SKA-India Transients SWG

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SKA-India Transients Team (26 members)

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Transients

- Compact and location of explosive dynamic events
- Extreme Astrophysics: represent extremes of gravitational field, magnetic field, velocity, temperature, density
- Collapsing stars, relativistic remnants, extremes of density, gravitational curvature, counterparts of GW, search lights of cosmological distances

Radio Transients

- Long time variability
  - minutes to days
  - Gamma Ray Bursts (GRBs), supernovae, novae etc.
- Short time variability
  - milliseconds to seconds

Observatories of coming decade - Optical/IR/UV

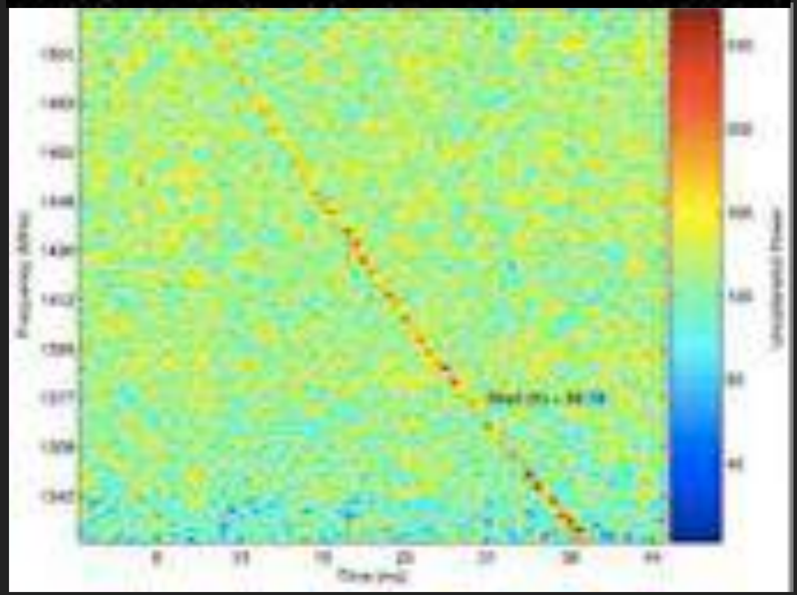
- James Webb Space Telescope (JWST) - 2018
- Thirty Meter Telescope (TMT) - 2020
- Giant Magellan Telescope (GMT) - 2021
- Large Synoptic Survey Telescope (LSST) - 2021
- European Extremely Large Telescope (E-ELT) - 2024

Observatories of coming decade (Other

- Advanced Telescope for High Energy Astrophysics (Athena) - 2028
- Square meter resolution arcsecond X-ray telescope (SMART-X)-2020s
- Space-based multi-band astronomical Variable Objects Monitor (SVOM- Chinese French mission for GRBs): Later this decade
- Advanced LIGO: (later this decade)

Classification based on emission mechanism

- Incoherent synchrotron emission
  - Relatively slow variability
  - Limited by brightness temperature
  - Discovered in images of sky
  - Supernovae, GRBs, tidal disruption events, X-ray binaries
- Non-thermal coherent emission
  - Fast variability
  - High brightness temperature
  - Polarization
  - Discovered in time series
  - Fast radio bursts, pulsars, flare stars etc.
- Thermal emission
  - Slow transients
  - Novae, symbiotic stars

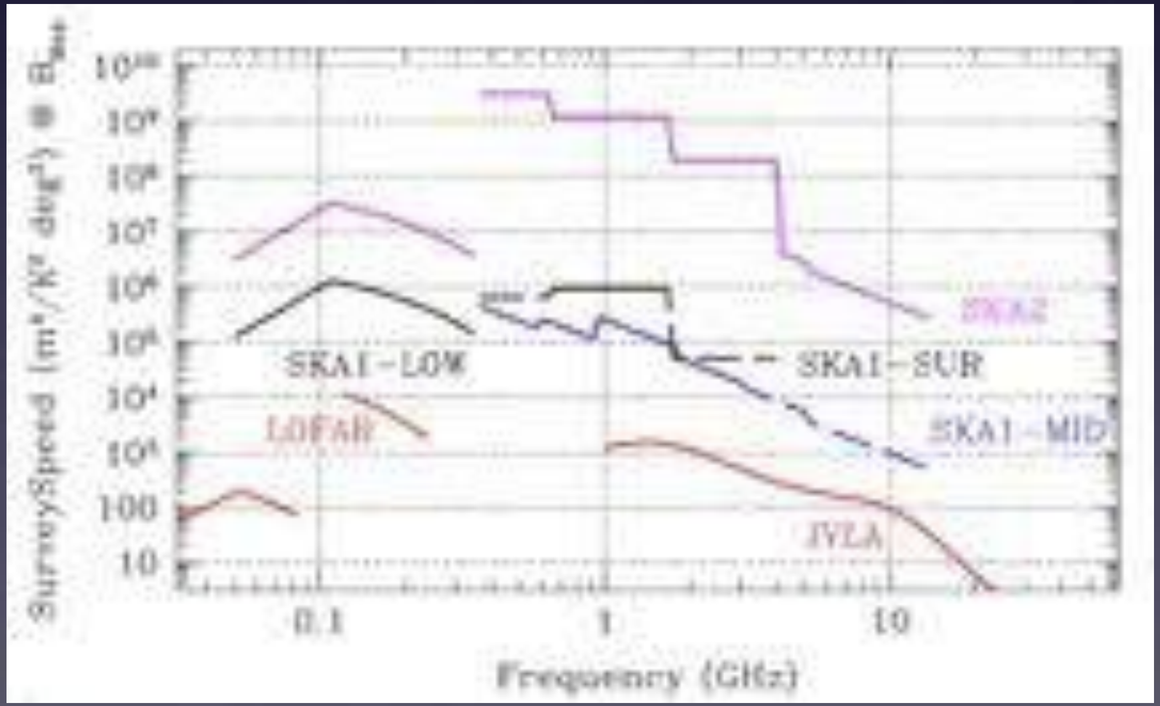


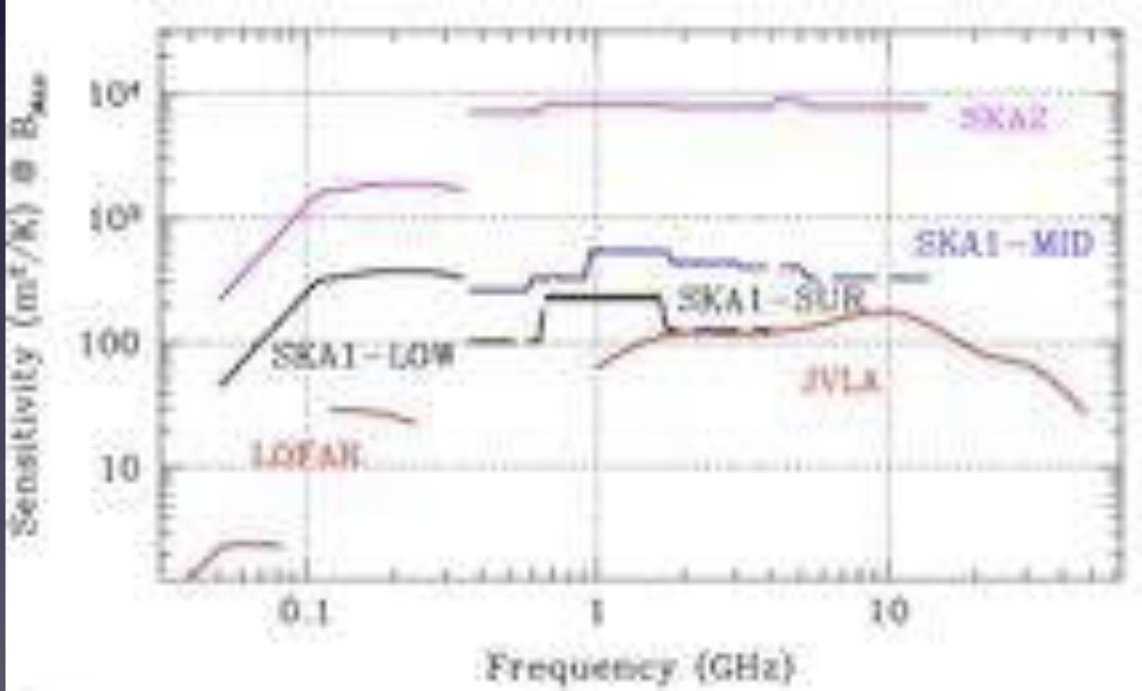
Searching for transients

- Combination of sensitivity, field of view and time on the sky - has been difficult to realise simultaneously.
- Variation in time scale, complex structures in frequency time plane makes it more complicated.

