Time Domain Astronomy in VizieR

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Outline

- Time Domain Astronomy: concept and examples
- Dedicated missions to study the variable sky
- Measuring time
- Combining data: mapping to a pivot format
- Time for VizieR: collecting metadata

What is time domain astronomy?

- Phenomena varying with time and having or triggering a follow-up observation

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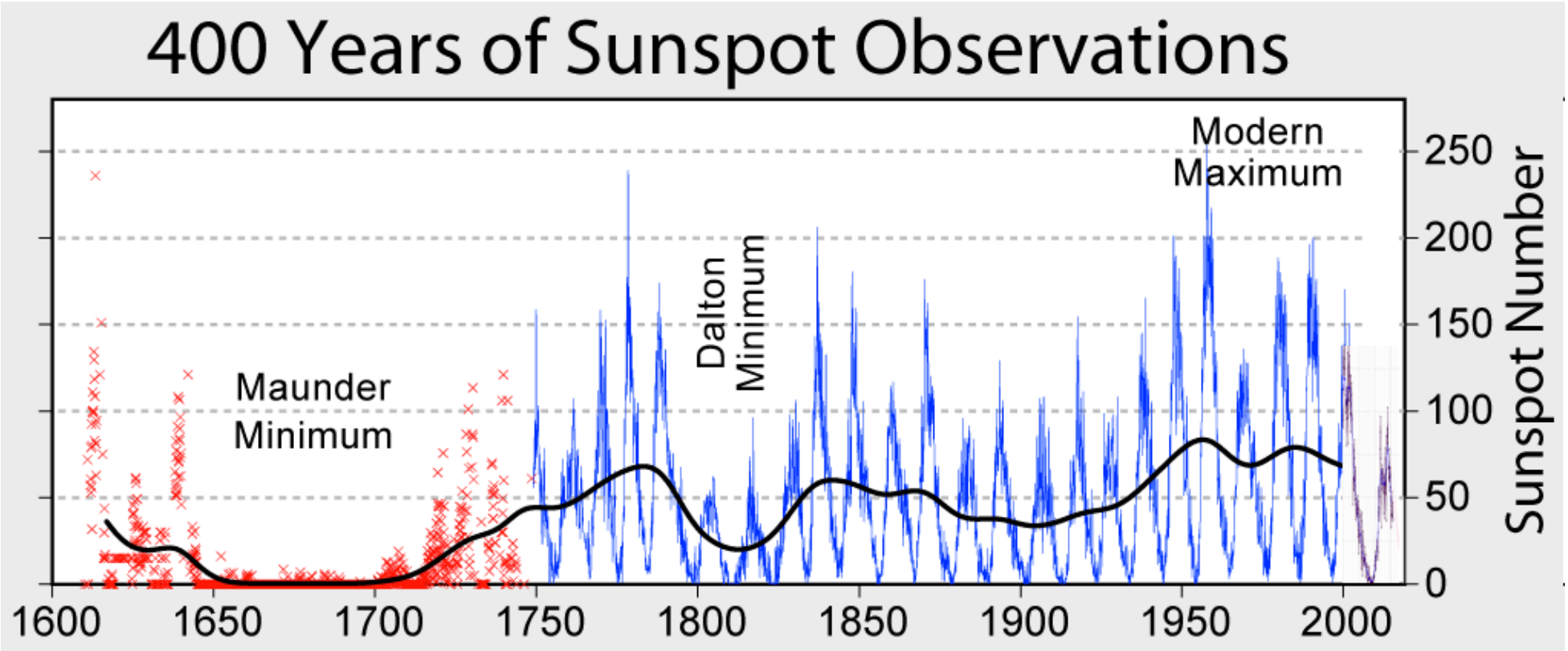
  - Sunspots varying along the year —> solar activity cycle



