UNIVERSITÀ DI TRENTO

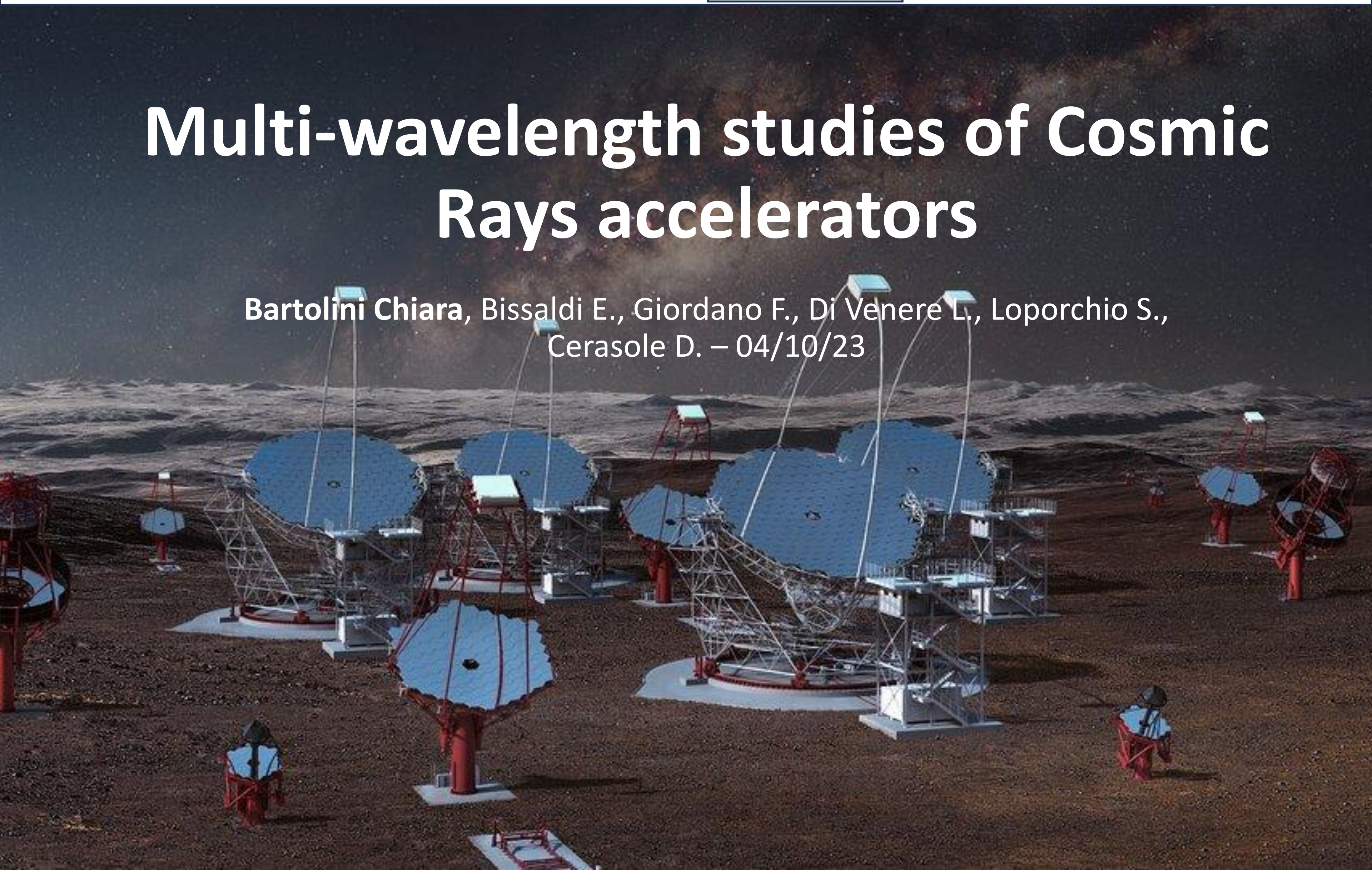
INFN BARI
Istituto Nazionale di Fisica Nucleare
Sezione di Bari

Fermi Gamma-ray Space Telescope

cta cherenkov telescope array

Multi-wavelength studies of Cosmic Rays accelerators

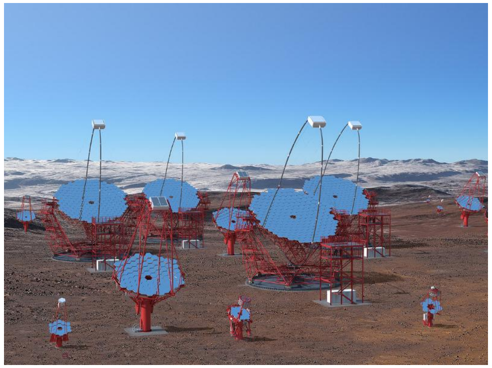
Bartolini Chiara, Bissaldi E., Giordano F., Di Venere L., Loporchio S., Cerasole D. – 04/10/23



Multi-wavelength and multi-messenger study goals

- Multi-wavelength and multi-messenger study of cosmic ray accelerators:
  - Galactic sources
    - Supernovae Remnants (SNRs)
  - Extragalactic sources
    - Active Galactic Nuclei (AGN)
    - Gamma Ray Bursts (GRB)
- How to do this:
  - Cherenkov Telescope Array (CTA)
    - Simulations of SNRs;
    - Comparative study of CTA middle-size telescopes array performances
  - MeV – GeV energy band with Fermi Telescope
    - Complementary study of SNRs;
    - Study of the flaring activity of Blazars;
    - Neutrino event follow-up search.

https://fermi.gsfc.nasa.gov

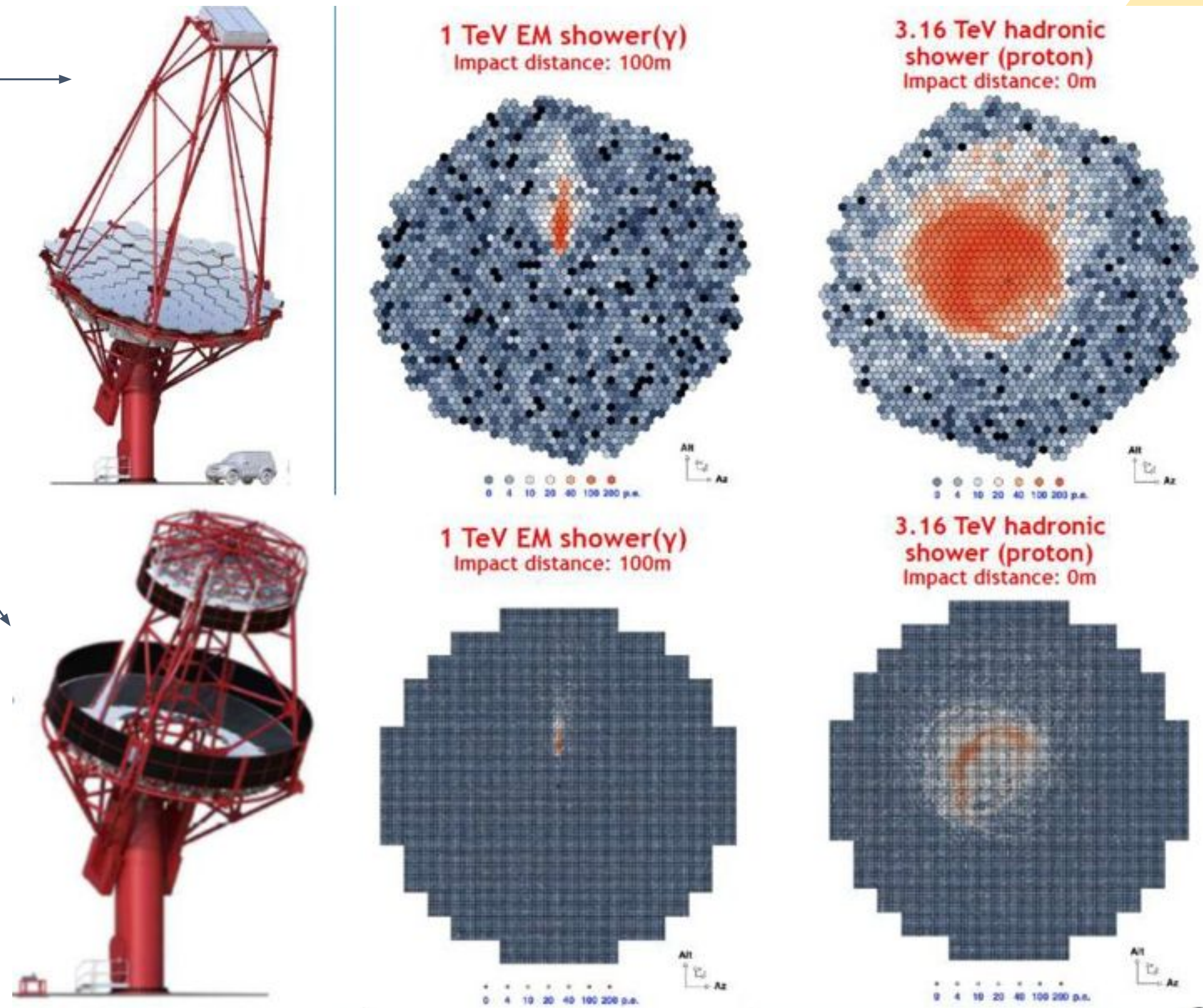


https://www.cta-observatory.org/

Single and dual mirror CTA Middle-Sized Telescopes

- MST Single Mirror
  Davies-Cotton
  ~2k PMTs

- MST Dual Mirror Schwarzschild-
  Couder
  ~12k SiPMs

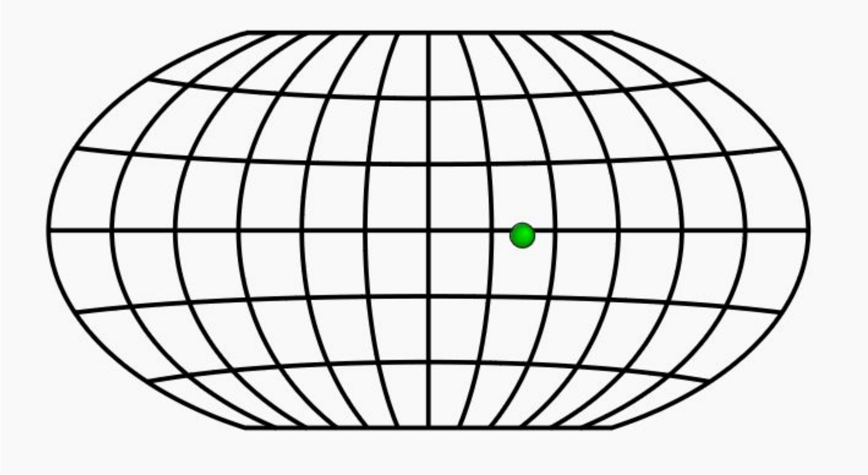


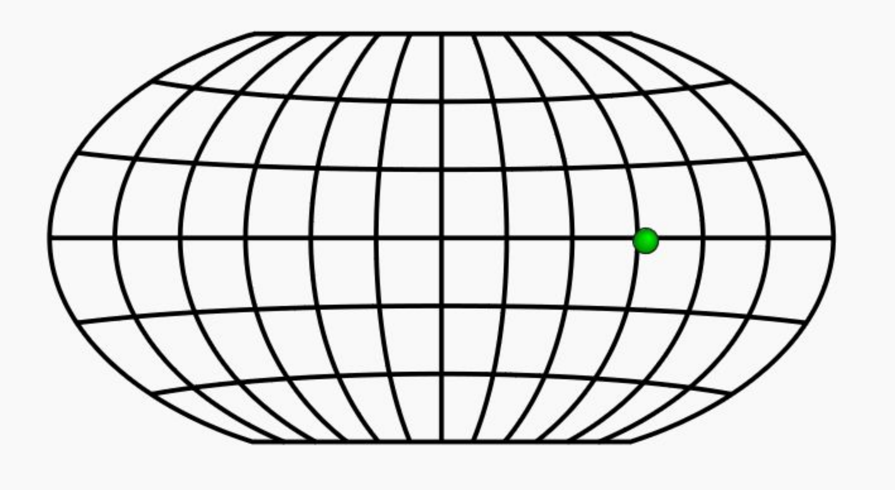
Main advantages:

- Superior angular resolution over a wide (~8°) field of view, especially for off-axis observations;
- Better gamma-hadron separation thanks to high resolution camera.

Set up of the simulations

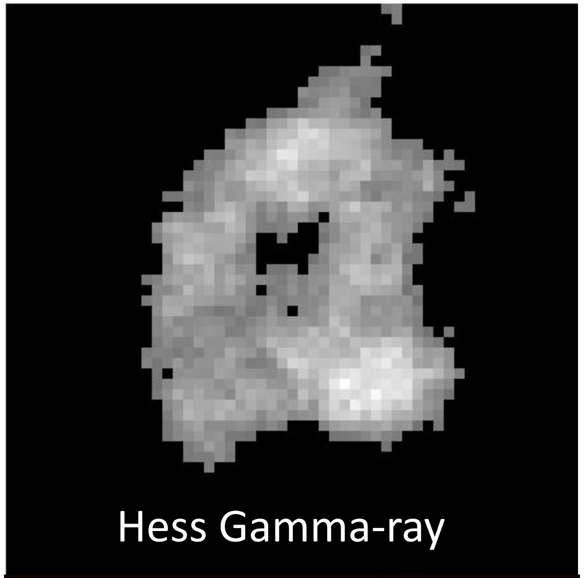
- **2 SNRs**:
  - RCW 86:
    - RA 220.72,
    - DEC -62.43,
    - Radius of 0.3 degrees,
    - Spectral index of –1.59;
  - RX J0852.0-4622:
    - RA 133.00,
    - DEC -46.37,
    - Radius of 1 degrees,
    - Spectra index of –1.79;

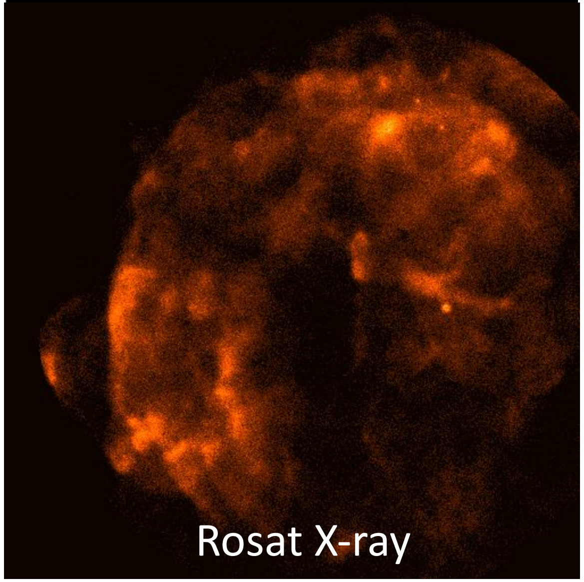




Set up of the simulations

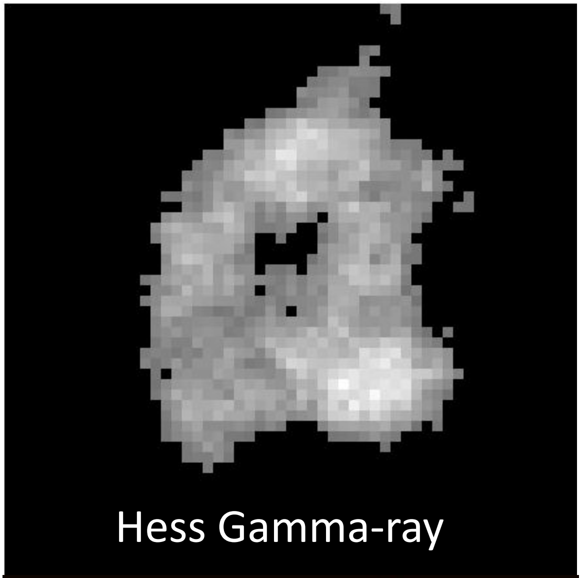
- **2 different fluxes:**
    - Real flux (10.8% of Crab's flux) for RCW86;
    - Real flux (103.2% of Crab's flux) for RXJ0852.0-4622;
- **6 Spatial models:**
    - Diffuse Source;
    - Point Source;
    - Radial Disk;
    - Radial Gaussian;
    - Radial Ring;
    - Radial Shell.

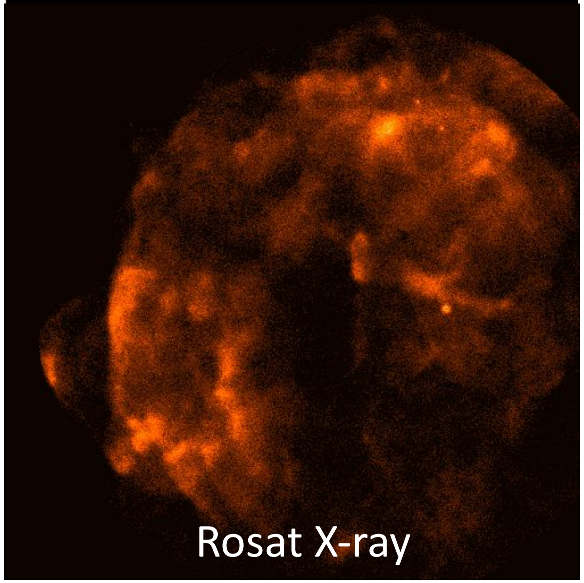




Set up of the simulations

- **4 CTA configurations:**
  - F4 - 14 MST
  - F5 - 14 SCT
  - C0 - 25 MST
  - M2 - 14 MST + 11 SCT
- Simulations include both CTA instrumental and galactic diffuse background;
- Only the coordinates were left fix ed;
- 20 hours of observation for both sources;
- Unbinned analysis.





