Radiatively Inefficient Accretion Flow Models of Sgr A*

Ramesh Narayan

Dim Galactic Nuclei

□ltra□□im □alactic N□clei

- **Sgr A*** e□em□lifies a famo□s old □ro□lem□

  SM□□s in the n□clei of normal □non□A□N□gala□ies are m□ch too dim
- □r□e□the gas s□□□□y is less than in a □right A□N
- □□t the gas s□□□□y is less □y only a few orders of magnit□de□not □y □□orders of magnit□de as **Sgr A*** s□l□minosity s□ggests
- A□art from the □ltra□low l□minosity□the s□ectr□m also s□ggests something other than the □s□al thin accretion dis□fo□nd in □S□s and □right A□N
- □hat is the mode of accretion□and what determines the l□minosity□
- If we co□ld fig□re this o□t in **Sgr A*** it wo□ld hel□□s to □nderstand a large class of galactic n□clei□and to fig□re o□t □□asar evol□tion

□□minosity of Sgr A*

- M□□ □ □□□□□□□M$_\epsilon$ (Schodel et al□ □□□□□□he□et al□□□□□□
- Sgr A* is e□tremely dim□

$$L_{submm} \sim 10^{36}\,\mathrm{erg/s} \sim 3\times10^{-9}\,L_{Edd}$$

$$L_{IR} \sim 10^{35}\,\mathrm{erg/s} \sim 3\times10^{-10}\,L_{Edd}$$

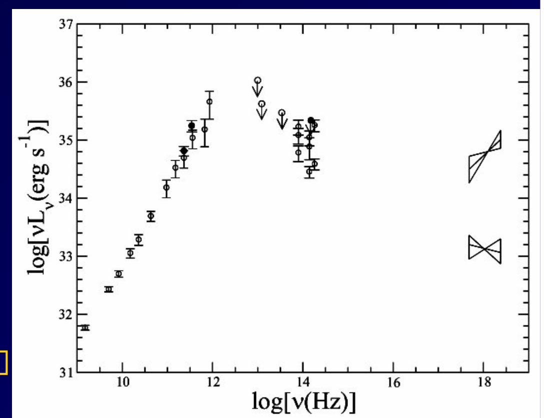
$$L_X \sim 2\times10^{33}\,\mathrm{erg/s} < 10^{-11}\,L_{Edd}$$

(brighter during flares)

□□aganoff et al□□□□□a□□□en□el et al□ □□□□□□he□et al□□□□□□

□ondi accretion rate□□□□□□M$_\epsilon$ □yr

□□□ect l□minosity□□□□□□erg□s



Sgr A*

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Accretion Sol□tions

- S□herical accretion □□ondi □□□□□□□□□□o ang□lar moment□m□
- □hin accretion dis□□Sha□□ra □S□nyaev □□□□□□√
- □wo□□em□erat□re sol□tion □Sha□iro□□ightman □□ardley □□□□□□□□□□thermally □nsta□le□
- Advection□□ominated Accretion Flow□A□AF □chimar□ □□□□□Narayan □□i □□□□□□□□□□□A□ramowic□et al□ □□□□□□□√

