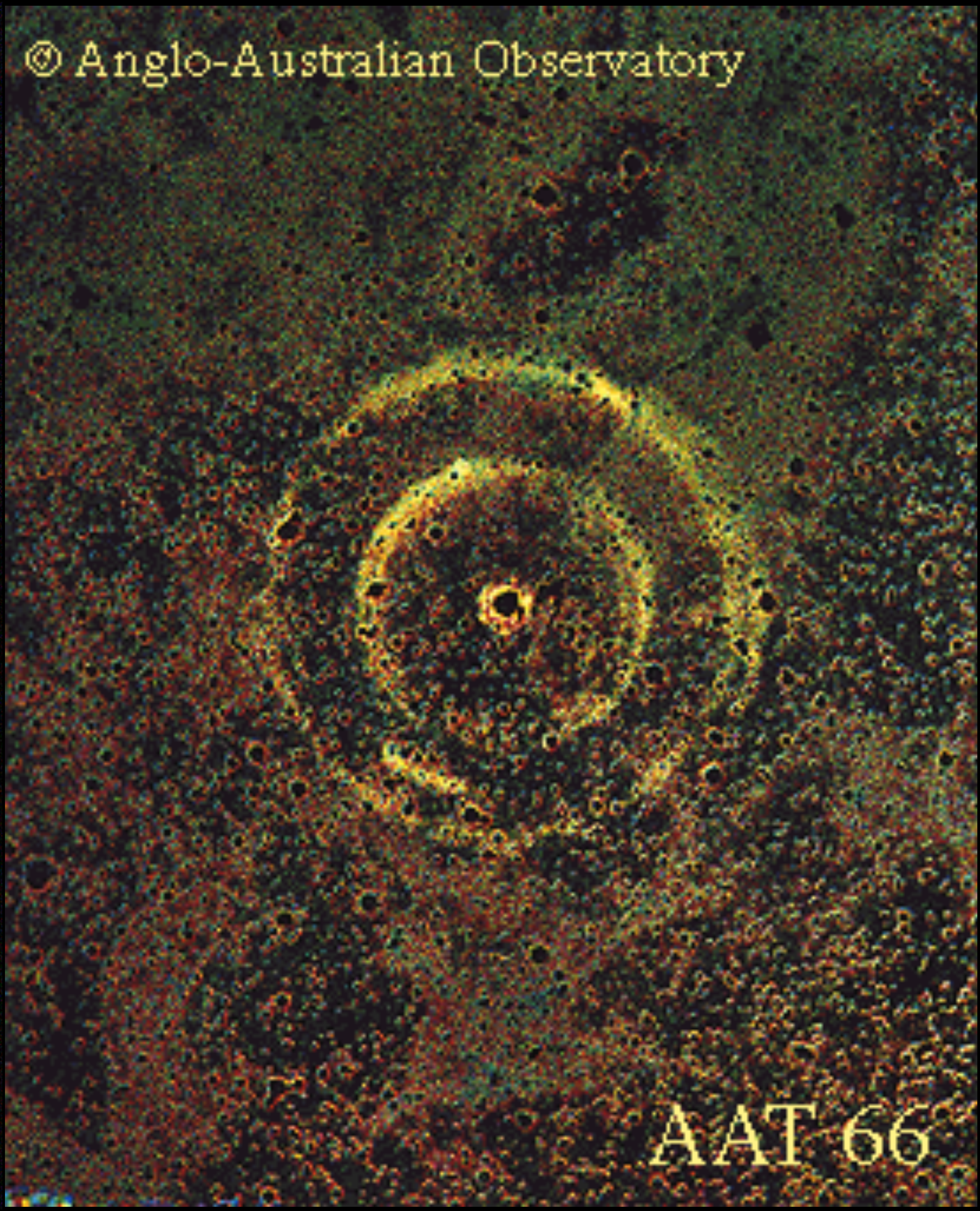
Things That Go Bang in the Night

Using X-ray Echolocation to Study the Milky Way

Lia Corrales
Einstein Fellow
University of Wisconsin - Madison

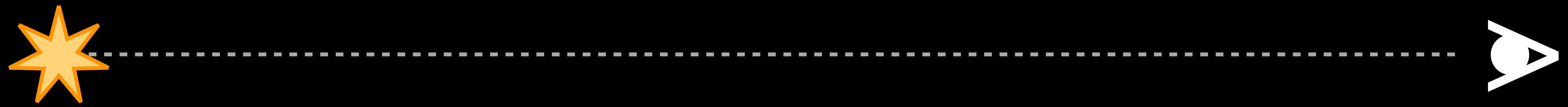
Some famous dust echoes

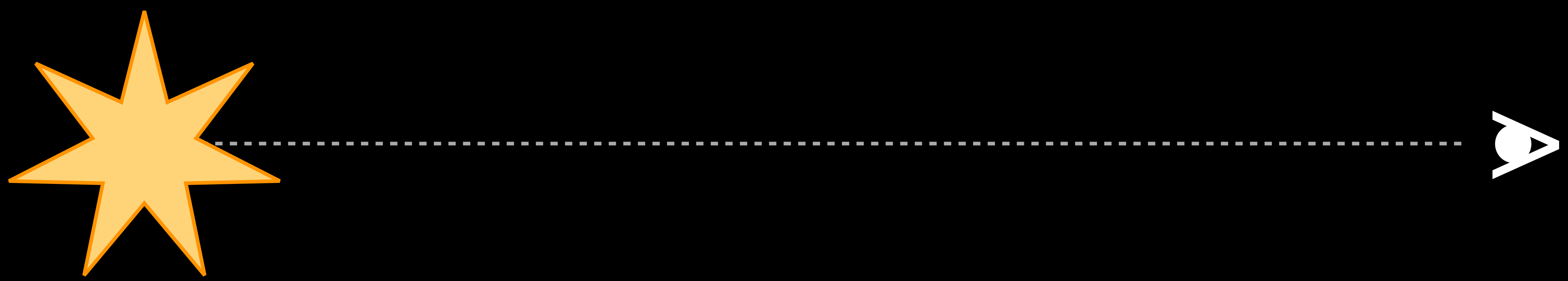


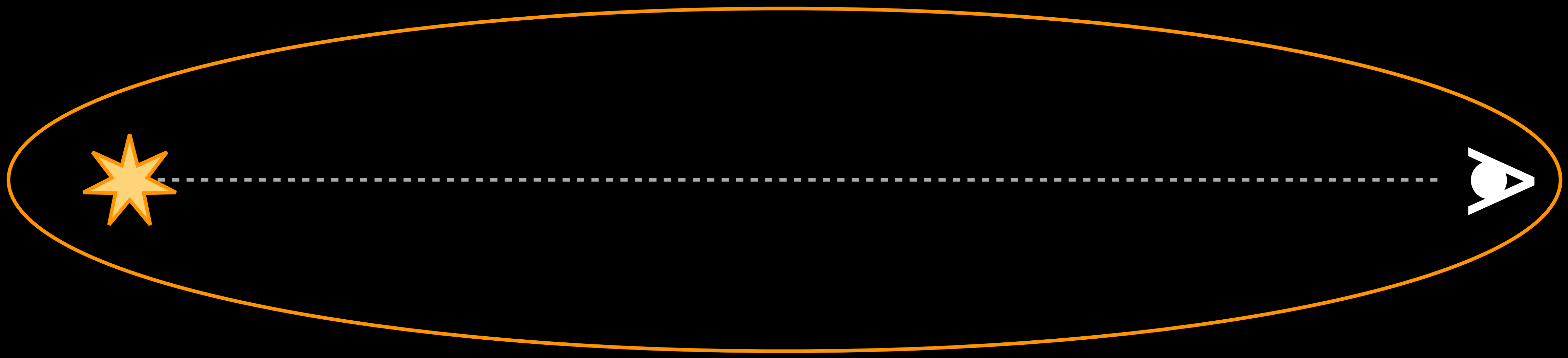
Nature's Recipe for Dust Scattering Echoes

Modern Findings

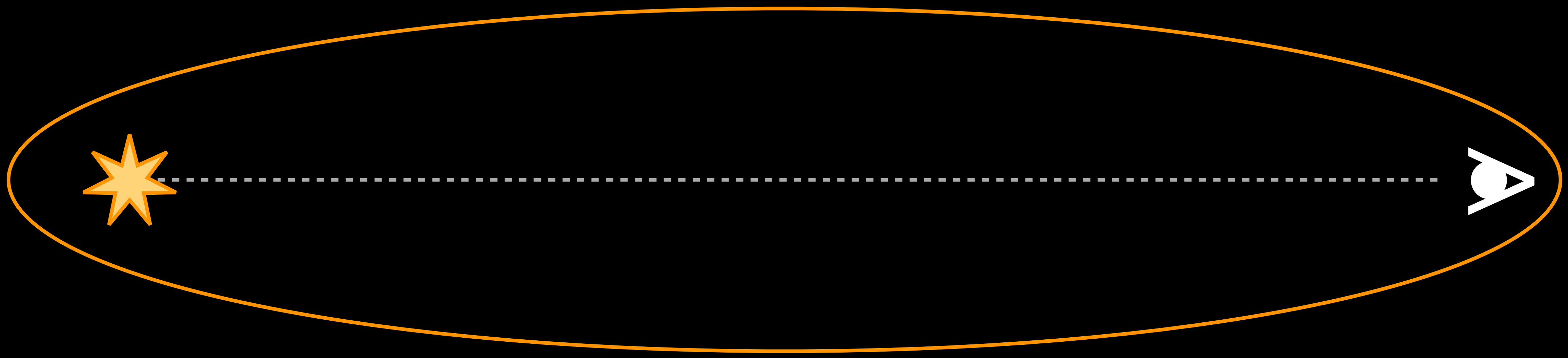
Future Prospects







X-rays are **forward** scattered



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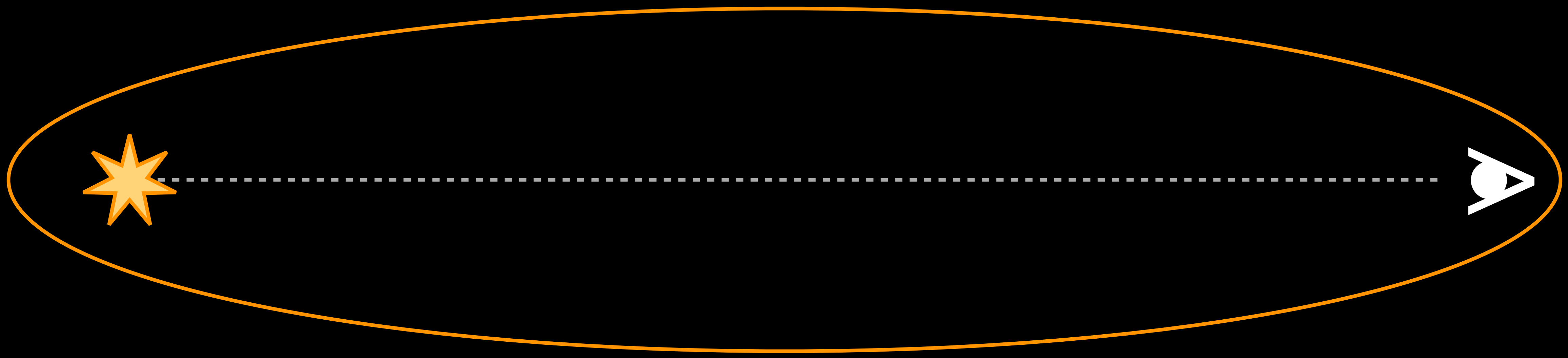
ISM is mostly **optically thin** in the X-ray



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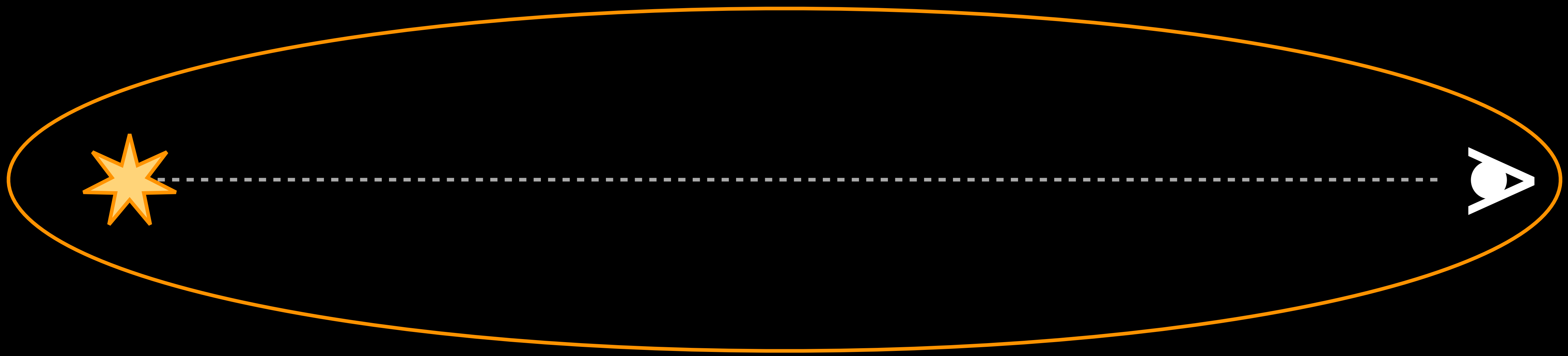

X-ray scattering probes everything **between** us and the source

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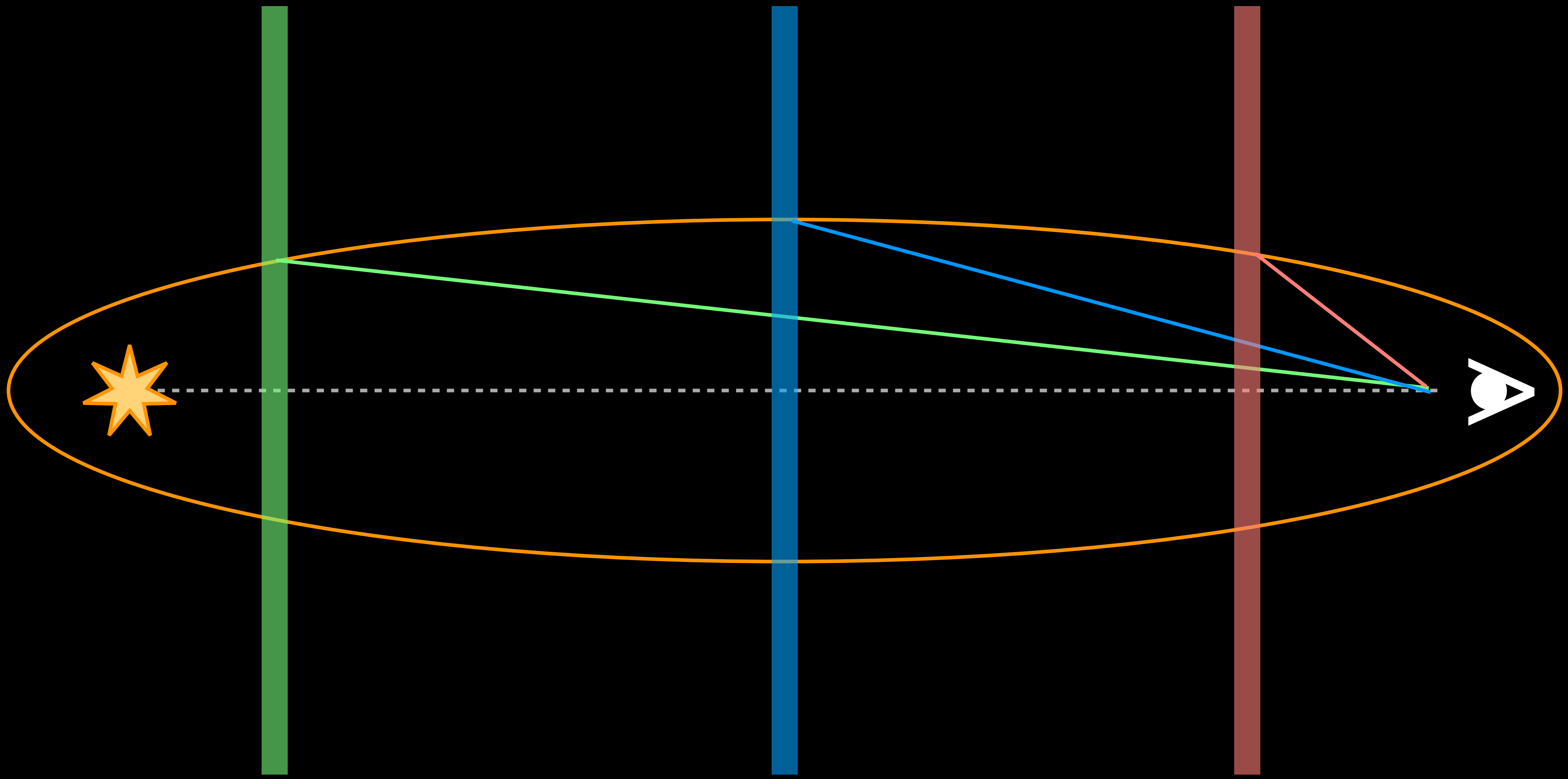

