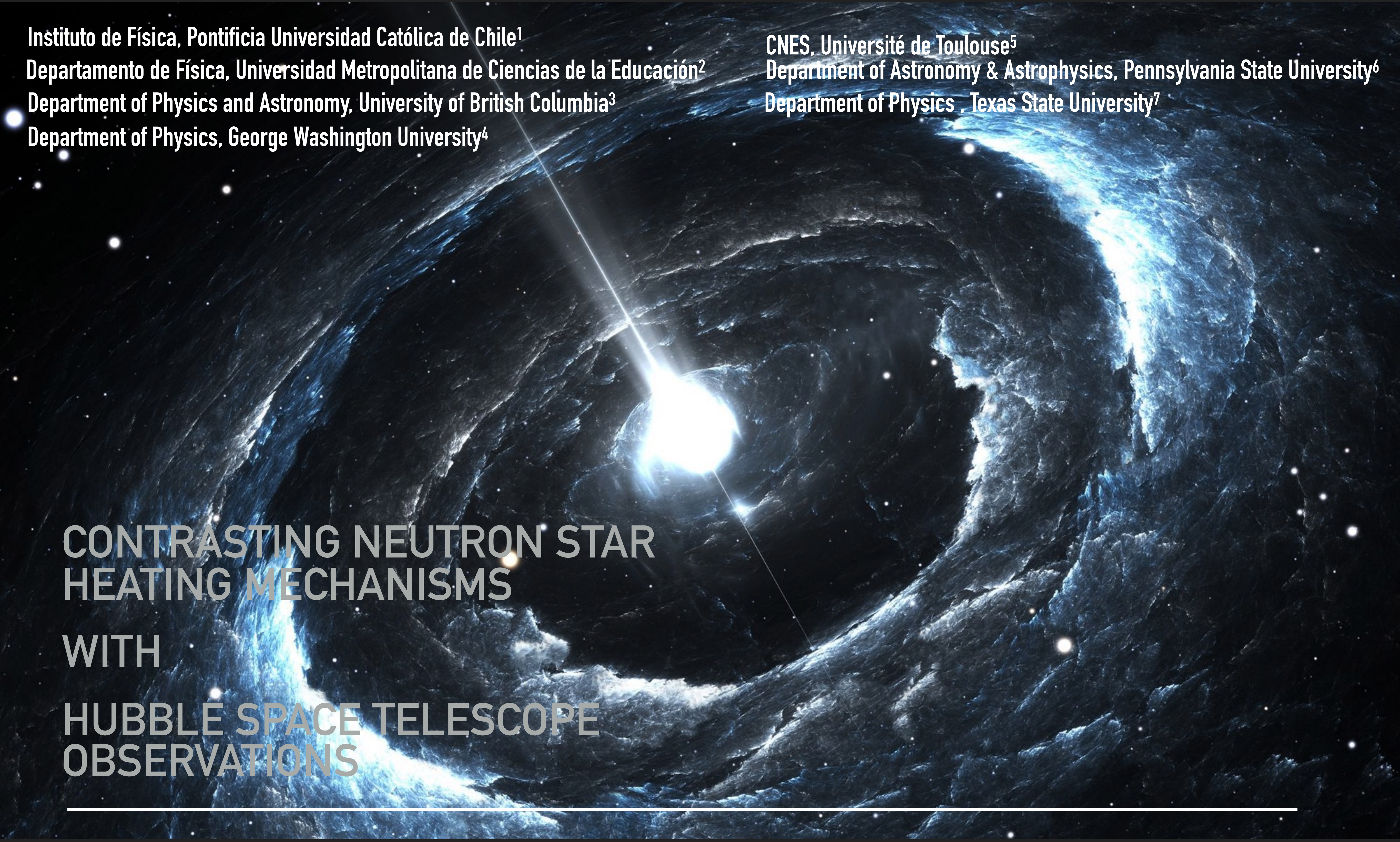
L. RODRIGUEZ[1], A. REISENEGGER[2], D. GONZALEZ-CANIULEF[3], G. PAVLOV[4], S. GUILLOT[5], O. KARGALTSEV[6], B. RANGELOV[7]

Instituto de Física, Pontificia Universidad Católica de Chile[1]
Departamento de Física, Universidad Metropolitana de Ciencias de la Educación[2]
Department of Physics and Astronomy, University of British Columbia[3]
Department of Physics, George Washington University[4]
CNES, Université de Toulouse[5]
Department of Astronomy & Astrophysics, Pennsylvania State University[6]
Department of Physics , Texas State University[7]



CONTRASTING NEUTRON STAR HEATING MECHANISMS

WITH

HUBBLE SPACE TELESCOPE OBSERVATIONS

OUTLINE

- Why neutron star cooling and UV observations?
- Contrasting of HST observations with neutron stars heating mechanisms
- Conclusions
- Further work

WHY

NEUTRON STAR COOLING AND UV OBSERVATIONS?

$P\,\dot{P}$ diagram of several neutron stars known so far. This figure was an internal contribution of a member of our group Cristóbal Espinoza.

TYPES OF NEUTRON STARS

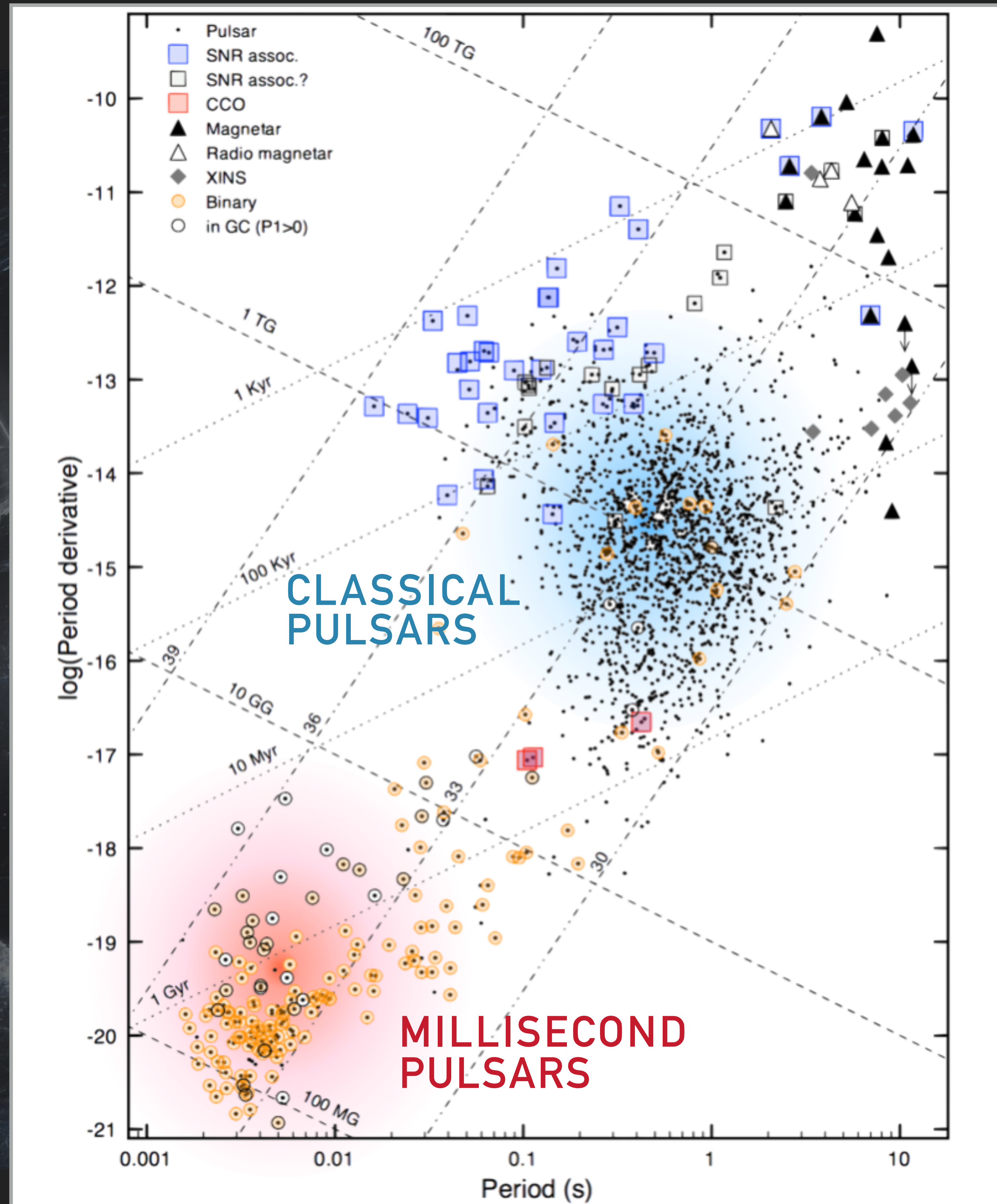
ASSUMING NSs AS ROTATING MAGNETIC DIPOLES

