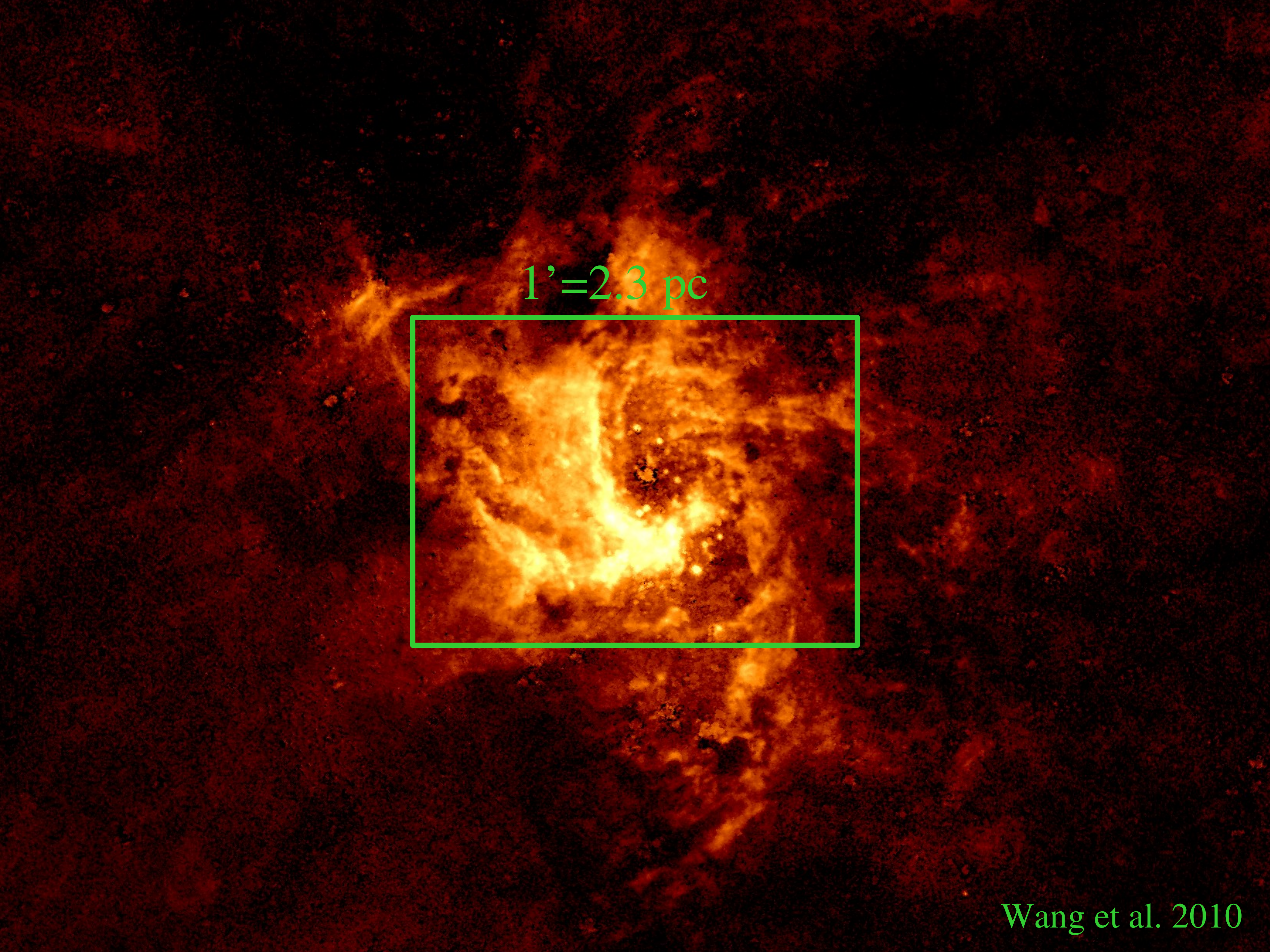
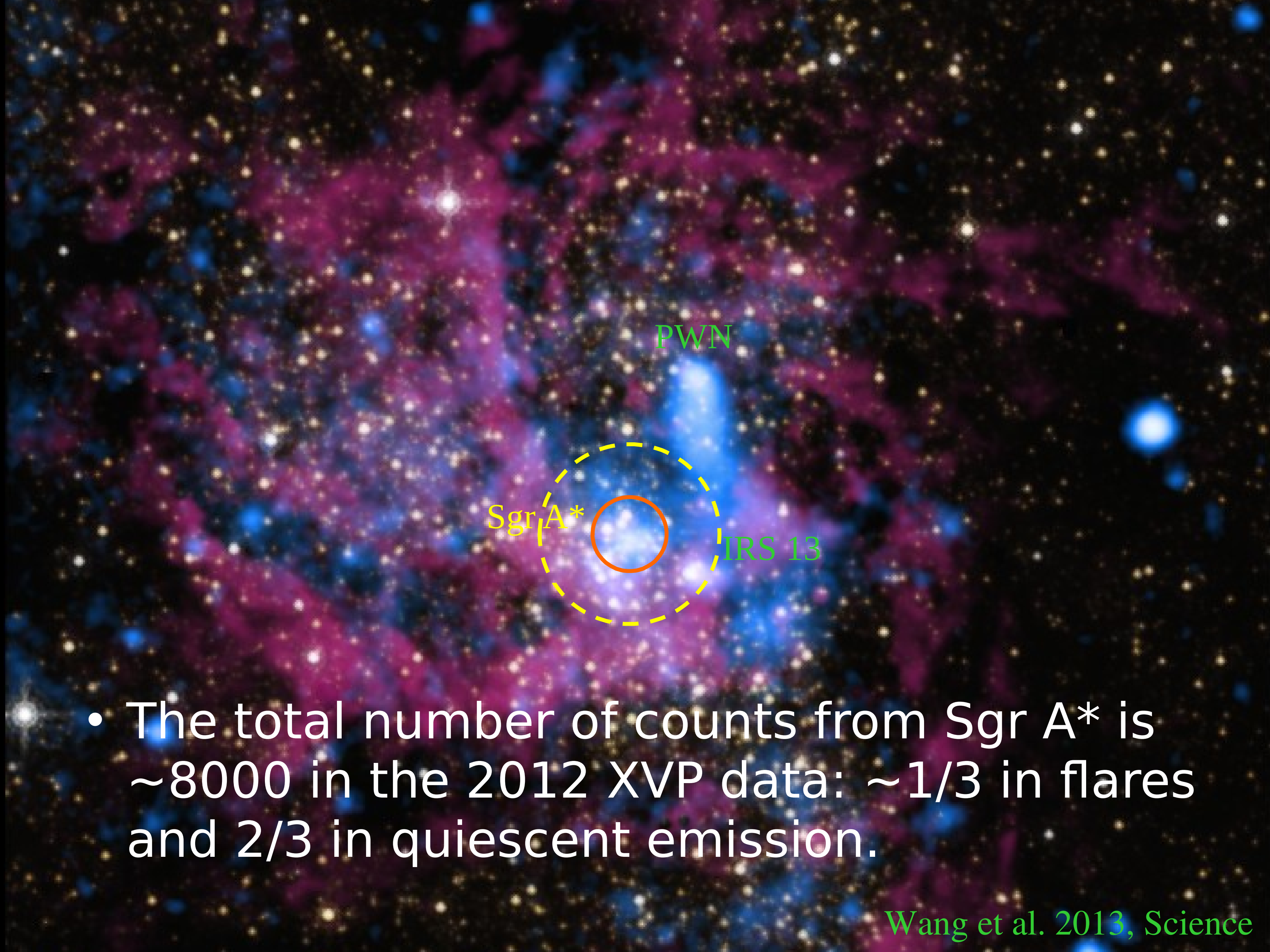