Set up of the simulations

- Main goals:
  - Comparison of the Test Statistic for detection (TS) of the diffuse source after 10 hours of observation;
  - Calculate the Akaike Information Criterion (AIC) parameter for every model:

$$AIC = 2 \times \text{Degree Of Freedom} + 2 \times \text{LogLikelihood}$$

  - See which spatial model is the best using ΔAIC:

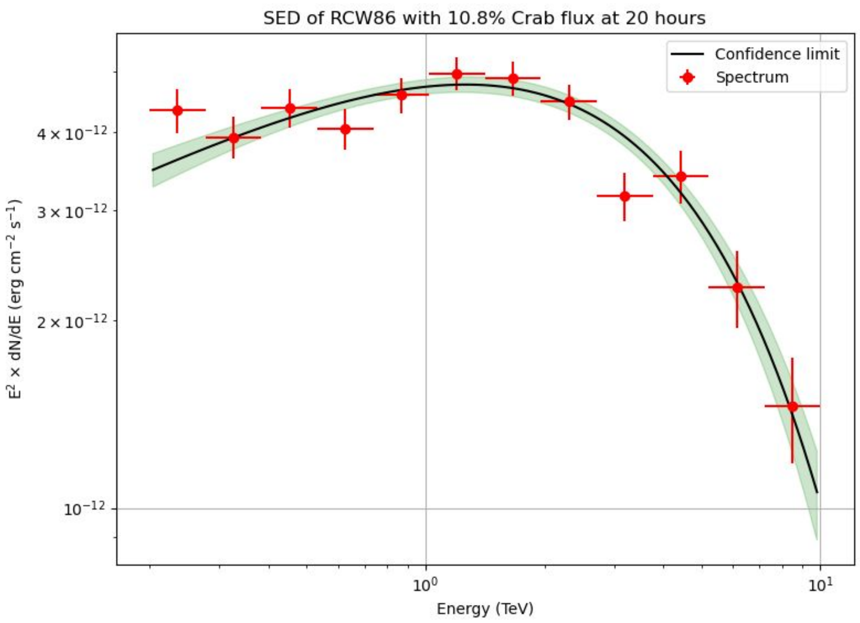
$$\Delta AIC = AIC_{model} - AIC_{min}$$

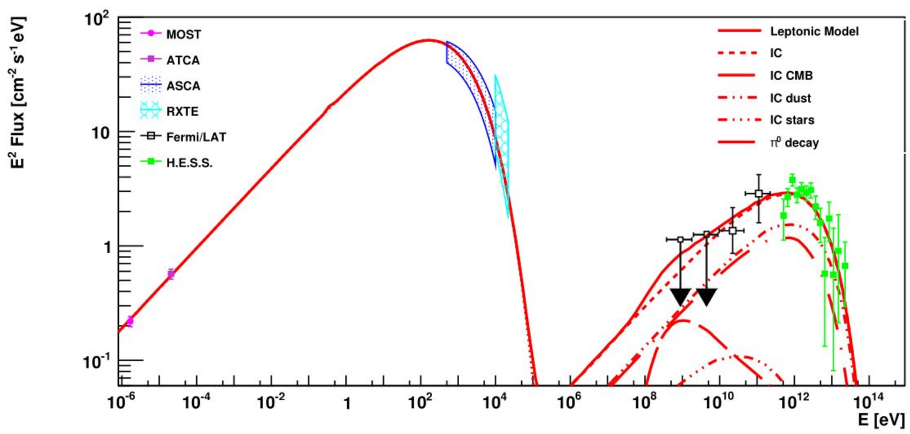
AIC_{model} : AIC of one of the models at *i* hours;
AIC_{min} : smallest AIC between all the models at *i* hours
i = 2.0, 4.0, 6.0, 8.0, 10.0...20.0

Spatial Models	Template	Point Source	Radial Disk	Radial Gaussian	Radial Ring	Radial Shell
DOF	3	3	4	4	5	5

SED of RCW86

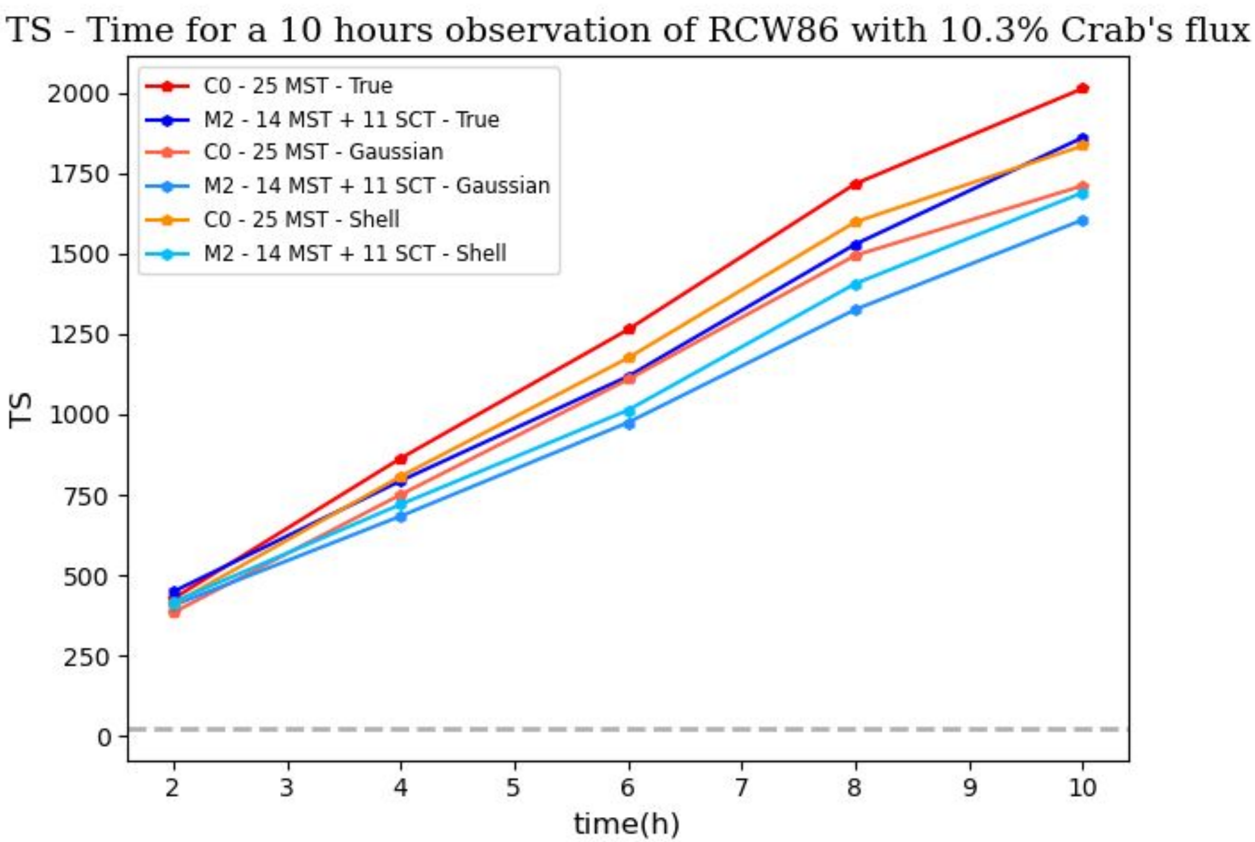
- Exponantially cut-off power law;
- Energy from 0.07 to 10 TeV;
- Comparison between the SED we obtained from the analysis and that analyzed by HESS collaboration, A&A 612, A4 (2018) .



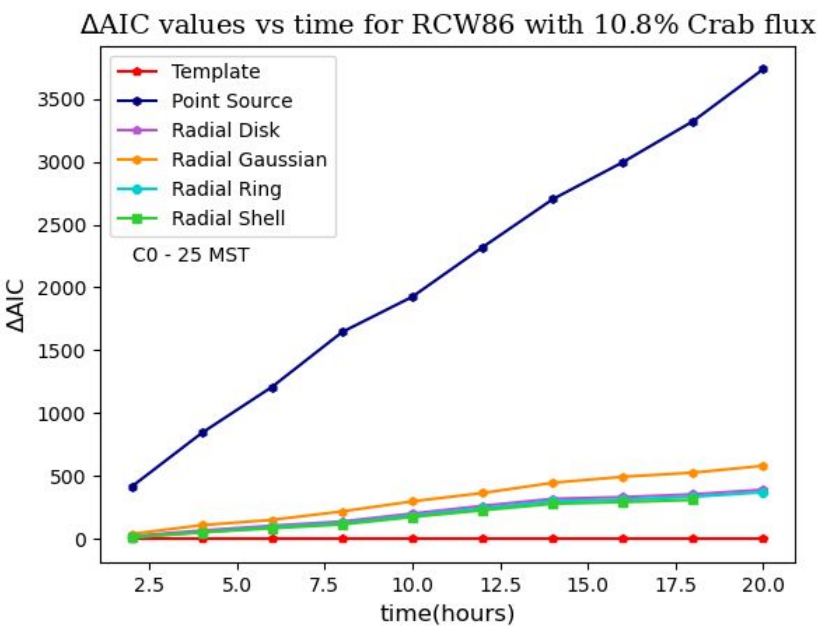


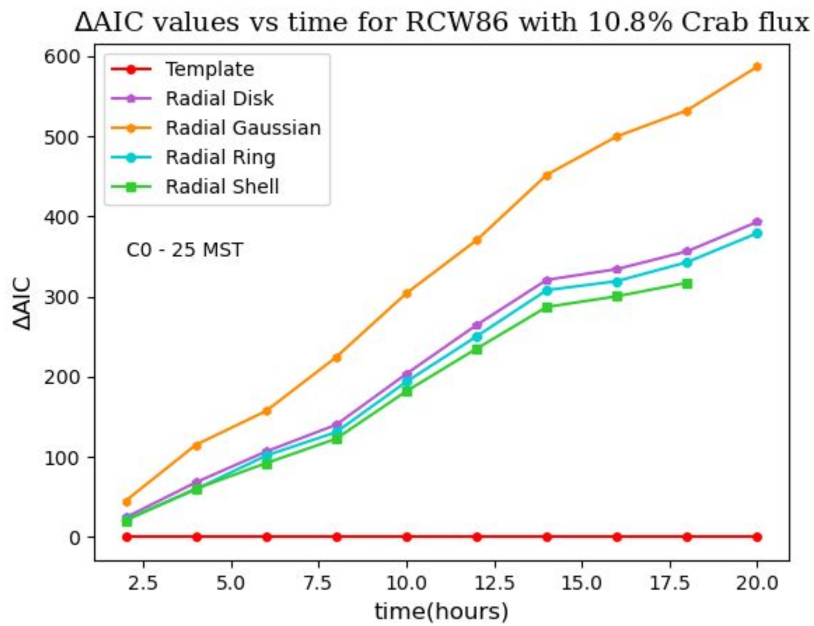
TS for RCW 86

M2 detects the source earlier than C0 at 2 hours. C0 TS values are 10% bigger than those of M2.



ΔAIC for RCW 86 (C0)





The best model of our analysis is the Diffuse Source, or Template, model. The worst is the Point Source model.

Trend without the Point Source model. SNRs are well described by Shell-like and Ring-like models. The Gaussian model is the worst as expected.

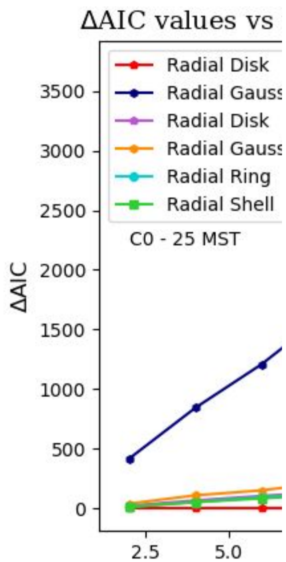
$\Delta AIC = AIC_{model} - AIC_{min}$

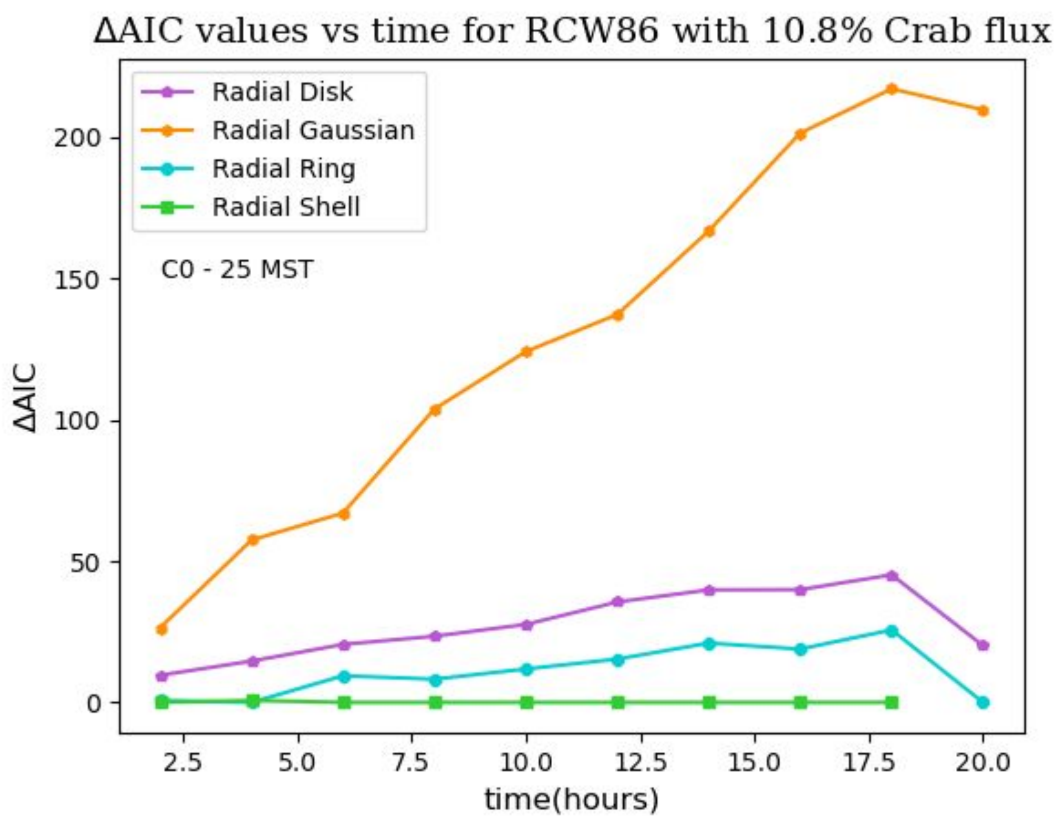
AIC_{model} : AIC of one of the models at *i* hours;

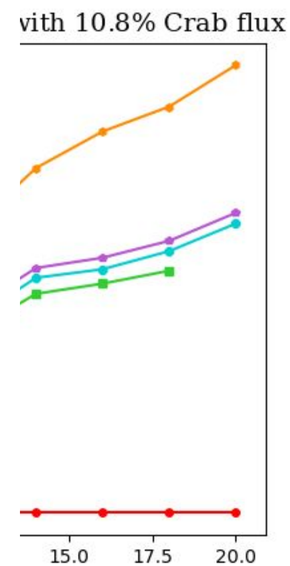
AIC_{min} : smallest AIC between all the models at *i* hours

i = 2.0, 4.0, 6.0, 8.0, 10.0...20.0

ΔAIC for RCW 86 (C0)







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Source
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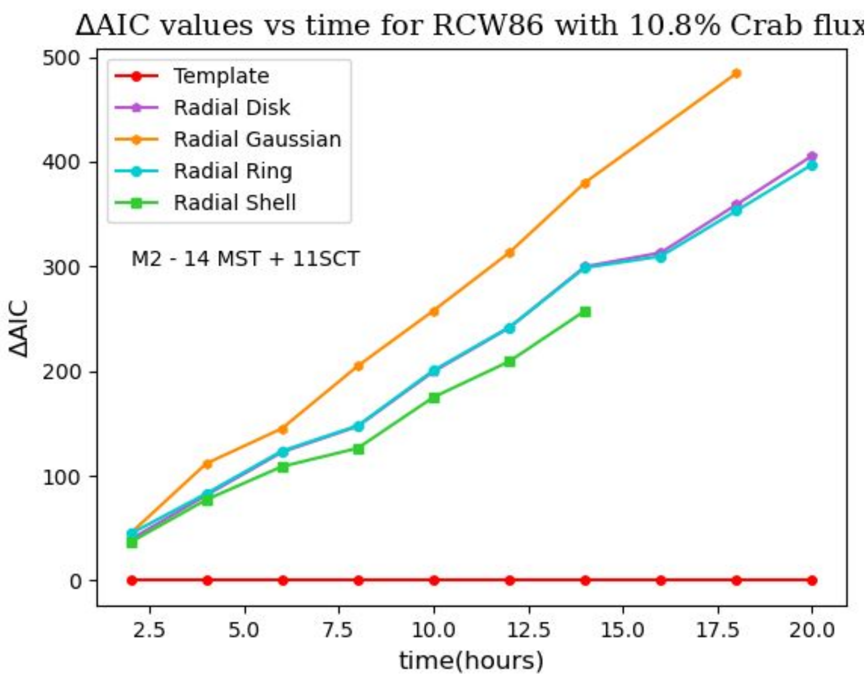
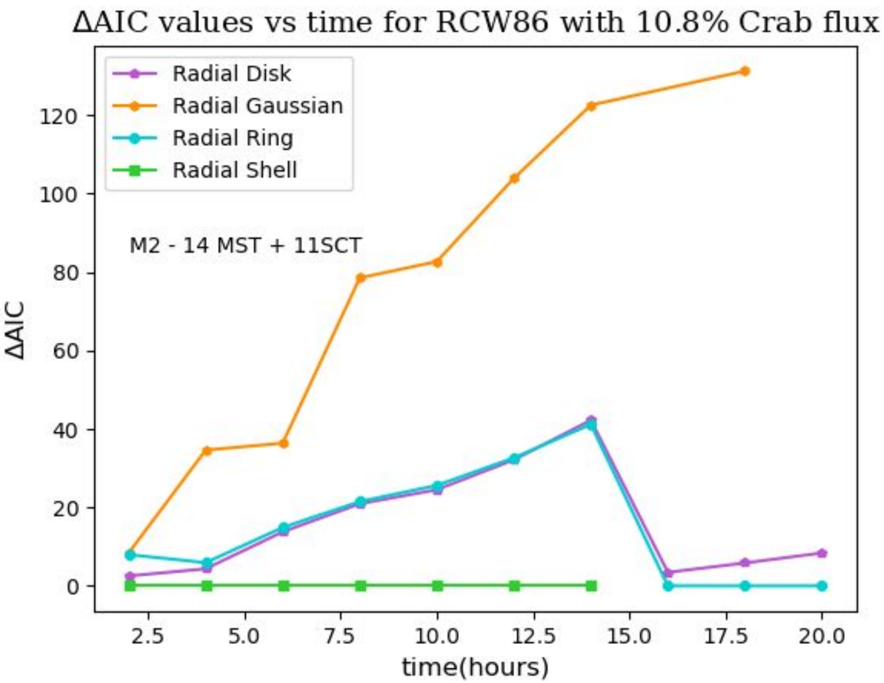
Gaussian model is the worst as expected.

$\Delta AIC = AIC_{model} - AIC_{min}$
AIC_{model} : AIC of one of the models at *i* hours;
AIC_{min} : smallest AIC between all the models at *i* hours
i = 2.0, 4.0, 6.0, 8.0, 10.0...20.0

ΔAIC for RCW 86 (M2)





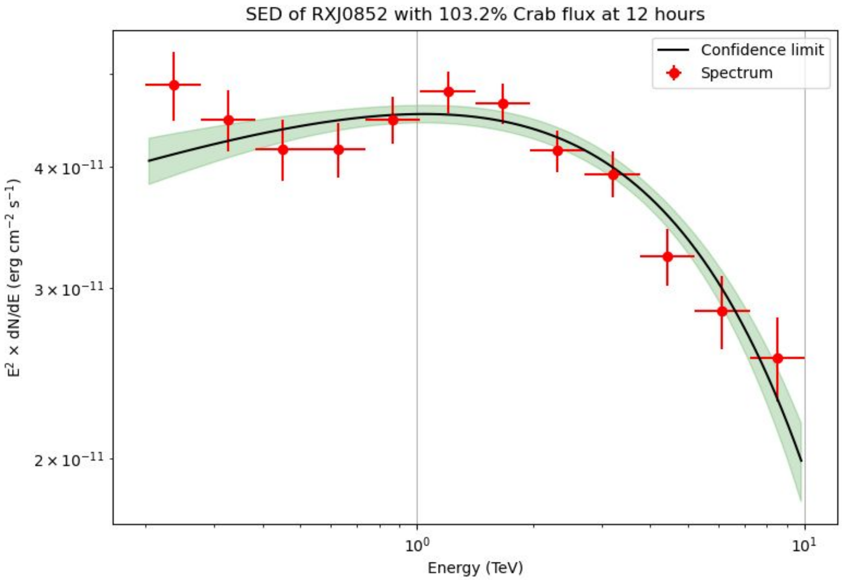
The best model of our analysis is the Diffuse Source, or Template, model.

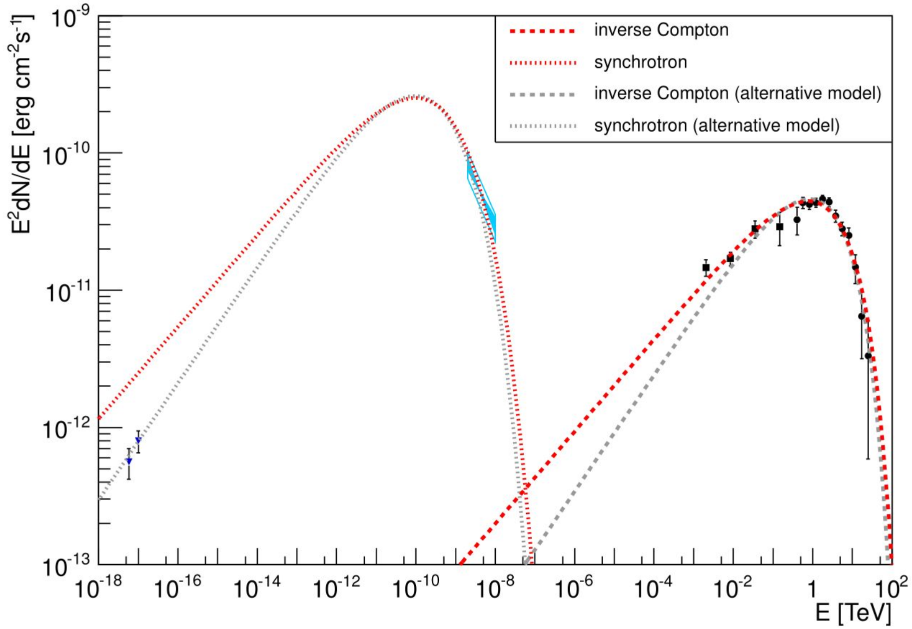
$\Delta AIC = AIC_{model} - AIC_{min}$
AIC_{model} : AIC of one of the models at *i* hours;
AIC_{min} : smallest AIC between all the models at *i* hours
i = 2.0, 4.0, 6.0, 8.0, 10.0...20.0

The Gaussian model is the worst as expected. The difference between the Gaussian and the Shell values are smaller in M2 than in C0.

