# MAVEN Science Closure Strategy

*Rob Lillis & the MAVEN Science Closure Working Group,*

*MAVEN Science Community Workshop*

*December 2, 2012*

# MAVEN Science Closure Team

Rob Lillis, Steve Bougher, Tom Cravens, Dave Brain, John Clarke, Ian Stewart, Nick Schneider, Jane Fox, Xiaohua Fang, Jared Espley, Janet Luhmann, François Leblanc, Ronan Modolo & Andy Nagy

# Outline

- Why do we need a “science closure” strategy?
- Philosophy of science closure strategy.
- Flowdown charts from data to answers
- Necessary software tools & model libraries.
- Pre-launch science closure tasks.
- Path forward: how the community can help.

# Why have a science closure strategy?

1) **Broadly,** to ensure that we are prepared to answer our top-level science questions:
   a) What is the current state of the upper atmosphere?
   b) What is the escape rate at the current epoch and how does it relate to the controlling processes?
   c) What has been the integrated loss over time?

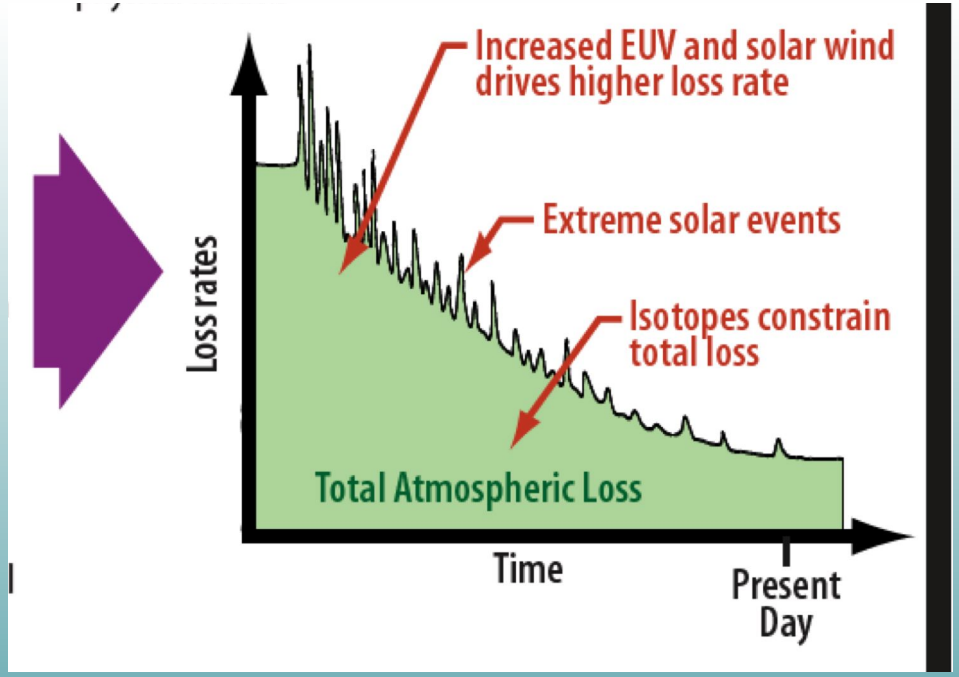
2) **Specifically,** to make sure we have tools in place to turn the first ~1000 orbits (~6 months) of data into defensible first-cut answers to our 3 main science questions.

# ‘Philosophy’ of Science closure path

- Question 1 (state of upper atmosphere) will be addressed organically with empirical and physical models.
- Question 2 (loss rates as a function of drivers) has been our priority recently because:
  - Neutral loss is not measured directly; we need a robust model-based operational capability of estimating it.
  - Substantial gaps in coverage of ion AND neutral loss during interesting events means interpolation will be necessary to obtain global estimates.
- While early results will be data-driven, models are an essential tool in informing us where the important gaps in our escape measurements *may* be lurking:
  - ‘Mock data’ forms the backbone of our early efforts.

# ‘Philosophy’ of Science closure path

- Question 3 (Extrapolation of loss back in time) will be addressed with answers from question 2 and an ‘iterative’ approach whereby atmosphere is ‘added’ to the models as we go back in time.



