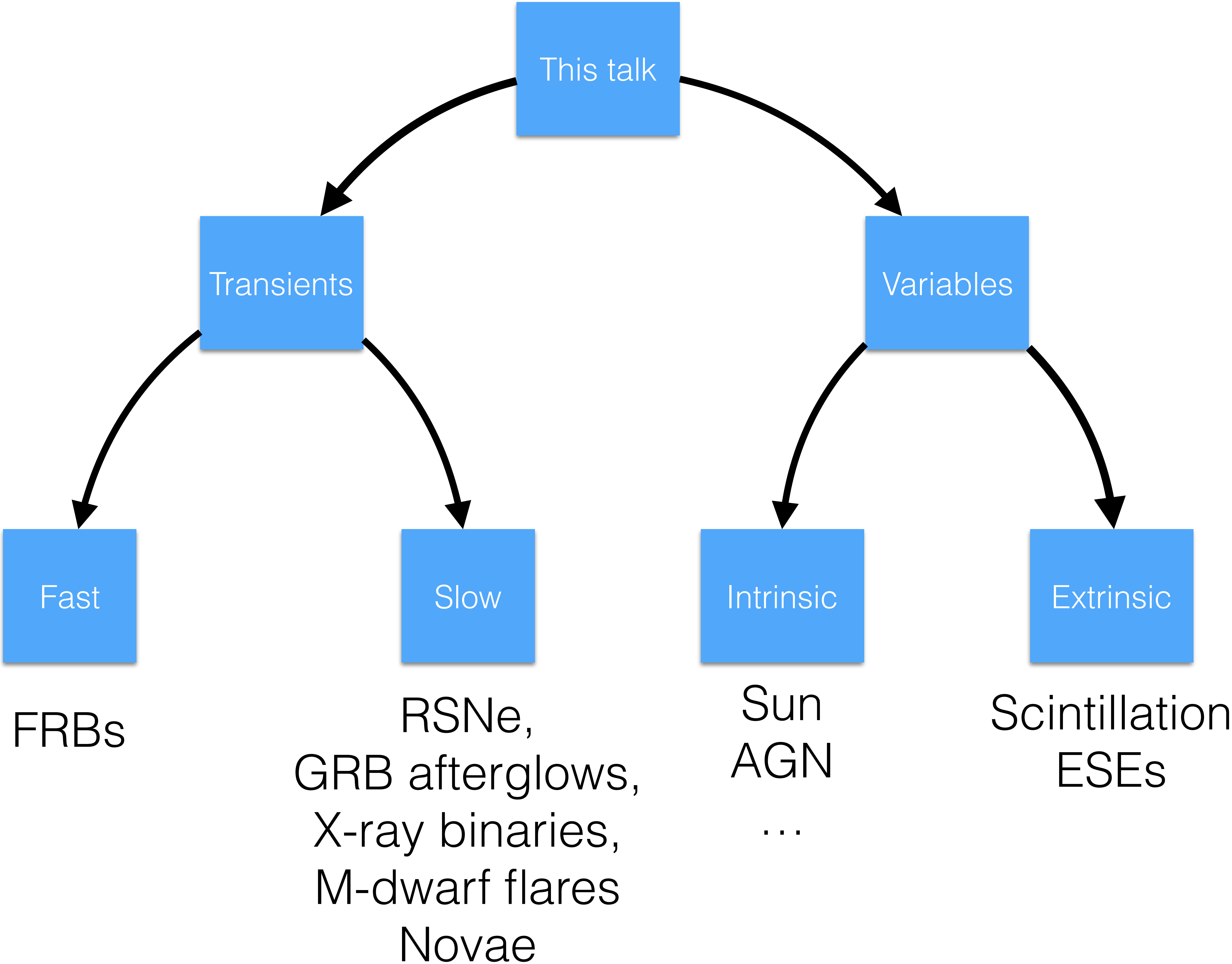
Radio transients
(and radio variables
(and the interstellar medium))

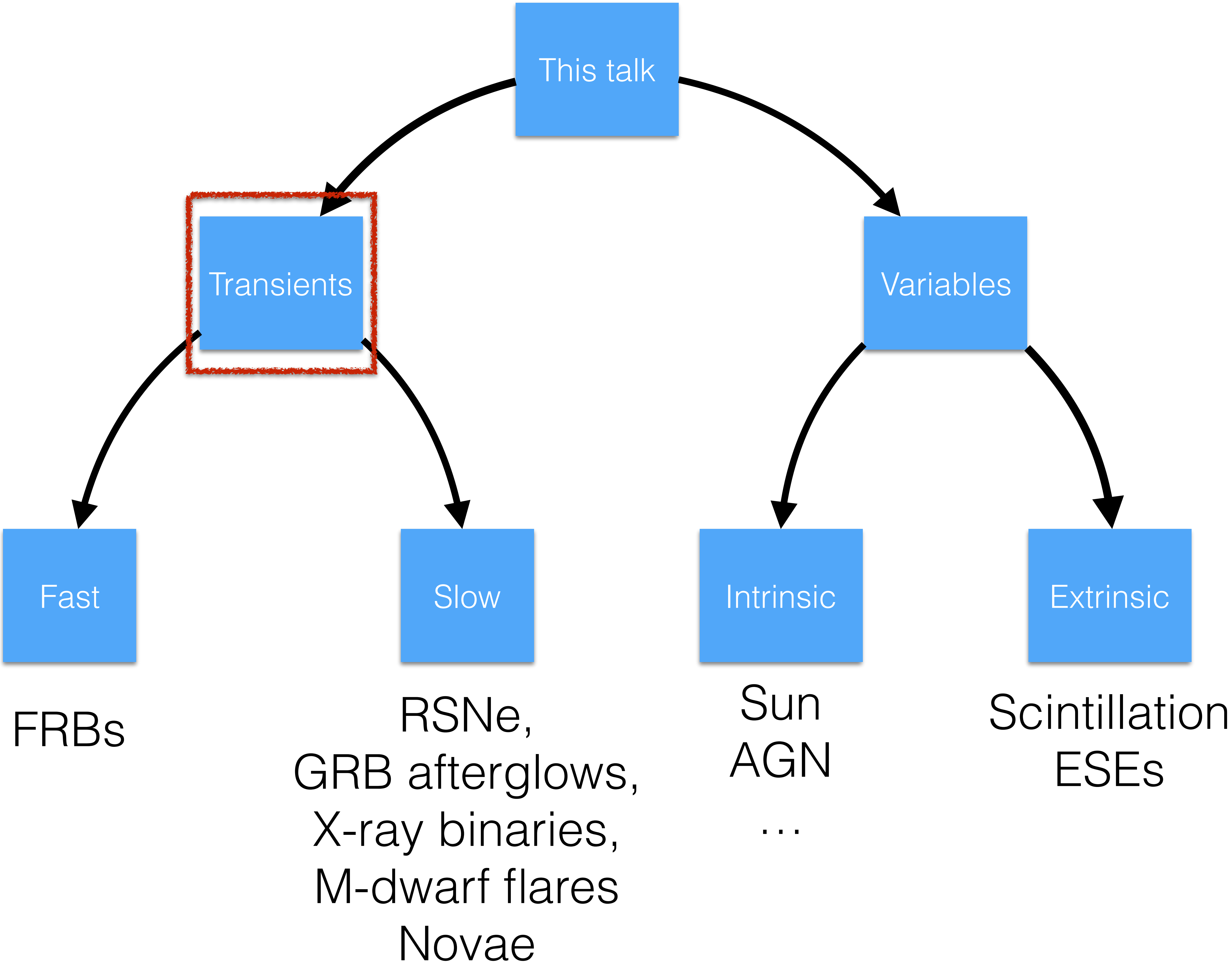
Keith Bannister (ATNF)
ATNF Radio School 2017

Warning

There’s a huge amount of different science on this topic.

This is just a flavour.


This talk
Transients
Variables
Fast
Slow
Intrinsic
Extrinsic
FRBs
RSNe,
GRB afterglows,
X-ray binaries,
M-dwarf flares
Novae
Sun
AGN
…
Scintillation
ESEs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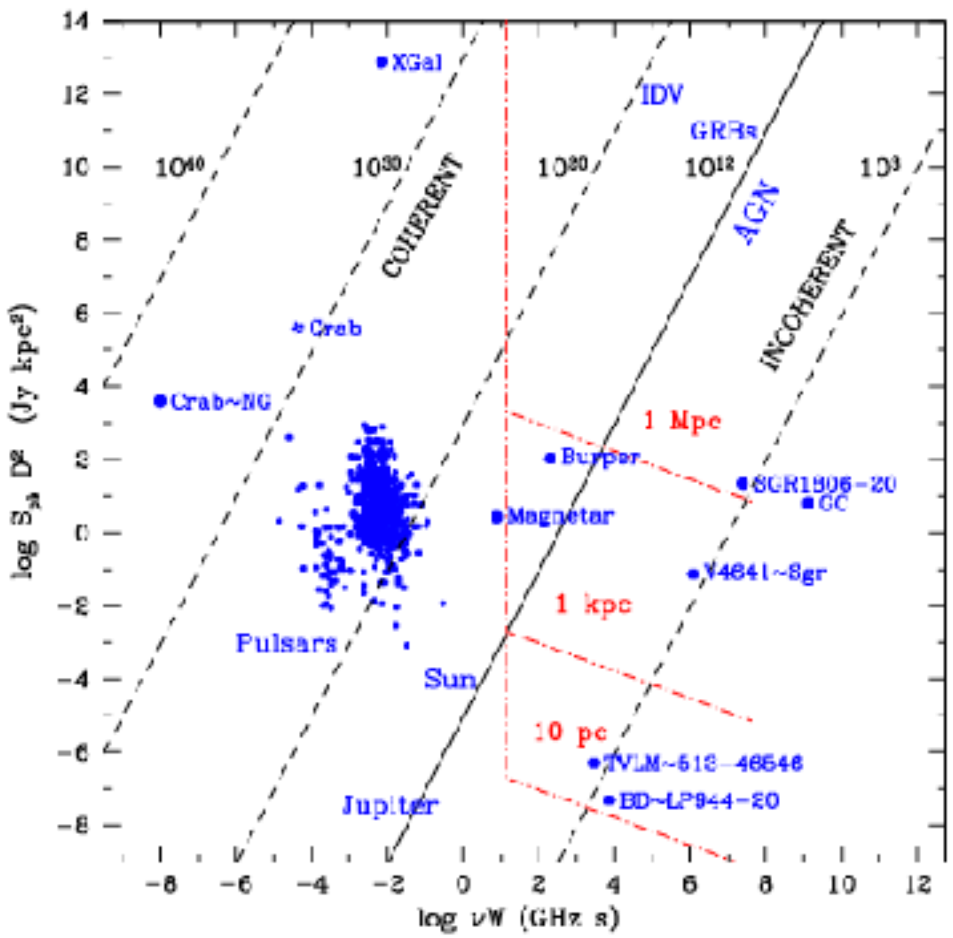
Transient parameter space (s)

Bright

Faint



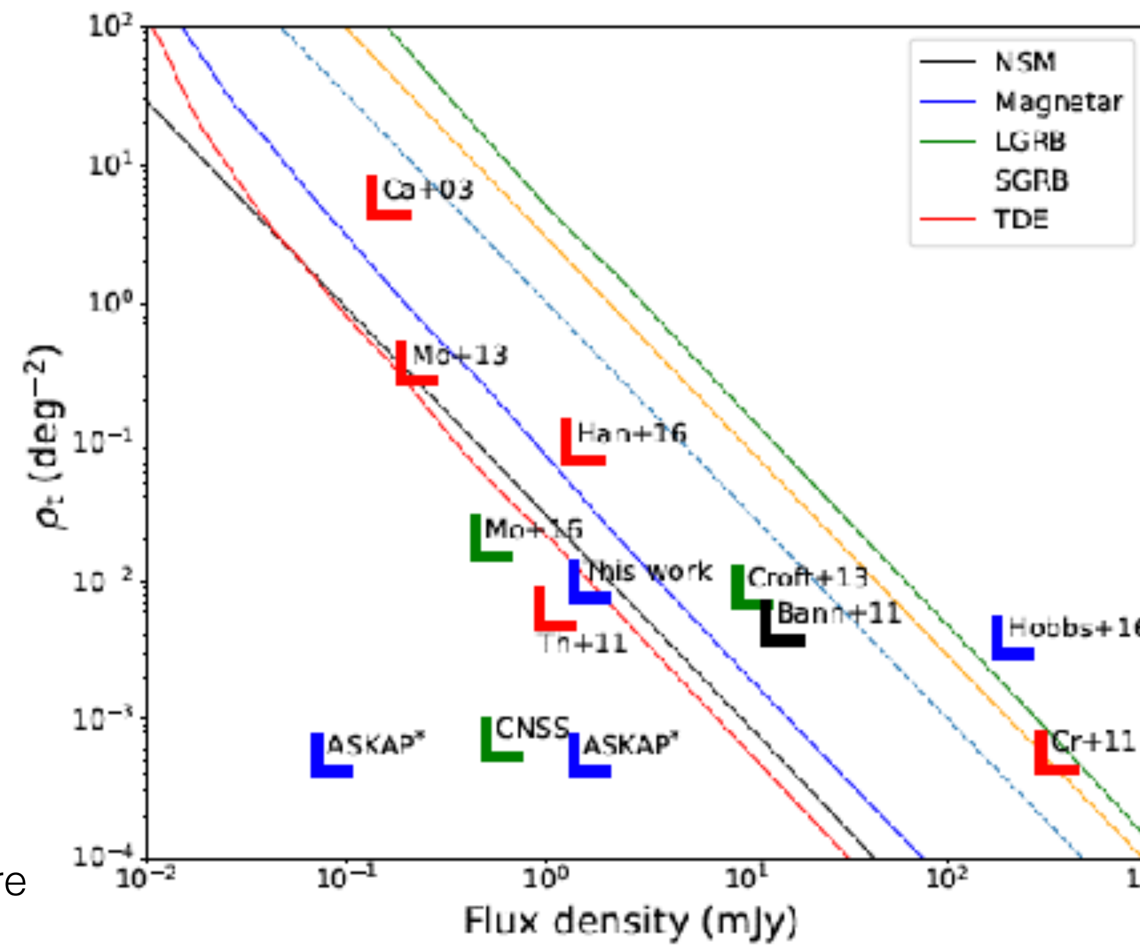
Fast

Slow

From Cordes+ 04

Common

Rare



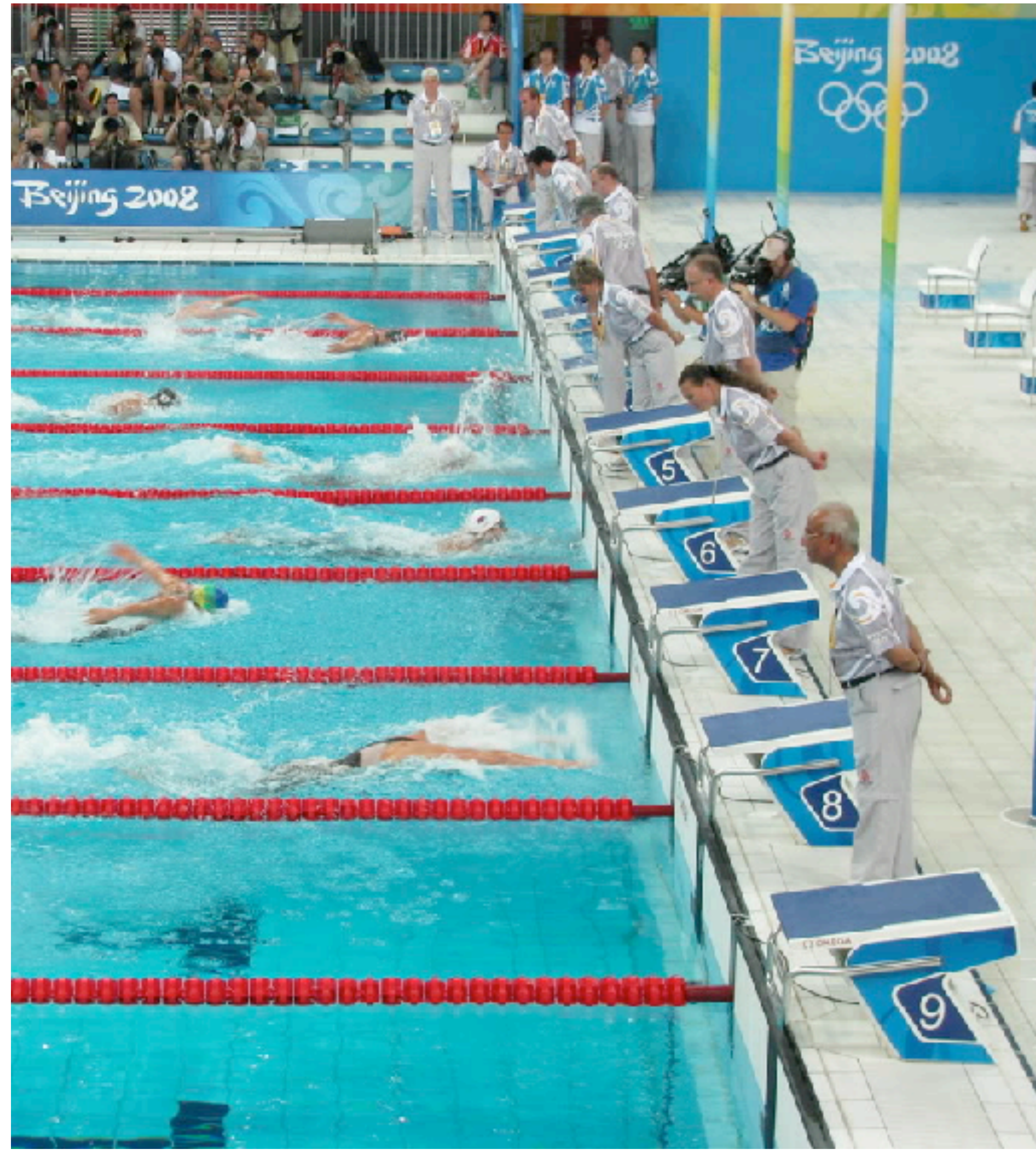
Faint

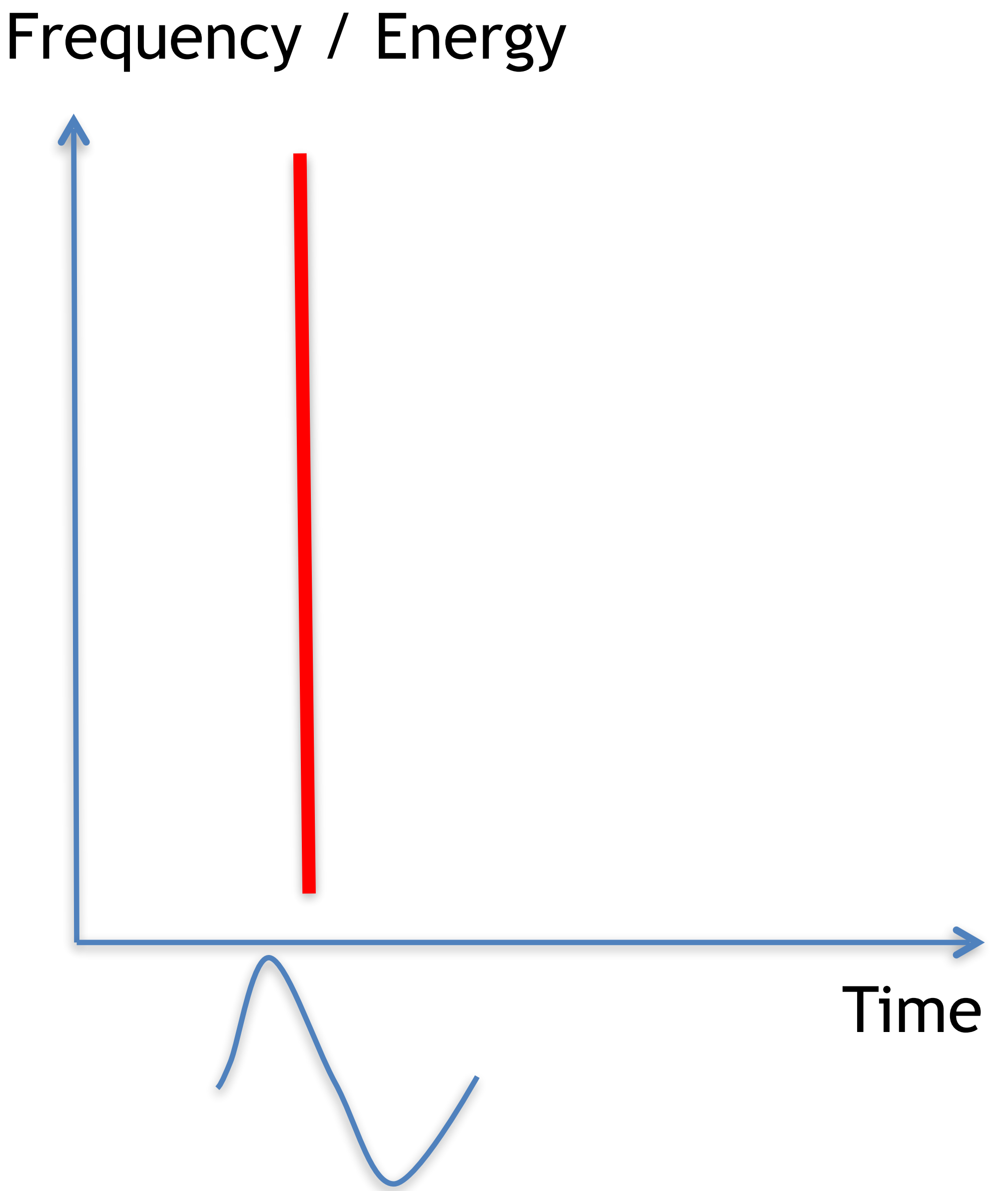
Bright

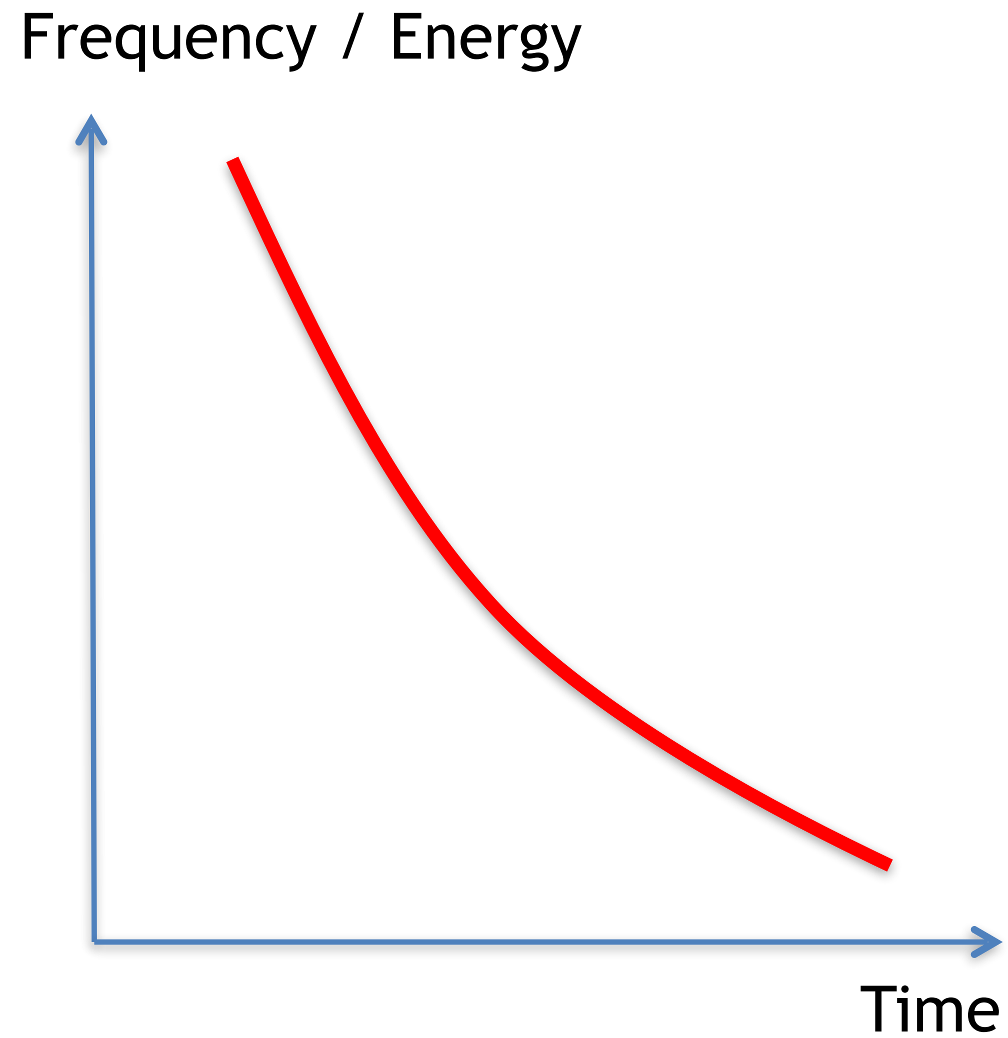
From Bhandari+ (in prep)

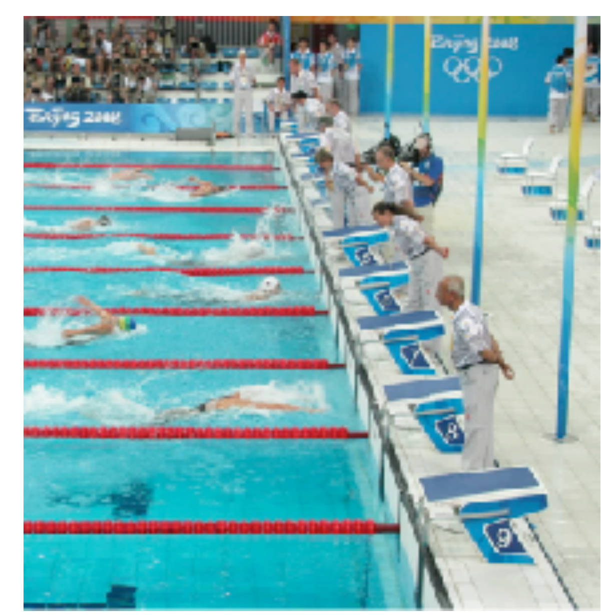
Dispersion


Sanex
arena
PHILIPS


Beijing 2008
Beijing 2008


Frequency / Energy
Time

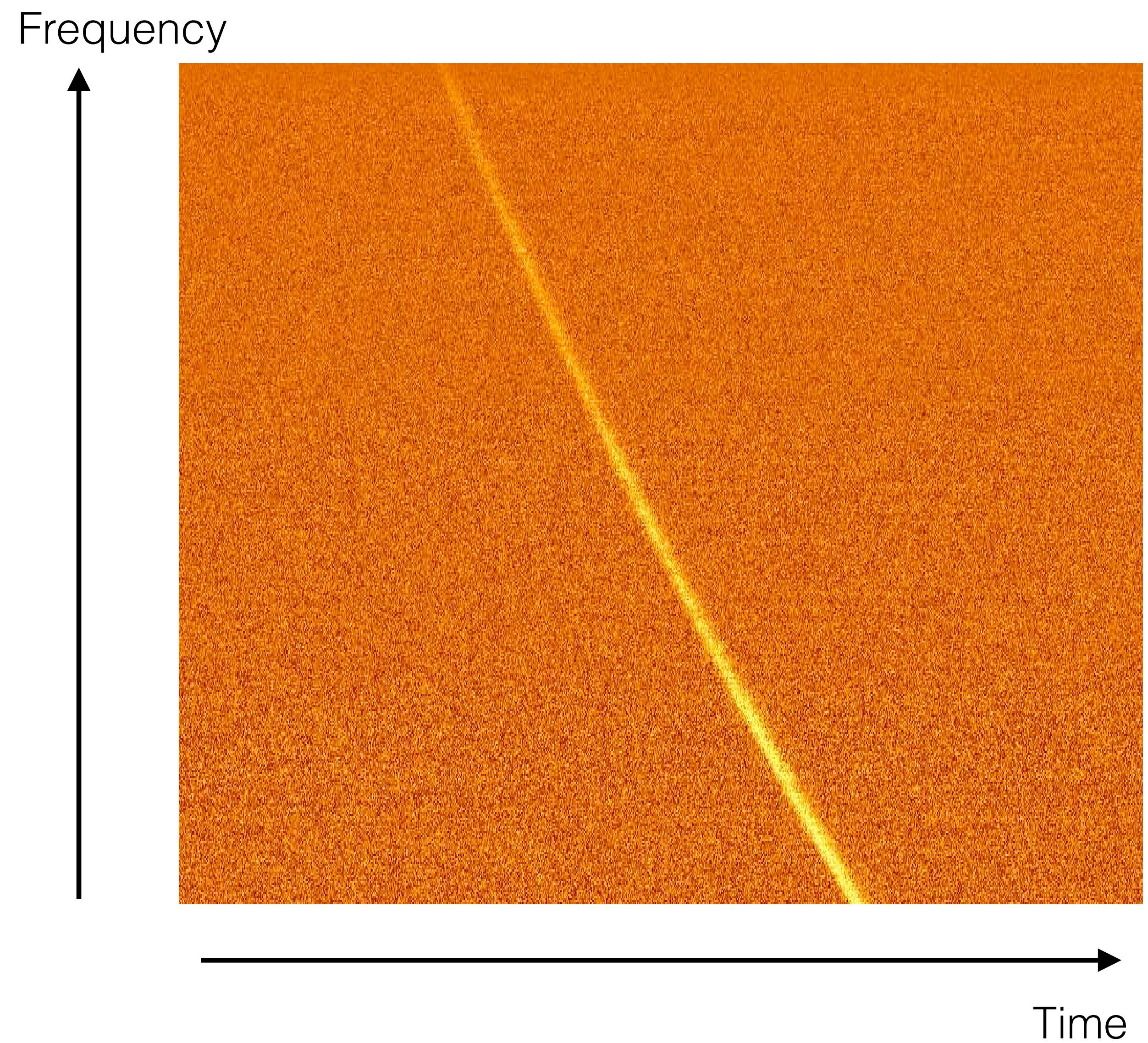

Frequency / Energy
Time

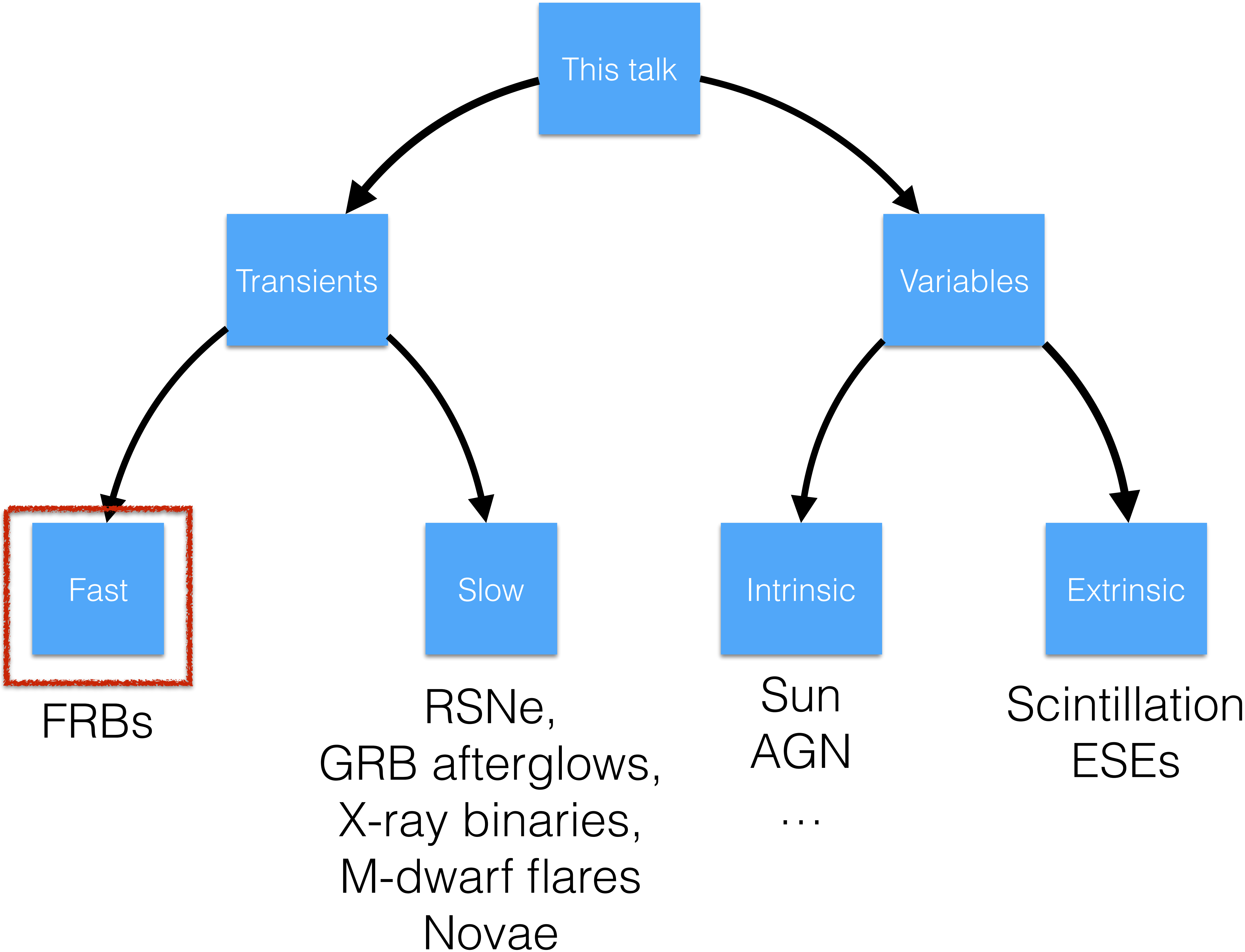


Dispersion

$$\frac{\Delta t}{\mathrm{ms}} = 4.15\mathrm{DM}\left(\left(\frac{\nu_1}{\mathrm{GHz}}\right)^{-2} - \left(\frac{\nu_2}{\mathrm{GHz}}\right)^{-2}\right)$$

