Impact of the LMC on DM indirect detection

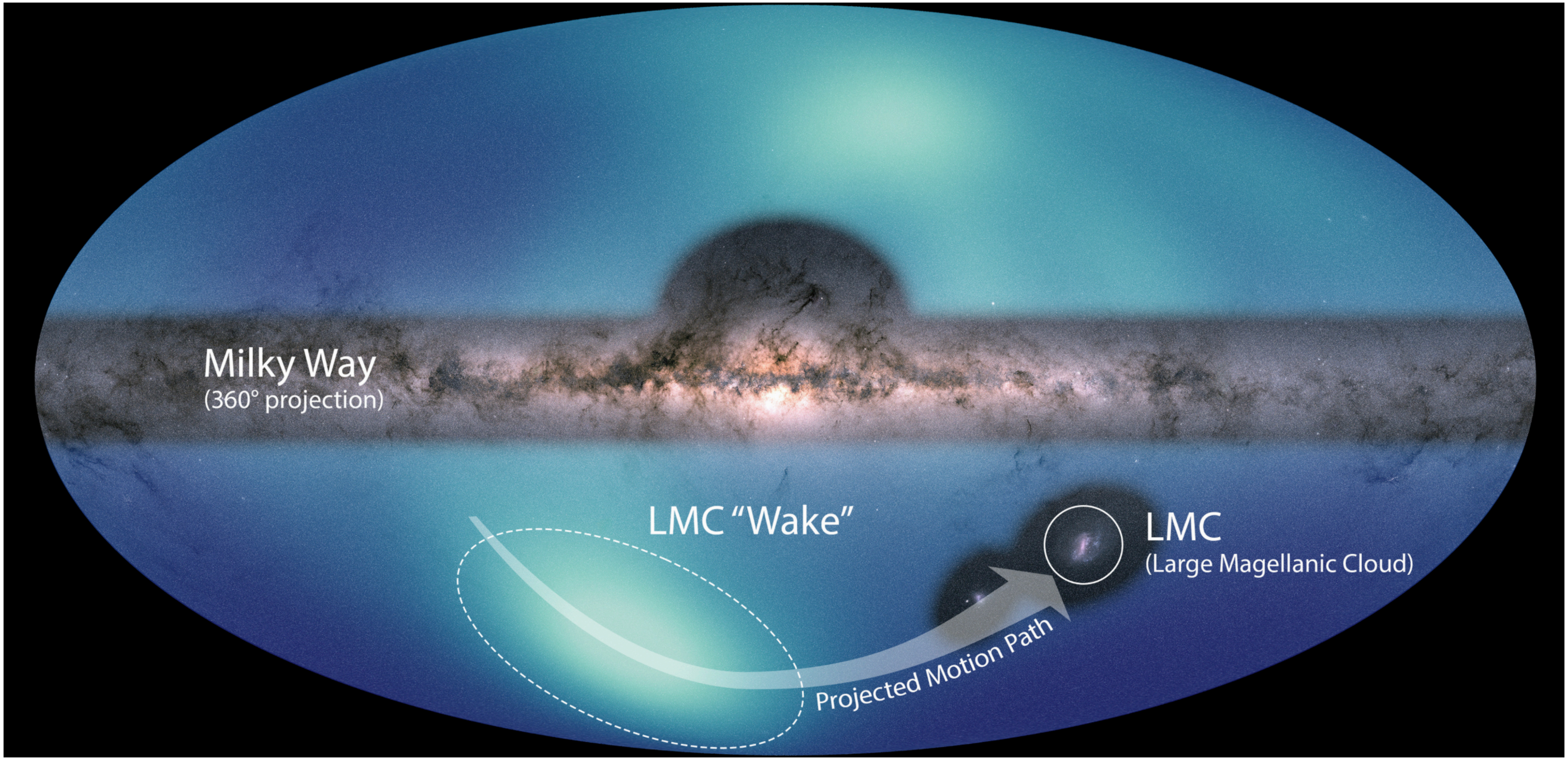
Evan Vienneau

Department of Physics
University of Alberta

May 2024

In Collaboration with N. Bozorgnia (supervisor), L. Strigari, O. Hartl and A. Evans

Large Magellanic Cloud



[Conroy et al. 21']

Large Magellanic Cloud

Properties

- Fourth largest galaxy in Local Group

[Besla 07']

- Just passed first pericenter approach

Large Magellanic Cloud

Properties

- Fourth largest galaxy in Local Group

[Besla 07']

- Just passed first pericenter approach

- Total Mass :

[Shipp 21']

  - $\sim 1.3 \times 10^{11}\ \mathrm{M}_{\odot}$

- Speed :

[Kallivayalil 13']

  - $321 \pm 24\ \mathrm{km/s}$

- Distance :

[Pietrzynski 19']

  - $49.59 \pm 0.09\ \mathrm{kpc}$

Large Magellanic Cloud

Properties

- Fourth largest galaxy in Local Group

[Besla 07']

- Just passed first pericenter approach
- Total Mass :

[Shipp 21']

  - $\sim 1.3 \times 10^{11}\ \mathrm{M}_{\odot}$
- Speed :

[Kallivayalil 13']

  - $321 \pm 24\ \mathrm{km/s}$
- Distance :

[Pietrzynski 19']

  - $49.59 \pm 0.09\ \mathrm{kpc}$

Impact on DM detection

- Direct detection :
  - injects high-speed DM particles into the solar neighbourhood
  - Authors used cosmological sims
  - This was also shown in idealized sims

[Smith-Orlik et al. 23']

Large Magellanic Cloud

Properties

- Fourth largest galaxy in Local Group

[Besla 07']

- Just passed first pericenter approach

- Total Mass :

[Shipp 21']
  - $\sim 1.3 \times 10^{11}\ \mathrm{M}_{\odot}$

- Speed :

[Kallivayalil 13']
  - $321 \pm 24\ \mathrm{km/s}$

- Distance :

[Pietrzynski 19']
  - $49.59 \pm 0.09\ \mathrm{kpc}$

Impact on DM detection

- Direct detection :
  - injects high-speed DM particles into the solar neighbourhood
  - Authors used cosmological sims
  - This was also shown in idealized sims

[Smith-Orlik et al. 23']

- Indirect detection :
  - triggers disequilibrium phenomena in the outer MW halo, found minimal impact on velocity *independent* DM annihilation
  - Authors used idealized sims

[Eckner 23']

Large Magellanic Cloud

Properties

- Fourth largest galaxy in Local Group

[Besla 07']

- Just passed first pericenter approach

- Total Mass :

[Shipp 21']

  - $\sim 1.3 \times 10^{11}\ \mathrm{M}_\odot$

- Speed :

[Kallivayalil 13']

  - $321 \pm 24\ \mathrm{km/s}$

- Distance :

[Pietrzynski 19']

  - $49.59 \pm 0.09\ \mathrm{kpc}$

Impact on DM detection

- Direct detection :
  - injects high-speed DM particles into the solar neighbourhood
  - Authors used cosmological sims
  - This was also shown in idealized sims

[Smith-Orlik et al. 23']

- Indirect detection :
  - triggers disequilibrium phenomena in the outer MW halo, found minimal impact on velocity *independent* DM annihilation
  - Authors used idealized sims

