Do Black Holes make Galaxies?

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Do Pulsars make Supernova

Ostriker & Gunn 1970

It is shown that both supernova remnants and visual supernovae require continuous energy input. The characteristics of pulsars, known to be associated with supernova remnants, make them ideal candidates for this energy source; in this picture both the expansion kinetic energy and the visual output are provided by the rotation of a neutron-star remnant. Comparisons with observations are made for the Crab Nebula, Vel X, Cas A, and η Car.
No!

But: Pulsar Wind Nebulae
Millisecond Magnetars as long GRBs?
Neutrinos
Do Black Holes make Galaxies?
No!

But: Heating of circumgalactic medium/cluster
    Relativistic Jets
    Accretion Disks
Simple Energetics

- $E_{AGN} \sim 3 \times 10^{61} M_{H8}$ erg
- $E_{stars} \sim 10^{62} M_{H8} \times$ erg
- $E_{SNR} \sim 10^{61} M_{H8}^y$ erg
- $E_{halo\ gas} \sim 3 \times 10^{59} M_{H8}^z$ erg
- Limit galaxy formation??
$L_{\text{disk}} < 3 \times 10^{34} \text{W}$

$L_{\text{jet}} \sim 4 \times 10^{37} \text{W}$

Limb brightening

0.01 light yr~$\sim$10 m

Six billion solar masses
AGN Spectroscopy for Dummies

![Graph](image)

MKN 421

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AGN Spectroscopy for Dummies

![Graph showing log(νL_ν) vs. log(ν) with annotations for mm-break, Inflection, and XUV excess. Mkn 586 (radio quiet) is noted.](image-url)
Gamma Ray Flares

- **Crab Nebula**
  - $\sim$5 PeV $e \rightarrow$ 300MeV $\gamma$
  - $L \sim 10$ lt yr; $\tau \sim 10$ hr

- **GRB 130427A**
  - $\sim$TeV $e \rightarrow$ 100 GeV $\gamma$
  - $L \sim 1$ lt hr; $\tau \sim 10$ ms

- **TeV Blazars (MKN 501)**
  - $t \sim 2-10$ min

- **GeV Quasar (3C279)**
  - $T \sim 5$ min; $t' \sim 3$ min, $t \sim 6$ s

Flaring common; beaming important
High efficiency, compact accelerator
EM dissipation (magnetoluminescence)
Astrophysical Black Holes

• Kerr Metric
  • $a < m$; $Q, ... = 0$, classical event horizons

• Observed Black Holes
  • BH binaries $\sim 4 - \sim 60 \ M_{\odot}$
  • AGN $\sim 10^5 - \sim 10^{10} \ M_{\odot}$
  • LIGO, Fe lines, EHT, QPO, soft landing, SS433

• Modes of Accretion
  • Intermediate -> thin, radiative disk (corona) [Quasar]
  • Low (+cool electrons) -> thick disk + wind [Radio Source]
  • High -> thick radiation-dominated disk + wind [BALQ]

• Magnetic Field
  • MRI - strongly magnetized flows
  • Disk and Hole - internal/external, thin/thick
  • Winds and Jets
  • Power and Torque - prodigal and industrious
Voltages, Currents, Discharges

- **Unipolar Induction:**
  - $V \sim \Omega \Phi \sim 100 I$

- **Crab:**
  - $V \sim 50 \text{ PV}; N'_{\text{min}} \sim 3 \times 10^{33} \text{ s}^{-1} \sim 10^{-7} N'_{\text{radio}}$

- **3C 279:**
  - $V \sim 300 \text{ EV}; N'_{\text{min}} \sim 2 \times 10^{37} \text{ s}^{-1} \sim 10^{-5} N'_{\text{radio}}$

- **GRB080916C**
  - $V \sim 100 \text{ ZV}; N'_{\text{min}} \sim 10^{40} \text{ s}^{-1} N'_{\text{pair}(0)} \sim 10^{56} \text{ s}^{-1}$
Power Output

• **Stellar Activity**
  – Starbursts, supernovae, OB winds, Cosmic rays…

• **Disk Photosphere**
  – Locally stellar?

