# Anorexic and Gluttonous Black Holes:

Radiatively Inefficient Accretion Flows and Narrow Line Seyfert 1 AGN

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# Outline

- Low $m_{dot}$: Radiatively Inefficient Accretion Flows
  - Simple Model: spherical Accretion
  - Model with spin: ADAF
  - Other models
- High $m_{dot}$ : Narrow Line Seyfert 1
  - Observed properties
  - Model for narrow lines
  - How to nail down $m_{dot}$ interpretation

# Glossary of acronyms

- RIAF:  Radiatively Inefficient Accretion Flow
- ADAF:  Advection Dominated Accretion Flow
- CDAF: Convection Dominated Accretion Flow
- ADIOS:  Advection Dominated Inflow-Outflow Solution

# Glossary II

- NLS1:  Narrow Line Seyfert 1
- BBB: Big Blue Bump

# Part 1: RIAFs, Dim Bulbs of the Universe

# Summary of Part 1

- Nuclei of some galaxies have $L<10^{-7\text{ to }-9}\,L_{Edd}$
- Low luminosity partially due to low accretion rate, partially small amount of energy turned into radiation
- ADAF most popular model for low radiative efficiency disk
- Convection/outflow model also works

# Sag A*: Our RIAF lab

- Comparatively close at 8.5 kpc
- Mass: $2.6 \times 10^6 L_o$ (Ghez et al. 2003)
- Observed luminosity: K band $L \leq 10^{35}$ erg/s (Genzel et al. 1997), X-rays $L = 2.2 \times 10^{33}$ erg/s (Baganoff et al. 2001)
- Normal AGN luminosity ($L = 0.1 L_{Edd}$) for that mass is $10^{43}$ erg/s

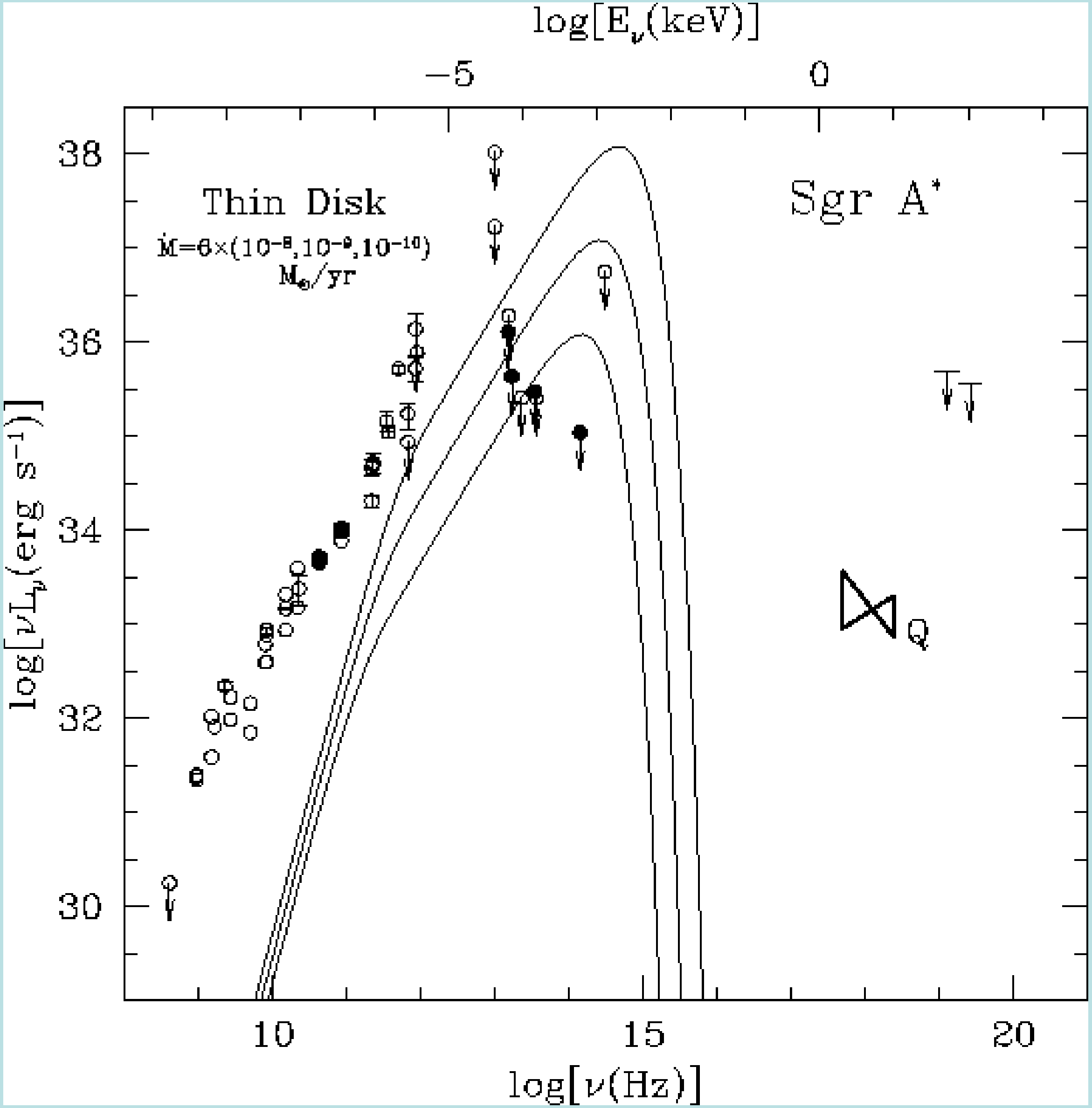
# No Disk in the Middle?

