SEARCHING FOR DARK DISKS USING GAIA

Katelin Schutz, UC Berkeley Student
with Tongyan Lin, Ben Safdi, and Chih-Liang Wu
TeVPA 2017

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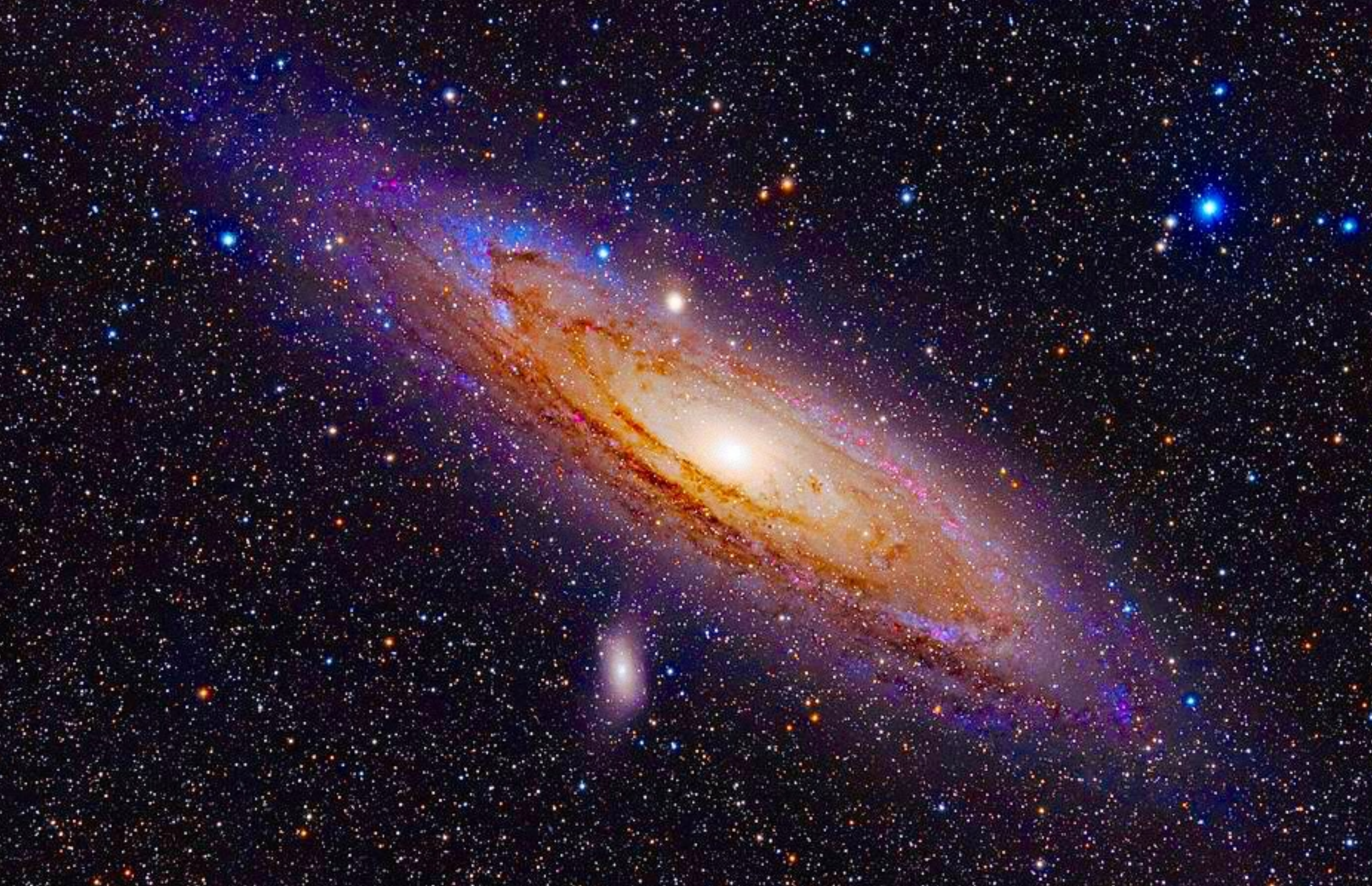
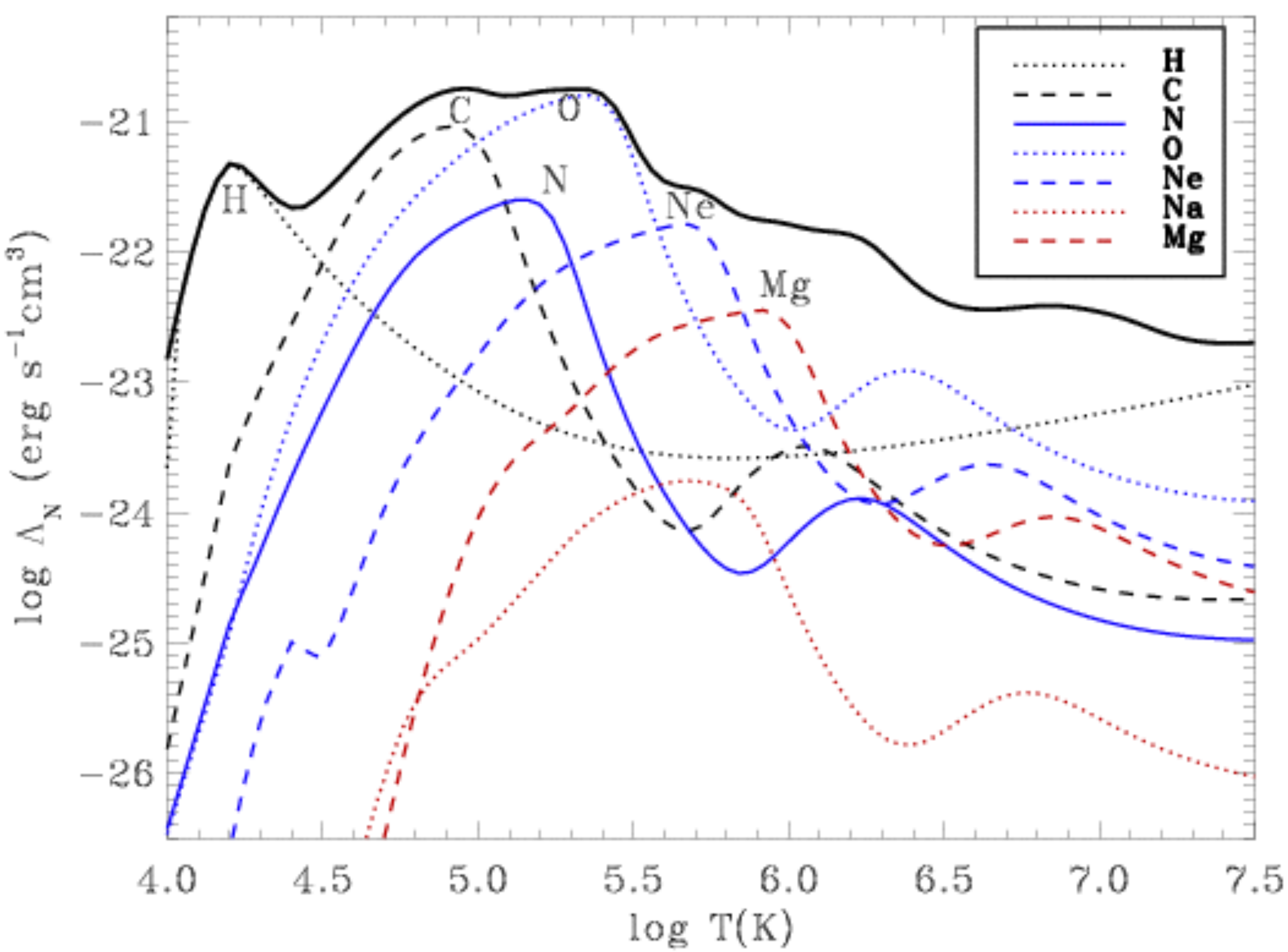
Work in prep (!)

