# Non-thermal emission from colliding-wind binaries

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# Investigating colliding-wind binaries

- **Shock physics**

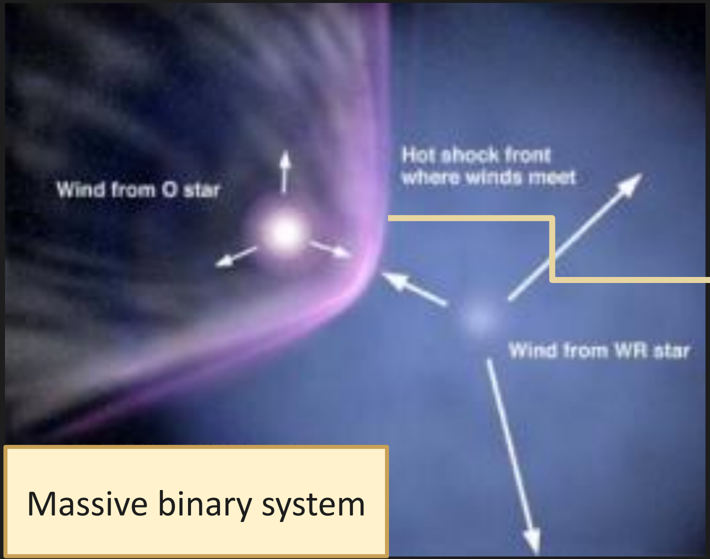
  (cooling processes, hydrodynamics...)
- **Particle acceleration**

  (acceleration efficiency, non-thermal particle content, contribution of CWBs to the observed cosmic-ray spectrum...)
- **High-energy emission**

  (potentially detectable at high energies, association with unidentified *Fermi* sources...)
- **Magnetic fields**

  (stellar surface magnetic field, magnetic field amplification mechanisms...)

# Colliding-wind binaries




Massive binary system

Wind collision region → Kinetic to internal energy

Kinetic to internal energy → Thermal emission → "Soft" X-R ($\varepsilon < 10$ keV)

Kinetic to internal energy → Non-thermal emission → Radio (cm), hard X-R, $\gamma$-R

