Beyond Astrognosy: LSST and Radio Stars as Probes of the Universe

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Radio Astronomy in the Era of LSST workshop, May 6, 2013

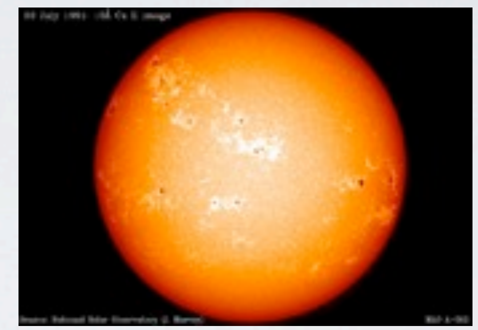
As`trog´no`sy

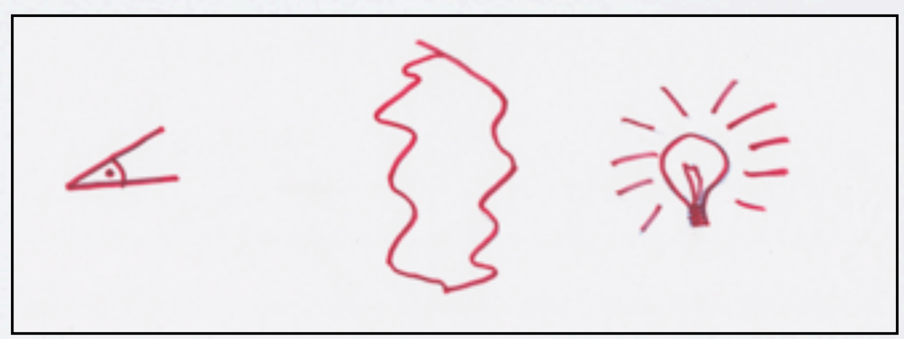
n. 1. The science or knowledge of the stars, esp. the fixed stars.

Webster's Revised Unabridged Dictionary, published 1913 by C. & G. Merriam Co.

OUTLINE

Two ways of thinking about stellar astronomy:

1. stars as stars  (or really )
   - learning about the detailed processes occurring on the stars themselves, how they affect immediate stellar environment (stellar evolution, planet formation & habitability)

2. stars as lightbulbs 
   - stellar illumination yields line-of-sight information on environs

CONNECTING LSST AND RADIO OBSERVATIONS OF STARS

- (from lsst.org): "LSST is ideally suited to answering the question: what are the fundamental properties of all the stars within 300 pc of the Sun"
  - ➡ a complete census of the solar neighborhood to a distance of 100 pc based on trigonometric parallax measurements for objects as faint as M_r=17
- Stellar radio observations (m/dm/cm/mm/sub-mm) are ideally suited to probing the presence & action of nonthermal particles, magnetic fields, cool neutral atomic & molecular gas & dust

interplay between these wavelength regions adds more bang for the scientific buck

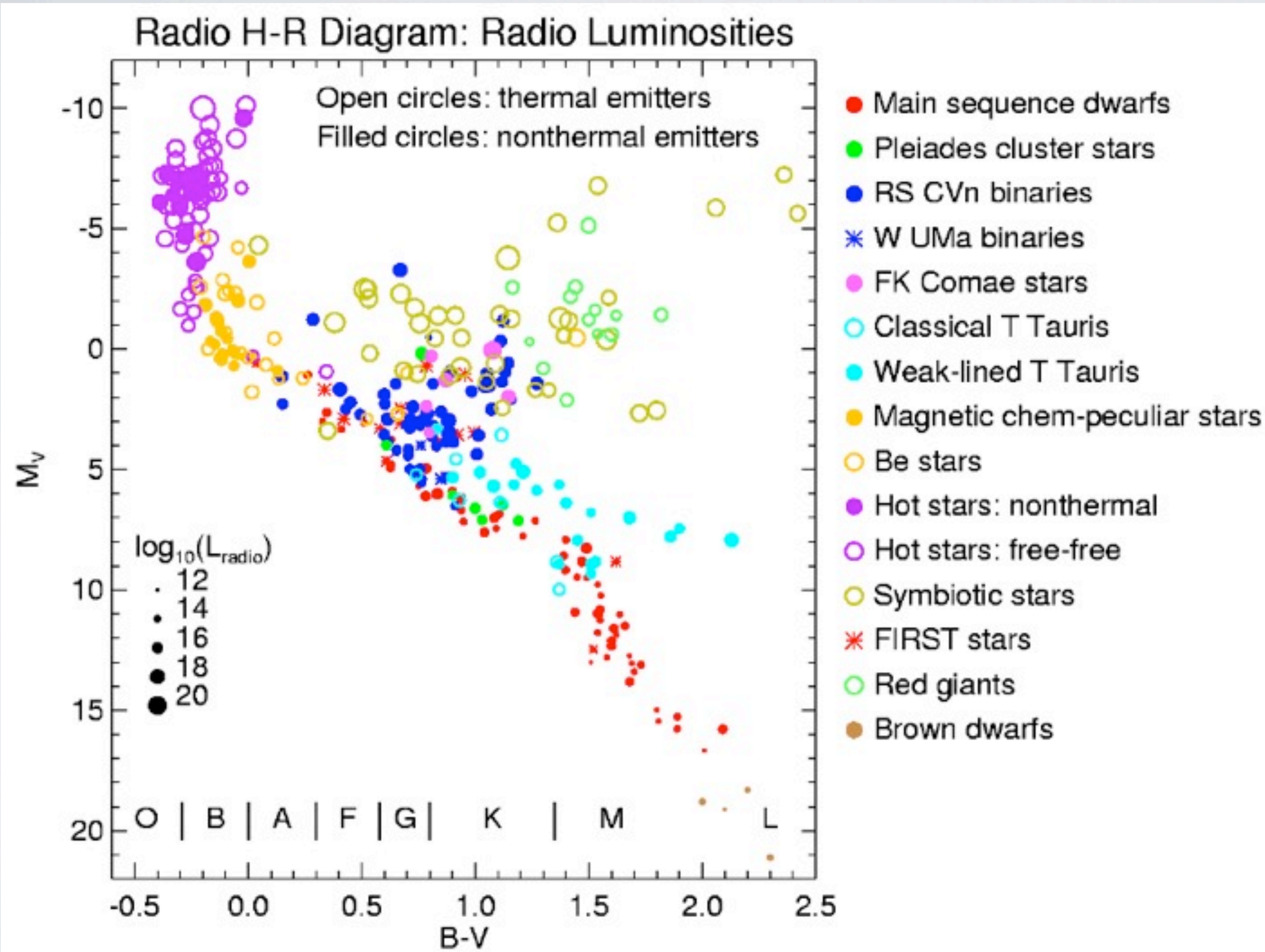


figure courtesy Stephen White

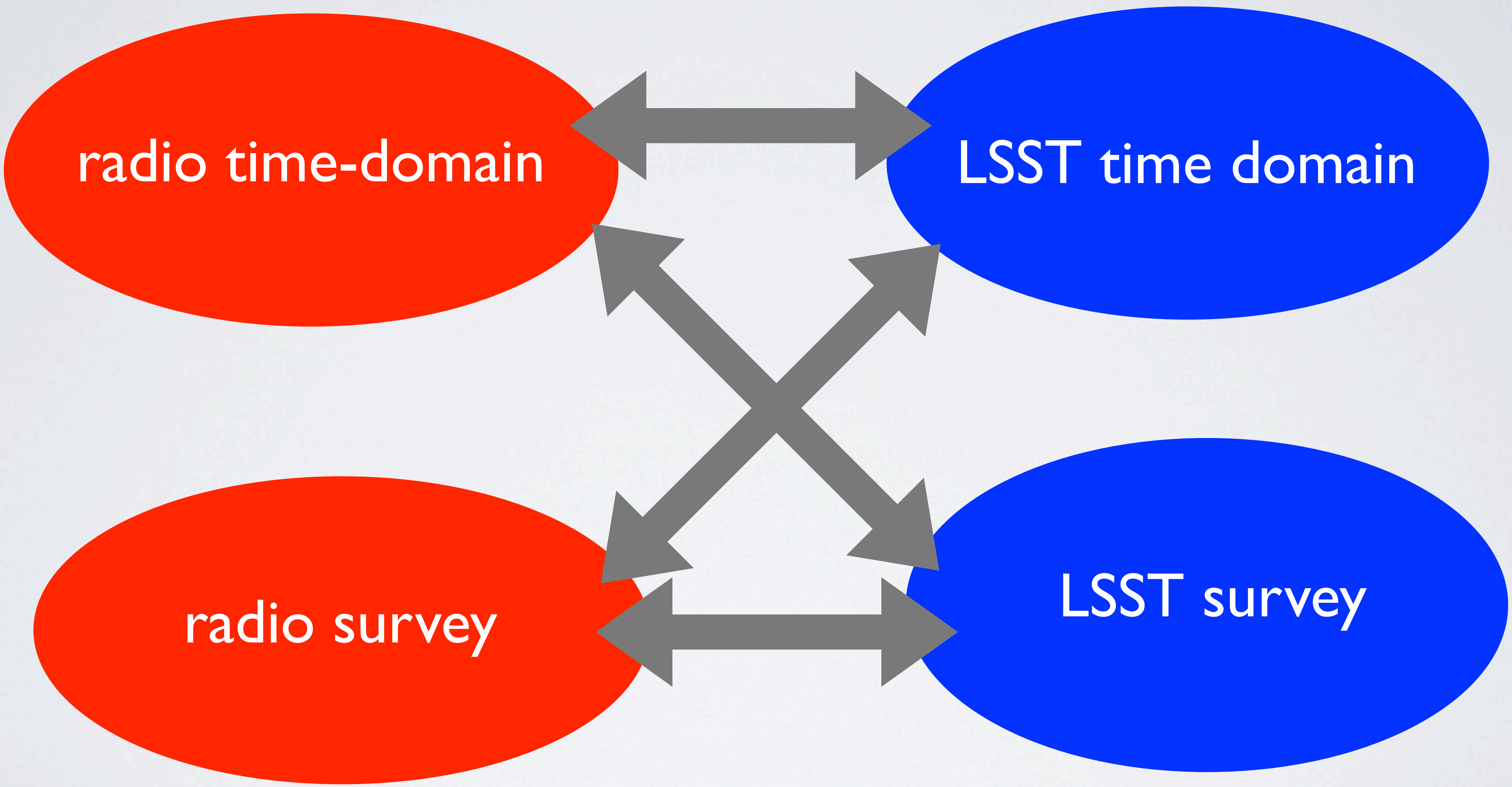
Nearly all stellar types exhibit radio emission of one form or another