Searching for *thin* dark disks



Why look for dark disks?

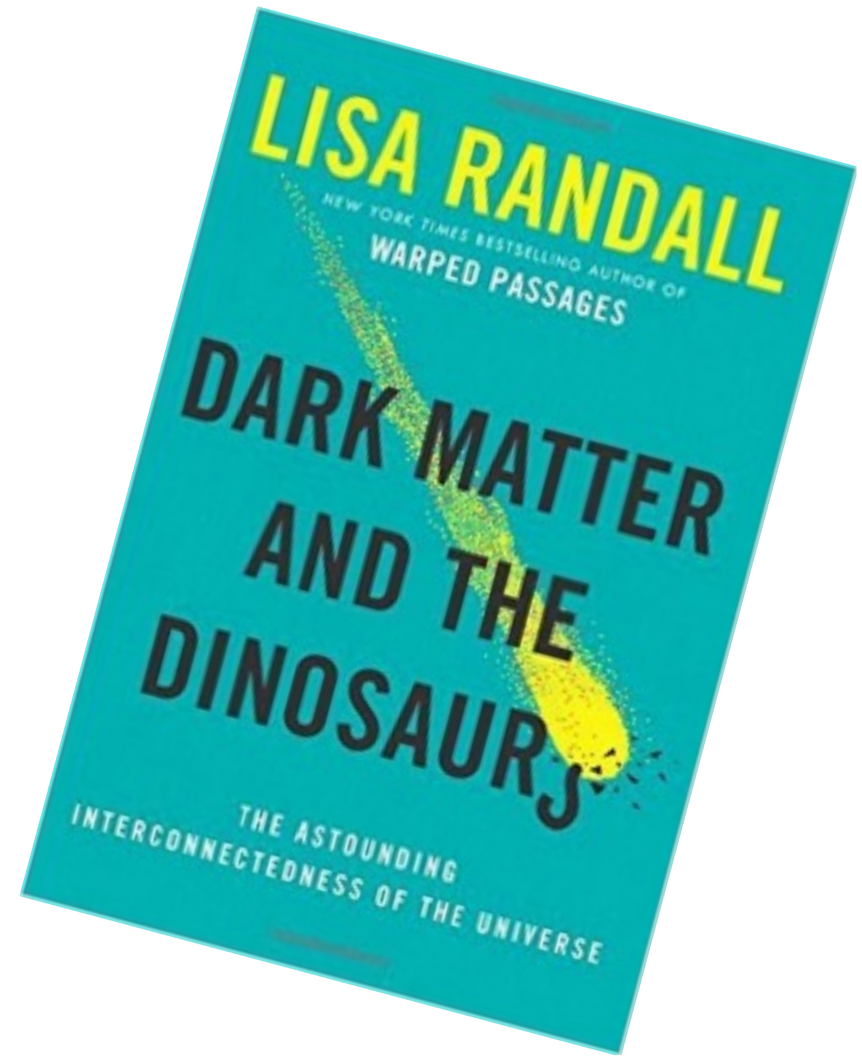
- In analogy to baryons, if dark matter has a way to dissipate energy, it can cool enough to pancake (Fan et al.)
- This can happen for a variety of mechanisms, as long as there is dissipation (McCullough & Randall)



- The dark matter would have to live in a multicomponent “hidden sector” where only a fraction is interacting strongly enough to cool substantially

Indirect signatures of dark disks

- Enhanced direct detection signal (McCullough & Randall, Bruch et al.)
- Co-rotation of Andromeda satellites (Randall & Scholtz)
- Periodic disruption of comet trajectories causing mass extinction events (Randall & Reece)
- Collapsed dark matter objects can account for the point-like nature of the inner galaxy GeV excess (Agrawal & Randall)
- Dynamical influence on local stars in the Milky Way (McKee et al., Kramer & Randall)