SED of RX J0852.0-4622

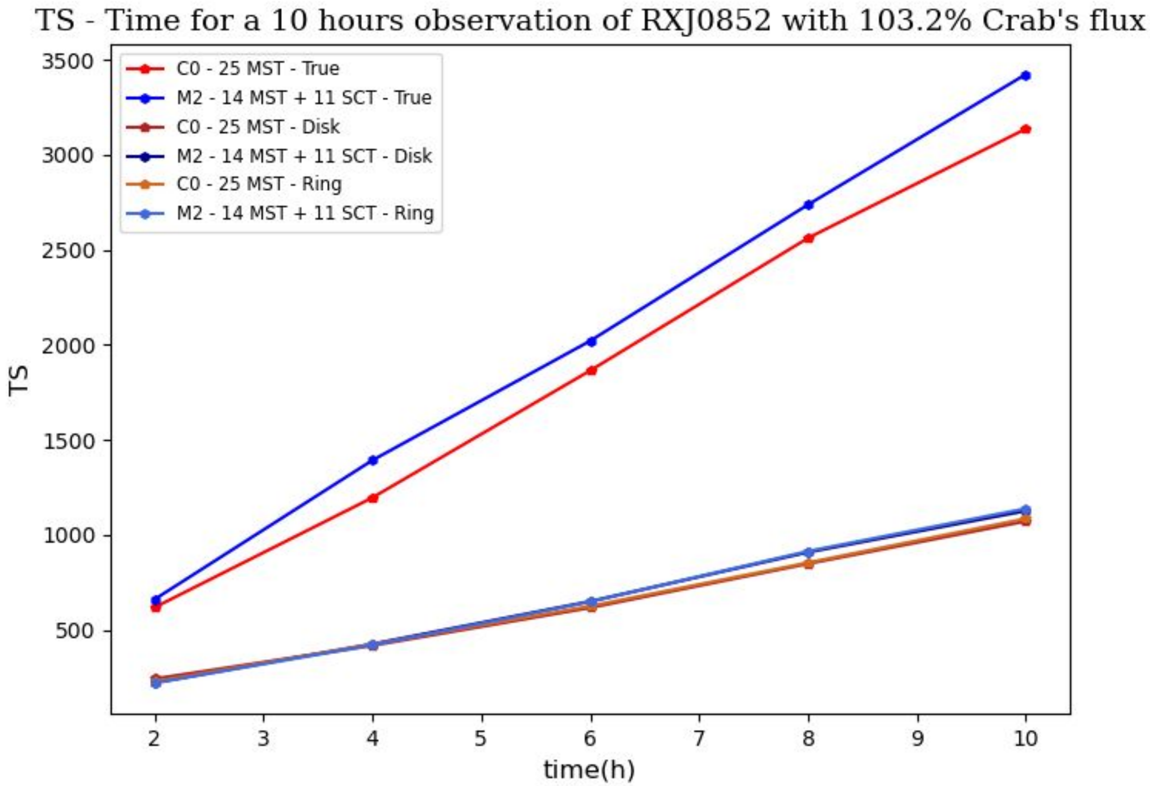
- Exponantially cut-off power law;
- Energy from 0.07 to 10 TeV;
- Comparison between the SED we obtained from our analysis and that analyzed by HESS collaboration, A&A 612, A7 (2018).



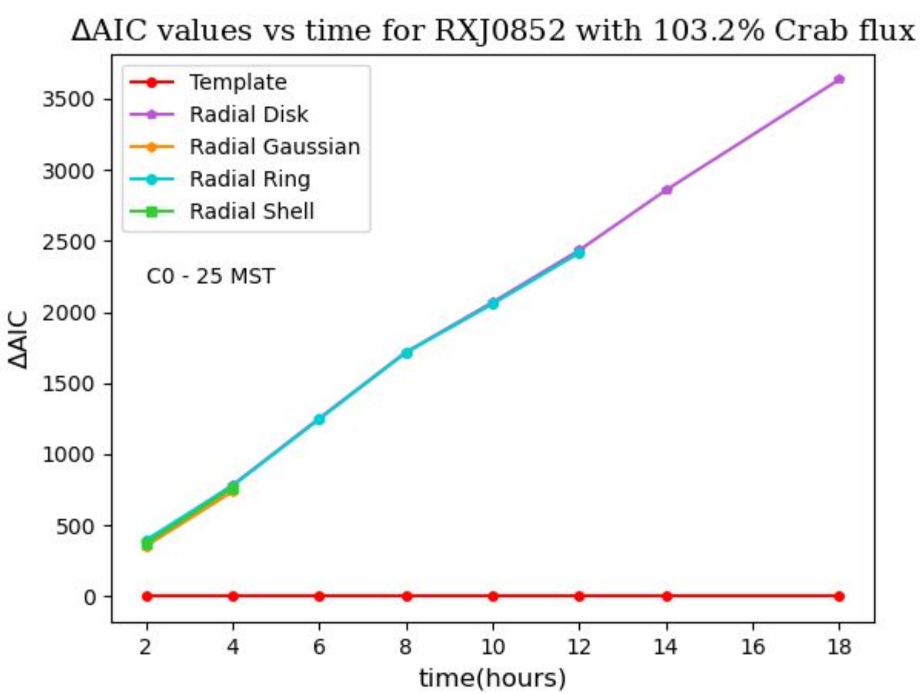


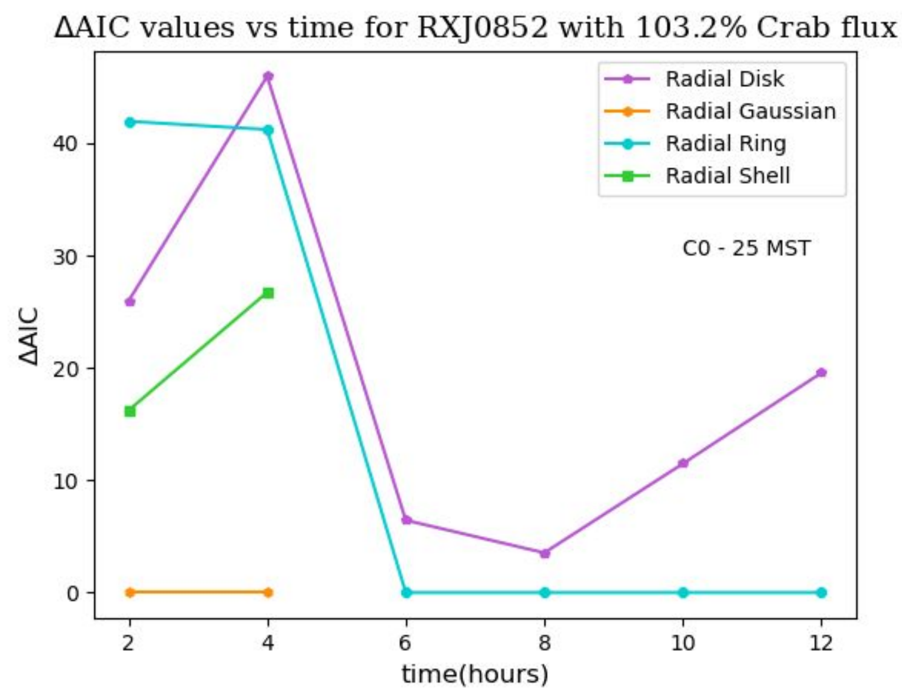
TS for RX J0852.0-4622

M2 detects the source always earlier than C0. M2 TS values are 7% bigger than those of C0.



ΔAIC for RX J0852.0-4622 (C0)

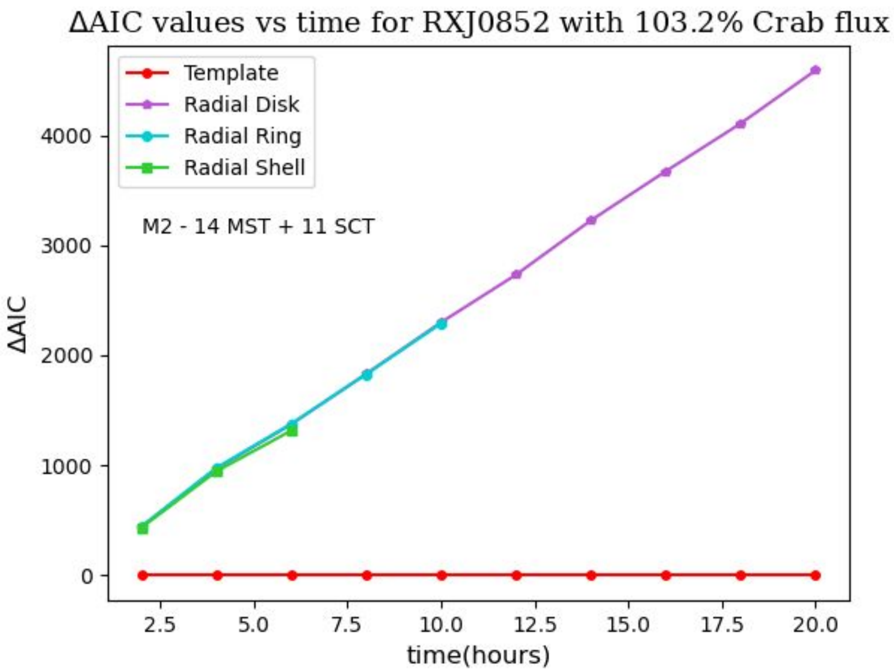


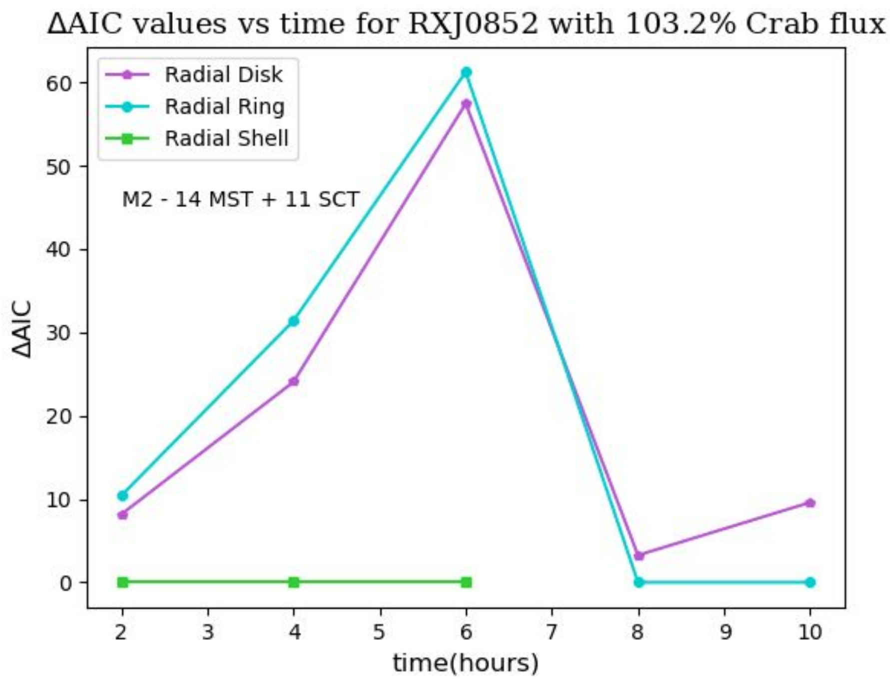


- For RXJ0852.0-4622 the Gaussian and Shell models do not describe well the SNR (bad fitting);
- Probably the models are not well suited for this SNR;
- Further investigation with alternative models and fitting algorithms ongoing.

$\Delta AIC = AIC_{model} - AIC_{min}$
AIC_{model} : AIC of one of the models at *i* hours;
AIC_{min} : smallest AIC between all the models at *i* hours
i = 2.0, 4.0, 6.0, 8.0, 10.0...20.0

ΔAIC for RX J0852.0-4622 (M2)





- The best models are the Template on the left and the Shell and the Ring on the right.
- Further investigation with alternative models and fitting algorithms ongoing.

$\Delta AIC = AIC_{model} - AIC_{min}$
AIC_{model} : AIC of one of the models at *i* hours;
AIC_{min} : smallest AIC between all the models at *i* hours
i = 2.0, 4.0, 6.0, 8.0, 10.0...20.0

Conclusions and future prospectives

- M2 has bigger TS values at few hours of observations;
- M2 is able to detect faint sources before C0;
- C0 is a better configuration for RCW86, possible explanations:
  - Sky region;
  - Background;
  - Shape of the Source.
- M2 is a better configuration for RXJ0852.0-4622 as expected;
- Both C0 and M2 are able to distinguish between a SNR and a Pulsar Wind Nebulae.

- **What to do next:**
  - Do again the simulations with different models and algorithms;
  - Change the IRFs for M2;
  - Simulate sources outside the Galactic Plane;
  - Simulate sources with different fluxes and different Spectral Index;
  - Analyze also Fermi-LAT datasets of these sources;
  - Analyze and simulate also Extragalactic Sources.

Thank you for your attention

Additional Slides

Schwarzschild -Couder Telescope and the CTA-South site

- It is a candidate for a Medium-Sized Telescope (MST) for CTA;
- Aplanar dual-mirror optical system based on the one proposed by Schwarzschild in 1905;
- ~8° Field of View;

•High imaging resolution , 0.8m diameter SCT camera woth 11238 pixels (SiPMs) of 0.067°

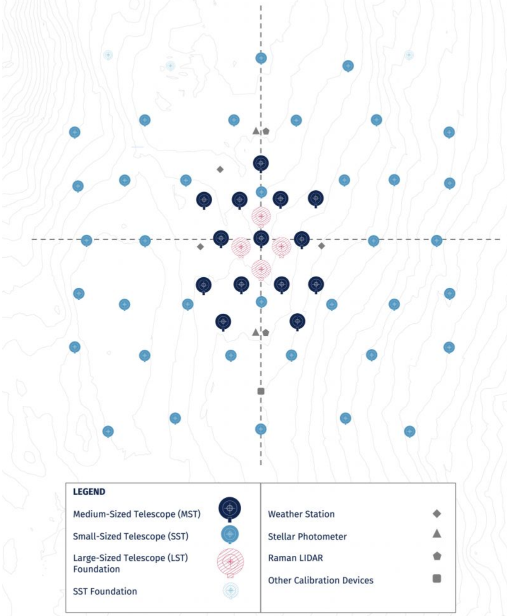
  - The equivalent Davis-Cotton version of the MST is assembled from 1570 pixels (PMTs) of 0.18° in a camera of 2.3m diameter.

- The approved Alpha configuration is to host in the CTA-South cite:
  - 14 Davis-Cotton Medium-Sized Telescopes;
  - 37 Small-Sized Telescopes;

•What we wantto prove:

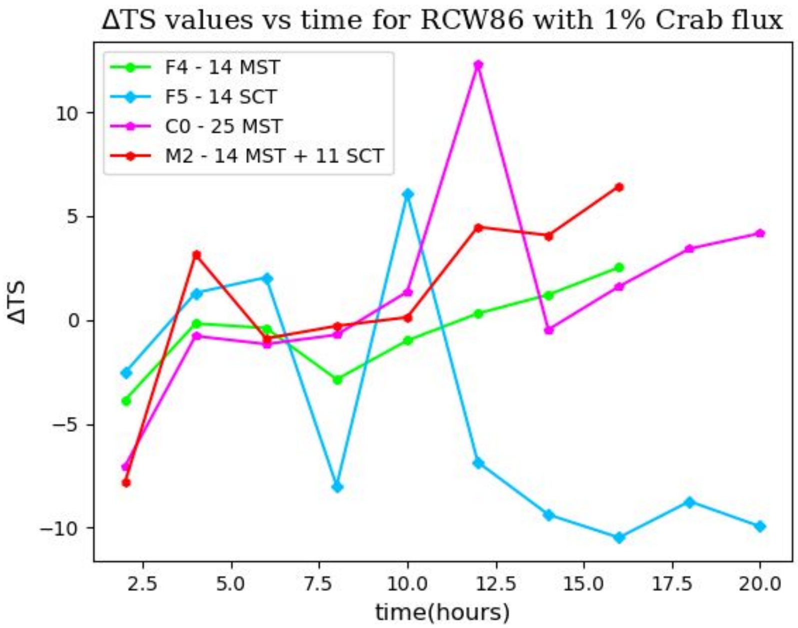
  - The performances of CTA-South improve adding SCT.

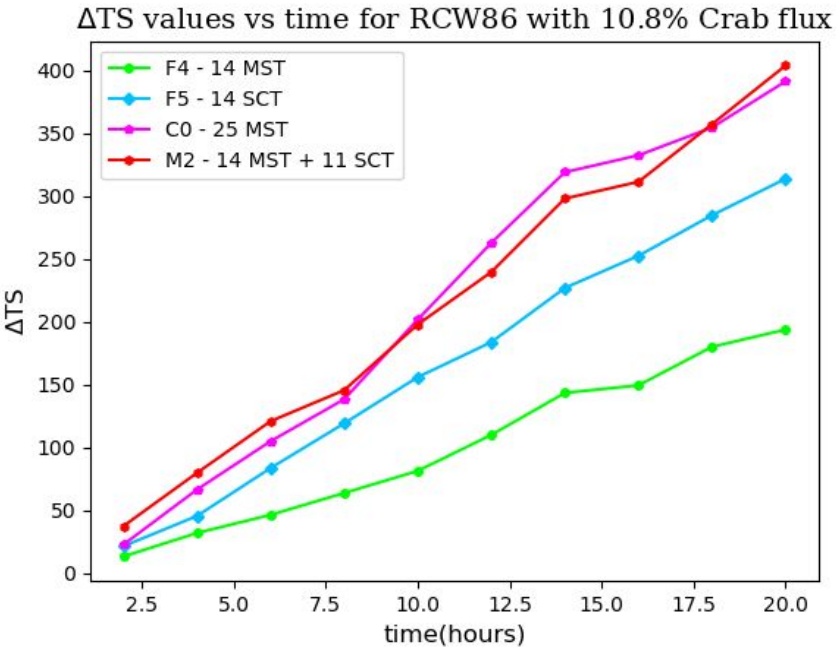
The pSCT at the Center for Astrophysics, Fred Lawrence Whipple Observatory (FLWO) in Amado, Arizona CTA pSCT.



