# HIGH-ENERGY VARIABILITY IN PWNE

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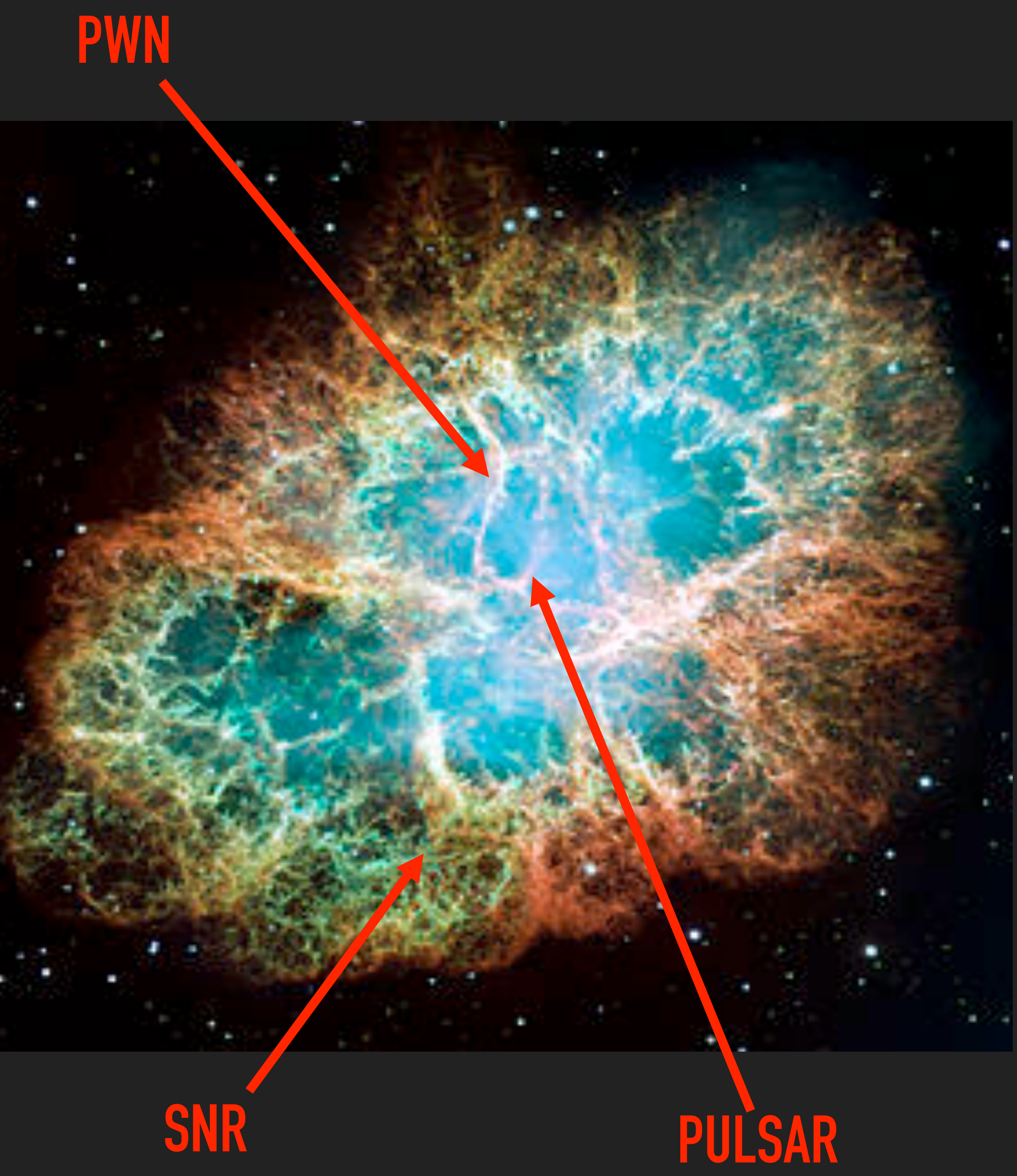
INFN Istituto Nazionale di Fisica Nucleare

# PWNE




PWNe are hot bubbles of relativistic particles and magnetic field emitting non-thermal radiation.

Originated by the interaction of the ultra-relativistic magnetized pulsar wind with the expanding SNR (or with the ISM)

Galactic accelerators. The only place where we can study the properties of relativistic shocks (as in GRBs and AGNs

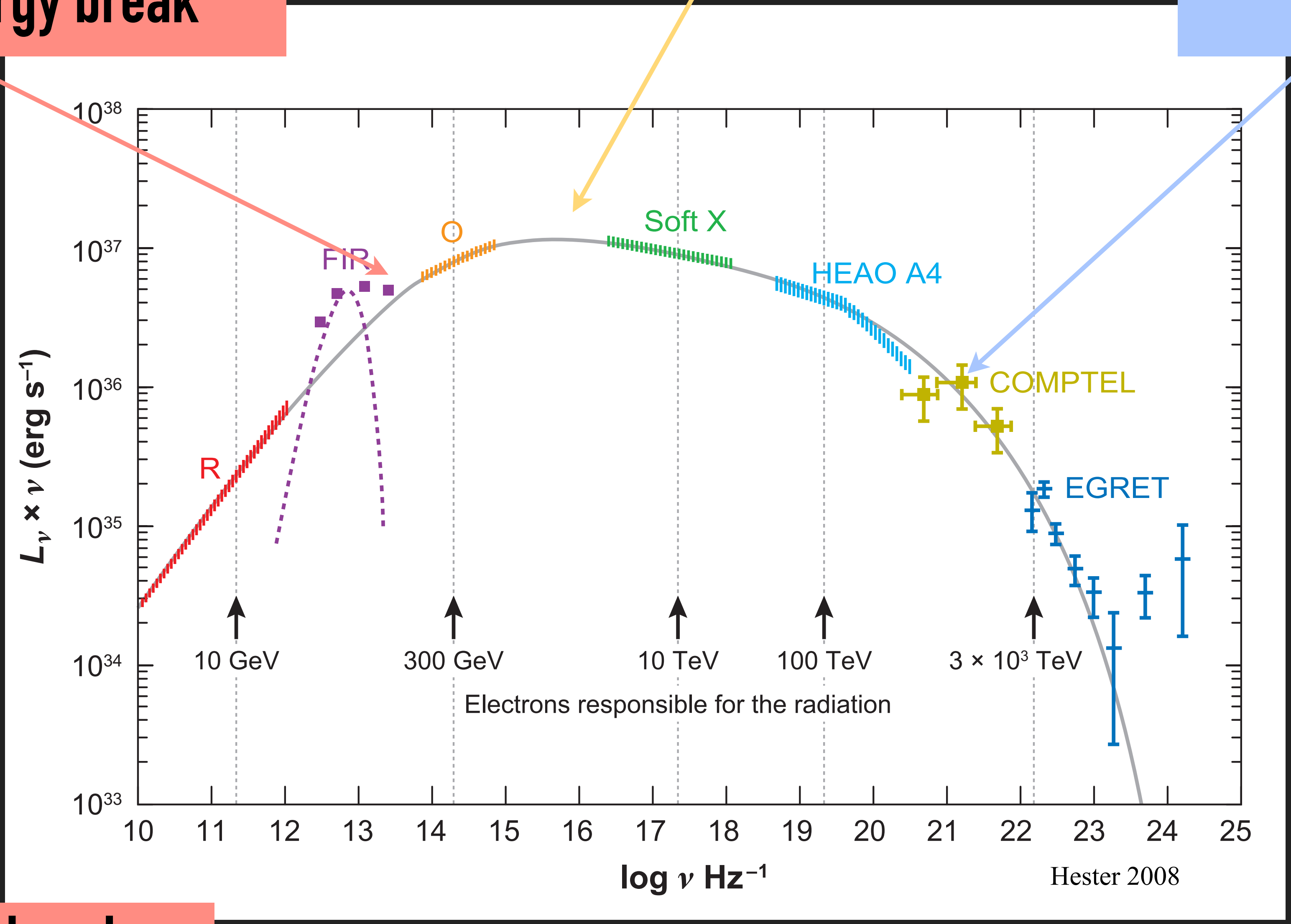
Allow us to investigate the dynamics of relativistic outflows

# CRAB SYNCHROTRON SPECTRUM

High energy break

Low energy break

MeV cutoff




Injection break

Synchr. cooling

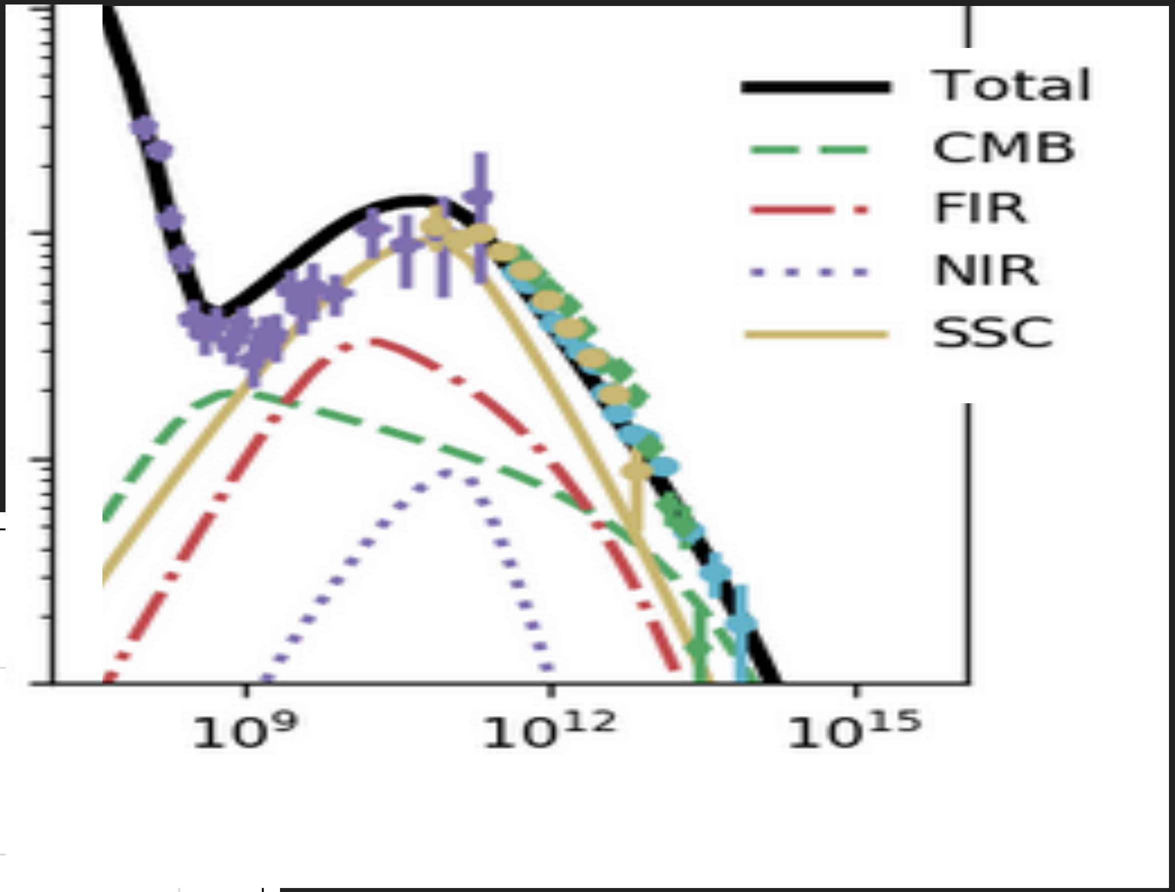
Acceler. cutoff

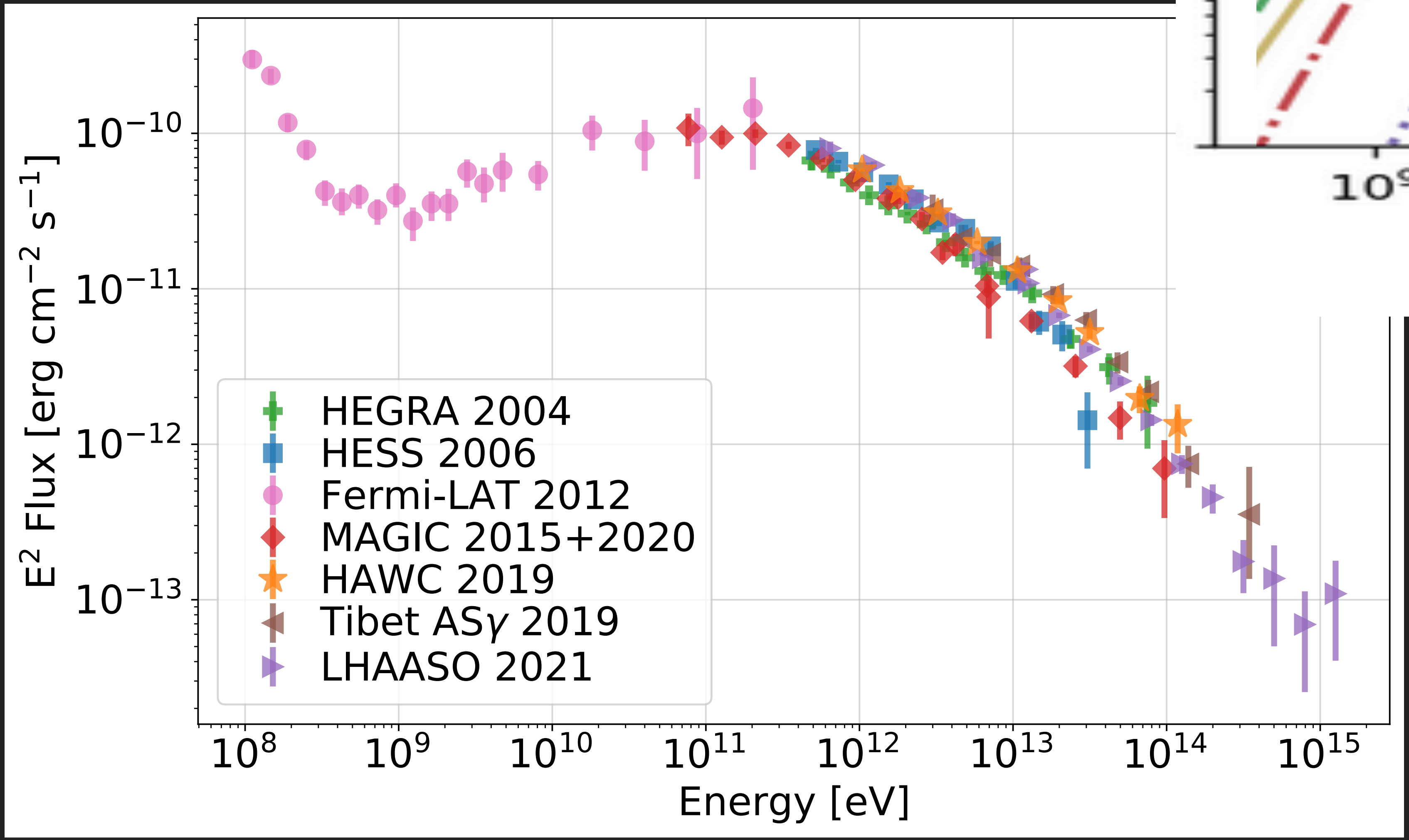
The most efficient non-thermal accelerator.

# IC GAMMA SPECTRUM

ONLY SYSTEM SSC DOMINATED

OTHER PWNE ARE NIR/FIR DOMINATED



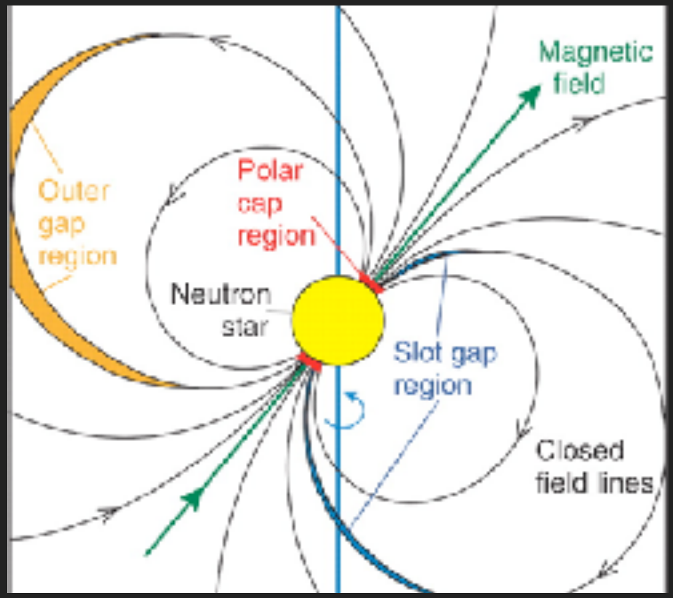




TREND SET BY RADIO-OPT PARTICLES

X-RAY PARTICLES IN KN

# ORIGIN OF THE SYNCHROTRON CUTOFF

## POTENTIAL LIMITED ACCELERATION




$$mc^2\gamma_{max} = e\sqrt{\frac{L}{c}} = e\Phi_{psr}$$

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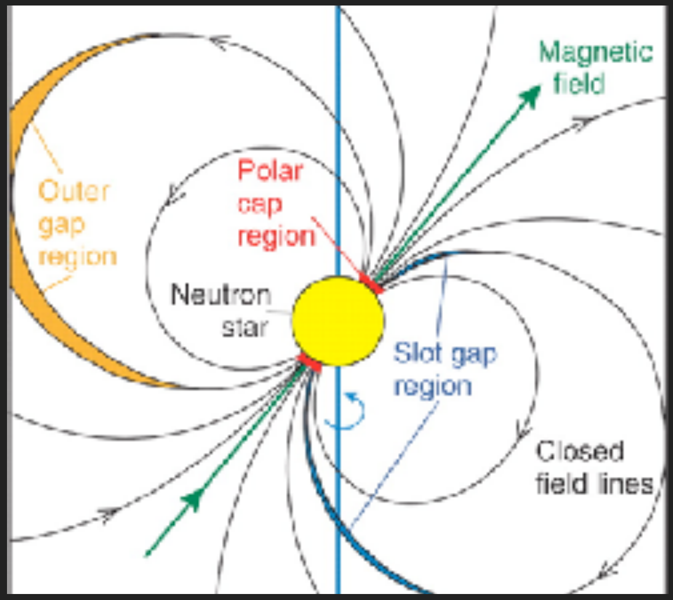


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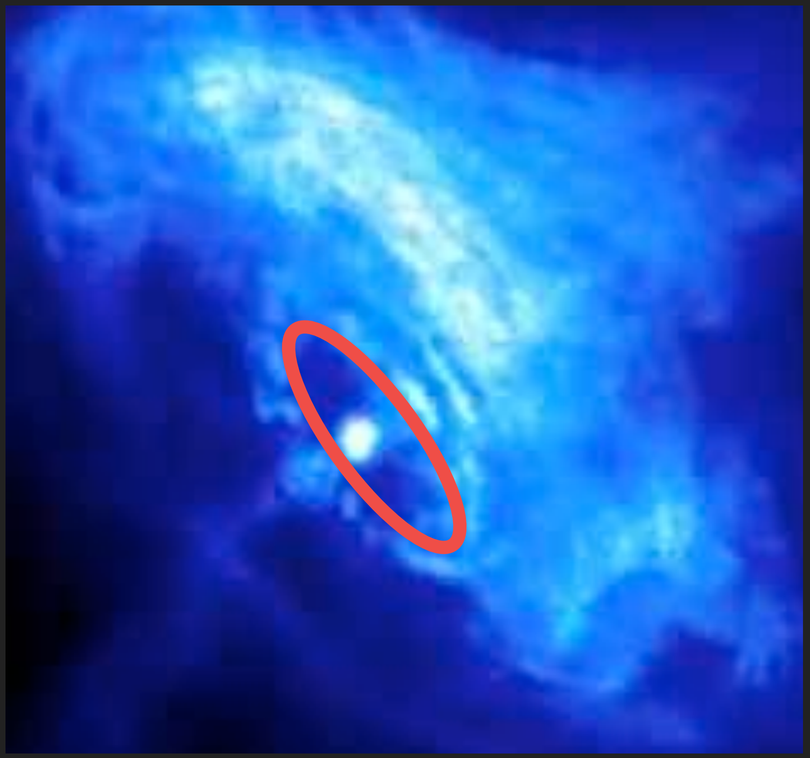


$$\frac{L}{4\pi c R_{ts}^2} = \frac{1}{2}\frac{3Lt}{4\pi R_n^3}$$

$$\frac{L}{4\pi c R_{ts}^2} = P_{neb} = \frac{1}{\sigma}\frac{B_{ts}^2}{8\pi}$$

$$R_{ts} = \frac{1}{B_{ts}}\sqrt{\frac{\sigma L}{c}}$$

$$\frac{eB_{ts}}{mc^2\gamma_{max}} = R_L = R_{ts}$$

$$\frac{mc^2\gamma_{max}}{eB_{ts}} = R_L = R_{ts}$$

$$\frac{E_{max}}{eB_{ts}} = e\sqrt{\frac{\sigma L}{c}} = e\Phi_{psr}\sqrt{\sigma}$$

## ACCELERATION LIMIT AT THE TS

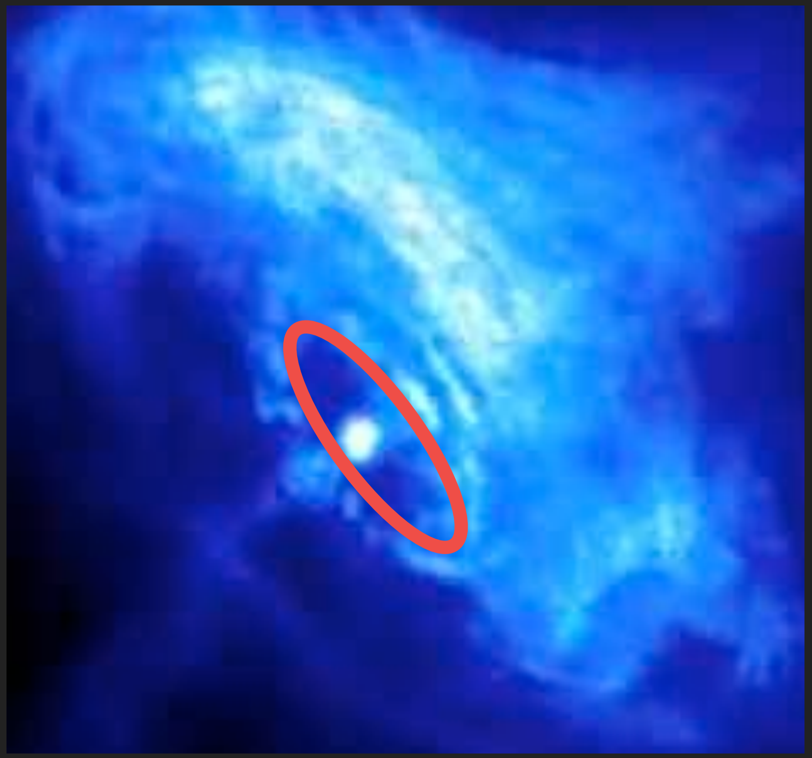
**MAGNETISATION IN THE CRAB IS JUST BELOW EQUIPARTITION**
**B ~ 150-120 UG**

# ORIGIN OF THE SYNCHROTRON CUTOFF

## LOSS LIMITED ACCELERATION

## COMPARING GYRO-PERIOD WRT SYNCH COOLING TIME

$$\tau_{gyr} = \frac{mc\gamma}{eB} \qquad \tau_{syn} = \frac{3m^3c^5}{2e^4B^2\gamma} \qquad \gamma_{max} \simeq 10^8 \frac{1}{\sqrt{B}}$$



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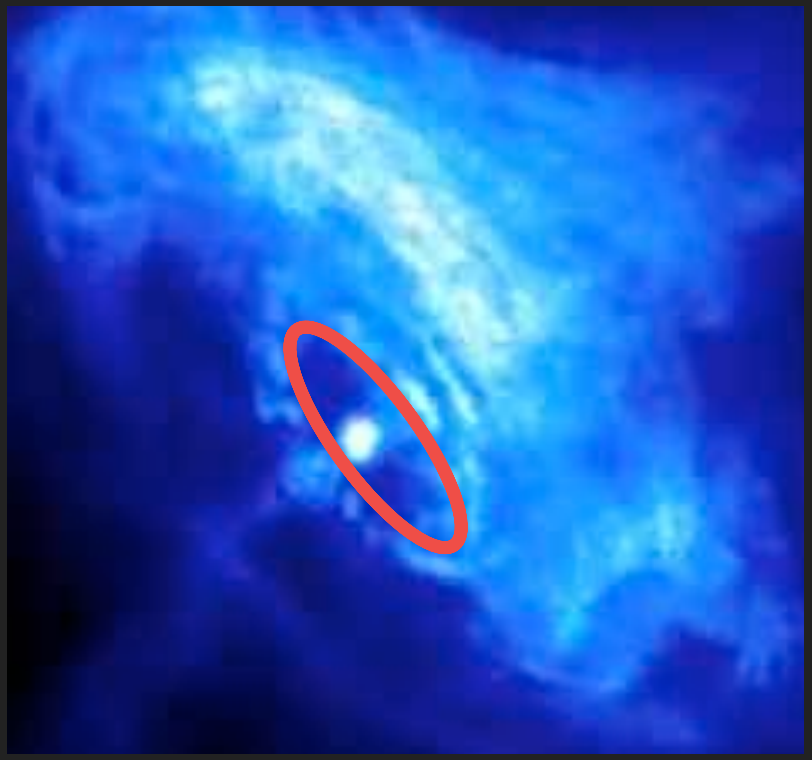

## MAXIMUM FREQUENCY IS FIXED

$$\nu_{syn,max} \simeq 150 MeV$$

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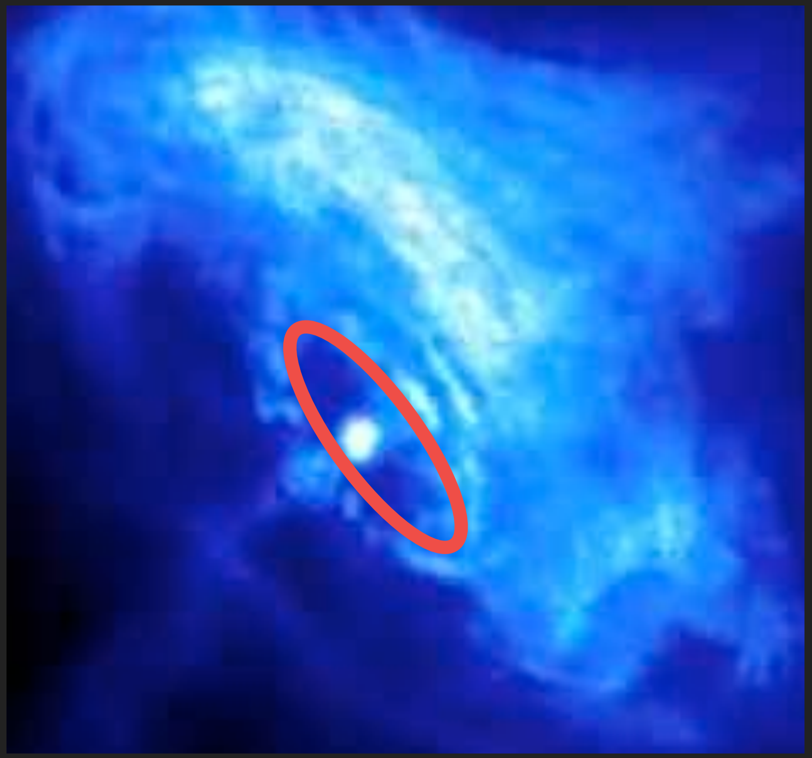

