DL3: AN OPEN HIGH-LEVEL FORMAT FOR GAMMA-RAY ASTRONOMY

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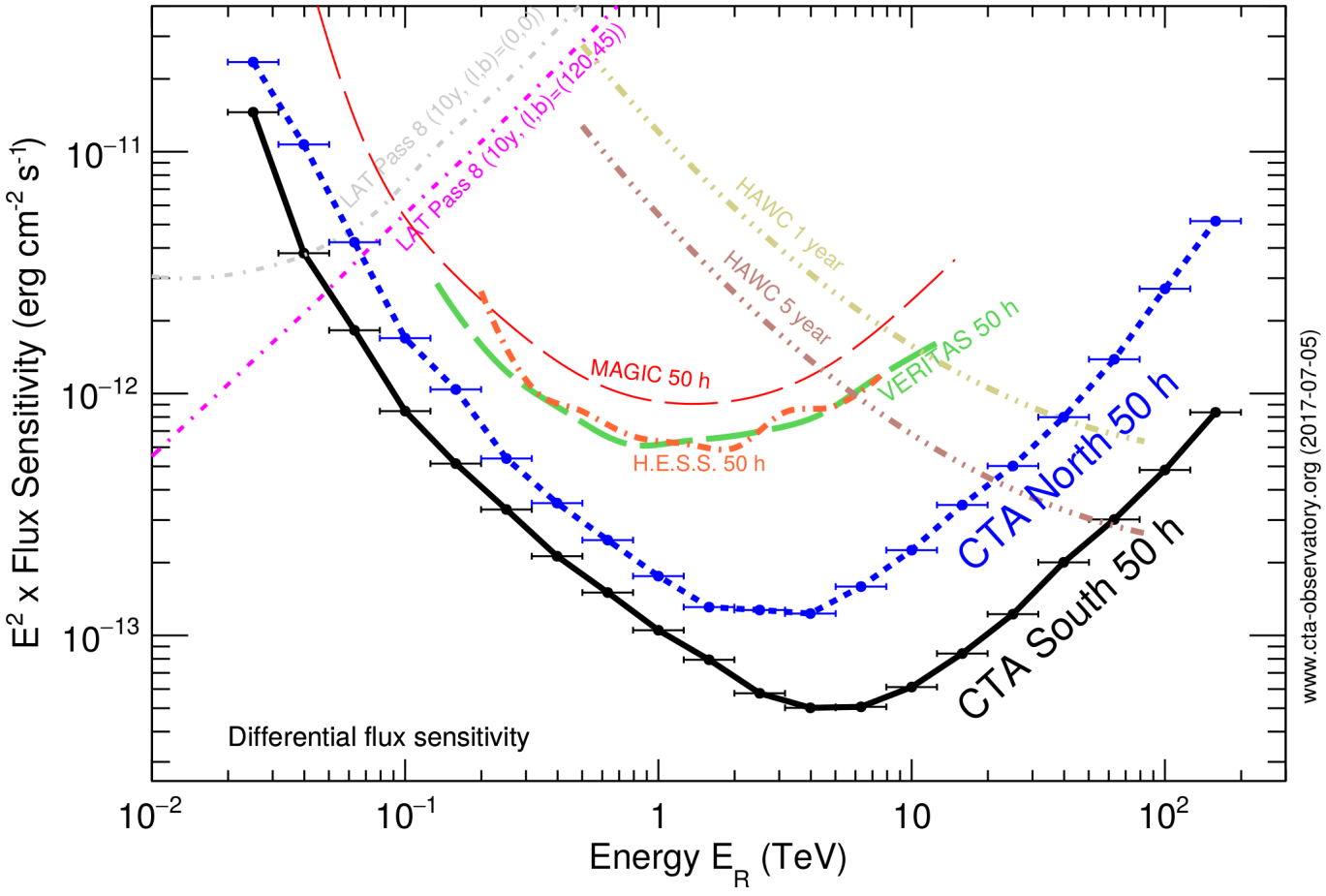
CURRENT/FUTURE INSTRUMENTS

- Exciting times for gamma-ray astronomy!



