ALMA Memo 464

Comparison of the audits of the AIPS++, GILDAS and MIRIAD packages for ALMA off-line data processing

J. Pety[1,2], F. Cosson[1], F. Gueth[1],
S. Guilloteau[1,3], R. Lucas[1],
P. Teuben[4] and M. Wright[5]

1. IRAM (Grenoble)
2. LERMA, Observatoire de Paris
3. European Southern Observatory
4. Astronomy Department, U. Maryland
5. Radio Astronomy Laboratory, U.C. Berkeley

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Abstract

In this memo, we compare the results of an audit of the AIPS++, GILDAS and MIRIAD packages for compliance with the ALMA Offline Data Processing Requirements. These audits show that about 2/3 of the SSR Requirements are fulfilled by each data reduction package, and almost 90% are fulfilled if we use existing software from all three packages.

In a companion memo (465), we thus argue that ALMA will benefit greatly by using software from the existing packages which were designed for millimeter arrays. Indeed ALMA would then benefit of the daily use and expertize for the current working millimeter arrays over the next 10 years of ALMA construction.

1 Introduction

This memo is a comparison of three different data reduction packages (DRP) with the aim to see how they fulfill the ALMA needs for off-line reduction software. The three packages, which represents the state-of-art of the data reduction packages for λ mm radio interferometry, are:

AIPS++ was developed by a consortium to fulfill the need of various λ cm radioastronomy telescope projects. The consortium was recently dissolved in order that the participants could focus on the specific needs of the individual telescope projects. The AIPS++ code generated by the consortium remains available to all. AIPS++ is the current baseline plan for the ALMA computing IPT for all reduction software (*i.e.* pipeline and off-line).

GILDAS is a collection of software developed at IRAM and Obs. de Grenoble. There is a general one for data visualization (GREG), one for single-dish spectrum analysis (CLASS), one for interferometer calibration (CLIC), one for bolometer data reduction (NIC), and one for aperture synthesis and deconvolution (MAPPING). Those programs are currently used by the IRAM millimeter telescopes: single-dish (30m) and interferometer (PdBI). CLASS is also used by many observatories over the world to reduce and analyse radioastronomy Single-Dish spectra.

MIRIAD was developed by a group of BIMA astronomers and programmers for use with the BIMA millimeter array (for a concise retrospective summary of MIRIAD see Sault, Teuben, & Wright, 1995). As it's acronym implies, the focus was on Multichannel Image Reconstruction, for which it is also widely used outside of BIMA institutions (notably ATNF and WSRT). The Image Analysis and Display part of MIRIAD is less well developed. Polarization processing was developed for use with the ATCA telescope with dual linear polarization and for the BIMA telescope with switched (time shared) circular, or linear polarization.

Benchmarking and other efforts have shown that GILDAS and MIRIAD are able to handle ALMA-size datasets. Current benchmarks show they are faster than AIPS++ for ALMA dataset on a representative set of today's machines (*e.g.* see phase III of AIPS++ Reuse Analysis Test). GILDAS and MIRIAD use older software techniques than AIPS++. However, what seems important to us is that these techniques enable us to produce robust and very fast programs without any cumbersome tuning (*i.e.* profiling). These software techniques are also easier to understand by most astronomers than brand new ones.

Section 2 makes a synthetic comparison of the ways GILDAS and MIRIAD handle the main different aspects of the off-line needs. To make a quantitative comparison, we have audited GILDAS and MIRIAD following the same template that was used for the AIPS++ audit for compliance with the ALMA Offline Data Processing Requirements (SSR). The detailed audits of the GILDAS and MIRIAD software packages may be found respectively in ALMA memos 462 and 463. Section 3 analyses the results of these audits.

2 Synthetic comparison of GILDAS and MIRIAD

This is a comparison of how GILDAS and MIRIAD handle the different parts of the off-line data reduction, *i.e.* the user interface, the data structure, the data calibration and editing, the imaging and data analysis. The way AIPS++ handles those aspects is not included because none of us is an AIPS++ specialist.