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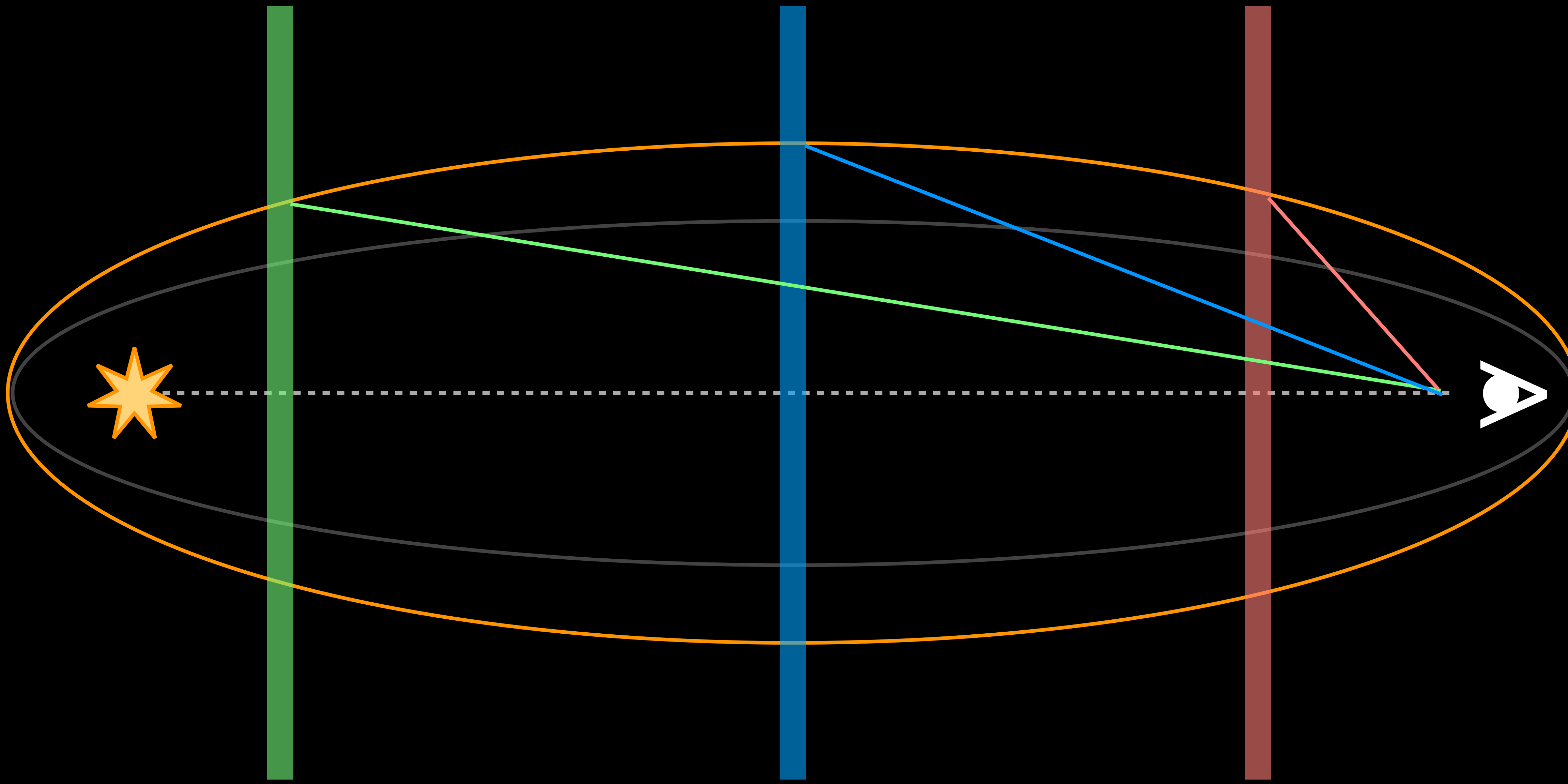
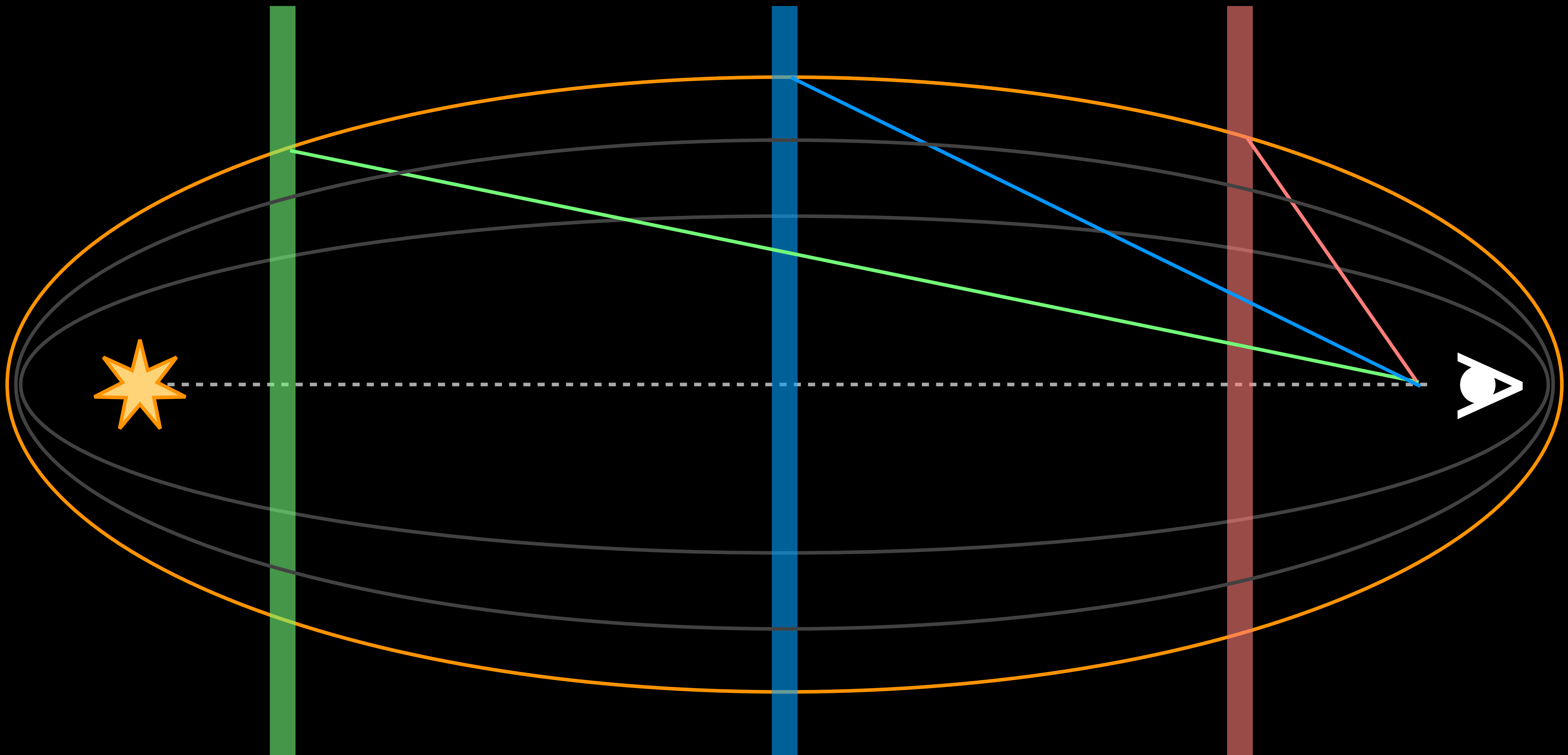
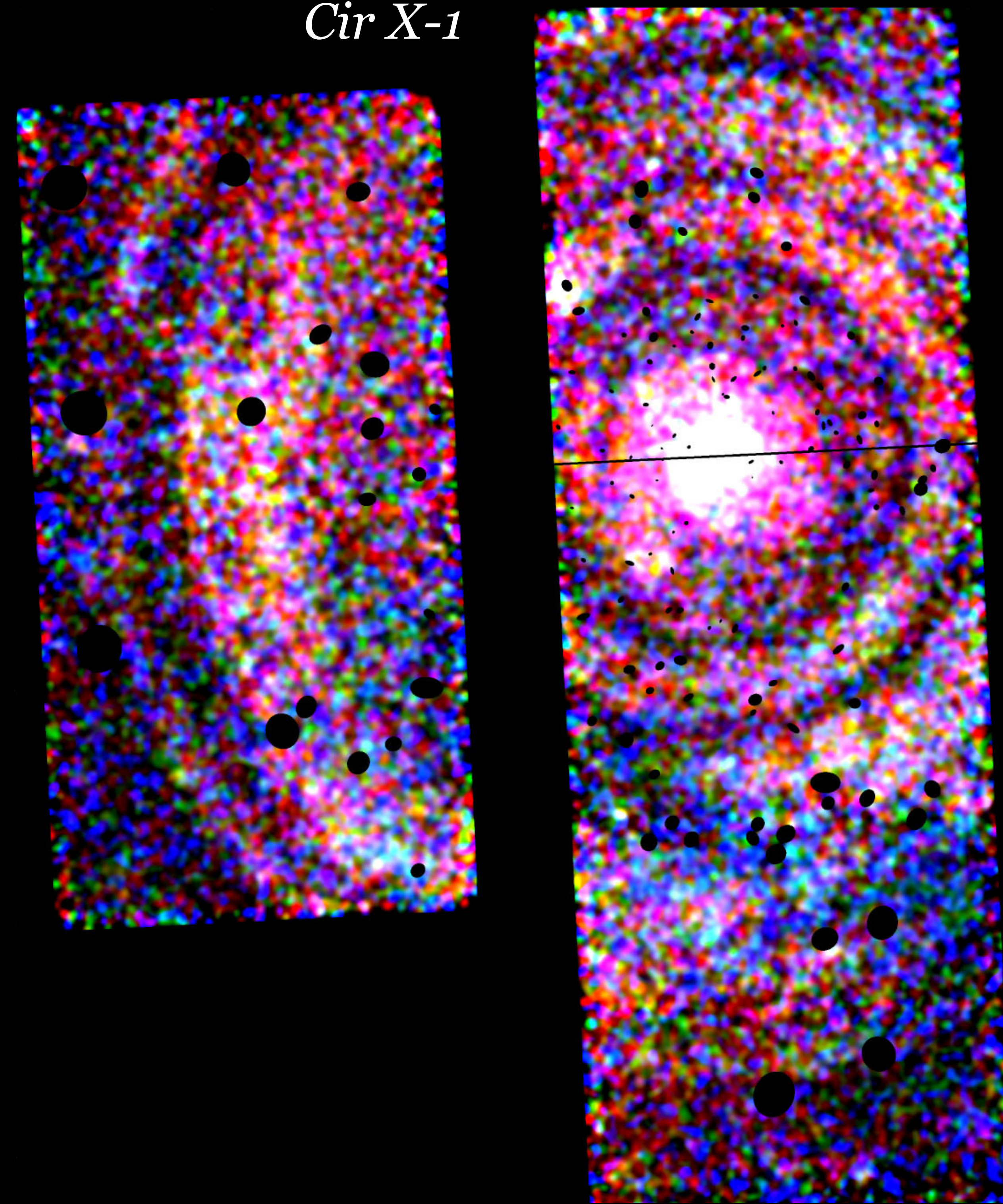




SGR J1550-5418

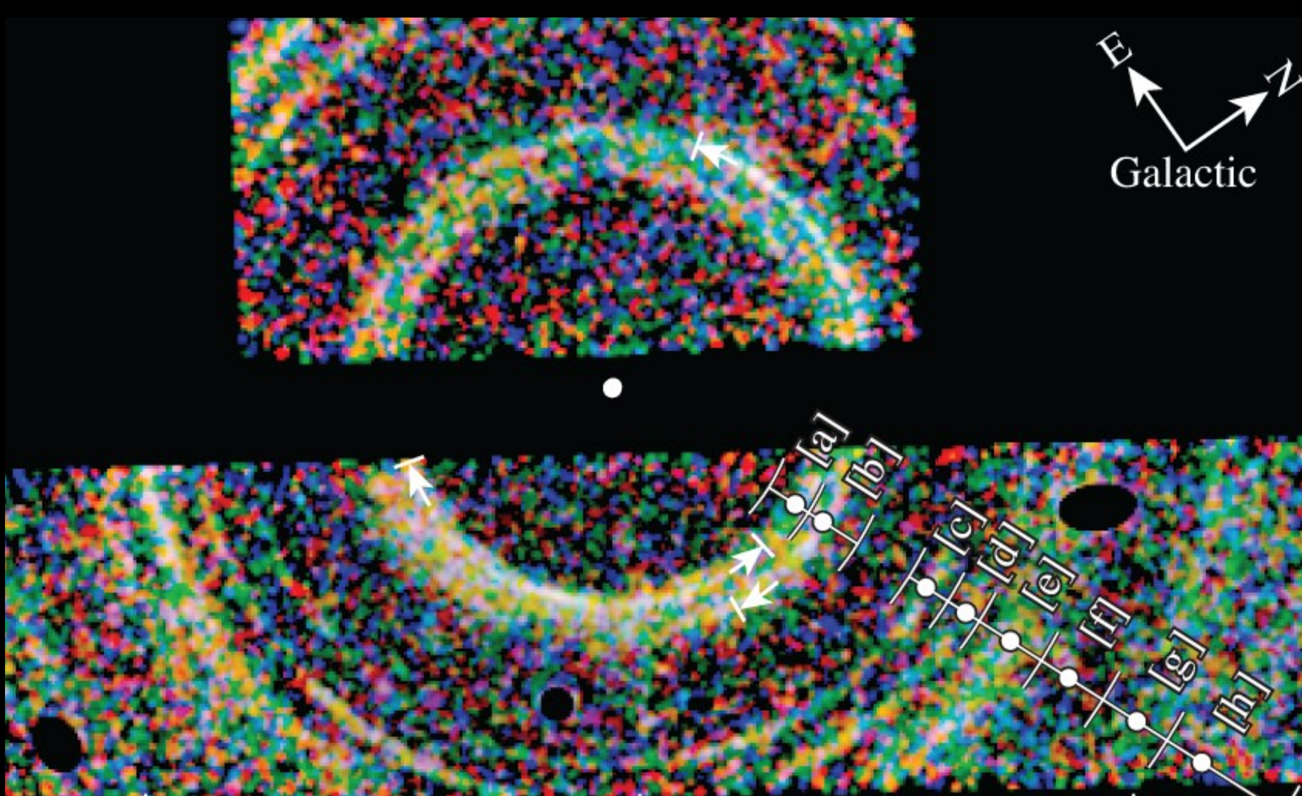
Tiengo et al. (2010) - movie by NASA/Swift/Halpern

Cir X-1



Heinz et al. (2015)

V404 Cygni



Heinz, Corrales, et al.

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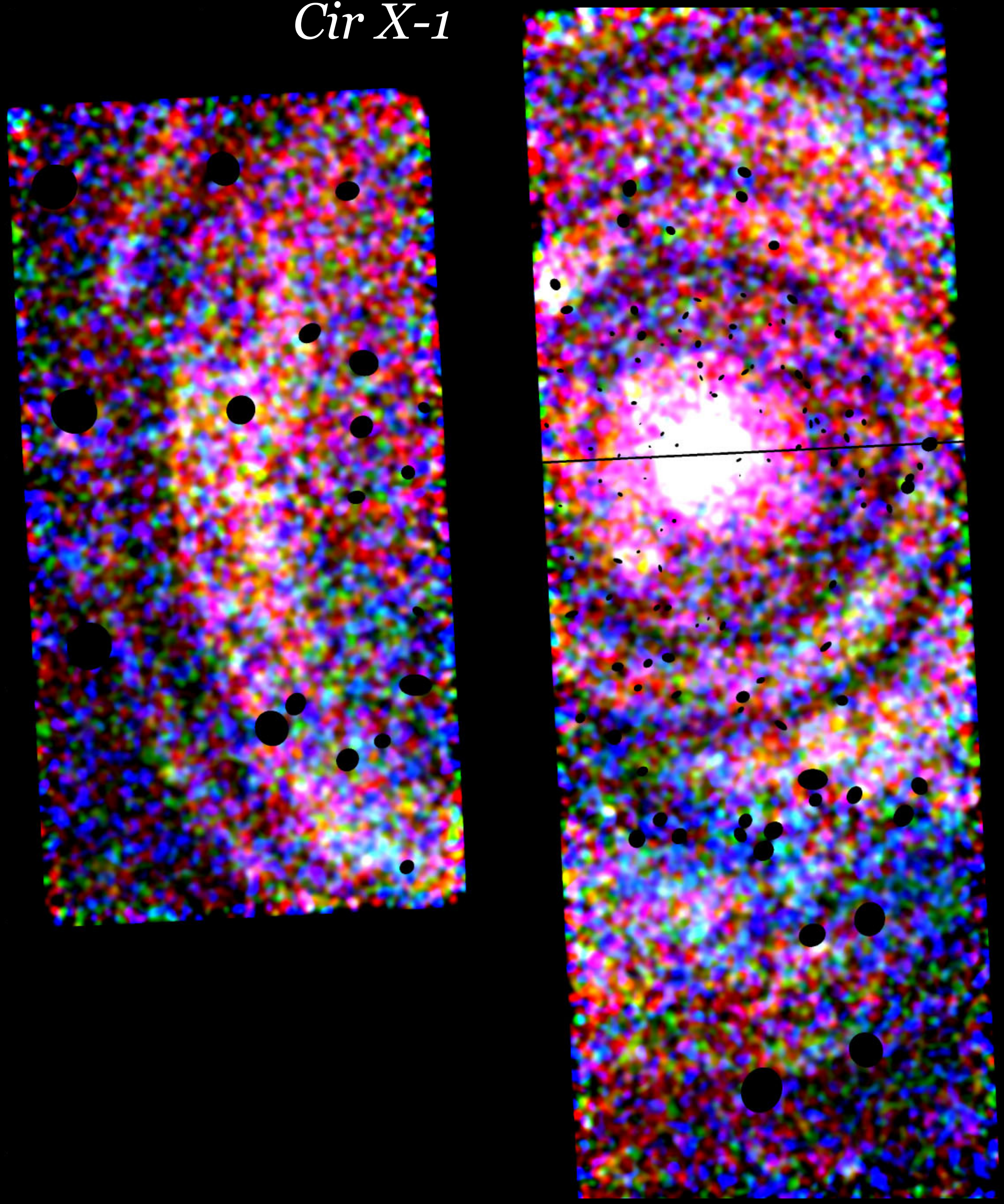

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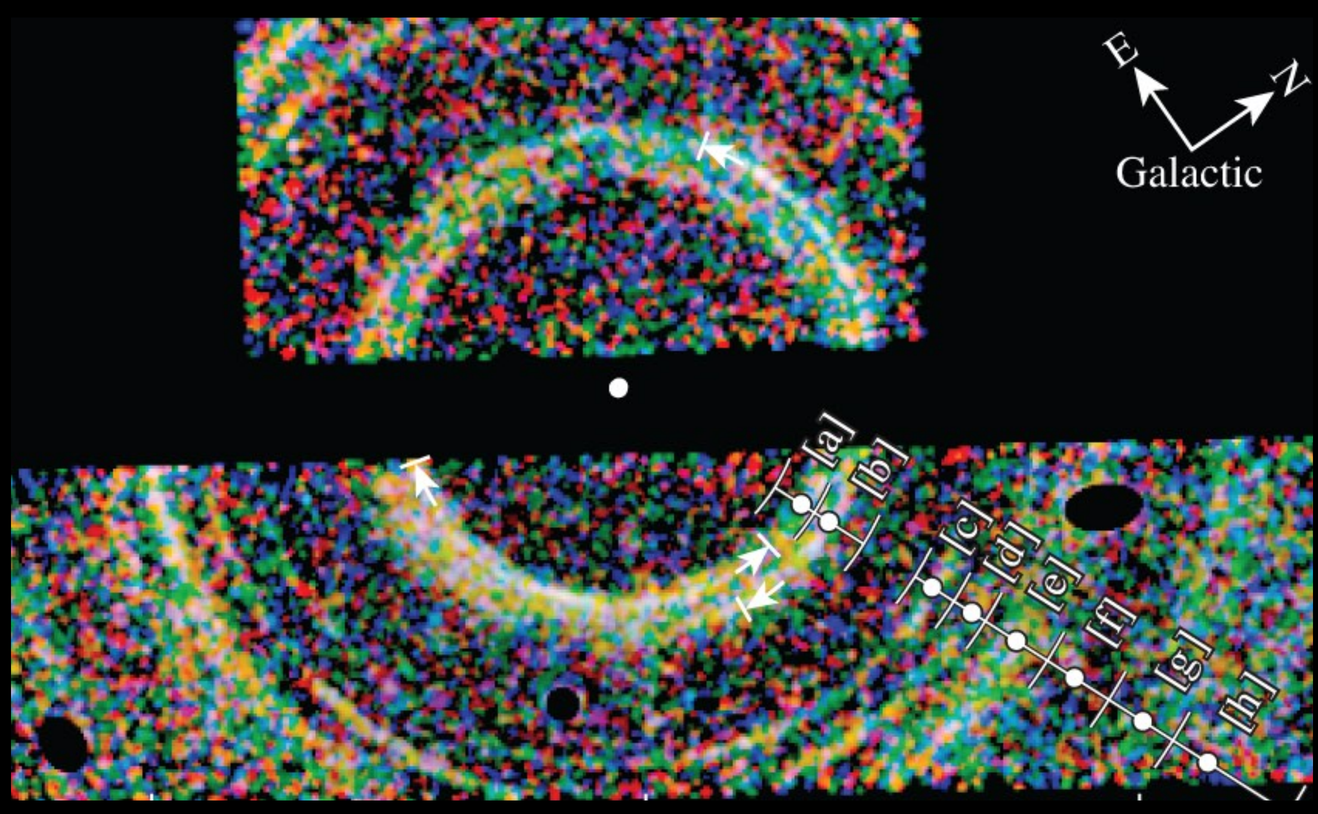
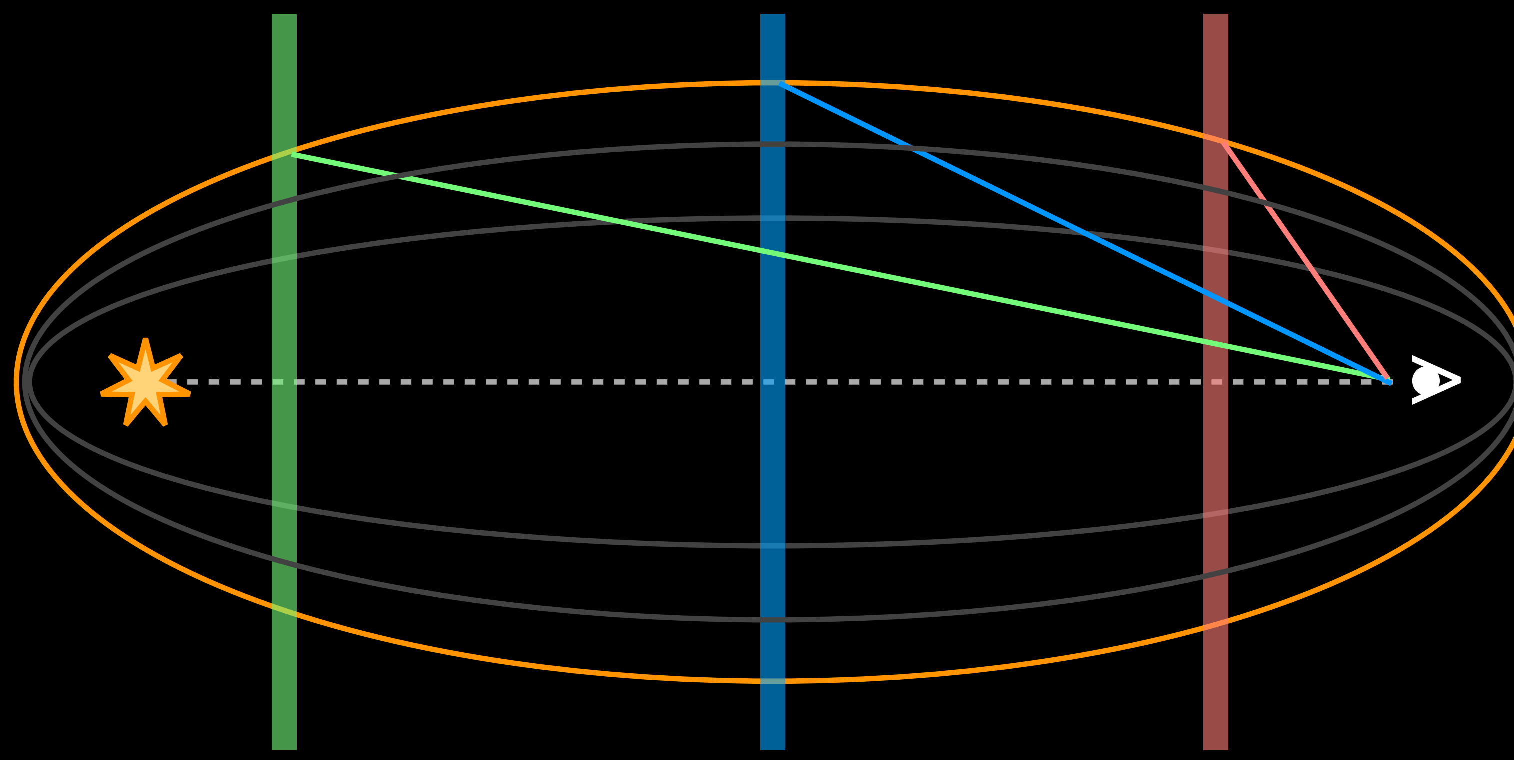


Heinz, Corrales, et al.