CURRENT PARADIGM

- Except Fermi-LAT, all VHE gamma-ray instruments have been operating as experiments:

  - Collect private data, distributed only within collaborators
  - Proprietary software (analysis tools)
  - Private data formats, not usable by the community

- This will change with the future Cherenkov Telescope Array (CTA)

  - Will operate as an open observatory
  - Open source software (analysis and science tools)
  - Data will become public as FITS files (DL3 format)

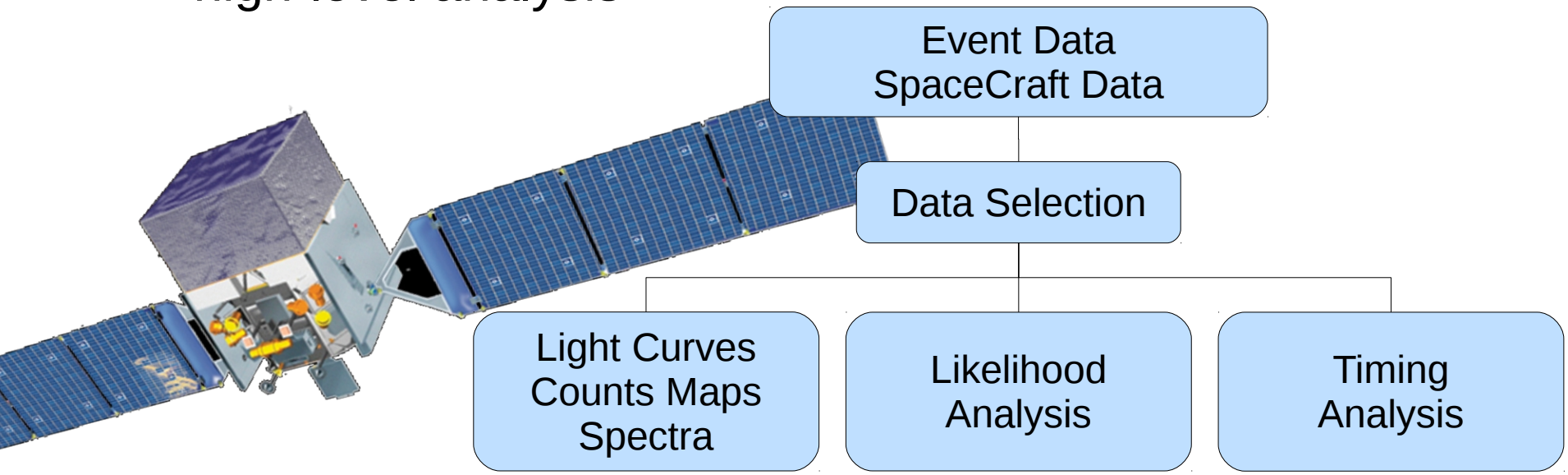
DL3 DATA FORMAT

- DL3 is the high-level product (FITS format) resulting from the analysis of collected data containing:
  - Event lists (event-wise energy, RA, DEC, time...) of gamma-like events
  - IRFs describing the instrument performance (Eff. Area, BG rate, direction/energy dispersion)
  - TECH data describing details of the observations (pointing, obs. conditions, etc..)

DL3 = EVT3 + IRF3 + TECH3

DL3 DATA FORMAT

- Fermi-LAT uses this (very successful) approach:
  - Scientists download event lists (EVT3) + spacecraft data (~TECH3)
  - Together with LAT IRFs (IRF3), gtools performs the high-level analysis



DL3 OBJECTIVES

- Initiative to develop an open DL3 data format (C. Deil)

- Common effort to define an open DL3 format by current IACT experiments:
  - Combined IACT analysis
  - Cross-calibration
  - Data archive

