A Proposal for an

Astrometry Data Exchange Standard

to be presented for adoption by

Commission 20: Position & Motion of Minor Planets, Comets & Satellites

of the

International Astronomical Union

Version 2015-July-15

1 Introduction

This document proposes an Astrometry Data Exchange Standard for small solar system objects, e.g., asteroids, comets, and natural satellites. It is intended to be proposed for adoption by IAU Commission 20 (Position and Motion of Minor Planets, Comets and Satellites) at the IAU General Assembly to be held in August 2015. For the purpose of this document we will refer to this standard as IAU2015.

In this document we propose a definition of data types/records that will facilitate transmission and storage of astrometric data, as generated by the observers, stored by the MPC, and processed by the orbit computers. In subsequent extensions to the standard we may propose also data types/record structures to handle other data products, e.g., orbits and ephemerides.

The standard defines certain data types, which are detailed lists of information that either can or must be included in data submission, storage and exchange. These lists can be thought of either as records, such as the ones in a database, or as object classes, user defined data types, and so on. However, the standard defines the information content, not how these structures are implemented in computer codes handling the data.

The proposed standard is based on an initiative undertaken starting in mid-2014 by S. R. Chesley (JPL), D. Farnocchia (JPL), A. Milani (Univ. Pisa), and F. Spoto (SpaceDyS). The standard was discussed with invited representatives of the interested community during a workshop hosted by the MPC on May 7 and 8, 2015. The MPC workshop attendees were

- A. B. Chamberlin (JPL)
- S. R. Chesley (JPL, IAU Comm. 20 President)
- E. Christensen (Univ. Arizona, Catalina Sky Survey)
- P. W. Chodas (JPL, NASA NEO Program Office Manager)
- L. Denneau (IfA, Univ. Hawaii, ATLAS & Pan-STARRS)
- D. Farnocchia (JPL)
- J. L. Galache (CfA, MPC)
- T. Grav (PSI, NEO-WISE)
- M. J. Holman (CfA, MPC Interim Director)
- S. Keys (CfA, MPC)
- R. S. McMillan (Univ. Arizona, Spacewatch)
- M. Micheli (ESA ESRIN, SpaceDys)
- A. Milani (Univ. Pisa, NEODyS, IAU Comm. X.2, incoming President)
- M. Rudenko (CfA, MPC)
- G. B. Valsecchi (INAF, IAU Div. F President)
- G. Williams (CfA, MPC Assoc. Director)

Following the May workshop a June 1 draft of the standard, representing a consensus among the attendees as the best path forward, was distributed to a somewhat broader group for feedback. The present draft includes additional feedback from the workshop attendees, as well as from Serge Chastel, Jon Giorgini, Bill Gray, Robert Jedicke, Mario Juric, Herbert Raab, Dave Tholen and Brian Warner.

2 Motivation

The MPC already has a standard format, referred to as MPC1992, and a message protocol for receiving astrometry, and it uses the same format to redistribute the data to users. This format is limited to 80 columns and comes with limitations such as:

- No characterization of astrometric and photometric errors;
- Insufficient precision in time and angle fields;
- Lack of flexibility and extensibility.

The purpose of this standard is to ensure that useful and available observational information is submitted, permanently stored, and disseminated as needed. Availability of more complete information will allow orbit computers to process the data more correctly, leading to better accuracy and reliability. In this way it will be possible to fully exploit the ever improving accuracy and increasing number of both optical and radar observations. For instance, the number of optical observations has increased by two orders of magnitudes in recent decades and the accuracy is soon likely to improve by two orders of magnitude over past performance.

3 Requirements

The new standard must comply with requirements related to data content and structure and with requirements related to packaging and format. A guiding principle for developing the standard is that implementation and data processing issues are to be decided and managed locally and should not be prescribed beyond what is necessary to efficiently communicate the desired information. Additionally, the standard should clearly discriminate between the data produced by the observers and those that are the output of orbit computers. The requirements for data content and structure are specified in Sections 4 and 5.

The requirements on format are not as strict and may be interpreted as objectives. The packaging and format approach for the standard is described in Sec. 6. As guidelines, the adopted format should have the following features:

- The number of fields present in a file and their order, should be flexible so that unused fields can be neglected;
- Some fields may be mandatory, others optional or encouraged;
- The format should be compatible with new fields, perhaps devised for local use and not envisioned by the standard;
- The format should be well-suited for computer input/output, ideally with established libraries in modern programming languages;

- The format should be reasonably convenient for human consultation/editing.

To achieve the desired flexibility and extensibility, the defined data records include fields that may be either mandatory or optional. Mandatory fields are required and the data record is considered invalid without them. Some optional fields may not be relevant to a particular observation. Other optional fields may be relevant but not available, a situation that will predominate for historical data that have been stored before the adoption of this standard. Also some observers may not be ready to fill new fields, even if such data necessarily exist in their processing procedure. Optional fields may be left blank, possibly to be supplied later if it becomes feasible. Among the optional fields, some are strongly encouraged and failure to provide them might result in de-weighting of the corresponding observations when fitting an orbit to the observations.

The MPC is responsible for permanently storing and for disseminating the data submitted by the observers. To preserve the exact reported values, the content of all fields, including numeric fields, should be treated as ASCII character strings. Leading and trailing blanks are ignored.