- Characteristic age

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

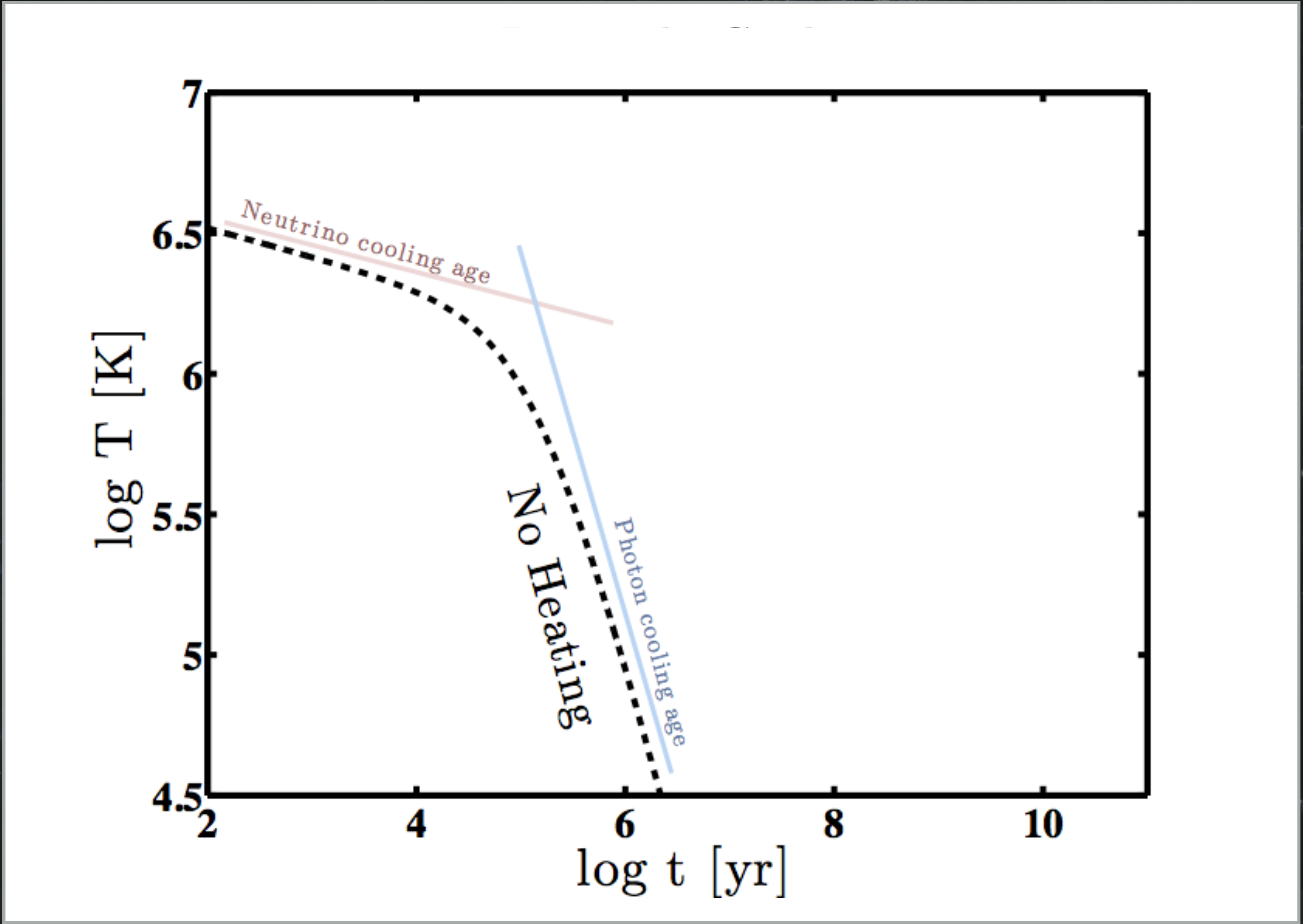
- Magnetic field

$$B^2 \propto P\dot{P}$$

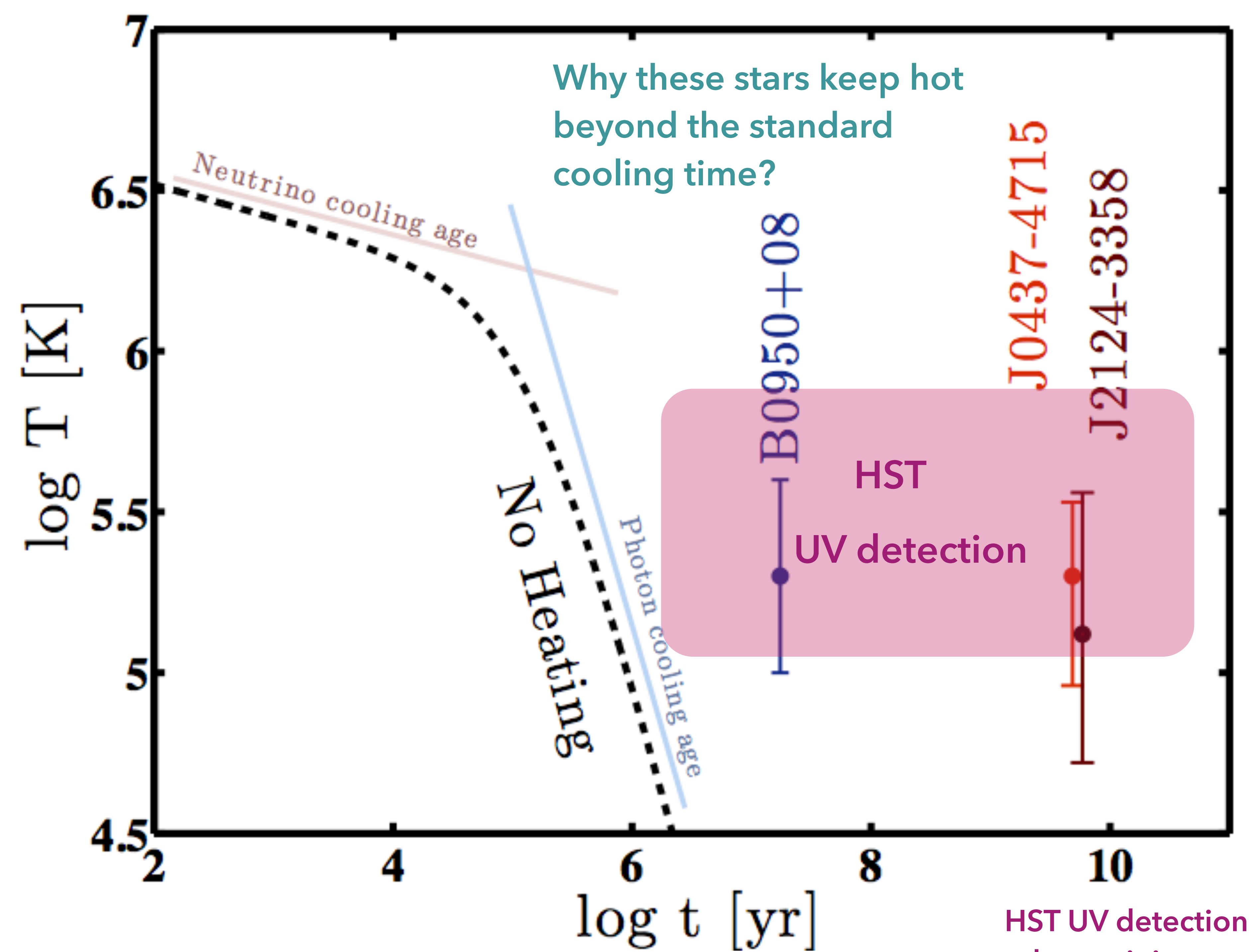


WE FOCUS ON CLASSICAL PULSARS AND MILLISECOND PULSARS

PASSIVELY COOLING NEUTRON STAR



PASSIVELY COOLING NEUTRON STAR



HST UV detection zone is a scheme, it is not to scale

SUMMARY OF THE OBSERVATIONS

Pulsar	*P* [ms]	log P^* [s^{-2}]	log B [G]	log $P/2P^*$ [yr]	log T_{BB} [K]	log T_H [K]
J0437-4715	5.75	-19.86	8.45	9.82	5.09 - 5.54	4.93 - 5.79
J2124-3358	4.93	-20.13	8.2	10	4.69 - 5.32	4.62 - 5.67
B0950+08	253	-15.6	11.38	7.24	5 - 5.47	4.98 - 5.84
J2144-3943	8510	-15.3	12.3	8.43	$\lesssim$4.68	$\lesssim$5.08

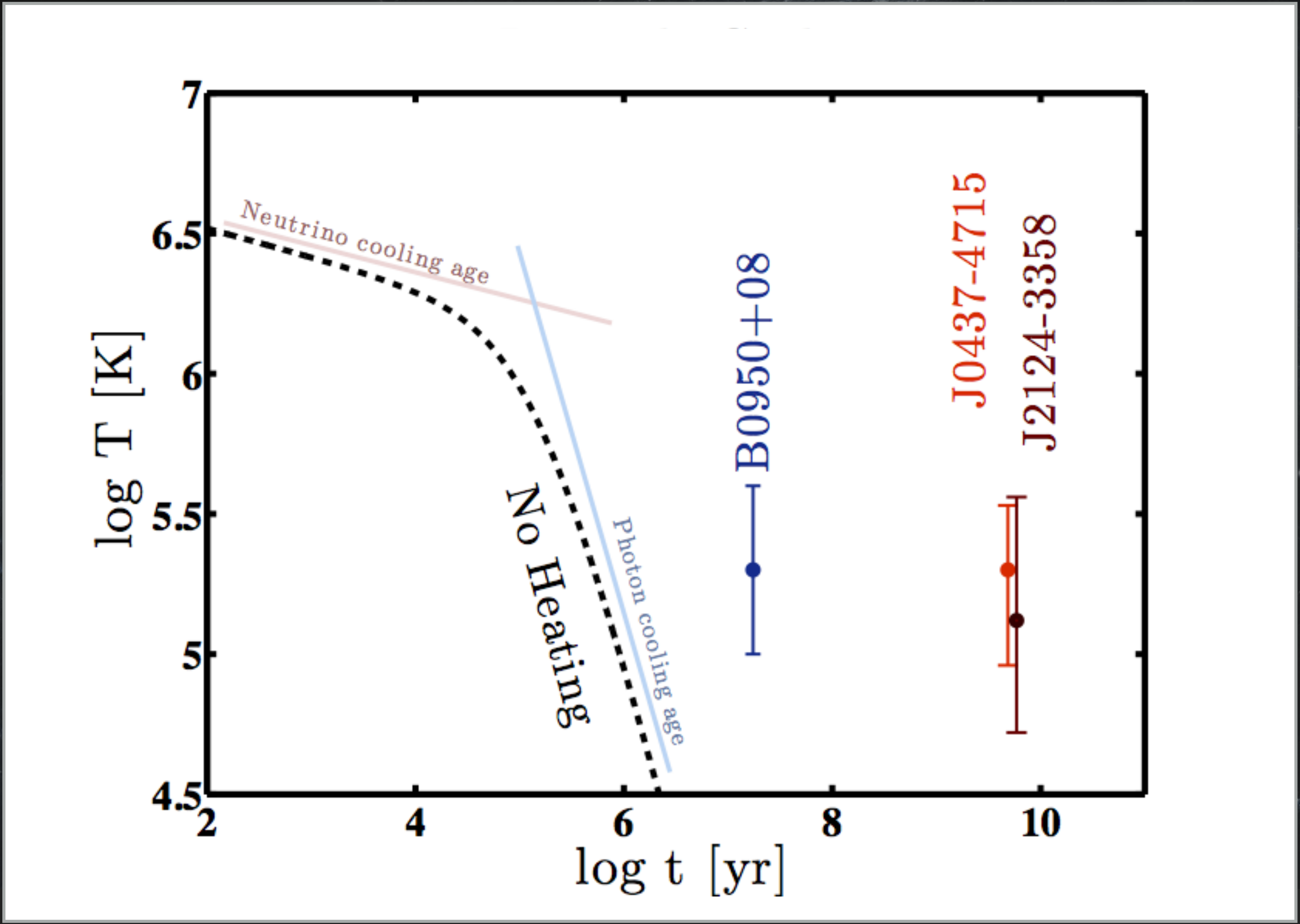
J0437-4715 Durant et al. 2012
J2124-3358 Rangelov et al. 2017
B0950+08 Pavlov et al. 2017
J2144-3943 Guillot et al. 2019




CONTRASTING HST OBSERVATIONS WITH

NS COOLING

PASSIVELY COOLING NEUTRON STAR



NEUTRON STAR COOLING

$$\frac{dT_\infty}{dt} = \frac{1}{C}\Big(- L_\nu - L_\gamma + \sum L_i^{HM}\Big),$$

Thorne (1977)