Credit wiki: 400 year sunspot history, including the Maunder Minimum

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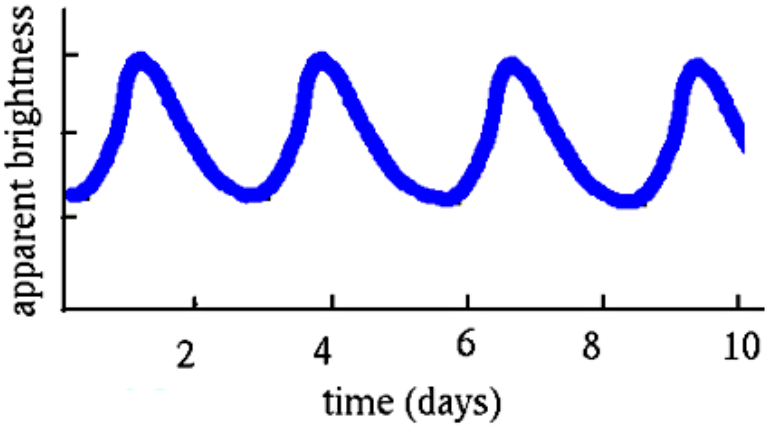
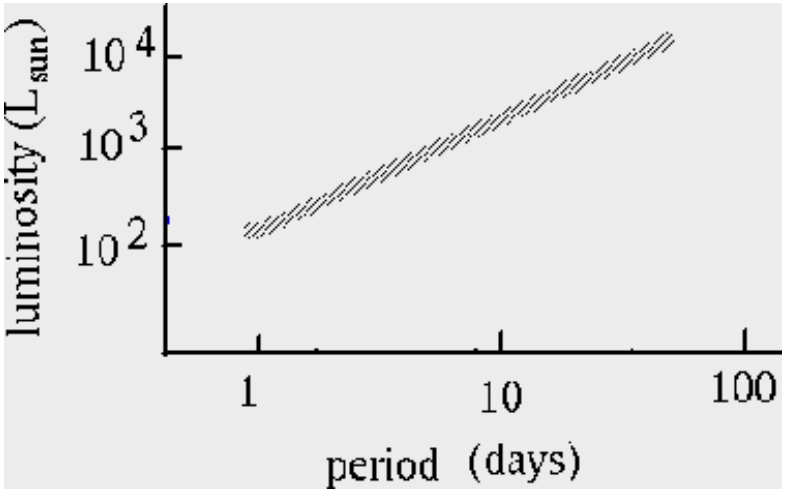
  - Magnitude changes in Cepheid variables —> determination of distances





https://starchild.gsfc.nasa.gov/docs/StarChild/questions/cepheids.html

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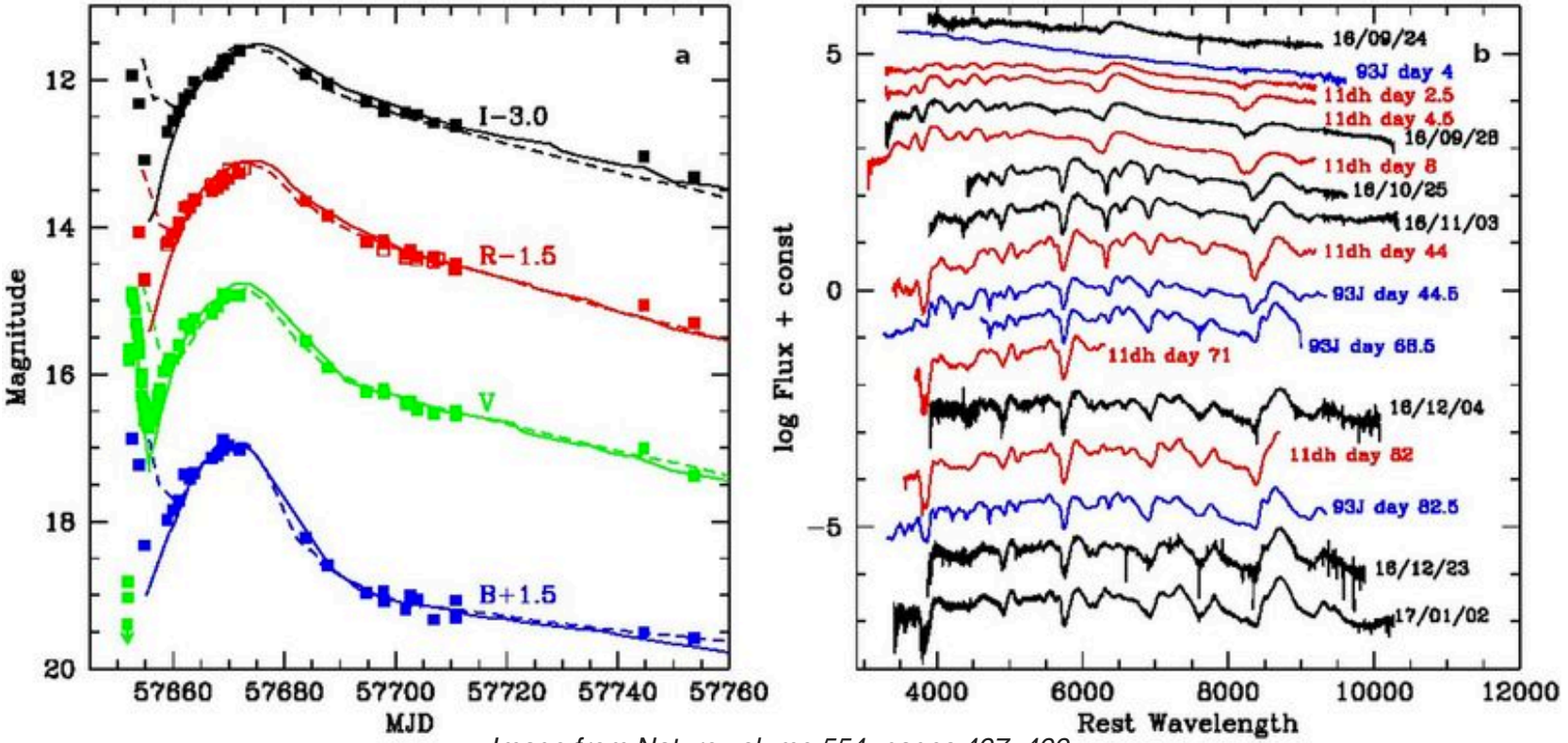

