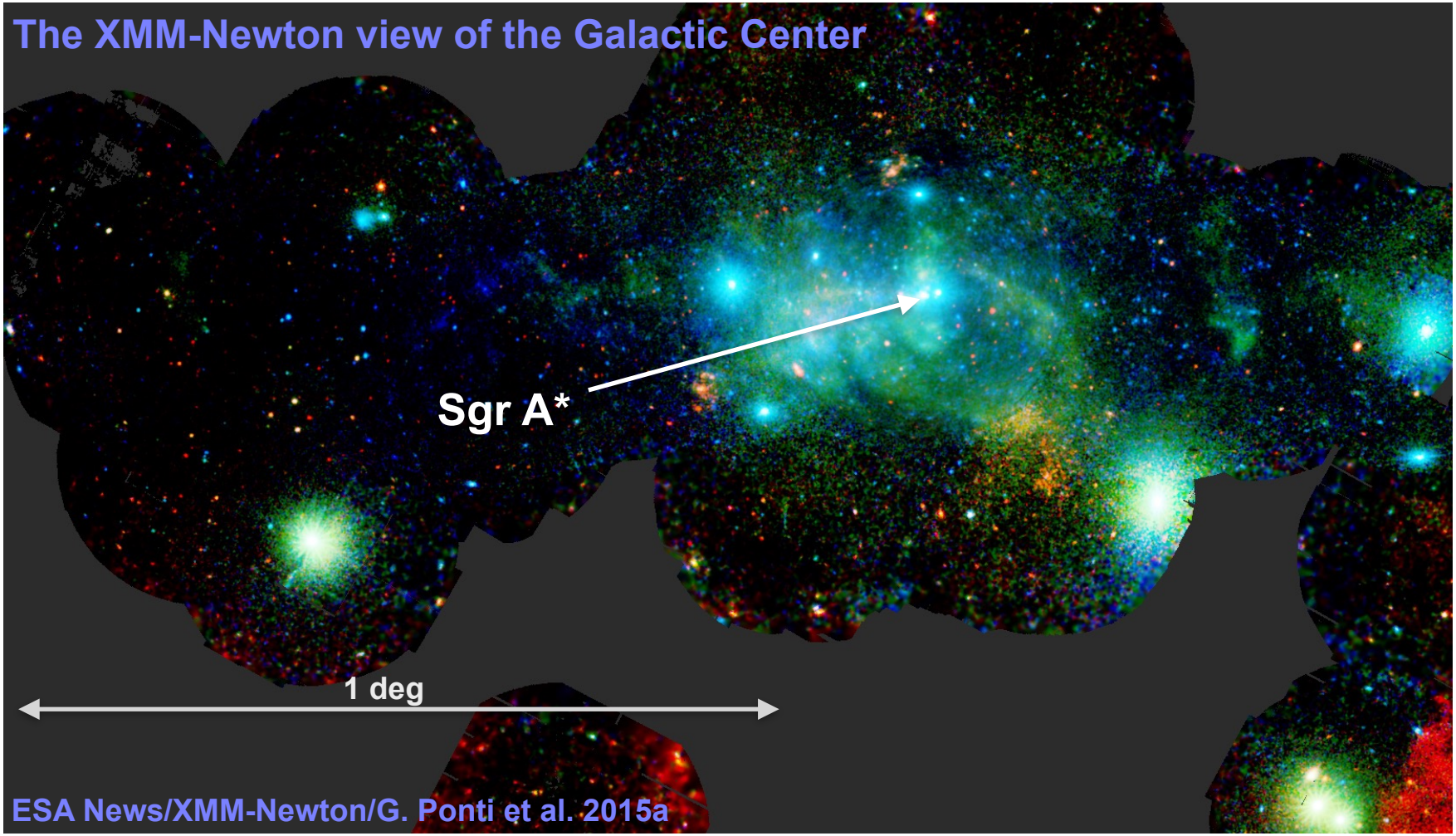
Approaching Sgr A: G2 and similar events*



Gabriele Ponti

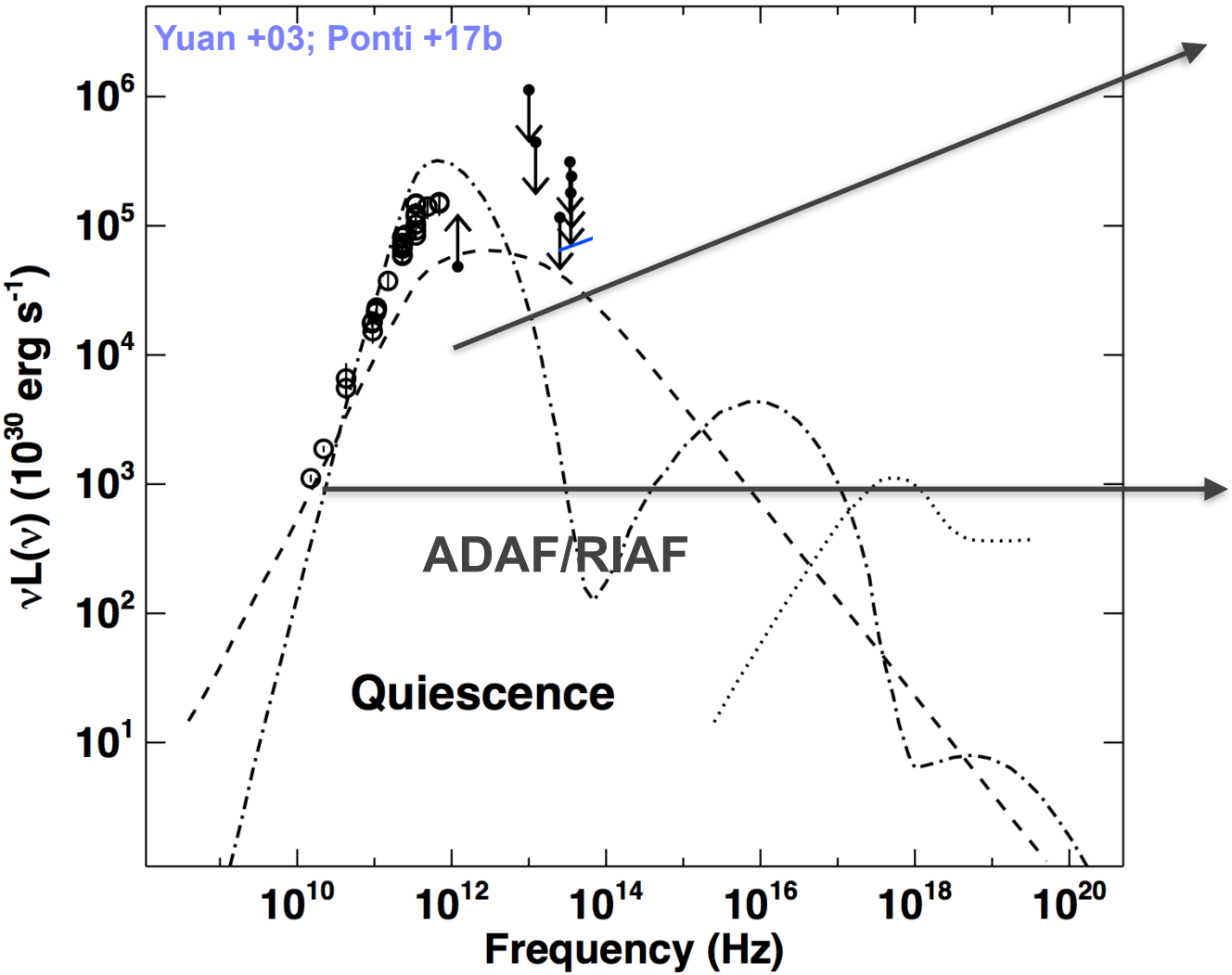
Max Planck Institute for Extraterrestrial Physics (Garching)

George, Scaringi, Zhang, Jin, Dexter, Terrier, Clavel, Degenaar, Eisenhauer, Genzel, Gillessen, Goldwurm, Habibi, Haggard, Hailey, Harrison, Merloni, Mori, Morris, Nandra, Pfuhl, Plewa, Ott, Waisberg

Sgr A's quiescent emission*

$L_{Sgr\ A^*} \sim 10^{-9}\ L_{Edd}$

Best target to study low luminosity accretion



Falcke +98; Markoff +01; Yuan +03; Zhao +03; +04; Baganoff +03; Herrnstein +04; An +05; Xu +06; Marrone +06; +07; Schoedel +07; +11; Dodds-Eden +09; Trap +11; Bower +15; Brinkerink +15; Liu +16; Stone +16

Optically thin synchrotron

$r \sim 10\ R_S$

Linearly polarised Marrone +06

Thermal e^- ($\gamma_e \sim 10$)

$B \sim 20$-50 G

$kT_e \sim 10^{10}$ K

$n_e \sim 10^6$ cm^{-3} Loeb +07; Genzel +10

$\dot{M} \sim 10^{-7}$-10^{-9} M_{Sun} yr^{-1} (Faraday rotation)

➜ **Event horizon telescope!**

Radio flattening

Either:

Non thermal e^- Oezel +00

(~1 % of steady electron energy)

Or:

Compact jet Falcke +98; Moscibrodzska +10

Sgr A*'s quies

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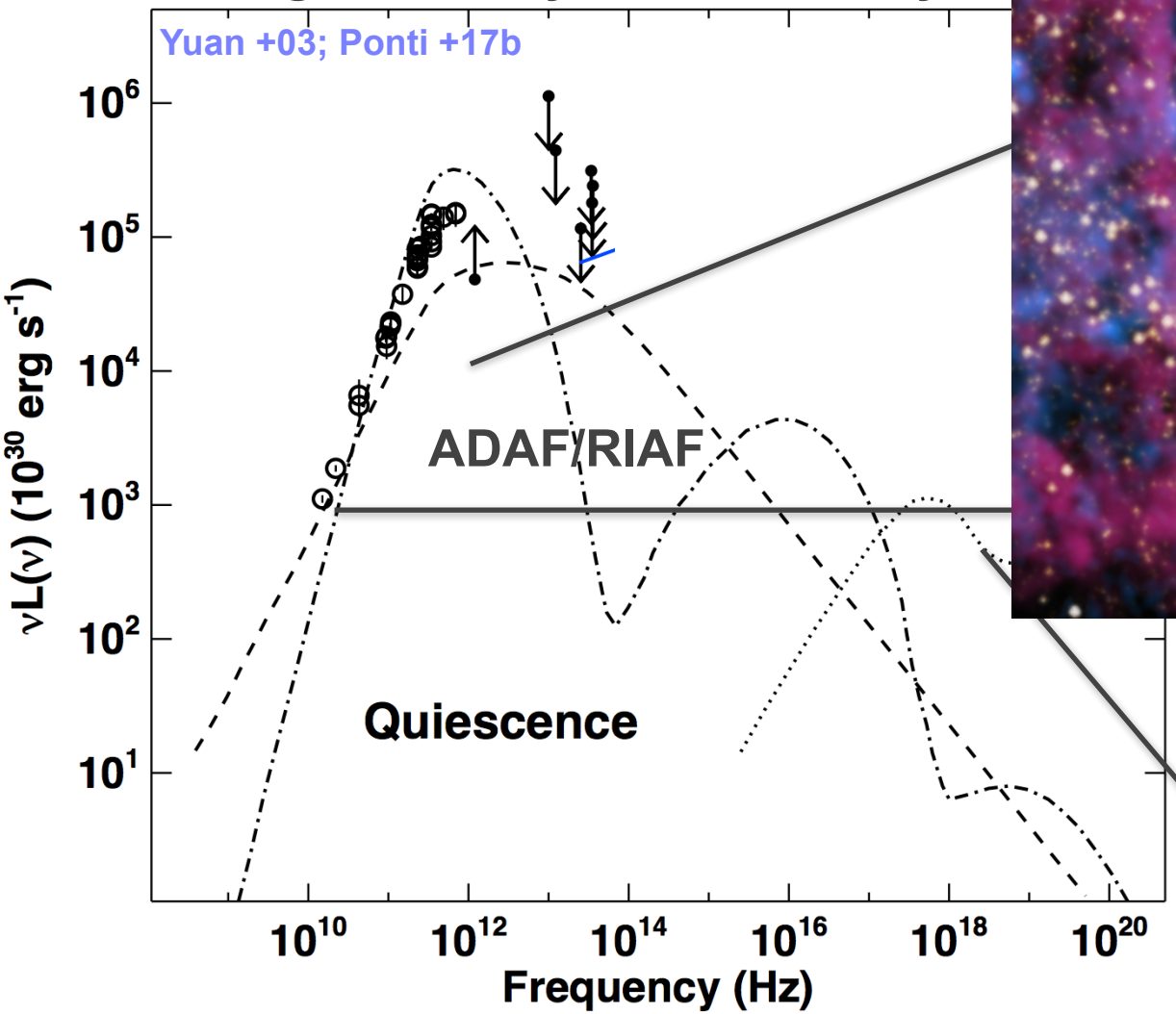

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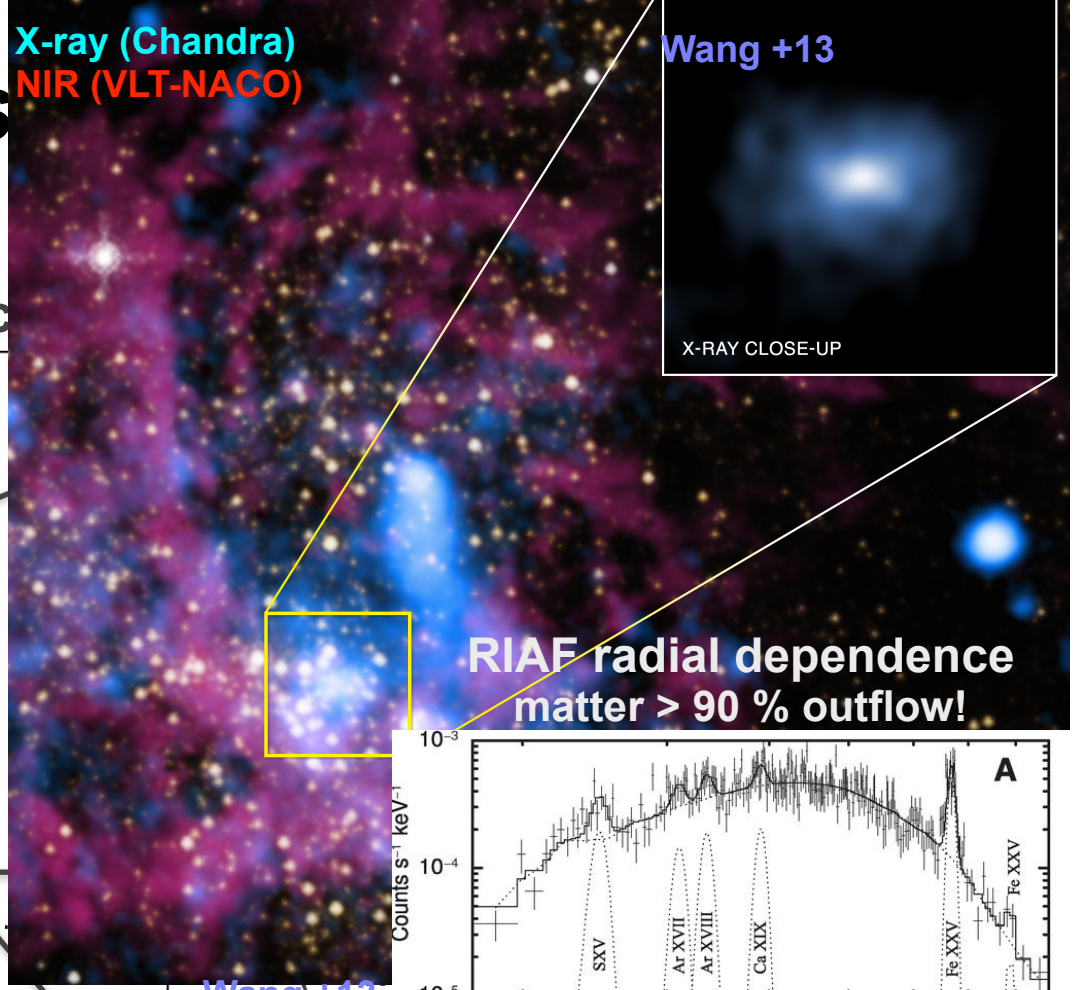

Wang +13

Or:

Com

Wang +13

Bremsstrahlung

r ~ 10^5 R_S

extended (~1") accretion from stars wind

$kT_e \sim 7\times10^7$ K

$n_e \sim 100$ cm^{-3}

$\dot{M} \sim 10^{-6}\ M_{Sun}\ yr^{-1}$

Melia +92; Quataert 02; Baganoff +03; Cuadra +05; Xu +06; Wang +13

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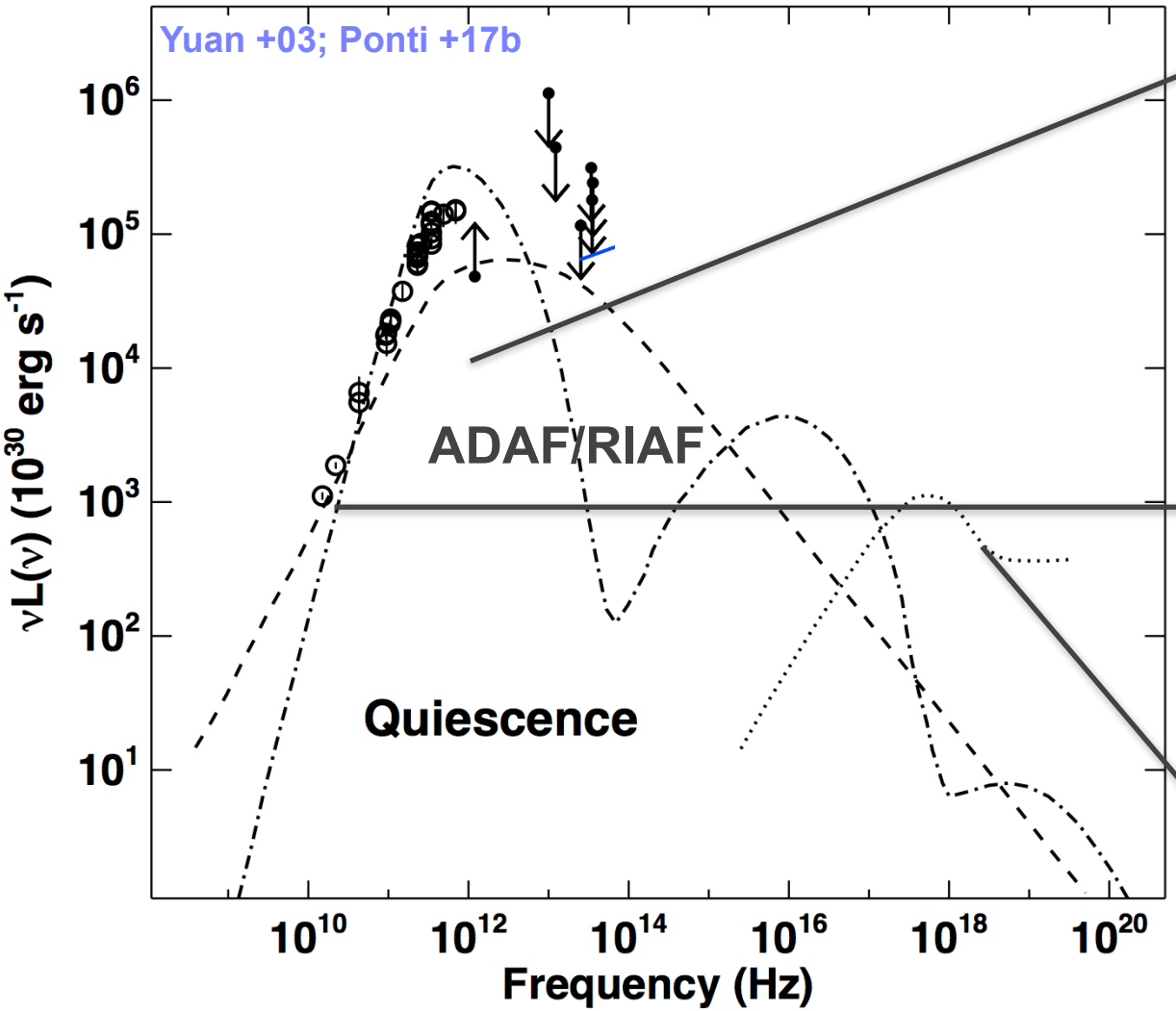

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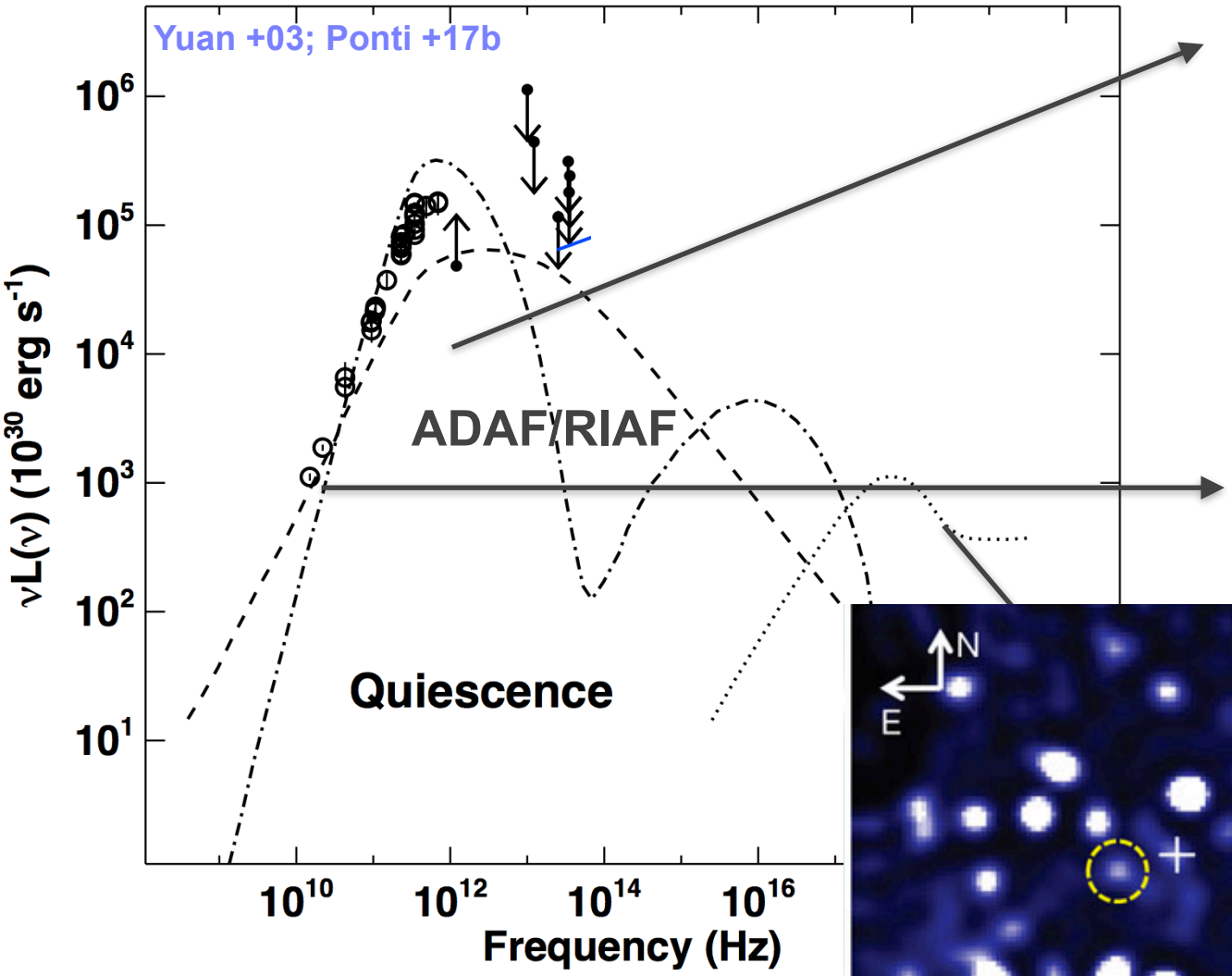

Optically thin synchrotron

r ~ 10 R_S

Linearly polarised Marrone +06

Thermal e^- (γ_e~10)

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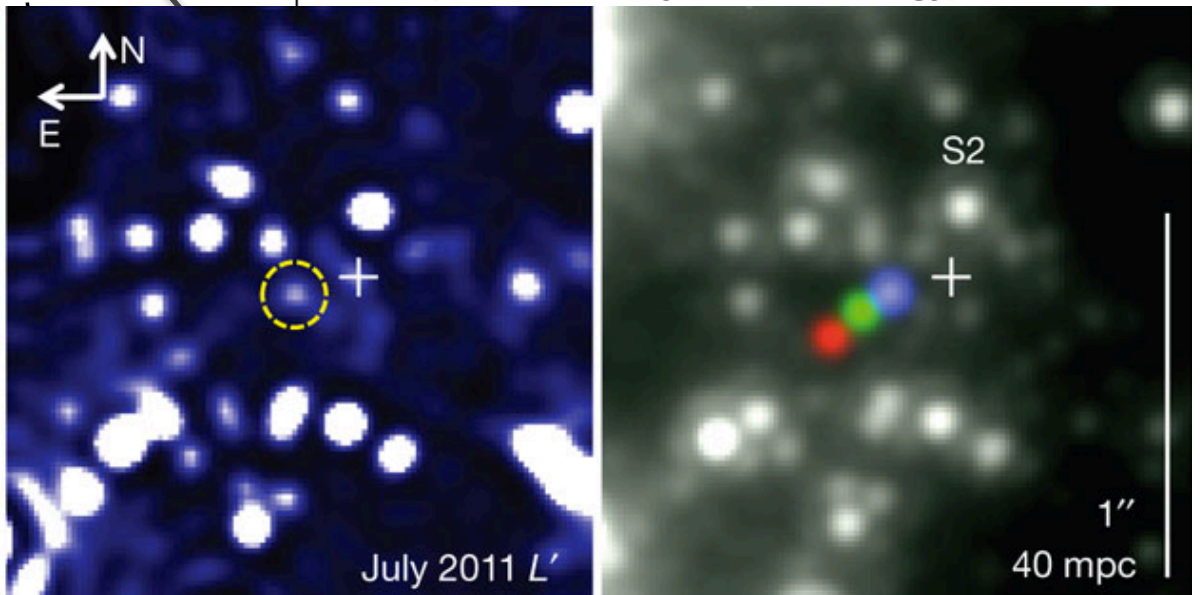
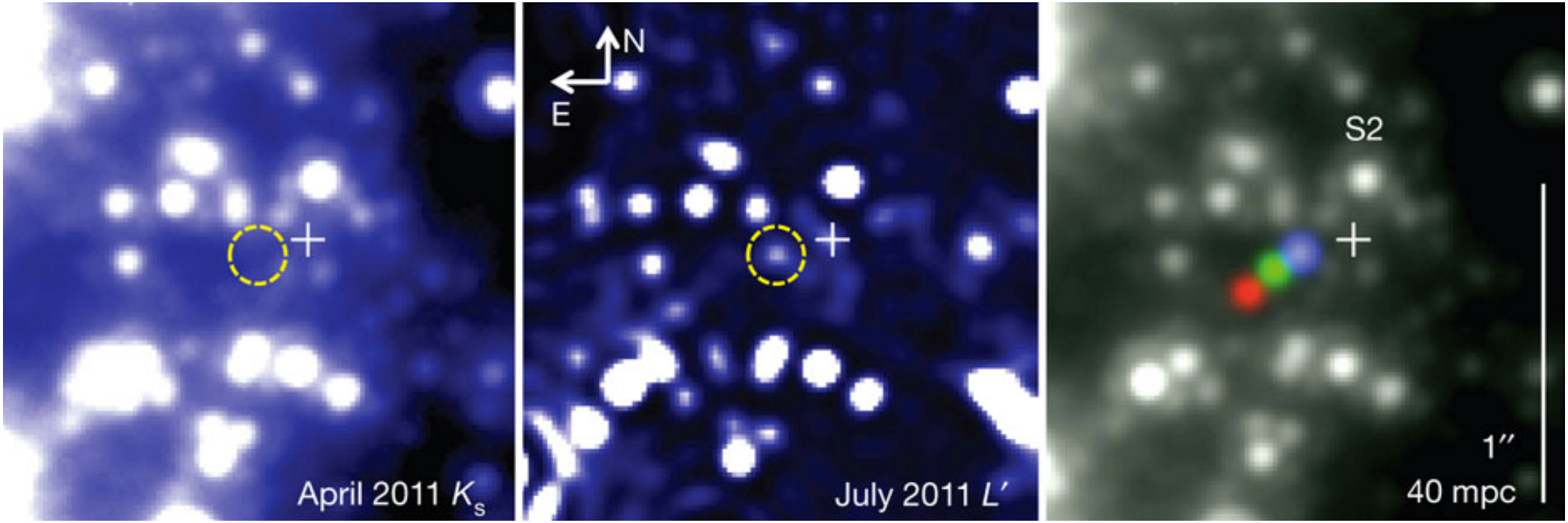


G2 ➜ Test of ADAF at r ~ 10^3 R_S

Gillessen +12; 13a,b;
Phifer +13; Phuhl +14; Witzel +14

What is G2?

Gillessen +12; 13a,b;
Phifer +13; Phuhl +14; Witzel +14



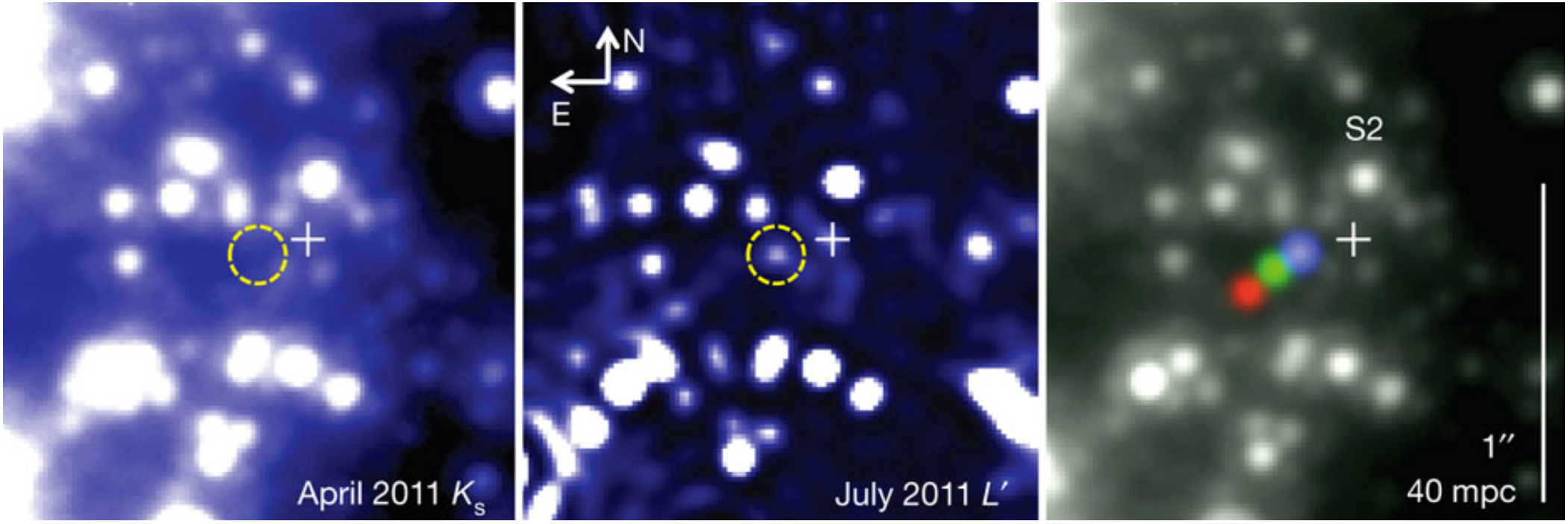
Cloud of 3 M_{Earth} falling on Sgr A*

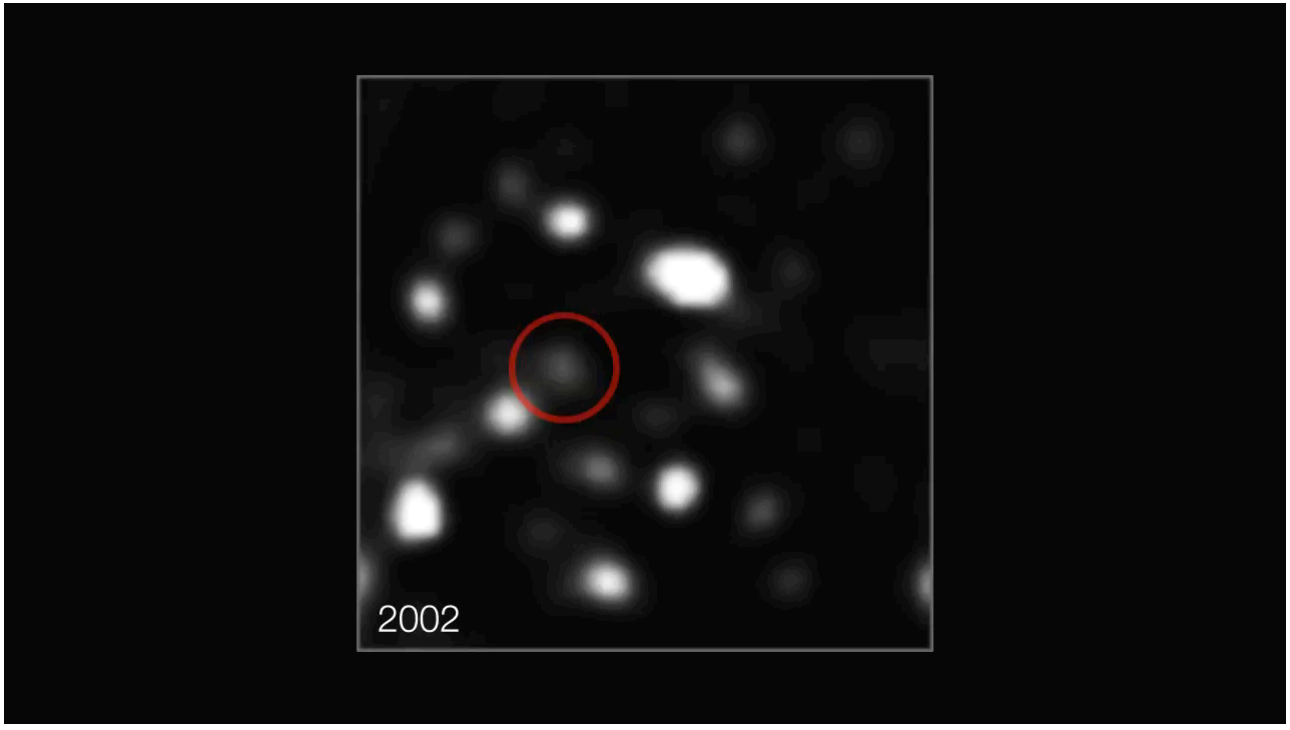
Unique probe of the hot accretion flow ➜ shocks with the hot gas ➜ induce X-ray emission and (maybe) minor accretion event ($10 \times L_{quies}$)

Gillessen +12; 13a,b; Shartmann +12;
Burkert +12; Ballone +12; Fragile +12

What is G2?