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  - Combined IACT analysis
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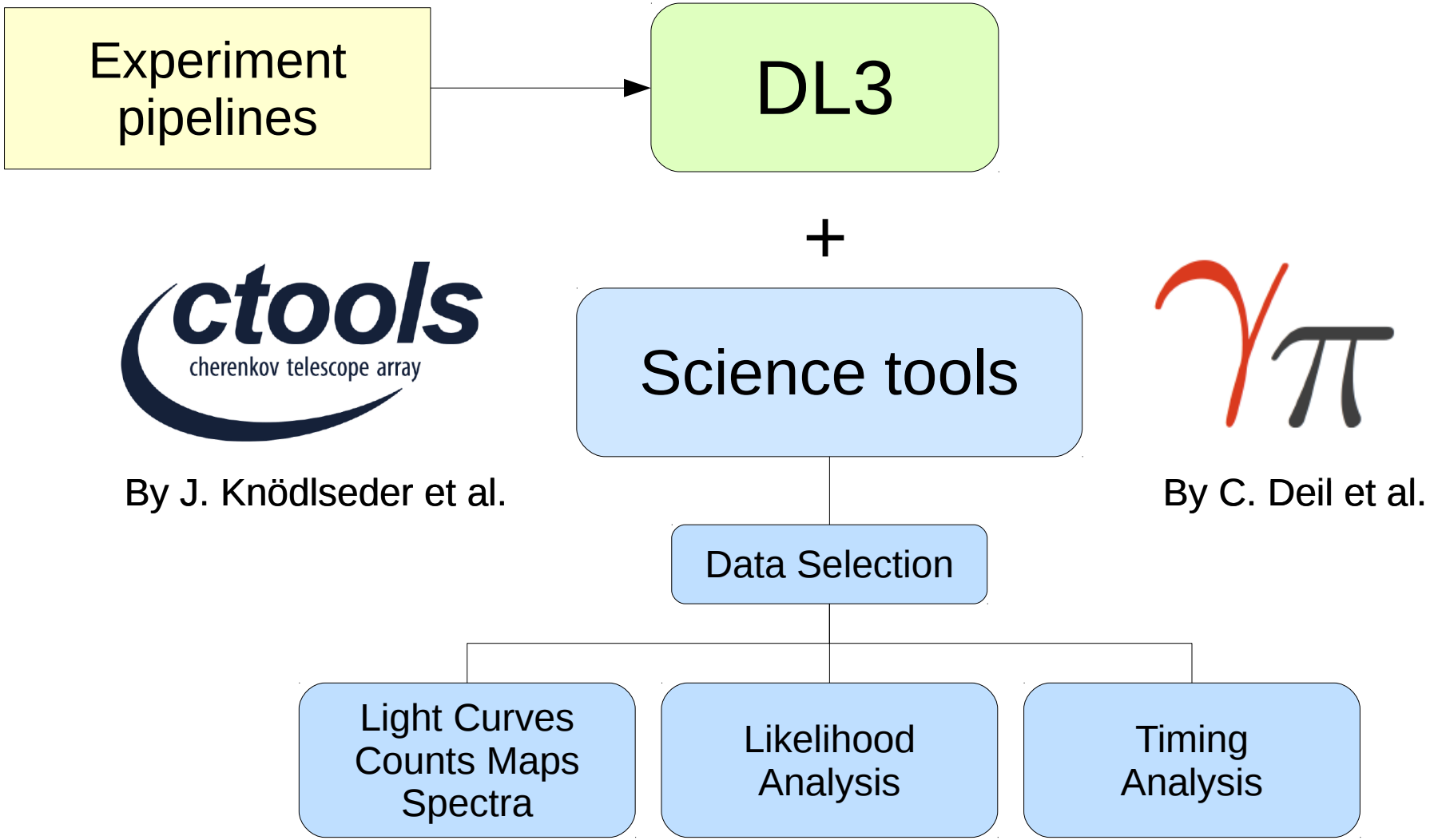
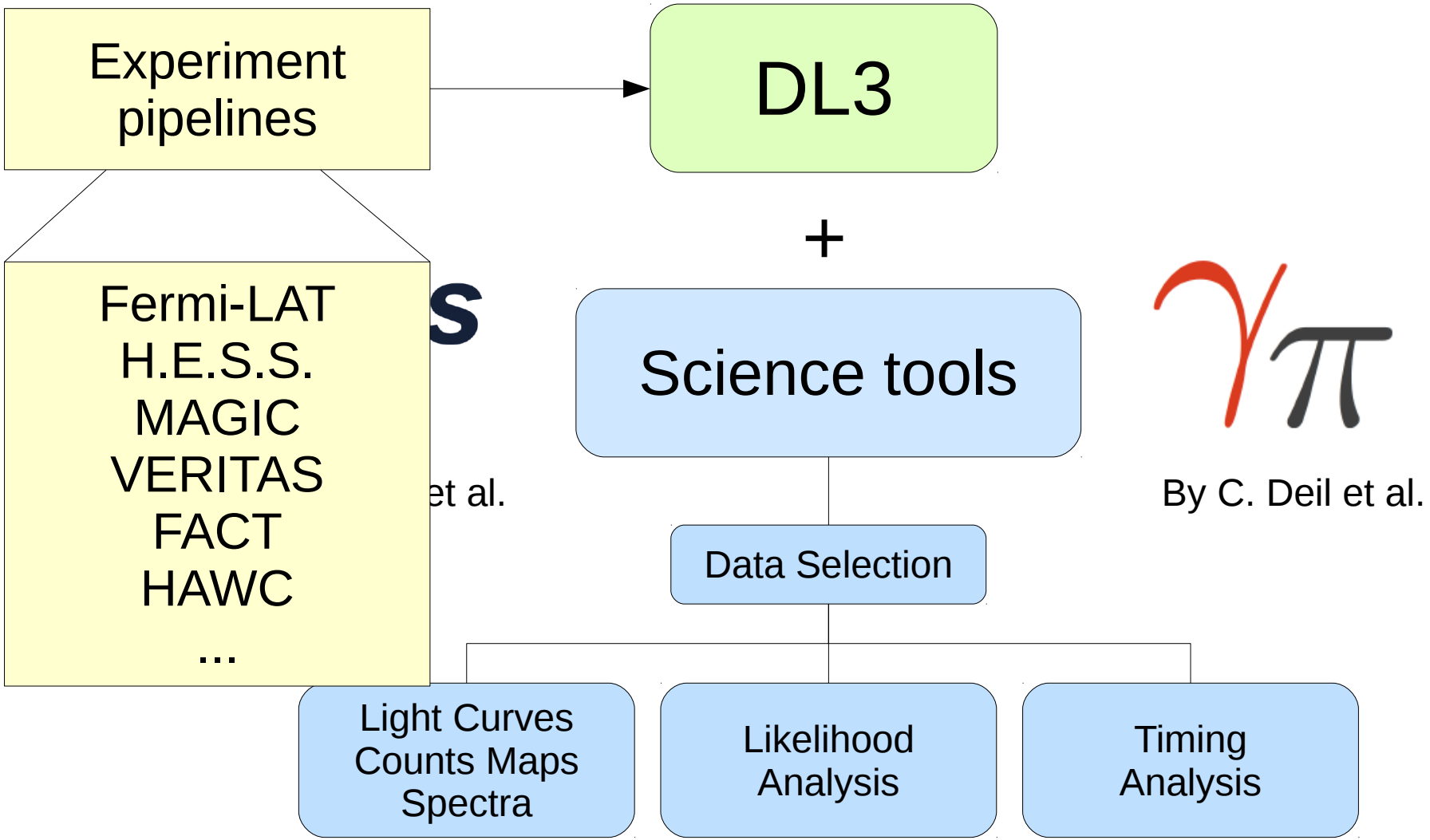
  - Data archive