$$DM = \int_0^{\mathrm{source}} n_e dl$$

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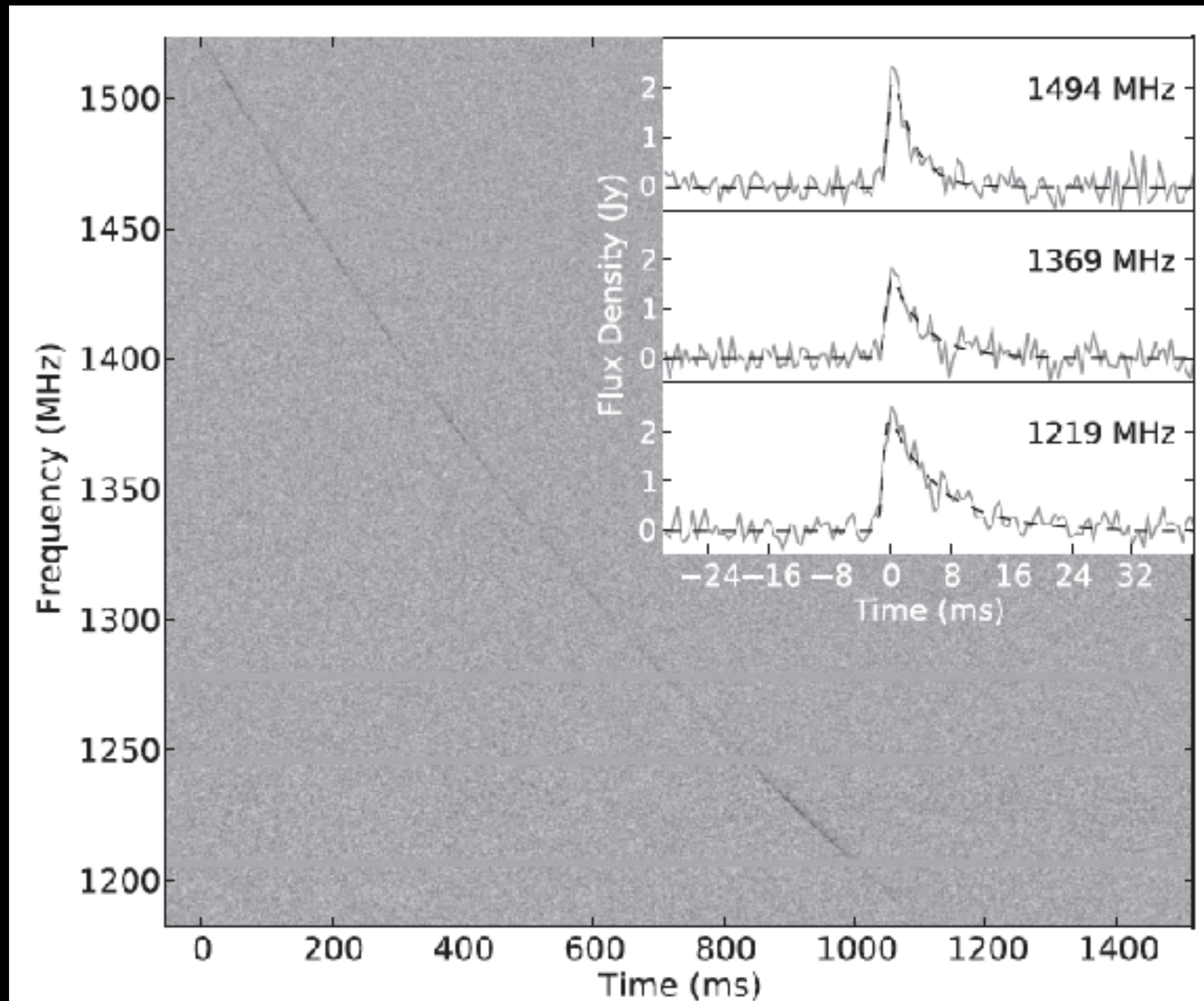


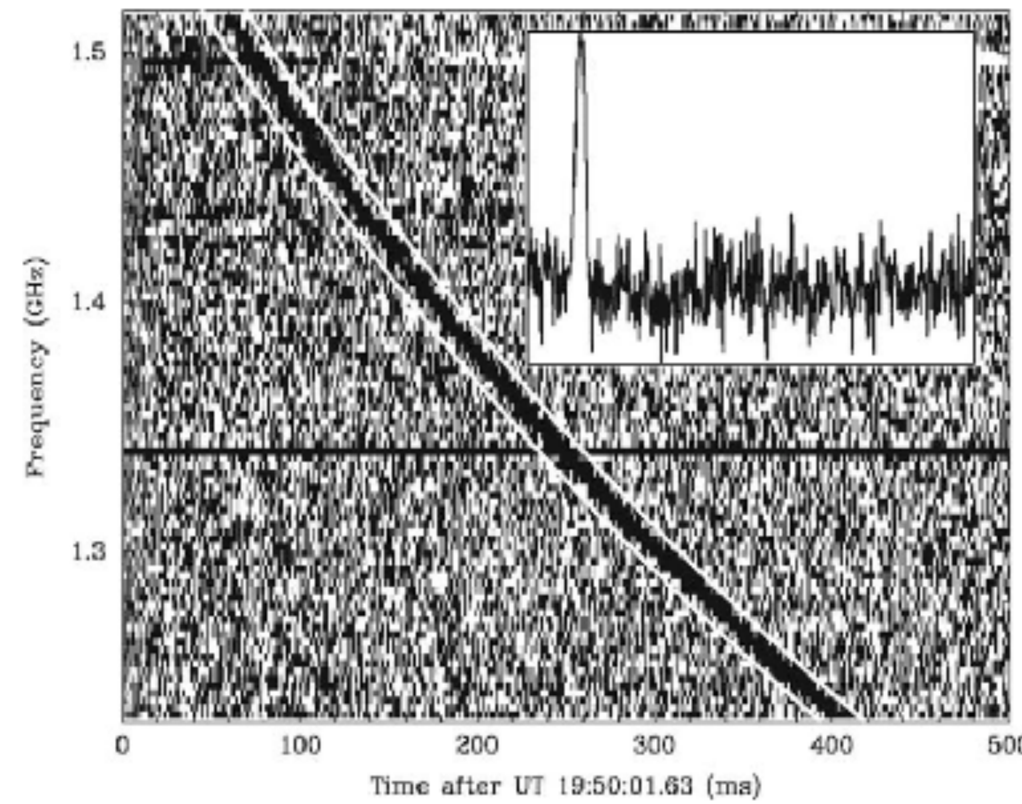
Fast Radio Bursts

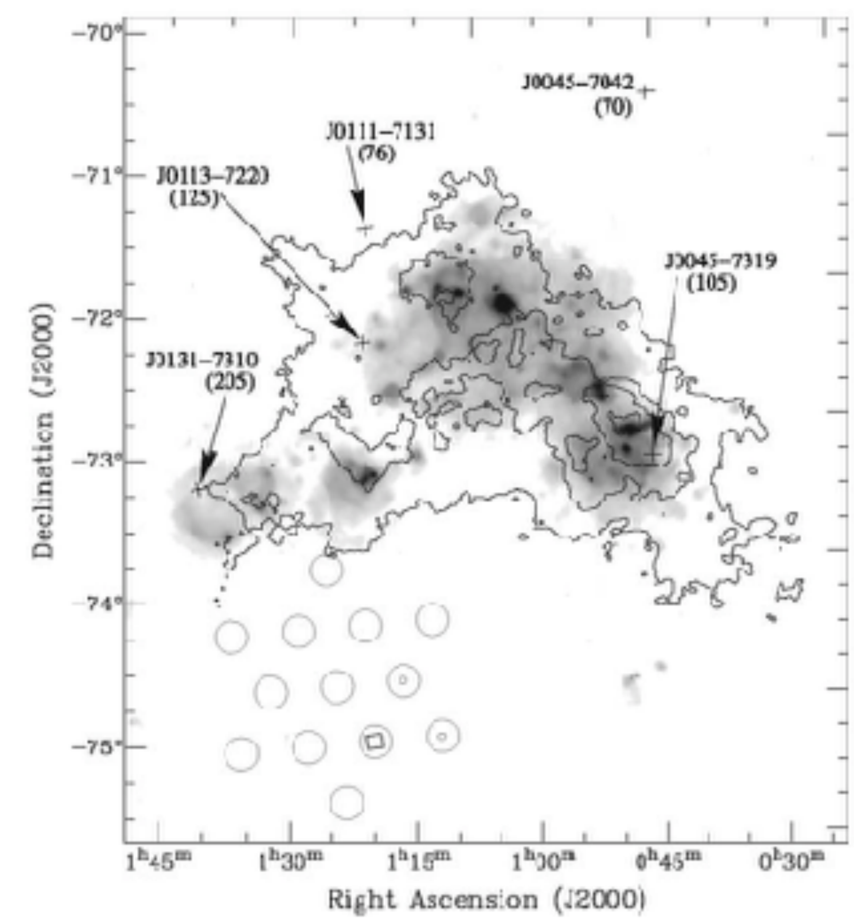
After 10 years, we still don’t know what they are

Fast Radio Bursts

$$\Delta t = 4.15\mathrm{DM}(\nu_1^{-2} - \nu_2^{-2})(\mathrm{ms})$$

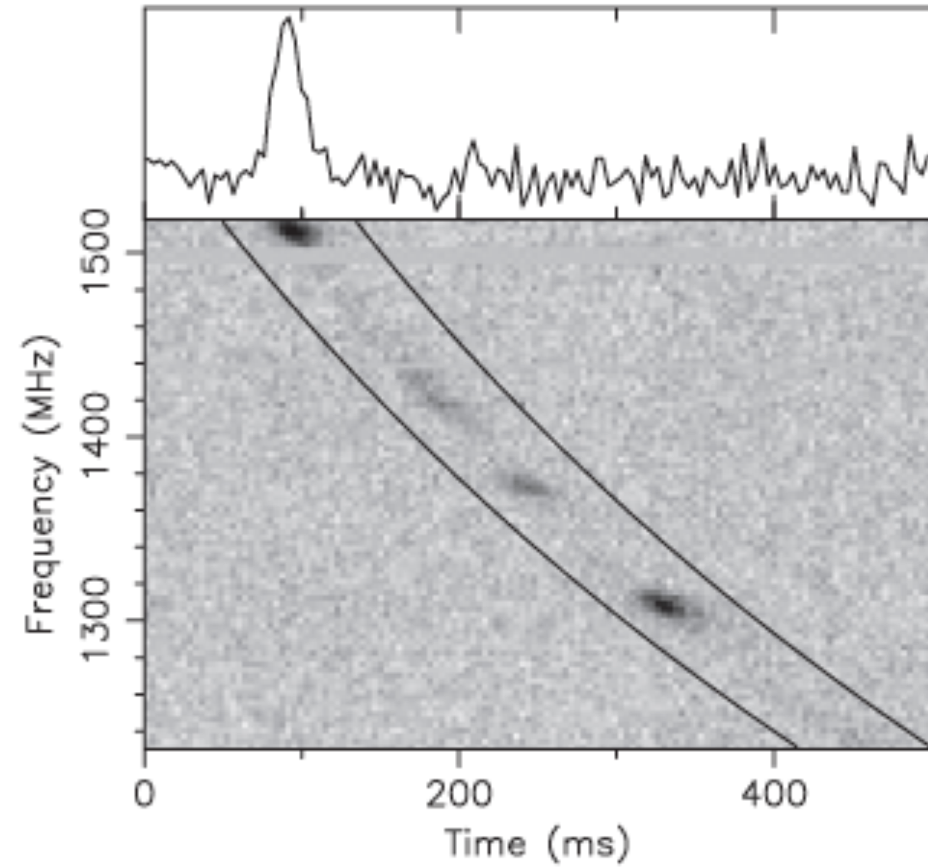
- Data recorded in 2001, but only discovered in 2007 (**old data is useful!**)
- Super bright: >> 30 Jy ms.
- Saturated 1 beam - found in 2 others
- Dispersion Measure >> than expected from the Milky Way and SMC
- *was* being looked for, but they were lucky not to delete it by accident: **be careful with your processing**

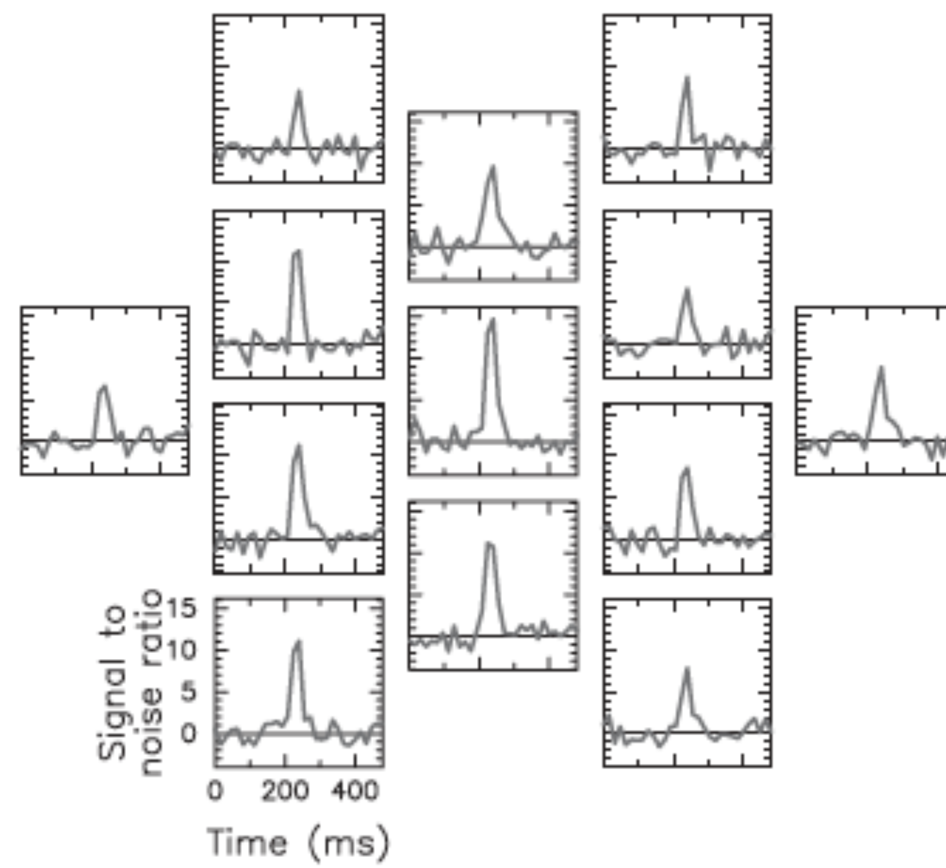




Perytons

Katherine Capach



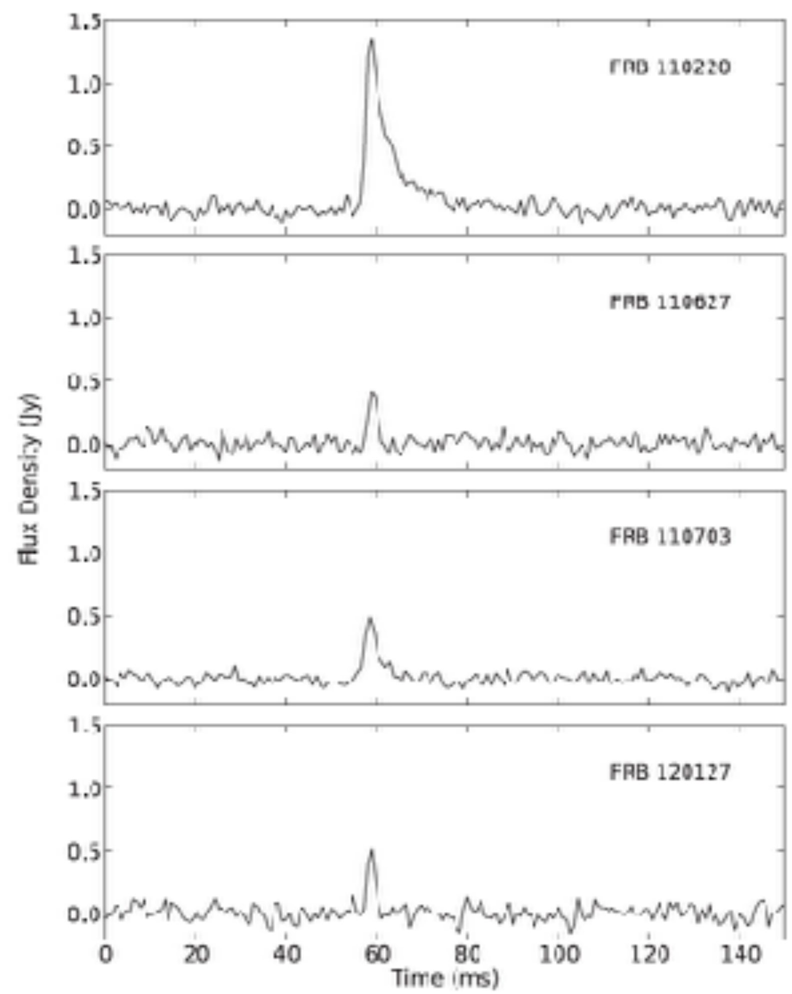


- Looked like FRBs
- Frequency-swept signal
- Found in all beams -> Terrestrial?
- Strong frequency structure
- What does this mean for the original FRB?

Burke-Spolaor+11

The d(r)ought breaks

- 4 more FRBs at Parkes
- Single beam
- Range of dispersion measures
- Good fit to cold plasma dispersion
- 5 more thereafter
- Why only Parkes?
- Are these just less weird Perytons?



Thornton+ 13

Perytons resolved!

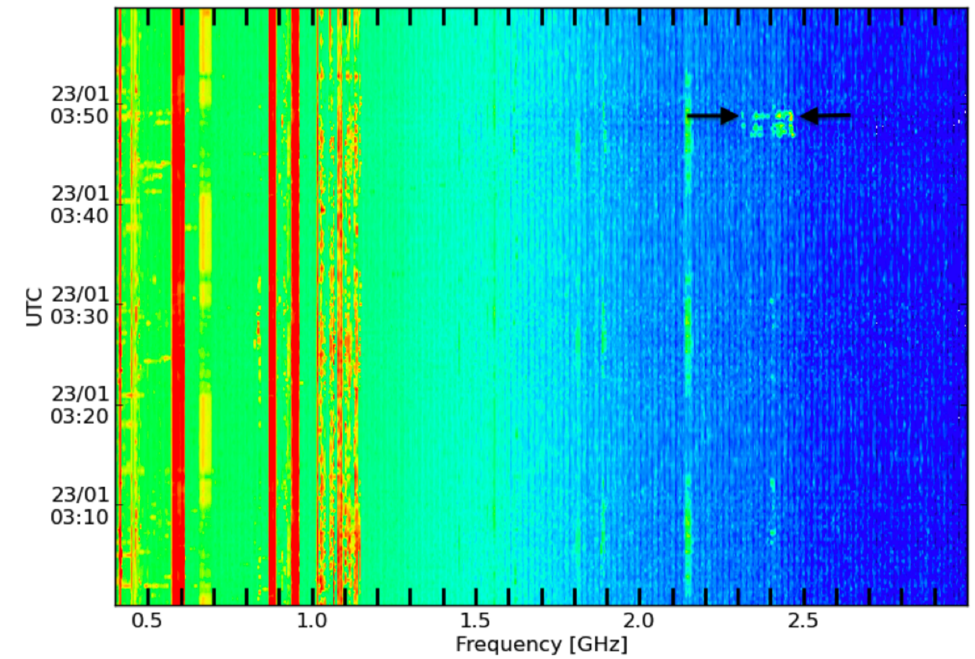
- RFI monitoring system installed (thanks Jamie! **Work with site staff & engineers - they're handy!**

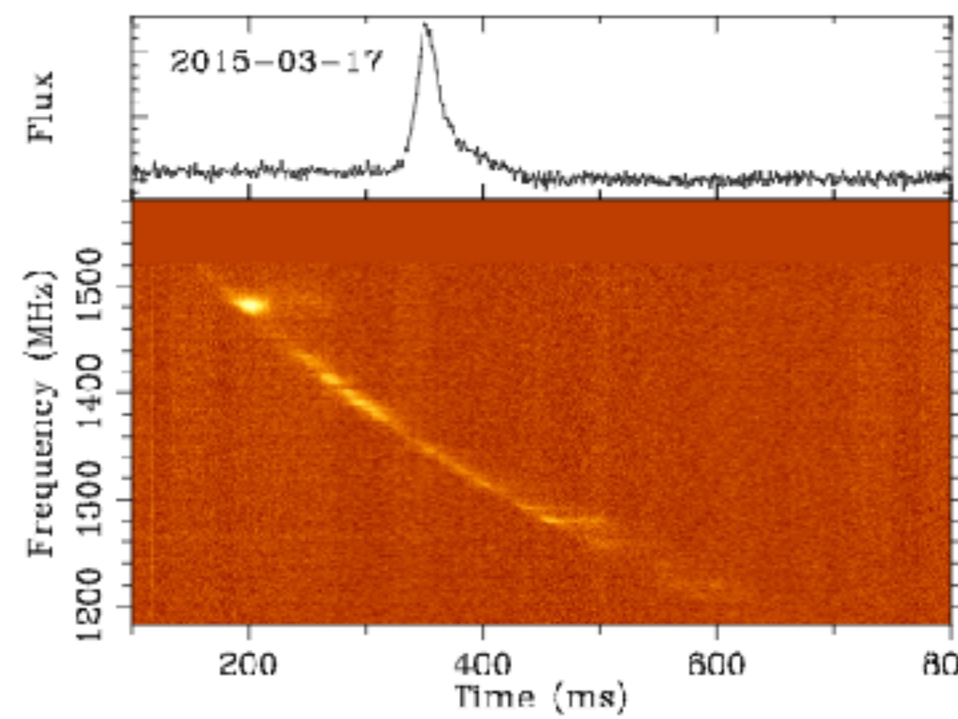
- A bit of background knowledge on how microwave ovens work.

- Resolved thanks to careful RFI monitoring and a cold lunch - **know your telescope and your environment.**

- But is the Lorimer burst real?

- Why only Parkes?

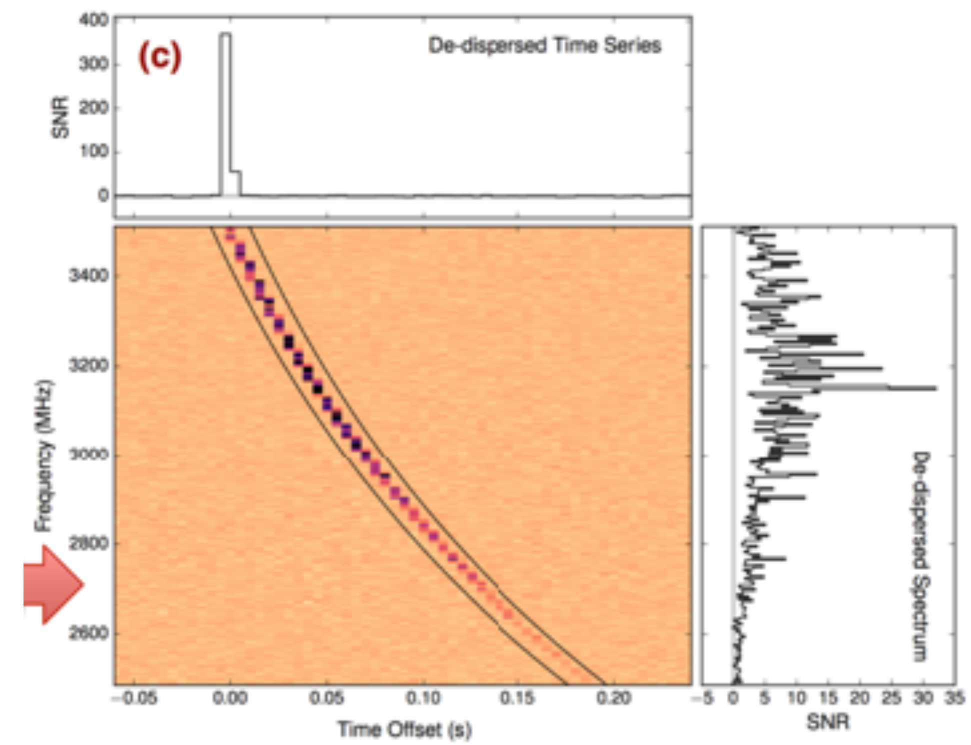


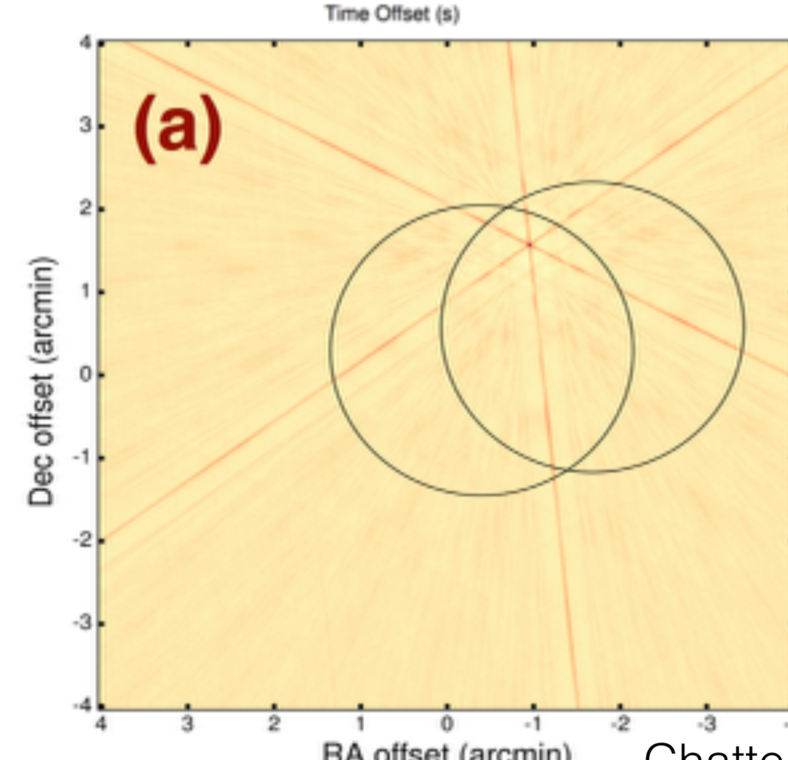


Petroff+ 15

“The Repeater”

- First discovered at Arecibo
- Discovered to repeat in follow-up observations
- Localised to << 1 arc second by the VLA
- Fringes on intercontinental baselines (VLBI)
- Located in a star-forming (Halpha bright) region in a dwarf galaxy at z=0.2 (1 Gpc!)
- Co-incident with a persistent, non-variable radio source
- Similar place to where we find long gamma ray bursts and super luminous supernovae - related?