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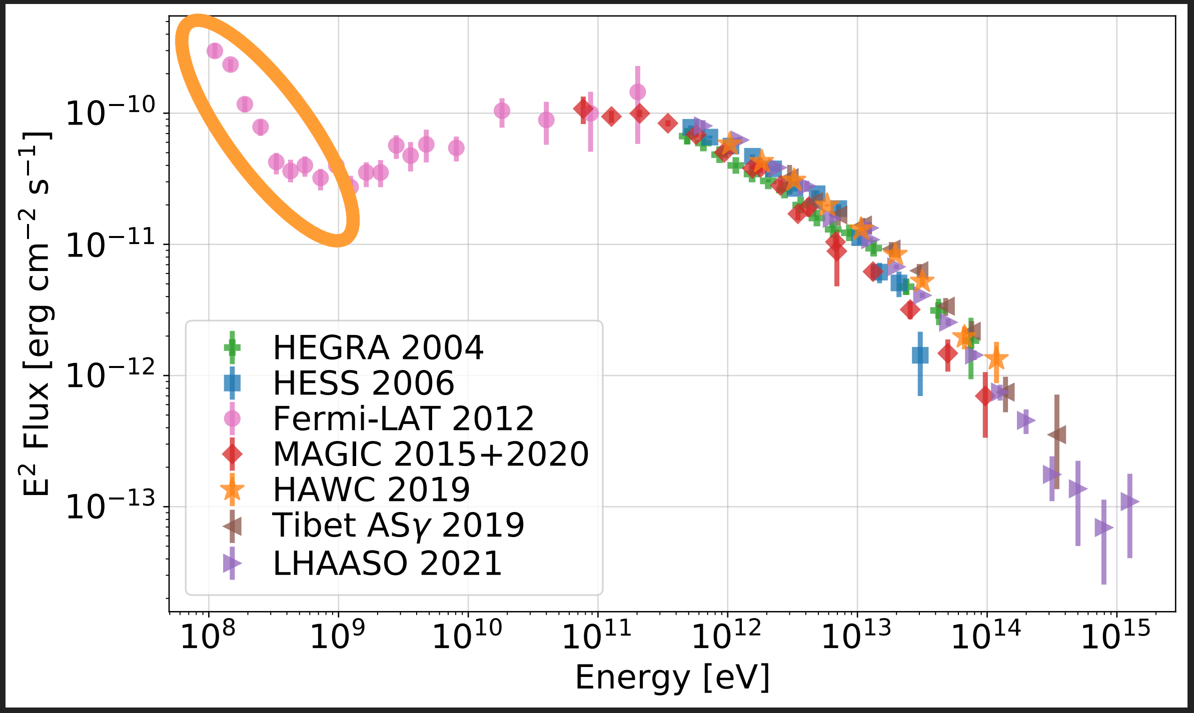
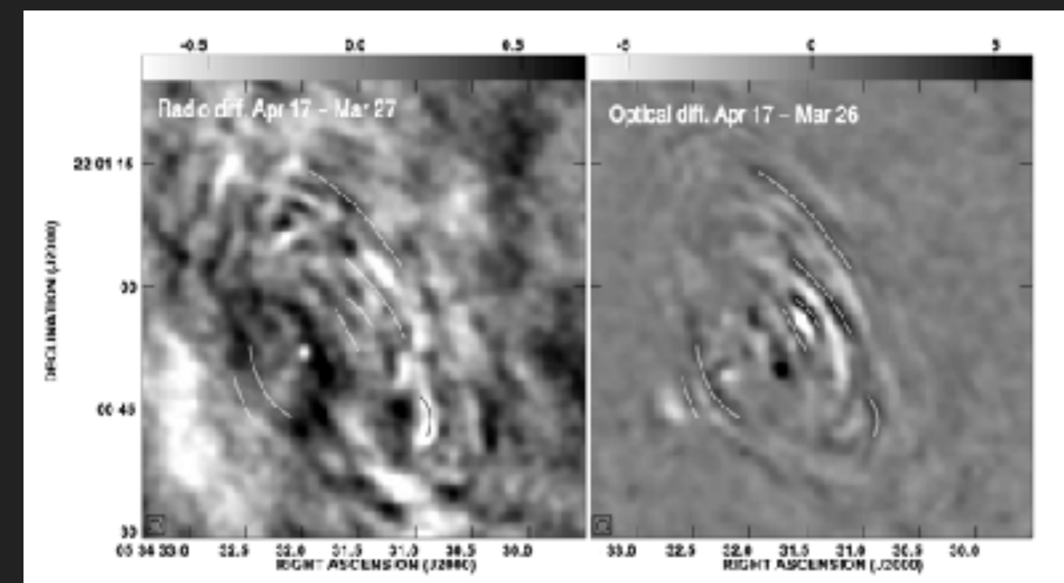
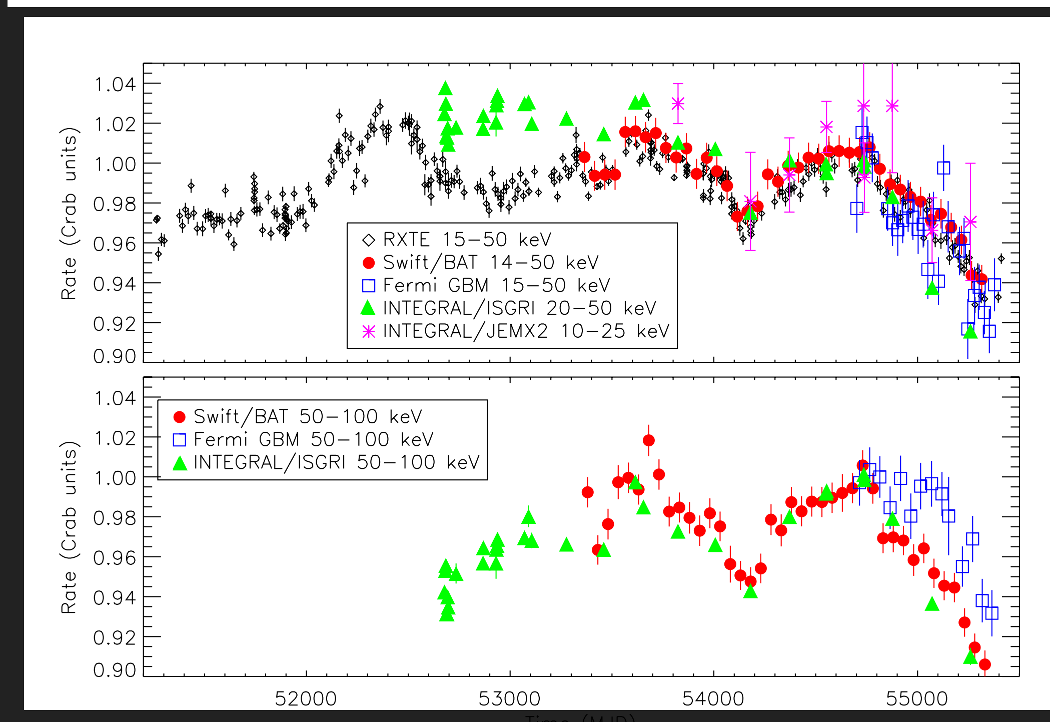
## IN CRAB THE LIMITS ALL COINCIDE

## OTHERS ALL POTENTIAL LIMITED



# VARIABILITY AT LOW ENERGY



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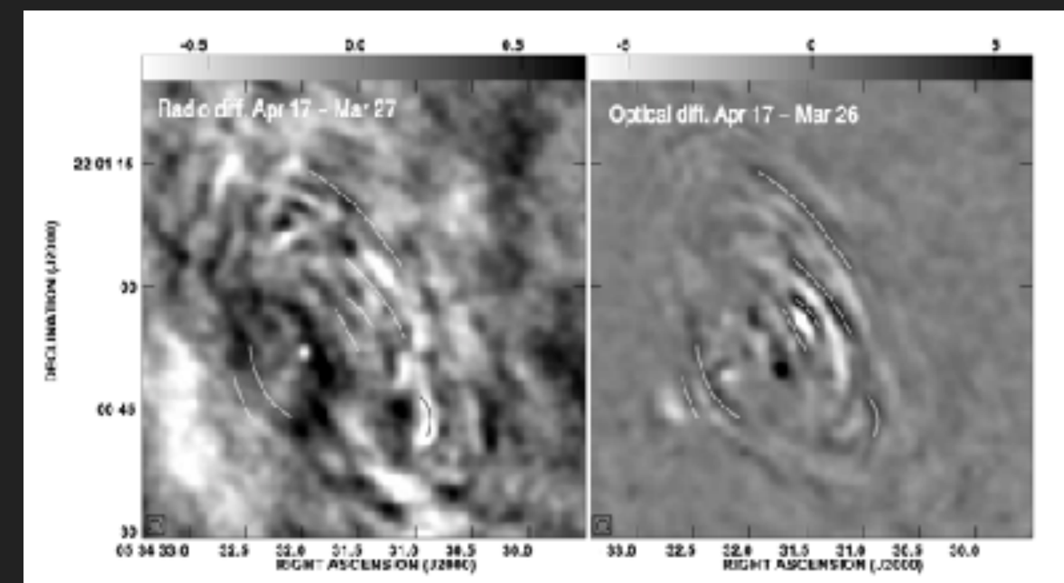


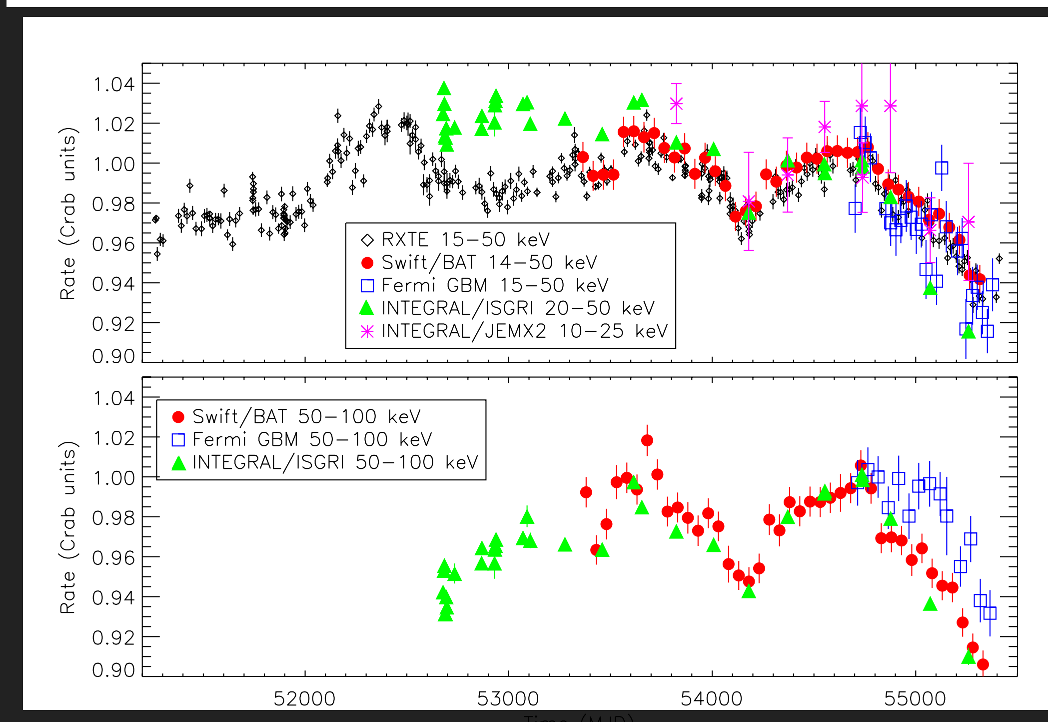

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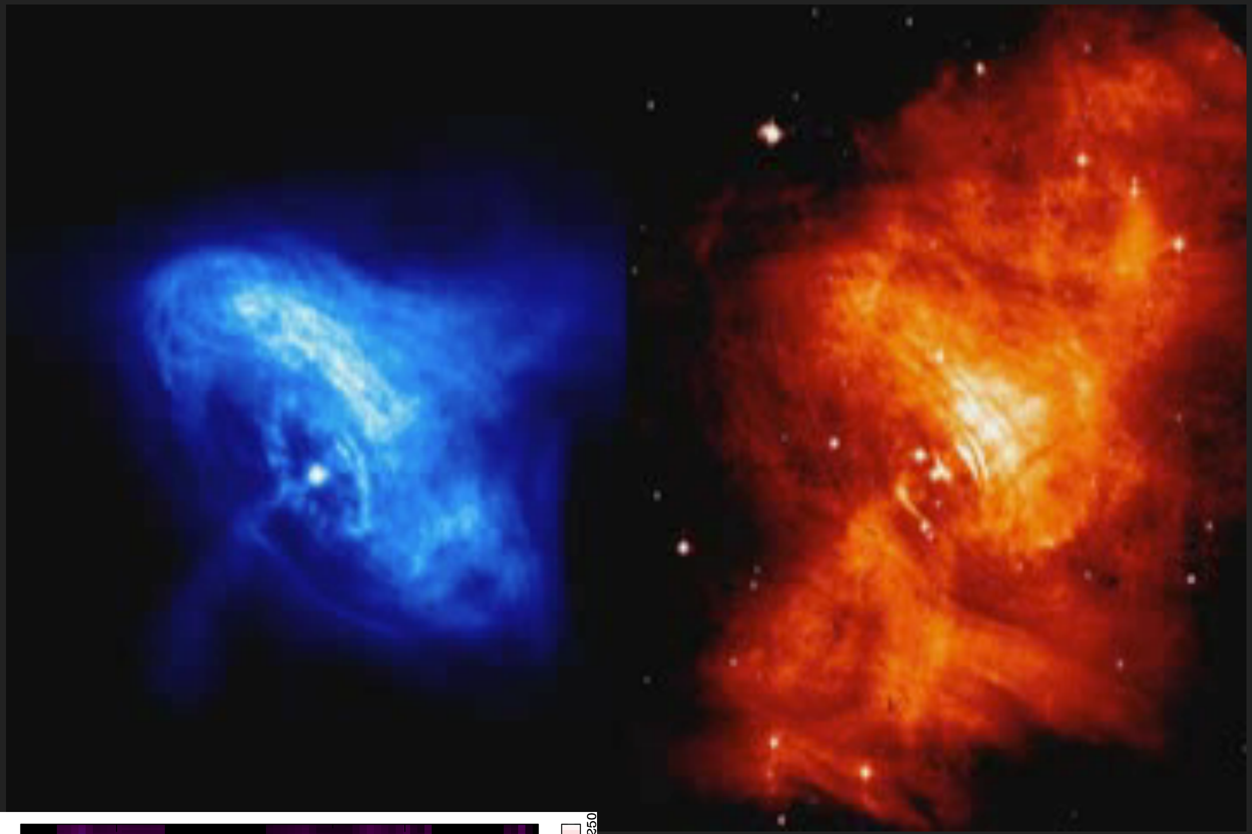

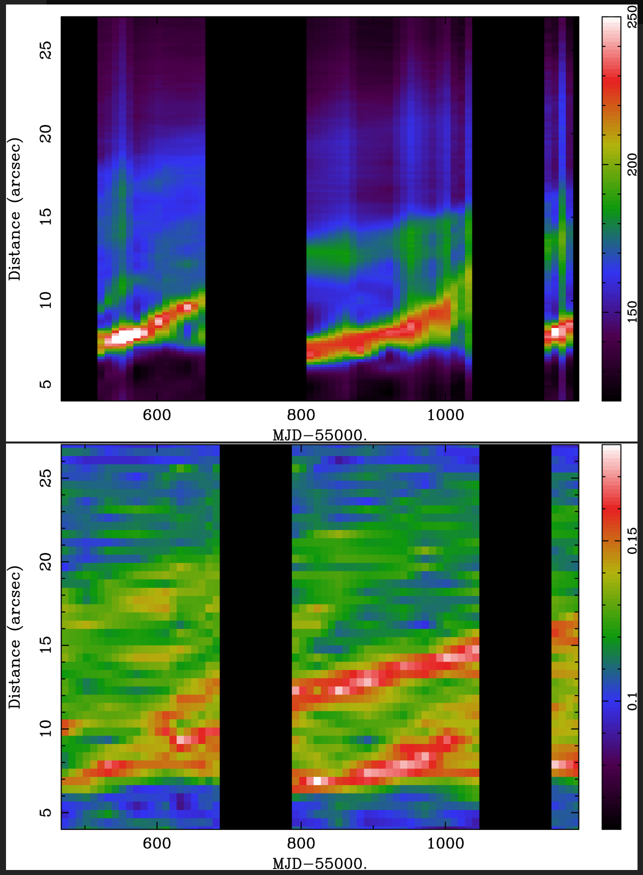


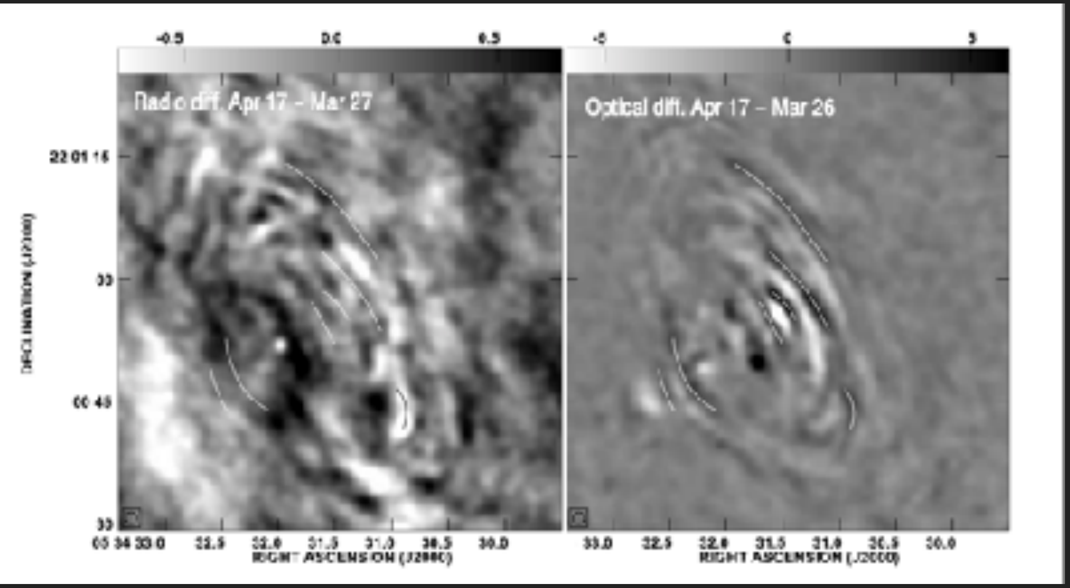


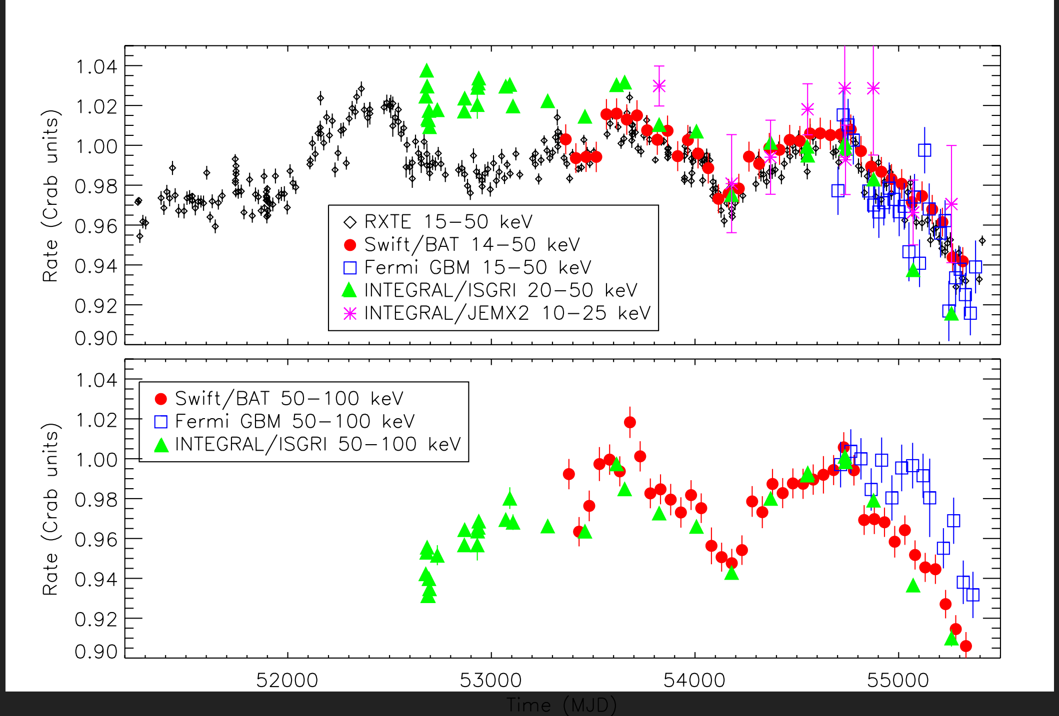

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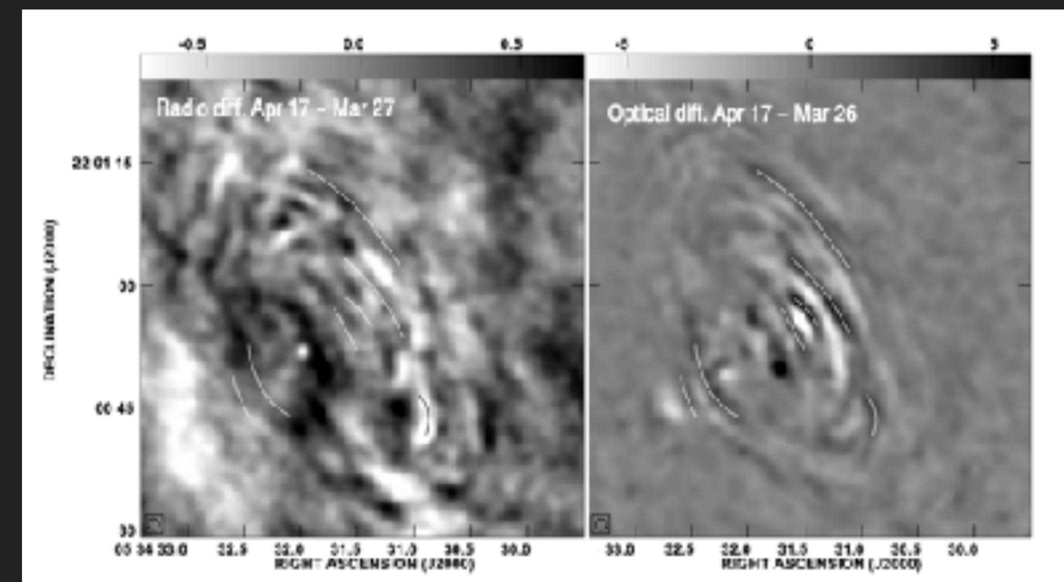


