
# Science Data Products

Scott England, Project Scientist
UCB/SSL

## Document Overview

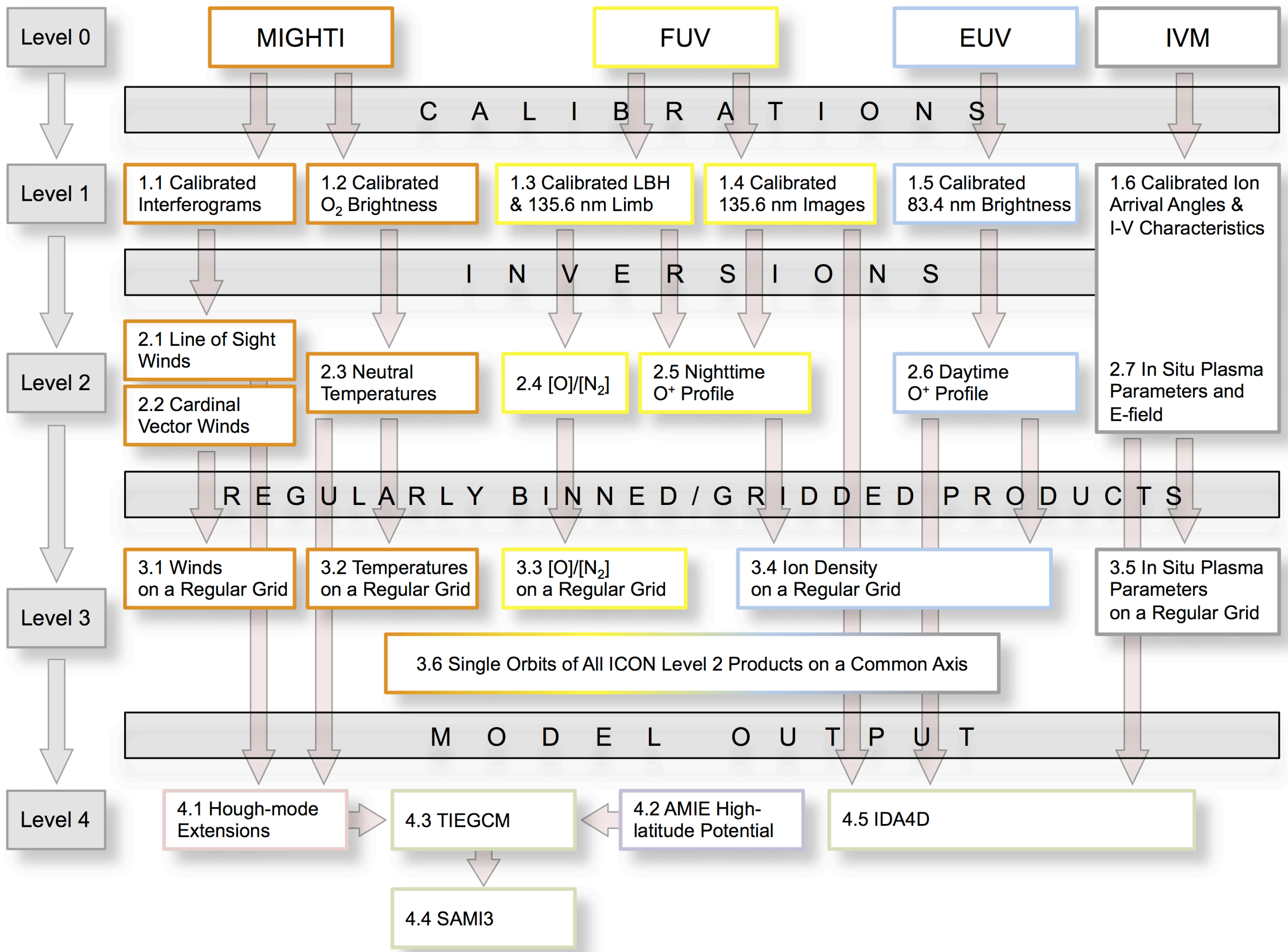
- This set of slides provide some high-level information about the standard data products that will be produced for ICON.
- This document reviews:
  - The data levels,
  - The flow / interdependency of each data product,
  - The Level 1-2 products associated with each measurement,
  - The basic method for producing each data product,
  - The quantities, resolution, ranges etc. that will be reported,
  - The Level 3 summary / survey products,
  - The Level 4 models, and their relation to the ICON data.
- These data products will be made available to the community as soon as possible – an estimated timeline is shown at the end.

## Science Data Products by Level

- **Level 0' –** Level 0 data are decompressed instrument telemetry files. Conversion from CCSDS packets to netCDF files is done, but no processing of the data other than quality checks are performed. Instrument data are in counts, rather than geophysical units.
- **Level 1 –** All Level 1 data are calibrated instrument observations, in physical units (such as brightness in Rayleighs, rather than instrument count rates). These data are at the same instrument resolution as the Level 0 data. Level 1 data are in instrument coordinates, and are not generally geo-referenced (although tangent point of the instrument boresight and corners are included).
- **Level 2** –Level 2 data are inverted geophysical parameters (plasma motions in m/s, ionospheric densities in $m^{-3}$ etc) specified at locations in geographic coordinates. These are at the highest possible resolution as determined by the instrument and inversion algorithm constraints.
- **Level 3 –** Geophysical variables mapped on uniform space-time grids, at a common sampling rate.
- **Level 4** – Level 4 data are outputs from numerical models.

- The above described ICON data levels are modified from the data levels given in "*Earth Science Reference Handbook—A Guide to NASA's Earth Science Program and Earth Observing Satellite Missions,* NASA 2006, p 31".

# Science Data Products
# Data Product Flow & Interdependence



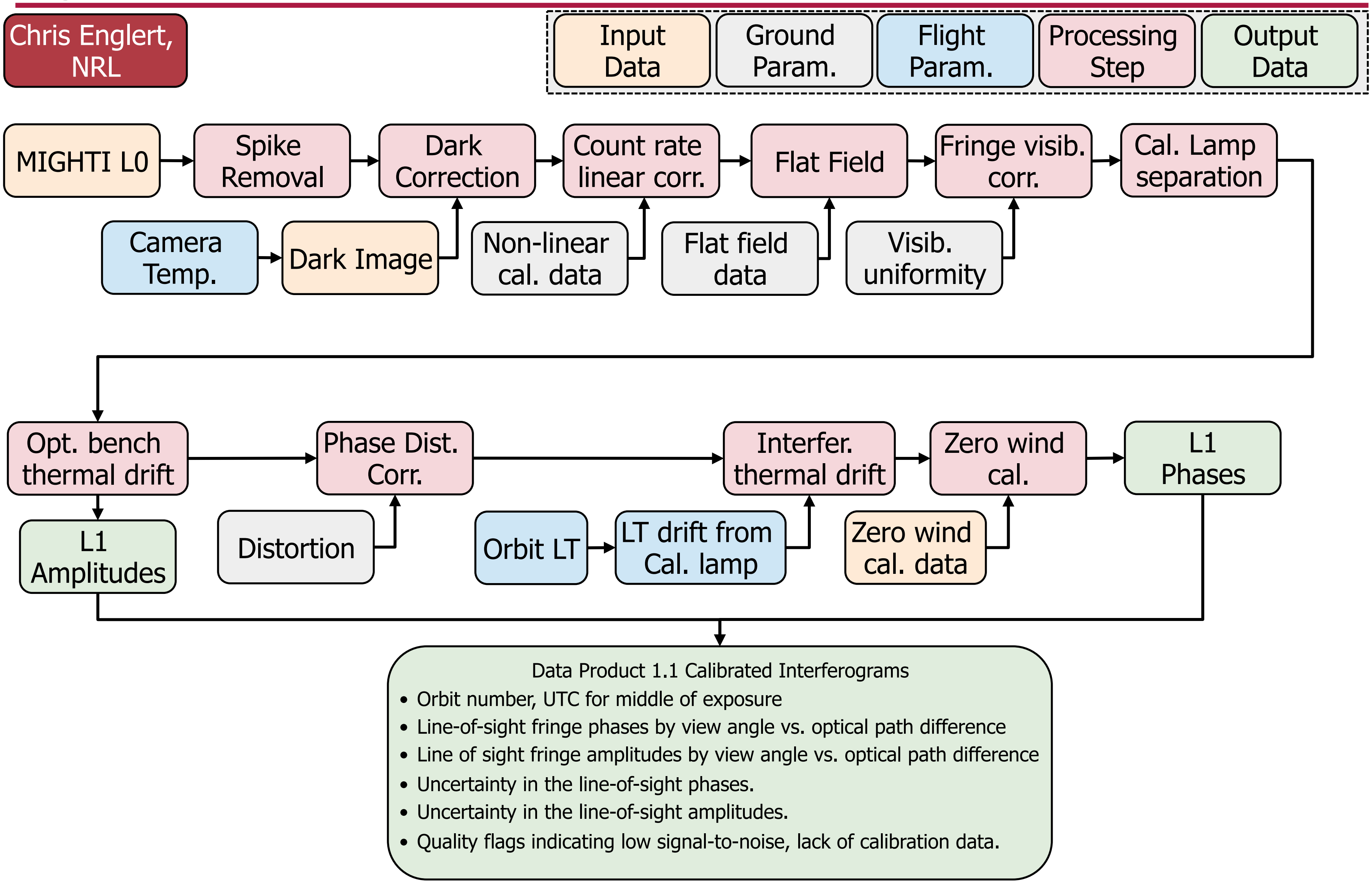

Level 1 through 4 science data products, their inputs, outputs, processing steps, assumptions, etc. are briefly outlined in this presentation.

