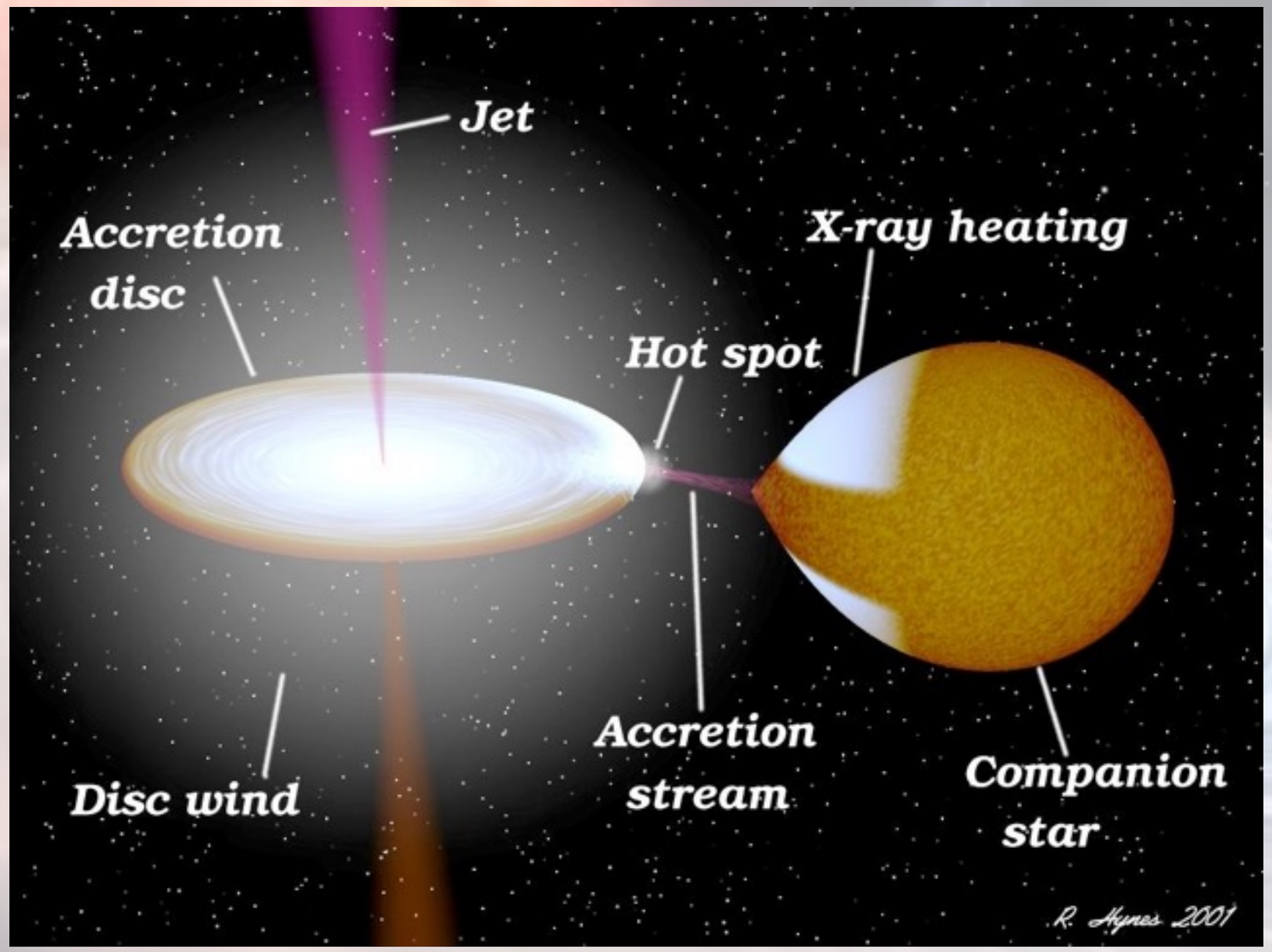
BLACK HOLES TRANSIENTS

with ALMA

Piergiorgio Casella
(INAF-OAR)

ALMA Workshop - Bologna 2019

BLACK HOLE TRANSIENTS



accessible timescales - high brightnesses - multi-λ

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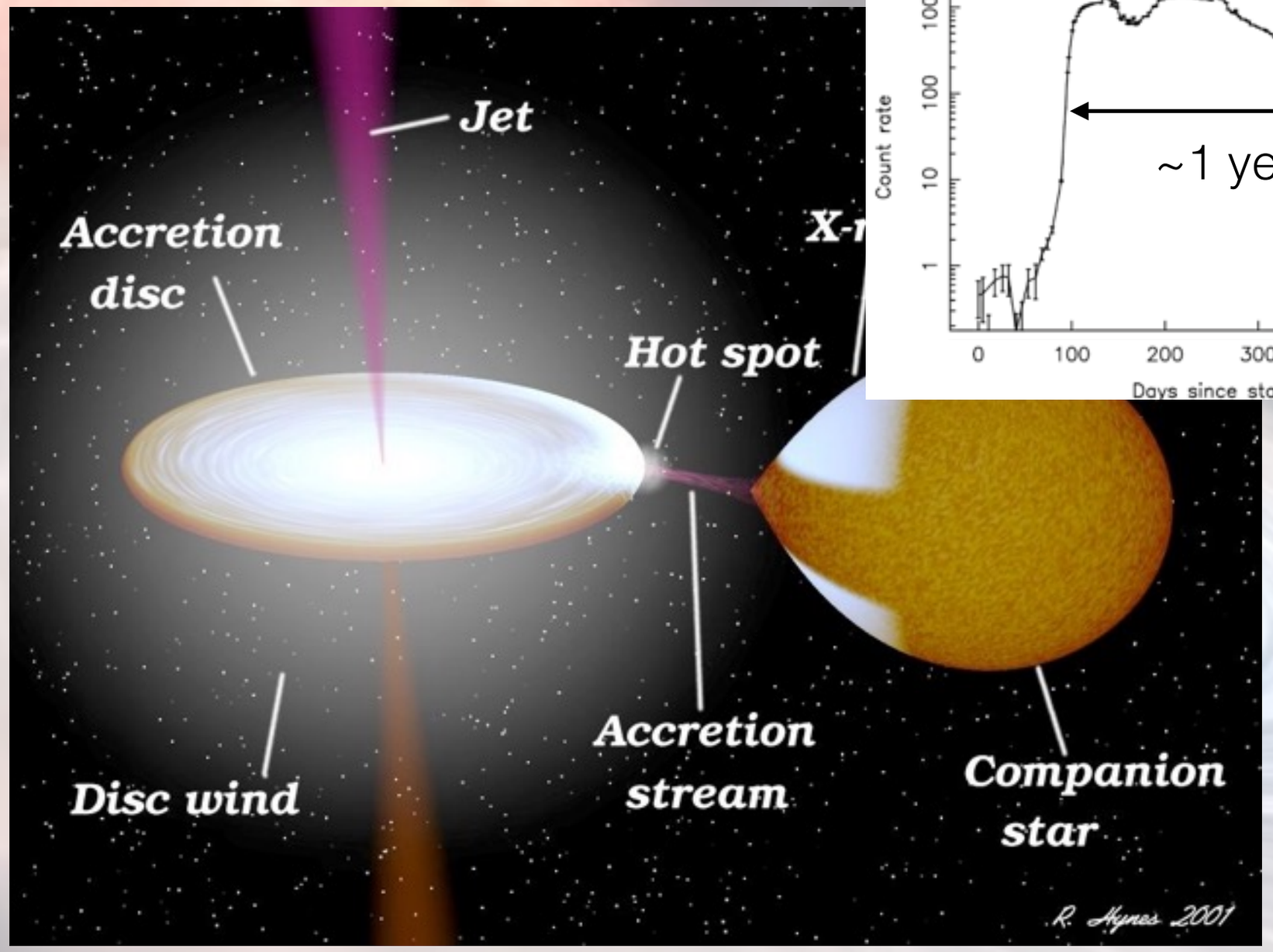

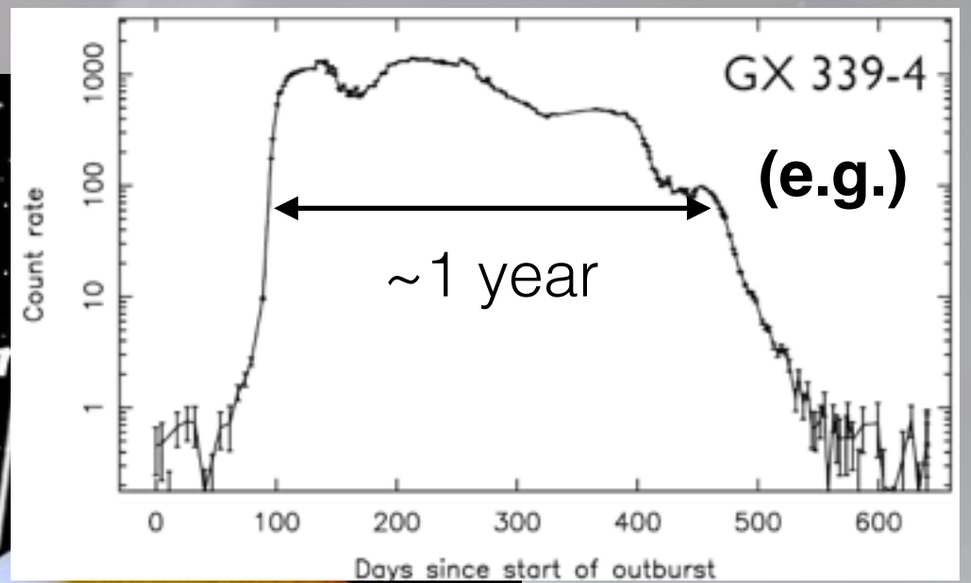

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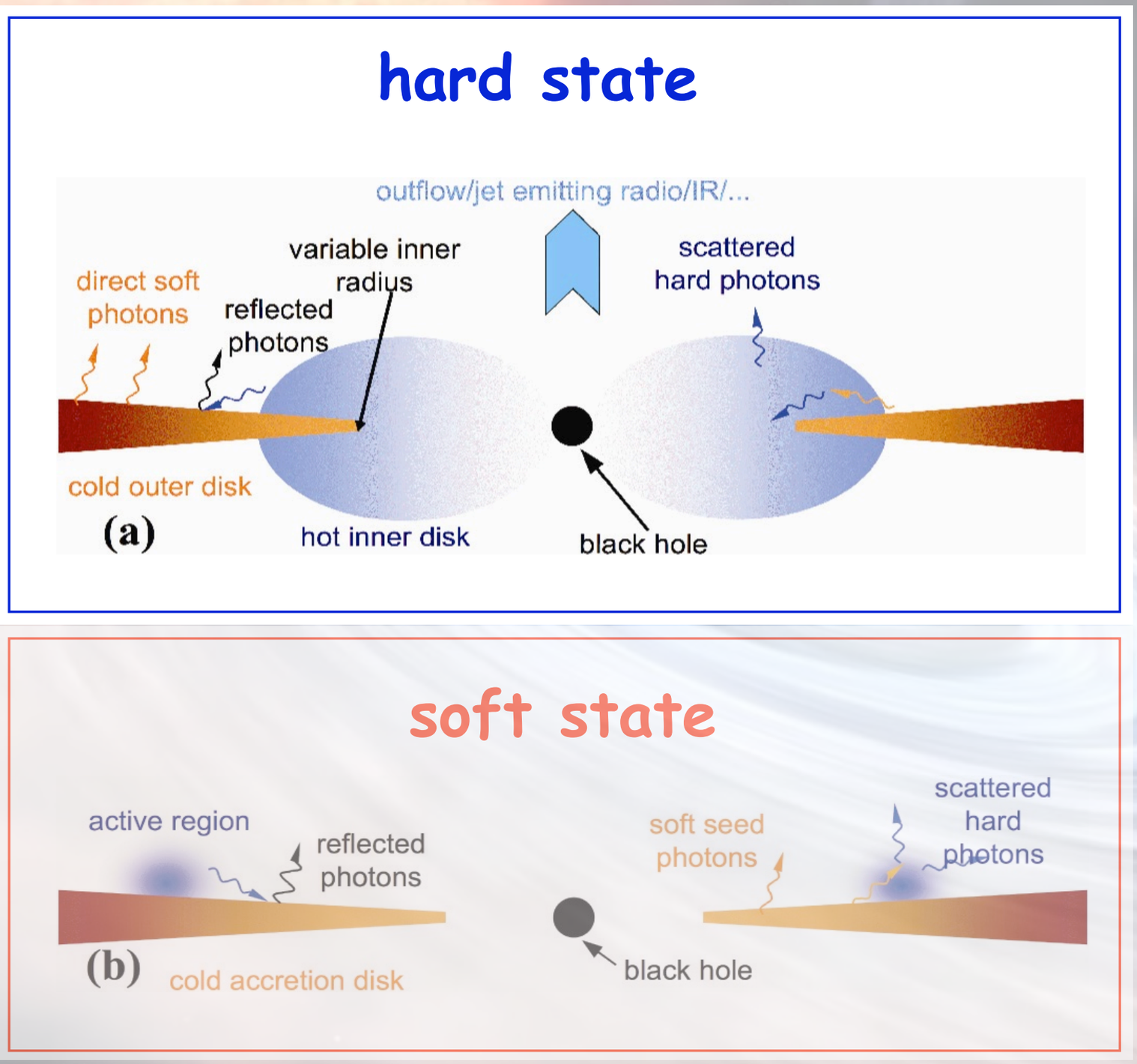
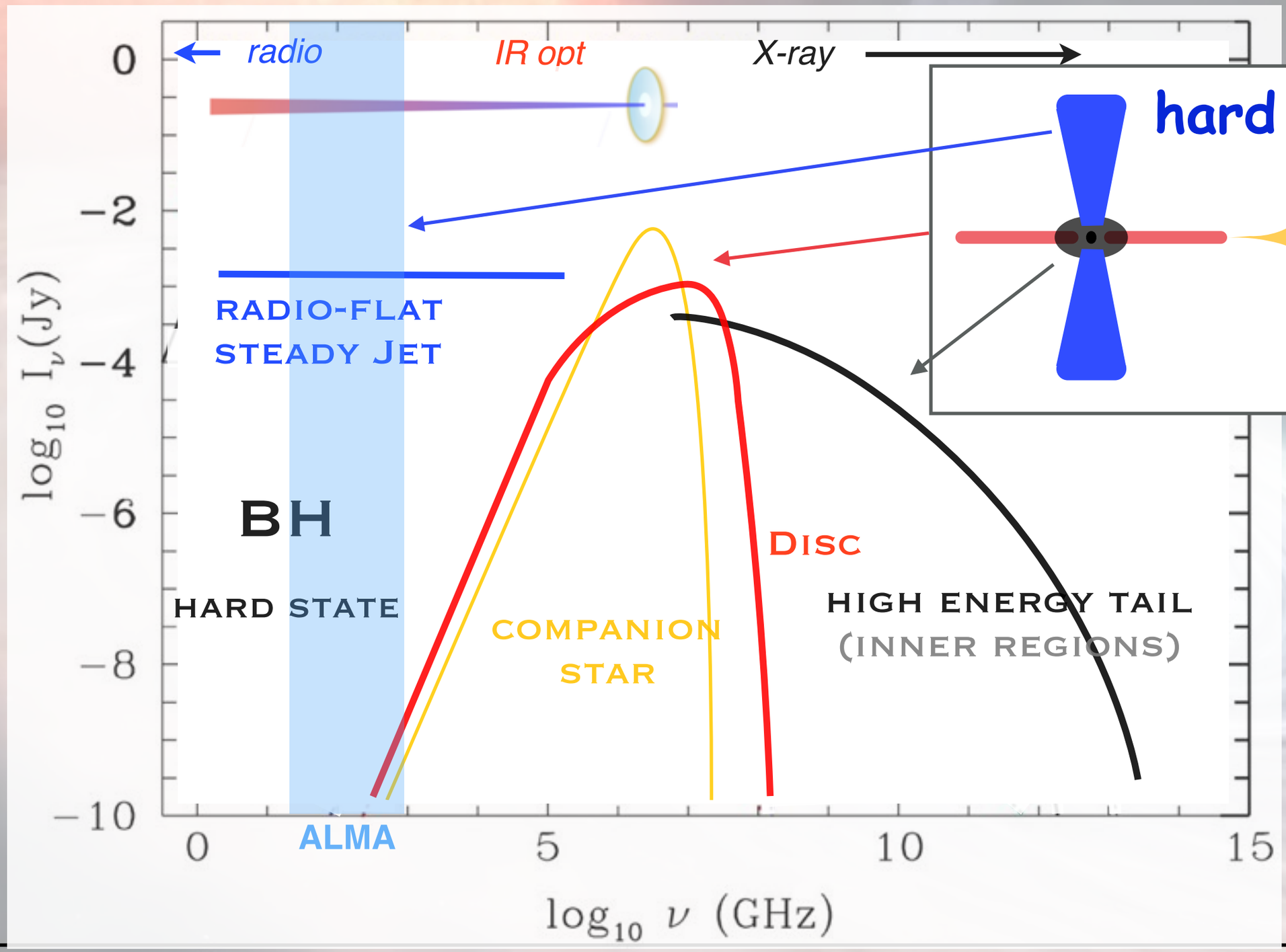
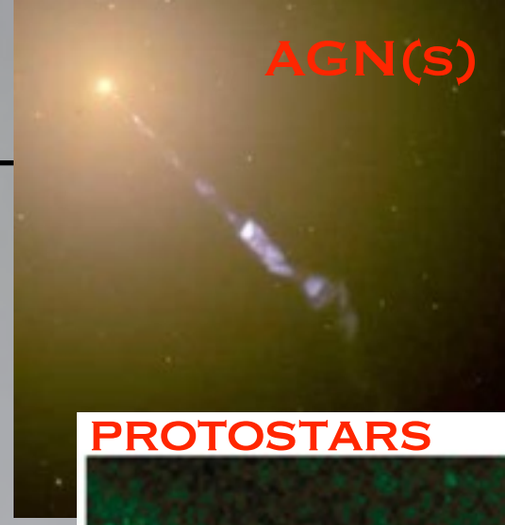


