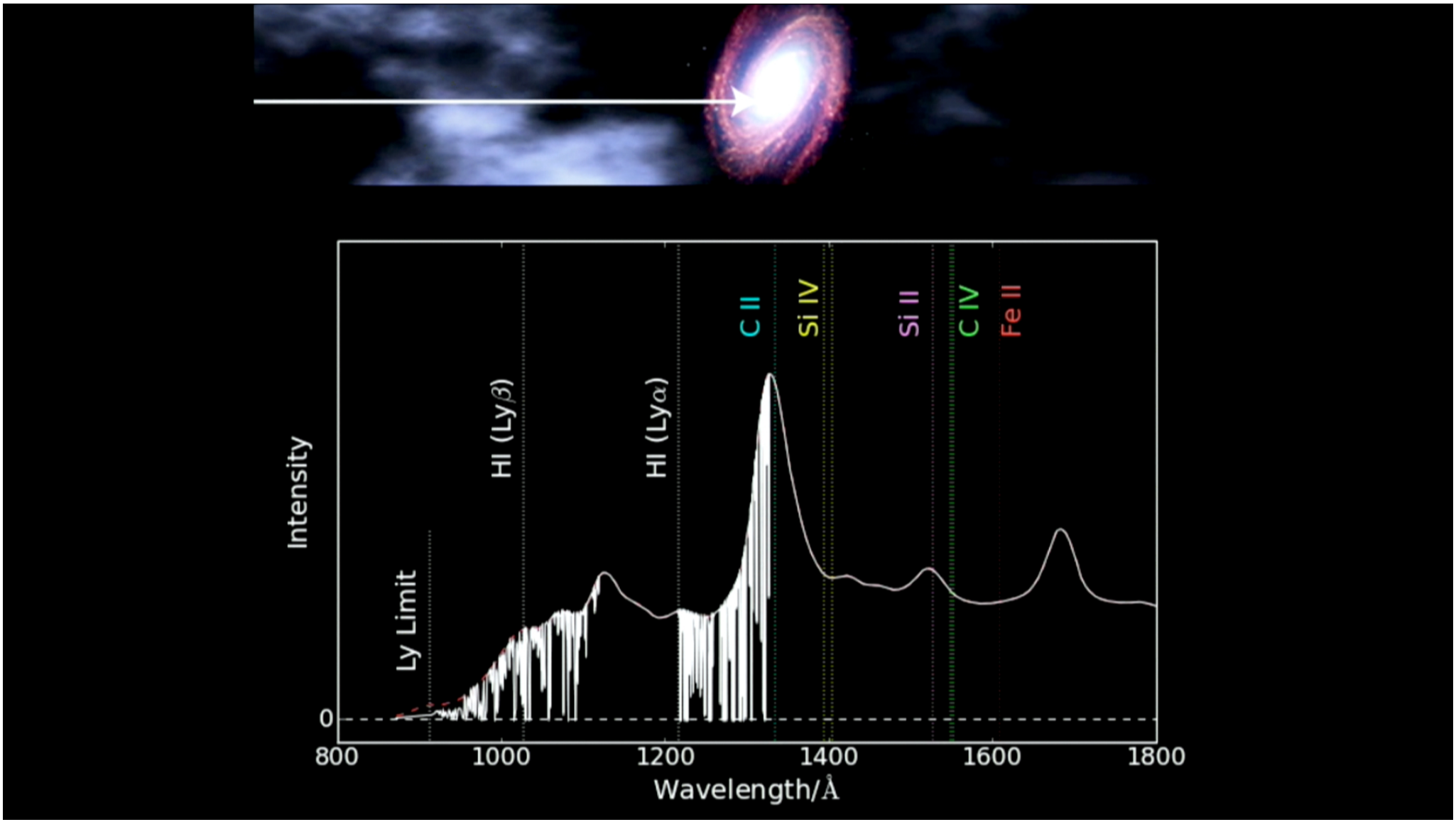
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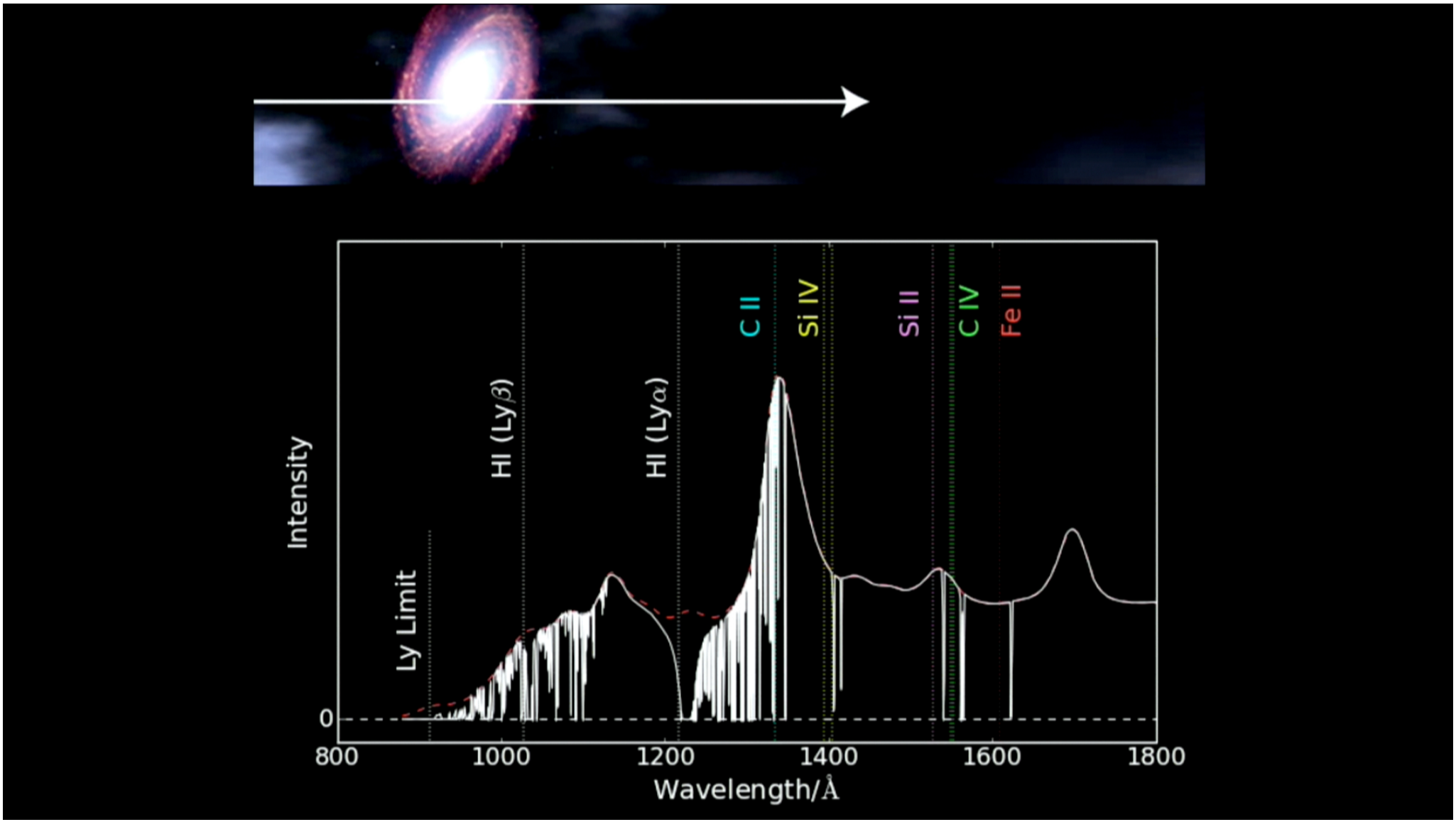
Wavelength/Å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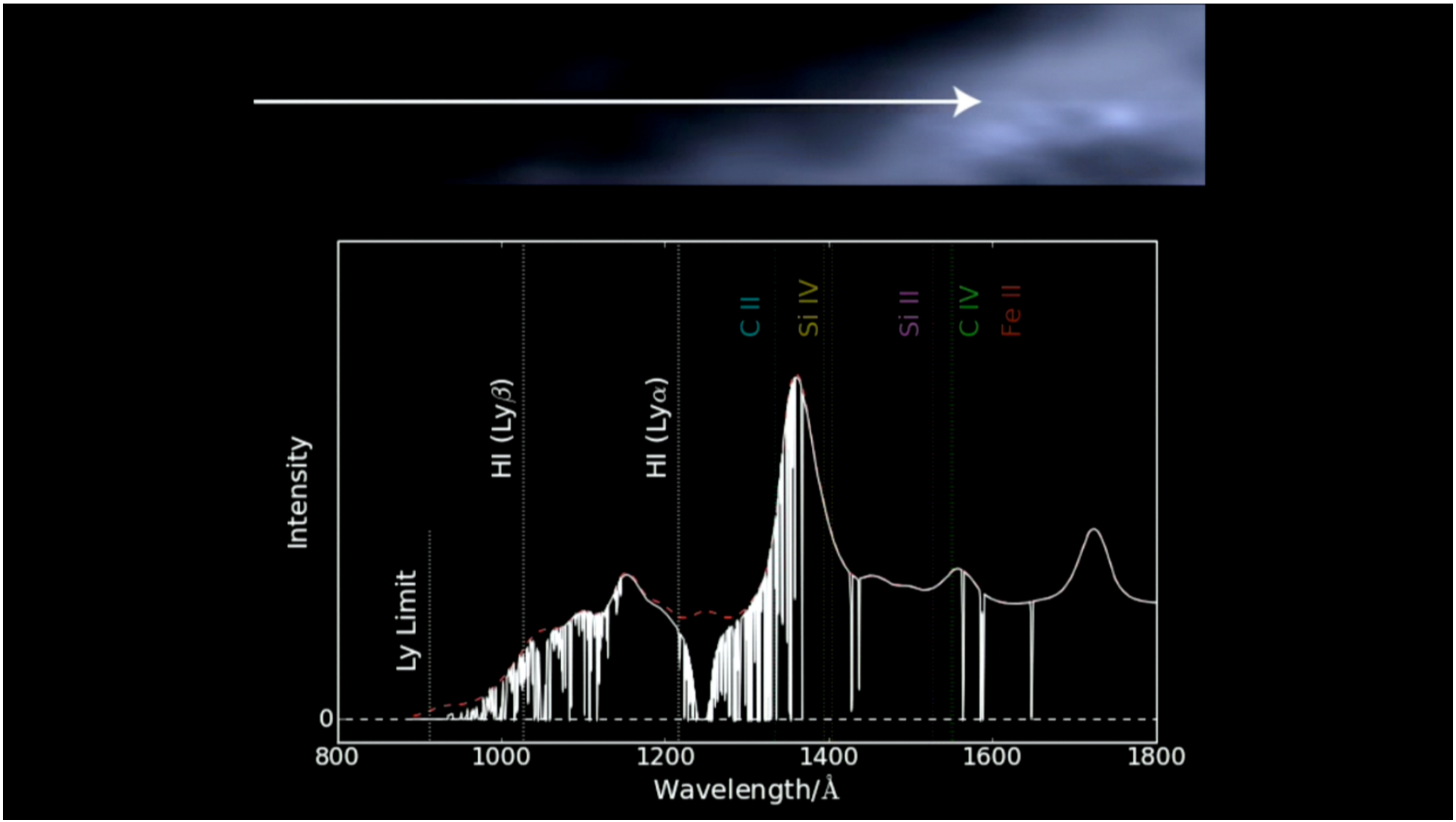
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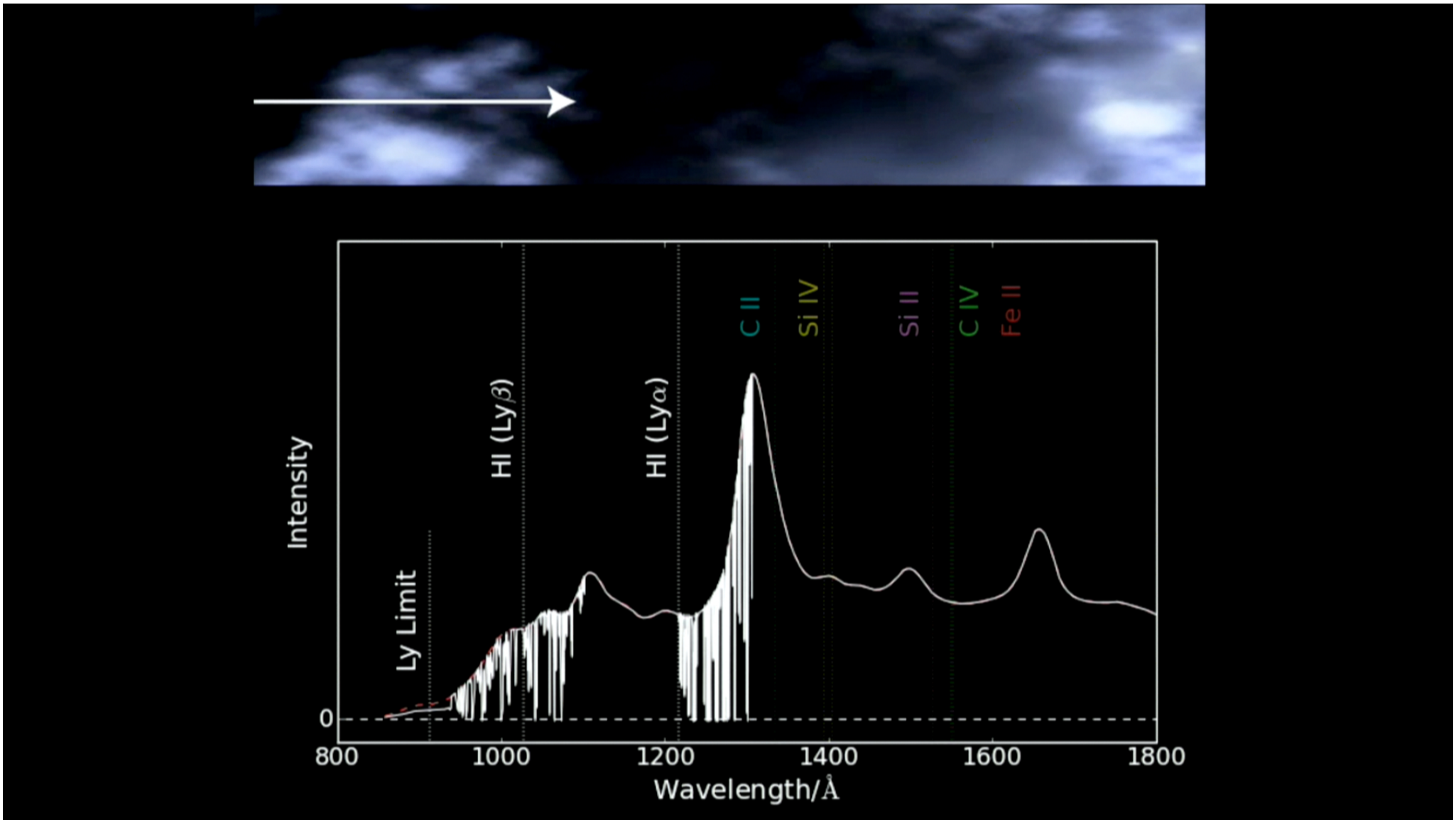
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Si II
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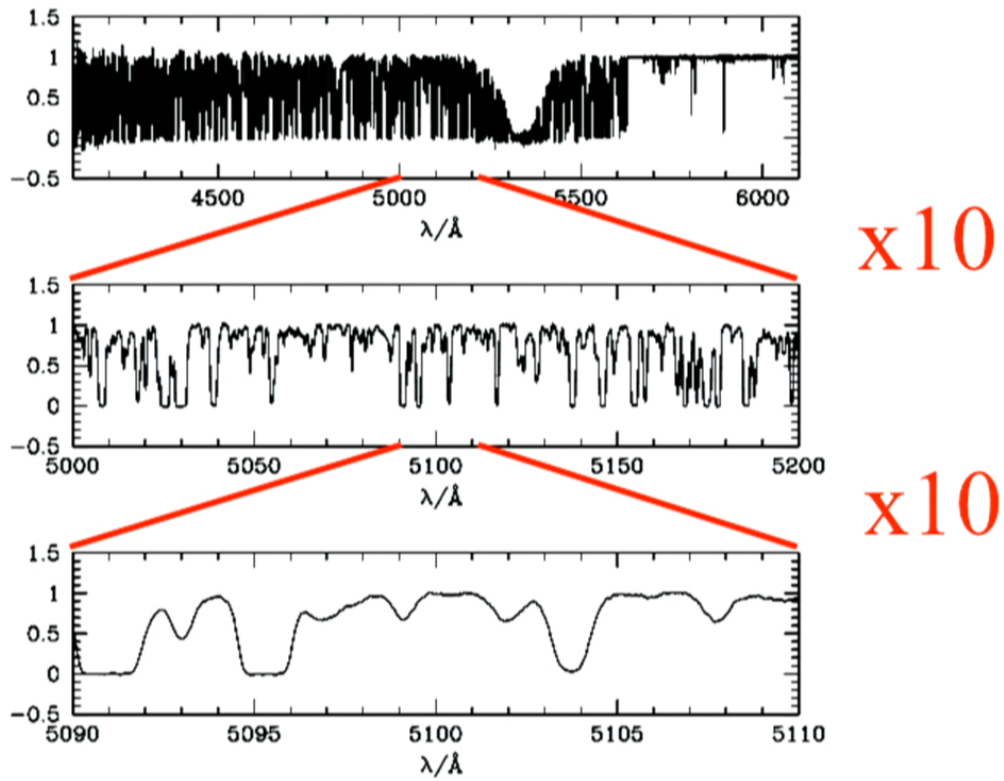
High resolution – High S/N!