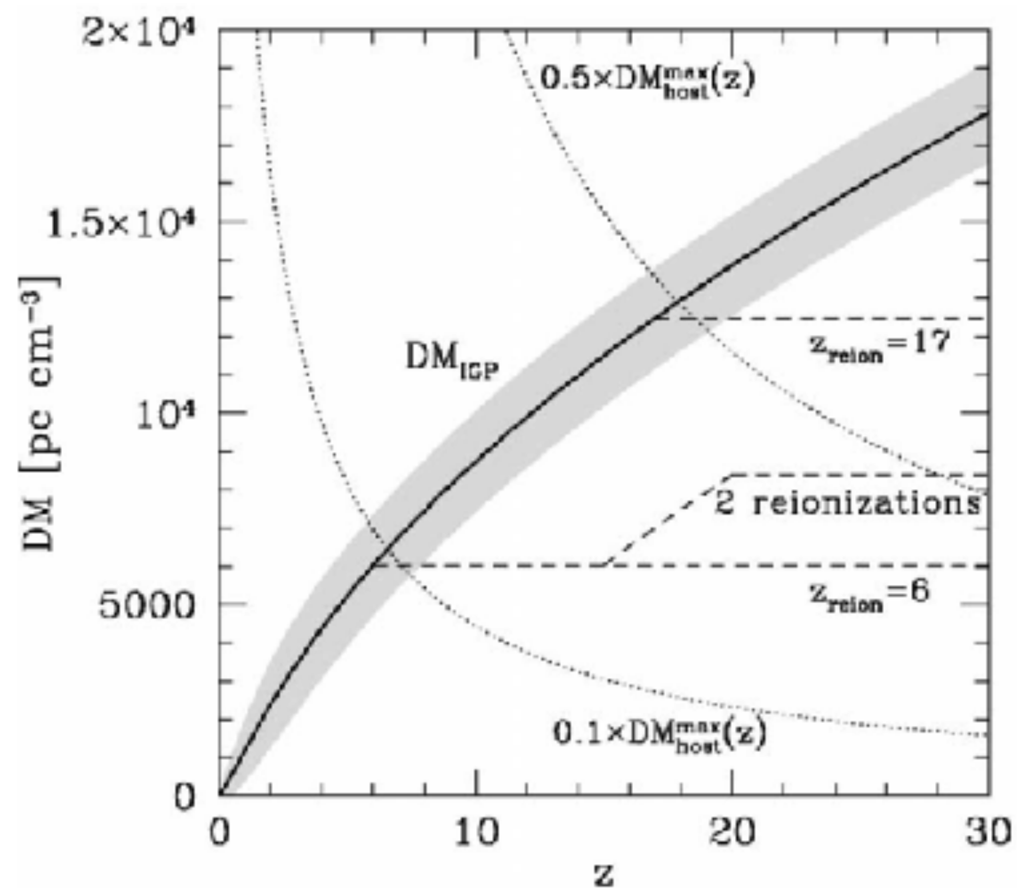




Chatterjee+ 17

Where are we now?

- 24 published bursts (Sep 2017)
- Largest DM = 2700 pc/cm3 (!)
- Ntheories > Nbursts
- Most localised to ~ 30 arcmin (Parkes)
- No afterglows discovered - even with a *lot* of follow-up.
- 1 repeater. Localised to ~millarcseconds
- >10 telescopes around the world searching for FRBs
- We want: more FRBs with ~arcsecond positions to get:
    - Better understanding of the population
    - Measurement of DM vs z -> Baryon content of the universe

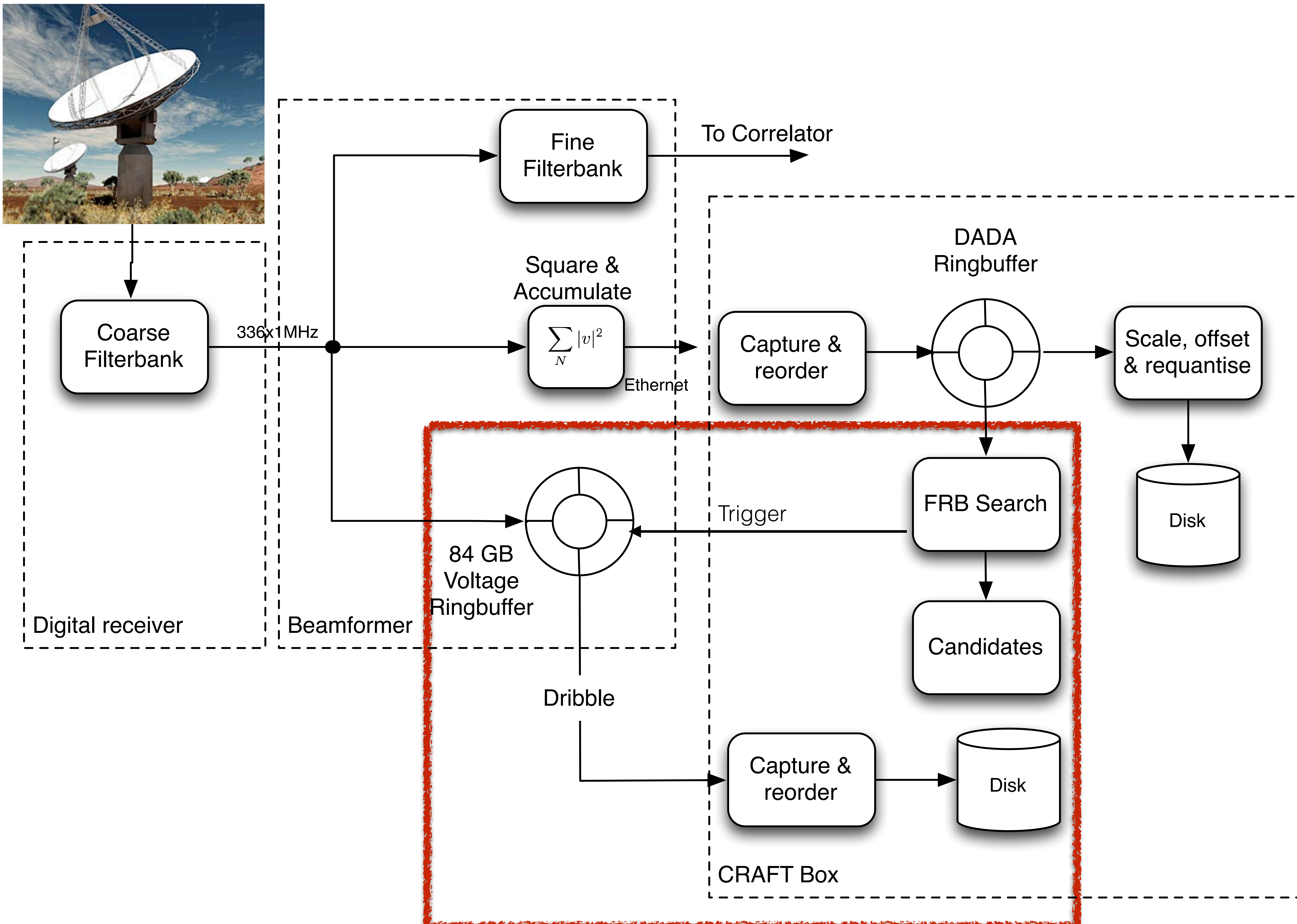


Ioka 03

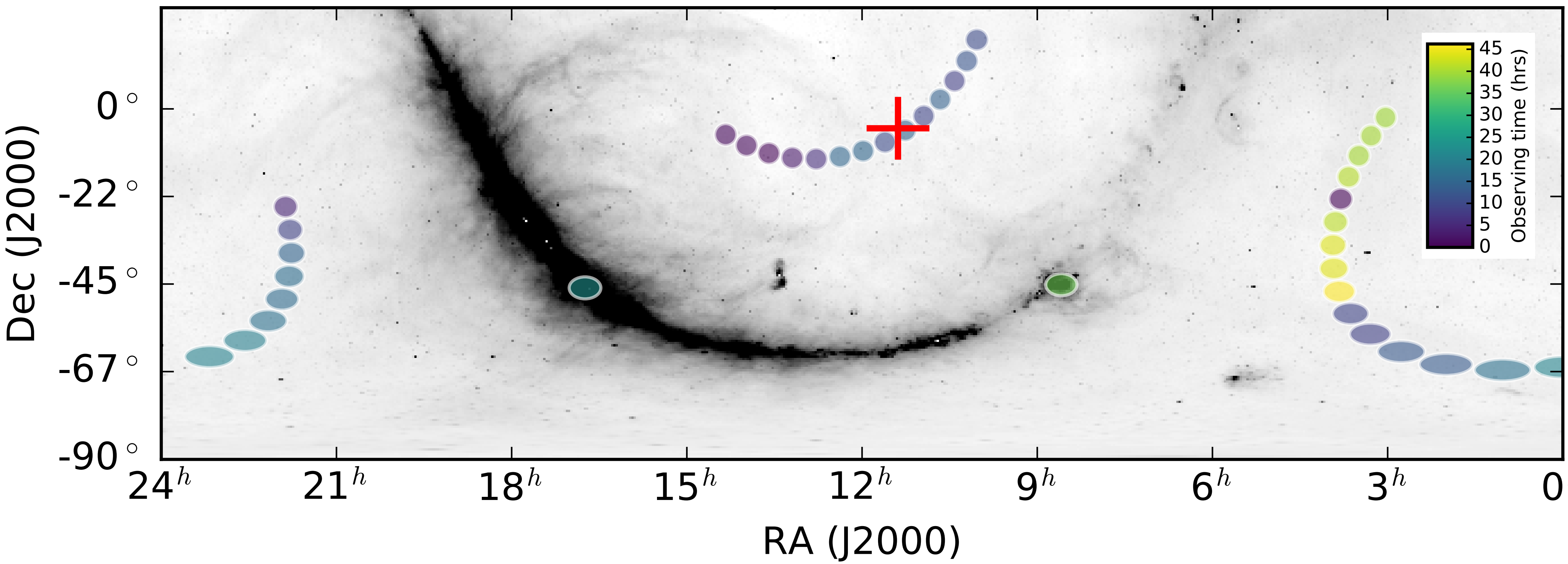
ASKAP will be…

- 36 antennas
- 36 beams = ~ 30 deg^2 per antenna
- 336 x 1 MHz channels (only 300 for interferometry)
- Tuning: 700-1800 MHz
- ~1ms time resolution

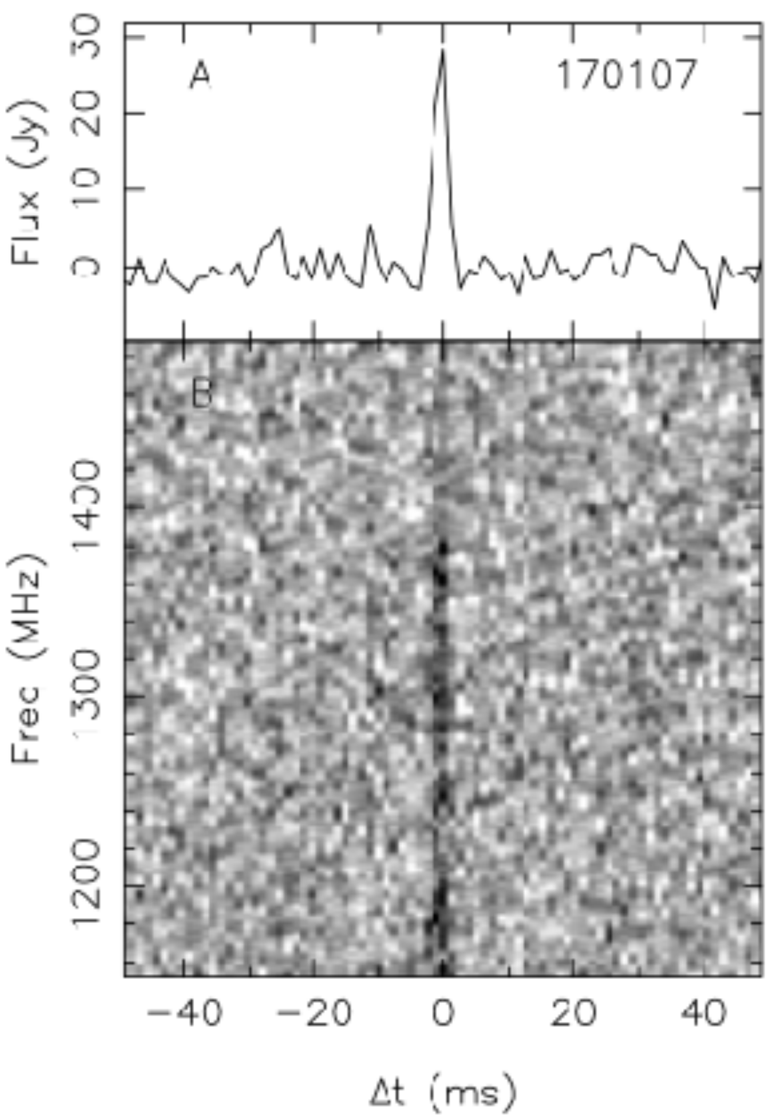
CRAFT - the next step



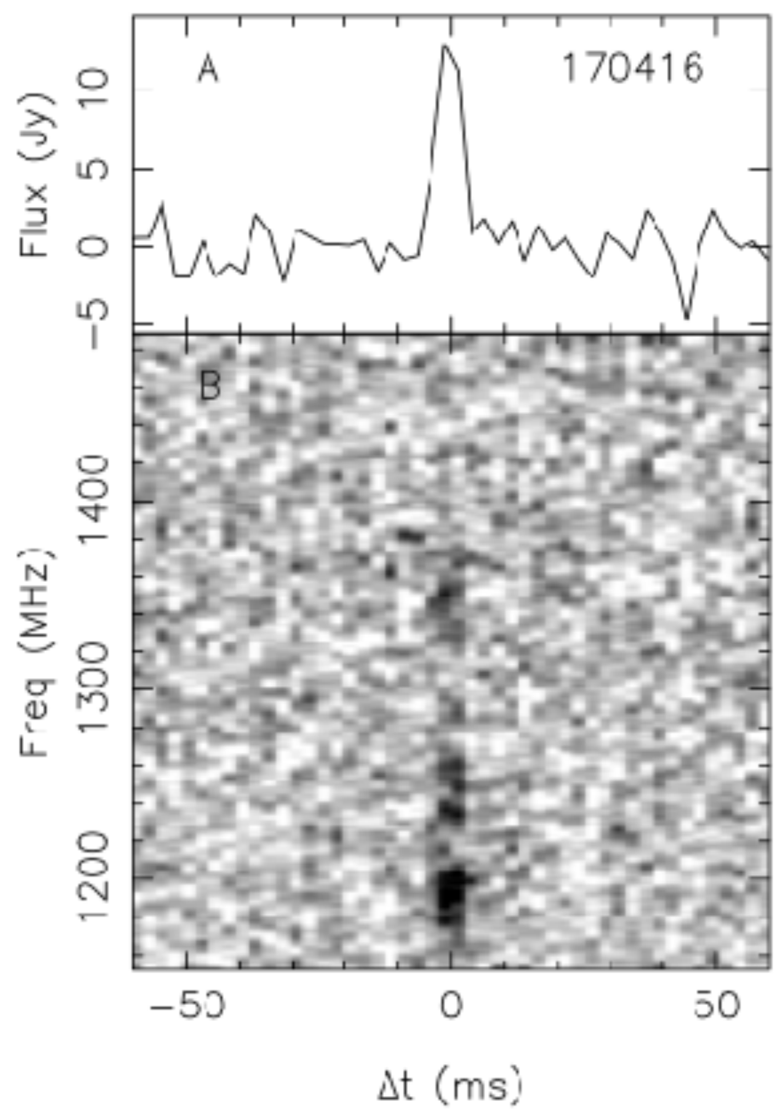
Innovation: Fly's-eye observing



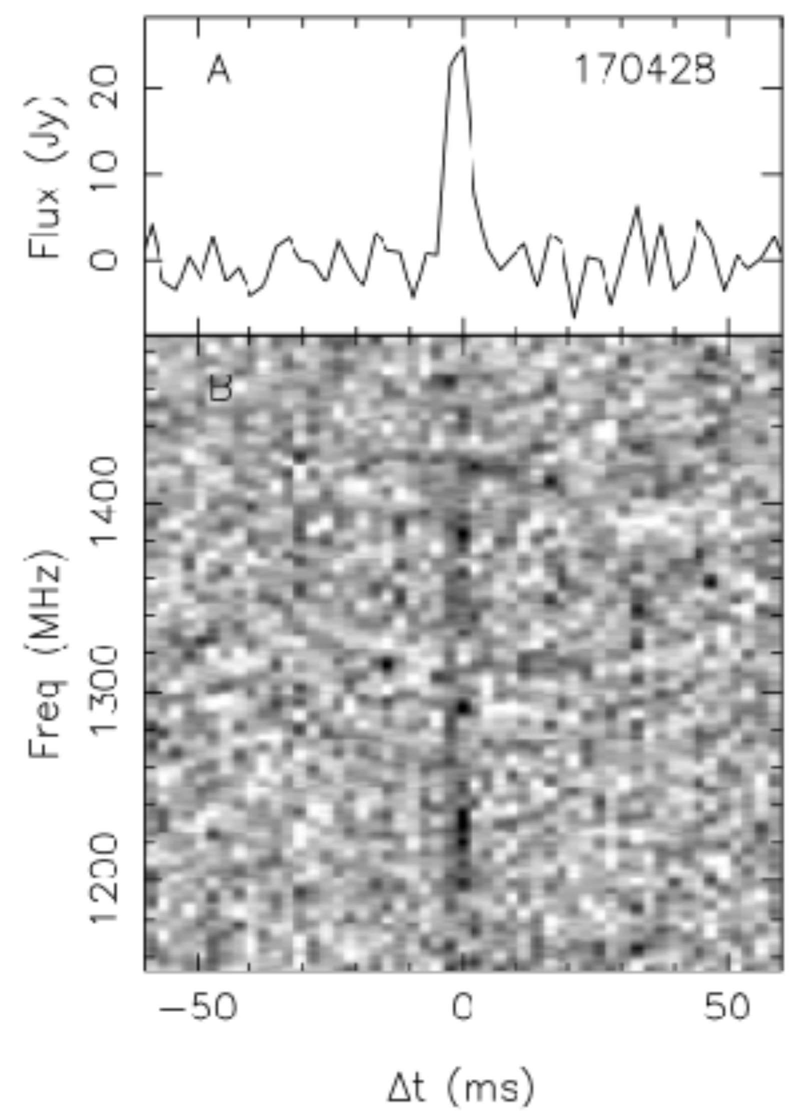
ASKAP's first 3 FRBs



FRB 170107
DM: 609.5 pc cm^{-3}

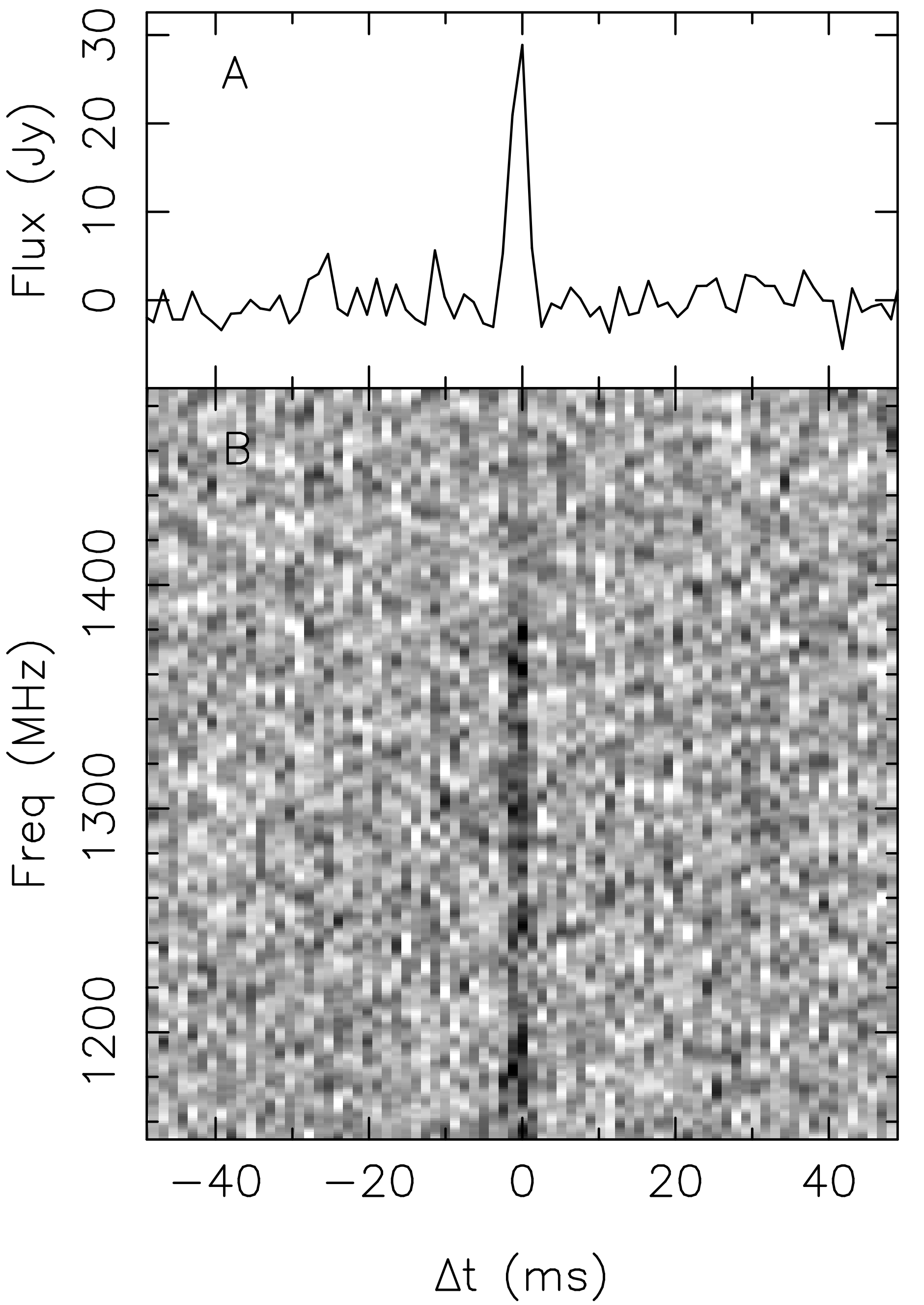


FRB 170416
DM: 523.2(2) pc cm^{-3}

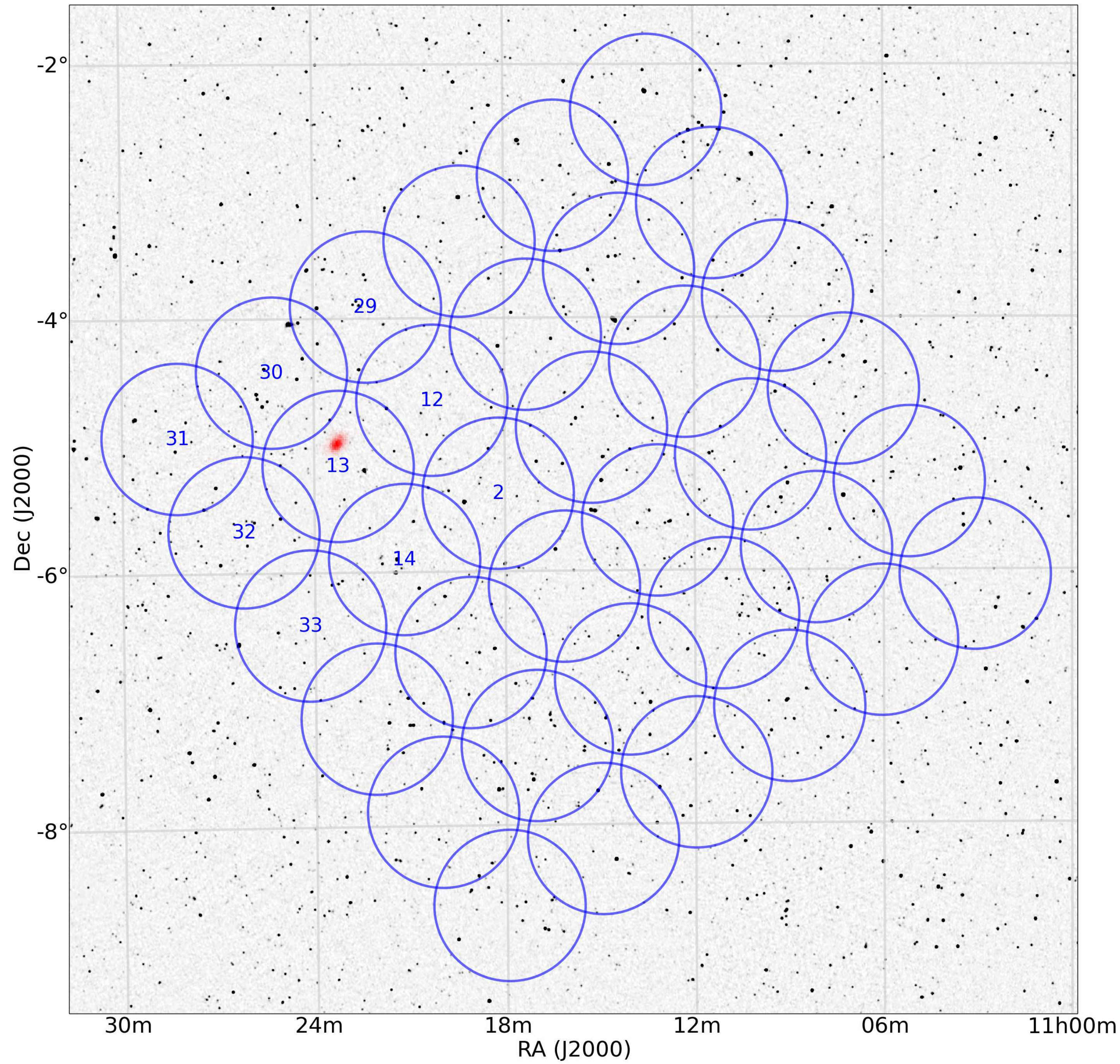


FRB 170428
DM: 991.7(8) pc cm^{-3}

FRB170107

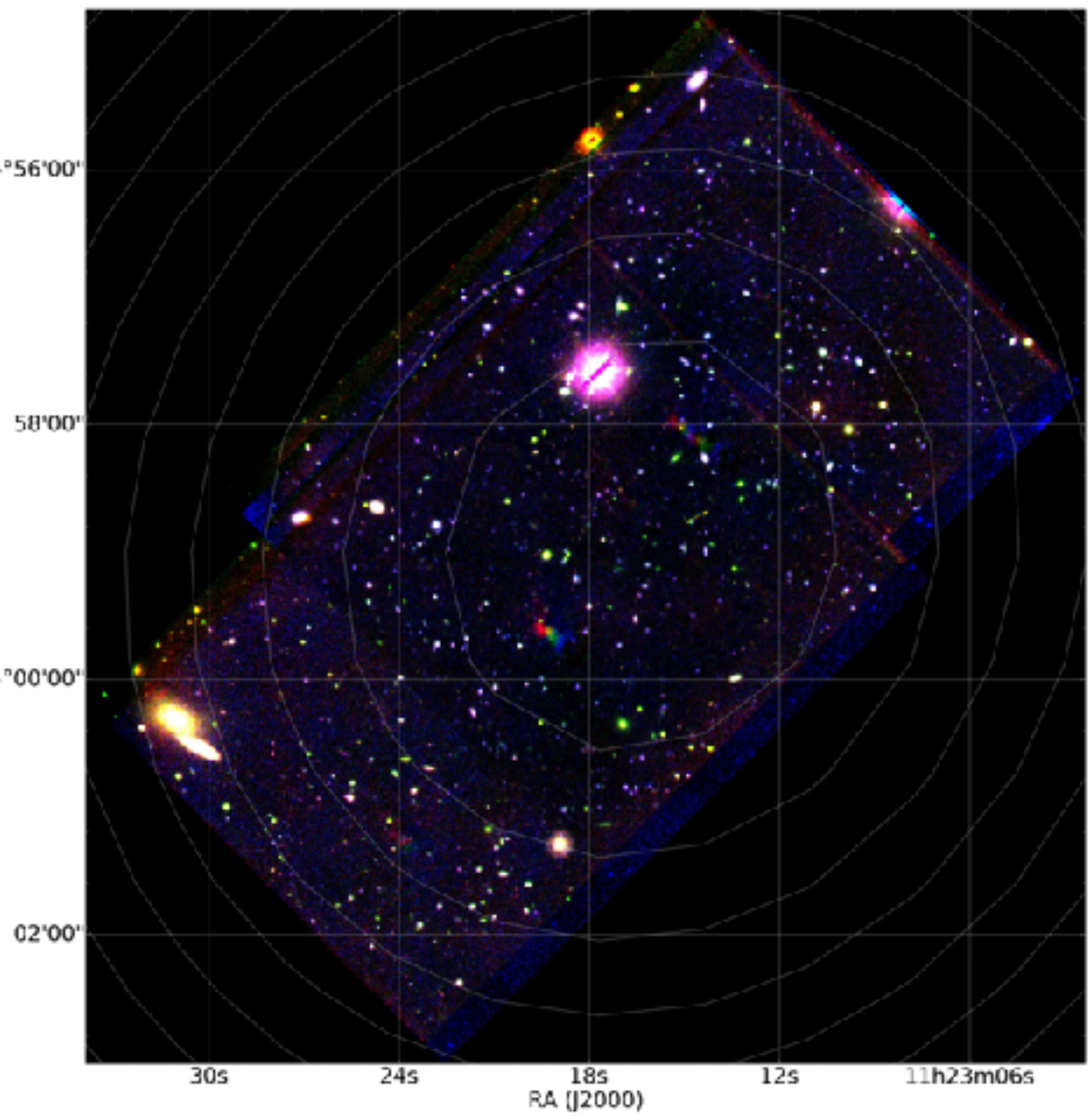


Spectral cutoff above 1.4 GHz
DM=610 pc/cm3
Fluence=58 Jy.ms

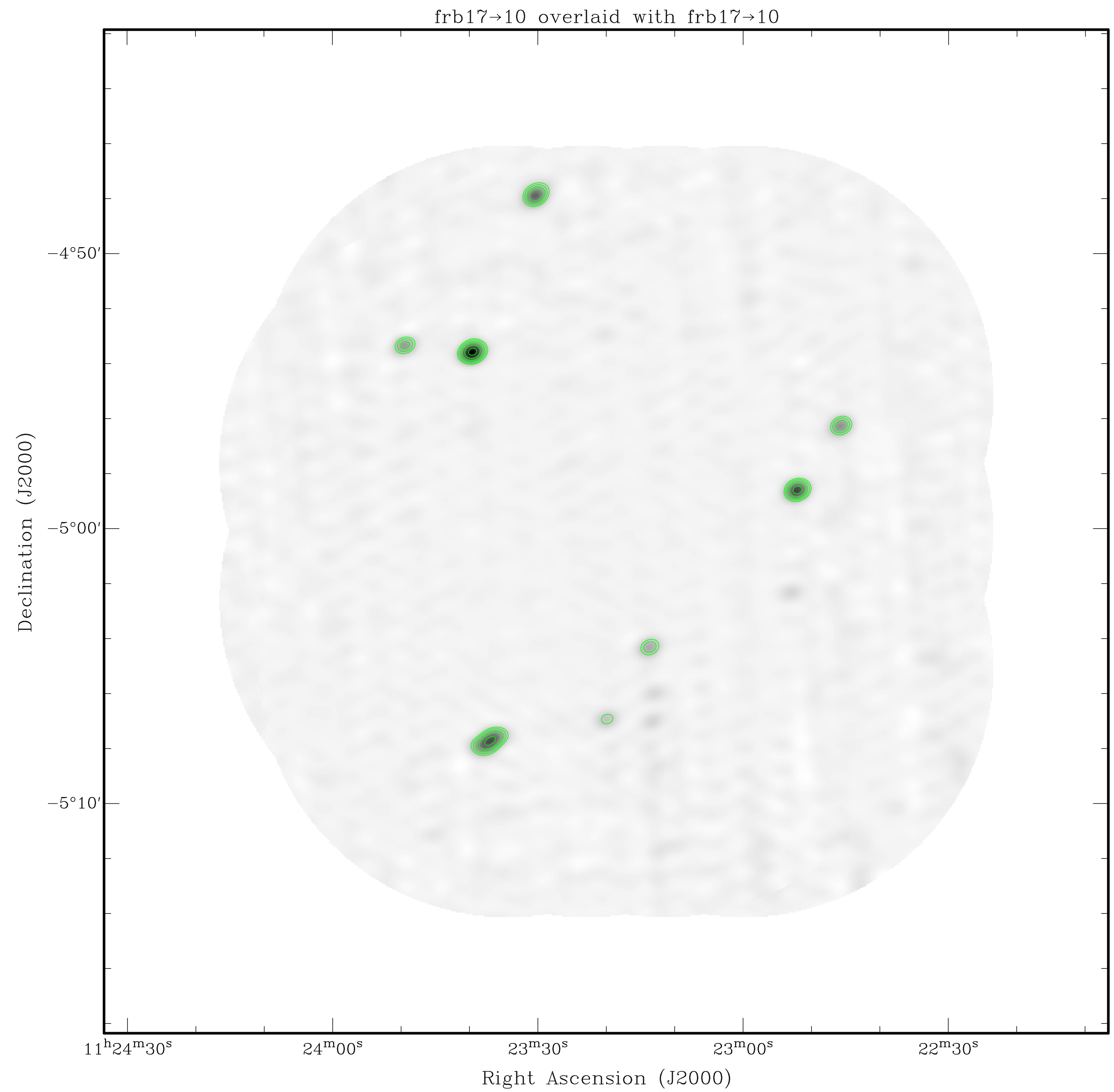


Localised to 8x8 arcmin
- thanks to fully-sampled focal plane!