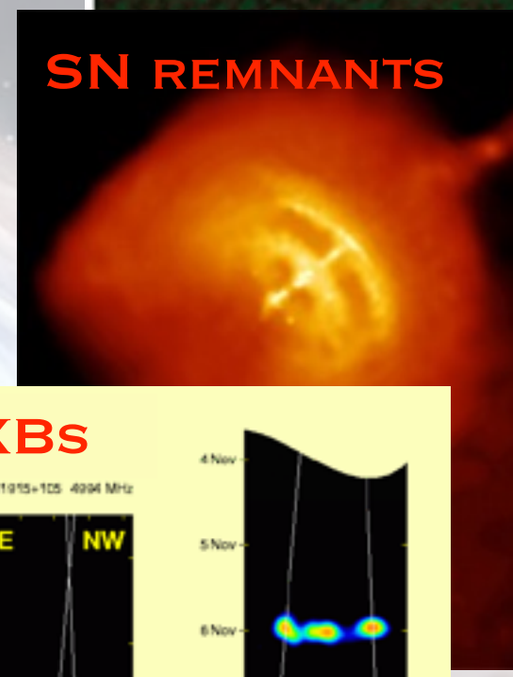
Zdziarski & Gierlinski (2004)

BLACK HOLE TRANSIENTS



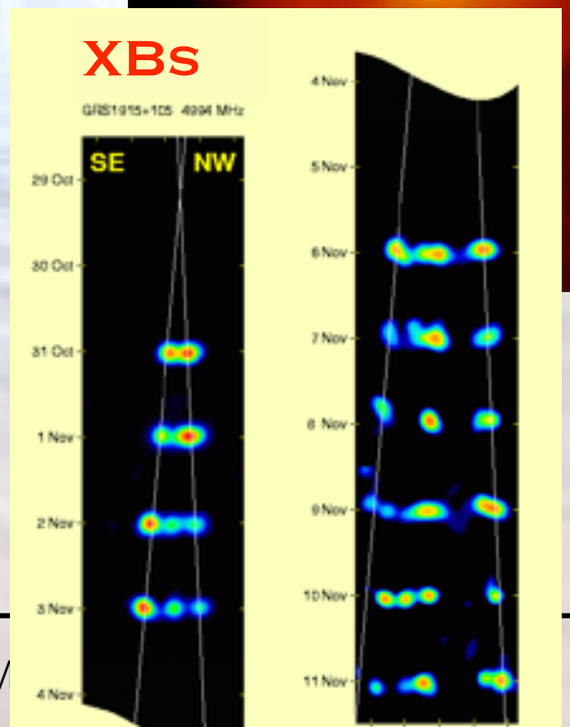
JETS



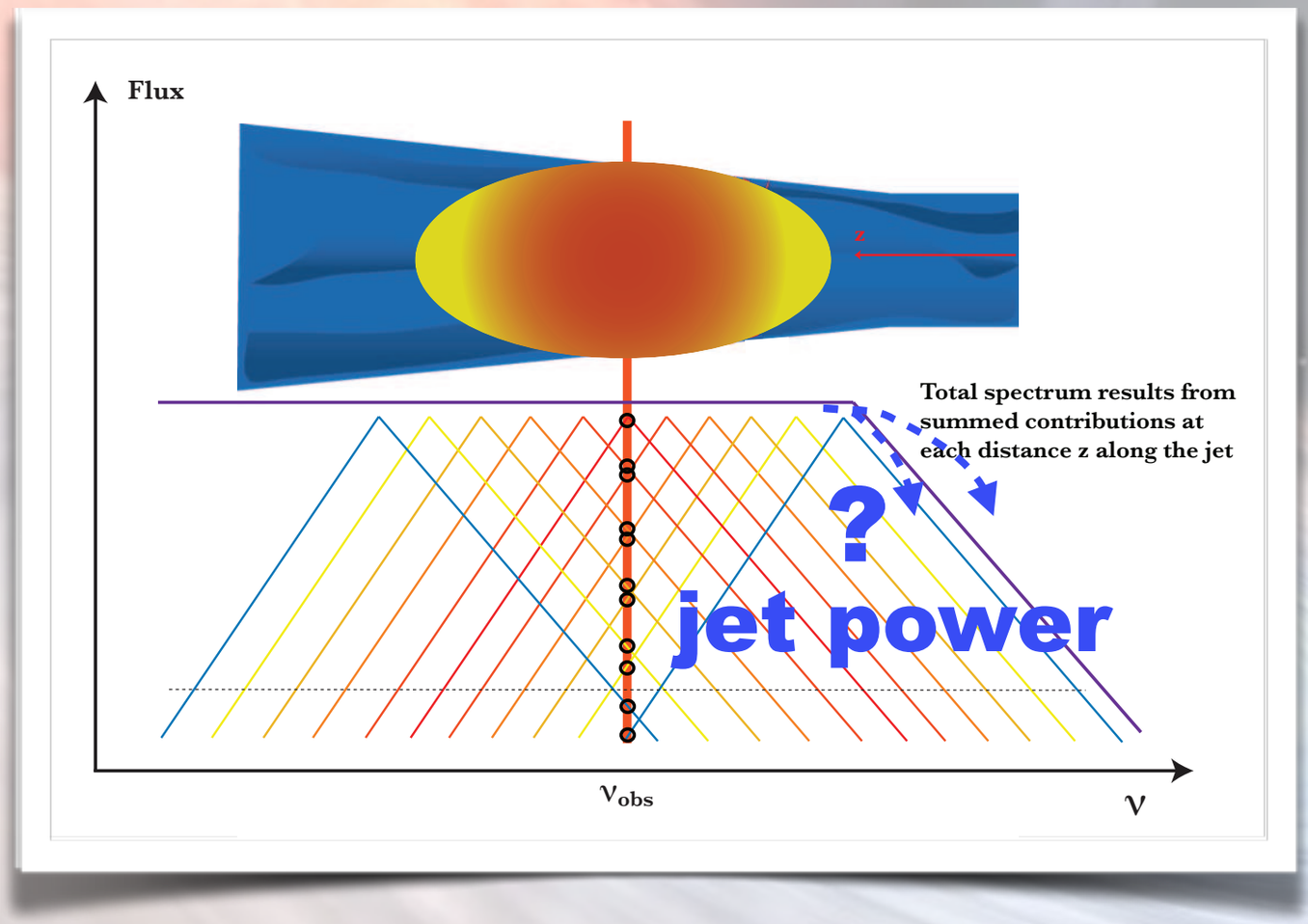


- Very common: associated with accretion processes at all scales
- GRBs - SNe - AGN - **X-ray Binaries** - WDs - Protostars - (ULXs?)
- Influence on their surroundings (ISM, IGM, SF)
- Influence on the evolution of the launching system
- Launched from, or close to, *strong-gravity* environments
  - Unknown launching mechanisms
  - Unknown geometry, structure, and composition
  - Unknown powering mechanism
- Jets in **XBs** are transient and variable

→ **EVOLUTION**



STANDARD STEADY-JET THEORY



Blandford & Konigl (1979)

picture from Markoff (2010)

Basic assumptions

$n=c\Upsilon^{-p}\sim r^{-2}$

$B(r) \sim r^{-1}$

+

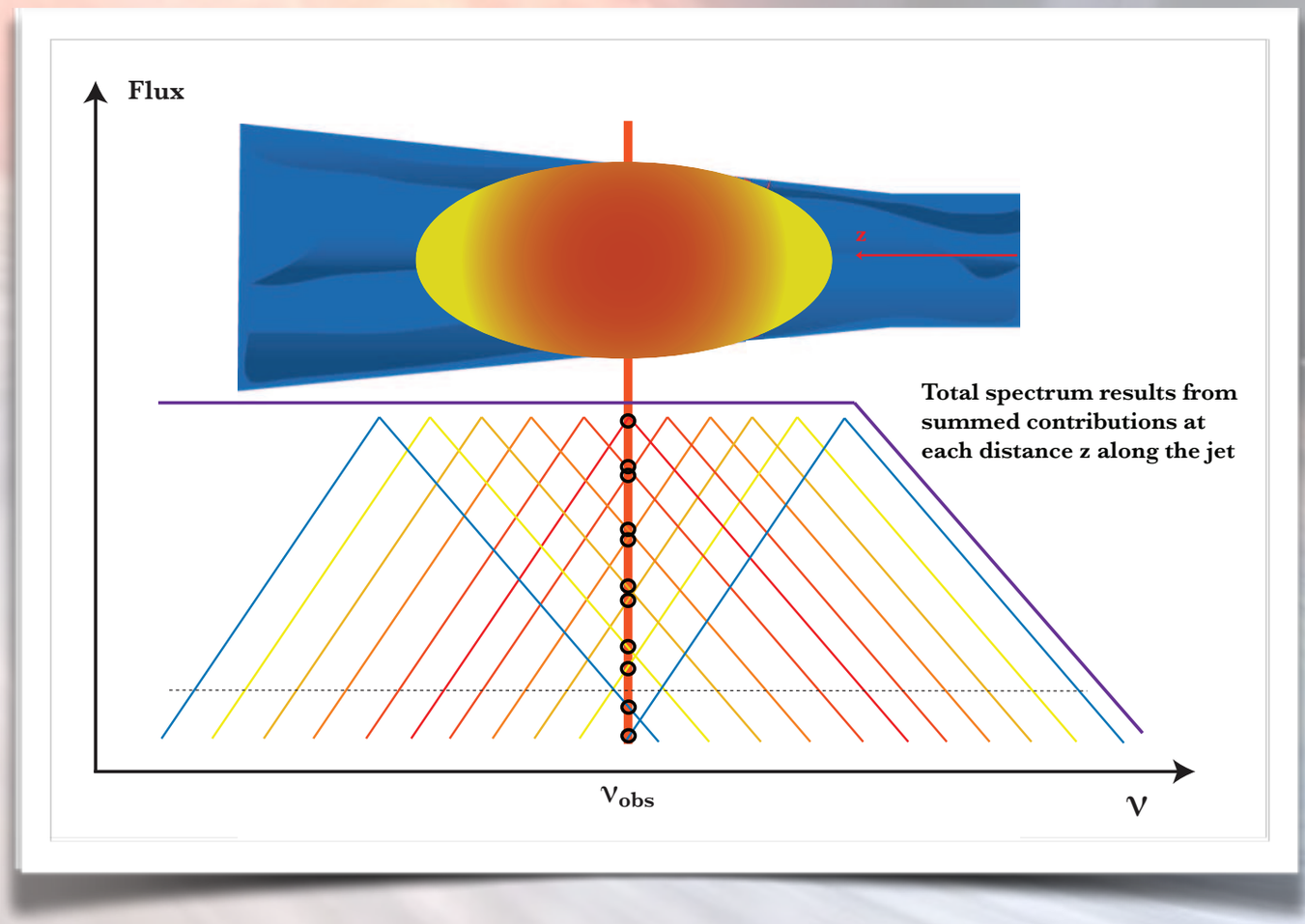
Basic synchrotron theory

$\nu_{break}=\nu|_{\tau_\nu=1} \sim r^{-1}$

=> **FLAT** radio spectrum

STANDARD STEADY-JET THEORY

the "missing-energy problem"