Nature's Recipe for Scattering Rings

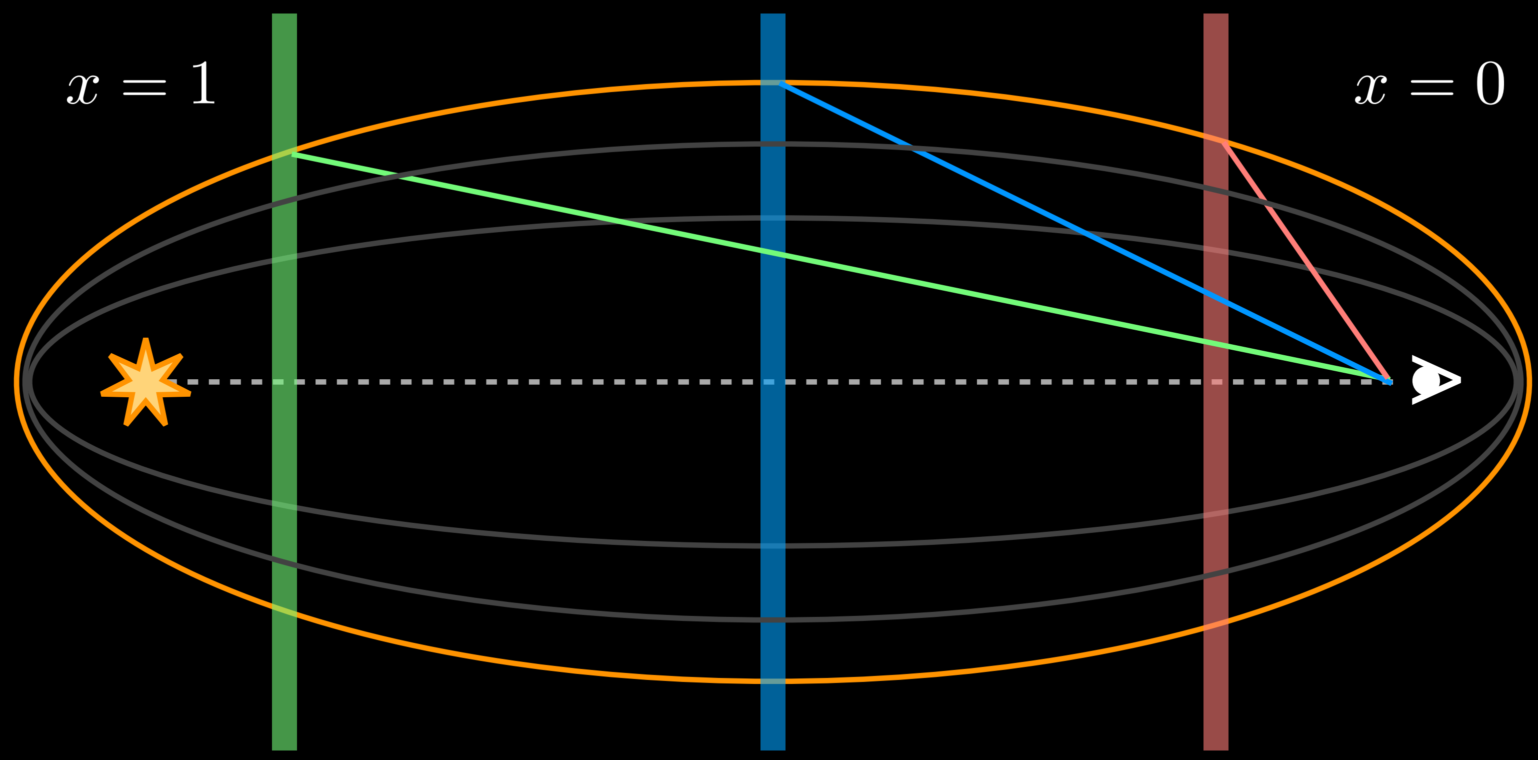


Bright outburst (0.1-1 Crab)

Brief outburst (3-10 days)

Fade to **quiescence** quickly (< 3 days)

To measure absolute distances, need to know **d** or **D**



$$\Delta t \approx 10 \text{ hours} \left(\frac{\theta}{\text{arcmin}}\right)^2 \left(\frac{D}{8 \text{ kpc}}\right) \frac{x}{(1-x)}$$

$$x \equiv \frac{d \text{ (cloud)}}{D \text{ (source)}}$$

– a job for multi-wavelength datasets!

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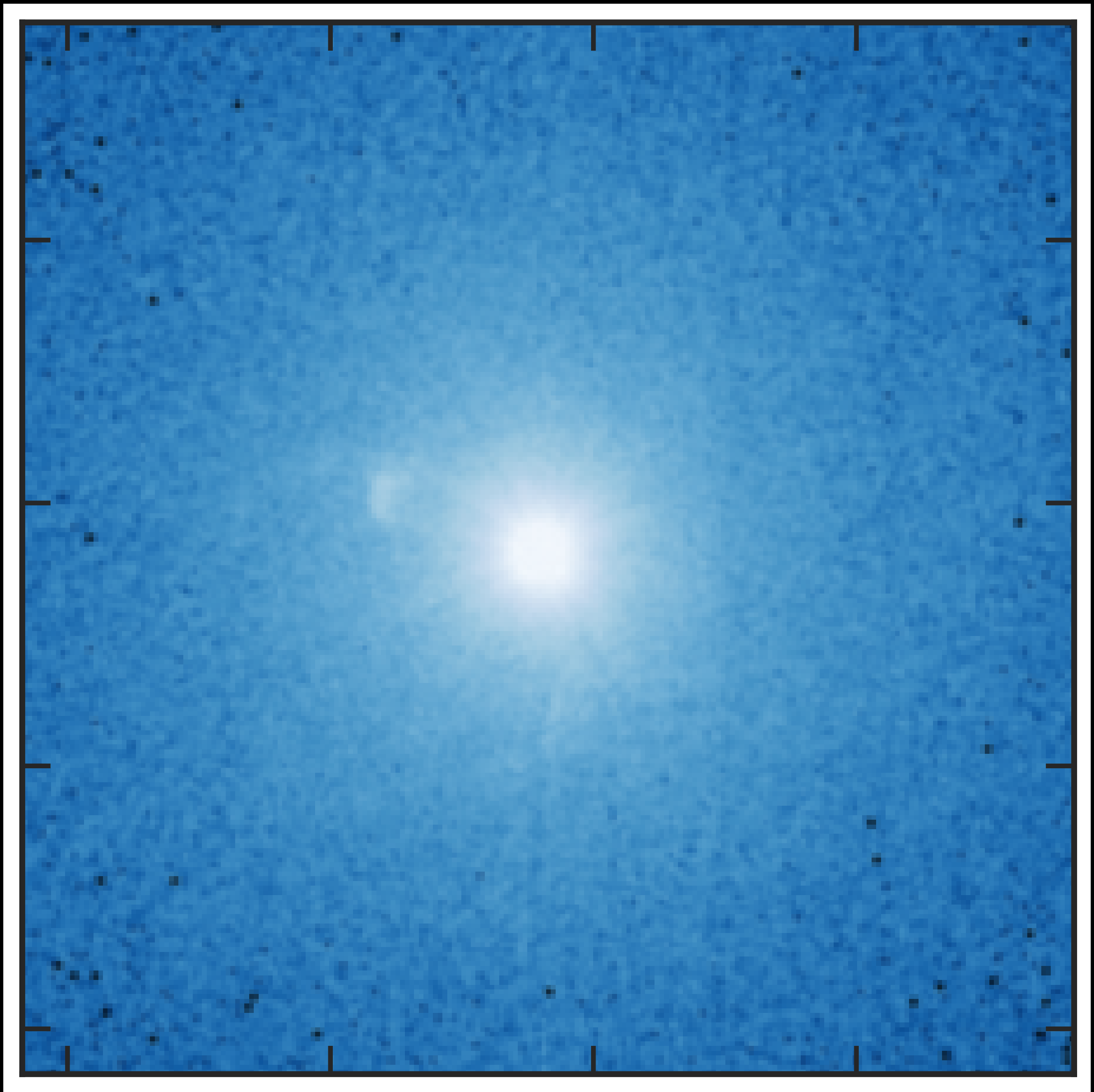
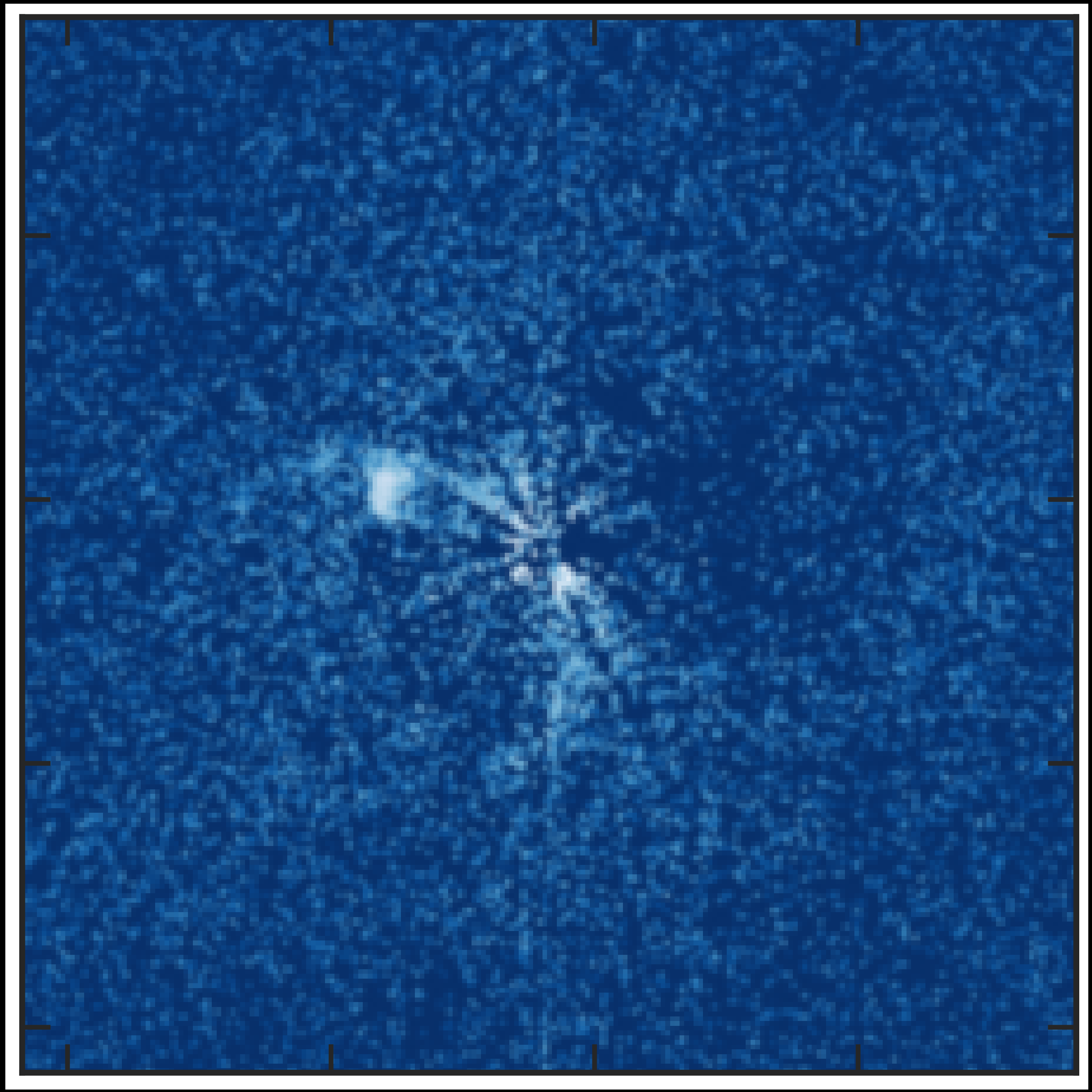
Cyg X-3's "Little Friend"

Cyg X-3 (Chandra)

D (Cyg X-3) = 7-13 kpc (Predehl+ 2000)



Cleaned image



After subtracting mean counts (vs radius)

McCollough et al. 2012, images by Corrales

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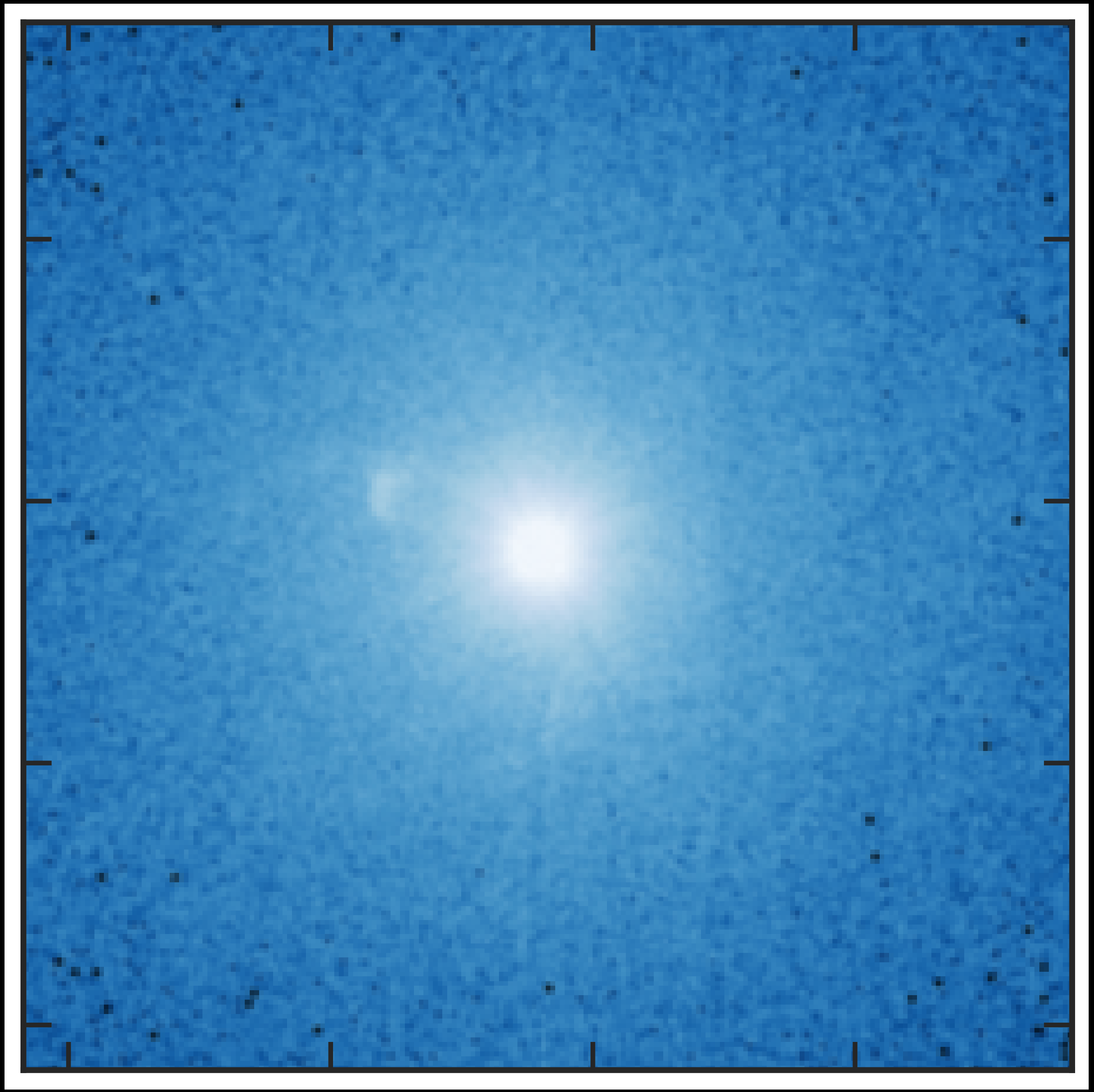

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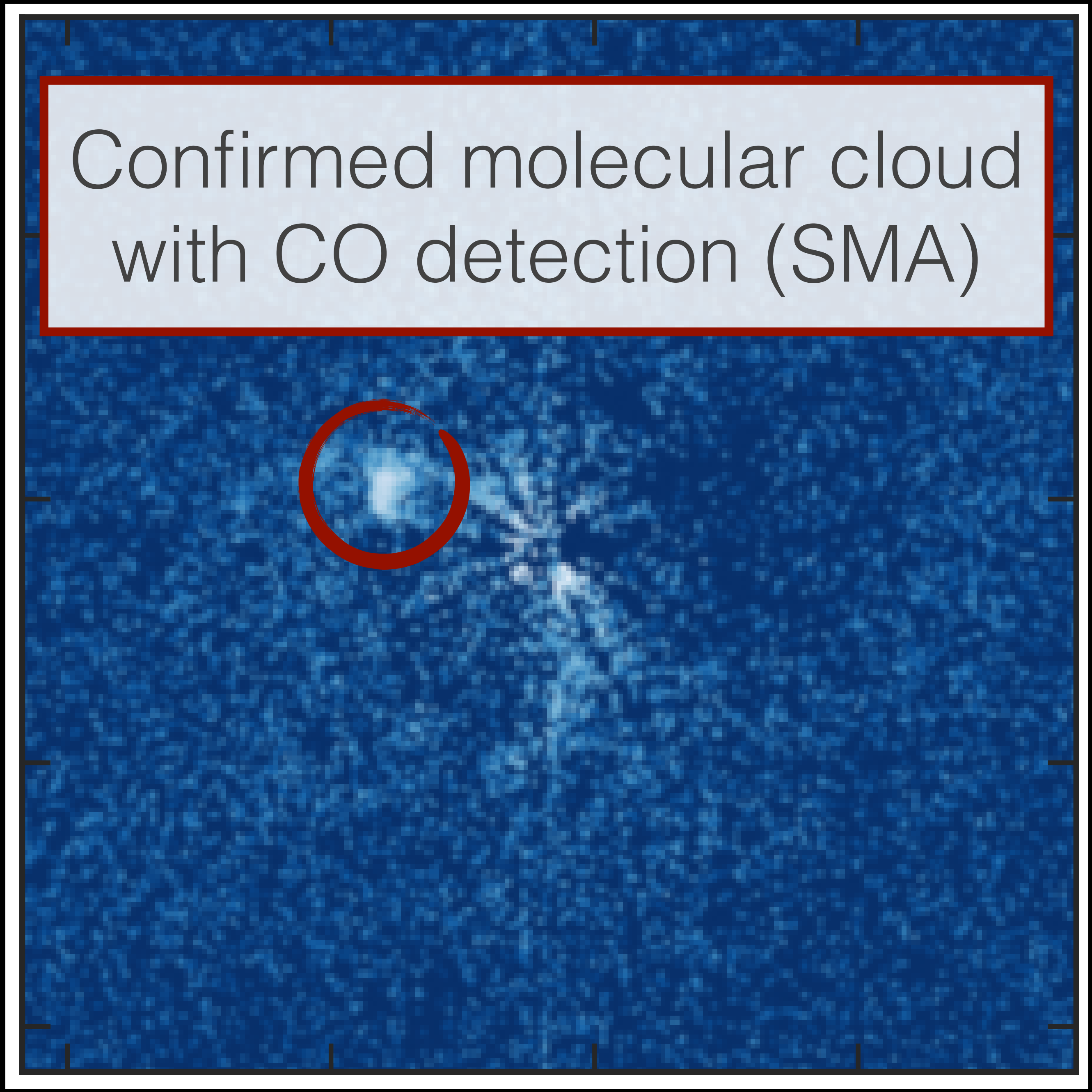

