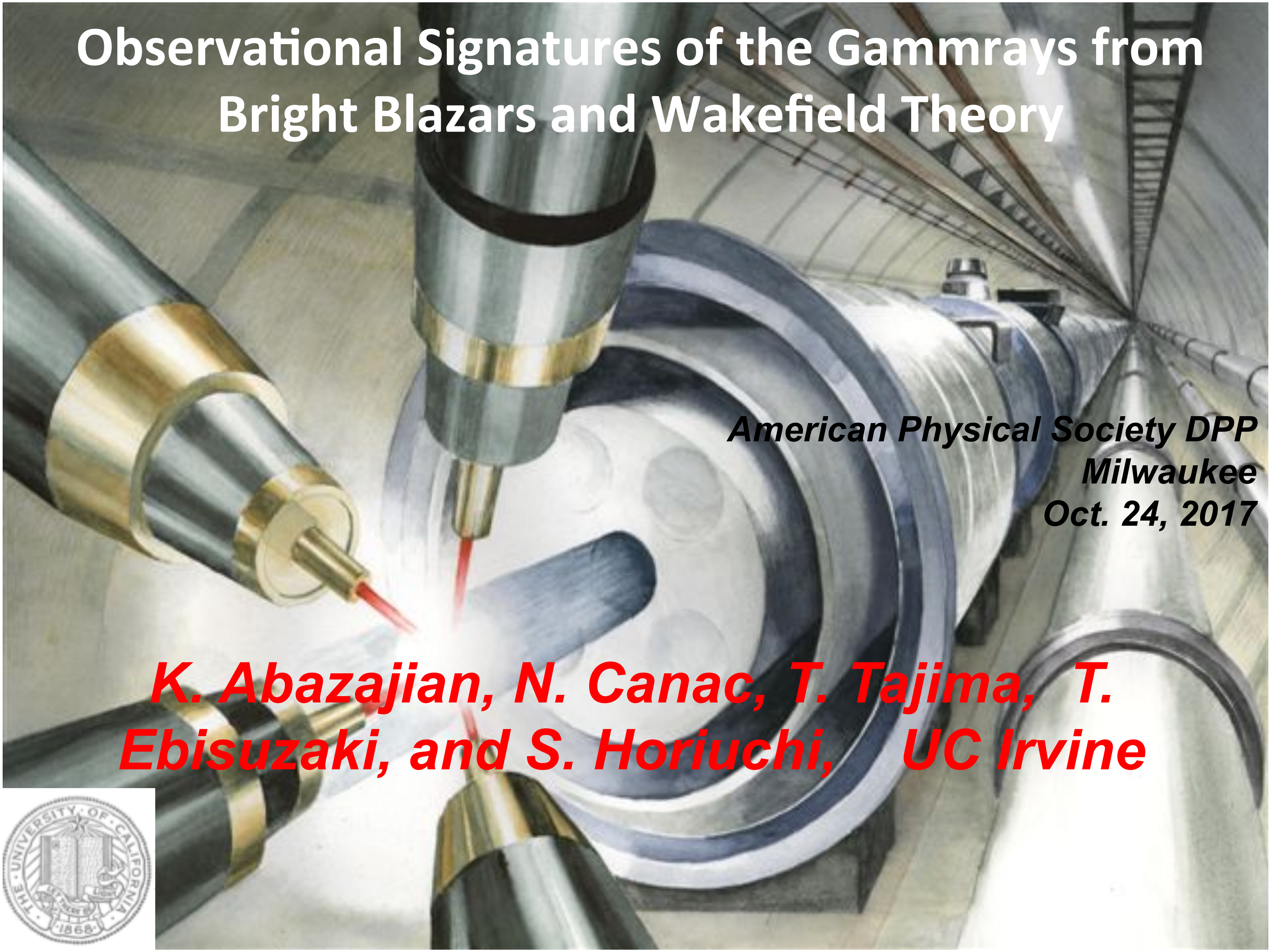
Observational Signatures of the Gammrays from Bright Blazars and Wakefield Theory