Gillessen +12; 13a,b;
Phifer +13; Phuhl +14; Witzel +14





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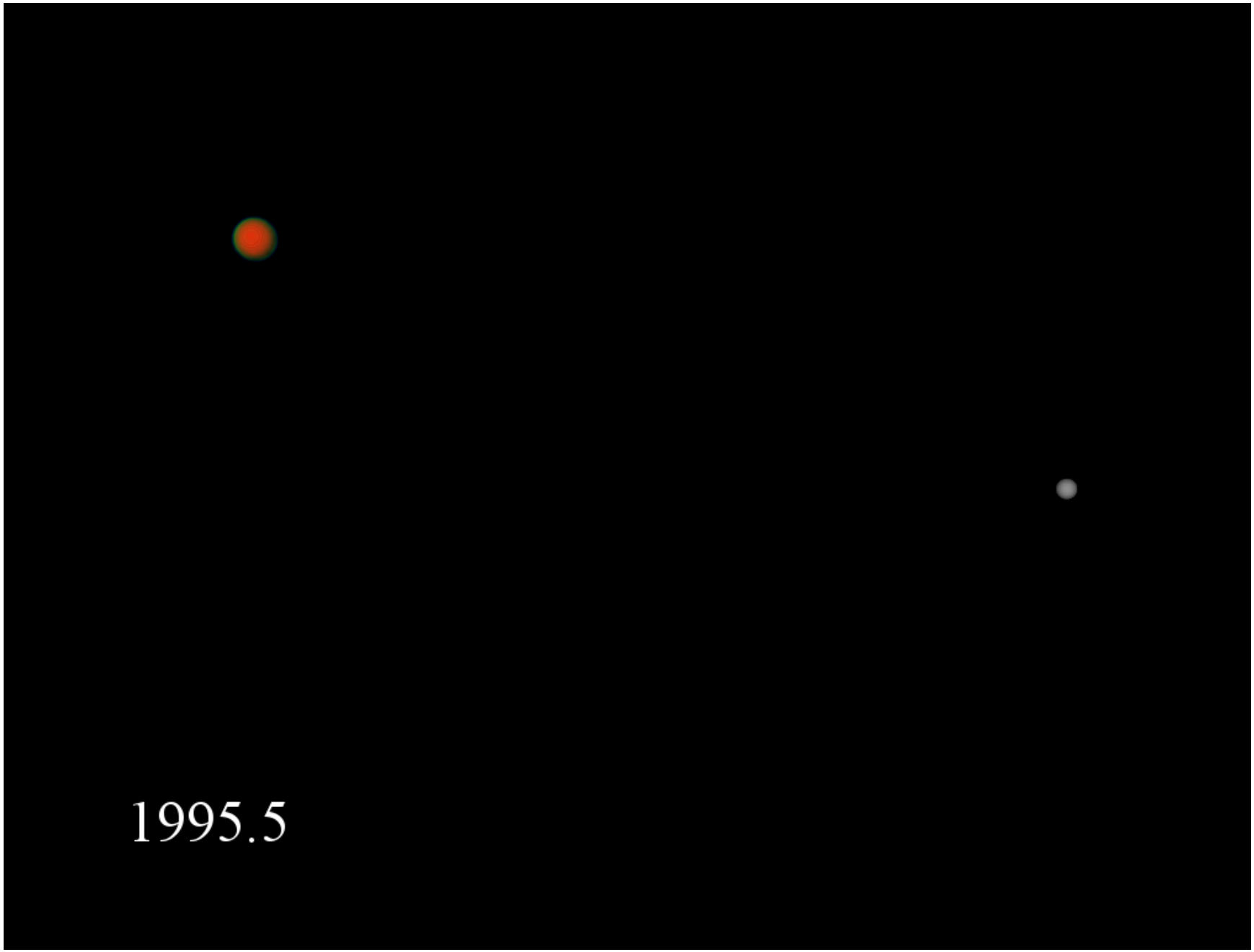
Gillessen +12; 13a,b; Shartmann +12;
Burkert +12; Ballone +12; Fragile +12

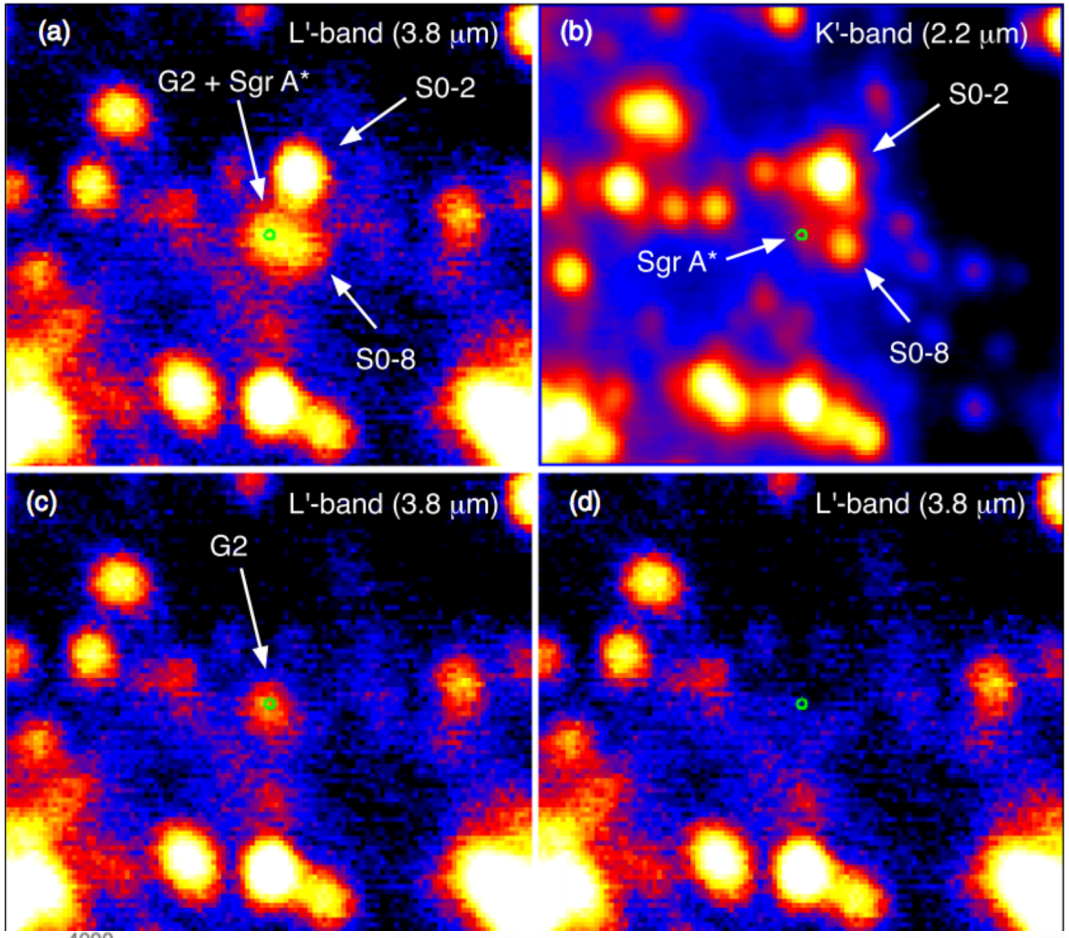
Predictions

Fragile +12



But cloud mass and internal structure are not well known

G2: IR observations of a dusty star

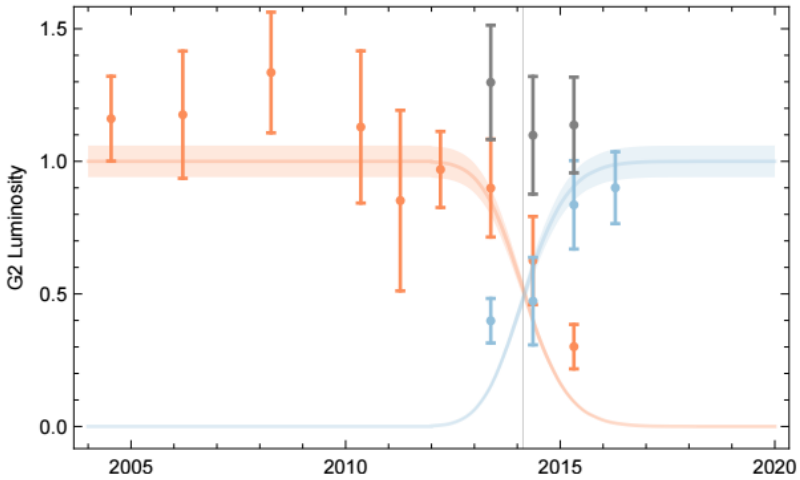


Witzel +14

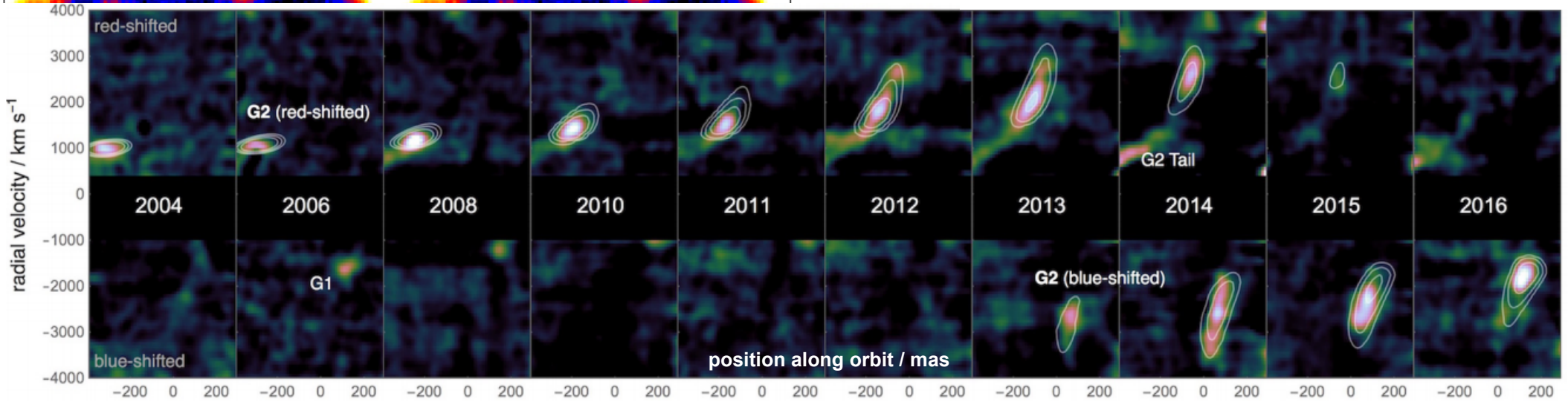
G2 survived peri-center ➜ contains a star

The gas component continues to follow a ballistic trajectory

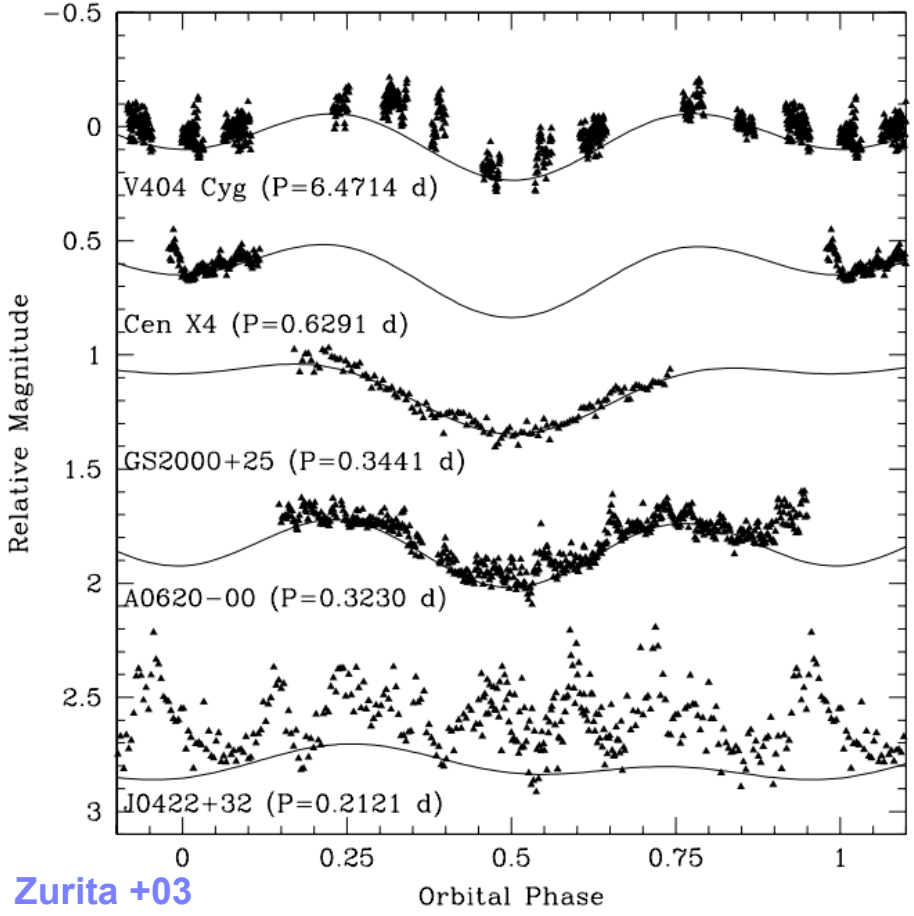
No drag force is observed ➜ ambient density $n_e < 10^3$ cm^{-3} at 1500 R_S



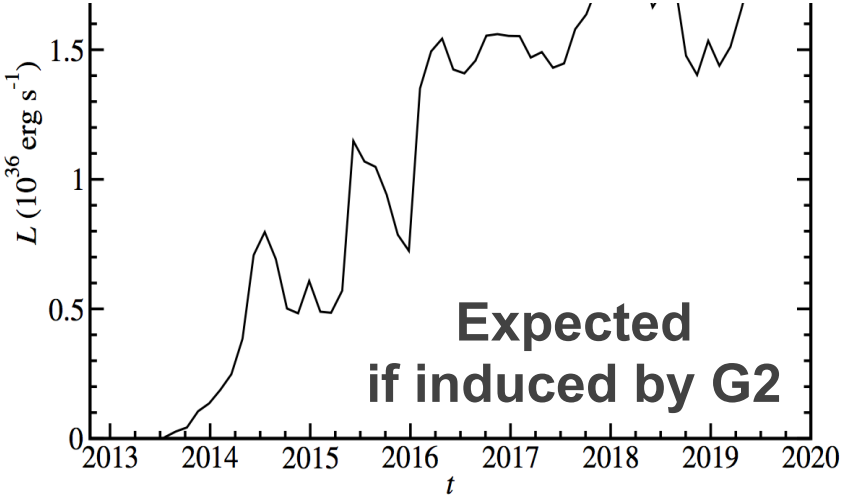
Plewa +17

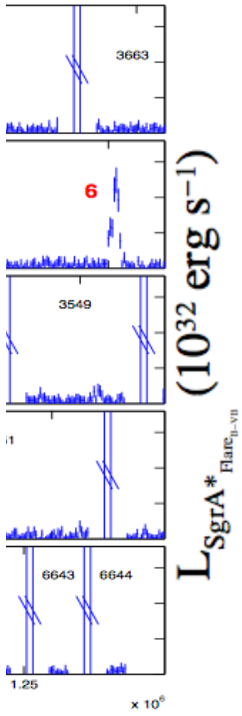


Increased flaring of Sgr A*: clustering or G2?

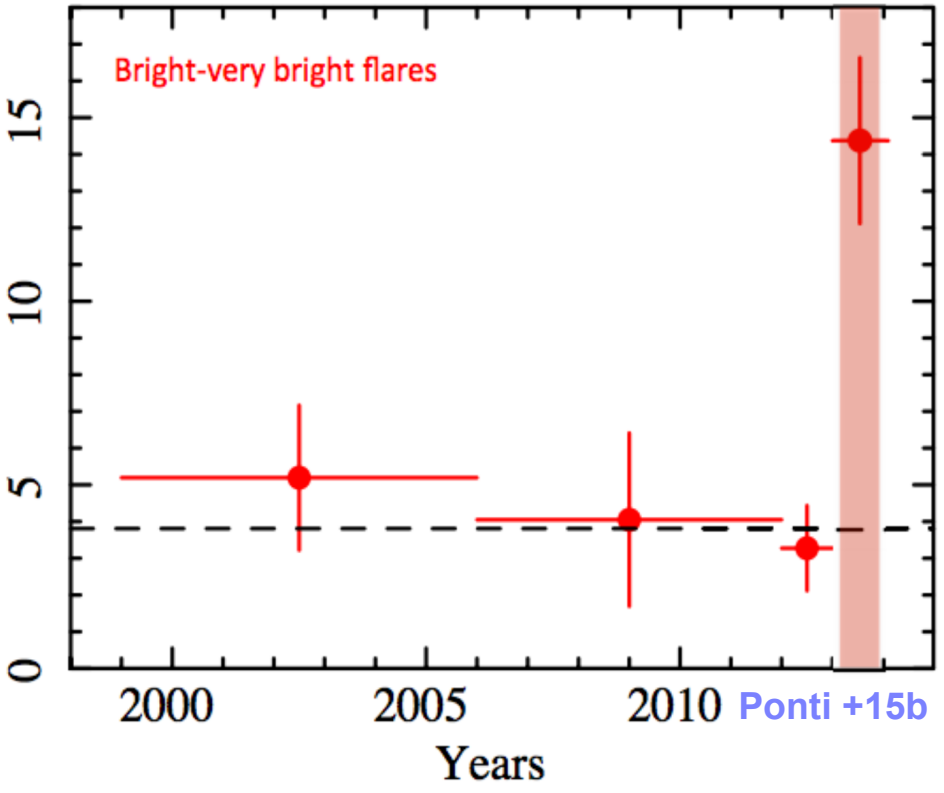


Zurita +03



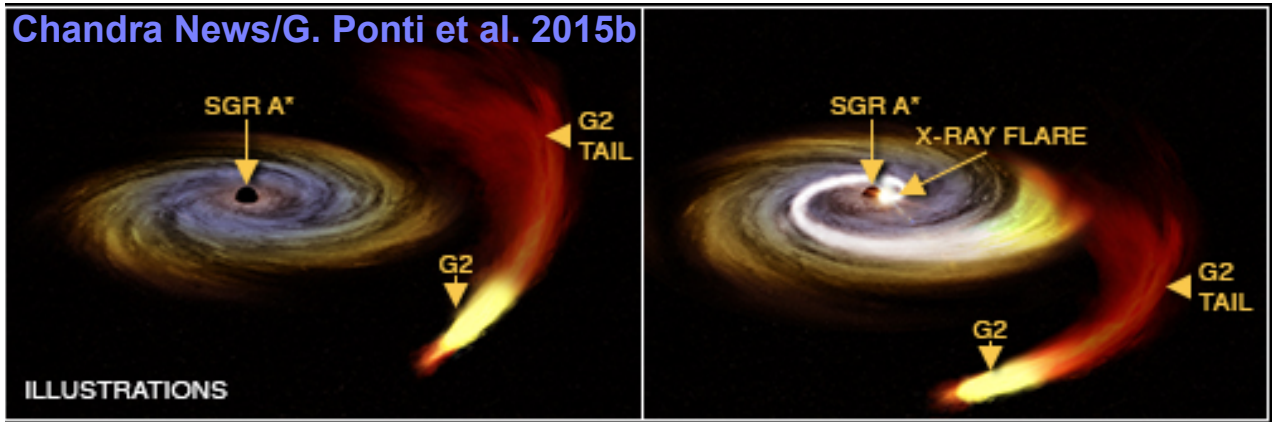


$L_{SgrA^*\,Flare_{B-VII}}$ (10^{32} erg s^{-1})



