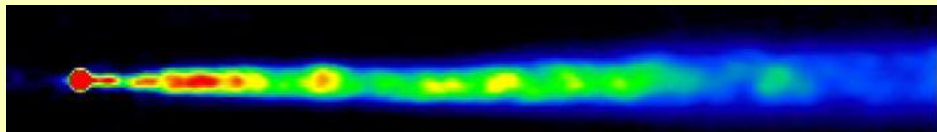
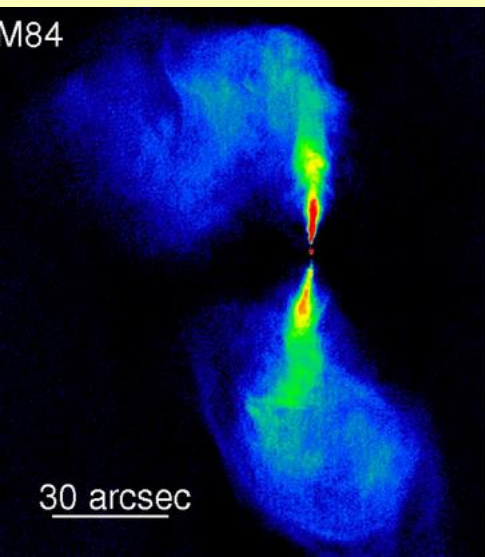


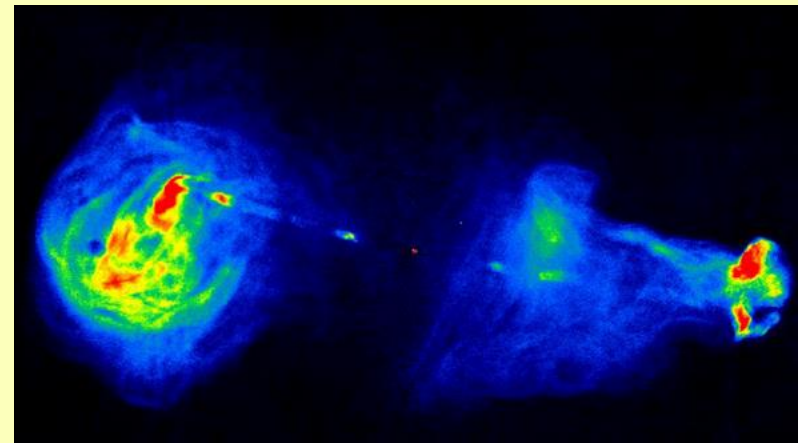
# Extragalactic Radio Jets: Cause and Effect



Roger Blandford  
KIPAC  
Stanford



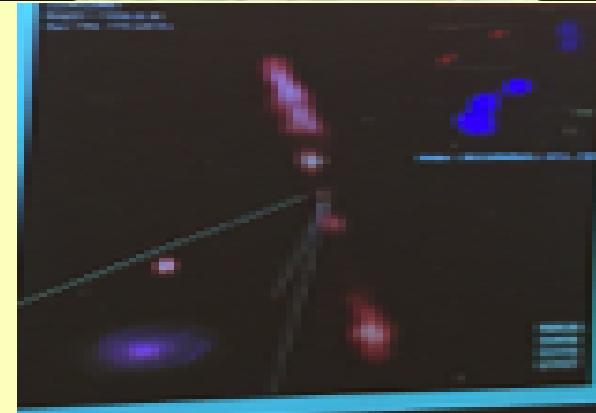
ICTS



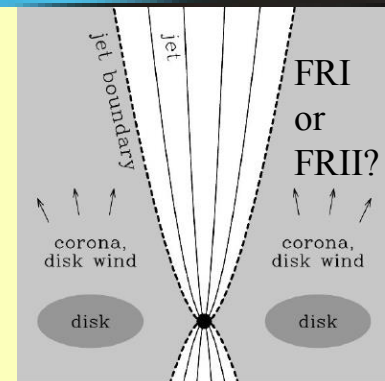
# The Naming of Jets

THE MORPHOLOGY OF EXTRAGALACTIC RADIO  
SOURCES OF HIGH AND LOW LUMINOSITY

*B. L. Fanaroff and J. M. Riley*



4  
3  
2  
1  
€



## • Fanaroff & Riley

- No reason to modify *Laing Shastri*

## • Blazars *Shastri, Potter*

- BLLacs + FSRQ

## • (Rare) Large Spiral Jets *Bagchi, Hota,*

- Seyferts *Orienti, Stalin*

## • Quasars for the Impatient

- GRB, pulsars, protostars...

- Microquasars *Blundell*

- Cyg X-3, Cyg A!, Binary black holes or QPOs

## • LE(R)G vs HE(R)G *Hardcastle, Laing*

- Why aren't blazars HERGS *Readhead*

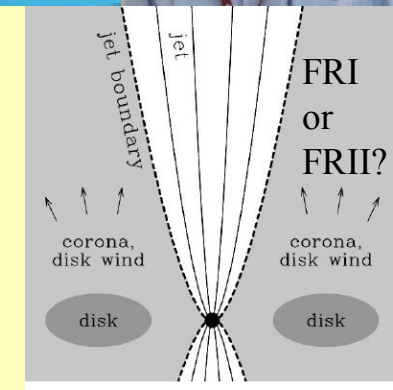
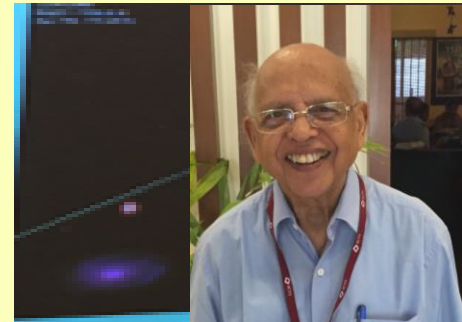
## • Radio Loud vs Radio Quiet *Laing*