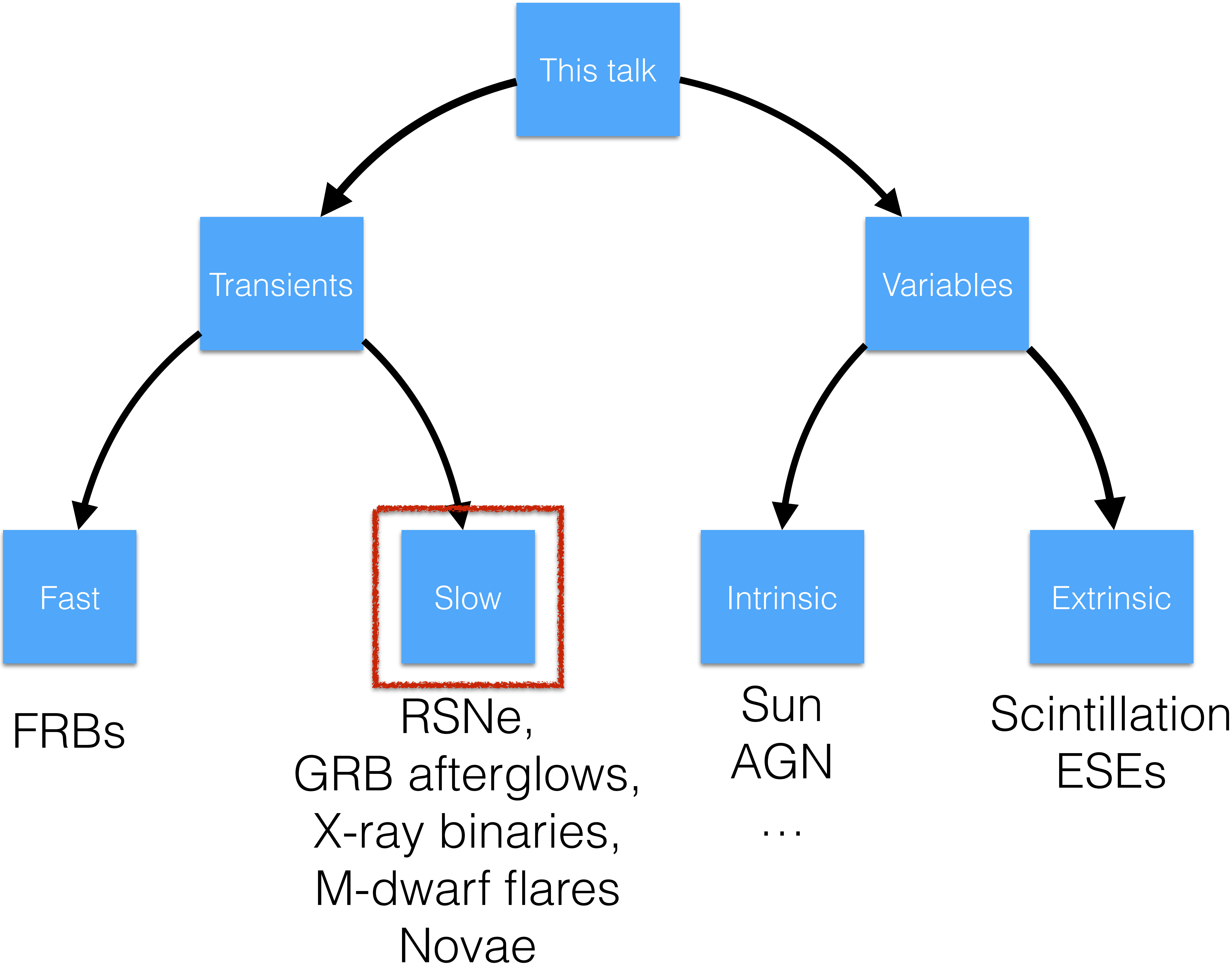
Multi-wavelength follow-up



Optical image
Keck (Caltech)



5.5 GHz image
ATCA (CSIRO)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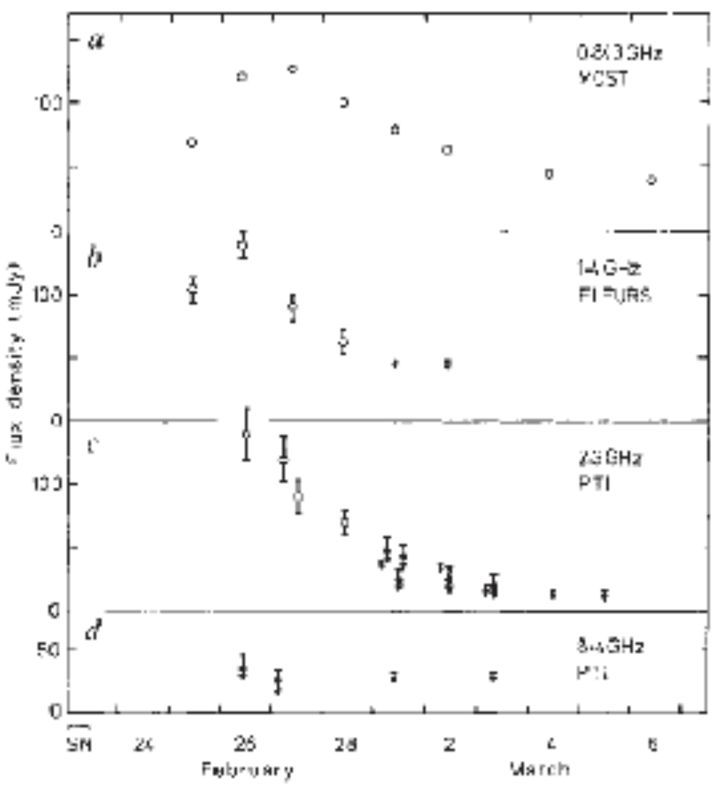
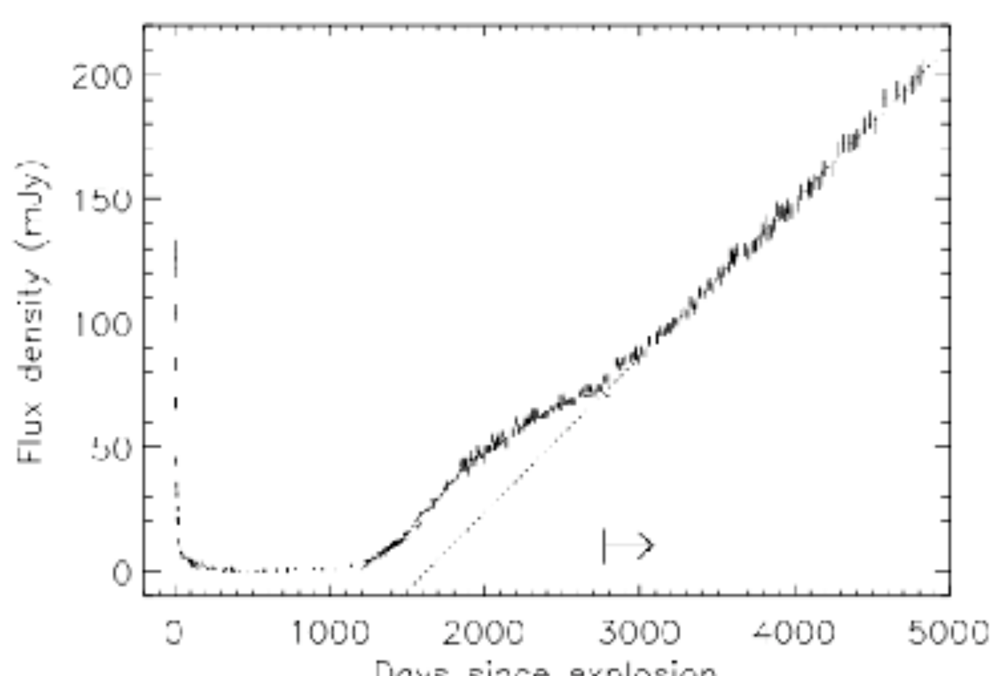
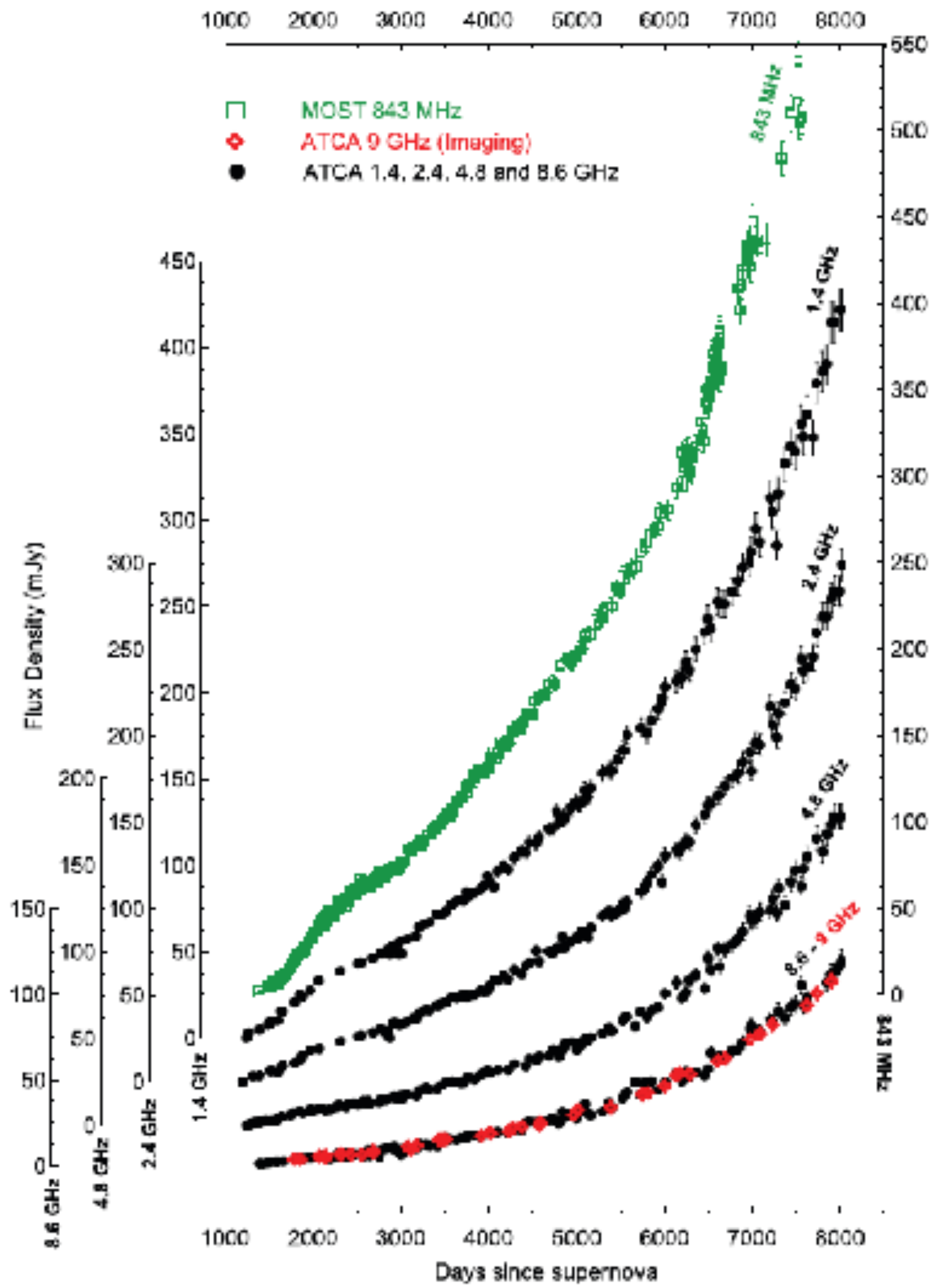
SN1987A - radio supernova

Turtle+87



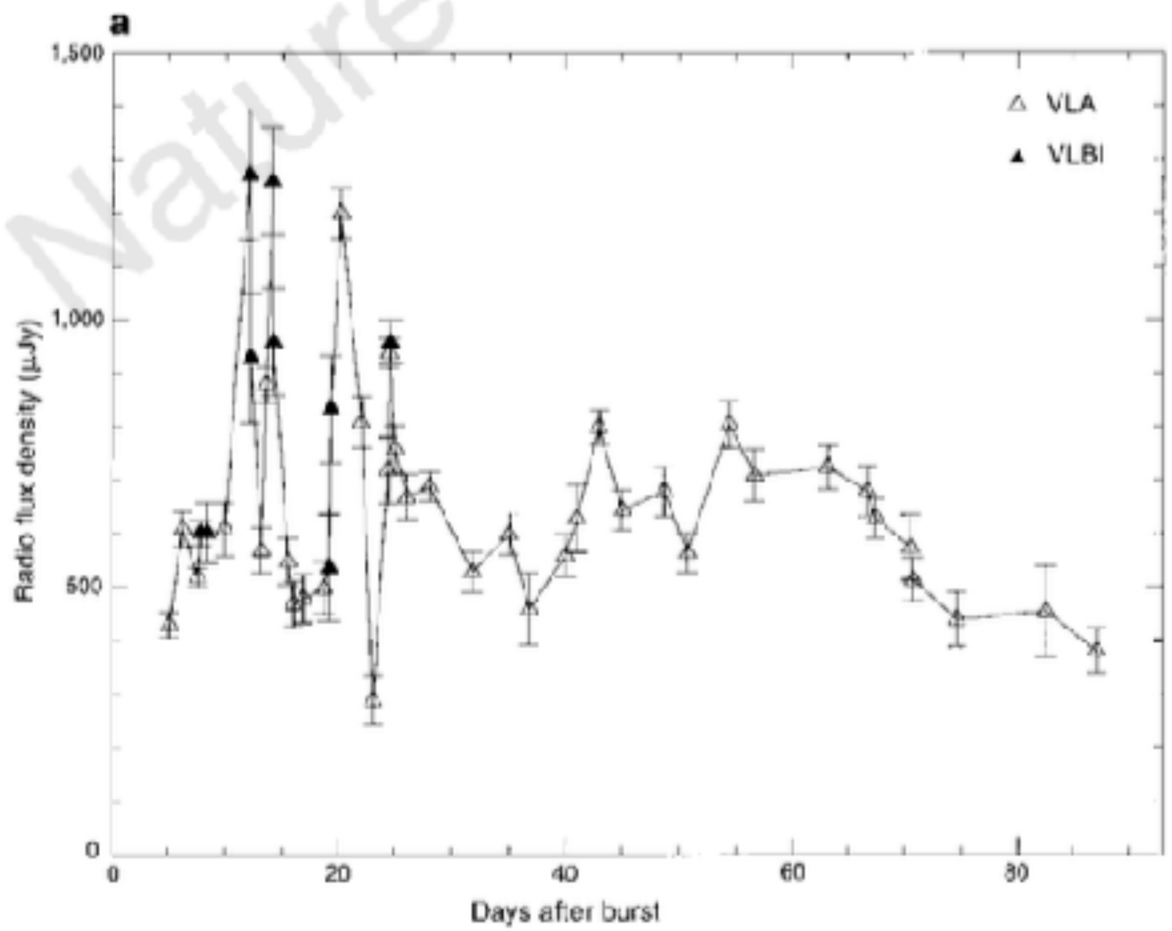
Ball+01

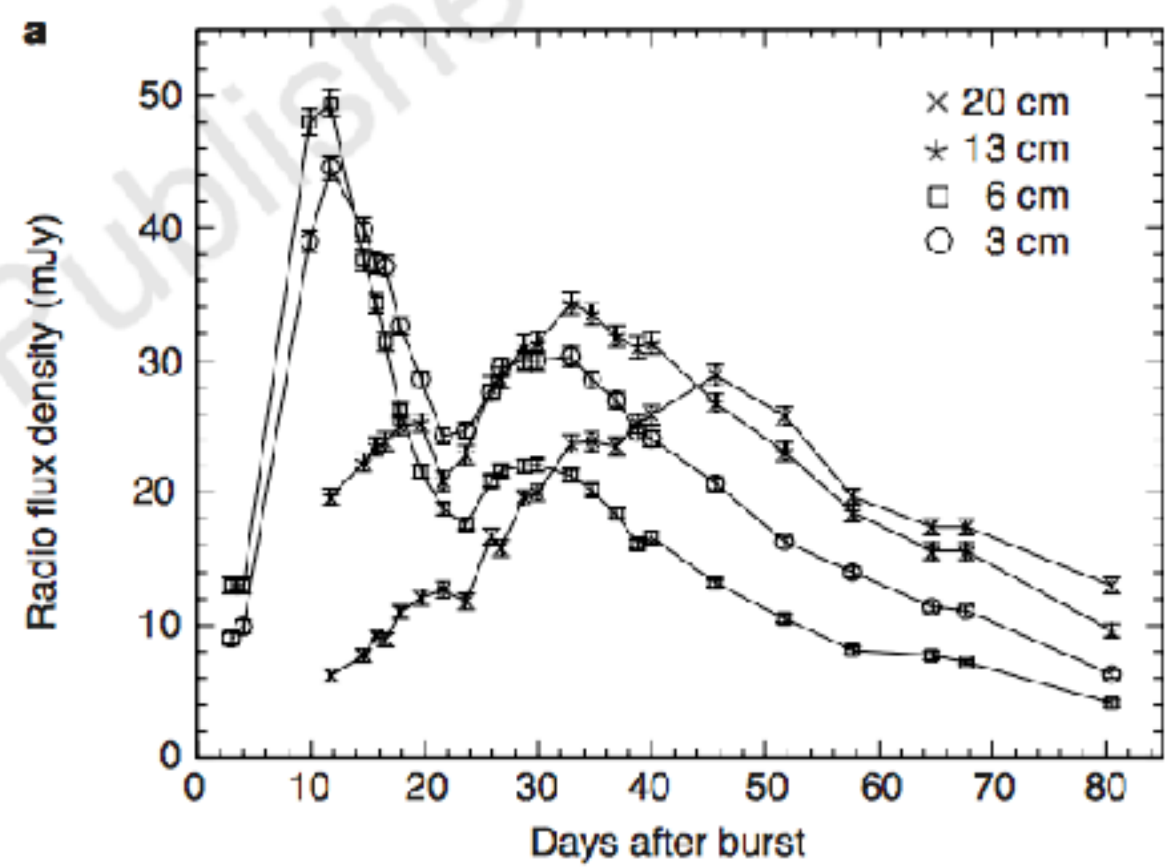




Zanado+ 2010

Gamma Ray Burst afterglows

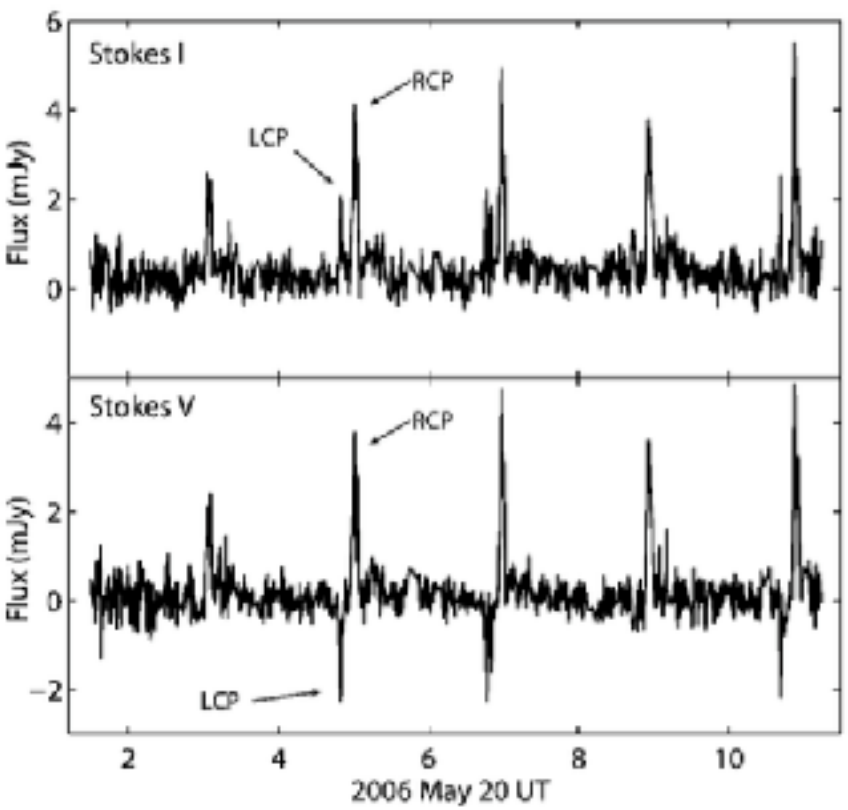




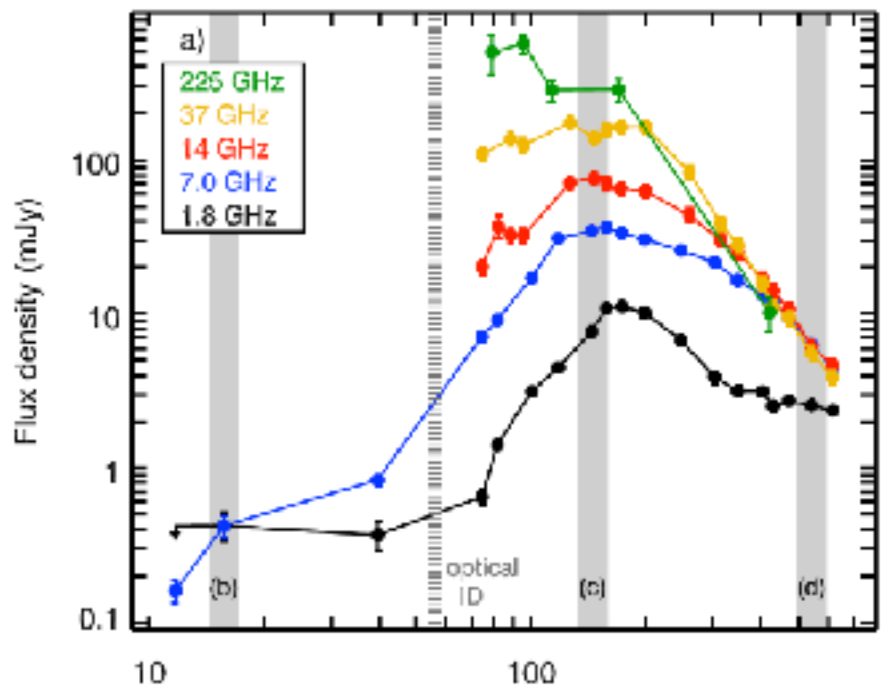
Frail+ 98
Damping of scintillations puts constraints on source size vs time = relativistic

Kulkarni+ 98
Radio emission from a gamma ray burst,
First association with a supernova
ATCA's highest cited paper (472)

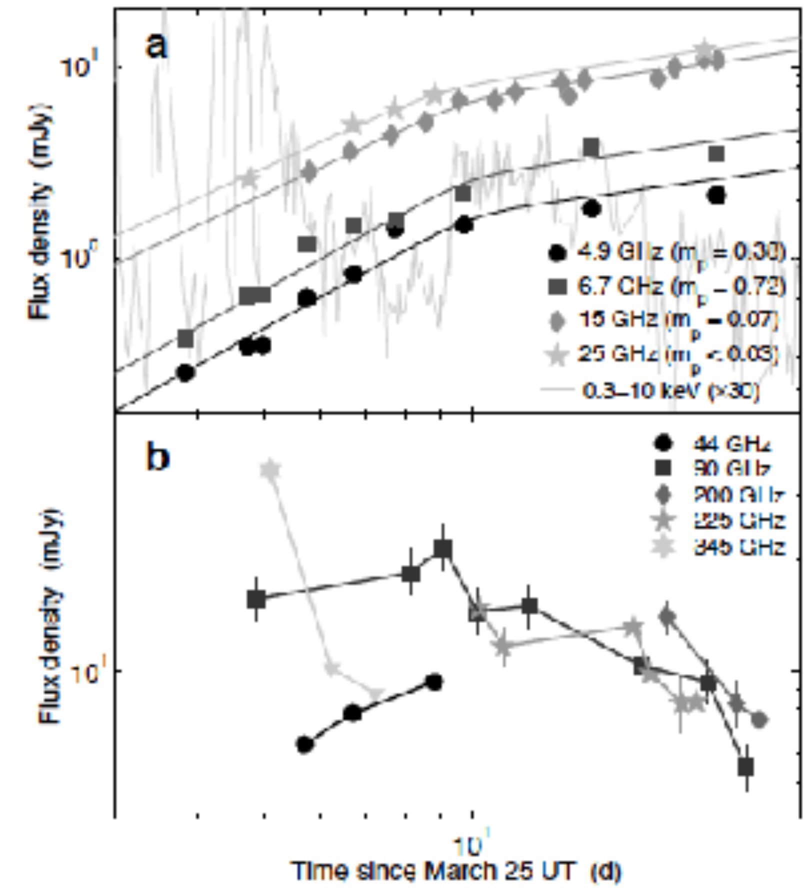
A zoo of transients



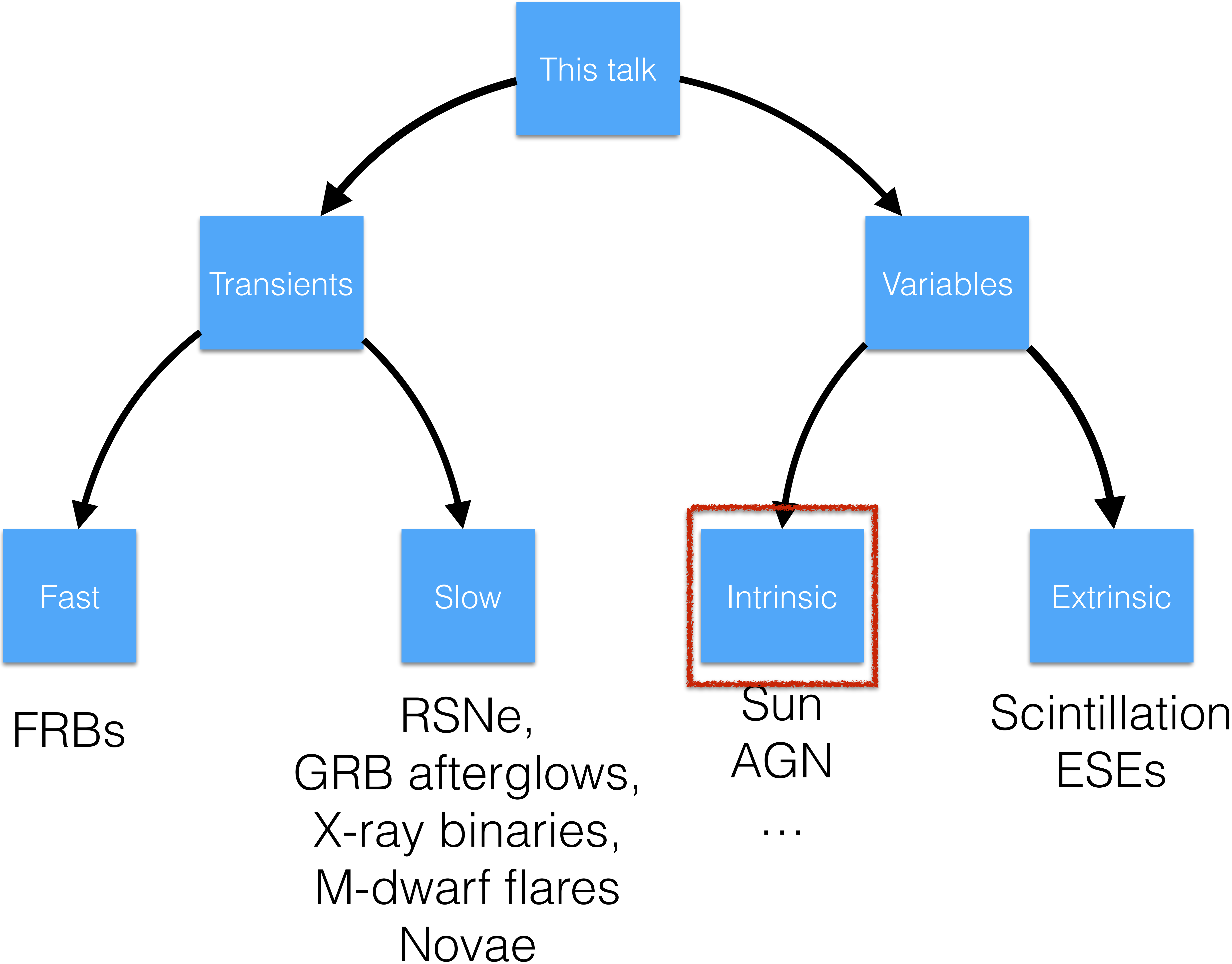
Hallinan+ 07
Periodic bursts from an ultra cool dwarf



