Kinematics of Giant Pulses

Scintillation resolves emission regions, suggesting highly relativistic motion

$\Gamma \sim 10^4$, $\sim R_{LC}$ on sky, $\sim \Gamma R_{LC}$ radially

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Robert Main, Rebecca Lin, Akanksha Bij
(and the scintillometry group, in particular
Dongzi Li, Hsiu-Hsien Lin, Nikhil Mahajan)

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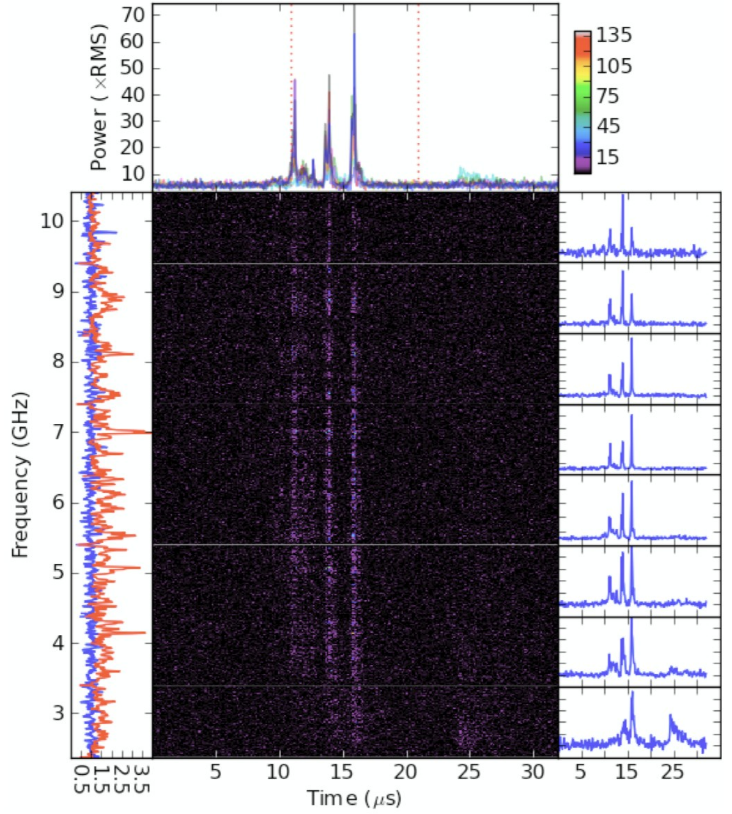
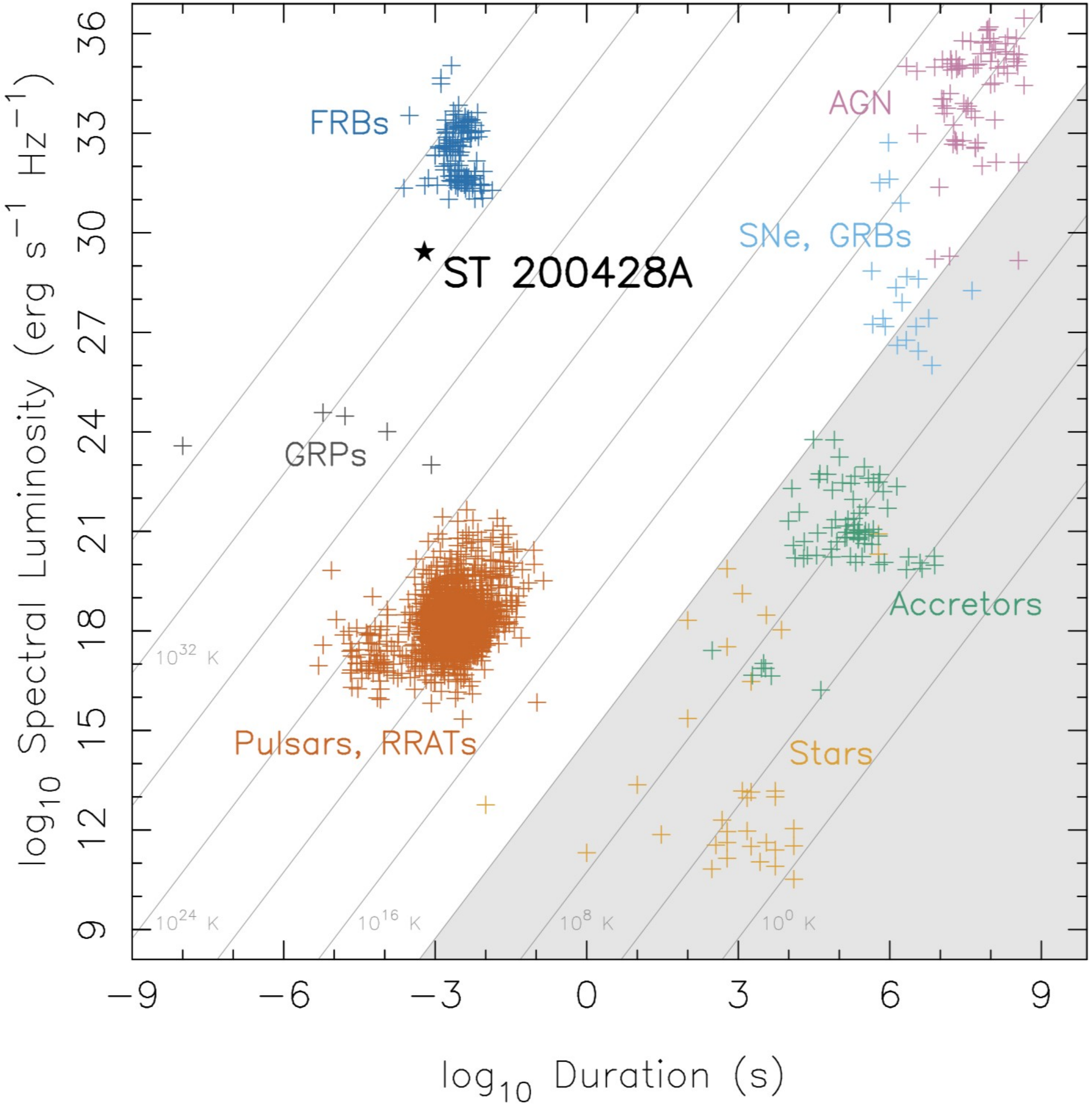
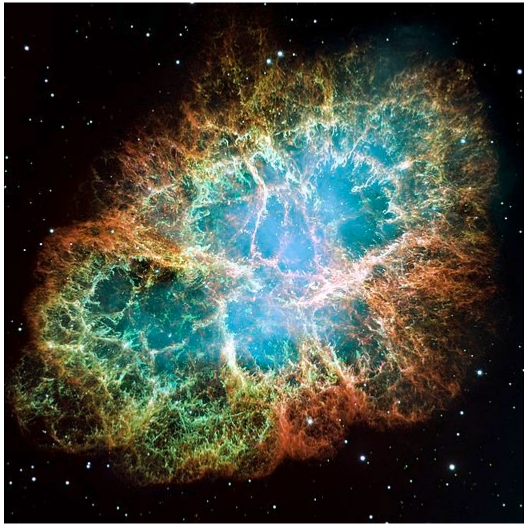
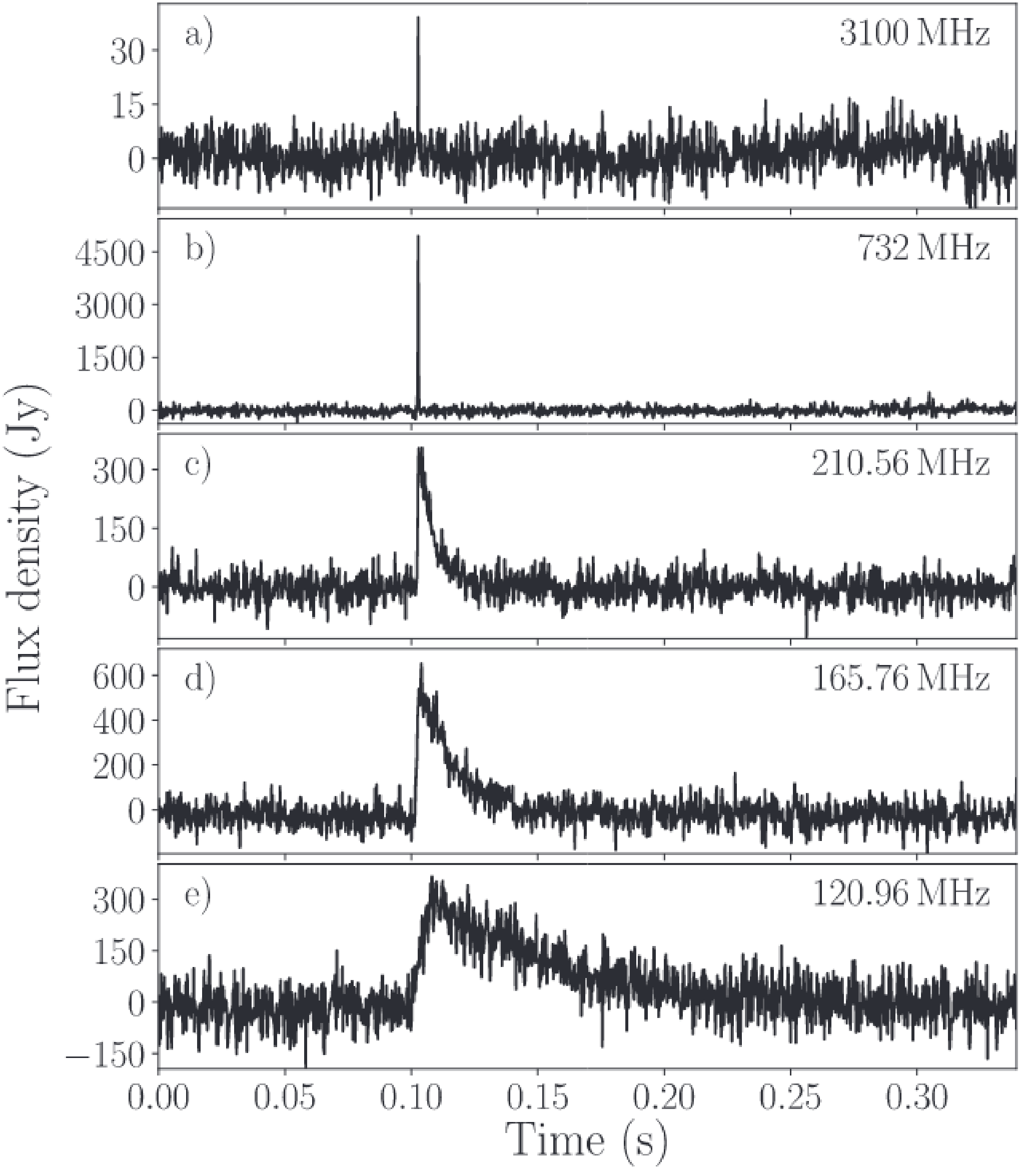




