Understanding the environment of Cen X−3 with RGS

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Introduction

The X-ray binary pulsar Cen X−3

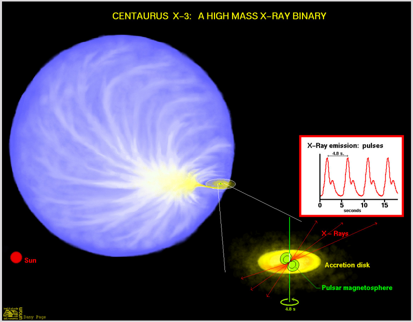

Image: Dany Page picture of the Cen X−3 system

Properties of the system

- An MK type O 6-8 III counterpart (**Hutchings et al. 1979**)
- $M_{\rm opt} \sim 20.5 \pm 0.7\,{\rm M}_\odot$ (**Ash et al. 1999**) and $R_{\rm opt} = 12.1 \pm 0.5\,{\rm R}_\odot$ (**Naik et al. 2011**)
- high X-ray luminosity
- accretion disc fed by Roche-lobe overflow (**Tjemkes et al. 1986**)

Introduction

Properties of the system

- A neutron star with $M_{\rm NS} = 1.34^{+0.16}_{-0.14}$ M$_\odot$ (**van der Meer et al. 2007**) and $P_{\rm NS} = 4.82$ s (**van der Meer et al. 2007**)
- Magnetic field $B = (2.4 - 3.0) \times 10^{12}$ G (**Naik et al. 2011**)

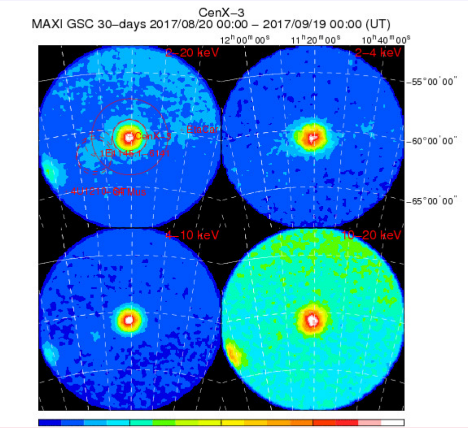

Image: `http://134.160.243.77/pubdata/v3/J1121-606/index.html`

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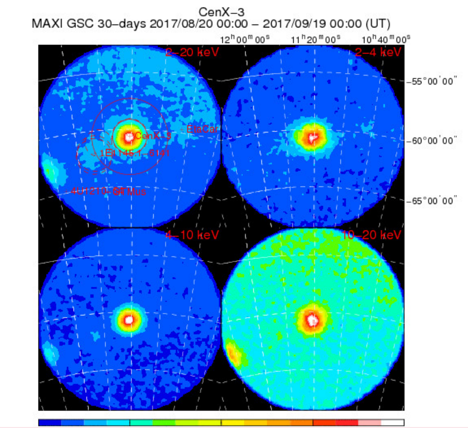
Introduction

Properties of the system

- Orbital period $P_{\rm orb} \sim 2.087$ d (**Falanga et al. 2015, Sanjurjo-Ferrín et al. 2021**)
- eccentricity $e < 0.0016$ (**Bildsten et al. 1997**)
- orbit inclination $i = 79^{\circ} \pm 3^{\circ}$ (**Sanjurjo-Ferrín et al. 2021**)
- distance: $d \sim 8$ kpc (**Krzeminski 1974**) – $d_{\rm Gaia} = 6.8^{+0.6}_{-0.5}$ kpc (**Bailer-Jones et al. 2021, Torregrosa et al. 2022**)



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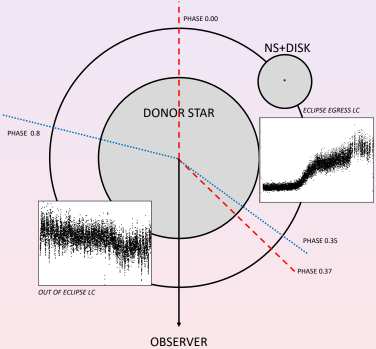
XMM-Newton/RGS observations

Both observations have been studied previously by Devasia et al. (2010), Naik & Paul (2012), Aftab, Paul & Kretschmar (2019), Sanjurjo-Ferrín et al. (2021).

