Plasma Astrophysics

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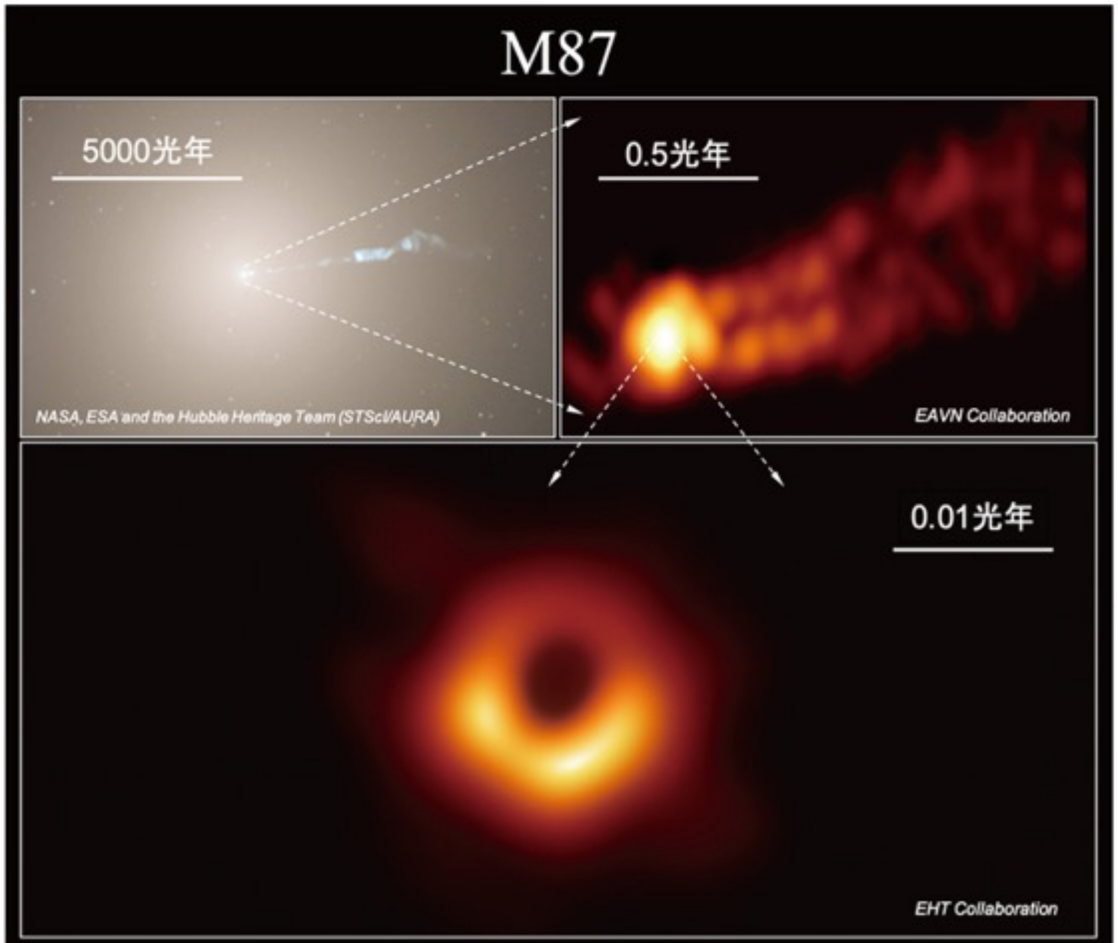
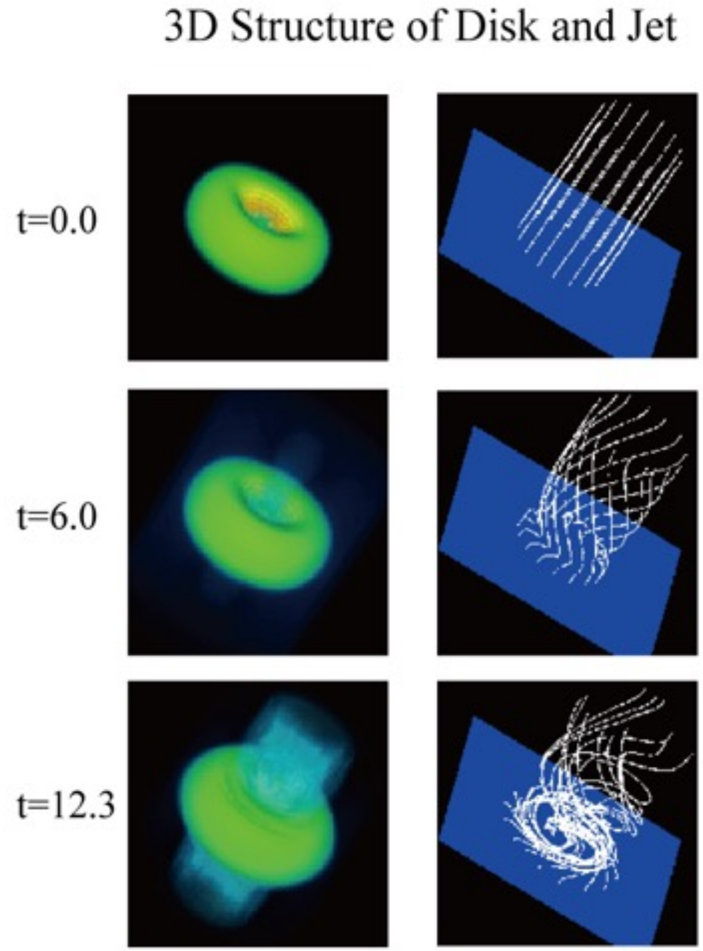
Class 1:PHY249 (2020Spring)





