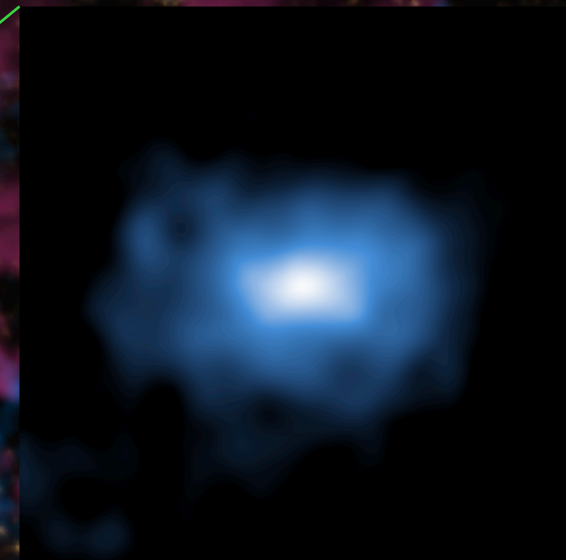
# Dissecting X-ray Emitting Gas Around the Center of the Galaxy

Based on the 0th-order ACIS-S data of the 3 Ms Chandra Sgr A* XVP



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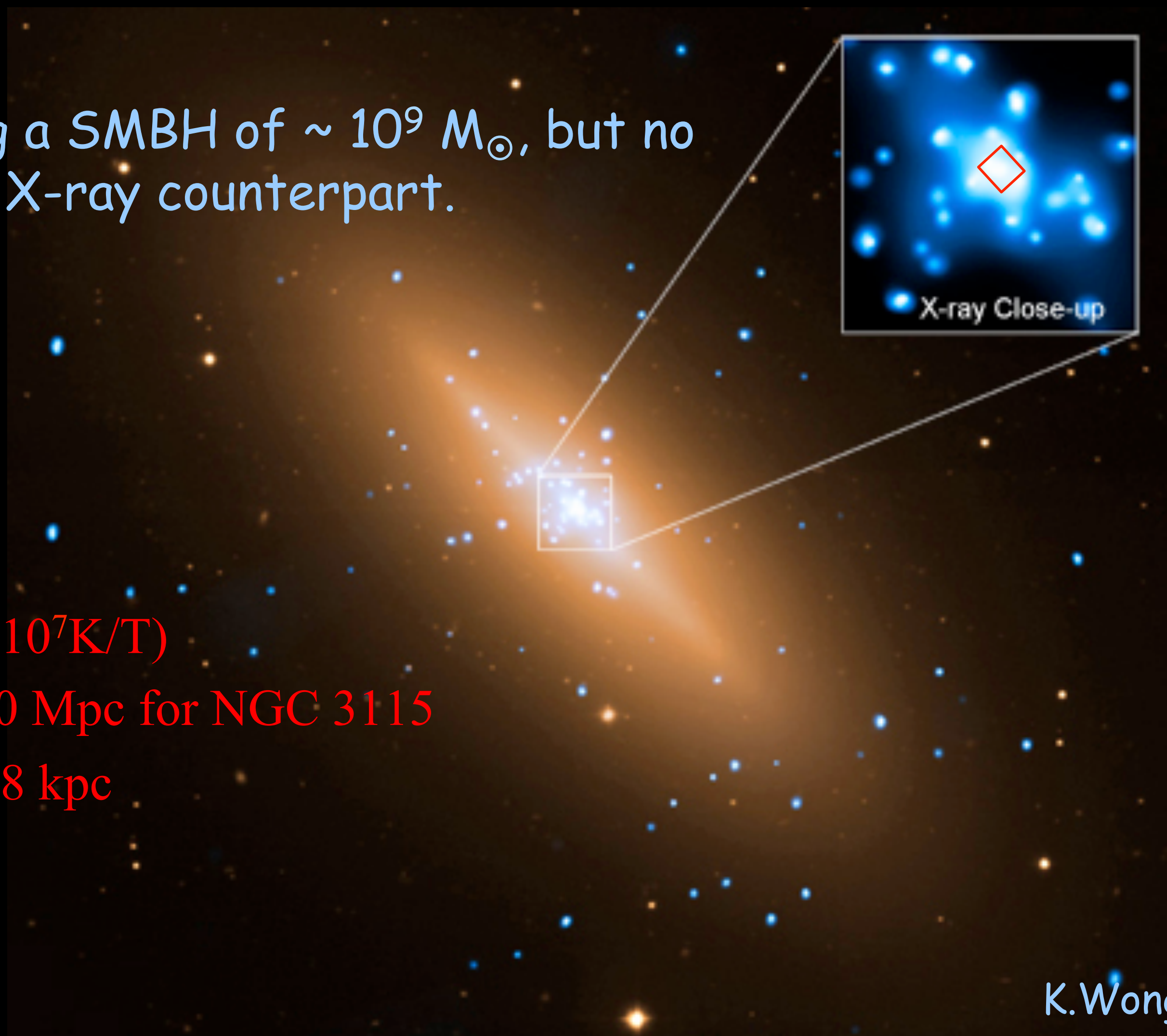
# Most SMBHs are undergoing the radiatively inefficient accretion: NGC 3115 as an example

Containing a SMBH of ~ $10^9\ M_\odot$, but no point-like X-ray counterpart.

