Investigation of possibilities and limitations for bulk automated analysis of big datasets of reflectance spectra of asteroids

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Outline

Major components of the project:

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1. Downloading data

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2. Taxonomic classification (CANA)

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4. Mineralogical content estimates based on empirical formulas

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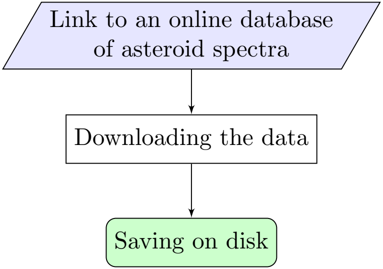
Major components of the project:

1. Downloading data
2. Taxonomic classification (CANA)
3. Automatic absorption band detection
4. Mineralogical content estimates based on empirical formulas
5. Visualisations with various plots

Downloading data

Development stages:

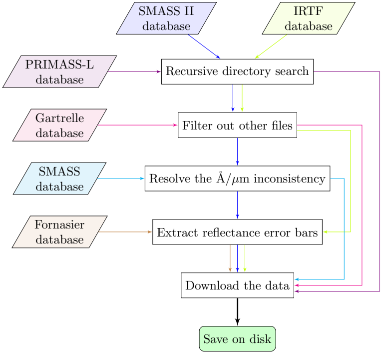
1. **Simple download**



Downloading data

Development stages:

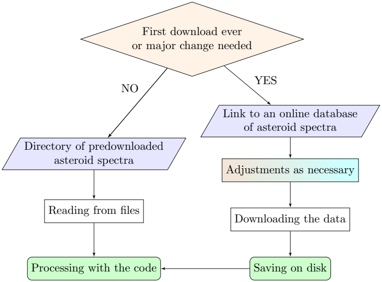
1. Simple download
2. **Unification between databases**



Downloading data

Development stages:

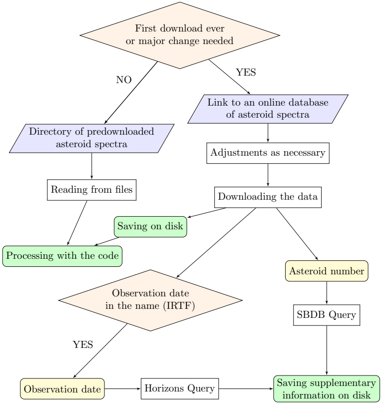
1. Simple download
2. Unification between databases
3. **Avoiding repeated downloads**



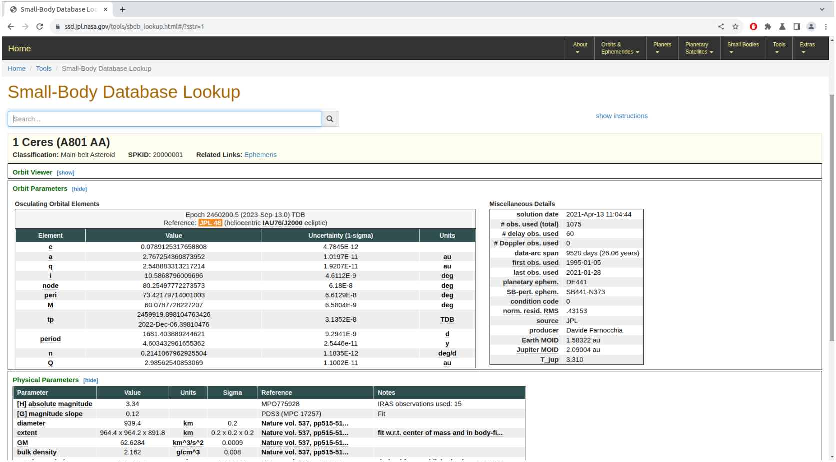
Downloading data

Development stages:

1. Simple download
2. Unification between databases
3. Avoiding repeated downloads
4. **Extracting supplementary information from JPL databases**



Small Body Database Lookup - not useful



Small-Body Database Lookup

ssd.jpl.nasa.gov/tools/sbdb_lookup.html#/?sstr=1

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Small-Body Database Lookup

Search... show instructions

1 Ceres (A801 AA)

Classification: Main-belt Asteroid **SPKID:** 20000001 **Related Links:** Ephemeris

Orbit Viewer [show]

Orbit Parameters [hide]

Osculating Orbital Elements

Epoch 2460200.5 (2023-Sep-13.0) TDB
Reference: JPL 48 (heliocentric **IAU76/J2000** ecliptic)

Element	Value	Uncertainty (1-sigma)	Units
e	0.0789125317658808	4.7845E-12	
a	2.767254360873952	1.0197E-11	au
q	2.548883313217214	1.9207E-11	au
i	10.5868796009696	4.6112E-9	deg
node	80.25497772273573	6.18E-8	deg
peri	73.42179714001003	6.6129E-8	deg
M	60.0787728227207	6.5804E-9	deg
tp	2459919.898104763426 2022-Dec-06.39810476	3.1352E-8	TDB
period	1681.403889244621 4.603432961655362	9.2941E-9 2.5446e-11	d y
n	0.2141067962925504	1.1835E-12	deg/d
Q	2.98562540853069	1.1002E-11	au