# MIGHTI Winds

# MIGHTI L0 to MIGHTI L1 Interferometer – Inputs & Overall concept

- The MIGHTI instrument measures the line of sight Doppler shifts of the 557.7 and 630.0 nm airglow lines.
- These Doppler shifts are measured from changes in the phase of the peaks in two interferograms created within the image.
- From these line of sight Doppler shifts, winds can be inferred at Level 2.
- The L1 product includes the calibrated Doppler shifts across the redline and greenline images taken by MIGHTI.
- MIGHTI makes 2 such measurements on the horizon, with views that are 90° apart, in order to reconstruct the horizontal wind velocity.
- During the day, the greenline image spans tangent altitudes of 90-170 km in 2.5 km bins.
- During the day, the redline image spans tangent altitudes of 170-300 km in 15 km bins.
- During the night, the greenline image spans tangent altitudes of 90-105 km in 2.5 km bins.
- During the night, the redline image spans tangent altitudes of 200-300 km in 15 km bins.
- Daytime images are taken every 30s (approximately 250 km along the orbit track) during normal operations.
- Nighttime images are taken every 60s (approximately 500 km along the orbit track) during normal operations.
- The tangent points associated with the image are quoted, but interpretation of what contribution comes from different remote locations is determined at Level 2.

# MIGHTI L0 to MIGHTI L1 Interferometer – Algorithm & Output

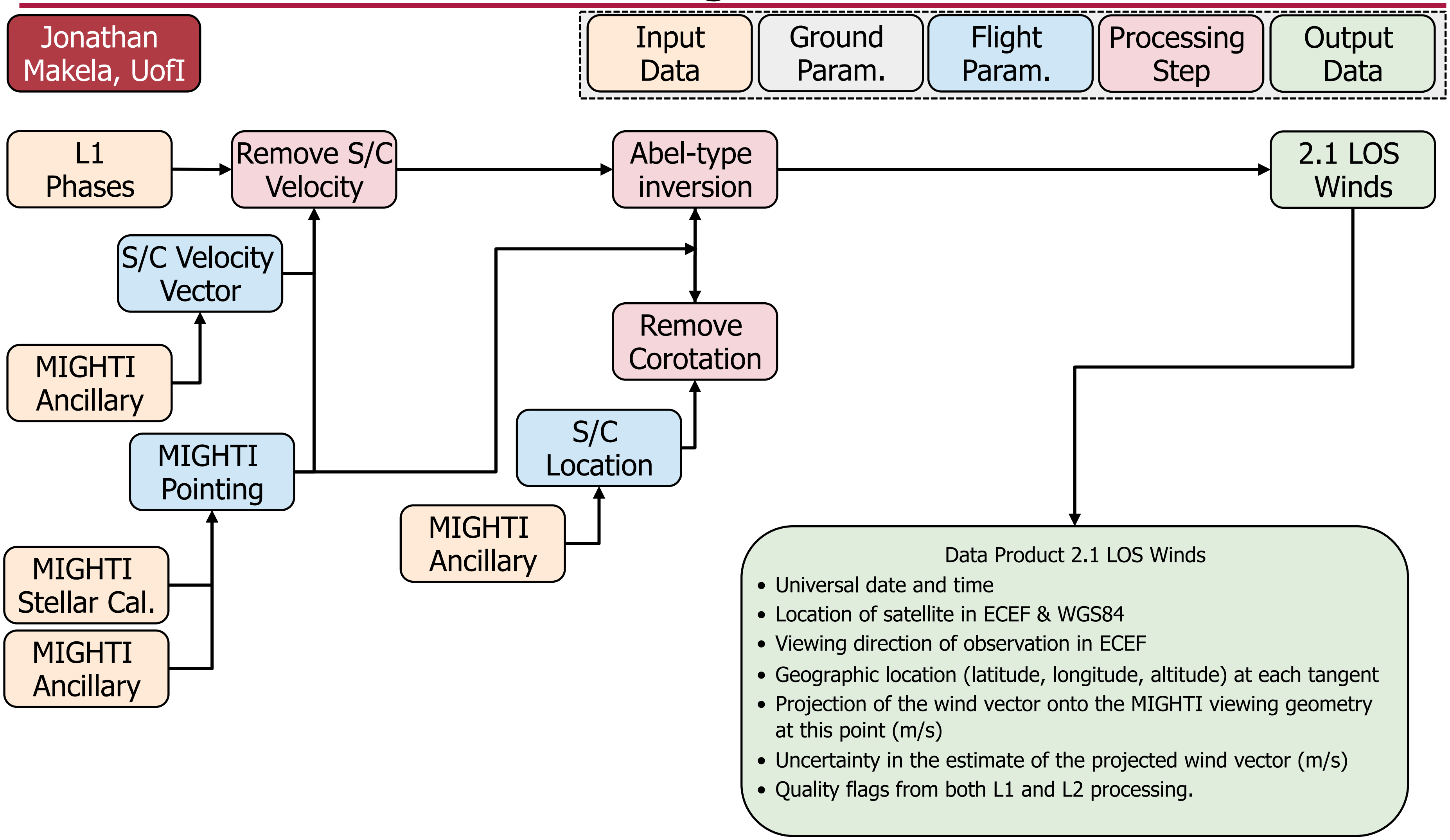


# MIGHTI L1 to MIGHTI L2.1 LOS Winds – Inputs & Overall concept

- The MIGHTI instrument measures the line of sight Doppler shifts of the 557.7 and 630.0 nm airglow lines.
- These Doppler shifts are measured from changes in the phase of the peaks in two interferograms created within the image.
- From these line of sight Doppler shifts, winds are inferred at Level 2.
- The L2.1 product includes the calibrated line of sight winds as a function of tangent altitude.
- These are done separately for each colour and each of the 2 MIGHTI channels.
- The LOS winds are attributed to the remote locations on the tangent (latitude, longitude, altitude etc).
- During the day, the greenline winds spans tangent altitudes of 90-170 km in 2.5 km bins.
- During the day, the redline winds spans tangent altitudes of 170-300 km in 15 km bins.
- During the night, the greenline winds spans tangent altitudes of 90-105 km in 2.5 km bins.
- During the night, the redline winds spans tangent altitudes of 200-300 km in 15 km bins.
- Daytime images are taken every 30s (approximately 250 km along the orbit track) during normal operations.
- Nighttime images are taken every 60s (approximately 500 km along the orbit track) during normal operations.

# MIGHTI L1 to 2.1 LOS Winds - Algorithm

Jonathan Makela, UofI



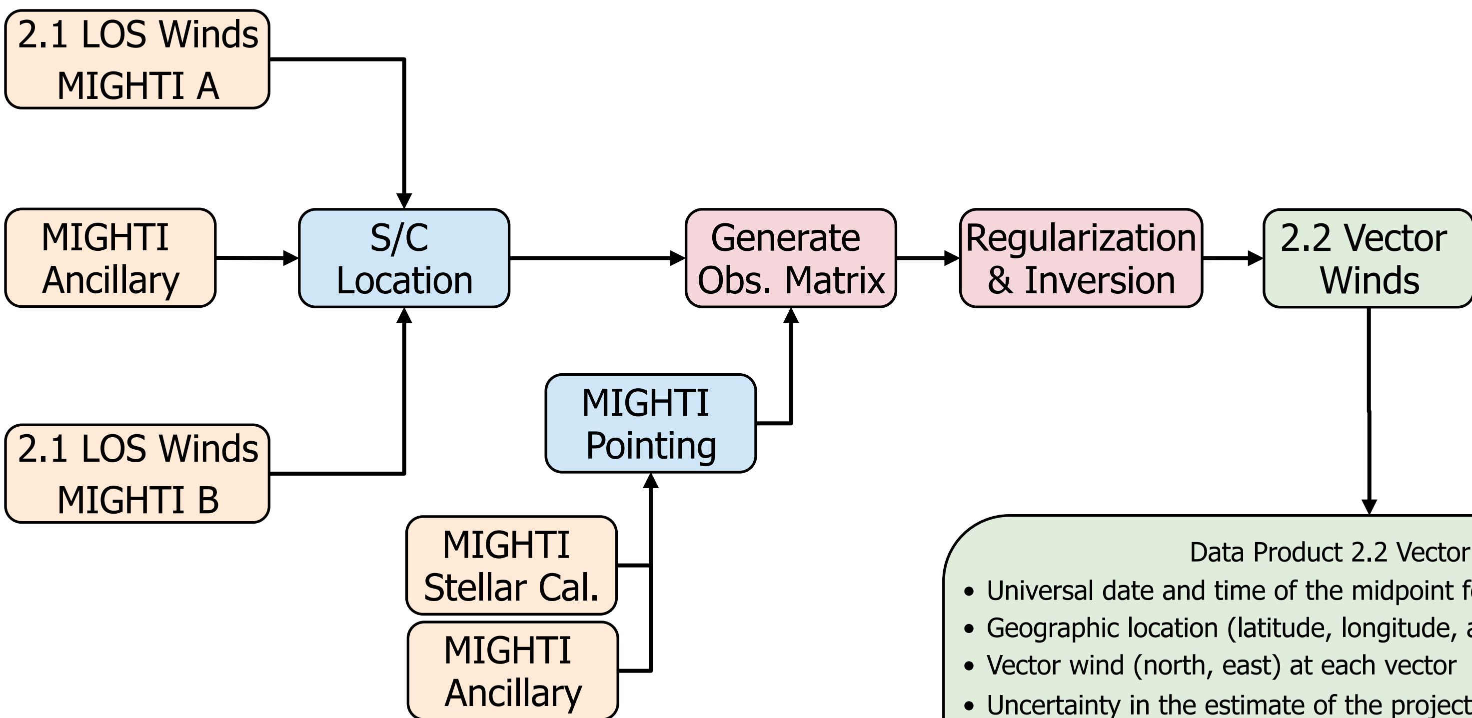
# MIGHTI L2.1 to MIGHTI L2.2 Vector Winds – Inputs & Overall concept

- The MIGHTI instrument measures the line of sight Doppler shifts of the 557.7 and 630.0 nm airglow lines.
- These Doppler shifts are measured from changes in the phase of the peaks in two interferograms created within the image.
- From these line of sight Doppler shifts, winds are inferred at Level 2.
- The L2.2 product includes the calibrated vector winds (zonal and meridional) as a function of tangent altitude.
- These are produced by combining the line of sight measurements from both MIGHTI instruments, but is done separately for each colour.
- The vector winds are attributed to the remote locations on the tangent (latitude, longitude, altitude etc).
- During the day, the greenline winds spans tangent altitudes of 90-170 km in 2.5 km bins.
- During the day, the redline winds spans tangent altitudes of 170-300 km in 15 km bins.
- During the night, the greenline winds spans tangent altitudes of 90-105 km in 2.5 km bins.
- During the night, the redline winds spans tangent altitudes of 200-300 km in 15 km bins.
- The vector winds are produced on a regularly spaced grid.

