

Strategic Management of Knowledge in Big Science

Agustí Canals

KIMO Research Group

Universitat Oberta de Catalunya - Barcelona

Agenda

1. Big Science organizations
2. Strategic knowledge mapping in big science projects: a methodology to identify and develop key strategic knowledge assets and explore their characteristics and relationships
3. Structure of interorganizational collaboration in scientific projects: analysis of collaboration networks
4. The role of simulations as a coordination mechanism in a big science project: simulations as dynamic boundary objects

Big Science Organizations

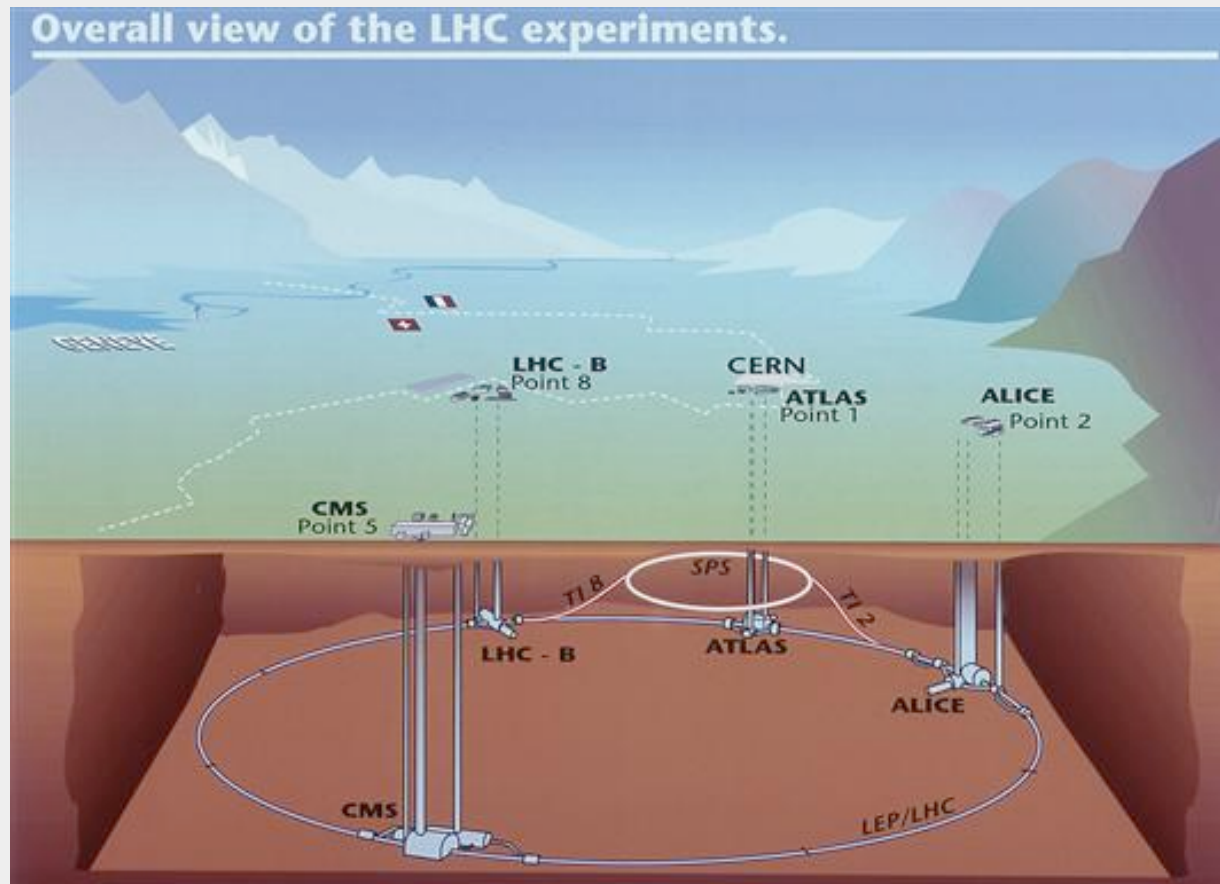
Big science

- In many areas (genomics, high energy physics, climate sciences, ecology, astronomy, nuclear fusion,...) scientific research has moved in the last decades from small or medium-sized experiments to large and complex collaborations (Galison 1992)
- The idea of 'big science' put forward in the 1960's by Weinberg (1961) and Price (1963) has become commonplace (Hicks & Katz 1996, Knorr-Cetina 1999, Etzkowitz & Kemelgor 1999)
- Big science is taking an important part of research funding and it is worth looking at its different aspects
- Big science experiments provide very interesting management and organizational insights
- A good example: CERN experiments

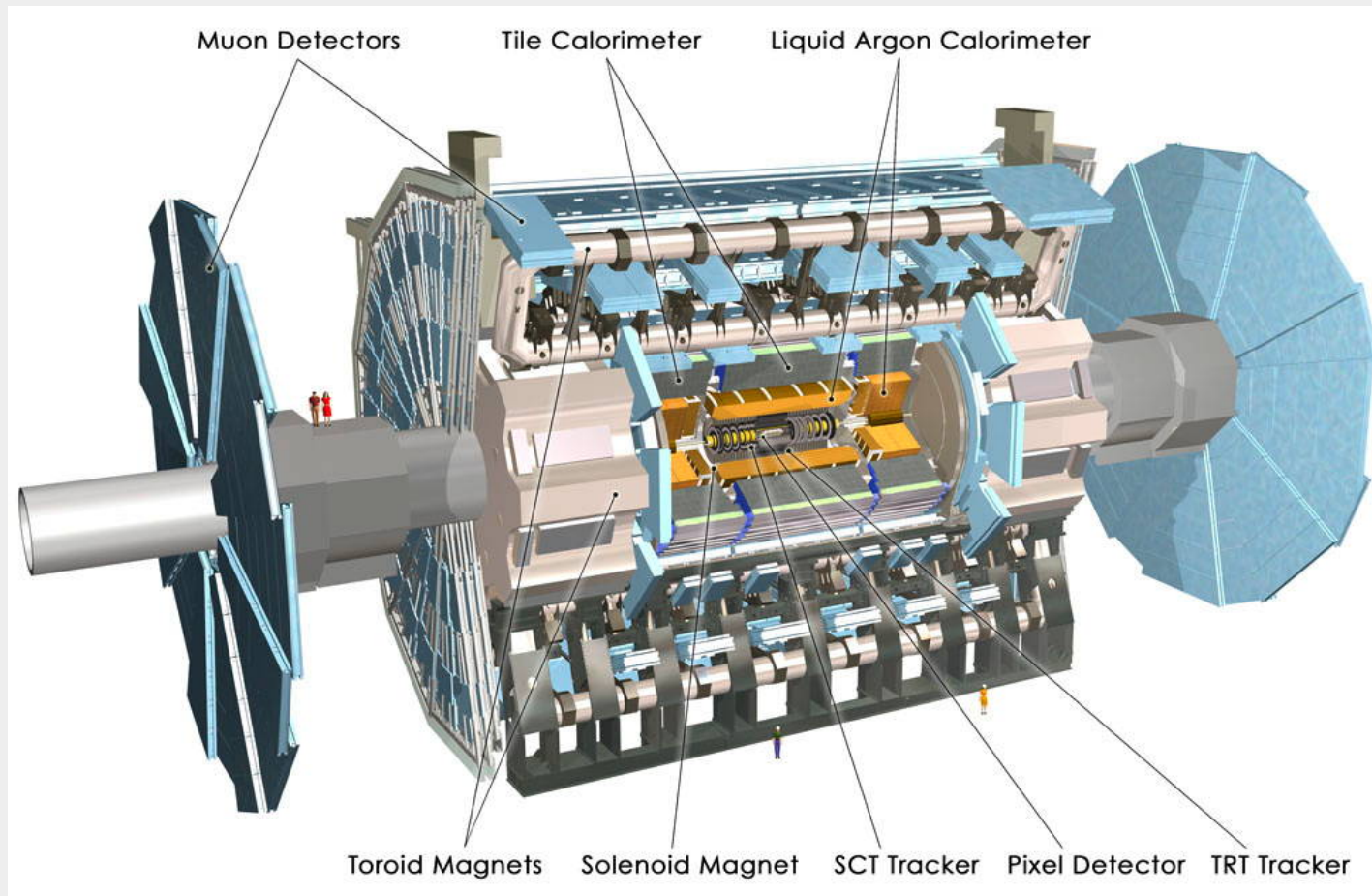
The Large Hadron Collider (LHC)



ATLAS: One of the LHC detectors



The ATLAS detector



The ATLAS Collaboration



A complex organization

3000 physicists

174 universities
and labs

38 countries



New kinds of organizations

- New virtual collaborations fostered by globalization and ICTs
- But managed in a traditional way: organizational authority systems and clear boundaries
- Some recent developments challenge this: distributed, non-hierarchical networks such as Linux
- Questions:
 - How is coordination actually achieved?
 - What happens when the task is complex and boundaries are fuzzy?
 - What level of complexity such networks can manage?
- The ATLAS case: bottom-up culture and very limited use of managerial authority

Three Questions

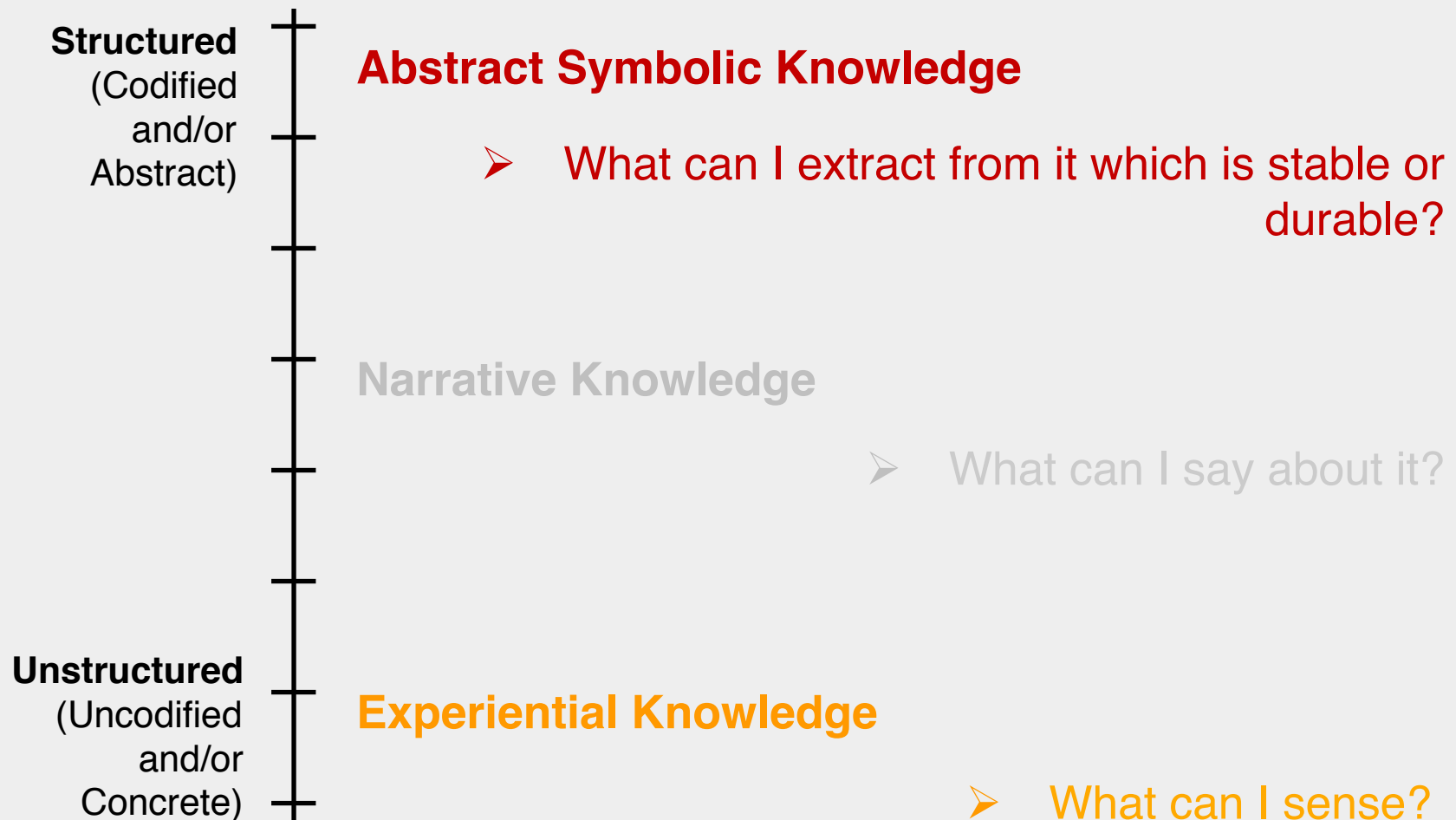
ATLAS is an exceptional knowledge-based organization!

