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MANGO: A Model for ANotating Generic Objects

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Abstract

The MANGO model proposes a flexible way to expose data related to astronomical source objects in an interoperable way. It takes into account the huge diversity of source data in terms of feature description, format and usage. The MANGO model attaches identifiers on astronomical sources and associates to each a flexible set of parameters (e.g. observed physical quantities) and other information like e.g. spectra, time series or preview images. Parameters are usually made of several columns of a data table. Additional data products are bound to the source to contribute to the science analysis and enhance data understanding. MANGO object parameters are built upon classes or extended classes of the IVOA Measure and Coordinates data models. It also reuse PhotDM and proposes its own classes for the quantities that are not covered by the imported models Associated data can be simple URLs or VO service endpoints. The roles of both parameters and associated data are qualified by semantic tags

Status of this document

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A list of current IVOA Recommendations and other technical documents can be found at http://www.ivoa.net/documents/.

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Model Name

This model was initially named with a very explicit but hard to remember acronym, `CAB-MSD` standing for Component and Association Based Model for Source Data. We decided later to rename it `MANGO` with reference to the inside out MANGO picture used to introduce the model in Groningen. As the tradition requires that such unexpected names are acronyms, let's assume that `MANGO` stands for Metadata ANnotation for Generic Objects (in astronomy).

Conformance-related definitions

The words “MUST”, “SHALL”, “SHOULD”, “MAY”, “RECOMMENDED”, and “OPTIONAL” (in upper or lower case) used in this document are to be interpreted as described in IETF standard RFC2119 (**?**).

The *Virtual Observatory (VO)* is a general term for a collection of federated resources that can be used to conduct astronomical research, education, and outreach. The International Virtual Observatory Alliance (IVOA) is a global collaboration of separately funded projects to develop standards and infrastructure that enable VO applications.

1 Introduction

Modeling data collected to study astronomical source objects has been a long term concern for the DM working group and more generally for the IVOA. In the past years, there were some proposals to design a global model for sources (Salgado and Lemson et al., 2016) as well as for catalogs (Osuna et al., 2006). Other proposals, more model-agnostic, were focused on the data annotation in VOTables (Demleitner and Ochsenbein et al., 2016) (Derriere, 2016). In this case the goal was no longer to design a source model but to provide a complete description of individual quantities (positions, velocity, fluxes, magnitudes…). None of these proposals have come to completion.

The source DM issue resurfaced at the spring 2018 Interop in Victoria during an hands-on session focusing on the tools available to work with VO data models and especially with VO-DML. The goal of this session was to

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Sorry - your ImageMagick (convert) does not support SVG import. If on Linux, installing librsvg2-bin should remedy this. Otherwise, please commit your SVG and ask the ivoatex creators to do the the conversion.

Figure 1: Architecture diagram for this document

annotate data from different origins in order to make them interoperable with each other. but indeed to the lack of models for sources. One of the main concerns outside de tools necessary to workout this notation was the lack of models for source objects. This is a big paradox in the VO world: source data which represent the basic building blocks of astronomers' work, is not modelled. This paradox can be explained by the fact that the observation of source objects is multi-faceted. In a general way, the way features for source data are described and organised depends on the targeted science case. Principal investigators and archive designers set up the data profile and structure it according to this goal which varies from one project to another. Therefore this diversity cannot be served by a single static data model describing a source item for all possible cases. Having a global source model would lead to a very complex solution not usable in practice.

This standard proposes to overcome this paradox and presents a template model gathering independent components from VO existing models together with VO data products and files embedded on demand in a container. The template supports fine grain association by composing classes as well as coarse grain relations to data products and files distributed within projects archive. MANGO is not designed to describe what a source is but to help clients to discover and to understand the quantities available for a particular source instance. VOtable data mapped on MANGO with Mivot (ref) annotations can be consumed quantity par quantity instead of column per column. The way complex quantities are built is described by MANGO but no longer by the clients.

1.1 Role within the VO Architecture

Fig. 1 shows the role this document plays within the IVOA architecture (Arviset and Gaudet et al., 2010).

2 Representing observed astronomical objects : Use Cases and Requirements

2.1 Use Cases

The following uses-cases have been collected since 2019 from representatives of various astronomical missions, archive designers and tools developers. The contribution was totally open. This gave a good picture of the needs but we do not pretend that everything will be supported by this first version.

All the use-cases summarized below are detailed in appendix.

2.1.1 Gaia

Gaia mission is producing the largest and more precise 3D map of our galaxy.

A non-exhaustive list of properties required for Gaia use cases would be composed of:

- identifier
- sky reference position
- proper motion
- parallax and distance
- source extension
- radial velocity
- redshift
- photometry
- date of detection
- correlation
- multiple detection

2.1.2 Euclid

Euclid telescope has been designed to unveil some of the questions about the dark Universe, including dark matter and dark energy, what would include, e.g. quite accurate measurements of the expansion of the Universe.

- identifier
- sky position
- correlation with other catalogues
- photometry (ground + satellite)
- morphology class
- redshift
- photometric redshift

2.1.3 Exoplanets

Annotation of (exo-)planetary records in catalogues requires some specific metadata or model.

The use cases identified requires the following metadata:

- the degree of confidence in the detection: exoplanets candidates w.r.t. confirmed ones, plus last update of the record content ;
- the method used in the discovery (since it affects the available stellar system description parameters);
- a set of stellar host characteristics (besides sky coordinates): activity, mass, type, metallicity, age, some systemic values, like the global RV (radial velocity) of the system, and so on;
- (exo-)planet parameters, like mass, orbital period, orbit's eccentricity, RV semi-amplitude, time at periastron (for RV detections) or central transit time (for transit method), longitude of periastron, and so on.

2.1.4 Morphologically Complex Structures

The ViaLactea Knowledge Base (VLKB, see Molinaro and Butora et al. (2016)) is a set of data resources and services built up to study the star formation regions and processes in the Milky Way. Besides 2-D images and 3-D radial velocity cubes, the VLKB exposes a bunch of source catalogues. A model that supports description of such catalogues will need a way to describe sources with:

- non-point-like positions;
- extended complex area, possibly as multiple detached areas;
- aggregation of sub-parts (that can be heterogeneous).

2.1.5 Chandra Archive

The Chandra Source Catalog(CSC) is the definitive catalog of serendipitous X-ray sources identified in publicly released imaging observations obtained by NASA's ChandraX-ray Observatory (CXO).

The catalog itself consists of approximately 1,700 columns covering properties at the individual observation and stacked analysis levels. Table 2 summarizes some of the basic catalog properties derived from standard CSCView queries.

2.1.6 Vizier catalog archive

VizieR provides science ready catalogs coming from space agencies or articles and covering number of different science cases. Published data encompass a very large set of measures (position, photometry, redshift, source type, etc.) depending on their origin. They can result from observations, simulations, models or catalog compilations. Individual Vizier tables can contain data all related to one source (e.g. time series of positions or magnitudes) or to a set of sources (one row per source) or a mix of both.

The MANGO model must be able to provide a standard representation of most of the metadata contained in Vizier query responses, whether native or computed by the CDS, simple quantities or associated complex data. MANGO is not meant to replace the current management of the meta-data, it is a way to make those meta-data understandable for a wide panel of VO-compliant clients.

2.1.7 Client on (Mark Taylor behalf)

Right now, the meta-data provided within the VOTable allow clients such Aladin or Topcat to run most of the functionalities expected by the user, either for data analysis of plotting. This information is often guess from UCDs, UTypes or columns name. It can also be given by the user. Clients have no expectations of working with full model instances but in some cases models can help to know how quantities in an input table relate to each other.

In most cases this is for visualisation, e.g.:

- what is the sky position for this row (what columns contain latitude and longitude, and what sky system are they in)

Per Source:
`Source name`
`Source position and position errors`
`Significance of the source (signal to noise)`
`Likelihood of the source (True, False, or Marginal detection)`
`Source extent flag`
`Variability flag`
`Spectral variability flag`
`Fluxes and flux errors in ACIS bands b, h, m, s, u`
`Flux and flux error in HRC band w`
`Hardness ratios and errors for hm, hs, ms colors`
`Short term (intra-obs) variability probability for each band`
`Long term (inter-obs) variability probability for each band`
`Spectral (hardness ratios) variability for each color`
Per Detection (at the stack level):
`Detection ID`
`Detection position and position errors`
`Flux significance of the detection (S/N)`
`Detection likelihood (True, False, or marginal detection?)`
`Source extent code (codification of source extent in different bands)`
`Variability flag`
`Spectral variability flag`
`Fluxes and flux errors in ACIS bands b, h, m, s, u`
`Flux and flux error in HRC band w`
`Hardness ratios and errors for hm, hs, ms colors`
`Short term (intra-obs) variability probability for each band`
`Long term (inter-obs) variability probability for each band`
`Spectral (hardness ratios) variability probability for each color`
Per Detection (at the observation level):
Note that source detection is done at the stack level, but properties are estimated for the detections at each observation using the detection region from the stack level.
`Detection ID`
`Detection position and position errors`
`Flux significance of the detection (S/N)`
`Detection likelihood`
`Source extent code (codification of source extent in different bands)`
`Variability code (applies to intra-obs only)`
`Fluxes and flux errors in ACIS bands b, h, m, s, u`
`Flux and flux error in HRC band w`
`Hardness ratios and errors for hm, hs, ms colors`
`Short term (intra-obs) variability probability for each band`

Table 1: Example Chandra Source Catalog Properties

- what +/-ERR error bars should I plot for these points (what column is a simple error for column A)
- what error ellipses should I plot for these sky positions (what columns provide ra_error, dec_error, ra_dec_corr, or how can I derive those from columns that do exist)
- where do I get the grid information for a column containing a vector of samples so I can label the X axis of a spectrogram (what column or parameter contains an axis vector matching the sample vectors)
- does this table contain sky positions, or HEALPix tiles, or both? What's the best way to represent it on the sky?
- What is the meaning of such URL found out in a table?s

But there are some other places too:

- how do I propagate this sky position to a future epoch (what columns contain pmra, pmdec, and maybe all the associated errors and correlation coefficients)
- what is the error ellipse/oid to use for a sky/Cartesian crossmatch (what columns provide the relevant errors and, if available, correlations)

This usage shows that MANGO must be designed in a way that individual measurements or quantities can be easily be identified as such and manipulated independently of the whole instance.