Image from Nature volume 554, pages 497–499

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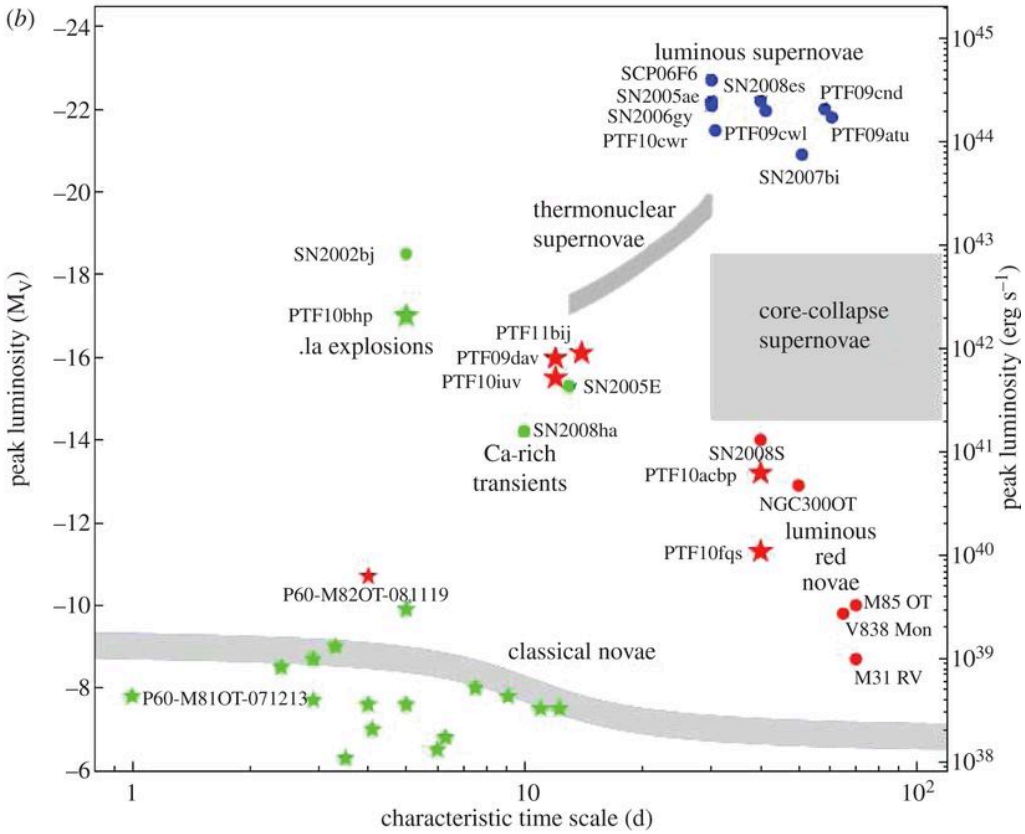
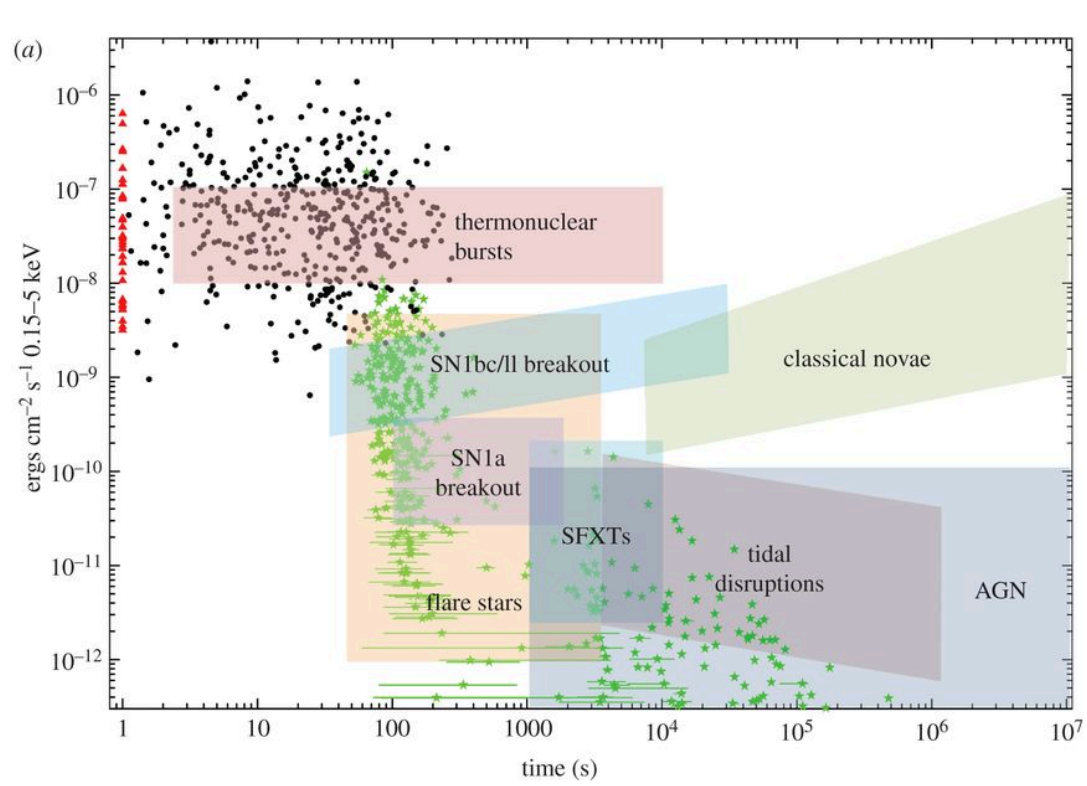
- All these can be relevant at all wavelengths from radio to gamma-rays and from time scales varying from seconds to years

What is time domain astronomy?

- Characteristic Time Scales of objects of different nature





(*a*) Typical observed X-ray flux plotted against variability time scale for a variety of source types (colour-shaded regions) and for the prompt and afterglow fluxes for GRBs detected by the Swift mission (individual points). Black points are swift Burst Alert Telescope (BAT) GRBs (with the T_{90}<1 s in red), green points are Swift X-ray Telescope GRB afterglow fluxes. AGN, active galactic nucleus; SFXT, supergiant fast X-ray transients. (*b*) Taken from Kulkarni [5] and shows the optical phase space of cosmic explosive events and their characteristic time scales. Image credits: (*a*) Julian Osborne and (*b*) Shri Kulkarni. (Online version in colour.)

Dedicated missions to study the variable sky

CRTS Catalina Real-Time Transient Survey

Pan-STARRS

SDSS

Stripe 82

LSST

Dedicated missions to study the variable sky

- There are dedicated missions but…
- Compiling data from different missions can also lead to interesting results:
  - DASCH project (looking back in time for over 100 years!)

- So, what astronomers call “Time series” can depend on the astronomer you ask.

- We can distinguish:
  - data coming from one origin
  - data coming from different missions
    - ➡need to bring coordinates to a common frame
    - ➡**need to bring time to a common scale**

How do we measure time?