Miscellaneous Details

solution date	2021-Apr-13 11:04:44
# obs. used (total)	1075
# delay obs. used	60
# Doppler obs. used	0
data-arc span	9520 days (26.06 years)
first obs. used	1995-01-05
last obs. used	2021-01-28
planetary ephem.	DE441
SB-pert. ephem.	SB441-N373
condition code	0
norm. resid. RMS	.43153
source	JPL
producer	Davide Farnocchia
Earth MOID	1.58322 au
Jupiter MOID	2.09004 au
T_jup	3.310

Physical Parameters [hide]

Parameter	Value	Units	Sigma	Reference	Notes
[H] absolute magnitude	3.34			MPO775928	IRAS observations used: 15
[G] magnitude slope	0.12			PDS3 (MPC 17257)	Fit
diameter	939.4	km	0.2	Nature vol. 537, pp515-51...	
extent	964.4 x 964.2 x 891.8	km	0.2 x 0.2 x 0.2	Nature vol. 537, pp515-51...	fit w.r.t. center of mass and in body-fi...
GM	62.6284	km^3/s^2	0.0009	Nature vol. 537, pp515-51...	
bulk density	2.162	g/cm^3	0.008	Nature vol. 537, pp515-51...	

Supplementary information with APIs

Information	Query link
SBDB Query: name, a[AU], e, $i[^\circ]$, diameter [km], synodic rotation period [h], albedo	*https://ssd-api.jpl.nasa.gov/sbdb_query.api?fields=name,a,e,i,diameter,rot_per,albedo&sb-cdata=%7B%20%22AND%22%20%3A%20%5B%20%22spkid%7CEQ%7C***20000001***%22%20%5D%20%7D%0A*
Horizons Query: observation phase angle	*https://ssd.jpl.nasa.gov/api/horizons.api?format=text&COMMAND=***"Name=Itokawa"***&OBJ_DATA="NO"&MAKE_EPHEM="YES"&EPHEM_TYPE="OBSERVER"&CENTER="geo"&TLIST="***2001-03-28***"&QUANTITIES="24"*
Horizons Query: X, Y, Z coordinates $\Longrightarrow$ $d[km] = \sqrt{X^2 + Y^2 + Z^2}$ heliocentric distance	*https://ssd.jpl.nasa.gov/api/horizons.api?format=text&COMMAND=***"Name=Itokawa"***&OBJ_DATA="NO"&MAKE_EPHEM="YES"&EPHEM_TYPE="VECTORS"&CENTER="@Sun"&TLIST="***2001-03-28***"&QUANTITIES="1"*

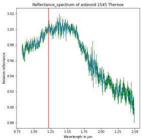
Small Body Database information - example

number	name	a [AU]	e	[i°]	diameter [km]	rotation period [h]	albedo
110	Lydia	2.733	0.0797	5.96	86.09	10.927	0.1808
125	Liberatrix	2.743	0.0807	4.67	48.418	3.968	0.182
129	Antigone	2.867	0.2129	12.27	113.0	4.9572	0.151
132	Aethra	2.613	0.3871	24.97	42.87	5.1684	0.199
135	Hertha	2.429	0.2072	2.3	79.24	8.403	0.1436
16	Psyche	2.924	0.1342	3.1	226.0	4.196	0.1203
161	Athor	2.38	0.1368	9.06	40.992	7.28	0.23
201	Penelope	2.679	0.1791	5.76	85.877	3.7474	0.04
216	Kleopatra	2.793	0.251	13.12	122.0	5.385	0.1164
22	Kalliope	2.911	0.0987	13.7	167.536	4.1483	0.166
224	Oceana	2.645	0.045	5.85	58.236	9.401	0.166
250	Bettina	3.144	0.1363	12.82	120.995	5.0545	0.112
325	Heidelberga	3.216	0.1513	8.57	75.72	6.737	0.1068
338	Budrosa	2.912	0.0181	6.04	50.506	4.6084	0.276
347	Pariana	2.615	0.1638	11.69	48.615	4.0529	0.19
369	Aeria	2.649	0.0974	12.72	73.767	4.778	0.127
382	Dodona	3.122	0.1704	7.39	65.209	4.113	0.129
418	Alemannia	2.593	0.1188	6.82	40.33	4.671	0.201
441	Bathilde	2.806	0.0817	8.16	65.131	10.446	0.204
498	Tokio	2.652	0.2238	9.5	81.83	41.85	0.0694
516	Amherstia	2.677	0.2752	12.95	65.144	7.4842	0.202
55	Pandora	2.759	0.1444	7.18	84.794	4.804	0.204
558	Carmen	2.907	0.0383	8.37	54.811	11.387	0.131
69	Hesperia	2.976	0.17	8.59	138.13	5.655	0.1402
755	Quintilla	3.187	0.1355	3.24	41.21	4.552	0.124
785	Zwetana	2.572	0.2086	12.77	49.46	8.8882	0.12
849	Ara	3.144	0.201	19.54	80.756	4.116	0.186
860	Ursina	2.797	0.1084	13.29	34.561	9.386	0.116
872	Holda	2.732	0.0798	7.39	34.431	5.945	0.165
97	Klotho	2.668	0.2581	11.78	100.717	35.15	0.128