  - Use case identification
  - DL3 format validation
  - Science tools validation

OPEN DATA WITH OPEN TOOLS



OPEN DATA WITH OPEN TOOLS



DL3 DEVELOPMENT

- On-going effort to define the specs of an open gamma-ray data format:

`https://github.com/open-gamma-ray-astro/gamma-astro-data-formats.git`

- Development of an open source C++ FITS IRF3 generator:

`https://github.com/cta-observatory/flexIRF.git`

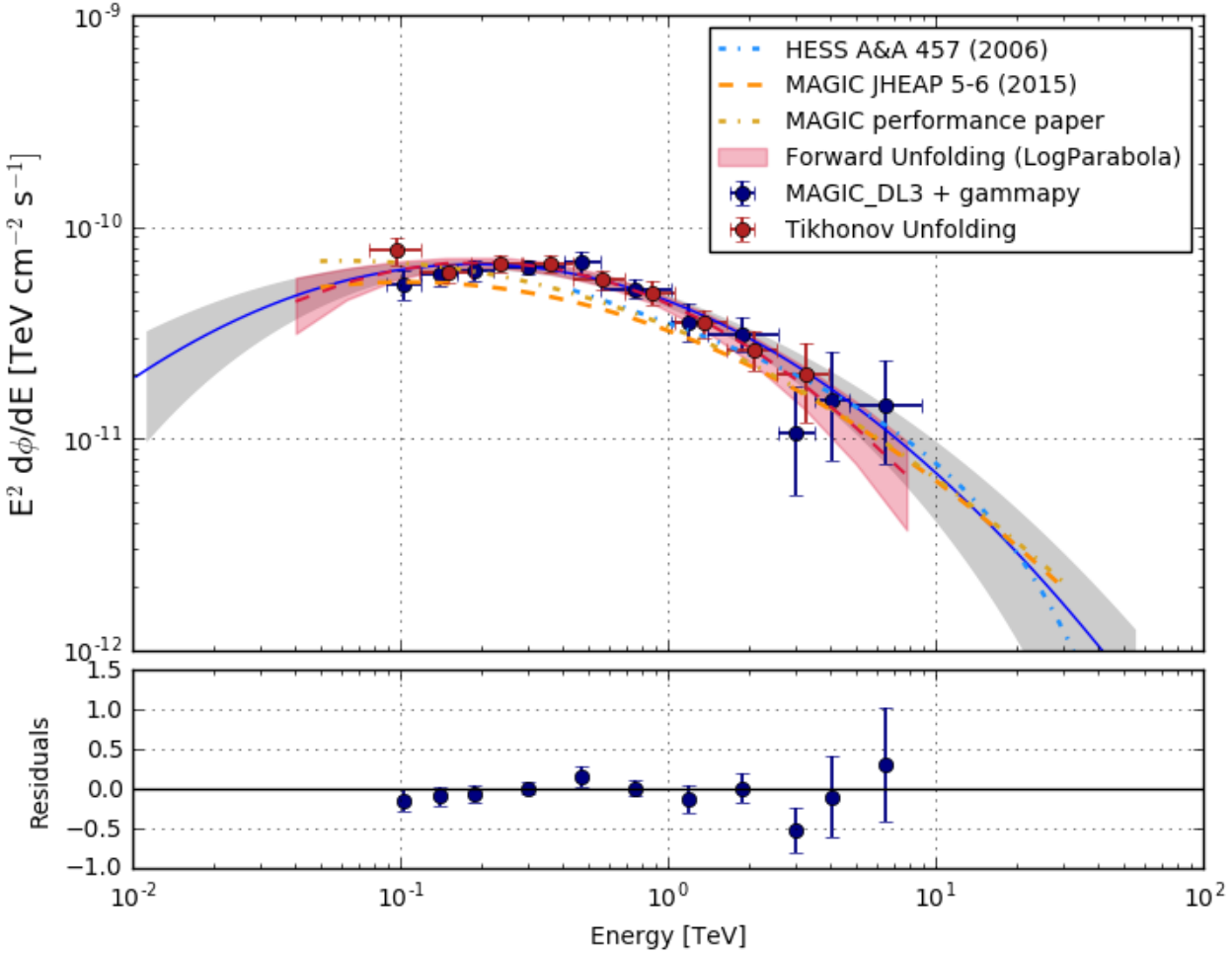
  - Served as prototype for the future CTA software
  - May be used by any experiment generating DL3 data (currently used for MAGIC DL3 data)

DL3 DEVELOPMENT

- Developed first MAGIC DL3 converter (private repo)
  - Recently validated by MAGIC Software Board
  - Starting to test and validate science tools

DL3 DEVELOPMENT

- First MAGIC spectrum without “MARS” (using gammapy)



DL3 DEVELOPMENT

- Developed first MAGIC DL3 converter (private repo)
  - Recently validated by MAGIC Software Board
  - Starting to test and validate science tools
- Currently working on a method paper to show the benefits of using the DL3 format:
  - Joint analysis of the Crab Nebula spectrum with data from several experiments
  - The objective is to encourage the use of DL3 in other experiments, openly releasing the data used and allow a common, reproducible analysis with open source tools

CONCLUSIONS

- The development of DL3 format specifications is still on-going, gaining from its use within some experiments
- Current generation of IACTs are starting to dedicate some man power to export their data to DL3 (mainly for multi-experiment analysis and data archive)
- A method paper is under development to encourage the use of this format, and allow a multi-experiment, reproducible, open-source analysis
- DL3 format seems to be a natural point to converge between different “event-based” experiments