SKA and transients

- Advent of multi-beam receivers on Parkes, Arecibo led to detection of RRATS, FRBs, but larger FOV required
- With its wider field of view and higher sensitivity, the SKA, holds great potential to revolutionize this relatively new and exciting



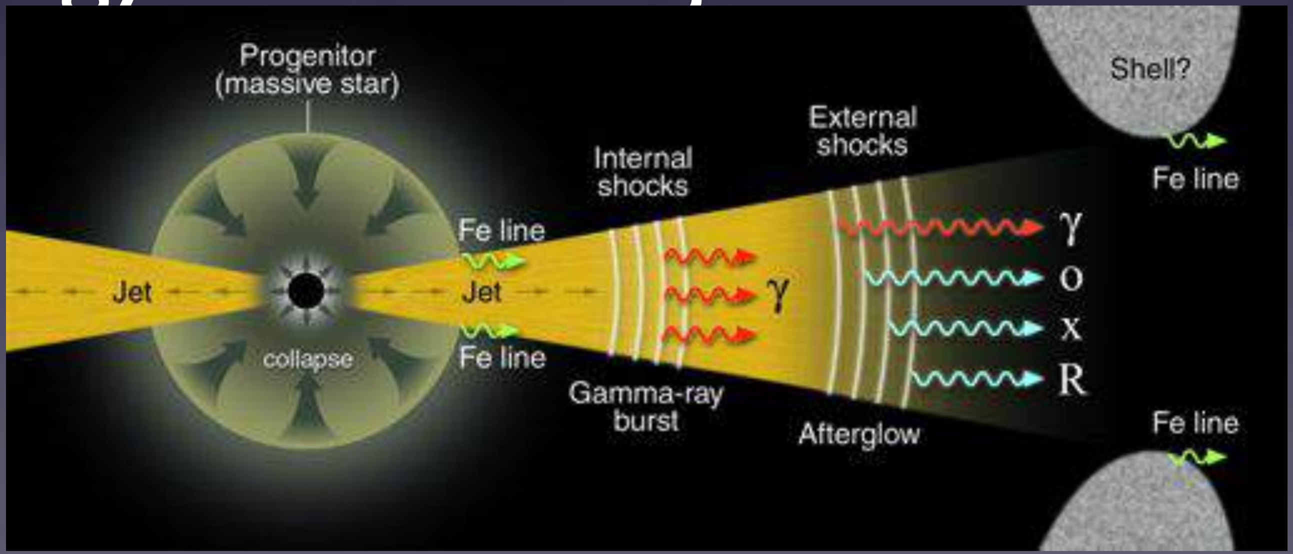


Transient research in India

- Supernovae
- Supernovae remnants
- Gamma Ray Bursts
- Pulsars and related phenomenology
- Novae
- X-ray binaries
- Tidal disruption events
- Galactic black hole candidates
- AGN variability
- Gravitational waves

Gamma Ray Bursts

- Most energetic explosions in the Universe
- GRBs are cosmological events
- The GRB jets are collimated within 5-10 degrees and moves with ultrarelativistic speeds
- The energy emitted in jets 1E51-1E52 ergs



Gamma Ray Bursts - research in India

- Theoretical modeling of Gamma Ray Bursts (Bhattacharya, Resmi)
- Radio follow up of GRB afterglows with VLA, GMRT (Chandra, Ray, Yadav, Resmi)
- Optical monitoring (Misra, Pandey, Sagar)
- Radio reverse shocks (Resmi, Chandra)
- Fermi GRBs (Misra, Chandra)

GRBs in radio bands

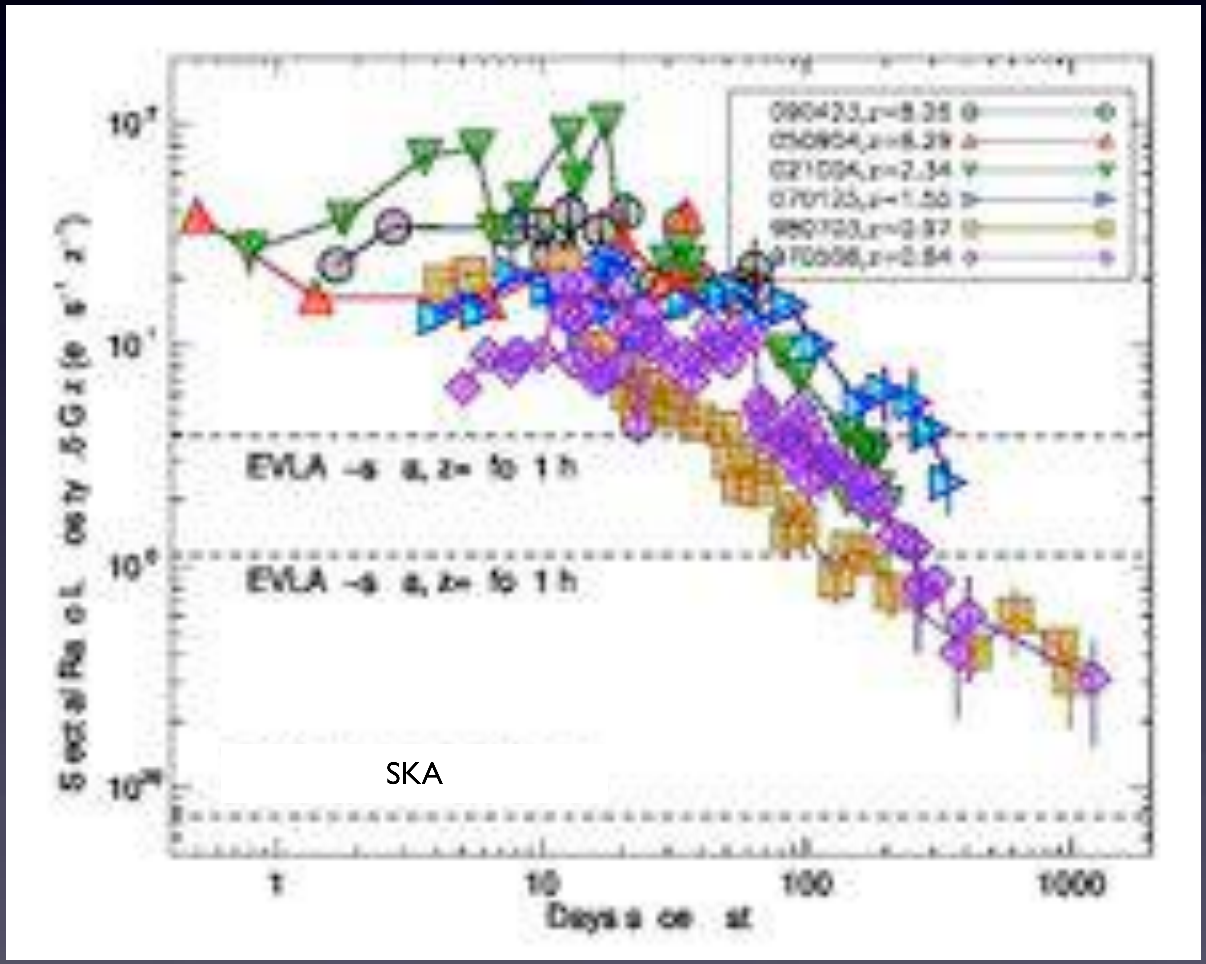
- Early time scintillation : Constraint on fireball size (e.g. GRB 970508; Frail et al. 97)
- VLBI- size of the fireball (e.g. 030329 Taylor et al. 2004)
- Synchrotron self absorption: circumburst density (e.g. GRB 070125 Chandra et al. 2008)
- Transition to non-relativistic regime (late time flattening): beaming independent calorimetry (e.g. GRB 970508 Frail et al. 2000)
- Detectable at high redshifts (e.g. GRB 090423, Chandra et al. 2010)
- Transitional objects like SN 2009bb and 2012ap (relativistic SNe without GRBs)
- One can also study GRB host galaxies in radio bands which are otherwise dust extincted in optical bands.

GRB Physics with SKA: Radio reverse shock

- Observe GRB very early and observe reverse shock.
- This will put constraints on the GRB central engine such as Γ and magnetic fields (Mundell et al. 2008).
- Early robotic trigger necessary.
- Best done with SKA-mid and SKA-survey.

