arXiv: 2309.07256

Refractive lensing of scintillating FRBs by sub-parsec cloudlets in the multi-phase CGM

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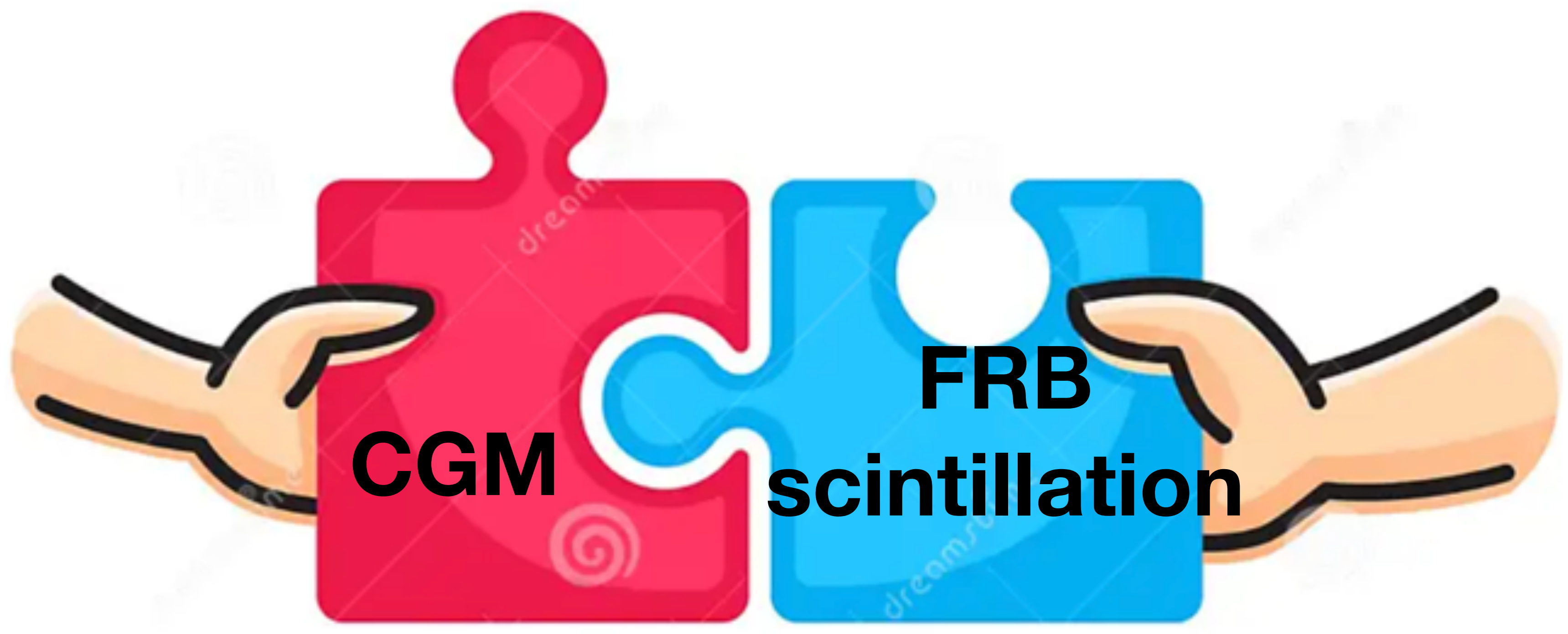
[6] *Dunlap Institute for Astronomy & Astrophysics, University of Toronto, AB 120-50 St. George Street, Toronto, ON M5S 3H4, Canada*

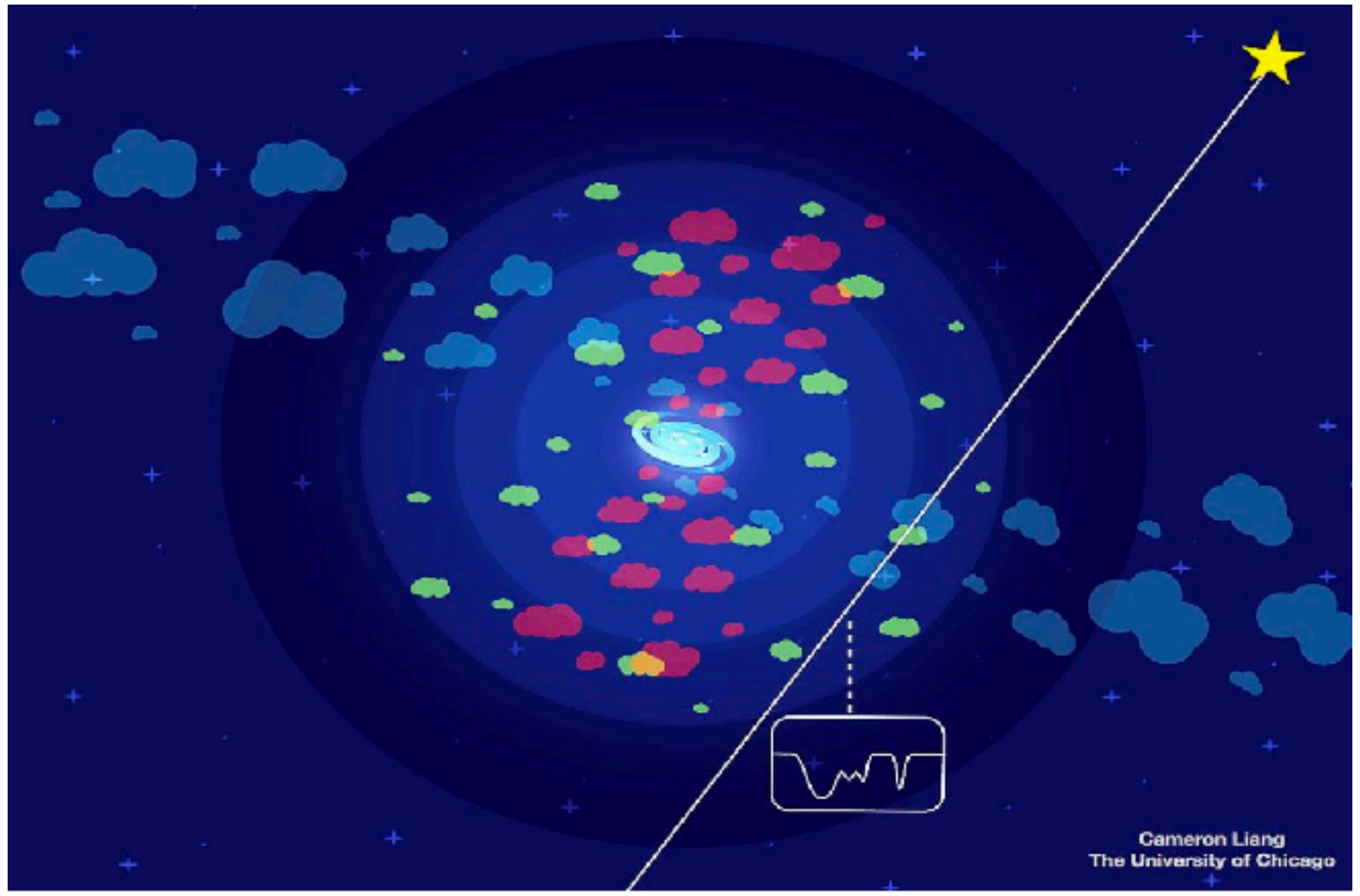


Presented by Xun Shi (SWIFAR Room 1212)
Nov 2023

Facts about **cool (~10^4K)** circumgalactic medium **(CGM)** from **quasar absorption line** observations

1. high density -> **small** volume filling fraction f_V

2. very **large** area covering fraction f_A



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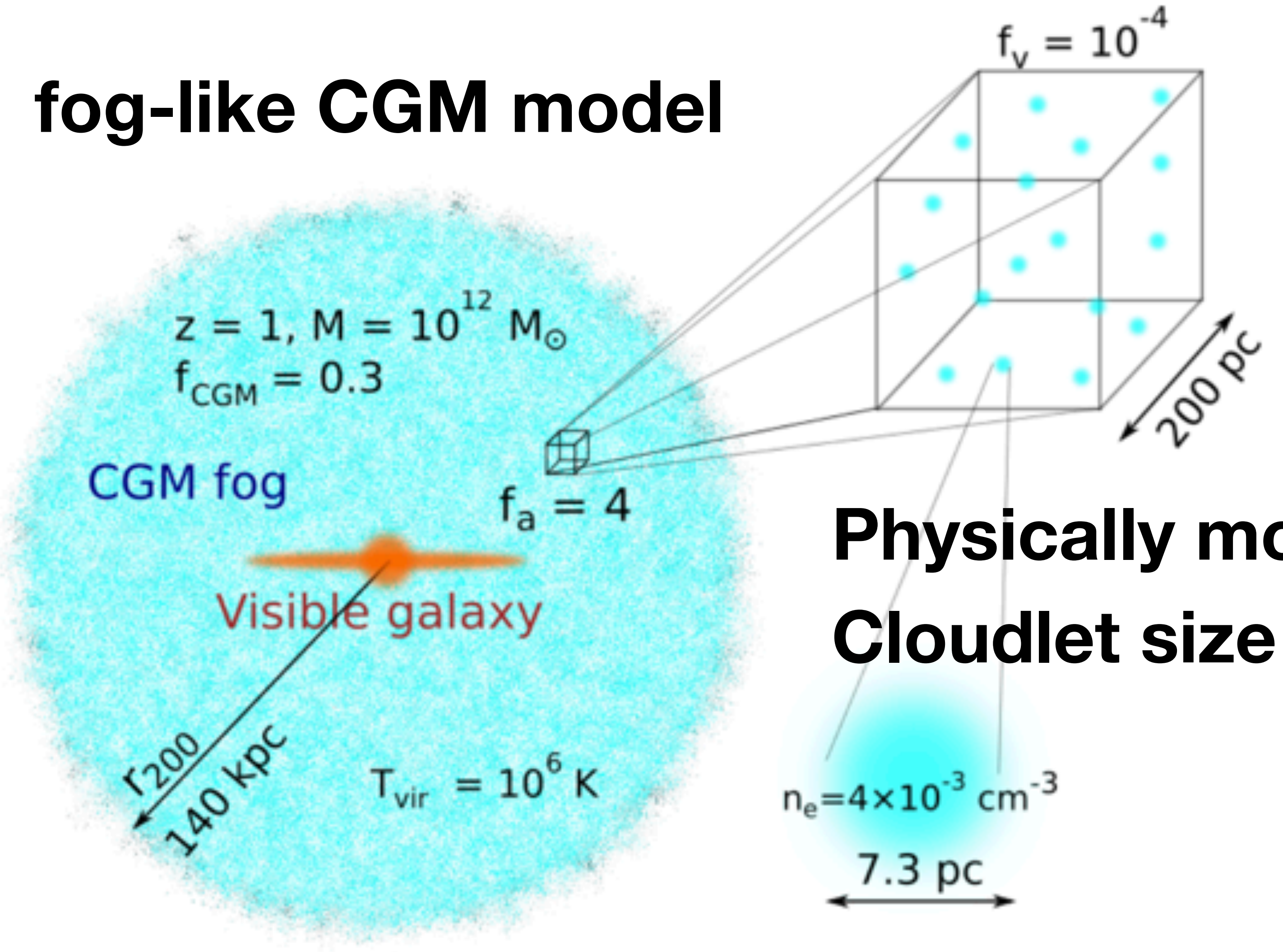

Physically motivated;
Cloudlet size $\ell \sim 0.1$ pc

McCourt et al. 2017
(Picture from Vedantham & Phinney 2018)