- Total specific heat

$$C = \sum_i \int dV\, c_{V,i},$$

- Heating mechanisms

$$L_H^\infty = \int dV Q_H e^{2\Phi},$$

- Thermal neutrinos

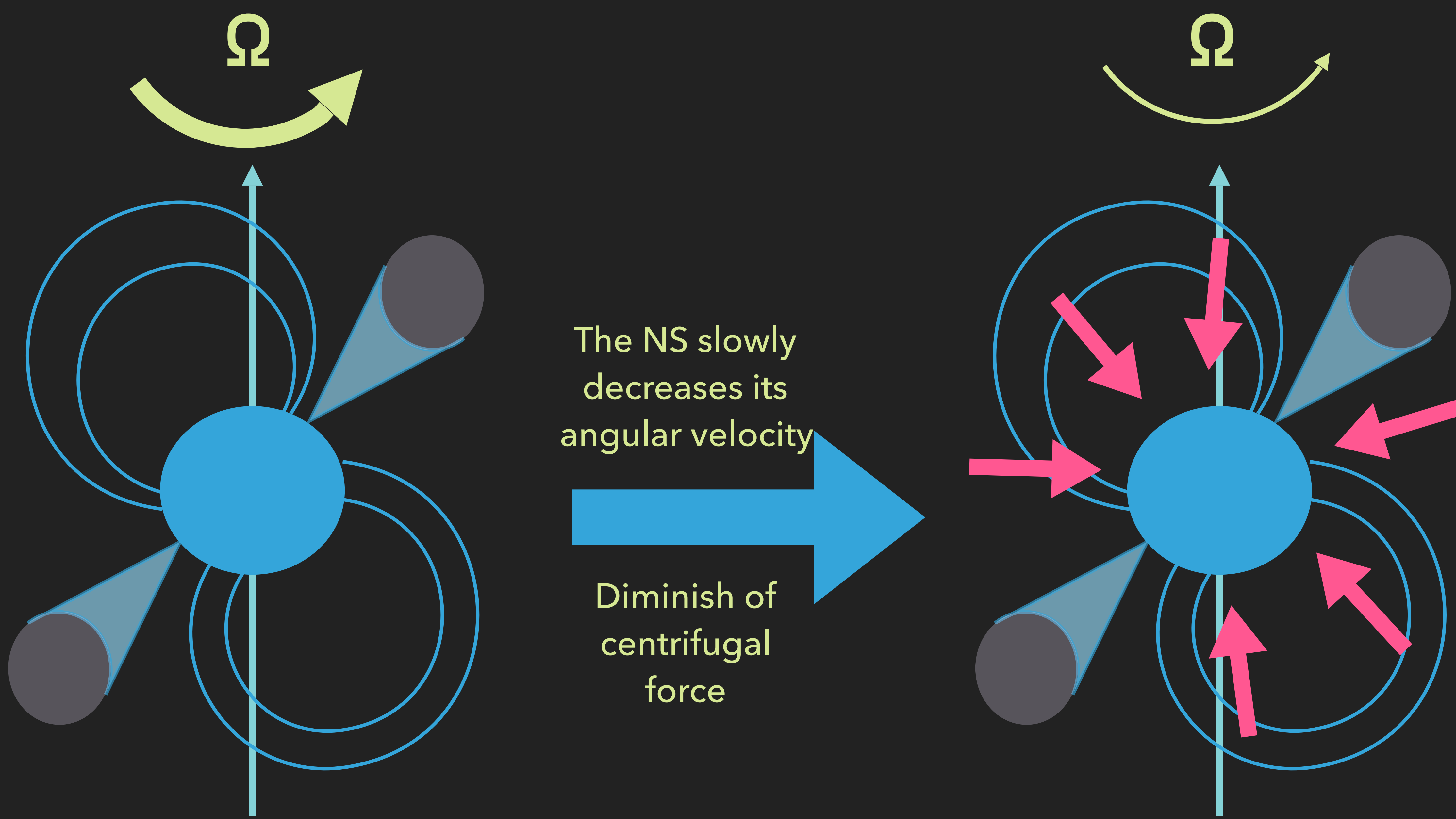
$$L_\nu^\infty = \int dV Q_\nu e^{2\Phi},$$

- Thermal Photons

$$L_\gamma^\infty = 4\pi\sigma R_\infty^2 (T_s^\infty)^4,$$

ROTOCHEMICAL HEATING

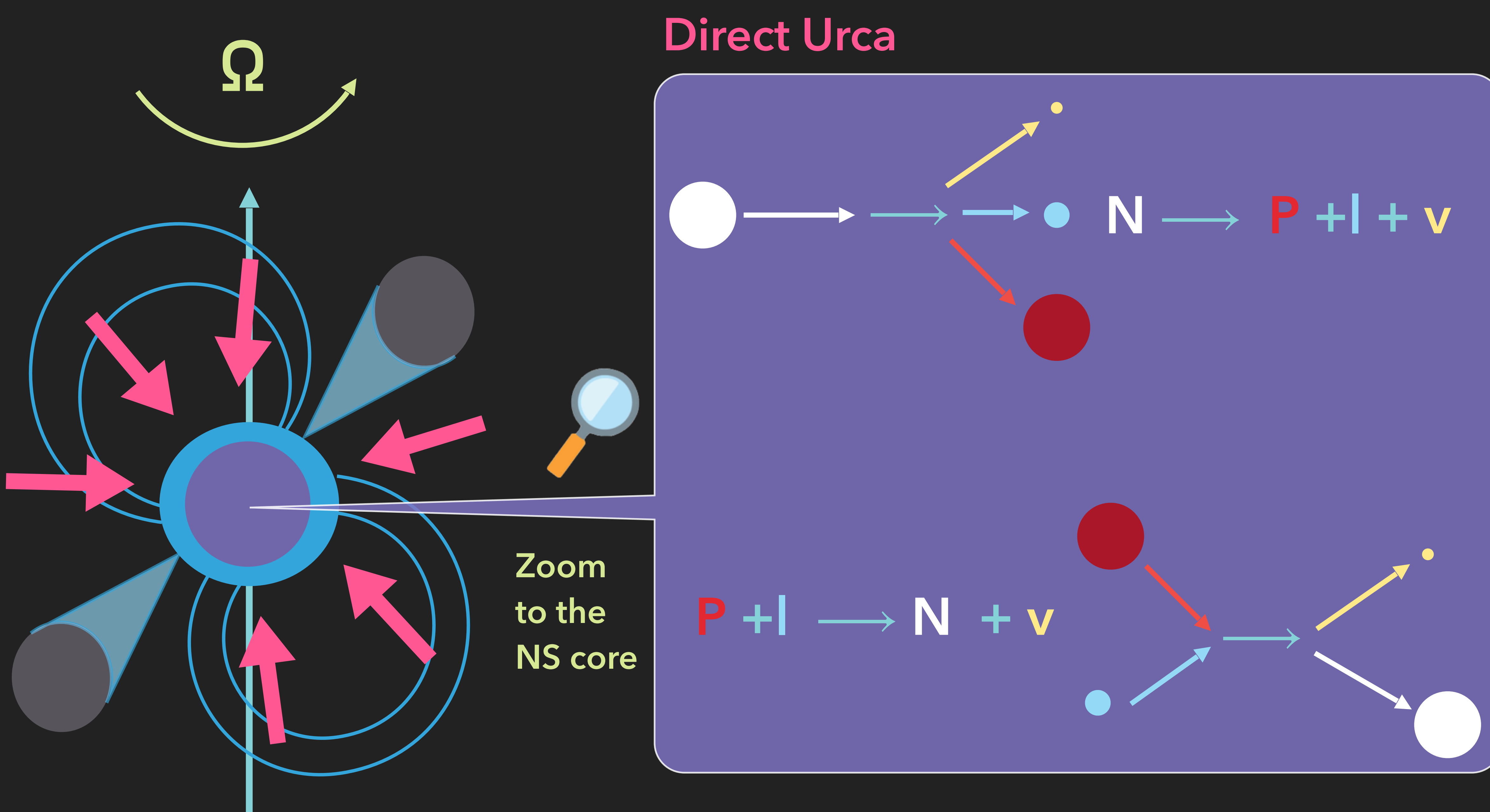
Reisenegger 1995



The compression makes that the neutron star rises its local pressure and density

ROTOCHEMICAL HEATING

Reisenegger 1995

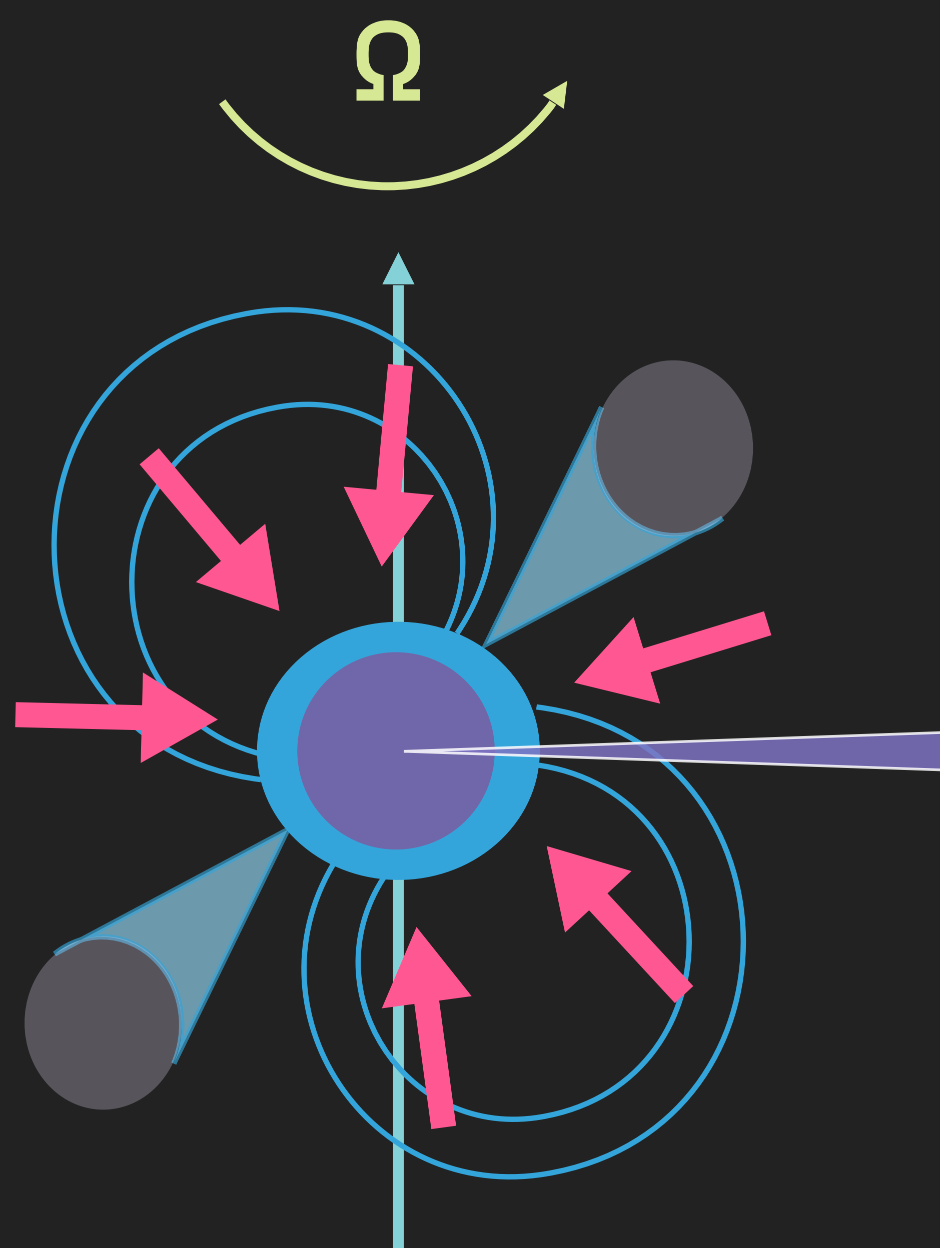


The neutron star rises its local pressure and density

This increases the chemical imbalances and produce non-equilibrium beta reactions in the core