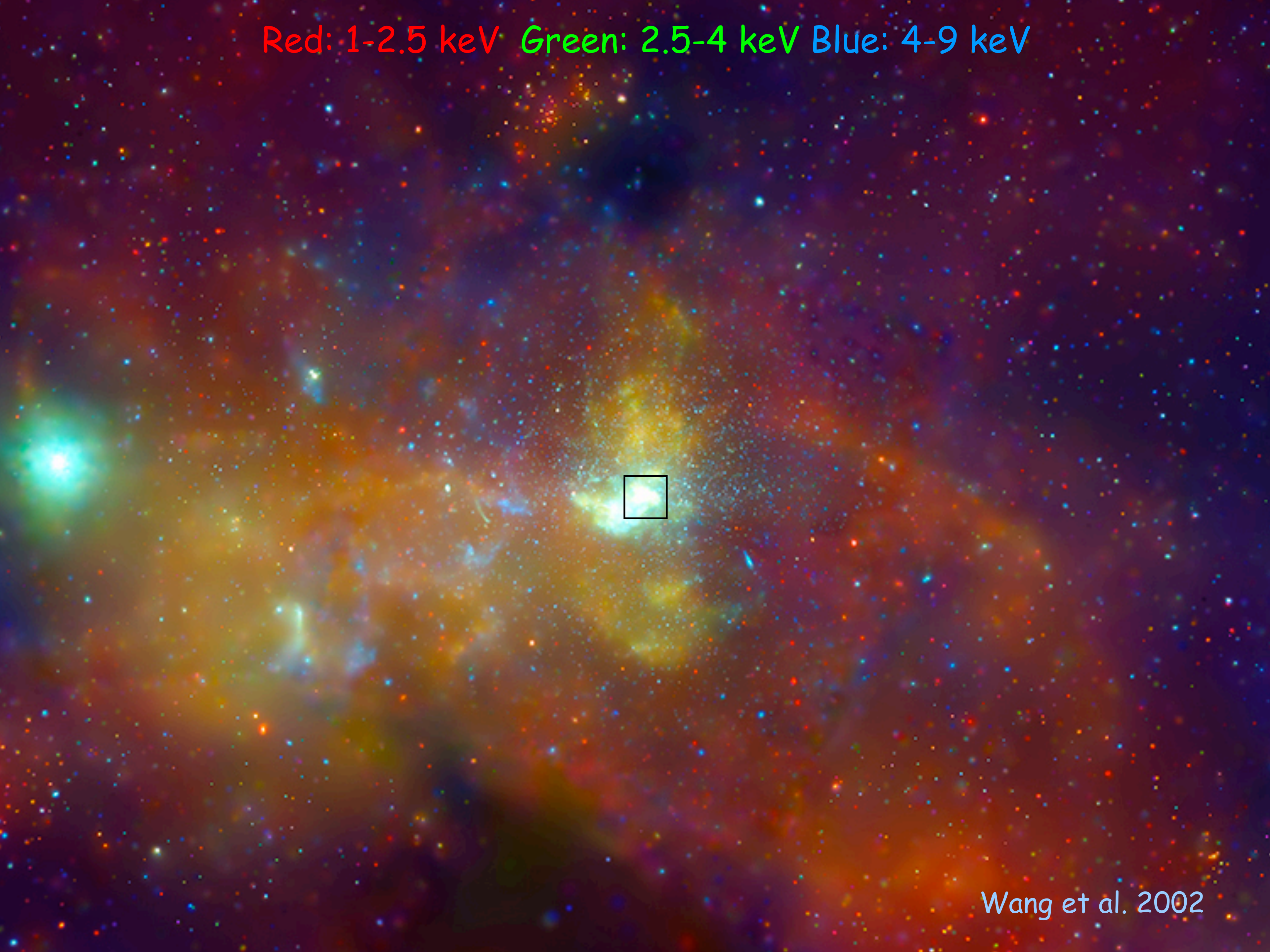



$R_B \sim 38$ pc$(10^7 K/T)$

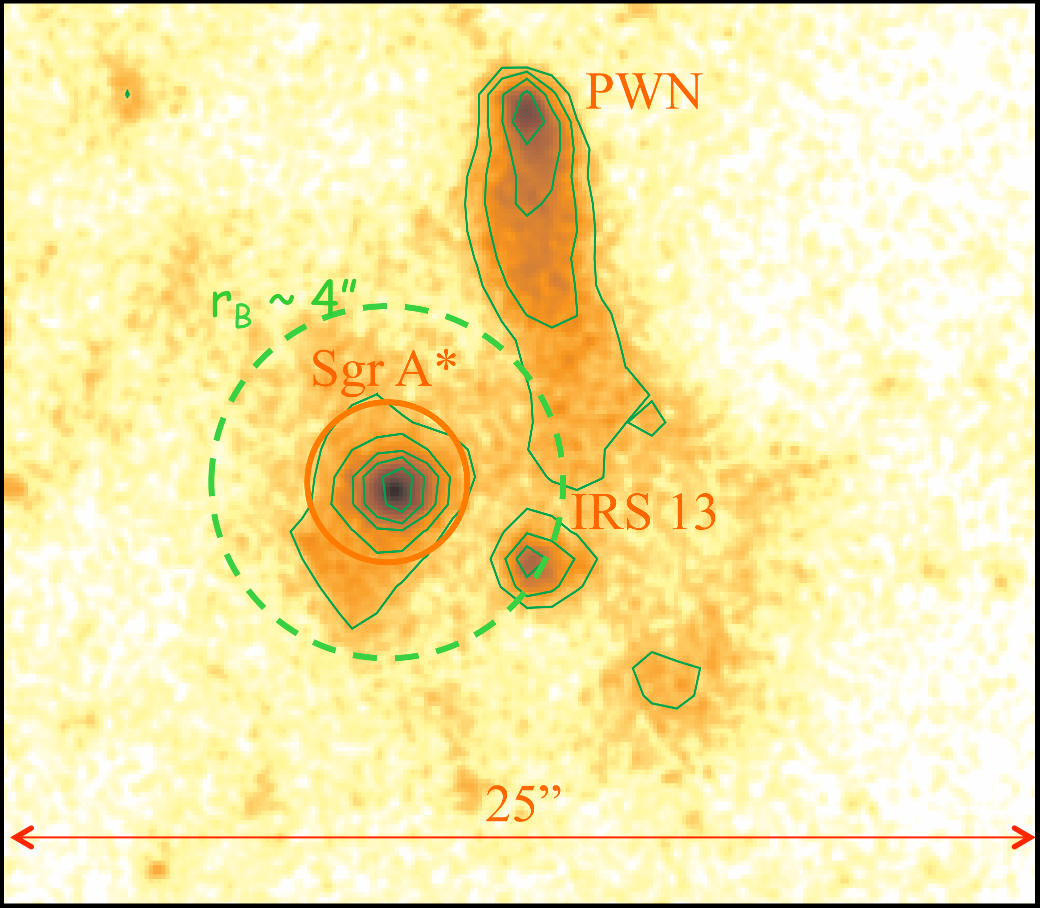
$\sim$ 1" at 10 Mpc for NGC 3115

$\sim 0.3^o$ at 8 kpc