Alpha Configuration for CTA-South CTAO Performance - Cherenkov Telescope Array (cta-observatory.org)

ΔTS for RCW 86 (radial disk)

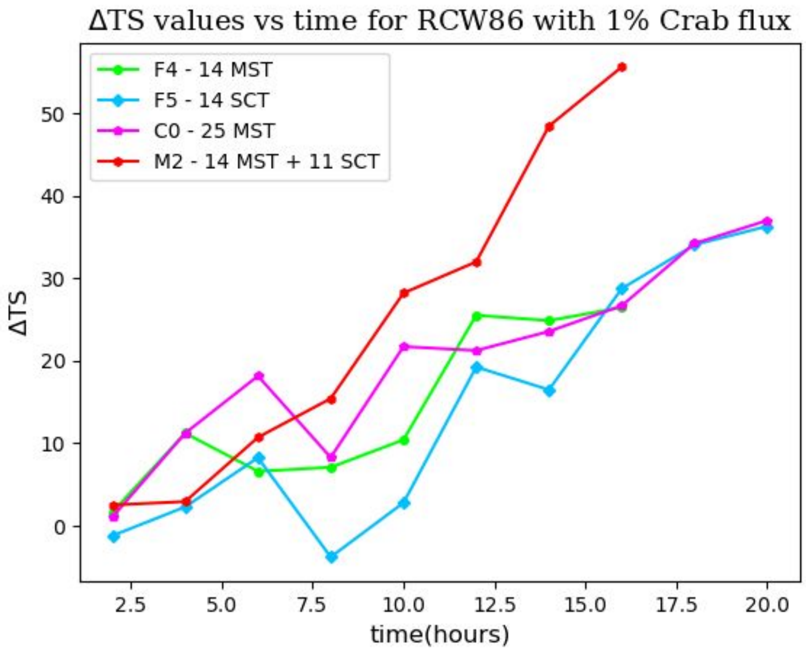


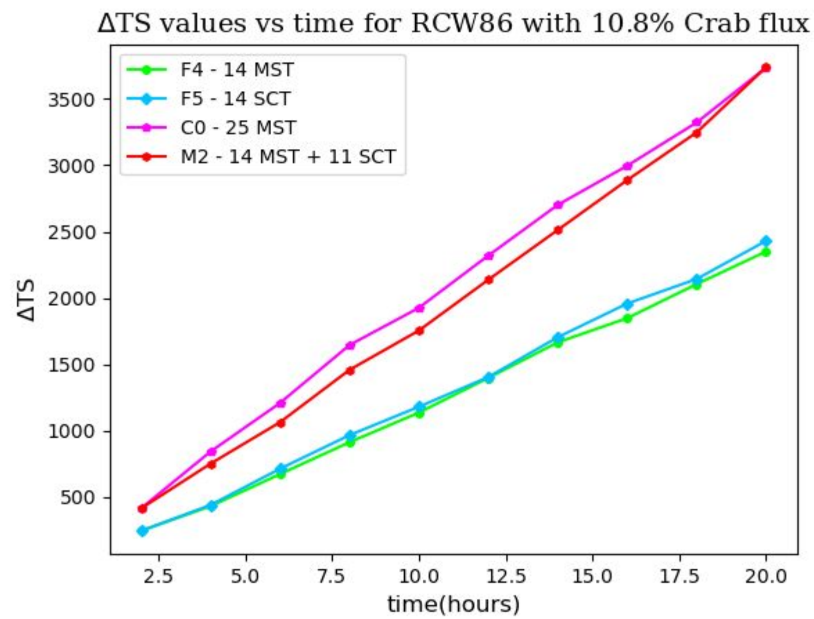


The ΔTS values are all smaller than 5, except only for C0 at 12 hours and M2 at 16 hours. Maybe the flux is too small to understand which spatial model describe better the source.

M2 ΔTS values are similar to those of C0 after 10 hours.

ΔTS for RCW 86 (Point Source)



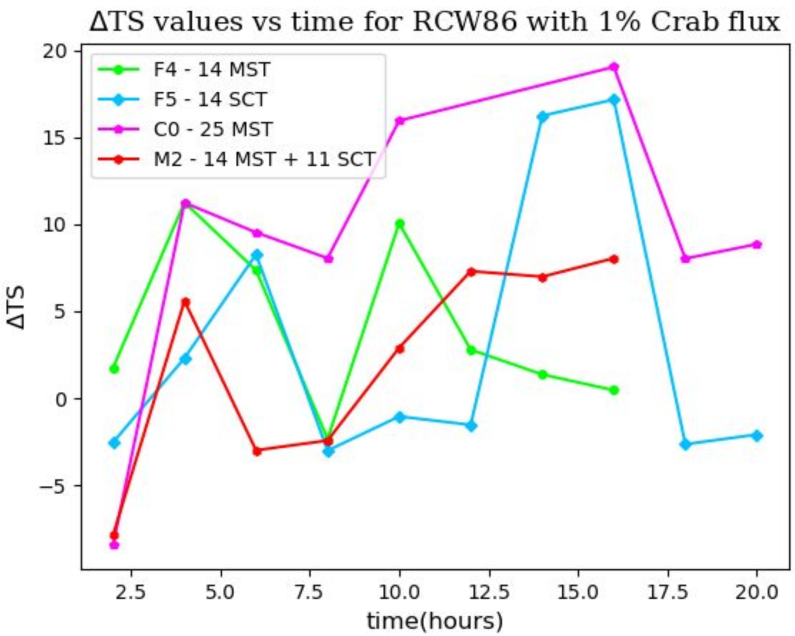


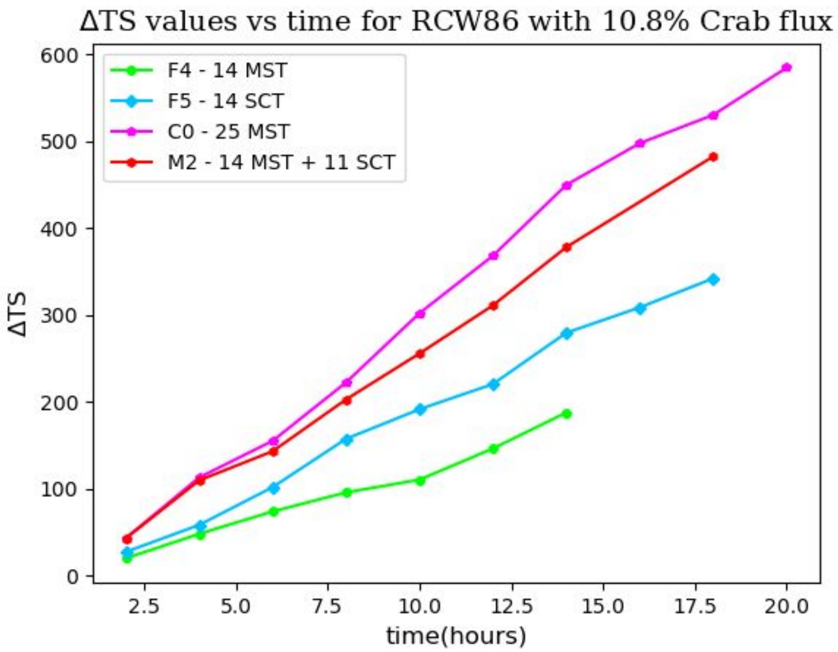
M2 configuration detects the source after 6 hours while C0 after 4 hours.
M2 TS values are 27% bigger than those of C0 after 14 hours.

M2 TS values are 3% smaller than those of C0 after 12 hours.

$\Delta TS = TS_{template} - AIC_{point\ source}$

ΔTS for RCW 86 (radial gaussian)

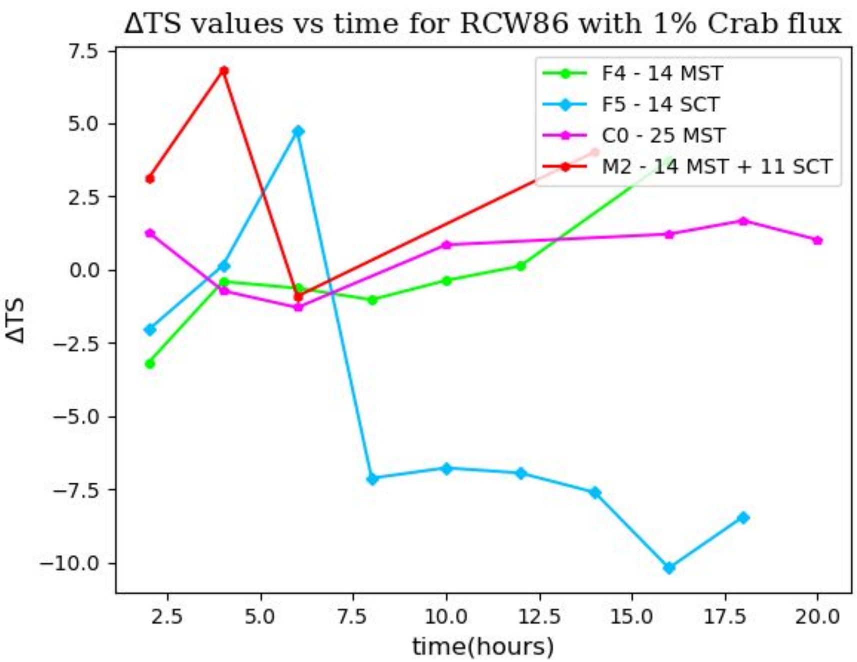


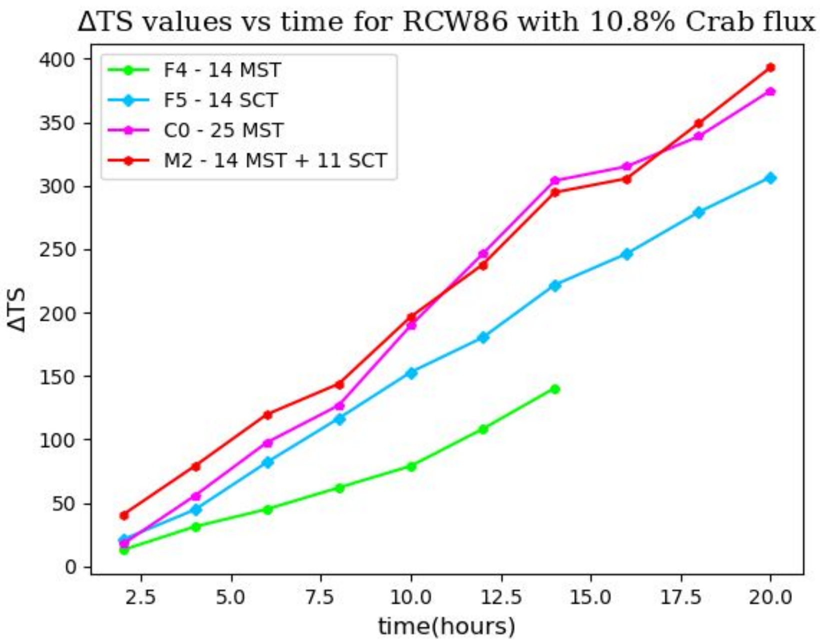


Maybe the flux is too small to understand which spatial model describe better the source at small hours.

M2 ΔTS values are 23% smaller than those of C0 after 14 hours.

ΔTS for RCW 86 (radial ring)

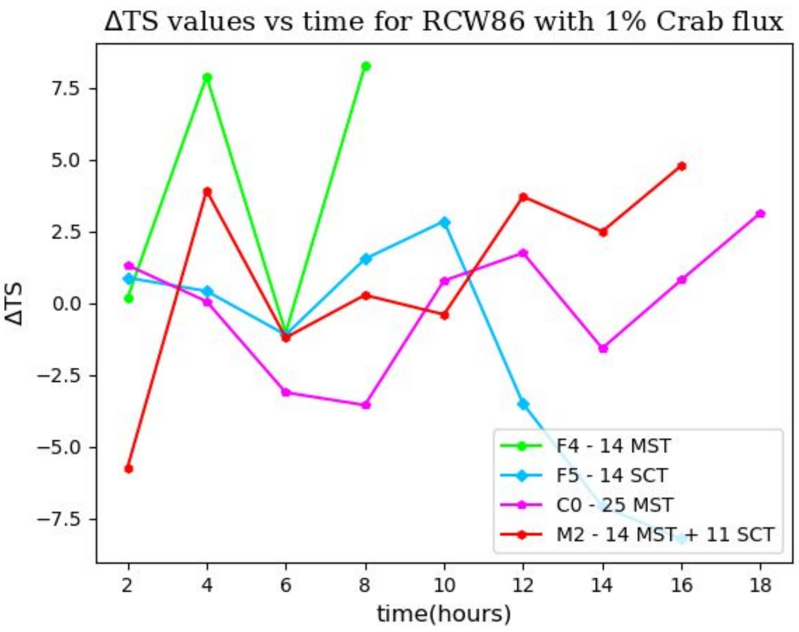


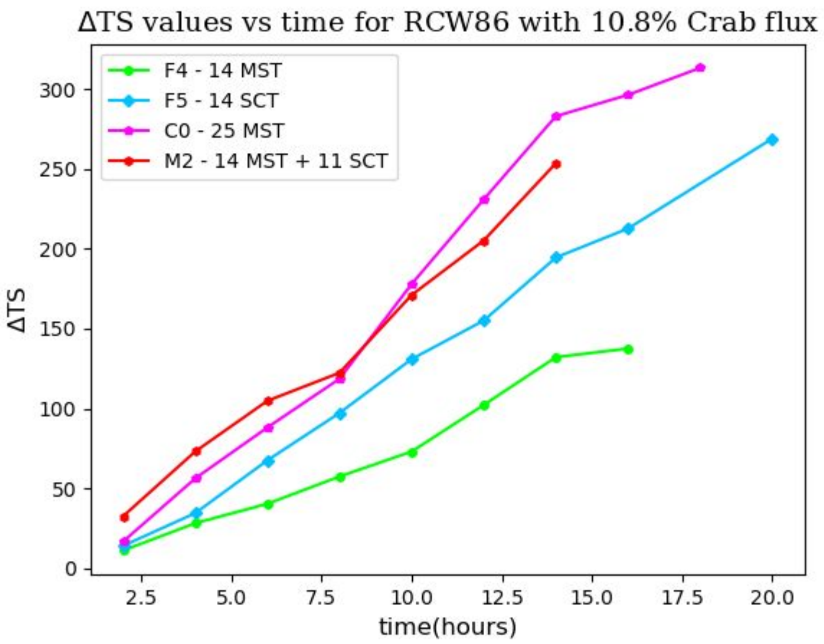


Maybe the flux is too small to understand which spatial model describe better the source.

M2 ΔTS values are similar to those of C0 after 8 hours.

ΔTS for RCW 86 (radial shell)

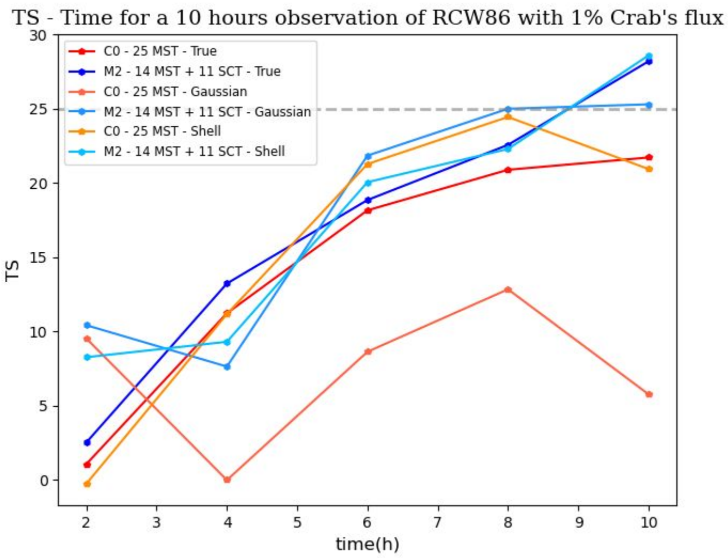




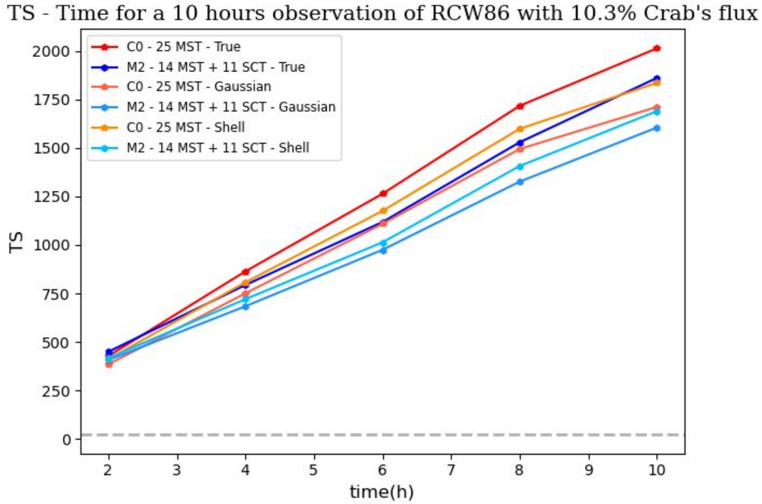
Maybe the flux is too small to understand which spatial model describe better the source.

M2 ΔTS values are 9% smaller than those of C0 after 10 hours.

TS for RCW 86 – focus on C0 and M2

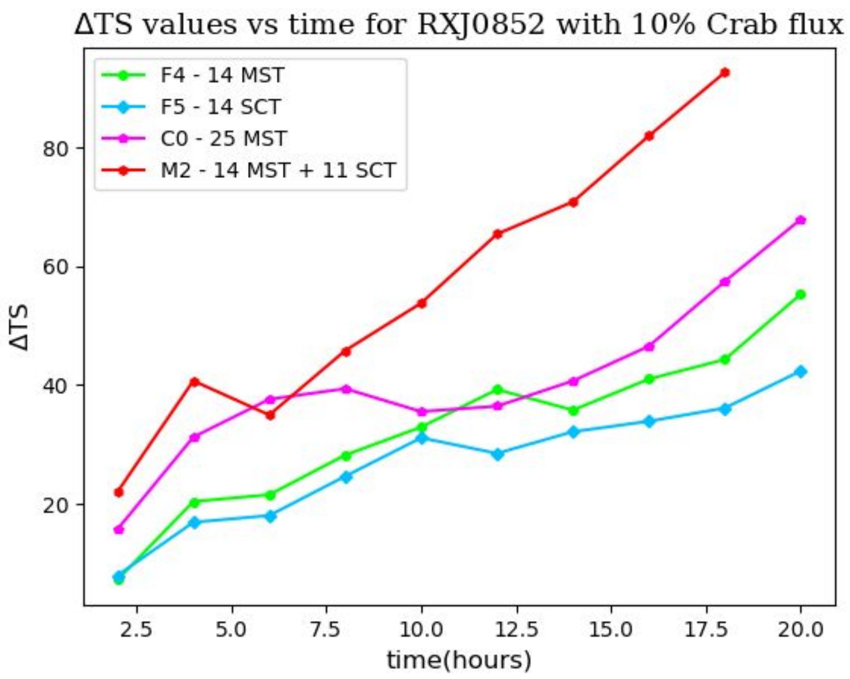


M2 detects the source always earlier than C0. M2 TS values are 29% bigger than those of C0.

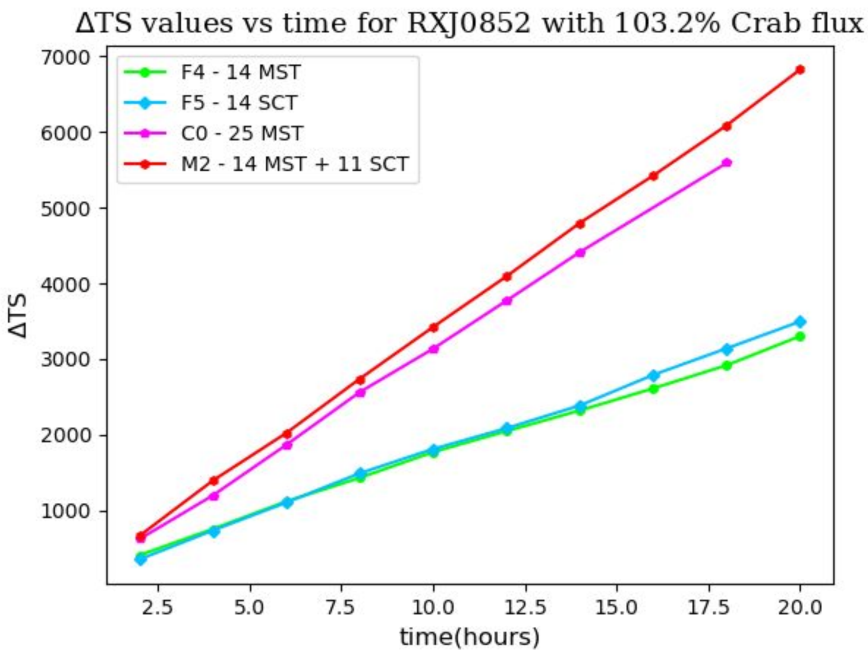


M2 detects the source earlier than C0 at 2 hours. C0 TS values are 10% bigger than those of M2.