The Gaia Mission

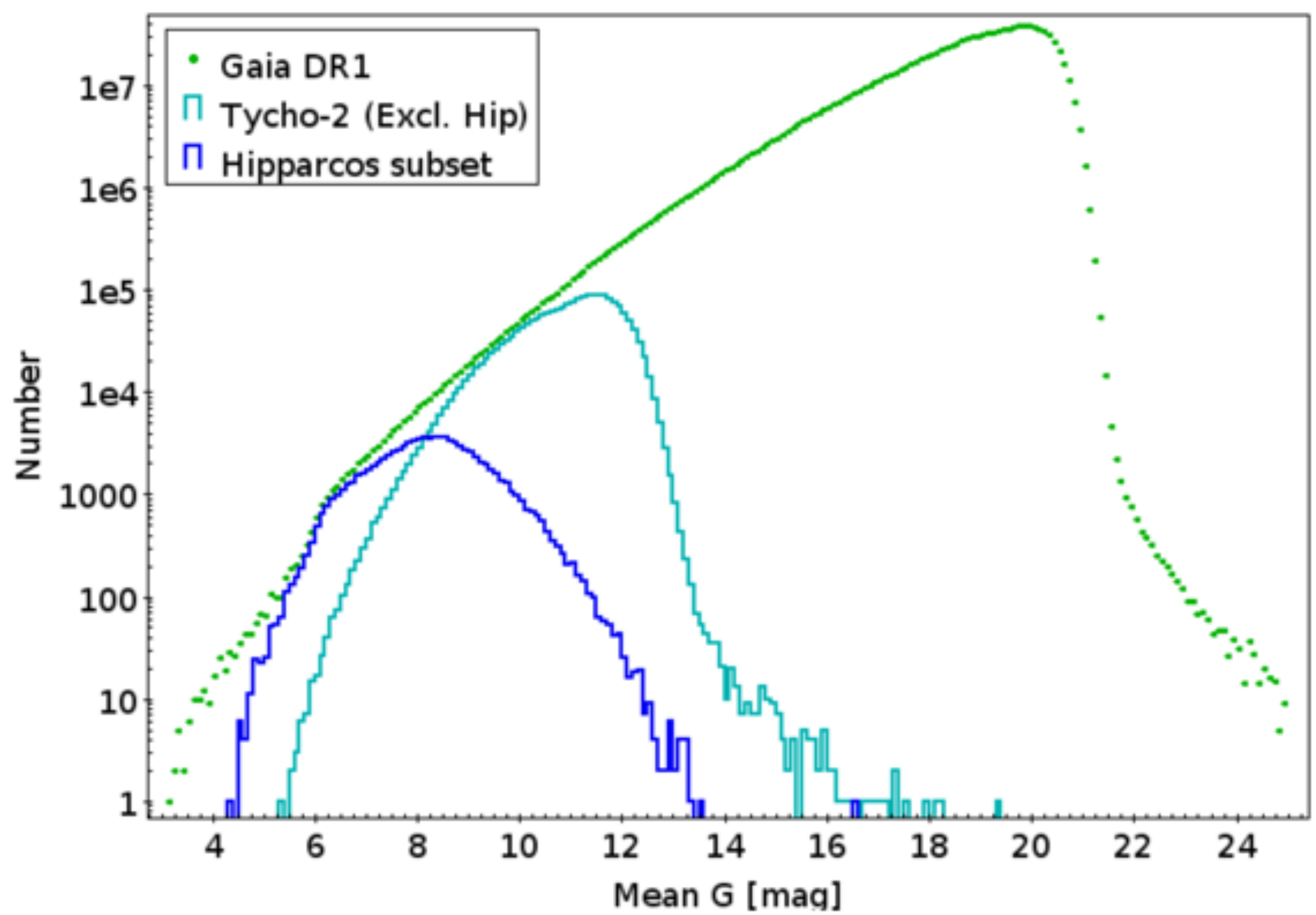
With Gaia's resolution you can resolve hairs on my head from Columbus while I visit the Golden Gate Bridge

Some goals of Gaia:

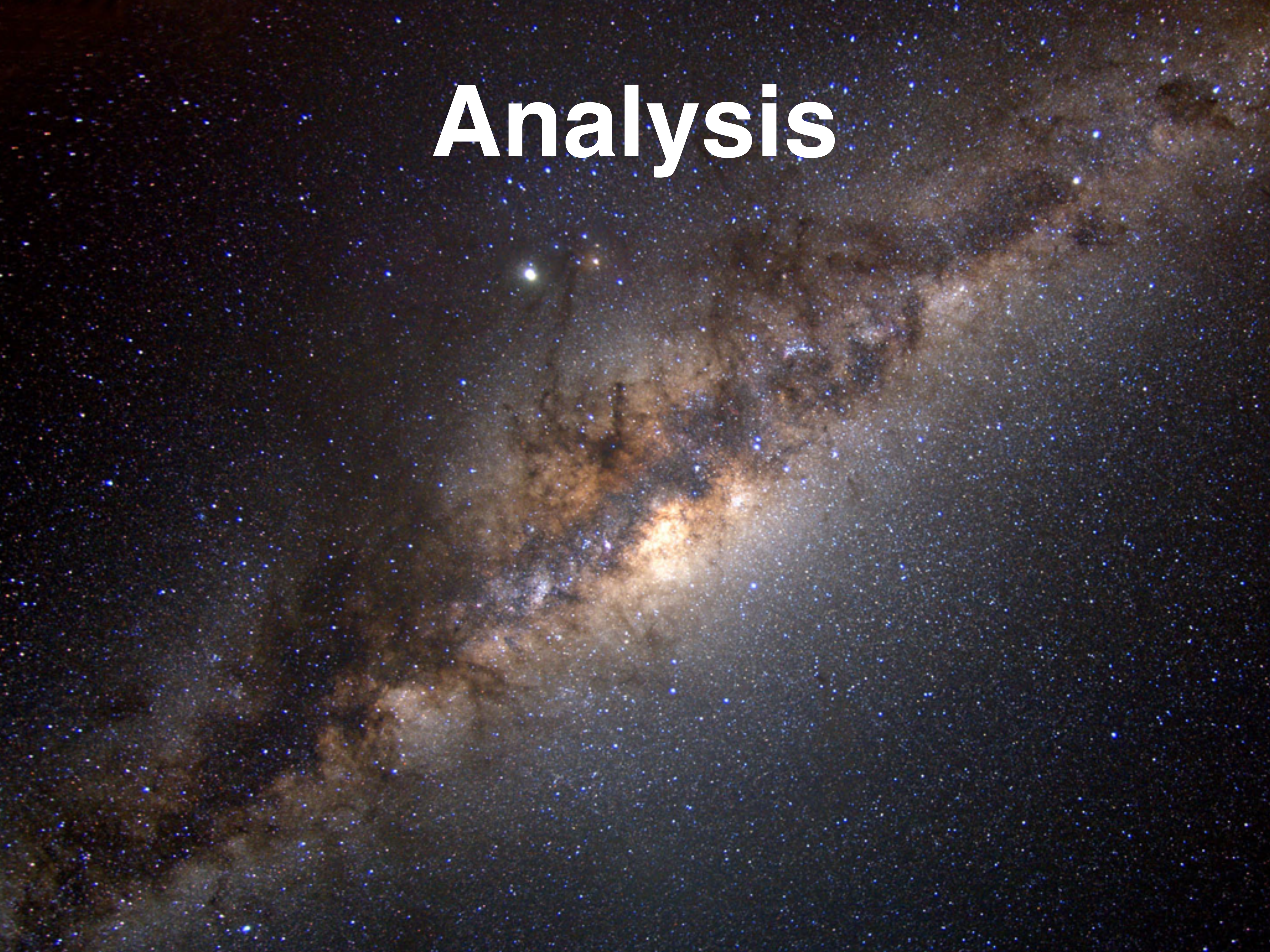
- High precision astrometry of ~1 billion stars (few percent of visible stars in Milky Way galaxy)
- Repeated monitoring of each target over a several year period means perpendicular velocity resolution of ~km/s and parallax distances with percent level accuracy
- On-board spectrometer to determine radial velocities
- Complete 6D phase space information even for dim, far stars (e.g. the sun at ~1 kpc) which means we are statistics limited near the galactic plane