Rationales for plasma astrophysics

- Most visible matter in Universe is **plasma** and we need to understand in order to understand major part of the Universe and the Mother Nature

  → 1. necessary to understand

- The Universe is (nearly infinitely) huge so that the plasma dynamics can play out without narrow boundary conditions so that the **nonlinear dynamics and structure formation** can be learned that is harder on laboratory scaled observations

  → 2. opportunity to learn

Paradigm Shift in Plasma Physics

- Instabilities dominant science and math (*not observable*)

↓

- Structure formation via nonlinear dynamics (Mother Nature *observed*)

Philosophy espoused in
“Plasma Astrophysics”
(Addison-Wesley, 1997)
by Tajima and Shibata

example (right): from accretion disk and jets emanated from NS-NS collision → GW emission and gamma emission

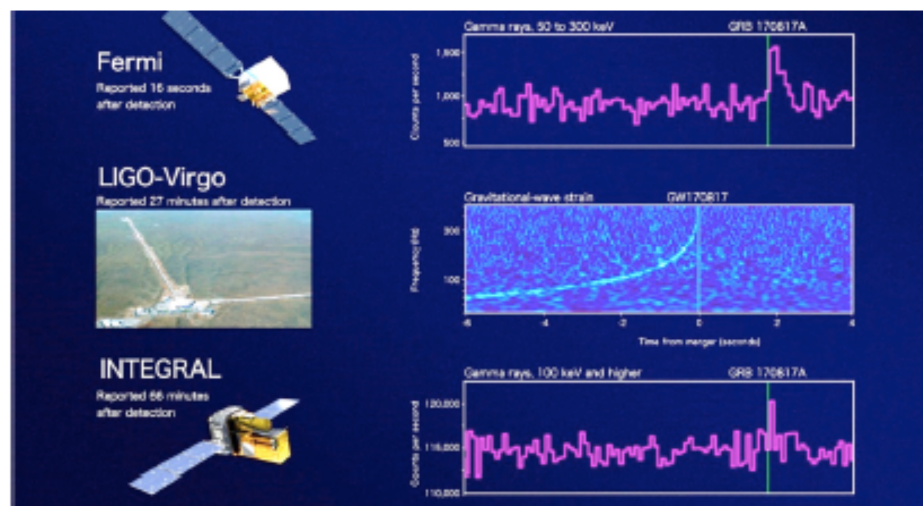


Fig. 5. Gamma-ray emission detected by Fermi and Integral satellites from the neutron star merging event (GW178017) delayed by 1.7 seconds compared with gravitational wave burst [79]. This time difference may be explained by the time to build-up the system for the acceleration of charged particles, described in the present

