Study of the optical and X-ray wisps in the Crab Nebula

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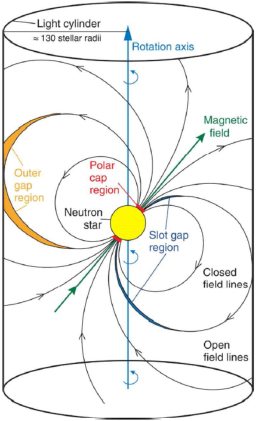
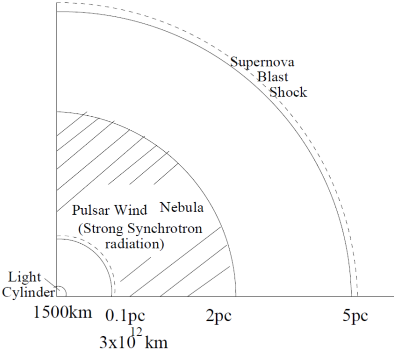
Outline

1. Introduction
2. Optical and X-ray study
3. Theoretical model
4. Conclusions
5. *Correlation study

Introduction

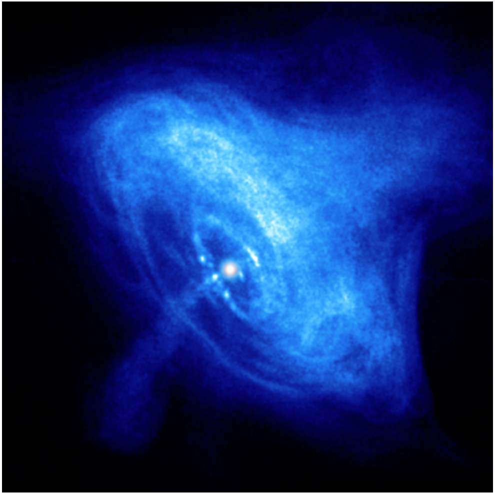
Crab nebula is a pulsar wind nebula





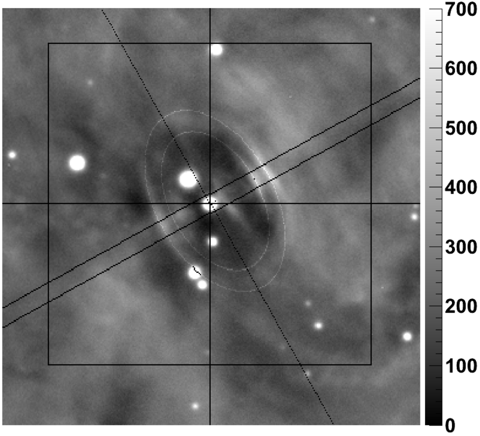
Introduction

Motivation – movie



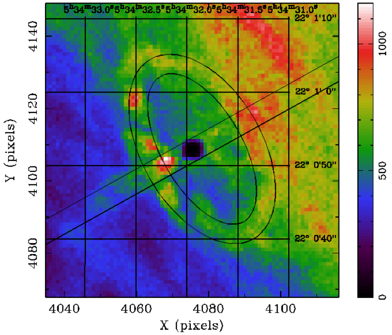
Optical observations

- Nordic Optical Telescope
  25 images (Nov 2010 - Sep 2012)
- Ellipses at 8.0" and 10.1"
- Aspect ratio 0.6
- Pulsar offset 0.8"



X-ray observations

- Chandra
  22 images (Sep 2010 - Sep 2012)
- Ellipses aspect ratio 0.49
- Pulsar offset 0.9"

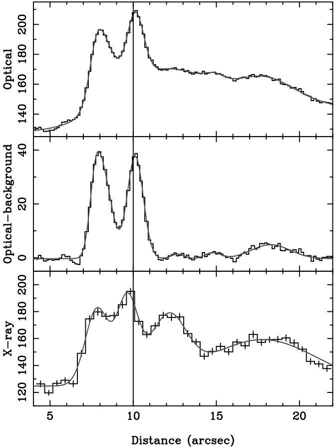


Radial profile analysis

Example of radial profile

- First peak = termination shock
- Peaks in optical and x-rays do not coincide

- Background substracted with TSpectrum::Background ROOT function
- X-ray histogram smoothed with TSpectrum::SmoothMarkov ROOT function

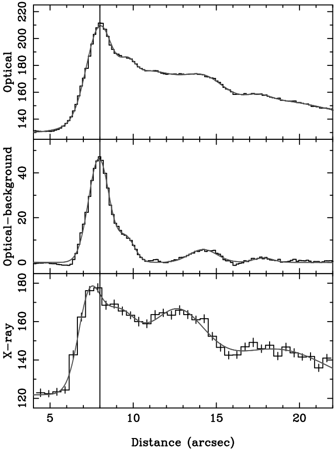


Radial profile analysis

Averaged radial profile

- First peak = termination shock
- Peaks in optical and x-rays do not coincide

- Background substracted with TSpectrum::Background ROOT function
- X-ray histogram smoothed with TSpectrum::SmoothMarkov ROOT function