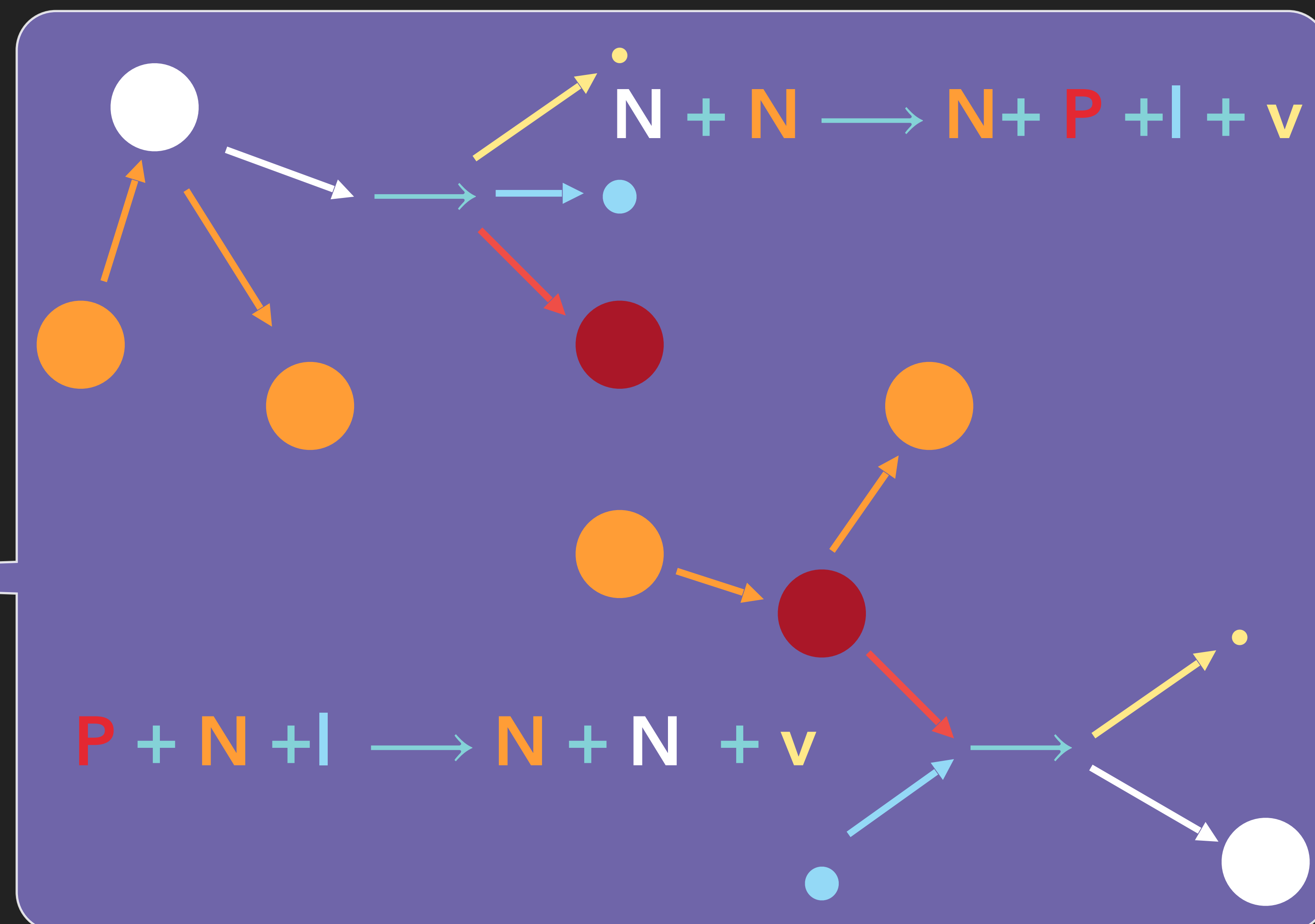
ROTOCHEMICAL HEATING

Reisenegger 1995



The neutron star rises its local pressure and density

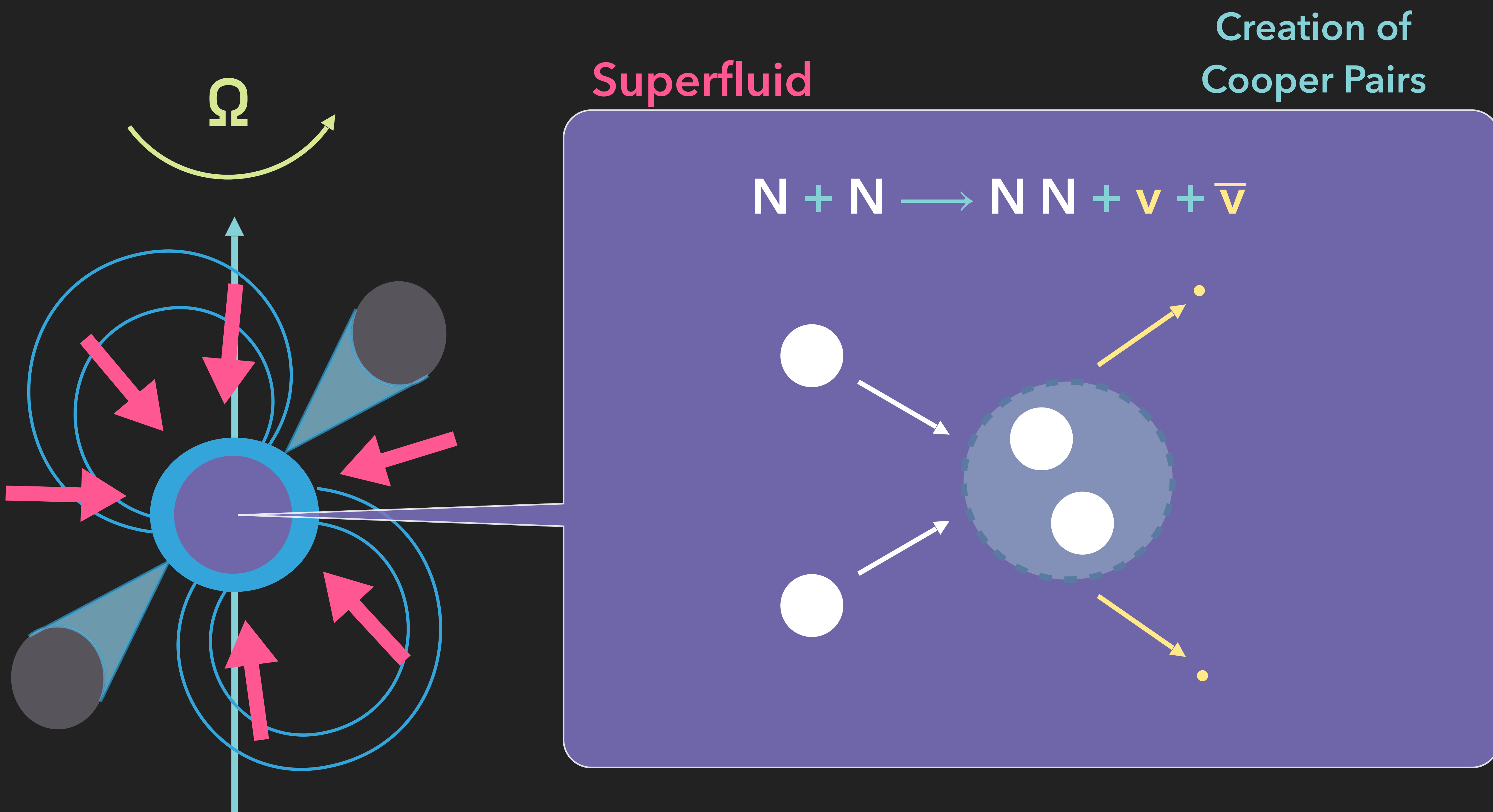
Modified Urca



This increases the chemical imbalances and produce non-equilibrium beta reactions in the core