2.1.8 Xmatch tool

The basic cross-match of two astronomical tables consists in associating pairs of sources – one from each table – fulfilling a given angular distance based criterion. In relational algebra terms, it is a theta-join on a distance predicate.

More generally, a cross-match is the association of sources from different tables given their proximity in an astrometric (but also possibly photometric, statistical, ...) parameter space (Pineau and Derriere et al., 2017) .

If proper motions (plus parallax and radial velocities) are available, the cross-match tool may propagate the positions of each table to a common epoch. It may also take into account positional uncertainties to reject the statistically unlikely associations.

In the latter case (cross-match between two tables taking into account positional errors), the tool needs to be able to retrieve the errors associated to the each position in each table.

UCDs may help in identifying the errors associated to a positional columns as shown in table, but this is not sufficient to table with more complex cases based on multi-parameter cases.

2.2 Requirements

2.2.1 Properties and Associated Data

From the use-cases description, several categories of features must provided or foreseen by the projects:

- The source *properties* astronomers will investigate for their science. They are measures provided as numerical values or classification tags exposed as numbers or simple strings. Usually one measure corresponds to one individual column or one group of columns.

- MANGO objects can be linked to external data referenced by WEB endpoints. Such links are considered as object properties for which the model provides an accurate way to specify the nature of these links. Usually object links are provided by DataLinks services, then this MANGO feature is proposed to annotate datasets issued by services that do not implement such services but provide URLs in their query responses.
- MANGO objects can be linked to other collections of MANGO objects, associating sources with their detections, for example.

2.2.2 Supported Quantities

- MANGO must provide unique source identifiers.
- MANGO must provide information about the source origin.
- The number of parameters attached to a MANGO instance must be free.

2.2.3 Properties

- MANGO must support explicit classes, native or imported from IVOA data-models, for the most used properties.
- MANGO must provide a generic way to support properties that do not enter the above category.
- MANGO object must support multiple instances of the same property class.
- The presence of any property in MANGO instances must be optional.
- MANGO must provide a way to identify the role of each property.
- MANGO must provide a way to purpose of linked properties.
- MANGO must provide a way to describe the meaning of flags or qualifiers.
- The role of each parameter should be machine-readable.
- It must be possible to group parameters in a free way. This allows to tag properties with timestamps or flags.
- MANGO must support references to other MANGO objects.

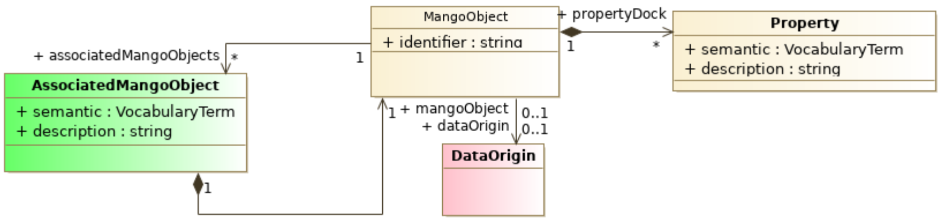

Figure 2: Model overview

3 Model Overview

Sky objects are represented by instances of the class `MANGOObject` which has only one mandatory attribute, an `identifier`. It is recommended the identifiers to be unique within a source collection e.g. a catalog.

In addition to the identifier, `MANGOObject` have 2 components:

- `dataOrigin`: origin of the `MANGOObject`. The structure of this class follows the recommendations of the DCP IG (time of writing).
- `popertyDock`: the place holder for all the `MANGOObject` properties. This is an open-ended collection. Each source property is hooked to the `MANGOObject` by a wrapping class (`Property`) that contains anything necessary to identify both its nature and its role. Properties can be linked together to represent logical parameter sets. These logical sets have no semantic. Their interpretation is in charge of the clients.

3.1 Properties

3.1.1 Parameter Identification

Since the set of properties associated with a particular instance is not defined by the model, MANGO cannot define a specific role for each property. However, the model provides different ways for the client to understand the actual nature of each property:

- **Class type**: often the scientific meaning of the quantity.
- **Semantic**: the semantic tag specifies the exact role of the property by referring to a standard vocabulary. The semantic tag can relate to the property itself or to the set formed by the property and its associated properties. For example, a signal amplitude associated with a time and position can be tagged as a photon event.
- **Description**: free text description.

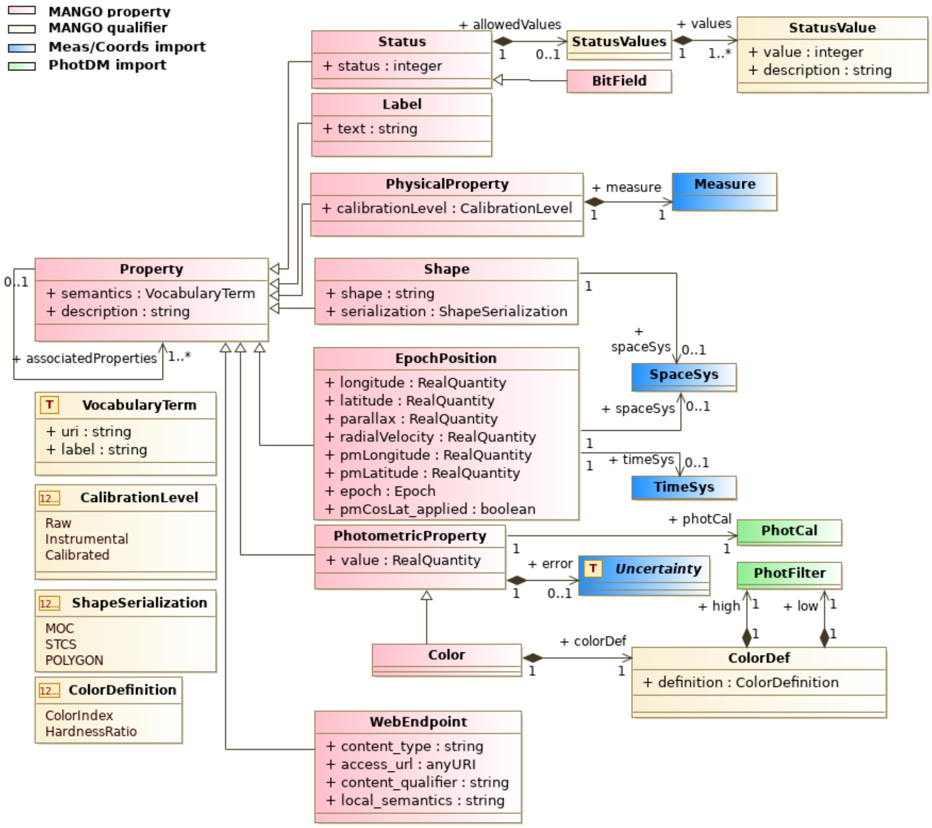

Figure 3: MANGO Properties

In addition to this, some property classes embed qualifiers telling how the quantity must be interpreted (e.g. colour vs hardness ratio)

4 Model: mango

Data model based oon components and data association for source data

4.1 AssociatedMangoObject

Class holder for linking the Mango object to another `MangoObject`.

4.1.1 AssociatedMangoObject.semantic

vodml-id: AssociatedMangoObject.semantic
type: mango:VocabularyTerm
multiplicity: 1
Semantic concept giving the nature of the associated data.

4.1.2 AssociatedMangoObject.description

vodml-id: AssociatedMangoObject.description
type: ivoa:string
multiplicity: 1
Free text description of the associated data

4.1.3 AssociatedMangoObject.mangoObject

vodml-id: AssociatedMangoObject.mangoObject
type: mango:MangoObject
multiplicity: 1
Reference of the associated `MangoObject`.

4.2 BitField

Property state for which each possible value is represented by a bit, so that multiple states can be contained in the same numerical value. The values defined in the related `StatusValues` must correspond to a bit patterns. This constraint is not enforced by the model.

4.3 Color

Property that describes a color of the `MangoObject`. The color is not an intrinsic property of the MANGO object, but a value relative to two filters or energy bands.

4.3.1 Color.colorDef

vodml-id: Color.colorDef
type: mango:ColorDef
multiplicity: 1
Color definition. Can be either a difference of magnitudes or a hardness ratio.

4.4 ColorDef

Class holder for a color definition. This definition includes how the color is calculated (Mag or HR) and the filters on which the color is based. In case of hardness ratio, the energy bands must be modeled as instances of `photdm:PhotFilter` with a flat transfert function.

4.4.1 ColorDef.definition

vodml-id: ColorDef.definition
type: mango:ColorDefinition
multiplicity: 1
Attribute giving the way the color is calculated (Mag or HR).

4.4.2 ColorDef.high

vodml-id: ColorDef.high
type: photdm:PhotFilter
multiplicity: 1
Reference to the `photdm:PhotFilter` corresponding the higher band of the color.

4.4.3 ColorDef.low

vodml-id: ColorDef.low
type: photdm:PhotFilter
multiplicity: 1
Reference to the `photdm:PhotFilter` corresponding the lower band for that color.

4.5 EpochPosition

This class is a view of `Astronomical Coordinates and Coordinate Systems` components that have been put together to form a consistent description of the position of an object moving over time. It consists of a celestial position, a proper motion, a radial velocity and a parallax. All components share the same coordinate systems for both time and space coordinates.