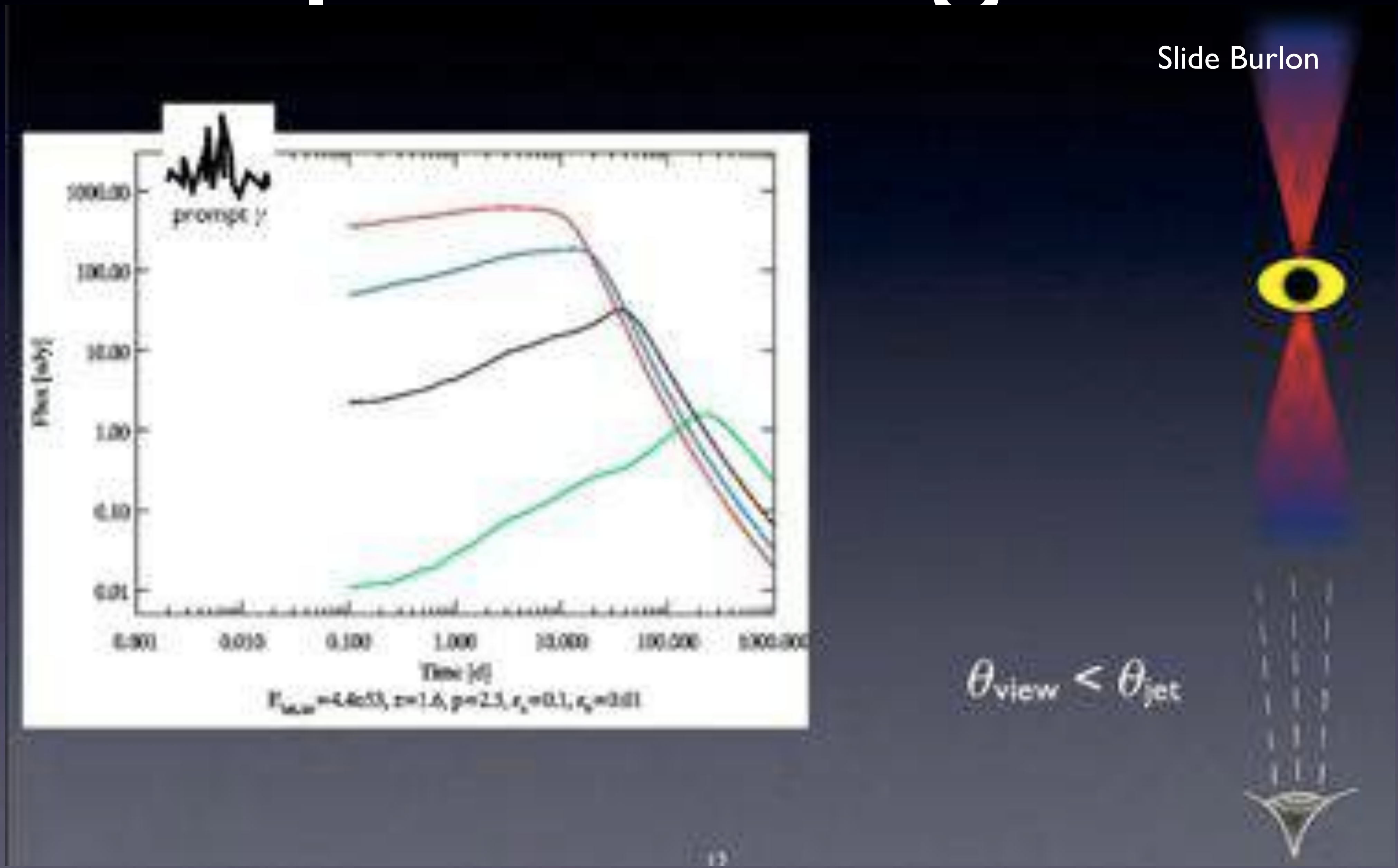
GRB Physics with SKA: Non-relativistic regime

Chandra and Frail 2012



- SKA can trace extremely faint afterglows to very long time when they reach non-relativistic regime.

GRB Physics with SKA: Orphan afterglows



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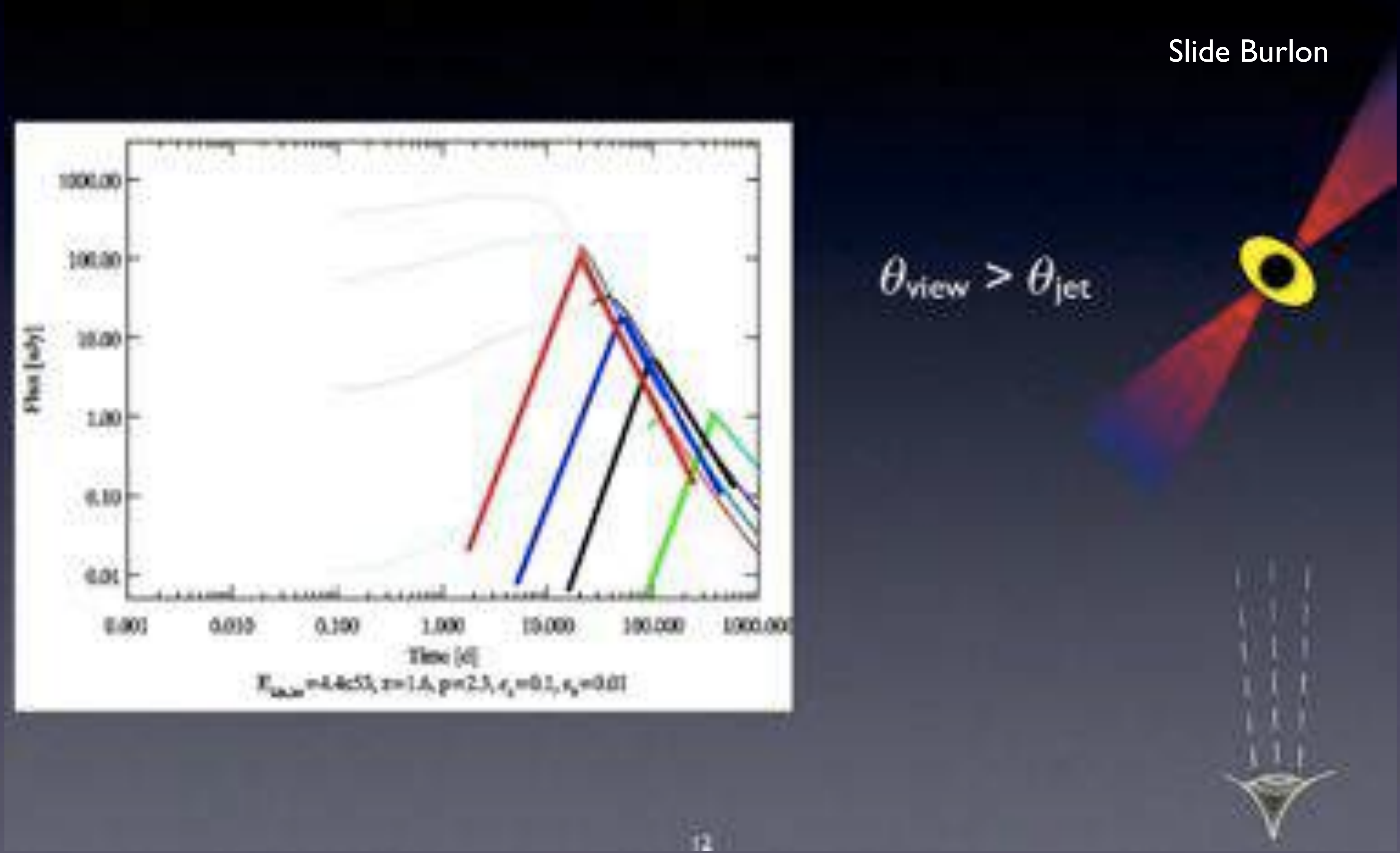
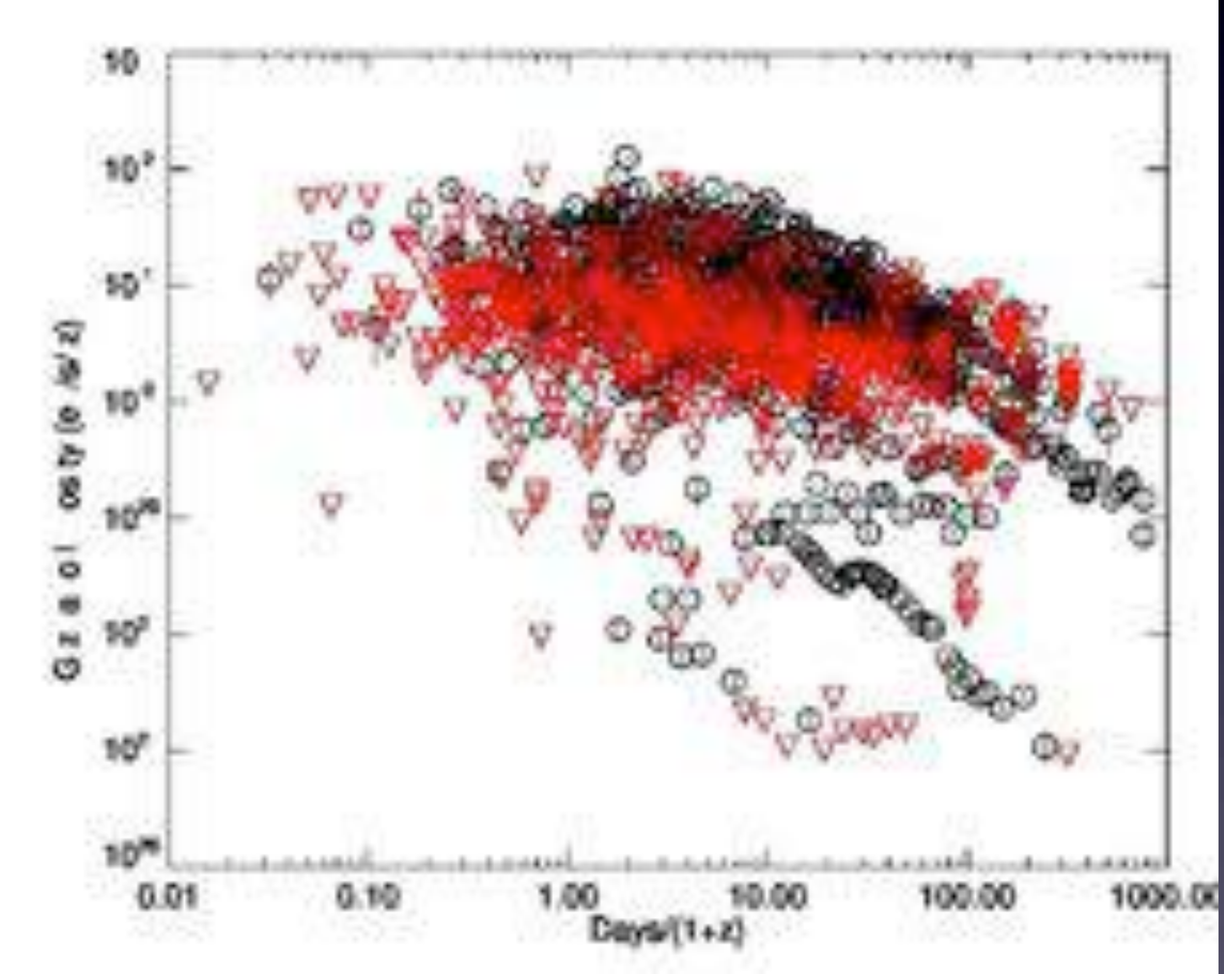


