Title: PHYS 781 - Final Presentations (Session 1)

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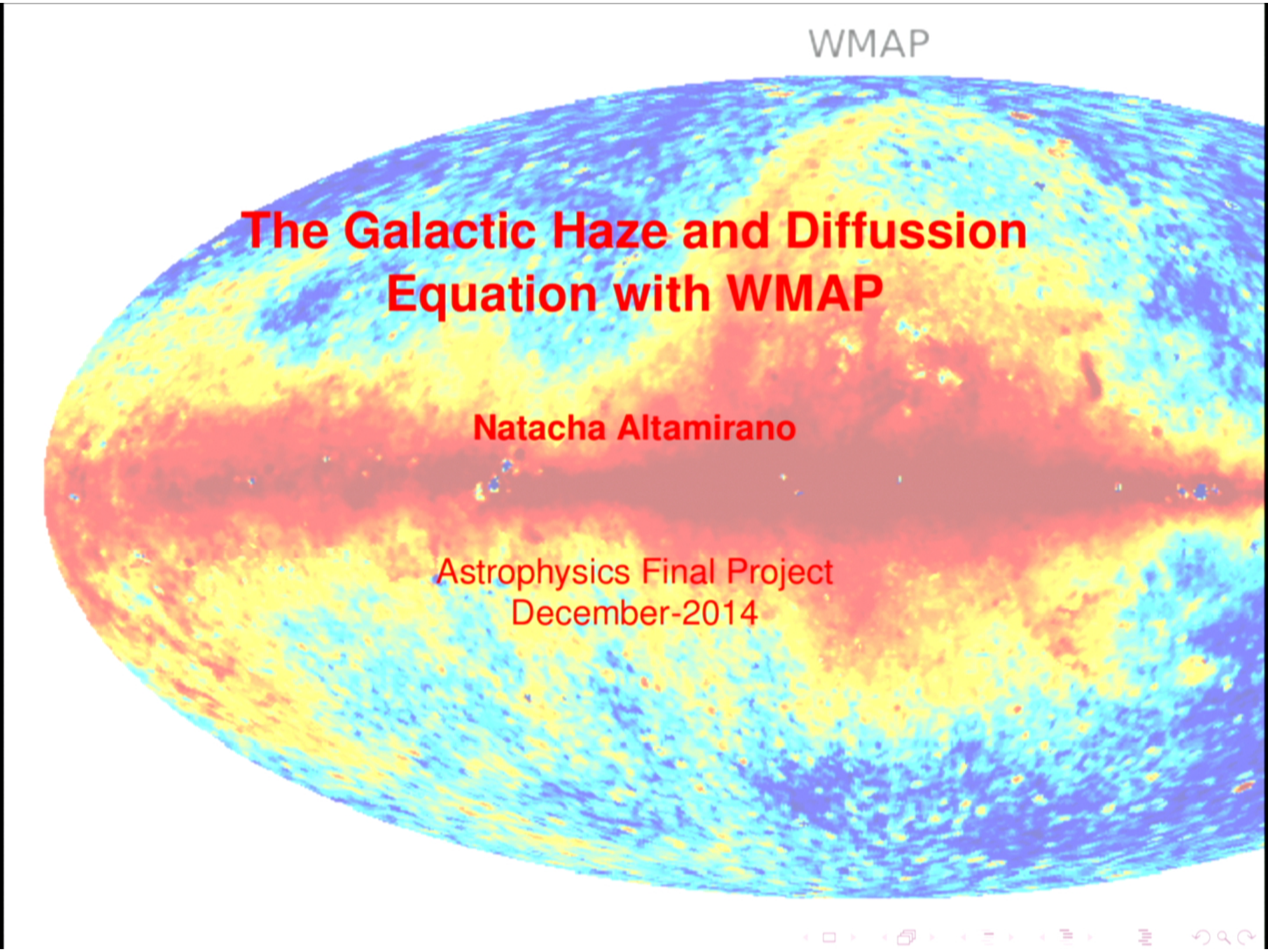
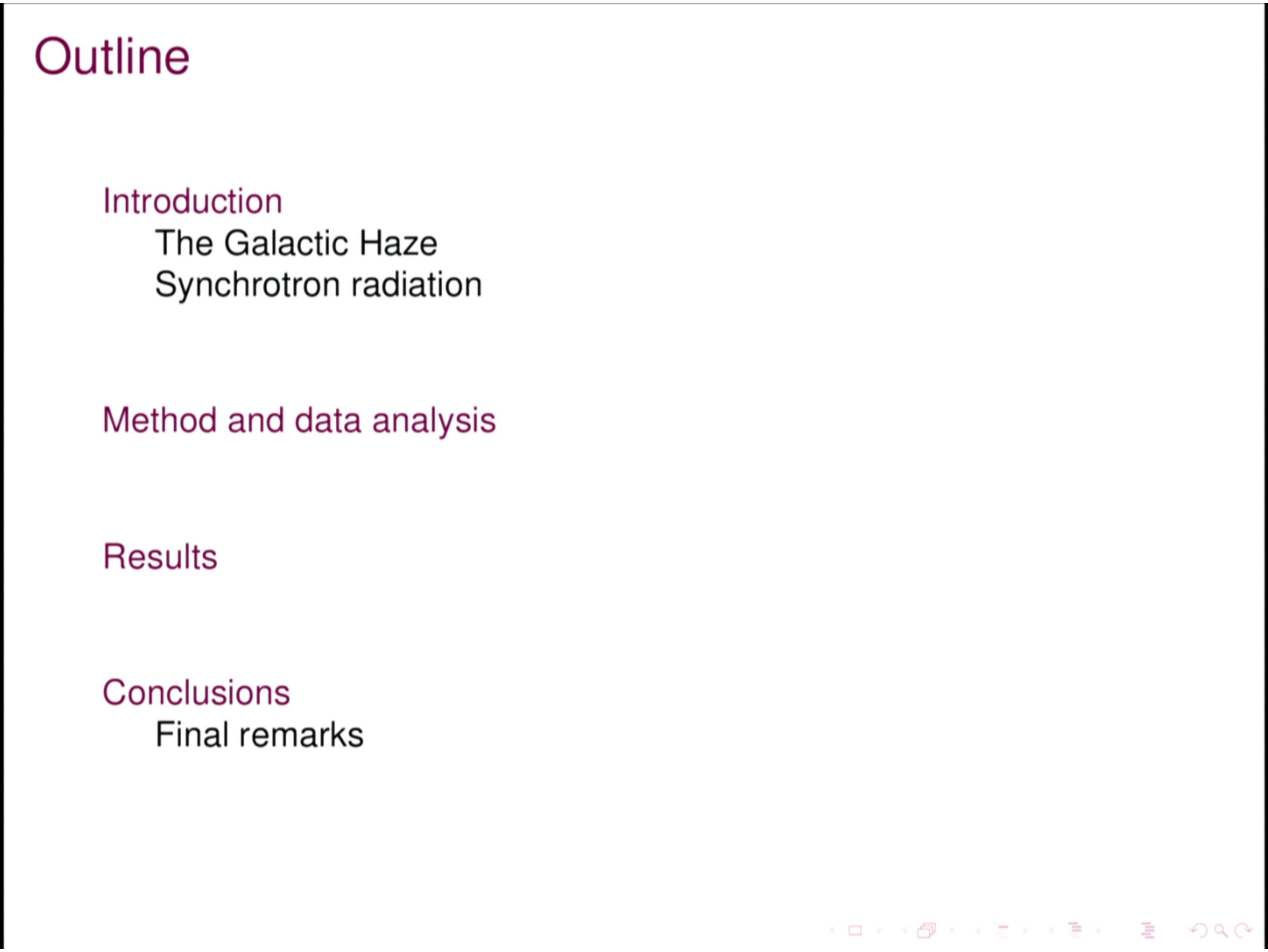
Abstract:



The Galactic Haze and Diffussion Equation with WMAP

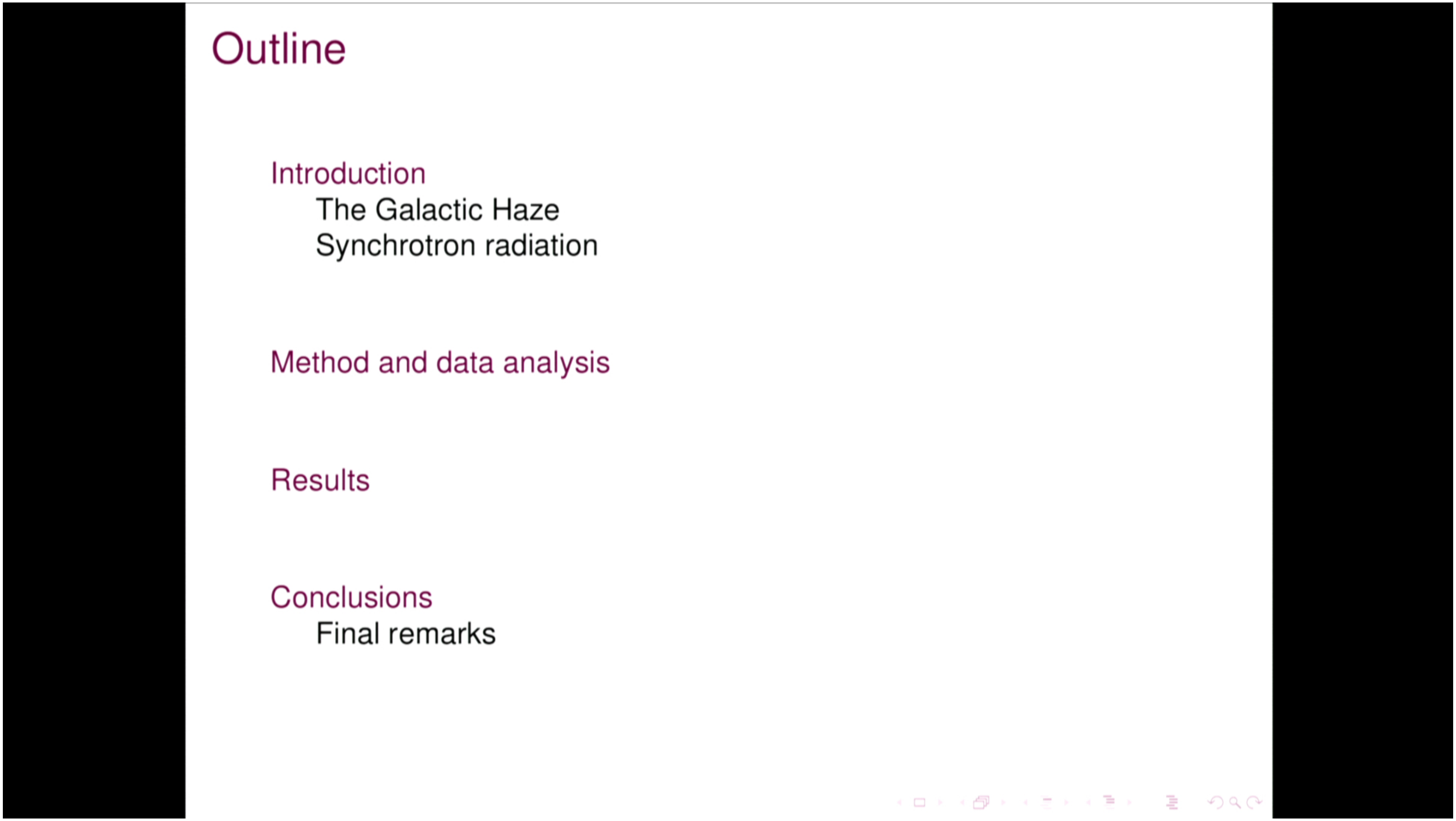
Natacha Altamirano

Astrophysics Final Project
December-2014



Outline

- Introduction
  - The Galactic Haze
  - Synchrotron radiation
- Method and data analysis
- Results
- Conclusions
  - Final remarks



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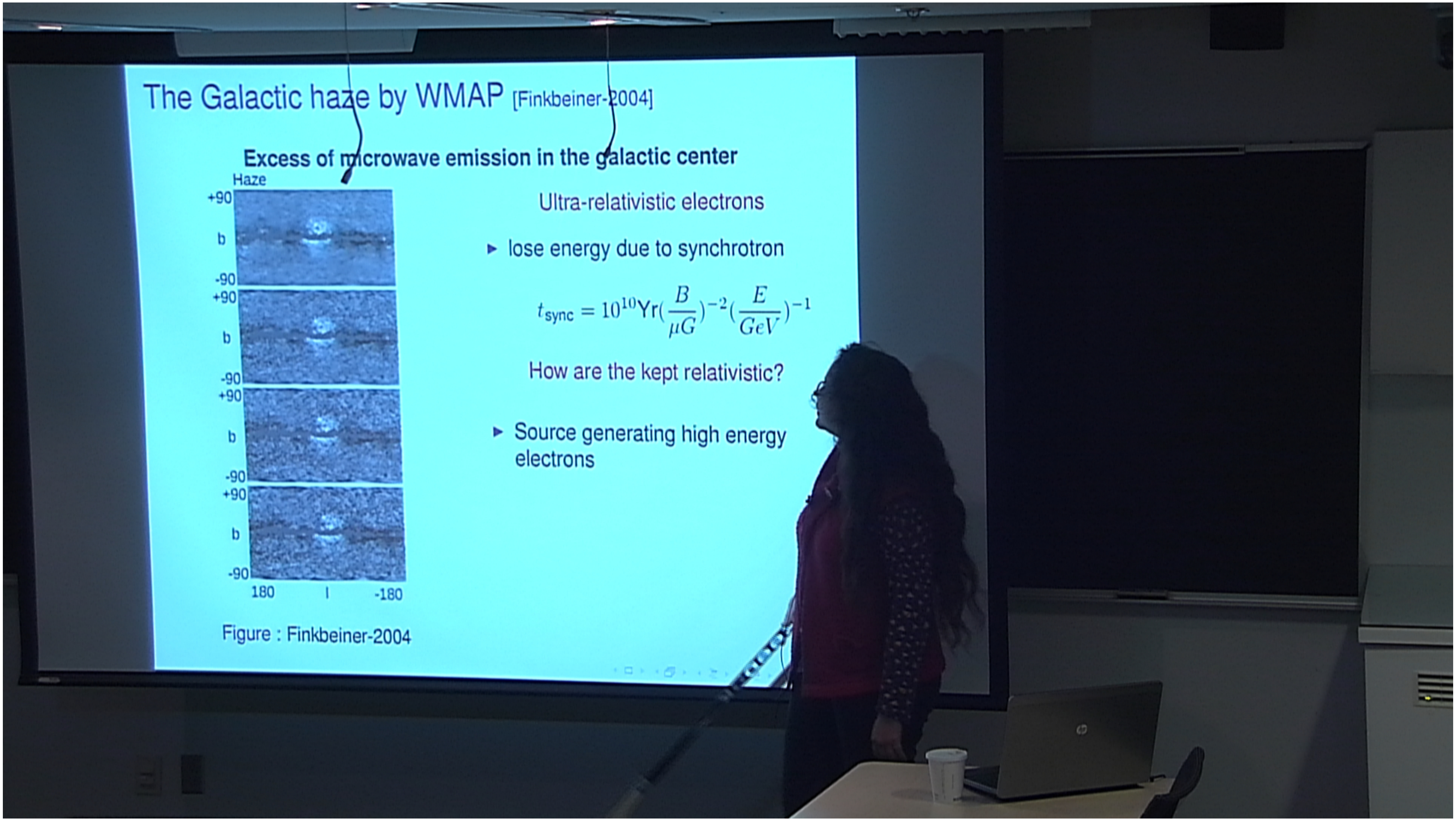


The Galactic haze by WMAP [Finkbeiner-2004]

Excess of microwave emission in the galactic center

Figure : Finkbeiner-2004

Ultra-relativistic electrons

- lose energy due to synchrotron

$$t_{\text{sync}} = 10^{10}\text{Yr}(\frac{B}{\mu G})^{-2}(\frac{E}{GeV})^{-1}$$

How are the kept relativistic?

- Source generating high energy electrons

The Galactic haze by Planck [Planck Collaboration IX-2013]

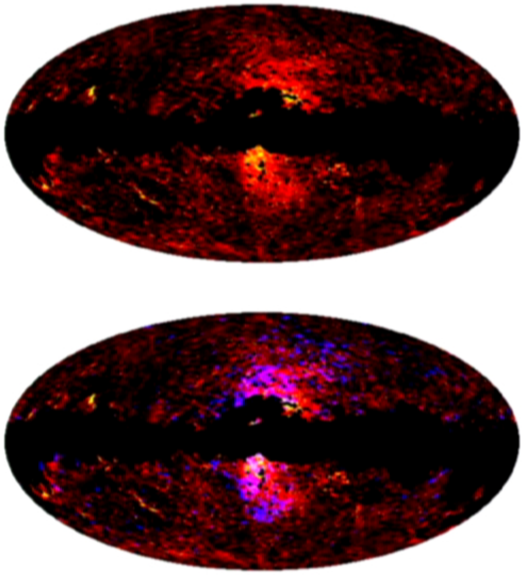


Figure : Frequencies of 30 (red) and 44 (yellow) GHz

Examples

- Dark matter annihilation [Hopper et al.-2008]
- Gamma ray burst [Broderick et al. not published]

Our goal

- model for energy lose and sources
- maps of source

The Synchrotron radiation

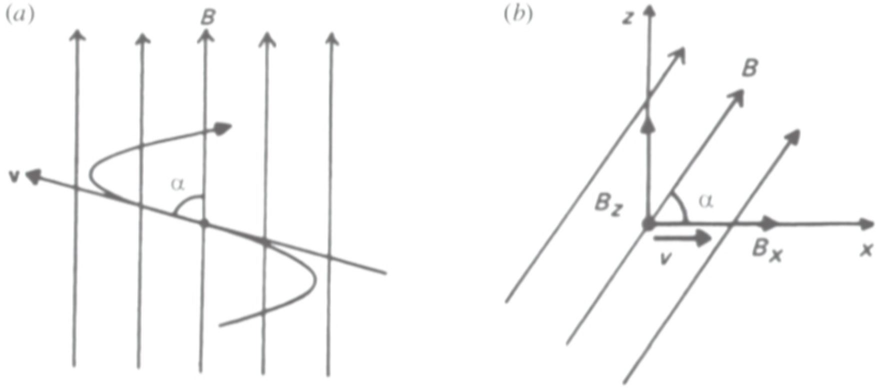


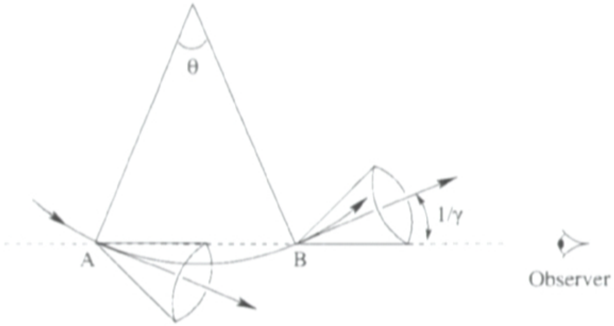
Figure : Credit: Longair M.S.

Accelerated electrons radiate

$$\dot{E} = \frac{2}{3}\frac{q^2 a^2}{c^3} \,,$$

$$\dot{E} = \frac{4}{3}(\sigma_t c \gamma^2 \beta^2) U_B \,.$$

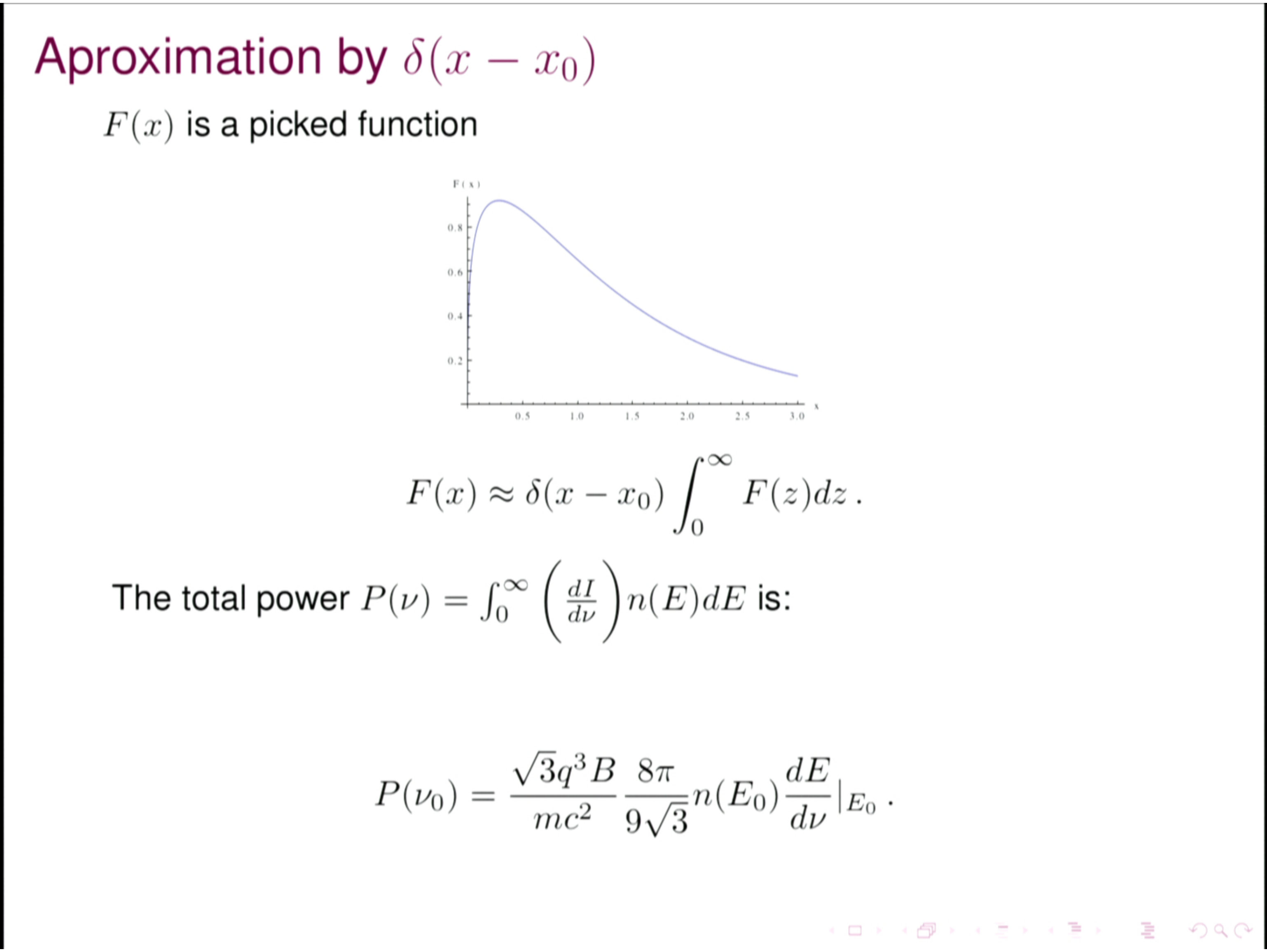
Synchrotron spectrum



$$\omega_{\mathsf{sync}} = \frac{1}{t_{\mathsf{obs}}} \approx \omega_c \gamma^2 \approx 10^2 \mathsf{MHz} \left(\frac{B}{\mu \mathsf{G}}\right) \left(\frac{E}{\mathsf{GeV}}\right)^2 .$$

spectral distribution $$\frac{dI}{d\nu} = \frac{\sqrt{3} q^3 B}{mc^2} F\left(\frac{\nu}{\nu_c}\right), \qquad F(x) = x \int_x^\infty K_{5/3}(z) dz$$ Bessel second kind

$$P(\nu) = \int_0^\infty \left(\frac{dI}{d\nu}\right) n(E) dE .$$



Aproximation by $\delta(x - x_0)$

$F(x)$ is a picked function

$$F(x) \approx \delta(x - x_0) \int_0^\infty F(z) dz \, .$$

The total power $P(\nu) = \int_0^\infty \left(\frac{dI}{d\nu}\right) n(E) dE$ is:

$$P(\nu_0) = \frac{\sqrt{3} q^3 B}{mc^2} \frac{8\pi}{9\sqrt{3}} n(E_0) \frac{dE}{d\nu}|_{E_0} \, .$$

Diffusion equation

PHYSICAL PROCESS

- **Cooling due to synchrotron emission**
- **Diffusion due to tangled magnetic field**
- **Source of electrons**

Diffusion equation

$$\frac{dn(E)}{dt} = -K\nabla^2 n(E) + \frac{d}{dE}\Big(b(E)n(E)\Big) + Q(E)\,.$$