Dim Galactic Nuclei

□nergy □□□ation

□□ □ □□□ □adv

□□□□A□r□□□□□□□□□□

□Sha□□ra □S□nyaev □□□□□
Novi□ov □ □horne □□□□□□□

Most of the visco□s heat energy is radiated

$$q^{-} \approx q^{+} \square \; q^{\mathrm{adv}}$$

$$L_{\mathrm{rad}} : \; 0.1 \dot{M} c^{2}$$

A□□□□□□□□□□□□ □□□□□□□
A□r□□□□□□□□□□□A□A□□

□Ichimar□□□□□□Narayan □□i
□□□□□□□□□□A□ramowic□et al□
□□□□□

Most of the heat energy is retained in the gas

$$q^{-} \square \; q^{\mathrm{adv}} \approx q^{+}$$

$$L_{\mathrm{rad}} \square \; 0.1 \dot{M} c^{2}$$

$$L_{\mathrm{adv}} : \; 0.1 \dot{M} c^{2}$$

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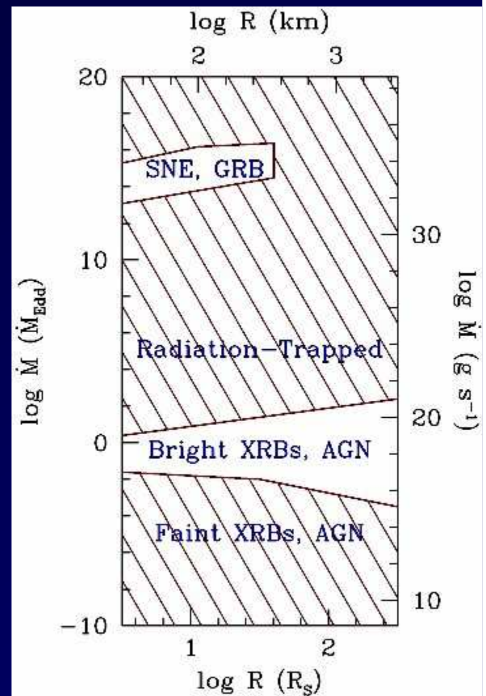
A□AF or RIAF□

- □nergy □□□ation□□□ □ □− □ □adv
- A□AF□Advection□□ominated Accretion Flow□□□ □ □adv ? □−
- RIAF□Radiatively Inefficient Accretion Flow□□− = □□ □ □adv
- □hey are really the same thing□
- A□AF □conce□t□general □□not limited to □artic□lar □ower□law sol□tion of N□□□□

Dim Galactic Nuclei

Mdot Regimes□□hin □is□vs A□AF

- □wo regimes for thin dis□□
  - □ower regime corres□onds to □right □R□s and A□N
  - □□□er regime corres□onds to SNe and □R□□ne□trino cooling□
- □verywhere else □shaded□ we have an A□AF
- Sgr A* is near the □ottom