2.1 User interface

"The user must be able to choose from a variety of interface styles, including a Command Line Interface (CLI), with access via both an interactive input and via script. A Graphical User Interface (GUI) must be provided for interactive processing." The two packages have had a different approach to these requirements. MIRIAD was designed as separate tasks which can be run from the host operating system. Each MIRIAD task has a number of parameters which can be specified using keywords. MIRIAD can be run using any language, shell or GUI which is able to parse a command line. The MIRIAD user interface is thus decoupled from GUI development, and it is easy to add one. The GILDAS package includes several interactive programs. All interactive programs uses the same built-in command line interface, SIC, and the same high level graphic library (GREG). SIC also incorporates a built-in GUI constructor. The GUI allows to setup any SIC variable, and to launch any SIC command or procedure.

2.2 Data handling

Both MIRIAD and GILDAS were designed for efficient handling of multichannel data. They have quite different internal data structures but they can exchange data using FITS.

MIRIAD has two types of data structures: uvdata and image data. Both are implemented as directory structures which have proved to be very flexible. The history of the observation and data reduction, including the steps and parameters used in observing and reducing the data are stored in the data structures, and other data such as WVR data, and a copy of the observing script and parameters, can be easily added.

GILDAS has a specific data handling scheme which distinguishes between raw and calibrated visibilities, and images. During calibration visibilities are stored in the calibration data format, which is an extensible format, with direct and indexed access for speed. When imaging is required, a simple table of calibrated UV data is created in the image format.

2.3 Calibration and editing

MIRIAD and GILDAS have calibration techniques which take into account low signal to noise conditions. They also use a similar model of separation of time and frequency dependence for gain and bandpass, namely: the antenna gains can vary with time but not frequency while the antenna bandpass can vary with frequency but not time. Gain and bandpass are complex values. In addition, MIRIAD is able to calibrate polarization leakage. GILDAS can perform antenna-based or baseline-based calibrations. GILDAS calibration curves are not stored on a value per sample basis. Instead the coefficients of the spline or polynomial fits are stored and the calibration computed on the fly when needed. This saves space.

MIRIAD calibration tables can be displayed, copied and to a limited extent edited or averaged. GILDAS has elaborate data flagging capabilities. Flags can be antenna or baseline based, and can be masked by the user. Separate named flags are available for various items of the interferometer (continuum sub-bands, line sub-bands) or potential problems (e.g. Timing, Pointing, LO2, shadowing, ...). GILDAS also has a quality indicator, ranging from 0 to 7, which can be used as a selection criterion.

2.4 Imaging

GILDAS and MIRIAD have intrinsic capabilities for spectral line imaging from a collection of uvdata sets. Several weighting options are supported (natural, uniform, robust, tapering). They both have mosaicing modes. Several deconvolution methods are available in each package. Both have several variants of the CLEAN algorithm. Maximum entropy methods are implemented inside MIRIAD while the WIPE deconvolution technique, which enables a determination of the major modes of deconvolution errors, is implemented inside GILDAS. MIRIAD is able to image Stokes I, Q, U, V parameters after applying polarization leakage calibration. Several deconvolution methods inside GILDAS are interactive, allowing the user to change support and loop gain on major cycles or to gracefully interrupt the deconvolution based on the flux convergence. GILDAS provides automatic parameter estimation, so that the whole imaging process can be done with one command with no parameters (*e.g.* GO IMAGE for single field).

2.5 Data analysis

GILDAS and MIRIAD aim at being "full service" data reduction packages for radio astronomy from data taking at the telescope to image analysis and publication quality displays.

For MIRIAD, the initial decision in 1988 was to develop a separate data analysis package. That development failed, and MIRIAD was extended to cover this area. Many users have contributed analysis tasks to MIRIAD; some of the tasks are quite old but the simple interfaces enabled these programs to be easily incorporated as separate tasks within the MIRIAD package, providing a core of well used analysis and display tasks which have stood the test of time (survival of the fittest ?).

