Title: Probing the primordial helium abundance and the effective number of neutrino species with CMB

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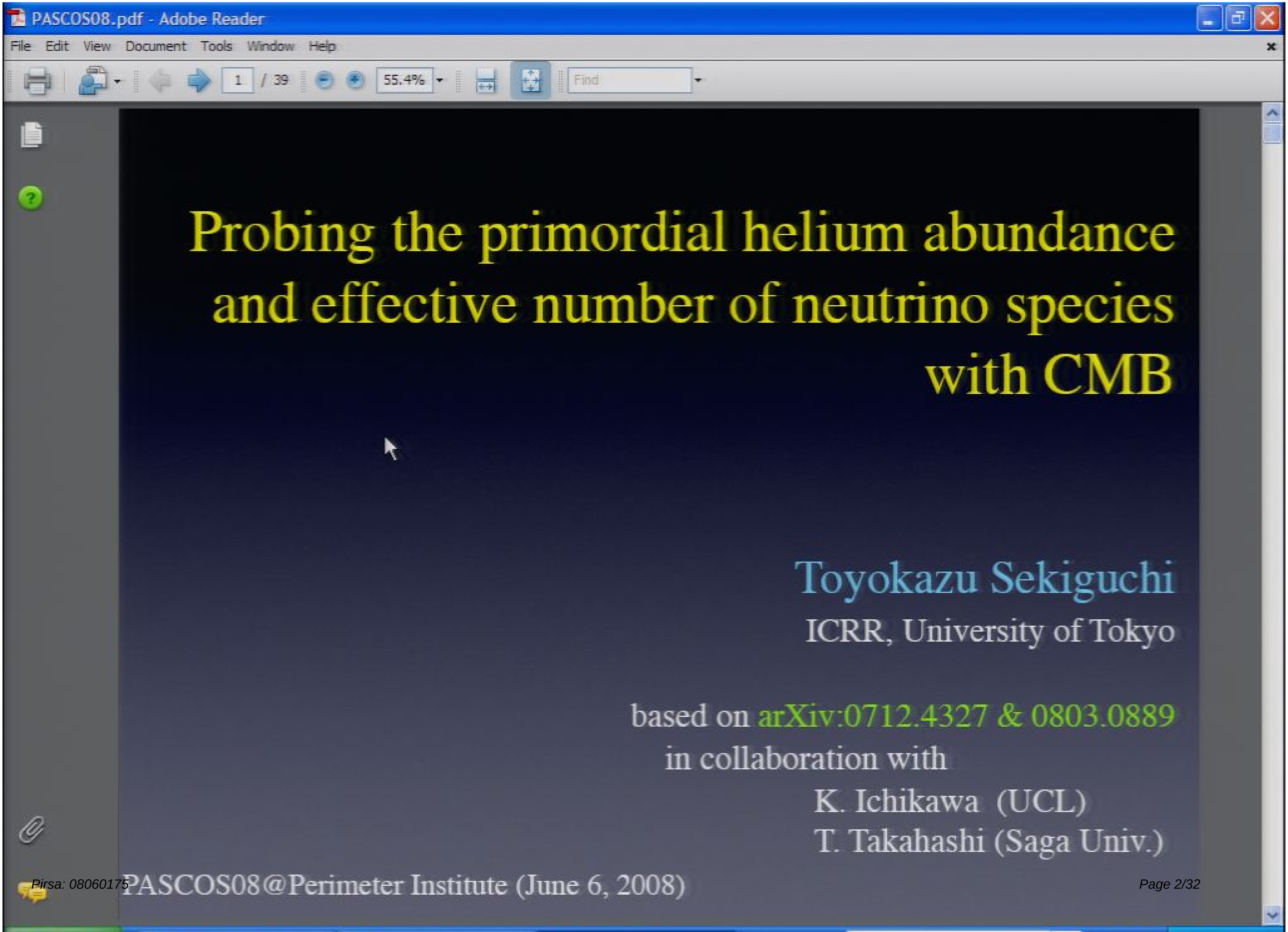
URL: http://pirsa.org/08060175

Abstract: We point out that light scalar fields with symmetries generically generate non-Gaussianity in the density fluctuations. Our observation makes the presence of the non-Gaussianity ubiquitous. When the inflationary scale and the properties of the scalar fields satisfy a certain relation, the non-Gaussianity becomes large enough to be observed by the ongoing and planned observations. We name such a particle responsible for a large non-Gaussianity as an \'ungaussiton\', and give explicit examples to realize the ungaussiton mechanism. We also derive a consistency relation between the bispectrum and the trispectrum, tau_NL = 10^3 f_NL^(4/3), which, if confirmed, will strongly support this mechanism.

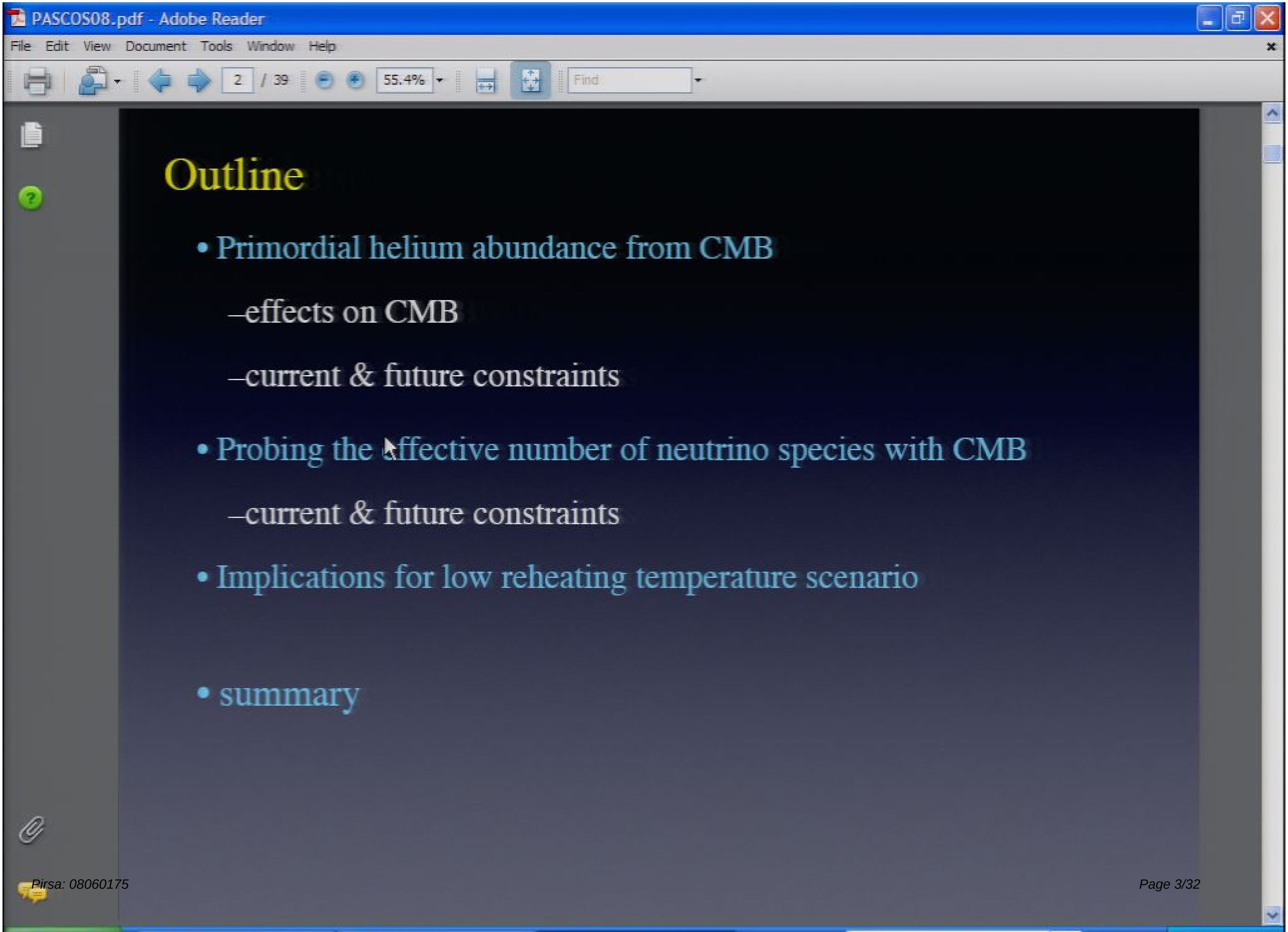


Probing the primordial helium abundance and effective number of neutrino species with CMB

Toyokazu Sekiguchi
ICRR, University of Tokyo

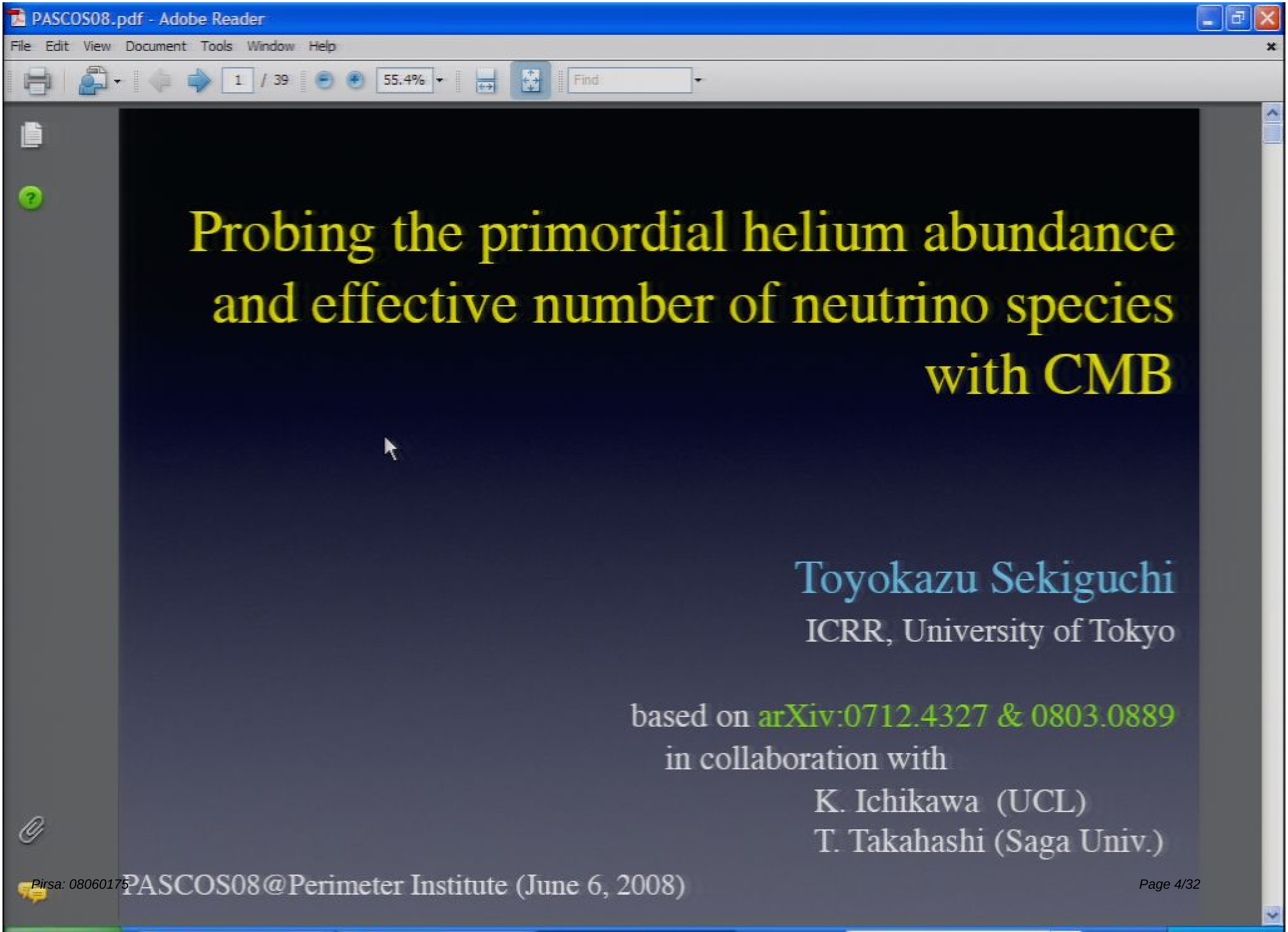
based on arXiv:0712.4327 & 0803.0889
in collaboration with
K. Ichikawa (UCL)
T. Takahashi (Saga Univ.)

PASCOS08@Perimeter Institute (June 6, 2008)



Outline

- Primordial helium abundance from CMB
  - –effects on CMB
  - –current & future constraints
- Probing the effective number of neutrino species with CMB
  - –current & future constraints
- Implications for low reheating temperature scenario
- summary



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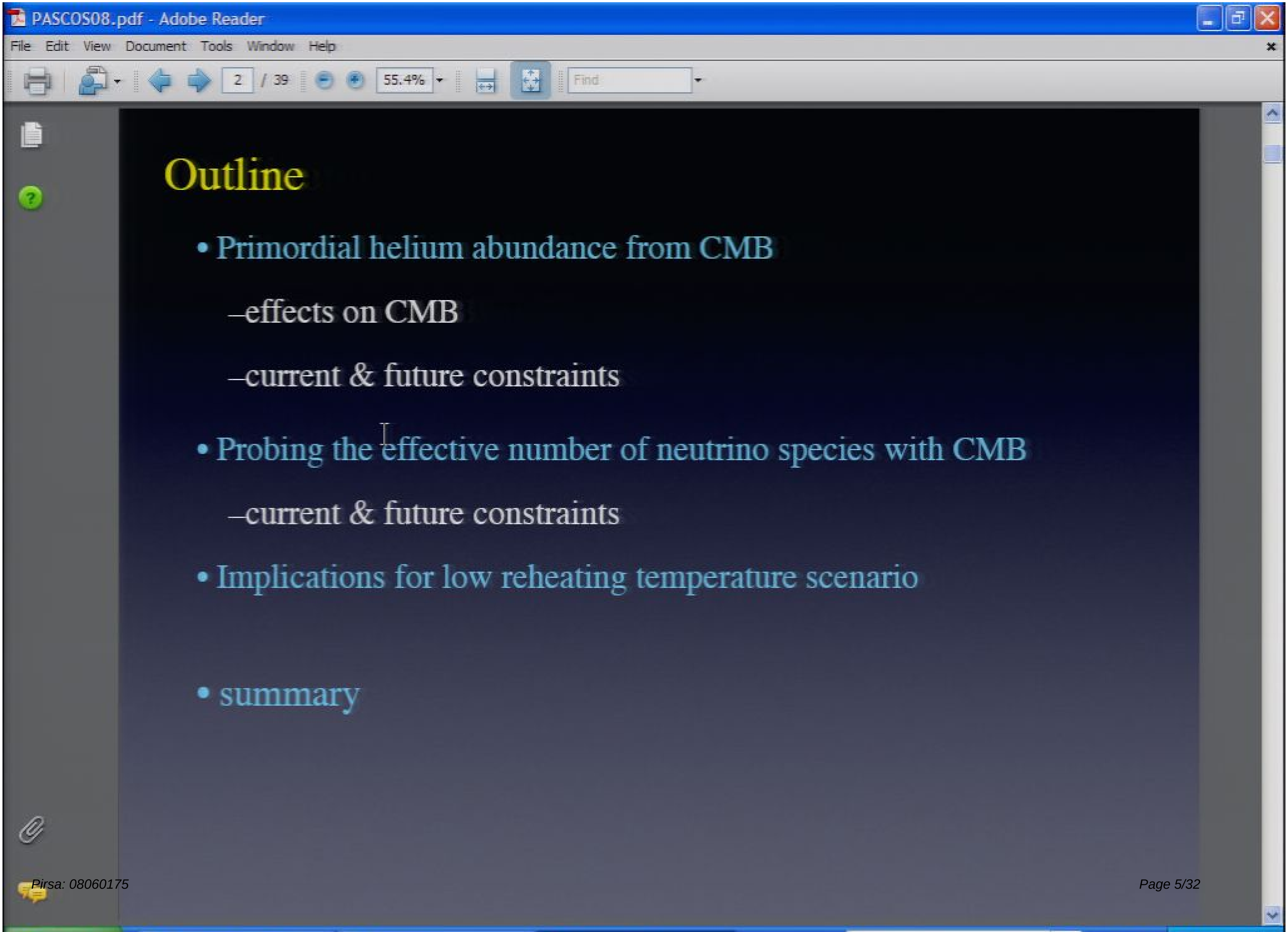