4 Observational data

This section lists the data fields that are a part of the various modes of observation, e.g., optical, radar, etc. Observational data submitted and accepted by the MPC must be stored and preserved at the MPC and disseminated to users. Data exchange may have one of three purposes: 1) Observer submission to the MPC, 2) MPC distribution to data users and 3) sharing of observational data among observers and data users. In the following descriptions some fields are identified as mandatory or optional, and in some cases this depends on whether the exchange is a part of an observer submission or a part of an MPC distribution. Sharing of data among users and observers must generally comply with the observer submission requirements, although observation headers are optional in this case. When observations that have been published by the MPC are subsequently shared among users it is strongly discouraged to strip any fields from the redistributed records.

The number of digits in the provided measurements should be consistent with the stated or assumed uncertainty. As a guide, observations should be reported with roughly 1.5 significant figures (a factor ~30) beyond the measurement accuracy, and uncertainties should be reported with 2-3 significant figures. Thus observations reported in degrees that have accuracies in the range 0.03-0.3 arcsec would reasonably be reported with six significant figures past the decimal point. Similarly, photometry with magnitude uncertainties in the range 0.1-1.0 may be reasonably reported to the nearest 0.01 mag. The MPC may reject observations reported with a gratuitous number of digits.

4.1 Optical observations

An optical observation contains information about the astrometry and optional photometry of an image source. Optical observations are usually assembled in tracklets. A tracklet is a group of observations that are confirmed as belonging to the same object by the observer through direct inspection of the frames (e.g., in a blinking sequence), or by a software package (e.g., via great circle fit). A tracklet is typically a set of 3 to 5 ground-based observations of a moving object over a time span of up to a few hours, or anyway from the same night.

The following table describes the field names for optical observations, including visible and infrared wavelengths. (Radio interferometry measurements of right ascension and declination should also be reported in this category.)

Field	Type	Description
`permID`	String	IAU permanent designation, i.e., IAU number. See Table 1 and Note 1, below. *Mandatory for MPC distribution of numbered objects. Encouraged for observer submission of targeted observations of numbered objects.*

provID	String	MPC provisional designation (unpacked form) for unnumbered objects. See Table 1 and Note 1, below. *Mandatory for MPC distribution of unnumbered objects. Encouraged for observer submission of targeted observations of designated objects.*
trkSub	String	Observer-assigned tracklet identifier, unique within submission batch. Typically the same as observer-assigned temporary designation currently employed for the MPC1992 format. Observers are encouraged to use values with eight or fewer alphanumeric characters. See Note 1, below. *Mandatory for observer submission if neither* `permID` *nor* `provID` *are filled. Can also be used by observers to distinguish individual tracklets among observations with the same designation (*`permID` *or* `provID`*) in a given batch. Not altered by the MPC.*
obsID	String	Globally unique alphanumeric observation identifier assigned by the MPC. See Note 1, below. *Mandatory for MPC distribution. For observers this field is used only to communicate a correction to a previously published observation, otherwise it must not be filled.*
trkID	String	Globally unique alphanumeric tracklet identifier assigned by the MPC. See Note 1, below. *Mandatory for MPC distribution. Observers should fill* `trkSub` *and not* `trkID`*.* `trkID` *entries in observation submissions will be ignored and overwritten by the MPC.*
mode	String	Mode of observation, e.g., CCD, Photo, Transit, Occultation, etc. Full list of acceptable field names to be provided and maintained by the MPC. *Mandatory.*
stn	String	Observatory code assigned by the MPC. The four character codes will be backward compatible, with a 4^{th} character being added to identify different telescopes on the same site, e.g., 568a, 568b, etc. List of observatory codes and associated locations to be provided and maintained by the MPC. *Mandatory.*
prg	String	Program code assigned by the MPC. The `prg` field is used to identify different observing programs/observers at the same telescope. For surveys and other large producers, the MPC will increment `prg` for a given observatory code to document a significant operational change reported by the observing team. *Optional.*

obsTime	String	UTC time of the observation in ISO 8601 extended format, i.e., `yyyy-mm-ddThh:mm:ss.ssZ`. The reported time precision should be appropriate for the astrometric accuracy. The trailing Z indicates UTC and is optional. (See Note 2 at bottom of table for discussion.) *Mandatory.*
ra, dec	Numeric	Astrometric equatorial right ascension and declination in decimal degrees in the reference frame specified by `frame`. Positive DEC values may optionally include a '+'-sign. (See Note 3 at bottom of table for discussion.) *Mandatory except for offset or occultation observation, in which case these fields must not be used.*
deltaRA, deltaDec	Numeric	Measured ΔRA*COS(DEC) and ΔDEC in arcsec. For offset measurements of a satellite with respect to its planet, or for occultation observations with respect to the star specified by `raStar` and `decStar` (below). *Mandatory for offset and occultation observations. Not to be filled otherwise.*
raStar, decStar	Numeric	Right ascension and declination in decimal degrees of the occulted star. *Mandatory for occultation observations. Not to be filled otherwise.*
frame	String	Reference frame for reported angular measurements, e.g., 'J2000' for J2000.0 equatorial. (This field is not anticipated to be used until a new reference epoch is identified, e.g., J2050.0.) *Mandatory if different from J2000.*
astCat	String	Star catalog used for the astrometric reduction or for the occulted star in the case of occultation observations. Full list of acceptable field names to be provided and maintained by the MPC. *Mandatory. (A specified value, e.g., 'UNK' will be used for some archival observations to indicate astrometric catalog unknown.)*
rmsRA, rmsDec	Numeric	Random component of the RA*COS(DEC) and DEC uncertainty (1σ) in arcsec as estimated by the observer as part of the image processing and astrometric reduction. Presumed systematic errors, e.g., those arising from star catalog biases, should not be folded into the uncertainties reported in this field. $\texttt{rmsRA}^2$ and $\texttt{rmsDec}^2$ are the diagonal elements of the RA-DEC covariance matrix, which convolves errors from target PSF fitting, telescope tracking, reference star fit, etc. *Optional (but strongly encouraged).*