The GILDAS environment has often been the basis of development of advanced techniques of scientific analysis by standard users. Those tools may be private, as radiative transfer tools adapted to the study of YSO disks. They may also be public, as GAUSSCLUMPS which decomposes a 3-dimensional data cube (2 spatial coordinates, one spectral coordinate) into a series of clumps with a Gaussian shape. GAUSSCLUMPS has been developped in Germany by a group of people led by J. Stutzki and C. Kramer (See Stutzki & Guesten, 1990 and Kramer et al., 1998).

3 Quantitative comparison of the three audits

In this section, we compare the audits of AIPS++, GILDAS and MIRIAD made for the purposes of ascertaining their compliance with the ALMA Offline Data Processing Requirements given in ALMA-SW Memo 18.

3.1 Conditions of the audits

The comparison was made using the following audits.

- The audit of the AIPS++ software Package was made in mid-2002 by S. Myers, F. Viallefond, K.-I. Morita. The auditing procedure was designed for this particular audit.
- The GILDAS audit was made by Pety, Gueth, Guilloteau and Lucas in January 2003. This audit may be found as ALMA memo 462.
- The MIRIAD audit was made by Wright and Teuben in March 2003. This audit may be found as ALMA memo 463.

The GILDAS and MIRIAD audits have been done using the same protocol, *i.e.* we have kept exactly the same priorities, the same grading system, the same way of giving comments when something must be improved or added. More precisely, ALMA Offline Data Processing Requirements given in ALMA-SW Memo 18 were graded using the following scheme (directly quoted from the AIPS++ audit):

- "We use a descriptive scheme, with a set of grade codes stating how well the Package fulfills a given requirement: Adequate (A), Inadequate (I), Not Available (N), and Unable to Evaluate (U). The latter is used for items could not be properly evaluated at this time (e.g. items related to the tbd ALMA data format). There is an additional qualifier for "adequate" items (A/E) that indicates desired enhancements to the package."
- "For items deemed inadequate (I) or missing (N), or which are adequate but enhancements are desired (A/E), the reasons for this are listed. Where possible, a *severity level* for the failure is noted: low, medium, high. This is based upon the importance of the requirement and the margin of failure of the package for the requirement. Note that a subjective choice is made between items at are adequate but could use further improvement (A/E), and those deemed (I) but low severity."
- "The priority codes, as given in ALMA-SW Memo 18 and repeated here, are:

  1 = critical

2 = important

3 = desirable

It is intended that Priority 1 items must be present in the Package and work with high efficiency. Priority 2 items should be in the Package, though there may have to be sacrifices in performance or availability may be delayed. We expect that the Package will fulfill all Priority 1 and 90% or more of Priority 2 requirements. Priority 3 items should be considered for upgrades or development."

3.2 Possible biases

Here is a collection of points that the reader must have in mind when analyzing the audit results:

- The AIPS++ audit is mainly based on documentation. In contrast, most of the features described in the GILDAS and MIRIAD audit are tested with daily usage.
- This kind of auditing is not a completely objective process. The grades and severities may depend a bit on the auditor. In particular, the boundaries between A and A/E and between A/E and I is sometimes thin. This probably leads to a 5% uncertainty level in the tables and the figures shown as pie-charts.
- Weighting the results by priorities is insufficient. Inside those grades, all the requirements have the same weights. For instance, the speed performances is one requirement (OL-1.1-R4) and thus has the same weight as one of the seven standard time systems (section OL-3.1-R8) or the 6 standard coordinate systems (section OL-3.1-R9) that should be supported. This is not quite right as it is larger problem to increase the speed of a package than to add a new time or coordinate system.
- The audit priorities are sometimes arguable. We must ensure that the DRP will allow ALMA to work in 2007. However are all the time tracking quantities and coordinate systems marked as priority 1 (section OL-3.1-R8 and OL-3.1-R9) are really needed early on? Wouldn't it be better to spend more times on a good interaction with astronomers that will be essential in the early science period?