- Unification *Hardcastle*

# The Naming of Jets

THE MORPHOLOGY OF EXTRAGALACTIC RADIO SOURCES OF HIGH AND LOW LUMINOSITY

*B. L. Fanaroff and J. M. Riley*



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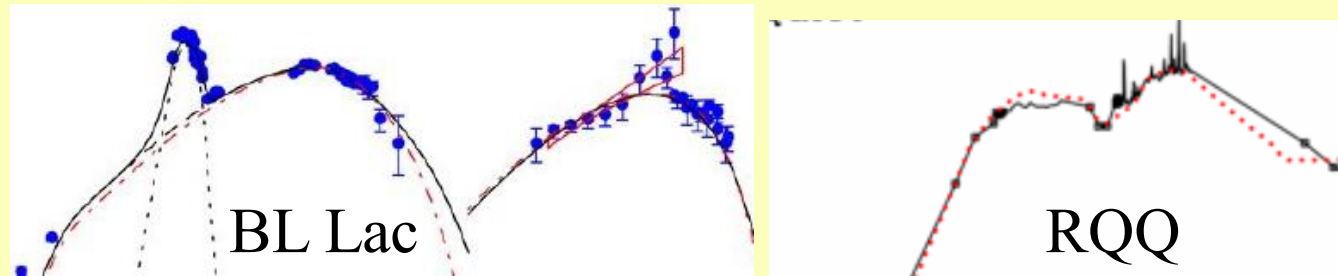
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# AGN Spectroscopy for Dummies



# AGN Spectroscopy for Dummies

**Bactrian**



*Reeves*

**Dromedary**

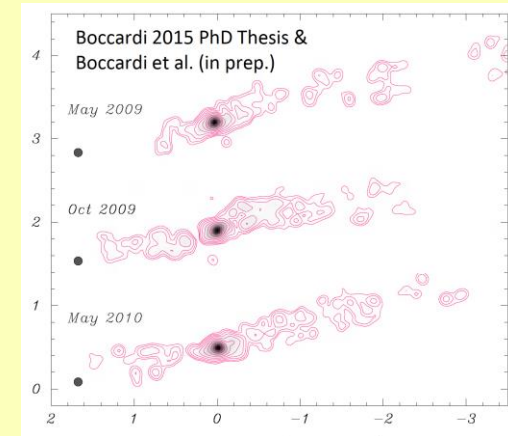
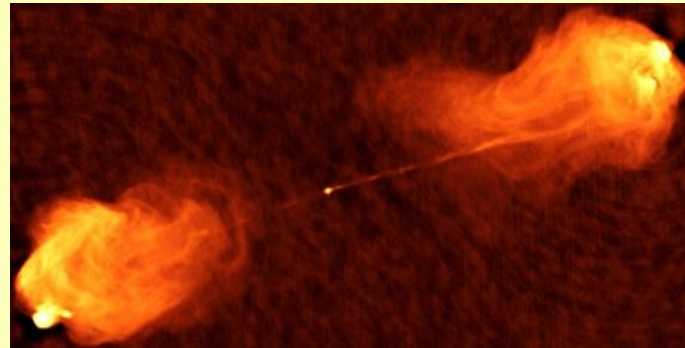
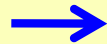
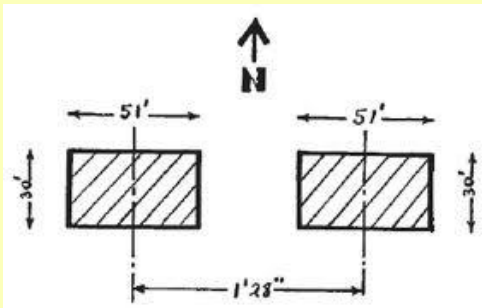




# RMS Progress

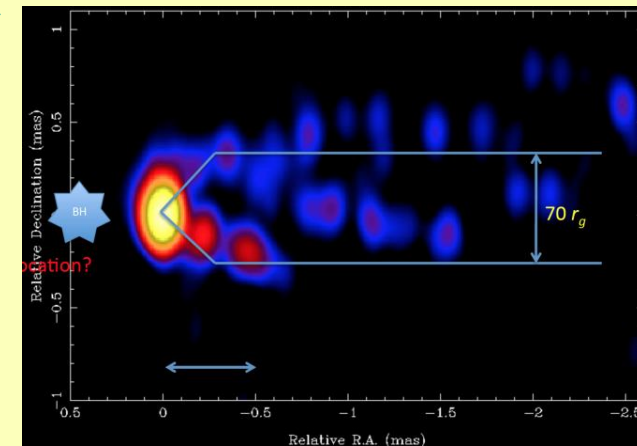


Jennison & Das Gupta 1953



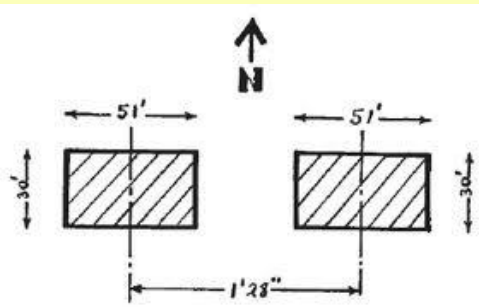
- **Exquisite imaging** *Zensus Falcke ...*
  - VLBI(gd+sp), EVLA, GMRT/LOFAR-> SKA
- **Systematic surveys** *Hovatta, Reeves*
  - MOJAVE, OVRO, FGAMMA
  - Multiwavelength esp.  $\gamma$ -rays
- **M87** *Nakamura*