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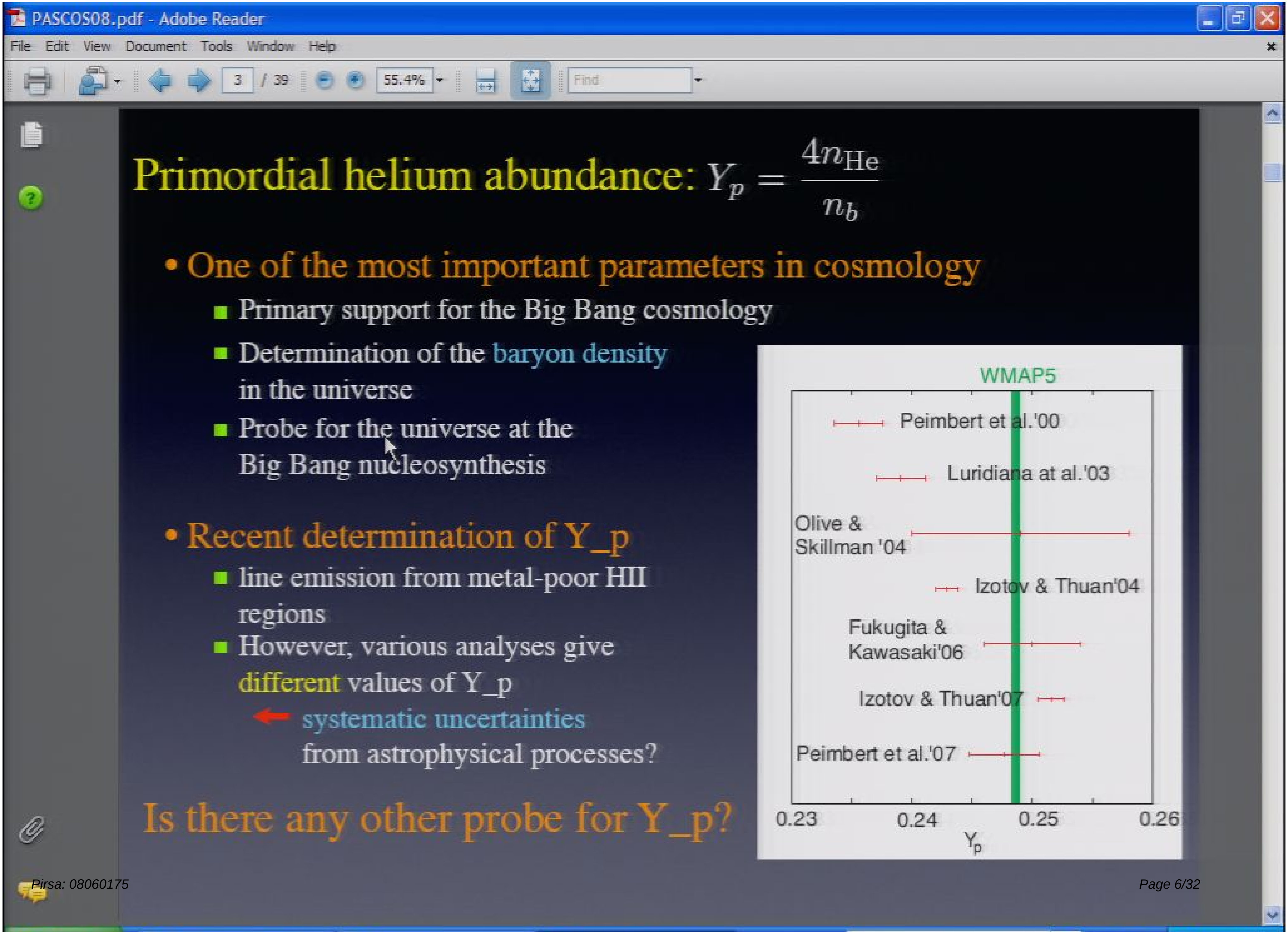
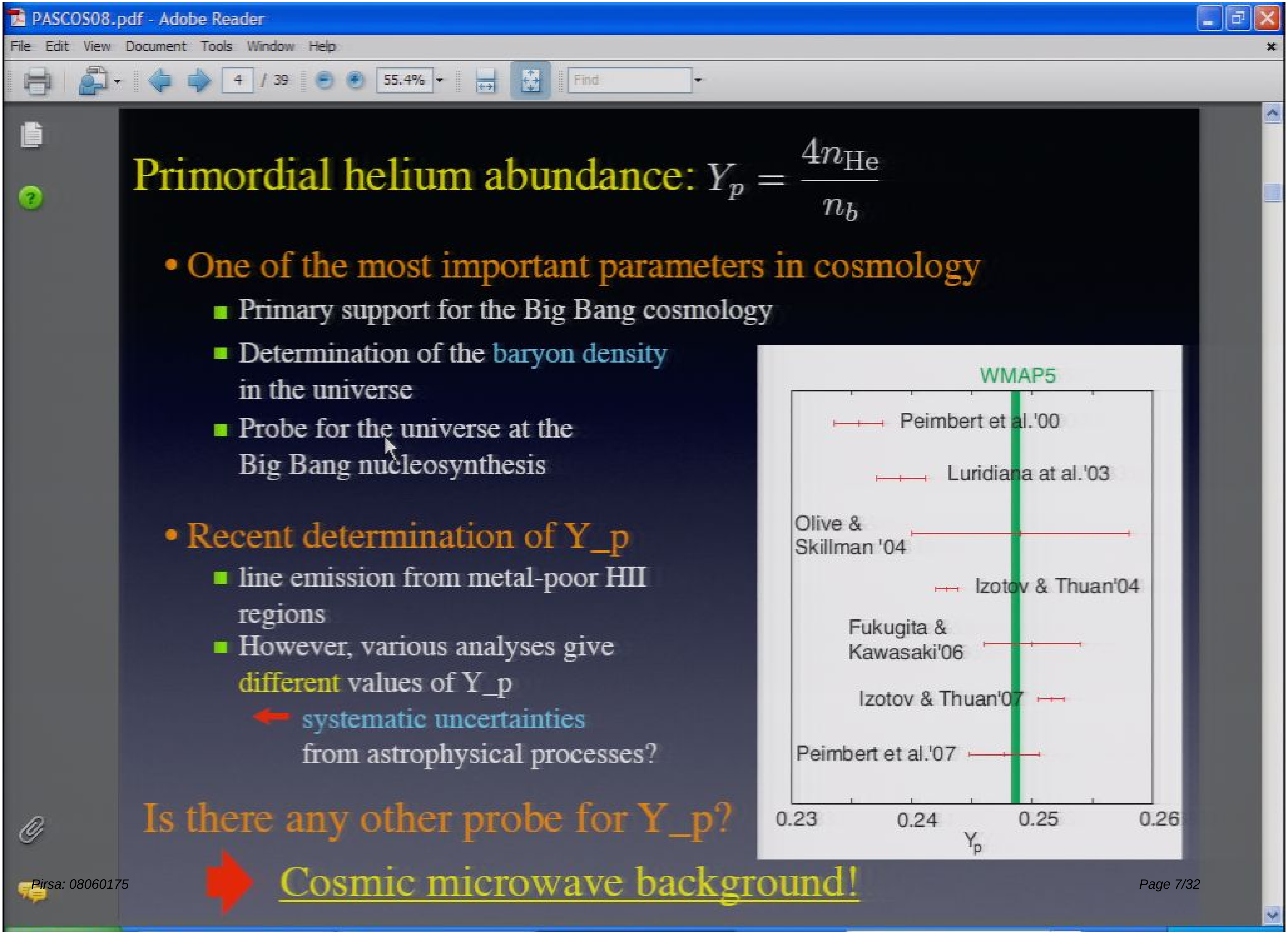


Primordial helium abundance: $Y_p = \dfrac{4n_{\mathrm{He}}}{n_b}$

- One of the most important parameters in cosmology
  - Primary support for the Big Bang cosmology
  - Determination of the baryon density in the universe
  - Probe for the universe at the Big Bang nucleosynthesis
- Recent determination of Y_p
  - line emission from metal-poor HII regions
  - However, various analyses give different values of Y_p
    ← systematic uncertainties from astrophysical processes?

Is there any other probe for Y_p?



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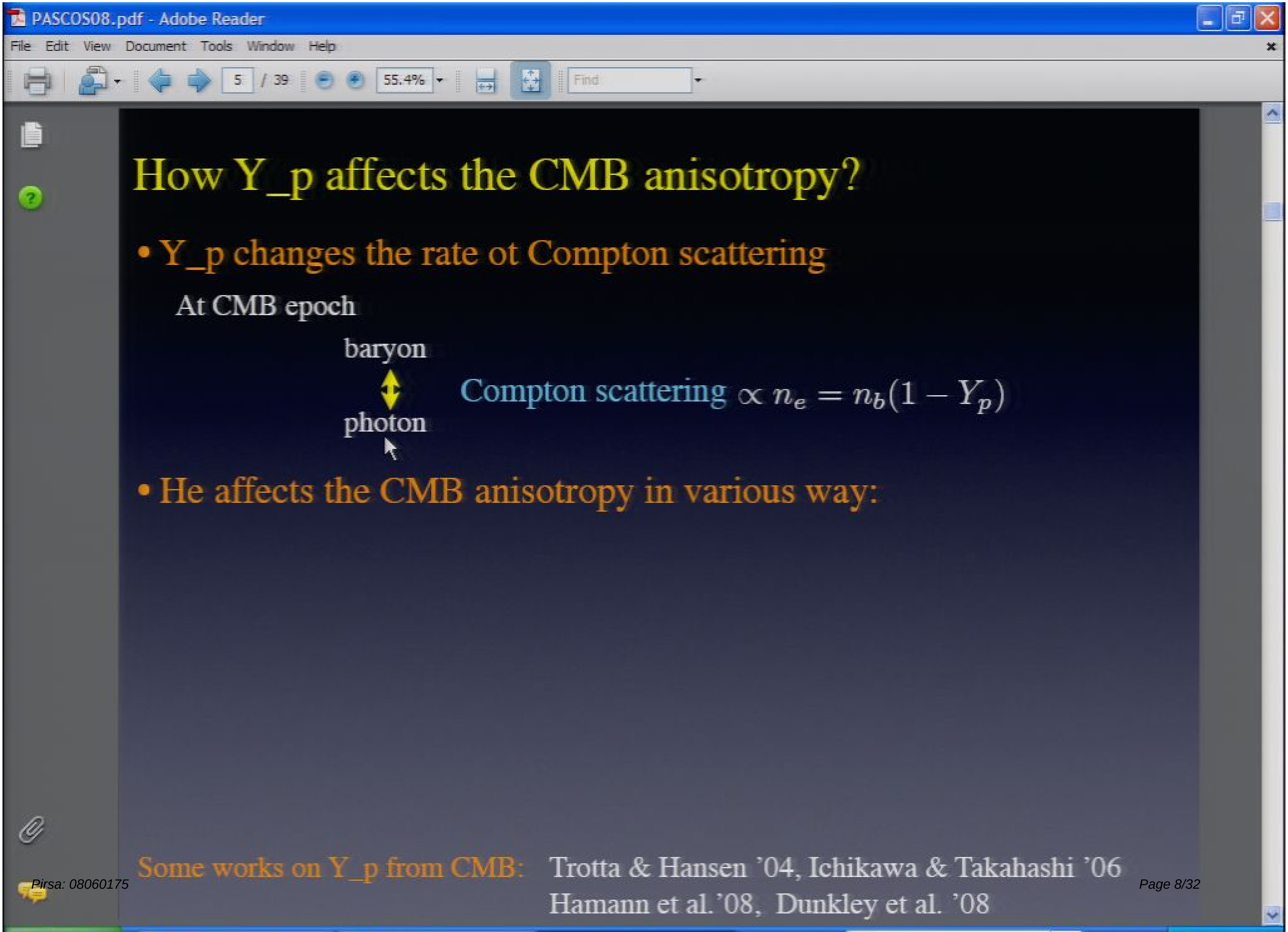
➡ Cosmic microwave background!



How Y_p affects the CMB anisotropy?

- Y_p changes the rate ot Compton scattering

At CMB epoch

baryon
↕
photon

Compton scattering $\propto n_e = n_b(1 - Y_p)$

- He affects the CMB anisotropy in various way:

Some works on Y_p from CMB: Trotta & Hansen ’04, Ichikawa & Takahashi ’06
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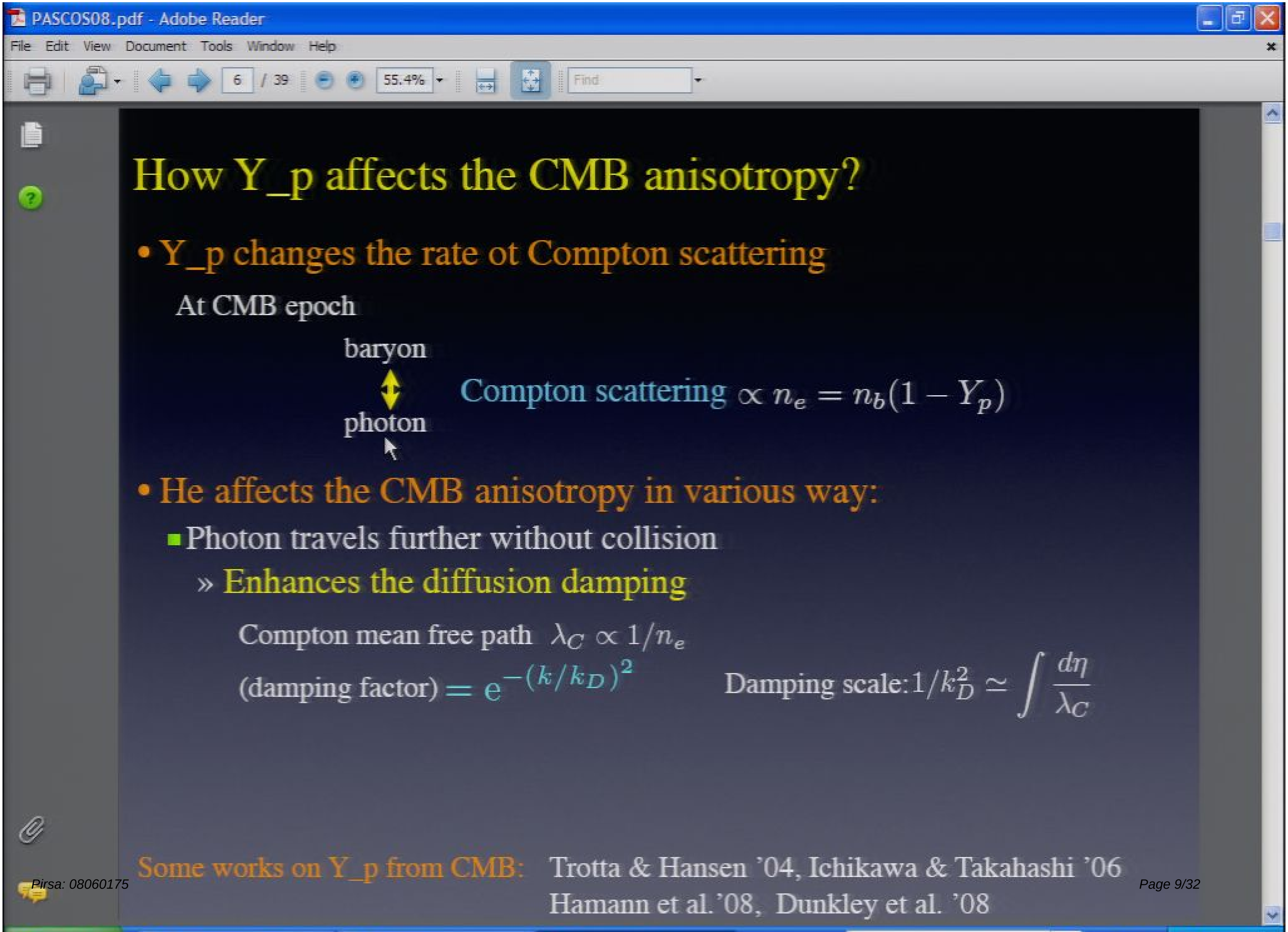