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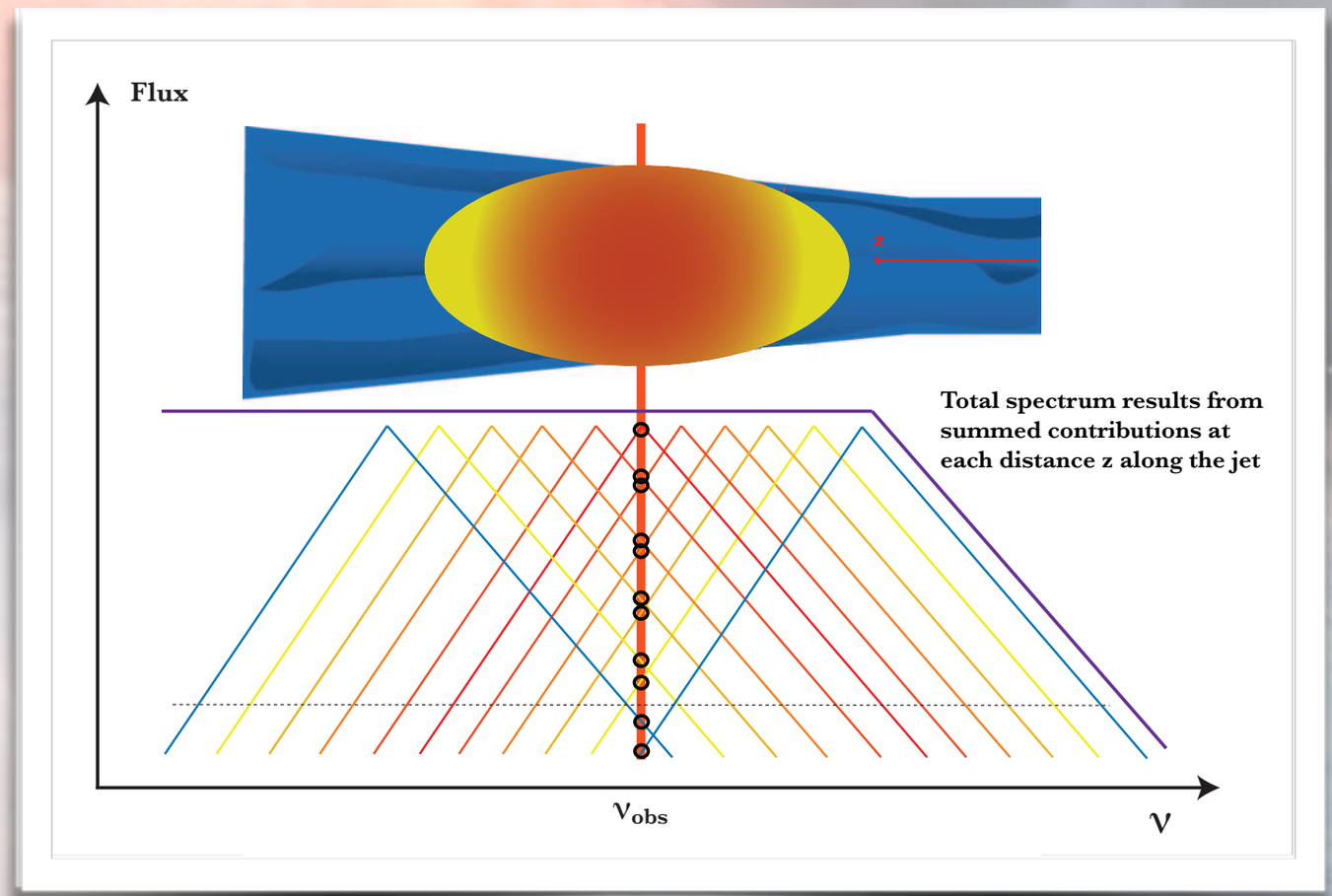


Blandford & Konigl (1979)

picture from Markoff (2010)

1979

(measured in the frame of the fluid) which will vary as r^{-}, where r is the distance from the apex (cf. the model of NGC 6251 in Readhead, Cohen, and Blandford 1978). We assume that relativistic electrons can be accelerated continuously within the jet, and that their distribution function is $N(\gamma_e) = K\gamma_e^{-2}$, with $\gamma_{e\,\min} < \gamma_e < \gamma_{e\,\max}$ and $\gamma_{e\,\max} \gg \gamma_{e\,\min}$. These electrons will radiate synchrotron radiation with a spectral index $\alpha = \frac{1}{2}$. The electron energy

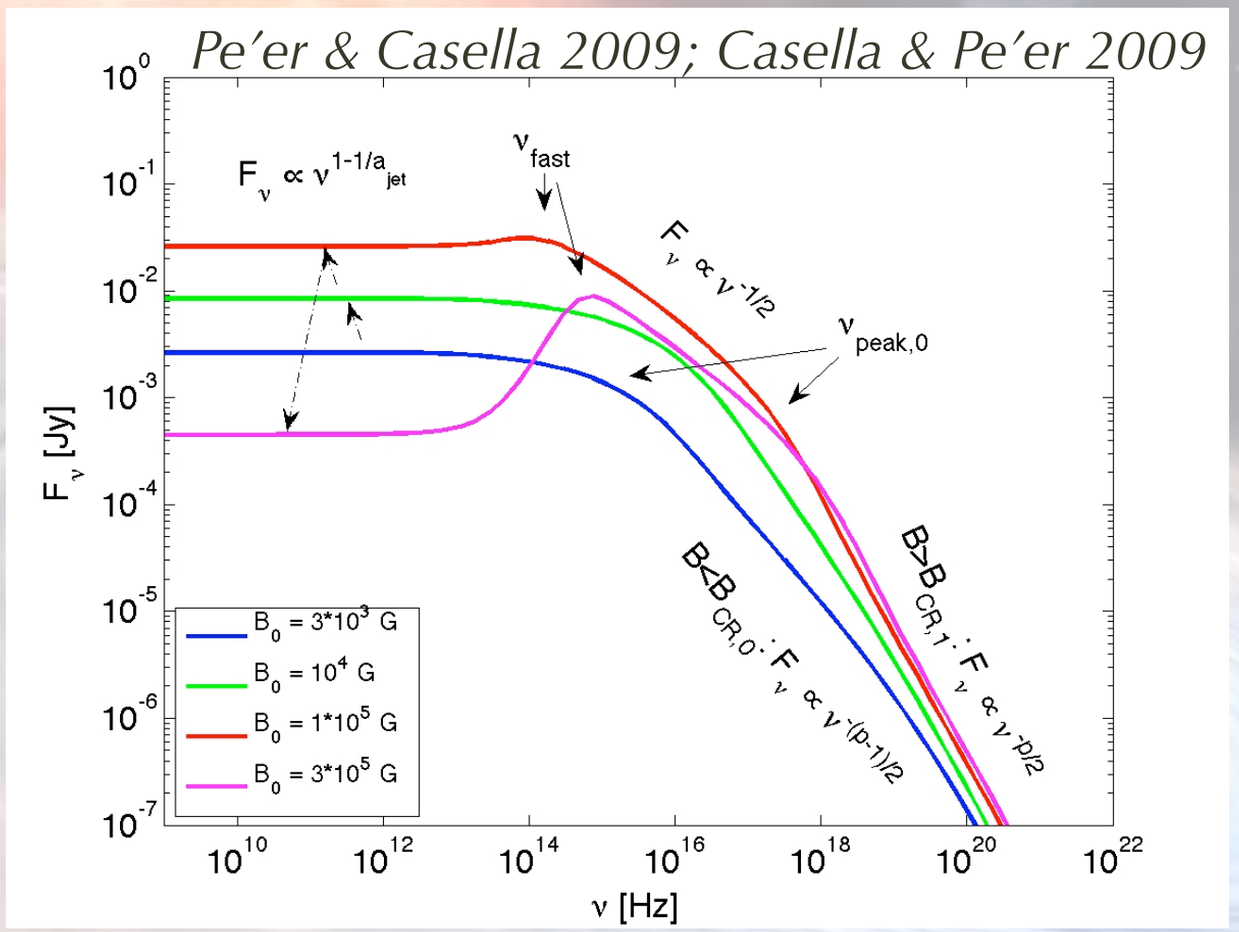
ENERGY LOSSES ACT VERY FAST:

WE SHOULD NOT SEE THE RADIO JET

STANDARD STEADY-JET THEORY

unexpected radiative properties?

e.g.:



1979

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ENERGY LOSSES ACT VERY FAST:

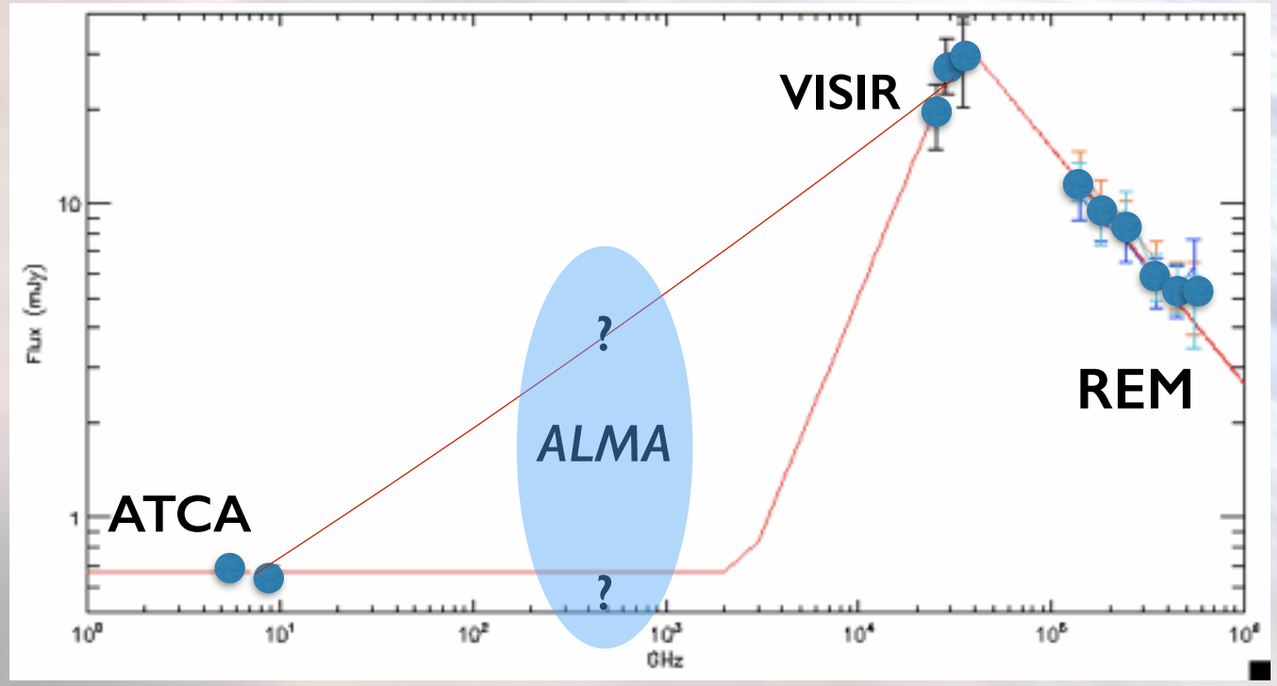
WE SHOULD NOT SEE THE RADIO JET

STANDARD STEADY-JET THEORY

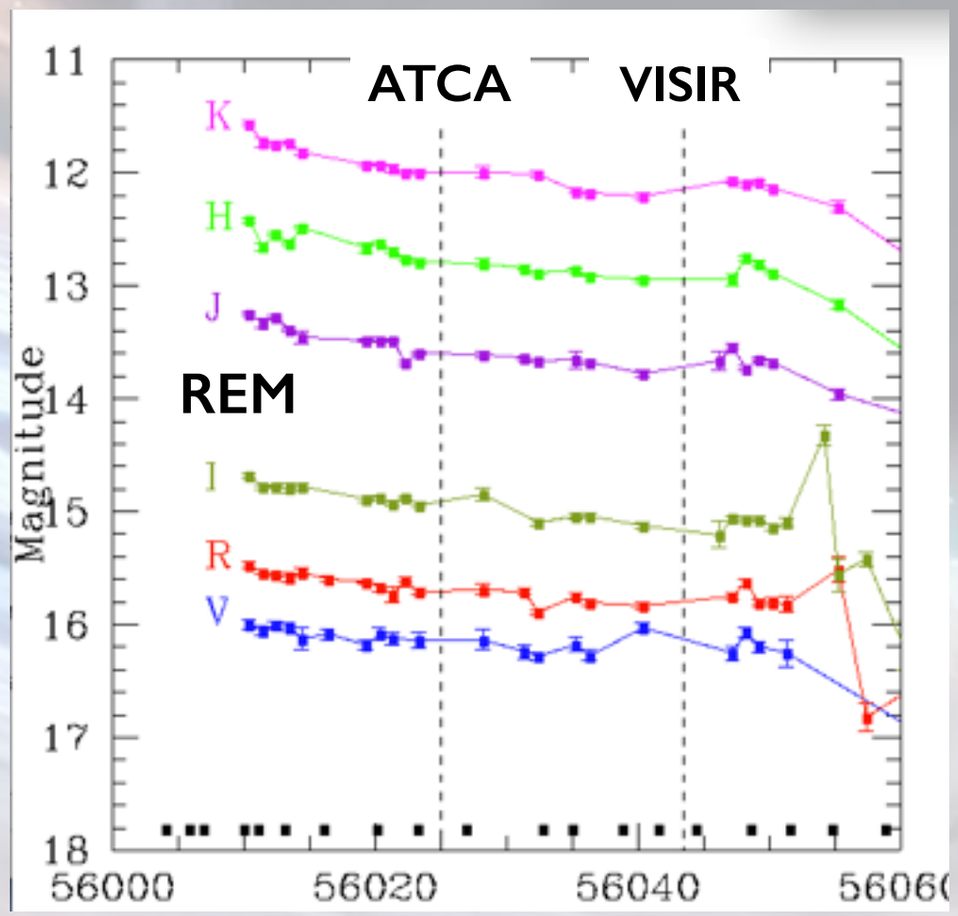
unexpected radiative properties?

SOMETIMES (perhaps) WE SEE THIS

Testa, Casella et al. (in prep.)