Gaia already has data

- DR1 is a continuation of Tycho with proper motions (TGAS)
- DR2 is scheduled for 2018 and will have the full 6D information (parallax, proper motions, etc)



Analysis

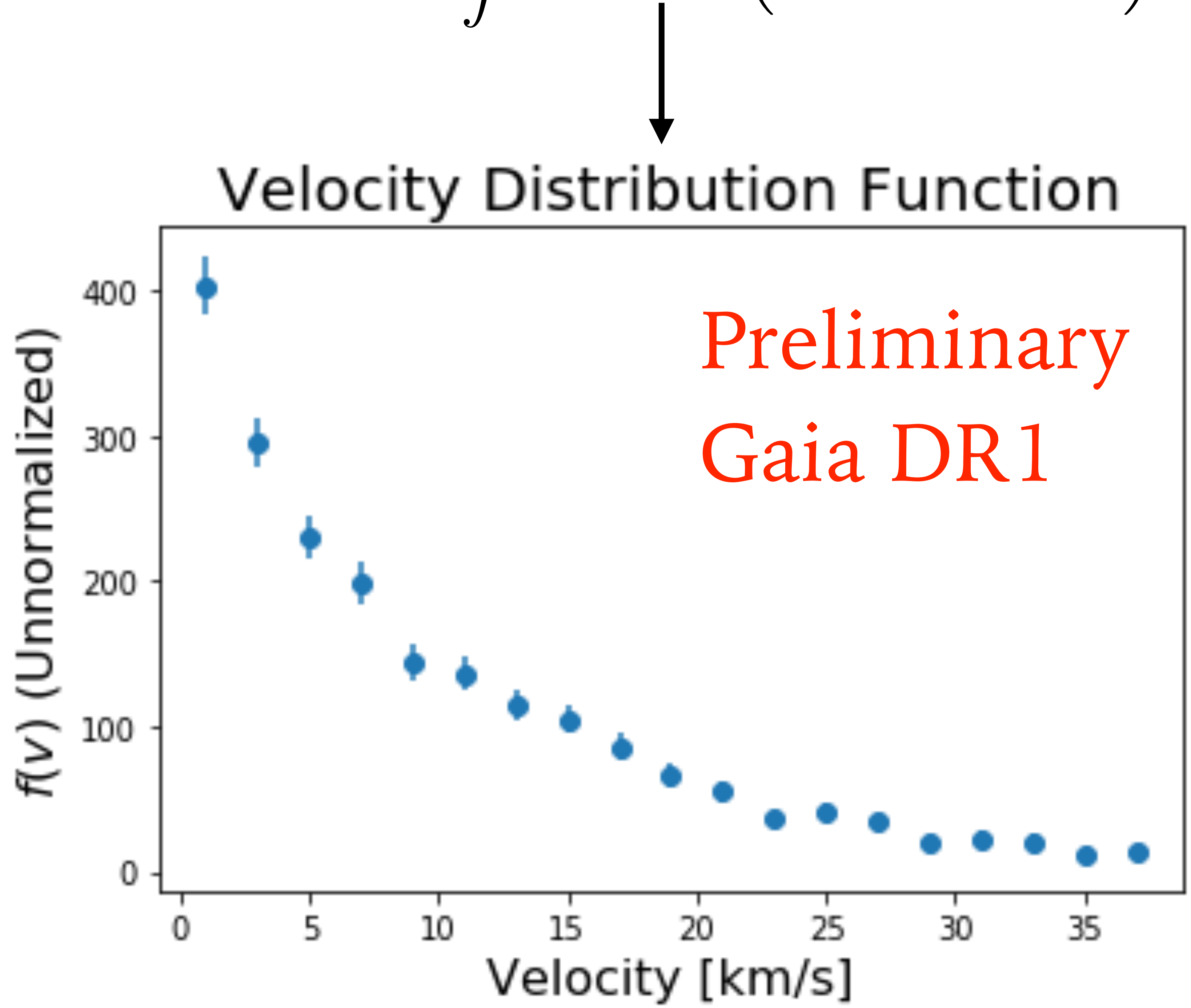


ANALYSIS METHODS IN THE LITERATURE

- Method 1: Calculate the total surface density and compare to the summed surface density of visible components, which is extrapolated from the central density. If there is a deficit then this can be a dark disk! (McKee et al., Bovy & Tremaine, etc.)
- Method 2: Don't extrapolate the central density, instead self-consistently include a dark disk and calculate the "pinching" effect it has on the visible components. A dark disk can make room for itself and thus this is the more self-consistent and conservative analysis. (Kramer & Randall)

PREDICTING THE TRACER PROFILE

$$\nu_A(z) = \nu_A(0) \int dv_z f_{A,0} \left(\sqrt{v_z^2 + 2\Phi(z)} \right)$$



Equations of Motion

$$\frac{\sigma_A^2}{\nu_A}\partial_z \nu_A + \partial_z \Phi = 0 \longrightarrow \nu_A(z) = \nu_A(0)\, e^{-\Phi(z)/\sigma_A^2}$$