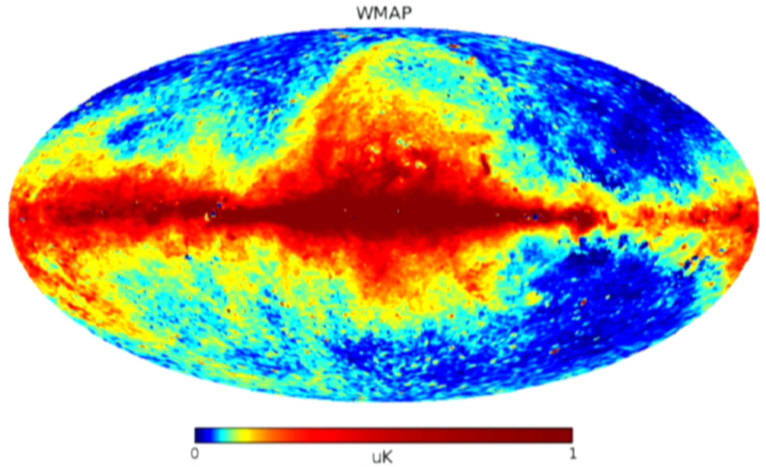
$$b(E) = \frac{4}{3}\sigma_t c\left(\frac{E}{mc^2}\right)^2 U_B\,, \qquad K\nabla^2 n(E) \to \frac{n(E)}{t_{\text{diff}}}$$

Steady state:

$$\left(-\frac{1}{t_{\text{diff}}} + b'\right)n(E) + b(E)n' = Q(E)\,,$$

$$\begin{aligned} B &= 5\mu\text{G}\,, \\ L &= 4\times\text{Kpc}\,, \\ t_{\text{diff}} &= 5\times 10^7\text{Yr}\,. \end{aligned}$$

WMAP data



$$\begin{aligned} \text{band K} &= 23\text{GHz}\,, \\ \text{band Ka} &= 33\text{GHz}\,, \\ \text{band Q} &= 41\text{GHz}\,, \\ \text{band V} &= 61\text{GHz}\,, \\ \text{band W} &= 94\text{GHz}\,, \end{aligned}$$

$$I = \frac{2k\nu^2}{c^2} T_{\text{ant}}$$

Procedure

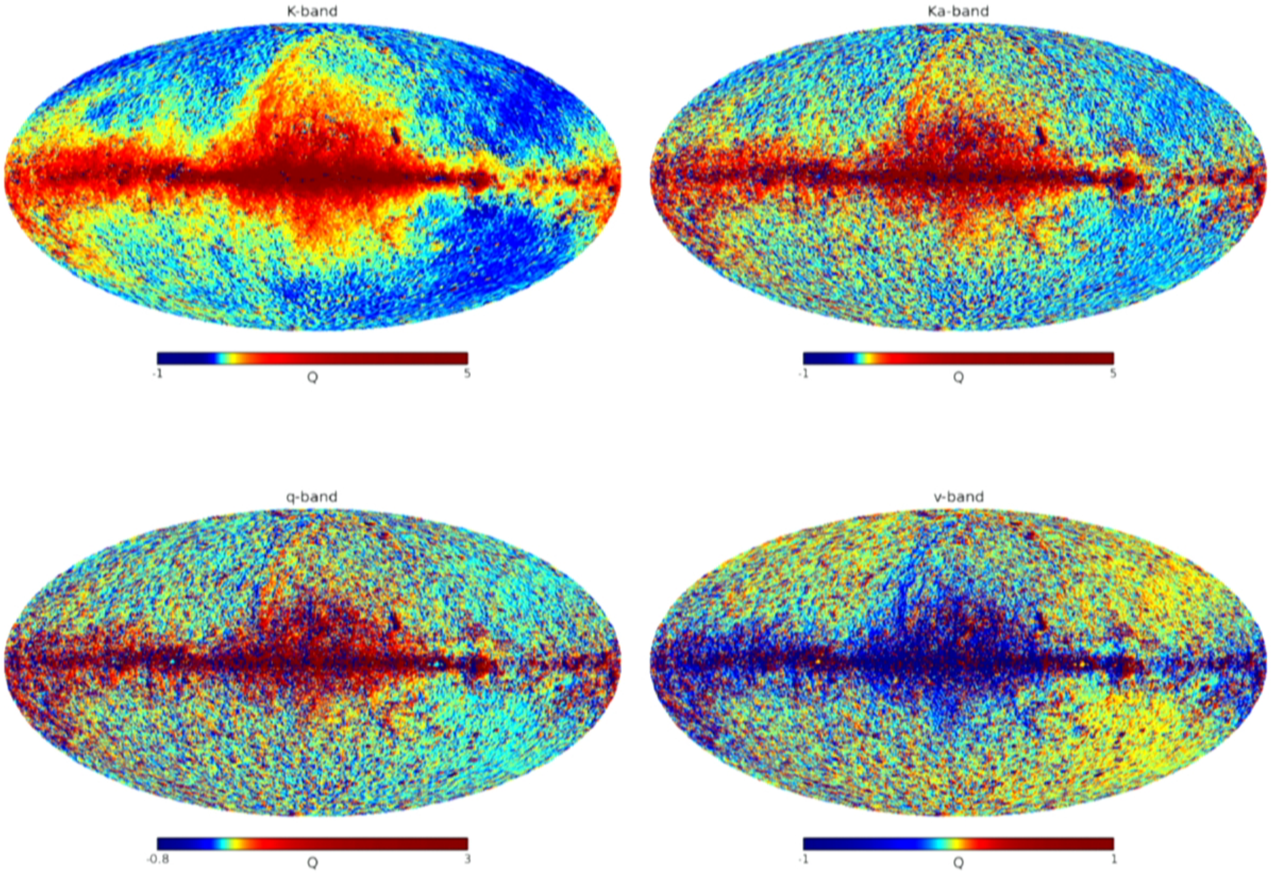
For each pixel in each map

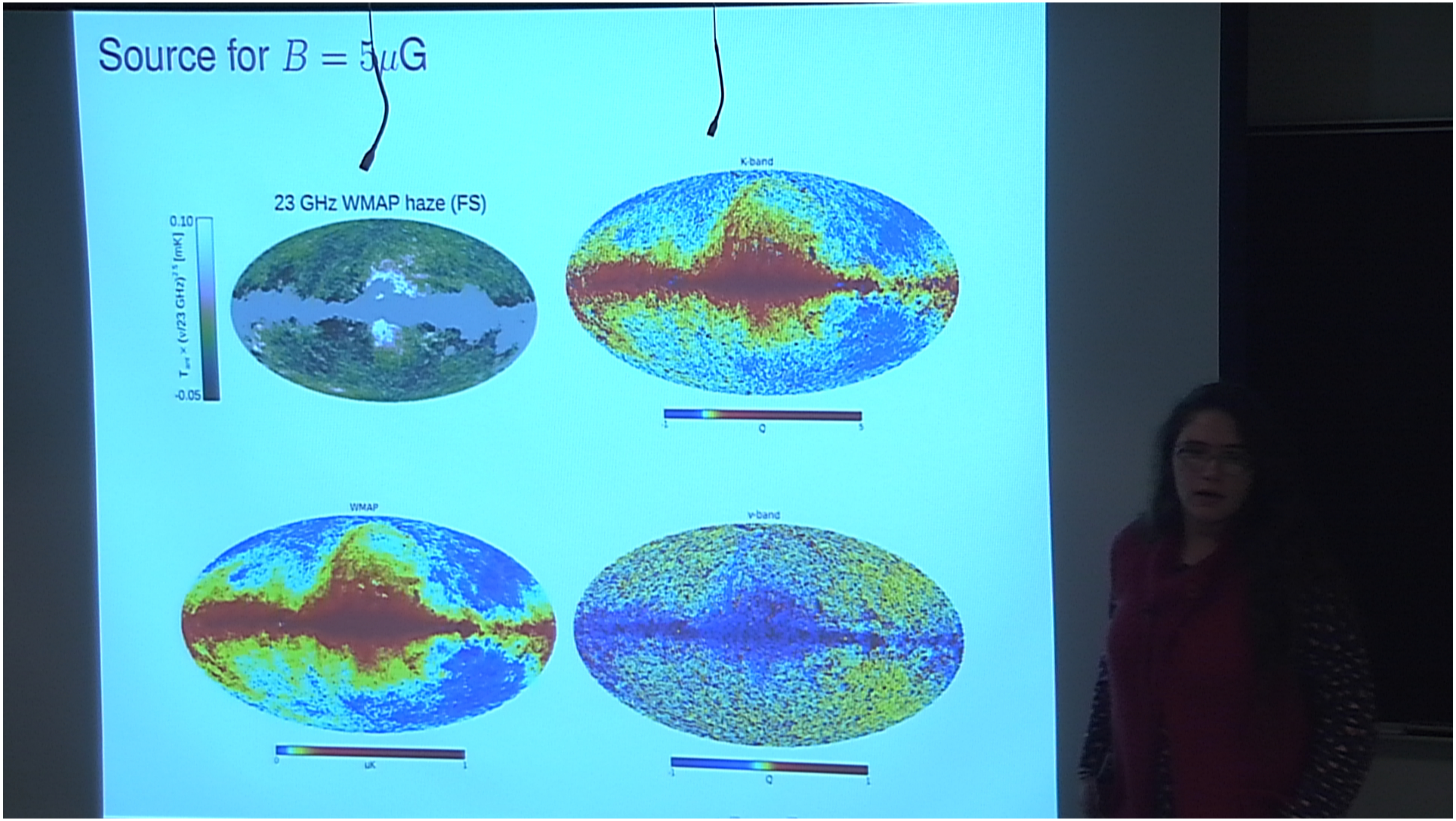
- $P = \frac{I}{D} = \frac{2k\nu_{\text{wp}}^2}{c^2 D} T_{\text{ant}}$
- Equate with definition of intensity:
  $\frac{\sqrt{3}q^3 B}{mc^2} \frac{8\pi}{9\sqrt{3}} n(E_{\text{wp}}) \frac{dE}{d\nu}|_{E_{\text{wp}}} = \frac{I}{D} = \frac{2k\nu_{\text{wp}}^2}{c^2 D} T_{\text{ant}}$
- Solve for $n(E_{\text{wp}})$
- Assume a power law behavior $n(E) = n_0 E^{-\xi}$ and fit for the parameters
- Use the diffusion equation to solve for $Q(E_{\text{wp}})$.

$$\left(-\frac{1}{t_{\text{diff}}} + b' \right) n(E) + b(E) n' = Q(E) \, ,$$

FOR EACH PIXEL IN EACH MAP I HAVE $Q(E_{\text{wp}})$. [Use of HEALPix]

Source for $B = 5\mu$G





Source for $B = 5\mu$G

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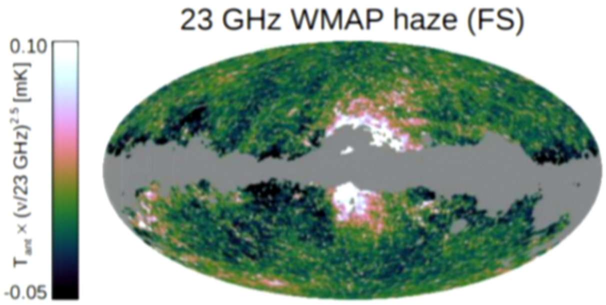
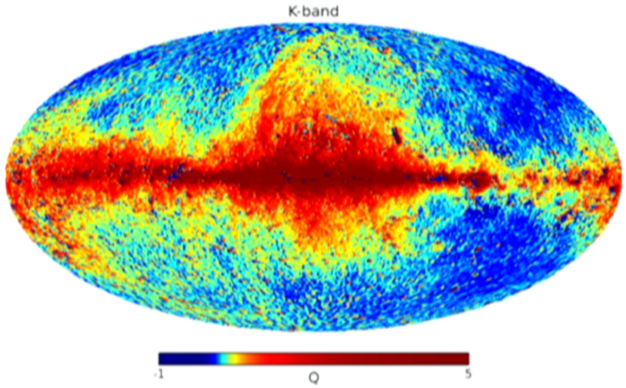
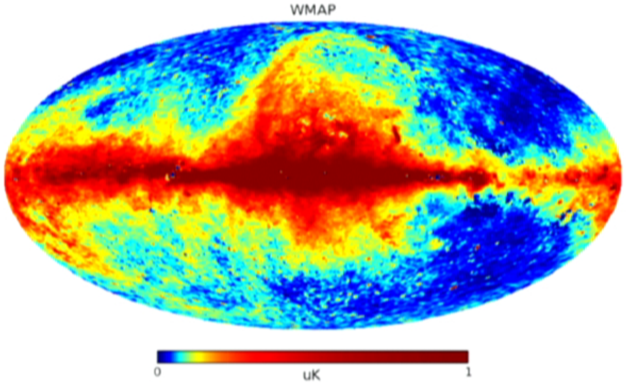
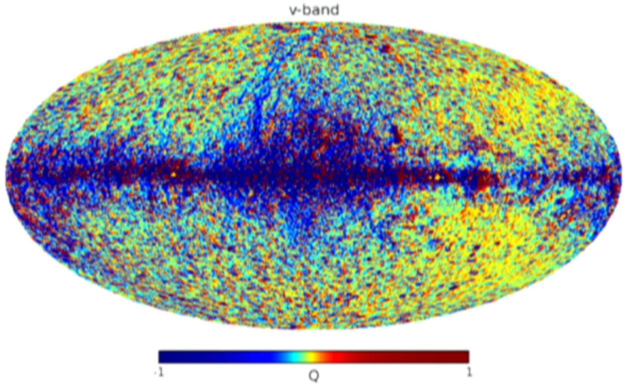
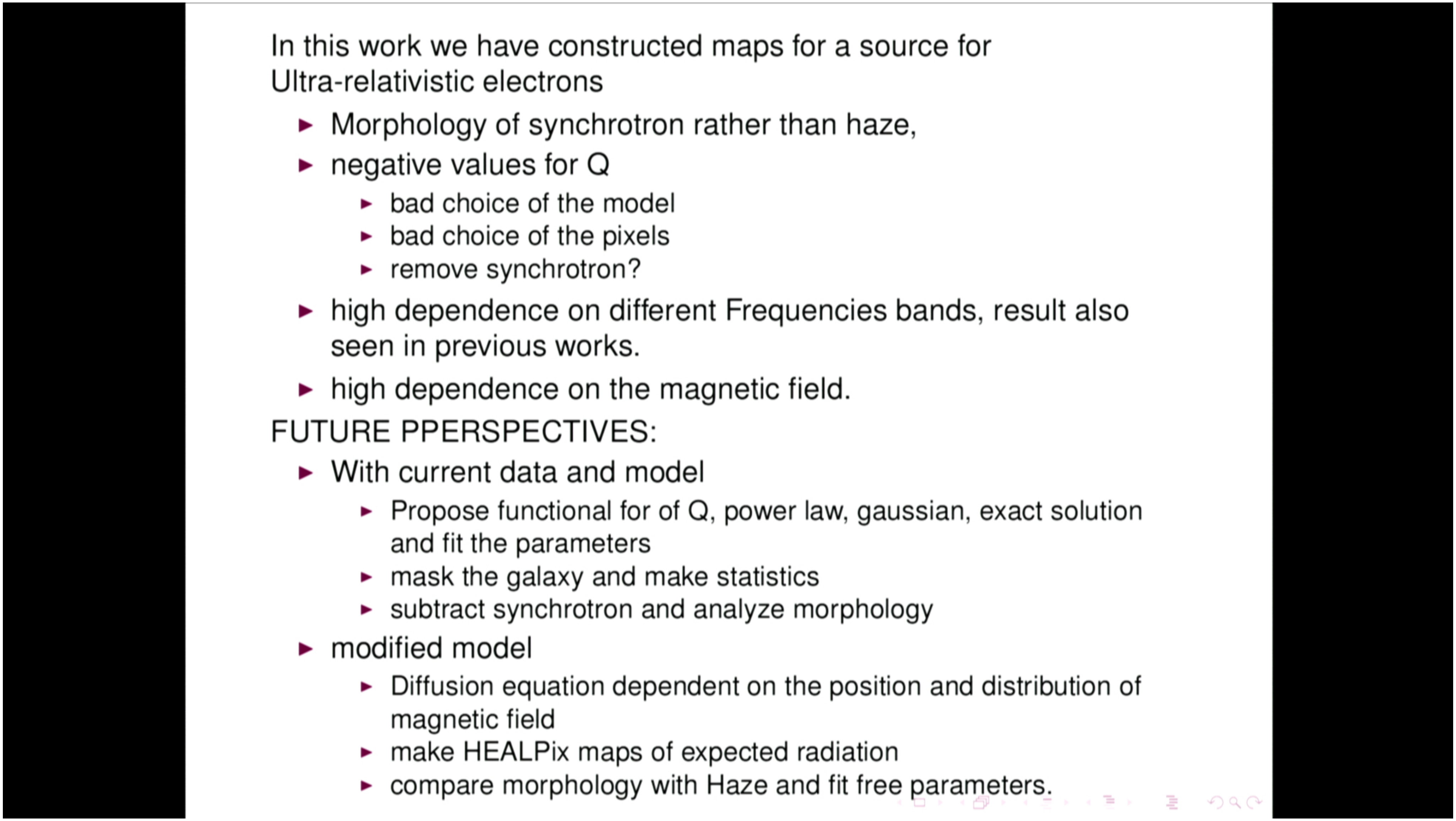










In this work we have constructed maps for a source for Ultra-relativistic electrons

- Morphology of synchrotron rather than haze,
- negative values for Q
  - bad choice of the model
  - bad choice of the pixels
  - remove synchrotron?
- high dependence on different Frequencies bands, result also seen in previous works.
- high dependence on the magnetic field.

FUTURE PPERSPECTIVES:

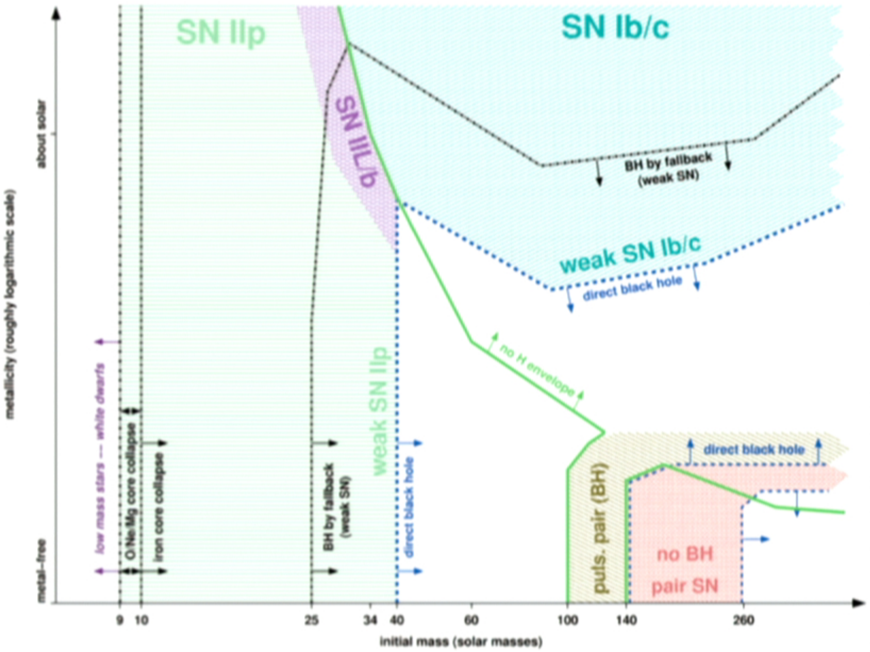
- With current data and model
  - Propose functional for of Q, power law, gaussian, exact solution and fit the parameters
  - mask the galaxy and make statistics
  - subtract synchrotron and analyze morphology
- modified model
  - Diffusion equation dependent on the position and distribution of magnetic field
  - make HEALPix maps of expected radiation
  - compare morphology with Haze and fit free parameters.

THANK YOU!

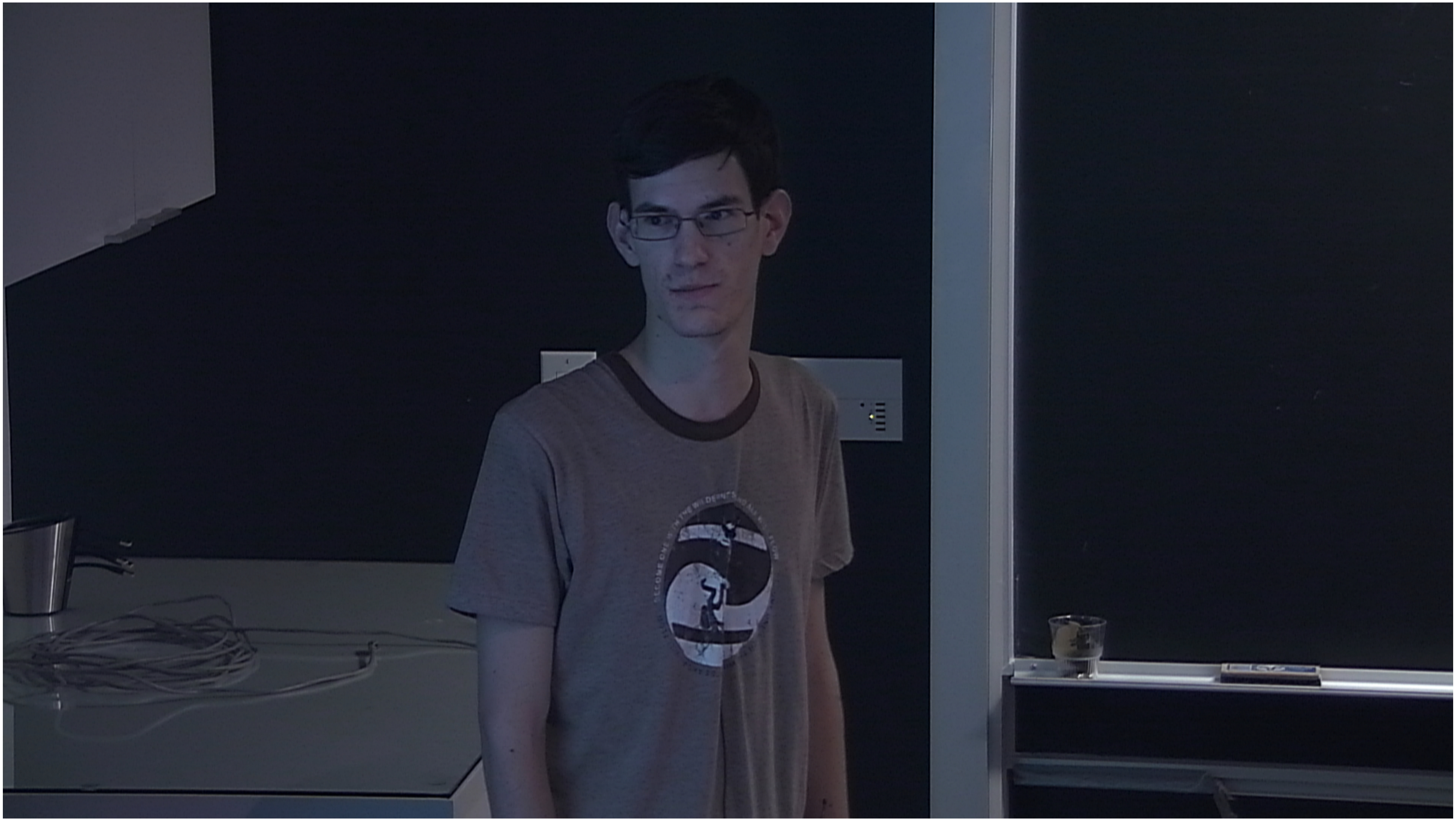
(In particular to Kendrick, Avery, Siavash and Niayesh!)