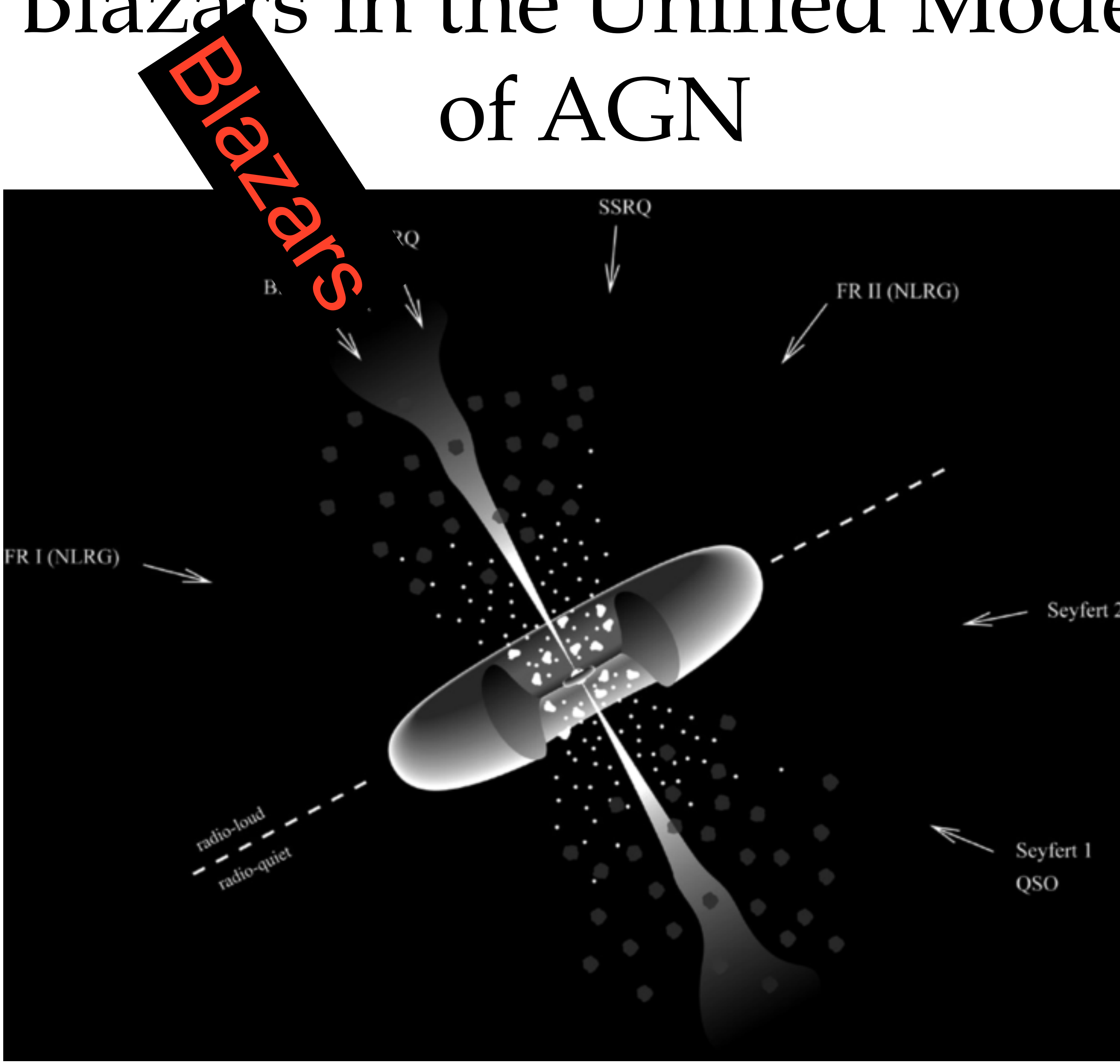
American Physical Society DPP
Milwaukee
Oct. 24, 2017