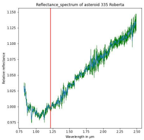
Taxonomic classification - theory

C-complex classes (carbonaceuous chondrite like)

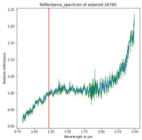
- B



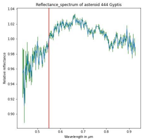
- C



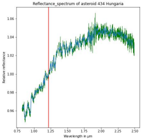
- Cb



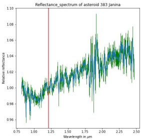
- Cg(*)



- Cgh

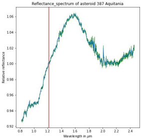


- Ch

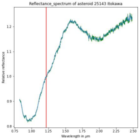


S-complex classes (Si, olivine/pyroxene, ordinary chondrites)

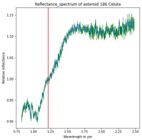
- S



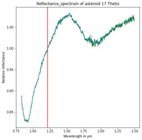
- Sa



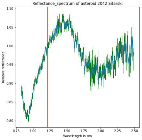
- Sq



- Sr



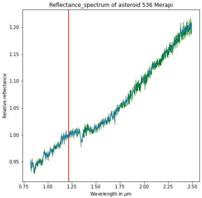
- Sv

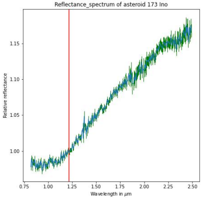


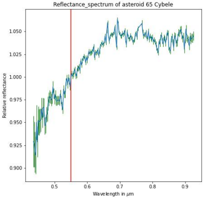
Taxonomic classification - theory

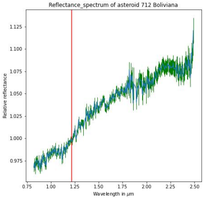
X-complex classes (few features, compositionally degenerate)

- X
- Xc(@)
- Xe(*)
- Xk





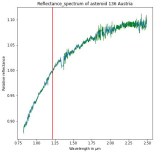




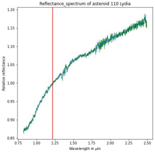
Taxonomic classification - theory

End member classes (extreme or distinct characteristics)

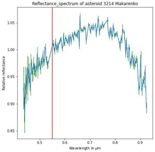
- T



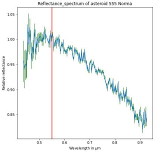
- D



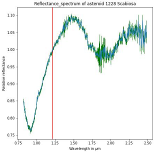
- Q(*)



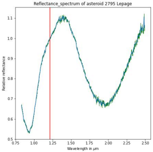
- O(*)



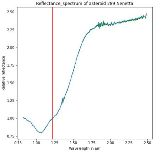
- R



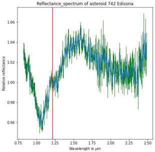
- V



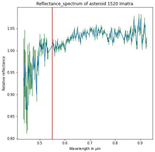
- A



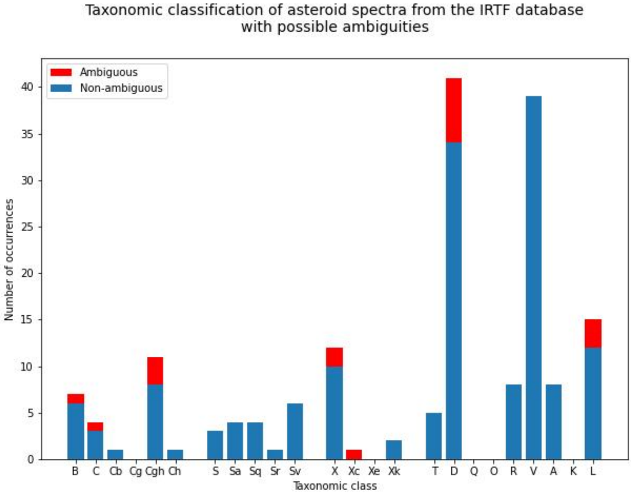
- L



- K

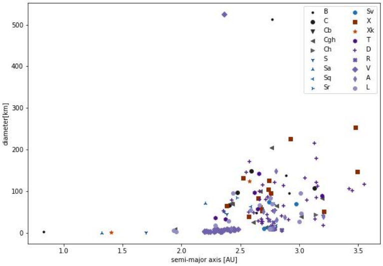


Taxonomic classification of the IRTF dataset

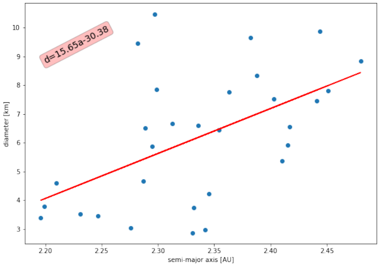


Parameter space representation

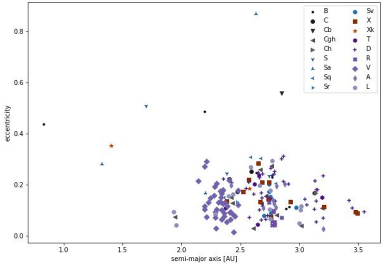
Taxonomic classification of asteroid spectra from the IRTF database,
in the parameter space of semi-major axis [AU] and diameter[km]