Instabilities vs **played-out structures**

Examples:

- Parker instability (see p. 158)

  → **jet formation** (observable) **and its magnetic fields**

- MRI (Magneto-Rotational Instability), or Balbus-Hawley instability (see p. 323)

  → episodic emission of **gamma-rays** (observable) via **wakefield** acceleration triggered by episodic eruptive accretion

Plasma beta β (ratio of plasma to magnetic pressures = $4\pi P / B^2$)

- Laboratory plasmas: mostly low β (β <<1, or < 1)

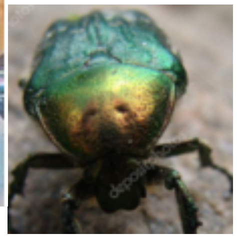
  plasma is **anchored** by the external magnets

- Astrophysical plasmas: mostly high β (β >> 1, or β > 1)

  magnetic fields **generated** in plasma, which tend to **escape** (other than exceptional cases s.a. neutron stars)

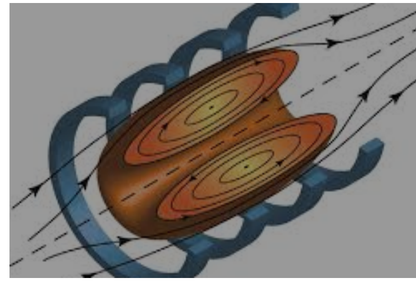
Low β and high β plasmas in lab and astrophysics

