

# **Cosmic Jets: What, How, Why and When?**

GLAST for lunch  
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## **Cosmic Jets**

- \* What are Jets?
- \* How do Jets Shine?
- \* Why do Jets Form?
- \* When were Jets Made?

## Assumptions

- \* Galaxies contain massive black holes which power AGN
- \* Gas accretes through a magnetized disk
- \* Blazars are relativistically beamed
- \* AGN jets emit nonthermally through synchrotron and inverse Compton radiation

## What are Jets?

- \* Ionic plasma moving with  $\Gamma \sim 10$ 
  - Also UHE proton beams?
- \* Pair plasma
  - Not close to the hole because of radiative drag
- \* Poynting flux
  - AC/DC

*All of the above?*

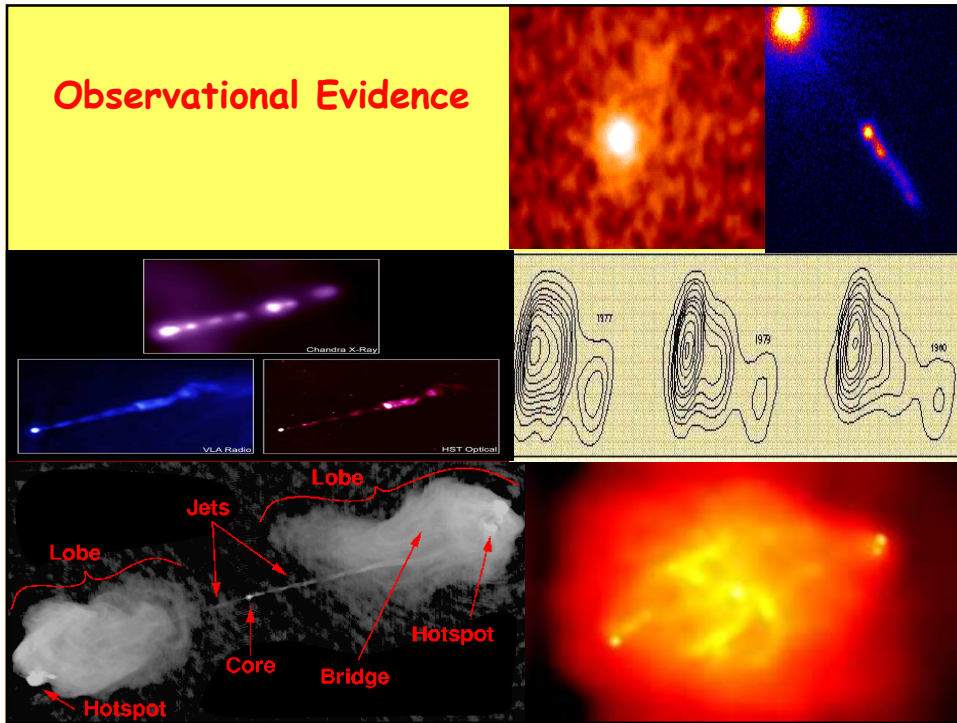
## (My) Theoretical prejudices

- \* Disks make mildly relativistic outflows; ultrarelativistic jets derive from black holes
- \* Pairs easy to create (and destroy)
- \* Entropy hard to create
- \* Poynting flux (DC) necessary for efficient collimation over large distances
  - Requires long term, organized field
- \* Jet deceleration through entrainment of ion plasma
- \* Jets have velocity gradient,  $\Gamma(r)$

## Observational Evidence

- \*  $\Gamma \sim 1-50$  (FRI-FRII)
  - GRB  $\Gamma \sim 300-1000$
- \* Observer outside jet
  - Cf GRBs
- \* M87 collimated at  $<300m$
- \* No SX precursors - no bulk Comptonization