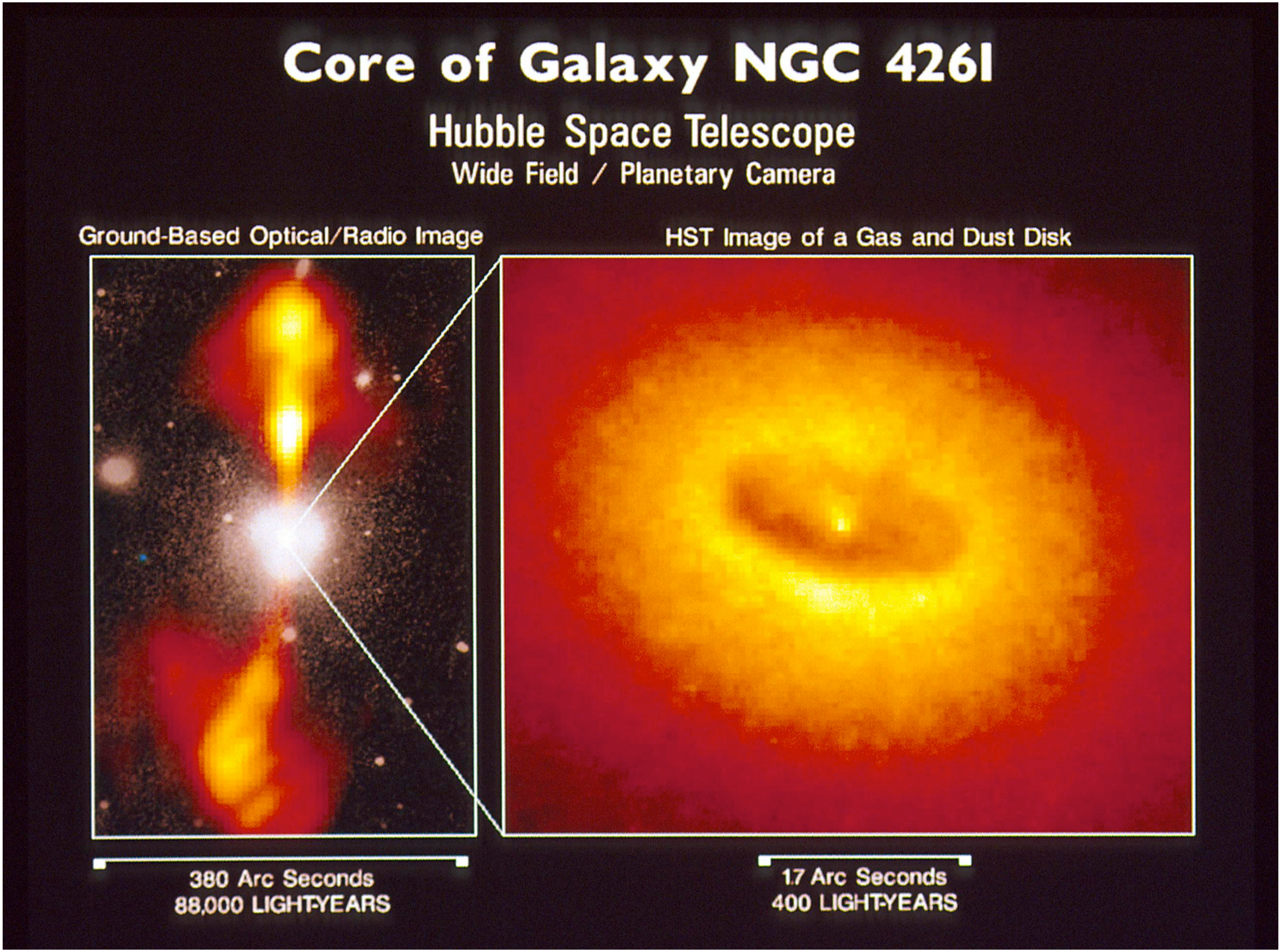
K. Abazajian, N. Canac, T. Tajima, T. Ebisuzaki, and S. Horiuchi, UC Irvine

