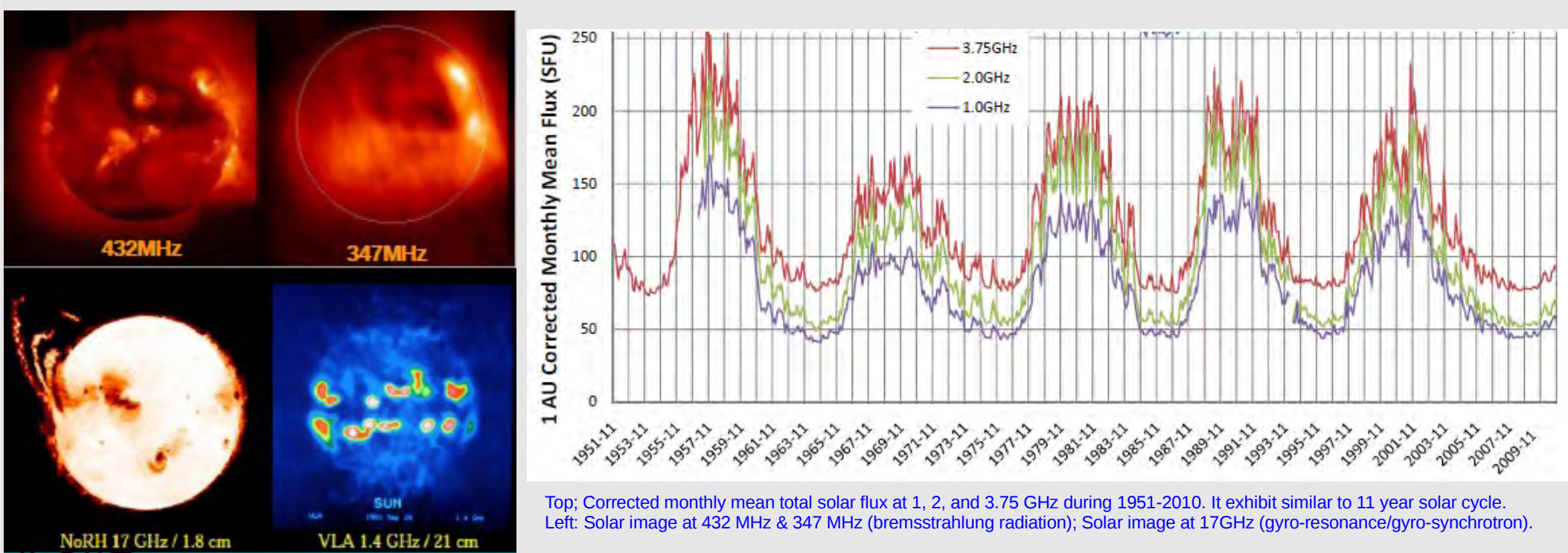


Radio Universe & Work @ IUCAA

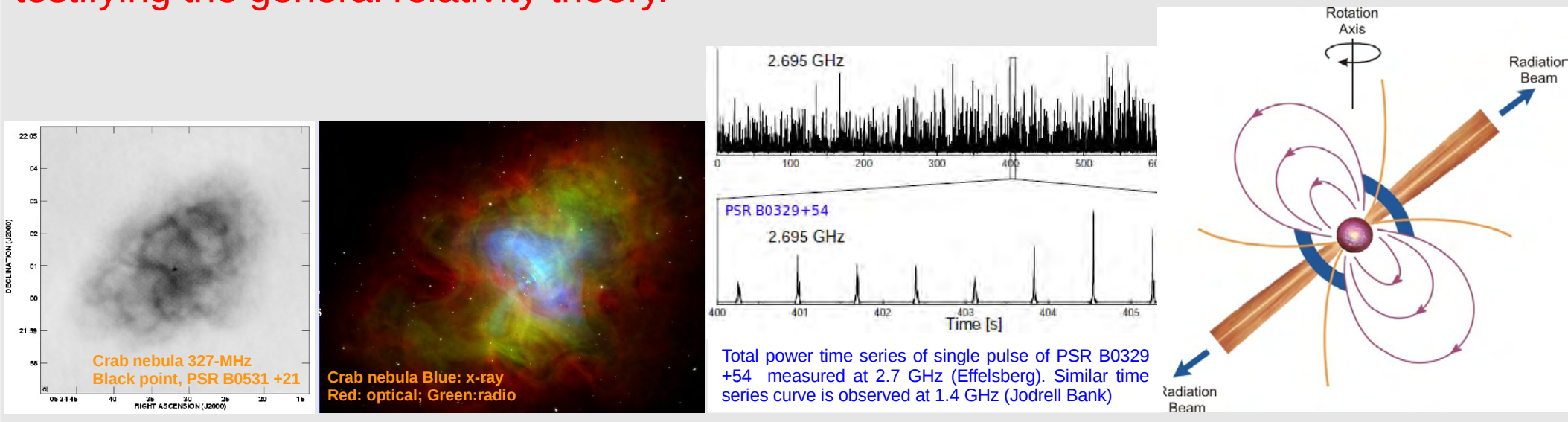
Radio Source I

● **STAR (Sun):** The radio emission mechanisms are thermal bremsstrahlung for quite sun, gyro-resonance for active region, and gyro-synchrotron during solar flare. The radio structures are located in the solar chromosphere and corona, it can estimate the coronal magnetic field, electron density, and can model the solar atmosphere.