M87



# RMS Progress

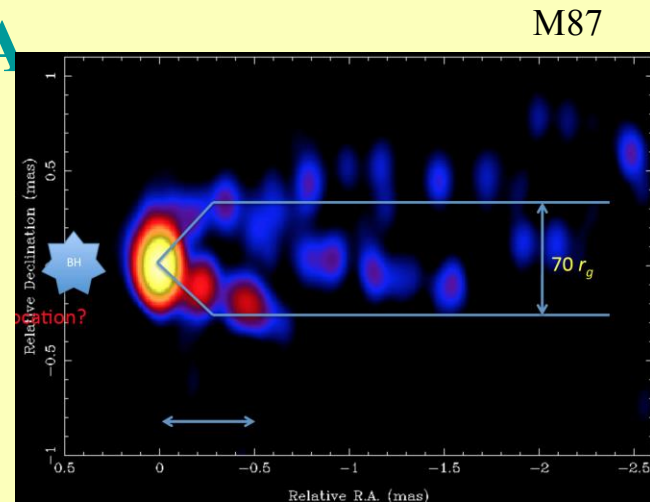
Jennison & Das Gupta 1953



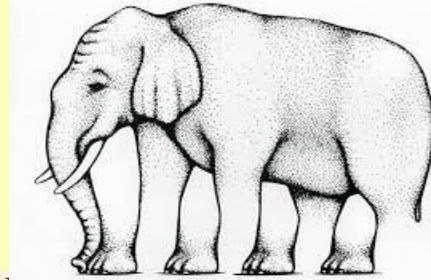
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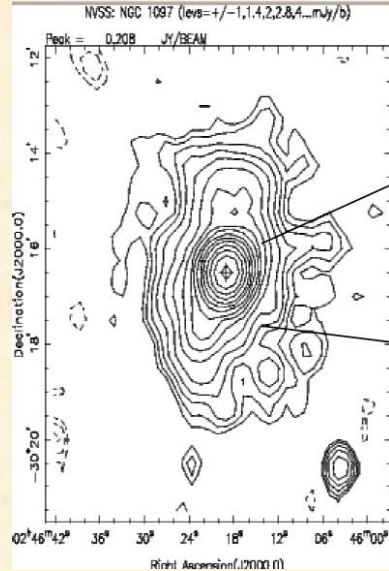
# Optical Illusion



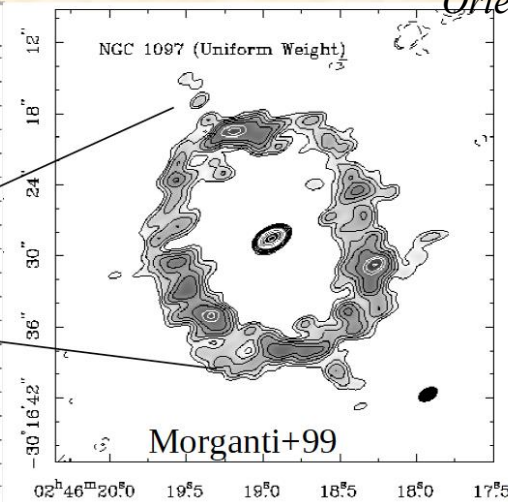
GALEX



NVSS

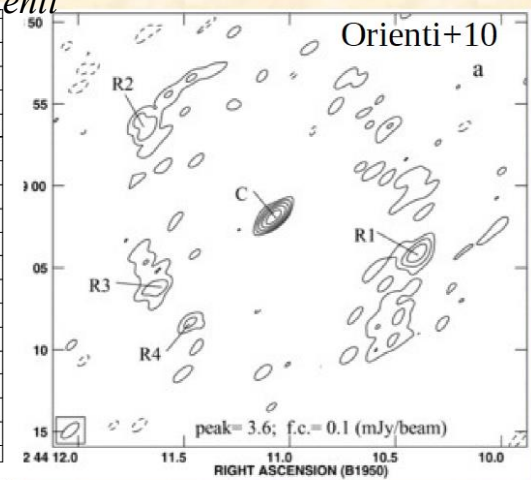


VLA-BnA C band



Oriente

VLA-A & DIII



- IGN = Inactive Galactic Nuclei are still nonthermal emitters
- Contribution to backgrounds
- Kepler data PSD *Wiita*
- Optical Polarimetry Surveys - flares *Pekeur*
  - QPO in PKS 2155-304?
- 4C 35.06 cD in formation *Biju*



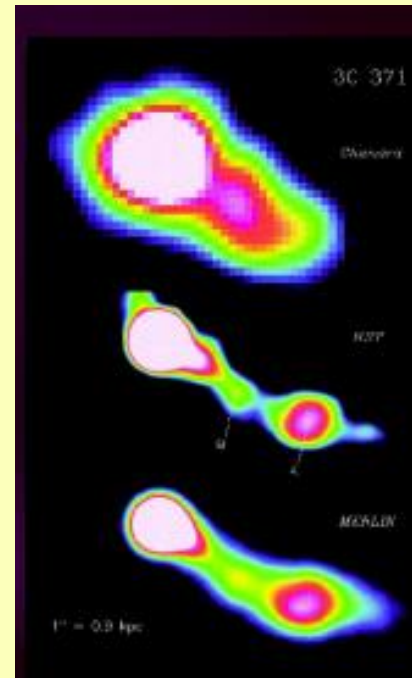
# X-ray Vision



- Chandra arcsecond! imaging *Marshall*
- Problem with ICCMB model? *Marshall, Meyer*
  - $\gamma$ -ray deficit
    - Could be KN suppression? *Sahayanathan*
  - But do see scattering of CMB in old lobes *Blundell*



*Wilson, Hardcastle (in prep.)*



- Interpretation of Knots *Sahayanathan*
- AstroSAT, Astro-H, X-ray Polarimetry?