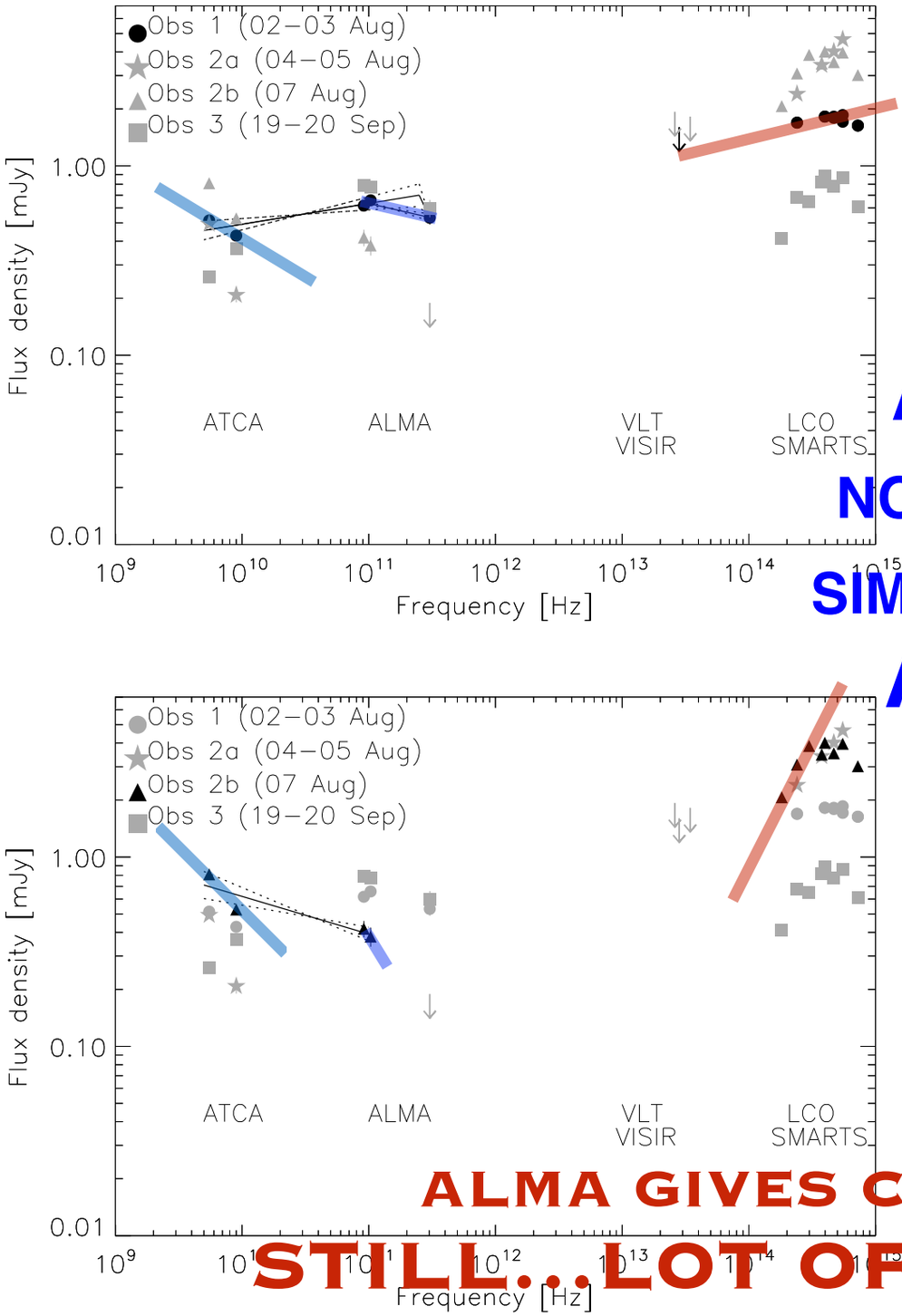


MAXI J1836-194



ALMA GIVES CRUCIAL COVERAGE

STANDARD STEADY-JET THEORY



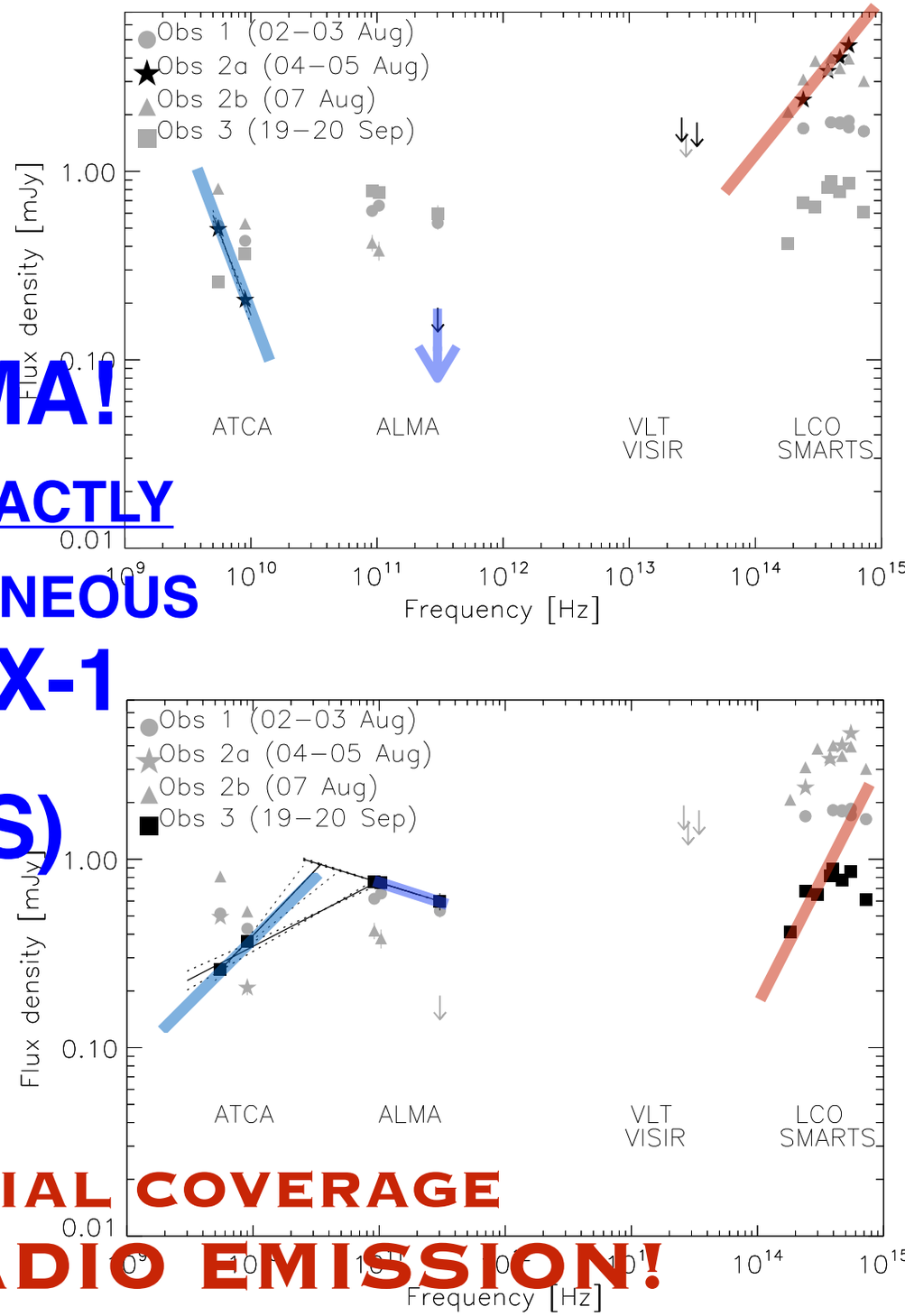
ALMA!

NOT EXACTLY

SIMULTANEOUS

Aql X-1

(NS)



ALMA GIVES CRUCIAL COVERAGE

STILL...LOT OF RADIO EMISSION!

Diaz-Trigo et al. 2018

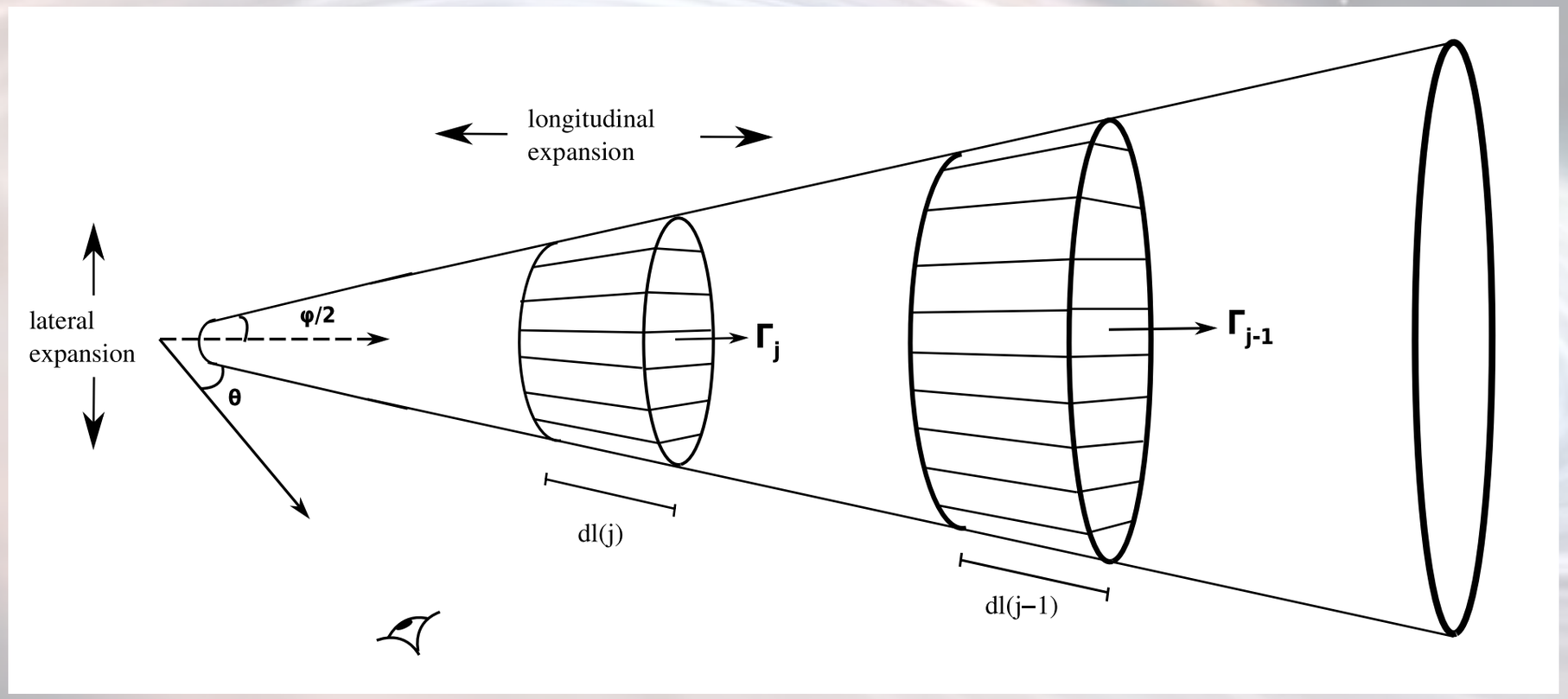
~~STANDARD STEADY~~-JET THEORY

POSSIBLE SOLUTION

RE-HEATING FROM INTERNAL SHOCKS

GRB jet emission theory ⟶ *blazars (Spada et al. 2001)*

recent works on XBs: Malzac 2013; Drappeau et al. 2014; Malzac et al. 2018; Péault et al. 2019

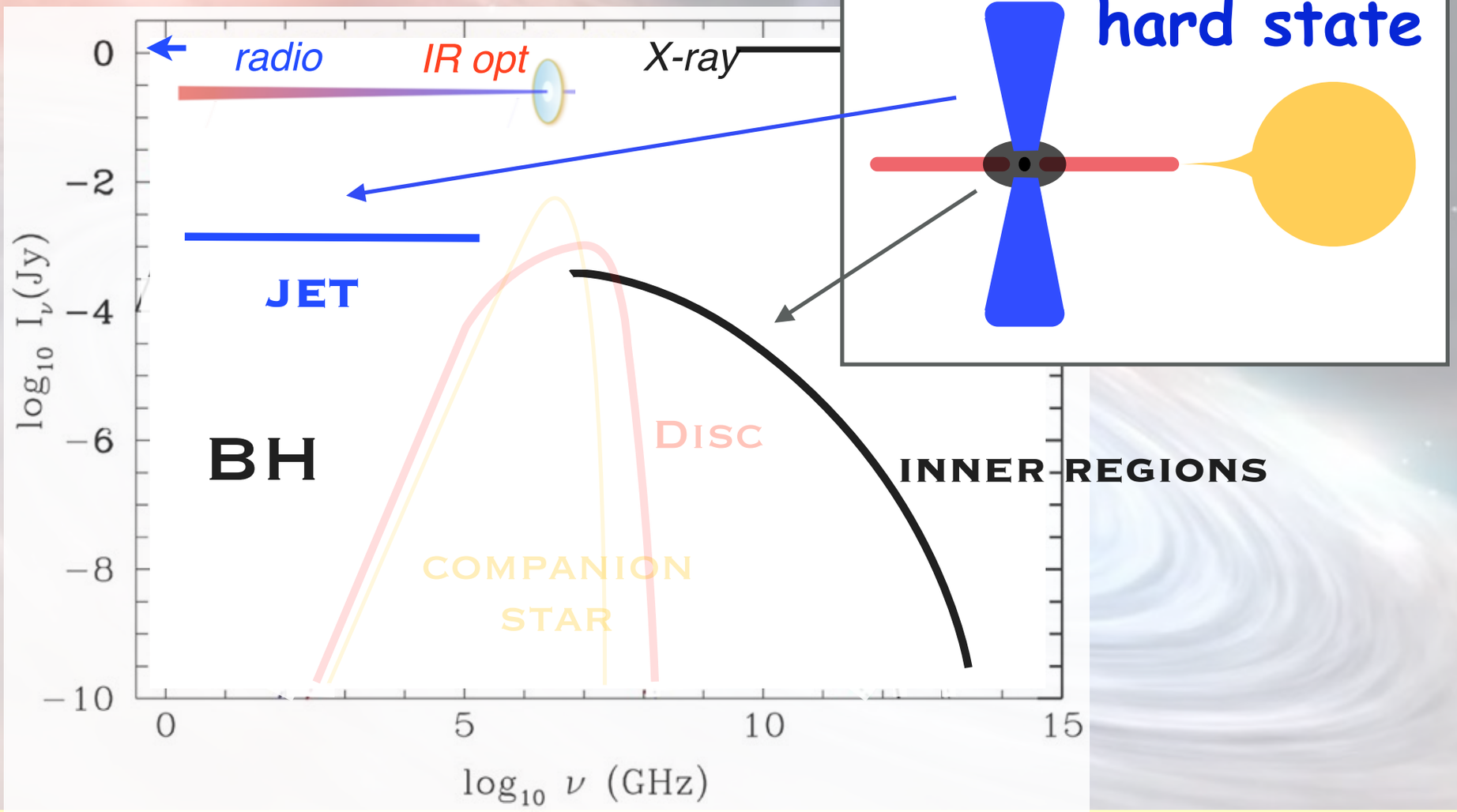


SHOCKS BETWEEN SHELLS GIVING EXTRA ENERGY?