3.3 Results

The grading system being quite detailed, we summarize the audits results in two tables showing the percentage of off-line requirements which were graded Available (A) or Available but needing Enhancement (A/E) for each DRP. These numbers represent the percentage of requirements which are fulfilled by the DRP. The complementary percentage represent the percentage of requirements which are not fulfilled by the DRP. To quantify the complementarity of the three DRP, those tables also show the percentage of requirements fulfilled by GILDAS and/or MIRIAD (GM symbol in the table) and fulfilled by AIPS++, GILDAS and/or MIRIAD (AGM symbol). Table 1 sorts the requirements by priorities (All meaning all priorities taken together) and Table 2 sorts the requirements by functionalities (GR: General Requirements, DH: Data Handling, UI: User Interface, Vi: Visualization, CE: Calibration and Editing, Im: Imaging, DA: Data Analysis, SF: Special Features, *i.e.* mostly VLBI, pulsars). No priority weighting has been applied in Table 2, *i.e.* critical, important and desirable requirements have the same weight here.

Table 1 shows that all packages fulfill almost 2/3 of the requirements. The core of the requirements seems fulfilled by all the packages. In the remaining parts, the packages are complementary; this is why adding the best grade in each package increases significantly the percentage of requirements fulfilled. The auditing method does not ensure that a particular DRP is adapted to ALMA needs. However it gives an idea of the strengths and weeknesses of each DRP as can be seen in Table 2. However, auditing is not the whole story as discussed in section 3.2. From the summaries of the audits (section 2) and other documents (*e.g.* phase II of the AIPS++ reuse test), the following description of strengths and weaknesses is probably closer to reality:

- Strengths:

AIPS++ Good deconvolution algorithms;

GILDAS Good visualization, good calibration algorithms for low SNR mm interferometry.

MIRIAD Completeness, simplicity of the architecture.

- Weaknesses:

AIPS++ Bad user interface linked to glish infrastructure.

GILDAS No polarization, experimental self-calibration.

MIRIAD User interface too simple by today's standards.

	All	Critical	Important	Desirable
AIPS++	59	66	57	31
GILDAS	67	74	55	54
MIRIAD	68	78	53	57
GM	76	83	64	68
AGM	85	89	80	72

Table 1: Percentage of off-line requirements which were graded Available (A) or Available but needing Enhancement (A/E) for each DRP. These numbers represent the percentage of requirements which are fulfilled by the DRP. To quantify the complementarity of the three DRP, this table also shows the percentage of requirements fulfilled by GILDAS and/or MIRIAD (GM symbol) and fulfilled by AIPS++, GILDAS and/or MIRIAD (AGM symbol). Requirements are here sorted by priorities (All meaning all priorities taken together).

	GR	DH	UI	Vi	CE	Im	DA	SF
AIPS++	55	68	76	40	26	65	57	32
GILDAS	87	66	88	80	63	63	54	24
MIRIAD	87	68	76	78	73	65	57	52
GM	87	74	94	87	74	74	68	56
AGM	87	89	96	92	75	84	84	64

Table 2: Same as Table 1, except that requirements are here sorted by functionalities (GR: General Requirements, DH: Data Handling, UI: User Interface, Vi: Visualization, CE: Calibration and Editing, Im: Imaging, DA: Data Analysis, SF: Special Features, *i.e.* mostly VLBI, pulsars). No priority weighting has been applied, *i.e.* critical, important and desirable requirements have the same weight here.

4 Conclusion

The audits show that about 2/3 of the ALMA off-line requirements as defined by the SSR group are fulfilled by each DRP (AIPS++, GILDAS and MIRIAD). Although the design and usage of the three packages is different, they have complementary strengths, and between them satisfy almost 90% of the SSR requirements.

MIRIAD and GILDAS could serve as the off-line software for ALMA as they have experience in λ mm interferometry and they are able to handle ALMA-size data sets. They use old computer technology but end-users do not care as long as the software is fast, robust and enables them to easily reduce their data.