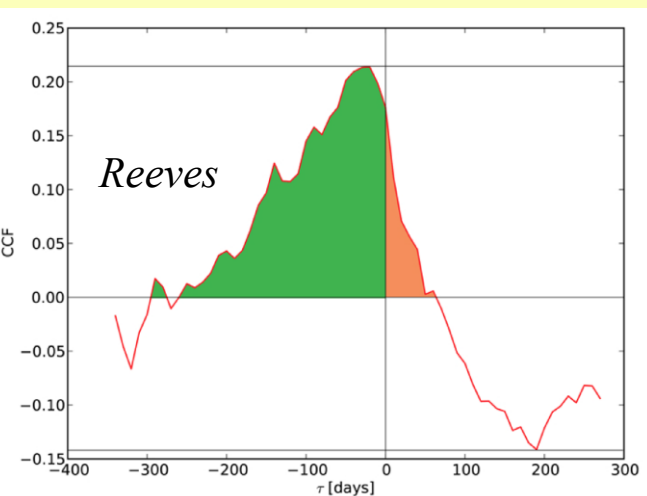
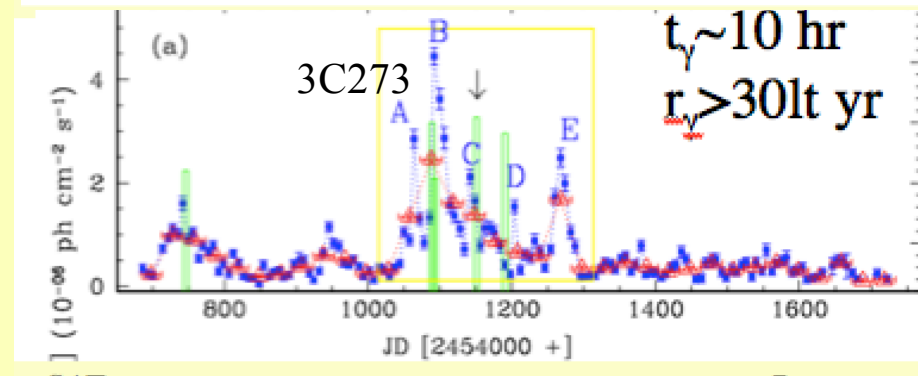
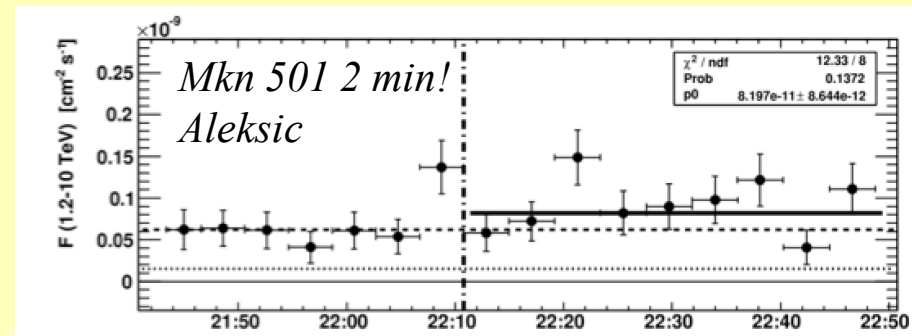
15

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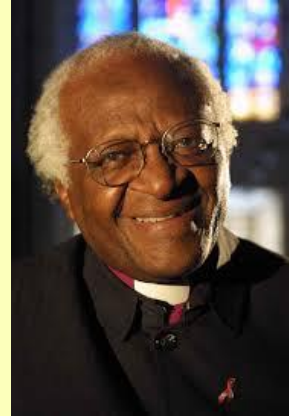
# Temperamental $\gamma$ -rays



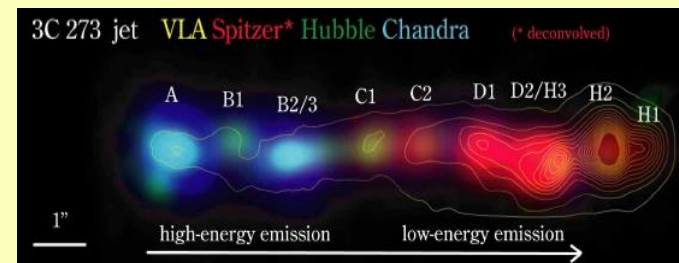
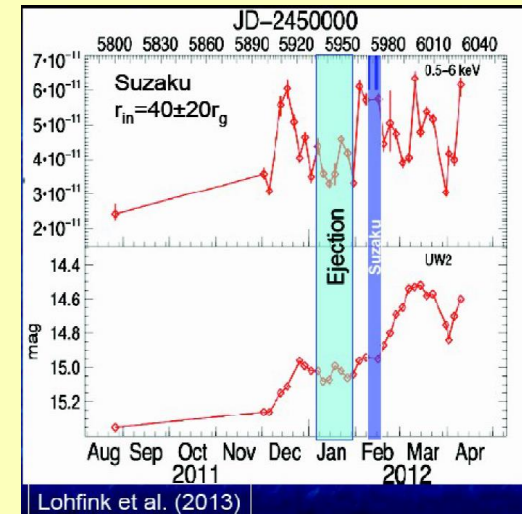
- **GeV and TeV blazars** *Rani, Bhattacharya Paliya Shastri, Sinha*
    - $R_{em} > R_{\gamma}$  (gammaspHERE)
    - Size < kinematic factor  $ct_{var}$
  - **Dramatic acceleration**
    - Ohmic dissipation
    - Also PWN, GRB
- $\gamma$  before R