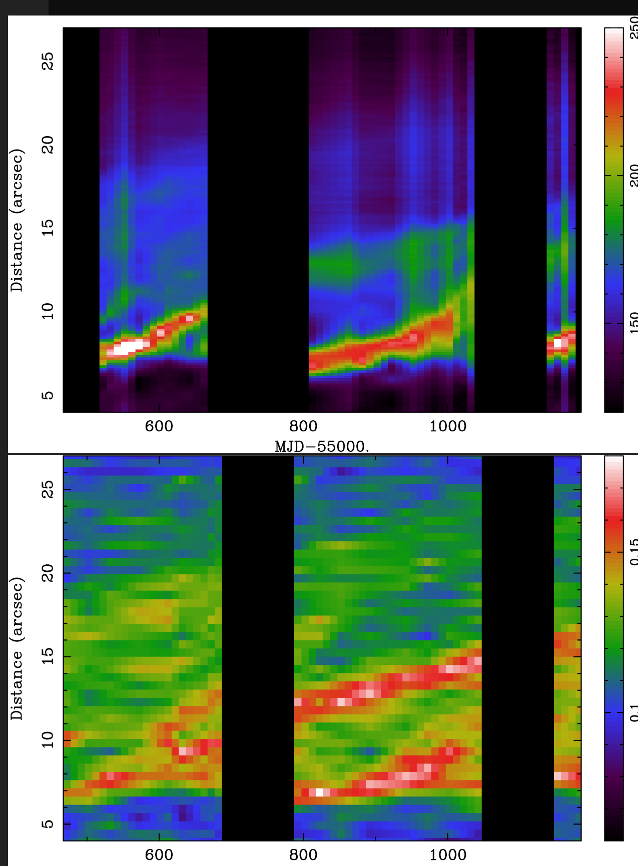


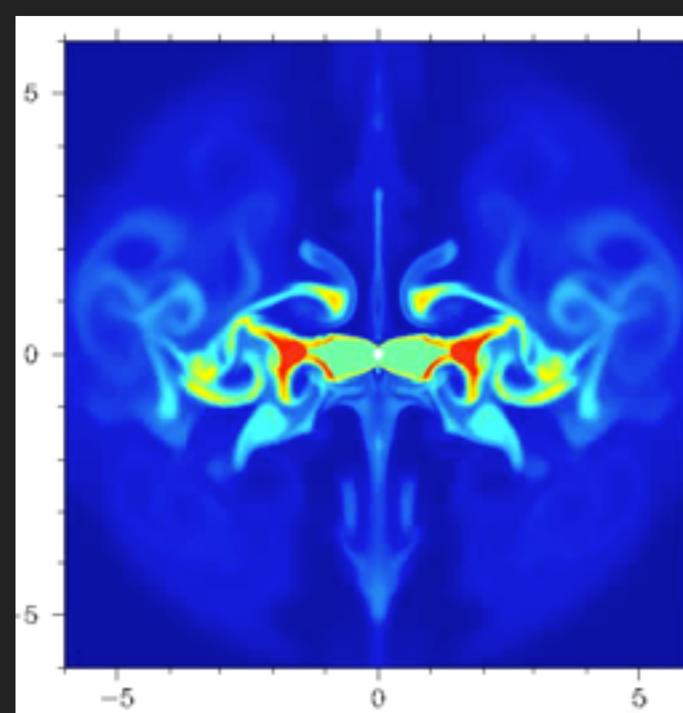

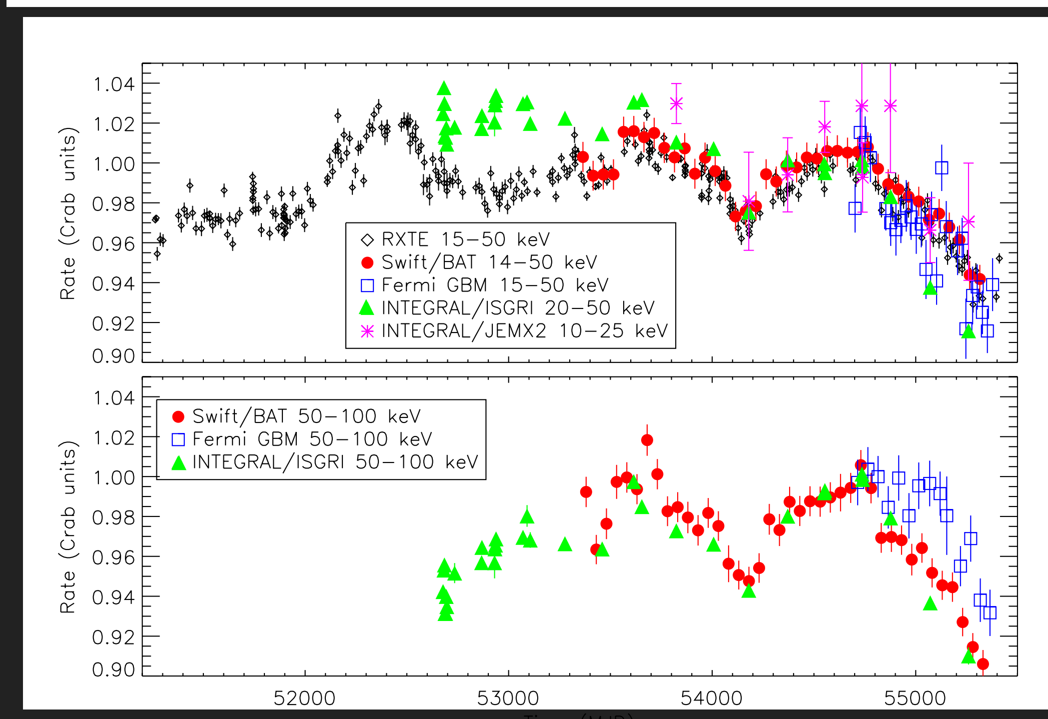

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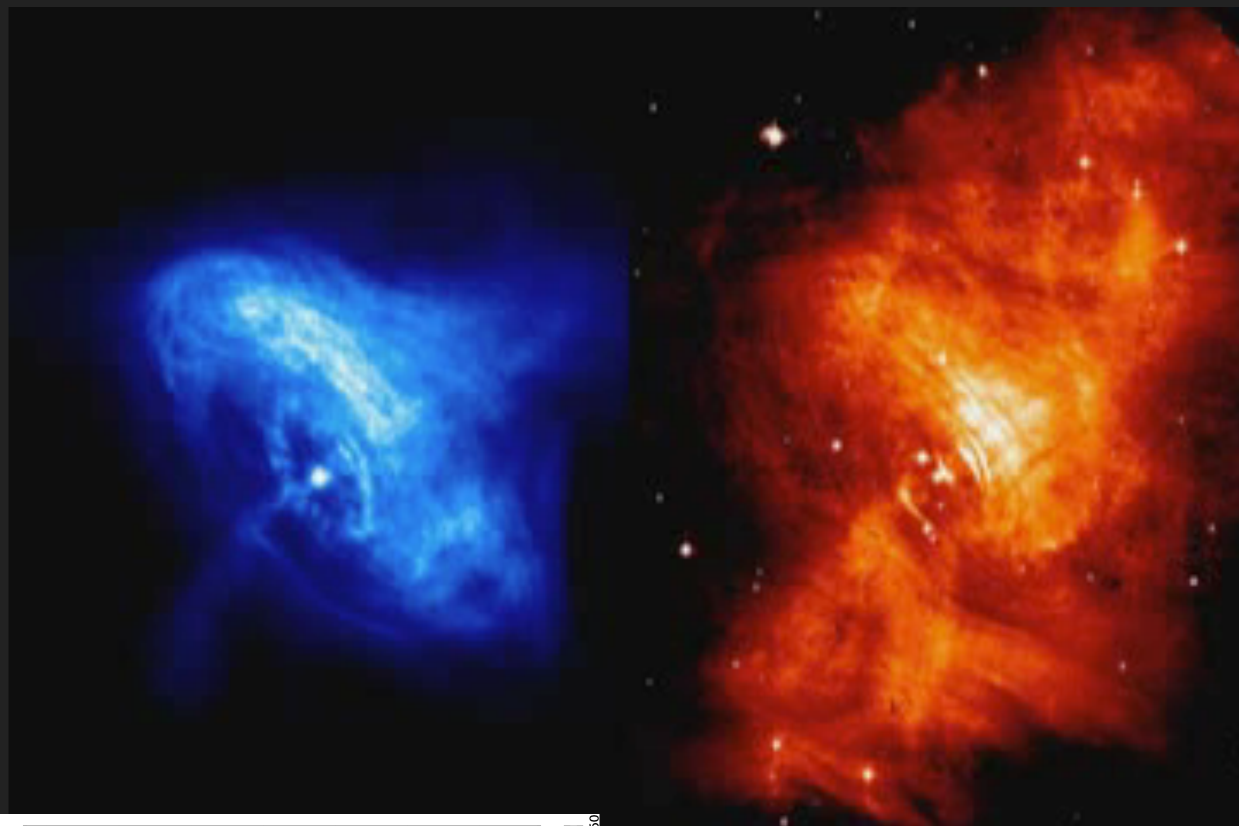
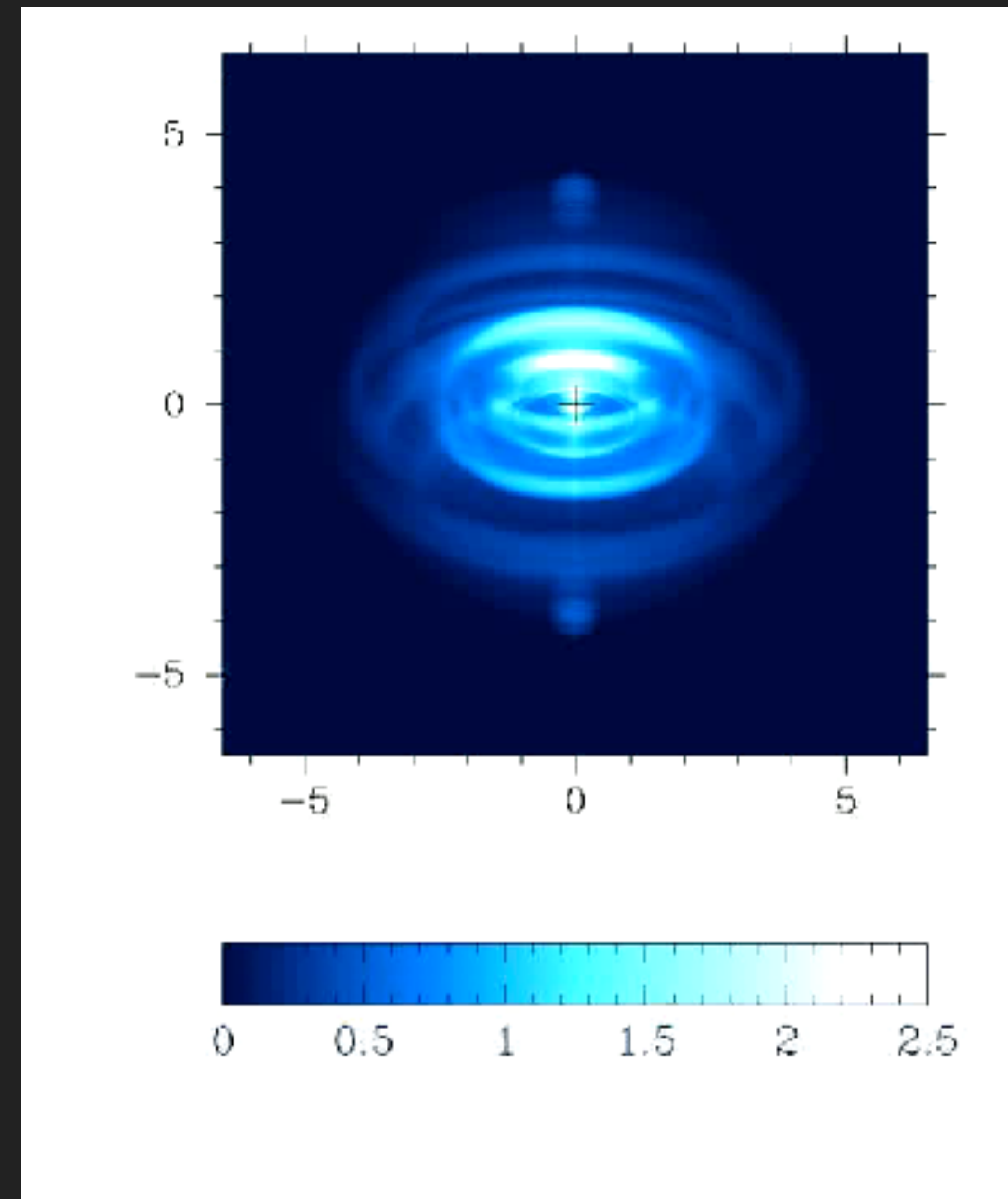
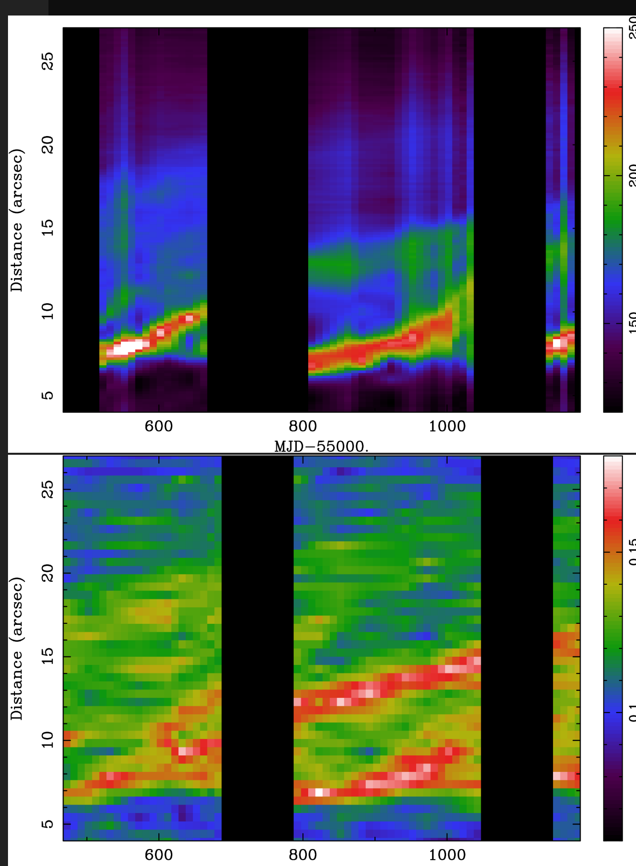
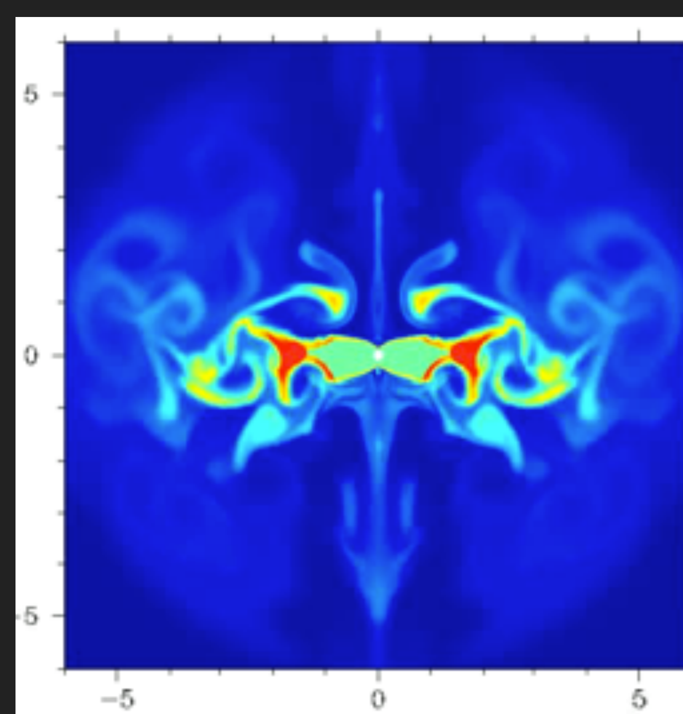
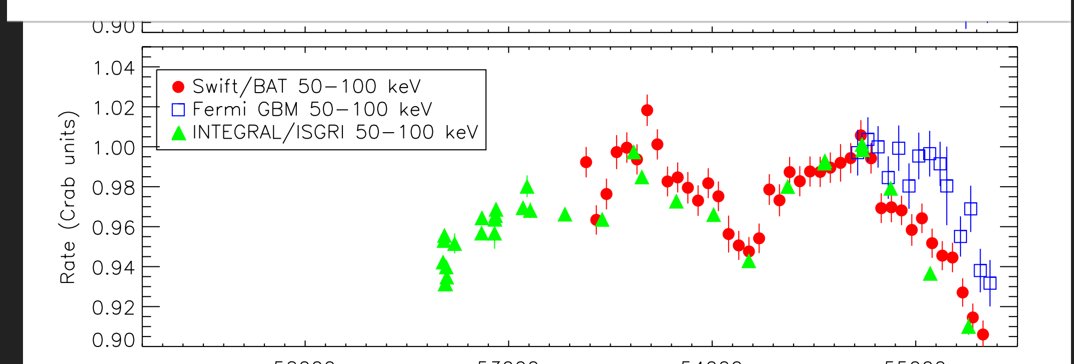




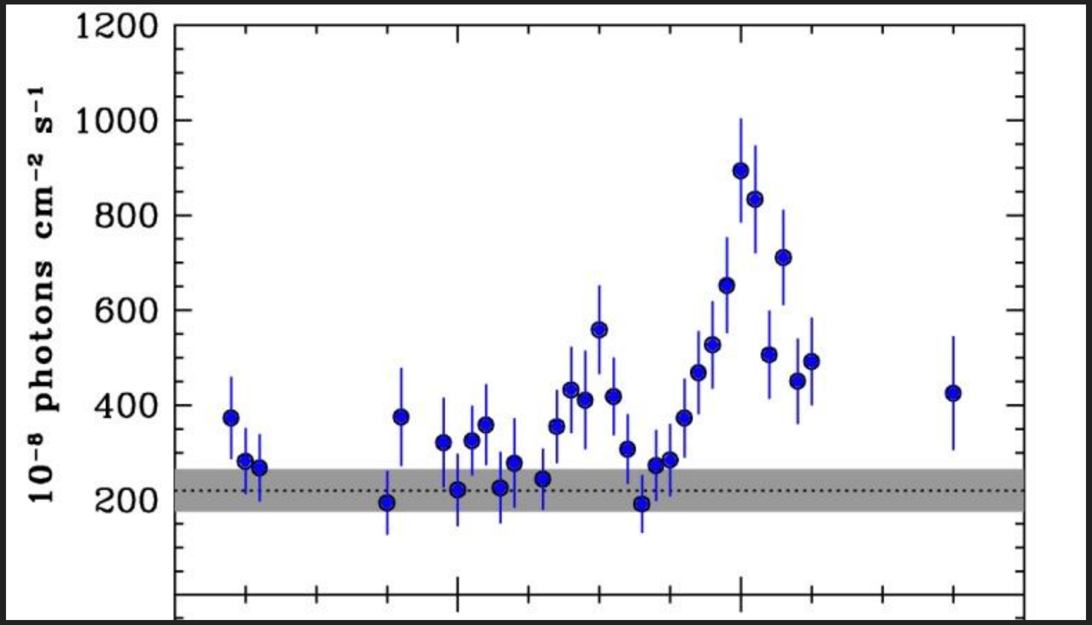



# 2010 FLARE

## ~4 TIME OVER QUIESCENT



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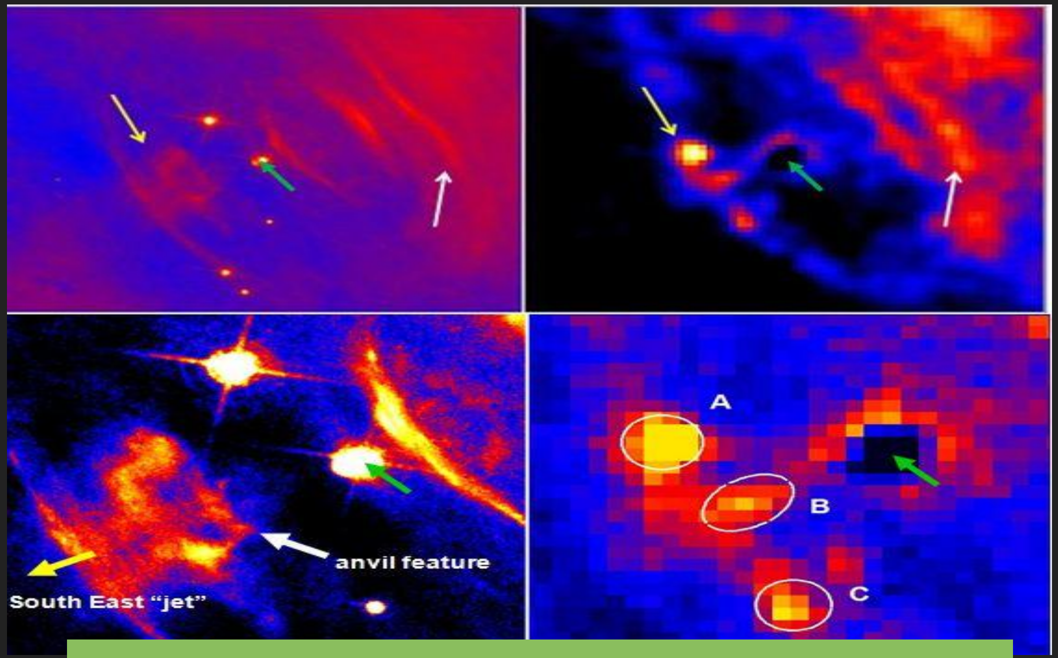
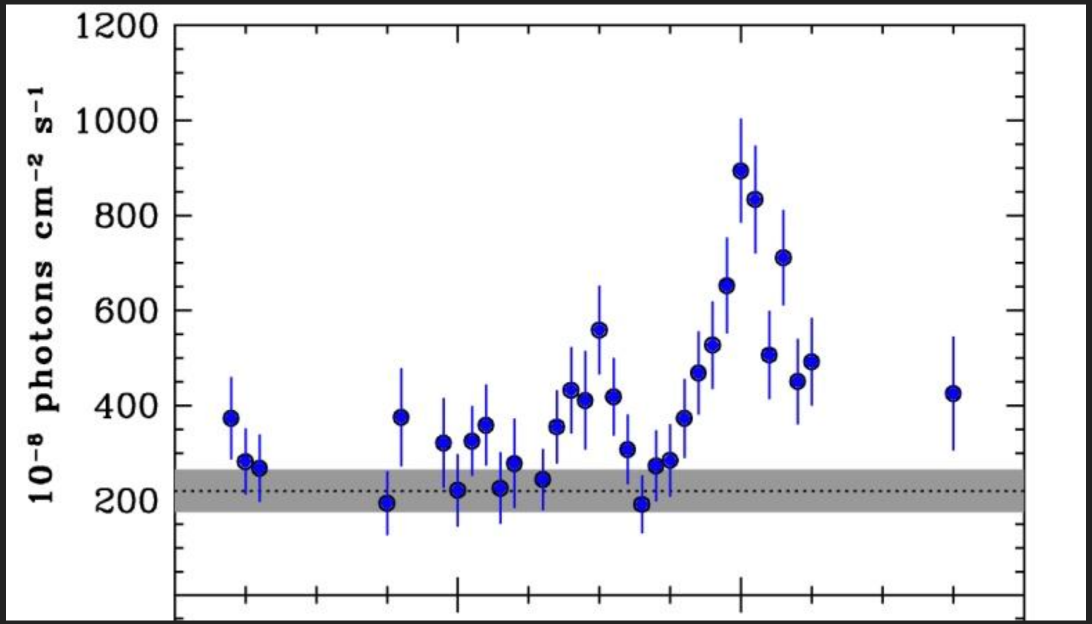



MINOR EVIDENCE IN X

~4 TIME OVER QUIESCENT



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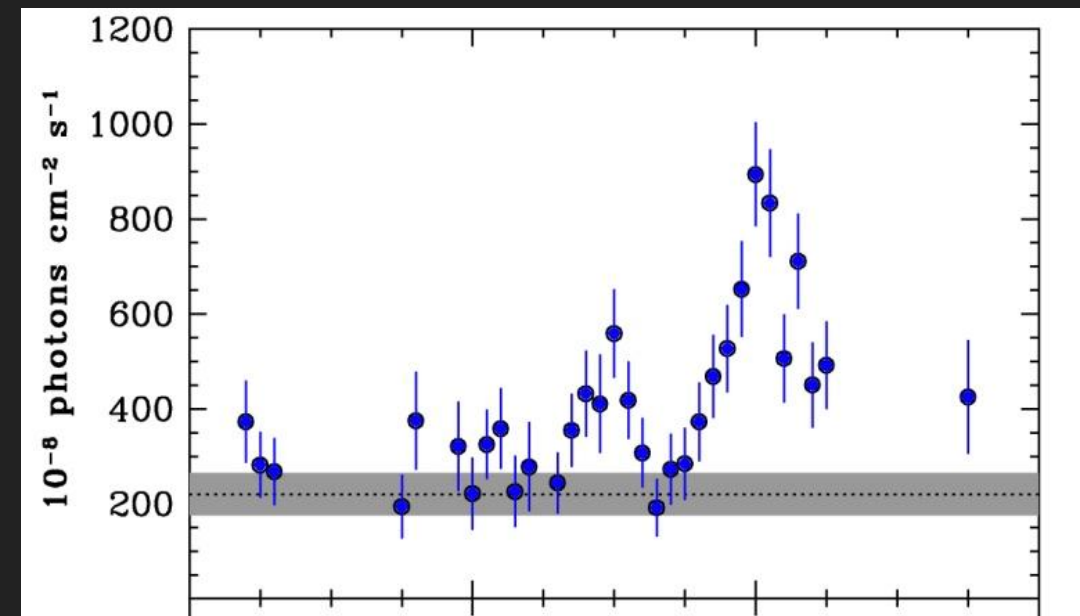


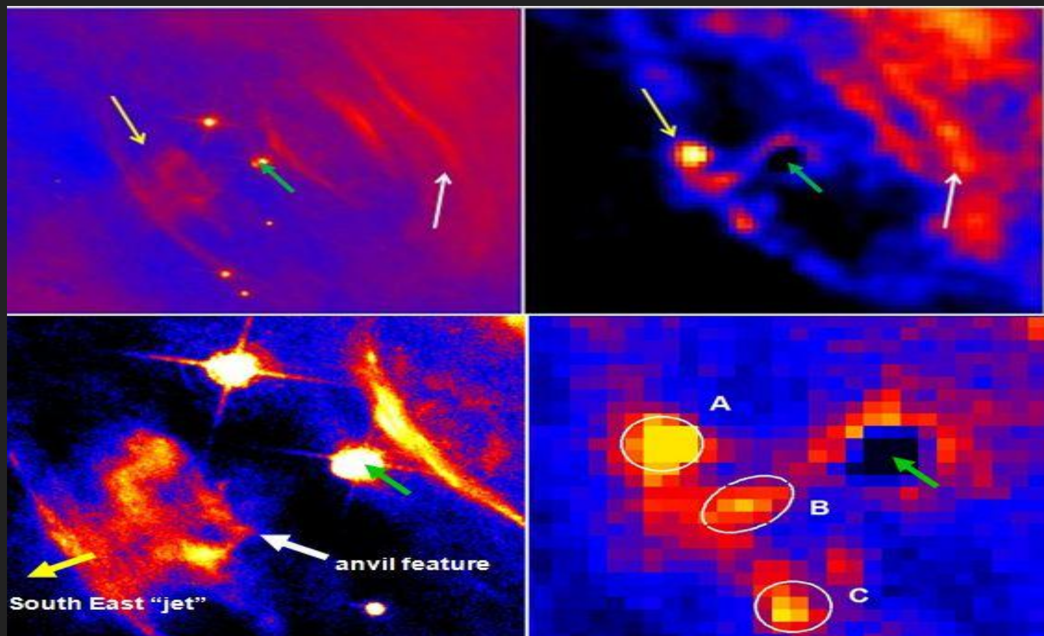


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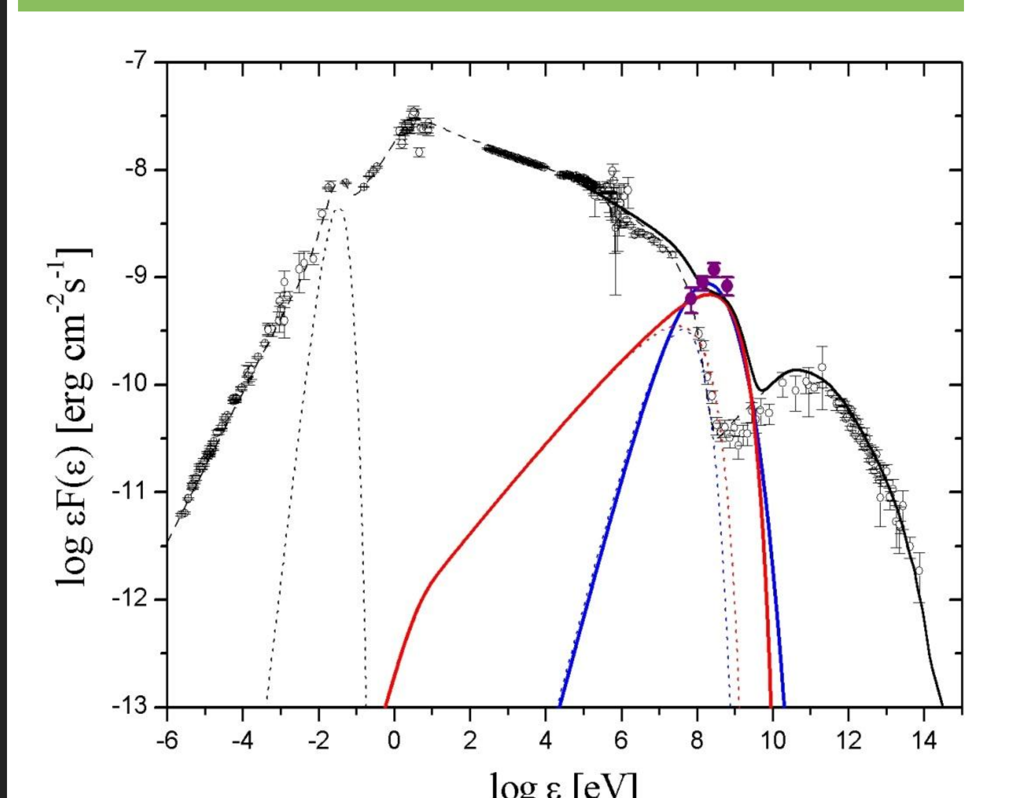