Connect this to the mass density profile with Poisson equation

$$\partial_z^2 \Phi = 4\pi G \rho$$

Single-population case:

$$\rho(z) = \rho(0)\,\mathrm{sech}^2\left(\sqrt{2\pi G \rho(0)}\, z/\sigma\right)$$

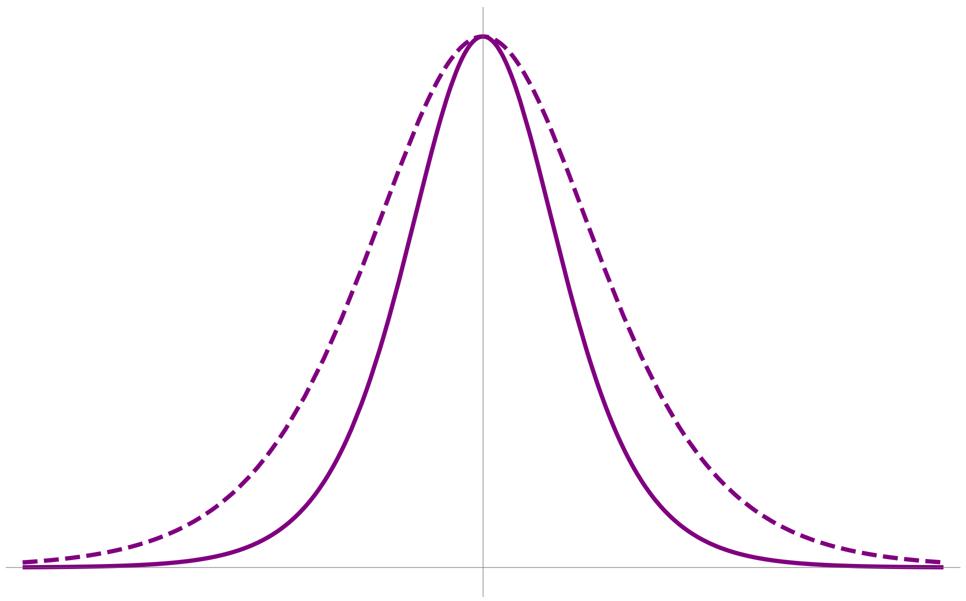
Equations of Motion

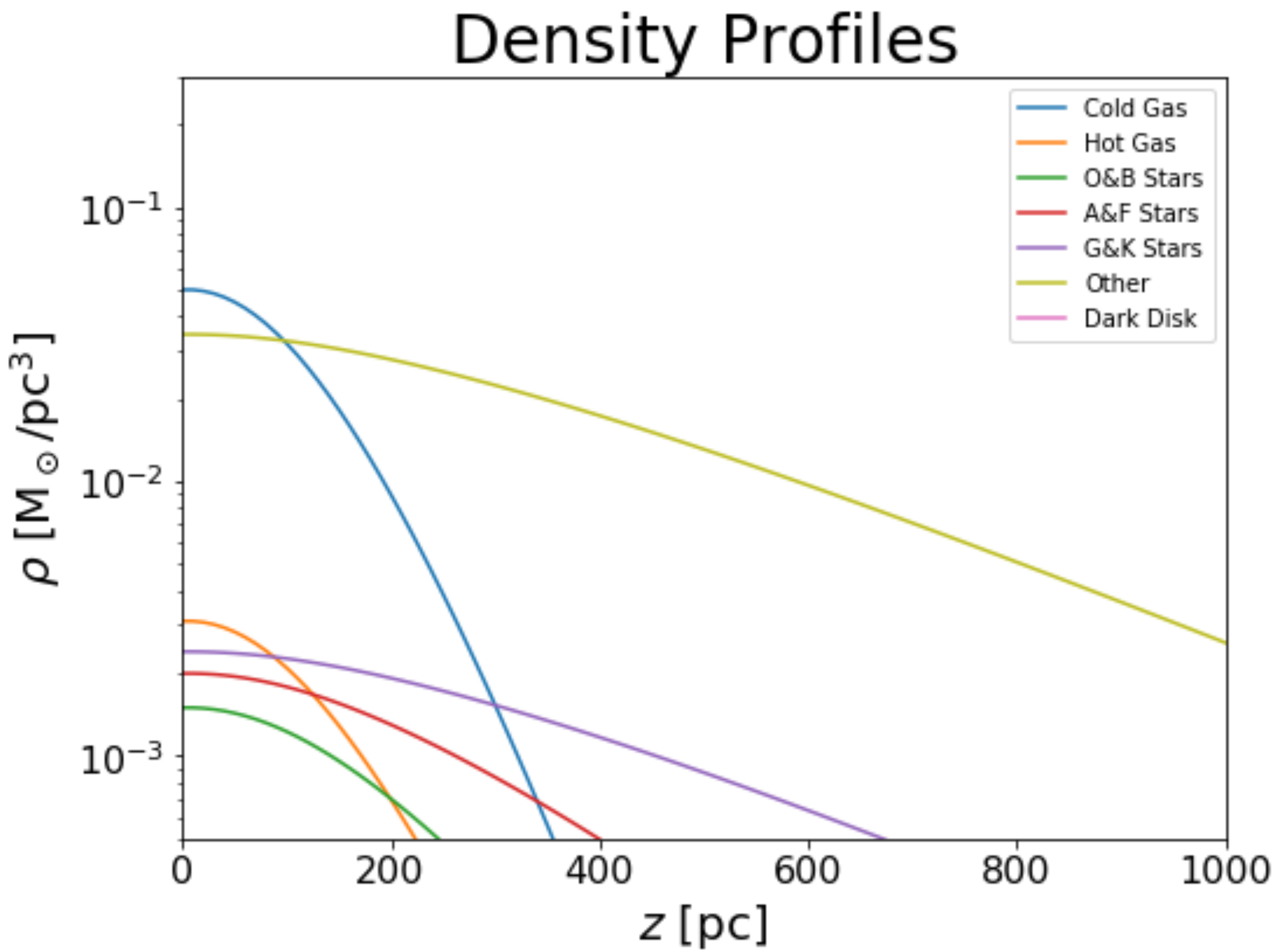
$$\frac{\sigma_A^2}{\nu_A}\partial_z \nu_A + \partial_z \Phi = 0 \longrightarrow \nu_A(z) = \nu_A(0)\, e^{-\Phi(z)/\sigma_A^2}$$