[Eckner 23']

We explore the LMC in the context of indirect detection using **cosmological simulations** and considering **velocity-dependent** annihilation models

Indirect detection

DM annihilation γ-ray flux

$$\frac{d\Phi_\gamma}{dE} = \frac{(\sigma_A v_{\rm rel})_0}{8\pi m_\chi^2}\frac{dN_\gamma}{dE} \int d\ell \int d^3\mathbf{v}_{\rm rel} P_{\mathbf{x}}(\mathbf{v}_{\rm rel}) \left(\frac{v_{\rm rel}}{c}\right)^n [\rho(\mathbf{x})]^2$$

Indirect detection

DM annihilation γ-ray flux

$$\frac{d\Phi_\gamma}{dE} = \underbrace{\frac{(\sigma_A v_{\rm rel})_0}{8\pi m_\chi^2} \frac{dN_\gamma}{dE}}_{\text{Particle}} \int d\ell \int d^3\mathbf{v}_{\rm rel} P_{\mathbf{x}}(\mathbf{v}_{\rm rel}) \left(\frac{v_{\rm rel}}{c}\right)^n [\rho(\mathbf{x})]^2$$

Indirect detection

DM annihilation γ-ray flux

$$\frac{d\Phi_\gamma}{dE} = \underbrace{\frac{(\sigma_A v_{\rm rel})_0}{8\pi m_\chi^2}\frac{dN_\gamma}{dE}}_{\text{Particle}} \underbrace{\int d\ell \int d^3\mathbf{v}_{\rm rel} P_{\mathbf{x}}(\mathbf{v}_{\rm rel}) \left(\frac{v_{\rm rel}}{c}\right)^n [\rho(\mathbf{x})]^2}_{\text{Astro}}$$

Indirect detection

DM annihilation γ-ray flux

$$\frac{d\Phi_\gamma}{dE} = \frac{(\sigma_A v_{\rm rel})_0}{8\pi m_\chi^2}\frac{dN_\gamma}{dE}\boxed{\int d\ell \int d^3\mathbf{v}_{\rm rel} P_{\mathbf{x}}(\mathbf{v}_{\rm rel})\left(\frac{v_{\rm rel}}{c}\right)^n [\rho(\mathbf{x})]^2}$$

J-Factor

Indirect detection

DM annihilation γ-ray flux

$$\frac{d\Phi_\gamma}{dE} = \frac{(\sigma_A v_{\rm rel})_0}{8\pi m_\chi^2}\frac{dN_\gamma}{dE} \underbrace{\boxed{\int d\ell \int d^3\mathbf{v}_{\rm rel} P_{\mathbf{x}}(\mathbf{v}_{\rm rel}) \left(\frac{v_{\rm rel}}{c}\right)^n [\rho(\mathbf{x})]^2}}_{\text{J-Factor}}$$

- DM density

$$[\rho(\mathbf{x})]^2$$

- n-th moment of relative velocity distribution

$$\mu_n(\mathbf{x}) = \int d^3\mathbf{v}_{\rm rel} P_{\mathbf{x}}(\mathbf{v}_{\rm rel}) \left(\frac{v_{\rm rel}}{c}\right)^n$$

Indirect detection

DM annihilation γ-ray flux

$$\frac{d\Phi_\gamma}{dE} = \frac{(\sigma_A v_{\rm rel})_0}{8\pi m_\chi^2} \frac{dN_\gamma}{dE} \underbrace{\boxed{\int d\ell \int d^3\mathbf{v}_{\rm rel} P_{\mathbf{x}}(\mathbf{v}_{\rm rel}) \left(\frac{v_{\rm rel}}{c}\right)^n [\rho(\mathbf{x})]^2}}_{\text{J-Factor}}$$

- DM density

$$[\rho(\mathbf{x})]^2$$

- n-th moment of relative velocity distribution

$$\mu_n(\mathbf{x}) = \int d^3\mathbf{v}_{\rm rel} P_{\mathbf{x}}(\mathbf{v}_{\rm rel}) \left(\frac{v_{\rm rel}}{c}\right)^n$$

S-wave (ℓ = 0, n = 0)

Indirect detection

DM annihilation γ-ray flux

$$\frac{d\Phi_\gamma}{dE} = \frac{(\sigma_A v_{\rm rel})_0}{8\pi m_\chi^2}\frac{dN_\gamma}{dE} \underbrace{\boxed{\int d\ell \int d^3\mathbf{v}_{\rm rel} P_{\mathbf{x}}(\mathbf{v}_{\rm rel})\left(\frac{v_{\rm rel}}{c}\right)^n [\rho(\mathbf{x})]^2}}_{\text{J-Factor}}$$

- DM density

$$[\rho(\mathbf{x})]^2$$

- n-th moment of relative velocity distribution

$$\mu_n(\mathbf{x}) = \int d^3\mathbf{v}_{\rm rel} P_{\mathbf{x}}(\mathbf{v}_{\rm rel})\left(\frac{v_{\rm rel}}{c}\right)^n$$

S-wave (ℓ = 0, n = 0)

P-wave (ℓ = 1, n = 2) , e.g. Majorana spin 1/2

[Kumar & Marfatia 13']

Indirect detection

DM annihilation γ-ray flux

$$\frac{d\Phi_\gamma}{dE} = \frac{(\sigma_A v_{\rm rel})_0}{8\pi m_\chi^2}\frac{dN_\gamma}{dE}\underbrace{\boxed{\int d\ell \int d^3\mathbf{v}_{\rm rel} P_{\mathbf{x}}(\mathbf{v}_{\rm rel})\left(\frac{v_{\rm rel}}{c}\right)^n [\rho(\mathbf{x})]^2}}_{\text{J-Factor}}$$

- DM density

$$[\rho(\mathbf{x})]^2$$

- n-th moment of relative velocity distribution

$$\mu_n(\mathbf{x}) = \int d^3\mathbf{v}_{\rm rel} P_{\mathbf{x}}(\mathbf{v}_{\rm rel})\left(\frac{v_{\rm rel}}{c}\right)^n$$

S-wave (ℓ = 0, n = 0)

P-wave (ℓ = 1, n = 2) , e.g. Majorana spin 1/2

[Kumar & Marfatia 13']

D-wave (ℓ = 2, n = 4) , e.g. real scalar

[Giacchino 13']

Indirect detection

DM annihilation γ-ray flux

$$\frac{d\Phi_\gamma}{dE} = \frac{(\sigma_A v_{\rm rel})_0}{8\pi m_\chi^2}\frac{dN_\gamma}{dE}\boxed{\int d\ell \int d^3\mathbf{v}_{\rm rel} P_{\mathbf{x}}(\mathbf{v}_{\rm rel})\left(\frac{v_{\rm rel}}{c}\right)^n [\rho(\mathbf{x})]^2}$$

J-Factor

- DM density

$$[\rho(\mathbf{x})]^2$$

- n-th moment of relative velocity distribution

$$\mu_n(\mathbf{x}) = \int d^3\mathbf{v}_{\rm rel} P_{\mathbf{x}}(\mathbf{v}_{\rm rel})\left(\frac{v_{\rm rel}}{c}\right)^n$$