since radio emission is typically only a fraction of L_{bol}, observations have tended to favor nearby, optically bright objects

Stellar Radio Emission and the Time Domain

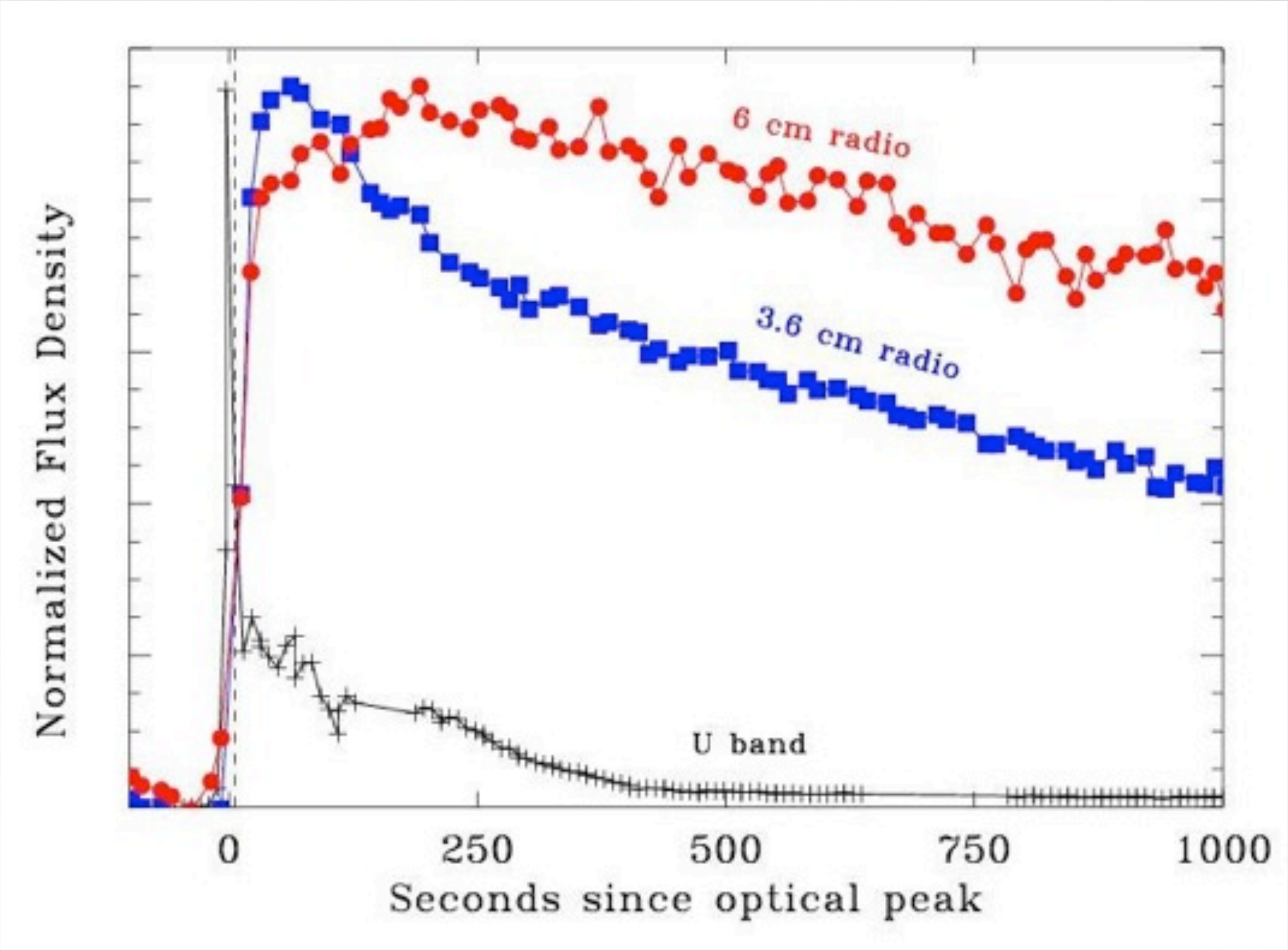
Wavelength	typical stellar radio emission	variable?
meter	coherent emission: plasma radiation or cyclotron maser emission	yes, short timescales
decimeter/centimeter	coherent emission incoherent emission: gyro/synchrotron, thermal atomic maser line emission	yes, short timescales yes, short+long timescales no/yes on long timescales no yes, long timescales
millimeter/submm	atomic, molecular line emission maser thermal disk emission	no yes, long timescales no?

CONNECTING RADIO OBSERVATIONS OF STARS TO LSST OBSERVATIONS OF STARS



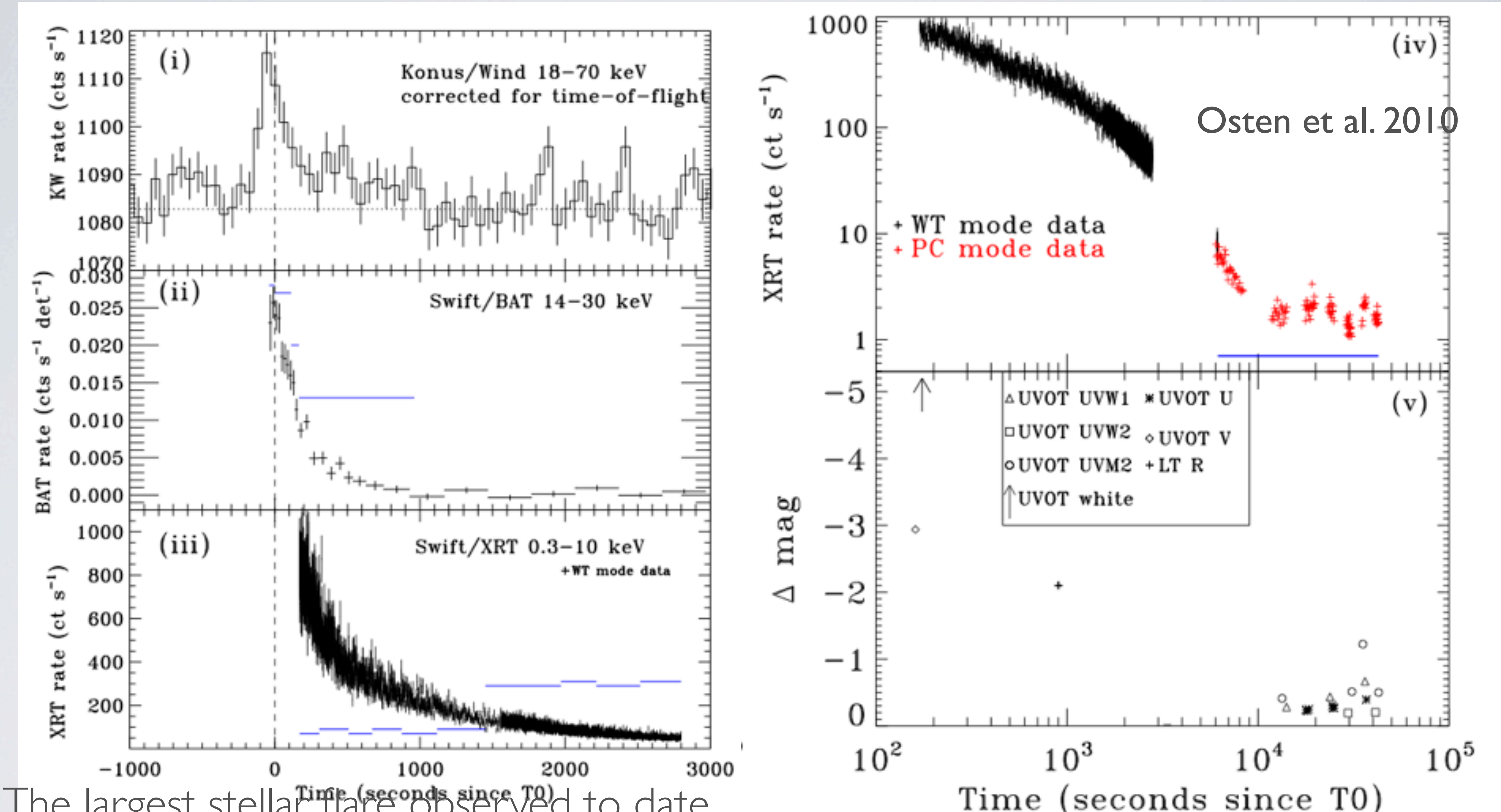
MULTI-WAVELENGTH TIME-DOMAIN STELLAR OBSERVATIONS

simultaneous, multi-wavelength observations targeting a single star to study time-domain astrophysics (magnetic reconnection, particle acceleration in this case). . .not the model for typical LSST/radio observations