GRB Physics with SKA: radio detections: sensitivity versus intrinsic

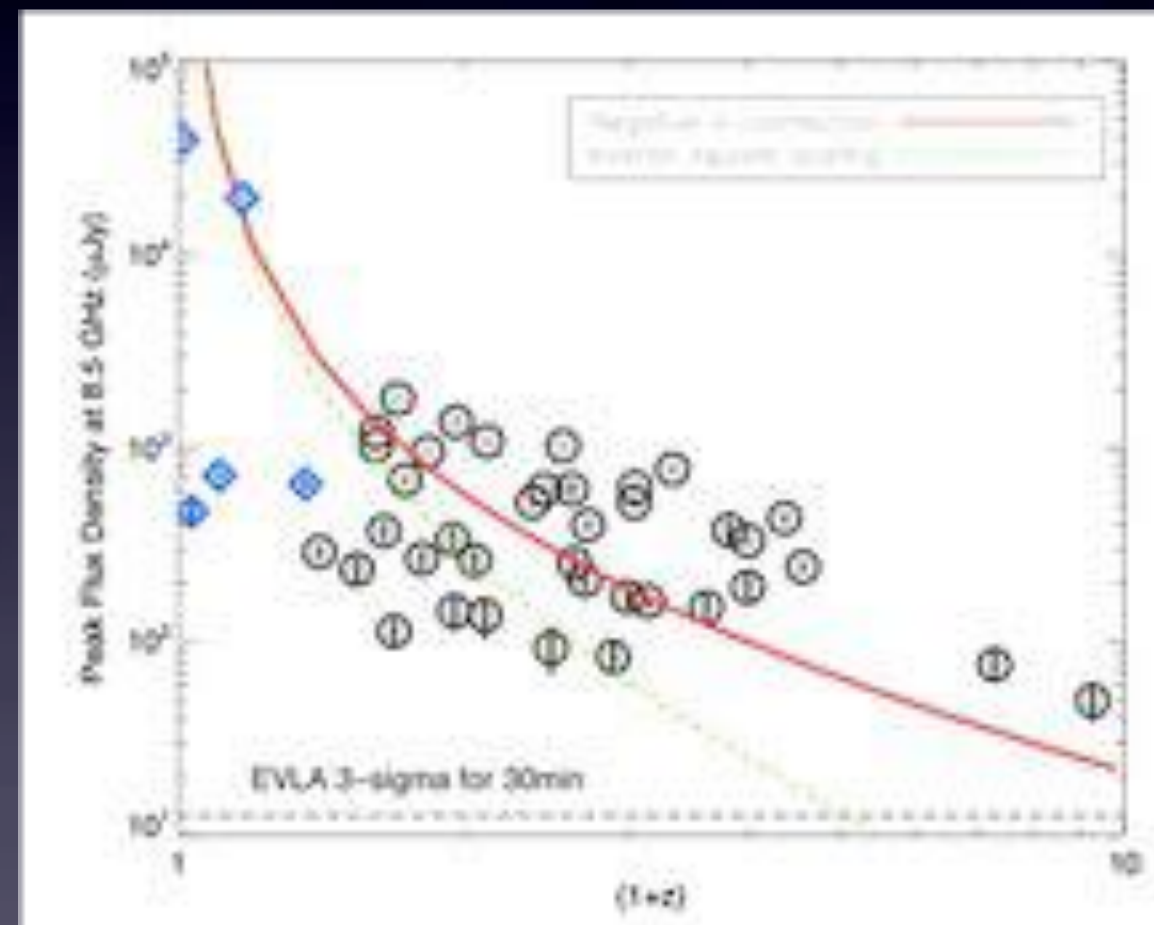
Chandra and Frail 2012



- Debate between Chandra & Frail (2012) versus Hancock et al. (2013)

GRB Physics with SKA: Early Universe

Chandra and Frail 2012, and
Frail et al. 2006

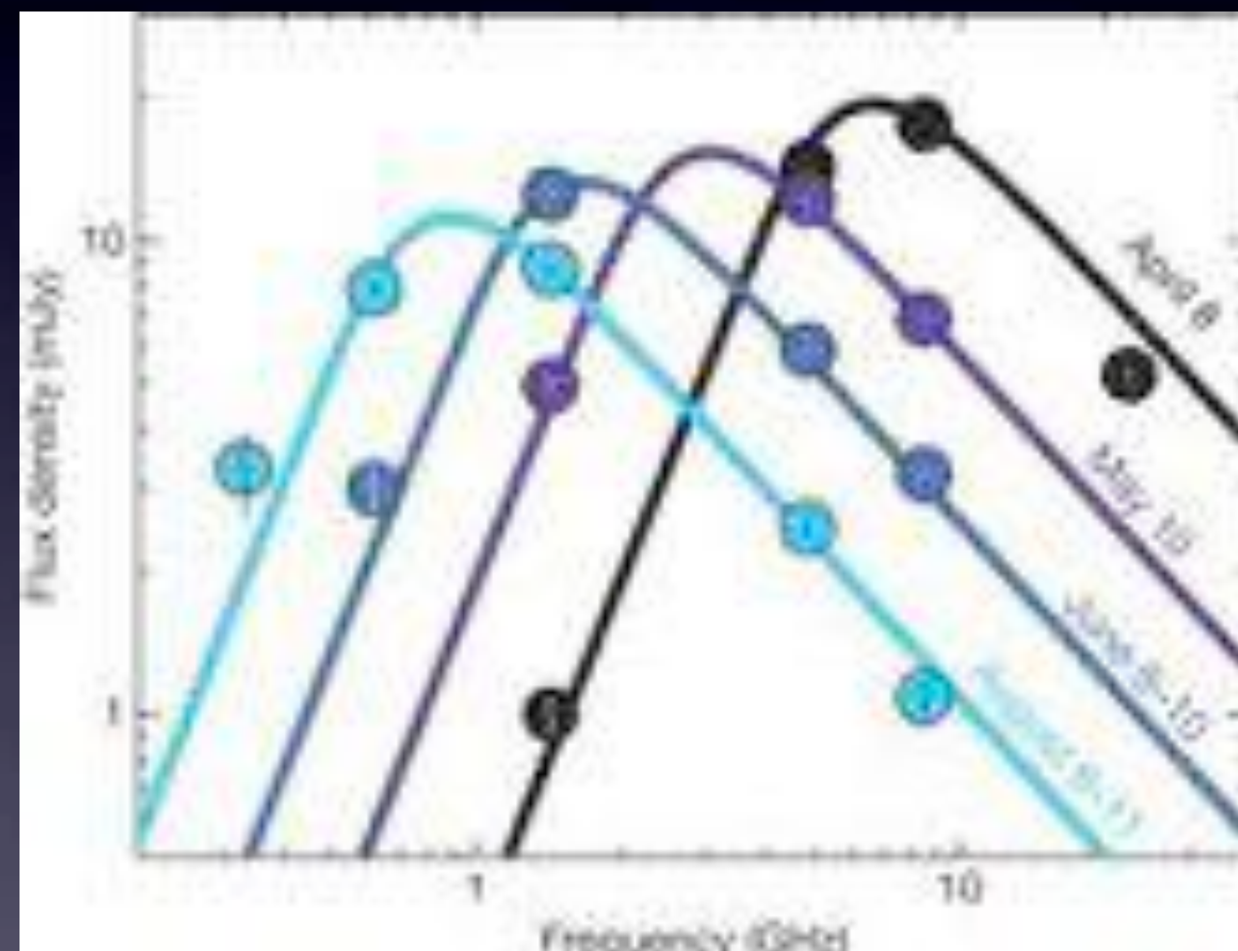


- SKA can detect very high redshift GRB.
- GRBs from first stars

GRB Physics with SKA: Transitional objects

Soderberg et al. 2009

- SN 2009bb and SN 2012ap.
- Possible with radio only because radio traces the fastest ejecta.