1’=2.3 pc
Wang et al. 2010

Existing Chandra observations

- 1.4 Ms ACIS-I exposure before 2012
- 3 Ms XVP ACIS-S/HETG exposure in 2012
- 0.8 Ms expsure (mostly ACIS-S) after 2012

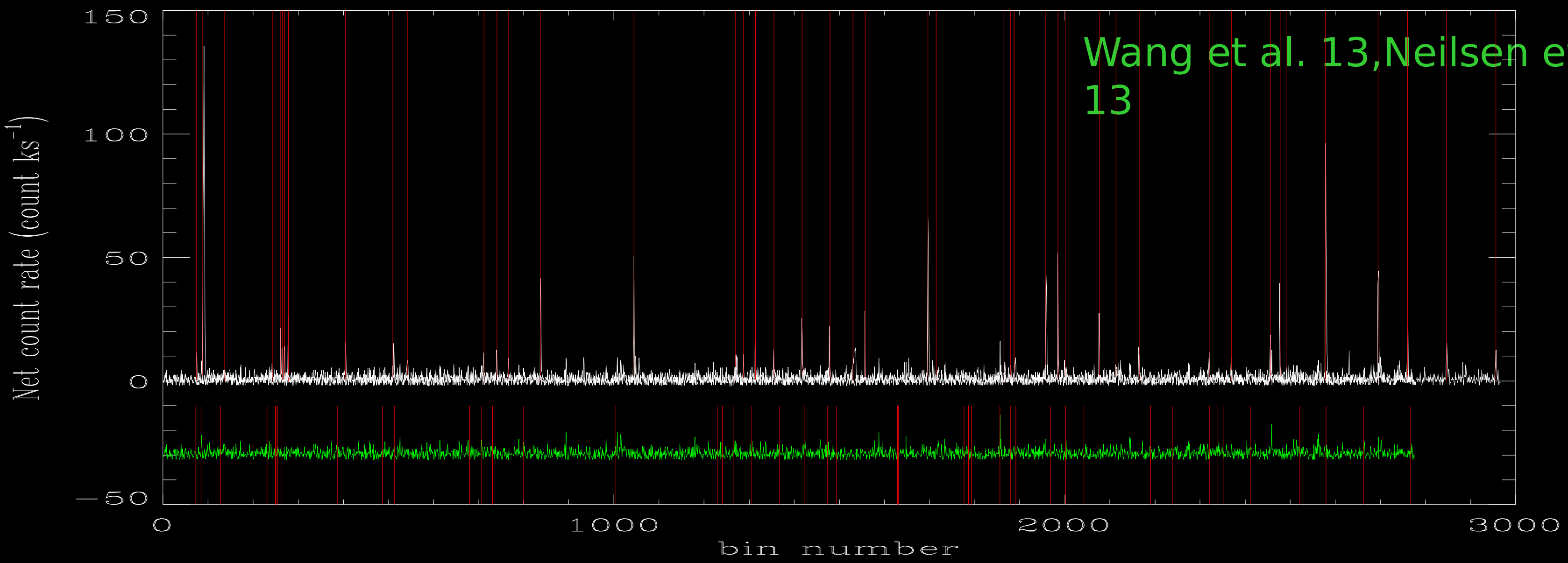
Wang et al. 2013, Science



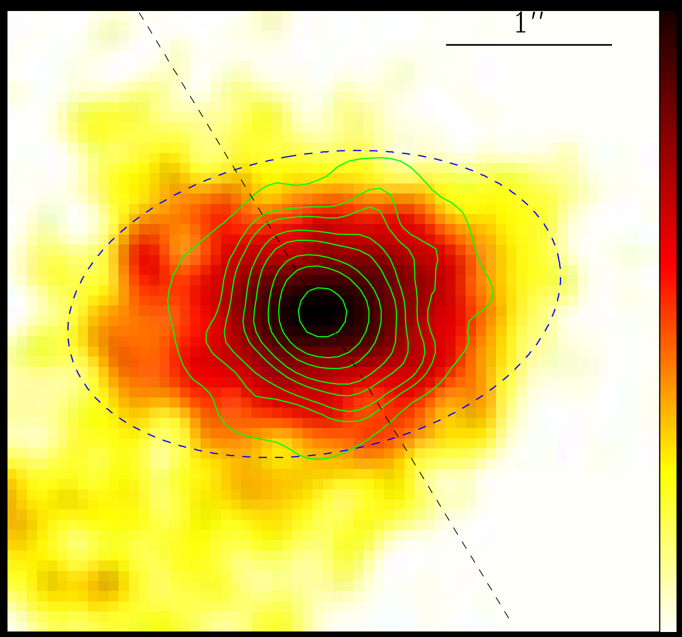
- The total number of counts from Sgr A* is ~8000 in the 2012 XVP data: ~1/3 in flares and 2/3 in quiescent emission.