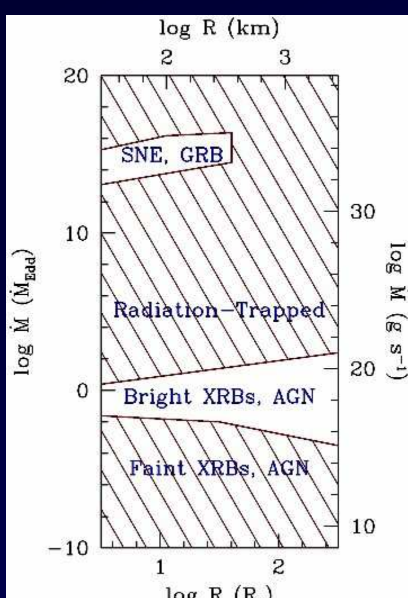


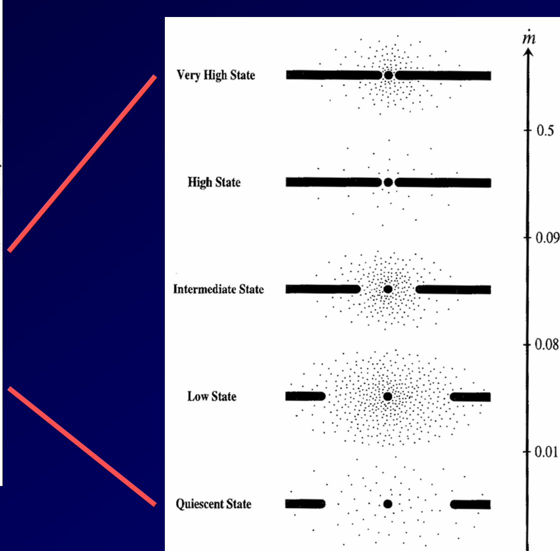
Narayan □ □ataert □□□□□□

M□□□□M$_\varepsilon$

Dim Galactic Nuclei

□hin □is□□A□AF and □□□S□ectral States





□sin et al□□□□□□□

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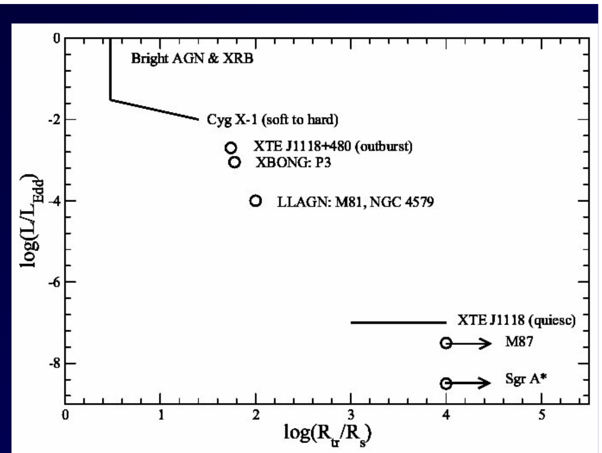
□o□ndary □etween □hin □is□and □ow□ Mdot A□AF



□□an □Narayan □□□□□□

- □o□ndary can □e estimated as a f□nction of l□minosity from o□servations of □S□IS□□S and □S systems □e□g□□□□an □Narayan □□□□□□
- Sgr A* corres□onds to the e□treme limit of the □S □□□there is no thin dis□at any radi□s

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Dim Galactic Nuclei

Not All the □as Availa□e to an A□AF Accretes onto the □□

- A□AFs are li□ely to have strong o□tflows □Narayan □□i □□□□□□□□□□□ □landford □□egelman □□□□□Stone et al□□□□□□Ig□menshchev et al□ □□□□□□□□□□□□awley □□al□s □□□□□and also to □e strongly convective □Narayan □□i □□□□□Narayan□Ig□menshchev □A□ramowic□□□□□□ □□ataert □□r□□inov □□□□□
- For □oth reasons□the mass accretion rate onto the □□is strongly red□ced □r□e also for □ondi accretion□cf□Ig□menshchev □N □□□□□□□

$$\dot M_{BH} \sim \dot M_{out} \left(R_S / R_c\right)^s$$

$$\rho(R) \sim \rho(R_c)\left(R / R_c\right)^{s-3/2}$$

- □ray data □□aganoff et al□□□□□□give density at large radi□s and radio □olari□ation data □Ait□en et al□□□□□□□ower et al□□□□□□constrain gas density at small radii □□□ataert □□r□□inov □□□□□Agol □□□□□□□ □om□ined data hel□determine the inde□s □□□□□□□□an et al□□□□□□

Dim Galactic Nuclei

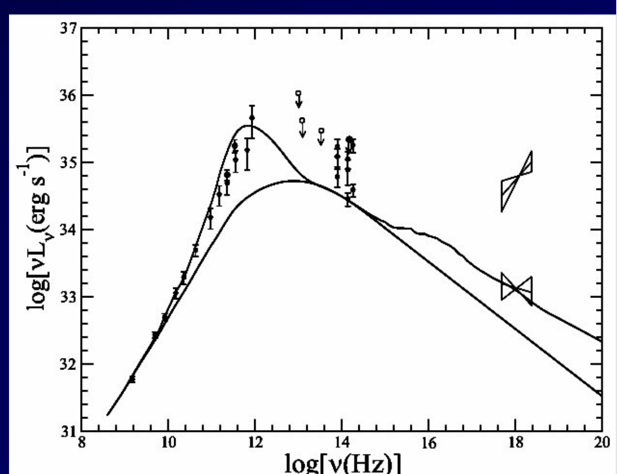
□is□Sol□tions and □□tflows

- □□□□□□□□□□
  - □as is strongly □o□nd□s□ecific energy □–□M□□R
  - Not easy to generate an o□tflow□□ □□□□□ □□□
- A□A□
  - □ittle energy is lost thro□gh radiation□gas retains its initial energy□□–□M□□R$_{o□t}$? –□M□□R
  - □iscosity transfers energy o□tward□th□s f□rther decreasing the □inding energy at each radi□s □N□□□□□□□□□□□□□□ convection assists this□□ositive energy□□erno□li □arameter
  - □□□ect a strong mass o□tflow□confirmed in sim□lations

