Multi-wavelength Observations of Sgr A*

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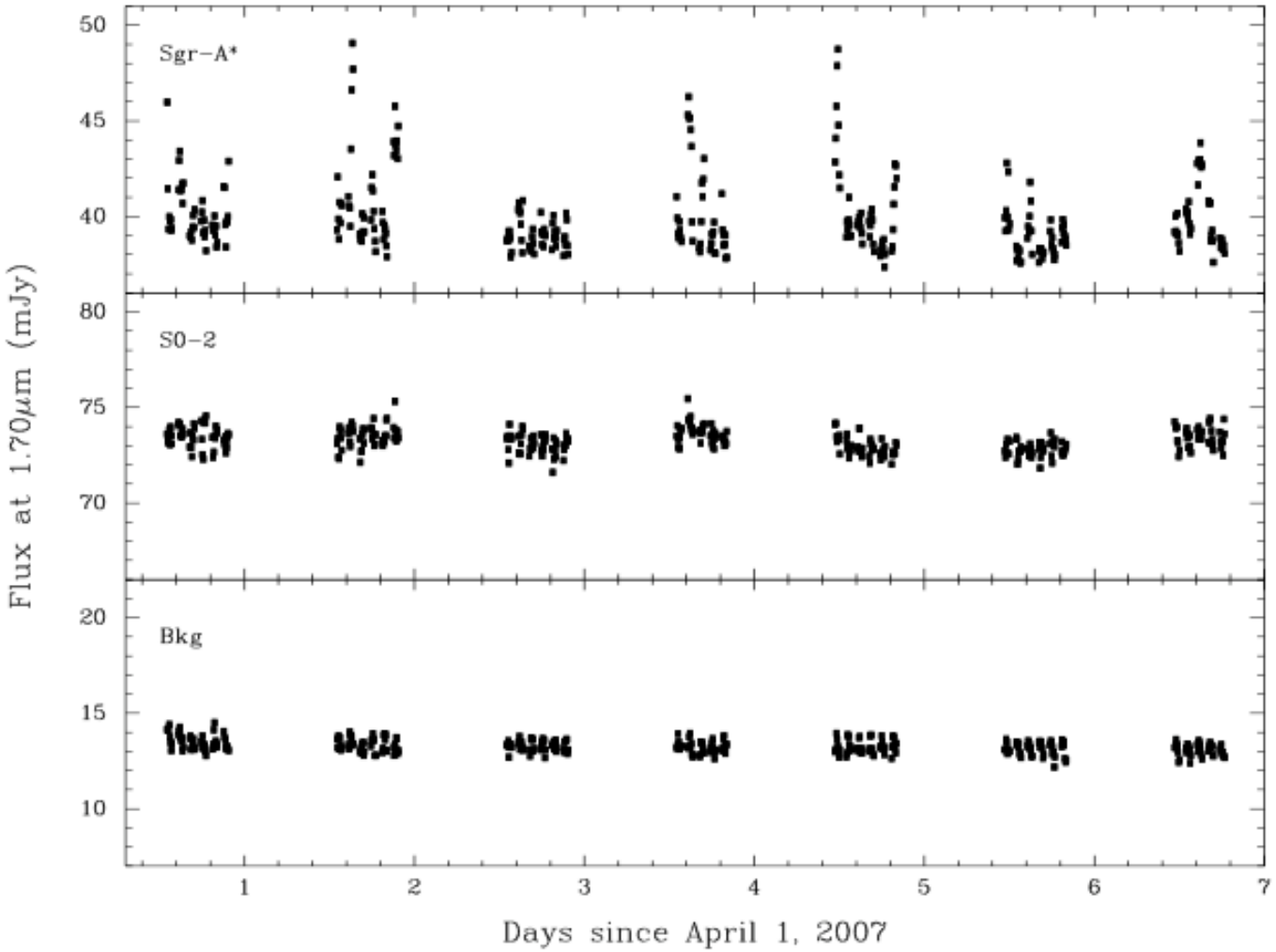
- A Study of Flare Emission
  - Motivation:
    - The emission mechanism in different bands
    - Sgr A* is underluminous
  - Highlights of the 2007 campaign
    - Inverse Compton scattering
    - X-rays/near-IR/radio emission : adiabatic expansion of hot plasma

X-Ray+γ-Ray (XMM+INTEG)	Near-IR (HST+VLT)	Sub-millimeter (CSO, SMT)	Millimeter (SMA, CARMA,IRAM)	Radio (VLA+GMRT+VLB)
• D. Porquet • N. Grosso • A. Goldwurm • G. Trap	• H. Bushouse • C. Heinke • K. Dodds-Eden • S. Gillessen	• D. Dowel • C. Martin Theory • M. Wardle	• D. Marrone • G. Bower • H. Wiesemeyer • H. Maness • Miyazaki • M. Tsuboi	• D. Roberts • M. Reid • A. Brunthaler • S. Pal • R. Rao