A treasure trove of information!

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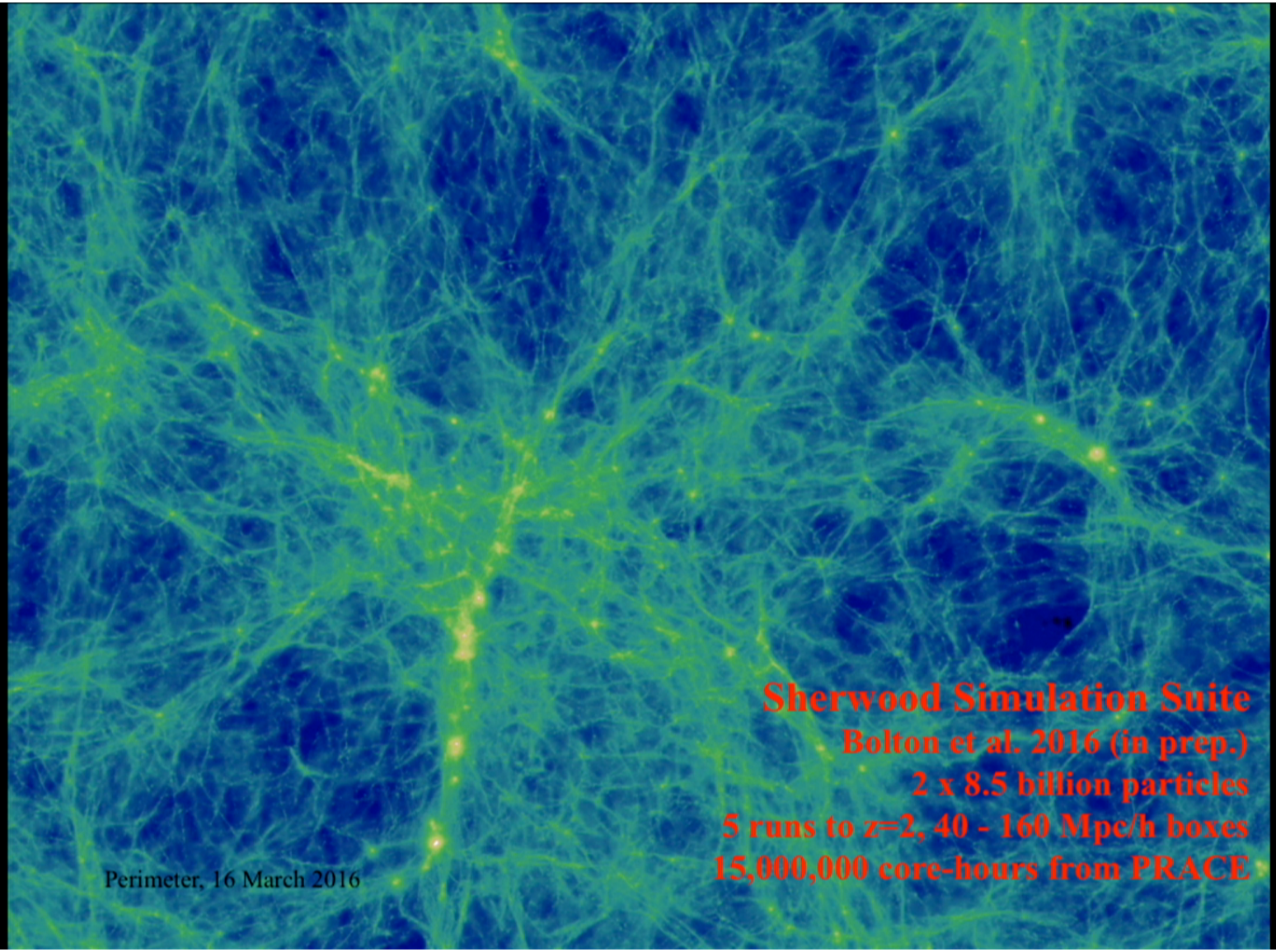
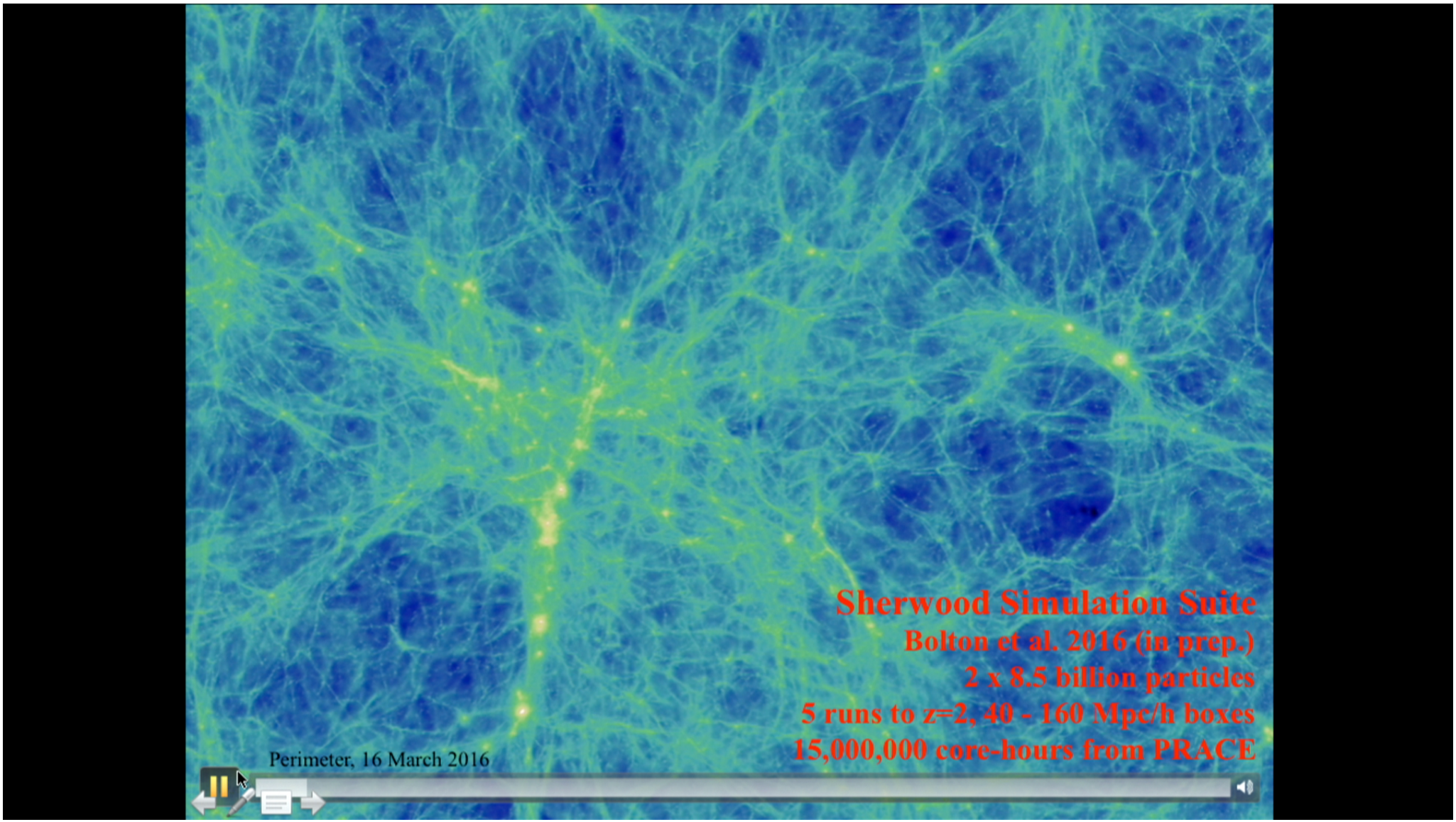