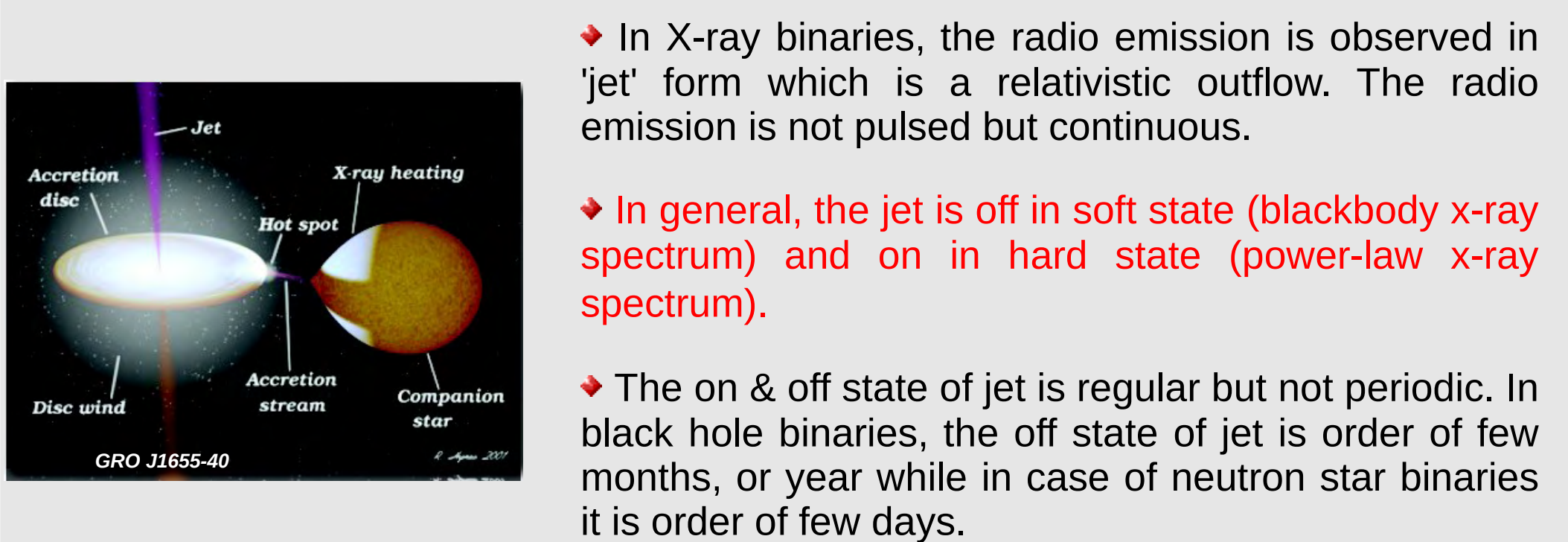
● **PULSAR:** Pulsars emit highly accurate beamed periodic signals (mostly in radio waves). Pulsar periods varied between 1.5ms to 8.5s and typically period increased by 1 part in 10^{15} . The periodic signals reveal the period of rotation of the pulsar. Pulsars are compact objects, neutron star. The radiation mechanism of pulsar is synchrotron radiation (curvature radiation); pulsars have magnetic field of order of 10^{12} G.

The pulsar studied is evident tool for exploring the internal structure of neutron star and testing the general relativity theory.



There are more over 1500 radio pulsar. Most of them isolated neutron star, some radio pulsars is binary of type either NS + NS, or NS + WD where, NS is neutron star & WD is white dwarf.

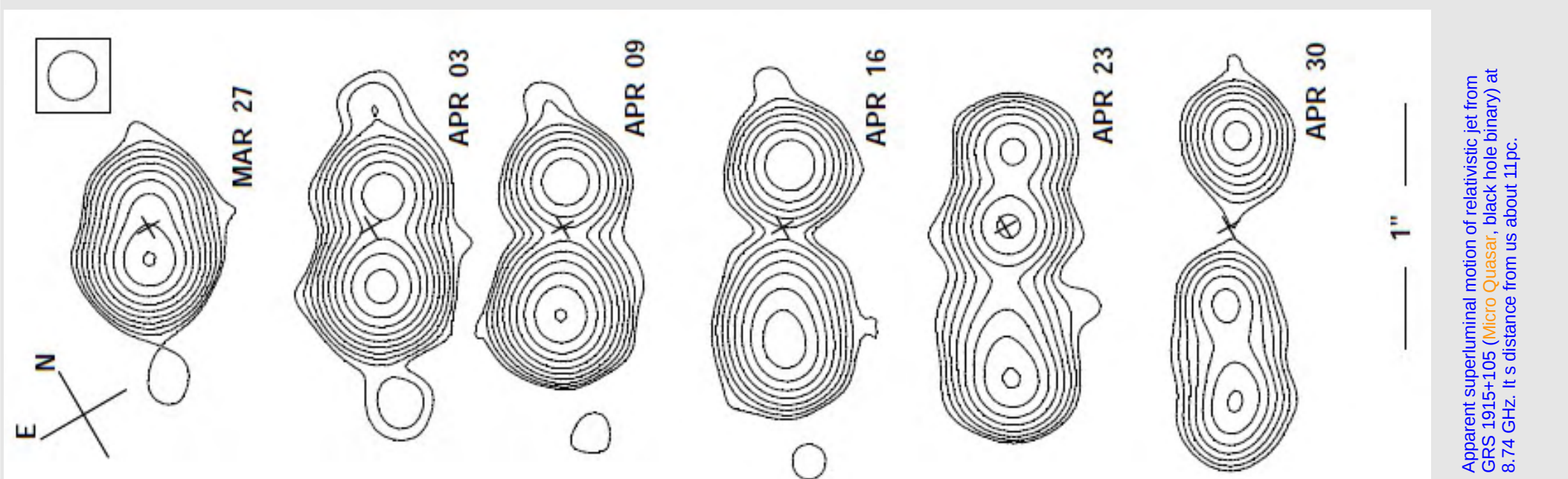
● **X-ray Binaries:** The X-ray binaries are a system where compact object accreted material from owns companion star (which may be a main sequence star, or post main sequence star). The compact objects are either black hole ($M_{BH} < 25 M_{sun}$ approx), or neutron star.