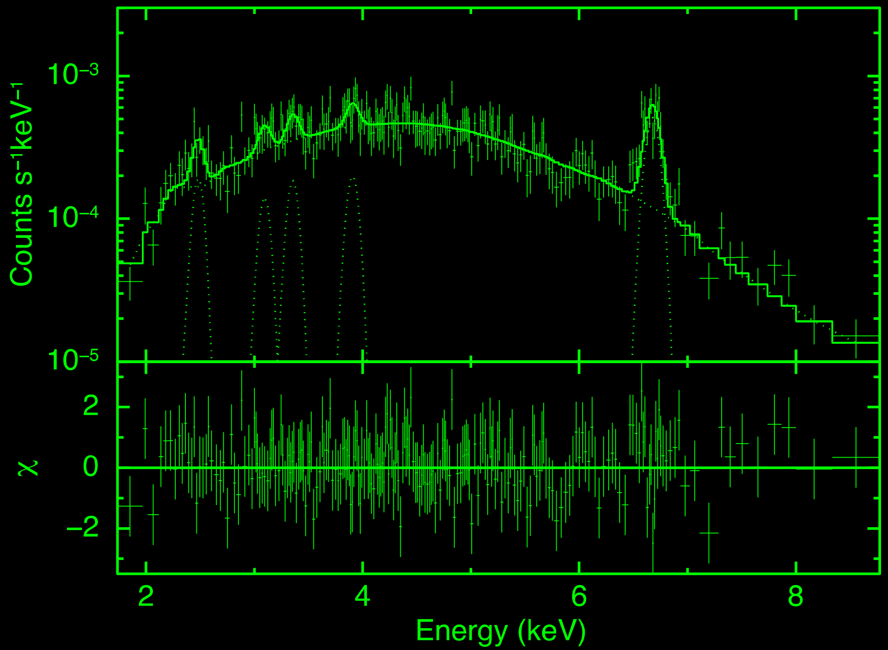
Wang et al. 2013, Science

Projections of Sgr A* XVP data



Wang et al. 13,Neilsen et al. 13





Sgr A*: new insights from X-ray observations

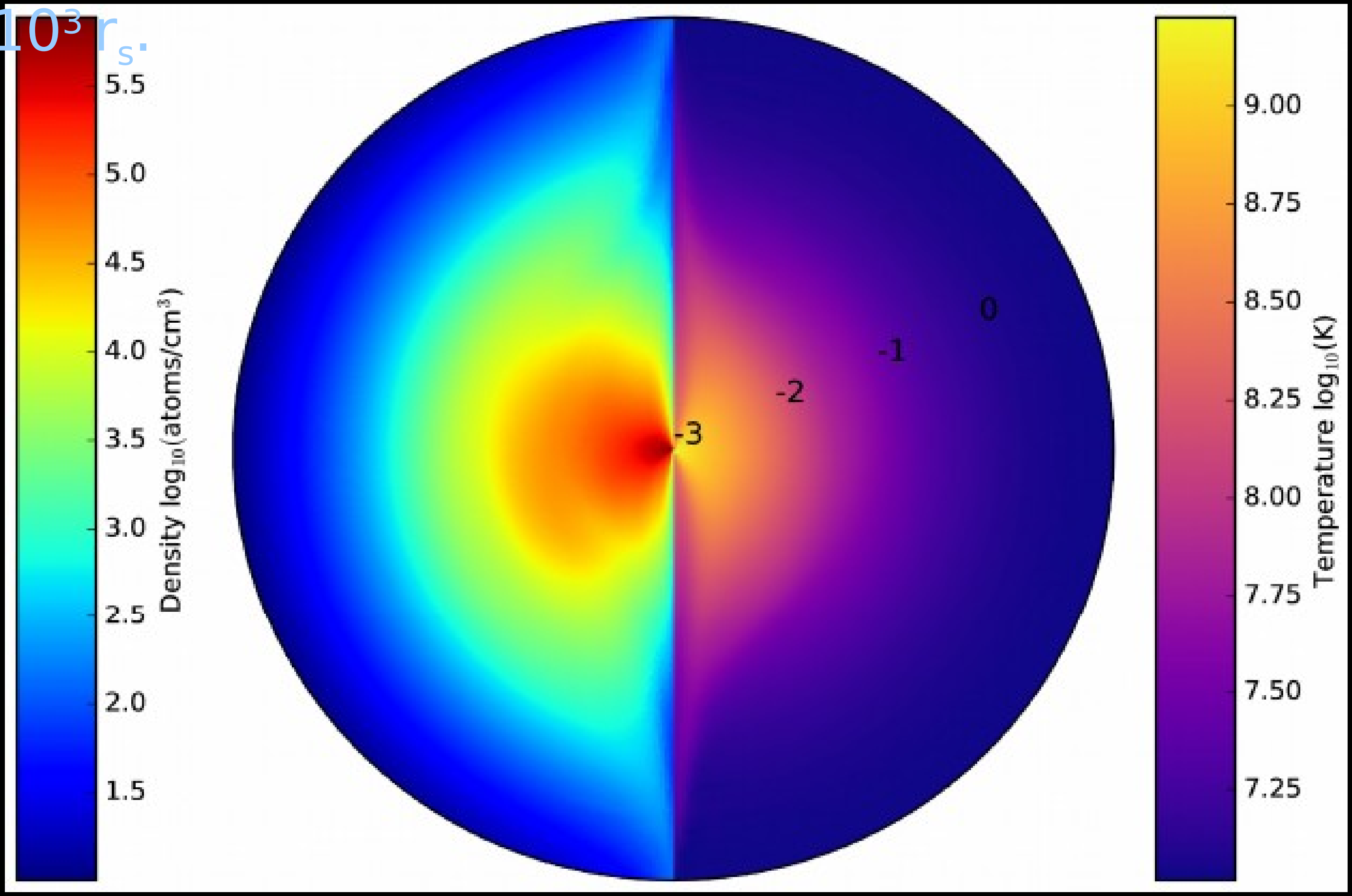
Q. Daniel Wang

(University of Massachusetts)