Osten et al. 2005; multi-wavelength observations (radio, optical, UV, X-ray)
white light flares dominate energy budget, radio observations constrain presence & action of nonthermal particles

A little prior knowledge is good when it comes to transients



- The largest stellar flare observed to date
- Rate of energy release is ~10^{6} times solar X-ray flare energy release
- Stellar flares ARE a minor contributor to the GRB population
- Stellar flares will be a major contributor to LSST transient population; knowing what the interesting objects to follow up will be key
- It's not just M dwarf flares…(Osten et al. 2012)

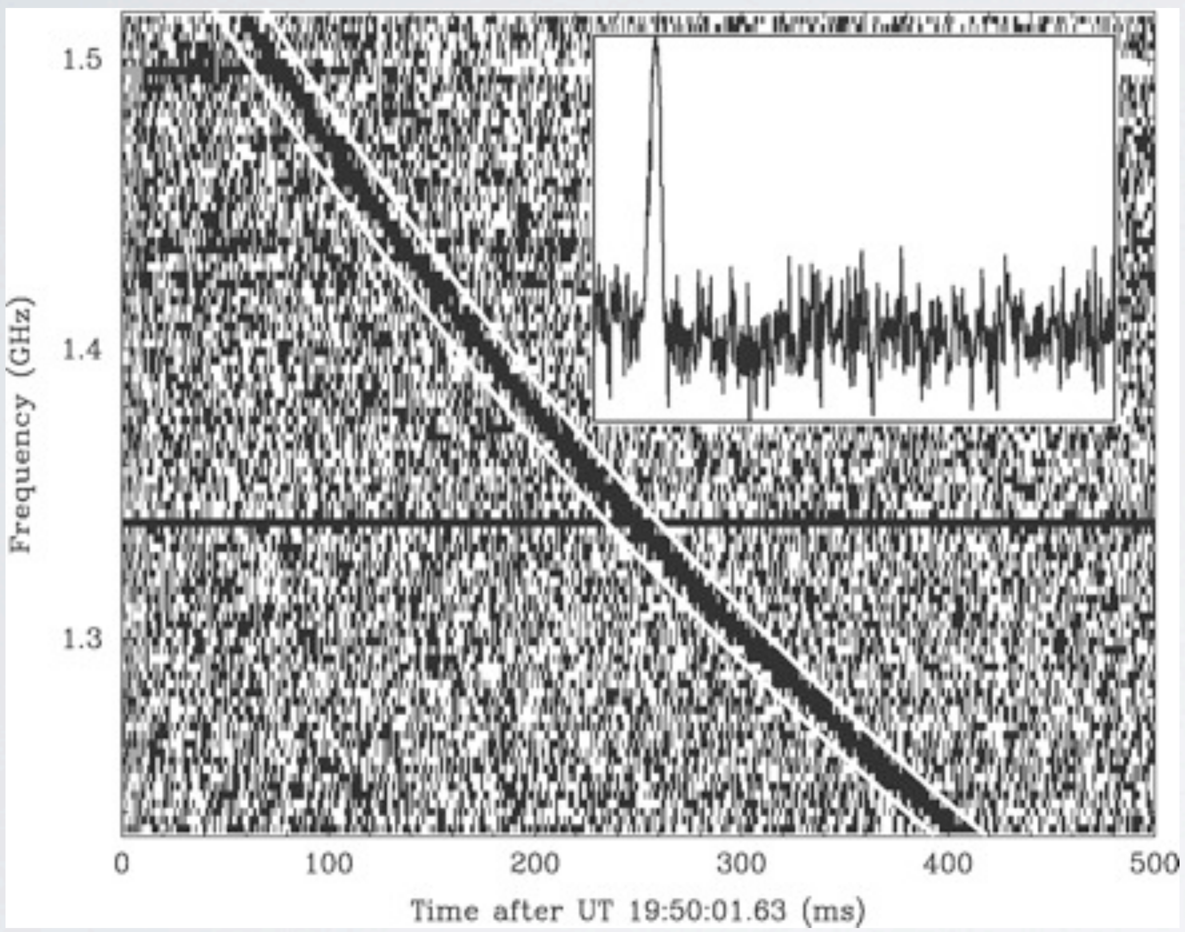
TWO CASE STUDIES

- study of drifting radio bursts to infer not only motions in the stellar atmosphere, but also gain constraints on interstellar electron densities from accurate distances determined by LSST

- study of evolved stars and their interaction with the ISM

DRIFTING RADIO BURSTS

propagation of radio signal through ISM introduces a delay in arrival time which is frequency dependent



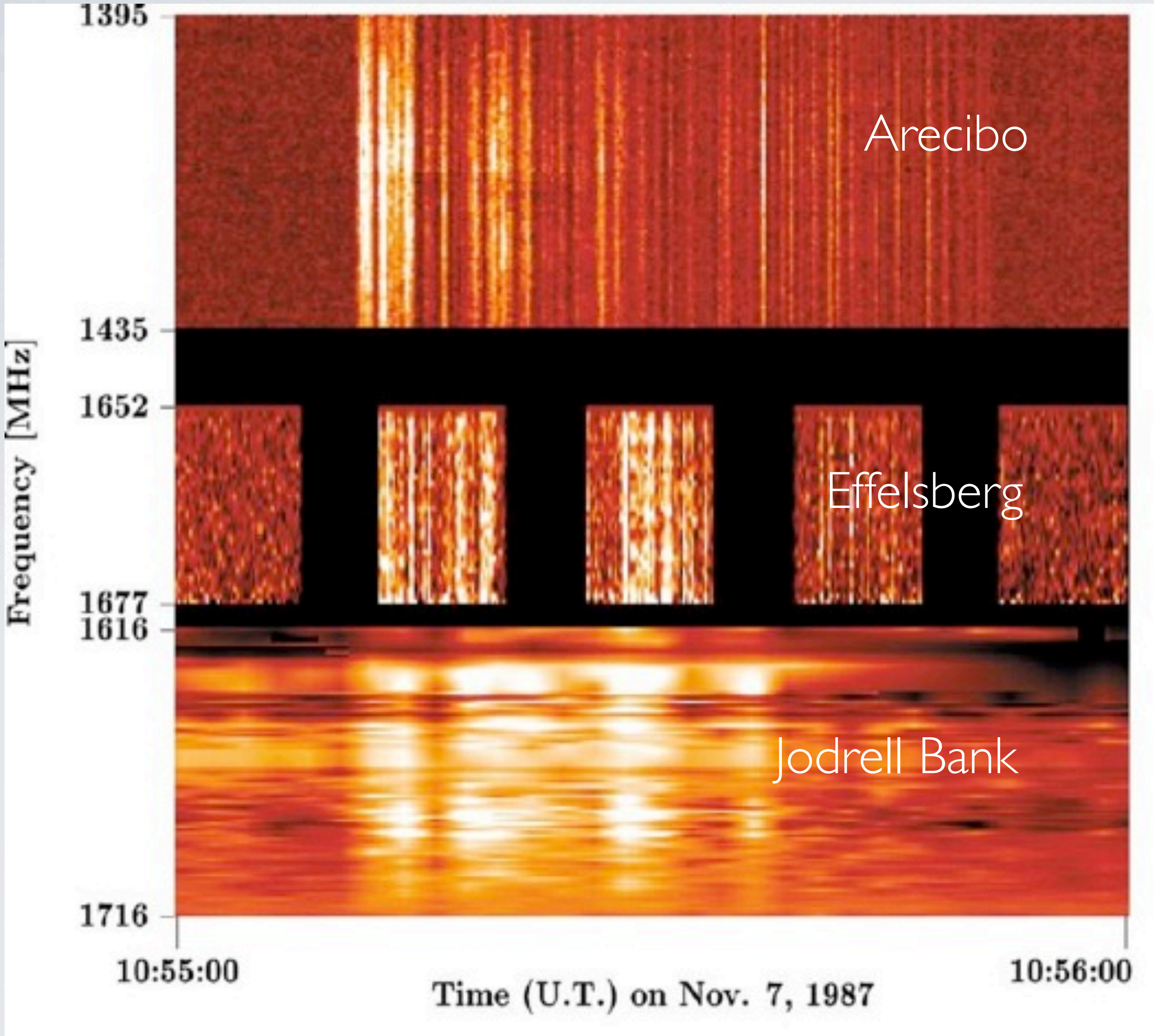
Lorimer et al. (2007) dynamic spectrum of an isolated drifting burst; inferred DM is 375 pc cm^{-3}

$$\Delta t_{\mathrm{DM}} = 8.3\ \mu\mathrm{s}\,\mathrm{DM}\,\Delta\nu_{\mathrm{MHz}}\nu_{\mathrm{GHz}}^{-3}$$

$$\mathrm{DM} = \int_0^D n_e(l)\,dl$$

dispersion measure contains integral of distance to object and integrated IS electron density