S-wave (ℓ = 0, n = 0)

P-wave (ℓ = 1, n = 2) , e.g. Majorana spin 1/2

[Kumar & Marfatia 13']

D-wave (ℓ = 2, n = 4) , e.g. real scalar

[Giacchino 13']

Sommerfeld (n = -1) , long range interaction

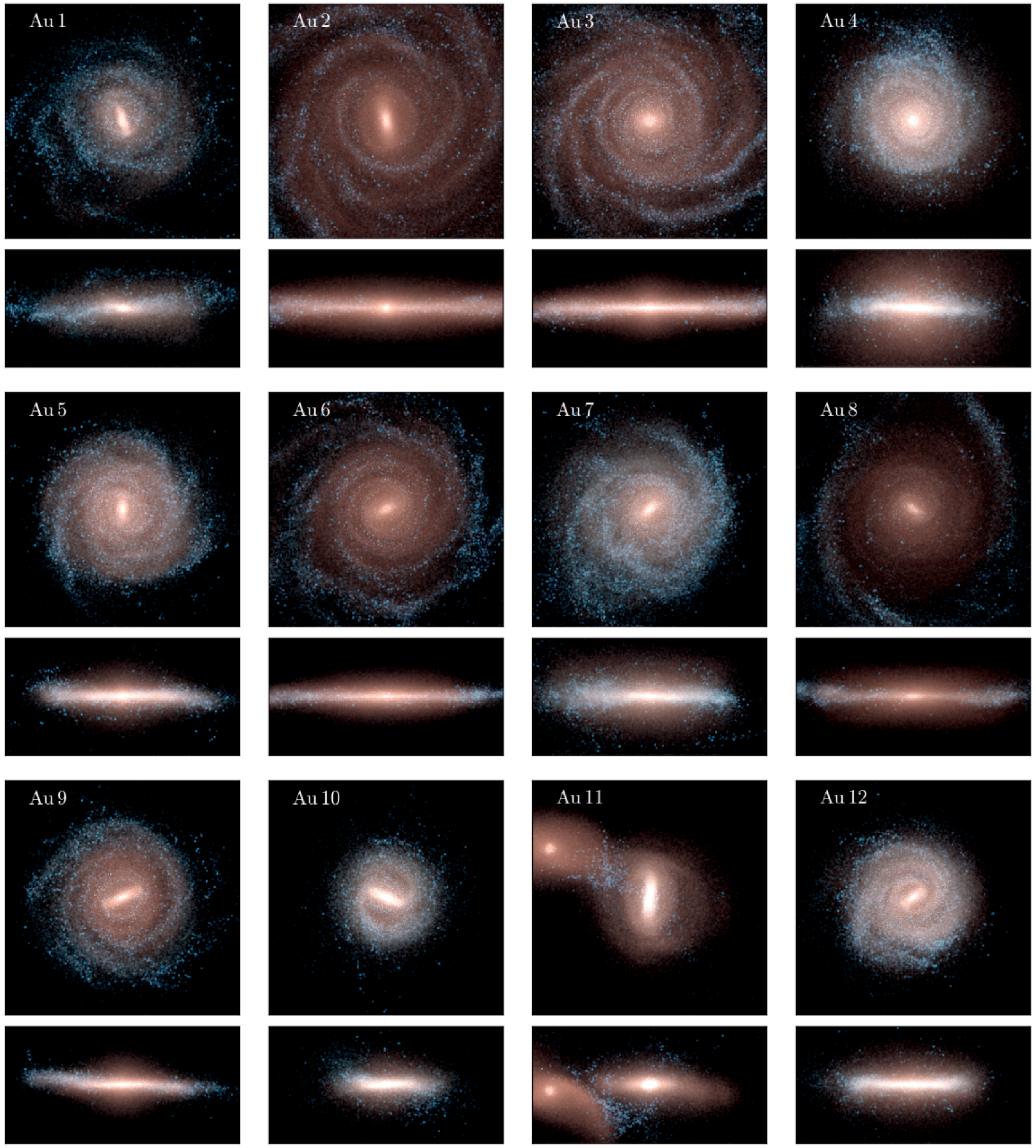
[Feng 10']

Simulated MW-LMC analogues

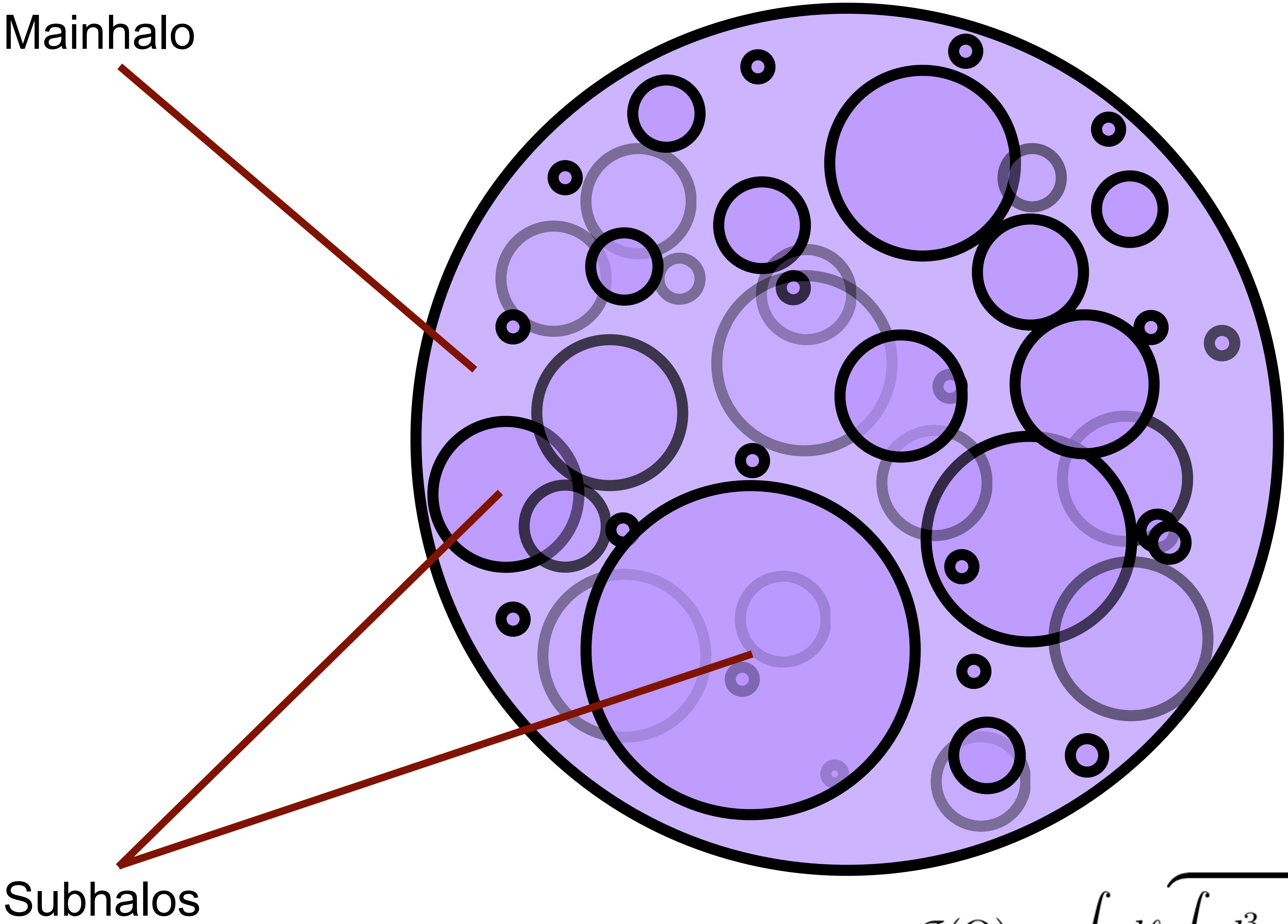
[Grand et al. 16']