- A systematic Chandra study of Sgr A⋆ flares (Qiang Yuan & QDW 16)
- Self-Consistent Modeling of the Sgr A* Accretion Flow: Linking Theory and Observation (Shawn Roberts, Yan-Fei Jiang, QDW, & Jerry Ostriker 16, submitted)
- 3-D hydro simulations of colliding Wolf-Rayet winds and comparison with the Chandra observation near the Bondi radius (Christopher Russell, QDW, & Jorge Cuadra, 16)

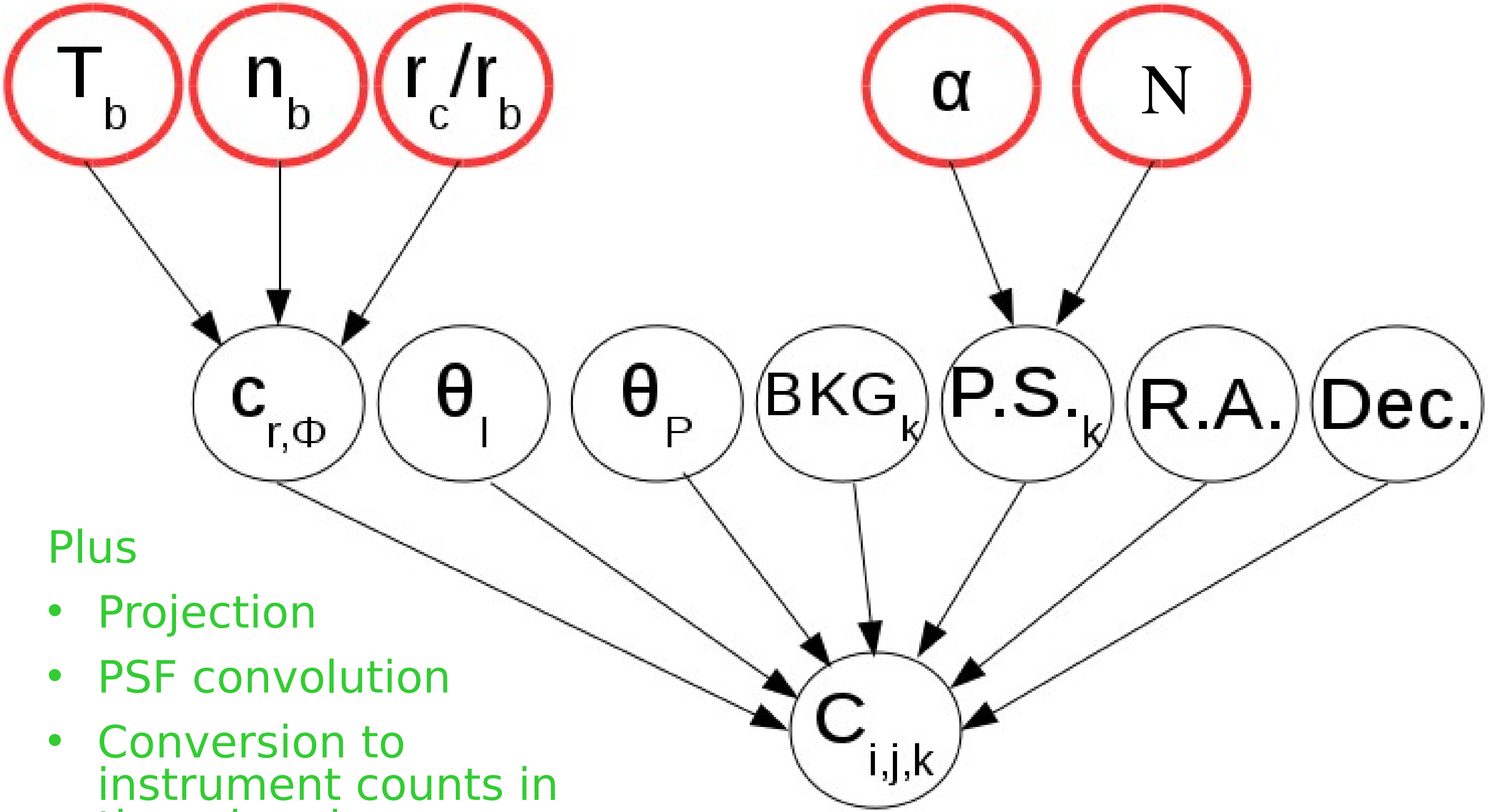
Time Averaged 2-D Athena Simulations

We performed a set of simulations with different angular momenta (or centrifugal radii r_c), which are scalable to cover all the parameter space of the accretion flow down to 10^3 r_s.



Roberts, Jiang, Wang, & Ostriker (2016)