Intro to Supernova

- 2 types of overarching mechanisms
- 1a: accretion of companion onto white dwarf
- All others (1b/c, II): core-collapse or pair instability
- Core-collapse leaves remnant (NS/BH)



Heger, et. al. 2003 ApJ 591, 288-300



Intro to Supernova

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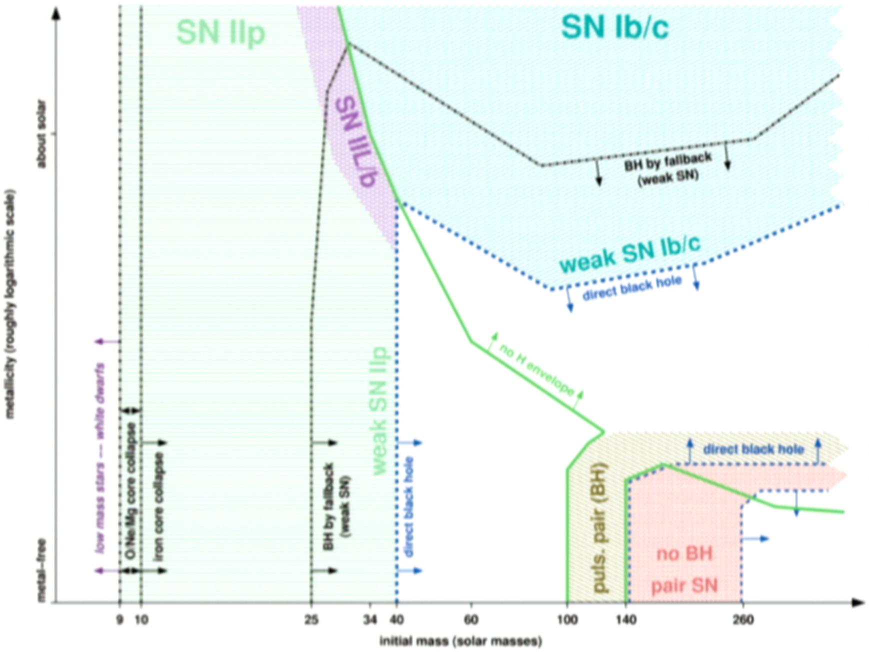

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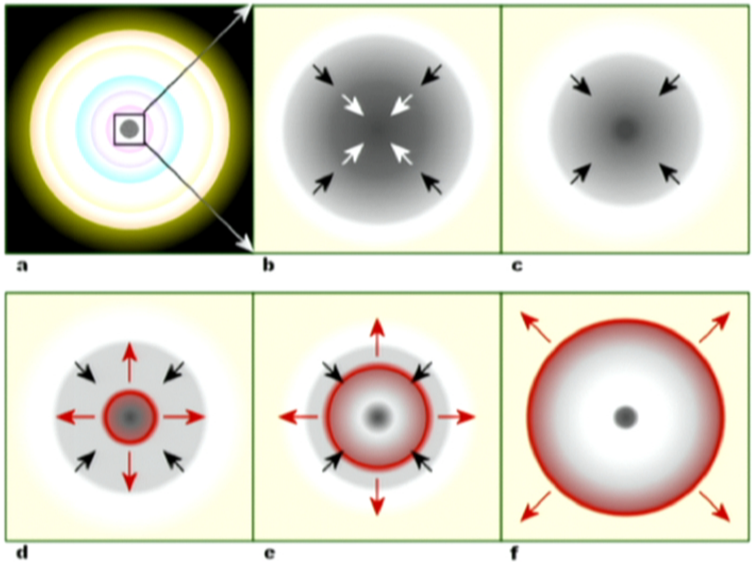
Core-Collapse

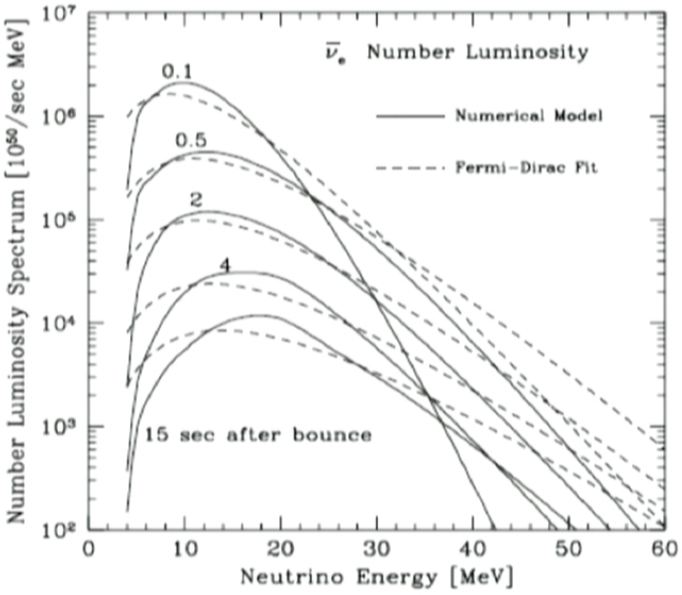
- Massive stars, 10-40 Msun
- 10^{53} ergs of energy, 99% ν
- 2 schools of thought on explosion mechanism
- Shock bounce from NS formation
- Shell removal immediately (fine tuning of EOS)
- Shell removal after shock neutrino heating



http://upload.wikimedia.org/wikipedia/commons/thumb/e/e9/Core_collapse_scenario.png/480px-Core_collapse_scenario.png

Simulations

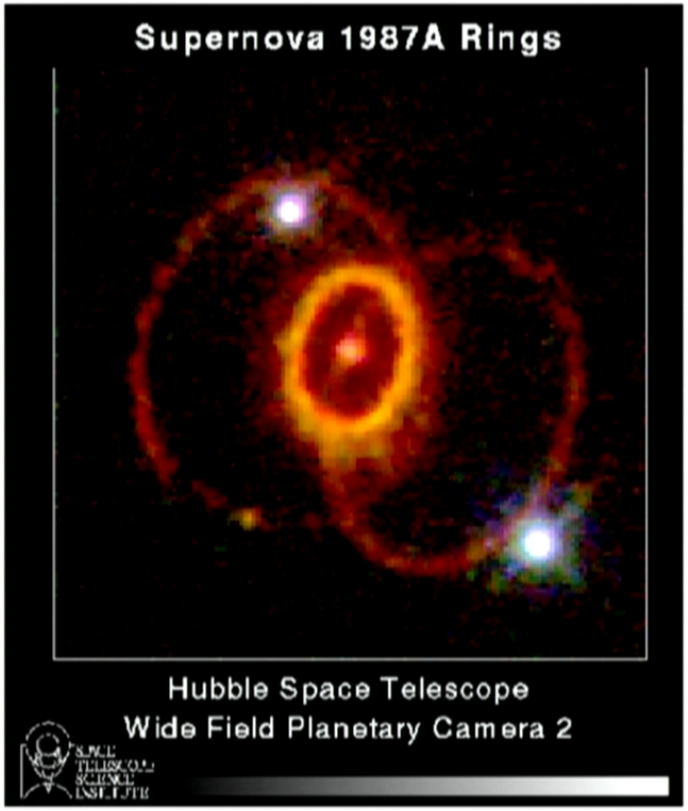
- Thermal Neutrinos: Fermi-dirac distribution
- Nearly no chemical potential
- Non-zero mass reduces luminosity at high and low energies
- Shape probes explosion mechanism: shock transparent to ν



Totani T., Sato K, Dalhed H.E., Wilson J.R., 1998, ApJ 496, 216-225

SN 1987

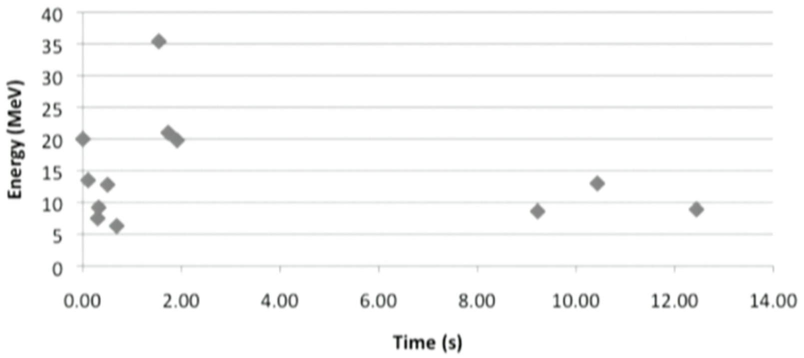
- Most Recent Supernova
- Core Collapse
- ~20 Neutrinos detected by Kamiokande II and IMB
- Schematically consistent with theory
- E_ν ~ 10-30 MeV



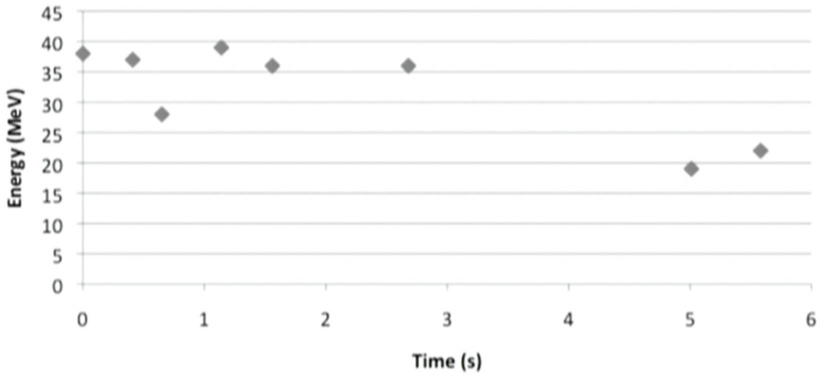
http://chem.tufts.edu/science/astronomy/images/sn1987a.jpg

KII and IMB Events

KII Detection Events

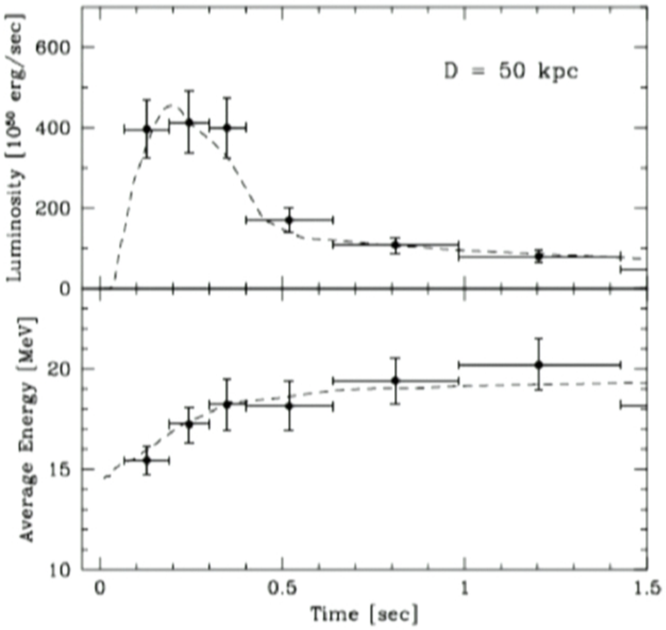


IMB Detection Events



Simulation for Super K

- 15x volume of KII
- Est. 10^2 events at 50kpc
- 10^4 events at 10kpc

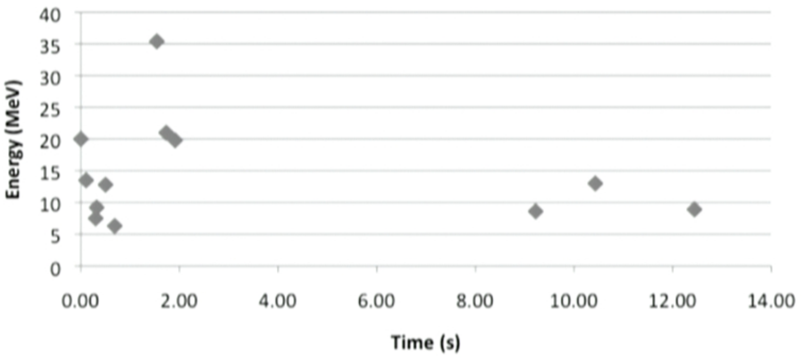


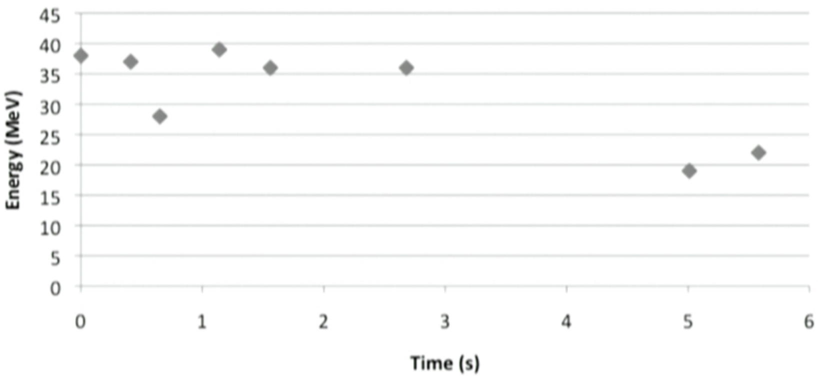
Totani T., Sato K, Dalhed H.E., Wilson J.R., 1998, ApJ 496, 216-225

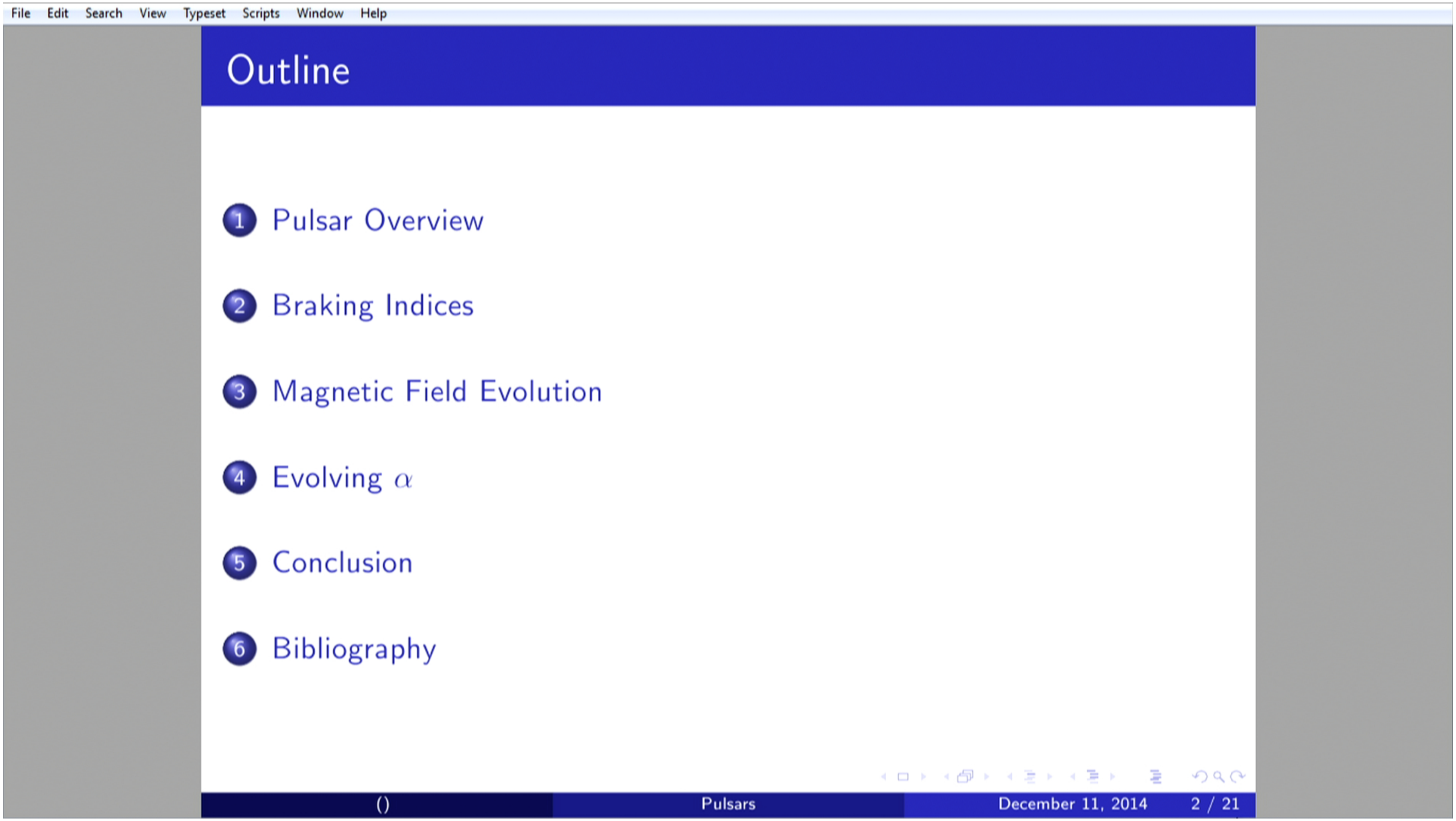
Flux Problem

- Signal decreases a D^2
- At 700 kpc (Andromeda), Super K detects 0.5 events per SN
- Need 200 SN events at 700 kpc of same type.
- At 10 Mpc, 0.01 events, need 10^4 SN of same type
- Asiago SN catalogue contains 6447 SN from 1885 to Nov 2014.
- All types, All distances
- At 100 detections per year, 100 years of observations

KII and IMB Events

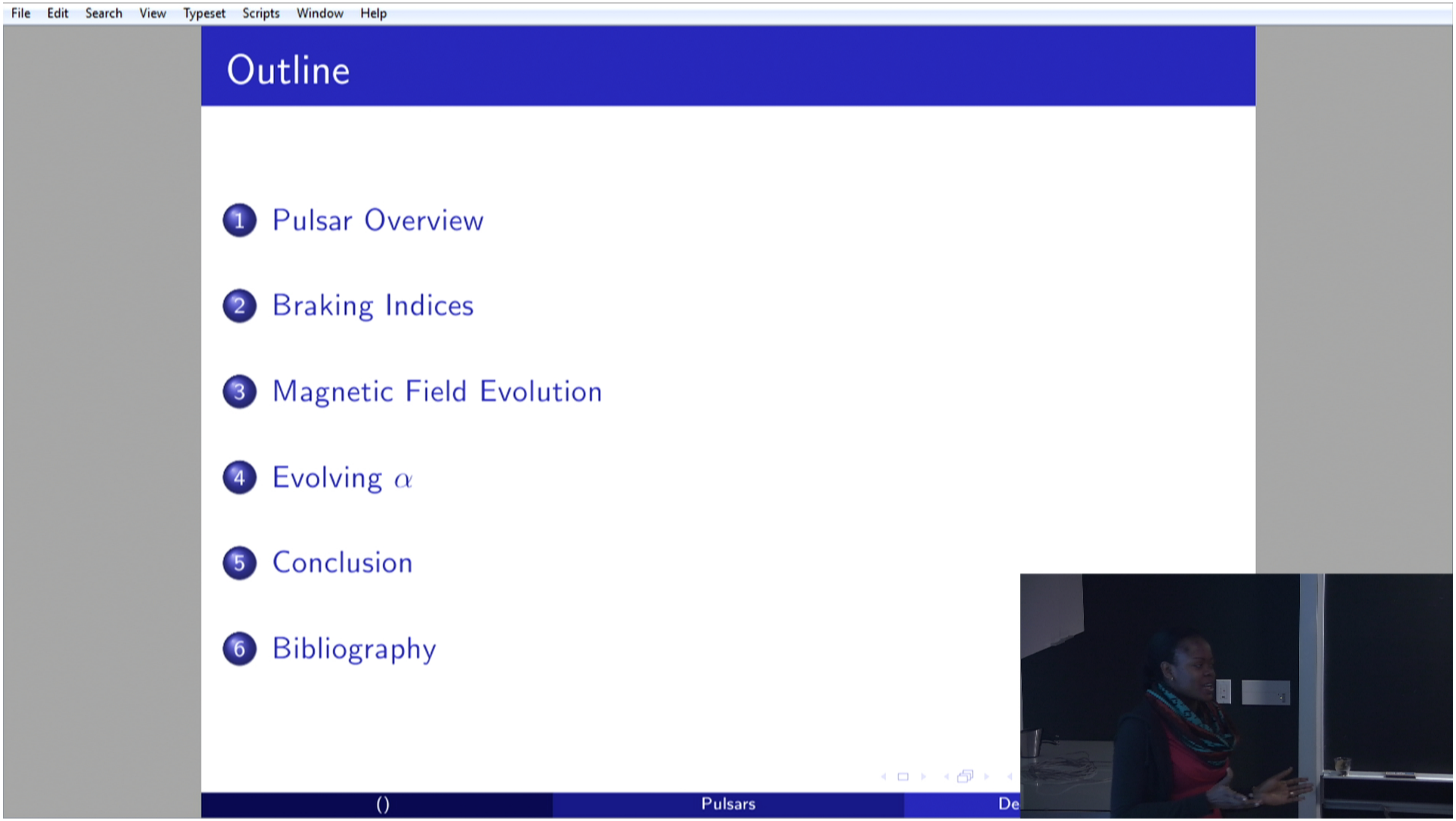

KII Detection Events


IMB Detection Events



Outline

1. Pulsar Overview
2. Braking Indices
3. Magnetic Field Evolution
4. Evolving α
5. Conclusion
6. Bibliography



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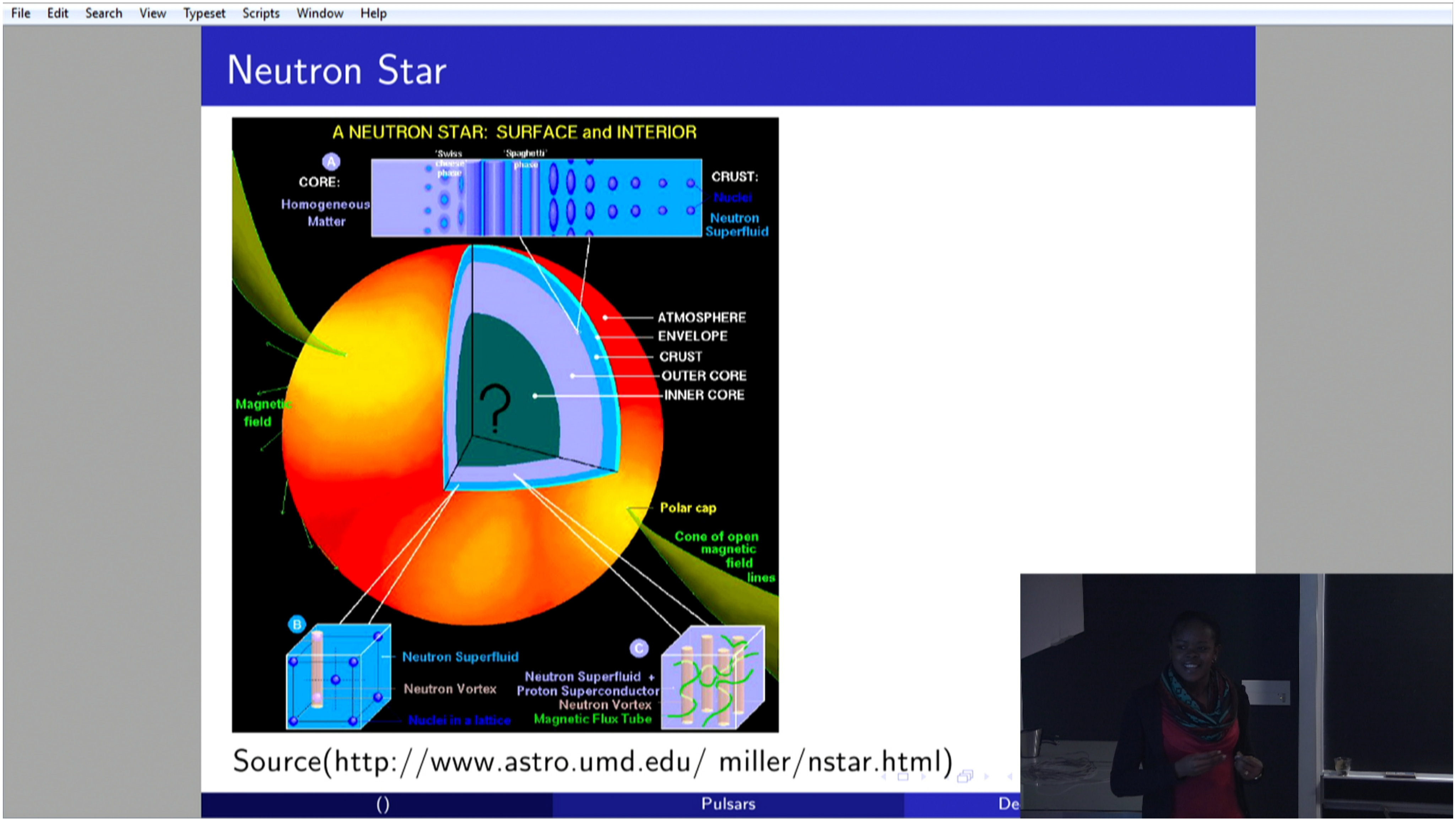
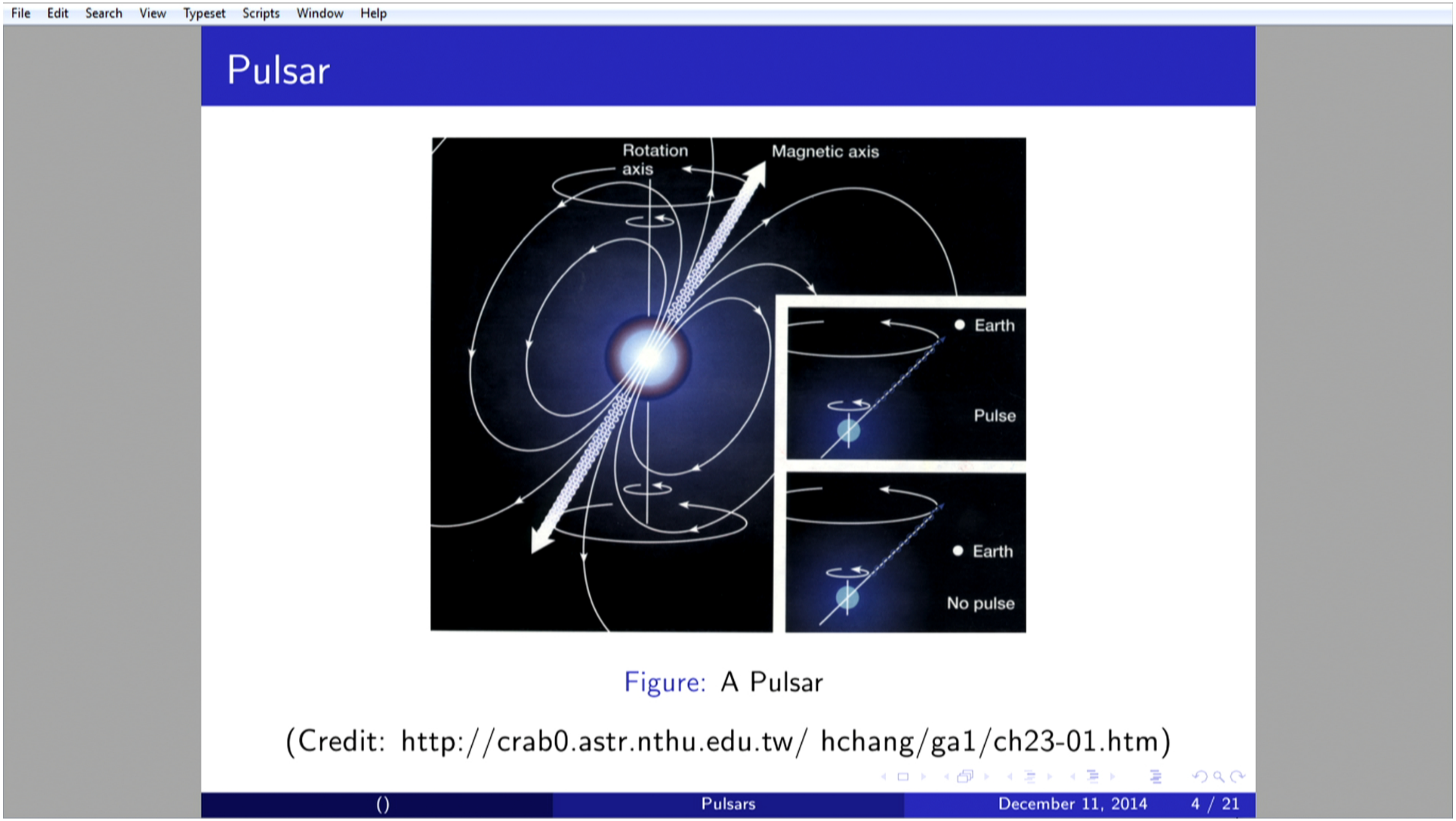