Auriga

- 30 cosmological zoom-in simulations of isolated MW analogues
- 15 MW-LMC analogues are selected
- 1 is chosen to be resimulated with finer time steps close to pericenter
- Study the Present day of the system and compare with the Isolated MW (no LMC)

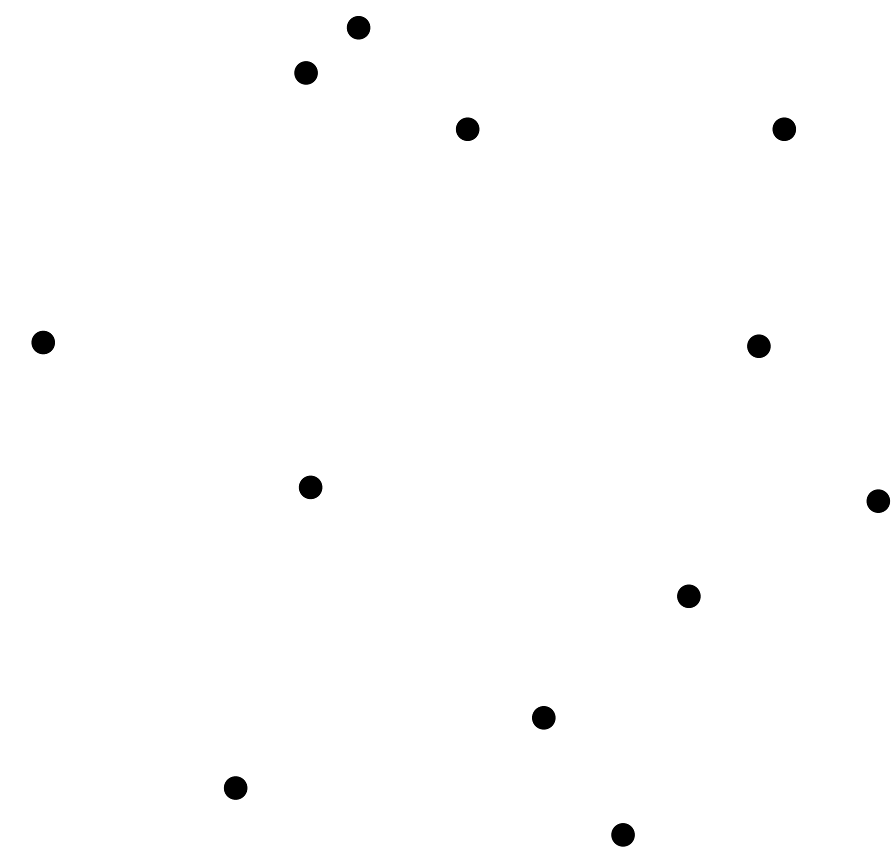


Local Density and Relative Velocity Computations



$$\mathcal{J}(\Omega) = \int d\ell \overbrace{\int d^3\mathbf{v}_{\rm rel} P_{\mathbf{x}}(\mathbf{v}_{\rm rel}) \left(\frac{v_{\rm rel}}{c}\right)^n}^{\mu_n(\mathbf{x})} [\rho(\mathbf{x})]^2$$

Mainhalo

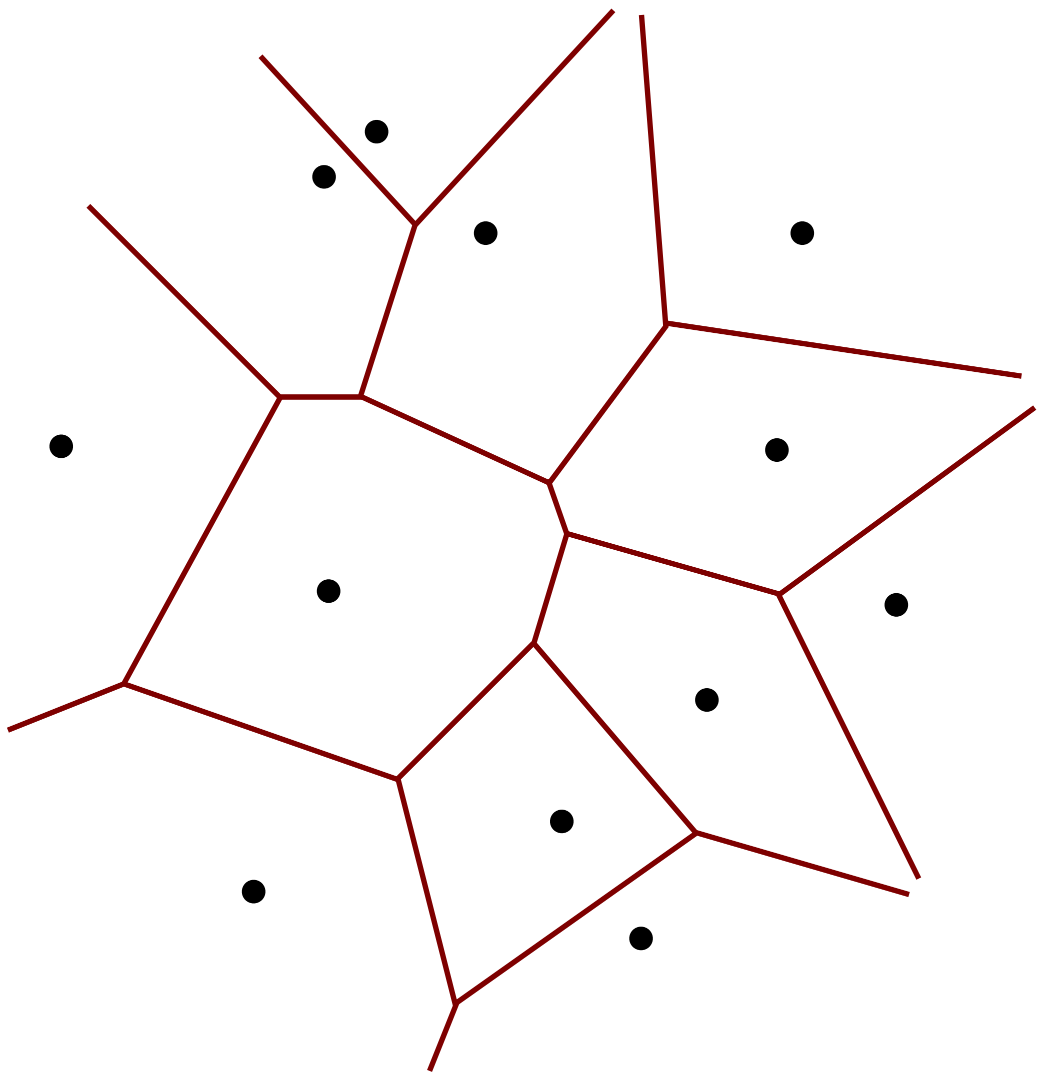


$$\mathcal{J}(\Omega) = \int d\ell \overbrace{\int d^3\mathbf{v}_{\mathrm{rel}} P_{\mathbf{x}}(\mathbf{v}_{\mathrm{rel}}) \left(\frac{v_{\mathrm{rel}}}{c}\right)^n}^{\mu_n(\mathbf{x})} [\rho(\mathbf{x})]^2$$