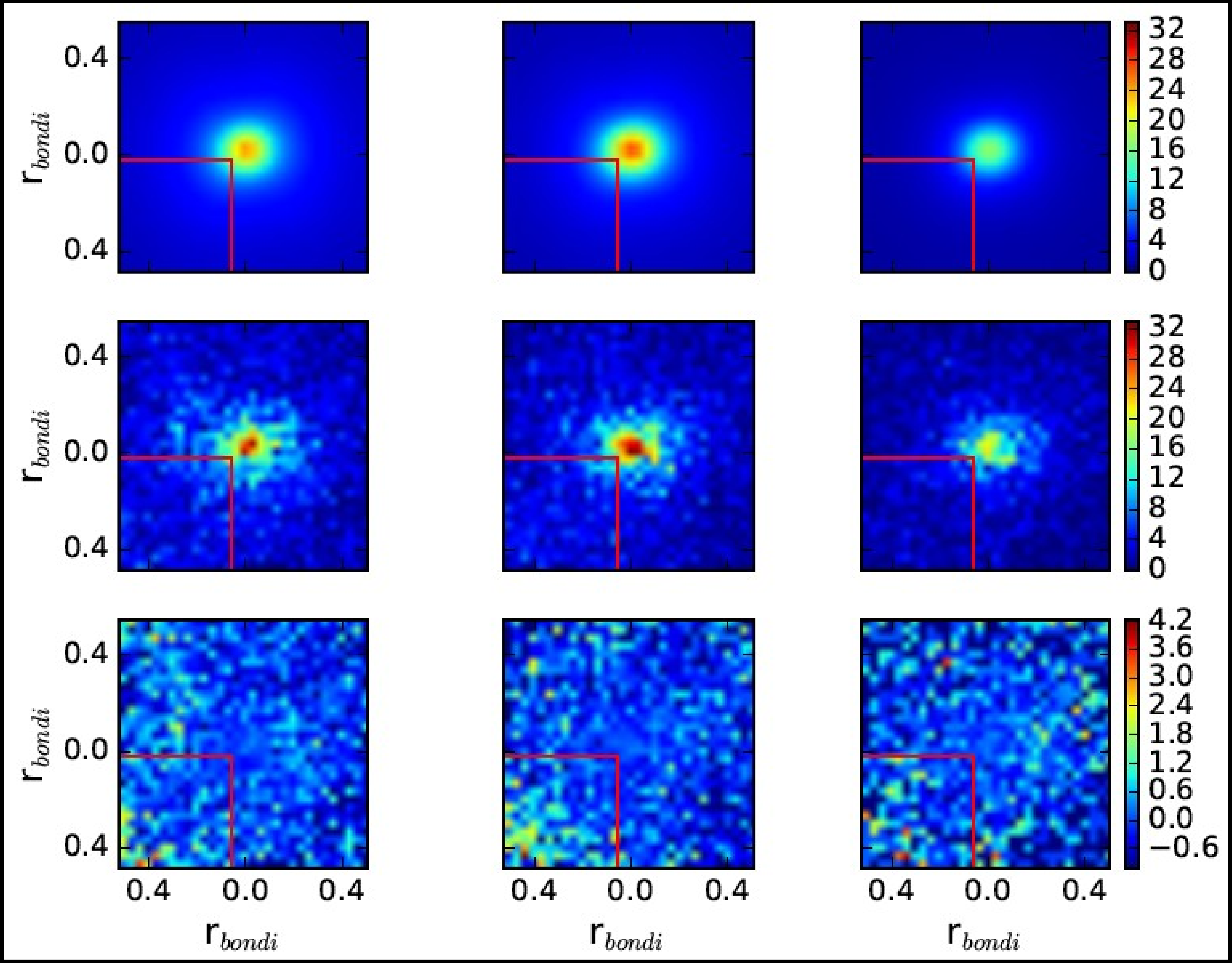
MCMC hierarchical Bayesian analysis to estimate the top level parameters



Plus

- Projection
- PSF convolution
- Conversion to instrument counts in three bands

Best-fit model, data, and residual images

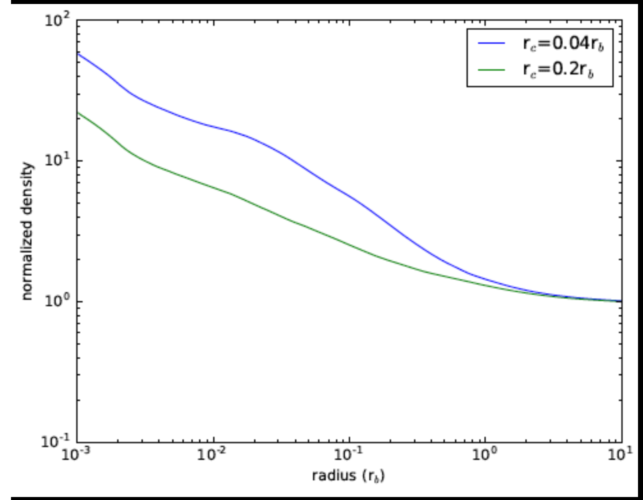


1-4 keV　　4-5.5 keV　　5.5-9 keV

Best fit and 1σ confidence intervals of free parameters

θ_I (deg.)	126.4 (122.6,130.4)
θ_P (deg.)	99.1 (96.3,101.8)
r_c/r_b	0.056 (0.048,0.066)
T_b (K)	1.28e7 (1.19e7,1.42e7)
n_b (cm^{-3})	101.6 (91.4,111.1)
BKG1 (counts/pix)	0.21 (0.01,0.45)
BKG2 (counts/pix)	0.41 (0.17,0.65)
BKG3 (counts/pix)	0.48 (0.30,0.69)
α	4.8 (3.5,7.5)
$\log_{10}(K)$ (ergs/s at 5 keV)	31.96 (31.32,32.18)