- Most energy of accretion not turned into radiation
- Shakura-Sunyaev disk very efficient at turning grav. potential energy into radiation via viscous dissipation
- Therefore, RIAFs like Sag A* don't have regular disk

•Sag A* SED from radio/sub-mm to X-ray

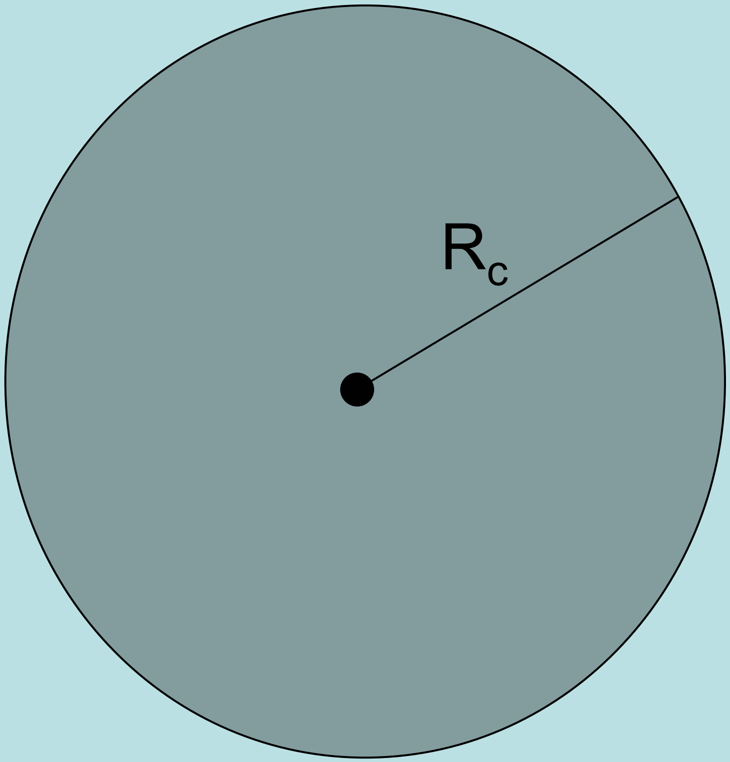
•Disk models with various accretion rates ($6x10^{-8}$ to $6x10^{-10}$ $M_o$/yr)

•Lack of fit is obvious



# One possible solution to low luminosity: low accretion rate

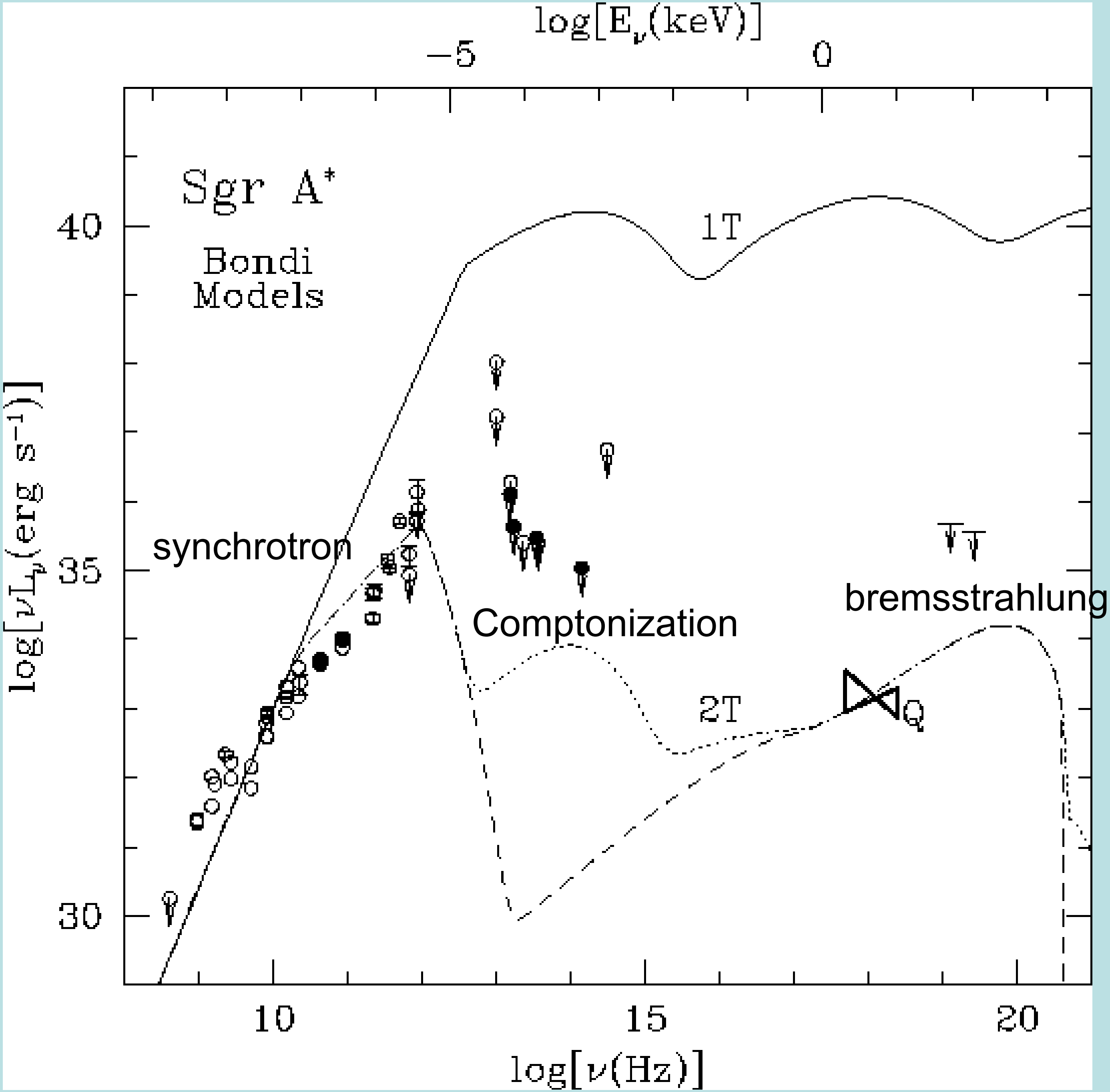
## Bondi (spherical) accretion (|L|=0)