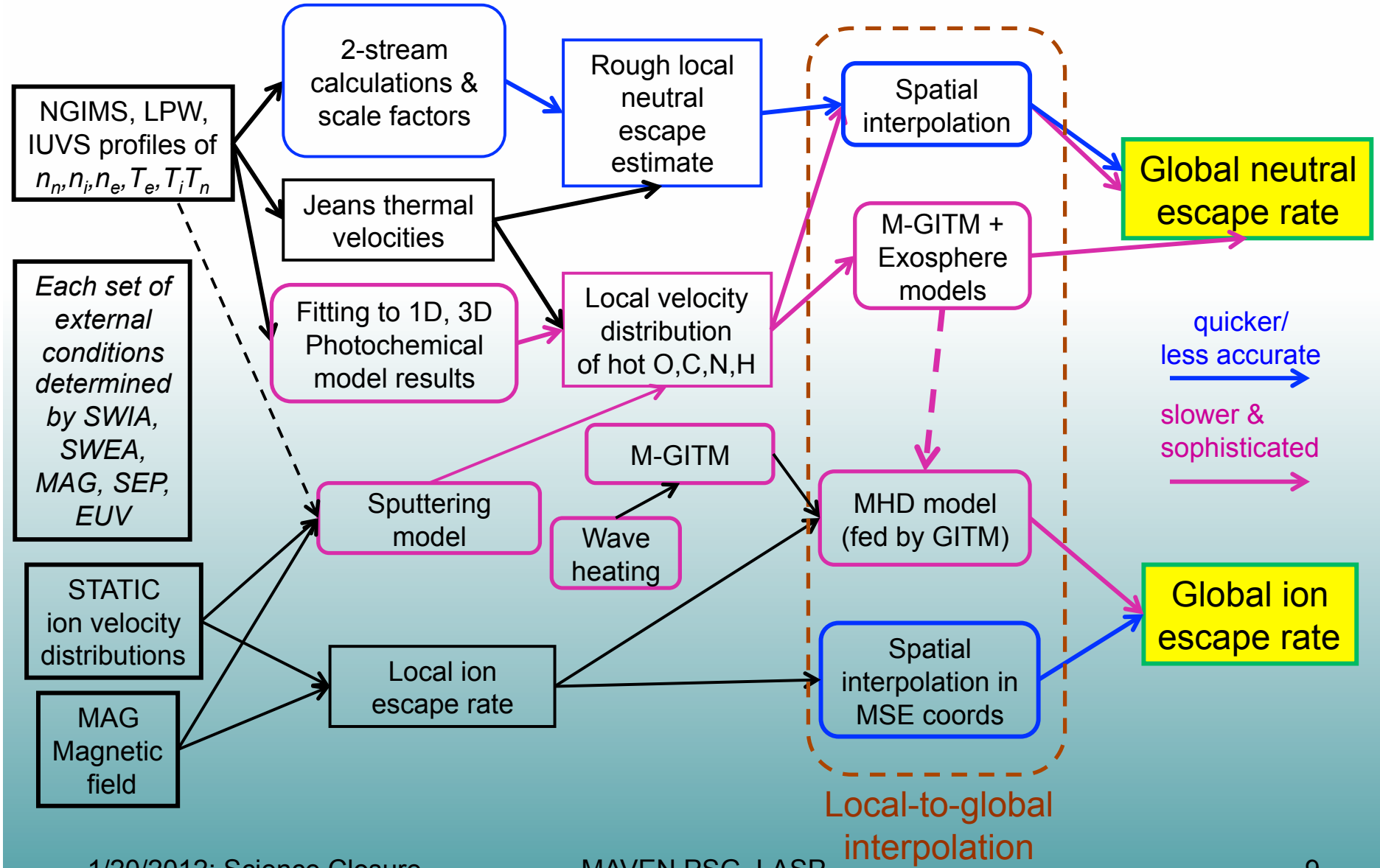
# Flow-down from data to answers

# Parameters driving escape

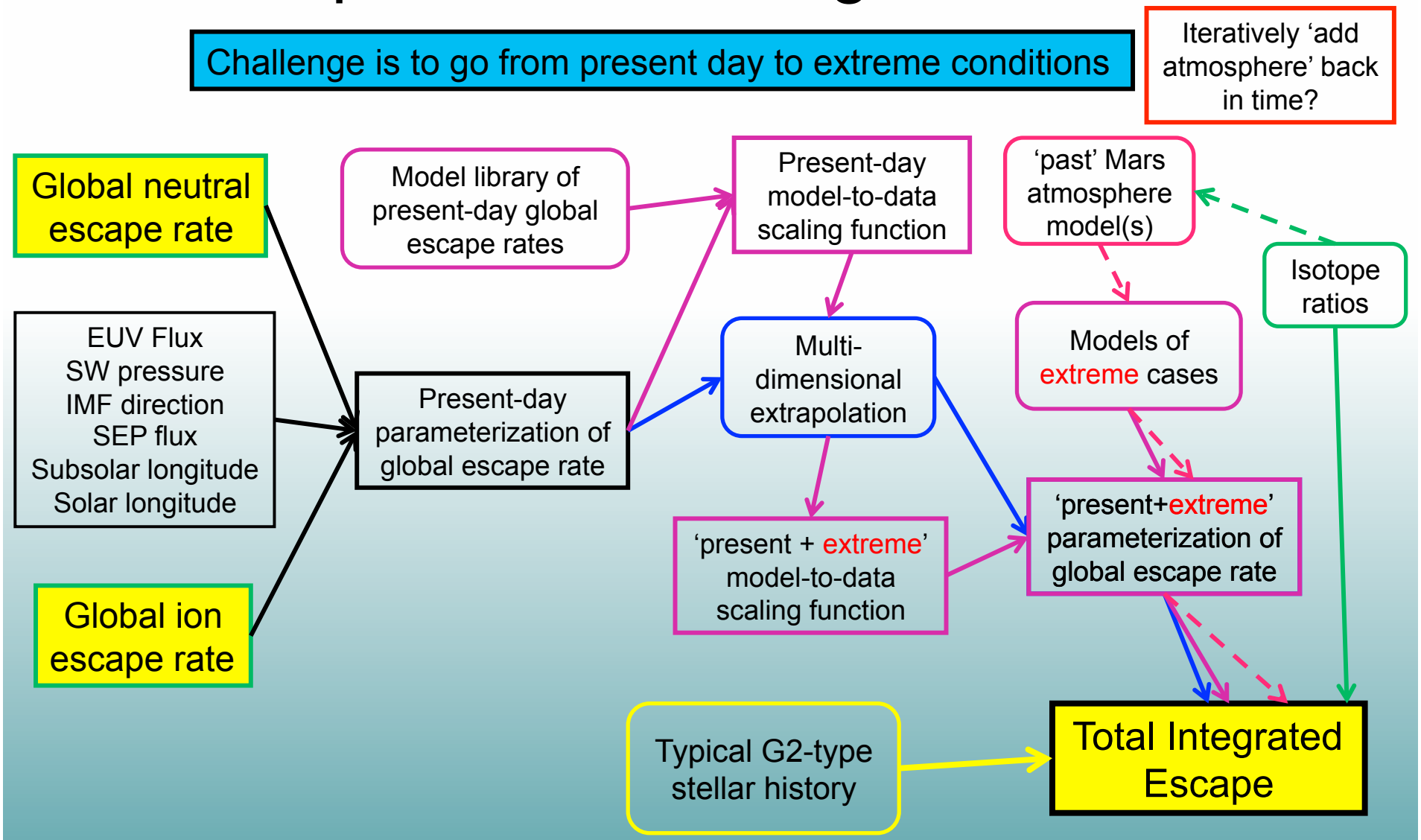
- EUV flux
- Solar wind pressure
- SEP flux
- IMF direction
- Subsolar longitude (i.e. crustal field location)
- Season (i.e. convolution of heliocentric distance and subsolar latitude).

6-D parameterization of total escape rate:
Escape Rate (EUV, IMF, SEP, $P_{SW}$, $L_s$, $\phi_{subsolar}$)