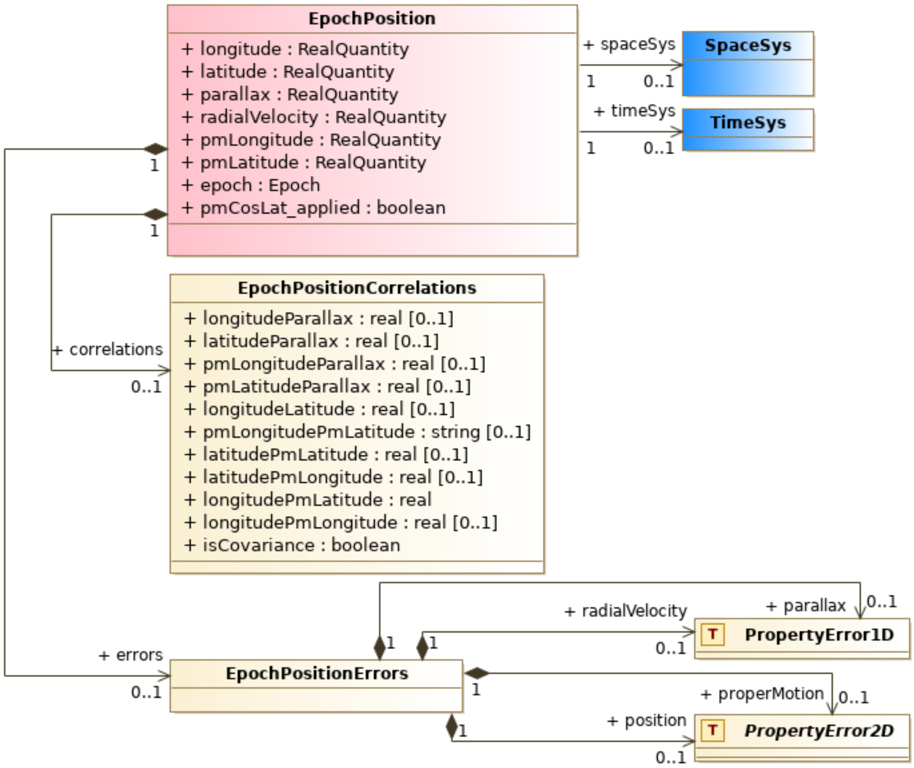

Figure 4: Class EpochPosition

- Both position and proper motion reuse the `coords:LonLatPoint` elements.
- The space coordinate system is imported from `coords:spaceSys`.
- The time coordinate system is imported from `coords:timeSys`.

The `EpochPosition` error is modeled by specific classes supporting covariance and/or correlation between components. All individual components have their own units which must be consistent to each others. This consistency is not enforced by the model.

4.5.1 EpochPosition.longitude

vodml-id: EpochPosition.longitude
type: ivoa:RealQuantity
multiplicity: 1
The longitude of the Point, as a Quantity with angular units (see `coords:LonLatPoint.lon`.

4.5.2 EpochPosition.latitude

vodml-id: EpochPosition.latitude
type: ivoa:RealQuantity
multiplicity: 1
The latitude of the Point, as a Quantity with angular units (see `coords:LonLatPoint.lat`.

4.5.3 EpochPosition.parallax

vodml-id: EpochPosition.parallax
type: ivoa:RealQuantity
multiplicity: 1
The measured parallax in the coordinate system of the `EpochPosition` instance.

4.5.4 EpochPosition.radialVelocity

vodml-id: EpochPosition.radialVelocity
type: ivoa:RealQuantity
multiplicity: 1
The measured Velocity along of the radius axis (see `meas:Velocity.coord`).

4.5.5 EpochPosition.pmLongitude

vodml-id: EpochPosition.pmLongitude
type: ivoa:RealQuantity
multiplicity: 1
Velocity along the longitude axis in angular distance per unit time (see `meas:ProperMotion.coord`). The current version of the model only allows a representation in the Polar coordinate space.

4.5.6 EpochPosition.pmLatitude

vodml-id: EpochPosition.pmLatitude
type: ivoa:RealQuantity
multiplicity: 1
Velocity along the latitude axis in angular distance per unit time (see `meas:ProperMotion.coord`). The current version of the model only allows a representation in the Polar coordinate space.

4.5.7 EpochPosition.epoch

vodml-id: EpochPosition.epoch
type: coords:Epoch

multiplicity: 1
Position epoch expressed within the common time system (see `coords:epoch`)

4.5.8 EpochPosition.pmCosLat_applied

vodml-id: EpochPosition.pmCosLat_applied
type: ivoa:boolean
multiplicity: 1
It is common, though not universal, practice to quote longitudinal proper motion pre-multiplied by cos(latitude) so that the magnitude of the quantity is not affected by its longitudinal position. We do not constrain the value to one form or the other in this model. Instead, this flag enables providers to convey whether or not the factor has been applied (see `meas:ProperMotion.cosLat_applied`)

4.5.9 EpochPosition.errors

vodml-id: EpochPosition.errors
type: mango:EpochPositionErrors
multiplicity: 0..1
Reference to the combined errors of the `EpochPosition` components.

4.5.10 EpochPosition.correlations

vodml-id: EpochPosition.correlations
type: mango:EpochPositionCorrelations
multiplicity: 0..1
Reference to the correlations between the `EpochPosition` components.

4.5.11 EpochPosition.spaceSys

vodml-id: EpochPosition.spaceSys
type: coords:SpaceSys
multiplicity: 0..1
System that applies the space coordinates.

4.5.12 EpochPosition.timeSys

vodml-id: EpochPosition.timeSys
type: coords:TimeSys
multiplicity: 0..1
System that applies the time coordinates (the epoch).

4.6 EpochPositionCorrelations

Class holder for the correlation coefficients between the `EpochPosition` components.

4.6.1 EpochPositionCorrelations.longitudeParallax

vodml-id: EpochPositionCorrelations.longitudeParallax
type: ivoa:real
multiplicity: 0..1
Correlation (or covariance) coefficient between the position longitude and the parallax

4.6.2 EpochPositionCorrelations.latitudeParallax

vodml-id: EpochPositionCorrelations.latitudeParallax
type: ivoa:real
multiplicity: 0..1
Correlation (or covariance) coefficient between the position latitude and the parallax

4.6.3 EpochPositionCorrelations.pmLongitudeParallax

vodml-id: EpochPositionCorrelations.pmLongitudeParallax
type: ivoa:real
multiplicity: 0..1
Correlation (or covariance) coefficient between the proper motion longitude and the parallax

4.6.4 EpochPositionCorrelations.pmLatitudeParallax

vodml-id: EpochPositionCorrelations.pmLatitudeParallax
type: ivoa:real
multiplicity: 0..1
Correlation (or covariance) coefficient between the proper motion latitude and the parallax

4.6.5 EpochPositionCorrelations.longitudeLatitude

vodml-id: EpochPositionCorrelations.longitudeLatitude
type: ivoa:real
multiplicity: 0..1
Correlation (or covariance) coefficient between the position longitude and the position latitude

4.6.6 EpochPositionCorrelations.pmLongitudePmLatitude

vodml-id: EpochPositionCorrelations.pmLongitudePmLatitude
type:
multiplicity: 0..1
Correlation (or covariance) coefficient between the proper motion longitude and the proper motion latitude

4.6.7 EpochPositionCorrelations.latitudePmLatitude

vodml-id: EpochPositionCorrelations.latitudePmLatitude
type: ivoa:real
multiplicity: 0..1
Correlation (or covariance) coefficient between the position latitude and the proper motion latitude

4.6.8 EpochPositionCorrelations.latitudePmLongitude

vodml-id: EpochPositionCorrelations.latitudePmLongitude
type: ivoa:real
multiplicity: 0..1
Correlation (or covariance) coefficient between the position latitude and the proper motion longitude

4.6.9 EpochPositionCorrelations.longitudePmLatitude

vodml-id: EpochPositionCorrelations.longitudePmLatitude
type: ivoa:real
multiplicity: 1
Correlation (or covariance) coefficient between the position longitude and the proper motion latitude

4.6.10 EpochPositionCorrelations.longitudePmLongitude

vodml-id: EpochPositionCorrelations.longitudePmLongitude
type: ivoa:real
multiplicity: 0..1
Correlation (or covariance) coefficient between the position longitude and the proper motion longitude

4.6.11 EpochPositionCorrelations.isCovariance

vodml-id: EpochPositionCorrelations.isCovariance
type: ivoa:boolean
multiplicity: 1

Boolean telling whether the correlations must be interpreted as covariance or as correlation coefficients.

4.7 EpochPositionErrors

Class holder for the errors of the EpochPosition attributes

4.7.1 EpochPositionErrors.parallax

vodml-id: EpochPositionErrors.parallax
type: mango:error.PropertyError1D
multiplicity: 0..1
Parallax error. This error is meant to be symmetrical

4.7.2 EpochPositionErrors.radialVelocity

vodml-id: EpochPositionErrors.radialVelocity
type: mango:error.PropertyError1D
multiplicity: 0..1
Error in the radial velocity. This error is meant to be symmetrical

4.7.3 EpochPositionErrors.position

vodml-id: EpochPositionErrors.position
type: mango:error.PropertyError2D
multiplicity: 0..1
Position error; can be an ellipse, a correlation matrix or a covariance matrix.

4.7.4 EpochPositionErrors.properMotion

vodml-id: EpochPositionErrors.properMotion
type: mango:error.PropertyError2D
multiplicity: 0..1
Position error; can be an ellipse, a correlation matrix or a covariance matrix.

4.8 Label

Free text label seen as a MANGO object property.