Neutron Star

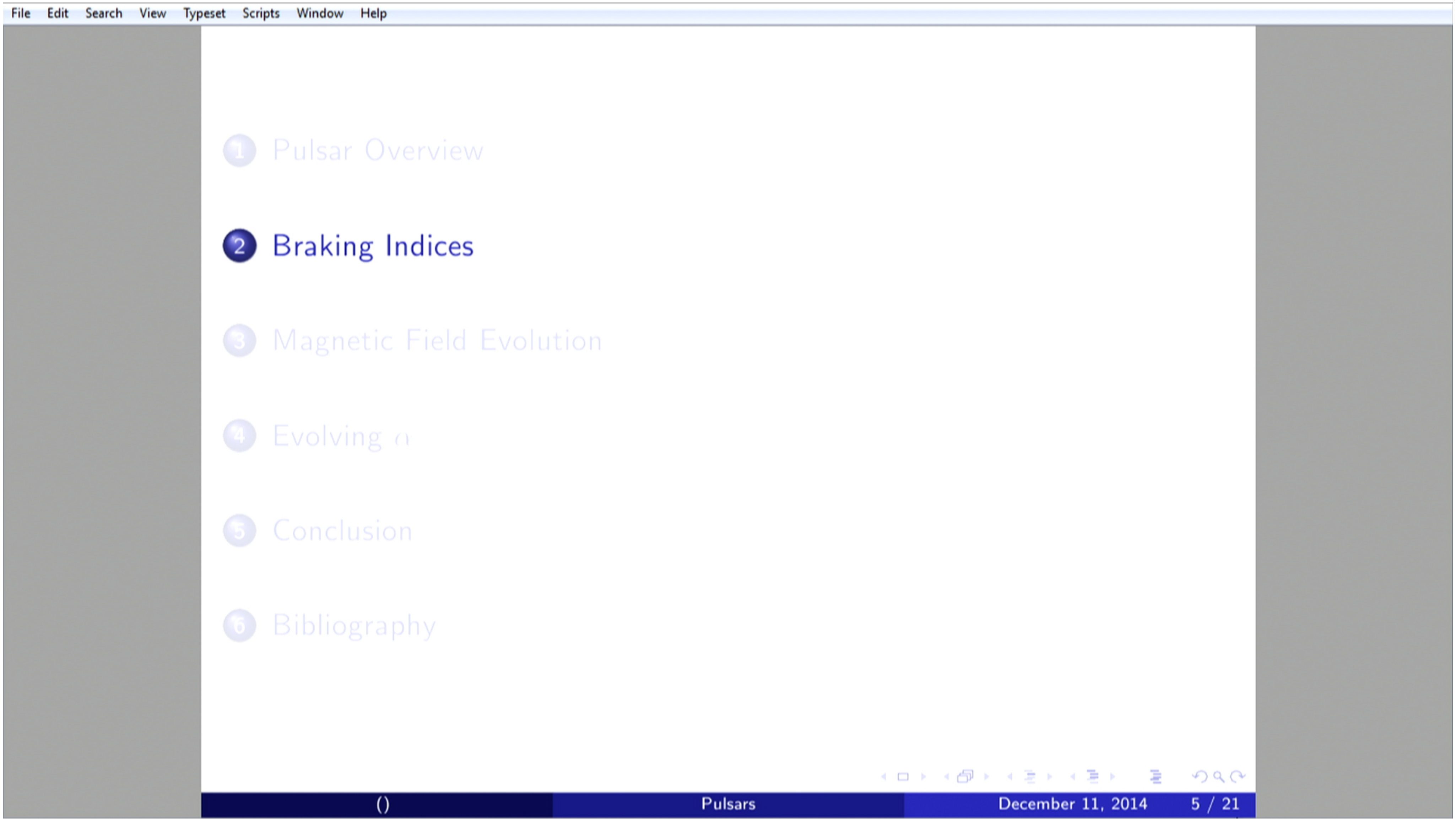
Source(http://www.astro.umd.edu/ miller/nstar.html)



Pulsar

Figure: A Pulsar

(Credit: http://crab0.astr.nthu.edu.tw/ hchang/ga1/ch23-01.htm)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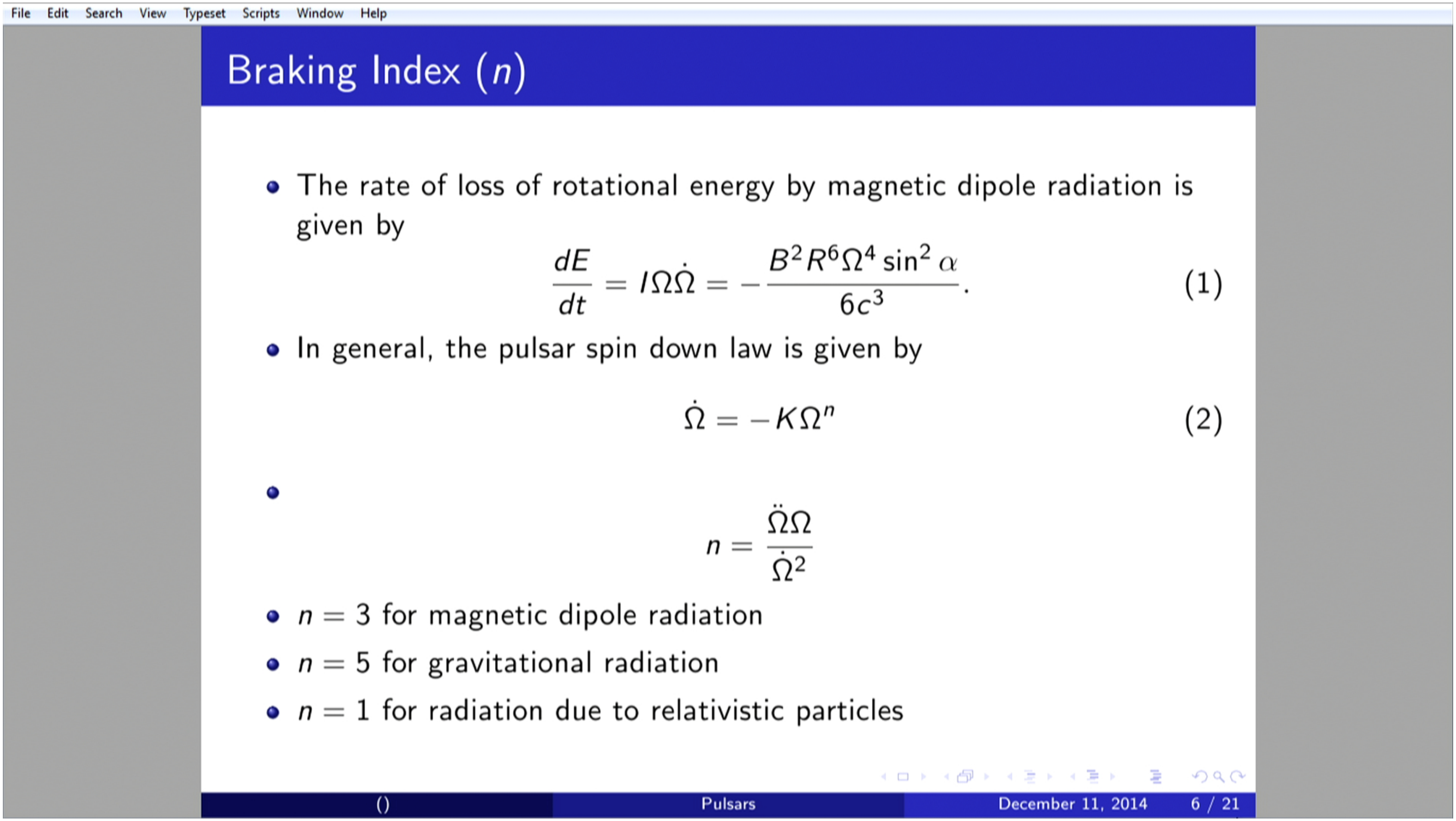


Braking Index (n)

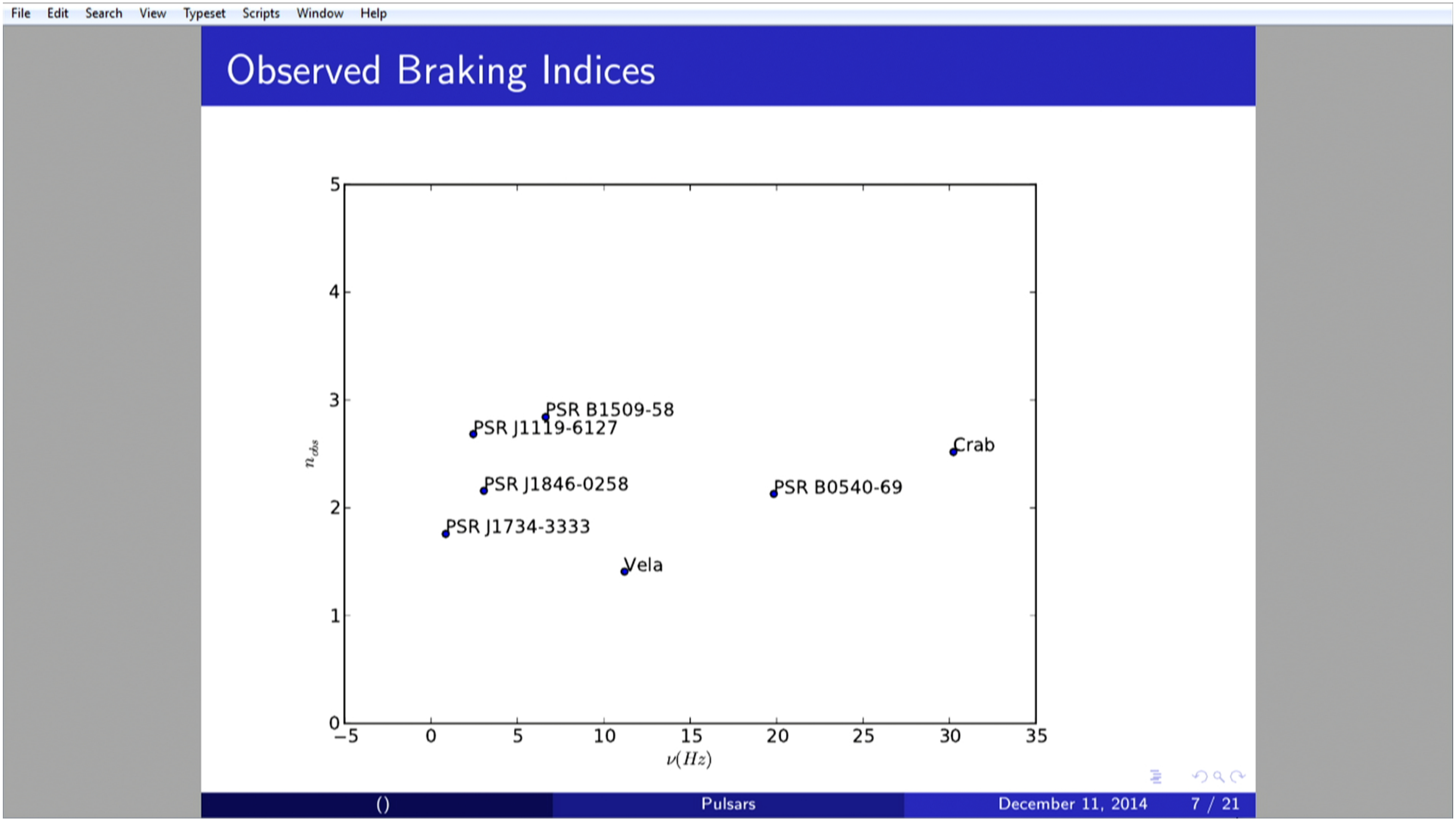
- The rate of loss of rotational energy by magnetic dipole radiation is given by

$$\frac{dE}{dt} = I\Omega\dot{\Omega} = -\frac{B^2R^6\Omega^4\sin^2\alpha}{6c^3}. \tag{1}$$

- In general, the pulsar spin down law is given by

$$\dot{\Omega} = -K\Omega^n \tag{2}$$

- $$n = \frac{\ddot{\Omega}\Omega}{\dot{\Omega}^2}$$
- $n = 3$ for magnetic dipole radiation
- $n = 5$ for gravitational radiation
- $n = 1$ for radiation due to relativistic particles



Observed Braking Indices

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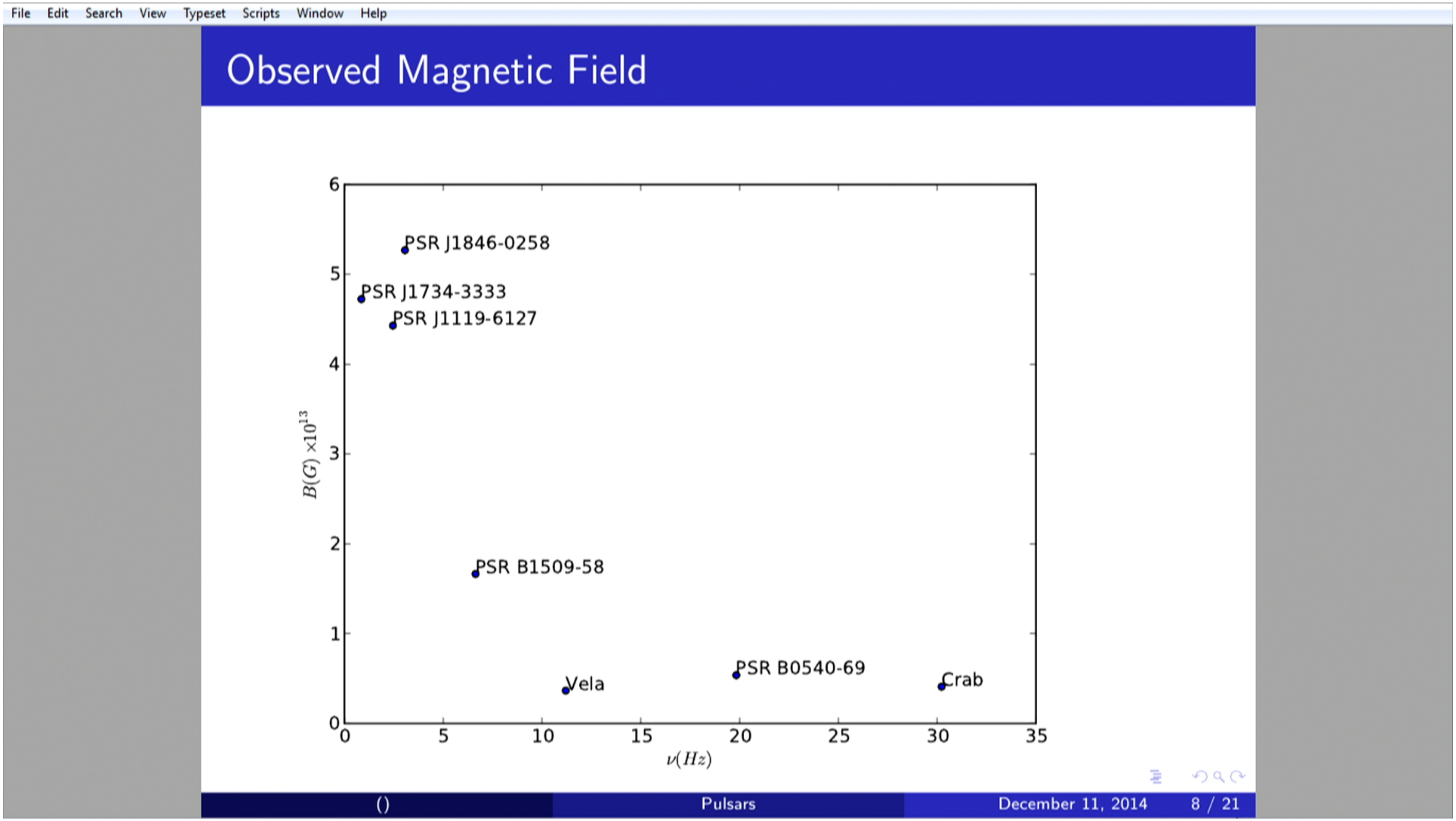
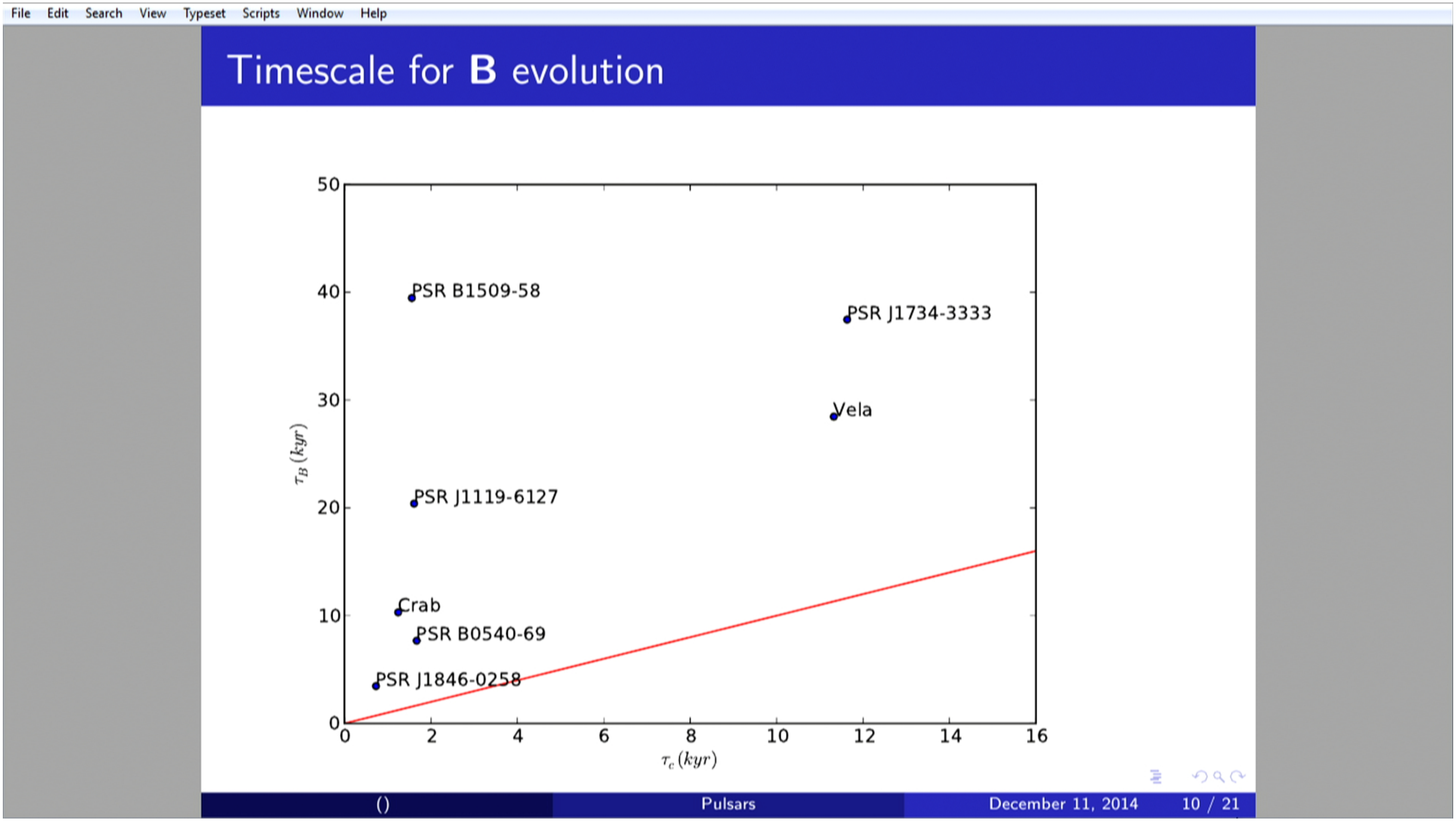


Observed Magnetic Field



Timescale for **B** evolution

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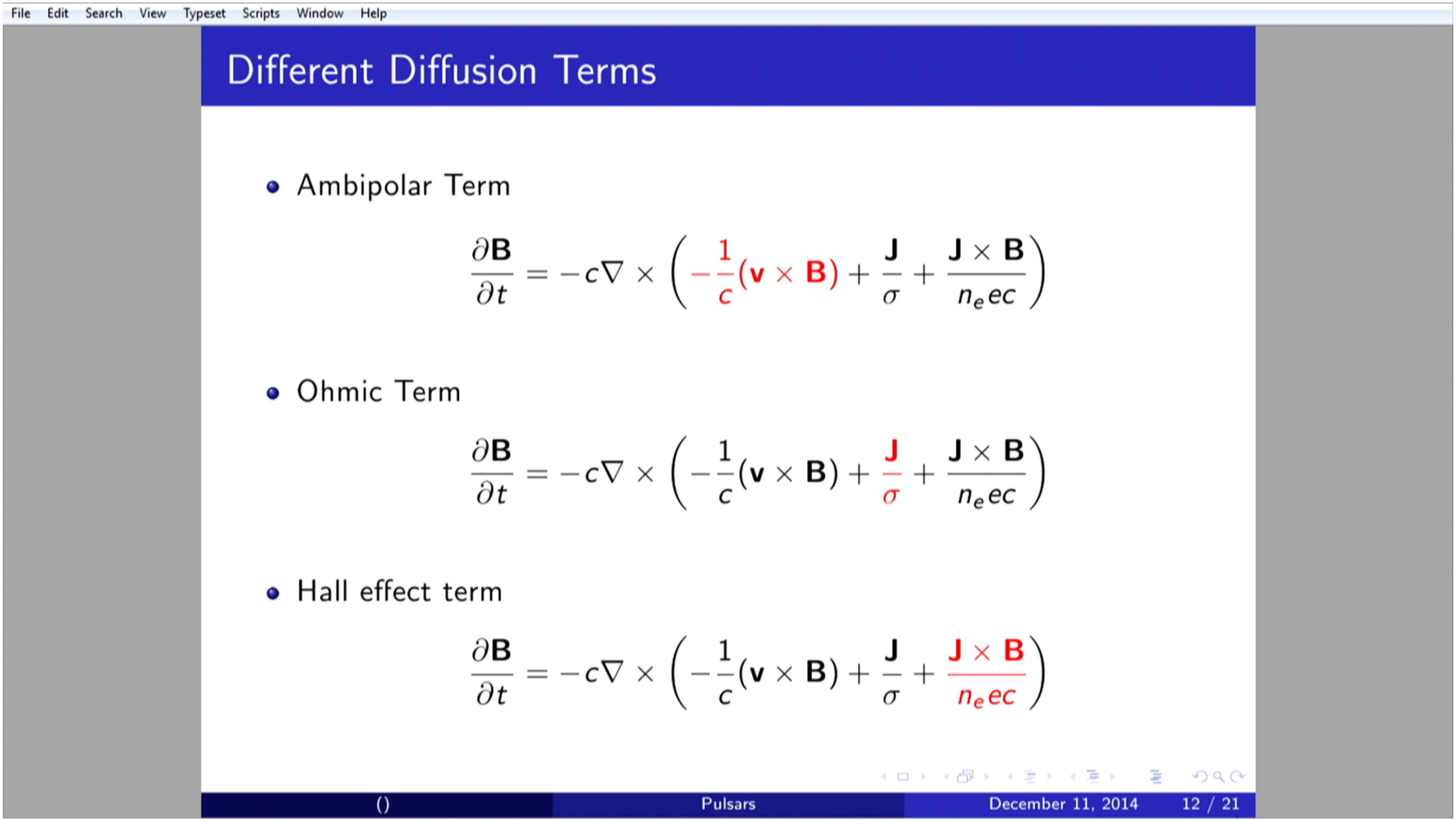