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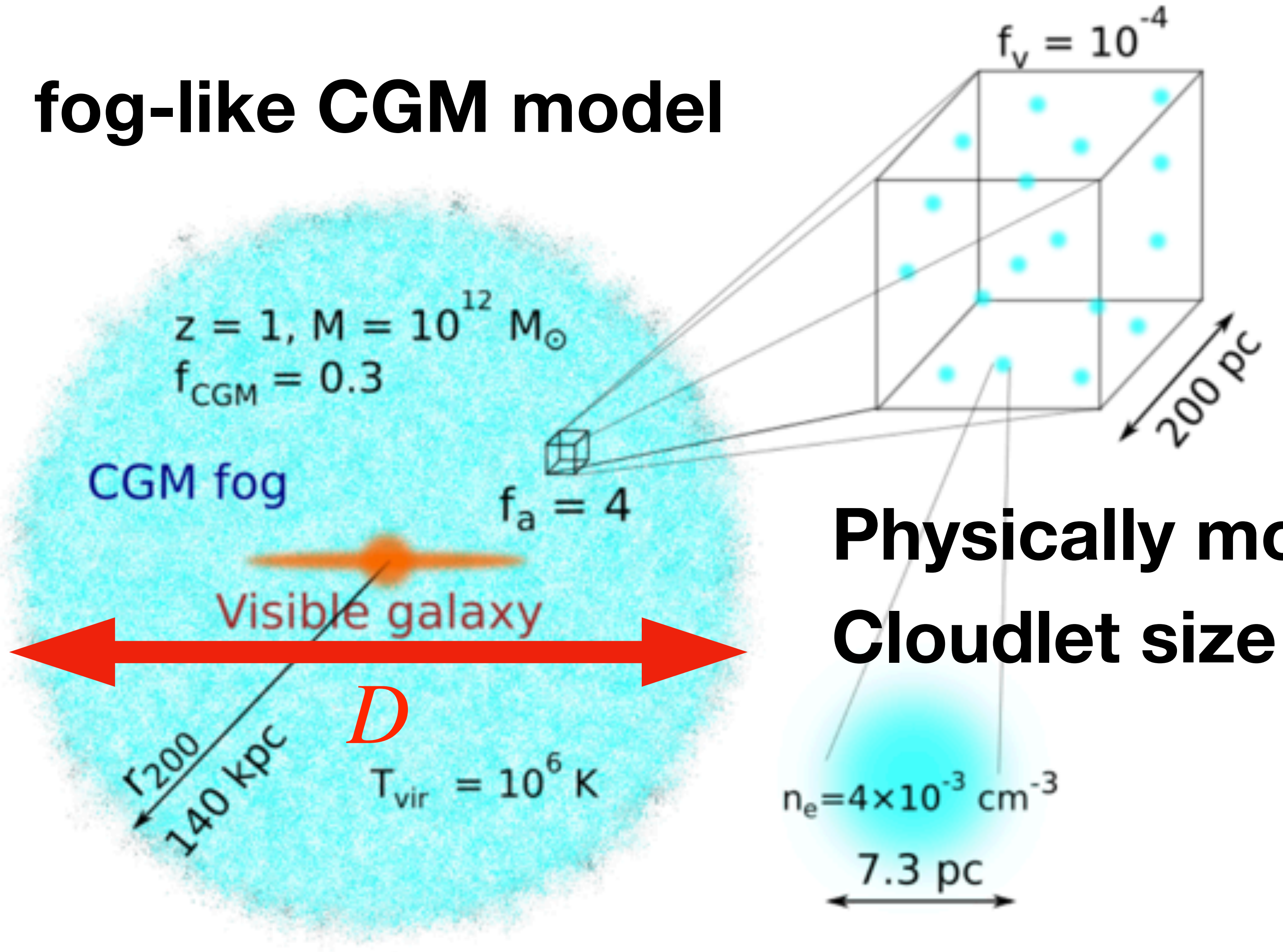

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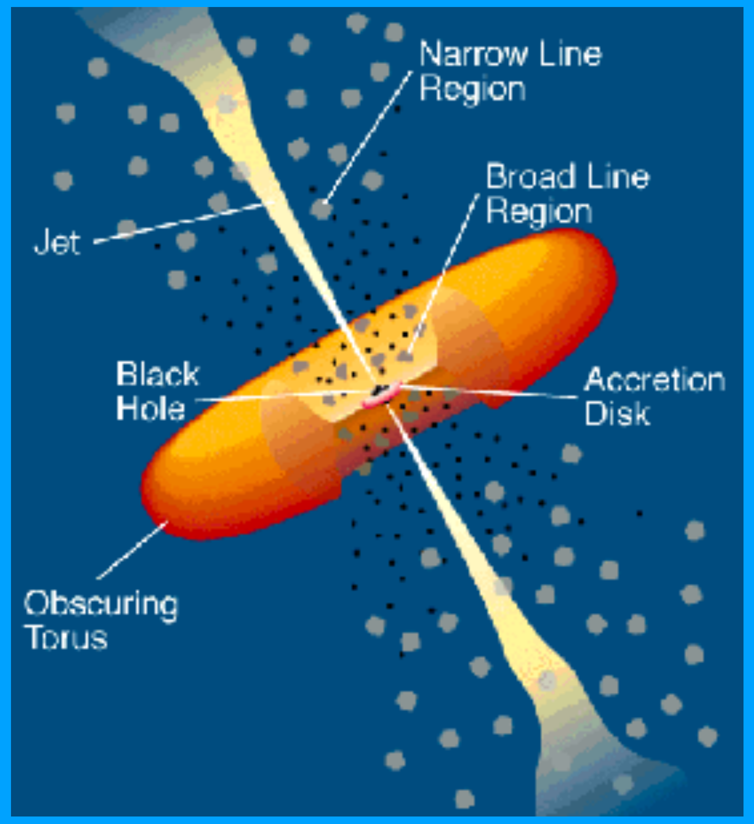

~ geometry of AGN broad line region

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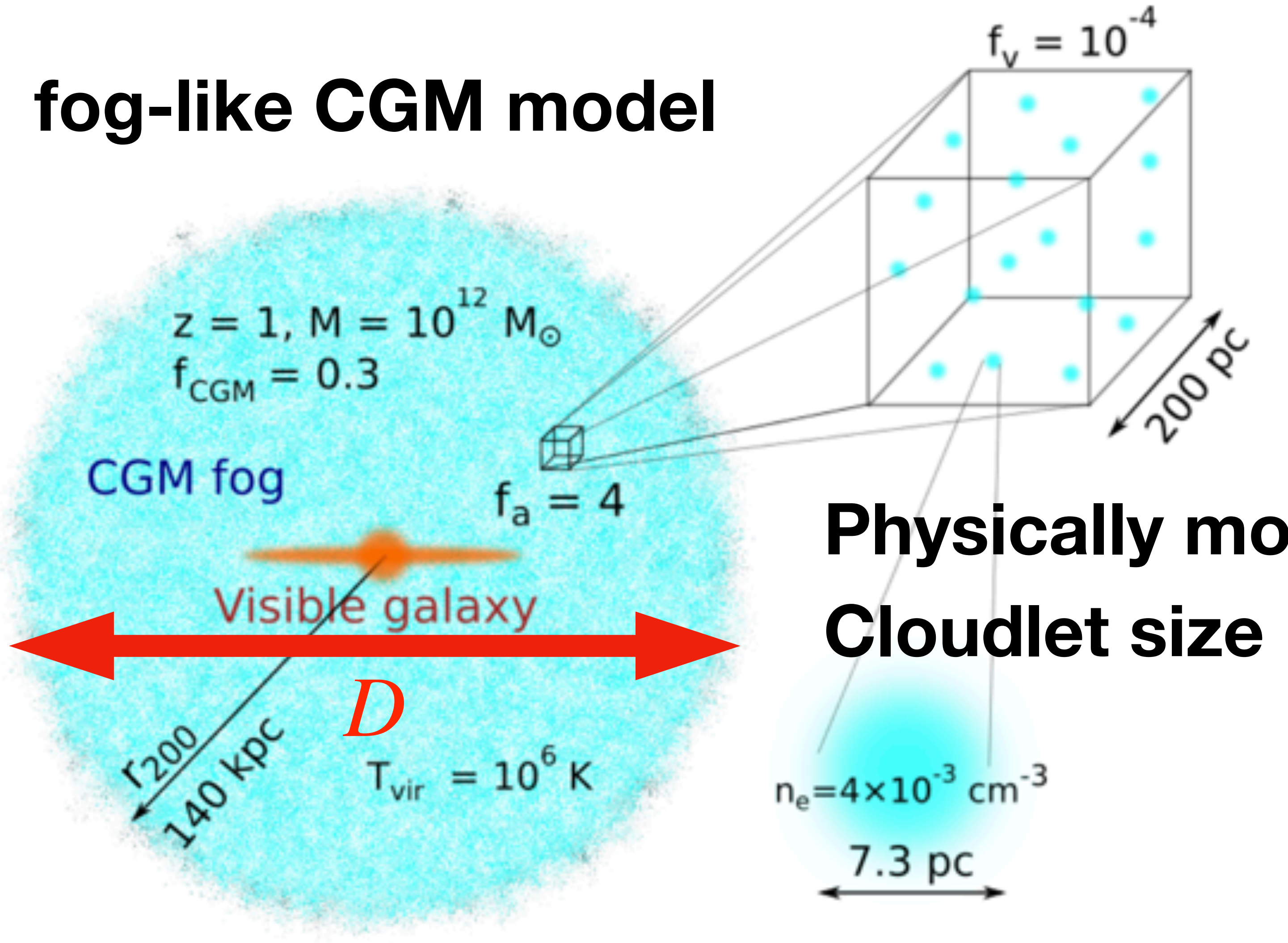

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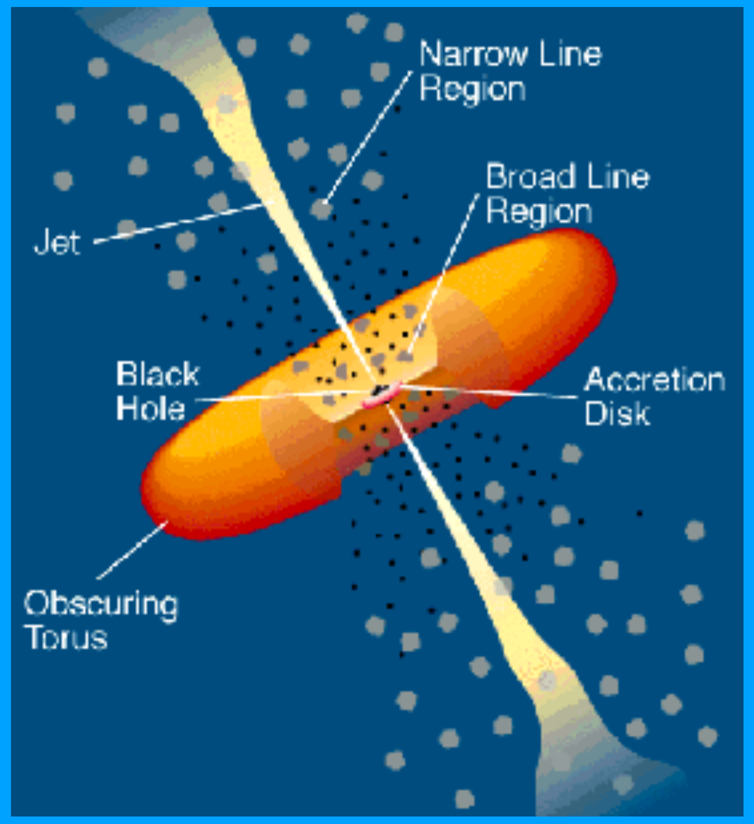
1. high density -> **small** volume filling fraction $f_V \lesssim 10^{-3}$

