Scientific Project Management

or...

Why do so many large projects experience problems ?

Michael Perryman

Preamble

Project Management:
What are we talking about?

- **project management** is the discipline of planning, organising, securing and managing resources to bring about the successful completion of specific project goals and objectives
- a **project** is a temporary endeavour, having a defined beginning and end (usually by date, but can be by funding or deliverables), and which is undertaken to meet unique goals and objectives
- the temporary nature of a project is in contrast to business-as-usual (or operations) which are repetitive or (semi-)permanent functional work to produce products or services
- the management of the two types is typically very different, and requires distinct technical skills, and separate management approaches

The primary challenge of project management is then:

1. to achieve the (engineering or scientific) project goals and objectives
2. while at the same time adhering to a set of agreed project constraints, which are typically scope (objectives), time, and budget

Caveats

- do **not** expect a magic formula for success
- good project management is mainly a question of:
    - an appropriate feasibility study
    - adopting realistic instrument/science objectives
    - appointing a suitably competent leader and team
    - having and assigning adequate resources:

      i.e. budget, time, people, and facilities
    - ensuring a proper structure, and information flow
    - establishing, and adhering to, progress milestones
    - anticipating problems

Part I

Two example problem situations

...we will see how easy it is for projects to get into difficulty, from which recovery is very difficult...

Example 1

- two projects have undergone technical feasibility studies. Both have been accurately costed, and realistic schedules have been defined:
    - project A: promises a fundamental contribution to some field A
    - project B: promises an equivalent contribution to a very different field B
    - project B is significantly **cheaper**, and can be done significantly **faster**
- which should be accepted?   which will be accepted?
- after Project B has been accepted, it reports a cost increase of 10% due to unforeseen technical difficulties. What to do?
- subsequent cost increases are 20%, then 50%, ...
- this type of problem is seen repeatedly: one solution to it is cancellation (but ESA has never invoked it)
- what can we learn from this?
    - the importance of experience and/or scepticism in judging a project's feasibility
    - problems arise whenever (scientific) enthusiasm/optimism is allowed to overtake realism
    - more cynically (for Team A), intellectual honesty and scientific integrity doesn't always pay
    - cancellation could be a powerful tool to encourage integrity and proper preparation

An example: BepiColombo

- Accepted in 2000:
  - Mercury orbiter + lander
  - cost: 450 M€
  - launch: 2008

- Current status (2013):
  - orbiter only (no lander)
  - cost: >1 B€
  - launch: 2015

Example 2

Gaia Phase B/C/D documentation from 1 industrial team (27 volumes)

40 experts participated in the review

reviews are of limited use if not conducted properly!

Part II

Some management theory

Can management be taught?

- The viewpoint of the 1960s-1970s:
  - management is mainly a matter of common sense
  - you either have the abilities of leadership and administration, or you do not
  - management, like parenting and politics, needs no training or qualifications (!)
- Thereafter a growing understanding that:
  - common sense is not always in abundance, nor is it an absolute (Einstein considered common sense to be '*the layer of prejudice laid down before the age of 18*')
  - leaders (and team members) do not always have an optimal skill set
  - the number of variables affecting any one project can be very large
  - predicting the outcome of multiple interactions is very difficult
- Projects are miniature societies, and are affected by politics, i.e:
  - the power and authority of the leader, and the needs and motivation of their team
  - their leadership skills: knowledge, experience, leadership style, ethical standards, project goals
  - techniques of communication and persuasion
  - the many variables affecting the outcome of their project, including:
    - the environment: resources, administrative structure, available technology
    - the individuals: abilities, personalities, experience, motivation, age

Common sense and intuitive leadership can be improved by:

1. an awareness of some basic principles and tools
2. a better understanding of how groups work together
3. learning from past problems or failures in similar fields
4. observing good (and bad) managers in action

Theories of Organisations

- ancient civilisations already 'discovered' how to organise large numbers of people efficiently
- more recent theories started off simple, and have progressively become more complicated:
  - scientific approach (1880s, F.W. Taylor): **plan ahead**, allocate **tasks** and **responsibilities**, **review results** - the basis of scientific project management
  - human relations (1930s, Chester Barnard): people are not easily regimented and need to be persuaded; nor are outside influences stable
  - bureaucracy (1940s, Max Weber): specifies roles, tasks, and structures
  - power and conflict (1950s): different parts of a structure have different goals, and often fight to achieve them
  - the role and complications created by technology (1960s)
  - systems thinking: everything affects everything else, nothing can be understood on its own - explains everything but predicts nothing (cf economics)
  - institutional: each institution has its own way of working