$$R_c = \frac{GM}{c_s^2}, \dot{M}_B = \pi R_c^2 \rho_0 c_s$$

from Chandra: n=100 cm-3, kT=2keV close to Sag A*

$$\dot{M}_B = 1.2 \times 10^{-5} \frac{M_o}{yr}, L_B \approx 10^4 L_{obs}$$



log[E_ν(keV)]
−5
0
Sgr A*
Bondi
Models
40
35
30
log[νL_ν(erg s^-1)]
1T
synchrotron
Comptonization
bremsstrahlung
2T
Q
10
15
20
log[ν(Hz)]

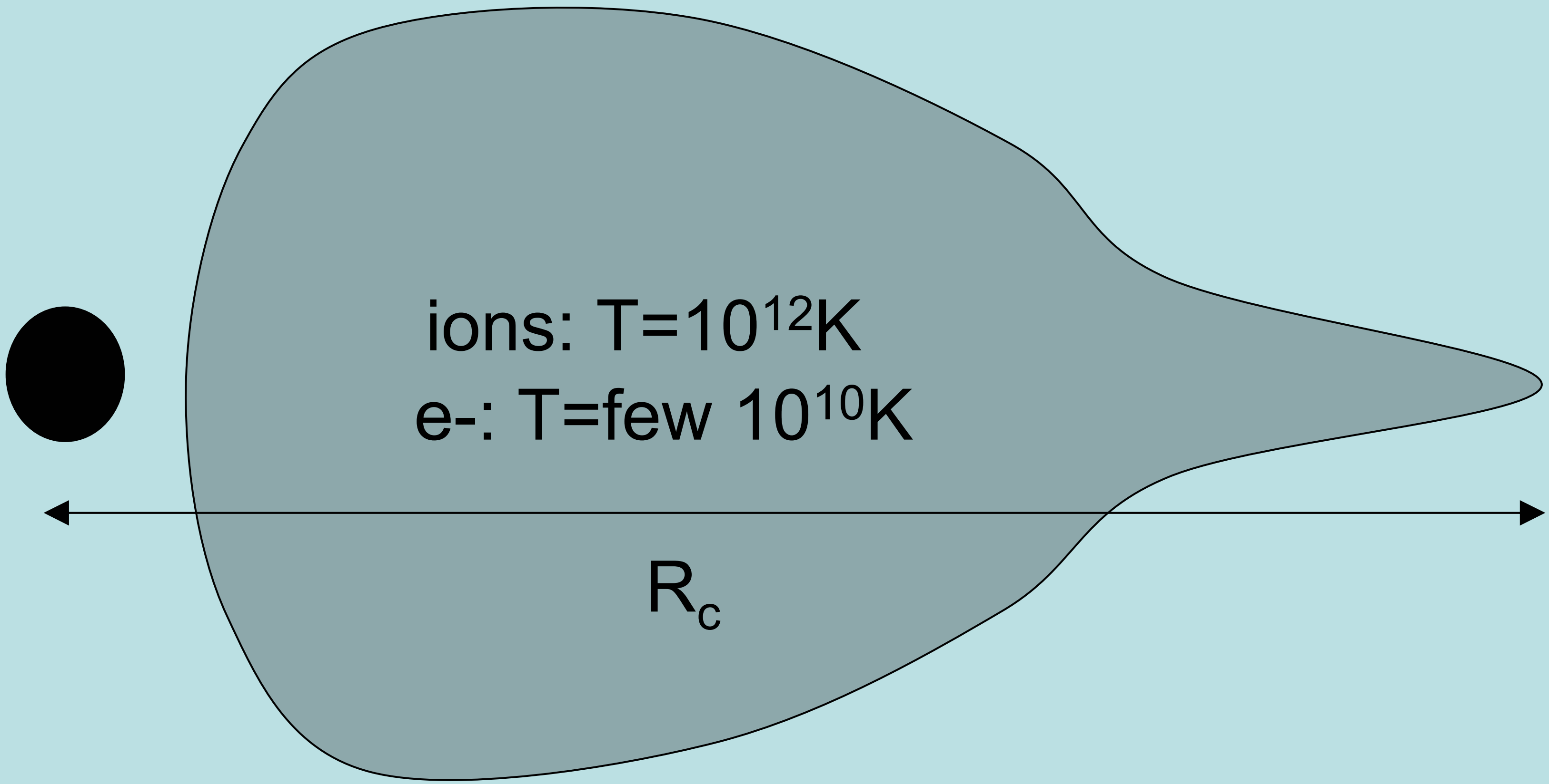
# 2-Temperature plasma

- Heating of gas with collapse due to compression, magnetic reconnection
- Electron radiation efficiency increases with temperature, so hot electrons too bright
- Coupling of e- and ions only through Coulomb forces at low density
- Electrons cool rapidly, ions retain high temp ($10^{12}$K)