ΔTS for RX J0852.0-4622 (Point Source)



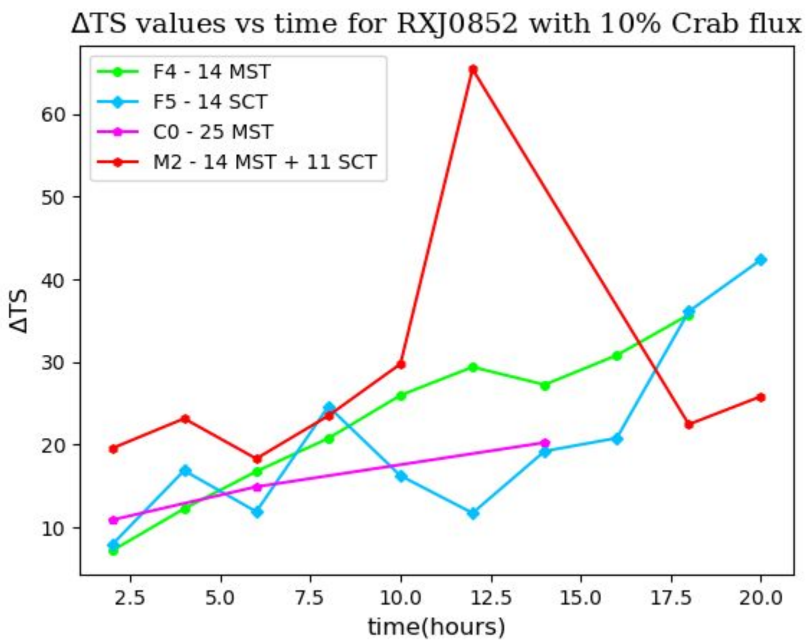
M2 shows 42% bigger values than C0 after 14 hours.

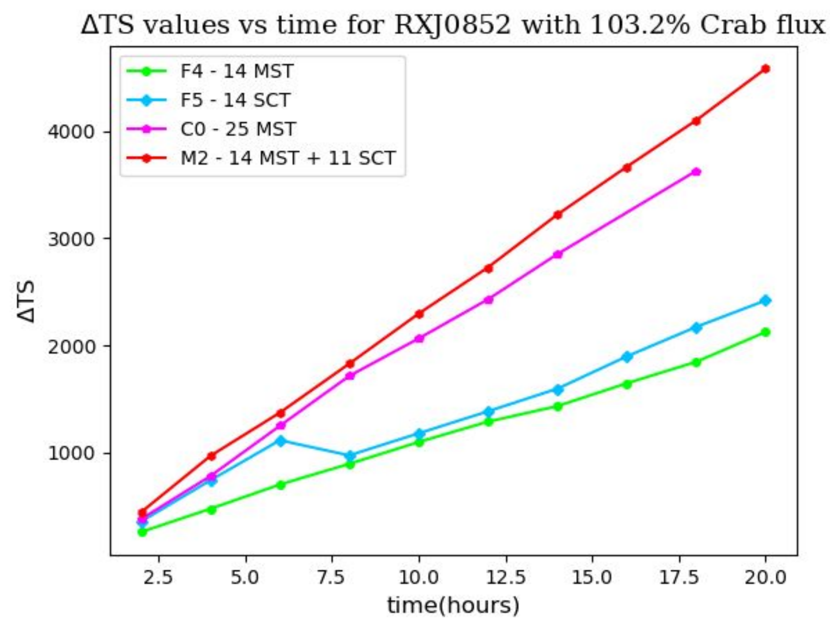


M2 shows 8% bigger values than C0 after 12 hours.

$\Delta TS = TS_{template} - AIC_{point\ source}$

ΔTS for RX J0852.0-4622 (radial disk)

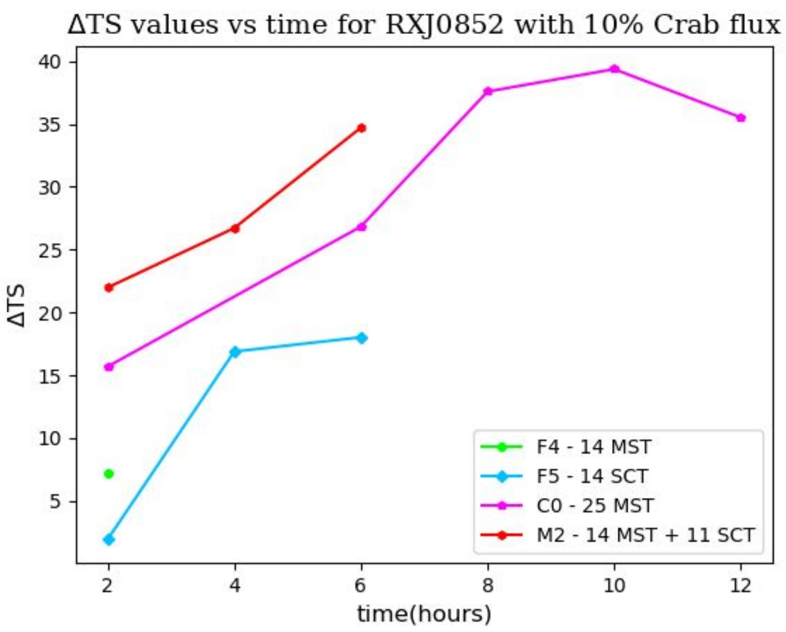


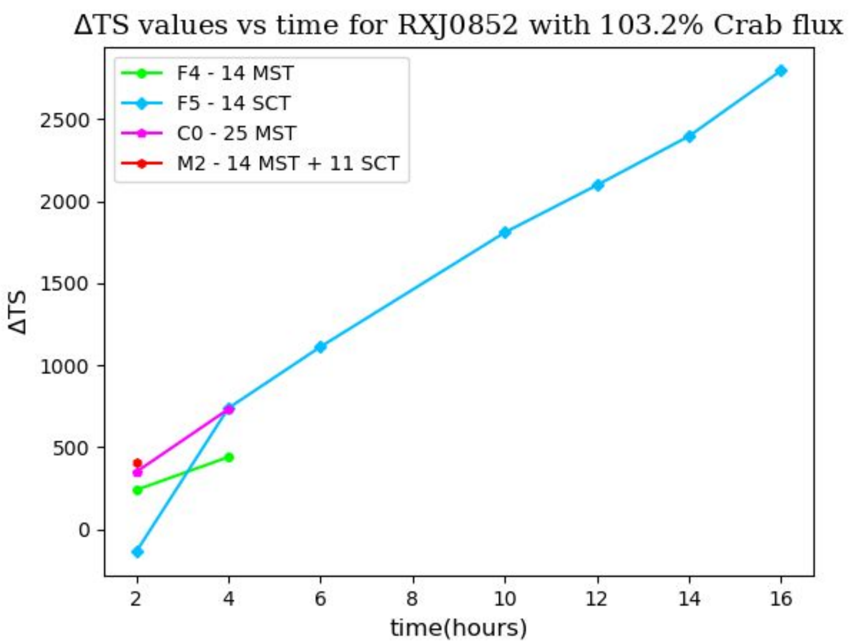


Maybe the flux is too small to understand which spatial model describe better the source.

M2 shows 11% bigger values than C0 after 12 hours.

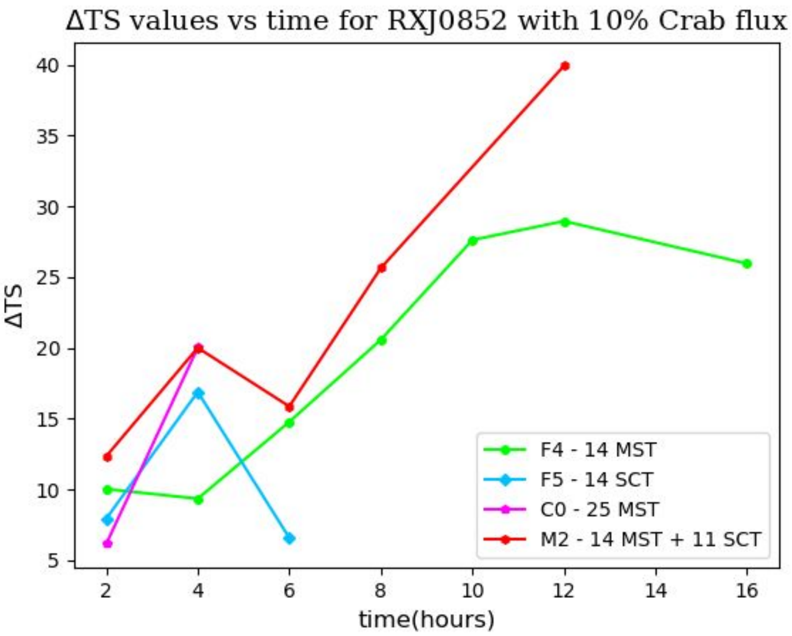
ΔTS for RX J0852.0-4622 (radial gaussian)

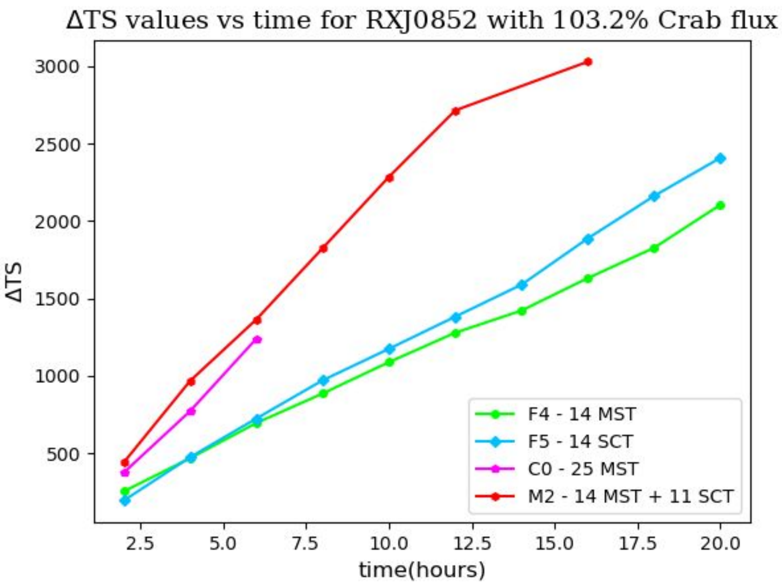




The radial gaussian is not a good model to describe this source.

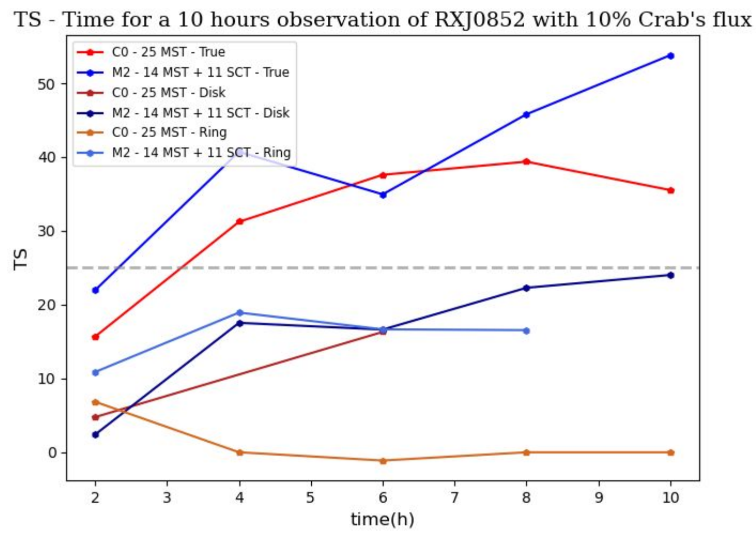
ΔTS for RX J0852.0-4622 (radial ring)



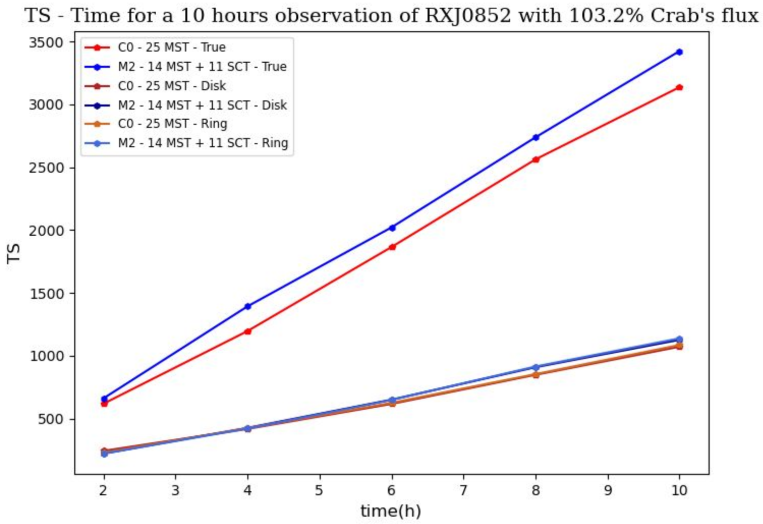


M2 shows 11% bigger values than the other configuration, but consider that C0 has few points.

TS for RX J0852.0-4622 – C0 and M2 comparison

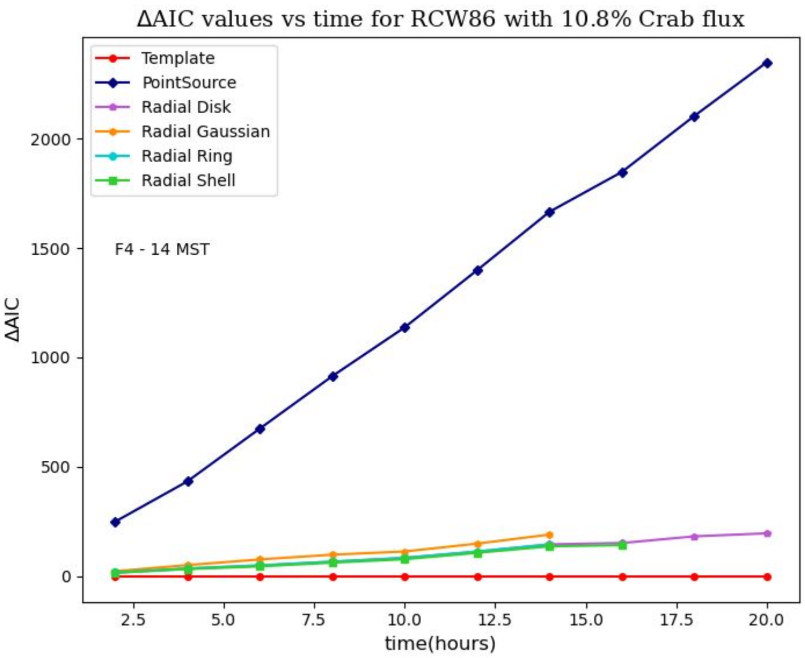


M2 detects the source earlier than C0. M2 TS values are 37% bigger than those of C0.

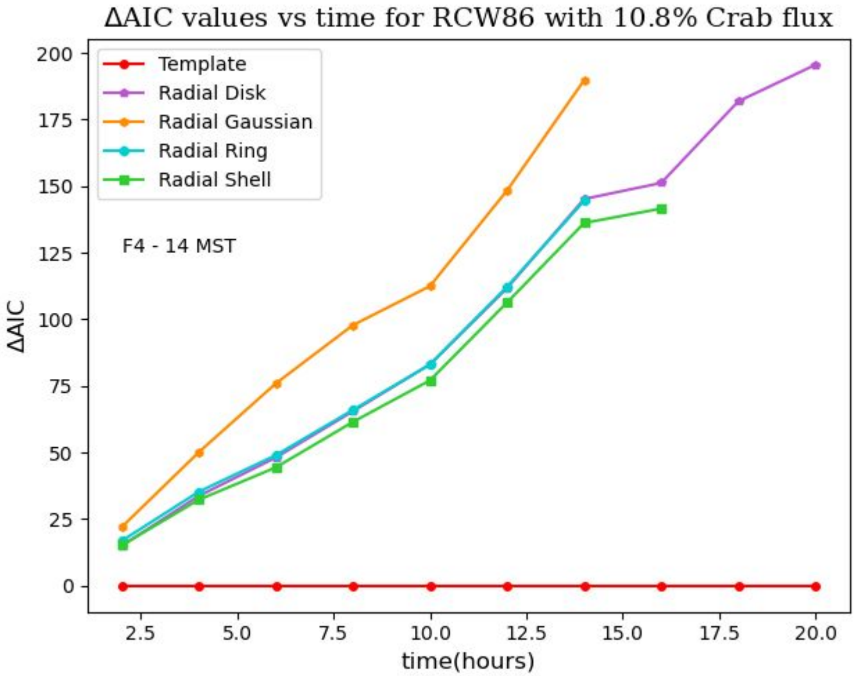


M2 detects the source always earlier than C0. M2 TS values are 7% bigger than those of C0.

ΔAIC for RCW 86 (F4)

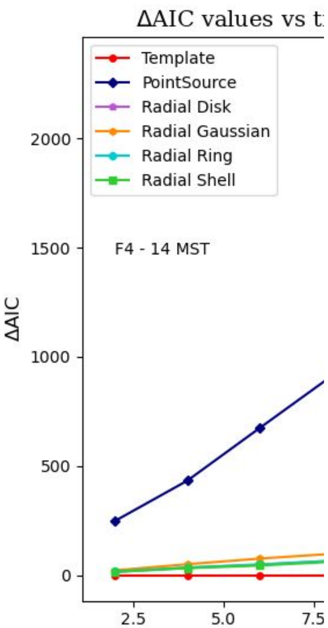


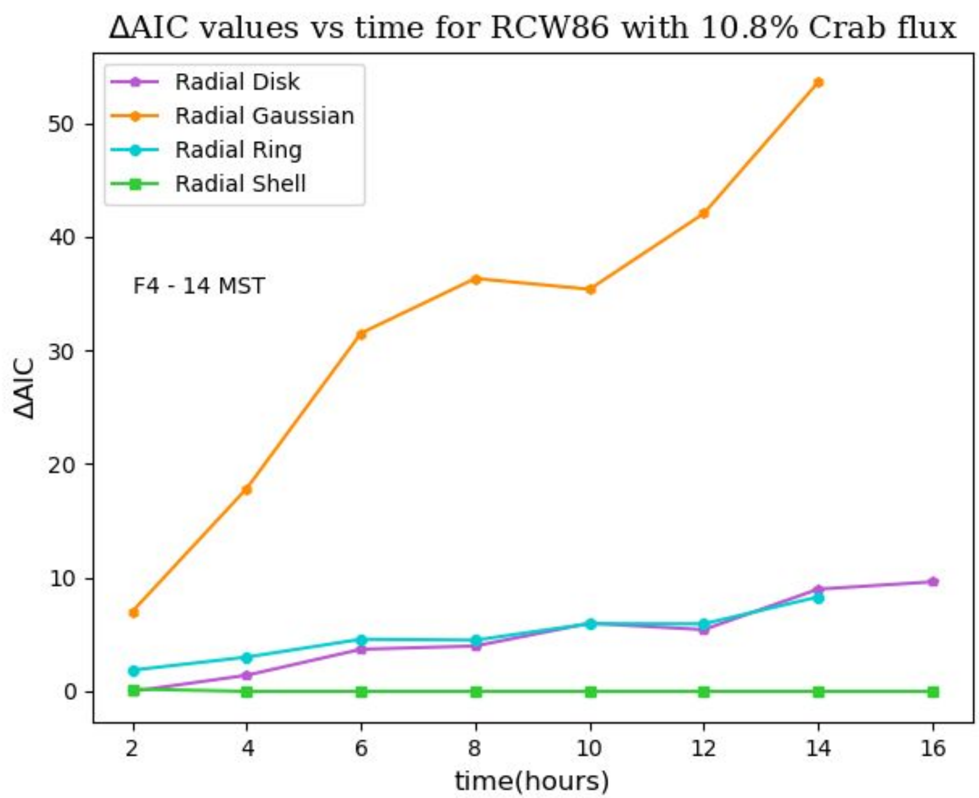
The best model of our analysis is the Diffuse Source, or Template, model. The worst is the Point Source model.