# Rainbow Nation



- 10MHz - 100 TeV
  - Scattering – pair production on CMB
- Multiwavelength monitoring
  - Huge campaigns anchored by Fermi *Paliya, Rani*
  - Must have well-defined samples *Readhead*
- Synchrotron
  - Requires 100TeV electrons
- Inverse Compton *Rani*
  - External (FSRQ-415), Internal (BLL-602)
    - Fast flares asymmetric; slow flares symmetric *Chatterjee*
    - Also hadronic models *Rani*



# The Whole Jet Disconnection

- 3DRHD/RFF simulations

- Efficient x 2; collimated, robust

- Thick disk
- Thin disk weaker jets

- Fundamental Plane *Saikia*

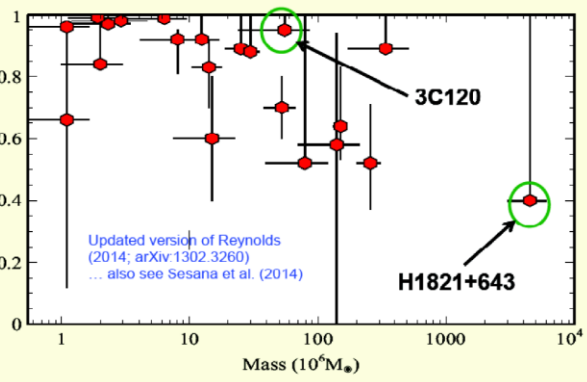
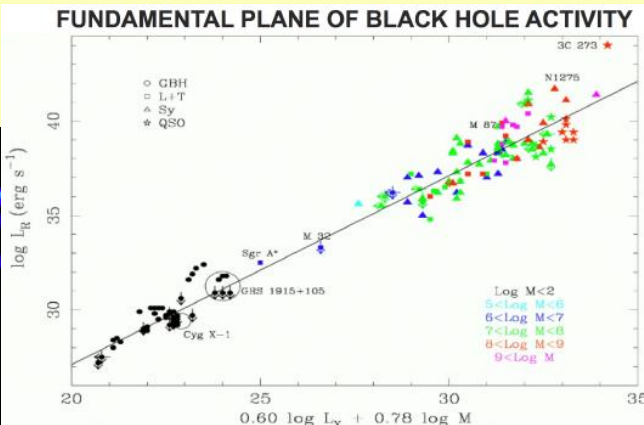
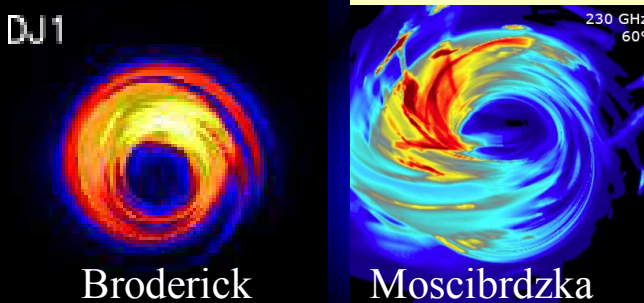
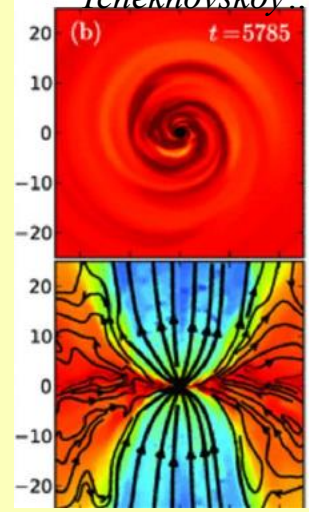
- Event Horizon Telescope (*Falcke, Readhead, Nakamura*)

- Already a success; how far can this go?

- Closure phases at 1mm
- Will SgrA\* be stable for long enough?  $m \sim 20s$  vs 10 hr for M87

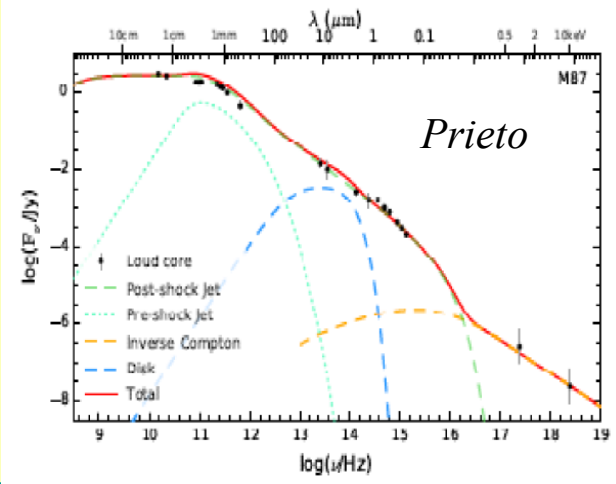
- EW baseline to Africa; NS to Greenland?