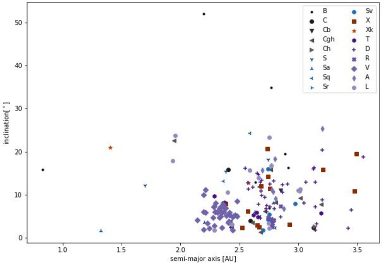
Closeup look on the small V class asteroid cluster



Taxonomic classification of asteroid spectra from the IRTF database,
in the parameter space of semi-major axis [AU] and eccentricity



Taxonomic classification of asteroid spectra from the IRTF database,
in the parameter space of semi-major axis [AU] and inclination[$^\circ$]



Absorption band detection - definitions

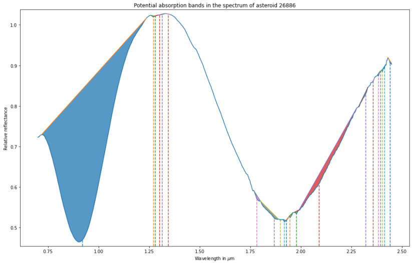
Continuum line:

$$cont(w) = r(w_{\text{min}}) + \frac{w - w_{\text{min}}}{w_{\text{max}} - w_{\text{min}}} \cdot (r(w_{\text{max}}) - r(w_{\text{min}}))$$

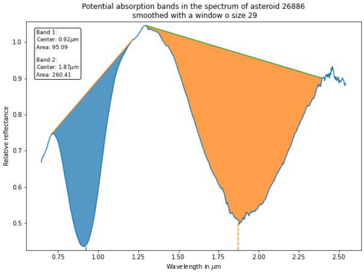
Band criterion:

$$V(w_{\text{min}}, w_{\text{max}}) = \begin{cases} 1 \text{ if } \forall_{w \in (w_{\mathbf{min}}, w_{\mathbf{max}})} r(w) < cont(w) \\ 0 \text{ otherwise} \end{cases}$$

Old algorithm



New algorithm



Absorption band detection - smoothing

Formula from the report (wrong):

$$\tilde{r}(w_i) = \frac{\sum\limits_{j=\max(-\lfloor\frac{n}{2}\rfloor, \mathbf{1}-i)}^{\min(-\lfloor\frac{n}{2}\rfloor+n-\mathbf{1}, N-i)} r\left(w_{i+j}\right)}{n}$$

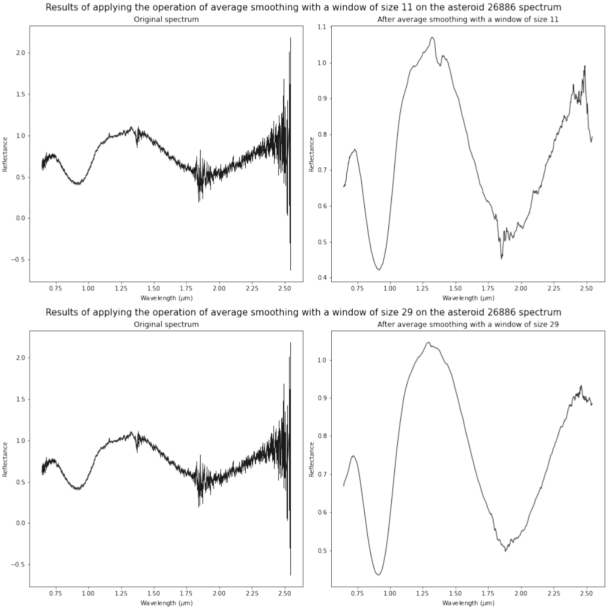
Correct formula:

$$\tilde{r}(w_i) = \frac{\sum\limits_{j=j_{\mathbf{1}}}^{\min(-\lfloor\frac{n}{2}\rfloor+n-\mathbf{1}, N-i)} r\left(w_{i+j}\right)}{j_{\mathbf{2}} - j_{\mathbf{1}} + 1}$$

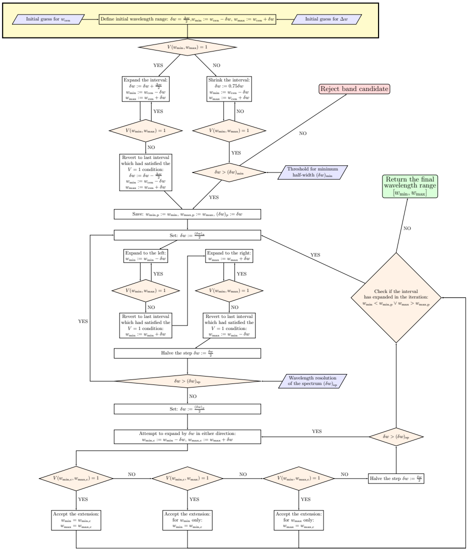
where:

$$j_{\mathbf{1}} = \max\left(-\lfloor\frac{n}{2}\rfloor, 1-i\right)$$

$$j_{\mathbf{2}} = \min\left(-\lfloor\frac{n}{2}\rfloor + n - 1, N - i\right)$$

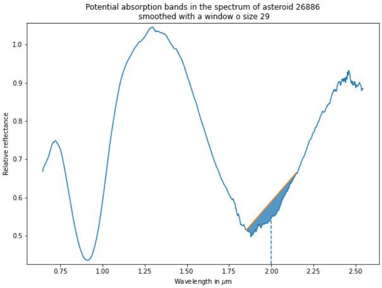


Absorption band detection - algorithm

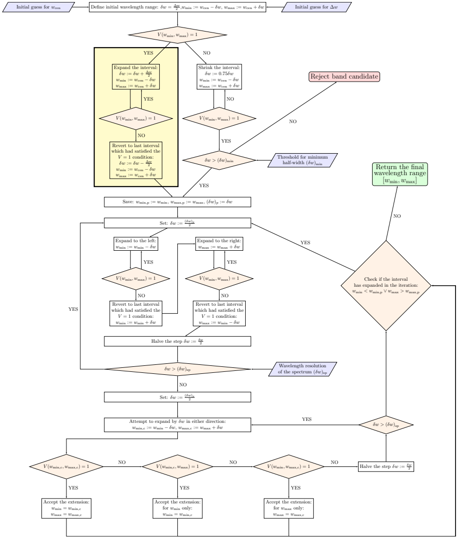


Initial guess

$$w_{max} - w_{min} = 0.3\mu m$$

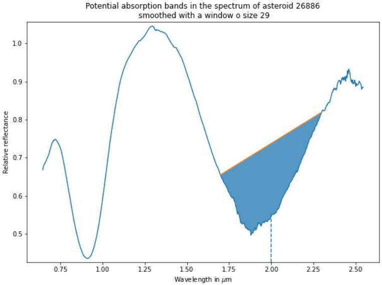


Absorption band detection - algorithm

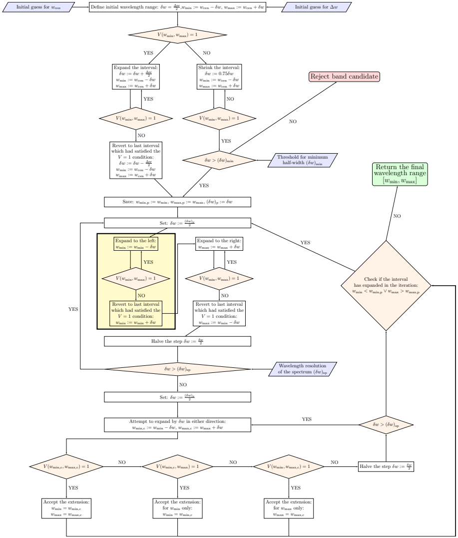


Expanding

$$w_{\max} - w_{\min} = 0.6\mu m$$

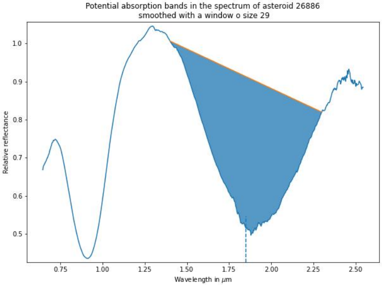


Absorption band detection - algorithm

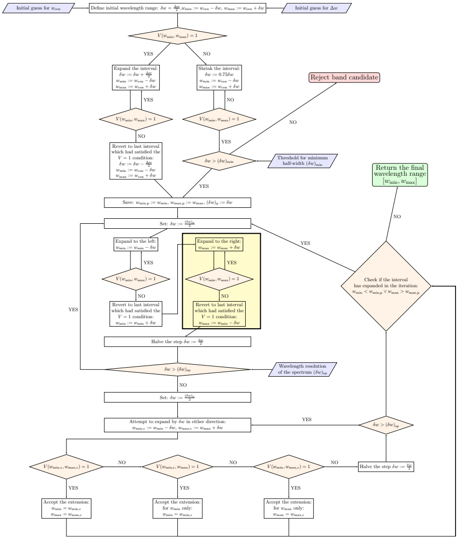


Moving left

$$w_{max} - w_{min} = 0.9\mu m$$

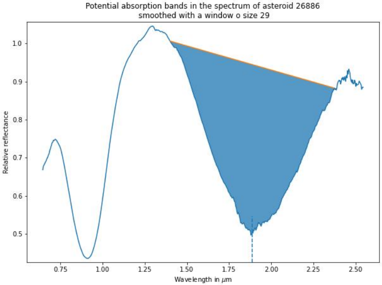


Absorption band detection - algorithm

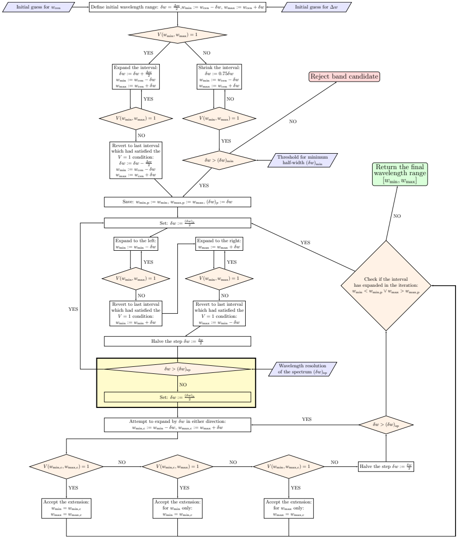


Moving right

$$w_{\max} - w_{\min} = 0.975\mu\text{m}$$