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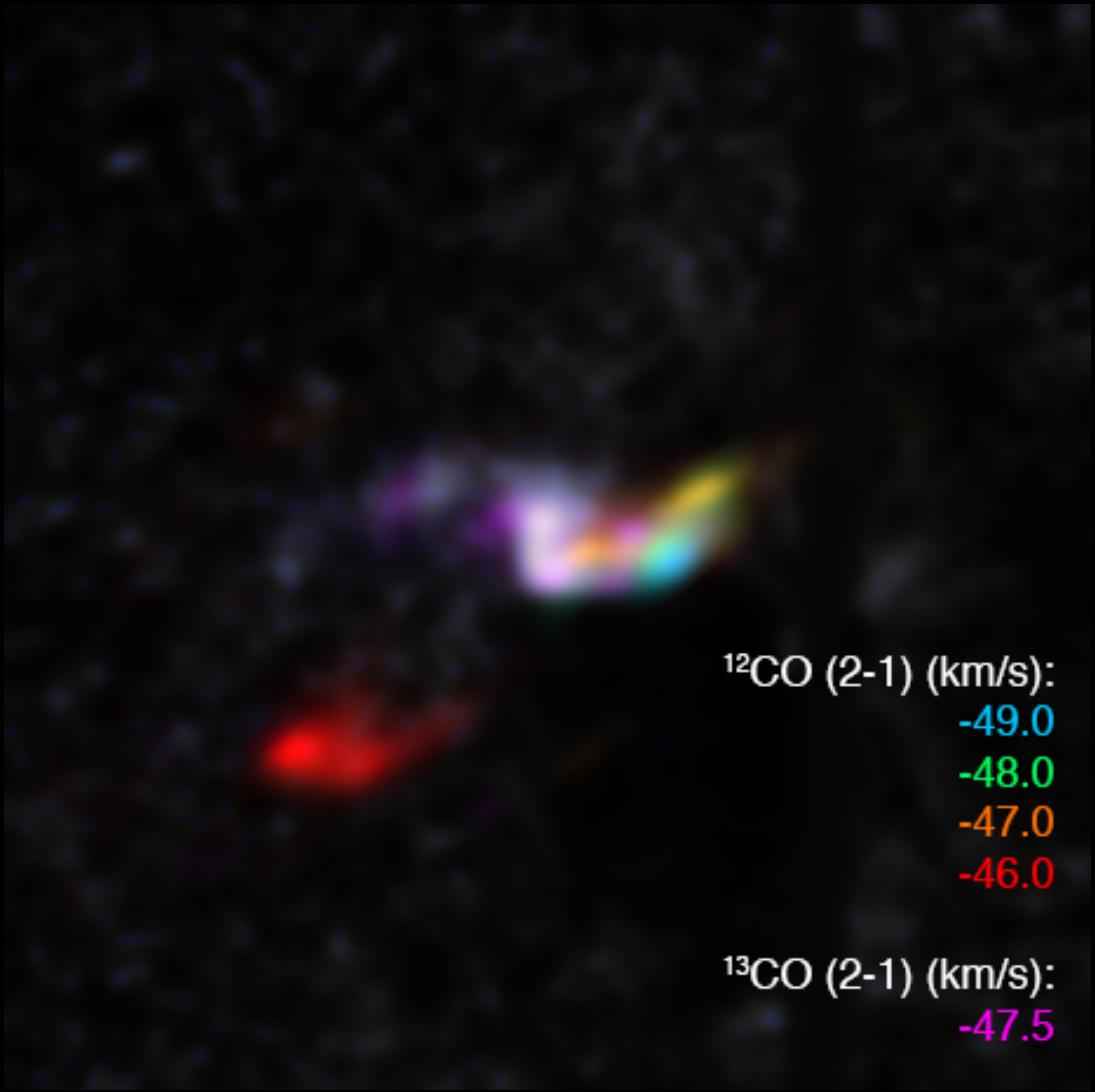

McCollough, Corrales, & Dunham (2016)

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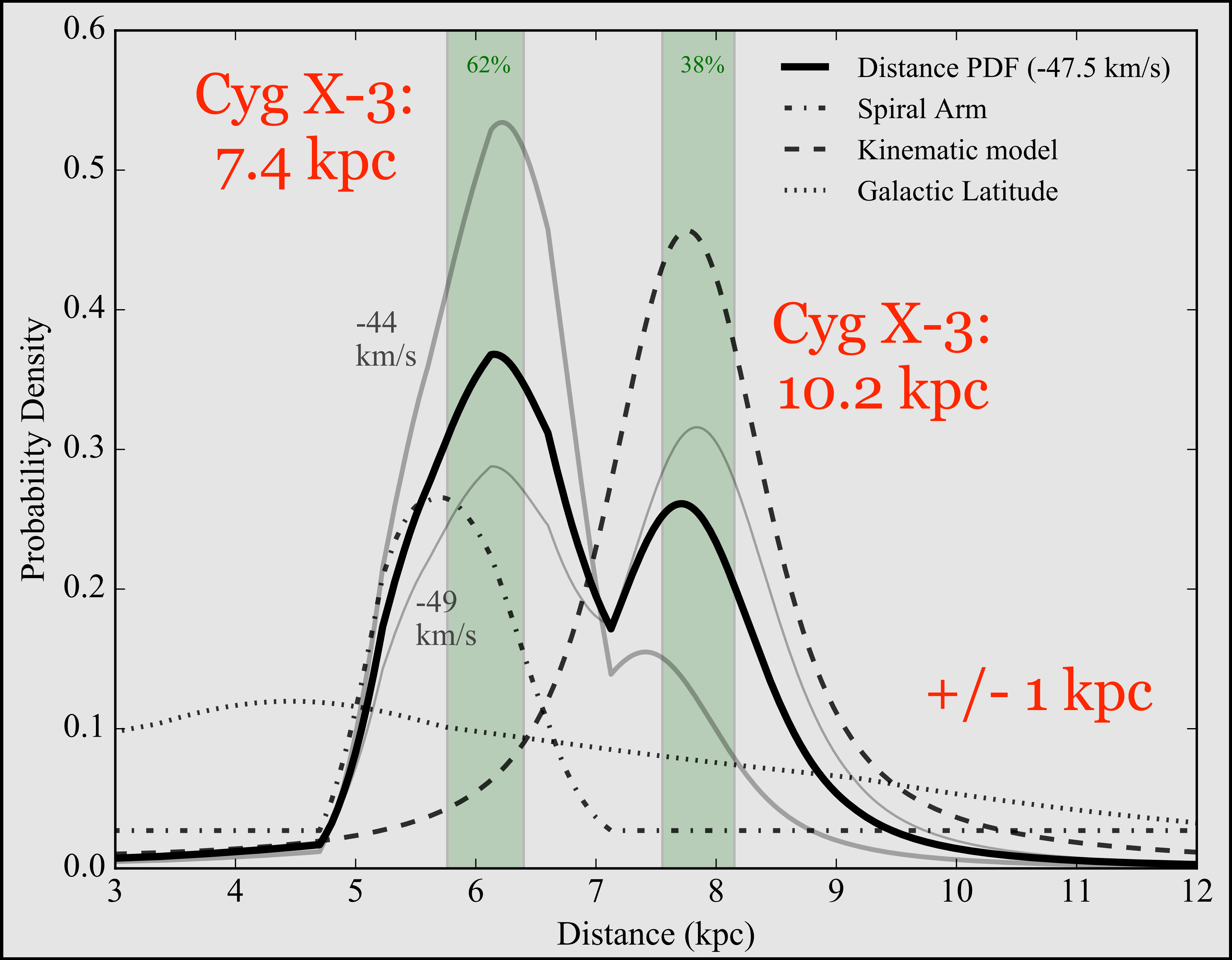


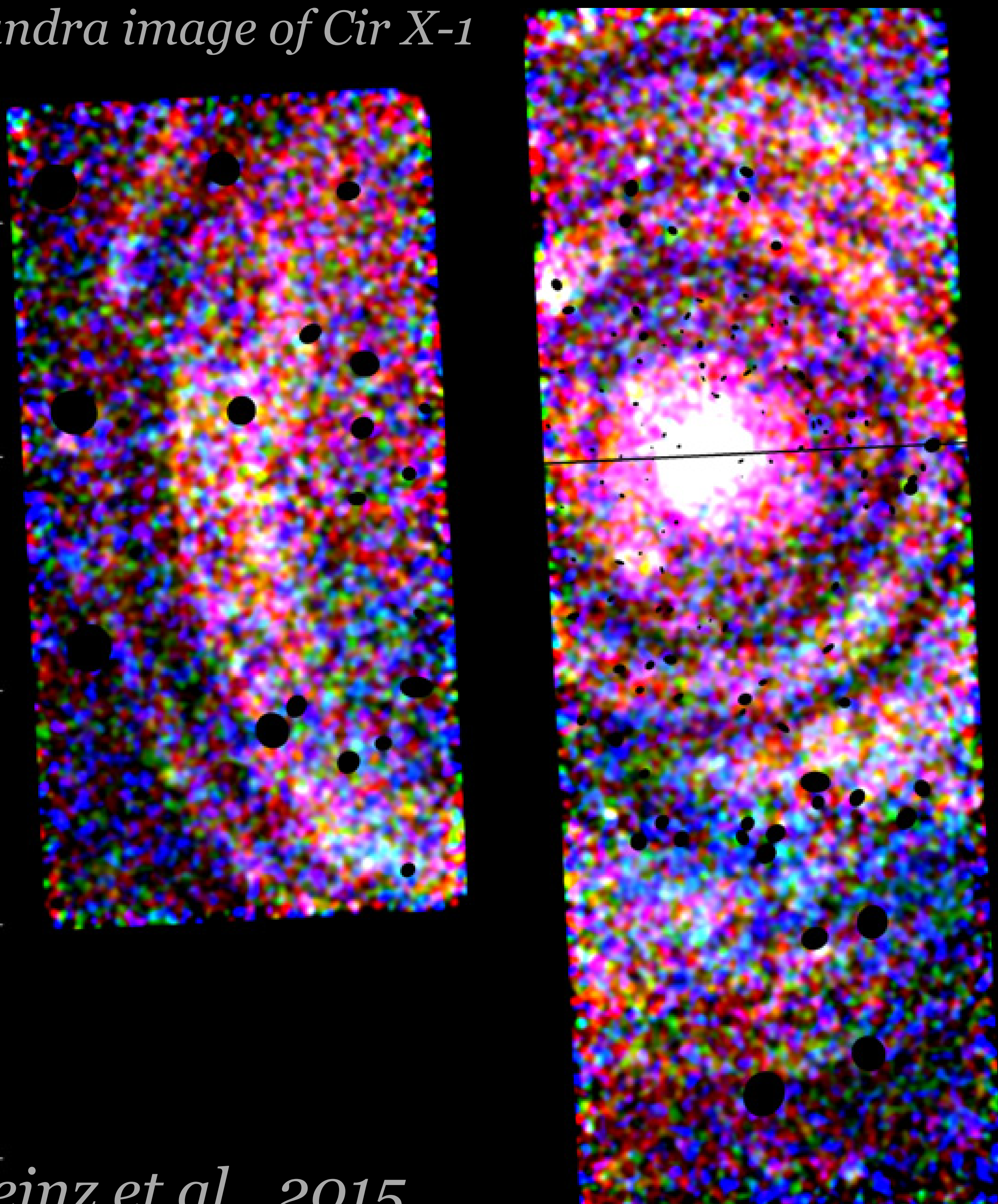
McCollough, Corrales, & Dunham (2016)

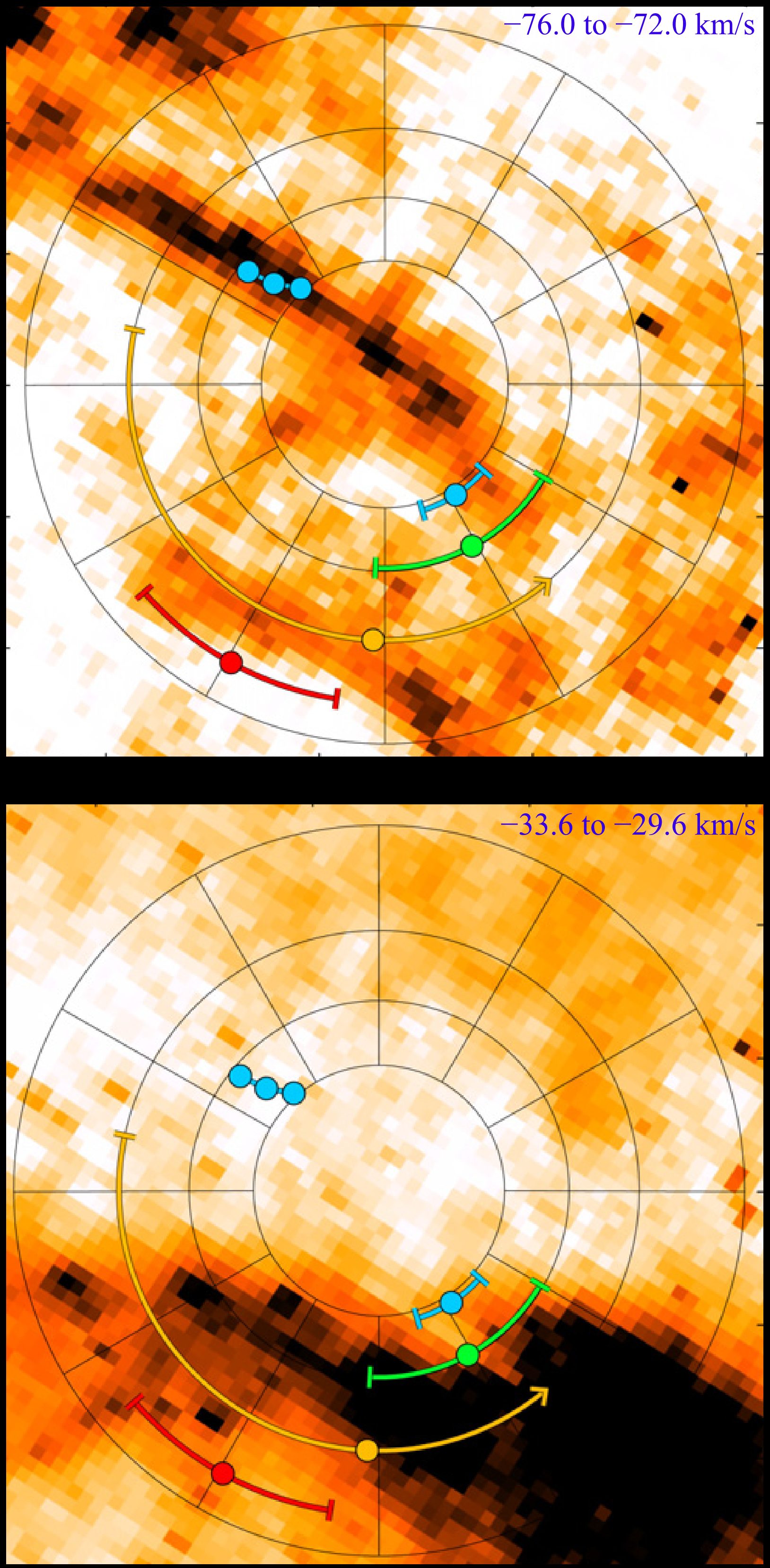
Circinus X-1

D ~ 4 - 11 kpc (previously)

D = 9.4 +/- 1 kpc (now)