4.8.1 Label.text

vodml-id: Label.text
type: ivoa:string
multiplicity: 1
Text of label property of the MANGO object.

4.9 MangoObject

Central model class: applied to a data table, each row can be modelled as a MangoObject instance. Each MangoObject hosts a collection of physical or calculated parameters, a collection of associated data, a description of the data origin and an identifier.

4.9.1 MangoObject.identifier

vodml-id: MangoObject.identifier
type: ivoa:string
multiplicity: 1
Unique identifier of the `MangoObject`. The uniqueness of that identifier is not managed by the model. The format is free.

4.9.2 MangoObject.propertyDock

vodml-id: MangoObject.propertyDock
type: mango:Property
multiplicity: 0..*
Reference to the open-ended collection of the `MangoObject` properties (physical or calculated).

4.9.3 MangoObject.dataOrigin

vodml-id: MangoObject.dataOrigin
type: mango:dataorigin.DataOrigin
multiplicity: 0..1
Reference to the description of the origin of the `MangoObject`.

4.9.4 MangoObject.associatedMangoObjects

vodml-id: MangoObject.associatedMangoObjects
type: mango:AssociatedMangoObject
multiplicity: 0..*
Abstract reference to a particular dataset associated to the MANGO entity. This class is used to specify the type of the associated dataset as well as its role.

4.10 PhotometricProperty

Observed brightness of the `MangoObject`. The distinction between fluxes and magnitudes is made by the unit. This property should refer to a photometric calibration as defined by the `PhotDM` model.

4.10.1 PhotometricProperty.value

vodml-id: PhotometricProperty.value
type: ivoa:RealQuantity
multiplicity: 1
Value of the photometric property associated with a photometric calibration as defined by the `PhotDM` model.

4.10.2 PhotometricProperty.error

vodml-id: PhotometricProperty.error
type: meas:Uncertainty
multiplicity: 0..1
Error on the `PhotometricProperty`, imported from `meas:Uncertainty`.

4.10.3 PhotometricProperty.photCal

vodml-id: PhotometricProperty.photCal
type: photdm:PhotCal
multiplicity: 1
Photometric calibration that applies to the photometric property. It must be an instance of `photdm:PhotCal`.

4.11 PhysicalProperty

Place holder for any quantity that can be hold by measure as defined in the `Astronomical Measurements Model`.

4.11.1 PhysicalProperty.calibrationLevel

vodml-id: PhysicalProperty.calibrationLevel
type: mango:CalibrationLevel
multiplicity: 1
Calibration level of the property (ObsCore).

4.11.2 PhysicalProperty.measure

vodml-id: PhysicalProperty.measure
type: meas:Measure
multiplicity: 1
Instance of `Astronomical Measurements Model` that holds the Property value(s).

4.12 Property

Class holder for a particular property, either physical or calculated, of the MANGO object. This class specifies both type and role of the property, and hosts the property instance itself.

constraint

detail: Property.One association at the time

4.12.1 Property.semantics

vodml-id: Property.semantics
type: mango:VocabularyTerm
multiplicity: 1
Reference to a semantic concept giving the nature of the parameter As long as the vocabulary is not set, the possible values of this attribute are given by the ParamSemantic enumeration.

4.12.2 Property.description

vodml-id: Property.description
type: ivoa:string
multiplicity: 1
Free text description of the property or of the set made of the property and its associated properties.

4.12.3 Property.associatedProperties

vodml-id: Property.associatedProperties
type: mango:Property
multiplicity: 1..*
Open-ended collection of MANGO properties associated with the `MangoObject`. These relationships are typically used to associate physical properties with time stamps and/or quality factors.

4.13 Shape

Description of the spatial extension of the MANGO object (for e.g. dust clouds).

4.13.1 Shape.shape

vodml-id: Shape.shape
type: ivoa:string

multiplicity: 1
String serialization of the spatial extension of the `MangoObject`.

4.13.2 Shape.serialization

vodml-id: Shape.serialization
type: mango:ShapeSerialization
multiplicity: 1
Serialization mode of the spatial extension of the MANGO entity.

4.13.3 Shape.spaceSys

vodml-id: Shape.spaceSys
type: coords:SpaceSys
multiplicity: 0..1
Coordinate system that applies for the shape.

4.14 Status

Property representing a status defined by a integer number that can only take on a defined number of values, each with its own description. Boolean status can be represented by `StatusValues` with 2 values e.g. 0 for False and 1 for True.

4.14.1 Status.status

vodml-id: Status.status
type: ivoa:integer
multiplicity: 1
Actual value of the status.

4.14.2 Status.allowedValues

vodml-id: Status.allowedValues
type: mango:StatusValues
multiplicity: 0..1
List of the allowed values for the status. Each value has its own free text description.

4.15 StatusValue

Value allowed for a status, contain the value with a free text description.

4.15.1 StatusValue.value

vodml-id: StatusValue.value
type: ivoa:integer
multiplicity: 1
Allowed value for a `Status`

4.15.2 StatusValue.description

vodml-id: StatusValue.description
type: ivoa:string
multiplicity: 1
Free text description on the allowed value for a `Status`

4.16 StatusValues

Class holder for the list of the allowed values for the status.

4.16.1 StatusValues.values

vodml-id: StatusValues.values
type: mango:StatusValue
multiplicity: 1..*
List of the allowed values for the status. Each value has its own textual description.

4.17 VocabularyTerm

Class holder for a term of a standardized vocabulary that applies to a property.

4.17.1 VocabularyTerm.uri

vodml-id: VocabularyTerm.uri
type: ivoa:string
multiplicity: 1
URI the vocabulary term.

4.17.2 VocabularyTerm.label

vodml-id: VocabularyTerm.label
type: ivoa:string
multiplicity: 1
Label attached to the vocabulary term. This is necessary because the URI may not contain any explicit label. This was the case for the IUA vocabulary until the Registry WG introduced rewriting rules that fix the issue.

4.18 WebEndpoint

Associated data referenced by an URL.

4.18.1 WebEndpoint.content_type

vodml-id: WebEndpoint.content_type
type: ivoa:string
multiplicity: 1
Mime type of the URL

4.18.2 WebEndpoint.access_url

vodml-id: WebEndpoint.access_url
type: ivoa:anyURI
multiplicity: 1
Web endpoint

4.18.3 WebEndpoint.content_qualifier

vodml-id: WebEndpoint.content_qualifier
type: ivoa:string
multiplicity: 1
TODO : Missing description : please, update your UML model asap.

4.18.4 WebEndpoint.local_semantics

vodml-id: WebEndpoint.local_semantics
type: ivoa:string
multiplicity: 1
TODO : Missing description : please, update your UML model asap.

4.19 ShapeFrame

Possible schemes to encode a shape in a string
Enumeration Literals

STC_S : **vodml-id:** ShapeFrame.STC_S
description: MOC serialization

MOC : **vodml-id:** ShapeFrame.MOC
description: STCs serialization

4.20 ShapeSerialization

Enumeration of the supported serialization modes for the shapes
Enumeration Literals

MOC : **vodml-id:** ShapeSerialization.MOC
description: Label indicating that the shape has been serialized as a S-MOC

STCS : **vodml-id:** ShapeSerialization.STCS
description: Label indicating that the shape has been serialized as a STCS string

POLYGON : **vodml-id:** ShapeSerialization.POLYGON
description: Label indicating that the shape has been serialized as a polygon (cf xtypes)

4.21 CalibrationLevel

Enumeration of different possible calibration status of the property (Obscore)
Enumeration Literals

Raw : **vodml-id:** CalibrationLevel.Raw
description: Raw instrumental data, in a proprietary or internal data provider defined format, that needs instrument specific tools to be handled (ObsCore)

Instrumental : **vodml-id:** CalibrationLevel.Instrumental
description: Instrumental data in a standard format which could be manipulated with standard astronomical packages (ObsCore).

Calibrated : **vodml-id:** CalibrationLevel.Calibrated
description: Science ready data with the instrument signature removed (ObsCore)

4.22 ColorDefinition

Enumeration of the different types of colors supported by the model.
Enumeration Literals

ColorIndex : **vodml-id:** ColorDefinition.ColorIndex
description: Difference of magnitudes: typically $M_B - M_v$

HardnessRatio : **vodml-id:** ColorDefinition.HardnessRatio
description: Normalized ratio of fluxes: $(F_{EB2} - F_{EB1})/(F_{EB2} + F_{EB1})$

5 Package: error

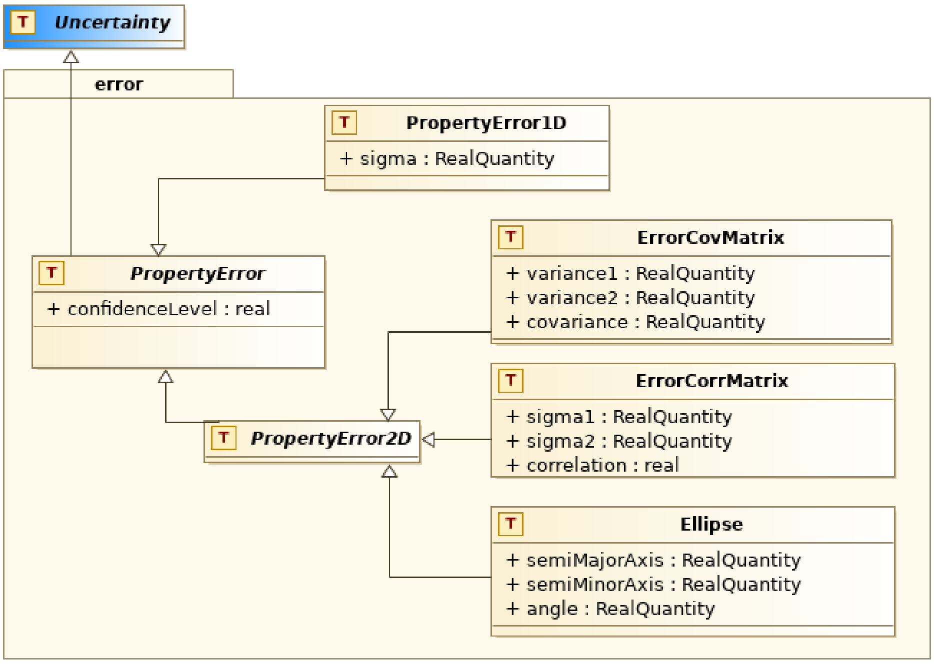

Figure 5: package error

The `error` package groups the MANGO built-in error classes. All these classes are derived from `meas:Uncertainty` to make them reusable by `meas:Measure` instances. Mango errors all have an attribute that specifies the confidence level

5.1 Ellipse

Elliptic error for 2D parameters such as sky positions. Major axis and minor axis have their own units, which must be the same for both. This is not enforced by the model.