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    - » Enhances the diffusion damping

Compton mean free path $\lambda_C \propto 1/n_e$

(damping factor) $= e^{-(k/k_D)^2}$

Damping scale: $1/k_D^2 \simeq \int \frac{d\eta}{\lambda_C}$

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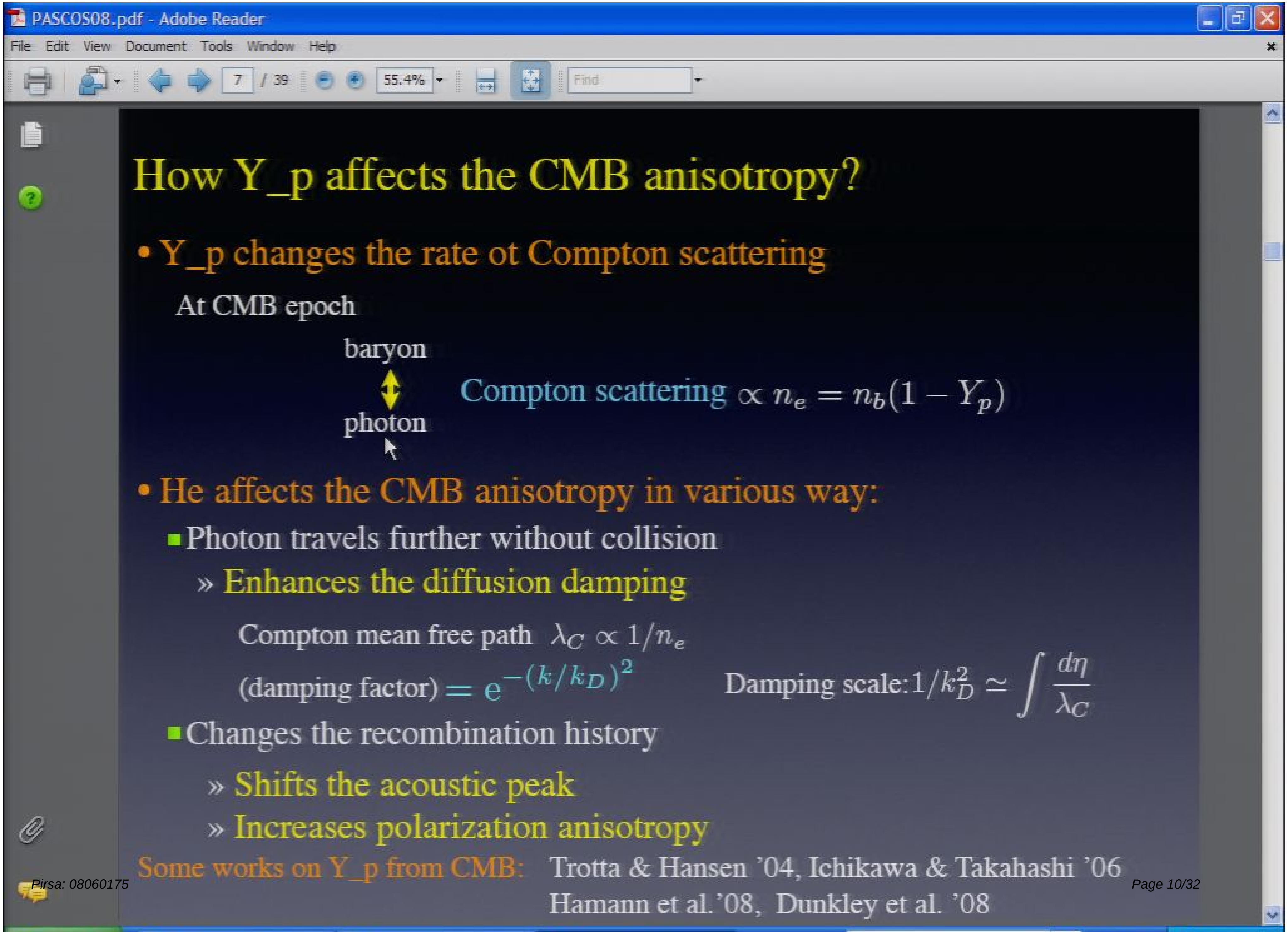

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  - Changes the recombination history
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    - » Increases polarization anisotropy

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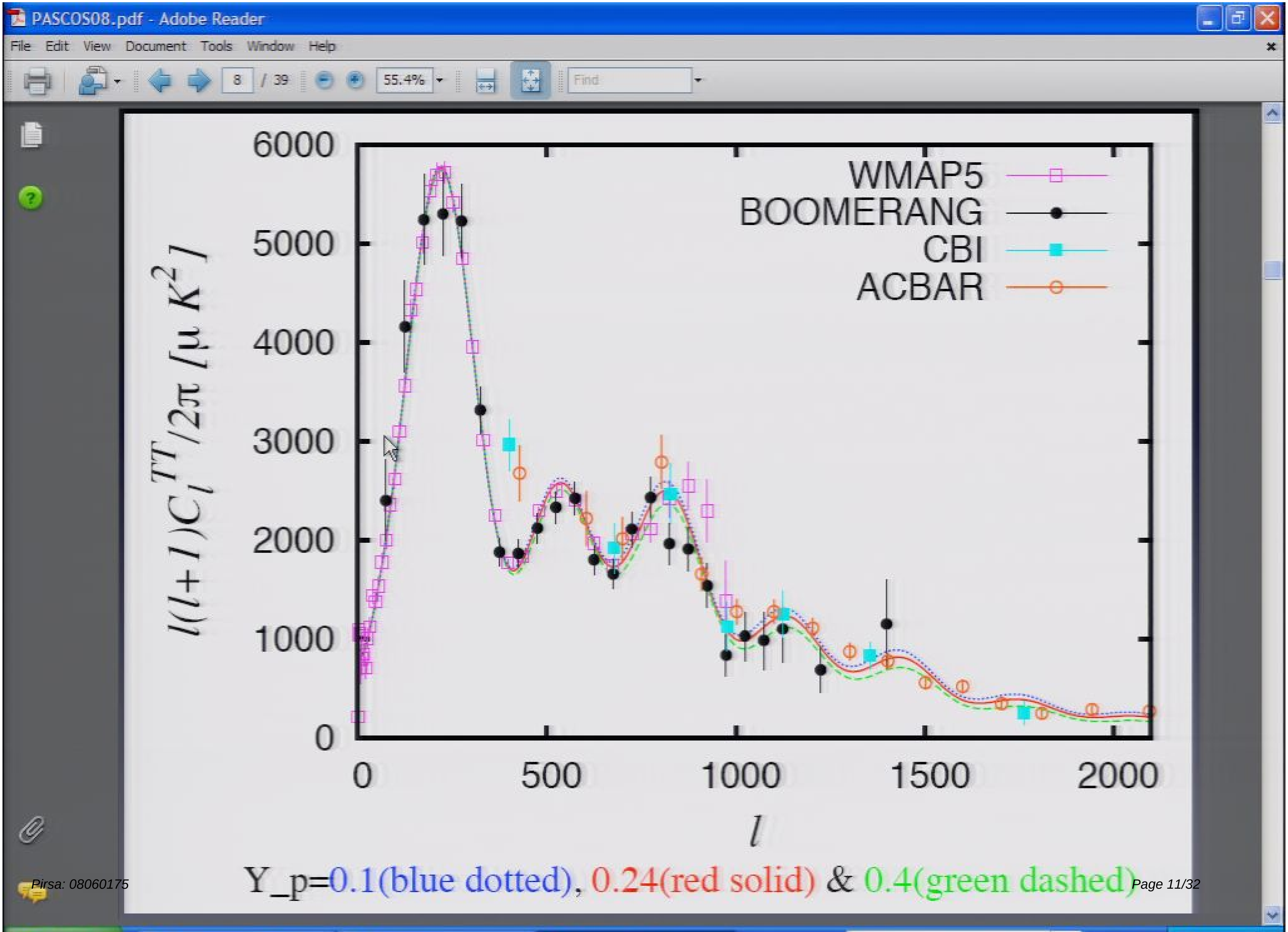
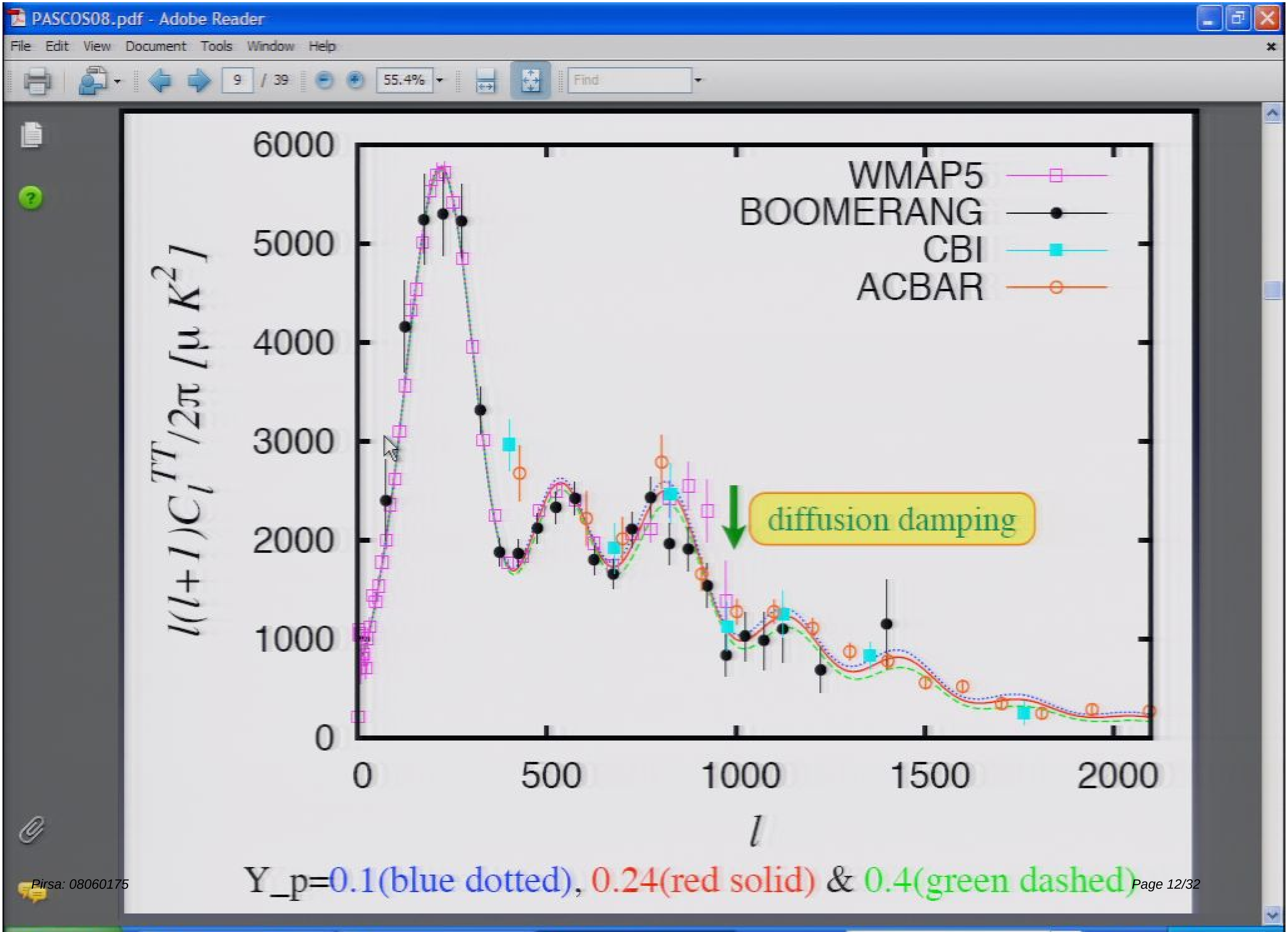


Y_p=0.1(blue dotted), 0.24(red solid) & 0.4(green dashed)