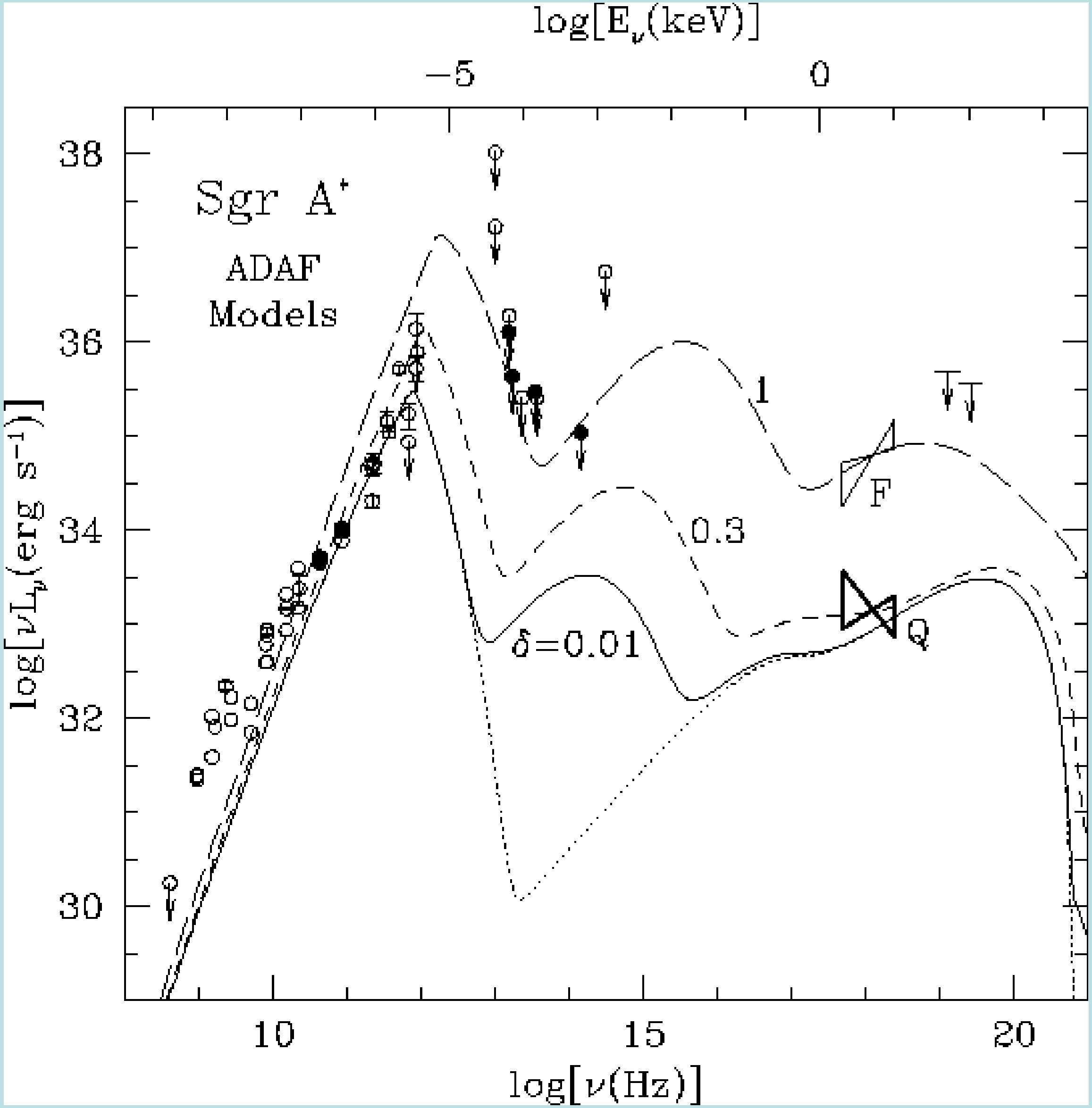
# ADAF

- Geometrically thick disk, hot ions puff to nearly spherical shell
- Energy from gravitational potential retained in gas as heat, swallowed by (advected into) BH
- Rotation in disk further reduces accretion rate below Bondi
- Coupling of viscous energy into electrons, $\delta$

# The Illustrated ADAF



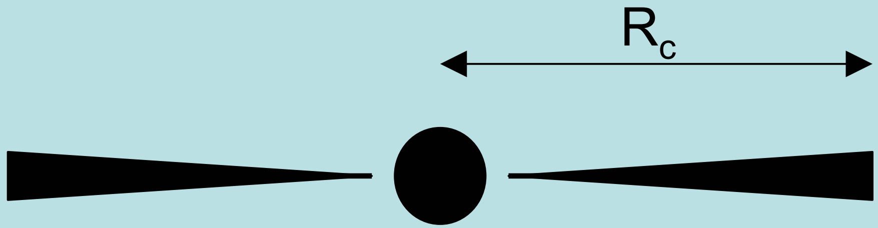
- Excellent fit for range of $\delta$
- No other parameters in model
- Flare observed in 2001 fits $\delta$=1. Also could be increased coupling of ions with e-, non-thermal electrons