5.1.1 Ellipse.semiMajorAxis

vodml-id: error.Ellipse.semiMajorAxis
type: ivoa:RealQuantity
multiplicity: 1
Half of the ellipse major axis

5.1.2 Ellipse.semiMinorAxis

vodml-id: error.Ellipse.semiMinorAxis
type: ivoa:RealQuantity
multiplicity: 1
Half of the ellipse minor axis

5.1.3 Ellipse.angle

vodml-id: error.Ellipse.angle
type: ivoa:RealQuantity
multiplicity: 1
Angle between the North Polar Cape (NCP) and the major axis. This angle must be positive taking into account that angles are positive from North to the East. The angle has its own unit.

5.2 ErrorCorrMatrix

Correlation matrix for the error of a 2D quantities. The correlation matrix is symmetrical.

5.2.1 ErrorCorrMatrix.sigma1

vodml-id: error.ErrorCorrMatrix.sigma1
type: ivoa:RealQuantity
multiplicity: 1
Error on the first dimension (right ascension in case of sky coordinates)

5.2.2 ErrorCorrMatrix.sigma2

vodml-id: error.ErrorCorrMatrix.sigma2
type: ivoa:RealQuantity
multiplicity: 1
Error on the second dimension (declination in case of sky coordinates)

5.2.3 ErrorCorrMatrix.correlation

vodml-id: error.ErrorCorrMatrix.correlation
type: ivoa:real
multiplicity: 1
Correlation coefficient between the 2 axis

5.3 ErrorCovMatrix

Covariance matrix for the error of a 2D quantities. The covariance matrix is symmetrical.

5.3.1 ErrorCovMatrix.variance1

vodml-id: error.ErrorCovMatrix.variance1
type: ivoa:RealQuantity
multiplicity: 1
Variance of the first dimension (right ascension in case of sky coordinates)

5.3.2 ErrorCovMatrix.variance2

vodml-id: error.ErrorCovMatrix.variance2
type: ivoa:RealQuantity
multiplicity: 1
Variance of the second dimension (declination in case of sky coordinates)

5.3.3 ErrorCovMatrix.covariance

vodml-id: error.ErrorCovMatrix.covariance
type: ivoa:RealQuantity
multiplicity: 1
Covariance of the 2 axis

5.4 PropertyError (Abstract)

Root (abstract) class of the errors that can be attached to a MANGO property. The class inherits from `meas:uncertainty` in order to be usable in the context of properties based on `Measures` classes.

5.4.1 PropertyError.confidenceLevel

vodml-id: error.PropertyError.confidenceLevel
type: ivoa:real
multiplicity: 1
Confidence level of the error. The confidence level must be in $[0, 1]$ (not enforced by the VO-DML schema).

5.5 PropertyError1D

Symetrical error for 1D parameters

5.5.1 PropertyError1D.sigma

vodml-id: error.PropertyError1D.sigma
type: ivoa:RealQuantity
multiplicity: 1
Magnitude of error on a one-dimensional parameter

5.6 PropertyError2D (Abstract)

Super (abstract) class for all errors of 2D parameters

6 Package: dataorigin

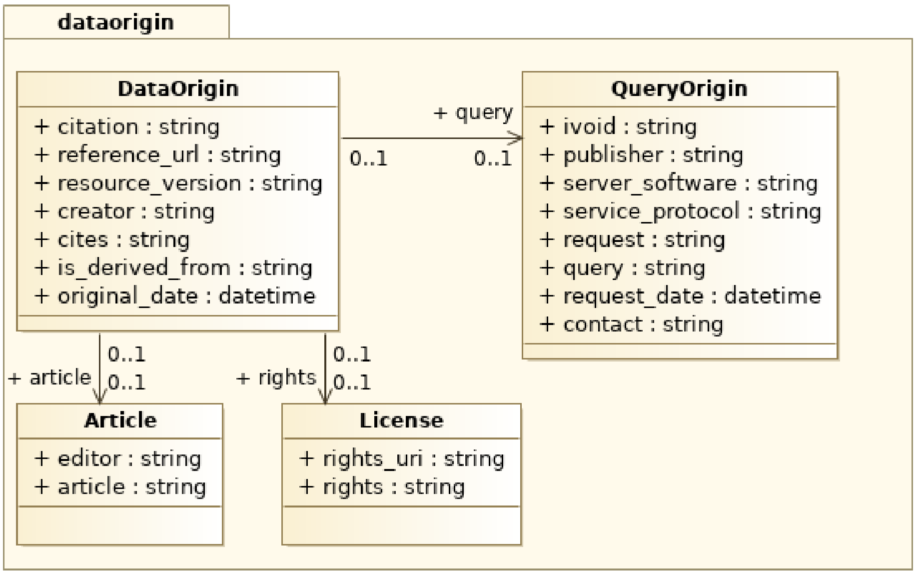

Figure 6: package dataorigin

Package grouping together all the components needed to model the origin of `MangoObject`.

6.1 Article

Reference article for the MANGO entity

6.1.1 Article.editor

vodml-id: dataorigin.Article.editor
type: ivoa:string
multiplicity: 1
Editor name (article)

6.1.2 Article.article

vodml-id: dataorigin.Article.article
type: ivoa:string
multiplicity: 1
Bibcode or DOI of the reference article

6.2 DataOrigin

Class representing the origin of the data following the DCP note (TBD)

6.2.1 DataOrigin.citation

vodml-id: dataorigin.DataOrigin.citation
type: ivoa:string
multiplicity: 1
Dataset identifier that can be used for citation (e.g. DOI)

6.2.2 DataOrigin.reference_url

vodml-id: dataorigin.DataOrigin.reference_url
type: ivoa:string
multiplicity: 1
Dataset landing page

6.2.3 DataOrigin.resource_version

vodml-id: dataorigin.DataOrigin.resource_version
type: ivoa:string
multiplicity: 1
Dataset version

6.2.4 DataOrigin.creator

vodml-id: dataorigin.DataOrigin.creator
type: ivoa:string
multiplicity: 1
Person(s) mainly involved in the creation of the resource, generally the author

6.2.5 DataOrigin.cites

vodml-id: dataorigin.DataOrigin.cites
type: ivoa:string
multiplicity: 1
Identifier (IVOID, DOI or Bibcode) of a second Resource using relation of type `cites` (`https://www.ivoa.net/rdf/voresource/relationship_type/`)

6.2.6 DataOrigin.is_derived_from

vodml-id: dataorigin.DataOrigin.is_derived_from
type: ivoa:string
multiplicity: 1
Identifier (IVOID, DOI or Bibcode) of a second resource using relation of type `is_derived_from` (`https://www.ivoa.net/rdf/voresource/relationship_type/`)

6.2.7 DataOrigin.original_date

vodml-id: dataorigin.DataOrigin.original_date
type: ivoa:datetime
multiplicity: 1
Date of the original resource from which the MANGO object is derived

6.2.8 DataOrigin.query

vodml-id: dataorigin.DataOrigin.query
type: mango:dataorigin.QueryOrigin
multiplicity: 0..1
Description of the request from which the data originates.

6.2.9 DataOrigin.rights

vodml-id: dataorigin.DataOrigin.rights
type: mango:dataorigin.License
multiplicity: 0..1
Reference to the rights that apply to the data.

6.2.10 DataOrigin.article

vodml-id: dataorigin.DataOrigin.article
type: mango:dataorigin.Article
multiplicity: 0..1
Reference to the article from which the data originates.

6.3 License

Place holder for the license covering the MANGO instance

6.3.1 License.rights_uri

vodml-id: dataorigin.License.rights_uri
type: ivoa:string
multiplicity: 1
Licence URI. Following Registry practice, this should come from SPDX https://spdx.org/licenses/, though Creative Commons URLs https://creativecommons.org are also admitted.

6.3.2 License.rights

vodml-id: dataorigin.License.rights
type: ivoa:string
multiplicity: 1
License or Copyright text

6.4 QueryOrigin

Description of the query the MANGO instance results from.

6.4.1 QueryOrigin.ivoid

vodml-id: dataorigin.QueryOrigin.ivoid
type: ivoa:string
multiplicity: 1
IVOID of the underlying data collection

6.4.2 QueryOrigin.publisher

vodml-id: dataorigin.QueryOrigin.publisher
type: ivoa:string
multiplicity: 1
Data center that produced the MANGO instance

6.4.3 QueryOrigin.server_software

vodml-id: dataorigin.QueryOrigin.server_software
type: ivoa:string
multiplicity: 1
Version of the software the produced the MANGO object instance. It is encouraged to follow `https://ivoa.net/documents/Notes/softid/index.html`.