rmsCorr	Numeric	Correlation between RA and DEC that may result from the astrometric reduction. It can be especially relevant for trailed images or cases with a poor distribution of reference stars. This is derived from the RA-DEC covariance matrix, where the off-diagonal term is `rmsCorr` × `rmsRA` × `rmsDec`. *Optional.*
mag	Numeric	Apparent magnitude in specified band. *Optional.*
band	String	Filter designation for photometry. Full list of acceptable field names to be provided and maintained by the MPC. *Mandatory if `mag` present.*
photCat	String	Star catalog used for the photometric reduction. Full list of acceptable field names to be provided and maintained by the MPC. *Mandatory for future submissions if `mag` is present.*
rmsMag	Numeric	Apparent magnitude uncertainty (1σ) in magnitudes. *Optional.*
photAp	Numeric	Photometric aperture radius in arcsec. *Optional, but particularly encouraged for comets.*
nucMag	Logical (Integer 0 or 1)	Nuclear magnitude flag for comets. 0 for total magnitude (i.e., for most archival comet observations and all asteroid observations), 1 for nuclear magnitude. Primarily used for archival data as `photAp` should be used to communicate this information in the new standard. *Optional.*
logSNR	Numeric	The log10 of the signal-to-noise ratio of the source in the image integrated on the entire aperture used for the astrometric centroid. *Mandatory for future submissions.*
seeing	Numeric	Size of seeing disc in arcsec, measured at Full Width Half Max (FWHM) of target point spread function (PSF). *Optional.*
exp	Numeric	Exposure time in seconds. Total exposure time in the case of stacked image detections. *Optional.*
rmsFit	Numeric	RMS of fit of astrometric comparison stars in arcsec. *Optional.*
nStars	Numeric	Number of reference stars in astrometric fit. *Optional.*
ref	String	Standard reference field used for citations. *Mandatory for MPC distribution. Not to be filled by observers.*

`disc`	String	Discovery flag. For example, '*' if a discovery observation. Filled by the MPC according to a list provided and maintained by the MPC. *Optional for MPC. Not to be filled by observers.*
`subFmt`	String	Format in which the observation was originally submitted to the MPC, e.g., M92 for MPC1992 format or I15 for this standard. Filled by the MPC according to a list provided and maintained by the MPC. *Mandatory for MPC distribution. Not to be filled by observers.*
`precTime`	Numeric	Precision in millionths of a day of the reported observation time for archived MPC1992 data records. See Note 2, below. *Mandatory for MPC distribution of MPC1992 or earlier submissions. Otherwise empty. Not to be filled by observers.*
`precRA`	Numeric	Precision in sec of the reported RA for archived MPC1992 data records. See Note 3, below. *Mandatory for MPC distribution of MPC1992 or earlier submissions. Otherwise empty. Not to be filled by observers.*
`precDec`	Numeric	Precision in arcsec of the reported DEC for archived MPC1992 data records. See Note 3, below. *Mandatory for MPC distribution of MPC1992 or earlier submissions. Otherwise empty. Not to be filled by observers.*
`uncTime`	Numeric	Estimated time uncertainty in seconds. Unlike the preceding RMS fields, which indicate random errors, this field indicates a presumed level of systematic clock error. NB: This field is generally only to be used to communicate exceptions and problems with clock calibration and is not intended to be used in routine submissions where clock errors are not a significant source of astrometric error. *Optional.*
`notes`	String	A set of one-character note flags to communicate observing circumstances. List of acceptable flags and their interpretation to be provided and maintained by the MPC. *Optional.*
`remarks`	String	Comment provided by the observer. This field can be used to report additional information that is not reportable in the `notes` field, but that may be of relevance for interpretation of the observations. Limited to 200 characters. *Optional, should be used sparingly by major producers.*

NOTES:

1) The use of the fields `permID`, `provID`, `trkID`, `trkSub`, and `obsID` depends on the designation status of the target and the purpose behind the exchange of data. For all observer submissions to the MPC, at least one of `permID`, `provID` or `trkSub` must be filled. For unlinked submissions to the MPC the `permID` and `provID` fields should not be filled and `trkSub` must include a user-assigned temporary designation, unique within the submission, for each tracklet in the submission. For targeted follow-up or recovery observations the user is encouraged to report the current designation of the target in either the `permID` or `provID` field, as the case may be. If an object is numbered then `provID` should not be filled and will be ignored by the MPC. For targeted follow up with more than one tracklet in the submission, the `trkSub` field should be used to distinguish the individual tracklets. `trkID` and `obsID` are only to be filled by the MPC and must be empty for MPC submissions of new data. Observers may submit corrections to published observations, in which case the `obsID` published by the MPC must be included. The following table indicates the correct approach for these fields.