Different Diffusion Terms

- Ambipolar Term

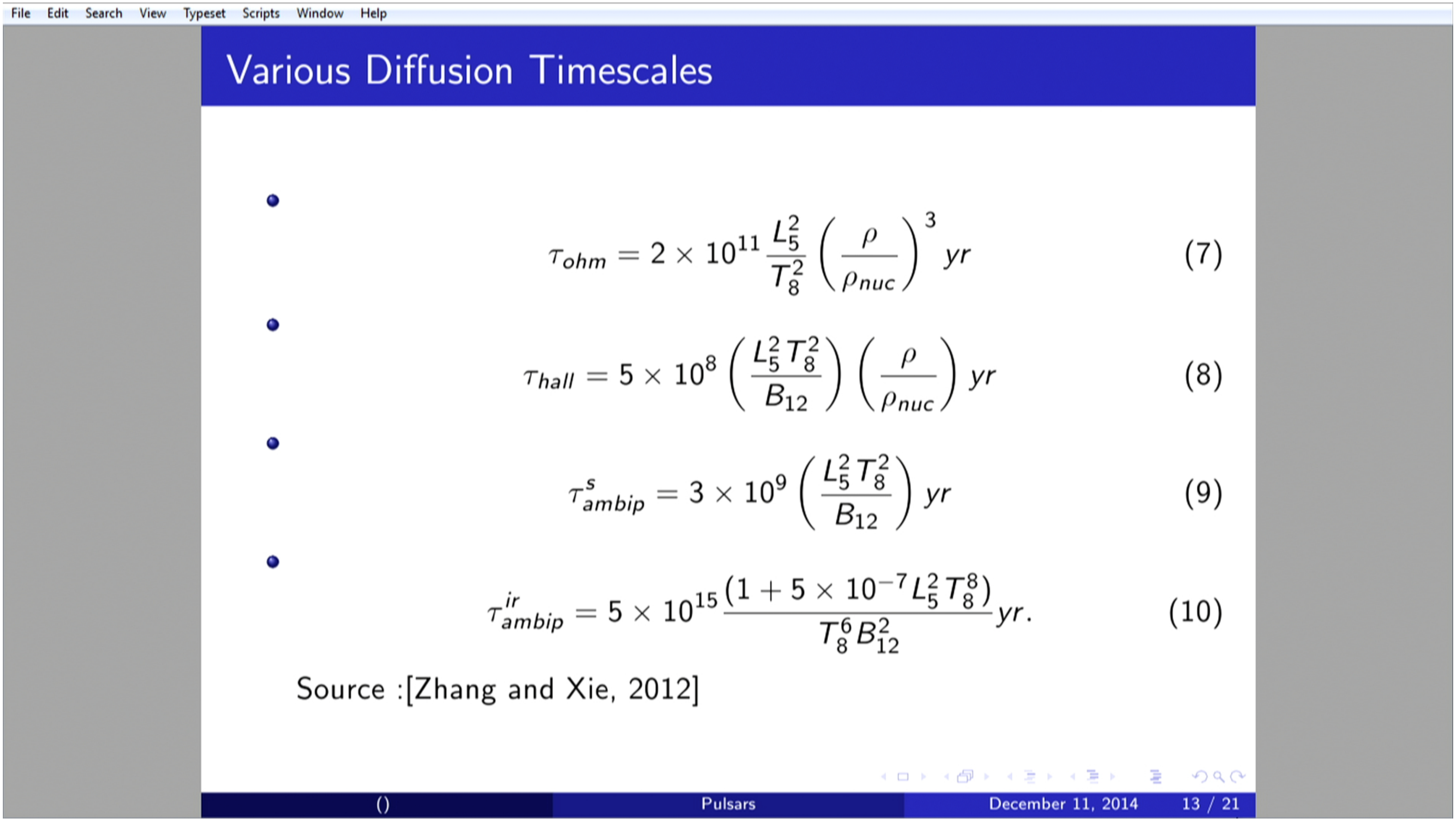
$$\frac{\partial \mathbf{B}}{\partial t} = -c\nabla \times \left(-\frac{1}{c}(\mathbf{v} \times \mathbf{B}) + \frac{\mathbf{J}}{\sigma} + \frac{\mathbf{J} \times \mathbf{B}}{n_e e c} \right)$$

- Ohmic Term

$$\frac{\partial \mathbf{B}}{\partial t} = -c\nabla \times \left(-\frac{1}{c}(\mathbf{v} \times \mathbf{B}) + \frac{\mathbf{J}}{\sigma} + \frac{\mathbf{J} \times \mathbf{B}}{n_e e c} \right)$$

- Hall effect term

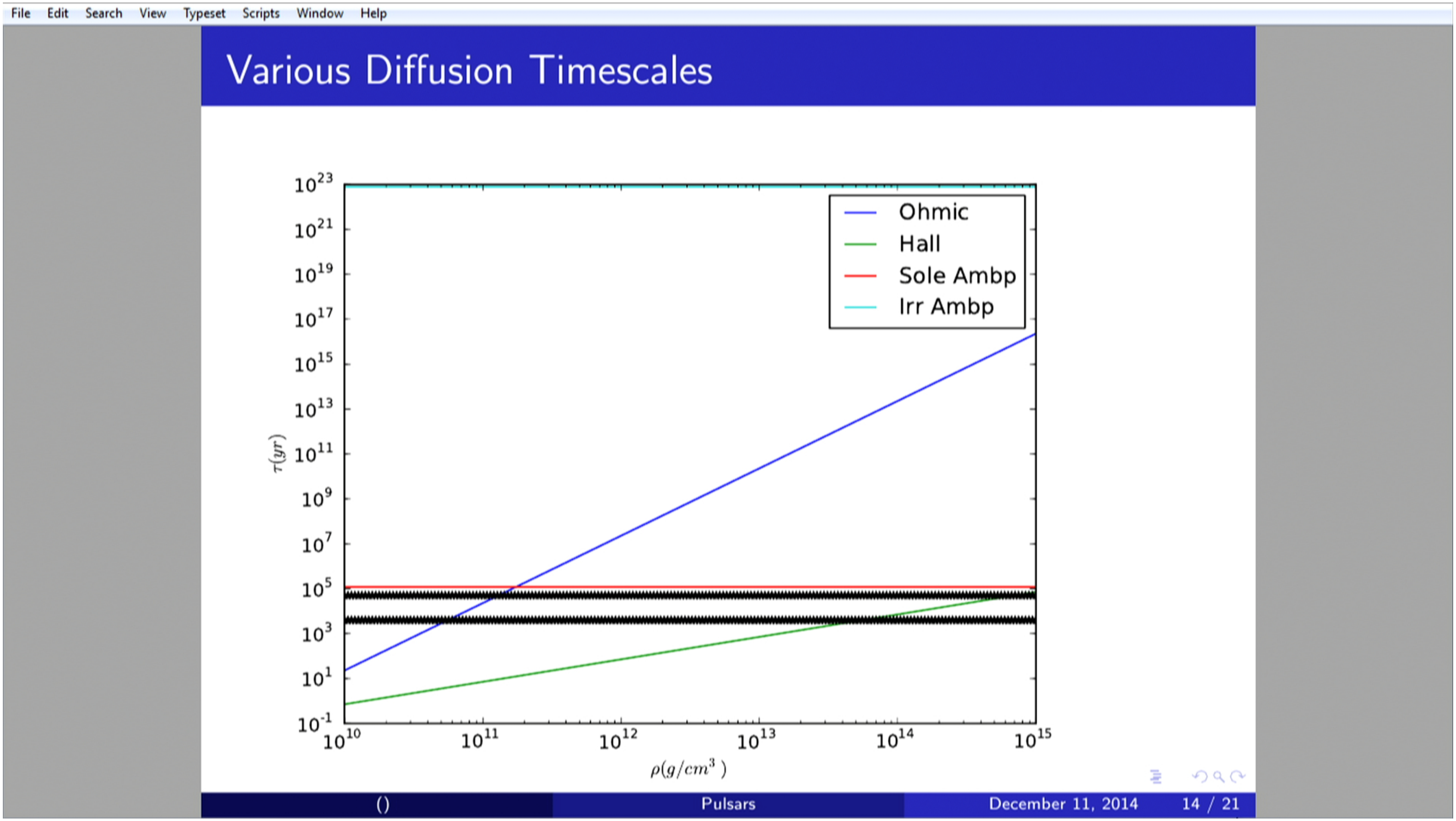
$$\frac{\partial \mathbf{B}}{\partial t} = -c\nabla \times \left(-\frac{1}{c}(\mathbf{v} \times \mathbf{B}) + \frac{\mathbf{J}}{\sigma} + \frac{\mathbf{J} \times \mathbf{B}}{n_e e c} \right)$$



Various Diffusion Timescales

- $$\tau_{ohm} = 2 \times 10^{11} \frac{L_5^2}{T_8^2} \left(\frac{\rho}{\rho_{nuc}} \right)^3 yr \tag{7}$$
- $$\tau_{hall} = 5 \times 10^{8} \left(\frac{L_5^2 T_8^2}{B_{12}} \right) \left(\frac{\rho}{\rho_{nuc}} \right) yr \tag{8}$$
- $$\tau^{s}_{ambip} = 3 \times 10^{9} \left(\frac{L_5^2 T_8^2}{B_{12}} \right) yr \tag{9}$$
- $$\tau^{ir}_{ambip} = 5 \times 10^{15} \frac{(1 + 5 \times 10^{-7} L_5^2 T_8^8)}{T_8^6 B_{12}^2} yr. \tag{10}$$

Source :[Zhang and Xie, 2012]



Various Diffusion Timescales

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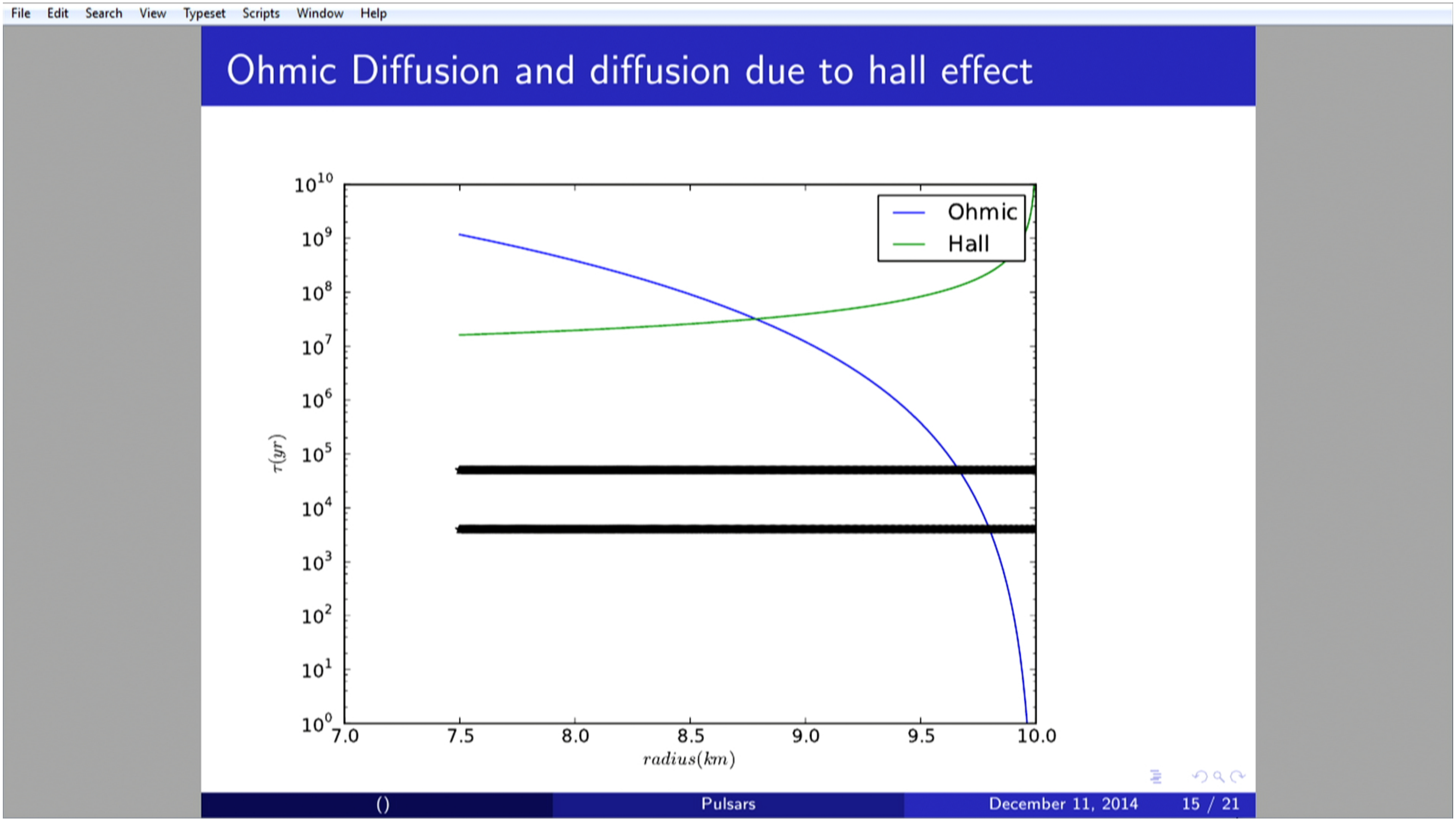
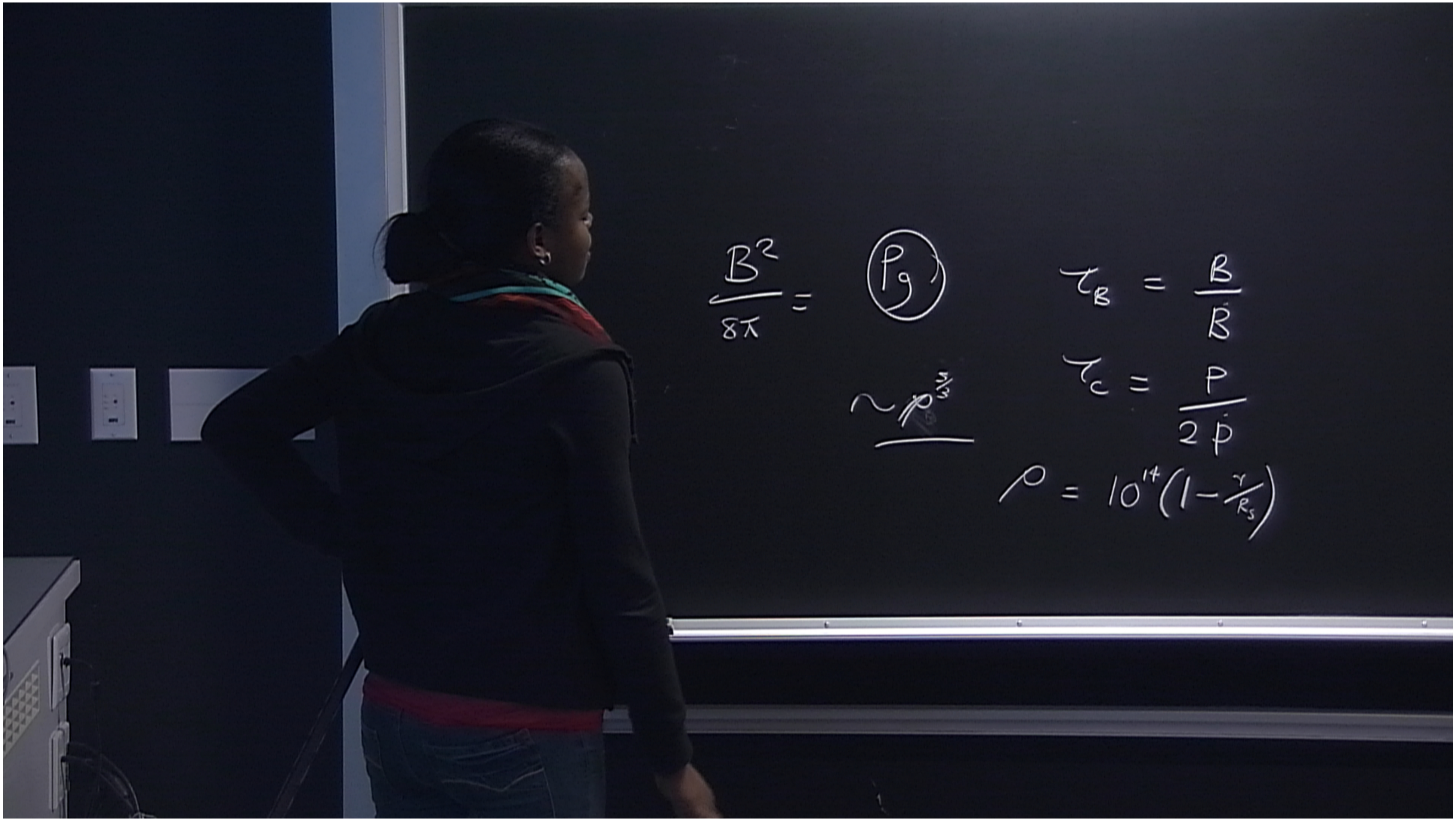
Pulsars

December 11, 2014



Ohmic Diffusion and diffusion due to hall effect

() Pulsars December 11, 2014 15 / 21



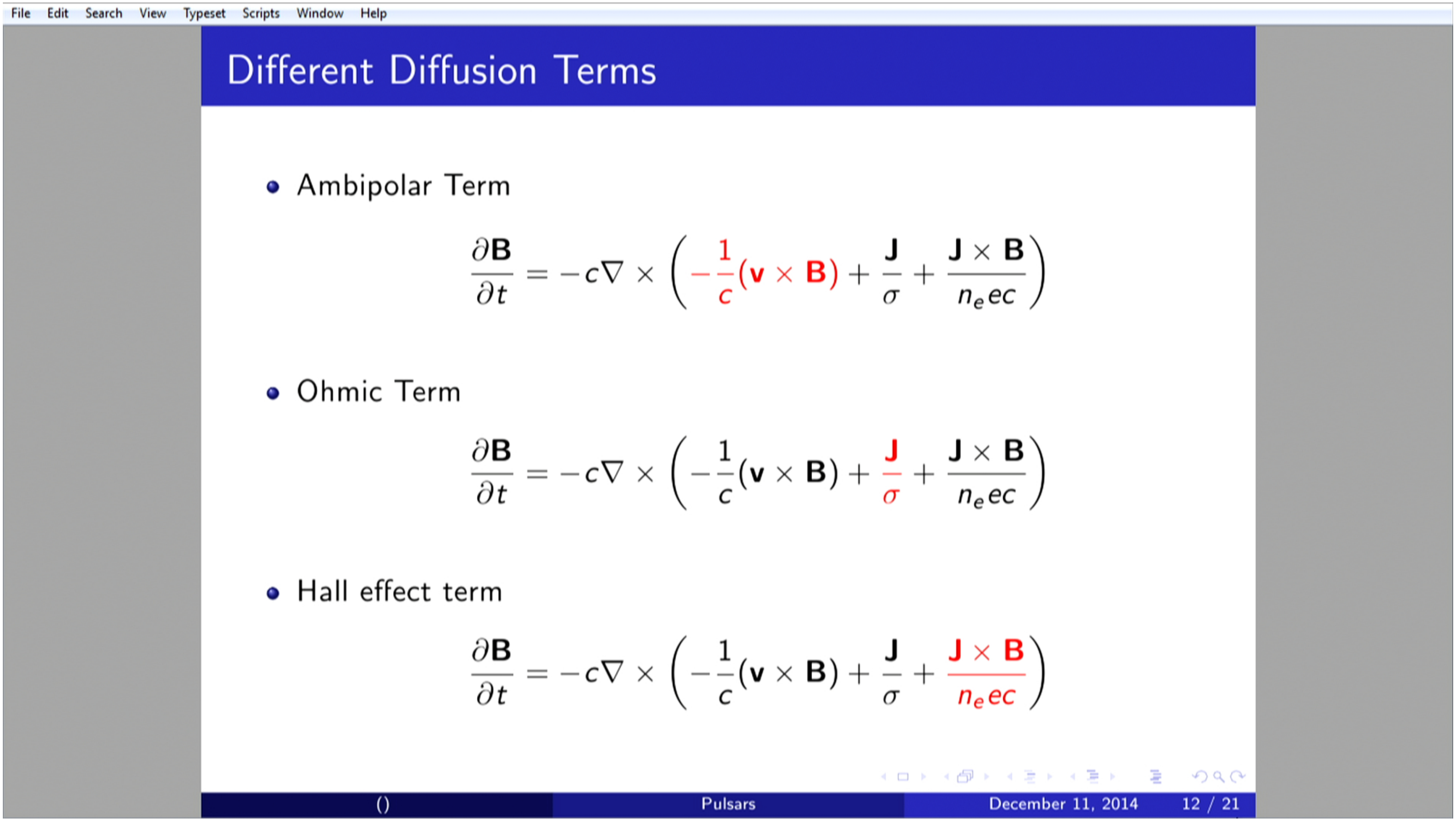
$$\frac{B^2}{8\pi} = \boxed{P_g}$$

$$\underline{\sim \rho^{5/3}}$$

$$\tau_B = \frac{B}{\dot{B}}$$

$$\tau_c = \frac{P}{2\dot{P}}$$

$$\rho = 10^{14}\left(1 - \frac{r}{R_s}\right)$$



Different Diffusion Terms

- Ambipolar Term

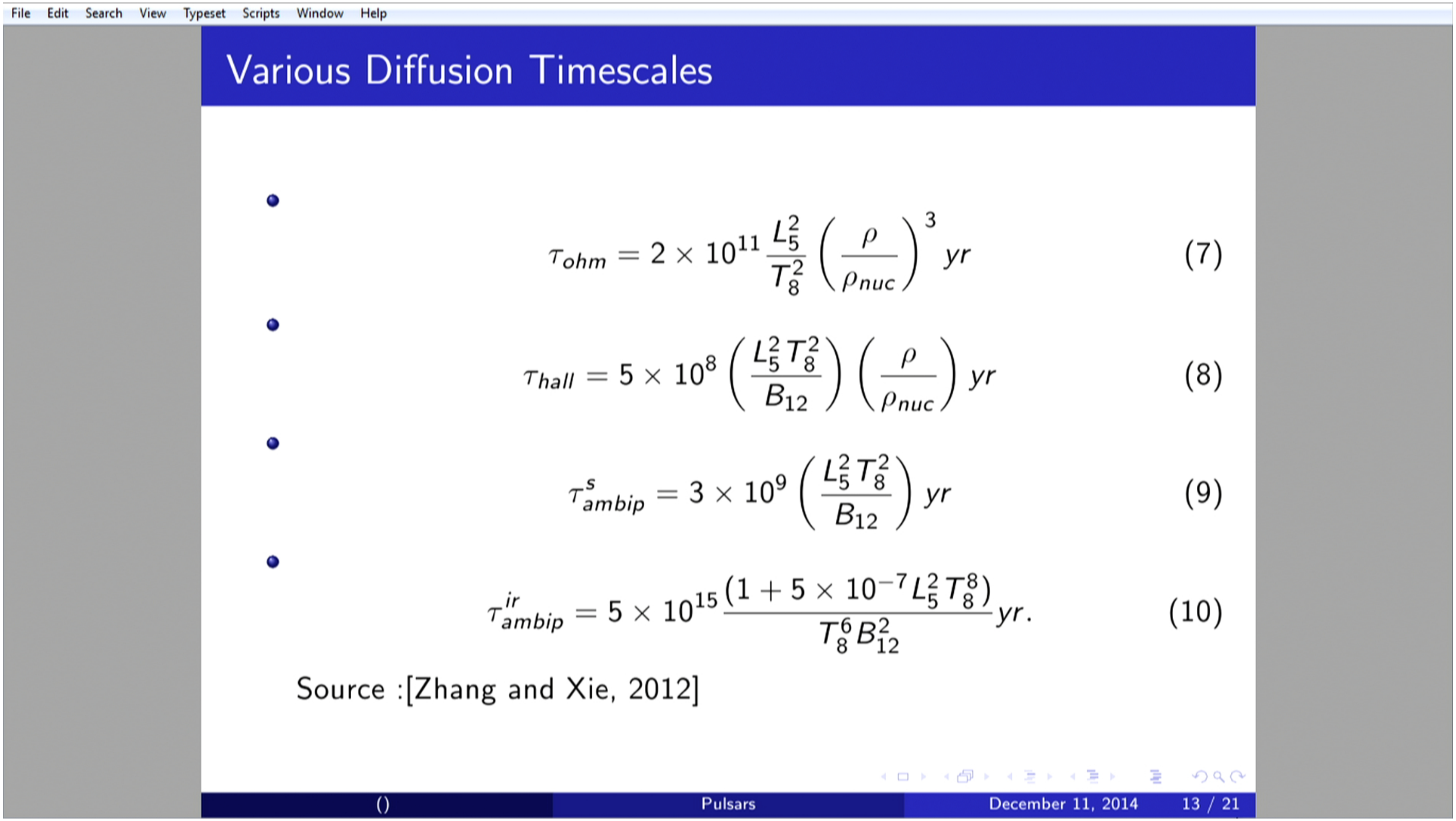
$$\frac{\partial \mathbf{B}}{\partial t} = -c\nabla \times \left(\textcolor{red}{-\frac{1}{c}(\mathbf{v} \times \mathbf{B})} + \frac{\mathbf{J}}{\sigma} + \frac{\mathbf{J} \times \mathbf{B}}{n_e ec} \right)$$