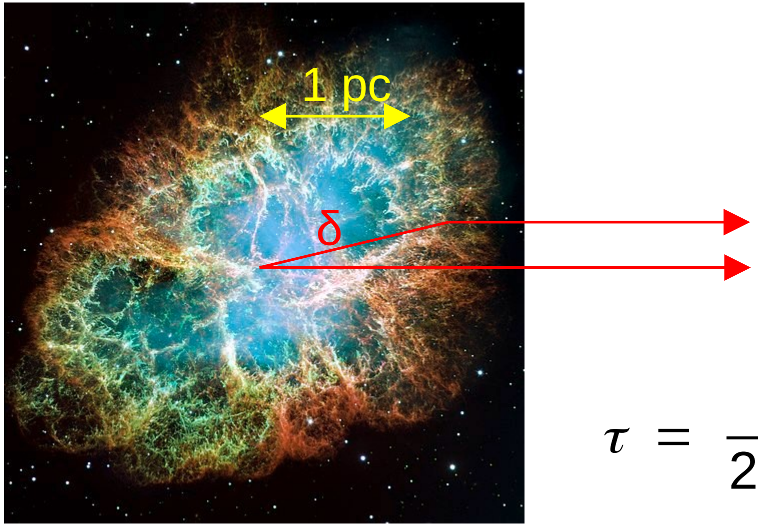
Bochenek et al., 2020, Nature 587, 59

- ~μs duration, composed of nanoshots
- Brightness temperatures up to 10^{41} K (Eilek & Hankins, 2016, J.Plasma Ph. 82).