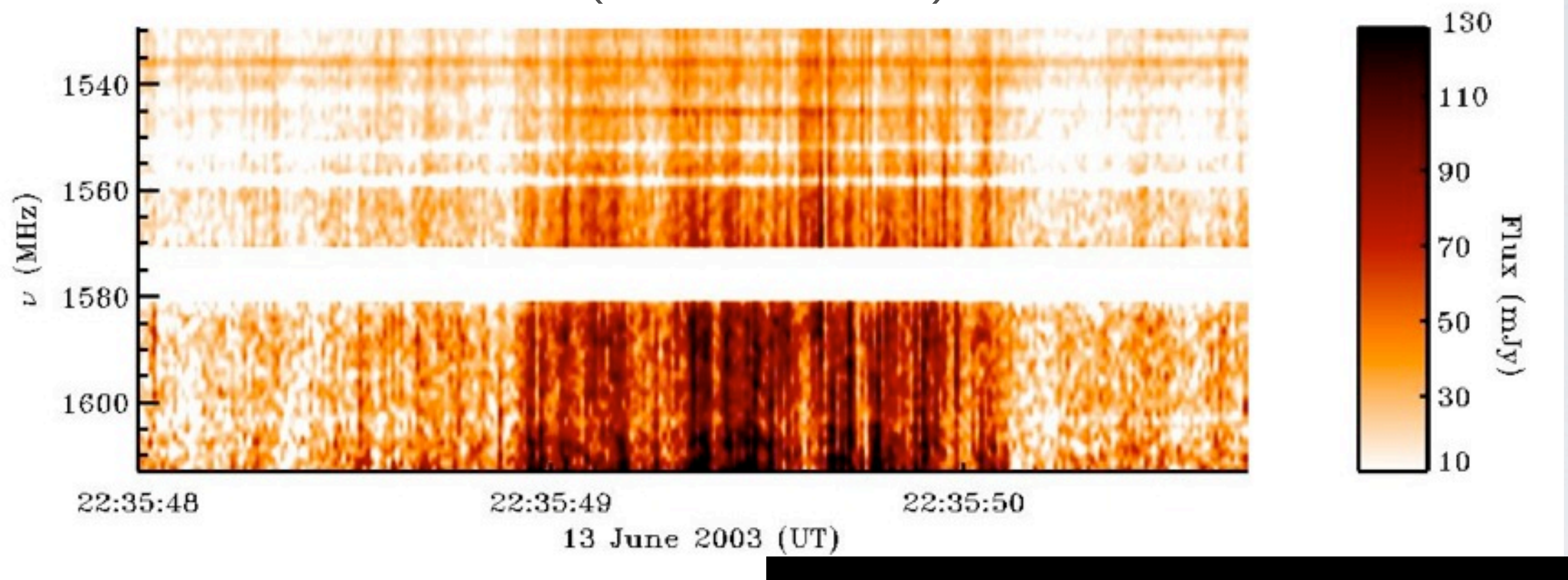
DRIFTING RADIO BURSTS OF THE NEARBY (STELLAR) VARIETY

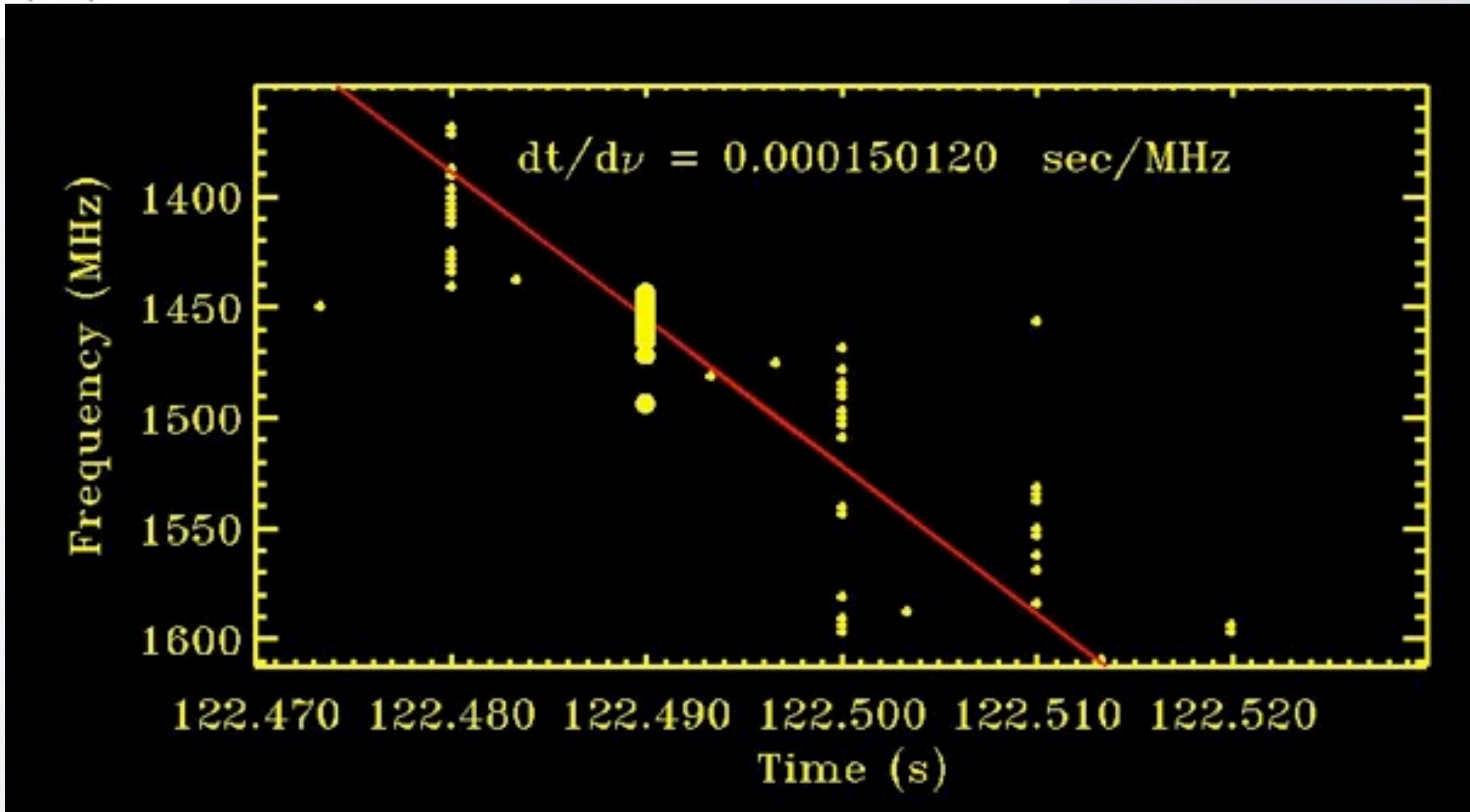


Güdel et al. (1989) coordinated single-dish observations of the dMe flare star AD Leo

serendipitously detected transient radio bursts from nearby active stars, including the "usual suspects" of known magnetically active stellar types: dMe flare stars, active binaries, and magnetic ultracool dwarfs