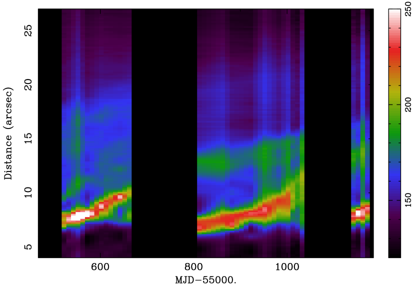


Wisps radial time-dependent evolution

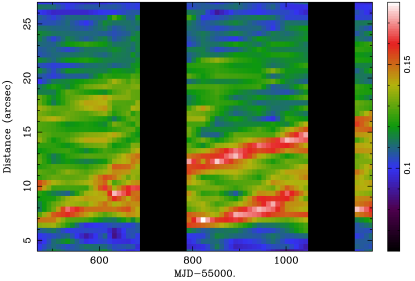
Interpolated

- 10-day time spacing
- Linear average

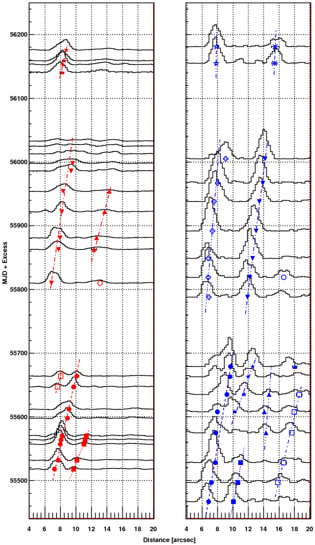
Optical

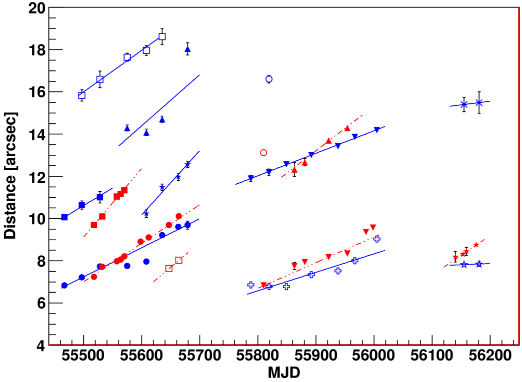


X-ray



Wisps radial time-dependent evolution





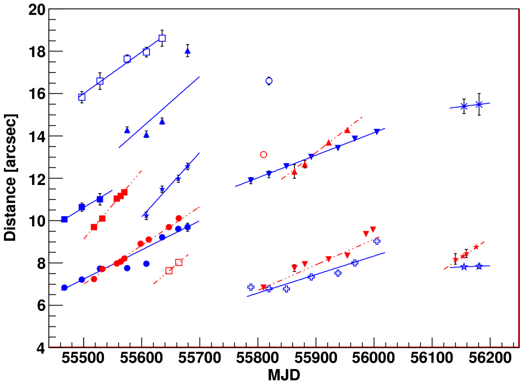
Wisps radial time-dependent evolution

Deprojection done assuming:

- Distance = 2 kpc
- Observation angle = 57°

symbol	″/day	$(v/c)^a$	$(v/c)^b$
Optical (red)			
circle	0.018	0.21	0.29
box solid	0.033	0.38	0.44
triangle up	0.021	0.24	0.32
triangle down	0.012	0.14	0.21
star	0.019	0.22	0.30
X-rays (blue)			
circle	0.014	0.16	0.24
box solid	0.017	0.19	0.28
box open	0.020	0.23	0.31
star solid	0.031	0.35	0.42
triangle up	0.024	0.28	0.36
triangle down	0.011	0.12	0.19
cross	0.009	0.10	0.16

[a] Apparent velocity on the sky.
[b] Deprojected velocity.



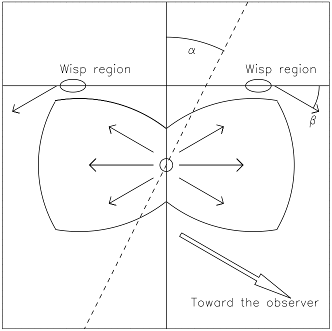
Theoretical model fitting

Existing MHD models (Komissarov & Lyubarski 2003, 2004; Del Zanna et al. 2004; Bucciantini et al. 2005; etc.) explain existence of the wisps.

Simplified model assumes:

- Ring-like structure of the wisps
- Luminosity differences of different regions of the wisps due to Doppler boosting

All alternative models (Spitkovsky & Arons 2004; Foy & Hester 2009) require Doppler boosting.