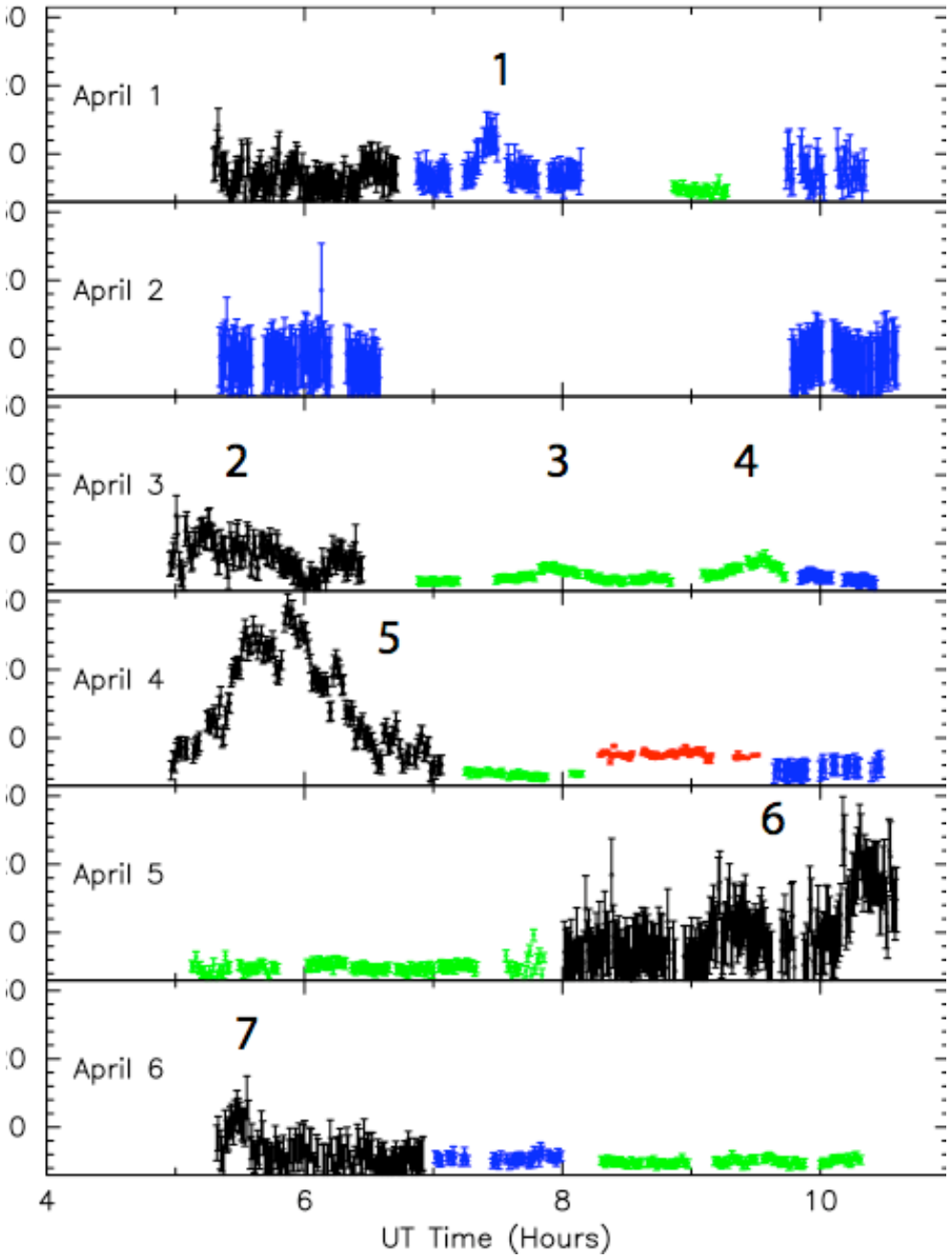
HST Light Curves (2007 April 1-7)

- The light curves of Sgr A* at 1.70μm for the seven windows of HST observations on 2007 April 1−7.
- HST 1.70μm light curves of Sgr A* (Top)
- S0-2 star (Middle)
- Background emission (Bottom)
- The constancy of the S0-2 and background emission: the variability emission is intrinsic to SgrA*.
- Typical flare lasts 20-40min