• **Disk Corona**
  – Compton scattering; pair limit?

• **Disk Winds**
  – MHD/centrifugal; FR I radio sources?
  – Radiative, BALQ…

• **Black Hole Spin**
  – Relativistic Jets; FRII radio sources?
Fluorescent Fe lines - Spin

- Thin disks, Seyferts, XRB
- Fluorescent Fe lines 6.4 keV (Tanaka)
  - Large spins
- Reverberation mapping (Uttley, Kara) suggests that continuum source (lamp-post) “suspended” above hole at 1-10m
- Could be a pair of stagnation points formed by centripetal launching of inflows?
  - High altitude out; low altitude in
X-ray Reverberation

"Lamppost" + Corona

Wrapped around the axle!

Ark 564
eg Chainukun et al 2017

Forced reconnection

Pair Plasma
Comptonised X-rays
Fe

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Relativistic Jets

• Pairs necessary in magnetospheres for $j, \rho$
  – Easy to create through $\gamma-\gamma$ or $\gamma-B$

• Ions may be entrained/transported
  – Disk, wind, ISM?

• Ions radiate much less than positrons and can be accelerated to higher energy
  – UHECR??

• Jets: EM$\rightarrow$ Flow?
  – Where?
Emission Mechanism

- **Synchrotron**
  - \( E < B \) (any frame) \( \Rightarrow \lambda > r_e, E_\gamma < 70\text{MeV} \)
    - Can be Doppler-boosted
    - Can get TeV synchrotron after pair production on PeV ions

- **Compton**
  - \( E_e > E_\gamma, m_e^2/E_s \)
    - TeV is Compton
    - External vs Internal

- **Sources are inhomogeneous**
  - Radius of gammasphere increases with \( E_\gamma \)
Future M87/EHT Observations

- **Linear polarization**
  - Helical field $\Rightarrow$ lateral shifts $\Rightarrow \Omega_H$
  - M87 jet inclination $\sim 20^\circ$ and angular momentum along receding jet

- **Circular polarization**
  - Pair vs ion plasma

- **Velocity**
  - Magnetic acceleration
  - Entrainment deceleration

- **Limb brightening**
  - Magnetic field?
  - Entrainment/shear?
  - Doppler boosting?
Cosmic Particle Acceleration

- **Evatrons and Zevatrons**
  - UHECR; protons or heavy elements

- **Tevatrons and Pevatrons**
  - Cosmic ray “shin”
    - Heavy nuclei at SN (or other) shocks? magnetars??
  - Relativistic jets (Blazars, GRB...)
    - GeV-PeV acceleration
  - Impulsive/rapid acceleration
    - electrons/positrons to TeV, PeV
    - Efficient, volumetric conversion of EM energy to pairs

- **Pulsars, Blazars, GRBs**

We are probably looking for common mechanisms
Steady Acceleration

• Most of the bolometric power of relativistic sources is emitted steadily

• Acceleration and radiation timescales can be longer than dynamical timescales
  – Crab – 1TeV electrons emit 3 eV synchrotron photons with cooling times ~ 100 yr
  – Blazar- radio-emitting electrons cool adiabatically
  – GRB- ~ MEV particles may not cool

• Slow reconnection may be adequate for most of power
Magnetoluminescence

- **Knot (eg trefoil)**
  - Describable by polynomials
    - Tait, Alexander, Jones…: \( t + t^3 - t^4 \)
  - Require reconnection to create and destroy
    - Slow
    - Change magnetic helicity \( \int \omega \cdot \mathbf{B} \)

- **Tangle (eg slip knot)**
  - Evolve to instability
    - Relativistic transition to lower energy state
    - \( H \) conserved
  - Runaway electron acceleration
    - Implosion, chain reaction?
    - \( E > B \)?
Unstable EM Configurations

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Yuan, Nalewajko, Zrake, East, RB
Happy Birthday Jerry!!!