Chomiuk+ 15
Radio emission from classical Nova



Zauderer+ 11
Tidal disruption event: i.e. a
Star falls into a supermassive black hole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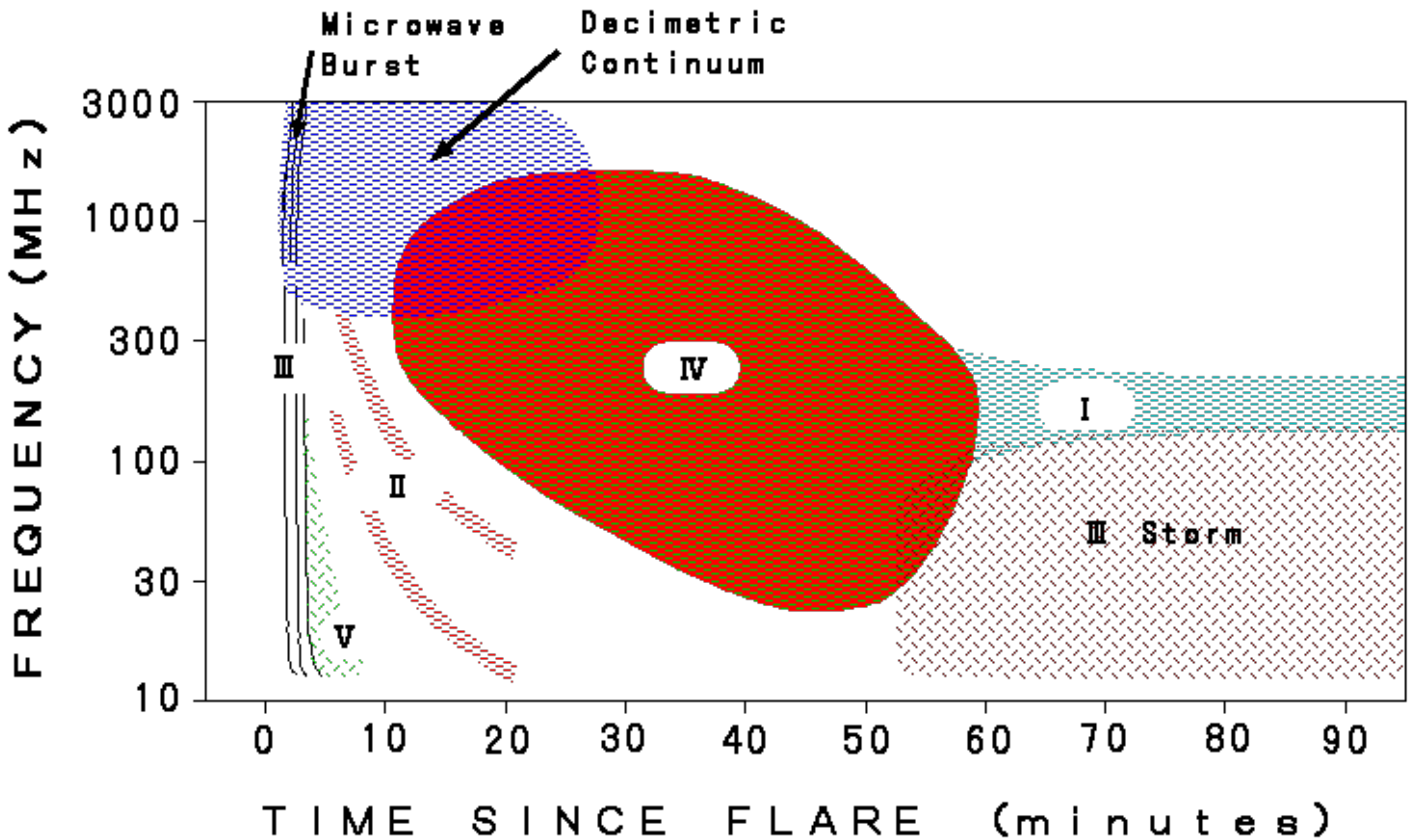
Radio Bursts from the Sun

Solar Radio Burst Classifications

TYPE	CHARACTERISTICS	DURATION	FREQUENCY RANGE	ASSOCIATED PHENOMENA
I	Short, narrow-bandwidth bursts. Usually occur in large numbers with underlying continuum.	Single burst: ~ 1 second Storm: hours - days	80 – 200 MHz	Active regions, flares, eruptive prominences.
II	Slow frequency drift bursts. Usually accompanied by a (usually stronger intensity) second harmonic.	3- 30 minutes	Fundamental: 20 – 150 MHz	Flares, proton emission, magnetohydrodynamic shockwaves.
III	Fast frequency drift bursts. Can occur singularly, in groups, or storms (often with underlying continuum). Can be accompanied by a second harmonic	Single burst: 1 - 3 seconds Group: 1 -5 minutes Storm: minutes - hours	10 kHz – 1 GHz	Active regions, flares.
IV	Stationary Type IV: Broadband continuum with fine structure	Hours - days	20 MHz – 2 GHz	Flares, proton emission.
	Moving Type IV: Broadband, slow frequency drift, smooth continuum.	30 – 2 hours	20 – 400 MHz	Eruptive prominences, magnetohydrodynamic shockwaves.
	Flare Continua: Broadband, smooth continuum.	3 – 45 minutes	25 – 200 MHz	Flares, proton emission.
V	Smooth, short-lived continuum. Follows some type III bursts. Never occur in isolation.	1-3 minutes	10 - 200 MHz	Same as type III bursts.

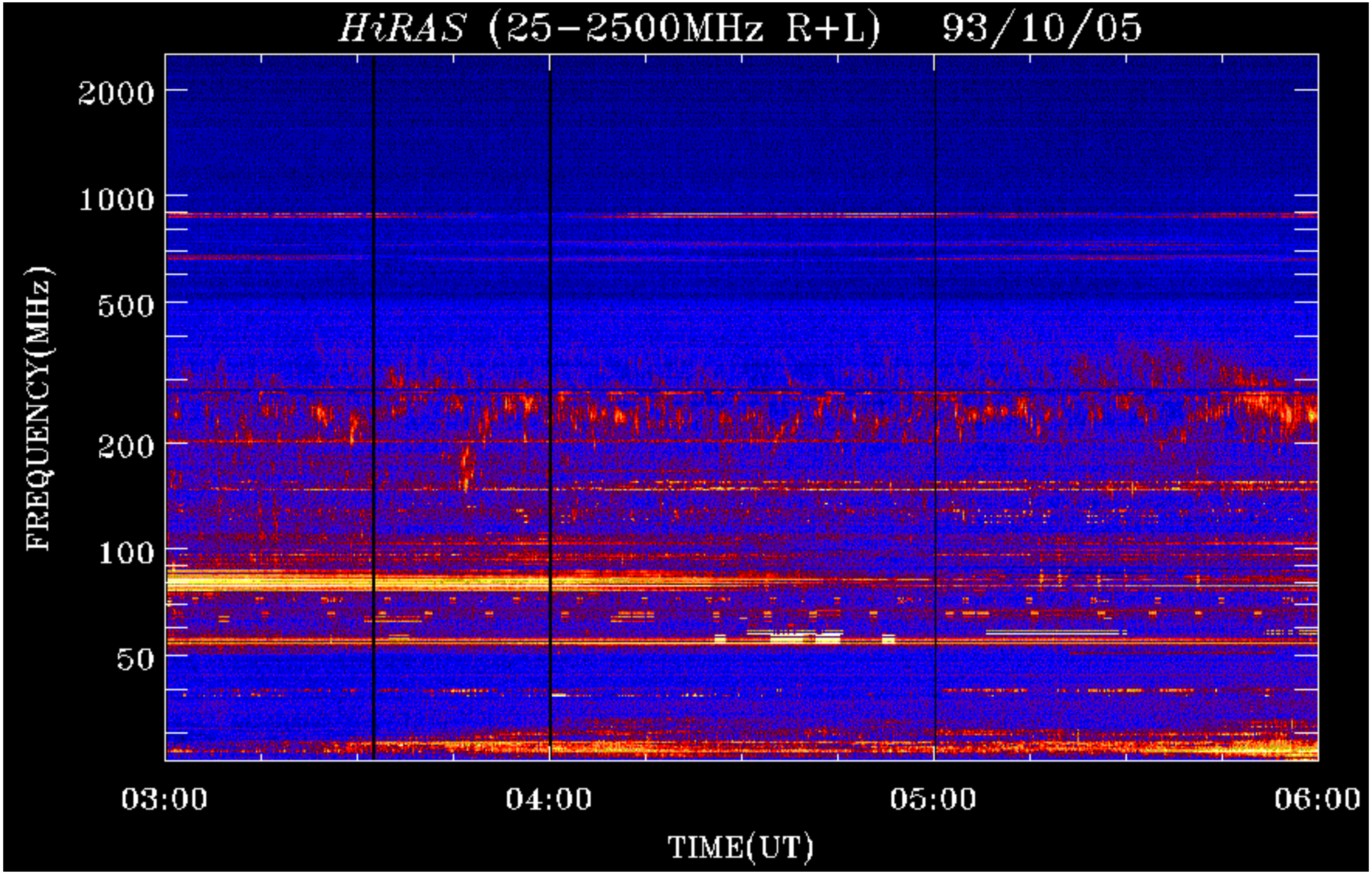
NOTES: In nearly all cases, drifting bursts drift from high to low frequencies.
The Frequency Range is the typical range in which the bursts appear – not their bandwidth.
The sub-types of type IV are not universally agreed upon and are thus open to debate.

Solar burst types

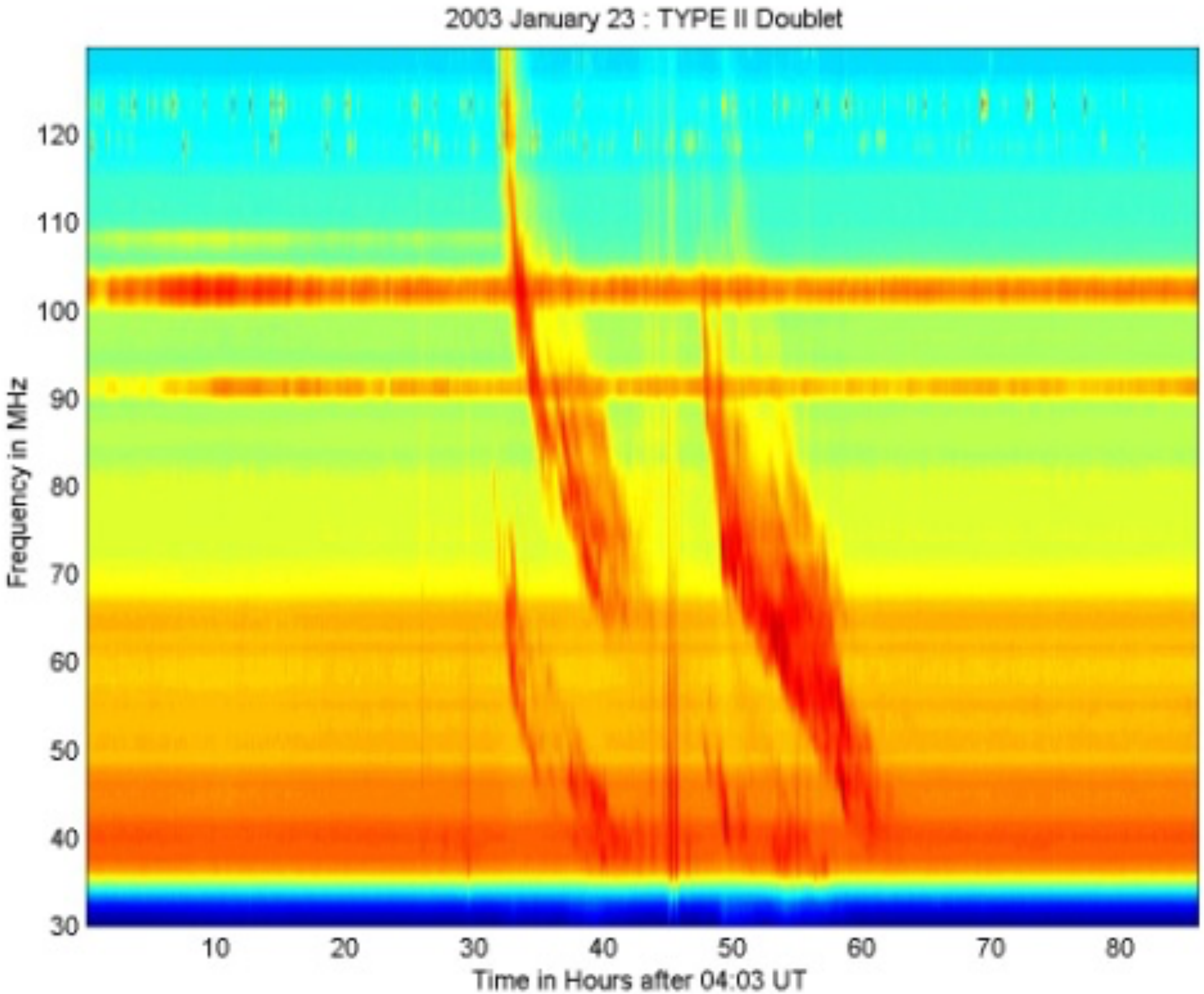


http://sunbase.nict.go.jp/solar/denpa/hiras/types.html

Type I

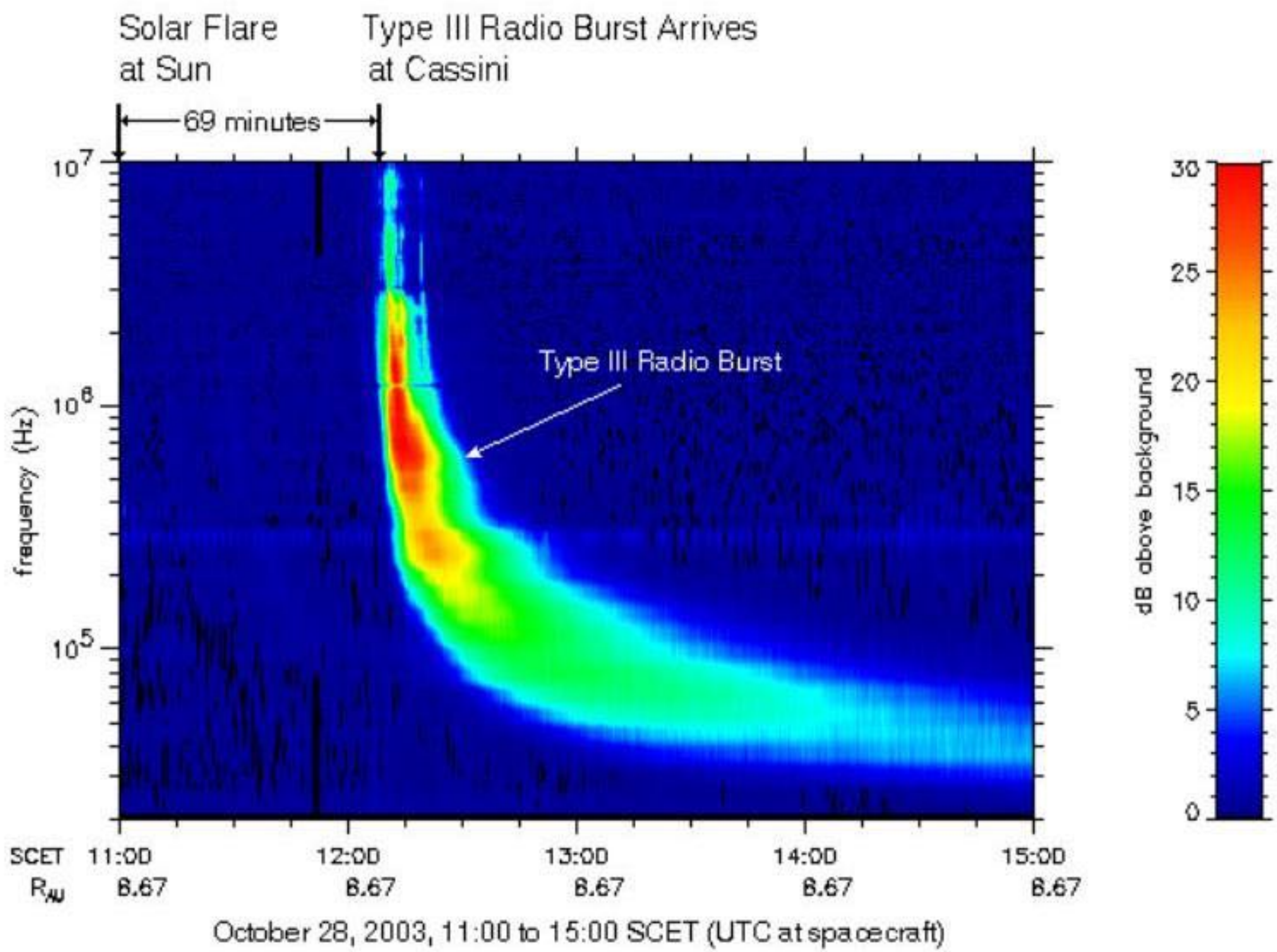

HiRAS (25-2500MHz R+L) 93/10/05
FREQUENCY(MHz)
2000
1000
500
200
100
50
03:00
04:00
05:00
06:00
TIME(UT)

Type II

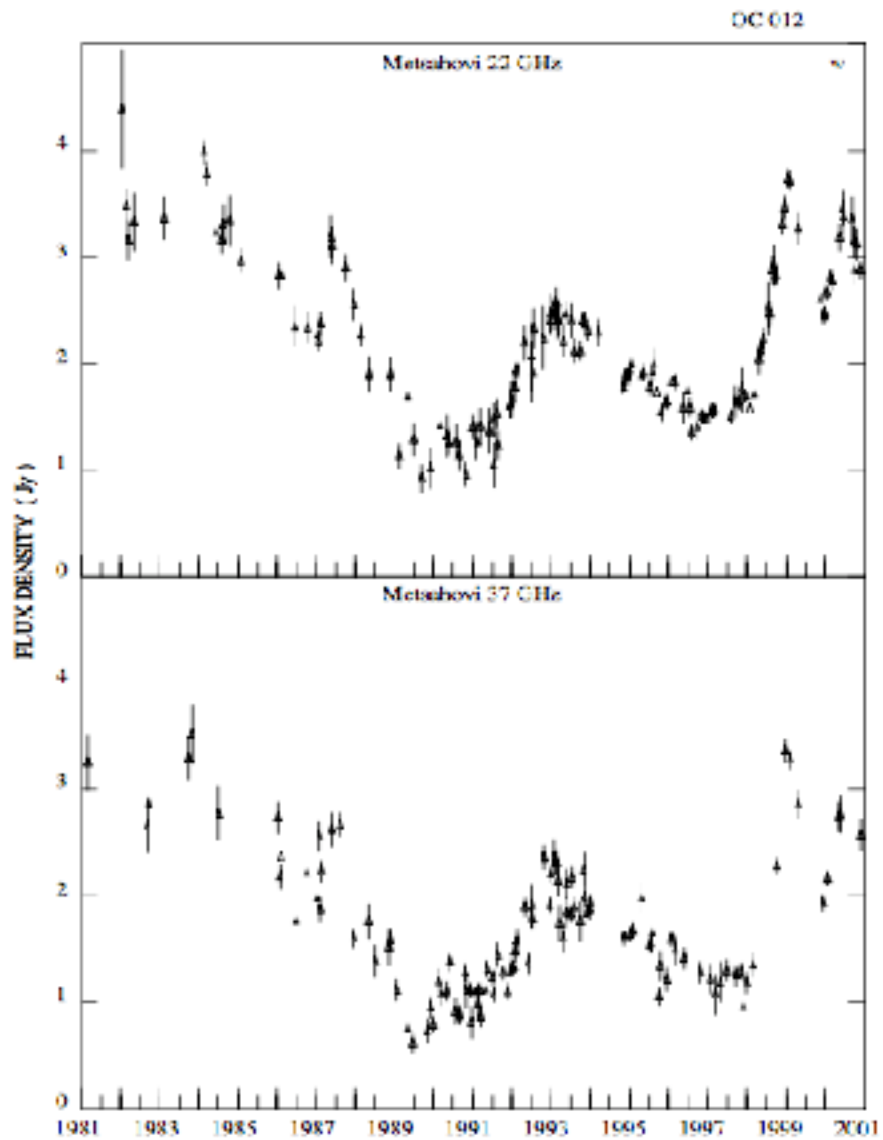


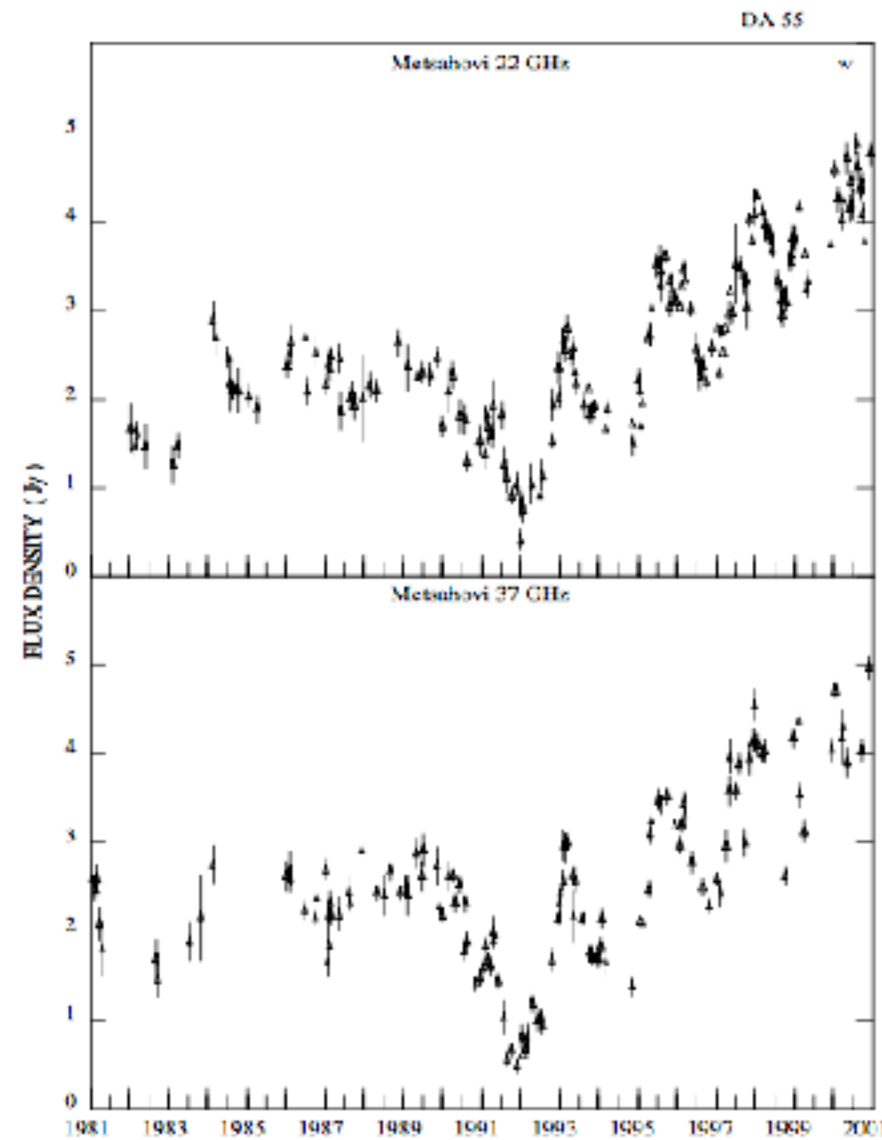
Doddamani+2013

Type III

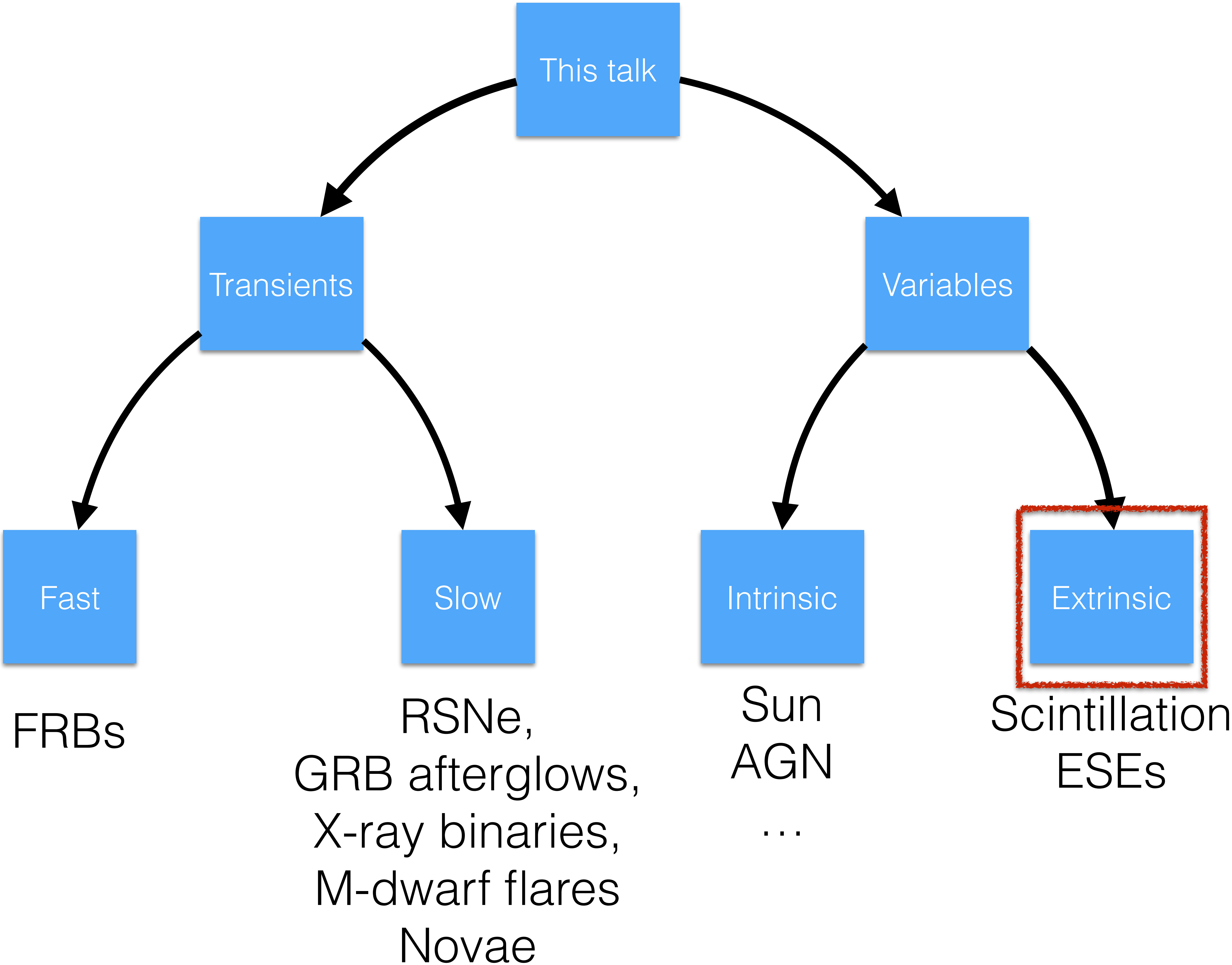

Solar Flare
at Sun
Type III Radio Burst Arrives
at Cassini
69 minutes
Type III Radio Burst
frequency (Hz)
10^7
10^6
10^5
dB above background
30
25
20
15
10
5
0
SCET
R_AU
11:00
12:00
13:00
14:00
15:00
8.67
8.67
8.67
8.67
8.67
October 28, 2003, 11:00 to 15:00 SCET (UTC at spacecraft)