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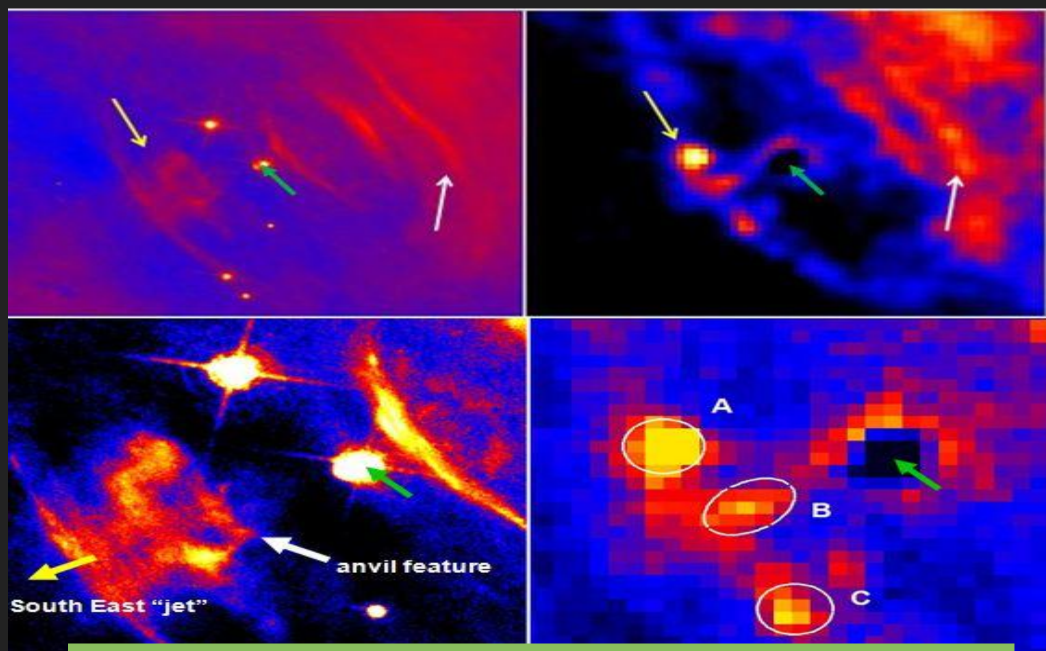


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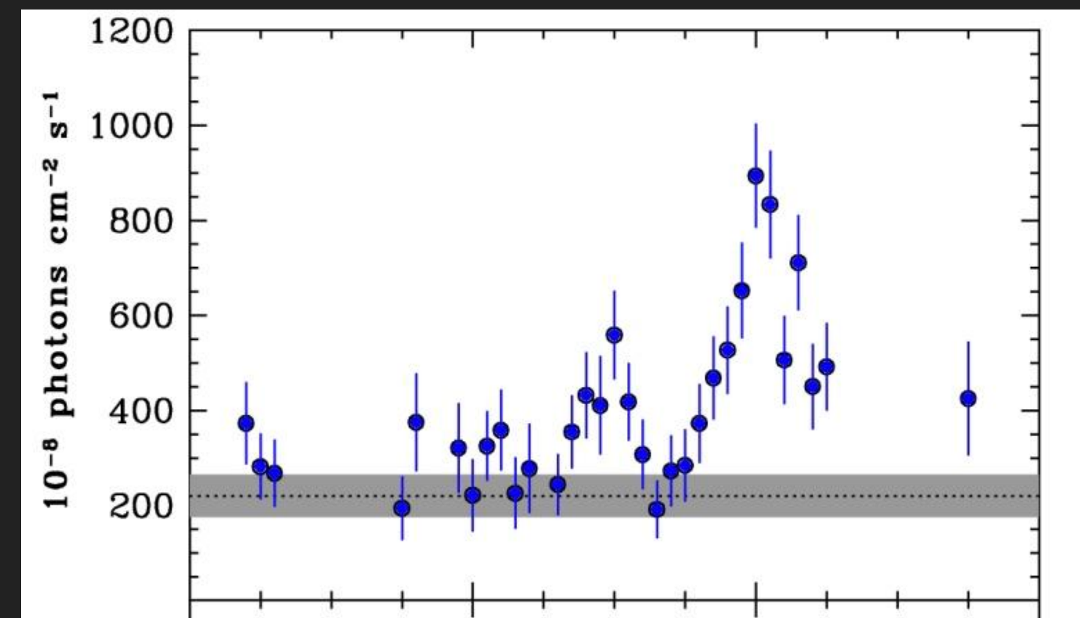


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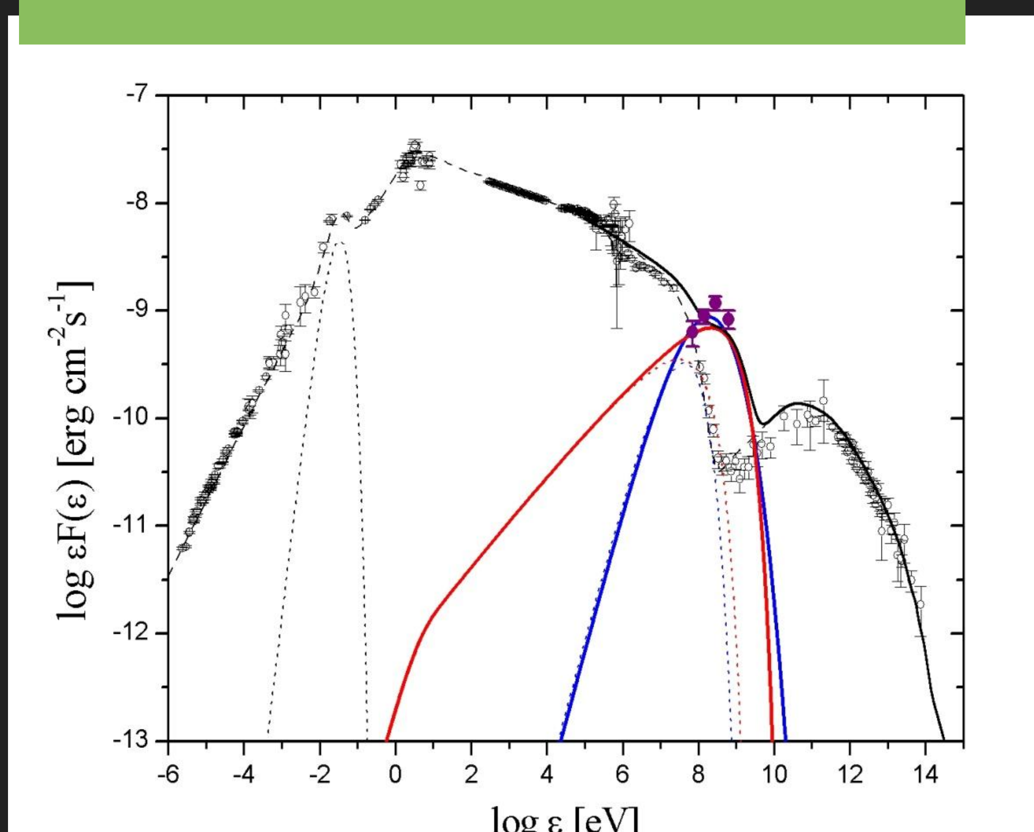
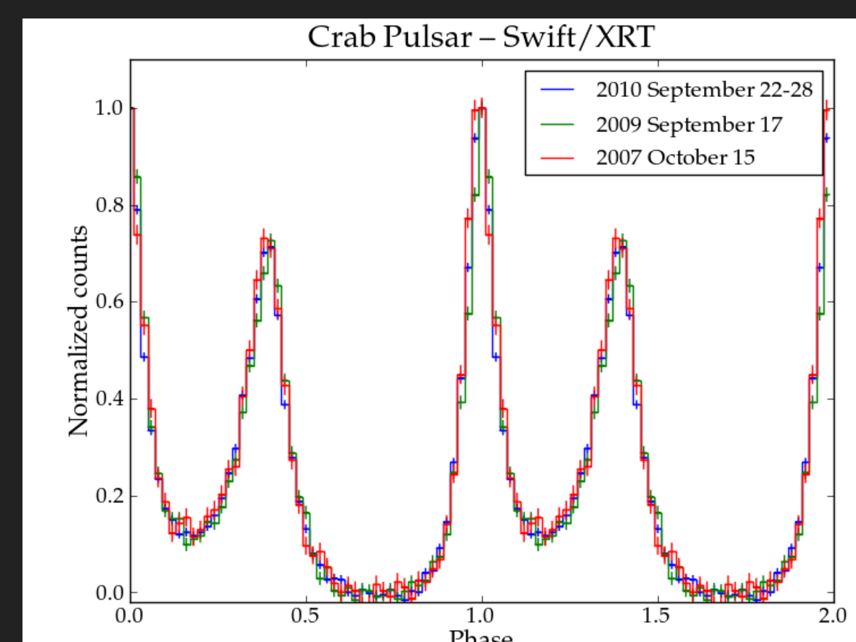
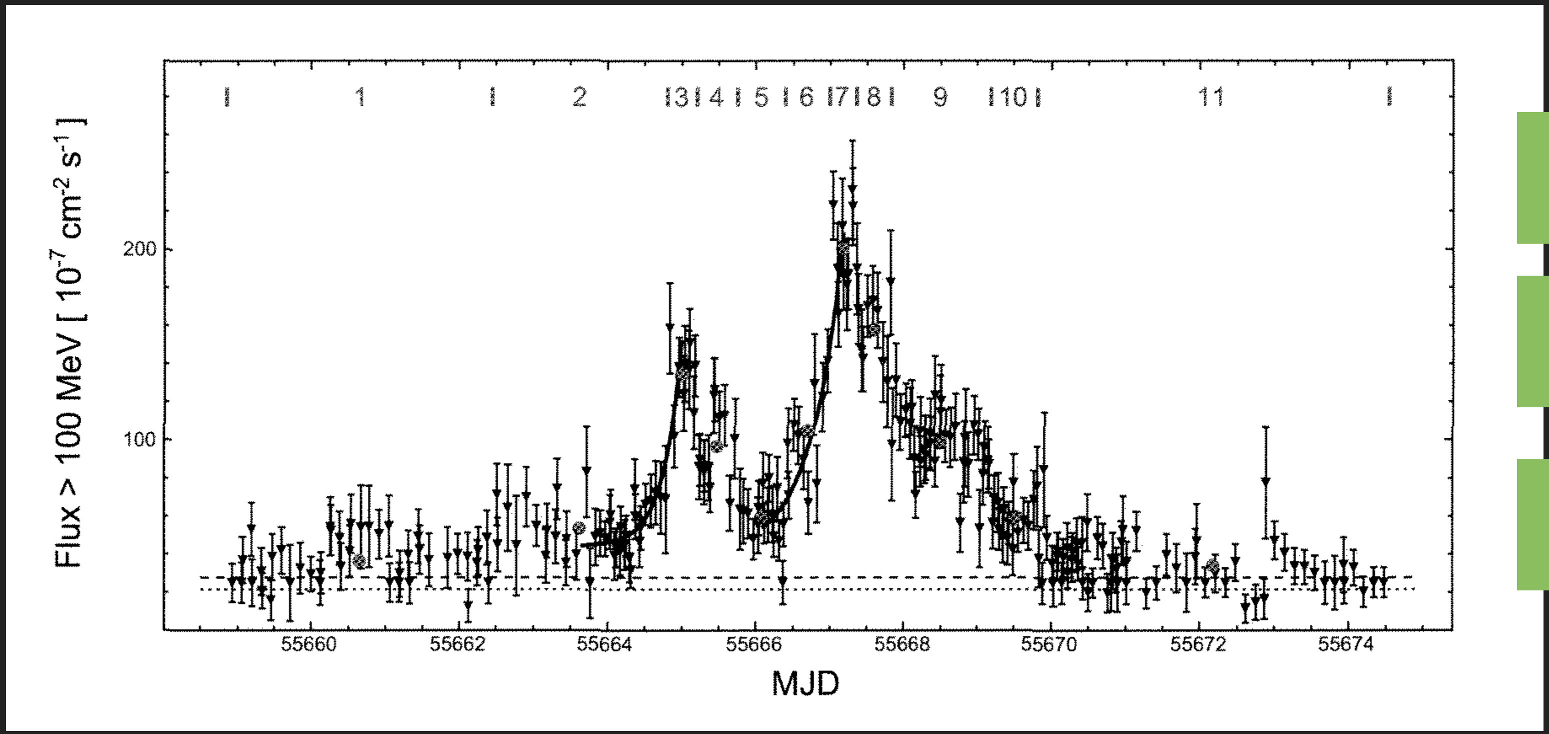



## NO CHANGE IN PSR



# 2011 FLARE




25 TIMES ABOVE QUIESCENT

FLARE IS STRUCTURED

FLARE DURATION DAYS-WEEK

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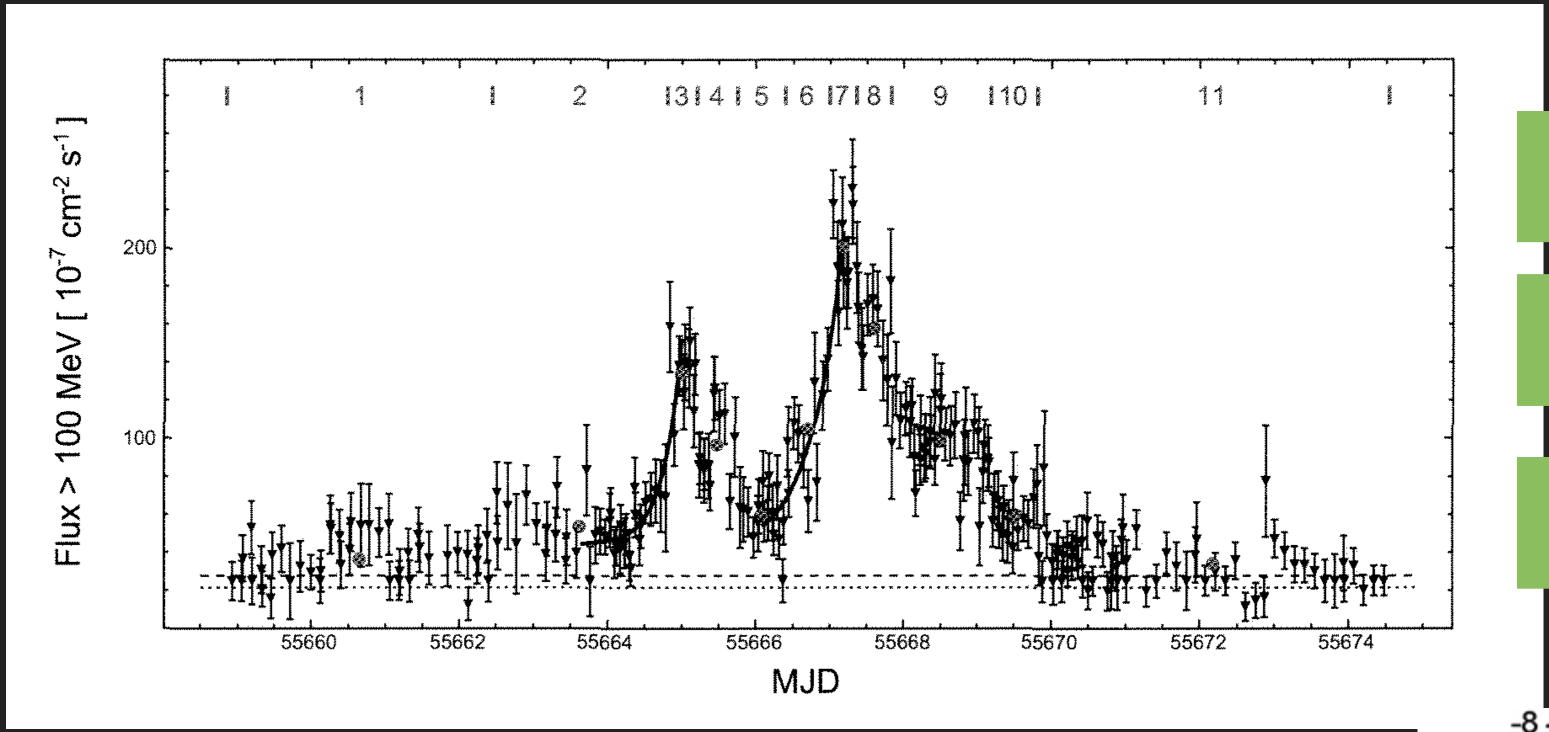



25 TIMES ABOVE QUIESCENT

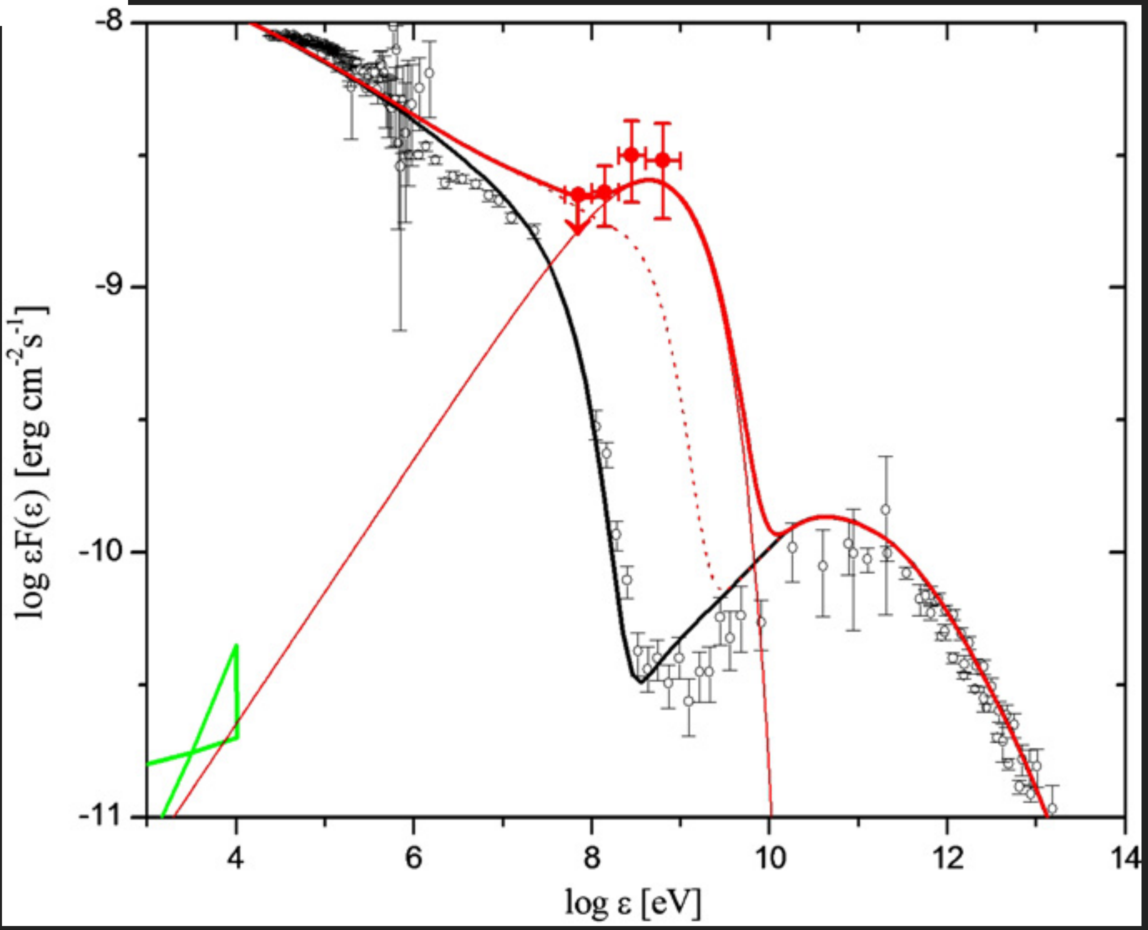
FLARE IS STRUCTURED

FLARE DURATION DAYS-WEEK

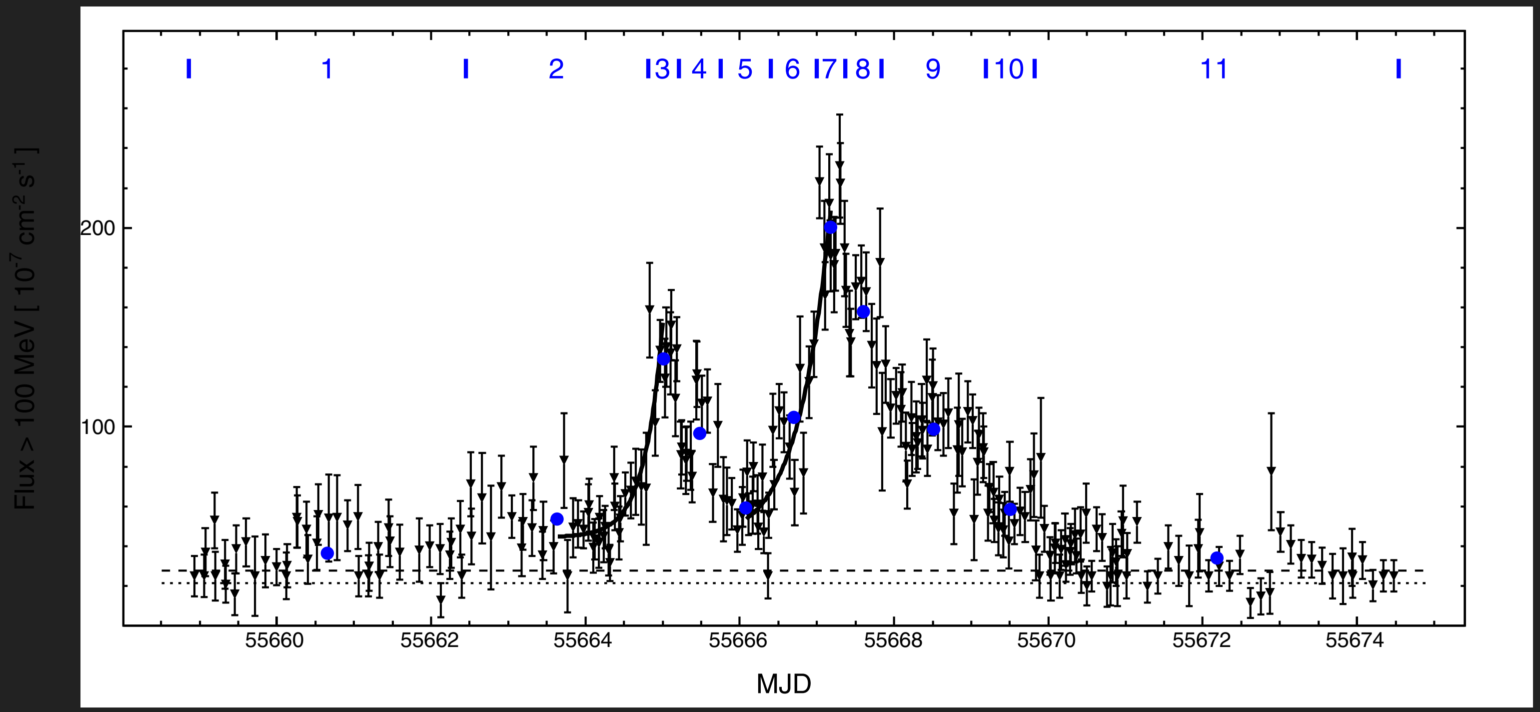
COMPATIBLE WITH ALMOST MONOCHROMATIC

REQUIRES DOPPLER BOOSTING

LOCATION – KNOT?