K.Wong et al, (2011)


Red: 1-2.5 keV Green: 2.5-4 keV Blue: 4-9 keV
Wang et al. 2002

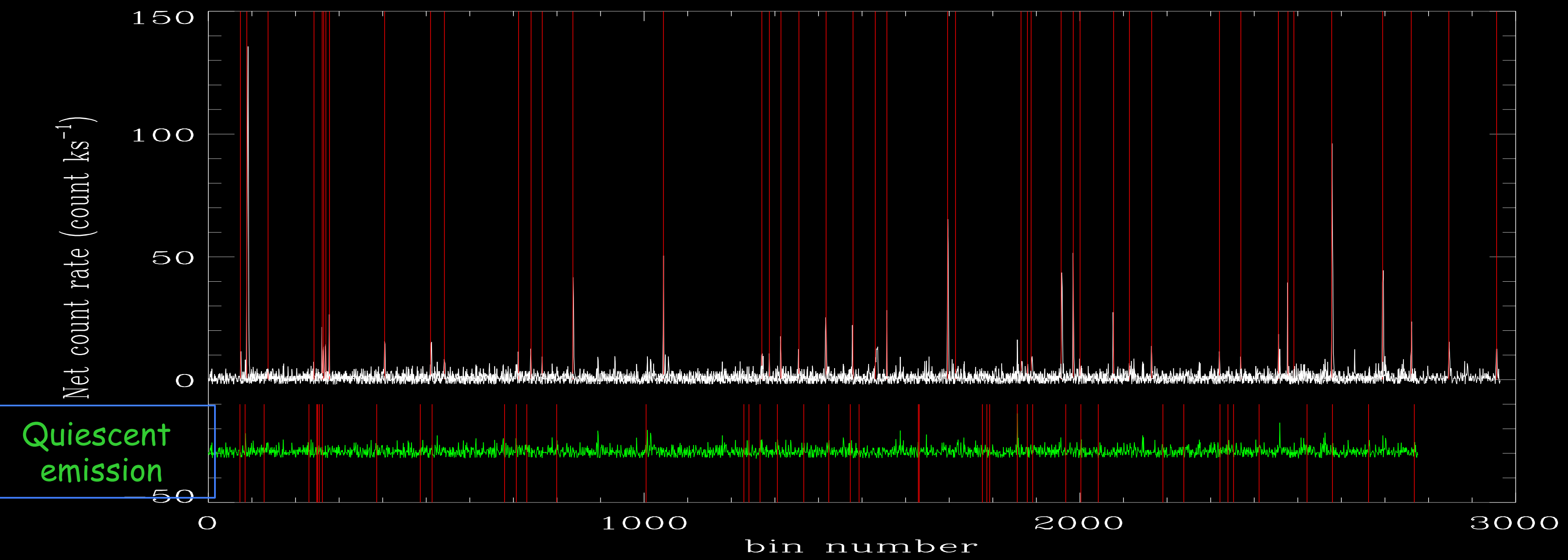
# Sgr A* and its vicinity: 1-9 keV image