# MIGHTI 2.1 LOS to 2.2 Vector Winds - Algorithm

Jonathan Makela, UofI

Input Data | Ground Param. | Flight Param. | Processing Step | Output Data




Data Product 2.2 Vector Winds

- Universal date and time of the midpoint for each vector
- Geographic location (latitude, longitude, altitude) at each vector
- Vector wind (north, east) at each vector
- Uncertainty in the estimate of the projected wind vector (m/s)
- Quality flags from both L1 and L2 processing

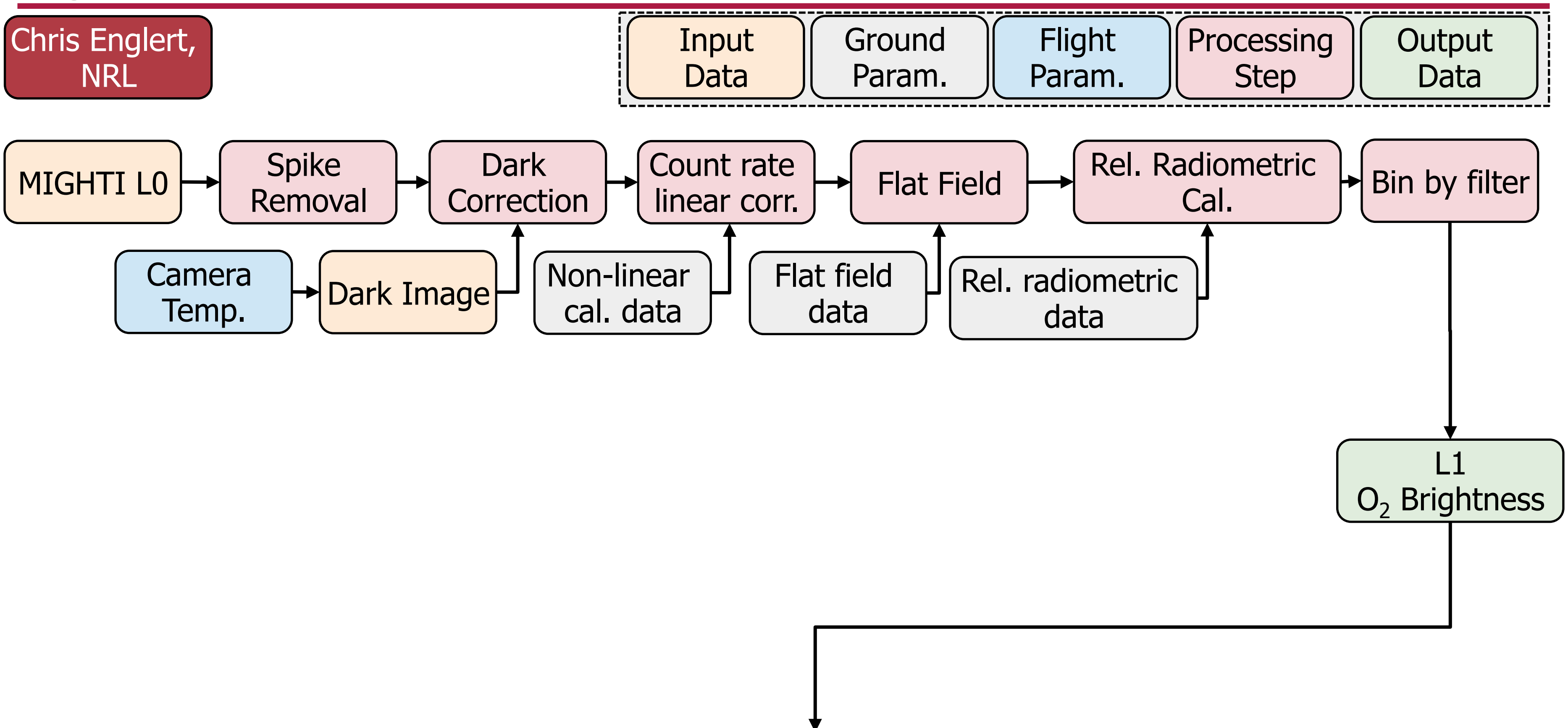
# MIGHTI Temperatures

# MIGHTI L0 to MIGHTI L1.2 $O_2$ Brightness – Inputs & Overall concept

- The MIGHTI instrument measures the brightness of the $O_2$ A-band in 3 bandpasses, plus 2 background channels.
- From these, the shape of the $O_2$ A Band is determined.
- The L1 product includes the calibrated relative brightness of the $O_2$ A band in these 3 wavelength ranges.
- The shape of the $O_2$ A Band can be used to infer neutral temperature (at Level 2).
- MIGHTI makes 2 such measurements on the horizon, with views that are 90° apart. Each provides an independent measure of temperature (the 2 are not combined).
- During the day, the $O_2$ A band image spans tangent altitudes of 90-150 km in 2.5 km bins.
- During the night, the $O_2$ A band image spans tangent altitudes of 90-105 km in 2.5 km bins.
- Daytime images are taken every 30s (approximately 250 km along the orbit track) during normal operations.
- Nighttime images are taken every 60s (approximately 500 km along the orbit track) during normal operations.
- The tangent points associated with the image are quoted, but interpretation of what contribution comes from different remote locations is determined at Level 2.

# MIGHTI L0 to MIGHTI 1.2 $O_2$ Brightness - Algorithm

Chris Englert, NRL




Data Product 1.2 Calibrated $O_2$ Brightness

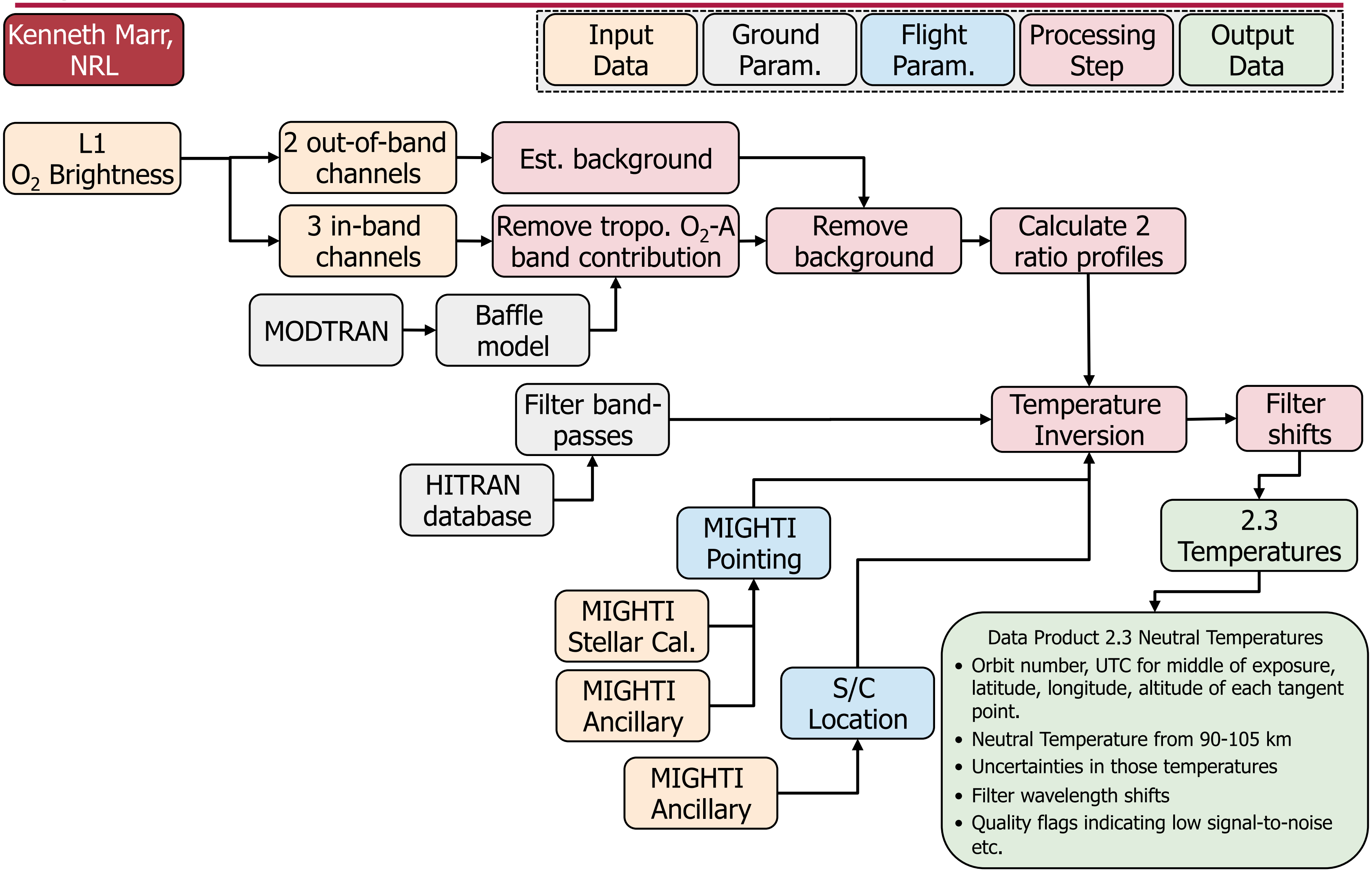
- Orbit number, UTC for middle of exposure
- Five intensity values, corresponding to five wavelength regions, by tangent view angle.
- Uncertainties of those intensities.
- Quality flags indicating low signal-to-noise etc.