Local Density and Relative Velocity Computations

Mainhalo

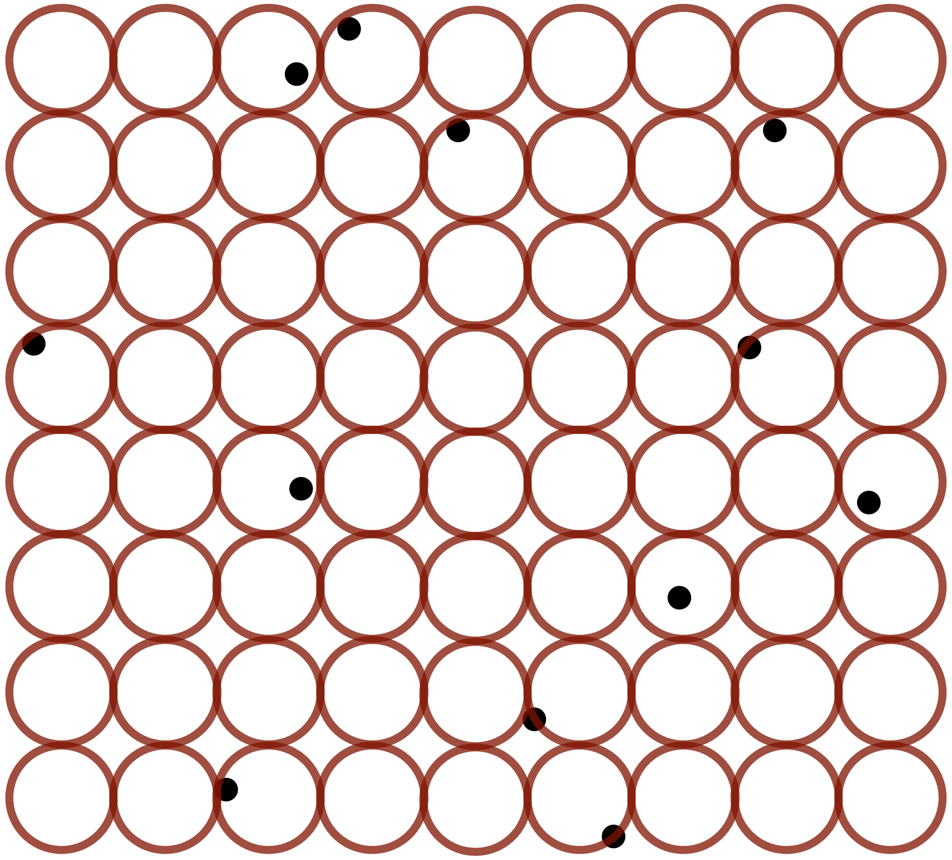
- Local density $\rho(\mathbf{x})$
  - voronoi tesselation



$$\mathcal{J}(\Omega) = \int d\ell \overbrace{\int d^3\mathbf{v}_{\rm rel} P_{\mathbf{x}}(\mathbf{v}_{\rm rel}) \left(\frac{v_{\rm rel}}{c}\right)^n}^{\mu_n(\mathbf{x})} [\rho(\mathbf{x})]^2$$

Mainhalo

- Local density $\rho(\mathbf{x})$
  - voronoi tesselation
- Local relative velocity $\mu(\mathbf{x})$
  - interpolation



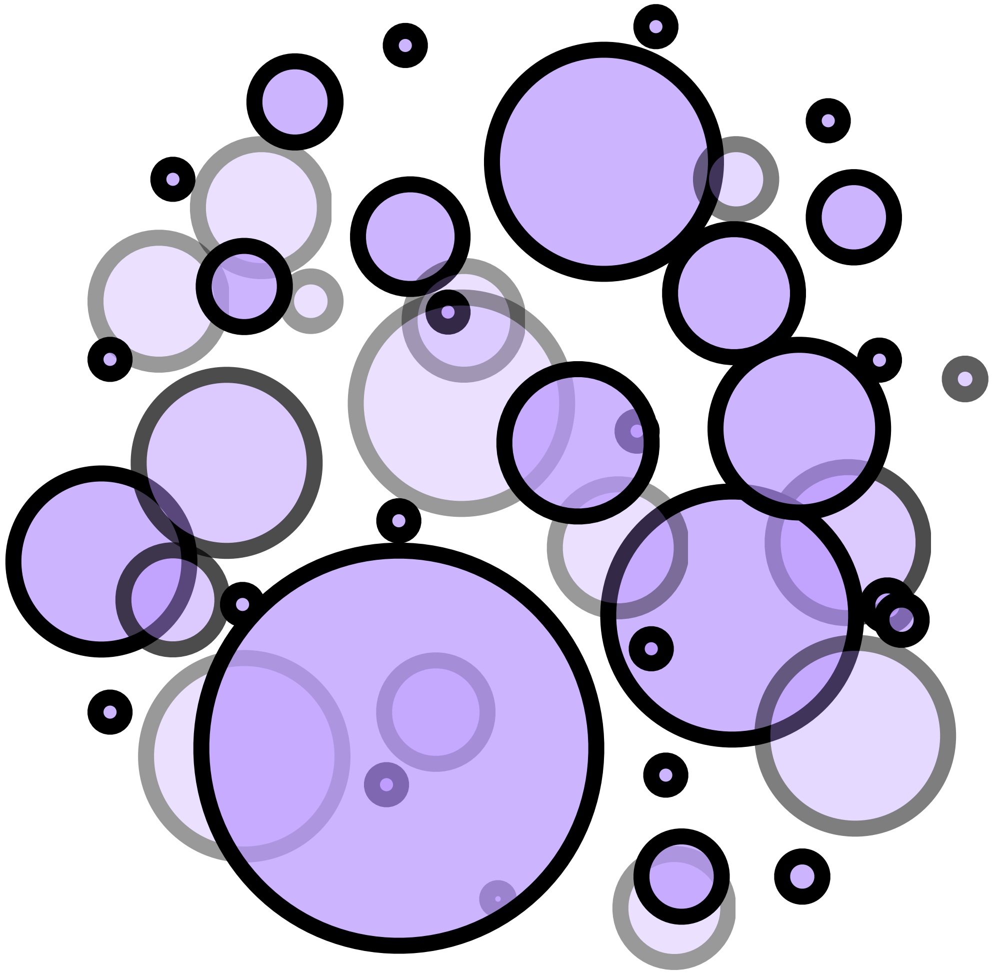
$$\mathcal{J}(\Omega) = \int d\ell \overbrace{\int d^3\mathbf{v}_{\rm rel} P_{\mathbf{x}}(\mathbf{v}_{\rm rel}) \left(\frac{v_{\rm rel}}{c}\right)^n}^{\mu_n(\mathbf{x})} [\rho(\mathbf{x})]^2$$