- What is time?
  - **How** do we measure it?
    - Time Scale: *"A time scale is simply a well defined way of measuring time based on a specific periodic natural phenomenon".*
      - SI (atomic) second: 9,192,631,770 cycles of the radiation corresponding to the ground state hyperfine transition of Cesium 133 (BIPM 1998). Since 1950 but before that…
      - Based on the rotation of the Earth (1 day)
  - **Where** do we measure it?
    - Reference: Earth? Satellite? Another planet? Satellite? Barycentre of the solar system?

How do we measure time?

Table 2 Recognized Time Scale Values[1,2]

TAI	(International Atomic Time): atomic time standard maintained on the rotating geoid
TT	(Terrestrial Time; IAU standard): defined on the rotating geoid, usually derived as TAI + 32.184 s
TDT	(Terrestrial Dynamical Time): synonym for TT (deprecated)
ET	(Ephemeris Time): continuous with TT; should not be used for data taken after 1984-01-01
IAT	synonym for TAI (deprecated)
UT1	(Universal Time): Earth rotation time
UTC	(Universal Time, Coordinated; default): runs synchronously with TAI, except for the occasional insertion of leap seconds intended to keep UTC within 0.9 s of UT1; as of 2012-07-01 UTC = TAI − 35 s
GMT	(Greenwich Mean Time): continuous with UTC; its use is deprecated for dates after 1972-01-01
UT()	(Universal Time, with qualifier): for high-precision use of radio signal distributions between 1955 and 1972; see Section A.9
GPS	(Global Positioning System): runs (approximately) synchronously with TAI; GPS ≈ TAI − 19 s
TCG	(Geocentric Coordinate Time): TT reduced to the geocenter, corrected for the relativistic effects of the Earth's rotation and gravitational potential; TCG runs faster than TT at a constant rate
TCB	(Barycentric Coordinate Time): derived from TCG by a 4-dimensional transformation, taking into account the relativistic effects of the gravitational potential at the barycenter (relative to that on the rotating geoid) as well as velocity time dilation variations due to the eccentricity of the Earth's orbit, thus ensuring consistency with fundamental physical constants; Irwin & Fukushima (1999) provide a time ephemeris
TDB	(Barycentric Dynamical Time): runs slower than TCB at a constant rate so as to remain approximately in step with TT; runs therefore quasi-synchronously with TT, except for the relativistic effects introduced by variations in the Earth's velocity relative to the barycenter; when referring to celestial observations, a pathlength correction to the barycenter may be needed which requires the Time Reference Direction used in calculating the pathlength correction
LOCAL	for simulation data and for free-running clocks.

Table 3 Standard Time Reference Position Values[1]

TOPOCENTER	Topocenter: the location from where the observation was made (default)
GEOCENTER	Geocenter
BARYCENTER	Barycenter of the Solar System
RELOCATABLE	Relocatable: to be used for simulation data only
CUSTOM	A position specified by coordinates that is not the observatory location
Less common allowed standard values are:	
HELIOCENTER	Heliocenter
GALACTIC	Galactic center
EMBARYCENTER	Earth-Moon barycenter
MERCURY	Center of Mercury
VENUS	Center of Venus
MARS	Center of Mars
JUPITER	Barycenter of the Jupiter system
SATURN	Barycenter of the Saturn system
URANUS	Barycenter of the Uranus system
NEPTUNE	Barycenter of the Neptune system

Representations of Time Coordinates in FITS (Rots et al. 2015)

Comparing data

- How do we **compare** times?
  - Keep track of the **time system** used —> what exactly?
  - Bring to a standard **pivot format** —> which among all?

- What needs to be kept track of in a time system
  - Where
  - How
  - Offsets in data (observations after GRB on date XXX)
  - Format (JD, ISO, random,…)
  - Units

- How are we keeping track of time series data in VizieR
- What are our plans for the future?

Meta data

- How have we been doing it in in VizieR:
  - Mostly text describing (MJD, HJD, … offsets,…) ?
  - Some ucds
  - kept track of format and units

- What are our plans for the future?
  - Describe the needed fields in tables with metadata
  - Similar as what is already done for the filters or for coordinates

- What are the needed fields? VizieR metadata tables.
- How will be know what the time systems is? that is, how to find the information?
  - For specific missions (big tables) it should be relatively easy to find.
  - For smaller catalogues and tables? First guess: caption or the tables.
  - If we don't know it? What next?
    - Are there default values which we could use without loosing too much precision?
    - Or should the corresponding fields be left empty?