# MIGHTI L1.2 to MIGHTI L2.3 Temperature – Inputs & Overall concept

- The MIGHTI instrument measures the brightness of the $O_2$ A-band in 3 bandpasses, plus 2 background channels.
- From these, the shape of the $O_2$ A Band is determined.
- The Level 2 product includes the calibrated neutral temperatures.
- The temperatures are attributed to the remote locations on the tangent (latitude, longitude, altitude etc).
- MIGHTI makes 2 such measurements on the horizon, with views that are 90° apart. Each provides an independent measure of temperature (the 2 are not combined).
- During the day, the $O_2$ A band image spans tangent altitudes of 90-150 km in 2.5 km bins.
- During the night, the $O_2$ A band image spans tangent altitudes of 90-105 km in 2.5 km bins.
- Daytime images are taken every 30s (approximately 250 km along the orbit track) during normal operations.
- Nighttime images are taken every 60s (approximately 500 km along the orbit track) during normal operations.

# MIGHTI 1.2 to MIGHTI 2.3 Temperature - Algorithm

Kenneth Marr, NRL



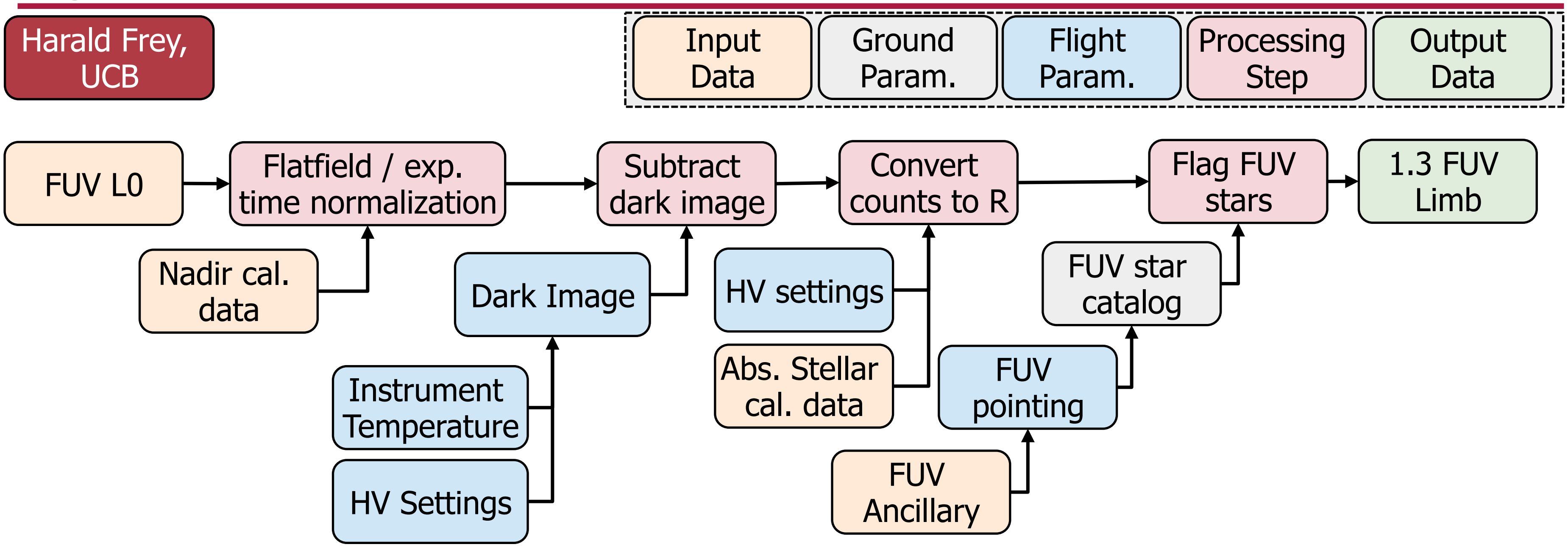
# FUV

# FUV L0 to FUV L1.3 FUV brightness – Inputs & Overall concept

- The FUV instrument measures the brightness of the 135.6 emission from O and a portion of the LBH band structure from $N_2$ on the limb and sub-limb.
- From these, the ratio of O to $N_2$ in the thermosphere can be determined during the day and the density of $O^+$ in the ionosphere can be determined during the night (Level 2 products).
- The L1 product includes the calibrated brigthness of the 135.6 and LBH emissions.
- The view direction of the FUV instrument is nominally 90° to the spacecraft track during day, and moves during nighttime to image along the local magnetic meridian.
- During the day, the 135.6 and LBH images are given in 6 horizontal and 256 vertical bins, spanning from below the limb to around 500 km altitude.
- During the night, a135.6 image is given in 6 horizontal and 256 vertical bins, spanning from below the limb to around 500 km altitude.
- During the night, a 2 dimensional 135.6 image is given that spans the 24 degree vertical and 18 degree horizontal field of view.
- During the night, no LBH data is collected during normal operations.
- Images are taken every 12s (approximately 80 km along the orbit track) during normal operations.
- The tangent points associated with the image are quoted, but interpretation of what contribution comes from different remote locations is determined at Level 2.

# FUV L0 to 1.3 Calibrated FUV Limb Brightness - Algorithm

Harald Frey, UCB




Data Product 1.3 Calibrated FUV Limb Brightness

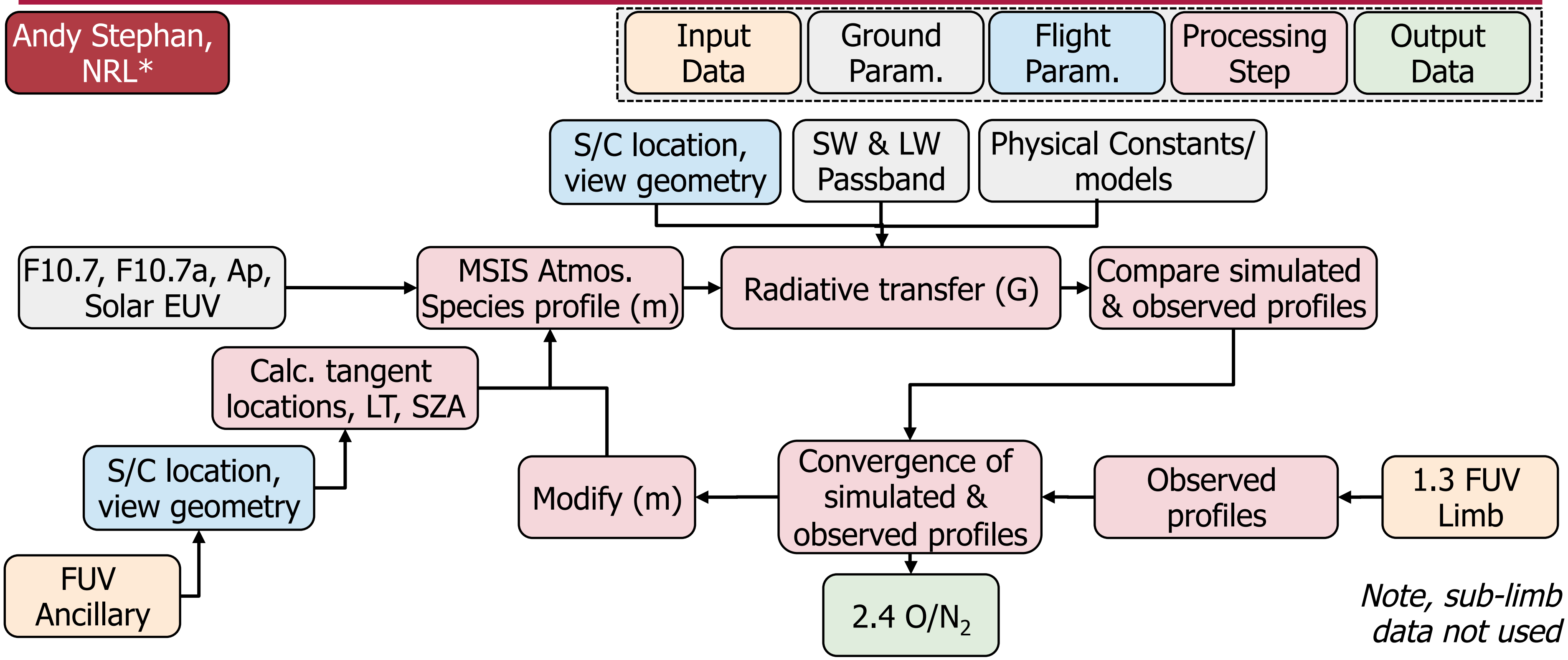
- Orbit number, UTC for middle of exposure
- Daytime – 6 vertical profiles of LBH and 135.6 nm
- Nighttime – 6 vertical profiles of 135.6 nm
- Quality flags indicating low signal-to-noise etc.