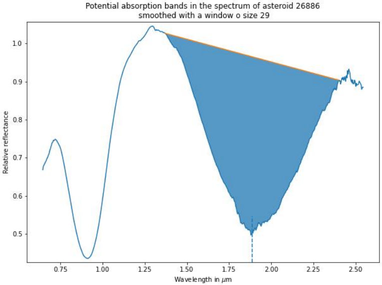


Absorption band detection - algorithm

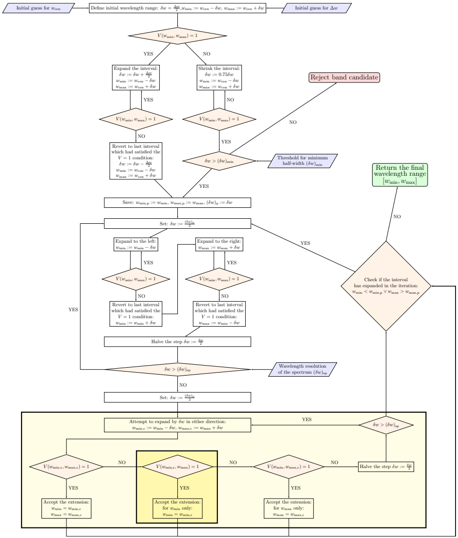


After the first loop

$$w_{\max} - w_{\min} = 1.031\mu m$$

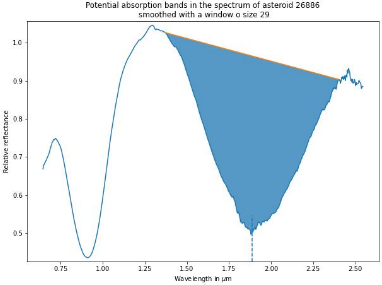


Absorption band detection - algorithm

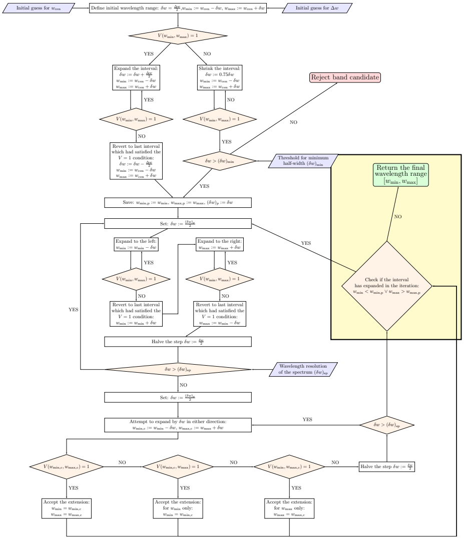


Halving a step until extended

$$w_{max} - w_{min} = 1.031\mu m$$

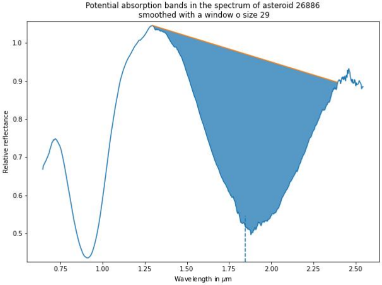


Absorption band detection - algorithm

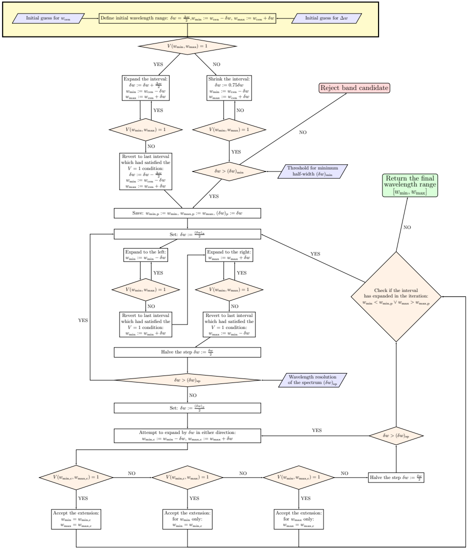


Completed

$$w_{max} - w_{min} = 1.097\mu m$$

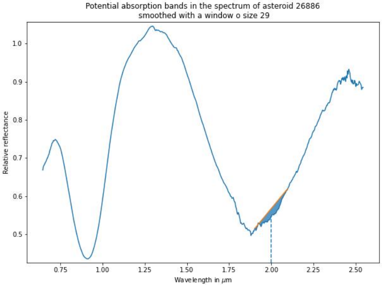


Absorption band detection - algorithm

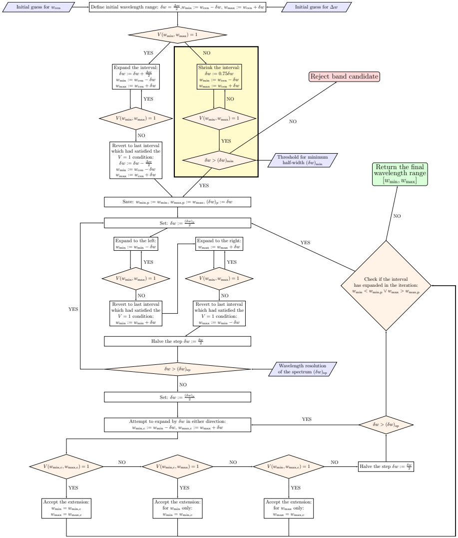


Initial guess

$$w_{\max} - w_{\min} = 0.2\mu\mathrm{m}$$

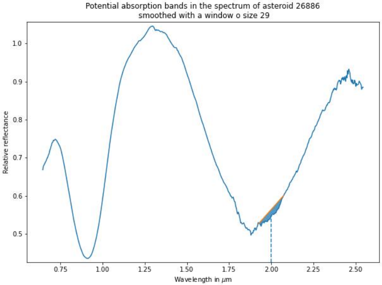


Absorption band detection - algorithm