Chandra image of Cir X-1



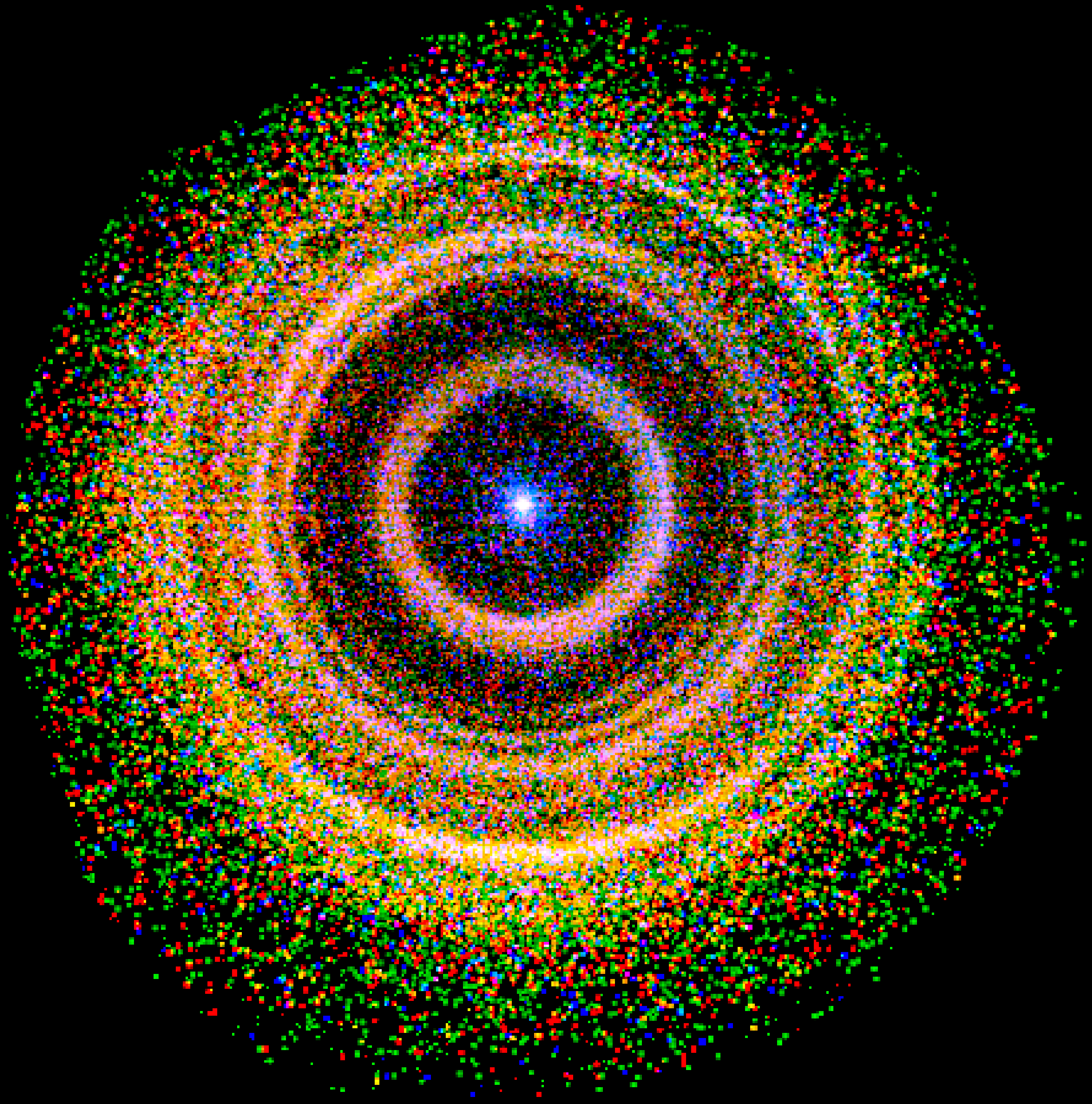


Heinz et al., 2015

Mopra CO maps

V404 Cygni

D (V404) = 2.39 +/- 0.14 kpc
VLBI, Miller-Jones+ 2009



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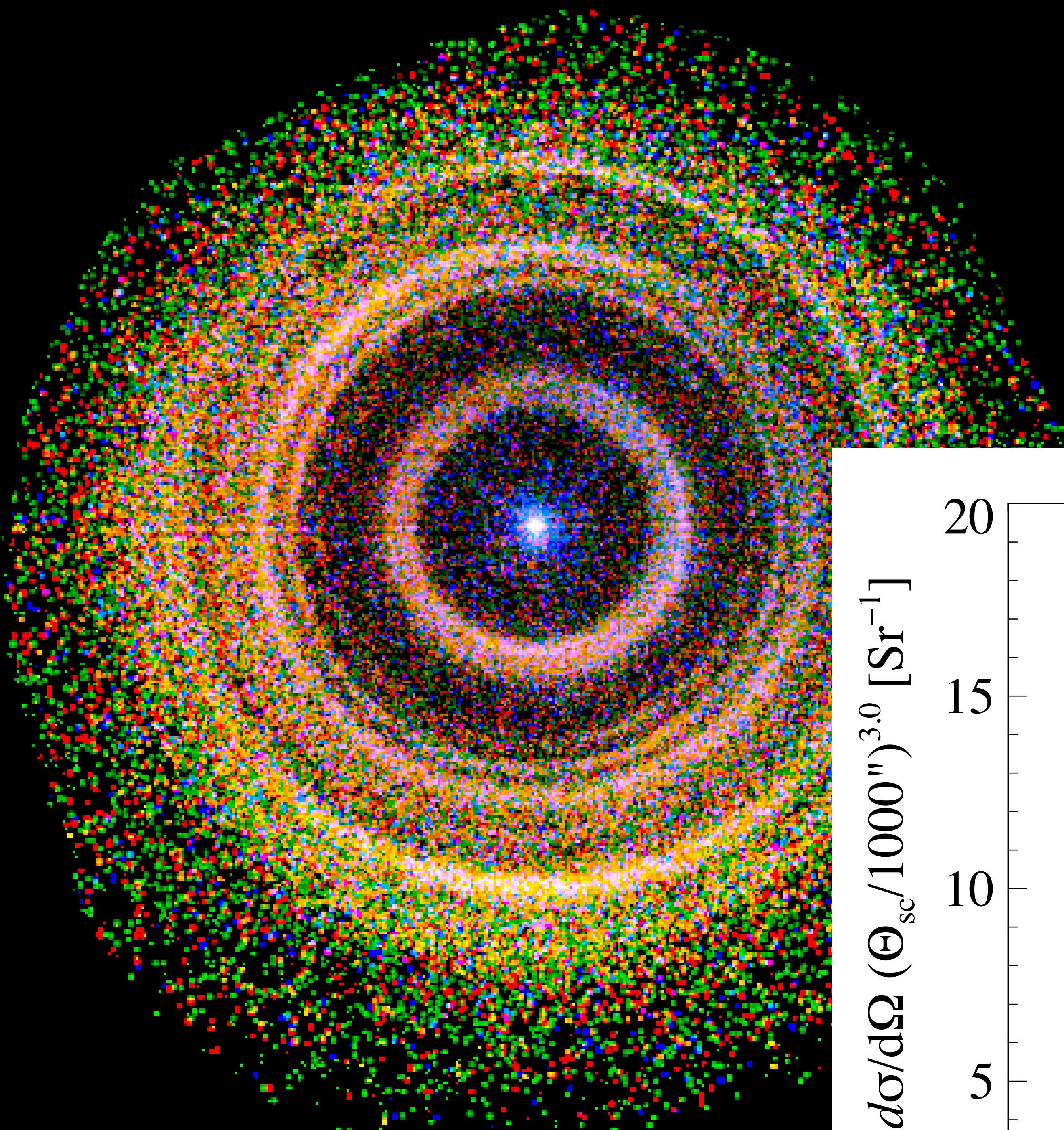
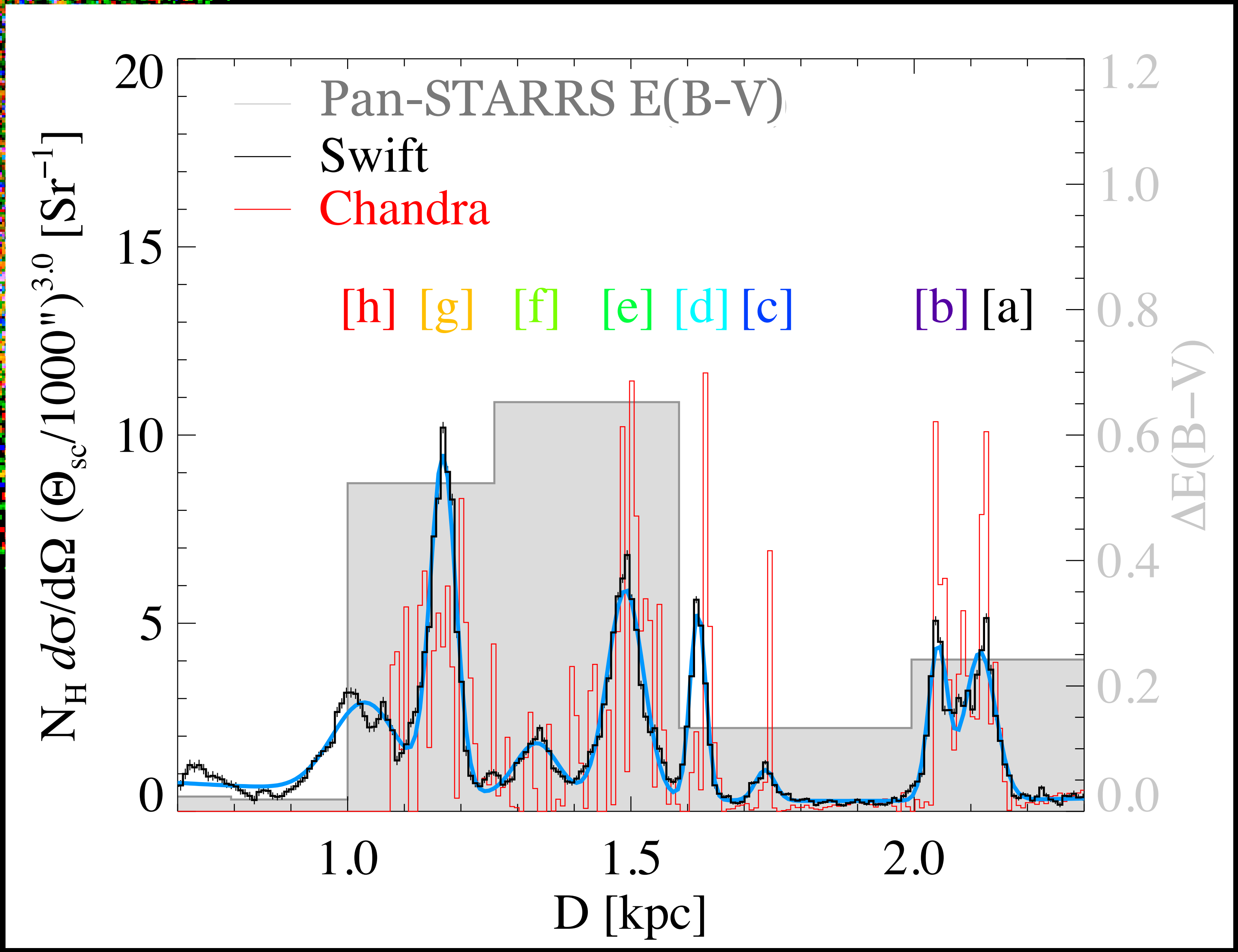
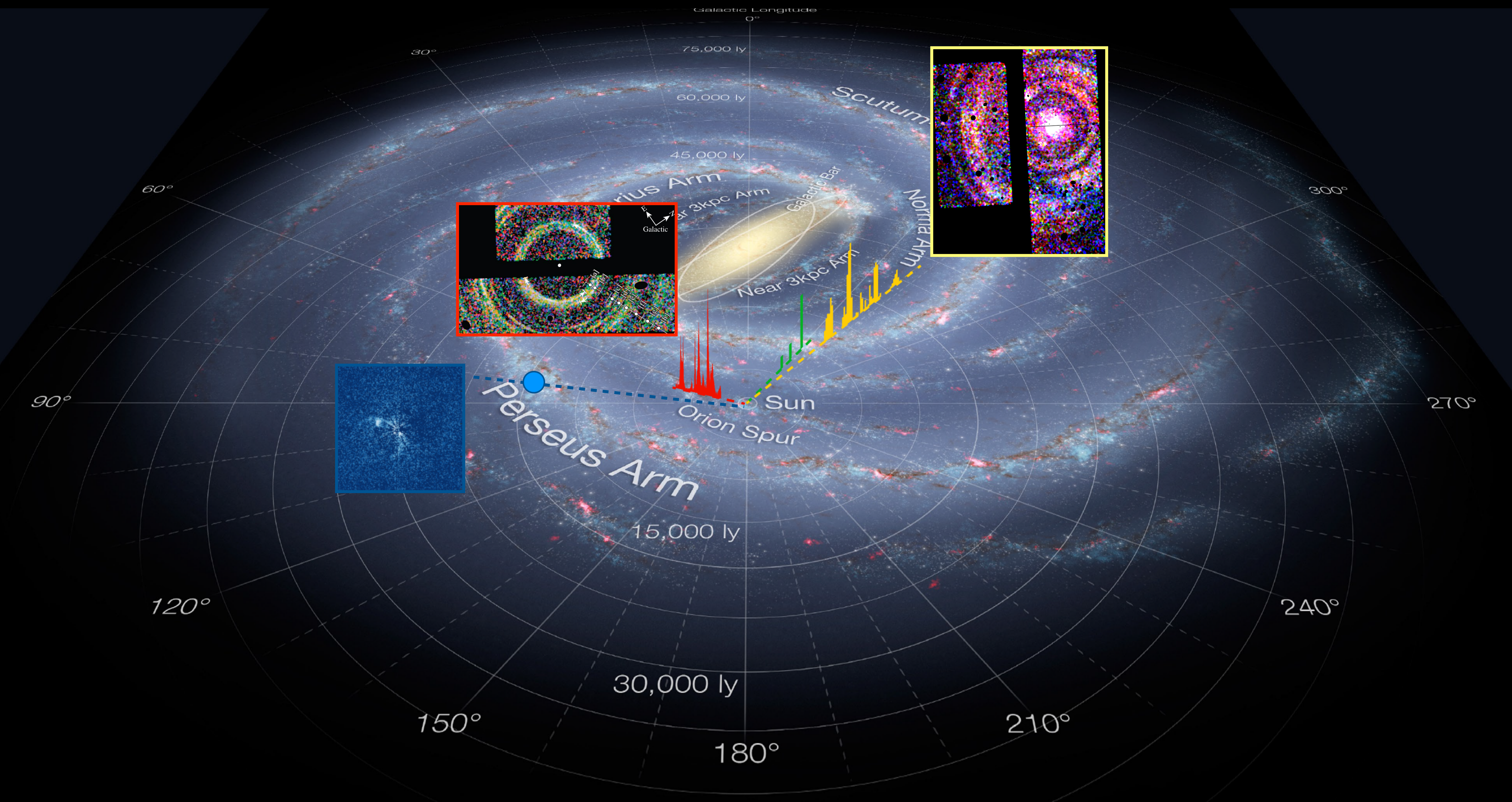




Heinz, Corrales, et al. 2016

X-ray scattering map of the Milky Way as of now



Dust echo brightness is directly proportional to **fluence** (time integrated flux)

Nature's Recipe for Dust Scattering Echoes

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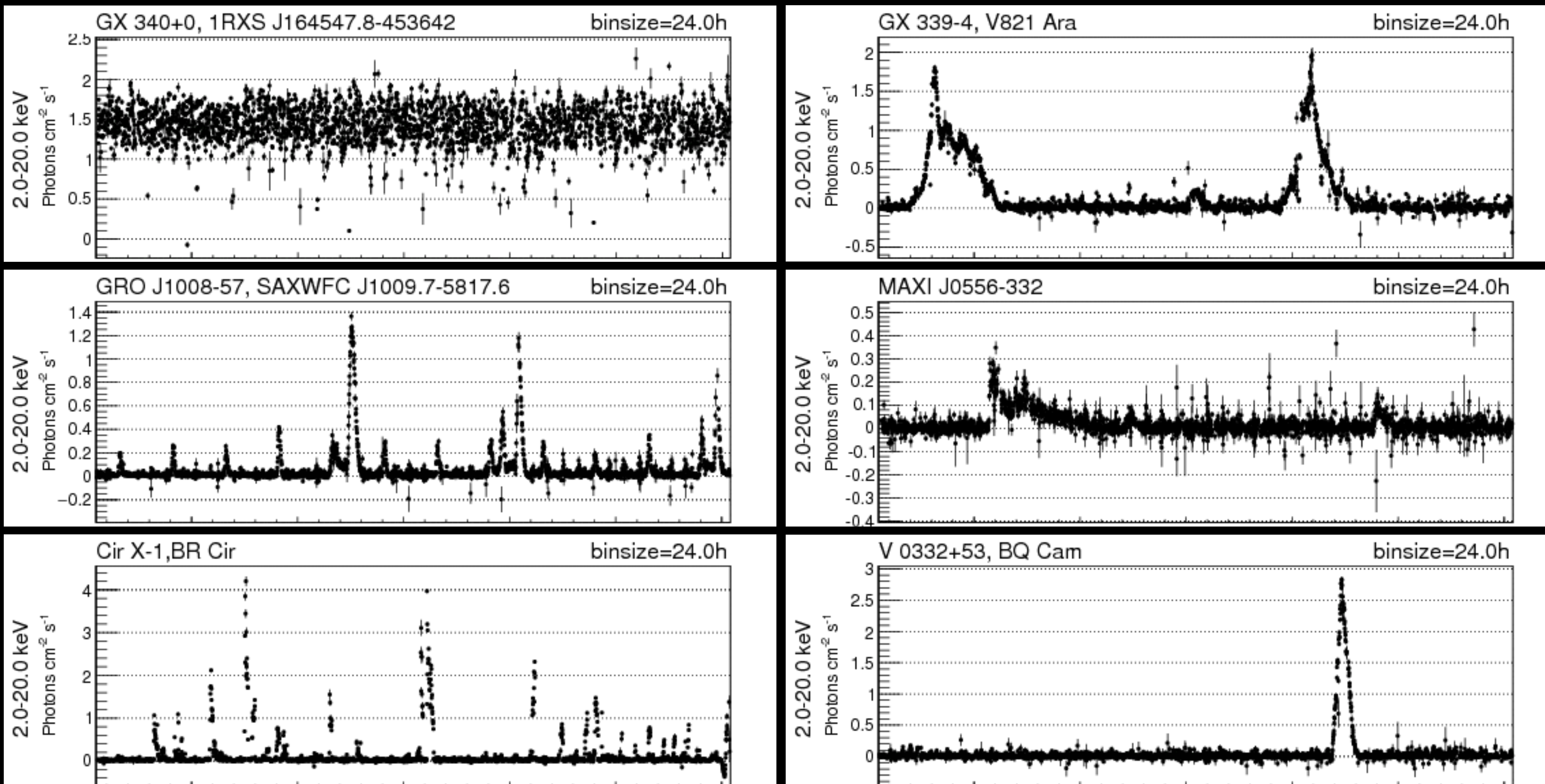
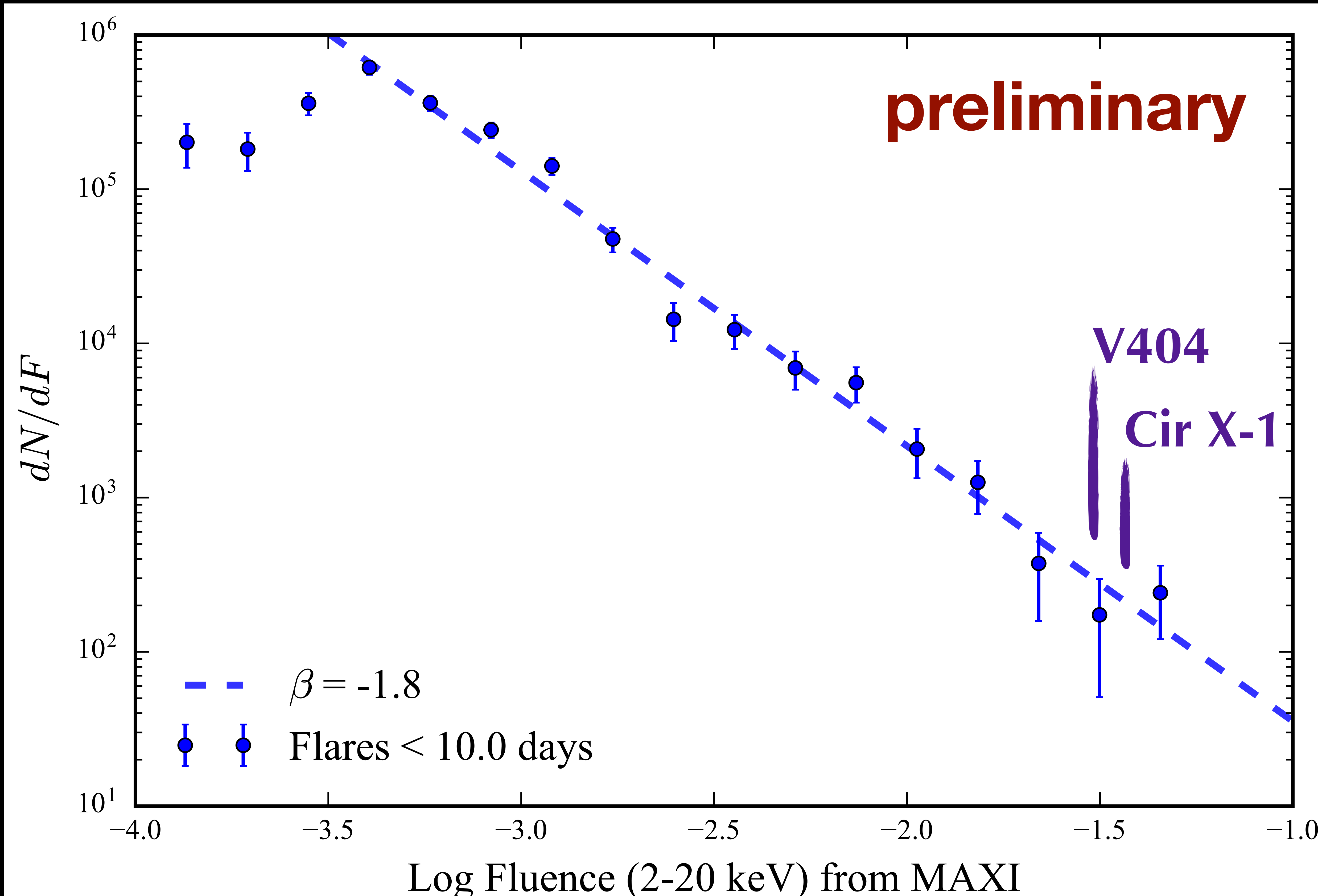
7 years of MAXI