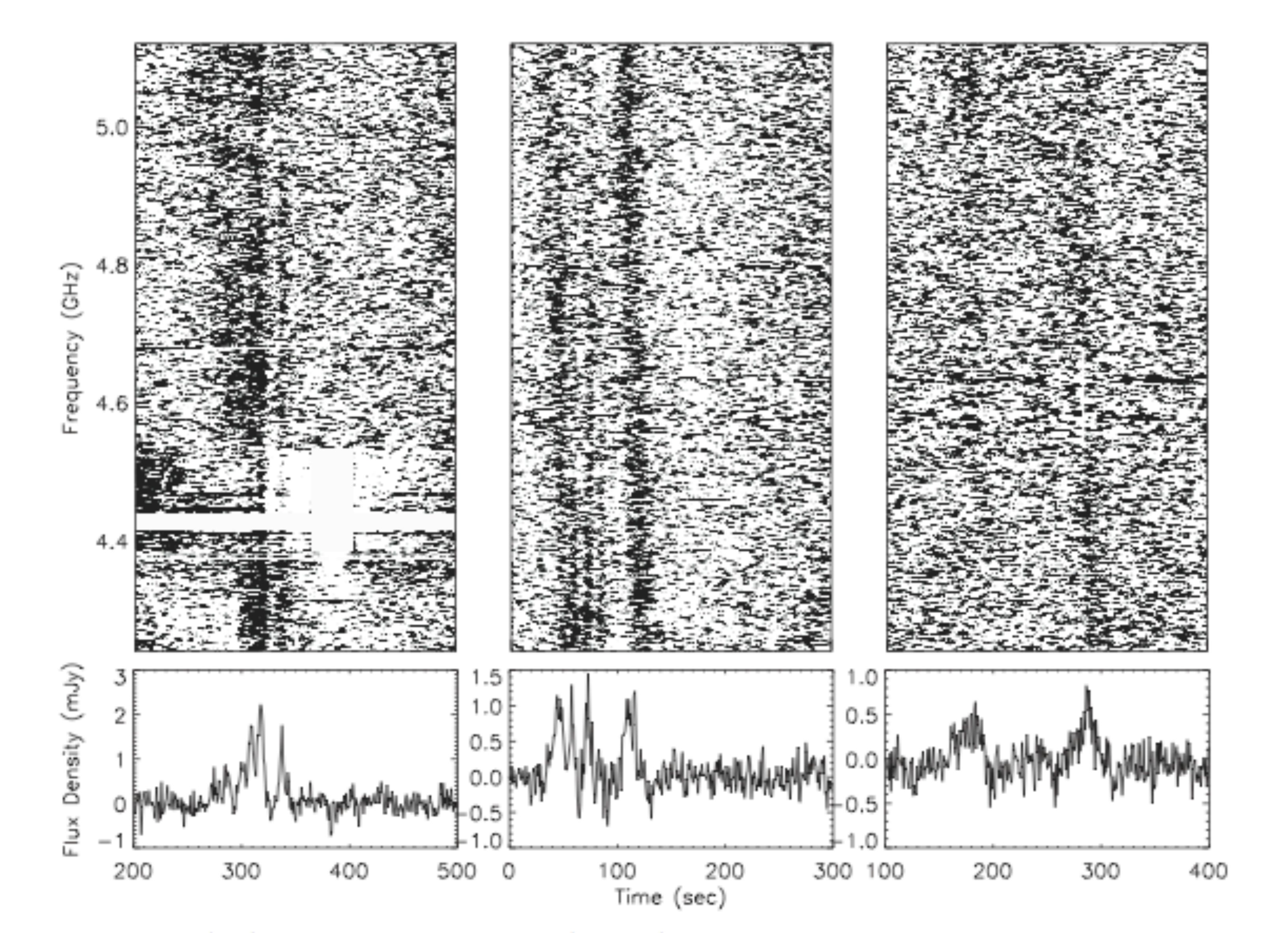
DRIFTING RADIO BURSTS OF THE NEARBY (STELLAR) VARIETY





Osten & Bastian 2006 wideband Arecibo observations of the dMe flare star AD Leo

DRIFTING RADIO BURSTS OF THE NEARBY (STELLAR) VARIETY



Route & Wolszczan (2012) drifting radio burst from a T6.5 dwarf observed with Arecibo

DRIFTING RADIO BURSTS OF THE NEARBY (STELLAR) VARIETY

- observed drifts at dm-cm frequencies interpreted as intrinsic motion in the atmosphere of the star/brown dwarf, rather than propagation through the ISM: coherent emission with $T_b > 10^{12}$K, as high as 10^{18} K

$$\frac{d\nu}{dt} = \frac{\partial\nu}{\partial n_e}\frac{\partial n_e}{\partial h}\frac{\partial h}{\partial s}\frac{\partial s}{\partial t}$$

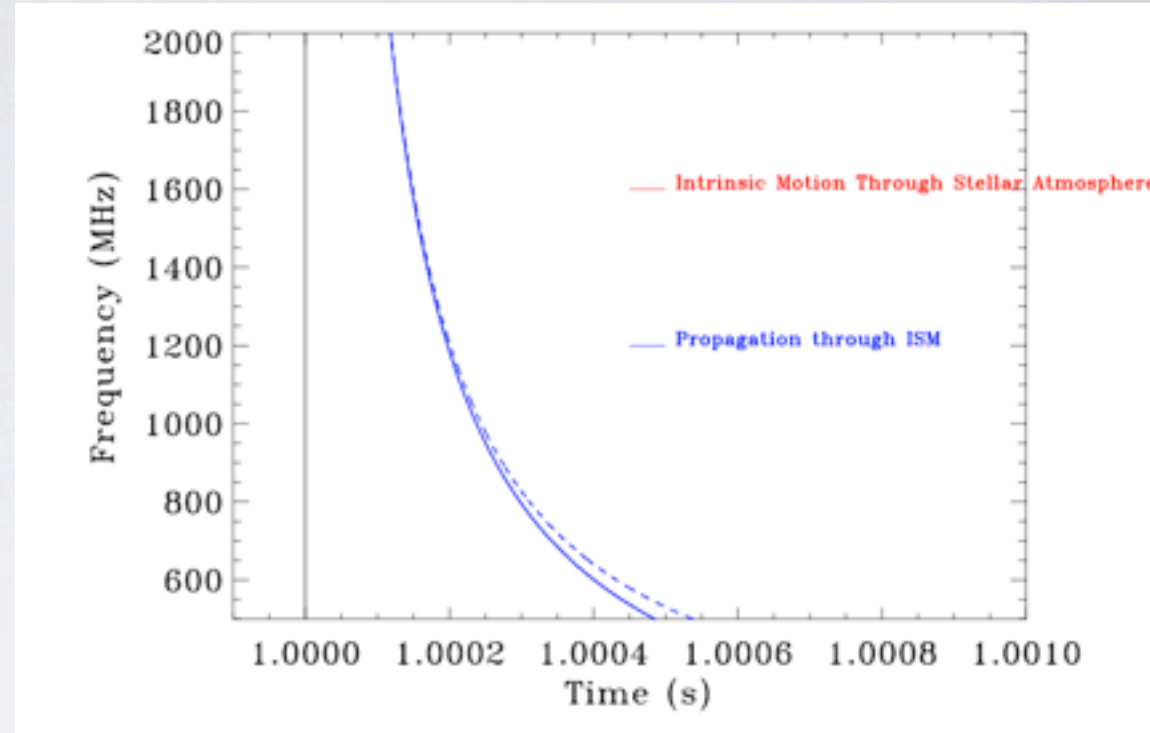
- distances to these objects known fairly accurately

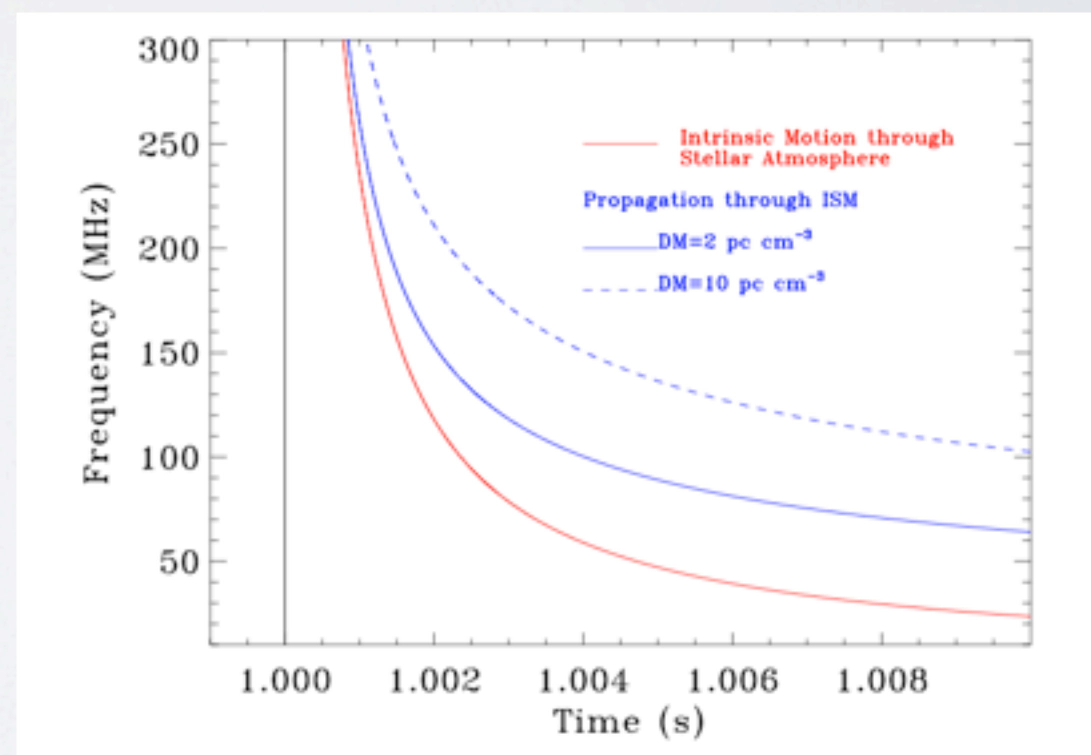
$$\frac{d\nu}{dt} = \frac{\partial\nu}{\partial B}\frac{\partial B}{\partial s}\frac{\partial s}{\partial t}$$

