Revised Outline (Scientific-Paper Style)

1. Introduction

1. **Motivation and Context**
   - State why tidal interactions and morphological transformations of M33 are scientifically interesting.
   - Summarize what past work suggests about tidal stripping, disk warping, and mass loss in dwarf or satellite galaxies (as in your current Introduction).
   - Cite the key references that inform the subject (e.g., Mayer et al. 2001, Lokas et al. 2015, etc.).
2. **Goals and Hypothesis**
   - Clearly list the scientific questions you aim to answer (e.g., "How does M33's disk become truncated over time?").
   - Present your hypothesis (e.g., "We hypothesize that repeated close passages with M31 will produce ∼10–20% mass loss and generate significant disk warping.").
3. **Plan of This Work**
   - Briefly preview *how* you will address these questions: "We use future-evolution snapshots from van der Marel et al. (2012), measure the Jacobi radius over time, compute mass-loss rates, and analyze changes in M33's surface density and morphology."

(In a final paper, you may merge "Goals and Hypothesis" into the Introduction text, but it's often helpful to keep them clearly identifiable.)

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2. Data and Simulation Overview

1. **Simulation Origin**
   - Describe the van der Marel & Besla (2012) simulation: its resolution, the kinds of particles (halo, disk, bulge), and the timespans covered (0–10 Gyr in steps of 1 Gyr).
2. **Coordinate Systems and Conventions**
   - Note how the snapshots are stored (e.g., "type=2 for disk stars," "columns are `x,y,z,vx,vy,vz`," etc.).
   - Clarify whether each snapshot is in a common reference frame or a galaxy-centric frame.
3. **Snapshot Files**
   - Indicate the naming scheme of your snapshot files (e.g., `M33_000.txt`, `M31_000.txt`).
   - State how many snapshots you use in total and over what time range.
4. **Data Availability**
   - (As per MNRAS style) reaffirm that no new data were generated, and that these simulation outputs are publicly available or upon request from the authors.

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3. Methods

This section merges your code-flow steps into scientifically oriented subsections. Each subsection explains both *why* and *how* you do a given computational step. In the final paper, you can keep the descriptions concise, referring to figure references and equations. In the notebook, you would have multiple cells corresponding to these subsections.

3.1 Overview of Analysis Pipeline

- **Summary of Pipeline**
  Give a high-level narrative of the entire procedure: "We read each snapshot, compute centers of mass, measure Jacobi radii, select bound particles, fit surface density profiles, measure morphological indicators, etc."

3.2 Data Parsing and Preparation

Reading Galaxy Snapshots (Code Cells #2.1, #2.3 in your outline)

1. **Purpose**: Import M31 and M33 data for each snapshot and isolate the relevant stellar particles.

2. **Implementation Details**:

   - *File Parsing Functions*: e.g. `parse_galaxy_file(filename)` that returns arrays of mass, coordinates, velocities.
   - *Center of Mass Computation*: a `center_of_mass()` function for each galaxy, ensuring we have M33's center precisely for each snapshot.
   - *Sanity Checks*: Print/log total mass, COM coordinates, etc., to confirm correct reading.

3. **Coordinate Centering**
   Justify why you recenter M33 data on its own COM: "This allows radial profiles to be computed from M33's center."

3.3 Mass-Loss Analysis

Jacobi (Tidal) Radius Computation (Code Cells #3.1.1–3.1.2)

1. **Theory**: Define the Jacobi radius
$$R_{\mathrm{J}} \approx R \left(\frac{M_{\mathrm{sat}}}{2\, M_{\mathrm{host}}} \right)^{1/3}.$$

2. **Implementation**: For each snapshot, measure the M31–M33 separation R, estimate M31's enclosed mass (e.g., via a Hernquist profile), and compute R_{J}.

3. **Outputs**: Store R_{J} versus snapshot time.

Bound Mass (Code Cells #3.2.1–3.2.2)

1. **Motivation**: We want to quantify how much of M33's disk remains bound over time.

2. **Implementation**: For each snapshot, select M33 stellar particles within $\min(R_{\mathrm{J}}, R_{\text{outer limit}})$. Sum the mass $\rightarrow M_{\mathrm{bound}}(t)$.

3. **Outputs**: Plot or tabulate $M_{\mathrm{bound}}(t)$ vs. time, note percentage mass loss.

4. **Interpretation**: Large declines in M_{bound} indicate strong tidal stripping.

3.4 Radial Surface Density Profiles and Fitting

Profile Generation (Code Cells #4.1.1–4.1.2)

1. **Method**: Compute $\Sigma(R)$ in radial bins for each snapshot.
2. **Implementation**:
   - Shift the coordinates to M33's COM.
   - Compute cylindrical radius $r = \sqrt{x^2 + y^2}$.
   - Bin particles in radius, summing mass/area to get $\Sigma(r)$.
3. **Outputs**: $\Sigma(r)$ for each snapshot. Possibly store them in arrays or `.csv` files.

Sérsic / Exponential Fits (Code Cells #4.2.1–4.2.3)

1. **Rationale**: Fitting reveals if the disk remains exponential or transitions to a truncated "tidal" profile.
2. **Implementation**:
   - Fit $\Sigma(r)$ with an exponential $\Sigma(r) = \Sigma_0 \, e^{-r/h}$ and/or a general Sérsic function.
   - Use `curve_fit` or an equivalent optimizer.
3. **Outputs**: Best-fit scale lengths, Sérsic index, effective radius, etc. Summarize them in a table or dictionary across time.
4. **Tidal Truncation Check** (Code Cells #4.3.1–4.3.2):
   - Check for a steep outer slope or abrupt cutoff in the profile.
   - Compare "observed truncation radius" with the Jacobi radius to see how well they correlate.