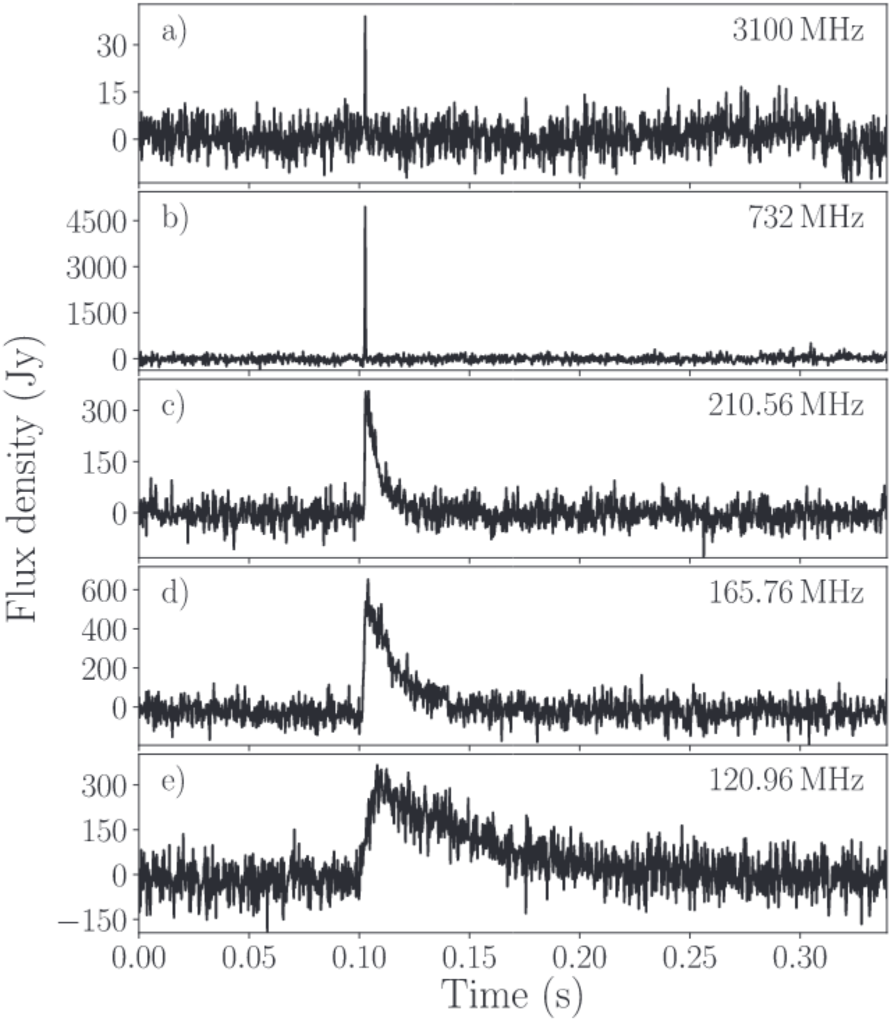




Meyers et al., 2017, ApJ 851:20



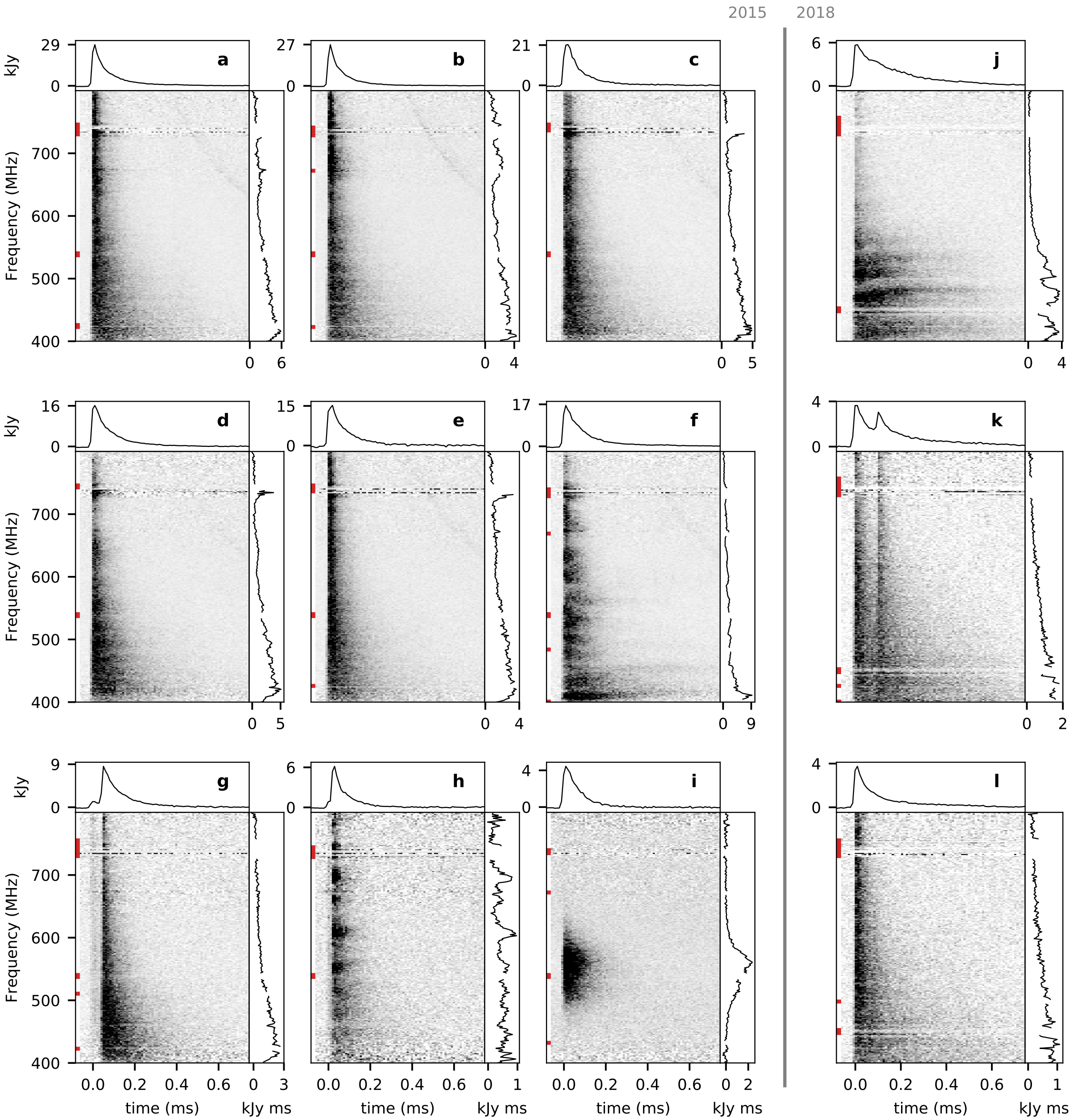
$$\tau = \frac{\delta^2}{2cd} \propto \lambda^4$$