Pointed observations

Pole-on scaled sketch of the system and the orbital phases covered by the two observations using the ephemeris of Falanga et al. (2015). The donor star radius, the orbit, and the accretion disc are to scale. **Image: Sanjurjo-Ferrín et al. 2021**



XMM-Newton/RGS observations

Reflection Grating Spectrometer

Analysis is focused on the high resolution spectra provided by the *RGS* instrument.

Observation data

ID	Instrument	Mode	Duration (s)
0111010101	RGS1	Spec HER + SES	65 922
0111010101	RGS2	Spec HER + SES	63 569
0400550201	RGS1	Spec HER + SES	80 370
0400550201	RGS2	Spec HER + SES	80 370

Table: XMM-Newton observation log.

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Spectral analysis

The fitting process with *SPEX*

- Description of the X-ray continuum by using the orbital-phase averaged spectrum.
- Fixing the continuum parameters and fitting the abundances.
- Checking different kind of absorbers: *absm*, *slab*, *warm*, *xabs*, *pion*.
- And trying also other continuum components: *bb*, *comt*, *rrc*, *pion*.

⇒ Defining our best fit model and aplying it to the time resolved spectroscopy.

- 0111010101 $\Rightarrow$ *(cie + cie)* $\times$ *hot*$_{\rm intrinsic}$ $\times$ *hot*$_{\rm ism}$, $\chi^2/dof = 516/391$
- 0400550201 $\Rightarrow$ *(mbb + cie)* $\times$ *xabs1* $\times$ *slab* $\times$ *xabs2* $\times$ *hot*$_{\rm ism}$, $\chi^2/dof = 1136/640$

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Fit model parameters: eclipse spectrum

Table: Spectral fit to the orbital phase averaged spectrum.

Component	Parameter	0111010101
$Hot_{\mathrm{intrinsic}}$	N_H (10^{26} m^{-2})	0.8±0.3
	kT (eV)	$41.3^{+2.4}_{-1.9}$
*Cie*1	ne nX V (10^{64} m^{-3})	$2.9^{+0.6}_{-0.5}$
	kT (keV)	$2.1^{+0.9}_{-0.4}$
	Flux (10^{-15} W m^{-2})	2.2±0.4
	Unabs. Flux (10^{-14} W m^{-2})	1.6±0.3
*Cie*2	ne nX V (10^{64} m^{-3})	$0.8^{+2.2}_{-0.5}$
	kT (keV)	$0.26^{+0.07}_{-0.08}$
	Abundance Ne	$1.6^{+0.4}_{-0.3}$
	Abundance Mg	$0.8^{+0.5}_{-0.2}$
	Abundance Fe	$0.14^{+0.06}_{-0.05}$
	Flux (10^{-16} W m^{-2})	$2.0^{+2.4}_{-1.5}$
	Unabs. Flux (10^{-14} W m^{-2})	3^{+8}_{-2}
	χ^2/dof	516/391