# SPECTRAL EVOLUTION



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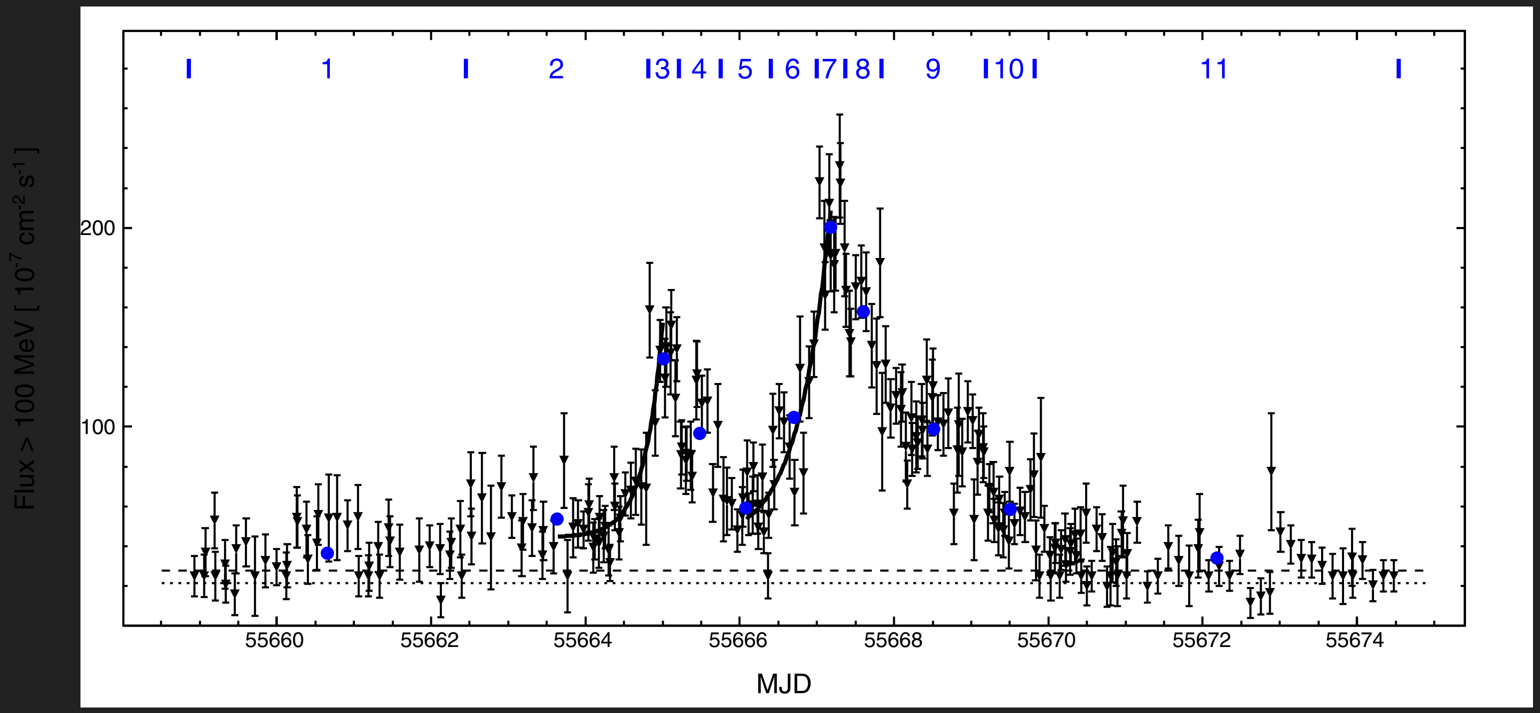


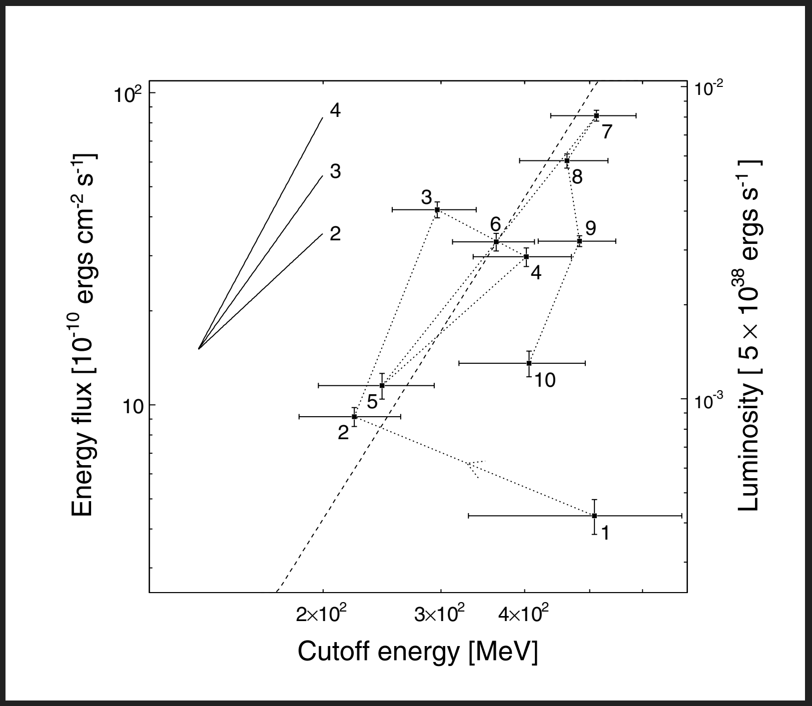


## CUTOFF ENERGY IS HIGHER AT PEAK

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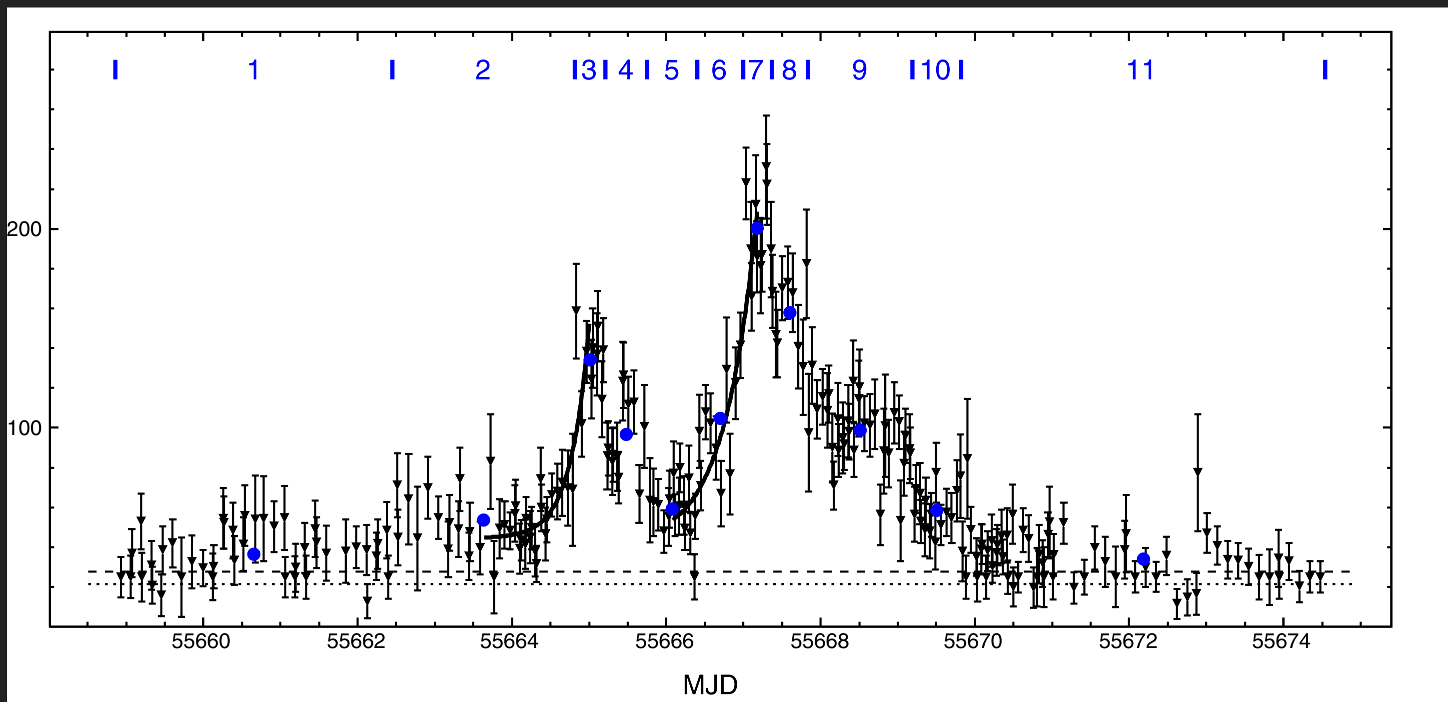
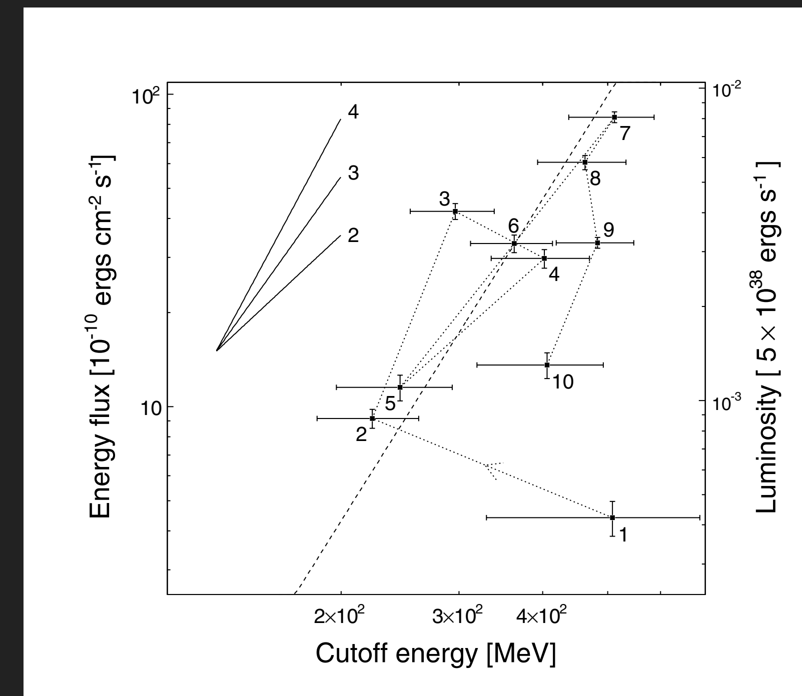


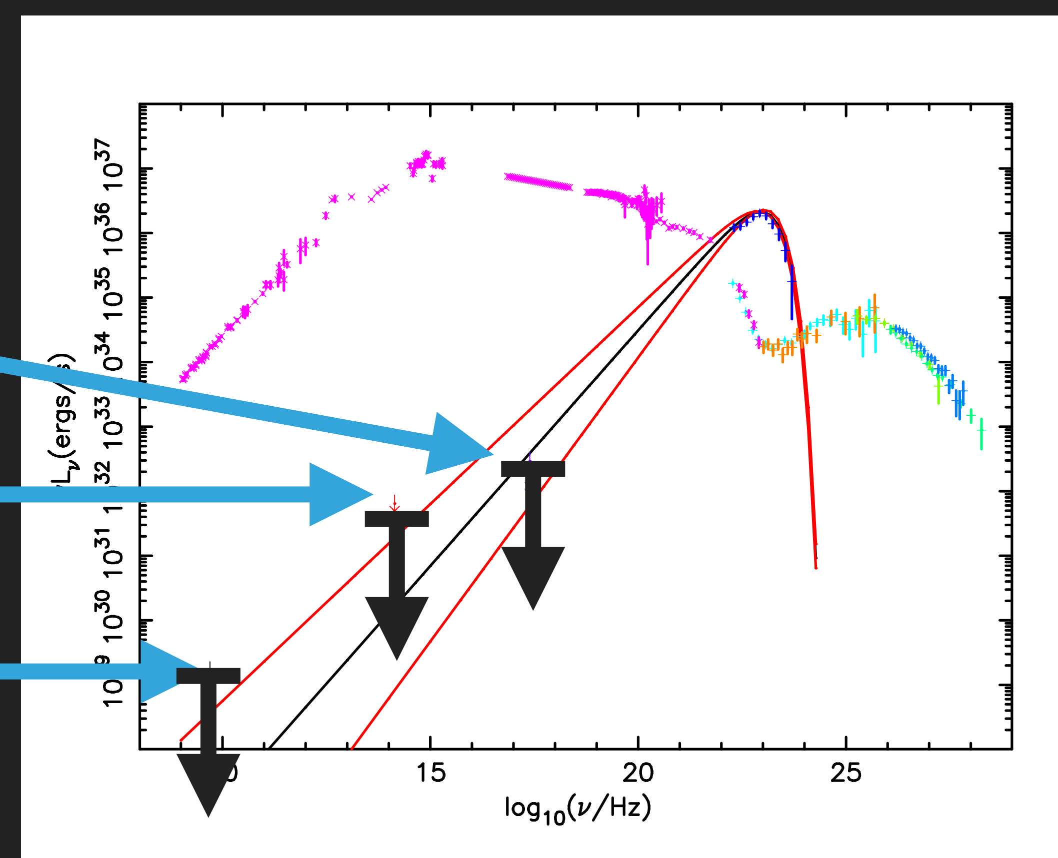




## CUTOFF ENERGY IS HIGHER AT PEAK

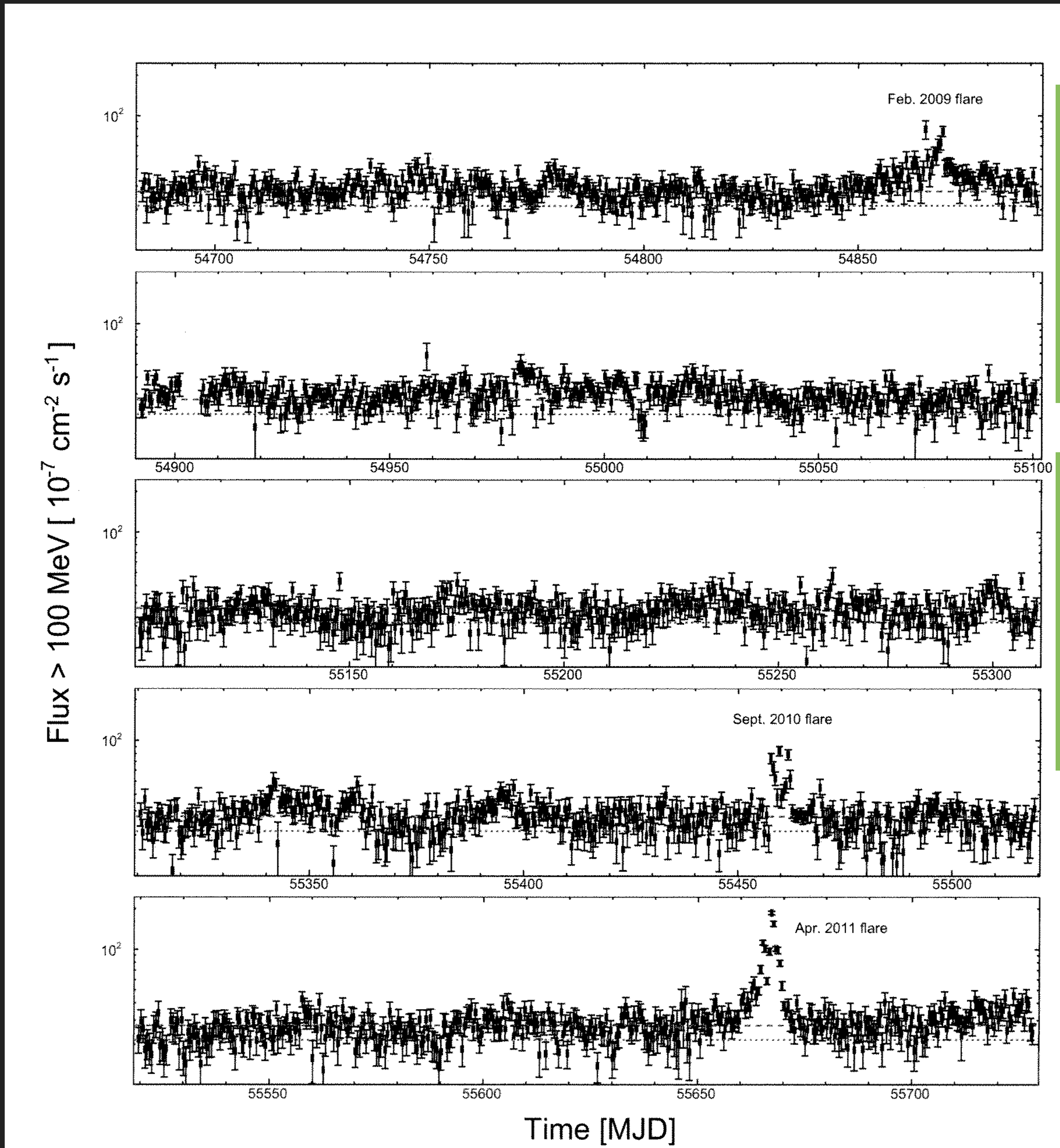
CHANDRA UPPER LIMIT

KNOT IR UPPER LIMIT

1GHZ VLA UPPER LIMIT



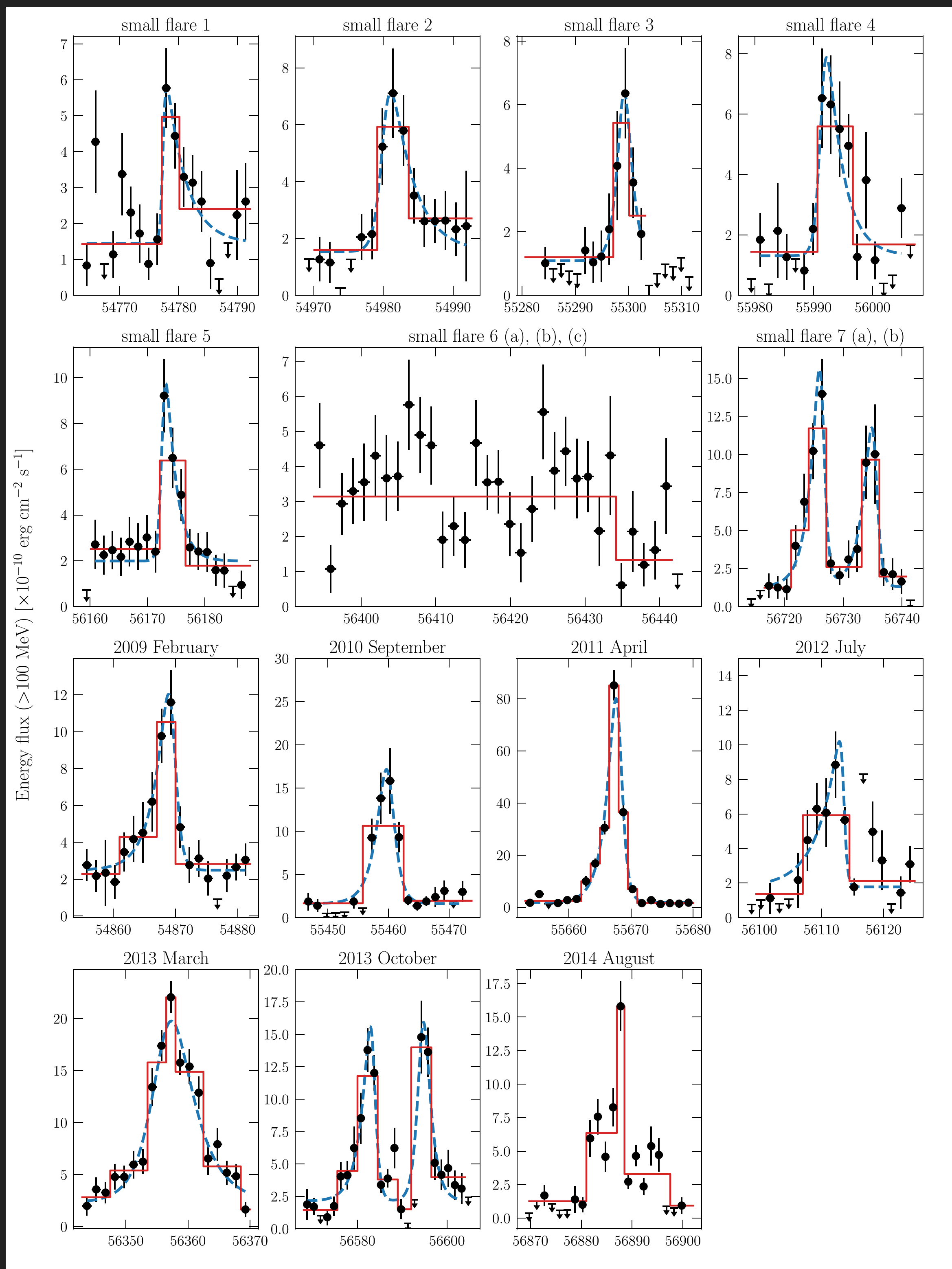
# GAMMA-RAY VARIBILITY

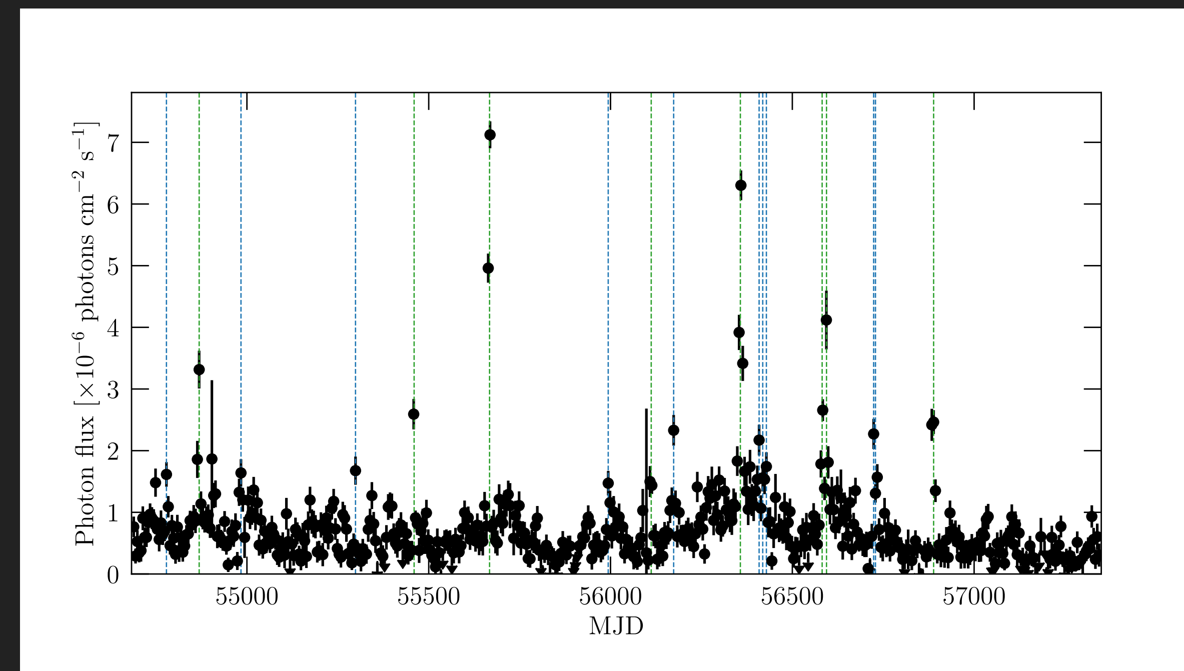


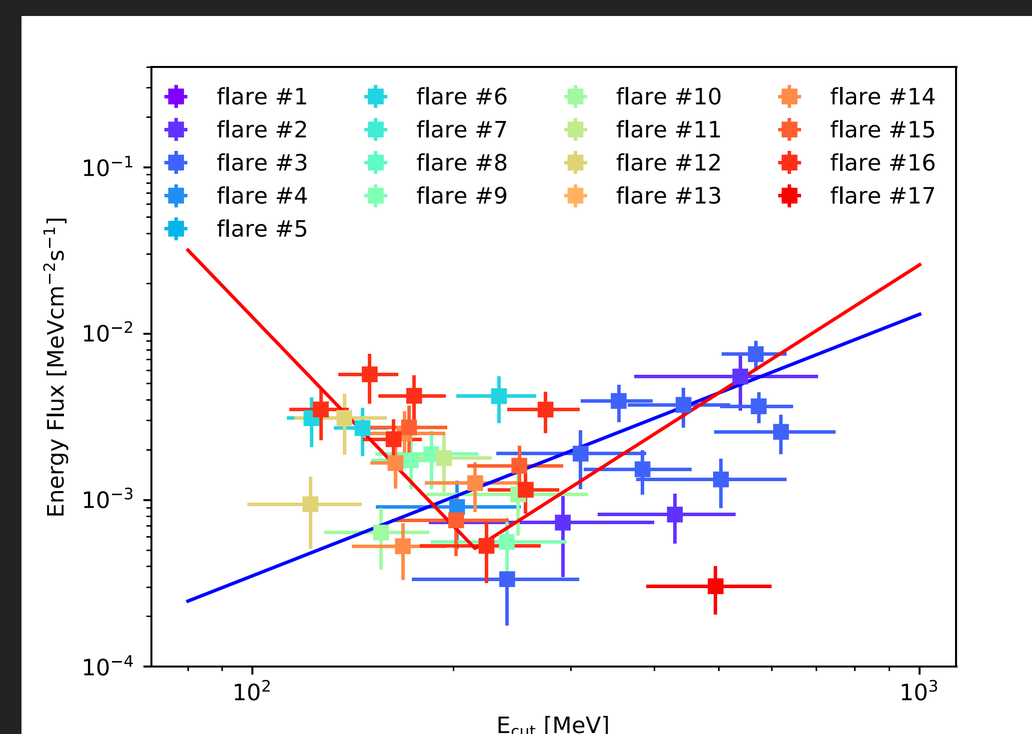

VARIABILITY PRESENT ALSO FOR QUIESCENT EMISSION IN THE FORM OF MONTH-LONG MODULATION

LIKELY ORIGINATING IN THE VARIABILITY OF THE WISPS KNOT REGION

# FLARES IN TIME



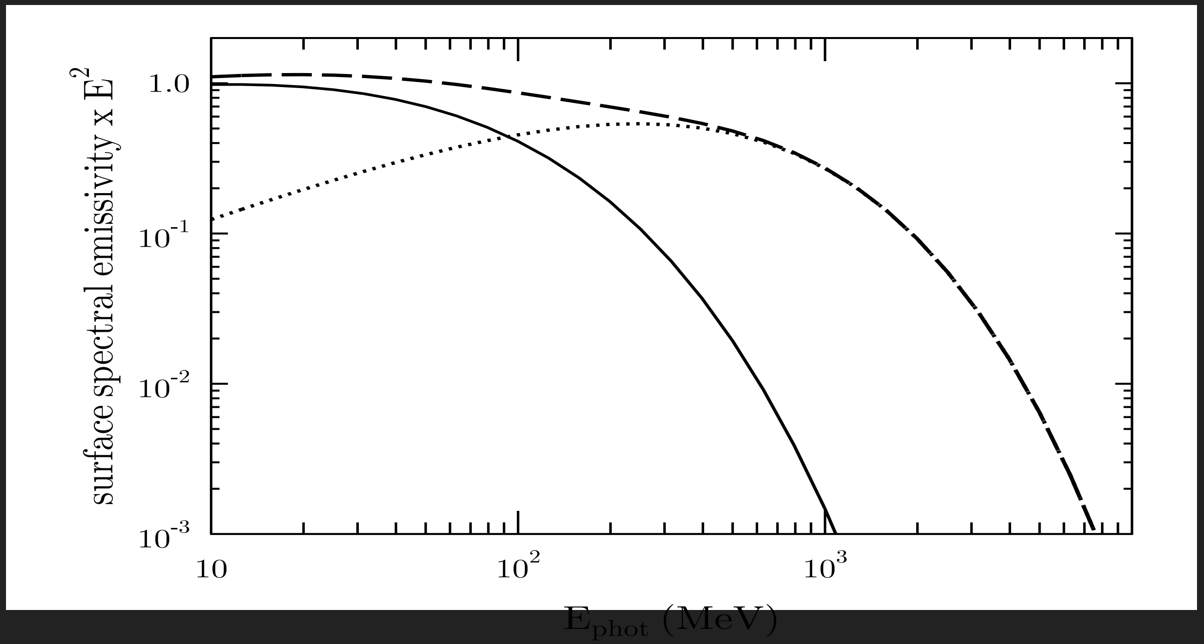
# TWINKING

IMPOSSIBLE TO GET ACCELERATION AND EMISSION FROM THE SAME REGION IN A NAIVE DSA APPROACH

DECOUPLE EMISSION FROM ACCELERATION

INTRODUCE REGIONS OF VERY HIGH MAGNETIC FIELD THAT ARE RESPONSIBLE FOR RADIATION

FLARE PROPERTIES DEPENDS ON THE MAGNETIC FIELD IN THESE REGIONS



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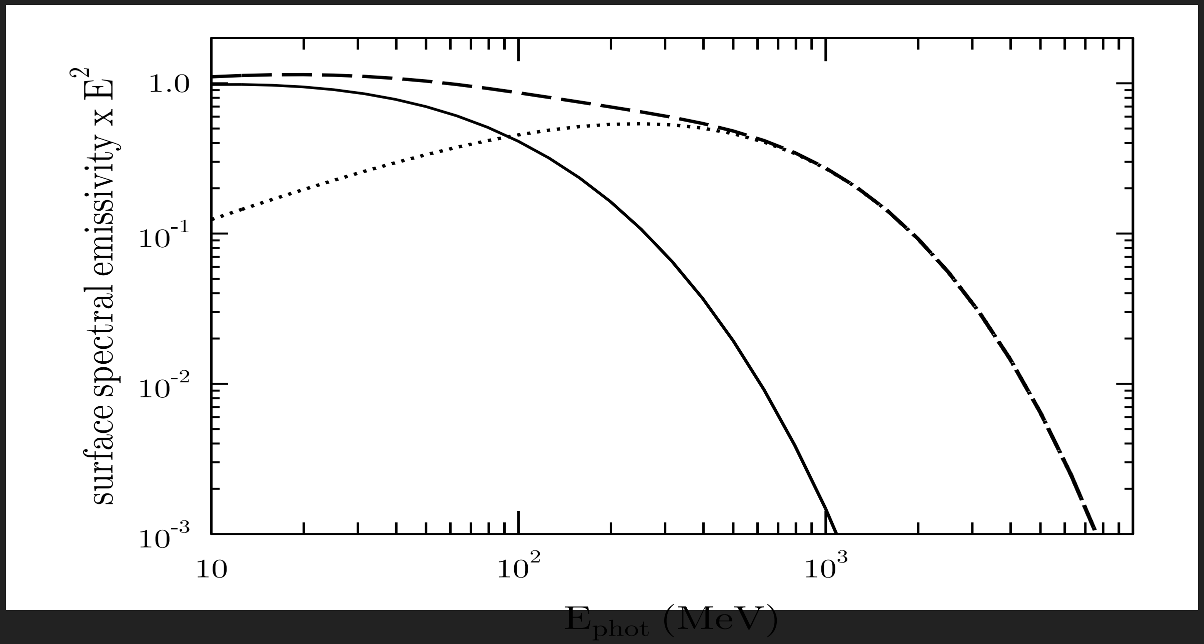