~~STANDARD STEADY~~-JET THEORY

POSSIBLE SOLUTION

RE-HEATING FROM INTERNAL SHOCKS



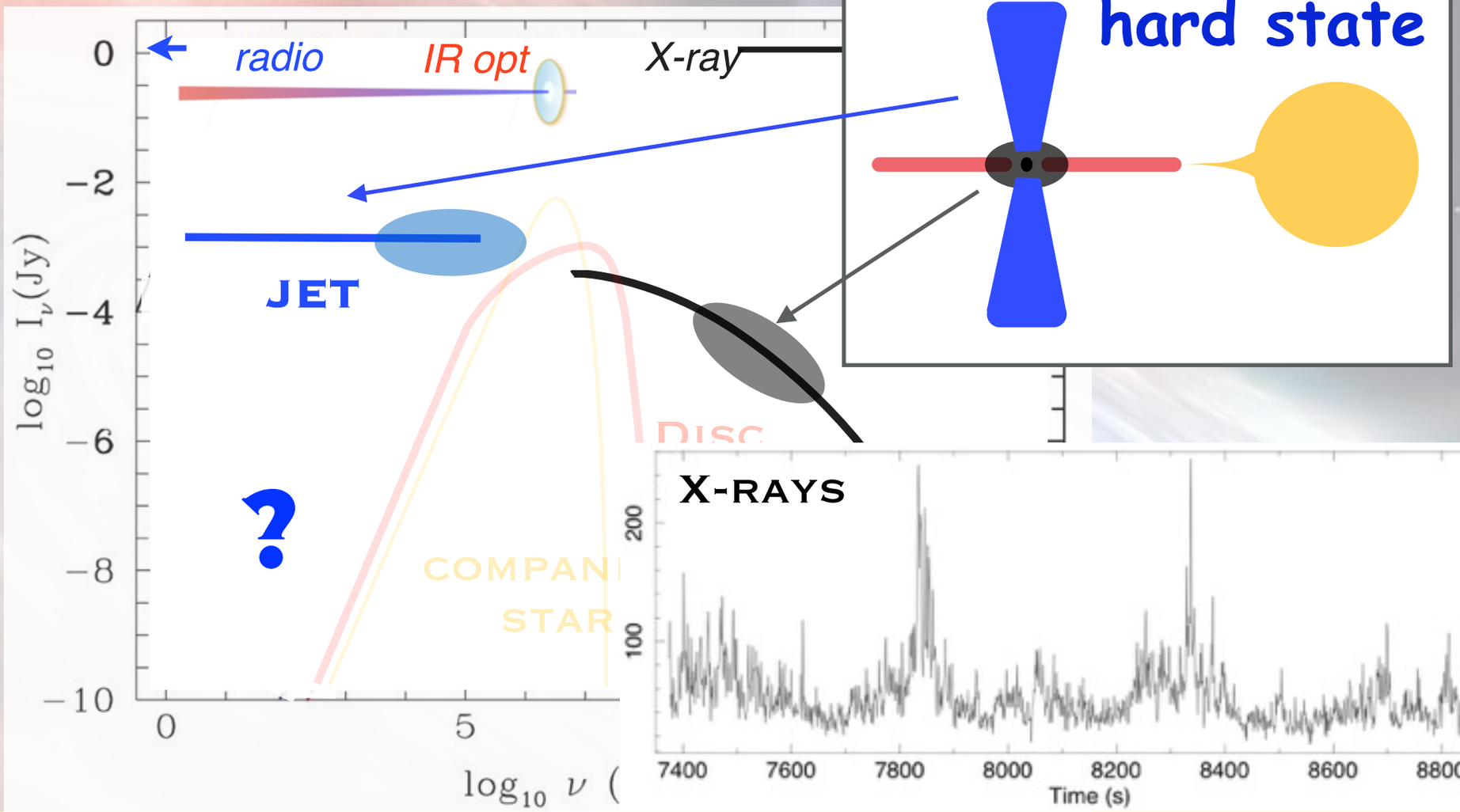
RE-HEATING LINKED TO INFLOW VARIABILITY?

BEST TO STUDY VARIABILITY: X-RAY BINARIES

~~STANDARD STEADY~~-JET THEORY

POSSIBLE SOLUTION

RE-HEATING FROM INTERNAL SHOCKS



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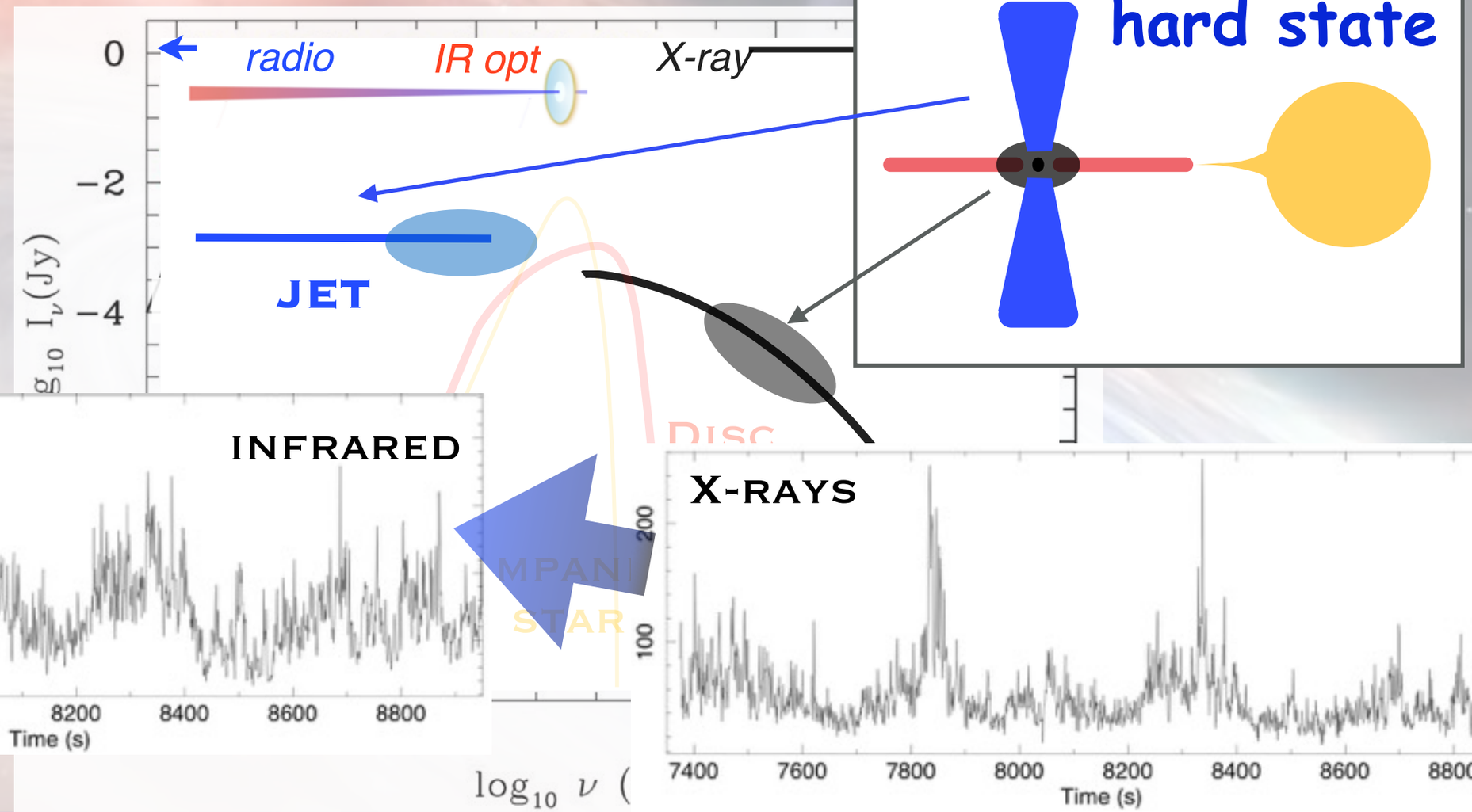
VARIABLE JETs

Casella et al. 2010



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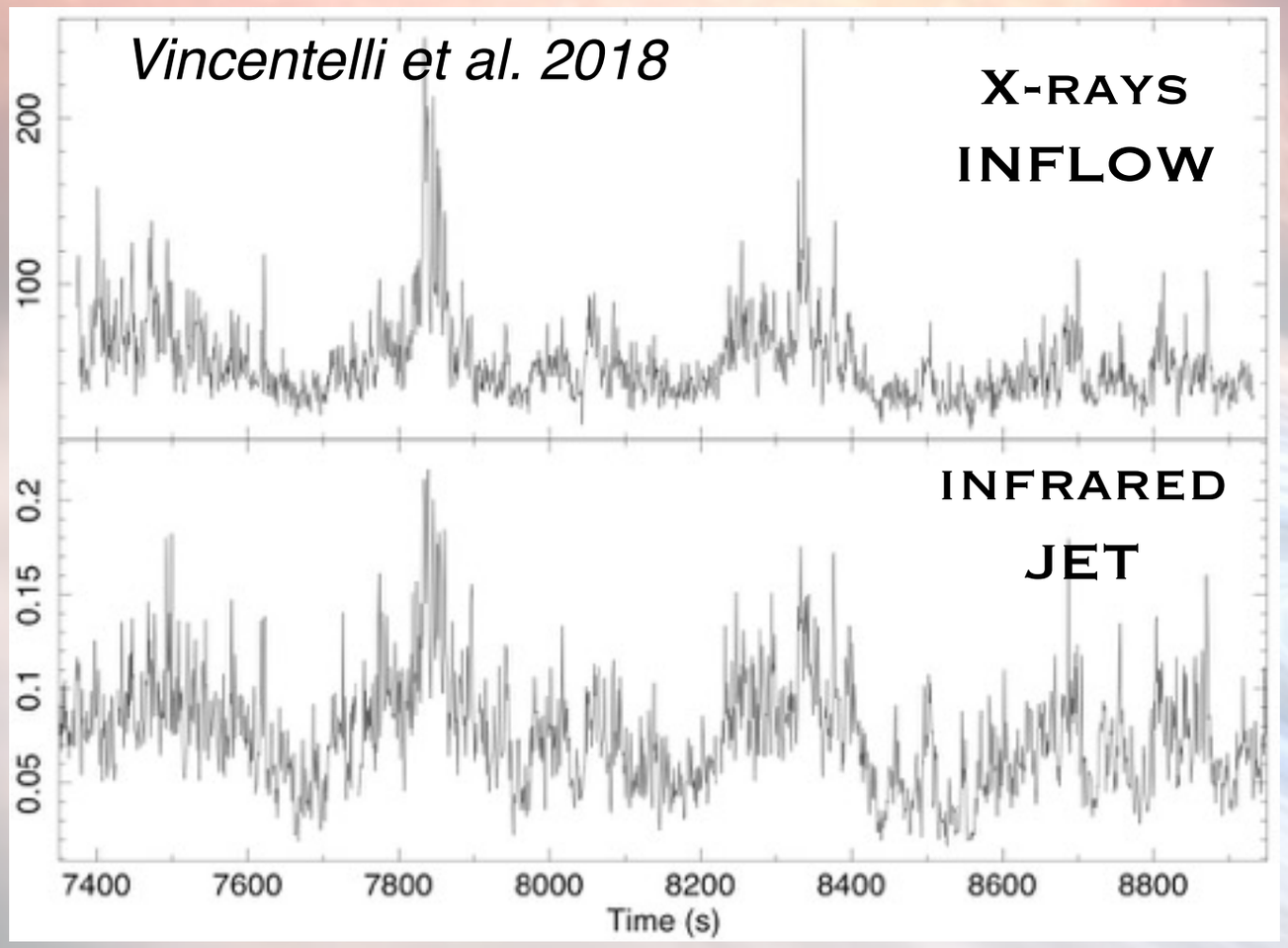
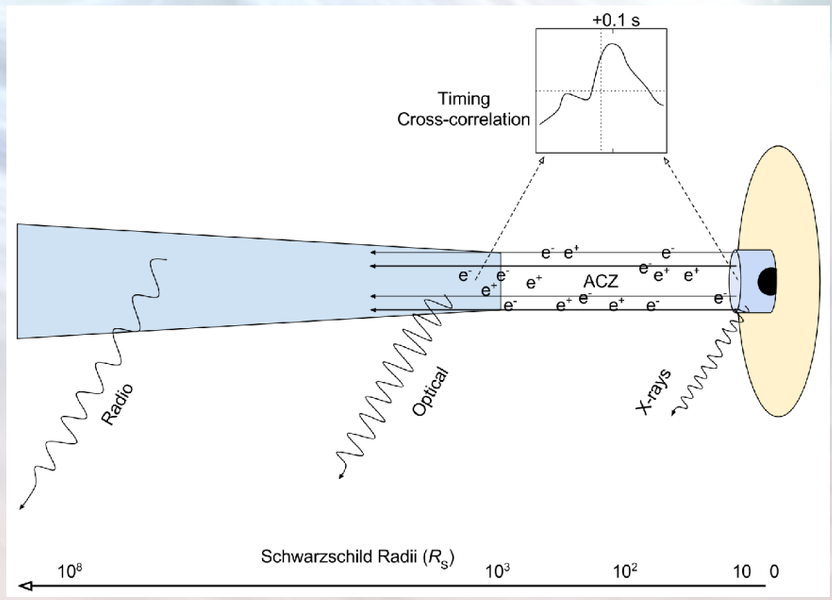


- **Variable** JET emission
- Correlated with INFLOW
- Delay of about 0.1 seconds…
- Same delay different objects
- -> JET speed ($\Gamma > 2$)



Gandhi et al. 2017

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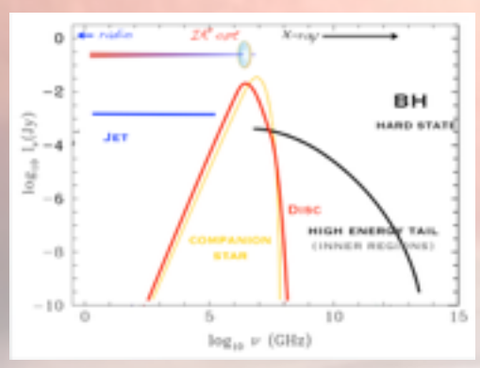
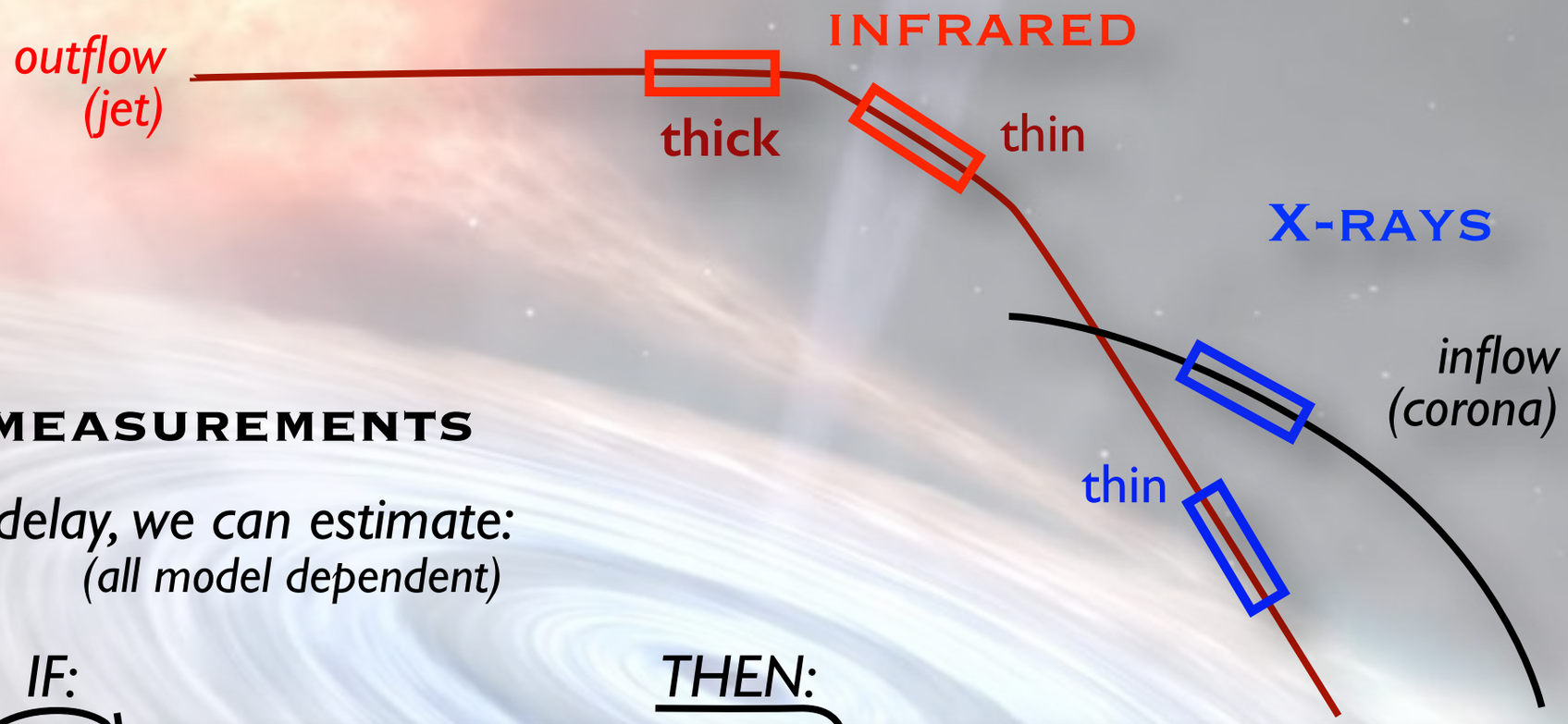
Casella et al. 2010