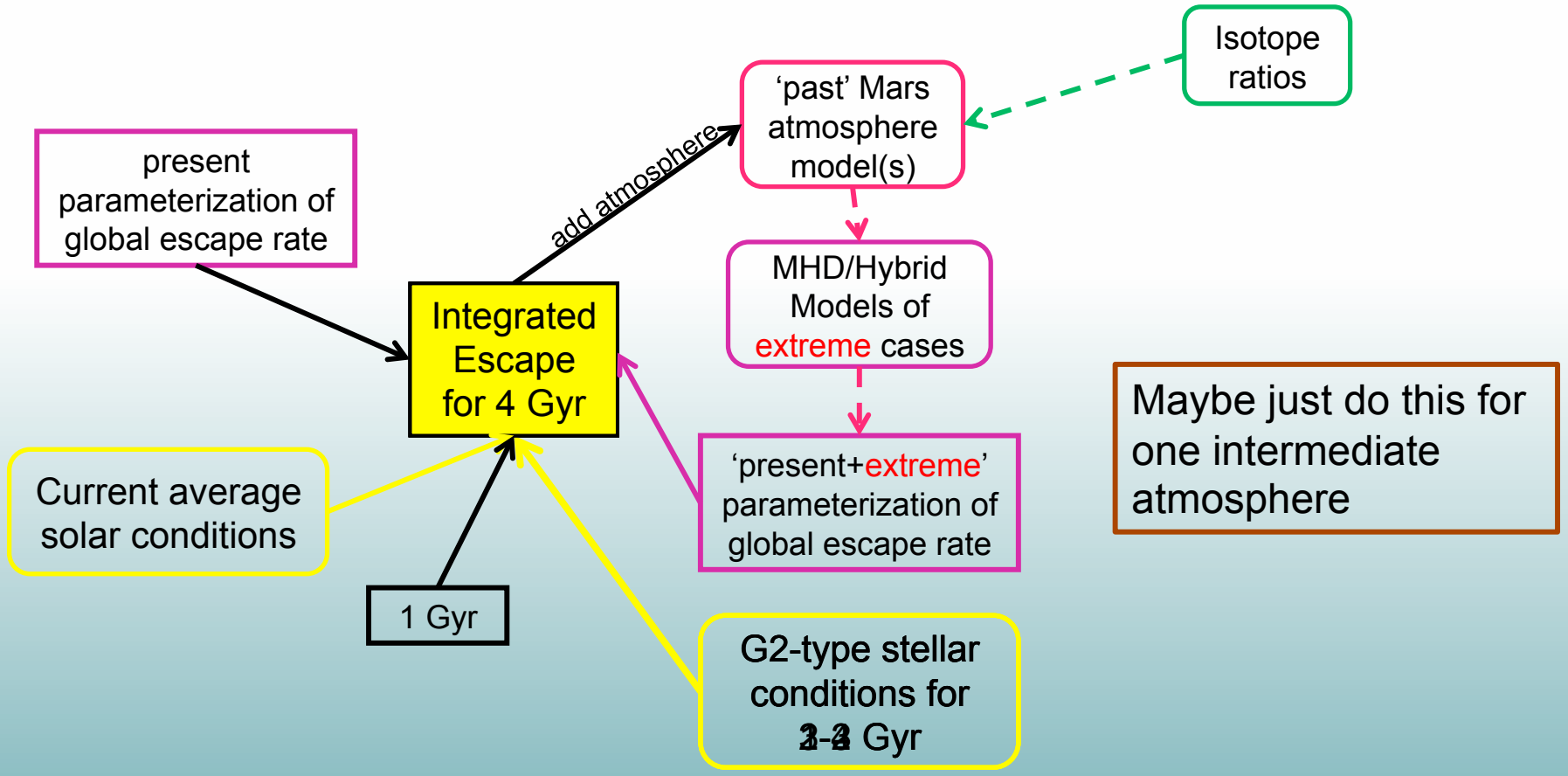
# Measurements to Escape Rates



# Escape Rates to Integrated Loss



# Iteratively adding atmosphere to estimate total escape.



# Multiple ‘degrees of difficulty’

- Several paths exist from science data to answers.
- We intend to get answers from multiple paths in parallel during the MAVEN prime mission.
- Unrealistic to go down the most sophisticated path within first 3-6 months.
- *We encourage the community to work with the MAVEN team to explore these different paths.*
- *The whole community can & should contribute, in terms of models and data analysis. There is no one ‘correct’ path!*

# Required tools/capabilities

1) Photochemical escape tool
   - Input: IUVS limb scans and NGIMS & LPW periapsis profiles.
2) Sputtered escape tool
   - Input: fluxes of sputtering agents (reimpacting pickup O+)
3) Model libraries of:
   a) 1D photochemical & Jeans models.
   b) 3-D global plasma models coupled to global exosphere and thermosphere-ionosphere models.
4) Multidimensional parameterization tool.
5) Software to create 'fake data' for PF, NGIMS and IUVS from 3-D models and spacecraft trajectories.