REQUIRE VERY LOCALISED REGIONS (FEW DAY LIGHT) WITH MAGNETIC FIELD UP TO MILLI-G

REQUIRE EMISSION TO COME TO REGIONS VERY CLOSE TO THE TS

# RECONNECTION

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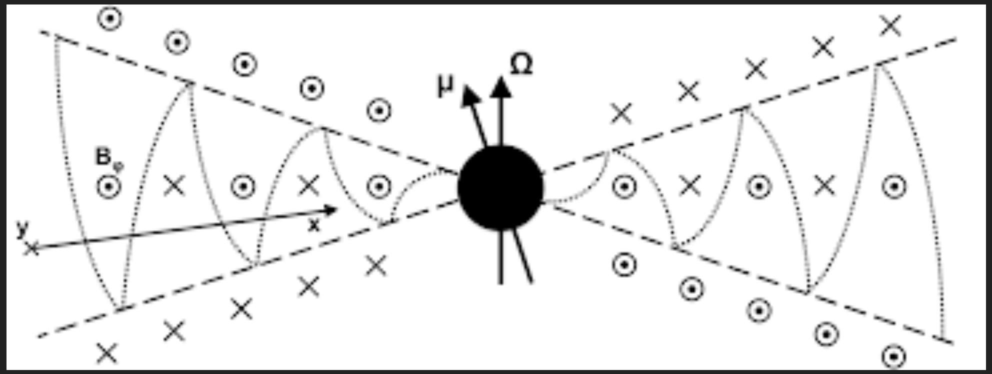
**PSR WINDS ARE STRIPED AND THIS IMPLIES ALTERNATING FIELD POLARITIES IN THE PWN**



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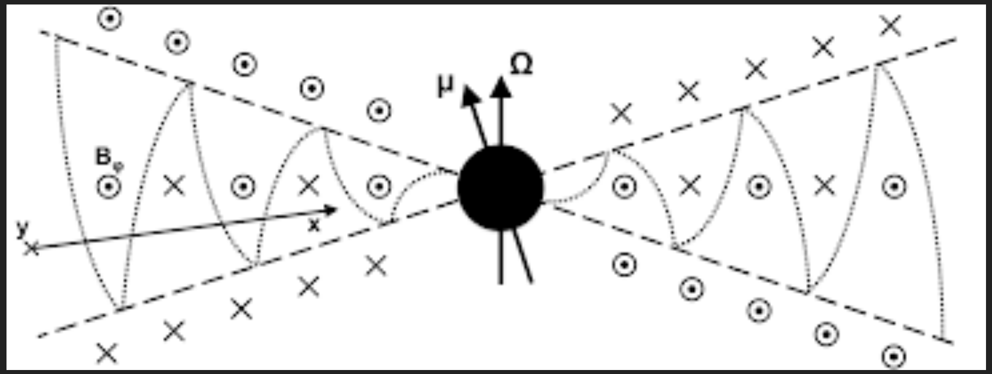

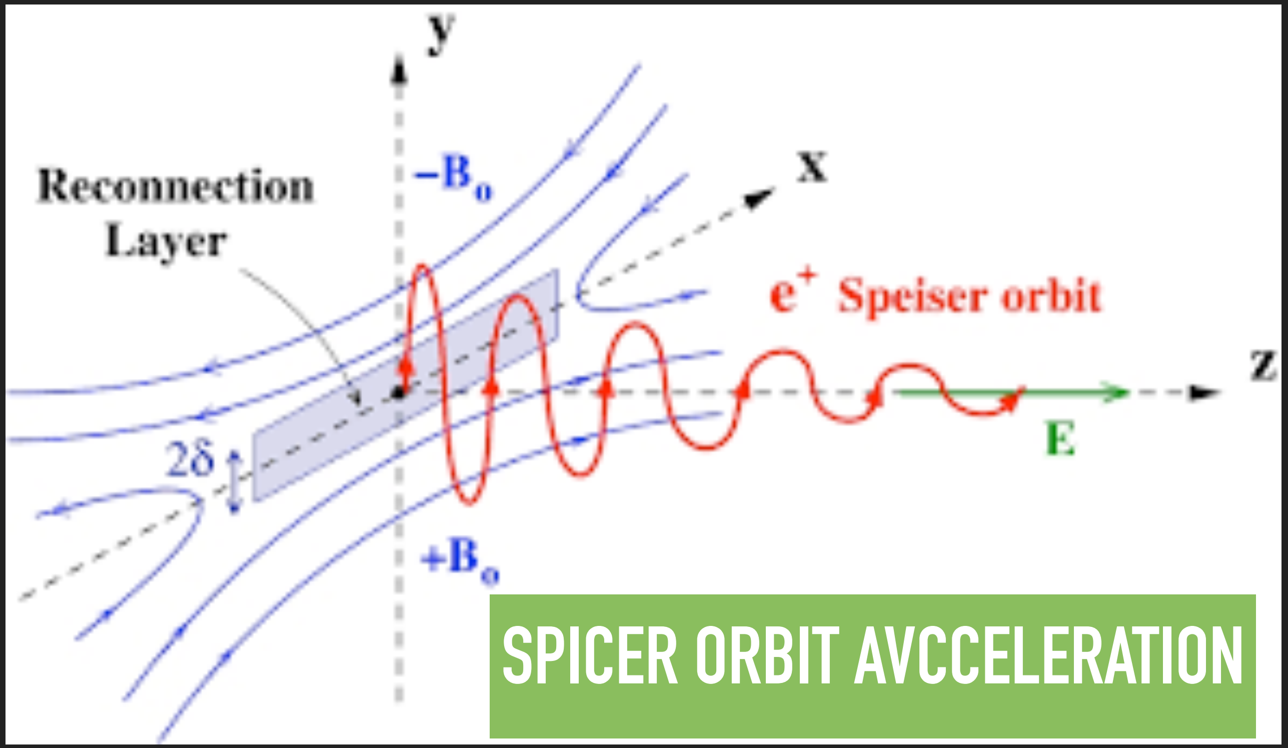


SPICER ORBIT AVCCELERATION

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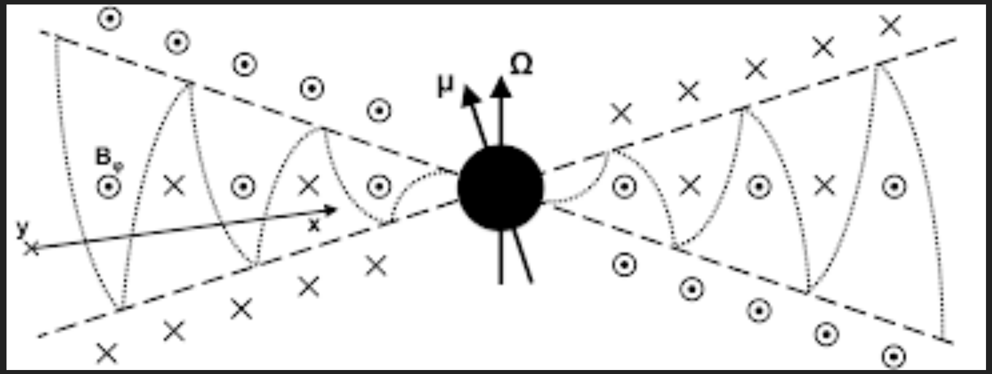
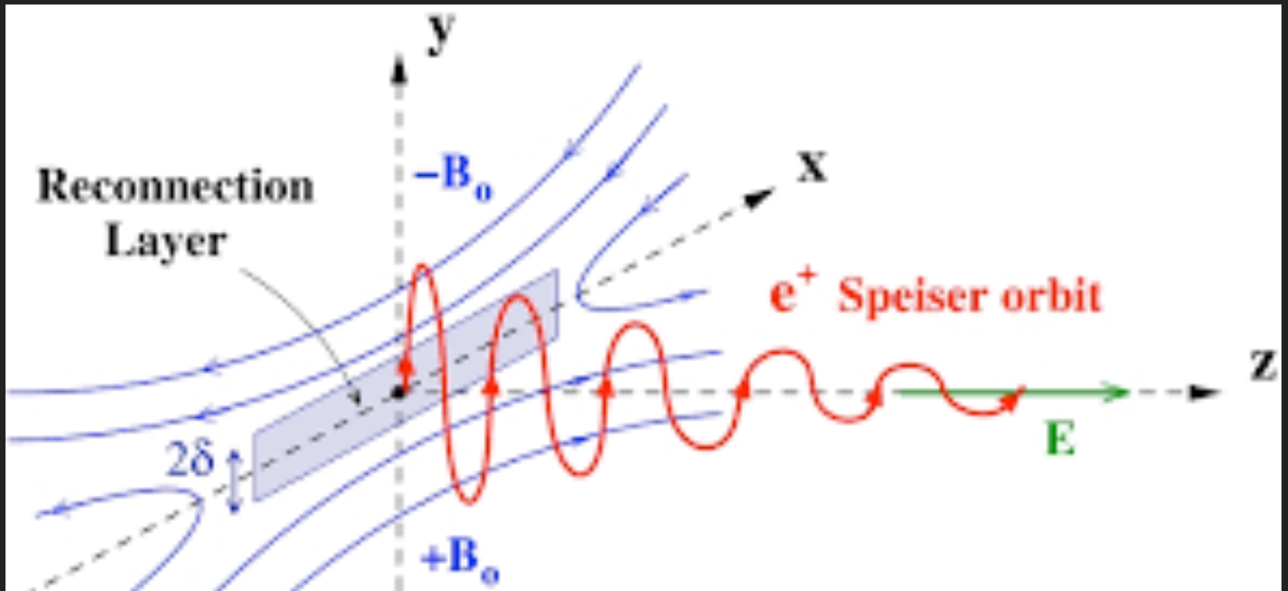
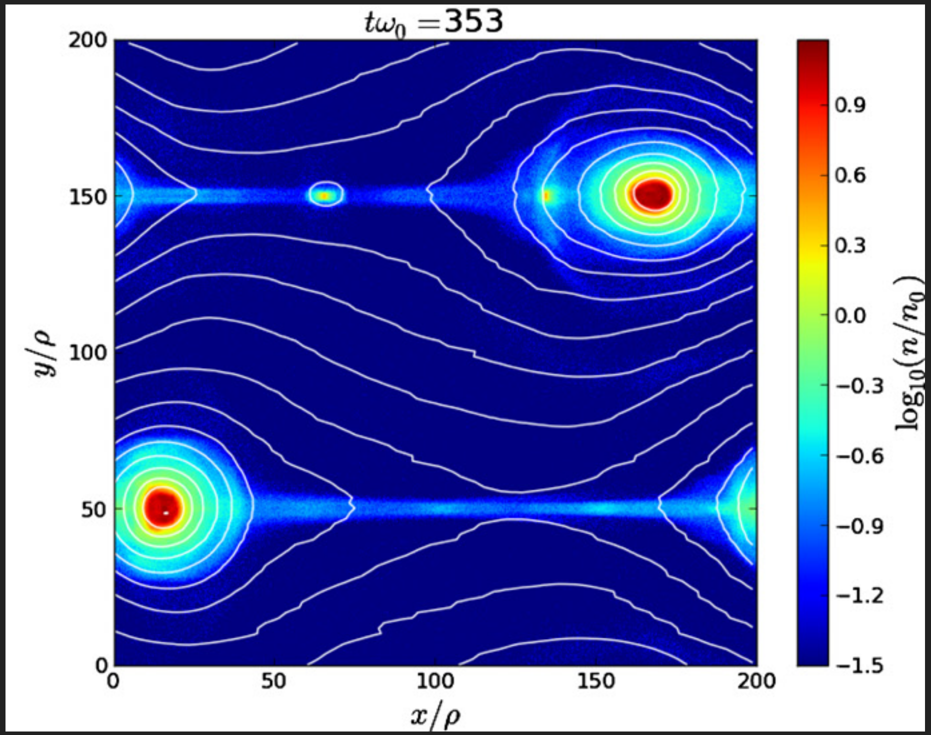