◆ In X-ray binaries, the radio emission is observed in 'jet' form which is a relativistic outflow. The radio emission is not pulsed but continuous.

◆ In general, the jet is off in soft state (blackbody x-ray spectrum) and on in hard state (power-law x-ray spectrum).

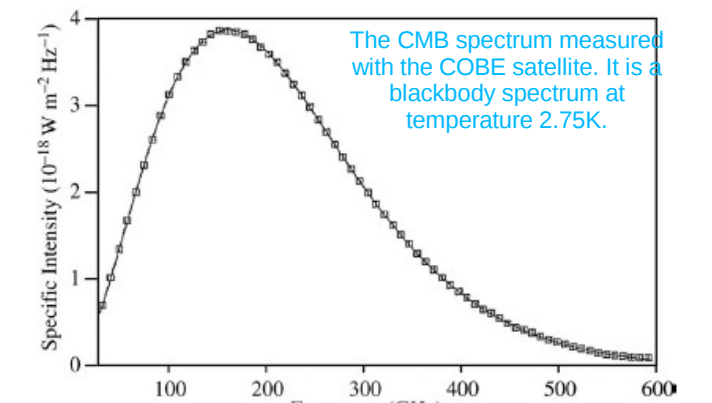
◆ The on & off state of jet is regular but not periodic. In black hole binaries, the off state of jet is order of few months, or year while in case of neutron star binaries it is order of few days.



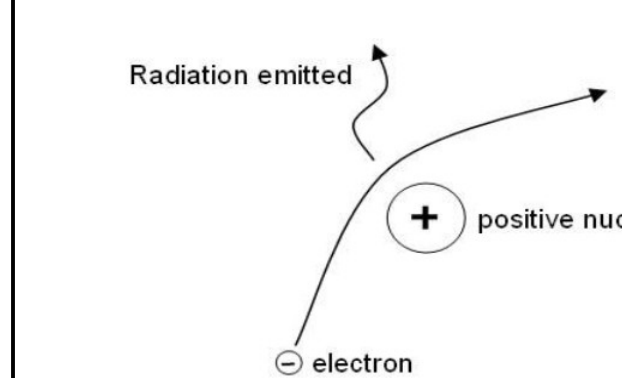
Radio Emission Mechanism

➤ **Thermal Radiation:**

The system at thermal equilibrium (temperature T) is exhibit a black body spectrum. For example, radio spectra from emission nebulae manifest the rising power-law character of blackbody radiation at low frequency.



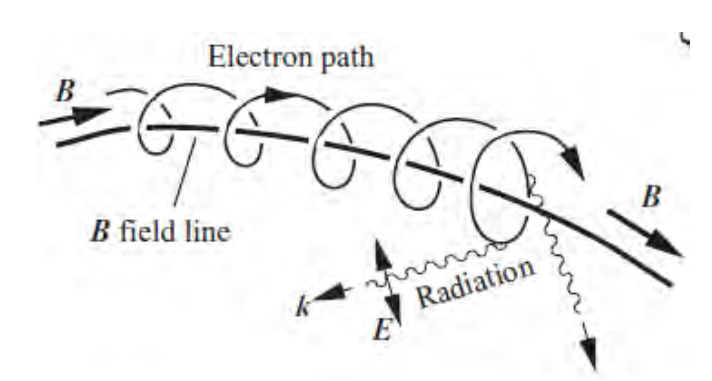
➤ **Bremsstrahlung Radiation:**



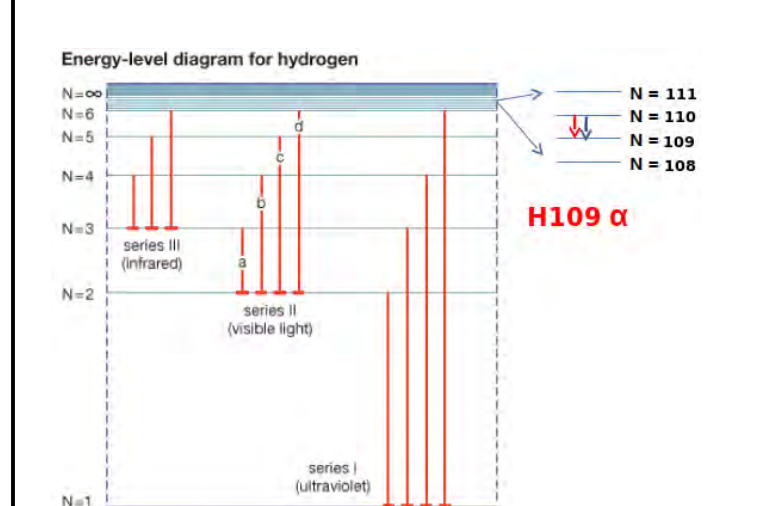
The radiation emitted during Coulomb collisions between electrons and ions in a hot ionized gas (plasma) is called bremsstrahlung. For example, the HII region (plasma) in thermal equilibrium at temperature 10^4 K show radio emission.