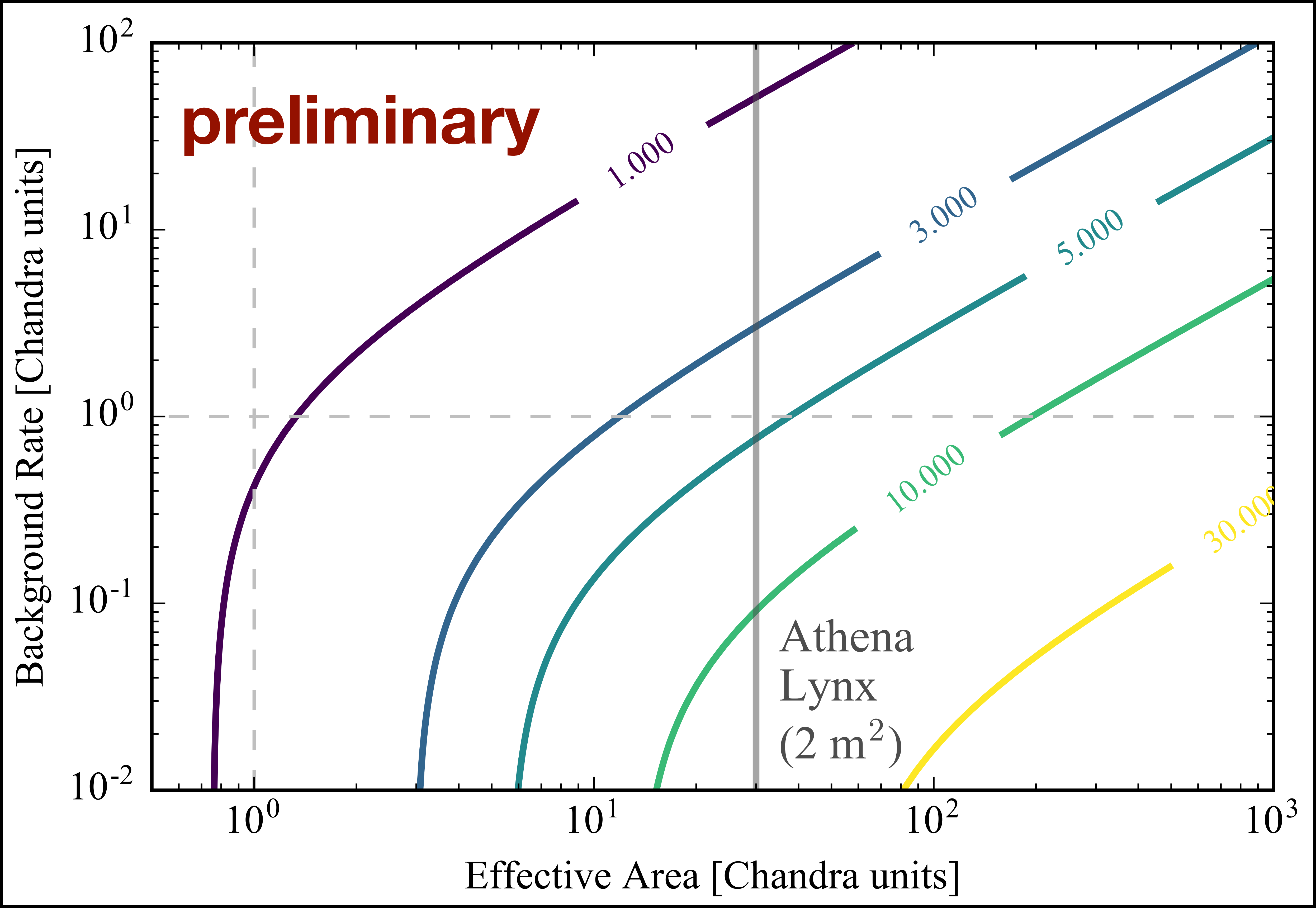
Use peak-finding algorithm and
calculate **fluence** of all **flare events**

Distribution of X-ray flares from all MAXI light curves



with Brianna Mills (REU student)

Echo discovery space compared to *Chandra*



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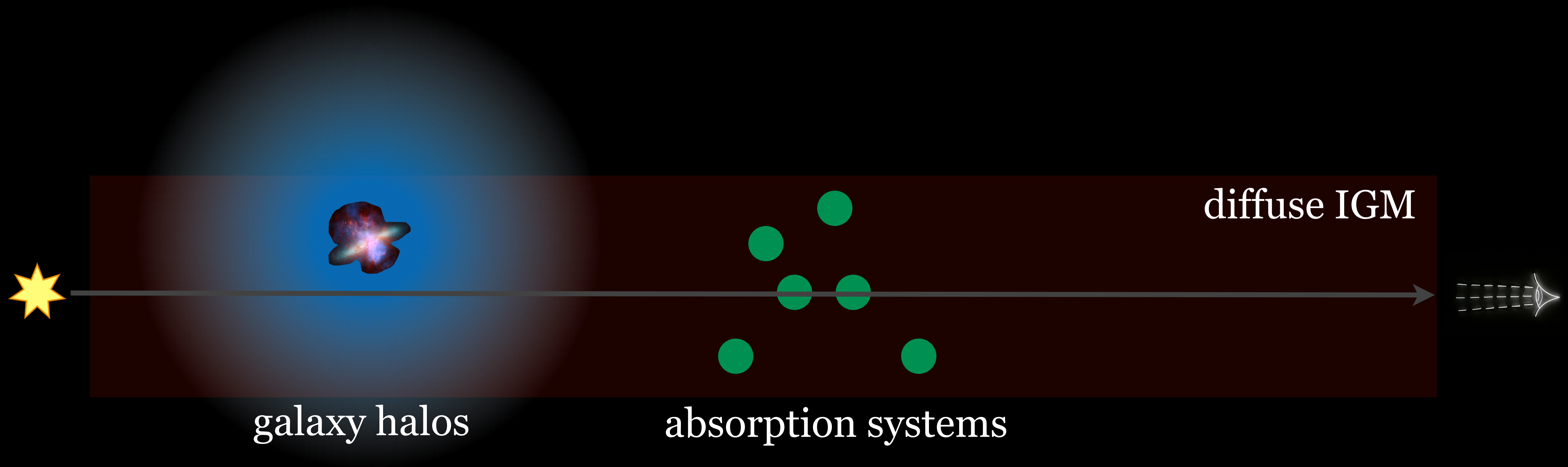
Search for extragalactic dust?



See works by:
Ménard et al. (2010)
Corrales & Paerels (2012)
Ménard & Fukugita (2012)
Peek, Ménard, & Corrales (2015)
Corrales (2015)

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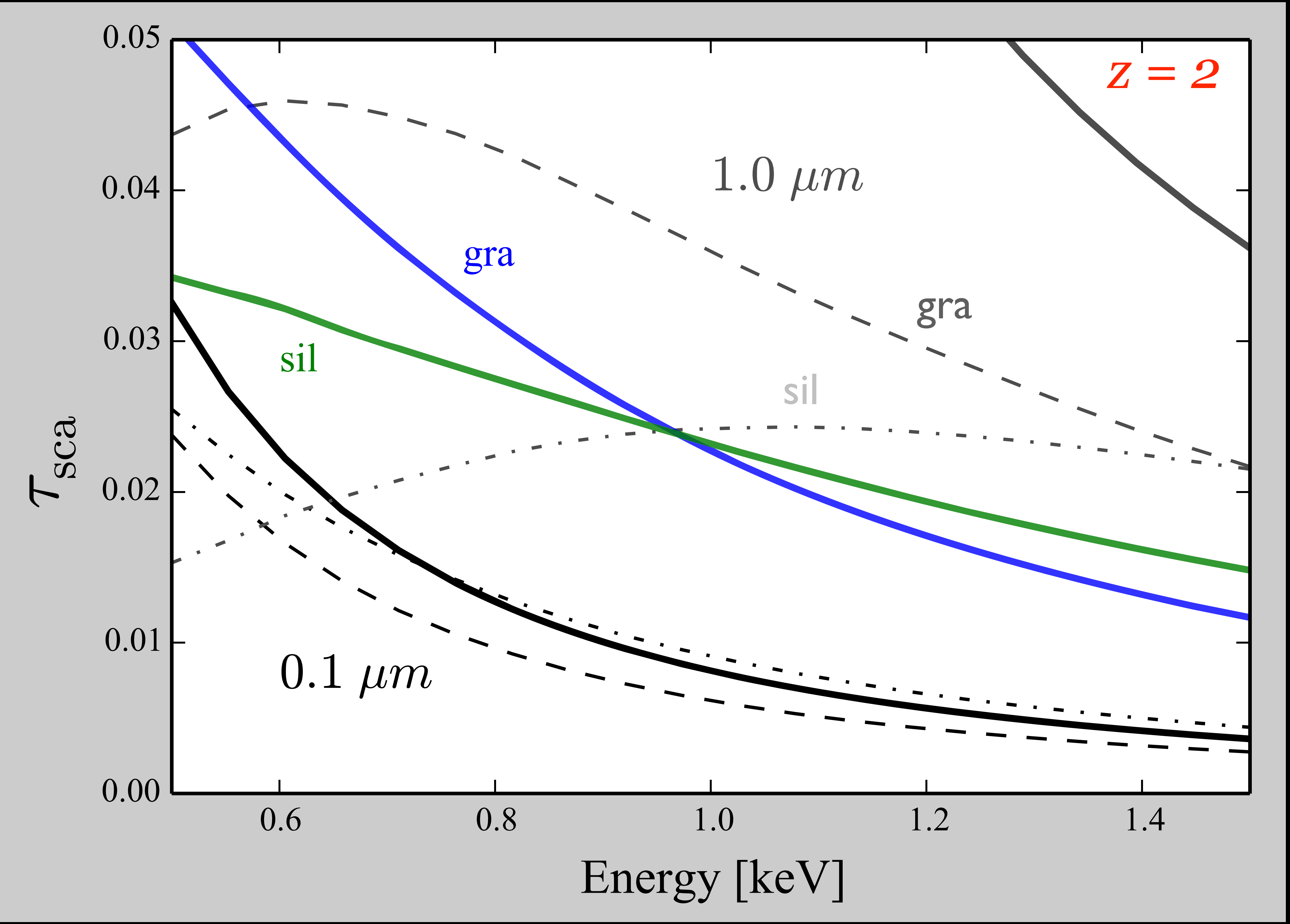
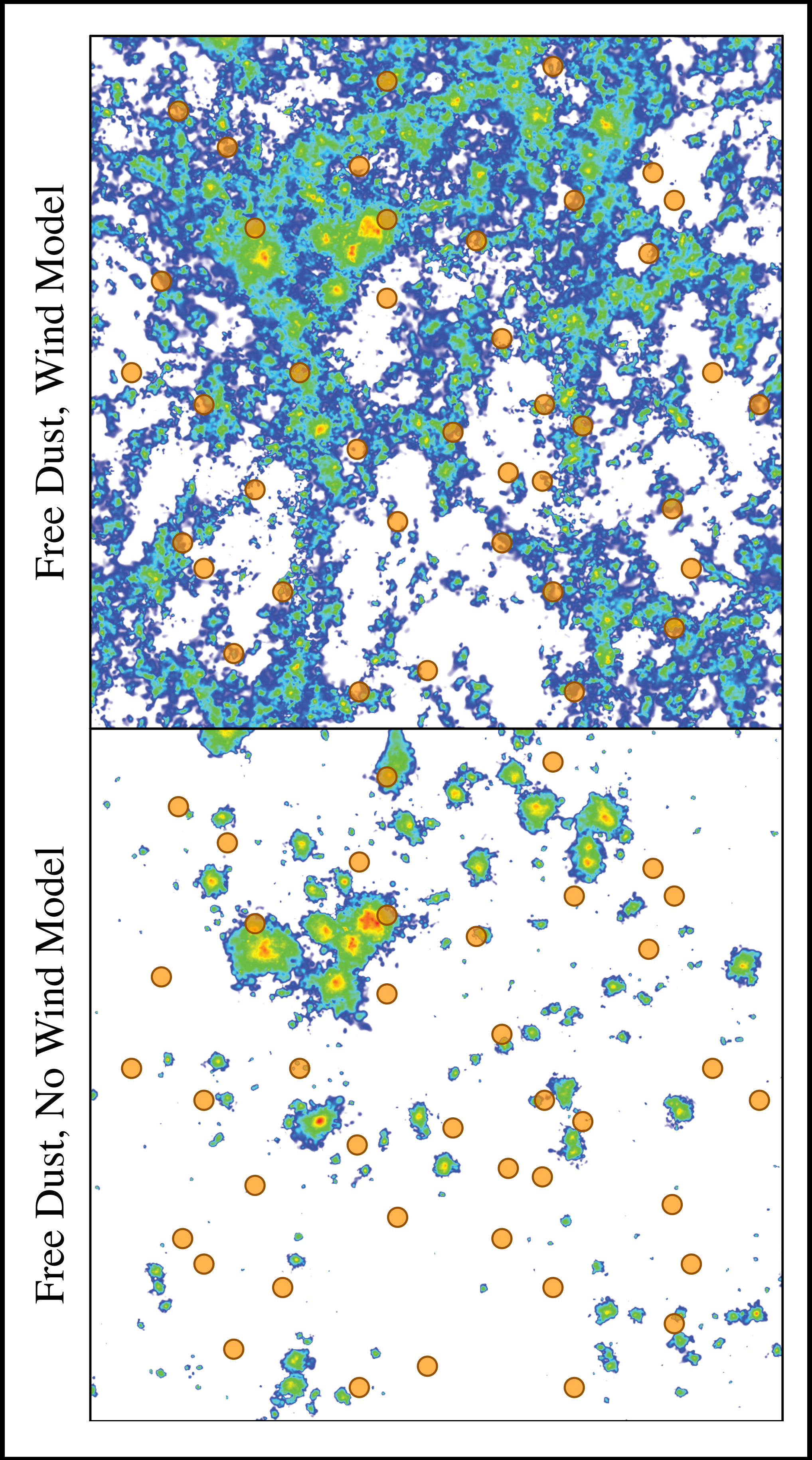
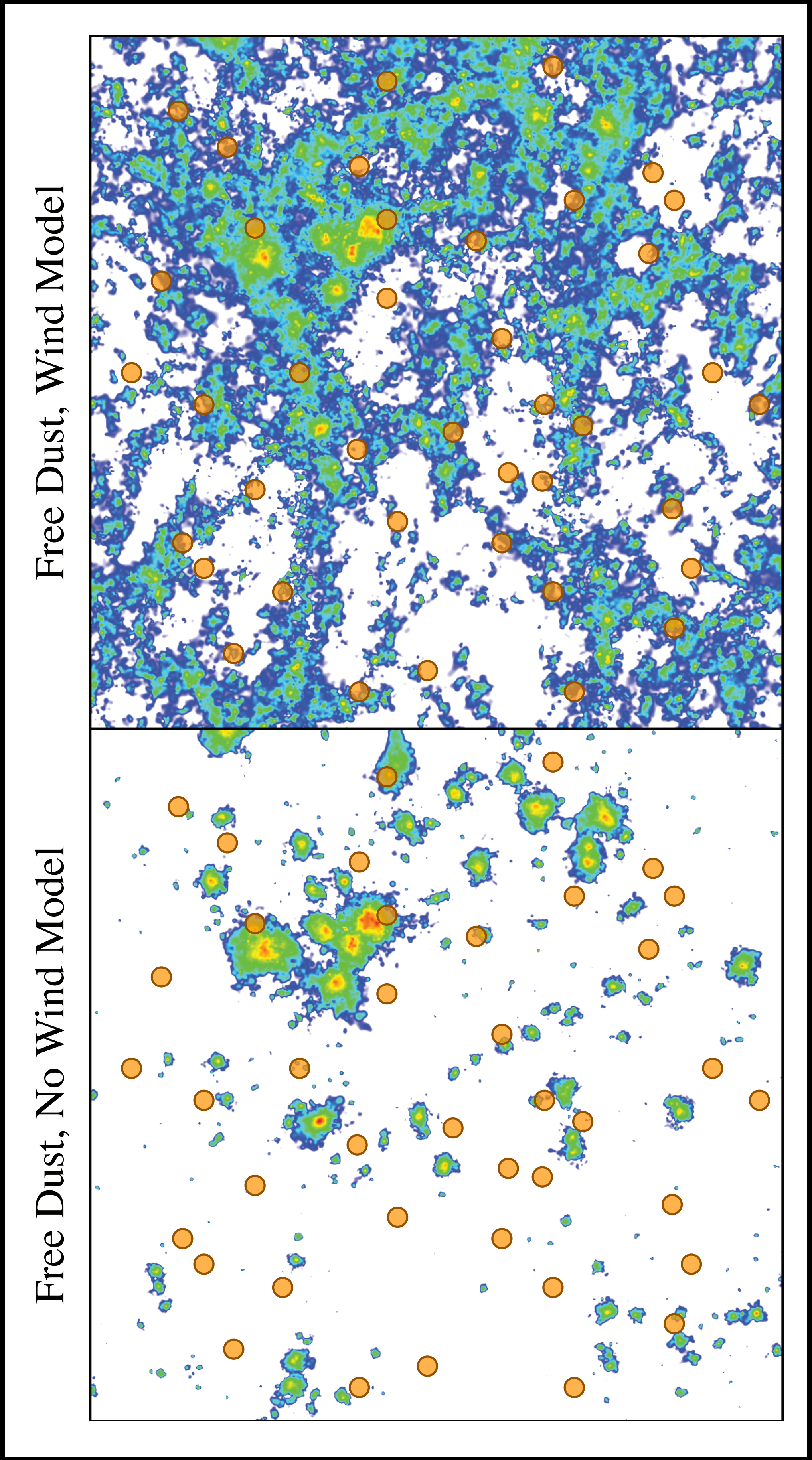
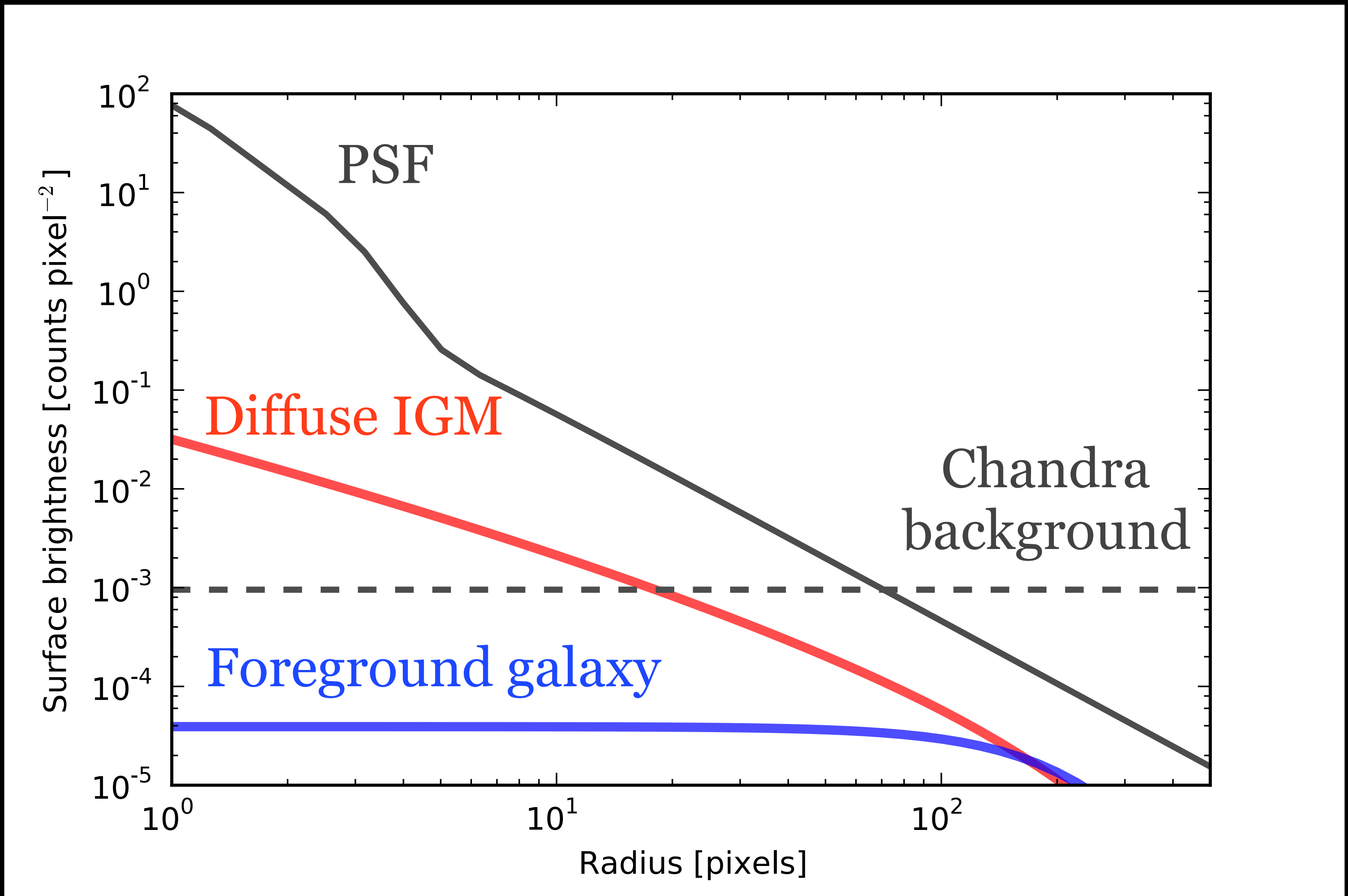