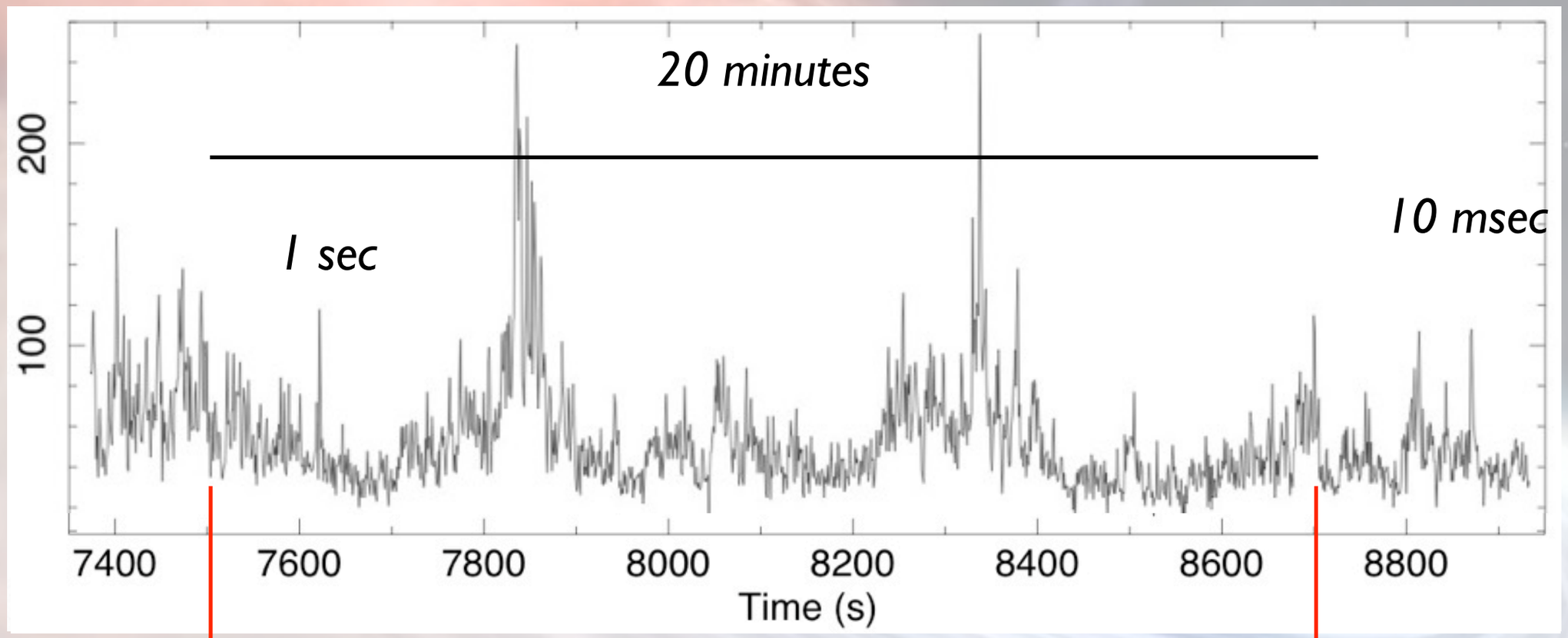
PHYSICAL MEASUREMENTS

From the 0.1s delay, we can estimate:
(all model dependent)

	IF:		*THEN:*
(1)	IR: **thick**	X-rays: thin	Γ jet > 2
(2)	IR: thin	X-rays: thin	B~10^4G *and* Γelec. ~10^4 → 50
(3)	IR: thin	X-rays: *inflow*	ejection timescale < 0.1 s
(4)	IR: **thick**	X-rays: *inflow*	Γ jet >> 2 *and* ejec. timesc. << 0.1s

TIMESCALES

GX 339-4 ~10 M_{sun}

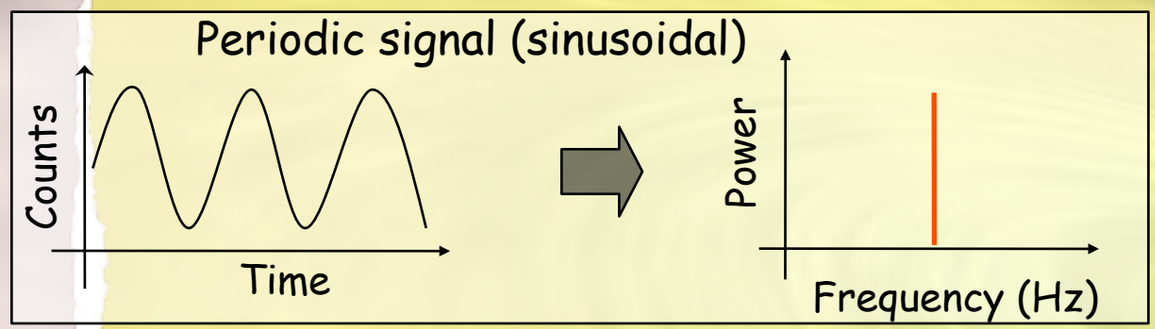


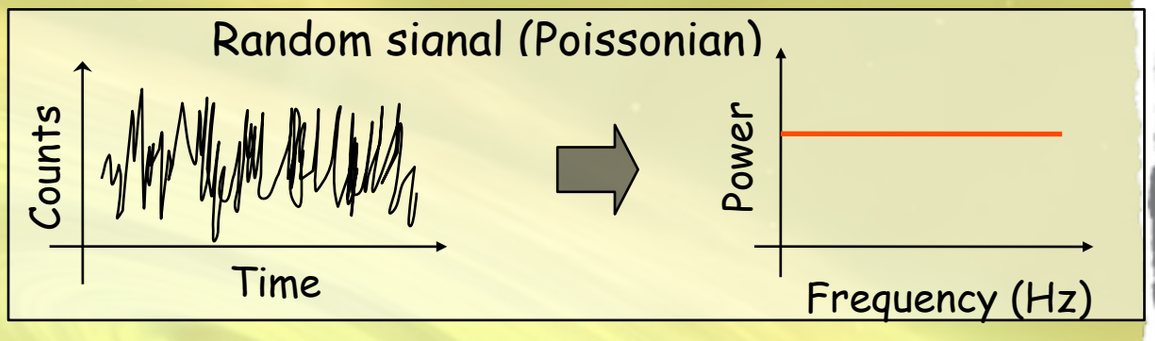
NGC 7213 ~10^8 M_{sun}

Timing analysis in a nutshell

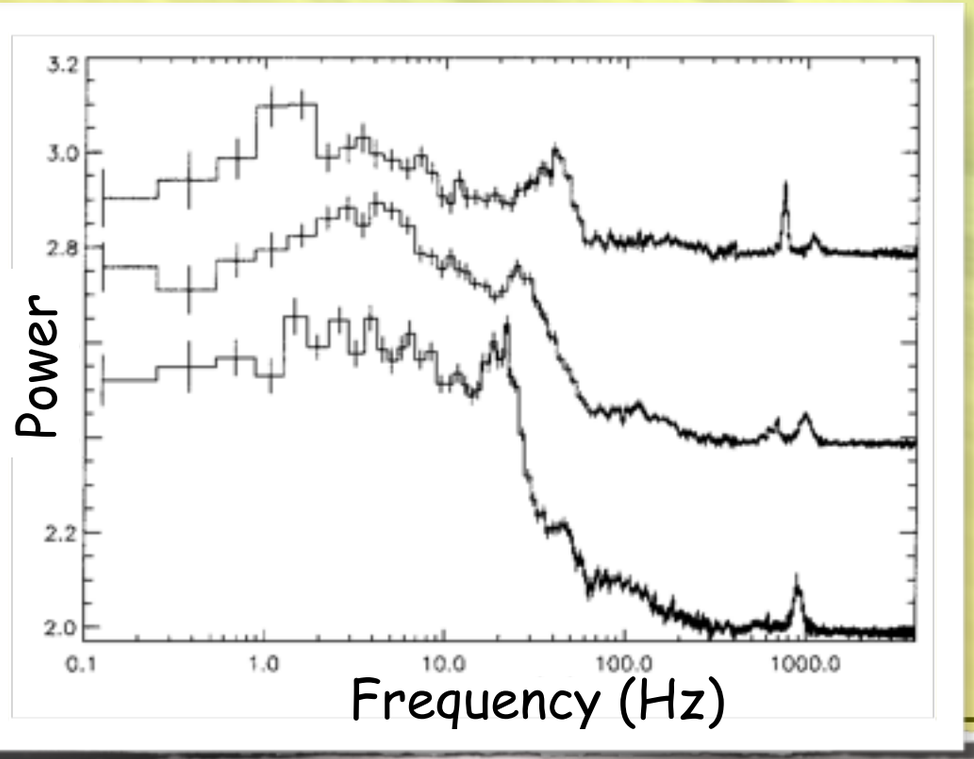
FOURIER ANALYSIS

Power Spectra $P_j = \frac{2}{N_\gamma}\left|a_j^2\right|$ a_j : Fourier coefficients



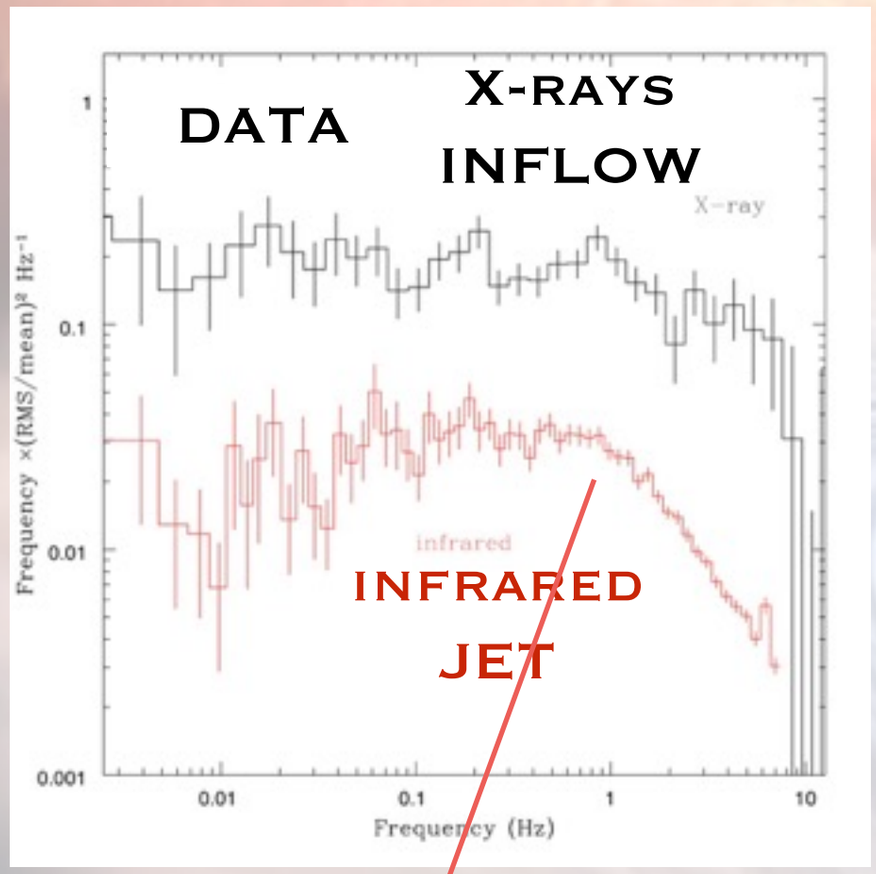


Real signal:



VARIABLE JETs

Fourier Power Spectra



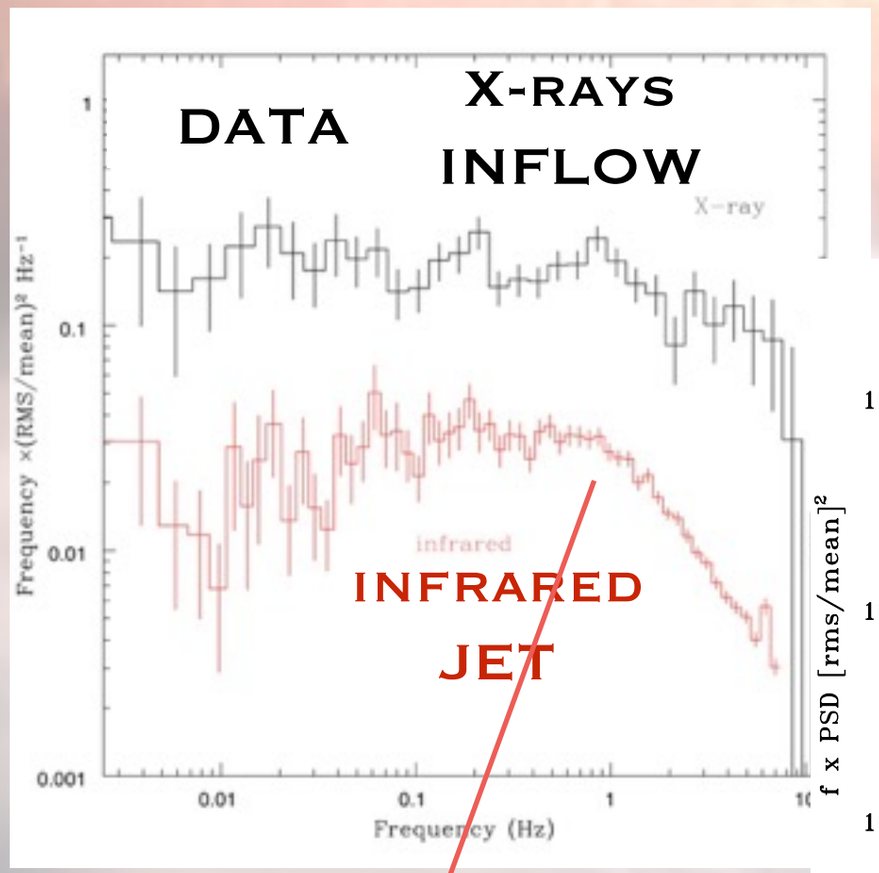
Casella et al. 2010

Constant in time?