abstract

1. Blazars emit γ-rays (observed: Fermi sat, etc.)
2. Blazars: AGN (blackhole) and their jets
3. → time variations show: luminosity *L* and the power index *p* anti-correlate
4. Wakefield in the AGN jets triggered by disk disruptions: episodic accelerator of high energy electrons (thus γ photons) and UHECR
5. → Wakefield acceleration: anti-correlated *L* and *p*

Blazars in the Unified Model of AGN




Core of Galaxy NGC 4261
Hubble Space Telescope
Wide Field / Planetary Camera
Ground-Based Optical/Radio Image
HST Image of a Gas and Dust Disk
380 Arc Seconds
88,000 LIGHT-YEARS
1.7 Arc Seconds
400 LIGHT-YEARS

Anti-correlation between the luminosity and the power index from blazars

Luminosity ***L*** and
Power index ***p*** in time

Blazar Variability from Wakefield Phenomena 5

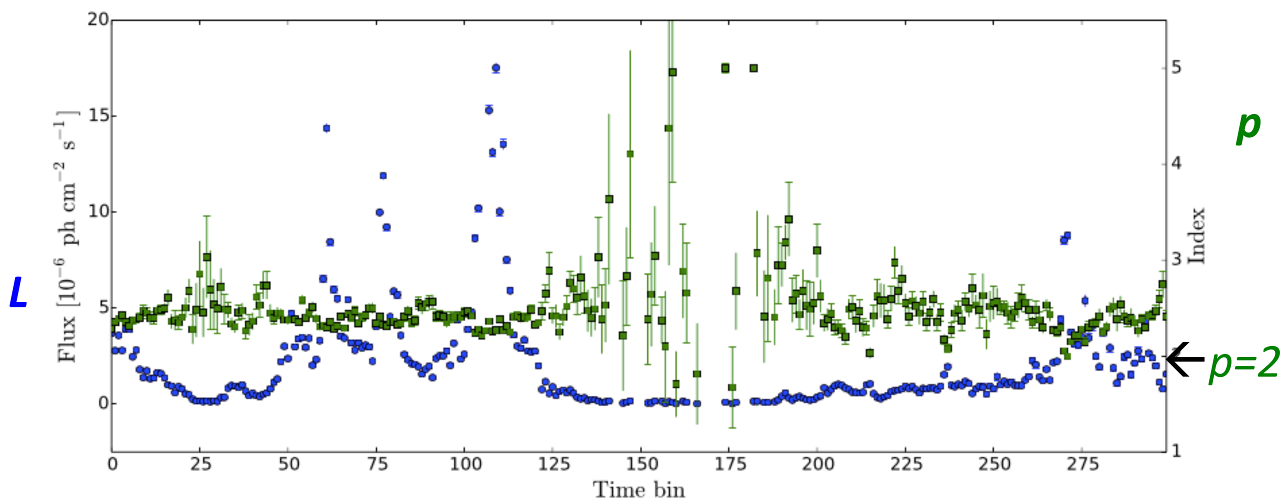
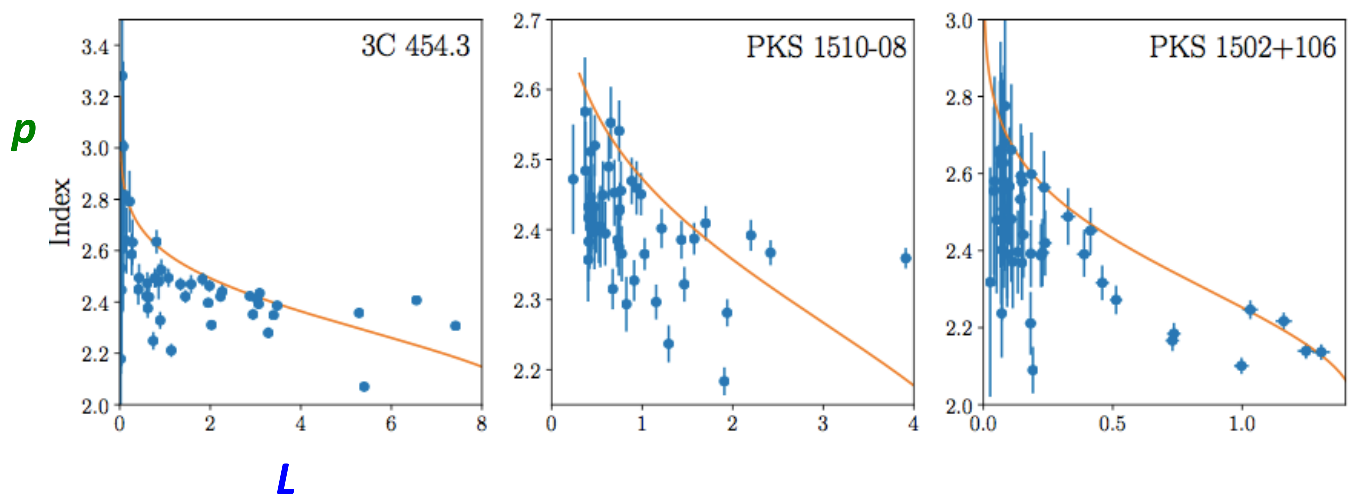


FIG. 2.— Shown are the flux (blue circles, left axis) and spectral index (green squares, right axis) for 3C 454.3 in 300 time bins of 7.9 days duration. An anti-correlation can be seen: the peaks in flux correspond to dips in the spectral index and vice versa.

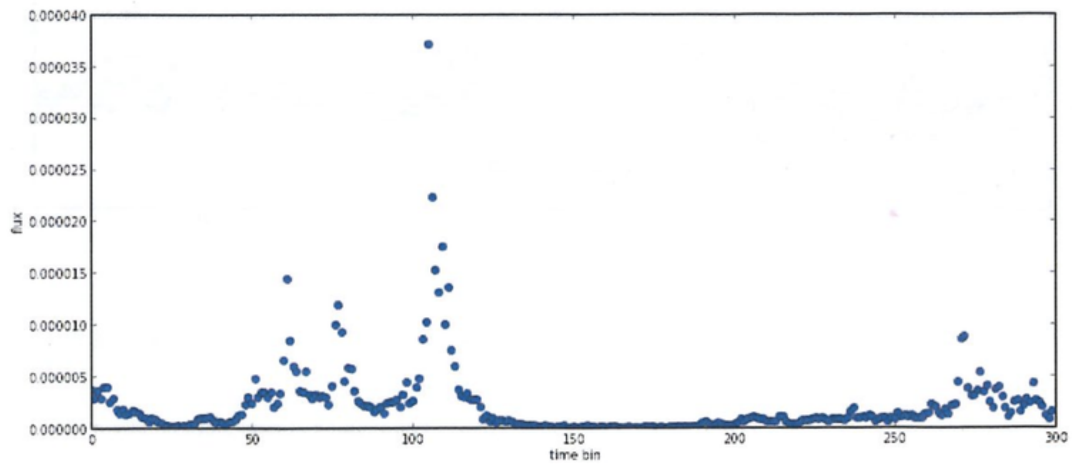


Power index ***p*** vs.
Luminosity ***L*** for several
Blazars (more in Abazajian et al. arXiv)

