Beyond X-ray timing:

fast multi-wavelength variability from jets in X-ray binaries

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WHY ARE JETS IMPORTANT?

Motivational Slides AGN - X-RAY BINARIES - GRBS - WDS - SNE - PROTOSTARS - (ULX?)

> * GENERAL PHENOMENON >>> GENERAL KNOWLEDGE







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Motivational Slides AGN - X-RAY BINARIES - GRBS - WDS - SNE - PROTOSTARS - (ULX?)

GENERAL PHENOMENON >>> GENERAL KNOWLEDGE

業 THEY INFLUENCE THE EVOLUTION OF THE LAUNCHING SYSTEM

* THEY INFLUENCE THEIR SURROUNDINGS (ISM, IGM)

JET LAUNCHING MECHANISMS ARE UNKNOWN

JET STRUCTURE AND COMPOSITION ARE OFTEN UNKNOWN

THEY CAN BE LAUNCHED FROM, OR CLOSE TO,

A STRONG-GRAVITY ENVIRONMENT



JETS IN XBS VARY ON TIMESCALES FROM YEARS TO MILLISECONDS



Piergiorgio Casc' - Agios Nikolaos Onal Motivational Notivations

fast variability from jets in XBs

WHY JET VARIABILITY?

REPROCESSED VARIABILITY:

X-RAYS GET REPROCESSED FROM THE OUTER DISK, AND FROM THE COMPANION... "DELAYED MULTIWAVELENGTH VARIABILITY

GEOMETRY OF THE SYSTEM

INTRINSIC VARIABILITY:

TRANSFERRED/MODIFIED THROUGH THE ACCRETION FLOW?

4/30

(OUTER DISK \rightarrow INNER DISK \rightarrow CORONA? \rightarrow JET?)

STRUCTURE AND ENERGY BUDGET OF THE ACCRETION FLOW

PROPERTIES OF DISK, CORONA, JET (THICKNESS, OPACITY, SIZE, VELOCITY, ...)





IS THE JET POWERED BY VARIABILITY FROM THE ACCRETION FLOW?







FIRST HINTS FOR JET VARIABILITY: X-RAY/OPTICAL CCFS

REPROCESSED VARIABILITY:





THE OPTICAL VARIABILITY IS ANTI-CORRELATED, AND **PRECEDES** THE X-RAYS! **NOT REPROCESSING...WHAT?** (e.g. Hynes et al. 2003)

Sout

AN EXPLANATION: A POWERFUL JET

THE "COMMON RESERVOIR MODEL" (MALZAC, MERLONI & FABIAN 2004)

JET-CORONA COUPLING THROUGH COMMON ENERGY RESERVOIR



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IF YOU WANT THE JET..GO WHERE THE JET IS



IF YOU WANT THE JET..GO WHERE THE JET IS



LET'S GO REDDER: INFRARED FAST PHOTOMETRY

SO FAR, IN OPTICAL. THE JET/DISK RATIO IS (MUCH) HIGHER IN <u>INFRARED</u>

GX 339-4 - ISAAC@VLT - 62.5MS - K=12.5



23" x 23"



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0

Time (s)

100

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***** INFRARED LAG X-RAYS BY 100 MILLISECONDS

- **VERY HIGH BRIGHTNESS TEMPERATURE (>10⁶K)**
- ***** FLAT SPECTRAL SLOPE
- **WE ARE OBSERVING THE JET VARYING**

ON TIMESCALES AS SHORT AS 67 MILLISEC.



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GX 339-4 - ISAAC@VLT - 62.5MS - K=12.5

- ***** INFRARED AND X-RAYS ARE CORRELATED
- ***** INFRARED LAG X-RAYS BY 100 MILLISECONDS
- ***** VERY HIGH BRIGHTNESS TEMPERATURE (>10⁶K)
- ***** FLAT SPECTRAL SLOPE
- * WE ARE OBSERVING THE JET VARYING

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GX 339-4 - ISAAC@VLT - 62.5MS - K=12.5

(I) IR: **thick** X-rays: inflow

- It takes 0.1s for the matter to get there
- we assume all jets in X-ray binaries are similar
- we scale from Cyg X-1 in radio to GX 339-4 in infrared
 - $R_{MAX} \sim \gamma^{-4/3} \beta^{-2/3} D^{2/3} SIN \theta^{-1/3} \Phi^{-1} L^{2/3} v^{-1}$ ("standard" formula by I
- we measure the speed for many sets of parameters

Γ > 2 A MEASURE OF THE JET SPEED



thin

inflow

(corona)

LET'S GO REDDER: INFRARED FAST PHOTOMETRY

SO FAR, IN OPTICAL. THE JET/DISK RATIO IS (MUCH) HIGHER IN <u>INFRARED</u>

GX 339-4 - ISAAC@VLT - 62.5MS - K=12.5

(2) IR: thin X-rays: inflow

a) before cooling: **T**eject > **0.1** s

A MEASURE OF THE EJECTION TIMESCALE

b) after cooling: can't be too far off the break... ... the jet size can be approximated as estimated if thick

Γ > 2 A MEASURE OF THE JET SPEED

LET'S GO REDDER: INFRARED FAST PHOTOMETRY



- The reasoning on the jet speed holds even better:

Γ > 2 A MEASURE OF THE JET SPEED



thin

thin

thin

LET'S GO REDDER: INFRARED FAST PHOTOMETRY

SO FAR, IN OPTICAL. THE JET/DISK RATIO IS (MUCH) HIGHER IN <u>INFRARED</u>

GX 339-4 - ISAAC@VLT - 62.5MS - K=12.5

(4) IR: thin X-rays: thin

- we observe a time delay: IR must come after cooling
- $T_{cooling} = 100 \text{ ms}$
- we assume $E_0 \sim X$ -rays and $E_1 \sim IR$
- we find a unique solution: $\gamma_0 \sim 10^4 \ \gamma_1 \sim 50 \ B \sim 10^4 \ G$

A GLIMPSE OF JET PHYSICS

- ABSOLUTE VALUES ARE PROBABLY NOT (YET) RELIABLE, BUT RELATIVE VALUES SHOULD BE...
- *** A 2ND** DATASET:
 - AGAIN GX 339-4, ONE YEAR LATER (2009), ANOTHER OUTBURST
 - AGAIN HARD STATE, A FACTOR OF ~4 BRIGHTER IN X-RAYS THAN 2008
 - JET SHOULD HAVE ACCELERATED....
 - BUT WE FIND:



fast variability from jets in XBs

NICE EXERCISES...WHAT'S NEXT? 1/2

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 - AGAIN GX 339-4, ONE YEAR LATER (2009), ANOTH
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 - JET SHOULD HAVE ACCELERATED....
 - BUT WE FIND:

IR LAGS X-RAYS BY ~200 MILLISECONDS

- WE MEASURE A LOWER JET SPEED...
- **POSSIBLE EXPLANATIONS:**
 - A) THE JET BREAK HAS MOVED (IR WAS THIN, NOW IS THICK)
 - **B) JET PRECESSION?**
 - C) DIFFERENT OUTBURSTS, DIFFERENT JET SPEED/POWER/B-FIELD
 - D) EJECTION TIMESCALE INCREASED?
 - E) THE SCALING FOR THE JET ELONGATION MIGHT NOT HOLD AT THESE HIGH FLUXES



- ABSOLUTE VALUES ARE PROBABLY NOT (YET) RELIABLE, BUT RELATIVE VALUES SHOULD BE...
- *** A 3RD** DATASET:
 - AGAIN GX 339-4, ANOTHER YEAR LATER (2010), ANOTHER OUTBURST
 - BRIGHT HARD (INTERMEDIATE) STATE, A FACTOR OF ~10 BRIGHTER THAN 2009
 - JET SHOULD HAVE ACCELERATED....
 - WE FIND:



27/30

- ABSOLUTE VALUES ARE PROBABLY NOT (YET) RELI BUT RELATIVE VALUES SHOULD BE...
- ***** A **3RD** DATASET:
 - AGAIN GX 339-4, ANOTHER YEAR LATER (2010), AI
 - BRIGHT HARD (INTERMEDIATE) STATE, A FACTOR OF
 - JET SHOULD HAVE ACCELERATED....
 - WE FIND:

IR LAGS X-RAYS BY 120 MILLISECONDS

WE WOULD MEASURE A HUGE JET SPEED...

HOWEVER, THE SCALING FOR THE JET ELONGATION DOES NOT HOLD!

MOREOVER:

- A) AGAIN DIFFERENT OUTBURSTS, DIFFERENT JET SPEED/POWER/B-FIELD
- **B) DIFFICULT TO COMPARE**
- c) THE EVIDENCE IS FOR THE TIME DELAY TO BE ALWAYS SIMILAR (WITHIN A FACTOR OF ~2, WITH A FACTOR OF ~50 IN X-RAY FLUX)







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CONCLUSIONS - FUTURE

WE HAVE MORE DATASETS (ANALYSIS IN PROGRESS), MORE NEEDED

- a) **TRACK AN ENTIRE BH OUTBURST** (SOME DONE, + SUBMITTED)
- b) USE OPTICAL AND IR TOGETHER (SOME DONE, + SUBMITTED)
- C) GO REDDER (SOME SPITZER DATASETS, SOME RADIO DATASETS)
- d) **GO FAINTER** (ONE QUIESCENT **BH** SCHEDULED)
- e) THE SAME FOR NSS (A FEW DONE, + SUBMITTED)
- A MORE ADVANCED TIMING TECHNIQUES (WORK IN PROGRESS)
- q) DEVELOP BETTER (REALISTIC AND VARIABLE) JET MODELS
- * This is a new field. There is much to do
- WE OBSERVE MATTER WHILE IT GOES ALONG THE JET. WE CM LEARN A LOT!
 - WE CAN **MEASURE** PHYSICAL QUANTITIES
 - (or at least we can try ...)

NEED NEW INSTRUMENTATION

- SIMULTANEOUS OPTICAL-INFRARED FAST TIMING (WE ARE DOING IT, BUT DIFFICULT)
- FAST-PHOTOMETERS PERMANENTLY MOUNTED, FOR TOO & MONITORING
- THE FUTURE: **E-ELT**: POPULATION STATISTICS!
- THE IDEAL FUTURE: FAST OPTICAL/IR MONITOR ON X-RAY SATELLITE