1st direct estimate of the centrifugal radius

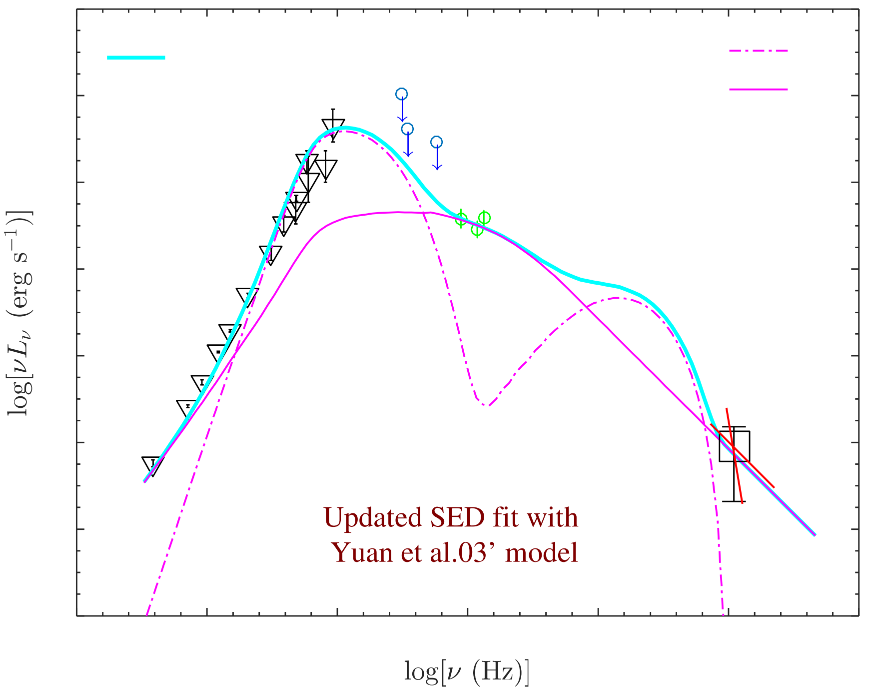


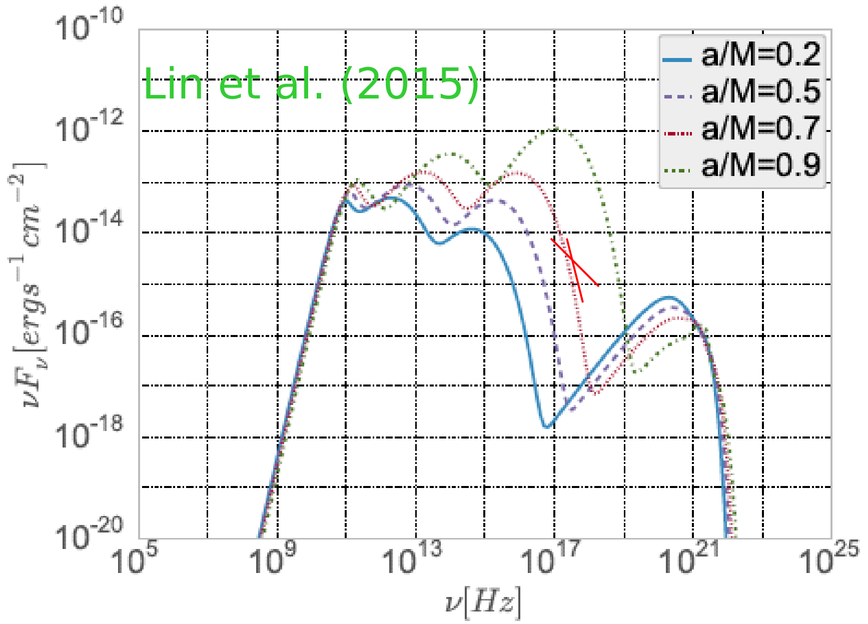
Angular momentum flattens the average radial density profile of the flow

The orientation of the accretion flow is consistent with the so-called clockwise stellar disk.

Consistent with a shocked stellar wind origin.

Point-like source





- ~4% of the quiescent emission arises from the point-like emission (within the inner boundary of the simulation r= 10^3 r_s).
- Emission Mechansim:
  - Bremsstrahlung (accretion flow)
  - Synchrotron of nonthermal electrons, plus minor contribution from IC of synchrotron emission from thermal electrons.

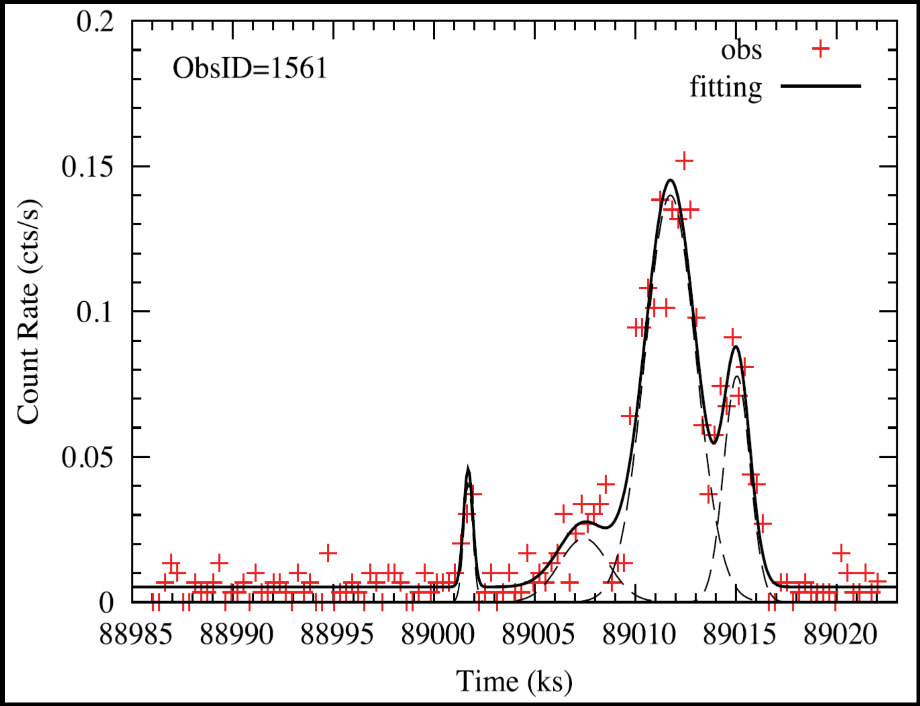
Detailed SED analysis could place strong constraints on the electron energy spectrum and potentially the spin parameter.

Summary

- The shocked stellar wind scenario for the accretion is confirmed by the fitted model parameters.
- We have made the first direct estimates of the centrifugal radius (~0.06 r_b) of the accretion flow and showed its angular momentum plays a critical role in determining the accretion rate.
- The point-like emission contributes only about ~4% of the quiescent emission, most likely due to the synchrotron emission from electrons with a steep power law energy distribution very close to the SMBH.
- Detailed 3-D MHD simulations can now be carried out for further comparison with such observations as Faraday's rotation measurements.
- The combination of the Chandra and EHT observations can be very powerful in probing Sgr A* and its related physics.

X-ray flare detection: method and results

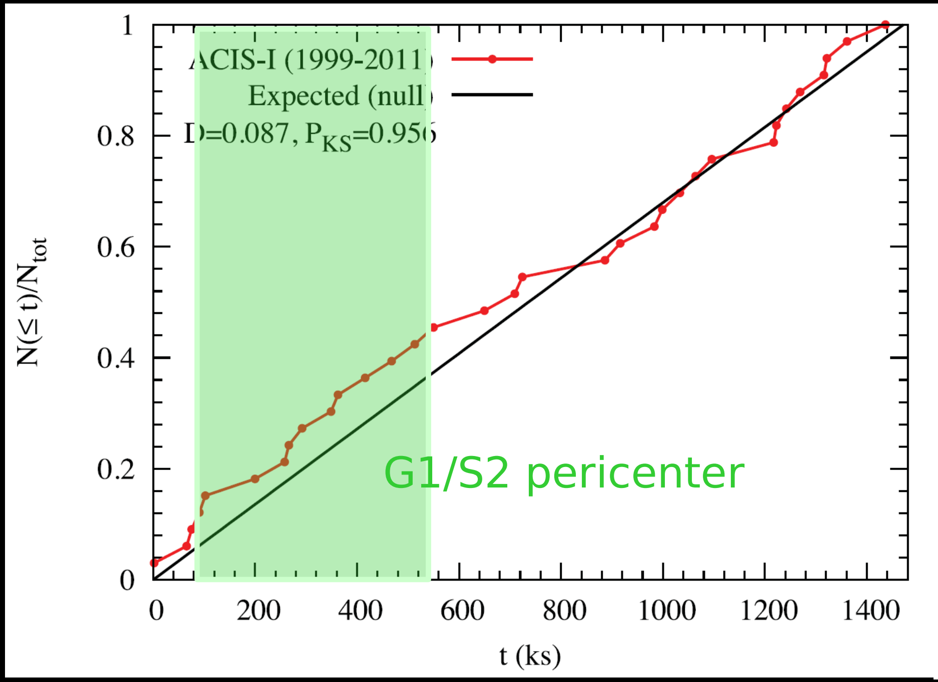
- Maximum likelihood fitting to the X-ray data with unbinned Cash statistics, assuming Gaussian flares.
- Pileup applied to the expected lightcurve.
- MCMC algorithm to better characterize the measurement of parameter uncertainties.
- 33 flares in 46 ACIS-I observations from 1999 to 2001, and 49 flares in 39 ACIS-S observations with high energy transmission gratings in 2012