➤ **Synchrotron Radiation:**

Synchrotron radiation occurs when relativistic charge particles spiraling around magnetic fields. For example, when 20 MeV electrons move with 10^4 m radius of curvature of high magnetic field line would emit ~ 500 MHz radio wave.

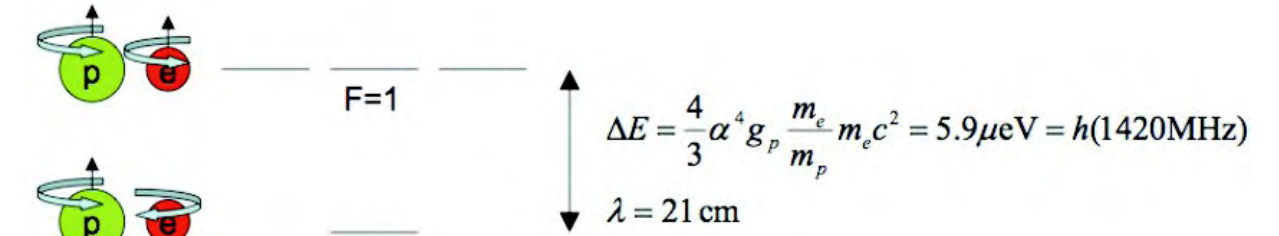


➤ **Recombination Lines:**



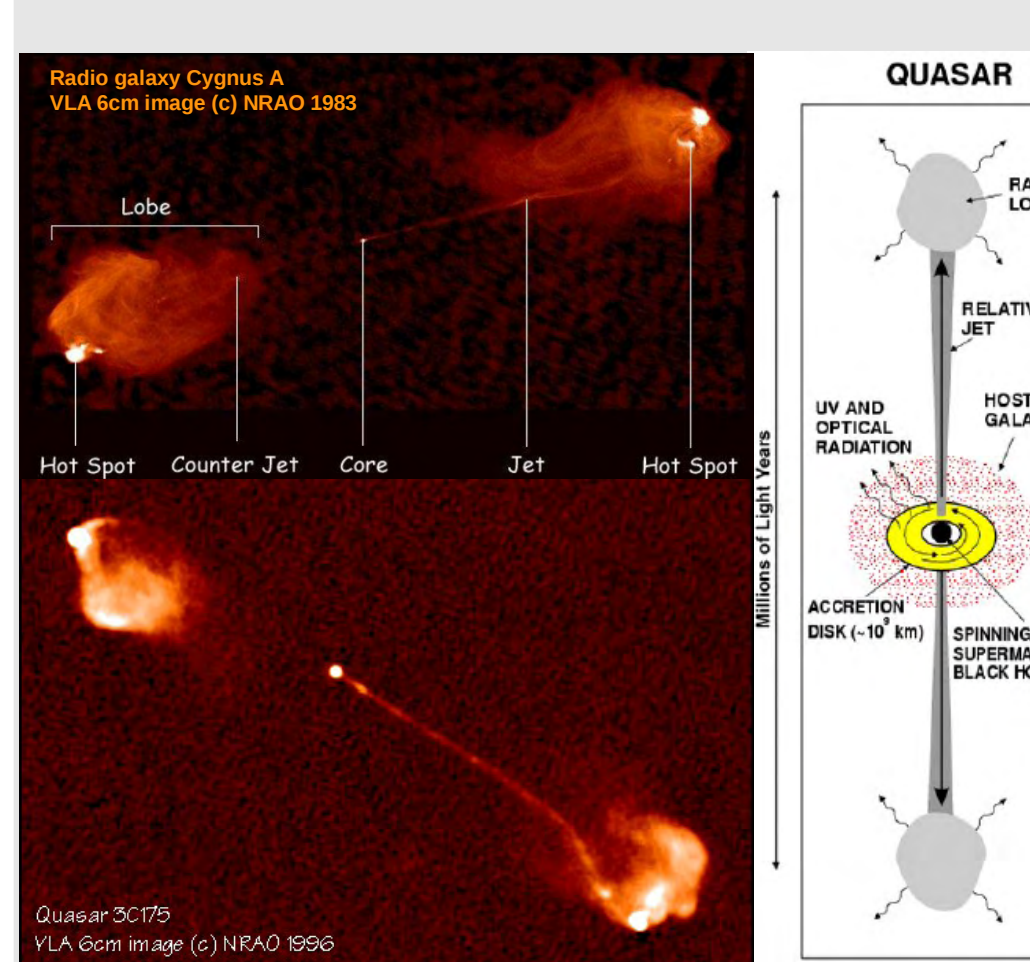
The radiative recombination process is inverse to photoionization, in which an electron is captured by an ion into a bound state n with emission of a photon.

➤ **21cm HI line:** 21 cm hydrogen line is hyperfine transition line. Radiative transitions from F=1 to F=0 are extremely rare (once every 10^8 year), but with the enormous abundance of neutral hydrogen, it is observable.



Radio Source II

● **AGN (Active Galactic Nuclei):** AGN refers to the existence of energetic phenomena in the nuclei, or central regions of galaxies. It is believed that black hole of mass 10^6 to 10^{10} solar mass is present at nuclei. **Radio quiet AGN:** Linear, Seyfert, Radio quiet quasar; **Radio loud AGN:** Radio galaxy, Blazar, Radio loud quasar.