- interpretation has centered on one of two fundamental processes associated with either plasma emission or cyclotron maser emission

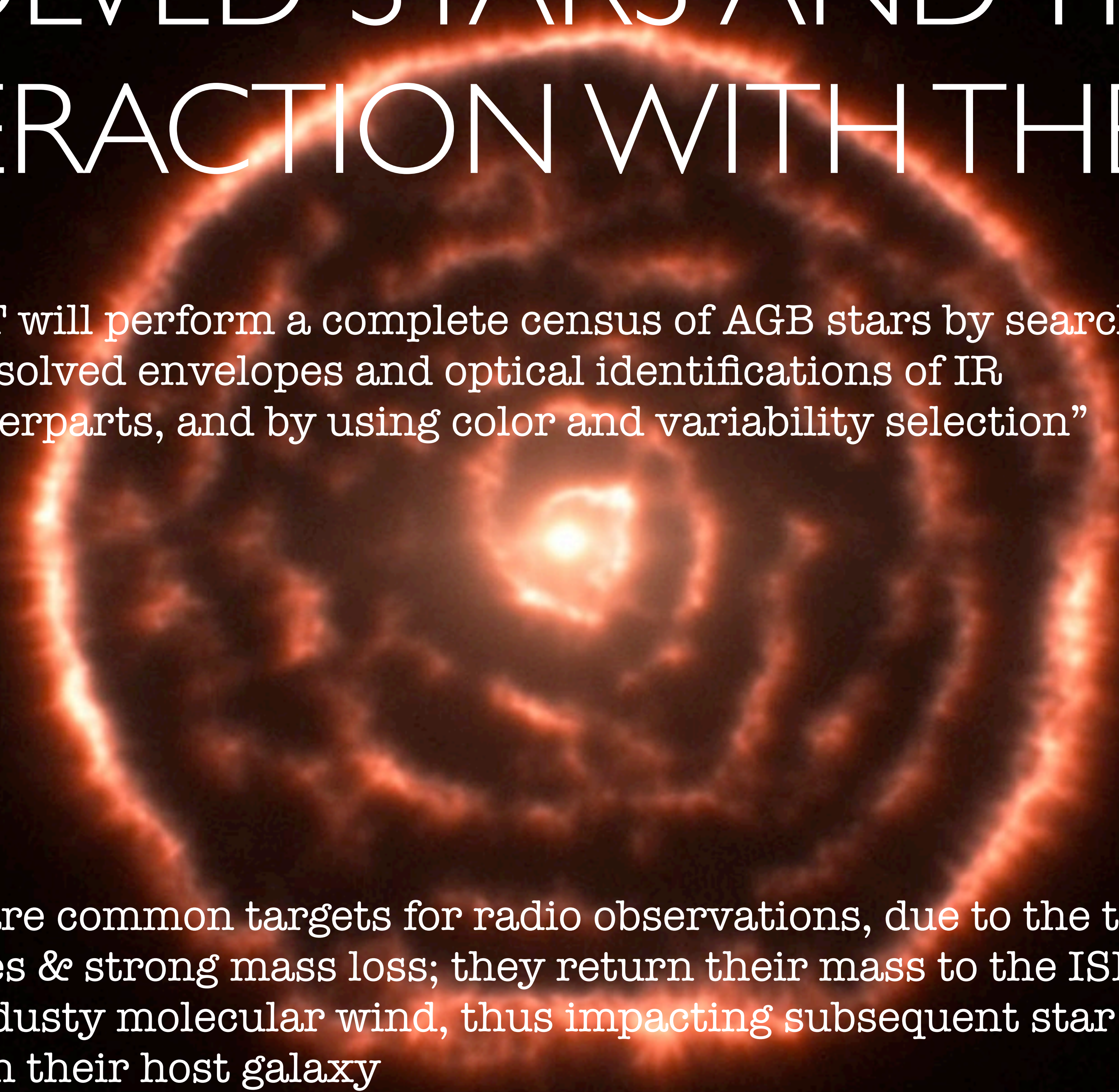
DRIFTING RADIO BURSTS

- at low frequencies, contribution of drift due to propagation through ISM in addition to intrinsic motion through stellar atmosphere
- LSST astrometry gets distances to 10% or better for $18<M_r<19$
- while distances are known accurately, constraint on dispersion measure, and n_e, important for local ISM.
- average interstellar electron density can vary by a factor of ~50 with the line of sight towards stars in the nearest 100 pc (Redfield & Falcon 2008). DM+distance to constrain interstellar n_e avoids the bias in atomic line measurements of ionization equilibrium, excitation temperature dependence, structure of local ISM





EVOLVED STARS AND THEIR INTERACTION WITH THE ISM

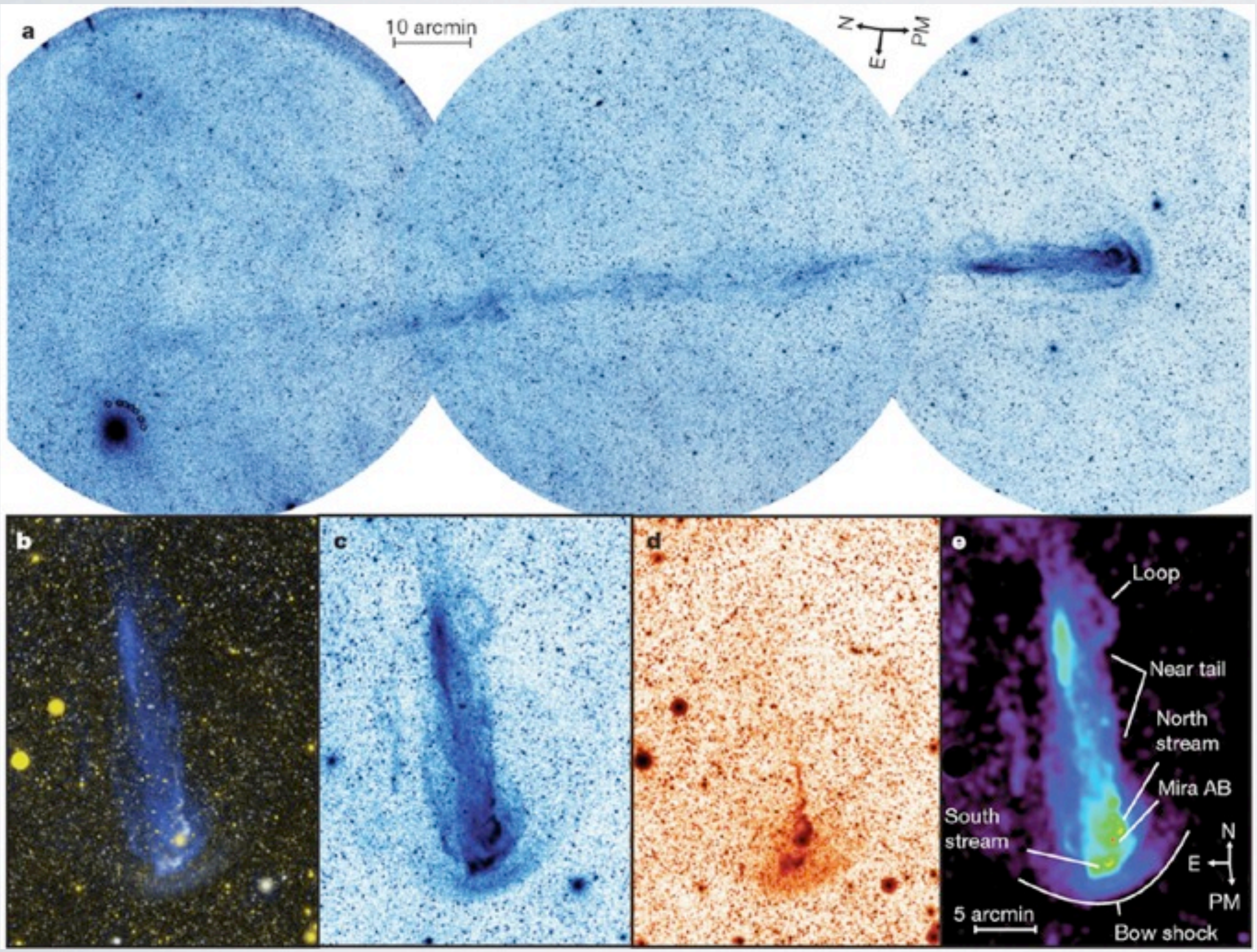


"LSST will perform a complete census of AGB stars by searching for resolved envelopes and optical identifications of IR counterparts, and by using color and variability selection"