6.4.4 QueryOrigin.service_protocol

vodml-id: dataorigin.QueryOrigin.service_protocol
type: ivoa:string
multiplicity: 1
IVOID of the protocol through which the data was retrieved

6.4.5 QueryOrigin.request

vodml-id: dataorigin.QueryOrigin.request
type: ivoa:string
multiplicity: 1
Full request URL including a query string. For the simple protocols,put the url-encoded form of the query parameters. For TAP queries, use the /sync UWS URL. The format is free for others request types.

6.4.6 QueryOrigin.query

vodml-id: dataorigin.QueryOrigin.query
type: ivoa:string
multiplicity: 1
Input query in a formal langage such as ADQL.equest types

6.4.7 QueryOrigin.request_date

vodml-id: dataorigin.QueryOrigin.request_date
type: ivoa:datetime
multiplicity: 1
Query execution date

6.4.8 QueryOrigin.contact

vodml-id: dataorigin.QueryOrigin.contact
type: ivoa:string
multiplicity: 1
Email or URL to contact the publisher

TODO:
must be updated and simplified

7 TAP and MANGO

This not normative section gives possible tips to save and discover MANGO instances in TAP services. We suppose that the TAP service hosts catalogs which sources are MANGO instances. These catalogs are named *MANGO Catalogs*.

7.1 Storing MANGO Catalogs in TAP

For now, this section only concerns the properties. The associated data will be taken into account later.

- One master table for the catalogs with various meta-data out of the MANGO scope plus a unique identifier (primary key).
- One master sources table for the source instances with the catalog identifier and a primary key safer than the MANGO identifier.
- One table for each supported parameter with a foreign key for the join with the master source table.

Although the model of the measures is hierarchical, it should be possible to flatten them in one single table considering that the model structure can be retrieved with the TAP_SCHEMA annotations (TBC)

This schema requires the server to explore all the parameter tables to retrieve whole MANGO instances. This process can be speed up by using the *MANGOCore* table.

7.2 *MANGOCore* Table

The discovery of *MANGO Catalogs* can be helped by a *MANGOCore* table located in the *schema* schema. As MANGO is not dedicated to any specific domain, we cannot define a set of core parameters, but parameters can be flagged as *Core Parameter*. This selection is left at the discretion of the curator. The *MANGOCore* table has set of columns per parameter class plus one for the catalog ID. It has one row per stored catalog. Each parameter has at least 2 columns: one with the UCD and one with the *Core* flag. TBC

A Gaia

Gaia mission is producing the largest and more precise 3D map of our galaxy.

Gaia core solution is able to solve the astrometric solution of more than 1 billion sources by complex models and algorithms (Lindegren and Lammers et al., 2012). Using a minimisation problem approach, different detections identified on different scans can be associated to the same astronomical source. Some of the properties would be direct measurements on single scans (e.g. positions or magnitudes). Also other properties like radial velocity (measured in redshift units) are also obtained at integration time of the scans.

Once detections on different scans are associated to a single astronomical source, these direct measurements can be combined to generate derived measurements. Trajectories on the sky for galactic objects are seen as spirals including the combination of the proper motion of the object (derived by the main vector of movement of the source) and the parallax (derived by the radius of the apparent spiral produced by the different angles of the Gaia observations at different periods).

From these properties, others could be also derived like, e.g. the distance, although the exact transformation from parallax to distance requires the use of accurate calculations and calibrations so, in general, only direct astrometric properties, like parallax, are usually provided into the catalogues.

Finally, other properties will be also obtained by the cross-identification of detections as a single astronomical source. For example, time series could be combined as the result of measurements of magnitudes from different scans detections.

Although it is not its main scientific target and apart from stellar objects, other extra-galactic sources could be also studied with Gaia. For example, QSOs are observed by Gaia as point-like sources with zero proper motion. For these kind of sources, typical extra-galactic properties like, redshift, could be also provided.

A non-exhaustive list of properties required for Gaia use cases would be composed of:

- identifier
- sky reference position
- proper motion
- parallax and distance
- source extension
- radial velocity
- redshift
- photometry
- date of detection
- correlation
- multiple detection

B Euclid

Euclid telescope has been designed to unveil some of the questions about the dark Universe, including dark matter and dark energy, what would include, e.g. quite accurate measurements of the expansion of the Universe.

Euclid will mainly observe extragalactic objects providing, e.g. information of the shapes of galaxies, gravitational lensing, baryon acoustic oscillations and distances to galaxies using spectroscopic data.

For this mission, and apart from the common metadata provided for extra galactic sources into astronomical catalogues, a good support for object taxonomy and shapes of objects will be required. As known due to general relativity effects, shapes far galaxies could be deformed due to gravitational lensing effects, producing convergence (visual displacements on the position) and rear (deformation of the shape) effects. All these metadata should be ready for annotations and, also, correlated to theoretical or real metadata in other datasets.

Finally, crossmatch information with other catalogues will be of crucial interest as data from other satellites and, more importantly, from ground based observatories will be combined with Euclid data to produce consistent scientific datasets.

A non-exhaustive list of properties required for Euclid use cases would be composed of:

- identifier
- sky position
- correlation with other catalogues
- photometry (ground + satellite)
- morphology class
- redshift
- photometric redshift

C Chandra Archive

The Chandra Source Catalog(CSC) is the definitive catalog of serendipitous X-ray sources identified in publicly released imaging observations obtained by NASA's ChandraX-ray Observatory (CXO). The CSC is developed and published by the ChandraX-ray Center (CXC) and is supported by NASA contract NAS 8-3060 to the Smithsonian Astrophysical Observatory for operation of the CXC. CSC Release 2.0 (Oct. 2019) includes properties for approximately 316,000 X-ray sources on the sky extracted from about 375,000 detections.

The catalog itself consists of approximately 1,700 columns covering properites at the individual observation and stacked analysis levels. Table 2 summarizes some of the basic catalog properties derived from standard CSCView queries.

Per Source:
`Source name`
`Source position and position errors`
`Significance of the source (signal to noise)`
`Likelihood of the source (True, False, or Marginal detection)`
`Source extent flag`
`Variability flag`
`Spectral variability flag`
`Fluxes and flux errors in ACIS bands b, h, m, s, u`
`Flux and flux error in HRC band w`
`Hardness ratios and errors for hm, hs, ms colors`
`Short term (intra-obs) variability probability for each band`
`Long term (inter-obs) variability probability for each band`
`Spectral (hardness ratios) variability for each color`
Per Detection (at the stack level):
`Detection ID`
`Detection position and position errors`
`Flux significance of the detection (S/N)`
`Detection likelihood (True, False, or marginal detection?)`
`Source extent code (codification of source extent in different bands)`
`Variability flag`
`Spectral variability flag`
`Fluxes and flux errors in ACIS bands b, h, m, s, u`
`Flux and flux error in HRC band w`
`Hardness ratios and errors for hm, hs, ms colors`
`Short term (intra-obs) variability probability for each band`
`Long term (inter-obs) variability probability for each band`
`Spectral (hardness ratios) variability probability for each color`
Per Detection (at the observation level):
Note that source detection is done at the stack level, but properties are estimated for the detections at each observation using the detection region from the stack level.
`Detection ID`
`Detection position and position errors`
`Flux significance of the detection (S/N)`
`Detection likelihood`
`Source extent code (codification of source extent in different bands)`
`Variability code (applies to intra-obs only)`
`Fluxes and flux errors in ACIS bands b, h, m, s, u`
`Flux and flux error in HRC band w`
`Hardness ratios and errors for hm, hs, ms colors`
`Short term (intra-obs) variability probability for each band`

Table 2: Example Chandra Source Catalog Properties

The following are some example usage threads which can be facilitated by this model. We provide a high-level summary here described in generic terms. For each case, we are generating detailed threads describing how each would be implemented using the Chandra Source Catalog.

Note: Most of these cases have been simplified to a level appropriate for this version of the model. More complete and accurate science threads could be defined using more complex types and associations which are out of the the current scope.

1. Searching for spectrally variable or flaring point sources:

    - Identifying spectrally variable point sources

        (a) From a catalog, identify a set of point sources with multiple spectrally-resolved observations

            - Sources are classified as point sources or have a source extent that is consistent with being a point source
            - Observations include detection properties in at least two user-specified wavebands
            - There are multiple observations associated with the source
            - If the catalog differentiates between detections and sources, each included detection must be uniquely associated with the source

        (b) From the set identified in (a), identify the subset of sources with significant spectral variability between observations

            - If the catalog includes hardness ratios in the user-specified wavebands, then identify sources with hardness ratios that vary by more than a user-specified confidence limit between observations
            - If the catalog does not include hardness ratios in the user-specified wavebands, then extract individual observation fluxes and associated confidence limits from the catalog and construct hardness ratios and associated confidence limits for each of the observations and then compare with the user-specified confidence limit
            - If hardness ratios and/or fluxes are computed using multiple methods, allow the user to specify which properties to use
            - If measurement probability density functions are provided rather than confidence intervals, allow those to be used instead

    - Identifying flaring point sources

        (a) From a catalog, identify a set of point sources

            - Sources are classified as point sources or have a source extent that is consistent with being a point source
            - If the catalog differentiates between detections and sources, each included detection must be uniquely associated with the source

(b) From the set identified in (a), identify the subset of sources with intra-observation variability greater than a user-specified amount in any waveband

(c) From the set identified in (b), extract the intra-observation lightcurves and associated confidence intervals

  – Apply a user-specified matched filter to the lightcurve and confidence information to search for flares

2. Find sources with changing properties:
Look for sources with changes of spectral slope and column density between observations so as function of time; this can easily be done across X-ray catalogs provided that the same spectral model (absorbed power-law) is used in the different catalogs. The changes in spectral slope and column density are measured in sigma using the errors as well on each quantity to evaluate the statistical significance of the changes.

   Properties needed:

   - time of observation
   - spectral parameters and their errors
   - measure of the quality of the spectral fit

   Procedure:
   For each source..