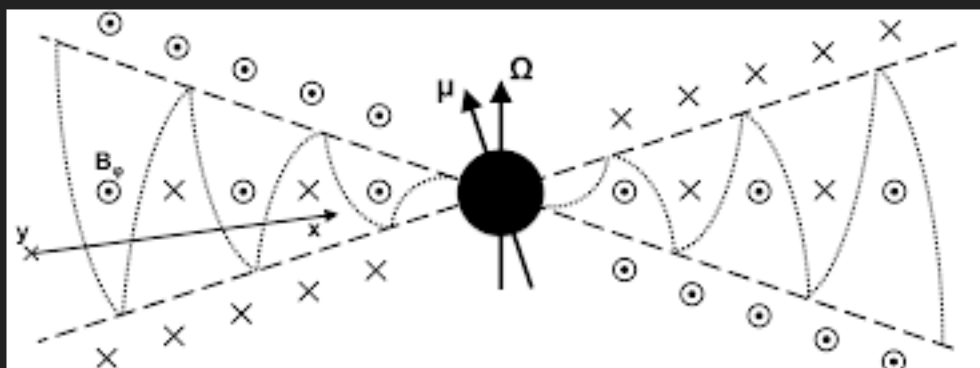

SPICER ORBIT AVCCELERATION

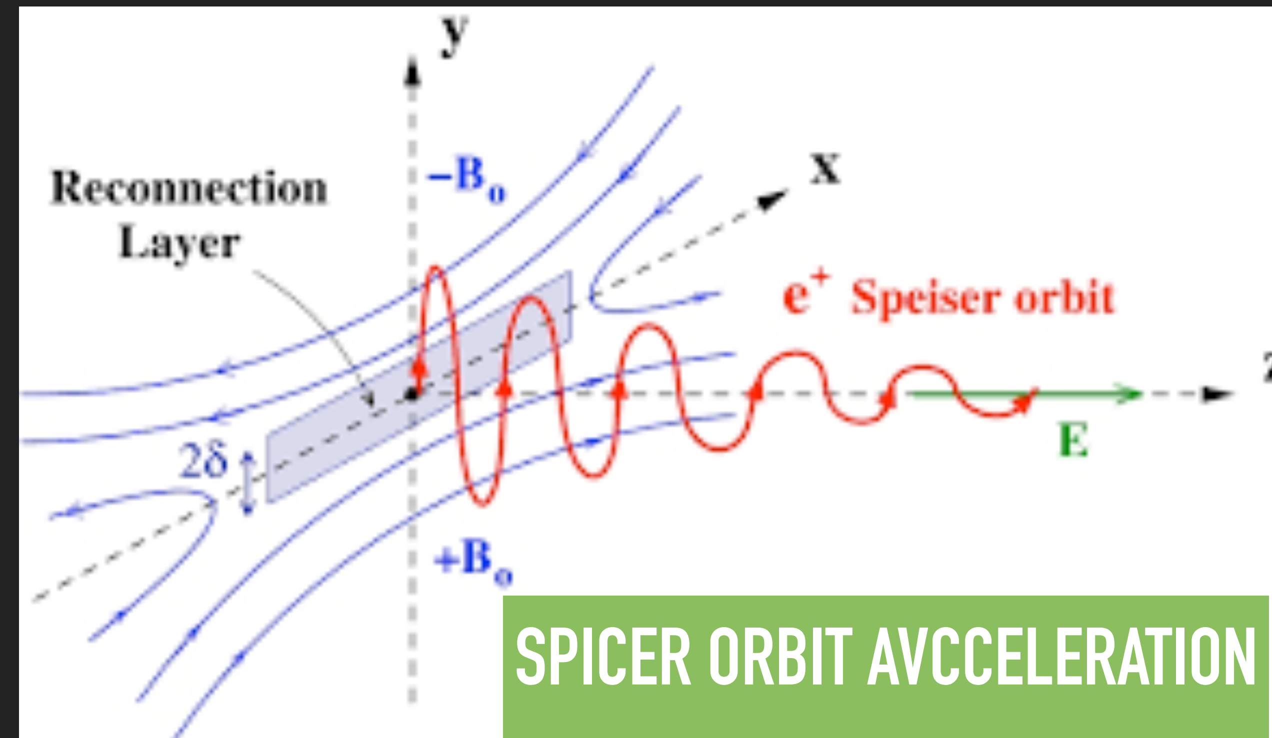
TEARING INSTAB



# RECONNECTION

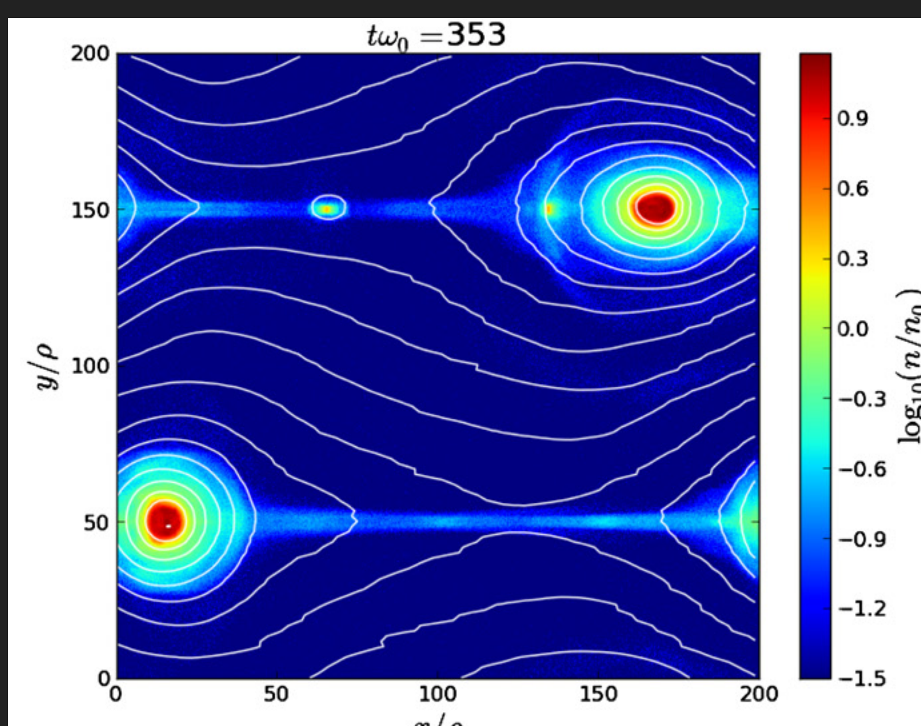
PSR WINDS ARE STRIPED AND THIS IMPLIES ALTERNATING FIELD POLARITIES IN THE PWN



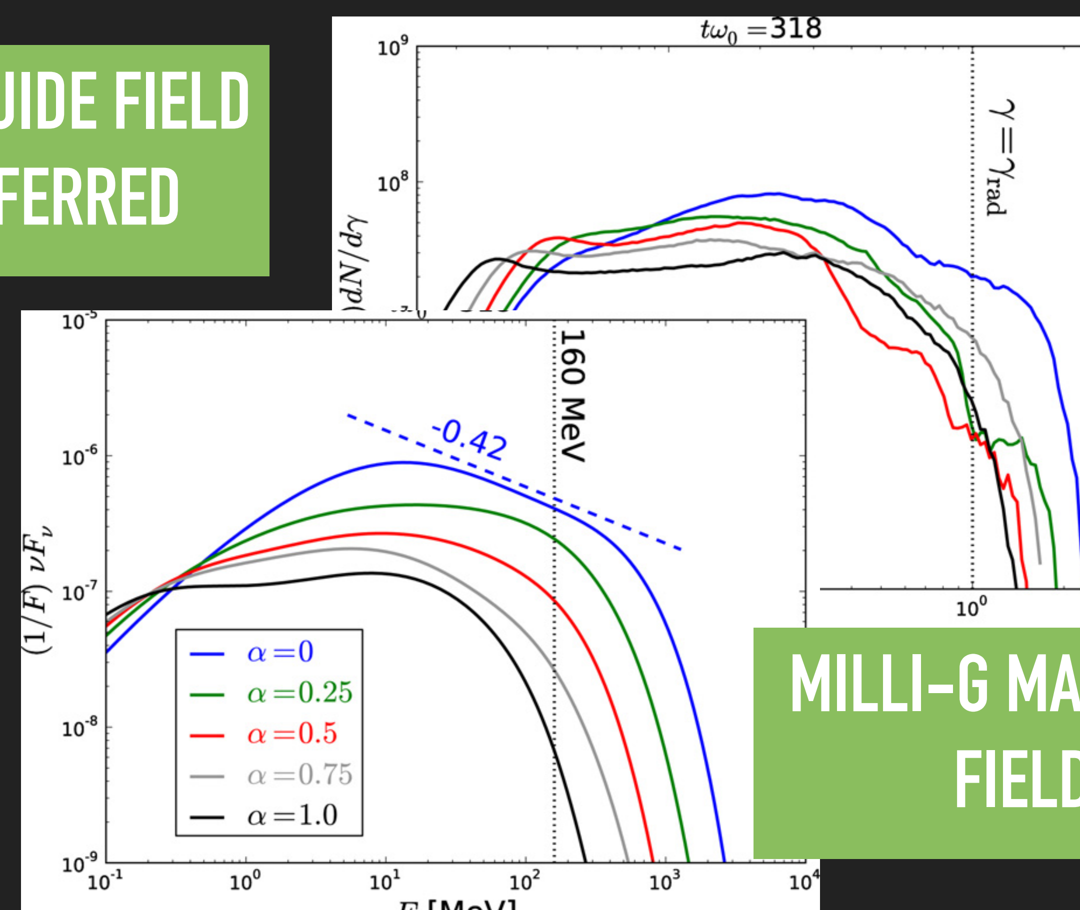




SPICER ORBIT AVCCELERATION

TEARING INSTAB



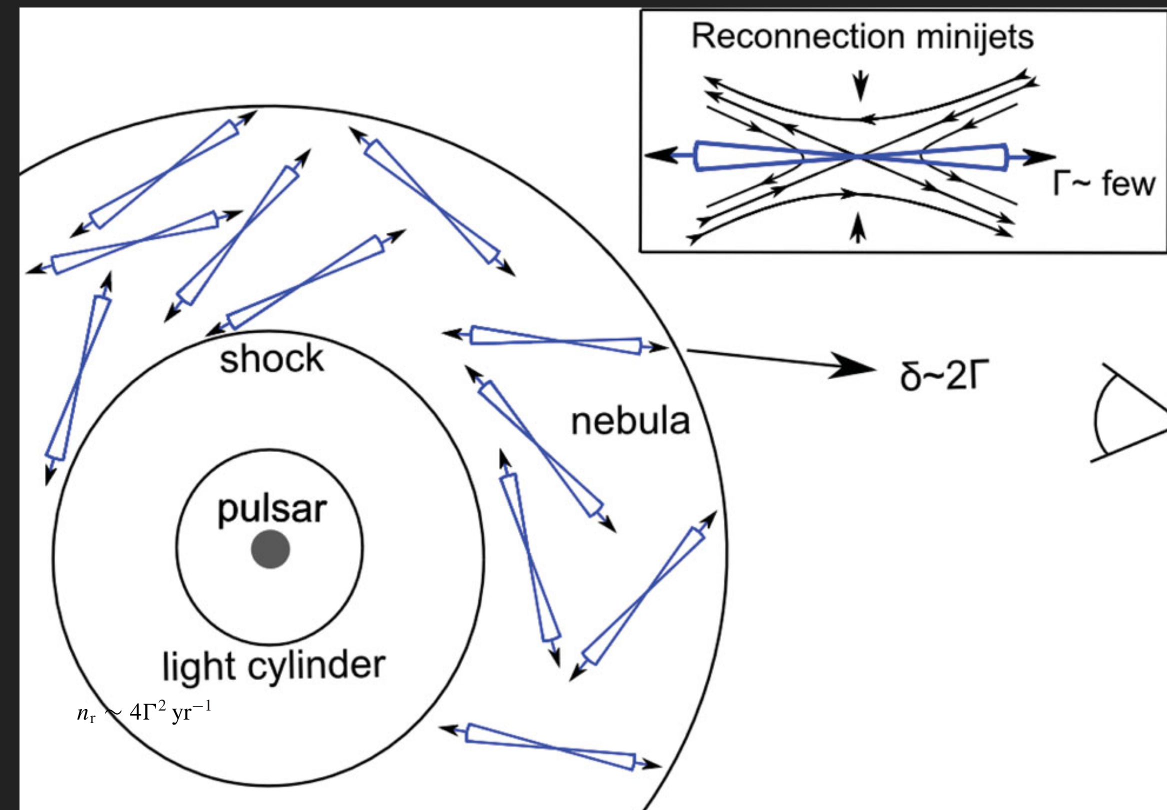

LOW GUIDE FIELD PREFERRED




MILLI-G MAGNETIC FIELD

# JETLETS

MINI JETS INSIDE THE NEBULA ARISING FROM RECONNECTION LED TO BEAMED PARTICLES THAT GIVES FLARE DUE TO DOPPLER BOOSTING



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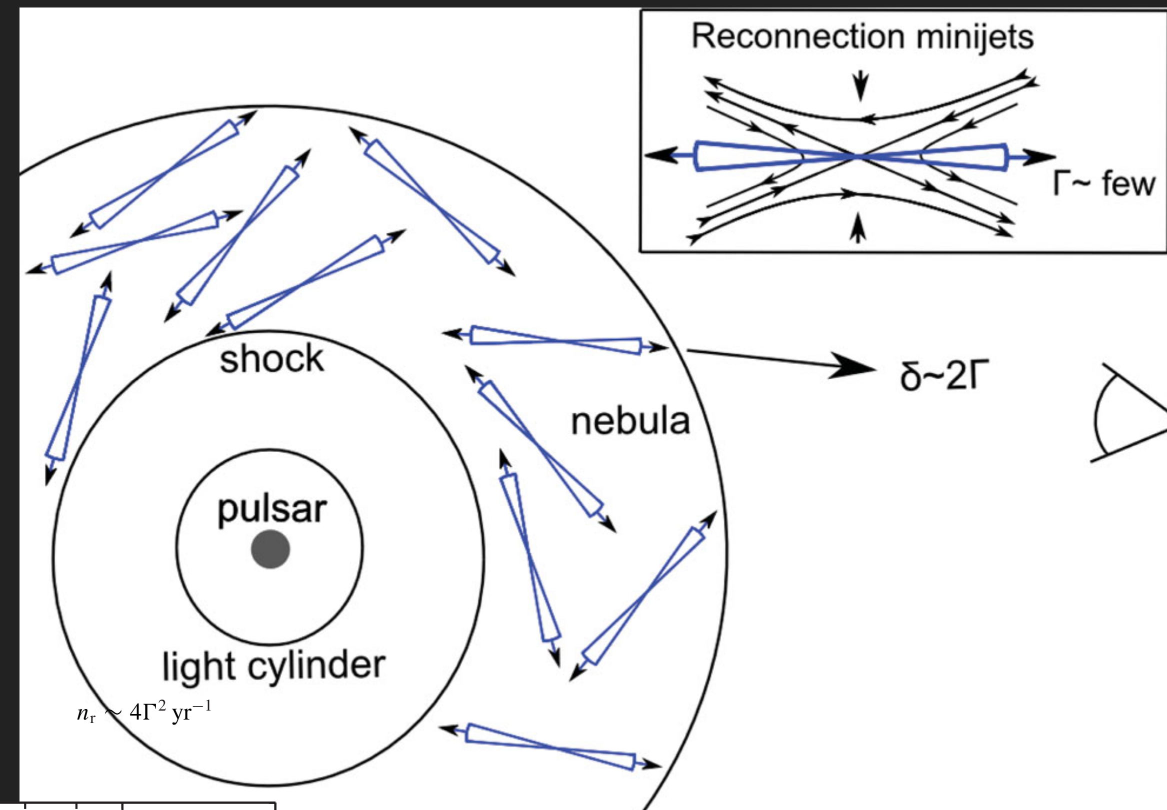
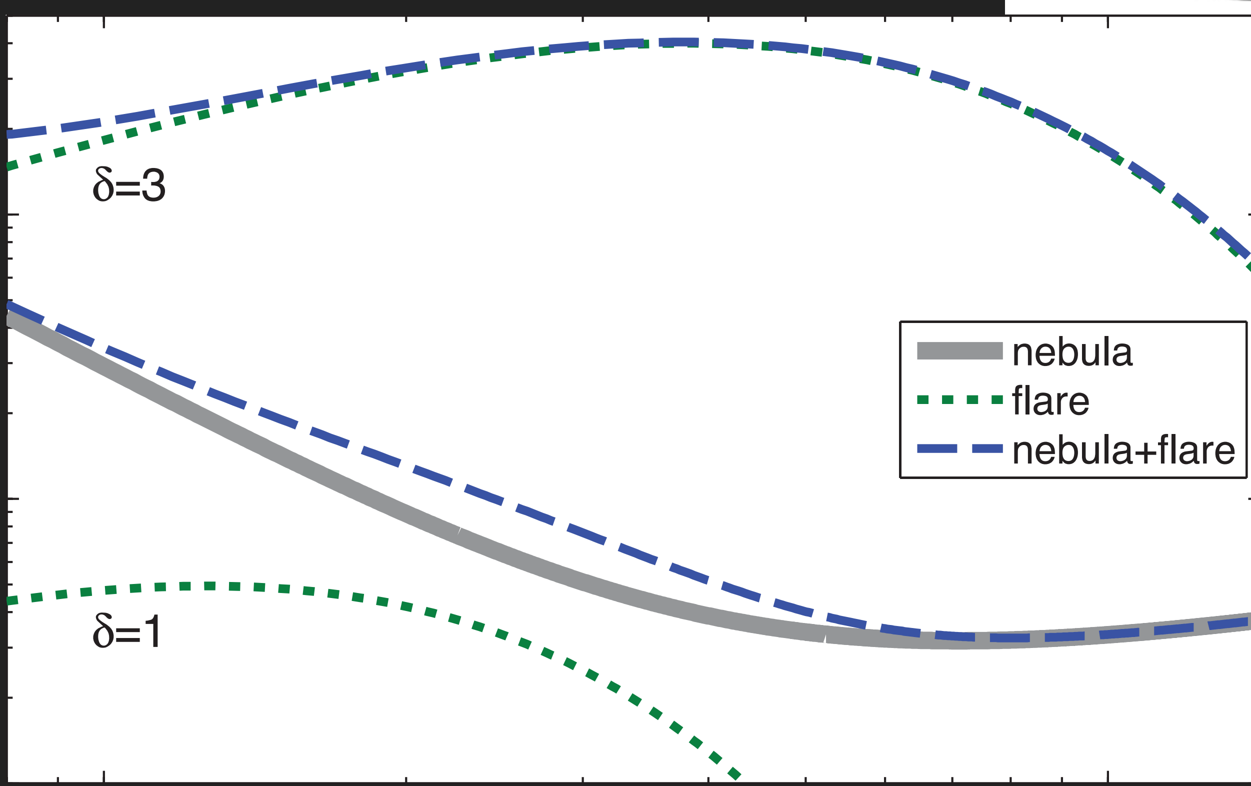


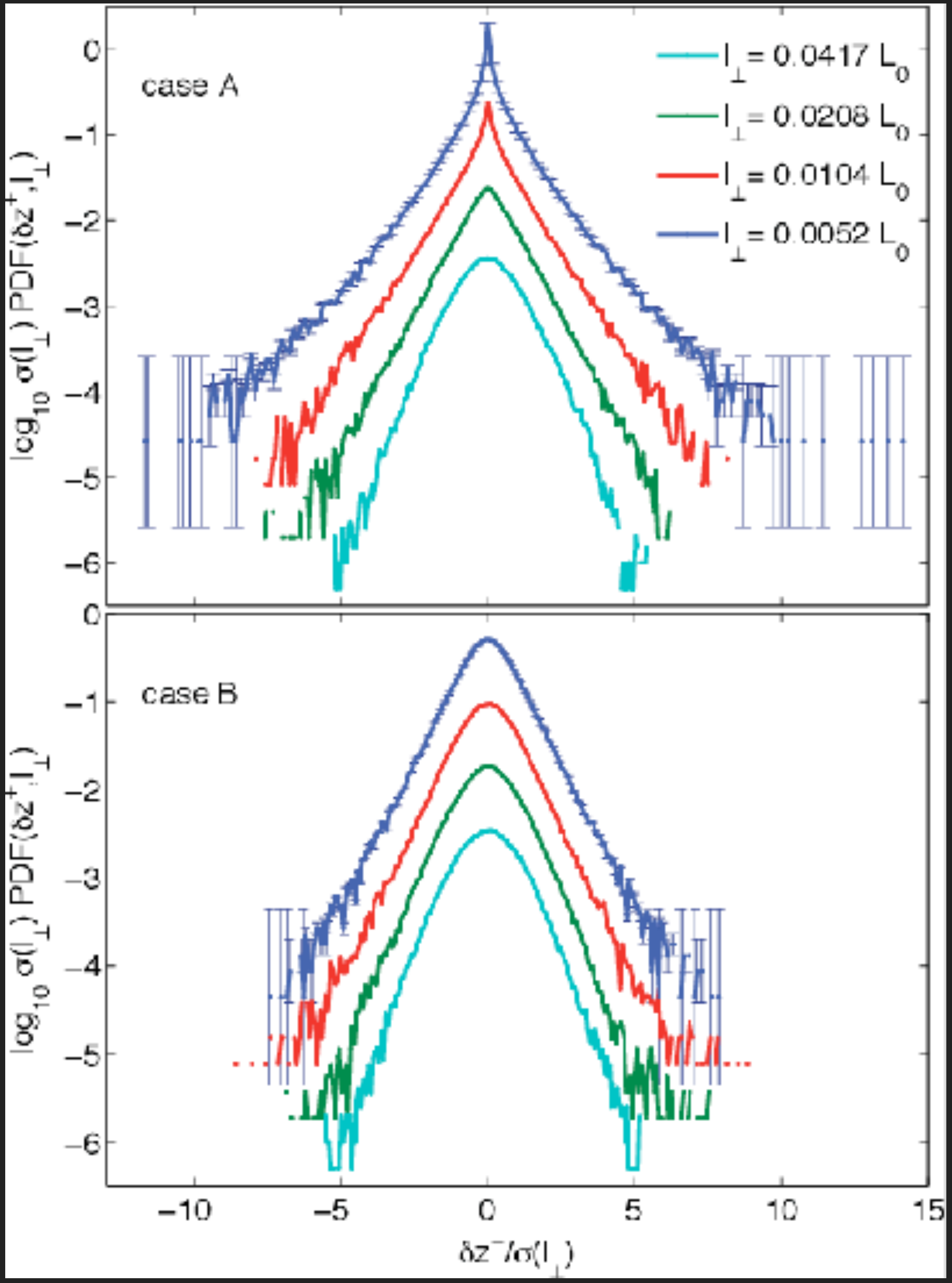




$$n_r \sim 4\Gamma^2 \, \mathrm{yr}^{-1}$$

BOOSTING OF ORDER 3 ARE REQUIRED

# INTERMITTENCY

## IN TURBULENCE INTERMITTENCY MANIFESTS AS HIGHER TAILS AT SMALL SCALE ON THE PDE



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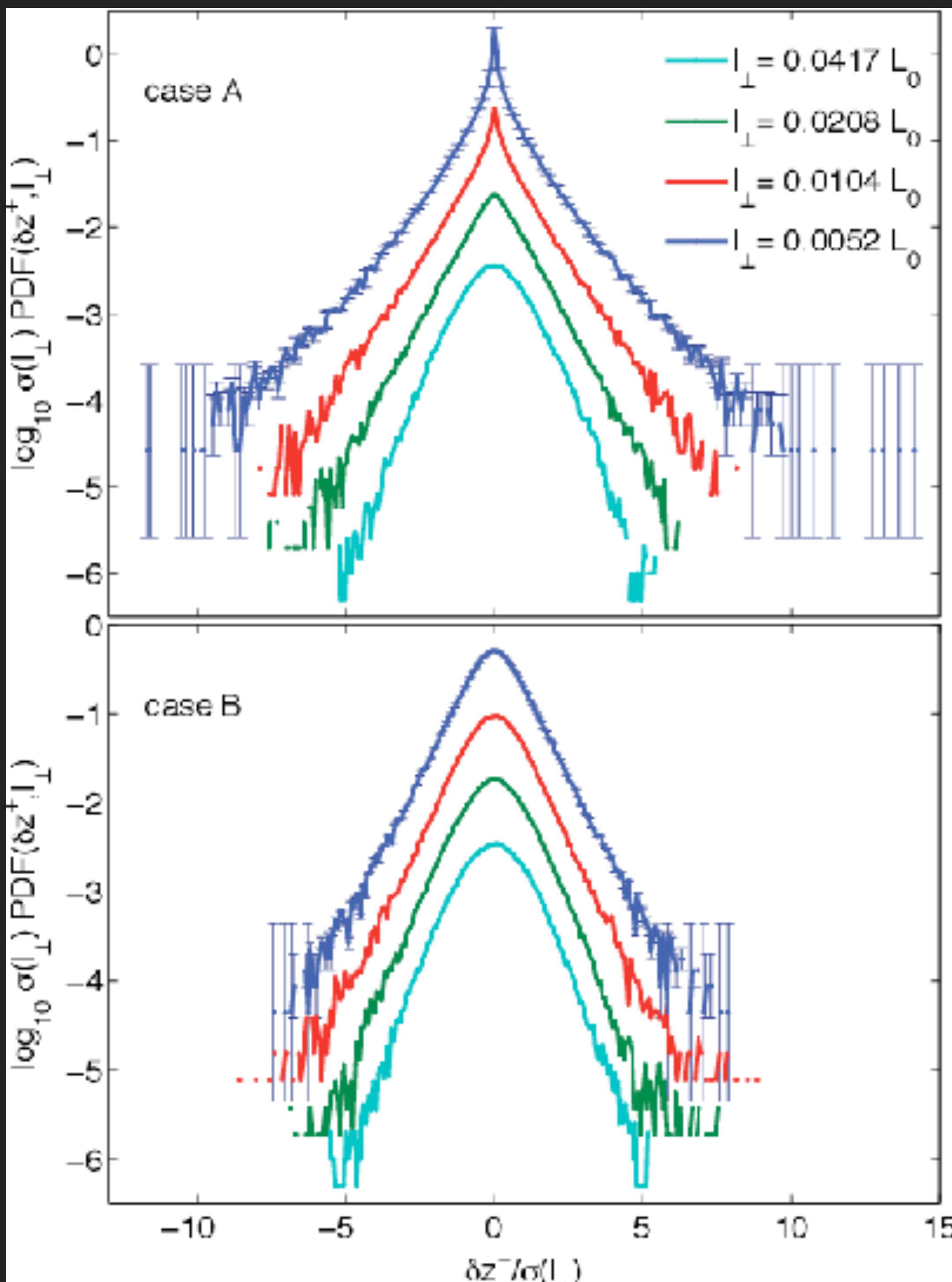


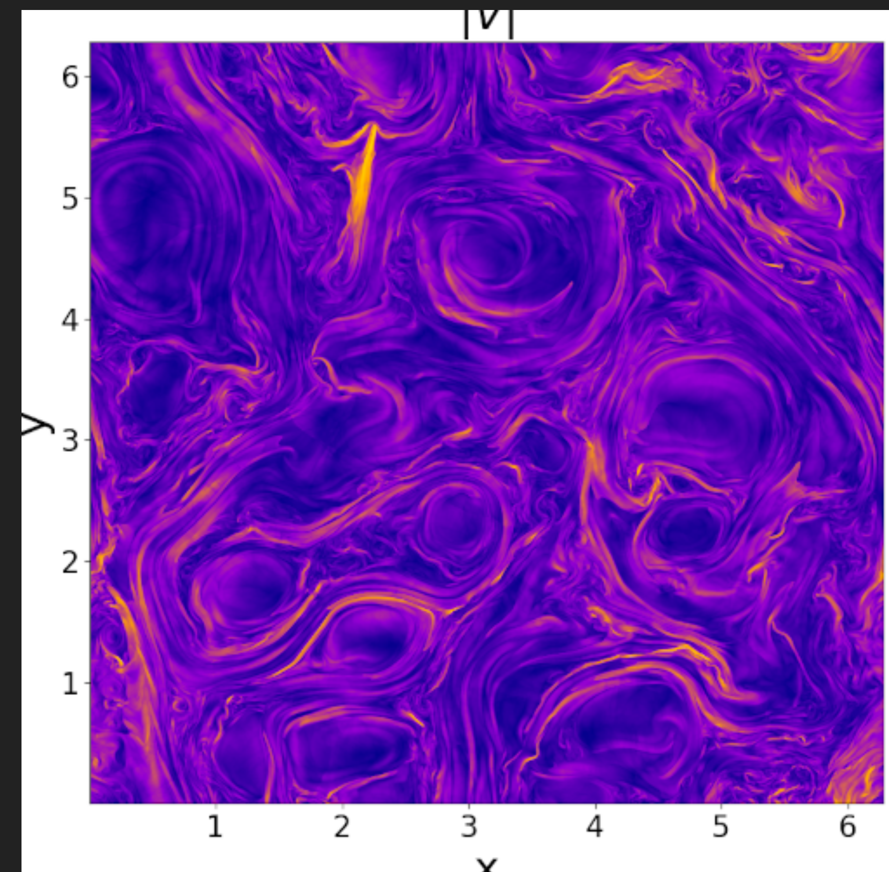

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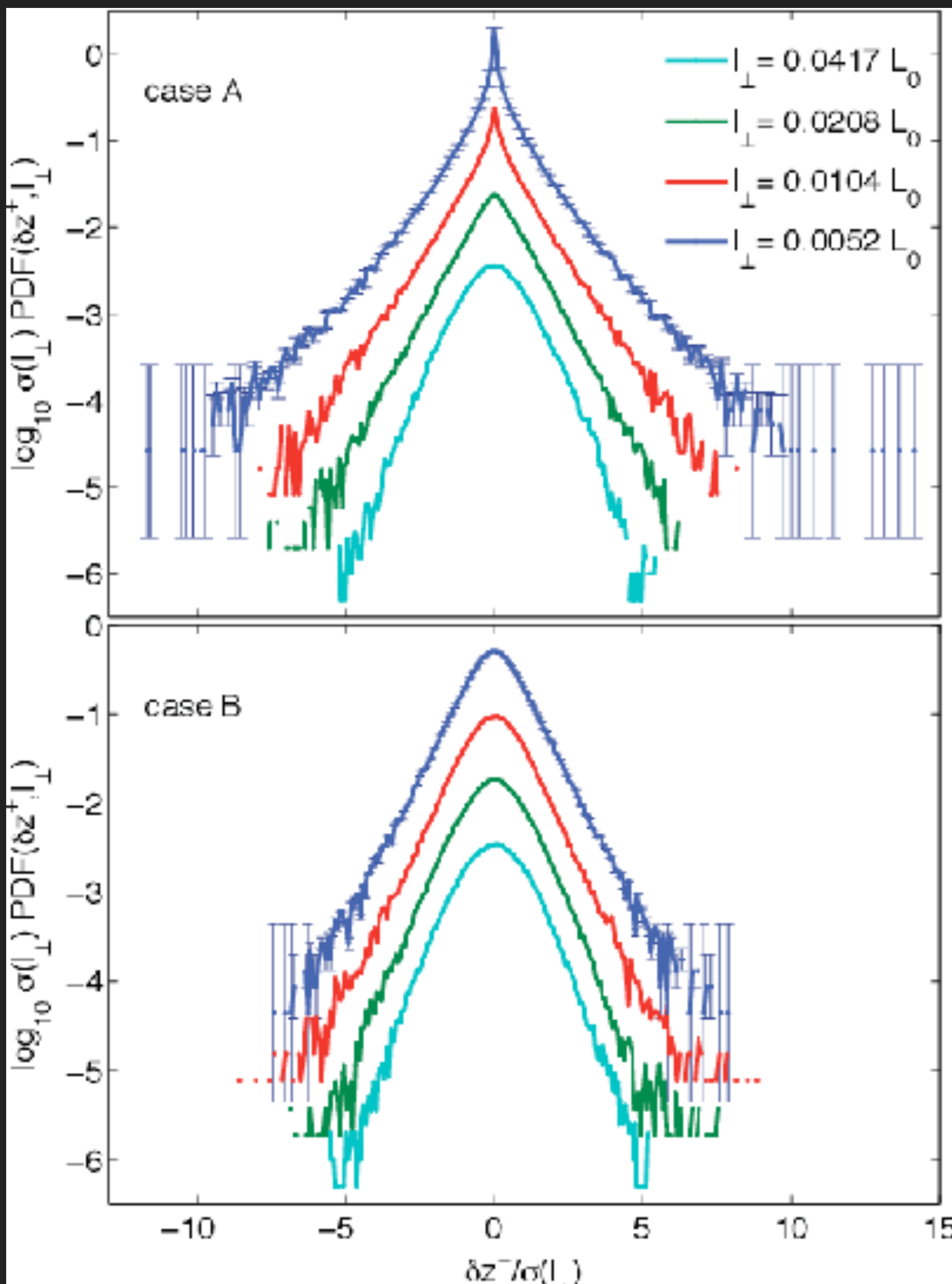