# FUV L1.3 to FUV L2.4 O/$N_2$ – Inputs & Overall concept

- The FUV instrument measures the brightness of the 135.6 emission from O and a portion of the LBH band structure from $N_2$ on the limb and sub-limb.
- The L1 product includes the calibrated ratio of O to $N_2$ in the thermosphere during the day.
- The view direction of the FUV instrument is nominally 90° to the spacecraft track during day.
- During the day, the 135.6 and LBH images are given in 6 horizontal and 256 vertical bins, spanning from below the limb to around 500 km altitude.
- On the limb, these are converted in O and $N_2$ as a function of tangent altitude. The remote locations (tangent latitude, longitude etc) associated with these remotely observed points are reported.
- The column ratio of O to $N_2$ is reported.
- Images are taken every 12s (approximately 80 km along the orbit track) during normal operations.

# FUV 1.3 to 2.4 $O/N_2$ - Algorithm

Andy Stephan, NRL*




*Note, sub-limb data not used*

Data Product 2.4 $O/N_2$ Ratio

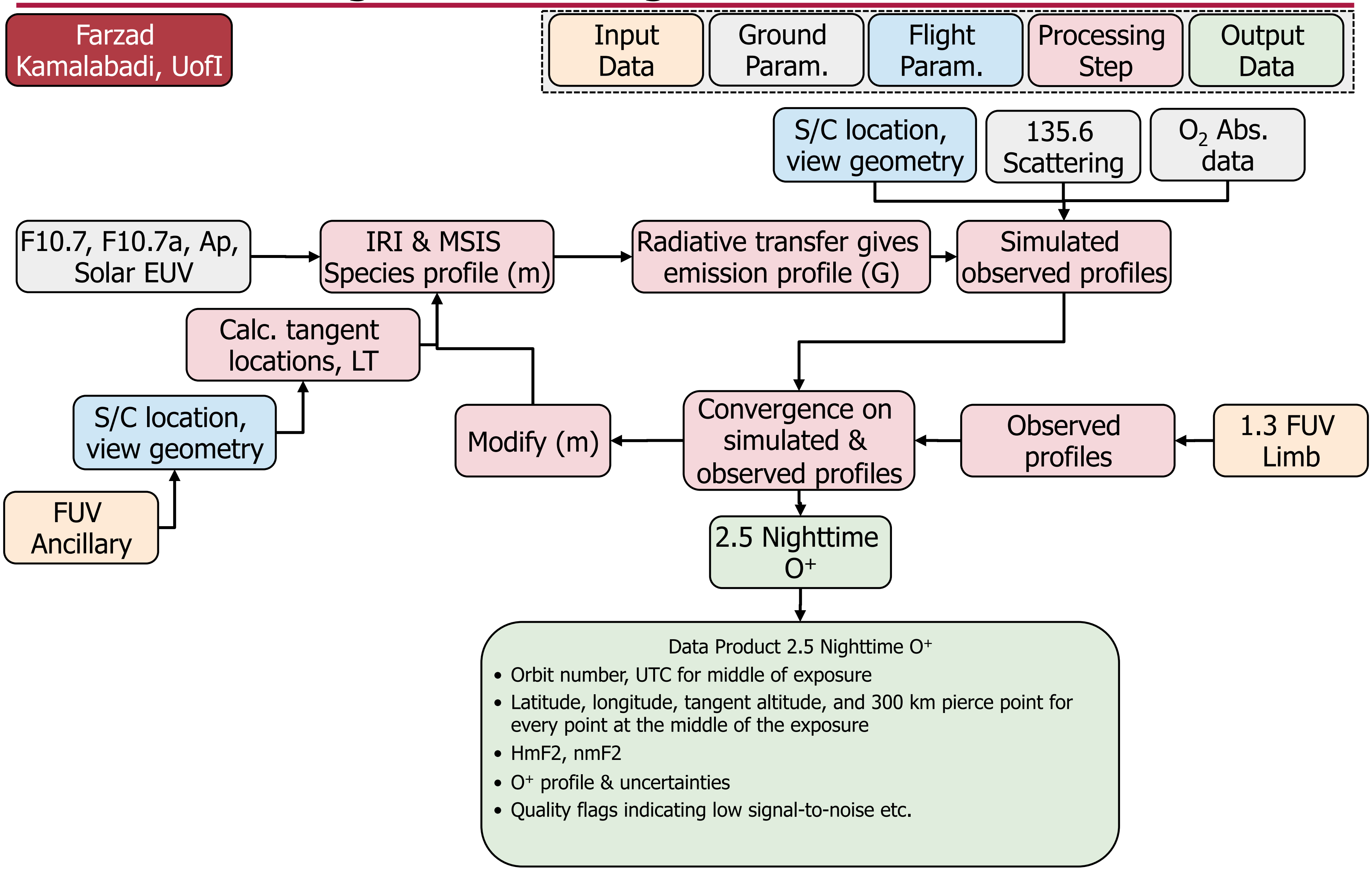
- Orbit number, UTC for middle of exposure
- Latitude, longitude, tangent altitude, and 150 km pierce point for every point at the middle of the exposure
- Column $O/N_2$ ratio
- O and $N_2$ profiles
- Depth of column integration altitude (km above WGS84)
- Uncertainties in $O/N_2$ ratio
- Quality flags indicating low signal-to-noise, lack of calibration data, lack of convergence, large chi squared values, high uncertainty in result, significant divergence from MSIS.

**Bob Meier is leading the current development. Andy Stephan has ultimate responsibility.*

# FUV L1.3 to FUV L2.5 Nighttime $O^+$ – Inputs & Overall concept

- The FUV instrument measures the brightness of the 135.6 emission from O and a portion of the LBH band structure from $N_2$ on the limb and sub-limb.
- The L1 product includes the calibrated $O^+$ density in the ionosphere during the night.
- The view direction of the FUV instrument moves to image as close to the local magnetic meridian as possible.
- During the night, a 135.6 image is given in 6 horizontal and 256 vertical bins, spanning from below the limb to around 500 km altitude.
- These are converted into a single 1x256 profile of O+ density on the limb / sublimb. The remote locations (tangent latitude, longitude etc) associated with these remotely observed points are reported.
- Images are taken every 12s (approximately 80 km along the orbit track) during normal operations.

# FUV 1.3 to 2.5 Nighttime $O^+$ - Algorithm



# EUV

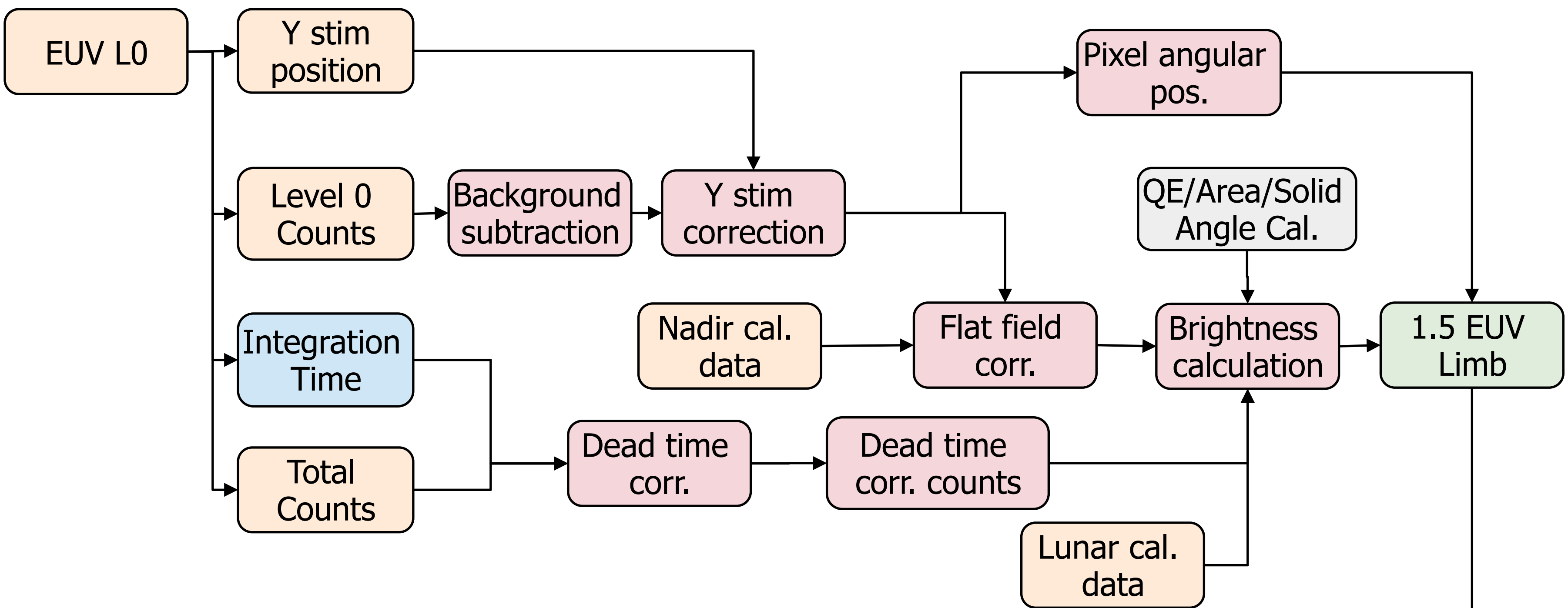
# EUV L0 to EUV L1.5 EUV brightness – Inputs & Overall concept

- The EUV instrument measures the brightness of the extreme ultraviolet on the limb, including the emissions from He at 58.4 nm, $O^+$ at 61.7 nm and $O^+$ at 83.4 nm,
- From these, the altitude profile of O+ can be determined during the daytime (Level 2 product).
- The L1 product includes the calibrated brigthness of the 61.7 and 83.4 nm emissions during the daytime (the EUV instrument does not collect data during the night).
- The view direction of the EUV instrument is 90° to the spacecraft track and spans tangent altitudes from the base of the ionosphere to 500 km.
- Images are taken every 12s (approximately 80 km along the orbit track) during normal operations.
- The tangent points associated with the image are quoted, but interpretation of what contribution comes from different remote locations is determined at Level 2.