From those two main conclusions, we argue in a companion memo that ALMA will benefit greatly by using, in addition to AIPS++, software from the existing packages which were designed for millimeter arrays. Indeed those packages summarize almost 15 years of experience in λ mm radio interferometry and will continue to benefit from daily confrontation with real λ mm data over the next 10 years of ALMA construction.

References

[1] Gueth, F., Guilloteau, S., Lucas, R. & Pety, J., 2003, "Audit of the GILDAS package for ALMA Off-line Data Processing", ALMA Memo 462.

[2] Myers, S., Viallefond, F. & Morita, K.-I., 2002, "Audit of the AIPS++ package for ALMA Off-line Data Processing", ALMA-SW memo 19.

[3] Pety, J., Baker, A., Coulais, A., Gueth, F., Shepherd, D., Testi, L. & Wilson, C., 2003, "AIPS++ Reuse Analysis Test: Report on Phase II".

[4] Pety, J., Gueth, F., Guilloteau, S., Lucas, R., Teuben, P. & Wright, M., 2003, "Case for interoperability as an ALMA off-line model.", ALMA Memo 465.

[5] Sault, R.J., Teuben, P.J., & Wright, M.C.H., 1995, in Astronomical Data Analysis Software and Systems IV, ed. R. Shaw, H.E. Payne, & J.J.E.Hayes, ASP Conf. Ser., 77, 433

[6] Wright, M.C.H. & Tauben, P.J., 2003, "Audit of the MIRIAD package for ALMA Off-line Data Processing", ALMA Memo 463.

A Minor comments about audit process

When auditing GILDAS and MIRIAD, we also encountered other minor problems that we list here with the hope that this will help future auditing processes. Some ALMA off-line requirements are:

- confusing: *e.g.* OL-6.3-R9.7 "Scalar arithmetic between different regions (including treatment of masked resions and differently shaped regions)".
  Comment: This may lead to different interpretation and thus to different gradings.

- not very good: *e.g.* OL-7.3-R3 "It shall be possible to interpolate or extrapolate any tabulated quantity onto a visibility or calibration solution point, and then manipulated these like extra visibility information."
  Comment: Is extrapolation a good practice?

- too shallow: *e.g.* OL-2.2-R3 "The use of the GUI shall not entail an excessive learning curve. Average users, with experience with the current generation of packages (e.g. AIPS, GILDAS, IRAF, MIRIAD) shall be able to become proficient in GUI use in a timescale of approximately 12 hours dedicated use, and truly neophyte users (e.g. graduate students) should be reach proficiency with an investment not exceeding 40 hours of dedicated use."
  Comment: 1-2 hours maximum should be enough for average users. 12 hours is not an acceptable target if ALMA wants to attract users.

- luxurious:

  - OL-2.5-R3.3 "Help materials shall also be available in printable formats, including standard document formats (pdf, postscript) and popular proprietary formats (MS-Word)"
    Comment: only PDF should be used (not MS-Word).
  - OL-3.2-R2 "Disk and offline data storage (*e.g.* DAT, DDS, DLT) must be supported. The project will maintain a list of media which the Package must support."
    Comment: Buffer to disk and use system. Anything else is a waste of time nowadays.
  - OL-6.3-R6.1 "Moments along arbitrary user-specified directions in the cube shall be possible."
    Comment: Why is arbitrary orientation needed?