Intrinsic AGN variability





Teräsranta+ 04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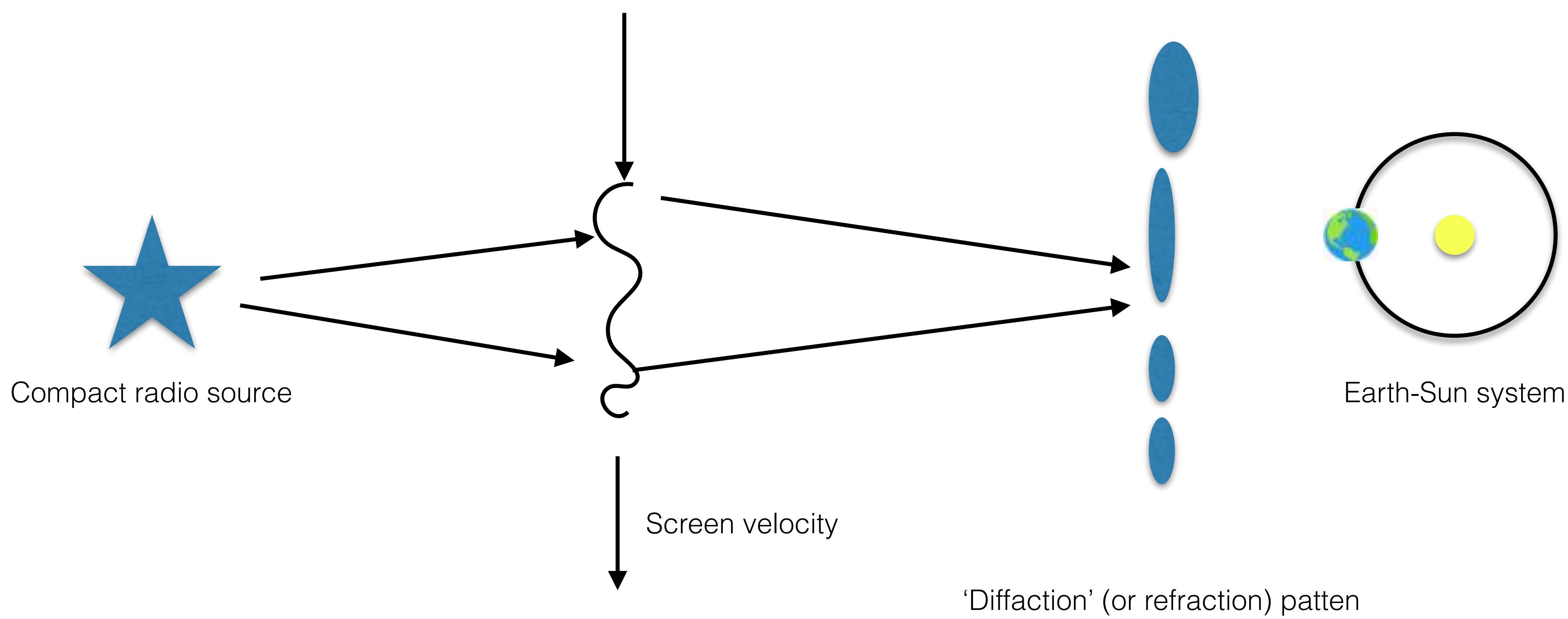
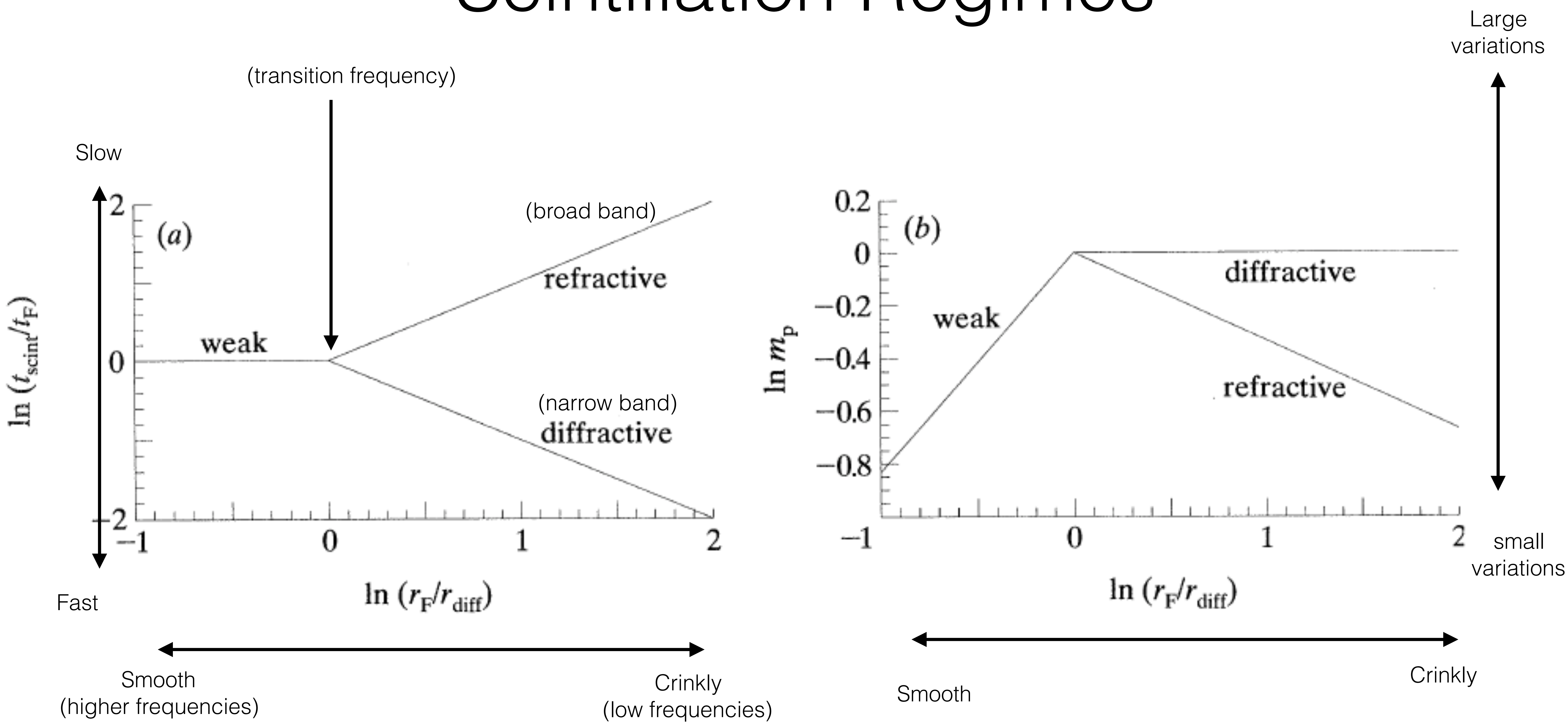
Extrinsic = propagation = scintillation a.k.a scattering

Turbulent ionised plasma in the interstellar medium
Often approximated as a thin ‘screen’
Diffraction and refraction happen here

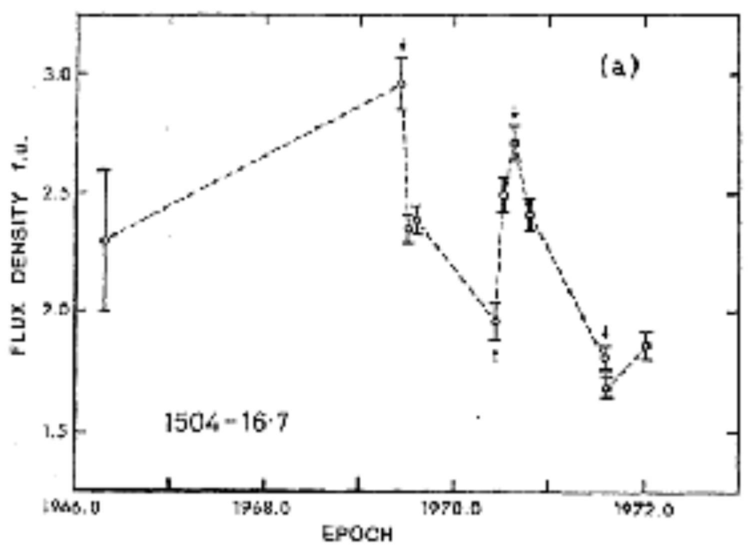


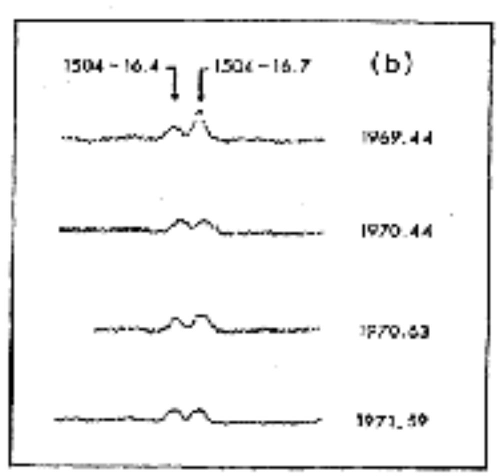
Scintillation Regimes



Narayan 92

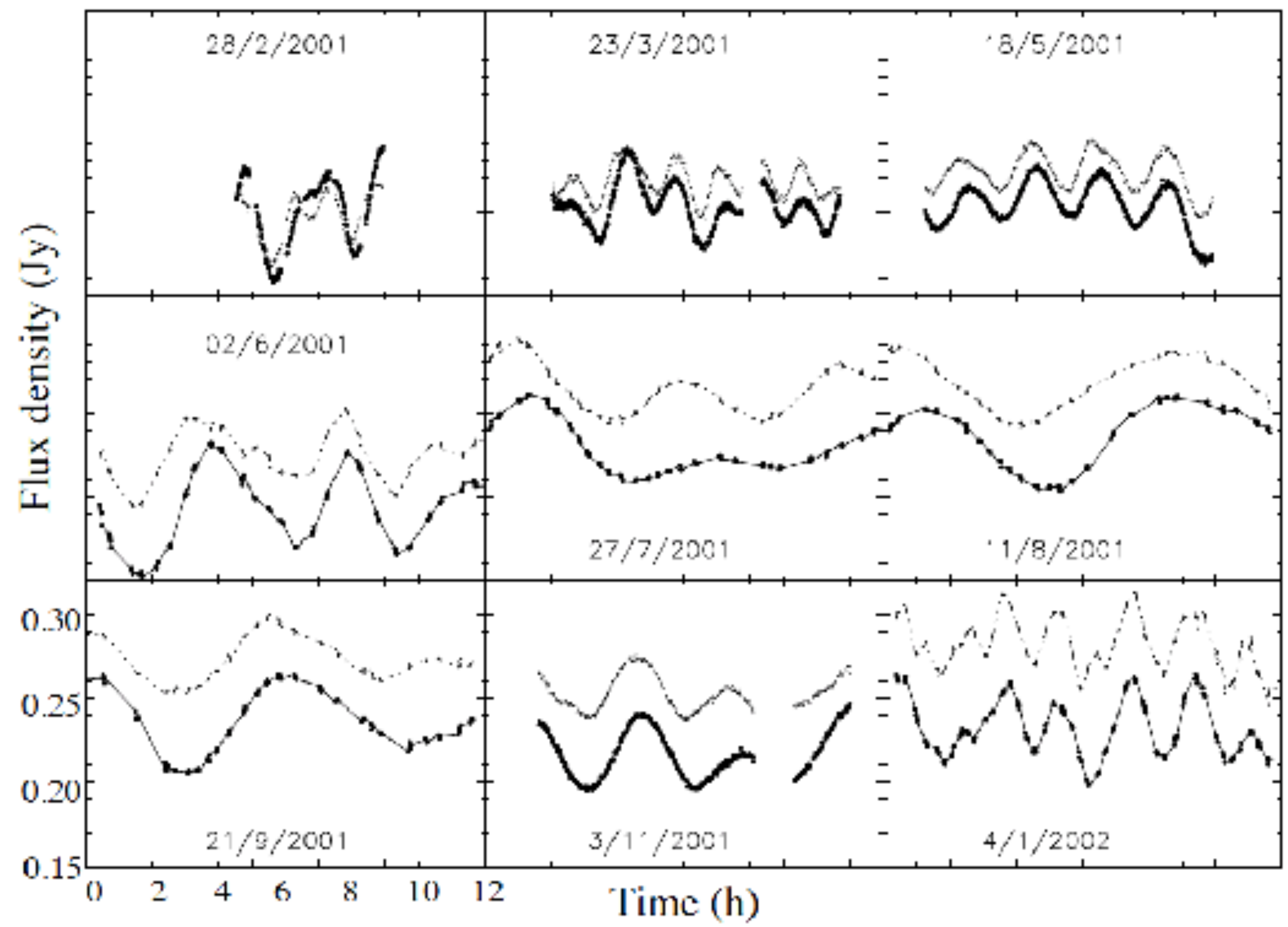
Refractive Scintillation Examples





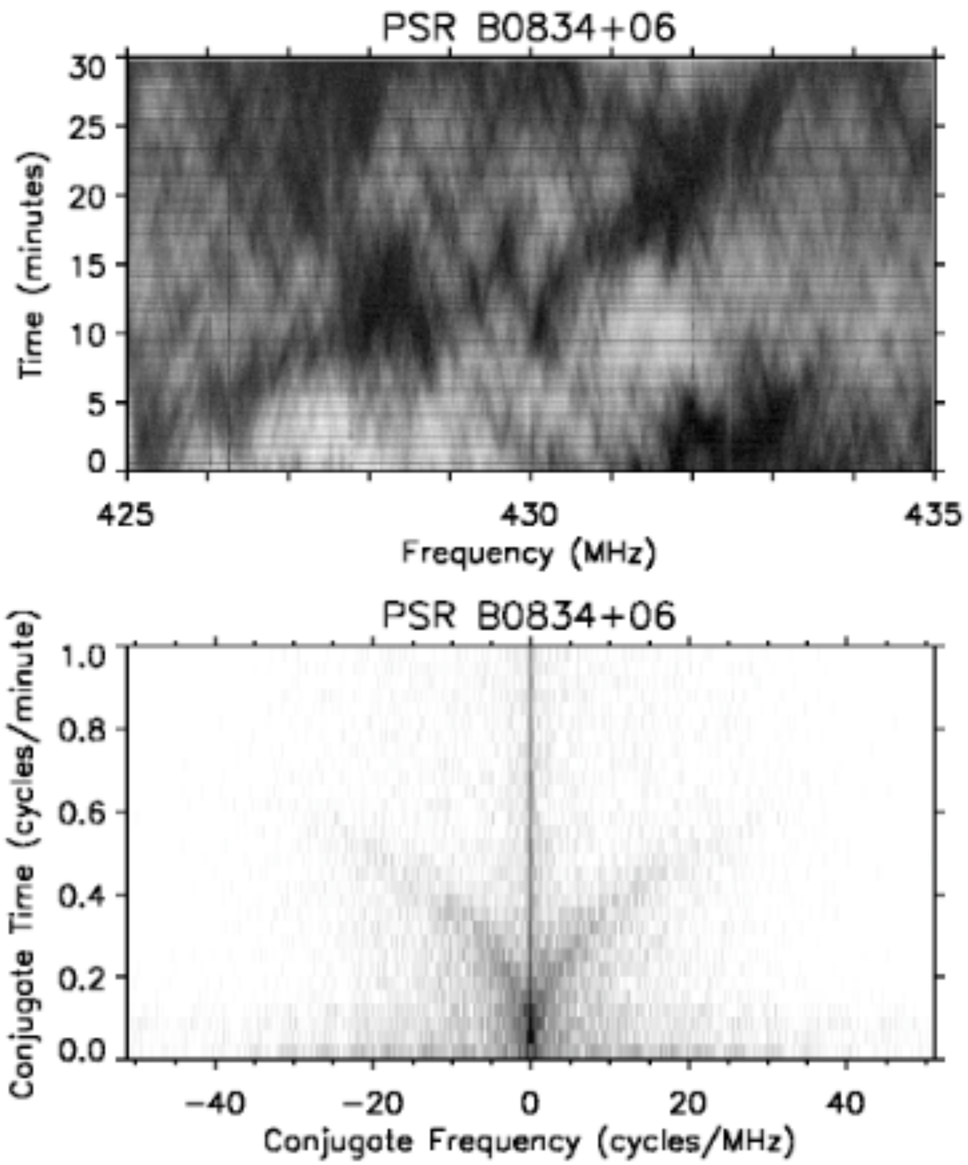
Hunstead+ 72
Discovery in AGN
-> Must be propagation

$$T_B \geqslant \frac{\Delta S D^2}{2 k_B \nu^2 \tau^2}$$

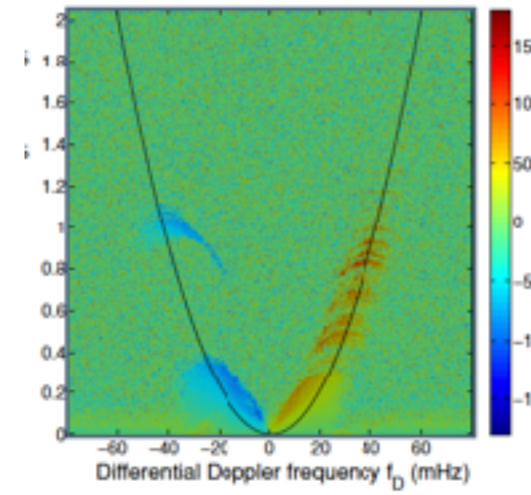


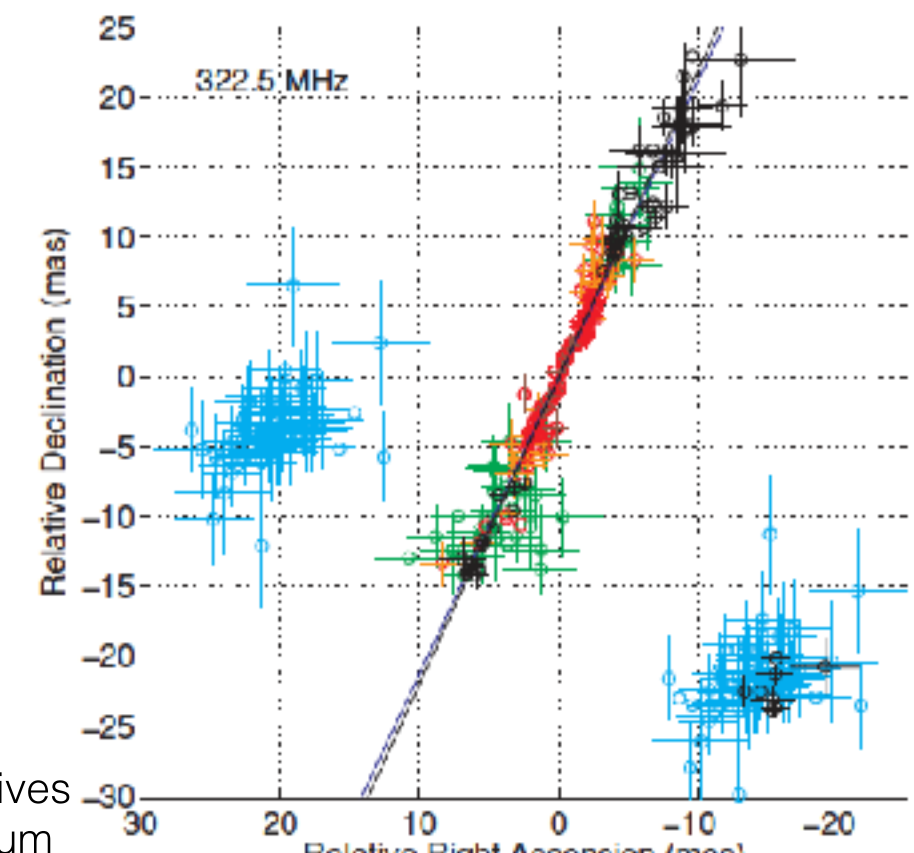
Bignall+ 2003
Intraday variability with annual cycles

Diffractive scintillation



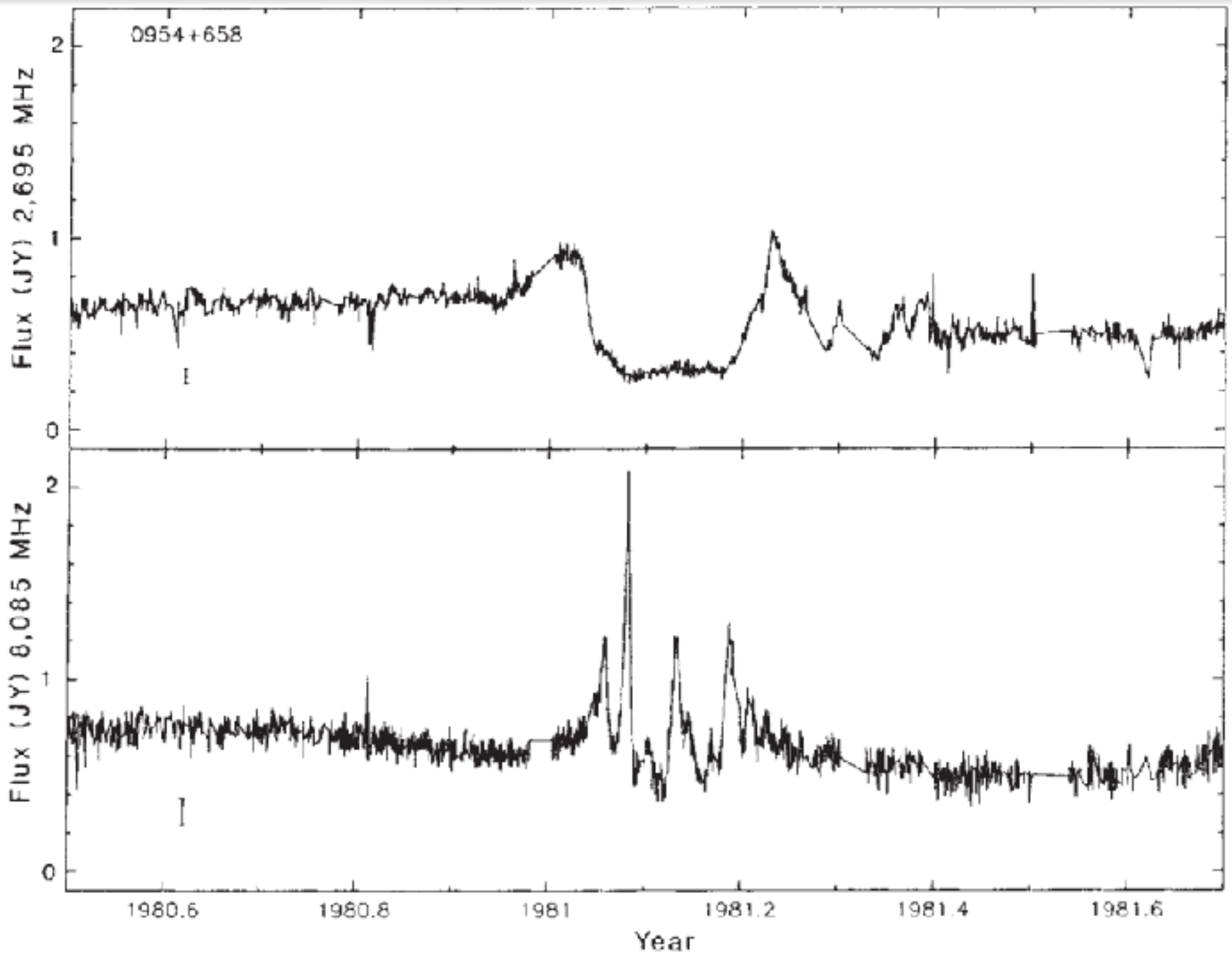
Strinebring+01
Pulsar scintillation Arcs





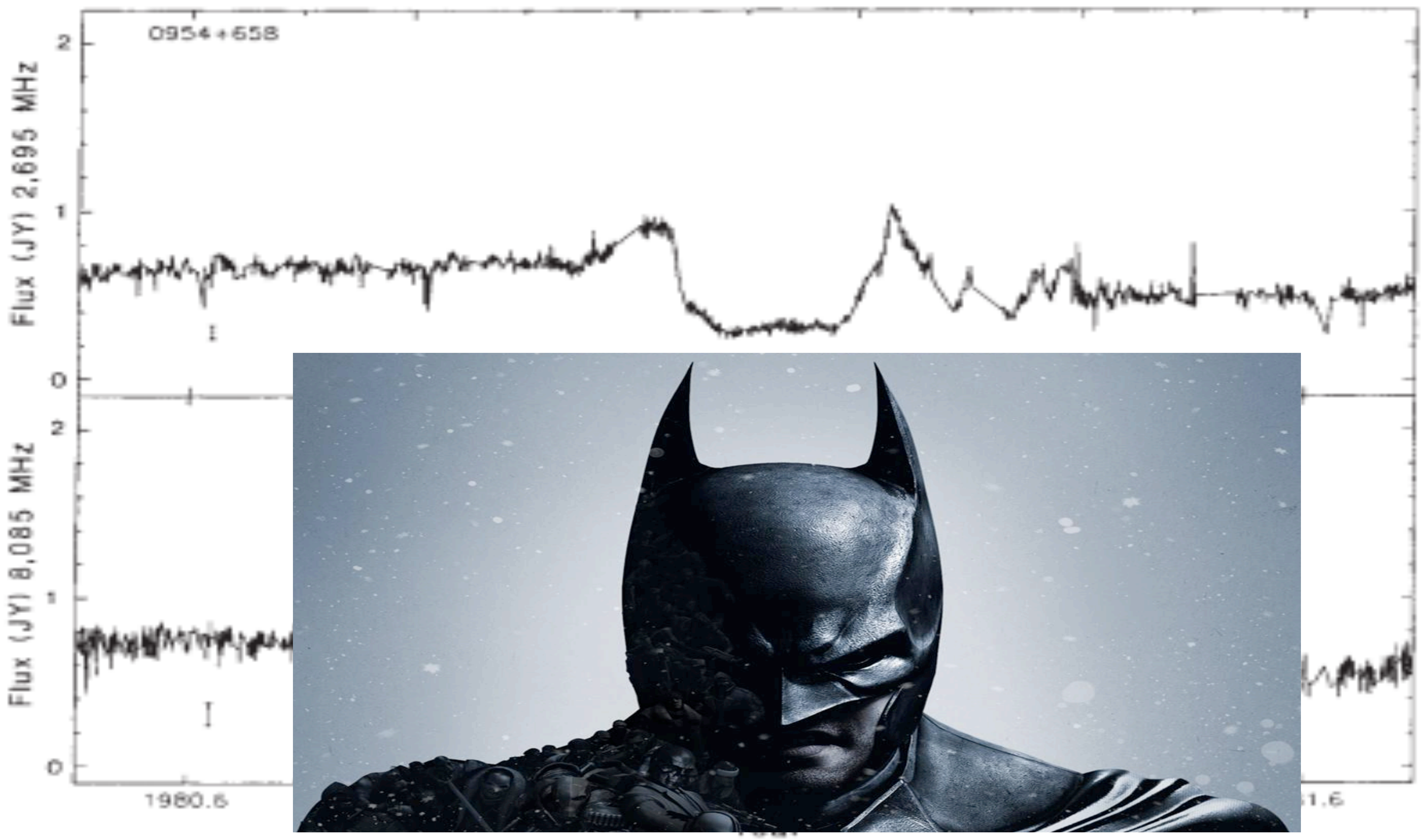
Brisken+ 10
Diffractive scintillation + VLBI gives images of the interstellar medium on microarcsecond scales!