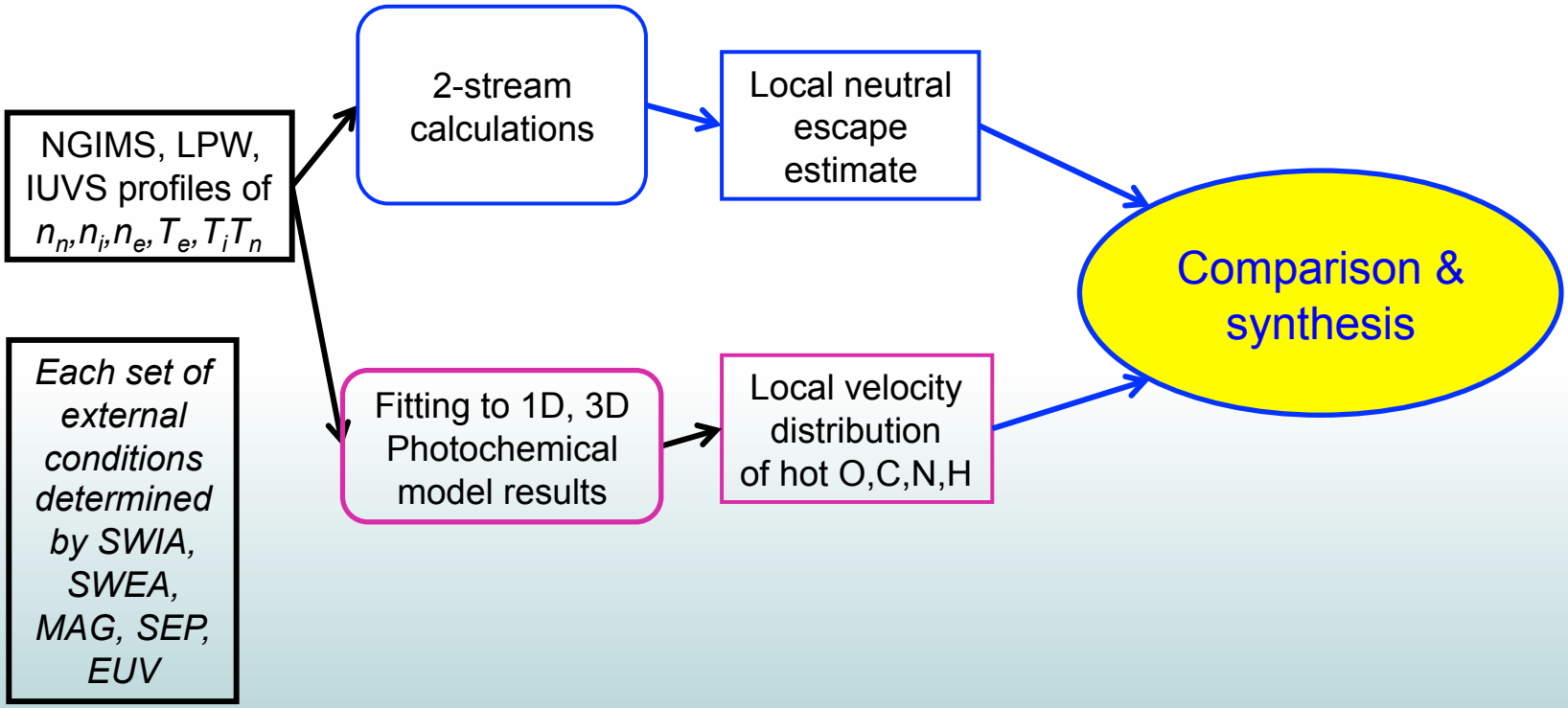
# Pre-launch science closure tasks

# Task 1: photochemical escape trial run

Responsible: T. Cravens, S. Bougher, A. Nagy, J. Fox, F. Leblanc, I. Stewart

- **Why: to quantify differences in escape estimates between a) photochemical models and b) methods of applying those models.**
- 2 M-GITM models, 2 trajectories
  - November 4, 2014 (Nominal Orbit) ~ 53N, 11AM, ~160 km
  - December 27, 2014 (Deep Dip#1 Orbit) 72-73N, 1 AM, ~128 km
- 3 Input profiles of $n_n$, $n_e$, $n_i$, $T_n$, $T_e$, $T_i$:
  - Radial slice down to 80 km (i.e. ideal, perfect sampling case).
  - NGIMS, LPW measurement cadence along real trajectory.
- Run models to get profiles of neutral velocity distributions (O, C, N, H)
  - Jane Fox photochemical model (up to 700 km)
  - Michigan DSMC model (up to 3 Mars radii)
  - F. Leblanc 1D multi-species and 3-D atomic species
- Compare with T. Cravens quick calculation of escape to judge effectiveness of a 'scaling factor' or 'scaling function' approach.
- Use these simulated profiles of hot neutrals to simulate IUVS coronal scans.

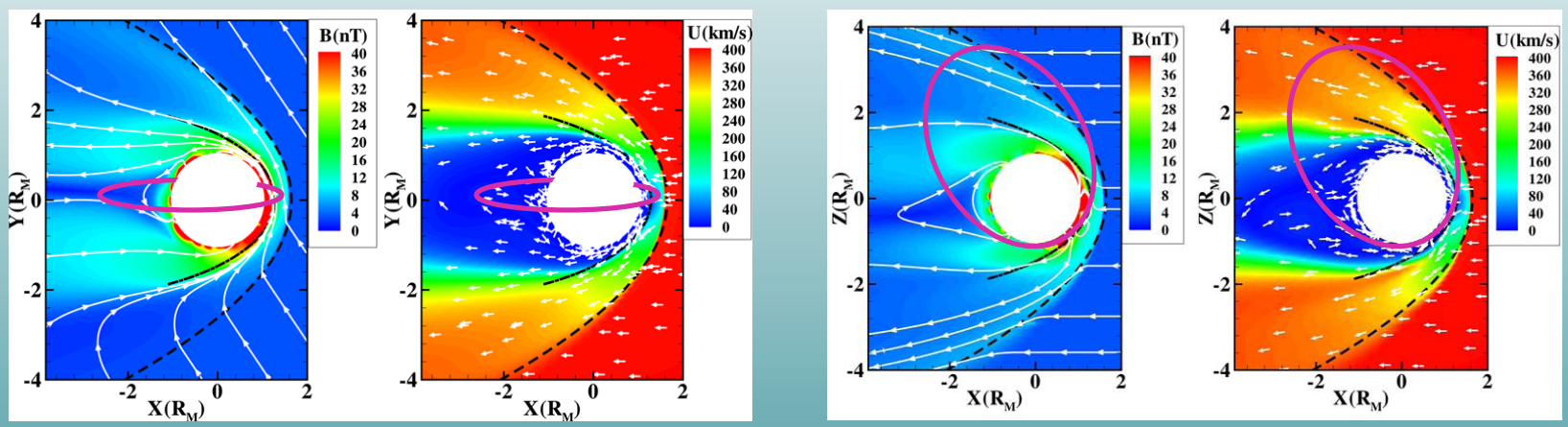
# Task 1: photochemical escape trial run



# Task 2: ion escape trial run

X. Fang, Y. Ma, C. Dong, D. Brain, J. Luhmann, S. Bougher, R. Modolo

- **Why: to quantify how gaps in trajectory and STATIC FOV will affect our ability to quantify pickup, bulk and ion outflow escape estimates.**
- Compare the global ion escape rate predicted by models with estimates based on interpolating between trajectories through those same models.
- 3 models:
  - Case 1 SW: 4 $cm^{-3}$ 400 km/s SMIN
  - Case 2 SW: 4 $cm^{-3}$ 400 km/s SMAX
  - Case 3 SW: 20 $cm^{-3}$ 1000 km/s SMAX (Extreme case)