# Other examples of RIAF

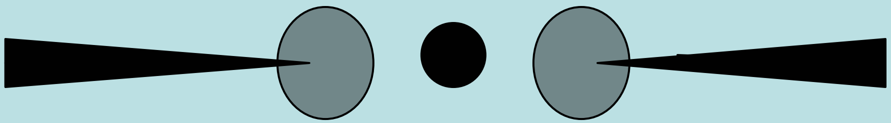
- Giant ellipticals like NGC 1399, NGC 4472 have dim nuclei $L_{acc} << 0.1\dot{M}_B c^2$
- Accretion rate in ADAF set from density at $R_c$, much less than Bondi rate, $\dot{m}_{1399} = 0.00011$
- Low luminosity AGN/LINERs show hybrid disk/ADAF

# 3-part accretion rate classification



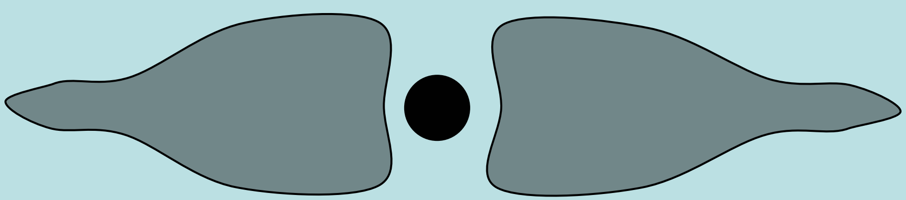

•Full Shakura-Sunyaev disk, standard AGN

$$L_{acc} = 0.1 - 1 L_{Edd}$$



•Transition object, LINER/LLAGN, M81, NGC4579

$$L_{acc} = 10^{-4} - 10^{-5} L_{Edd}$$



•Rad. inefficient accretion, ADAF, Sag A*, NGC 1399

$$L_{acc} = 10^{-8.5} L_{Edd}$$

# Convection Dominated Flows

- Heating of gas during infall causes it to become unstable to convection
- Gas in ADAF nearly unbound; addition of convective energy reduces accretion rate, luminosity

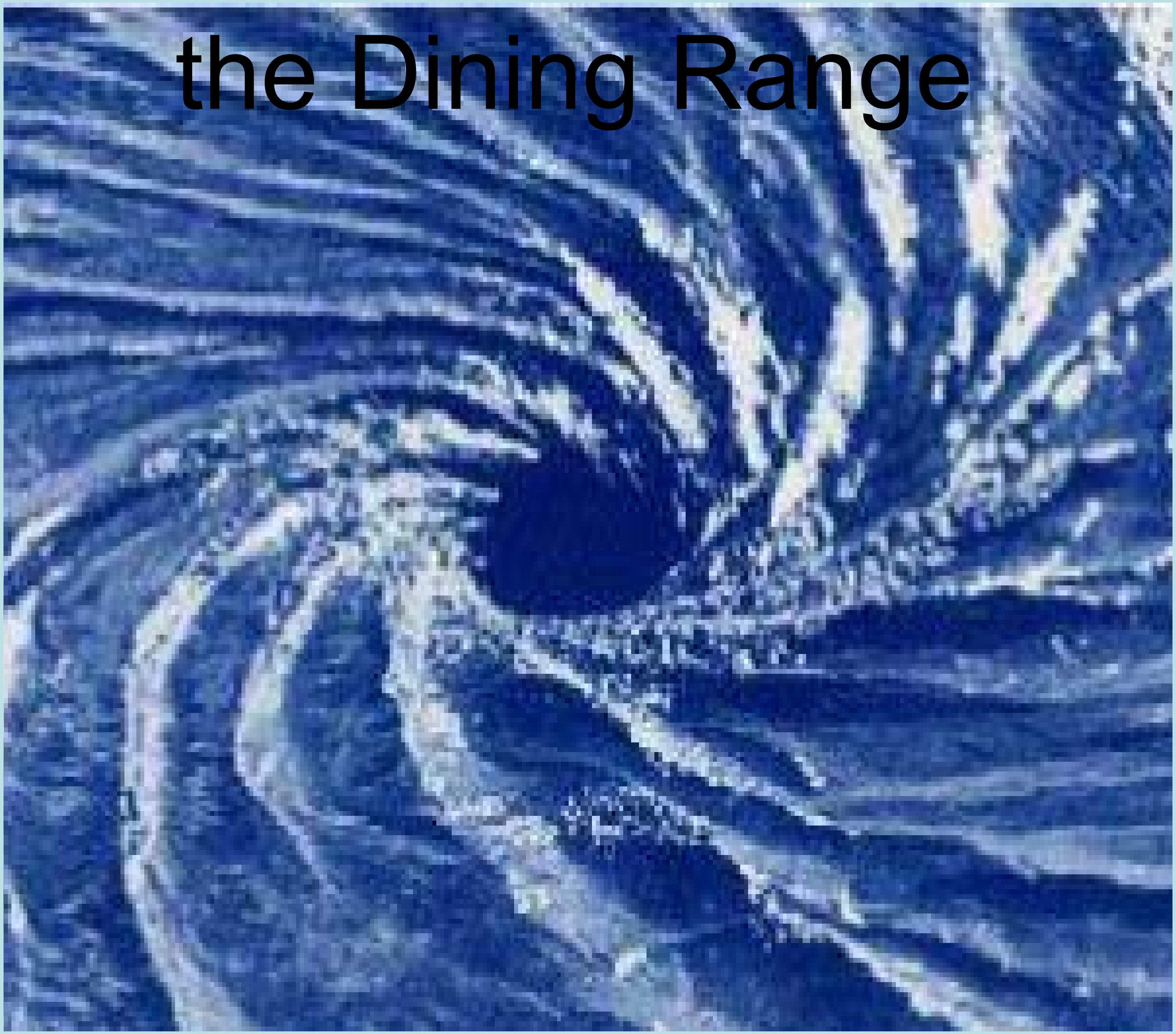
# ADIOS: Inflow & Outflow

- Radial density profile $\rho \propto R^{-3/2+p}$
- p=0 for standard ADAF
- Convection causes profile to be flatter, 0<p<1
- CDAF acts like model with p=1
- Effects of CDAF would be seen in mm/radio (reduction in synchrotron emission)