$\dot{M} \sim 10^{-6}\ \mathrm{M_\odot\ yr^{-1}}$

$v_\infty \sim 1000\ \mathrm{km\ s^{-1}}$

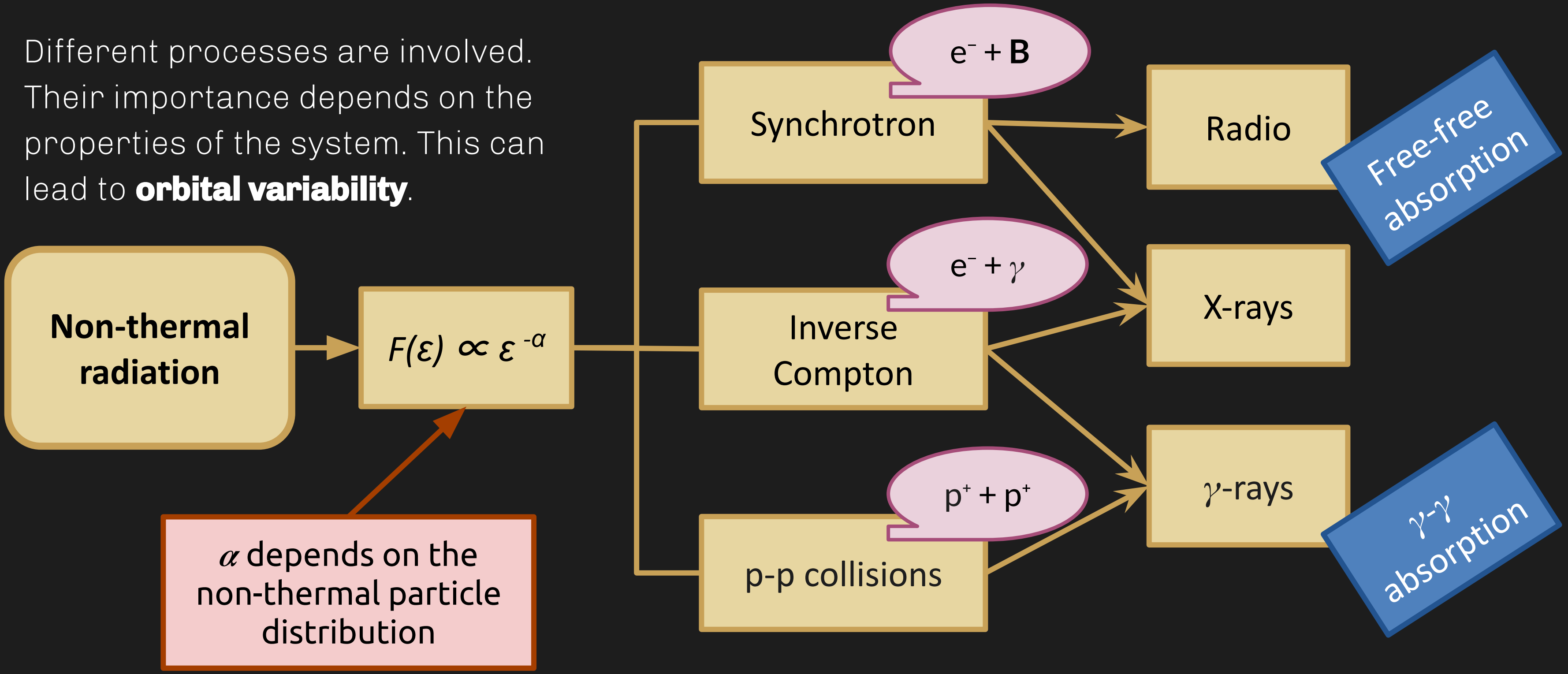
⇩

$P_{\rm kin} \sim 10^{36}\ \mathrm{erg\ s^{-1}}$

$E \sim 10^{50}\ \mathrm{erg}$

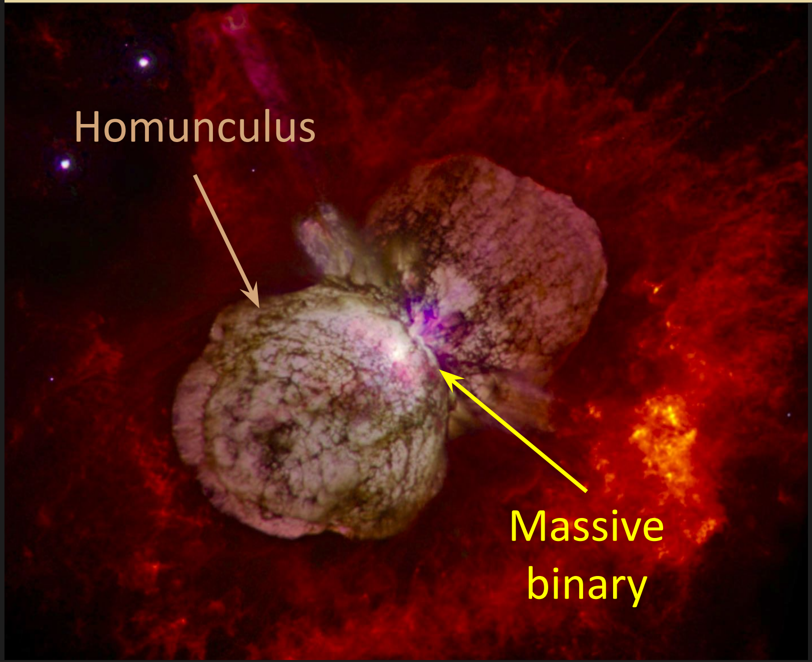
# Non-thermal emission

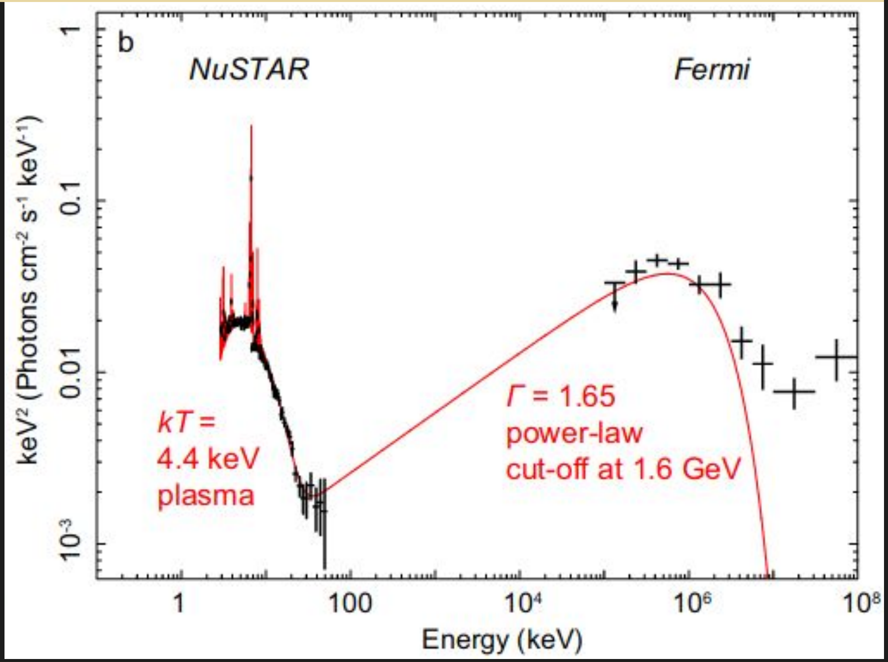
Different processes are involved. Their importance depends on the properties of the system. This can lead to **orbital variability**.



# A very special CWB

The exceptional system **$\eta$-Carinae** drives **the strongest colliding wind shock**. Non-thermal hard X-rays detected near periastron (Hamaguchi+2018). The first CWB to be detected in $\gamma$-rays: HE emission modulated with the orbital period (Martí-Devesa+2021), VHE emission also detected (H.E.S.S. Coll. 2020).




(Hamaguchi+2018, Nature Ast.)