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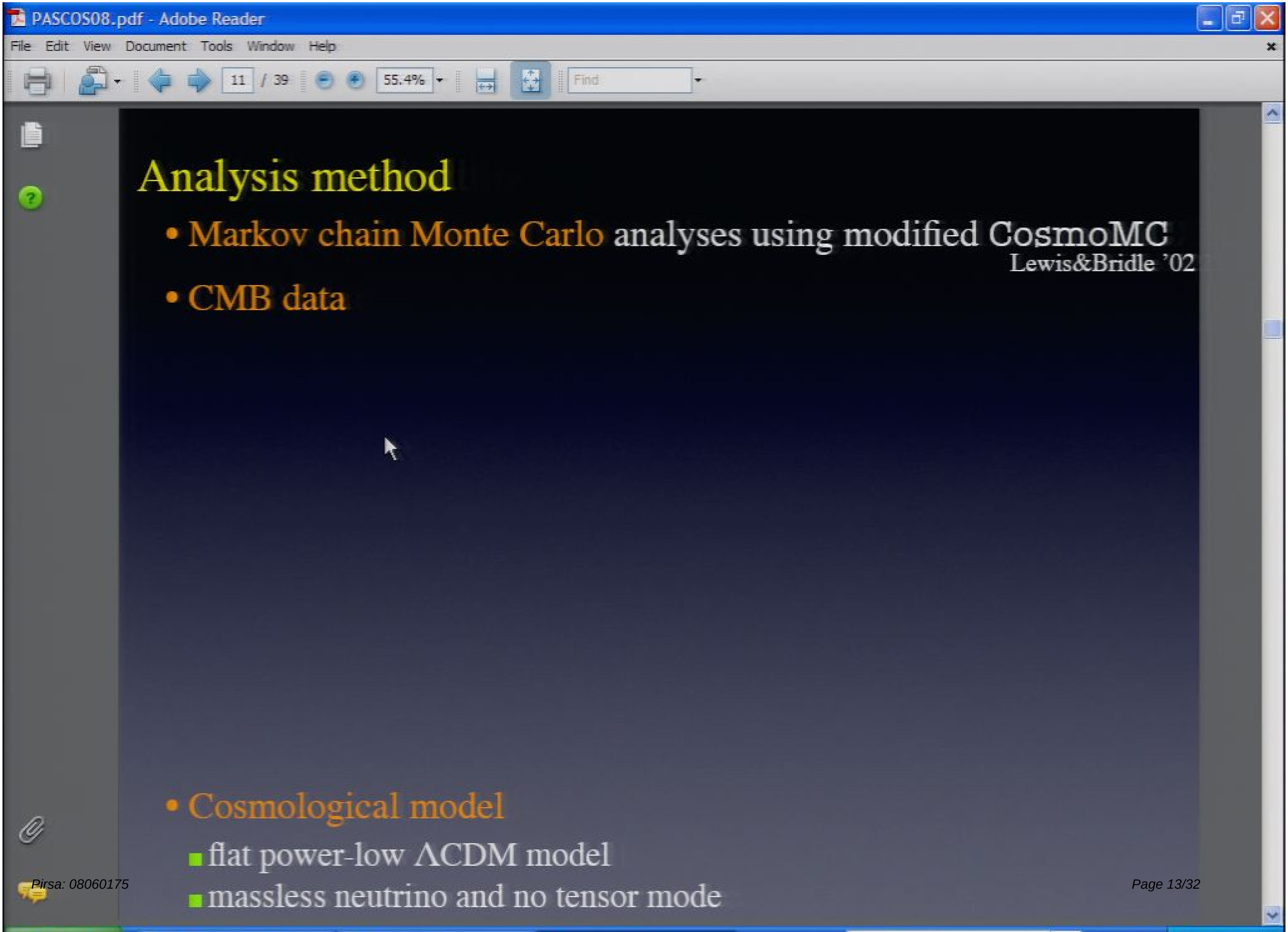
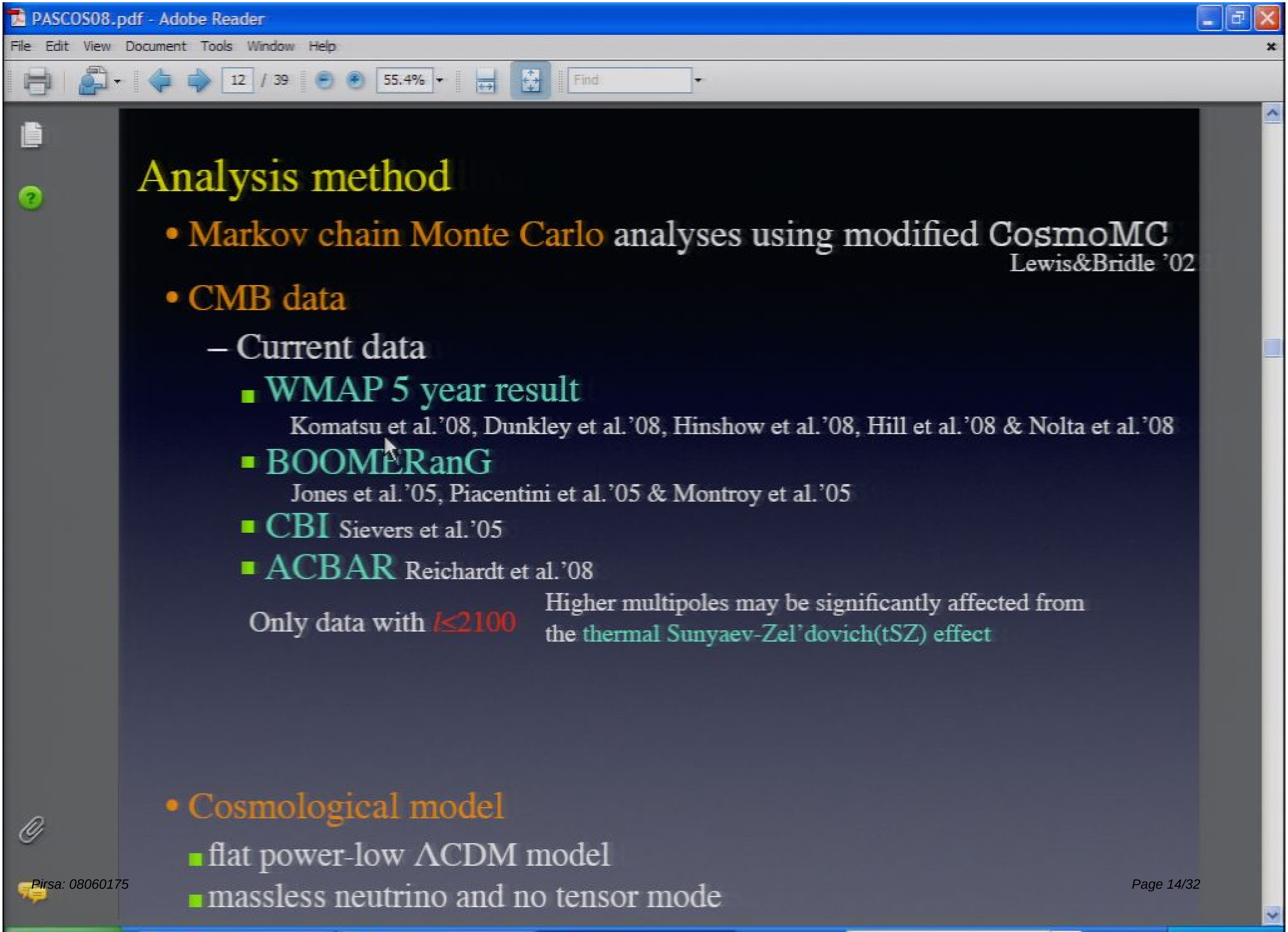


Analysis method

- Markov chain Monte Carlo analyses using modified CosmoMC
  Lewis&Bridle '02
- CMB data
- Cosmological model
  - flat power-low ΛCDM model
  - massless neutrino and no tensor mode



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  - Current data
    - WMAP 5 year result
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Only data with $l \leq 2100$

Higher multipoles may be significantly affected from the thermal Sunyaev-Zel'dovich(tSZ) effect

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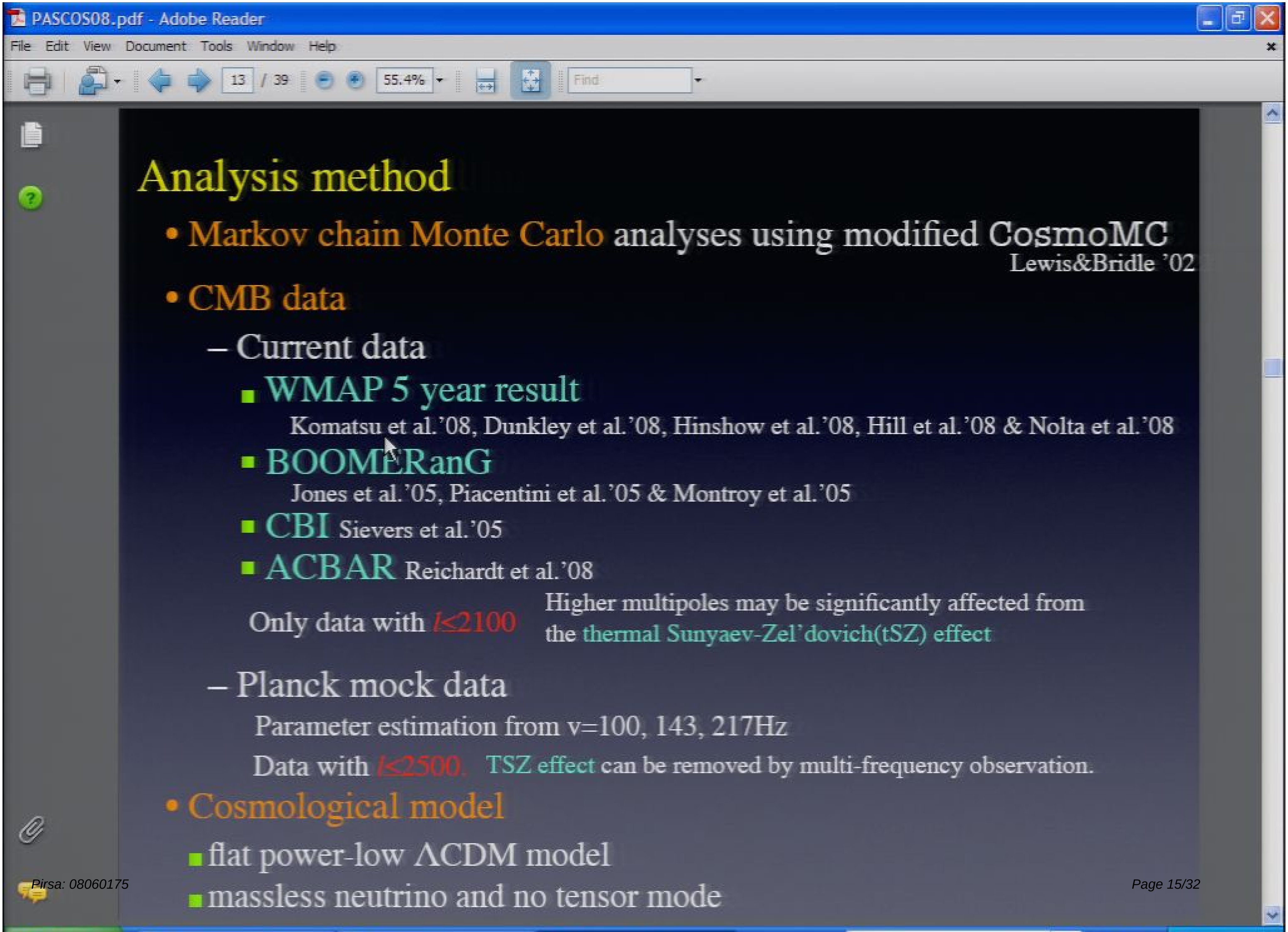

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    Only data with $l \lesssim 2100$

    Higher multipoles may be significantly affected from the thermal Sunyaev-Zel'dovich(tSZ) effect
  - Planck mock data

    Parameter estimation from ν=100, 143, 217Hz

    Data with $l \lesssim 2500$. TSZ effect can be removed by multi-frequency observation.
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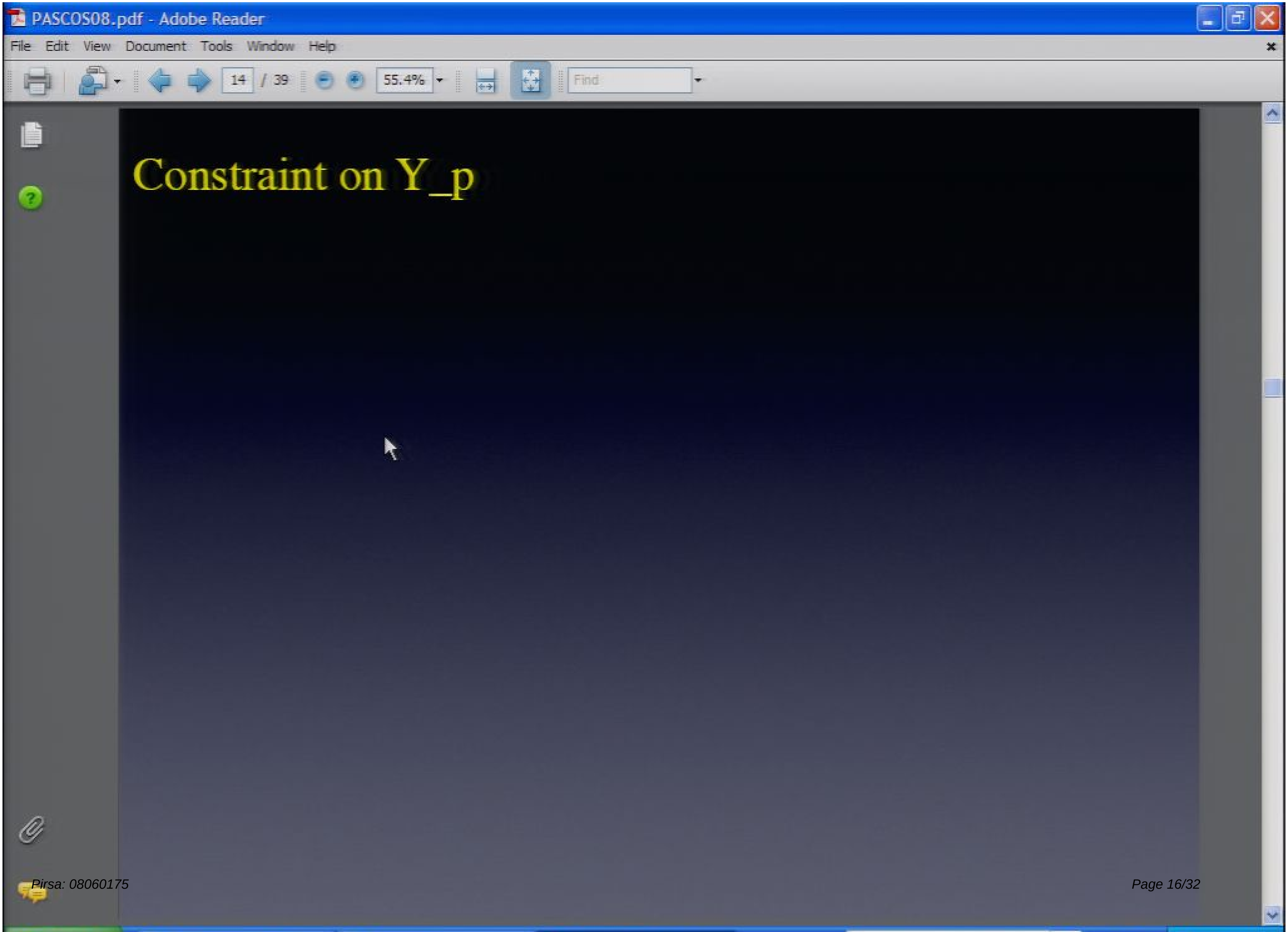
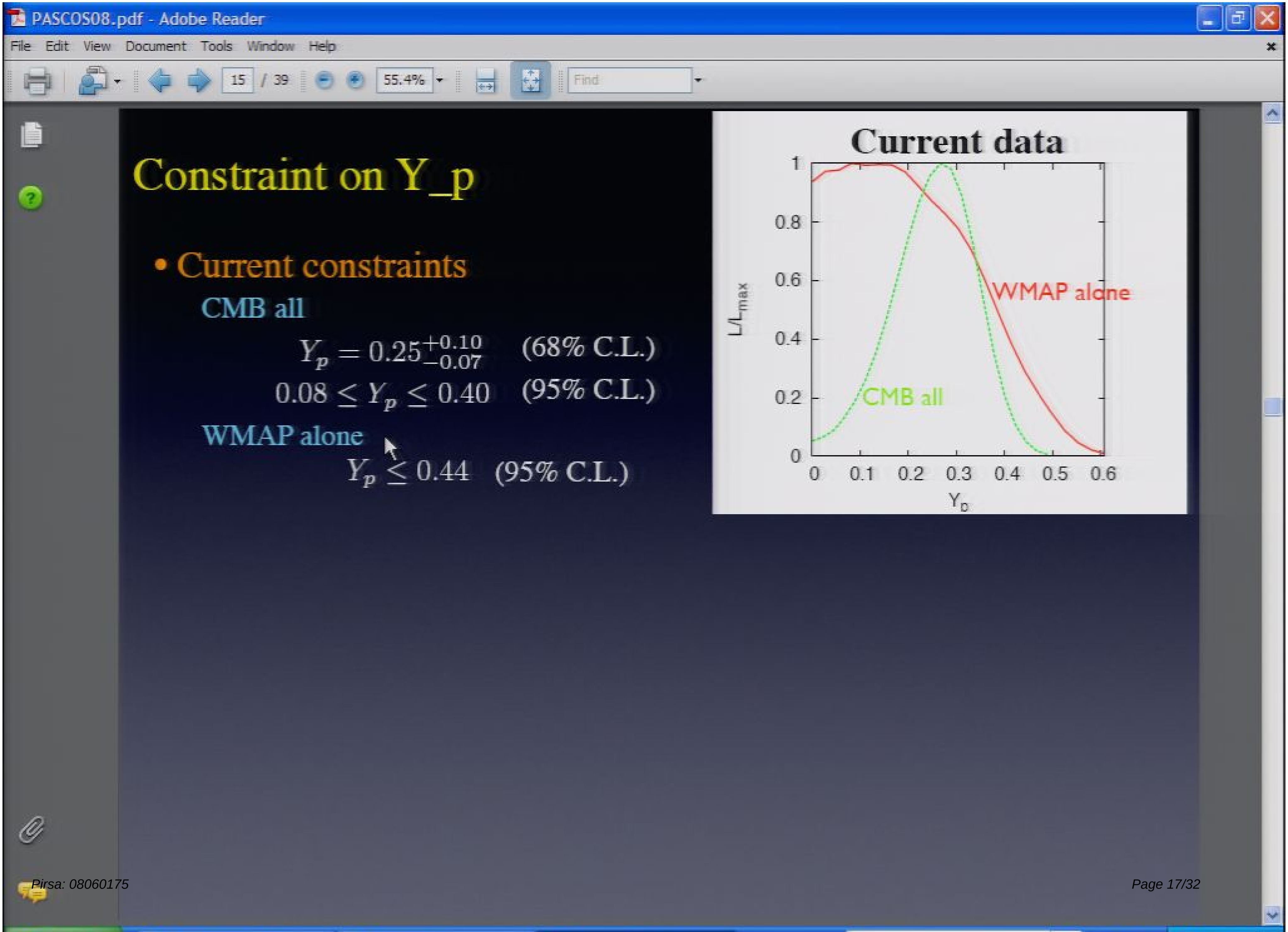