Supernova

- Explosion of massive stars
- Also thermonuclear detonation of white dwarf in a binary system.
- Core collapse versus thermonuclear supernovae
- Optical supernovae: IIA, ARIES, TIFR
- Radio Supernovae: NCRA, TIFR, ARIES, IIA

Supernovae Science with SKA

- Supernovae rate problem
- Dust extincted supernovae. Wrong rate of supernovae explosions
- Instead of following the optically detected SNe in radio, we can have unbiased radio sample of supernovae.
- SKA+LSST, follow supernovae from very

Expectations from SKA

- Only 10% supernovae radio detected. Roughly 2 per year. SKA will have around 50 SNe per year.
- The commensal, wide-field, blind transient survey observations would result in an essentially complete census of all CCSNe in the local universe, as well as an accurate determination of the true volumetric

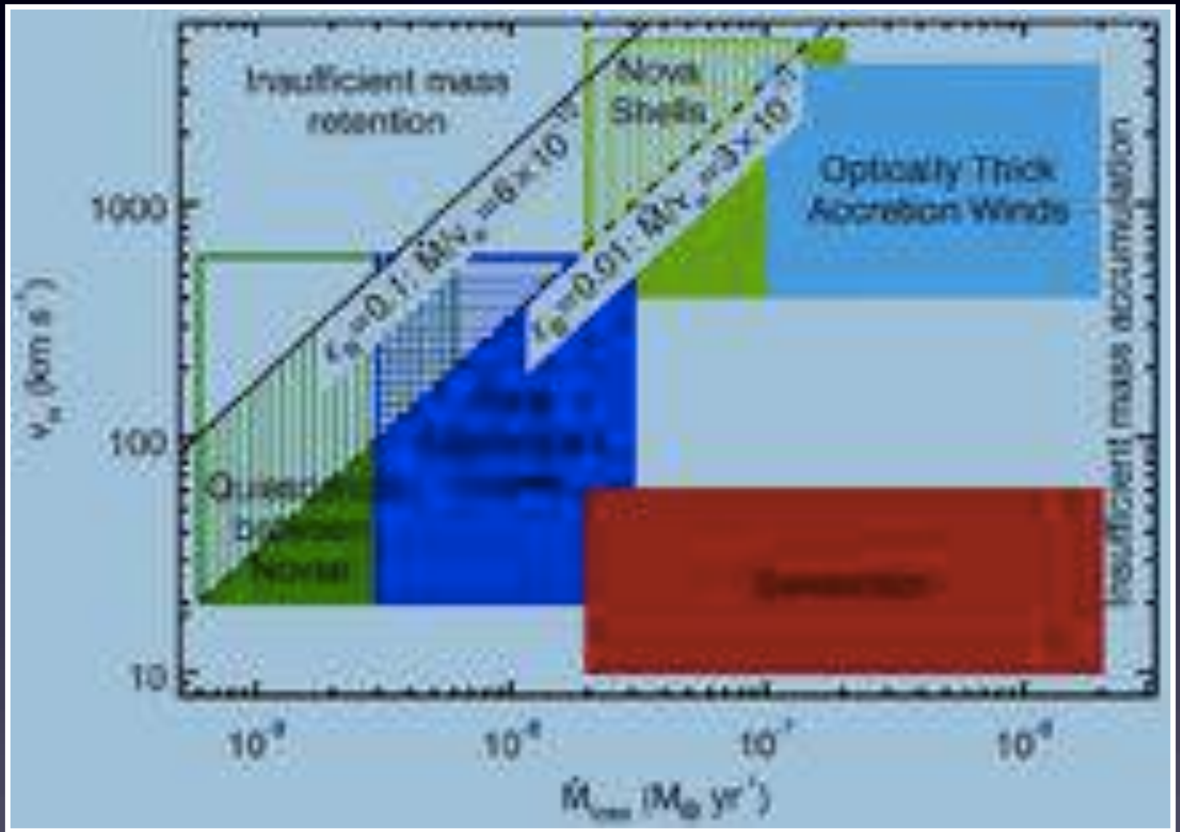
Expectation with SKA

- SKA1-sur at a frequency of 1.7 GHz, angular resolution 1", FoV 18 deg^2, good sensitivity 3.7 uJy/beam.
- SKA1-sur has survey speed 13 times of SKA1-mid. With an improved sensitivity level of 1 uJy, one can detect the brightest of radio SNe, such as the Type IIn SN 1988Z at the cosmologically interesting

Thermonuclear supernovae

Choumik et al. 2012, Perez-torrez et al. 2014

- Two scenarios SD versus DD
- No consensus
- Patat, Chandra et al. 2007 claimed circumstellar medium in SN 2006X
- Non-detection of SN 2014J (M82) puts mass loss rate limits <3E-8 M_{sun}/yr.
- Need to go <1E-10 M_{sun}/yr to rule out SD model.



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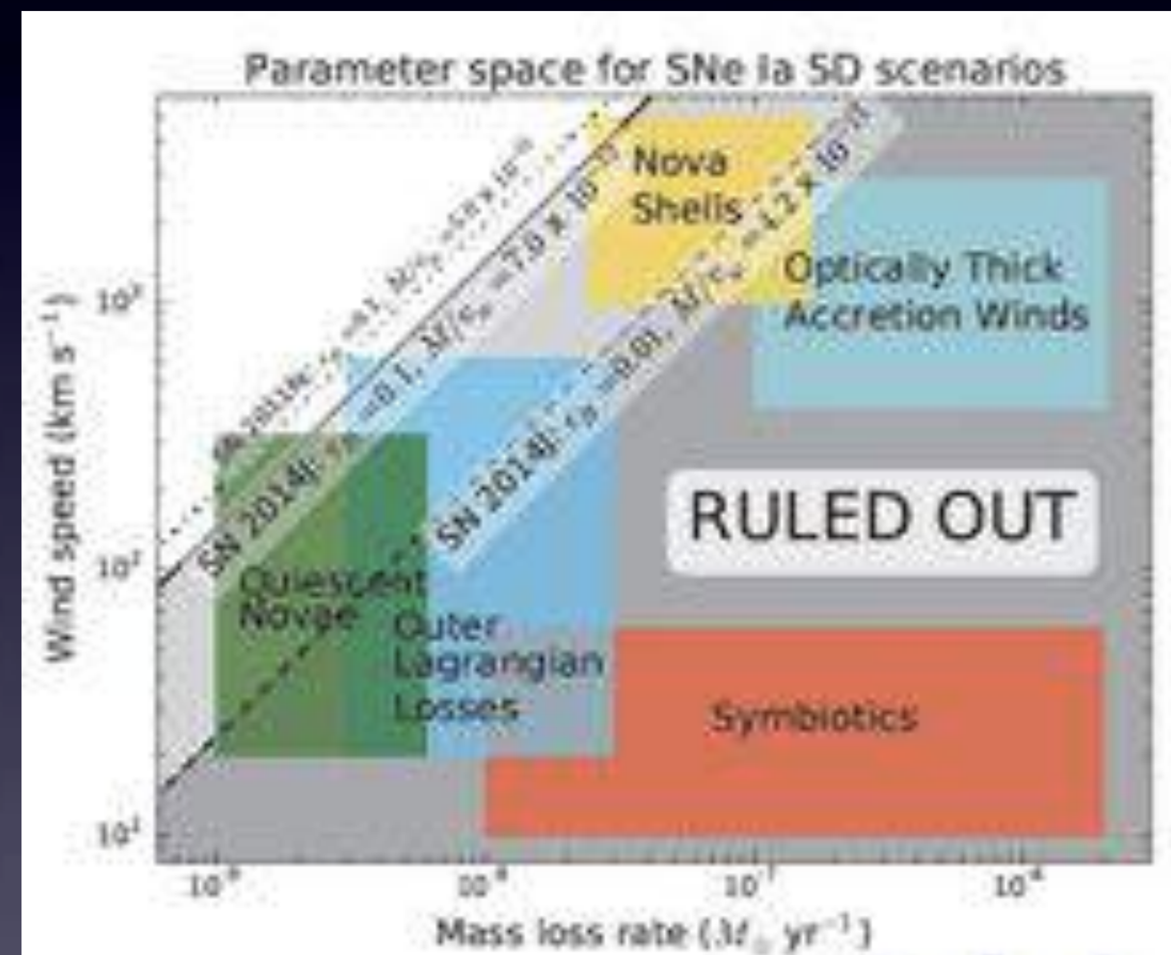
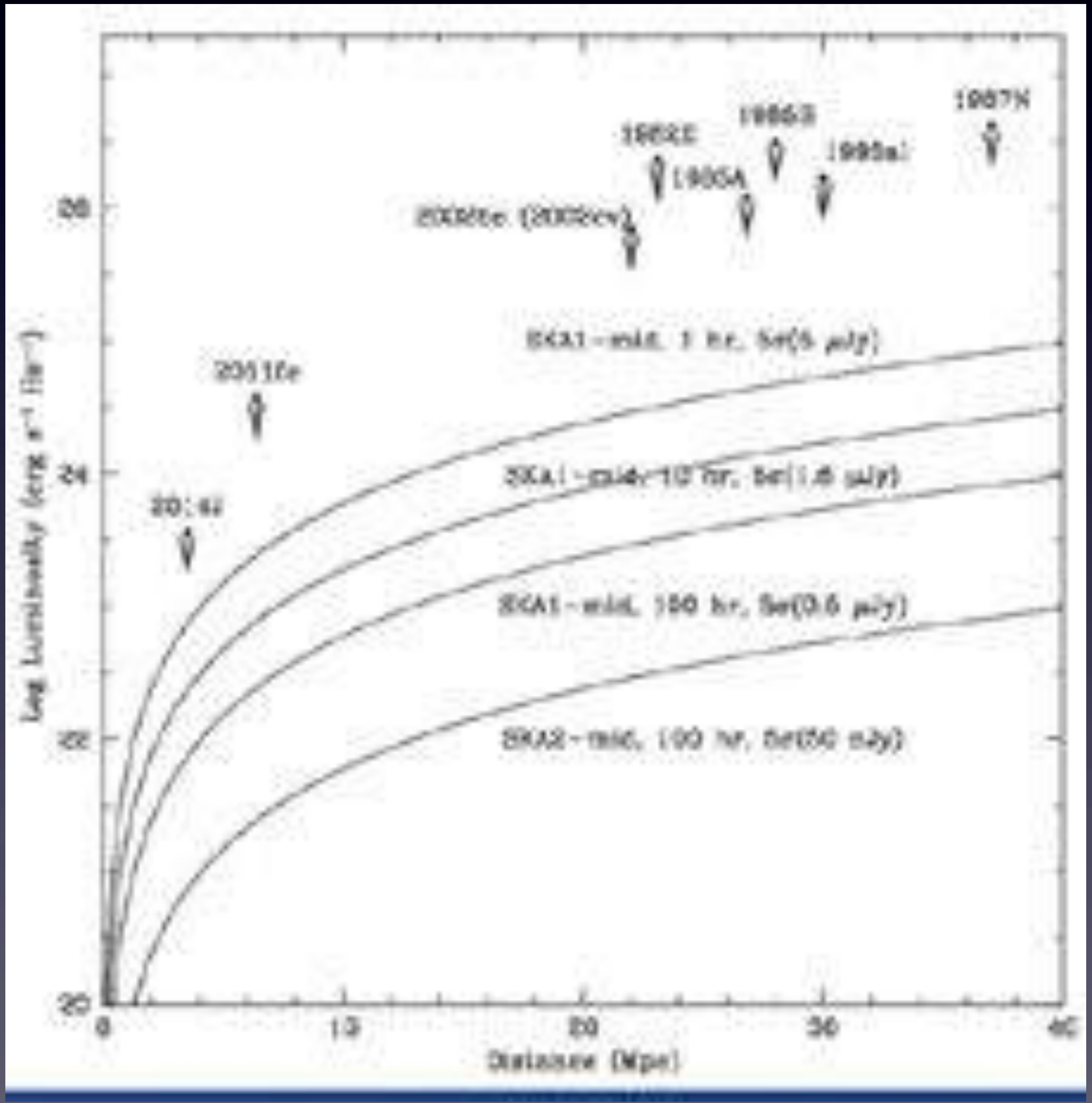