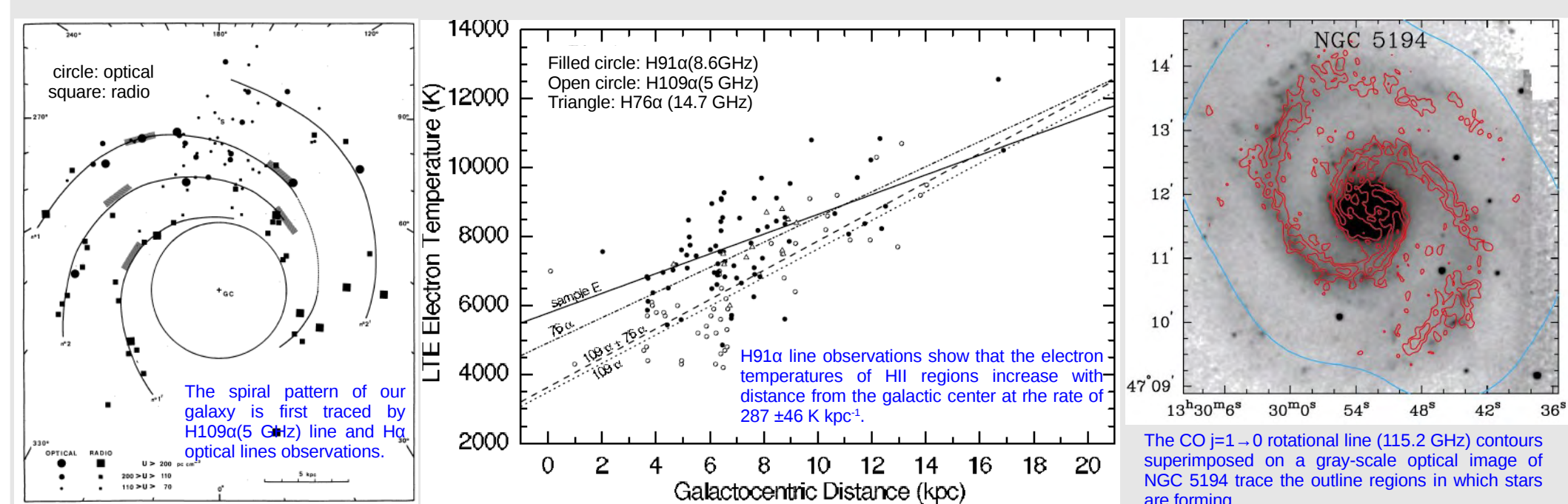
◆ The radio luminosity of radio galaxy is more than optical luminosity. Quasars are hosted by elliptical galaxies similar to radio galaxies.

◆ Blazars shown strong and variable radio emission.

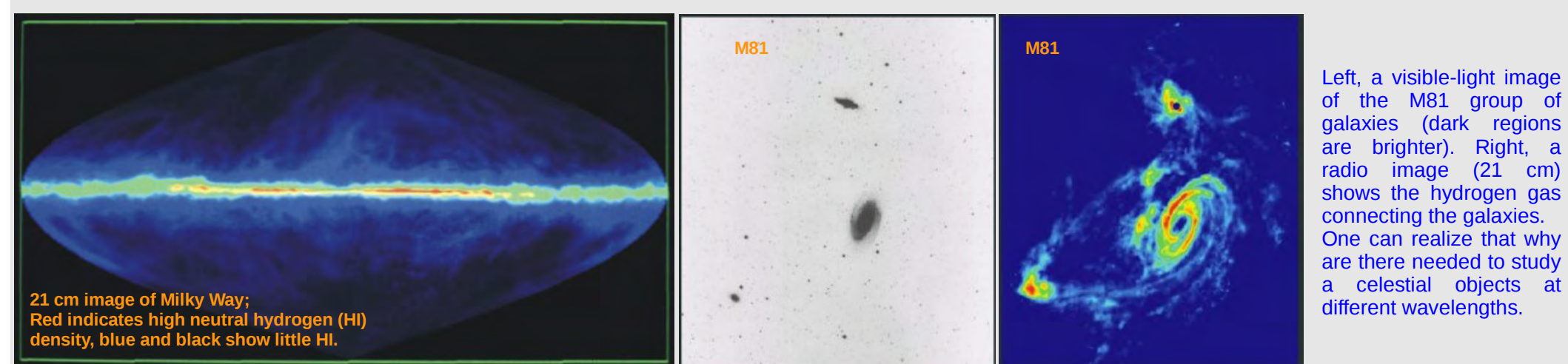
◆ The radio emission (lobe) is vary far away (~parsec) from the central engine (except core dominated). The Jet is relativistic, some times its motion appear to superluminal.

◆ The radio emission is mostly due to synchrotron radiation from ultra-high energetic electron with magnetic field $\sim 10 \mu$ G.

● **Radio Spectral lines:** The radio spectral lines are either recombination line, or rotationally excited molecular (non-zero electric dipole moments) line. The recombination lines of H, He, and C are observed. Radio recombination lines for example, H, are good tracer of HII regions and it can estimate the electron temperature of that region. A glycoaldehyde (a building block for DNA & RNA) molecule is identified on Sagittarius B2 by radio molecular lines.