- $M_{BH}$=4x10$^6$$M_\odot$
- $L_x$= 3x10$^{33}$ erg/s,
  or ~ 10$^{-11}$ $L_E$
- $L_{bol}$= a few x10$^{36}$ erg/s, mostly in radio to submm.
- What is the mode of the accretion, and what determines the luminosity?

If we have answers to these questions, we may understand a large class of ultra-dim galactic nuclei.

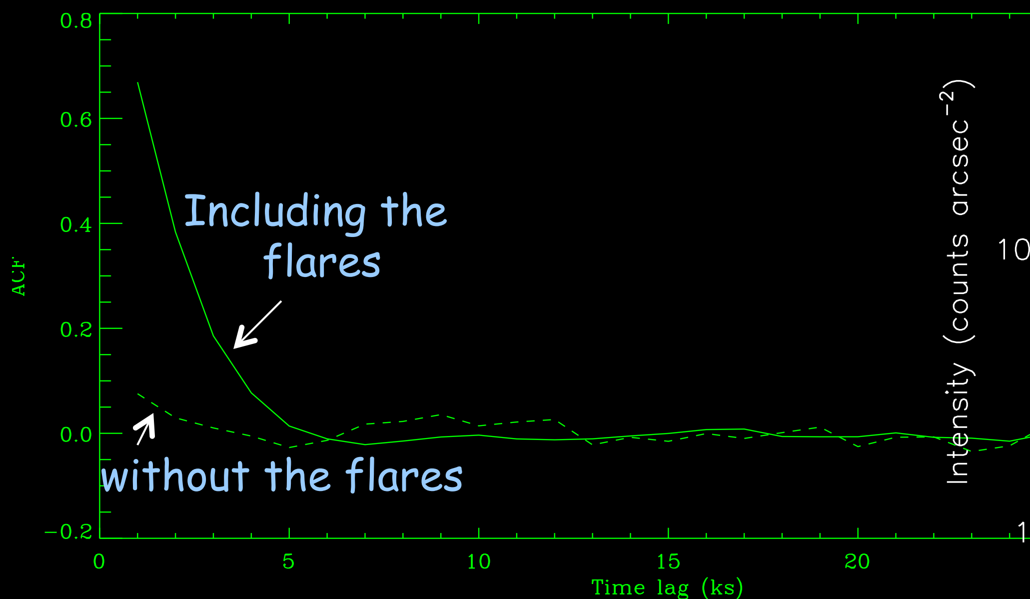
# Temporal decomposition of the Sgr A* X-ray data

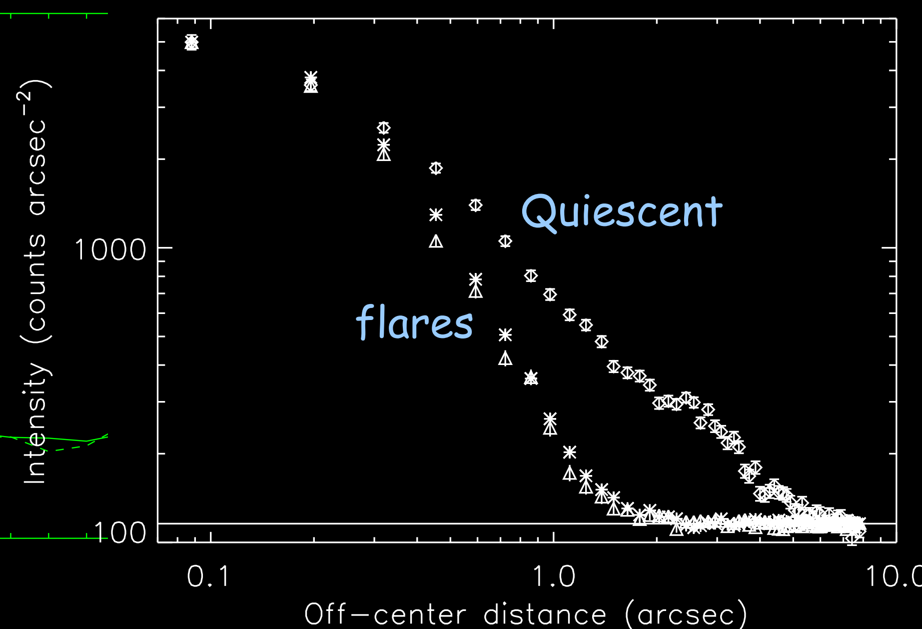



Detected flares account for ~1/3 of the total X-ray flux of Sgr A* (J. Neilsen et al. 2013).