Near-Infrared Flares

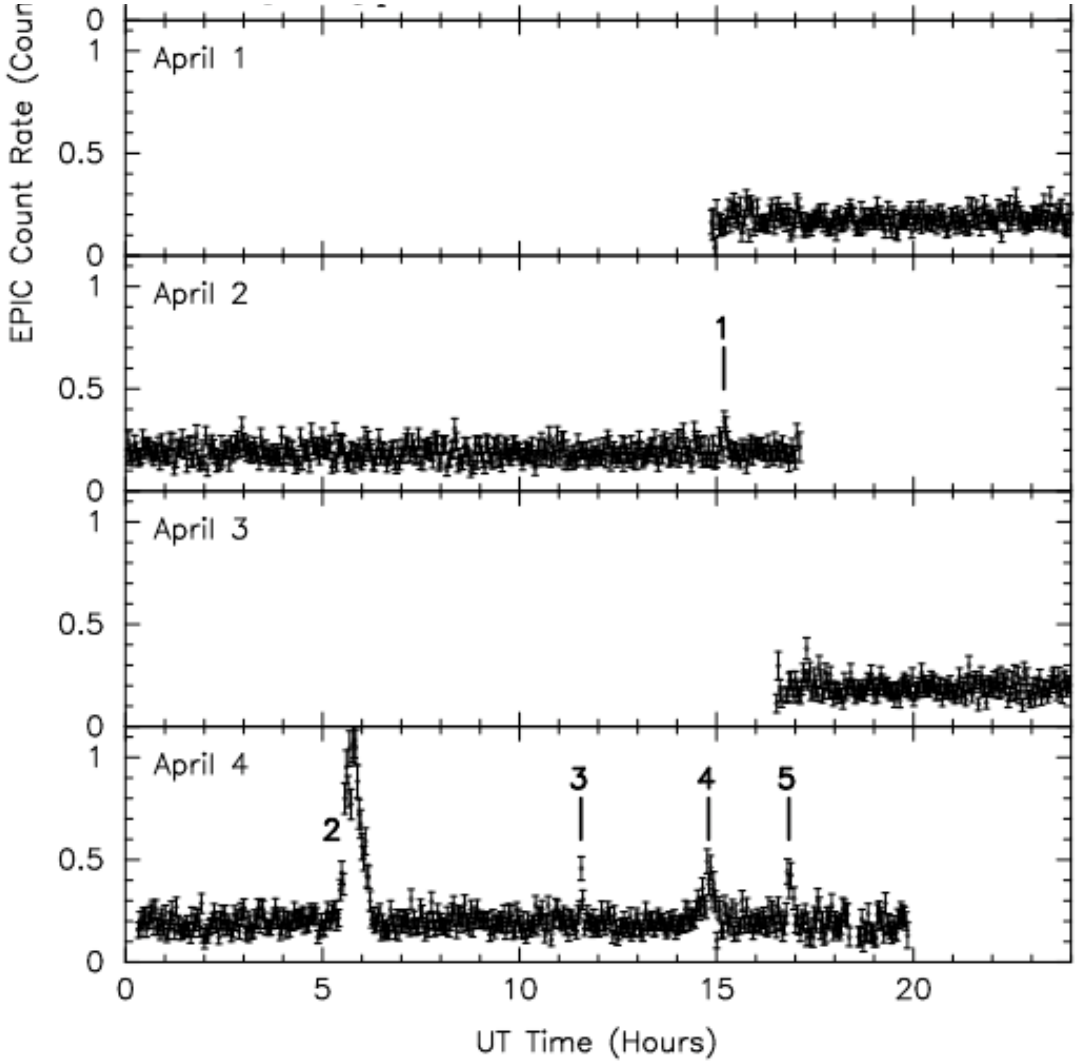
- Light curves of Sgr A* for April 1-6 at H(1.66μm), in red, Ks (2.12μm), in green and blue and L (3.8μm) band, in black, bands.
- There are a total of seven periods of flaring events.
- The brightest flare occurred on 2007, April 4.



Dodds-Eden et al. 2009

X-ray Flares

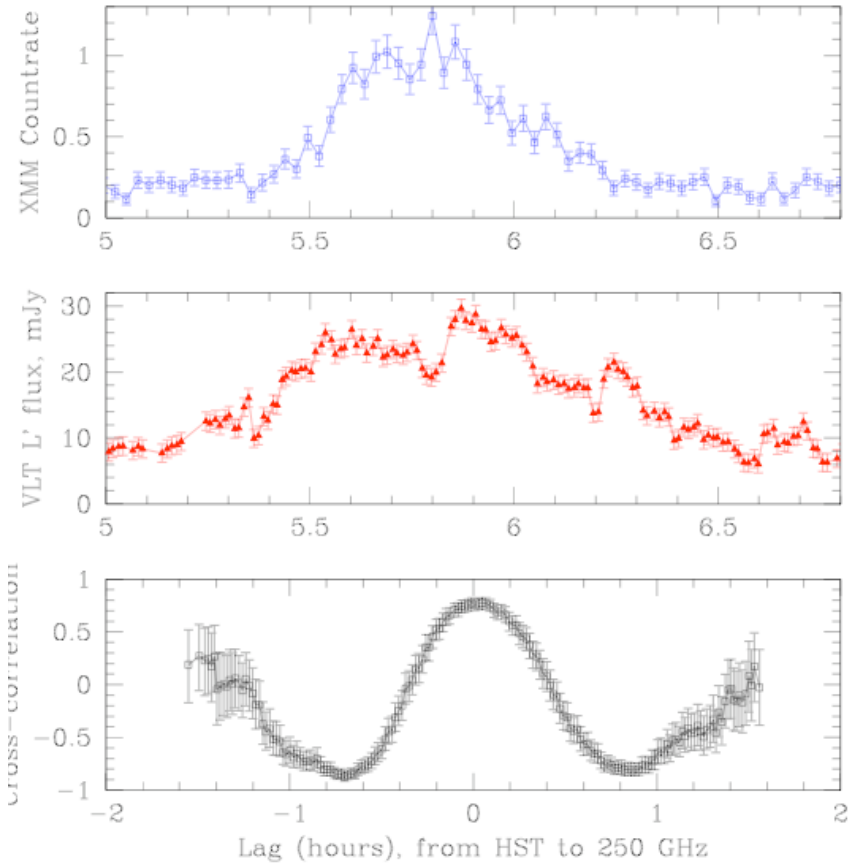
- Light curves of all the X-ray data taken with the XMM Newton during the 2007 April observing campaign.
- The data are averaged over a 144sec sampling. Five X-ray flares are detected.
- The brightest flare occurred on 2007, April 4 with X-ray luminosity 2.5×10^{35} erg/s