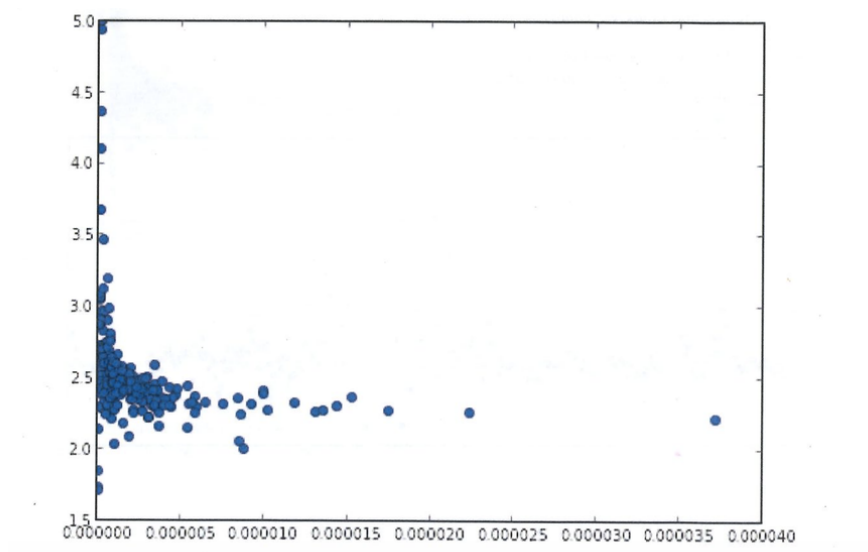
Luminosity of gamma ray emission and the spectrum AGN 3C454.3 with $M = 10^7 M_\odot$

Strong accretion
→ strong wakefield

Luminosity L



Spec. Index p



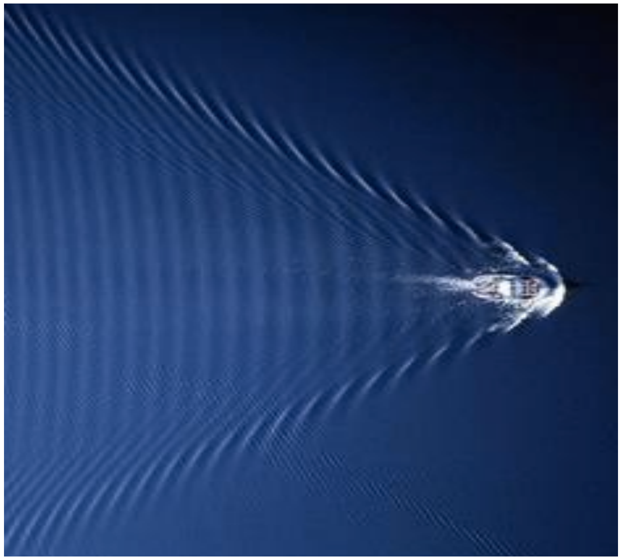
Luminosity L

Ideal episode for wakefield:
index $p = 2$,
Otherwise $p > 2$
(Mima et al. 1991; Ebisuzaki et al. 2014)

Laser Wakefield (LWFA):

Wake phase velocity >> water movement speed maintains **coherent** and **smooth** structure

Tsunami phase velocity becomes ~0, causes **wavebreak** and **turbulence**

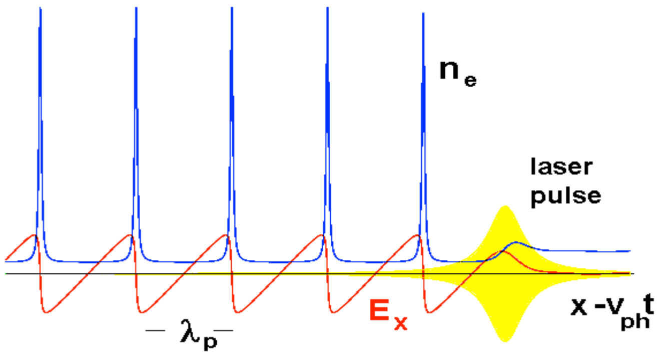


vs

Strong beam (of laser / particles) drives plasma waves to saturation amplitude: $E = m\omega v_{ph} / e$

No wave breaks and wake **peaks** at v≈c

Wave **breaks** at v<c



← relativity regularizes (***relativistic coherence***)

Relativistic coherence enhances beyond the Tajima-Dawson field $E = m\omega_p c / e$ (~ GeV/cm)

Wakefield excited on the jets excited by MRI-driven disk disruption from BH: genesis of EHECR and gamma bursts

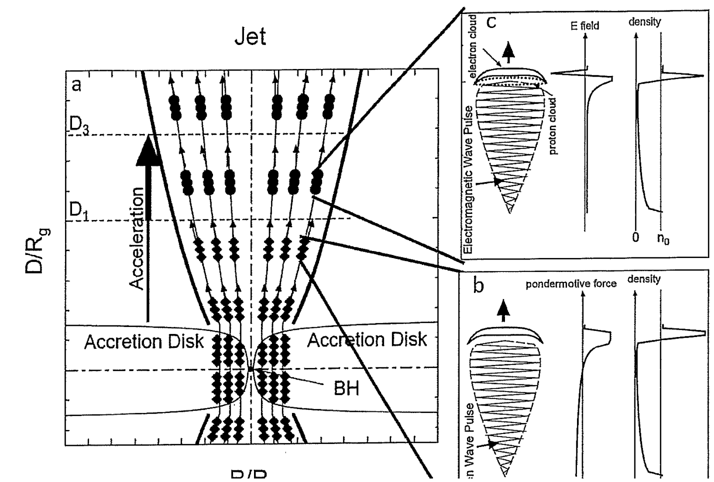


Fig. 2. (a
the magn
wave pul
accelerati
wakefielc

log (ω/Hz)