The original ESE: 0954+658

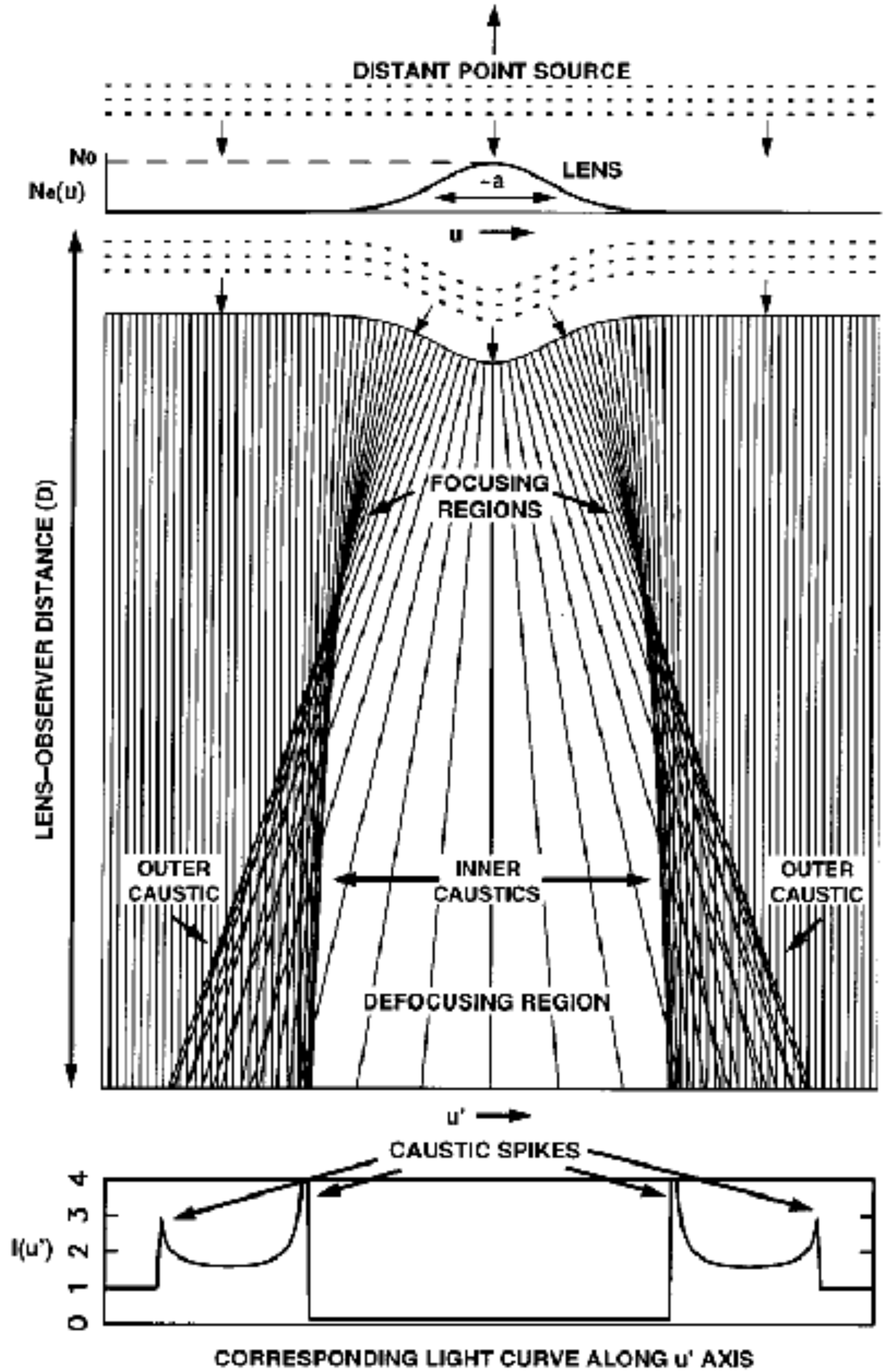


Fiedler+ 1987

The original ESE: 0954+658



Plasma Lenses



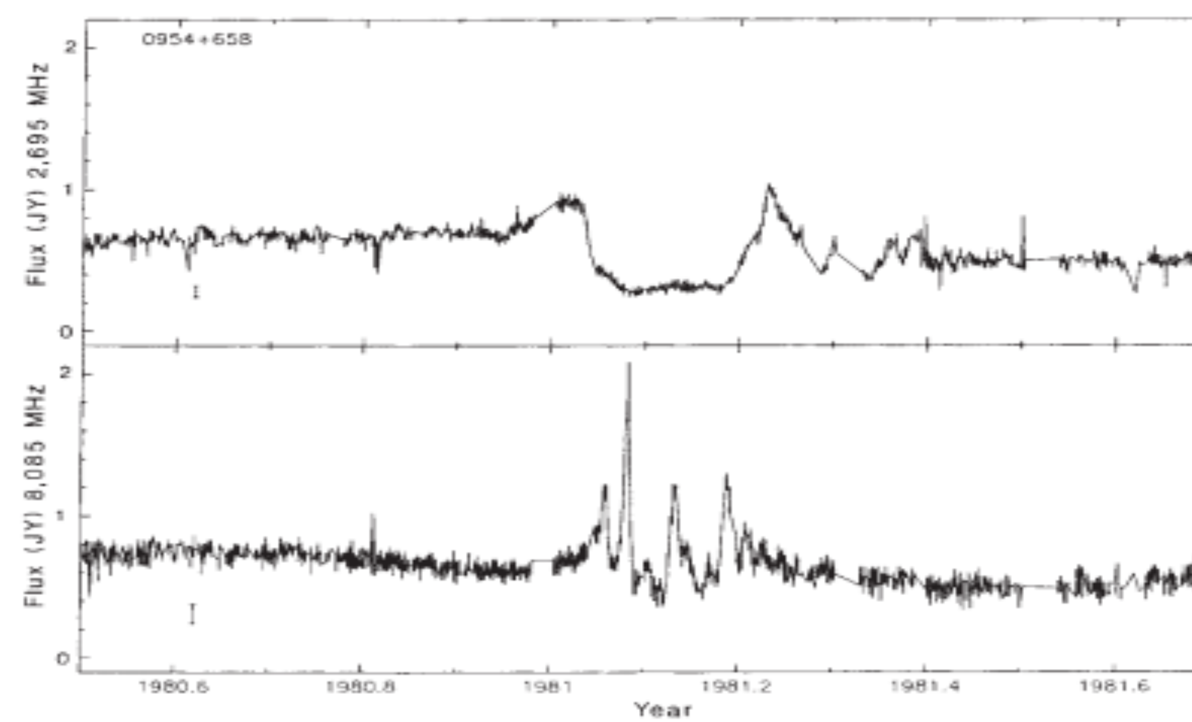
Size ~1AU

Clegg+98

Plasma lenses do different things to different colours

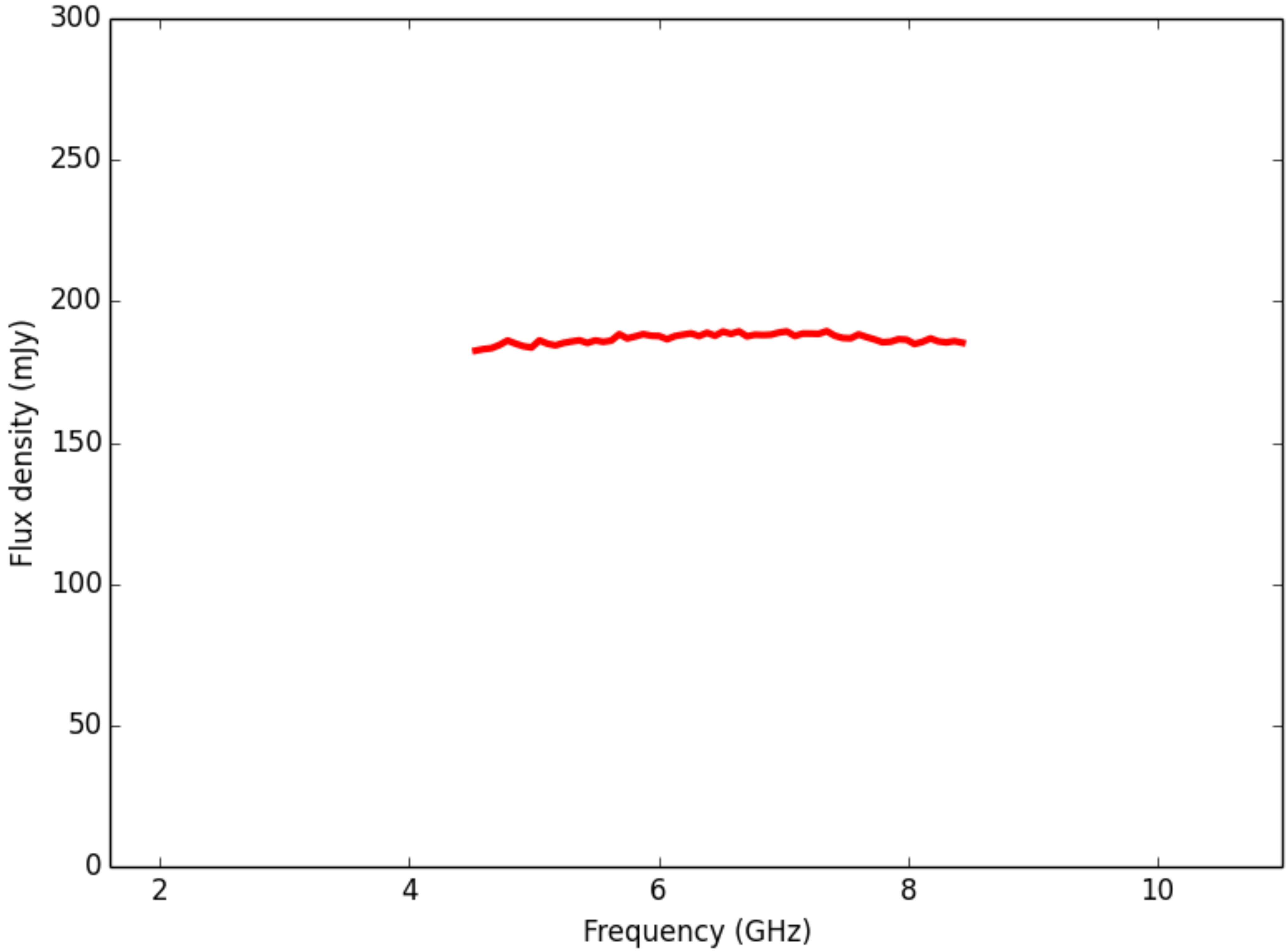
The ATESE Survey

- Cold plasma refractive index $\propto \lambda^2$
- Spectrum of an ESE in-progress should be highly structured
- Select 1200 AGN from AT20G
- Get 4-8 GHz spectra ~monthly
- Look for things with crazy spectra