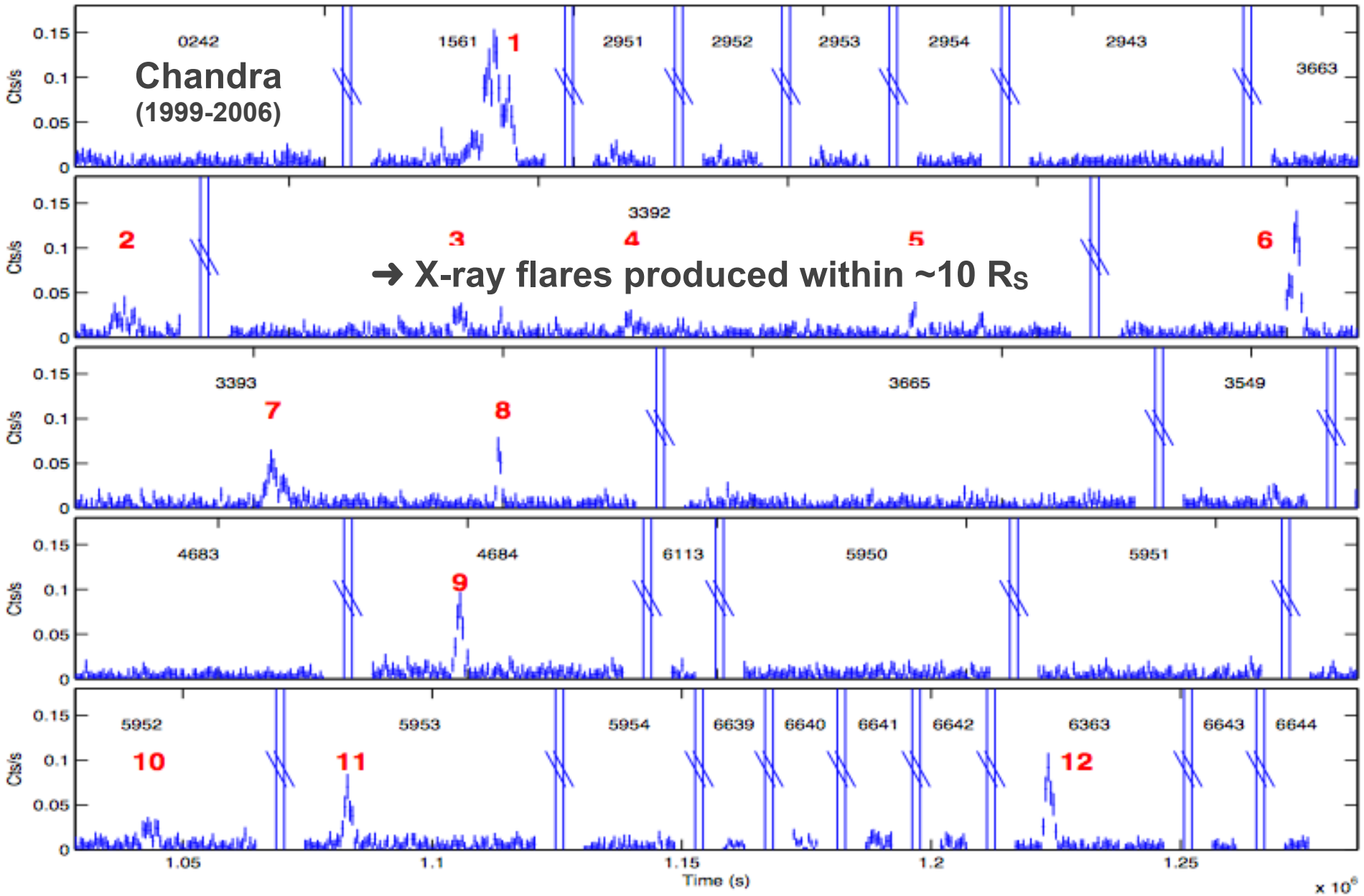
➜ Activity due to G2's passage?

➜ Due to flare clustering? (such as in quiescent GBH)



*X-ray flares of Sgr A**

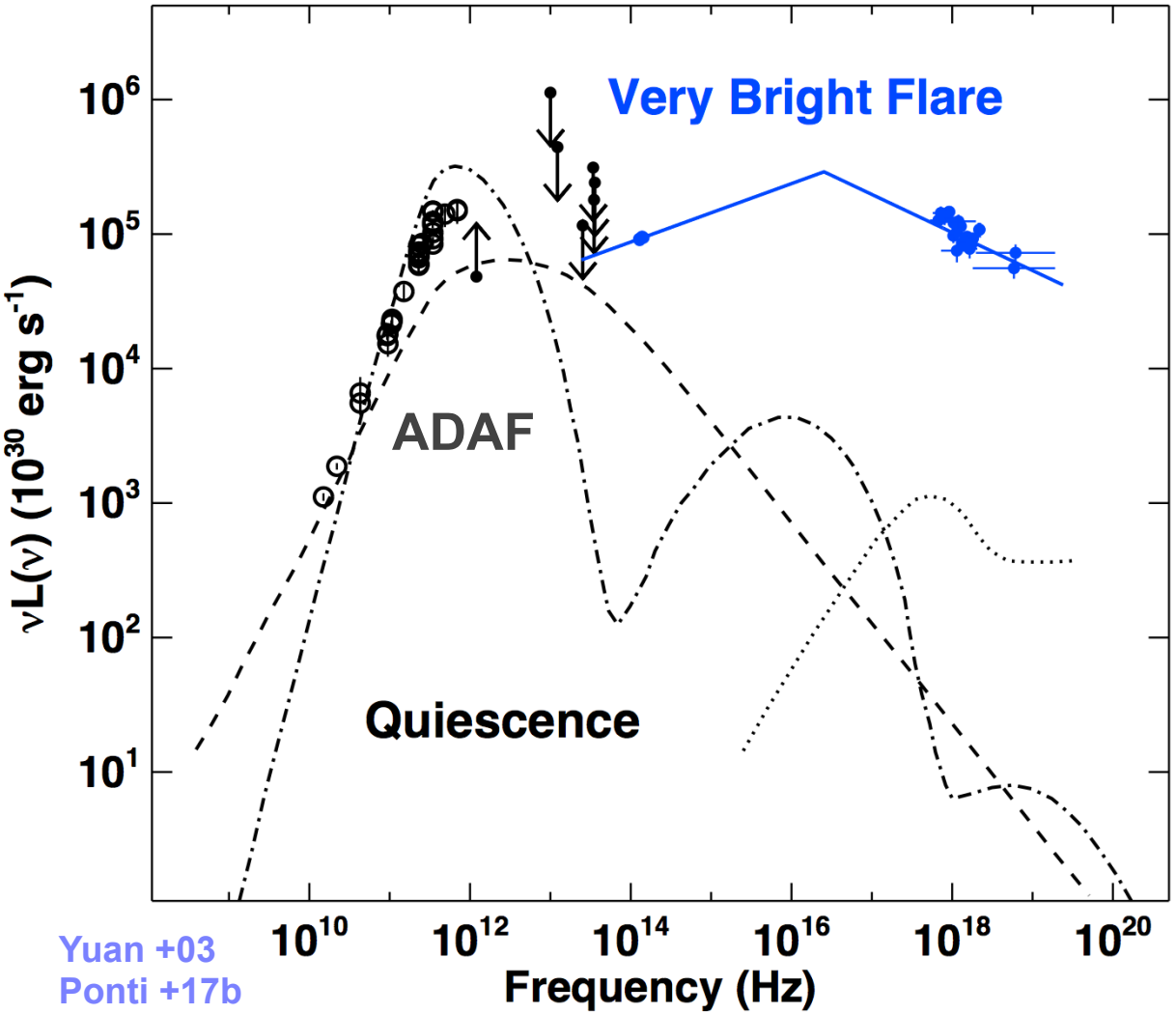
Ponti +15b



Baganoff +01; Goldwurm +03; Porquet +03; 08; Belanger +05; Nowak +12; Neilsen +13; Barriere +14; Ponti +15b

Sgr A's emission during flares?*

Best target to study low luminosity accretion



Yuan +03
Ponti +17b

During flares
$\Gamma_{IR} \sim 1.6$
IR polarised
➜ Synchrotron

What is the radiative process in X-ray?

Thanks to XMM scheduling team!

Major question since 15 yr…
We've solved it! Ponti +17b

Are X-rays inverse-Compton radiation?

Jet?

Hot flow
(ADAF/RIAF?)

$r \sim 10\ R_S$

Thermal e^- ($\gamma_e \sim 10$)

$B \sim 20\text{-}50$ G

$kT_e \sim 10^{10}$ K

$n_e \sim 10^6$ cm^{-3}

$M \sim 10^{-7}\text{-}10^{-9}\ M_{Sun}\ yr^{-1}$

BH

Heating/accelerating
particles - IC

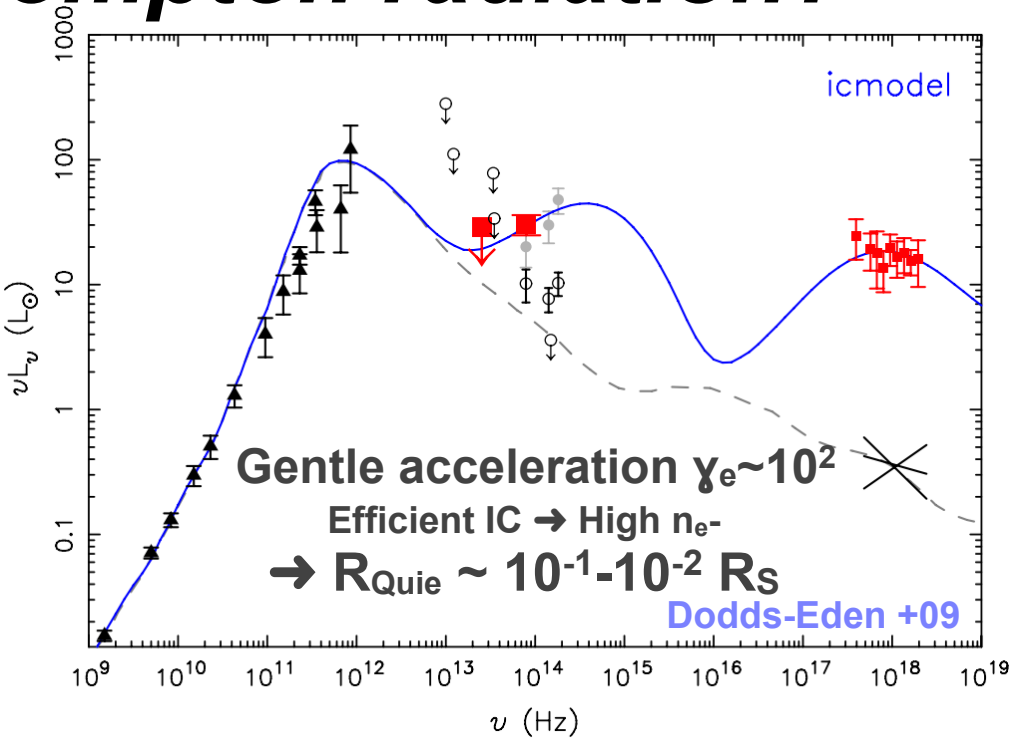
e^- with $kT_e \sim 10^2\ m_e c^2$

$B \sim 10^2$ G ➜ L_{NIR} synchro

Quie e^- + L_{NIR} ➜ IC
➜ L_X

Quie e^-

Eckart +04; 06; +08; +09; +12;
Yusef-Zadeh +06; +08; +09;
Hornstein +07; Marrone +08;
Trap +11; Barriere +14



Are X-rays Synchrotron self Compton?

Jet?

Hot flow (ADAF/RIAF?)

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BH

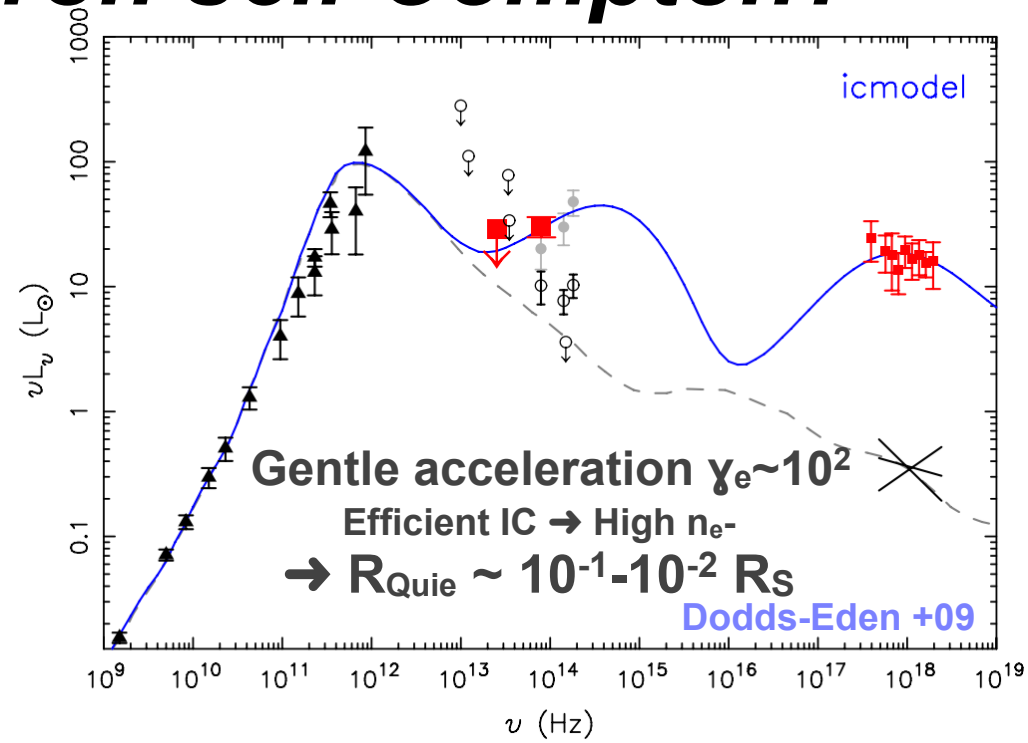
Heating/accelerating particles - SSC

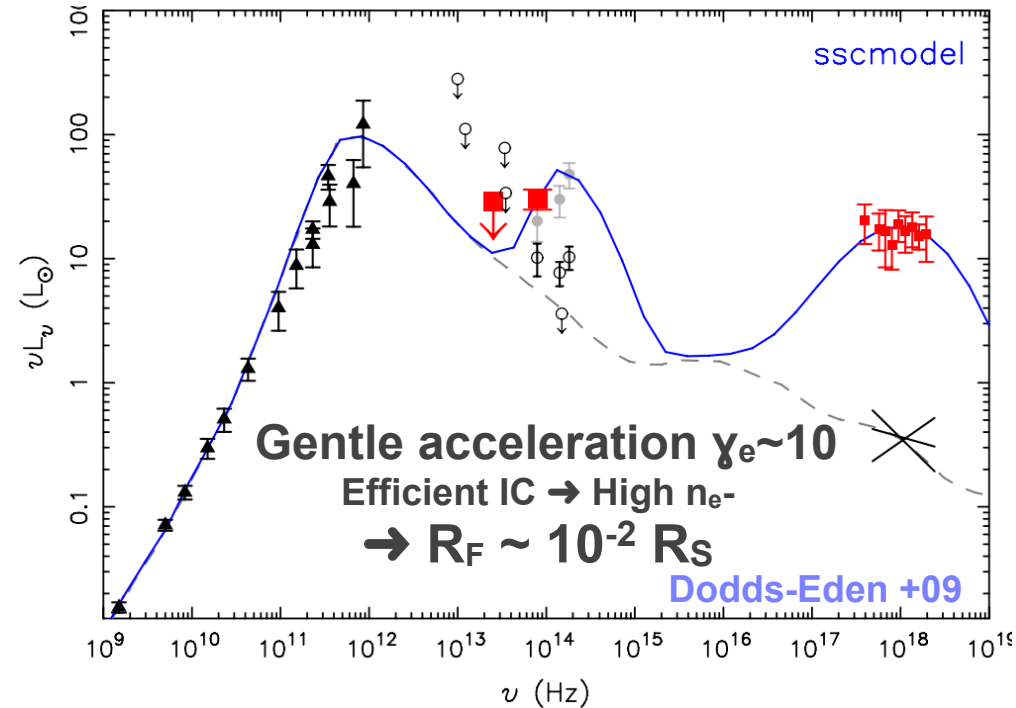
e^- with $kT_e \sim 10\ m_e c^2$

$B \sim 10^4$ G → L_{NIR} synch

SSC → L_X

Eckart +04; 06; +08; +09; +12;
Yusef-Zadeh +06; +08; +09;
Hornstein +07; Marrone +08;
Trap +11; Barriere +14





Are X-rays Synchrotron?