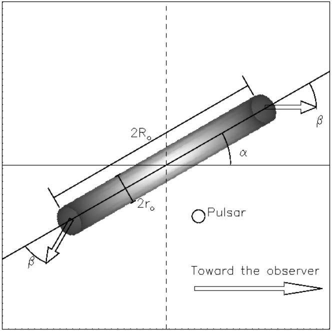
Theoretical model fitting

Parameters used:

- R_0 – major radius
- r_0 – minor radius
- V_{fl} – flow speed
- α – observation angle
- β – flow angle

Procedure summary:

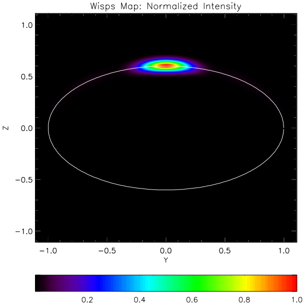
- Select a set of paramters
- Build emission map
- Compare simulated profiles with data (in 2D)
- Chose best fit (minimising the resituals in the brigtest part)

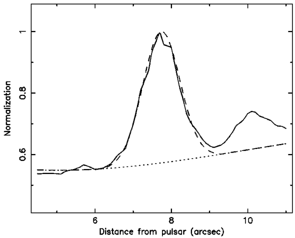


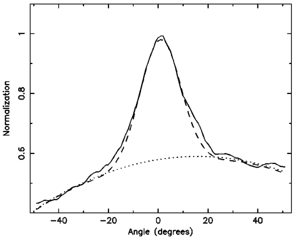
Theoretical model fitting

Results:

- $0.8c < V_{fl} < 0.95c$
- $\alpha = \beta = 37^\circ \pm 4^\circ$
- $r_0/R_0 < 0.1$







Theoretical model fitting

Comparison between x-rays and optical azimuthal profiles done (using average profiles over epoch).

Results:

- $r_0/R_0 = 0.1$
- $\alpha = \beta = 35^\circ$
- $V_{fl} = 0.6c \pm 0.1c$ (X-ray) and $0.91c \pm 0.03c$ (optical)

Corresponding boosting factor $U_{fl} = (V_{fl}/c)/\sqrt{1-(V_{fl}/c)^2}$:

0.75 (X-ray) and 2.35 (optical)

Conclusions

Conclusions

- Optical and x-ray wisps appear in $\approx 1y$ intervals
- Optical and x-ray wisps are not always co-aligned
- Apparent speed of the wisps $\approx 0.1c - \approx 0.4c$
- Optical and x-ray wisps seem to be produced by different particle populations
- Origin of pulsar offest remains unknown
- Possible correlation between wisps and γ-ray flares

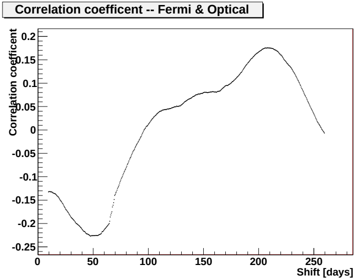
Results presented in:

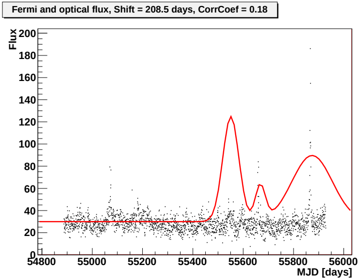
"Characterisation of the optical and X-ray properties of the northwestern wisps in the Crab Nebula" –

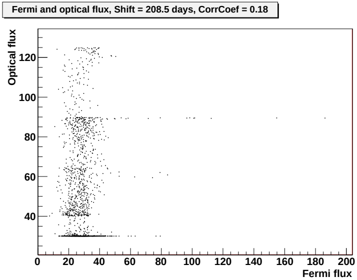
– T. Schweizer, N. Bucciantini, W. Idec, K. Nilsson, A. Tennant, M.C. Weisskopf, R. Zanin

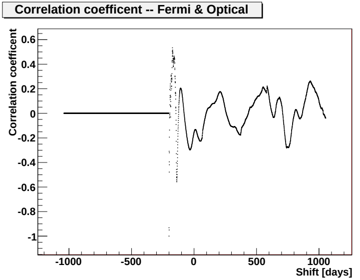
arXiv:1301.1321 [astro-ph.HE] (submitted to MNRAS)

Correlation study

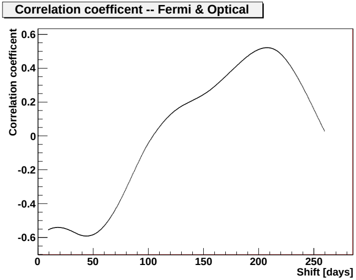


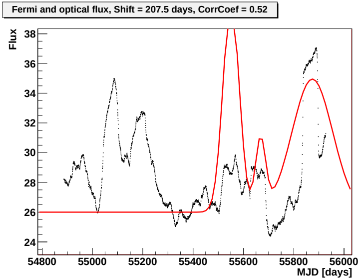


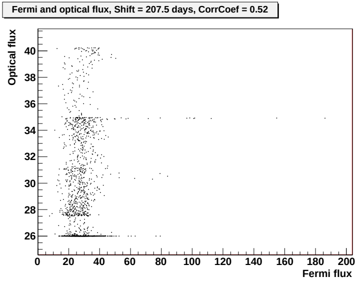


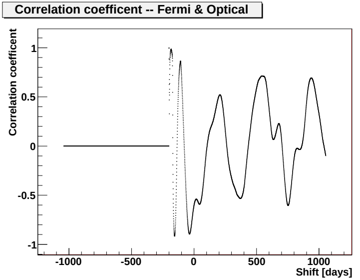


Correlation study – average over 30 days









Correlation study – gausian blur