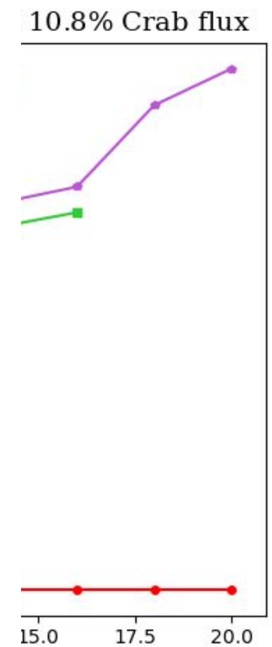


Trend without the Point Source model. The Gaussian model is the worst as expected.

ΔAIC for RCW 86 (F4)







The best model

Diffuse Source,

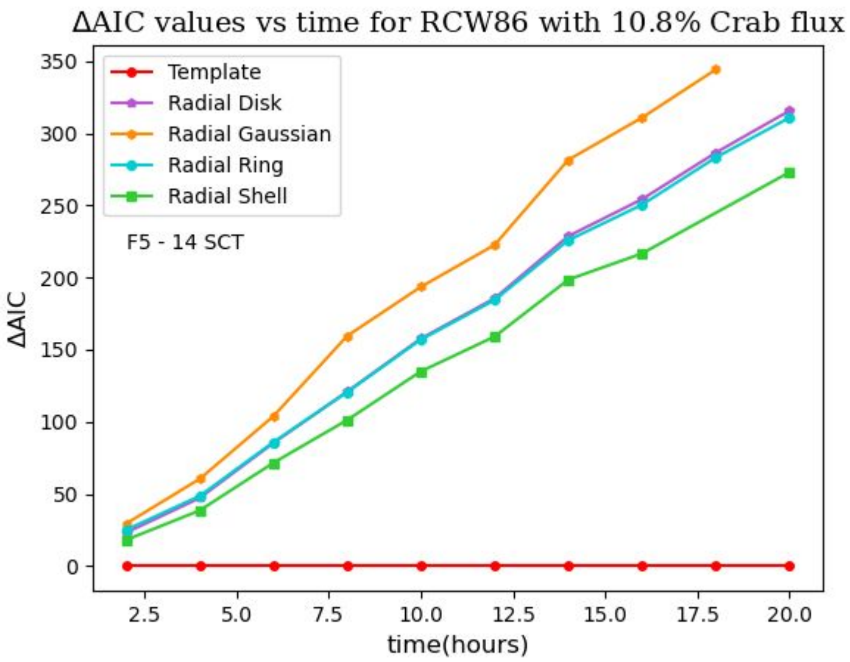
worst is the Point Source model.

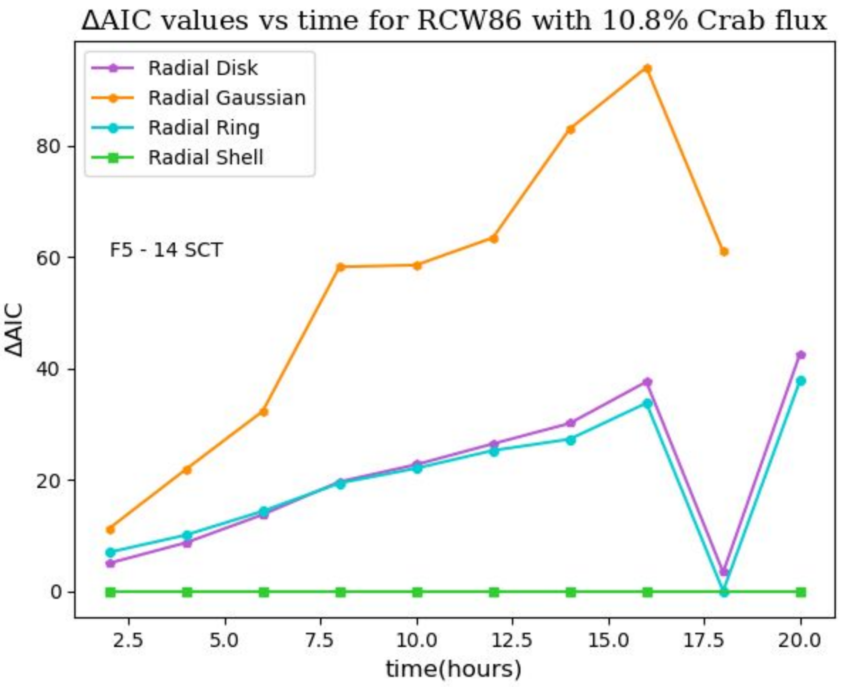
ource

el is the

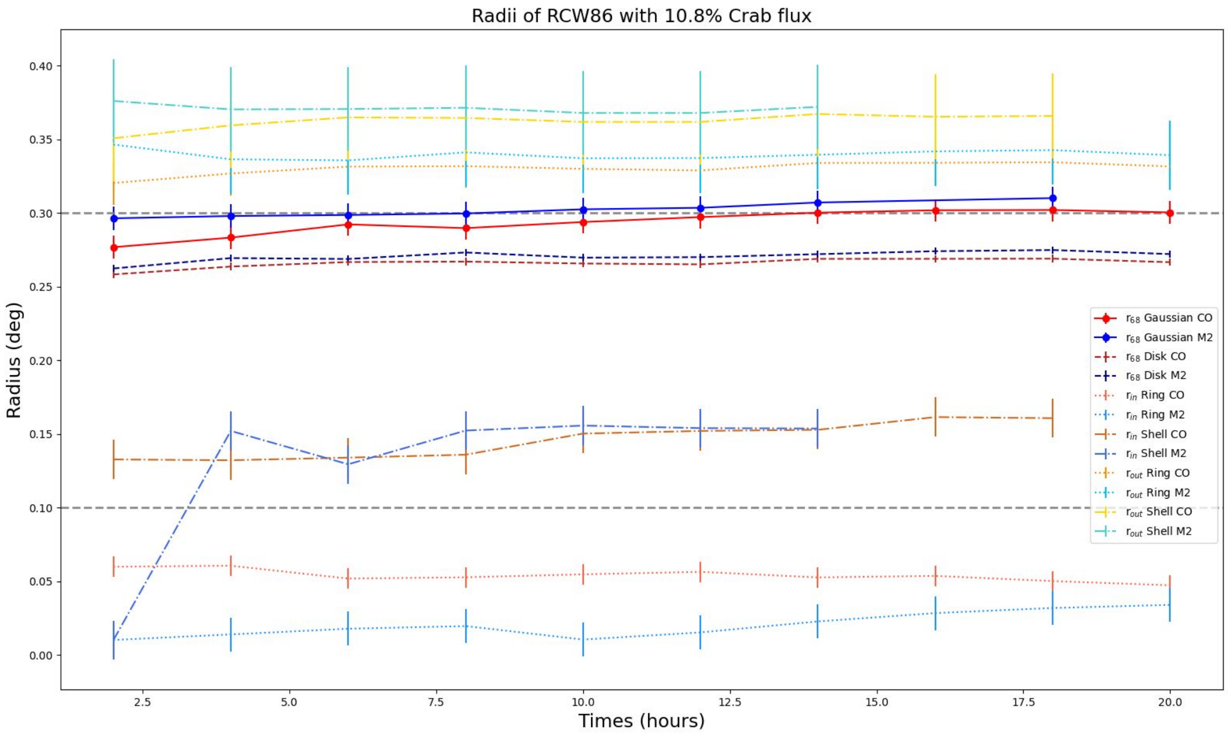
worst as expected.

ΔAIC for RCW 86 (F5)



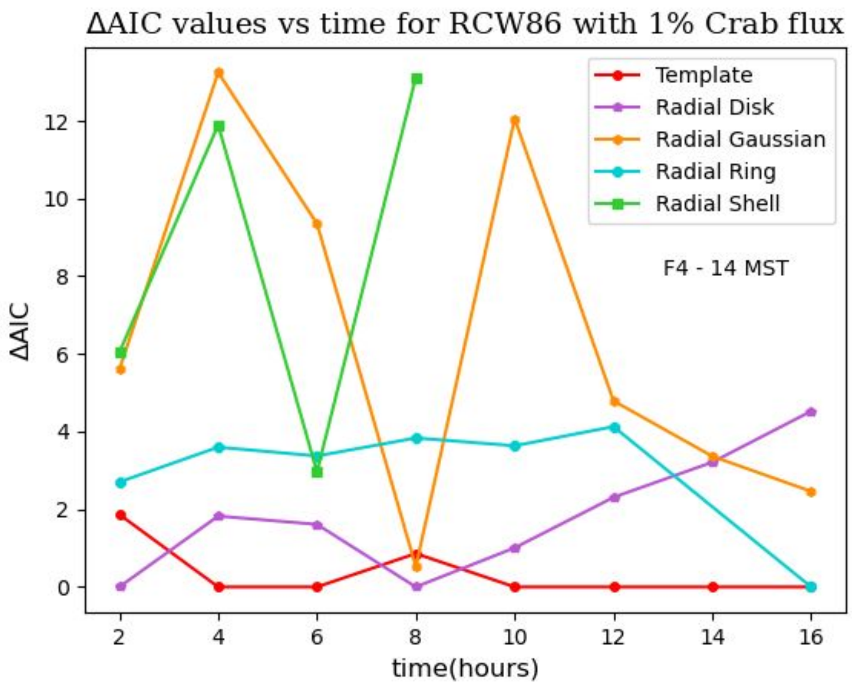


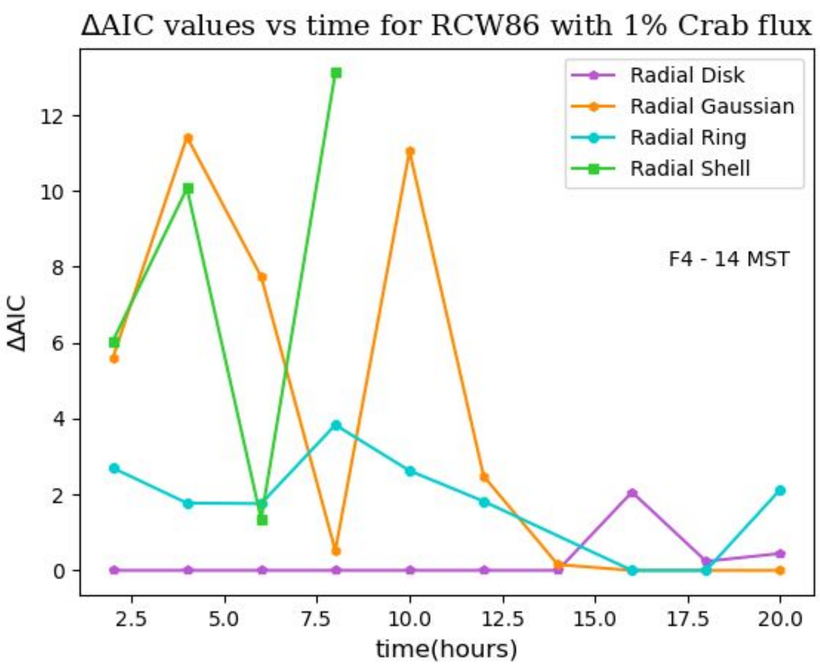
Radii comparison for RCW 86 (C0 and M2)



r_{68} is the radius inside which there is the 68% of the source emission.

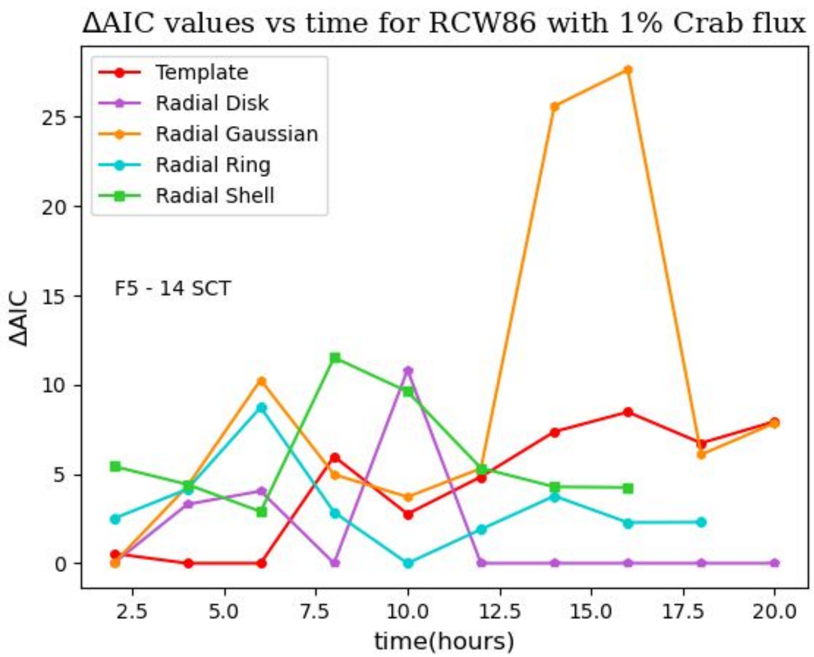
ΔAIC for RCW 86 (F4)

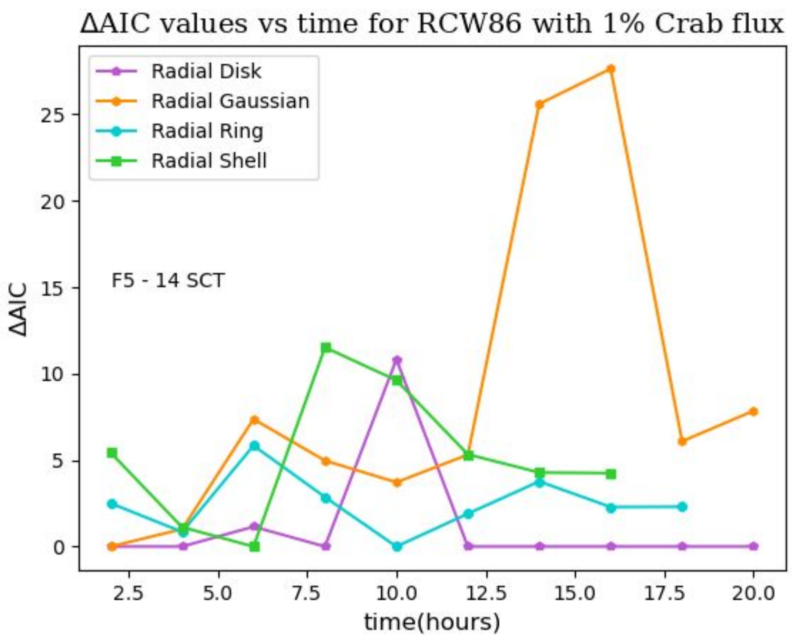




In the 1% case, the number of photons and the statistics are lower, so it is more difficult to understand which model is better.

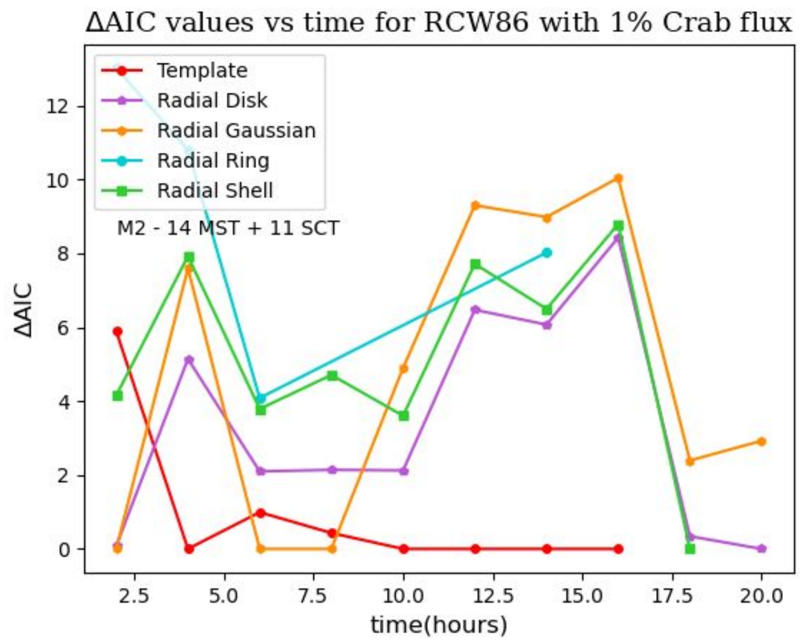
ΔAIC for RCW 86 (F5)

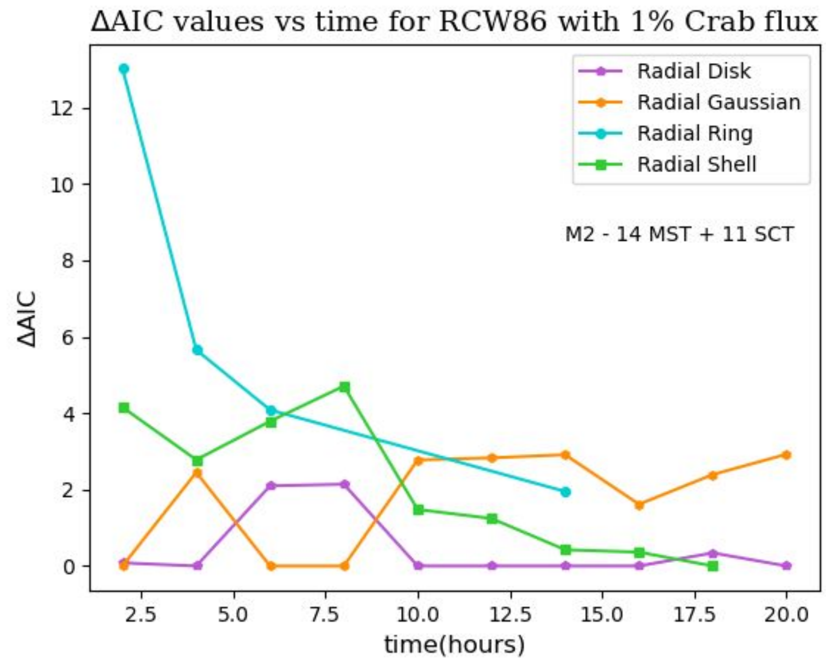




The worst model is the Gaussian one. The best one is the Disk one.

ΔAIC for RCW 86 (M2)

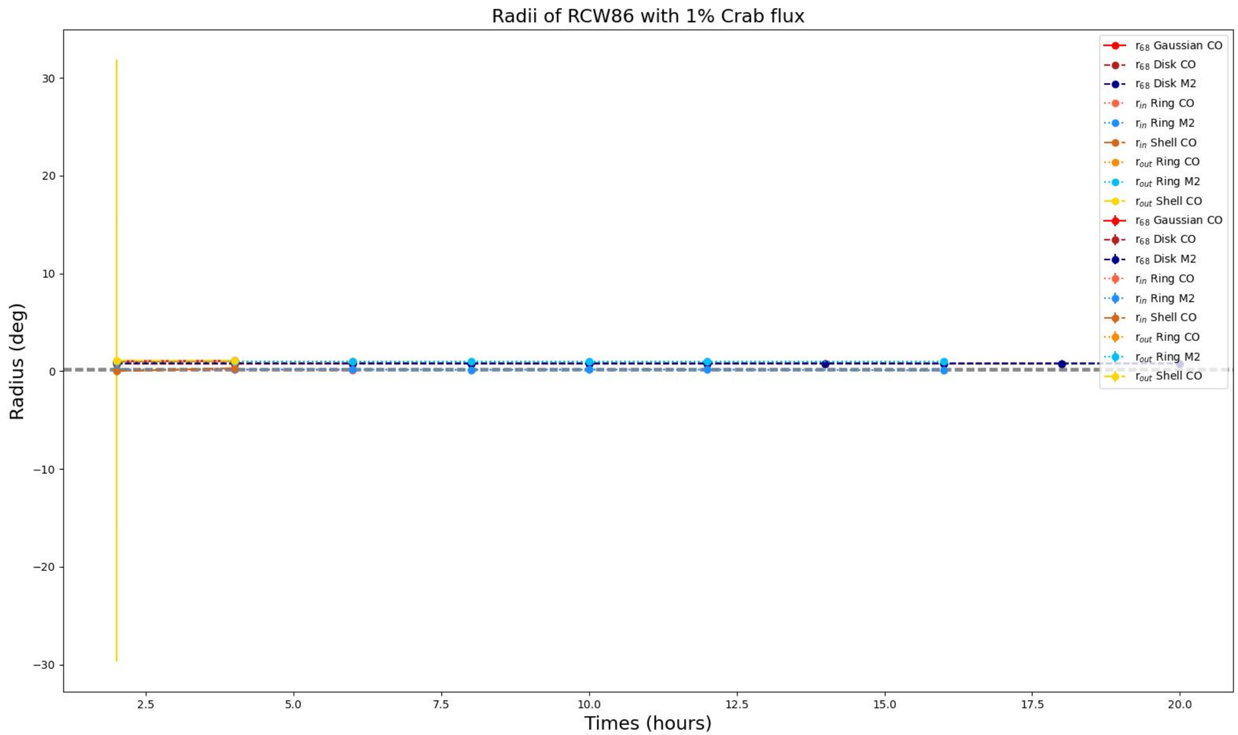




- The best models are the Template on the left and the Disk on the right.
- The difference between the Gaussian and the Shell values are smaller in M2 than in C0.