low β lab plasma



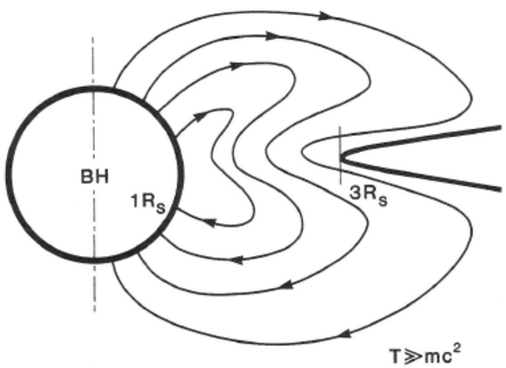
tokamak

high β lab plasma



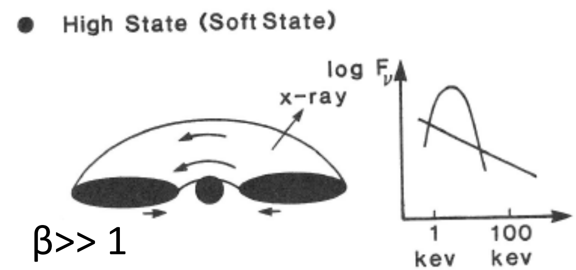
FRC

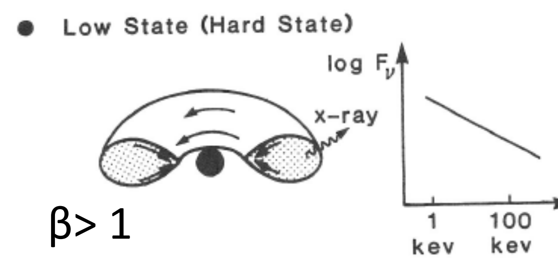
Modest β astro plasma



near a blackhole (or NS)
p. 120

high β astro plasma





Low and high state transitions of accretion disk p. 348

Examples of base processes

Parker instability

(ballooning instability) → **Flux buoyancy**

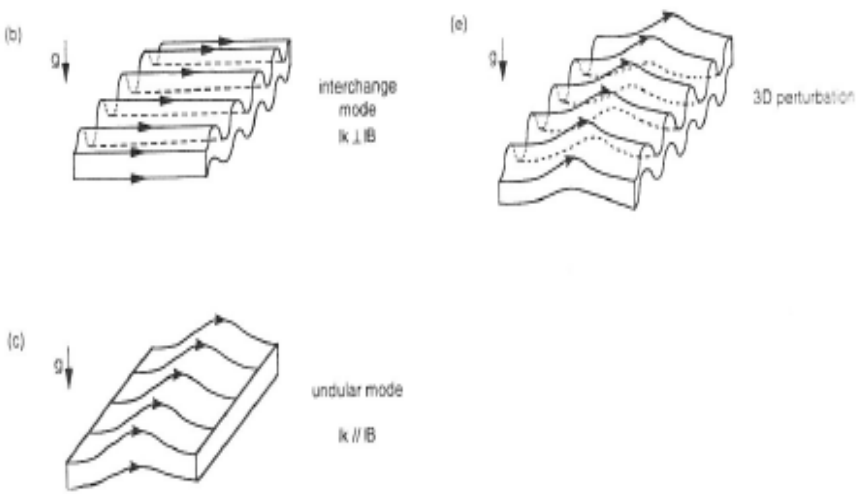


FIGURE 3.18 Interchange mode and undular (Parker) mode of magnetic buoyancy instability.

3.2.1.2 Magnetic Buoyancy Instability and Parker Instability

MRI → twisted magnetic amplification; jet formation

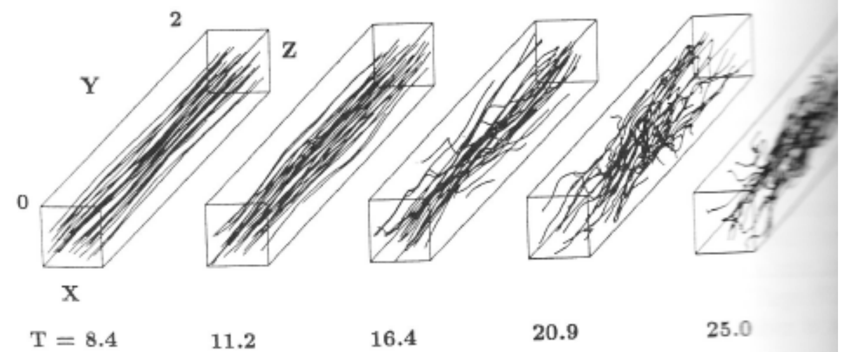


FIGURE 4.27 Magnetic field lines for model T in the eigenmode growth state $[t = (8.4 - 16.4$ … saturation stage $[t = (20.9 - 25.0/\Omega]$ (Matsumoto and Tajima, 1995).

4.2.3.6 Effects of the Parker Instability*

When the vertical gravity is included, magnetic field escapes from the disk … due to the Parker instability (the magneto-buoyancy instability; see Sec. … growth rate of the Parker instability is $2 - 5H/v_A$, the growth rate of the Parker … becomes comparable to that of the magnetic shearing instability as β approaches …

Text p.158-196

Text p. 329-342

What part of astrophysics?

- Frontiers of astrophysics only (that are not yet well understood):

  highest energy particles (e.g. of cosmic rays > 10^20eV, high energy neutrinos)

  highest energy photons (e.g. γ-rays up to TeV /PeV)

  most violent processes (e.g. disruptive accretion; jets)

  episodic and eruptive (e. g. γ-ray bursts)

  young objects (e. g. AGN, Blazars)

  neutron-star x neutron-star collision→ plasma plays essential role

  ……….