# Conclusions to Part 1

- No disk in center of Sag A* due to low luminosity, other spectral features
- Low accretion rate not enough to explain low luminosity
- 2-temp plasma with nearly spherical geometry provides acceptably low efficiency (ADAF)
- Rate further decreased by outflow due to convection

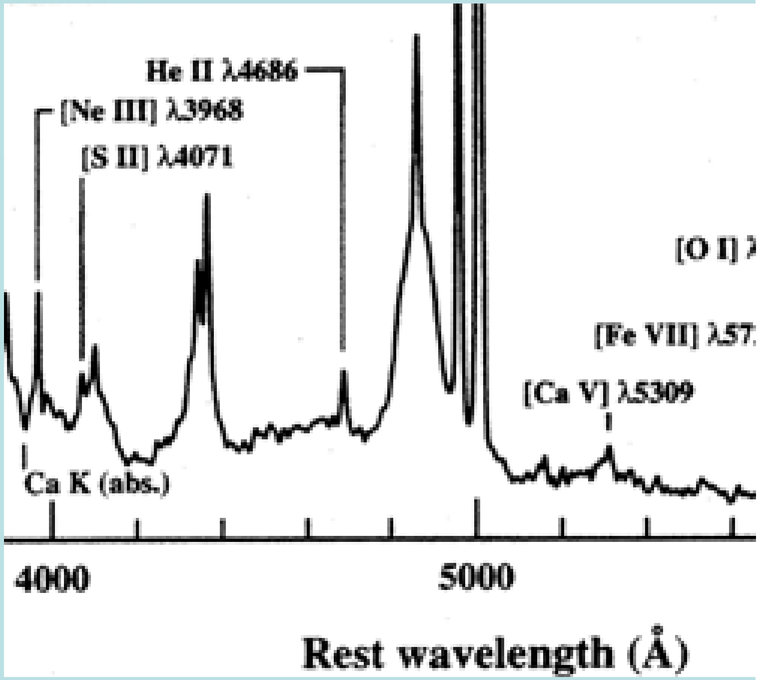
# Part 2: NLS1s, The Other Side of the Dining Range



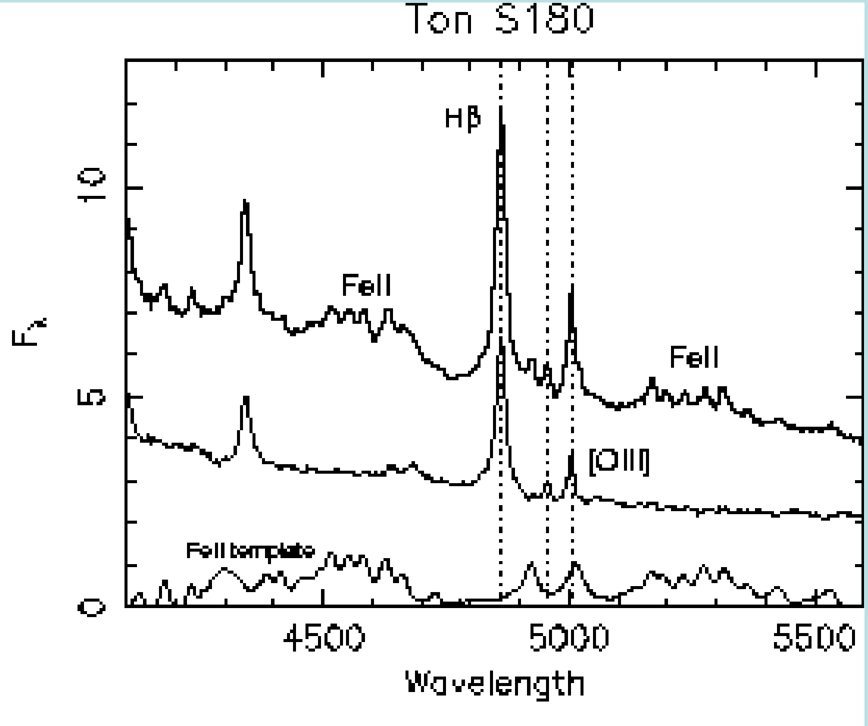
# Summary of Part 2

- Objects found with narrow Balmer Lines (FWHM H$\beta$<2000 km/sec), but other properties like type 1 AGN
- Correlations of emission lines put these objects at an extremum of some process, $m_{dot}$
- Some observed X-ray properties confirm, others yet to be discovered