Motivation

- a project leader must motivate and maintain the morale of the team, especially important in finishing projects (simple check on leadership)
- much research about what motivates an individual
- people choose professions according to orientation:
  - e.g. realists (engineering), intellectual (science, teaching), social (counseling), conventional (administration), enterprising (sales, politics), artistic (writing, music)
- motivation arises from various needs, notably:
  - power:
    - high need for power alone results in non-constructive authoritarianism
    - combined with need for **achievement** can be very productive
    - necessary but insufficient for a good manager
  - achievement:
    - high achievers like responsibility, risk, and feedback
    - but high achievers may be individualistic
  - affiliation:
    - concerned with developing/maintaining relations instead of decisions/tasks
    - present, but seldom dominant, in successful achievers
- managers should think what they are asking of their team, and how they control, motivate, and reward

Douglas McGregor: The Human Side of Enterprise

- proposed two extremes of assumptions about people:
    - the average person is inherently lazy, lacks ambition, dislikes responsibility, and prefers to be led

      ☞ managers must direct, motivate, persuade, control, reward, and punish

    - motivation, potential for development, and capacity for responsibility are all present, although they may have become passive due to past experience

      ☞ managers must arrange conditions so that individuals can achieve these goals

- a higher fraction of astronomy-based project teams may well comprise the latter type, but:
    - tasks, phases, and individuals may contain elements of the former
    - the intellectual drive of the scientist may dominate/perturb the practical demands or priorities of project work, unless adequately controlled

Leadership (1/3)

- a complex field, central to project teams. Questions include:
    - can anyone make a good leader?
    - are there certain characteristics which ensure a good leader?
- approaches fall under three headings - all are considered to have some truth, but all fail to fully explain (in-)effectiveness
- trait theories, e.g. identifying:
    - intelligence: above average but not genius, good at solving complex/abstract problems
    - **initiative/proactive**: good at perceiving the need for action, and the urge to do it
    - self-assurance
    - enthusiasm, sociability, integrity, courage, imagination, **decisive, determined, energy**
    - do you agree? or have other character traits to add?
- does it follow that a project leader with skills missing, or at a lower level, will face increased problems as the project proceeds?
- higher managers have an obligation to select correct leaders

Groups (1/4)

- much is written in management theory, covering:
  - what is a group?
  - what is the purpose of the group?
  - is there an optimum size? yes
  - are there guidelines for their composition? yes
- what is a group?
  - can be formal (project team, committee, board) or informal (ad hoc, discussions)
  - can be permanent or temporary
  - can be liked by its members, or considered a total waste of time
  - can contain individualists (who dislike them) or team players (want participation by all)
  - can be effective in blocking ideas/progress, or the best way of putting them to work
  - can be established to terminate an activity or group, or to support and expand it
- groups are of crucial importance for most scientific projects:
  - first look at some theoretical results
  - apply to some real project examples
  - suggest that this is carefully considered by all projects, with due guidance

Groups (3/4)

- size of the group (e.g. science advisory team):
  - the larger the group, the greater the spread of talent, skills and knowledge (+)
  - the larger the group, the less chance of any given individual participating (-)
  - some people talk more easily than others (and these may be seen as having greatest influence); the influence pattern shifts to different personalities as the group gets larger
  - one task of the chair is to encourage those that have something to say, and vice versa
  - studies suggest 5-7 is optimum: yielding highest involvement, cohesiveness, and satisfaction
  - if larger groups are needed (knowledge breadth), the chair must be aware of size/influence
  - larger groups tend to have more absenteeism and lower morale

- composition of the group:
  - leader and members must have the necessary skills and abilities
  - but a mix of characteristics and personalities is also necessary:
    - similar attitudes/values may result in a more stable team, promoting satisfaction
    - more heterogeneous groups may have more conflict, but may be more productive (its nature is important: wide variations in sensitivity/aggression can be negative)
    - a variation of influence within the team can be important
  - bottom line: teams need variety but compatibility - a team needs people who think differently, but not so differently that communication is impossible

Groups (4/4)

- Meredith Belbin identified the 'Apollo Syndrome' (see wikipedia): unexpectedly poor results were generally found with teams comprising many sharp analytical minds and high IQs