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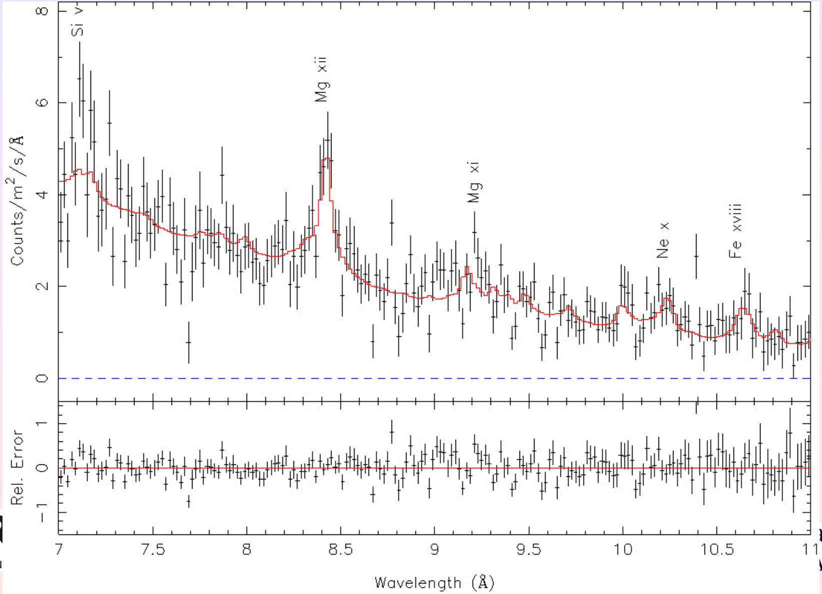
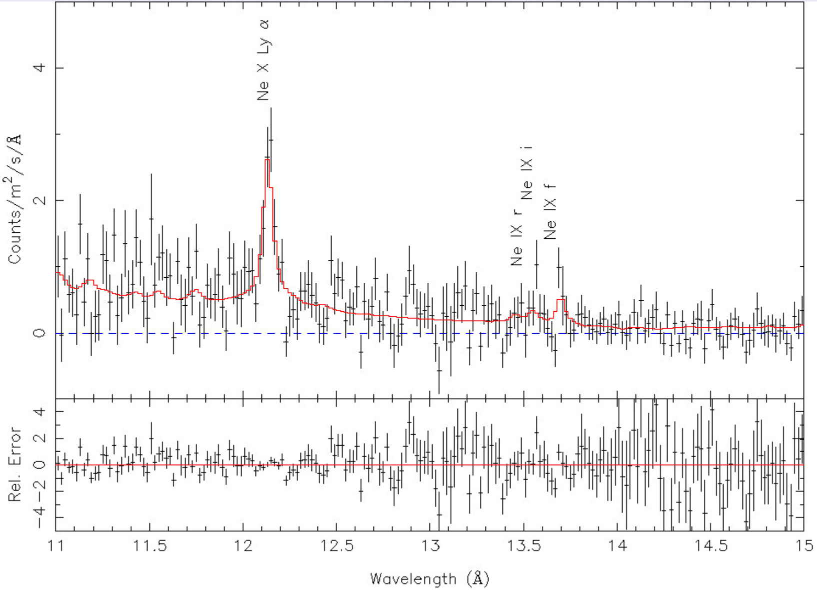
XMM-Newton Obs ID 0111010101: RGS spectrum



XMM-Newton Obs ID 0111010101: RGS spectrum



Results

The eclipse case

- **Wavelength range** reduced to **(7–15)** Å.
- This observation cover the **orbital phase period** $\phi = (0.00 - 0.37)$.
- **Emission lines** of **Ne X** at 12.134 Å, **Fe XVIII** at 10.627 Å, **Ne X** at 10.24 Å, **Mg XI** at 9.232 Å, **Mg XII** at 8.421 Å, **Si V** at 7.126 Å.
- If present, **He-like emission lines** of **Ne IX** at 13.447 Å and **Mg XI** at 9.232 Å were too blended and could not be resolved clearly.
- Simultaneously, ***EPIC/pn*** **detected the presence** of **Fe I-XIV** at 6.4 keV, **Fe XXV** at 6.7 keV and **Fe XXVI** at 6.97 keV (Naik & Paul 2012) $\Longrightarrow \xi \sim 10^{3.4}$ erg cm s^{-1}.
- Each ***CIE component*** could explain two different **circumstellar X- ray emission**: scatter in the stellar wind and from matter in the surroundings of the neutron star.

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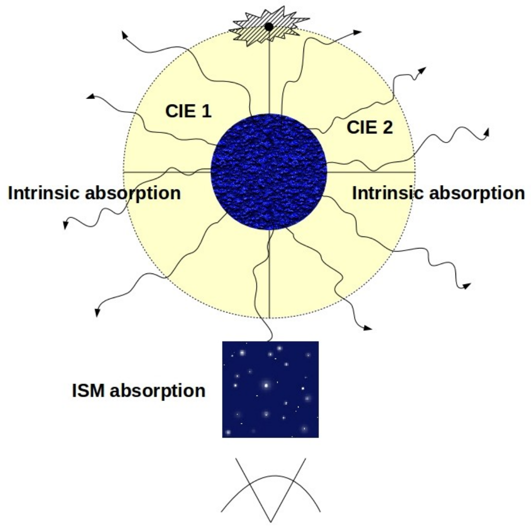
Eclipse case



Fit model parameters: out-of-eclipse spectrum

Table: Spectral fit to the orbital phase averaged spectrum.