# Physical processes

In order to derive physical constraints from the observed non-thermal emission we must take into account:

- How relativistic particles are **accelerated and transported**
- How these particles **emit** radiation
- How this emission is affected by **absorption** processes

↓

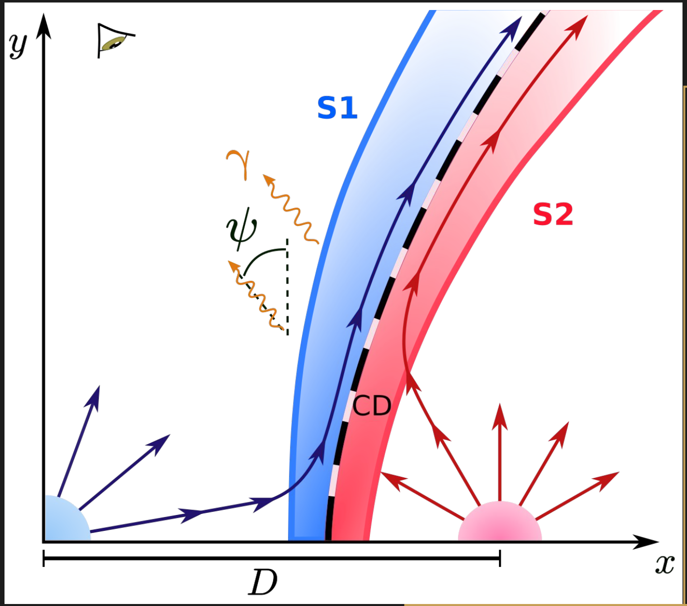
**Theoretical models**

# Extended emitter model

1. Wind-collision region = axisymmetric surface.
2. Adiabatic shock + laminar flow (x2).

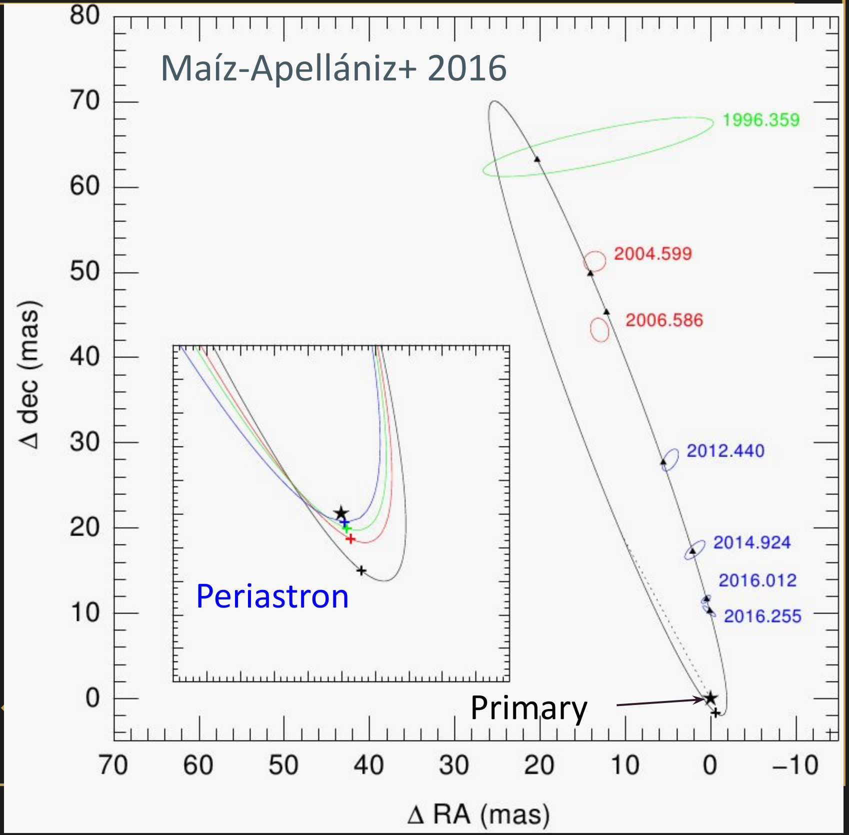
   Semi-analytical prescriptions of the shocked fluid.
3. Relativistic particles accelerated at the shocks as $Q(E) \propto E^{-p}$ , with $p$ given by radio observations.
4. Compute the non-thermal emission (sync., IC, p-p) and absorption processes (FFA, R-T, $\gamma$-$\gamma$).
5. <u>Free parameters:</u> magnetic field intensity ($B$) and fraction of energy injected in relativistic particles ($f_{NT}$).

del Palacio+2016



# The system HD 93129A

- ★ HD 93129A is one of the most extreme and massive CWBs in our Galaxy.
- ★ Long period orbit: $P \sim 100$ yr, $a_p \sim 10$ AU.
- ★ Non-thermal emission from the wind-collision region resolved in radio (Benaglia+ 2015).
- ★ Possible non-thermal source at high energies (hard X-rays/$\gamma$-rays)