- RMHD models

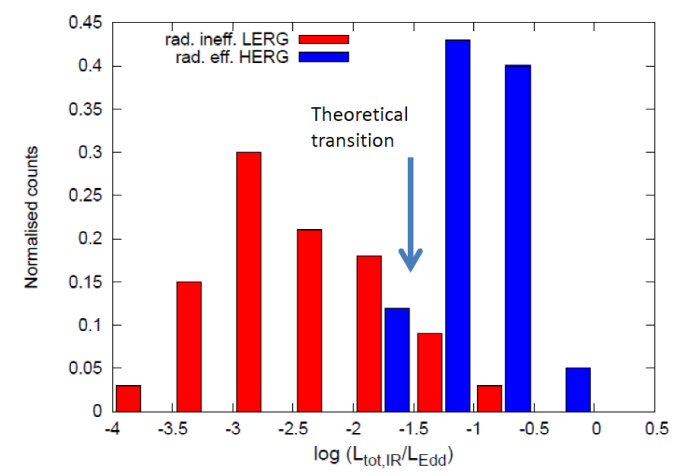


# Cost of Jet Fuel

- MRI -> MHD disks
  - MAD simulations *Tchekhovskoy*
- $L_{\text{disk}} \ll P_{\text{jet}}$  sometimes
  - Mass accretion  $\sim < 10^{-4}$  supply?
  - ADAF vs ADIOS
- Lines?
  - Big and little tori; support?; warped disk
  - Rawlings-Saunders correlation?
- Accretion limit cycles *Hardcastle, Potter*
  - LERGs and HERGs different modes?
  - Mode changing in SS433 *Blundell*
  - Not Bondi accretion *Hardcastle*



Accretion switch current status





# Go with the Flow

## • Superluminal Expansion

–  $V \sim 1-30c$

- $\sim 7c$  on kpc scales; (GRB:  $\Gamma \sim 1000$ ?) *Meyer*

## • Composition

– Cen A *Wykes*

## • Kinematics

– Spine-Sheath?

– Acceleration/deceleration *Nakamura, Perucho*

- At Bondi radius? *Nakamura, Potter*

– Precessing jets

- Bends *Singhal*
- Hydra A *Nawaz*

– Orbiting jets?

- 3C31,  $\Omega$  jet *Laing*

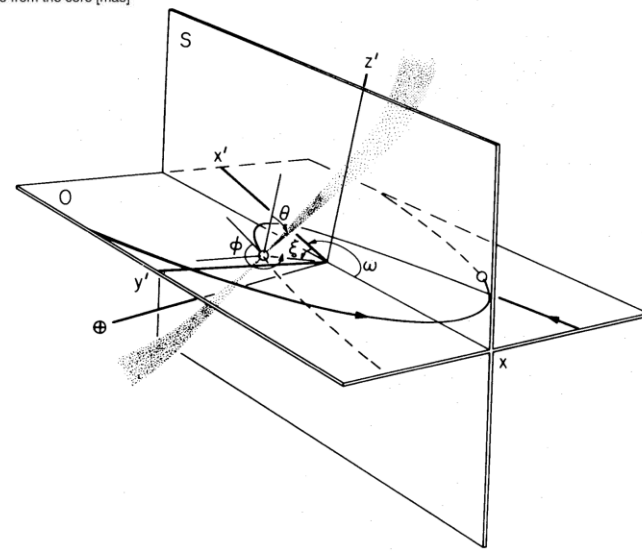
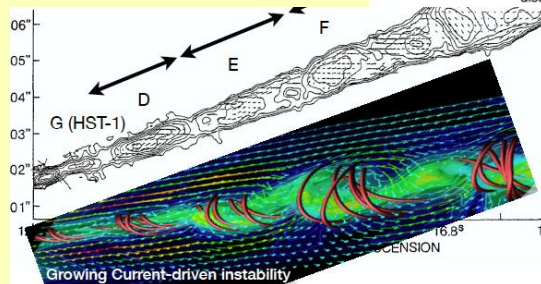
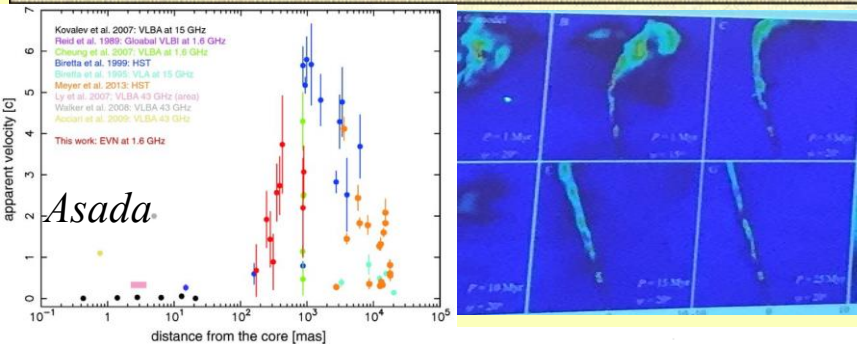
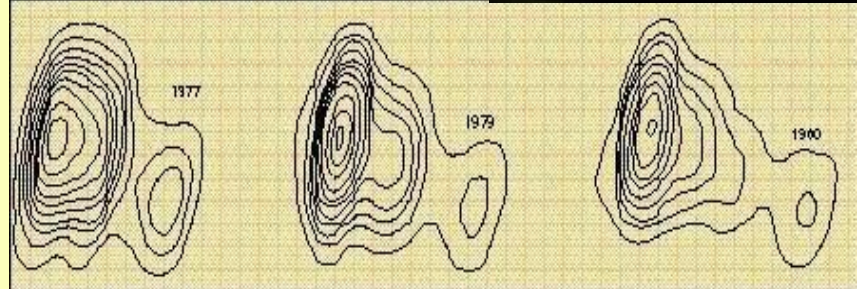
## • Dynamics