ROTOCHEMICAL HEATING

Reisenegger 1995

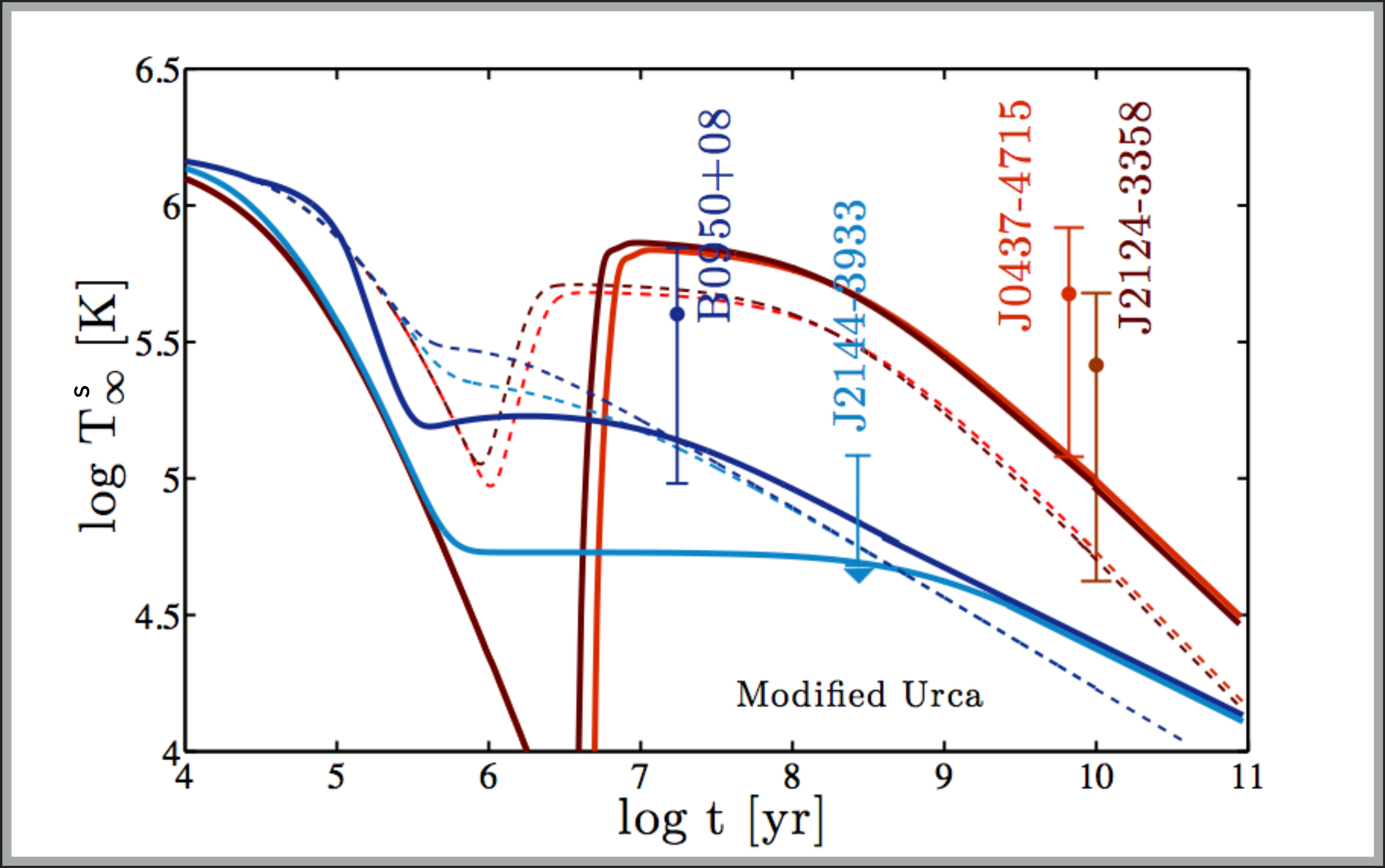


Neutrons may experiment a phase transition when their temperature is below T_c

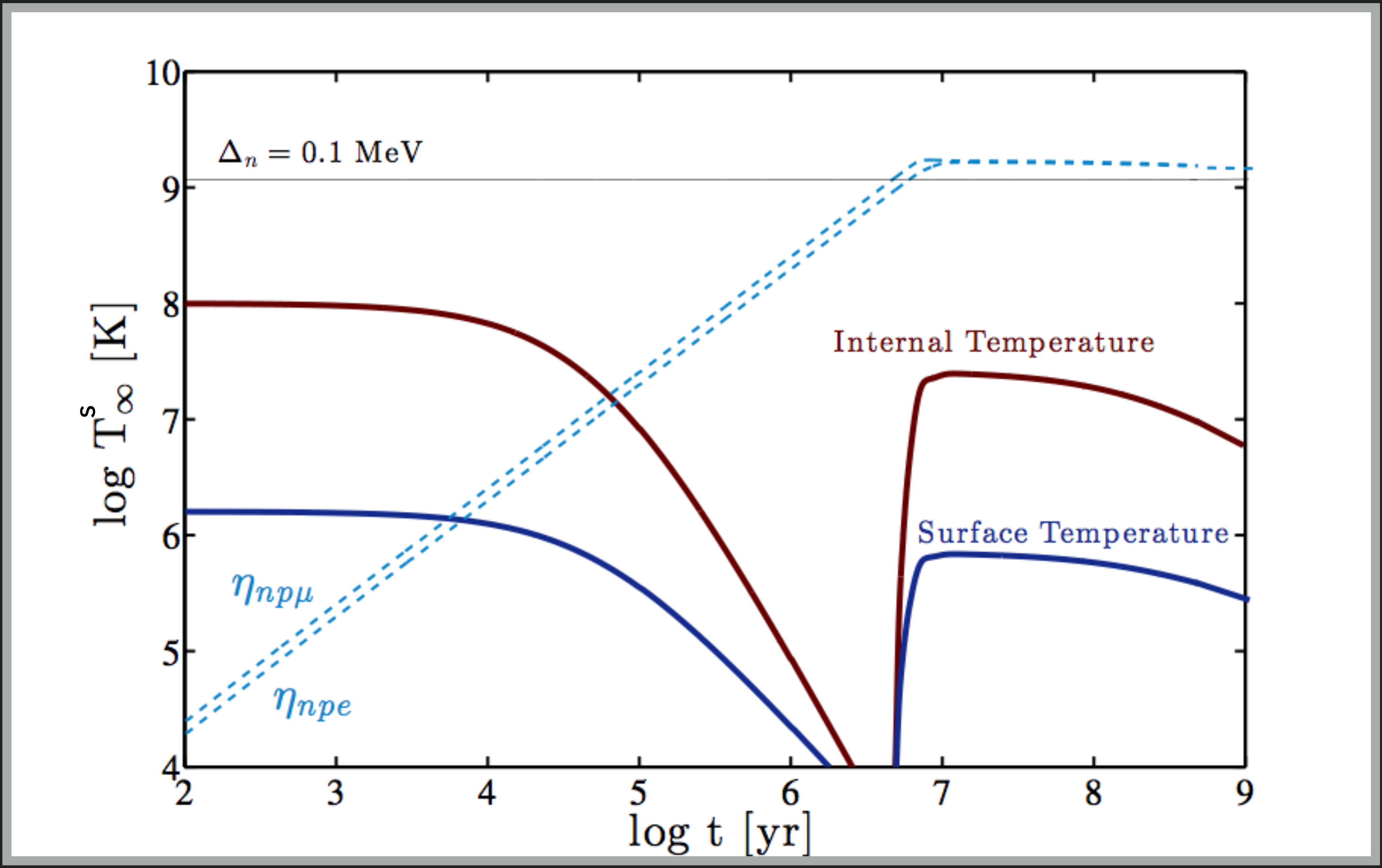
The superfluid is characterized by the addition of a energy gap Δ_n and the suppression of the specific heat of neutrons

We want to know the value of Δ_n !