Vincentelli et al. 2019 (in prep.)

VARIABLE JETs

Fourier Power Spectra



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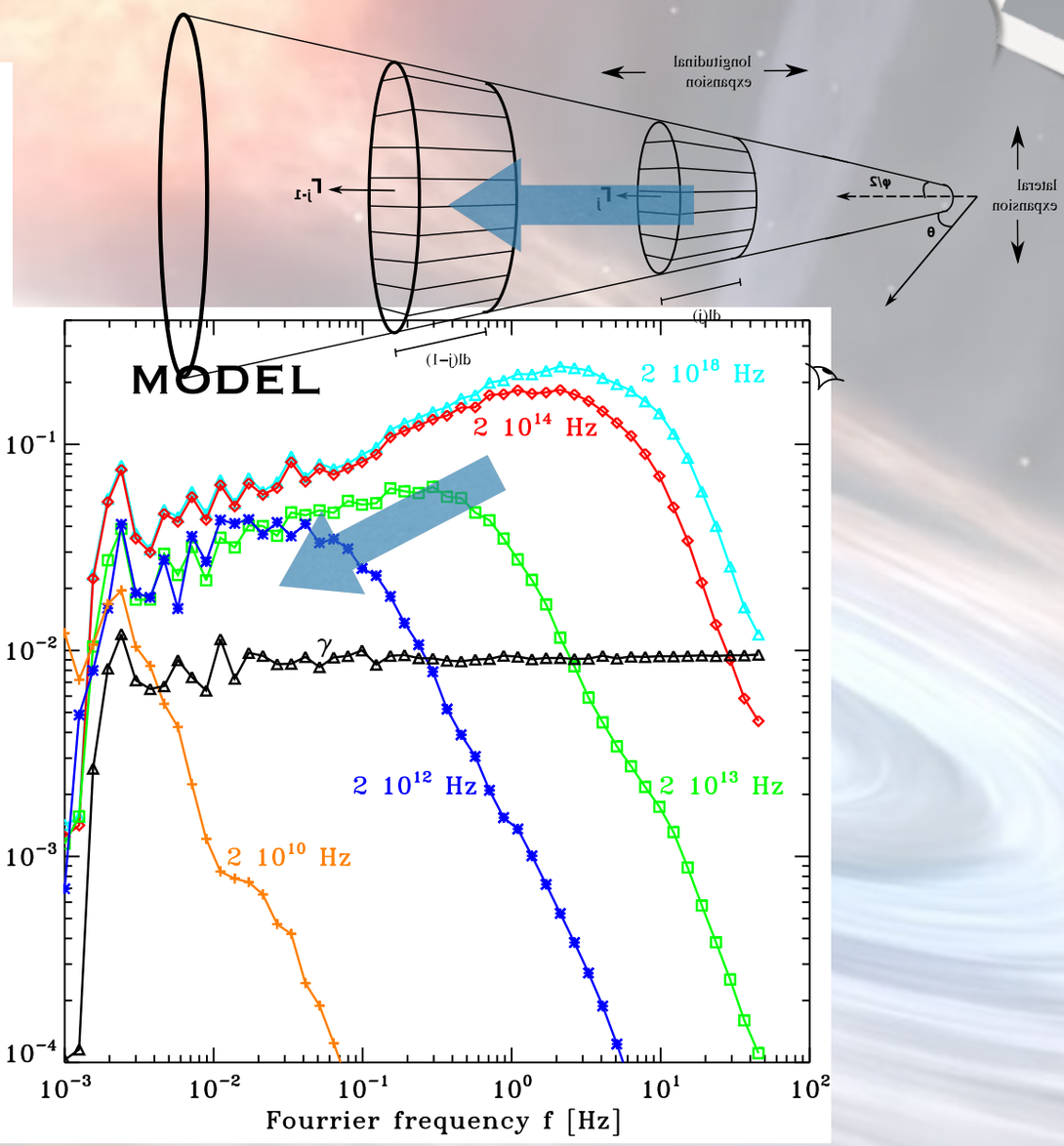


Malzac et al. 2014

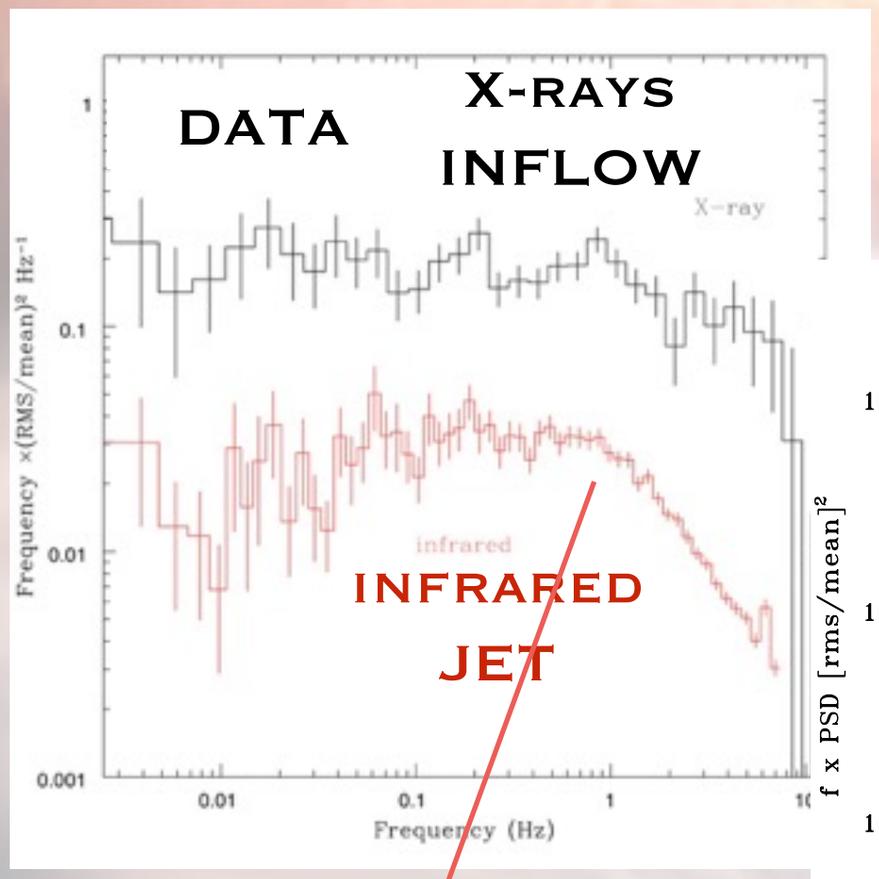
CONSTANT IN TIME?

Vincentelli et al. 2019 (in prep.)

DEPENDS ON JET GEOMETRY AND MODEL

VARIABLE JETs

Fourier Power Spectra



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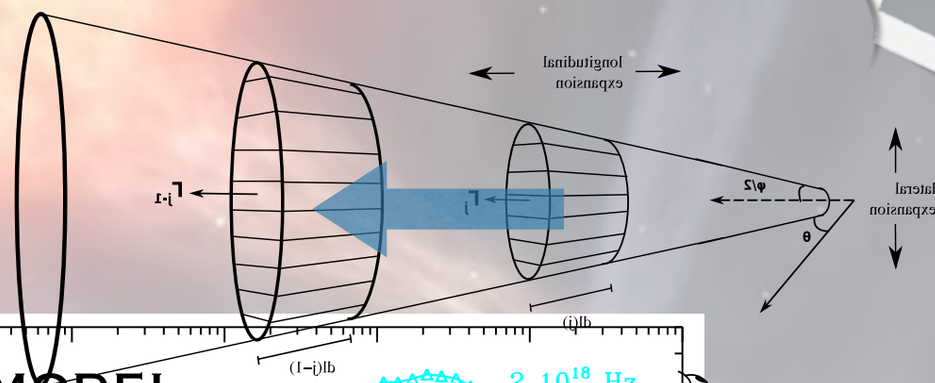

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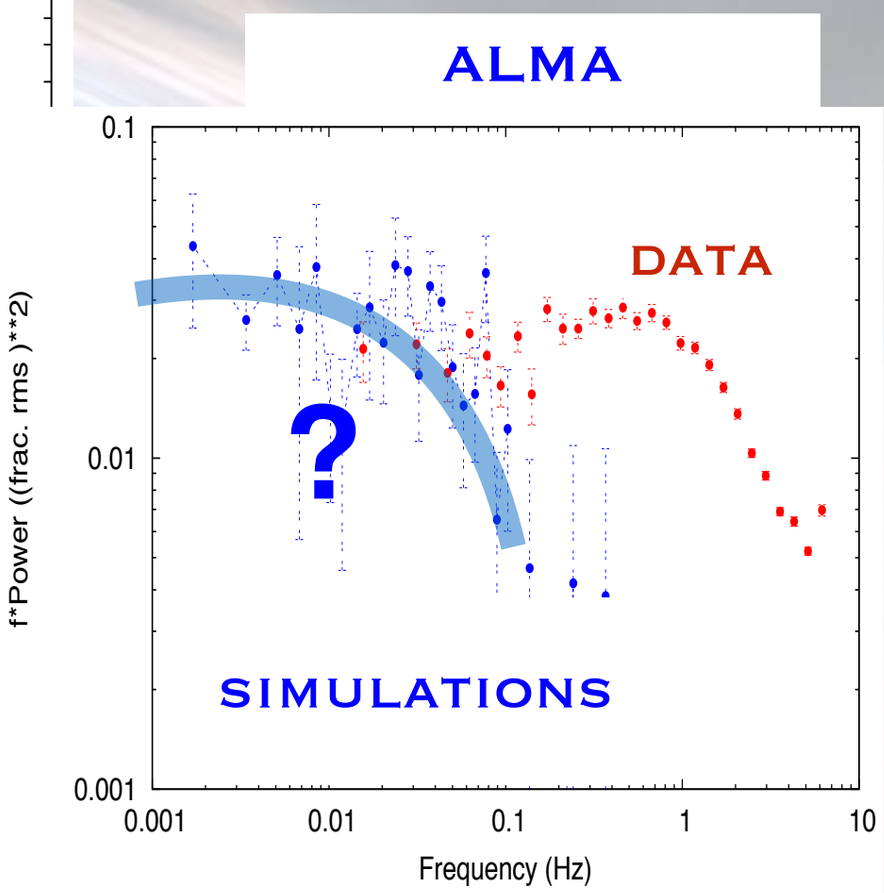

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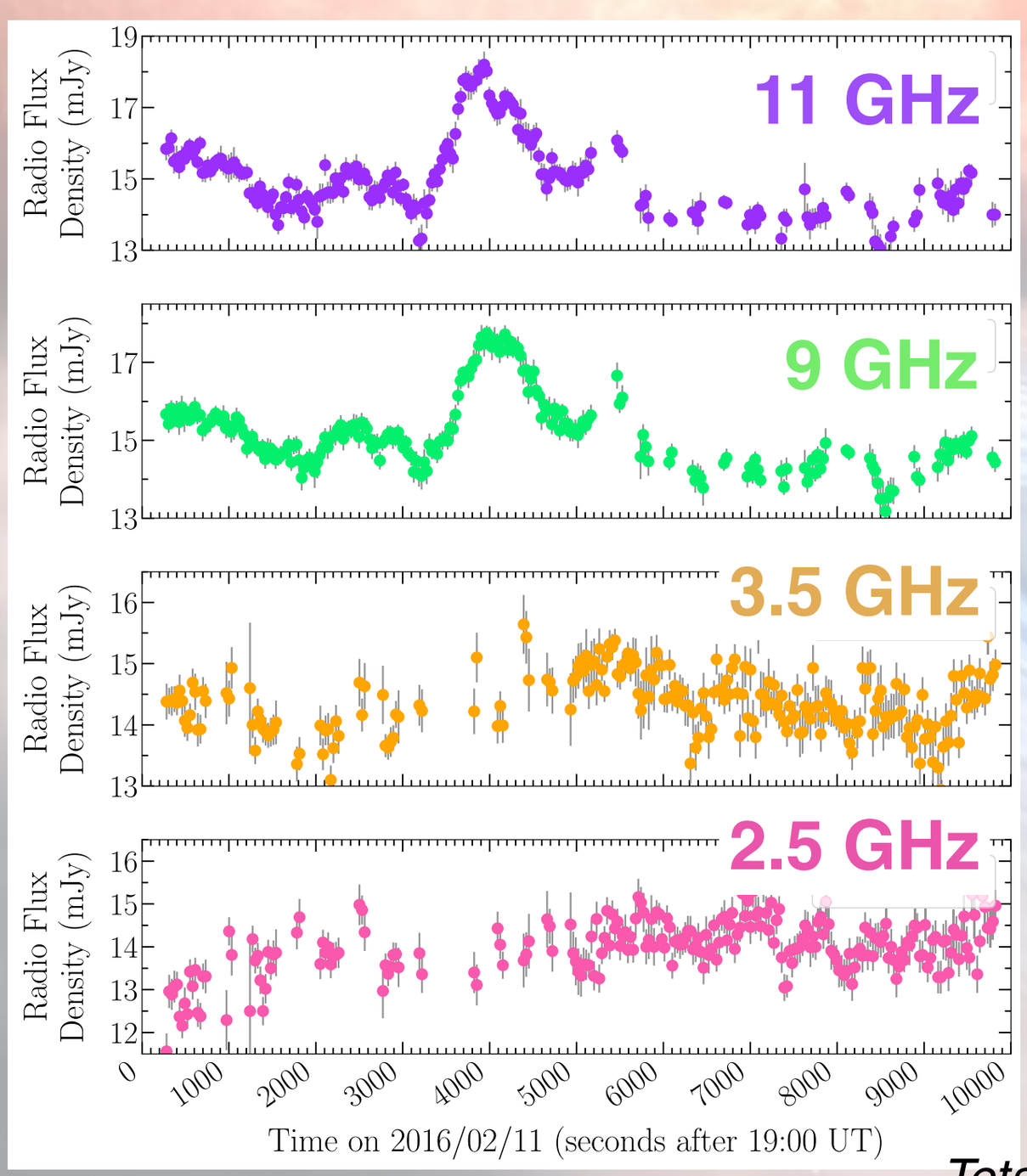
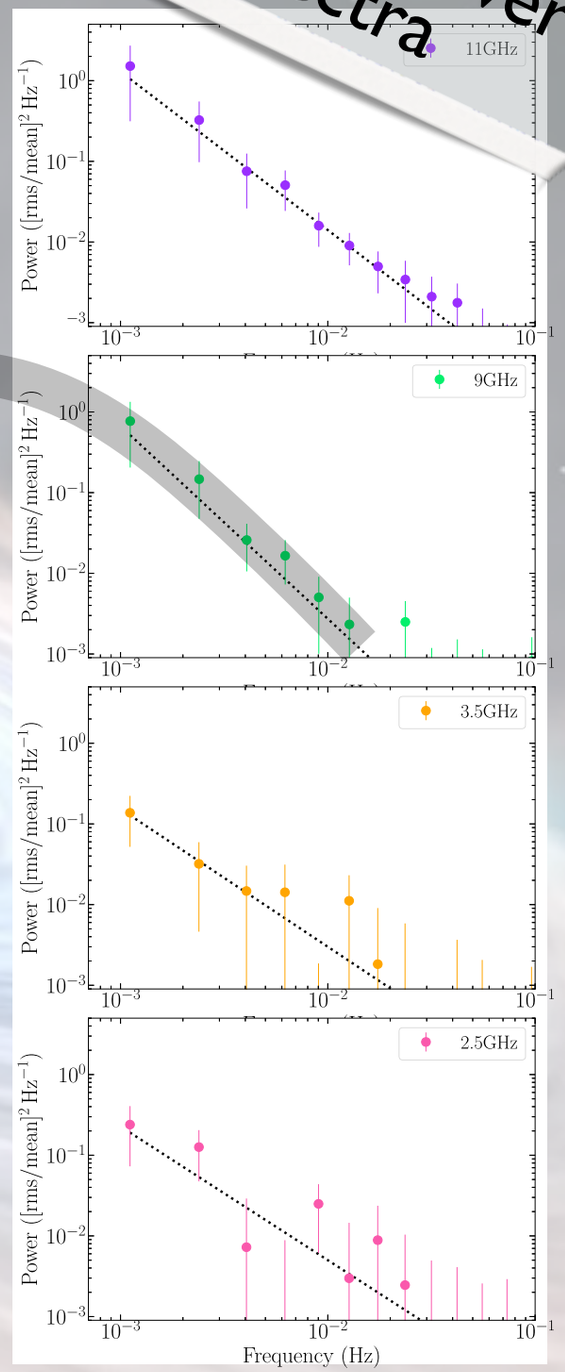