# EUV L0 to 1.5 Calibrated EUV Limb Brightness - Algorithm

Eric Korpela, UCB

Input Data | Ground Param. | Flight Param. | Processing Step | Output Data



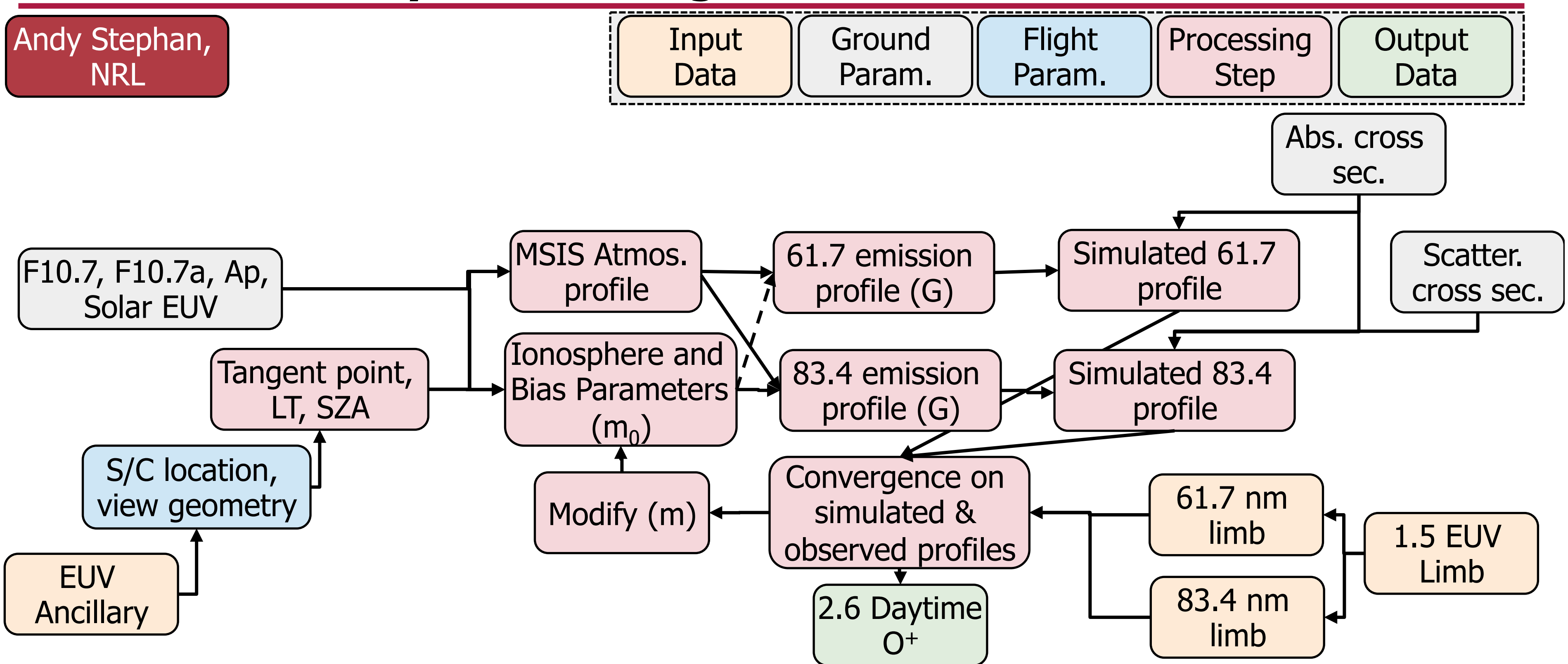

Data Product 1.5 Calibrated EUV Limb Brightness

- Orbit number, UTC for middle of exposure
- Brightness vs. Pixel for 58.4, 61.7, 834. nm
- Uncertainty in brightness vs. Pixel for 58.4, 61.7, 83.4 nm
- Quality flags indicating low signal-to-noise etc.

# EUV L1.5 to EUV L2.6 Daytime $O^+$ – Inputs & Overall concept

- The EUV instrument measures the brightness of the extreme ultraviolet on the limb, including the emissions from He at 58.4 nm, $O^+$ at 61.7 nm and $O^+$ at 83.4 nm,
- From these, the altitude profile of O+ can be determined during the daytime (Level 2 product).
- The inversion of the 61.7 an 83.4 nm emissions into $O^+$ makes use of the fact that the 61.7 nm emission is optically thin, whereas the 834 nm emission is resonantly scattered by ionospheric $O^+$.
- The density of O+ as a function of tangent altitude, latitude, longitude etc reported.
- Images are taken every 12s (approximately 80 km along the orbit track) during normal operations.

# EUV 1.5 to 2.6 Daytime $O^+$ - Algorithm




Data Product 2.6 Daytime $O^+$

- Orbit number, UTC for middle of exposure
- Latitude, longitude, tangent altitude for every point at the middle of the exposure
- Fitted Chapman parameters – hmF2, NmF2, $H_0$
- Uncertainties in the Chapman parameters
- Quality flags indicating low signal-to-noise etc.

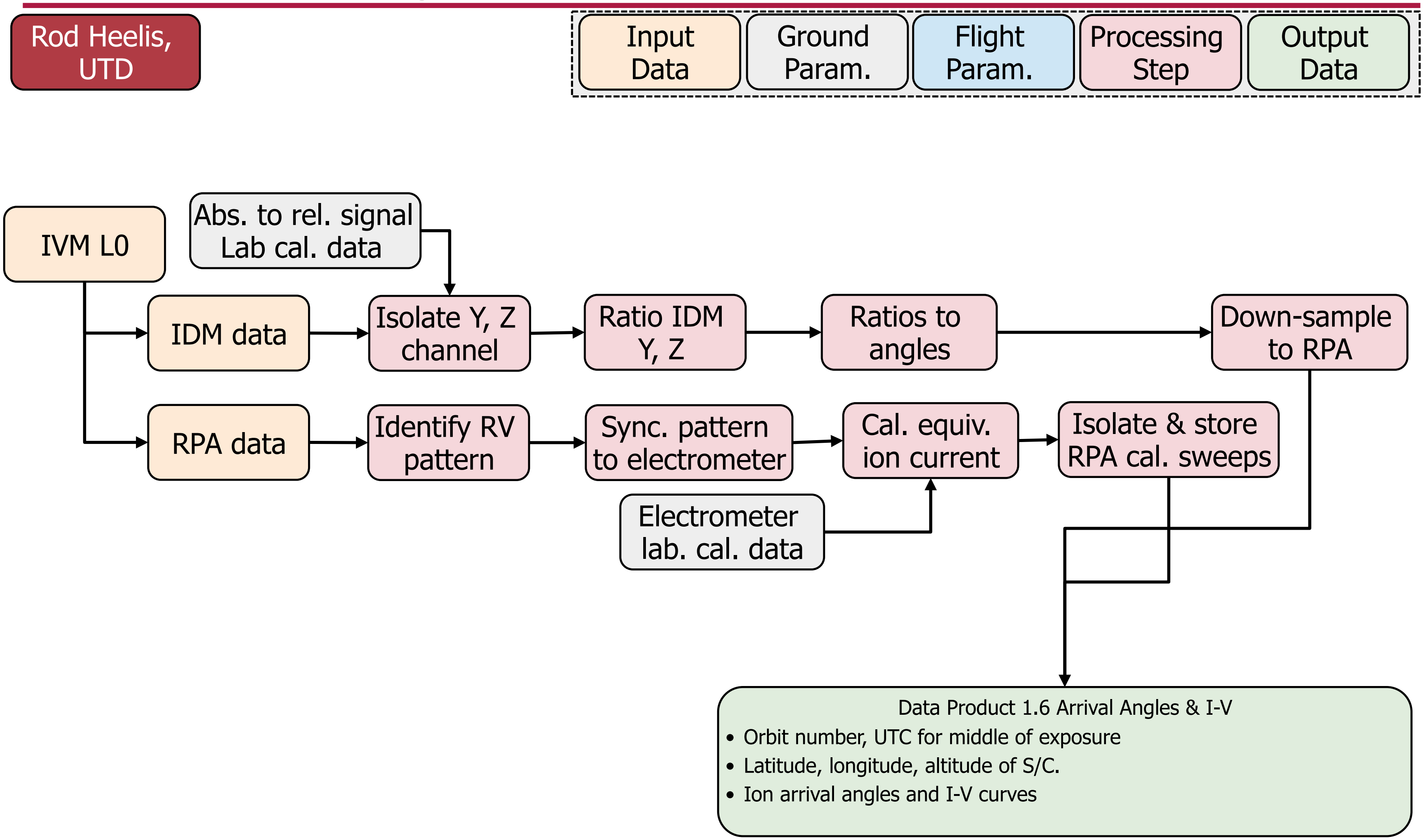
# IVM

# IVM L0 to IVM L1.6 Calibrated Arrival Angles and I-V – Inputs & Overall concept

- The IVM instrument measures the arrival angle of positively charged ions relative to spacecraft ram, and the number of ions arriving in spacecraft ram. By increasing a retarding voltage, the instrument measures the number of ions arriving as a function of this voltage.
- From the arrival angle, the velocity of the ions perpendicular to the instrument can be found (Level 2 product). From the number of ions arriving as a function of retarding voltage, the ion composition, temperature and velocity in the spacecraft track can be found (Level 2 product). Together, this gives the 3 dimensional velocity vector of the ions *in situ*.
- The Level 1 product includes calibrated arrival angles and ion current as a function of retarding voltage.
- The nominal view direction of the IVM instrument is along the spacecraft track.
- A second IVM instrument is mounted in nominal spacecraft wake. Whenever the spacecraft is turned around, this second instrument continues the same observation as the first.
- Measurements are taken every 4 seconds when the spacecraft is between ±15° magnetic latitude, and more intermittently at higher latitudes as a result of the spacecraft operations. At least 3 measurements every 32s are made during nominal operations (equivalent to around 250 km of spacecraft motion).
- Operations are identical during day and night.