Type of observation	**`permID`**	**`provID`**	**`trkID`**	**`trkSub`**	**`obsID`**
Submission of targeted follow up observations	Permanent designation of target if applicable.	Provisional designation of target if applicable. Ignored by MPC for numbered objects. Could be an NEOCP temporary designation.	Empty	When submission includes multiple tracklets of a targeted object then each tracklet should be identified by a locally unique code	Empty
Submission of routine and unlinked survey detections	Empty	Empty	Empty	Observer-assigned identifier for each tracklet in submission.	Empty
MPC distribution	Permanent designation of target if applicable. (filled or vetted by MPC)	Provisional designation of target for observations submitted prior to numbering (filled or vetted by MPC)	Filled by MPC with globally unique value	As in observer submission	Filled by MPC with globally unique value
Submission of correction to already published observation	As published	As published	As published	As published (unless part of correction)	As published

The `permID` and `provID` fields carry the permanent or provisional designation of the object, respectively. (The past use of an MPC "packed" designation has been dropped, primarily because it is generally less readable, and the sorting advantages of the packed format require preservation of leading blanks and zeros, which is not in accord with the IAU2015 formatting guidelines.) For minor planets and comets, the `permID` and `provID` format follows the formal designation very closely, with the exception of removing parentheses around numbered minor planets and eschewing subscripting in provisional designations of minor planets. For comets, the formal `permID` and `provID` entries are identical, including the fragment descriptor. For planetary satellites the `permID` entry uses only the first letter of the planet followed by the Arabic number of the satellite. The specification of the permanent and provisional designation fields is given by examples in the following table:

Object Type	Desig. Type	permID	provID
Minor Planet	Permanent	1	
Minor Planet	Permanent	433	
Minor Planet	Permanent	134340	
Minor Planet	Provisional		2014 AA
Minor Planet	Provisional		2014 AA1
Minor Planet	Provisional		2014 AA360
Minor Planet	Provisional		2014 AA12345
Minor Planet	Provisional		2001 P-L
Minor Planet	Provisional		2801 T-2
Comet	Permanent	1P	
Comet	Permanent	257P	
Comet Fragment	Permanent	73P-C	
Comet Fragment	Permanent	73P-AC	
Comet	Provisional		P/1998 QP54
Comet	Provisional		C/1997 BA6
Comet	Provisional		C/1999 K7
Comet	Provisional		C/1931 AN
Comet	Provisional		P/1886 S1
Comet Fragment	Provisional		P/1994 P1-B
Comet Fragment	Provisional		C/1996 J1-A
Satellite	Permanent	J13	
Satellite	Provisional		S/2001 S 31
Satellite	Provisional		S/2001 U 9

2) The MPC1992 astrometry format recorded the date and time of observation in decimal day format. The IAU2015 standard breaks from that historical format to use the ISO 8601 standard date/time format. (See, for example, https://en.wikipedia.org/wiki/ISO_8601.) There are a number of advantages to this standard, including wide availability of libraries in many programming

languages for input/output of the ISO 8601 time format, reduced ambiguity for times near leap seconds, and human readability. Additionally, radar astrometry measurements (discussed below) are reported as normal points with a time tag at an integer UT second, and so are not well suited for decimal day representation. A key reason to prefer the decimal day form was that the MPC1992 observations use this format and the precision of the submitted time can be of interest in some cases. To address this need, the time precision of MPC1992 observation records will be preserved in the `precTime` field, allowing the end-user to reconstruct the decimal day string used in the original MPC1992 submission.

3) At the workshop there was a lengthy discussion on decimal vs. sexagesimal reporting of angles; however, the clear consensus was to opt for decimal degrees. The primary reasons for continuing with sexagesimal are a) existing data are already in sexagesimal format and alteration of submitted data is undesirable, and b) the sexagesimal format makes it convenient to plan the sequence of observations during an observing night (by reference to the local apparent sidereal time). The key justification for moving away from sexagesimal representation is that a) it is not suitable for automated data validation of astrometry records using standard computing tools, b) many routine data manipulations and database searches become cumbersome with sexagesimal, for example, selection of observations near a given position (for linkage problems), differencing of sequential positions, routine plotting, etc., c) bugs in the countless different implementations of decimal to sexagesimal conversion tools are persistent and frustrating (e.g., the negative declination bug or "60" appearing in the arcmin or arcsec position), and d) the data exchange standard should mirror the mass data storage format insofar as is practicable, again to avoid alteration of submitted data.

   While some operational situations may require sexagesimal values, e.g., for telescope control, ephemeris generation services will continue to provide sexagesimal outputs on request. Typically, targeted observation planning is based on such tabular ephemerides, but in cases where observers instead use astrometric records to sequence observations the conversion to sexagesimal format is straightforward. The IAU2015 standard only specifies a mode of exchange, and users are free to repackage astrometry in whatever form is judged appropriate for local purposes.

   The reported precision in archival MPC1992 data records will be preserved in the `precRA` and `precDec` fields, which may be useful for correct treatment of the observations and will allow an accurate reconstruction of the original MPC1992 RA and DEC fields.

Variable Station Position. Additional information must be provided for satellite and roving observations, for which the position of the observer is required. Satellite and roving observations can be recognized by the presence and the value of the `sys` field.

Field	Type	Description
`sys`	String	Coordinate system for station coordinates. Roving: • 'WGS84' (geodetic reference ellipsoid, GPS coordinates are normally obtained in this frame) • 'ITRF' (cylindrical) • 'IAU' (IAU planetary cartographic model for bodies other than Earth) Space-based (Cartesian): • 'ICRF_AU' • 'ICRF_KM' *Mandatory when `stn` is on the MPC maintained list of approved roving and satellite observatory codes. Invalid otherwise.*
`ctr`	Numeric	Origin of the reference system. Use public SPICE codes, e.g., 399 is geocenter, 10 is Sun center. (See http://naif.jpl.nasa.gov/pub/naif/toolkit_docs/C/req/naif_ids.html - NAIF Object ID numbers) *Mandatory when `sys` is present. Invalid otherwise. NOTE: `sys`=WGS84 implies `ctr`=399.*
`pos1`, `pos2`, `pos3`	Numeric	Position of observer. • For WGS84: E longitude (deg), latitude (deg), and altitude (m). • For ITRF: E long (deg), R_{xy} (km), R_z (km). • For IAU: longitude (deg), latitude (deg), and altitude (m) as defined by the corresponding IAU cartography standard (http://astrogeology.usgs.gov/groups/IAU-WGCCRE) • For ICRF: equatorial rectangular coordinates (au or km) in reference frame given by `frame`. The number of digits provided should be consistent with the uncertainty of the coordinates. *Mandatory when sys is present. Invalid otherwise.*
`posCov11`, `posCov12`, `posCov13`, `posCov22`, `posCov23`, `posCov33`	Numeric	Upper triangular part of POS covariance matrix in same units of position coordinates (e.g., km^2 if sys = 'ICRF_KM'). Missing fields are presumed zero. *Optional when sys is present. Invalid otherwise.*