- why?
  - failure followed from fundamental flaws in the way such a team interacts
  - excessive time was spent in destructive debate: each trying to persuade others to adopt their view, or focused on identifying weaknesses in others arguments
  - difficulties in decision making, with little coherence in decisions reached
  - team members tended to act along their own favoured directions
  - showed little account of what other team members were doing or saying
  - the Apollo teams generally proved difficult to manage

- there were some successful Apollo teams, characterised by:
  - the absence of highly dominant individuals
  - a particular leadership style: sceptical/suspicious, focusing attention on setting objectives and priorities

Meredith Belbin: Management Teams
- Why They Succeed or Fail, 1981

Belbin's Teams - eight roles

- chair: presides and coordinates:
  - talker/listener; need not be brilliant/creative; works well through others; disciplined, focused, balanced; good judge of people and things
- shaper:
  - outgoing/dominant, drives the action, has passion for the task
- plant:
  - intellectually dominant, imaginative, source of ideas, may be introverted
- monitor-evaluator:
  - intelligent, analytic rather than creative, dissects ideas and identifies flaws
- resource-investigator:
  - supplies new contacts/ideas; extrovert/sociable; not necessarily original or driver
- company worker:
  - organiser, scheduler/planner, methodical/efficient; not side-tracked by vision
- team worker:
  - holds the team together, supports/encourages others; popular/uncompetitive
- finisher:
  - meets deadlines, checks details, worries about schedules, injects a sense of urgency

- + specialist (1988): brings 'specialist' knowledge to the team

Sir Hermann Bondi's Position,

letter to The Times, 31 May 1995

...addressing the massive cost and time overruns in recent UK Ministry of Defense projects

- Director General of ESRO (forerunner of ESA), 1967-1971
- UK Chief Scientific Advisor to the Ministry of Defense, 1971-77
- Chief Scientific Advisor to the Department of Energy, 1977-1980
- Chairman, Natural Environment Research Council, 1980-1984

Projects prosper if there is a powerful, centralised, unified project management team in place, with a project manager who is responsible for the project from cradle to grave

Once this manager has become familiar with the proposed task, the first essential job is to specify the resources of money, staff, time, and facilities required for completion, and to offer milestones of achievement along the way

The whole undertaking is likely to take many years, during which period none of the key staff should change

If the task is successfully accomplished in the time and with the resources they specified, a double promotion should be the reward; if they fail to deliver, retirement may well be appropriate

By contrast, insufficient authority for the management team, with frequent changes of its personnel, is a sure recipe for disaster

Part III

Project phases and schedules

Preamble: ECSS

The European Cooperation for Space Standardisation (ECSS):

- a coherent set of standards for use in European space activities
- standards include management and software engineering
- PI institutes (e.g. MPIA) probably use, e.g. clean room standards, procurement standards, testing standards, etc.
- details: www.ecss.nl