Dim Galactic Nuclei

A□AF□RIAF Model of Sgr A* in □□iescence

- □rimarily thermal electrons□□□t a fraction η have a □ower□aw distri□□tion□n γ□□γ□□
- □ives a reasona□le fit to the s□ectr□m with η □ □□□□□and □□ □
- □hermal electrons contri□□te to s□□mm □□m□and □□esc□rays
- □□electrons contri□□te to the radio and IR and also the flares



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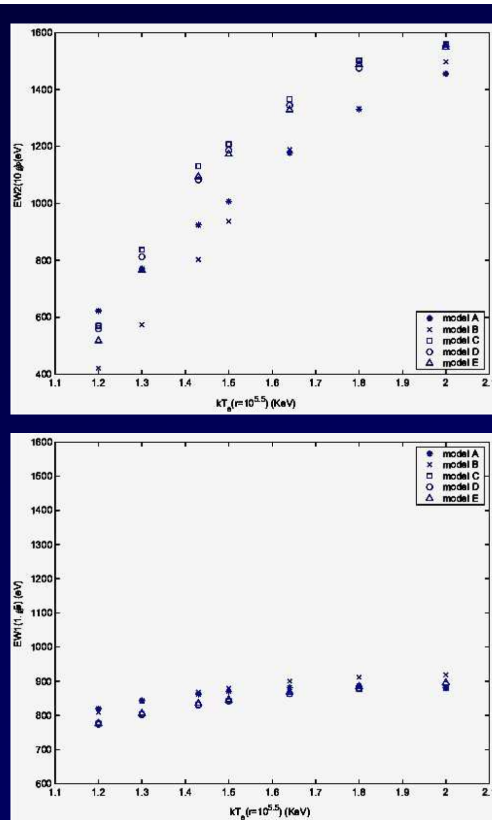
Dim Galactic Nuclei

Iron □ine



□□□

□□□□

□□iescent □□rays □rimarily from o□ter thermal gas

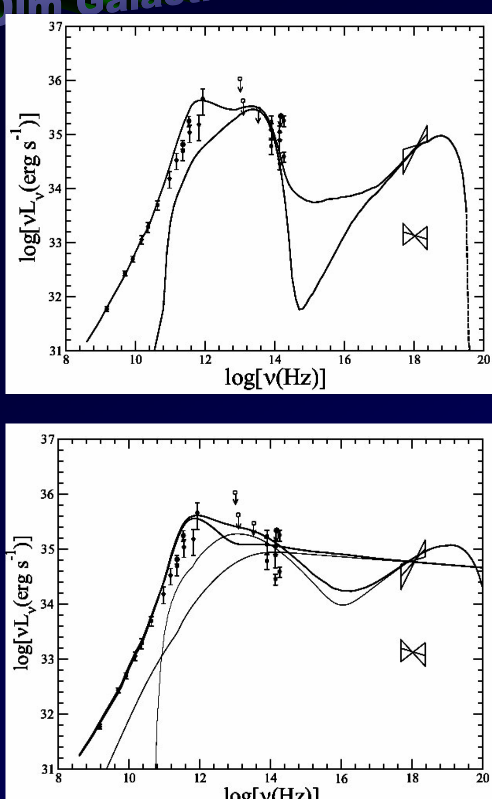
□□□□e□□□□ iron line inside □□□consistent with model

□□□□□□□□□e□iron line sho□ld □e seen inside □□□□ □□□et al□□□□□□□

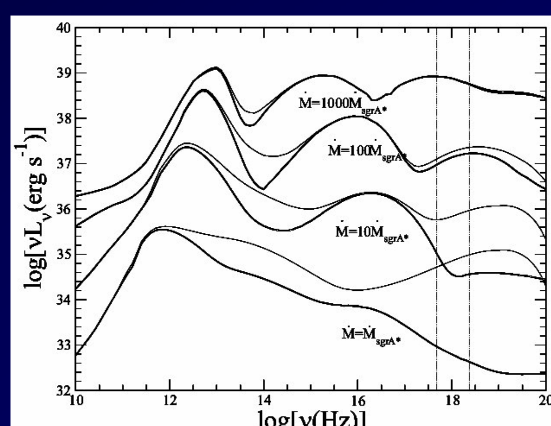
For □□solar□□□□□□e□

□esta□le □rediction

Dim Galactic Nuclei



□□ray and Infrared Flares



□□an et al□□□□□□□□□□

□□□□electrons□

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□ifferent □om□onents in the System