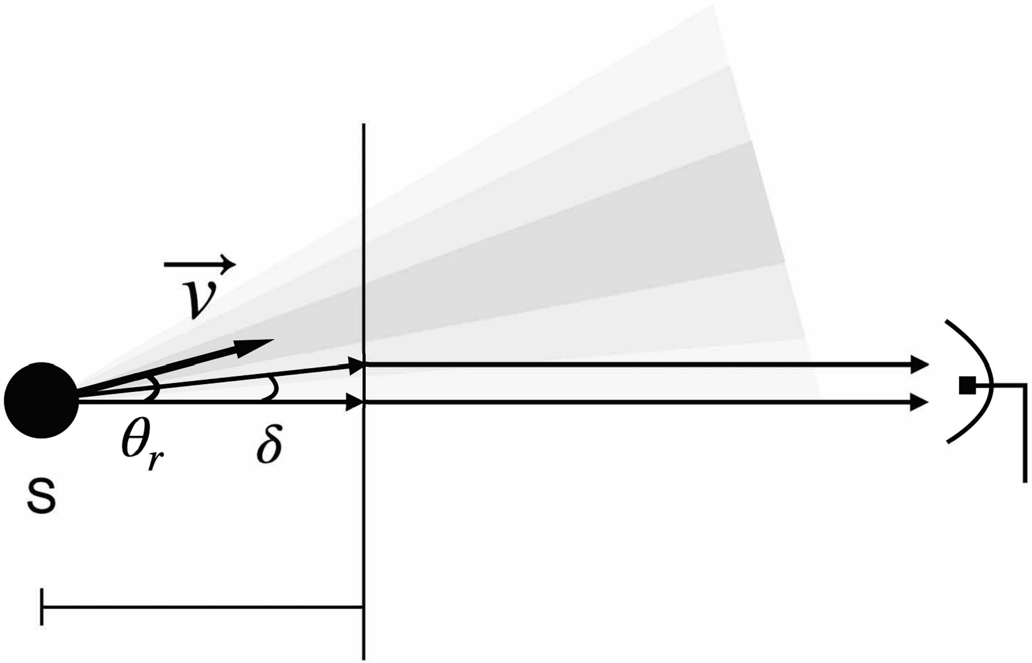
Meyers et al., 2017, ApJ 851:20

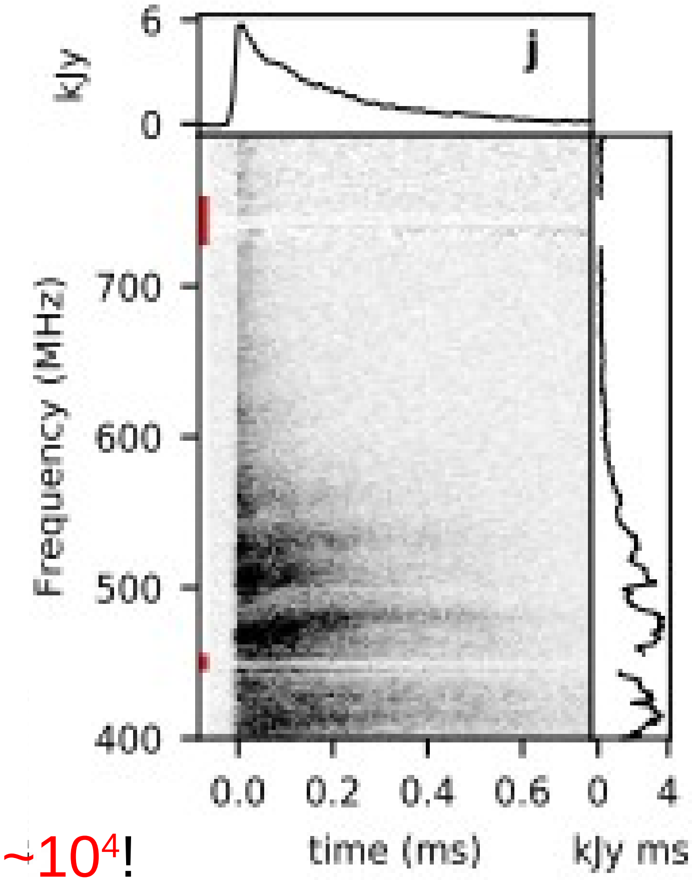
Giant pulses from ARO

- CHIME band: see scattering tails (longer in 2018).
- Some have bands: represents interference between nanoshots.
- Some *drift!* How can this happen given that viewing angle only changes by ~0.6”?



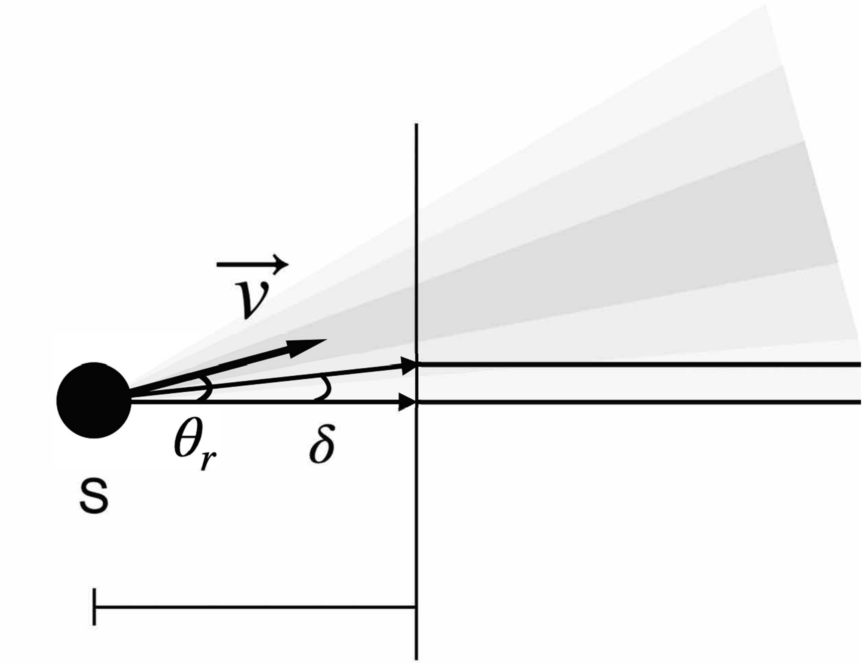
Bij et al., 2021, ApJ 920:38

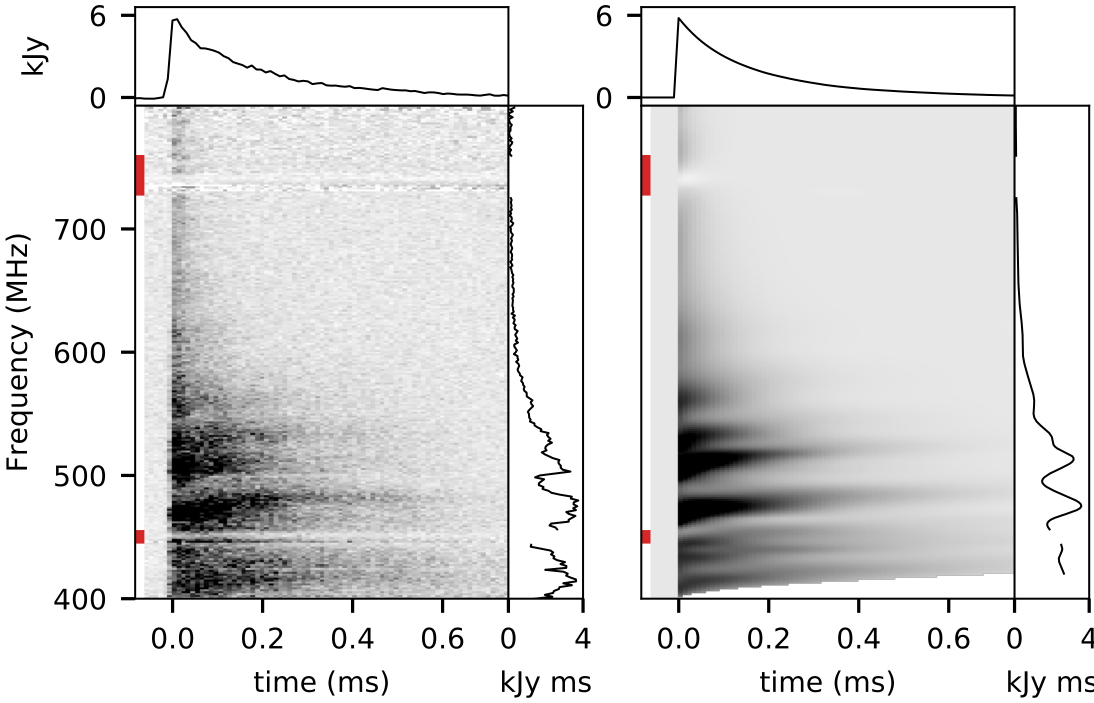




Bij et al., 2021, ApJ 920:38

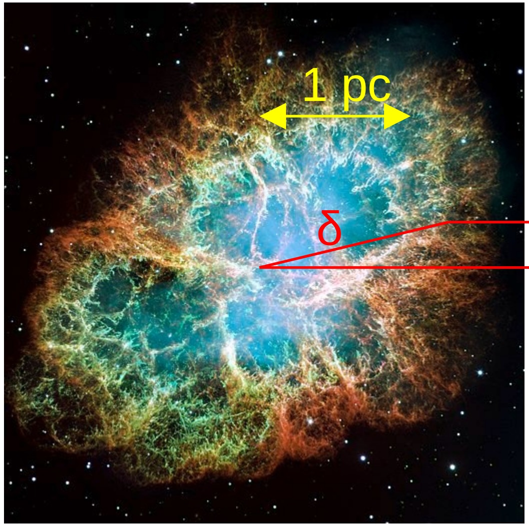
- Doppler shift? Has expected $t^{1/2}$ dependence.
- But to get ~5% shift with $\theta_r \sim \delta \sim 0.6''$, need $\Gamma \sim 10^4$!