2. very **large** area covering fraction f_A

$$\frac{f_A}{f_V} \sim \frac{D}{\ell}$$



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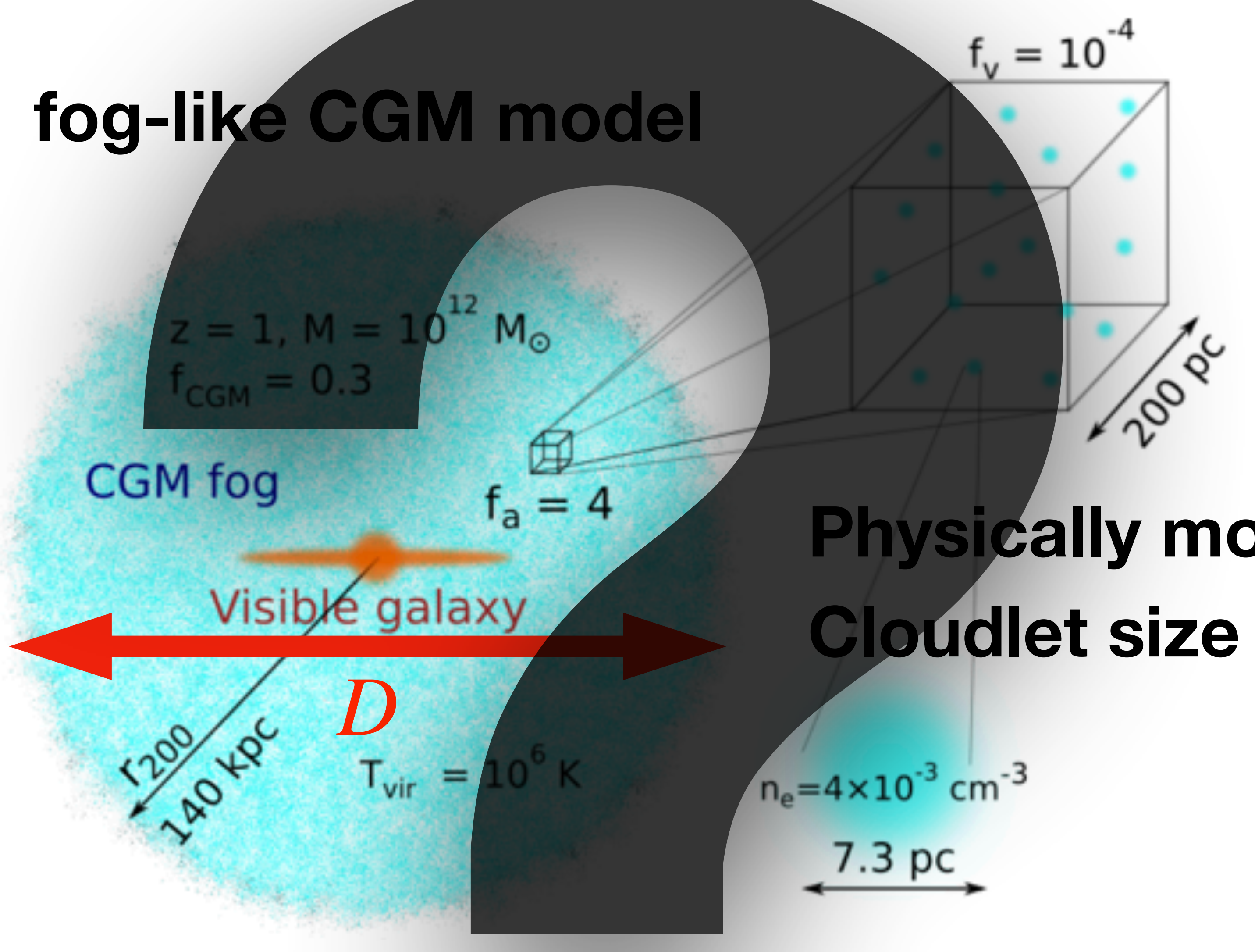

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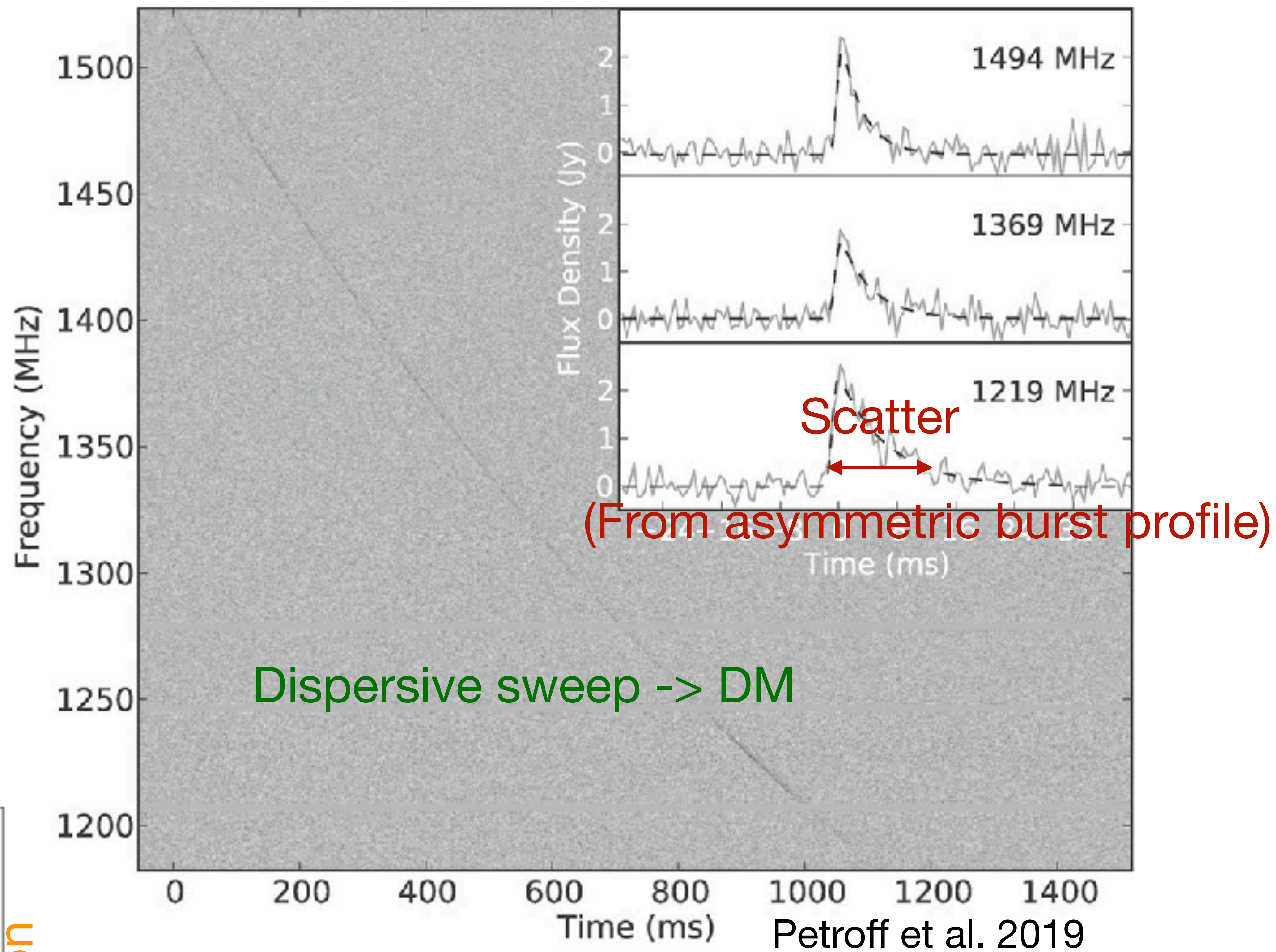
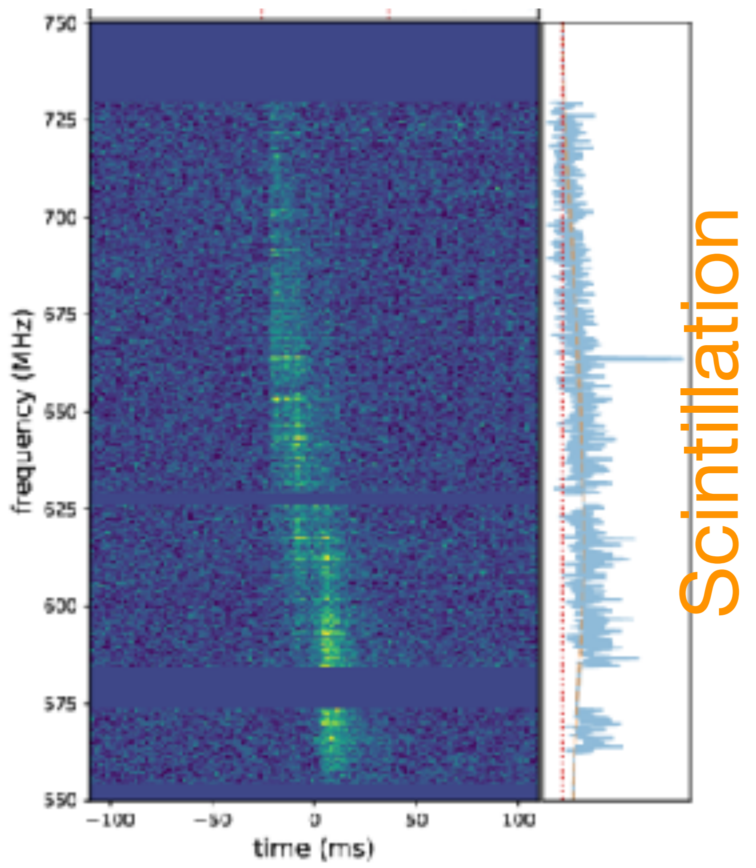
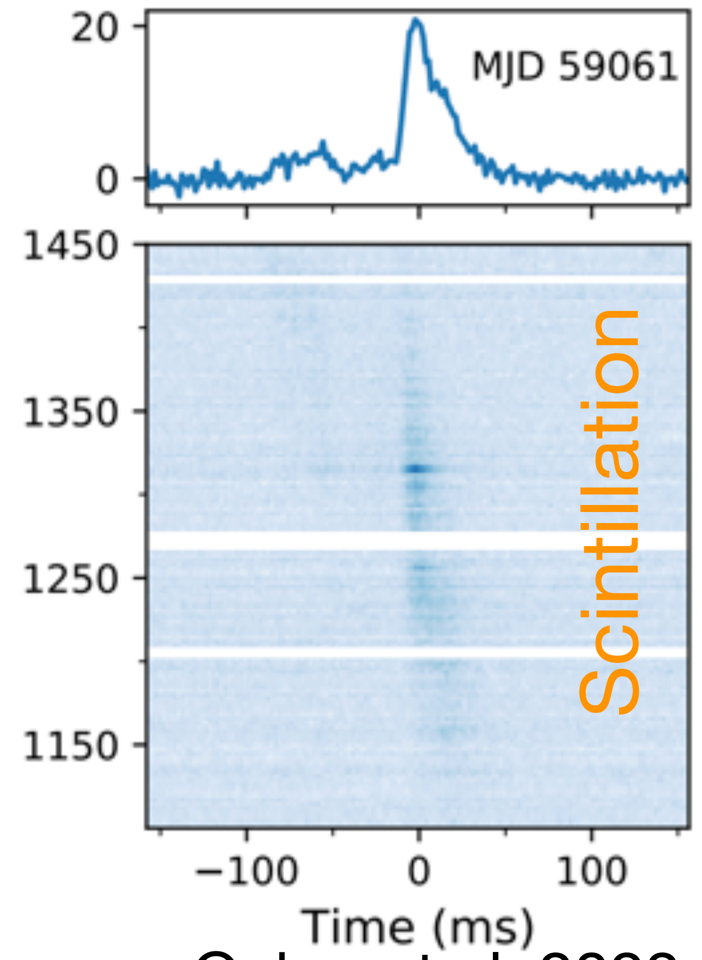