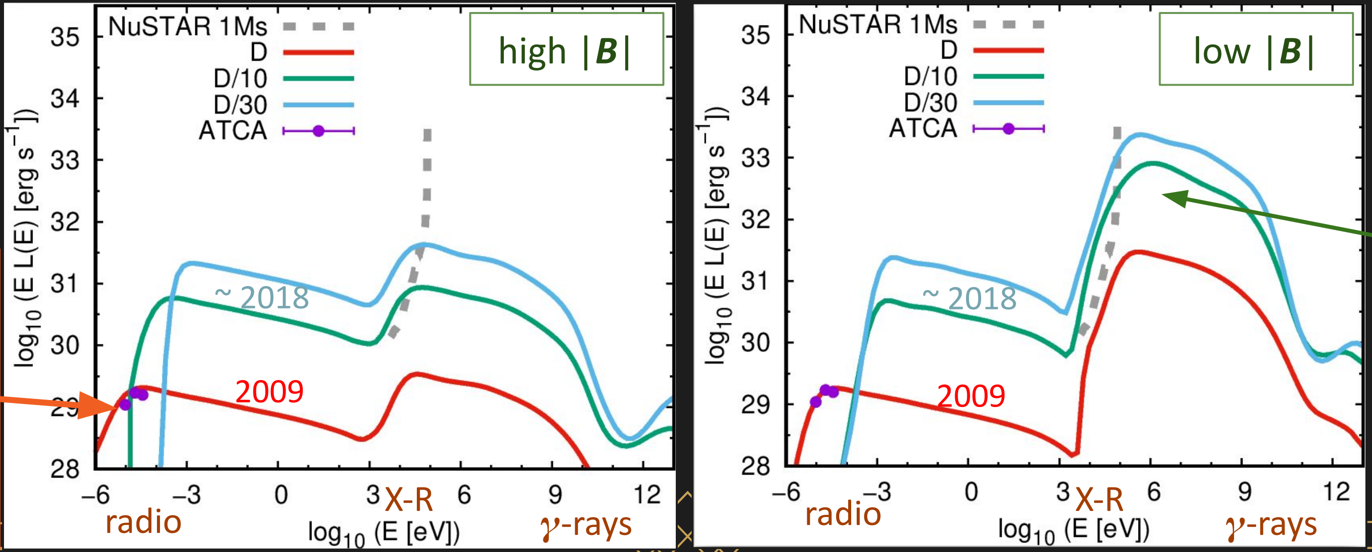


# The system HD 93129A

Model degeneracy: high $B$ and low $f_{NT}$, or viceversa? Radio data is not enough

Goal: Break the degeneracy by studying the high-energy IC component

Fit to the radio data from 2009

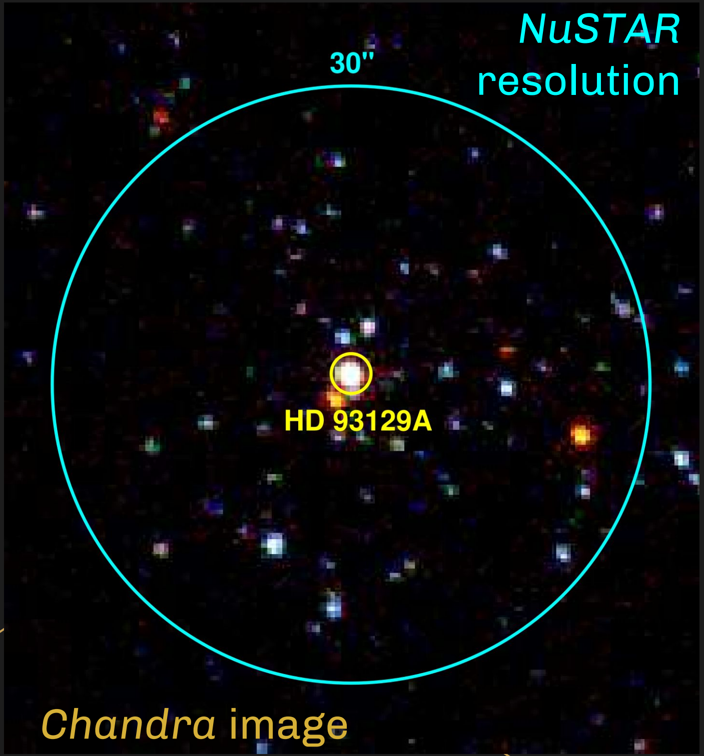



del Palacio+2016

Detectable high-energy emission close to periastron?

# The system HD 93129A

- Observational campaign during 2018 periastron passage.
- The source is in a crowded field; angular resolution is an issue.
- **Quasi-simultaneous observations with *Chandra* and *NuSTAR*.**
- Non-detection of $\gamma$-rays with *AGILE*.