AGB stars are common targets for radio observations, due to the tenuous atmospheres & strong mass loss; they return their mass to the ISM through a processed, dusty molecular wind, thus impacting subsequent star and planet formation in their host galaxy

Maercker et al. 2012

EVOLVED STARS AND THEIR INTERACTION WITH THE ISM



Martin et al. (2007) GALEX extended comet-like tail to Mira* extending ~2 degrees in size seen in FUV and NUV emission

*one of the first variable stars discovered

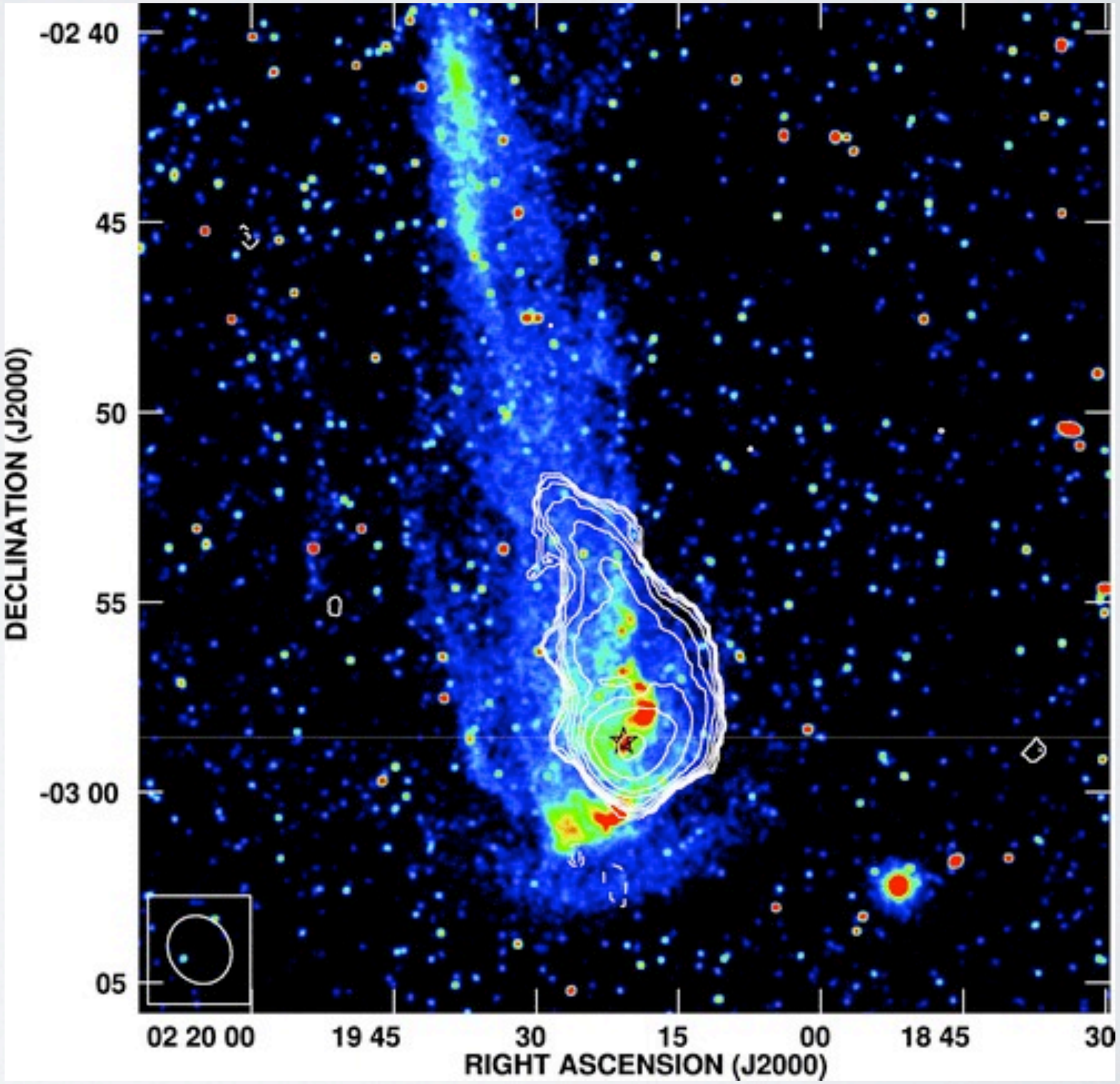
EVOLVED STARS AND THEIR INTERACTION WITH THE ISM

Matthews et al. (2008) detected an extended HI counterpart to the extended tail seen in the FUV

HI tail extends 88' north of Mira, extends mass loss history to 120,000 years

→HI observations give kinematics, mass-loss history

“We propose that detectable tails of H I are likely to be a common feature of red giants undergoing mass loss.”