Thermonuclear supernovae with SKA

- SKA phase I will be able to go below any of the upper limits on radio luminosity obtained so far.



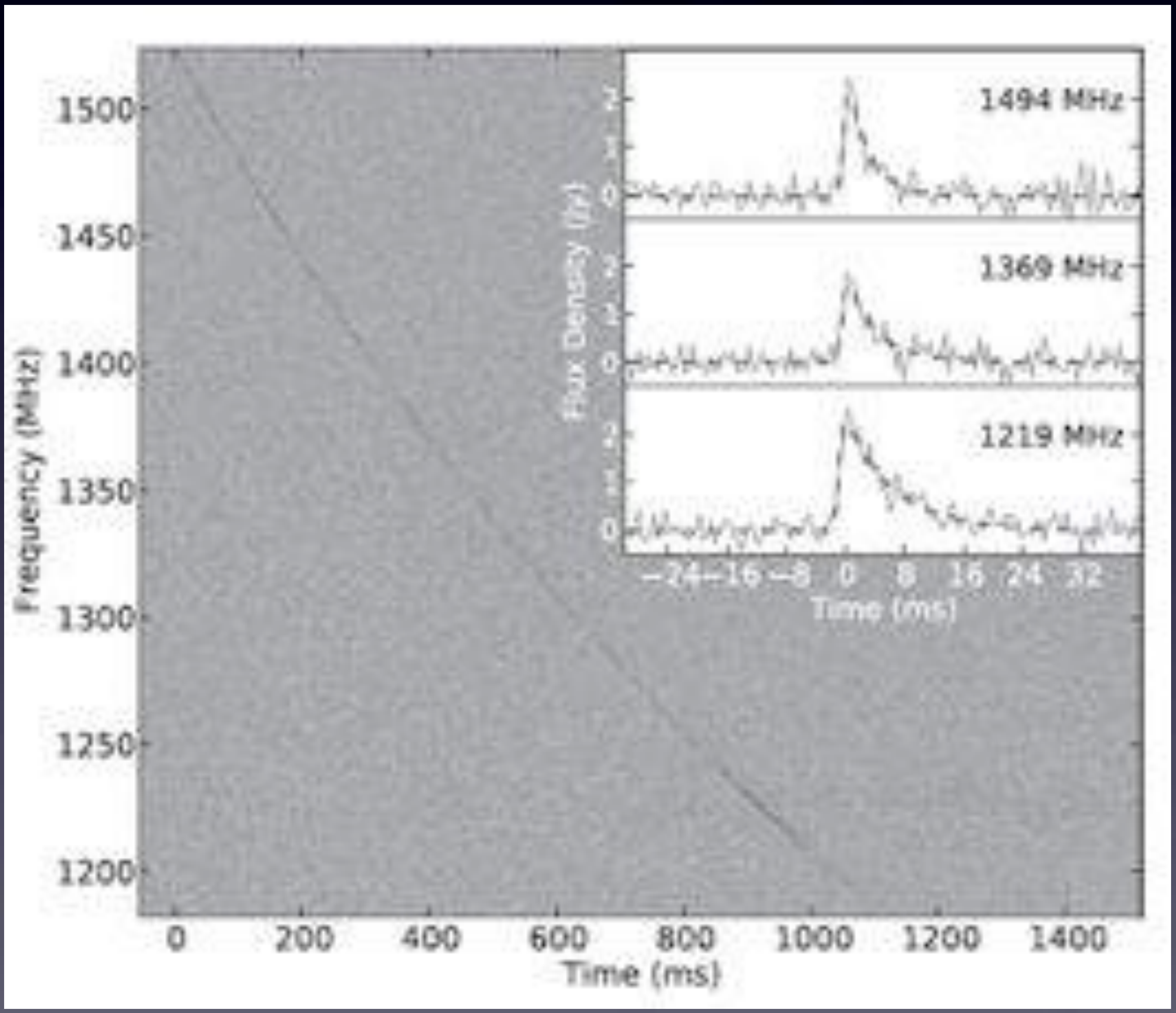
Slide: Wang

Fast Radio Bursts

Thornton et al. 2013

FRB 110220, DM=944 pc/cm^3, z~0.8

- High fluence 10 Jy.ms
- Energy release ~10^{40} erg
- Almost a dozen events, some with Parkes and some with Arecibo (multi-beam receiver)
- 10^4 /sky/day
- High DM, off the Galactic plane, Consistent with scattering in turbulent plasma ν^{-4}
- Most likely extragalactic
- So far no host galaxy association