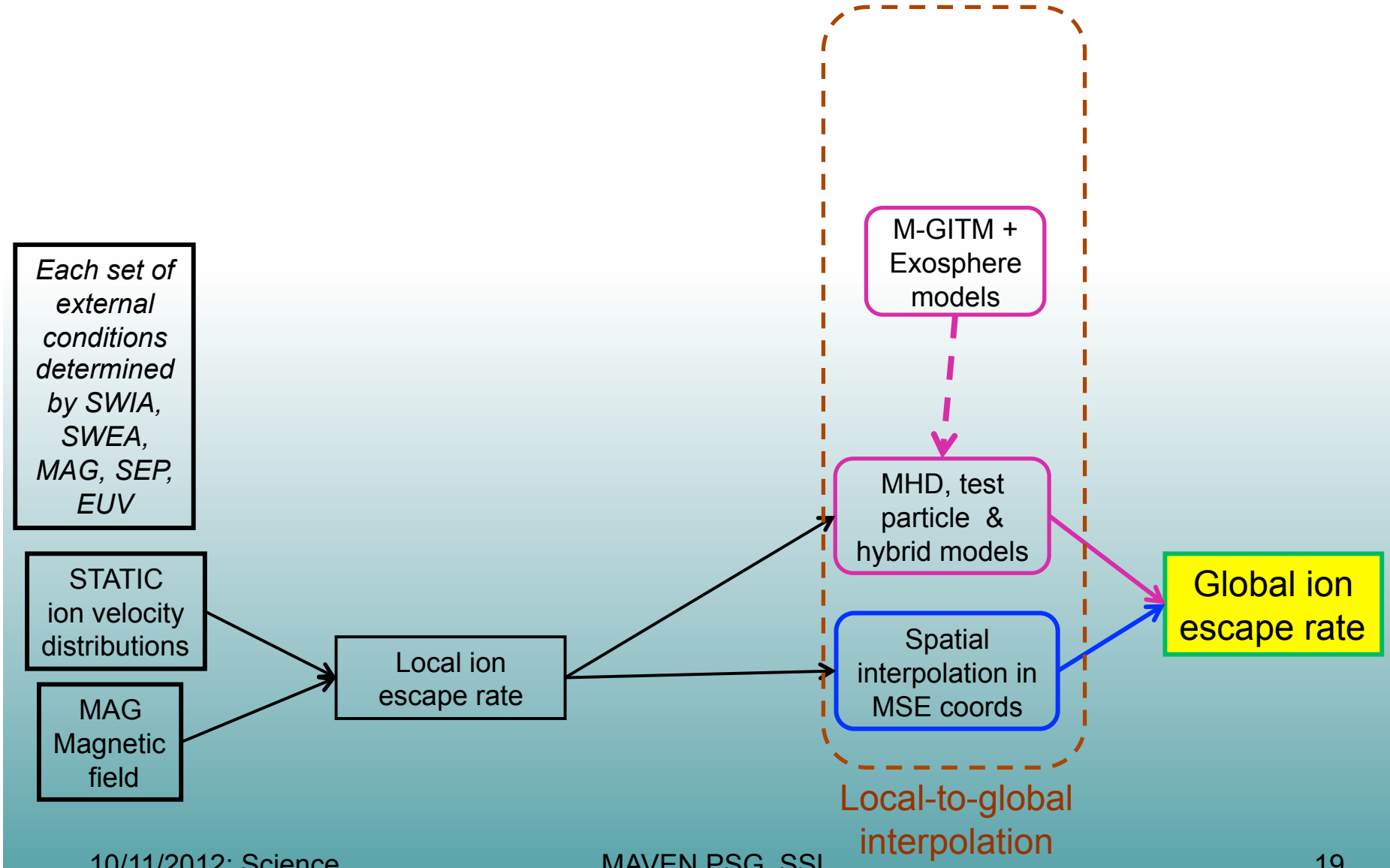


# Task 2: ion escape trial run

X. Fang, Y. Ma, C. Dong, D. Brain, J. Luhmann, S. Bougher, R. Modolo

- **Why: to quantify how gaps in trajectory and STATIC FOV will affect our ability to quantify pickup, bulk and ion outflow escape estimates.**
- Compare the global ion escape rate predicted by models with estimates based on interpolating between trajectories through those same models.
- 3 models:
  - Case 1 SW: 4 $cm^{-3}$ 400 km/s SMIN
  - Case 2 SW: 4 $cm^{-3}$ 400 km/s SMAX
  - Case 3 SW: 20 $cm^{-3}$ 1000 km/s SMAX (Extreme case)
- Total and trajectory-derived estimates will be calculated 2 ways:
  - From ion velocities and densities in the MHD and hybrid models.
  - Test particle code with field inputs from the MHD.
- Interpolate spatially using simple function and model results.
- **What we expect to learn**:
  - For a given set of input conditions, N orbits will be required to adequately sample ion escape?
  - How does this minimum number of orbits change throughout the mission?
  - What is the most effective method of spatial interpolation?
  - How do answers differ between:, MHD-only , MHD+test-particle , Hybrid model?