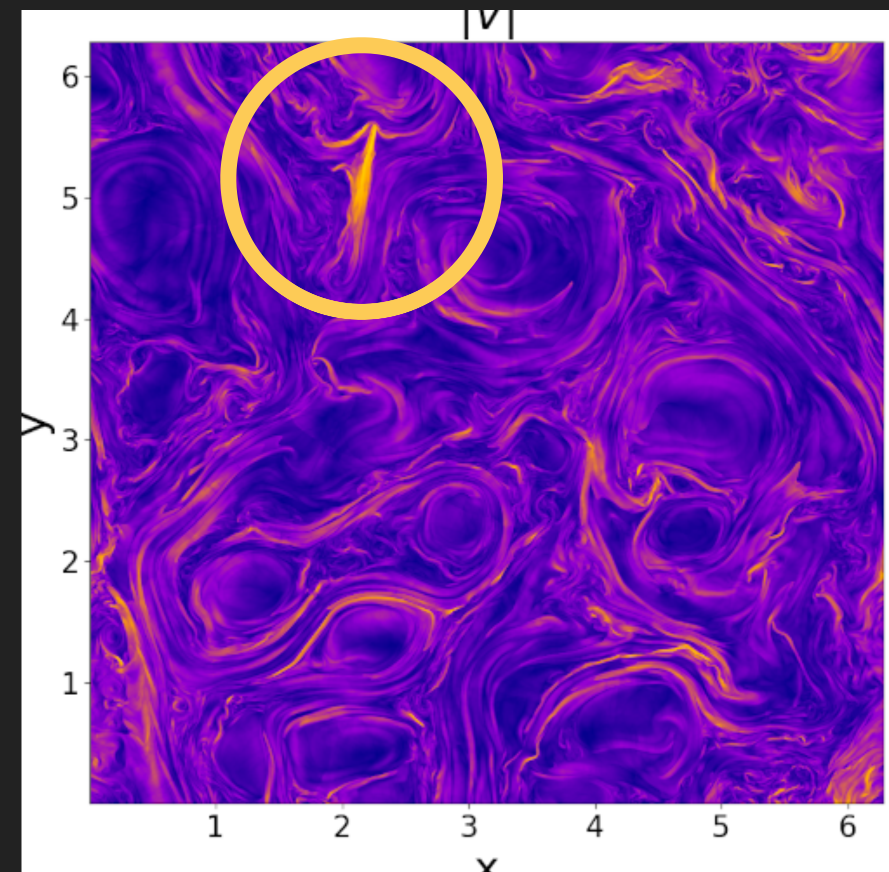

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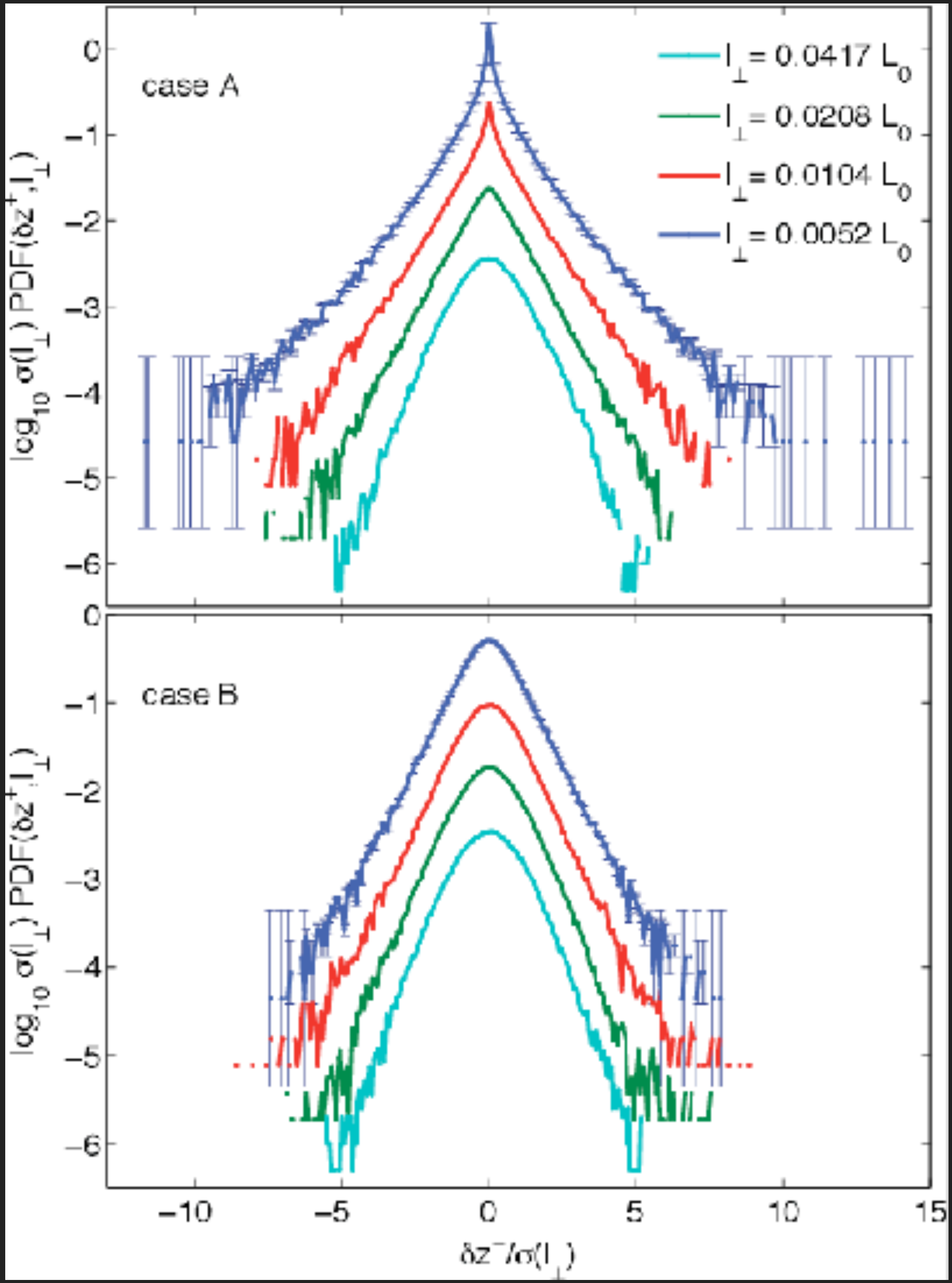
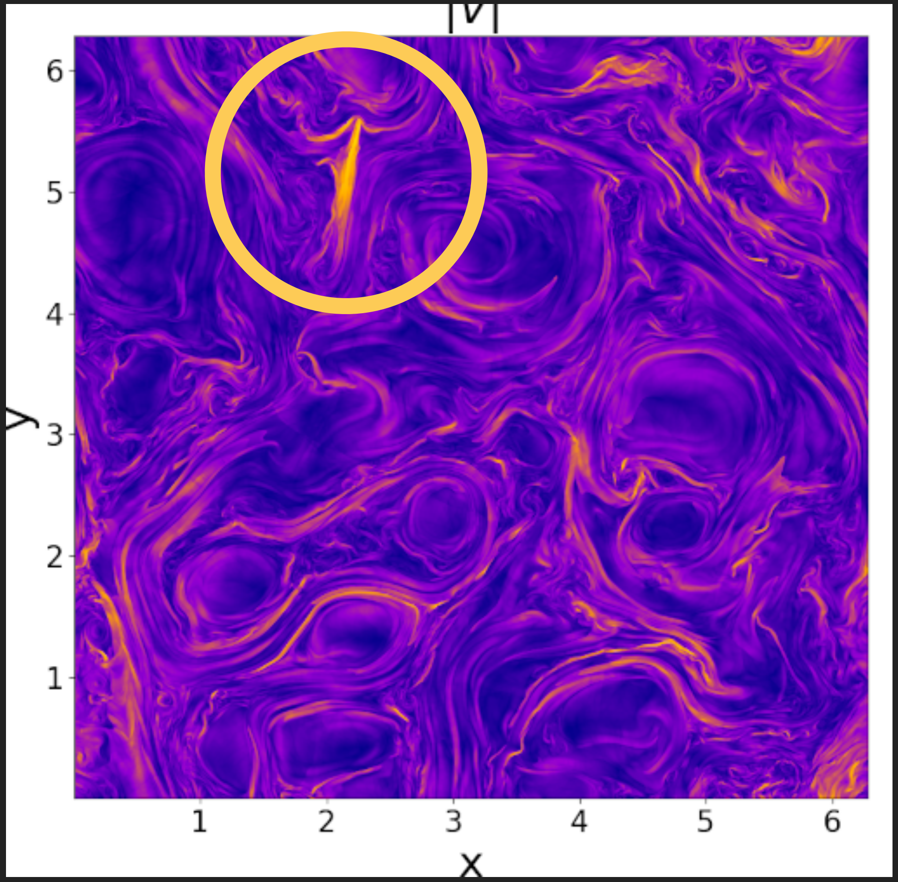
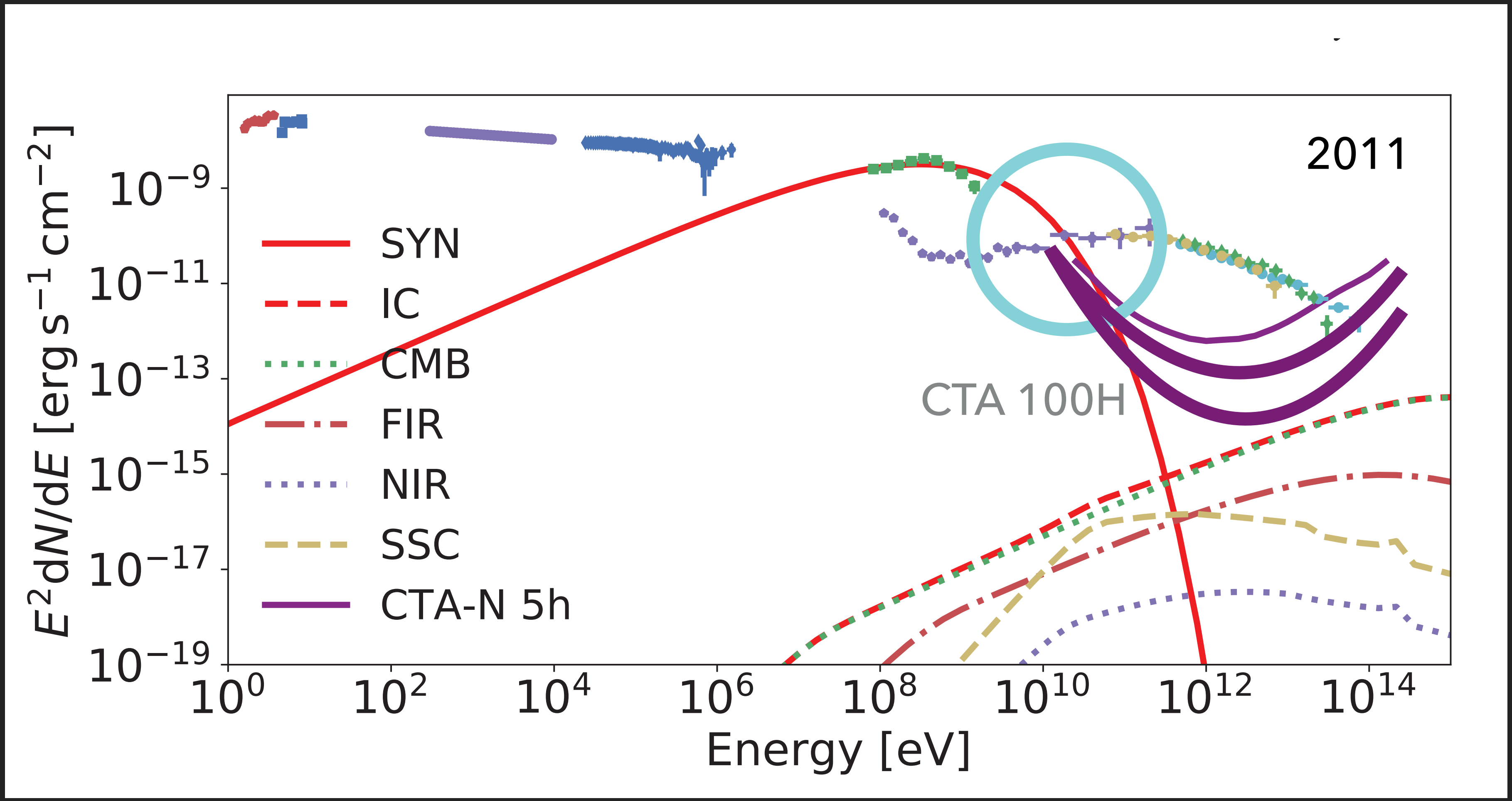



NOT CLEAR IF STATISTICS OF INTERMITTENCY COMPATIBLE WITH MILL-G FIELD

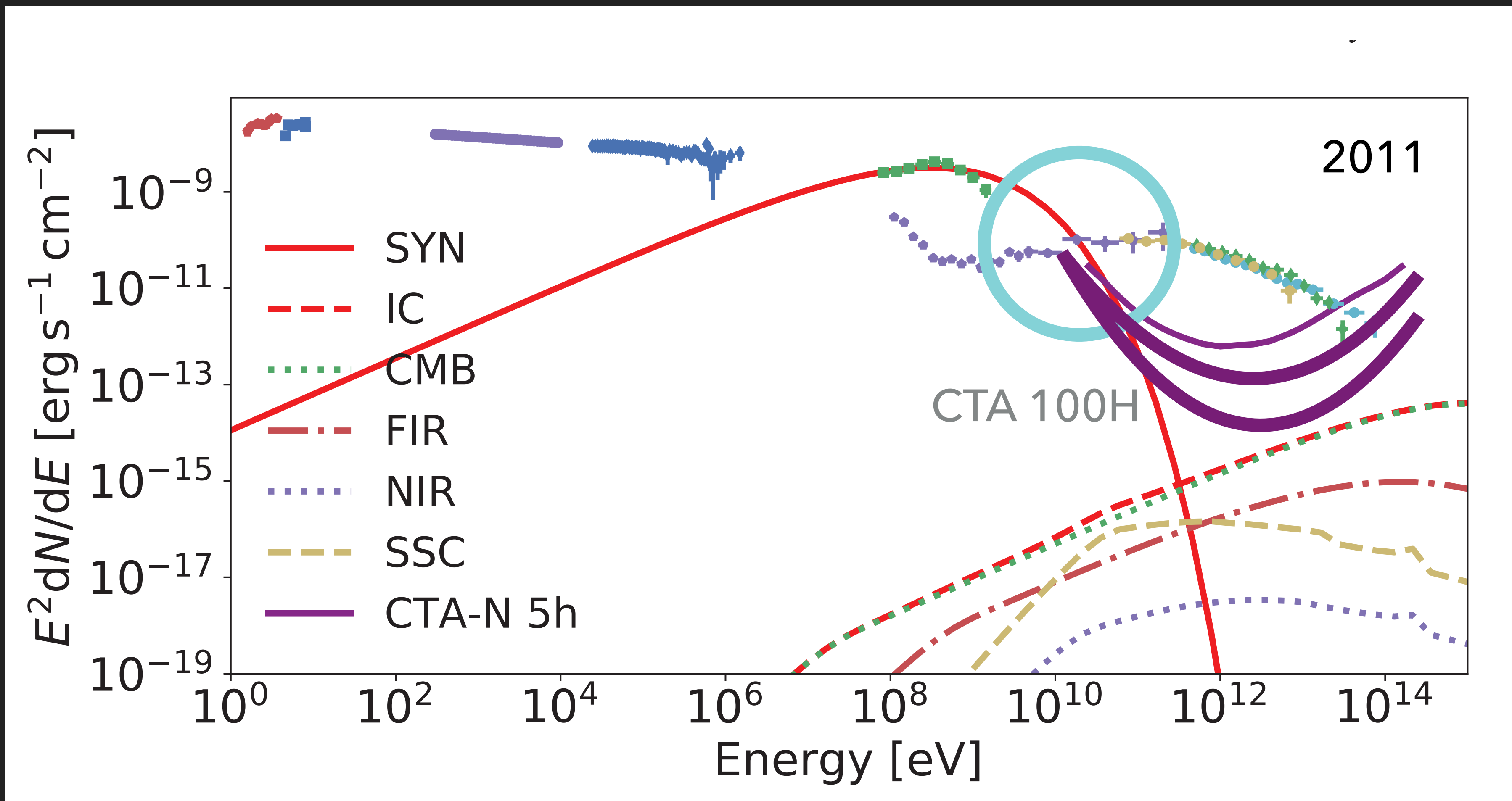
# FLARES VISIBILITY WITH CTA




2013

CTA 100H

# FLARES VISIBILITY WITH CTA




ONLY MAJOR FLARES POTENTIALLY VISIBLE BY CTA OVER 100H

HIGHLY DEPENDENT ON SHAPE OF THE CUTOFF

2013

CTA 100H

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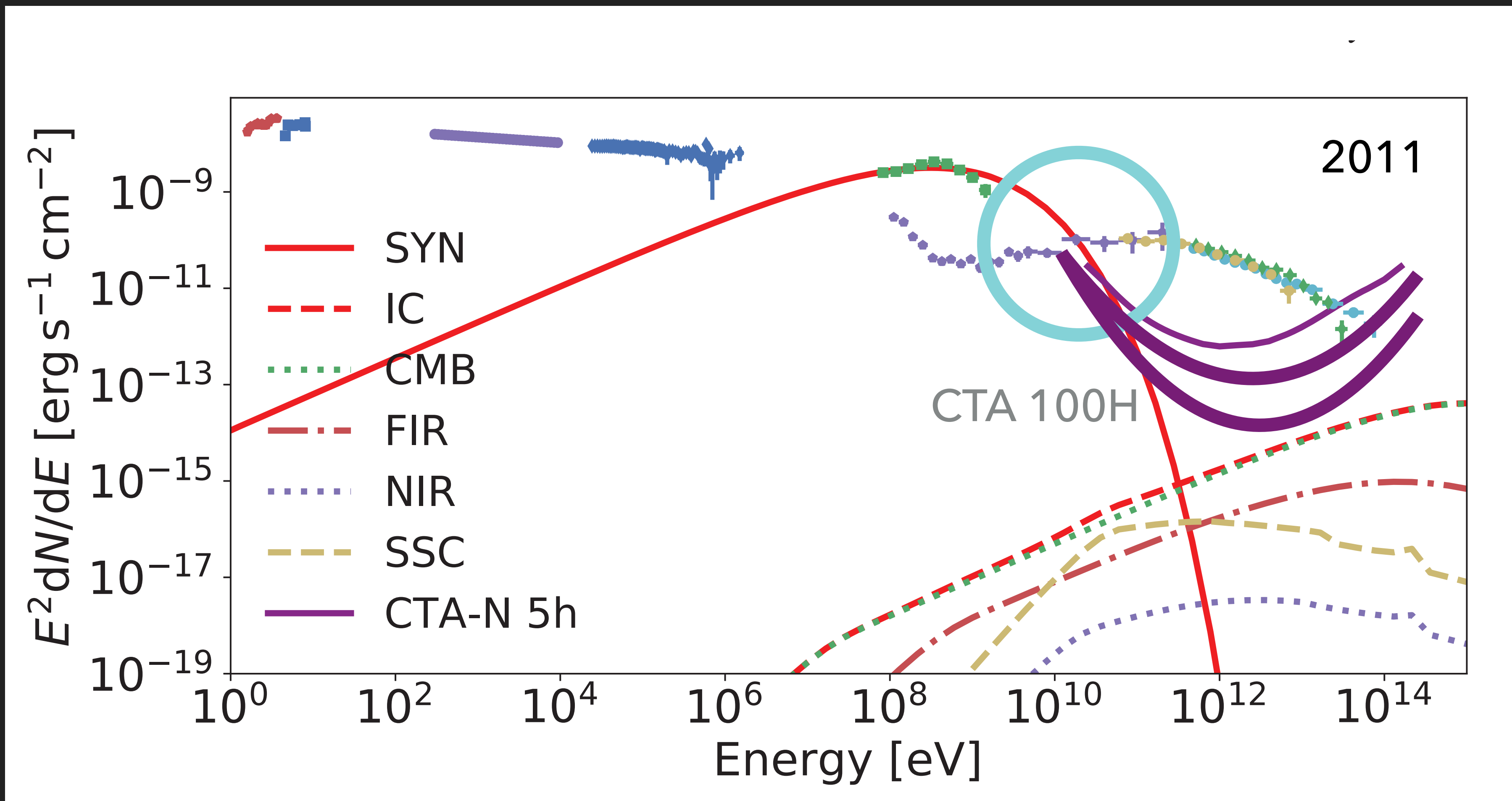


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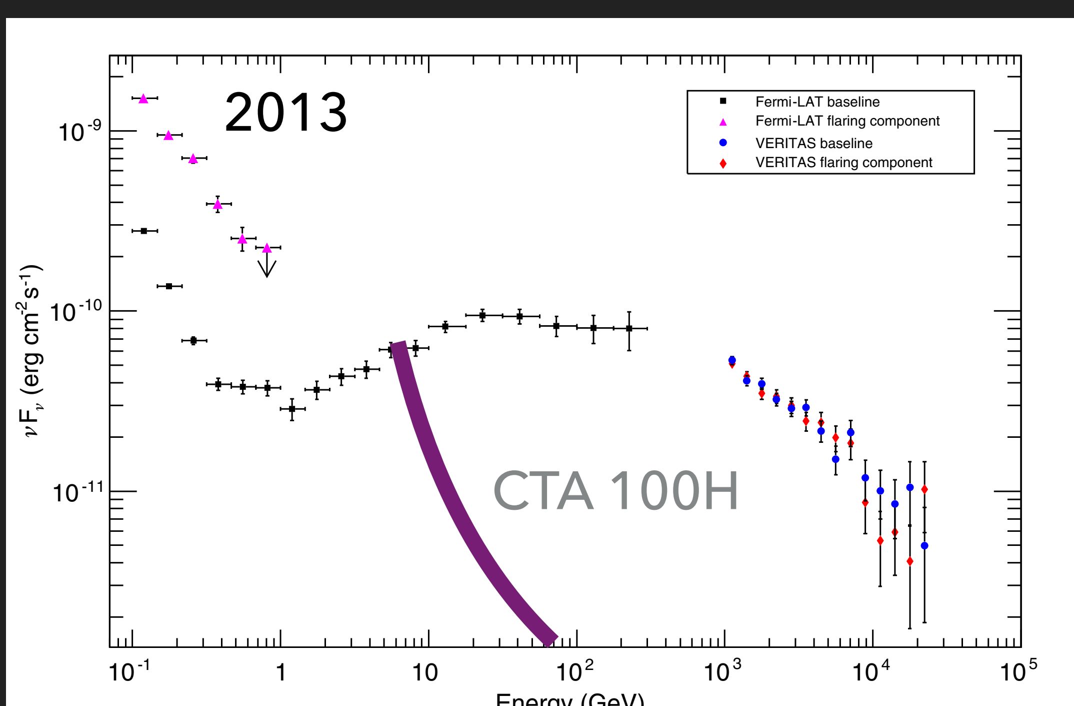

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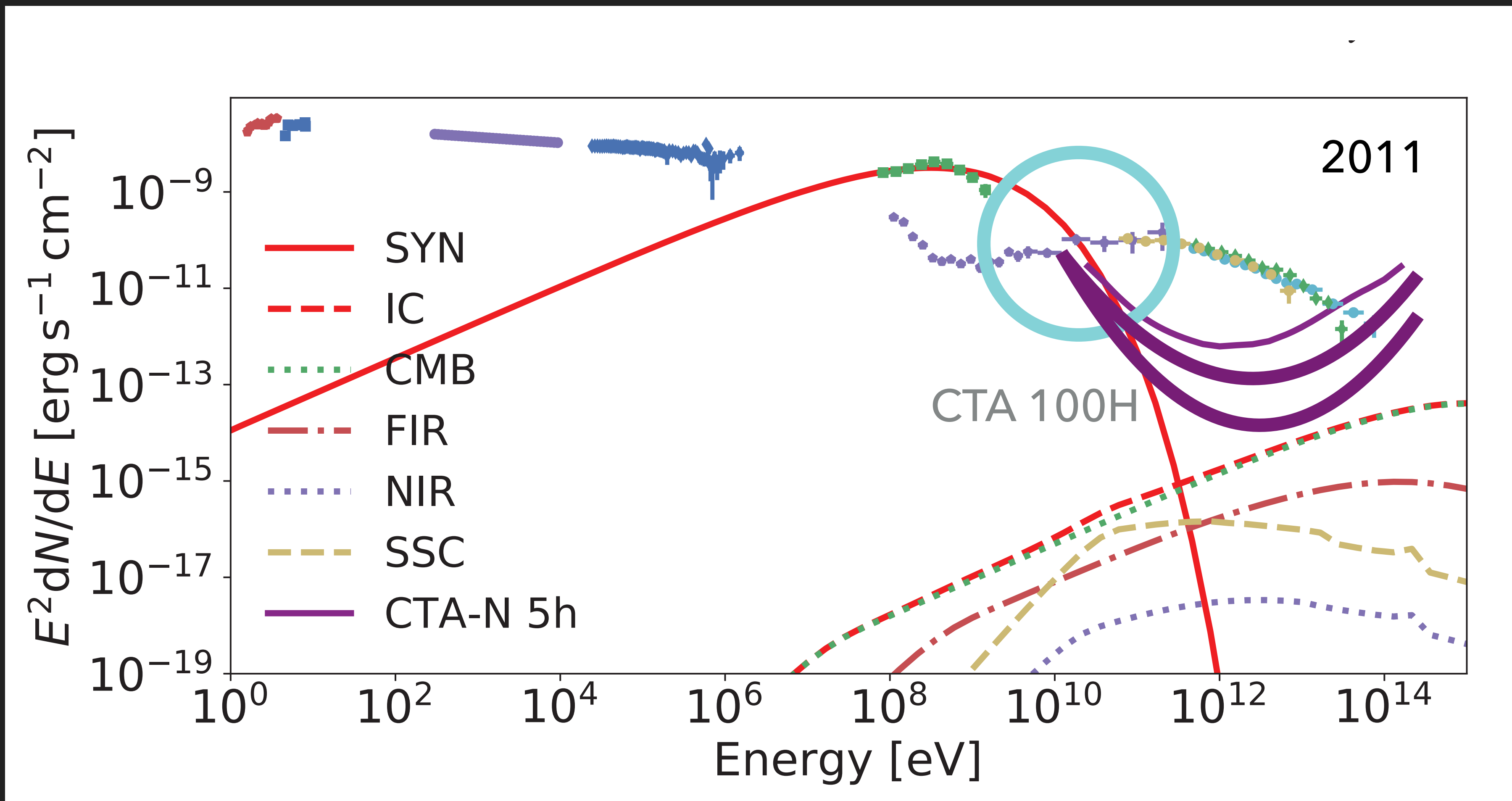


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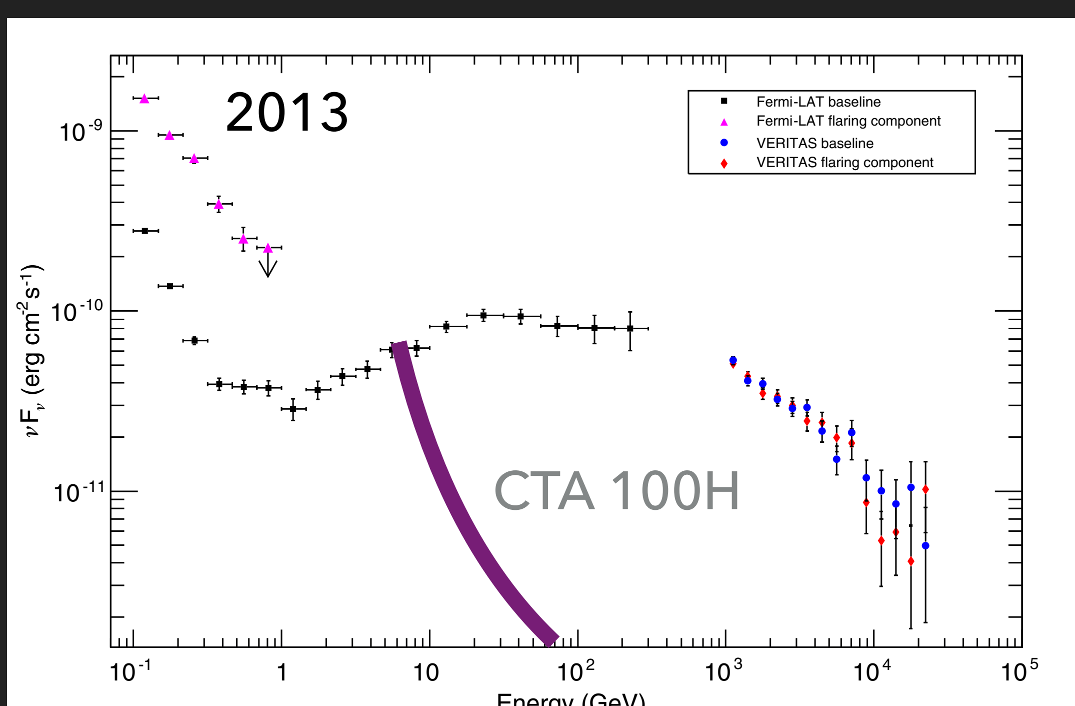
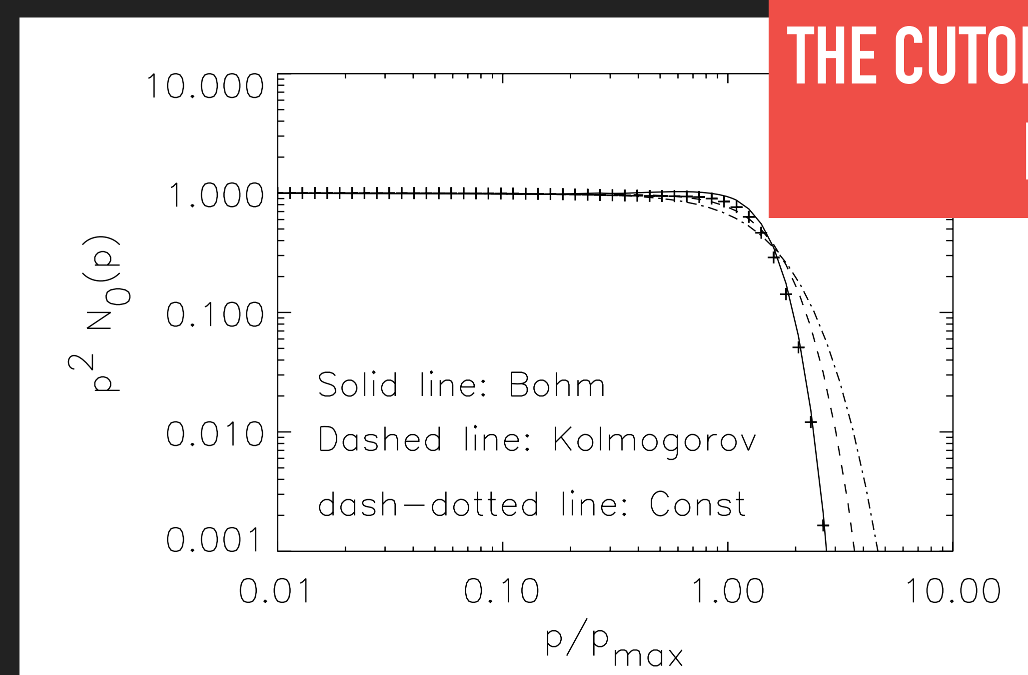



AT THE SYNCH LIMIT THE CUTOFF IS SUPER-EXP



# CONCLUSIONS

FLARES IN CRAB DEFIES CURRENT DSA AND LOSS LIMITS

FLARES LIKELY VERY COMMON IN ALL PWNE

FLARES DO NOT SHOW EVIDENT COUNTERPART AT ANY OTHER WAVELENGTH

LACK OF GOOD CONSTRAINTS ON THE SED

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DETECTABILITY OF MAJOR FLARES AT THE VERY EDGE OF CTA CAPABILITY

MUCH OF IT DEPENDS ON SED CUTOFF SHAPE