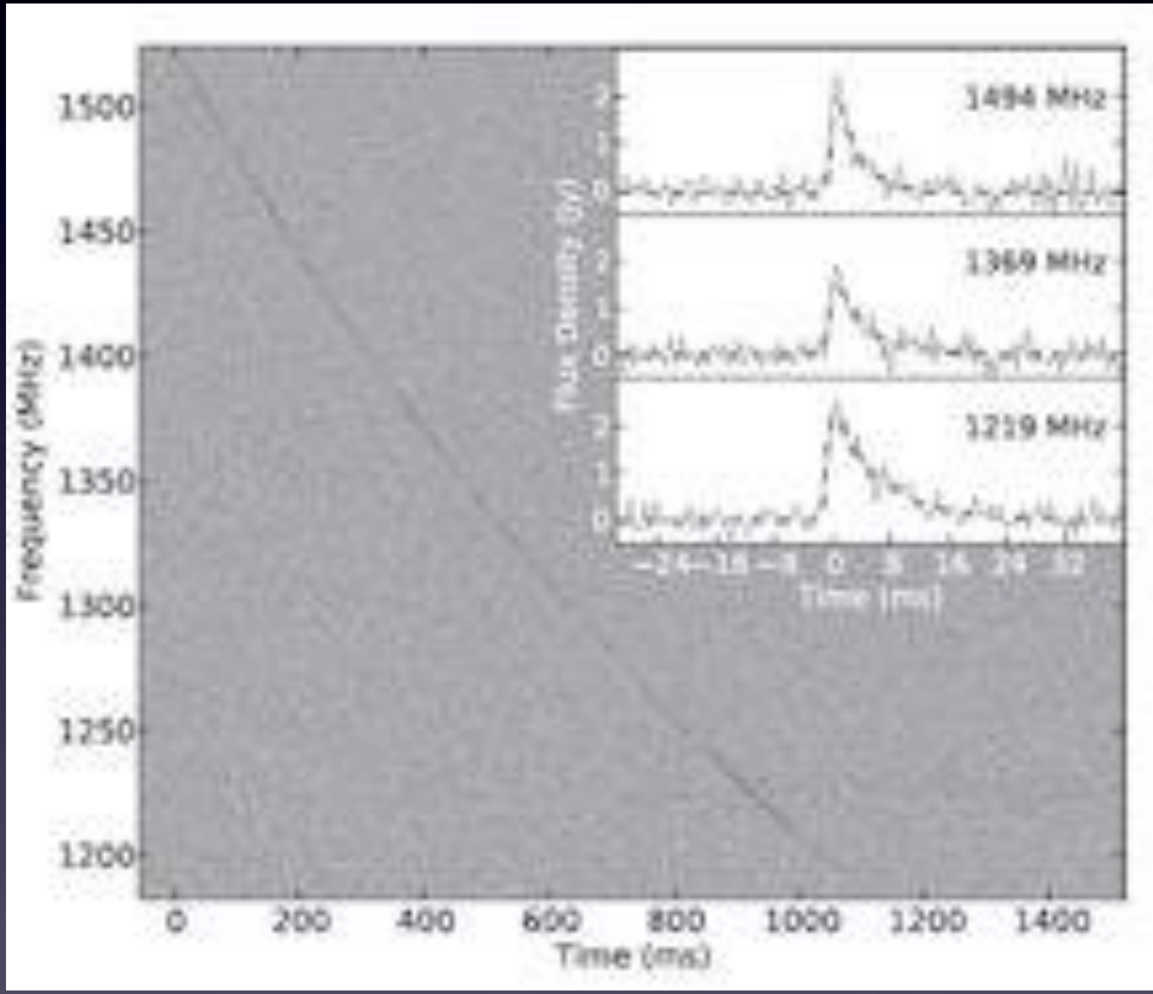
What FRBs are not?

- Not Galactic flare stars. Considered by Loeb et al 2013. But discarded since the free-free optical depth required for radiation to escape is incredibly high (Luan & Goldrich 2014)
- Not nearby supernovae and GRBs (e.g. GRB 140514, Petroff et al. 2015)

FRBs and missing baryons

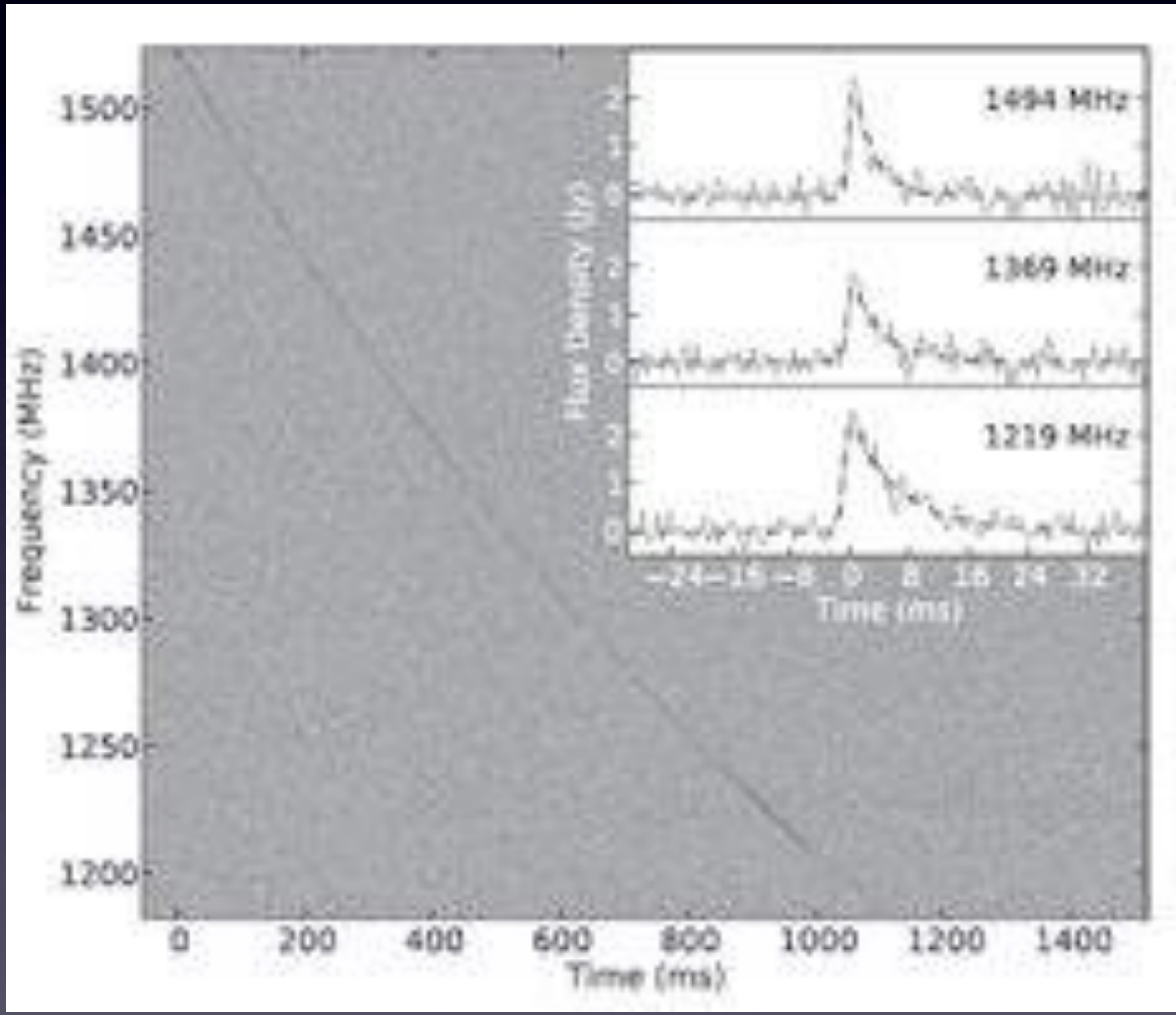
- Most of the baryons in IGM at very low T and ρ, difficult to detect (>50%)

- FRB DM measurement probes IGM densities as DM is sum of DM from Milky way, FRB, FRB host and IGM.