## Observational Evidence



## What GLAST can tell us

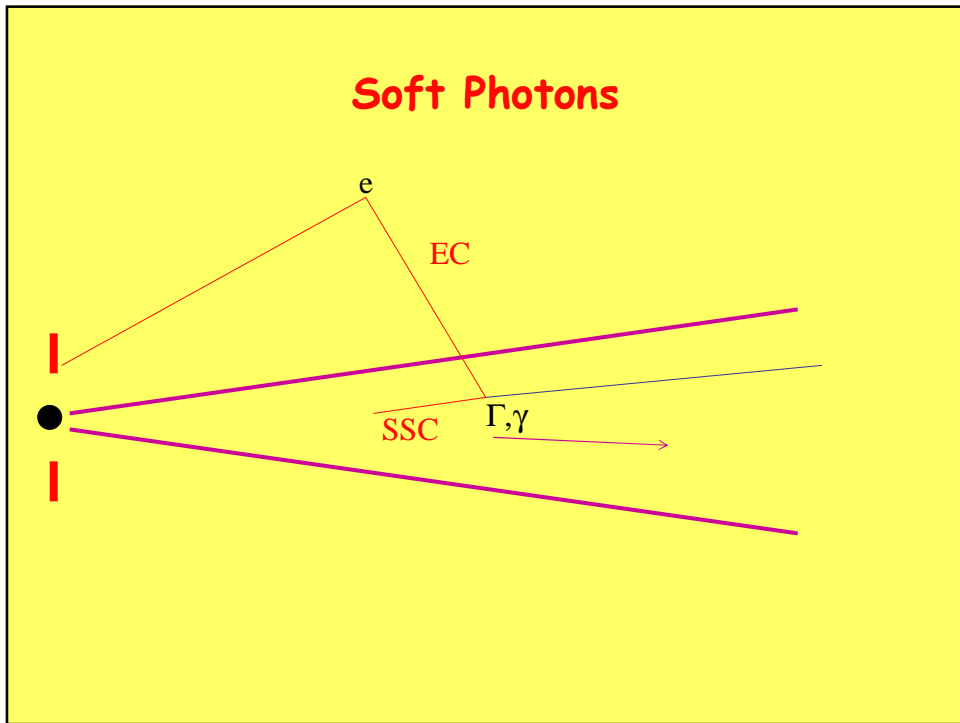
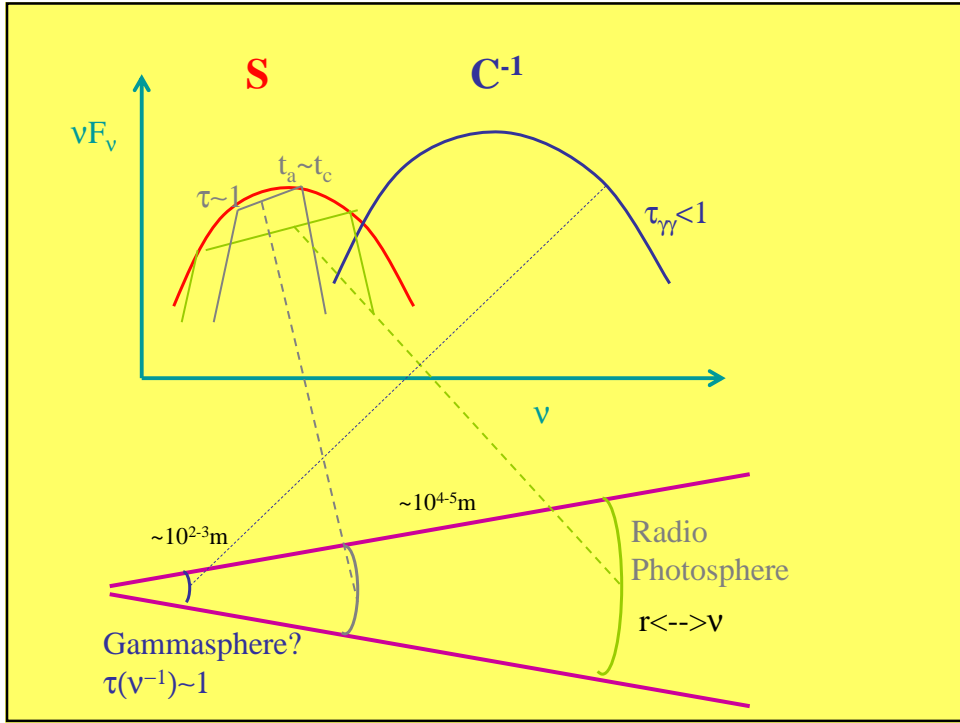
- \* Locate radius of gamma ray emission
  - Variability, correlated variation
  - Bulk Comptonization?
- \* Are radio jets pair plasmas?
  - VLBI Polarization observations
    - Faraday rotation/pulsation
- \* Is there toroidal field?
  - VLBI Faraday rotation gradients
- \* GeV Polarization???
  - RHESSI 80 percent???