Petroff et al. 2019



Main et al. 2021



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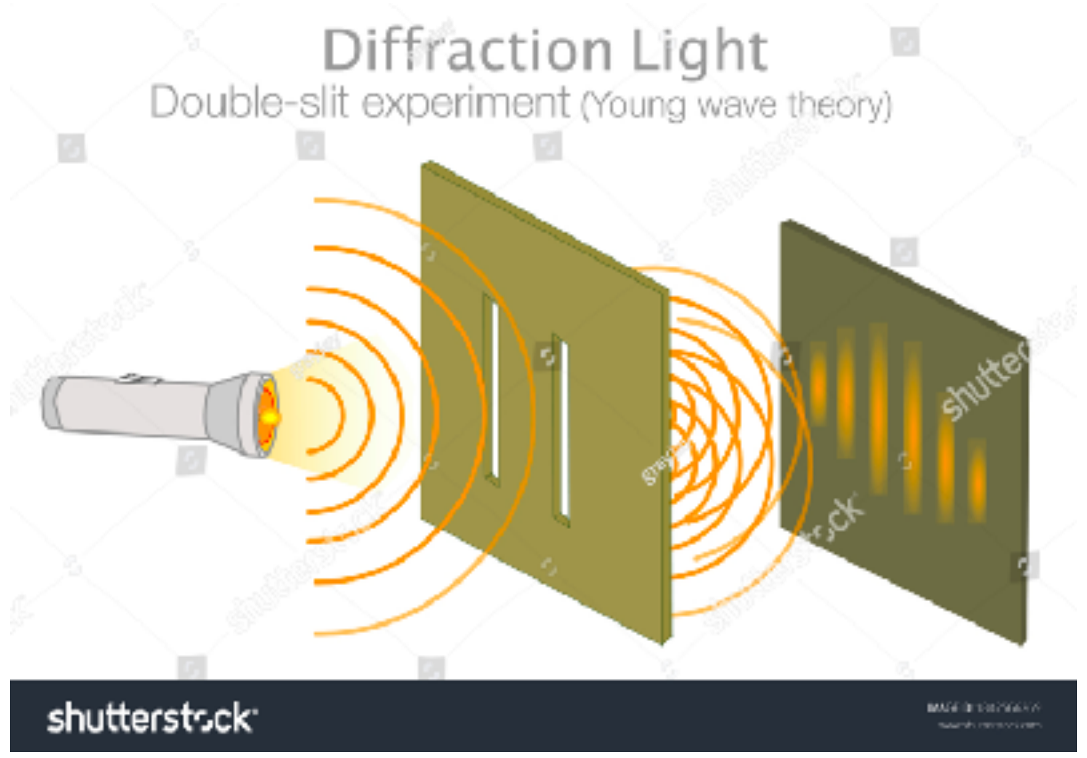
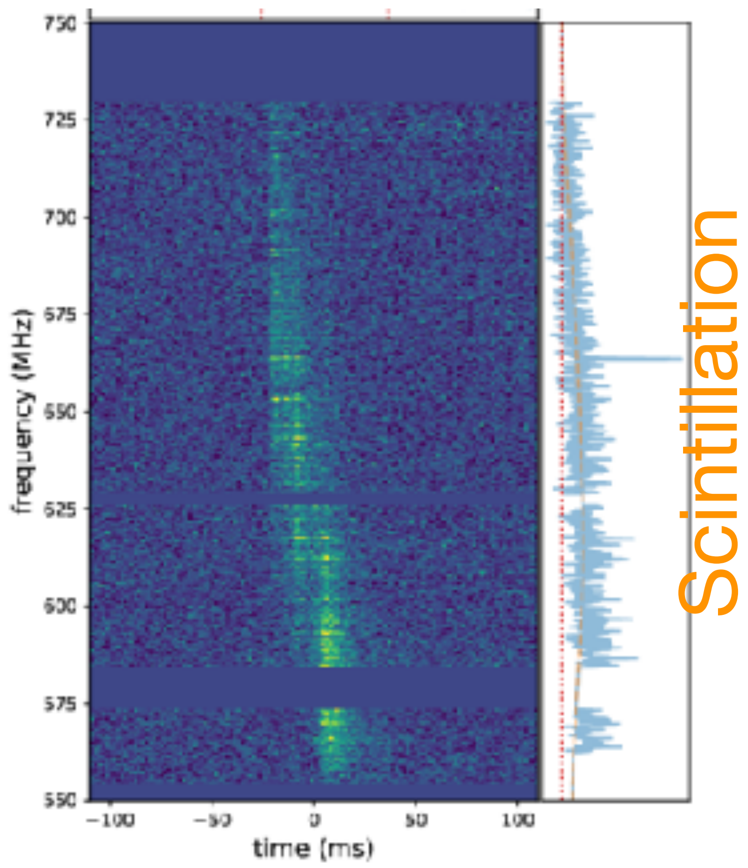


interference between images
-> flux modulation



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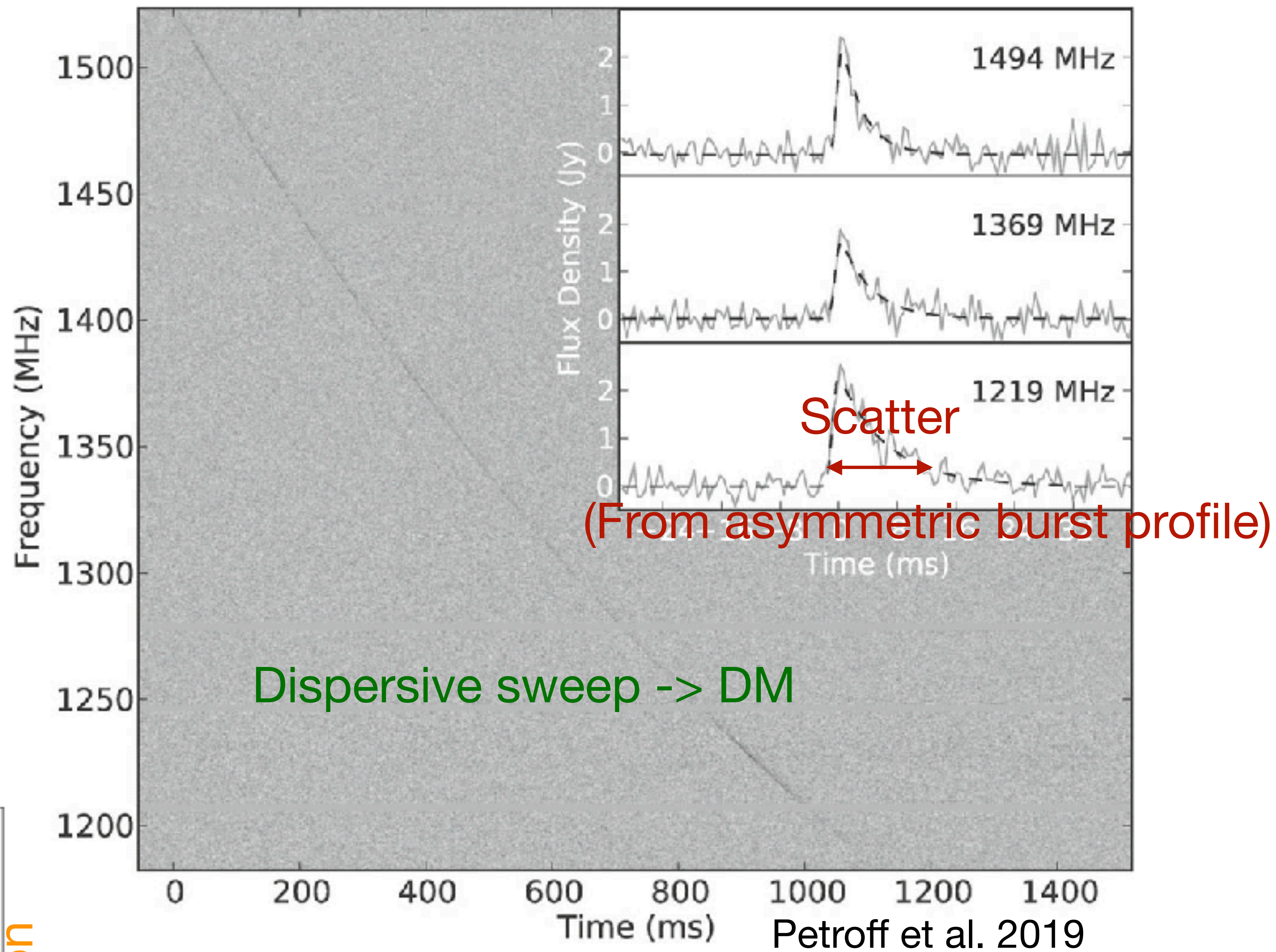

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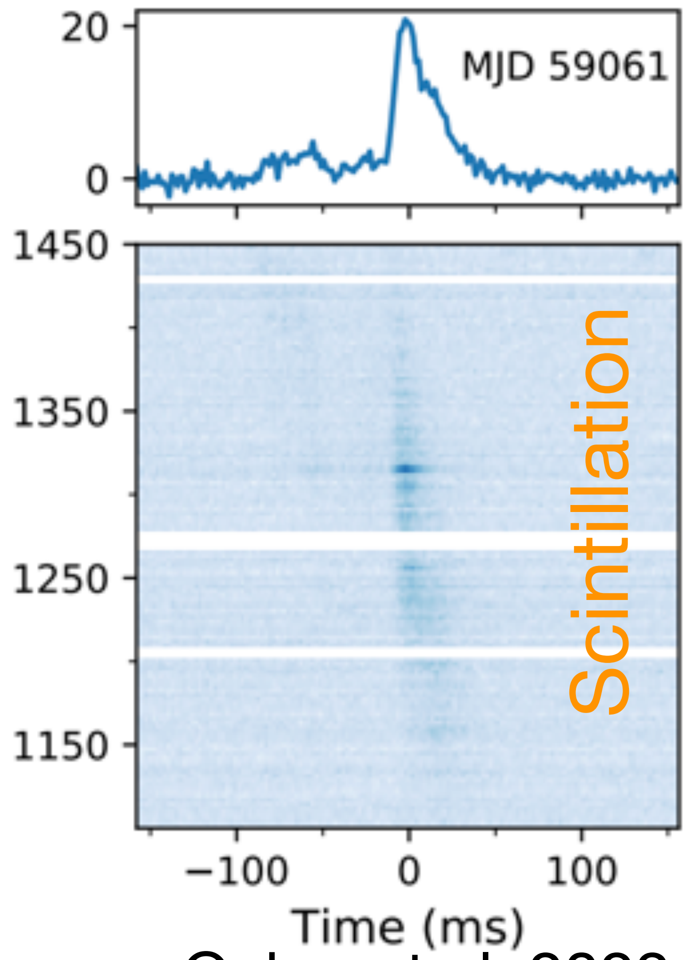

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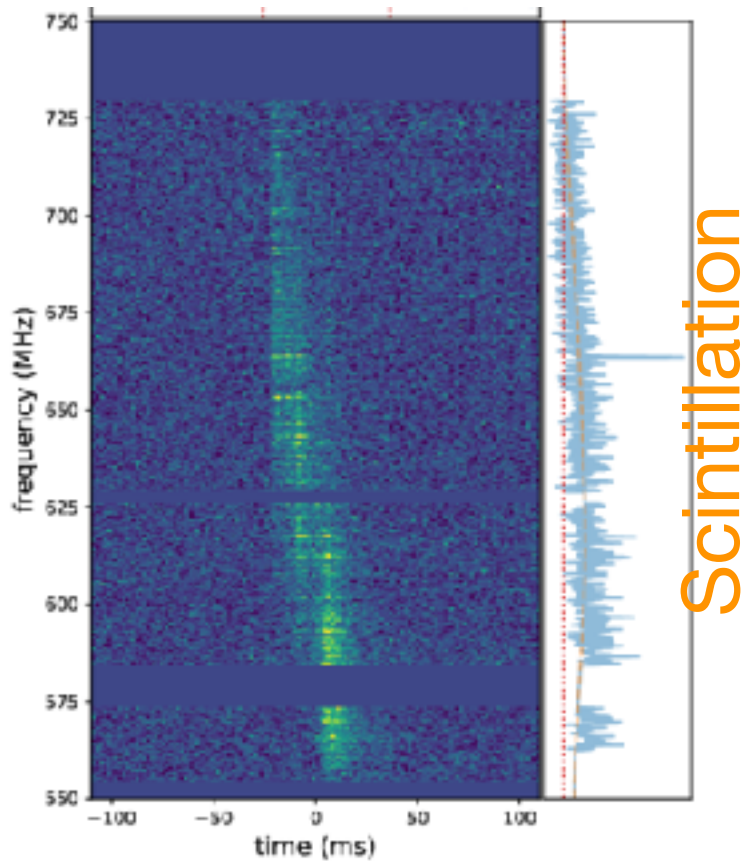