Porquet et al. 2008

Near-IR vs. X-Ray Cross Correlation

- The top and middle plots show the X-ray and Near-IR light curves taken on 2007, April 4.
- The cross correlation plot in the bottom panel indicates a peak at -0.5(+7.0, -6.5} minute time delay.
- Near-IR: Synchrotron with typical electron energy of E_e=1.1 GeV, a magnetic field of B_{eq}=10G and a lifetime of τ_{nir}= 35min.
- The X-ray Synchrotron lifetime is short ($\tau_{x\text{-}ray}$= 30sec for 100 GeV electrons)



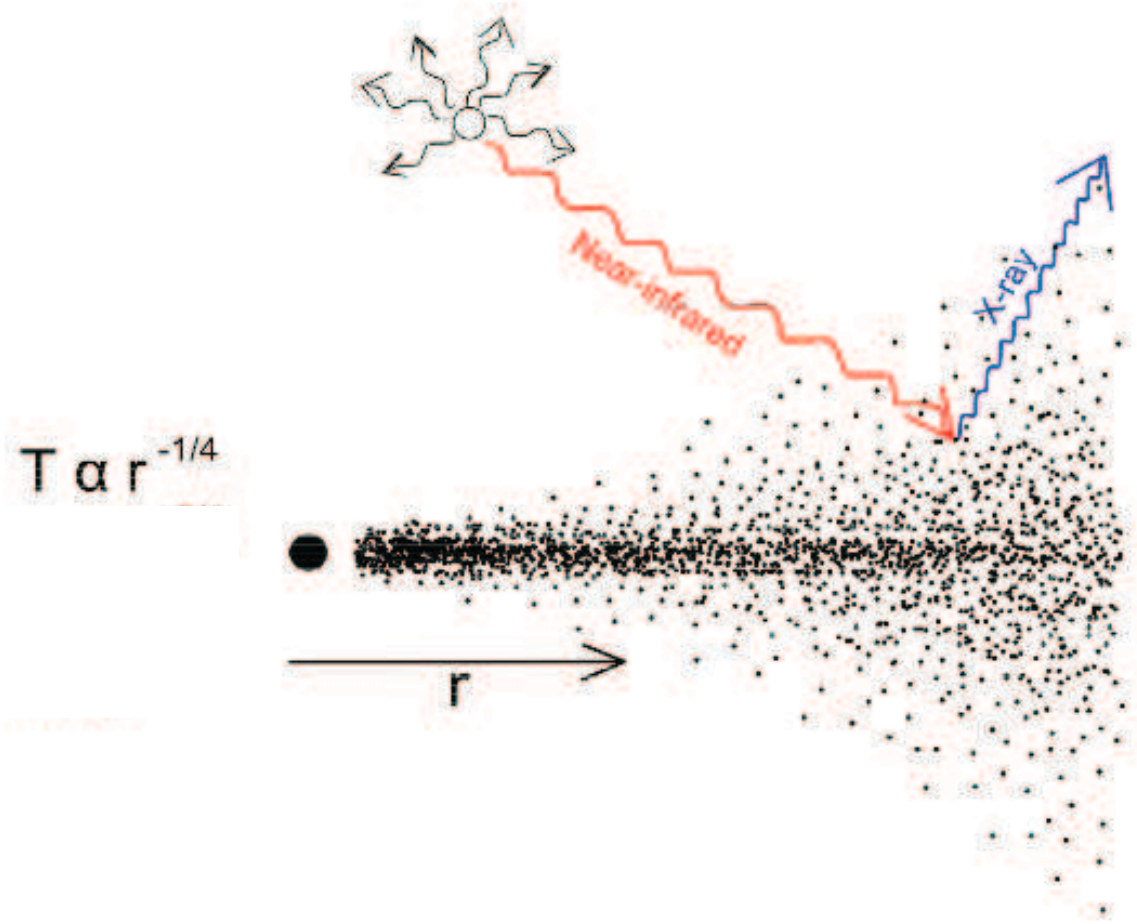
X-ray (XMM)