## How do Jets Shine?

- \* Radio - synchrotron
  - cyclotron maser?
- \* Gamma rays - inverse Compton
  - external (high power)
  - internal (low power)
- \* X-rays
  - inverse Compton (high power)
  - synchrotron (low power)
  - bulk Compton

## Theoretical prejudices

- \* Particle acceleration
  - Strong (non-relativistic) shocks
    - *Not in electromagnetically-dominated jets*
  - Relativistic shocks conserve energy per particle?
  - Stochastic acceleration
  - Pair production EASY
    - *Charge limited production may follow from turbulence cascade*
- \* Relativistic beaming is a very powerful amplifier
  - $\sim \Gamma^{2(3)+\alpha}$
  - See  $\Gamma \sim \theta^{-1}$
- \* Coherent (cyclotron maser?) emission
  - High brightness temperature radio emission



## Observational Evidence

- \* Spectral variability greater above peak
- \* Large, directly measured brightness temperatures => coherent emission?

## What GLAST can tell us

- \* Better sampling of variability in brightest sources
  - TeV varies in 30 min in Mkn 421
  - Does GeV vary faster?
    - *Gamma sphere emission?? =>  $t \sim \nu$*
  - Locate source of GeV, TeV emission
    - *Multi wavelength campaigns*

## Why do Jets Form?

### \* Accretion Disk Exhausts

- Remove angular momentum - up not out
  - *cf the Sun*
- Remove energy - adiabatic accretion
  - *Low mass supply rate, two temperature thick disk, MHD wind*
- Maximal Speed?

### \* Black Hole Power

- Original (vs venial?) Spin
  - *From the ergosphere not the horizon*
- Efficiency?

### \* Is there a Universal Jet Mechanism?

## Theoretical Prjudice

Ultrarelativistic jets are basically currents driven by unipolar induction

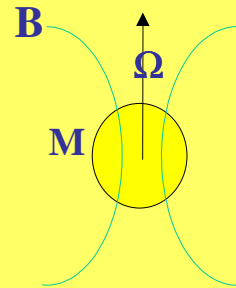
## Unipolar Induction

\* Rules of thumb:

$$\Phi \sim B R^2; V \sim \Omega \Phi;$$

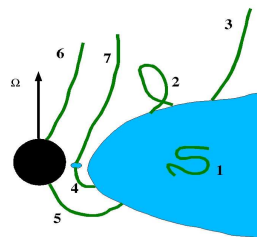
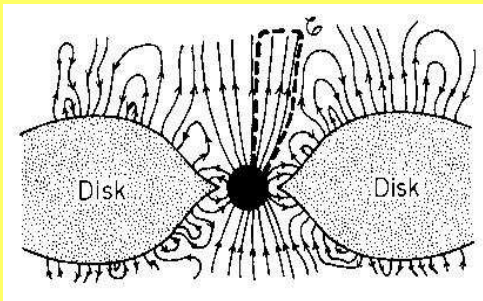
$$I \sim V / Z_0; P \sim V I$$

	PWN	AGN	GRB
<b>B</b>	100 MT	1 T	1 TT
<b>v</b>	10 Hz	10 $\mu$ Hz	1 kHz
<b>R</b>	10 km	10 Tm	10 km
<b>V</b>	3 PV	300 EV	30 ZV
<b>I</b>	300 TA	3 EA	300 EA
<b>P</b>	100 XW	1 TXW	10 PXW



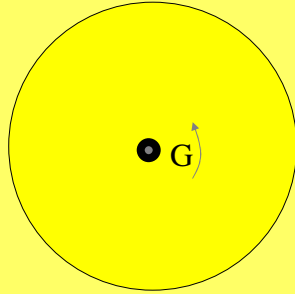
UHECR!