- Ohmic Term

$$\frac{\partial \mathbf{B}}{\partial t} = -c\nabla \times \left(-\frac{1}{c}(\mathbf{v} \times \mathbf{B}) + \textcolor{red}{\frac{\mathbf{J}}{\sigma}} + \frac{\mathbf{J} \times \mathbf{B}}{n_e ec} \right)$$

- Hall effect term

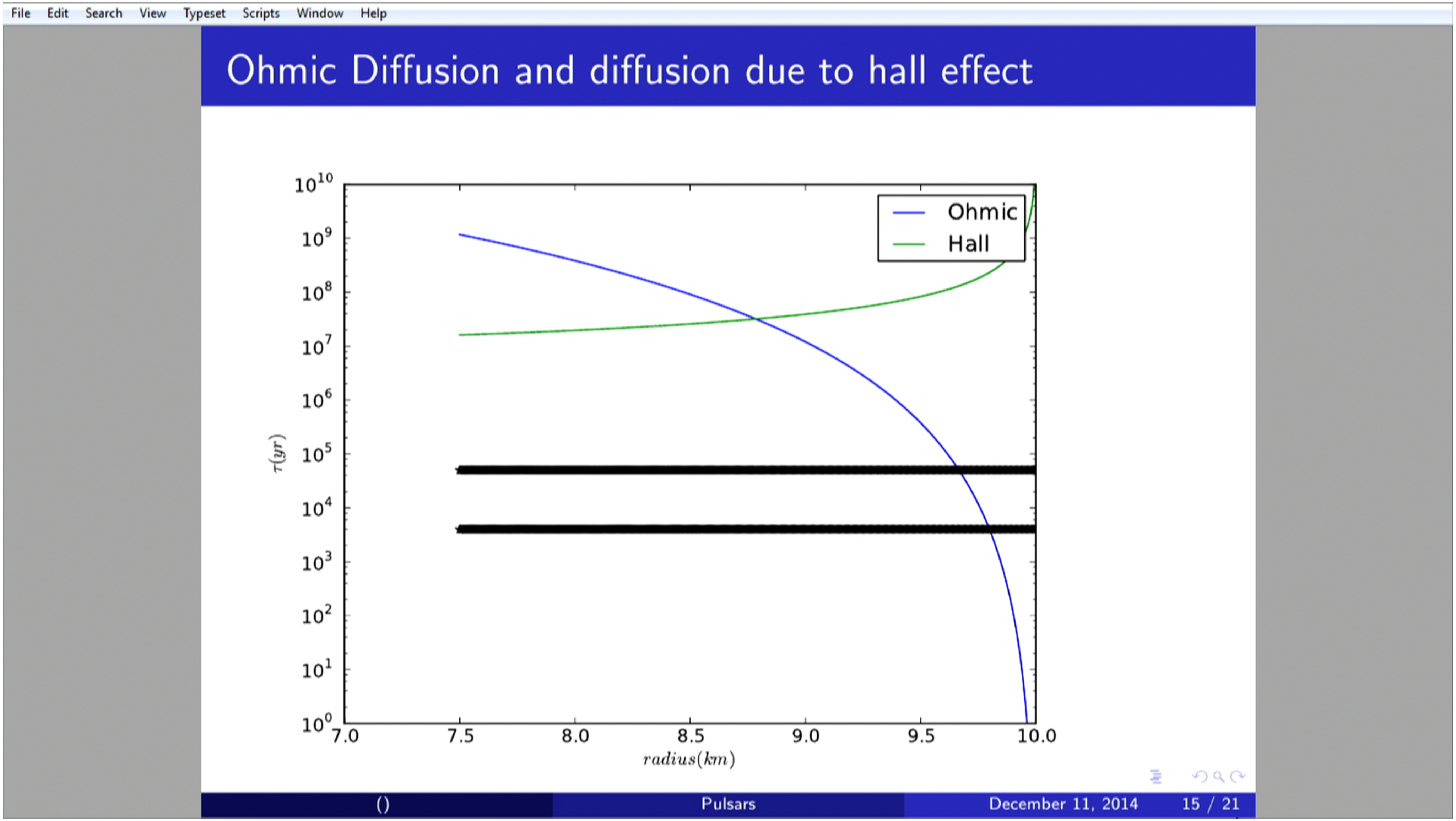
$$\frac{\partial \mathbf{B}}{\partial t} = -c\nabla \times \left(-\frac{1}{c}(\mathbf{v} \times \mathbf{B}) + \frac{\mathbf{J}}{\sigma} + \textcolor{red}{\frac{\mathbf{J} \times \mathbf{B}}{n_e ec}} \right)$$



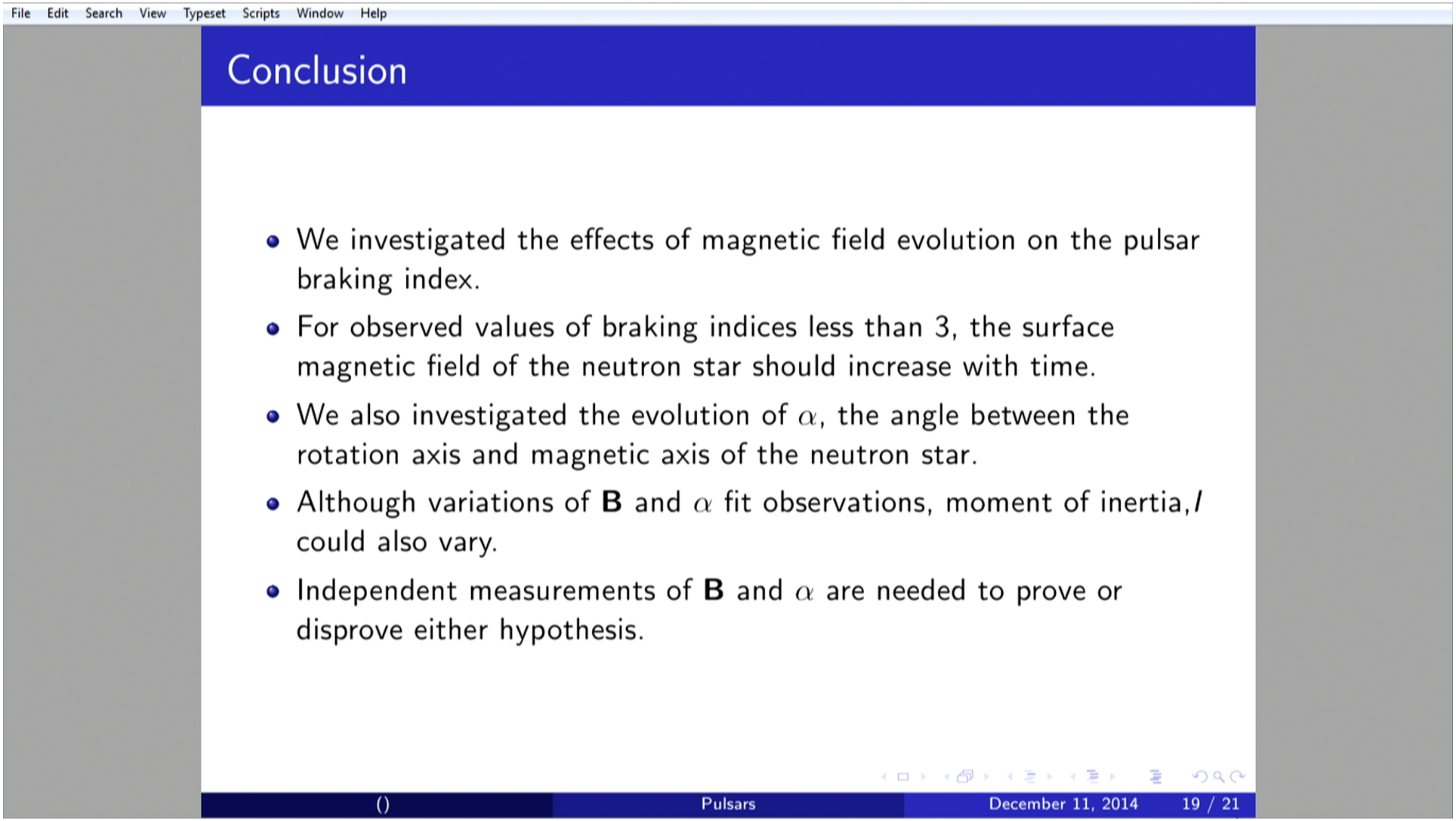
Various Diffusion Timescales

- $$\tau_{ohm} = 2 \times 10^{11} \frac{L_5^2}{T_8^2} \left(\frac{\rho}{\rho_{nuc}} \right)^3 yr \qquad (7)$$
- $$\tau_{hall} = 5 \times 10^{8} \left(\frac{L_5^2 T_8^2}{B_{12}} \right) \left(\frac{\rho}{\rho_{nuc}} \right) yr \qquad (8)$$
- $$\tau^{s}_{ambip} = 3 \times 10^{9} \left(\frac{L_5^2 T_8^2}{B_{12}} \right) yr \qquad (9)$$
- $$\tau^{ir}_{ambip} = 5 \times 10^{15} \frac{(1 + 5 \times 10^{-7} L_5^2 T_8^8)}{T_8^6 B_{12}^2} yr. \qquad (10)$$

Source :[Zhang and Xie, 2012]

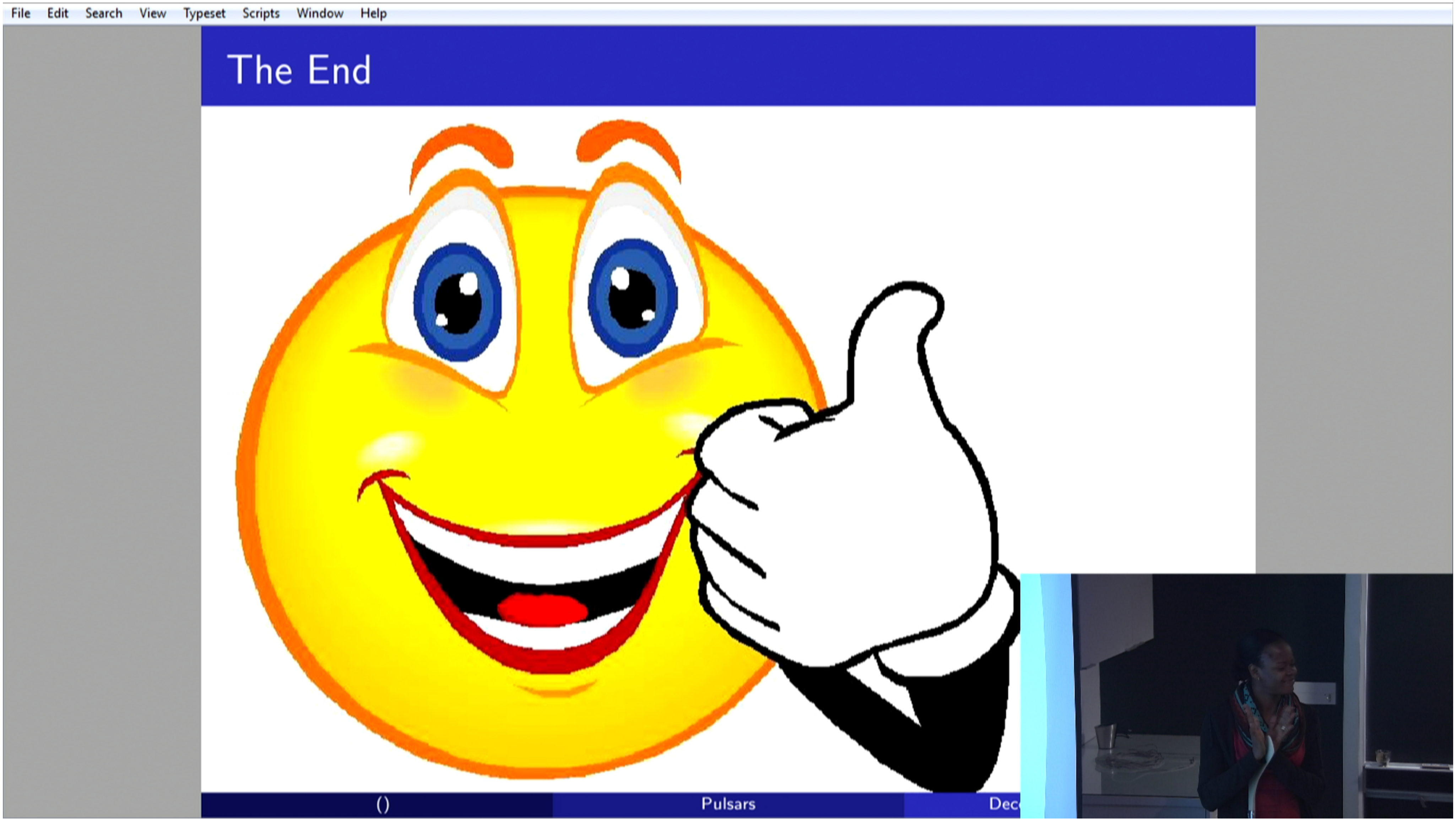


Ohmic Diffusion and diffusion due to hall effect



Conclusion

- We investigated the effects of magnetic field evolution on the pulsar braking index.
- For observed values of braking indices less than 3, the surface magnetic field of the neutron star should increase with time.
- We also investigated the evolution of α, the angle between the rotation axis and magnetic axis of the neutron star.
- Although variations of **B** and α fit observations, moment of inertia,I could also vary.
- Independent measurements of **B** and α are needed to prove or disprove either hypothesis.



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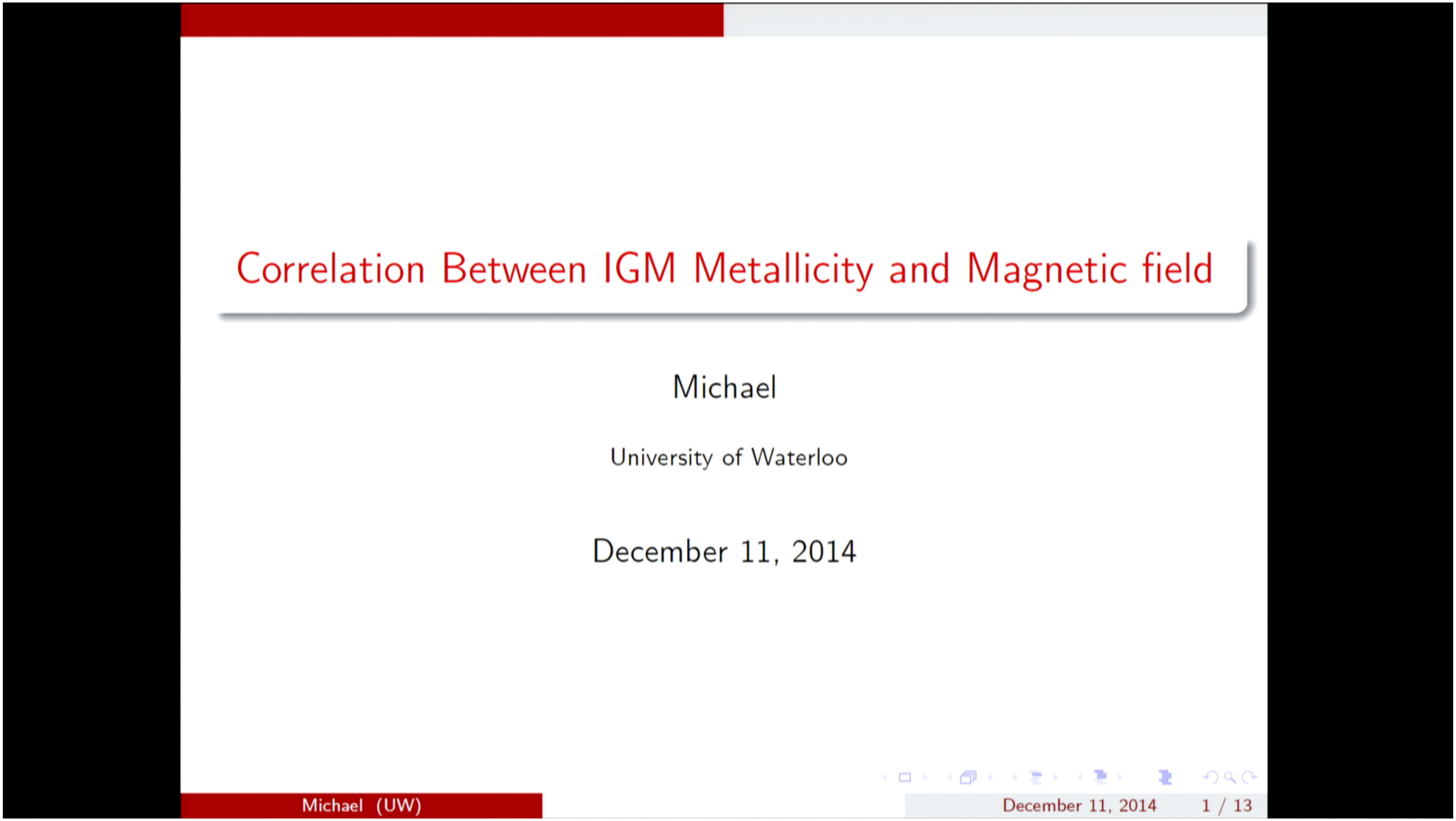


Correlation Between IGM Metallicity and Magnetic field

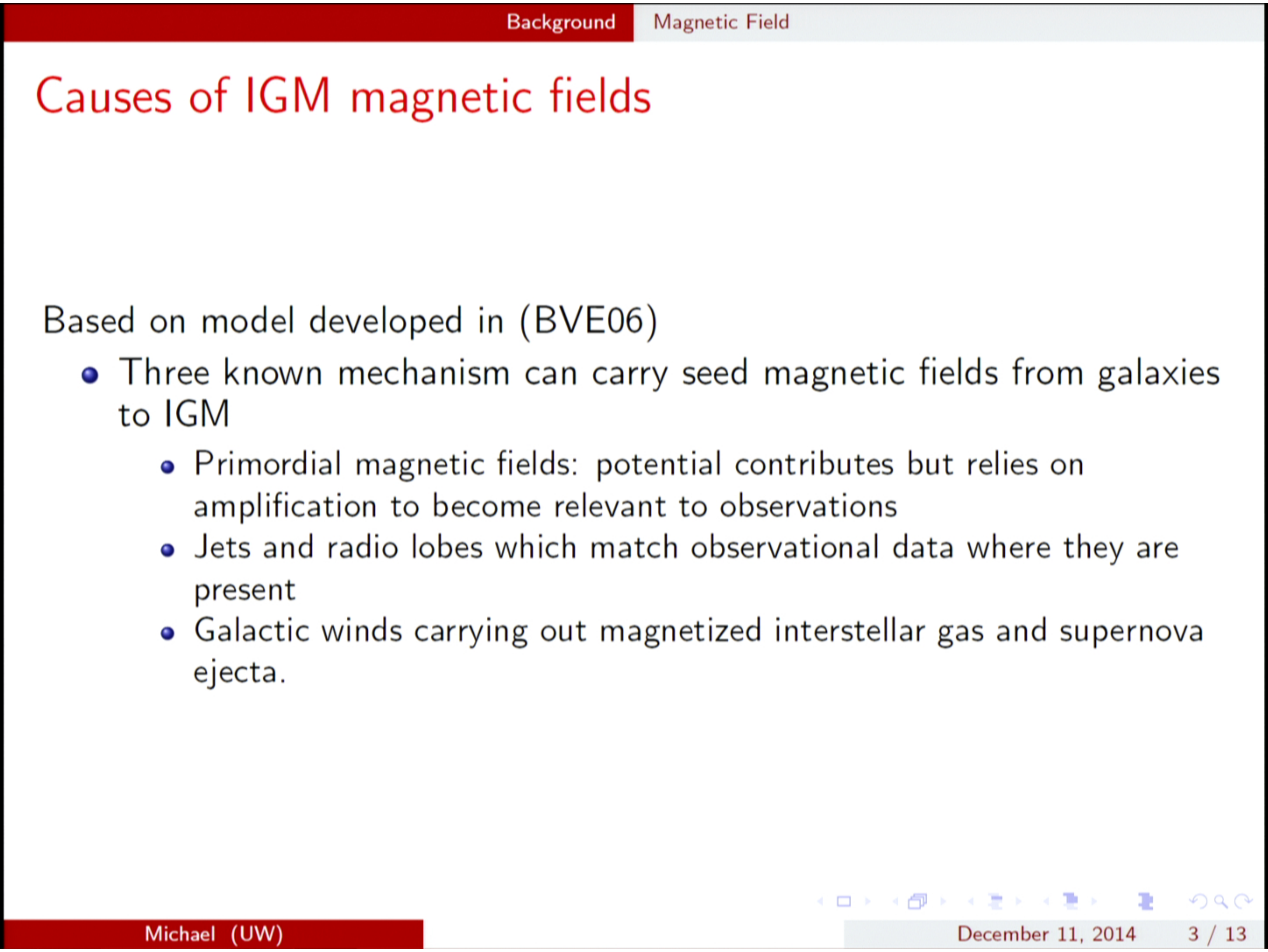
Michael

University of Waterloo

December 11, 2014

Overview

1. Background
    - Magnetic Field
    - Metallicity
2. Analysis
3. Conclusion



Causes of IGM magnetic fields

Based on model developed in (BVE06)

- Three known mechanism can carry seed magnetic fields from galaxies to IGM
    - Primordial magnetic fields: potential contributes but relies on amplification to become relevant to observations
    - Jets and radio lobes which match observational data where they are present
    - Galactic winds carrying out magnetized interstellar gas and supernova ejecta.