Bij et al., 2021, ApJ 920:38

- Doppler shift? Has expected $t^{1/2}$ dependence.
- But to get ~5% shift with $\theta_r \sim \delta \sim 0.6''$, need $\Gamma \sim 10^4$!
- Will lead to apparent superluminal motion on sky.

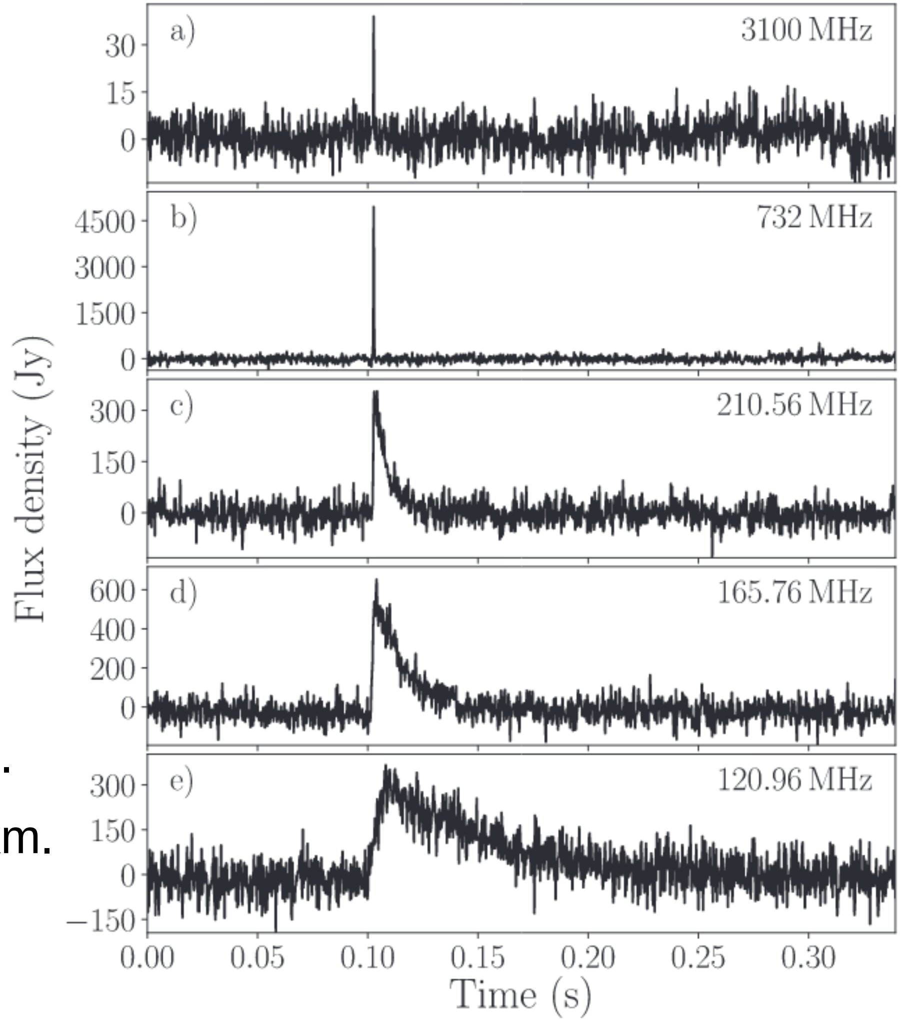


$$\tau = \frac{\delta^2}{2cd} \propto \lambda^4$$

$$\Delta x \simeq d\frac{\lambda}{D} = \lambda\sqrt{\frac{d}{8c\tau}}$$

At 1.5 GHz, τ ~ μs,
hence ~500 km resolution.

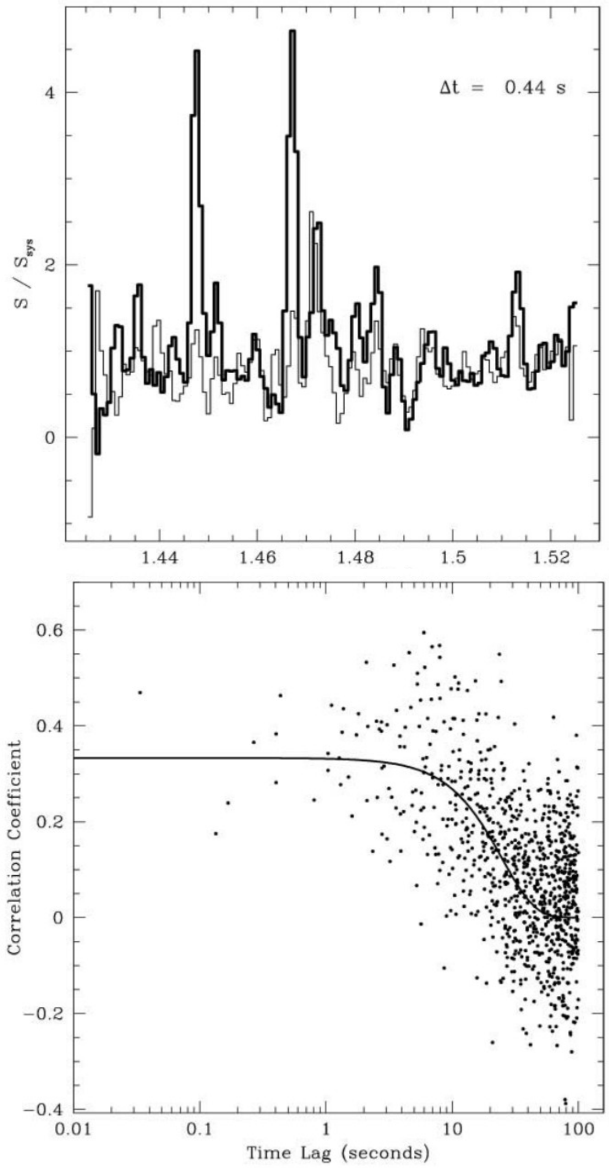
Compare with R_{LC}~1600 km.