Corrales & Paerels 2012, Corrales 2015

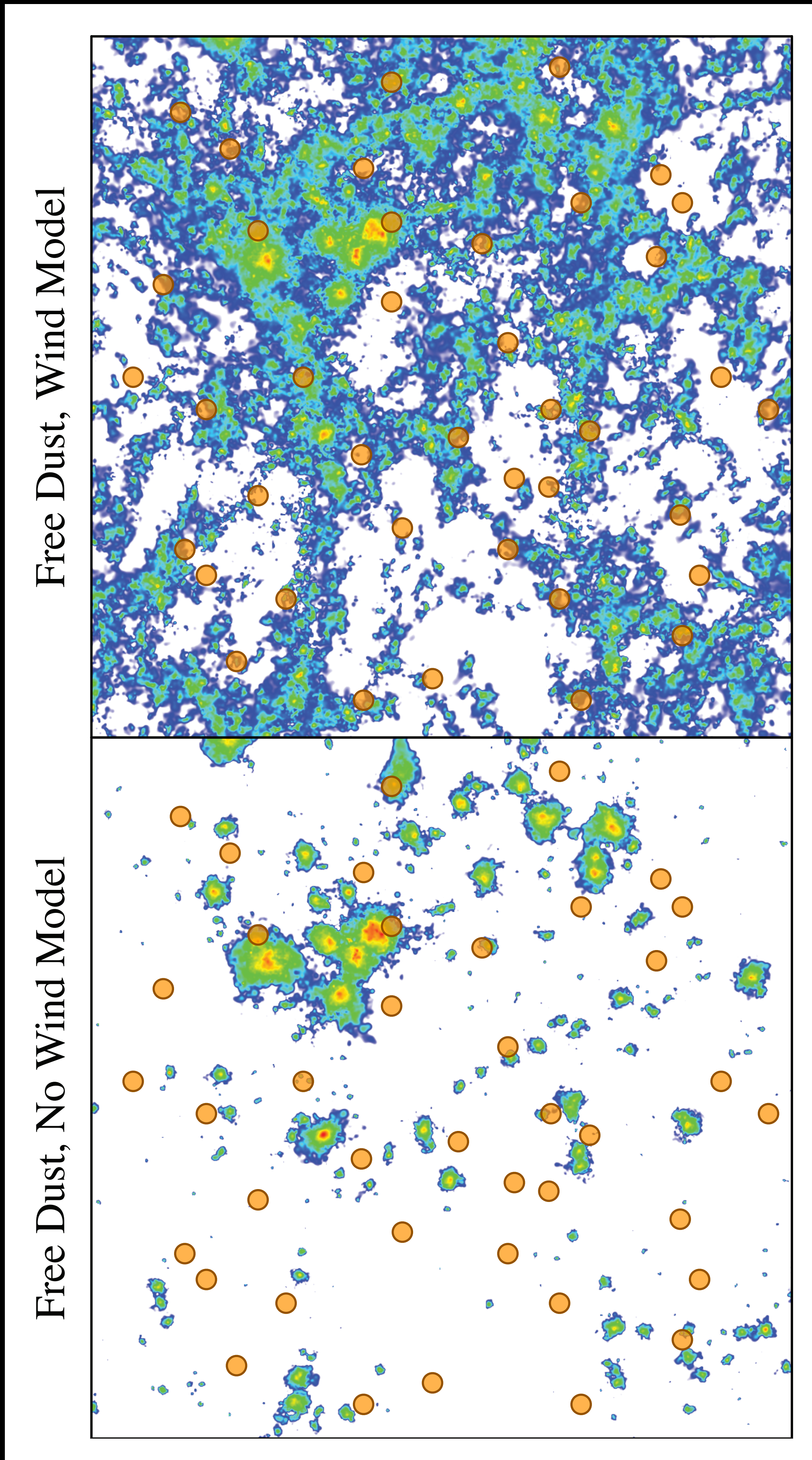


Zu+ (2010)


Free Dust, Wind Model
Free Dust, No Wind Model


PSF
Diffuse IGM
Chandra background
Foreground galaxy
Surface brightness [counts pixel^{-2}]
Radius [pixels]
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{0}
10^{1}
10^{2}

Zu+ (2010)



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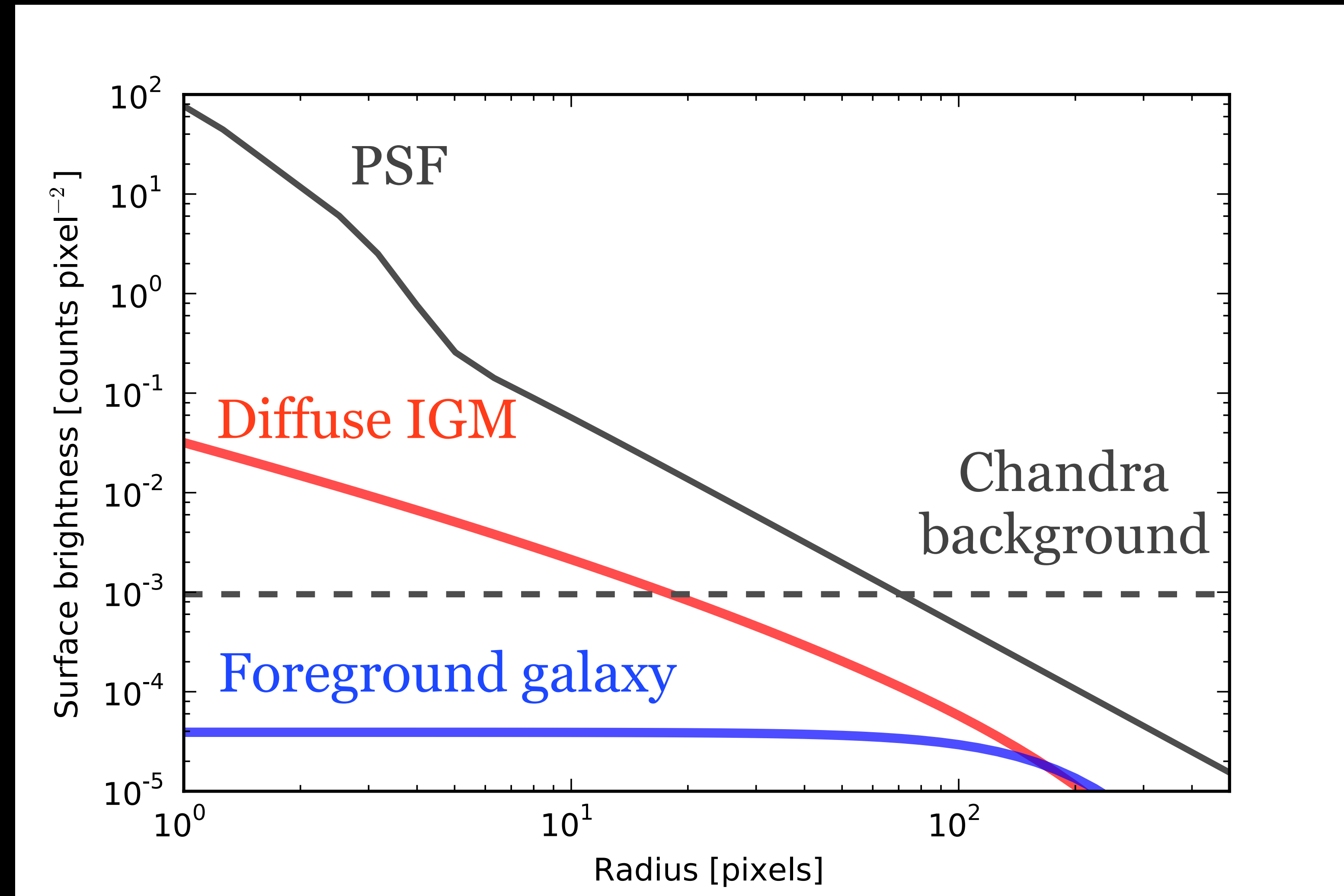
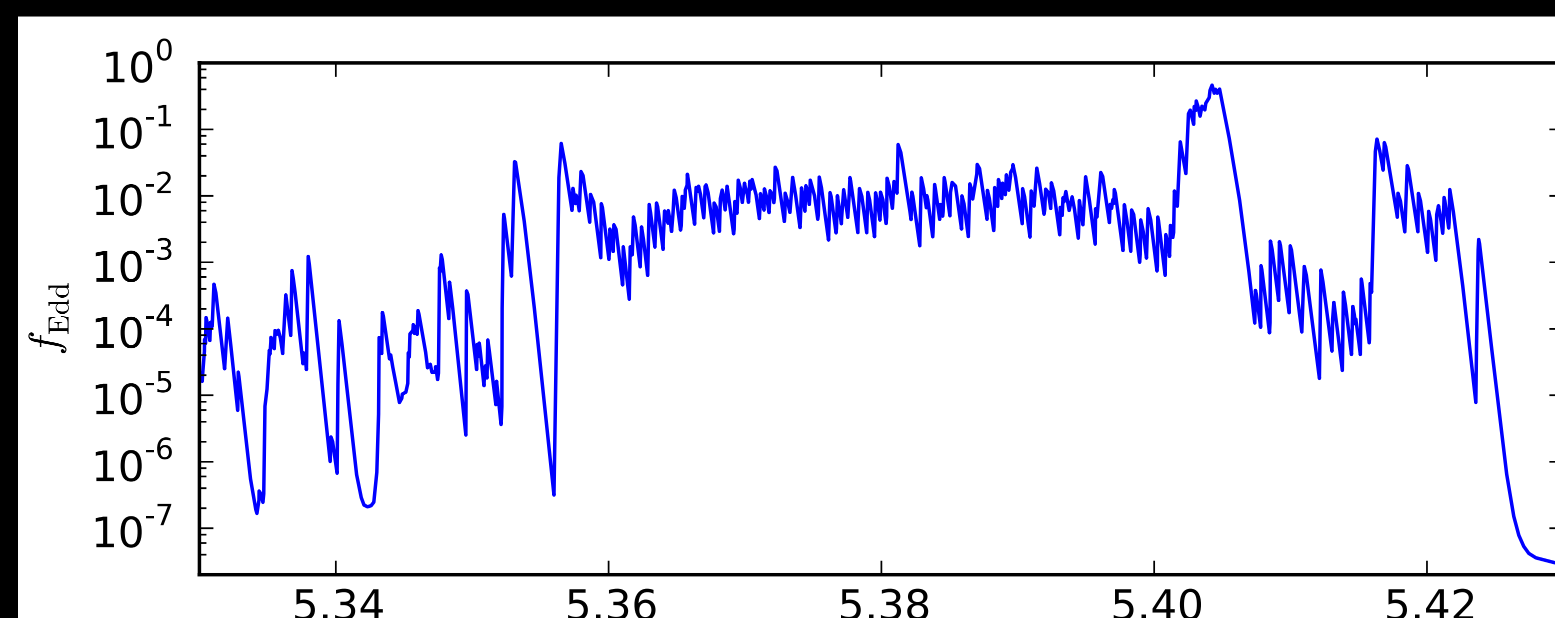
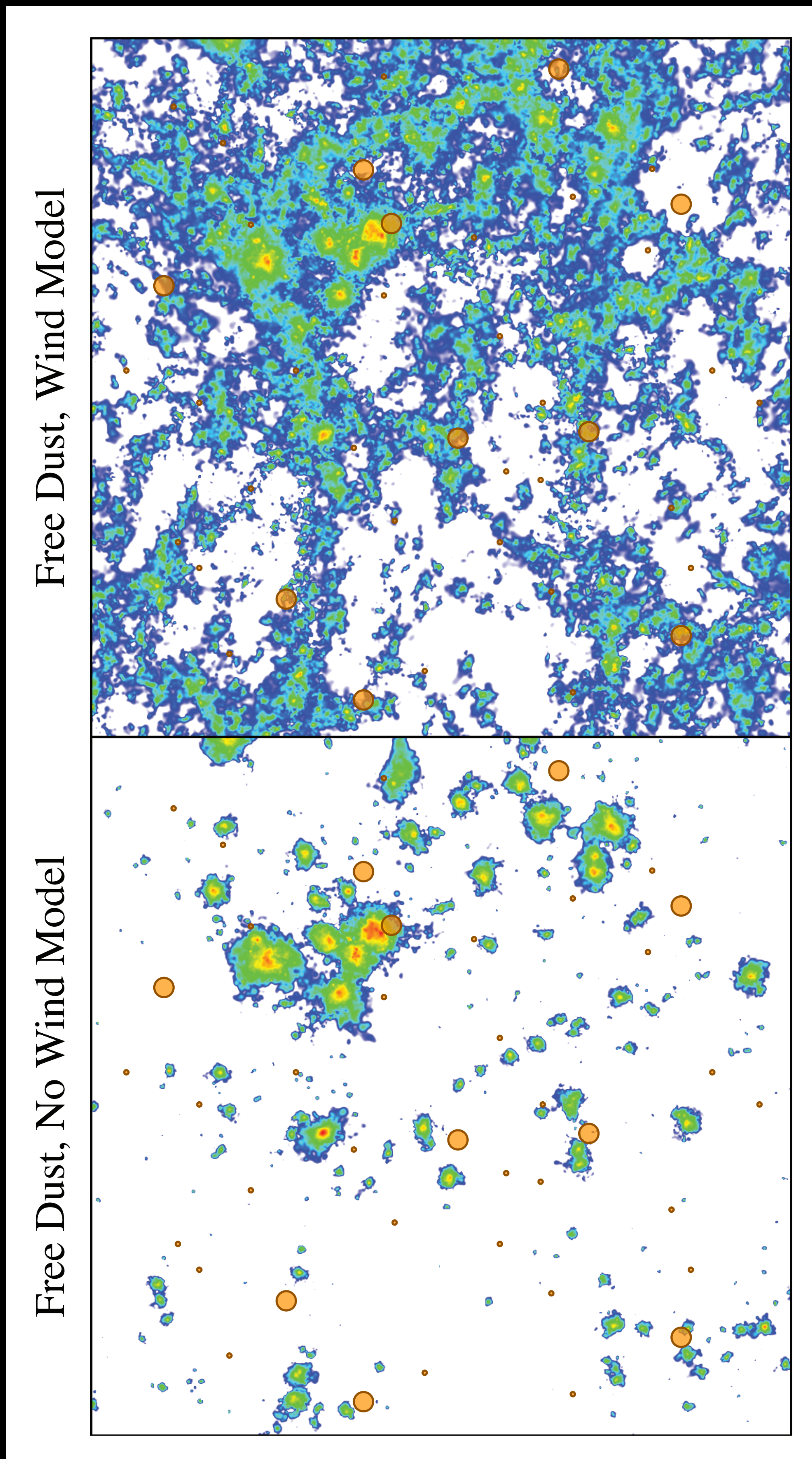




Novak+ (2011)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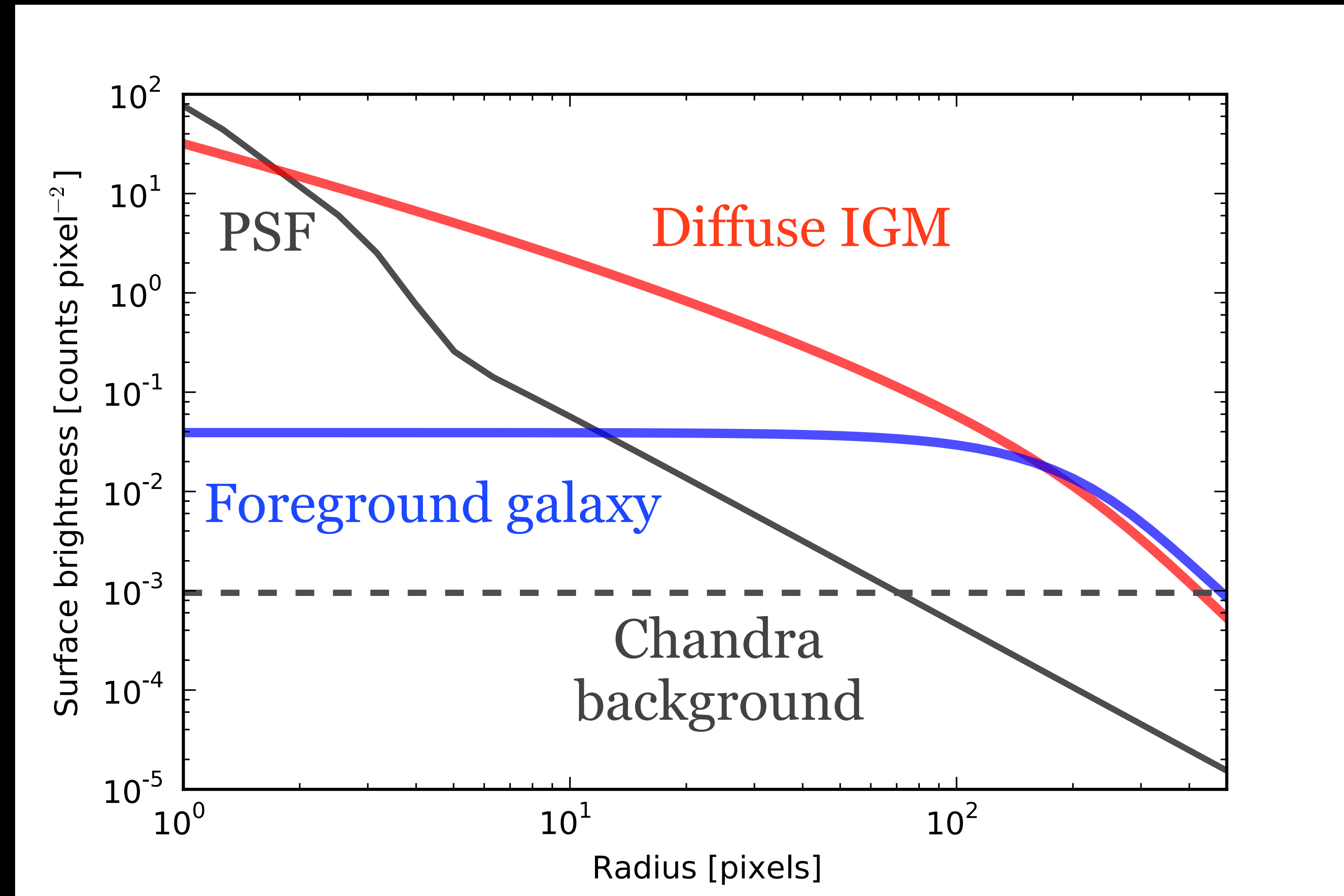
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10^{2}
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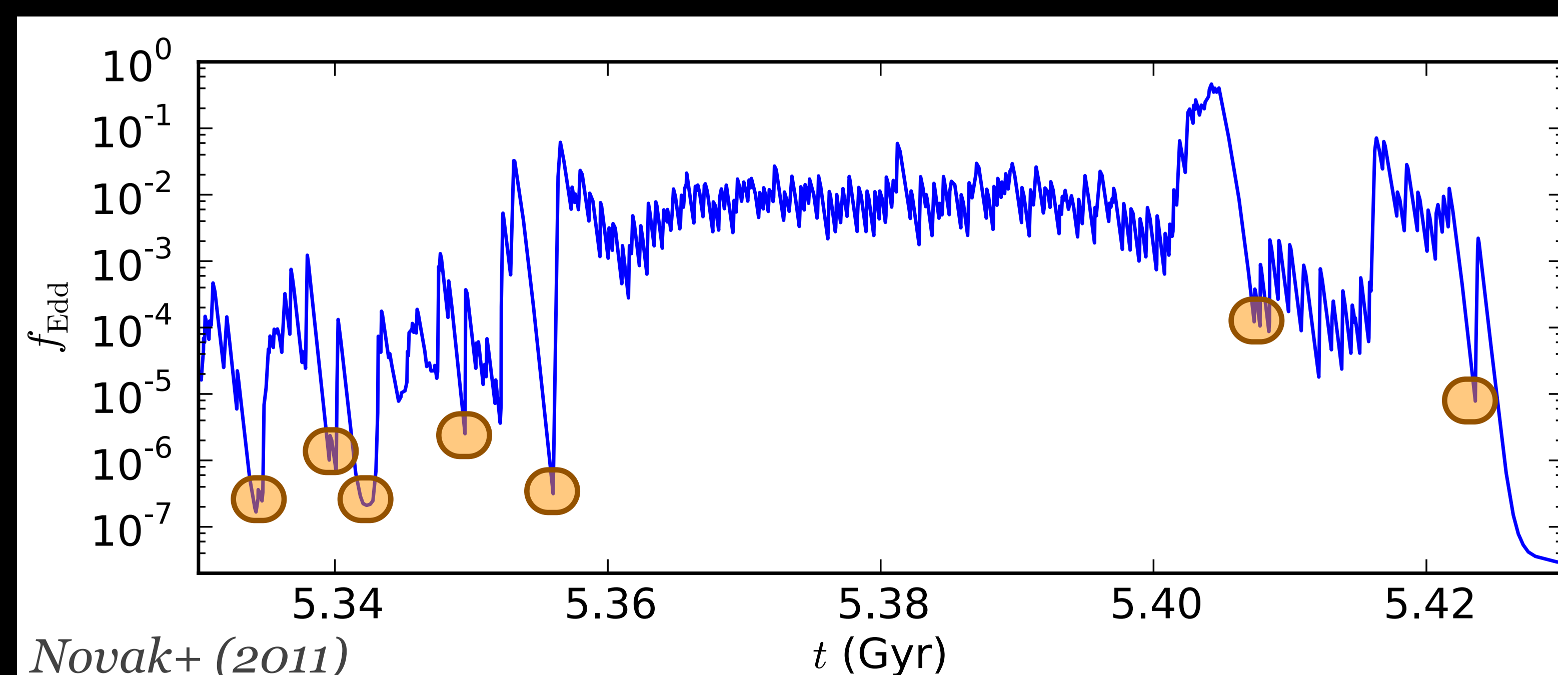
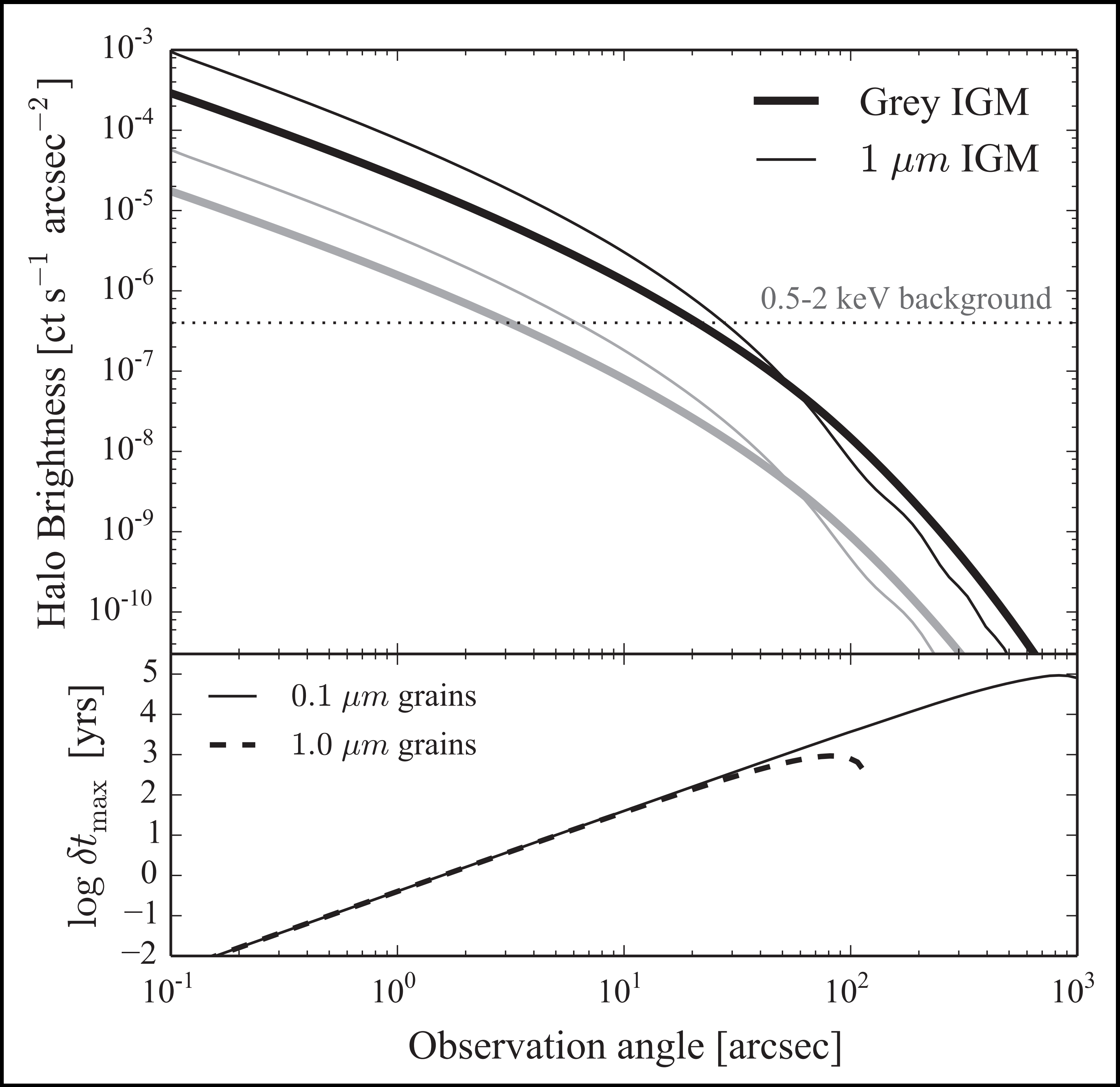
10^{-5}