3.5 Morphological and Kinematic Evolution

Face-On / Edge-On Views (Code Cells #5.1.1–5.1.2)

1. **Purpose**: Visually diagnose changes in disk shape, thickness, bars, or lumps.
2. **Implementation**:
   - Compute M33's total angular momentum vector, rotate coordinates so that the disk is in the XY-plane.
   - Make 2D histograms or density plots for face-on and edge-on perspectives.
3. **Outputs**: Series of plots over time, saved for reference.

Spiral Arms & Pitch Angle (Code Cells #5.2.1–5.2.2)

1. **Motivation**: Tidal encounters can distort spiral arm morphology.
2. **Implementation**: Fit θ vs. $\ln(r)$ or use pattern-recognition to estimate pitch angle.
3. **Outputs**: Timeseries of pitch angle, commentary on whether arms loosen/tighten or get disrupted.

Warp and Scale Height (Code Cells #5.3.1–5.3.3)

1. **Warp**: Subdivide the disk radially, measure local normal vectors, track the tilt relative to the inner disk.
2. **Scale Height**: Compute the vertical dispersion σ_z or half-height in radial bins.
3. **Interpretation**: Evaluate if M33's disk gets thicker (tidal heating) or more warped near pericenters with M31.

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4. Results

Here, you *present* the outcomes from the methods above, referencing the same plots, tables, and metrics that your code cells generate. In your actual paper, you might place figures directly in this section. In your notebook, you might finalize them at the end of each method subsection; how you do it is up to you. Typical results sections in an astronomy paper might include:

1. **Time Evolution of Jacobi Radius and Bound Mass**
   - Show a figure of $R_\mathrm{J}(t)$ and $M_\mathrm{bound}(t)$.
   - Note key times of large mass drop, e.g., "At $t \approx 5$ Gyr, M33 loses 15% of stellar mass."
2. **Disk Density Profiles and Fits**
   - Compare the initial and final radial profiles, overplotting exponential or Sérsic fits.
   - Show how the scale length or Sérsic index changes with time (e.g., figure or table).
   - State evidence for tidal truncation if the outer slope steepens.
3. **Morphological Signatures**
   - Include face-on snapshots, a pitch-angle vs. time plot, and warp-angle plots.
   - If you see a bar forming or the spiral arms disappearing after a certain epoch, highlight that.

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5. Discussion

1. **Interpretation of Results**
   - Summarize how the mass-loss timescale compares to theoretical predictions (resonant stripping, etc.).
   - Comment on how warps or scale-height changes appear in comparison to earlier literature.
2. **Implications for Galaxy Evolution**
   - Extend your findings to the broader context: "These results illustrate how repeated tidal passes in a group environment can transform a late-type dwarf into a more spheroidal system over $\sim$5–10 Gyr."
3. **Limitations and Caveats**

- Note any caveats about simulation resolution, orbit uncertainties, or simplified assumptions (e.g., "We assumed no major halo shape change for M31.")

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6. Conclusion and Future Work

1. **Summary of Key Findings**
   - Recap how much mass was lost, how the disk structure changed, and whether your hypothesis was validated.
2. **Future Directions**
   - Suggest follow-up angles: e.g., "Incorporating gas physics or star formation might reveal triggered starbursts in the outer disk," or "Similar analysis on M33's dark matter distribution is needed."
3. **Data & Code Availability**
   - Reiterate that the simulation data are from van der Marel et al. (2012), and your analysis code will be shared in a public repository if desired.

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7. Appendices (Optional)

If there are lengthy derivations (e.g., the exact formulae for your warp angles or the full definition of the Hernquist mass profile) or extra figures, you can put them in an Appendix for completeness.

How to Use This Outline

1. **In Your Jupyter Notebook**:
   - Organize cells to reflect these sections. For instance, you might have top-level Markdown headings that read "## Introduction," "## Data & Simulation," "## Methods," etc.
   - Within "## Methods," you can create subheadings "### 3.1 Data Parsing," "### 3.2 Mass Loss," etc., each of which corresponds to the code blocks you already outlined.
   - Every time you create a figure, mention "Figure X" in the Markdown cell so you can easily cross-reference in the written text.
2. **In Your Final Paper**:
   - Convert these section headings (Introduction, Methods, Results, Discussion, Conclusion) into your LaTeX MNRAS template.
   - Bring in your final plots as `\begin{figure} ... \end{figure}` inserts at appropriate places, referencing them in the text.
   - Summarize your code steps as the "analysis pipeline." You don't have to copy every detail of the code—just enough for reproducibility.

3. **Maintaining Scientific Rigor**:

    - Where the code outline says "we do X, Y, Z," the paper text should say *why* each operation is done and *what it reveals* scientifically (e.g., "We compute the Jacobi radius to approximate the tidal boundary of M33, which helps us quantify how much of the outer disk is being stripped at each snapshot.").

By adopting this structure, you will have a **unified** notebook that both runs your analysis and aligns with standard scientific-paper organization—making it straightforward to generate publication-ready figures, interpret results, and weave them into a coherent narrative.

References

Lokas E. L., Semczuk M., Gajda G., D'Onghia E., 2015, Astrophysical Journal, 810, 100

Mayer L., Governato F., Colpi M., et al., 2001, Astrophysical Journal, 559, 754

van der Marel R. P., Besla G., et al., 2012, Astrophysical Journal, 753, 9