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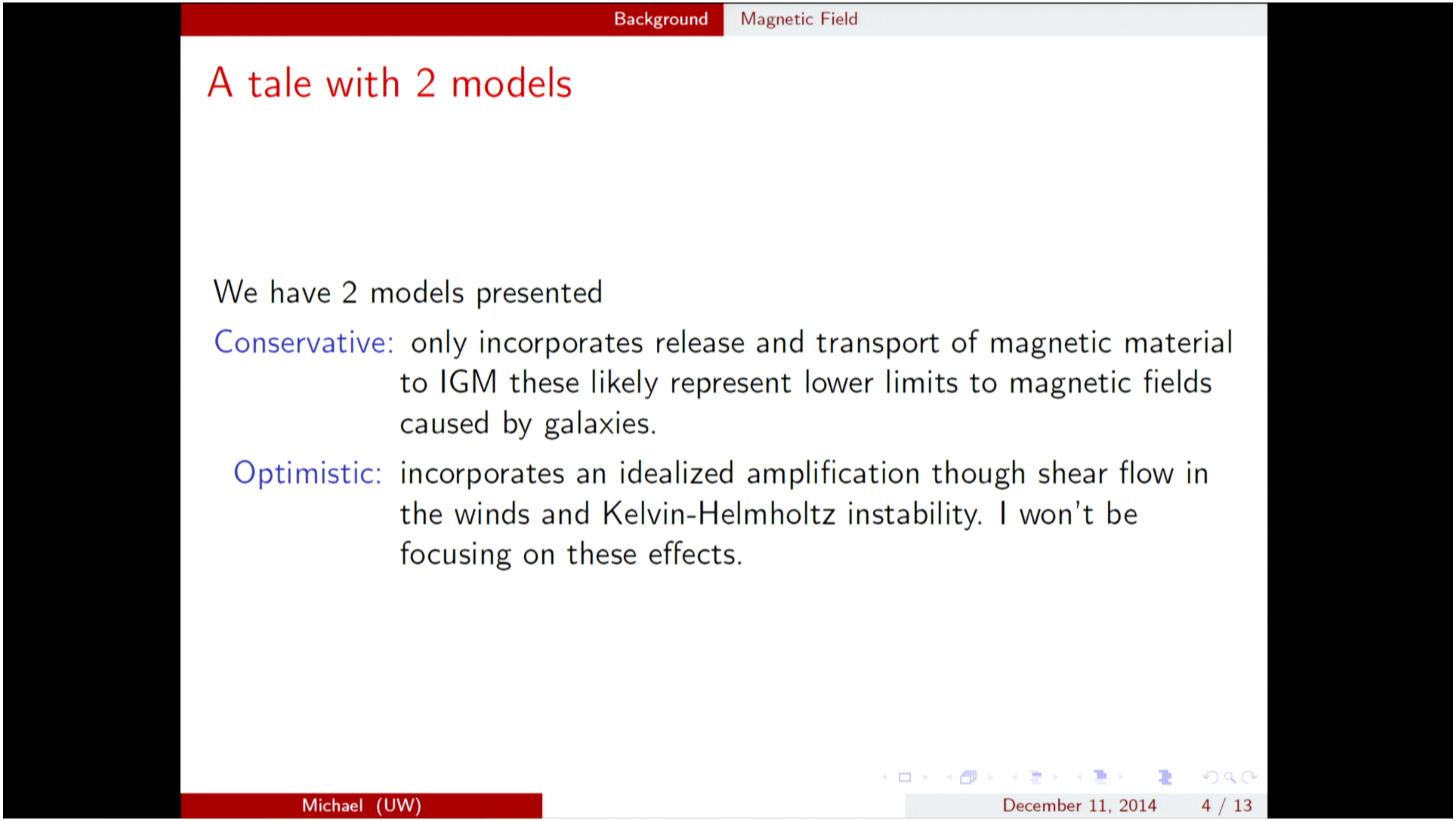
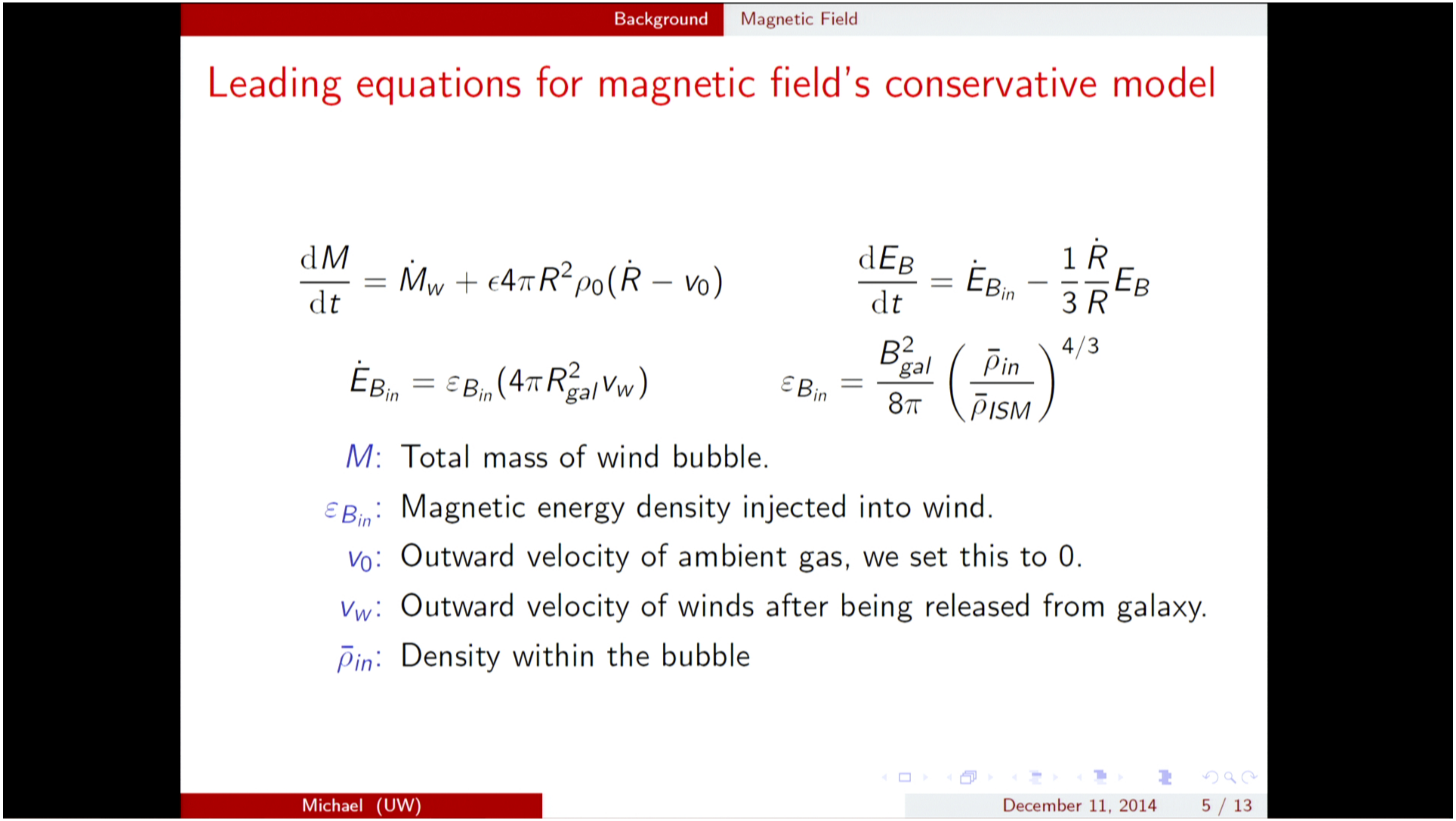


A tale with 2 models

We have 2 models presented

Conservative: only incorporates release and transport of magnetic material to IGM these likely represent lower limits to magnetic fields caused by galaxies.

Optimistic: incorporates an idealized amplification though shear flow in the winds and Kelvin-Helmholtz instability. I won't be focusing on these effects.



Leading equations for magnetic field's conservative model

$$\frac{\mathrm{d}M}{\mathrm{d}t} = \dot{M}_w + \epsilon 4\pi R^2 \rho_0 (\dot{R} - v_0) \qquad \frac{\mathrm{d}E_B}{\mathrm{d}t} = \dot{E}_{B_{in}} - \frac{1}{3}\frac{\dot{R}}{R}E_B$$

$$\dot{E}_{B_{in}} = \varepsilon_{B_{in}}(4\pi R_{gal}^2 v_w) \qquad \varepsilon_{B_{in}} = \frac{B_{gal}^2}{8\pi}\left(\frac{\bar{\rho}_{in}}{\bar{\rho}_{ISM}}\right)^{4/3}$$

M: Total mass of wind bubble.

$\varepsilon_{B_{in}}$: Magnetic energy density injected into wind.

v_0: Outward velocity of ambient gas, we set this to 0.

v_w: Outward velocity of winds after being released from galaxy.

$\bar{\rho}_{in}$: Density within the bubble

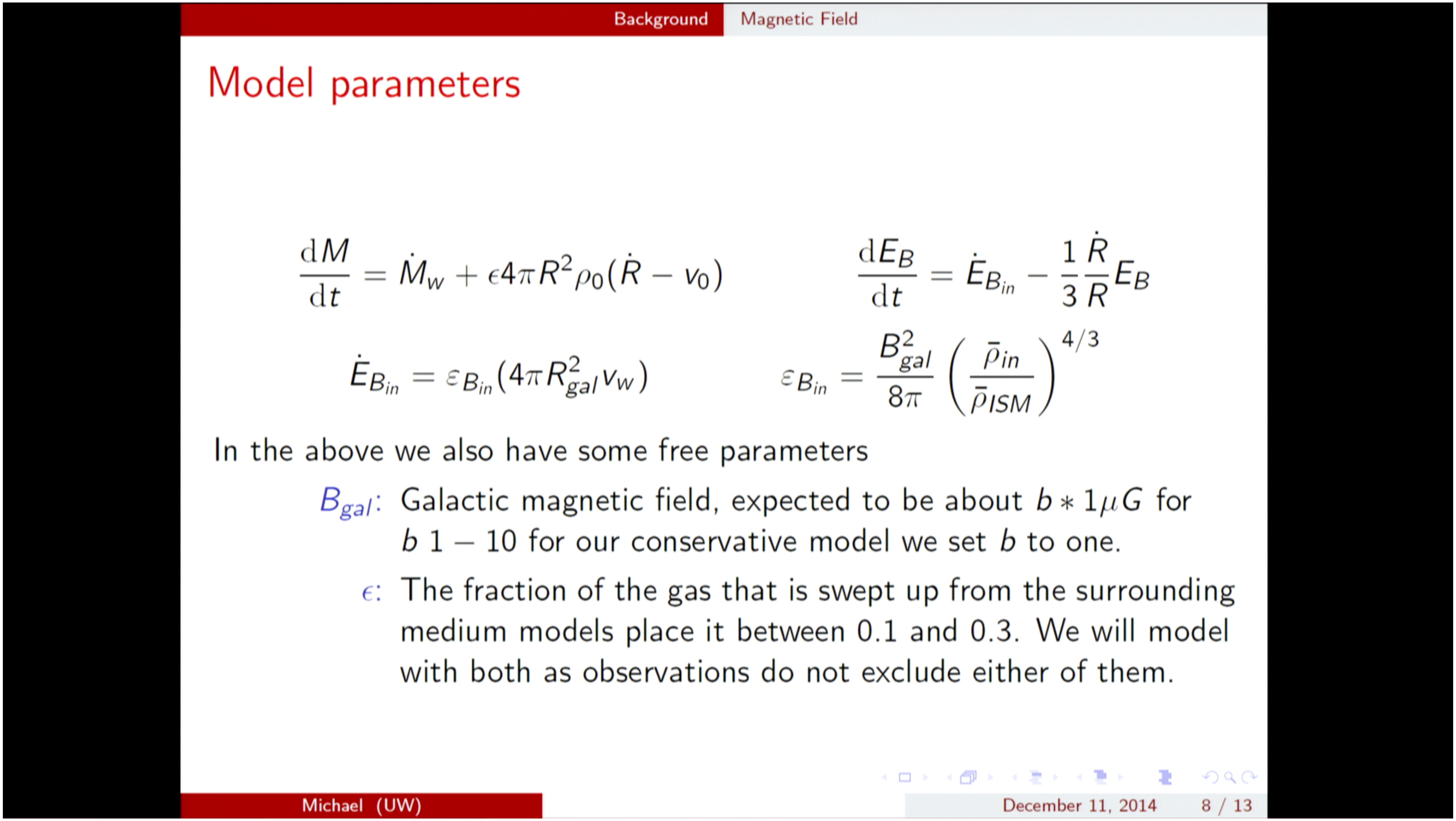
Flow rates

Initial condition were calibrated by (SMM05) to match observations leading to

$$\dot{M}_w = 5\dot{M}_*^{0.71} K M_\odot yr^{-1} \qquad v_w = 320 M_*^{0.145} K^{-1/2} kms^{-1}$$

$\dot{M}_*$: Star formation rate in solar masses per year.

K: An amalgamated constant that summarized ISM properties it is held at 0.5 and results do not strongly correlate to it (BVE06).



Model parameters

$$\frac{\mathrm{d}M}{\mathrm{d}t} = \dot{M}_w + \epsilon 4\pi R^2 \rho_0(\dot{R} - v_0) \qquad \frac{\mathrm{d}E_B}{\mathrm{d}t} = \dot{E}_{B_{in}} - \frac{1}{3}\frac{\dot{R}}{R}E_B$$

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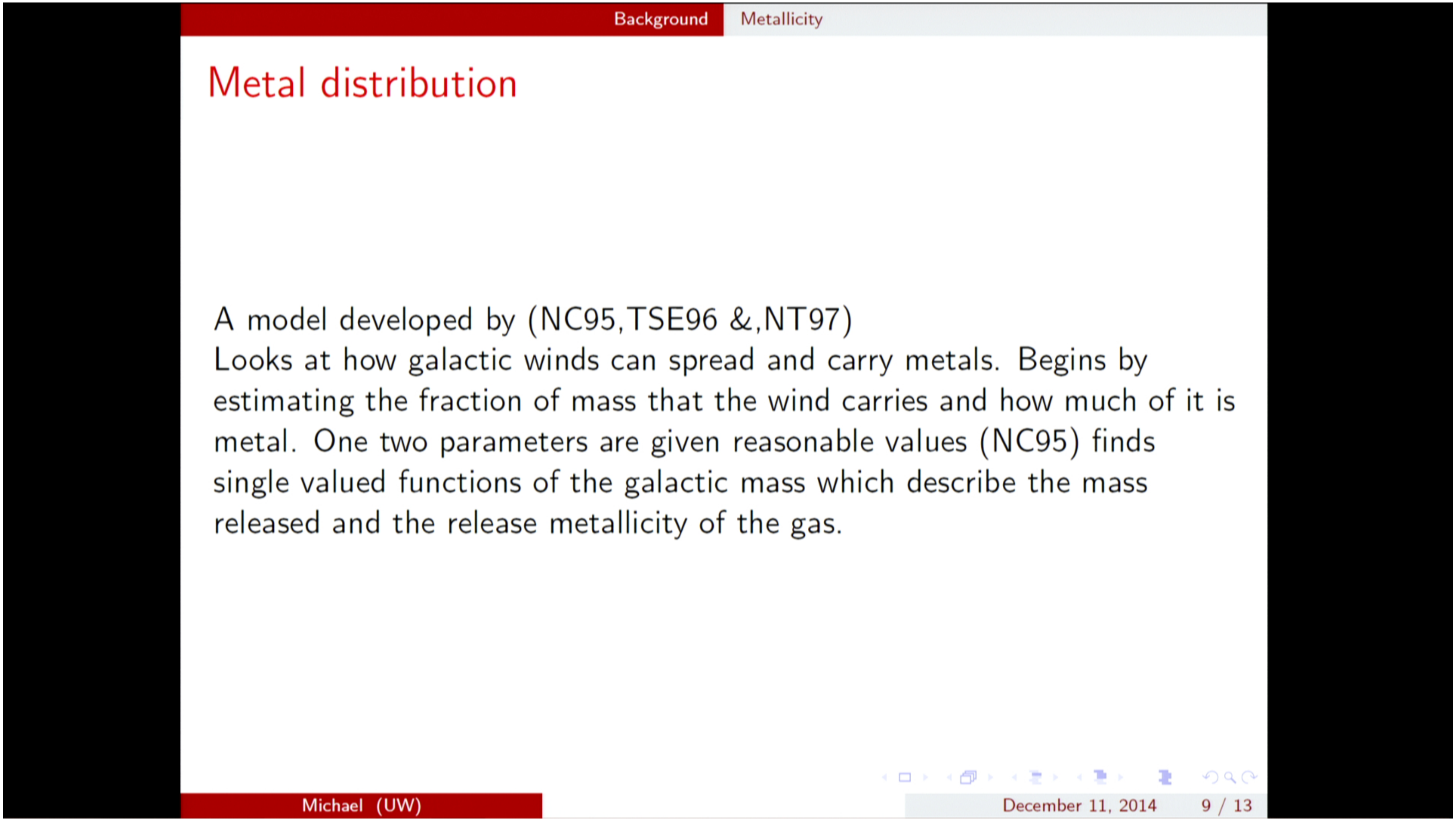
In the above we also have some free parameters

B_{gal}: Galactic magnetic field, expected to be about $b * 1\mu G$ for b $1 - 10$ for our conservative model we set b to one.

ϵ: The fraction of the gas that is swept up from the surrounding medium models place it between 0.1 and 0.3. We will model with both as observations do not exclude either of them.



Metal distribution

A model developed by (NC95,TSE96 &,NT97)
Looks at how galactic winds can spread and carry metals. Begins by estimating the fraction of mass that the wind carries and how much of it is metal. One two parameters are given reasonable values (NC95) finds single valued functions of the galactic mass which describe the mass released and the release metallicity of the gas.

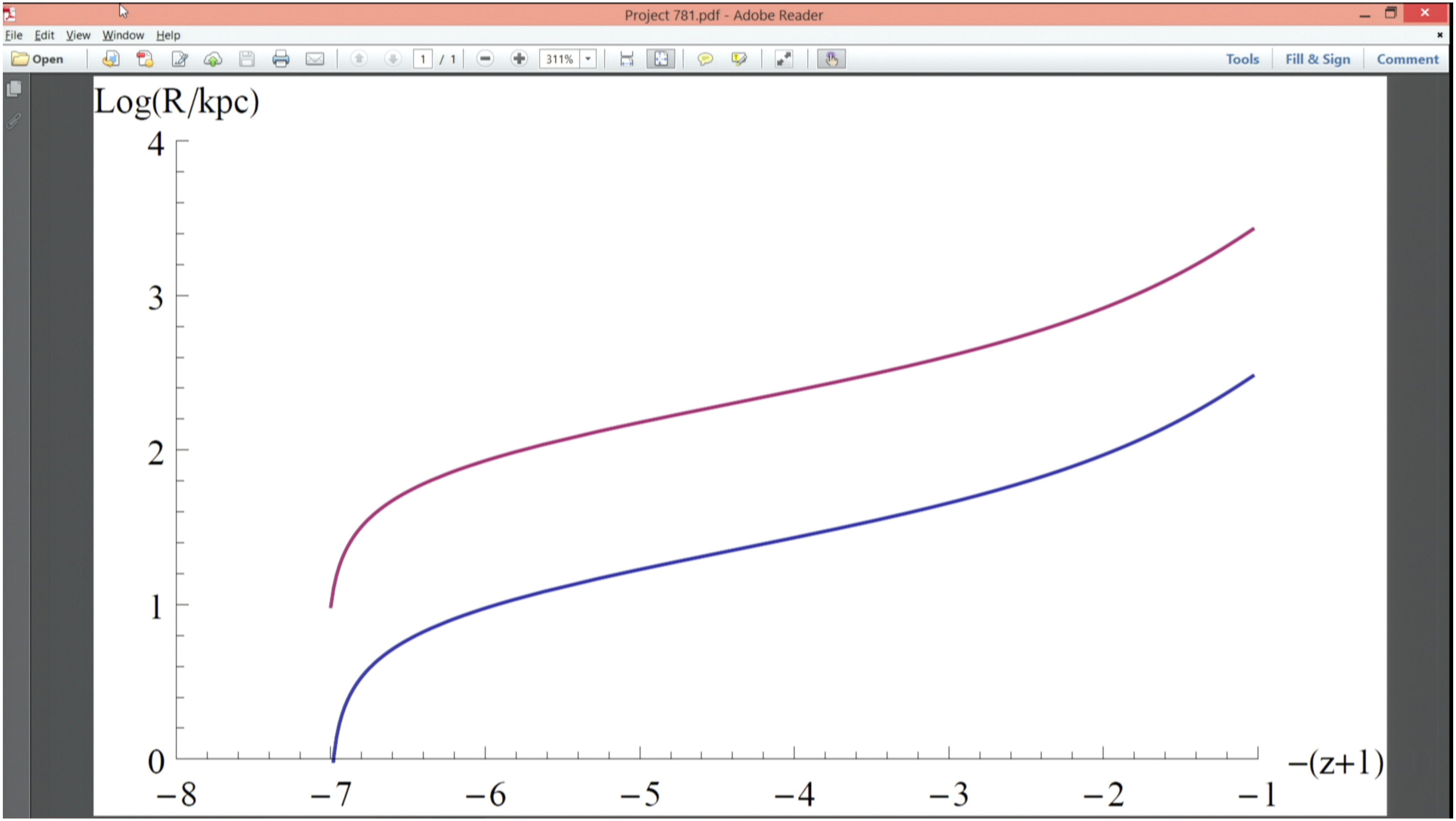
Important Equations

$$\ddot{R} = \frac{8\pi p G}{\Omega_{IGM} H_0^2 R} - \frac{3}{R}(\dot{R} - H_0 R)^2 - (\Omega_D M_{gal} + \frac{\Omega_{IGM}}{2})(\frac{H_0^2 R}{2})$$

$$\frac{\mathrm{d}E_t}{\mathrm{d}t} = L_{sn} - 4\pi p R^2 \dot{R} - L_{brem} - L_{comp} \qquad E_t = \frac{3}{2} pV$$

$$R_0 = 1.2 \times 10^2 \left(\frac{M_{gal}}{10^1 2 M_\odot} \right)^{0.55} Kpc \qquad \dot{R}_0 = 100 kms^{-1}$$

$$L_{sn} \sim \frac{M_b}{M_\odot} L_\odot \qquad L_{comp} \propto TV(1+z)^4$$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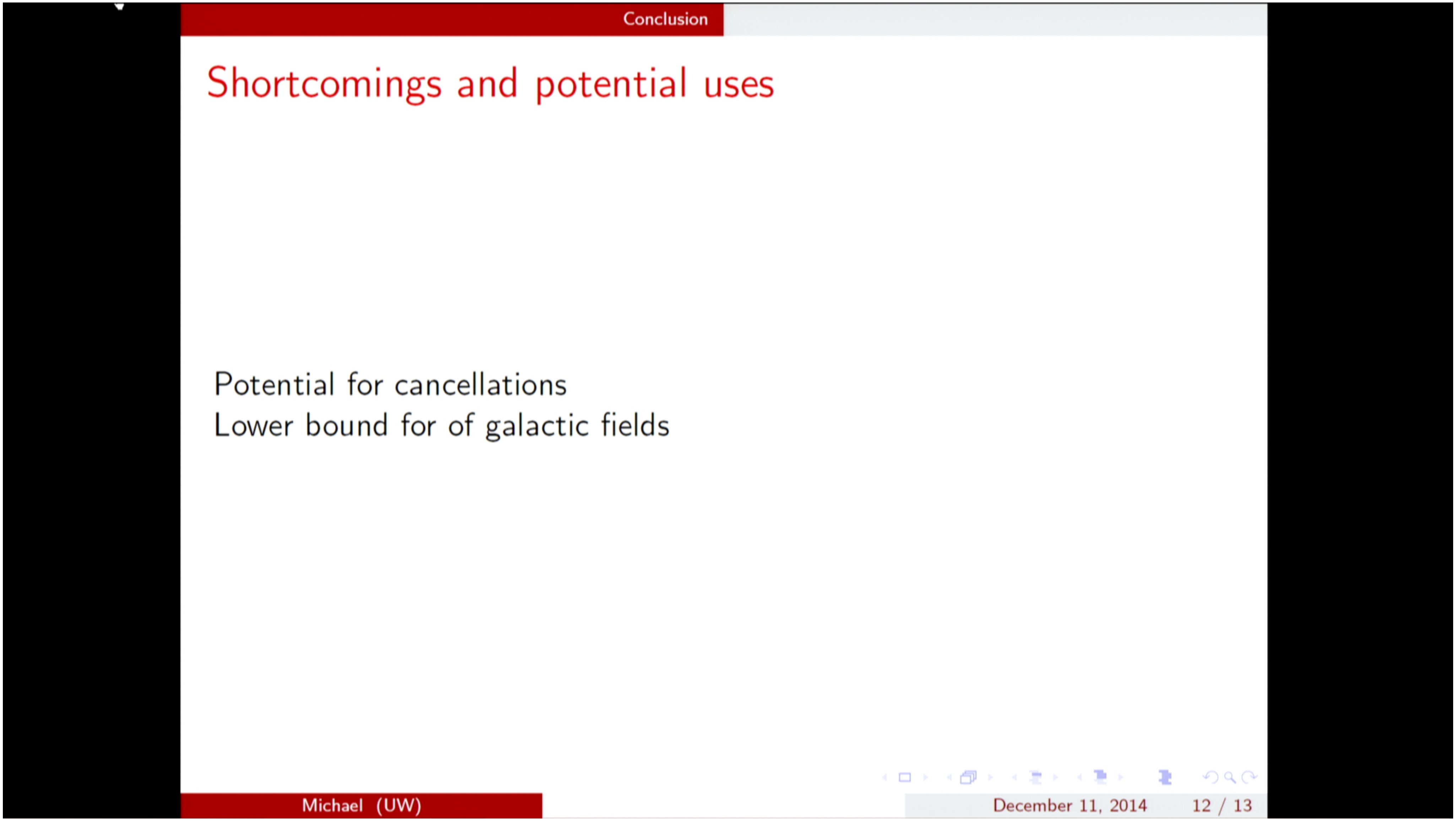
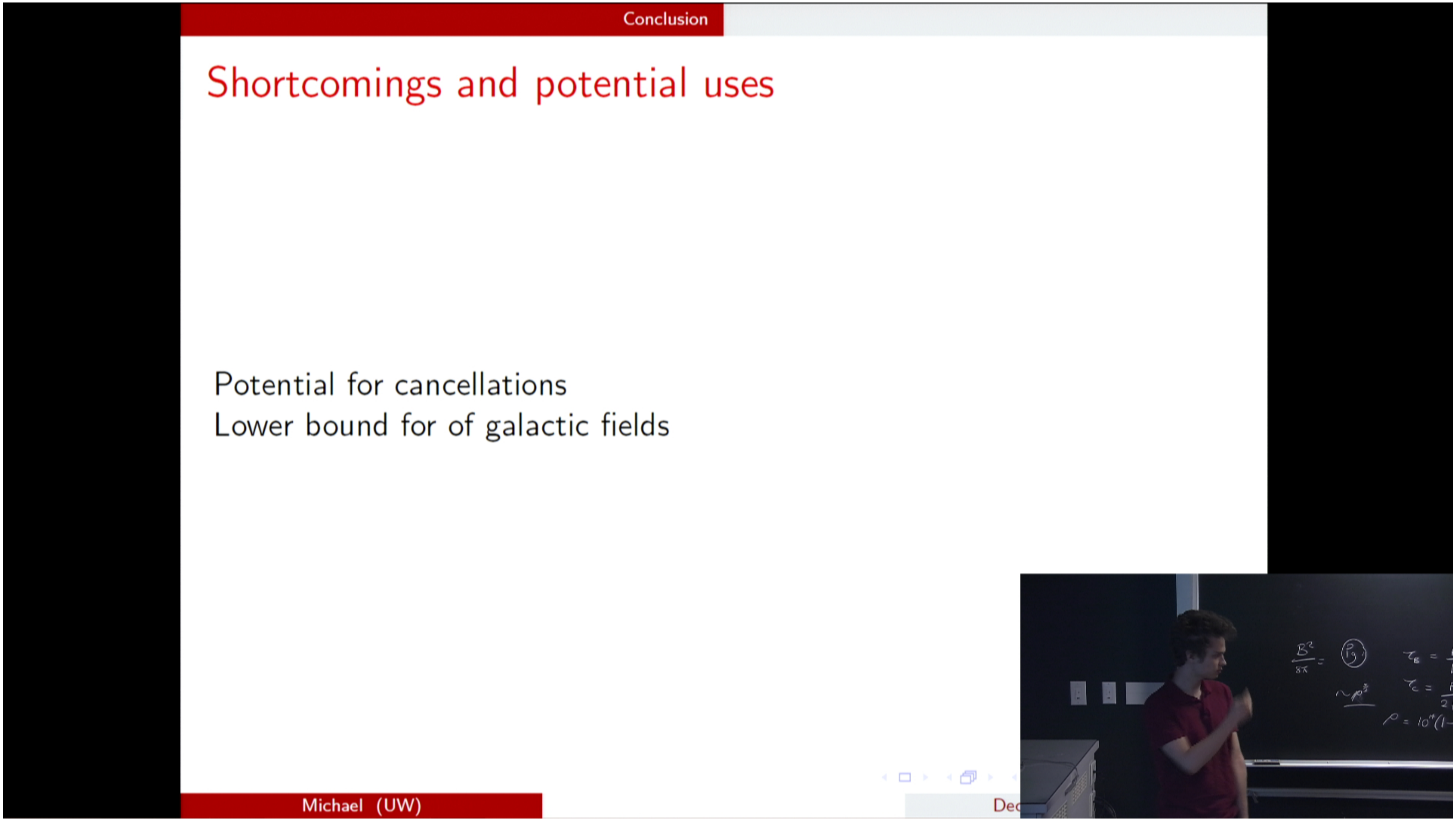