Meyers et al., 2017, ApJ 851:20

Giant pulses from Arecibo

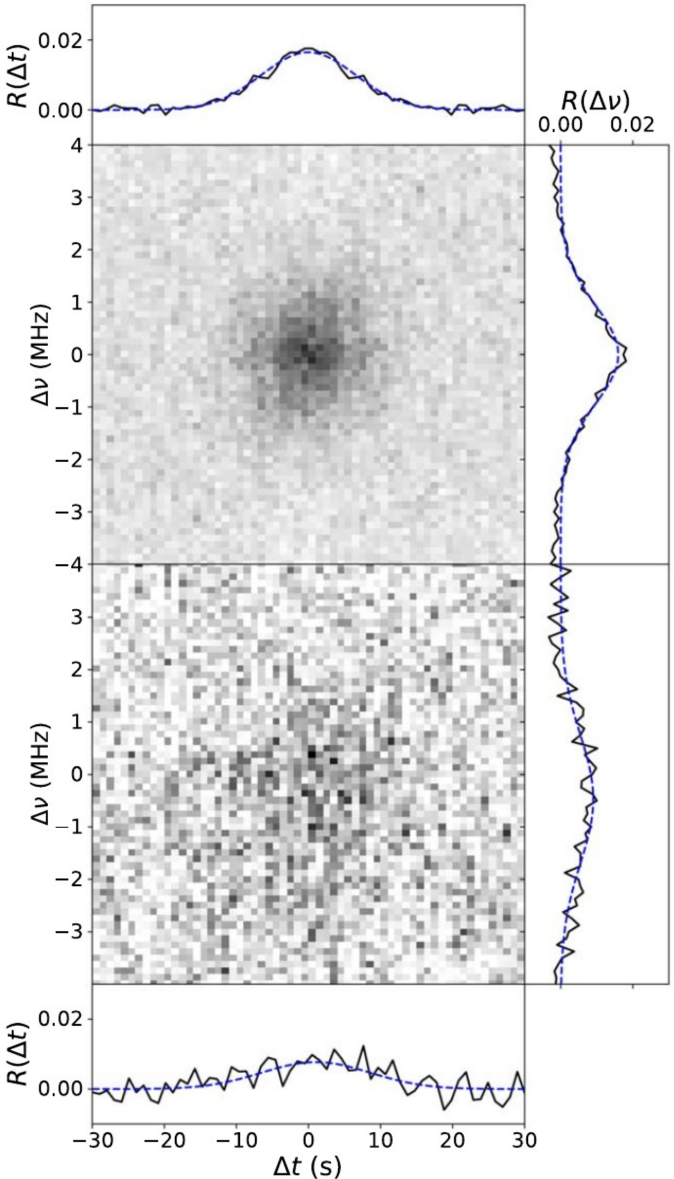
- Maximum correlation of 1/3 due to internal pulse structure.
- Timescale consistent with resolution and pulsar velocity.



Cordes et al., 2004, ApJ 612, 375

Giant pulses from Westerbork

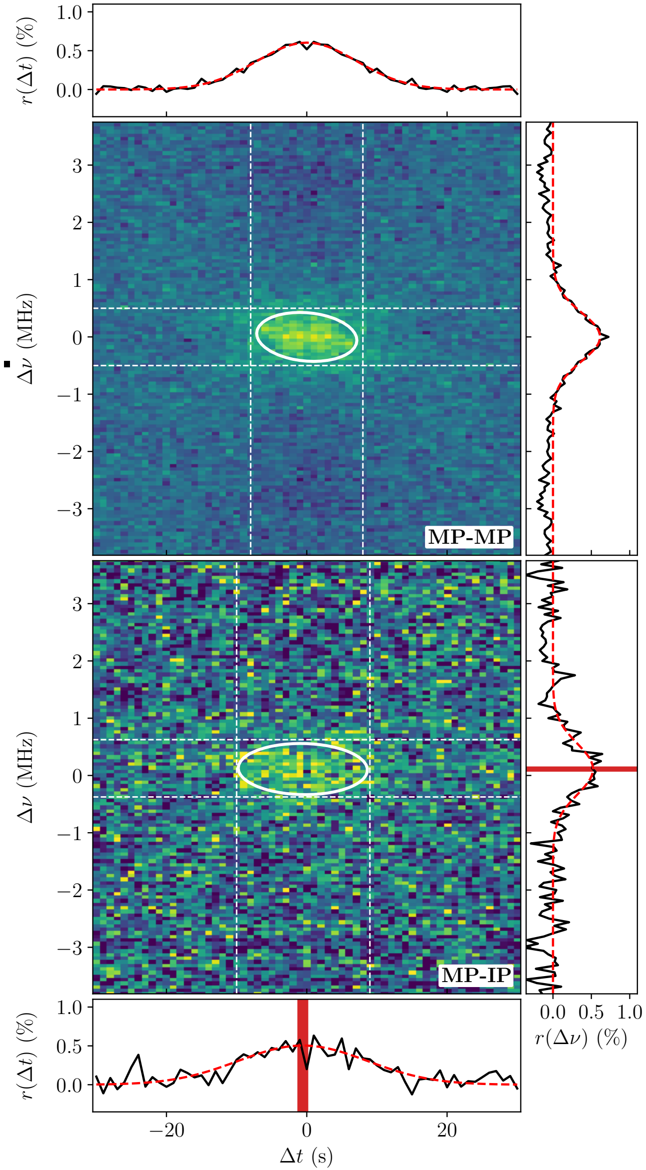
- Timescale bit shorter (resolution better).
- Interpulse region larger.
- Interpulse possibly offset on sky.
- Amplitude strangely low, ~2%
- τ~1μs, Δν~1.1MHz, hence 2πτΔν~7, not ~unity.



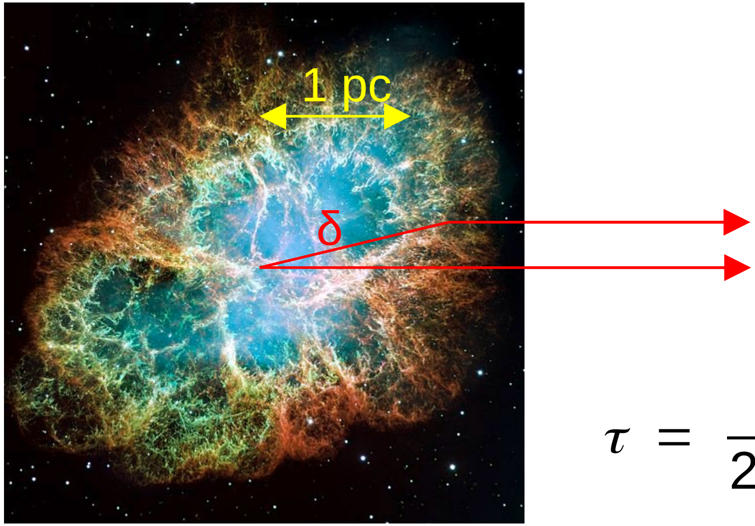
Main et al., 2021, ApJ 915:65

Giant pulses from EVN

- Stronger scattering, hence higher resolution.
- Timescale similar: dominated by size of emission region, ~850 km.
- Interpulse clearly larger, ~1050 km.
- Amplitude now *very* low, ~0.8%, hence pulse pairs mostly *resolved*.
- τ~5μs, Δν~0.46MHz, hence 2πτΔν~14, not ~unity.