   (a) retrieve all available spectral properties as function of time
   (b) compare the properties
   (c) select sources with extreme changes (3 sigma difference with respect to the average)

3. Building a lgN-lgS:
Source number counts are really important for comparison with population synthesis models. Moreover, number counts tell us the total resolved fraction of the CXB for comparison between different catalogs.
Properties needed:

   - Fluxes computed in a homegeneous way by all the different catalogs and reported in the same band.
   (e.g. flux in the same 90% PSF fraction for each telescope and computed with the same spectral model)

   Procedure:
   For each source..

   (a) retrieve the fluxes and compute the lgN-lgS given the catalog sensitivity

(b) compare between telescopes, only possible if fluxes are computed with the same assumptions for sources in different X-ray telescopes.

4. Finding Tidal Disruption Events in the CSC:
Tidal Disruption Events (TDEs) happen when a star falls into the tidal radius of a super-massive black hole and gets disrupted by the ensuing forces exerted. Non-thermal X-ray emission is produced from a relativistic jet associated with the accretion, but thermal X-ray emission is also generated in the inner part of the accretion disk formed from the stellar debris. The transition between non-thermal and thermal emission results in an outburst that is spectrally soft during the luminosity peak, and stays soft in timescales of several years as their X-ray luminosity decreases. In order to spot these objects, we need to look at how the hardness ratios change over time.
Properties needed:

   - A measurement of the time-dependent fluxes of the source in different bands (for example hard, medium and soft energy bands), for all epochs in which the source is observed. Source model should either provide access to band-specific fluxes and flux errors for each epoch the source was observed, or to measurements of the hardness ratios (colors) for the different epochs, with associated errors.
   - If only the per-epoch flux measurements are available, the hardness ratio variability can be estimated probabilistically as a likelihood ratio test between the null hypothesis of constant hardness ratios vs variable hardness ratios. In this case, the hardness ratio probability density function (or confidence interval) should first be estimated from the confidence intervals of the fluxes, and then the confidence intervals derived for the hardness ratios are confronted with two hypotheses: one in which all hardness ratios measured for a source are consistent with a single true value, and one in which the true value is allowed to vary.

   Procedure:
   The following procedure assumes that the X-ray catalog measures fluxes and hardness ratios in at least two bands, a hard band, and a soft band. With a broad band flux we refer to the band that encompasses the majority of valid photon detections, i.e., those falling in an energy window with good nominal quantum efficiencies and effective areas. For Chandra, this is within 0.5 and 7.0 keV.

   (a) From an X-ray catalog, identify all extra-galactic ($|b|>5$) sources that have measured long-term spectral variability, i.e., sources should be detected in more than one observation, and in these observations the hardness ratios between at least two bands should be different at a significant level. In CSC2 for example, this means var_inter_hard_flag should be set. Alternatively, if no variability flag is available, the spectral variability probability should be larger than 0.5.

- Sources need to be detected at a significance larger than 3 (S/N>3) in at least 2 observations
- Sources need to be compact, either slightly extended or point-like. Extremely extended sources are those where the extent of the emission is more than about 20% of the PSF size should be excluded.
- Sources should have $|b| > 5$ arcseconds (extragalactic)

(b) TDEs have a transient nature with an initial increase in luminosity of between 1 and 3 orders of magnitude, and a slower decrease in luminosity that can last several years. Therefore, for this search, sources that have a flux variability probability in the broad band larger that 50%, and that have inter-observation flux differences of at least a factor of 3 (this is a conservative limit) should be selected.

(c) Ideally, observations should cover several years. If this is not the case, it suffices to determine if the source has had an increase in luminosity and is currently in a luminous, soft state. These sources can be identified as sources that are soft in at least one observation (e.g for Chandra, o.hard_hs < 0.5), and that either were not detected in previous existing observations, or that were previously detected with a harder state and a broad band flux that is at least 3 times dimmer than in the soft state.

(d) For the selected sources, take the set of the per-observation b-band fluxes and hardness ratios (for all available hardness ratios). Generate plots that allow to visualize simultaneously the time evolution of flux and hardness ratio. As opposed to Active Galactic Nuclei, for which the hardness ratio hardens as they become less luminous, for TDEs, the emission tends to remain soft.

(e) Identify TDEs and separate them from AGN flares. TDEs will likely appear as transient soft sources that remain soft regardless of epoch and regardless of luminosity. They are also typically softer than AGN flares. AGN flares will show an anti-correlation between the broad band flux and the hard-to-soft hardness ratio. As the flare becomes dimmer, it also becomes harder. In order to discriminate between TDEs and AGN flares, do the following:
1. Select the observations at peak luminosity and after the peak.

    2. Compute the standard deviation of the hardness ratios for the observations 3. Calculate the average of the individual hardness ratio uncertainties 4. If the standard deviation is less than the average, flag the sources as a TDE candidate. This condition guarantees that the variation of the hardness ratios over time is slow.

   (f) As long as the latter condition is true for at least one of the hard-to-soft hardness ratios, flag the source as a TDE candidate. Otherwise, flag it as a possible AGN flare.

   (g) If the catalog does not contain a measure of hardness ratio variability probability, but it contains either a probability density function for the hardness ratio values, or their confidence intervals, then a measure of hardness ratio variability can be obtained from a likelihood analysis. One can assume that the hardness ratio is variable if the likelihood of all individual measurements being drawn from a single true flux (assuming Gaussian errors) is smaller that the likelihood of each individual measurement being produced by a different true flux.

5. Quick, rough identification of AGN, galaxies, and stars:
   Properties needed:

   - CSC columns required: At stack level: flux_<model>_aper_i
   - XMM columns required: At stack level: EP_FLUX

   Procedure:
   Applicable to all CSC2/4XMM sources with optical counter parts.

   (a) With CSC2/4XMM and other optical catalogs (e.g., SDSS, Legacy, PS),
   (b) Define energy bands, X-ray emission model for X-ray (and optical)
   (c) Cross-check CSC2 and 4XMM data in different energy bands/-models
   (d) If necessary, convert 4XMM (or CSC2) to the common energy-band/model
   (e) Cross-check different optical catalogs in different energy bands
   (f) Calc fx/fo for individual CSC2/4XMM sources with optical counter parts.
   (g) Also provide the range of pre-defined fx/fo for known samples.

6. Lx: useful for many follow-up research
   Properties needed:

   - CSC columns required: At stack level: flux_<model>_aper_i

- From optical catalogs: spec-z or photo-z

Procedure:
Applicable to all CSC2/4XMM sources with known spec-z or photo-z

(a) From the cross-matches, identify spec-z or photo-z
(b) Cross-check photo-z for those with both
(c) If possible, preset models which is most appropriate for a source type (e.g., given by fx/fo)
(d) Calc Lx in multiple energy bands/models
(e) If necessary, convert 4XMM (or CSC2) to the common energy band/model

7. Lx: Spectral decomposition of X-ray sources
Analog to bulge-disk decomposition by fitting the optical radial profile.

Usage:

- separation XRB and hot gas emissions from the entire galaxy
- separation AGN and hot gas emissions from the central region

Procedure:
Applicable to X-ray sources identified as (A) galaxy and (B) AGN by cross-matches or by fx/fo

(a) Mapping CSC2/4XMM spectral info (e.g., hardness ratio) into a combination of softer hot gas (~1 keV APEC) and harder point source (7 keV BREM or photon index 1.7 power-law)

8. Using CSC 2.0 data to create Color-Color-Intensity plots(CCI) to try and identify the nature of extragalactic XRBs.

TODO:
Details TBD

D Vizier

VizieR provides science ready catalogues coming from space agencies or articles and covering number of different science cases. Published data encompass a very large set of measures (position, photometry, redshift, source type, etc.) depending on their origin. They can result from observations, simulations, models or catalog compilations. Individual Vizier tables can contain data all related to one source (e.g. time series of positions or magnitudes) or to a set of sources (one row per source) or a mix of both. Data sets are ingested in Vizier on author request. Before to be put online they are processed and documented by documentalists so as to ensure a certain level of interoperability. This work relies on the analyse of both data content and scientific paper.

- Missing meta-data, e.g. space frames or filters, are added when available in the paper.
- Columns are renamed following the Vizier nomenclature in order make them compliant with the DBMS and to facilitate the grouping of all values related to one particular quantities (e.g. quality flag for a radial velocity)
- UCDs are checked or set for all columns.
- README files are generated. A README is a text file with a specific layout making it machine readable.
- Some values, not part of the original data but assigned by the CDS, are added to the tables (e.g. identifier, ICRS positions)
- Ancillary data pointing on associated data (e.g. spectra) or on linked services (e.g. visualisation), can also be added to enrich the table content.

All Vizier meta data are gathered in a specific resource in a way to facilitate the localisation of data of interest. The main specificity of the data is their heterogeneity

- Huge variety of data provenance and processing
- Meta data heterogeneity
- Table content heterogeneity
- Huge variety of possible measures
- Huge variety of patterns of measure groups
- Use of different coordinate systems
- Large variety of associated data

The Mango model must be able to provide a standard representation of most of the metadata contained in Vizier query responses, whether native or computed by the CDS, simple quantities or associated complex data. Mango is not meant to replace the current management of the meta-data, it is a way to make those meta-data understandable for a wide panel of VO-compliant clients.

Vizier gathers and delivers a curated version of published catalogs from various missions and experiments. It also distributes results of scientific papers, based on the computation , comparison and classification of sources extracted from archived data after science analysis. Vizier handles a very large set of measures in position, photometry, redshift, source type, etc. It adds value to it by recomputing additional quantities in various reference frames or equivalent spectral bands, units conversions , etc . It binds the resulting object description to other data sets representing the object, or its counterparts, or neighbourhood on sky (image), its spectral behaviour (spectrum, spectral energy distribution) or evolution through time (light curve, radial velocity curve, time series, etc.). Currently the binding and structure of the quantities is done by column grouping.