How does it work?

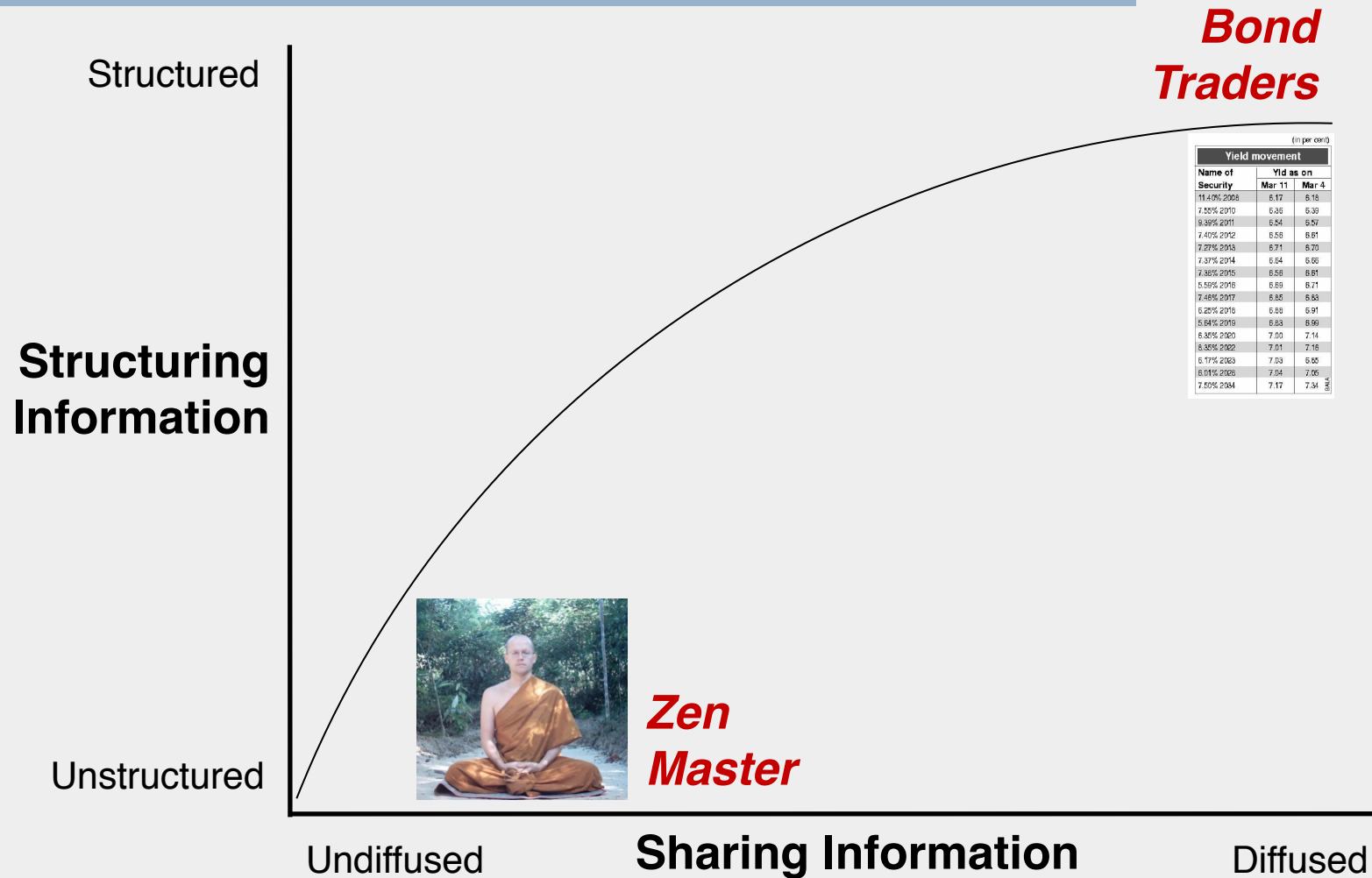
- What are the critical knowledge assets that allow ATLAS to perform at such high levels?
- How is the structure of internal collaboration?
- How is coordination achieved in this complex, non-hierarchical knowledge system?