Constraint on Y_p



Constraint on Y_p

- Current constraints

CMB all

$$Y_p = 0.25^{+0.10}_{-0.07} \quad \text{(68\% C.L.)}$$

$$0.08 \leq Y_p \leq 0.40 \quad \text{(95\% C.L.)}$$

WMAP alone

$$Y_p \leq 0.44 \quad \text{(95\% C.L.)}$$

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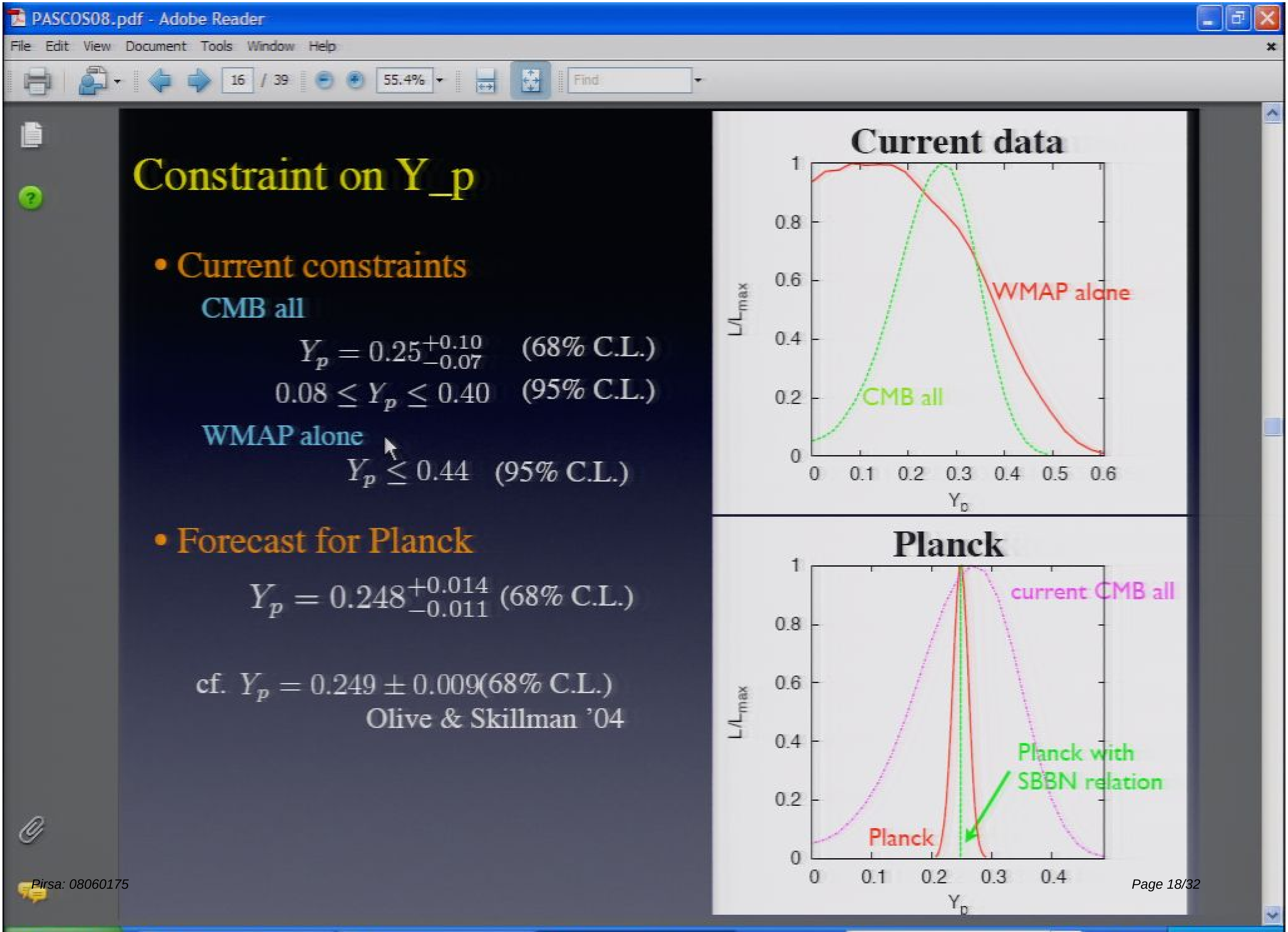

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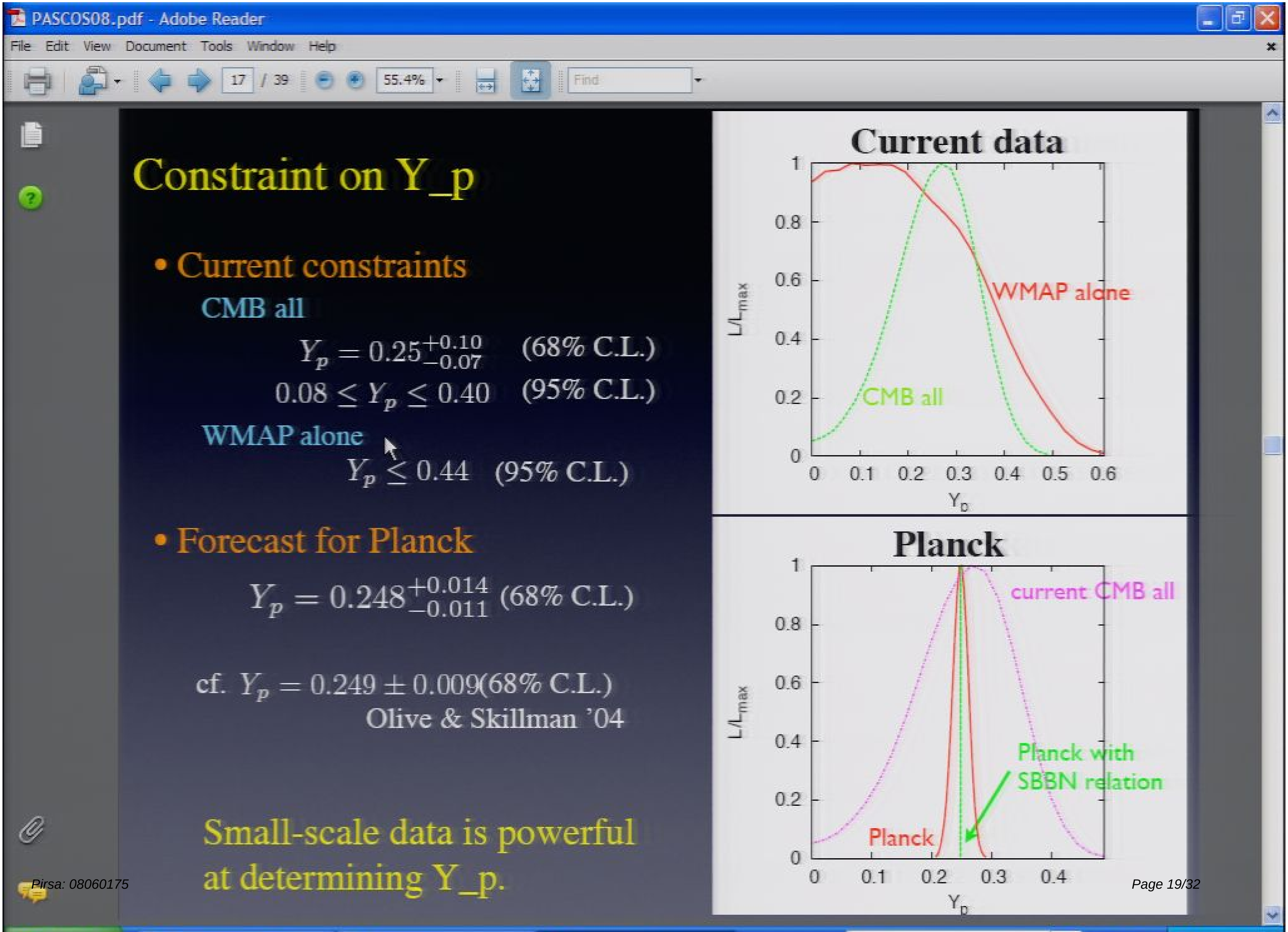
- Forecast for Planck

  $$Y_p = 0.248^{+0.014}_{-0.011} \; (68\% \text{ C.L.})$$

  cf. $Y_p = 0.249 \pm 0.009 (68\% \text{ C.L.})$

  Olive & Skillman '04



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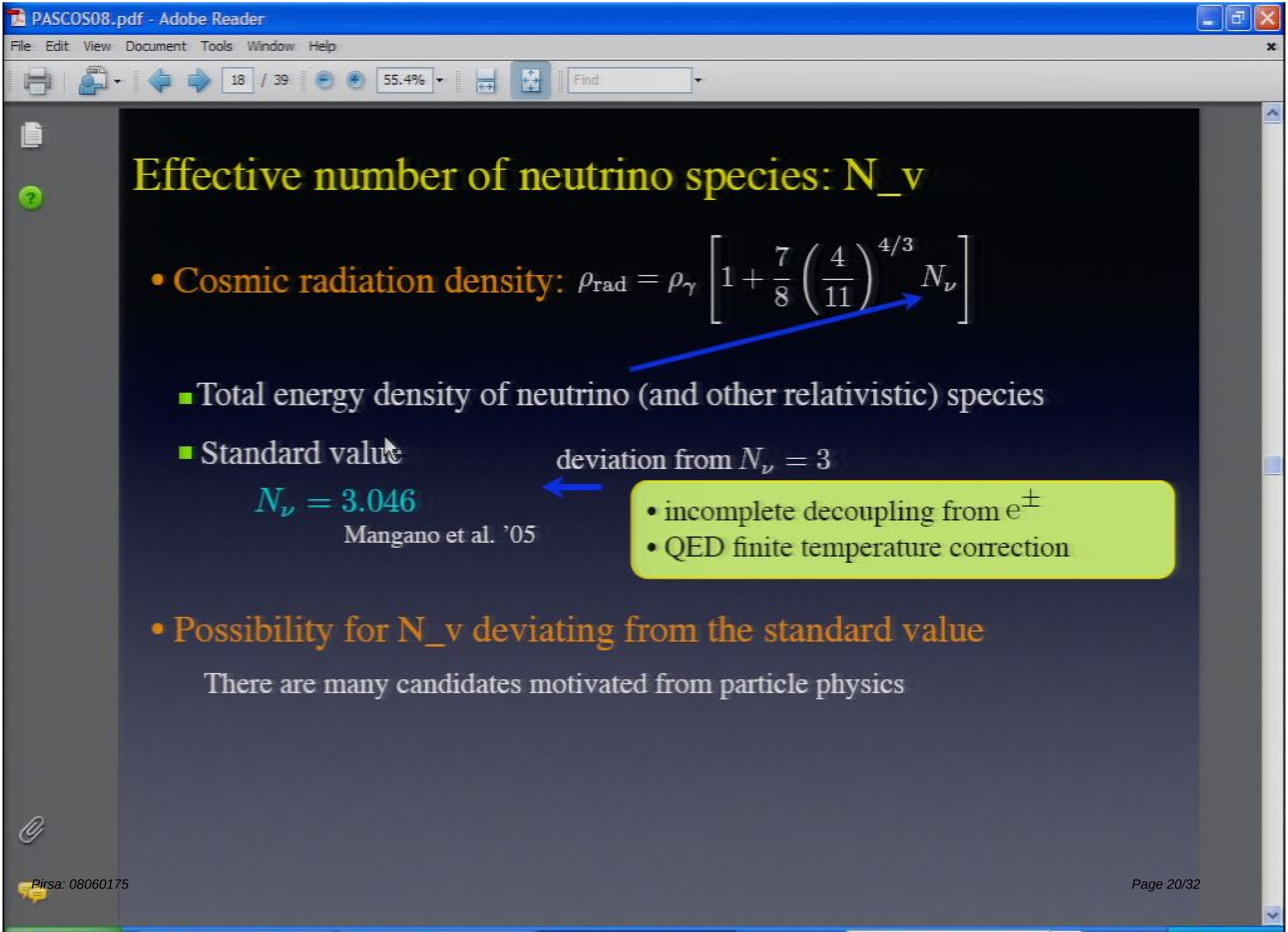
Small-scale data is powerful at determining Y_p.