- pre-existing data
- grouping columns
- lots of available metadata
- column name formatting
- one column different frames

E Morphologically Complex Structures

The ViaLactea Knowledge Base (VLKB, see Molinaro and Butora et al. (2016)) is a set of data resources and services built up to study the star formation regions and processes in the Milky Way. Besides 2-D images and 3-D radial velocity cubes, the VLKB exposes a bunch of source catalogues. These catalogues can be categorised as:

- compact sources catalogues: where each source can be simply described by position and (usually) ellipsoidal extension plus some photometric flux(es);
- a band merged catalogue: where each source record combines the single band source of the previous type into a multi-center/multi-positional record;
- diffuse objects of two types, bubbles and filaments, where the positional description cannot be simplified by a point in the sky and some geometric error/shape value.

The first type of catalogue presents only a small issue, related to the ellipsoidal description of the extension of the single records/sources. For these catalogues the ellipsoidal (or circular) counterpart of the position is not to be considered as a positional uncertainty, but actually some level of confidence on the actual extension of the source at the observed frequency band, thus, besides a position on the celestial sphere, a minor axis, a major axis and a positional angle are needed to describe the source.

The band merged catalogue requires an extra step, that is the aggregagtion of multiple single band sources (potentially degenerate depending on the observational waveband) to be able to provide a sort of SED of the aggregated source.

A different type of challenge is presented by filaments and bubbles where (not approximating bubbles to simple circles) the source morphology requires or a complex geometrical shape, like single or multiple polygons, or a description based on tessellation (where the order of the tessels should fit the resolution/uncertainty of the source borders). Moreover, while bubbles can be fully described by a centroid and a single complex (multi-)polygon or set of tessels, filaments are themselves complex objects such that their description includes so-called branches, spines and nodes (areas, broken-lines, points in spherical geometry).

Thus, a model that supports description of such catalogues will need a way to describe sources with:

- non-point-like positions;
- extended complex area, possibly as multiple detached areas;
- aggregation of sub-parts (that can be heterogeneous).

The VLKB tried[1] to describe, both by (custom) contour polygons and MOCs, the bubbles and filaments having the main use case of cross-matching or distance measuring diffuse objects w.r.t. compact sources. However, work progressend slowly and anyway the proper model annotations were never investigated properly.

MANGO could be useful to serve nicely annotated and usable records for sources as the ones described above.

F Exoplanets

Annotation of (exo-)planetary records in catalogues requires some specific metadata or model.

This was initially made clear when trying to allow discoverability of exoplanets time series (Molinaro and Benatti et al. (2020)) where (exercising the ObsCore model with specific use cases) information like stellar host characteristics together with stellar system details turned out to be required for a proper description of the catalogue records.

[1] if you want to have a look at the plain content, there's a TAP service at http://vlkb.dev.neanias.eu:8080/vlkb/tap (http://saada.unistra.fr/taphandle?url=http%3A//vlkb.dev.neanias.eu%3A8080/vlkb/tap/) that can be accessed, even if not complete with descriptions nor registered

The use cases identified, besides some refinement needed in the ObsCore time axis annotation, the following metadata:

- the degree of confidence in the detection: exoplanets candidates w.r.t. confirmed ones, plus last update of the record content ;
- the method used in the discovery (since it affects the available stellar system description parameters);
- a set of stellar host characteristics (besides sky coordinates): activity, mass, type, metallicity, age, some systemic values, like the global RV (radial velocity) of the system, and so on;
- (exo-)planet parameters, like mass, orbital period, orbit's eccentricity, RV semi-amplitude, time at periastron (for RV detections) or central transit time (for transit method), longitude of periastron, and so on.

The scenario gained some further complexity, but also better stated the idea of modelling datasets and catalogue records in the (exo-)planetary systems subdomain, incorporating requirements from exoplanets atmosphere simulations and (first efforts) observations.

Specific metadata additions were not specified exactly, but a draft model to describe stellar systems was developed, specifically trying to solve the issue in adding metadata elements to describing orbiting celestial objects (Molinaro and Alei et al. (2019)).

The model identified the main concepts and classes as:

- Celestial Object, typed/subclassed as: Star, Binary Star, Planet, Satellite, Brown Dwarf, Trojan, and so on;
- Orbit, as the class keeping the information needed to describe the orbit of a couple (or more) Celestial Objects.

Specific (exo-)planets metadata included: atmosphere with molecular composition, bulk details (mass, radius, . . .).

A catalogue service that could make use of model metadata is the ExoMerCat (Alei and Claudi et al. (2020)) catalogue (or the other available exoplanets' catalogues), already available in a VO-aware solution[2], but using only simple UCD description of the exposed information.

TODO:
mention the involved projects : examples ? GAPS, TESS?

TODO:
For GAPS I can add specifics later, if implementation can (re)start

[2]ivo://ia2.inaf.it/catalogues/exomercat

F.0.1 Client on (MT behalf)

Right now, the meta-data provided within the VOTable allow clients such Aladin or Topcat to run most of the functionalities expected by the user, either for data analysis of plotting. This information is often guess from UCDs, UTypes or columns name. It can also be given by the user. Clients have no expectations of working with full model instances but in some cases models can help to know how quantities in an input table relate to each other. In most cases this is for visualisation, e.g.:

- what is the sky position for this row (what columns contain latitude and longitude, and what sky system are they in)
- what +/-ERR error bars should I plot for these points (what column is a simple error for column A)
- what error ellipses should I plot for these sky positions (what columns provide ra_error, dec_error, ra_dec_corr, or how can I derive those from columns that do exist)
- where do I get the grid information for a column containing a vector of samples so I can label the X axis of a spectrogram (what column or parameter contains an axis vector matching the sample vectors)
- does this table contain sky positions, or HEALPix tiles, or both? What's the best way to represent it on the sky?
- What is the meaning of such URL found out in a table?s

But there are some other places too:

- how do I propagate this sky position to a future epoch (what columns contain pmra, pmdec, and maybe all the associated errors and correlation coefficients)
- what is the error ellipse/oid to use for a sky/Cartesian crossmatch (what columns provide the relevant errors and, if available, correlations)

This usage shows that MANGO must be designed in a way that individual measurements or quantities can be easily be identified as such and manipulated independently of the whole instance.

G Xmatch tool

The basic cross-match of two astronomical tables consists in associating pairs of sources – one from each table – fulfilling a given angular distance based criterion. In relational algebra terms, it is a theta-join on a distance predicate.

More generally, a cross-match is the association of sources from different tables given their proximity in an astrometric (but also possibly photometric, statistical, ...) parameter space (Pineau and Derriere et al., 2017) .

If proper motions (plus parallax and radial velocities) are available, the cross-match tool may propagate the positions of each table to a common epoch. It may also take into account positional uncertainties to reject the statistically unlikely associations.

In the latter case (cross-match between two tables taking into account positional errors), the tool needs to be able to retrieve the errors associated to the each position in each table.

UCDs may help in identifying the errors associated to a positional columns as shown in table 3.

Error type Parameters	**UCD**	**Description**
Circular error		
`epos`	`stat.error;pos.eq`	See "possible ambiguity for circular errors"
Uncorrelated errors		
`eRA`	`stat.error;pos.eq.ra`	Error on ‘RA cos(Dec)‘
`eDec`	`stat.error;pos.eq.dec`	Error on ‘Dec‘
Correlated errors		
`eRa`	`stat.error;pos.eq.ra`	Error on ‘RA cos(Dec)‘
`eDec`	`stat.error;pos.eq.dec`	Error on ‘Dec‘
`corRADec`	`stat.covariance; pos.eq.ra; pos.eq.dec`	Correlation factor
Oriented Ellipse		
`a`	`phys.angSize.smajAxis; pos.errorEllipse`	Error ellipse semi-major axis
`b`	`phys.angSize.sminAxis; pos.errorEllipse`	Error ellipse semi-minor axis
`theta`	`pos.posAng; pos.errorEllipse`	Error ellipse position angle

Table 3: Table of the different possible representations of positional errors that can be found in astronomical catalogues

But this is not sufficient to table with more complex cases based on multi-parameter cases:

- Catalogues like AllWISE provides a co-sigma instead of the correlation factor of the covariance matrix. Co-sigma is the sign of the correlation factor time the square root of the covariance.

- Table fields UCDs may be too loose: for example `stat.error;pos.eq` is often used in place of `phys.angSize.smajAxis;pos.errorEllipse` or `phys.angSize.sminAxis;pos.errorEllipse`.

- The location of the column to be used for the Xmatch can be ambiguous. For instance, if several pairs of position are provided in a table, there is currently no way to associate unambiguously uncertainties with the (right) pair of coordinates.

- Possible ambiguity for circular errors. When the provided uncertainty is the parameter of a circular error, it may be:

  - either the 1 dimensional component on each axis of a symmetric 2-dimensional Gaussian distribution: $\sigma = \sigma_{\alpha \cos \delta} = \sigma_{\delta}$;
  - or the parameter of the radial error distribution (i.e. of the Rayleigh distribution): $\sigma = \sqrt{\sigma^2_{\alpha \cos \delta} + \sigma^2_{\delta}}$ with $\sigma_{\alpha \cos \delta} = \sigma_{\delta}$

- Possible ambiguity on the confidence level The provided error is usually the 1sigma error. It (theoretically) means that the "true" position has:

  - either 68% chances to be at a distance lower than the radial error from the position's mean value.
  - or 39% chances to be inside the error ellipse (or circle) around the position's mean value.

  But depending on the catalogue, the provided error parameters can correspond to different confidence levels.

H Imported Models Instance

I Changes from Previous Versions

No previous versions yet.

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