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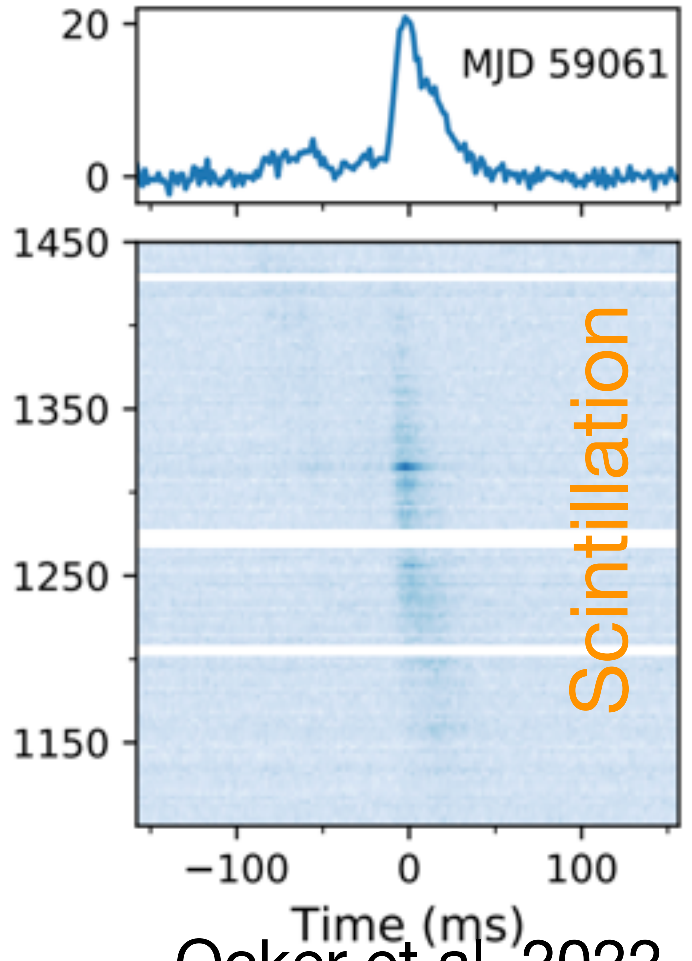

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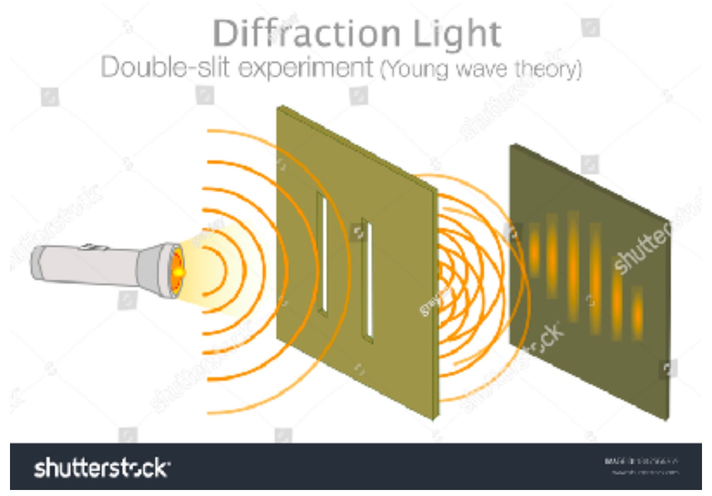
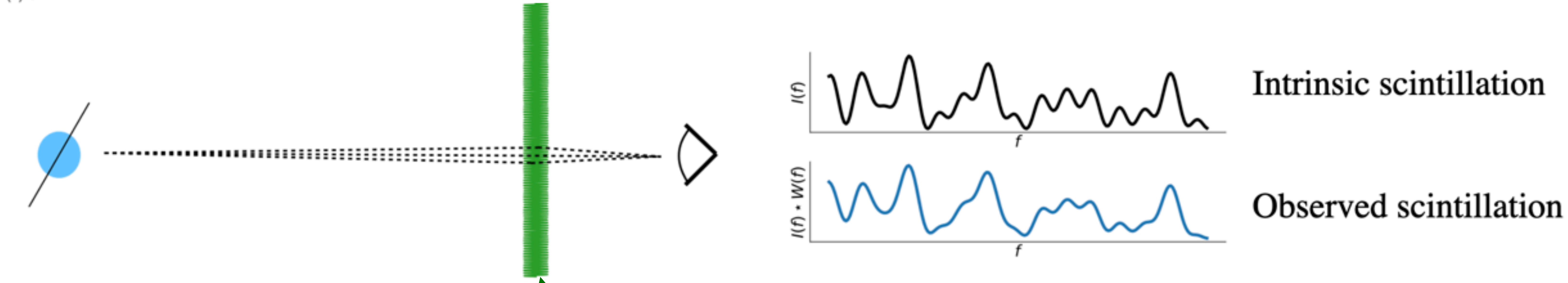


interference between images -> flux modulation

Local (plasma) lens



$df \sim 1/\tau_{max}$

Milky Way ISM

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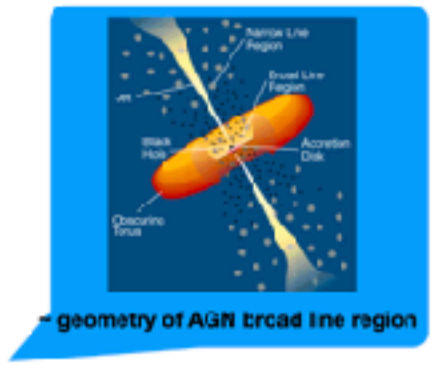

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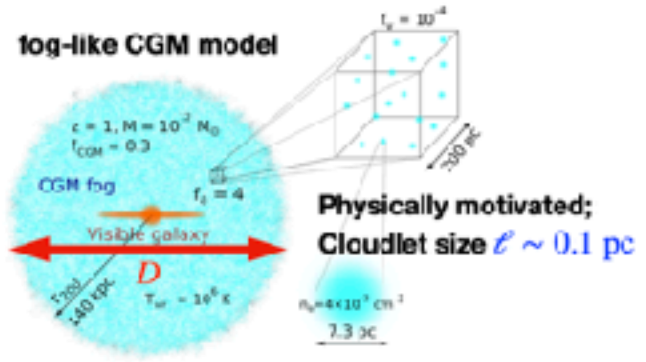

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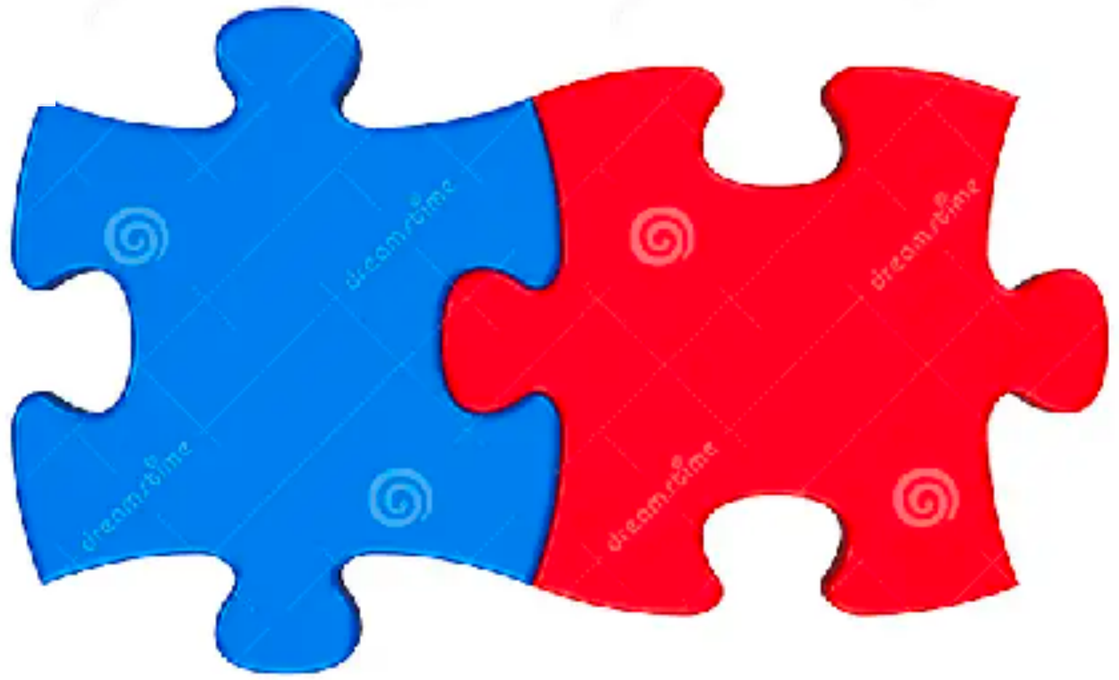

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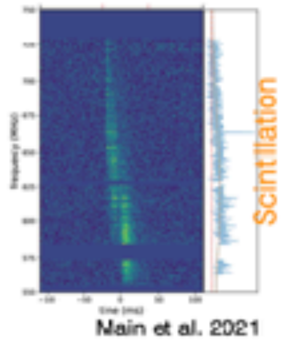

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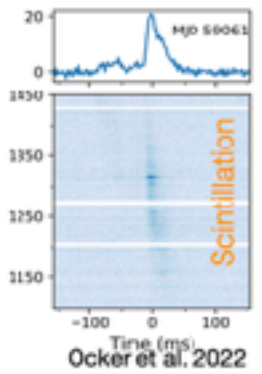

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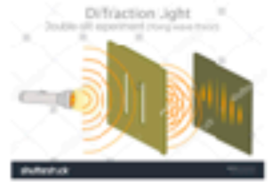