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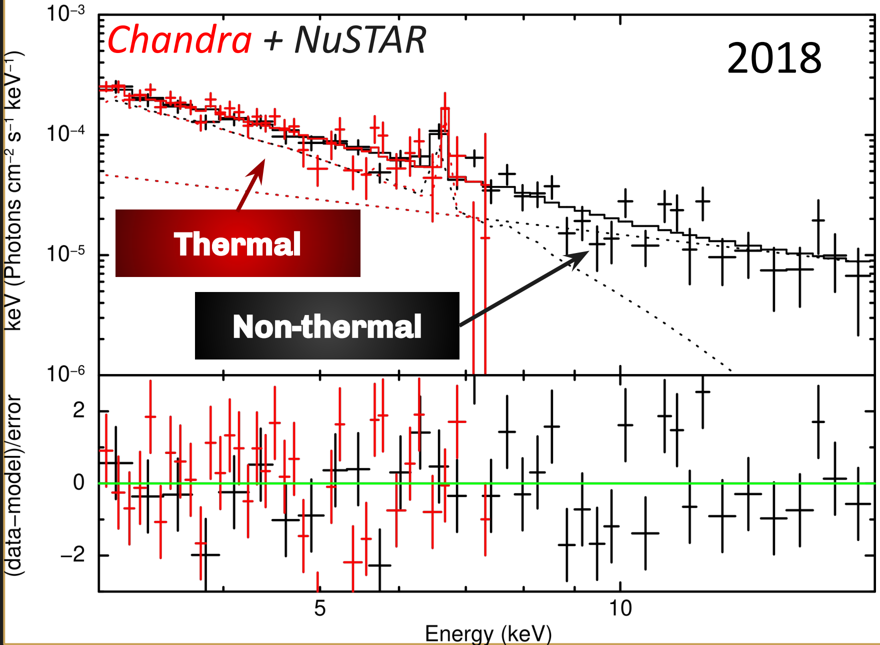
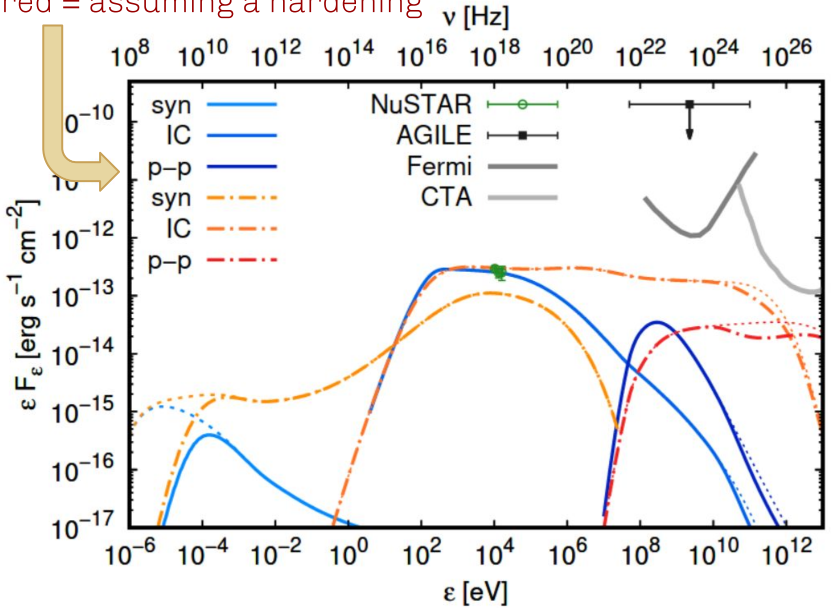



blue = soft spectrum (radio)
red = assuming a hardening

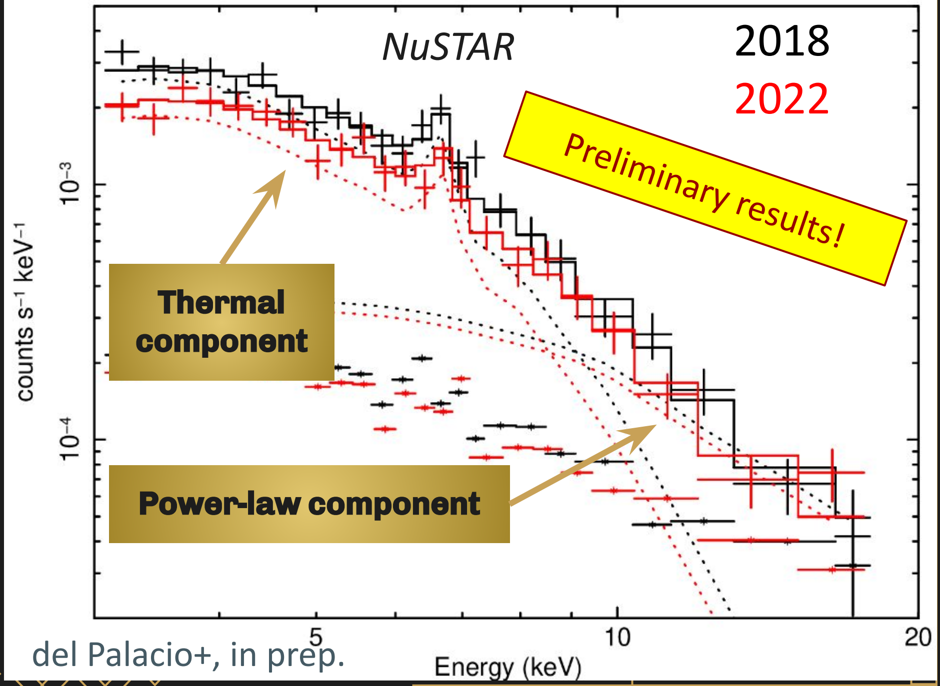
del Palacio+2020




The 2018 X-ray observations allowed us to constrain $B$ and $f_{NT}$ → we estimated $f_{NT,e}$ ~ 0.6% and $B$ ~ 0.5 G