Strategic Knowledge Mapping

Three kinds of knowledge



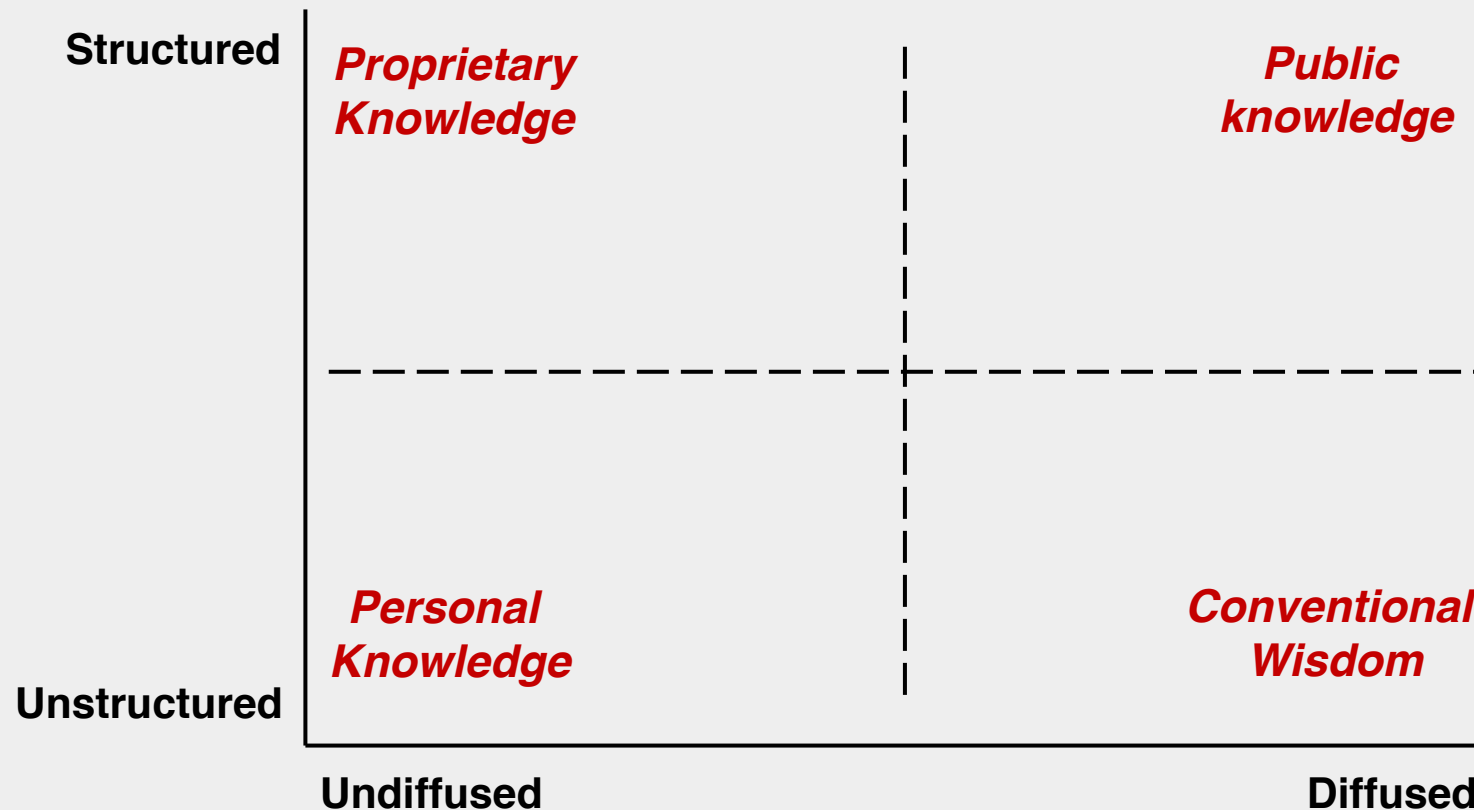
The I-Space



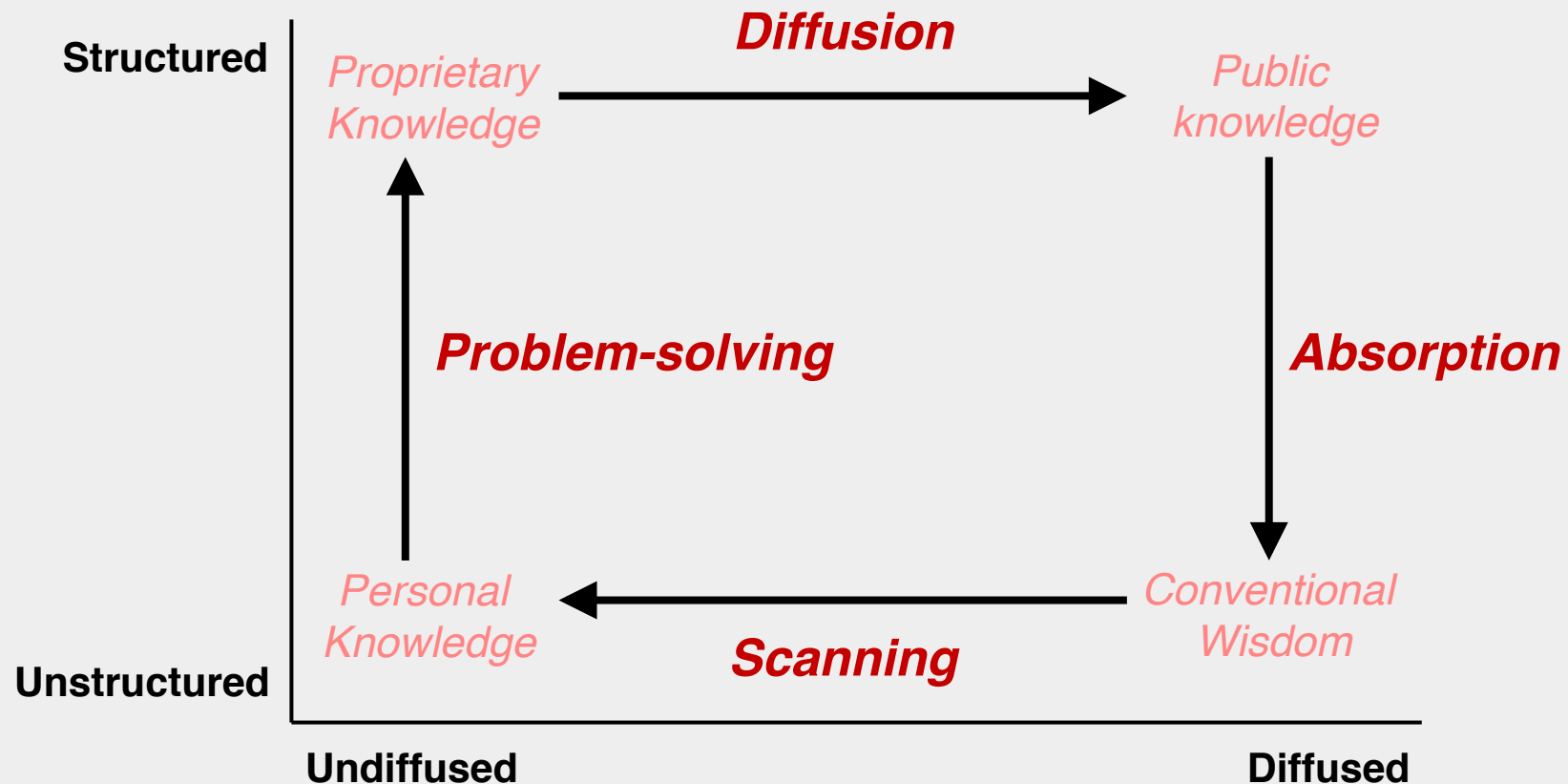
(in per cent)

Name of Security	Yield movement	
	Mar 11	Mar 4
11.40% 2008	6.17	6.18
7.55% 2010	6.35	6.39
9.38% 2011	6.54	6.57
7.40% 2012	6.56	6.61
7.27% 2013	6.71	6.70
7.37% 2014	6.64	6.65
7.38% 2015	6.58	6.61
5.59% 2016	6.69	6.71
7.48% 2017	6.65	6.63
6.25% 2018	6.66	6.91
5.64% 2019	6.63	6.99
6.35% 2020	7.00	7.14
6.35% 2022	7.01	7.16
6.17% 2023	7.03	6.65
6.01% 2026	7.04	7.06
7.55% 2034	7.17	7.34

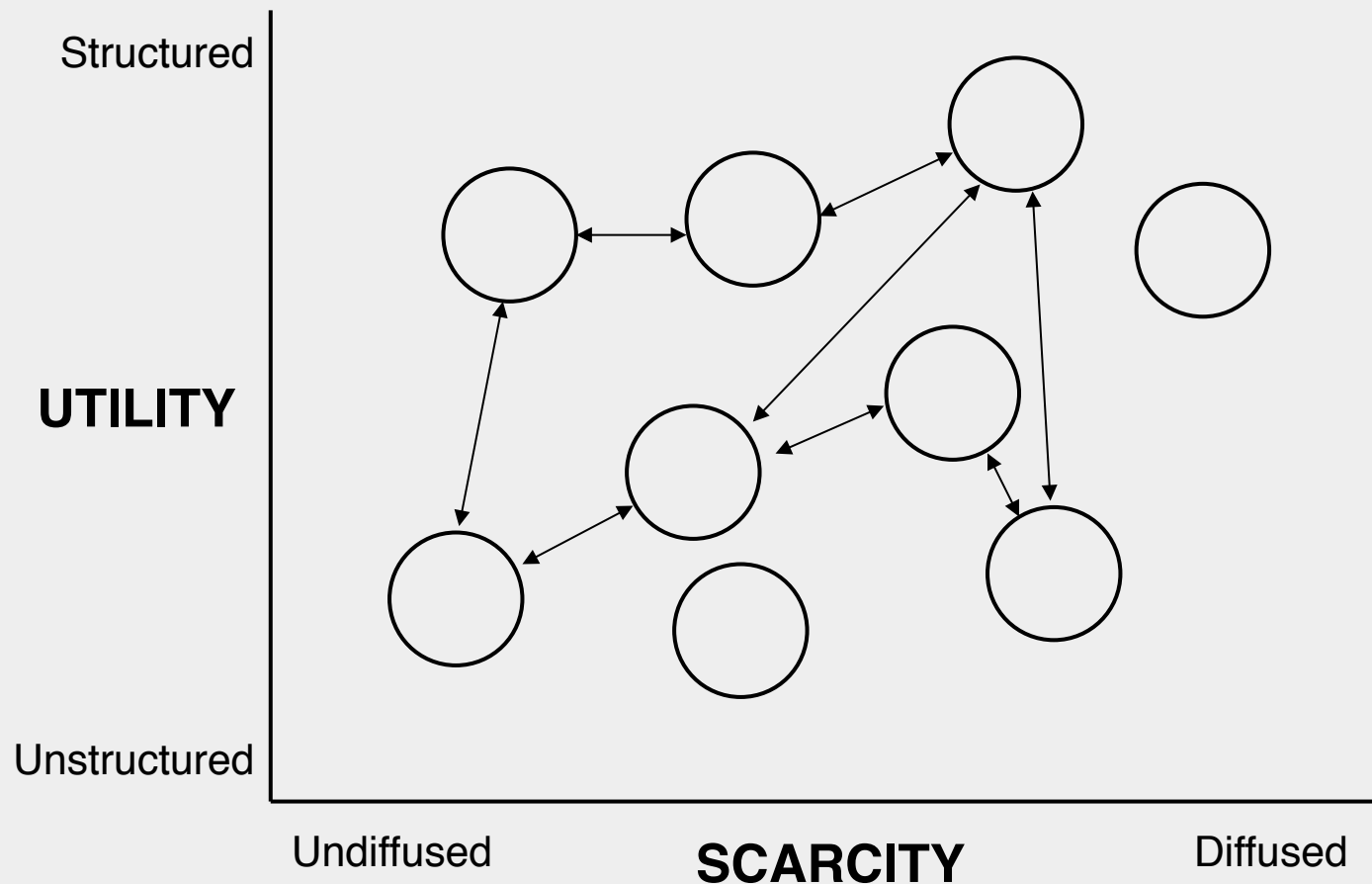
Knowledge in the I-Space



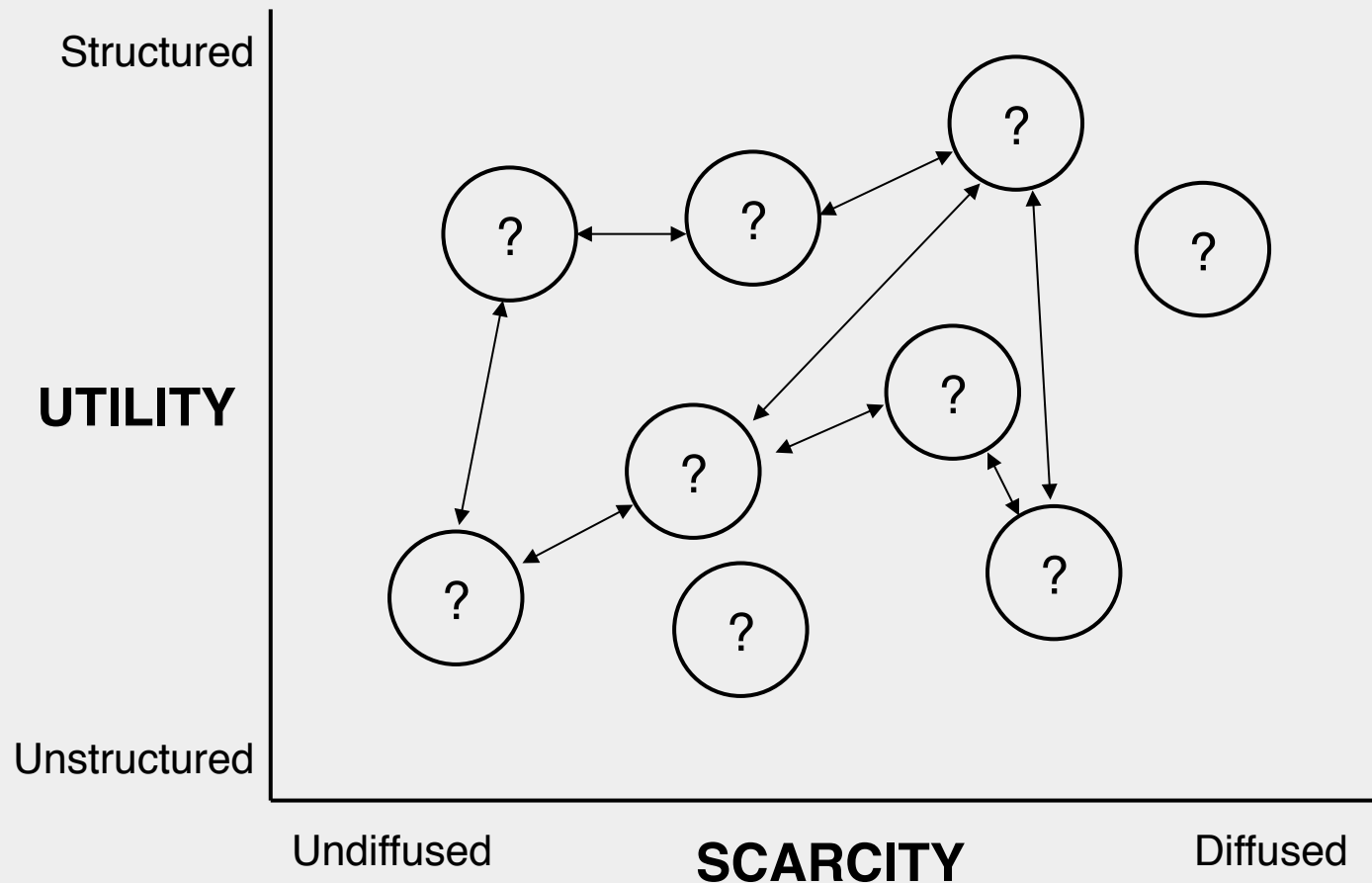
The Social Learning Cycle (SLC)



Portfolio of knowledge assets



Mapping the ATLAS knowledge



Strategic Knowledge Mapping Process

1. What are the organization's critical performance dimensions?
2. What are the knowledge assets that support those performance dimensions?
3. Where are the knowledge assets located in the *I-Space*?
4. What are the strategic implications of the knowledge map?
5. How can the knowledge system develop?