Fig. 3. P
distance

strong pondermotive force. Eq. 25 holds as far as Z_{acc} is greater than D. The distance D_3 is where the acceleration finishes, defined by the equation

$$D_3 = Z_{pd} = ac/\omega_A. \quad (28)$$

We find that particles arrive at D_1 before D_3, in other words:

$$D_3/3R_g = 3.9 \times 10^5(\dot{m}/0.1)^{5/3}(m/10^8)^{1/3} > D_1/3R_g. \quad (29)$$

The energy spectrum of the accelerated charged particles has the power-law with the index of −2 in the 1-D model due to the multiple dephasing occurrences when particles ride on and off different peaks of the pondermotive or wakefield hills when the waves contain multiple frequencies (but with again the same phase velocity ~ c; [8]), i.e., $f(W) = A(W/W_{min})^{-2}$. As noted earlier, when the driving Alfven waves and their driven pondermotive fields hold a broad band of frequencies, their phase velocities and group velocities, respectively, are again close to the speed of light, providing the basis for the robust accelerating structure. When Alfven waves have two or three dimensional features, the dephasing is more prompt, leading to higher index of the spectrum (less than −2). Let κ be the energy conversion efficiency of the acceleration (including the mode convergence efficiency mentioned earlier), then $\kappa E_B = AW^2_{min} ln(W_{max}/W_{min})$, i.e.

$$A = 1.6 \times 10^{33}\kappa\dot{m}m^2[W^2_{min} ln(W_{max}/W_{min})]^{-1}. \quad (30)$$

The recurrence rate ν_A of the Alfven pulse burst is evaluated as:

$$\nu_A = \eta V_{AD}/Z_D = 1.0 \times 10^2 \eta m^{-1}\ \mathrm{Hz}, \quad (31)$$

where η is episode-dependent, and on the order of unity. This is consistent with the 3-dimensional simulations conducted by O'Neill [12]. They found magnetic fluctuations, called Long Period Quasi Periodic Oscillations (LPQPO) with the period 10–20 times the Kepler rotation period. The luminosity L_{UHECR} of ultra-high energy cosmic rays is:

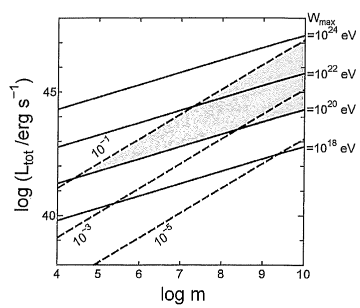


Fig. 4. The total luminosities of accreting blackholes are plotted against the blackhole mass (in the unit of solar mass) for various maximum attainable energy W_{max} (solid lines) for the case of $\Gamma = 20$ and $\xi = 10^{-2}$. Dashed lines are drawn for the values $\dot{m} = 10^{-5}, 10^{-3}$, and 10^{-1}. The grey triangle represents the parameter sets which allow the acceleration of UHECRs ($\geqslant 10^{20}$ eV). We set the upper limit of $\dot{m}$ to be around 0.1 for the pondermotive/wakefield acceleration to work, since the accretion disk becomes radiation dominant as $\dot{m}$ approaches unity, and the Alfven wave pulse becomes weaker than the estimate in the present paper.

4. Astrophysical implications and blazar characteristics

Radio galaxies belong to one category of AGN, which has radio lobes connected to the nucleus by relativistic jets. Their central engines are accreting supermassive ($m = 10^6 - 10^{10}$) blackholes. Urry and Padovani [27] pointed out that there are parent (or misaligned)