# The system HD 93129A

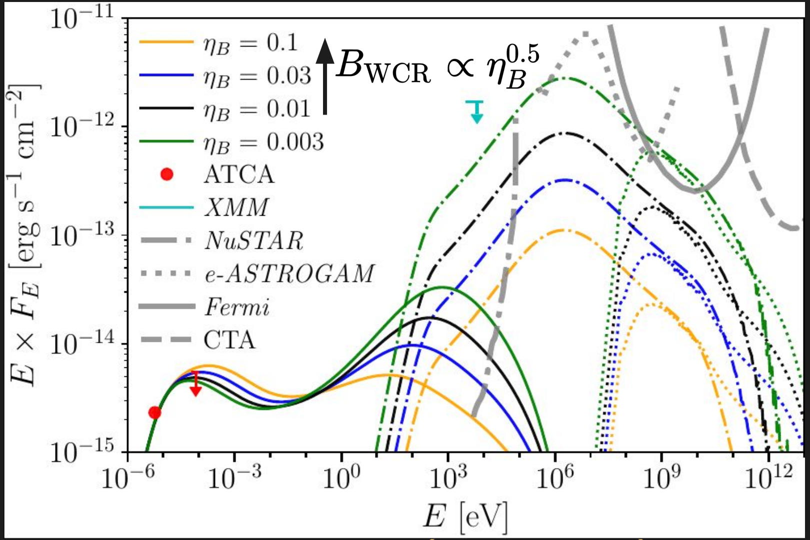
- Follow-up campaign during 2022 to monitor the post-periastron evolution (in progress).
- Quasi-simultaneous observations with *Chandra* and *NuSTAR.*
- Hint of a small decrease in the hard X-ray luminosity in 2022 (orbital variability?).




del Palacio+, in prep.

# The system *Apep*

del Palacio+2022




Using our non-thermal emission model we could:

- Estimate the projection angle on the sky ($\psi$ ≅ 85°).
- Better constrain the wind mass-loss rates.
- Constrain the magnetic field intensity and the fraction of power converted to non-thermal particles

$$B_{\rm WCR} \sim 0.08 - 0.4\ {\rm G}$$

$$f_{\rm NT} \approx 0.5\% - 13\%$$

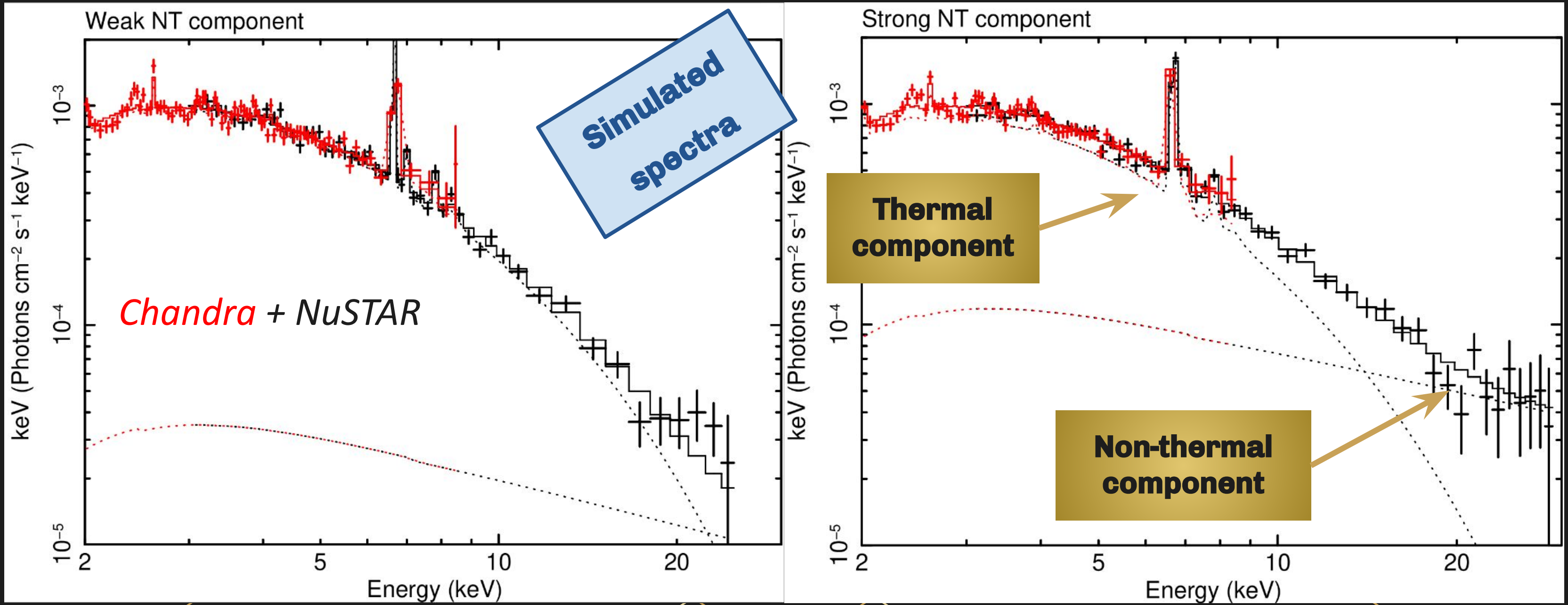
- Estimate the high-energy emission from the source → **possibility of detection at hard X-rays**

The electrons that produce the synchrotron emission also produce IC emission

Higher B = less emission at high energies

# The system *Apep*

*NuSTAR* observations to try to detect the IC emission in hard X-rays (soon, in 2022)




The non-thermal component can overcome the thermal component at $\varepsilon$ > 13-20 keV

# Conclusions

- **Radio observations are insufficient** to characterise the non-thermal emission from CWBs. Great **synergy with observations at high-energies** (X-rays and $\gamma$-rays).
- Multi-wavelength observations combined with detailed **theoretical modelling** can shed light on the **properties of CWBs** (magnetic fields, particle-acceleration efficiency…).
- **CWBs are faint high-energy sources**, with very few detections. We need observational campaigns focused on promising sources during carefully selected epochs.