Shortcomings and potential uses

Potential for cancellations
Lower bound for of galactic fields



Shortcomings and potential uses

Potential for cancellations
Lower bound for of galactic fields

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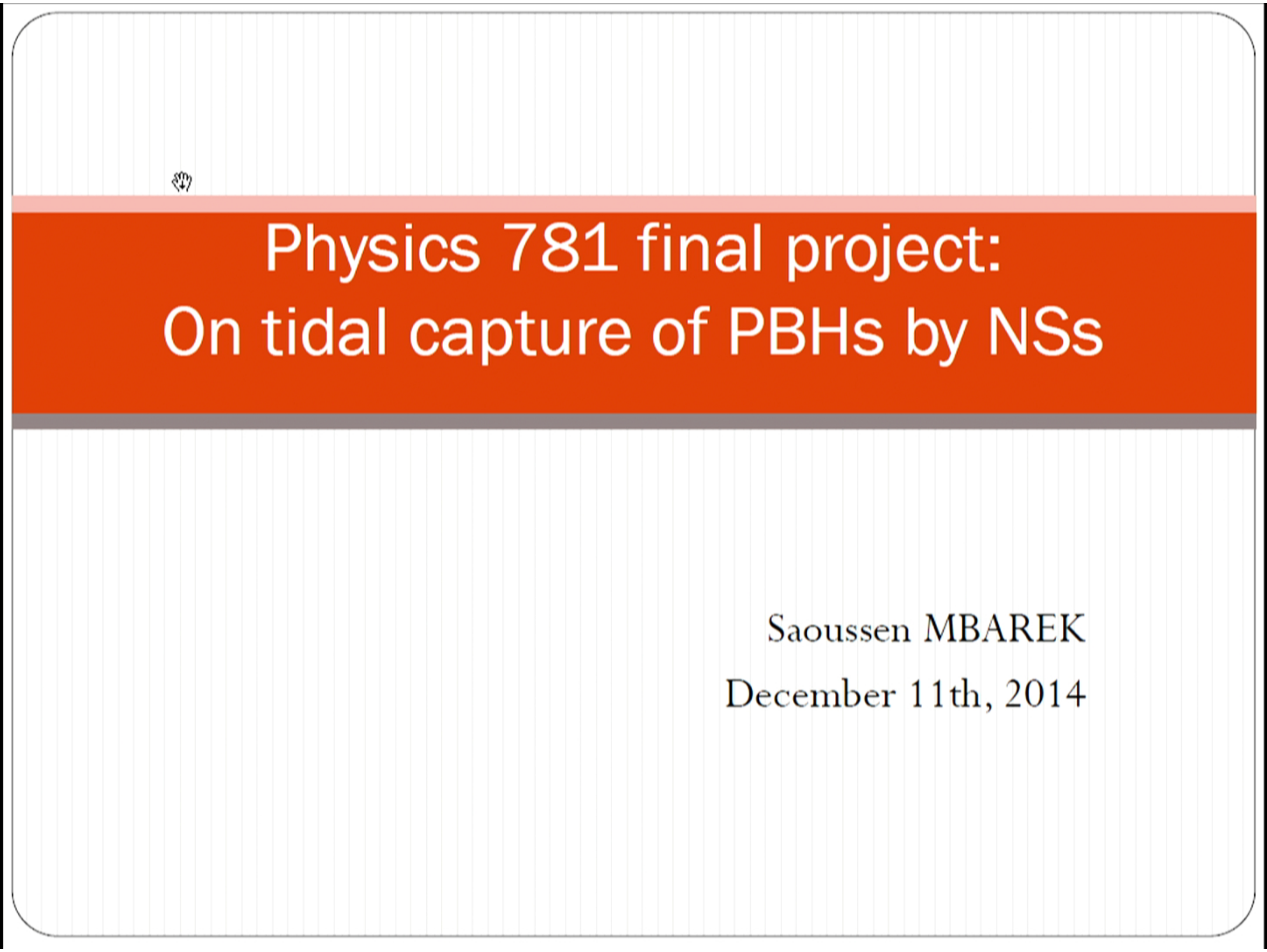


Physics 781 final project:
On tidal capture of PBHs by NSs

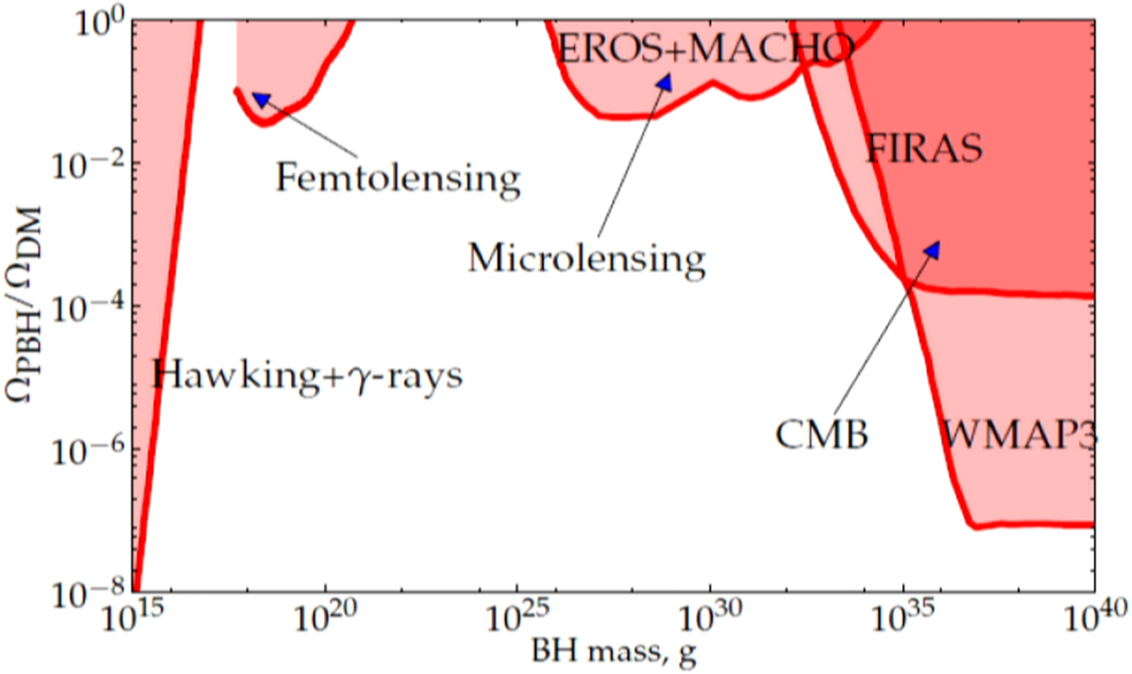
Saoussen MBAREK

December 11th, 2014

Introduction

- PBHs are good condidates for dark matter.
- The are:
  - Cold, dark and weakly interacting.
  - They don't require a modification of the SM
  - They have microscopic size: $r \approx 10^{-8}\, cm \left(\frac{m_{BH}}{10^{20}}\right)$
- There exist a number of observational constraints on the fraction of PBHs in the total amount of DM:

Introduction



F. Capela, 2014

$$\frac{B^2}{8\pi} = \boxed{P_g}$$

$$\underline{\sim \rho^{5/3}}$$

$$\rho$$

NS–PBH encounter

- PBH loses energy and becomes gravitationally captured by the NS.
- Using E_{loss}, we can calculate t_{loss}.
- Few different models are working on this mechanism using two diffents approches:
  - Dynamical friction approach: Capela et al. 2013
  - Exitation of oscillation modes approach: Pani&Loeb 2014 and Defillon et al. 2014

Dynamical Friction

- NS is a sum of particles that interact individually with the PBH.

$$E_{\rm loss} = \frac{4G^2 m_{\rm BH}^2 M}{R^2} \left\langle \frac{\ln \Lambda}{v^2} \right\rangle$$

$$E_{\rm loss}/m_{\rm BH} = 6.3 \times 10^{-12} \left(\frac{m_{\rm BH}}{10^{22}{\rm g}} \right)$$

$$t_{\rm loss} \simeq 4.1 \times 10^4 {\rm yr} \left(\frac{m_{\rm BH}}{10^{22}{\rm g}} \right)^{-3/2}$$

$$m_{\rm PBH} \gtrsim 2.5 \times 10^{18}\ {\rm g}$$

$$F_0 = \sqrt{6\pi} \frac{\rho_{\rm DM}}{m_{\rm BH}} \frac{R_g R}{\bar{v}(1 - R_g/R)} \left(1 - \exp\left(-\frac{3E_{\rm loss}}{m_{\rm BH}\bar{v}^2} \right) \right)$$

$$\frac{\Omega_{\rm PBH}}{\Omega_{\rm DM}} \leq \frac{1}{t_{\rm NS} F_0}.$$

Capelo et al. 2013

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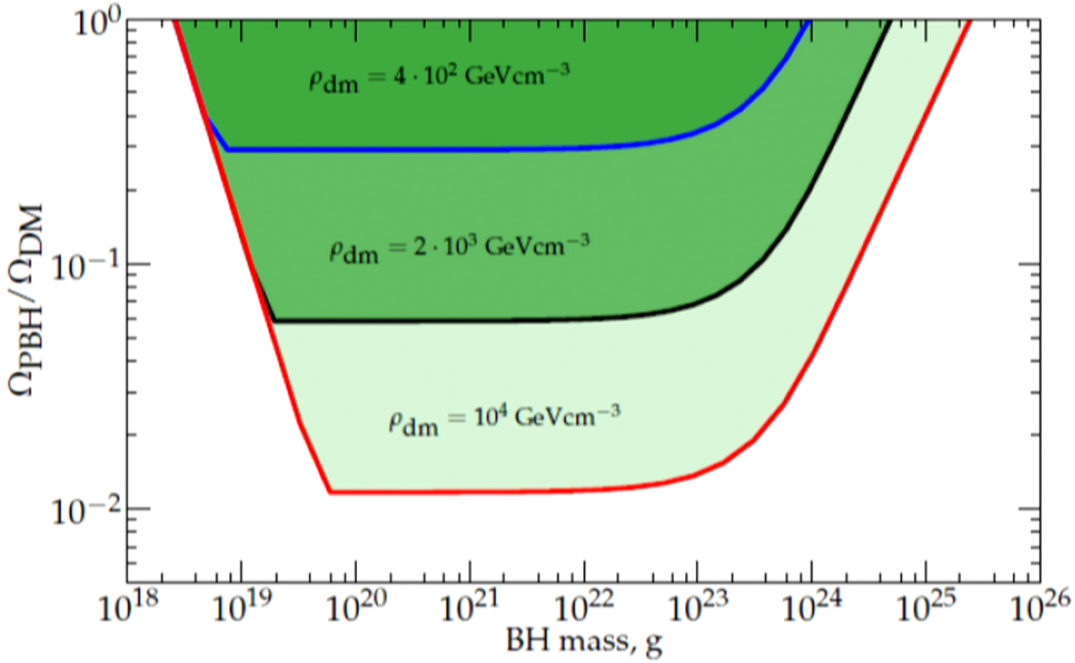
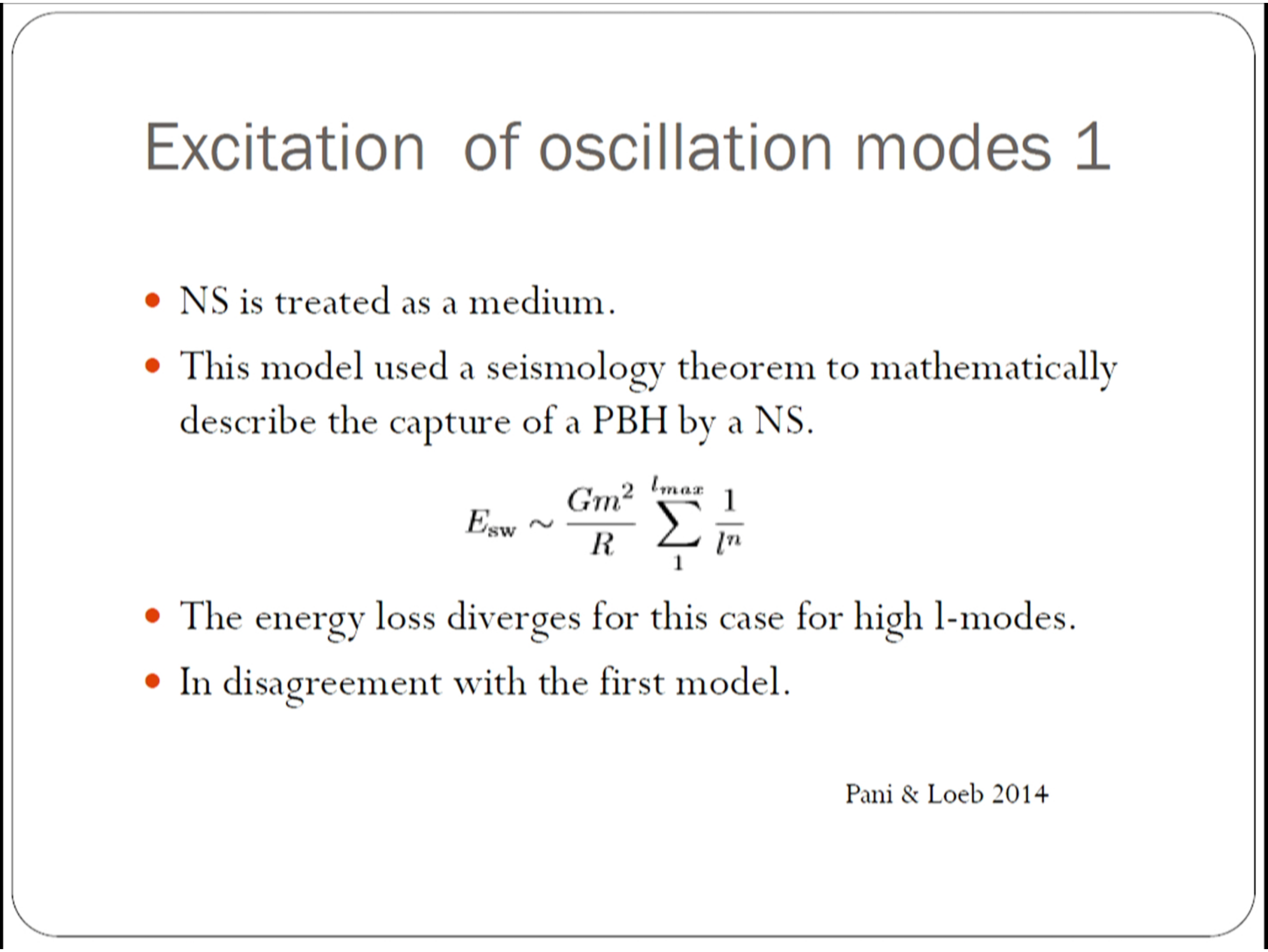
Capelo et al. 2013

Dynamical friction



F. Capelo 2014



Excitation of oscillation modes 1

- NS is treated as a medium.
- This model used a seismology theorem to mathematically describe the capture of a PBH by a NS.

$$E_{\mathrm{sw}} \sim \frac{Gm^2}{R} \sum_{1}^{l_{max}} \frac{1}{l^n}$$

- The energy loss diverges for this case for high l-modes.
- In disagreement with the first model.

Pani & Loeb 2014

$$\frac{B^2}{8\pi} = \boxed{P_g}$$

$$\underline{\sim \rho^{5/3}}$$

$$\tau_B = \frac{B}{\dot{B}}$$

$$\tau_c = \frac{\rho}{2\dot{\rho}}$$

$$\rho = 10^{14}\left(1 - \frac{r}{R_s}\right)$$

$$P = K \rho^{1+\frac{1}{n}} \nwarrow$$

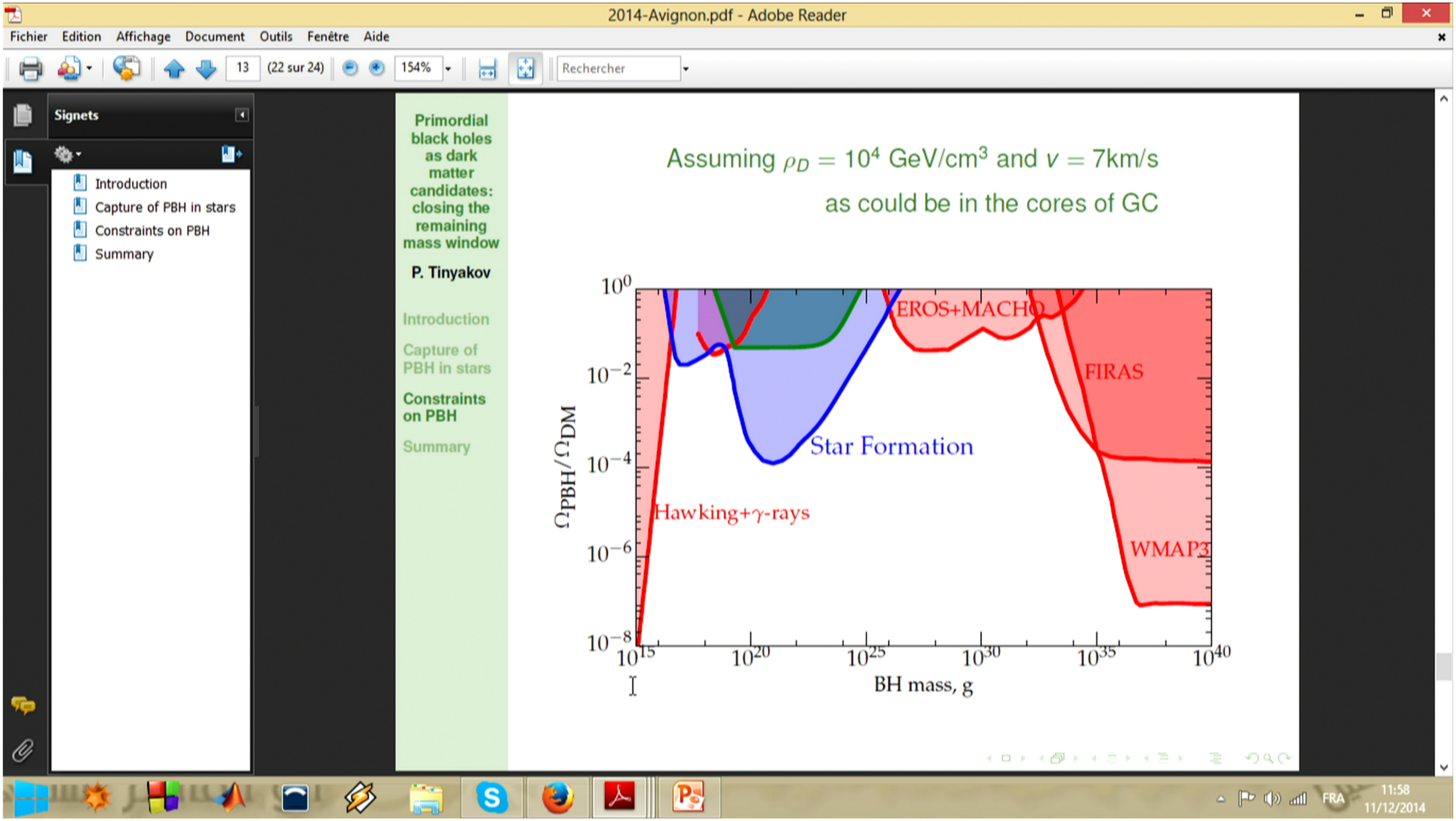
Excitation of oscillation modes 2

- The NS is treated as a medium.
- The energy loss of the PBH is calculated via the excitation of the oscillation modes on the surface of the NS.
- Assumptions:
  - pressureless NS
  - Flat NS then generalization for the spherical NS

Defillon et al. 2014

Future work

- Combination of the first model with the third one.
- Mapping the regions that should be observed to exclude entirely PBHs as DM condidates.
- …



Primordial black holes as dark matter candidates: closing the remaining mass window

P. Tinyakov

Introduction

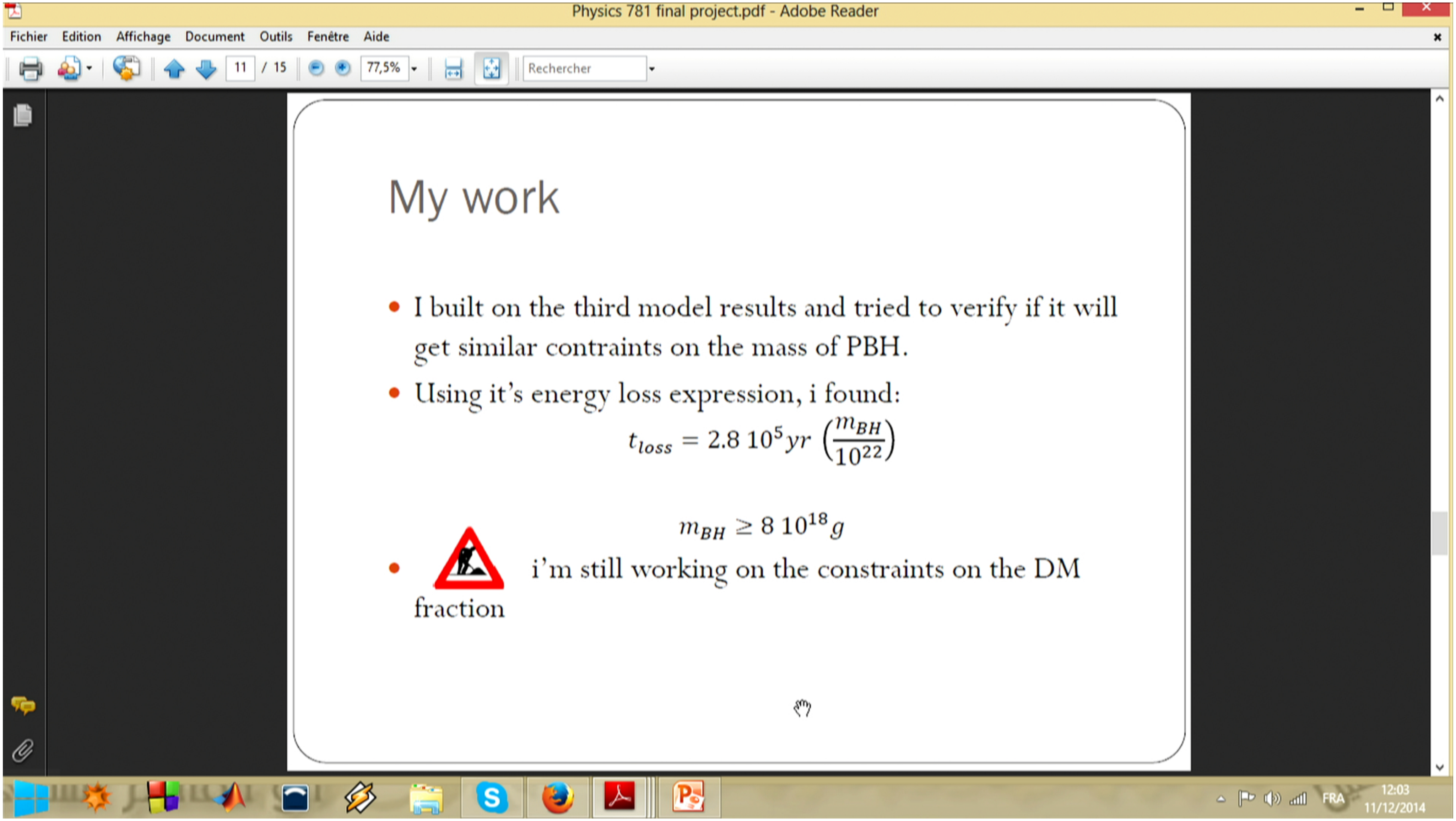
Capture of PBH in stars

Constraints on PBH

Summary

Assuming $\rho_D = 10^4$ GeV/cm^3 and $v = 7$km/s

as could be in the cores of GC



My work

- I built on the third model results and tried to verify if it will get similar contraints on the mass of PBH.
- Using it's energy loss expression, i found:

$$t_{loss} = 2.8\ 10^5 yr \left(\frac{m_{BH}}{10^{22}}\right)$$

$$m_{BH} \geq 8\ 10^{18} g$$

- i'm still working on the constraints on the DM fraction