# IVM L0 to 1.6 Calibrated Arrival Angles and I-V Characteristics - Algorithm

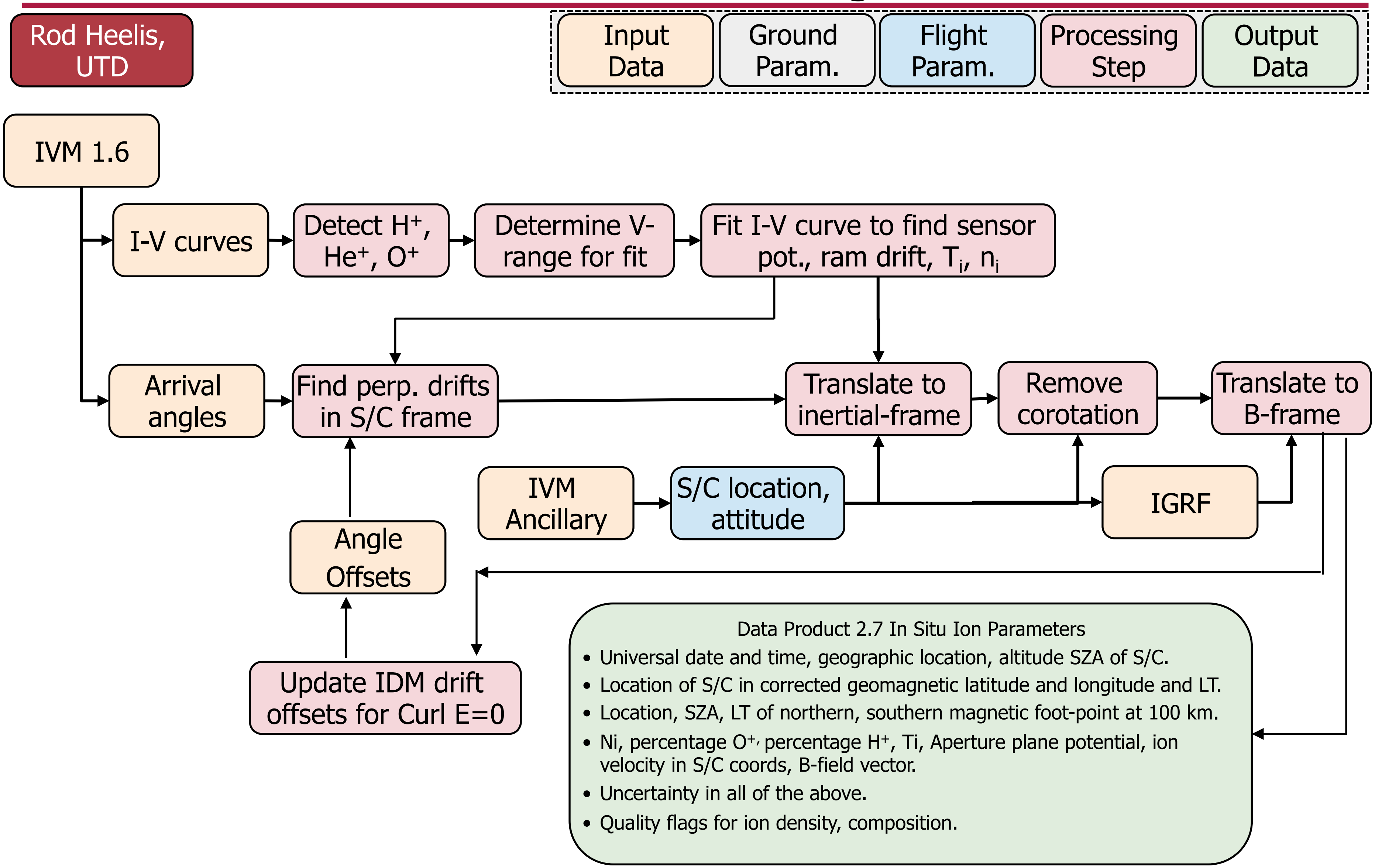
Rod Heelis, UTD



# IVM L1.6 to IVM L2.7 *In situ* ion parameters – Inputs & Overall concept

- The IVM instrument measures the arrival angle of positively charged ions relative to spacecraft ram, and the number of ions arriving in spacecraft ram. By increasing a retarding voltage, the instrument measures the number of ions arriving as a function of this voltage.
- From the arrival angle, the velocity of the ions perpendicular to the instrument can be found (Level 2 product). From the number of ions arriving as a function of retarding voltage, the ion composition, temperature and velocity in the spacecraft track can be found (Level 2 product). Together, this gives the 3 dimensional velocity vector of the ions *in situ*.
- The Level 2 product includes calibrated ion drifts parallel and perpendicular to the local magnetic field, the ion density, the $O^+/He^+$ ratio and the ion temperature *in situ*.
- A second IVM instrument is mounted in nominal spacecraft wake. Whenever the spacecraft is turned around, this second instrument continues the same observation as the first.
- Measurements are taken every 4 seconds when the spacecraft is between ±15° magnetic latitude, and more intermittently at higher latitudes as a result of the spacecraft operations. At least 3 measurements every 32s are made during nominal operations (equivalent to around 250 km of spacecraft motion).
- Operations are identical during day and night.

# IVM 1.6 to 2.7 In Situ Ion Parameters - Algorithm

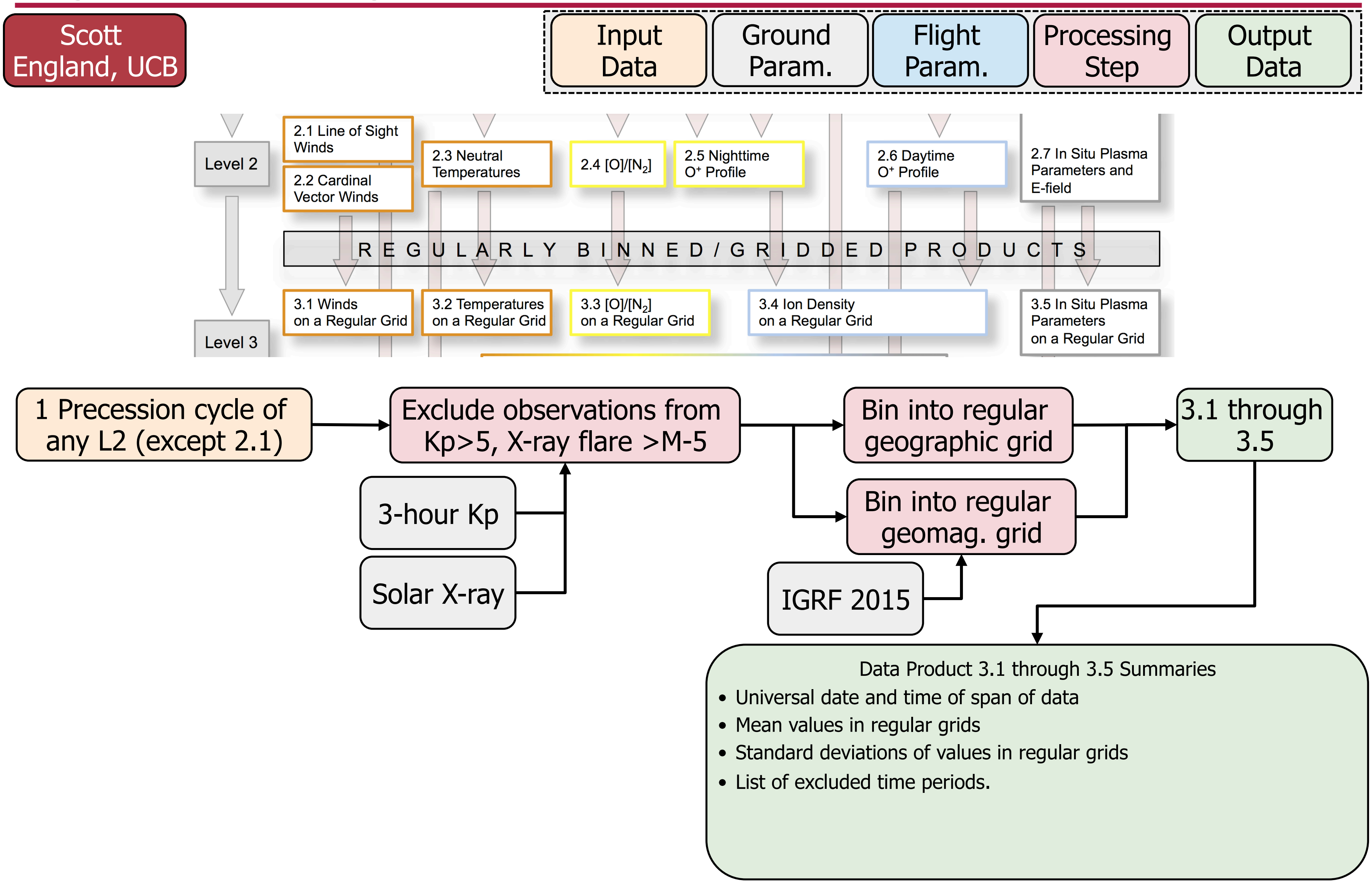


# Level 3 – Survey Data

# L2 to L3 – Summaries of the Observations of Regular Grids – Inputs & Overall concept

- The Level 3 Summary products are climatological summaries of each the level 2 products (except 2.1, line-of-sight velocities).
- Data for each Level 2 product from a whole precession cycle of the spacecraft is used to generate a data array that covers all measured latitudes, longitudes, altitudes and local times.
- For certain data types, measurements made during extremely disturbed conditions (major solar flare etc), are excluded as these do not represent the climatology.
- All data are binned into regular grids prior to producing the level 3 product.  2 grids are used - both geographic and geomagnetic.