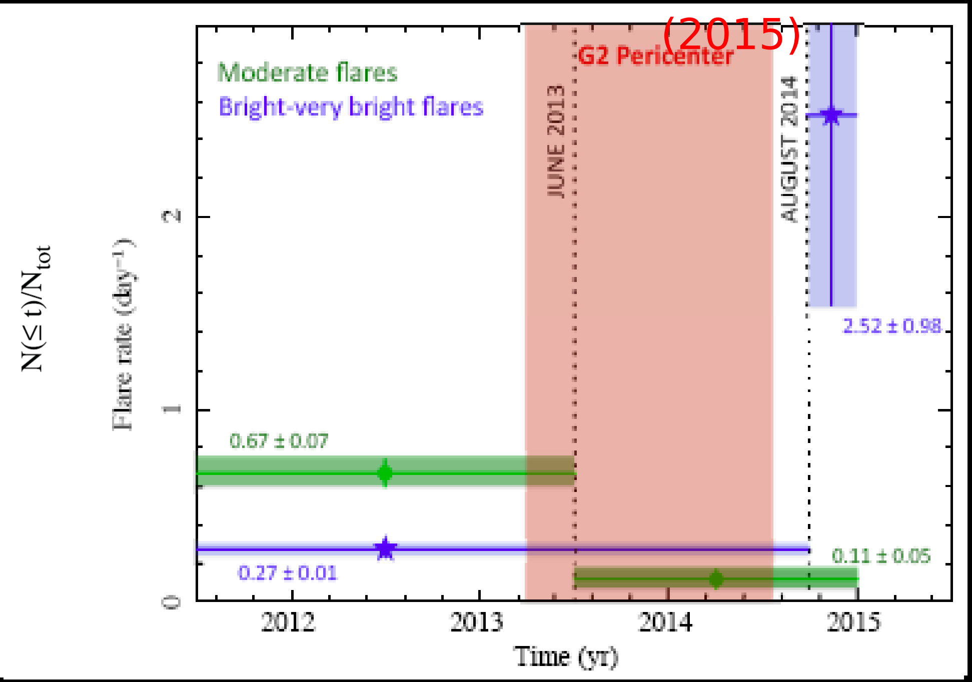


Yuan & Wang (2016)

No significant change in the flare rate

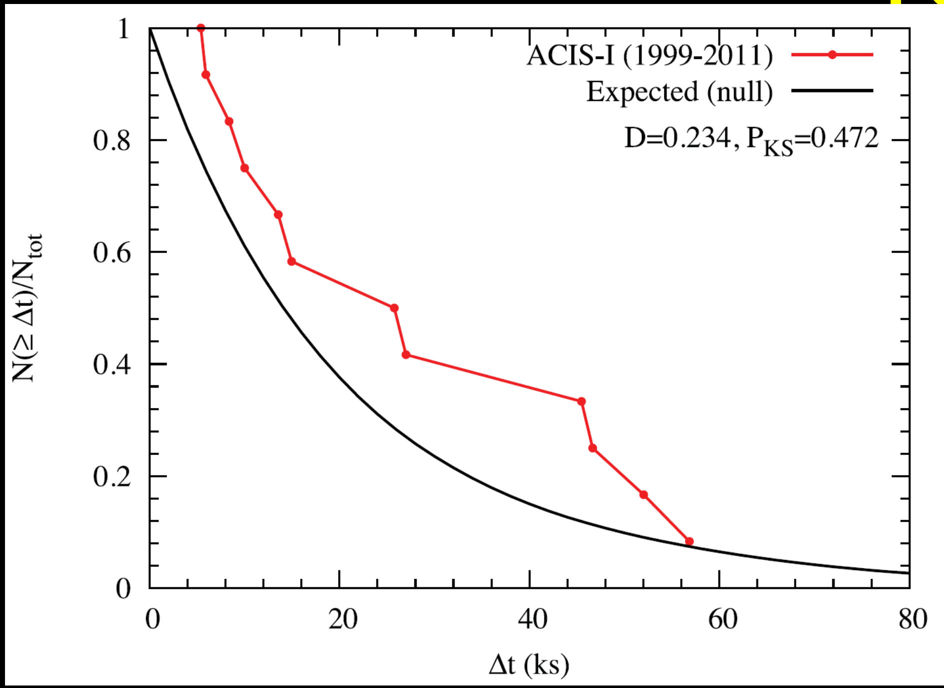
Ponti et al. (2015)