ROTOCHEMICAL HEATING – SUPERFLUID NEUTRONS

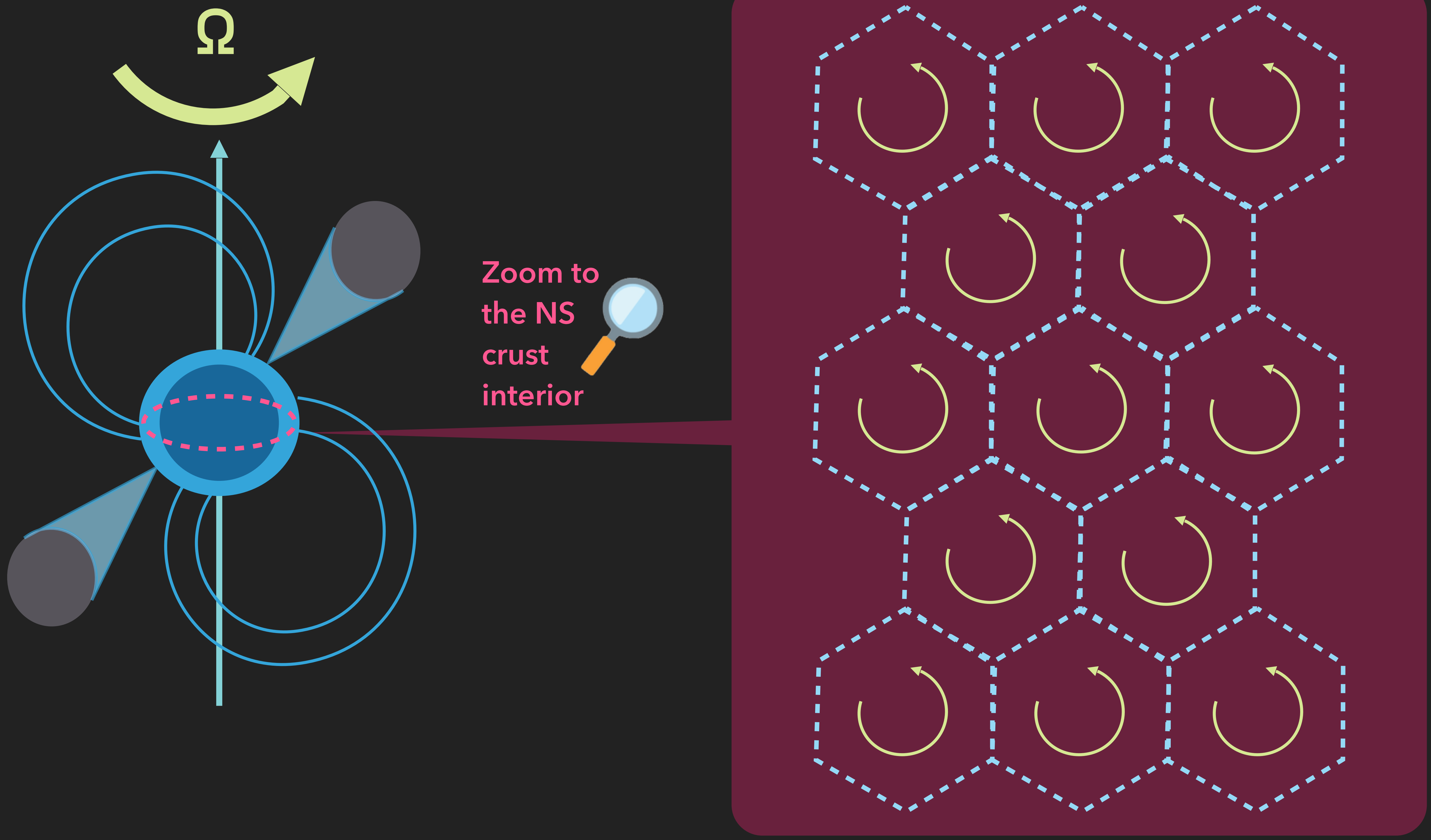


ROTOCHEMICAL HEATING – SUPERFLUID NEUTRONS



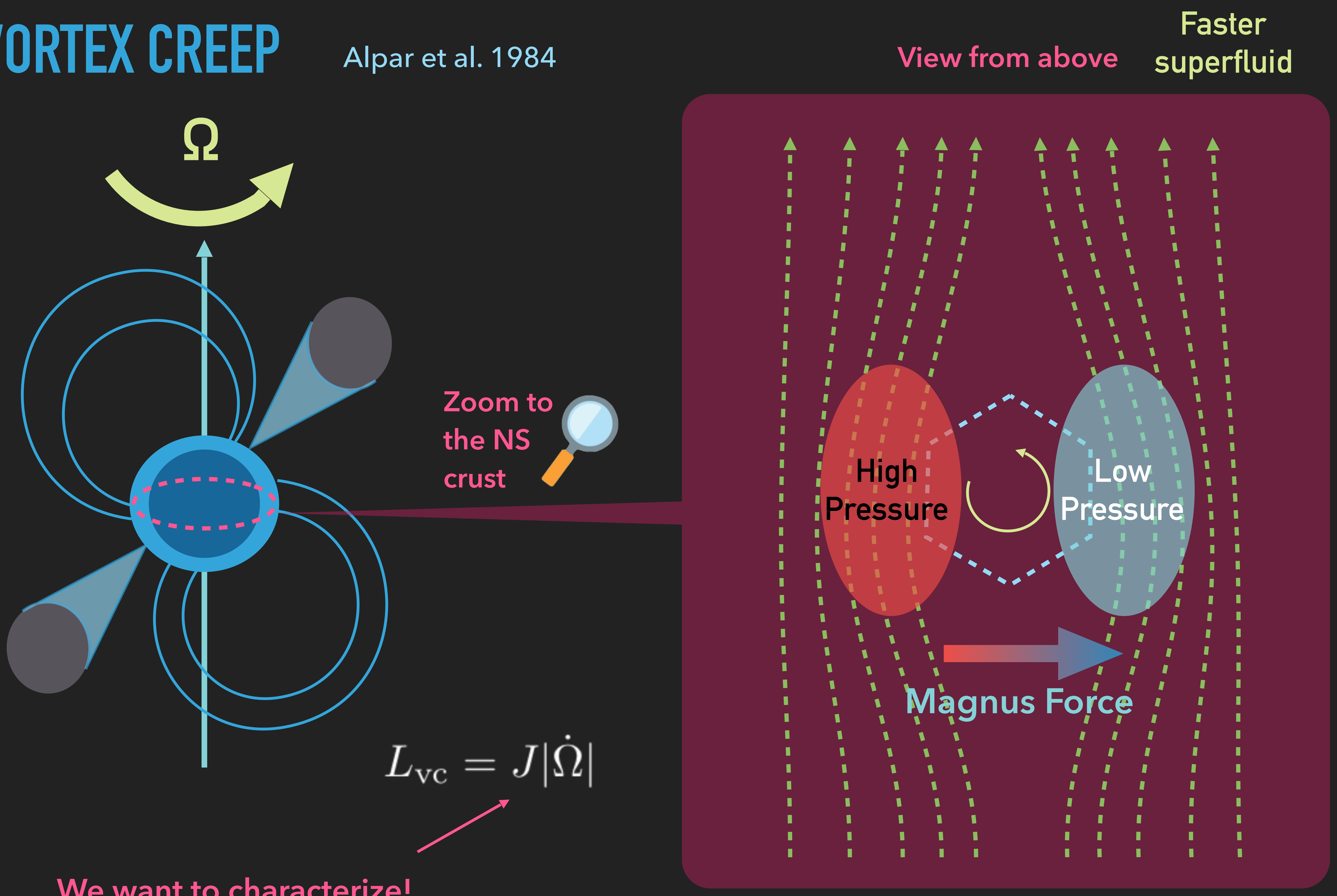
VORTEX CREEP

Alpar et al. 1984



VORTEX CREEP

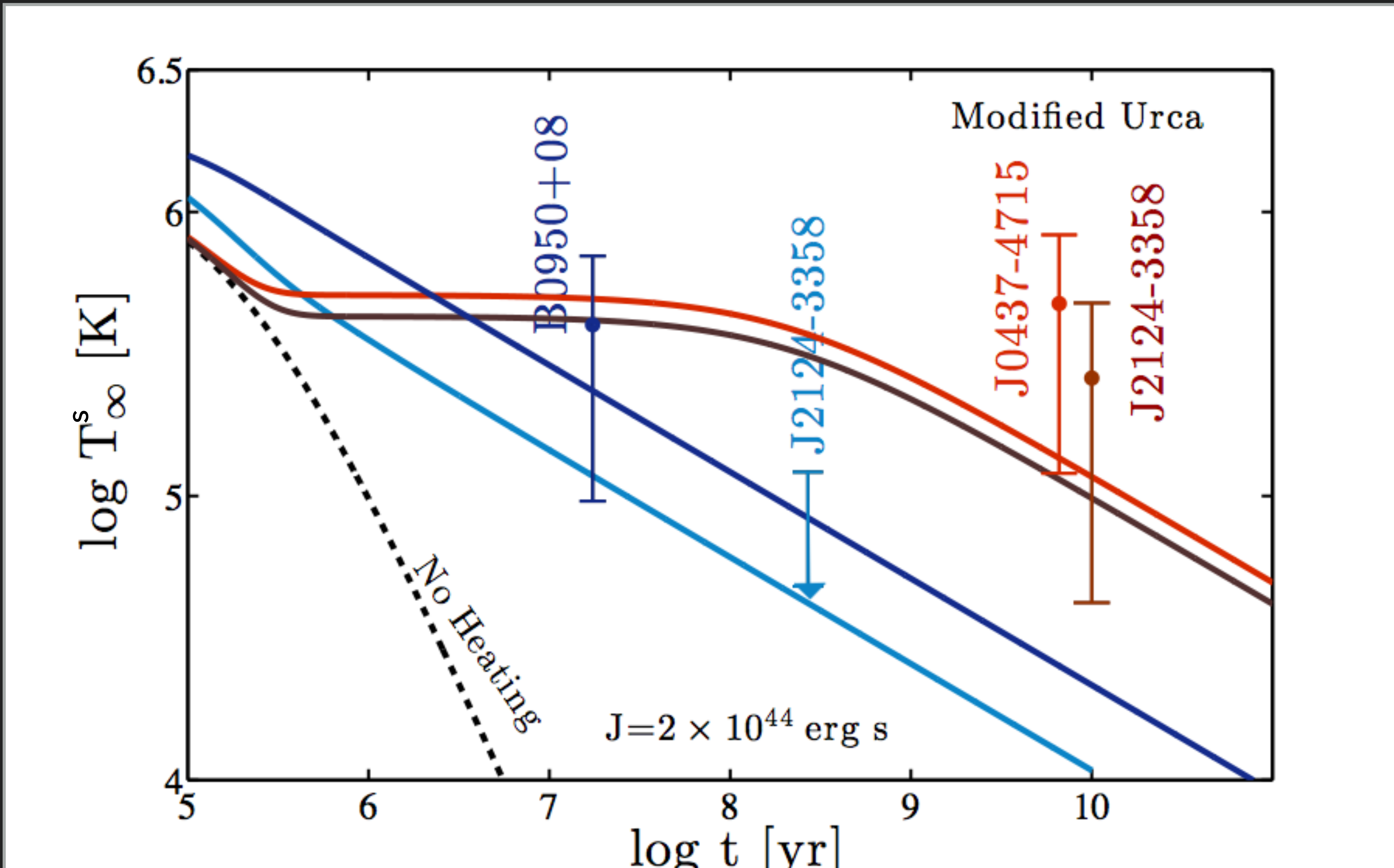
Alpar et al. 1984



$$L_{\rm vc} = J|\dot{\Omega}|$$

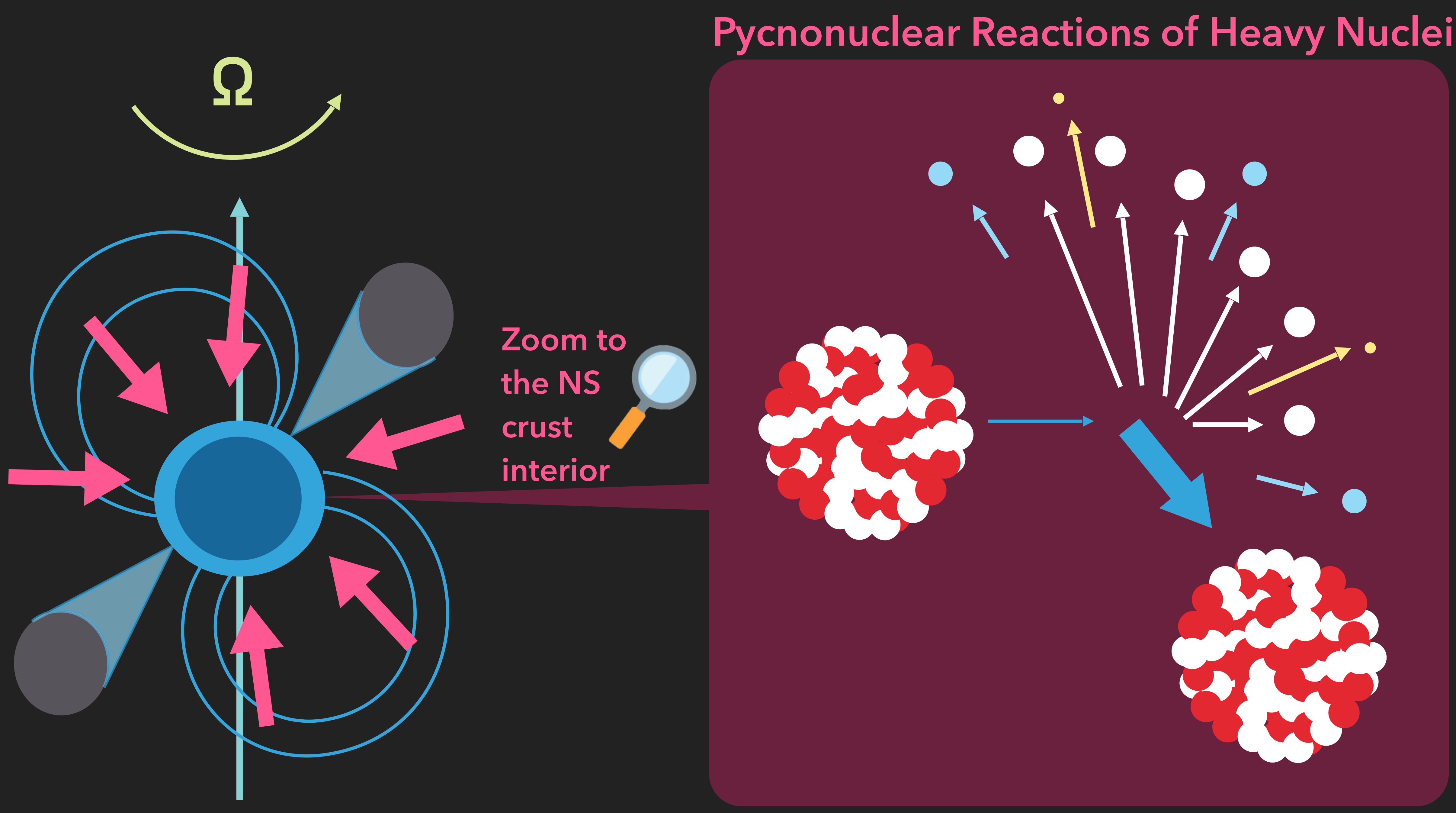
We want to characterize!