## Black Holes and Disks



## Torque Transports Energy

### Angular Momentum Transport



$$F_L = G - \dot{M} L \sim r^{1/2} \sim 0$$

### Energy Transport

$$F_E = G \Omega - \dot{M} B \sim r^{-1} \sim 0$$

$$B = \frac{1}{2} V^2 + \Phi + W \sim \Omega L > 0$$

Bernoulli Function

Energy transport from small  $r$   
by torque unbinds gas at large  $r$ .

## "Adiabatic" Accretion Flows

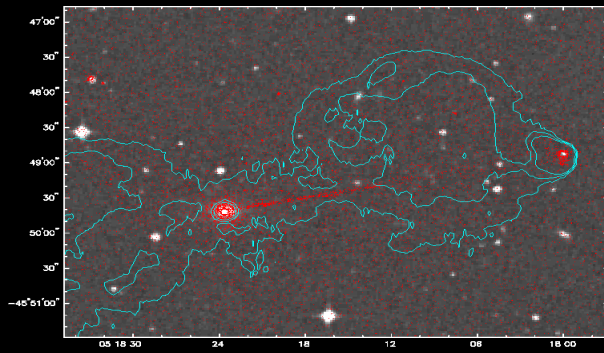
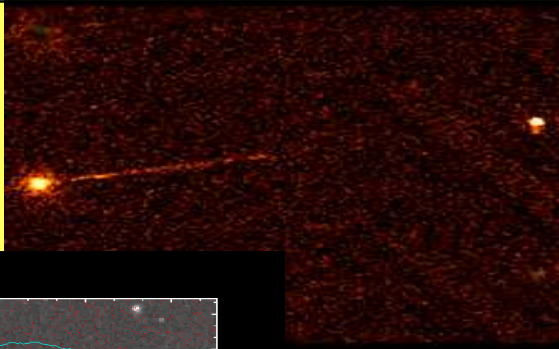
### \* Underfed Accretion ( $\ll$ Edd), eg Galactic Center

- Viscosity large and heats ions
  - rapid inflow
  - negligible electron heating and radiative loss
  - $\gamma \sim 5/3$
  - Ultrarelativistic outflows?

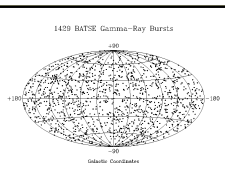
### \* Overfed Accretion ( $\gg$ Edd), eg BALQ, GRB

- Photons trapped by Thomson scattering
  - $r/m < (dM/dt)/(dM/dt)_{\text{Edd}}$
  - independent of viscosity
  - $\gamma \sim 4/3$
  - $C_p$  large
  - Mildly relativistic outflows?

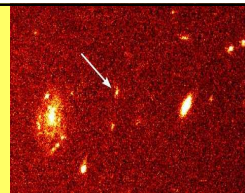
## Observational Evidence Pictor A



Active collimation?