Metadata associated to time in VizieR

☐	METAtimeScaleRef	Time scale reference table; PK=$time_{scale}id$
☐	METAtimeFrameRef	Time Frame position reference table; PK=$time_{frame}id$
☐	METAtimeRepstRef	Time Representation reference table; PK=$time_{rep}id$
☐	METAtimeSystem	General Time System table; PK=$time_{syst}id$
☐	METAtimeCol	Time table applied to columns
☐	METAtimeRel	Related time columns
☐	METAtimeSyst	Time System view
☐	METAtime	Time catalogue view

☐ ALL Reset All Show table details *or* Query selected Catalogs

META VizieR META catalogue Describes the Catalogues and Tables accessible via VizieR (also [METAcat] [METAcells] [stats]called ReferenceDirectory) *Post annotation* [footprint] — Similar Catalogs — ReadMe+ftp

1.METAtimeScaleRef Time scale reference table; PK=time$_{scale}$id *(released 2000-01-01)* [METAtab] [METAcola]

Simple Constraint | List Of Constraints — Submit — Reset All

Query by Constraints applied on Columns *(Output Order:* + / - *)* [METAcola]

Show	*Sort*	*Column*	Clear	*Constraint*	*Explain*
☑	○	time_scale_id			Time scale identification (PK)
☑	○	name		(char)	Tme scale name
☑	○	description		(char)	Description

☐ **ALL** cols — Reset All — Clear — (i)indexed column — Submit

METAtimeScaleRef Time scale reference table; PK=time$_{scale}$id [METAtab] [METAcola] [stats]
Post annotation

plot the output — query using TAP/SQL

time_scale_id	name	description
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Similar Catalogs | ReadMe+ftp

1.METAtimeFrameRef Time Frame position reference table; PK=time$_{frame}$id *(released 2000-01-01)*
[METAtab] [METAcola]

Simple Constraint | List Of Constraints

Submit | Reset All

Query by Constraints applied on Columns *(Output Order:* + - *)* [METAcola]

Show	*Sort*	*Column*	Clear	*Constraint*	*Explain*
☑	○	time_frame_id			Time frame identification (PK)
☑	○	name		(char)	Time frame position name
☑	○	description		(char)	Description

☐ **ALL** cols | Reset All | Clear | (i)indexed column | Submit

time_frame_id	name	description
1	TOPOCENTER	Topocenter: the location from where the observation was made (default)
2	GEOCENTER	Geocenter
3	BARYCENTER	Barycenter of the Solar System
4	RELOCATABLE	Relocatable: to be used for simulation data only
5	CUSTOM	A position specified by coordinates that is not the observatory location
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8	EMBARYCENTER	Earth-Moon barycenter
9	MERCURY	Center of Mercury
10	VENUS	Center of Venus
11	MARS	Center of Mars
12	JUPITER	Barycenter of the Jupiter system
13	SATURN	Barycenter of the Saturn system
14	URANUS	Barycenter of the Uranus system
15	NEPTUNE	Barycenter of the Neptune system

dd/mm/yyy

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1.METAtimeRepstRef	Time Representation reference table; PK=time$_{rep}$id *(released 2000-01-01)* [METAtab] [METAcola]		

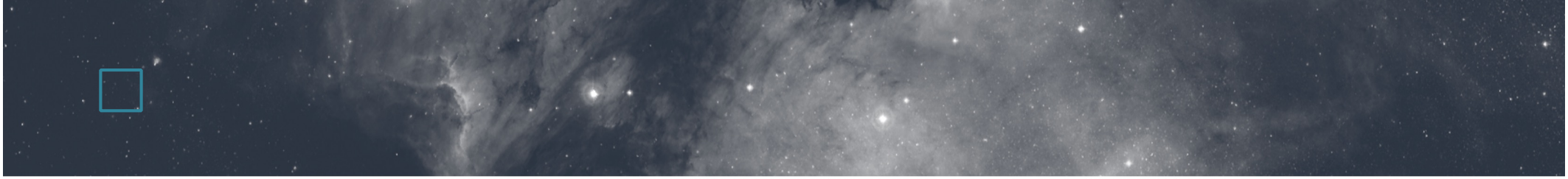
Simple Constraint | List Of Constraints — Submit — Reset All

Query by Constraints applied on Columns *(Output Order:* + - *)* [METAcola]

Show	*Sort*	*Column*	Clear	*Constraint*	*Explain*
☑	○	time_rep_id			Time representation identification (PK)
☑	○	name		(char)	Format/representation name