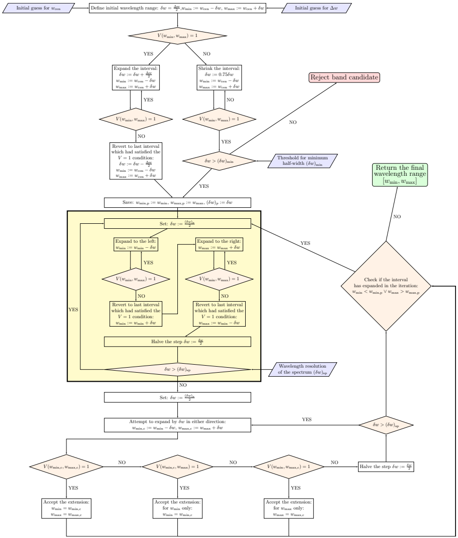


Shrinking

$$w_{\max} - w_{\min} = 0.15\mu m$$

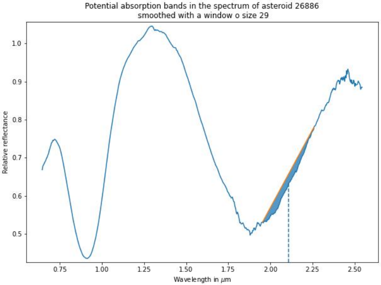


Absorption band detection - algorithm

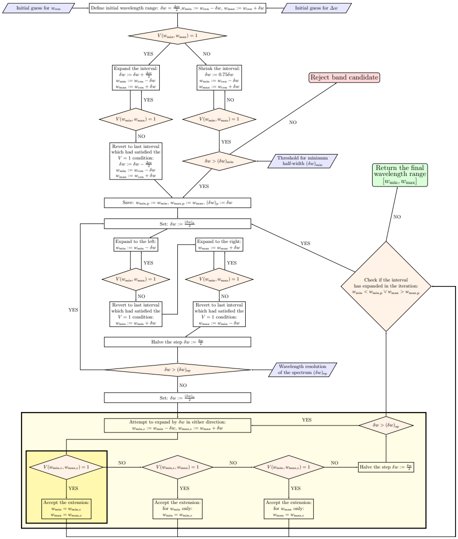


After the first loop

$$w_{max} - w_{min} = 0.309\mu m$$

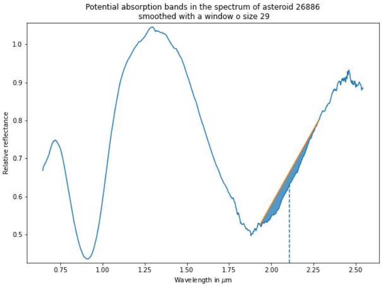


Absorption band detection - algorithm

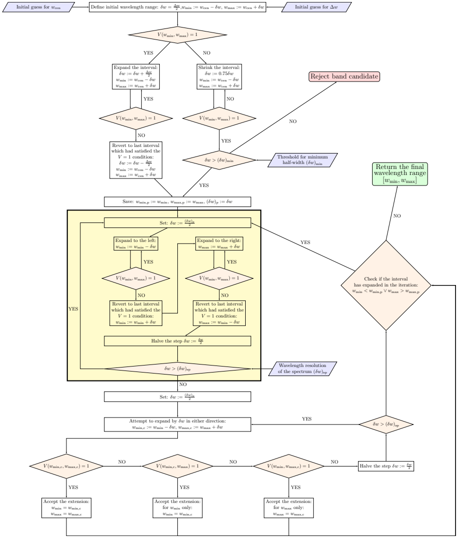


Halving a step until extended

$$w_{max} - w_{min} = 0.347\mu m$$

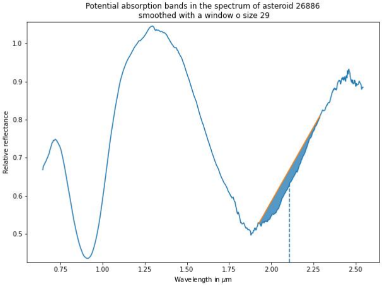


Absorption band detection - algorithm



Another iteration

$$w_{\max} - w_{\min} = 0.366\mu\text{m}$$



Empirical formulas - corrections

Temperature:

$$T = \sqrt[4]{\frac{(1-A)L_{\odot}}{16\epsilon\sigma d^2}}$$

$$\Delta\mathrm{BAR} = 0.00075\,T - 0.23$$

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Ordinary chondrites (S-complex?)