– Recollimation

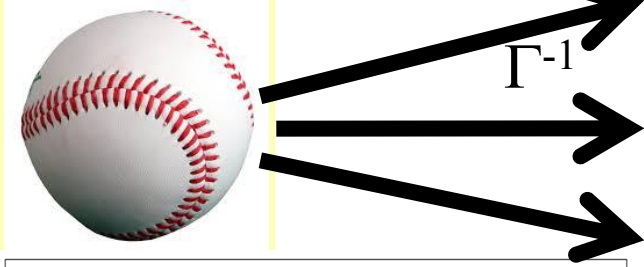
- Gas dynamics OR hoop stress

– Instability *Nakamura*

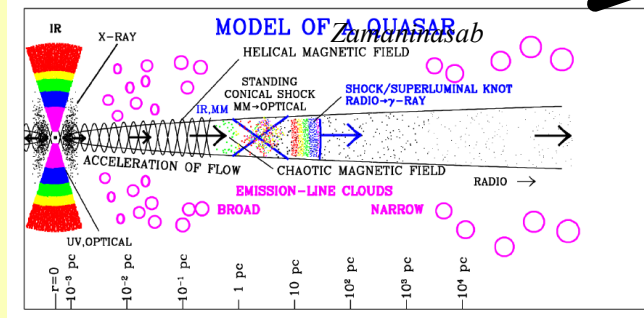
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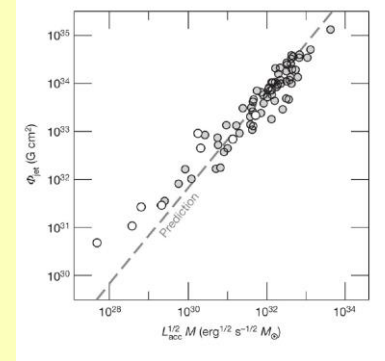
# Field of Dreams



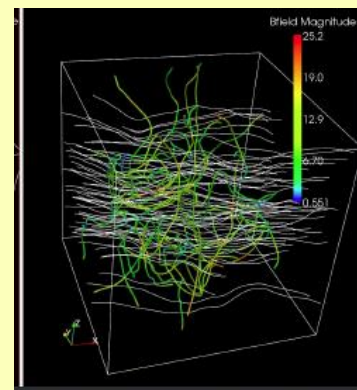
- Strength  $\sim 1T - \sim 1nT$ 
  - $B_{\parallel} \sim A^{-1}; B_{\phi} \sim w^{-1}$ 
    - Helical? and reverse fields *Gabuzda*



- Core shifts  $\rightarrow \Phi$  *Falcke*
  - Simplistic model; learn about  $w(r)$ ?
- Parallel  $\rightarrow$  perpendicular *Laing, Joshi, Wills*
  - Faraday rotation  $\leftrightarrow$  disk polarity *Gabuzda Wills*
  - Dipolar vs Quadrupolar Fields
  - No sign of current (disk field polarity) reversal? *Joshi*



- Magnetic collimation *Hardcastle*
  - Invisible sheath  $\beta < 1$ ; luminous core  $\beta > 1$
- Mediate Particle transport *Reville*



# Electromagnetic Combustion Engine

- Basic Relativistic Jet Scenario

- Spinning BH  $\rightarrow$  high  $\sigma$  outflow  $E \sim B \rightarrow$  PP, entrainment  $\rightarrow \sigma \sim < 1$
- EM field  $\rightarrow$  relativistic particles  $\rightarrow$  photons

- Need 100 TeV electrons; cf  $V \sim EV-ZV!$

- Many acceleration regimes

- Second order [wave-particle] *Reville*

- Shocks *Reville*

- NR Efficient amplify  $B$  high energy

- ER Inefficient at high energy

- EM detonation:  $E > B$  in oblique shock front; radiation reaction limited

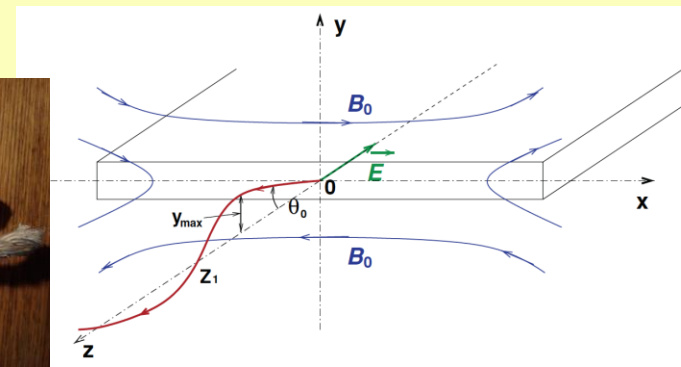
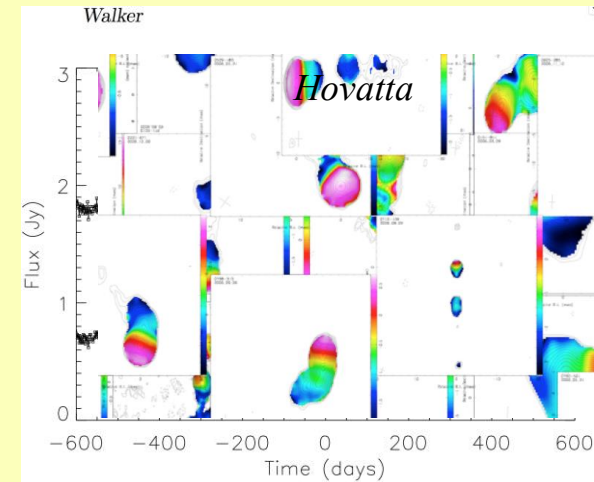
- Reconnection

- NR inefficient; ER efficient?;  $E > B$ ?