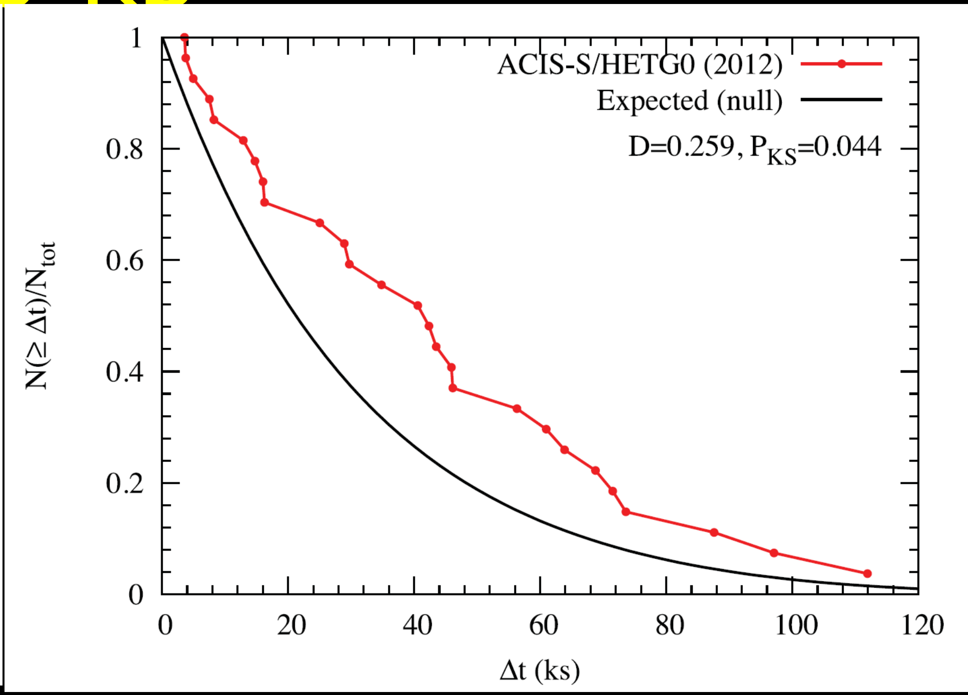




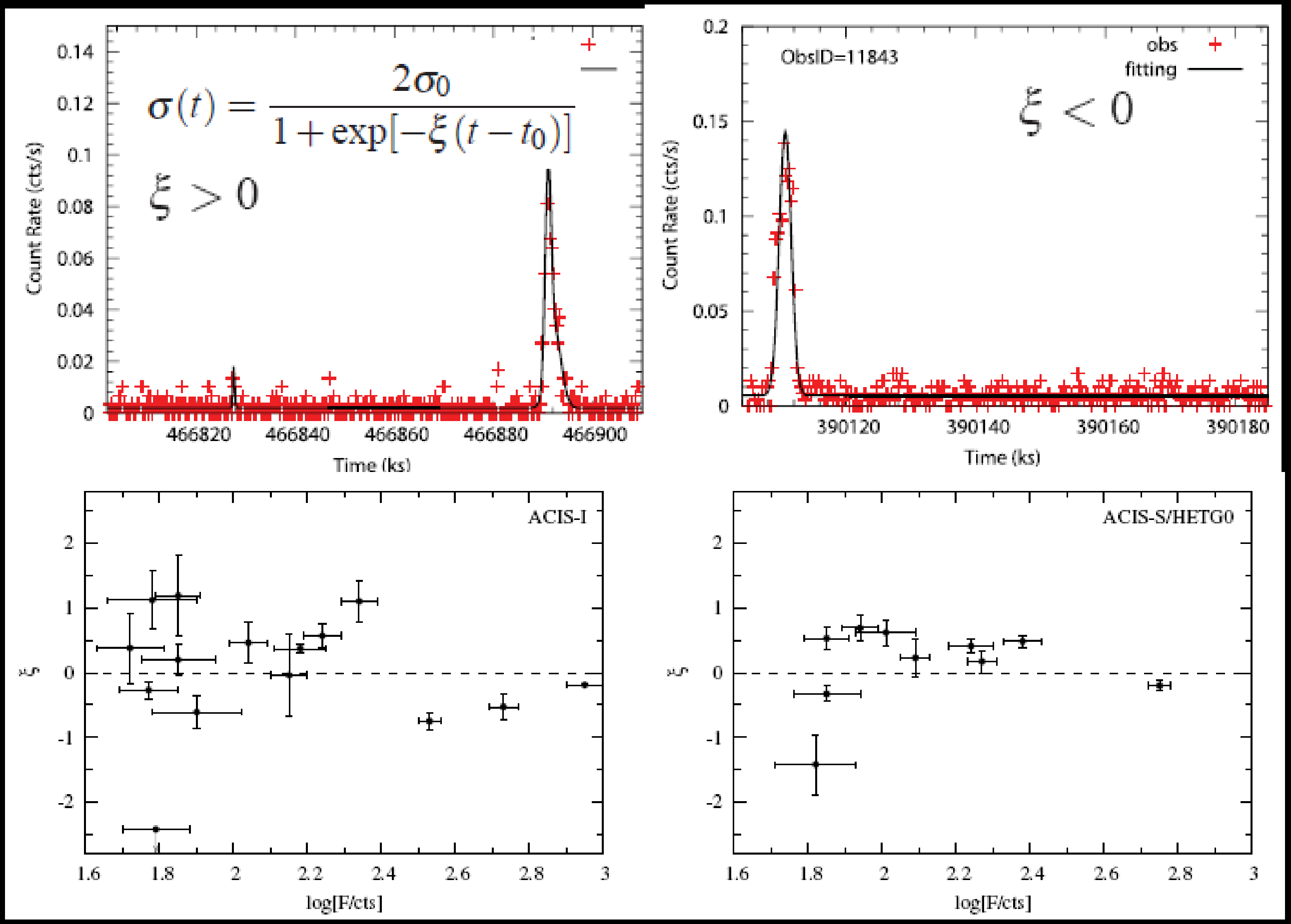
No significant change in either the quiescent flux or he flare rate between 1999 and 2012, although an increase of the bright flare rate during 2013 and 2014, about half year after G2 peri-center passage, has been claimed (Ponti et al. 15).

Evidence for short-term clustering of the flares at ~40 ks





Flare profile



- Most scenarios expect “fast rising slow decay”
- Data suggest roughly half-half
- Lensing effect by the black hole?

Yuan & Wang (2016b, in prep.)

Conclusions

- The quiescent X-ray emission is now reasonably well understood, although further observational tests are desirable.
- We still need substantially more counts (e.g., > 10^4), especially for the study of the timing and spectral properties of the flares.
- Multi-wavelength coordinated observations still remain the best hope to understand the nature of the flare emission and the role of the strong gravity.

Flare profile

- Most scenarios expect “fast rising slow decay”
- Data suggest roughly half-half
- Lensing effect by the black hole?