B Visual comparison of the AIPS++, GILDAS and MIRIAD audits

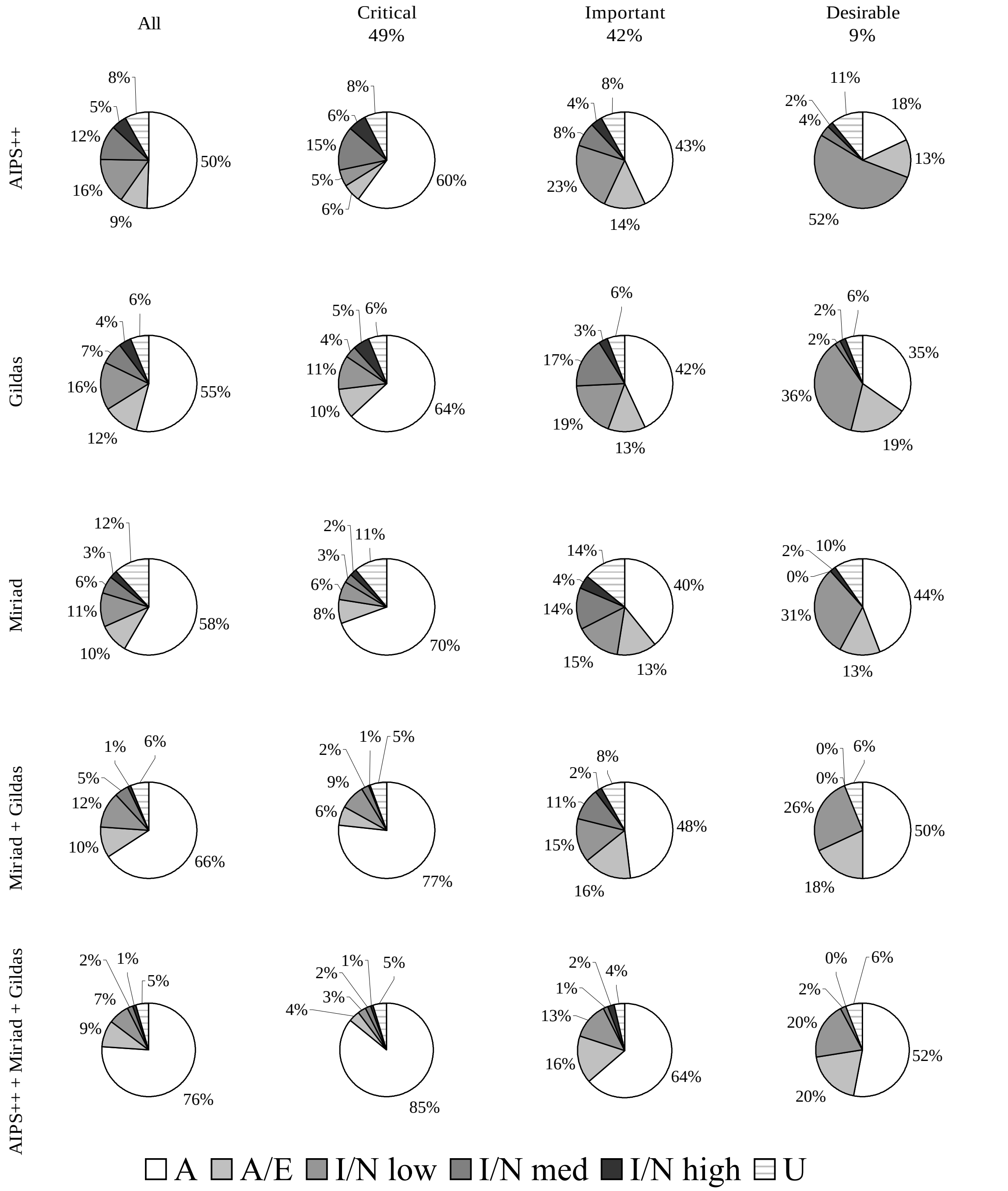

Figure 1: Pie-charts of off-line requirements which were graded Available (A), Available but needing Enhancement (A/E), Inadequate or Not available (I/N) and Unable to evaluate (U). For this last grade, a severity (low, medium, high) were added. All requirements are considered whatever their functionalities. They are sorted by priorities (*i.e.* critical, important and desirable). This has been done for each DRP and for combinaison of DRP. In this latter case, the best grade has been used.