Selecting knowledge assets



Please select from the list below the two most important knowledge domains that you currently apply in executing your work:

- | | | |
|---|--|---|
| <input type="checkbox"/> Standard Model | <input type="checkbox"/> Operating Systems | <input type="checkbox"/> Presentation Skills |
| <input type="checkbox"/> Beyond Standard Model | <input type="checkbox"/> Software Analysis and Design | <input type="checkbox"/> Interpersonal Communication Skills |
| <input type="checkbox"/> General P-P Collision | <input type="checkbox"/> Programming | <input type="checkbox"/> Detector Readout and Instrumentation |
| <input type="checkbox"/> Overall View of The State of The Art of Electronics | <input type="checkbox"/> Database Technologies (Hardware and Software) | <input type="checkbox"/> LHC Machine Parameters |
| <input type="checkbox"/> FPGA (Field Programmable Gate Arrays) and DSP (Digital Signal Processes) | <input type="checkbox"/> Networking and Point-to-Point Links | <input type="checkbox"/> MC Simulation |
| <input type="checkbox"/> Fast Memories | <input type="checkbox"/> Project Management | <input type="checkbox"/> Overview of The ATLAS Experiment |
| <input type="checkbox"/> Radiation Hard Electronics | <input type="checkbox"/> Financial Management | <input type="checkbox"/> Overview of The ATLAS Collaboration |
| <input type="checkbox"/> Backplanes and High Speed Serial Links | <input type="checkbox"/> People Management | <input type="checkbox"/> Outreach |
| <input type="checkbox"/> Hardware (Servers, Modular Electronics, ...) | <input type="checkbox"/> Meeting Management & Participation | |

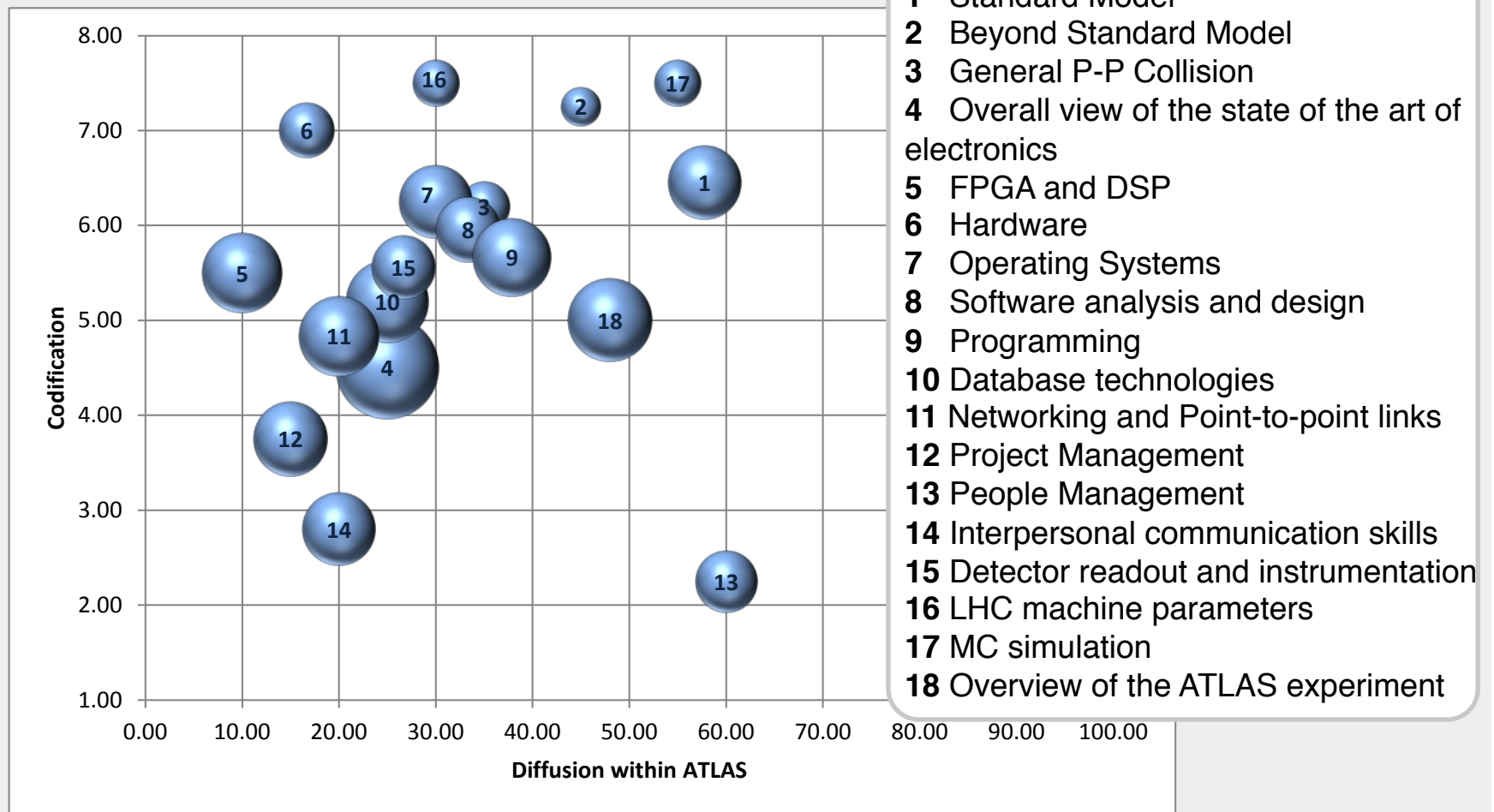
In what follows and for each knowledge domain, you will be asked six questions, each of which requires you to answer yes or no. In addition, you will be asked two questions requiring you to assign a score, plus two questions requiring a simple numerical estimate.

TDAQ Questionnaire: Basic Statistics

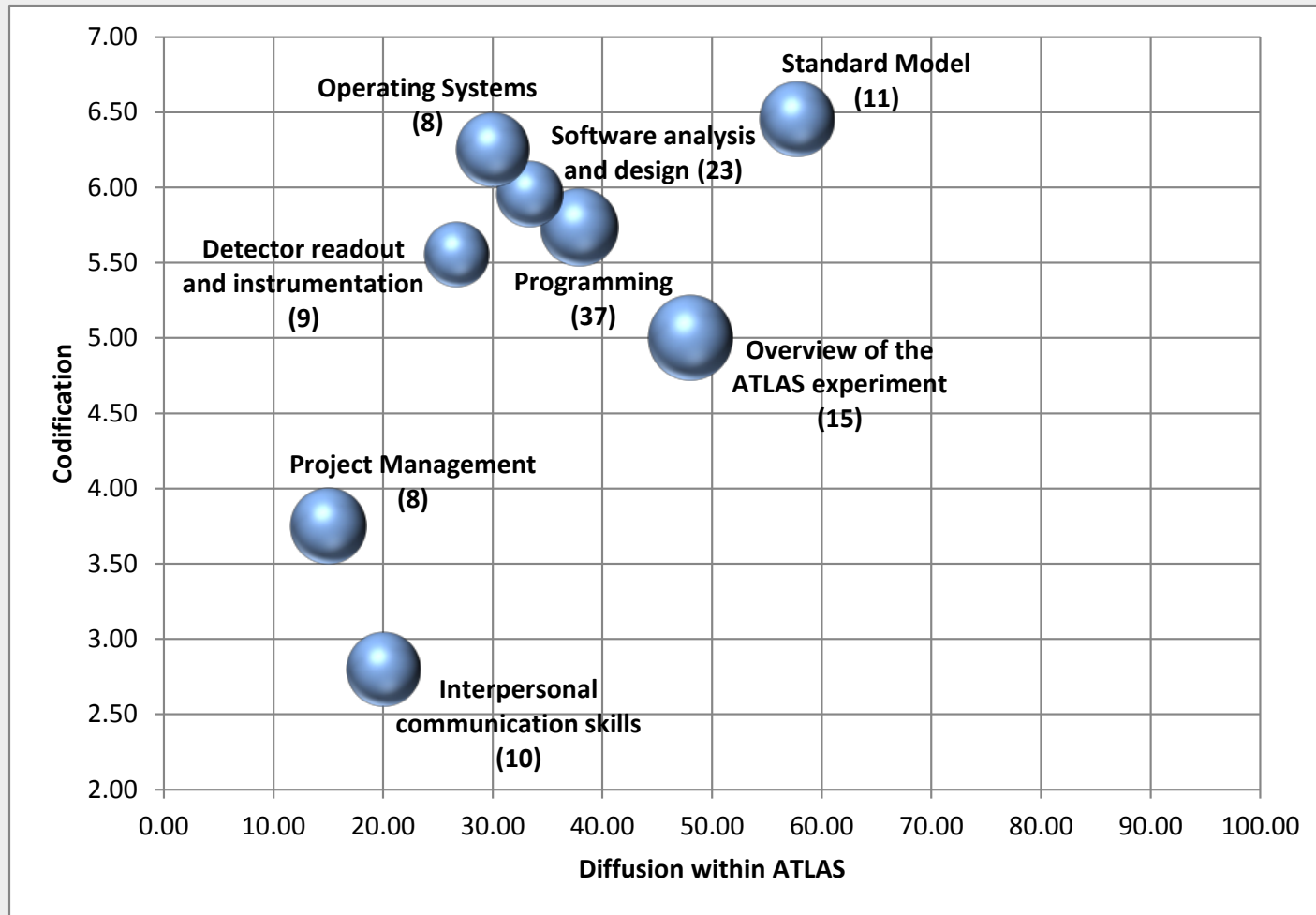
GENERAL SURVEY COMPARISON STATISTICS

	First Round		Second Round		Both Rounds	
Number of people approached	74		101		175	
Questionnaire hits	43	58.11%	89	88.12%	132	75.43%
Responses	41	55.41%	49	48.51%	90	51.43%
Complete responses	36	48.65%	38	37.62%	74	42.29%
Knowledge responses	82		81		163	