4.2 Radar observations

Radar astrometry is reported as either the time delay or Doppler frequency shift between transmitter and receiver. It is fundamentally different from optical astrometry not only because of the different observable, but also because the individual data points are one-dimensional and of high fractional precision, potentially at the few meter level in accuracy.

The radar-specific fields, all of which are mandatory, are tabulated below, while the following radar fields are as described above for optical observations:

- `permID` or `provID` – applicable field is always mandatory for radar observations
- `obsID` – only filled by the observer to report a correction to previously reported astrometry
- `mode` – delay or Doppler
- `obsTime` – since radar astrometry is a normal point representing data taken over an extended period, the observation time is chosen by the measurer to an integral second (usually but not always to an integral minute) and has no error
- `logSNR` – optional for radar observations
- `ref` – assigned by MPC
- `subFmt` – only filled by MPC and should always indicate IAU2015 until current standard is superseded
- `remarks` – up to 200 characters

Field	Type	Description
`valRad`	Numeric	Value of the observed quantity in s for delay, Hz for Doppler. *Mandatory.*
`rmsRad`	Numeric	Measurement uncertainty (1σ) in μs for delay, Hz for Doppler. *Mandatory.*
`com`	Logical (Integer 0 or 1)	Flag to indicate that the observation is reduced to the center of mass. False implies a measurement to the peak power position, which is usually interpreted as the leading edge of the target, with the reflection point being modeled one object radius prior to the center of mass. *Mandatory when false, optional otherwise.*
`frq`	Numeric	Carrier reference frequency in MHz. *Mandatory.*
`trx`	String	Station code of transmitting antenna. List of station codes and associated locations provided by the MPC. *Mandatory.*
`rcv`	String	Station code of receiving antenna. List of station codes and associated locations provided by the MPC. *Mandatory.*

4.3 Observation submission header

An information header, e.g., to list observers and measurers, accompanies the submission of observational data to the MPC. Below are the fields to be included in the submission header. Note that the various fields are organized into groups to facilitate parsing and that not all field names are unique.

Group Name	Element Name	Description
`observation`		
	`count`	Number of observations in batch. *Mandatory.*
	`type`	Description of type of object(s) included in batch, e.g., NEO, NEOCP, TNO, COMET, NATSAT. Full list of acceptable field values to be provided and maintained by the MPC. *Optional, however this field may be required to ensure that observations receive appropriate and prompt processing, e.g., for NEO and NEOCP observations. Neglecting this field may lead to a delay in MPC processing.*
`observatory`		
	`mpcCode`	Observatory code (of receiver for radar). List of possible observatory codes provided by the MPC. It must match the `stn` field (`rcv` for radar) in the observation records. *Mandatory.*
	`name`	Observatory name. *Optional.*
`contact`		
	`name`	Contact name (initials then surname). *Mandatory.*
	`address`	Contact Address. *Optional.*
	`ackMessage`	Acknowledgement message text. (See Note, below.) *Optional.*
	`ackEmail`	Valid email address(es) to which the acknowledgement text is sent. (See Note, below.) *Mandatory.*
`observers`		
	`name`	Observer name (initials then surname). Multiple observers each have a `name` tag. *Mandatory.*
`measurers`		
	`name`	Measurer name (initials then surname). Multiple observers each have a `name` tag. *Mandatory.*
`telescope`		
	`name`	Name of telescope. *Optional.*

	design	Optical system type, e.g., reflector, Schmidt, Schmidt-Cassegrain, etc. *Mandatory, except for radar.*
	aperture	Aperture in meters. *Mandatory, except for radar.*
	detector	Detector description, e.g., CCD. *Mandatory, except for radar.*
	fRatio	Focal ratio. *Optional.*
	filter	Filter description. *Optional.*
	arraySize	Array size (X × Y), after binning, of the individual detector chip. *Optional.*
	pixelScale	Pixel scale in arcsec. *Optional.*
software		
	astrometry	Description of software for astrometry. *Optional.*
	fitOrder	Order of fit for astrometric solution. *Optional.*
	photometry	Description of software for photometry. *Optional.*
	objectDetection	Description of software for object detection if different from `astrometry` or `photometry` software. *Optional.*
comment		Explanatory remarks. *Optional.*
coinvestigators		
	name	List of co-investigators (initials then surname). Multiple co-investigators each have a `name` tag. *Optional.*
collaborators		
	name	List of collaborators (initials then surname). Multiple collaborators each have a `name` tag. *Optional.*
fundingSource		Description of funding source. *Optional.*

NOTE: The `ackMessage` and `ackEmail` fields are private and will not be publicly distributed by the MPC.