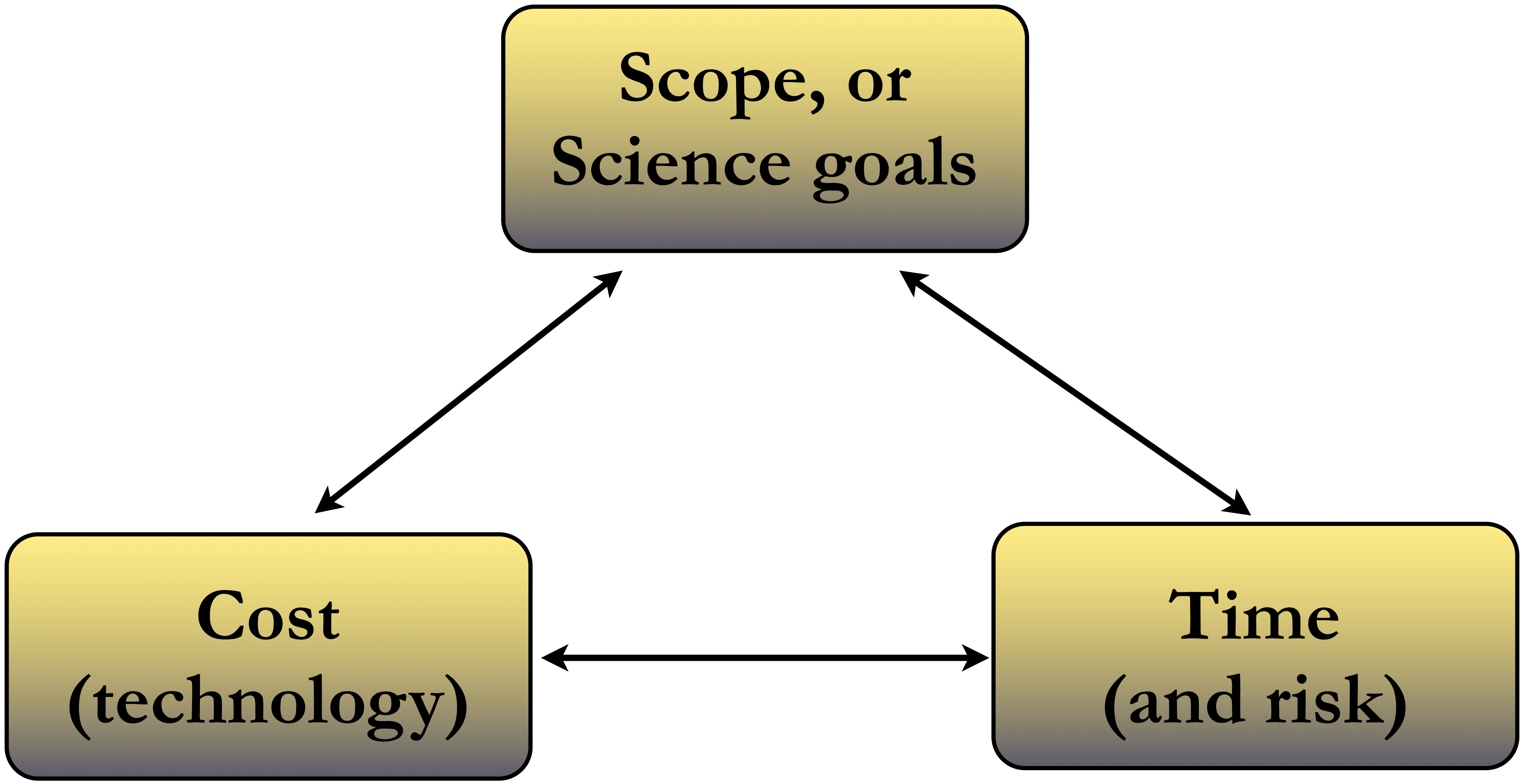
ECSS Example Publications

ESA typical mission lifecycle

target: ~8 years

Duration	Phase	Reviews: (see ECSS)	Objective:
1-2 yr	Pre-Phase A Concept Study		
1-2 yr	Phase A Preliminary Analysis		preliminary plan with cost data
1-2 yr	Phase B Definition Phase	system requirements review (SRR) system design review (SDR)	baseline technical solution, with requirements, schedules, and specifications
3-4 yr	Phase C/D Design & Development	preliminary design review (PDR) critical design review (CDR) test readiness review (TRR) flight readiness review (FRR)	building and integrating subsystems/experiments into a single spacecraft + assembly, integration, test
	Phase E Mission Operations & Data Analysis		

The Triple Constraints:
scope versus cost and time



first order cost estimates for ESA satellites:

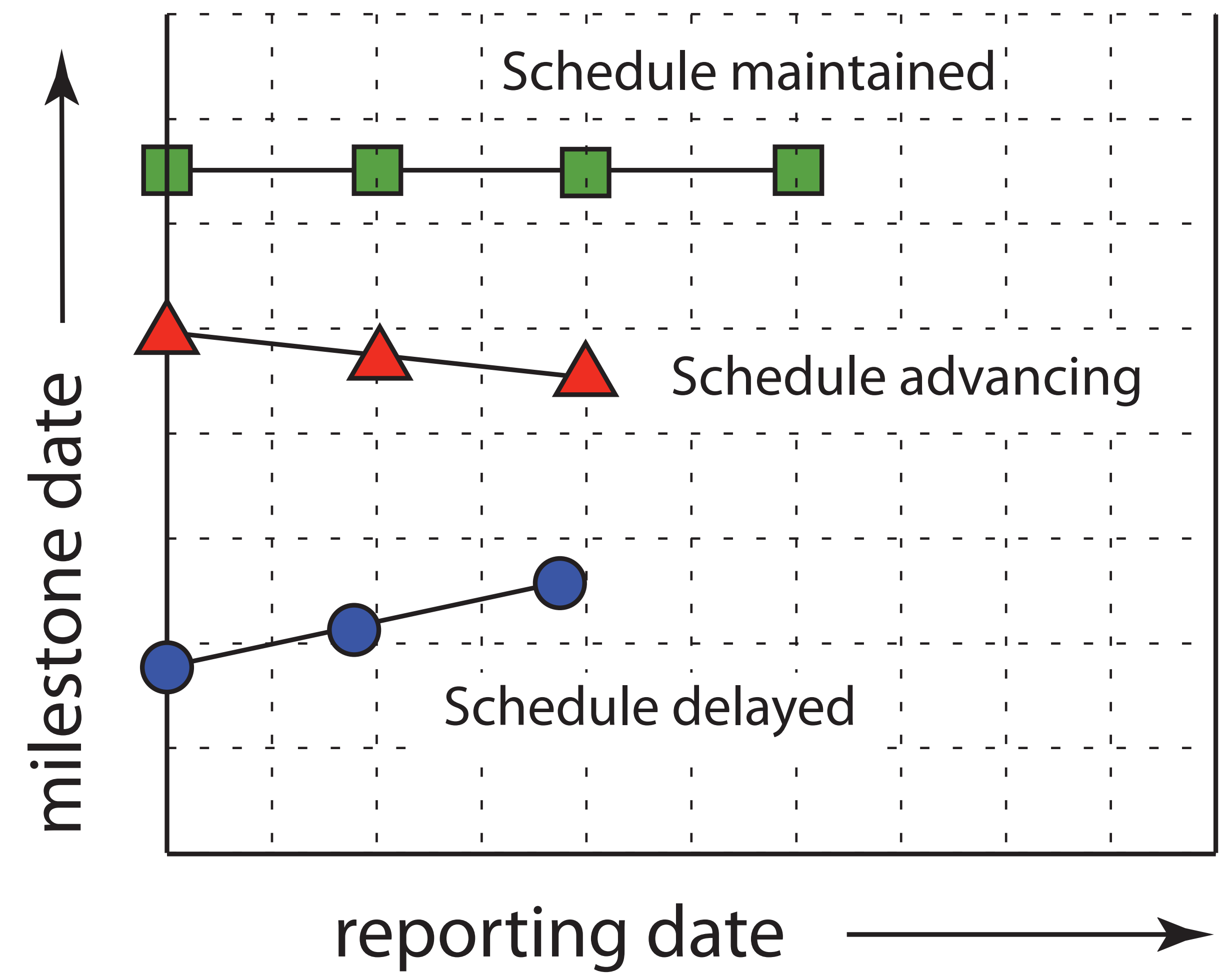
- price per kg for optics, electronics, etc
- according to off-the-shelf, or development needed

Example: ESA's Concurrent Design Facility

For new major projects, it may be useful to consider use of this - or other similar - facilities?

Milestone Trend Analysis

- task scheduling is usually a standard aspect of the technical development of astronomy instrumentation projects
- it may be useful for the scientific development aspects, including the data analysis development
- it is an area where those with hardware development expertise could pass knowledge to the scientific teams to assist their schedule planning
- tracking/reporting tools include milestone trend analysis
- trends and deviations from the planned schedule can be recognised quickly



Caveat:
Colin Powell's Lesson 8

from his leadership primer,
http://www.chally.com/enews/powell.html

'Organisation doesn't really accomplish anything.
Plans don't accomplish anything, either.
Theories of management don't much matter.
Endeavours succeed or fail because of the people involved.
Only by attracting the best people will you accomplish great deeds.'

Part IV

Software

Software (1/3)

- For large astronomy projects, software can be a very major contribution (SDSS, Gaia, Planck, ...)
- there are estimation techniques for resources and cost: e.g. industrial guidelines target *n* lines of code per day, where *n* = ?
- from the start, a project must consider:
  - the overall management plan, reporting, and overall schedule (ECSS M10)
  - the software requirements and software engineering approach (ECSS E40)
  - the processing requirements (FLOPS, data storage)
  - the work package breakdown
  - which software must be developed in parallel with instrument development
  - define software interfaces with an ICD (Interface Control Document)
  - for Gaia, groups such as Sloan and CERN were happy to pass on experience
  - developments such as cloud computing (e.g. Amazon) can be considered
- software tools include:
  - version control (e.g. GNU CVS, Apache SubVersion): client-server checkout
  - bug tracking (e.g. Mantis for Gaia, JIRA for bug/issue tracking for Herschel)

Software (2/3)