Effective number of neutrino species: N_v

- Cosmic radiation density: $\rho_{\mathrm{rad}} = \rho_\gamma \left[1 + \frac{7}{8} \left(\frac{4}{11} \right)^{4/3} N_\nu \right]$
  - Total energy density of neutrino (and other relativistic) species
  - Standard value

$N_\nu = 3.046$

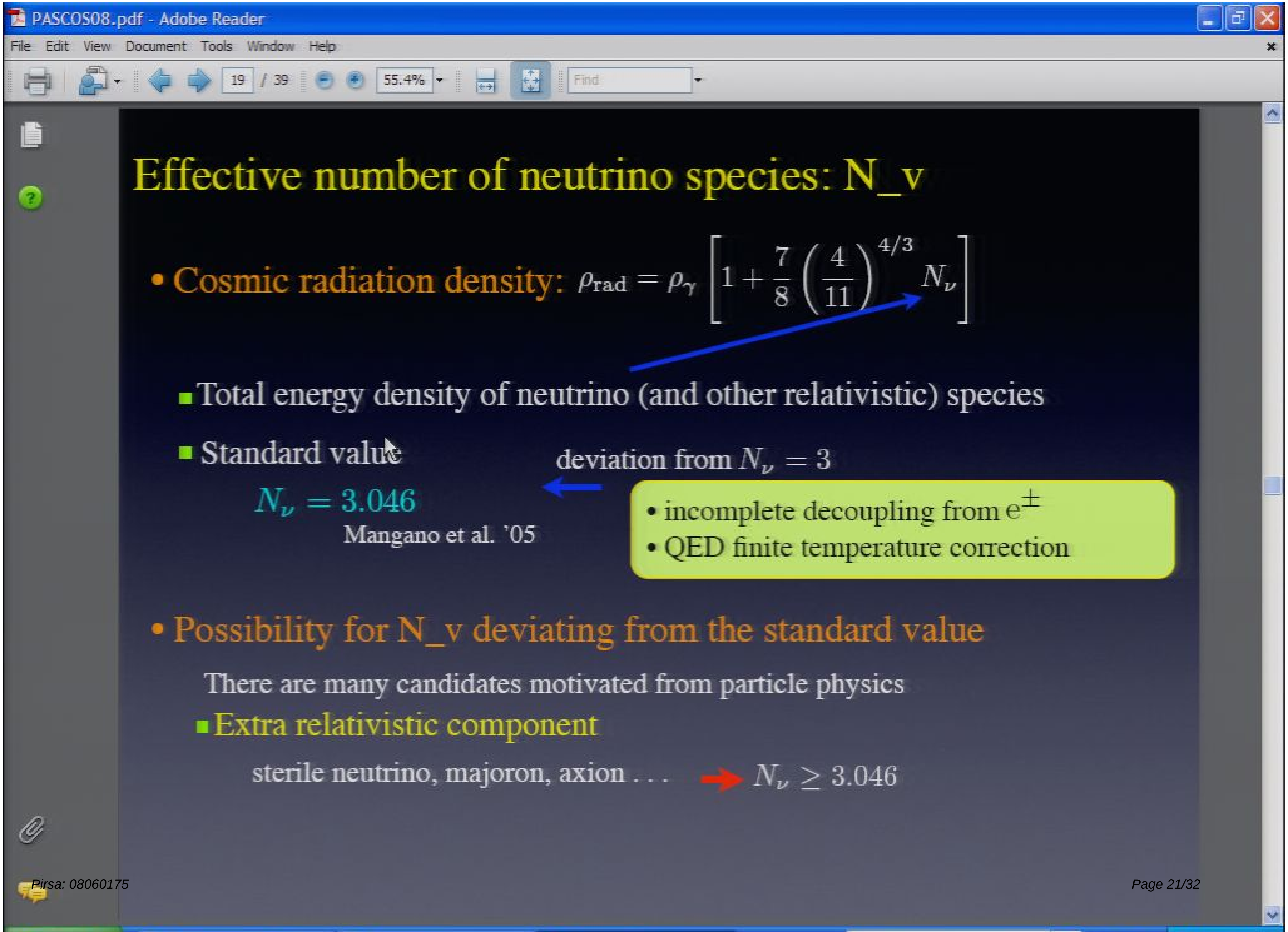
Mangano et al. '05

deviation from $N_\nu = 3$

- incomplete decoupling from $e^{\pm}$
- QED finite temperature correction

- Possibility for N_v deviating from the standard value

There are many candidates motivated from particle physics



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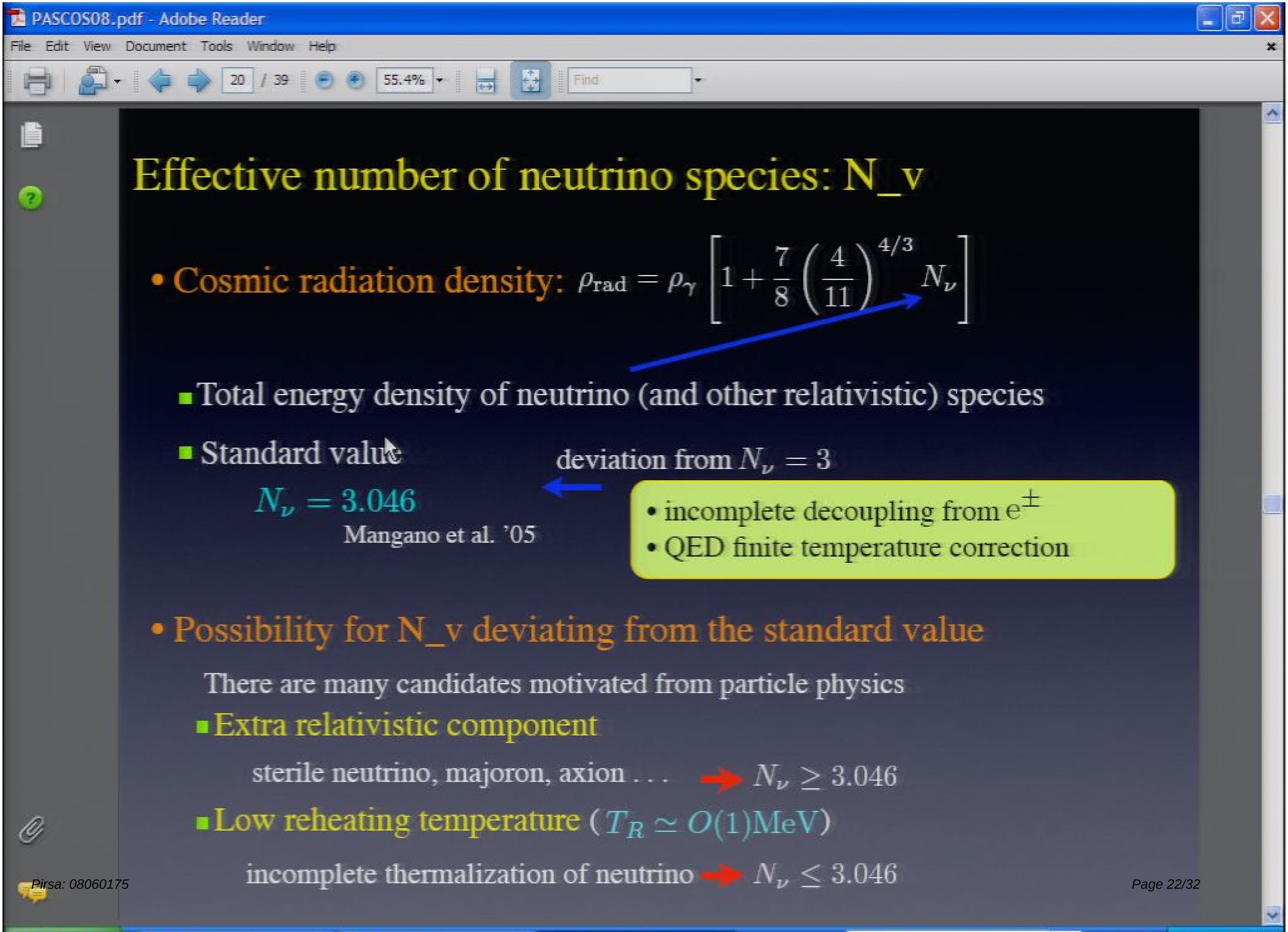
sterile neutrino, majoron, axion . . . → $N_\nu \geq 3.046$



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  - Low reheating temperature ($T_R \simeq O(1)\mathrm{MeV}$)

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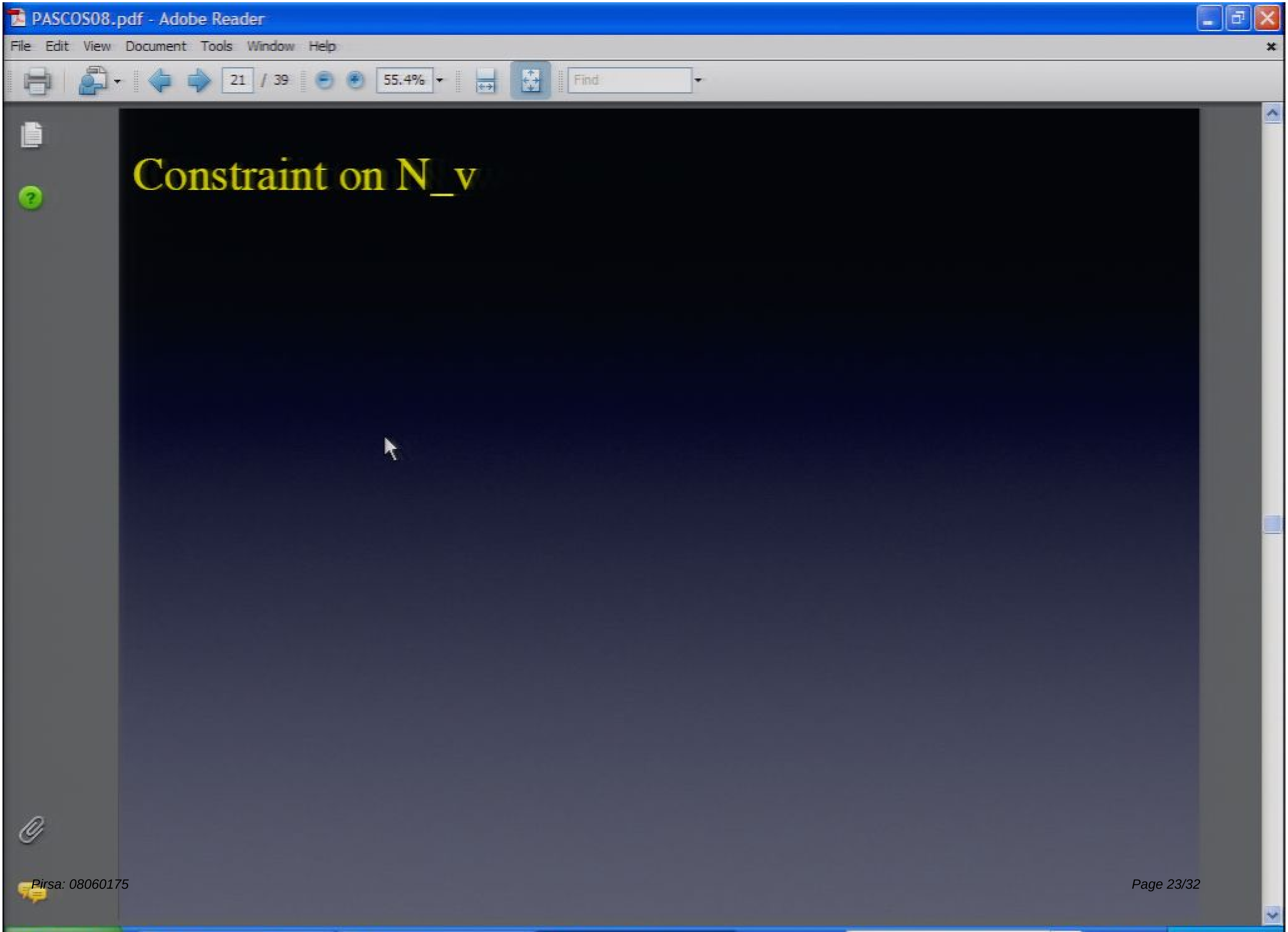

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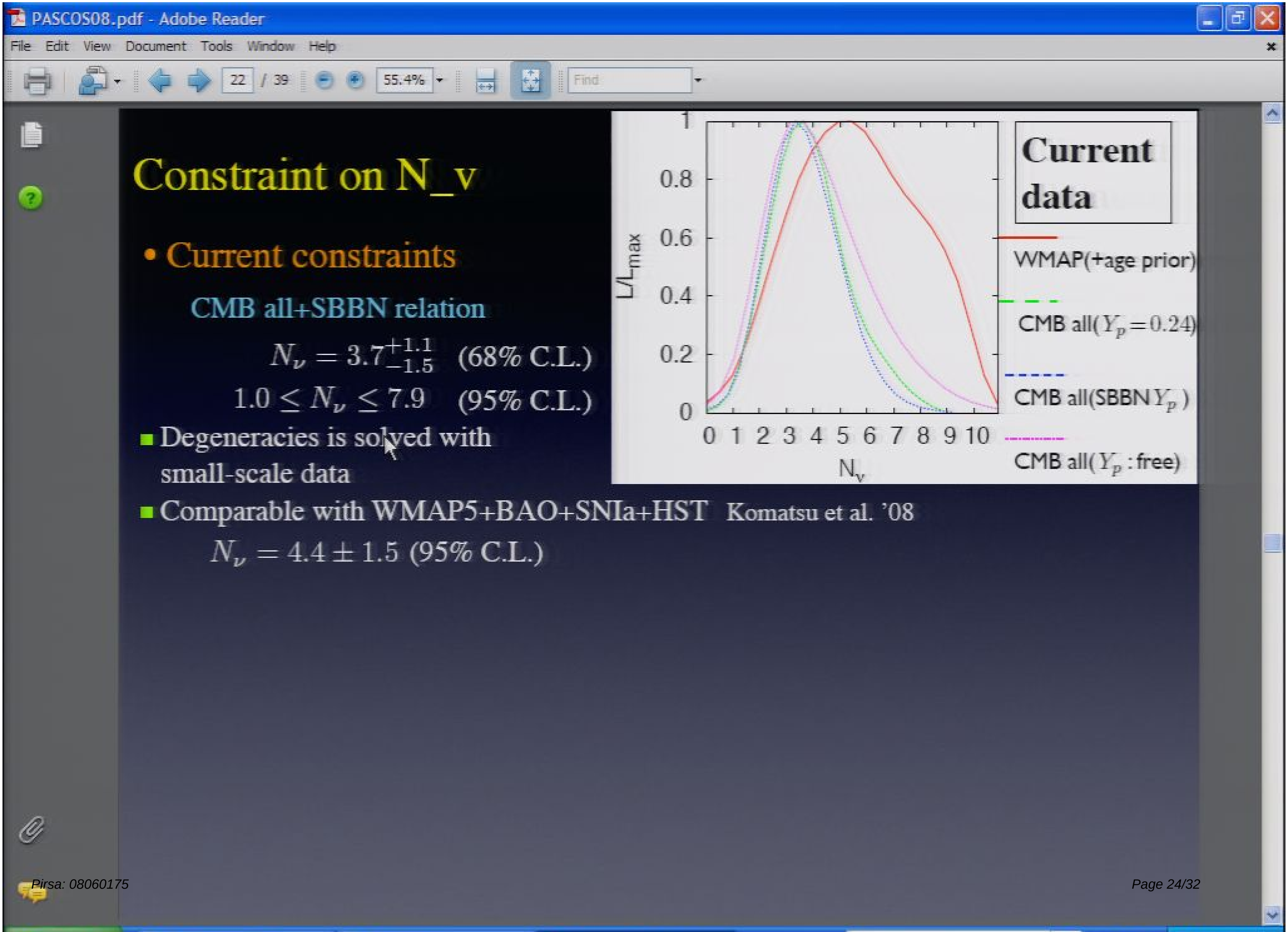


