Class 18: Jets!
RECAP

- Properties of active galactic nuclei (AGN)
  - Radio observations ➔ relativistic jets
  - Optical/UV observations ➔ accretion disk (+ maybe jet)
  - X-ray observations ➔ corona of inner accretion disk
This class

- Relativistic jets
  - The radio galaxy “zoo”
  - The one sidedness of jets
  - Ultra high resolution imaging of jets
  - How do we really know they are relativistic?
    - Superluminal motion
Observed properties of jets:

- Often single-sided (e.g. M87/Virgo-A)
- Clearest in radio emission, but emit across spectrum
- Often fairly (but not exactly) straight
- Always connect back to core of galaxy
- Some start dim and then brighten to edge...
- Some start bright and then darken to edge...
- And some are just weird!
M87/Virgo A (3C274)
Cygnus A
Example of “Edge Brightening”

Discussion – what are the interesting aspect here?
3C296
Example of "Edge Dimming"
3C129... a “head-tail” source
• Jets are clearly seen to interact with surrounding matter
  • “Hot spots” in radio emission correspond to the point where the jet “splashes” (shocks!) against surrounding matter
  • Jets can bend if they hit interstellar gas clouds
  • Can see shock waves and other disturbances in surrounding matter (often best seen in X-rays)
Radio view (jet plasma) X-ray view (surrounding gas)

Computer simulation of jetted AGN (Dr. Brian Morsony / UMd)
Radio
Radio + X-ray
II: Relativistic effects

- One sidedness of jets

- Looks strange!
- Why would such powerful jets be created asymmetrically?
- In fact, this is illusion created by relativistic beaming
- Approaching jets appears much brighter than receding one
- Correcting for this, jets seem to be symmetric
Superluminal motion

- Recall diffraction limit for telescopes
  \[ \theta \approx 70^0 \times \frac{\lambda}{D} \]

- Can link radio telescopes across the global to make D=diameter of Earth...
  - Very Long Baseline Interferometry (VLBI/VLBA)
  - Can obtain resolutions of 0.001 arcsec or less
  - Can examine jets close to where they are created

- Find that jets are knotty
  - And knots move
  - ... very fast! Often appear to be traveling out >c
  - In fact, this is a dramatic confirmation of Special Relativity!
3C120 with the VLBA
VLBA 22 GHz Observations of 3C120

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Decreasing line of sight angle
III : Formation of Jets

- Jets are clearly accelerated and collimated in the immediate environment of the black hole
- Currently favored theoretical model...
  - Central spinning black hole
  - Threaded by magnetic field generated by accretion disk
  - Then... black hole rotation twists fields into “coils” which expand away from black hole
  - Energy comes from black hole rotation
  - Example of a Penrose Process (magnetic form attributed to Blandford & Znajek 1977)
- Explains why some AGN have no/weak jets
  - need both the black hole spin and the magnetic field!
  - If you lag either ingredient, no jets.