Sherwood Simulation Suite
Bolton et al. 2016 (in prep.)
2 x 8.5 billion particles
5 runs to z=2, 40 - 160 Mpc/h boxes
15,000,000 core-hours from PRACE
Perimeter, 16 March 2016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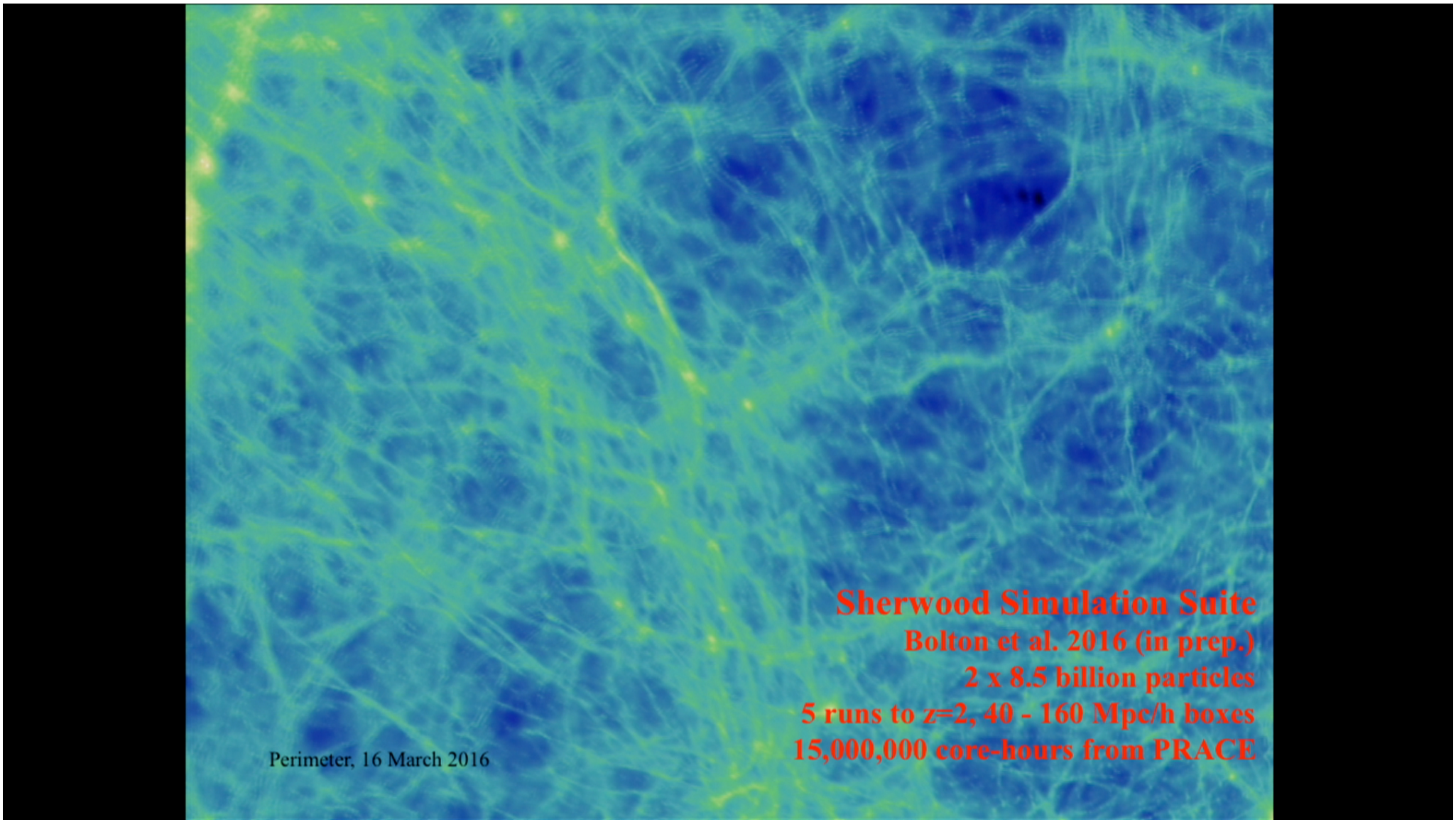
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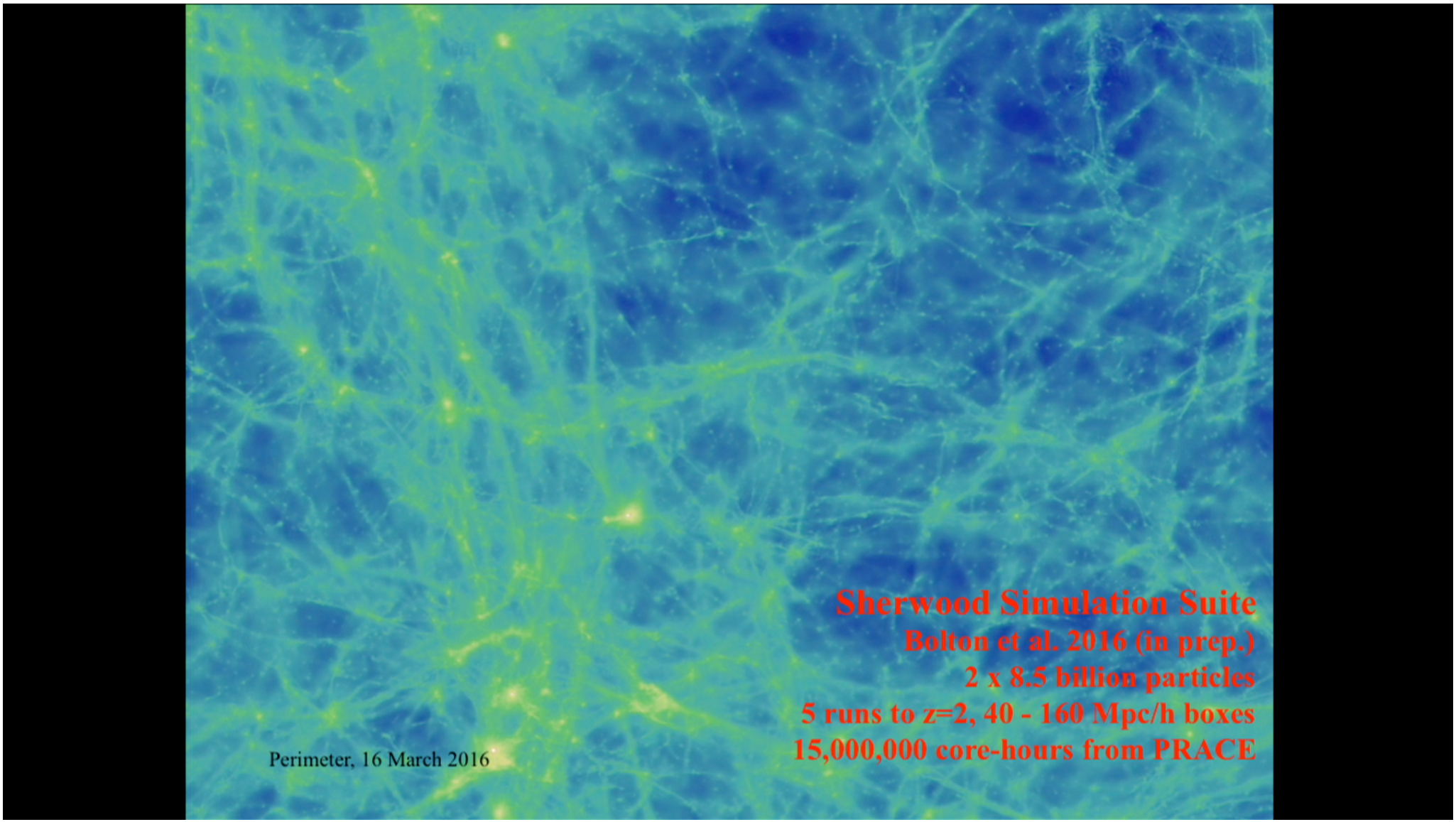
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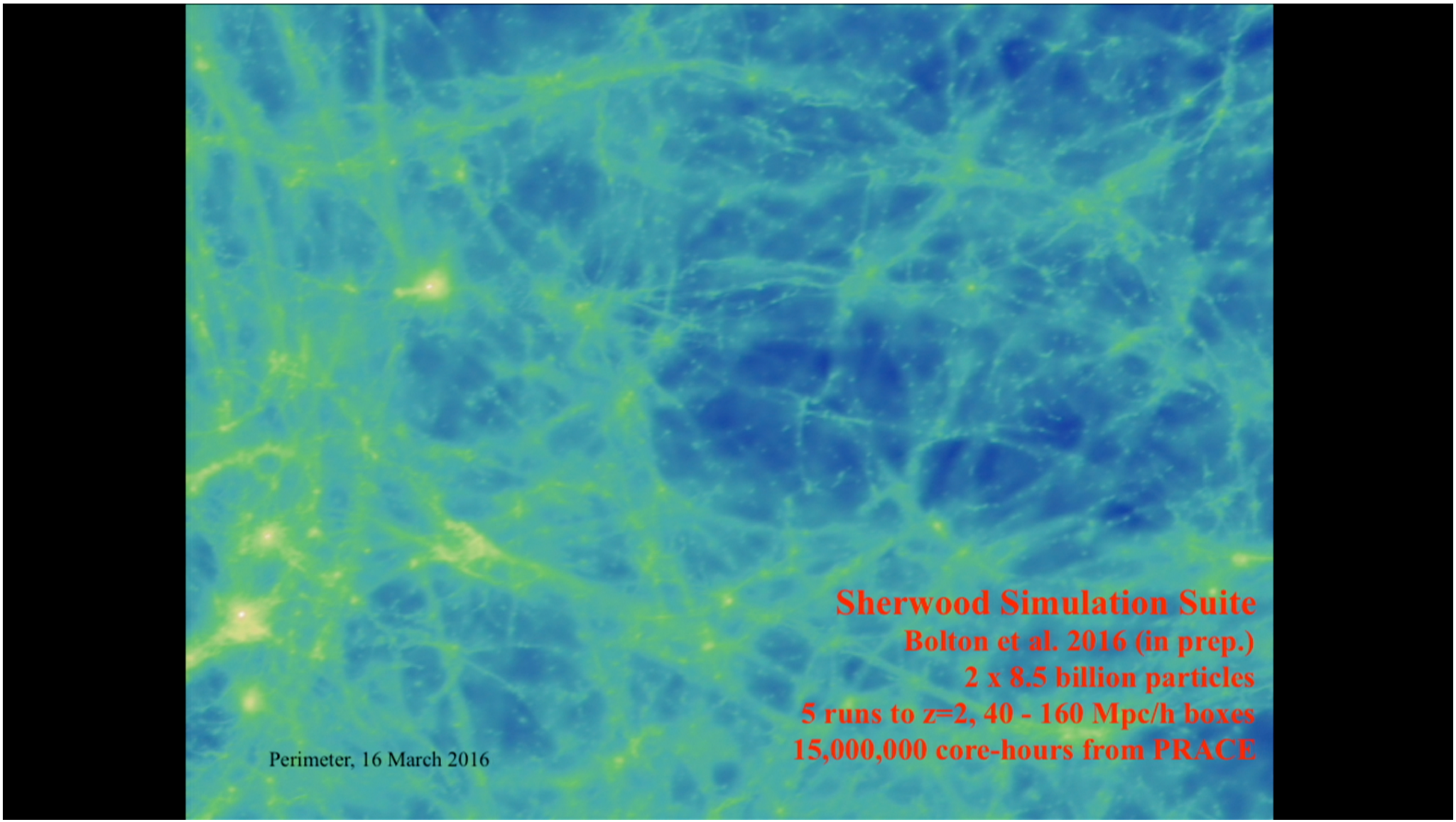
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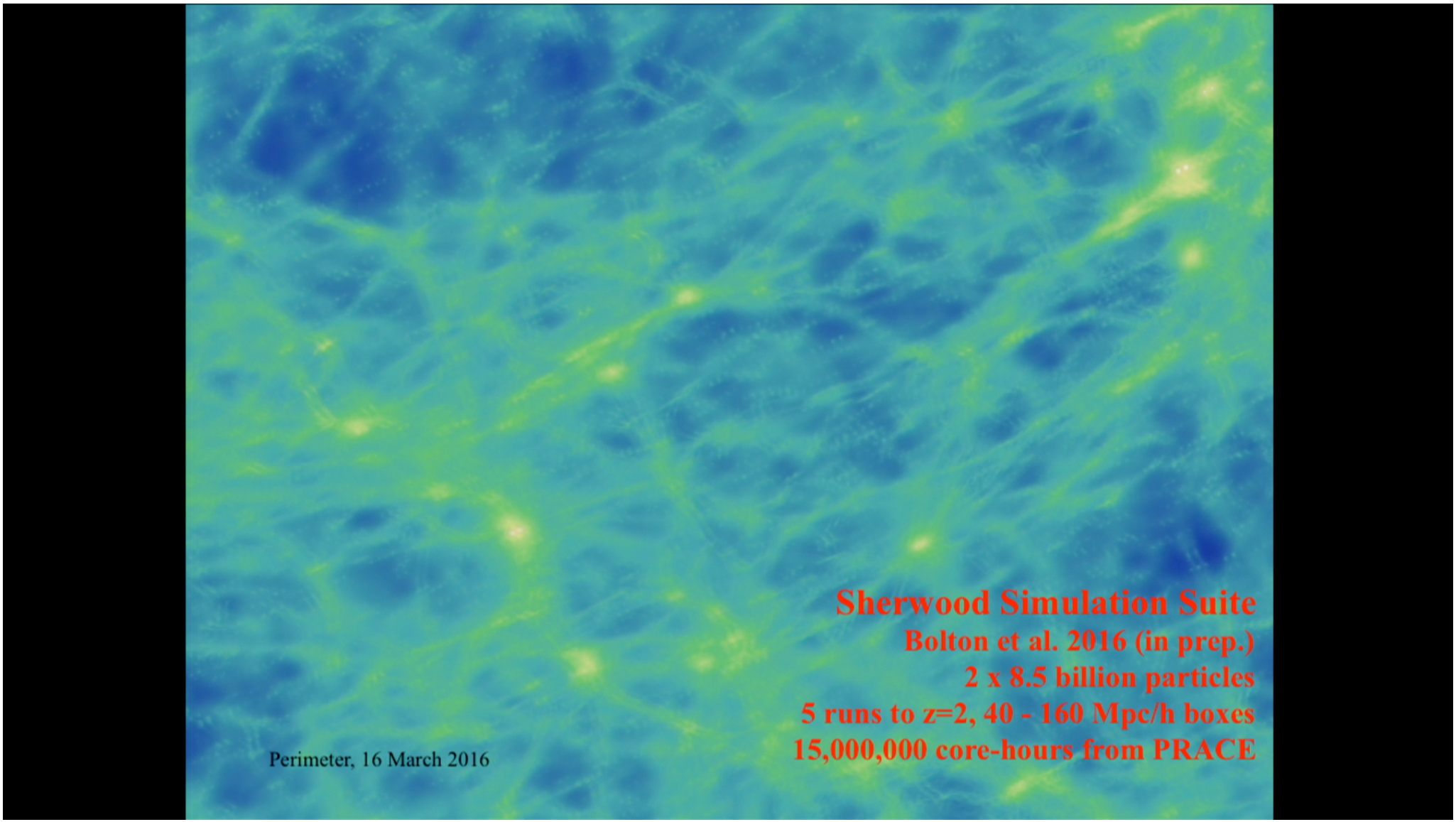
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Perimeter, 16 March 2016

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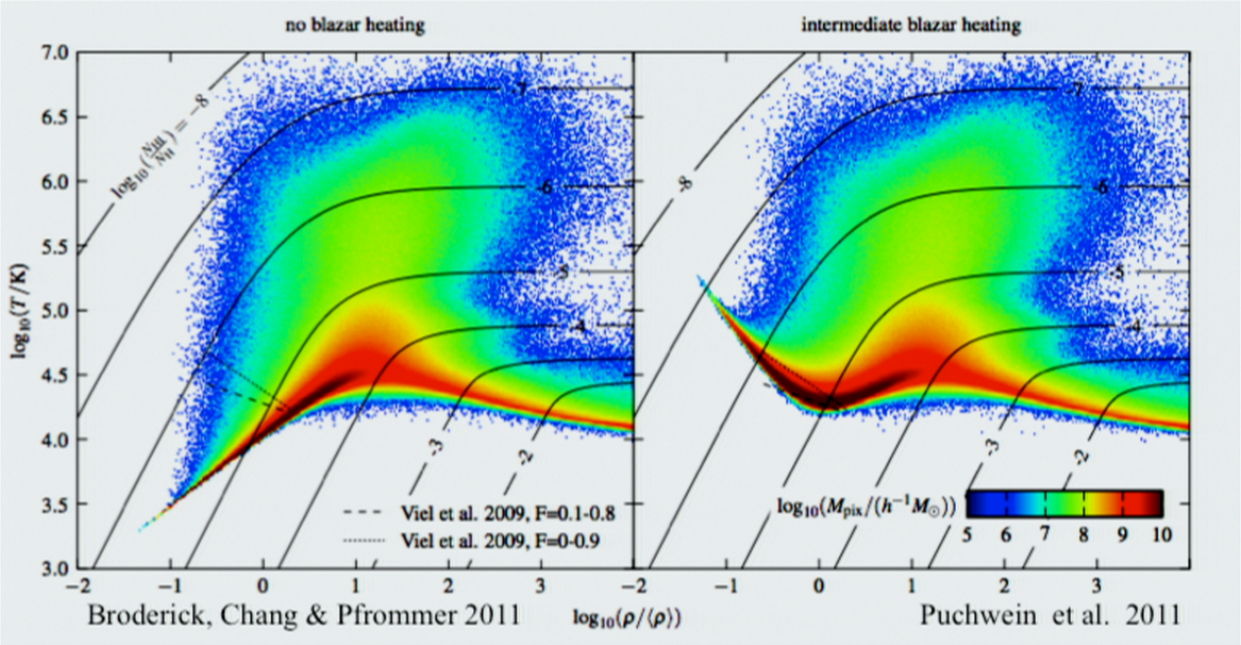
Home » Feedback over 44 orders of magnitude: from Gamma-rays to the Universe