# Task 2: Ion escape trial run



# Task 3: IUVS Coronal modeling effort

J. Clarke, N. Schneider, I. Stewart

- **Why: to 'practice' deriving escape estimates from IUVS scans of the bound corona. This is critical owing to the indirect detection of escaping species with the IUVS.**
- The IUVS team is developing 1-D models of the Mars O bound corona and escaping component and will simulate IUVS coronal scans of these populations.

- **What we may learn from these methods**:
  - The sensitivity of IUVS observations to populations of cold, hot and escaping O atoms in the martian corona.

# Task 4: coupled model library of global interactions

S. Bougher, C. Dong, Y. Ma, X. Fang, V. Tenishev, Y. Lee, S. Bougher, R. Modolo, F. Leblanc, F. Forget

- **Why: need to simulate the Martian upper atmosphere and space environment under a range of conditions.**
  - to compare directly with data to elucidate physical processes.
  - for interpolation, both spatially and across parameter space, of neutral & ion escape rates between measurements.
- Michigan: 3 coupled models will be used:
  - M-GITM atmosphere general circulation model covering 0-250 km.
  - DSMC 3-D kinetic exosphere model.
  - BATSRUS multi-fluid MHD Mars-solar wind plasma interaction model.
- HeliosARES: models for at least some of the runs in this library.
  - R. Modolo hybrid global plasma model.
  - Yagi/Chaufray 3-D Monte Carlo exosphere model.
  - Forget/Chaufray/González-Galindo LMD-MGCM ground-to-exosphere atmospheric/ionospheric model.

# Task 5: photochemical escape tool & model library

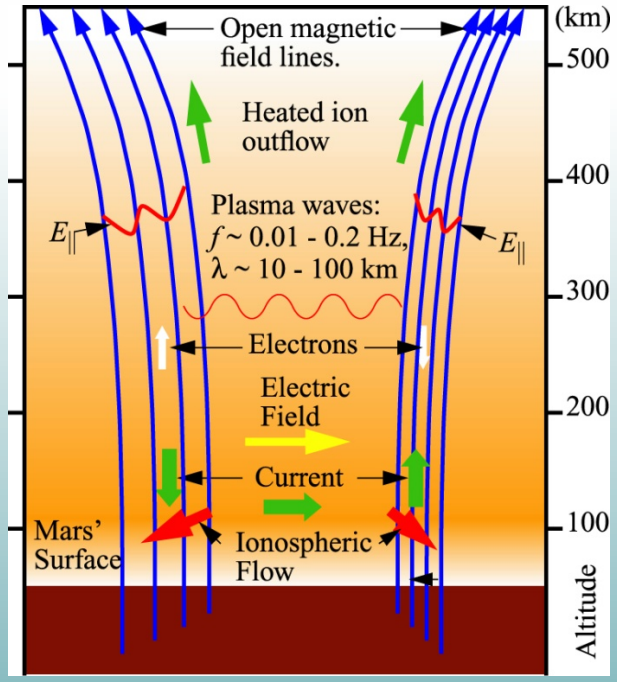
J. Fox, F. LeBlanc, T. Cravens, A. Nagy, J. Luhmann, S. Bougher, J. Clarke

- **Why: we need an operational tool for estimating photochemical escape rates for each periapsis pass.**
- Input for such a tool:
  - NGIMS, LPW profiles of $n_n$, $n_e$, $n_i$, $T_n$, $T_e$, $T_i$.
  - IUVS limb scan-derived altitude profiles of:
    - CO2, CO, O, C & N down to the ionospheric peak (130-160 km).
    - C+, CO+ down to 100 km.
- Will be based on Cravens/Nagy 'quick' 2-stream escape calculations, scaled by careful Fox/LeBlanc/Tenishev model runs.

# Task 6: Ion heating simulations

Responsible: L. Andersson, S. Bougher, J. Espley, D. Brain

- Why: to determine whether ion wave heating is a significant-enough source of energy to the thermosphere to impact escape rates.
- Method:
  1. CAPIT code will be run with a range of wave powers, to determine wave heating and ion density profiles back to M-GITM.
  2. The resulting effects on escape rates will be calculated by passing the altered M-GITM results to the MHD model.