VLA

Cyg X-1

Fourier Power Spectra



Tetarenko, Casella et al. 2018

CONCLUSIONS & OUTLOOK

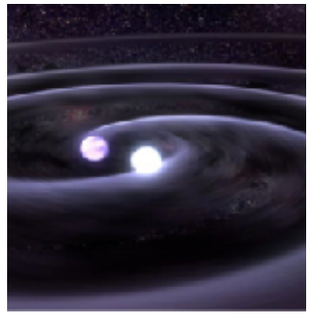
- Jets in **XBs** vary on timescales from years to milliseconds.
- Jet variability is connected with inflow variability.
- Jet variability can be used to measure jet properties.
- Variability propagates through the jet and is observed at different wavelengths.
- ALMA is crucial to solve data degeneracies and test models.
- ALMA (interferometers in general) ***CAN*** produce time series.
- A novel, innovative, and ambitious use of ALMA. Difficult, but feasible.

THANKS

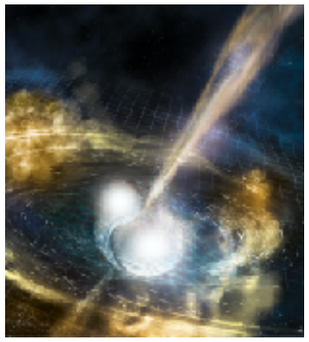
EXTRA SLIDES on GWs

(on behalf of ENGRAVE & GRAWITA)

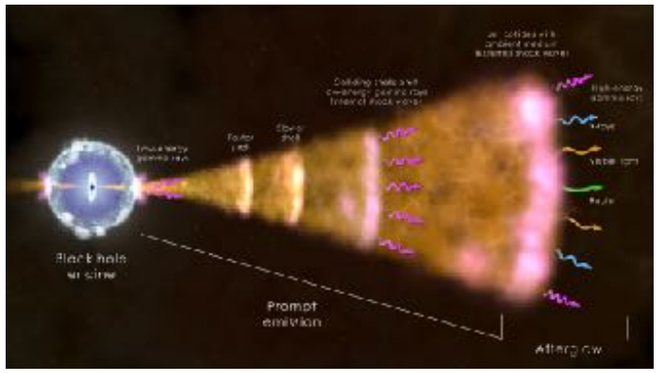
GW170817 detection timeline



merger



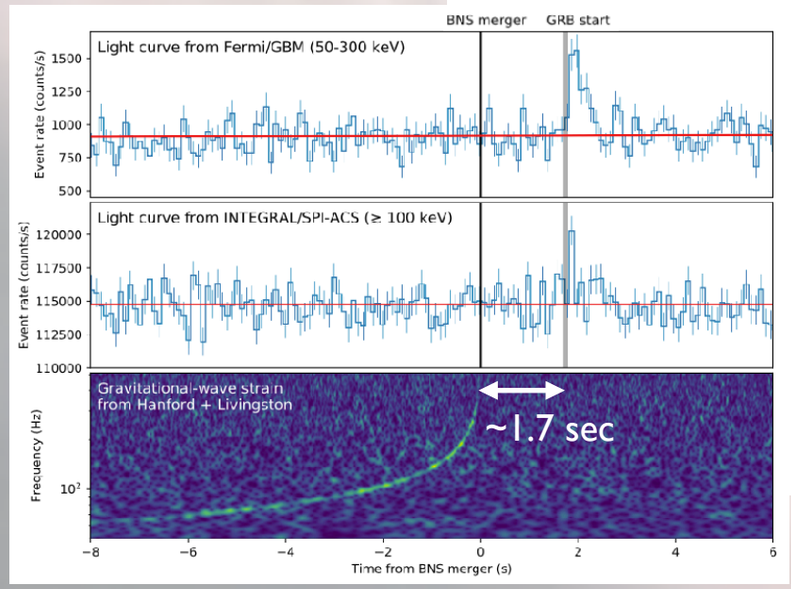
short GRB



X-ray afterglow

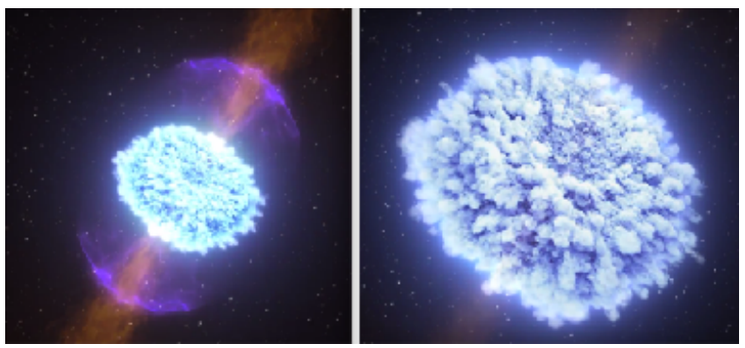
radio afterglow

t0 +1.7 sec +10.87 hours +9 days +16 days



optical counterpart

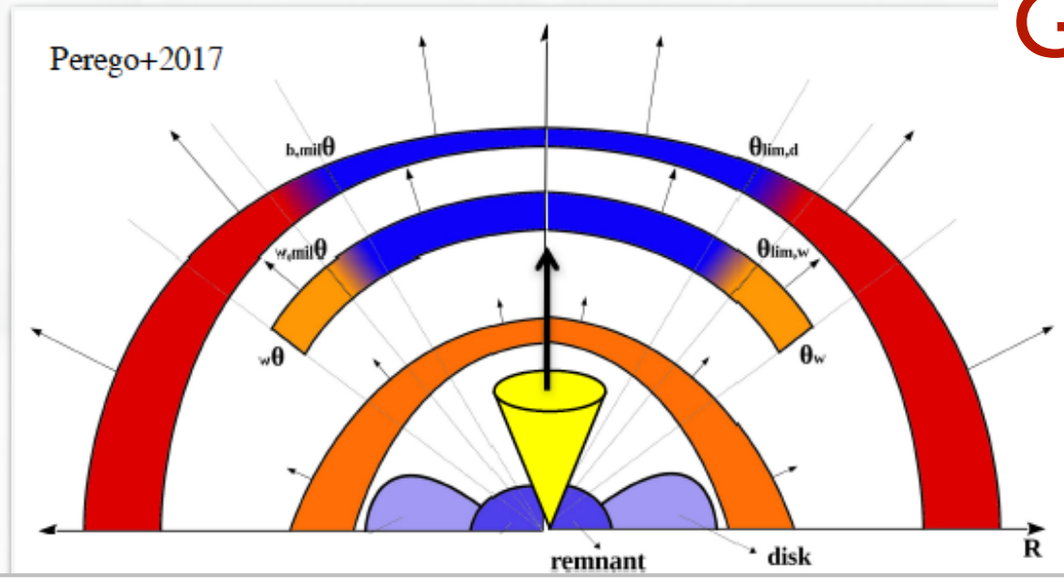
kilonova



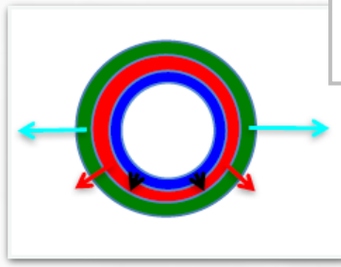
Courtesy of R.Ciolfi

S.D. Vergani - Aspen - 02.10.2019

GW170817

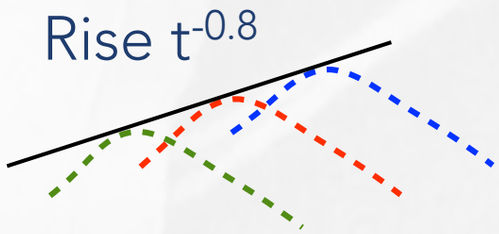


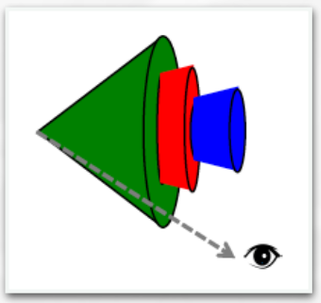
radial or angular structure due to the interaction of the jet head with the merger ejecta



Choked jet (not successful)
radial structure
some degree of anisotropy
$\Gamma_1 < \Gamma_2 < \Gamma_3$
$E_1 > E_2 > E_3$
$E_{jet} < E_{ejecta}$

Rise $t^{-0.8}$





Structured Jet (successful)
off-axis jet
+ angular structure
$\Gamma_1 > \Gamma_2 > \Gamma_3$
$E_1 > E_2 > E_3$
$E_{jet} < E_{ejecta}$

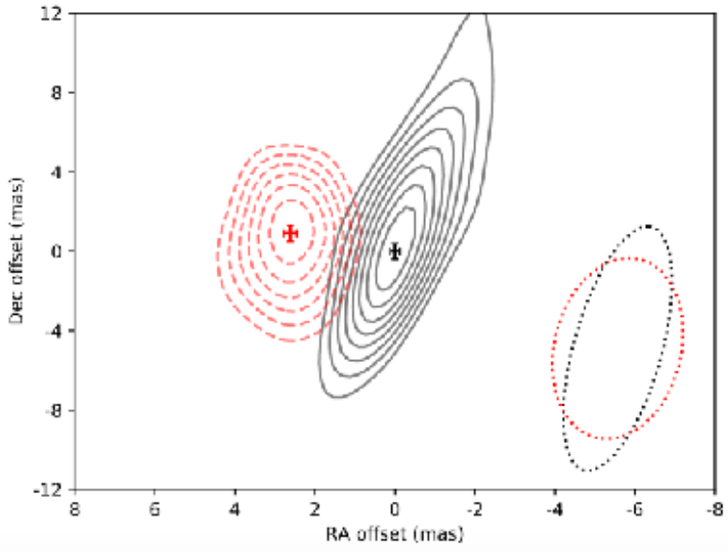
Courtesy of S.D.Vergani & G.Ghirlanda

VLBI observations

GW170817

global network of 32 radio telescopes

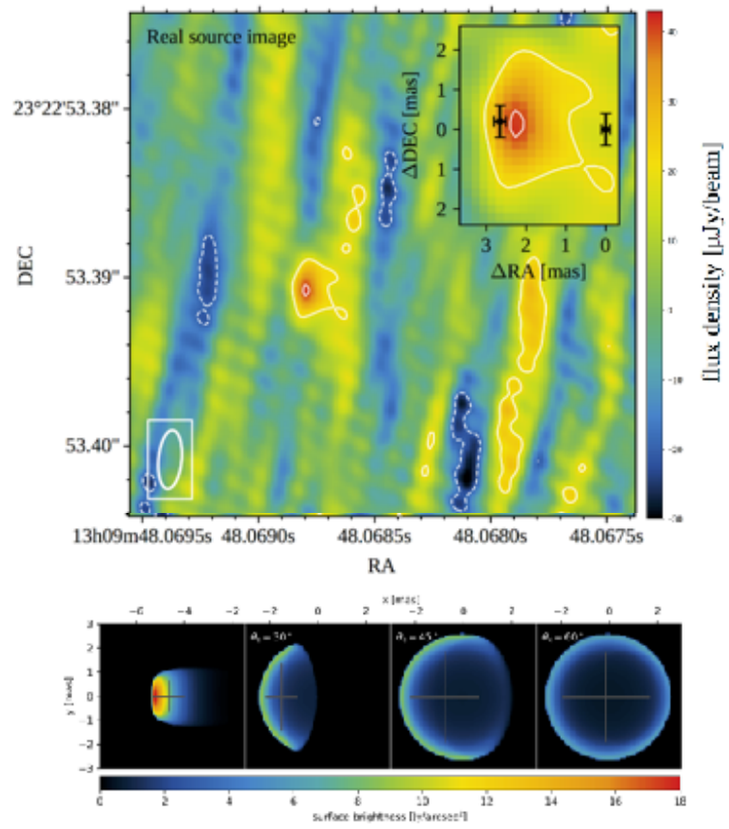
Mooley et al. 2018



apparent superluminal motion
between 75 and 230 days

source is moving relativistically (and getting closer)

Ghirlanda et al. 2018



source size < 2 m arcseconds @ 207 days

source is still rather compact!

Courtesy of R.Ciolfi

GW NS-(NS/BH) events the role of ALMA

- SED building
- SED time evolution (spectral break moving through ALMA bands)
- Polarimetry measurements -> diagnostic for jet geometry
- Absorption/emission lines (e.g. CO [1-0]) -> environment