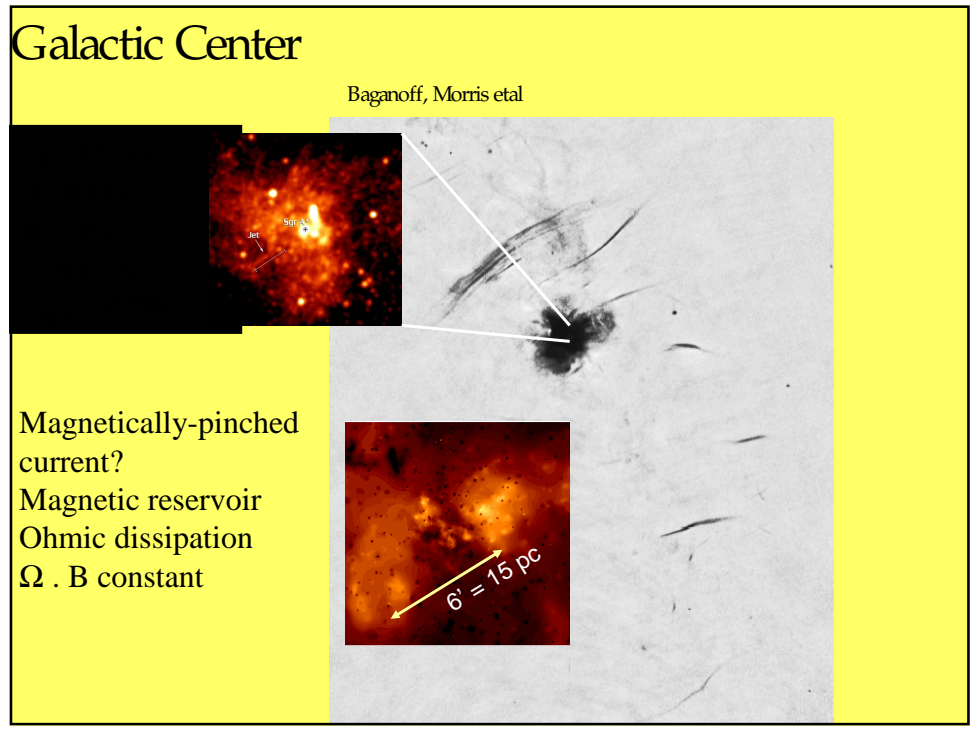
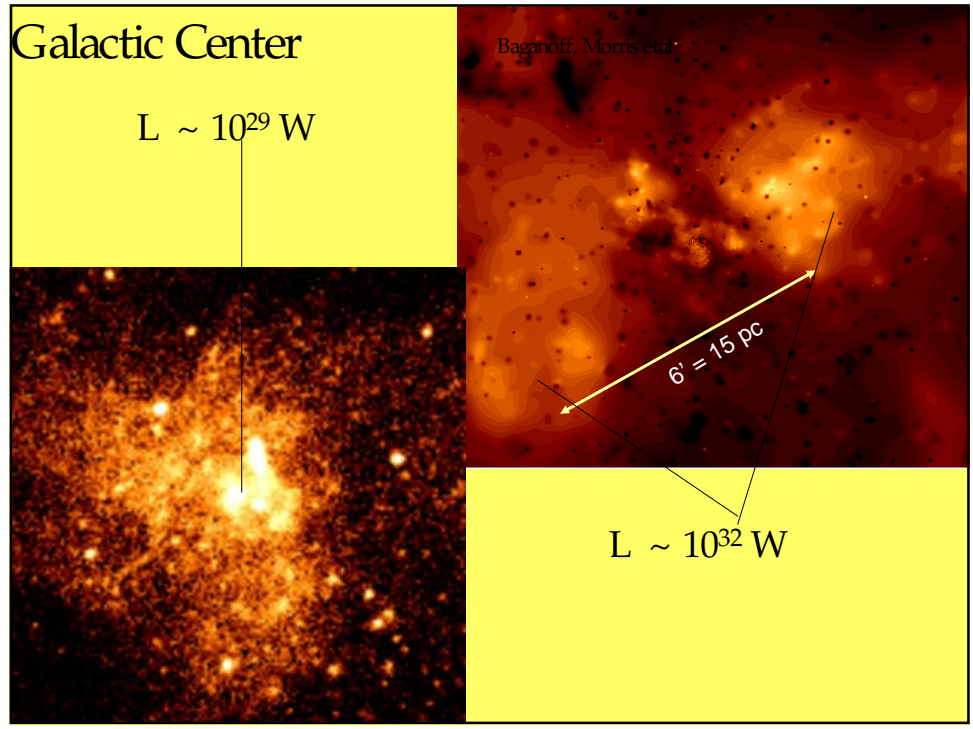