- Java provides a viable baseline for astronomy software:
  - an extensive trade-off study was made for Gaia (document available)
  - offers machine independence to a large degree (as others)
  - has significant productivity advantages: it is considered easier to write correct code, especially concerning pointer errors (compared with C/C++)
  - numerical libraries are satisfactory
  - examples: Gaia/Herschel operational software is Java (C/C# for SDSS)
    Latter is a 'multi-paradigm programming language encompassing imperative, declarative, functional, generic, object-oriented, and component-oriented programming disciplines'

- Agile programming:
  - development methodology based on iterative and incremental development
  - requirements and solutions evolve through collaboration between self-organizing, cross-functional teams (15 people for Gaia at ESAC)
  - breaks tasks into small increments with minimal planning (stories)
  - iterations are short time frames (timeboxes) that typically last 1-4 weeks
  - emphasises:
    - **individuals and interactions** (over processes and tools)
    - **working software** (over comprehensive documentation)
    - **customer collaboration** (over contract negotiation)
    - **responding to change** (over following a plan)

Software (3/3): Parameter Data Base

- In a large collaboration, tracking changes in numerical parameters is a major problem, especially crucial for high-accuracy work
- those new to such a task will not necessarily believe this, but:
  - different values can be adopted even for fundamental constants (AU, π)
  - instrument parameters change as design evolves (throughput, pixel scale)
  - some parameters are specifically relevant for simulations or calibrations
  - changes not communicated, overlooked, unsynchronised, not implemented, or implemented incorrectly
  - very difficult to trace the presence and implications of such inconsistencies
- parameter data base for Gaia (Perryman et al, 2008ExA....22..143P):
  - central data base compiles notation, explanation, and numerical values
  - mathematical, physical/astronomical constants, satellite/subsystem parameters
  - one person is responsible for the data base content
  - version control: 'live' + previous 'reference' versions of the full database
  - query results in HTML, Java, ANSI-C, C++, Ruby, or XML
  - for direct inclusion into software codes (with unique parameter names)
  - can be used by industry and mission/science operations
- other users are welcome! see me or other co-authors