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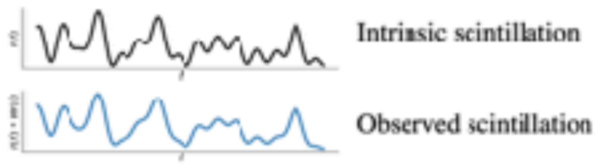
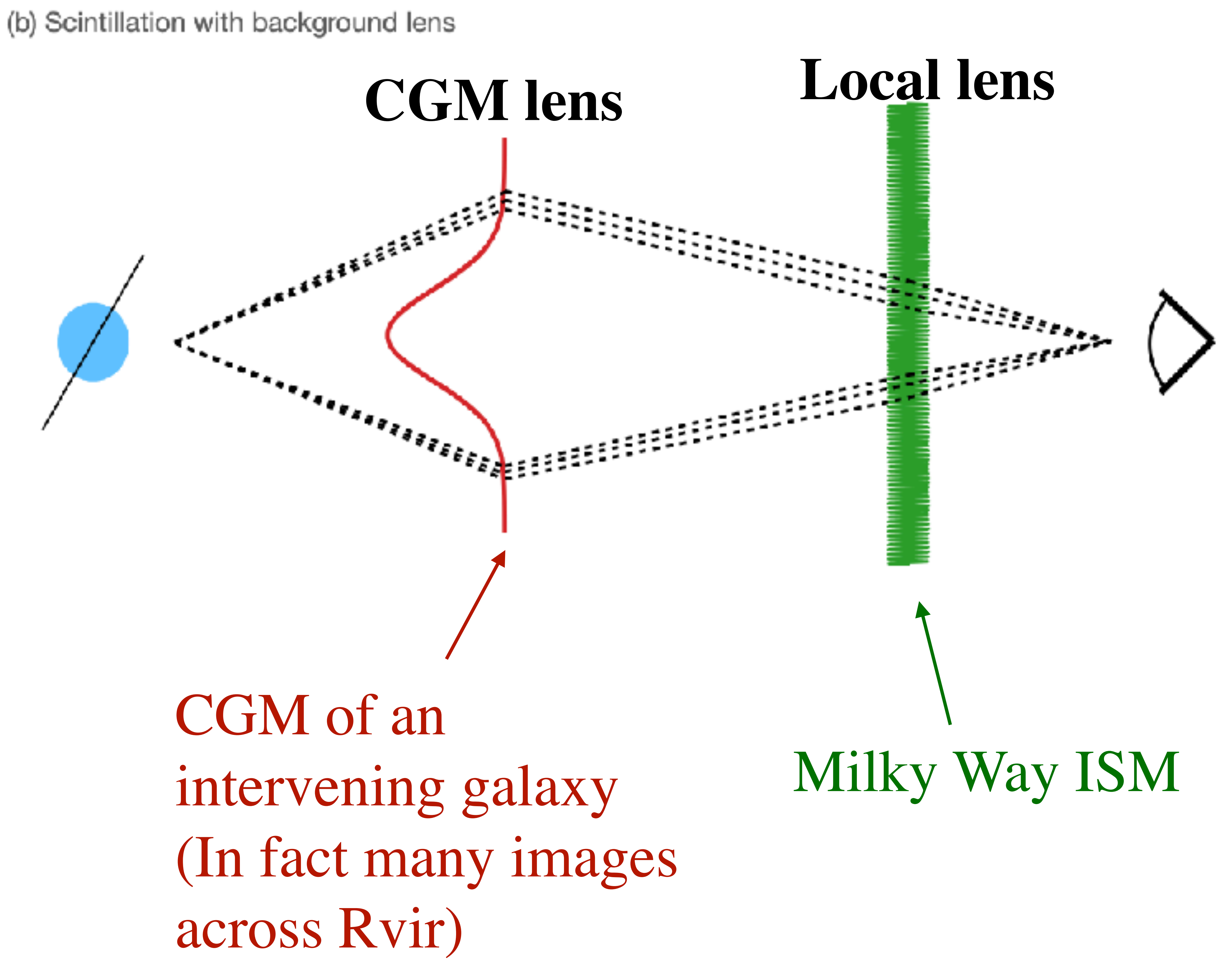
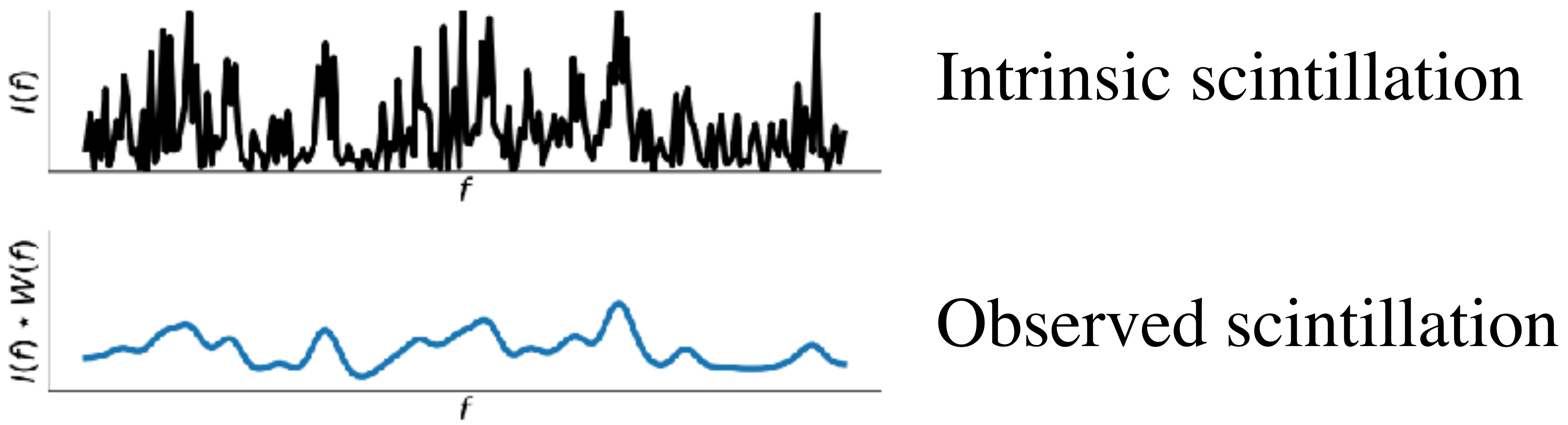
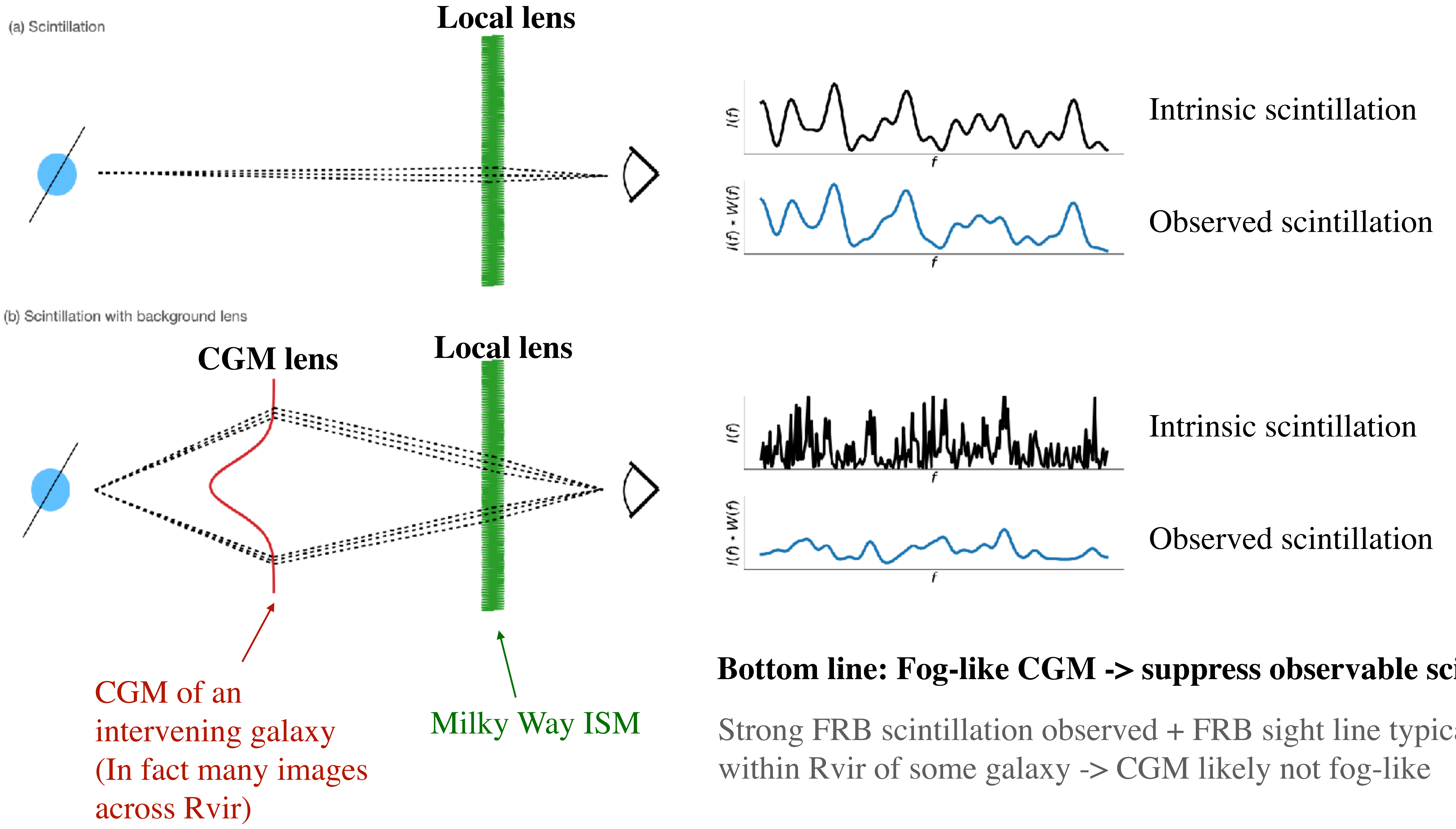