## Gamma Ray Bursts



- \* **Long bursts**
  - ~3-100 s E  $\sim 10^{51}$  erg (beaming)
  - ~1d -1yr afterglows
  - Associated with SNIc; BH/NS formation
  - Achromatic breaks => jets?
  - Gamma ray escape =>  $\Gamma > 300$ ?
- \* **Short bursts**
  - 0.1-3 s
  - ?





## What GLAST can tell us

- \* Observing indirectly close to source in powerful objects
- \* Detect (or limit) non-blazar FRIs
  - eg Cygnus A
  - Sins of transmission not emission
  - FRIs may be better

## When were Jets Made?

- \* AGN evolution - chickens and eggs
- \* Role of Black Holes in galaxy formation and evolution
  - Side show or instigator?

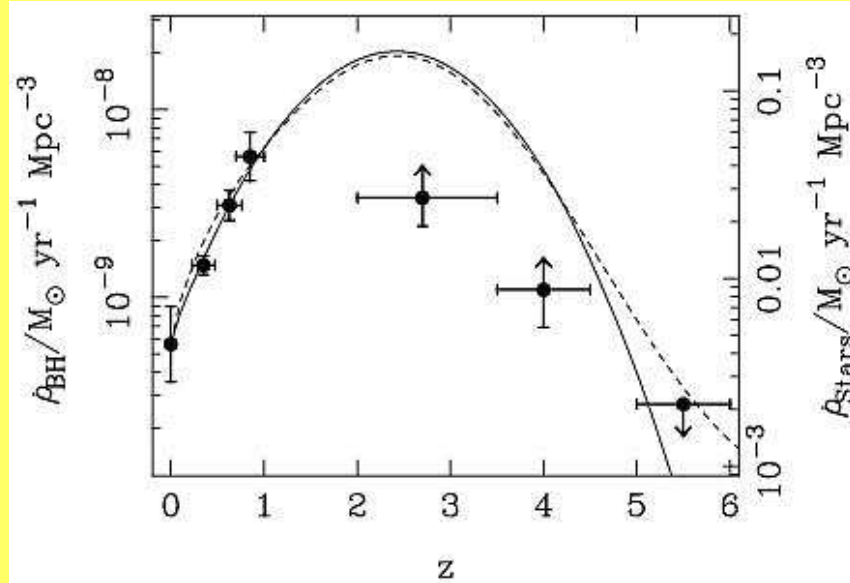
## Theoretical prejudice

- \* AGN have large role in galaxy formation and evolution
- \* Early growth may be dominated by radiation-dominated high mass supply case => jets are more local

## Observational Evidence

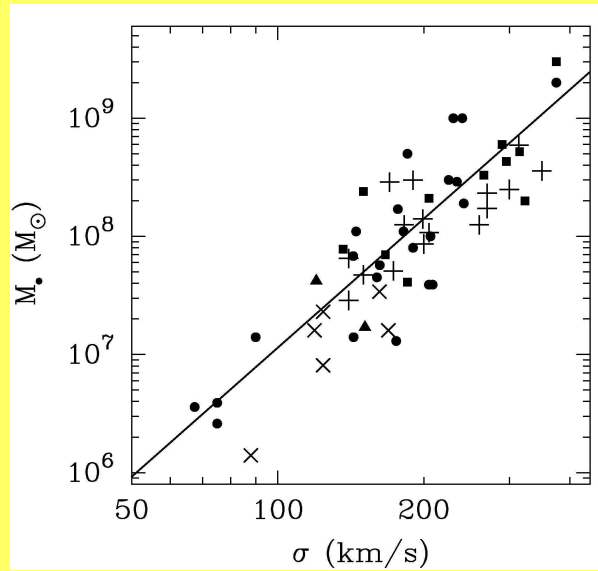
- \* High power AGN  $10^3$  times more plentiful when  $t \sim 3\text{Gyr}$
- \* Contrast less for low power AGN
- \* Blazars appear to be more local still
- \* X-ray background contributed by older (closer) AGN
- \* Compact doubles maybe baby radio sources