FEEDBACK OVER 44 ORDERS OF MAGNITUDE: FROM GAMMA-RAYS TO THE UNIVERSE

Conference Date: Monday, March 14, 2016 (All day) to Wednesday, March 16, 2016 (All day)
Scientific Areas: Cosmology



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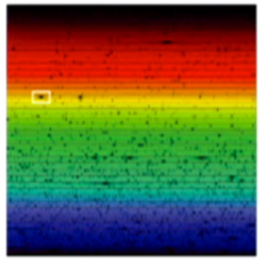
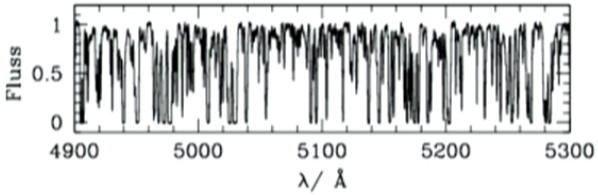
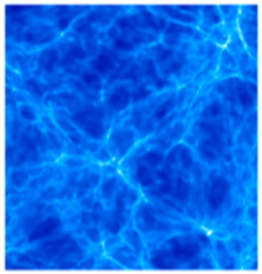
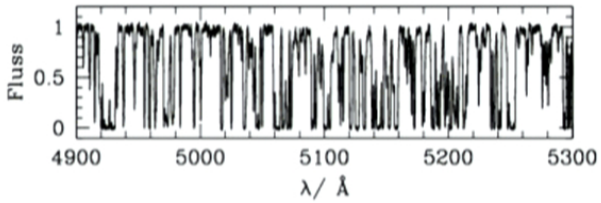
- matter power spectrum on small and intermediate scales
- (high-redshift galaxies)
- (metal enrichment)
- ionization state of the IGM
- thermal history of the IGM
- (reionization)



observed







simulated

Big telescopes and big computers!

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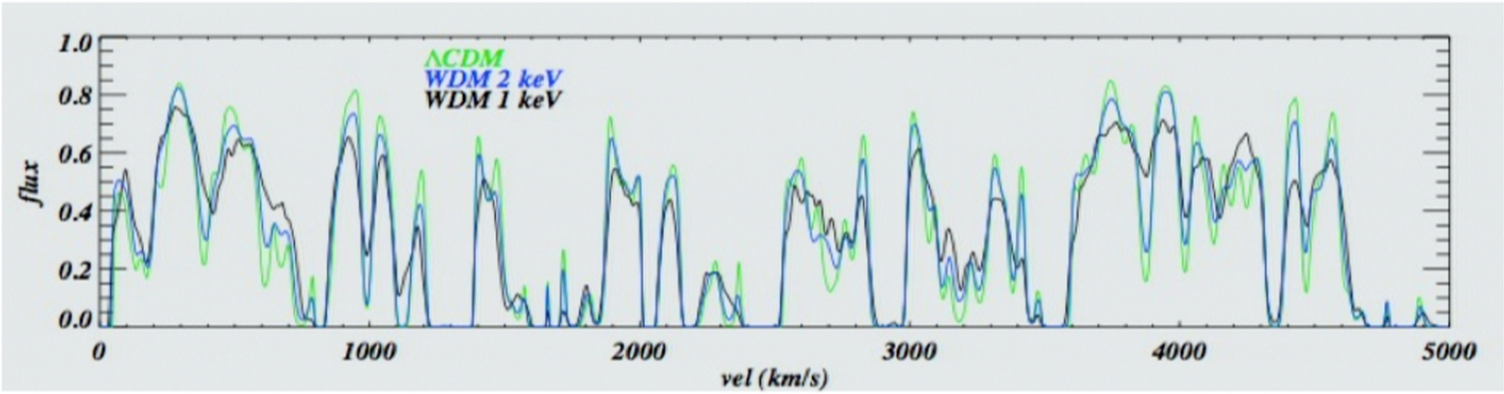

The effect of the free-streaming of (warm) dark matter on the small scale structure in the flux distribution.

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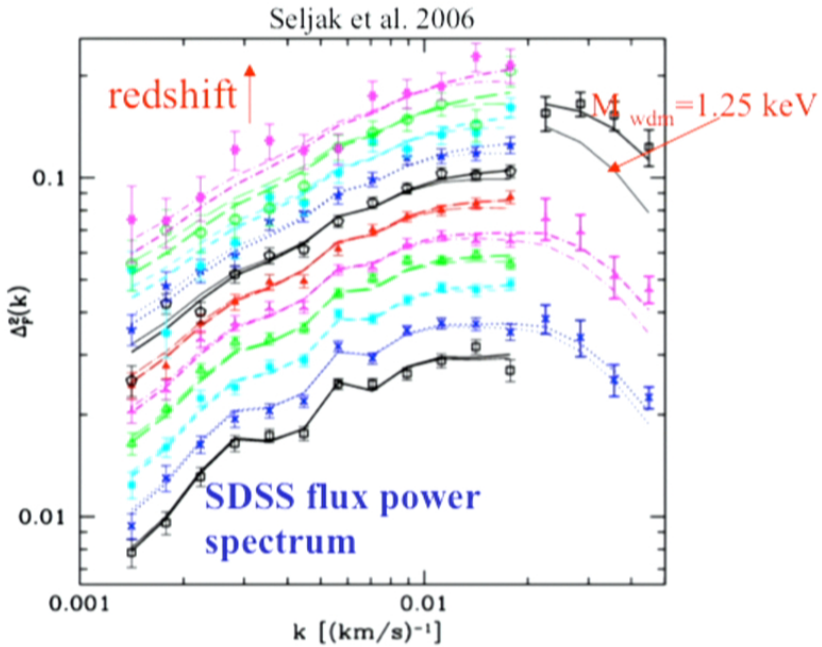
Observational results



large scales small scales

M_{wdm}>2.4 keV

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

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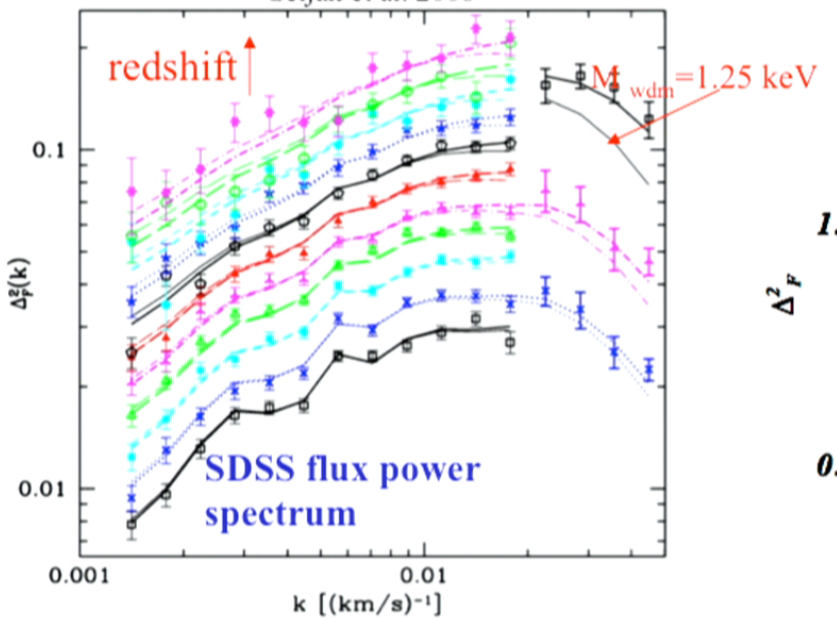
Observational results

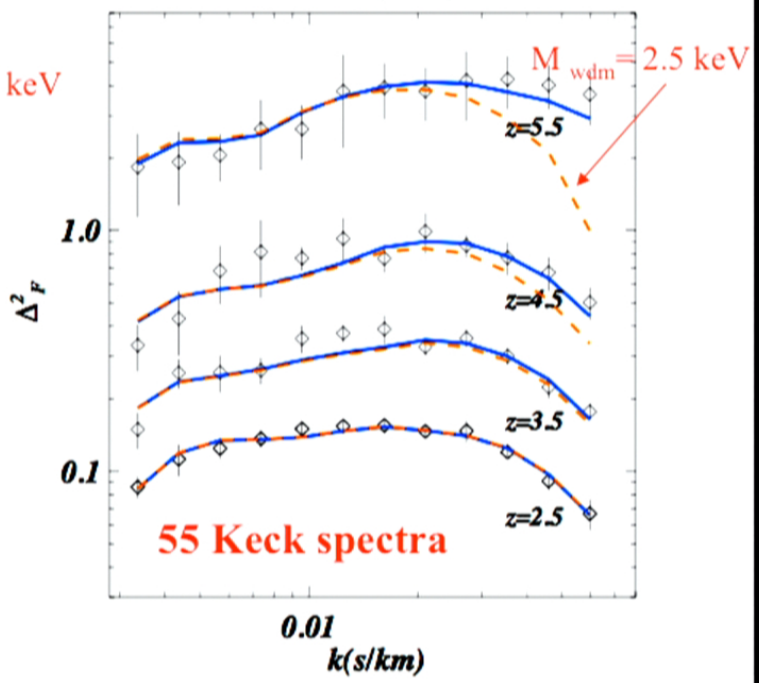
Seljak et al. 2006



large scales small scales

M_{wdm}>2.4 keV

Viel et al. 2006,2007,2008



M_{wdm} > 4 keV

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

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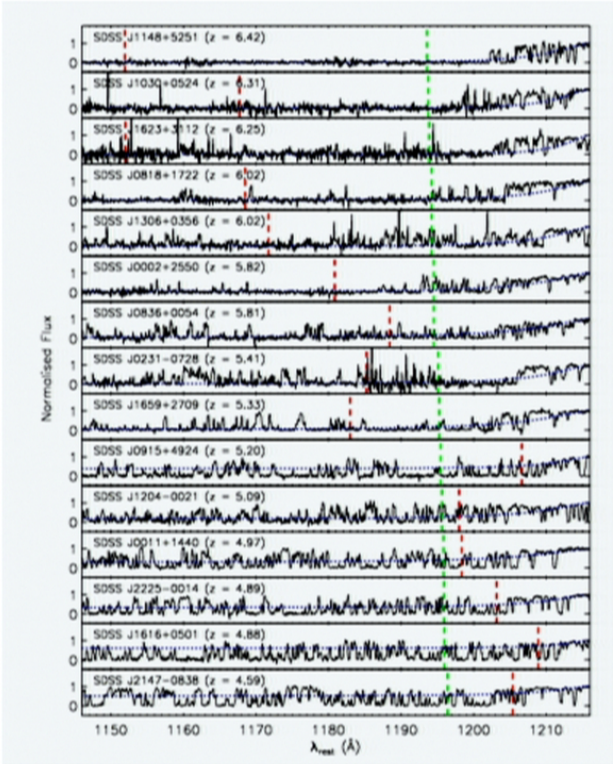

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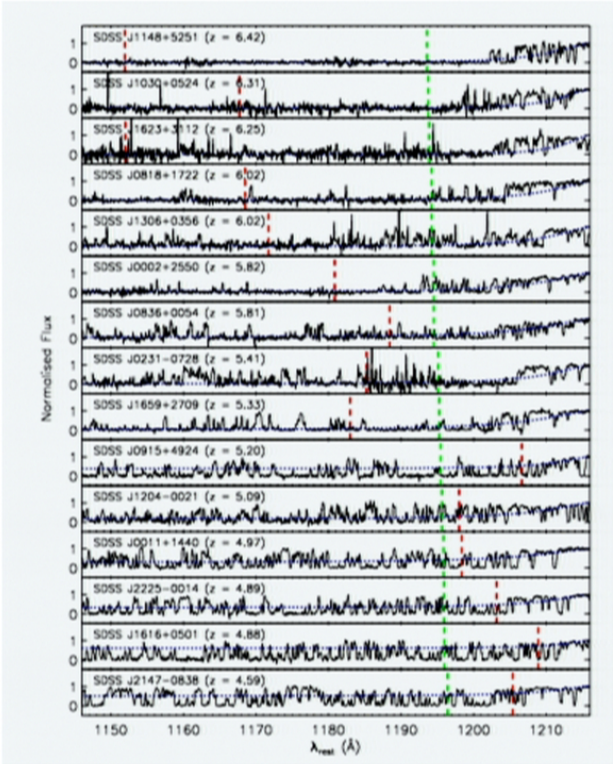
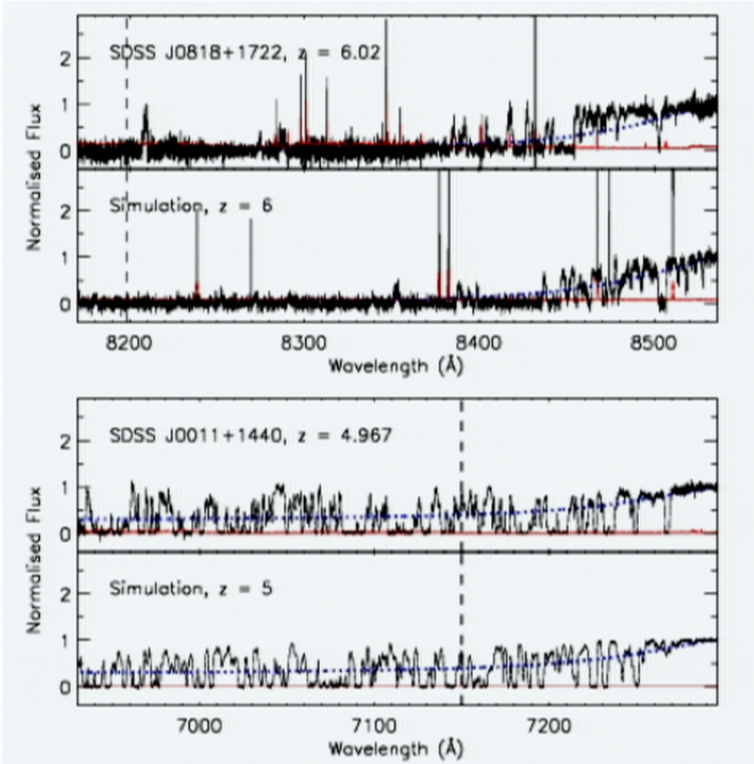
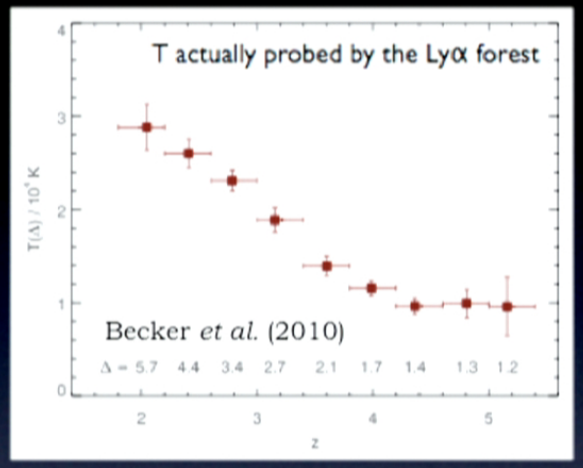