NGC 1275




Ton S180




Broad (left) versus Narrow (right) line Seyfert 1 galaxies

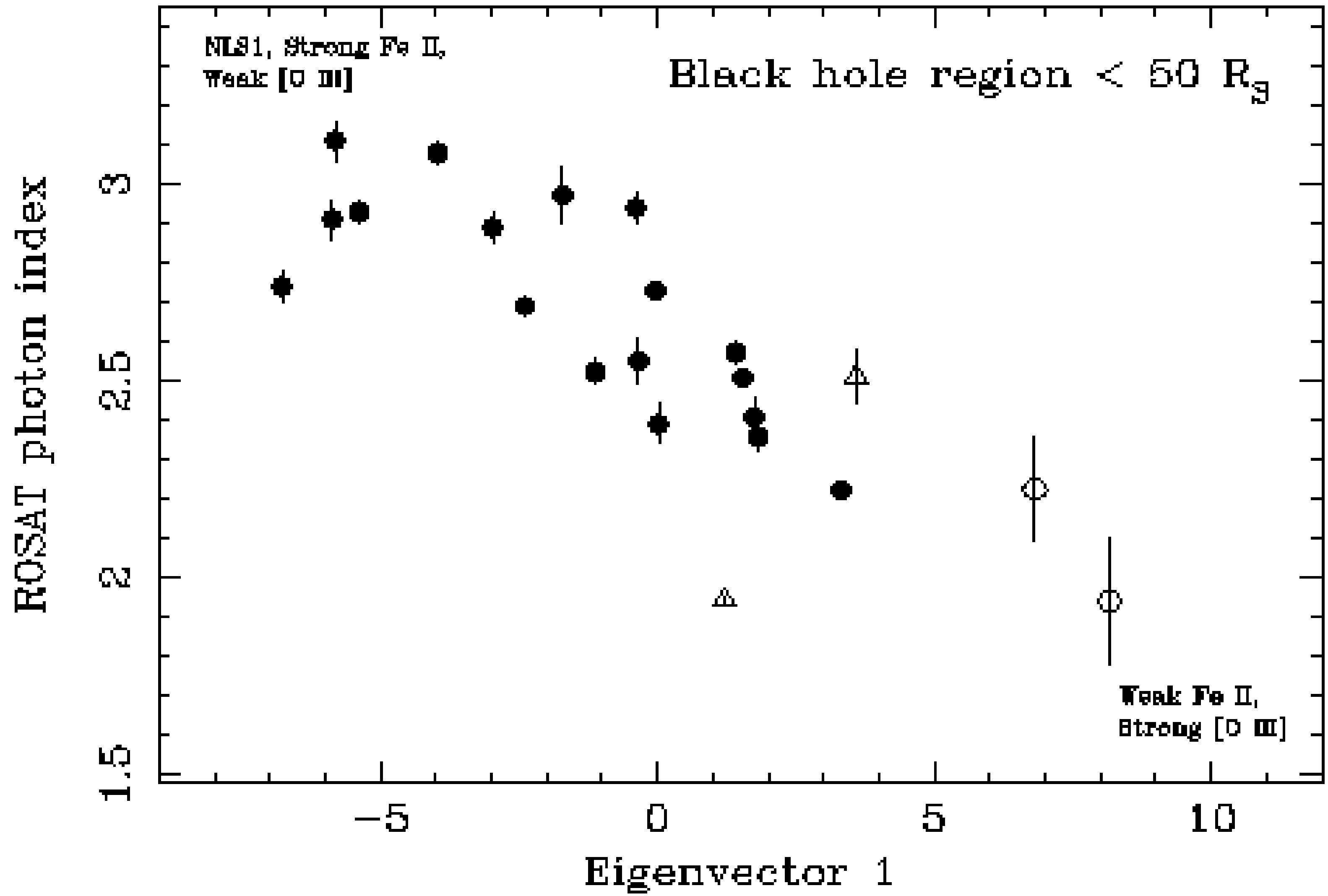
Also note presence/absence of FeII

Definition: NLS1 has FWHM of Hb < 2000 km/sec

Under represented in surveys made in hard X-rays

# Primary Eigenvector

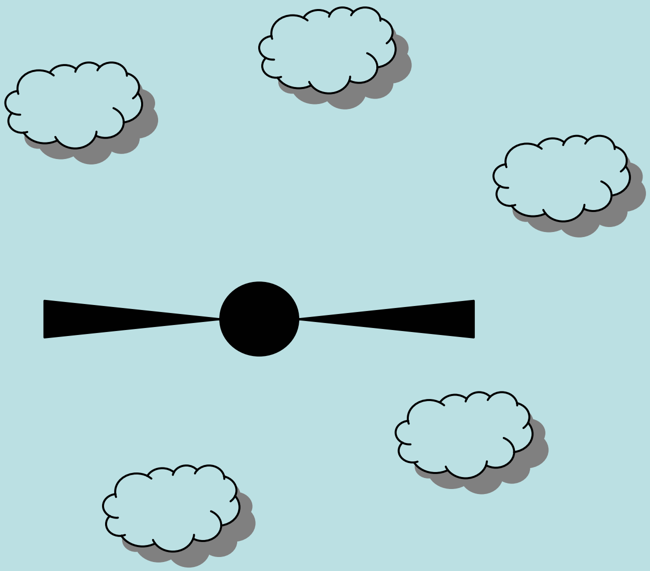
- Correlation between FeII, [OIII], and Balmer line widths/shapes
- NLS1 at one end of relation
- Reference Boronson & Green 1992
- More on this Wednesday


NLS1, Strong Fe II,
Weak [O III]
Black hole region < 50 $R_g$
Weak Fe II,
Strong [O III]
ROSAT photon index
1.5
2
2.5
3
−5
0
5
10
Eigenvector 1