5 Observation residuals

Once an orbit is computed by fitting the observational data, some users may wish to exchange the information on the residuals as well as the information on the statistical treatment applied to the observations. These fields are usually filled by orbit computing centers and can be consulted by observers to assess their astrometric performance. None of these fields is required for submitting astrometry to the MPC, nor is the MPC expected to store these data in case the observer provides them.

The inclusion of the residuals as part of the standard was discussed at length at the workshop. The reasons for including residuals in the astrometry exchange standard are the following:

- Residuals, at least for asteroids, are generally reflective of the observational errors and, especially for well constrained orbits, are not very sensitive to the dynamical model;
- Observers are interested in knowing the quality of their observations;
- Residuals afford an assessment of the internal consistency of a tracklet, which is not visible in the astrometry itself;
- Availability of residuals facilitates research on the statistical treatment of astrometry and photometry.

Residuals not only depend on the astrometric and photometric measurements but also on a specific trajectory, i.e., osculating orbit, dynamical model, and photometric model. This information is not captured explicitly in the present form of the data exchange standard, but is indirectly referenced through the `orbId` field.

5.1 Observation residual header

Field	Type	Description
`orbProd`	String	Orbit producer. Can be institution, individual, or even email address, e.g., ‘MPC’. *Mandatory if residuals are reported.*
`photProd`	String	Producer of photometric residuals. Can be institution, individual, or even email address, e.g., ‘MPC’. *Mandatory if photometric residuals are reported.*

5.2 Optical astrometry and photometry residuals

Field	Type	Description
`resRA`, `resDec`	Numeric	Residuals in RA*COS(DEC) and DEC in arcsec. *Optional, but if one is present then both must be present.*
`orbId`	String	Local reference for orbit, e.g., ‘JPL 7’ or ‘MPO 12345’. *Mandatory if residuals are reported.*

selAst	1 char	Inclusion/rejection flag for astrometry. Valid values are 'A'/'D' for automatic accept/delete, 'a'/'d' for manual accept/delete. *Mandatory if `resRA` and `resDec` present.*
sigRA, sigDec	Numeric	Adopted RA*COS(DEC) and DEC uncertainties (1σ) in arcsec. May be different from the observer provided uncertainties. *Mandatory if different from 1 arcsec and `resRA` and `resDec` present.*
sigCorr	Numeric	Adopted correlation between RA*COS(DEC) and DEC. May be different from the observer provided correlation. *Mandatory if different from 0 and `resRA` and `resDec` present.*
sigTime	Numeric	Adopted time uncertainty (1σ) in seconds. May be different from the observer provided uncertainty. *Mandatory if different from 0 and `resRA` and `resDec` present.*
biasRA, biasDec	Numeric	Adopted RA*COS(DEC) and DEC biases in arcsec. *Mandatory if different from 0 and `resRA` and `resDec` present.*
biasTime	Numeric	Adopted time bias in seconds. *Mandatory if different from 0 and `resRA` and `resDec` present.*
resMag	Numeric	Photometric residual in magnitudes. *Optional.*
selPhot	1 char	Inclusion/rejection flag for photometry. Valid values are 'A'/'D' for automatic accept/delete, 'a'/'d' for manual accept/delete. *Mandatory if `resMag` present.*
sigMag	Numeric	Adopted magnitude uncertainty (1σ) in magnitudes. Could be different from the observer provided uncertainty. *Mandatory if different from the observer provided uncertainty and `resMag` present.*
biasMag	Numeric	Adopted photometric bias in magnitudes. *Mandatory if different from 0 and `resMag` present.*
photMod	String	Description of the photometric model. For example, a value of 'G=0.35' indicates the value of G in the H-G system. Other standard values for this field will be established by the MPC in consultation with the research community. *Mandatory if photometric residuals are reported and the model is different from the standard H & G model with G=0.15.*

5.3 Radar residuals

Field	Type	Description
`resRad`	Numeric	Residual of the radar measurement in μs for delay, Hz for Doppler. *Optional.*
`orbId`	String	Local reference for orbit, e.g., 'JPL 7' or 'MPO 12345'. *Mandatory if `resRad` present.*
`selRad`	1 char	Inclusion/rejection flag for radar astrometry. Valid values are 'A'/'D' for automatic accept/delete, 'a'/'d' for manual accept/delete. *Mandatory if `resRad` present.*
`sigRad`	Numeric	Adopted uncertainty for the radar measurement in μs for delay, Hz for Doppler. *Mandatory if different from the observer provided uncertainty and `resRad` present.*

6 Format and Packaging

After extensive discussion at the MPC workshop, a consensus was reached that the new standard should support two file formats. XML was selected as the primary vehicle for exchanging data, in large part because of its advantages for computer input/output applications. Among other modern data exchange standards, XML was judged to have the desired maturity and stability (in terms of standards, schema, user base and available libraries) in comparison to some more recent developments that are still evolving, e.g., JSON. XML files are more verbose than those of less flexible formats, but they typically afford excellent compression ratios (e.g., 10:1 and better), substantially mitigating file transmission issues.

However, XML is not suited for plain text viewing and editing, and thus a PSV format (i.e., Pipe Separated Value, similar to CSV) that carries the same information as the XML format will be supported by the standard, although exchange in this format is not encouraged. Rather, we consider it preferable for users to convert PSV files to XML after viewing and editing and before transmission. This has the advantage of automatic data validation and avoids issues with email line wrapping. We anticipate that tools allowing convenient viewing and editing of XML files will be developed by the research community, and that as these tools become available many PSV users will find it more convenient to work directly with XML.