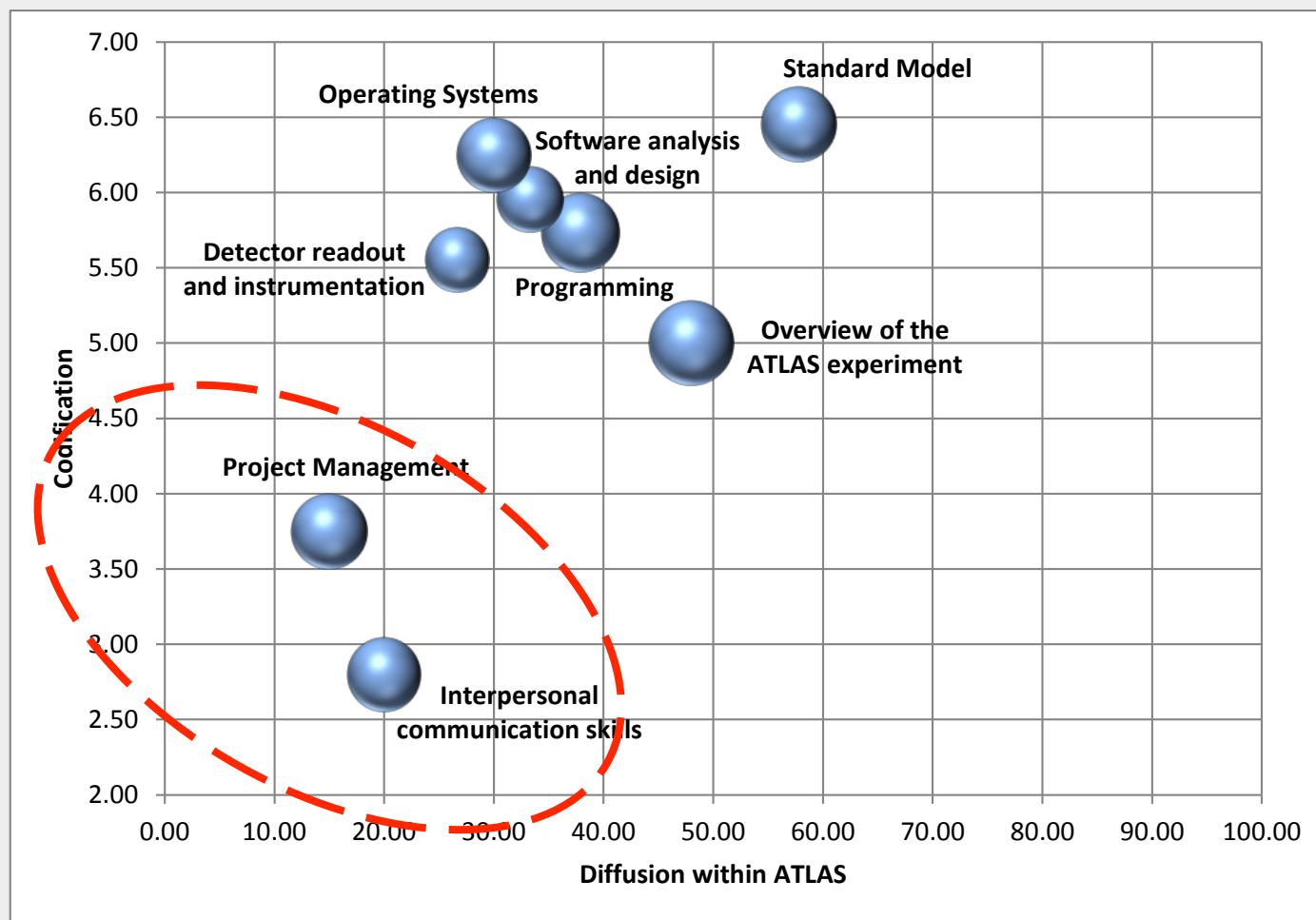
TDAQ Knowledge Map



What is the most salient knowledge?



Soft/Management Skills in ATLAS



Challenges for ATLAS

- Strategically developing value (competitive advantage)
 - Understanding the nature of one's core competences
 - Over and beyond the ATLAS project cycle (15 years)
- Fostering the further development of soft skills in ATLAS?
 - Manpower development in High Energy Physics
 - Formal courses (upper I-Space)
 - Apprenticeships (lower I-Space)
 - Correlation between position and choice of soft-skills?
- Managing the flow of people in and out of projects and between home institutions and ATLAS
 - Knowledge walking out of the door

Structure of Interorganizational Collaboration


Scientific collaboration

- Scientific collaboration has a direct effect on the impact of the resulting publications (Benavent-Pérez et al. 2012), accentuated in the case of international collaboration (Kronegger et al. 2011)
- Important public funding is applied to scientific collaboration
- It can be analyzed from different perspectives: authors, institutions, countries (Sonnenwald 2007)
- In order to analyze it, scientific collaboration must be contextualized: by discipline, by geographical area, by type of research, ... (Gzani, Sugimoto & Didegah 2012)
- We are interested in understanding collaboration patterns in 'big science'

Studying scientific collaboration

- Usual methodology: co-authorship networks (Sonnenwald 2007)
- ... but in big science co-authorship networks of published papers might be misleading

In big science: genomics


International weekly journal of science

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Human Genome

Nature **409**, 860-921 (15 February 2001) | doi:10.1038/35057062; Received 7 December 2000; Accepted 9 January 2001

article

Initial sequencing and analysis of the human genome

International Human Genome Sequencing Consortium Eric S. Lander¹, Lauren M. Linton¹, Bruce Birren¹, Chad Nusbaum¹, Michael C. Zody¹, Jennifer Baldwin¹, Keri Devon¹, Ken Dewar¹, Michael Doyle¹, William FitzHugh¹, Roel Funke¹, Diane Gage¹, Katrina Harris¹, Andrew Heaford¹, John Howland¹, Lisa Kann¹, Jessica Lehoczy¹, Rosie LeVine¹, Paul McEwan¹, Kevin McKernan¹, James Meldrim¹, Jill P. Mesirov¹, Cher Miranda¹, William Morris¹, Jerome Naylor¹, Christina Raymond¹, Mark Rosetti¹, Ralph Santos¹, Andrew Sheridan¹, Carrie Sougnez¹, Nicole Stange-Thomann¹, Nikola Stojanovic¹, Aravind Subramanian¹ & Dudley Wyman¹ for Whitehead Institute for Biomedical Research, Center for Genome Research; Jane Rogers², John Sulston², Rachael Ainscough², Stephan Beck², David Bentley², John Burton², Christopher Clee², Nigel Carter², Alan Coulson², Rebecca Deadman², Panos Deloukas², Andrew Dunham², Ian Dunham², Richard Durbin², Lisa French², Darren Grafham², Simon Gregory², Tim Hubbard², Sean Humphray², Adrienne Hunt², Matthew

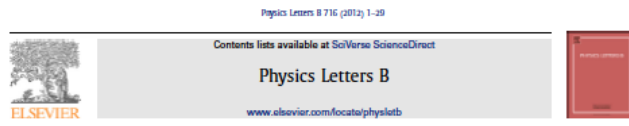
Full Author List

Genome Sequencing Centers. The centers are listed in order of total genomic sequence contributed.

Whitehead Institute for Biomedical Research, Center for Genome Research, Nine Cambridge Center, Cambridge, MA 02142, USA: Emmanuel Adcock, Mostafa Ait-Zahra, Nicole Allen, Mechele Anderson, Scott Anderson, Faina Anufriev, Jeff Ambruster, Kifle Ayale, Jodi Baker, Jennifer Baldwin, Nicole Barna, Verilda Bastien, Serafim Batzoglou, Reem Beckerly, Felicien Bede, John Bernard, Bruce Birren, Bruce Birren, Brendan Blumenfeld, Leonid Boguslavsky, Boris Boukhalter, Adam Brown, Greg Burkett, Jody Camarata, Amy Campopiano, Herman Carneiro, Zhuan Chen, Yama Choephel, Mary Colangelo, Sonya Collins, Alville Collymore, Patrick Cooke, Christopher Davis, Tenzin Dawoe, Kurt DeArrellano, Keri Devon, Ken Dewar, J. Sebastian Diaz, Sheila Dodge, Elizabeth Donelan, Kunzang Dorjee, Michael Doyle, Antonine Dube, Alan Dupes, Matt Edrizzzi, Abderrahim Farina, Susan Faro, Diallo Ferguson, Pat Ferreira, Heather Fischer, William FitzHugh, Ken Flaherty, Karen Foley, Rod Funke, Diane Gage, James Galagan, Stephanie Gardys, Diane Gilbert, Samir Ginde, Antonio Gomes, Mary Goyette, Joseph Graham, Leslie Graham, Edward Grandhois, Nerline Grand-Pierre, George Grant, Dave Gregoire, Roth Guerrero, Birhane Hagos, Katrina Harris, David Hart, Beah Hatcher, Andrew Heaford, Lloyd Horton, Catherine Hovage-Norman, John Howland, Bill Hulme, Ilian Iliev, Robin Johnson, Charlein Jones, Marie Joseph, Mathew Judd, Lisa Kann, Aysen Karatas, Damian Kelley, Merrill Kelly, Dawa Lama, Jenny Lamazares, Eric S. Lander, Thomas Lander, Addie Lane, Keri LaRocque, Heidi LeBlanc, Jean-Pierre Leger, Jessica Lehoczy, Rosie LeVine, Doreen Lewis, Tammy Lewis, Charlien Lieu, Lauren Linton, Grace Liu, Xiaohong Liu, Kim Locke, Yeshi Lokiyang, Pen Macdonald, Rogelio Martinez, Kebede Mars, Megan McCarthy, Paul McEwan, Tina McGhee, Brian McGing, Aisling McGurk, Kevin McKernan, Jacques McLaughlin, Robert McPheters, James Meldrim, Louis Menuus, Jill Mesirov, Tanya Mihova, Cher Miranda, Val Mlenga, Michelle Modski, Geoff Montello, William Morris, Jenn Morrow, Leon Mulrain, Thomas Murphy, Josef Mychaleckyj, Jerome Naylor, Christian Newes, Tsering Ngodup, Cindy Nguyen, Thu Nguyen, Chou Dolma Norbu, Nyima Norbu, Chad Nusbaum, Tara O'Connor, Paula O'Donnell, Youssef Okaf, Dominic O'Neil, Jon O'Shea, Sahal Osman, Matt Paresi, Boris Pavlin, K.M. Peterson, Pema Phunkang, Nadia Pierre, Victor Pollara, Christina Raymond, Melanie Rieback, Beckie Riley, Cecil Rise, Peter Rogov, Joe Roman, Magaly Roman, Mark Rosetti, Deborah Rothman, Alice Roy, Karen Roycroft, Ralph Santos, Steven Schauer, Rebecca Schupbach, Steven Seaman, Andrew Sheridan, Cherylyn Smith, Carrie Sougnez, Thomas Speer, Brian Spencer, Nicole Stange-Thomann, Nikola Stojanovic, Casey Stone, Nathaniel Strauss, Aravind Subramanian, Jessica Talamas, Pierre Tchings, Mark Tenencko, Pema Tenzin, Senait Tesfaye, Jounathe Theodore, Andrea Tirrell, Imani Torruella-Miller, Tze Trac, Mary Travers, Niki Travis, James Triglia, Elva Tsao, Helen Vasiliev, Rose Veil, Andy Vo, Alan Wagner, Jamie Walsh, Tsering Wangdi, Jamey Wierzbowski, Bennett Wilson, Xaiyuan Wu, Dudley Wyman, Wen Juan Ye, Shane Yeager, Rabel Retta Yeshitela, Geneva Young, Joanne Zainoun, Andrew Zimmer and Michael C. Zody