No sign of line emission in detected flare spectrum.

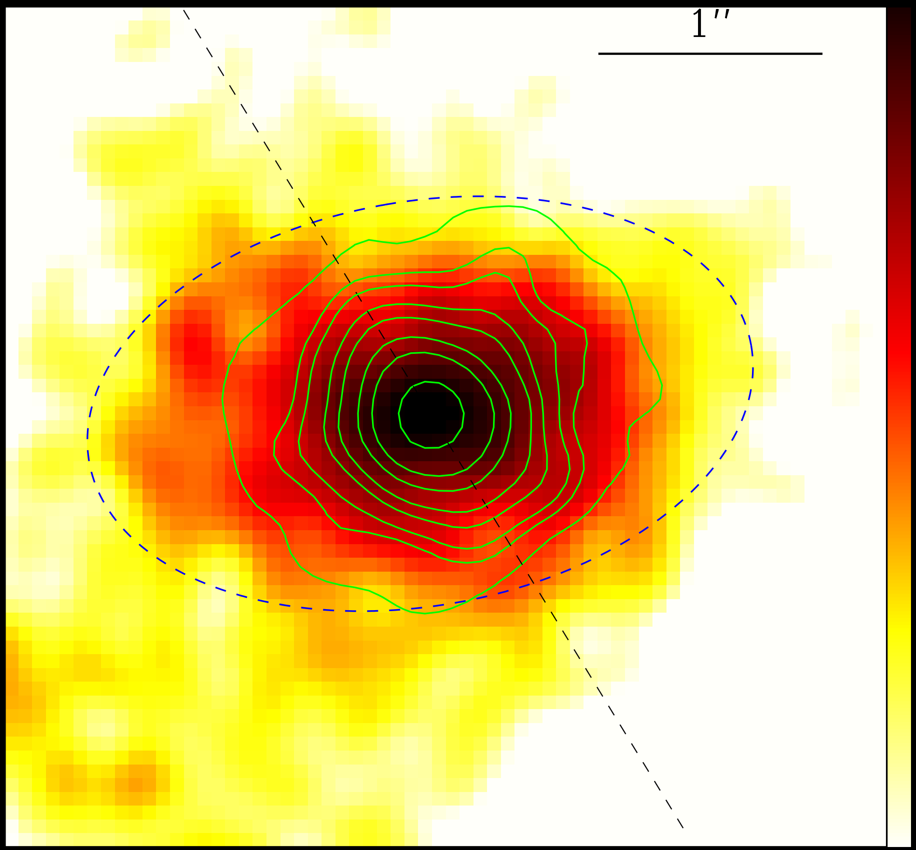
# Flare and quiescent emissions: timing and spatial properties