Because of its inherent flexibility, there are no significant packaging challenges with XML. A data file may have only observations, only residuals, or both. Also an XML file may have multiple data types (e.g., radar, ground-based optical, space-based optical, occultation or offset observations) within a file without difficulty. And header information is readily absorbed into the XML file structure, even for multiple batches in a single file. Such flexibility can be preserved in the PSV file format, but not with the same elegance afforded by XML.

The proposed standard will include open source I/O libraries in a number of programming languages, and conversion scripts to and from XML and PSV. This software will allow for robust error checking, file merging/splitting, and other utility functions. For the current version of the standard a requirement of lossless conversion between XML and PSV will be enforced, both for data records and submission headers.

6.1 Primary exchange format – XML

The exact formulation of the XML format is under development, but it should be similar to the example given in the figure below, where an `observationBatch` element includes an `observationContext` sub-element (i.e., the header) and an `observations` sub-element, which holds the observations. Multiple `observationBatch` blocks may be included in one submission file when, for example, the header information changes within a given submission. In the XML format users are discouraged from adding leading or trailing blanks. Keywords are written in so called lowerCamelCase, i.e., lowercase except that wordbreaks are marked by an uppercase letter. Initialisms and acronyms (e.g., ID, RA, SNR, RMS) are written in all uppercase or all lowercase.

Example XML file structure


```
 <observationBatch>
 <observationContext>
  <observation>
   <count>12</count>
  </observation>
  <observatory>
    <mpcCode>F51</mpcCode>
    <name>Pan-STARRS 1</name>
  </observatory>
  <contact>
    <name>P. Villa</name>
    <ackMessage>Sample header</ackMessage>
    <ackEmail>pancho.villa@gmail.com</ackEmail>
  </contact>
  <telescope>
    <aperture>1.5</aperture>
    <design>Reflector</design>
    <detector>CCD</detector>
  </telescope>
  <observers>
    <name>P. Villa</name>
    <name>F. Madero</name>
  </observers>
  <measurers>
    <name>P. Villa</name>
    <name>F. Madero</name>
  </measurers>
 </observationContext>
 <observations>
  <optical>
   <provID>2015 HD76</provID>
   <trkSub>aa</trkSub>
   <mode>CCD</mode>
   <notes>Klmn</notes>
   <stn>F51</stn>
   <prg>31</prg>
   <obsTime>2015-04-25T12:32:34.5</obsTime>
   <ra>215.65605</ra>
   <dec>-13.547872</dec>
   <astCat>2MA</astCat>
   <rmsRA>0.15</rmsRA>
   <rmsDec>0.13</rmsDec>
   <rmsCorr>0.21</rmsCorr>
   <mag>21.9</mag>
   <photCat>2MA</photCat>
   <band>w</band>
   <rmsMag>0.25</rmsMag>
   <logSNR>0.775</logSNR>
   <remarks>High winds affected tracking</remarks>
  </optical>
  <optical>
   ...
  </optical>
  <optical>
   ...
  </optical>
  <optical>
   ...
  </optical>
 </observations>
</observationBatch>
```

6.2 Secondary format – PSV

Despite its advantages, XML is inconvenient for visual inspection of observation files and for manually editing records, which is sometimes required. Therefore the IAU2015 standard accommodates an alternate exchange format, namely a plain text Pipe Separated Values (PSV) file. (An example is depicted at right.) Blanks will normally be used as padding to obtain column alignment of the data fields, but this is not strictly necessary. Since the pipe character '|' serves as delimiter it is not an allowed character in the fields defined by this standard. Null fields are empty (i.e., consecutive delimiters: '||') or filled with blanks in the blank-padded format.

In the PSV format a *submission batch* includes a *header block* and one or more *data blocks*. Each data block starts with a *keyword record* that specifies the keywords and their order, followed by a series of *data records* that follow the structure of the keyword record. Multiple data blocks can follow a single header block, and multiple submission batches can be concatenated into one PSV file. The header information is generally optional, but mandatory for MPC submissions. The keyword record is a mandatory first record for any data block.

The header section loosely follows the structure in the XML example above, but without the use of XML tags. The higher-level "group" keywords are preceded by a '#' character and the lower-level "element" keywords are preceded by a '!' character. For example,

```
# observers
! name P. Villa
! name F. Madero
# telescope
! aperture 1.5
! design Reflector
! detector CCD
# comment This is a comment. And it
# comment can be quite long.
```

New submission batches are distinguished by a new header block, and new data blocks are identified by their keyword records. Each data block can have a different keyword list, as defined by the corresponding keyword record. In this way, for instance, different data types (e.g., optical and radar) can be in the same file without necessarily including all possible fields on each data record.

The first non-blank record following the header block must be a *keyword record*, a PSV record specifying the keywords and the order that they take in the current batch.