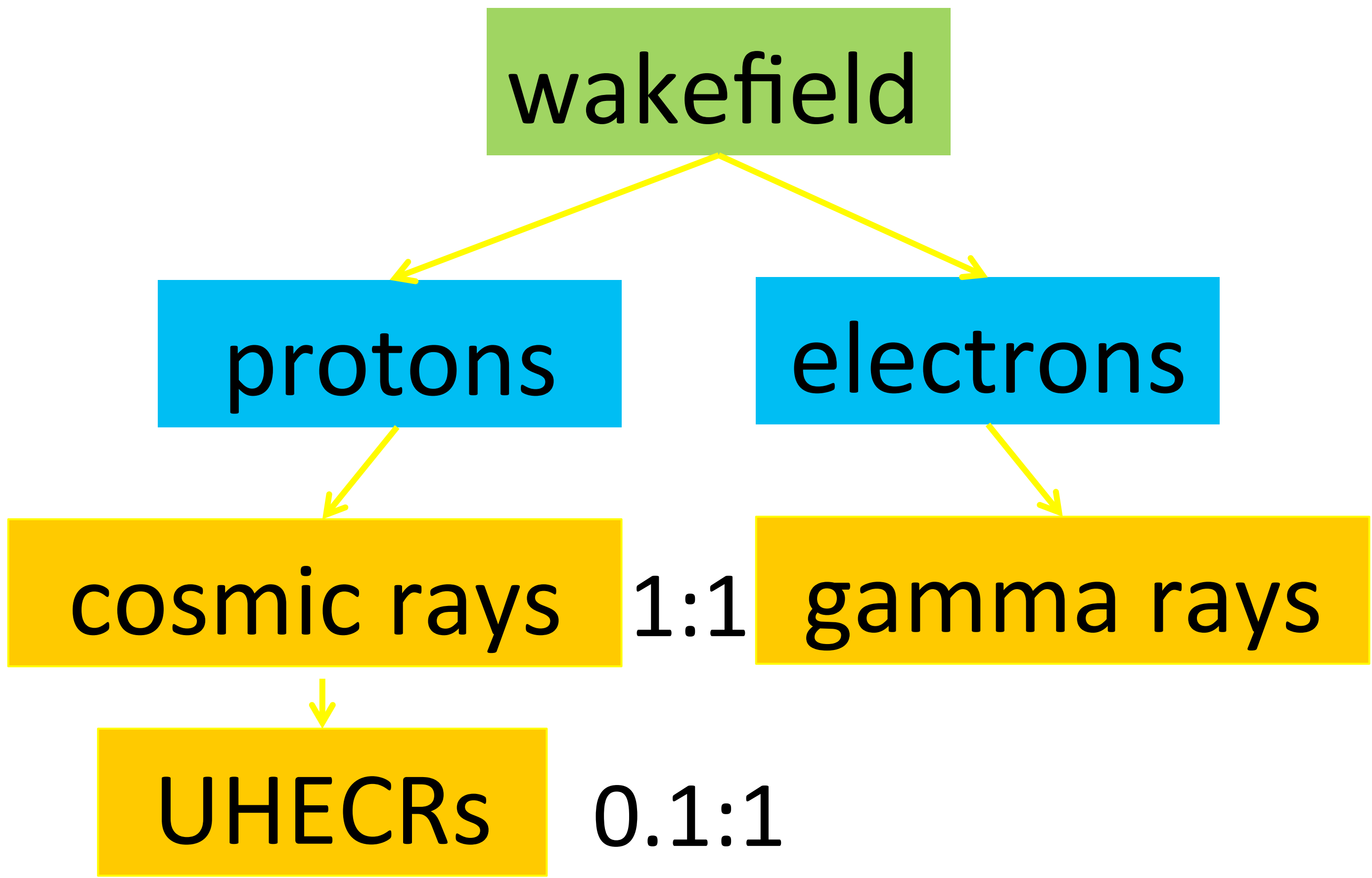
Gamma emission luminosity by wakefield

$$L\gamma \sim 10^{33}\ (\kappa / 0.1)\ \eta\ m'\ m \qquad (\mathrm{erg/s})$$

κ (efficiency), η (episode dependent ~1)

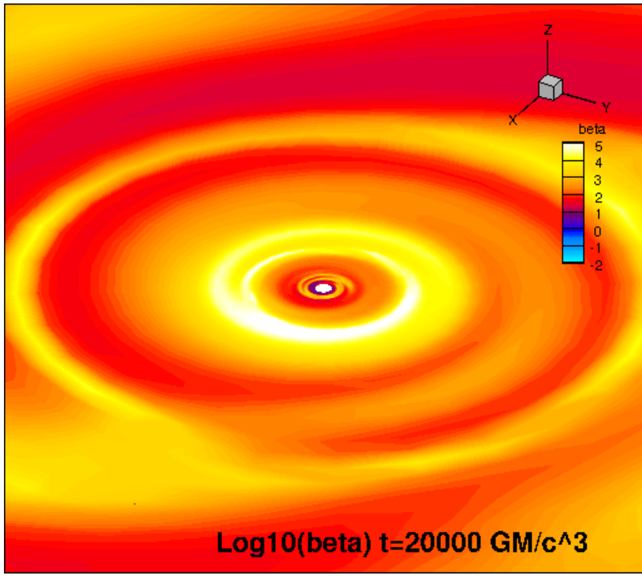
(Ebisuzaki & Tajima: Astropart. Phy., 2014)