Component	Parameter	0400550201
$Xabs_{\rm intrinsic1}$	N_H (10^{26} m^{-2})	2^{+7}_{-1}
	$\log\xi$ (10^{-9} W m)	$3.8^{+0.1}_{-0.4}$
$Xabs_{\rm intrinsic2}$	N_H (10^{26} m^{-2})	$8.7^{\pm}0.3$
	$\log\xi$ (10^{-9} W m)	$1.41^{+0.05}_{-0.03}$
	Covering fraction	0.899 ± 0.006
Modified BB	Norm (10^{26} m$^{0.5}$)	$0.80^{+0.05}_{-0.03}$
	t (keV)	$0.598^{+0.012}_{-0.011}$
	Flux (10^{-13} W m^{-2})	$1.11^{+0.07}_{-0.04}$
	Unabs. Flux (10^{-12} W m^{-2})	$4.7^{+0.3}_{-0.2}$
Cie	ne nX V (10^{64} m^{-3})	56^{+5}_{-6}
	$k\,T$ (keV)	1.07 ± 0.03
	Flux (10^{-15} W m^{-2})	$8.8^{+0.8}_{-0.9}$
	Unabs. Flux (10^{-13} W m^{-2})	$5.3^{+0.5}_{-0.6}$
Slab	log Mg IX (m^{-2})	$20.36^{+0.15}_{-0.16}$
	χ^2/dof	1136/640