- Magnetoluminescence

- Caustics?

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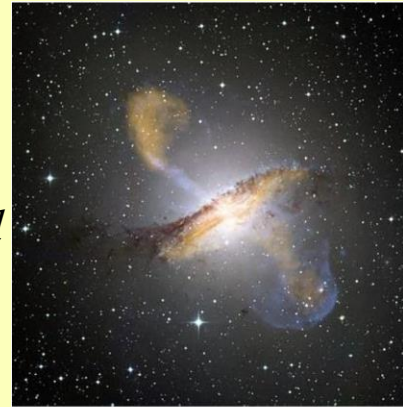
# Environmental Impact Statement

## – Serious heating of ICM *Birzan, Prasad, Kale*

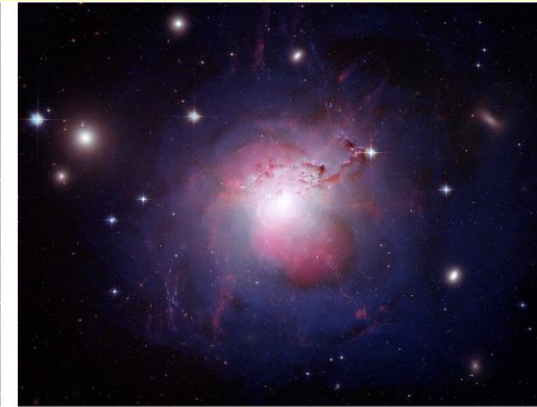
- Sloshing turbulence, internal waves...
  - *Mystery cooling?*
- Plasma heating *Meyer*

## – Feedback Cycle

- Associated outflows *Chand*
- Cold gas
  - *Trigger nuclear activity*
  - *Observations and simulations!*



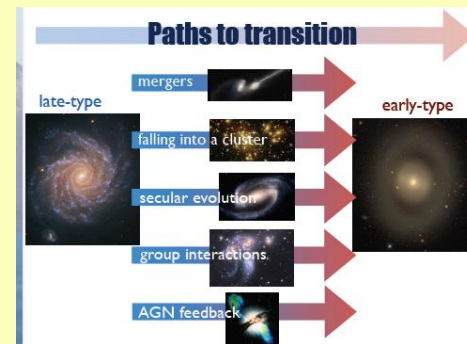
Cen A – e.g. Hardcastle+ 07



Perseus A – e.g. Fabian+05

## – Galaxy formation and evolution *Alatalo, Lanz, Hota, Mukherjee,*

- Moderates mass function
- ALMA-> Inflow/Outflow
- Wet simulations



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- Dust crucial *Singh*

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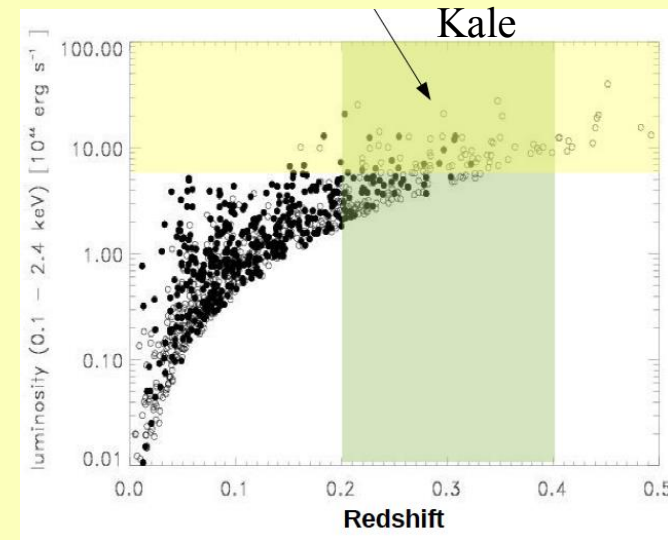
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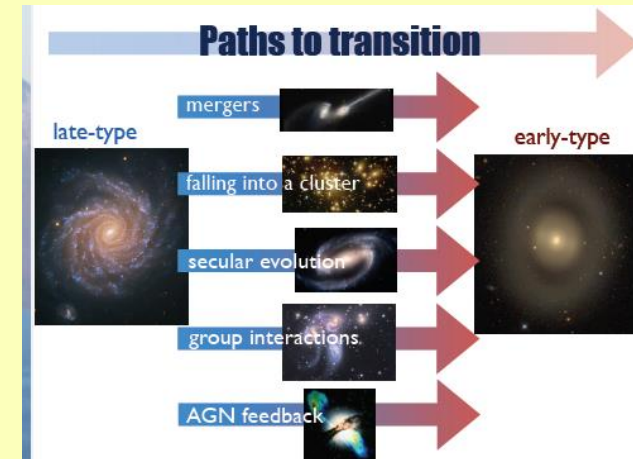
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# Metaphysico-theologico-cosmolo-nigogology



- Can jets contribute to modern cosmology?
  - **Positively through EBR**
    - Also primordial B??
  - **Negatively through galactic and cluster feedback!**
    - Cosmographic systematics
  - **Possible kinematically**
    - Eg an extragalactic counterpart to SS433
  - **As sources for EoR absorption studies**

# B2230+114

C.T.A. 102 Year over year receiving you  
Signals tell us that you're there  
We can hear them loud and clear  
We just want to let you know  
That we're ready for to go  
Out into the universe  
We don't care who's been there first  
On a radio telescope  
Science tells us that there's hope  
Life on other planets might exist

*McGuinn 1967*