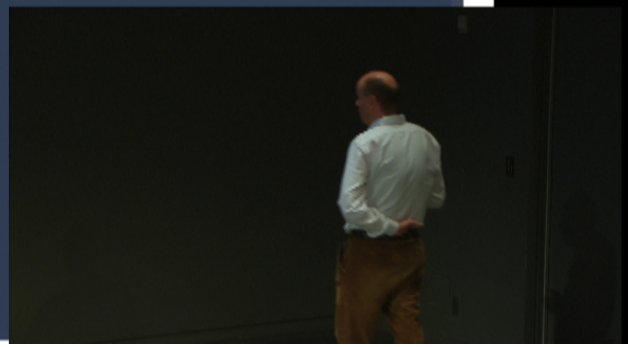
Perimeter, 16 March 2016

Temperature Measurements

- Compare large set of high-resolution QSO spectra to a suite of hydro simulations
- Measure temperatures in the density range probed by the Lyα forest
- Most precise temperature measurements to date
- Results consistent with extended He II reionization ending at z~3



$$T \propto \rho^{(\gamma-1)}$$



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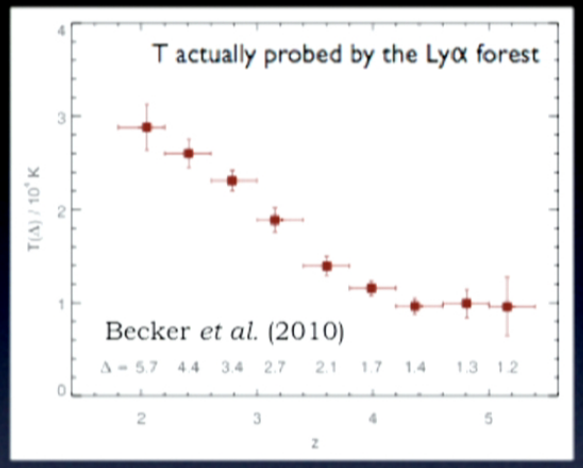
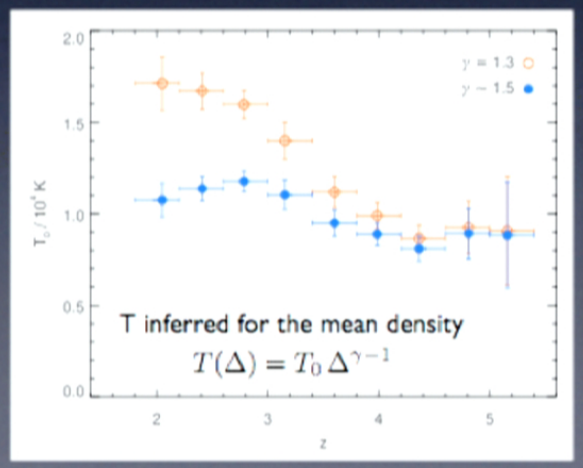
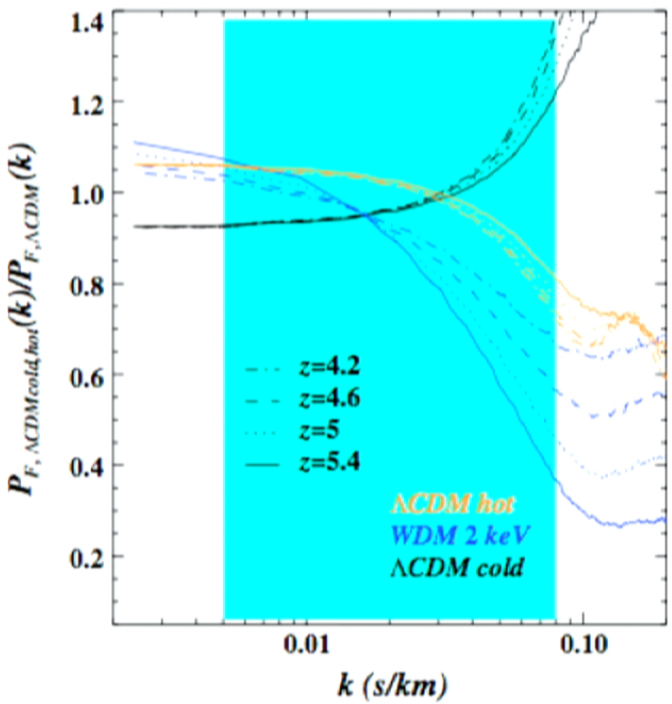




The effects of temperature and free streaming are not degenerate



Viel, Becker, Bolton, Haehnelt 2013

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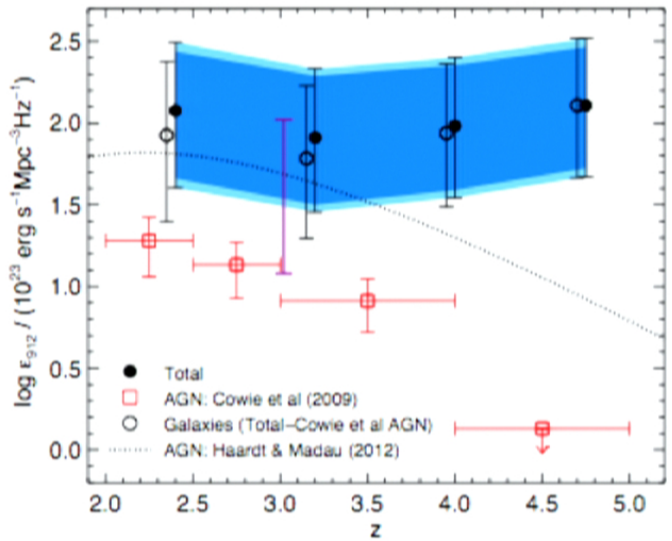
The ionizing emissivity



Becker &Bolton 2013

$$\tau \propto \frac{\alpha \hat{\rho}^2}{\Gamma_{\text{phot}}}$$

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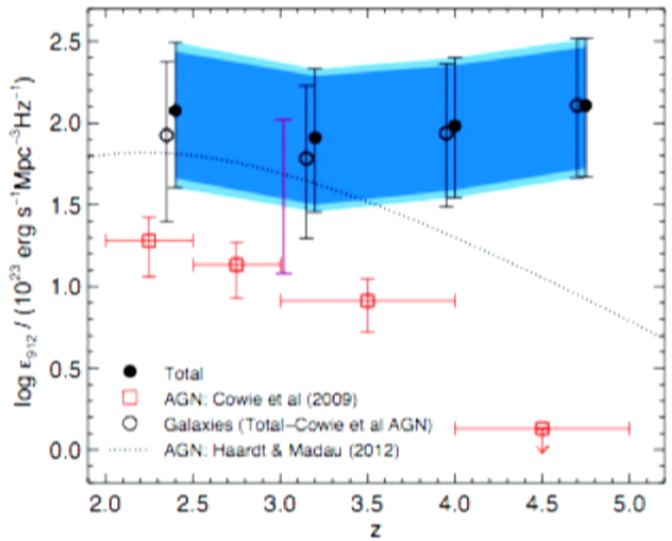
The ionizing emissivity



Becker &Bolton 2013

$$\tau \propto \frac{\alpha \hat{\rho}^2}{\Gamma_{\text{phot}}}$$

corresponds to about 1-2 ionizing photons per hydrogen atom
"photon-starved reionization"

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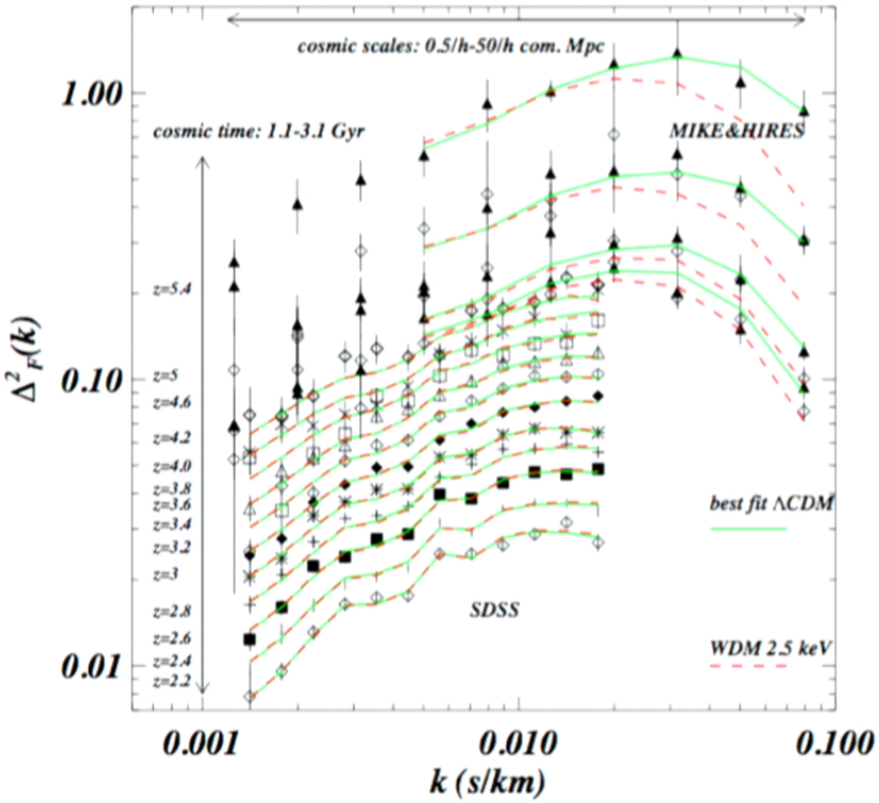
Our "best" WDM results



- more and better data
- more and better simulations
- extensive scrutiny for systematic errors
- improved and conservative analysis

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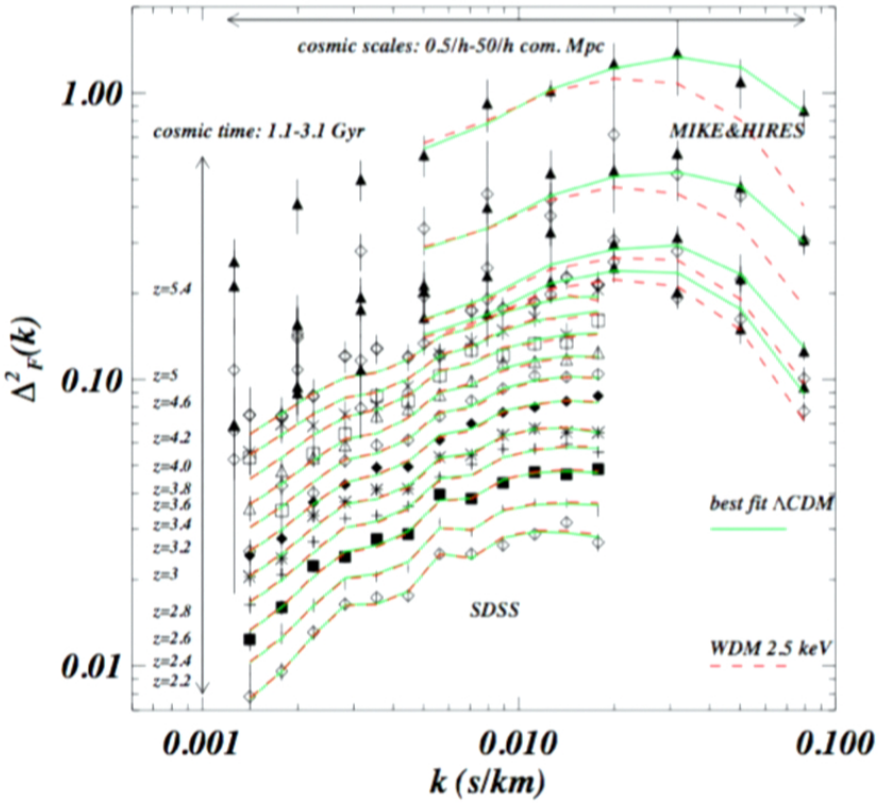
Viel, Becker, Bolton, Haehnelt 2013

Our "best" WDM results



- more and better data
- more and better simulations
- extensive scrutiny for systematic errors
- improved and conservative analysis

$M_{wdm} > 3.3$ keV (2σ C.L)

2 keV WDM disfavoured at about 4σ!