## Cosmic BH/star formation

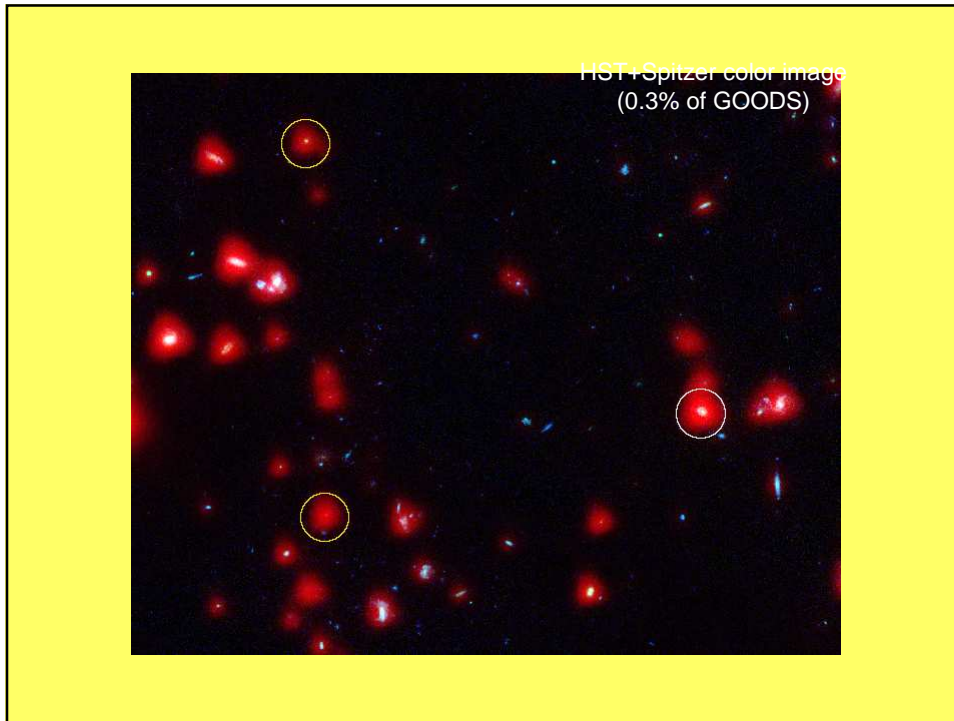


Dunlop 1999

$M_{\text{BH}}$  related  
to galaxy  
bulge in  
normal and  
active  
galaxies



Kormendy & Gebhardt 2001



### The first supermassive black holes?

- \* 7 X-ray sources with
  - no optical counterpart (HST)
  - detected in K band
  - $L_*$  host galaxy would be visible to  $z \sim 7$
- Ø *Detected with Spitzer*
- Ø *One or two may be the most distant AGN ever ( $z > 7$ )*
- Ø *5 are dusty AGN at  $z \sim 3$*

## What GLAST can tell us

- \*  $10^4$  GLAST blazars with 0.02 power may sort out evolutionary properties
  - M, M' evolution or environment
    - Collimation, nuclear density?
- \* Gamma ray background
  - Resolved sources?
    - Blazars, clusters, XRB....
    - High latitude source vs diffuse energy density; 6% -> 20%?
  - GeV cosmic rays in intergalactic shocks in dense environments??
    - $\pi^0$  decay line feature
  - Early XRB arguments can be used.

## Summary

- \* GLAST can address fundamental questions re AGN, black holes, jets
- \* Multi-wavelength observations crucial and must be planned well ahead of time
  - Surveys
  - VLBI
  - TeV
- \* Lot of discovery space