`KEY1 | KEY2 | KEY3 | …`

To readily recognize the keyword record when parsing the file we require that the first keyword be `permID`, even when it has a null value. Thus, the keyword record is by having `permID` as the first six non-blank characters.

```
permID|provID|trkSub|mode|stn|prg|obsTime|ra|dec|astCat|rmsRA|rmsDec|rmsCorr|mag|band|photCat|rmsMag|photAp|logSNR|seeing|exp|notes|obsID|trkID|remarks
      |          |P109wX4|CCD|568a|23|2015-04-25T12:34:45.6    |215.65605   |   13.54787  |2MA| 0.15 | 0.13 | 0.21|21.9 |  w|2MA|0.25| 2.0|0.70|0.7|9999|    K|123456789012345678|abcdefgh|This is a remark
      |1998 QW345 |      a|CCD|568a|23|2015-04-25T12:34:45.6    |215.65605   |   13.54787  |2MA| 0.15 | 0.13 |-0.34|21.9 |  w|2MA|0.25| 2.0|0.48|1.1|99.9|    K|123456789012345678|abcdefgh|Another remark

permID|provID|trkSub|mode|stn |prg|obsTime              |ra       |dec      |astCat|rmsRA|rmsDec|rmsCorr|mag |band|photCat|rmsMag|photAp|logSNR|seeing|exp |notes|remarks
134340|      |     a|CCD |568a| 23|2015-04-25T13:45:56.7|  3.56123|-13.54787|   2MA| 0.16| 0.23 |   0.21|20.9|   w|    2MA| 0.25 | 2.0  |0.70  | 1.1  | 100|df   |High winds affected tracking
73P-A |      |     b|CCD |568a| 23|2015-04-25T14:56:01.0| 89.12345| -3.54787|   2MA| 0.17| 0.33 |       |18.1|   w|    2MA| 0.25 | 2.0  |0.70  | 1.1  |1200|as   |Fuzzy and faint, large coma
```

After the keyword record, the observation data records are reported as `VALUE1 | VALUE2 | VALUE3 | …` For easier visual inspection and editing, the PSV file can optionally be blank-padded for column alignment. The blank padding can be extended to the keyword record, which will keep the keywords above their data columns, or the blank padding can include only the data records, which will generally lead to a more compact format.

Default PSV. As a convenience for some users, the standard does define a default PSV template that is compliant with the standard. This template will afford a human readable format that can be widely used for many basic astrometric submission purposes. The table at right lists the field names, their order and the field width for this default format. Any fields present in the record but not listed in the table will be placed in arbitrary order between the `notes` and `remarks` fields. (The first three records in the PSV example above use the default PSV form. The last three records in the example show an alternate form of blank padding.) With this format the record length is 156 characters (plus optional fields after the `notes` and any `remarks`). Conversion utilities will include the option to produce files with the default template. However, use of the default template is not required: the only requirement for submission is the compliance with the general standards detailed in this document.

Default PSV Guidelines

Field Name	Width	Justification
permID	7	R
provID	11	L
trkSub	7	R
mode	3	R
stn	4	L
prg	2	R
obsTime	23	L
ra	11	D4
dec	11	D4
astCat	3	R
rmsRA	6	D3
rmsDec	6	D3
rmsCorr	5	D2
mag	5	D3
Band	3	R
photCat	3	R
rmsMag	4	D2
photAp	4	D3
logSNR	4	D2
seeing	3	D2
exp	4	R
notes	5	L
remarks	Variable	L

NOTES: The tabulated column width is a minimum and may be expanded if alignment with field names is requested. Justification is either right (R), left (L) or by placing the decimal point in a given column within the field (e.g., D3 makes the decimal point the 3rd character within the field).

6.3 Packaging

After adoption by the IAU and the MPC, IAU2015 will become the MPC's primary means of submission and dissemination and observers are strongly encouraged to adopt the new format as soon as practicable. (The 80-column MPC1992 format will be deprecated but continue to be accepted for an indefinite but limited time period.) The submission of IAU2015 observations to the MPC will be possible in three ways: Web form, cURL, and email (XML only).

The only acceptable format for email submission is anticipated to be XML, either compressed or uncompressed. For the observers who prefer the PSV format, a web interface to upload observation submissions will be provided. The backend engine of the web interface will convert the supplied data file to XML and validate it as a part of the ingestion pipeline at the MPC. The MPC will also disseminate the data in the XML form of the IAU2015 standard, eventually with the option of downloading the observation residual data and submission headers. Users may use local scripts or MPC web forms to convert from XML to PSV and back. Scripts will provide a user option to include or exclude header information when converting from XML to PSV format.

The observational data defined in Sec. 4 must be packaged within a single file. In particular, when satellite or roving observations are exchanged the information on the observer location must be contained in the same file as the observations, rather than in a separate file. On the other hand, the residuals and related fields may be included in the observation file or stored in a separate file. In the case of a single file, the observation residual fields have to be horizontally concatenated to the observational data and the residual header has to be vertically concatenated to the submission header. In the case of two different files, `obsID` should be reported on each record in the residual file to allow cross-referencing with the observation records.

6.4 Input/Output Software

To support the transition to the new format, software tools will be made publicly available. An ad hoc volunteer software committee was formed at the MPC workshop. Co-chairs are A. Chamberlin and L. Denneau. Additional membership includes P. Chodas, T. Grav, S. Keys and A. Milani. The objective of this committee is to facilitate the development of software and libraries in a number of widely used languages, e.g., Perl, Python, FORTRAN, C++. The software packages will include I/O libraries for extending custom software and scripts for file utilities such as error checking, conversion (between PSV and XML), merging and splitting.

Software packages should append a checksum value to the end of an XML file. If provided, it should be the last line in the file and its value is the MD5 checksum of the file prior to appending the MD5 element onto it. This can be used for submissions by curl to check if there was any corruption in the transmission of the file. Upon receipt, the MPC would compute the MD5 checksum of the file without the line containing the MD5 element and report an error back to the submitter if the values disagreed.

Please note that potential users should not begin to write source code to accommodate the new exchange standard before communicating with the software committee. The standard will eventually include XML schema files and XSLT files for translation from XML to PSV, and the software committee will develop these as standard data products that will be under centralized control to ensure compliance with the standard. Also, numerous finer details remain to be resolved, many of which will not be obvious nor fully resolved until the software implementation is complete.