Thank you

# Transport equation

## Stationary and inhomogeneous structure made up of multiple 1-D emitters

For a given 1-D linear emitter we obtain *N(E)* at each position:

- First cell ( $j = i_{min}$ ):

$$N_0(E, i_{\rm min}) \approx Q(E, i_{\rm min})\, \min(t_{\rm cell}, t_{\rm cool})$$

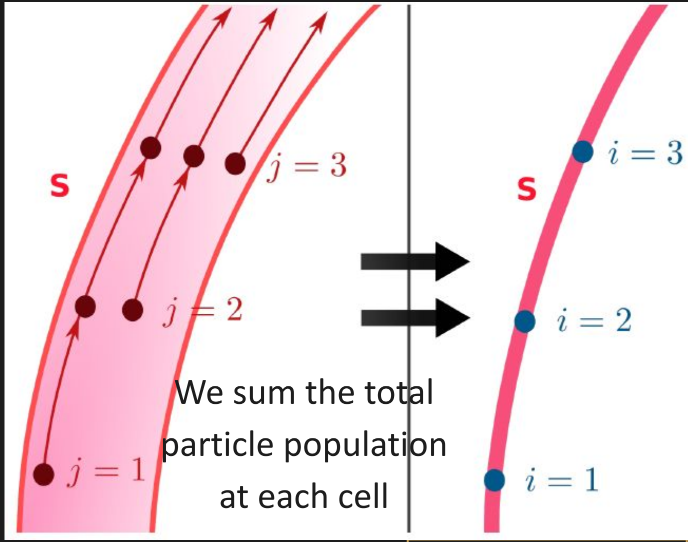
$$L_{\rm NT}(i_{\rm min}) = f_{\rm NT} L_{{\rm w},\perp}(i_{\rm min})$$

- Next cells ( $j > i_{min}$ ):

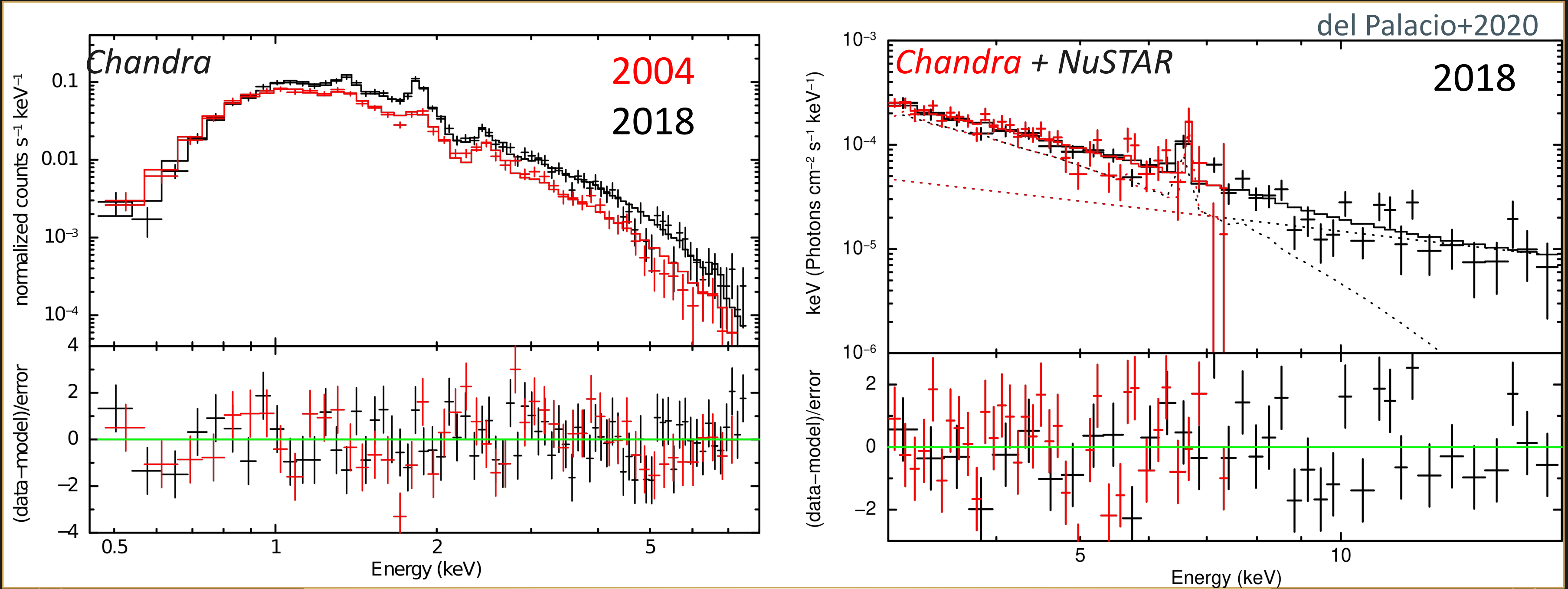
$$N(E', i+1) = N(E, i) \frac{|\dot{E}(E, i+1)|}{|\dot{E}(E', i+1)|} \frac{t_{\rm cell}(i+1)}{t_{\rm cell}(i)}$$