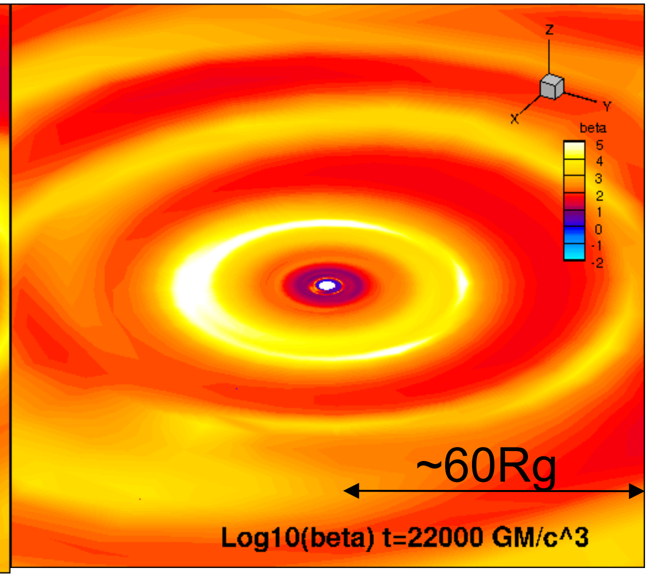
Energy Flow and Spectra

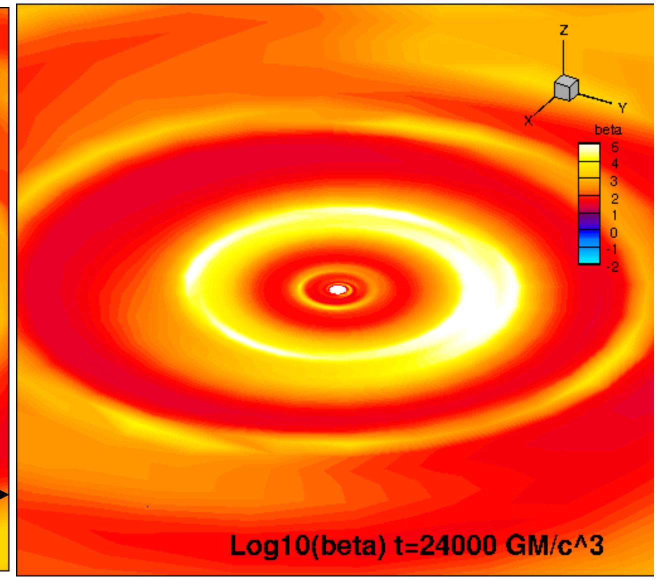


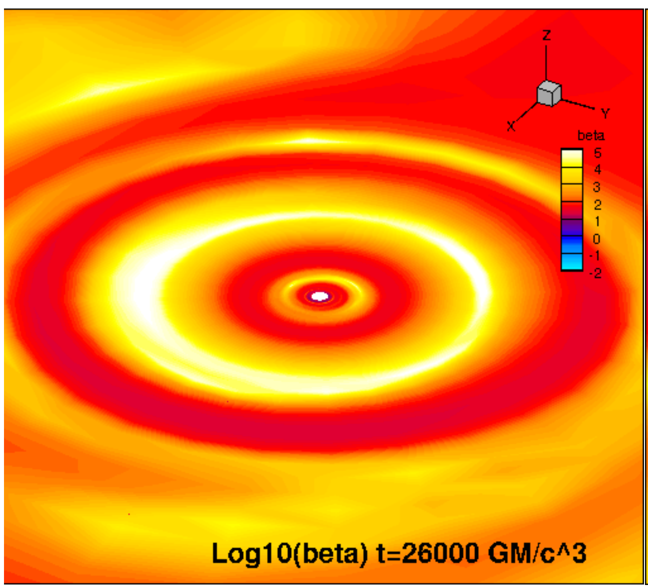
$$F(E) \propto E^{-2}$$

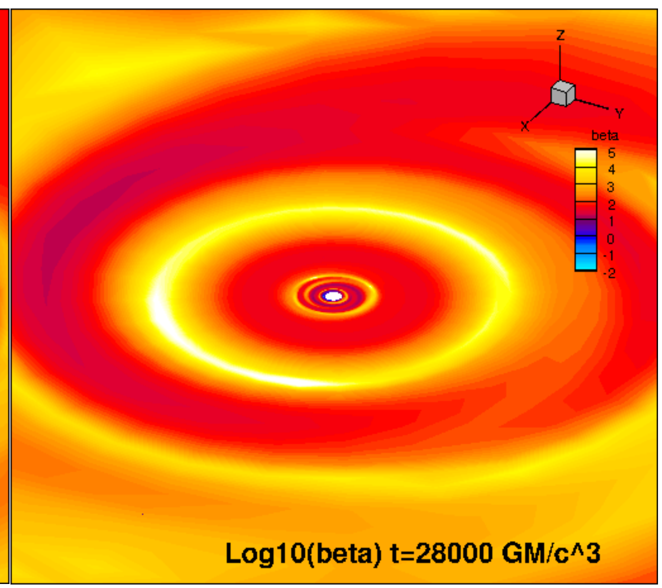
Time evolution log10(plasma beta=P_{Gas}/P_{Mag}) @ equatorial plane











- Plasma beta ~1 near the horizon.
  (short time variability =~10)
- anti-symmetric mode
- stratified structure

Summary

1. Observe→ Anti-correlation of time series of Blazars: Luminosity *L(t)* vs. Power Index *p(t)*
   For Blazar whose mass is known (or guessed) the above rise and interval times proportional to the central mass, whose absolute times: in reasonable agreement below

2. Theory→ Wakefield acceleration theory predicted the same above
   Unlike Fermi mechanism difficulties, no limit in energies (no synchrotron, no confinement limits)

3. General Relativistic MHD simulation→ episodic disruption whose time scales in agreement with the observed time series features above

K. Abazajian, et al. (2017): http://arxiv.org/abs/1709.06535


Thank you!