The Sanger Centre, The Wellcome Trust Genome Campus, Hinxton, Cambridgeshire CB10 1RQ, United Kingdom: Zahra Abdellah, Alireza Ahmadi, Shahana Ahmed, Matthew Aimable, Rachael Ainscough, Jeff Almeida, Andrew Ambler, Karen Ambrose, Kerrie Ambrose, Daniel Andrews, Neil Andrews, Hazel Arbery, Beth Archer, Gareth Ash, Kevin Ashcroft, Jennifer Ashurst, Robert Ashwell, Deborah Askin, Andrea Atkinson, John Atwood, Keith Ashin, Terry Avis, Anne Babhage, Joanne Bacon, Claire Baguley, Jonathan Bailey, Andrew Baker, Simon Bartill, Darren Barker, Karen Barlow, Laurent Baron, Anika Barrett, Rebecca Bartlett, David Basham, Victoria Basham, Alex Bateman, Karen Bates, Caroline Baynes, Lisa Beard, Susan Beard, David Beare, Alastair Beasley, Oliver Beasley, Stephan Beck, Emma Bell, Damian Bellerby, Tristram Bellerby, Richard Bemrose, James Bennett, David Bentley, Mary Berks, Michael Berks, Graeme Bethel, Christine Bird, Ewan Bimey, Helen Bissell, Suzanne Blackburne-Maze, Sarah Blakey, Ralph Bonnett, Richard Boer, Nicola Brady, Jason Bray, Sarah Bray-Allen, Anne Bridgeman, Jonathan Brook, Shane Brooking, Andrew Brown, Clive Brown, Jacqui Brown, Margaret Brown, Mary Brown, Richard Bruskiewicz, Jackie Bryant, David Buck, Veronica Buckle, Claire Budd, Jill Burberry, Deborah Burford, Joanne Burgess, Wayne Burtill, Christine Burrows, John Burton, Phil Butcher, Adam Butler, Murray Cairns, Bruce Canning, Carol Carder, Paul Carder, Nigel Carter, Tamara Cavanna, Ka Chan, Joanna Chapman, Rachel Charles, Tom Chrobis, Connie Chui, Michele Clamp, Anthea Clark, Graham Clark, Kevin Clark, Sarah Clark, Sue Clark, Betty Clarke, Eddie Clarke, Kay Clarke, Chris Cle, Sheila Clegg, Karen Clifford, Julia Coates, Victoria Cobley, Alison Coffey, Penelope Coggill, Lotte Cole, Rachael Collier, Simon Collins, John Collins, Philip Collins, Richard Connor, Jennie Conner, Donald Conroy, Doug

In big science: H.E. Physics



Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC^{1,2}

ATLAS Collaboration³

This paper is dedicated to the memory of our ATLAS colleagues who did not live to see the full impact and significance of their contributions to the experiment.

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ABSTRACT

A search for the Standard Model Higgs boson in proton-proton collisions with the ATLAS detector at the LHC is presented. The datasets used correspond to integrated luminosities of approximately 4.8 fb⁻¹ collected at $\sqrt{s} = 7$ TeV in 2011 and 5.8 fb⁻¹ at $\sqrt{s} = 8$ TeV in 2012. Individual searches in the channels $H \rightarrow ZZ^{(0)} \rightarrow 4\ell$, $H \rightarrow \gamma\gamma$ and $H \rightarrow WW^{(0)} \rightarrow \ell\nu\ell\nu$ in the 8 TeV data are combined with previously published results of searches for $H \rightarrow ZZ^{(0)}$, $WW^{(0)}$, $b\bar{b}$ and $\tau^+\tau^-$ in the 7 TeV data and results from improved analyses of the $H \rightarrow ZZ^{(0)} \rightarrow 4\ell$ and $H \rightarrow \gamma\gamma$ channels in the 7 TeV data. Clear evidence for the production of a neutral boson with a measured mass of 126.0 ± 0.4 (stat) ± 0.4 (sys) GeV is presented. This observation, which has a significance of 5.9 standard deviations, corresponding to a background fluctuation probability of 1.7×10^{-9} , is compatible with the production and decay of the Standard Model Higgs boson.

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1. Introduction

The Standard Model (SM) of particle physics [1–4] has been tested by many experiments over the last four decades and has been shown to successfully describe high energy particle interactions. However, the mechanism that breaks electroweak symmetry in the SM has not been verified experimentally. This mechanism [5–10], which gives mass to massive elementary particles, implies the existence of a scalar particle, the SM Higgs boson. The search for the Higgs boson, the only elementary particle in the SM that has not yet been observed, is one of the highlights of the Large Hadron Collider [11] (LHC) physics programme.

Indirect limits on the SM Higgs boson mass of $m_H < 158$ GeV at 95% confidence level (CL) have been set using global fits to precision electroweak results [12]. Direct searches at LEP [13], the Tevatron [14–16] and the LHC [17,18] have previously excluded, at 95% CL, a SM Higgs boson with mass below 600 GeV, apart from some mass regions between 116 GeV and 127 GeV.

Both the ATLAS and CMS Collaborations reported excesses of events in their 2011 datasets of proton-proton (pp) collisions at centre-of-mass energy $\sqrt{s} = 7$ TeV at the LHC, which were compatible with SM Higgs boson production and decay in the mass region 124–126 GeV, with significances of 2.9 and 3.1 standard deviations (σ), respectively [17,18]. The CDF and D0 experiments at the Tevatron have also recently reported a broad excess in the mass region

120–135 GeV, using the existing LHC constraints, the observed local significances for $m_H = 125$ GeV are 2.7σ for CDF [14], 1.1σ for D0 [15] and 2.8σ for their combination [16].

The previous ATLAS searches in 4.6–4.8 fb⁻¹ of data at $\sqrt{s} = 7$ TeV are combined here with new searches for $H \rightarrow ZZ^{(0)} \rightarrow 4\ell$, $H \rightarrow \gamma\gamma$ and $H \rightarrow WW^{(0)} \rightarrow \ell\nu\ell\nu$ in the 5.8–5.9 fb⁻¹ of pp collision data taken at $\sqrt{s} = 8$ TeV between April and June 2012.

The data were recorded with instantaneous luminosities up to 6.8×10^{33} cm⁻²s⁻¹; they are therefore affected by multiple pp collisions occurring in the same or neighbouring bunch crossings (pile-up). In the 7 TeV data, the average number of interactions per bunch crossing was approximately 10; the average increased to approximately 20 in the 8 TeV data. The reconstruction, identification and isolation criteria used for electrons and photons in the 8 TeV data are improved, making the $H \rightarrow ZZ^{(0)} \rightarrow 4\ell$ and $H \rightarrow \gamma\gamma$ searches more robust against the increased pile-up. These analyses were re-optimised with simulation and data before looking at the 8 TeV data.

In the $H \rightarrow WW^{(0)} \rightarrow \ell\nu\ell\nu$ channel, the increased pile-up deteriorates the event missing transverse momentum, $E_{\text{miss}}^{\text{tr}}$, resolution, which results in significantly larger Drell-Yan background in the same-flavour final states. Since the $e\mu$ channel provides most of the sensitivity of the search, only this final state is used in the analysis of the 8 TeV data. The kinematic region in which a SM Higgs boson with a mass between 110 GeV and 140 GeV is

ATLAS Collaboration / Physics Letters B 716 (2012) 1–29

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ATLAS Collaboration

G. Aad⁴⁸, T. Abajyan²¹, B. Abbott¹¹¹, J. Abdallah¹², S. Abdel Khalek¹¹⁵, A.A. Abdelatif⁴⁹, O. Abdinov¹¹, R. Aben¹⁰⁵, B. Abi¹¹², M. Abolins⁸⁸, O.S. Abouzaid¹⁵⁷, H. Abramowicz¹⁵⁷, H. Abreu¹⁵⁸, B.S. Acharya^{164a,164b}, L. Adamczyk³⁸, D.L. Adams²⁵, T.N. Adye⁵⁶, J. Adelman¹⁷⁰, S. Adomeit⁹⁸, P. Adragna⁷⁵, T. Aducci¹²⁹, S. Aefsky²³, J.A. Aguilar-Saavedra^{124b,c}, M. Agustoni¹⁷, M. Aharouch⁸¹, S.P. Ahlen²², F. Ahles⁴⁸, A. Ahmad¹⁴⁸, M. Ahsan⁴¹, G. Aielli^{133a,133b}, T. Aklonis^{15a}, T.P.A. Akesson⁷⁹, G. Akimov¹⁵⁵, A.V. Akimov⁹⁴, M.S. Alam², M.A. Alam⁷⁶, J. Albert¹⁶⁹, S. Albrand⁵⁵, M. Aleksa³⁰, I.N. Aleksandrov⁶⁴, F. Alessandria^{89a}, C. Alexa^{26a}, G. Alexander¹⁵³, G. Alexandre⁴⁹, T. Alexopoulos¹⁰, M. Alhoob^{164a,164b}, M. Aliev¹⁶, G. Alimonti^{89a}, J. Alison¹²⁰, B.M.M. Allbrooke¹⁸, P.P. Allport⁷², S.E. Allwood-Spiers⁵³, J. Almond⁸², A. Aloisio^{102a,102b}, R. Alon¹⁷², A. Alonso⁷⁹, F. Alonso⁷⁰, A. Altheimer³⁵, B. Alvarez Gonzalez⁸⁹, M.G. Alvigi^{102a,102b}, K. Amako⁶⁵, C. Amelung²³, V.V. Ammosov^{128a}, S.P. Amor Dos Santos^{124a}, A. Amorim^{124a,b}, N. Amram¹⁵³, C. Anastopoulos³⁰, L.S. Ancu¹⁷, N. Andari¹¹⁵, T. Andeen³⁵, C.F. Anders^{58b}, G. Anders^{58a}, K.J. Anderson³¹, A. Andreazza^{89a,89b}, V. Andrei^{58a}, M.-L. Andrieux⁵⁵, X.S. Anduaga⁷⁰, S. Angelidakis⁹, P. Anger⁴⁴, A. Angerami³⁵, F. Anghinolfi³⁰, A. Anisenkov¹⁰⁷, N. Anjos^{124a}, A. Annovi⁴⁷, A. Antonaki⁹, M. Antonelli⁴⁷, A. Antonov⁹⁶, J. Antos^{144b}, F. Anulli^{132a}, M. Aoki¹⁰¹, S. Aoun⁸³, L. Aperio Bella⁵, R. Apoll^{13a,c}, G. Arabidze⁸⁸, I. Aracena¹⁴³, Y. Arai⁶⁵, A.T.H. Arce⁴⁵, S. Arfaoui¹⁴⁸, J.-F. Arguin⁹³, E. Arik^{13a,c}, M. Arik^{13a}, A.J. Armbruster⁸⁷, O. Arnaez⁸¹, V. Arnal⁸⁰, C. Arnau¹¹⁵, A. Arriaguer⁹⁵, G. Artoni^{132a,132b}, D. Arutinov²¹, S. Asai¹⁵⁵, S. Ask²⁸, B. Asman^{146a,146b}, L. Asquith⁶, K. Assamagan²⁵, A. Astbury¹⁶⁹, M. Atkinson¹⁶⁵, B. Aubert⁵, E. Auge¹¹⁵, K. Augsten¹²⁷, M. Auroousseau^{145a}, G. Avolio¹⁶³, R. Avramidou¹⁰, D. Axen¹⁶⁸, G. Azuelos^{93,d}, Y. Azuma¹⁵⁵, M.A. Baak³⁰, G. Baccagioni^{89a}, C. Bacci^{134a,134b}, A.M. Bach¹⁵, H. Bachacou¹³⁶, K. Bachas³⁰, M. Backes⁴⁹, M. Backhaus²¹, J. Backus Mayes¹⁴³, E. Badescu^{26a}, P. Bagnaia^{132a,132b}, S. Bahinipati³, Y. Bai^{33a}, D.C. Bailey¹⁵⁸, T. Bain¹⁵⁷, J.T. Baines¹²⁹, O.K. Baker¹⁷⁶, M.D. Baker²⁵, S. Baker⁷⁷, P. Balek¹²⁶, E. Banas³⁹, P. Banerjee⁹³, Sw. Banerjee¹⁷³, D. Banti³⁰, A. Bangert¹⁵⁰, V. Bansal¹⁶⁹, H.S. Bansal¹⁸, L. Barak¹⁷², S.P. Baranov⁶⁴, A. Barbaro Galtieri¹⁵, T. Barber⁴⁸, E.L. Barberio⁸⁶, D. Barberis^{50a,50b}, M. Barbero²¹, D.Y. Bardin⁶⁴, T. Barillari⁹⁹, M. Barisonzi¹⁷⁵, T. Barklow¹⁴³, N. Barlow²⁸, B.M. Barnett¹²⁹, R.M. Barnett¹⁵, A. Barone^{134a}, G. Barone⁴⁹, A.J. Barr¹¹⁸, F. Barreiro⁸⁰, J. Barreiro Guimarães da Costa⁵⁷, P. Bartlillon¹¹⁵, R. Bartoldus¹⁴³, A.E. Barton⁷¹, V. Bartsch¹⁴⁹, A. Bayle¹⁶⁵, R.L. Bates⁵³, L. Batkova^{144a}, J.R. Batley²⁸, A. Battaglia¹⁷, M. Battistin³⁰, F. Bauer¹³⁶, H.S. Bawa^{143,c}, S. Beale⁹⁸, T. Beau⁷⁸, P.H. Beauchemin¹⁶¹, R. Beccherle^{50a}, P. Bechtel²¹, H.P. Beck¹⁷, A.K. Becker¹⁷⁵, S. Becker⁹⁸, M. Beckingham¹³⁸, K.H. Becks¹⁷⁵, A.J. Beddall^{19c}, A. Beddini^{19c}, S. Bedikian¹⁷⁶, V.A. Bednyakov⁶⁴, C.P. Bee⁸³, L.J. Beemster¹⁰⁵, M. Begel²⁵, S. Behar Harpaz¹⁵², P.K. Behara⁵², M. Beimforde⁹⁹,