Near-IR (VLT)

Cross correlation

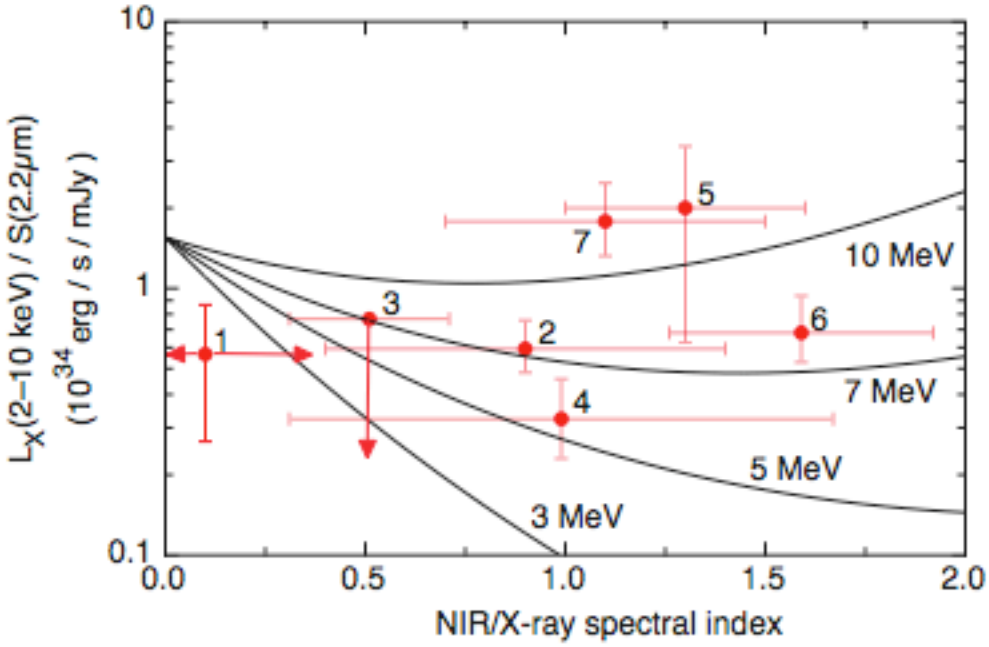
X-rays via Inverse Compton Scattering

- A schematic diagram of the Inverse Compton Scattering of NIR flare emission by the electrons in the disk of Sgr A*
- Flux at 2μm=10 mJy
- Electron energy =30 MeV
- Post main flare X-ray emission from the outer envelope of the disk



Inverse Compton Scattering

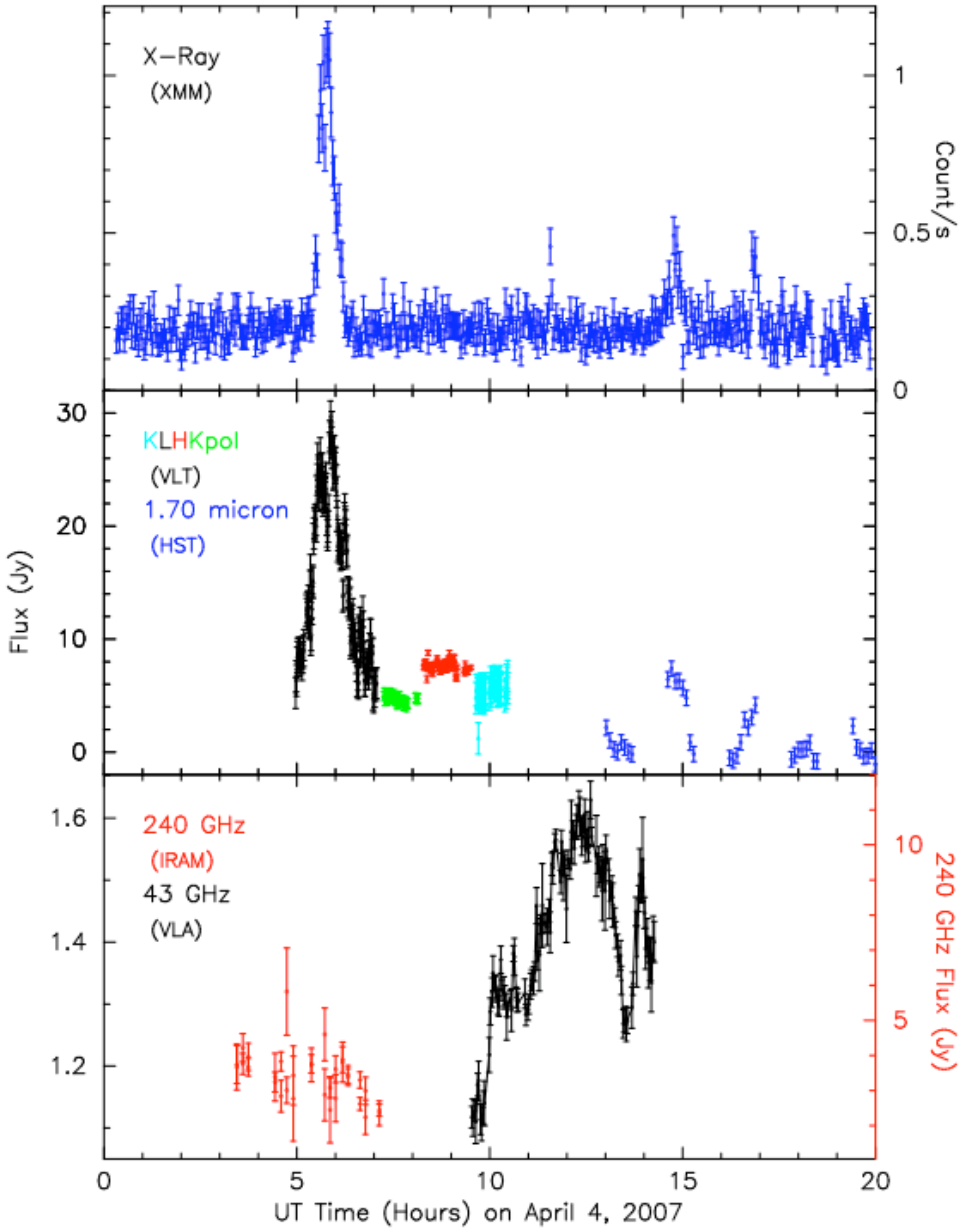
- The ratio of inverse Compton X-ray luminosity (2--10 keV) to near-IR synchrotron flux (at 2.2μm) as a function of near-IR or X-ray spectral index.
- Points labeled 1 to 7 indicate the measured ratios and near-IR spectral indices of the seven X-ray flares with known near-IR counterparts.
- All the X-ray/near-IR measurements are consistent with the inverse Compton scattering model.