# X-ray slope

- Optical emission powered by inner parts of disk
- BBB extension into soft x-rays, origin believed to be thermal inner disk
- Lots of emission from inner disk makes x-ray spectrum soft, could indicate large accretion rate

# Model for NLS1



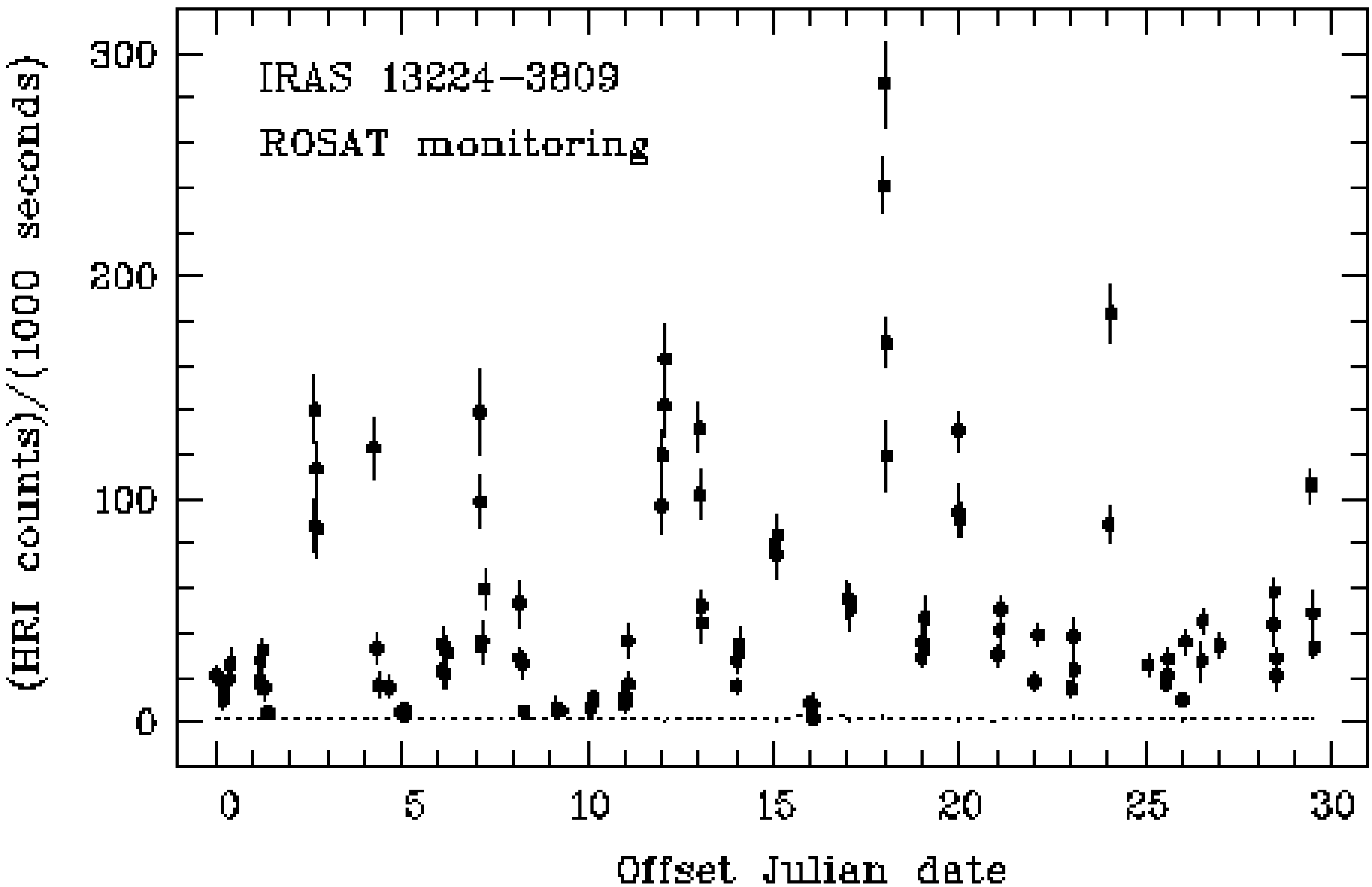
Broad Line Region clouds virialized, radius proportional to luminosity

For fixed luminosity, emission at close to $L_{Edd}$ → small mass

Low mass means clouds move more slowly

# Variability of X-rays

- Flux varies by large amount and on short timescales, more so than other types of AGN of similar luminosity
- Rapid fluctuation implies coordinated emission, possibly relativistic jets
- Comparison to similar states in galactic black holes show the latter more stable on very short timescales


IRAS 13224−3809
ROSAT monitoring
(HRI counts)/(1000 seconds)
300
200
100
0
0
5
10
15
20
25
30
Offset Julian date

# Alternatives to $m_{dot}$

- From Boronson & Green 92: If [O III] isotropic, cannot be nuclear orientation
- Black hole spin:
  - Radio loud QSOs at high end of primary eigenvector
  - NLS1 have non-spinning BH
  - Analysis of Fe Ka line

# Conclusions

- Low accretion rate produces a thin, 2-temperature plasma that forms an ADAF, very low $L/L_{Edd}$
- High accretion rate makes a hot disk around a low mass BH for a fixed L, soft X-ray continuum, and narrow lines from slow moving BLR clouds

# References


- Brandt, W. N.
- Leighly, K. M. astro-ph/0402676
- Narayan, R. astro-ph/0201260
- Quataert, E. astro-ph/0304099
- …and references therein