Connect this to the mass density profile with Poisson equation

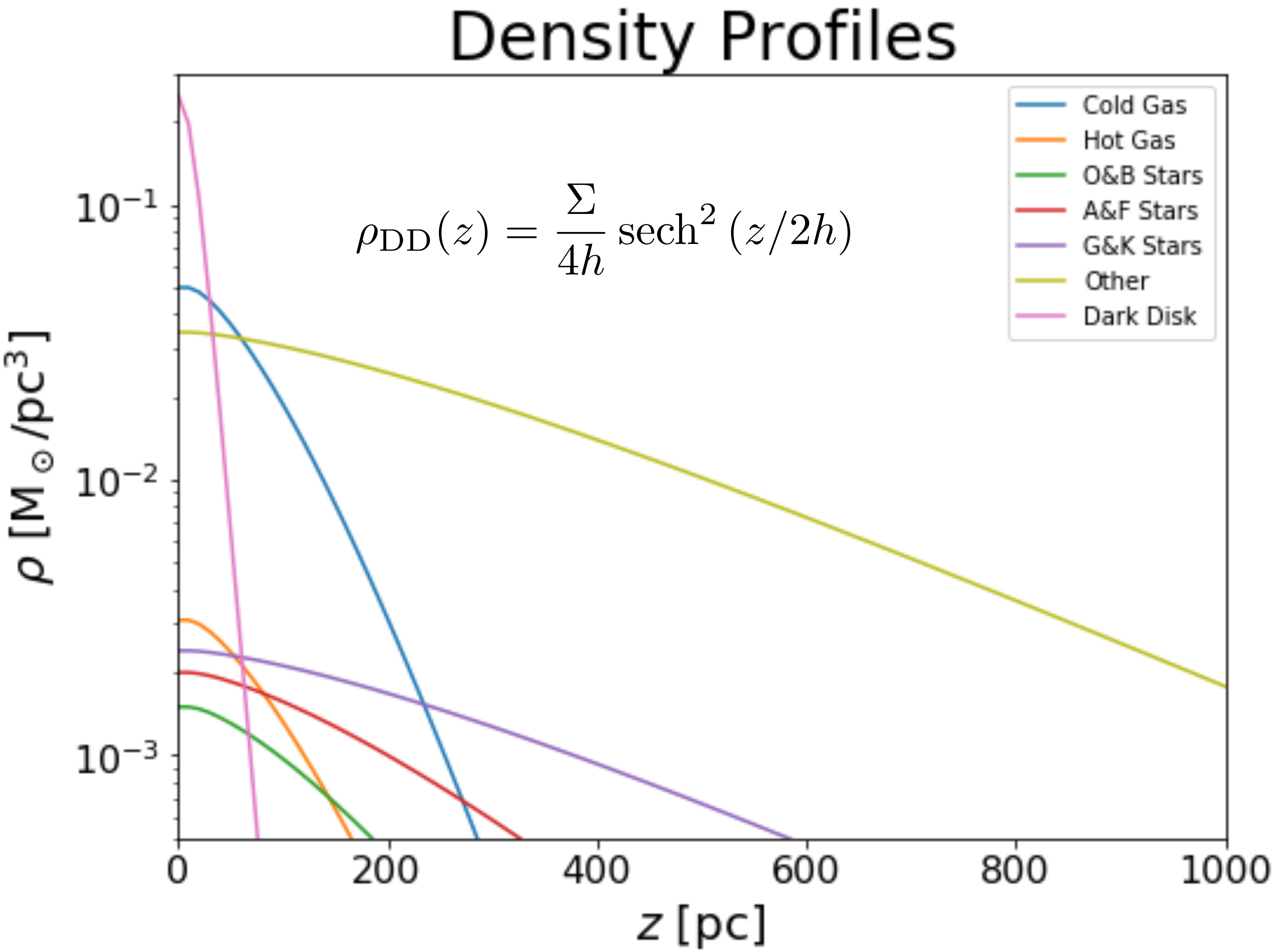
$$\partial_z^2 \Phi = 4\pi G \rho$$

Multiple populations:





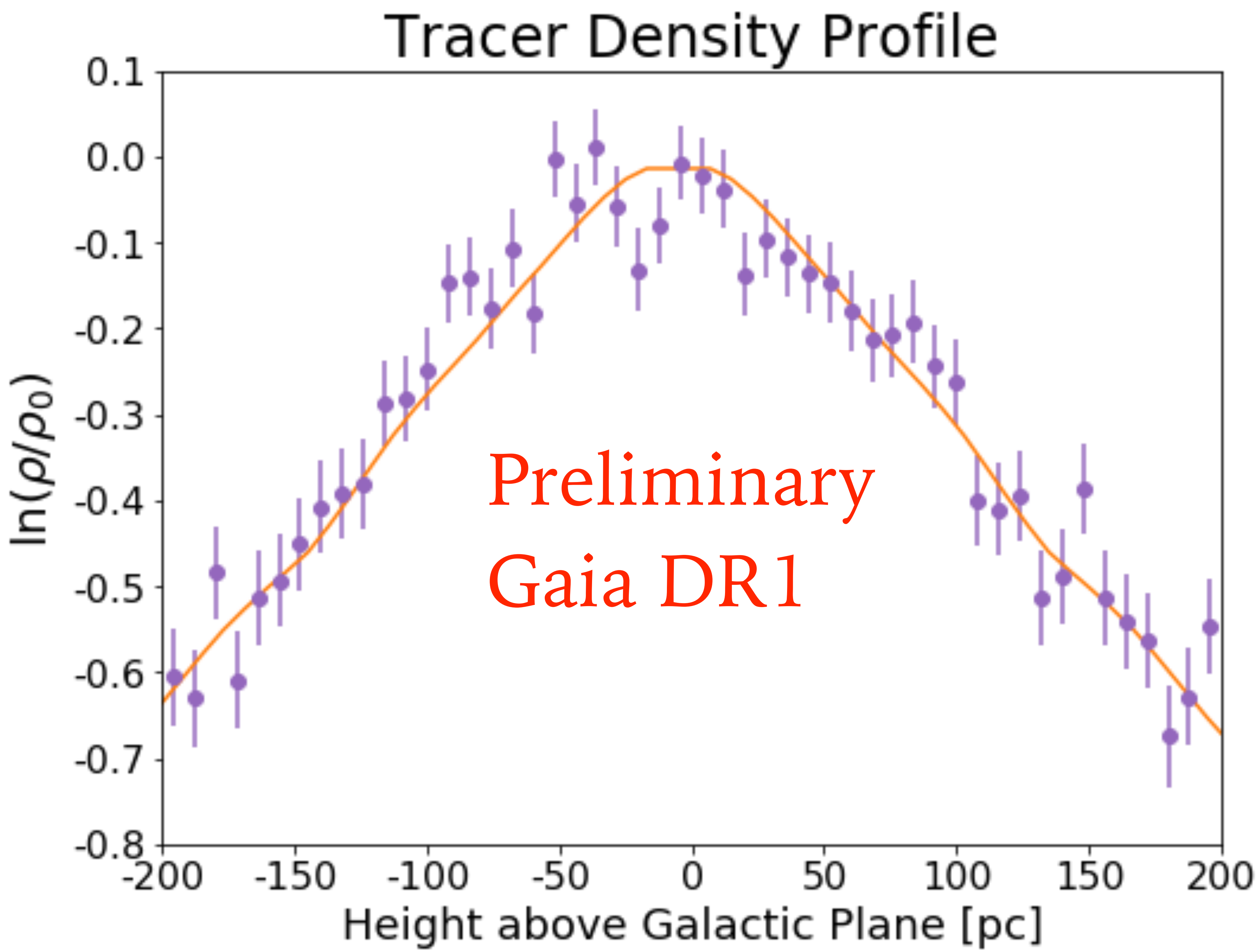
Density Profiles
Cold Gas
Hot Gas
O&B Stars
A&F Stars
G&K Stars
Other
Dark Disk
10^{-1}
10^{-2}
10^{-3}
ρ [$M_\odot$/pc^3]
0
200
400
600
800
1000
z [pc]


Density Profiles
$\rho_{\rm DD}(z) = \frac{\Sigma}{4h}\,\mathrm{sech}^2\,(z/2h)$
Cold Gas
Hot Gas
O&B Stars
A&F Stars
G&K Stars
Other
Dark Disk
ρ [$M_\odot$/pc^3]
10^{-1}
10^{-2}
10^{-3}
0
200
400
600
800
1000
z [pc]

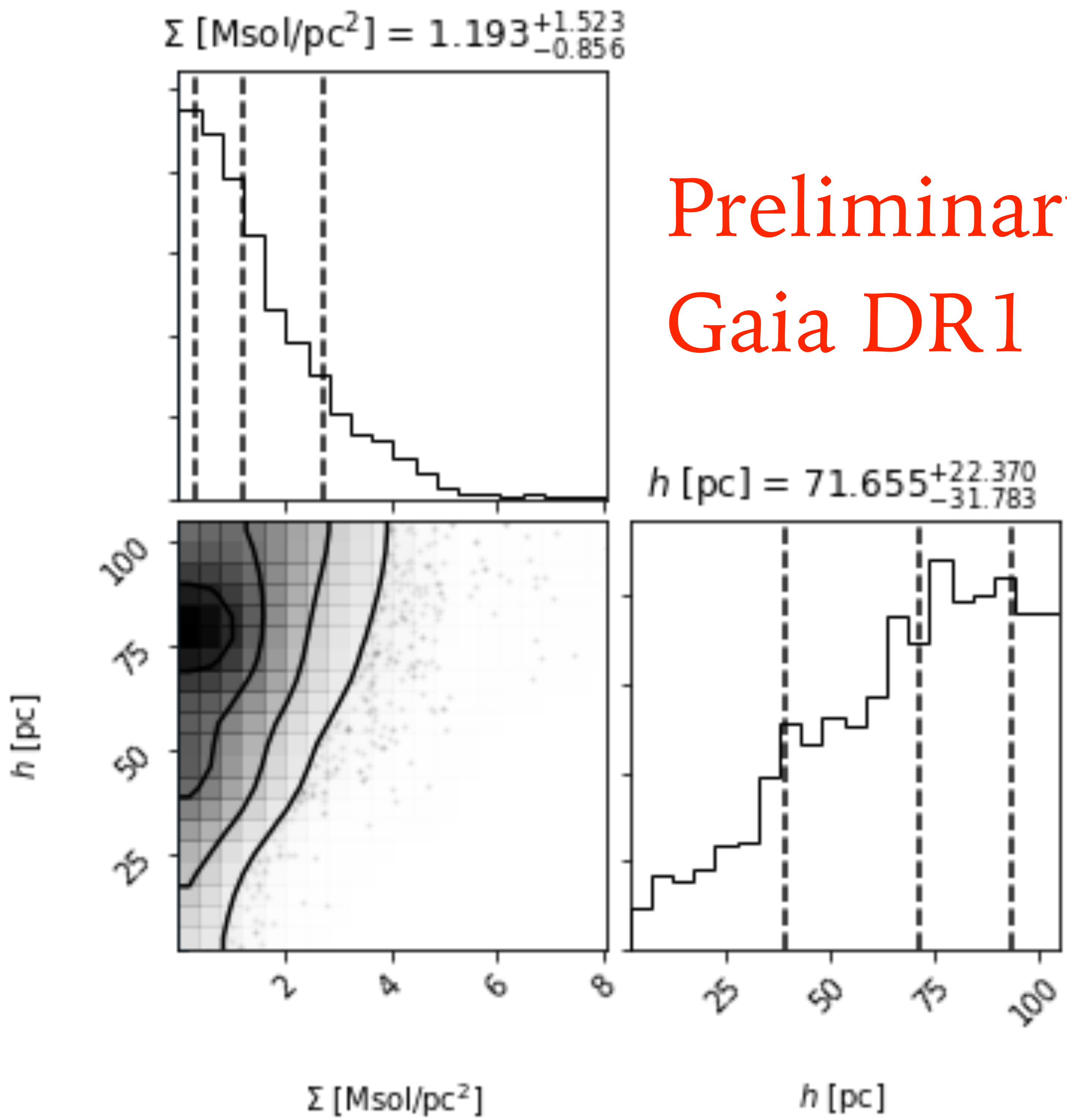
WHAT'S DIFFERENT ABOUT OUR ANALYSIS?