VORTEX CREEP



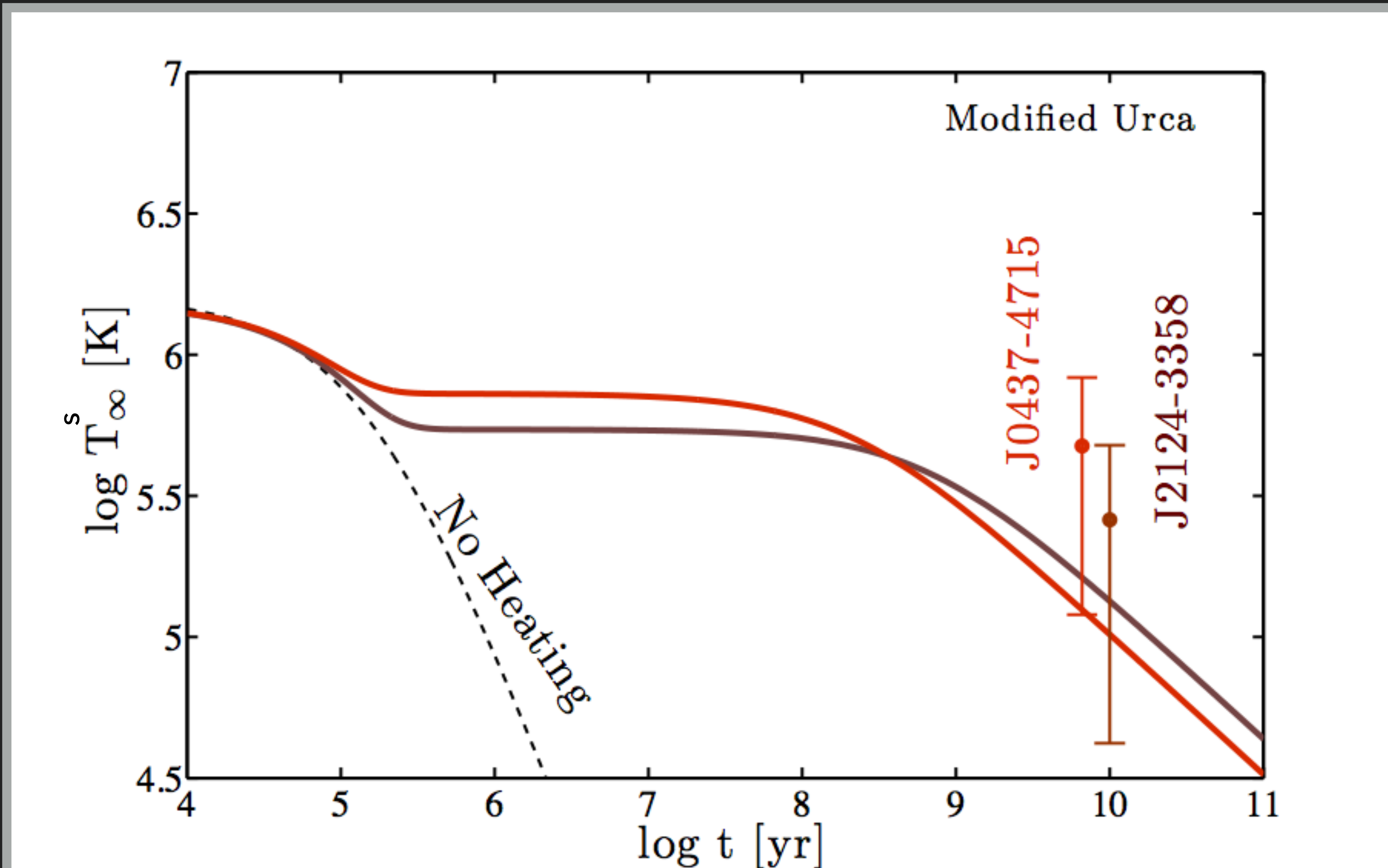
CRUSTAL HEATING

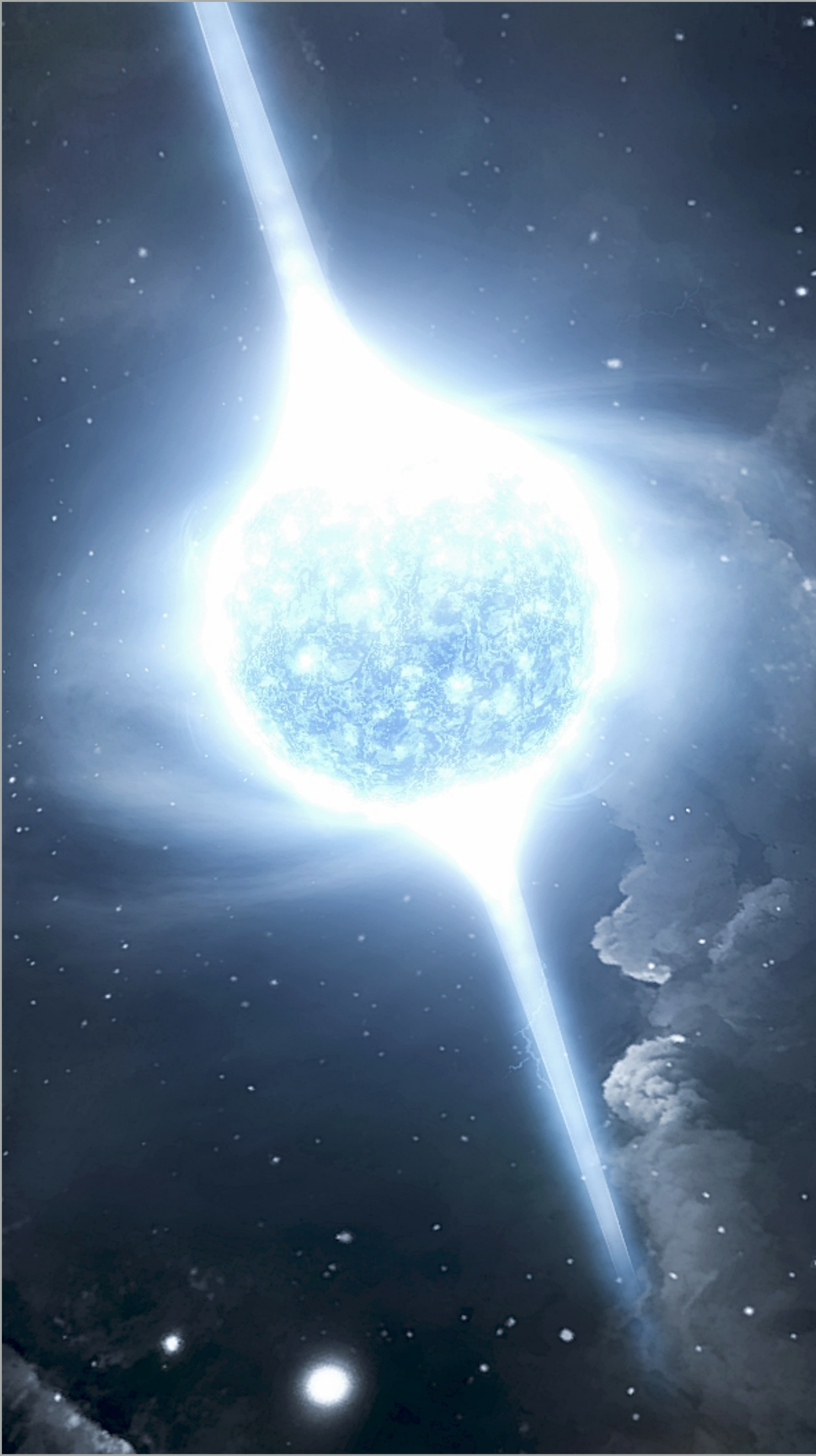
Gusakov, Kantor & Reisenegger (2015)



This increases the nuclear imbalances and produce pynocuclear reactions in the deep layers of the crust