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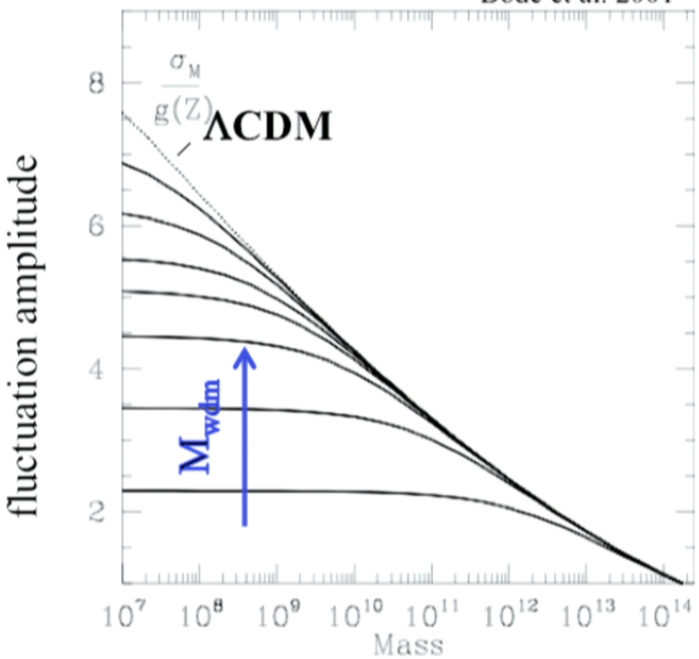
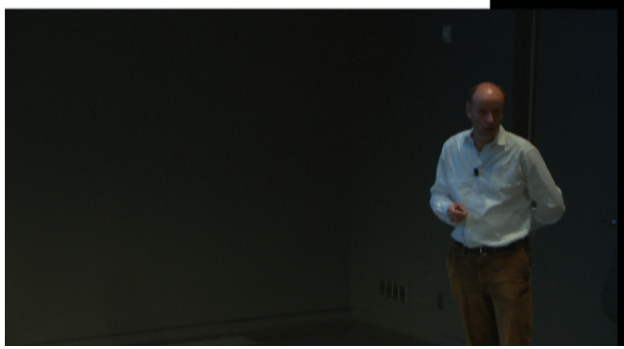
Viel, Becker, Bolton, Haehnelt 2013

DM is pretty cold

Bode et al. 2001





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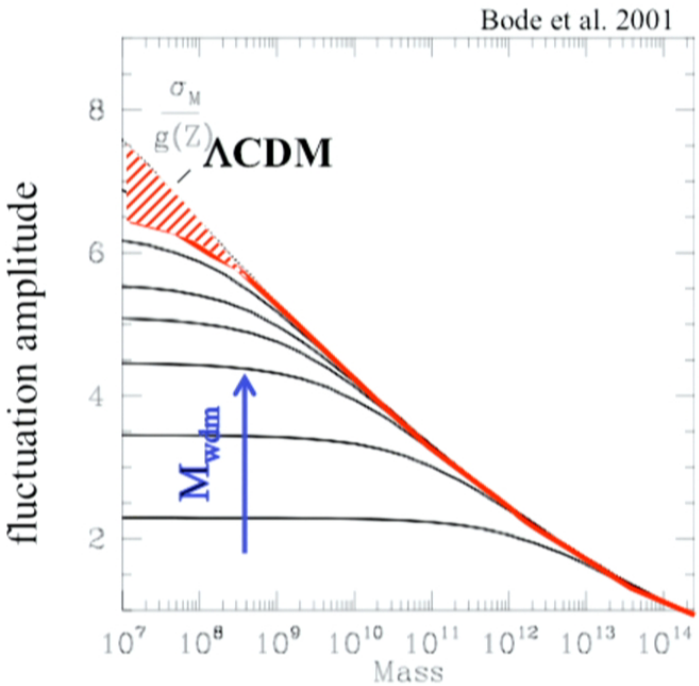
DM is pretty cold

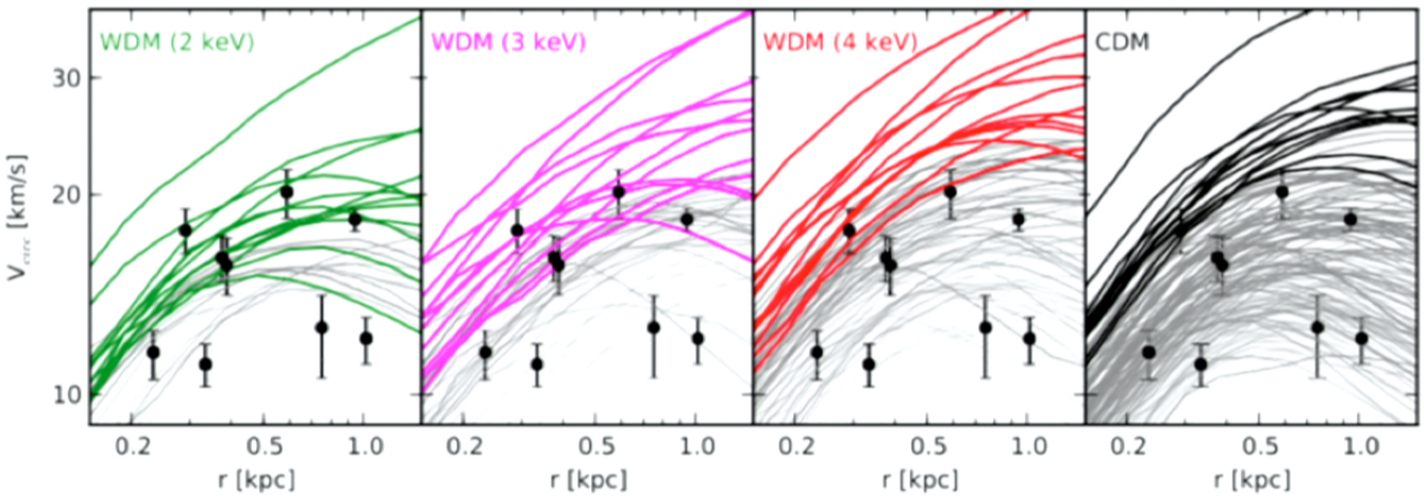


There is little room left for the effect of warm DM on the DM halo mass function (or DM halo profiles).

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

Warm Dark Matter: The End is Nigh

Aurel Schneider[1*], Donnino Anderhalden[2], Andrea V. Macciò[3], and Jürg Diemand[2]
[1] *Department of Physics and Astronomy, University of Sussex, Brighton, BN1 9QH, UK*
[2] *Institute for Theoretical Physics, University of Zurich, 8057 Zurich, Switzerland*
[3] *Max Planck Institut für Astronomie, Königstuhl 17, D-69117 Heidelberg, Germany*
(Dated: September 25, 2013)



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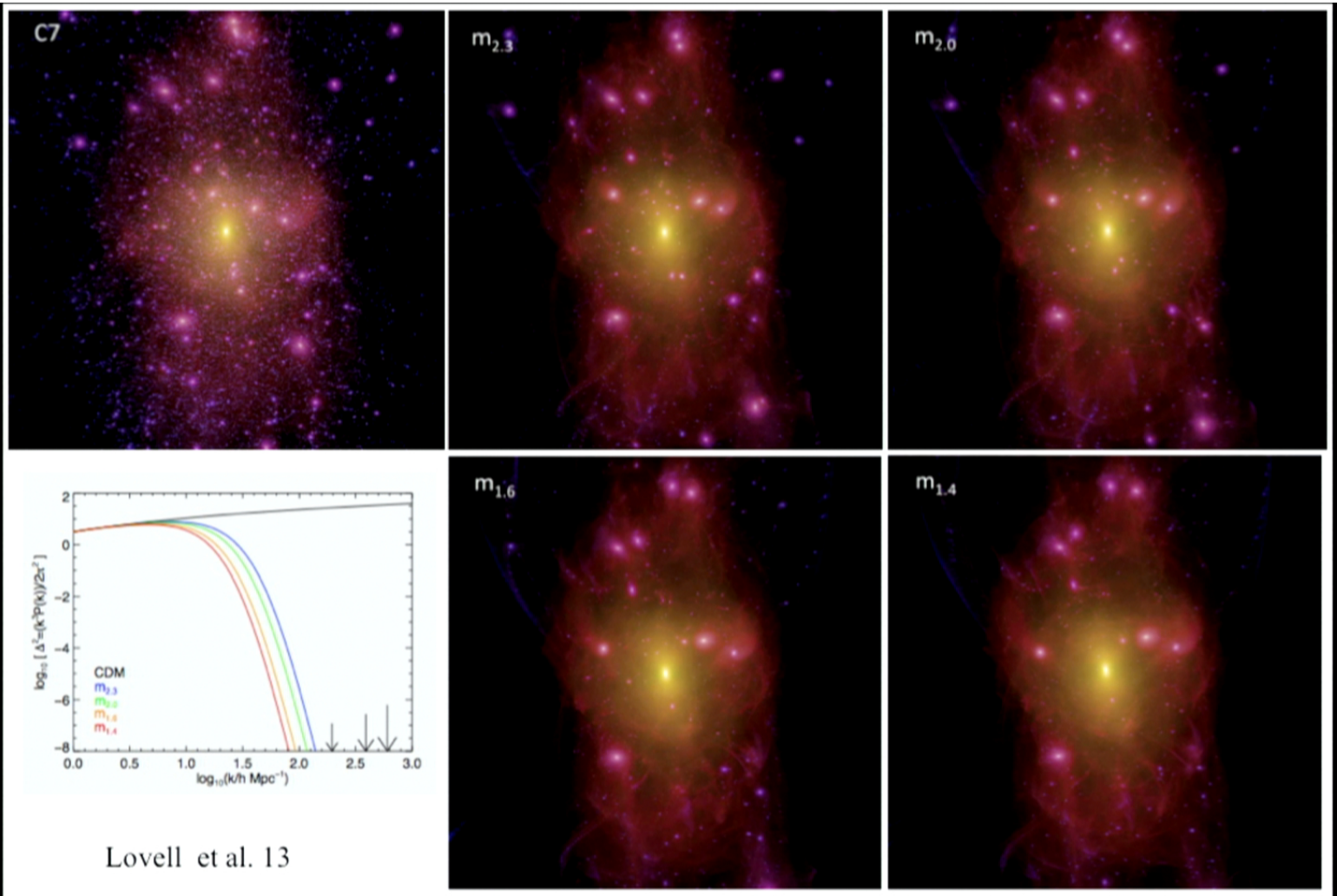

Lovell et al. 13

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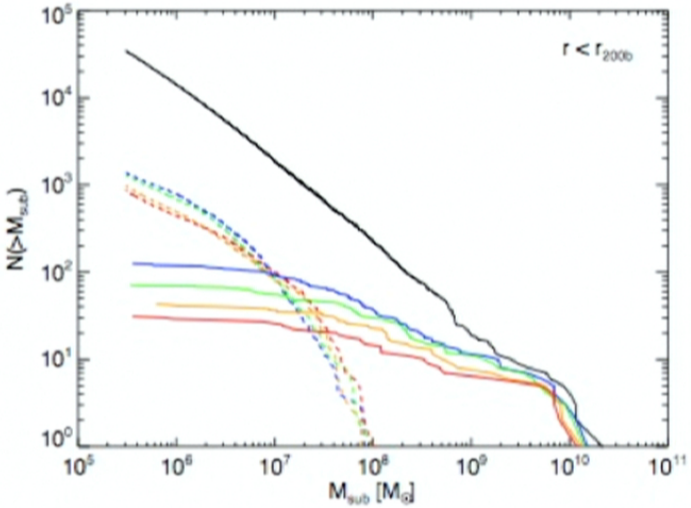
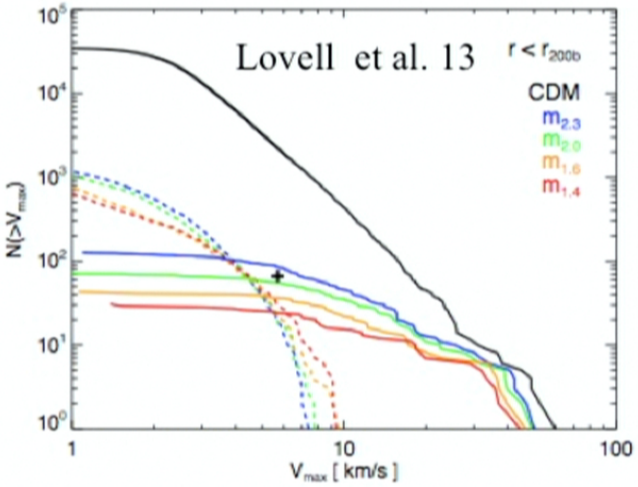
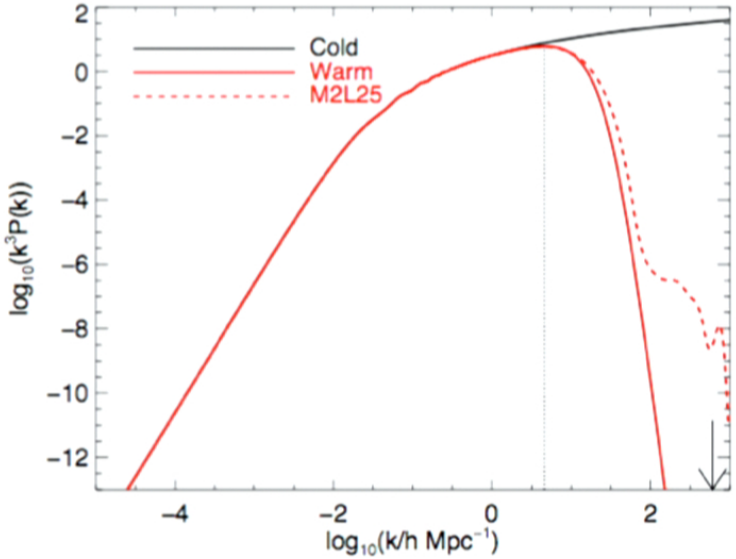
$M_{wdm} > 1.6$ keV (2σ C.L)





But predictions should depend strongly on the Milky way mass and cosmological parameters

2keV sterile neutrino vs 1.4 keV thermal relic



The relation of sterile neutrono masses to free-streaming length is model-dependent and not straightforward. Sterile neutrinos can act as WDM , CDM or a mixture of the two.