Local Density and Relative Velocity Computations

Mainhalo

- Local density $\rho(\mathbf{x})$
  - voronoi tesselation
- Local relative velocity $\mu(\mathbf{x})$
  - interpolation

Subhalos

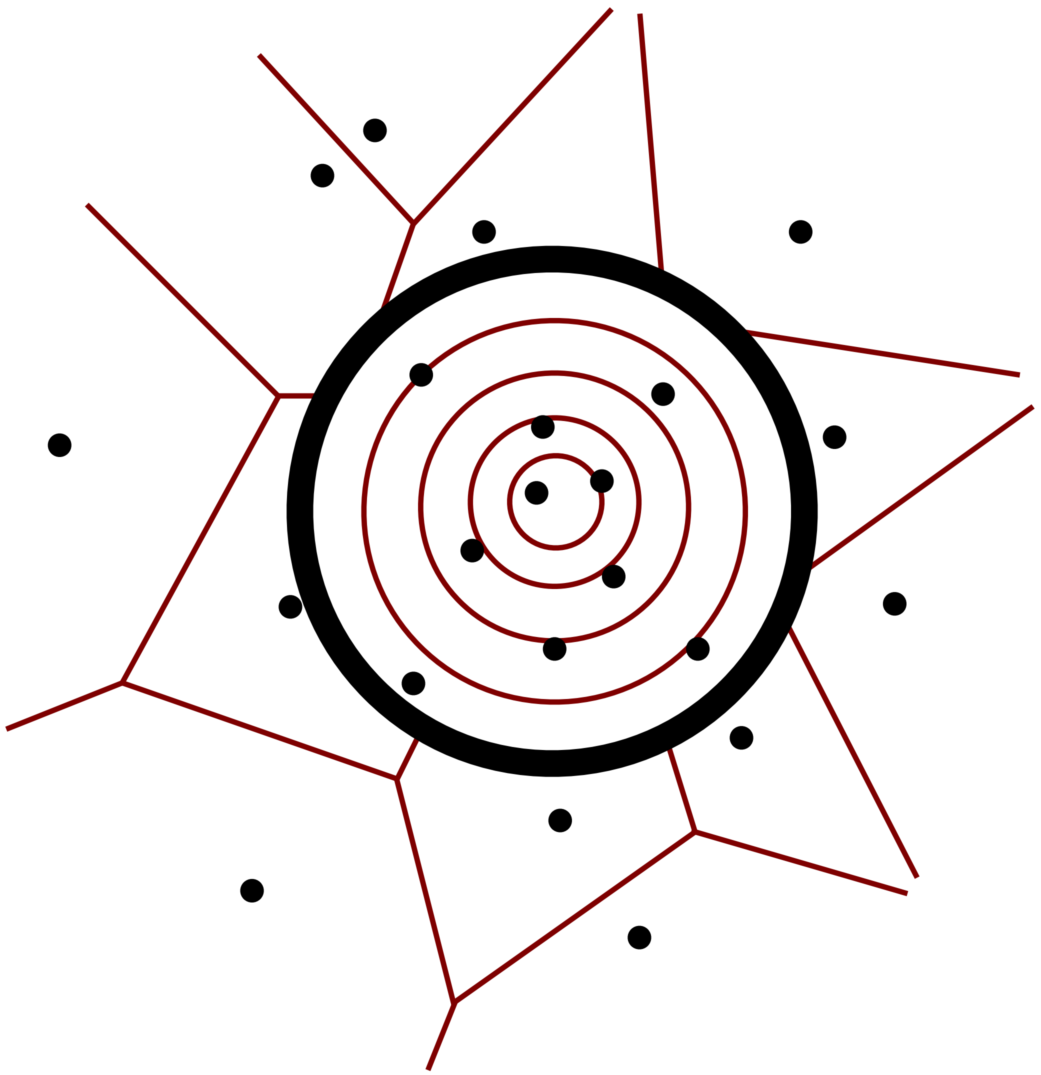


$$\mathcal{J}(\Omega) = \int d\ell \overbrace{\int d^3\mathbf{v}_{\mathrm{rel}} P_{\mathbf{x}}(\mathbf{v}_{\mathrm{rel}}) \left(\frac{v_{\mathrm{rel}}}{c}\right)^n}^{\mu_n(\mathbf{x})} [\rho(\mathbf{x})]^2$$

Local Density and Relative Velocity Computations

Mainhalo

- Local density $\rho(\mathbf{x})$
  - voronoi tesselation
- Local relative velocity $\mu(\mathbf{x})$
  - interpolation



Subhalos

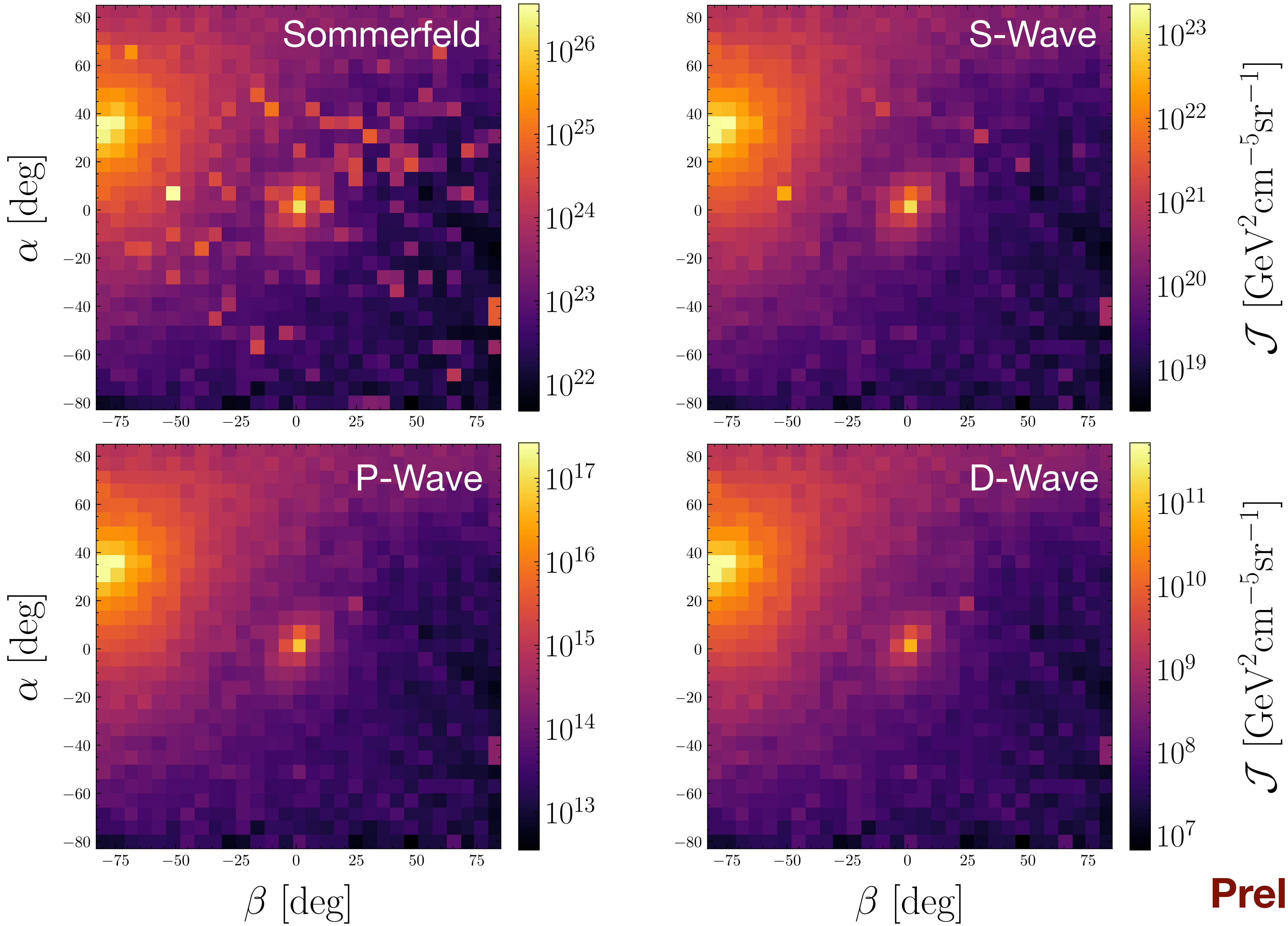
- Local density $\rho(\mathbf{x})$
  - < Rmax → best fit radial density profile
  - > Rmax → voronoi tesselation
- Local relative velocity $\mu(\mathbf{x})$
  - numerical integration over shells