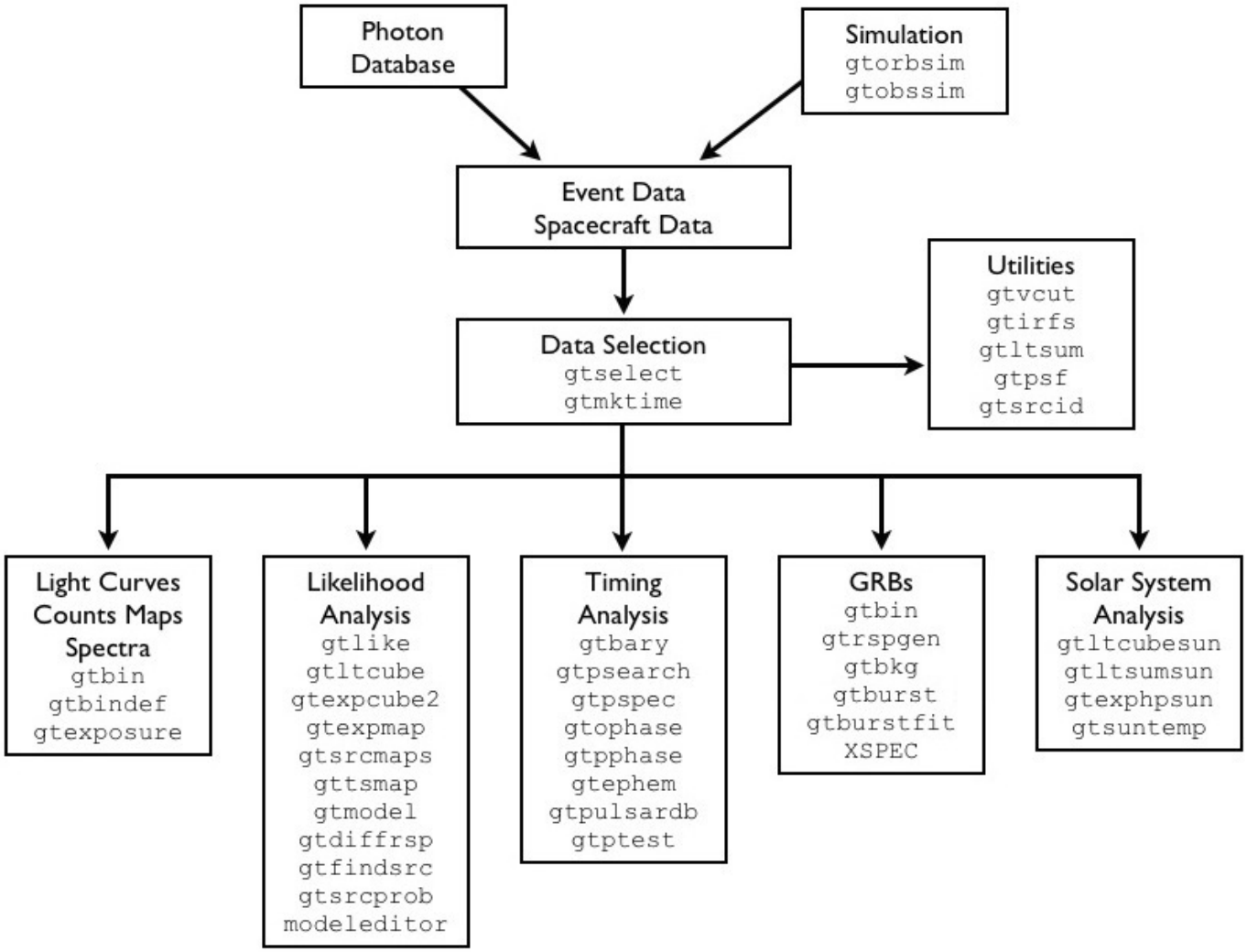

BACKUP

DL3 DEVELOPMENT – EVENT LISTS

Event list

Select / All / Invert	EVENT_ID 1E Modify	TIME 1E ms Modify	RA 1E deg Modify	DEC 1E deg Modify	ENERGY 1E TeV Modify	DETX 1E deg Modify
1	2.102000E+03	-1.235358E+04	8.300000E+01	2.200000E+01	4.158058E-02	-3.782977E-01
2	2.128000E+03	-1.235348E+04	8.300000E+01	2.200000E+01	8.006359E-01	7.463800E-02
3	2.132000E+03	-1.235347E+04	8.300000E+01	2.100000E+01	5.360562E-02	2.766988E-01
4	2.233000E+03	-1.235303E+04	8.500000E+01	2.200000E+01	5.537908E-02	3.413149E-01
5	2.251000E+03	-1.235295E+04	8.200000E+01	2.100000E+01	1.010068E-01	-1.937702E-01
6	2.262000E+03	-1.235291E+04	8.400000E+01	2.200000E+01	5.455283E-02	4.099209E-01
7	2.263000E+03	-1.235291E+04	8.400000E+01	2.200000E+01	2.786112E-01	-1.931990E-02
8	2.272000E+03	-1.235288E+04	8.400000E+01	2.100000E+01	4.362389E-02	4.822730E-01
9	2.303000E+03	-1.235270E+04	8.300000E+01	2.200000E+01	4.249199E-02	-7.881756E-02
10	2.361000E+03	-1.235245E+04	8.300000E+01	2.200000E+01	3.423890E-02	-3.592524E-01
11	2.378000E+03	-1.235238E+04	8.400000E+01	2.200000E+01	3.749027E-02	4.004716E-01
12	2.405000E+03	-1.235224E+04	8.300000E+01	2.100000E+01	3.146259E-01	7.247214E-01
13	2.427000E+03	-1.235213E+04	8.300000E+01	2.200000E+01	2.106351E-01	-4.061462E-01
14	2.550000E+03	-1.235168E+04	8.200000E+01	2.300000E+01	3.580425E-01	-1.274018E+00
15	2.596000E+03	-1.235140E+04	8.400000E+01	2.100000E+01	9.791556E-02	9.428987E-01
16	2.610000E+03	-1.235133E+04	8.400000E+01	2.200000E+01	8.045276E-02	-4.927695E-01
17	2.617000E+03	-1.235130E+04	8.300000E+01	2.200000E+01	1.284512E-01	-3.097619E-01
18	2.625000E+03	-1.235127E+04	8.300000E+01	2.200000E+01	5.889448E-02	5.282745E-02
19	2.636000E+03	-1.235123E+04	8.300000E+01	2.200000E+01	6.852181E-02	-1.694564E-01
20	2.660000E+03	-1.235113E+04	8.300000E+01	2.200000E+01	7.210232E-02	-7.135937E-01

FERMI-LAT ANALYSIS SCHEME



MAGIC DL3 FITS FILE

Index	Extension	Type	Dimension	View
0	Primary	Image	0	Header | Image | Table
1	EVENTS	Binary	7 cols X 515913 rows	Header | Hist | Plot | All | Select
2	GTI	Binary	2 cols X 1 rows	Header | Hist | Plot | All | Select

```
XTENSION= 'BINTABLE'           / binary table extension
BITPIX  =                    8 / 8-bit bytes
NAXIS   =                    2 / 2-dimensional binary table
NAXIS1  =                   28 / width of table in bytes