del Palacio+2022

del Palacio+2016



# CWB - HD 93129A

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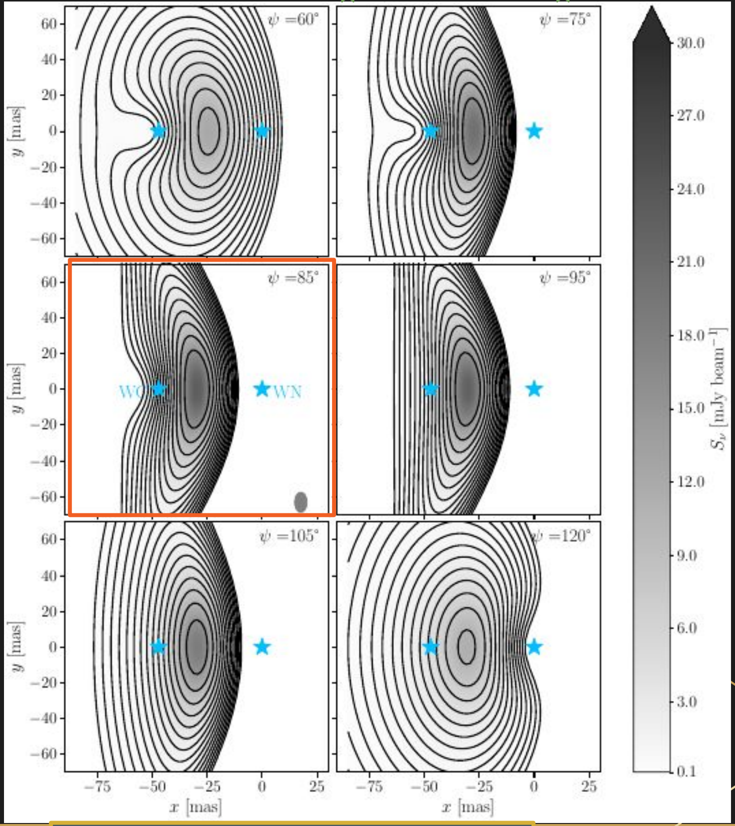
# The system *Apep*

del Palacio+2022




Synthetic emission maps

Using our non-thermal emission model we could:

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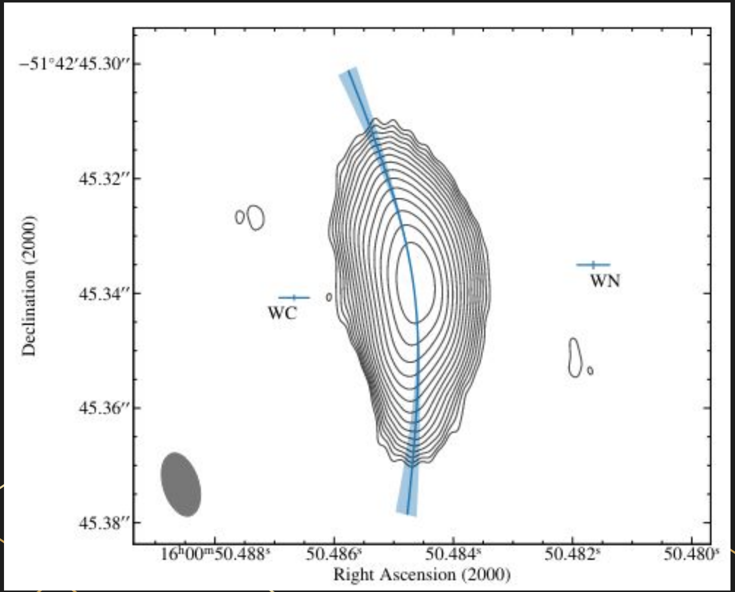

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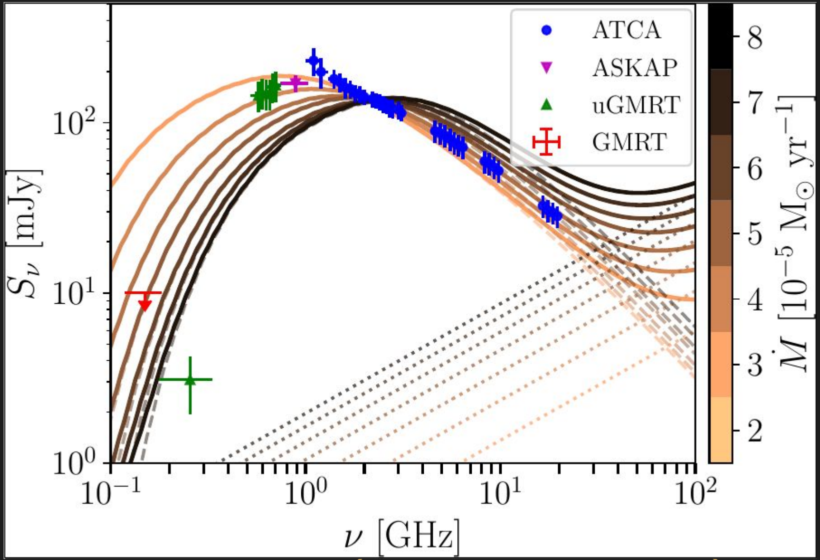
del Palacio+2022

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