Jet?

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BH

Heating/accelerating particles

e^- with $\gamma_e > 10^6$

B~10 G ➜ synchro from NIR to X

Eckart +04; 06; +08; +09; +12;
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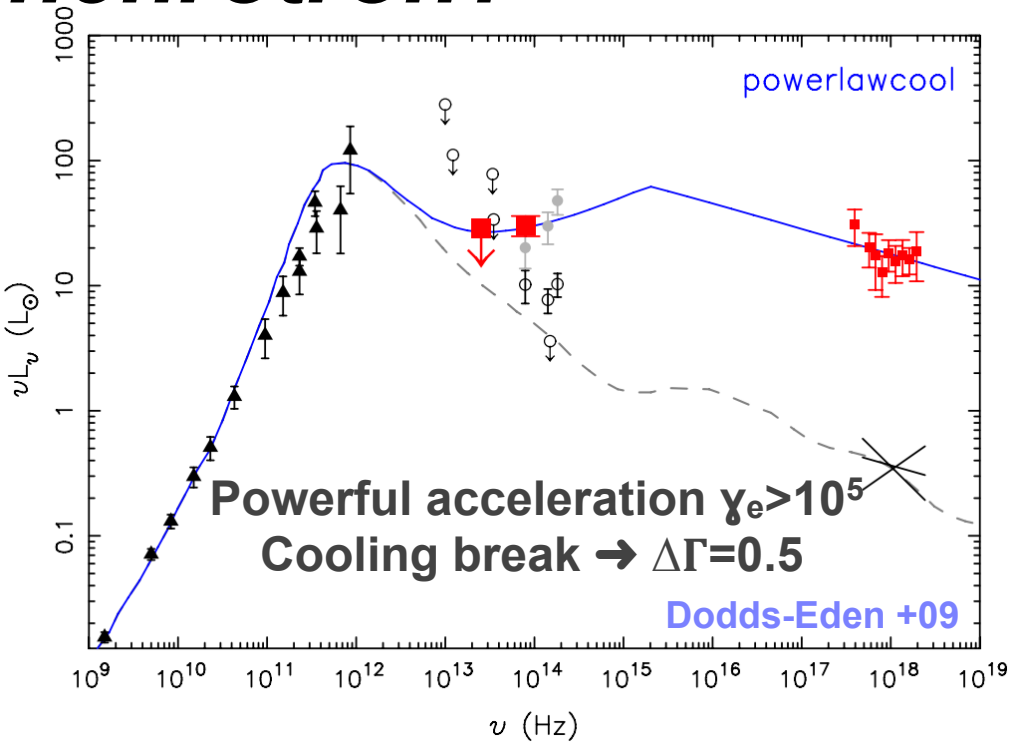

What is the origin of Sgr A*'s X-ray emission?

Jet?

Hot flow (ADAF/RIAF?)

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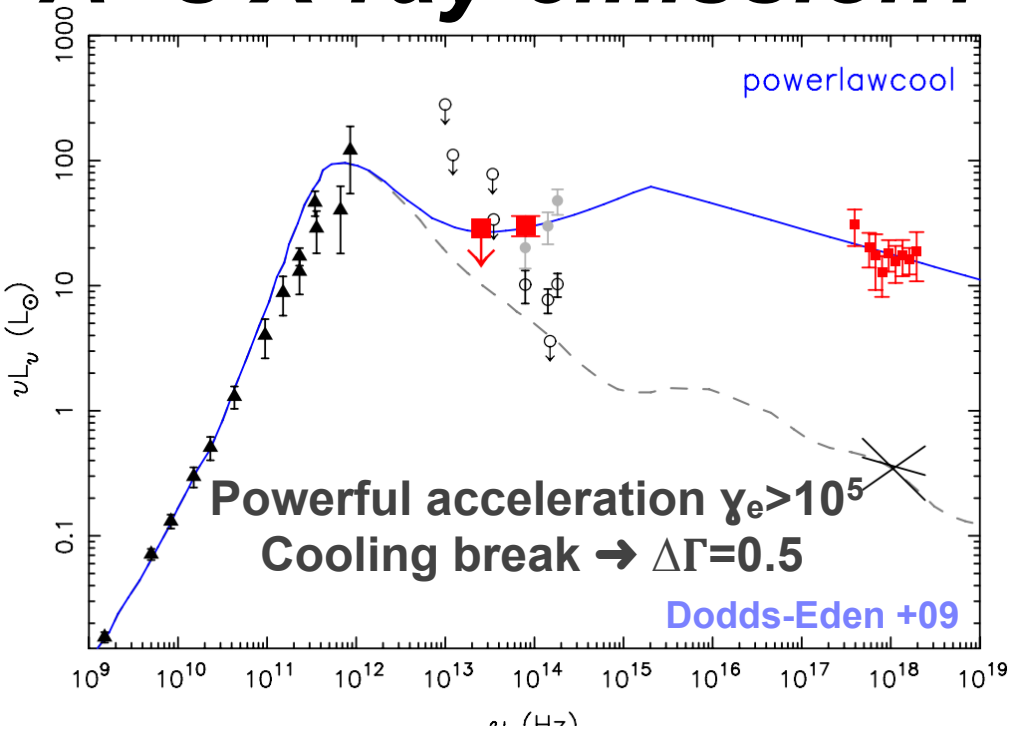
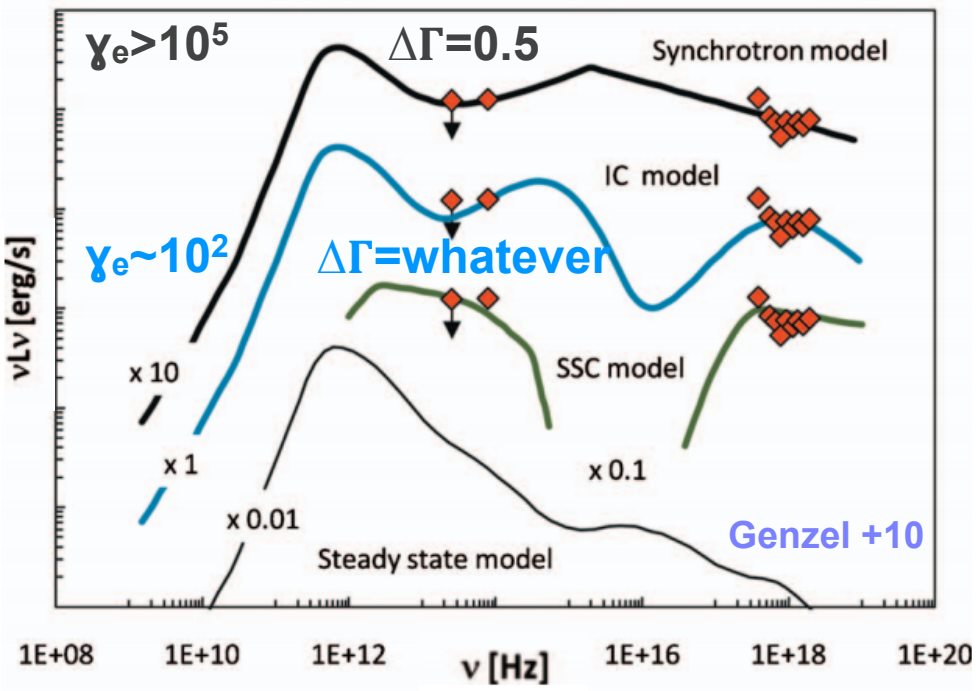
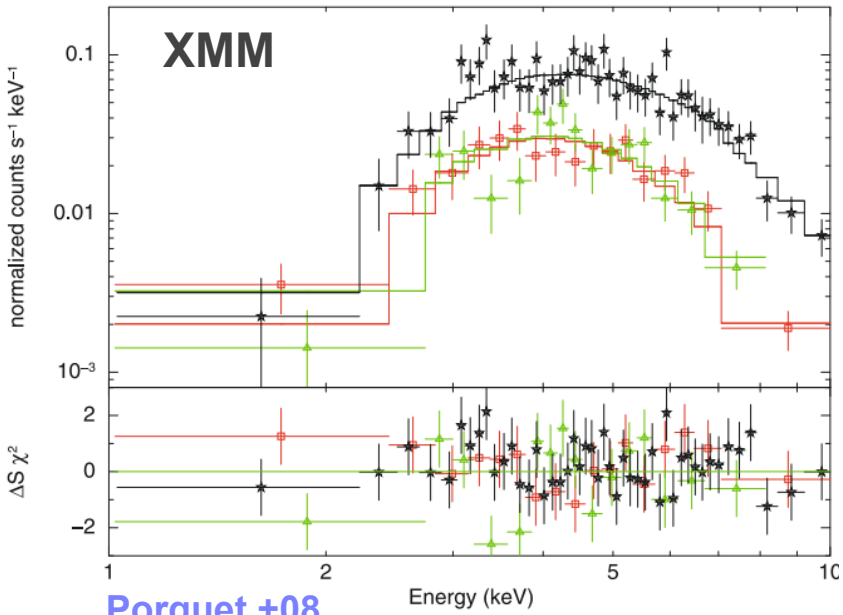
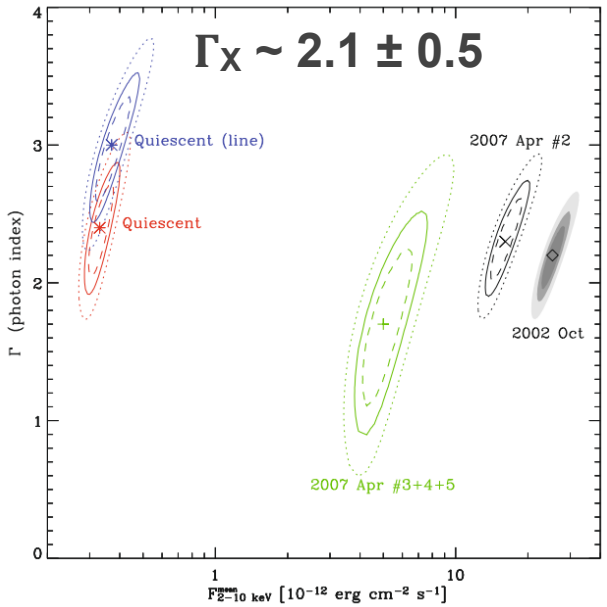
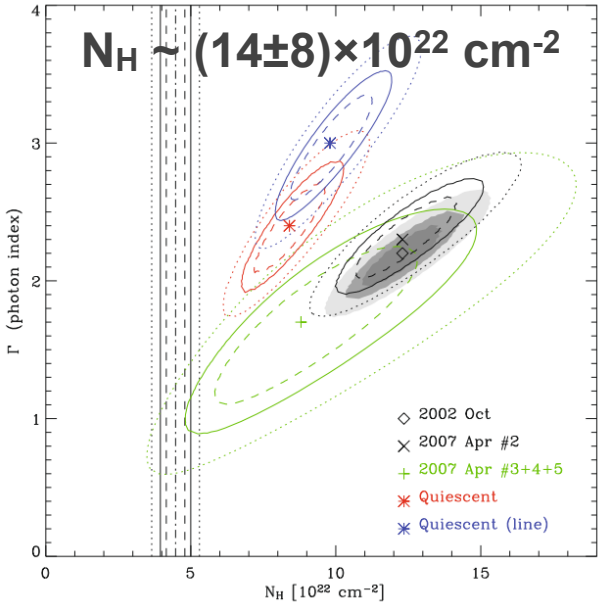




X-ray slope during bright flares

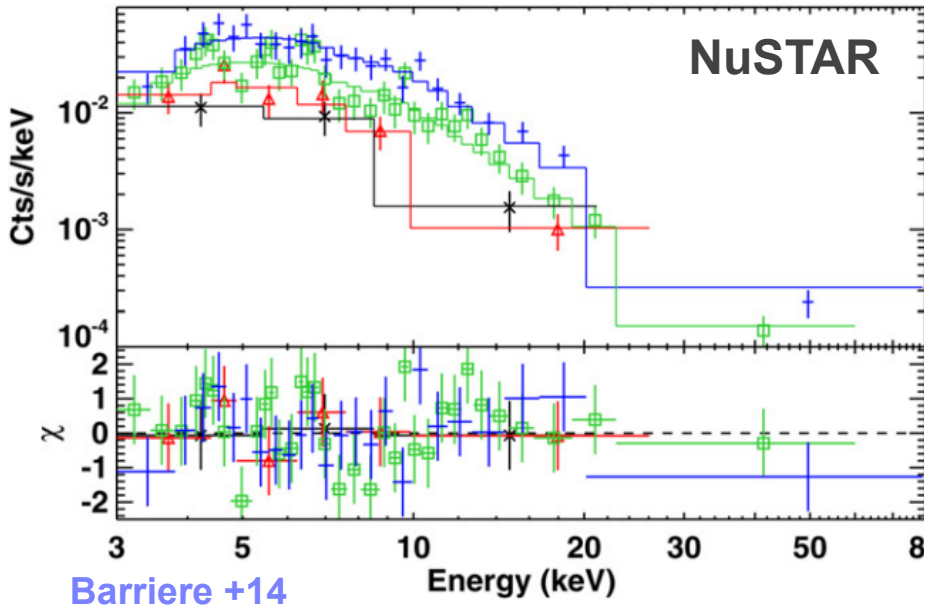




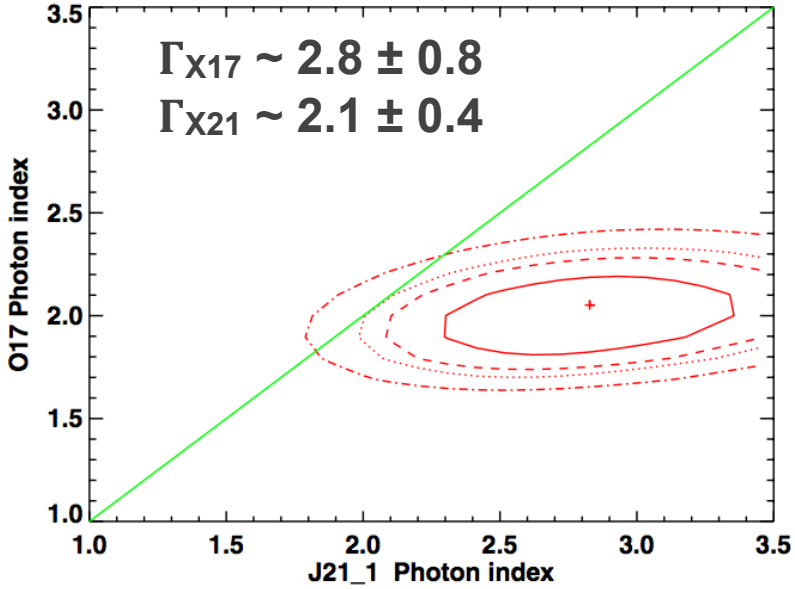


Porquet +08

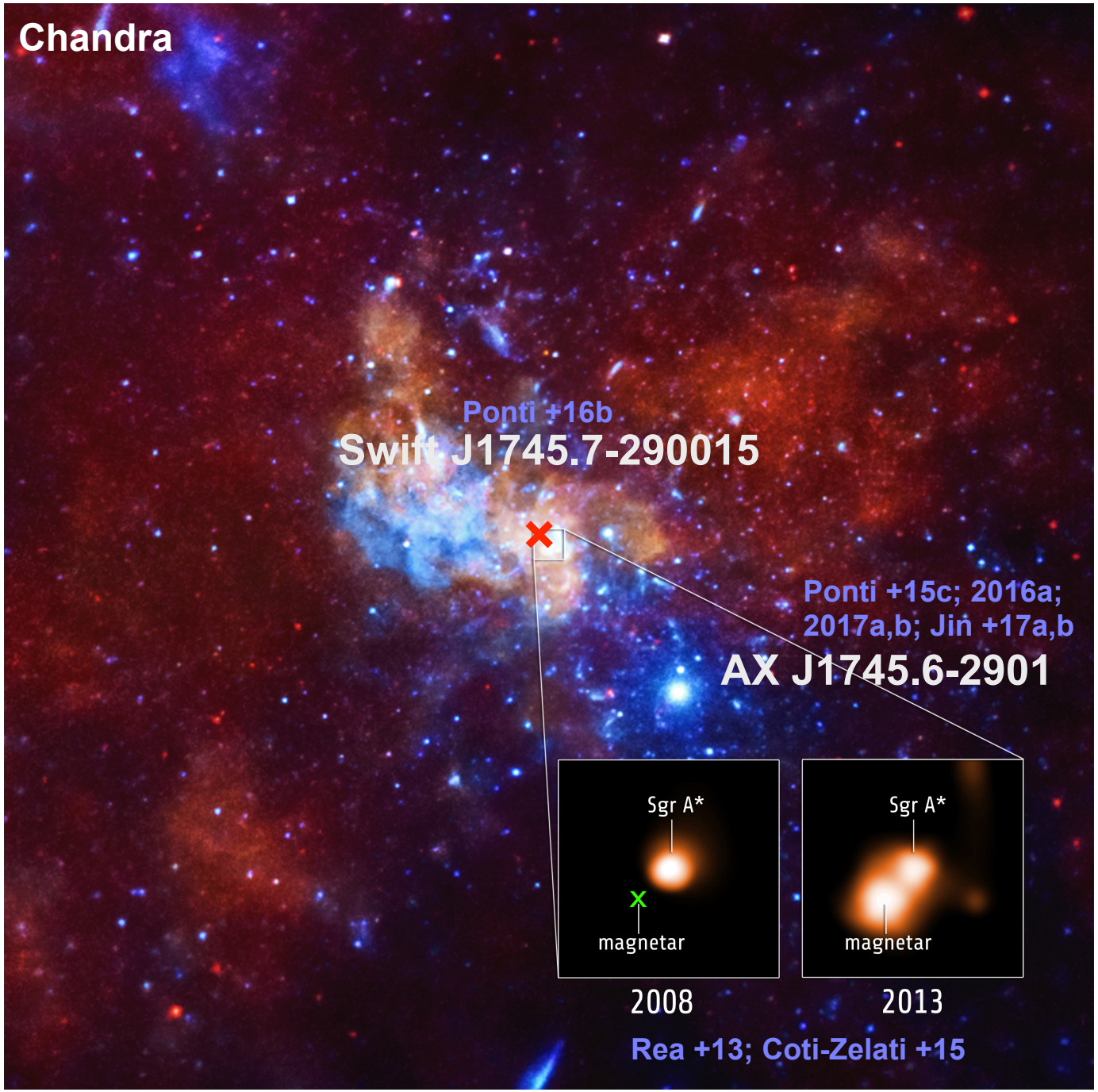
Variable N_H not well justified…



Barriere +14



Absorption towards nearby transients



SGR J1745-2900 (magnetar)
Swift J1745.7-290015
➜ same N_H of Sgr A*
XMM-DDT: Ponti +16b