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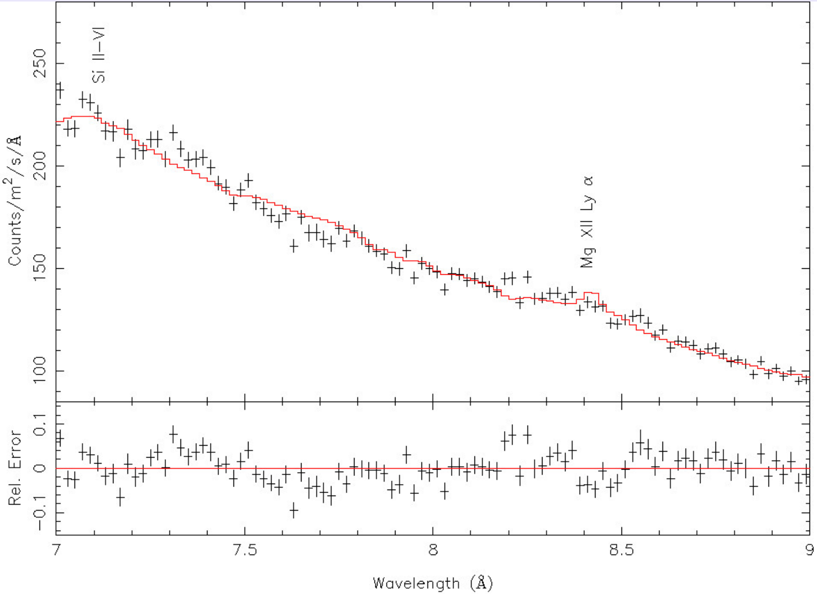
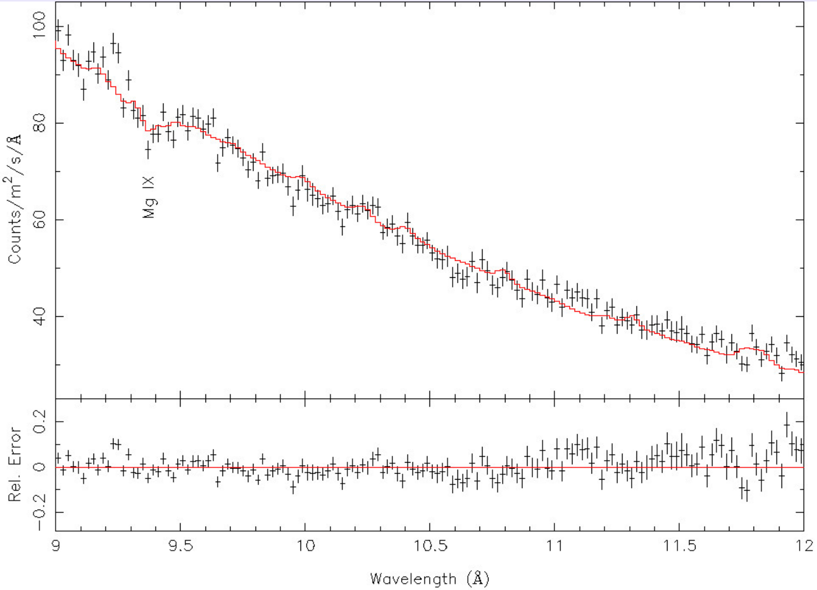
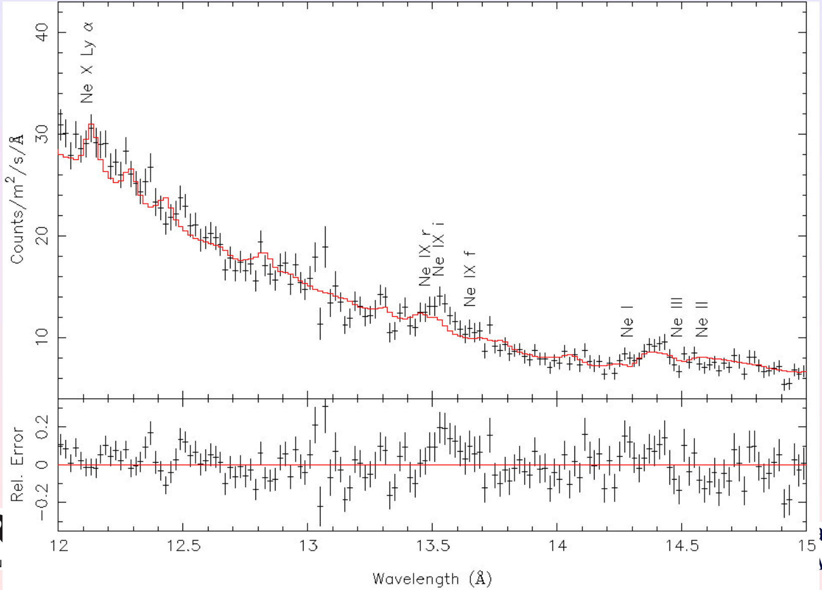
XMM-Newton Obs ID 0400550201: RGS spectrum



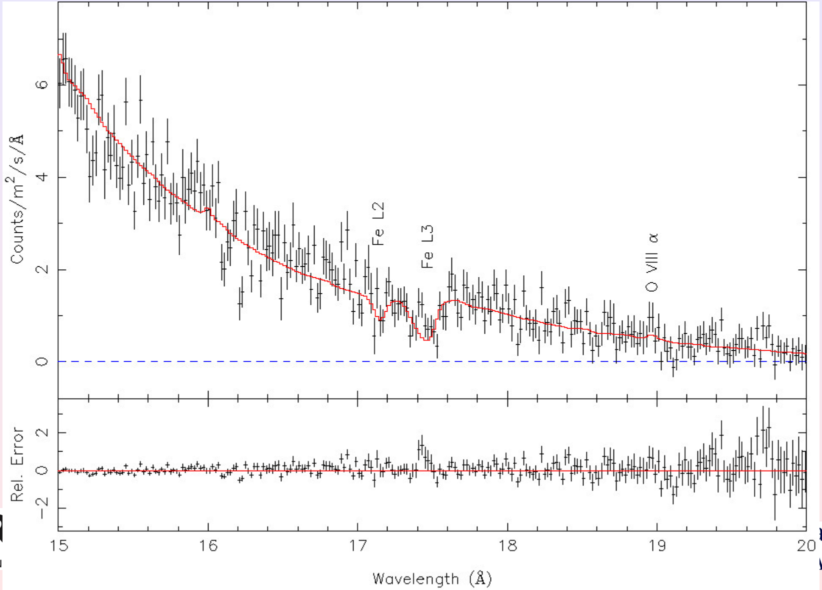
XMM-Newton Obs ID 0400550201: RGS spectrum