Eckart et al. 2006
Belanger et al. 2005
Hornstein et al. 2007
Marrone et al. 2008
Porquet et al. 2008
Dodd-Eden et al. 2009

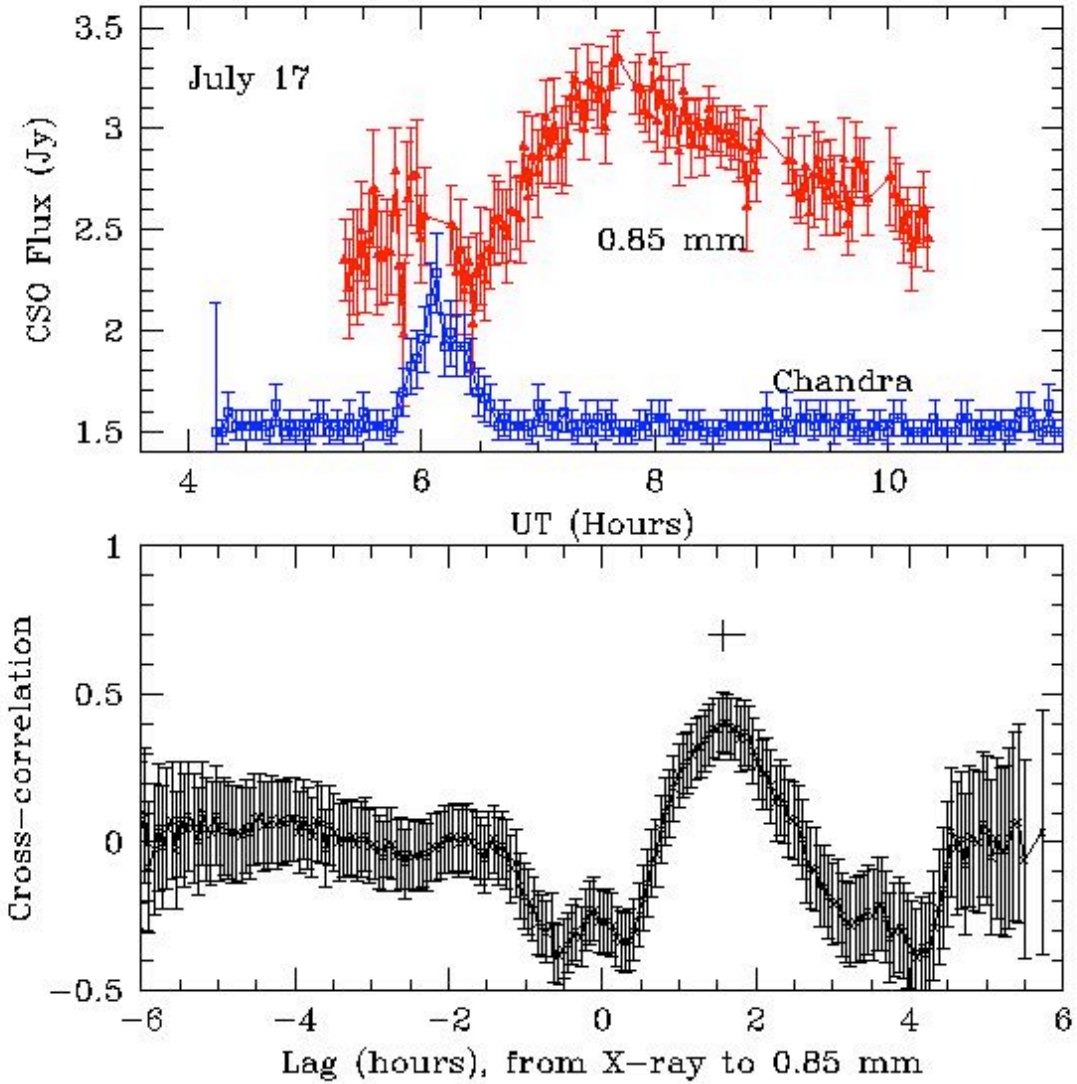
The 2007 April 4 Flare

- Simultaneous light curves
  - X-ray (blue, top panel)
  - Near-IR (black, middle panel)
  - Millimeter and radio (bottom panel)



Cross-Correlation of Light Curves: Maximum Likelihood Delays