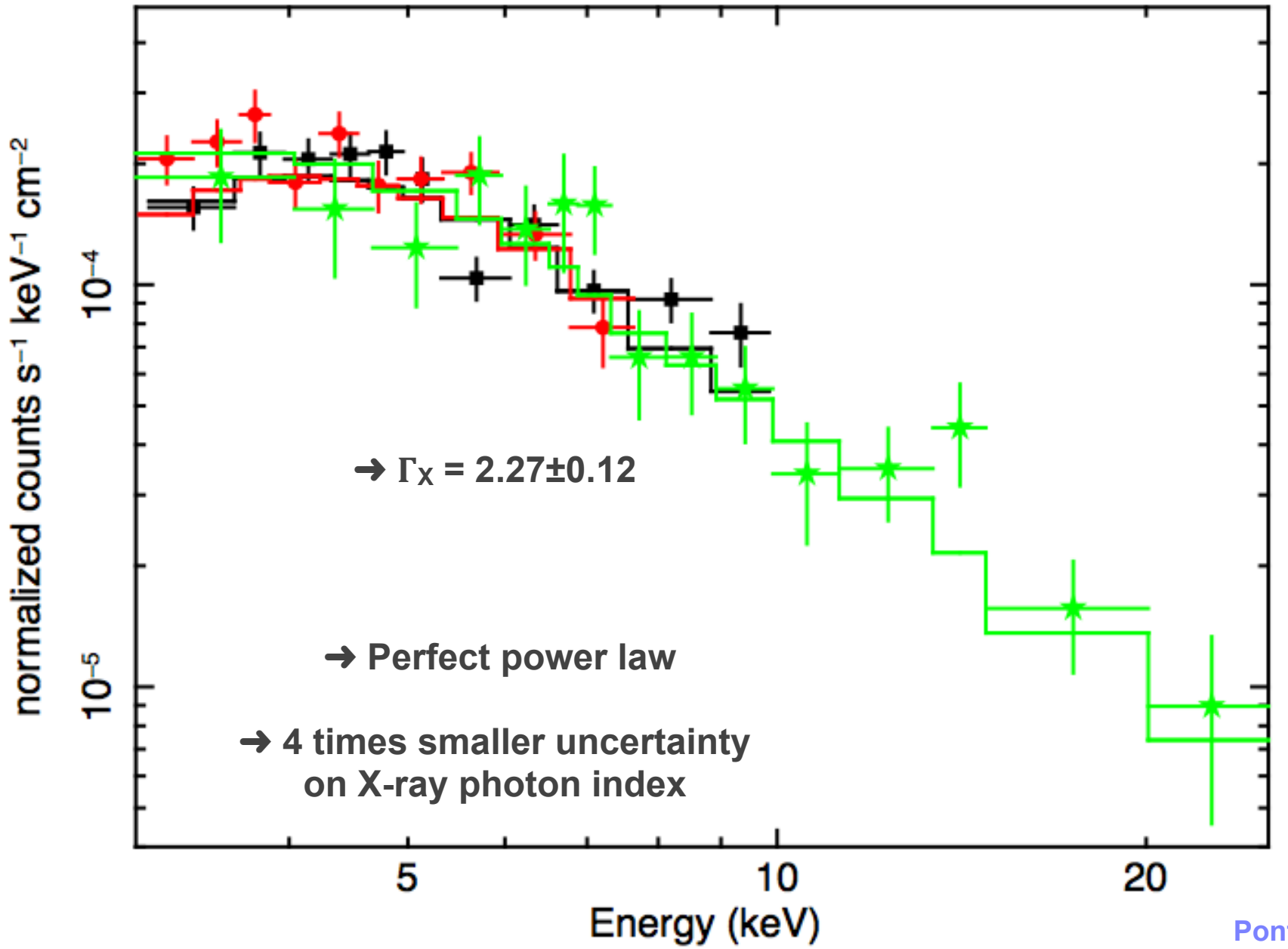
Rotation measure
➜ absorption in spiral arms
Bower +14; Roy +13

Dust scattering halo
of AX J1745.6-2901
➜ two components

The foreground
component
➜ same N_H of Sgr A*
Jin +17a,b; Ponti +17b

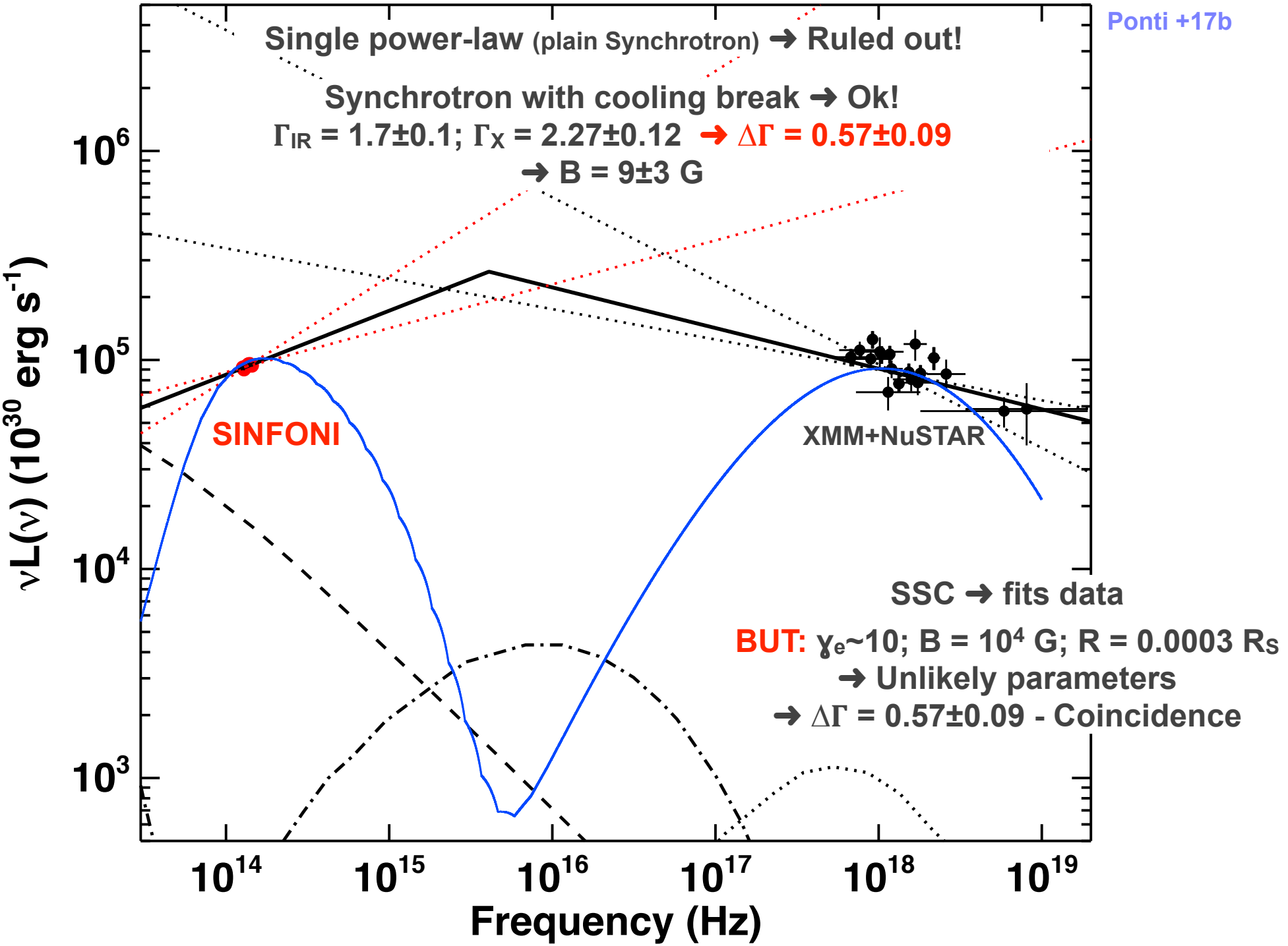
➜ The NH towards Sgr A*
is due to ISM
Ponti +17b

XMM+NuSTAR spectrum of a very bright flare



Ponti +17b

First NIR and X-ray spectrum of a flare!



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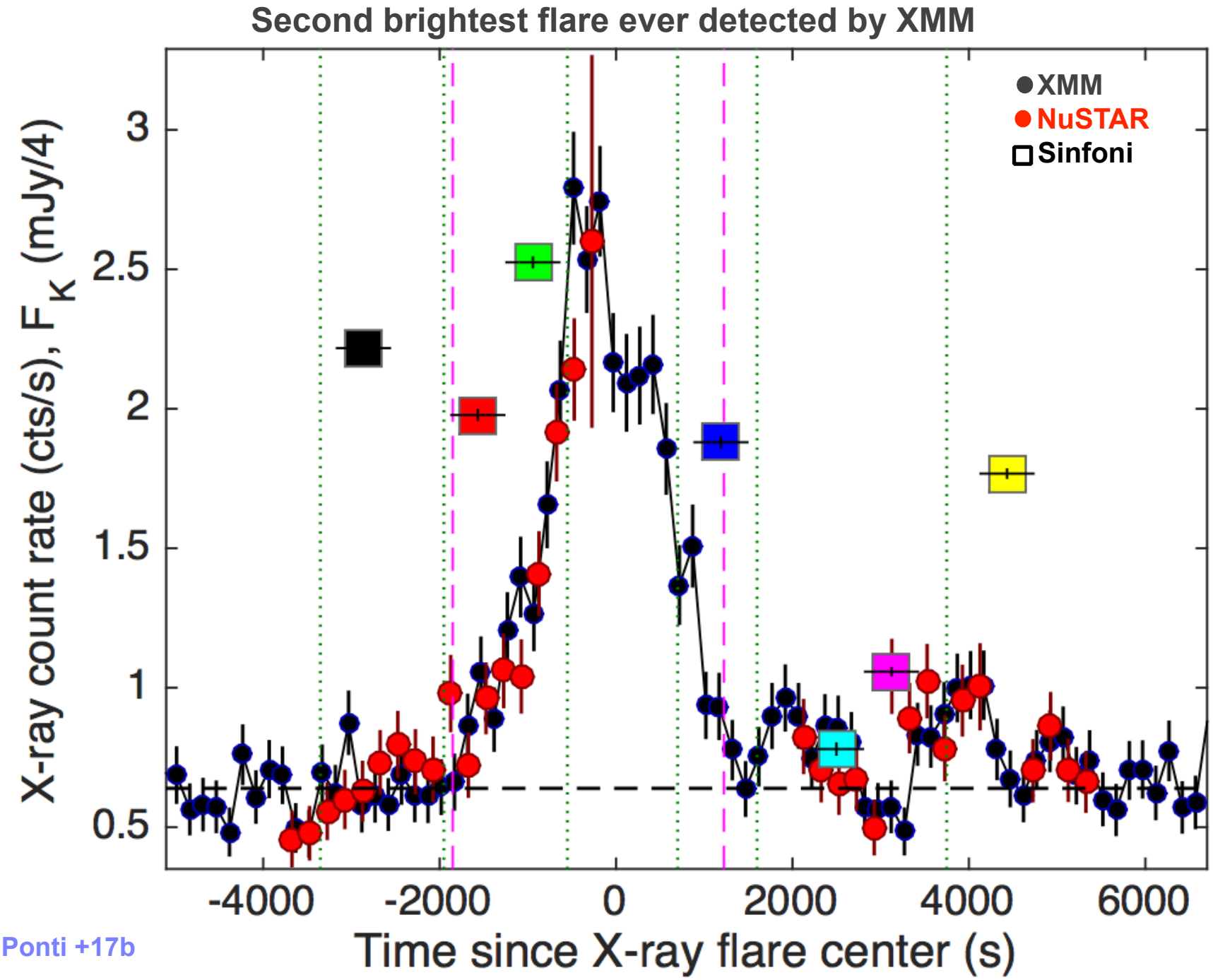
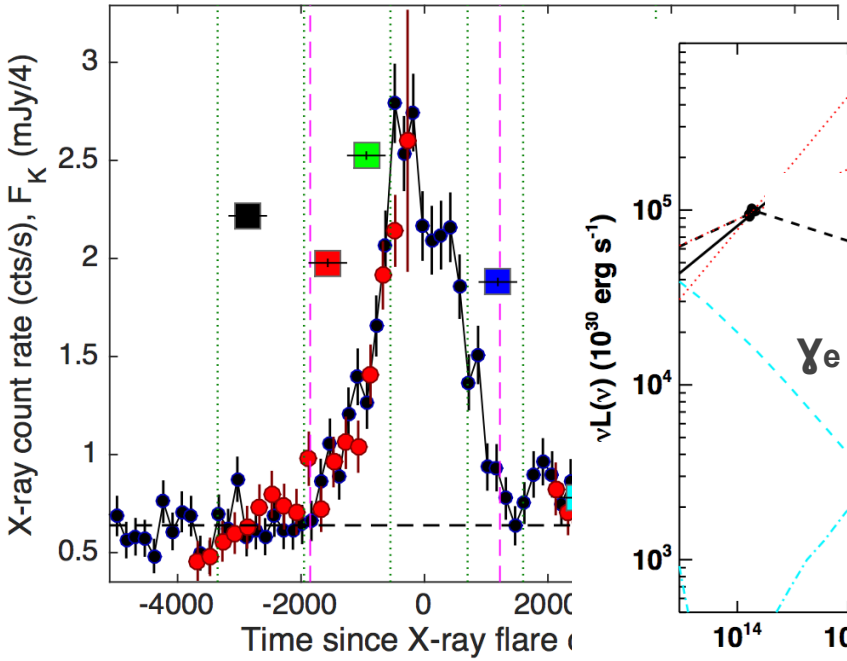


Ponti +17b

Evolution of γ_e during flares?



Ponti +17b

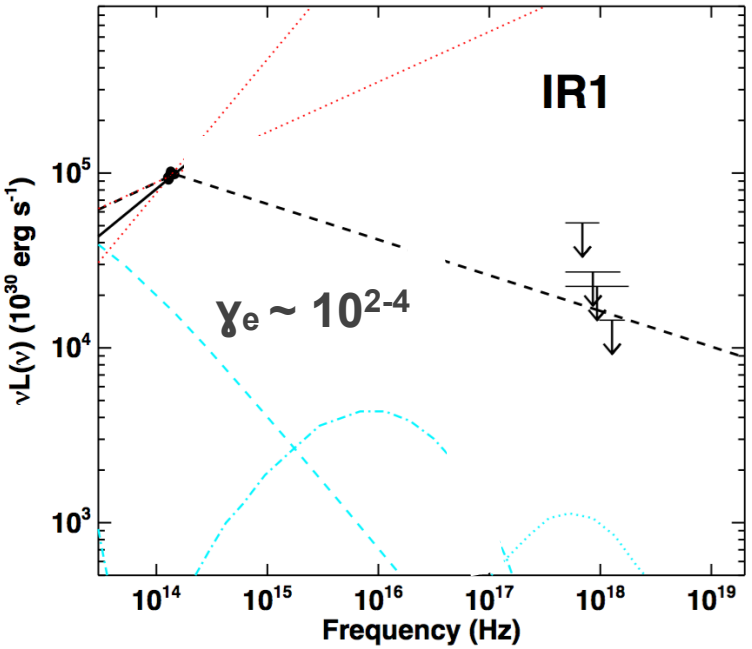
Synchrotron with cooling and $\gamma_e > 10^5$

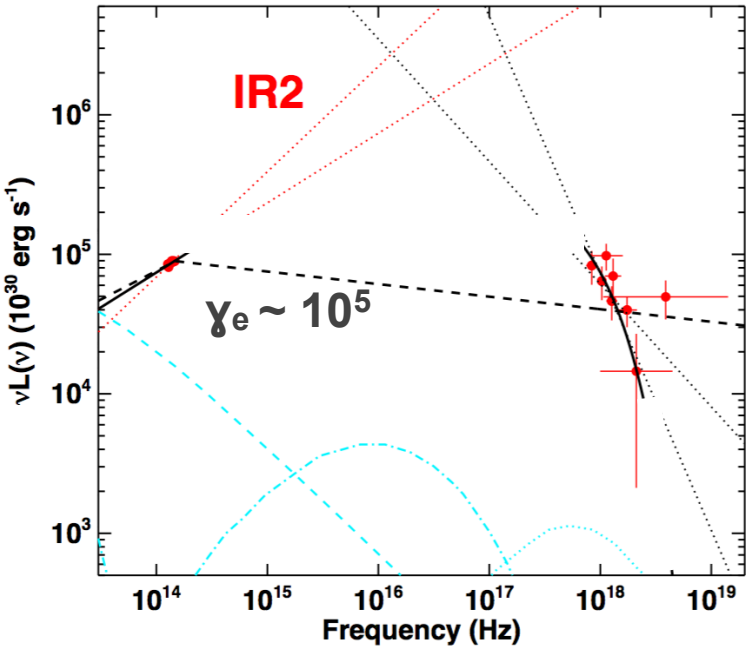
Break in NIR ➜ No
IR2 slope ➜ No
IR1 already cooled ➜ No