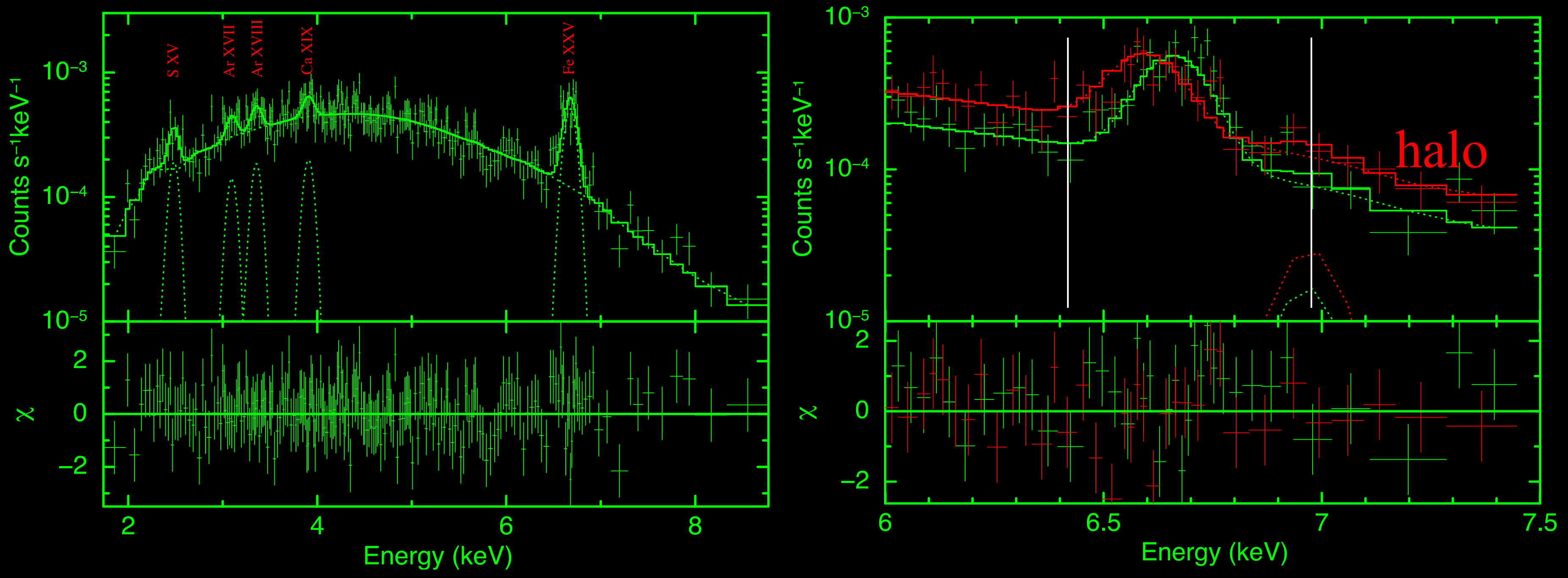

- Contamination from flares is insignificant (< 10%).
- The flare emission is point-like.
- The quiescent emission is extended on 1″-5″ scales.

# Spatial decomposition of the Sgr A* quiescent X-ray emission




- Point-like component accounting for < 20% of the total flux within 1.5″ radius.
- Extended component with an elongated morphology on 1″ scales.
- Elongation direction consistent with the orientation of the clockwise massive stellar disk.

# X-ray emission line spectroscopy



# Major Classes of Radiatively Inefficient Accretion Flow (RIAF)

- Advection-dominated accretion flow (ADAF; Narayan & Yi 1994)
- Adiabatic inflow-outflow solution (ADIOS; Blandford & Begelman 1999, 2004; Begelman 2012).
- Convection-dominated accretion flow (CDAF; Quataert & Gruzinov 2000)

These self-similar solutions are partly consistent with various HD and MHD simulations (e.g., Radiating Rotating Inflow-Outflow Solutions, RRIOS; Ostriker's talk ).

# X-ray spectral model of RIAF solutions

$$T = T_o(r_o/r)^{\theta}$$
$$n = n_o(r_o/r)^{3/2-s}$$
$$\dot{M} = \dot{M}_o(r/r_o)^{s}$$
$$dEM/d\log(T) \propto (T_o/T)^{\gamma}$$
$$(\text{where } \gamma = 2s/\theta)$$

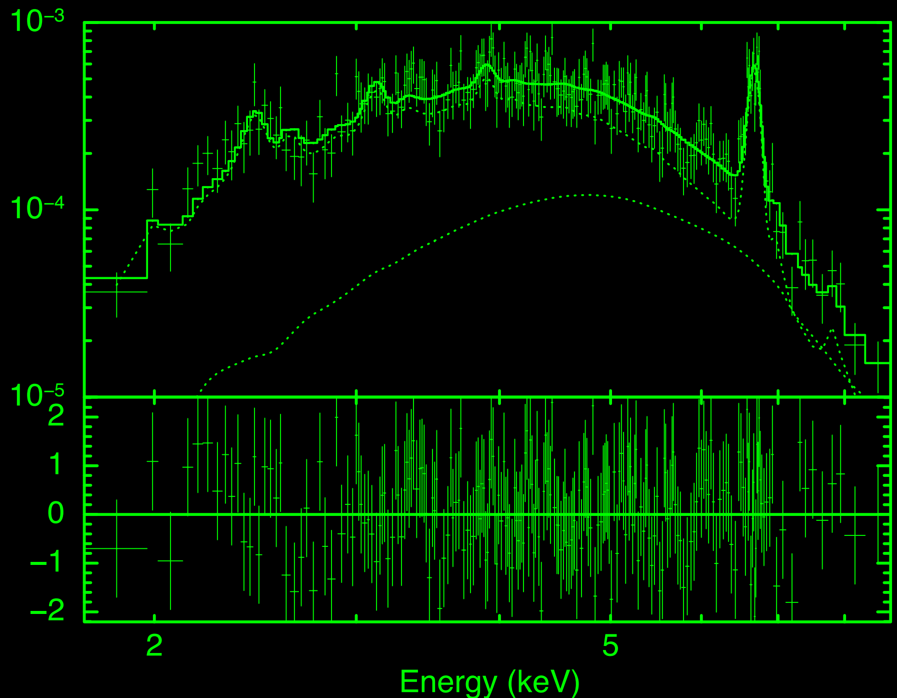
s varies from 0 (ADAF) to 1 (ADIOS).