$f_{\rm Edd}$
t (Gyr)
5.34
5.36
5.38
5.40
5.42
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
Novak+ (2011)

Zu+ (2010)

$$N_{ech} = \delta t_{max} \ \nu_{fb} \ N_q(F \geq F_{th}, z > 1)$$



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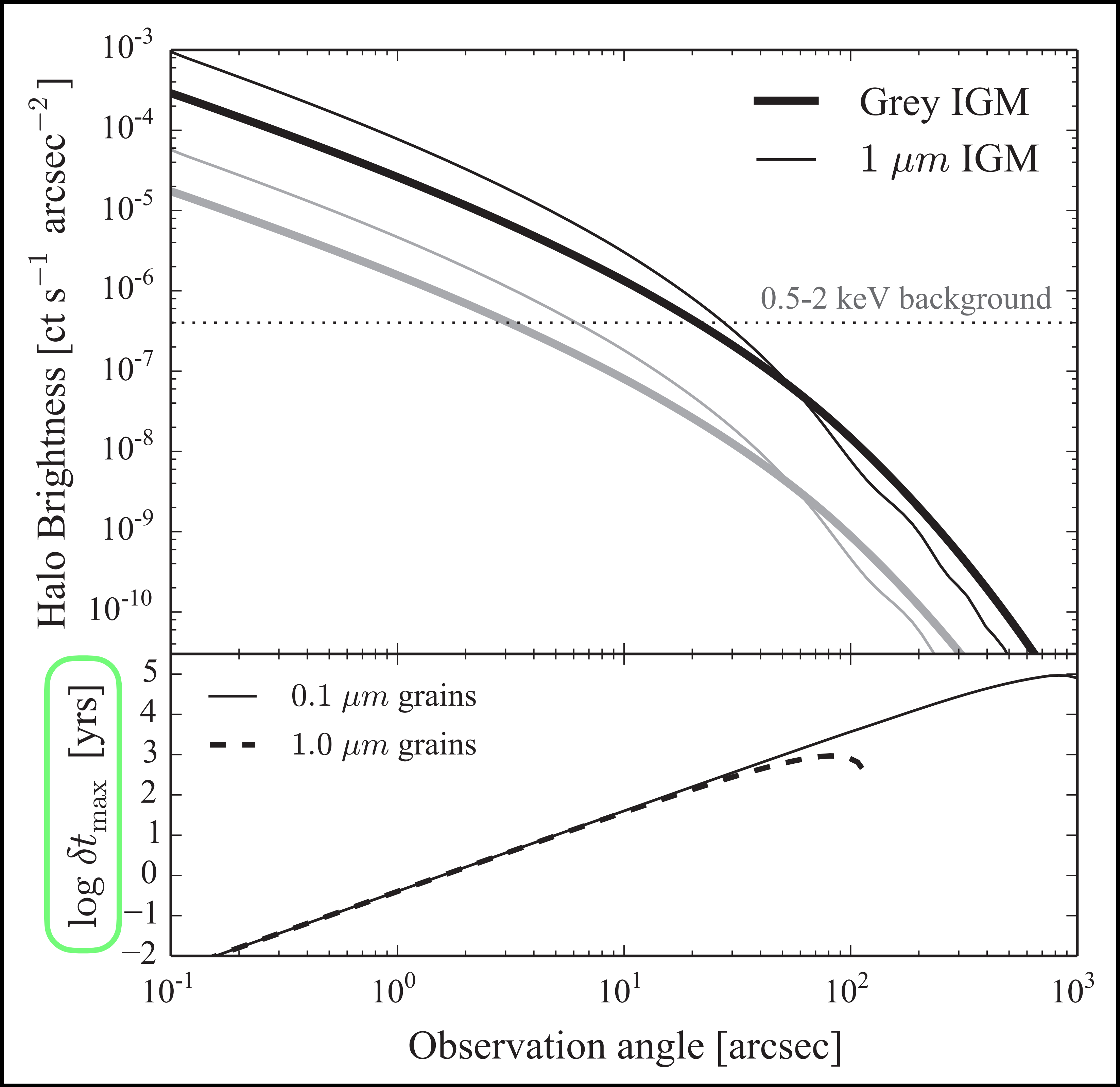

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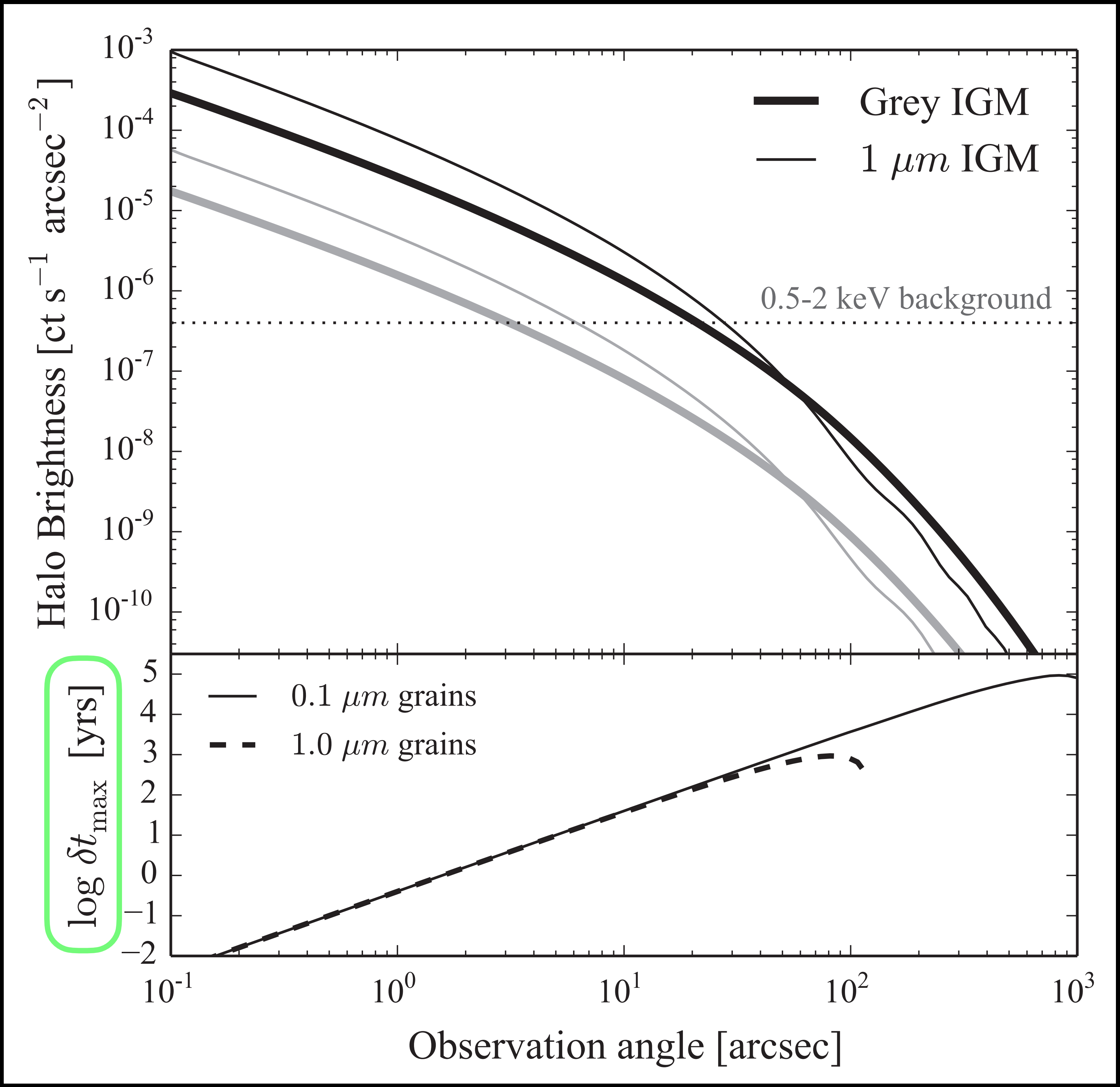

ν_{fb}

once every

$10^3 - 10^6$ yrs

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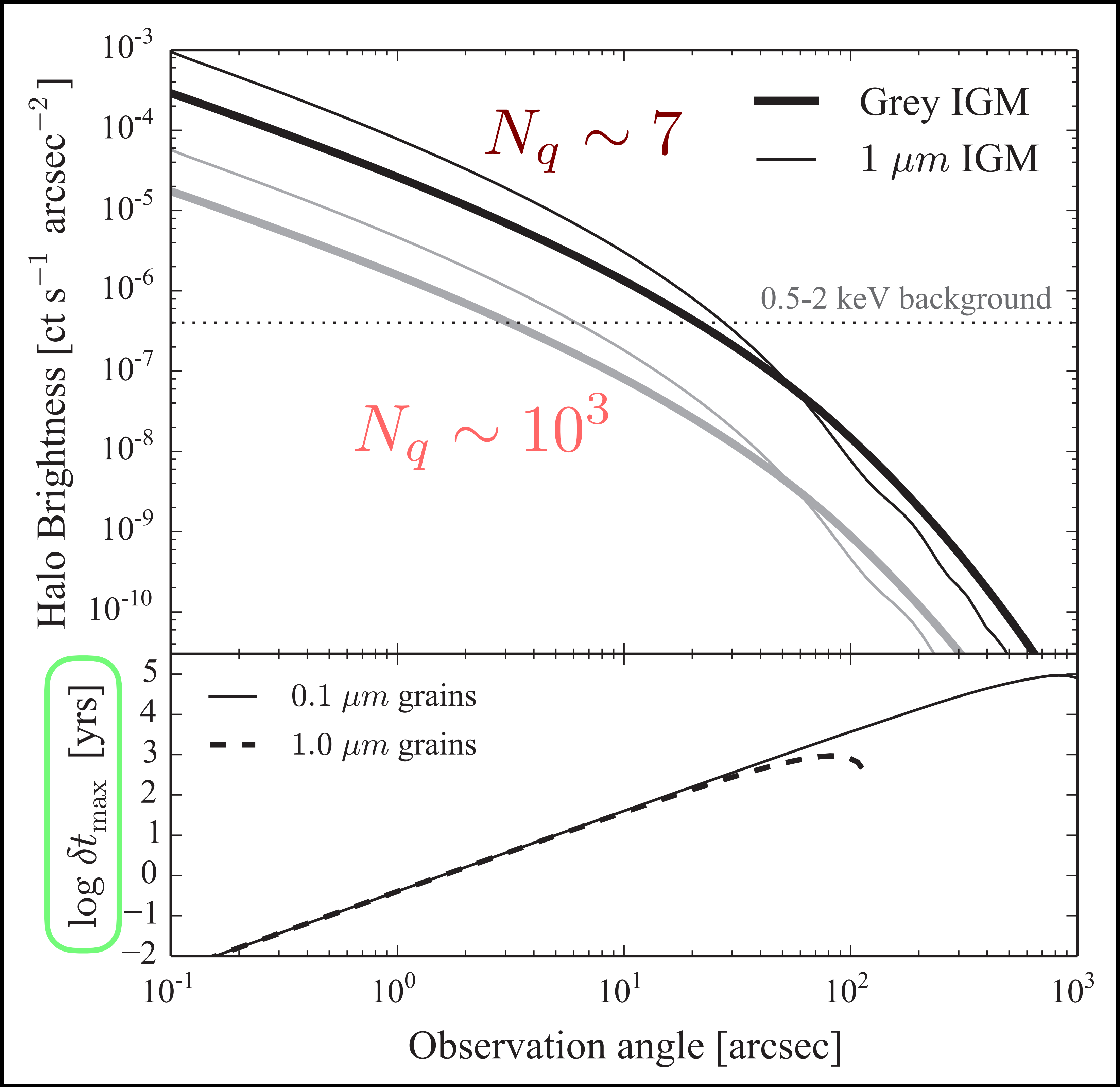

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Depends on telescope sensitivity

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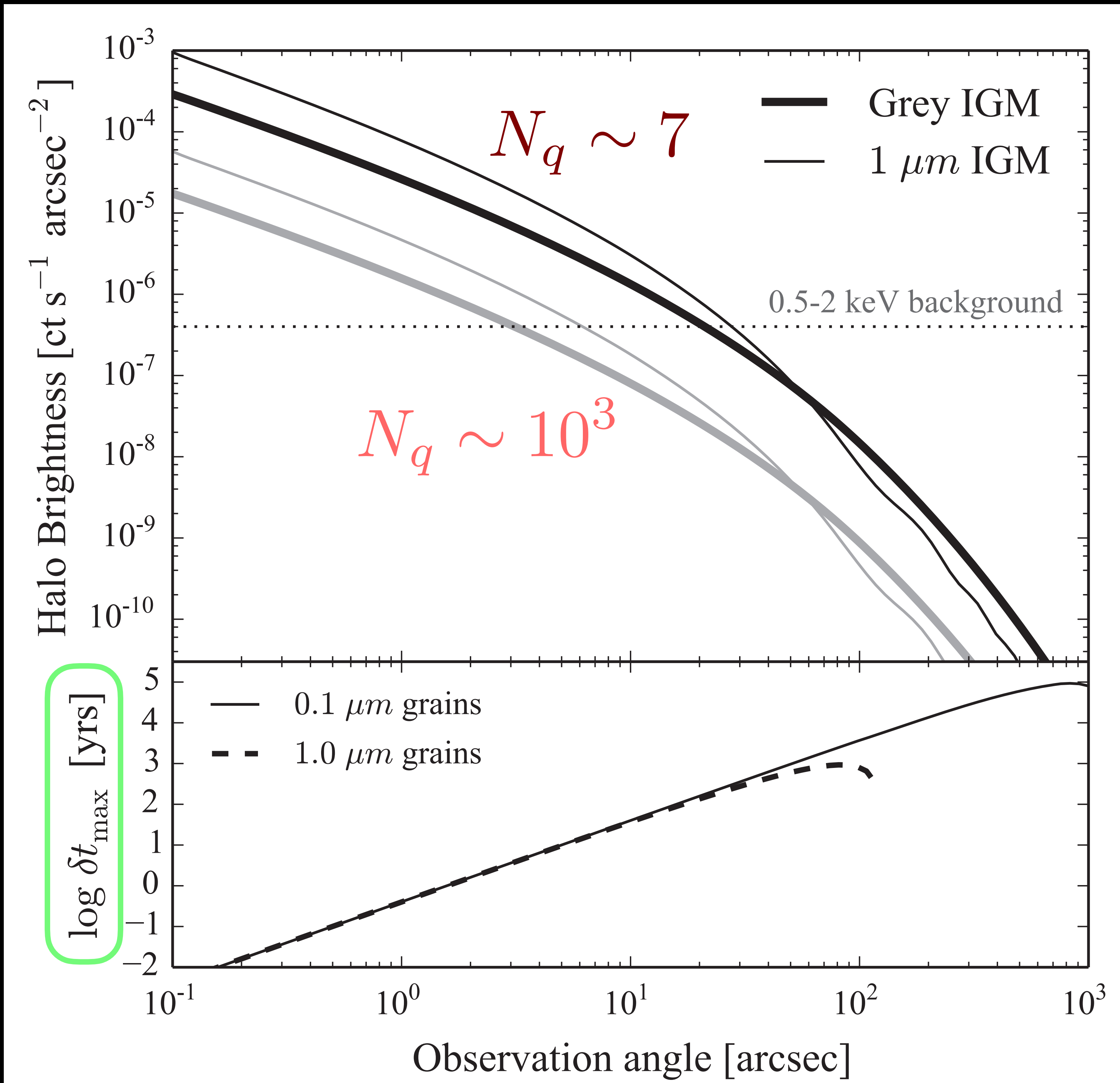

ν_{fb}

once every

$10^3 - 10^6$ yrs

Depends on telescope sensitivity

$N_{ech} \sim 5 - 10$

if we increase sensitivity by factor of 10

Corrales (2015)

Dust scattering echoes provide a window on
ISM dust structure with unprecedented **detail**

ISM is relatively optically thin to X-rays,
allowing us to **probe structure from a large distance**

Next generation of X-ray telescopes
can provide many more dust scattering echoes

Potential to probe **dusty extragalactic structures**
in conjunction with **AGN variability time scales**