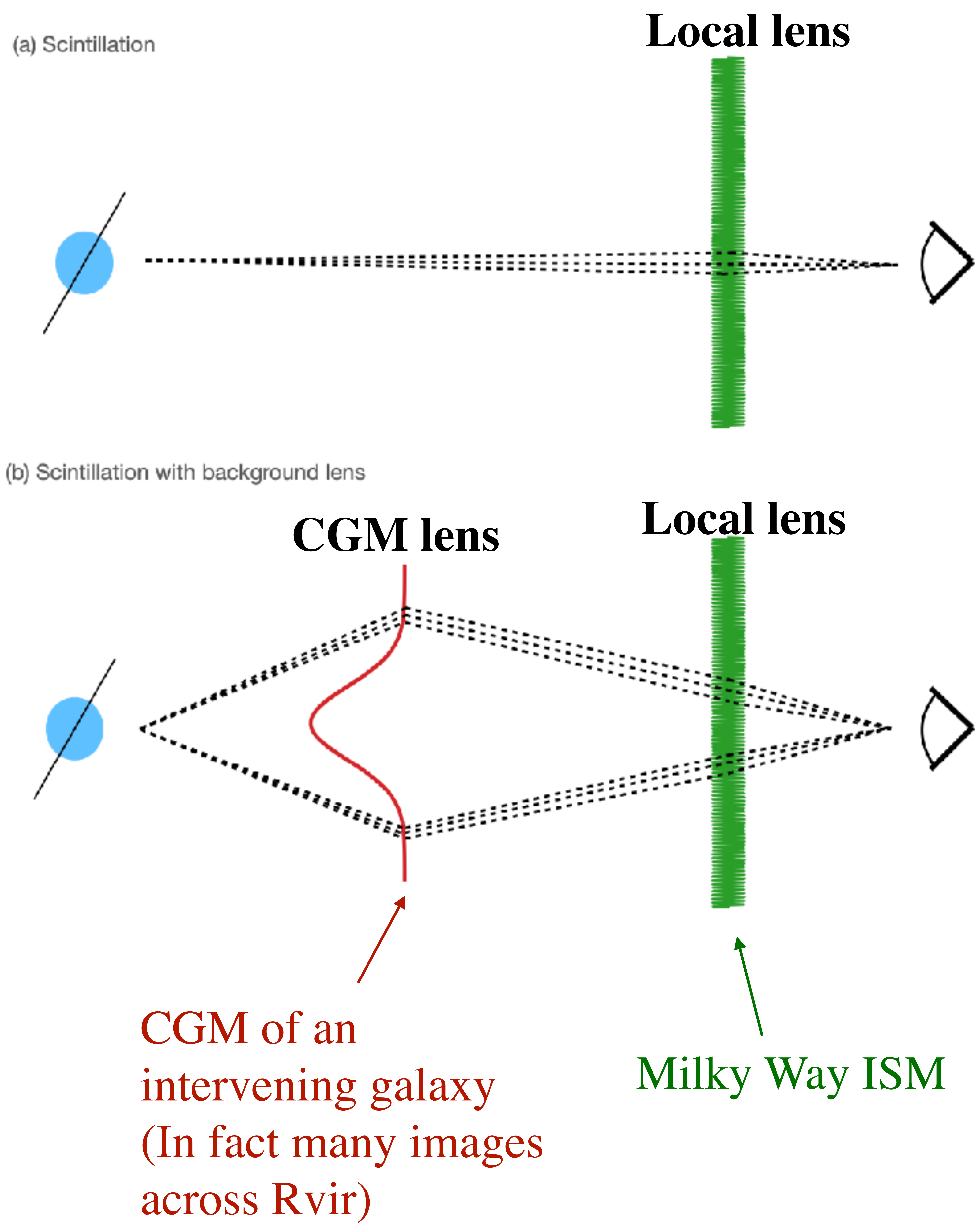
$$df \sim 1/\Delta\tau_{max}$$

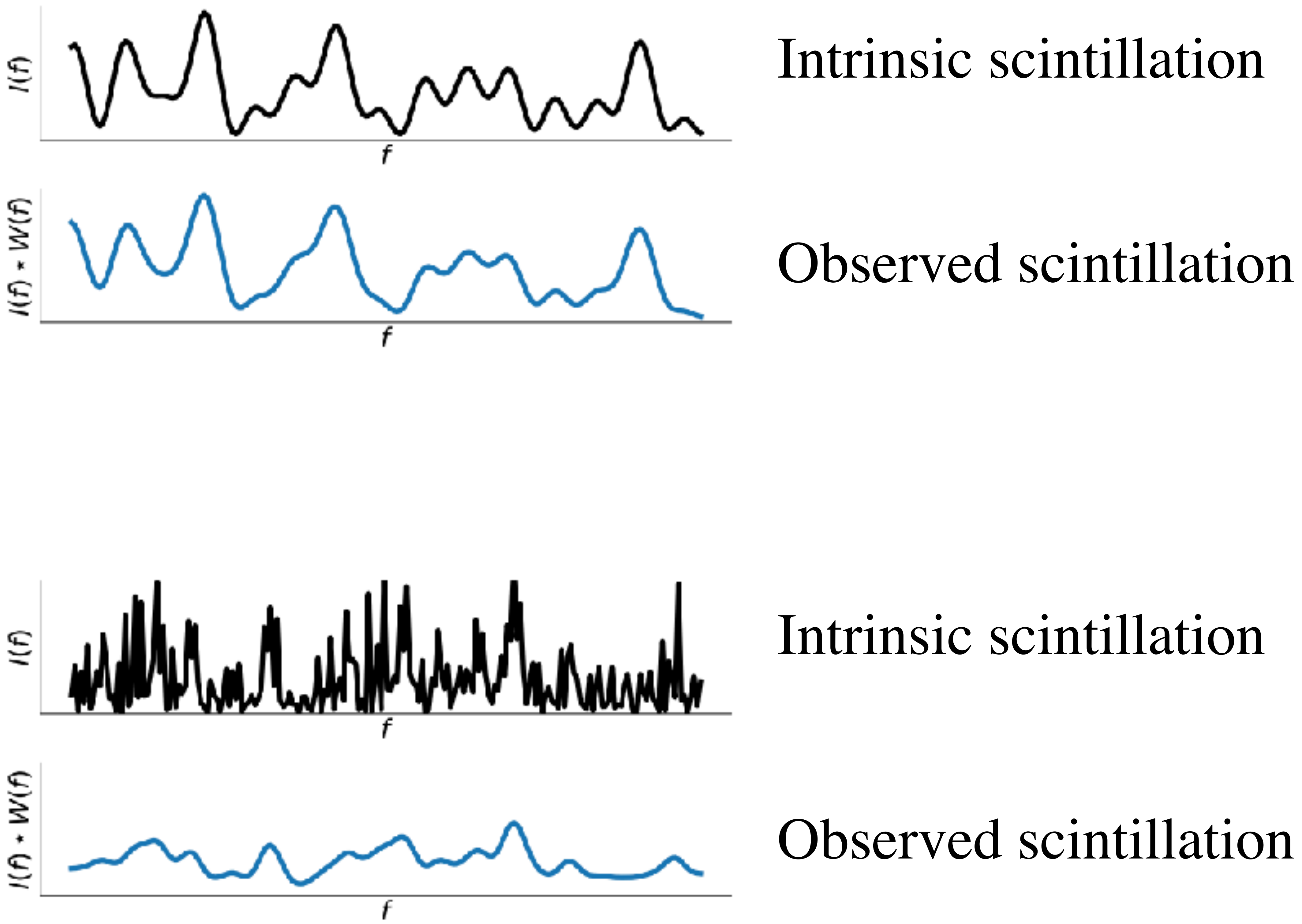
CGM lens -> increase maximum time delay among images $\Delta\tau_{max}$ -> reduce intrinsic decorrelation frequency df -> suppress scintillation when df < frequency resolution



Bottom line: Fog-like CGM -> suppress observable scintillation

Strong FRB scintillation observed + FRB sight line typically lies within Rvir of some galaxy -> CGM likely not fog-like





Bottom line: Fog-like CGM -> suppress observable scintillation

Strong FRB scintillation observed + FRB sight line typically lies within Rvir of some galaxy -> CGM likely not fog-like

Way out: sheet-like CGM -> fewer deflected flux at the CGM lens -> less suppression

Why I recommend this paper:

1. Links different research areas: CGM, FRB, radio wave scintillation, 2-screen lensing

2. Good logical inferences: CGM lens screen (if fog-like) + ISM lens screen -> suppress observed frequency modulation of FRB

3. Meaningful implications: CGM is likely not fog-like, can be possibly sheet-like

4. Testable predictions (falsifiable): more FRB scintillation observations; relative suppression at different frequencies; other observations of CGM…

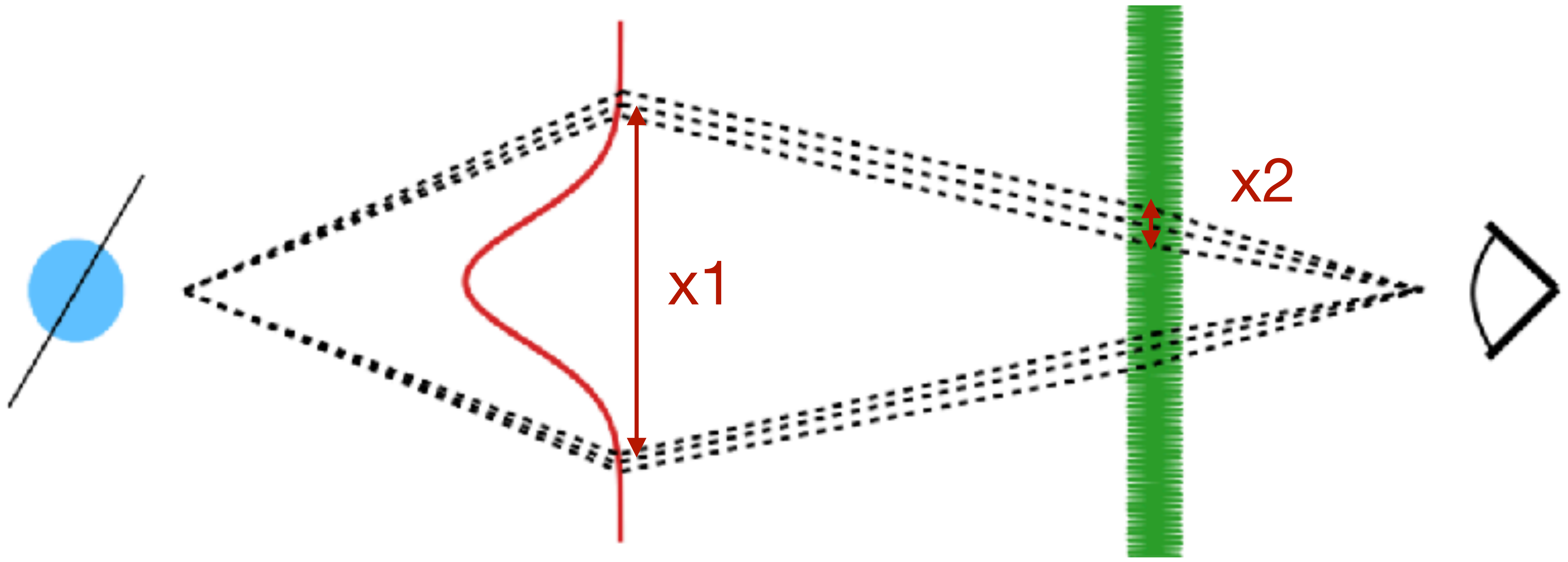
Backup slides

Physical picture of the creation of ~ 0.1 pc cloudlets in the CGM

McCourt et al. 2017

Suppression of scintillation by the 2nd screen

— A condition for suppression: screen1 and screen2 ‘**resolve**’ each other



resolve: $x_1 x_2 > D_{12}\lambda$

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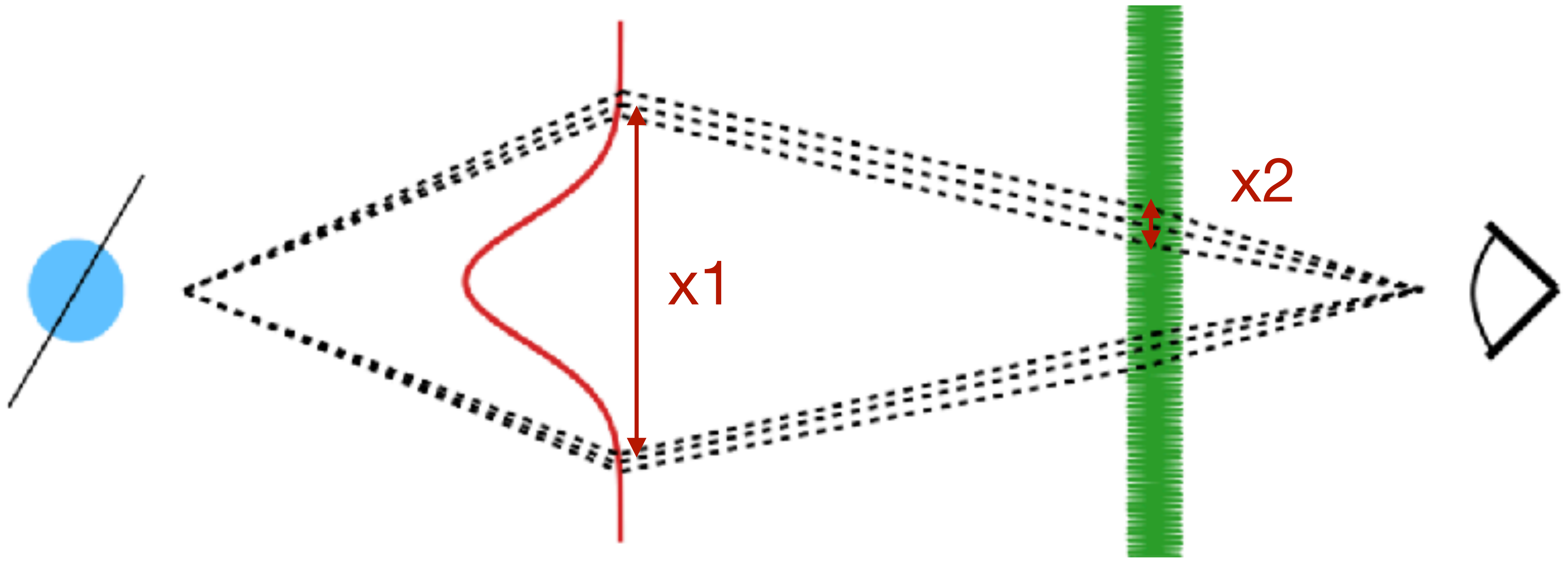

resolve: $x_1 x_2 > D_{12}\lambda$

Other examples of such suppression

- in the argument that FRB scattering is dominated by the host galaxy
- Low scintillation modulation of the Crab pulsar (suppression by lensing by the Crab Nebula)

From pulsar scintillation we know x2 ~ AU. Take D12 ~ Gpc, lambda ~ m. To resolve, we need x1 > 10^3 AU ~ 10^{-2} pc

For a screen1 within the Galaxy (in the case of Crab pulsar), take D12 ~ kpc, lambda ~ m. To resolve, we need x1 > 10^{-3} AU ~ 10^5 km

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2. Many with large scatter (~ ms at ~GHz) from host galaxy