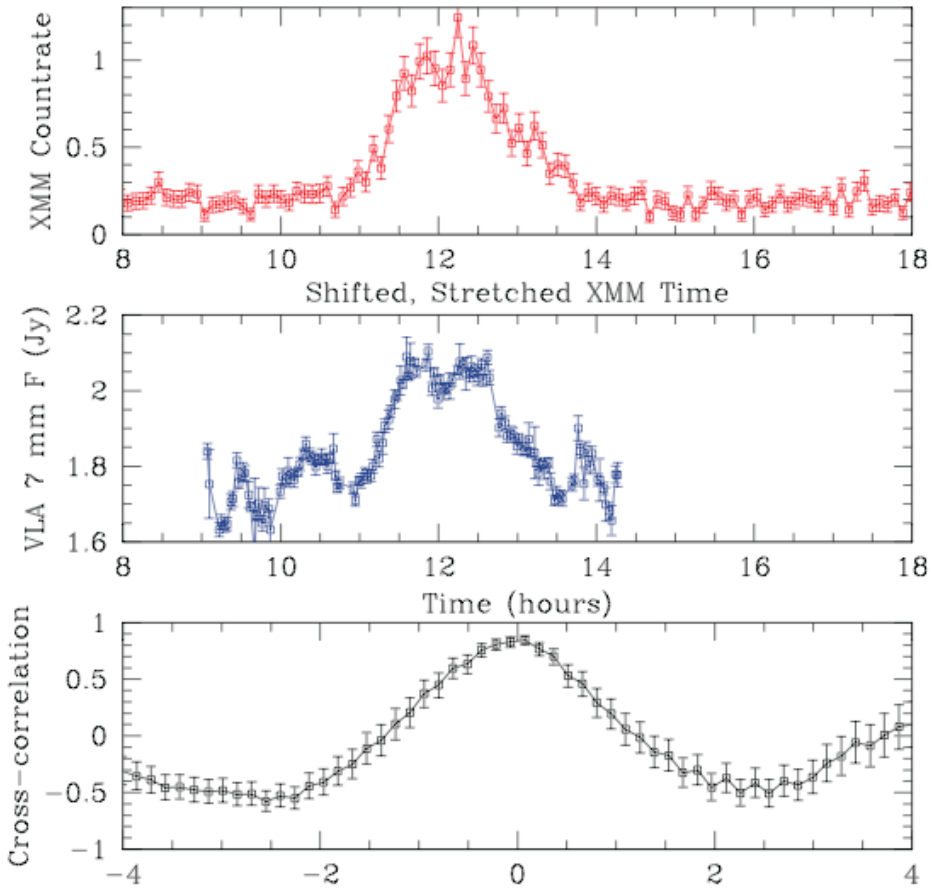
X-rays - 850μm
τ=110(-17, +17) min



FYZ et al. 2008

Cross Correlation of Radio and X-Ray Flares

- The X-ray light curve is shifted in the time axis by 5.25 hours and stretched by a factor of 3.5
- The maximum likelihood delay of 4.6 (-7.6, +9.4) minutes is consistent with zero time delay