¹ © CERN for the benefit of the ATLAS Collaboration.

² E-mail address: atlas.physics@cern.ch.

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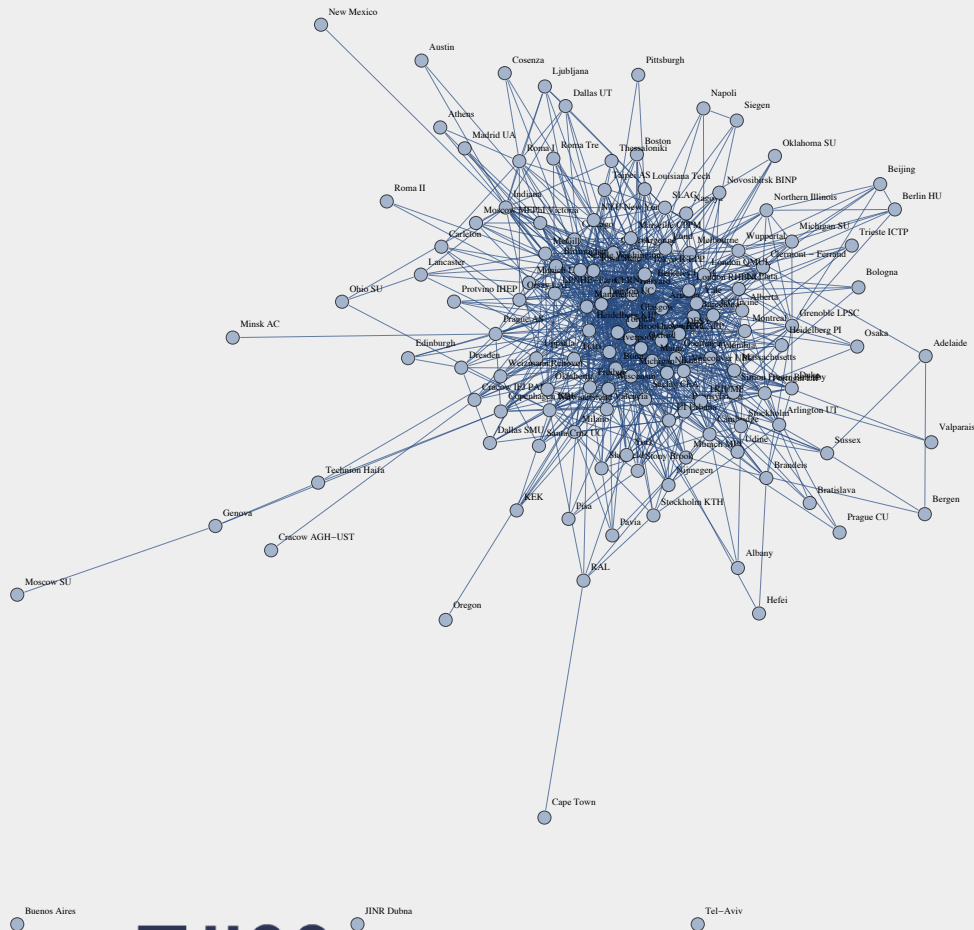
Collaboration in Physics

- Most of studies look at the institutional level
- High degree of inter-institutional ($\sim 50\%$) and international ($\sim 30\%$) collaboration (Gazni et al. 2012, Benavent-Pérez et al. 2012)
- Higher degree of international collaboration (especially in Europe) and influence of geographical distance
- In a longitudinal analysis, Lorigo & Pellacini (2007) observe:
 - An increase in the number of inter-institutional collaborations
 - An increase in the strength of inter-institutional collaborations (number of papers)
 - An increase in the percentage of nodes belonging to the largest connected component
 - Loss of centrality of CERN as an institutional node
- As Huang et al. (2012) suggest, collaboration networks like CERN need to be studied in depth

Research design

- Access to internal ATLAS data
 - Preprints database of the physical analysis phase (with editors)
 - Authors list with institutions
- Data (until 31/12/2012):
 - 371 papers
 - 1543 authors
 - 217 institutes
- Co-authorship network analysis at the institutional level

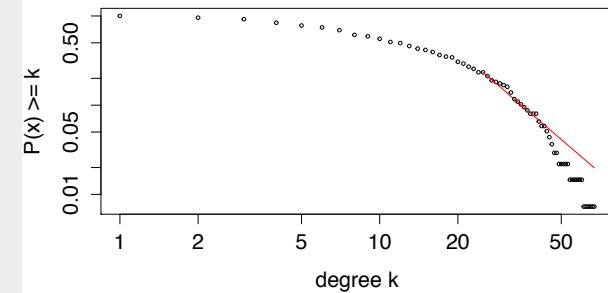
Co-authorship network



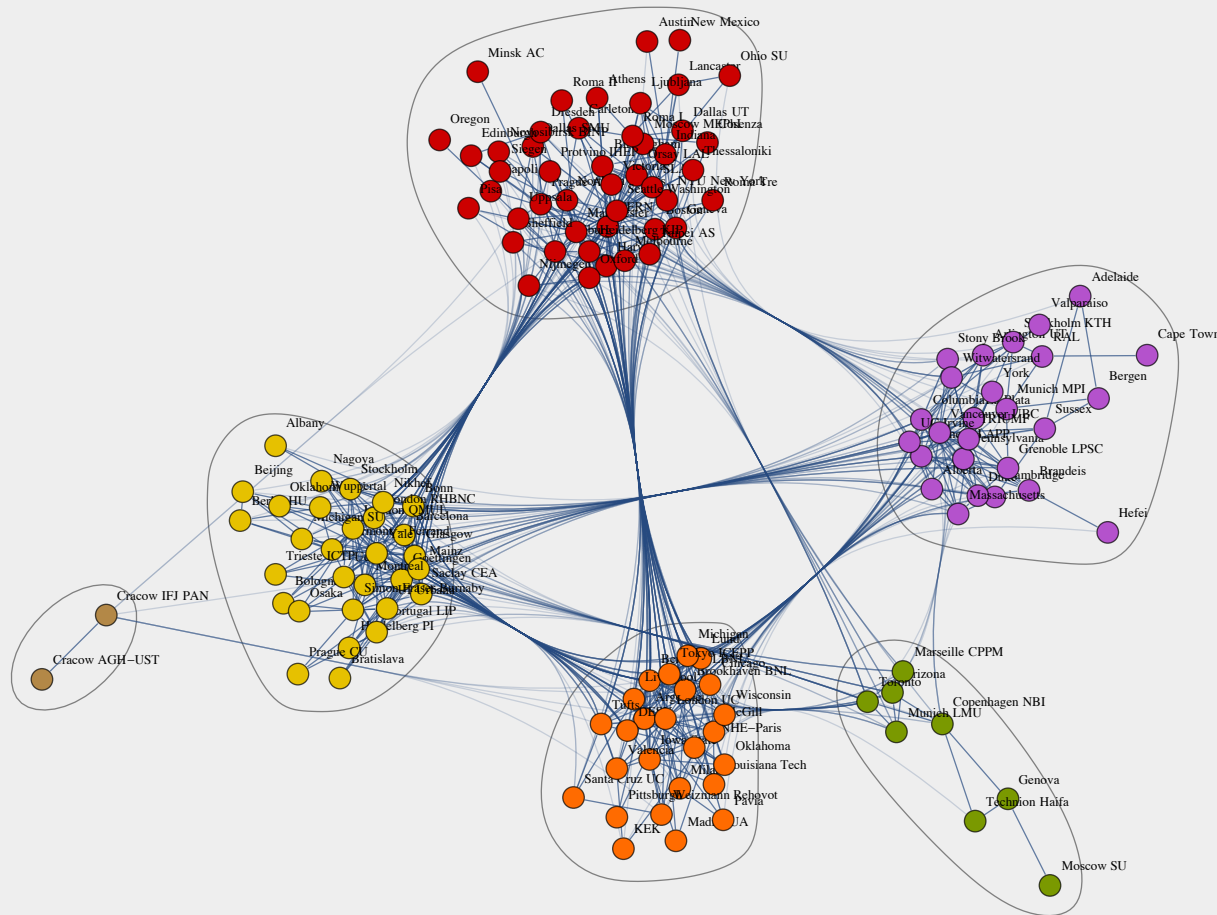
140 vertices
1073 edges
density = 0.11

avg degree = 15.33

clust. coef. = 0.39



Community analysis



Modularity
method
(Greedy
algorithm)