☐ **ALL** cols — Reset All — Clear — (i)indexed column — Submit

name	time_rep_id
MJD	1
JD	2
ISO	3
CUSTOMIZED	4



META VizieR META catalogue Describes the Catalogues and Tables accessible via [METAcat] [METAcells] [stats]VizieR (also called ReferenceDirectory) *Post annotation*

Similar Catalogs | ReadMe+ftp

1.METAtimeSystem General Time System table; PK=time$_{syst}$id *(released 2000-01-01)*
[METAtab] [METAcola]

Simple Constraint | List Of Constraints — Submit | Reset All

Query by Constraints applied on Columns *(Output Order:* + / - *)* [METAcola]

Show	Sort	Column	Clear	Constraint	Explain (UCD)
☑	○	time_syst_id			System identification (PK)
☑	○	time_scale_id			Time scale identification FK(METAtimeScaleRef)
☑	○	time_frame_id			Time Frame position identification FK(METAtimeFrameRef)
☑	○	time_systematic_err			If time scale and/or reference position is missed, you can provide them as UNKNOWN and set the systematic error/uncertainty to 1000 s. If only the time scale is unknown set this to 100s
☑	○	name		(char)	System name
☑	○	description		(char)	Description

☐ **ALL** cols — Reset All — Clear — (i)indexed column — Submit

time_syst_id	time_scale_id	time_frame_id	time_systematic_err	name	description
0			1000	UNKNOWN	Default Time system
1	12	3	0	GAIA	Time (Barycentric JD in TCB). https://www.cosmos.esa.int/documents/29201/1645651/GDR2_DataModel_draft.pdf/ a08d-b63c-67e7-eae778c9a657

META

VizieR META catalogue Describes the Catalogues and Tables accessible via VizieR (also [METAcat] [METAcells] [stats]called ReferenceDirectory)
Post annotation [footprint]

Similar Catalogs | ReadMe+ftp

1.METAtimeCol — Time table applied to columns *(released 2000-01-01)*
[METAtab] [METAcola]

Simple Constraint | List Of Constraints

Submit | Reset All

Query by Constraints applied on Columns *(Output Order:* + / - *)* [METAcola]

Show	*Sort*	*Column*	Clear	*Constraint*	*Explain*
☑	○	id			Related columns identifier
☑	○	catid			Catalogue identifier
☑	○	tabid			Table identifier
☑	○	colid			Column identifier
☑	○	time_offset			Offset related to a reference date
☑	○	time_uncertainty			Uncertain time
☑	○	time_rep_id			Time represnetation identifier FK(METAtimeRepstRef)
☑	○	time_syst_id			System identification FK(METAtimeSystem)
☑	○	flags			Flag time role : 0x1=start_time, 0x2=end_time

☐ **ALL** cols | Reset All | Clear | (i)indexed column | Submit

id	catid	tabid	colid	time_offset	time_uncertainty	time_rep_id	time_syst_id	flags
1	1337	8	3	2.4552e+06		2	1	0
3	2320	2	4	2.4e+06		2	0	0
4	18060052	2	10	0		2	0	0
2	1345	13	3	2.4552e+06	44	2	1	0
5	1345	13	9	2.4552e+06	5	2	1	0
6	1345	13	15	2.4552e+06	5	2	1	0

plot the output — query using TAP/SQL

Metadata associated to time in VizieR

META	VizieR META catalogue Describes the Catalogues and Tables accessible via VizieR (also [METAcat] [METAcells] [stats]called ReferenceDirectory) *Post annotation* [footprint]	Similar Catalogs	ReadMe+ftp
1.METAtimeRel	Related time columns *(released 2000-01-01)* [METAtab] [METAcola]		

Simple Constraint | List Of Constraints — Submit — Reset All

Query by Constraints applied on Columns *(Output Order:* + / - *)* [METAcola]

Show	*Sort*	*Column*	Clear	*Constraint*	*Explain*
☑	○	catid			Catalogue identifier
☑	○	tabid			Table identifier
☑	○	colid			Column identifier
☑	○	time_rel_id			Related columns identifier

ALL cols — Reset All — Clear — (i)indexed column — Submit

catid	tabid	colid	time_rel_id
1345	13	4	2
1345	13	7	2
1345	13	13	5
1345	13	10	5
1345	13	16	6
1345	13	19	6