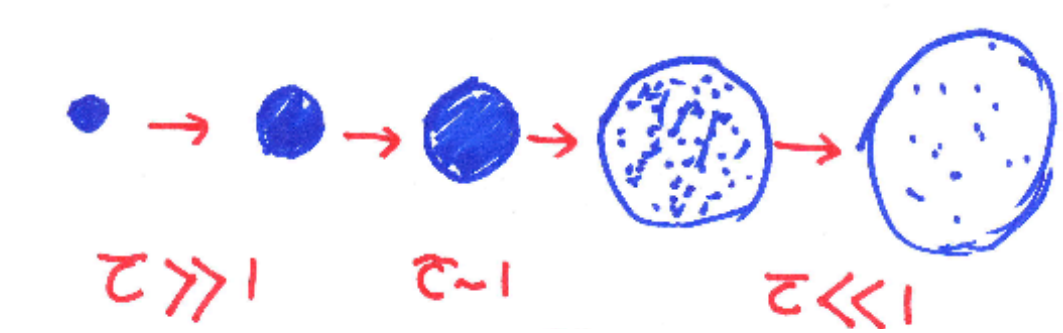
X-ray (XMM)

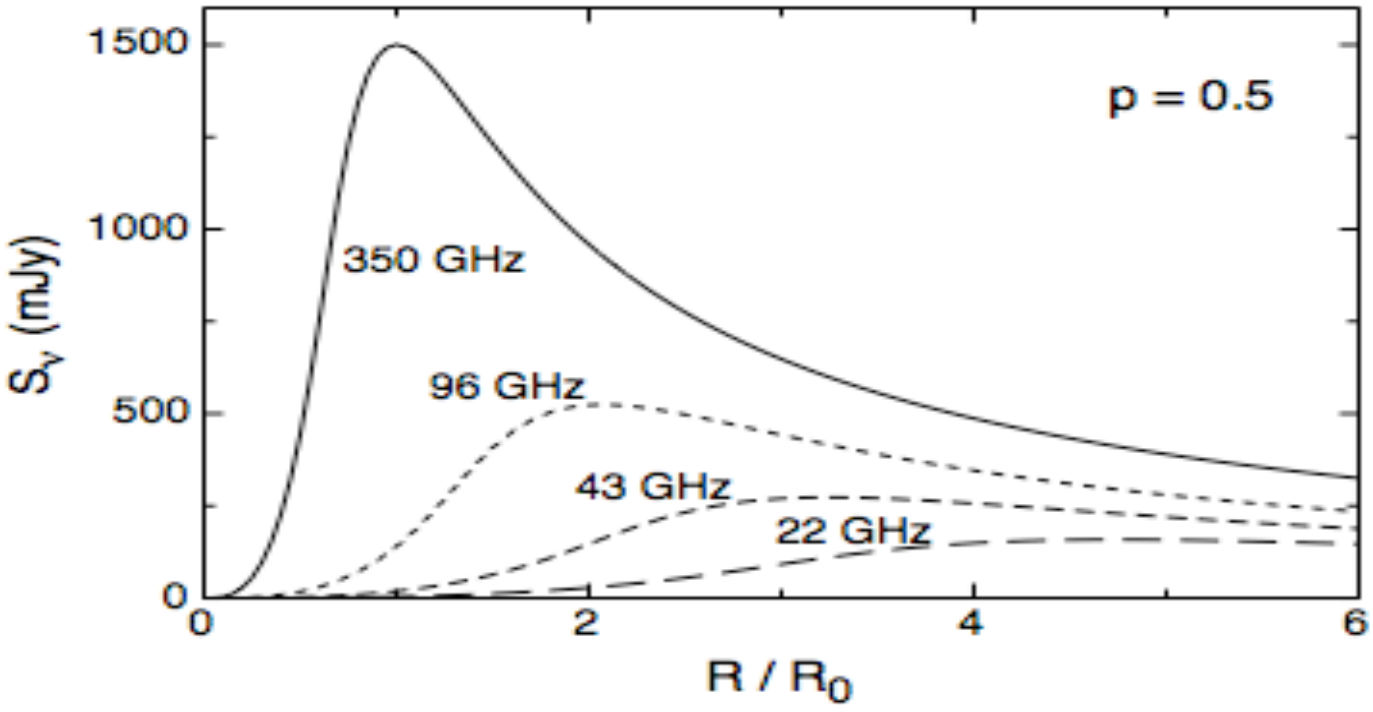
Radio (7mm)

Cross correlation

Expanding Blob to Explain Synchrotron Light Curves

- Time delay : consistent with the expanding hot plasma model (Van der Laan 1964)
- Synchrotron optical depth $\tau \sim \nu^{-2.5}$
- Optically thin gas decays (Near-IR wavelength)
- Optically thick gas grows and then decays (radio wavelength)





Conclusions

- Flaring Component of the Sgr A* spectrum
  - Near-IR emission is due to synchrotron
  - The origin of X-ray production in the context of inverse Compton scattering: the seed photons associated with flare in near-IR wavelengths are upscattered by the sea of electrons the accretion disk
  - A prediction of this model is a time delay between the peaks of X-ray and Near-IR flare emission.
  - Expanding self-absorbed synchrotron blob explains the shift in the peak flux of flare emission with respect to X-ray and near-IR flare emission