● **21cm line:** 21cm line is good tracer of neutral hydrogen. 21 cm line has cosmological implications, likely, probing the epoch of reionization, precise constrained on cosmological parameters, since 21 cm line would be absorbed in 'dark age of universe'. **GMRT is extensively involved in 21 cm line survey.**



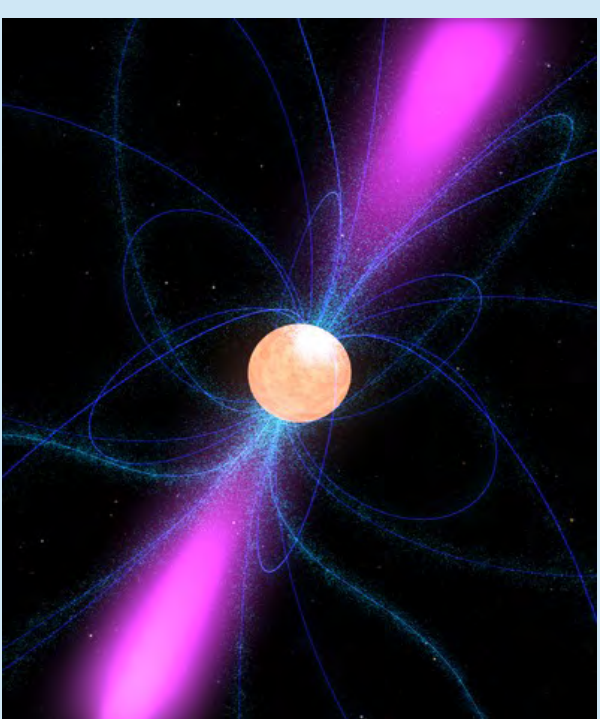
● **CMBR (Cosmic Microwave Background Radiation):** The cosmic microwave background (CMB) is a relic of the 'big bang'. CMBR photons are signature of last scattering surface where photons decoupled from matter. The before last scattering, electrons and photons were in equilibrium, the hot universe should have a blackbody spectrum. Since universe is expanding, it was estimated that, present temperature of the universe should be ~ 3 K. In radio observations, the 3K background radiation is detected.

COBE, WMAP, & PLANCK are satellite mission for studying CMBR. CMBR are powerful probe of early universe by constraining the cosmological parameter.

Research @ IUCAA

Pulsars

- A typical Neutron Star produced in a stellar collapse would possess a strong (Tera gauss)
- Magnetic field and very rapid spin (period ranging from milliseconds to seconds).
- They produce strong, beamed radio emission from their magnetic polar regions.
- As the beam sweeps past us, we see a pulse of the radio emission - such objects are called Pulsars. These are among the most accurate known clocks.
- Millisecond pulsars (pulsars with millisecond periodicity) are Superb Tools for Fundamental Physics



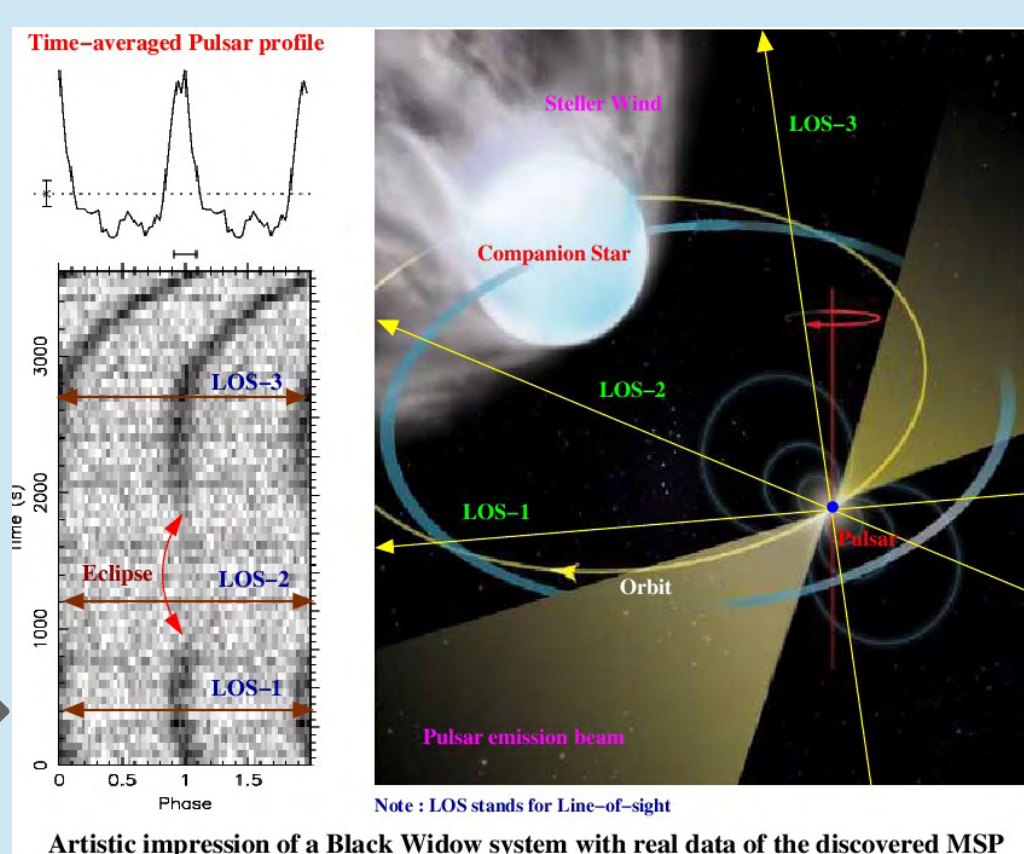
Discovery of 6 interesting MSPs from the ongoing survey