NAXIS2  =               515913 / number of rows in table
PCOUNT  =                    0 / size of special data area
GCOUNT  =                    1 / one data group (required keyword)
TFIELDS =                    7 / number of fields in each row
TTYPE1  = 'EVENT_ID'           / label for field   1
TFORM1  = '1J      '           / data format of field: 4-byte INTEGER
TZERO1  =           2147483648 / offset for unsigned integers
TSCAL1  =                    1 / data are not scaled
TTYPE2  = 'TIME    '           / label for field   2
TFORM2  = '1D      '           / data format of field: 8-byte DOUBLE
TTYPE3  = 'RA      '           / label for field   3
TFORM3  = '1E      '           / data format of field: 4-byte REAL
TTYPE4  = 'DEC     '           / label for field   4
TFORM4  = '1E      '           / data format of field: 4-byte REAL
TTYPE5  = 'ENERGY  '           / label for field   5
TFORM5  = '1E      '           / data format of field: 4-byte REAL
TTYPE6  = 'DETX    '           / label for field   6
TFORM6  = '1E      '           / data format of field: 4-byte REAL
TTYPE7  = 'DETY    '           / label for field   7
TFORM7  = '1E      '           / data format of field: 4-byte REAL
EXTNAME = 'EVENTS  '           / name of this extension
DSTYP1  = 'TIME    '           / Data selection type
DSUNI1  = 's       '           / Data selection unit
DSVAL1  = 'TABLE   '           / Data selection value
DSREF1  = ':GTI    '           / Data selection reference
DSTYP2  = 'ENERGY  '           / Data selection type
DSUNI2  = 'TeV     '           / Data selection unit
DSVAL2  = '0.05:100'           / Data selection value
DSTYP3  = 'POS(RA,DEC)'        / Data selection type
DSUNI3  = 'deg     '           / Data selection unit
DSVAL3  = 'CIRCLE(83.63,22.01,5)' / Data selection value
NDSKEYS =                    3 / Number of data selections
CREATOR = 'GammaLib'           / Program which created the file
TELESCOP= 'CTA     '           / Telescope
OBS_ID  =                    0 / Observation identifier
DATE_OBS= '2000-01-01'         / Observation start date
TIME_OBS= '11:58:56'           / Observation start time
DATE_END= '2000-01-01'         / Observation end date
TIME_END= '16:58:56'           / Observation end time
TSTART  =     0.0000000000E+00 / [s] Mission time of start of observation
TSTOP   =     1.8000000000E+04 / [s] Mission time of end of observation
```