- I have no time to cover:

  old objects (e.g. our galaxy, our Sun, our solar system), gravitational dominants

  quiet, steady-state objects

  objects where little plasma such as the Moon ("the older, the less plasma")

  single particle interacts with astronomical object

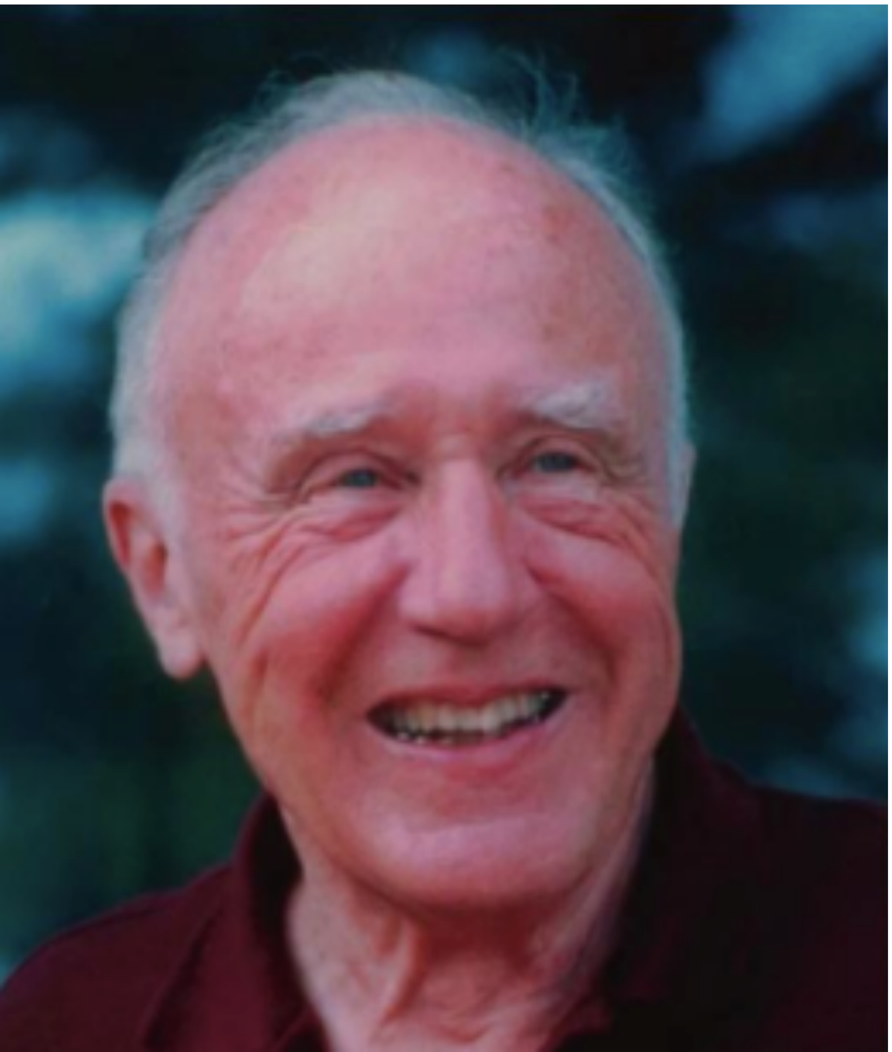
  ………..

(our textbook covers some of both kinds)

What can/should we do by the end of the Quarter? (if you are lucky)

- Survey nonlinear plasma evolution, such as wakefields
- Why wakefields are there (does not disappear) and robust?
- What are the Universe's long standing nonlinear structures?
- Imagine where Mother Nature wishes to excite wakefields?
- Predict what happens if you make violent plasma excitation?
- Acceleration, emission of gammas, protons, neutrons
- What magnetic fields do in active Universe? Why are they there?
- What kind of structure formations? Accretion disks, jets, collisions of stars (and galaxies),…….
- What can you predict from all these?
- ………

John A. Wheeler



"Toshi, do you know what a professor is about?
A professor is a person who learns from students."

Sept., 1980,
Prof. Wheeler at Univ. of Texas at Austin