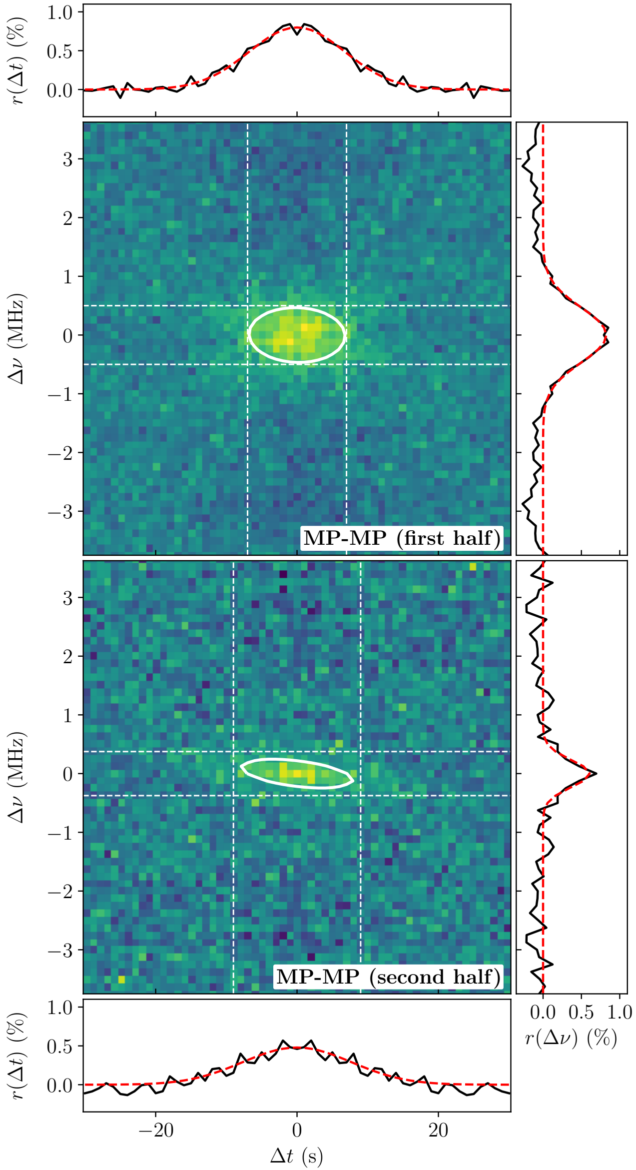
Lin et al., 2022, in preparation



$$\tau \;=\; \frac{\delta^2}{2\,c\,d} \;\propto\; \lambda^4$$

$$\Delta x \;\simeq\; d\,\frac{\lambda}{D} \;=\; \lambda\sqrt{\frac{d}{8\,c\,\tau}}$$

- First half lower resolution, hence broader.
- Timescale similar: really dominated by size of emission region.