# L2 to L3 – Summaries of the Observations of Regular Grids - Algorithms



# L2 to L3 – Observations on a Common Axis – Inputs & Overall concept

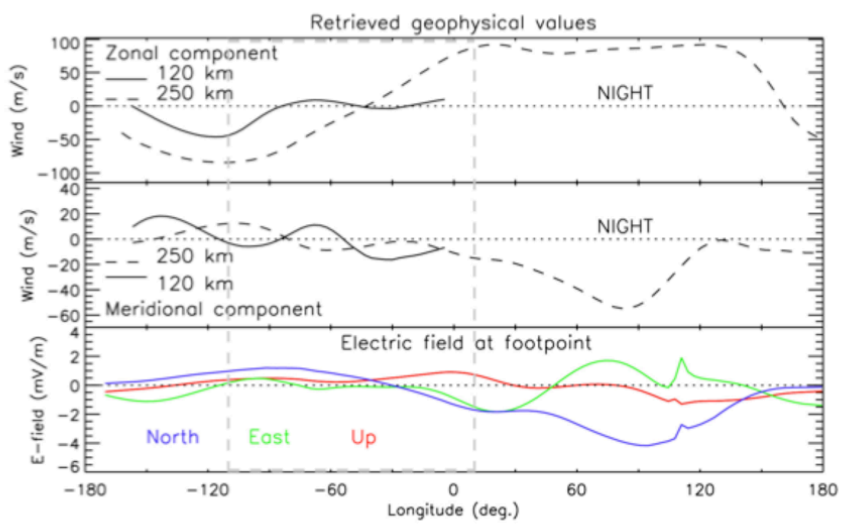
- The Level 3 common axis products are plots of the data for a single orbit of all data collected.
- The instantaneous data taken by the remote and *in situ* observations do not relate to the same place (for example MIGHTI A looks ahead of the S/C and MIGHTI B looks behind).
- For these plots, all are translated onto a common axis – observational longitude (which is the longitude that corresponds to that observation, and not the location of the spacecraft at the time of observation).

# L2 to 3.6 – Observations on a Common Axis

Scott England, UCB

Input Data | Ground Param. | Flight Param. | Processing Step | Output Data

24 hours of all L2 (except 2.1) → Shift / interpolate onto remote longitude axis → Summary Plot




Data Product 3.6 Data on Common Axis

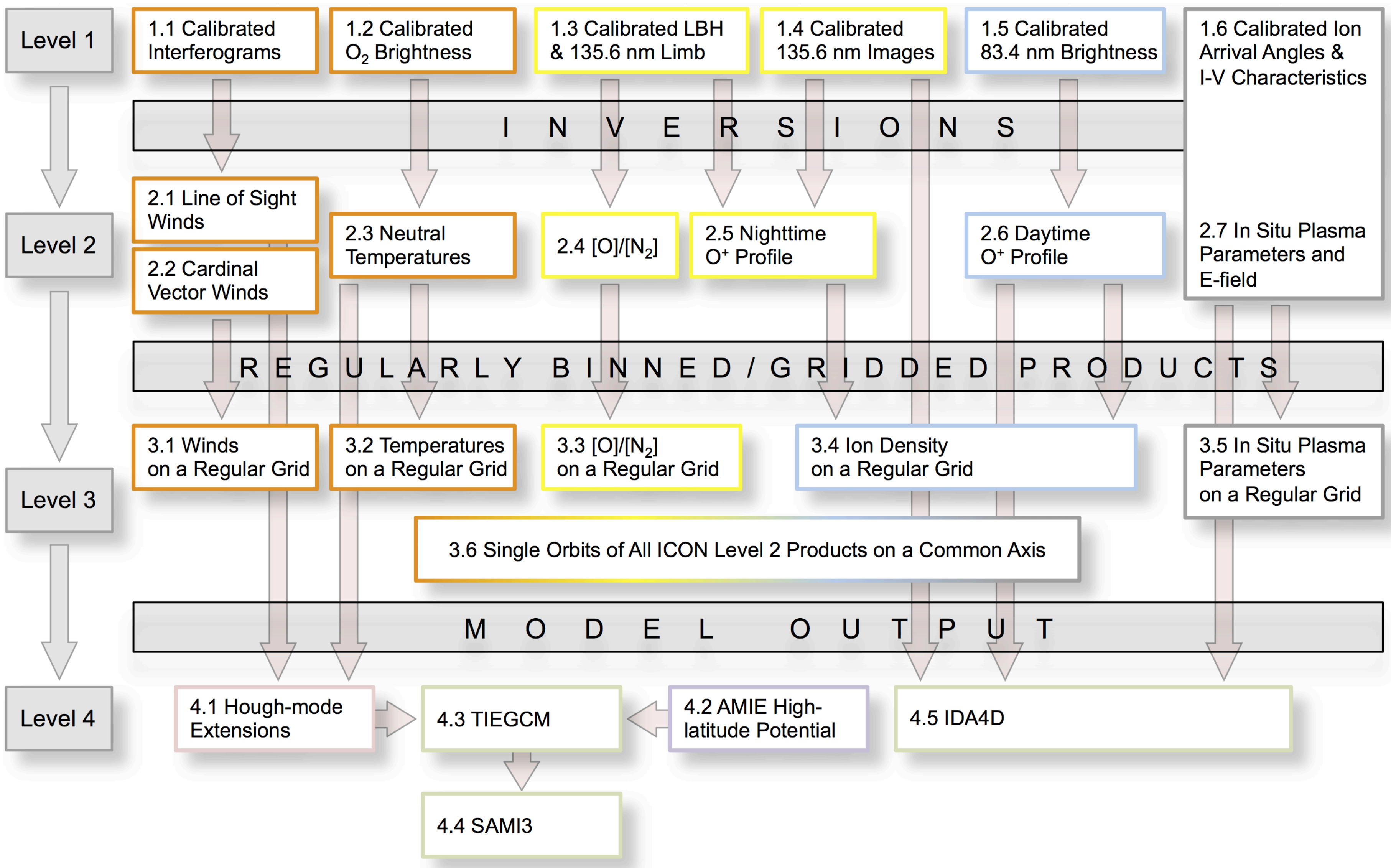
- Universal date and time of span of data
- Daily summary images

# Level 4 – Numerical Models

# L4 – Models – Inputs & Overall concept

- The Level 4 products are outputs of numerical models. These models are documented extensively elsewhere.
- The figure on the following slide shows the data inputs from ICON that are used in these models (e.g. the IDA4D model assimilates the L1 FUV nighttime 135.6 nm and L2 EUV $O^+$ data).
- Each of these models will be run for the entire prime mission of ICON, and the output files will be distributed along with the observational data.

# Level 4 Models & Relation to ICON data



# Implementation
# Science Data Production Timeline

Initial Production:

- Estimated latency of first data production by data level has been estimated.
- First delivery of calibrated data to SPDF is due 180 days into Phase E, which we expect to meet with margin.

| | Step | Predecessor | Time Allocated | Cumulative time | Comment |
|---|---|---|---|---|---|
| 1 | TLM downlink | N/A | N/A | ~5 hours | 5 downlinks/day |
| 2 | TLM to L0 processing at MOC | 1 | ~1 hour | ~6 hours | |
| 3 | Transfer of L0 from MOC to SOC | 2 | ~1 hour | ~7 hours | MOC and SOC are co-located |
| 4 | Generation of First In-Flight Calibration Database | 3 | 28 days | 29 days | 28 days allows for full moon for EUV |
| 5 | L0 to calibrated L1 processing at SOC | 4 | 1 day | 30 days | |
| 6 | Science Team Validates L1 data | 5 | 60 days | 90 days | Tasks performed iteratively. Meets L2-SCI-11g. |
| 7 | L1 data reprocessed if required | 6 | | | |
| 8 | L1 to L2 processing at SOC | 6, 7 | 10 days | 100 days | CPU intensive, thus 10 days are allocated. |
| 9 | Science Team Validates L2 data | 8 | 20 days | 120 days | Will commence as soon as L1 available. Meets L2-SCI-11h. |
| 10 | L2 data reprocessed if required | 9 | | | |
| 11 | First Delivery of Calibrated and Validated data to SPDF | 6, 9 | 1 day 59 days margin | 180 days | Meets L2-SCI-11f. |