: These are the first Galactic disk MSPs discovered with the GMRT

● Majority of MSPs are naturally expected to be in binaries (i.e. orbiting around another star); 87% of MSPs in binaries

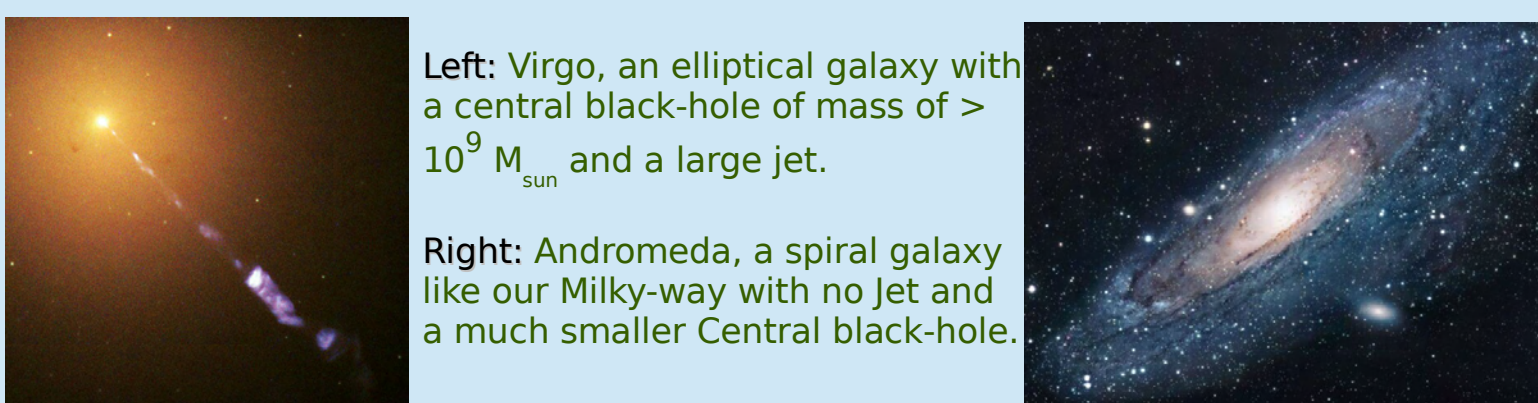
● Isolated MSPs are thought to be formed in binary systems where pulsar radiation can ablate companion ! : Such systems are called **Black Widow** systems star

One of the newly discovered MSP in a Black Widow system



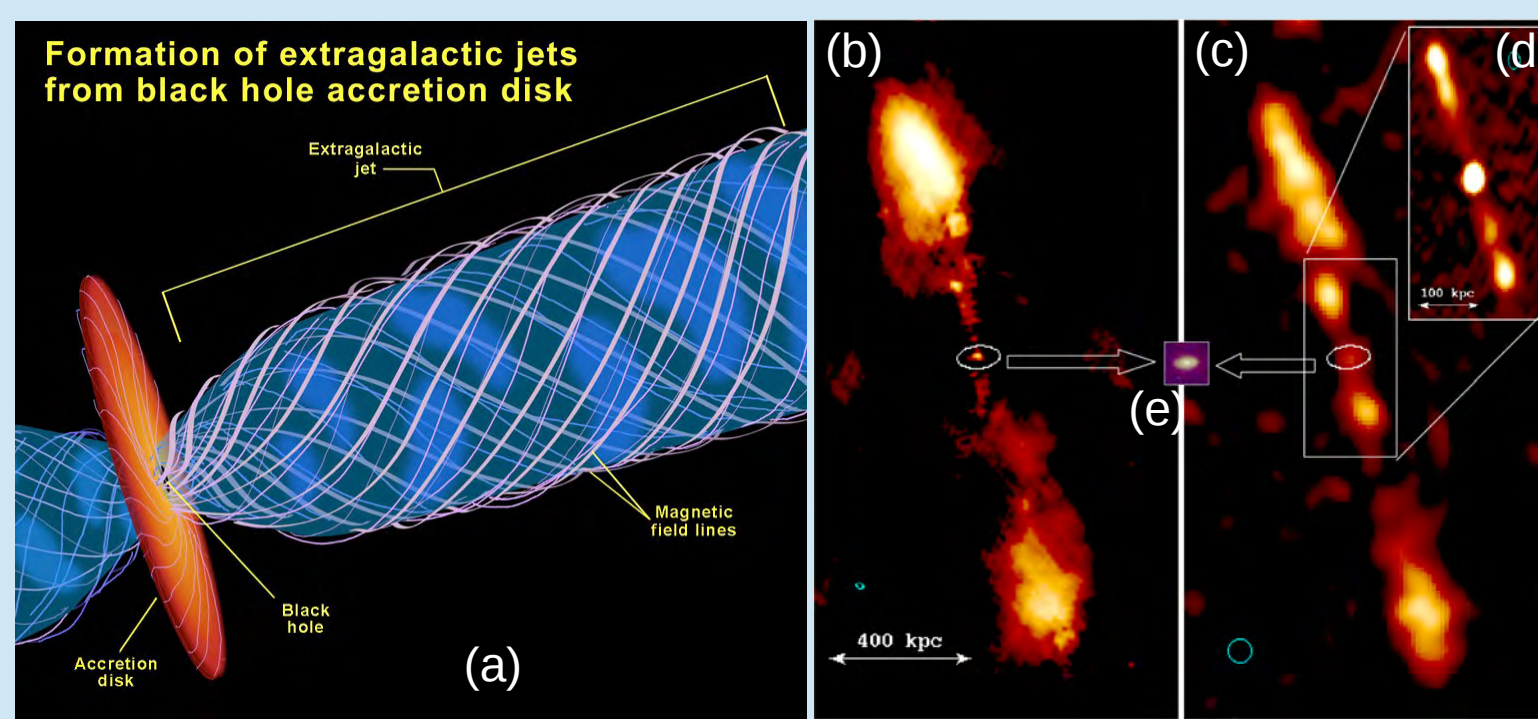
Eclipse material extends well beyond maximum radius at which it remain gravitationally bound to companion. Pulsar is ablating its companion and creating significant amount of intra binary emission to block pulsar emission.