$$\mathcal{J}(\Omega) = \int d\ell \overbrace{\int d^3\mathbf{v}_{\rm rel} P_{\mathbf{x}}(\mathbf{v}_{\rm rel}) \left(\frac{v_{\rm rel}}{c}\right)^n}^{\mu_n(\mathbf{x})} [\rho(\mathbf{x})]^2$$

J-Factor

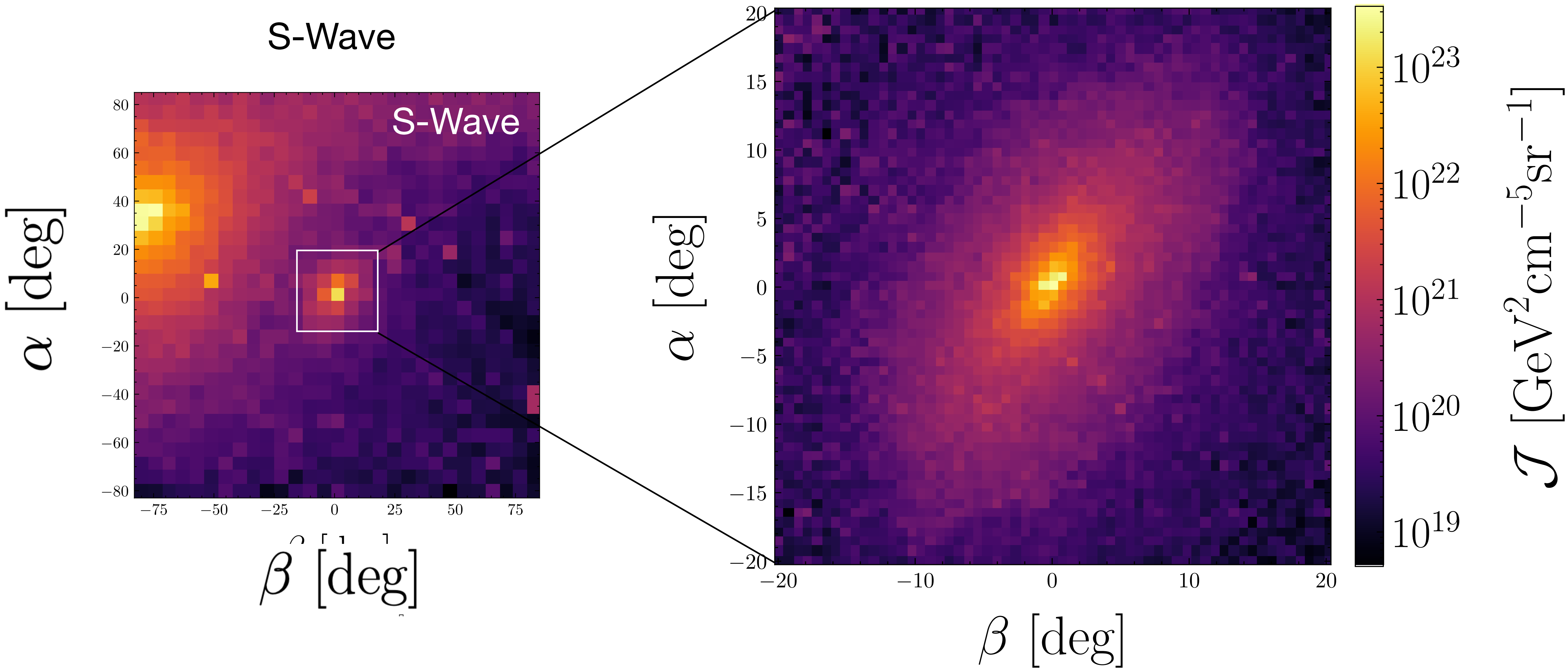
- Solar position is selected to match the LMC's sky position with respect to the MW center then the line of sight integral is computed in square bins on the sky