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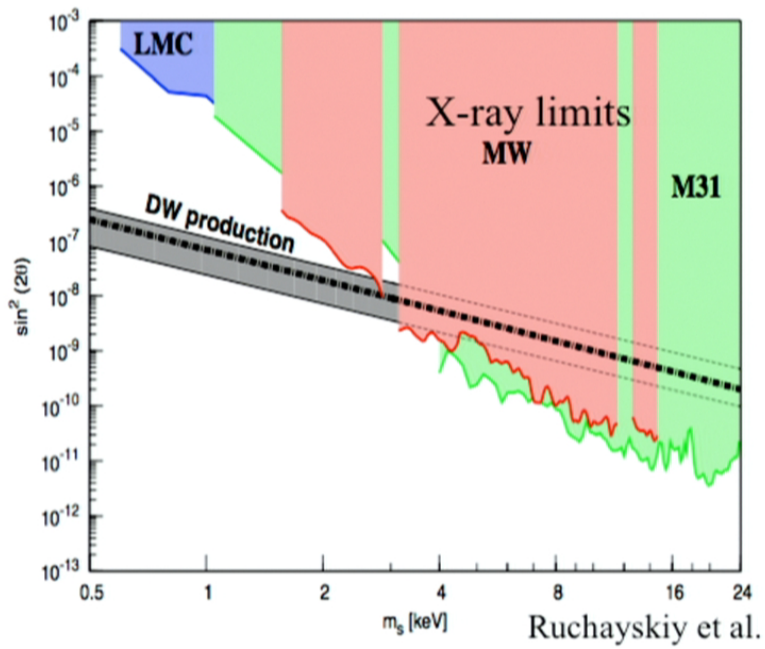
Lovell et al. 12

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



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.

My (slightly provocative) conclusions

1) It appears doubtful that we have seen any astrophysical effects of WDM.

2) Astrophysical effects can only put constraints on the free-streaming of dark matter but not exclude WDM (it could be lukewarm instead).

3) Astrophysical effects cannot rule out sterile neutrinos (they could again be lukewarm DM or mixed DM (cold plus warm)

4) The window for sterile neutrinos to act as astrophysically interesting WDM appears to be closed.

The Future

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European Research Council

The E-ELT
European Research Council

140 M
120 M
100 M
80 M
60 M
40 M
20 M
The E-ELT
European Research Council

Cerro Armazones
-24.58°N -70.18°W
3064 m
Cerro Paranal
-24.6°N -70.4°W
2600 m
©2009 Google
European Research Council

European Research Council

Year	ELT-IFU	ELT-CAM	ELT-MIR	ELT-MOS	ELT-HIRES	ELT-6	ELT-PCS
2014	Decide science requirements, AO architecture.		VISIR start on-sky	Develop science requirements for MOS/HIRES			Start ETD
2015	UK-led			Cal for Proposals Start Phase A			
2016			small UK contribution	Consortium Selection for construction		Call for proposals	
2017				major UK contribution			
2018							TRL check
2019						Selection	Start when ready
2020							
2021							
2022							
2023							
2024	E-ELT first light now planned for 2024						

	Pre-studies taking the form of phase A or delta-phase A work and/or ESO-funded Enabling Technology Development (ETD)
	Decision point
	Development of Technical Specifications, Statement of Work, Agreement, Instrument Start.

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The HIRES Initiative

An Initiative Toward the Realisation of the best High Resolution Spectrograph for the E-ELT

Home | Organisation | Science | Instrument

- Italy
- UK (Cambridge, Durham, ATC Edinburgh, Herriot-Watt)
- Switzerland

- Chile
- Germany
- France
- Portugal
- Spain
- Sweden

Has now turned into HIRES consortium.
Kick-off of Phase A study 22Mar. 2016
Additional members: Brasil, Poland and Denmark

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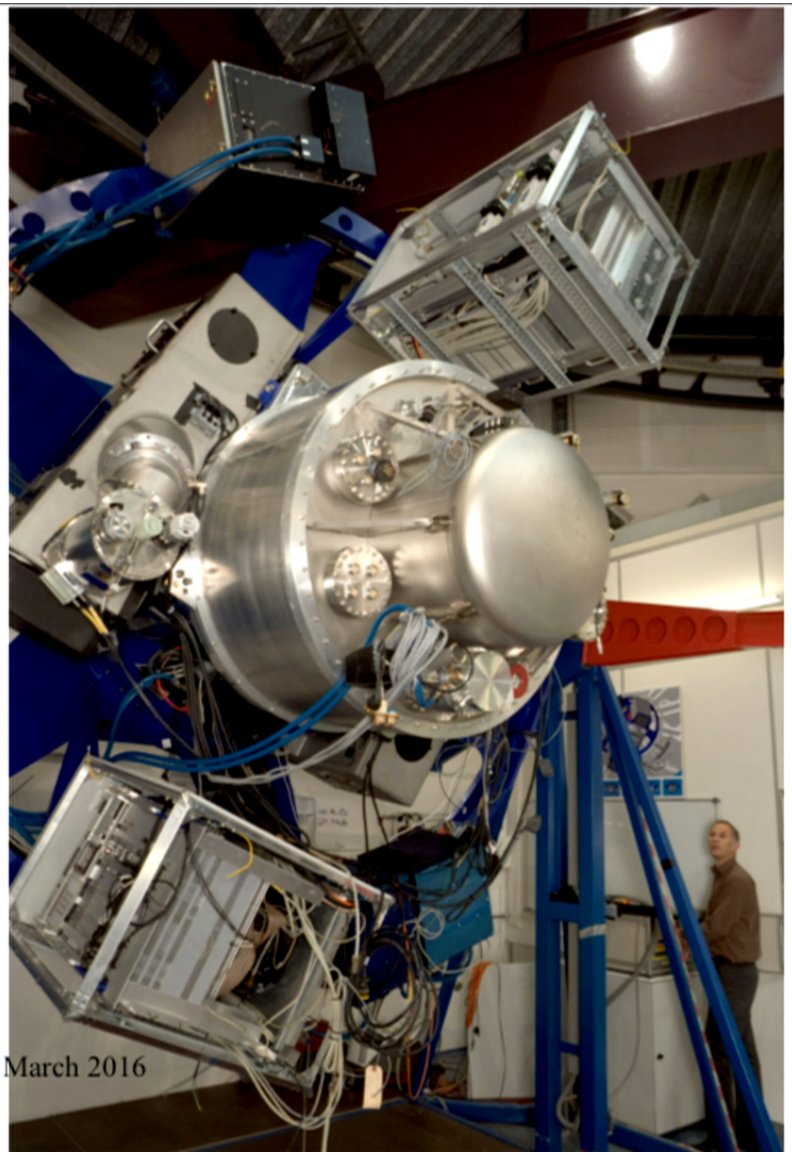

X-shooter

Currently the most oversubscribed instrument at the VLT

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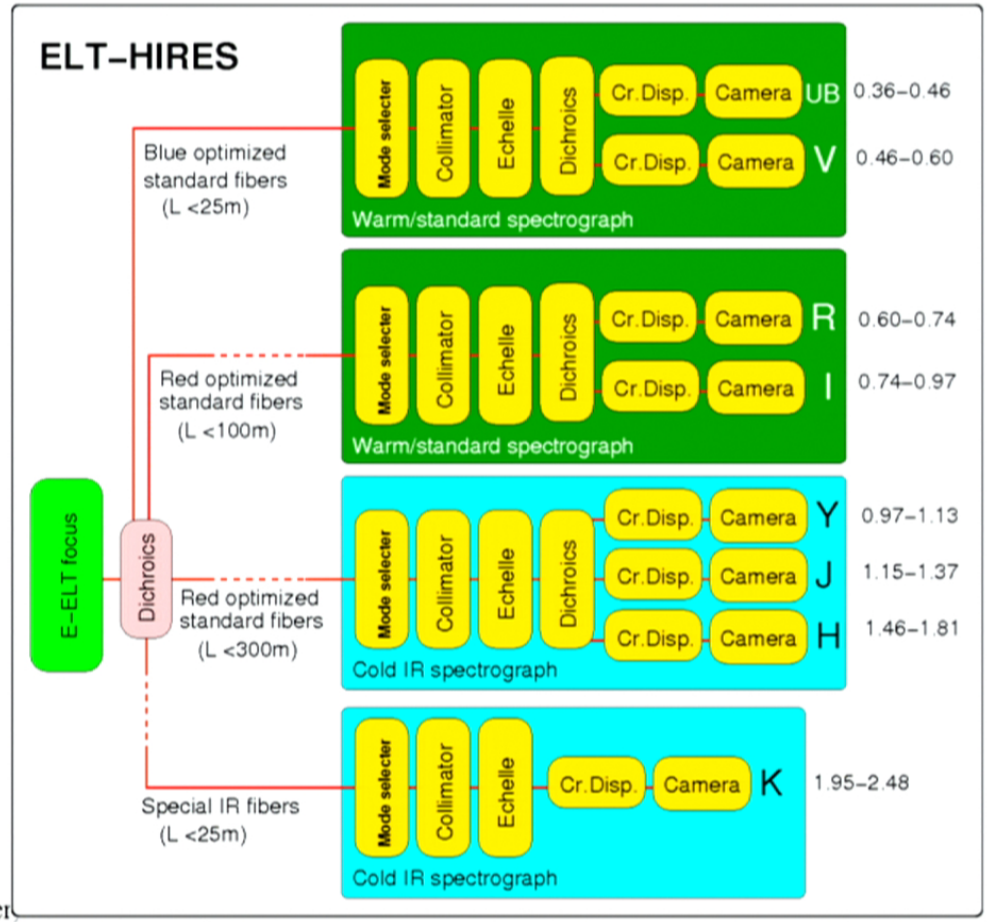
HIRES: a highly modular concept (easy to upgrade or to descope)

E-ELT-HIRES possible scheme of instrument modules



Perimeter

HIRES: A very exciting and wide-ranging science case

Exo-Earths atmospheres: detecting atmospheres of rocky exo-planets and signatures of life. The exoplanets community is making HIRES their ELT flagship

Stellar and planet formation: protoplanetary/protostellar disks and jets

The Galactic and local ISM: unprecedented mapping of the Galaxy chemistry and ISM physics

Astro-archeology: low luminosity (old) stars, extension to Local Group and beyond

Galaxy evolution: exploiting the full, simultaneous spectral coverage to sample galaxy evolution, ~10 "super X-shooter's" deployed on the ELT focal plane

IGM tomography: 3D mapping of the IGM large scale structure and metal enrichment tomography

PopIII stars: detecting the signatures of the first generation of stars through their chemical imprint in primordial galaxies

Fundamental physics: variation of α and μ, (acceleration of the Universe)

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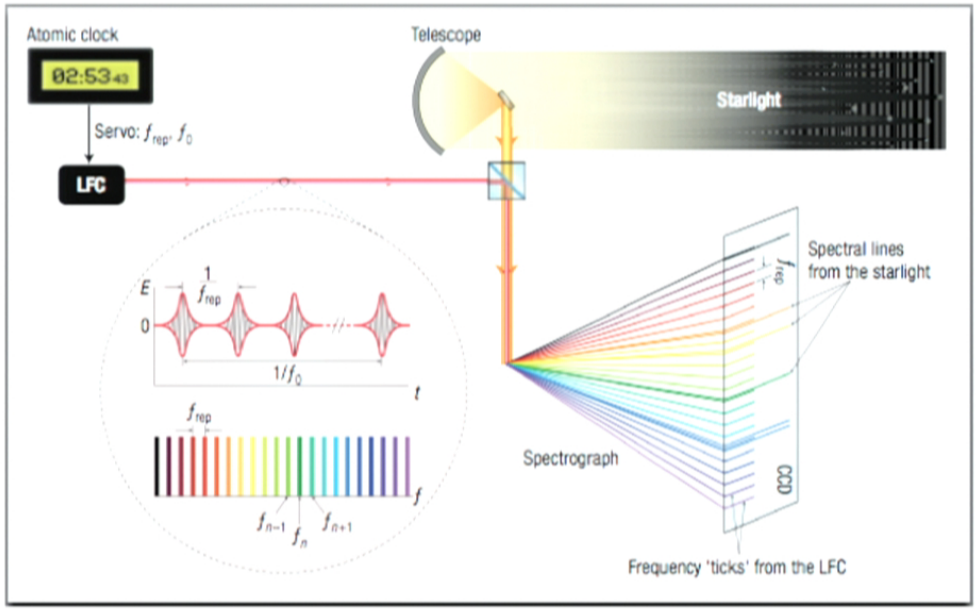
cm/s precision



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

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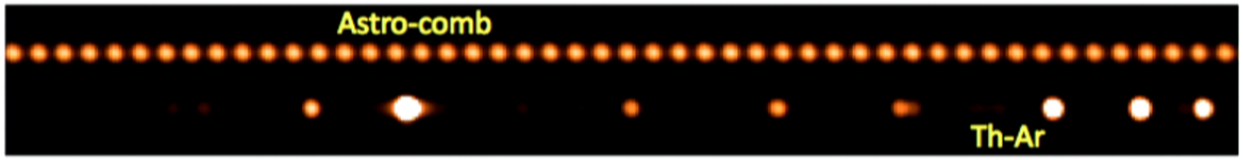
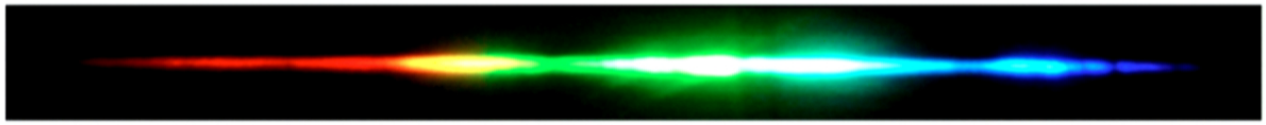
The Laser Frequency Comb: A revolution in calibrating spectra



Th-Ar: ~150 lines per order
7cm/sec RMS repeatability, with 72 orders

Astro-comb: ~350 lines per order
2.5cm/sec PHOTON NOISE LIMITED stability in short term
Achieved spectral coverage > 100 nm (~ 25 orders)



LFC progress

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courtesy Gaspary Locurto

European Research Council

Stability of fundamental constants

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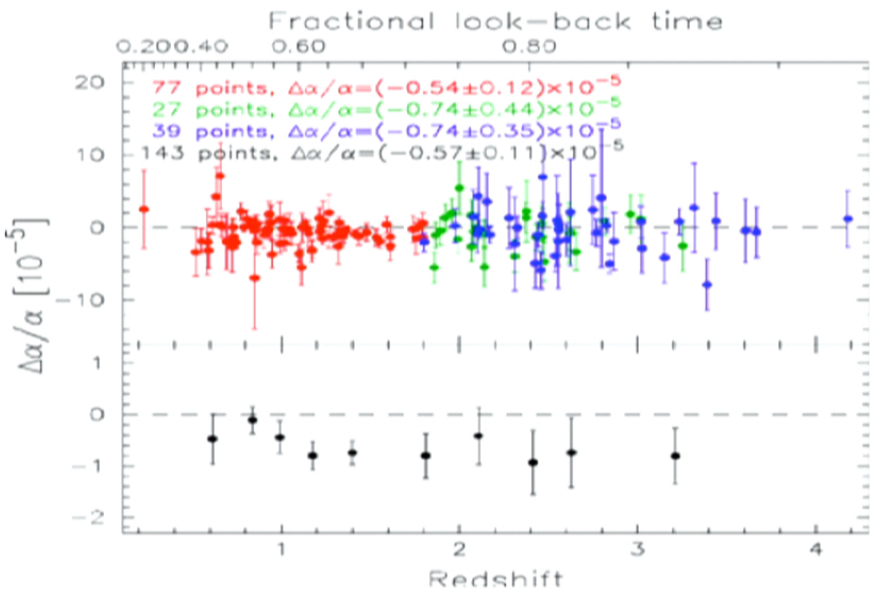
Variability ot the fine structure constant?