- □hermal electrons at small r□s□□mm □□m□ □heart of the accretion engine□
- □hermal electrons at large r□□□iescent □□rays
- □ower□law electrons at small r□IR and □□ray flares
- □ower□law electrons at intermediate r□radio

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Radiatively Inefficient or Mass □□tflow□

- Strong o□tflow occ□rs □□□□if the accreting gas is advection□dominated□radiatively inefficient
- □orrect □□estion□Is Sgr A* dim
  - only □eca□se the gas is radiatively inefficient □old A□AF□□or
  - is it a com□ination of □oth radiative inefficiency and a large mass o□tflow □new A□AF□□
- Answer□□□□□□r □from □olari□ation data□co□□led with strong theoretical arg□ments and sim□lations□
- □imness of Sgr A* is d□e to □□ro□ghly e□□al□factors□
  - Ins□fficient mass s□□□ly□Mdot$_{□ondi}$ □ □□$^{□□}$Mdot$_{□ld}$
  - Radiative inefficiency□ Mdot$_{□□}$ □ □□$^{□□□}$Mdot$_{□ondi}$
  - Mass o□tflow□ □$_{acc}$ □ □□$^{□}$ □□□□Mdot$_{□□}$ c□□

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Accretion vers□s □et

- □ardly any difference □etween the A□AF and the □□ase□□ore of the □et□□□□asi□thermal electrons□
- □hermal electrons are almost certainly in the A□AF
- □ower□law electrons may well □e in a □et □Falc□e□ Mar□off□□tho□gh A□AF not r□led o□t
- □hoice is not A□AF model vs □et model
- □hoice is □□re A□AF model vs □et□A□AF model

Dim Galactic Nuclei

SM□□ □rowth d□ring A□AF □hase

- □ow m□ch mass wo□ld Sgr A* accrete in a □□□□e time □□□□□yr□□

Accretion Model	*Mdot □M$_\varepsilon$□yr□*	*ΔM □M$_\varepsilon$□*	*ΔM□M□□*
□ondi	[illegible]	[illegible]	[illegible]
A□AF □s□□□	[illegible]	[illegible]	[illegible]
A□AF □s□□□□□	[illegible]	[illegible]	[illegible]
Rad□□fficient	[illegible]	[illegible]	[illegible]

- SM□□s s□end most of their time in an A□AF state□□□t they accrete most of their mass in a radiatively efficient thin dis□□hase □as □□asars□
- □onsistent with mean rad□efficiency of SM□□s □Soltan□□□□ □remaine□

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□hat □ave □e □earned from Sgr A*□

- Accretion mode is different from a thin dis□□□□: advection□dominated□radiatively inefficient □A□AF□RIAF□
- □im galactic n□clei are not □□st dim versions of A□N □□□: their accretion flows corres□ond to very different □hysics
- □verything cons□ires to ma□e Sgr A* □ltra□dim□
  - □ess gas ⇒ $\dot{M}_{\rm Bondi}$ □ $10^{-4}\,\dot{M}_{\rm Edd}$ □□right A□N □ □□□□□Mdot□dd□
  - □ho□ed off accretion ⇒ $\dot{M}_{\rm BH}$ □ $10^{-2.5}\,\dot{M}_{\rm Bondi}$
  - Radiatively inefficient ⇒ $L_{\rm acc} \sim 10^{-2}\left(0.1\dot{M}_{\rm BH}c^2\right)$
- Mostly thermal electrons in A□AF□□□t also an im□ortant fraction of nonthermal electrons □□erha□s in a □et□
- Negligi□le SM□□mass growth d□ring A□AF □hase