Select / All	EVENT_ID 1J	TIME 1D	RA 1E	DEC 1E	ENERGY 1E	DETX 1E	DETY 1E
Invert	Modify	Modify	Modify	Modify	Modify	Modify	Modify
1	1	2.397572994232E-02	8.353593E+01	2.215344E+01	8.455203E-02	1.434710E-01	-8.712047E-02
2	2	8.855068484741E-01	8.338653E+01	2.195801E+01	6.720489E-02	-5.780557E-02	-2.258224E-01
3	3	6.328638792038E-01	8.365913E+01	2.202861E+01	2.487579E-01	1.861718E-02	2.700173E-02
4	4	8.609145879745E-01	8.372632E+01	2.199091E+01	1.695516E-01	-1.906472E-02	8.930850E-02
5	5	2.928359031677E+00	8.362905E+01	2.197774E+01	4.313511E-01	-3.826523E-02	-8.767702E-04
6	6	3.496328294277E+00	8.364494E+01	2.198923E+01	1.299195E+00	-2.076370E-02	1.384718E-02
7	7	3.575277268887E+00	8.383803E+01	2.206729E+01	6.010984E-02	5.748410E-02	1.927874E-01
8	8	3.589436173439E+00	8.356826E+01	2.214618E+01	5.440156E-02	1.361896E-01	-5.718500E-02
9	9	3.690046191216E+00	8.366623E+01	2.196728E+01	9.453136E-02	-4.272123E-02	3.359674E-02
10	10	3.754259884357E+00	8.359633E+01	2.198341E+01	2.497413E-01	-2.658356E-02	-3.121975E-02
11	11	4.319278458553E+00	8.354993E+01	2.209559E+01	9.216410E-02	8.561151E-02	-7.419150E-02
12	12	4.349958181381E+00	8.363425E+01	2.196966E+01	5.602710E-01	-4.033871E-02	3.940071E-03
13	13	4.985730230808E+00	8.356156E+01	2.205876E+01	3.919547E-01	4.877189E-02	-6.342776E-02
14	14	5.203840672970E+00	8.360130E+01	2.203228E+01	2.080766E-01	2.228508E-02	-2.660451E-02
15	15	5.258406239510E+00	8.362759E+01	2.194611E+01	2.995812E-01	-6.388974E-02	-2.230369E-03
16	16	6.177644848884E+00	8.367763E+01	2.205482E+01	7.104060E+00	4.488873E-02	4.414181E-02
17	17	6.200068771839E+00	8.362698E+01	2.198557E+01	2.075521E+00	-2.443545E-02	-2.801457E-03
18	18	6.817017197609E+00	8.363071E+01	2.204873E+01	3.110885E+00	3.872707E-02	6.649218E-04
19	19	6.981744108200E+00	8.366418E+01	2.193019E+01	8.429521E-02	-7.981040E-02	3.170175E-02
20	20	7.428642749786E+00	8.366555E+01	2.194017E+01	8.972213E-02	-6.982647E-02	3.297719E-02
21	21	7.571149289608E+00	8.355811E+01	2.190122E+01	1.928910E-01	-1.087616E-01	-6.669964E-02
22	22	7.784871039391E+00	8.360066E+01	2.184618E+01	6.759296E-02	-1.638156E-01	-2.722808E-02
23	23	8.338782250881E+00	8.345876E+01	2.176492E+01	5.452184E-02	-2.449886E-01	-1.590407E-01