Wavelength calibration?

Murphy et al. 2004

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

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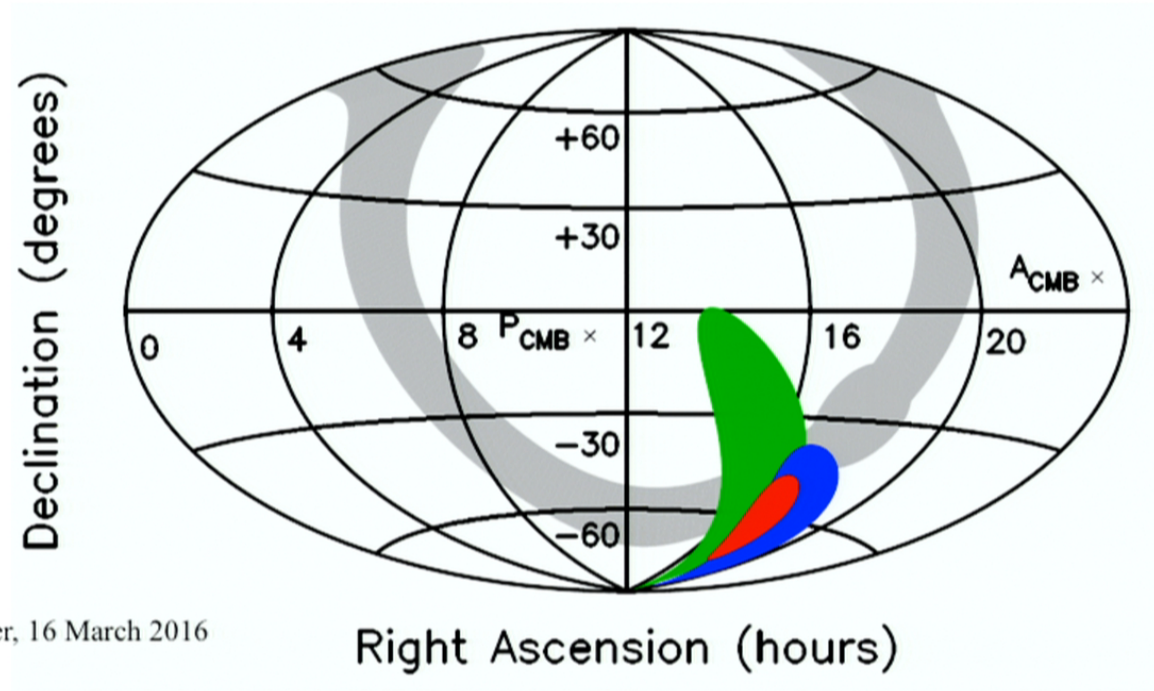
Evidence for spatial variation of the fine structure constant

J. K. Webb[1], J. A. King[1], M. T. Murphy[2], V. V. Flambaum[1], R. F. Carswell[3], and M. B. Bainbridge[1]
[1] *School of Physics, University of New South Wales, Sydney, NSW 2052, Australia*
[2] *Centre for Astrophysics and Supercomputing, Swinburne University of Technology, Mail H39, PO Box 218, Victoria 3122, Australia and*
[3] *Institute of Astronomy, Madingley Road, Cambridge, CB3 0HA, England.*
(Dated: August 25, 2010)



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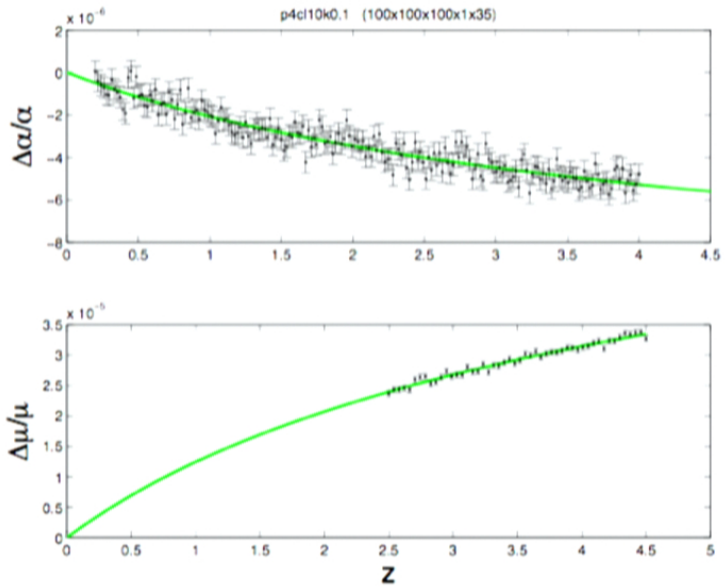
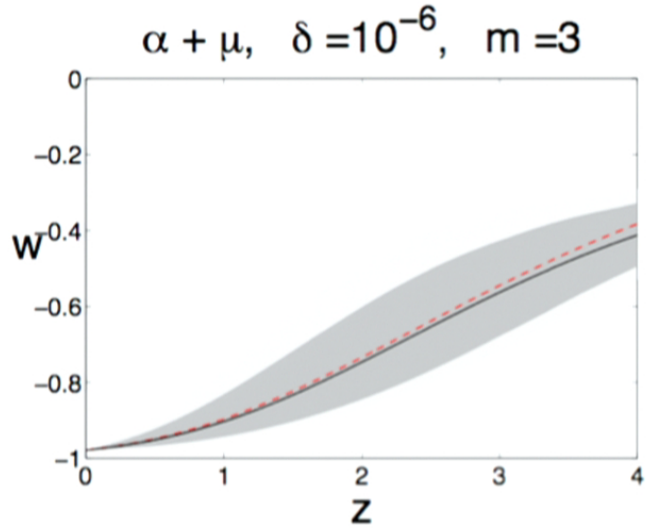
Perhaps the dark energy couples to electro-magnetic fields?





Avelino et al. 2006, Nunes

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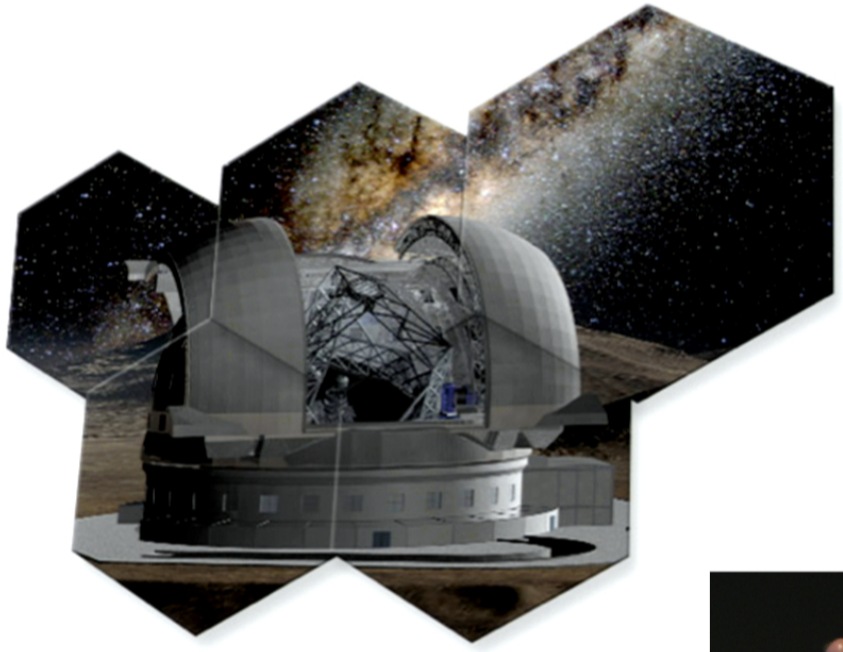
The End



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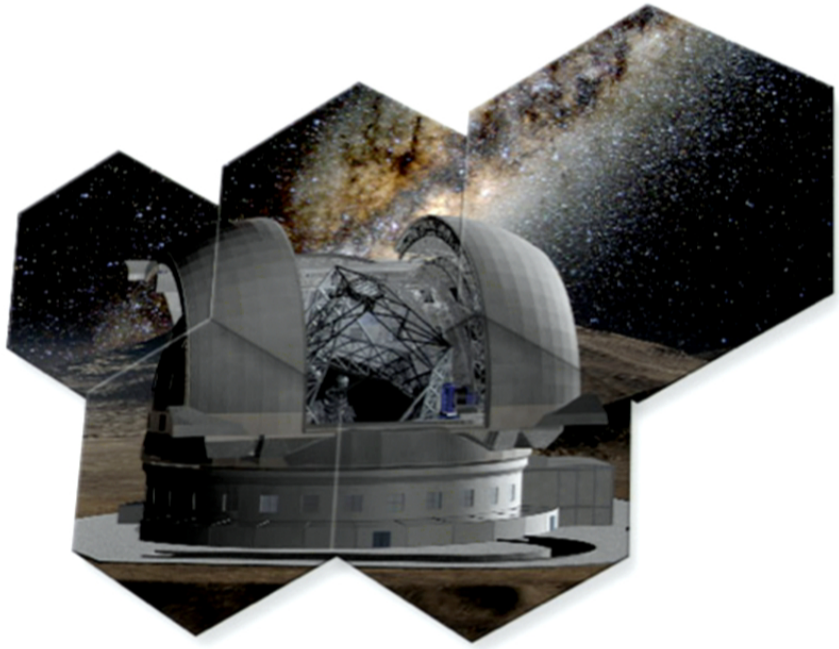
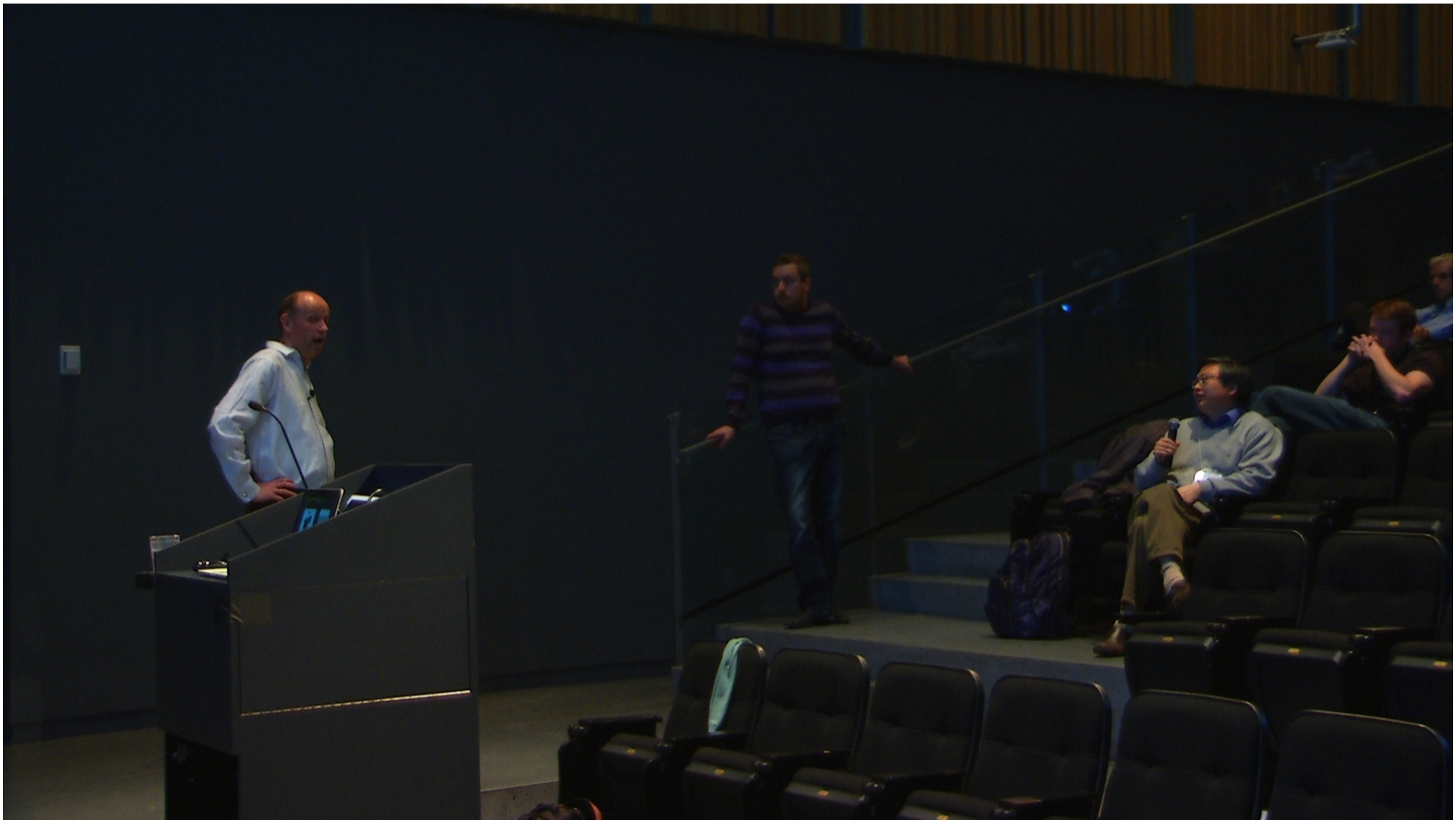
The End



Perimeter, 16 March 2016