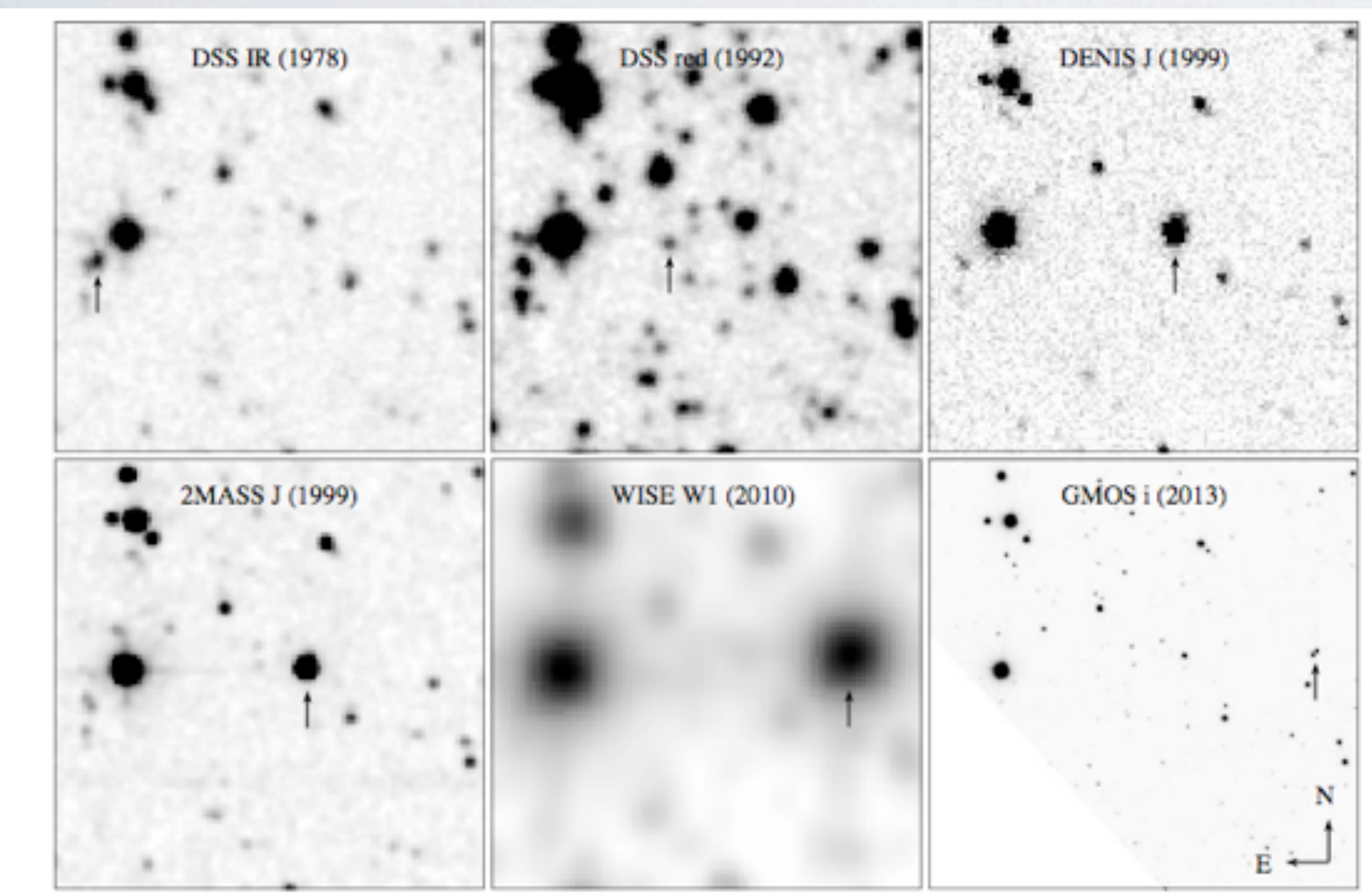
EVOLVED STARS AND THEIR INTERACTION WITH THE ISM

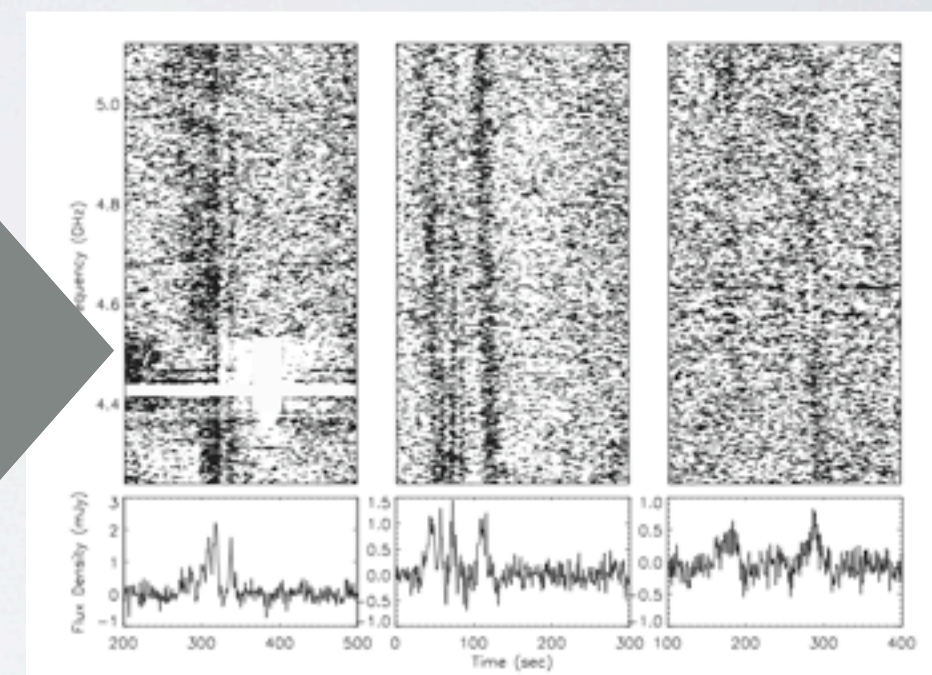
LSST will have 3.5 degree diameter field of view, 0.3-1.1 micron wavelength range; an intermediate mass star with strong winds moving through a locally dense ISM will form bow shocks. These shocked gas structures would potentially be visible in deep LSST exposures.

LSST will complete the census of AGB stars (able to detect and resolve an IRC+10216-like envelope at a distance of 15 kpc), radio observations can follow up with probes of the extended stellar atmospheres, interaction with ISM

DETERMINATION OF ADDITIONAL FUNDAMENTAL PROPERTIES OF STARS

- LSST will ID properties of stars within 300 pc: photometry, proper motion. complete census of moving groups. These results can be used to pick targets for pointed follow-up RMS observations





example: Luhman 2013 discovery of WISE J104915.57-531906.1, a brown dwarf binary (L8,T1) at a distance of 2.0±0.15pc

DETERMINATION OF ADDITIONAL FUNDAMENTAL PROPERTIES OF STARS

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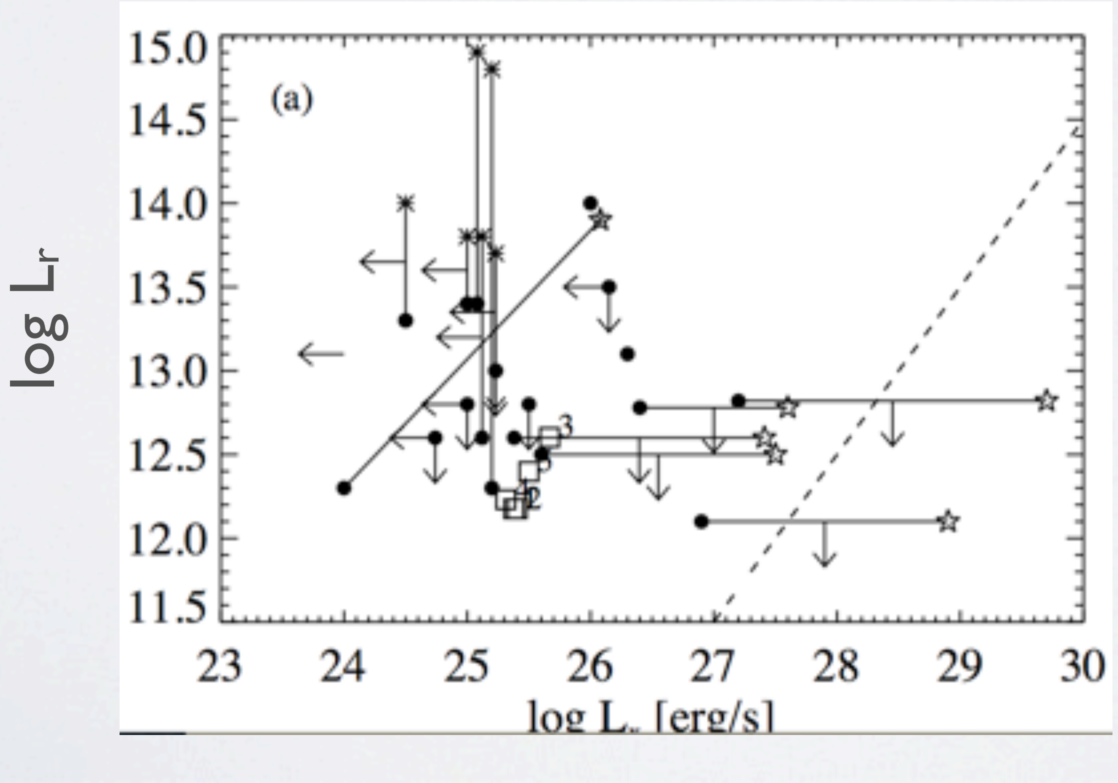
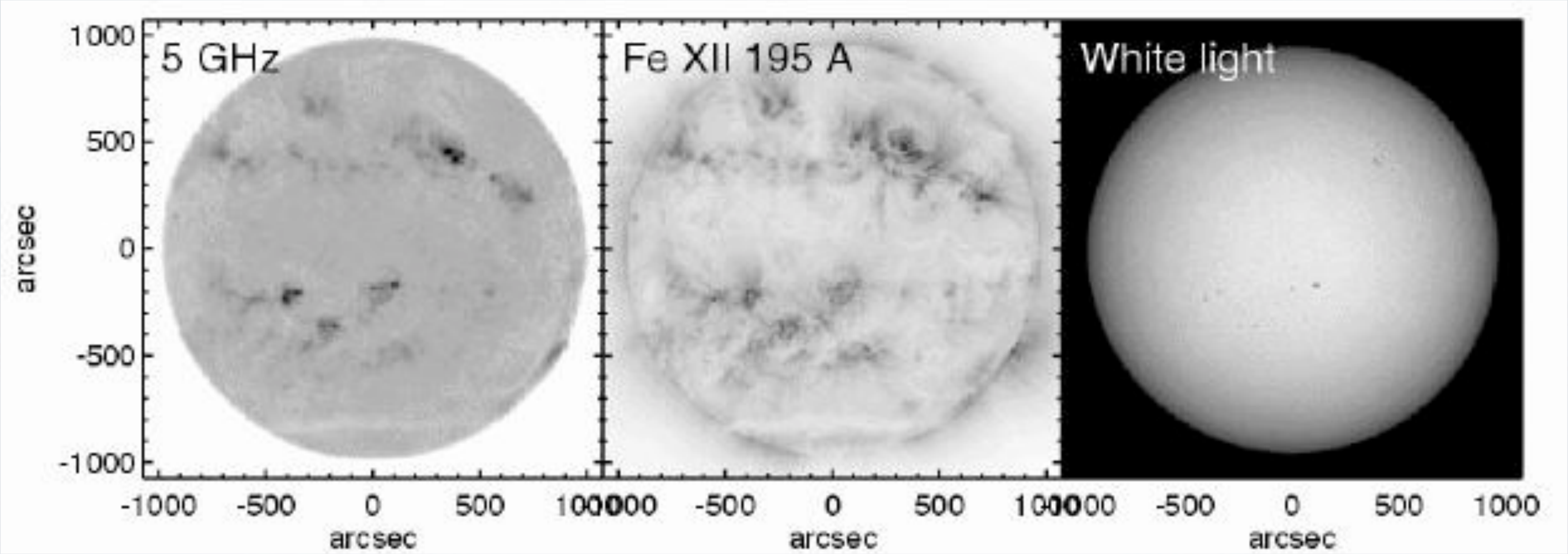
- radio properties of young-ish stars, especially young brown dwarfs. Census of X-ray flaring rates of young low mass stars (0.1-0.3 M_{sun}) shows little difference in behavior compared to higher mass, solar-like stars (Caramazza et al. 2007). When does the radio, X-ray dichotomy exhibited by nearby very low mass stars turn on?



SUMMARY

- radio landscape for LSST: need sensitive radio telescopes for all wavelengths probed by RMS, multi-band capability
- different framework for thinking about multi-wavelength observations: combination of time-domain and survey, different ways of combining the two for multi-wavelength investigations
- wants: "co-observing" → new name for simultaneous multi-wavelength observing during deep drilling: multiplexing
- need sensitive radio follow-up of interesting stellar targets
- studies benefit both types of stellar astronomy, range of stellar types

MAGNETIC FIELDS IN RADIO AND OPTICAL



White et al. (1999)

of course, LSST won't look at the Sun…but most radio facilities do!