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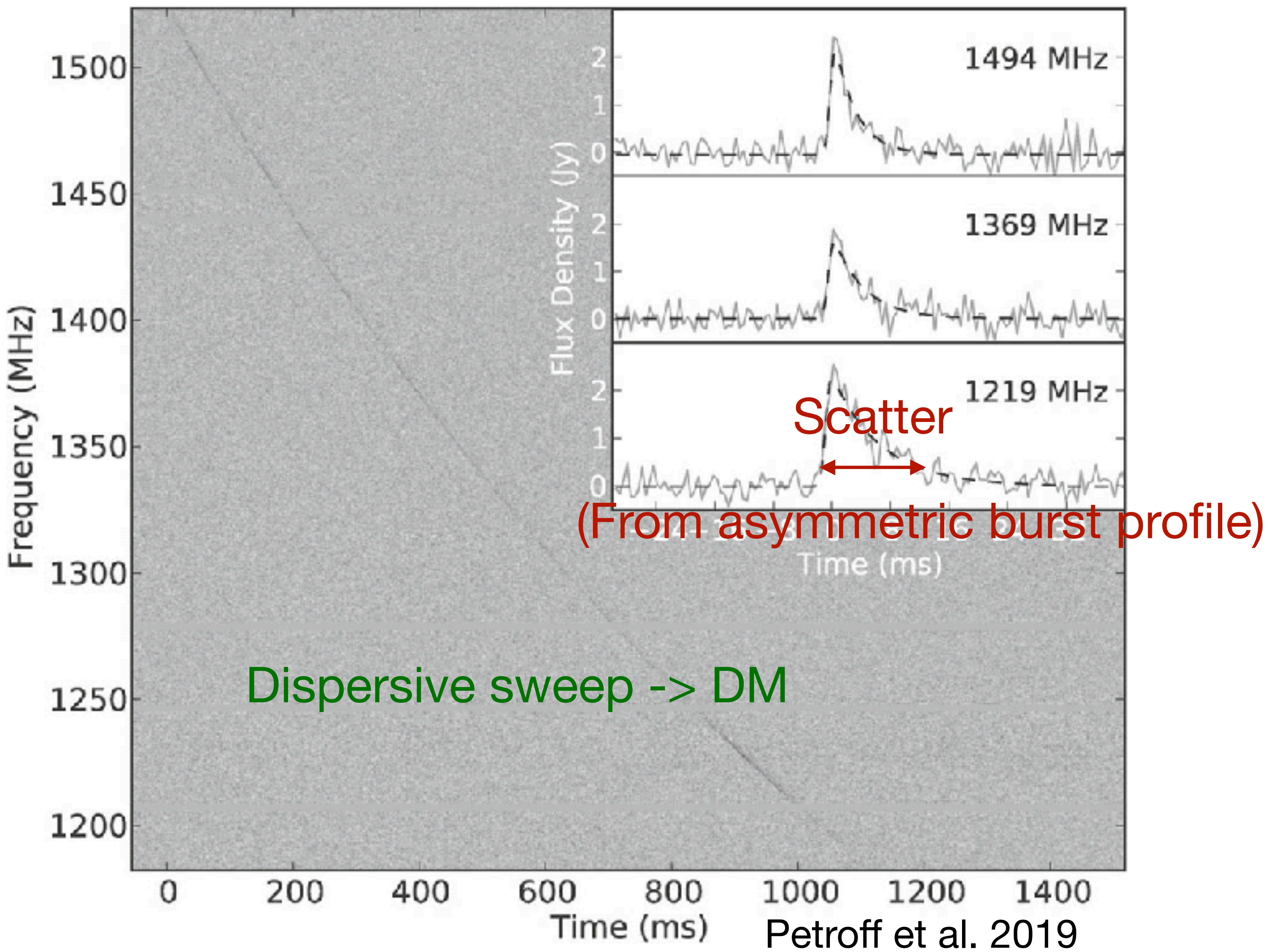
Why observed DM, scatter and frequency modulation are associated with different medium?



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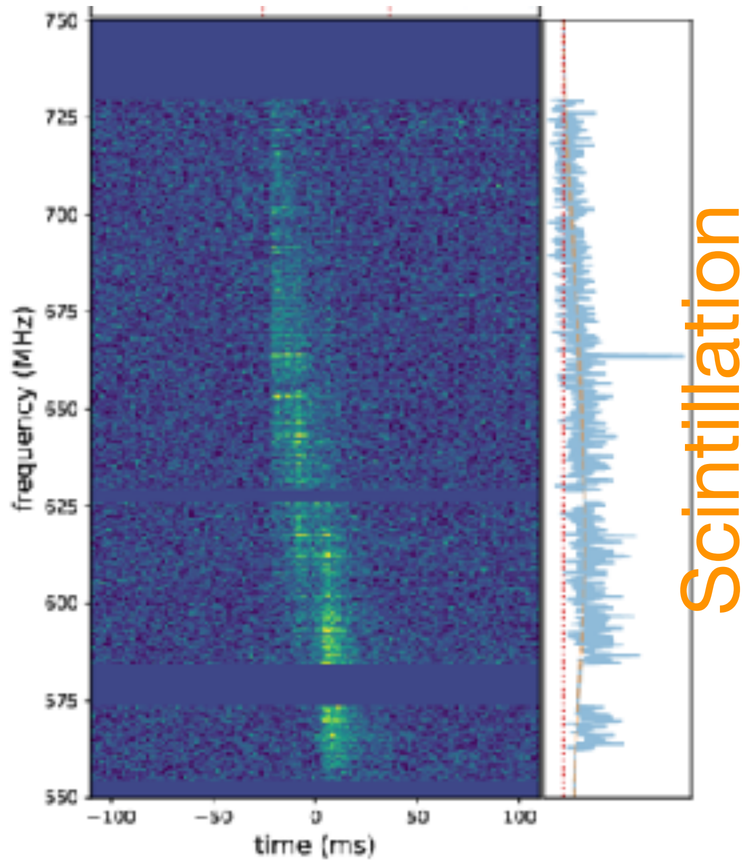

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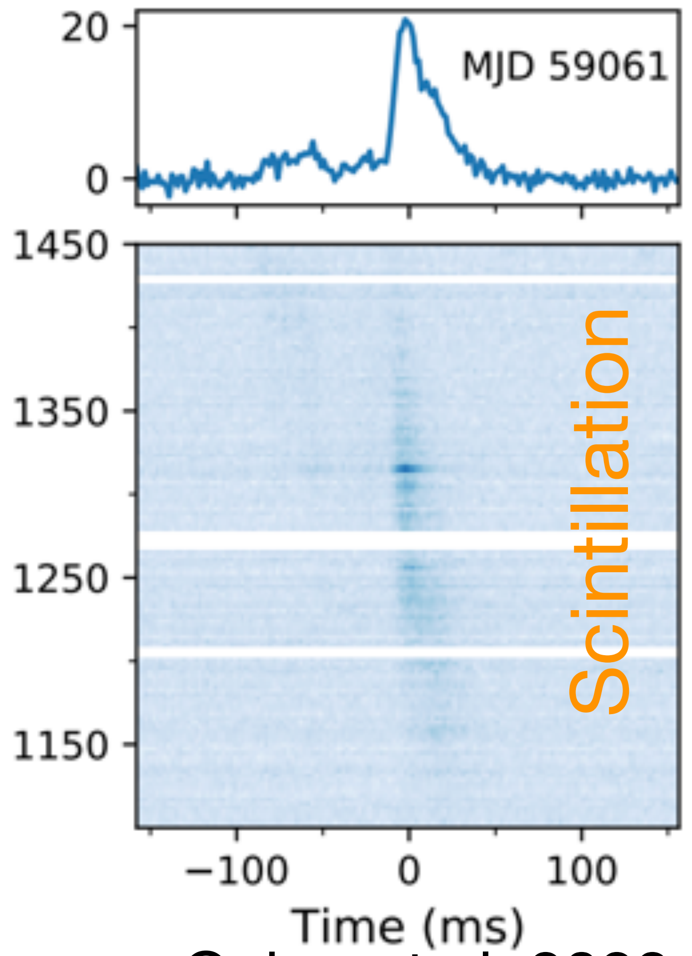
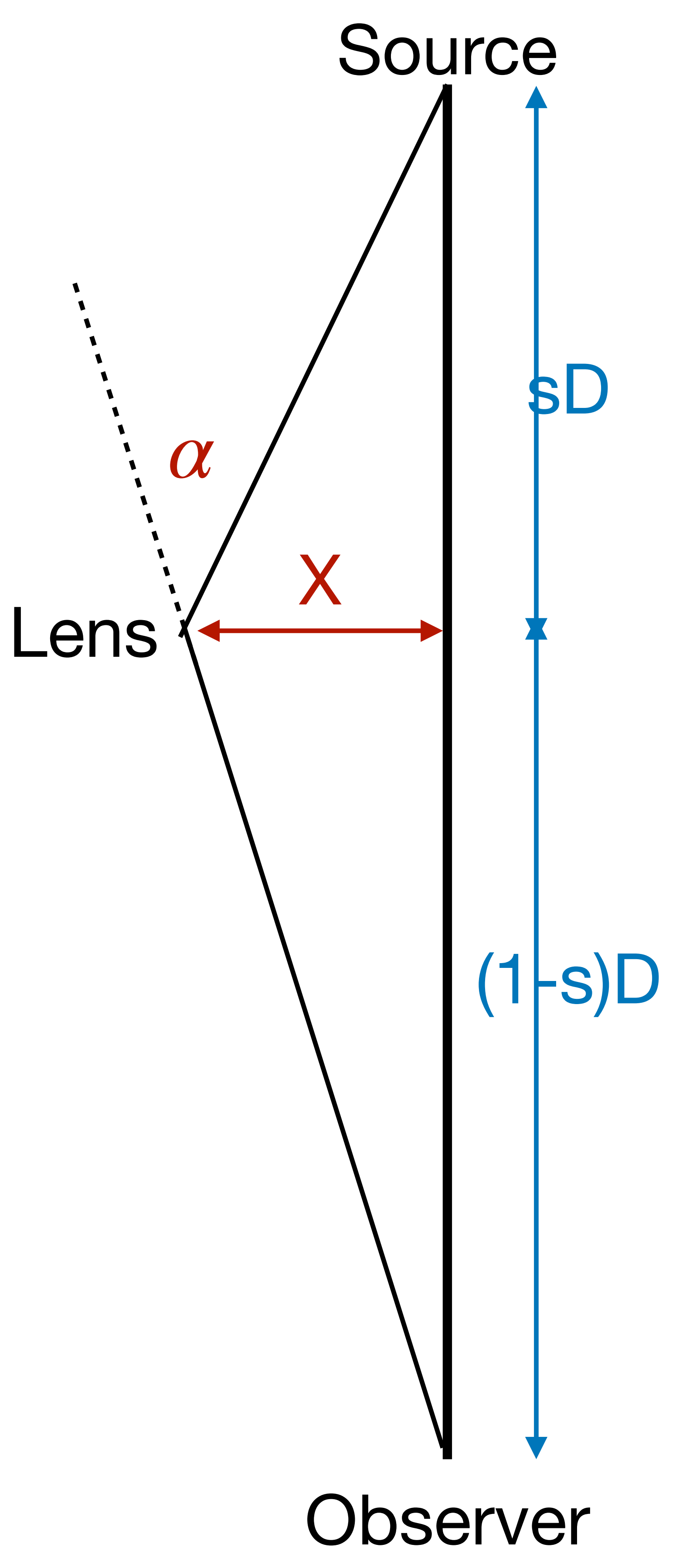


Ocker et al. 2022

Why observed DM, scatter and frequency modulation are associated with different medium? Esp. why scatter is attributed to the host galaxy?
— Again related to a geometry problem!



Scatter ~ time difference $\Delta\tau$ of the two paths

$$\Delta\tau = \frac{x^2}{2cDs(1-s)} = \frac{s(1-s)D\alpha^2}{2c}$$

Lensing strength is characterized by the largest deflection angle α.

At a fixed α:

- **Largest $\Delta\tau$ when s = 0.5;**
- **When s~0 (host galaxy) or s~1 (Milky Way), very small $\Delta\tau$**

At a fixed $\Delta\tau$:

- **Largest x when s=0.5 -> easy to 'resolve'**

Take D ~ Gpc, $\Delta\tau$ ~ ms, we have x ~ 0.1 pc $\sqrt{s(1-s)}$ -> can resolve x2 when 0.1< s < 0.9 -> only when s~0 or s~1, suppression of scintillation does not happen. We know Galactic $\Delta\tau$ is insufficient (rule out s~1) -> attribute $\Delta\tau$ to host galaxy.