Metadata associated to time in VizieR

META — VizieR META catalogue Describes the Catalogues and Tables accessible via VizieR (also called ReferenceDirectory)
[METAcat] [METAcells] [stats] Similar Catalogs ReadMe+ftp
Post annotation [footprint]

1. METAtimeSyst — Time System view *(released 2000-01-01)*
[METAtab] [METAcola]

Simple Constraint | List Of Constraints — Submit — Reset All

Query by Constraints applied on Columns *(Output Order:* + / - *)* [METAcola]

Show	Sort	Column	Clear	Constraint	Explain
☑	○	time_syst_id			System identification
☑	○	scale_name		(char)	Time scale name
☑	○	frame_name		(char)	Frame name
☑	○	time_systematic_err			If time scale and/or reference position is missed, you can provide them as UNKNOWN and set the systematic error/uncertainty to 1000 s. If only the time scale is unknown set this to 100s
☑	○	name		(char)	System name
☑	○	description		(char)	Description

☐ ALL cols — Reset All — Clear — (i) indexed column — Submit

time_syst_id	scale_name	frame_name	time_systematic_err	name	description
0			1000	UNKNOWN	Default Time system
1	TCB	BARYCENTER	0	GAIA	Time (Barycentric JD in TCB). https://www.cosmos.esa.int/documents/29201/1645651/GDR2_DataModel_draft.pdf/938f48a2-a08d-b63c-67e7-eae778c9a657

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1.METAtime	Time catalogue view *(released 2000-01-01)* [METAtab] [METAcola]		

Simple Constraint | List Of Constraints — Submit — Reset All

Query by Constraints applied on Columns *(Output Order:* + / - *)* [METAcola]

Show	Sort	Column	Clear	Constraint	Explain
☑	○	catid			Catalogue identification
☑	○	tabid			Table identification
☑	○	colid			Column identification
☑	○	time_syst_id			System identification
☑	○	scale_name		(char)	Time scale name
☑	○	frame_name		(char)	Frame name
☑	○	time_systematic_err			Systematic error (sec)
☑	○	name		(char)	System name
☑	○	description		(char)	Description
☑	○	time_offset			Offset related to a reference date
☑	○	time_uncertainty			Uncertain time
☑	○	time_representation		(char)	Time representation

☐ ALL cols — Reset All — Clear — (i)indexed column — Submit

Metadata associated to time in VizieR

catid	tabid	colid	time_syst_id	scale_name	frame_name	time_systematic_err	name
1337	8	3	1	TCB	BARYCENTER	0	GAIA
2320	2	4	0			1000	UNKNOWN
18060052	2	10	0			1000	UNKNOWN
1345	13	3	1	TCB	BARYCENTER	0	GAIA
1345	13	9	1	TCB	BARYCENTER	0	GAIA
1345	13	15	1	TCB	BARYCENTER	0	GAIA

description	time_offset	time_uncertainty	time_representation
Time (Barycentric JD in TCB). https://www.cosmos.esa.int/documents/29201/1645651/GDR2_DataModel_draft.pdf/938f48a2-a08d-b63c-67e7-eae778c9a657	2.4552e+06		JD
Default Time system	2.4e+06		JD
Default Time system	0		JD
Time (Barycentric JD in TCB). https://www.cosmos.esa.int/documents/29201/1645651/GDR2_DataModel_draft.pdf/938f48a2-a08d-b63c-67e7-eae778c9a657	2.4552e+06	44	JD
Time (Barycentric JD in TCB). https://www.cosmos.esa.int/documents/29201/1645651/GDR2_DataModel_draft.pdf/938f48a2-a08d-b63c-67e7-eae778c9a657	2.4552e+06	5	JD
Time (Barycentric JD in TCB). https://www.cosmos.esa.int/documents/29201/1645651/GDR2_DataModel_draft.pdf/938f48a2-a08d-b63c-67e7-eae778c9a657	2.4552e+06	5	JD

Metadata associated to time in VizieR

- But this is outrageous! That's too much! Crazy astronomers really need this?
- Yes, we do, take as example where we mix information of data taken at different seasons
- But… shortcuts without loosing information are possible.
- If we don't know —> set to UNKOWN and there will be default values that will be set to the different columns.
- Diagnostic of effort should be carried out:
  - number of tables with information on time ?
  - How to proceed?
    - VizieR Time Domain Crunch Session