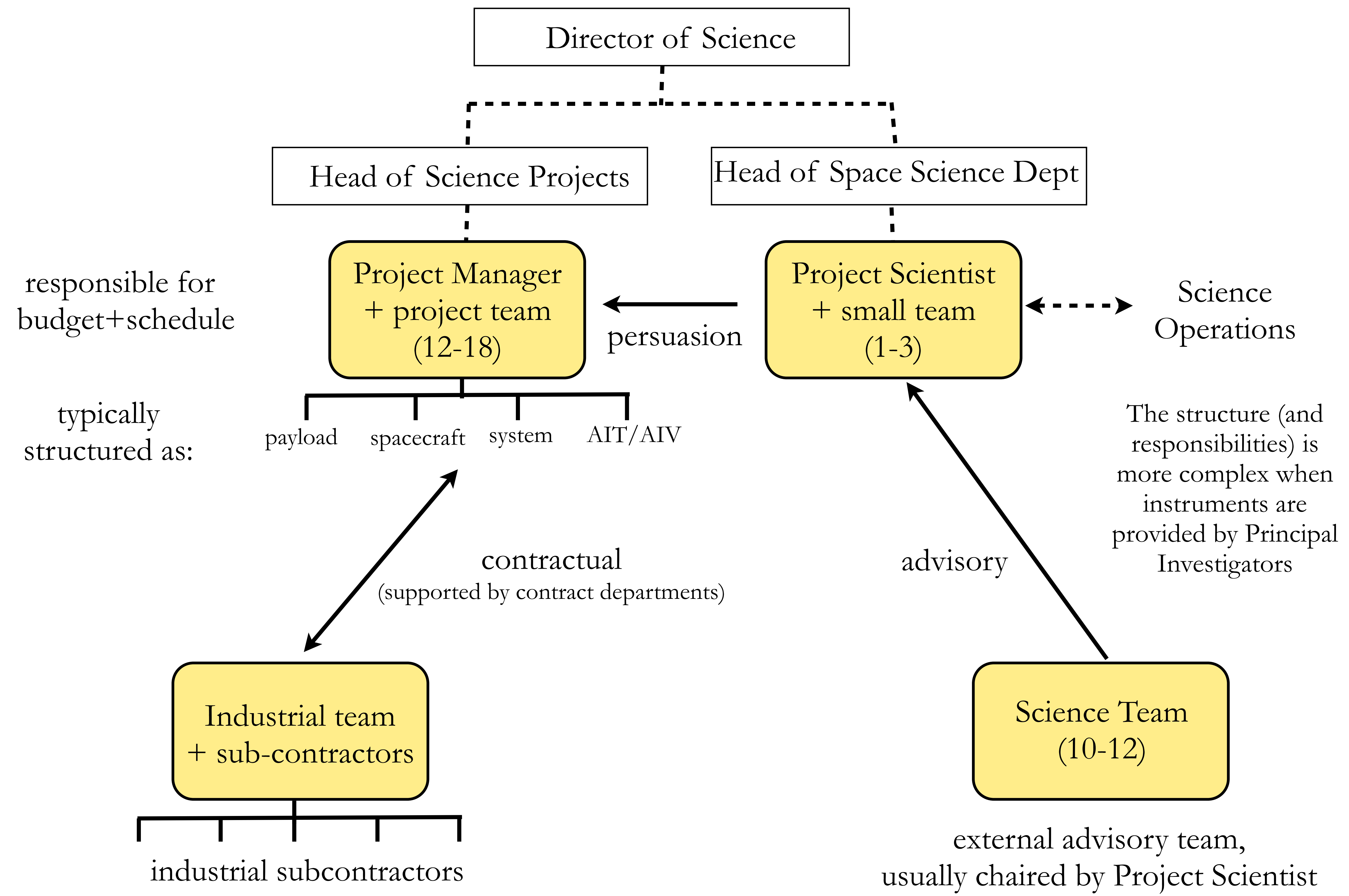
Part V

Project Structures

~

ESA, ESO, and MPIA...

Structure of ESA Scientific Projects in Phases B/C/D: the model



Conducting Science Team Meetings

- Preparation:
  - for maximum participation: fix an agreed date for **next** meeting at each meeting
  - regular non-attendees: the project is low priority, or the meetings are badly run
  - 3-4 weeks in advance of meeting:
    - circulate a draft agenda, with topics/names/durations; invite feedback
    - remind (individually if necessary) of any action items outstanding
- Participation:
    - science team + project team + industrial team, as appropriate
- Conduct:
  - agree on agenda according to **priorities**, and meeting schedule (and stick to it!)
  - review actions (and expect a convincing explanation if not completed!)
  - meetings (as reflected by the agenda) serve to: exchange information, review and establish priorities, fix and record decisions, plan future progress, etc
  - agree actions as agenda proceeds: clear details, **name of actionee**, and **due date**
- Follow-up:
  - draft minutes in 1-2 weeks (not 5-6 months), comments in 2-3 days, then finalise
  - minutes can be short, but should record: major items agreed + explicit actions

Part VII

Time Management

Time Management: Personal

- objectives: to be more efficient, to save time, or to keep to schedules
- we all know how to manage our time, but reminders are always useful!
- personal time management skills include:
  - setting goals
  - setting priorities
  - planning and setting schedules, according to the **needs** (see next)
  - making decisions - do not put off what has to be done anyway (procrastination generates an unnecessary sense of unease)
  - delegating (if you have someone to delegate to!)
  - don't waste your time doing things that don't need doing
  - estimate how long a task deserves, and try to adhere to that
- once goals and schedules are set:
  - maintain a prioritised 'to do' list (paper or electronic)
  - list tasks to be done by priority, e.g. today, this week, or low priority
  - cross off items as you complete them
  - revise on a daily basis
  - keep a list of what you are expecting, from who, and when (see next)

Time Management: within a Team

- the same principles apply when working with a team, but in addition:
- setting deadlines:
  - should be done with due courtesy and respect, and preferably by consensus
  - the future project schedule will often depend on earlier deadlines, therefore...
  - let your team know you are serious in maintaining them
  - this may make you unpopular*, but it may keep your project on schedule (example of a specific conference proceedings: submission date, subsequent tasks, and handling protests)
  - in very extreme cases: remove people from the team who do not cooperate
- maintain a list of actions or answers expected:
  - keep track of actions expected (date due) or requests that have been made
  - never assume that because you have asked, you will be answered, therefore...
  - issue reminders well in advance of due dates
  - do not assume that what you asked has been correctly understood (interface)

*Colin Powell's Lesson 1:
'Being responsible sometime means pissing people off'

Time Management: Synopsis

- whether you are working alone, or leading a task involving (many) others, you can (if you choose):
  - determine how much time the task deserves
  - break down the task into manageable parts
  - establish a provisional schedule, with margins
  - continuously prioritise to maintain that schedule
  - do this also for your team - guide them as to how much time you think that they should invest
- if you are serious about managing a project well, you (and your superiors) must ensure that adequate time is made available for you to manage properly
- whether such efforts are recognised by our system is another question!