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Howardites and eucrites (V class)

$$\Delta \text{BI} = 0.01656 - 0.0000552T$$

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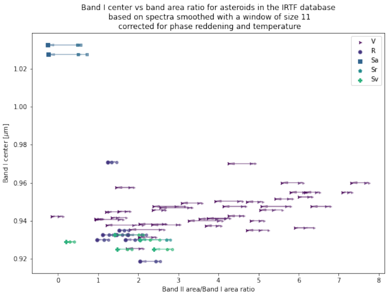
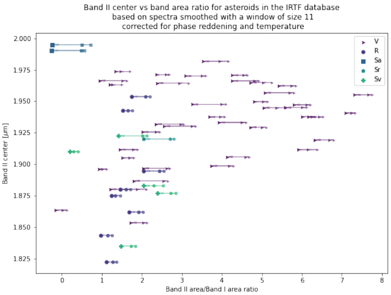
Phase angle:

$$\Delta \mathrm{BAR} = -0.0292 \cdot \alpha$$

Corrections in practice





Empirical formulas - mineralogy

Ordinary chondrites (S-complex?)

$$\frac{\mathrm{opx}}{\mathrm{opx}+\mathrm{ol}} = 0.242 \cdot \mathrm{BAR} + 0.272 \ , \ \frac{\mathrm{ol}}{\mathrm{opx}+\mathrm{ol}} = -0.242 \cdot \mathrm{BAR} + 0.728$$

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$$\frac{\mathrm{fa}}{\mathrm{ol}} = -12.849\cdot(\mathrm{BI})^2+26.565\cdot\mathrm{BI}-13.423$$

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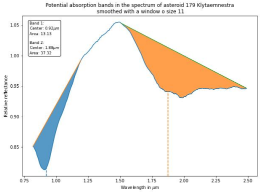
Howardites and eucrites (V class)

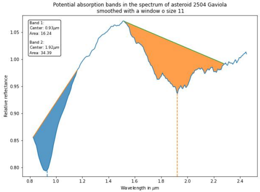
$$\frac{\mathrm{fs}}{\mathrm{px}} = 10.234 \cdot \mathrm{BI} - 9.1382$$

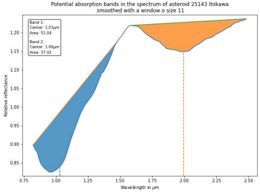
$$\frac{\mathrm{wo}}{\mathrm{px}} = 3.961 \cdot \mathrm{BI} - 3.6055$$

IRTF S-complex asteroids

Asteroid	$\frac{\text{opx}}{\text{opx+ol}}$	$\frac{\text{fa}}{\text{ol}}$	$\frac{\text{fs}}{\text{px}}$
	Sv class		
1662 Hoffmann	**63.0%**	17.8%	15.7%
179 Klytaemnestra	85.0%	17.8%	15.7%
1858 Lobachevskij	32.0%	18.7%	16.4%
2042 Sitarski	76.5%	21.0%	18.0%
2504 Gaviola	**61.3%**	19.5%	16.9%
	Sr class		
17 Thetis	76.6%	18.8%	16.5%
	Sa class		
25143 Itokawa	*21.5%*	30.6%	25.3%
43 Ariadne	*21.1%*	30.7%	25.4%

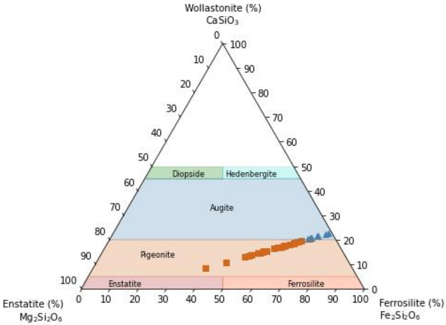


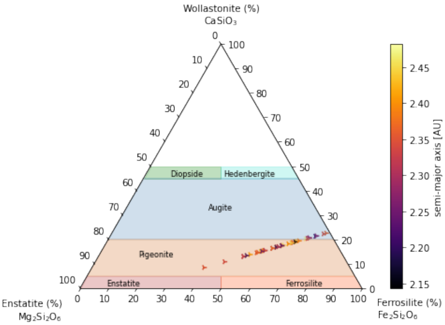




IRTF V class asteroids

$$\frac{fs}{px} = 10.234 \cdot BI - 9.1382 \; , \; \frac{wo}{px} = 3.961 \cdot BI - 3.6055$$





Conclusions

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- Including Modified Gaussian Model and Shkuratov model in the code could help support the statements made and discover further insights into the data