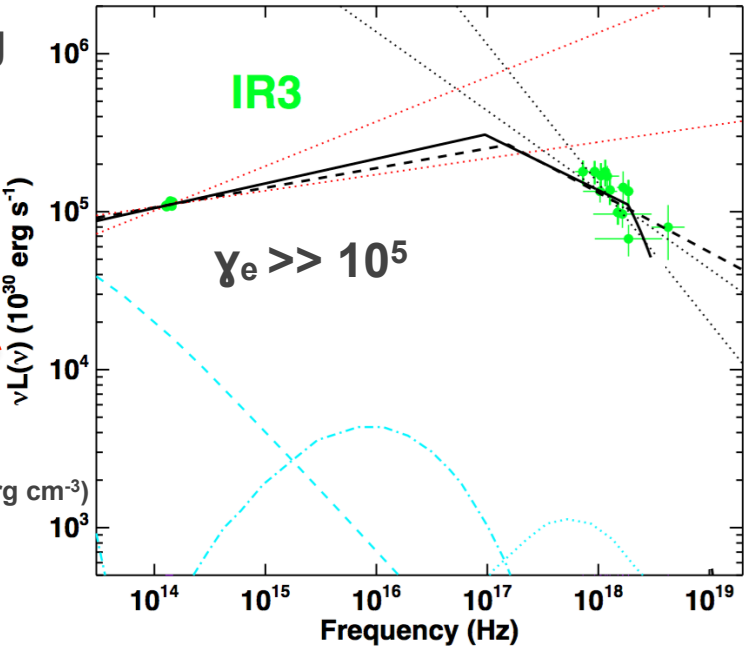
~~**➜ Hide radiation via SSC**~~
~~**But:**~~
~~u_B (16-64 erg cm^{-3}) >> u_{rad} (0.03-0.3 erg cm^{-3})~~
~~**unless R < 10^2 R_S!**~~

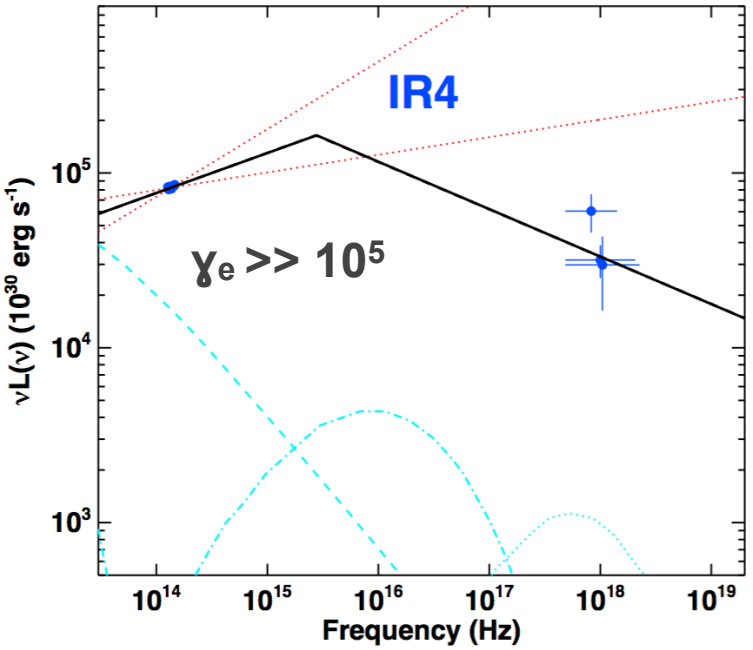
➜ Slow evolution of γ_e

SED evolution during very bright flare



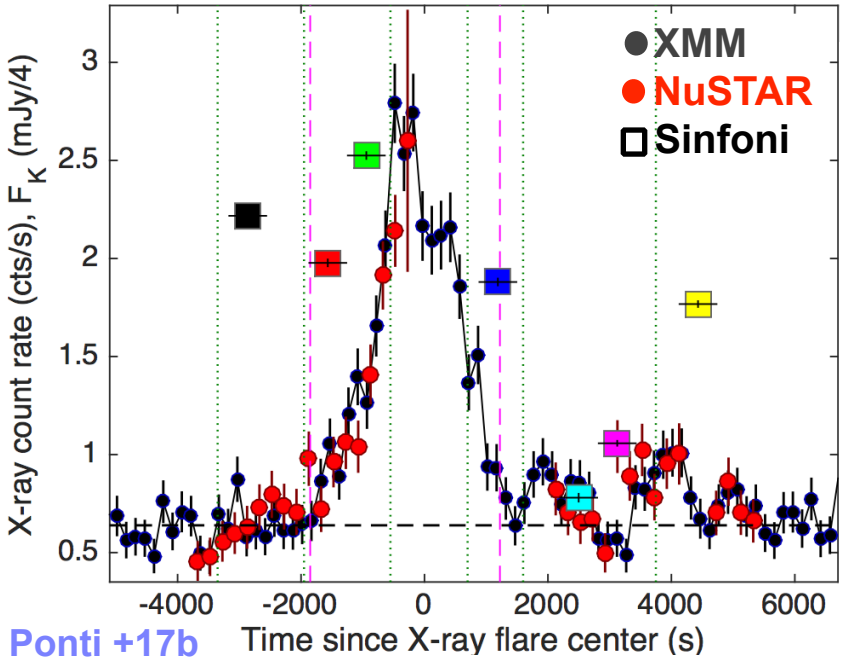






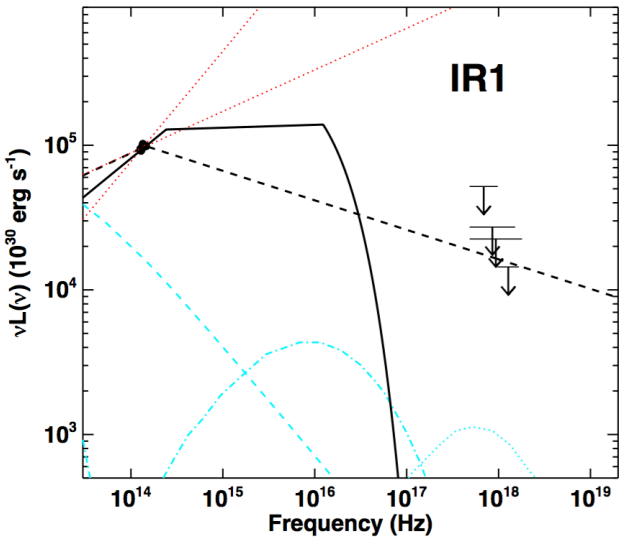
Ponti +17b

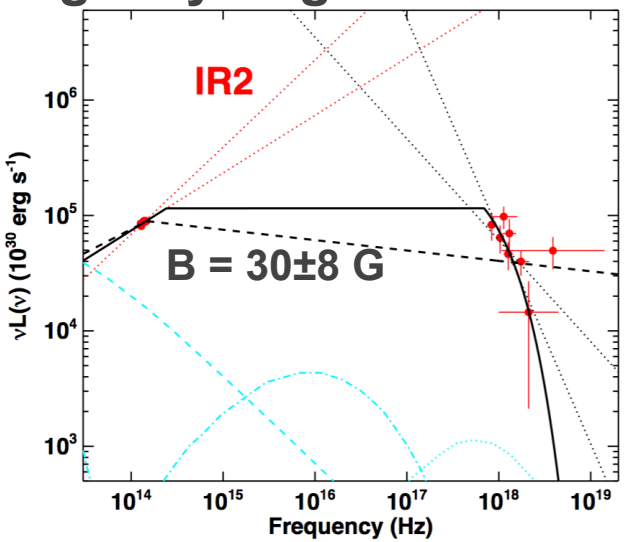
Evolution of B during flares!

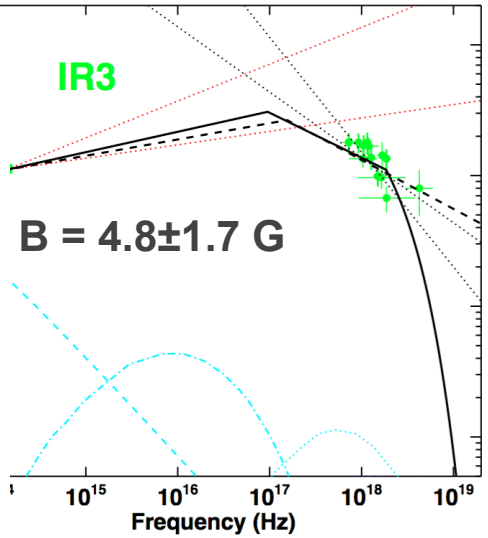


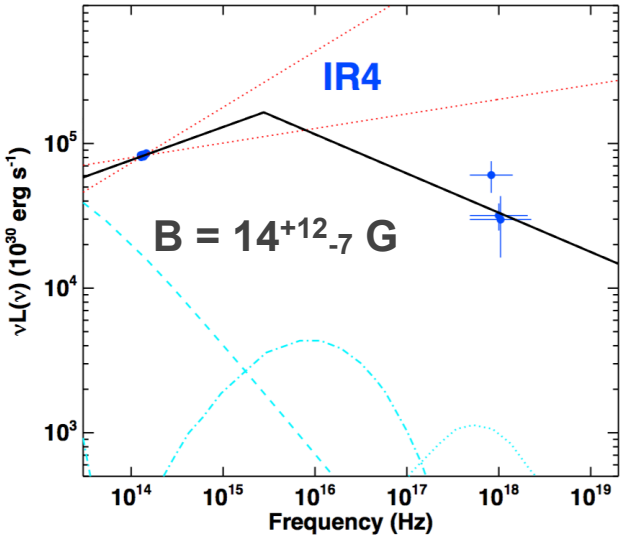
Ponti +17b

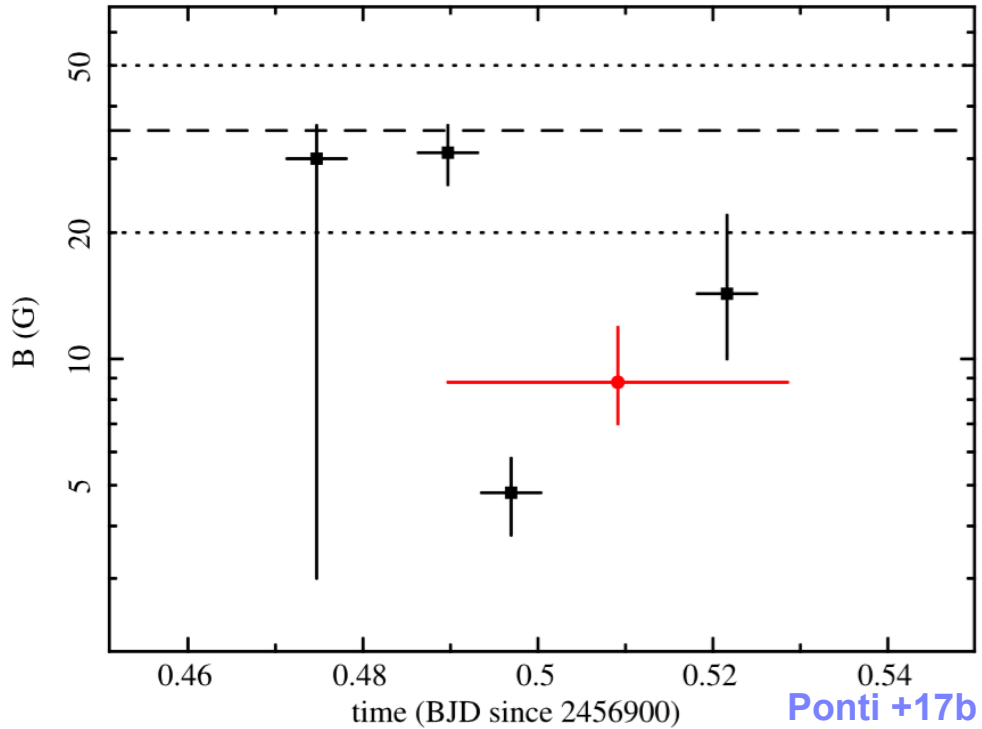
SED evolution during very bright flare











Ponti +17b

Evolution of ➜ magnetic field

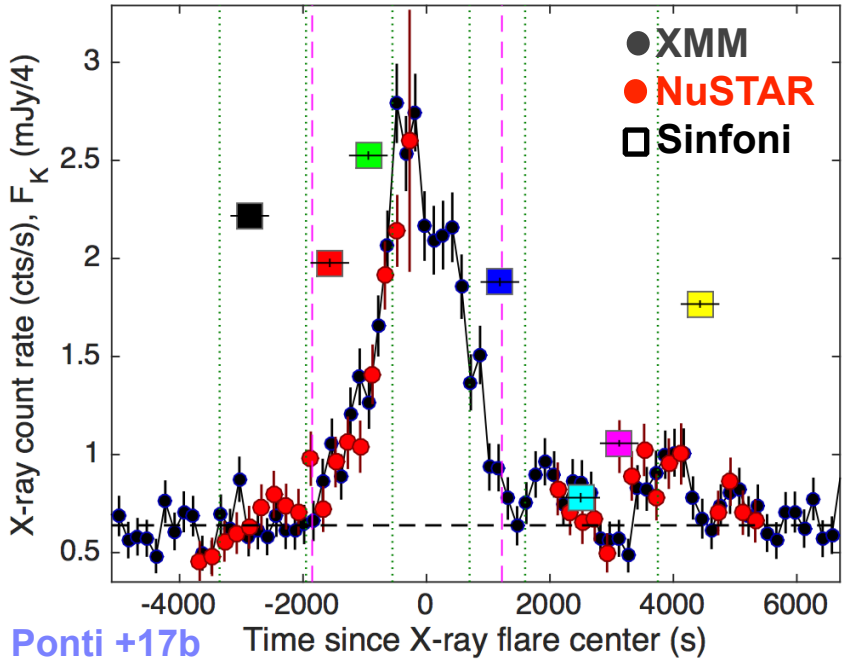
➜ Flares powered by magnetic energy

$\Delta E_{magnetic} \approx \Delta E_{particles}$

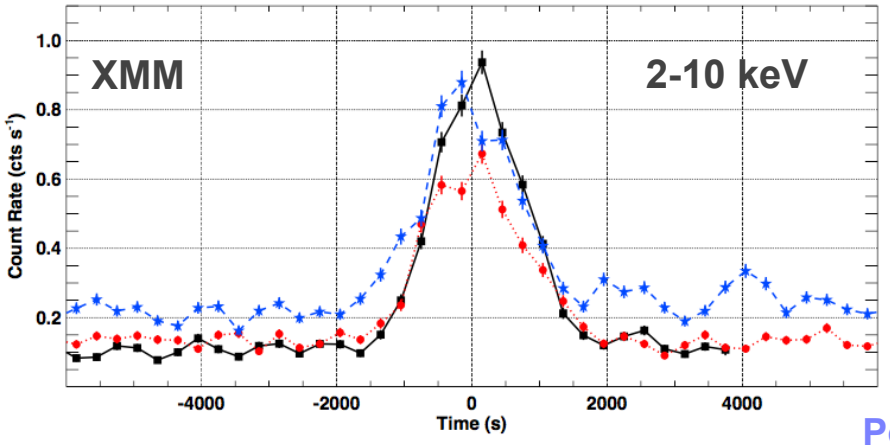
➜ magnetic reconnection

Ponti +17b

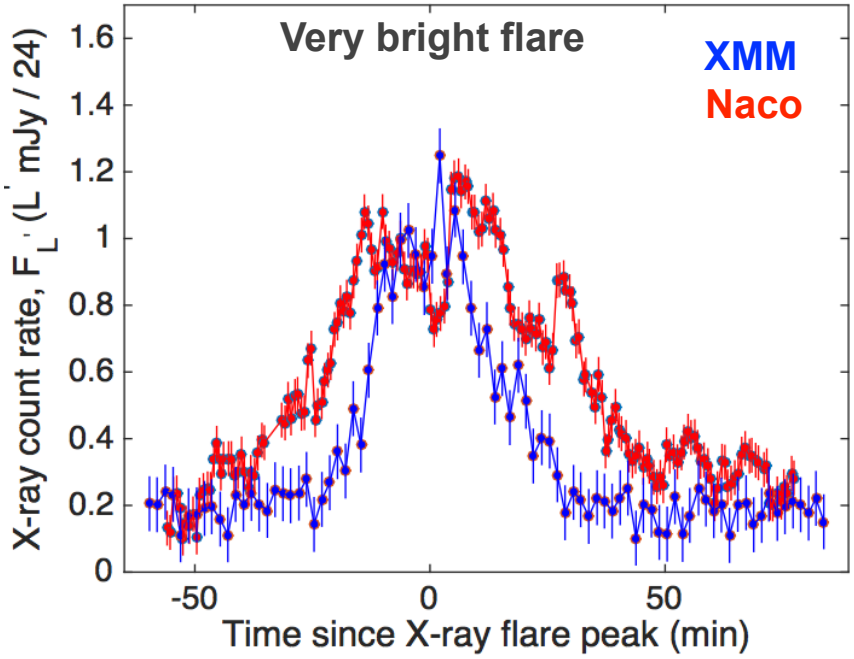
Slow acceleration of e⁻? ➜ X-ray light-curves