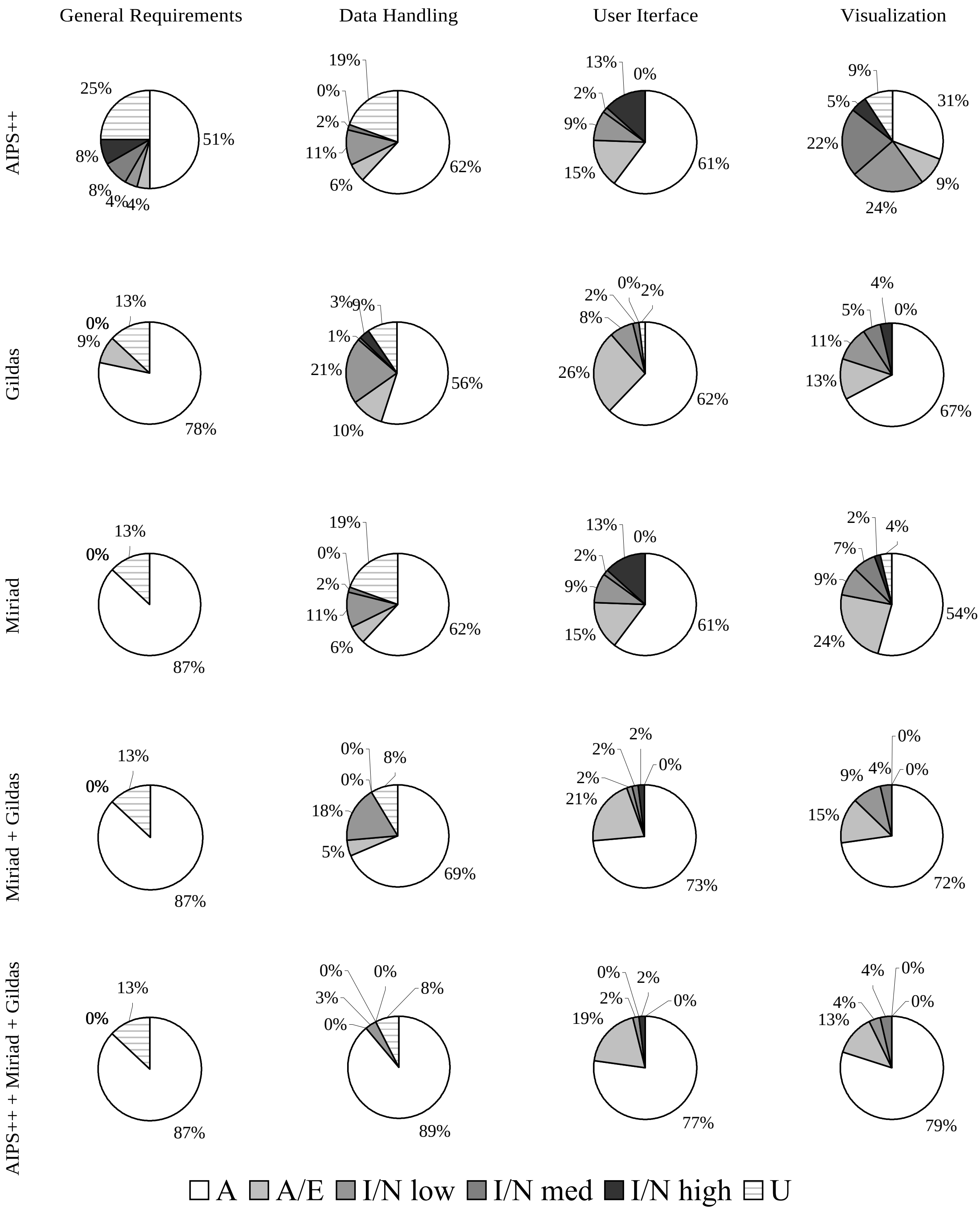

Figure 2: Same as Fig. 1 except that requirements are sorted by functionalities related to user interface: general requirements, data handling, user interface and visualization. Critical, important and desirable features have the same weight.