- Full MCMC exploration of parameter space, including "nuisance" parameters of baryonic physics, merger history, height of the sun, etc.
- Testing whether dark disk can be absorbed into uncertainties in e.g. gas parameters and being as conservative as possible about possible degeneracies
- Using Gaia DR1 data A-G stars (20x more stars than previous analyses), including selection function to account for relative statistical completeness (Bovy, 2017)

The "zero-parameter" fit



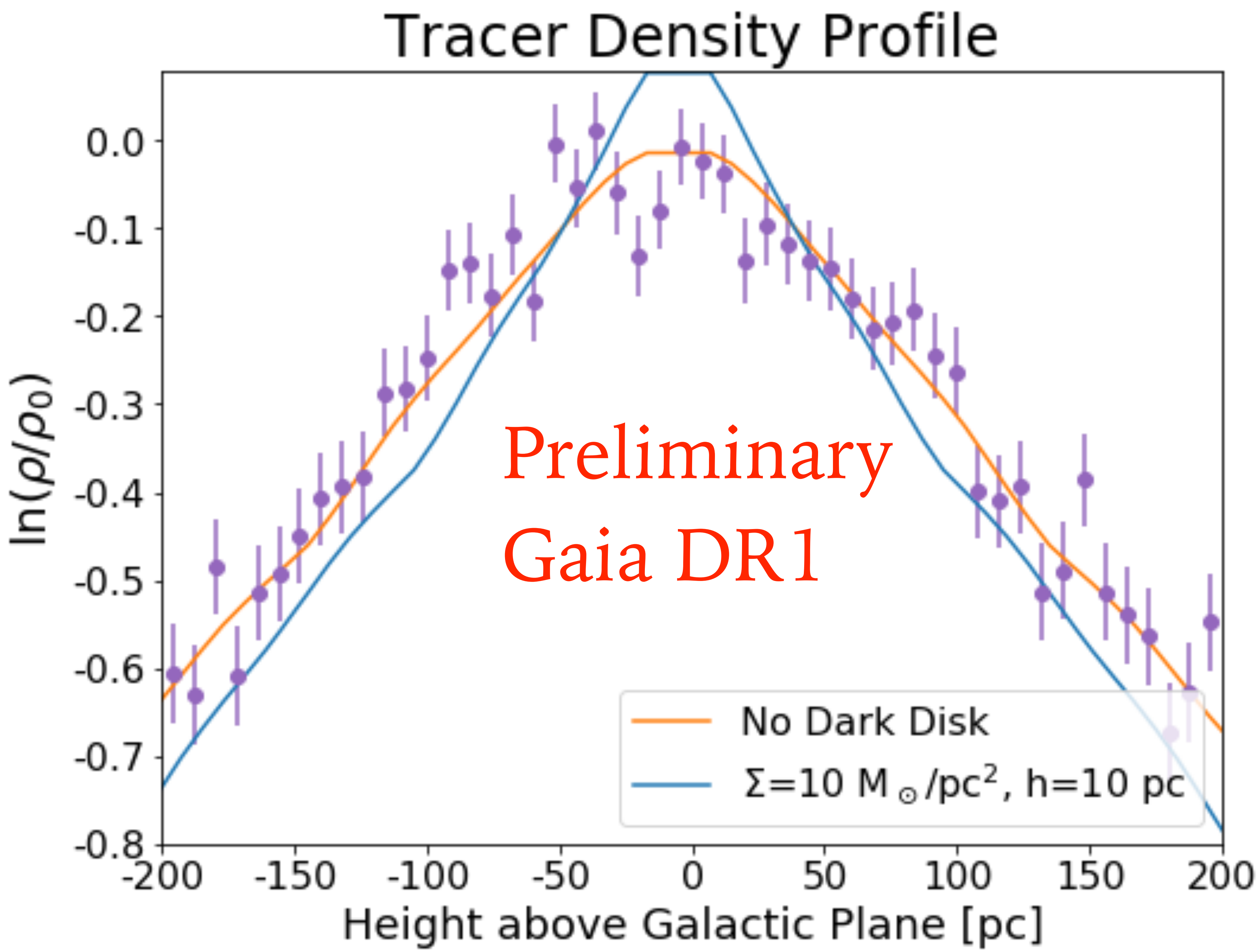
Marginalized Posteriors



Preliminary
Gaia DR1

- Marginalized over uncertainties in baryonic mass model, time variations in profile shape, height of the sun, normalization
- Dark disk, if present has to be small, quantifying this statement is still in prep (MCMCs are running)

Best fit for a nontrivial dark disk



DARK DISK IMPLICATIONS (REVISITED)

- Enhanced direct detection signal $\Sigma \sim 40\ M_{\odot}/pc^2$ (very ruled out)
- Co-rotation of Andromeda satellites $\Sigma \sim 10\ M_{\odot}/pc^2$, h~50 pc (ruled out at $\sigma \sim 3.5$, $\Delta \ln \mathcal{L} \sim 12$)
- Periodic disruption of comet trajectories causing mass extinction events $\Sigma \sim 10\ M_{\odot}/pc^2$, h~10 pc (ruled out, $\Delta \ln \mathcal{L} \sim 35$)
- Collapsed dark matter objects can account for the point-like nature of the inner galaxy GeV excess $\Sigma \sim 10\ M_{\odot}/pc^2$, h~10 pc (ruled out, $\Delta \ln \mathcal{L} \sim 35$)
- Dynamical influence on local stars in the Milky Way (non-equilibrium method) $\Sigma \sim 14\ M_{\odot}/pc^2$, h~10 pc (very ruled out, $\Delta \ln \mathcal{L} \sim 60$)

Preliminary

SUMMARY

- Dark disks arise in models of dark matter where there are substantial dissipations
- They can have interesting observable implications
- Gaia is sensitive to the presence of dark disks via how stars trace the potential
- Given Gaia DR1, any dark disk that exists would have to be too small to have the observable consequences claimed in the literature
- Plenty more ideas for using Gaia to constrain properties of dark matter and more!