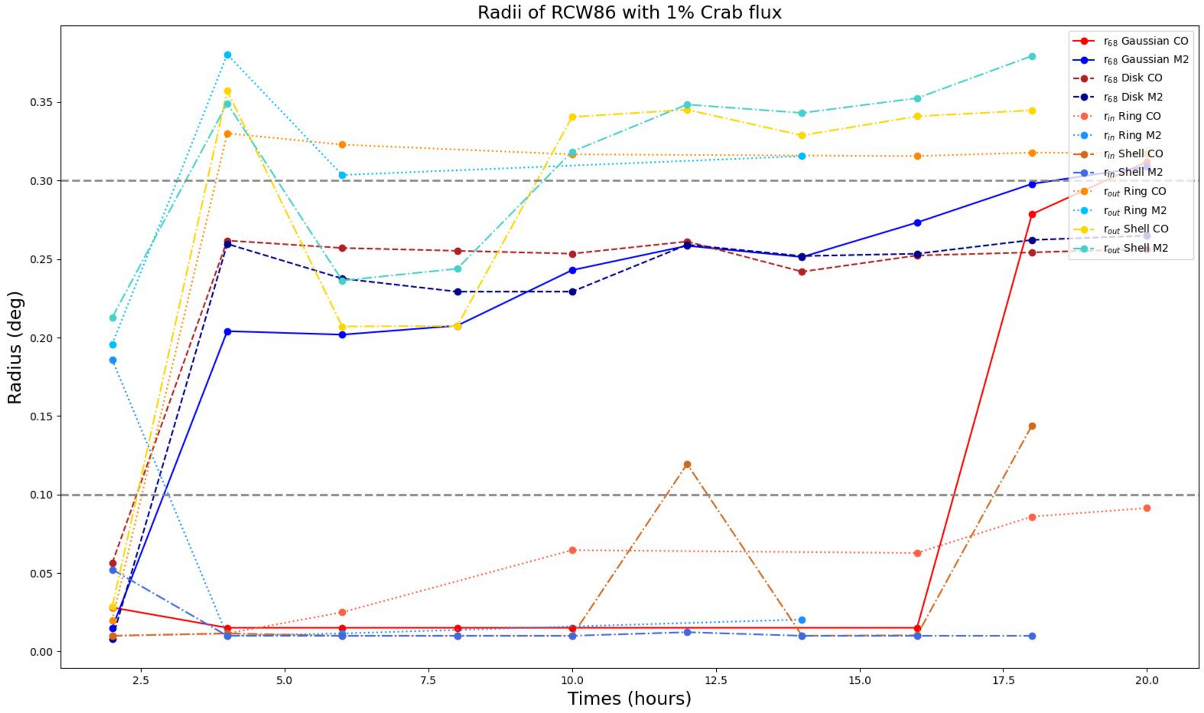
$\Delta AIC = AIC_{model} - AIC_{min}$
AIC_{model} : AIC of one of the models at *i* hours;
AIC_{min} : smallest AIC between all the models at *i* hours
i = 2.0, 4.0, 6.0, 8.0, 10.0...20.0

Radii comparison for RCW 86 (C0 and M2)



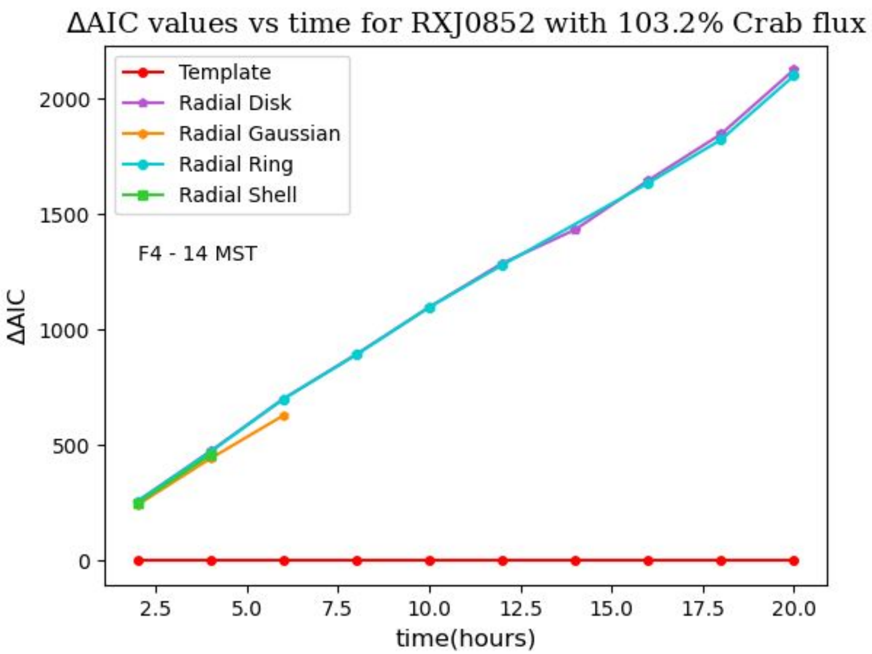
The errors on the radii are so big!

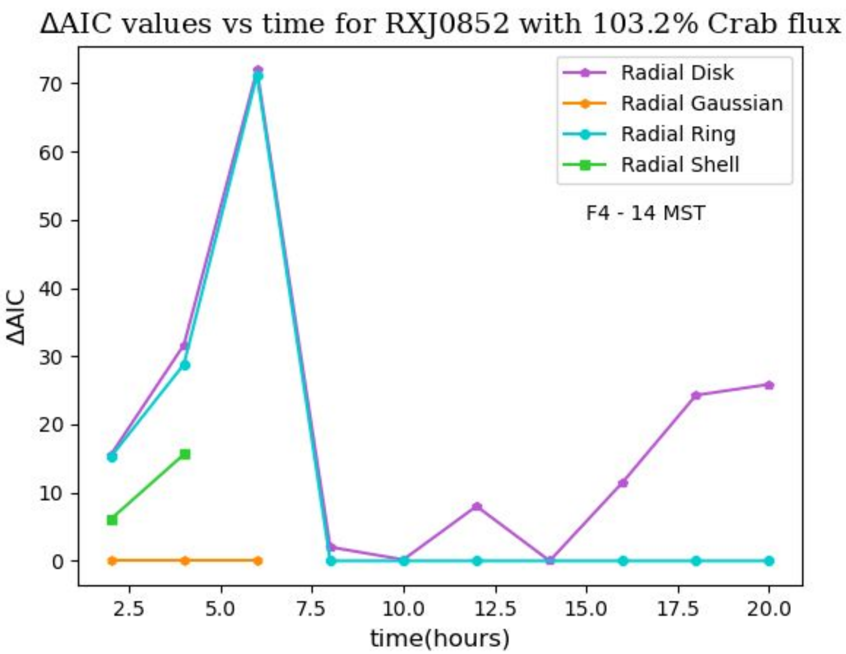
Radii comparison for RCW 86 (C0 and M2)



r_{68} is the radius inside which there is the 68% of the source emission.

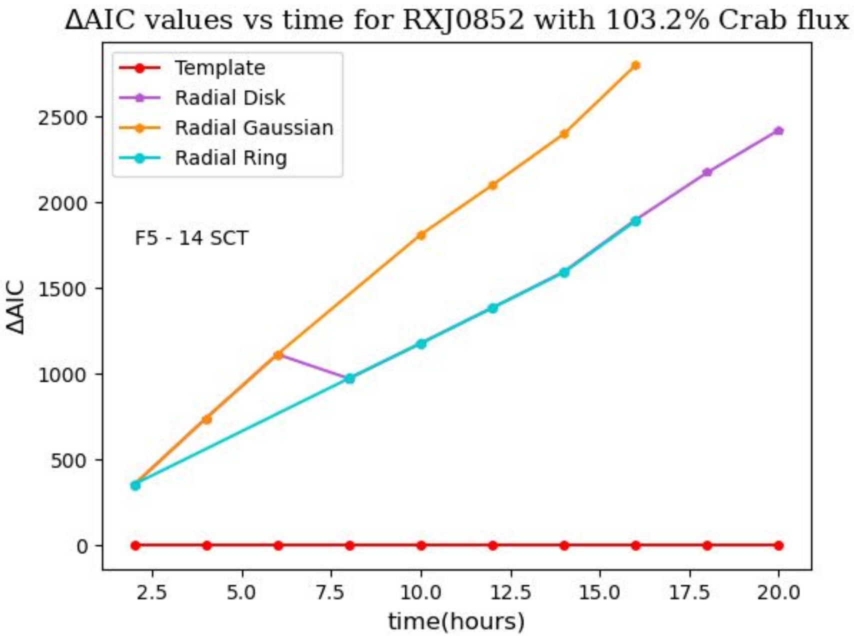
ΔAIC for RX J0852.0-4622 (F4)

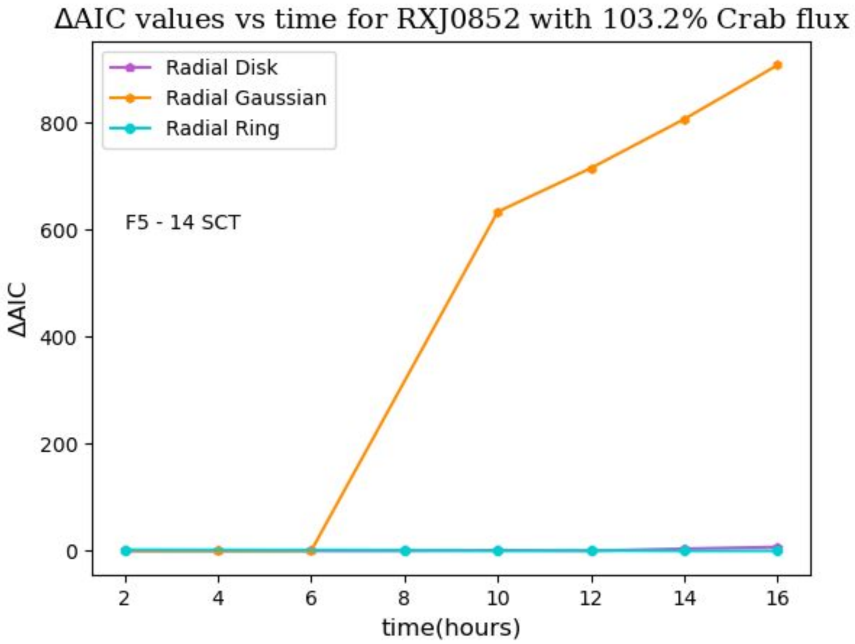




The best models are the Template on the left and the Ring on the right.

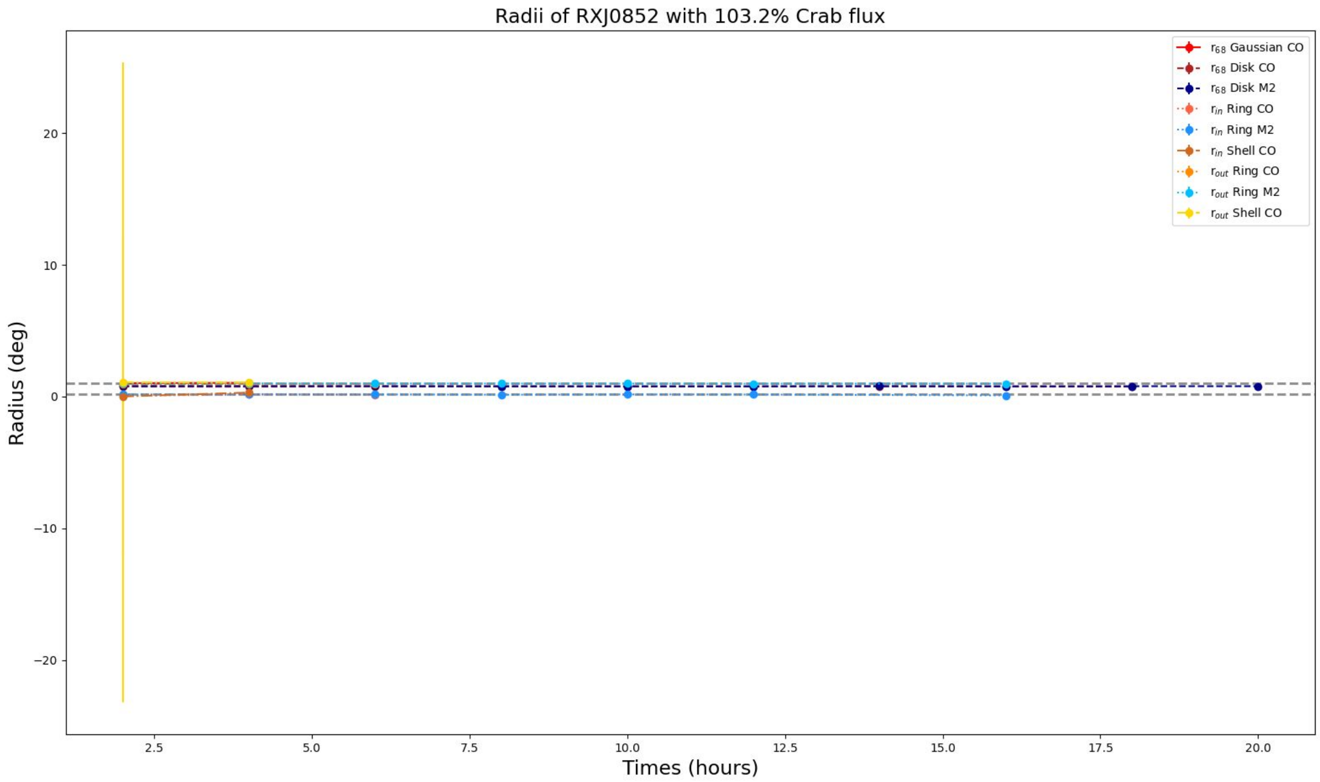
ΔAIC for RX J0852.0-4622 (F5)





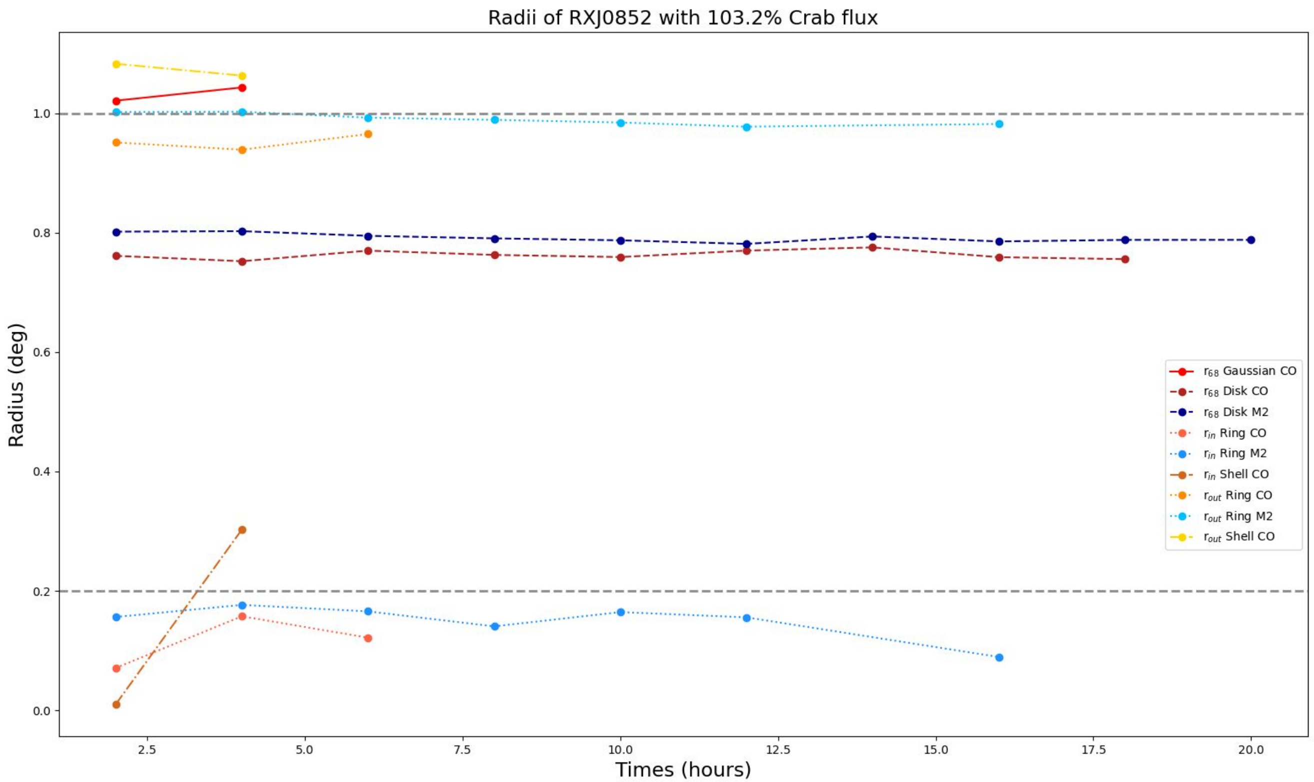
The best models are the Template on the left and the Ring on the right.

Radii comparison for RXJ0852.0-4622 (C0 and M2)



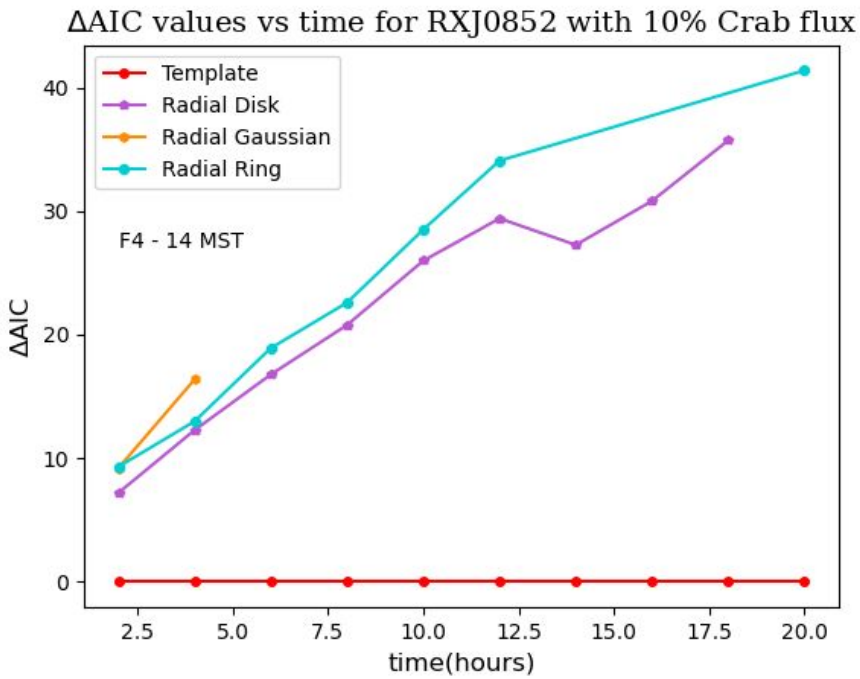
The errors on the radii are so big!