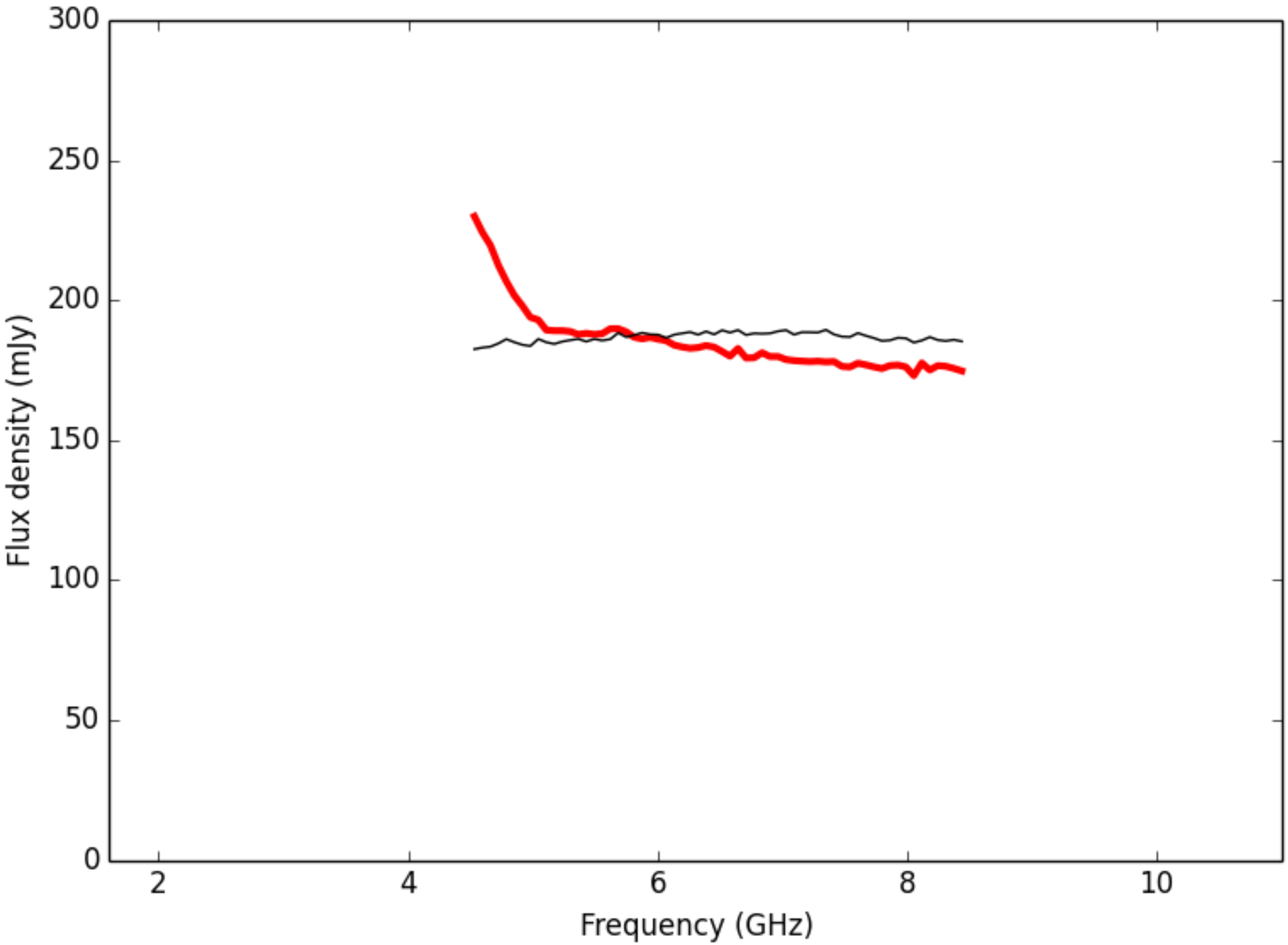
Keith Bannister

PKS 1939-315



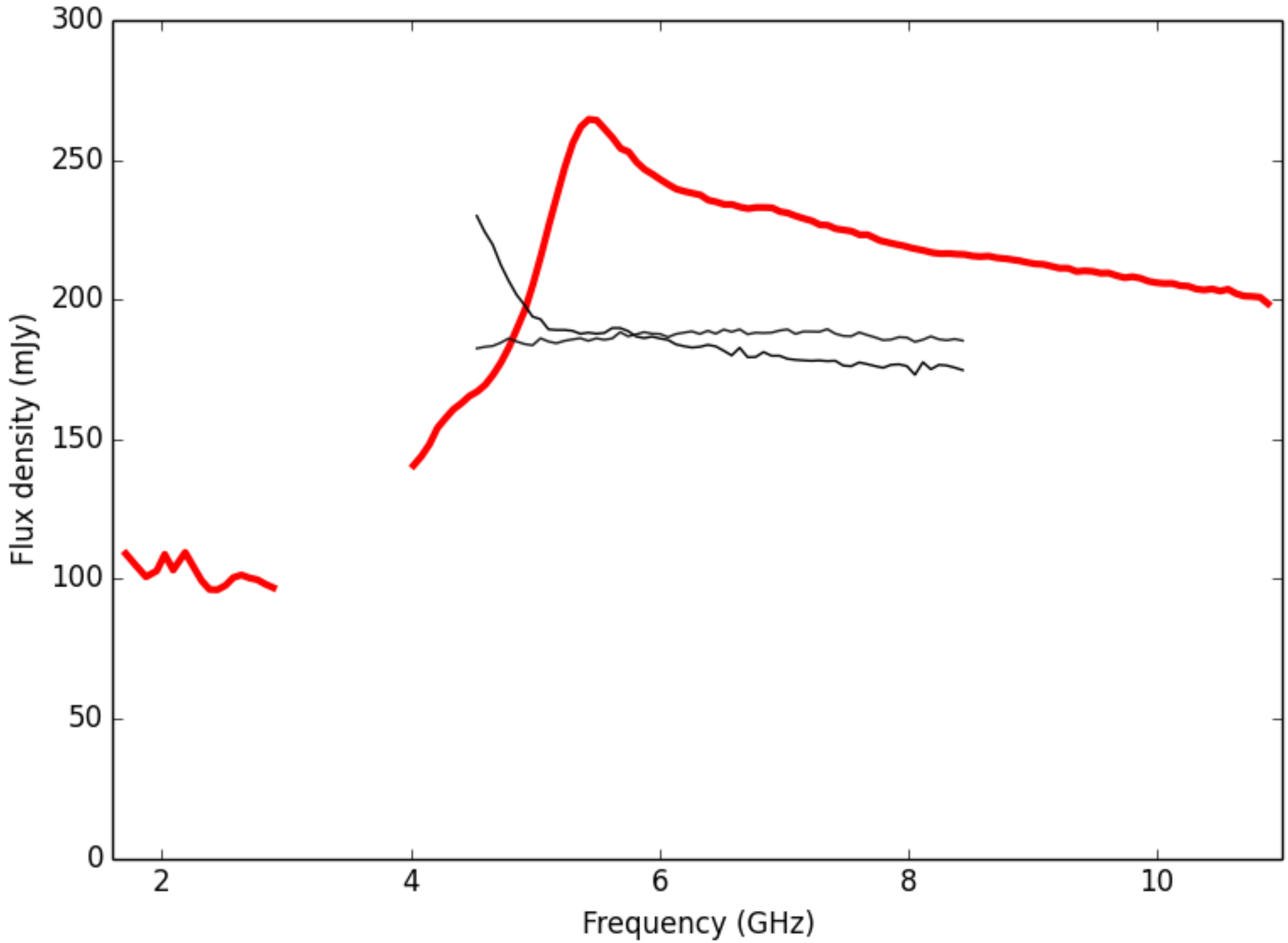
Keith Bannister

PKS 1939-315



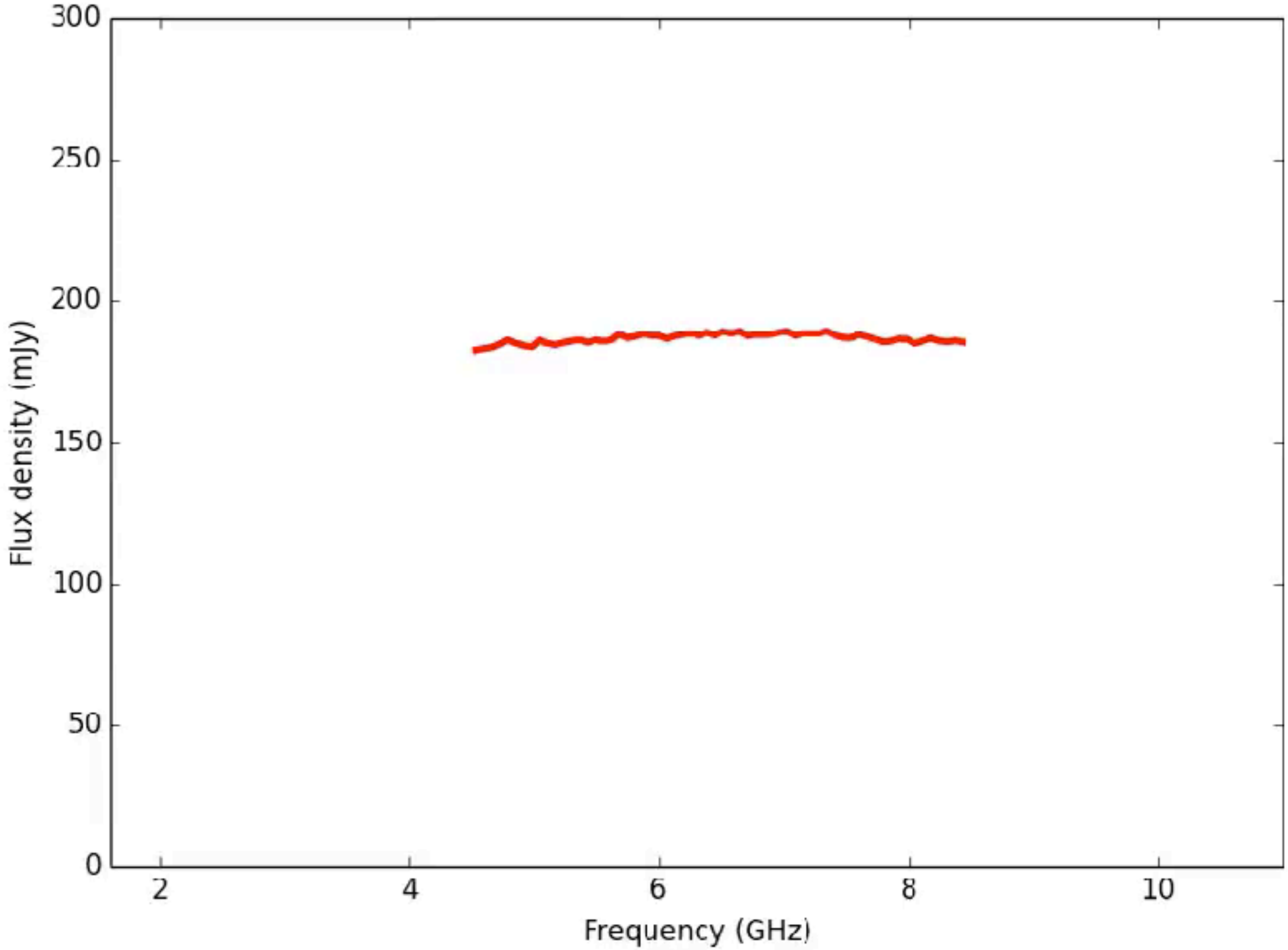
Keith Bannister

PKS 1939-315



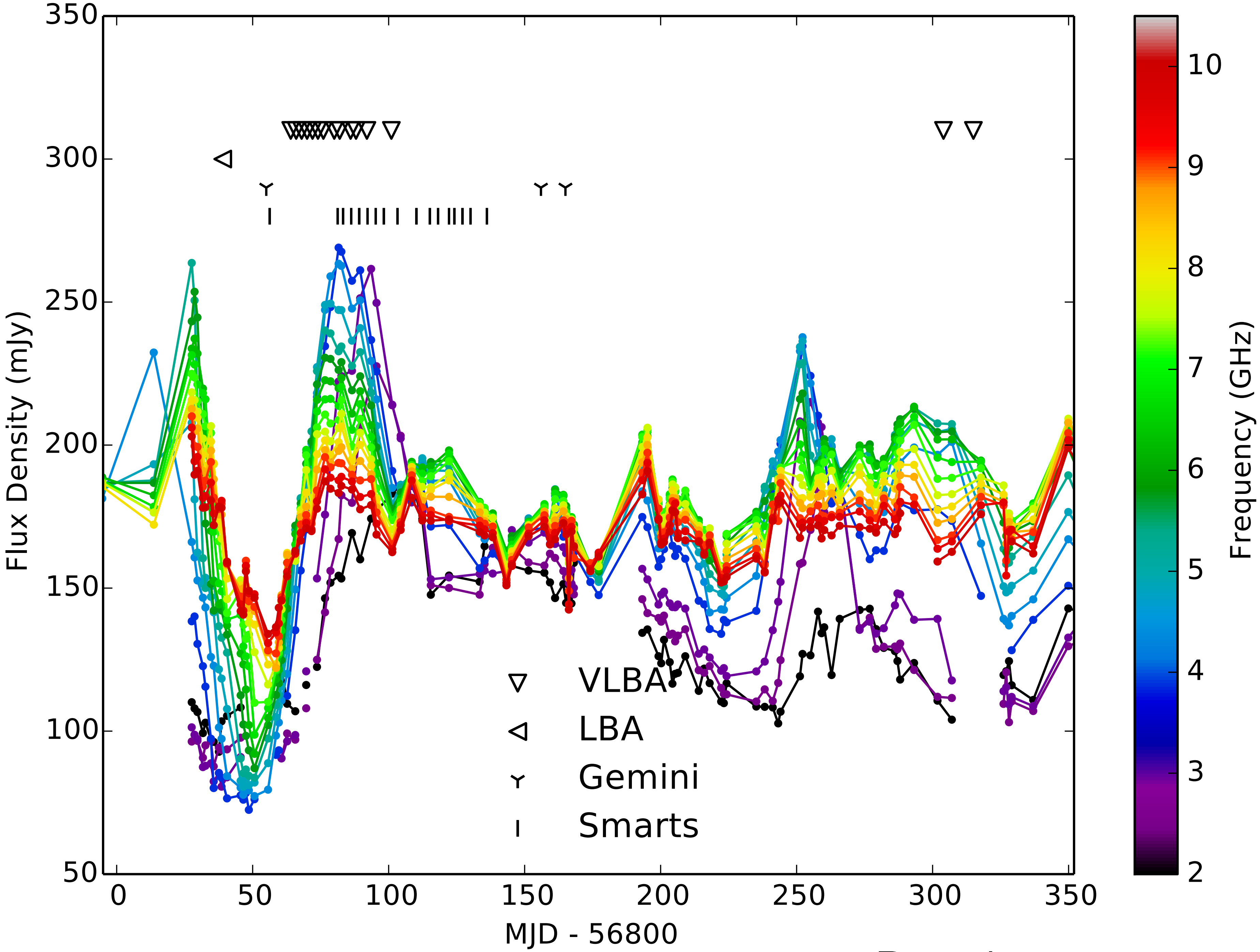
Keith Bannister

PKS 1939-315



Keith Bannister

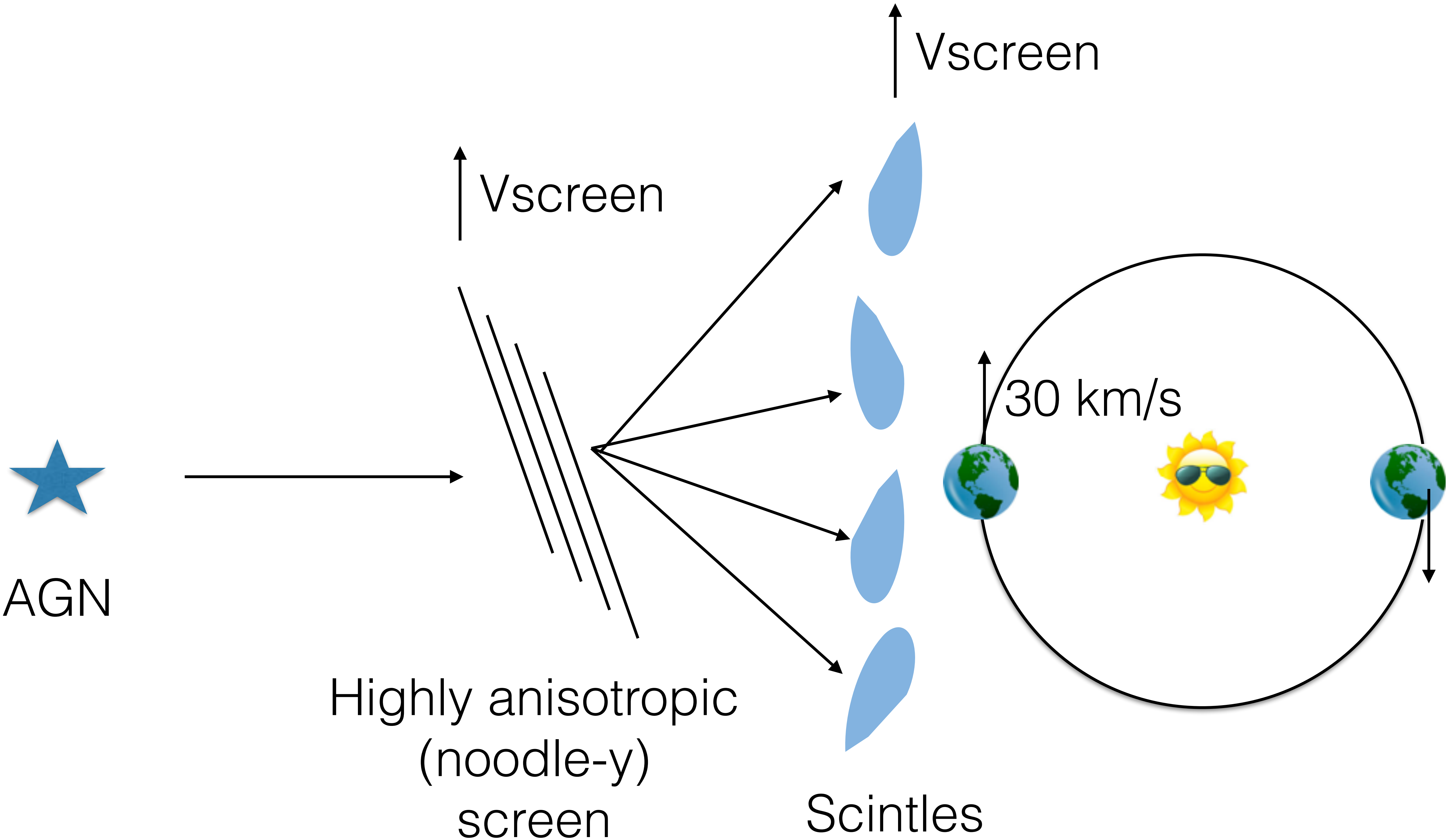
PKS 1939-315



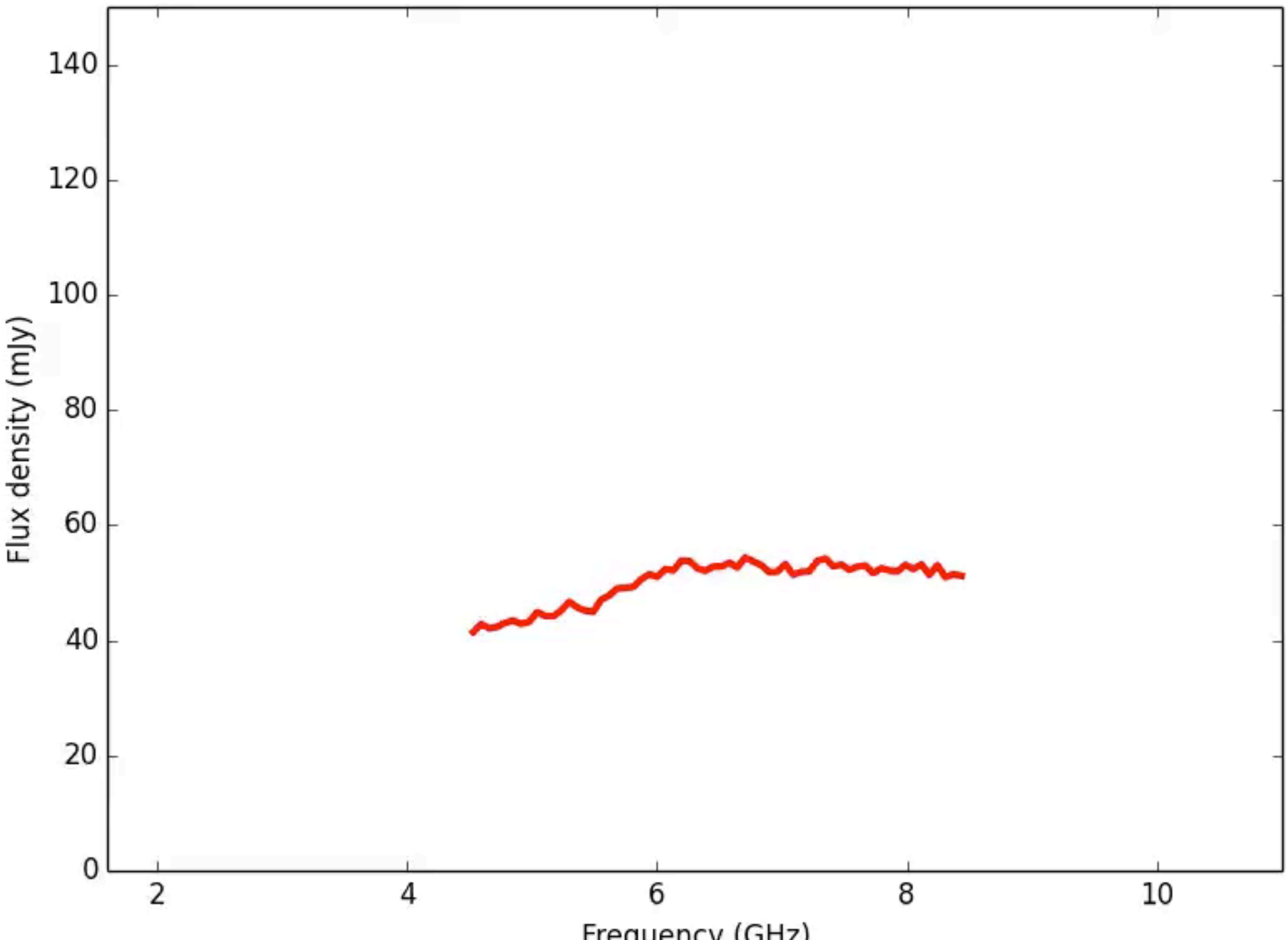
Bannister+ 16

Keith Bannister

Intraday Variability

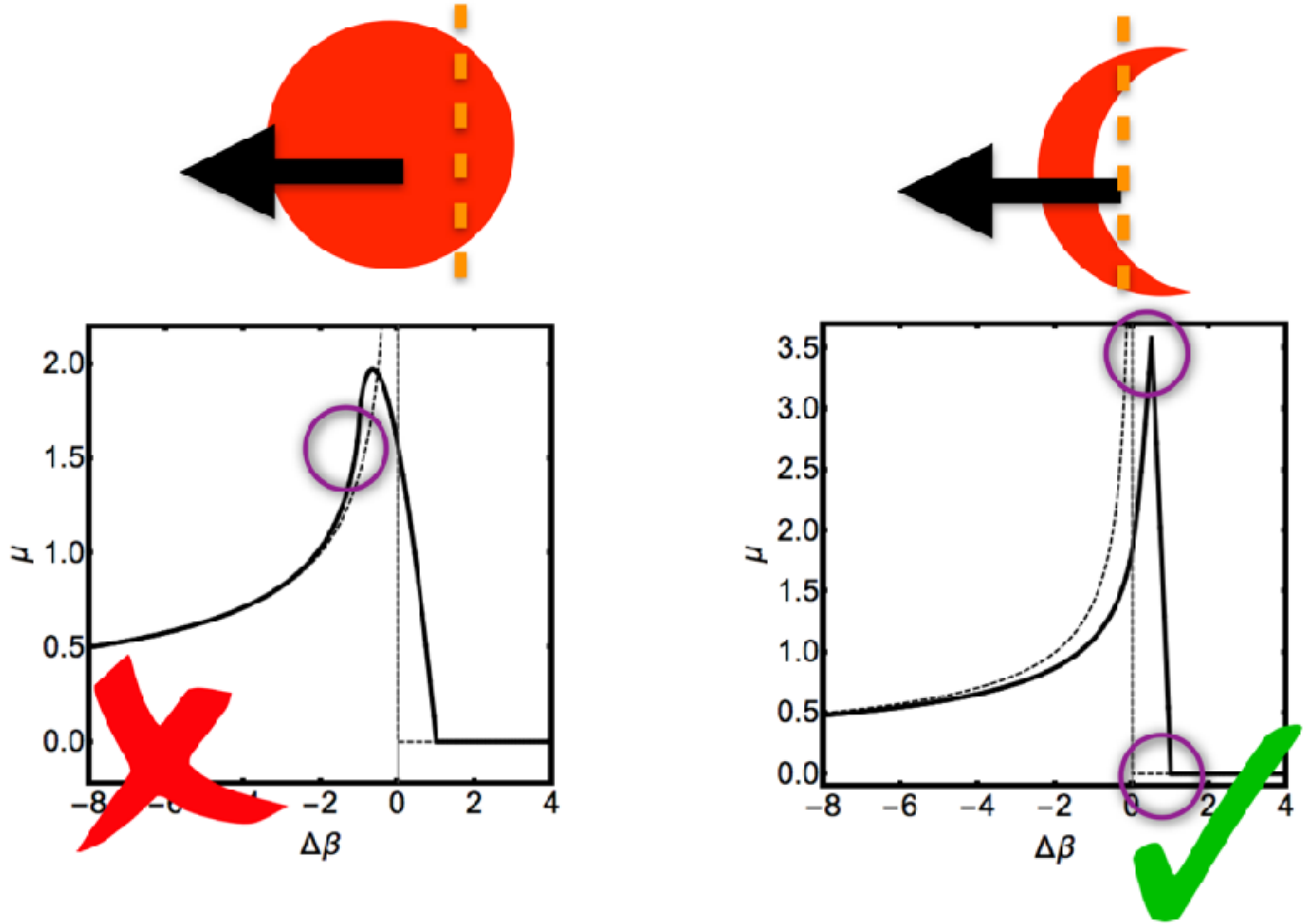


Intraday Variable



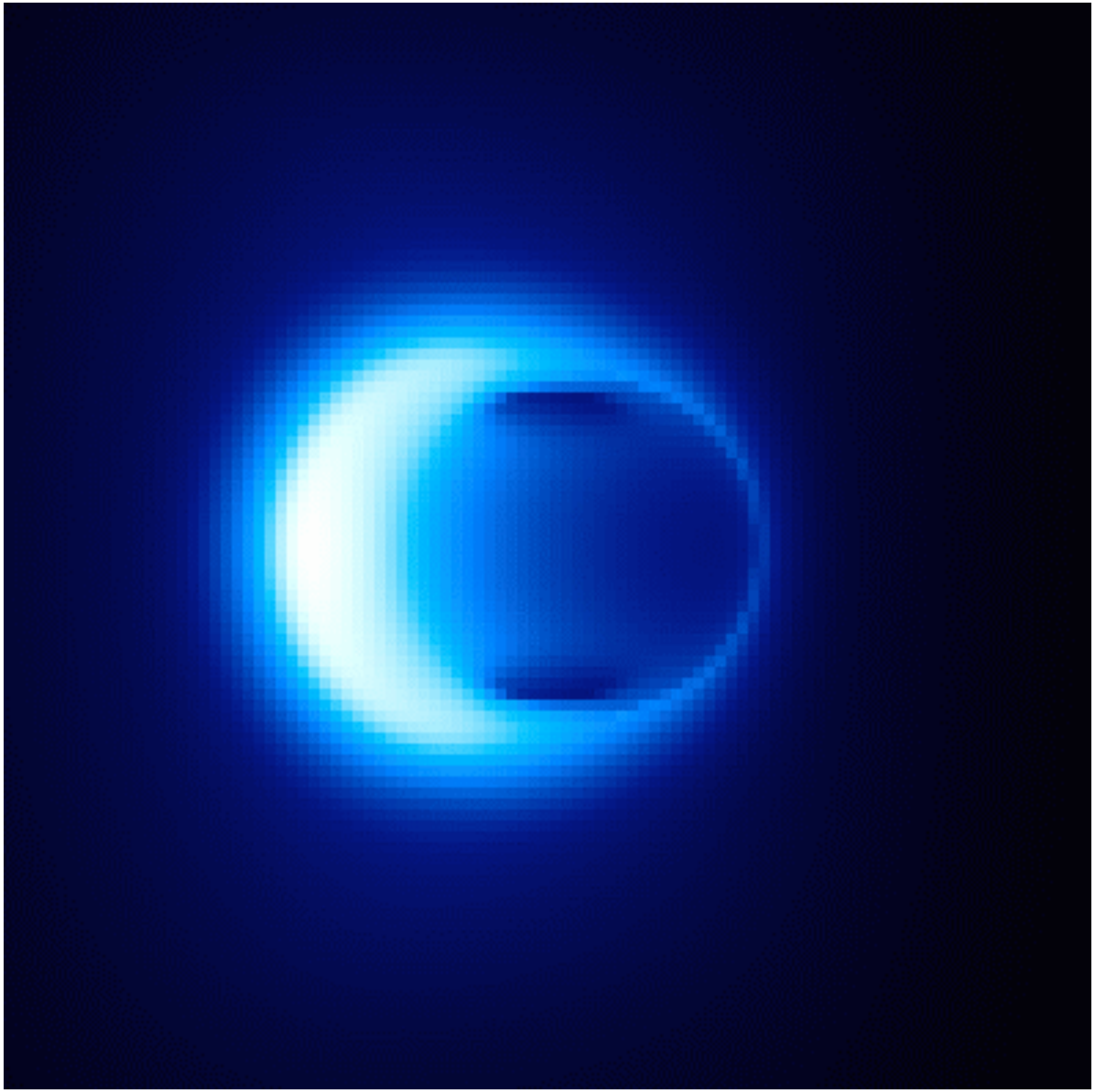
Bannister

Emission region is croissant-shaped

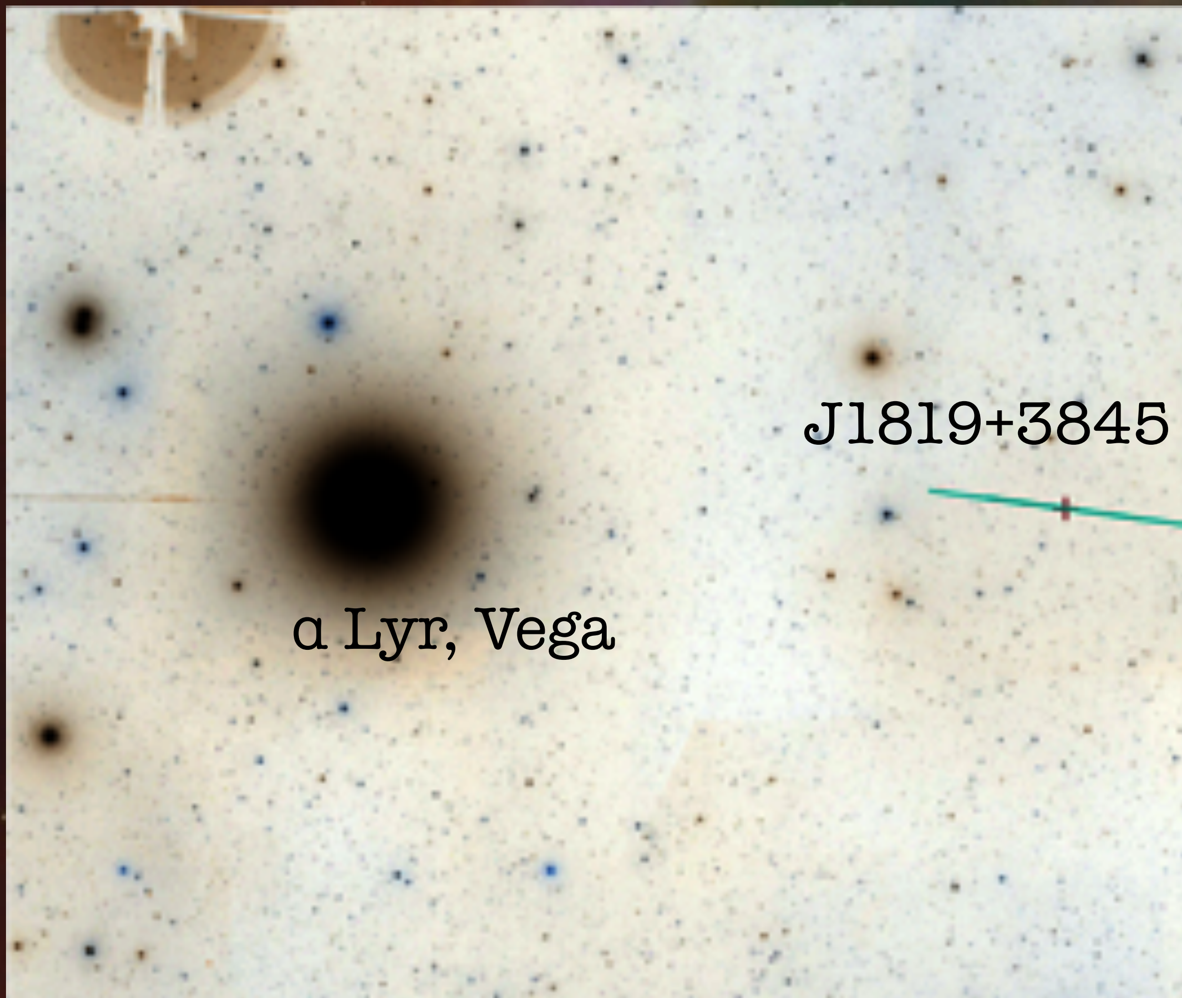


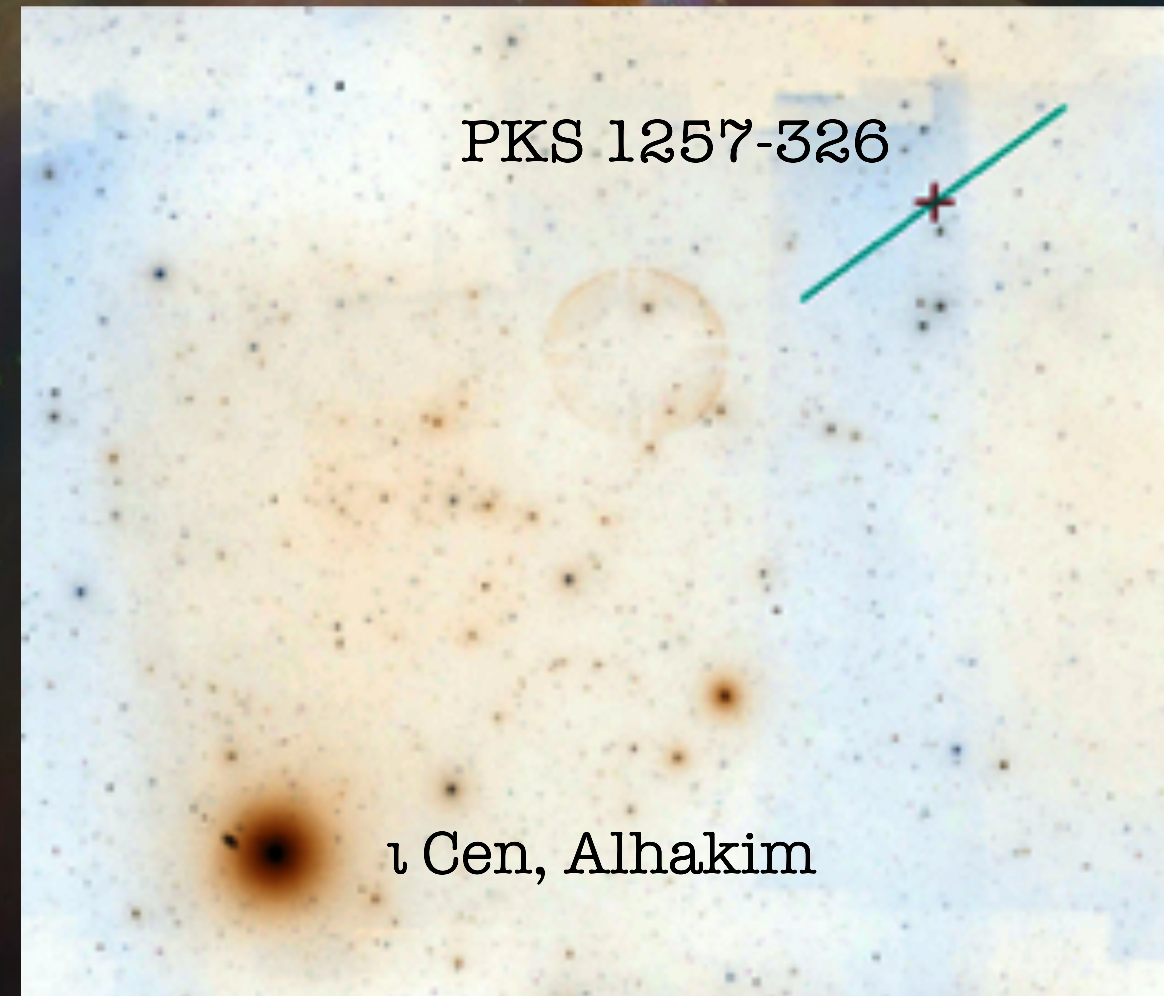
Tuntsov et al. 2017 , *Scintillation kinks, bumps and wiggles in the radio spectrum of the quasar PMN J1106-3647,* MNRAS, 469, 5023

Black Hole event horizon?



Matches and alignments

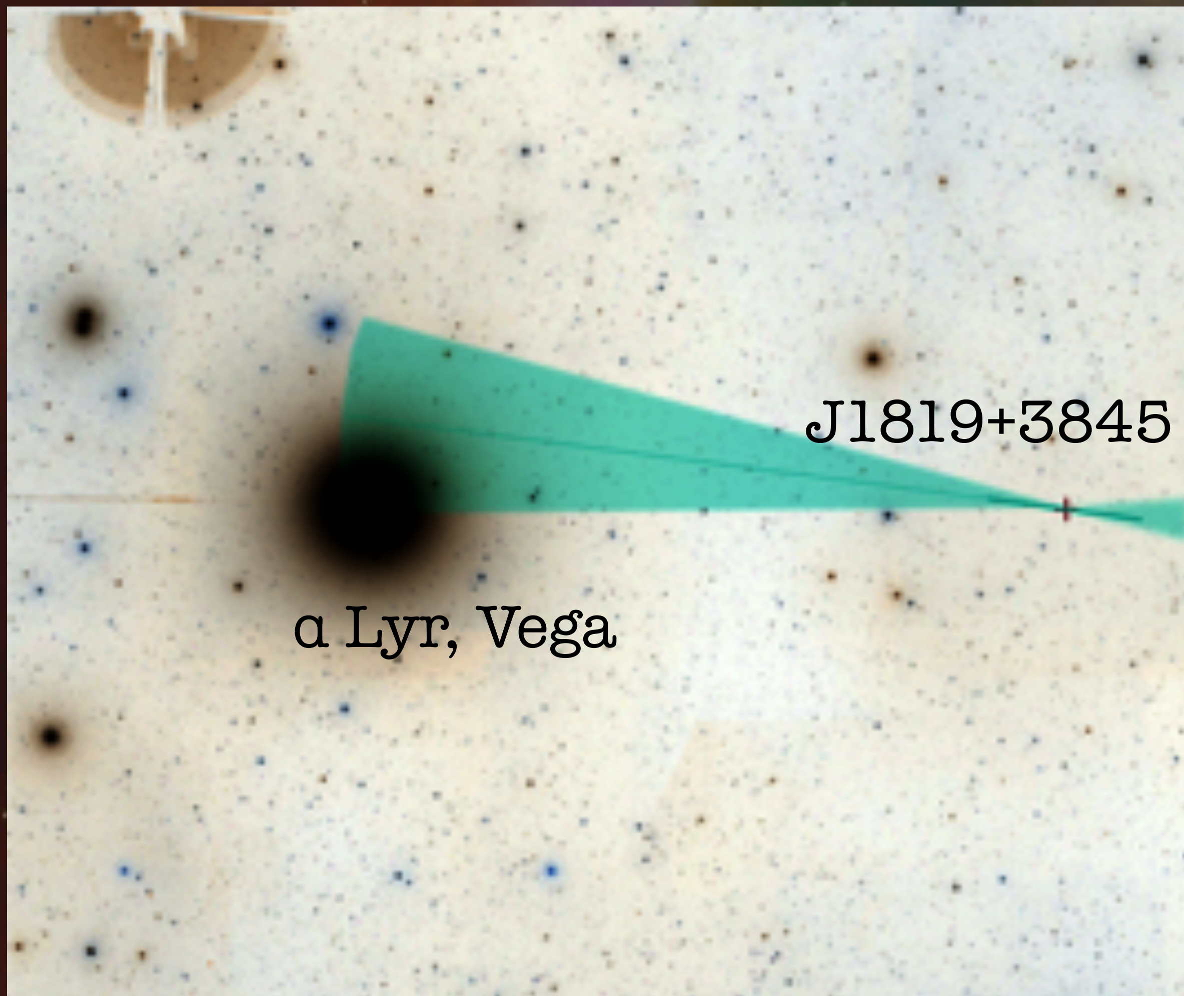


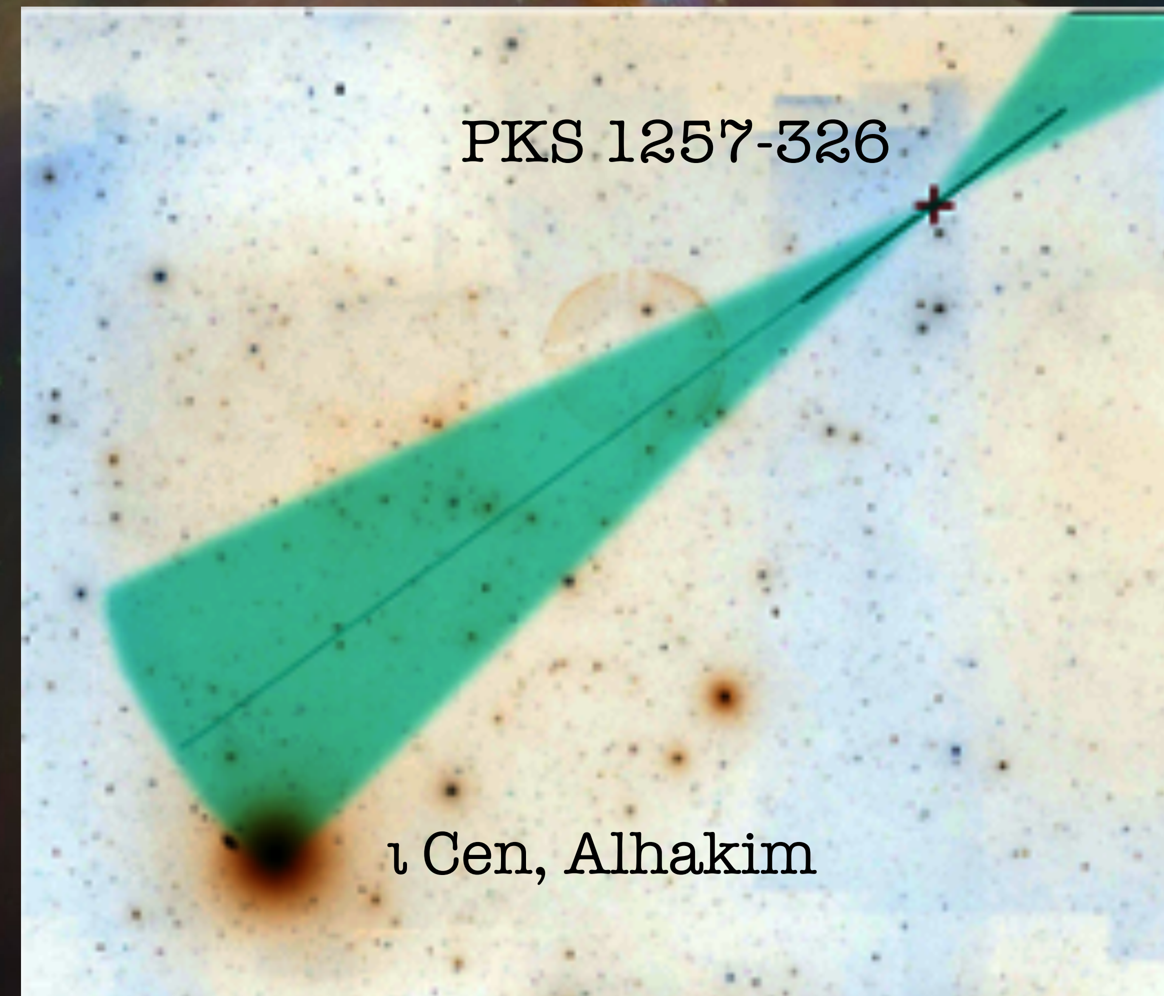


-97° vs **-92°**	Major axis direction (N→E)	127° vs **134°**
19.7 vs **10.0**	⊥ velocity, km/s	20.5 vs **22.4**
11 vs **7.7**	Screen distance, pc	14 vs **17.9**
0.46	Distance from l.o.s., pc	1.75

Walker et al. 2017

Matches and alignments





Prob. of chance coincidence	Vega (A0)	Alhakim (A2)
Position		
(along & across l.o.s. + PA)	1.0×10^{-4}	3.0×10^{-3}
⊥ Velocity	0.23	0.058
Product	2.4×10^{-5}	1.7×10^{-4}

Combined **6.8×10^{-8}**

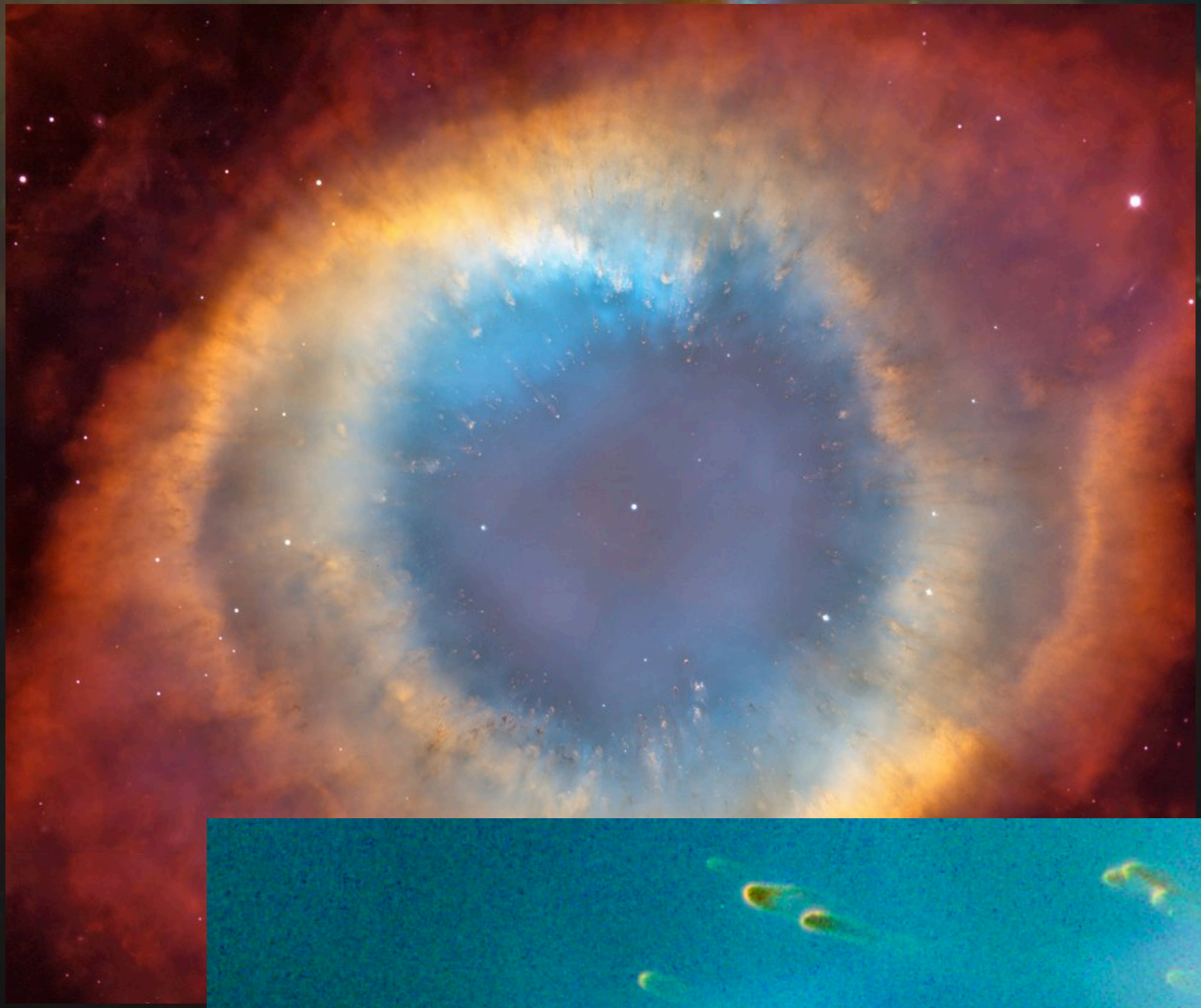
Manly Astrophysics

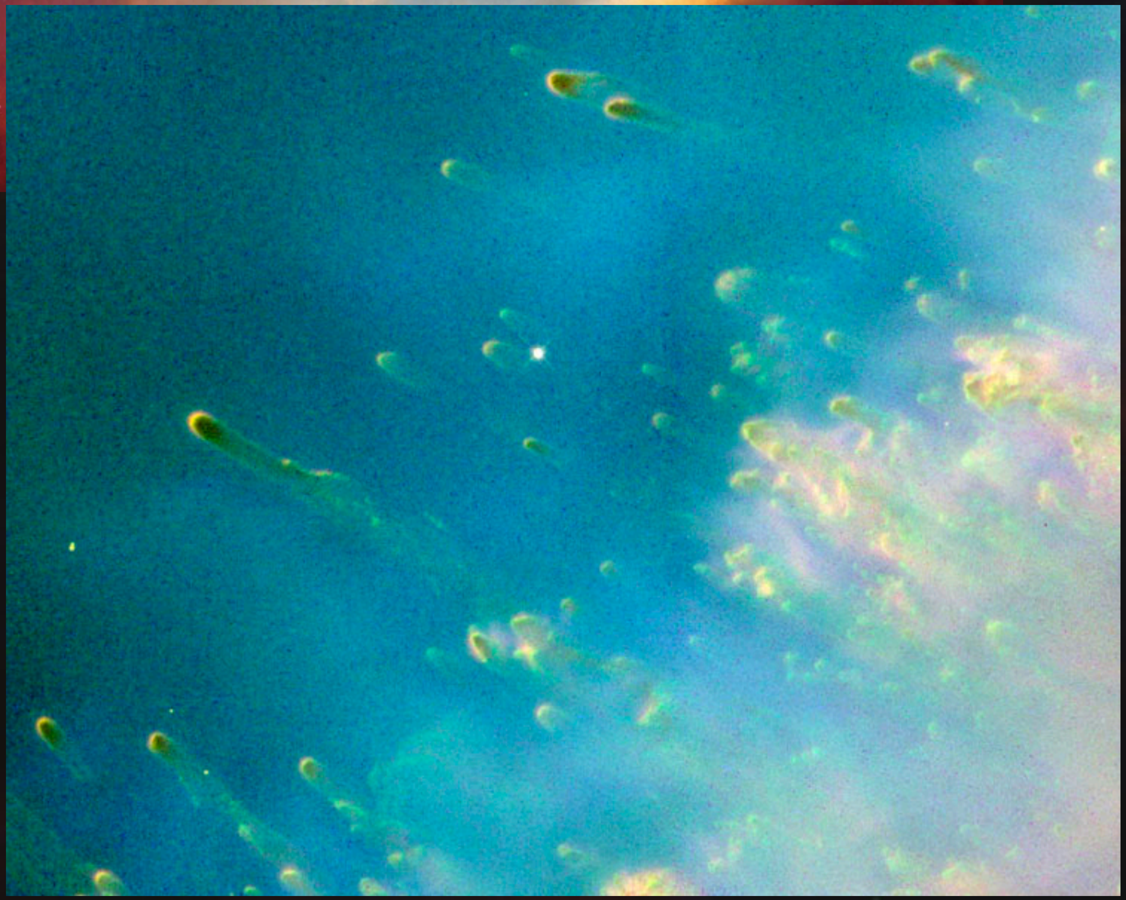
Walker et al. 2017

Cometary knots in the Helix nebula

- $\lesssim$0.4 pc from the central hot (but faint!) star
- R ~ 10^2 AU
- ~10^5 per star
- Radially elongated
- (Photo?) Ionised skins
- Dense, Molecular bulk
- Earth-mass ~$10^{-5} M_\odot$
- Assumed to form at late evolutionary stages

(Meixner et al. 2005)





Summary

- It's an exciting time in radio transients (and variables)
- Know your telescope and your data
- Follow crazy ideas
- Work with wacky people - it's fun!
- The most useful equation in radio astronomy is $$\theta = \frac{\lambda}{D}$$