Part IX

Miscellaneous Points

Information Flow

- information flow within a project is often given little attention (i.e. badly implemented)
- inadequate information (e.g. on status, priorities, problems, politics) can cause misunderstandings, dissatisfaction, and frustration
- it is a challenging problem, with team members typically complaining that they have either too much information, and too many meetings, or too little
- adequate time should be set aside for it, and time spent thinking what is needed, and how information flow is best managed within each project
- seek feedback from team members on requirements

Terms of Reference: Leaders and Teams

- many key individuals (project scientist, instrument scientist, principal investigator, project manager) and many key teams (science teams, instrument teams, advisory teams) often:
  - have no written terms of reference
  - have different meanings/understandings across different organisations
  - have different meanings to individuals even within the same organisation
- this leads to:
  - misunderstandings of responsibilities
  - incorrect assignment of resources since the tasks are unspecified
  - conflicts of understanding
  - frustrations as the project evolves in contrast to each actor's understanding of the constraints
- consequently:
  - there should be terms of reference for each such role (can be brief)
  - the question is of additional importance for multi-institute collaborations

Memorandum of Understanding

- deliverables from industrial contractors are usually covered by contracts, covering schedules, costs, penalty clauses, etc
- for scientific collaborations, deliverables are often less strictly specified, and left to less formal agreements, or best efforts
- for larger collaborations, when schedules and costs are important, Project Scientists should prepare a Memorandum of Understanding, specifying, e.g.
  - deliverables and schedules
  - points of contact
  - reporting and advisory structures
  - data rights
  - contingency plans in case of over-runs, including cancellation/withdrawl
- for MPIA, templates could be used from project to project
- what is the situation for SPHERE, LINC, PRIMA, etc?

Evolving Boundary Conditions

- scope creep (or requirement creep):
  - is the incremental expansion of a project's scope: introducing new requirements not part of the initial planning, while failing to adjust the schedule and budget
  - it may be (in-)appropriate, depending on the boundary conditions
  - it may accompany the 'scientific mode of thinking' (let's try to do things better), and may contribute to why scientists are not necessarily good project managers
  - if you are responsible for a project (either as leader or higher manager) be aware of this phenomenon
- procurement of additional resources:
  - working in the opposite sense, a project scientist may be less constrained by boundary conditions in finding collaborators in other institutes to share the load and maintain the schedule
  - be creative in finding solutions (including extra resources)
  - but be aware that more people means more interfaces, a greater potential for misunderstandings, and more time needed to manage

What to do when things go wrong...

- when does schedule, cost, or performance first start to become of concern? Requires judgement/experience
- questions/answers are linked to the topics covered so far - including, is the schedule or goal important?
- is it a problem for one project, or the institute culture?
- role of upper management
- brainstorming across the team:
    - understanding what is going wrong
    - how important is it to solve?
- what solutions are possible?
    - increase cost, lengthen schedule, descope scientific and/or technical goals
    - procuring more resources (slide 2)
    - removing 'nice-to-have's
    - strengthening or replacing team members - or leaders
    - canceling the project (is this covered in the original MoU?)

Summary of Key Lessons

1. ensure that the concept/feasibility study results in a plausible project, given the resources available
2. ensure that the project is led by the right people with the right skill set
3. set simple, understandable, project-wide scientific and technical goals, supported by a detailed error budget
4. establish a well-structured organigram, which meets the project needs, not those of the individual players
5. establish an appropriate scientific advisory team, and keep the management/advisory structure simple
6. prepare a MoU covering deliverables, reporting structure etc.
7. set up the appropriate administrative system (terms of reference, planning, scheduling, actions, reviews, documentation, information flow) but do not add layers of bureaucracy for the sake of it
8. plan ahead, be proactive, look for potential problems
9. adopt a systems approach, with parallel development of all tasks
10. provide proper reward/recognition for success, and vice versa

A Final Word of Wisdom:

van der Hulst's Law

(Henk van der Hulst, Leiden Observatory, 1918-2000)

- *it's hard doing science on your own...*
- *it's harder doing it in collaboration with other people!*