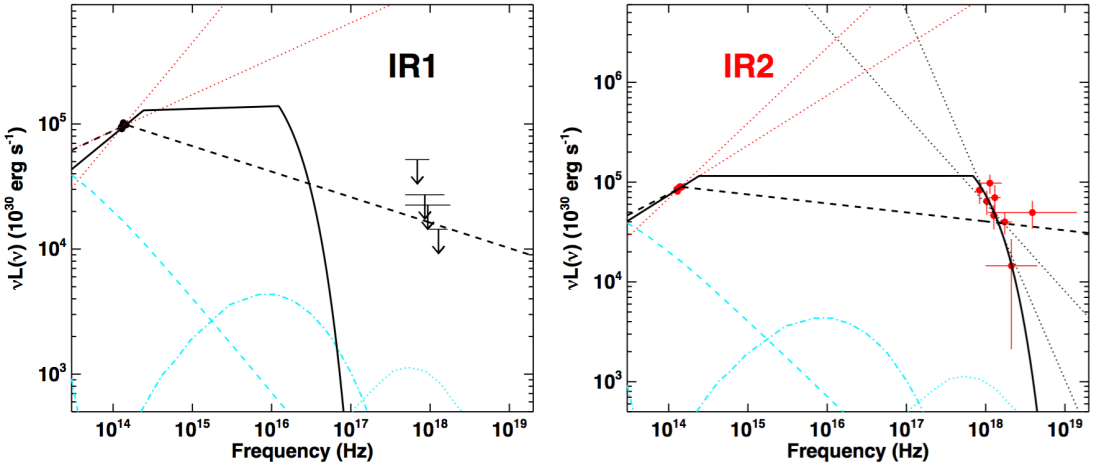
Ponti +17b



Ponti +17b

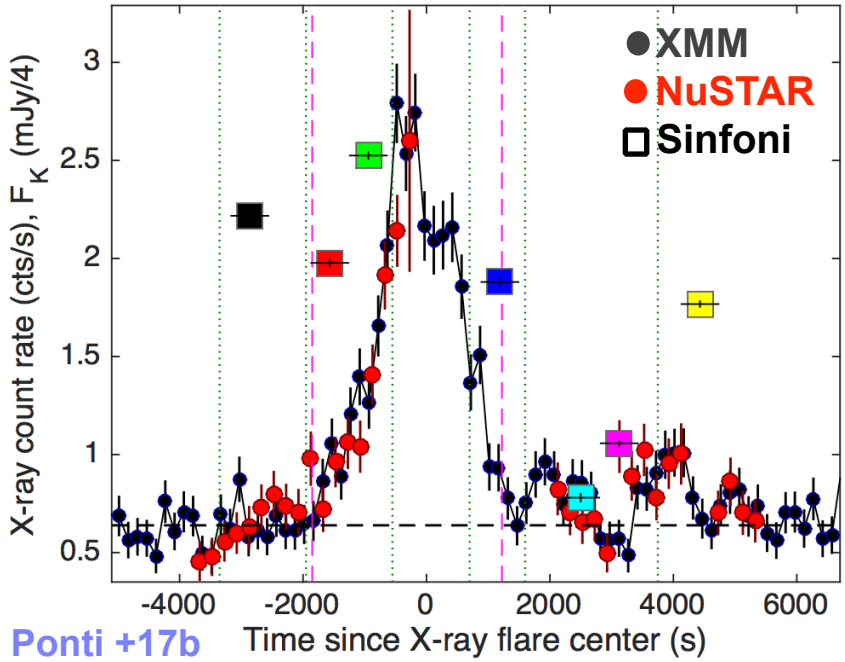


Dodds-Eden +09

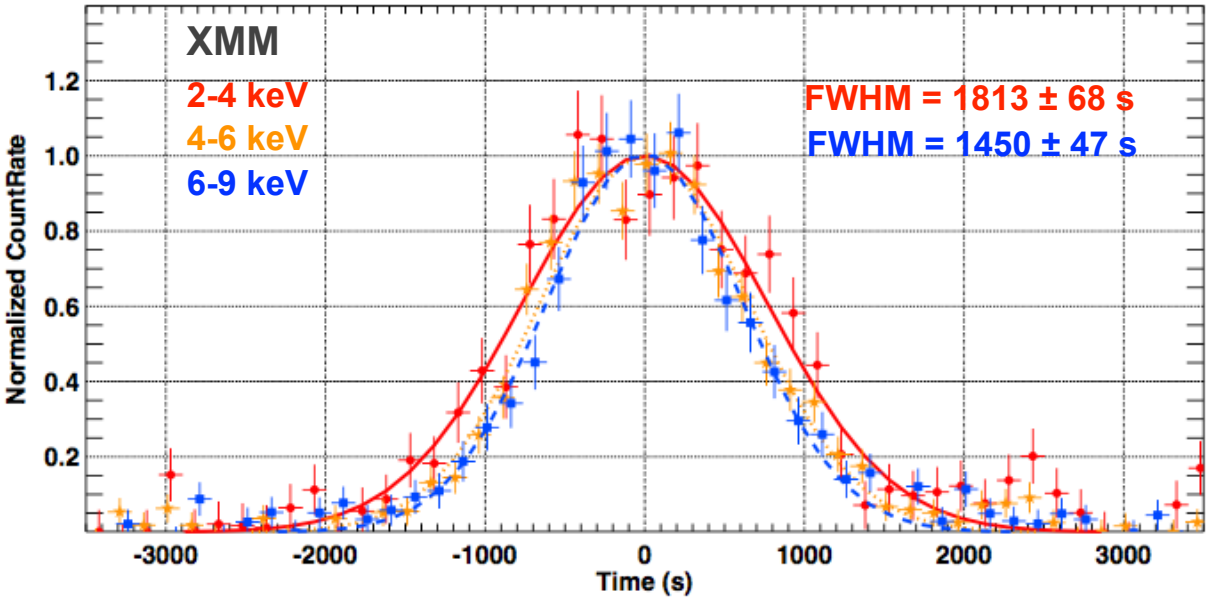


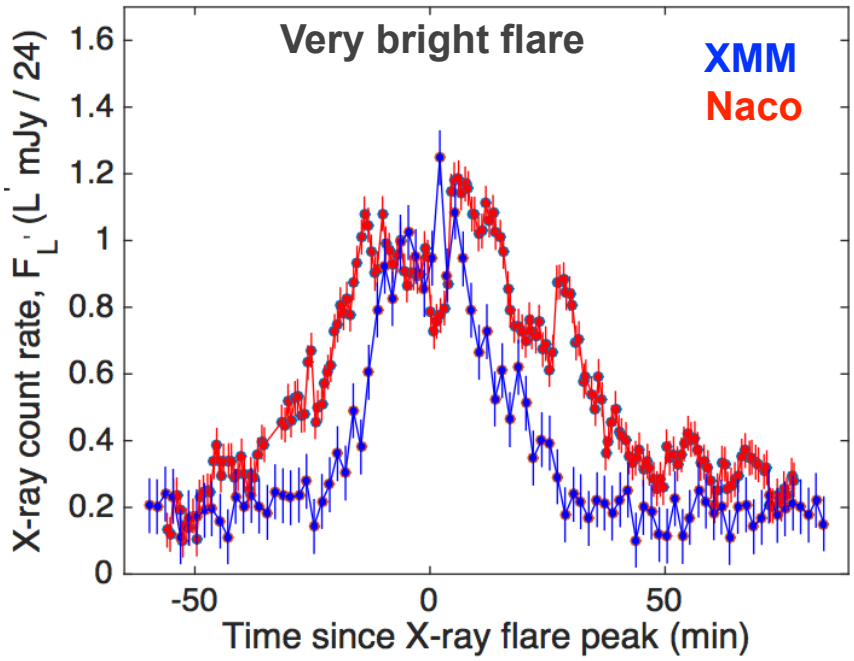
Does variation of γ_e induce shorter flares at high energy?

X-ray flares shorter in hard X-rays



Ponti +17b





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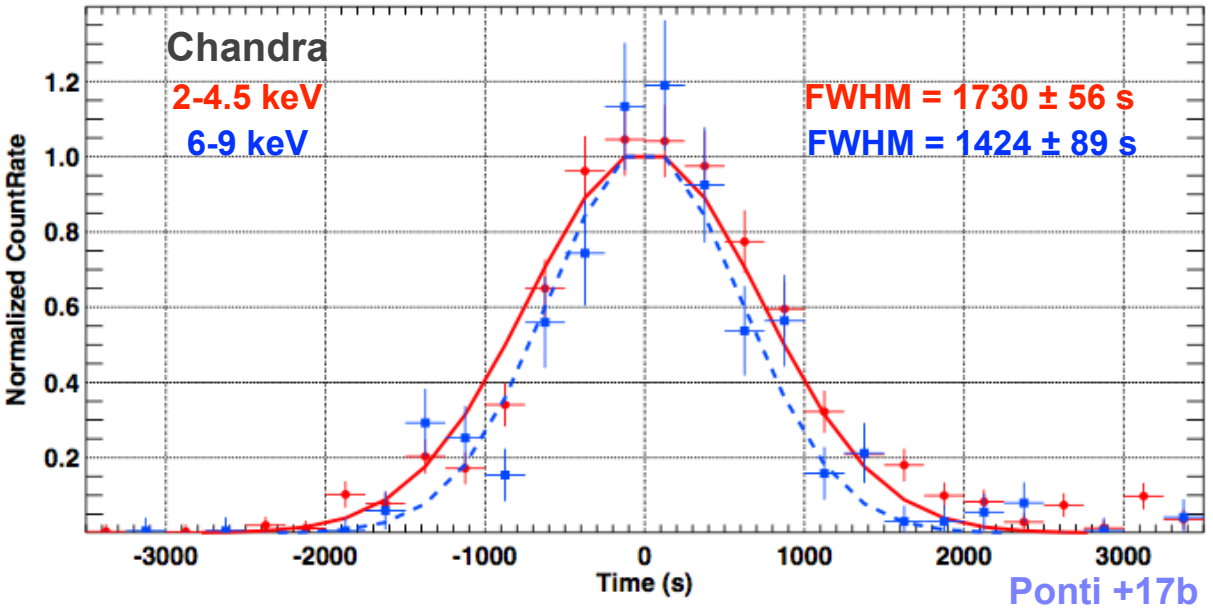


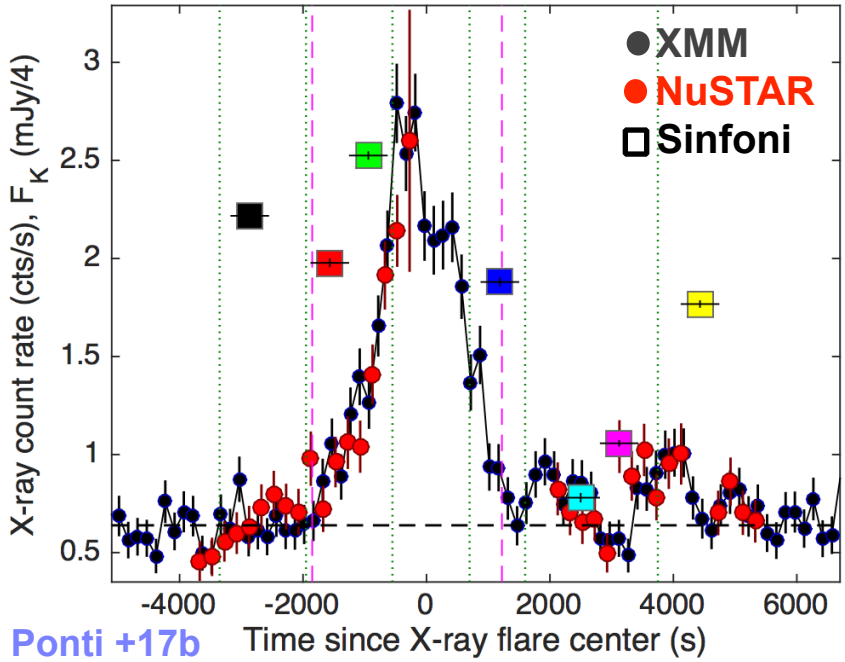
Ponti +17b

➜ Flares shorter in hard X-rays

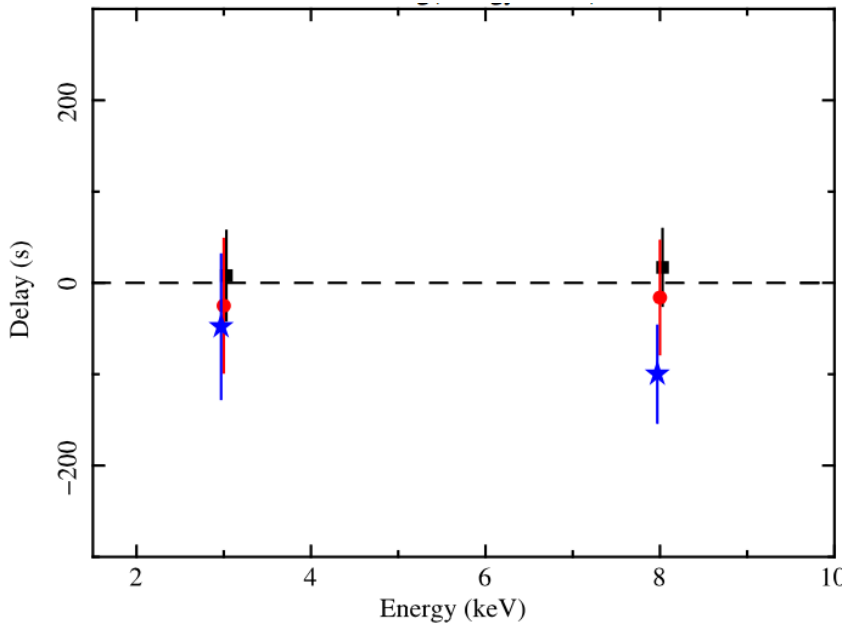
➜ Evolution of γ_e

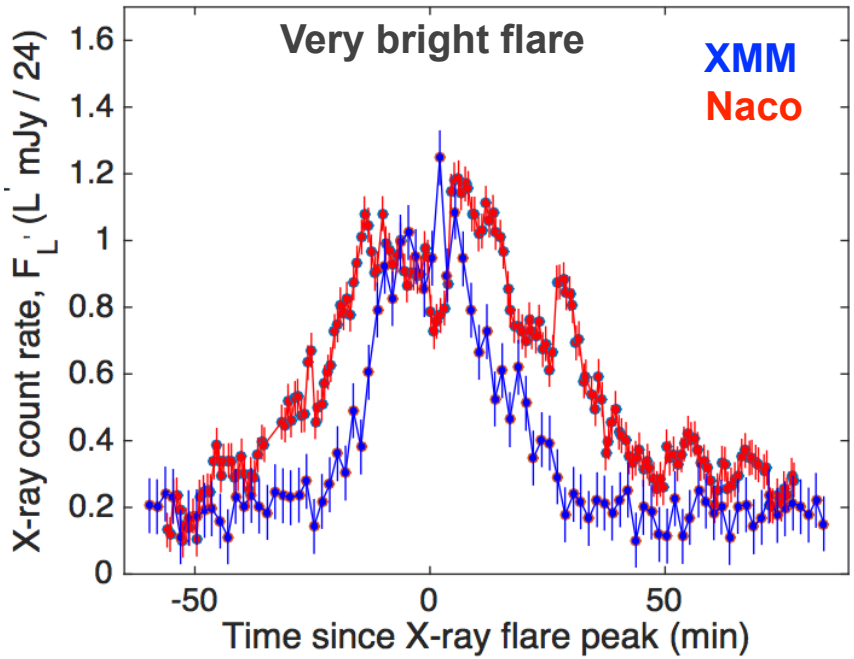
Significance ~ 4.5 σ

Same evolution from NIR to X-rays

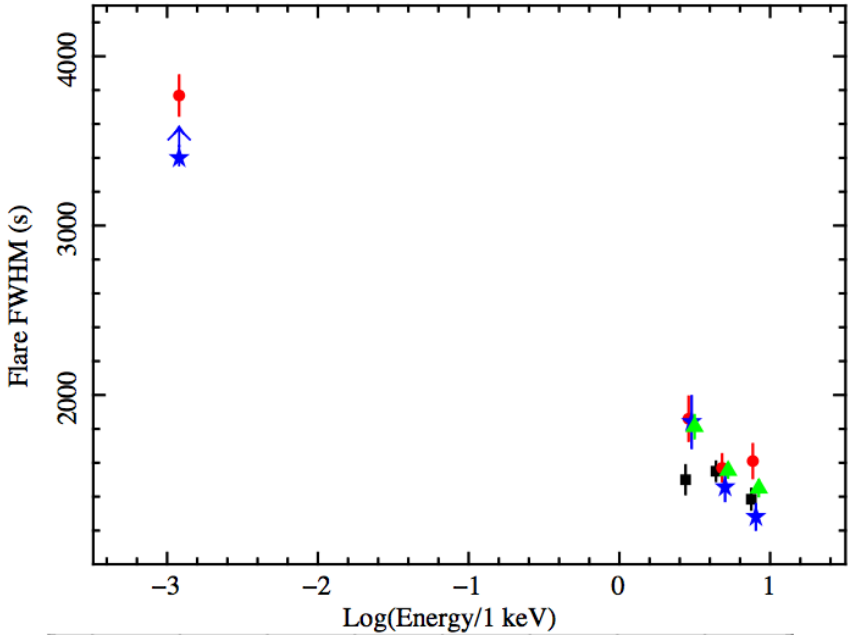


Ponti +17b





Dodds-Eden +09



Ponti +17b

➜ **Continuous acceleration**

NIR - X-rays phenomenology dictated by γ_e

Conclusions:

➜ First simultaneous NIR and X-ray spectra of a bright flare of Sgr A*

$\Gamma_{IR} = 1.7\pm0.1$; $\Gamma_X = 2.27\pm0.12$ ➜ $\Delta\Gamma = 0.57\pm0.09$

➜ Synchrotron with cooling break!

Evolution of cooling break ➜ Magnetic energy in particle acceleration

➜ Magnetic reconnection!

Flare SED evolution and X-ray light curves ➜ Slow evolution of γ_e

➜ Slow (stochastic?) acceleration

➜ Most of the N_H of Sgr A* has a ISM origin

➜ *Powerful flares from Sgr A* confirm the synchrotron origin of the X-ray emission*