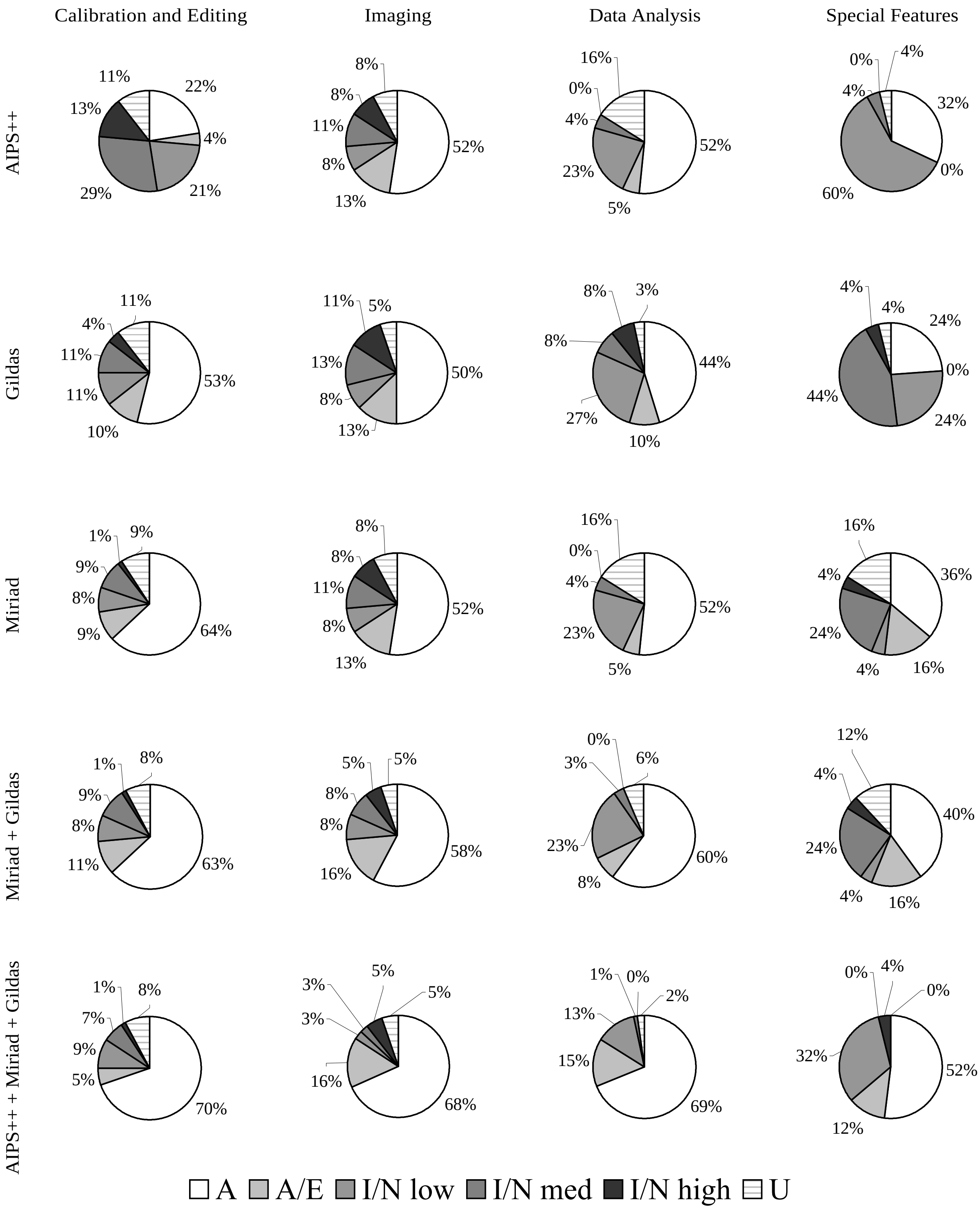

Figure 3: Same as Fig. 1 except that requirements are sorted by functionalities related to reduction steps: calibration and editing, imaging, data analysis and special features (Solar system, VLBI, pulsar). Critical, important and desirable features have the same weight.