Constraint on N_v

- Current constraints

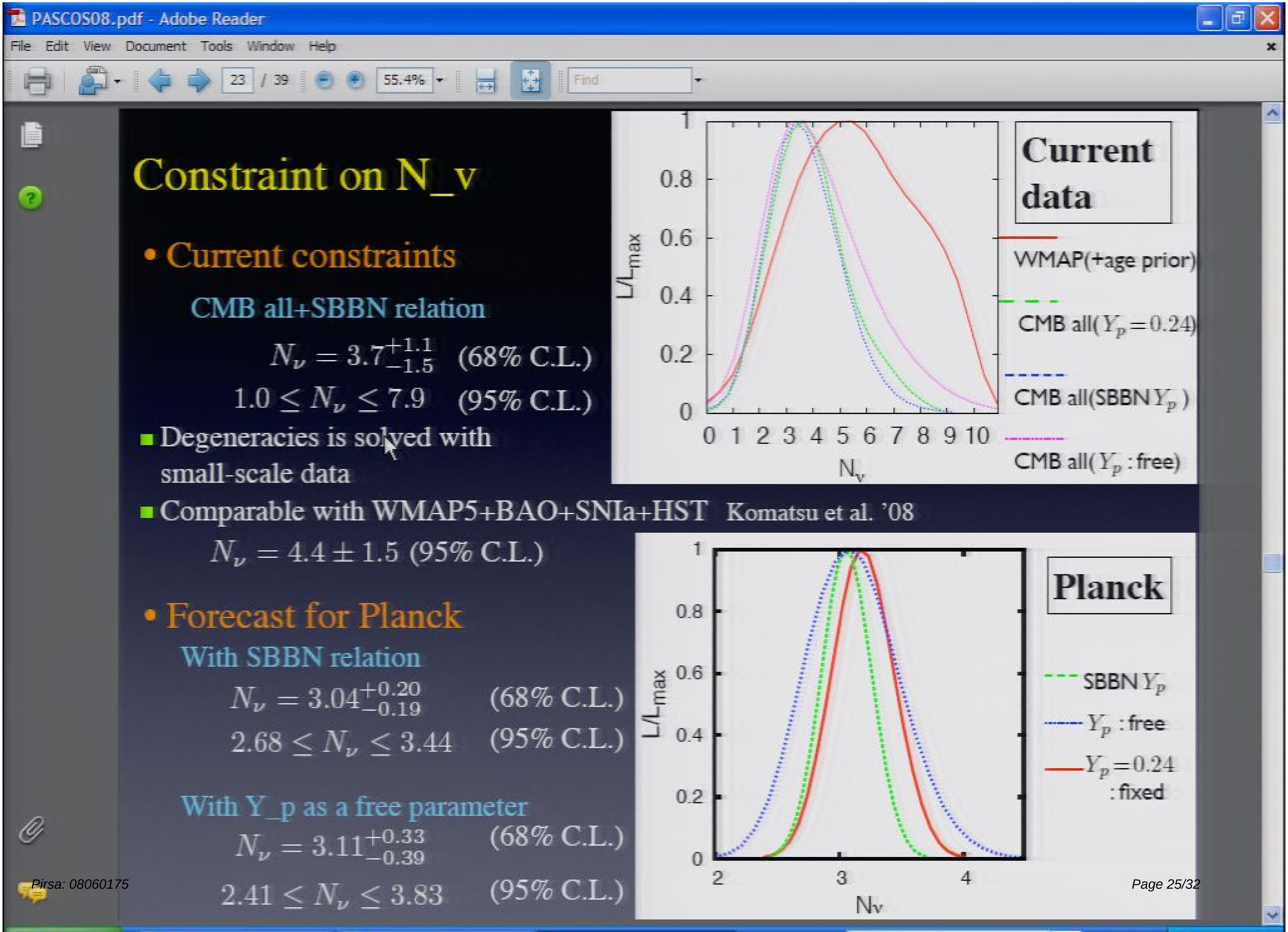
CMB all+SBBN relation

$$N_\nu = 3.7^{+1.1}_{-1.5} \quad \text{(68\% C.L.)}$$

$$1.0 \le N_\nu \le 7.9 \quad \text{(95\% C.L.)}$$

- Degeneracies is solved with small-scale data
- Comparable with WMAP5+BAO+SNIa+HST Komatsu et al. '08

$$N_\nu = 4.4 \pm 1.5 \text{ (95\% C.L.)}$$



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- Forecast for Planck

With SBBN relation

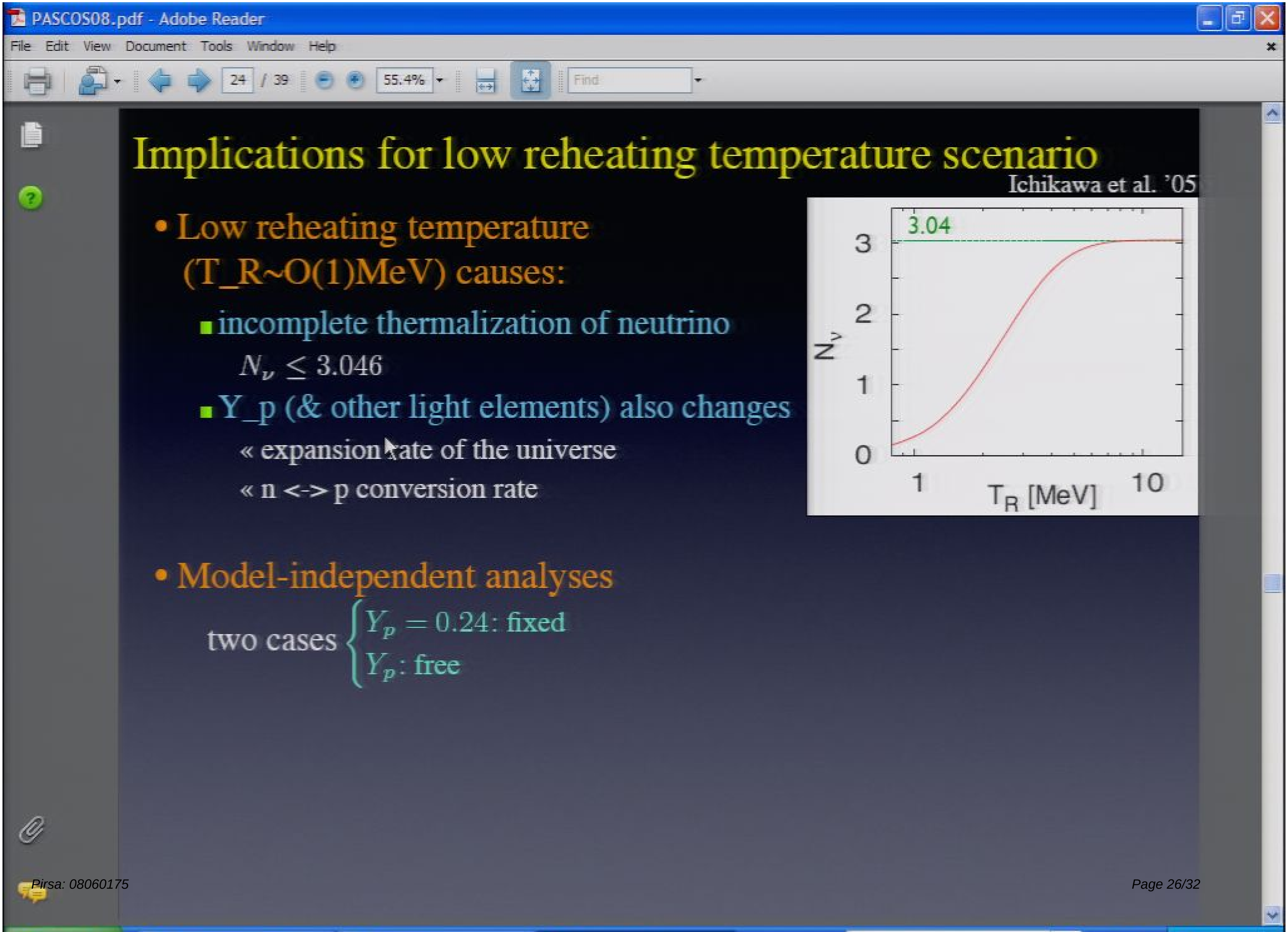
$$N_\nu = 3.04^{+0.20}_{-0.19} \quad (68\%\ \text{C.L.})$$

$$2.68 \le N_\nu \le 3.44 \quad (95\%\ \text{C.L.})$$

With Y_p as a free parameter

$$N_\nu = 3.11^{+0.33}_{-0.39} \quad (68\%\ \text{C.L.})$$

$$2.41 \le N_\nu \le 3.83 \quad (95\%\ \text{C.L.})$$



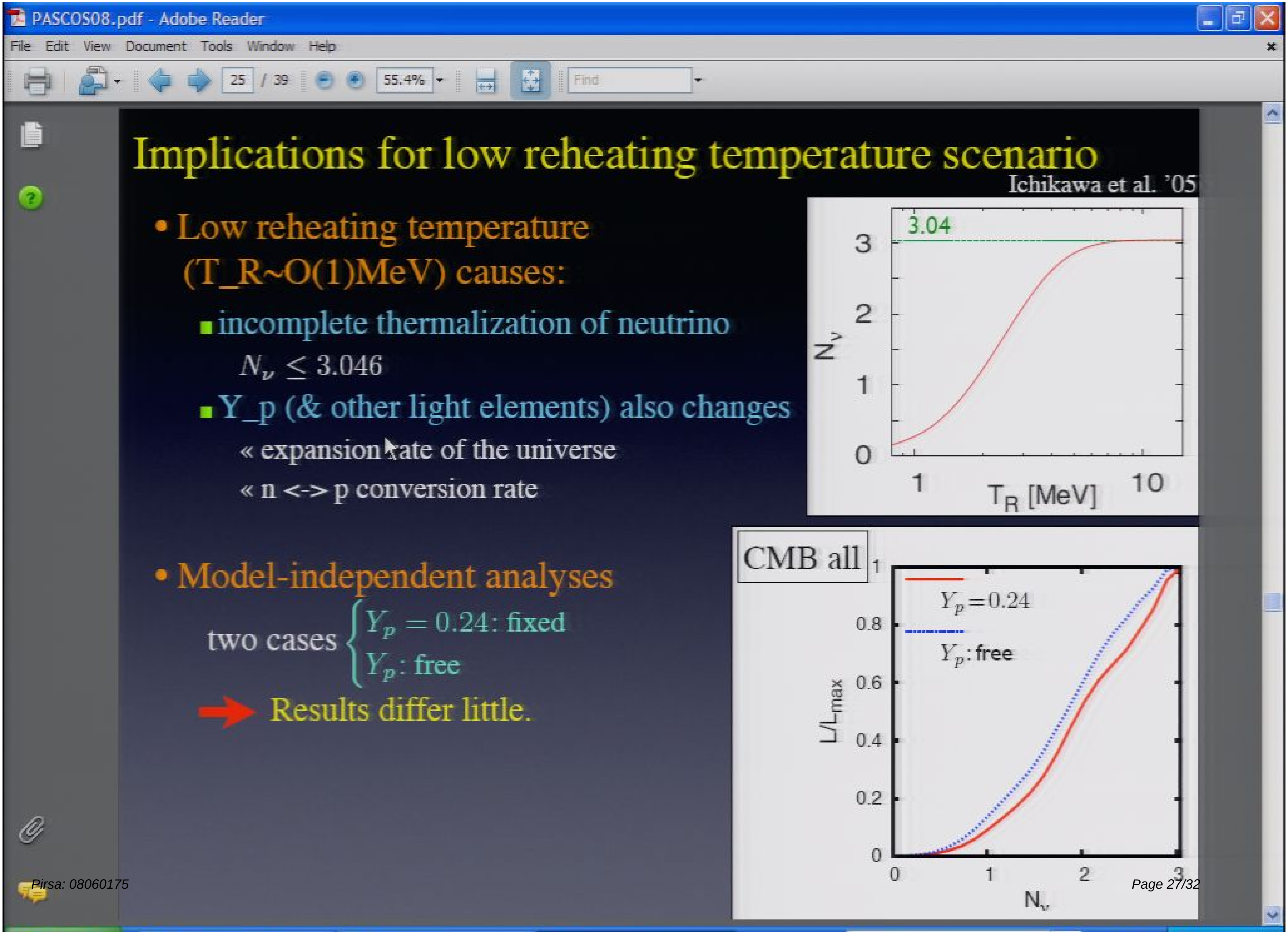
Implications for low reheating temperature scenario

Ichikawa et al. '05

- Low reheating temperature (T_R~O(1)MeV) causes:
  - incomplete thermalization of neutrino
    $N_\nu \leq 3.046$
  - Y_p (& other light elements) also changes
    « expansion rate of the universe
    « n <-> p conversion rate

- Model-independent analyses

$$\text{two cases}\begin{cases} Y_p = 0.24\text{: fixed} \\ Y_p\text{: free} \end{cases}$$



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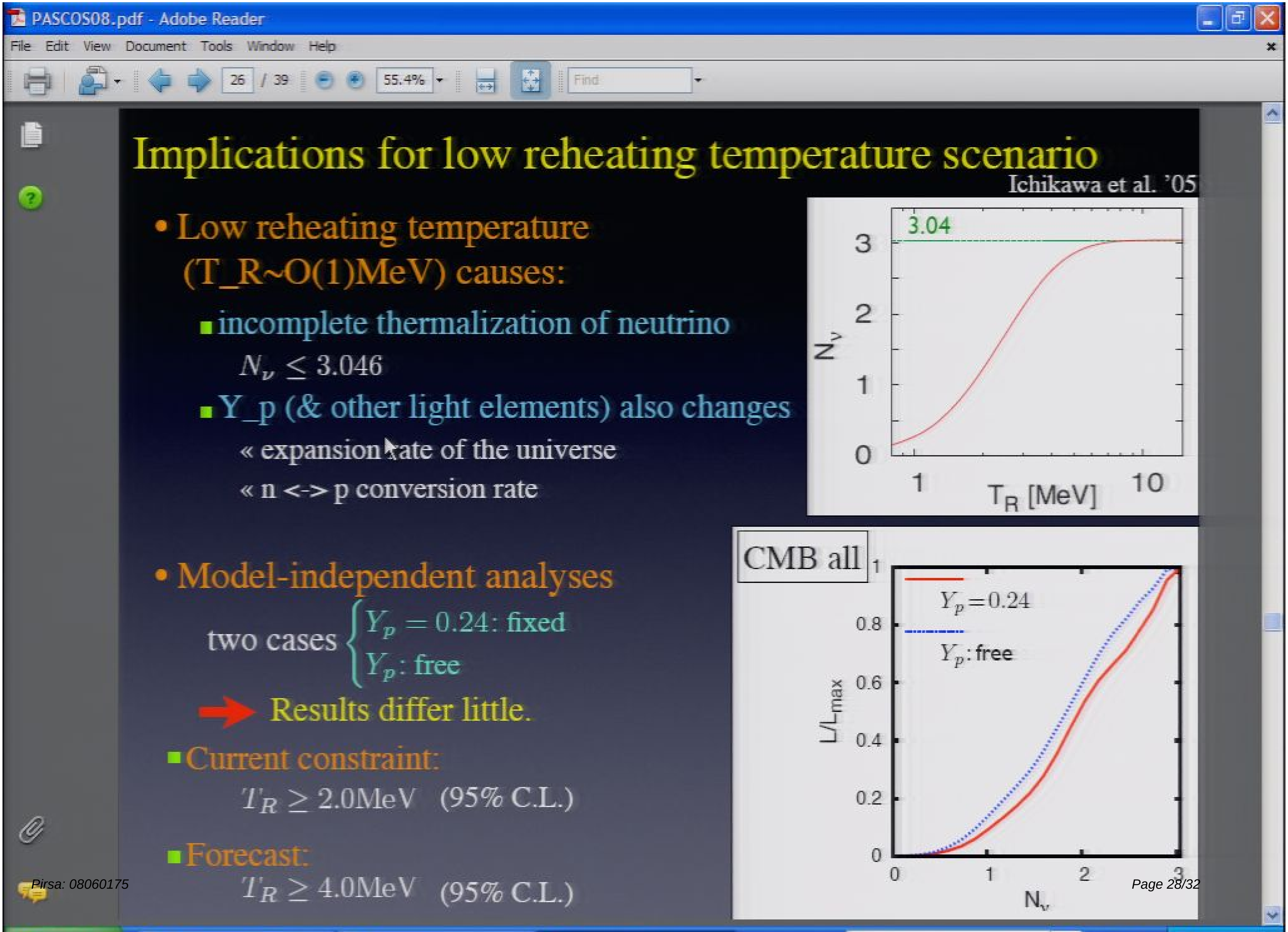