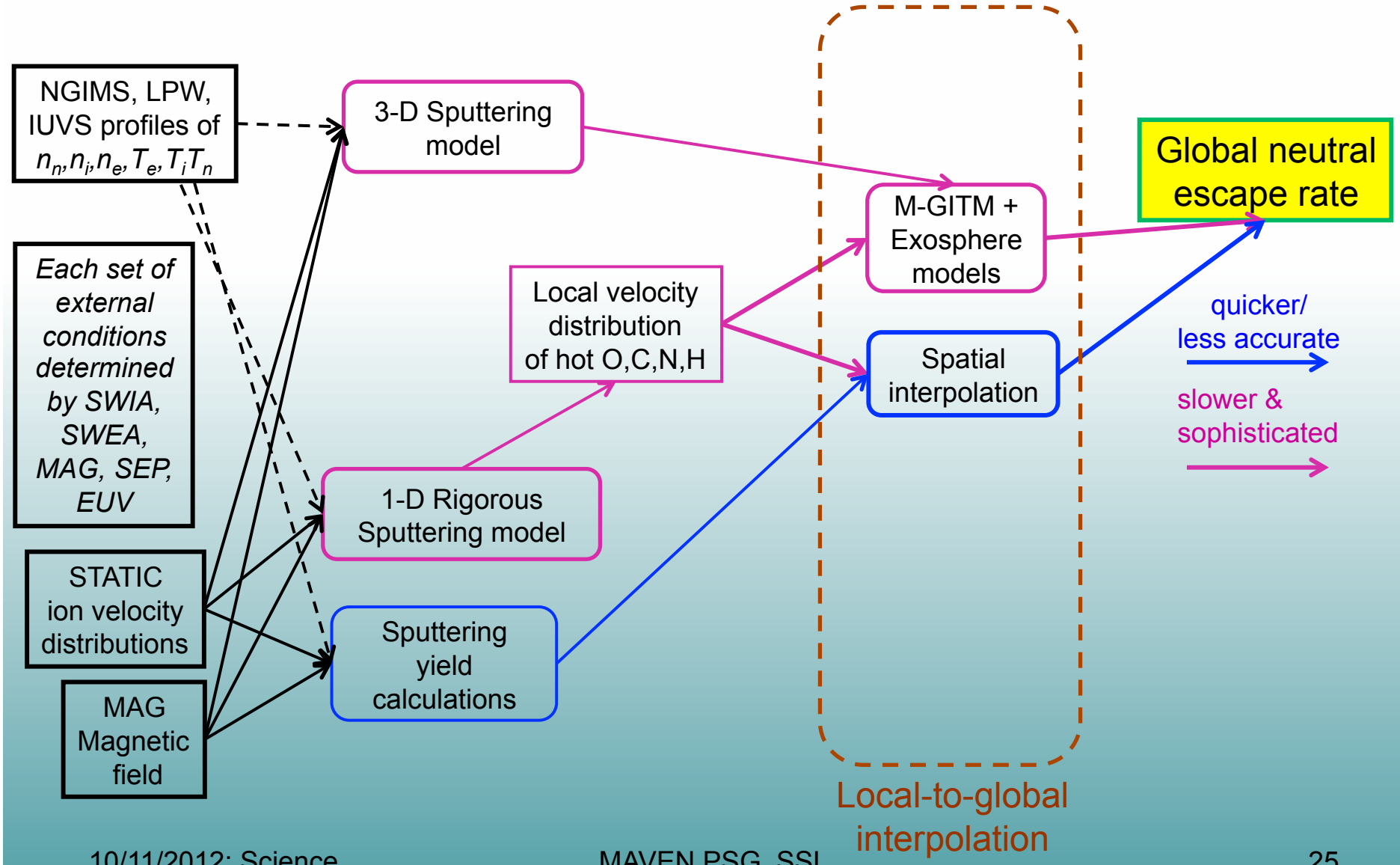

Ergun et al., 2006

# Tasks 7/8: Sputtering Escape tool and model library

F. LeBlanc, X. Fang, J. Wang, R. Modolo, J. Luhmann, J. Clarke

- **Why: we similarly need an operational tool to estimate sputtered escape for each periapsis pass.**
- Build up maps (MSO coords) of impacting pickup ions from X. Fang test particles and R. Modolo corresponding hybrid model run.
- Strategy will be similar to photochemical escape tool:
  - Based on fast sputtering yield calculations, [Luhmann & Kozyra,1991].
  - These calculations will be calibrated (i.e. matched using a scaling function) by François LeBlanc's more rigorous 1-D and 3-D models.
- Fly through these global sputtering simulations with MAVEN trajectories (and preferably STATIC FOV) to obtain mock sputtered escape estimates similar the situation on orbit.
- **We expect to learn** :
  - differences between rigorous simulation and sputtering yield calculations.
  - How many MAVEN orbits are we likely to need to adequately cover the impacting pickup ions and characterize sputtering escape adequately.

# Task 7: Sputtering escape tool



# Science Closure Task questions

- For detailed questions regarding the modeling & science integration the MAVEN team is already planning/doing, please contact:
  - Rob Lillis (rlillis@ssl.berkeley.edu)
  - Photochemical escape tasks:
    - Steve Bougher (bougher@umich.edu)
    - Tom Cravens (cravens@ku.edu)
  - Ion Escape Tasks
    - Dave Brain (brain@lasp.colorado.edu)
  - Sputtering Task:
    - Francois LeBlanc (fleblanc@lmd.jussieu.fr)

# Science closure: it takes a community.

- The MAVEN team (including PS) will follow a clear path to answering the top-level science questions.
- However, this is not the only valid path & we strongly encourage community involvement in data analysis and supporting model investigation to decipher Mars' atmospheric history.