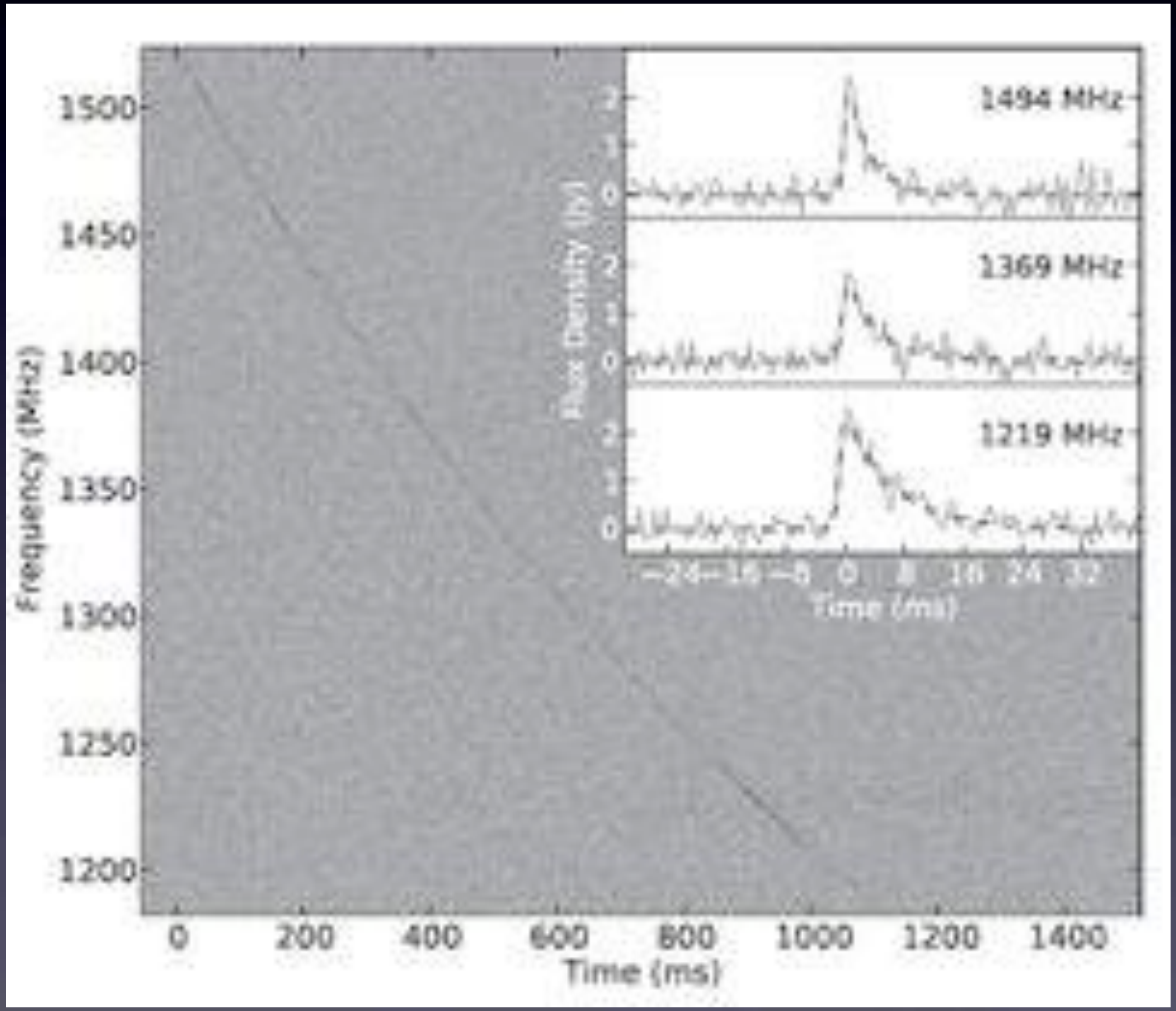
FRBs are cosmic rulers

- Dark energy content of the universe known upto z~1.5 (Type Ia SN)
- Dark energy equation at much larger redshifts
- But many 100s of FRBs to detect before we can carry out this.



FRBs and Gravitational Waves

- Gravitational waves may produce coherent low frequency emission (Moortgaat & Kuijpars 2014).



FRBs with SKA

- Tens of thousands FRBs needed to carry out the above goals.
- High resolution needed to look for host galaxy (Parkes 14')
- The SKA can achieve this with a design that has a wide field of view, a substantial fraction of its collecting area in a compact configuration (80% within a 3 km radius), and a capacity to process high time resolution (1ms) signals.
- SKA1-LOW and SKA1-Survey will be the useful telescope for this.

Novae outbursts

- Runaway thermonuclear reaction at the surface of accreting white dwarf in interacting binary system
- Time domain astronomy of thermal sources
- Help understand stellar evolution, accretion, thermonuclear burning, outflows, shocks

Novae

- Current novae rate ~30 per year
- LSST expected to increase
- Nearby observatories to study extreme astrophysics

Radio emission from novae

- So far most information comes from optical

- Radio to understand puzzling aspect of accretion, outbursts and interaction with the environment.

- Radio emission lasts for months

Radio emission from novae

- Primary mechanism thermal bremsstrahlung from warm ejecta
- For novae in dense environment, non-thermal synchrotron also possible (GK Per)
- Shock interaction can also lead to high energy emission (e.g. V407 Cyg2010)

Radio emission from novae and SKA

- Radio emission traces thermal free-free emission, i.e. mass of the ejecta
- If the ejecta is lower mass, low optical depth, earlier, fainter peak
- How ejecta profile and dynamic mass loss evolve with time
- Novae at various epochs of outburst (G-novae)
- Thermal mostly >1 GHz as fainter at <1GHz
- SKA can detect thermal as well as non-thermal emission from <1 GHz
- Also study why non Type Ia SN radio bright!

Novae with SKA

- SKA-MID is the best telescope
- Efficient, frequent observations
- Multiband observations

Stellar mass compact objects

- X-ray binaries (XRBs)
- Ultraluminous X-ray sources (ULX)
- Isolated Black holes
- RRATS

Rotational radio transients (RRATS)

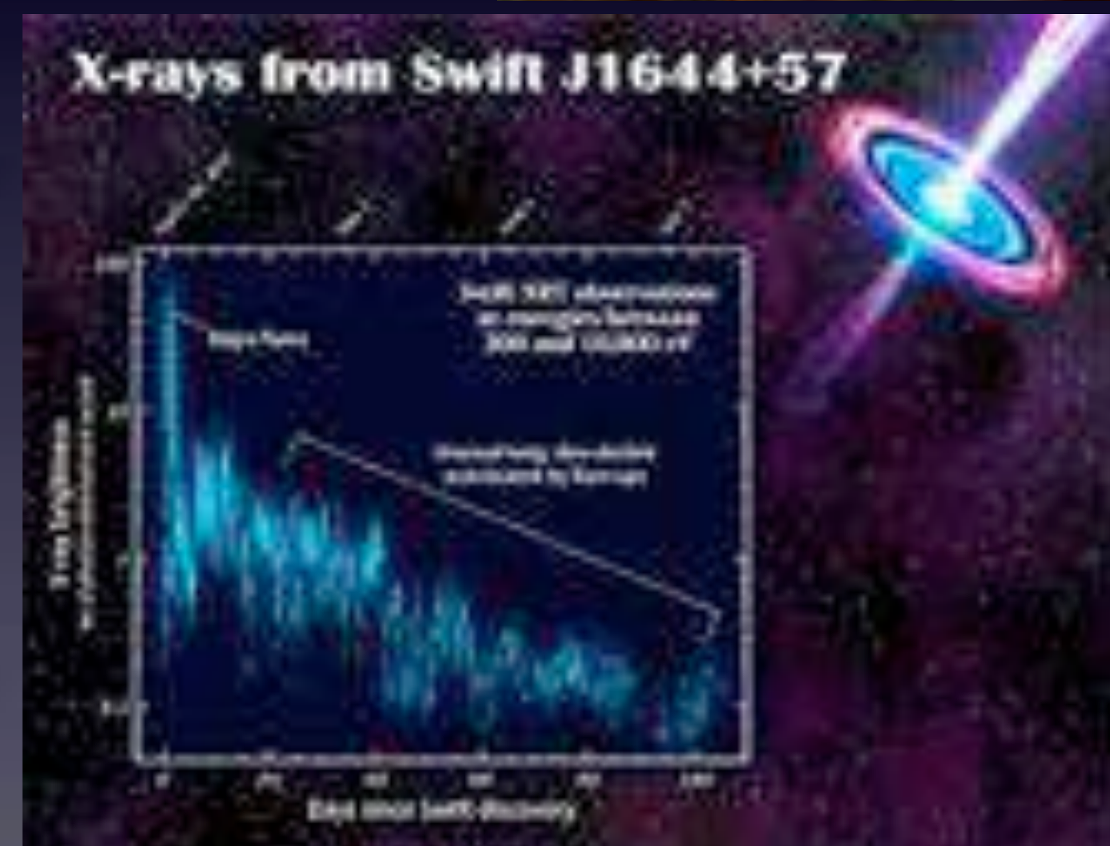
- Because small no. of pulses detected, period measurements not available for all.
- Only 25% RRATS have measured pulse derivatives
- Whether ordinary pulsar population or a special class of neutron stars.
- SKA capabilities to search more of them and obtain period derivative measurements.

X-ray binaries (XRBs)

- Jets of XRBs imaged in radio.
- Strength and nature of the jet evolves with intensity and state evolution of XRBs.
- Study of correlation of jet with various timing and spectral features in X-ray, IR etc probe accretion-ejection mechanism strong gravity regime.
- Crucial to detect jets in short time scales.
- SKA can detect faint jets also

Tidal disruption events E.g. Swift 1644+5

- A stars is disrupted by the supermassive black hole at the center of the galaxy.
- Probes properties like mass, spin, density, GWs. In optical and X-rays typically thermal flares.
- Bright radio counterpart from ultrarelativistic jets
- Fast Survey mode of SKA- 100s of TDE per year
- Study super-eddington accretion



Credit: NASA/Goddard Space Flight Center/Swift

Multimessenger Astronomy

- Collaboration in IceCube. Radio counterparts of Astrophysical events associated with neutrinons
- radio follow ups of SGRBs associated with GWs
- GW triggered searches for radio counterparts associated with compact binary mergers

SKA and advanced-LIGO

- Advanced LIGO, realistically expected to made gravitational wave detection
- Problem in position accuracy.
- Wide field and rapid slewing capability of SKA and precursors.
- Observe in day time also
- Can see through extinction

Summary

- Gravitational wave counterparts
- TDEs are often accompanied by jets so visible in radio
- GRB orphan afterglow
- Local CCSNe (Unbiased)
- Classical novae, radio total ejecta mass

Expectations with SKA

- 1 Tidal disruption event per week (SKA-MID, SURVEY)
- 1 FRB per day (SKA-MID, SURVEY)
- High flux MHz transients (like 10Jy@60MHz with LOFAR)- 100s per day (SKA-LOW)

Two recommendations by international transients SWG in SKA-I phase design

- Commensal transient searches
  - Near real-time search for all data for transient events
  - Report detection widely, globally, quickly
  - Increase transient detection by order of magnitude
- Rapid (robotic) response to triggers
  - Robotic response to external triggers
  - Automatic follow up of high priority events
  - Very early time coherent, prompt radio emission (e.g. GRBs)

Thanks