9 communities

Discussion and conclusions

- Interesting findings
 - High degree of collaboration
 - Not a scale free network, as opposite to the co-authorship network of published articles (Newman 2001)
 - Apparently no effect of geographical distance
- Conclusions
 - Big science collaborations have an internal structure, sometimes different from the rest
 - In spite of the “one case” limitation, we may conclude that in disciplines where big science has become important, traditional co-authorship analysis should be taken with care when studying scientific collaboration

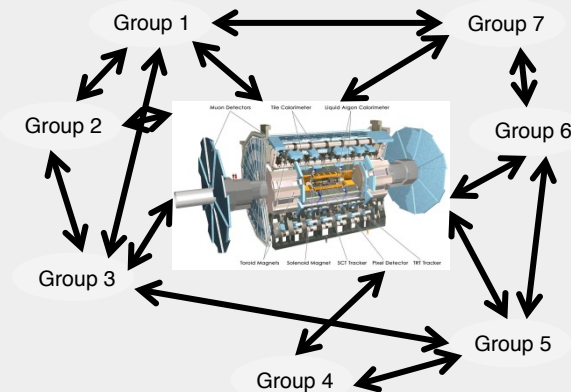
Simulations as Boundary Objects

Coordination

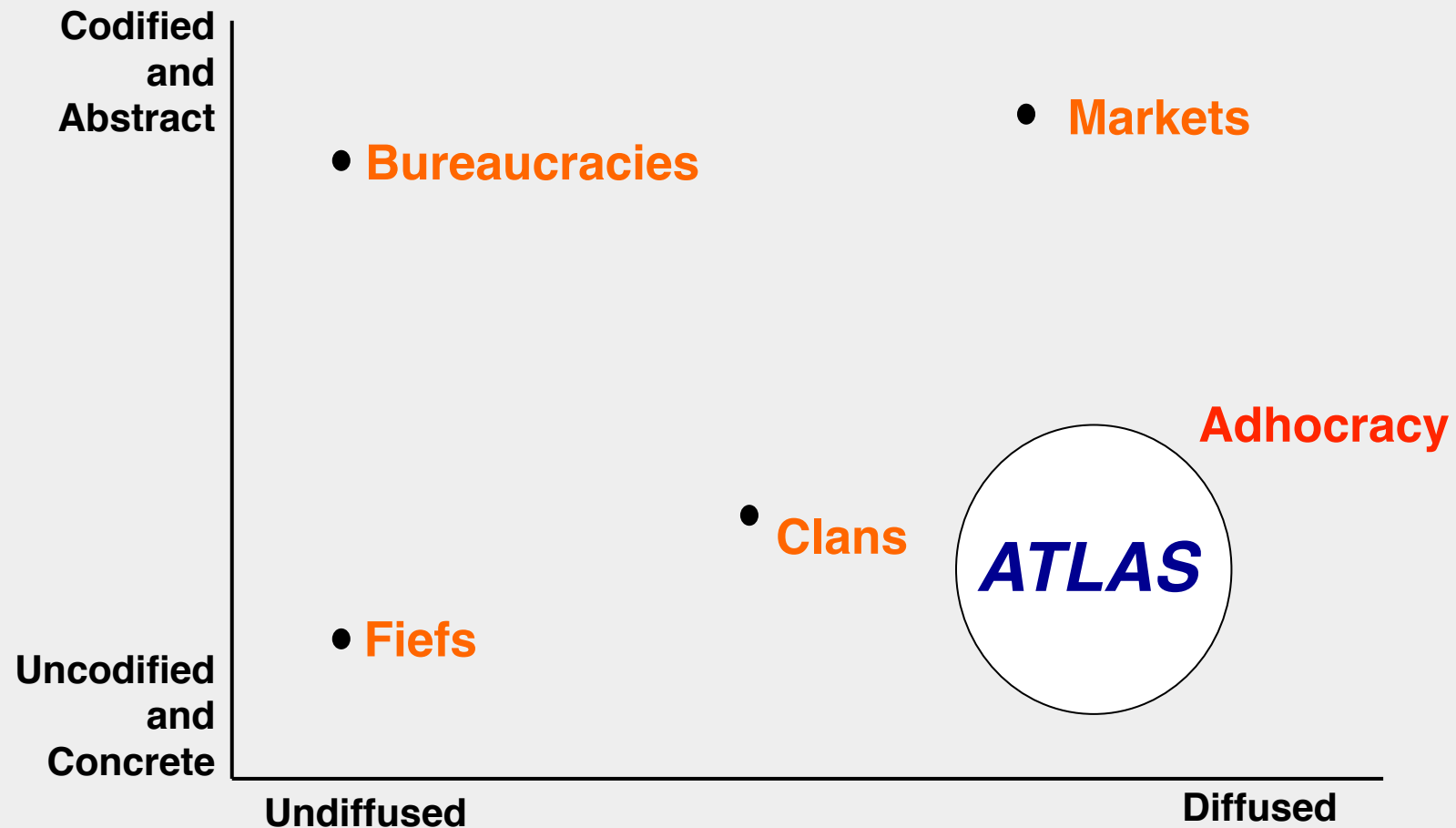
- Cooperation needs transactions, that present some problems (bounded rationality, information asymmetries)
- Traditional solution: Management (“visible hand”) through hierarchical control
- Alternatives:
 - Routines and rules: only effective under conditions of repetition
 - When all members agree upon the goals of the organization and the techniques for achieving these goals are within the ability of all members, few or no rules are required: small organizations oriented around expressive needs
- Under certain circumstances, the latter can apply to fairly large and geographically scattered organizations like ATLAS

The ATLAS Puzzle

- A complex task
- A project-oriented structure
- A complex organization
 - 3000 physicists
 - 175 universities and laboratories
 - 38 countries
- A non-hierarchical organization
 - Held together by Memoranda of Understanding
 - Decision making is bottom-up
 - Decision making is distributed



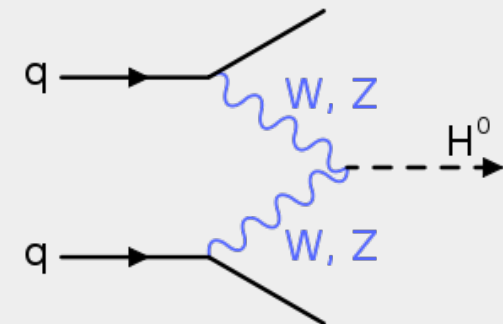
ATLAS in the I-Space



Boundary objects

- Boundary objects (Star 1989, Carlile 2002, 2004) act as a scaffolding that enables people to:
 - Gradually build up a shared understanding of common tasks facilitating knowledge flows
 - Provide coherence across intersecting social groups
- Examples of boundary objects: blueprints, maps, common interests, rules, plans, conceptual frameworks.

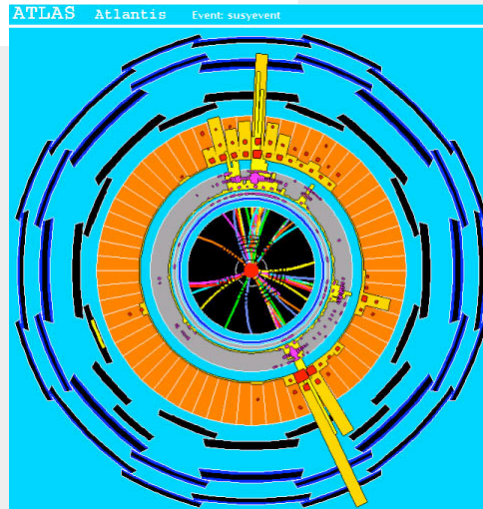
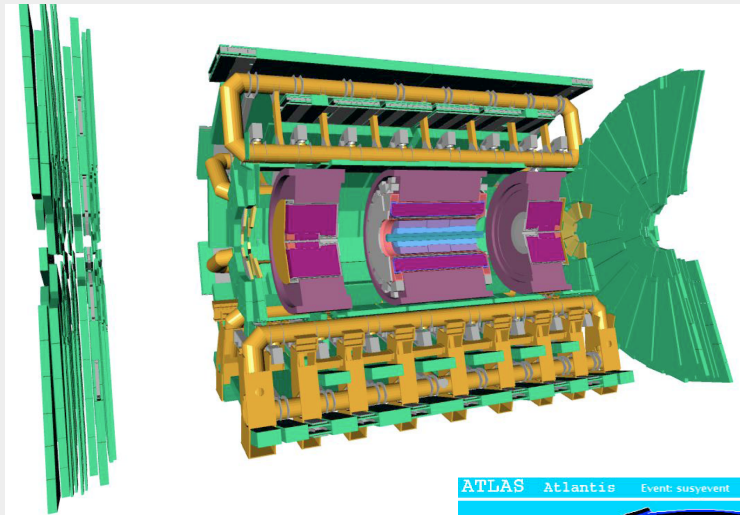
Feynman diagrams



Research design

- Case study developed between March and December of 2009
- Part of a wider investigation about different aspects of knowledge creation, transfer and use within the ATLAS Collaboration
- Data collected through 30 semi-structured interviews to members of the Collaboration (9 senior members and 21 group leaders)
- Complemented with archival information from the ATLAS Collaboration and participating observation

Key role of simulations



- Monte Carlo simulation techniques
- Co-evolution of prototypes and simulation in the design phase
- Necessary to interpret the results in the operation phase

Simulations as boundary objects

***The beginning of this experiment was a simulation.** You simulate the whole experiment first until you're confident that all the bits and pieces which you imagine... all the different things you imagine you put them into the simulation and see how they perform.*

*So you're really evolving two objects. **You're evolving a virtual object and you're evolving a real object.** [...] **And both are equally complex.** The one on the computer may even be more complex because it contains all the detail.*

*[That core simulation is an object...] **Not only to co-ordinate but to feed everybody with all the necessary information that the person needs in order to perform** within a complex...*

*[...in bio-technology you've got lots of prejudices that compete with each other with people having different ways of doing...] Yeah, yeah. **Well here also, but here you use the simulation to iron them out.***

Some insights

- Clans are governed by the *intangible hand* of trust and mutual esteem, what requires personalized interaction and, therefore, are limited in size, but the ATLAS case suggests that clans can be expanded through the use of external scaffolding acting as boundary objects
- Simulation absorbs complexity by capturing it in a “black box” and behaves as a boundary object that facilitates alignment between groups
- The needed coordination is provided by culture and boundary objects: the “intangible hand”
- Main implication: In cases of task complexity, boundary objects together with clan or adhocratic cultures may substitute for the traditional coordination mechanisms

Conclusions and implications

- Is the ATLAS case unique?
- The ATLAS culture produced an 'organized anarchy' that works
- In *The rise of the creative class*, Florida (2002) suggests that this kind of organizations are set to grow
- The ATLAS case suggests that they may be not necessarily small scale organizations with few coordination problems, but also larger and more focused organizations

Thank you!

Questions?

Agustí Canals
acanalsp@uoc.edu