XMM-Newton Obs ID 0400550201: RGS spectrum



XMM-Newton Obs ID 0400550201: RGS spectrum



Results

The out-of-eclipse case

- **Wavelength range** reduced to (7–20) Å.
- This observation cover the **orbital phase period** $\phi = (0.36 - 0.80)$.
- **Emission lines** present in the out-of-eclipse spectrum $\Longrightarrow$ **difficult to distinguish** of the X-ray continuum.
- Simultaneously, ***EPIC/pn*** **detected the presence** of **Fe I-XIV** at 6.4 keV, AND ALSO **Fe XXV** at 6.7 keV and **Fe XXVI** at 6.97 keV, BUT with lower EW than in eclipse $\Longrightarrow \xi \sim 10^{3.4}\ \mathrm{erg\,cm\,s^{-1}}$.
- **Identified** an absorption feature **Mg XI** at 9.378 Å.
- It seems that **the (un)resolved triplet of Ne XI** is present and the forbidden line is nearly suppressed for this ion.

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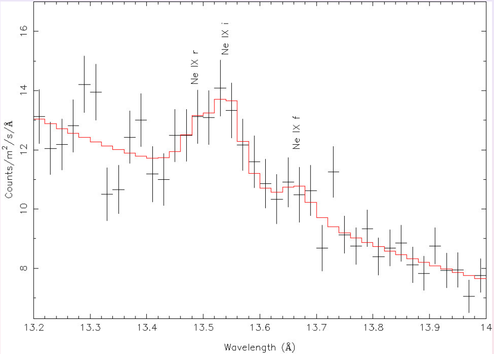
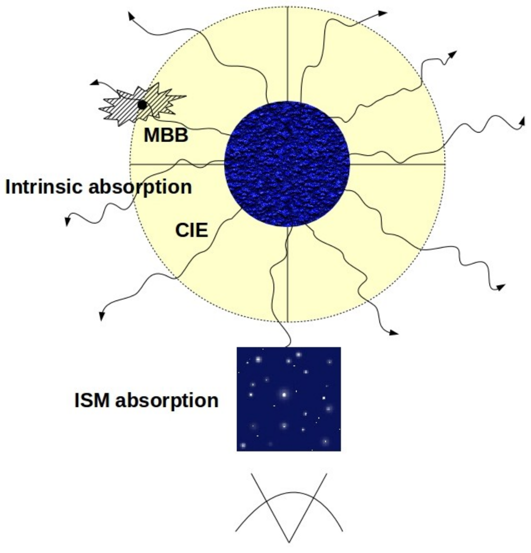
Results

The He-like triplet of Ne

- $\mathcal{R}_{\rm obs} = f/i = 0.3^{+0.4}_{-0.3} \Longrightarrow$ UV photospheric field seems to be important at the line production site (**Porquet & Dubau 2000**)
- Electron density should be $\gtrsim 10^{12}$ cm^{-3} supported by $\mathcal{G}_{\rm obs} = (f+i)/r = 2.5 \pm 2.4$ (**Porquet & Dubau 2000**)
- May be a hybrid plasma where the effect collisional plasma should be present



Out-of-eclipse case



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Conclusions

Cen X-3 as seen by RGS

Cen X-3 was observed with the ***XMM-Newton*** satellite covering **two different orbital ranges**. A more complex model is needed to describe the out-of-eclipse spectrum compared with the two temperature CIE absorbed model for the eclipse-egress spectrum.

- We detected **emission lines from hydrogenic/helium ions** of Ne and Mg.
- **Different ionization states** in a hybrid plasma.
- The **continuum spectra** are **reasonable fitted** with *SPEX* models in and out-of-eclipse.
- BUT, **some limitations of the best fitting models** such as **RGS absorption lines blend** and **not unique solutions**.

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THANK YOU FOR YOUR ATTENTION!!

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