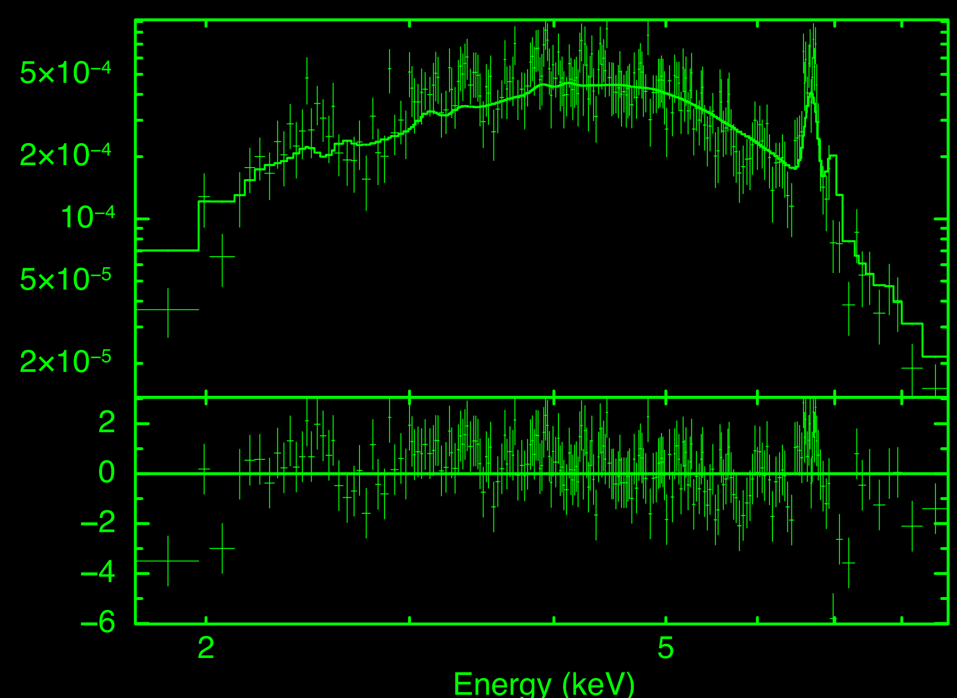
This component applies for r >$10^2$ $R_s$.

A bremsstrahlung continuum with fixed $kT_i$=100 keV is added for electrons with an saturated energy.

The two component model is used to fit the observed spectrum with the key parameters: γ, abundance, and the two normalizations; weak dependence on $T_o$.

# Spectral testing of RIAF solutions




- The best-fit s=1.0(0.8-1.3) (for θ~1) is consistent with the exact prediction of ADIOS; both the fitted abundance and $N_H$ are also as expected.
- Smaller p would give a too large FeXXVI/FeXXV Kα ratio and a too flat spectral shape to be consistent with obs.

# The X-ray spectrum is consistent with the ADIOS or RRIOS

- $T_o \sim 10^7$K at the outer radius $r_o \sim 10^5 R_s$.
- $n = 160\ cm^{-3} (r_o/r)^{-1/2} \xi^{-1/2}$.
- Combining the above with the mass rate limits from the Faraday rotation measure →

$\dot{M} \sim 10^{-4} (r_o/r)^{-1} M_\odot/yr$ all the way down to $r \sim 10\text{-}10^2\ R_s$.

- The 100 keV bremsstrahlung component accounts for ~10% of the total flux.