J-Factor - LMC



Preliminary

J-Factor - LMC



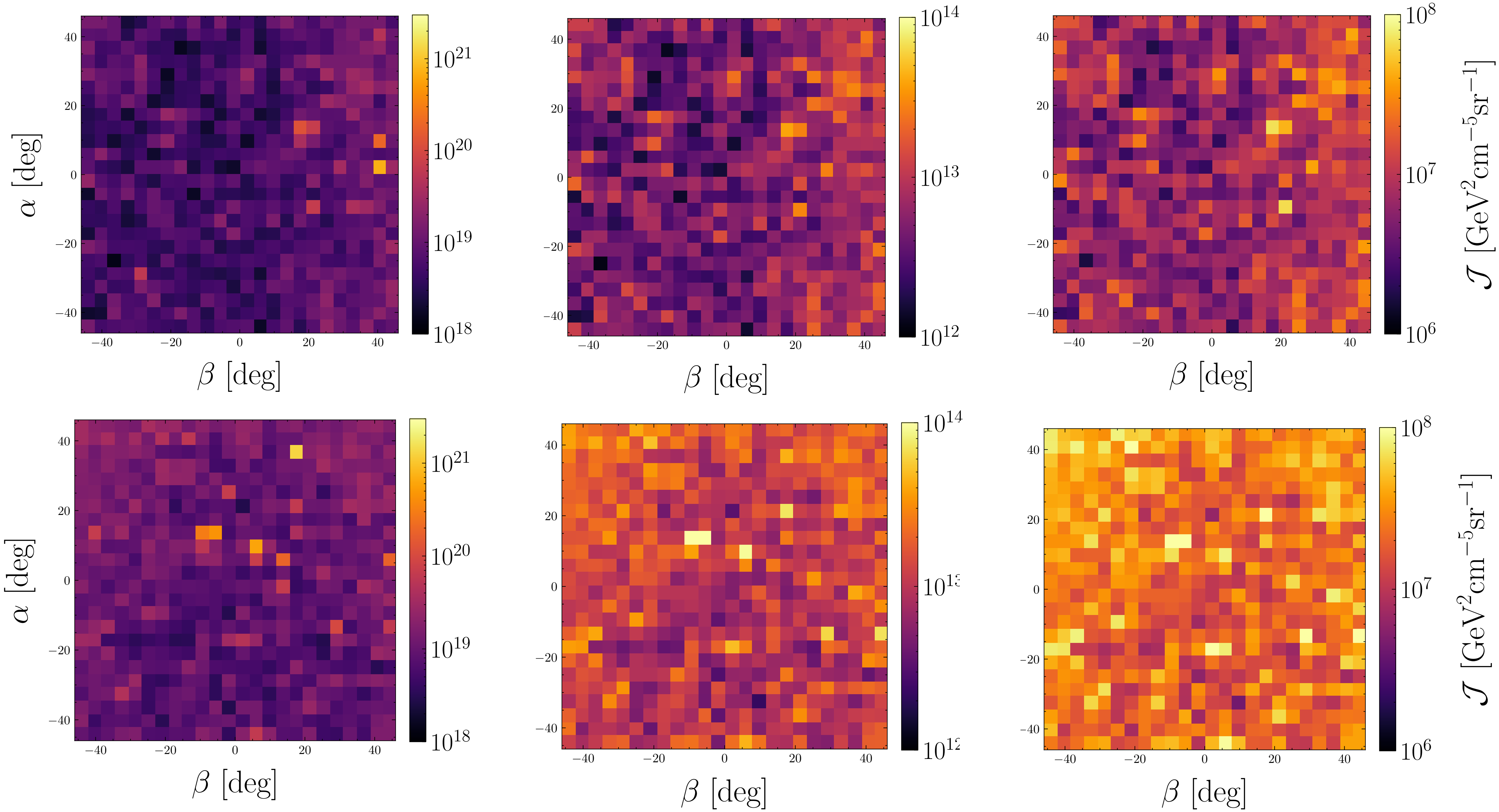
Preliminary

J-Factor - Outer Halo

S-Wave **P-Wave** **D-Wave**

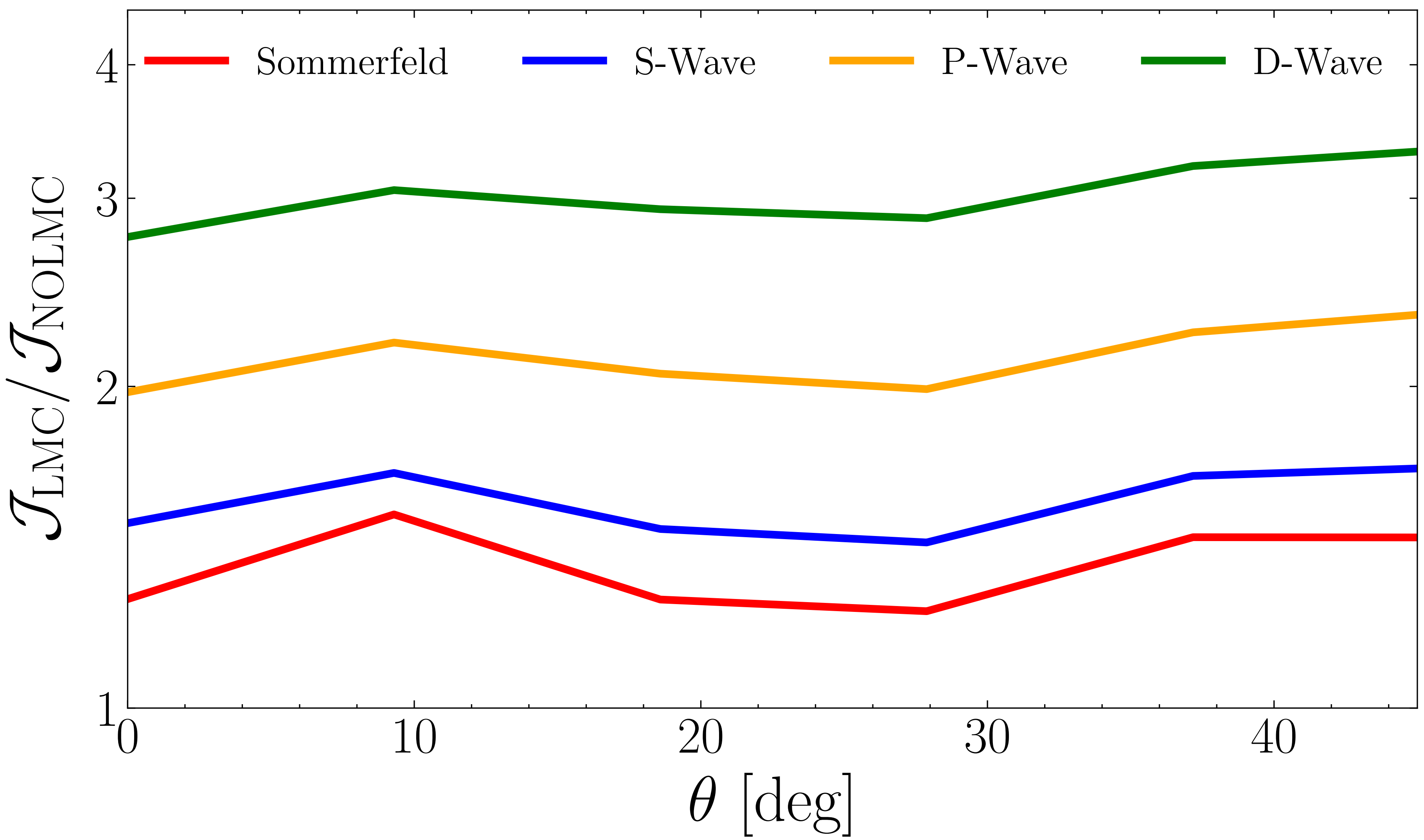
w/out LMC

w/ LMC



Preliminary

J-Factor - Outer Halo



- The LMC changes the J-Factors in a region of the outer halo for all waves
- Most significant for **P-Wave** and **D-Wave**

Preliminary

Next Steps

- Compute exclusion limits by comparing our maps with Fermi-LAT observations
- Search for the LMC wake and compute the J-Factor of that region
- Compare results with the other 15 MW-LMC analogues

Next Steps

- Compute exclusion limits by comparing our maps with Fermi-LAT observations
- Search for the LMC wake and compute the J-Factor of that region
- Compare results with the other 15 MW-LMC analogues

Thank you

Backups

Local Density and Relative Velocity Computations

$$V_{\text{circ}}(r) = \sqrt{\frac{GM(<r)}{r}}$$