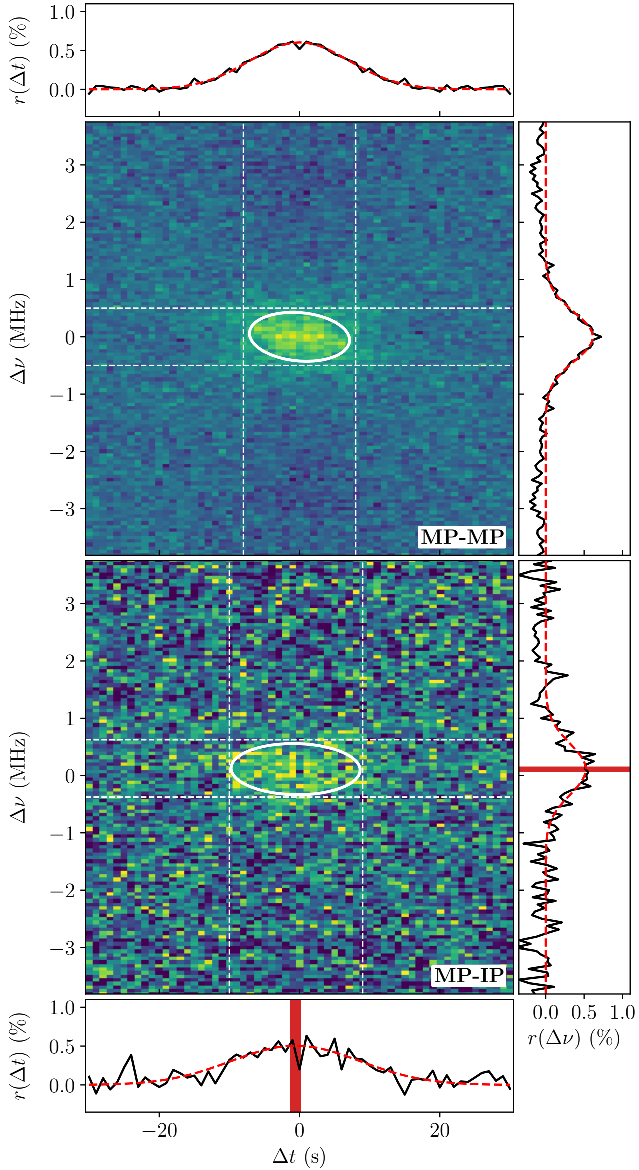


Lin et al., 2022, in preparation

Giant pulses from EVN

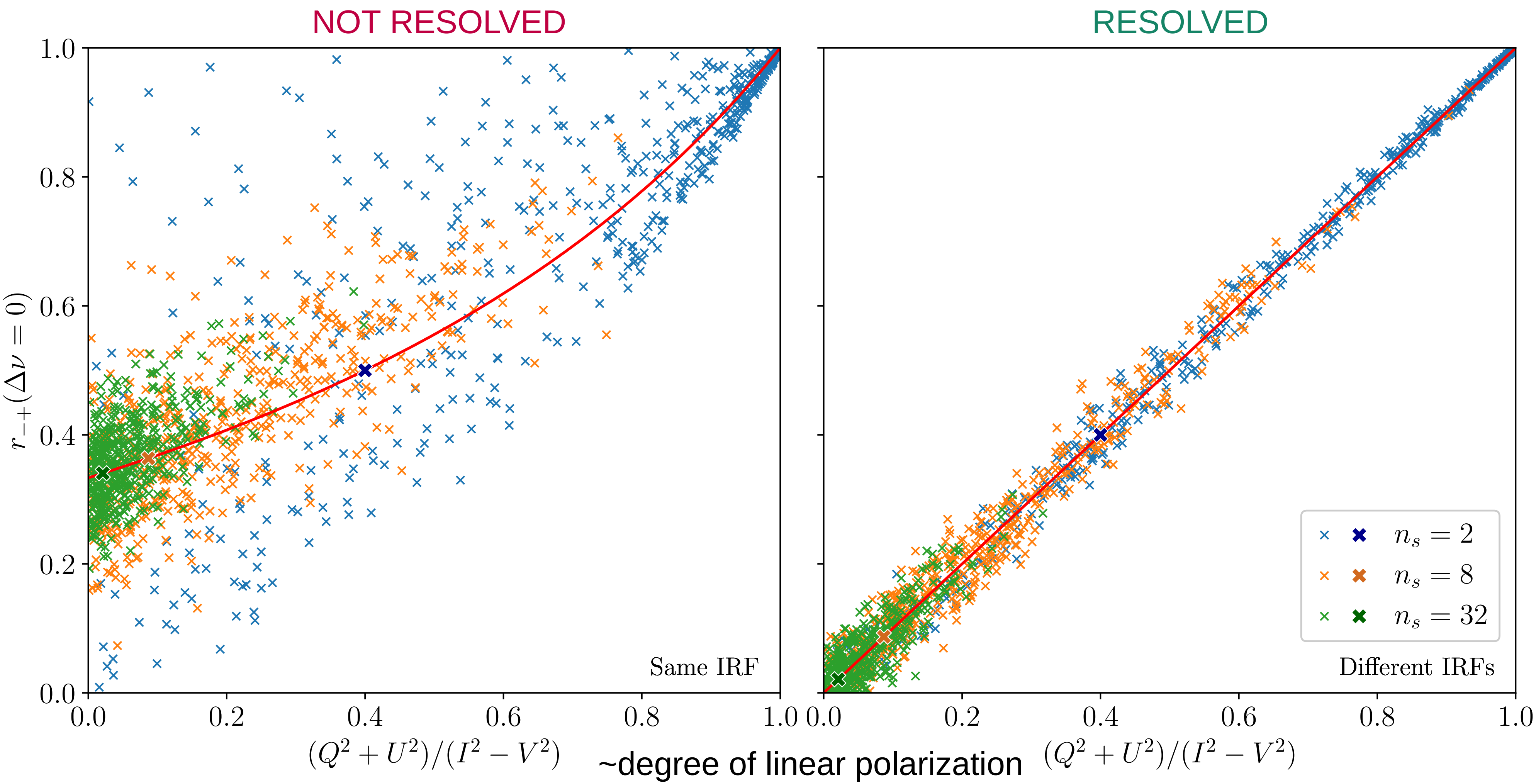
- Stronger scattering, hence higher resolution
- Timescale similar: dominated by size of emission region, ~850 km.
- Interpulse clearly larger, ~1050 km.
- Amplitude now *very* low, ~0.7%, hence pulse pairs mostly *resolved*.
- τ~5μs, Δν~0.46MHz, hence 2πτΔν~14, not ~unity. (but ~1/√A)
- Can all be understood quantitatively! (Gwinn et al. 1998, ApJ, 505, 928; Lin et al. 2022)

- But what about nanoshot constituents? Are those resolved? Test using left vs right polarization.



Lin et al., 2022, in preparation

SIMULATIONS



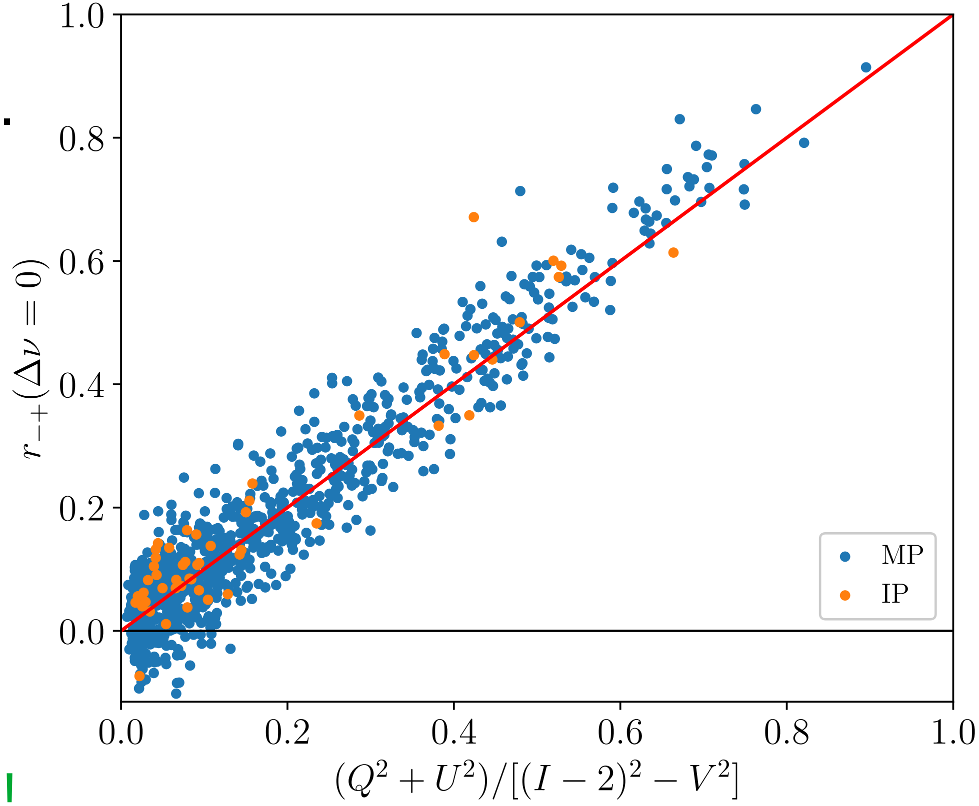
~degree of linear polarization

Lin et al., 2022, in preparation

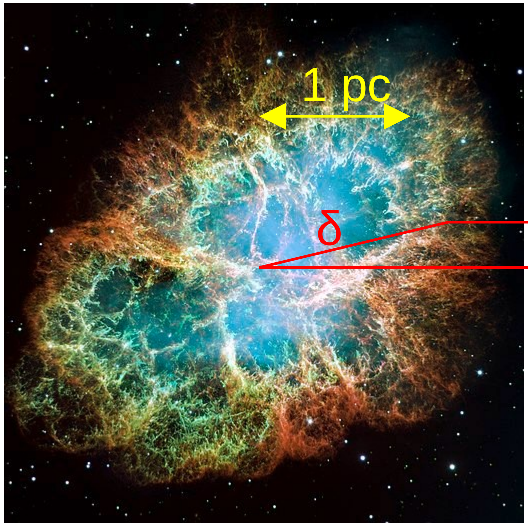
Giant pulses from EVN

- Correlation between polarizations depends on degree of polarization.
- Goes to zero: hence individual nanoshots that make up giant pulses are *resolved.* (Independently: power spectra have unity modulation)

- *WEIRD*: separated by ~μs, hence ~300 m light travel time.
  How can such small sizes be resolved?
  Superluminal motion to the rescue!



Lin et al., 2022, in preparation



Conclusions

Using the nebula as a microscope

- Resolve main and interpulse emission regions and measure velocity of emitting plasma: $\Gamma \sim 10^4$, $\sim R_{LC}$ on sky, $\sim \Gamma R_{LC}$ along line of sight
- If similar for FRBs, much reduced energy budget.
- Consistent with free electron maser picture of Lyutikov 2021, ApJ 922:166
- Or cause emission as “moving mirrors”? Yalinewich & Pen, 2022, MNRAS 515, 5682

Alternative: scattering in striped wind? (i.e., nanoshots are echos)