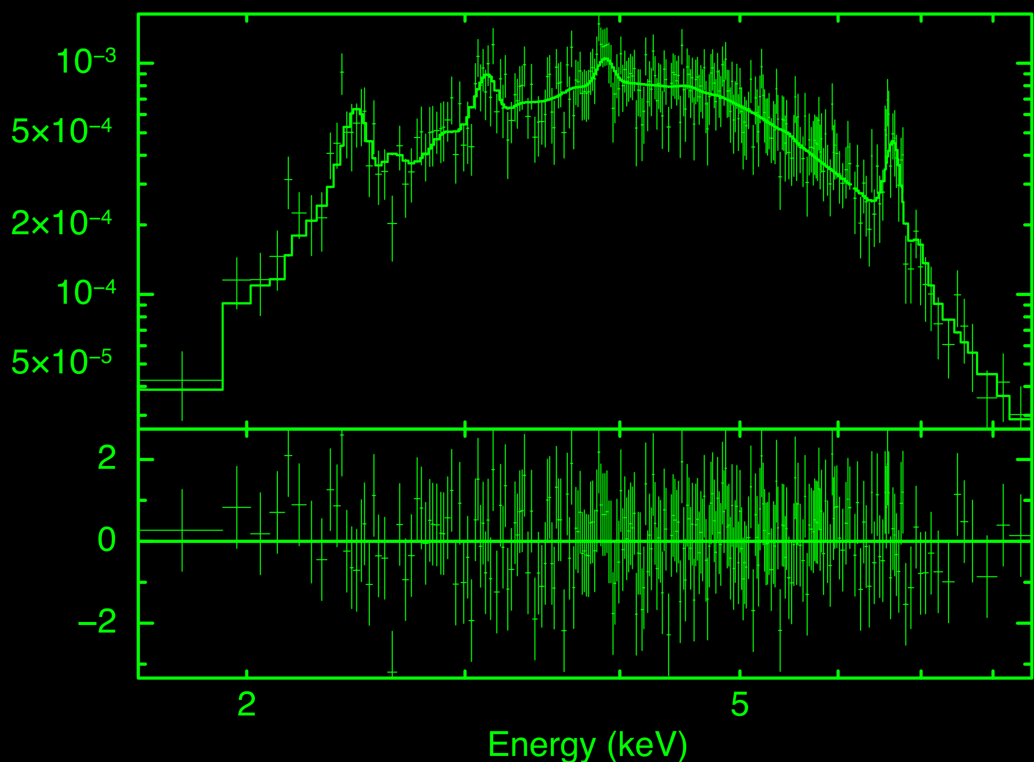
# Summary

- No evidence for significant stellar coronal X-ray emission, hence a putative stellar cusp at the Galactic center.
- Detection of Kα line emission from hot S, Ar, and Ca, as well as Fe known previously, in the quiescent spectrum.
- >99% of the initially captured matter is ejected in the $r \sim 10^4 - 10^5\ r_s$ range, as inferred from the global spectral fit, as well as Fe XXVI/FeXXV K ratio (< 0.06) .
- Extended emission with the morphology and orientation consistent with a known tilted disk of massive stars on ~1" scales. On larger scales, diffuse X-ray emission appears lumpy.

# Outstanding Questions and Approaches to Answer Them

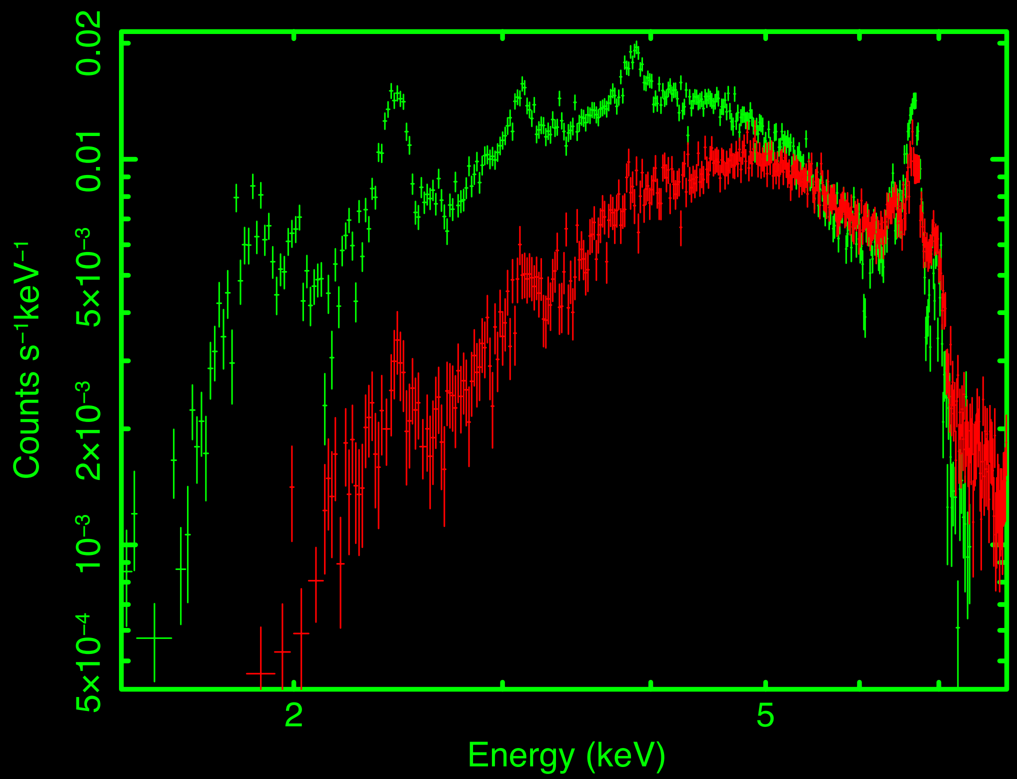
- How does the angular distributions of the temperature and density affect the results? (A: e.g., spatially-resolved spectroscopy + Ostriker's model)
- What are the nature and energetics of the outflow and how does it affect the circumnuclear environment? (A: spectroscopy of the Sgr A* halo region and beyond)
- How may the results be scaled up to explain observations of other low-L SMBHs? (A: new simulations from Ostriker et al. + data on M81* etc.)

# Plasma properties in the Sgr A* halo region




- A 2-T plasma fits well to the halo spectrum.
- The low-T component of T ~ $10^7$ K, consistent with the thermalized stellar wind.
- The high-T component of T > $3\times10^8$ K, probably representing an energetic outflow from the RIAF.

# Comparison with discrete sources




Discrete sources are on average substantially harder than that of the diffuse emission and may represent magnetic CVs with strong intrinsic abs.