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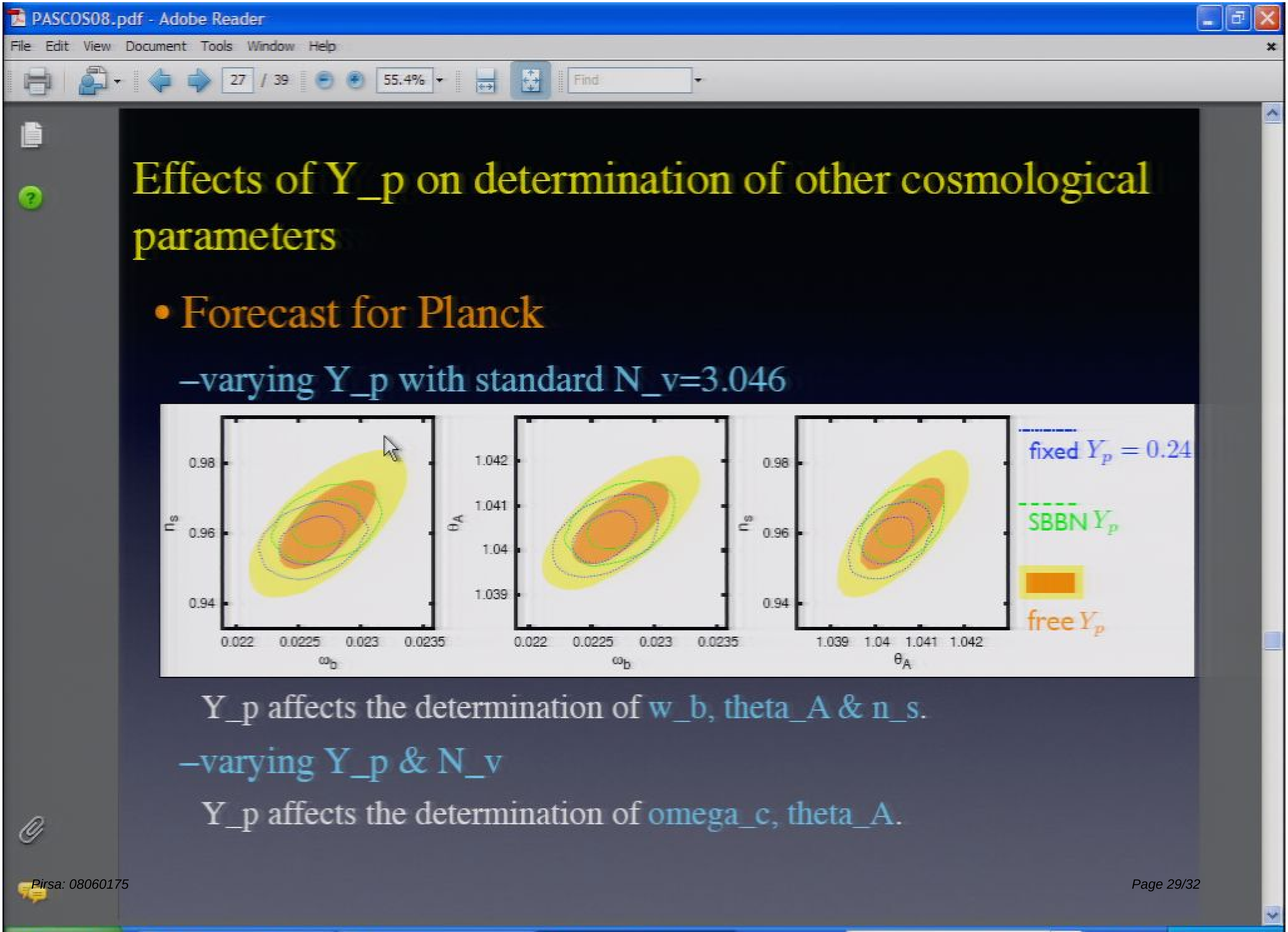
  → Results differ little.
  - Current constraint:
    $T_R \geq 2.0\text{MeV}$ (95% C.L.)
  - Forecast:
    $T_R \geq 4.0\text{MeV}$ (95% C.L.)



Effects of Y_p on determination of other cosmological parameters

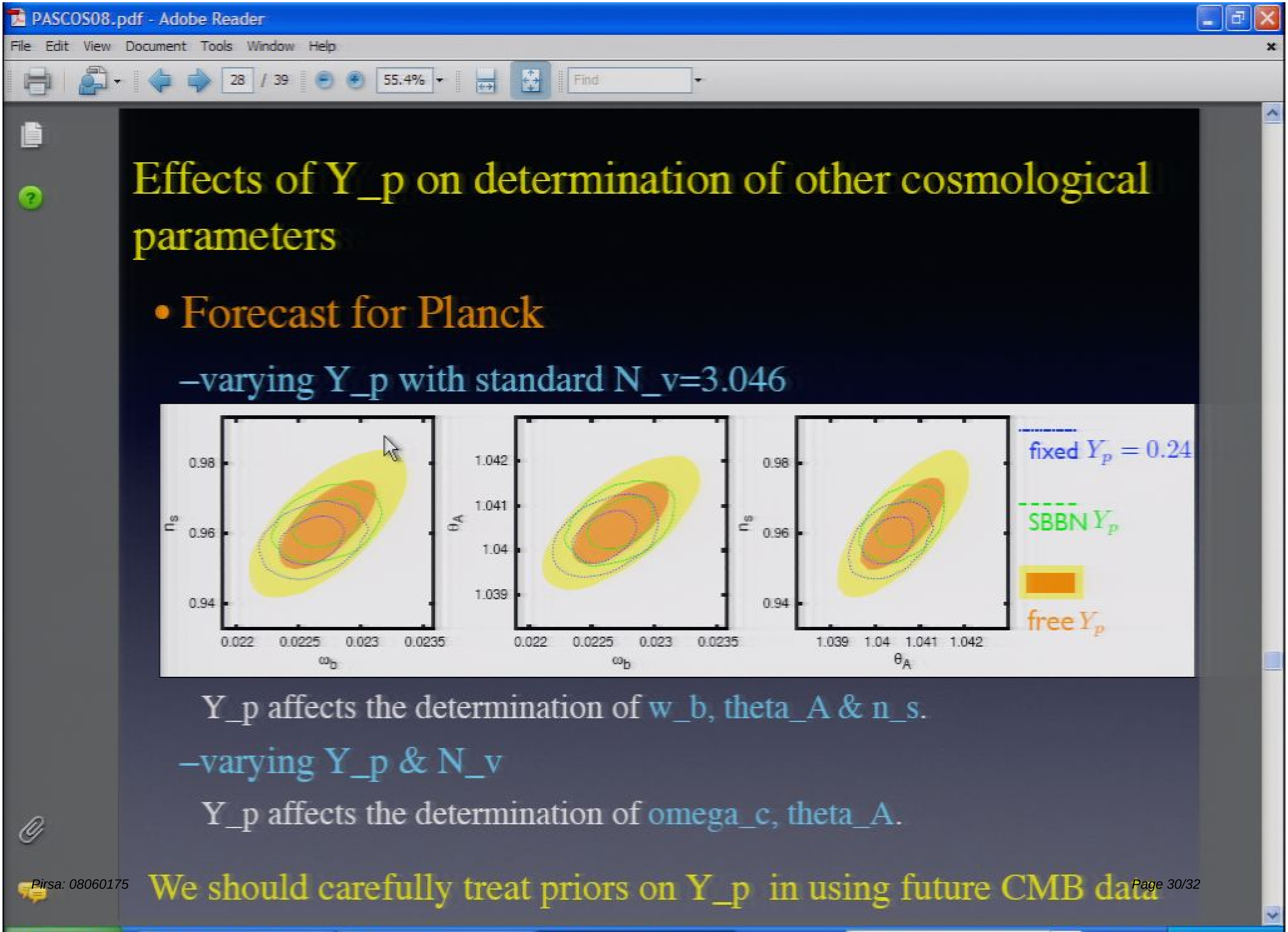
- Forecast for Planck

–varying Y_p with standard N_v=3.046

Y_p affects the determination of w_b, theta_A & n_s.

–varying Y_p & N_v

Y_p affects the determination of omega_c, theta_A.



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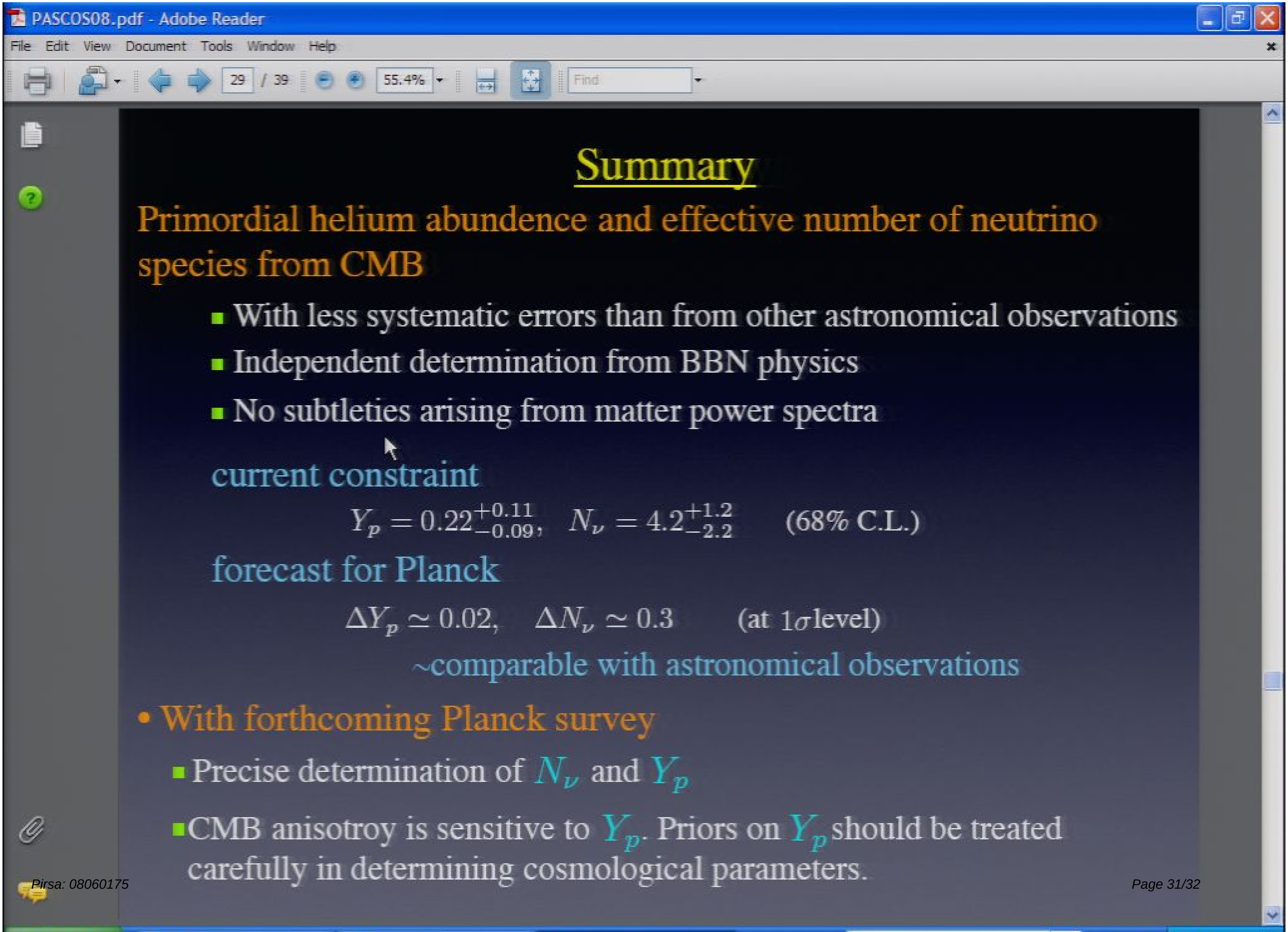
We should carefully treat priors on Y_p in using future CMB data



Summary

Primordial helium abundence and effective number of neutrino species from CMB

- With less systematic errors than from other astronomical observations
- Independent determination from BBN physics
- No subtleties arising from matter power spectra

current constraint

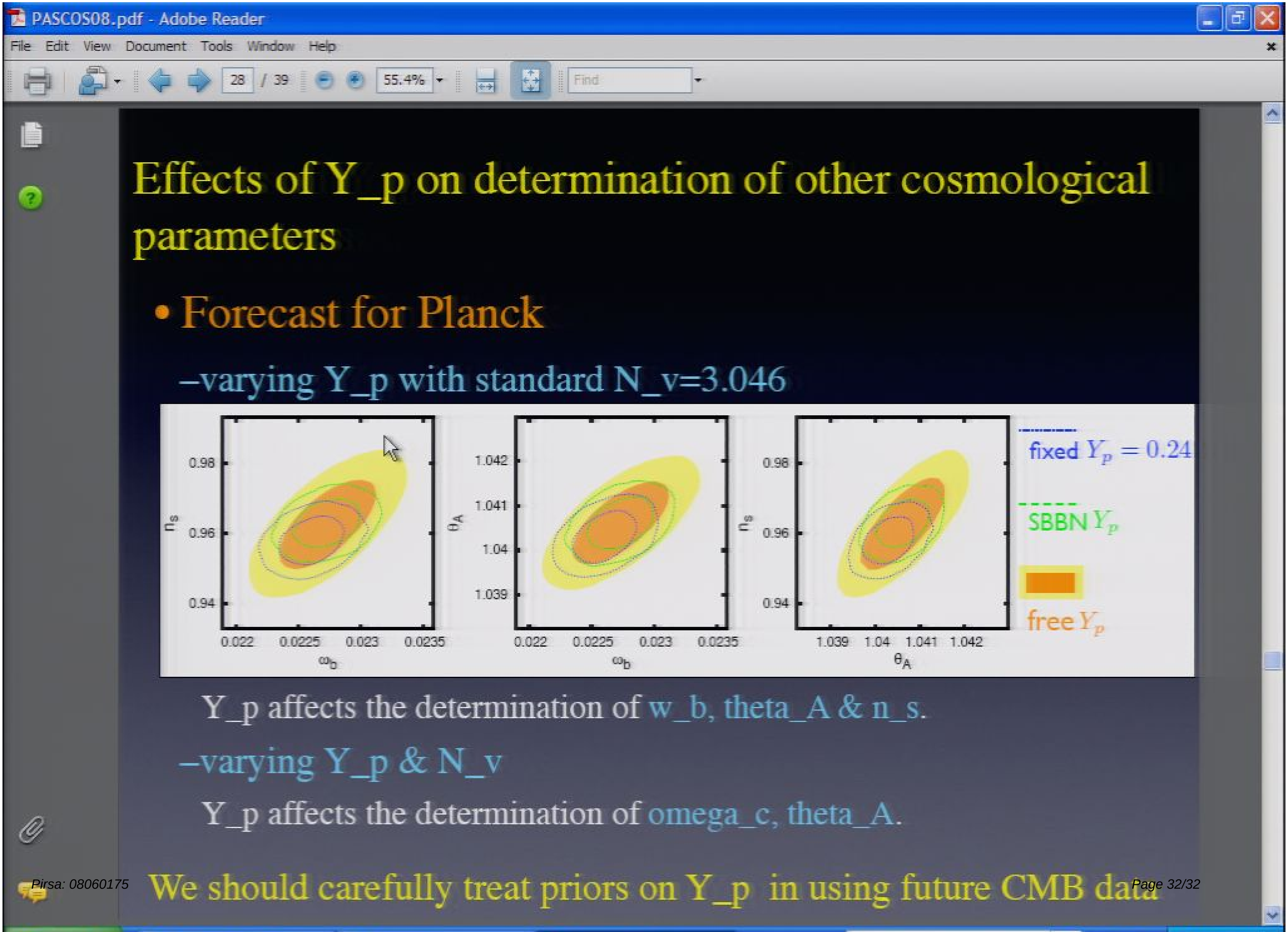
$$Y_p = 0.22^{+0.11}_{-0.09}, \quad N_\nu = 4.2^{+1.2}_{-2.2} \qquad \text{(68\% C.L.)}$$

forecast for Planck

$$\Delta Y_p \simeq 0.02, \quad \Delta N_\nu \simeq 0.3 \qquad \text{(at } 1\sigma \text{ level)}$$

~comparable with astronomical observations

- With forthcoming Planck survey
  - Precise determination of N_ν and Y_p
  - CMB anisotroy is sensitive to Y_p. Priors on Y_p should be treated carefully in determining cosmological parameters.



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