Discovery of a unique object: Radio jet in a spiral galaxy



● Radio jets are commonly found in elliptical galaxies with super-massive black-hole at the centre but, not in flat spiral galaxies. Recently **IUCAA Scientists** discovered such an extremely rare phenomena of **relativistic jets ejected from a spiral galaxy** on scale of 5.2 billion light years, the largest known so far.

● This spiral galaxy has unusually large rotational velocity of 429 ± 30 km/s and extremely large mass. Stars in the central regions moves extremely fast and randomly indicating presence of a central **super-massive black-hole** $> 10^8 M_{sun}$, which is exceptional for a spiral type galaxy.

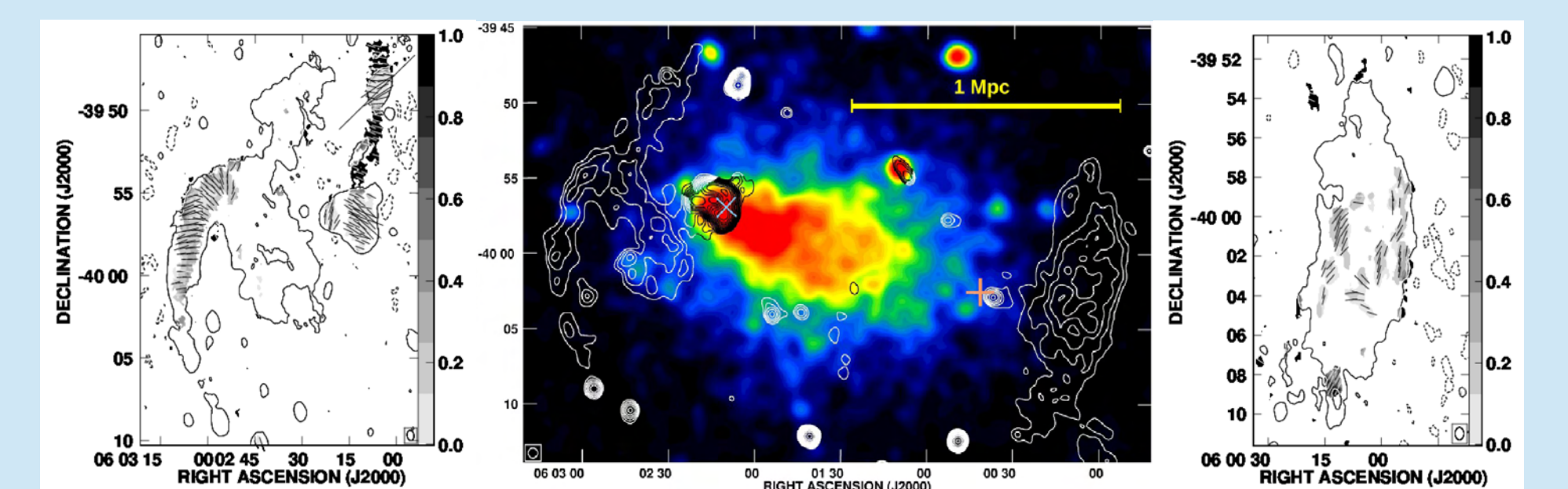


(a) An artistic impression of radio jet, accretion disk and central black hole.
 (b) The 325 MHz image taken with GMRT.
 (c) VLA 1.4 GHz image, taken from the NRAO VLA Sky Survey (NVSS).
 (d) VLA 4.8 GHz image of the inner radio-double showing the AGN core, bipolar radio-jets and the lobes.
 (e) A color composite is shown, obtained from sub-arcsecond resolution, deep optical images taken with the MegaCam on Canada-France-Hawaii Telescope (CFHT). 30 kpc is 9.78×10^4 light years.

Large Scale structures in Radio waves

● IUCAA scientists have discovered giant, **arc-like radio relics** located almost symmetrically around the X-ray emission from the cluster of galaxies Abell-3376, which is more than **600 million light-years** from Earth. [See below: Radio Map of GMRT]

● Their discovery provides tantalizing new information about how such galaxy clusters are assembled, about orientation of **magnetic fields** and the origin of cosmic rays, the **mysterious ultra-high energy particles**.



● They were revealed because fast-moving electrons in cosmic magnetic fields emit radio waves as synchrotron radiation. The world's most sensitive radio telescope at meter wave, the Giant Meter-Wave Radio Telescope (GMRT, Pune), was needed to map these feeble radio emitting ring-like structures. In X-ray they found a spectacular, "speeding bullet" shaped region of X-rays coming from gas heated to 60 million degrees Kelvin.

● IUCAA scientists calculate that in Abell 3376 the shock-waves are so powerful and so large that they will easily provide the right amount of "kick" to accelerate the cosmic rays (protons and atomic nuclei) to about **100 million times more energy than the highest energy achieved so far** in any man-made particle accelerator.