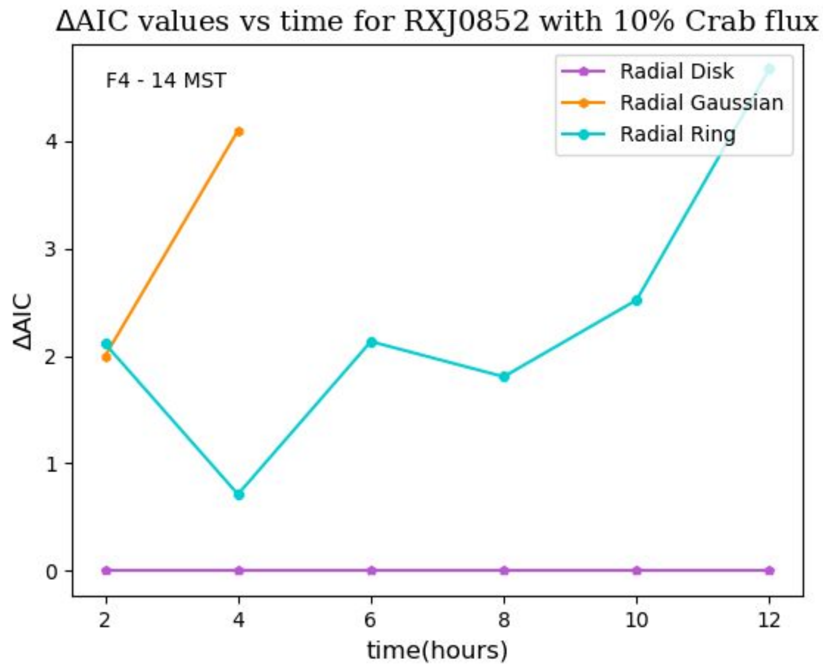
Radii comparison for RXJ0852.0-4622 (C0 and M2)



The errors on the radii are so big!

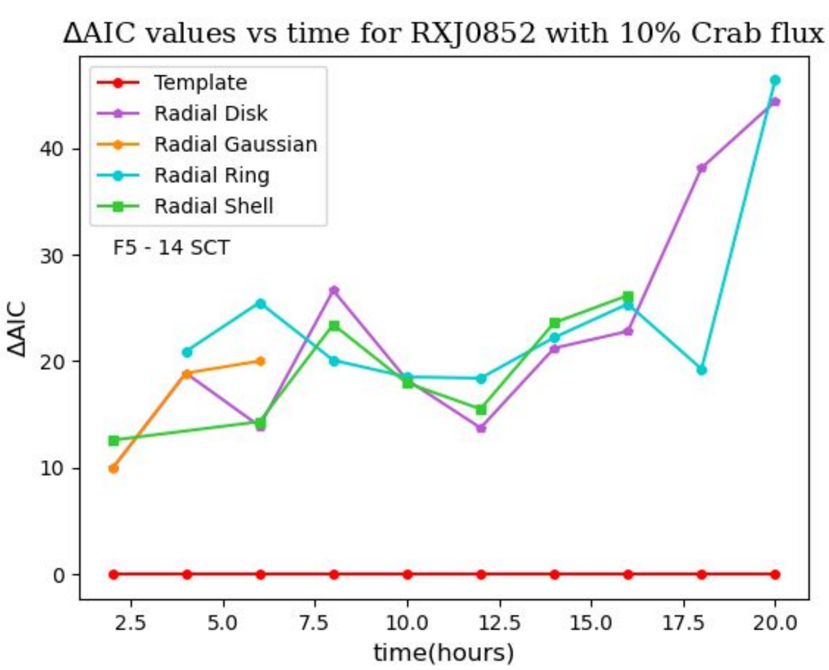
ΔAIC for RX J0852.0-4622 (F4)

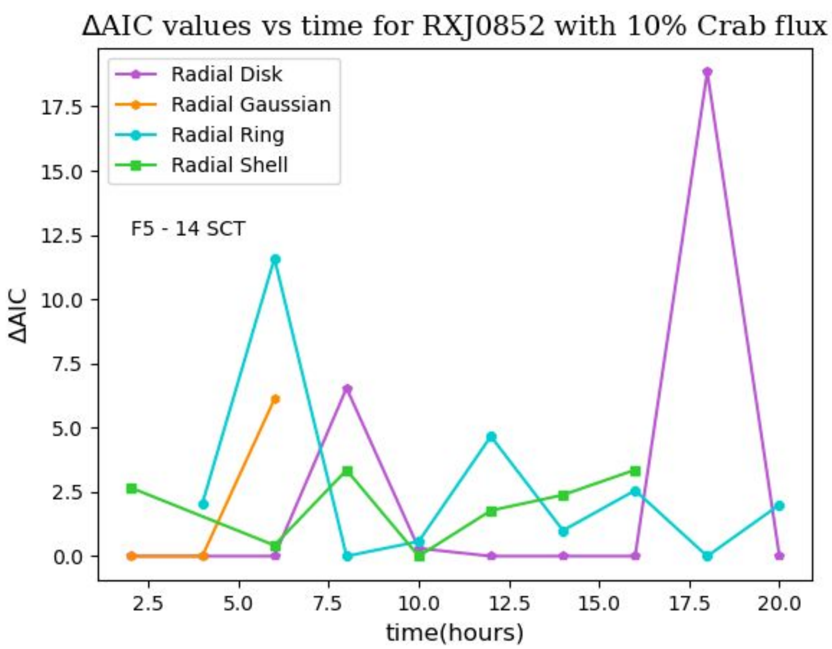




The best models are the Template on the left and the Disk on the right.

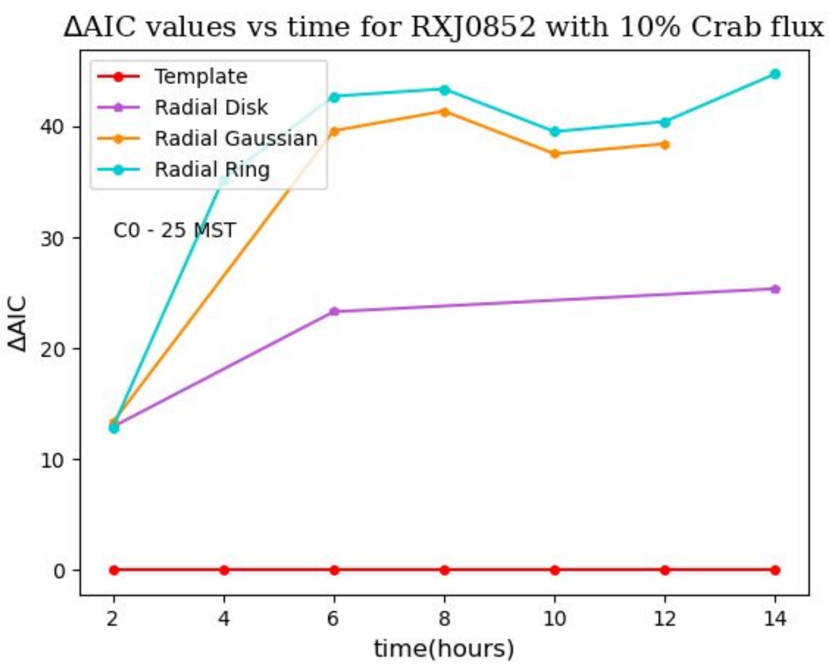
ΔAIC for RX J0852.0-4622 (F5)

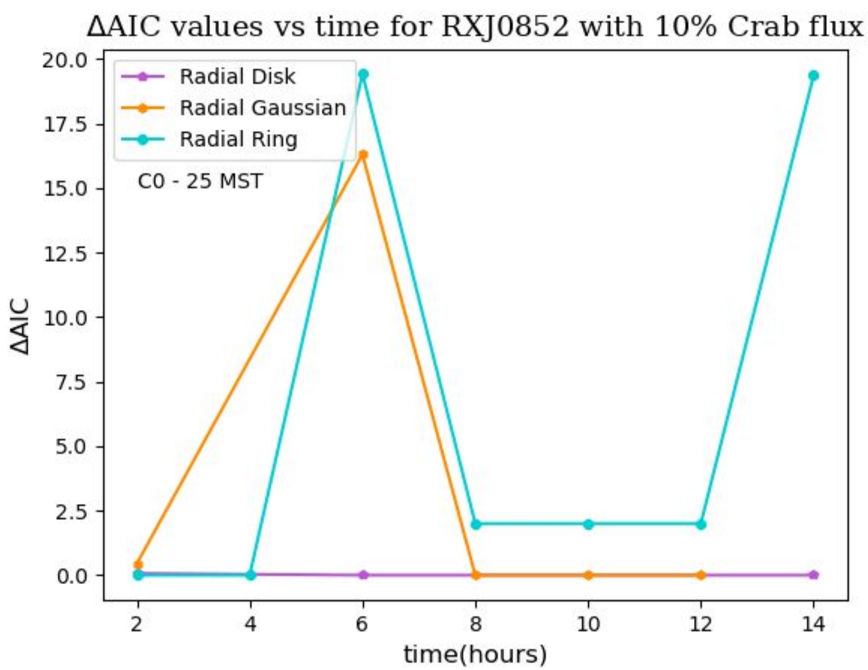




The best models are the Template on the left and the Disk on the right.

ΔAIC for RX J0852.0-4622 (C0)





- The best models are the Template on the left and the Disk on the right.
- Further investigation with alternative models and fitting algorithms ongoing.

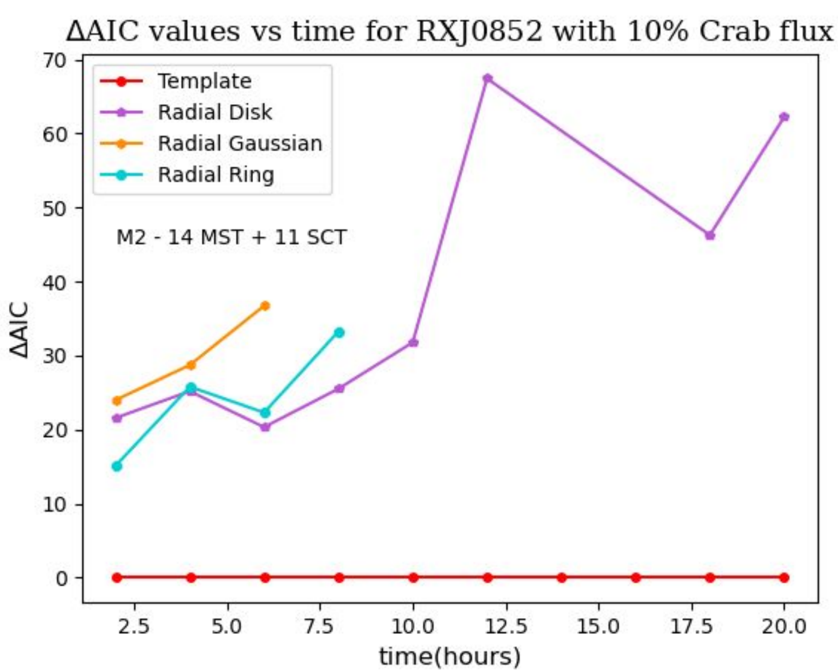
$\Delta AIC = AIC_{model} - AIC_{min}$

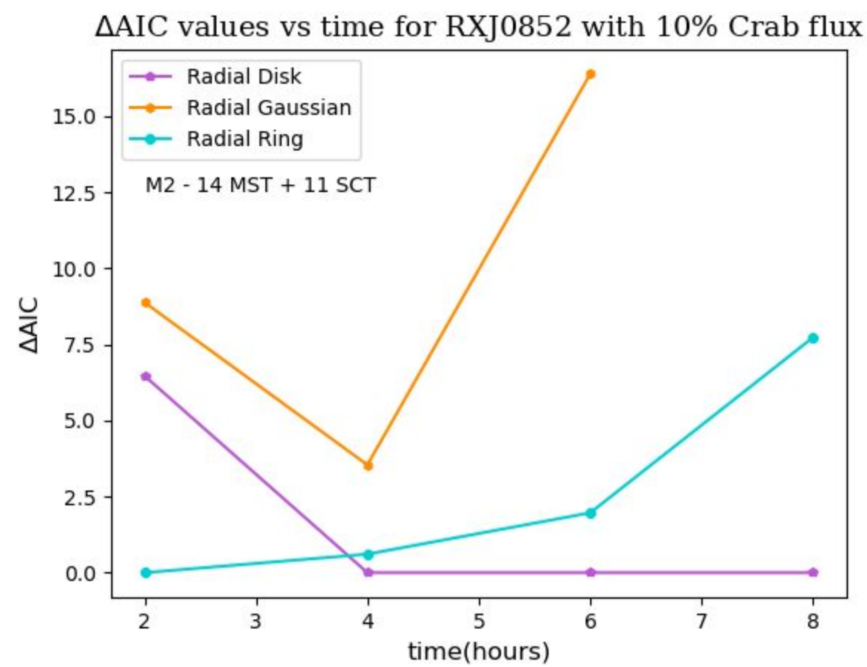
AIC_{model} : AIC of one of the models at *i* hours;

AIC_{min} : smallest AIC between all the models at *i* hours

i = 2.0, 4.0, 6.0, 8.0, 10.0...20.0

ΔAIC for RX J0852.0-4622 (M2)

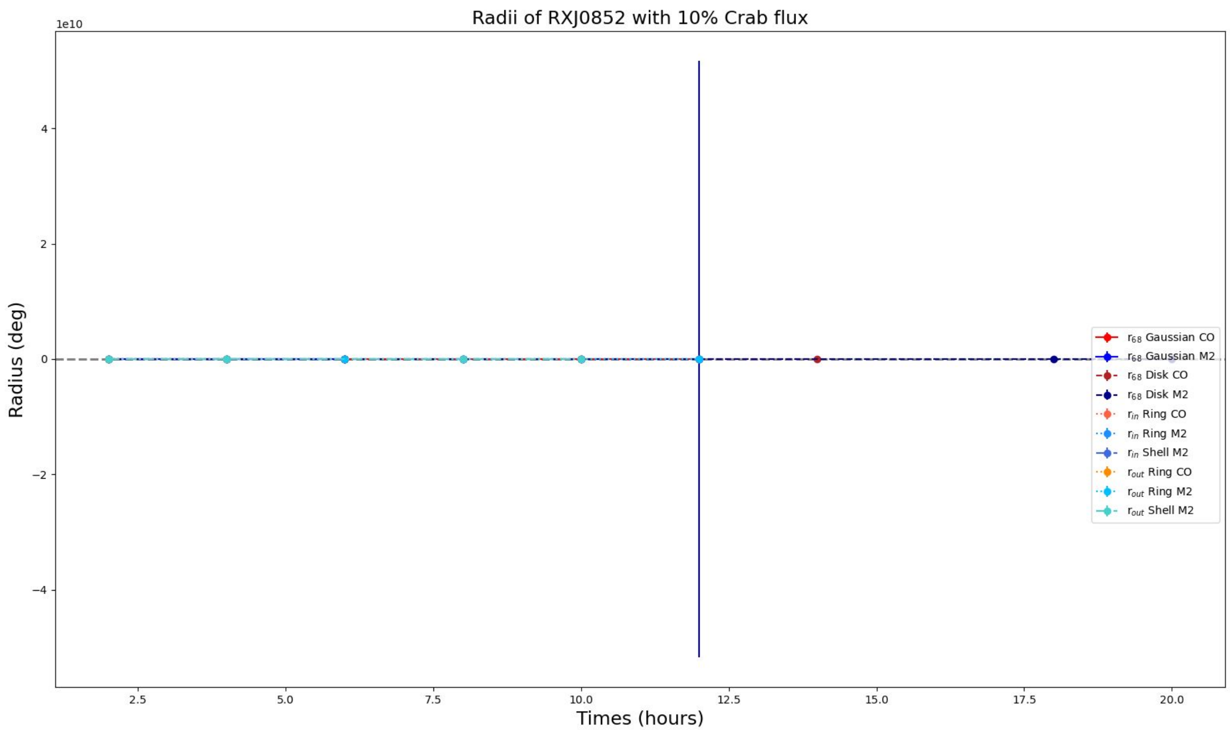




- The best models are the Template on the left and the Disk on the right.
- Further investigation with alternative models and fitting algorithms ongoing.

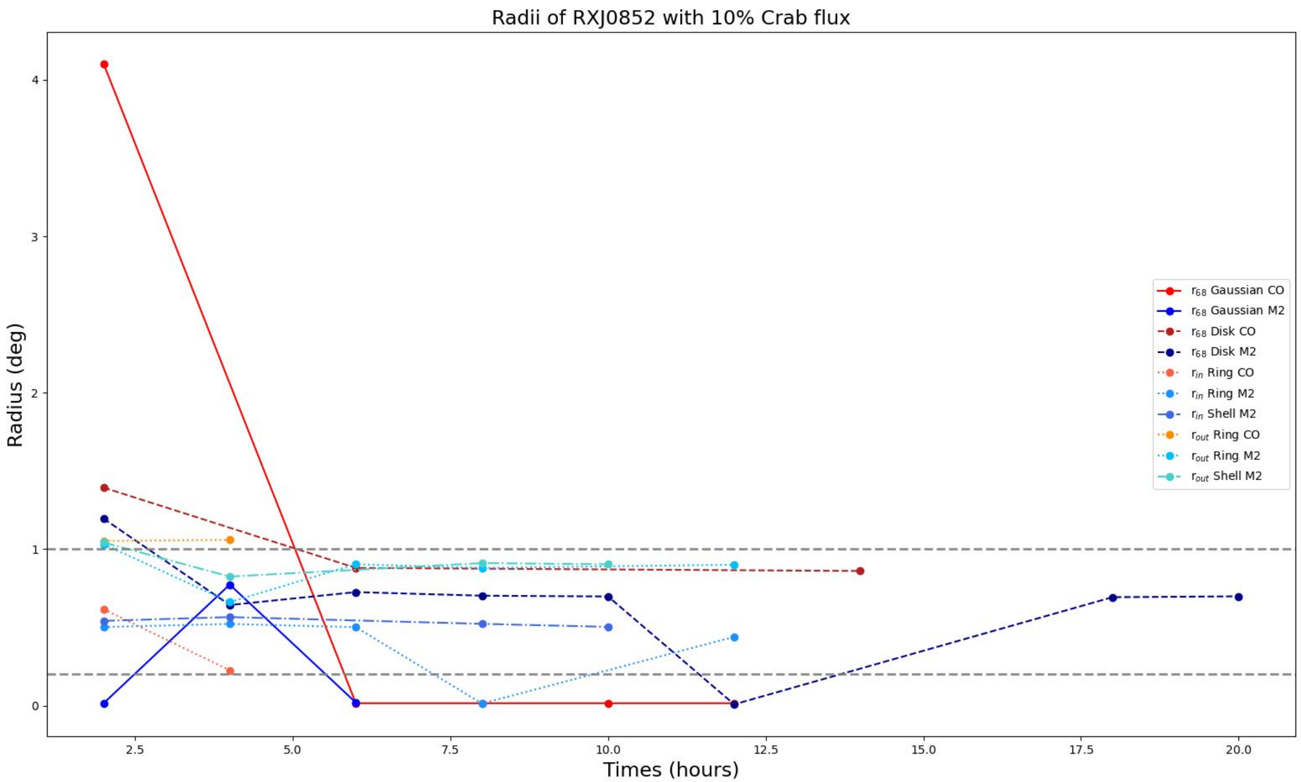
$\Delta AIC = AIC_{model} - AIC_{min}$
AIC_{model} : AIC of one of the models at *i* hours;
AIC_{min} : smallest AIC between all the models at *i* hours
i = 2.0, 4.0, 6.0, 8.0, 10.0...20.0

Radii comparison for RXJ0852.0-4622 (C0 and M2)



The errors on the radii are so big!

Radii comparison for RXJ0852.0-4622 (C0 and M2)



The errors on the radii are so big!