CRUSTAL HEATING

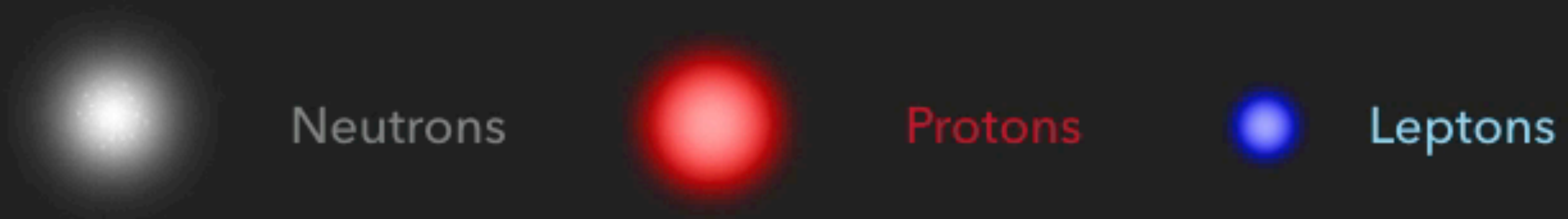




CONCLUSIONS

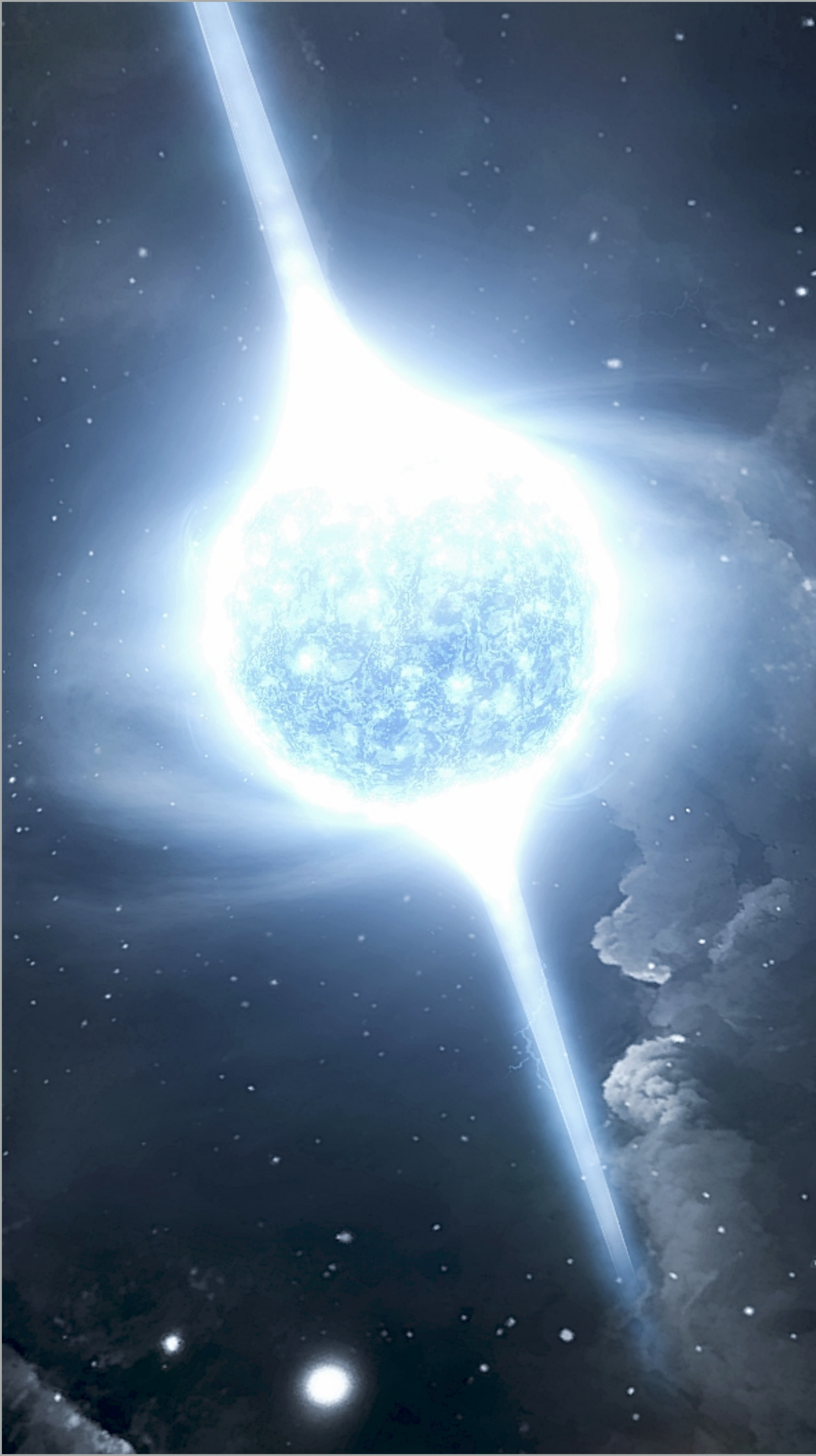
SUMMARY AND CONCLUSIONS

Temperatures are compatible with NSs cores composed by



SUMMARY AND CONCLUSIONS

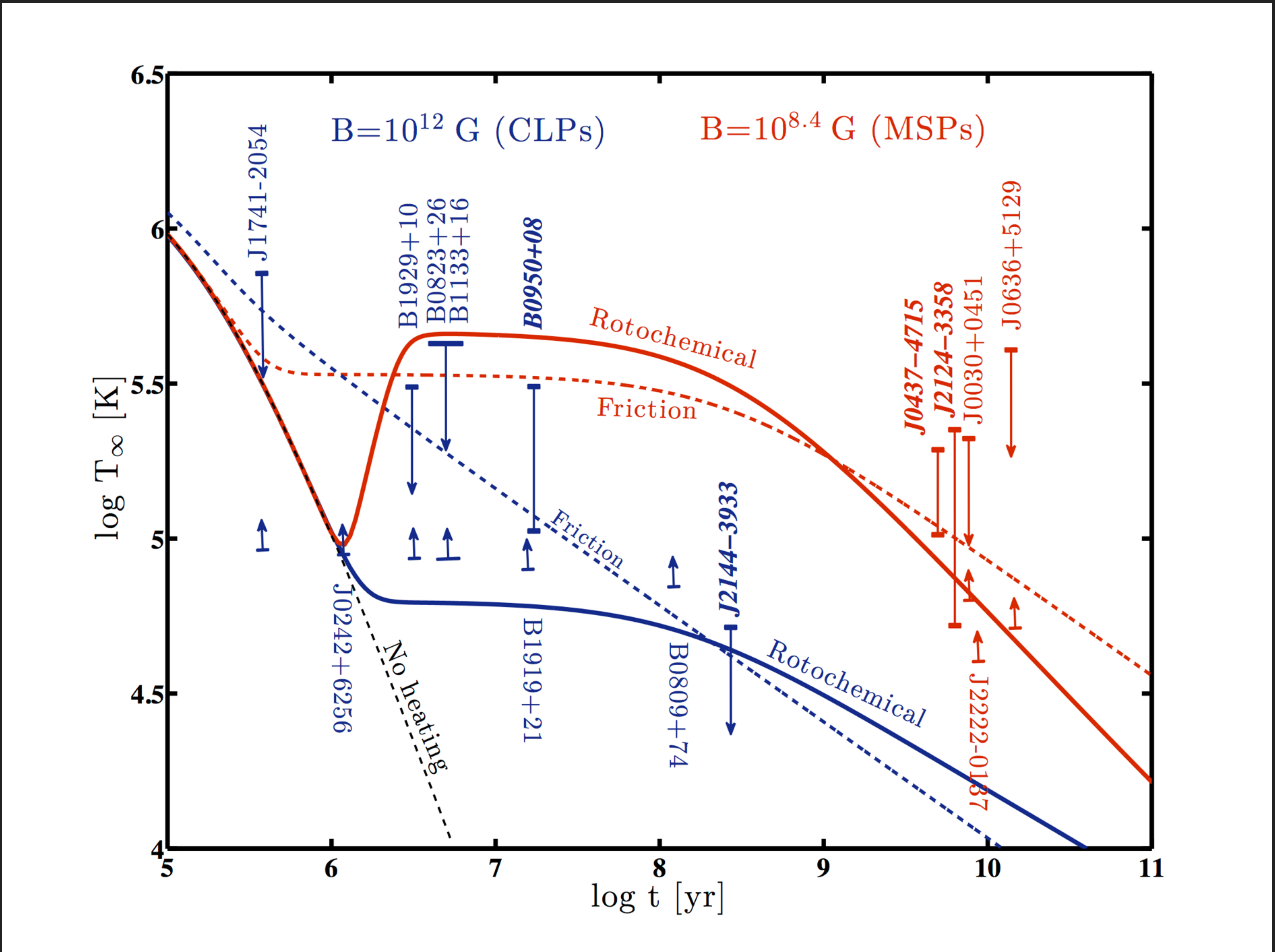
Mechanisms	
Rotochemical Heating Non superfluid	?
Rotochemical Heating Superfluid Neutrons	✓
Vortex Creep	✓
Crustal heating	✓
All of them acting at the same time	✓

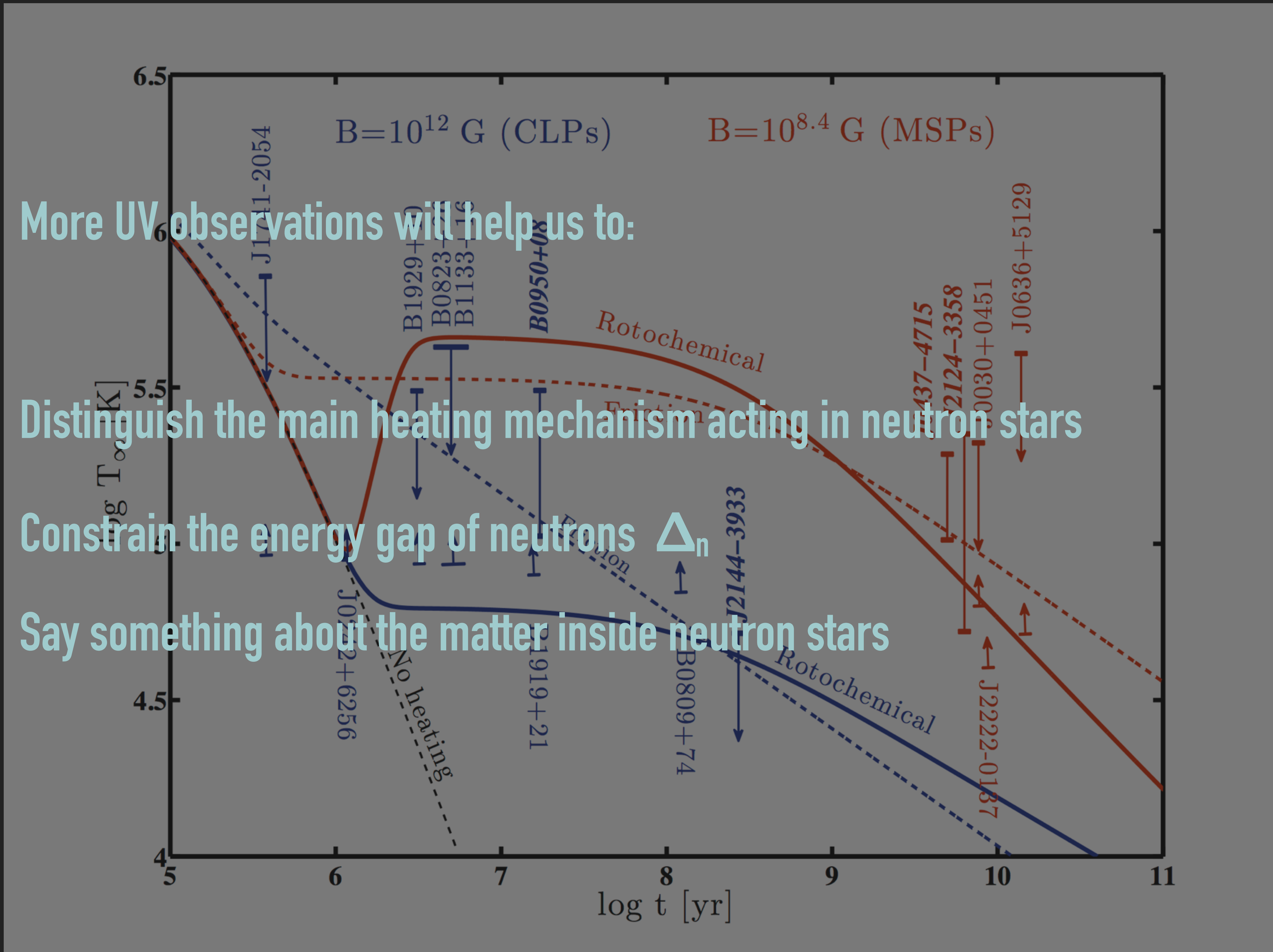


FURTHER WORK

WHY WE NEED MORE UV OBSERVATIONS ?

CONTRASTING NEUTRON STAR HEATING MECHANISMS WITH HUBBLE SPACE TELESCOPE OBSERVATIONS





More UV observations will help us to:

Distinguish the main heating mechanism acting in neutron stars

Constrain the energy gap of neutrons Δ_n

Say something about the matter inside neutron stars

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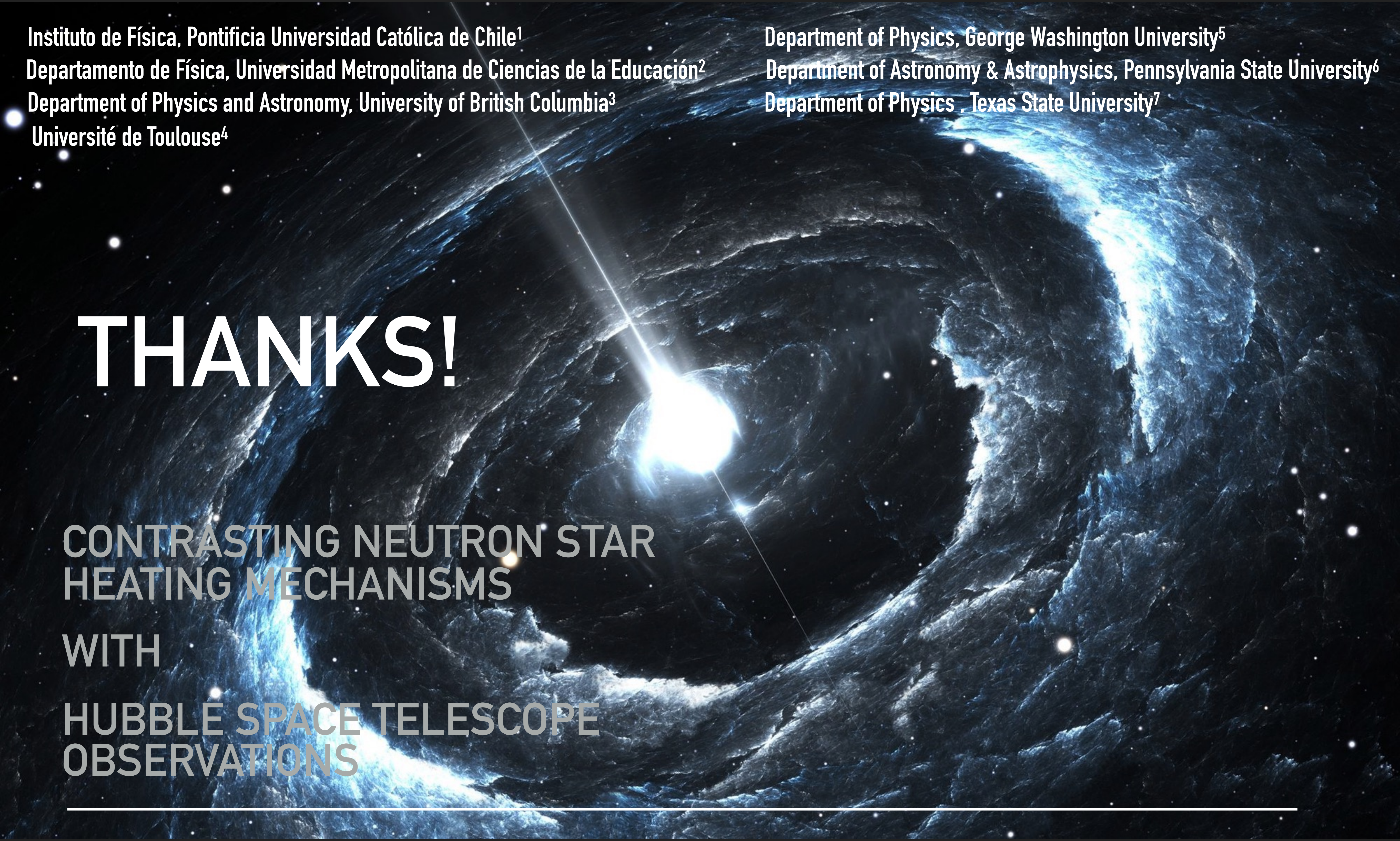

THANKS!

CONTRASTING NEUTRON STAR HEATING MECHANISMS

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